

## Q 3 Poster Quanteninformation, -kommunikation und Quantencomputer

Zeit: Freitag 11:00–12:30

Raum: Poster HU

Q 3.1 Fr 11:00 Poster HU

**Towards probabilistic entanglement of distant atoms** — ●MARKUS HENNRICH, FELIX ROHDE, CARSTEN SCHUCK, and JÜRGEN ESCHNER — ICFO - Institut de Ciències Fotòniques, Jordi Girona 29, Nexus II, 08034 - Barcelona, Spain

Non-local entanglement is considered a key resource in future quantum information processing. One of its applications is the implementation of quantum communication schemes over long distances [1]. Such non-local entanglement has been realized e.g. between two photons [2] and between an atom and a photon [3]. A proximate step towards distributed quantum information processing is the generation of entanglement of distant massive particles like single atoms, as e.g. proposed by Cabrillo et al. [4]. This scheme relies on the projective measurement of photons scattered from two distant atoms after excitation by a common laser pulse. Here we describe our plans for an experimental realization of this scheme.

- [1] H.-J. Briegel et al., *Phys. Rev. Lett.* **81**, 5932 (1998).
- [2] P. G. Kwiat et al., *Phys. Rev. Lett.* **75**, 4337 (1995).
- [3] B. B. Blinov et al., *Nature* **428**, 153 (2004).
- [4] C. Cabrillo et al., *Phys. Rev. A* **59**, 1025 (1999).

Q 3.2 Fr 11:00 Poster HU

**A Novel Scheme for the Generation of Single Photons of alternating Polarization** — ●TATJANA WILK, HOLGER SPECHT, AXEL KUHN, and GERHARD REMPE — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching

In the last two years, single-photon generation from atom-cavity systems has been successfully demonstrated in several experiments [1–3]. In these experiments, photons are produced by Raman transitions between electronic or hyperfine levels, and a time-consuming repumping to the initial state is required between two emissions. Here, we propose a new scheme where a Raman transition is driven between two Zeemann sub-levels,  $m_F = \pm 1$ , of a  $F=1$  hyperfine state of a single atom. A cavity couples these states to a  $F'=0$  hyperfine level of an electronically excited state. In addition, a magnetic field is applied that lifts the degeneracy of the  $m_F = \pm 1$  levels. Therefore a Raman transition can be driven in one direction only, i.e. from  $m_F = +1$  to  $m_F = -1$  (or vice versa), by exposing the atom to a laser pulse tuned to the respective resonance. If, e.g., a laser pulse of frequency  $f^-$  resonantly drives the  $m_F = -1$  to  $m_F = +1$  transition, a  $\sigma^-$  photon is generated. A subsequent laser pulse of frequency  $f^+$  driving the transition in the opposite sense then generates a  $\sigma^+$ -photon. This scheme requires no repumping between successive emissions and produces a stream of photons with alternating  $\sigma^+$  and  $\sigma^-$  polarization.

- [1] Kuhn et al. *Phys. Rev. Lett.* **89**, 67901 (2002)
- [2] McKeever et al. *Science* **303**, 1992 (2004)
- [3] Keller et al. *Nature* **431**, 1075 (2004)

Q 3.3 Fr 11:00 Poster HU

**Entanglement studies on the photoionization of few-electron ions** — ●THOMAS RADTKE, ANDREY SURZHYKOV, and STEPHAN FRITZSCHE — Institut für Physik, Universität Kassel, D-34132, Germany

The phenomenon of entanglement is known to play a key role in quantum computation and quantum cryptography and, hence, has been studied intensively during recent years [1–3]. Special attention in these studies was placed, in particular, on the *physical processes* which may be utilized for the observation and manipulating of the quantum entanglement. One of such processes, which was recently discussed by Kim and co-workers [3], is the ionization of a few-electron atoms (or ions) by circularly polarized light. However, while some of the general features of the entanglement change in atomic photoionization were shown in Ref. [3], no *systematic* investigation on the (quantum) information transfer from the incoming photons to the emitted photoelectrons has been performed until now. In this contribution, Dirac's approach is applied to study the photoionization of few-electron ions within both, the nonrelativistic and relativistic framework. Detailed calculations show the dependence of the entanglement change as a function of the energy and the polarization of incoming light, the nuclear charge and the emission angle of the photoelectrons.

- [1] C. H. Bennett et al., *Phys. Rev. Lett.* **70** (1993) 1895.
- [2] N. Chandra et al., *J. Phys. B: At. Mol. Opt. Phys.* **35** (2002) 2219.
- [3] Y. S. Kim et al., *Phys. Scr.* **T110** (2004) 79.

Q 3.4 Fr 11:00 Poster HU

**Dekohärenz in geschüttelten Ionenfallen** — ●THIMO GROTZ, LIBBY HEANEY und WALTER STRUNZ — Physikalisches Institut der Universität Freiburg, Hermann-Herder-Strasse 3, 79106 Freiburg

Motiviert durch Dekohärenzexperimente in Ionenfallen betrachten wir die zeitliche Entwicklung einer Superposition von kohärenten Zuständen in einer Ionenfalle, die in zufälliger Weise "geschüttelt" wird. Die Dynamik des Ions in der Falle wird durch den harmonischen Oszillator beschrieben, welcher durch einen linearen Verschiebungsterm  $F(t)q$  ergänzt wird. Dabei ist  $F(t)$  eine stochastisch auf das Ion wirkende Kraft mit beliebiger Korrelationsfunktion  $\langle F(t)F(t') \rangle$ . Wir leiten weiterhin eine exakte Mastergleichung für den über die fluktuierende Kraft gemittelten Dichteoperator des Systems her und zeigen, dass diese selbst für farbiges Rauschen in zeitlokaler Form geschrieben werden kann.

