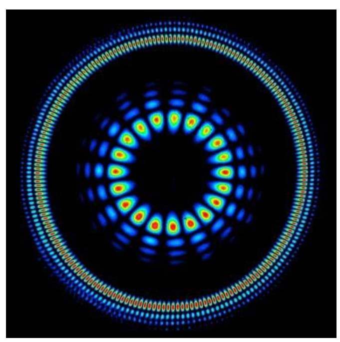
Quantum Physics of Nature

QuPoN 2015

18 – 22 May 2015

Vienna, Austria



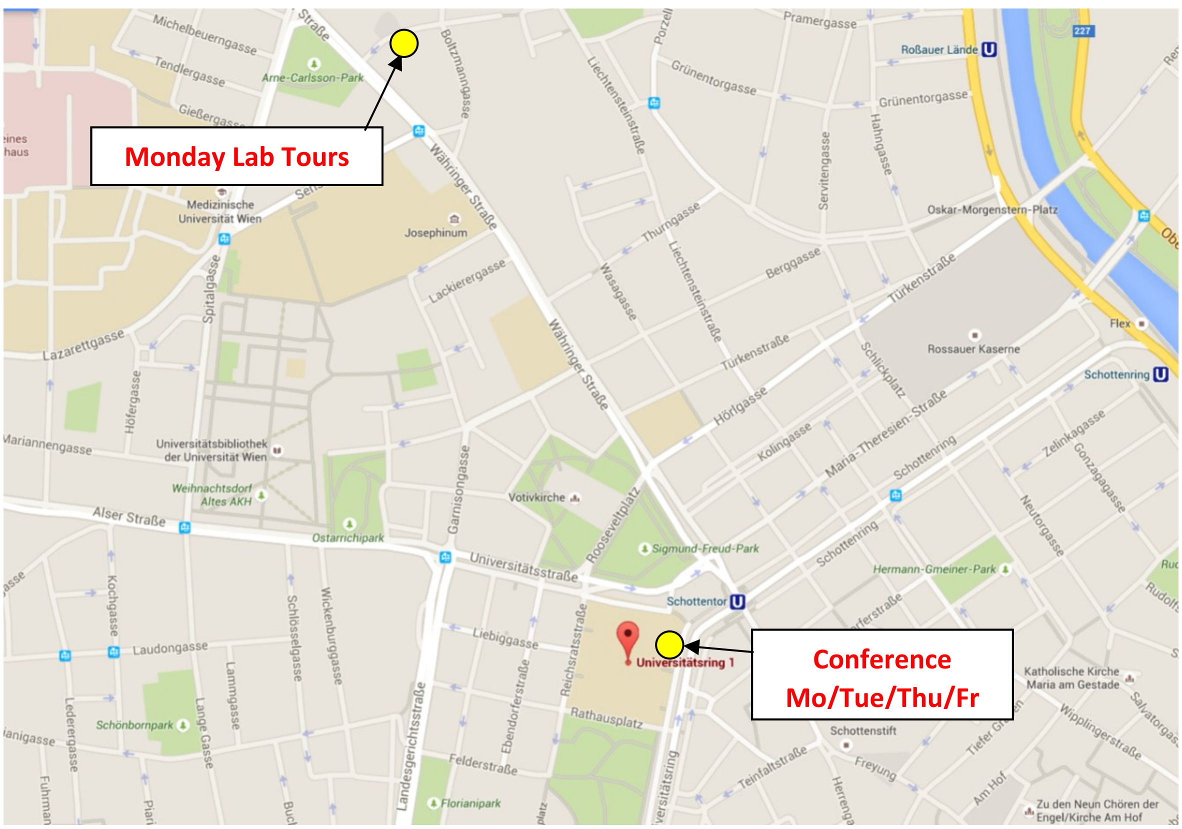
Book of Abstracts

INVITED TALKS

Monday-Friday, 18 -22 May 2015

Main Ceremonial Hall, University of Vienna, Universitätsring 1, 1010 Vienna

Sorted alphabetically by speaker name



Markus Arndt
University of Vienna, VCQ, QuNaBioS

From Quantum Football to Matter-waves of Biomolecules and Nanoparticles

The quantum superposition principle is a key factor in modern physics as well as in emergent technologies. It is also at the basis of several dualities that involve a simultaneity of explored possibilities and question our notions of space, time, reality and information. It is therefore intriguing to ask for possible experimental limits of the superposition principle.
In this talk I will sketch an experimental journey through time and Hilbert space that explores the wave-particle duality of complex things, from the world's smallest football [1] to the world's most complex particles in matter-wave interferometry today [2].
New interferometer techniques [3-5] have opened matter-wave physics to a plethora of different molecules and molecular clusters. They have made quantum interferometry a universal tool for fundamental physics [6] and metrology [7] also with massive nanoparticles [8] and biomolecular nanomatter [7,9] in the near future.

[1] M. Arndt, O. Nairz, J. Vos-Andreae, C. Keller, G. van der Zouw, A. Zeilinger, Wave-particle duality of C_{60} molecules, Nature 401, 680 (1999).

[2] S. Eibenberger, S. Gerlich, M. Arndt, M. Mayor, J. Tüxen, Matter-wave interference of particles selected from a molecular library with masses exceeding 10 000 amu, Phys. Chem. Chem. Phys. 15, 14696 (2013).

[3] S. Gerlich, L. Hackermüller, K. Hornberger, A. Stibor, H. Ulbricht, M. Gring, F. Goldfarb, T. Savas, M. Müri, M. Mayor, M. Arndt, A Kapitza-Dirac-Talbot-Lau interferometer for highly polarizable molecules, Nature Physics 3, 711 (2007).

[4] T. Juffmann, A. Milic, M. Müllneritsch, P. Asenbaum, A. Tsukernik, J. Tüxen, M. Mayor, O. Cheshnovsky, M. Arndt, Real-time single-molecule imaging of quantum interference Nature Nanotechn. 7, 297 (2012).

[5] P. Haslinger, N. Dörre, P. Geyer, J. Rodewald, S. Nimmrichter, M. Arndt, A universal matter-wave interferometer with optical ionization gratings in the time domain, Nature Physics 9, 144 (2013).

[6] M. Arndt, K. Hornberger, Insight review: Testing the limits of quantum mechanical superpositions, Nature Physics 10, 271 (2014).

[7] M. Arndt, De Broglie's meter stick: Making measurements with matter waves, Phys. Tod., 67,30 (2014).

[8] P. Asenbaum, S. Kuhn, S. Nimmrichter, U. Sezer, M. Arndt,
Cavity cooling of free silicon nanoparticles in high-vacuum, Nature Communications 4, 2743 (2013).

[9] U. Sezer, L. Wörner, J. Horak, L. Felix, J. Tüxen, C. Götz, A. Vaziri, M. Mayor, M. Arndt,
Laser-induced acoustic desorption of natural and functionalized biochromophores,
Anal. Chem. May 2015, DOI: 10.1021/acs.analchem.5b00601.

Alain Aspect
Institut d'Optique Graduate School, Palaiseau

An atomic Hong-Ou-Mandel experiment

Although it was discovered and demonstrated after the experimental evidence of Bell's inequalities violations, the Hong-Ou-Mandel effect is a conceptually simpler manifestation of two particle interference effects, impossible to describe in classical terms. Three decades after its demonstration with photons, we have observed it with pairs of He* atoms. This opens the path towards a Bell's inequalities test with mechanical observables of massive particles.

Markus Aspelmeyer
VCQ, University of Vienna

New Frontiers in Quantum Optomechanics: from levitation to gravitational quantum physics

Mechanical systems coupled to optical cavities have originally been studied from the early 1970s on in the context of gravitational wave antennas. The last few years have seen a completely new generation of nano- and micro-optomechanical devices with diverse application domains ranging from classical sensing to quantum information processing. One of the fascinating prospects of quantum optomechanics is to coherently control the motional degree of freedom of a massive object in an unprecedented parameter regime of large mass and long coherence time, hence opening up a new avenue for macroscopic quantum experiments that may even enable table-top experiments at the interface between quantum physics and gravity. In this talk I will give a brief and anecdotic review - with a somewhat Austrophilic focus - of the development and recent advancements of the field.

Victor Balykin
Institute for Spectroscopy, Troitsk

From Classical to Quantum Plasmonics: Classical Emitter and SPASER

The key advantage of plasmonics is in pushing our control of light down to the nanoscale. It is possible to envision lithographically fabricated plasmonic devices for future quantum information processing or cryptography at the nanoscale in two dimensions. A first step in this direction is a demonstration of a highly efficient plasmonics source.

Surface plasmons share fundamental properties of both their electronic and photonic features that are modified in the quantum regime. The control over the particle like part of the surface plasmons is a necessary condition for quantum transfer of information, which could lead to secure information routing along metal nanowires and plain films. One key issue is the preservation of quantum coherence of surface plasmons routing along metal nanowires or plain films. Ohmic losses and metal roughness are known to degrade the coherence of propagating surface plasmons.

Here we demonstrate nanoscale sources of optical fields: (1) from classical metallic nanoparticles emitter to (2) nanohybrids system of quantum emitter plus metallic nanoparticles with quantized plasmons – Spaser. We discuss fabrication of the nanoscale optical sources and the propagation of surface plasmons over large distances and preservation the first and second-order correlation of surface plasmons from these nanoscale emitters.

Herman Batelaan
University of Nebraska-Lincoln

Controlled double slit electron diffraction

Quantum interference explains the stability of matter, guided the construction of the laser, and led to many applications. So what is this quantum interference about? Feynman considered the double-slit experiments for electrons to contain “the only mystery”, insofar as it concerns quantum interference [1]. To get as close to Feynman's description of double-slit diffraction we closed the individual slits on demand (see figure). Following Tonomura’s famous interference build-up movie for a biprism wire [2], we also recorded a movie of the build-up of the diffraction pattern one particle at a time for the double slit [3].
In recent work done in Paris, macroscopic particle-wave duality with bouncing oil droplets was demonstrated for a double slit [4]. This was supposed not to be possible. What does that mean for microscopic or quantum-mechanical particle-wave duality for electrons? This means a lot to an international group of physicists labeled to be a “band of rebels” according to Morgan Freeman’s show “Through the Wormhole” [5]. However this appears not to be the message presented in the past three years to many high school students through our educational movie “The Challenge of Quantum Reality” [6]. In the presentation this issue will be discussed.

[1] Feynman, R., Leighton, R. B. & Sands, M. L. Quantum Mechanics, vol. 3 (Addison Wesley, 1965).

[2] Demonstration of single-electron buildup of an interference pattern. Tonomura, A., Endo, J., Matsuda, T., Kawasaki, T. & Ezawa, H. Am. J. Phys. 57, 117 (1989).

[3] Controlled double-slit electron diffraction. R. Bach, D. Pope, S. H. Liou, H. Batelaan, Roger Bach et al., New J. Phys. 15 033018 (2013).

[4] Single-particle diffraction and interference at a macroscopic scale. Couder, Y. & Fort, E. Phys. Rev. Lett. 97, 154101 (2006).

[5] “How Does the UniverseWork". Through the Wormhole, With Morgan Freeman. Science Channel. 13 July 2011. Television.

[6] “The Challenge of Quantum Reality“, www.perimeterinstitute.ca/outreach/teachers/class-kits/challenge-quantum-reality, http://www.youtube.com/watch?v=wihrAjFXg3o

Charles H. Bennett
IBM Research Division

Boltzmann's Brain and Wigner's Friend

Modern cosmology has given new urgency to some early 20th century puzzles that had seemed to be more in the realm of unanswerable philosophy than science: the Boltzmann's brain problem of whether we might be merely a rare statistical fluctuation in an old dead universe, rather than inhabitants of a thriving young one, and the Wigner's friend problem, of what it feels like to be inside an unobserved quantum superposition. Though dynamical considerations, such as the form of the Hamiltonian, are needed get definitions of classicality off the ground by identifying subsystems, we attempt to proceed statically thereafter, defining classicality, complexity, and observership as properties of (some) quantum states. We regard classicality as a prerequisite for complexity, and complexity as a prerequisite for observers. We use the quantum Darwinism approach to define classicality via redundant correlations, and the logical depth approach to define complexity as the presence of internal classical evidence of a nontrivial causal history. In this talk we propose to continue in that direction and define observership as a static property, representing not consciousness, but internal classical evidence of scientific activity, i.e. of a more or less successful effort by the system to understand or explain its own plausible causal history.

Stefan Bernet
Medical University of Innsbruck

Light field control with "thick" spatial light modulators and diffractive optical elements

Liquid Crystal Spatial light modulators (LC-SLMs) allow for phase modulation of a reflected light wave with high spatial resolution, which, e.g., can be used to project complex holograms. Modern LC-SLMs additionally allow to modulate the reflected phase front by several multiples of a wavelength. These "thick" phase patterns have similar properties as volume holograms, showing wavelength and angular selectivity when reconstructed. Applications range from color hologram projection to wavelength-multiplexed optical traps and spatial light filtering in microscopy.

Another implementation of "thick" phase patterns is demonstrated by combining a pair of specially designed diffractive optical elements (DOEs). The joint element has adjustable optical properties which can be controlled by a mutual rotation of the elements. Experimentally realized optical elements are diffractive lenses with a widely tunable focal length, and spiral phase plates which can produce doughnut beams with an adjustable helical charge.

Rainer Blatt
University of Innsbruck & IQOQI Innsbruck

Quantum Information Science with Trapped Ca+ Ions

In this talk, the basic tool box of the Innsbruck quantum information processor based on a string of trapped Ca+ ions will be reviewed. For quantum information science, the toolbox operations are used to encode one logical qubit in entangled states distributed over seven trapped-ion qubits. We demonstrate the capability of the code to detect one bit flip, phase flip or a combined error of both, regardless on which of the qubits they occur. Furthermore, we apply combinations of the entire set of logical single-qubit Clifford gates on the encoded qubit to explore its computational capabilities. The quantum toolbox is further applied to carry out both analog and digital quantum simulations. The basic simulation procedure will be presented and its application will be discussed for a variety of spin Hamiltonians. Finally, the quantum toolbox is applied to investigate the propagation of entanglement in a quantum many-body system represented by long chains of trapped-ion qubits. Using the ability to tune the interaction range in our system, information propagation is observed in an experimental regime where the effective lightcone picture does not apply. These results will enable experimental studies of a range of quantum phenomena, including transport, thermalization, localization and entanglement growth, and represent a first step towards a new quantum-optic regime of engineered quasiparticles with tunable nonlinear interactions.

