Quantum Information Processing and Communication (QIPC) 2011

International Conference at ETH Zurich
September 5 – 9, 2011

⟨+| QIPC '11 |+⟩

www.qipc2011.ch

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Quantum Information Processing and Communication (QIPC) 2011

International Conference at ETH Zurich

September 5-9, 2011

Welcome Address

The QIPC 2011 program and organizing committees welcome you to ETH Zurich and wish you a successful conference and a great time in Switzerland!

After Barcelona'07 and Rome'09, the third **International Conference on Quantum Information Processing and Communication (QIPC) 2011** is held at ETH Zurich from **September 5 - 9, 2011**. The conference program includes 30 invited talks, 70 contributed talks and more than 100 poster presentations covering a broad range of topics such as quantum information and quantum communication, physical realizations of quantum systems for information technology such as photons, single atoms, ions, molecules, nuclear and electron spins, superconducting circuits, micro- and nano-mechanics, hybrid quantum systems, topical subjects, including cavity QED, optical lattices, quantum memories, foundations of quantum information, and many-body systems.

In an industry session with 4 invited speakers, insight into commercial developments of current and future quantum technologies is given. Funding opportunities and future strategies are presented in a funding session featuring national and EU funding experts.

The conference brings together scientists from 30 different countries. Participants represent more than 120 different universities and institutes including Basel, Berlin, Berkeley, Chalmers, Delft, Geneva, Harvard, Max Planck Institutes, MIT, Munich, Paris, Santa Barbara, Tokyo, ETH Zurich and many more. Also companies such as IBM and ID Quantique and funding agencies such as the European Commission and national funding organizations are represented. More than 60 participants are leading principal investigators with professorial degrees, more than 200 hold PhDs and about 100 participants are pursuing research toward their PhD degree.

The conference is hosted by ETH Zurich and supported by the EU Coordination Action QUIE2T (Quantum Information Entanglement-Enabled Technologies) the European Integrated Projects AQUTE, QESSENCE and SOLID, the National Centre of Competence in Research QSIT and the City of Zurich.

The conference is preceded by a school aimed at beginning graduate students held in the Swiss Alps at Berghaus Diavolezza, September 2-4, 2011. Seven lecturers provide an introductory course on quantum information science and technology to 46 students from all over the world.

We hope that you will enjoy the scientific program, the interaction with your colleagues as well as the great opportunities that Zurich and Switzerland have to offer to you.

Andreas Wallraff
for the QIPC 2011 committees

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QIPC 2011
Conference Information

Organization

Local Coordination Team

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We also thank many others who contribute to make the conference a success.

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Program: program@qipc2011.ethz.ch

Sponsors

QUIE2T	Quantum Information Entanglement-Enabled Technologies, FP7 EU Coordination Action
AQUTE	Atomic Quantum Technologies, FP7 EU Large-Scale Integrating Project
Q-ESSENCE	Quantum Interfaces, Sensors, and Communication based on Entanglement, FP7 EU Large-Scale Integrating Project
SOLID	Solid State Systems for Quantum Information Processing, FP7 EU Large-Scale Integrating Project
QSIT	Quantum Science and Technology, National Center of Competence in Research, SNF

Stadt Zürich
Kanton Zürich
We also thank those invited speakers who donated their travel allowance towards student support.

Host Institution

ETH Zurich - Eidgenössische Technische Hochschule Zürich

Local Organizing Committee

Gianni Blatter (Quantum Condensed and Coherent Systems, ETHZ)
Christian Degen (The Degen Lab, MIT, ETHZ)
Klaus Ensslin (Nanophysics, ETHZ)
Tilman Esslinger (Quantum Optics, ETHZ)
Jonathan Home (Trapped Ion Quantum Information, ETHZ)
Atac Imamoglu (Quantum Photonics, ETHZ)
Frederic Merkt (Molecular Physics and Spectroscopy, ETHZ)
Renato Renner (Quantum Information Theory, ETHZ)
Gian Salis (IBM Research Zurich)
Matthias Troyer (Computational Physics, ETHZ)
Andreas Wallraff (Quantum Device Lab, ETHZ)
Werner Wegscheider (Advanced Semiconductor Quantum Materials, ETHZ)

Program Committee

Michel Devoret (Quantum Electronics and Mesoscopic Physics, Yale)
Tilman Esslinger (Cold Atoms, ETHZ)
Nicolas Gisin (Photonics, Geneva)
Atac Imamoglu (Semiconductor Quantum Dots and Photonics, ETHZ)
Tobias Kippenberg (Nano & Micromechanics, EPF Lausanne)
Daniel Loss (Condensed Matter Theory and Quantum Computation, Basel)
Gerard Milburn (Quantum Optics Theory, Brisbane)
Renato Renner (Quantum Information Theory, ETHZ)
Andreas Wallraff (Quantum Devices and Hybrid Systems, ETHZ)
Dave Wineland (Atomic Physics, Boulder)
Peter Zoller (Quantum Information and Quantum Optics, Innsbruck)

Invited Speakers

Jürgen Appel (Industry Session), Niels Bohr Institute, Copenhagen
David Awschalom, Awschalom Group, UC Santa Barbara
Charles Bennett, IBM Research, New York
Rainer Blatt, Quantum Optics and Spectroscopy, Innsbruck
Immanuel Bloch, Quantum Optics Group, LMU
Matthias Christandl, Quantum Information Theory, ETHZ
Ignacio Cirac, Quantum Optics, Max Planck Institute
Jens Eisert, Quantum Information Theory, Podsdam
Nicolas Gisin, GAP-Optique, Geneva
Fabian Hassler, Theoretical Nanophysics, Leiden University
Paul Kwiat, Quantum Information Group, Illinois
Konrad Lehnert, Lehnert Laboratory, JILA
Mikhail Lukin, Quantum Optics, Harvard
Charles Marcus, Mesoscopic Physics, Harvard
Florian Marquardt, Nanophysics and Quantum Optics, Erlangen
John Martinis, Josephson Junction Quantum Computing, UCSB
Dieter Meschede, Quantum technologies with single neutral atoms, Bonn
Chris Monroe, Trapped Ion Quantum Information Group, Maryland
Andrea Morello, Centre for Quantum Computation & Communication Technology, Sydney
Yasunobu Nakamura, Green Innovation Research Labs., NEC Corporation
Tobias J. Osborne, Institute of Theoretical Physics, Hannover University
Oskar Painter, Micro- and Nano-Photonics Group, Caltech
Eugene Polzik, Quantum Optic Lab, University of Copenhagen
Grégoire Ribordy (Industry Session), ID Quantique SA, Geneva
Bruno Michel (Industry Session), IBM Research GmbH, Zurich
Christophe Salomon, Laboratoire Kastler Brossel, Paris
Bruno Sanguinetti (Industry Session), GAP, University of Geneva
Irfan Siddiqi, Quantum Nanaoelectronics Laboratory, UC Berkleley
John Teufel, NIST, Boulder Laboratories
Philipp Treutlein, Quantum Atom Optics Lab, Basel
Lieven Vandersypen, Kavli Institute of NanoScience, TU Delft
Andreas Winter, Quantum Information Theory, Bristol
Amir Yacoby, Yacoby Research Group, Harvard
Peter Zoller, Quantum Optics, Innsbruck

Plenary Program, QIPC 2011 @ HCI G3, ETH Hönggerberg, Zurich

		Monday, Sep. 5	Tuesday, Sep. 6	Wednesday, Sep. 7	Thursday, Sep. 8	Friday, Sep. 9
	9:00		**Young Investigator Award**	EU Funding Note		
	9:15	Opening Address	R. Hanson and S. Pironio			
		Atomic Systems (Tilman Esslinger)	**Superconducting Circuits** (Christoph Bruder)	**Photons** (Matthias Christandl)	**Mechanical Oscillators** (Tobias Kippenberg)	**Qu. Information Theory** (Gianni Blatter)
	9:30	Immanuel Bloch	Andrew Cleland	Eugene Polzik	Oskar Painter	Charles Bennett
	10:10	Aurelian Dantan	Andreas Dewes	Igor Dotsenko	Albert Schliesser	Beni Yoshida
	10:30	Stephen Hogan	Chris Wilson	Jeremy O'Brien	Mika Sillanpää	Florian Fröwis
		Coffee Break, 30'				
Fri 2 - Sun 4 **QIPC School 2011** @ Berghaus Diavolezza	**11:20**	Rainer Blatt	Irfan Siddiqi	Konrad Lehnert	Florian Marquardt	Andreas Winter
	11:50	Peter Zoller	Yasunobu Nakamura	Paul Kwiat	John Teufel	Tobias Osborne
		Lunch, 1 h 20'	Lunch and odd numbered Posters, 2 h	Lunch and even numbered Posters, 2 h 13:20 -14:10 **EU Funding Session** @ E Floor Cafeteria	Lunch and odd numbered Posters, 1 h 20'	Lunch and even numbered Posters, 2 h
		Quantum Communication (Renato Renner)	**Parallel Sessions** **14:20** - 16:00, 5 x 20'	**Industry Session** **14:20** - 16:00 (Nicolas Gisin)	**Parallel Sessions** **13:40** - 15:20, 5 x 20'	**Parallel Sessions** **14:20** - 16:00, 5 x 20'
	13:40	Nicolas Gisin			E: Charges & Spins @ G3 F: Special Topics @ G7 G: Photons @ J3	
	14:20	Jürgen Eschner	A: Atomic Systems @ G3	Bruno Michel, 14:20		H: Mech. Oscillators @ G3
	14:40	Lars Lydersen	B: Qu. Communication @ G7	Grégoire Ribordy, 15:00		I: Atomic Systems @ G7
	15:00	Matthias Christandl	C: Supercond. Circuits @ J3	Jürgen Appel, 15:20	Coffee Break, 30'	J: Qu. Inf. Theory @ J3
	15:30	Jens Eisert	D: Charges & Spins @ J7	Bruno Sanguinetti, 15:40		
		Coffee Break, 30'			**Atomic Systems** **15:50** - 18:10 (Jonathan Home)	Coffee Break, 30'
		Charges & Spins (Daniel Loss)	**Special Topics** (Peter Zoller)	**Charges & Spins** (Thomas Ihn)	Chris Monroe, 15:50	**Topical Sessions**
	16:30	Amir Yacoby	Ignacio Cirac	Misha Lukin	Kenton Brown, 16:30	Geometric and Topological Phases @ G7
Sun 4, 17 - 20:00 **Welcome Reception** @ Faculty Lounge, ETH Main Building	17:10	Sergey Frolov	Philip Walther	Matthieu Delbecq	Stephan Ritter, 16:50	
	17:30	Peter Leek	Philippe Corboz	Ronald Hanson	Philipp Treutlein, 17:10	
	17:50	Lieven Vandersypen	Christophe Salomon	David Awschalom	Dieter Meschede, 17:40	Q-ESSENCE Business Meeting @ J7
	18:20	Charles Marcus	Fabian Hassler	Andrea Morello	Bus Transport to Kunsthaus at **18:30** & **18:45**	
			20:00 - 23:00 **Open Mike Discussion** @ Vis Dome, ETH Main Building		19:00 - 24:00 **Conference Event and Dinner** @ Kunsthaus	
	Colors:	Invited Introductory, 40'	Contributed Hot Topic, 20'	Invited Topical, 30'	Contibuted, 5 x 20'	Other Events and Sessions

Parallel Sessions Program, QIPC 2011 @ HCI, ETH Hönggerberg, Zurich

Room	Time	Tuesday, Sep. 6	Time	Thursday, Sep. 8	Time	Friday, Sep. 9
Sessions @ HCI G3		**A: Atomic Systems** (Philipp Treutlein)		**E: Charges & Spins** (Gian Salis)		**H: Mechanical Oscillators** (Christian Degen)
	14:20	Roee Ozeri	**13:40**	Geraldine Haack	**14:20**	Ewold Verhagen
	14:40	Jordi Mur-Petit	14:00	Bruno Küng	14:40	Maria Korppi
	15:00	Alexei Ourjoumtsev	14:20	Luca Chirolli	15:00	Nicolas Didier
	15:20	Andreas Walther	14:40	Hideo Kosaka	15:20	Michael Hartmann
	15:40	Anna Grodecka-Grad	15:00	Pawel Szumniak	15:40	Andreas Jöckel
Sessions @ HCI G7		**B: Quantum Communication** (Grégoire Ribordy)		**F: Special Topics** (Florian Marquardt)		**I: Atomic Systems** (Stephen Hogan)
	14:20	Tim Bartley	**13:40**	Roman Orús	**14:20**	Tatjana Wilk
	14:40	Felix Bussieres	14:00	Jan Kolodynski	14:40	Kensuke Inaba
	15:00	Cosmo Lupo	14:20	Dimitris Angelakis	15:00	Ferdinand Schmidt-Kaler
	15:20	Matthias Staudt	14:40	Giovanna Morigi	15:20	Robert Spreeuw
	15:40	Nuala Timoney	15:00	Jin-Shi Xu	15:40	Carlos Navarrete-Benlloch
Sessions @ HCI J3		**C: Superconducting Circuits** (Andreas Wallraff)		**G: Photons** (Atac Imamoglu)		**J: Quantum Information Theory** (Joseph Renes)
	14:20	Jonas Bylander	**13:40**	Nicolas Cerf	**14:20**	Gilles Dowek
	14:40	Jerry Chow	14:00	Adetunmise Dada	14:40	David Reeb
	15:00	Christopher Eichler	14:20	Alois Regensburger	15:00	Vahid Azimi Mousolou
	15:20	Vladimir Stojanovic	14:40	Mohamed Bourennane	15:20	Nicolas Brunner
	15:40	Mikko Möttönen	15:00	Seung-Sup Lee	15:40	Ognyan Oreshkov
Session @ HCI J7		**D: Charges & Spins** (Klaus Ensslin)				
	14:20	Ingmar Jakobi				
	14:40	Sander Onur				
	15:00	Hugo Ribeiro				
	15:20	Jeremie Viennot				
	15:40	Alessandro Rossi				

Information for Presenters

Oral Sessions

Oral sessions include:

- Invited Introductory talks: 40 min (including 8 min of discussion)
- Invited Topical talks: 30 min (including 6 min of discussion)
- Industry Session talks: according to the schedule
- Contributed hot topic talks: 20 min (including 4 min of discussion)
- Contributed talks: 20 min (including 4 min of discussion)

We ask speakers to bring their own laptop and/or a USB memory stick (as a backup) with their presentation. Projectors and VGA connection for laptops are available in the lecture halls. Overhead projectors may not be available.

Presenting authors should test the connectivity between their laptop and the projector at least 15 min before the session starts. All rooms are open thirty minutes before the beginning of the session and during the session breaks.

Poster Sessions

The poster contributions are grouped by subject. All posters will be up for the full duration of the conference. Each day the extended lunch breaks (2 hours) and the two coffee breaks (30 min each) are available for poster presentations. Thus, there is ample time for all conference participants to view the posters, and for poster authors to get feedback on their work.

Schedule - Presenters with odd poster number are asked to please attend their posters for discussion on Tuesday (Sep. 6) and Thursday (Sep. 8) and presenters with even poster number on Wednesday (Sep. 7) and Friday (Sep. 9). In this way both poster presenters and attendees are given the opportunity to present their own posters and have discussions with other poster presenters from their own and other subject areas. For numbering of posters please consult the abstract book.

Format - The size of the poster board is 120 cm x 180 cm (width x height). We suggest A0 protrait format poster size.

Setting-up and removing - Poster may be put up at any time on Monday, Sep. 5. Materials for setting-up will be available in the poster area. Posters must be removed before 18:00 on Friday (Sep. 9). Any remaining posters will be removed and discarded after this time.

Areas and locations - The poster areas are located on the F- and G- floors of the HCI building. Please set-up your poster according to its number. Plans of these floors including the position of your poster are available at the end of this book.

Registration & Conference Office

All attendees have to register for the meeting. To pick up your registration materials, please visit the QIPC 2011 registration desk during Conference Office hours. You will receive the conference attendance confirmation and receipt, the abstract book, program, a ticket for public transport (ZVV 5-day pass) and your badge at the conference desk. The badge must be worn visibly during the entire conference. If you forget or lose your badge please visit the conference office.

The organizers, staff of the conference desk and the student assistants wear colored badges. Please contact them if you have any questions. When you check in at the meeting you will be asked either for your printed confirmation or an ID.

The registration fee includes

- access to all oral and poster sessions of the conference
- lunches and coffee breaks during the conference
- the welcome reception
- the conference dinner (registration after July 15 does not include the conference dinner)
- a 5-day pass, from Monday to Friday, for public transport in Zurich (ZVV - zone 10)

Registration & Conference Office Hours

At the Welcome reception

Time and date: 17:00 - 20:00, Sunday, September 4, 2011

Location: ETH Zurich Campus Zentrum, Dozentenfoyer, Rämistrasse 101, 8092 Zürich. Maps are available at the end of this book.

During the conference

The registration desk & conference office are located next to the lecture halls and poster areas in the HCI building. Maps are available at the end of this book.

Monday	September 5	8:00 - 12:30	Entrance hall, E-floor
Monday	September 5	12:30 - 19:30	Room F8
Tuesday	September 6	8:30 - 19:30	Room F8
Wednesday	September 7	8:30 - 19:30	Room F8
Thursday	September 8	8:30 - 19:00	Room F8
Friday	September 9	8:30 - 17:00	Room F8

Student support

The conference supports students presenting a poster or a talk through partial reimbursement of the registration fee. To receive this reimbursement in cash, please visit the conference office during the following opening hours: Tuesday, September 6, 2011, 12:00 - 14:00, ETH Zurich Campus Hönggerberg (Science City), HCI building, room F8. We kindly ask students who request reimbursement to show a valid confirmation of their student status.

The Conference Venue

Location

All conference activities, with the exception of the Welcome reception, the Tuesday evening discussion session and the conference dinner, will take place at ETH Zurich Campus Hönggerberg (Science City). The campus is located on the top of a hill close to the city centre. The campus can be easily reached from all of Zurich by public transport provided by ZVV.

Address of the lecture hall center HCI: Wolfgang Pauli Str. 10, ETH Zurich, 8093 Zurich.

Access to ETH Zurich Campus Hönggerberg (Science City)

From Zurich airport

- Follow the "Bahn/Railway" signs and take an escalator down to platforms 3 or 4. Trains to *Zurich Oerlikon* leave approximately every 10 min. Get off the train at *Zurich Oerlikon* and walk to bus stop *Zurich Bahnhof Oerlikon Nord*. Take *bus 80* (direction Triemlisptal) to ETH Hönggerberg. The total journey takes about 25 min.
- A taxi ride from the airport to ETH Hönggerberg or to the down town hotels takes approx. 20-30 mins and costs about 40-50 CHF.

From the main station

- In front of the main station (tram stop: *Bahnhofquai/HB* or *Bahnhofstrasse/HB*) take *tram 11* (direction Auzelg), exit at *Bucheggplatz* and change onto *bus 69* (direction ETH Hönggerberg) to ETH Hönggerberg. The total journey takes approx. 25 min.
- In front of the main station (tram stop: *Bahnhofquai/HB* or *Bahnhofstrasse/HB*) take *tram 14* (direction Seebach), exit at *Milchbuck* and change onto *bus 69* (direction ETH Hönggerberg) to ETH Hönggerberg. The total journey takes approx. 25 min.
- From the main station take the *S-Bahn 9* (direction Zug), or *S-Bahn 8* (direction Wintertuhur HB), or *S-Bahn 14* (direction Hinwil) to *Zurich Oerlikon*. Walk to the bus stop *Zurich Bahnhof Oerlikon Nord* and take *bus 80* (direction Triemlisptal) to ETH Hönggerberg. The total journey takes approx. 25 min.

- A taxi ride from the main station to ETH Hönggerberg takes approx. 15 min and costs about 40 CHF.

Public Transport Tickets

Tickets for public transport can be purchased at the ticket office or from automatic ticket machines. A 5-day (Monday through Friday) ZVV pass for public transport is provided as part of the registration.

Internet Access

During the conference, participants will have the possibility to access WLAN everywhere on the ETH campus. To access wireless LAN follow these steps:

1. Connect to access point “public”
2. Open a browser, you will be guided to a login site
3. Login name and password will be given at the registration

The service *eduroam* will work for the access points “public” and “eduroam” too.

Cash Machines and Post Office

Two cash machines (ATM) are located in the entrance area of the HIL building at Campus Hönggerberg, where you will also find a public post office.

Lunch, Coffee & Dining

Conference coffee breaks and lunches are included in the registration fee. All alternative options are not included.

Conference Coffee Breaks

Coffee and pastries are available during the coffee breaks in the poster areas on the G- and F-floors as well as in the restaurant of the HCI building located on the F-floor.

Conference Lunch

Lunch will be served exclusively to conference attendees during lunch breaks in the restaurant of the HCI building located on the F-floor. The daily varying menu includes a main course (with a vegetarian option) and a salad. Drinking water is available from water fountains in the restaurant (remember to pick up a glass). Other drinks may be purchased. Important: it is required to present your QIPC 2011 conference badge to obtain lunch. Please show your badge to the cashier. If you forget or lose your badge, please visit the conference office (HCI, F8) during business hours.

Alternative Coffee and Dining Options

A number of other dining and coffee options are available on the ETH Zurich Campus Hönggerberg (Science City) at your own expense. In particular, the Chemie Cafeteria in the conference building (HCI) provides coffee, espressos and snacks all day long. Note that dinner and coffee options on the campus might be a lower-cost alternative to having dinner in town.

- *Chemie Cafeteria* - Daily varying lunch menus, pasta, take-away, cakes, biscuits, pastries and coffee. Location and opening hours: HCI building, Mo-Fr 7:30 to 16:00
- *Physikrestaurant* - Daily varying lunch and dinner menus, salad buffet, cakes, pastries and coffee. If your budget is limited, it is a good option to have dinner at the Physikrestaurant. Dinner is served from 17:30 to 19:15. Location and opening hours: HPH building, Mo-Fr 7:30 to 19:30
- *Alumni Lounge* - Snacks, deserts, coffee, beer, wine and cocktails. Location and opening hours: HIL building, Mo-Fr 8:00 to 21:00
- *Woka* - Wok buffet and wok menus, sandwiches and coffee. Location and opening hours: HIT building, Mo-Fr 10:00 to 15:00
- *Bistro* - Coffee (including the best Cappuccino on campus), snacks, sweets, beer, drink and wine. Location and opening hours: HPI building, Mo-Fr 8:00 to 20:30

Shops

Three small shops are located near the "ETH Hönggerberg" bus stop in the HPI building:

- *SAB-shop* - Office supplies, greeting cards, etc.
- *Kiosk* - Newspapers, soft drinks, beer, sandwiches, etc.
- *Student bookshop* - Bookshop and Campus Information Desk.

Sport Facilities

The Academic Sports Association Zurich (ASVZ) offers over 80 sports activities as well as the possibility for individual training. Conference attendees can purchase an ETH sports pass for the duration of the conference at the registration desk. For just 10 CHF this card will provide access to all sports facilities and training sessions of the ASVZ. The new Science City Sport Center in the HPS building is just a two minute walk away from the lecture hall of the conference.

Events

Welcome Reception

The welcome reception will take place in the Faculty Restaurant (Dozentenfoyer) located on the top floor of the ETH main building. From its roof top terrace, high above Zurich's skyline, it offers a spectacular view on the city, the lake and the mountains. You will also be able to register for the conference during reception.

Time and date: 17:00 to 20:00, Sunday, September 4, 2011

Location: ETH Zurich Campus Zentrum, Dozentenfoyer, Rämistrasse 101, 8092 Zürich. Maps are available at the end of this book.

Young Investigator Award

The QIPC Young Investigator Award is presented to outstanding young researchers in the field of Quantum Information Processing and Communication during the QIPC international conference at ETH Zurich on September 6, 2011. The award consists of a diploma and a lump sum of 4000 €. Eligible researchers must be less than 35 years old on the 1st of September 2011. The 2011 European Quantum Information Young Investigator Award is awarded jointly to

Dr. Ronald Hanson - ***For his experimental work on the coherent control and measurements of single spins in solids, and his proven leadership and independence through the successful establishment of his own research group***

and to

Dr. Stefano Pironio - ***For his theoretical contributions to the study of quantum correlations and quantum communications, concerning in particular device-independent quantum cryptography***

Award Committee Members

Daniele Binosi (Villazzano), Rainer Blatt (Innsbruck), Harry Buhrman (Amsterdam), Vladimir Buzek (Bratislava), Nicolas Cerf (Brussels), Ignacio Cirac (Munchen), Elisabeth Giacobino (Paris), Nicolas Gisin (Geneva), Artur Ekert (Cambridge, Oxford), Atac Imamoglu (Zurich), Massimo Inguscio (Florence), Sir Peter Knight (London), Leo Kouwenhoven (Delft), Maciej Lewenstein (Barcelona), Martin Plenio (London), Eugene Polzik (Copenhagen), Gerhard Rempe (Munich), Ian Walmsley (Oxford), Reinhard Werner (Hannover), Anton Zeilinger (Vienna), Peter Zoller (Innsbruck).

Time and date: 9:00 to 9:30, Tuesday, September 6, 2011

Location: ETH Zurich Campus Hönggerberg (Science City), HCI G3. See maps at the end of this book.

Open Mike Discussion Session on Quantum Information Science and Technology

For the first time QIPC will feature a “rump session”. The rump session is intended to be an informal session (3 hours) in which participants give short presentations on recent results, work in progress, and other topics of interest to the QIPC community. This open microphone session is to stimulate a discussion of the future of quantum information processing and communication. It will be held under the dome of the ETH main building in down town Zurich.

The presentations will be embedded into a relaxed atmosphere including complementary food and drinks being served during the whole session. In order to contribute to this spirit, non-technical and humorous contributions are highly encouraged.

The length of a rump session presentation should be anything between 3 and 7 minutes. Possible topics for presentation include

- Preliminary research results that are not ready for presentation in a formal setting
- Ideas or suggestions for new experiments
- Discussion of emerging applications
- Perspectives on the status of the field
- Presentation of upcoming conferences/meetings/funding opportunities

The session is open to all participants of the QIPC 2011 conference. Submissions of potential contributions consisting of a title and possibly a short description should be sent to the email address suggestions@qipc2011.ethz.ch. Presenters selected by the program and session chairs will make short contributions (no more than 3-7 minutes each). Everyone is invited to provide feedback to the statements and add their own opinionated contributions.

The dome of the ETH main building provides an excellent amphitheater-like atmosphere for a pointed and vibrant discussion on the questions and answers that will shape the future of our field.

Time and date: 20:00 - 23:00, Tuesday, September 6, 2011

Location: ETH Zurich Campus Zentrum, Vis Dome, Rämistrasse 101, 8092 Zürich. Area map and Building plan are available at the end of this book.

Program and session chairs: Renato Renner, Atac Imamoglu, Andreas Wallraff

EU Funding Note

Time and date: 9:00 - 9:30, Wednesday, September 7, 2011

Location: ETH Zurich Campus Hönggerberg (Science City), HCI G3. See maps at the end of this book.

Industry Session

After the successful Industry Sessions held at the previous QIPC meetings in Barcelona'07 and Rome'09, this year's Industry Session will again offer a platform for exchanges between academic researchers and industry leaders. On the industry side, we will hear **Dr. Bruno Michel**, *Head of the Science and technology Department of IBM-Zurich*, and **Dr. Grégoire Ribordy**, *CEO of ID Quantique* who are celebrating their 10 years anniversary. On new and promising potential applications in quantum metrology we have two researchers, **Dr. Jurgen Appel** from the *Niels Bohr Institute in Copenhagen*, and **Dr. Bruno Sanguinetti** from the *Group of Applied Physics in Geneva*.

Time and date: 14:20 - 16:00, Wednesday, September 7, 2011

Location: ETH Zurich Campus Hönggerberg (Science City), HCI G3. See maps at the end of this book.

Conference Dinner

The social event and conference dinner will be hosted at Kunsthaus Zürich.

The Kunsthaus is Zurich's main art gallery. It features paintings by Picasso, Leger, Matisse, Chagall, Mondrian, Klee and many more. Before the dinner and the reception you may explore the exhibitions and collections of the museum at your leisure.

The museum visit will be followed by a reception to socialize with colleagues and friends. The conference dinner will be served in the auditorium of the Kunsthaus, right adjacent to the collection. Reception and the dinner are catered by Segantini.

Time and date: 19:00 - 24:00, Thursday, September 8, 2011

Location: Kunsthaus Zürich, Heimplatz 1, 8001 Zurich. See map at the of this book.

Transportation from the campus to Kunsthaus Zurich is arranged. Two conference busses will depart from the ETH Hönggerberg bus stop of line 37 at 18:30 and 18:45.

Zurich Information

“Contemporary Zurich might still be home to the world’s fourth-biggest stock exchange and remains Switzerland’s financial engine, but it’s also (whisper it softly) surprisingly vibrant and trendy. Located on a picturesque river and lake whose water you can drink, easy to get around and a stranger to the hassled lifestyle that defines bigger cities, this affluent, fashion-conscious place enjoys the finest things in life.” Source: Lonely Planet.

Leisure Activities

- Bahnhofstrasse - Zurichs main downtown street, one of the world’s most exclusive shopping avenues
- Niederdorf - pedestrian zone with a big variety of bars, restaurants and shops
- Lindenhof - nice view to the old town, historical site of the former Roman castle
- Fraumünster - admire Marc Chagall’s stained-glass windows in the Fraumünster
- St. Peter Church - with the largest church clock-face in Europe
- Waterfront - head to a waterfront bar, either on Lake Zurich or the Limmat River
- Boat trip - "Zürichsee Schiffahrt" offers short trips (1.5h), as well as longer trips (4h)
- Uetliberg - take a train up Uetliberg for excellent panoramic views
- Alpamare in Pfäffikon, Schwyz - biggest indoor waterpark and spa in Europe

For more information on activities including a list of suggested restaurants and bars see www.qipc2011.ch.

Useful phone numbers

Police	117
Fire brigade	118
Ambulance	144
Toxicology Emergency Centre	145
Medical and Dental Emergency Services	+41 44 421 21 21
Directory enquiries within Switzerland	1818
Lost property office (City of Zurich)	+41 44 412 25 50

Plenary Sessions
Program and Abstracts

Atomic Systems

(Lecture room HCI G3; Chaired by Tilman Esslinger)

Mon	9:30 - 10:10	Immanuel Bloch Controlling and Observing Quantum Matter at the Single Atom Level
Mon	10:10 - 10:30	Aurélian Dantan Cavity EIT and all-optical switching using ion Coulomb crystals
Mon	10:30 - 10:50	Stephen Hogan Driving Rydberg-Rydberg transitions from a co-planar waveguide
Mon	11:20 - 11:50	Rainer Blatt Quantum Information Processing and Quantum Simulations with Trapped Ca^+ Ions
Mon	11:50 - 12:20	Peter Zoller Quantum Information with Engineered Dissipation in Quantum Optical Systems

Monday 9:30

Controlling and Observing Quantum Matter at the Single Atom Level

I. Bloch[1,2]
[1]Max-Planck Institut für Quantenoptik, Hans-Kopfermann Str. 1, 85748 Garching, Germany.
[2]Ludwig-Maximilians Universität, Schellingstrasse 4/II, 80799 Munich, Germany.

Over the past years, ultracold quantum gases in optical lattices have offered remarkable opportunities to investigate static and dynamic properties of strongly correlated bosonic or fermionic quantum many-body systems. In this talk I will show how it has recently not only become possible to image such quantum gases with single atom sensitivity and single site resolution, but also how it is now possible to coherently control single atoms on individual lattice sites within a strongly correlated quantum gas. These novel control and observation techniques have allowed us to detect hidden non-local order parameters of a many-body system that have previously been thought to be impossible to detect in an experiment. I will furthermore show how, by using optical superlattice structures in two dimensions, correlated quantum states such as a Resonating Valence Bond state can be prepared and its dynamical evolution observed.

Monday 10:10

Cavity EIT and all-optical switching using ion Coulomb crystals

A. Dantan, M. Albert, M. Drewsen
QUANTOP, Department of Physics and Astronomy, Aarhus University, DK-8000, Aarhus, Denmark.

Ensemble of cold ions, laser cooled to an ion Coulomb crystal, are a unique medium for CQED investigations [1]. Using $^{40}Ca^{+}$ ion crystals placed in an optical cavity, we report on observations of cavity Electromagnetically Induced Transparency and all-optical switching [2]. Changes from full absorption to full transmission of a single photon cavity probe field are observed in transparency windows of a few tens of kHz. These unprecedented narrow transparency windows are exploited to implement an EIT-based all-optical switching scheme, in which the transmission of the probe field is controlled by another weak cavity field. These results are promising for realizing quantum information processing devices, such as e.g. single-photon quantum memories and transistors, or for cavity optomechanics investigations.

[1] P. Herskind *et al.*, *Nature Physics* **5**, 494-498 (2009).

[2] M. Albert *et al.*, arxiv:1102.5010 (2011).

Monday 10:30

Driving Rydberg-Rydberg transitions from a co-planar waveguide

S. D. Hogan[1], T. Thiele[2], S. Filipp[2], J. Agner[1], F. Merkt[1] and A. Wallraff[2]
[1]Laboratory of Physical Chemistry, ETH Zurich, CH-8093, Zurich, Switzerland.
[2]Quantum Device Lab, ETH Zurich, CH-8093, Zurich, Switzerland.

With a view to investigating the coupling of Rydberg atoms to superconducting transmission line resonators [1], in the context of hybrid cavity quantum electrodynamics [2], we report on the resonant interaction of helium Rydberg atoms with microwave photons confined in co-planar waveguides. Using a pulsed, supersonic beam of helium Rydberg atoms that traverses a co-planar waveguide cooled to ~ 4 K, we have studied microwave transitions between Rydberg states, over a range of principal quantum numbers, by state-selective pulsed electric field ionization. From these measurements, the effects of stray electric fields, arising from surface-patch-potentials, on the transition line-widths and coherence times have been determined.

[1] A. Wallraff, D. I. Schuster, A. Blais, L. Frunzio, R.-S. Huang, J. Majer, S. Kumar, S. M. Girvin and R. J. Schoelkopf, *Nature* **431**, 162 (2004).

[2] J. M. Raimond, M. Brune and S. Haroche, *Rev. Mod. Phys.* **73**, 565 (2001).

Monday 11:20

Quantum Information Processing and Quantum Simulations with Trapped Ca^{+} Ions

Rainer Blatt[1,2]
[1]Institut für Experimentalphysik, Universität Innsbruck, A-6020, Innsbruck, Austria.
[2]Institut für Quantenoptik und Quanteninformation (IQOQI), Österreichische Akademie der Wissenschaften, A-6020 Innsbruck, Austria.

Trapped strings of cold ions provide an ideal system for quantum information processing. The quantum information can be stored in individual ions and these qubits can be individually prepared; the corresponding quantum states can be manipulated and measured with nearly 100% detection efficiency. With a small ion-trap quantum computer based on up to fourteen trapped Ca^{+} ions as qubits, GHZ-states were created and their decoherence was investigated [1]. Repetitive quantum error correction was realized with three qubits [2].

For quantum simulations we distinguish between analog and digital approaches. For analog quantum simulations a Hamiltonian is engineered exactly matching the system Hamiltonian while for digital quantum simulations we make use of a quantum computer as a quantum simulator. For this the system's quantum dynamics is decomposed into a sequence of quantum gate operations.

Analog quantum simulations were performed simulating the Dirac equation [3] and the scattering dynamics of relativistic quantum particles [4]. Digital quantum simulations were carried out using up to six qubits. With the available quantum gate toolbox, consisting of single qubit operations, two-qubit entangling operations and partial dephasing we engineer many-body interactions and perform open systems quantum simulations[5]. Using a Trotter expansion of the system Hamiltonians we simulate interacting spin-1/2 systems involving up to six ionic qubits with sequences of more than 100 fundamental gate operations.

[1] Th. Monz et al., Phys. Rev. Lett. **106**, 130506 (2011).

[2] P. Schindler et al., Science **332**, 1059-1061 (2011).

[3] R. Gerritsma et al., R. Gerritsma et al., Nature **463**, 68 (2010).

[4] R. Gerritsma et al., Phys. Rev. Lett. **106**, 060503 (2011).

[5] J. T. Barreiro et al., Nature **470**, 486 (2011).

Monday 11:50

Quantum Information with Engineered Dissipation in Quantum Optical Systems

P. Zoller[1], M. A. Baranov[1], S. Diehl[1], E. Rico[1]
[1]Institute for Theoretical Physics, University of Innsbruck, and Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020 Innsbruck.

We discuss various scenarios where engineered dissipation is used to generate and manipulate entangled states, and the implementation of these ideas with cold atoms and ions. In particular, we will show that topological states of matter can be obtained by controlled coupling to an environment. Up to now topological quantum phases have been discussed exclusively in the context of Hamiltonian systems. We will study in some detail the example of a driven dissipative 1D quantum wire which can be realized with cold fermionic atoms in an optical lattice[1]. The key feature is the existence of an invariant subspace hosting Majorana edge modes. The dissipative dynamics acts to isolate this subspace from the bulk via a Quantum Zeno effect. We demonstrate robustness against static disorder as well as nonabelian braiding statistics in a dissipative interferometer setup, obtained from adiabatic parameter changes in the Liouville operator generating dissipative dynamics.

[1] P. Zoller, M. A. Baranov, S. Diehl, E. Rico, unpublished.

Quantum Communication

(Lecture room HCI G3; Chaired by Renato Renner)

Mon	13:40 - 14:20	Nicolas Gisin Quantum Communications
Mon	14:20 - 14:40	Jürgen Eschner Entanglement-preserving absorption of single photons by a single atom
Mon	14:40 - 15:00	Lars Lydersen Superlinear threshold detectors in quantum cryptography
Mon	15:00 - 15:30	Matthias Christandl Quantum State Tomography
Mon	15:30 - 16:00	Jens Eisert A quantum information view on equilibration and the emergence of quantum statistical ensembles

Monday 13:40

Quantum Communications

N. Gisin
Group of Applied Physics, University of Geneva, Switzerland

Quantum communications is, on the application side, already relatively advanced with QRNG and QKD finding niche markets. However, on the academic research side quantum communication has still a long way to go until a functional quantum repeater can be developed. Quantum repeaters require, among others, quantum memories with memory times close to a second; this represents one grand challenge for quantum communication. Another grand challenge is the demonstration of device independent QKD.

Monday 14:20

Entanglement-preserving absorption of single photons by a single atom

J. Eschner[1,2], J. Huwer[1,2], J. Ghosh[1], M. Schug[1], N. Piro[2], C. Kurz[1], J. Brito[1]
[1]Experimentalphysik, Universität des Saarlandes, 66123 Saarbrücken, Germany.
[2]ICFO - Institut de Ciencies Fotoniques, 08860 Castelldefels (Barcelona), Spain.