Q 3.5 Fr 11:00 Poster HU

**Quantum cellular automata with locally conserved quantities** — ●HOLGER VOGTS and REINHARD F. WERNER — Institut für Mathematische Physik, TU Braunschweig, www.imaph.tu-bs.de

A quantum lattice gas is a cellular automaton, i.e., a discrete time lattice system with strictly finite propagation speed, in which the conservation of the number of particles is guaranteed by the local transition rule. The dynamics can therefore be restricted to states with fixed particle number, obtaining a system of interacting quantum random walkers. Apart from conserved quantities which are sums of one-site terms, we also consider quantities containing interaction terms. A typical example is the energy of the XY spin chain, which is a conserved quantity for a certain Clifford cellular automaton.

Q 3.6 Fr 11:00 Poster HU

**Asymptotic behavior and scattering theory of quantum random walks** — ●ANNETTE MARIA GATTNER and REINHARD F. WERNER — Institut für Mathematische Physik, TU Braunschweig, www.imaph.tu-bs.de

We consider the one-dimensional quantum walk with Hadamard coin as the free time evolution for scattering problems. The analogue of a scattering potential is a local modification of the quantum walk dynamics. This can be studied by comparing the modified dynamics with the free walk at large times.

Q 3.7 Fr 11:00 Poster HU

**Computational equivalence of quantum Turing machines and quantum cellular automata** — ●TORSTEN FRANZ and REINHARD F. WERNER — Institut für Mathematische Physik, TU Braunschweig, www.imaph.tu-bs.de

Turing machines and cellular automata are two computational models, which in the classical case are known to be equivalent to within polynomial bounds. Here we show how a quantum Turing machine can be considered as a special kind of quantum cellular automaton. On the other hand, we show how to simulate the parallelism of quantum cellular automata by a sequential quantum computation. The relationship to other computational models, such as the one-way computer, the gate model, and adiabatic computation is discussed.

Q 3.8 Fr 11:00 Poster HU

**Towards Storing Single Photons in Atomic Vapor** — ●MATTHIAS SCHOLZ, SVEN RAMELOW, THOMAS AICHELE, and OLIVER BENSON — Humboldt-Universität zu Berlin, AG Nanooptik, Hausvogteiplatz 5-7, 10117 Berlin

We exploit the potential of long-living coherent spin-excitations in hot atomic vapor as a storage medium for photonic quantum states. This idea may lead to an interface between quantum information encoded in stationary (atomic) and flying (photonic) qubits. By use of electromagnetically induced transparency,  $^{133}\text{Cs}$  vapor loses its opaqueness for a particular electronic transition, accompanied by a steep slope in the index of refraction. Single photons, emitted on this transition, will be slowed down to group velocities as low as 20,000 meters per second. These photons can be generated either by a source for single photons based on quantum dot emission existing in our lab or by narrow-bandwidth parametric down-conversion.

In the field of quantum information, the fundamental interest in single photon storage is stimulated by theoretical research on quantum repeaters that may help to increase the communication range of fiber-based quantum cryptographic systems limited to about 150 km today. Other applications of this storage device cover the shape control of photon wave packets and experiments in non-linear optics.

Q 3.9 Fr 11:00 Poster HU

**Alignment structures for a fiber resonator using deep UV lithography** — ●MARCO WILZBACH<sup>1</sup>, SÖENKE GROTH<sup>1</sup>, ALBRECHT HAASE<sup>2</sup>, BJÖRN HESSMO<sup>2</sup>, XIYUAN LIU<sup>3</sup>, MICHAEL SCHWARZ<sup>1</sup>, and JÖRG SCHMIEDMAYER<sup>1</sup> — <sup>1</sup>Physikalisches Institut der Universität Heidelberg, Philosophenweg 12, D-69120 Heidelberg, Germany. — <sup>2</sup>Royal Institute of Technology, Dept. of Microelectronics and IT, Electrum 229, Isafjordsgatan 22, S-16440 Kista, Sweden. — <sup>3</sup>Lehrstuhl für Optoelektronik, Universität Mannheim, B6 23-29, D-68131 Mannheim, Germany.

On atom chips various atom optical elements have been realized using magnetostatic and electrostatic potentials created by surface-mounted microscopic wire structures. Here we present a next step to make these atom chips become an universal toolbox for fundamental experiments in quantum optics as well as for possible applications like quantum information processing. Our first experiments aim at the detection of single atoms in miniaturized traps using optical fibre cavities. For the integration of the fibre cavities we developed passive alignment structures on an atom chip. We will describe our setup, show the first measurements with these structures and give first experimental results.

Q 3.10 Fr 11:00 Poster HU

**Programmable discrimination for unknown qudit states** — ●STEFAN T. PROBST-SCHENDZIELORZ<sup>1</sup>, MATTHIAS FREYBERGER<sup>1</sup>, JÁNOS BERGOU<sup>2</sup>, and IGOR JEX<sup>3</sup> — <sup>1</sup>Abteilung für Quantenphysik, Universität Ulm, 89069 Ulm — <sup>2</sup>Department of Physics, CUNY Hunter College, 695 Park Avenue, New York, NY 10021, USA — <sup>3</sup>Department of Physics, FNSPE, Czech Technical University Prague, Brehova 7, 115 19 Praha, Czech Republic

Unambiguous discrimination of two unknown quantum states, especially if they are non-orthogonal, is a challenging problem. But if there are copies of the states provided, the discrimination of the states is possible based on symmetry arguments. We present a POVM for this scheme generalized for d-dimensional systems. To optimize our POVM, we need to know the occurrence probabilities. Therefore, we adapt stepwise the parameters of the POVM and compare this to projection measurements.