Dirk Bouwmeester
University of Leiden

Knots of light, gravitational radiation, and plasma

The Maxwell equations in vacuum are invariant under conformal transformations. This allows for the construction of topologically nontrivial solutions of light. The most elementary of such solutions is based on the Hopf map and leads to electric field lines and magnetic fields lines that are all circles that lie on nested toroidal surfaces. Each E (B) field circle is linked once with every other circle. We show how this concept can be generalized, quantized, and expanded to include also gravitational radiation. Furthermore we show how the linked structures of the magnetic field can form the skeleton of realistic plasma configuration. Using Full MHD simulations we present a self-confining plasma knot

Caslav Brukner
Quantenoptik, Quantennanophysik und Quanteninformation

Reconstructions of quantum theory: pros and contras

In recent years, several reconstructions of quantum theory — derivations of the theory from a small set of axioms — have been proposed. A frequent response to these schemes is that such reconstructions are devoid of ontological commitments. The critics often argue that reconstructions deduce quantum theory “only” at the operational level, i.e. in terms of the primitive operations an observer conducts in a laboratory, and that nothing can be generally concluded from them about the status of the notion of physical reality. It seems to me that the critics frequently underestimate the success of the reconstructions. The point of such approaches is that the very idea of quantum states as representatives of information — information that is sufficient for computing probabilities of outcomes following specified preparations — has the power to explain why the theory has the very mathematical structure it does. This in itself contains an important message. Using the examples of the “subspace axiom” and the “purification axiom”, I will argue that reconstructions provide us with new insights into lasting debates about violations of Bell’s inequalities and the Wigner-friend thought experiment, respectively.

Artur Ekert
Oxford University

The ultimate physical limits of privacy for the paranoid ones

Among those who make a living from the science of secrecy, worry and paranoia are just signs of professionalism. Can we protect our secrets against those who wield superior technological powers? Can we trust those who provide us with tools for protection? Can we even trust ourselves, our own freedom of choice? Recent studies in quantum randomness and cryptography show that some of these questions can be addressed and discussed in precise and operational terms, suggesting that privacy is indeed possible under surprisingly weak assumptions.

Nicolas Gisin
Group of Applied Physics, University of Geneva

Spins, Magnets, PR-boxes and Weak Measurements

Quantum theory describes classical measurements as weak measurement, i.e. measurements that barely disturb the system at the cost of providing only little information. An example is the measurement of the direction in which a magnet points: this doesn't "collapse" the spins that make-up the magnet while providing good enough-but-not-complete information on the magnet direction. This raises several questions:
Could weak measurements characterize "classicality"? If Alice and Bob share N singlets and Alice measures (strongly) all her spins along a direction of her choice, this prepares all Bob's N spins parallel or anti-parallel to that direction. The fluctuation of the order $\sqrt{N}$ can be arbitrarily large. Why can't Bob deduce from such a large magnetic moment the direction chosen by Alice?
If Alice and Bob share a single singlet, can Bob make a measurement weak enough that the disturbed state still contains quantum nonlocality, but at the same time strong enough that his data violate the CHSH-Bell inequality with Alice's data? How long can a chain of independent Bobs be such that each Bob violates the CHSH-Bell inequality with Alice?
Can the concept of weak measurements be generalized to one PR-box? Or at least to large ensembles of PR-boxes? If not, can PR-boxes still be considered as plausible physical models.

Philippe Grangier
Institut d'Optique / CNRS

Contexts, Systems and Modalities: a new ontology for quantum mechanics

We propose a way [1] to make usual quantum mechanics fully compatible with physical realism, defined as the statement that the goal of physics is to study entities of the natural world, existing independently from any particular observer's perception, and obeying universal and intelligible rules. Rather than elaborating on the quantum formalism itself, we propose to modify the quantum ontology, by requiring that physical properties are attributed jointly to the system, and to the context in which it is embedded. In combination with a quantization principle, this non-classical definition of physical reality sheds new light on counter-intuitive features of quantum mechanics such as the origin of probabilities, non-locality, and the quantum-classical boundary.

[1] Alexia Auffèves and Philippe Grangier, http://arxiv.org/abs/1409.2120

Rudolf Grimm
Universität Innsbruck / IQOQI Innsbruck

Atom interferometry in a Fermi sea

Simon Gröblacher
Kavli Institute of Nanoscience, Delft University of Technology

Quantum experiments: from small to large

We will review quantum experiments that we have performed over the past 10 years, ranging from very small photonic quantum systems to large, massive optomechanical devices. An outlook of possible experiments designed to test the very foundations of quantum physics will be given.

Serge Haroche
College de France, Paris

Dipole-dipole interactions in a cold Rydberg atom gas explored by microwave spectroscopy

The strong dipole-dipole interaction between cold Rydberg atoms is the object of intense theoretical and experimental interest, since it opens exciting perspectives for the study of a wide range of collective quantum phenomena. The resonant laser excitation of a dense sample of cold atoms into Rydberg states leads to the observation of the dipole blockade effect, a single Rydberg atom preventing the excitation of other atoms within a several microns “Rydberg blockade radius” in its neighbourhood. On the contrary, non-resonant laser excitation results in the preparation of “seed” Rydberg atoms around which other excited atoms form clusters, with interatomic distances smaller than the Rydberg blockade radius. We perform experiments in which these Rydberg structures are created in an ultra-cold atomic gas trapped on a superconducting atom chip. Microwave spectroscopy of the excited atomic gas directly reveals the dipole-dipole many-body interaction energy spectrum and provides information about the interatomic distances within the Rydberg sample. By analysing how this spectrum depends upon the delay between the atomic excitation and the microwave probing, we observe the expansion of the Rydberg cloud under the effect of repulsive van der Waals forces, in a regime where the frozen gas approximation breaks down. This work opens promising routes for the quantum simulation of many-body systems, including the transport of quantum information in chains of strongly interacting Rydberg atoms.

Stefan W. Hell
Max Planck Institute for Biophysical Chemistry, Göttingen & German Cancer Research Center (DKFZ), Heidelberg

Optical microscopy: the resolution revolution

Throughout the 20th century it was widely accepted that a light microscope relying on conventional optical lenses cannot discern details that are much finer than about half the wavelength of light (200-400 nm), due to diffraction. However, in the 1990s, the viability to overcome the diffraction barrier was realized and microscopy concepts defined, that can resolve fluorescent features down to molecular dimensions. In this lecture, I will discuss the simple yet powerful principles that allow neutralizing the limiting role of diffraction[1,2]. In a nutshell, feature molecules residing closer than the diffraction barrier are transferred to different (quantum) states, usually a bright fluorescent state and a dark state, so that they become discernible for a brief period of detection. Thus, the resolution-limiting role of diffraction is overcome, and the interior of transparent samples, such as living cells and tissues, can be imaged at the nanoscale.

[1] Hell, S.W. Far-Field Optical Nanoscopy. *Science* **316**, 1153-1158 (2007).
[2] Hell, S.W. Microscopy and its focal switch. *Nature Methods* **6**, 24-32 (2009).

Thomas Jennewein
Institute for Quantum Computing and Department of Physics and Astronomy, University of Waterloo

Testing quantum correlations of three entangled photons generated in cascaded parametric down-conversion

Non-classical states of light are of fundamental importance for emerging quantum technologies. All optics experiments producing multi-qubit entangled states have until now relied on outcome post-selection, a procedure where only the measurement results corresponding to the desired state are considered. This method severely limits the usefulness of the resulting entangled states. Here, we show the direct production of polarization-entangled photon triplets in a Greenberger-Horn-Zeilinger (GHZ) state [1], by cascading two entangled down-conversion processes[2]. First, a Sagnac source [3] produces non-degenerate entangled photon pairs at 776 nm and 842 nm in a Bell state. The 776 nm photon is sent through a polarizing Mach-Zehnder interferometer with a down-conversion crystal in each arm. If it is downconverted, a photon pair is created in modes 2 and 3 with a polarization state depending on the pump photon. The photon triplets ends up in the GHZ-state:
Detecting the triplets with high-efficiency superconducting nanowire single-photon detectors allows us to fully characterize them through quantum state tomography. We use our three-photon entangled state to demonstrate the ability to herald Bell states, a task that was not possible with previous three-photon states, and test local realism by violating the Mermin and Svetlichny inequalities. These results represent a significant breakthrough for entangled multi-photon state production by eliminating the constraints of outcome post-selection, providing a novel resource for optical quantum information processing.

[1] D. M. Greenberger, M. A. Horne, A. Shimony, and A. Zeilinger. Bell's theorem without inequalities. Am. J. Phys., 58(12):1131–1143, 1990.

[2] Deny R. Hamel, Lynden K. Shalm, Hannes Huebel, Aaron J. Miller, Francesco Marsili, Varun B. Verma, Richard P. Mirin, SaeWoo Nam, Kevin J. Resch, and Thomas Jennewein. Direct generation of three-photon polarization entanglement. NATURE PHOTONICS, 8(10), Oct 2014.

[3] Taehyun Kim, Marco Fiorentino, and Franco N. C. Wong. Phase-stable source of polarization-entangled photons using a polarization sagnac interferometer. Physical Review A (Atomic, Molecular, and Optical Physics), 73(1):012316, 2006.

Tony Klein
University of Melbourne

Some early experiments in neutron optics presented in honour of Anton Zeilinger

Several experiments in neutron optics, involving Fresnel Diffraction and Interferometry, were carried out in the 1970’s and 80’s by the Melbourne Group, with significant input by Anton Zeilinger. They are reviewed here and their implications for the foundations of Quantum Mechanics are highlighted.

Johannes Kofler
Max Planck Institute of Quantum Optics (MPQ)

Requirements for a loophole-free Bell test using imperfect setting generators

Experimental violations of Bell inequalities are in general vulnerable to so-called “loopholes.” A loophole-free Bell test, closing all major loopholes simultaneously in a single experiment, is still an outstanding goal in the community. In this talk, the characteristics of a definitive Bell test are analyzed, closing simultaneously the locality, freedom-of-choice, fair-sampling (i.e. detection), coincidence-time, and memory loophole. Particular focus will lie on non-ideal random number generators for the setting choices, whose finite autocorrelation allows a certain amount of predictability. I will discuss a necessary adaptation of the CH/Eberhard inequality bound when using such imperfect devices, the role of bias in the setting choices, and – using Hoeffding's inequality and Doob's optional stopping theorem – the run time for a statistically significant Bell test. (This talk is based on J. Kofler and M. Giustina, arxiv:1411.4787.)

Paul Kwiat
University of Illinois

Superdense Teleportation Using Hyperentangled Photons

The transfer of quantum information over long distances has long been a goal of quantum information science. Loss and random fluctuations are particularly devastating to quantum communication channels, as quantum states cannot be amplified and error correction protocols are presently very difficult to implement. Here we describe our experiments using photon pairs hyperentangled in polarization and orbital angular momentum to implement a novel entanglement-enhanced quantum state communication technique, known as SuperDense Teleportation (SDT), to transmit quantum information between remote parties with reduced resources and simplified measurements, compared to quantum teleportation and remote state preparation. Specifically, two-party maximally entangled states of the for m ($|00\rangle + |11\rangle + |22\rangle + |33\rangle$) are used to teleport the n phases of the unimodular state ($|0\rangle + e^{i\phi 1}|1\rangle + e^{i\phi 2}|2\rangle + e^{i\phi 3}|3\rangle$) with only $\log_2(n)$ bits of classical information (less than the classical information required to teleport a similar number of continuous parameters).

To implement such four-dimensional SDT, we have constructed an experimental setup that uses photons hyperentangled in polarization and orbital angular momentum. One photon of the hyperentangled state is sent to Bob while the other is given to the sender, who controls the inter-term phases using liquid crystals. The classical results of a measurement on the sender's photon are sent to Bob, who can use them to convert his photon into the desired state, in principle with 100% efficiency and accuracy. In our experiment the average fidelity over all the measured teleported states was 87.0±0.1 %, approximately twice the 44% average fidelity expected for classical teleportation of a such a unimodular ququart state. To our knowledge this is the largest reported improvement for a non-probabilistic entanglement-enhanced state communication technique over its corresponding classical counterpart. Despite the success of our proof-of-principle demonstration, the actual implementation would be unsuitable for any practical application – the spatial mode encoding is simply too susceptible to disruption by turbulence. Thus, we are now implementing a realization using polarization and time-bin entanglement, which may enable space-to-Earth superdense teleportation.

Nathan Langford
QuTech and Kavli Institute of Nanoscience, Delft University of Technology

Digital quantum simulation of the ultrastrongly coupled Rabi model in a circuit QED system

The Rabi model of an electric dipole coupling with an electromagnetic field mode is one of the most successful and widely applicable descriptions of quantum light-matter interactions in nature. Rapid progress in cavity QED has seen strong, single-excitation interactions achieved in diverse systems, including atoms and ions in optical and microwave Fabry-Perot cavities, and microfabricated artificial atoms in 2D and 3D gigahertz resonators. But while couplings have increased beyond system linewidths, they typically remain only a small fraction of the natural system frequencies. In this regime, the Rabi interaction reduces via a rotating-wave approximation to the simpler, extensively studied Jaynes-Cummings model. Phenomena like quantum phase transitions often only occur in the regime where the rotating-wave approximation breaks down, but it is experimentally very challenging to produce interactions in this ultrastrong coupling regime, where they are comparable with field and atom frequencies.

Extending a proposal by Mezzacapo et al., we combine digital and analog quantum simulation approaches to study the full Rabi model, beyond the rotating-wave approximation, in a superconducting circuit QED architecture limited to the Jaynes-Cummings regime. We carry out detailed modelling, with realistic experimental considerations, to determine feasible operating parameters and on-chip design using transmons and 2D coplanar microwave waveguide resonators. Using the Wigner function of the conditional cavity state, we show that onset of Schroedinger "cat"-like entanglement generation between the atom and the cavity state provides a signature for crossing into the ultrastrong coupling regime. Finally, we report on the current status of our experiments implementing a transmon-based design allowing independent qubit and cavity preparation and readout.

[1] A. Mezzacapo, U. Las Heras, J. S. Pedernales, L. DiCarlo, E. Solano & L. Lamata, Sci. Rep. 4, 7482 (2014).

Mikhail Lukin
Harvard University

New interface between quantum optics and nanoscience

We will discuss recent developments at a new scientific interface between quantum optics and nanoscience. Specific examples include the use of quantum optical techniques for manipulation of individual atom-like impurities at a nanoscale and for realization of hybrid systems combining quantum emitters and nanophotonic devices. We will discuss how these techniques are used for realization of quantum nonlinear optics and quantum networks, and for new applications such as magnetic resonance imaging with single atom resolution, and nanoscale sensing in biology and material science.

Gabriel Molina-Terriza
Macquarie University

Controlling the interaction of photons with nanostructures

In this talk I will review some of our recent findings on the use of the angular momentum and the helicity of light in the fields of quantum optics and nanophotonics. In my group we are exploiting the quantum correlations, polarization and spatial properties of photons in order to control the interaction of light with structures smaller than the wavelength of the electromagnetic field used.

Some of our recent experimental results include the control over the temporal correlations of biphoton states by projecting the photons into modes with different angular momentum content. We have shown that we can switch the temporal correlations from bunching to anti-bunching by exploiting the spatiotemporal correlations inherent in parametric down-conversion processes.

The temporal control of photons is very important when interacting with nanostructures, as it is controlling their angular momentum and helicity properties. We have observed that the transmission of light through small circular apertures or the scattering of light from dielectric spheres depends critically on these parameters. In particular, we can change the transmission through a nanohole by two orders of magnitude by switching the circular polarization of the input mode. This relies on the fact that different input modes will induce different multipolar moments on the nanostructure. This allows us a pathway to control the localized modes of the nanostructures. When using multiphoton entangled states, this has enormous consequences on the kind of interaction that can be achieved and the resulting multiphoton state.