We observe the absorption of single down-conversion photons by a single $^{40}Ca^{+}$ ion, heralded by the detection of the partner photons. A photon absorption event induces a quantum jump in the ion. The correlation function of the quantum jumps and the arrival times of the partner photons reveals the coincidence between the two events [1]. We demonstrate by quantum tomography that the polarization entanglement of the photon pairs is preserved in the absorption process.

[1] N. Piro *et al.*, *Nature Physics* **7**, 17 (2011).

Monday 14:40

Superlinear threshold detectors in quantum cryptography

L. Lydersen[1,2], N. Jain[3,4], C. Wittmann[3,4], Ø. Marøy[1,2], J. Skaar[1,2], C. Marquardt[3,4], V. Makarov[1], G. Leuchs[3,4]
[1]Department of Electronics and Telecommunications, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway.
[2]University Graduate Center, NO-2027 Kjeller, Norway.
[3]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany.
[4]Institut für Optik, Information und Photonik, University of Erlangen-Nuremberg, 91058 Erlangen, Germany.

Highly superlinear threshold detectors in quantum key distribution (QKD) allow eavesdropping the full secret key without being revealed [1]. Here, we discuss how this detector control attack performs against QKD with moderately superlinear detectors. The superlinearity of superconducting and avalanche photodiode (APD) threshold detectors is quantified, and shows that both types allow imperfect eavesdropping. The superlinearity of the APD allows eavesdropping using less than 120 photons per pulse. This is hardly revealed using an optical power meter at the receiver entrance.

[1] L. Lydersen *et al.*, *Nature Photonics* **4**, 686–689 (2010).

Monday 15:00

Quantum State Tomography

M. Christandl[1]
[1]Department of Physics, ETH Zürich, CH-8093, Zürich, Switzerland.

The reconstruction of a density matrix from experimental data is plagued by the problem of negative eigenvalues and the question of how to determine error bars. We propose a new method for quantum state tomography that provides natural solutions to both issues. Practical examples will illustrate this method.

Monday 15:30

A quantum information view on equilibration and the emergence of quantum statistical ensembles

J. Eisert[1], C. Gogolin[1], A. Riera[1], M. P. Müller[2], A. Flesch[3], M. Cramer[4], U. Schollwoeck[5], I. Bloch[5], S. Trotzky[5], Y. A. Chen[5]
[1]Freie Universität Berlin, 14195 Berlin, Germany.
[2]Perimeter Institute, Waterloo, ON N2L 2Y5, Canada.
[3]Forschungszentrum Jülich, 52425 Jülich, Germany.
[4]Universität Ulm, D-89069 Ulm, Germany.
[5]Ludwig-Maximilians-Universität, 80798 Munich, Germany.

This talk will be concerned with recent progress on understanding how quantum many-body systems out of equilibrium eventually come to rest. The first part of the talk will highlight theoretical progress on this question - employing ideas of Lieb-Robinson bounds, quantum central limit theorems and of concentration of measure [1, 2, 3, 4]. These findings will be complemented by experimental work with ultra-cold atoms in optical lattices, constituting a dynamical "quantum simulator", allowing to probe physical questions that are presently out of reach even for state-of-the-art numerical techniques based on matrix-product states [5]. The last part of the talk will sketch how based on the above ideas, a fully certifiable quantum algorithm preparing Gibbs states can be constructed, complementing quantum Metropolis algorithms [6].

[1] "Absence of thermalization in non-integrable systems", Phys. Rev. Lett. **106**, 040401 (2011).

[2] "Concentration of measure for quantum states with a fixed expectation value", Commun. Math. Phys. **303**, 785 (2011).

[3] "A quantum central limit theorem for non-equilibrium systems: Exact local relaxation of correlated states", New J. Phys. **12**, 055020 (2010).

[4] "Exact relaxation in a class of non-equilibrium quantum lattice systems", Phys. Rev. Lett. **100**, 030602 (2008).

[5] "Probing the relaxation of a strongly correlated 1D Bose gas towards equilibrium", submitted to Nature Physics (2011).

[6] "Gibbs states, exact thermalization of quantum systems and a certifiable algorithm for preparing thermal states", arXiv:1102.2389, submitted to Phys. Rev. Lett. (2011).

Charges and Spins

(Lecture room HCI G3; Chaired by Daniel Loss)

Mon	16:30 - 17:10	Amir Yacoby Control and Manipulation of Two-Electron Spin Qubits in GaAs Quantum Dots
Mon	17:10 - 17:30	Sergey Frolov Quantum information processing using semiconductor nanowires
Mon	17:30 - 17:50	Peter Leek Coupling a double quantum dot to a microwave resonator
Mon	17:50 - 18:20	Lieven Vandersypen Coherent control and correlations of electron spins in quantum dots
Mon	18:20 - 18:50	Charles Marcus Using a spin qubit to measure the fluctuating hyperfine environment

Monday 16:30

Control and Manipulation of Two-Electron Spin Qubits in GaAs Quantum Dots

A. Yacoby[1], H. Bluhm[1], O. Dial[1], M. Schulman[1]
[1]Department of Physics, Harvard University, Cambridge, MA.

Few electron spin qubits offer intriguing possibilities as carriers of quantum information. A leading example is the logical qubit composed of two-electron spins operated within a restricted subspace of the singlet (S) and the m=0 triplet (T0). Single qubit operations within this subspace are constructed out of the exchange interaction that controls the energy difference between the S and T0 states and a magnetic field gradient that mixes them. In this talk we will review some of the recent understanding of the noise spectrum associated with the exchange operation and its implications towards entangling two qubits. We will also present for the first time entangling operations between two such qubits based on full two bit tomography.

Monday 17:10

Quantum information processing using semiconductor nanowires

S. Frolov[1], S. Nadj-Perge[1], E. Bakkers[1,2], J. van den Berg[1], V. Pribiag[1], V. Mourik[1], K. Zuo[1], I. van Weperen[1], S. Plissard[2] and L. Kouwenhoven[1]
[1]Kavli Institute of Nanoscience, Delft University of Technology, The Netherlands.
[2]Department of Applied Physics, TU Eindhoven, The Netherlands.

I will describe our progress in the implementation of various elements of a nanowire-based quantum computer. We use nanowires of group III-V semiconductors that exhibit strong spin-orbit interaction, namely InAs and InSb. We have recently demonstrated spin-orbit qubits that are carried by single electrons and controlled by gigahertz electric fields [1]. Our current efforts are aimed at the generation of Majorana fermion bound states in nanowire/superconductor hybrids. This effort is driven by the prospects of topological protection of quantum states from a large variety of decoherence sources [2].

[1] S. Nadj-Perge, S.M. Frolov, E.P.A.M. Bakkers and L.P. Kouwenhoven, *Nature* **468**, 1084 (2010).

[2] R.F. Service, *Science* **332**, 193 (2011).

Monday 17:30

Coupling a double quantum dot to a microwave resonator

P. J. Leek[1], T. Frey[1], M. Beck[1], T. Ihn[1], A. Wallraff[1], K. Ensslin[1]
[1]Department of Physics, ETH Zürich, CH-8093, Zürich, Switzerland.

The fields of semiconductor quantum dots and superconducting circuits have both moved forward at a remarkable pace in the last 5 years, with both quantum technologies now holding great promise for practical quantum information processing (QIP). The concept of circuit quantum electrodynamics (QED), in which qubits are coupled to single microwave photons in a superconducting resonator has enabled much recent progress with superconducting circuits, and is a promising architecture for strong coupling cavity QED and QIP with a variety of other qubit systems. In this talk, I will present recent results of coupling a double quantum dot in GaAs, to a superconducting microwave resonator. The resonator transmission is used to measure the double dot system far into the regime in which transport is blocked to the leads, and coupling and coherence in the hybrid quantum circuit are analyzed.

Monday 17:50

Coherent control and correlations of electron spins in quantum dots

L. M. K. Vandersypen

Advances in nanotechnology and quantum engineering have made it possible to probe single spins in the solid-state. Today, we can routinely trap individual electrons in quantum dots defined by gates in a semiconductor 2D electron gas. Using a fully electrical approach, we can achieve coherent manipulation of the spin state of individual electrons, and coherent exchange of neighbouring spins. Independent read-out of two spins permits us to study this quantum dynamics, and to expose correlations in the spin states. Electron spin decoherence is dominated by hyperfine interactions with nuclear spins in the substrate. We are pursuing two methods to extend the coherence time: to reduce the randomness in the nuclear spin polarization, and to build quantum dots from zero-nuclear-spin materials. These should offer many orders of magnitude separation time between coherence times and gate operation times.

Monday 18:20

Using a spin qubit to measure the fluctuating hyperfine environment

J. Medford[1], C. Barthel[1], F. Kuemmeth[1], A. Higginbotham[1], C. M. Marcus[1], Ł. Cywiński[2], M. P. Hanson[3], A. C. Gossard[3]
[1]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA
[2]Institute of Physics, Polish Academy of Sciences, al. Lotników 32/46, PL 02-668 Warszawa, Poland
[3]Materials Department, University of California, Santa Barbara, California 93106, USA

The scaling of coherence time, T_2 with the number of echo pulses provides information about the spectral content of the dephasing environment of a qubit. For a power-law noise spectrum, theory relates this scaling to the functional form of recovered signal amplitude with echo sequence duration as well as to the exponent of the power-law that characterizes the environmental noise spectrum. This talk will present results of experimental studies by our group and on these scaling relations for spin qubits. In our lab, the experimental system is a two-electron double quantum dot formed by gates on the surface of a GaAs heterostructure. Excellent agreement with the power-law model is obtained, lending support to this simple model of the environment.

This research is supported by NSF Materials World Network, IARPA MQCO Program, and the DARPA QuEST program.

Superconducting Circuits

(Lecture room HCI G3; Chaired by Christoph Bruder)

Tue	9:30 - 10:10	Andrew Cleland A scalable quantum architecture for the phase qubit
Tue	10:10 - 10:30	Andreas Dewes Quantum Process Tomography and Grover's Algorithm on a 2 Transmon Quantum Processor
Tue	10:30 - 10:50	Christopher Wilson Using superconducting circuits to produce correlated microwave photons
Tue	11:20 - 11:50	Irfan Siddiqi Continuous monitoring of a superconducting qubit
Tue	11:50 - 12:20	Yasunobu Nakamura Superconducting qubits made of epitaxially grown Josephson junctions

Tuesday 9:30

A scalable quantum architecture for the phase qubit

Andrew N. Cleland, John M. Martinis, Matteo Mariantoni, H. Wang, T. Yamamoto, M. Neeley, Radoslaw C. Bialczak,Y. Chen, M. Lenander, Erik Lucero, A. D. O'Connell, D. Sank, M. Weides, J. Wenner, Y. Yin, J. Zhao, A. N. Korotkov
Department of Physics, University of California, Santa Barbara, Ca 93106, USA.

We have implemented a new and scalable quantum architecture for the superconducting phase qubit. The classical von Neumann architecture constituted a historic cornerstone in the conceptual development of today's classical computer. Building a similar architecture on a scalable quantum-mechanical platform represents a major advance towards the realization of a quantum processor. We have developed such an approach, where our hardware comprises a quantum central processing unit exchanging information with a quantum random access memory, integrated on a single chip in a von Neumann configuration. The design includes two superconducting qubits coupled through a quantum bus, two quantum memories, and two zeroing registers. The processing unit has been tested by performing a number of experiments controlling "classical" as well as entangled photons in the quantum memories, and has also been used to demonstrate the quantum Fourier transform as well as three-qubit Toffoli-class gates. We believe that the combination of the quantum von Neumann architecture, together with a software concept we term the "RezQu protocol", provides a clear and compelling path towards the implementation of a superconducting quantum computer

Tuesday 10:10

Quantum Process Tomography and Grover's Algorithm on a 2 Transmon Quantum Processor

A. Dewes[1], V. Schmitt[1], R. Lauro[1], F. Ong[1], P. Bertet[1], D. Vion[1], D. Esteve[1]
[1]DSM/IRAMIS/SPEC, Commisariat à l'Energie Atomique, F-91191, Gif Sur Yvette, France.

We present an experiment performed on two coupled Transmon[1] qubits forming a universal $i\mathbb{SWAP}^{1/2}$ quantum logic gate. Each of the qubits is equipped with its own circuit for driving and single-shot readout[2] and a fast flux line for frequency tuning. We perform quantum process tomography to characterize the operation of the $i\mathbb{SWAP}^{1/2}$ gate and obtain a fidelity of 88 %. Furthermore we run Grover's search algorithm on the system and obtain single-shot fidelities above the classical bound of 50 %, demonstrating quantum speed-up for this particular search problem.

[1] A. Wallraff *et al.*, *Nature* **431**, (2004).

[2] F. Mallet *et al.*, *Nature Physics* **5**, (2009).

Tuesday 10:30

Using superconducting circuits to produce correlated microwave photons

C. M. Wilson[1], I. Hoi[1], A. Pourkabiran[1], G. Johansson[1], P. Delsing[1]
[1]Chalmers Unversity, Gothenburg, Sweden.

Here we describe a series of experiments where we produce correlated microwave photons using superconducting circuits. In the first experiment, we study photon generation in an open transmission line with a nonadiabatically modulated boundary condition, where we are able to observe broadband two-mode squeezing of the emitted radiation. In the second experiment, we have embedded an artificial atom, a superconducting "transmon" qubit, in a 1D open space and investigated the scattering of incident microwave photons. When an input coherent state, with an average photon number much less than 1, is on resonance with the artificial atom, we observe extinction of up to 99% in the forward propagating field. We also study the statistics of the reflected and transmitted beams, which are predicted to be nonclassical states. In particular, we demonstrate photon antibunching in the reflected beam by measuring the g2 function.

Tuesday 11:20

Continuous monitoring of a superconducting qubit

D. Slichter[1], R. Vijay[1], I. Siddiqi[1]
[1]Quantum Nanoelectronics Laboratory, University of California, Berkeley, USA.

Great advances have been made in superconducting qubit technology since the first demonstration of coherent oscillations more than 10 years ago. Coherence times have improved by several orders of magnitude, basic gate operations and three qubit entanglement have been demonstrated, but the continuous, high-fidelity monitoring of the qubit state has remained an elusive target. This functionality can play a key role in quantum state feedback, and in particular measurement based error correction. We realize such a readout using a wide bandwidth, phase-sensitive parametric amplifier operating near the quantum noise limit. With this level of sensitivity, quantum jumps between the qubit states in a transmon and in a flux qubit are readily resolved in real time. I will discuss the statistics of the quantum jumps as well as the evolution of the qubit under simultaneous measurement and excitation.

Tuesday 11:50

Superconducting qubits made of epitaxially grown Josephson junctions

Y. Nakamura[1,2]
[1]NEC Green Innovation Research Laboratories, Tsukuba, Ibaraki 305-8501, Japan.
[2]RIKEN Advanced Science Institute, Wako, Saitama 351-0198, Japan.

Coherence of superconducting qubits is often affected by the presence of microscopic objects giving parasitic two-level systems. For reducing the density of those decoherence sources, improving the material and interface properties of the junctions and electrodes is needed. To this end, efforts for making epitaxial Josephson junctions have been made. Here we demonstrate transmon qubits using epitaxially grown NbN/AlN/NbN Josephson junctions. Dispersive measurement of the qubits coupled to a coplanar waveguide resonator show the energy relaxation time of $\sim$200–400 ns. We also observe that there remain a number of two-level systems coupled to the qubits. Besides the characterization, circuit quantum electrodynamics experiments with those qubits will be presented.

Special Topics

(Lecture room HCI G3; Chaired by Peter Zoller)

Tue	16:30 - 17:10	Ignacio Cirac Engineered dissipation and quantum information
Tue	17:10 - 17:30	Philip Walther Photonic Quantum Simulation of Frustrated Spin Systems
Tue	17:30 - 17:50	Philippe Corboz Recent advances in the simulation of strongly correlated systems in two dimensions with tensor network algorithms
Tue	17:50 - 18:20	Christophe Salomon Quantum Simulation of Strongly Correlated Quantum Gases
Tue	18:20 - 18:50	Fabian Hassler Top-transmon: hybrid superconducting qubit for parity-protected quantum computation

Tuesday 16:30

Engineered dissipation and quantum information

J. I. Cirac
Max Planck Institute für Quantenoptik, Hans-Kopfermann-Str. 1, 85748, Garching, Germany.

I will show how engineered dissipation can be used in order to build quantum repeaters, quantum memories, and other quantum information devices. I will also present possible implementations of those ideas with quantum optical systems.

Tuesday 17:10

Photonic Quantum Simulation of Frustrated Spin Systems

X. S. Ma[2], B. Dakic[1], W. Naylor[2], A. Zeilinger[1,2], P. Walther[1,2]
[1]Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, Austria. [2]Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences, Austria.

The precise single-particle addressability [1] and tunable measurement-induced interactions allow entangled photonic systems for the simulation of four spin-1/2 particles interacting via any Heisenberg-type Hamiltonian. The ground state properties of such quantum magnets may be important for the understanding of high-Tc superconductors, thus raising significant interest in the so-called valence-bond states. Depending on the interaction strength, frustration within the system emerges such that the ground state evolves from a localized to a resonating valence-bond state. The high level of single-particle quantum control allows to obtain fundamental insights by studying entanglement dynamics among individual particles [2].

[1] S. Barz, G. Cronenberg, A. Zeilinger, P. Walther, *Nature Photon.* **4**, 533 (2010)

[2] X.Ma, B.Dakic, W.Naylor, A.Zeilinger, P.Walther, *Nature Physics* **7**, 399 (2011)

Tuesday 17:30

Recent advances in the simulation of strongly correlated systems in two dimensions with tensor network algorithms

P. Corboz[1,2], B. Bauer[1], F. Mila[2], M. Troyer[1], G. Vidal[3], S. R. White[4]
[1]Theoretische Physik, ETH Zürich, CH-8093, Zürich, Switzerland.
[2]Institute for theoretical Physics, EPFL, CH-1015 Lausanne, Switzerland.
[3]School of Mathematics and Physics, Univ. of Queensland, QLD 4072, Australia.
[4]Dep. of Physics and Astronomy, Univ. of California, Irvine, CA 92697-4575 USA.

The simulation of strongly correlated fermionic and frustrated systems in two dimensions is one of the biggest challenges in computational physics. Through combining ideas from quantum information and condensed matter physics a new class of simulation techniques for many-body systems, the so-called tensor network algorithms, have been developed in the last few years. These algorithms have been generalized to fermionic systems recently. We demonstrate that infinite projected entangled-pair states (iPEPS) can compete with the best known variational methods. In particular, we show that for the t-J model iPEPS yields a lower variational energy than variational Monte Carlo and fixed-node Monte Carlo based on Gutzwiller projected ansatz wave functions.

Tuesday 17:50

Quantum Simulation of Strongly Correlated Quantum Gases

C. Salomon[1], N. Navon[1], S. Nascimbène[1], F. Chevy[1], B. Rem[1], S. Piatecki[1], K. Günter[1], W. Krauth[1], S. Pilati[2], S. Giorgini[2], A. Georges [3]
[1] Département de physique de l'Ecole Normale Supérieure, CNRS, UPMC 24 rue LHOMOND, 75231 Paris, France.
[2] Dipartimento di Fisica, Universit'a di Trento and INO-CNR BEC Center, I-38050 Povo, Trento, Italy.
[3] Centre de Physique Théorique, CNRS, Ecole Polytechnique, route de Saclay, 91128 Palaiseau Cedex, France and Collège de France, 11 place Marcellin Berthelot, 75005 Paris, France

Ultracold dilute atomic gases can be considered as model systems to address some pending problem in Many-Body physics that occur in condensed matter systems, nuclear physics, and astrophysics. We have developed a general method to probe with high precision the thermodynamics of locally homogeneous ultracold Bose and Fermi gases [1, 2, 4]. This method allows stringent tests of recent many-body theories. For attractive spin 1/2 fermions with tunable interaction (6Li), we will show that the gas thermodynamic properties can continuously change from those of weakly interacting Cooper pairs described by Bardeen-Cooper-Schrieffer theory to those of strongly bound molecules undergoing Bose-Einstein condensation. First, we focus on the finite-temperature Equation of State (EoS) of the unpolarized unitary gas. Surprisingly, the low-temperature properties of the strongly interacting normal phase are well described by Fermi liquid theory [3] and we localize the superfluid phase transition. A detailed comparison with theories including Monte-Carlo calculations has revealed some surprises and the Lee-Huang-Yang corrections for low-density bosonic and fermionic superfluids are quantitatively measured for the first time. Despite orders of magnitude difference in density and temperature, our equation of state can be used to describe low density neutron matter such as the outer shell of neutron stars. The equation of state of a strongly interacting 7Li Bose gas has also been measured and showed the universality of the first order beyond mean-field correction [4].

[1] S. Nascimbène, N. Navon, K. Jiang, F. Chevy, and C. Salomon, *Nature* **463**, 1057 (2010).

[2] N. Navon, S. Nascimbène, F. Chevy, and C. Salomon, *Science* **328**, 729 (2010)

[3] S. Nascimbène, N. Navon, S. Pilati, F. Chevy, S. Giorgini, A. Georges, and C. Salomon, *Phys. Rev. Lett.* ,**106**, 215303 (2011),

[4] N. Navon, S. Piatecki, K. Günter, B. Rem, T. C Nguyen, F. Chevy, W. Krauth, and C. Salomon, arXiv 1103.4449, to appear in Phys. Rev. Lett. (2011)

Tuesday 18:20

Top-transmon: hybrid superconducting qubit for parity-protected quantum computation

Fabian Hassler, Anton Akhmerov, and C. W. J. Beenakker
Instituut-Lorentz, Universiteit Leiden, P.O. Box 9506, 2300 RA Leiden, The Netherlands

Qubits constructed from uncoupled Majorana fermions are protected from decoherence, but to perform a quantum computation this topological protection needs to be broken [1]. Parity-protected quantum computation breaks the protection in a minimally invasive way, by coupling directly to the fermion parity of the system — irrespective of any quasiparticle excitations [2, 3]. Here, we propose to use a superconducting charge qubit in a transmission line resonator (a so-called transmon qubit [4]) to perform parity-protected rotations and read-out of a topological (top) qubit. The advantage over an earlier proposal using a flux qubit [3] is that the coupling can be switched on and off with exponential accuracy, promising a reduced sensitivity to charge noise [5].

[1] C. Nayak, S. H. Simon, A. Stern, M. Freedman, and S. Das Sarma, Rev. Mod. Phys. **80**, 1083 (2008).

[2] A. R. Akhmerov, Phys. Rev. B **82**, 020509(R) (2010).

[3] F. Hassler, A. R. Akhmerov, C.-Y. Hou, and C. W. J. Beenakker, New J. Phys. **12**, 125002 (2010).

[4] J. Koch, T. M. Yu, J. Gambetta, A. A. Houck, D. I. Schuster, J. Majer, A. Blais, M. H. Devoret, S. M. Girvin, and R. J. Schoelkopf, Phys. Rev. A **76**, 042319 (2007).

[5] F. Hassler, A. R. Akhmerov, and C. W. J. Beenakker, arXiv:1105.0315 (2011).

Photons

(Lecture room HCI G3; Chaired by Matthias Christandl)

Wed	9:30 - 10:10	Eugene Polzik Quantum interface between light and matter
Wed	10:10 - 10:30	Igor Dotsenko Quantum feedback loop for on-demand preparation and stabilization of photon number states in a cavity
Wed	10:30 - 10:50	Jeremy O'Brien Integrated Quantum Photonics
Wed	11:20 - 11:50	Konrad Lehnert Quantum state tomography of itinerant microwave fields
Wed	11:50 - 12:20	Paul Kwiat (Hyper)Entanglement (Un)bound

Wednesday 9:30

Quantum interface between light and matter

E. S. Polzik
Niels Bohr Institute, Copenhagen University

In recent years engineering of quantum states of macroscopic atomic objects with light has led to a number of advances [1, 2], such as quantum memory, teleportation and entanglement-assisted precision measurements below the level of quantum fluctuations dictated by the Heisenberg uncertainty principle for independent atoms. Key operations, such as generation of entangled states of atoms and light, quantum non-demolition measurements, and swapping of quantum states between photons and atoms have been demonstrated. Recent experiments with macroscopic room temperature atomic ensembles on entanglement-assisted magnetometry [3] and memory for EPR states [4] will be briefly reviewed, followed by the report on entanglement generated by dissipation. Typically, coupling of a system to an environment inhibits entanglement. Very recently we have demonstrated that dissipation in the form of collective photon scattering induces entanglement between two macroscopic objects rather than impairing it [5]. In the first experiment, entanglement is generated by dissipation and maintained for 0.04s. In the second experiment, the dissipative mechanism is combined with continuous measurements and we demonstrate steady state entanglement observed for up to an hour. Ways to extend quantum interface principles demonstrated for collective spin states of atomic gases to solid state devices, such as micro- and nano-electromechanical systems will be presented [6, 7].

[1] K. Hammerer, A. S. Sørensen, and E.S. Polzik,*Reviews of Modern Physics* **82**, 1041 (2010).

[2] H. J. Kimble. *Nature* **452**, 1023 (2008).

[3] W. Wasilewski *et al. Phys. Rev. Lett.*, **104**, 133601 (2010).

[4] K. Jensen *et al. Nature Physics* **7**,13 (2011).

[5] H. Krauter, C. A. Muschik, K. Jensen, W. Wasilewski, J. M. Petersen, J. I. Cirac, and E. S. Polzik, arXiv:1006.4344.

[6] K. Usami, A. Naesby, T. Bagci, B. Melholt Nielsen, J. Liu, S. Stobbe, P. Lodahl, and E.S. Polzik. arXiv:1011.3974.

[7] J. Taylor, A.S. Sørensen, C.M. Marcus, and E.S. Polzik. Laser cooling of LC electronic circuits. In preparation.

Wednesday 10:10

Quantum feedback loop for on-demand preparation and stabilization of photon number states in a cavity

I. Dotsenko[1], C. Sayrin[1], X. Zhou[1], B. Peaudecerf[1], S. Gleyzes[1], M. Brune[1], J. M. Raimond[1], S. Haroche[1,2]
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[2]Collège de France, 11 place Marcelin Berthelot, 75231 Paris Cedex 05, France.

We report on realization of a quantum feedback loop for deterministic preparation of photon number (Fock) states in a microwave cavity and their continual recovery after decoherence-induced quantum jumps [1]. The scheme [2] is based on weak quantum non-demolition field measurement with Rydberg atoms followed by real-time quantum state estimation. The loop is closed by injecting into the cavity a coherent pulse chosen to maximize the population of the target state. Starting from classical field and iterating the loop, we thus generate and stabilize Fock states of up to 4 photons.

[1] C. Sayrin *et al.*, *submitted*.

[2] I. Dotsenko *et al.*, *Phys. Rev. A* **80**, 013805 (2009).

Wednesday 10:30

Integrated Quantum Photonics

K Aungskunsiri[1], D Bonneau[1], E Engin[1], D Fry[1], P Kalasuwan[1], T Lawson[1], E Martin-Lopez[1], JCF Matthews[1], J Meinecke[1], A Peruzzo[1], K Poulios[1], P Shadbolt[1], P Jiang[1], A Laing[1], M Lobino[1], A Politi[1], X-Q Zhou[1], MG Thompson[1], JL O'Brien[1] & non-Bristol collaborators
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We have developed photonic devices for high performance, miniaturised quantum circuits, including multimode quantum interference devices with up to eight inputs and outputs [1], quantum walks of correlated particles in arrays of coupled waveguides [2] and efficient implementations of quantum logic circuits [3, 4]. Here we describe the latest applications of these techniques to reconfigurable quantum devices, quantum algorithms, quantum simulations, quantum metrology and quantum communication.

[1] A. Peruzzo *et al.*, *Nature Comm.* **2**, 224 (2011).

[2] A. Peruzzo *et al.*, *Science* **329**, 1500 (2010).

[3] X.Q. Zhou *et al.*, *Nature Comm.* to appear.

[4] R. Okamoto *et al.*, *Proc. Natl. Acad. Sci* to appear.

Wednesday 11:20

Quantum state tomography of itinerant microwave fields

K. W. Lehnert[1], F. Mallet[1], H. S. Ku[1], W. F. Kindel[1], S. Glancy[2], G. C. Hilton[2], K. D. Irwin[2], E. Knill[2], L. R. Vale[2].
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[2]National Institute of Standards and Technology, Boulder CO, 80305-3337, USA.

In an increasing number of experiments, information is encoded in the quantum state of a microwave signal confined in a cavity. For example, the state of superconducting qubits[1] and the position of mechanical oscillators[2] have been efficiently encoded into states of the microwave field. Once the microwave fields have exited the cavity, our ability to measure and manipulate those states is not as advanced. This is regrettable because a future quantum information processor may need to work with these itinerant modes. In this talk, I describe our effort to measure and control these modes. For example, we use quantum efficient Josephson parametric amplifiers[3] (JPAs) to tomographically reconstruct a squeezed state of a microwave field[4], which was itself created by another JPA. Furthermore pairs of such squeezed states can be combined on a beam splitter to create entanglement between two modes of the microwave field, forming the basis of a general quantum information processing strategy. We have begun to measure the correlations between these two modes. If these correlations exceed a classical bound, we will have shown that these two-modes are entangled.

[1] A. A. Houck *et al*, *Nature*, **449**, 328Ű331 (2007).

[2] J. D. Teufel *et al*, *Nature Nanotech.*, **4**, 820-823 (2009).

[3] M. A. Castellanos-Beltran *et al.*, *Nature Phys.* **4**, 929 (2008).

[4] F. Mallet *et al.*, *Phys. Rev. Lett.*, in press (2011).

Wednesday 11:50

(Hyper)Entanglement (Un)bound

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[2]Institut fuer Experimentalphysik, Universitaet Innsbruck, Innsbruck, Austria

In addition to its intrinsic importance as a central phenomenon–arguably the defining phenomenon–of quantum mechanics, entanglement is believed to be the critical resource for many applications in quantum information (QI). Indeed, optical entanglement has enabled many interesting and important milestones in QI, e.g., stringent tests of nonlocality, implementations of quantum cryptography and teleportation, and small quantum algorithms. Nevertheless, despite that photonic entanglement for QI was the first to be produced, experiments thus far have been limited to the probabilistic construction of larger multi-party entangled states from photon pairs (usually from parametric down conversion), and this method inherently scales exponentially poorly in the absence of on-demand sources of single photons and entangled photon pairs. One simple method to circumvent these limits is to use the extra entanglement already present in the photons pairs produced via down-conversion. In particular, it is now well verified that the photons can be prepared in states that are simultaneously entangled in multiple degrees of freedom (hyper-entangled), and also entangled across degrees of freedom (hybrid-entangled). Because such states reside in a larger Hilbert space, they can enable QI tasks that are otherwise very difficult (e.g., multi-qubit logic, or realizing more than a few qubits) or impossible (e.g., full Bell state analysis). Here we describe our efforts to use hyper-entanglement to produce states that are "bound entangled", i.e., they satisfy entanglement criteria despite that no entanglement can be distilled from them.

Industry Session

(Lecture room HCI G3; Chaired by Nicolas Gisin)

Wed	14:20 - 15:00	Bruno Michel Computing After Scaling: New Computation Paradigms
Wed	15:00 - 15:20	Grégoire Ribordy Commercializing Quantum Information Technology for 10 Years
Wed	15:20 - 15:40	Jürgen Appel Mesoscopic atomic superposition states for metrology and quantum information
Wed	15:40 - 16:00	Bruno Sanguinetti Quantum Cloning for Absolute Radiometry

Wednesday 14:20

Computing After Scaling: New Computation Paradigms

B. Michel
IBM Zurich Research Laboratory, Saeumerstr. 4, CH-8803 Rueschlikon, Switzerland

Wednesday 15:00

Commercializing Quantum Information Technology for 10 Years

G. Ribordy
ID Quantique SA, Chemin de la Marbrerie 3, CH-1227 Carouge, Switzerland

In this presentation, we will discuss the first applications of quantum information technology, which started to emerge about ten yeas ago, as well as current use cases.

Wednesday 15:20

Mesoscopic atomic superposition states for metrology and quantum information

J. Appel[1], S. Lund-Christensen[1], J.B. Beguin[1], P. Windpassinger[2], D. Oblak[3], J. Renema, A. Louchet[4], N. Kjærgaard[5], E. Polzik[1]
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[2] Present address: Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany
[3] Present address: IQIS, University of Calgary, 2500 University Drive NW, T2N 1N4 Calgary, Alberta
[4] Present address: LNE-SYRTE, Observatoire de Paris, CNRS, UPMC, 61 avenue de l'Observatoire, 75014 Paris, France.
[5] Present address: University of Otago, PO Box 56, Dunedin 9054, New Zealand

Neutral atoms are a well understood, controllable, cleanİphysical system and due to the identical electronic structure of each atom the coupling between light and matter can be easily enhanced by using ensembles.

Since the collective quantum state of the atoms is entangled with a light pulse propagating through and emerging from such an ensemble, by measuring the optical state and its quantum fluctuations, quantum noise limited measurements of the atomic state can be performed: optically dense atomic ensembles can be used for metrology as sensitive field sensors or for atomic clocks with a precision beyond the standard quantum limit.

Using shot noise limited Quantum-Non-Demolition measurements we prepare an entangled and spin squeezed ensemble of 10^5 cold Cs atoms [1] which we use to improve the precision of an atomic clock by $> 1\,\mathrm{dB}$ beyond the projection noise limit [2].

Non-Gaussian states are a valuable resource for quantum information and computation. We report on progress towards applying our method for realizing and characterizing such atomic states by performing a non-Gaussian measurement on the entangled light pulse and on using an ensemble of laser cooled atoms trapped along a nano-fiber [3].

[1] J. Appel *et al.*, *Proceedings Of The National Academy Of Sciences*, **106**:10960–10965, June 2009.

[2] A. Louchet-Chauvet *et al.*, *New Journal Of Physics*, **12**(6):065032, June 2010.

[3] E. Vetsch *et al.*, *Physical Review Letters*, **104**(20):203603, May 2010.

Wednesday 15:40

Quantum Cloning for Absolute Radiometry

B. Sanguinetti[1], E. Pomarico[1], T. Guerreiro[1], P. Sekatski[1] , R. Thew[1],
H. Zbinden[1], N. Gisin[1]
[1]Group of Applied Physics, University of Geneva, CH-1211 Geneva 4, Switzerland.

Comparing the performance of different devices, as well as comparing the results of different experiments is a crucial aspect of development in both industry and research. Accurate and accessible standards must therefore be developed. Here we will present how quantum cloning can be used to measure the absolute radiance of a source.

Max Planck's description of blackbody radiation [1] drew an initial fundamental link between quantum mechanics and radiometry. This link has been revived by the ability to precisely manipulate photonic system at the quantum level. Over the years, Quantum Radiometry has demonstrated its qualities as primary standard in the photon counting regime [2].

Recently we have demonstrated that through a good understanding of quantum cloning [3], quantum radiometry techniques can be extended to higher optical powers and that using a single-mode fibre based device significantly reduces the complexity of the system [4]. Our initial proof-of-principle experiment was able to measure absolute luminous power with an accuracy of 4%. The collaboration between the University of Geneva and PTB aims at reducing this uncertainty to below 1%.

[1] M. Planck. *Verhandlungen der Deutschen physik. Gesellschaft*, 2(13):687, 1901.

[2] S. V. Polyakov and A. L. Migdall. *J Mod Optic*, 56(9):1045–1052, 2009.

[3] N. Gisin and S. Massar. *Phys Rev Lett*, 79(11):2153–2156, Sept. 1997.

[4] B. Sanguinetti, E. Pomarico, P. Sekatski, H. Zbinden, and N. Gisin. *Phys Rev Lett*, 105(8), 2010.

Charges and Spins

(Lecture room HCI G3; Chaired by Thomas Ihn)

Wed	16:30 - 17:10	Misha Lukin Spin quantum bits in diamond: from long-lived memory to quantum interfaces.
Wed	17:10 - 17:30	Matthieu Delbecq Dynamics of a Kondo impurity coupled to an on-chip microwave cavity
Wed	17:30 - 17:50	Ronald Hanson Measurement-based initialization, manipulation and single-shot readout of a multi-spin quantum register
Wed	17:50 - 18:20	David Awschalom Quantum control and storage with single spins in diamond
Wed	18:20 - 18:50	Andrea Morello Single-shot readout and magnetic resonance of the electron and nuclear spins of a single phosphorus atom in silicon

Wednesday 16:30

Spin quantum bits in diamond: from long-lived memory to quantum interfaces.

Misha Lukin

We will discuss recent developments involving the use of quantum optical techniques for manipulation of individual spins and photons using atom-like impurities in diamond and control of light-matter interactions using sub-wavelength localization of optical fields. Applications of these techniques ranging from realization of long-lived quantum memory and novel approaches to quantum computation at room temperature to implementation of quantum optical networks and nanoscale magnetic sensing will be discussed.

Wednesday 17:10

Dynamics of a Kondo impurity coupled to an on-chip microwave cavity

M. R. Delbecq[1], V. Schmitt[1], F. D. Parmentier[1], N. Roch[1], J .J. Viennot[1], G. Fève[1], B. Huard[1], C. Mora[1], A. Cottet[1], T. Kontos[1]
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The recent development of circuit quantum electrodynamics has brought the possibility to study the interactions between light and circuits of arbitrary complexity on chip. Here, we demonstrate a hybrid architecture using single wall carbon nanotube based quantum dot (QD) inserted in a superconducting microwave cavity. At low temperature, this QD behaves as a tunable artificial atom where the Kondo effect is observable. Simultaneously to the low frequency transport spectroscopy, we study the response of the microwave cavity when the dot is in the Kondo regime. This allows us to probe dynamical aspects of the Kondo effect which are inaccessible to conventional transport measurements.

Wednesday 17:30

Measurement-based initialization, manipulation and single-shot readout of a multi-spin quantum register

L. Robledo[1], L. Childress[2], H. Bernien[1], T. van der Sar[1], G. de Lange[1], B. Hensen[1], M.S . Blok[1], R.Hanson[1],
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Nitrogen-Vacancy (NV) centers in diamond are promising building blocks for future quantum technologies, as they combine excellent spin coherence with a robust optical interface. Here, we demonstrate independent initialization and single-shot readout of the NV center electron spin and of individual surrounding hyperfine-coupled nuclear spins. Furthermore, we implement a universal set of quantum gates on the coupled electron-nuclear spin register. By integration of the gate action with dynamical decoupling techniques, high-fidelity operation is achieved even for gates that take much longer than the spin-echo decay time T_2. The combination of initialization, coherent control and readout paves the way for the first test of Bell's inequalities on solid-state spins and implementation of few-qubit algorithms in diamond.