Q 3.11 Fr 11:00 Poster HU

**Phasenmessung mit verschränkten gequetschten Zuständen** — ●DANIELA DENOT, THORSTEN BSCHORR und MATTHIAS FREYBERGER — Abteilung Quantenphysik, Universität Ulm, 89069 Ulm

Die Bestimmung kleiner Phasenänderungen ist ein wichtiges Problem der Quantenoptik. Wir untersuchen dazu realistische interferometrische Messungen mit verschränkten Zuständen. Eine Möglichkeit bilden gequetschte Zustände, die über lineare optische Elemente korreliert werden. Die Wirkung eines Phasenschubs auf einen solchermaßen verschränkten Zustand analysieren wir mit Hilfe einer geeigneten Homodyn-Detektion. Unser Ergebnis ist eine Phasenverteilung in einem verallgemeinerten zwei Moden Phasenraum. Die zugehörige Phasenvarianz kann dann in Abhängigkeit von der mittleren Photonenzahl der gequetschten Zustände minimiert werden. Wir diskutieren zudem die Verwendung anderer Eingangszustände und die Möglichkeit einer adaptiven Messung zur Verbesserung der Ergebnisse.

Q 3.12 Fr 11:00 Poster HU

**Bi-partite and global entanglement in a many-particle system with collective spin coupling** — ●CRISTIAN IONESCU<sup>1,2</sup>, RAZMIK UNANYAN<sup>1,3</sup>, and MICHAEL FLEISCHHAUER<sup>1</sup> — <sup>1</sup>Fachbereich Physik, Technische Universität Kaiserslautern — <sup>2</sup>Institute for Space Science, Bucharest, Romania — <sup>3</sup>Institute for Physical Research of Armenian National Academy of Sciences, Ashtarak, Armenia

Bipartite and global entanglement are analyzed for the ground state of a system of  $N$  spin 1/2 particles interacting via a collective spin-spin coupling described by the Lipkin-Meshkov-Glick (LMG) Hamiltonian. Under certain conditions which includes the special case of a supersymmetry, the ground state can be constructed analytically.

In the case of an antiferromagnetic coupling and for an even number of particles this state undergoes a smooth crossover as a function of the con-

tinuous anisotropy parameter  $\gamma$  from a separable ( $\gamma = \infty$ ) to a maximally entangled many-particle state ( $\gamma = 0$ ). From the analytic expression for the ground state bipartite and global entanglement are calculated. In the thermodynamic limit a discontinuous change of the scaling behavior of the bipartite entanglement is found at the isotropy point  $\gamma = 0$ . For finite systems with total spin  $J = N/2$  the scaling behavior changes at  $\gamma_{\text{crit}} = 1/J$ .

Q 3.13 Fr 11:00 Poster HU

**Erzeugung gequetschten Lichts in mikrostrukturierten Fasern bei 800 nm** — ●CHRISTOPH MARQUARDT, METIN SABUNCU, ULRIK L. ANDERSEN und GERD LEUCHS — Institut für Optik, Information und Photonik, Max-Planck Forschungsgruppe, Universität Erlangen-Nürnberg, Günther-Scharowsky-Str. 1 / Bau 24, 91058 Erlangen

Gequetschtes Licht ist ein Grundbaustein in der Quanteninformatonsverarbeitung mit kontinuierlichen Variablen. Es dient z.B. als Quelle für verschränktes Licht oder wird für Quantum-Non-Demolition (QND) Messungen benötigt. Ausserdem findet es Anwendung in der Quanteninterferometrie.

In Fasern wird gequetschtes Licht üblicherweise mit kurzen Pulsen bei 1550 nm erzeugt [1]. Wir stellen eine Quelle gequetschten Lichts um 800 nm vor, die die hohen Nichtlinearitäten mikrostrukturierter Fasern ausnutzt. Dieser Wellenlängenbereich besitzt den Vorteil geringer Absorption in der Atmosphäre bei Freiraumübertragungen und die Ausnutzung hocheffizienter Si-Photodioden. Ausserdem ermöglicht es einem die Kopplung des Lichts mit Atomübergängen von Rb und Cs, was für die Realisierung von Quantenspeichern wichtig ist.

[1] S. Schmidt et al., Phys. Rev. Lett. 81, 2446 (1998)

Q 3.14 Fr 11:00 Poster HU

**GRIN-lens detector for observation of a single atom on a microchip** — ●AKIFUMI TAKAMIZAWA<sup>1</sup>, TILO STEINMETZ<sup>1</sup>, RÉMI DELHUILLE<sup>1</sup>, THEODOR W. HÄNSCH<sup>1</sup>, and JAKOB REICHEL<sup>1,2</sup> — <sup>1</sup>Max-Planck-Institut für Quantenoptik und Sektion Physik der Ludwig-Maximilians-Universität, München, Germany — <sup>2</sup>Laboratoire Kastler Brossel de l'E.N.S., Paris, France