Markus Oberthaler
Kirchhoff Institut für Physik, University of Heidelberg

Entanglement in mesoscopic atomic systems

The detection of entanglement in many particle systems is still a big challenge since standard techniques like state tomography fail. Additionally the bottom-up approach building many particle entangled states by entangling individual qubits has its limitation in reaching the regime of few hundreds of entangled particles. With the advent of weakly interacting Bose Einstein condensates a new experimental system has become available which provides strong enough interaction that many particle quantum correlations can be generated as well as the possibility to detect single atoms one by one for state analysis.

In this presentation I will shortly summarize what have been the achievements in the last years in the field of quantum atom optics. This will range from the generation of one mode squeezed states [1], two mode squeezed states [2] and non-Gaussian entangled states [3]. Special emphasize will be given to the question how entanglement is detected in these systems revealing that interferometry is one of the main routes for giving bounds on the entanglement present. Thus, there is a very direct connection to quantum metrology which allows for parameter estimation beyond classical statistical limits given useful entanglement has been generated and can exploited by the available detection schemes.

[1] Nonlinear atom interferometer surpasses classical precision limit, C. Gross, T. Zibold, E. Nicklas, J. Esteve and M. K. Oberthaler, Nature 464, 1165 (2010).

[2] Atomic homodyne detection of continuous variable entangled twin-atom states, C. Gross, H. Strobel, E. Nicklas, T. Zibold, N. Bar-Gill, G. Kurizki and M.K. Oberthaler, Nature 480, 219 (2011).

[3] Fisher information and entanglement of non-Gaussian spin states , H. Strobel, W. Muessel, D. Linnemann, T. Zibold, D. Hume, L. Pezzé, A. Smerzi, and M. K. Oberthaler, Science, 345, 424, (2014)

Jian-wei Pan
University of Science and Technology of China

Scalable quantum information processing with photons and atoms

Over the past three decades, the promises of super-fast quantum computing and secure quantum cryptography have spurred a world-wide interest in quantum information, generating fascinating quantum technologies for coherent manipulation of individual quantum systems. However, the distance of fiber-based quantum communications is limited due to intrinsic fiber loss and decreasing of entanglement quality. Moreover, probabilistic single-photon source and entanglement source demand exponentially increased overheads for scalable quantum information processing. To overcome these problems, we are taking two paths in parallel: quantum repeaters and through satellite. We used the decoy-state QKD protocol to close the loophole of imperfect photon source, and used the measurement-device-independent QKD protocol to close the loophole of imperfect photon detectors—two main loopholes in quantum cryptograph. Based on these techniques, we are now building world's biggest quantum secure communication backbone, from Beijing to Shanghai, with a distance exceeding 2000 km. Meanwhile, we are developing practically useful quantum repeaters that combine entanglement swapping, entanglement purification, and quantum memory for the ultra-long distance quantum communication. The second line is satellite-based global quantum communication, taking advantage of the negligible photon loss and decoherence in the atmosphere. We realized teleportation nd entanglement distribution over 100 km, and later on a rapidly moving platform. We are also making efforts toward the generation of multiphoton entanglement and its use in teleportation of multiple properties of a single quantum particle, topological error correction, robust Schrodinger cat state, quantum algorithms for solving systems of linear equations and machine learning. Finally, I will talk about our recent experiments on quantum simulations on ultracold atoms.

Ernst Rasel
Leibniz University Hannover

Quantum Gravimetry

The pioneering work of Anton Zeilinger on diffracting de-Broglie-waves with standing light waves challenged the atomic sources available at that time. Today, matter wave interferometers employing Bose-Einstein condensates and Delta-Kick collimation pave the way for employing crystals of light for long baseline interferometry. They open new prospectives for tests of the Einstein principle of equivalence (EP) as well as for gravity monitoring. We have been performing the first quantum test of the EP employing synchronous matter wave interferometry with two different atomic species. The use of ultracold atoms allows to enhance the precision and accuracy of these measurements by reducing systematic errors and by extending the time of free fall of the atoms. While on ground long free-fall times require large baseline interferometers due to gravity, these tests can be performed without the strong bias of gravity in space or in microgravity. We follow both strategies to close the sensitivity gap between ground and future space based experiments. Novel robust and compact atomic sources provide the means for realising mobile BEC interferometers. We achieved a compact high-flux atom-chip based BEC source and demonstrate the first chip-based quantum gravimeter, which will allow further miniaturisation and improved performance of these devices for continuous absolute gravity measurements.

Helmut Rauch
Atominstitut, Vienna University of Technology

Anton: his time as neutron scientist

Anton Zeilinger started his career at the Atominstitut of the Austrian Universities at a 100 kW (later 250 kW) reactor where scientists could freely decide which experiments they wanted to do and how to do them. Bertram Brookhouse`s and Cliff Shull`s experiments were well known at the time and then we also had same input from Maier-Leibnitz’ group in Munich where an interesting programme on neutron optics experiments was pursued. The rather low intensity of our reactor made it necessary to avoid triple axis spectroscopy and to stay with elastic scattering processes. Thus, a polarized neutron instrument to perform neutron depolarization experiments was installed. In January 1974 we could operate the first perfect crystal neutron interferometer. This motivated Anton to join the interferometer group where he becomes involved in the experiment to verify the 4π symmetry of spinor wave functions. This has been demonstrated in 1975 at our Dortmund-Vienna interferometer set-up at the high flux reactor in Grenoble. Furthermore, he contributed to various spin-superposition experiments and neutron radiographic inspection work. After that Anton spent sabbatical years with Cliff Shull at MIT and he performed basic neutron optics experiments at an optical bench together with Roland Gähler at the ILL in Grenoble. They verified standard optical phenomena like single slit, double slit, edge and Fresnel diffraction and used dynamical diffraction phenomena to identify effective mass effects and coherence features with neutron beams.

Terry Rudolph
Imperial College London

How Einstein and/or Schroedinger should have discovered Bell's Theorem in 1936

I will discuss how one can be led to Bell's Theorem from considerations of quantum steering (in the sense of Schroedinger and Einstein, i.e. not EPR-steering). We begin with Einstein's demonstration that, assuming local realism, quantum states must be in a many-to-one ("incomplete") relationship with the real physical states of the system. We then consider some simple constraints that local realism imposes on any such incomplete model of physical reality, and show they are not satisfiable. In particular, we present a very simple demonstration for the absence of a local hidden variable incomplete description of nature by steering to two ensembles, one of which contains a pair of non-orthogonal states. Historically this is not how Bell's theorem arose - there are slight and subtle differences in the arguments - but it could have been.

Kaoru Sanaka
Department of Physics, Faculty of Science, Tokyo University of Science

Tokyo, Vienna, Stanford and Now

Kaoru Sanaka presents a summary talk about experimental works of his graduate dates at Tokyo, and post doctoral terms at Vienna, and Research associate term at Stanford. The main subject at Tokyo and Vienna was the photon-photon interaction experiments using parametric down-conversion and photon counting methods. At Stanford, semiconductor nanodevices were introduced to demonstrate an integrated single-photon source and quantum two-photon interference.

Jörg Schmiedmayer
Vienna Center for Quantum Science and Technology (VCQ), Atominstitut, TU-Wien

Does an isolated many body quantum system relax?

Interfering two isolated one-dimensional quantum gases we study how the coherence created between the two many body systems by the splitting process slowly degrades by coupling to the many internal degrees of freedom available [1]. Two distinct regimes are clearly visible: for short length scales the system is characterized by spin diffusion, for long length scales by spin decay [2]. For a sudden quench the system approaches a pre-thermalized state [3], which is characterized by thermal like correlation functions in the observed interference fringes with an effective temperature over five times lower than the kinetic temperature of the initial system. A detailed study of the time evolution of the correlation functions reveals that these thermal-like properties emerge locally in their final form and propagate through the system in a light-cone-like evolution [4]. Furthermore we demonstrate, that the pre-thermalized state is described by a generalized Gibbs ensemble [5]. This is verified through a detailed study of the full non-translation invariant phase correlation functions up to 10th order. Finally we show two distinct ways for subsequent evolution away from the pre-thermalized state. One proceeds by further de-phasing, the other by higher order phonon scattering processes. In both cases the final state is indistinguishable from a thermally relaxed state. We conjecture that our experiments points to a universal way through which relaxation in isolated many body quantum systems proceeds if the low energy dynamics is dominated by long lived excitations (quasi particles).
Supported by the Wittgenstein Prize, the Austrian Science Foundation (FWF) SFB FoQuS: F40-P10 and the EU through the ERC-AdG QuantumRelax

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Rupert Ursin
IQOQI - Vienna

Experiments with quantum entanglement in space

It is an open issue whether quantum laws, originally established to describe nature at the microscopic level of atoms, are also valid in the macroscopic domain on distances accessible in space. Some proposals predict that quantum entanglement is limited to certain mass and length scales or altered under specific gravitational circumstances. Testing the quantum correlations over distances achievable with systems placed in the Earth orbit or even beyond would allow to verify both the validity of quantum physics and the preservation of entanglement over distances impossible to achieve on ground. Another area of applications is in metrology, where quantum clock synchronization and quantum positioning are studied. We proposed to the European Space Agency (ESA to perform a ground-to-space quantum communication tests from the International Space Station (ISS) orbiting at a height of approximately 400 km as well as to mini-satellites. We present the proposed experiments in space as well as the design of a space based quantum communication payload and the feasibility experiments performed on the Canary Islands over a 144 km link. Additionally we will present the ongoing R&D activities performed in a consortium consisting of partners from academia as well as from industry.

Alipasha Vaziri
Institute for Molecular Pathology (IMP) & University of Vienna

Towards a dynamic map of neuronal circuits

Knowledge on structural connectivity in neuronal circuits is necessary for understanding information representation and processing in local circuits. However, as some examples of well-characterized neuronal architectures illustrate, structural connectivity alone it is not sufficient to predict how input stimuli are mapped onto activity patterns of neuronal populations and how the collective dynamics of all neurons in the network leads to behavior. Addressing this challenge has been hampered by lack of appropriate tools and methods that allow parallel and spatiotemporally specific application of excitation patterns onto neuronal populations while capturing the dynamic activity of the entire network at high spatial and temporal resolution. The combination of new optical excitation techniques, optogenetics and high speed functional imaging are providing new opportunities to address this question and move towards a dynamic map of neuronal circuits.

I will address a number advances in that respect that we have recently implemented in our lab using two different technologies. One approach relies on “sculpting” the excitation volumes in biological samples using non linear optics and the other relies on light field imaging, a tomography type approach for simultaneous readout of neuronal activity in 3D. Using these techniques we have recently shown brain-wide functional imaging of entire nervous systems at single cell resolution. Further, we demonstrate intrinsically simultaneous volumetric Ca-imaging in the entire brain of larval zebrafish during sensory stimulation. We are able to track the activity of 5000 neurons distributed throughout the brain at 20Hz volume rate. The simplicity of this technique and the possibility of the integration into conventional microscopes make it an attractive tool for high-speed volumetric functional-imaging. These tools combined with high speed optogenetic control of neuronal circuits, advanced statistics tools and mathematical modeling and will be crucial to move from an anatomical wiring map towards a dynamic map of neuronal circuits.

Julian Voss-Andreae

Portland Oregon

Sculptures inspired by Physics, Proteins, and People

Julian Voss-Andreae will present about his sculptures, often inspired by his background in physics and his interest in protein structure. He did his graduate work in Anton Zeilinger's lab with Markus Arndt, participating in the buckyball diffraction experiment of 1999. Julian's sculpture, heavily influenced by his background in science, has captured the attention of multiple news media, museums and collectors in the U.S. and abroad. Recent institutional commissions include large-scale outdoor sculptures for the new Physics and Nanotech Building of the University of Minnesota, Rutgers University (New Jersey), and Texas Tech University.

Ian Walmsley

Oxford University

A la recherche du clair perdu: quantum memories for the real world

I will discuss progress toward operational quantum memories for arbitrary quantum states of light, from single photons to complex multi-photon states. Ensembles of absorbers that each have internal optical transitions accessing a metastable state enable a broadband, fully reversible memory for quantum light by means of controlled Raman scattering. The essential performance parameters of such memories include efficiency, bandwidth, time-bandwidth product, lifetime and storage and retrieval noise. The current status and prospects for a room-temperature, GHz-bandwidth quantum memory suitable for applications from network synchronisation to long-distance quantum repeaters based on atomic gases in ambient conditions will be presented.

Philip Walther

VCQ, University of Vienna

Photonic Quantum Computation and Quantum Simulation

The advantages of the photons makes optical quantum system ideally suited for a variety of applications in quantum information processing. Here I will discuss new experimental insights into resource-efficient intermediate quantum computing utilizing the Bosonic nature of photons, and the quantum simulation of two interacting spins, as well as new quantum computational concepts that superimpose the order of quantum gates.

Gregor Weihs

Universität Innsbruck

Photon Sources and the Foundations of Quantum Mechanics

Sources of quantum states of light power applications in quantum information and communication and they enable experimental tests of the foundations of quantum mechanics. I will present our work on semiconductor sources of nonclassical light, which is one the one hand based on single self-assembled quantum dots for the realization of extremely clean single photons and single entangled photon pairs and on the other hand on nonlinear optics in semiconductor waveguides, which targets an integrated room-temperature electrically pumped source of entangled photon pairs.

As an application, I will discuss our multipath interferometric tests for possible generalizations of quantum mechanics. These could results in higher order interference or other deviations that are experimentally testable. Our most recent realizations of these interferometers are based on laser-written glass waveguides, where we achieve excellent visibility and stability.

Harald Weinfurter

Faculty of Physics, LMU Munich

Verschränkt - not only entangled

Enconters, from neutrons to photons to atoms, from interference to entanglement, from HOM to BSA to GHZ to Bell.

David Wineland

NIST, Boulder Colorado

Exploring quantum with trapped ions

As a group, we live in an exciting time where we can explore some of the foundational issues in quantum mechanics and also look forward to possible applications of the techniques we develop. In this talk, I will try to highlight a few trapped-ion experiments in the general area of quantum information and quantum-limited measurements that enable us to investigate both of these areas.

Peter Zoller
Institute for Theoretical Physics, University of Innsbruck / IQOQI Austrian Academy of Science

Quantum Optics of Chiral Networks with Atoms, Photons and Spins

We study driven-dissipative dynamics of two-level atoms (spin-½ systems) coupled to (infinite) chiral 1D bosonic waveguides. By chiral coupling we mean an asymmetric coupling of the atomic decay to the left and right propagating guided modes. We formulate a quantum optical master equation treatment for this non-equilibrium dynamics eliminating the wave guide as a reservoir. Remarkably, our master equation predicts steady states in form of pure states consisting of quantum dimers between pairs of two level systems. Our model has a natural realization with atoms coupled to nanofibers or nanostructures. In addition, we propose a realization, where the 1D wave guides are represented by spin-chains with dipolar couplings, where the spin-chain is terminated by a spin - optics transducer, converting the spin excitations to optical photons. This points towards a novel quantum optics with spin-excitations (magnons). As specific examples we discuss realizations with a chain of trapped ions and polar molecules. Finally, our spin-chain formulation of quantum optics also leads to a new theoretical framework for quantum optics, where modern quantum many-body techniques are applied to efficiently compute non-Markovian system-reservoir dynamics.