Wednesday 17:50

Quantum control and storage with single spins in diamond

G. D. Fuchs, B. B Buckley, L. C. Bassett, and D. D. Awschalom
Center for Spintronics and Quantum Computation,
University of California, Santa Barbara, CA 93106, USA

The electronic spins of individual Nitrogen-vacancy (NV) centers in diamond are promising solid-state qubits because they can be initialized, manipulated, and measured at room temperature. Nonetheless, it remains a major challenge to couple many NV centers in a scalable architecture. To help meet this challenge we explore built-in interactions and resources that are present for every NV center. First, we demonstrate a room temperature quantum memory formed from the nuclear spin of the intrinsic nitrogen atom of the NV center [1]. Using rapid (120 ns) Landau-Zener transitions across a hyperfine-mediated avoided level crossing, we coherently store the NV center electronic spin state in the nitrogen nuclear spin with a fidelity of $88 \pm 6\%$. Next, we explore the low temperature (≈10 K) coherence between a single NV center spin and the polarization of near-resonant light [2]. Using this interaction, we can non-destructively measure the spin state by measuring the polarization of the transmitted light, and we can coherently manipulate the spin with optical pulses. Finally, we demonstrate that we can electrically tune the coherent optical transitions by applying voltages to lithographic gates [3], using the DC Stark effect to control the orbital Hamiltonian and compensate for sample inhomogeneities. With the incorporation of optical cavities to enhance the spin-photon coupling strength, these techniques could provide coherent coupling between single NV center spins and single photons in a scalable photonic network.

[1] G. D. Fuchs *et al.*, *submitted* (2011).

[2] B. B. Buckley *et al.*, *Science* **330**, 1212 (2010).

[3] L. C. Bassett *et al.*, *submitted* (2011) arXiv:1104.3878v1 [cond-mat.mes-hall].

Wednesday 18:20

Single-shot readout and magnetic resonance of the electron and nuclear spins of a single phosphorus atom in silicon

A. Morello[1], J. J. Pla[1], K. Y. Tan[1], J. J. L. Morton[2], J. P. Dehollain[1], W. H. Lim[1], F. A. Zwanenburg[1], C. Y. Jang.[3], D. N. Jamieson[3], A. S. Dzurak[1]
[1]CQC^{2}T and School of Elec. Eng. & Telecomm., University of New South Wales, Sydney NSW 2052, Australia.
[2]Department of Materials, Oxford University, Oxford OX1 3PH, United Kingdom.
[3]CQC^{2}T and School of Physics, University of Melbourne, VIC 3010, Australia.

Silicon is an ideal host for spin-based qubits in solid state [1]. It offers the potential for long spin coherence through isotopic purification of the nuclear bath [2], weak spin-orbit coupling, and compatibility with established nanofabrication techniques. The spin of a single dopant represents the ultimate frontier in miniaturization of solid-state qubits, and has the additional benefit of being coupled to a unique nuclear spin which can be used as ancilla qubit or quantum memory.

Using a new architecture for spin-to-charge conversion, based on tunnel-coupling a single P atom to a MOS single-electron transistor [3], we have demonstrated the ability to read out in single-shot the electron spin of a single P atom in silicon – with a visibility > 90 % – and measured a record spin lifetime $T_1 \approx 6$ s [4]. The spin readout technique opens the path to the observation of coherent spin dynamics in the electron and nuclear spin of a P atom.

We have added a broadband on-chip microwave transmission line to the spin readout device to perform single-electron spin resonance (ESR), detected by counting spin excited states in single-shot. We resolved the two hyperfine-split resonance lines of the ^{31}P donor and observe quantum jumps of the nuclear spin state. The nuclear spin readout fidelity is > 99.9 %. Through an electron-nuclear double-resonance experiment we verified the gyromagnetic ratio of the ^{31}P nuclear spin, providing uncontroversial proof that we measure a single P donor. The combined delivery of ESR and NMR pulses will allow the coherent control of the electron and nuclear spin of the P atom, and the demonstration of entanglement and conditional logic operations between the two spins.

[1] B. E. Kane *et al.*, *Nature* **393**, 133–137 (1998).

[2] W. M. Witzel *et al.*, *Phys. Rev. Lett* **105**, 187602 (2010).

[3] A. Morello *et al.*, *Phys. Rev. B* **80**, 081307(R) (2009).

[4] A. Morello *et al.*, *Nature* **467**, 687–691 (2010).

Mechanical Oscillators

(Lecture room HCI G3; Chaired by Tobias Kippenberg)

Thu	9:30 - 10:10	Oskar Painter Optomechanical crystals and their quantum optical applications
Thu	10:10 - 10:30	Albert Schliesser Optomechanically Induced Transparency
Thu	10:30 - 10:50	Mika Sillanpää Towards quantum limited electromechanical microwave amplification
Thu	11:20 - 11:50	Florian Marquardt Dynamics of optomechanical arrays
Thu	11:50 - 12:20	John Teufel Sideband cooling micromechanical motion to the quantum ground state

Thursday 9:30

Optomechanical crystals and their quantum optical applications

O. Painter[1], A. Safavi-Naeini[1], J. Chan[1], T. P. Meyer Alegre[1], J. T. Hill[1], A. Krause[1], S. Gröblacher[1]
[1]Thomas J. Watson, Sr., Laboratory of Applied Physics, California Institute of Technology, Pasadena, CA 91125

In the last several years, rapid advances have been made in the field of cavity optomechanics, in which the usually feeble radiation pressure force of light is used to manipulate (and precisely monitor) mechanical motion [1, 2, 3]. These advances have moved the field from the multi-km interferometer of a gravitational wave observatory, to the optical table top, and now all the way down to a silicon microchip [4]. In this talk I will describe these advances, and discuss our own work to realize radiation pressure within nanoscale structures in the form of coupled photonic and phononic crystals, dubbed optomechanical crystals [5]. Applications of these new nano-opto-mechanical systems include: all-optically tunable photonics, optically powered RF and microwave oscillators, and precision force/acceleration and mass sensing. Additionally there is the potential for these systems to be used in hybrid quantum networks, enabling storage or transfer of quantum information between disparate quantum systems. I will introduce several conceptual ideas regarding phonon-photon translation [6] and slow light effects [7] which may be used in such quantum settings, and discuss recent experiments to realize them in practice [8].

[1] T. Kippenberg *et al.*, *Science* **321**, 1172-1176 (2008).

[2] I. Favero *et al.*, *Nature Physics* **3**, 201-205 (2009).

[3] D. Van Thourhout *et al.*, *Nature Photonics* **4**, 211-217 (2010).

[4] M. Li *et al.*, *Nature* **456**, 480-484 (2008).

[5] M. Eichenfield *et al.*, *Nature* **462**, 78-82 (2009).

[6] A. Safavi-Naeini *et al.*, *New Journal of Physics* **13**, 013017 (2011).

[7] D. Chang *et al.*, *New Journal of Physics* **13**, 023003 (2011).

[8] A. Safavi-Naeini *et al.*, *Nature* **472**, 69-73 (2011).

Thursday 10:10

Optomechanically Induced Transparency

A. Schliesser[1,2], S. Weis[1], R. Rivière[2], S. Deléglise[1], E. Verhagen[1], E. Gavartin[1], O. Arcizet[2], T. J. Kippenberg[1,2]
[1]École Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland.
[2]Max-Planck-Institute of Quantum Optics, 85748 Garching, Germany

In atoms and molecules, electromagnetically induced transparency occurs when the presence of a control field induces quantum interference of excitation pathways for an electronic transition driven by a probe field. Here, we report the observation of the conceptually related effect of "Optomechanically induced transparency" (OMIT). An optical control beam tuned to a sideband transition of an optomechanical system leads to destructive interference for the excitation of an intracavity probe field. This results in a transparency window for the probe beam, whose depth, width, and dispersion can be tuned by the control beam. OMIT can therefore be used to switch, slow and store light all-optically in on-chip optomechanical arrays, and may enable photon-phonon quantum state transfer [1].

[1] S. Weis *et al.*, *Science* **330**, 1520–1523 (2010).

Thursday 10:30

Towards quantum limited electromechanical microwave amplification

F. Massel[1], T. Heikkilä[1], J. Pirkkalainen[1], S. U. Cho[1], P. Hakonen[1] and M. Sillanpää[1]
[1]Low Temperature Laboratory, Aalto University, Finland.

Micromechanical resonators affected by radiation pressure forces allow to address fundamental questions on quantum properties of mechanical objects, or, to explore quantum limits in measurement and amplification. A promising setup for the purpose is an on-chip microwave cavity coupled to a micromechanical resonator. We demonstrate, both theoretically and experimentally, the possibility of using its sideband regime as a microwave amplifier, with noise properties approaching the quantum regime. Under blue sideband irradiation, pump photons will be down-converted, transferring energy into the mechanical resonator. We will here show that addition of a probe signal will induce coherent stimulated emission, leading to its amplification up to 30 dB. A full quantum theory is found to be in a good agreement with the experiment. In the opposite regime, by pumping the red sideband, we cooled the 30 MHz mechanical mode to thermal occupancy of only 1.5 quanta.

Thursday 11:20

Dynamics of optomechanical arrays

F. Marquardt[1], M. Ludwig[1], G. Heinrich[1], J. Qian[2], A. Kronwald[1], M. Schmidt[1], B. Kubala[1]
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Cavity optomechanical systems are a new class of systems being studied at the intersection of nanophysics and quantum optics. Localized mechanical modes are coupled to the radiation forces exerted by light circulating in a laser-driven optical resonance. The recent introduction of optomechanical photonic crystals opens the door towards exploiting many coupled optical and vibrational modes. In this talk, I will present our ideas on the collective dynamics of optomechanical arrays. As I will show, these systems could be used to observe classical synchronization physics, perform tasks of continuous variable quantum information processing, and study questions of nonequilibrium quantum many-body physics.

Thursday 11:50

Sideband cooling micromechanical motion to the quantum ground state

J. D. Teufel[1], T. Donner[2], Dale Li[1], J. W. Harlow[2,3], M. S. Allman[1,3], K. Cicak[1], A. J. Sirois[1,3], J. D. Whittaker[1,3], K. W. Lehnert[2,3] and R. W. Simmonds[1]
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Accessing the full quantum nature of a macroscopic mechanical oscillator first requires elimination of its classical, thermal motion. The flourishing field of cavity opto- and electro-mechanics provides a nearly ideal architecture for both preparation and detection of mechanical motion at the quantum level. We realize such a system by coupling the motion of an aluminum membrane to the resonance frequency of a superconducting, microwave circuit. When this âĂŸcavityâĂŹ is excited with coherent microwave photons near its resonance, the displacement of the membrane becomes encoded as modulation of this tone. The microwaves, in turn, also impart forces back on the oscillator, which enforce the Heisenberg limits on measurement and can also be exploited either to cool or amplify the motion. The electromechanical coupling is sufficient for the driven system to enter the strong-coupling regime, where the normal modes are now hybrids of the original radio-frequency mechanical and the microwave electrical resonances. This normal-mode splitting is verified by direct spectroscopy of the âĂŸdressed statesâĂŹ of the hybridized cavity resonance, showing excellent agreement with theoretical predictions [1]. The radiation pressure force of the coherent drive also damps and cools the membrane motion, analogously to laser cooling of trapped ions. A nearly shot-noise limited, microwave Josephson parametric amplifier is used to detect the mechanical sidebands of this microwave excitation and quantify the thermal motion of the oscillator as it is cooled with radiation pressure forces to its quantum ground state [2].

[1] J. D. Teufel *et al.*, *Nature* **471**, 204-208 (2011).

[2] J. D. Teufel *et al.*, *Nature*, to be published (2011).

Atomic Systems

(Lecture room HCI G3; Chaired by Jonathan Home)

Thu	15:50 - 16:30	Chris Monroe Quantum Networks of Trapped Atoms
Thu	16:30 - 16:50	Kenton Brown Single quantum exchange between ions in separate locations
Thu	16:50 - 17:10	Stephan Ritter A single-atom quantum memory
Thu	17:10 - 17:40	Philipp Treutlein Quantum metrology with ultracold atoms on a chip
Thu	17:40 - 18:10	Dieter Meschede Bottom up to Discrete Quantum Simulation with Neutral Atoms

Thursday 15:50

Quantum Networks of Trapped Atoms

C. Monroe, M. Bedi, W. Campbell, S. Clark, S. Debnath, E. Edwards, B. Fields, D. Hayes, D. Hucul, R. Islam, S. Korenblit, A. Lee, L. Luo, K. Lee, A. Manning, J. Mizrahi, C. Senko, J. Smith
Joint Quantum Institute, University of Maryland Department of Physics and National Institute of Standards and Technology, College Park, Maryland 20742, USA.

Trapped atoms are among the most promising candidates for quantum information processing, with each atom typically storing a single quantum bit (qubit) of information in appropriate internal electronic levels. Entangling operations are then accomplished through a suitable interaction between the atoms, usually controlled through external fields. All of the fundamental quantum operations have been demonstrated between small numbers of trapped atoms, and the central challenge now is how to scale the system to larger numbers of interacting qubits. This introductory lecture concentrates on the use and scaleup of trapped atomic ions, although many of these ideas are also applicable to neutral atoms.

The Coulomb interaction between trapped ions allows entangling operations through the collective motion of the ion crystal, which is excited through the application of external electromagnetic fields. Such a quantum network may be limited in size by the stability and coherence of the motion of larger ion crystals, and current efforts are devoted to the physical movement of individual atomic ions through complex ion trap structures [1] or alternatively by mapping qubits onto photons that can allow the probabilistic entanglement between remotely-located atomic crystals [2]. Work on both fronts will be reported, including quantum simulations of magnetism with $N = 16$ atomic qubits as well as progress on operating deterministic gates between atoms separated by macrosccopic distances.

[1] D. Kielpinski *et al.*, *Nature* **417**, 709 (2002).

[2] L.-M. Duan and C. Monroe, *Rev. Mod. Phys.* **82**, 1209 (2010).

Thursday 16:30

Single quantum exchange between ions in separate locations

K. R. Brown[1,2], C. Ospelkaus[1], Y. Colombe[1], A. C. Wilson[1], D. Leibfried[1], D. J. Wineland[1]
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The Coulomb-mediated couping of ions held in separate trapping potentials has potential applications in quantum simulation, logic, and spectroscopy. If the ion motional frequencies are tuned into resonance, energy will periodically exchange between the ions due to their coupling. However, at the single quantum level such an exchange had not been observed until recently [1]. Here we trap two $^{9}Be^{+}$ ions in separate potential minima above a surface electrode ion trap with cryogenically cooled electrodes. Microfabricating the trap and cooling the electrodes enables a coupling rate that exceeds the rate of motional decoherence. This work was supported by IARPA, DARPA, ONR and the NIST Quantum Information Program.

[1] K. R. Brown *et al.*, *Nature* **471**, 196–199 (2011).

Thursday 16:50

A single-atom quantum memory

S. Ritter, H. P. Specht, C. Nölleke, A. Reiserer, M. Uphoff, E. Figueroa, G. Rempe
Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str.1, D-85748 Garching

The implementation of quantum networks requires efficient memories for arbitrary quantum states. We report on the most fundamental implementation of a photonic quantum memory, based on a single atom trapped inside a high-finesse optical cavity [1]. In the storage process, the polarization state of a single photon is mapped onto the internal Zeeman state of the atom. After a variable storage time, it can faithfully be recreated with a fidelity of 93 %. Atom-cavity systems have great prospects as universal quantum nodes that can send, receive, store and process photonic quantum information. In future quantum networks, these nodes could be entangled by producing a single photon entangled with its emitting atom and sending it to a remote node where it is absorbed. We will discuss our progress towards a first demonstration of this deterministic protocol with two remote, independent systems.

[1] H. P. Specht *et al.*, *Nature* **473**, 190–193 (2011).

Thursday 17:10

Quantum metrology with ultracold atoms on a chip

R. Schmied[1], C. Ockeloen[1], P. Böhi[1], M. F. Riedel[1], P. Treutlein[1]
[1]Department of Physics, University of Basel, CH-4056 Basel, Switzerland.

We present our work on quantum metrology with ultracold atoms on an atom chip. In our experiment, we generate entanglement in a two-component Bose-Einstein condensate by controlling collisional interactions with a state-dependent microwave potential. We employ this technique to generate spin-squeezed states of the BEC that are a useful resource for quantum metrology with chip-based atomic clocks [1]. The observed reduction in spin noise combined with the spin coherence implies multi-particle entanglement.
To characterize the quantum state of the atoms, we have developed a new technique for quantum state tomography on the Bloch sphere and use it to reconstruct the Wigner function of the squeezed BEC [2]. Our reconstruction technique naturally takes finite experimental resolution and noise into account. From the reconstructed Wigner function we determine the quantum Fisher information, which quantifies the usefulness of the produced state for quantum metrology.
High-resolution imaging of electromagnetic fields is a metrology task for which atom chips are well-suited. We have used ultracold atoms for microwave field imaging near on-chip waveguides [3]. This novel technique is of interest for testing and optimizing integrated microwave circuits, which are at the heart of modern communication technology.

[1] M. F. Riedel *et al.*, Nature **464**, 1170 (2010).

[2] R. Schmied and P. Treutlein, arXiv:1101.4131 (2011), to appear in New J. Phys.

[3] P. Böhi *et al.*, Appl. Phys. Lett. **97**, 051101 (2010).

Thursday 17:40

Bottom up to Discrete Quantum Simulation with Neutral Atoms

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Atomic many body quantum systems promise to provide experimental tools that can be used to realize so called quantum simulators or to implement processes in quantum information science. Current methods based on systems of neutral atoms can be roughly divided into two classes: The top-down approach begins with a large ensemble of ultra cold atoms, e.g. a Bose-Einstein condensate. In contrast, the bottom-up approach seeks to initially prepare individual atoms and construct many body systems step by step. Here, one of the most interesting topics is the creation, investigation and application of many body quantum correlations.

The microscope image (Fig. 1) shows a coherently split single atom. I will discuss the necessary tools to realize this non-local situation: Tools for preparing, trapping, selectively addressing and transporting individual atoms, for storing and retrieving information from the atomic qubits. In quantum simulators self interference and interference of different atomic trajectories plays an important role. We have studied such matter wave interferences at the single trapped atom level including a realization of the quantum analogue of Brownian motion, the quantum walk and a single atom interferometer. I will also discuss the perspectives of realizing controlled atom-atom interactions in our experiments.

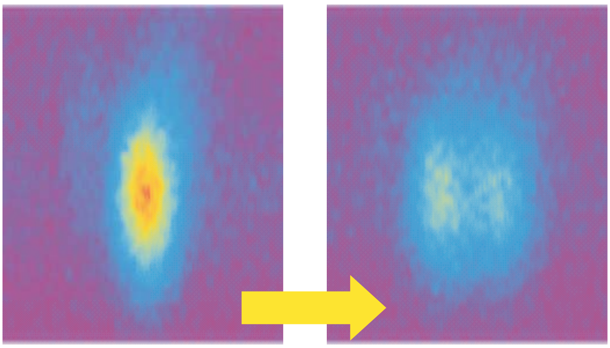

Figure 1: A single atom is prepared (upper image) and subsequently promoted to a spin up- spin down superposition state. A second image is taken after transporting the partial waves by 3 μm to opposite sides. The image is an average of 1000 shots.

Quantum Information Theory

(Lecture room HCI G3; Chaired by Gianni Blatter)

Fri	9:30 - 10:10	Charles Bennett
Fri	10:10 - 10:30	Beni Yoshida Feasibility of self-correcting quantum memory and thermal stability of topological order
Fri	10:30 - 10:50	Florian Fröwis Stable Macroscopic Quantum Superpositions
Fri	11:20 - 11:50	Andreas Winter Structure of LOCC
Fri	11:50 - 12:20	Tobias Osborne The variational method, quantum fields, and cavity QED

Friday 9:30

Abstract not available

C. Bennett

Friday 10:10

Feasibility of self-correcting quantum memory and thermal stability of topological order

B. Yoshida[1]
[1] Center for Theoretical Physics, MIT, Cambridge, Massachusetts, USA.

Recently, it has been realized that thermal stability of topologically ordered systems, as discussed in condensed matter physics, can be analyzed by addressing the feasibility of efficient self-correcting quantum memory, as studied in quantum information science. Here, with this correspondence in mind, we propose a model of quantum codes which may cover a large class of physically realizable quantum memory. The model is supported by a certain class of gapped spin Hamiltonians with translation symmetries and a small number of ground states that does not grow with the system size. We provide a complete solution of the model and show that the model does not work as self-correcting quantum memory, and thus, does not have topological order at any finite temperature.

[1] B. Yoshida, *Annals of Physics* **326**, 15-95 (2011).

[2] B. Yoshida, arXiv:1103.1885 (2011).

Friday 10:30

Stable Macroscopic Quantum Superpositions

F. Fröwis[1], W. Dür[1]
[1]Institut für Theoretische Physik, Universität Innsbruck, A-6020, Innsbruck, Austria.

We study the stability of superpositions of macroscopically distinct quantum states under decoherence. We introduce a class of quantum states with entanglement features similar to Greenberger-Horne-Zeilinger (GHZ) states, but with an inherent stability against noise and decoherence. We show that in contrast to GHZ states, these so-called concatenated GHZ states remain multipartite entangled even for macroscopic numbers of particles and can be used for quantum metrology in noisy environments. This can be shown by explicit master equation simulations. We also propose a scalable experimental realization of these states using existing ion-trap setups. [1].

[1] F. Fröwis and W. Dür, Phys. Rev. Lett. **106**, 110402 (2011).

Friday 11:20

Structure of LOCC

A. Winter[1,2]; joint work with E. Chitambar, D. Leung and T. Moriarty
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[2]Centre for Quantum Technologies, National University of Singapore, Singapore 117542.

Even more mysterious than the set of separable quantum states, the class of local operations and classical communication (LOCC) on a composite quantum system is an object almost not understood at all. The reason that we care about separable states is that entanglement in mixed states is in the end defined as non-separability. Likewise, the quantitative theory of entanglement rests on the axiom of monotonicity under LOCC.

In this talk we will review certain basic, if not elementary, facts about LOCC, including rigorous mathematical definitions of LOCC and its finite-round subsets. We will see that each round of communication may strictly increase the power of the accessible transformations. Furthermore, in contrast to many other natural classes of state transformations, we can show that the class LOCC (with unbounded rounds) is not closed. As a corollary, we conclude that there are tasks that cannot be performed by LOCC, although they can be solved to arbitrary precision, requiring more and more rounds of communication. In the process we encounter a number of interesting state discrimination and entanglement distillation tasks and protocols.

Friday 11:50

The variational method, quantum fields, and cavity QED

T. J. Osborne[1], J. I. Cirac[2], J. Eisert[3], J. Haegeman[4], H. Verschelde[4], F. Verstraete[5]
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[2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, Garching, D-85748, Germany.
[3]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany.
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[5]University of Vienna, Faculty of Physics, Boltzmanngasse 5, A-1090 Wien, Austria.

During the past 20 years the variational method has enjoyed considerable success in the study of one-dimensional strongly interacting quantum lattice systems. This is due, largely, to the expressive power of a variational class of states known as *matrix product states* (MPS). Recently, based on insights emerging from quantum information theory in the study of quantum entanglement, several new variational classes have been introduced: *projected entangled-pair states* (PEPS), generalising MPS for higher dimensional lattice systems, and the *multiscale entanglement renormalisation ansatz* (MERA), for critical lattice systems. Here I report on work extending the MPS, PEPS, and MERA classes to the setting of strongly interacting quantum fields [1, 2, 3, 4]. I'll also describe connections with the formalism exploited in the study of the variational method applied to these classes with cavity QED.

[1] F. Verstraete, J. I. Cirac, *Phys. Rev. Lett.* **104**, 190405 (2010).

[2] T. J. Osborne, J. Eisert and F. Verstraete, *Phys. Rev. Lett.* **105**, 260401 (2010).

[3] J. Haegeman, J. I. Cirac, T. J. Osborne, H. Verschelde, F. Verstraete, *Phys. Rev. Lett.* **105**, 251601 (2010); PoS FacesQCD 029 (2010).

[4] J. Haegeman, T. J. Osborne, H. Verschelde, F. Verstraete, arXiv:1102.5524.

Parallel Contributed Sessions
Program and Abstracts

Session A: Atomic Systems

(Lecture room HCI G3; Chaired by Philipp Treutlein)

Tue	14:20 - 14:40	Roee Ozeri Single-ion quantum lock-in amplifier
Tue	14:40 - 15:00	Jordi Mur-Petit Temperature independent quantum logic for molecular spectroscopy
Tue	15:00 - 15:20	Alexei Ourjoumtsev Observation of squeezed light from one atom excited with two photons
Tue	15:20 - 15:40	Andreas Walther High precision measurement techniques for improving the scalability of ion trap quantum computing
Tue	15:40 - 16:00	Anna Grodecka-Grad Spatial multimode quantum memories based on Λ-type atomic ensembles

Tuesday 14:20

Single-ion quantum lock-in amplifier

S. Kotler, N. Akerman, Y. Glickman, A. Keselman, and R. Ozeri
Department of Physics of Complex Systems, Weizmann Institute of Science, Rehovot 76100, Israel.

Ultra-cold trapped ions can be used as highly sensitive quantum probes. In this work we use a single trapped-ion as a quantum lock-in amplifier, where all the lock-in operations: modulation, detection and mixing, are performed via the application of non-commuting quantum operators on its electronic spin state. We thus significantly increase its sensitivity to external fields while extending phase coherence to more than one second. With this technique we measure frequency shifts (magnetic fields) with an uncertainty below 10 mHz (350 fT). This sensitivity is sufficient for the detection of the magnetic field of a single electronic-spin one micrometer from an ion-detector. As a first application of this technique we perform precision light shift spectroscopy of a narrow optical quadruple transition [1].

[1] S. Kotler, N. Akerman, Y. Glickman, A. Keselman, and R. Ozeri, *Nature* **473**, 61-65 (2011).

Tuesday 14:40

Temperature independent quantum logic for molecular spectroscopy

J. Mur-Petit[1], J. Pérez-Ríos[1], J. Campos-Martínez[1], M. I. Hernández[1], S. Willitsch[2], J. J. García-Ripoll[1]
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[2]Department of Chemistry, University of Basel, Basel, Switzerland.

Very recently, trapping and cooling to the mK regime has been extended to molecular ions in well defined internal states [1], opening a new window for precision spectroscopy of molecular species. We propose a fast, non-destructive and temperature independent spectroscopy method for molecular ions that implements quantum logic schemes [2] between an atomic ion and the molecular ion of interest,using optical forces on the atom, and optical forces or magnetic field gradients on the molecule. This method applies to a wide range of molecular ionic species and sets a starting point for a hybrid quantum computation scheme with molecular and atomic ions, covering the measurement and entangling steps.

[1] X. Tong, A. H. Winney, and S. Willitsch, *Phys. Rev. Lett.* **105**, 143001 (2010).

[2] P. O. Schmidt *et al.*, *Science* **309**, 749-752 (2005).

Tuesday 15:00

Observation of squeezed light from one atom excited with two photons

A. Ourjoumtsev[1,2], A. Kubanek[1], M. Koch[1], C. Sames[1], P. W. H. Pinkse[1], G. Rempe[1], K. Murr[1]
[1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany
[2]Laboratoire Charles Fabry de l'Institut d'Optique, CNRS UMR 8501, Université Paris Sud XI, 2. Av. Augustin Fresnel, RD 128, F-91127 Palaiseau, France

We generated squeezed light with a single atom in a high-finesse optical resonator. The strong coupling of the atom to the cavity field induces a genuine quantum mechanical nonlinearity, several orders of magnitude larger than for usual macroscopic media. This produces observable quadrature squeezing with an excitation beam containing on average only two photons per system lifetime. The ability of a single atom to induce strong coherent interactions between propagating photons opens up new perspectives for photonic quantum logic with single emitters [1].

[1] A. Ourjoumtsev *et al.*, *arXiv:1105:2007*, accepted in Nature (2011).

Tuesday 15:20

High precision measurement techniques for improving the scalability of ion trap quantum computing

A. Walther, U. Poschinger, F. Ziesel, M. Hettrich, A. Wiens, M. Schnorr, J. Welzel, K. Singer and F. Schmidt-Kaler
Institut für Quantenphysik, Uni Mainz, Staudingerweg 7, 55128 Mainz, Germany

Two techniques for advancing the state of scalable quantum computing (QC) in ion traps are presented. The first one is a novel homodyne detection of the interference between two parts of an ion wavepacket, where the motional state of the ion is entangled with its spin state [1]. We use this technique to characterize the phase space trajectory of the ion with high enough accuracy to find deviations from the linear approximation to the spin dependent light force. Secondly, we employ a single ion to measure a magnetic field gradient with a relative sensitivity of $\Delta B/B \sim 5 \cdot 10^{-7}$ over a 100 μm distance, which is shown to be quantum shot noise limited [2]. The compensation of gradients helps to increase the coherence time of transported qubits in scalable QC.

[1] U. Poschinger *et al.,* Phys. Rev. Lett. **105**, 263602 (2010).

[2] A. Walther *et al.*, preprint available at arXiv:1105.1710v1 (2011).

Tuesday 15:40

Spatial multimode quantum memories based on Λ-type atomic ensembles

A. Grodecka-Grad[1], E. Zeuthen[1], A. S. Sørensen[1]
[1]QUANTOP, Danish National Research Foundation Center for Quantum Optics, Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen Ø, Denmark

Efficient and multimode quantum interfaces between light and matter are crucial building blocks for quantum communication. We develop a three dimensional theory for spatial quantum memories based on Λ-type atomic ensembles of finite spatial extent [1]. We study the influence of the optical depth and the Fresnel number of the atomic ensemble on the efficiencies of memories. We show that optically dense atomic medium can serve as highly efficient memory even for small Fresnel numbers $F \geq 0.1$. We demonstrate that such quantum light-atom interfaces are capable of storing many transverse spatial modes and can thus act as spatial multimode quantum memories. Finally, we calculate the capacity of such spatial quantum memories and its dependence on the physical parameters.

[1] E. Zeuthen, A. Grodecka-Grad, and A. S. Sørensen, submitted (May 2011).

Session B: Quantum Communication

(Lecture room HCI G7; Chaired by Grégoire Ribordy)

Tue	14:20 - 14:40	Tim J. Bartley Toolbox for robust, scalable distillation of continuous variable entanglement
Tue	14:40 - 15:00	Félix Bussières A solid-state quantum memory for entangled photons
Tue	15:00 - 15:20	Cosmo Lupo Optimal resources for multimode quantum teleportation
Tue	15:20 - 15:40	Matthias Staudt Towards a coherent quantum microwave to optical photon interface
Tue	15:40 - 16:00	Nuala Timoney Atomic frequency comb memory with spin wave storage in $^{153}Eu^{3+}:Y_2SiO_5$

Tuesday 14:20

Toolbox for robust, scalable distillation of continuous variable entanglement

T. J. Bartley[1], H. Coldenstrodt-Ronge[1], G. Donati[1], L. Zhang[1], A. Datta[1], X. Jin[1], B. Smith[1], I. A. Walmsley[1]
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Efficient distribution of entanglement is of fundamental importance in facilitating worldwide quantum communication. To overcome degradation of entanglement one can interact a set of weakly entangled states to generate a smaller set of more entangled states, known as entanglement distillation. A scalable approach to entanglement distillation in the continuous variable (CV) regime has been theoretically proposed by Browne *et al* [1]. Central to measuring CV entanglement and verifying distillation is the phase between the entangled modes. We present a set of tools to perform and verify this protocol, which are robust to phase fluctuations between the entangled modes and scalable to include multiple sources of two-mode entanglement.

[1] D. Browne *et al.*, *Phys. Rev. A* **67**, 6, 062320 (2003).

Tuesday 14:40

A solid-state quantum memory for entangled photons

C. Clausen[1], I. Usmani[1], F. Bussières[1], N. Sangouard[1], M. Afzelius[1], H. de Riedmatten[1,2], N. Gisin[1]
[1]Group of Applied Physics, University of Geneva, CH-1211, Genève, Switzerland.
[2]ICFO, Mediterranean Technology Park, 08860 Castelldefels, Barcelona, Spain.

Large experimental efforts are devoted to harnessing entanglement between light and material systems due to its prospective role in future quantum information networks. We demonstrate entanglement between a photon at telecommunication wavelength and a single collective atomic excitation stored in a crystal. One photon from an energy-time entangled pair is mapped onto a crystal and then released into a well-defined spatial mode after a predetermined storage time. The other photon is at telecommunication wavelength and is sent directly through a 50 m fiber link to an analyzer. Successful storage of entanglement in the crystal is proven by a violation of a Bell inequality. We believe these results are an important step towards multiplexed quantum repeaters for long-distance quantum networks [1].

[1] C. Clausen *et al.*, *Nature* **469**, 508 (2011).

Tuesday 15:00

Optimal resources for multimode quantum teleportation

C. Lupo[1], A. Christ[2,3], Ch. Silberhorn[2,3]
[1]School of Science and Technology, University of Camerino, 62032 Camerino, Italy.
[2]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany.
[3]Applied Physics, University of Paderborn, 33098 Paderborn, Germany.

We introduce a multiplexed information coding for quantum teleportation with continuous variables. We quantify the performances of the quantum teleportation protocol in terms of the quantum capacity of the teleportation channel, that is, the highest rate of reliable transfer of quantum information. We show that a true quantum link, with nonzero quantum teleportation capacity, is established only for nonlocal squeezing above a threshold value. For given pump power, the optimal teleportation resources are shown to be multimode entangled states, which can be engineered in waveguide parametric down-conversion [1]. Compared to the single-mode setting, multimode encoding allows higher teleportation capacity and robustness against linear loss.

[1] B. Brecht *et al.*, arXiv:1101.6060 (2011).

Tuesday 15:20

Towards a coherent quantum microwave to optical photon interface

M. U. Staudt[1], M. Afzelius[2], N. Sangouard[2], H.H. Segnorile [1], G. Johansson[1], V. Shumeiko, P. Delsing[1], C. M. Wilson.[1]
[1]Chalmers University of Technology, SE-412 96 Gothenburg, Sweden.
[2]Group of Applied Physics, University of Geneva, CH-1211 Geneva 4, Switzerland.

We have demonstrated the collective coupling of an Er spin ensemble in a crystal to a coplanar waveguide cavity. We have measured a collective coupling of 5 MHz, suggesting of order 10^{12} spins are participating in the ensemble. We have used an Erbium-doped Y_2SiO_5 crystal placed directly on top of a niobium cavity with a resonance frequency of 5 GHz and a gap spacing of 100 microns. We have measured the sample down to 50 mK in a dilution refrigerator equipped with an NMR magnet. By applying an external magnetic field we tune the Zeeman splitting of the spins until they are in resonance with the cavity. When the resonance condition is achieved, the spins effectively damp the cavity leading to an increase in the observed width of the resonance. By exploiting this coupling we intend to realize a coherent quantum microwave to optical photon interface.

Tuesday 15:40

Atomic frequency comb memory with spin wave storage in $^{153}Eu^{3+}:Y_2SiO_5$

N. Timoney[1], B. Lauritzen[1], N. Gisin[1], M. Afzelius[1]
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Multimode quantum memories are an essential requirement for future quantum communication networks [1]. Europium doped Y_2SiO_5 crystals are a promising candidate for the realization of an atomic frequency comb (AFC) based multimode memory with an on demand readout. The measured hyperfine coherence time of 15 ms suggests it should be possible to realize long lived quantum memories with tens of modes [2], exceeding the capabilities of a praseodymium based memory [3]. An AFC memory with spin wave storage is demonstrated for the first time in $Eu:Y_2SiO_5$.

[1] N. Sangouard *et al*, *Rev. Mod. Phys.* **1**, 33-34 (2011).

[2] M. Afzelius *et al*, *Phys. Rev. A* **79**, 052329 (2009).

[3] M. Afzelius *et al*, *Phys. Rev. Lett.* **104**, 040503 (2010).

Session C: Superconducting Circuits

(Lecture room HCI J3; Chaired by Andreas Wallraff)

Tue	14:20 - 14:40	Jonas Bylander Noise spectroscopy of a flux qubit via dynamical decoupling
Tue	14:40 - 15:00	Jerry Chow Implementation of a microwave-tunable universal two-qubit gate on fixed-frequency superconducting qubits
Tue	15:00 - 15:20	Christopher Eichler Tomography and Correlation Function Measurements of Itinerant Microwave Photons
Tue	15:20 - 15:40	Vladimir M. Stojanovic Quantum control of interacting qubit arrays
Tue	15:40 - 16:00	Mikko Möttönen Geometric non-Abelian phases using Josephson devices

Tuesday 14:20

Noise spectroscopy of a flux qubit via dynamical decoupling

J. Bylander[1], S. Gustavsson[1], F. Yan[1], F. Yoshihara[2], K. Harrabi[2], G. Fitch[3], D. G. Cory[1,4], Y. Nakamura[2,5], J.-S. Tsai[2,5], W. D. Oliver[1,3]
[1]Massachusetts Institute of Technology, U.S.A.
[2]RIKEN, Japan.
[3]MIT Lincoln Laboratory, U.S.A.
[4]University of Waterloo and Perimeter Institute, Canada.
[5]NEC Corporation, Japan.

Decoherence can be mitigated with multi-pulse refocusing techniques that dynamically decouple a quantum system from environmental noise. First, we employ these methods to demonstrate a nearly relaxation-limited coherence time $T_2 = 2\,T_1$ and pure dephasing time $T_\varphi > 100\,\mu$s in a flux qubit with long $T_1 = 12\,\mu$s. Second, we use the spectral filtering property of the dynamical-decoupling sequence to directly probe the flux noise over a wide frequency range $0.2-20$ MHz, observing a $1/f^{0.9}$ distribution. Noise spectroscopy enables the design of optimized coherent-control methods, and promotes materials engineering and device design to minimize decoherence [1].

[1] J. Bylander *et al.*, *Nature Physics* DOI:10.1038/NPHYS1994 (2011).

Tuesday 14:40

Implementation of a microwave-tunable universal two-qubit gate on fixed-frequency superconducting qubits

Jerry M. Chow[1], A. D. Córcoles[1], Jay M. Gambetta[1], Chad Rigetti[1], J. A. Smolin[1], B. R. Johnson[2], Mark B. Ketchen[1], M. Steffen[1]
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We present a high-fidelity all microwave-control two-qubit gate for superconducting qubits. The gate is implemented for a pair of capacitively-shunted flux qubits coupled through a resonator by driving one of the qubits at the frequency of the other qubit. The effective two-qubit interaction is tunable via the amplitude of the applied cross-resonance irradiation. Quantum process tomography gives a two-qubit gate fidelity of 81%, which is near the limit imposed by coherence and gate times. This two-qubit gate opens a new paradigm for quantum computation for superconducting qubits as it allows the qubits to be operated at their optimal bias points, without sacrificing tunability of an effective two-qubit interaction. The protocol is simple, with no additional subcircuitry and permits two-qubit operations on qubits which are non-nearest neighbors in frequency and in space.