A single atom detector is necessary if single atoms are used for quantum information and computing. For the observation on a microchip, we are developing a fluorescence detector with a tiny gradient-index-lens (GRIN lens). The resonant fluorescence from a Rb atom with a wavelength of 780 nm is collected by the GRIN lens with a large NA of about 0.5 and coupled into a single mode fiber 4 mm behind the lens to take the fluorescence out of a vacuum chamber. In order to avoid the atom getting out of the detection region, optical dipole trapping will be performed at the focal spot of a laser beam with a wavelength of 830 nm introduced through the fiber. In preparatory measurements, we measured that the 830 nm-light is focused 8.6  $\mu\text{m}$  farther from the lens than the 780 nm-light due to chromatic aberration. However, in spite of the aberration, the ratio of the fluorescence coupled into the fiber with respect to the total fluorescence is estimated to be  $1.5 \times 10^{-3}$ , which value is sufficient for photon counting for the single atom detection. In this presentation, we will talk about the progress of the experiment of atom detection on a chip.

Q 3.15 Fr 11:00 Poster HU

**A high-finesse optical Fabry-Perot resonator for cavity QED experiments** — ●IGOR DOTSENKO, WOLFGANG ALT, MKRTYCH KHU-DAVERDYAN, DIETER MESCHÉDE, YEVHEN MIROSHNYCHENKO, DOMINIK SCHRADER, and ARNO RAUSCHENBEUTEL — Institut für Angewandte Physik, Universität Bonn, Wegelestr. 8, 53115 Bonn

A realization of a controlled coherent interaction between neutral atoms is the main milestone on the way to quantum computation with neutral atoms. For this purpose we plan to deterministically place two atoms into the cavity mode of an optical Fabry-Perot resonator, where the interaction between them can be enhanced by the exchange of a virtual cavity photon. Essential demands on cavities used in quantum information experiments are a high stability of the resonator frequency with respect to the atomic resonance and a photon lifetime much longer than the timescale of an atom-photon coupling. We have recently fulfilled these both requirements. We present a high-finesse ( $F=1.000.000$ ) cavity which length is actively and continuously stabilized to the subpicometer precision required for the cavity QED experiments. In addition, we discuss realistic entanglement schemes compatible with our experimental parameters.

Q 3.16 Fr 11:00 Poster HU

**Ultrashort-pulse pumped spontaneous parametric down-conversion for entangled photons** — ●SEBASTIAN BANGE, MARTIN OSTERMEYER, and RALF MENZEL — University of Potsdam, Am Neuen Palais 10, 14469 Potsdam

During the last decade, the process of spontaneous parametric down-conversion (SPDC) in non-centrosymmetric crystals has been proven to be a reliable source for pairs of entangled photons. In recent years, SPDC-pumping with ultrashort laser pulses in the pico- and femtosecond regime has attracted increasing attention. The higher intensities allow for the generation of entangled multi-photon states as well as new imaging techniques based on the higher flux of entangled photons [1].

Envisaging experiments in the field of quantum information, we are presenting a setup for picosecond-pulse pumped SPDC. Careful engineering of the quantum state is critical for the fidelity of the entanglement especially when working with ultrashort pulses [2]. The special needs of compensation schemes for runtime differences in this regime are discussed. Furthermore the ramifications of the entanglement with regard to a broader bandwidth in the emission of the photons is considered.

[1] A. Gatti, E. Brambilla and L.A. Lugiato, Phys. Rev. Lett. **90**(13) 133603 (2003)

[2] Y.-H. Kim and W. P. Grice, J. Mod. Opt **49**(14/15) 2309 (2002)

Q 3.17 Fr 11:00 Poster HU

**Transport-Induced Adiabatic Passages.** — ●MKRZYCH KHUDEVRYAN, WOLFGANG ALT, IGOR DOTSENKO, LEONID FÖRSTER, DIETER MESCHÉDE, YEVHEN MIROSHNYCHENKO, ARNO RAUSCHENBEUTEL, and DOMINIK SCHRADER — Institut für Angewandte Physik, Wegelerstr.8, 53115 Bonn

We demonstrate a robust scheme for selective spin flips within a string of optically trapped individual neutral Cs atoms using microwave induced adiabatic passages. The atoms are imaged with a CCD camera and their transition frequency is position dependently shifted with a magnetic field gradient. A spin flip on a selected atom is accomplished by sweeping the microwave frequency across the respective resonance frequency. We analyze the addressing resolution of this scheme. In a second experiment we induce a spin flip with a fixed microwave frequency by deterministically transporting the atoms across the position of resonance. Our experiments are an important step towards quantum logic operations with atoms.

Q 3.18 Fr 11:00 Poster HU

**Rearranging individual neutral atoms in two crossed standing wave dipole traps** — ●LEONID FÖRSTER, WOLFGANG ALT, IGOR DOTSENKO, MKRZYCH KHUDEVRYAN, YEVHEN MIROSHNYCHENKO, ARNO RAUSCHENBEUTEL, DOMINIK SCHRADER, and DIETER MESCHÉDE — Institut für Angewandte Physik, Wegelerstr.8, 53115 Bonn

By optical imaging we have determined the positions of individual Cs atoms in a standing wave dipole trap with a sub-wavelength resolution of 130nm. This allows us to resolve the 532nm-periodical structure of the trapping potential [1]. Together with our optical conveyor belt technique [2], we have transported single atoms, which were initially loaded at a random lattice site, to a predetermined position along the dipole trap axis with an accuracy of 300nm. In order to rearrange a string of atoms we have constructed an auxiliary orthogonal standing wave dipole trap. Using it as optical tweezers, we pick out a selected atom and place it back at a desired destination. The resolution and performance of this set up will be analysed. Possible applications are the preparation of a quantum register [3] of equally spaced neutral atoms and their delivery to a high finesse cavity.