*) Work performed in collaboration with H. Pichler, T. Ramos, B. Vermersch, P. Hauke, and H. Tercas (Innsbruck), and M. Lukin’s group at Harvard.

Marek Zukowski
University of Gdansk, Inst. Theor. Phys. and Astorphysics

Swapping Entanglement with Quanton

In this very short talk I shall try give my personal account on the development of ideas which led to a series of three “Innsbruck” papers on entanglement swapping (1993-1997), which gave operational methods to engineer multiphoton entanglement, and interference of photons from independent emissions/sources. The final result was our joint Rev. Mod. Phys. (2012, with Jian-Wei, Zeng-Bing, Chao-Yang and Harald). If I find time, I will advertise our recent Gdansk results on redefinition of Stokes Parameters, or something else.

Wojciech Zurek
Los Alamos National Laboratories

Quantum Theory of the Classical:
Decoherence, Quantum Darwinism, and Objective Reality

I will describe recent insights into the transition from quantum to classical. I will start with a minimalist (decoherence-free) derivation of preferred states. Thus, pointer states that define events (e.g., measurement outcomes) arise without the need to appeal to Born's rule ($p_k=|\Psi_k|^2$) . Probabilities and Born's rule can be then deduced from the symmetries of entangled quantum states. With probabilities one can analyze information flows from the system to the environment in course of decoherence. They explain how robust classical reality emerges from the quantum substrate by accounting for the familiar symptoms of objective existence of pointer states of quantum systems through redundancy of their records in the environment.

W. H. Zurek, Physics Today 10, 44-50 (2014).

HOT-TOPIC TALKS

Tuesday, 19 May 2015

Main Ceremonial Hall, University of Vienna, Universitätsring 1, 1010 Vienna

Sorted alphabetically by speaker name

Kathrin Buczak
Atominstitut TU Wien

Creation and charge state dynamics of NV centres for quantum applications

Co-authors: Wachter, Georg (Atominstitut TU Wien, Vienna, Austria / Österreich); Schrempf, Dominik; Dobes, Katharina; Aumayr, Friedrich (Institute of applied physics, Vienna, Austria / Österreich); Schmiedmayer, Jörg; Trupke, Michael (Atominstitut TU Wien, Vienna, Austria / Österreich)

In the past decades the negative nitrogen-vacancy (NV-) centre in diamond has demonstrated its versatility both as a sensor for temperature, electrical and magnetic fields, and as a promising solid-state system for quantum information processing.
The negative charge state is photochemically not stable and loses the essential properties for the mentioned applications as soon as it converts to the neutral charge state, NV0. Thus, the charge state conversion dynamics of the NV centre play a key role in the understanding and application of the color centre.
We show measurements of the charge state dynamics for NV centre ensembles close to the surface of an artificial diamond. We implanted 1010 – 1013/cm2 nitrogen ions 14N4+ (8 keV) into a CVD diamond with initially <100ppb nitrogen content. As a result we created 25 different NV centre densities within a thin layer, just 12nm below the diamond surface. Through two-color laser excitation pulse sequences we have explored the time dependence of ionization (NV- → NV0) and recombination (NV0→ NV-). This allowed us to measure laser-induced conversion processes. In the course of this study, we discovered that charge conversion also takes place spontaneously and the characteristics of the decay (NV- → NV0) depend strongly on the density of the color centres.
The characterization of these processes is of importance for numerous applications of NV centres, including sensing of charges and fields near the surface of the diamond, as the decay process limits the coherence time – and thus the sensitivity – of NV-based sensors.
Deterministic placement of NV centres is essential for their use in photonic and electrical structures. We are now exploring the potential of masked implantation via electron-beam lithography and subsequent nitrogen implantation to create arrays of implanted NV defects. Fine-tuning the initial mask resist parameters and the implantation fluence has enabled us to scale NV creation down to single NV centres. The nanometer-scale accuracy of this process, combined with the fabrication of electrical and microwave structures on the diamond surface, will allow the creation of large-scale arrays of sensors and quantum devices.

Lauriane Chomaz
University of Innsbruck, IQOQI

Dipolar quantum physics with strongly magnetic atoms

Co-authors: Baier, Simon; Frisch, Albert; Aikawa, Kiyotaka; Mark, Manfred J.; Petter, Daniel; Ferlaino, Francesca (University of Innsbruck, IQOQI, Innsbruck, Austria)

Given their strong magnetic moment and exotic electronic configuration, rare-earth atoms disclose a plethora of intriguing phenomena in ultracold quantum physics. In our team in Innsbruck, we report on the first Bose–Einstein condensate and degenerate Fermi gas of erbium atoms. In this poster, we report on our latest experimental results. In particular, we study the impact of the anisotropy and long-range character of the dipole-dipole interaction in elastic scattering of both bosonic and fermionic erbium. We demonstrate that the ultracold scattering of identical fermions follows a universal behavior solely dictated by the magnetic moment and the atom's mass. At the many-body level, we prove the long-standing prediction of a deformed Fermi surface in dipolar gas.

Philipp Haslinger
UC Berkeley

Atom-interferometry constrains on dark energy theories

Co-authors: Hamilton, Paul; Jaffe, Matt; Simmons, Quinn (UC Berkeley, Berkeley, USA); Khoury, Justin (University of Pennsylvania, Philadelphia, USA); Müller, Holger (UC Berkeley, Berkeley, USA)

If dark energy, which drives the accelerated expansion of the universe [1], consists of a light scalar field, it might be detectable with normal-matter objects. The simplest such models would lead to a fifth force in conflict with results from experiments using macroscopic test masses such as torsion balances [2]. These constraints on fifth forces can be easily evaded through a variety of screening mechanisms in the presence of typical laboratory matter densities.
However, dilute atoms in an ultra-high vacuum environment can serve as ideal test masses which avoid this screening [3]. In our recently developed optical cavity atom interferometer [4] we place new limits [5] on anomalous accelerations at millimeter scale distances from a spherical source mass. These limits rule out a large parameter range of scalar field theories, such as chameleons, which would be consistent with the cosmological dark energy density. With further improvements in sensitivity, atom interferometry will be able to rule out many scalar field dark energy theories with coupling strengths up to the Planck mass.

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Georg Heinze
ICFO - The Institute of Photonic Sciences

Controlled rephasing of single collective spin excitations in a cold atomic ensemble for temporally multiplexed quantum memories

Co-authors: Albrecht, Boris; Farrera, Pau; Cristiani, Matteo; de Riedmatten, Hugues (ICFO - The Institute of Photonic Sciences, Castelldefels (Barcelona), Spain)

Future applications in quantum information science critically rely on realistic quantum memories (QM) for light [1]. Such devices allow coherent and reversible transfer of quantum information between flying qubits (typically encoded in photons) and long-lived matter qubits (typically encoded in atomic states). Photonic QMs constitute for example central building blocks in linear optics quantum computing or long-distance quantum communication based on quantum repeaters [2]. An important benchmark for realistic QMs is the capability of storing several qubits at the same time and selectively read them out afterwards, using e.g. temporal multiplexing. This ability holds great promise for significant speedup in quantum communication tasks [3]. Although cold atomic ensembles provide excellent QMs, temporal multiplexed storage of single photons has not been achieved in these systems yet. We now demonstrate a significant step towards this goal [4].

We apply laser cooled Rubidium atoms, to form a QM based on the DLCZ-scheme [5]. A weak write pulse drives the cold atomic ensemble in a single collective spin excitation via off-resonant Raman scattering. The creation of this so-called spin-wave is heralded by the detection of a corresponding write photon. To obtain the temporal multiplexing capability, we combine the DLCZ-memory with an inhomogeneous broadening of the spin transition, which can be externally controlled by a magnetic gradient. The induced broadening leads to a fast dephasing of the spin-wave and hence to a rapid decay of the retrieval efficiency if we read out the memory by the inverse Raman process. However, if we invert the sign of the gradient in middle of a chosen storage time, the spin-wave rephases at that storage time and we receive an echo-like signature in the retrieval efficiency of the DLCZ-memory. We obtain up to 60% of the readout efficiency measured in a standard DLCZ experiment and storage times in the range of several tens of microseconds.

We also investigate the single photon nature of restored read photons by measuring their antibunching in a Hanbury Brown Twiss setup. For sufficiently low write photon detection probabilities of less than 0.5%, we observe normalized autocorrelation functions smaller than one conditioned on the detection of a write photon, with the smallest measured value of 0.2. We prove the multiplexing capability of the memory, by sending two write pulses shortly after each other within the same trial to the memory. This can result in creation of two spin-wave modes with different phase evolutions and hence different rephasing times. When reading out the memory, we observe the expected signature of two temporally separated echoes in the retrieval efficiency. We show that the read photons are correctly correlated with the corresponding write process. This enables creation, storage and selective readout of single collective excitations in different temporal modes within the same atomic ensemble, an essential enabling step towards the realization of a temporally multiplexed quantum repeater node with atomic ensembles.

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Ana Predojevic
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Quantum effects from quantum dots embedded in photonic nanowires

Co-authors: Huber, Tobias; Prilmüller, Maximilian; Weihs, Gregor (University of Innsbruck); Khoshnegar, Milad (Institute for Quantum Computing & Waterloo Institute for Nanotechnology, University of Waterloo); Dalacu, Dan; Poole, Philip J. (National Research Council of Canada, Ottawa); Majedi, Hamed (Inst. for Quantum Computing and Waterloo Institute for Nanotechnology, University of Waterloo)

Quantum information processing needs efficient and compact sources of single photons and entangled photons pairs. Quantum-dot based sources are very appealing because of their compactness, intrinsic sub-Poissonian photon statistics [1], and potential to generate photons deterministically [2]. Additionally, they can be integrated in a semiconductor-based optical circuit.
In the absence of the fine structure splitting the quantum dot biexciton-exciton cascade should give photons entangled in polarization [3]. Unfortunately, this is not straightforward to accomplish since quantum dots are commonly subject to an in-plane geometrical asymmetry that splits the exciton states and therefore, reduces the achievable degree of entanglement. In this respect, quantum dots embedded in nanowires were proposed to have an intrinsic geometrical symmetry [4].
Here, we present entanglement of photon pairs generated from such a structure: a single InAsP quantum dot embedded in an InP nanowire [5]. This is a novel type of quantum dot device that is additionally interesting due to the following reasons: the wires are grown in a site-controlled way and they exhibit high photon extraction efficiency. To access the generated degree of entanglement we performed state tomography. The state exhibits a concurrence of 0.57(6) and fidelity with a maximally entangled state of 0.74(2).
Photonic nanowires can be grown containing only a single quantum dot but also having several quantum dots grown one on top of each other. It has been proposed that such a system equipped with controlled coupling between quantum dots can be used as a qubit register. Here, we show, for the first time observed, coupling between two quantum dots within the same nanowire. The coupling is observed as a Coulomb blockade between two emitters.

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Daqing Wang
Max Planck Institute for the Science of Light

A sub-λ^3-volume cantilever-based Fabry-Pérot resonator for cavity-QED studies

Co-authors: Hrishikesh, Kelkar; Cano, Diego-Martin; Hoffmann, Björn; Christiansen, Silke; Götzinger, Stephan; Sandoghdar, Vahid (Max Planck Institute for the Science of Light, Erlangen, Germany / Deutschland)

We report on the realization of an open plane-concave Fabry-Pérot resonator with a mode volume of $\lambda^3/2$ at optical frequencies [1]. Being based on low-reflectivity micromirrors fabricated on a silicon cantilever, our experimental arrangement provides broadband operation, tunability of the cavity resonance, lateral scanning, strong Purcell modification for quantum emitters and promise for optomechanical studies.

The interaction between a single emitter and confined radiation in a cavity results in novel effects like enhanced or inhibited spontaneous emission and vacuum Rabi oscillations. In conventional cavity QED, this interaction is enhanced by employing highly reflective mirrors resulting in a high quality factor (Q). However, the interaction also depends inversely on the square root of the volume (V) of the optical mode, which is usually left at hundreds or thousands of $\lambda^3/2$ [2]. Combination of very high Qs and very low Vs has proven to be challenging and has been only demonstrated for photonic crystal structures, where in return one suffers from difficult tunability and integration of emitters. Tunable microcavities are well suited for coupling narrowband emitters. To that end, open Fabry-Pérot micorcavities have been realised that employ mirrors with low numerical aperture (NA) and radii of curvature of tens of micrometers [3,4,5]. The low numerical aperture limits the mode volume to be larger than 10 μm^3. Here we report on a tunable and scannable microcavity with an ultralow mode volume below $\lambda^3/2$ (0.5 μm^3). The cavity is made of a curved micromirror fabricated using focused ion beam milling and a planar distributed Bragg reflector. The micromirror has a radius of curvature of 2.6 µm and a NA of 0.4. The high NA of the mirror results in a cavity mode waist below 800 nm. A further important feature of our design is maintaining a low Q of about 150, corresponding to a cavity linewidth of 3 THz. Such a broad resonance allows simultaneous coupling to detuned transitions and substantially reduces stabilization difficulties.

We present our results on the investigation of the effect of a single gold nanoparticle on the cavity resonance and Q [1]. Furthermore, we discuss ongoing work on the coupling of single organic molecules to the microcavity at cryogenic temperatures, where a modest Purcell factor of 25 is expected to have a substantial influence on the emission branching ratio of the excited state. Finally, we will discuss the potential of our experimental arrangements for novel studies of nonlinear quantum optical effects and optomechanics.

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Samuel Werner
Neutron Physics Group, NIST

Neutron Interferometry beyond Newton

Gravitationally-induced quantum interference was first observed by R. Colella, A.W. Overhauser and S.A. Werner (COW) in a neutron interferometry experiment in Ann Arbor in 1975. The accuracy of that experiment was about 10 %. More sophisticated versions of that experiment were carried out over the years in Columbia, Missouri.* The 1998 experiment of K.C. Littrell, et al. utilized two deBroglie neutron wavelengths (harmonics of each other) simultaneously in an effort to accurately correct for the effects of bending of the silicon interferometer under its own weight. The accuracy of this experiment was about 0.2 %. But, the results for the COW phase shift differed from theory by about 0.8%. From the early days, considerable interest (and many theoretical papers) was generated by these experiments primarily focusing on the possibility of observing general relativistic (GR) contributions to the quantum phase shift. This possibility led to the atom-beam interferometry experiments of M. Kasevich and S. Chu. More recently, H. Muller, et al. have suggested that the Kasevich-Chu interferometer technique is sensitive to the gravitational redshift. This claim is controversial. I will summarize the GR predictions for the neutron experiments, and suggest a new scheme of the COW-type experiment utilizing the direct observation of the Pendellosung interference fringes, and a Si interferometer floating in a fluid of density equal to that of silicon. This idea was first proposed by Anton Zeilinger about 25 years ago.