Tuesday 15:00

Tomography and Correlation Function Measurements of Itinerant Microwave Photons

C. Eichler[1], D. Bozyigit[1], C. Lang[1], L. Steffen[1], J. M. Fink[1], M. Baur[1], S. Filipp[1], M. P. da Silva[2], A. Blais[2], A. Wallraff[1]
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A wide range of experiments studying microwave photons localized in superconducting cavities have made important contributions to our understanding of the quantum properties of radiation. Propagating microwave photons, however, have so far been studied much less intensely. Here we present measurements in which we characterize the radiation emitted from a pulsed single photon source. We measure temporal correlation functions as well as the Wigner function for itinerant single photon Fock states and their superposition with the vacuum using linear amplifiers and quadrature amplitude detectors [1, 2].

[1] D. Bozyigit *et al.*, *Nature Physics* **7**, 154-158 (2011).

[2] C. Eichler *et al.*, arXiv:1011.6668 (2010).

Tuesday 15:20

Quantum control of interacting qubit arrays

V. M. Stojanovic[1], R. Heule[1], D. Burgarth[2], C. Bruder[1]
[1]Department of Physics, University of Basel, CH-4056 Basel, Switzerland.
[2]Quantum Information Group, EEE, Imperial College London, London, UK.

Linear arrays of qubits interacting by a Heisenberg oder anisotropic XXZ interaction can be controlled by acting on one of the qubits at the end of the chain. In a recent theoretical study, we have determined the control sequences to implement a number of gates in small N-qubit systems ($N = 3$ or 4) in a minimal time [1, 2]1,2. In the anisotropic case, the shortest gate times are achieved for values of the anisotropy parameter Δ larger than 1. To study the influence of possible imperfections in experimental realizations of qubit arrays, we analyze the robustness of the gate fidelities to random variations in the control-field amplitudes and finite rise times of the pulses. We also discuss applications of our results to arrays of superconducting qubits.

[1] R. Heule, C. Bruder, D. Burgarth, and V.M. Stojanovic, Phys. Rev. A **82**, 052333 (2010).

[2] R. Heule, C. Bruder, D. Burgarth, and V.M. Stojanovic, EPJD **63**, 41 (2011).

Tuesday 15:40

Geometric non-Abelian phases using Josephson devices

M. Möttönen[1,2], P. Solinas[1], I. Kamleitner[3], J.-M. Pirkkalainen[2], C. Müller[3], J. P. Pekola[2], A. Shnirman[3]
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[2]Low Temperature Laboratory, Aalto University, POB 13500, 00076 AALTO, Finland.
[3]Institut für Theory der Kondensierten Materie, Karlsruher Institut für Technologie, 76128 Karlsruhe, Germany.

We propose two schemes for implementing geometric adiabatic quantum computing: a system of three Transmon qubits coupled to a single superconducting cavity, for which an effective tripod Hamiltonian is obtained in a rotating frame and any single-qubit operation can be carried out by controlling the local Rabi frequencies [1]; and two-island flux-tunable qubits, for which universal quantum computing is possible in the ground-state in the laboratory frame [2].

[1] I. Kamleitner*et al.*, arXiv:1104.0159, to be published in *Phys. Rev. B*, (2011).

[2] P. Solinas *et al.*, *Phys. Rev. A* **82**, 052304 (2010).

Session D: Charges and Spins

(Lecture room HCI J7; Chaired by Klaus Ensslin)

Tue	14:20 - 14:40	Ingmar Jakobi Entanglement of solid-state based electronic spins at ambient conditions
Tue	14:40 - 15:00	Sander Onur Quantum optics with semiconductor spin ensembles
Tue	15:00 - 15:20	Hugo Ribeiro Harnessing the GaAs nuclear spin for quantum control
Tue	15:20 - 15:40	Jeremie Viennot Towards an “all-electric” control of a ferromagnetic spin qubit
Tue	15:40 - 16:00	Alessandro Rossi Charge sensing in silicon quantum dots for quantum computation

Tuesday 14:20

Entanglement of solid-state based electronic spins at ambient conditions

I. Jakobi[1], F. Dolde[1], B. Naydenov[1,2], S. Pezzagna[3], J. Meijer[3], C. Trautmann[4], P. Neumann[1], F. Jelezko[2], J. Wrachtrup[1]
[1]3. Physikalisches Institut, Universität Stuttgart, D-70550 Stuttgart, Germany
[2]Institut für Quantenoptik, Universität Ulm, D-89081 Ulm, Germany
[3]RUBION, Ruhr-Universität Bochum, D-44780 Bochum, Germany
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The negatively charged nitrogen-vacancy defect center (NV) in diamond is a promising solid-state system for quantum information processing. Both its electronic and nuclear spins can be initialized, readout and manipulated and have long coherence times. However, in order to achieve scalable quantum gates, NV spins need to be entangled and therefore have close distances (< 20nm). While coupling between electronic spins of two NVs has already been shown [1], it has not been possible to create entanglement so far. Here we report the preparation of entangled spin states between two artificially created NV centers. This is to our knowledge the first demonstration of electronic spin entanglement based on solid-states at room-temperature.

[1] P. Neumann *et al.*, *Nature Physics* **6**, 249-253 (2010).

Tuesday 14:40

Quantum optics with semiconductor spin ensembles

A. R. Onur[1], A. U. Chaubal[1], M. Sladkov[1], M. P. Bakker[1], J. Sloot[1], D. Reuter[2], A. Wieck[2], C. H. van der Wal[1]
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[2]Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany

We present quantum optical studies with ensembles of donor-bound electron spins in ultra-pure GaAs materials with Si doping at very low concentrations (10^{13}-10^{14} cm^{-3}). These donor-bound electrons (D^0 systems) provide unique system properties for solid state quantum information processing, since they combine a high level of ensemble homogeneity (as for atomic vapors) with strong optical transitions and the ability to nano-fabricate and integrate very compact optoelectronic devices with semiconductor processing tools. Specifically, we report the observation of dynamic nuclear polarization in this material [1], using electromagnetically induced transparency as a driving mechanism and as a probe for the effective magnetic (Overhauser) field.

[1] M. Sladkov *et al.*, *Phys. Rev. B* **82**, 121308 (2010).

Tuesday 15:00

Harnessing the GaAs nuclear spin for quantum control

H. Ribeiro[1], J. R. Petta[2], G. Burkard[1]
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We theoretically show that hyperfine interactions can be harnessed for quantum gate operations in GaAs semiconductor quantum dots [1]. In the presence of an external magnetic field B, which splits the triplet states, the hyperfine interaction results in an avoided crossing between the spin singlet S and spin triplet T_+, which form the basis of a new type of spin qubit. Coherent quantum control for this qubit is achieved through Landau-Zener-Stückelberg transitions at the S-T_+ avoided crossing [2, 3]. A set of suitable transitions allows to build any single qubit gates on timescales shorter than the decoherence time $T_2^* \sim 16\mathrm{ns}$ [1]. We also show how to build a conditional two-qubit gate by capacitively coupling two S-T_+ qubits.

[1] H. Ribeiro, J. R. Petta, and G. Burkard, *Physical Review B* **82**, 115445 (2010).

[2] H. Ribeiro and G. Burkard, *Physical Review Letters* **102**, 216802 (2009).

[3] J. R. Petta, H. Lu, A. C. Gossard, *Science* **327**, 669-672 (2010).

Tuesday 15:20

Towards an "all-electric" control of a ferromagnetic spin qubit

J. J. Viennot, M. R. Delbecq, A. Cottet, T. Kontos
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The natural weak coupling of the electronic spin to its environment makes it a pertinent candidate for the realization of quantum bits. Obtaining a strong spin-photon coupling and performing local spin manipulations without a strong external magnetic field seem very challenging. A first step is the implementation of an "all electric" control of a single spin within a hybrid nano-circuit using ferromagnetic contacts. Our architecture consists of a carbon nanotube-based double quantum dot, in wich ferromagnet interface exchange fields induce effective Zeeman splittings, and therefore gate voltage-dependent spin states. This system can furthermore be embedded into a superconducting coplanar cavity and would allow spin manipulation and readout using cavity QED techniques [1].

[1] A. Cottet *et al.*, *Phys. Rev. Let.* **105**, 160502 (2010).

Tuesday 15:40

Charge sensing in silicon quantum dots for quantum computation

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High-fidelity detection of single-electron tunnelling in silicon quantum dots opens the way to use this category of devices for quantum computation while keeping full compatibility with the standard semiconductor technology. Charge sensing in both single and double quantum dot architectures has been successfully achieved by capacitively coupling the dots to single-electron tunnelling devices realised in degenerately doped silicon[1]. Operations under different bias regimes allow one to detect the number of excess charges in each dot, observe directly the transitions due to tunnelling and study bias-dependent modifications of the tunneling rate. Ultimately, precise control of charge occupancy can lead one to attain the low electron-number regime instrumental to perform spin manipulations. This is suitable for the implementation of a hybrid charge/spin quantum bit architecture.

[1] A. Rossi *et al.*, *Appl. Phys. Lett.* **97**, 223506 (2010).

Session E: Charges and Spins

(Lecture room HCI G3; Chaired by Gian Salis)

Thu	13:40 - 14:00	Géraldine Haack Coherence of Single Electron Sources from Mach-Zehnder Interferometry
Thu	14:00 - 14:20	Bruno Küng Irreversibility on the Level of Single-Electron Tunneling
Thu	14:20 - 14:40	Luca Chirolli Time-bin entanglement of quasi-particles in semiconductor devices
Thu	14:40 - 15:00	Hideo Kosaka Time-bin photonic state transfer to electron spins in a semiconductor
Thu	15:00 - 15:20	Pawel Szumniak Gated Combo Nanodevice for Sequential Coherent Operations on Single Heavy Hole Spin State

Thursday 13:40

Coherence of Single Electron Sources from Mach-Zehnder Interferometry

G. Haack[1], M. Moskalets[2], J. Splettstoesser[3] and M. Büttiker[1]
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[3]Institut für Theorie der Statistischen Physik, RWTH Aachen University, 52058 Aachen, Germany.

A new type of single electron sources (SES) has emerged which permits to inject single particles in a controllable manner into an electronic circuit. Multiparticle exchange, two-particle interference effects and entanglement have already been proposed [1]. Here we determine the coherence length of the single-particle states analyzing the decay of Aharonov-Bohm oscillations as a function of the imbalance of a Mach-Zehnder interferometer connected to an SES [2]. This single-particle coherence length is of particular importance as it is an intrinsic property of the source in contrast to the dephasing length.

[1] J. Splettstoesser, M. Moskalets, M. Büttiker, PRL **103**, 076804 (2009).

[2] G. Haack, M. Moskalets, J. Splettstoesser, M. Büttiker, arXiv: 1103.2260 (2011).

Thursday 14:00

Irreversibility on the Level of Single-Electron Tunneling

B. Küng[1], C. Rössler[1], M. Beck[2], T. Ihn[1], K. Ensslin[1]
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[2]Institute for Quantum Electronics, ETH Zürich, CH-8093, Zürich, Switzerland.

Devices used for quantum information processing are microscopic from the point of view of thermodynamics. The second law is not valid for them as their entropy may decrease during a short time: these entropy fluctuations are instead described by the fluctuation theorem [1]. Using real-time charge sensing with a quantum point-contact, we test the fluctuation theorem for electron transport through a GaAs/AlGaAs double quantum dot. Our data validate the theoretical predictions for various temperatures, and both close to equilibrium (small source-drain bias) and in strong nonequilibrium conditions (large bias). This is in contrast to previous experiments [2] which found discrepancies on the quantitative level.

[1] D. J. Evans and D. J. Searles, *Adv. Phys.* **51**, 1529 (2002).

[2] S. Nakamura *et al.*, *Phys. Rev. Lett.* **104**, 080602 (2010); Y. Utsumi *et al.*, *Phys. Rev. B* **81**, 125331 (2010).

Thursday 14:20

Time-bin entanglement of quasi-particles in semiconductor devices

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[2]Centre for Quantum Technologies & Department of Physics, National University of Singapore, 3 Science Drive 2, Singapore 117543.

We propose a scheme to produce time bin entangled pairs of electrons and holes based on high frequency time-resolved single electron source from a quantum dot coupled to 1D chiral channels. Operating the device in the weak tunneling regime we show that at the lowest order in the tunneling rate, an electron-hole pair is emitted in a coherent superposition state of different time bins determined by the driving pulse sequence.

Thursday 14:40

Time-bin photonic state transfer to electron spins in a semiconductor

H. Kosaka[1], T. Inagaki[1], R. Hitomi[1], F. Izawa[1], Y. Rikitake[2], H. Imamura[3], Y. Mitsumori[1], K. Edamatsu[1]
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We experimentally demonstrate the direct transfer from a time-bin state of light to a spin state of electrons in a semiconductor nanostructure. The transfer is based on the relative difference in spin dynamics between an electron and hole that are pair-created by a photon forming a coherent exciton and are naturally entangled but can be disentangled after their different time evolutions in the spin space. The transfer scheme is applicable to various materials and qubit systems, and opens a path toward hybrid quantum systems. This work was supported by CREST-JST, SCOPE-MIC, Kakenhi(A)-JSPS, DYCE-MEXT, FIRST, and JSPS Research Fellowships.

Thursday 15:00

Gated Combo Nanodevice for Sequential Coherent Operations on Single Heavy Hole Spin State

P. Szumniak[1,2], S. Bednarek[1], B. Partoens[2] and F.M. Peeters[2]
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[2]Department of Physics, University of Antwerp, Groenenborgerlaan 171, B-2020 Antwerpen, Belgium.

We propose a novel spintronic nanodevice in which an arbitrary sequence of three basic quantum single qubit gates (negation, Hadamard, and phase shift) can be performed on a single heavy hole spin state. It acts in a similar way as devices proposed in recent paper [1]1 but with the added advantages that it is smaller and more immune to the decoherence caused by the hyperfine interaction with nuclear spins. Spin transformations are realized by transporting the hole around a closed loop in a gated semiconductor nanodevice. Our proposal is supported by quantum mechanical time dependent calculations in the two band Luttinger-Kohn model which are compared with a single heavy hole band approach.

[1] S. Bednarek, B. Szafran, Phys. Rev. Lett. 101, 216805 (2008).

Session F: Special Topics

(Lecture room HCI G7; Chaired by Florian Marquardt)

Thu	13:40 - 14:00	Roman Orús Studying the robustness of topological phases with infinite-PEPS and pCUT methods
Thu	14:00 - 14:20	Jan Kołodyński Fundamental bounds on quantum metrology in the presence of decoherence
Thu	14:20 - 14:40	Dimitris Angelakis Photonic Quantum Simulators: Mimicking Condensed Matter Physics with Light
Thu	14:40 - 15:00	Giovanna Morigi Linear-zigzag quantum phase transition in ion Coulomb chains.
Thu	15:00 - 15:20	Jin-Shi Xu Experimental entanglement-assisted entropic uncertainty principle

Thursday 13:40

Studying the robustness of topological phases with infinite-PEPS and pCUT methods

R. Orús[1], S. Dusuel[2], M. Kamfor[3,4], M. D. Schulz[3,4], K. P. Schmidt[3], and J. Vidal[4].
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[2]Lycée Saint-Louis, 44 Boulevard Saint-Michel, 75006 Paris, France
[3]Lehrstuhl für Theoretische Physik I, TU Dortmund, 44221 Dortmund, Germany
[4]Laboratoire de Physique Théorique de la Matière Condensée, CNRS UMR 7600, Université Pierre et Marie Curie, 75252 Paris Cedex 05, France

We investigate the stability of the topological phases of the $\mathbf{Z}_2$ and $\mathbf{Z_3}$ Toric Code models in the presence of uniform magnetic fields by means of infinite Projected Entangled Pair State algorithms (iPEPS) and perturbative Continuous Unitary Transformations (pCUT). We find that when the perturbation is strong enough, the system undergoes a topological phase transition whose first- or second-order nature depends on the field orientation and symmetry. The phase diagrams of these systems are explored, and we see that they offer a very rich behavior in terms of different universality classes and phase transitions breaking topological order.

Thursday 14:00

Fundamental bounds on quantum metrology in the presence of decoherence

J. Kołodyński[1], R. Demkowicz-Dobrzański[1]
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Recent results show that, if decoherence is incorporated into quantum models, even infinitesimally dosed, it disallows the scaling of the estimated parameter's precision to asymptotically be better than in classical strategies. In the case of phase estimation with photonic loss, when no a priori knowledge is available, we have proven that the quantum precision enhancement amounts at most to a constant factor improvement [1]. Similar behaviour of the precision scaling may be observed also for other metrological models, such as frequency calibration under the influence of dephasing [2, 3]. We investigate the mathematical structures responsible for this behaviour and try to assess its generality.

[1] J. Kołodyński, R. Demkowicz-Dobrzański, *Phys. Rev. A* **82**, 053804 (2010).

[2] S.F. Huelga *et al.*, *Phys. Rev. Lett.* **79**, 3865 (1997).

[3] B. M. Escher *et al.*, *Nature Physics* **7**, 406-411 (2011).

Thursday 14:20

Photonic Quantum Simulators: Mimicking Condensed Matter Physics with Light

Dimitris G. Angelakis
Technical University of Crete and Centre for Quantum Technologies.

I will start by describing the basic motivation for using photons as quantum simulators and briefly review our founding results on the Mott transition in coupled cavities doped with two level systems, and the applications in the photonic simulation of quantum spin models and the Fractional Hall effect [1]. I will then analyze the work in the simulation of quantum Luttinger liquids and spin-charge separation using photons in a hollow fiber filled with atoms [2]. Finally I will briefly present recent progress towards the realization of a photonic "pinning transition" and ongoing efforts in the simulation of the Thirring model and the BCS/BEC transition using photons.

[1] D.G. Angelakis, et al., Phys. Rev. A, **76** (2007) R05709; J. Cho, et al., Phys. Rev. Lett. **101**, 246809 (2008)

[2] D.G. Angelakis et al., Phys. Rev. Lett. **106**, 153601 (2011); M. Huo, D. Angelakis, arXiv:1103.4856.

Thursday 14:40

Linear-zigzag quantum phase transition in ion Coulomb chains.

G. Morigi[1], J. Baltrusch[1], C. Cormick[1], G. De Chiara[2], S. Montangero[3], T. Calarco[3], A. del Campo[3], A. Retzker[3], M. B. Plenio[3], E. Shimshoni[4], Sh. Fishman[5].

[1] Theoretical Physics, Saarland University, D-66123 Saarbrücken; [2] Dept. of Physics, Universitat Autónoma de Barcelona, E-08193 Barcelona; [3] Physics Faculty, University of Ulm, D-89069 Ulm; [4] Dept. of Physics, Bar-Ilan University, Ramat-Gan 52900, Israel; [5] Dept. of Physics, Technion, 32000 Haifa, Israel.

Ion Coulomb crystals constitute a promising platform for a quantum simulator. A prominent example is the linear chain and its structural transition into a zigzag structure. We show that the linear-zigzag transition is a quantum phase transition, which can be experimentally realized and probed [1]. When quantum effects can be neglected, defect formation by quenching the trap frequency across the critical value is shown to obey the scaling predicted by the Kibble-Zurek mechanism [2]. We finally discuss how to create a quantum superposition of crystalline structures by means of optical potentials.

[1] E. Shimshoni *et al.*, *Phys. Rev. Lett.* **106**, 010401 (2011).

[2] A. del Campo *et al.*, *Phys. Rev. Lett* **105**, 075701 (2010).

Thursday 15:00

Experimental entanglement-assisted entropic uncertainty principle

J.-S. Xu[1], C.-F. Li[1], X.-Y. Xu[1], K. Li[1], G.-C. Guo[1]
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The uncertainty principle, which bounds the uncertainties about obtaining precise outcomes of two complementary variables on a quantum particle, is a crucial aspect in quantum mechanics. Recently, the uncertainty principle in terms of entropy has been extended to the case involving quantum entanglement. We experimentally demonstrate the entanglement-assisted uncertainty principle in an all-optical setup. The lower bound of the uncertainty is demonstrated and the uncertainty is shown to be near zero in the presence of quasi-maximally entanglement. The new uncertainty relation is further used to witness entanglement and is compared with the common entanglement measurement, i.e., concurrence. The verified entropic uncertainty principle implies that the uncertainty principle is not only observable-dependent, but also observer-dependent, which provides an intriguing perspective on it. [1].

[1] C.-F. Li *et al.*, *arXiv:1012.0361* (2011).

Session G: Photons

(Lecture room HCI J3; Chaired by Atac Imamoglu)

Thu	13:40 - 14:00	Nicolas J. Cerf Heralded phase-insensitive optical squeezer
Thu	14:00 - 14:20	Adetunmise Dada Experimental Eleven-Dimensional Two-Photon Entanglement
Thu	14:20 - 14:40	Alois Regensburger Experiments on quantum walks: Zitterbewegung, Bloch oscillations, Landau-Zener tunneling and particle dissipation
Thu	14:40 - 15:00	Mohamed Bourennane Experimental four-qubit bound entanglement
Thu	15:00 - 15:20	Seung-Sup Lee Experimental construction of an optimal witness for unknown two photon-polarization qubit entanglement

Thursday 13:40

Heraled phase-insensitive optical squeezer

N. J. Cerf[1], C. N. Gagatsos[1], and E. Karpov[1]
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An heralded *noiseless linear amplifier*, which circumvents the inherent quantum noise in an amplification process albeit on a probabilistic basis, has recently been proposed and experimentally demonstrated [1, 2] . Here, we exhibit another remarkable feature of this peculiar amplifier, namely its ability to effect single-mode squeezing on a quantum state *regardless* of the quadrature component that is initially squeezed. Hence, it acts as an heralded *phase-insensitive* optical squeezer, conserving the signal-to-noise ratio just as a phase-dependent optical amplifier but for all quadratures at the same time, which may offer new perspectives in quantum optical communications. Although this ability to squeeze all quadratures seemingly opens a way to instantaneous signaling following Diek's approach to the quantum no-cloning theorem, we show that the probability for such a causality violation vanishes.

[1] G. Y. Xiang *et al.*, *Nature Photonics* **4**, 316 (2010).

[2] F. Ferreyrol *et al.*, *Phys. Rev. Lett.* **104**, 1235603 (2010).

Thursday 14:00

Experimental Eleven-Dimensional Two-Photon Entanglement

A. Dada[1], J. Leach[2], G. S. Buller[1], M. J. Padjett[2], E. Andersson[1]
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[2]Department of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom.

High-dimensional entanglement is of great interest due to the extended possibilities it enables in quantum information science. We have measured previously untested correlations between two photons to experimentally demonstrate high-dimensional entangled states. We obtain violations of Bell-type inequalities generalised to d-dimensional systems [1] with up to $d = 12$, with violations strong enough to indicate genuine 11-dimensional entanglement. Our experiments use photons entangled in orbital angular momentum (OAM) [2], generated through spontaneous parametric down-conversion (SPDC) [3], and manipulated using computer controlled holograms.

[1] D. Collins *et al.*, *Phys. Rev. Lett.* **88**, 040404 (2002).

[2] L. Allen *et al.*, *Phys. Rev. A* **45**, 8185–8189 (1992).

[3] S. P. Walborn *et al.* *Phys. Rev. A* **69**, 023811 (2004).

Thursday 14:20

Experiments on quantum walks: Zitterbewegung, Bloch oscillations, Landau-Zener tunneling and particle dissipation

Alois Regensburger[1,2], Christoph Bersch[1,2], Benjamin Hinrichs[1,2], Georgy Onishchukov[1], Andreas Schreiber[1], Christine Silberhorn[2,3], Ulf Peschel[1]
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Quantum walks have the potential to improve many algorithms in quantum computing. But they are also an interesting physical system by themselves. For implementing the quantum walk, we use a system of coupled fiber loops that are operated at telecommunication wavelength. We focus on coherent wave interference during the discrete time evolution and experimentally observe effects known from solid state physics like Zitterbewegung, Bloch oscillations and Landau-Zener tunneling [1]. Moreover, we study the consequences of controlled particle dissipation on the formation of coherent field structures.

[1] A. Regensburger *et al.*, *arXiv*:1104.0105v1 [quant-ph] (2011).

Thursday 14:40

Experimental four-qubit bound entanglement

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Entanglement is one of the most puzzling features of quantum theory and of great importance for the new field of quantum information. Being a peculiar form of entanglement, bound entanglement emerges in certain mixed quantum states. This form of entanglement is not distillable by local operators and classical communication. Bound-entangled states are different from both the free entangled (distillable) and separable states. Here we report on the experimental demonstration of class of four-qubit polarization bound-entangled states, the generalized Smolin states. We have fully characterized their entanglement properties[1]. Moreover, we have realized unlocking of the entanglement protocol. The special properties of the Smolin states constitute a useful quantum resource for new multiparty communication schemes.

[1] E. Amselem and M. Bourennane, *Nature Physics* **5**, 748-752 (2009).

Thursday 15:00

Experimental construction of an optimal witness for unknown two photon-polarization qubit entanglement

S.-S. B. Lee[1], H. S. Park[2], H. Kim[2], S.-K. Choi[2], H.-S. Sim[1]
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Whether entanglement in a state can be detected, distilled, and quantified without full state reconstruction is a fundamental open problem. We demonstrate a new scheme encompassing these three tasks for arbitrary two-qubit entanglement, by constructing the optimal entanglement witness for polarization-entangled mixed-state photon pairs without full state reconstruction. With better efficiency than quantum state tomography, the entanglement is maximally distilled by newly developed tunable polarization filters and quantified by the expectation value of the witness, which equals the concurrence. This scheme is extendible to multiqubit Greenberger-Horne-Zeilinger entanglement [1].

[1] H. S. Park *et al.*, *Phys. Rev. Lett.* **105**, 230404 (2010).

Session H: Mechanical Oscillators

(Lecture room HCI G3; Chaired by Christian Degen)

Fri	14:20 - 14:40	Ewold Verhagen Strong optomechanical coupling in the quantum regime
Fri	14:40 - 15:00	Maria Korppi Optomechanical Coupling of Ultracold Atoms and a Membrane Oscillator
Fri	15:00 - 15:20	Nicolas Didier Synthesis of quantum phonon states and manipulation of entanglement with photons
Fri	15:20 - 15:40	Michael Hartmann Stationary phonon Fock states of nanomechanical oscillators
Fri	15:40 - 16:00	Andreas Jöckel Tuning the quality factor of a miromechanical membrane oscillator

Friday 14:20

Strong optomechanical coupling in the quantum regime

E. Verhagen[1], S. Deléglise[1], S. Weis[1], A. Schliesser[1,2], T. J. Kippenberg[1,2]
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We demonstrate strong optomechanical coupling between an optical and a mechanical mode of an optical microcavity, which is cooled close to the quantum ground state. A novel silica toroidal microresonator design is presented that shows a large optomechanical coupling strength while exhibiting small dissipation. Combined with a 600-mK ^{3}He cryogenic environment, it enables resolved sideband cooling of a 80 MHz mechanical mode to occupancies of approximately two phonons. We show that the rate at which the optical and mechanical modes exchange energy can be larger than 5 MHz, exceeding both the cavity decay rate as well as the thermal decoherence rate of the mechanical oscillator. This observation is a necessary first step towards coherent control of quantum states of a mechanical oscillator by the light field.

Friday 14:40

Optomechanical Coupling of Ultracold Atoms and a Membrane Oscillator

M. Korppi[1,2,3], A. Jöckel[1], S. Camerer[2,3], D. Hunger[2,3], T. W. Hänsch[2,3], P. Treutlein[1,2,3]
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[2]Ludwig-Maximilians-Universität, München, Germany
[3]Max-Planck-Institut für Quantenoptik, Garching, Germany.

We have realized a hybrid optomechanical system by coupling ultracold atoms to a micromechanical membrane. The atoms are trapped in an optical lattice, which is formed by retro-reflection of a laser beam from the membrane surface. In this setup, the lattice laser light mediates an optomechanical coupling between membrane vibrations and atomic center-of-mass motion. We observe both the effect of the membrane vibrations onto the atoms as well as the backaction of the atomic motion onto the membrane. By coupling the membrane to laser-cooled atoms, we can engineer the dissipation rate of the membrane. Our observations agree quantitatively with a simple model. In the long term such a system could be use to study sympathetic cooling of the membrane with the atoms towards the quantum groundstate.

Friday 15:00

Synthesis of quantum phonon states and manipulation of entanglement with photons

N. Didier[1], S. Pugnetti[1], Y. M. Blanter[2], R. Fazio[1]
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Mechanical oscillators are becoming macroscopic quantum objects with great potential. We propose a scheme to synthesize arbitrary quantum phonon states as well as to generate and measure entanglement between phonons and photons by a linear coupling with a microwave resonator. Quantum phonon states are created with a high fidelity from an appropriate photonic wave-function and entanglement is measured with the quantum tomography of the microwave resonator. Phonon blockade can also be detected with the photon statistics [1]. Our device takes advantage of the recent experimental breakthroughs both in the field of nano-electromechanical systems and the physics of microwave photons in circuit quantum electrodynamics.

[1] N. Didier, S. Pugnetti, Y. M. Blanter, and R. Fazio, arXiv:1007.4714 (2010).

This work is supported by the QNEMS European project.

Friday 15:20

Stationary phonon Fock states of nanomechanical oscillators

S. Rips, M. Kiffner, I. Wilson-Rae, M.J. Hartmann
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We propose a scheme to prepare nanomechanical oscillators in non-classical steady states, characterized by a pronounced negative Wigner function. In our optomechanical approach, the mechanical oscillator couples to multiple laser driven resonances of an optical cavity. By lowering the resonance frequency of the oscillator via an inhomogeneous electrostatic field, we significantly enhance its intrinsic geometric nonlinearity per phonon. This causes the motional sidebands to split into separate spectral lines for each phonon number and transitions between individual phonon Fock states can be selectively addressed. We show that this enables preparation of the nanomechanical oscillator in a single phonon Fock state [1]. Our scheme can for example be implemented with a carbon nanotube dispersively coupled to the evanescent field of a state of the art whispering gallery mode microcavity.

[1] S. Rips, M. Kiffner, I. Wilson-Rae and M.J. Hartmann, arXiv:1104.5665 (2011).

Friday 15:40

Tuning the quality factor of a miromechanical membrane oscillator

A. Jöckel[1,2,3], M. Korppi[1,2,3], M. Rakher[1], D. Hunger[2,3], S. Camerer[2,3], M. Mader[2], T. W. Hänsch[2,3], P. Treutlein[1,2,3]
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We report on the characterization and tuning of the mechanical modes of high-Q SiN-membrane oscillators. Such membranes are used in many optomechanical experiments and have Q-factors up to 10^7 with frequencies in the hundreds of kHz regime and masses of a few ng, resulting in large ground state and thermal amplitudes. We show that the membrane eigenfrequencies can be tuned by locally heating the membranes with laser light, resulting in a release of intrinsic stress. The frequencies of several modes were measured with a Michelson interferometer. We observe that the Q-factor changes dramatically while tuning and reveals resonances in the mechanical dissipation, which allows us to tune the Q-factor over two orders of magnitude. Using this we achieve an improvement over the bare membrane Q-factor.

Session I: Atomic Systems

(Lecture room HCI G7; Chaired by Stephen Hogan)

Fri	14:20 - 14:40	Tatjana Wilk Temporal photon patterns emitted from a strongly driven atom-cavity system
Fri	14:40 - 15:00	Kensuke Inaba Quantum entanglement generation using ultracold fermionic atoms in an optical lattice
Fri	15:00 - 15:20	Ferdinand Schmidt-Kaler Rydberg excitation of trapped cold ions: A detailed case study
Fri	15:20 - 15:40	Robert Spreeuw Rydberg Interactions On An Atom Chip
Fri	15:40 - 16:00	Carlos Navarrete-Benlloch Simulating quantum-optical phenomena with cold atoms in optical lattices

Friday 14:20

Temporal photon patterns emitted from a strongly driven atom-cavity system

T. Wilk[1], M. Koch[1], C. Sames[1], H. Chibani[1], M. Balbach[1], A. Kubanek[1], K. Murr[1], G. Rempe[1]
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We study the quantum dynamics of a strongly driven, strongly coupled single-atom-cavity system by evaluating time-dependent second- and third-order correlations of the emitted photons. In the second-order correlations we observe the coherent energy exchange between the atom and the cavity mode (vacuum-Rabi oscillations), as well as the coherent energy exchange between the atom-cavity system and the driving field, which we call super-Rabi oscillations. Regarding three-photon correlations we can identify photon patterns indicating that the system is undergoing a certain quantum trajectory. A pronounced time-asymmetry in the third-order correlations makes it possible to distinguish a real photon pattern from its time inverted copy. This is a consequence of the breakdown of detailed balance in our system.

Friday 14:40

Quantum entanglement generation using ultracold fermionic atoms in an optical lattice

K. Inaba[1,3], Y. Tokunaga[2,3], K. Tamaki[1,3], K. Igeta[1,3], M. Yamashita[1,3]
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We propose a method to create the cluster state of fermionic atoms in an optical lattice. It is based on the pair-wise Ising interaction arises from the virtual excitations between the lowest and the second lowest Wanier states across adjacent lattice sites. This scheme can be implemented by adding simple modulation to the ordinary sinusoidal lattice potentials. This Ising interaction strength can be enhanced using a Feschbach resonance. We numerically examine the performance of our approach by applying the exact diagonalization method to four- and six-qubits systems. The result confirms the generation of high-fidelity entangled states for both systems. Further scalability can be expected by the fact that the interaction is pair-wise.

Friday 15:00

Rydberg excitation of trapped cold ions: A detailed case study

F. Schmidt-Kaler, T. Feldker, D. Kolbe, J. Walz, M. Müller, P. Zoller, W. Li, I. Lesanovsky
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We provide a detailed conceptual study to excite Rydberg states of ions trapped in a Paul trap. The goal of our starting experiment is exploiting strong state dependent interactions between Rydberg ions for implementing QIPC protocols and simulating dynamics of strongly interacting spin systems. The promises of this approach are based on the high degree of control and readout of quantum states in trapped ion crystals and the novel and fast gate schemes based on interacting giant Rydberg atomic dipole moments[1].

[1] F. Schmidt-Kaler, et. al., "Rydberg excitation of trapped cold ions: A detailed case study", arXiv:1104.3102 (2011) .

Friday 15:20

Rydberg Interactions On An Atom Chip

A. Tauschinsky[1], Y.F.V. Leung[1], H.B. van Linden van den Heuvell[1], R.J.C. Spreeuw[1]
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We aim to develop a scalable quantum information platform based on a two-dimensional lattice of microscopic traps on a magnetic-film atom chip. The chip hosts hundreds of microtraps, each holding tens to several hundred ^{87}Rb atoms. The microtraps can be individually resolved, optically addressed, and cooled to quantum degeneracy; the lattice can be spatially manipulated as a shift register [1]. Using electromagnetically induced transparency (EIT), we characterize the level shifts and broadenings of Rydberg states in the proximity of the chip surface [2]. This opens the way to use the dipole blockade among Rydberg atoms to mediate switchable, long-range ($\sim 10\mu$m) interaction inside and among mesoscopic ensembles on the lattice.

[1] S. Whitlock, *et al.*, New J. Phys. **11**, 023021 (2009).

[2] A. Tauschinsky, *et al.*, Phys. Rev. A **81**, 063411 (2010).

Friday 15:40

Simulating quantum-optical phenomena with cold atoms in optical lattices

C. Navarrete-Benlloch[1], I. de Vega, D. Porras[2], and J. I. Cirac[3]
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Ultracold atoms trapped in optical lattices are well known as quite versatile simulators of a large class of many-Ůbody condensed-Űmatter Hamiltonians. In this communication, and exploiting currently available technology only, we will show that they can also be used to simulate phenomena traditionally linked to quantum-Űoptical systems [1, 2]. We will explain in particular how to observe phenomena arising from the collective spontaneous emission of atomic and harmonic oscillator ensembles such as sub/superradiance or directional emission, including some phenomena which still lack experimental observation [2].

[1] I. de Vega *et al.*, *Physical Review Letters* **101**, 260404 (2008).

[2] C. Navarrete-Benlloch *et al.*, *New Journal of Physics* **13**, 023024 (2011).

Session J: Quantum Information Theory

(Lecture room HCI J3; Chaired by Joe Renes)

Fri	14:20 - 14:40	Gilles Dowek The physical Church-Turing thesis as a consequence of the principles of quantum theory
Fri	14:40 - 15:00	David Reeb Extension theorems for quantum operations
Fri	15:00 - 15:20	Vahid Azimi Mousolou Non-Abelian quantum holonomy of hydrogen-like atoms
Fri	15:20 - 15:40	Nicolas Brunner Large violation of Bell inequalities using both particle and wave measurements
Fri	15:40 - 16:00	Ognyan Oreshkov Quantum correlations with no causal order

Friday 14:20

The physical Church-Turing thesis as a consequence of the principles of quantum theory

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Notoriously, quantum computation shatters complexity theory, but is innocuous to computability theory [Deutsch85]. Yet several works have shown how quantum theory as it stands could breach the physical Church-Turing thesis [Nielsen97,Kieu03]. We draw a clear line as to when this is the case, in a way that is inspired by Gandy [Gandy80]. Gandy formulates postulates about physics, such as homogeneity of space and time, bounded density and velocity of information — and proves that the physical Church-Turing thesis is a consequence of these postulates. We provide a quantum version of the theorem. Thus this approach exhibits a formal non-trivial interplay between theoretical physics symmetries and computability assumptions. Proofs are available at [1].

[1] P. Arrighi, G. Dowek. *The physical Church-Turing thesis and the principles of quantum theory*, pre-print arXiv:1102.1612

Friday 14:40

Extension theorems for quantum operations

D. Reeb[1], M. Wolf[1], A. Jivulescu[2], T. Heinosaari[3]
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Given two sets of quantum states at an initial and at a final instance, we ask the question of whether there exists a quantum operation, i.e. any general quantum-mechanical time evolution, that maps each of the initial states to the corresponding final state. We present criteria under which such a linear map can be found and in which cases this map may be chosen to be (completely) positive and/or trace-preserving. Furthermore, as the answers to the above questions are not continuous in the given quantum states, we provide efficient ϵ-versions of these criteria in the form of a semidefinite program. Such criteria help determine whether an experimentally measured quantum-mechanical time evolution may arise from a (possibly probabilistic) Markovian process, i.e. in which the environment is memoryless [1].

[1] D. Reeb *et al.*, arXiv:1102.5170 (section VII), and in preparation (2011).

Friday 15:00

Non-Abelian quantum holonomy of hydrogen-like atoms

Vahid Azimi Mousolou[1], Carlo M. Canali[1], Erik Söqvist[2]
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Uhlmann's quantum holonomy along density operators is a concept employed in the studies of geometric phases of general quantum states undergoing arbitrary quantum evolutions. Its relevance to various aspects of physics have been demonstrated in the past. Parts of these efforts have been triggered by the conjectured robustness of holonomic quantum gates for quantum computation and the need to understand the behavior of geometric phases in the presence of noise and decoherence. We study the geometrical nature of this concept by considering the case of spin-orbit (LS) coupled hydrogen-like atoms subject to a slowly varying magnetic field. We examine the Uhlmann holonomy and the corresponding phase of the Wilson loop variable for the orbital angular momentum and spin subsystems, and the one for the whole system. Based on the results for this model system we provide a comparison between the phase of the Wilson-loop variable associated to the Uhlmann holonomy and earlier definitions of the geometric phase for mixed states, which can be measured experimentally.