[1] I. Dotzenko et al., submitted to Phys. Rev. Lett. [2] S. Kuhr et al., Science **293**, 278 (2001) (published online: 10.1126/science.1062725) [3] D. Schrader et al., Phys. Rev. Lett. **93**, 150501-4 (2004)

Q 3.19 Fr 11:00 Poster HU

**Atomdetektion auf einem Atomchip mit Hilfe eines integrierten optischen Mikroresonator** — ●YVES COLOMBE<sup>1</sup>, TILO STEINMETZ<sup>1</sup>, PHILIPP TREUTLEIN<sup>1</sup>, BENJAMIN LEV<sup>2</sup>, THEODOR W. HÄNSCH<sup>1</sup> und JAKOB REICHEL<sup>1,3</sup> — <sup>1</sup>Max-Planck-Institut für Quantenoptik und Sektion Physik der Ludwig-Maximilians-Universität München, Germany — <sup>2</sup>Norman Bridge Laboratory of Physics, California Institute of Technology, Pasadena, U.S.A. — <sup>3</sup>Laboratoire Kastler Brossel de l'ENS, Paris, France

In vielen Vorschlägen zu Quanteninformationsexperimenten dienen Einzelatomzustände als Qubits; für solche Experimenten braucht man

neben einer präzisen Adressierung die Möglichkeit einzelne Atome zu detektieren. In unserer Gruppe beschäftigen wir uns damit unterschiedliche optische Resonator zu entwickeln, die auf einem Atomchip integriert werden können, unter anderem ein Fabry-Perot Mikroresonator. Dieser besteht aus zwei gekrümmten, verspiegelten Faserendflächen die in einem Abstand von 40µm gegeneinander ausgerichtet sind. Hier zeigen wir die ersten erfolgreichen Experimente zur on-chip Detektion geringer Atomzahl ( $N < 10$ ).

Q 3.20 Fr 11:00 Poster HU

**Surface Quality of Atom Chips** — ●SÖNKE GROTH<sup>1,2</sup>, PETER KRÜGER<sup>1</sup>, STEPHAN WILDERMUTH<sup>1</sup>, DIANA MAHALU<sup>2</sup>, ISRAEL BAR-JOSEPH<sup>2</sup>, and JÖRG SCHMIEDMAYER<sup>1</sup> — <sup>1</sup>Physikalisches Institut, Heidelberg, Germany — <sup>2</sup>Weizmann Institute of Science, Rehovot, Israel

Neutral Atoms are trapped and cooled to BEC with Atom Chips. Advantages of Atom Chips are high current densities, submicron shaped wires with thickness from nm to µm scale for exactly defined potentials and serial production. Nanofabrication lithography enables to produce high quality surfaces. These are used as mirrors for laser cooling and are important for well defined current flow in the wires, as the trapped atoms are sensitive on small changes in the potential. Different materials were tested on their surface qualities and usability. Also further developments of Atom Chips are shown.

Q 3.21 Fr 11:00 Poster HU

**Charakterisierung und Weiterentwicklung von Faserresonatoren** — ●DAVID HUNGER<sup>1</sup>, TILO STEINMETZ<sup>1</sup>, JAKOB REICHEL<sup>1,2</sup> und THEODOR W. HÄNSCH<sup>1</sup> — <sup>1</sup>Max-Planck-Institut für Quantenoptik und Sektion Physik der Ludwig-Maximilians-Universität München, Germany — <sup>2</sup>Laboratoire Kastler Brossel de l'ENS, Paris, France

Die Verwendung von Fabry-Perot Faserresonatoren auf Atomchips ist eine vielversprechende Möglichkeit, die Methoden der Kontrolle magnetisch gefangener Atome in Gebieten wie Cavity QED oder Quanteninformationsverarbeitung anzuwenden.

Die erfolgreiche Implementierung eines stabilen Resonators in einem unserer Mikrofallenexperimente ermöglicht z.B. die Detektion von Atomen (siehe Vortrag von Tilo Steinmetz). Zur Verbesserung und Weiterentwicklung studieren wir die Eigenschaften stabiler Mikroresonatoren und entwickeln neue Methoden zur Herstellung von Resonatoren hoher Finesse (>10.000). Dabei ist neben der Qualität der Verspiegelung in erster Linie die Geometrie und die Oberflächenrauigkeit des Substrates ausschlaggebend für die Verluste im Resonator und damit für die maximal erreichbare Finesse.

Zum Erreichen möglichst starker Kopplung zwischen Atom und Lichtfeld konzentrieren wir uns zudem auf die Minimierung des Modenvolumens.