*A summary of these experiments is given in chapter 8 of the book Neutron Interferometry: Lessons in Experimental Quantum Mechanics, Wave-Particle Duality, and Entanglement by H. Rauch and S.A. Werner. 2nd Edition. Oxford University Press (2015).

Andrew White
University of Queensland

Going down drains into blind alleys: from reality to causality in the quantum world

The quantum wavefunction is at the heart of our best description of nature, yet we don't know what this object actually represents. Does it correspond to physical reality—the psi-ontic interpretation—is it a representation of knowledge or information about an underlying reality—the psi-epistemic interpretation—or is there no reality at all and the wavefunction just represents our subjective experience?
The psi-epistemic viewpoint appears very compelling in that it offers intuitive and simple explanations for many puzzling quantum phenomena. Whether it is indeed compatible with quantum mechanics and the notion of an objective observer-independent reality has, on the other hand, long been an open question.

We have recently demonstrated experimentally that no realist psi-epistemic model can fully explain the imperfect distinguishability of non-orthogonal quantum states—one of the fundamental features of the theory. Here we discuss improvements on this experiment and challenges on the way to more and more

stringent bounds on the explanatory power of such models.
In contrast to the no-go theorems of Pusey, Barrett, Rudolph and others, our experiment requires no fundamental assumptions such as a certain structure of the underlying ontic state space. We thus capture all interpretations of quantum mechanics that feature an observer-independent reality and just require a fair-sampling assumption due to imperfect detection efficiencies.
Our results thus suggest that maintaining a notion of objective, observer-independent reality requires a psi-ontic interpretation, which assigns objective reality to the wavefunction. If we wish to maintain the epistemic character of the wavefunction we are thus lead to rejecting the notion of observer-independent reality in our physical world.
Alternatively one could also reject the ontological model framework and consider more exotic alternatives, such as retrocausal influences. Indeed, Bell's famous theorem already show that our classical notion of causality is incompatible with quantum mechanics. Well-established causal discovery methods fail to produce conclusive results in the face of Bell-inequality scenarios unless one considers loopholes such as fine-tuned communication channels.
We explore generalization of causality to the quantum regime and revisit the role of cause and effect. Going a step further, we experimentally demonstrate that not even a causal connection between Alice and Bob can explain quantum correlations. These and other results suggest that the notion of causality might have to change at the quantum level and could possibly even be harnessed as a resource for quantum computation.

*With apologies to Feynman for the title.

Magdalena Zych
University of Queensland

Bell Inequalities for Temporal Order of Events

Co-authors: Costa, Fabio (University of Queensland, Brisbane, Australia / Australien); Pikovski, Igor (ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, USA); Brukner, Caslav (IQOQI, Vienna, Austria / Österreich)

Violations of Bell's theorem show that in quantum mechanics physical quantities do not have predefined values. However, the causal relations between events, such as the preparation of a setting or a measurement, do retain an absolute status in quantum theory - they are assumed to be fixed by the space-time structure. In general relativity space-time itself is a dynamical filed which can be changed by the presence of massive objects. Here we show that if the state of a massive system is a specific quantum superposition, the order between time-like events in the resulting space-time is not necessarily classically defined. We discuss a situation where the temporal order between two time-like separated events becomes "entangled" with the order between another pair of time-like events. A protocol is then proposed in which two distant pairs of agents, acting locally on initially uncorrelated systems, prepare an entangled state exploiting the "entanglement of temporal orders". If the temporal order is predefined, no local protocol can succeed in this task.

POSTER CONTRIBUTIONS

Monday, 18 May 2015

Arcades, University of Vienna, Universitätsring 1, 1010 Vienna

Sorted alphabetically by poster title

A cavity-based single ion optical interface

Presenter: Tim Ballance
Affiliation: University of Bonn

We investigate a single trapped ion coupled to a optical fibre cavity for use as a node in a quantum network [1]. Of particular interest are the photon emission and absorption properties of the system. Single photons emitted by the ion-cavity system carry polarisation state information which is correlated with the spin state of the ion. In addition, a Purcell enhancement of photon absorption due to the presence of the cavity is observed [2]. A second ion-cavity system is under construction in preparation for future expansion of our network.

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A loophole-free Bell test with spin qubits in diamond

Presenter: Bas Hensen
Affiliation: Kavli Institute of Nanoscience Delft, Delft University of Technology

Co-Authors: Bernien, Hannes; Dreau, Anais; Reiserer, Andreas; Ruitenberg, Just; Blok, Machiel; Taminiau, Tim (Kavli Institute of Nanoscience Delft, Delft University of Technology); Wehner, Stephanie (QuTech, Delft University of Technology); Hanson, Ronald (Kavli Institute of Nanoscience Delft, Delft University of Technology)

One of the most intriguing phenomena in quantum physics is the entanglement of spatially separated objects. The benchmark to prove the fundamental non-locality of remote entanglement is provided by the famous Bell's inequality [1]. Nevertheless, all experimental implementations of the Bell test to date open the door to loopholes that restrict the practical validity of this theorem. These loopholes are particularly important in a cryptography setting where Bell violations have been shown to enable fully device-independent protocols for quantum key distribution [2] and certified generation of randomness

[3].

Here we will present the design considerations and latest experimental results towards the realization of the Bell test, aimed at closing the detection loophole and addressing the locality and freedom-of-choice loopholes in a single experiment. The experiment relies on the strong control achieved on the qubit associated with the electronic spin of the nitrogen-vacancy (NV) center in diamond. An efficient remote entanglement protocol [4] allows us to generate entangled qubit pairs located in two labs separated by 1.3 km on the TU Delft campus. This distance is long enough to allow space-like separation between the two qubits during their measurement. The heralded nature of the entanglement generation and efficient qubit readout [5] allows us to use all entangled pairs without relying on the fair-sampling assumption.

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[2] J. Barrett et al., Phys. Rev. Lett. 95, 010503 (2005).

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[4] H. Bernien et al., Nature 497, 86-90 (2013).

[5] L. Robledo et al., Nature 574, 477 (2011).

A new hierarchy approach to describe open quantum systems

Presenter: Ines de Vega
Affiliation: Ludwig Maximilian University

We derive and analyse a non-perturbative master equation from the exact stochastic Liouville von-Neumann (SLN) equation (A.J. Stöckburger and H. Grabert. PRL 88, 170407 (2002)). The latter depends on two correlated noises and describes exactly the dynamics of an oscillator coupled to an environment at thermal equilibrium. The newly derived master equation is obtained by performing analytically the average over different noise trajectories. It is found to have a complex hierarchical structure that might also be helpful to explain the convergence problems occurring when performing numerically the stochastic average of trajectories given by the SLN equation.

A pulsed matter-wave interferometer for testing the mass limits of quantum mechanic

Presenter: Jonas Rodewald
Affiliation: University of Vienna, VCQ

Co-Authors: Dörre, Nadine; Geyer, Philipp; Haslinger, Philipp; Arndt, Markus (University of Vienna, VCQ, Vienna)

We demonstrate a matter-wave interferometer in the time domain (OTIMA) as a powerful tool for testing the validity of quantum theory for large particles [1,2]. The interferometer operates in the near-field regime and utilizes three pulsed standing laser wave gratings. These imprint a periodic phase pattern on to the traversing matter waves while additionally the photo depletion probability is modulated periodically with the distance from the reflecting mirror. Depending on the particle's ionization or fragmentation cross section and their optical polarizability the gratings thus act as absorptive masks and phase gratings with an exceptionally small grating period of less than 80 nm [3,4].
The pulsed experimental scheme facilitates interference measurements in the time domain which offers high count rate, visibility and measuring precision [3]. Since the action of pulsed optical gratings is non-dispersive the experiment is well suited for interference experiments on an increasingly large mass scale in the quest for novel decoherence effects, such as continuous spontaneous localization [4]. Additionally, the ability to resolve fringe shifts as small as a fraction of the grating period opens up to measuring optical and electrical nanoparticle properties in the OTIMA interferometer with time domain enhanced precision [5]. Experiments with various organic clusters and monomers have demonstrated the functionality of the interferometer and serve as a motivation for exploring the wave-particle character of particles with masses up to 10^5 amu and beyond.

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A Source of Single Photons Tailored to Atomic Transitions

Presenter: Amirhosein Mohammadi Moqanaki
Affiliation: University of Vienna, VCQ

Co-Authors: Walther, Philip (University of Vienna, VCQ)

Narrow-band (few MHz band-width) single photons are an essential tool for a variety of quantum information studies, atomic quantum memories, quantum networks, and studying atom-light interactions. Spontaneous Parametric Down-Conversion (SPDC) has proven to be a robust, relatively easy, bright, probabilistic source of single photons. But the typical phase-matching band-width is broad (about 100 GHz or more) and filtering such leads to very poor brightness. On the other hand, SPDC inside a high finesse cavity can enhance the narrow-band emission by a factor of finesse squared and drastically improve the brightness. But for single longitudinal mode operation of the enhancing cavity, additional external filters (either atomic line, or filtering cavities) are necessary. This mode filtering comes at the cost of losing photon counts and adding complexity to the setup. In this poster a novel mode-filter-free, frequency degenerate, type-II phase-matched, SPDC based source of single photons tailored to Rb D2 line (780nm) is introduced. An intra-cavity Pockels cell tunes the signal and idler photons free spectral ranges such that they satisfy the doubly resonant condition and render the cavity single mode. This technique improves the brightness and packs a compact, robust setup.

An atom-photon quantum gate

Presenter: Bastian Hacker
Affiliation: Max-Planck-Institut für Quantenoptik

Co-Authors: Welte, Stephan; Reiserer, Andreas; Kalb, Norbert; Ritter, Stephan; Rempe, Gerhard (Max-Planck-Institut für Quantenoptik, Garching)

Quantum gates between light and matter qubits are essential building blocks for future applications in quantum information science. They allow for interactions between remote quantum network nodes, promise to bridge the gap between photonic and matter-based approaches to quantum information processing and allow for the nondestructive d etection of an optical photon [1] . Recently we have experimentally demonstrated a quantum gate between the polarization of a photon and a single atom trapped in a high-finesse optical cavity [2] . The gate mechanism is based on the reflection of the photon from the resonant one-sided cavity. It requires excellent control over both internal and external state of the trapped atom. For more complex tasks in quantum information processing the degree of control needs to be improved even further. We will present ongoing experiments with single atoms and atom-photon gates and will discuss future challenges and perspectives.

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An entanglement-enhanced microscope

Presenter: Takafumi Ono
Affiliation: University of Bristol/Hokkaido University/Osaka University

Co-Authors: Okamoto, Ryo; Takeuchi, Shigeki (Kyoto University, Japan)

Entanglement is the key resource in optical phase measurement with better accuracy than the classical limit[1]. The phase sensitivity of coherent light (and hence of all classical light) is limited by the shot noise of independent photon detection events to the standard quantum limit(SQL). This limit can be overcome by entangled photons. Progress has been made with trapped ions and atoms, while high precision optical phase measurements have many important applications, including microscopy, gravity wave detection, measurements of material properties, and medical and biological sensing. Recently, the SQL has been beaten with two photons[2,3] and four photons[4,5].

Perhaps the natural next step is to demonstrate entanglement-enhanced metrology. Among the applications of optical phase measurement, microscopy is essential in broad areas of science from physics to biology. The differential interference contrast microscope (DIM) is widely used for the evaluation of opaque materials or the label-free sensing of biological tissues, where the resolution is determined by the signal to noise ratio of the measurement, which has been limited by the SQL.

In this poster presentation, we propose our new concept `an entanglement-enhanced microscope'[6], which consists of a confocal-type differential interference contrast microscope[7] equipped with an entangled photon source as a probe light source. An image of a glass plate sample, where a Q shape is carved in relief on the surface with a ultra-thin step of ∼ 17 nm, is obtained with better visibility than with a classical light source. The improvement of the SNR is 1.35 ±0.12, which is consistent with the theoretical prediction of 1.35. We also confirm that the bias phase dependence of the SNR completely agrees with the theory without any fitting parameter. The success of this research will enable more highly sensitive measurements of living cells and other objects, and it has the potential for application in a wide range of fields, including biology and medicine.

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[6] T. Ono, R. Okamoto and S. Takeuchi, Nat. Commun. 4, 2426 (2013)

Ancilla-Assisted Measurement of Photonic Spatial Correlations and Entanglement

Presenter: Malena Hor-Meyll
Affiliation: Federal University of Rio de Janeiro

Co-Authors: Almeida, Jessica; Lemos, Gabriela; Souto Ribeiro, Paulo; Walborn, Stephen (Federal University of Rio de Janeiro, Rio de Janeiro, Brazil)

We report an experiment in which the moments of spatial coordinates are measured in down-converted photons directly, without having to reconstruct any marginal probability distributions. We use a spatial light modulator to couple the spatial degrees of freedom and the polarization of the fields, which acts as an ancilla system. Information about the spatial correlations is obtained via measurements on the ancilla qubit. Among other applications, this new method provides a more efficient technique to identify continuous variable entanglement.

Anti-Bunching Characteristics of Attenuated Field Source via Post-Selected Intensity Correlation

Presenter: Jeongwoo Jae
Affiliation: Department of Physics, Hanyang University

Co-Authors: Seol, KangHee; Hong, SungHyuk; Lee, Jinhyoung (Department of Physics, Hanyang University, Seoul, South Korea)

A light source of the single photon has been widely proposed in quantum information science, even though it is difficult to handle the light source in a single photon level. Herald method was suggested by using nonlinear material. We consider the weak fields of the coherent state as a potential single photon source. We do as it is easier to manipulate, even though the distribution of the photons is Poissonian, i.e., quite random. To the end, we employ post-selection and investigate its effects. As a measure of anti-bunching degree, we employ a modified g(2) function. This function characterizes the intensity correlation between the light modes passing through many beam splitters positioned as tree structure. However, it deal with intensity only of the first two modes while other many behind-modes play a role of dividing photons. We then remove the multi-photon events, simultaneous measured events, in order to increase the probability of the single photon state with the post-selection. We show that the anti-bunching degree depends on the number of beam splitters and the initial average photon number. It is also shown that, after post-selection, the degree of anti-bunching of even weak coherent state is larger than any classical light fields. Furthermore, we also theoretically discuss how it behaves under infinite size of tree structure that anti-bunching degree of classical and quantum lights.