Friday 15:20

Large violation of Bell inequalities using both particle and wave measurements

N. Brunner[1], D. Cavalcanti[2], P. Skrzypczyk[1], A. Salles[3], V. Scarani[2]
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[2]Centre for Quantum Technologies, National University of Singapore, Singapore.
[3]Niels Bohr Institute, Blegdamsvej 17, 2100 Copenhagen, Denmark.

When separated measurements on entangled quantum systems are performed, nonlocal correlations are obtained as witnessed by the violation of Bell inequalities. All optical demonstrations of such violations have involved discrete degrees of freedom and are plagued by the detection-efficiency loophole. A promising alternative is to use continuous variables combined with highly efficient homodyne measurements. However, all schemes proposed so far use states or measurements that are extremely difficult to achieve, or produce very weak violations. Here we show that large violations for feasible states can be achieved if both photon counting and homodyne detections are used [1]. Our scheme may lead to the first violation of Bell inequalities using continuous-variable systems and pave the way for a loophole-free Bell test.

[1] D. Cavalcant *et al.*, preprint arXiv:1012.1916.

Friday 15:40

Quantum correlations with no causal order

O. Oreshkov[1], F. Costa[2], C. Brukner[2]
[1]QuIC, Université Libre de Bruxelles, 1050 Brussels, Belgium.
[2]Faculty of Physics, University of Vienna, A-1090 Vienna, Austria.

We develop a framework for multipartite quantum correlations that does not presume any space-time or causal structure, but simply that experimenters in their local laboratories can perform arbitrary quantum operations. All known situations that respect causal order, including signaling and no-signaling correlations between time-like and space-like separated experiments, respectively, as well as probabilistic mixtures of these, are captured by this framework in a unified way. Remarkably, we discover situations where two experiments can be correlated in a way that is neither causal, nor a probabilistic mixture of definite causal orders. Such correlations are shown to violate a causal inequality, enabling a communication task that is impossible if the operations can be ordered according to a background time. We further show that in a classical limit causal order always arises, suggesting that space-time may be an emergent phenomenon.

[1] O. Oreshkov, F. Costa, and C. Brukner, e-print arXiv: to appear.

Poster Sessions
Program and Abstracts

Information for Poster Sessions

The poster contributions are grouped by subject. All posters will be up for the full duration of the conference. Each day the extended lunch breaks (2 hours) and the two coffee breaks (30 min each) are available for poster presentations. Thus, there is ample time for all conference participants to view the posters, and for poster authors to get feedback on their work.

Schedule - Presenters with odd poster number are asked to please attend their posters for discussion on Tuesday (Sep. 6) and Thursday (Sep. 8) and presenters with even poster number on Wednesday (Sep. 7) and Friday (Sep. 9). In this way both poster presenters and attendees are given the opportunity to present their own posters and have discussions with other poster presenters from their own and other subject areas. For numbering of posters please consult the abstract book.

Format - The size of the poster board is 120 cm x 180 cm (width x height). We suggest A0 protrait format poster size.

Setting-up and removing - Poster may be put up at any time on Monday, Sep. 5. Materials for setting-up will be available in the poster area. Posters must be removed before 18:00 on Friday (Sep. 9). Any remaining posters will be removed and discarded after this time.

Areas and locations - The poster areas are located on the F- and G- floors of the HCI building. Please set-up your poster according to its number. Plans of these floors including the position of your poster are available at the end of this book.

Atomic Systems

AS 1 **Durga B Rao Dasari:** Decoherence control in Quantum Computing protocols using Rydberg atoms

AS 2 **Mustafa Gündoğan:** Towards long-lived solid-state quantum memories for single photons

AS 3 **Ekatherina Karatsuba:** Computing the atomic inversion in the Jaynes-Cummings model

AS 4 **Shinya Kato:** Spectroscopic study of the Mott-insulator transition with an atomic clock transition

AS 5 **Adam Kaufman:** Towards ultracold single neutral atoms in microscale optical dipole traps

AS 6 **Daniel Kienzler:** Ion traps for quantum information and quantum simulation

AS 7 **Martin Mücke:** Remote entanglement between a single atom and a BEC

AS 8 **Caspar Ockeloen:** Multiparticle Entanglement on an Atom Chip

AS 9 **Jinwoo Park:** Quantum nonlocality tests for atom-field entangled states

AS 10 **Florentin Reiter:** Entangled steady-states of two atoms in optical cavities generated by engineered decay

AS 11 **Renat Sultanov:** Computation of the quantum entanglement effects between two indistinguishable polar molecules: HD+HD ultracold collision

AS 12 **Tobias Thiele:** Towards Hybrid Cavity Quantum Electrodynamics with Atoms and Circuits

AS 13 **Lucile Veissier:** Experimental developments for the deterministic entanglement of distant memories

AS 1 Tue & Thu

Decoherence control in Quantum Computing protocols using Rydberg atoms

Durga B Rao Dasari and Klaus Mølmer
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It has been proposed and demonstrated that the long range interactions among Rydberg atoms can be used to implement interesting quantum gates [1]. In addition to the huge enhancement of the qubit Rabi frequencies by collectively encoding the information of single qubit in large number of atoms, the inhomogeneous broadening however small will destroy the coherent superposition of the qubit levels. Further, loss of atoms and spontaneous emission of intermediate levels can make the fidelities of quantum gates using these qubits quite small. We present here optimal control theory methods to avoid errors due to such processes and help keep the gate fidelity high throughout the computation.

[1] M. Saffman, T. G. Walker and Klaus Mølmer, *Rev. Mod. Phys.* **82**, 2313 (2010).

AS 2 Wed & Fri

Towards long-lived solid-state quantum memories for single photons

M. Gündoğan[1], A. Almasi[1], M. Cristiani[1], H. de Riedmatten[1,2]
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Quantum memories (QM) are crucial building blocks for potential applications in quantum information and communication science. Rare-earth ion doped crystals are promising candidates for QM because they provide a large number of stationary atoms with good coherence properties. The recent demonstrations of quantum light storage in solids have been performed using storage in the excited state, leading to short storage times (<200 ns) [1]. In order to achieve significantly longer storage times, the storage in long lived spin states is required. Here we present our initial experiments with Pr^{3+} :Y_2SiO_5 crystal aimed to realize a long-lived spin wave QM for single photons.

[1] C. Clausen *et al.*, *Nature* **469**, 508 (2011), E. Saglamyurek *et al.*, *Nature* **469**, 512 (2011).

AS 3 Tue & Thu

Computing the atomic inversion in the Jaynes-Cummings model

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A new approach to the study of the function of atomic inversion in the model of interaction of a single two-level atom with a single mode of the quantized electromagnetic field in the coherent state in an ideal resonator [1] is discussed. It's based on an application of certain tools from number theory to approximation of trigonometric sums of a special form. New asymptotic formulas for the atomic inversion are found[2],[3]. These asymptotics allow us to predetermine the details of the behavior of the inversion on various time intervals depending on the parameters of the system.

[1] E. T. Jaynes and F. W. Cummings, *Proc. IEEE*, **51**, 89–109 (1963).

[2] A. A. Karatsuba, E. A. Karatsuba, *Analysis and Math. Phys.:Trends in Math. Phys.*, Birkh.Verl., Basle, 209–230 (2009).

[3] A. A. Karatsuba, E. A. Karatsuba, *J. Phys. A: Math. Theor.* **42**, 195304, 1–16 (2009).

AS 4 Wed & Fri

Spectroscopic study of the Mott-insulator transition with an atomic clock transition

S. Kato[1], M. Yamashita[2,3], K. Shibata[1], R. Yamamoto[1], Y. Yoshikawa[1], Y. Takahashi[1,3]
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[3]JST, CREST, Chiyoda-ku, Tokyo 102-0075, Japan.

An ultra-narrow optical transition of an alkaline-earth-like atom plays an important role of an optical lattice clock and also has a great advantage for spectroscopic study. We use such an ultra-narrow optical transition of a Ytterbium atom to observe the superfluid to Mott insulator transition in a three-dimensional optical lattice. A variation of an atomic distribution in a lattice potential during the phase transition is observed as the change of the excitation spectra. We successfully determine a scattering length between the ground state and the excited state from the clearly resolved peaks in the spectra, which is dramatically different from the one between the ground states.

AS 5 Tue & Thu

Towards ultracold single neutral atoms in microscale optical dipole traps

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We seek to create a small array of single neutral atoms laser-cooled to their motional ground state for quantum logic and simulation. We study atoms in microscale optical dipole traps; experiments in such traps have demonstrated versatile capabilities in quantum logic and atom-light coupling, but to-date the atomic motion has been uncontrolled and often limiting. We envision a few movable traps created with a high numerical aperture lens, providing access to interactions used in experiments with quantum gases in optical lattices. In contrast to lattice experiments we focus on small sets of atoms, but hope to benefit from the ability to individually initialize quantum degrees of freedom (motion and spin) of the atoms. We present our initial studies of trapping and laser cooling a single ^{87}Rb atom.

AS 6 Wed & Fri

Ion traps for quantum information and quantum simulation

D. Kienzler[1], J. Alonso[1], L. E. deClercq[1], B. Keitch[1], F. M. Leupold[1], F. Lindenfelser[1], H.-Y. Lo[1], M. K. Paesold[1], J. P. Home[1]
[1]Department of Physics, ETH Zürich, CH-8093, Zürich, Switzerland.

We are developing two new experimental setups for quantum information processing, simulation and state engineering with trapped atomic ions. Both systems are designed to simultaneously trap both $^{9}Be^{+}$ and $^{40}Ca^{+}$ ions. The first system comprises a segmented linear Paul trap which will be run at room temperature. The second consists of a micro-fabricated surface trap which will operate at 4 Kelvin.

AS 7 Tue & Thu

Remote entanglement between a single atom and a BEC

M. Mücke, M. Lettner, S. Riedl, C. Vo, C. Hahn, S. Baur, J. Bochmann, S. Ritter, S. Dürr, G. Rempe
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The distribution of entanglement between remote atomic systems is a key resource for quantum networks. In our experiment we create remote entanglement between a single atom trapped inside a high-finesse optical cavity and a Bose-Einstein condensate (BEC) [1]. In a first step, atom-photon entanglement is generated by emitting a single photon from the atom-cavity system. The photon is transported to the BEC and converted into a collective excitation, thereby entangling the BEC with the single atom. The entanglement has been shown to survive more than $100\,\mu\mathrm{s}$. Subsequently the matter-matter entanglement is mapped onto two single photons. The resulting two-photon state is found to have a fidelity of 95% with a maximally-entangled Bell state, proving that the entanglement survives all described mapping procedures with negligible degradation.

[1] M. Lettner *et al.*, arXiv:1102.4285 (2011).

AS 8 Wed & Fri

Multiparticle Entanglement on an Atom Chip

C. F. Ockeloen[1], M. F. Riedel[1], P. Böhi[1], R. Schmied[1], P. Treutlein[1]
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We present experiments where we generate multi-particle entanglement on an atom chip [1] by controlling elastic collisional interactions with a state-dependent microwave near-field potential [2]. We employ this technique to generate spin-squeezed states of a two-component Bose-Einstein condensate and show that they are useful for quantum metrology. The observed reduction in spin noise combined with the spin coherence imply at least four-partite entanglement between the atoms and could be used to improve an interferometric measurement over the quantum limit. Our data allow us to reconstruct the Wigner function of the spin-squeezed condensate on the full Bloch sphere. The techniques demonstrated here could be directly applied in chip-based atomic clocks which are currently being set up.

[1] M. F. Riedel *et al.*, *Nature* **464**, 1170 (2010).

[2] P. Böhi *et al.*, *Nat. Phys.* **5**, 592 (2009).

AS 9 Tue & Thu

Quantum nonlocality tests for atom-field entangled states

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We investigate nonlocality tests for atom-cavity field entangled states where photon on/off measurements and photon parity measurements are employed, respectively. When on/off measurements are used, Bell function reaches its maximum 2.61, and photon detection efficiency higher than 0.5 is required to see violation of Bell's inequality. When parity measurements are used, Bell function reaches its maximum $2\sqrt{2}$. However, due to the difficulty in measuring the microwave field, we modify the test scheme with parity measurement by adding a Rydberg atom to indirectly measure the parity of the cavity field [1]. Finally, we calculate decoherence effects from cavity dissipation and spontaneous emission along with atom-cavity interactions, and discuss possible loopholes.

[1] B. Englert *et al.*, *Optical Communication* **100**, 526 (1993).

AS 10 Wed & Fri

Entangled steady-states of two atoms in optical cavities generated by engineered decay

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We present schemes for the realization of an entangled steady-state between two atoms in an optical cavity by means of dissipation [1, 2]. Employing the naturally occurring sources of decay, spontaneous emission and cavity photon loss, we engineer effective decay processes in order to create an entangled state of two atoms as the unique fix-point of dissipative time evolution. Our studies show promising performance of our schemes for the parameters of existing cavity experiments and unveil a qualitative improvement in the scaling of the fidelity error with $1/\mathcal{F}$ (with $\mathcal{F}$ being the finesse of the cavity), as opposed to $1/\sqrt{\mathcal{F}}$ for coherent unitary protocols [1, 2].

[1] M. J. Kastoryano, F. Reiter, A. S. Sørensen, *Phys. Rev. Lett.* **106**, 090502 (2011)

[2] F. Reiter, M. J. Kastoryano, A. S. Sørensen, in preparation

AS 11 Tue & Thu

Computation of the quantum entanglement effects between two indistinguishable polar molecules: HD+HD ultracold collision

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The coherent control of identical polar diatomic molecules is considered in this work. In the framework of the ultracold HD+HD scattering we investigate the effects of entanglement between two polar indistinguishable molecules. A quantum-mechanical close coupling approach is used to carry out computation of the differential and integral cross sections in the HD+HD scattering with the use of precise H_4 potential energy surface [1]. The strong connection between quantum entanglement effects in the initial rotational-vibrational states and calculated cross sections is investigated.

[1] A.I. Boothroyd, P.G. Martin, W.J. Keogh, M.J. Peterson, *J. Chem. Phys.*, **116**, 666-689 (2002).

AS 12 Wed & Fri

Towards Hybrid Cavity Quantum Electrodynamics with Atoms and Circuits

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In cavity quantum electrodynamics (QED) experiments, atoms located in high-Q cavities are used to study coherent interactions between matter and light. We present a new experiment designed to couple Rydberg atoms with long lifetimes to a chip-based transmission line cavity. This approach is compatible with a circuit QED architecture, where superconducting quantum circuits are coupled to photons within a microwave resonator, to form a coherent interface between the superconducting circuits and atoms in the vicinity of the resonator. This potentially opens a path towards quantum computation with fast gate operations in the circuits and a long quantum memory in the atoms. It may also permit investigations of many-body physics using chip-based trapping techniques for Rydberg atoms.

AS 13 Tue & Thu

Experimental developments for the deterministic entanglement of distant memories

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Storage of entanglement in matter systems is a critical resource for quantum networking, e.g. for quantum repeaters. The continuous-variable regime enables deterministic operations, and in particular can offer the possibility of deterministic entanglement of quantum memories. We will report experimental progresses towards such capability. Our experiment involves two ensembles of cold Cesium atoms, a squeezed light source producing 3 dB of squeezing and a reversible mapping based on electromagnetically-induced transparency.

Charges and Spins

CS 1	**Feras Alkhalil:** Realization of an integrated double spin qubit device on ultra-thin Silicon-on-insulator
CS 2	**Morten Bakker:** Solid-state cavity QED using polarization-degenerate micropillar cavities
CS 3	**Pierre Barthelemy:** Towards quantum simulations in quantum dots: Nagaoka's ferromagnetism
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CS 17	**Jarryd Pla:** Spin resonance of a single phosphorus atom in silicon
CS 18	**Lucio Robledo:** High-fidelity preparation and detection of spin qubits in diamond by projective single-shot readout
CS 19	**Pasquale Scarlino:** Si-Ge spin qubits for ultra-long coherence
CS 20	**Patrick Maletinsky:** A scanning quantum system for nanoscale imaging applications

CS 1 Tue & Thu

Realization of an integrated double spin qubit device on ultra-thin Silicon-on-insulator

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This work presents a Si-based double spin qubit device integrated with a single electron electrometer and a u-ESR. Structural design and analysis was performed using 3D FEM simulations, dynamical analysis of single electron turnstile operation is demonstrated using Monte Carlo single electron simulations [1]. The spin qubits and the electrometer are realized as SOI nanowires (NWs) with an upper metal gate, which induces an inversion layer in the NW channels, and multiple lower Poly-Si control gates to enable single electron turnstile operations. The device was successfully fabricated using e-beam lithography with subsequent pattern transfer by deposition and dry etching.

[1] F. Alkhalil *et al.*, *ESSDERC/ESSCIRC Fringe, Seville*, (2010).

CS 2 Wed & Fri

Solid-state cavity QED using polarization-degenerate micropillar cavities

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We describe a technique to entangle a single photon with an electron (or hole) spin in a quantum dot in the weak coupling cavity QED regime. In order to do so sufficient coupling between matter and photons is required. For this we use self-assembled InAs/GaAs quantum dots embedded inside micropillar high-quality optical cavities. Electrical contacts allow charge state control and frequency tuning of the optical transitions by the Stark effect. For entanglement it is essential that the fundamental cavity mode is polarization degenerate. Due to residual strain in the structure and small shape asymmetries it is however split into two linearly-polarized submodes. We demonstrate a technique where by applying a combination of anisotropic and isotropic strain we permanently tune a dot optical transition on resonance with a polarization-degenerate cavity.

CS 3 Tue & Thu

Towards quantum simulations in quantum dots: Nagaoka's ferromagnetism

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Laterally defined quantum dots allow to control electrically the properties of single electrons. One can widely tune the chemical potential of the electrons in the dots, as well as the tunnel coupling between dots. This allows also an electrical control of the spin state in a multi-dot geometry. One can see these quantum dots as a fully-tunable system displaying the physics of the Hubbard model. In this poster we propose to use these quantum dots to simulate interesting phases of the Hubbard model. In particular, we show that a plaquette of four quantum dots, populated with three electrons could present a ferromagnetic interaction, called Nagaoka's ferromagnetism[1]. We discuss the influence of a magnetic field on this system, showing that, counterintuitively, the magnetic field favors spin misalignement.

[1] Y. Nagaoka , *Phys. Rev.* **147**, 392 (1966).

CS 4 Wed & Fri

Coupling 2-electron spin states by photon-assisted tunneling

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Gate-defined quantum dots containing just one or two electrons provide a powerful platform for studies of orbital and spin quantum dynamics in nanoscale devices. Here we demonstrate the ability to excite tunneling transitions between different spin states of 2 electrons in a double quantum dot in a GaAs/(Al,Ga)As 2DEG. The dominant mechanism responsible for violation of spin conservation is the spin-orbit interaction. Mixing rates for the different transitions are experimentally determined from time-resolved measurements. These transitions make it possible to perform detailed microwave spectroscopy of the molecular spin states and open up the possibility of realizing full quantum control of a two spin system via microwave excitation.

CS 5 Tue & Thu

Integration of quantum dots with superconducting microwave circuits

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The realization of circuit QED has led to significant progress in control and coupling of microwave photons and superconducting qubits, by trapping photons in an on-chip cavity. Coupling the electromagnetic field of such a resonator to other quantum systems such as semiconductor quantum dots opens up the possibility of hybrid quantum information processing, in which the advantages of different systems can be exploited in one device. Here we report on progress towards combining an on-chip superconducting microwave cavity with quantum dots defined in GaAs heterostructures, and discuss a first experiment in which we characterize the resonator by monitoring the current through a nearby quantum dot.

CS 6 Wed & Fri

The role of hyperfine interaction for cavity-mediated coupling between spin qubits

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We consider two qubits interacting by means of an optical cavity, where each qubit is represented by a single electron spin confined to a quantum dot. It is known that electron spins in III-V semiconductor quantum dots are affected by the decoherence due to the hyperfine interaction with nuclear spins. Here we show that the interaction between two qubits is influenced by the Overhauser field as well. Starting from an unpolarisied nuclear ensemble, we investigate the dependance of the fidelities for two-qubit gates on the Overhauser field. We include the hyperfine interaction pertubatively to second order in our analytical results, and to arbitrary precision numerically [1]1.

[1] J. Hildmann and G. Burkard, *arXiv:1103.3435*.

CS 7 Tue & Thu

Optical orientation of nuclear spins in solids

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Nuclear spins are important to quantum information processing both as quantum state with long coherence times and as a source of decoherence for electron spins. In both situations it is important to achieve highly oriented, pure spin states. We discuss methods to optically orient and control the bulk nuclear spin system in diamond and semiconductors such as gallium arsenide. In diamond we have discovered a new regime of optical nuclear hyperpolarization[1]. Nitrogen vacancy centers (NV- centers) in diamond can be optically oriented by unpolarized optical irradiation. Proximate nuclei are then polarized by thermal contact with the dipolar interaction reservoir of the NV- spins. This thermal contact is mediated by the anisotropic dipolar hyperfine interaction. A highly oriented, inverted population is attained in the bulk ^{13}C nuclear spin system.

[1] J. King *et al.*, *Phys. Rev. B* **81**, 073201 (2010).

CS 8 Wed & Fri

Observation of few-electron regime and suppression of inter-dot tunneling in silicon quantum dots

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Electron spins in Si quantum dots (QDs) have been attracted much attention because they are predicted to possess long coherence time due to weak hyperfine coupling. However, achieving few-electron regime in Si QDs is still challenging because of relatively large electron effective mass. We fabricate lithographically-defined Si QDs to obtain well-defined confinement potentials. We then observe a few-electron regime in single QDs and suppression of inter-dot tunneling in double QDs probably due to Pauli-blockade.

CS 9 Tue & Thu

Excited-state spectroscopy in a few-electron silicon quantum dot via charge sensing and pulsed-gating technique

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The conventional method to probe the excited states in a few-electron quantum dot is by performing bias spectroscopy, in which the conductance through the dot is monitored as a function of source-drain bias. This requires two leads with large enough tunnel coupling to allow electron transport which can be difficult in the few-electron regime. Here we present excited-state spectroscopy in a quantum dot using dynamic charge sensing and a pulsed-gating technique [1] with no transport through the dot. Orbital excited states are observed and their level spacings decrease as the dot size increases. We study the spin filling of the first 4 electrons in a parallel magnetic field and experimentally extract a valley splitting of $\sim$250 μeV. Our results provide optimism for the realization of spin-based silicon qubits.

[1] J. M. Elzerman *et al.*, *Applied Physics Letters* **84**, 23 (2004).

CS 10 Wed & Fri

Design and fabrication of single electron spin qubits in lithographically defined silicon quantum dots

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Electron spins in Si quantum dots (QDs) provide an attractive alternative to their GaAs conterparts due to their much longer spin relaxation times[1]. We realise a pair of SOI-based double quantum dot (DQD) transistors facing each other with only a 50nm separation via E-Beam lithography and high resolution HSQ resist. A VLSI compatible fabrication process is implemented allowing for future scalability in quantum systems. We propose a new method of single electron detection verified by Monte-Carlo based simulations making use of the periodicity in the charge stability diagram of a DQD.

[1] C. B. Simmions *et al.*, *Phys. Rev. Lett.* **106**, 156804 (2011).

CS 11 Tue & Thu

Long-lived solid-state room-temperature quantum memory

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One of the major obstacles in quantum information technology is to prevent a quantum bit (qubit) from dephasing, while still being able to manipulate and read-out the qubit state on a fast time scale. We report the realization of a room temperature quantum register that maintains it's quantum mechanical nature for up to a seconds. To achieve this, we utilize a quantum register consisting of an electronic spin and a proximal nuclear spin; the register is associated with single nitrogen-vacancy (NV) defect centers in diamond. In order to maximize the coherence time of the nuclear spin, we employ dynamical decoupling using microwave and optical pulses. The realization of a solid state quantum memory with long coherence times at room temperature opens up new possibilities for applications of quantum information systems.

CS 12 Wed & Fri

Si Double Quantum Dots for Quantum Information Processing

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Our work aims at controlling the spin states of individual electrons in double silicon quantum dots with the ultimate goal of realizing silicon single-electron spin quantum bits as building blocks for future solid-state quantum computers [1]. Silicon is an intrinsically promising semiconductor for controlling electron spins, because of the weak spin-orbit coupling, predominantly spin-zero nuclei, and the absence of piezo-electric electron-phonon coupling with spin coherence times expected to be much longer than in GaAs-based systems. Pauli spin blockade in the few-electron regime in highly tunable MOS silicon double QDs opens the pathway to the rotation of an electron spin into a superposition of spin-up and spin-down.

[1] D. Loss and DiVincenzo, *Phys. Rev. A* **57**, 120 (1998).

CS 13 Tue & Thu

Implementation of an quantum error correction protocol in a small quantum register

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Electron spins associated with the nitrogen-vacancy (NV) defect in diamond are promising candidates for quantum information processing at room temperature. For practical applications, however, the quantum information stored in a spin qubit has to be protected from phase and bit-flip errors. The technique of applicating an error correction protocol involving a proximal nuclear spin is discussed.

CS 14 Wed & Fri

Autonomous quantum logic

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We propose new architecture of quantum computation in which no real-time external control to the quantum register is necessary. Each quantum gate is imprinted on a spin network chip as a form of spin interactions and is driven by a program counter made of a spin chain. Whole sequence of unitary gates is autonomously accomplished by applying only a pair of external signals. No energy is consumed even including the external circuitry, thus featuring the original spirit of the reversible computation. Accuracy of each quantum gate is calibrated at the chip fabrication stage with an arbitrary care until it fulfills fault tolerance criterion. The operation is robust against the real-time environmental fluctuation since the quantum state evolution inside the chip is autonomous. [1] T. Ohshima et al, quant-ph/0702019, [2] T. Ohshima, quant-ph/0806.4548

CS 15 Tue & Thu

Entanglement generation by superradiance in ensemble of double quantum dots

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When an ensemble of two-level systems is coupled to a common bosonic field, the Dicke's superradiance takes place [1]. The emission of a boson creates an entangled state, which results in an enhancement of the subsequent radiation. We theoretically study the superradiance of optical phonons in the transport through an ensemble of double quantum dots (DQDs). We propose an experimental setup to observe the dynamical generation of entanglement. We consider a set of DQDs, $(\mathrm{L}_j, \mathrm{R}_j)$ $(j = 1, 2, \ldots, N)$. The current flows through the DQDs in parallel: from the source lead to L_j, and from R_j to the drain lead. N electrons are confined in L_j in the initial state. We show the enhanced current due to this superradiance. If specific DQDs are connected to the drain strongly, the measurement of the current breaks the entangled state. The superradiance is hardly observed in such a situation.

[1] H. Dicke, *Phys. Rev.* **93**, 99 (1954); T. Brandes, *Phys. Rep.* **408**, 315 (2005).

CS 16 Wed & Fri

Robust optical orientation of spins in Ge/SiGe quantum wells

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Compared to other materials systems, group IV compounds have a greater potential in the field of spintronics because of the long spin coherence time and because Si and Ge can be isotopically purified. Despite such advantages, initialization of spins by angular momentum transfer from light is still one of the main challenges in Si-based systems, and efficient, optical initialization remains to be demonstrated. Our approach, accomplished via band-structure engineering, tackles such long-standing issue. By measuring circular polarization of luminescence above 80%, we demonstrate spin orientation for photo-excited carriers at type I Ge/SiGe quantum wells. Spin orientation is observed even after carrier relaxation from Γ to L minima of the conduction band, paving the way towards joint implementations of spin and photonic functionalities onto mainstream Si electronics.

CS 17 Tue & Thu

Spin resonance of a single phosphorus atom in silicon

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We present the first experimental demonstration of electrically–detected electron– and nuclear–spin resonance of a single P atom in silicon. We read out the electron spin state in single-shot using our novel spin-charge conversion technique [1], and control its state with microwave pulses delivered by an on-chip broadband transmission line. Since the electron resonance occurs at two possible frequencies depending on the ^{31}P nuclear state, we achieve single-shot nuclear spin readout, and observe time-resolved nuclear quantum jumps. The ^{31}P spin resonances are detected by adding an NMR excitation.

[1] A. Morello *et al.*, *Nature* **467**, 687–691 (2010).

CS 18 Wed & Fri

High-fidelity preparation and detection of spin qubits in diamond by projective single-shot readout

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Spins in Nitrogen Vacancy (NV) centers are attractive candidates for quantum bits, owing to their excellent coherence properties and controllability. Here we use the spin selectivity of optical transitions to implement single-shot readout of the NV center's electron spin. To reach the required large photon collection efficiency, we fabricate solid immersion lenses into the host diamond crystal, deterministically positioned onto pre-selected NV centers. Individual hyperfine-coupled nuclear spins can be measured in a single shot by entangling them with the NV electron spin followed by electron spin readout. As this measurement is projective, it also serves as initialization step. We demonstrate that by repeatedly applying the initialization and readout step the fidelity can be increased significantly.

CS 19 Tue & Thu

Si-Ge spin qubits for ultra-long coherence

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Coherent electron spin manipulation for quantum information processing has already been successfully investigated in electrostatically-defined III-V semiconductor quantum dots (QDs). However, there the dephasing time T_2^*(20 ns for GaAs) is limited by the hyperfine interaction with the nuclear spin bath. To overcome this limitation we form a double QD in SiGe, a mainly nuclear spin-free host material, for which recently single shot spin read-out was demonstrated [1]. Compared to GaAs, the large effective Si electron mass hinders control of the tunnel barriers and valley degree of freedom might complicate the spin read-out by Pauli blockade. Here, we demonstrate formation and tuning of a few electron double QD in SiGe. The charge state is detected by a quantum point contact. Barriers to the leads and the interdot barrier are characterized by pulse spectroscopy. Measurements towards Pauli spin blockade will be discussed.

[1] C.B.Simmons *et al.*, *PRL* **106**, 156804(2011).

CS 20 Wed & Fri

A scanning quantum system for nanoscale imaging applications

P. Maletinsky[1], S. Hong[2],M. S. Grinolds[1], B. Hausmann[2], M. D. Lukin[1], R. L. Walsworth[3], M. Loncar[2], A. Yacoby[1]
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Individual quantum systems hold great potential as sensitive tools for nanoscale imaging and metrology. Possible applications cover topics as diverse as electric and magnetic field imaging or near-field optical microscopy with single quantum emitters, all with nanometric resolutions. Here, we present a robust experimental realization of such a scanning “quantum-probe microscope” based on an individual Nitrogen Vacancy (NV) center in diamond. Our apparatus is based on a combined atomic force (AFM) and optical microscope, where the AFM tip consists of a high purity, single crystalline diamond nanopillar holding a single NV center at its end. This geometry ensures high spatial resolution, long NV coherence times and high NV fluorescence collection efficiency. We demonstrate the excellent resulting imaging performance by mapping nanoscale magnetic field distributions on a magnetic memory and by performing single-photon optical imaging of metallic nanostructures.

Quantum Communication

QC 1 **Gonzalo A. Alvarez:** Localization effects induced by decoherence in many-spins quantum states superpositions

QC 2 **Koji Azuma:** Optimal coherent-state-based entanglement generation

QC 3 **Christoph Clausen:** Heralded entanglement of two rare-earth-ion doped crystals

QC 4 **Marcos Curty:** Performance of heralded qubit ampliÞers for practical device-independent quantum key distribution

QC 5 **Michael Schug:** Efficient generation of single-mode photons from single ions

QC 6 **Thierry Ferrus:** Manipulation of charge qubit states in an isolated silicon double quantum dot

QC 7 **Joe Ghalbouni:** Evaluation of a correlated photon pair source fidelity in a multiuser distribution system

QC 8 **Sylvain Guilbaud:** Optimization of a narrow bandwidth entangled photon source

QC 9 **Evgueni Karpov:** Close-to-optimal information transmission via bosonic Gaussian channels with memory

QC 10 **Luis Lizama:** Perfect Secrecy in Quantum Key Distribution

QC 11 **Christian R. Muller:** Probabilistic Scheme for Phase-Concentration and Cloning of Coherent States without a Phase Reference

QC 12 **Clara Osorio:** Qubit Amplification and Qutrit Teleportation

QC 13 **Guilherme P. Temporão:** Can a polarization scrambler really depolarize light?

QC 14 **Enrico Pomarico:** Faithful Entanglement Swapping based on Sum-Frequency Generation at the single photon level

QC 15 **Analia Zwick:** Robustness of spin-coupling distributions for perfect quantum state transfer

QC 1 Tue & Thu

Localization effects induced by decoherence in many-spins quantum states superpositions

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The spurious interaction of quantum systems with their environment known as decoherence leads, as a function of time, to a decay of coherence of superposition states. Since the interactions between system and environment are local, they also cause a loss of spatial coherence: correlations between spatially distant parts of the system are lost and the equilibrium states are localized. This effect limits the distance over which quantum information can be transmitted, e.g., along a spin chain. We investigate this issue in a NMR quantum simulator, where it is possible to monitor the spreading of quantum information in a three-dimensional network: states that are initially localized on individual spins (qubits) spread under the influence of a suitable Hamiltonian apparently without limits. If we add a perturbation, the spreading stops and the system reaches a limiting size, which becomes smaller as the strength of the perturbation increases. This limiting size represents a dynamical equilibrium.

QC 2 Wed & Fri

Optimal coherent-state-based entanglement generation

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A principal goal of quantum information theory is evaluating the potential to distribute entanglement through an optical channel, which is becoming more important in conjunction with development of fiber-based quantum key distribution, free-space quantum communication, and quantum repeaters. Here we present an optimal bound for arbitrary entanglement distribution based on the transmission of an optical pulse in coherent states over lossy channels, which is determined only by the channel loss. We also provide a simple but optimal protocol based on linear optical elements and a quantum nondemolition (QND) measurement. Even if we replace the QND measurement with photon detectors for the realization, the protocol works as entanglement distribution outperforming all known protocols (e.g., [1]).

[1] P. van Loock *et al.*, Phys. Rev. Lett. **96**, 240501 (2006); K. Azuma *et al.*, Phys. Rev. A **80**, 060303(R) (2009).

QC 3 Tue & Thu

Heralded entanglement of two rare-earth-ion doped crystals

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The realization of quantum networks based on quantum repeaters requires the heralded creation of entanglement between quantum memories at distant locations. Important and promising results have been obtained with quantum memories based on rare-earth-ion doped (REID) crystals [1, 2, and references therein]. We have successfully entangled two such crystals, separated by a few centimeters, via the transfer of entanglement from two spatial modes of a heralded single photon. This matter-matter entanglement is characterized by analyzing the photons released from the crystals after a storage time of 33 ns. Although not directly applicable to quantum repeaters, our results show that photonic sources of entanglement and REID crystals are realistic candidates for quantum networks.

[1] C. Clausen *et al.*, *Nature* **469**, 508 (2011)

[2] E. Saglamyurek *et al.*, *Nature* **469**, 512 (2011)

QC 4 Wed & Fri

Performance of heralded qubit ampliÞers for practical device-independent quantum key distribution

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Device-independent quantum key distribution does not need a precise quantum mechanical model of employed devices to guarantee security. Despite of its beauty, it is still a very challenging experimental task. We compare a recent proposal by Gisin *et al.* [1] to close the detection loophole problem with that of a simpler quantum relay based on entanglement swapping with linear optics. Our full-mode analysis for both schemes confirms that, in contrast to recent beliefs, the second scheme can indeed provide a positive key rate which is even considerably higher than that of the first alternative. The resulting key rates and required detection efficiencies of approx. 95% for both schemes, however, strongly depend on the underlying security proof.

[1] N. Gisin *et al.*, *Phys. Rev. Lett.* **105**, 070501 (2010).

QC 5 Tue & Thu

Efficient generation of single-mode photons from single ions

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We operate two independent linear Paul traps with single ^{40}Ca^{+} ions, a highly modular setup for implementing quantum networking tools [1, 2]. For quantum communication applications, we efficiently generate near-bandwidth-limited, single-mode (sm) fiber-coupled photons at 397 nm with tailored temporal shape and bandwidth. We reach $8 \cdot 10^5 \mathrm{s}^{-1}$ detected sm photons per ion in cw operation, or $8 \cdot 10^3 \mathrm{s}^{-1} \mathrm{MHz}^{-1}$ generated sm photons in triggered mode. For the latter value, we exploit constructive interference of light from the ion and its mirror image.

[1] M. Almendros et al., PRL **103**, 213601 (2009).

[2] N. Piro *et al.*, Nature Physics **7**, 17 (2011).

QC 6 Wed & Fri

Manipulation of charge qubit states in an isolated silicon double quantum dot

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The implementation of double dot charge qubits in an electrically isolated structure has proven to possess numerous advantages, including a long decoherence time and an easy scalability while keeping a high compatibility with standard commercial fabrication techniques [1]. Despite the lack of directly connected leads, the basis states could be detected and manipulated by using a nearby single electron transistor in the cotunneling regime [2]. Experiments have been carried out with a custom CMOS 100 kHz bandwidth amplifier at low temperature. Successful unitary qubit operations have been realized via photon excitation in the GHz range, using a distant antenna. The decoherence time is predicted to be significantly larger than the one obtained in similar but connected structures. Such a leadless operation is expected to improve substantially the scalability to multi-qubit devices.

[1] J. Gorman *et al.*, *Phys. Rev. Lett.* **95**, 090502 (2005)

[2] T. Ferrus *et al.*, *arXiv:* 0907.2635 (2011);*J. Appl. Phys.* **106**, 033705 (2009)

QC 7 Tue & Thu

Evaluation of a correlated photon pair source fidelity in a multiuser distribution system

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When using a polarization entangled photon source, in order to establish a quantum channel between two users A and B, the source fidelity must be high. The different filters we employ to distribute the photons to frequency separated channels can exhibit a dissymetry with respect to the filter's central frequency. This, along with the accumulated losses through the propagation in the optical chain, can degrade the source's fidelity. We evaluate in two ways this fidelity, in the case of a multiuser distribution of polarized entangled photons through classical telecommunication demultiplexers: in a theoretical way, by using experimental data that describe the shape of our filters and in an experimental way by measuring the counts on a pair of symmetric channels and the coincidences between them.[1]

[1] J.L. Smirr *et al.*, *Optics Express* **19**, 616-627 (2011).