Q 3.22 Fr 11:00 Poster HU

**Long-Distance Free-Space Distribution of Quantum Entanglement over Vienna** — ●MICHAEL LINDENTHAL<sup>1</sup>, KEVIN RESCH<sup>1</sup>, BIBIANE BLAUENSTEINER<sup>1</sup>, HANNES BÖHM<sup>1</sup>, ALESSANDRO FEDRIZZI<sup>1</sup>, ANDREAS POPPE<sup>1</sup>, TOBIAS SCHMITT-MANDERBACH<sup>2</sup>, MICHAEL TARABA<sup>1</sup>, RUPERT URSIN<sup>1</sup>, PHILIP WALTHER<sup>1</sup>, HENNING WEIER<sup>2</sup>, HARALD WEINFURTER<sup>2,3</sup>, and ANTON ZEILINGER<sup>1,4</sup> — <sup>1</sup>Institut für Experimentalphysik, Universität Wien, Boltzmannngasse 5, A-1090 Wien, Austria — <sup>2</sup>Sektion Physik, Ludwig-Maximilians-Universität, D-80797 München, Germany — <sup>3</sup>Max-Planck-Institut für Quantenoptik, D-85748 Garching, Germany — <sup>4</sup>Institut für Quantenoptik und Quanteninformation, Österreichisch Akademie der Wissenschaften, Boltzmannngasse 3, A-1090 Wien, Austria

We have established a real-world free-space quantum channel over 7.8 km and demonstrate the distribution of entangled photons. The transmitter is placed at an observatory and the receiver on the 46th floor of an office skyscraper in Vienna, Austria. Using locally-recorded time stamps and a public internet channel, coincident counts from correlated photons are demonstrated to violate a Bell inequality by over ten standard deviations. This confirms the high quality of the shared entanglement. In this experiment the horizontal free-space distance is chosen, so that the attenuation the light undergoes corresponds approximately to the attenuation from space to earth. This work is an encouraging step towards satellite-based distribution of quantum entanglement and future intra-city quantum networks.

Q 3.23 Fr 11:00 Poster HU

**Untersuchungen der Depolarisation und Polarisationsmoden-Dispersion an Glasfasern zur Übertragung polarisationsverschränkter Photonen** — ●ANDREAS POPPE<sup>1</sup>, LUKAS BURGER<sup>1</sup> und ANTON ZEILINGER<sup>1,2</sup> — <sup>1</sup>Institut für Experimentalphysik, Universität Wien, Boltzmannngasse 5, 1090 Wien, Österreich — <sup>2</sup>Institute for Quantum Optics and Quantum Information, Österreichische Akademie der Wissenschaften, Boltzmannngasse 3, 1090 Wien, Österreich

Die Weiterentwicklung von EPR-Quellen zur Erzeugung von polarisationsverschränkten Photonenpaaren bei der Telekomwellenlänge von 1550nm löste eine detaillierte Untersuchung über den Zusammenhang von Depolarisation (Degree Of Polarization, DOP) von polarisierten Photonen bei der Propagation über Fasern mit Polarisations-Moden-Dispersion (PMD) aus. Die Depolarisation messen wir mit einer polarisierten, breitbandigen ASE-Quelle, deren Spektrum wir mit verschiedenen spektralen Filtern gezielt begrenzen können. Mit einem Polarisationssteller kompensieren wir die reversible Polarisationsdrehung, um einen möglichst guten Kontrast zwischen den beiden Armen eines fasergekoppelten Polarisationsstrahlteilers (PBS) zu erlangen. Bei manchen längeren Fasern (z.B. 50km) kann dieses Verhältnis auf 10:1 absinken, das wir dann mit gemessenen Werten der PMD vergleichen. Dabei stellt sich zwar ein prinzipieller Anstieg der Depolarisation bei erhöhter gemessener PMD von Fasern unterschiedlicher Länge heraus, es ist jedoch sehr schwierig, nur von der gemessenen PMD auf die Depolarisation rückzuschließen.

Q 3.24 Fr 11:00 Poster HU

**Performance of quantum key distribution protocols based on coherent states and homodyne detection under realistic conditions** — ●MATTHIAS HEID<sup>1,2</sup> and NORBERT LÜTKENHAUS<sup>1,2</sup> — <sup>1</sup>Institut für theoretische Physik I, Universität Erlangen-Nürnberg — <sup>2</sup>Institut für Optik, Information und Photonik (Max-Planck Forschergruppe), Universität Erlangen-Nürnberg

Quantum key distribution (QKD) protocols can be implemented with many different signal sources and detection devices. In practice, QKD with single photon sources and single photon counting suffers from the fact that the source is experimentally still hard to implement. Weak coherent pulses are therefore often used instead. An alternative approach uses coherent states together with variations of homodyne detection. The aim here is to use a detection setup which can operate at high repetition rates to boost the secret key rate.

In a practical implementation however, one has also to take into account that the error correction procedure used by the honest parties to correct for errors in their data never work at the ideal theoretical limit. This reduces the secret key rate.

We analyse the influence of this effect on the expected secret key rates for various schemes based on postselection [1] or reverse reconciliation [2]. As signals we assume a discrete distribution of coherent signal states and take imperfect detectors into account.

[1] Ch. Silberhorn, T. C. Ralph, N. Lütkenhaus, G. Leuchs, Phys. Rev. Lett., Vol. 89, 167901 (2002)

[2] F. Grosshans et al., Nature, Vol. 421, 238 (2003)

Q 3.25 Fr 11:00 Poster HU

**Entanglement in a weak coherent pulse protocol** — ●JOHANNES RIGAS and NORBERT LÜTKENHAUS — University Erlangen-Nürnberg, Institute of Theoretical Physics I, Quantum Information Theory Group

The detection of quantum correlations in the observed data of a QKD protocol is crucial for its security[1]. We investigate the possibilities to detect such correlations in the data of a specific “prepare & measure” protocol: This protocol is implemented in a setup using two polarization-modulated weak coherent pulses with a significant overlap and using a tomographical-complete heterodyning measurement as receiver with data postselection[2].

We derive conditions that verify the underlying quantum correlations. They are based on the knowledge of signal preparation and overlap and purity of the conditional states detected by the receiver.