Cavity cooling of dielectric nanoparticles: Towards matter-wave experiments

Presenter: Stefan Kuhn
Affiliation: University of Vienna, VCQ

Co-Authors: Asenbaum, Peter; Sezer, Ugur (University of Vienna, VCQ); Kosloff, Alon (School of Chemistry, Tel Aviv University); Sclafani, Michele (University of Vienna, VCQ); Wachter, Georg; Trupke, Michael (Vienna University of Technology, VCQ); Stickler, Benjamin; Nimmrichter, Stefan; Hornberger, Klaus (University of Duisburg-Essen); Cheshnovsky, Ori; Patolsky, Fernando (School of Chemistry, Tel Aviv University); Arndt, Markus (University of Vienna, VCQ)

Resonant laser cooling techniques have given a great boost to the field of atomic physics throughout the last 30 years. Complex molecules and nanoparticles, however, cannot yet be controlled by these methods due to the lack of addressable cyclic transitions. In reply to this need, cavity cooling has been proposed more than 15 years ago [1, 2] and has recently been realised with nanoparticles [3,4,5].
Here we present our results on cooling silicon nanoparticles with a mass of 1010 amu in a high-finesse cavity [4]. In addition to that we discuss our ongoing efforts to cool 30 nm particles in dedicated micro-cavity arrays etched into silicon wafers. This shall enhance the cavity – particle coupling to improve the cooling even of particles in the 10^6 - 10^7 amu range, which is closer to matter-wave interferometry in the near future [6]. Finally, we show first results on tracing and manipulating prolate nanoparticles through their interaction with intense intra-cavity fields.

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Characterizing the output state of a synchronously-pumped optical parametric oscillator - application to cluster state quantum computing

Presenter: William Plick
Affiliation: CNRS - Télécom ParisTech

The cluster state (also called measurement-based) model of quantum computing offers several advantages over the, more traditional, circuit model. The chief difficulty of the measurement-based approach is the production of the cluster state itself - a highly multi-mode entangled state. In recent years much effort has been focused into using an optical parametric oscillator pumped in a synchronous manner with a frequency comb to produce such states. What has remained somewhat elusive is the direct theoretical characterization of the output of this process without additional post-processing. In this poster we present such a characterization and investigate the potential advantages of moving to an "intermediate regime" of pumping that is still bright and highly multi-mode, but which presents a more tractable cluster state structure for practical use.

Circular patch resonators for cavity QED in the THz region

Presenter: Christian G. Derntl
Affiliation: Photonics Institute - Vienna University of Technology
Co-Authors: Bachmann, Dominic; Unterrainer, Karl; Darmo, Juraj (Vienna University of Technology)

Cavity quantum electrodynamic (CQED) systems are suitable to push the limits of light-matter interaction. Especially solid state quantum systems showed tremendous progress in recent years by reaching the ultrastrong coupling regime [1,2], where the vacuum Rabi frequency Ω becomes a considerable fraction of the bare intersubband transition frequency ω0. The present world record is Ω/ω_0 = 0.87 and was established by Maisson et al. using cyclotron transitions in 2D electron gases coupled to planar metamaterials (regular array of planar metallic resonators) [3]. According to De Liberato [4] even the deep strong coupling regime with $\Omega/\omega_0 > 1$ will be achieved soon. Of particular note is that resonators used to demonstrate ultrastrong coupling have typically quality factors smaller than 20. On the one hand this is because of the weak in-coupling for single or few cycle light pulses to high-Q resonators, used to probe ultrastrong coupling. On the other hand intersubband cavity polaritons get lost by decoherence or dissipation before they could be coupled out. This is caused by the fact that the lifetime of an intersubband plasmon in a quantum well (typical a few picoseconds) is shorter than the lifetime of a localized plasmon in a high-Q resonator (e.g. $\tau_{resonator}$~16ps for Q=100, ν=1 THz). To overcome these drawbacks, which are associated with a high quality factor, it requires time-controlled transfer of energy from one to another plasmonic mode. Beneficially, these modes are localized on different metallic resonators to enable higher flexibility and to reduce thermal perturbation of the cavity QED system. To steer the flow of energy from one to another metallic resonator switching mechanisms are required that are faster than the lifetime of an intersubband cavity polariton. This is fulfilled by a photoconductive switch for certain materials.

Here we present a metallic resonator offering a strongly confined mode with a high quality factor accessible via the electric near-field of a neighboring metallic resonator. By switching coupling paths or certain plasmonic modes, energy can be transferred between neighboring metallic resonators. Double-metal plasmonic structures are appropriate for such purposes because they offer high field confinement and enable extremely small mode volumes [5,6]. The design presented here is a circular patch resonator with toroidal structured dielectric with and without broken rotational symmetry. In Fig. 1a one of our designs is illustrated. The rotational symmetry of the resonator is broken by a gap that splits the circular patch into two halves. The holes in the top layer are required to isotropically etch a toroidal cavity into the dielectric layer beneath the patch. Despite the broken symmetry the lowest order axisymmetric mode still exists, see top of Fig. 1b. This mode has no electric net dipole moment and the magnetic field is enclosed within the plasmonic patch resonator and therefore it properly matches our requirement of a quasi non-interacting meta-atom. Furthermore the broken symmetry generates another related mode where the fields and currents in the first half of the patch resonator oscillate with a π phase shift relative to the second half, see bottom of Fig. 1b. As a consequence this mode has a net dipole moment allowing efficient coupling to free space.

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[6] B. Paulillo et al., Optics Express 22, 18, 21302-21312 (2014)

Conditional state-engineering quantum processes: implementation & characterization

Presenter: Michal Karpinski
Affiliation: University of Oxford

Co-Authors: Cooper, Merlin; Wright, Laura J.; Smith, Brian J. (University of Oxford)

Conditional quantum optical processes enable a wide range of technologies from generation of highly non-classical states to implementation of quantum logic operations. A number of system parameters affects the process fidelity that can be achieved in a realistic implementation. Here we experimentally examine Fock state filtration, an important example of a broad class of conditional quantum operations acting on a single optical field mode. This operation is based on interference of the mode to be manipulated with an auxiliary single-photon state at a beam splitter, resulting in the entanglement of the two output modes. A conditional projective measurement onto a single photon at one output mode heralds the success of the process. This operation, which implements a measurement-induced nonlinearity, is capable of suppressing particular photon-number probability amplitudes of an arbitrary quantum state. We employ coherent-state process tomography to determine the precise operation realized in our experiment, by analysing the output of the process in response to a set of well-characterized coherent states. This enables us to obtain the process tensor, which encapsulates complete information about the action of the process within the 6-photon subspace of the Hilbert space of a single optical mode. To identify the key sources of experimental imperfection, we develop a model of the process and identify three main contributions that significantly hamper its efficacy. The reconstructed tensor is compared with a model of the process taking into account sources of experimental imperfection with fidelity better than 0.95. This enables us to identify three key challenges to overcome in realizing a Fock state filter with high fidelity - namely the single-photon nature of the auxiliary state, high-mode overlap, and the need for number resolving detection when heralding. Our experimental results show that the filter does indeed exhibit a nonlinear response as a function of input photon number and preserves the phase relation between Fock layers of the output state, providing promise for future applications. We further discuss tools that may lead to addressing some of the experimental challenges identified above. To address mode-matching between optical fields we investigate methods to actively manipulate pulsed spectral-temporal modes of single photons heralded from spontaneous parametric down conversion sources, employing a technique based on electro-optic phase modulation. We work in a regime where the optical pulse duration is shorter than variations in the phase modulation [2]. This enables us to imprint a variety of deterministic temporally varying phases on the pulse, e.g. a linear temporal phase that implements a spectral shear of the wave packet. To achieve a spectral shear of significant magnitude requires use of state-of-the-art electro-optic modulation operating at high frequency (40 GHz). We demonstrate deterministic frequency shifts of near infrared (830 nm central wavelength), heralded single photon pulses in wave packets of approximately 1 ps duration by more than 1 nm. We confirm preservation of non-classical photon number statistics through the process. We discuss applications of the technique to improving the mode matching between spectral-temporal modes in multiphoton interference experiments, as well as to quantum key distribution and spectral engineering of heralded single-photon sources.

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[2] C. Dorrer and I. Kang, Opt. Lett. 28, 477 (2003); I. Kang et al., ibid., 28, 2264.

Contextuality in phase space

Presenter: Ali Asadian

We present a general framework for contextuality tests in phase space using displacement operators. First, we derive a general condition that a single-mode displacement operator should fulfill in order to construct Peres-Mermin square and similar scenarios. This approach offers a straightforward scheme for experimental implementations of the tests via modular variable measurements. In addition to the continuous variable case, our condition can be also applied to finite-dimensional systems in discrete phase space, using Heisenberg-Weyl operators. This approach, therefore, offers a unified picture of contextuality with a geometric flavor.

Cooling charged nanospheres in a hybrid electro-optical trap

Presenter: James Millen
Affiliation: University College London

Trapping and manipulating nanoscale objects offers the potential to explore the limits of quantum physics, and the role of gravity in quantum science, as well as offering the potential to perform ultra-sensitive force measurements. If one wants to see effects on the quantum level then the nano-object must be cooled to it's motional ground state in ultra-high vacuum. It has proved challenging to stably trap nanoparticles in a vacuum while implementing the necessary cooling, due to instabilities induced by optical cooling fields. In this work we levitate charged silica nanospheres in a Paul trap, and cool them with a weak optical cavity field. This hybrid method allows stable trapping and cooling at low pressures, paving the way to the quantum control of nanoscale objects.

Could quantum theory purely dichotomic?

Presenter: Matthias Kleinmann
Affiliation: University of the Basque Country UPV/EHU

Co-Authors: Lima, Gustavo (Universidad de Concepción, Chile); Cabello, Adán (Universidad de Sevilla, Spain)

The standard formulation of quantum theory contains a very particular prediction: in some situations, the number of outcomes of a measurement is by itself a quantum phenomenon. This prediction is not dictated by the structure of quantum theory but emerges from the convenient assumption that all self-adjoint operators correspond to measurements. We construct a class of toy theories with weaker forms of this assumption. The difference between those theories and standard quantum theory can be verified only in particular Bell-type experiments. Indeed, recent experiments recorded correlations that suggest a contradiction to the simplest of the toy theories in which all the »quantumness« of a measurement is dichotomic

Coulomb effects in quantum ion channels transport

Presenter: Nicole Martins De March
Affiliation: Universidade Federal do Rio Grande do Sul

Co-Authors: Gregory Brunnet, Leonardo; Denise Prado, Sandra (Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil)

Recently it was demonstrated that long-lived quantum coherence exists during excitation energy transport in photosynthesis. It has also been suggested that the selectivity filter of ion channels may exhibit quantum coherence which might be relevant for the process of ion selectivity and conduction. A. Vaziri and Martin Plenio (2010) showed in a very simple model of a single particle that quantum resonances could provide an alternative approch to ultrafast 2D spectroscopy to probe these quantum coherences. In this work, we have refined Plenio et al model introducing two ions in the channel taking into account the effect of Coulomb repulsion for the conduction (This is work in progress).

Coupling Spins and Diamond Color Centers to Superconducting Cavities

Presenter: Stefan Putz
Affiliation: Technische Universität Wien

Co-Authors: Angerer, Andreas; Glattauer, Ralph; Krimer, Dmitry; Rotter, Stefan; Schmiedmayer, Jörg; Majer, Johannes (Technical University of Vienna)

Hybrid quantum systems based on spin ensembles coupled to superconducting microwave cavities are promising candidates for robust experiments in cavity quantum electrodynamics (QED) and for future technologies employing quantum mechanical e ects. We present recent experimental results of strong coupling between an ensemble of nitrogen-vacancy center electron spins in diamond and a superconducting microwave coplanar waveguide resonator. Although the coupling between a single spin and the electromagnetic eld is typically rather weak, collective enhancement allows entering the strong coupling regime. Currently the main source of decoherence in these systems is inhomogeneous spin broadening, which limits their performance for the coherent transfer and storage of quantum information. Here we study the dynamics of a superconducting cavity strongly coupled to an ensemble of nitrogen-vacancy centers in diamond. We experimentally observe for the first time, how decoherence induced by inhomogeneous broadening can be suppressed in the strong-coupling regime, a phenomenon known as "cavity protection". To demonstrate the potential of this effect for coherent control schemes, we show how appropriately chosen microwave pulses can increase the amplitude and decay rate of coherent oscillations between the cavity and spin ensemble by two orders of magnitude.

Putz, S. et al. Nat. Phys. 10, 720-724 (2014)

Coupling, controlling and processing non-transversal photons with a single atom

Presenter: Michael Scheucher
Affiliation: VCQ - Vienna University of Technology

Co-Authors: Will, Elisa; Hilico, Adèle; Volz, Jürgen; Rauschenbeutel, Arno (VCQ - Vienna University of Technology)

In our experiment we investigate the strong interaction between single rubidium atoms and light confined in a bottle microresonator, a novel type of whispering-gallery-mode (WGM) microresonator. These resonators offer the advantage of very long photon lifetimes in conjunction with near lossless in- and out-coupling of light via tapered fiber couplers. In addition, we recently showed that the longitudinal polarization component of their evanescent field results in an inherent link between the local polarization of the light and its propagation direction. This fundamentally alters the physics of light-matter interaction leading to a new class of optical microresonators based on chiral interaction of light and matter [1].

Building on these properties, we recently realized a fiber-integrated optical Kerr-nonlinearity. There, the presence of the atom results in a strong nonlinear response of the resonator to the number of incident photons. As a consequence, we observe a nonlinear phase shift close to the maximum value of π between the cases where one or two photons pass the resonator [2]. Furthermore, we show that this results in entanglement between the two previously independent photons.

[1] C. Junge et al., Phys. Rev. Lett. 110, 213604 (2013)'
[2] J. Volz et al., Nature Photon. 8, 965 (2014)

Demonstration of measurement-only blind quantum computing

Presenter: Chiara Greganti
Affiliation: University of Vienna

Co-Authors: Philip Walther (University of Vienna, VCQ)

Blind quantum computing allows for secure cloud networks of quasi-classical clients and a fully-edged quantum server. Recently, a new protocol has been proposed, which requires a client to perform only measurements. We demonstrate a proof-of-principle implementation of this measurement-only blind quantum computing, exploiting a photonic set-up to generate four-qubit cluster states for computation and veri fication. Less demanding technological requirements for the client and fully device-independent security make this scheme very applicable for future secure quantum networks.

Directional photon emission - beyond paraxial approximation

Presenter: Stefan Walser
Affiliation: Vienna University of Technology

Co-Authors: Petersen, Jan; Volz, Jürgen; Rauschenbeutel, Arno Vienna University of Technology

Electromagnetic radiation is typically considered as a fully transverse polarized wave, where the electric field is always perpendicular to the propagation direction. However this is only valid in the paraxial approximation. Beyond this approximation longitudinal polarization components can appear in highly confined light fields. Together with the transversal components this leads to local circular polarization where the sense of rotation (spin) of the electric field vector depends on the propagation direction. Thus the internal spin of photons gets coupled to their propagation direction and photons obtain chiral character. This effect breaks the mirror symmetry of the scattering of light. Positioning a gold nano-particle on the surface of a nano-photonic waveguide we thereby realize a chiral waveguide coupler in which the handedness of the incident light determines the propagation direction in the waveguide [1]. With this chiral waveguide coupler we demonstrate an practical way of directly probing the local polarization state, in particular, the focus region of a highly focused beam.