QC 8 Wed & Fri

Optimization of a narrow bandwidth entangled photon source

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Quantum entanglement storage is a major challenge for future quantum networks. We develop a source of entangled photon pairs at telecom wavelength with a narrow spectral width of the order of 40 MHz to be able to interact with a solid state quantum memory. The photon pairs are created by spontaneous parametric downconversion inside a PPLN nonlinear crystal, which is placed inside a cavity so as to enhance the emission of photons inside very narrow spectral modes. Polarisation entanglement is realized thanks to a double pass setup and the pairs are eventually coupled into a singlemode fiber. Thanks to a theoretical model specifically developped for such a SPDC source, the setup is being carefully optimized to reduce coupling losses that could limit the fidelity of the source. The key parameters, apart from the nonlinear interaction in the crystal, are focusing, phase mismatch and filtering and they determine the design of the cavity[1].

[1] J.L. Smirr *et al.*, *J. Opt. Soc. Am. B*, **28**, 832–841 (2011).

QC 9 Tue & Thu

Close-to-optimal information transmission via bosonic Gaussian channels with memory

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Entangled signal states can enhance the information transmission rate for certain quantum channels with memory. For the bosonic memory channel with Gauss-Markov noise we have found the optimal Gaussian states that saturate the “Gaussian capacity” in the quantum water-filling regime [1]. These multipartite entangled states are possibly difficult to implement, however, we demonstrate that Gaussian matrix product states (GMPS) [2, 3] provide an approximation which is close-to-capacity achieving. Based on the scheme by Adesso et al. [3] we propose a compact setup which realizes sequential generation of these entangled multi-mode signal states.

[1] J. Schäfer *et al.*, *Phys. Rev. A* **80**, 062313 (2009).
[2] N. Schuch *et al.*, *Commun. Math. Phys.* **267**, 65 (2006).
[3] G. Adesso *et al.*, *Phys. Rev. A* **74**, 030305 (2006).

QC 10 Wed & Fri

Perfect Secrecy in Quantum Key Distribution

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Perfect secrecy is achieved when two parties share a cryptographic key whose length grows linearly with the length of the plain text. Here, we present Quantum Perfect Secrecy (QPS) in the context of Continuous Variable (CV) Quantum Key Distribution (QKD) that uses Gaussian modulated coherent states [1], as follows: instead of the cipher text, Alice will send the plain text to Bob using the two bits coherent states used in CV-QKD and forming a stack of them. The structured key thus obtained is such that it contains two columns due to the non commuting observables and a number of rows due to the number of coherent states sent by Alice. We have found that the attacker Eve cannot perform a simple Quantum memory attack because she needs to capture both observables of each coherent state.

[1] F. Grosshans *et al.*, *Letters to Nature* **421**, 238-241 (2003).

QC 11 Tue & Thu

Probabilistic Scheme for Phase-Concentration and Cloning of Coherent States without a Phase Reference

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The No-Cloning theorem is formulated in terms of deterministic operations only, such that probabilistic schemes offer quantum mechanical operations beyond the limits following from this theorem. We present a probabilistic scheme for phase concentration and cloning of coherent states. Our approaches are based solely on phase-randomized displacements and photon counting omitting the need for non-classical resources, non-linear materials and a phase reference. We discuss the characteristics of the scheme and illustrate the performance on the basis of experimental results [1].

[1] M.A. Usuga and C.R. Muller *et al.*, *Nature Physics* **6**, 767-771 (2010).

QC 12 Wed & Fri

Qubit Amplification and Qutrit Teleportation

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Heralded qubit amplification has been proposed as a means of realising device independent quantum key distribution [1]. Such an amplifier is based on the quantum scissors scheme [2, 3], and it has been realise for coherent states [4, 5]. We have studied the feasibility of an amplifier for polarisation qubits, and used it as the basis for a qutrit teleportation experiment. We will present the latest results in this direction.

[1] Nicolas Gisin *et al.*, *PRL* **105**, 070501 (2010).

[2] David T. Pegg *et al.*, *PRL* **81**, 1604-1606 (1998).

[3] T. C. Ralph *et al.*, *arXiv:0809.0326v1*.

[4] G. Y. Xiang *et al.*, *Nature Photonics* **4**, 316 - 319 (2010).

[5] F. Ferreyrol *et al.*, *PRL* **104**, 123603 (2010).

QC 13 Tue & Thu

Can a polarization scrambler really depolarize light?

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According to quantum theory, two ensembles of quantum systems that are described by the same density matrix are indistinguishable. For example, unpolarized light can be obtained either by a mixture of the four BB84 states or by tracing out a photon from a Bell state. In both cases one is unable to determine the outcome of any polarization measurement, but the reasons are conceptually different: whereas the first case is a matter of *classical* ignorance (the photons were prepared in a definite but unknown way), the second one is of the *quantum* ignorance kind [1] - if one cannot access the other degrees of freedom of the quantum state, there is no information that could be used to predict a measurement result. We use these concepts to discuss the quantum-physical interpretation of the degree of polarization of light and whether a polarization scrambler can really depolarize light.

[1] N. Herbert, *Quantum Reality*, Anchor Books (1985).

QC 14 Wed & Fri

Faithful Entanglement Swapping based on Sum-Frequency Generation at the single photon level

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Entanglement swapping that makes use of pairs of photons produced by SPDC can be made faithful without the need of postselection by adopting sum-frequency generation (SFG) at the single photon level for the Bell state measurement, as recently proposed in [1]. This scheme is able to outperform existing six-photon protocols for heralding the creation of maximally entangled photon pairs. We show that this is experimentally fesible using SFG in PPLN waveguides with an efficiency of the order of 10^{-7}. This proposal also offers attractive solutions for the generation of triplets at a distance and for overcoming the problem of losses in device-independent quantum key distribution.

[1] N. Sangouard *et al.*, *Phys. Rev. Lett.* **106**, 120403 (2011).

QC 15 Tue & Thu

Robustness of spin-coupling distributions for perfect quantum state transfer

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The transmission of quantum information between different parts of a quantum computer is of fundamental importance. Spin chains have been proposed as quantum channels for transferring information. Different configurations for the spin couplings can optimize the transfer. As imperfections in these specific spin-coupling distributions can never be completely avoided, it is important to find out which systems are optimally suited for information transfer by assessing their robustness against imperfections. We analyze different spin coupling distributions of spin chains designed for perfect quantum state transfer. We study the transfer of an initial state from one end of the chain to the other end. We quantify the robustness of different coupling distributions against perturbations and we relate it to the properties of the energy eigenstates and eigenvalues. We find that the localization properties of the systems play an important role for robust quantum state transfer.

Quantum Information Theory

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QIT 3 **Kuan-Peng Chen:** Construction and Classification of Quantum Codes

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QIT 1 Tue & Thu

Bell inequalities with no quantum violation and unextendible product bases

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The strength of classical correlations is subject to certain constraints, commonly known as Bell inequalities. Violation of these inequalities is the manifestation of non-locality displayed in particular by quantum mechanics, meaning that quantum mechanics can out-perform classical physics at tasks associated with such Bell inequalities. Interestingly, however, there exist situations in which this is not the case. We associate an intriguing class of bound entangled states, constructed from Unextendible Product Bases with a wide family of tasks, for which (i) quantum correlations do not out-perform the classical ones but (ii) there exist supra-quantum non-signalling correlations that do provide an advantage [1].

[1] R. Augusiak *et al.*, arXiv:1101.4893.

QIT 2 Wed & Fri

Quantum Discord in Bell-diagonal two-qudit states

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Widely understood quantum correlations are found to be the key resource in Quantum Information Theory. Hence fundamental question is which states contain them and which are only classicaly correlated. Since quantum discord quantifies all quantum correlations, we need to characterize set of zero-discord states. We analize a class of two-qudit Bell-diagonal states and give necessary and suficient conditions on zero-discord. Intrestingly, for systems where d is a prime number, restrictions are stronger than for others. We also propose a necessity criterion for zero discord in qubit-qudit states, analogous to Peres-Horodecki criterion for separability, and compare both results for two-qubit systems.

QIT 3 Tue & Thu

Construction and Classification of Quantum Codes

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During the processes of transmission of quantum information, errors occur occasionally because the information interacts banefully with the environment. To protect the information against errors in quantum communication and quantum computation, error correction codes are essential to safeguard the quantum data. In this report, a systematic method based on the *group structure* of a unitary Lie algebra described in [1] is proposed to generate an enormous number of quantum codes. Furthermore, according to the duality between some *initial* quantum states and *codeword operators*, the generated quantum codes including the *additive* and *nonadditive* codes can be classified into four kinds. In terms of the map from the unitary Lie algebra to the additive group, the classical correspondences of some of these quantum codes can be rendered as well. The scheme is a useful tool and helps constructing new kinds of quantum codes that may have higher efficiency or capability for error corrections.

[1] Z.-Y. Su (2006), quant-ph/0603190.

QIT 4 Wed & Fri

Convergence to equilibrium under random Hamiltonian

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We analyse time of equilibration of subsystem of a larger system under a randomly chosen total Hamiltonian. We pick a basis of the Hamiltonian according to Haar measure. We than obtain that the time of equilibration [1] is of order of inverse of arithmetic average of Bohr frequences. To compute the average over random basis, we need to compute inverse of a matrix of overlaps of operators which permute four systems. We first obtain results on such matrix determiend by representation of arbitrary group, and then apply it to our representation of permutation group.

[1] N. Linden *et al.*, *New Journal of Physics* **12**, 055021 (2010).

QIT 5 Tue & Thu

Pólya number of the continuous-time quantum walks

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We propose a definition for the Pólya number of continuous-time quantum walks to characterize their recurrence properties. The definition involves a series of measurements on the system, each carried out on a different member from an ensemble in order to minimize the disturbance caused by it. We examine various graphs, including the ring, the line, the higher-dimensional integer lattices, and a number of other graphs, and we calculate their Pólya number. For the timing of the measurements, a Poisson process as well as regular timing are discussed. We find that the speed of decay for the probability at the origin is the key for recurrence [1].

[1] Z. Darázs, T. Kiss, *Phys. Rev. A* **81**, 062319 (2010).

QIT 6 Wed & Fri

Information processing with locally quantum systems under reversible dynamics

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The information processing capabilities of quantum theory outperform those of any classical theory in tasks such as computation, cryptography or teleportation. Complementarily, its power seems to be constrained for other tasks such as communication complexity or nonlocal games . What physical/informational principles are responsible for the information processing power of quantum theory and why is it not even more powerful?. To answer this, we consider theories in which quantum theory holds locally [1, 2] and restrict to reversible dynamics to study what joint states and correlations emerge [3].

[1] H. Barnum et al *Phys.Rev.Lett.* **104**, 140401,2010

[2] A.Acin et al *Phys.Rev.Lett.* **104**, 140404 (2010)

[3] G. de la Torre, Ll. Masanes, J. Oppenheim, A.J. Short *in preparation*

QIT 7 Tue & Thu

Multipartite entanglement detection from correlation tensors

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Multipartite entanglement can be exploited to enable numerous tasks in quantum information processing. Recently, progress has been made in finding sufficient conditions for a state to be genuine multipartite entangled (GME) or at least non-fully separable (NFS). In this contribution we approach this problem using correlation tensors, i. e. the coefficients characterizing a density matrix when it is written in a local operator basis. We will show that using this same piece of information sufficient conditions for both GME and NFS states can be established. We will show the power of our conditions compared to previous criteria. In particular, for GME detection our conditions seem to be most powerful when the dimensionality of the subsystems increases. Regarding NFS states, our conditions take advantage of the fact that they contain information on all m-body correlations overcoming the limitations of the previous criteria based on two-body correlations.

QIT 8 Wed & Fri

Topological one-way quantum computation on verified logical cluster states

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We propose topological fault-tolerant quantum computation on the verified logical cluster states to improve the noise threshold. Certain cluster states of finite size, say star clusters, are constructed with logical qubits through a verification process to achieve high fidelity. Then, the star clusters are connected near-deterministically with verification to form a 3D cluster state to implement the topological one-way computation. The necessary postselection for verification is localized within the star clusters, ensuring the salability of computation. This scheme works with a high error rate $\sim 1\%$ and reasonable resources comparable to or less than those for the other fault-tolerant schemes, suggesting potentially a noise threshold higher than 5% [1].

[1] K. Fujii and K. Yamamoto, Phys. Rev. A **82**, 060301(R) (2010).

QIT 9 Tue & Thu

A new approach towards proving the minimum output entropy conjecture for Gaussian bosonic channels

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One of the oldest open problems in quantum information theory is calculating the classical information capacity of an optical communication channel. It has been conjectured that capacity is achieved by random coding of coherent states using an isotropic Gaussian distribution. We show that proving the conjecture for an ideal (quantum-limited) amplifier is sufficient. The unitary dilation of an ideal amplifier being a two-mode squeezer, we rephrase the original conjecture in terms of the entanglement shared by its output modes. Finally, we use the connection between majorization and entanglement to prove the conjecture for a reduced class of states, and to perform a systematic numerical analysis. Apart from reinforcing the conjecture, we believe that our analysis offers a new possible approach to its proof.

QIT 10 Wed & Fri

Estimating mixed qudits: hedging, entropy, and adaption

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Reconstruction of a completely unknown quantum state from limited resources, i. e. when only a small number of identically prepared states is available, must be considered an important challenge in the field of quantum information. This challenge grows with the dimension of Hilbert space and when taking mixed states into account. We present Monte-Carlo simulations (cf. [1]) of estimation processes for mixed qu$d$its (d-level states), comparing different estimation methods, namely standard maximum likelihood estimation and modifications of it, hedged maximum likelihood [2] as well as “maximum likelihood-maximum entropy” estimation [3]. The latter two promise better estimation quality for mixed states. Additionally, we discuss adaptive methods to further improve estimation quality for these schemes.

[1] C. J. Happ and M. Freyberger, *Phys. Rev. A* **78**, 064303 (2008).

[2] R. Blume-Kohout, *Phys. Rev. Lett.* **105**, 200504 (2010).

[3] Y. S. Teo *et al.*, arXiv:1102.2662 [quant-ph] (2011).

QIT 11 Tue & Thu

Concurrence in Disordered Systems

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Quantum systems exist at finite temperatures and are likely to be disordered to some level. Since applications of quantum information often rely on entanglement, we require methods which allow entanglement measures to be calculated in the presence of disorder at non-zero temperatures. We demonstrate how the disorder averaged concurrence can be calculated using thermal many-body perturbation theory. Our technique can also be applied to other entanglement measures. To illustrate, we find the disorder averaged concurrence of an XY spin chain.

QIT 12 Wed & Fri

Weak joint probabilities as informationally complete representation of quantum statistics

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It is pointed out that the joint probabilities obtained in weak measurements for any pair of mutually overlapping orthogonal basis sets provide a complete and physically meaningful description of the density operator of the initial quantum state [1]. Based on the corresponding operator expansion of observables and quantum states, the non-classical relations between different measurements can then be expressed in terms of complex statistics that (a) reproduce classical determinism in the continuous and noisy limit, and (b) explain quantum paradoxes in terms of transformations between different basis systems [2].

[1] H. F. Hofmann, Phys. Rev. A **81**, 012103 (2010).

[2] H. F. Hofmann, e-print arXiv:1104.0062v1 (2011).

QIT 13 Tue & Thu

On no-cloning and no-broadcasting of nonsignalling boxes

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We deal with families of probability distributions called nonsignalling boxes. We consider class of operations that transform local boxes into local ones (the one that admit LHV model) and prove that any operation from this class can neither clone nor even broadcast a nonlocal box in 2x2 case. We have two approaches, one exploiting geometry of nonsignalling boxes, and the other using more general arguments.

QIT 14 Wed & Fri

Entanglement, frustration, and factorization: A quantum informatic approach to collective quantum phenomena

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Quantum information theory applied to quantum many-body systems includes the concept of modular entanglement that allows the engineering of arbitrary long-distance two-qubit gates in quantum spin chains [1]. The scaling properties of the corresponding entanglement spectra allow to relate area law behaviors to the existence of factorized ground states [2]. In turn, factorization plays a relevant role in the study of frustrated systems [3]. Indeed, a universal measure of frustration can be defined thanks to a general inequality holding between entanglement and ground-state overlaps [4].

[1] G. Gualdi *et al.*, *Phys. Rev. Lett.* **106**, 050501 (2011).

[2] S. M. Giampaolo *et al.*, arXiv:1106.4566 (2011).

[3] S. M. Giampaolo *et al.*, *Phys. Rev. Lett.* **104**, 207202 (2010).

[4] S. M. Giampaolo *et al.*, arXiv:1103.0022 (2011).

QIT 15 Tue & Thu

The Cutoff Phenomenon for Products of Quantum Channels and its Applications to Quantum Information Theory

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We study the convergence behavior of time-continuous Markovian quantum channels, which are constructed as tensor sums of local Liouvillians. We adapt well known tools from the classical theory of Markov Chain Mixing times in order to fully characterize both the asymptotic and the pre-asymptotic convergence behavior of these channels. In particular, we introduce the notion of a *Cutoff Phenomenon* within the framework of Quantum Information Theory (QIT). We apply these new ideas and methods to the problems of (i) passive error protection, (ii) the Chernoff bound in the presence of noise, and (iii) the efficient dissipative preparation of Stabilizer States.

QIT 16 Wed & Fri

Spatiotemporal multipartite entanglement

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Numerous works have addressed the problem of characterization of multipartite entanglement for continuous variables (CV). We propose, following the spirit of quantum imaging [1], to generalize the theory of multipartite entanglement for the CV Gaussian states by considering the *correlation matrix* $\sigma_{ij}(s, s')$ at two different spatio-temporal points $s = (\vec{\rho}, t)$ and $s' = (\vec{\rho}', t')$ with $\vec{\rho}$ being the transverse coordinate. For stationary and homogeneous systems one can also introduce the spatio-temporal Fourier components of the correlation matrix $\sigma_{ij}(\vec{q}, \Omega)$. All the formalism of the symplectic eigenvalues ν_i can be straightforwardly generalized to the frequency-dependent symplectic eigenvalues $\nu_i(\vec{q}, \Omega)$. This generalized theory allows, in particular, to introduce the characteristic spatial area and time of the multipartite entanglement, which in general depend on the number of "parties" in the system.

[1] M. I. Kolobov (Ed.), *Quantum Imaging* (Springer, NY, 2007).

QIT 17 Tue & Thu

Complete operational characterization of three–partite entanglement

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We characterize the entanglement contained in a pure three–qubit state via operational entanglement measures. To this end we derive a new decomposition for arbitrary three–qubit states which is characterized by five parameters (up to local unitary operations). We show that these parameters are uniquely determined by bi-partite entanglement measures. These quantities measure on the one hand the entanglement required to generate the state and on the other hand the entanglement contained in the state and have a clear physical meaning. Moreover, we show that the classification of states obtained in this way is strongly related to the one obtained when considering more general operations, like local operations and classical communication [1].

[1] J. deVicente, C. Streitberger, T. Carle, B. Kraus, in preparation.

QIT 18 Wed & Fri

Backaction dephasing induced by coupling with an environment containing a quantum dot detector out of equilibrium

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A fundamental consequence of the uncertainty principle is that the act of measurement necessarily perturbs the measured system; such measurement induced disturbance is termed *backaction*. The backaction effects are particularly important in experiments involving the readout of the qubits in solid state based quantum information processing. To discuss the backaction dephasing induced by coupling with an environment containing a quantum dot detector (QDD), we introduce an Aharonov-Bohm (AB) interferometer containing a double quantum dot as a measured system. We employ the nonequilibrium perturbation theory, and investigate the dephasing rate and the visibility of the AB oscillations in the transport properties through an AB interferometer. In particular, we discuss the mechanism of the backaction induced by the QDD out of equilibrium.

QIT 19 Tue & Thu

Fault Tolerant Quantum Computation with Nondeterministic Gates.

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In certain approaches to quantum computing the operations between qubits are nondeterministic and likely to fail. For example, a distributed quantum processor would achieve scalability by networking together many small components; operations between components should be assumed to be failure prone. In the ultimate limit of this architecture each component contains only one qubit. Here we derive thresholds for fault-tolerant quantum computation under this extreme paradigm. We find that computation is supported for remarkably high failure rates (exceeding 90%) providing that failures are heralded; meanwhile the rate of unknown errors should not exceed 2 in 10^4 operations.

[1] Ying Li, Sean D. Barrett, *et al.*, Phys. Rev. Lett. 105, 250502 (2010).

QIT 20 Wed & Fri

Genuine multipartite entanglement in a Spin-Star Network and Ising model interaction at Thermal Equilibrium

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We consider the central one-qubit system in a quantum Heisenberg XY-type spin star environment, which is supposed that the spins of environment are the same and interact with one-dimensional Ising model. We identify genuinely multipartite entangled mixed quantum states in case of thermal quantum states by using the concurrence and entanglement witnesses.

[1] Dong-ling Deng *et al.*, *Annals of physics* **325**, 367-372 (2010).

QIT 21 Tue & Thu

Quantum bit commitment under Gaussian constraints

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Quantum bit commitment has long been known to be impossible. Nevertheless, just as in the classical case, imposing certain constraints on the power of the parties may enable the construction of asymptotically secure protocols. We introduce a quantum bit commitment protocol using currently available quantum optical components and prove that it is asymptotically secure if cheating is restricted to Gaussian operations [1]. This protocol exploits continuous-variable quantum optical carriers, for which such a Gaussian constraint is experimentally relevant as the high optical nonlinearity needed to effect deterministic non-Gaussian cheating is inaccessible.

[1] A. Mandilara and N. J. Cerf, arXiv:1105.2140.

QIT 22 Wed & Fri

Scavenging quantum information

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Given a system that has already been measured optimally, can one still extract any information about the original unknown state? Clearly, the state of the system ÔcollapsesÕ into a post-measurement state from which the same observer cannot obtain further information about the original state. However, the system still encodes a significant amount of information for a second observer who is unaware of the doings of the first one. We study how a series of independent observers can obtain, or scavenge, this information. We also address generalizations which require the use of weak measurements: (i) a task where the measurement apparata are such that provide the same quality of the estimation for all observers and (ii) the complementary case where all observers use the very same apparatus, but tailored in such a way that a *privileged* observer obtains the best estimate [1].

[1] P. Rapcan *et al.*, to appear (2011).

QIT 23 Tue & Thu

Ergodicity from Nonergodicity in Quantum Correlations of Low-dimensional Spin Systems

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Correlations between the parts of a many-body system, and its time dynamics, lie at the heart of sciences, and they can be classical as well as quantum. Quantum correlations are traditionally viewed as constituted out of classical correlations and magnetizations. While that of course remains so, we show that quantum correlations can have statistical mechanical properties like ergodicity, which are not inherited from the corresponding classical correlations and magnetizations, for the transverse anisotropic quantum XY model in one-, two-, and quasi two-dimension, for suitably chosen transverse fields and temperatures [1]. The results have the potential for applications in decoherence effects in realizable quantum computers.

[1] R. Prabhu, Aditi Sen(De), Ujjwal Sen, arXiv:1103.3836 (2011).

QIT 24 Wed & Fri

Bilocality : characterizing the effects of the topology of local variables

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When considering tripartite quantum experiments sharing two pairs of local variables the quantum physicist can ask (i) if local correlations are really described by an hidden local variable shared by the three parties or (ii) if the distribution of local variables should be restricted to the topology of the quantum state whose correlations they try to reproduce.We note that this question is relevant for N-partite systems with $N > 2$. We will see that the set of correlations obeying ii) is non-convex and can be characterized in some subspaces by nonlinear equivalents of Bell inequalities.

QIT 25 Tue & Thu

Permutationally invariant tomography of symmetric Dicke states

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Standard quantum state tomography suffers from an exponentially scaling measurement effort with the number of qubits. However, for permutationally invariant states such as GHZ, W or symmetric Dicke states the problem can be recast such that the measurement effort scales quadratically [1]. Here, we apply this scalable and efficient method to experimentally analyze symmetric four and six photon Dicke states as produced by parametric downconversion.

[1] G. Tóth *et al.*, *Phys. Rev. Lett* **105**, 250403 (2010).

QIT 26 Wed & Fri

Optimal estimation of entanglement and quantum discord in optical qubit systems

G. Brida[1], I. P. Degiovanni[1], A. Florio[1], M. Genovese[1], P. Giorda[2], A. Meda[1], M. G. A. Paris[3], A. P. Shurupov[1]
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Any procedure aimed to evaluate the amount of entanglement of a quantum state is ultimately a parameter estimation problem. An optimization problem thus naturally arises, which may be properly addressed in the framework of quantum estimation theory. We present the results of an experiment [1] where, the amount of entanglement of two-qubit photon states is estimated, by quantum correlations measurement, with the ultimate precision allowed by quantum mechanics. Also we propose an optimal measurement of classical correlation in this system, which allows us to estimate quantum discord.

[1] G. Brida *et al.*, *Phys. Rev. Lett.* **104**, 100501 (2010); *Phys. Rev. A* **83**, 052301 (2011).

QIT 27 Tue & Thu

Quantifying mixed-state quantum entanglement by optimal entanglement witness

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We develop an approach of quantifying entanglement in mixed quantum states by the optimal entanglement witness operator. We identify the convex set of mixed states for which a single witness provides the exact value of an entanglement measure, and show that the convexity and symmetries of entanglement or of a target state considerably fix the form of the optimal witness. This greatly reduces difficulty in computing and experimentally determining entanglement measures. As an example, we show how to experimentally quantify bound entanglement in four-qubit noisy Smolin states and three-qubit Greenberger-Horne-Zeilinger (GHZ) entanglement under white noise [1].

[1] S.-S. B. Lee and H.-S. Sim, preprint (2011).

QIT 28 Wed & Fri

Additivity Breaking of Minimum Output Rényi Entropy for Quantum Channels

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In Quantum Information Theory (QIT) very important is a question of additivity for some quantities. One of them is a problem of additivity for quantum channels. Now we know that general conjecture of additivity for quantum channels is false. The most beautiful recent result is Hastings' proof of the existence of counterexamples to the additivity conjectures (Hastings, 2008). But still we have not good method to finding constructive counterexamples for additivity violation. In this presentation I suggest some extend of method which were proposed in (Grudka et al. 2010). This approach is strictly connected with representation theory of symmetric groups especially Shur-Weyl duality.

QIT 29 Tue & Thu

Non-classical correlations beyond entanglement in continuous variable systems

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[2]Department of Optics, Palacký University, Olomouc, Czech Republic.
[3]School of Mathematical Sciences, University of Nottingham, United Kingdom.

We introduce a new measure of quantum correlations, the Gaussian ameliorated measurement-induced disturbance defined by optimizing over all bi-local Gaussian positive operator valued measurements [1]. By evaluating and comparing quantum discord, measurement-induced disturbance, and this new measure on Gaussian states, we provide better insight into quantum correlations beyond entanglement in continuous variable bipartite systems. Our findings reaffirm the genuinely quantum nature of Gaussian states, and yet reveal that non-Gaussian measurements can play a crucial role for the optimized extraction and potential exploitation of non-classical correlations in Gaussian states. We then extend our analysis to non-Gaussian states.

[1] L. Mista, R. Tatham, D. Girolami, N. Korolkova and G. Adesso *Phys. Rev. A* **83** 042325 (2011)

Mechanical Oscillators

MO 1 Tue & Thu

Optomechanical entanglement and teleportation in the pulsed regime

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Entangling a mechanical oscillator with an optical mode is an enticing but, at the same time, very challenging goal in optomechanics. Here we propose a pulsed scheme which allows the creation and unambiguous verification of EPR–type entanglement in optomechanical systems. We consider its application as a resource for continuous variable teleportation, analyze the teleportation fidelity under the influence of thermal noise and determine the optimal parameter regime. Owing to its pulsed nature, our scheme is robust against mechanical decoherence and it is shown to work in current state-of-the-art systems.

MO 2 Wed & Fri

Entangling two distant oscillators with a quantum reservoir

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[2]Institute of Quantum Physics, Ulm University, D-89069 Ulm, Germany.
[3]Física Teòrica: Informació i Processos Quàntics, UAB, E-08193 Bellaterra, Spain.
[4]Grup d'Òptica, Departament de Física, UAB, E-08193 Bellaterra, Spain.
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The generation of entanglement between two oscillators that interact via a common reservoir is theoretically studied. The reservoir is modeled by a one-dimensional harmonic crystal initially in thermal equilibrium. Starting from a separable state, the oscillators can become entangled after a transient time, that is of the order of the thermalization time scale. This behavior is observed at finite temperature even when the oscillators are at a distance significantly larger than the crystal's interparticle spacing. The underlying physical mechanisms can be explained by the dynamical properties of the collective variables of the two oscillators which may decouple from or be squeezed by the reservoir [1]. Our predictions can be tested with an ion chain in a linear Paul trap.

[1] A. Wolf, G. De Chiara, E. Kajari, E. Lutz, and G. Morigi, arXiv:1102.1838.

MO 3 Tue & Thu

Micromechanical resonator coupled to a transmon qubit

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We discuss a system of micromechanical resonator coupled capacitively to a transmon qubit. The mechanical resonator is fabricated either by focused ion beam cutting [1] to create an in-plane beam resonator with a narrow 10 nm vacuum slit, or by using sacrificial layer to realize an out-of-plane bridge resonator [2]. These fabrication methods allow strong coupling energies up to 10 MHz between the mechanical resonator and the charge-insensitive transmon qubit. The electromechanical interaction in the setup can be observed by studying energy level shifts of the qubit. The mechanical resonator is also coupled to the coplanar waveguide of the transmon in order to facilitate characterization of the mechanical resonance.

[1] J. Sulkko *et al.*, *Nano Letters* **10**, 4884-4889 (2010).

[2] To be published.

Photons

Ph 1 Tue & Thu

Generation of entangled photon pairs from the polariton vacuum state in a switchable optical cavity

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Intersubband cavity polaritons are the fundamental excitations of a planar microcavity embedding a sequence of quantum wells that contain a two-dimensional electron gas [1]. The ground state of the system, the polariton vacuum, contains a finite number of photons in the ultrastrong coupling regime, which might be released by a non-adiabatic tuning of the light-matter interaction [1, 2]. We investigate theoretically the polariton vacuum state in order to determine the entanglement between two photons. By post-selection, we consider only two different frequencies and restrict the analysis to photons having opposite in-plane wave vectors. In this case we find that there is some entanglement, which we quantify by the concurrence C.

[1] C. Ciuti *et al.*, *Phys. Rev. B* **72**, 115303 (2005).

[2] S. De Liberato *et al.*, *Phys. Rev. Lett.* **98**, 103602 (2007).

Ph 2 Wed & Fri

Bright single photon emission from color centers in diamond and coupling to photonic crystal cavities

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Diamond is an attractive material for quantum information due to the extraordinary properties of color centers enabling e.g. single photon emission and spin quantum bits. To control emitted photons and to interconnect distant quantum bits, micro-cavities directly fabricated in the diamond material are desired. We report bright single photon emission from silicon-based (SiV) color centers in nanodiamonds grown on iridium. These centers exhibit very narrow zero-phonon-lines (ZPL) down to 0.7 nm at room temperature and high single photon count rates > 5 Mcps [1]. We use a similar material system, i.e. single crystal diamond on iridium, to fabricate one- and two-dimensional photonic crystal microcavities with quality factors of up to 700. Using a post-processing etching technique, we tune the cavity modes into resonance with the ZPL of SiV centers and observe emitter-cavity coupling.

[1] E. Neu *et al.*, *New J. Phys.* **13**, 025012 (2011).

Ph 3 Tue & Thu

A same-setting Bell test with application to a hybrid optical setup

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We analyse a generic setup for probing the CHSH Bell inequality involving two observers who choose from a set of two observables (the same for both parties) of which one is a projection onto a pure state wheras the other may have a degenerate eigenspace. We show that maximimal violation of CHSH can be reached and identify states reaching the maximum. We further apply our analysis to the recent proposal by Cavalcanti *et al.* [1] which combines homodyne and single-photon detection. We demonstrate that the optimal states for this scheme are infinite-energy states and hence maximal violation cannot be reached in any realistic implementation. When the photon number is limited to at most 2 in any mode, the maximal violation is 2.31 close to the 2.25 obtained by a 2-photon noon-state in [1]. Finally, we extend our analysis beyond CHSH to multiple-party scenarios.

[1] D. Cavalcanti, N. Brunner, P. Skrzypczyk, A. Salles, V. Scarani, *arXiv* **quant-ph**, 1012.1916v1 (2010).

Ph 4 Wed & Fri

Spontaneous Parametric Down-Conversion Photon Sources for Applications in Quantum Information

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Spontaneous Parametric Down-Conversion (SPDC) is often used to provide single photons for quantum information applications. We discuss our degenerate SPDC source based on periodically poled potassium titanyl phosphate (PPKTP) waveguide chips with detection rates up to 10^6 photon pairs per second and mW pump-power at 404 nm.

Specifically, we focus on two applications: The first is an implementation of a heralded single photon source for quantum key distribution based on the BB84 protocol. Using a combination of 50:50 and polarizing beamsplitters our setup does not need separate electro-optic modulators or quantum random number generators in order to set the polarization of the photons used for the key exchange. The second application is the set-up of a two-photon source based on the feedback of one of the SPDC photons into the waveguides. We will discuss the current state of both experiments.

Ph 5 Tue & Thu

Higher quantum dimensionality by exploiting the photonic orbital angular momentum

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Single photons offers a variety of degrees of freedom in which quantum information can be encoded. By exploiting these resources, it is possible to implement high-dimensional quantum states, or qudits, which enable higher security in quantum cryptographic protocols, as well as implications in fundamental quantum mechanics theory. In this framework, the orbital angular momentum of photons, being defined in an infinitely dimensional Hilbert space, offers a promising resource for high-dimensional optical quantum information protocols. We will present the experimental generation of a hybrid ququart encoded in the polarization and orbital angular momentum of a single photon and its optimal quantum cloning [1].

[1] E. Nagali,*et al.*, *Phys. Rev. Lett.* **105**, 073602 (2010); E. Nagali, and F. Sciarrino *Optics Express* **18**, 18243 (2010); E. Nagali,*et al.*, *Phys. Rev. A* **81**, 052317 (2010).

Ph 6 Wed & Fri

On-chip single-photon sources and detectors for integrated quantum photonics

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We report an approach to the monolithic integration of single-photon sources, detectors and passive circuits on a single semiconductor chip. The single-photon sources are based on single InAs quantum dots coupled to ridge or photonic crystal waveguides on GaAs substrates. Antibunching experiments confirm that single photons are efficiently emitted into a propagating mode of the waveguide. Waveguide single-photon detectors have also been fabricated by patterning a superconducting nanowire on top of a GaAs/AlGaAs ridge waveguide, resulting in a quantum efficiency $\sim 10\ \%$, nanosecond response time and < 100 ps jitter. These technologies are fully compatible with each other and with the realisation of GaAs-based passive waveguide circuits and thus open the way to fully-integrated optical quantum information processing.

Ph 7 Tue & Thu

Analysis of uncertainties in the experimental determination of joint probabilities for photon polarization

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The results of weak measurements can be explained in terms of negative joint probabilities for non-commuting observables. However, the joint probabilities obtained experimentally for sequential measurements of the two observables are always positive. In this presentation, we investigate the role of measurement uncertainties using the experimental data obtained from a recently introduced setup for a variable strength measurement of photon polarization[1]. The experimental joint probabilities can be interpreted as statistical mixture obtained by random polarization flips from an intrinsic joint probability distribution. We can then show how the negative probabilities in the intrinsic distribution are converted to observable positive statistics by variable combinations of resolution and back-action uncertainties.

[1] M. Iinuma *et al.*, *New Journal of Physics* **13**, 033041 (2011).

Ph 8 Wed & Fri

A nonlinear waveguide source of spatially pure photon pairs

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Generation of entangled photons in nonlinear waveguides opens up new promising routes to engineer characteristics required for implementing quantum information protocols. Here we report experimental realisation of a bright ($5 \times 10^4\,\mathrm{s}^{-1}\mathrm{nm}^{-1}$ pairs per 1 mW of pump power) source of photon pairs in the 800 nm spectral region, using type-II parametric down-conversion in a multimode KTP waveguide. We demonstrate that the photons can be produced in well defined spatial modes through a careful control of the spectral degree of freedom following the method suggested in [1], without any spatial filtering at the output. This is verified by area-integrated detection of two-photon polarisation interference in the Shih-Alley arrangement, with the visibility exceeding 80%. Bypassing spatial filtering can remove one of major contributions, apart from detection efficiency, to the effective loss of photon number correlations in down-conversion experiments.

[1] M. Karpiński *et al.*, *Appl. Phys. Lett.* **94**, 181105 (2009).

Ph 9 Tue & Thu

Integrated photonic devices for polarization qubits

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Integrated waveguide technologies open new perspectives to manipulate quantum states of light both for fundamental tests of quantum mechanics and for novel technological applications. However, the possibility of handling polarization encoded qubits is still missing in quantum optical circuits. Femtosecond laser writng on a glass allows to realize circular transverse waveguide profiles which support the propagation of Gaussian modes with any polarization state. Directional couplers and polarizing beam splitters may be realized by this technique. We present the results obtained with polarization-entangled states and the realization of an integrated photonic CNOT gate for polarization qubits [1], [2].

[1] L. Sansoni *et al.*, *Phys. Rev. Lett.* **105**, 200503 (2011).

[2] A. Crespi *et al.*, *arXiv:1105.1454* .

Ph 10 Wed & Fri

Characterization of two-photon mixed states employed with polarization entangled-classical hybrid photon source

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We experimentally prepare bi-photon mixed states in polarization employed with entangled-classical hybrid photon emitter which will properly model solid-state photon sources. Photon-pairs in totally mixed states are embodied with classical radiation, while the polarization- correlated photon pairs in a Bell state are generated by conventional parametric down conversion. The generated bi-photon states were characterized with a linear entropy-tangle plane, which has successfully revealed the two-qubit Werner state formation. A direct way to evaluate the Werner states with minimal coincidence counts measurements is proposed, which can be widely applicable when the contribution of each photon sources is discriminable. Due to expected robustness of the Werner state in solid-state media, this simple method will be highly beneficial for examining entangled photon-pair states generated from the solid-state sources including the temporal-correlation-free background.

Ph 11 Tue & Thu

Engineering and Applications of High-Efficiency Heralding of Single Photons

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Single photons are the bedrock of many quantum information protocols, but efficiently generating them remains difficult [1]. Spontaneous parametric down-conversion SPDC can be used to generate heralded single photons, but typically with a low overall efficiency [2]. We will present experimental work on increasing the efficiency due to careful spatial mode selection and high efficiency spectral filters, as well as applications for quantum cryptography, on-demand single photons, and loophole-free tests of Bell's inequality.

[1] Special issue on Single Photon Sources, Detectors, Applications, and Measurement Methods, edited by J. Cheung, A. Migdall, and M.-L. Rastello [*J. Mod. Opt.* **56**, 139 (2009)].

[2] C. Kurtsiefer, M. Oberparleiter, and H. Weinfurter, *Phys. Rev. A* **64**, 023802 (2001).