[1] M. Curty, M. Lewenstein, N. Lütkenhaus: Entanglement as precondition for secure quantum key distribution; Phys. Rev. Lett. 92, 217903 (2004)

[2] S. Lorenz, N. Korolkova, G. Leuchs: Continuous variable quantum key distribution using polarization encoding and post selection; Appl. Phys. B 79, 273-277 (2004)

Q 3.26 Fr 11:00 Poster HU

**Optical Depolarization Through Random Scattering** — ●D. VOIGT, G. PUENTES, A. AIELLO, and J.P. WOERDMAN — Huygens Laboratory, Leiden University, The Netherlands (molphys.leidenuniv.nl/qo)

An intriguing universality relation in light scattering was recently predicted. [1] It relates the depolarizing power of a scattering optical medium to its polarization entropy. Using a Mueller-Stokes analysis, we investigate experimentally both deterministic and stochastic scattering media such as, e.g., multi mode optical fibers and milk, respectively. The data are in excellent agreement with theory, i.e depolarizing power and entropy of the various media are found within the analytical constraints of the universality relation. These results may be particularly relevant in quantum communication, where optical depolarization is synonymous to decoherence.

[1] A. Aiello and J.P. Woerdman, arXiv:quant-ph/0407234.

Q 3.27 Fr 11:00 Poster HU

**Vakuum Squeezing durch Austauschen von Seitenbändern** — ●JESSICA SCHNEIDER, OLIVER GLÖCKL, ULRIK L. ANDERSEN und Gerd Leuchs — Institut für Optik, Information und Photonik, Max-Planck Forschungsgruppe, Universität Erlangen-Nürnberg, Günther-Scharowsky-Str.1, 91058 Erlangen

Gequetschte Vakuumzustände sind ein wichtiger Baustein in der Quantenoptik. Wir stellen ein Experiment vor, das es ermöglicht, Vakuum Squeezing für bestimmte Seitenbandfrequenzen aus gequetschtem, hellem, gepulstem Licht mit Hilfe eines Mach-Zehnder-Interferometers zu produzieren[1].

Mit diesem Interferometer, welches zwei verschieden lange Arme besitzt, wird Vakuum Squeezing erzeugt, indem die Seitenbänder eines hellen amplitudengequetschten Strahls (entstanden in einem Faser-Sagnac-Interferometer durch Ausnutzen der Kerr-Nichtlinearität) mit denen eines Vakuumeingangs vertauscht werden. Der zweite Ausgang ist dann ein heller kohärenter Strahl. Die Quadraturlfluktuationen des gequetschten Vakuumzustands werden mit Homodyndetektion gemessen, wobei der kohärente Strahl als Lokaloszillator dient. Auf diese Weise kann die vollständige Quantentomographie eines Kerr-gequetschten Zustands erfolgen.

[1] O. Glöckl et al., Opt. Lett. **29**, 1936 (2004)

Q 3.28 Fr 11:00 Poster HU

**Independent Sources for Quantum Communication** — ●RAINER KALTENBAEK<sup>1</sup>, BIBIANE BLAUENSTEINER<sup>1</sup>, MARKUS ASPELMEYER<sup>1</sup>, and ANTON ZEILINGER<sup>1,2</sup> — <sup>1</sup>Institut für Experimentalphysik, Universität Wien — <sup>2</sup>Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften

We present a scheme for the generation of entangled pairs of photons from independent sources, a necessary ingredient for future quantum repeaters.

Q 3.29 Fr 11:00 Poster HU

**Tools for long distance quantum communications** — ●FELIX TIEFENBACHER — Institut für Experimentalphysik der Universität Wien, Boltzmannngasse 5, A-1090 Wien

To build up a real world quantum network and profit by the properties of quantum communications over long distances new tools and methods need to be developed.

A fiber-based, long distance quantum repeater requires that the fiber length inevitable fluctuations must be compensated and stabilized within the micro meter regime to get a temporal overlap at the Bell-state analyzer's beamsplitter. There, the two independent photons must be superposed within their coherence time. Thermal fluctuations of the fiber length reduce the overall fidelity of the teleportation. We present an experimental method to determine the maximally acceptable, thermally induced fiber length fluctuations for fiber based quantum teleportation in a quantum repeater configuration.

Furthermore, we present results of a feasibility study for quantum communications in space where we show that quantum communications using a satellite-based source of entangled photons with ground-based receivers is feasible with today's technology.

Q 3.30 Fr 11:00 Poster HU

**Spektrale Charakterisierung von Einzelphotonen-Quellen** — •BIBIANE BLAUENSTEINER<sup>1</sup>, ANDREAS POPPE<sup>1</sup>, MARKUS ASPELMEYER<sup>1</sup> und ANTON ZEILINGER<sup>1,2</sup> — <sup>1</sup>Institut für Experimentalphysik, Universität Wien, Boltzmanngasse 5, 1090 Wien — <sup>2</sup>Institut für Quantenoptik und Quanteninformation, Österr. Akademie der Wissenschaften, Boltzmanngasse 3, 1090 Wien

In Quantenkommunikations- und Quantenkryptographie-Experimenten, die spezielle Eigenschaften von Einzelphotonen und verschränkten Photonenpaaren nutzen, ist eine genaue Kenntnis des optischen Spektrums dieser Photonen von großer Bedeutung.