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Dissipative cooling of a one-dimensional Bose gas

Presenter: Bernhard Rauer
Affiliation: Vienna University of Technology

Co-Authors: Jörg Schmiedmayer (Vienna University of Technology)

Degenerate atomic gases are among the most versatile tools to study fundamental many-body physics. Almost all realisations of these systems rely on the technique of evaporative cooling. Highly energetic particles are selectively removed from the trap reducing the average energy per particle. A crucial ingredient in this scheme is the continuous rethermalization of the system to an equilibrium energy distribution. However, for one- dimensional Bose gases it has been shown that thermalization is strongly inhibited rendering standard evaporative cooling ineffective.

In our experiment we study the effects of uniform particle dissipation on a one-dimensional quasi-condensate created on an atom chip. We observe a cooling process which is reminiscent but distinctly different from standard evaporative cooling. This process proceeds through non-equilibrium dephasing without the need for thermalization or an energy-selective out-coupling mechanism. Furthermore we discuss the effects of quantum noise which is expected to enter the system through the dissipation process.

Dissipative Few-Body Quantum Systems

Presenter: Clemens Jochum
Affiliation: IST Austria

Co-Authors: Kaczmarczyk, Jan; Lemeshko, Mikhail (IST Austria)

In recent papers by Lemeshko and Weimer it was demonstrated that controlled dissipation can be used to create metastable bonds between two Rydberg-dressed ultracold atoms [1,2]. This bond arises due to the dipole-dipole interaction which is restricted to one of the lower electronic energy states, resulting in the distance-dependent coherent population trapping. Here we expand the system to three particles, with an aim to find a dissipative Borromean state. Such an inherently three-body bound state occurs even if no two-body bound states between the particles are possible. In the context of open quantum systems, this would correspond to the driven-dissipative analogue of the Efimov effect [3], actively studied in ultracold atoms.
In order to tackle the three-body problem we develop an effective model, disentangling the internal and motional atomic degrees of freedom. This drastically reduces the computational cost and makes the solution with the Stochastic Wavefunction Monte-Carlo Technique possible.

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Dissipative preparation of antiferromagnetic order in the Fermi-Hubbard model

Presenter: Jan Kaczmarczyk
Affiliation: Institute of Science and Technology Austria

Co-Authors: Weimer, Hendrik (Leibniz Universität Hannover); Lemeshko, Mikhail (Institute of Science and Technology Austria)

We study the Fermi-Hubbard model in the presence of dissipation as can be realized in current experiments with ultracold atoms in optical lattices. We show that, by using the combination of Raman-assisted hopping and sideband cooling, it is possible to design the jump operators in such a way that the antiferromagnetic (AF) phase is the dark state of the dissipative dynamics. Consequently, starting from an arbitrary initial state, the system develops the AF order. To elucidate the development of the AF order we employ two complementary techniques: the stochastic wave function Monte Carlo and the recently proposed variational method for open quantum systems [1] . We observe substantial AF magnetization appearing within the experimentally accessible times on the order of 100 ms. We show that the predicted effects can be observed in current experiments on ultracold fermions in optical lattices. We exemplify possible experimental realizations by evaluating the magnitudes of the jump operators for the case of fermionic 40K.

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Dynamics of Quantum Emitters Interacting with Plasmonic Nanostructures

Presenter: Emmanuel Paspalakis
Affiliation: University of Patras

Co-Authors: Kallos, Efthymios (University of Patras, Greece); Yannopapas, Vassilios (National Technical University of Athens)

In recent years there is increasing interest in the study of the interaction of quantum emitters (such as atoms, molecules and semiconductor quantum dots) with plasmonic nanostructures The main reason for this is that the large fields and the strong light confinement associated with the plasmonic resonances enable strong interaction between the electromagnetic field and the quantum emitters near plasmonic nanostructures. In this work, we present new theoretical results on the dynamics of two quantum emitters mediated by a plasmonic metamaterial, specifically a periodic two-dimensional array of metal-coated dielectric nanospheres. For the study of the system's dynamics, we combine the density matrix approach for the quantum systems with ab initio electromagnetic calculations for the plasmonic metamaterial. We then present results for the time evolution of quantum correlations, using different measures for their quantification, between the two quantum emitters in both the presence and the absence of the plasmonic nanostructure, and for different initial conditions for the quantum systems. We find that for certain initial conditions of the quantum systems the presence of the plasmonic nanostructure strongly enhances quantum correlations.

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Efficient quantum circuits to implement continuous-time quantum walks

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Continuous-time quantum walk is currently a subject of intense theoretical and experimental studies due to its established role in quantum computation and quantum simulation. Moreover, any dynamical simulation of a Hamiltonian system in quantum physics and chemistry can be discretized and mapped onto a continuous-time quantum walk on some specific graphs. The primary difficulty of such a discretized numerical simulation lies in the exponential scaling of the Hilbert space as a function of the system size, making real-world problems intractable on classical computers. Quantum computers, on the other hand, promise unprecedented computing power if an efficient quantum circuit can be constructed to implement the required numerical simulation procedure, or its equivalent continuous-time quantum walk.

There are two distinct types of quantum walks: the continuous-time quantum walk (CTQW) and the discrete-time quantum walk (DTQW). While DTQWs on several classes of graphs have been shown to be efficiently implementable in terms of a sequence of quantum logic gate operations [1-4], quantum circuit implementation of CTQWs has remained virtually unexplored [5]. The implementation of the DTQW time-evolution operator U(t)=(SC)t for any time t is simplified by the fact that t is discrete and the evolution is repetitive. Here S and C are the shift and coin operator, respectively. As a result, if we can implement a single time-step U in a quantum circuit, the implementation for U(t) can be generated by repeating the same circuit t times. Another property of DTQWs to be exploited in quantum circuit design is that the single time-step operator U acts locally on the vertex-coin states encoding the graph. In other words, applying U to the vertex-coin states associated with a particular vertex will only propagate the corresponding amplitudes to adjacent vertices, so vertices that are more than 2 distance apart do not affect each other in the single time-step. This means that the local structure of the graph is the primary consideration in implementing DTQWs. Taking these into account, quantum circuits to implement DTQWs on sparse graphs [2,3], graphs with a high degree of symmetry such as vertex-transitive graphs [1], and certain types of non-degree-regular graphs [4] have been constructed.

However for CTQWs, the above two properties of DTQWs do not carry over, which makes the design of quantum circuits substantially more difficult. First, the time-evolution operator U(t) for CTQW is defined as a continuous function of t, requiring a time-dependent quantum circuit implementation. Second, the CTQW does not act locally on vertices - any two even distantly connected vertices on a graph will propagate amplitudes to each other in CTQW. Consequently, the global structure of a graph must be taken into account in designing quantum circuits to implement CTQWs.

In the poster, we will present a general approach for the construction of quantum circuits to implement continuous-time quantum walks, which may help solving certain quantum many-body problems otherwise computationally intractable. As an example we demonstrate that, if a problem can be mapped onto a continuous-time quantum walk on a circulant graph, a highly efficient quantum circuit may be constructed to obtain its solution.

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Entangling two ions inside a cavity via a cavity photon

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Co-Authors: Lee, Moonjoo; Casabone, Bernardo; Fioretto, Dario; Schüppert, Klemens; Ong, Florian; Blatt, Rainer; Northup, Tracy (Institut für Experimentalphysik, Universität Innsbruck)

Entanglement is an important resource for quantum information processing and quantum communication. It is possible to generate entanglement between two qubits inside a cavity, mediated by their interaction via the cavity mode. In the optical domain, this long-standing goal of cavity quantum electrodynamics has only recently come within reach of experiments due to the increase of control over individual quantum systems. We use a scheme for the entanglement of two trapped ions inside an optical cavity, which takes into account all decoherence channels of the system [1]. This scheme is also of interest in the context of sub- and superradiance, as it uses a minimal instance of the Dicke model.
In our experiment, two 40Ca+ ions are coupled to a cavity and initally prepared in a product state, ion 1 being in a state A, ion 2 in a state B. A single cavity photon is then generated from ion 1 by driving a cavity-mediated Raman transition which connects states A and B. The second ion can reabsorb this photon. During this process, i.e., between the emission of the photon from ion 1 and absorption by ion 2, the two ions are entangled. By changing the pulse length of the Raman laser, the evolution of the ions' state can be reconstructed. Additionally, full state tomography at a specific time reveals the entanglement in the system.

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Experimental Observation of Transition between Strong and Weak Non-Markovianity

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We experimentally observed in an optical setup and using full tomography process the so-called weak non-Markovian dynamics of a qubit [1], implementing the collisional model proposed in [2] to investigate the non- markovian dynamics of an open quantum system. Through careful control of the environment state of our open system, we also also observed the transition from weak to strong (essentiall) non-Markovianity.
In our all-optical setup, a single photon system, initially entangled in polarization with an ancilla, is made to sequentially interact with a sequence of liquid crystal retarders driven by proper electric pulses and simulating the environment. Depending on how the voltage is applied on each liquid crystal, it will work as a half-wave plate with di erent orientations. By properly the parameters of the qubit-environment interactions, the system dynamics can su ffer a transition from weak to strong non-Markovianity.
In the strong regime, the full reconstruction of the entangled state was made by single entanglement witness between system and ancilla, showing a backflow of information, while, in the weak regime, given the contractive unital map feature, we can only measure the dynamics by a full process tomography analysis, searching for the violation of the divisibility map criterion.

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Exploiting spatial information in multiphoton storage and interferometry

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Here we propose and demonstrate in the experiments two schemes where spatially multimode structure of photons can bring an enhancement in the interferometry precision and can accelerate the rate of N-photon generation perquisite for linear optics quantum computing (LOQC). They both rely on the state-of-the-art setup for ultra-low-noise and high-speed intensified sCMOS camera capable to count with high spatial resolution [1,2] photons generated either in the spontaneous parametric down-conversion (SPDC) or in the Raman scattering in a warm atomic memory.

In the first scheme we shall consider the realistic scenario where the imperfections in the modal structure of probes, such as photons sent to an interferometer, could severely reduce its phase-sensitivity and ultimately preclude beating the classical limits. In particular, in the canonical example of a balanced Mach-Zehnder interferometer the residual spectral distinguishability of interfering photons has a dramatically deleterious effect on the precision of local phase estimation which becomes divergent around the operating point when the photons coalesce pairwise.

We present a proof-of-principle experiment which reveals that by controlling carefully the spatial structure of interfering photons and extracting complete spatial information at the detection stage it is nevertheless possible to achieve sub-shot-noise precision in the operating regimes that otherwise cannot even attain shot-noise limit. We utilize highly-indistinguishable photon pairs from SPDC in bulk PPKTP crystal, pre-filtered by a single mode fiber. Then, a specific mode separation between photon leads to the detected coincidence pattern which is super-sensitive to phase difference between paths of the interferometer. We demonstrate that the precision of the phase estimation from measured data beats the classical limits which would be unattainable with no access to spatial information.

Our second scheme, for enhancing the rate of generating n-photons for LOQC, utilizes an intrinsic multimode structure of the light generated via collective Raman scattering in atomic ensembles. Here we rely on the first to our knowledge high-capacity, spatially multimode warm atomic memory operating at a single-photon-level.

Our implementation utilizing spontaneous write-in inside the memory overcomes the need of matching the heralded photons from the external source with the atoms. Instead, the write-in is heralded by the Stokes scattered photons which are generated inside the memory [3].

We present that the photons stored up to several microsecond, after retrieval, demonstrate excellent g(2) cross-correlations with their Stokes heralds. Specifically, a Stokes photon detected at a certain scattering angle heralds the write-in of an excitation in a one atomic spin-wave, which can be readout yielding on-demand generation of an anti-Stokes photon within a known narrow angle. We achieved storage and retrieval of up to 120 modes, which is the first demonstration of single-photon-level correlations between heralding and retrieved photons in the spatially-multimode regime. With such a multimode memory now we can subsequently herald N independent spin-wave excitation, which can be further readout simultaneously on demand in the scheme equivalent to using N-independent memories [4].

Both presented schemes demonstrate that the spatial degree of freedom is a powerful, yet relatively unexplored, resource for quantum protocols which now can be implemented thanks to the recent experimental breakthroughs in generation, storage and detection of a spatially multimode light.

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Fabry-Perot Interferometer with Quantum Mirrors

Presenter: Filippo Fratini
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Optical transport represents a natural route towards fast communications on which we are about to embark. The progressive miniaturization of devices for information processing calls for the tailoring of light transport at microscopic length scales, and thus for the fabrication of microscopic optoelectronic devices, such as single photon optical diodes. We show that a one dimensional wave-guide with two embedded two-level systems represents a valid candidate for such an optical diode.

Faking energy-time violation of the CHSH inequality with classical light

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Co-Authors: Jogenfors, Jonathan (Department of Electrical Engineering, Linköping, Sweden); Abdelrazig, Ashraf; Ahrens, Johan; Borennane, Mohamed (Quantum Information and Quantum Optics, Stockholm, Sweden)

We show how to build a classical source that fakes standard avalance photodetector outputs of a Franson interferometer, so that the Clauser-Horne-Shimony-Holt (CHSH) inequality is maximally violated at very high detector efficiency. Such a violation would normally be taken as evidence that no local hidden-variable model can exist for the system, for example ensuring security of a quantum key distribution (QKD) system. In this case, the classical source is built using such a model. The violation can be faked because of the postselection used in the interferometer; this is a severe loophole. This shows that stronger inequalities (and fast switching) or a changed setup is needed to properly exclude local hidden variables, so that a faked sources of this kind is excluded.

First event signalling correlations

Presenter: Debashis Saha
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After the formulation of Bell's Theorem showing the incompatibility between quantum mechanics and local realism [1], the studies of nonlocality naturally evolved to more general scenarios. One direction was to devise inequalities involving more parties [2], the other to consider stronger than quantum (QM) correlations [3]. Of particular interest is the intersection of these approaches: generalized multipartite correlations. Research in this area was pioneered by Svetlichny who introduced the notion of bilocal (BL) inequalities [4]. They are satisfied by every theory in which the set of parties can be divided into two groups sharing only classical correlations while any type of probability distribution is allowed inside both groups. This "anything goes" behavior in the groups clearly allows for some probability distributions impossible in quantum mechanics but the most interesting result of [4] was that there are QM correlations which violate BL inequalities. This leads to the introduction of the notions of genuine multiparty entanglement and nonlocality. The idea of BL correlations was further developed in [5] where two, weaker versions of them were introduced: no-signalling bilocal (NSBL) and time-ordered bilocal (TOBL) to understand genuine tripartite nonlocality from a better physical as well as operational point of view.