Ph 12 Wed & Fri

A Negativity bound for non-Gaussian states generation with Optical Parametric Oscillators

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Superposed coherent states, i.e. Schroedinger's cat states, is a central resource for quantum networking in the continuous-variable regime. One way to generate these non-Gaussian states consists in subtracting single photons from a squeezed vacuum. We consider here the case where this initial squeezed light is generated from an optical pametric oscillator. The negativity of the Wigner function of the prepared state depends on the squeezing and also strongly on the purity of the squeezed state. We show that taking into account the physical description of an optical parametric oscillator, it exists a boundary on the achievable negativity, which can be expressed as a function of the experimental parameters.

Ph 13 Tue & Thu

Realization of a photonic quantum circuit combining effective optical nonlinearities

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The lack of highly efficient optical Kerr nonlinearities at single photon level was a major obstacle for quantum information science with photons. In a breakthrough, Knill, Laflamme and Milburn (KLM) showed that such an efficient nonlinearity can be achieved using only linear optical elements, auxiliary photons, and measurement [1]. They proposed a heralded controlled-NOT (CNOT) gate for scalable quantum computation using a photonic quantum circuit to combine two such nonlinear elements. We developed a stable architecture to realize the required four-photon network of nested multiple interferometers. This result confirms the first step in the original KLM 'recipe' for all-optical quantum computation.

[1] E. Knill, R. Laflamme, G. J. Milburn *Nature* **409**, 46-52 (2001).

Ph 14 Wed & Fri

Quantum state of a single photon emitted from a single polariton

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We investigate the optimal conditions for a high fidelity deterministic transfer from a single polariton state to a single photon state and subsequent homodyne detection of the single photon. An ensemble of ^{87}Rb atoms in a λ three-level scheme placed in a F $\sim$ 100 cavity is initially prepared in a single polariton state. We control the photon retrieval and homodyne efficiencies choosing the experimental parameters ranges which, accordingly to a previous theoretical analysis, maximize both efficiencies. The single-excitation shape and the retrieval efficiency could be manipulated by the detuning, shape and intensity of the strong read beam as well by the cavity detuning. Additional frequency terms could be added on the local oscillator field in order to optimize the overlap with the single photon and therefore the homodyne signal.

Ph 15 Tue & Thu

A semiclassical description for the spatial distributions of correlated photons generated by spontaneous parametric down-conversion.

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Departing from the phase-matching conditions we introduce a simple theoretical model to analyze the spatial distributions of the correlated photon pairs produced by spontaneous parametric down conversion. Our theoretical predictions are in good agreement with the experimental data obtained for correlated photon pairs generated with a type-I BBO crystal, pumped with a 405 nm laser.

Ph 16 Wed & Fri

Controlling the quantum state of a single photon emitted from a single polariton

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We investigate in detail the optimal conditions for a high fidelity transfer from a single polariton state to a single photon state and subsequent homodyne detection of the photon. We assume that a cloud of atoms in a low-finesse cavity has been initially prepared in a single polariton state by various possible techniques. The photon retrieval efficiency is first optimized with respect to the cavity detuning and then the homodyne efficiency is maximized by optimizing the frequency shift of the local oscillator. We find that both efficiencies can have values close to one in a large region of experimental parameters. The metastable state in the present scheme can be substituted by a long-lived Rydberg one and then consider transfers between few-polariton and few-photon states under the influence of Rydberg interactions.

Ph 17 Tue & Thu

Fusion strategies for photonic W states

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Availability of quantum tools to prepare and manipulate entangled states of various structures will immensely contribute to quantum information science. Recent progress in quantum information science has led to experimental demonstrations of preparation, expansion and fusion gates for multipartite entangled states. A quantum parity checking gate can be used as fusion and expansion gates for GHZ and cluster states. Techniques to grow W states into large scales are being sought. Here we introduce a two-input gate composed of a PBS, a HWP and two detectors which cannot discriminate the polarization states of incoming photons to fuse arbitrary size W states. We will discuss various fusion strategies and present the cost of preparing larger W states by fusing smaller size W states using this gate. [1].

[1] S. K. Özdemir, E. Mastunaga, T. Tashima *et al.*, arXiv. 1103.2195.

Special Topics

ST 1 Tue & Thu

Pinning quantum phase transition of photons in a hollow-core fiber.

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We show that a pinning quantum phase transition for photons could be observed in a hollow-core one-dimensional fiber loaded with a cold atomic gas. Utilizing the strong light confinement in the fiber, a range of different strongly correlated polaritonic and photonic states, corresponding to both strong and weak interactions can be created and probed. The key ingredient is the creation of a tunable effective lattice potential acting on the interacting polaritonic gas which is possible by slightly modulating the atomic density. We analyze the relevant phase diagram corresponding to the realizable Bose-Hubbard (weak) and sine-Gordon (strong) interacting regimes and conclude by describing the measurement process. The latter consists of mapping the stationary excitations to propagating light pulses whose correlations can be efficiently probed once they exit the fiber using available optical technologies.

[1] M.X. Huo and D.G. Angelakis, arXiv:1103.4856.

ST 2 Wed & Fri

A Luttinger liquid of photons and spin-charge separation in hollow-core waveguides

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In this work we show that light-matter excitations (polaritons) generated inside a hollow one-dimensional fiber filled with two types of atoms, can exhibit Luttinger liquid behaviour. We explain how to prepare and drive this quantum-optical system to a strongly interacting regime, described by a bosonic two component Lieb Lininger model. Utilizing the connection between strongly interacting bosonic and fermionic systems, we show how spin-charge separation could be observed by probing the correlations in the polaritons. This is performed by first mapping the polaritons to propagating photon pulses and then measuring the effective photonic spin and charge densities and velocities by analyzing the correlations in the emitted photon spectrum. The necessary regime of interactions is achievable with current quantum optical technology.

[1] D.G. Angelakis *et al.*, *Phys. Rev. Lett.* **106**, 153601 (2011).

ST 3 Tue & Thu

Quantum walk on a star graph with additional bonds

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Continuous-time quantum walks (CTQWs) are associated with coherent transport processes of, say, energy, mass or charge and are applicable to many fields of science from polymer physics to quantum computation. It has been shown in [1] that transfer processes depend on the network topology. The symmetry of the networks such as stars or rings can be destroyed by adding randomly B additional bonds, see, e.g., Ref. [2]. This creates shortcuts, and a walker can find shorter ways between pairs of nodes. In the following, we randomly add bonds to the star graph (forbidding so-called self- and double-connections), and investigate the transition from the star graph to the complete graph [3].

[1] O. Mülken and A. Blumen, *Phys. Rev. E* **71**, 066117 (2006).

[2] O. Mülken, V. Pernice, and A. Blumen, *Phys. Rev. E* **76**, 051125 (2007).

[3] A. Anishchenko, A. Blumen, and O. Mülken, in preparation.

ST 4 Wed & Fri

Quantum System Identification

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The aim of quantum system identification is to estimate the ingredients inside a black box, in which some quantum-mechanical unitary process takes place, by just looking at its input-output behavior. Here we establish a basic and general framework for quantum system identification, that allows us to classify how much knowledge about the quantum system is attainable, in principle, from a given experimental setup. Prior knowledge on some elements of the black box helps the system identification. We present an example in which a Bell measurement is more efficient to identify the system. When the topology of the system is known, the framework enables us to establish a general criterion for the estimability of the coupling constants in its Hamiltonian. In particular we show that many quantum systems can be efficiently estimated by accessing only their surface [1].

[1] D. Burgarth and K. Yuaza, arXiv:1104.0583.

ST 5 Tue & Thu

Microwave guiding of electrons in a planar quadrupole guide

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We demonstrate the transverse confinement and guiding of free space electrons in a linear quadrupole guide [1]. The guiding potential is generated by a microstructured planar electrode pattern similar to surface-electrode Paul traps. By driving the voltage on the electrodes at microwave frequencies we obtain stable trajectories of low energy electrons in the transverse plane. We report on the first implementation on an electrically short substrate and comment on the extension to structures supporting travelling microwave excitations and enabling the splitting of a guided electron beam. Combining the electron guide with a fully coherent and Heisenberg limited electron source should permit a direct population of low lying quantum states of the transverse potential without need for cooling the electrons. With this novel technique of electron guiding new types of guided matter-wave experiments should become feasible.

[1] J. Hoffrogge *et al.*, *Physical Review Letters* **106**, 193001 (2011).

ST 6 Wed & Fri

Quantum metrology with entangled coherent states using linear and nonlinear phase operations

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We present an improved phase estimation scheme employing entangled coherent states and demonstrate that the states give the smallest variance in the phase parameter (with linear phase operation) in comparison to NOON and BAT states under perfect and lossy conditions [1]. In addition, we investigate the phase enhancement of these states in a generalized non-linear phase operation. As these advantages emerge for very modest particle numbers, the optical version of entangled coherent state metrology is achievable with current technology.
This work is supported by the European Project Q-ESSENCE.

[1] J. Joo, W. J. Munro, and T. P. Spiller, arxiv:quant-ph/1101.5044.

ST 7 Wed & Fri

Simulating interacting relativistic theories with photons in hollow waveguides

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Photonic quantum simulations of one dimensional many-body systems have attracted renewed interest lately with works on photon crystallization and Luttinger liquids[1]. In this work we show that the quantum Thirring model for interacting fermions in (1+1) dimensions can be realized using stationary polaritons in hollow waveguides filled with atoms. By controlling optical parameters such as one-photon detunings and external laser intensities, the massless and the massive Thirring models are realizable. Coherently mapping the polaritons into propagating photons allows for the direct probing of the relevant correlation functions and scaling behaviours characteristic of the underlying theories in question.

[1] D. E. Chang, et al., Nat. Phys. **4**, 884 (2008); D.G. Angelakis et al., Phys. Rev. Lett. **106**, 153601 (2011).

ST 8 Tue & Thu

Quantum simulation of the Dirac-Majorana equation in 1+1D

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Since the gradual realization that neutrinos have non-zero mass, the Majorana equation has received renewed interest as a potential equation of neutrinos. The most general equation contains both the Dirac and the Majorana mass terms, and implies that massive neutrinos are Majorana fermions[1], which are charge-conjugation invariant. In particular, it is shown that the Majorana equation, which doesn't obey Hamiltonian dynamics, can be broken down into two Dirac equations for Majorana fermions. We derive the result starting from the Dirac-Majorana equation and discuss its implications on quantum simulations of the Dirac-Majorana equation.

[1] Carlo Giunti and Chung W. Kim *Fundamentals of Neutrino Physics and Astrophysics* (Oxford University Press, 2007).

ST 9 Wed & Fri

Counter-rotating terms and the Aharonov-Anandan phase

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The ultra-strong-coupling regime for photons is attracting an increasing interest recently. Among other peculiarities of ultra-strongly coupled systems, the counter-rotating terms in the Hamiltonian are supposed to give rise to new phenomena in this regime. In this work we show how counter-rotating terms originating from a linear term in the Hamiltonian can result in the appearance, during the time evolution, of a complex phase that can be given a geometrical interpretation in terms of the Aharonov-Anandan phase[1]. This fact is very general and this geometric phase can show up in very different contexts, from cold atoms to circuit QED.

[1] Y.Aharonov and J. Anandan, *Phys. Rev. Lett.* **58**, 1593 (1987).

ST 10 Tue & Thu

Simulating the BCS-BEC transition using photons in nonlinear fibers

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Strongly correlated photonic states in optical fibers have recently emerged as an attractive platform to simulate 1D quantum liquids [1]. Here, by using slow-light techniques, we analyze how a hollow-core one-dimensional fiber filled with two atomic species may be used to simulate a two component Bose-Hubbard model with tunable interactions. We show that it is possible to tune the interactions to the necessary regime in order to mimic Cooper pairing and the BCS-BEC transition in this optical system. We conclude by analyzing the measurement process which entails releasing the trapped excitations and probing the correlations of the output signal using available optical technology.

[1] Chang, Nature Phys. **4**, 884 (2008); D.G. Angelakis et al., Phys. Rev. Lett. **106**, 153601 (2011); M. Huo, D. Angelakis, arXiv:1103.4856.

ST 11 Wed & Fri

Designing atom and ion surface traps for quantum simulation

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Progress in the bottom-up construction of interacting quantum systems (e.g. quantum simulators of lattice spin models) depends crucially on the fabrication of microstructured arrays of traps. Within such microtraps, the carriers of quantum information (whether ions, single atoms, BECs, or a mixture of these) can be controlled individually and with excellent flexibility; the interactions between microtraps can be taylored to any desired geometry. We present optimizing methods for designing complicated trap geometries, and review recent experimental progress in their fabrication: microtrap lattices for ultracold atoms being fabricated in Amsterdam, and few-ion cluster traps in a collaboration with Sandia/Boulder/Freiburg. We further propose a quantum simulator for the hexagonal Kitaev model, to be implemented with an array of microtrapped ions on an optimized surface-electrode chip, promising an experimental foray into the simulation of topological phases.

ST 12 Tue & Thu

Fault-tolerant topological quantum computation with probabilistic gates

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We demonstrate that fault-tolerant topological one-way computation can be performed even if the entangling two-qubit gates succeed with a small probability less than 1/2 [1]. This allows us to use non-deterministic gates, e.g., entangling matter qubits mediated by photons [2, 3] or linear optical gates [4], where imperfections such as photon loss and detector inefficiency are heralded, to construct 3D cluster states for fault-tolerant quantum computation.

[1] K. Fujii and Y. Tokunaga, *Phys. Rev. Lett.* **105**, 250503, Dec. (2010).

[2] S. Barrett and P. Kok, *Phys. Rev. A* **71**, 060310(R) (2005).

[3] Y.-L. Lim, A. Beige and L.-C. Kwek, *Phys. Rev. Lett.* **95**, 030505, (2005).

[4] D. Browne and T. Rudolph, *Phys. Rev. Lett.* **95**, 010501 (2005).

Superconducting Circuits

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SC 2 **Simon Berger:** Measurements of Geometric Phase in Superconducting Multi-Level Systems

SC 3 **Giuseppe Falci:** Coherent control of superconducting three-level artificial atoms

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SC 1 Tue & Thu

Ultrastrong coupling in circuit QED

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[3]CSIC-Universidad de Zaragoza, Zaragoza, Spain
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In circuit quantum electrodynamics, the coupling strength can be increased to a significant fraction of the system energy and ultrastrong light-matter interaction can be observed. We present spectroscopy data of a superconducting flux qubit ultrastrongly coupled to a transmission line resonator. The rich variety of spectroscopic features can be well understood, providing experimental evidence for the breakdown of the Jaynes-Cummings-model [1]. This work is supported by SFB 631, NIM, Basque Government IT4720-10, Spanish MICINN FIS2009-12773-C02-01, and EU project SOLID.

[1] T. Niemczyk *et al.*, *Nature Physics* **6**, 772-776 (2010).

SC 2 Wed & Fri

Measurements of Geometric Phase in Superconducting Multi-Level Systems

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Geometric phases, which depend only on the trajectory of the quantum system in parameter space and therefore exhibit some noise resilience, are commonly studied in 2-level systems. Here, however, we study the geometric phase in a multi-level system, using a superconducting transmon-type qubit embedded in a transmission line resonator, in an architecture known as circuit quantum electrodynamics (QED). Due to its reduced anharmonicity compared to the Cooper-Pair-Box qubit, the transmon lends itself well to observing multi-level phenomena. We measure geometric phases in good agreement with theoretical predictions, confirming the effect of higher levels.

SC 3 Tue & Thu

Coherent control of superconducting three-level artificial atoms

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Features of multilevel quantum coherence have been recently observed in superconducting nanocircuits, mostly in the Ladder scheme, while early proposals focused on Λ-scheme, allowing for several coherent control protocols as STIRAP, which is based on the adiabatic evolution of a "dark state".

We study the effect of broad band noise on such class of protocols, and find that efficiecy loss is mainly due to dephasing of the qubit levels, due to very low frequency fluctuations of the solid-state environment. Efficiency can be recovered via Zener tunneling, for a careful design of qubit parameters. Counterintuitively devices best protected against noise turn out to be not useful for such protocols. We finally show how design of correlations between energy levels fluctuations may allow to overcome the limitation imposed by selection rules. This scheme is applicable to phase qubits, showing the importance of nanodevice band-structure engineering for multilevel coherent control.

SC 4 Wed & Fri

Generation of multi-qubit entanglement in circuit QED architecture

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Multi-particle entanglement is a corner stone of many fundamental phenomena in quantum mechanics. Experimental demonstration of two- and three-qubit [1, 2] entanglement is also an important step towards implementation of a scalable quantum information processor. Here we present three different entangling protocols that were implemented in our circuit QED setup to produce maximally entangled states (Bell states). The different methods use the resonant interaction between the qubits and the cavity, the avoided crossing of the $|11\rangle - |02\rangle$ states and the transverse coupling between the qubits. First results with an implemented three-qubit circuit QED quantum processor are also discussed.

[1] L. DiCarlo *et al.*, *Nature* **467**, 574-578 (2010).

[2] M. Neeley *et al.*, *Nature* **467**, 570-573 (2010).

SC 5 Tue & Thu

Symmetry-Selective Rabi Oscillations and Observation of Subradiance in Circuit QED

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Symmetry relations between qubit states and a driving field determine selection rules and the formation of dark states. In a circuit quantum electrodynamics setup, where two resonant superconducting qubits are coupled through an on-chip cavity, one of the symmetric or anti-symmetric eigenstates remains dark, when driving transitions via the common cavity field. Here, we demonstrate that the dark state properties can be investigated by individually addressing the qubits using local phase control of the microwave drive signal. The dark state transition can be turned on and off by switching the symmetry of the drive, which leads to selective Rabi oscillations. Moreover, we verify that the decay of the dark state by spontaneous emission into the cavity is forbidden by symmetry, a characteristic signature of subradiance. Multi-qubit extensions of this control technique can be used to prepare and study highly correlated quantum states of cavity-coupled qubits.

SC 6 Wed & Fri

Generation of non-classical states from a superconducting artificial atom in a 1D open transmission line

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We have embedded an artificial atom, a superconducting "transmon" qubit, in a 1D open space and investigated the scattering of incident microwave photons [1]. When an input coherent state, with an average photon number much less than 1, is on resonance with the artificial atom, we observe extinction of up to 99% in the forward propagating field. We also study the statistics of the reflected and transmitted beams, which are predicted to be nonclassical states. In particular, we demonstrate photon antibunching in the reflected beam and photon bunching in the transmitted beam by measuring the g2 function (second order correlation function).

[1] Io-Chun Hoi *et al.*, arXiv:1103.1782v1(2011).

SC 7 Tue & Thu

Progress toward building multi-qubit, multi-cavity circuit QED architectures

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I will report on progress toward scaling up the circuitQED architecture to a system with multiple qubits and multiple cavities. This effort includes testing of a modified capacitively shunted flux qubit (CSFQ) design that can inductively or capacitively couple to two cavities. This allows the creation of a T structure where the multiply-coupled qubit is situated at a location which minimizes the direct capacitive coupling between cavities.

SC 8 Wed & Fri

Generating on chip distributable and unconditional entanglement at microwave frequencies

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Entanglement, the unique feature of quantum mechanics, is the central resource of quantum information. In the strategy of continuous-variables quantum information processing, unconditional and distributable entanglement can be obtained by combining two squeezed states on a balanced beam splitter. Our group has recently demonstrated the generation of squeezed microwave states using a Josephson Parametric Amplifier [1] and implemented on-chip balanced beam splitters [2]. This poster will present a device that combines all these components on a single chip. The design requirements for such an “on-chip entangler” of the electromagnetic field modes will be discussed.

[1] M. A. Castellanos-Beltran*et al.*, *Nature Physics* **4**, 929 (2008).

[2] Hsiang-Sheng Ku *et al.*, arXiv:1010.3232v1.

SC 9 Tue & Thu

Reproducibility of the transmon qubit plasma frequency

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Within the field of circuit quantum electrodynamics (cQED), many implementations of superconducting qubits rely on their plasma frequency predictability. Control of the plasma frequency is essential in order to build scaled up quantum processors as well as tailoring quantum-optics-on-chip experiments. In the case of the transmon qubit, the main contribution to this uncertainty is associated with the reproducibility of the Al/AlO_x/Al tunnel barriers in the fabrication of the qubits. By studying the intra-chip and chip-to-chip standard deviations of the normal state resistance of the junctions, statistics for the reproducibility was extracted. Another essential property of the qubit is its relaxation time, T_1. It has been shown that a large channel of decoherence is the dielectric losses. Therefore, we will investigate whether fabricating the qubits on top of SiN membranes will increase T_1.

SC 10 Wed & Fri

Measuring at microwaves on chip distributable and unconditional entanglement

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A squeezed mode of the light field exhibits reduced fluctuations, below the vacuum level, along one of its quadratures and conversely amplified fluctuations along the conjugate quadrature. In that sense, it is the electromagnetic analog of the particle states used by Einstein-Podolsky-Rosen to derive their famous paradox. By combining two such squeezed modes on a balanced beam splitter, entanglement can be generated, in an unconditional and distributable way. Such experiments have been performed for some years at optical frequencies. This poster will present an experimental attempt to generate and characterize entanglement with squeezed light at microwaves frequencies, using superconducting electrical circuits. We will discuss the achieved degree of entanglement from the perspective of implementing quantum teleportation protocols at microwave frequencies.

SC 11 Tue & Thu

Observation of Photon Blockade in Circuit QED using Correlation Function Measurements

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Circuit quantum electrodynamics (QED) provides an attractive platform to study photon-photon interactions mediated by their strong and resonant coupling to a superconducting qubit embedded into a transmission line resonator. Driving the coupled system with a coherent microwave frequency tone the anharmonicity of the Jaynes-Cummings ladder blocks the transmission of more than a single photon through the resonator at a time. Using on-chip microwave beam splitters, linear amplifiers, and quadrature amplitude detectors we observe resonance fluorescence and Rayleigh scattering in Mollow-triplet-like spectra. Through second-order correlation function measurements, we clearly demonstrate antibunching in a continuously pumped source of single microwave photons [1].

[1] C. Lang *et al.*, Phys. Rev. Lett. **106**, 243601 (2011).

SC 12 Wed & Fri

Lasing, trapping states, and multistability in a circuit quantum electrodynamical analogue of a single-atom injection maser

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We study a superconducting single-electron transistor (SSET) which is coupled to a LC-oscillator via the phase difference across one of the Josephson junctions. This leads to a strongly anharmonic coupling between the SSET and the oscillator. The coupling can oscillate with the number of photons which makes this system very similar to the single-atom injection maser. However, the advantage of a design based on superconducting circuits is the strong coupling and existence of standard methods to measure the radiation field in the oscillator. This makes it possible to study many effects that have been predicted for the single-atom injection maser in a circuit quantum electrodynamics setup.

SC 13 Tue & Thu

Distributed ultrastrong coupling of superconducting resonators

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Recent work on superconducting flux quantum circuits [1] explores a novel regime of light-matter physics, where the coupling energy becomes a significant fraction of the self energy. We discuss how to reach this ultrastrong coupling regime for two degenerate microstrip resonators with distributed coupling. Explaining surprising spectroscopic features with a microscopic model, we find a ratio of 18% between coupling and self energy as well as the possibility for a two-mode squeezing Hamiltonian.

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[1] T. Niemczyk *et al.*, *Nature Physics* **6**, 772 - 776 (2010).

SC 14 Wed & Fri

State reconstruction of propagating quantum microwaves

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The state of propagating quantum microwaves can be reconstructed in a dual-path configuration with correlation measurements despite the presence of noisy linear amplifiers [1]. In such a setup a flux-driven Josephson parametric amplifier can serve as a squeezed state source and as a near quantum limited amplifier. We have characterized such a device and find a maximum degenerate gain of 25.5 dB, a signal bandwidth of 1.8 MHz at 5.64 GHz and discuss its squeezing properties.

This work is supported by SFB 631, NIM, Basque Government IT4720-10, Spanish MICINN FIS2009-12773-C02-01, and EU project SOLID.

[1] E. P. Menzel *et al.*, *PRL* **105**, 100401 (2010).

SC 15 Tue & Thu

Entangling ISWAP gate using frequency shifted anharmonic qubits

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In this talk, we examine the coupling between frequency separated qubits, typical of superconducting implementations. We show how to correct for errors coming from finite turn-on time (corresponding to bringing the qubits into resonance) as well as leakage error (corresponding to exciting population out of the qubit manifold), namely by bringing the qubits in and out of resonance repeatedly to cancel out the unwanted parts of the Hamiltonian. The gates presented are smooth and robust and represent a whole class of analytic and numeric solutions for the evolution of the composite system..

SC 16 Wed & Fri

Qudit Quantum Computation in the Jaynes-Cummings Model

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We have developed methods for performing qudit quantum computation in the Jaynes-Cummings model with the qudits residing in a finite subspace of individual harmonic oscillator modes. One scheme uses a combination of analytic and numerical methods to determine control sequences for the one- and two-qudit gates necessary for universal quantum computation. This method involves breaking down the desired unitary transformations into a series of state preparations, then combining ideas from inhomogeneous control with the Law-Eberly scheme to perform the state preparation. We have also explored an approach that directly optimizes the evolution of the system, without breaking the evolution up into a series of state preparations.

SC 17 Tue & Thu

Time Resolved Entanglement Dynamics in circuit QED

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The resonant coupling of spatially separated and non interacting two level systems to a cavity can lead to strong mutual interaction where excitations between the qubits can be shared via the resonator. We study the dynamics of such a coupling with up to three superconducting qubits strongly coupled to a microwave resonator. Since resonant interactions are comparably fast to off-resonant dynamics they might be used to speed up gate times in quantum information processes. We prepare different initial states and study the system dynamics in the time domain. By applying tomography we get snapshots of the emerging entangled states as for example the W-state.

SC 18 Wed & Fri

Quantum parametric frequency conversion in a superconducting circuit (1)

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Early theory [1] predicted that parametric frequency conversion could be a way to implement a tunable direct coupling between quantized modes of different energies, that can be described as a generalized beam splitter interaction. This can be combined with the powerful tools already available in cavity QED in superconducting circuits. We have prepared a superposition of a single photon in two different frequency states (7 GHz detuned), and made it interfere using this parametric beam splitter.

[1] J. Tucker and D. Walls. Quantum theory of parametric frequency conversion. *Annals of Physics* **52**, 1Ű15 (1969).

SC 19 Tue & Thu

Quantum parametric frequency conversion in a superconducting circuit (2)

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Early theory [1] predicted that parametric frequency conversion could be a way to implement a tunable direct coupling between quantized modes of different energies. Circuit Quantum Electrodynamics provides powerful tools to investigate such interactions in model systems. We have measured the coherent dynamics of a single photon between the first three internal resonant modes of a superconducting cavity, coupled through a flux-modulated SQUID. This works opens the way to more complex manipulations, based on multi-photons interferences in a frequency basis.

[1] J. Tucker and D. Walls. Quantum theory of parametric frequency conversion *Annals of Physics* **52**, 1-15 (1969).

SC 20 Wed & Fri

Andreev level ionization

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Motivated by recent experiments [1], we investigate theoretically the effect of external electromagnetic radiation of frequency ω on a point contact between two superconductors with gap Δ. Radiation causes small-amplitude fluctuations of the Andreev bound state, which is formed in a phase-biased contact. These variations may cause ionization of the Andreev state, and we evaluate the rate of such a process. We find a generic square-root dependence of the rate on $\omega-\omega_A$, where ω_A is the ionization threshold. For small normal-state-conductance of the junction, resulting in $\hbar\omega_A \ll \Delta$, the ionization rate exhibits a pronounced maximum at $\omega \approx 2\omega_A$. In the presence of an Andreev level, radiation may break Cooper pairs even at $\hbar\omega < 2\Delta$. The two created quasiparticles then populate the Andreev level. We evaluate the rate of such a process, at arbitrary phase bias φ and conductance of the junction. The rate is found to be maximal when $\varphi = \pi$, and suppressed for $\varphi = 2\pi m$.

[1] M. Zgirski *et al.*, *Phys. Rev. Lett.*, **106**, 257003 (2011).

SC 21 Tue & Thu

Preservation of bipartite entanglement in nanodevices using Dynamical Decoupling

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A crucial challenge for future quantum technologies is to protect fragile entanglement against environment-induced decoherence [1]. Various Dynamical Decoupling (DD) sequences emerged recently as high-order decoherence suppression schemes for single qubit systems. How bipartite entanglement can be effectively preserved via DD is still a open problem. Here we address this issue considering two independent superconducting qubits subject to quantum bistable fluctuators. The effect of DD on entanglement revival for non-Markovian noise and entanglement sudden death for Markovian noise is investigated. Protection of entanglement via the quantum Zeno effect is found under special conditions.

[1] B. Bellomo *et al.*, *Phys. Rev. A* **81**, 062309 (2010).

SC 22 Wed & Fri

Geometric Phase of a Harmonic Oscillator in Circuit QED

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The phase accumulated by an evolving quantum system can be decomposed into a dynamical and a geometric part. The latter depends only on the trajectory of the state in the Hilbert space, making geometric manipulations interesting for quantum information processing due to their lower susceptibility to noise. We present a measurement of the geometric phase of a harmonic oscillator in a circuit QED setup. By applying a slowly varying microwave drive to a transmission line resonator, we adiabatically displace the resonator field along a closed path in phase space. Using a dispersively coupled transmon qubit as a readout tool, we observe the accumulated geometric phase. We verify that the phase is approximately independent of the length of the manipulation sequence and scales linearly with the area enclosed by the coherent state trajectory. It persists even if the process is not ideally adiabatic. In this regime, we study dephasing caused by non-adiabatic effects of the drive.

SC 23 Tue & Thu

Approaching perfect microwave photodetection in circuit QED

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In this work we propose a microwave photon detector which successfully reaches 100% efficiency with only one absorber [1]. Our design consists of a metastable quantum circuit coupled to a semi-infinite transmission line which performs highly efficient photodetection in a simplified manner as compared to previous proposals. We extensively study the scattering properties of realistic wavepackets against this device, thereby computing the efficiency of the detector. We find that the detector has many operating modes, can detect detuned photons, is robust against design imperfections and can be made broadband by using more than one absorbing element in the design.

[1] B. Peropadre *et al.*, arXiv:1101.0016

SC 24 Wed & Fri

Recent progress at IBM with three-dimensional superconducting cavities and qubits

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Transmon-style qubits in three-dimensional superconducting cavities have recently been shown (arXiv:1105.4652) to exhibit very long coherence times and exceptional stability. These results provide evidence that small angle evaporated junctions themselves do not currently pose limits to T1 and T2, even at the longer time scales reported, and they raise interesting questions and possibilities for scaling the circuit-QED architecture. We report on recent developments from the Quantum Computing group at IBM on this topic, including experimental work to confirm the Yale results using qubits fabricated in our own process, and work towards understanding further limits to coherence times and the development of multi-qubit coupling schemes.

SC 25 Tue & Thu

Probing a Microwave field at the single photon level with a Josephson parametric amplifier

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Over the last few years, quantum objects designed with superconducting circuits allowed mesoscopic physicists to realize important progress in areas as wide as electro-mechanical systems, quantum optics and quantum information. Their power mainly stems from their coupling to microwave electromagnetic fields. But fine control of these objects requires to resolve energies at the single photon level, a microwave photon being 100 000 times less energetic than an optics one. We have developed a microwave amplifier based on a ring of four Josephson junctions. This ring can be viewed as a non-linear medium which allows the coupling of two modes which are separated both spatially and temporally. Finally, to demonstrate that our amplifier can be operated close to the quantum limit, we resolved the transition from quantum to classical in the noise emitted by one of the most simple mesoscopic object: a tunnel junction.

SC 26 Wed & Fri

Quantum and Classical Chirps in a Superconducting Anharmonic Oscillator

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Superconducting Josephson phase circuits are tunable anharmonic quantum systems. As such, they provide an attractive platform for measuring the state dynamics in different regimes. We measure the state evolution during a frequency-chirped drive at different anharmonicities and drive parameters. We find fundamentally distinct state evolution, as these parameters are varied. At small anharmonicity the evolution is governed by wavepacket dynamics and is explained by autoresonance, a well known classical phenomena. At large anharmonicity, the evolution is governed by the discrete structure of the energy levels. We map the transition between these two regimes as a function of drive and system parameters and explain the results with theory.

SC 27 Tue & Thu

Flux-pumped, lumped-element, Josephson parametric amplifier

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With the advances in superconducting quantum circuits the interest for low noise amplifiers has grown significantly given that the measurement time for second order correlation measurements scales with the fourth power of the noise temperature. The theoretical prediction of bringing the noise temperature down to the quantum noise limit has led to several parametric amplifier designs, using different nonlinearities such as Josephson junctions and the kinetic inductance. We present a design and some preliminary measurements of a flux-pumped, lumped-element, Josephson parametric amplifier. This design has a small footprint and promises a larger dynamic range compared to the traditional current-pumped Josephson parametric amplifier.

SC 28 Wed & Fri

Quantum process tomography of entangling gates in circuit QED

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Cavity quantum electrodynamics with superconducting circuits (circuit QED) is one of the promising solid state architectures for the implementation of a quantum information processor. An important step towards the realization of quantum algorithms is the creation of multi-qubit entangled states. In order to analyze different entangling gates and improve their performance, a tool for their characterization is needed. Such a tool is provided by quantum process tomography. Performing state tomography on the output states of the process for a certain set of input states, together with a maximum likelihood procedure allows to fully reconstruct the χ-matrix representing the examined process. Here we demonstrate the implementation of quantum process tomography on multi-qubit entangling gates in our circuit QED setup. The process fidelity is then obtained by comparing the measured χ-matrices to the theoretically expected ones.

SC 29 Tue & Thu

Superradiant Phase Transitions and the Standard Description of Circuit QED

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We investigate the equilibrium behaviour of a superconducting circuit QED system containing a large number of artificial atoms. It is shown that the currently accepted standard description of circuit QED via an effective model fails in an important aspect: it predicts the possibility of a superradiant phase transition, even though a full microscopic treatment reveals that a no-go theorem for such phase transitions known from cavity QED applies to circuit QED systems as well. We generalize the no-go theorem to the case of (artificial) atoms with many energy levels and thus make it more applicable for realistic cavity or circuit QED systems.

SC 30 Wed & Fri

High fidelity continuous measurements of superconducting qubits for quantum feedback and control

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Recent progress in the development of quantum noise limited amplifiers has enabled high fidelity, continuous measurements of superconducting qubits in the circuit QED architecture, leading to the observation of quantum jumps [1]. This opens up the possibility of using weak measurements to control quantum bits via quantum feedback techniques. The efficiency of such a scheme depends crucially on reaching the quantum limit of measurement i.e. when the measurement rate and the measurement induced dephasing rate are equal. I will describe experiments where we use a Transmon qubit in the circuit QED architecure to implement such a measurement scheme with the help of low noise parametric amplifiers. I will discuss the challenges involved in achieving the quantum limit and using the measurement signal to feedback on the quantum state of the qubit.

[1] R. Vijay, D. H. Slichter, I. Siddiqi, Phys. Rev. Lett. 106, 110502 (2011)

SC 31 Tue & Thu

Circuit Quantum Photonics: entanglement through disorder

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We introduce a novel architecture for building a photonic crystal in the microwave regime made of superconducting transmission lines interrupted by Josephson Junctions. To do this, we study the scattering properties of a single Junction in the line. Our first result shows that the junction behaves as perfect mirror when the photon frequency matches the josephson frequency. We generalize our calculations to a periodic arrangement of junctions, demonstrating a band engineering for the photon transport. We call it circuit quantum crystal. As a possible application, we study the possibility of creating stationary entanglement between two superconducting qubits interacting through a disorder media, made of these "structured" transmission line (quantum circuit photonic crystals).

Topical Session: Geometric and Topological Phases

(Lecture room HCI G7; Chaired by Stefan Filipp)

Fri	16:30 - 17:00	Yuval Oreg What are Majoranas and where to find them
Fri	17:00 - 17:30	Jingfu Zhang Geometric phase with nonunitary evolution in presence of a quantum critical bath
Fri	17:30 - 17:55	Yuval Gefen Spin-Charge Interplay in a Quantum Dot: the role of Berry Phase
Fri	17:55 - 18:20	Marek Pechal Geometric Phase of a Harmonic Oscillator in Circuit QED
Fri	18:20 - 18:45	Ingo Kamleitner A time-local Master equation for adiabatic systems

Friday 16:30

What are Majoranas and where to find them

Yuval Oreg
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Topological quantum computation provides an elegant way around decoherence, as one encodes quantum information in a nonlocal fashion that the environment finds difficult to corrupt. Zero energy Majorana Fermion states (Majorans for short) emerges as a key concept for a realization of nonlocal encoding. In this talk we will discuss what are Majoranas? What makes them nonlocal? and how one may create and manipulate them. In particular we will discuss recipes for driving semiconducting wires into a topological phase supporting Majoranas. In this setting Majoarans can be transported, created, and fused by applying locally tunable gates to the wire. More importantly, we will show that networks of such wires allow braiding of Majoranas fermions and that they exhibit non-Abelian statistics like vortices in a p+ip superconductor.

Friday 17:00

Geometric phase with nonunitary evolution in presence of a quantum critical bath

F. M. Cucchietti[1], J.-F. Zhang[2], F. C. Lombardo[3], P. I. Villar[3,4] and R. Laflamme[2,5]
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Geometric phases, arising from cyclic evolutions in a curved parameter space, appear in a wealth of physical settings. Recently, and largely motivated by the need of an experimentally realistic deĄPnition for quantum computing applications, the quantum geometric phase was generalized to open systems. The deĄPnition takes a kinematical approach, with an initial state that is evolved cyclically but coupled to an environment – leading to a correction of the geometric phase with respect to the uncoupled case. We obtain this correction by measuring the nonunitary evolution of the reduced density matrix of a spin one-half coupled to an environment. In particular, we consider a bath that can be tuned near a quantum phase transition, and demonstrate how the criticality information imprinted in the decoherence factor translates into the geometric phase. The experiments are done with a NMR quantum simulator, in which the critical environment is modeled using a one-qubit system.

Friday 17:30

Spin-Charge Interplay in a Quantum Dot: the role of Berry Phase

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The physics of quantum dots can be described within the scheme of Universal Hamiltonian, which takes into account the effect of electron-electron interaction within a quantum dot in a controlled way. According to that scheme interactions are represented as the sum of three spatially independent terms, associated respectively with charging, spin-exchange and Cooper channel.

Considering charging and spin-exchange interactions within the Universal Hamiltonian is challenging, as this leads to a bosonic non-Abelian action. In an earlier publication [Pis'ma v ZhETF **92**, 202 (2010)], an exact analytical solution of the probem, in particular, in the vicinity of the Stoner instabilty point, has been found. Several observables have been calculated, including the tunneling density of states (TDOS) and the spin susceptibility. Near the instability point the TDOS exhibits a non-monotonous behavior as function of the tunneling energy, even at temperatures higher than the exchange energy. Here we report on an alternative geometric approach to this problem [*Manuscript under preparation*], specifically inside the mesoscopic Stoner instable regime. We show that in the adiabatic limit of this problem, the system is described by an effective action which is composed of the longitudinal and transverse fluctuations of the effctive spin of the quantum dot and a Berry phase term. The Berry phase, which is geometric in nature, can become very important in describing experimentally measurable quantities like magnetic susceptibility. The latter, in the close vicinity of the Stoner instability point, agrees with the results of the exact solution.