Da kommerziell erhältliche Spektrometer in diesem Bereich nicht brauchbar sind, wurde ein tragbarer fasergekoppelter Einzelphotonen-Monochromator entwickelt, der durch speziell angepasste Hard- und Software die nötige Effizienz und Auflösung besitzt und auf den spektralen Bereich des nahen Infrarots optimiert ist. Dies ist durch die Wahl der optischen Komponenten und die Verwendung von Photonen-Detektoren (basierend auf SiAPDs) möglich. Eine Auflösung von 0.21nm und eine Effizienz von 14% wurden in diesem Bereich erreicht. Der Messprozess ist weitgehend automatisiert und wird von einem PC über ein grafisches Interface gesteuert und ausgewertet.

Durch die Möglichkeit, direkt die spektrale Verteilung der Photonen (auch in Koizidenz) zu analysieren, können theoretische Voraussagen überprüft, die Quellen optimiert oder durch eine passende Wahl von Filtern die Qualität der quantenkryptographischen Anwendungen verbessert werden. Dies wurde anhand von SPDC Quellen demonstriert.

Q 3.31 Fr 11:00 Poster HU

**Functional quantum programming languages** — •WOLFGANG MAUERER<sup>1</sup>, NORBERT LÜTKENHAUS<sup>1</sup>, and VOLKER STREHL<sup>2</sup> — <sup>1</sup>University Erlangen-Nuremberg, Institute of Theoretical Physics I, Quantum Information Theory Group — <sup>2</sup>University Erlangen-Nuremberg, Institute of Computer Science 8, Artificial Intelligence

We present a functional language based on Selinger's quantum programming language[1]. It is suitable for programming universal quantum computers, has a denotational semantics, and can be used to specify and describe quantum communication problems. Especially the last point makes it unique among the small family of already existing quantum programming languages.

The denotational semantics assigns mathematically well defined meaning to all language elements and is based on partial orders of Kraus operators. It can be used to eg. prove equivalence transforms between programs. We hope that it will be an aid for security proofs of communication protocols.

We implemented a compiler for the language to explore quantum programming. In the design of the compiler, much effort has gone into making it flexible and easy to modify so that it can act as a testbed for new ideas. We use Ömer's quantum computing library[2] as backend, though other variants can be supported without too much hassle.

[1] P. Selinger, *Math. Struct. in Computer Science* 14(4):527–586, 2004.

[2] B. Ömer, *Structured Quantum Programming*, TU Vienna, 2003.

Q 3.32 Fr 11:00 Poster HU

**Die Ionenfalle als analoger Quantencomputer** — •H. SCHMITZ, A. FRIEDENAUER und T. SCHÄTZ — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Die Idee für einen Quantencomputer wurde aus der Einsicht in die Schwierigkeit klassischer Computer geboren, komplexe Quantensysteme effektiv zu beschreiben.

In dem vorgestellten Ansatz für einen „analogen“ Quantencomputer sollen Effekte in Quanten-Spin-Systemen simuliert werden – ohne den Umweg einer Übersetzung in die Sprache der „digitalen“ Gatter eines Quantenalgorithmus: Die Dynamik der mit den Ionen realisierbaren effektiven Spins wird vom selben Hamiltonian beschrieben wie z. B. Hochtemperatursupraleiter und Quantenmagnete. Anders als in Festkörpern lassen sich hier einzelne Spins individuell adressieren und auslesen, sowie die Spin-Spin-Wechselwirkung in Stärke und Reichweite über weite Bereiche variieren, an- und ausschalten. Unser experimenteller Ansatz folgt einem Vorschlag von Cirac und Porras [1]. Wir erwarten, in dieser Machbarkeitsstudie bereits an wenigen Ionen Effekte zu beobachten, die für große Teilchenzahlen Quanten-Phasenübergänge darstellen.

[1] *Phys. Rev. Lett.* 92, 207901 (2004)

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Q 3.33 Fr 11:00 Poster HU

**Scaling up Diamond Based Quantum Computing: Controlled Coupling of Single Defects** — •MICHAEL DOMHAN<sup>1</sup>, CHRISTOPHER WITTMANN<sup>1</sup>, TORSTEN GAEBEL<sup>1</sup>, IULIAN POPA<sup>1</sup>, JAN MEIJER<sup>2</sup>, BERND BURCHARD<sup>2</sup>, JAMES RABEAU<sup>3</sup>, STEVEN PRAWER<sup>3</sup>, FEDOR JELEZKO<sup>1</sup>, and JÖRG WRACHTRUP<sup>1</sup> — <sup>1</sup>3. Physikalisches Institut, Universität Stuttgart, Germany — <sup>2</sup>Experimentalphysik III, Ruhr-Universität Bochum, Germany — <sup>3</sup>University of Melbourne, Australia

Readout and manipulation of the single spin states are crucial basics for spin-based quantum information processing. As formerly shown optically detected magnetic resonance techniques can be used to investigate single paramagnetic nitrogen-vacancy (NV) defect centers in diamonds. As two-qubit operations on single NV-defect centers with neighbouring <sup>13</sup>C have already been performed, the effort will now be concentrated on controlled magnetic dipolar coupling between different NV-centers.

Dipole-dipole interaction can only be observed below distances of 10nm between two NV-centers. For obtaining this the generation of NV-defects at well defined positions close to each other is necessary. To produce interacting nitrogen-ion pairs molecular nitrogen has been implanted locally in type-IIa diamond. During annealing vacancies produced by implantation bind to implanted nitrogen pairs forming two NV centers. Our latest measurement results concerning decoherence time and observation of coupling are presented. Understanding the state evolution will allow addressing and scaling up NV based quantum computation.