Friday 17:55

Adiabatic and Non-Adiabatic Geometric Phases of a Harmonic Oscillator in Superconducting Circuits

M. Pechal[1], A. A. Abdumalikov Jr.[1], S. Berger[1], S. Filipp[1], A. Wallraff[1]
[1]Department of Physics, ETH Zürich, CH-8093, Zürich, Switzerland.

Geometric phase is an interesting phenomenon arising in quantum mechanics due to non-trivial geometric properties of complex Hilbert spaces. This component of the phase accumulated by a quantum system is determined solely by the trajectory of the state in the projective Hilbert space and is independent of the Hamiltonian. We measured the geometric phase of a harmonic oscillator realized as an on-chip superconducting transmission line resonator whose frequency is controlled by the state of a qubit coupled to it. We make use of the high level of control we have over the state of the system to probe the fundamental features of the geometric phase. Additionally, we study the transition between the adiabatic and the non-adiabatic regime where we observe corrections to the geometric phase and dephasing of the qubit due to entanglement.

Friday 18:20

A time-local Master equation for adiabatic systems

I. Kamleitner[1], A. Shnirman[1]
[1]Institut für Theory der Kondensierten Materie, Karlsruher Institut für Technologie, 76128 Karlsruhe, Germany.

Using Floquet theory and approximations suitable for adiabatically evolving systems, we derive a simple master equation which is of Lindblad type. Contrary to most previous work, we explicitely take into account the time dependence of the Hamiltonian and therefore find time-dependent Lindblad operators. We demonstrate our theory on two examples which could potentially be tested against experiments, and compare our results with previously proposed master equations.

QIPC 2011 School

Invited Lecturers

Alexandre Blais	Physique de l'information quantique, Sherbrooke
David DiVincenzo	JARA, Jülich Aachen Research Alliance
Jonathan Home	Trapped Ion Quantum Information, ETHZ
Florian Marquardt	Nanophysics and Quantum Optics, Erlangen
Renato Renner	Quantum Information Theory, ETHZ
Seigo Tarucha	Tarucha lab, Tokyo
Ian Walmsley	Ultrafast Quantum Optics Group, Oxford

Lectures Schedule, QIPC 2011 School @ Berghaus Diavolezza

Time	Friday, Sep. 2	Saturday, Sep. 3	Sunday, Sep. 4
09:00 - 10:30		**David DiVincenzo**	**Alexandre Blais**
10:30 - 11:00		Coffee break	
11:00 - 12:30		**Renato Renner**	**Seigo Tarucha**
12:30 - 14:00			Lunch
14:00 - 15:30		Free time	**Florian Marquardt**
16:00 - 17:00	Welcome and registration		
17:00 - 18:30	**David DiVincenzo**	**Jonathan Home**	
18:30 -20:00	Dinner & Free time		
20:00 - 21:30	**Renato Renner**	**Ian Walmsley**	

Useful information

Registration

The registration for the QIPC 2011 School and Conference will be done at the site of the school. You will also receive your badges and the abstract book for the conference. Please do not discard or loose your badge as it entitles you to attend sessions and take advantage of amenities such as the QIPC 2011 conference dinner.

Clothing

Please be aware that the school takes place at 3000 m above sea level. Even in summer it can get cold. Therefore you should bring warm clothing with you, e.g.: long trousers, jumper/fleece, robust wind jacket, gloves and a winter cap.

Since there is also some spare time, you might feel motivated to enjoy the nice surrounding during a hike. We suggest to take the following items with you for hiking: sunscreen, a hat, hiking boots, a water jug, sun glasses (UV safe), energy bars or some other sort of snack, necktie. There will be free tea, so bringing a thermos bottle along will be useful.

Potential Dangers

When spending extended periods of time at high altitudes the chance of anoxia (altitude sickness) increases, especially if you are not used to mountain climate. Typical signs are sickness, loss of appetite, weakness, dizziness and insomnia. It is recommended to drink a lot of water and not to take additional medicine. In case symptoms don't vanish, a descend might be necessary.

If you go hiking, never go alone. Always go in groups of at least 2, ideally 3 people. You need to be equipped appropriately and have a map with you. Also inform the organizers of the school before you leave for an extended hike and leave a note of your destination.

Accomodation

Bedlinen will be provided at the School. Students will be hosted in shared sleeping quarters. Lecturers will be hosted in single rooms. For more information about the accomodation see the venue section.

Travel

Please note that the last cable car ride to or from Diavolezza will be leaving at 17.00 o'clock! For more information about how to reach the school site see the travel section.

Meals

Breakfast, lunch and dinner are included in the price and will be served at the domicile. One week before the School starts, the menues will be posted here.

There will be no tapwater, but free tea served. To bring a thermos bottle will be useful. Tea may be filled in PET bottles, but is not recommended.

School Schedule and Abstracts

Fri	17:00 - 18:30	David DiVincenzo Basic Concepts of Quantum Information Processing I
Fri	20:00 - 21:30	Renato Renner Quantum Information Theory (tutorial lecture) I
Sat	9:00 - 10:30	David DiVincenzo Basic Concepts of Quantum Information Processing II
Sat	11:00 - 12:30	Renato Renner Quantum Information Theory (tutorial lecture) II
Sat	17:00 - 18:30	Jonathan Home Quantum information and simulation with trapped atomic ions
Sat	20:00 - 21:30	Ian Walmsley Quantum information processing using light
Sun	9:00 - 10:30	Alexandre Blais Quantum information processing and quantum optics with superconducting circuits
Sun	11:00 - 12:30	Seigo Tarucha Charges and spins in quantum information processing
Sun	14:00 - 15:30	Florian Marquardt Introduction to optomechanics

Friday 17:00

Basic Concepts of Quantum Information Processing

D. P. DiVincenzo
[1]RWTH Aachen.

I will begin with the qubit and its dual role as an abstract concept in representing the basic carrier of quantum information, and as a physical object that can be constructed in the laboratory. I will state the basic notions of formal computation that define the use of qubits, introduce the notion of a quantum logic gate, and state the premise of universality of gates for quantum computation. Quantum gates involve both coherent evolution (e.g, the CNOT) and noncoherent action – measurement. The dual use of unitary evolution and measurement is crucial in many quantum computing protocols, for example in quantum error correction. I will survey the major instances of qubits in the laboratory, concentrating on two of current interest: spins in quantum dots, and Josephson-junction devices. I will discuss the criteria for successfully achieving quantum computation in the lab.

Friday 20:00 and Saturday 11:00

Quantum Information Theory (tutorial lecture)

R. Renner[1]
[1]Department of Physics, ETH Zurich, CH-8093, Zurich, Switzerland.

The goal of this tutorial lecture is to give an overview on the state-of-the-art of research in quantum information theory (QIT). I will start with the basic notions of QIT, and explain them from a modern perspective (which enables a largely simplified treatment). The lecture will consist of an applied part, devoted to practical methods (e.g., for entanglement witnessing) that are currently used in experiments, as well as a theoretical part, where I will explain what QIT can tell us about the structure of quantum physics in general.

Saturday 17:00

Quantum information and simulation with trapped atomic ions

J. P. Home
[1]Department of Physics, ETH Zürich, CH-8093, Zürich, Switzerland.

I will provide an introduction to the primary techniques used for the realization of quantum information protocols and quantum state control with atomic ions trapped in ultra-high vacuum. Trapped-ions have been used to demonstrate all of the techniques for realizing quantum computation, including incorporation of approaches which are suitable to scaling up to a large scale processor. This has produced demonstrations of a range of quantum information protocols such as teleportation, entanglement swapping and quantum error correction. Quantum gates have now been performed at fidelities in excess of 99%, and entanglement generated between 14 qubits. On top of direct applications to quantum computation, I will describe how the precise control of trapped ions has been applied to frequency metrology and quantum simulation.

Saturday 20:00

Quantum information processing using light

I. A. Walmsley
University of Oxford, Department of Physics, Clarendon Laboratory, Parks Rd., Oxford, OX1 3PU, UK .

Light provides some unique capabilities for quantum enhanced technologies. It is the clear choice for communications between nodes of an information processing network, as it has a large potential information capacity, as well as a reasonable immunity to data corruption by environmental noise. Further, the ability to synthesize effective interactions between photons by means of measurements has led to proposals for using light as the basis of quantum computers.

In this lecture, I will give an overview of the sorts of enhancements that optics can provide, deriving from some basic considerations of the quantum properties of photons, such as the noise and correlations of light beams. Further, I will give a short survey of potential applications. These will include quantum interferometry and metrology, microscopy, communications, cryptography, frequency standards and clock synchronization, as well as computation.

The major sources of imperfections in quantum optical implementations of these technologies, including low fidelity quantum states, non-deterministic processes, photon loss, and inefficient detectors, will be discussed, and their impact on developing real-world photonic technologies considered.

Sunday 9:00

Quantum information processing and quantum optics with superconducting circuits

A. Blais[1]
[1]Département de Physique, Université de Sherbrooke, Sherbrooke, Québec, J1K 2R1 Canada.

The quality of experiments involving superconducting qubits has improved tremendously in the past ten years. Since the first experiment at NEC in 1999, coherence times have risen by four orders of magnitudes, several readout mechanisms have reached the single-shot regime and logical gates can be implemented with sub-percent error rates. Highly entangled states can now be generated routinely by several groups and simples quantum algorithms have been implemented. Beyond applications to quantum information processing, superconducting qubits can now also play the role of artificial atoms in quantum optics experiments in the microwave regime. In some cases, these on-chip “photon laboratories" can reach regimes unexplored in traditional quantum optics. In this lecture, I will review the basic ideas required to understand these experiments.

Sunday 11:00

Charges and spins in quantum information processing

S. Tarucha
Department of Applied Physics, The University of Tokyo, Tokyo 113-8656, JapanPhysics.

Recent advances in semiconductor quantum dot (QD) technologies have enabled us to coherently manipulate and detect spins and charges in quantum information processing. To date a great deal of effort has been devoted to implement technical elements and concepts of unitary quantum computing (QC). Spin states are generally well isolated from the environment as compared to charge states, and therefore predicted to be good candidates as qubits. In practice spin-based QC is more intensively studied than charge-based QC. Now two types of spin qubits with quantum dots have been established: superposition of two Zeeman states for one electron in a single QD and that of spin singlet and triplet state for two electrons in a dou-ble QD. Then combining the qubit manipulation with spin-spin exchange control in double QDs various kinds of two qubit gates such as entanglement control and SWAP/SWAP1/2 can be realized. On the other hand, charge qubits have been realized using superposition of two charge states having one electron in either of two tunnel coupled QDs. Two-qubit gates can be also realized using two capacitively coupled double QDs, each having one charge qubit. In this lecturer I will review the current status of charge or spin qubit technologies as building blocks to prepare a universal set of logical QC operations and the underlying physics including qubit multiplication, readout of qubit states and decoherence problems.

Sunday 14:00

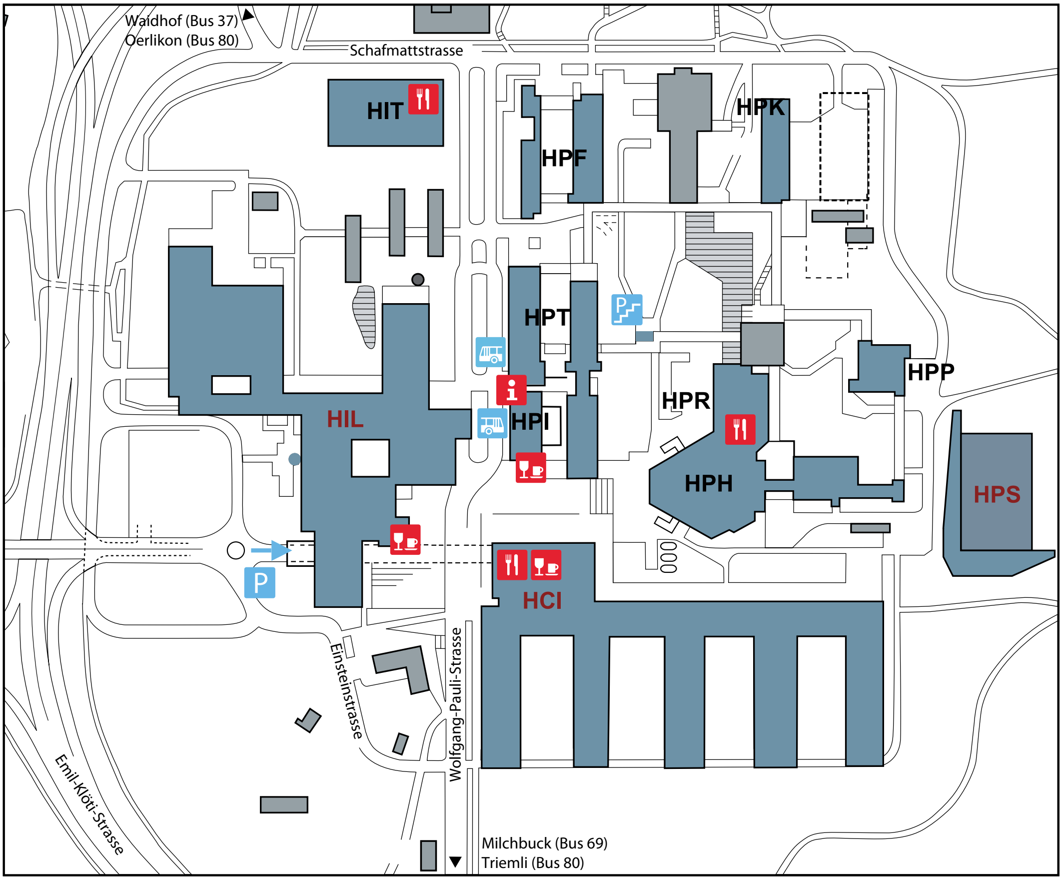
Introduction to optomechanics

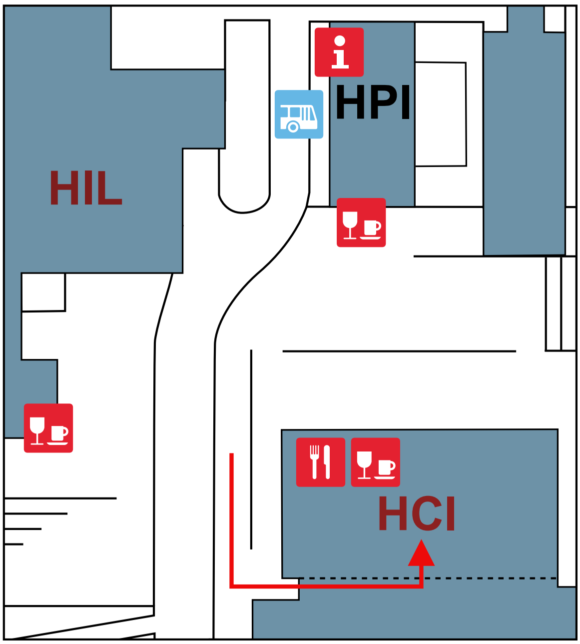
F. Marquardt
[1]University of Erlangen-Nuremberg, 91058 Erlangen, Germany.

This lecture will offer a tutorial introduction to the new field of cavity optomechanics, where one studies the interaction between light and nanomechanical motion. I will discuss how the radiation pressure force induced by the light field circulating in a laser-driven cavity affects the motion of a micro- or nanomechanical resonator. Topics to be discussed are: laser-cooling to the mechanical ground state, quantum-limited displacement detection, creating squeezed and entangled states of light and motion, and potential quantum information applications, such as converting quantum information from GHz to optical frequencies.

Maps and Plans

ETH Hönggerberg

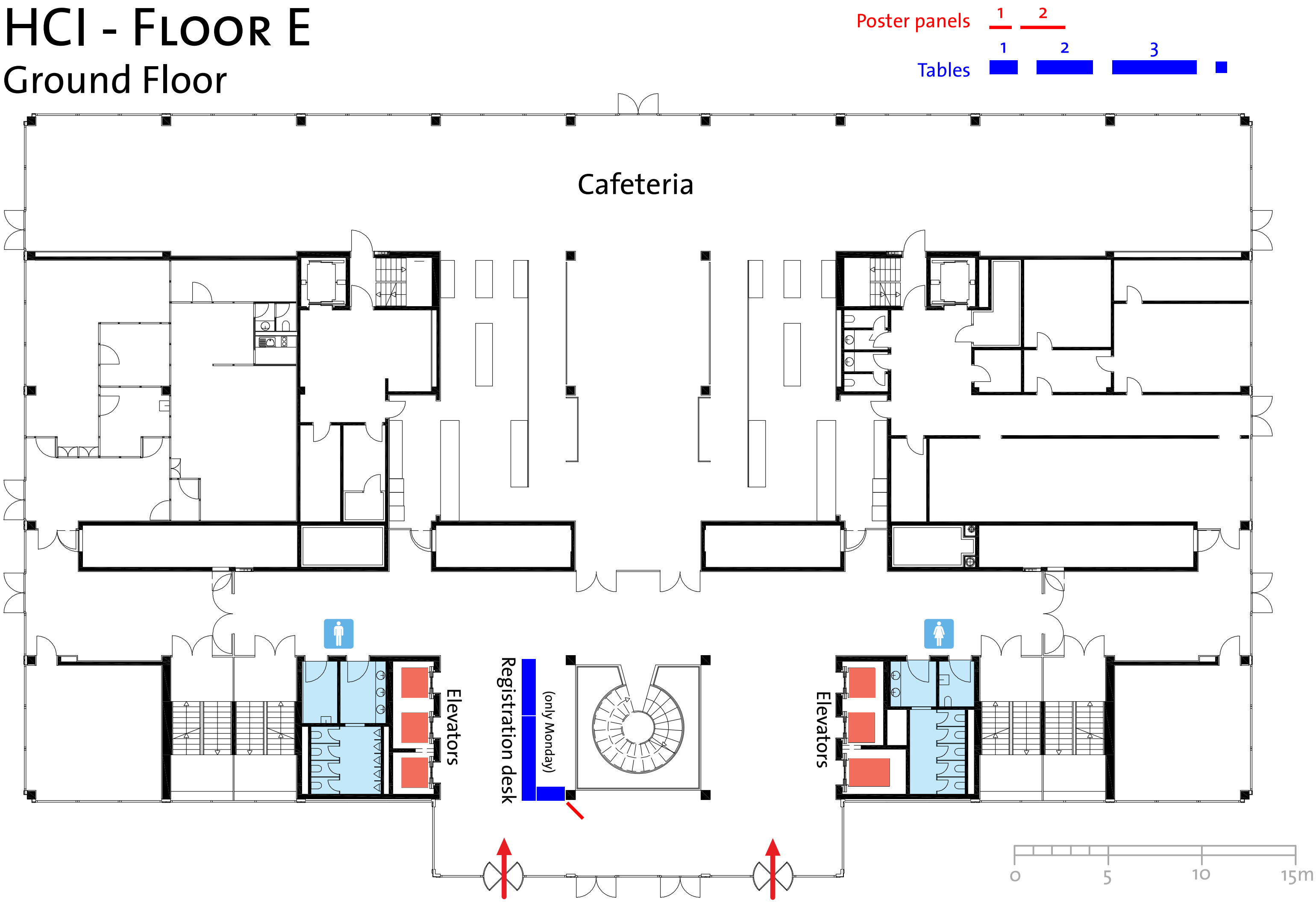




HCI ... Lecture Halls / Posters
HIL ... Post Office / ATM
HPS ... Sport Centre

- Parking Garage
- Bus stop (80/69)
- Bus stop (37)
  Transport to the Conference Dinner
- Canteen
- Cafeteria
- Information desk

HCI - FLOOR E
Ground Floor



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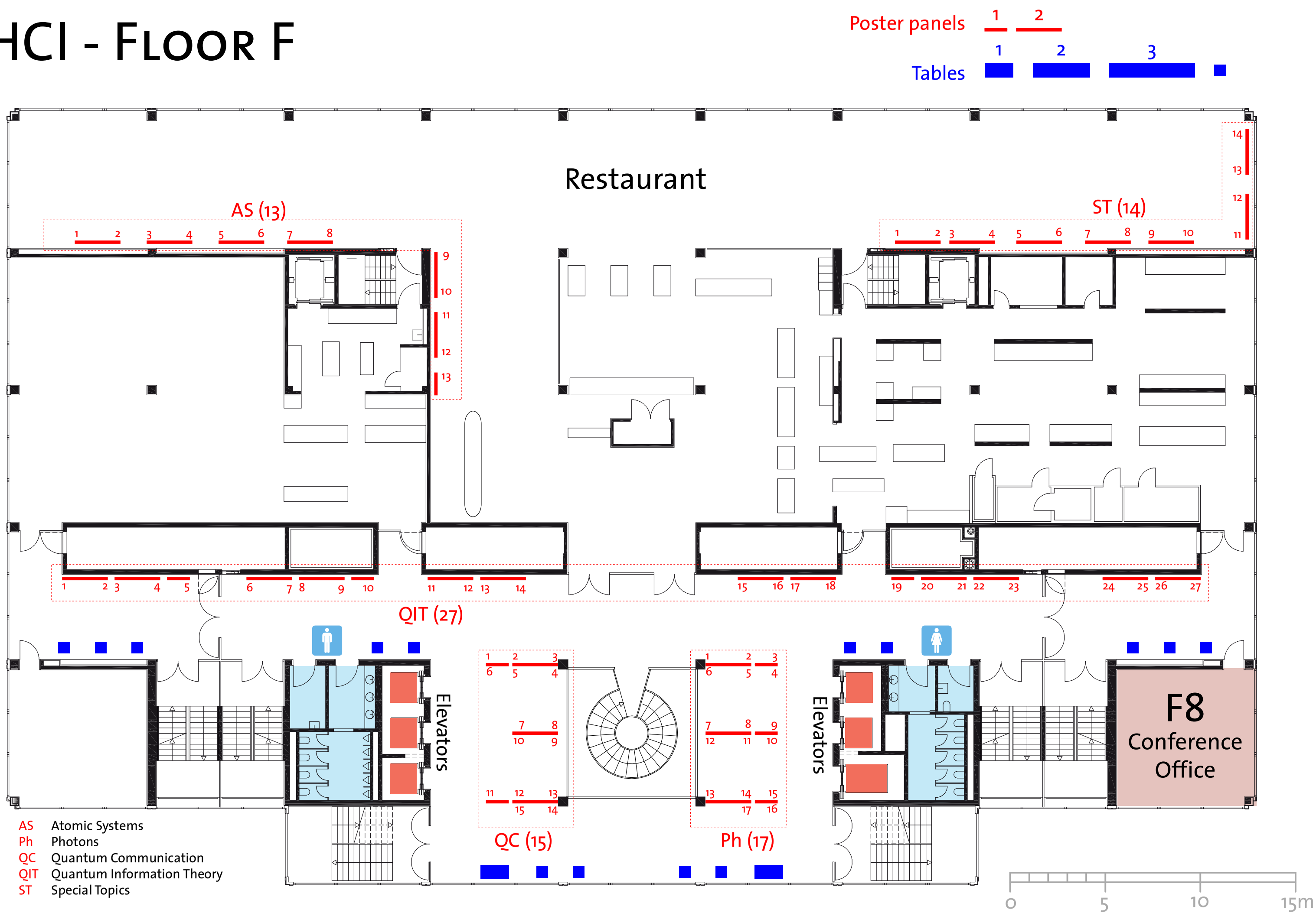
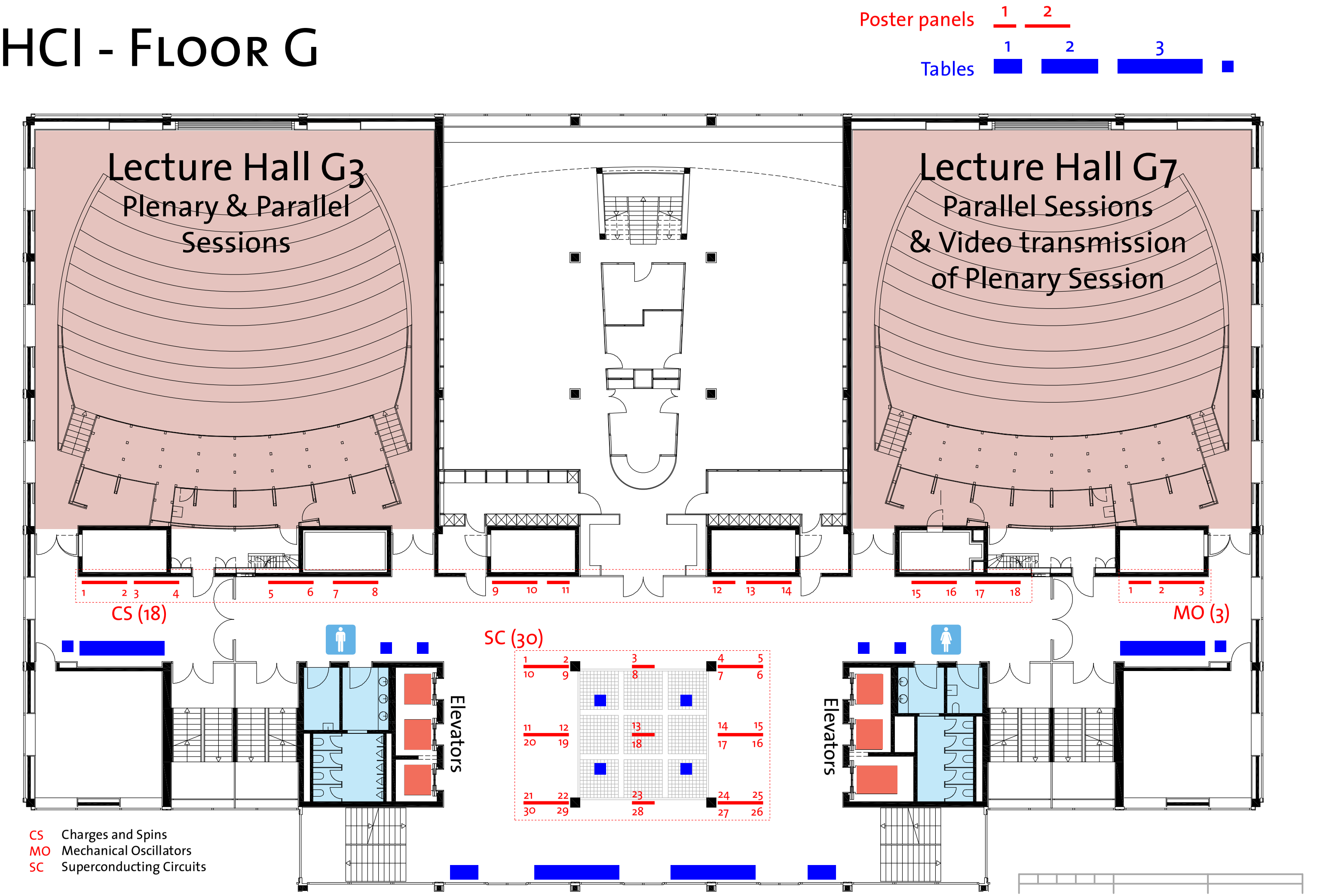


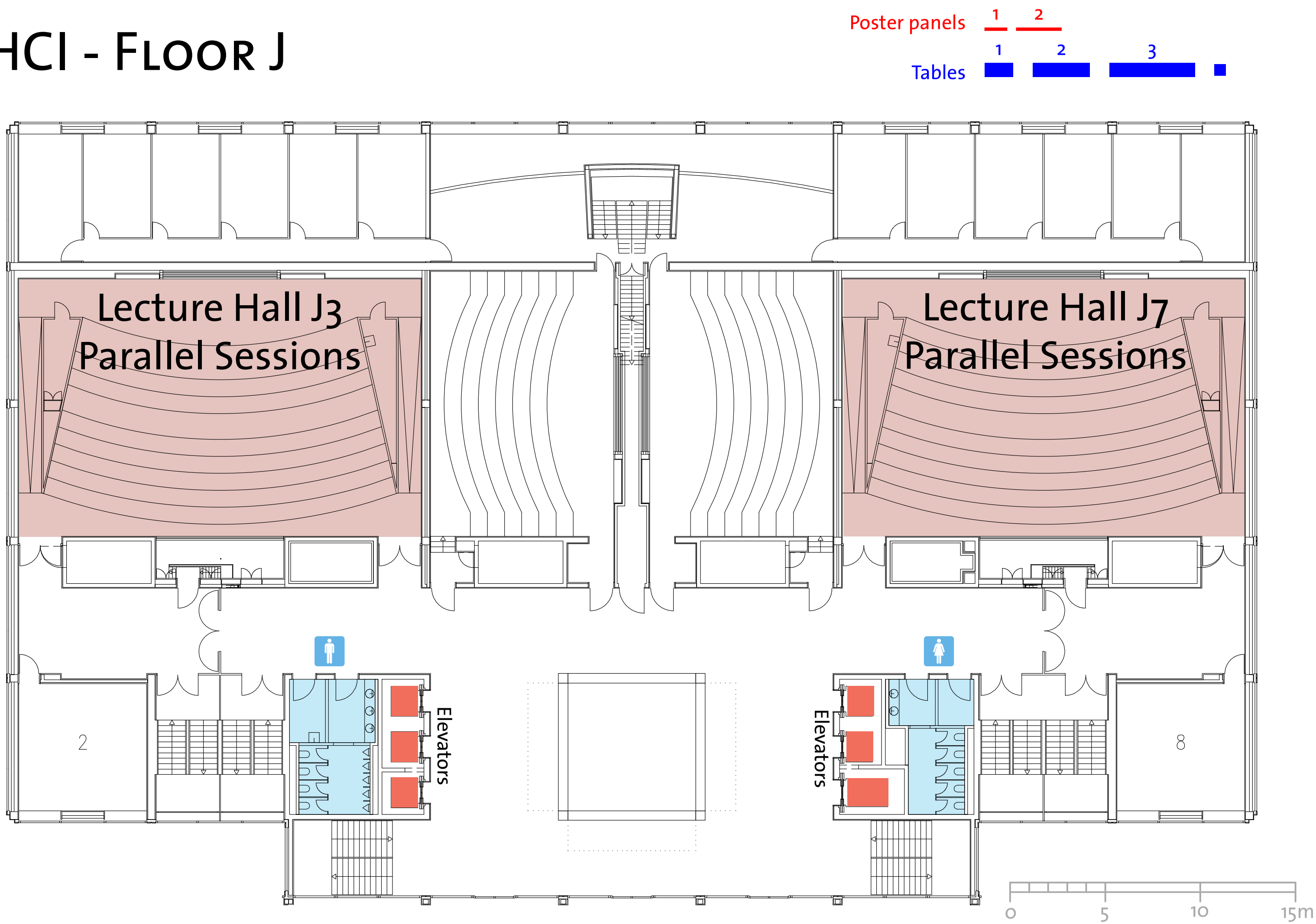
Poster panels
Tables
Restaurant
AS (13)
ST (14)
QIT (27)
QC (15)
Ph (17)
Elevators
Elevators
F8
Conference
Office
AS Atomic Systems
Ph Photons
QC Quantum Communication
QIT Quantum Information Theory
ST Special Topics
0
5
10
15m

HCI - Floor G



Poster panels
1
2
Tables
1
2
3
Lecture Hall G3
Plenary & Parallel Sessions
Lecture Hall G7
Parallel Sessions & Video transmission of Plenary Session
CS (18)
MO (3)
SC (30)
Elevators
Elevators
CS Charges and Spins
MO Mechanical Oscillators
SC Superconducting Circuits
0
5
10
15m

HCI - Floor J



Poster panels 1 2
Tables 1 2 3
Lecture Hall J3
Parallel Sessions
Lecture Hall J7
Parallel Sessions
Elevators
Elevators
2
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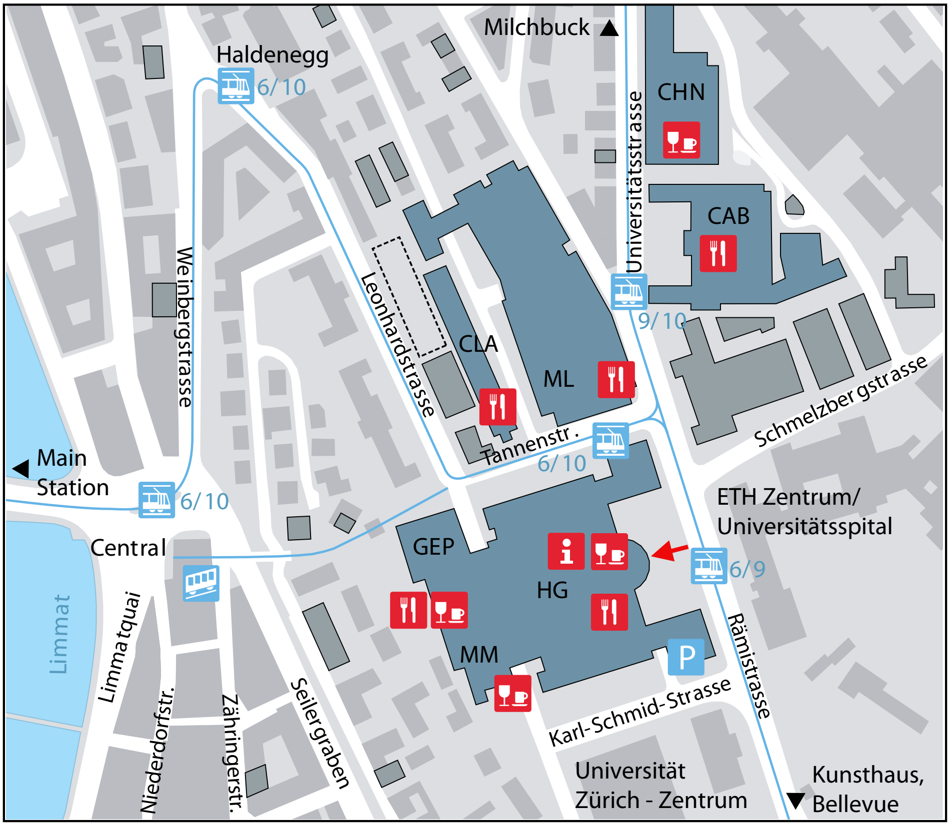
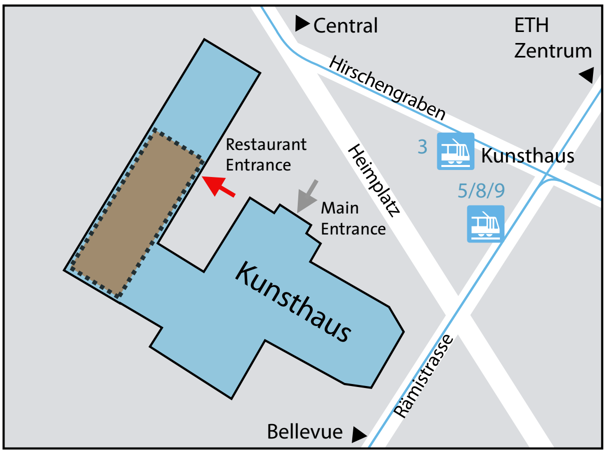
0 5 10 15m

ETH Zentrum



Kunsthaus Zurich

Conference Dinner

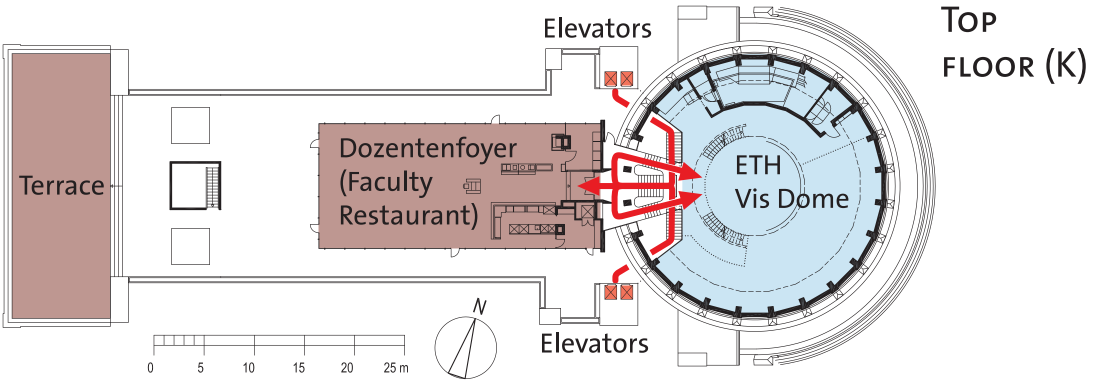


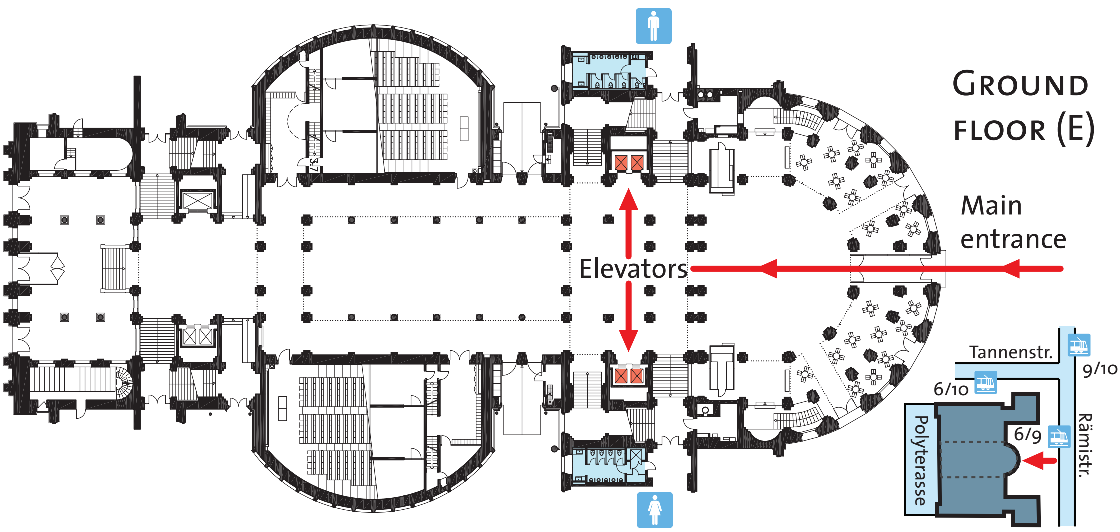
- Tram stop
- Cable Car "Polybahn"
- P Parking Garage
- Canteen
- Cafeteria
- Information desk

ETH Main Building (HG)

Welcome Reception

Discussion Session





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