This work introduces the notion of First Event Signalling (FES) correlations in multipartite scenario where the first measurement on one subsystem influences the measurement outcomes of all the other local subsystems. In a preferred reference frame one measurement event can always be unambiguously identified as occurring first. We allow this particle to send the information about the choice and the outcome of the measurement to all the other parties. Hence, we call these first event signalling (FES) correlations. Note that we do not know what this preferred frame of reference is and it can change in time. Moreover the particles can have access to shared randomness so in each round the measurement on a different one can be the first. It is shown that these correlations are related to bilocal ones but stronger than their variations NSBL and TOBL. We propose a new Bell inequality which is satisfied by all FES models and subsequently generalize it for multiparty scenario. Then we show quantum mechanical violation of this inequality, which can be regarded as an alternative definition of a stronger type of genuine multipartite nonlocality and a proof that quantum mechanics exhibits even more powerful correlations than these already known. We also introduce another Bell inequality which is satisfied by all BL correlations but violated by FES. The study of our new inequalities and the ones introduced previously allows us to analyze the relation between different types of tripartite nonlocality which reveals a very complex and interesting structure.

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Forward-backward analysis of the photon number evolution in a cavity

Presenter: Stefan Gerlich
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A quantum system can be monitored through repeated interactions with meter systems. The state of the system at time t, represented by the density matrix ρ(t), then becomes conditioned on the information obtained by the meters detected until that time. More insight in the state of the system at any time t is provided, however, by taking into account all meters interacting with the system both in the past and in the future of time t.
We present experiments that use near-resonant atomic probes to monitor the evolution of the quantized field in a cavity. The application of a forward-backward smoothing algorithm to this quantum problem, justified by the past quantum state formalism [B.Gammelmark et al., Phys. Rev. Lett. 111, 160401 (2013)], leads to a considerable noise reduction and allows us to resolve dynamics, which are not reflected by the usual quantum state ρ(t).

Gaussian and non-Gaussian phase-fluctuations between two 1D quasi-condensates in and out of equilibrium

Presenter: Thomas Schweigler
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We show experimentally and theoretically how tunnel-coupling between two 1D quasicondensates can lead (depending on its strength) to Gaussian or non-Gaussian phase fluctuations for the thermal equilibrium state. Moreover, we show result for a quench from finite to vanishing tunnel-coupling. Starting from a non-Gaussian initial state, a Gaussian fixed point of the dynamics is approached

Generalized multi-photon quantum interference

Presenter: Max Tillmann
Affiliation: Quantenoptik, Quantennanophysik und Quanteninformation

Co-Authors: Tan, Si-Hui (Singapore University of Technology and Design); Stoeckl, Sarah (University of Vienna,); Sanders, Barry (University of Calgary, Alberta); de Guise, Hubert (Lakehead University, Thunder Bay, Canada); Heilmann, René; Nolte, Stefan; Szameit, Alexander (Friedrich-Schiller University Jena); Walther, Philip (University of Vienna,)Non-classical interference of photons lies at the heart of optical quantum information processing. This effect is exploited in universal quantum gates as well as in purpose-built quantum computers that solve the BosonSampling problem. Although non-classical interference is often associated with perfectly indistinguishable photons this only represents the degenerate case, hard to achieve under realistic experimental conditions. Here we exploit tunable distinguishability to reveal the full spectrum of multi-photon non-classical interference. This we investigate in theory and experiment by controlling the delay times of three photons injected into an integrated interferometric network. We derive the entire coincidence landscape and identify transition matrix immanants as ideally suited functions to describe the generalized case of input photons with arbitrary distinguishability. We introduce a compact description by utilizing a natural basis which decouples the input state from the interferometric network, thereby providing a useful tool for even larger photon numbers.

High order nonlinearity from single photons

Presenter: Petr Marek
Affiliation: Palacky University, Olomouc

Quantum nonlinearity is at the core of quantum optics. It could even be said that without it, there would not be any quantum optics at all. Both the discrete single photon states and the continuous squeezed states, which are, respectively, the key resources for discrete variable (DV) and continuous variable (DV) quantum optics, are generated by a nonlinear process. Specifically, the second order nonlinear parametric down-conversion.

However, for the more advanced quantum information protocols, such as quantum computation, higher order nonlinear processes are required. Unfortunately, these high order nonlinearities (one example being the famous Kerr nonlinearity) are not available with sufficient interaction strengths.

In this contribution we propose implementation of a third order nonlinear operation by manipulating light on the single photon level. The process involves preparation of a specific resource state containing the nonlinearity and the subsequent deterministic mapping of this nonlinearity onto the signal. We also report on the experimental steps that were taken towards this goal: preparation of the resource state and nonlinear feed-forward required for achieving the deterministic nature of the operation

High-Q membrane mechanical oscillators made from InxGa1-xP for cavity optomechanics experiments

Presenter: Garrett Cole

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Quantum experiments performed with cavity optomechanical systems hinge on the availability of mechanical oscillators with both a low decoherence rate and large optomechanical coupling. Here, we present membrane mechanical oscillators constructed from a novel material system that could pave the way to achieve these goals. Our membranes are fabricated from a 30 nm thick, slightly tensile strained In_xGa_1-xP layer and can be regarded as a convergence of two successful technologies: (i) high-Q membranes made from SiN and (ii) single-crystaline semiconductor GaAs membranes. In first measurements, we determine Q factors up to 10^6 at room temperature and a Qf-product of up to 10^{12}. At low temperatures we measure slight improvements in Q factors.

In the future, we will impart larger tensile strain in the In_xGa_1-xP layer to further increase the mechanical frequency. Assuming the mechanical dissipation to be independent of the applied tensile strain this leads to higher Qf-products. The InxGa1-xP material system is promising for a wide range of experiments, such as fully monolithic cavity-optomechanical systems, stacked membranes and optoelectronically-active mechanical resonators.

Infinite-dimensional quantum systems on indefinite causal structures

Presenter: Flaminia Giacomini

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Co-Authors: Brukner, Caslav; Castro Ruiz, Esteban (IQOQI & University of Vienna, VCQ);

Standard Quantum Mechanics assumes that events are embedded in a global causal structure. The process matrix framework keeps the local validity of standard Quantum Mechanics while relaxing the assumption on the global causal structure. This leads to multipartite correlations which lie outside the usual causally ordered framework, and opens interesting perspectives on our understanding of the nature of space and time. So far, the formalism has been developed only for finite-dimensional systems. Here we address the generalization to infinite-dimensional Hilbert spaces, with the long-term goal of formulating quantum fields on indefinite causal structure.

Interfacing single molecules with optical nanofibers

Presenter: Hardy Schauffert
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Tapered optical fibers with a nanofiber waist have proven to be a highly sensitive tool for surface spectroscopy. A route towards extending the range of applications to the single-molecule level is to deposit dye-doped organic crystals of sub-micron size, in our case terrylene-doped p-Terphenyl onto the nanofiber and to interface them with the evanescent field of the fiber-guided light. In previous studies different ways of deposition and preparation of the crystal have been developed, so that we are now able to efficiently detect single molecules by fluorescence excitation spectroscopy. We will present the most recent results on single molecule spectroscopy and give an outlook on the use of this advantageous system for single photon sources and big optical nonlinearities.

Interferometric tests of mass-energy equivalence principles for single photons

Presenter: Francesco Massa
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Co-Authors: Hilweg, Christopher; Zych, Magdalena; Brukner, Caslav; Walther, Philip (University of Vienna, VCQ)

Quantum theory and general relativity are considered the two pillars of modern physics. Their predictions are verified with spectacular precision on scales covering several orders of magnitude . Despite their success in describing nature, a unique framework reconciling these two theories is still missing. This is also due to the absence of experiments where both quantum and relativistic effects play an important role. Even regimes where quantum theory applies and gravity is treated classically have not been verified experimentally yet . This projects aims to realize the first table-top experiments probing jointly the quantum superposition principle and the mass-energy equivalence principle for single photons, both for inertial and gravitational mass. In order to achieve this goal we will build huge stable fibre-based interferometers whose arms will be at different non-inertial or gravitational potentials. These fundamental insights will be pivotal for further experiments aiming to test a genuine interplay between general relativity and quantum optics.

Irreversibility and the arrow of time in a quenched quantum system

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We address the issue of testing experimentally the thermodynamic arrow of time by using a nuclear magnetic resonance set-up that allows for the determination of the nonequilibrium entropy produced in an isolated spin-1/2 system following fast quenches of an external magnetic field. We demonstrate that the macroscopic average entropy production equals the entropic distance between a microscopic process and its time-reversal. This thus establishes a microscopic foundation of irreversibility beyond the linear response regime and both elucidates and quantifies the physical origin of the arrow of time in a quantum setting.

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Laser cooling and slowing of CaF molecules

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Producing ultra-cold and dense samples of polar molecules is a technical challenge that has been investigated with several techniques over the last decade, including direct laser cooling [1-4]. Some of the future applications are related to quantum information, ultra-high resolution spectroscopy, tests of fundamental symmetries and ultra-cold chemistry.
I will present our progress towards a magneto-optical trap (MOT) of CaF molecules. Following our successful demonstration of longitudinal laser cooling and slowing in a pulsed, seeded supersonic beam[1], we recently implemented a cryogenic buffer gas source with beam velocities below 200 m/s. To slow the molecules further down to the capture velocity of a MOT, we will apply a new type of Sisyphus decelerator, which uses permanent magnets in combination with optical pumping.

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Levitate Optomechanics for Fundamental Physics

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Optomechanics with levitated nano- and microparticles is believed to form a platform for testing fundamental principles of quantum physics, as well as find applications in sensing. We will report on a new scheme to trap nanoparticles, which is based on a parabolic mirror with a numerical aperture of 1. Combined with achromatic focussing, the setup is a cheap and readily straightforward solution to trapping nanoparticles for further study. Here, we report on the latest progress made in experimentation with levitated nanoparticles; these include the trapping of 100 nm nanodiamonds (with NV-centres) down to 1 mbar as well as the trapping of 50 nm Silica spheres down to 10^{-6} mbar without any form of feedback cooling. We will also report on the progress to implement feedback stabilisation of the centre of mass motion of the trapped particle using digital electronics. Finally, we argue that such a stabilised particle trap can be the particle source for a nanoparticle matterwave interferometer. We will present our Talbot interferometer scheme, which holds promise to test the quantum superposition principle in the new mass range of 10^6 amu.

Light interfaces for nitrogen-vacancy centres in diamond

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Nitrogen-vacancy (NV) centres in diamond show great promise for many applications, including ultra-compact magnetic and electric field sensing and quantum information technology [1,2]. All of these applications require the light emitted from NV centres to be efficiently collected.
At low temperatures the excited state of an NV centre displays a rich fine structure, which is exploited in quantum information experiments [3]. In such experiments, it is often necessary to apply oscillating and static magnetic fields and electric fields in order to manipulate the excited and ground state manifolds. This makes collecting emission from NV centres in a cryogenic environment, in a time-stable manner, technically challenging.
We present a robust and integrated setup which enables the high stability required for long measurements at low temperatures, while applying external fields. Combining our solid immersion lenses with this integrated setup, will allow both high light collection and stable low temperature measurements for quantum information applications.

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Macroscopic Leggett-Garg tests using quantum non-demolition measurements

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Making analogies to Bell inequalities [1], Leggett and Garg (LG) [2] proposed a test for quantum behavior of macroscopic systems undergoing coherent evolution. The resulting Leggett-Garg inequalities (LGIs) aim to distinguish a hypothesized philosophical position of macrorealism (MR) from quantum physics, and ultimately to test this position against Nature. The MR position holds that arbitrarily low-disturbance measurements should be possible, in contradiction of the Heisenberg uncertainty principle.

Here [3] we show how a test of macroscopic realism based on Leggett-Garg inequalities (LGIs) can be performed in a macroscopic system. Using a continuous-variable approach [4], we consider quantum non-demolition (QND) measurements [5] applied to atomic ensembles undergoing magnetically-driven coherent oscillation. We identify measurement schemes requiring only Gaussian states as inputs and giving a significant LGI violation with realistic experimental parameters and imperfections. The predicted violation is shown to be due to true quantum effects rather than to a classical invasivity of the measurement. Using QND measurements to tighten the “clumsiness loophole” [6] forces the stubborn macrorealist to re-create quantum back action in his account of measurement [7].

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Magnetometry with diamond NV centres

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Nitrogen-vacancy (NV) centres in diamond offer remarkable opportunities for the sensing of electric and magnetic fields. We have developed a magnetometer which consists of a diamond sample containing a dense ensemble of NV centres and is connected to a multimode optical fiber. The fiber is used to deliver excitation light to the NV centres and to read out their spin state. This device allows the measurement of magnetic fields with sub-nanotesla sensitivity, limited by the collection efficiency of the fiber and the coherence lifetime of the NV ensemble.

We have furthermore developed methods to improve the sensitivity and stability of single-defect sensors using inherent properties of the electronic energy level structure of the defects. We have shown that it is possible to extend the sensitivity range for long measurement times by reducing the sensitivity of the defect to other environmental fluctuations.

Both methods are of interest for the implementation of NV defects in practical sensing devices.

Many-body theory of molecular rotation inside superfluid helium nano-droplets

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Superfluid helium nano-droplets have been used to trap and study neutral and charged molecular species for several years [1]. The main motivation comes from the fact that the ro-vibrational spectra of molecules are almost undisturbed by the superfluid environment, which allows to perform high-precision spectroscopy and isolate the species, which are unstable in the gas phase. In numerous studies, it has been observed that the rotational spectrum of molecules inside superfluid helium droplets is renormalized compared to the gas phase. Namely, a molecule acquires an effective moment of inertia due to the interaction with helium, resulting in a reduced rotational constant. This is qualitatively similar to the effective mass concept used to describe a linear motion of polarons in solids. Although there have been some qualitative explanations of such a renormalization (based e.g. on the two-fluid model), as well as several quantum chemistry calculations for particular species [1], a general many-body theory of molecular rotation in superfluid helium has never been developed. Furthermore, recently the dynamics of molecules excited with short laser pulses has been studied experimentally in helium droplets [2]. As for now, even a qualitative understanding of this experimental data is lacking. Recently, Schmidt and Lemeshko developed a general many-body theory for molecular rotation coupled to a many-body bath of bosons, which is based on the quasiparticle concept of an angulon - a quantum rotor dressed by a quantum field. Here we apply the angulon theory to the linear-rotor molecules immersed into the superfluid helium bath in order to evaluate the effect of environment on the rotational spectra. Helium is a strongly interacting superfluid, therefore an exact solution of the problem is challenging. Thus, we develop an effective model Hamiltonian for the molecule-helium coupling, based on realistic potential energy surfaces for the two-body interactions. Using a variational ansatz for the many-body wavefunction based on single-phonon excitations, we evaluate the effective rotational constants for several molecules and compare them to the experimental data. This study is the first step towards understanding non-adiabatic molecular dynamics inside superfluid helium.

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Matter-wave interference and quantum-assisted metrology with large organic molecules

Presenter: Sandra Eibenberger
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Kai Walter, Stefan Nimmrichter, Klaus Hornberger (University of Duisburg Essen)

Quantum interference experiments with large molecules have allow for studies of the quantum superposition principle with particles of increasing mass and complexity. Kapitza-Dirac-Talbot-Lau interferometry [1] has enabled quantum experiments with a wide variety of macromolecules, even using particles with a mass exceeding 10 000 amu [2]. These experiments define the currently most stringent bound of the experimental macroscopicity parameter for quantum superpositions [3]. Typical de Broglie wavelengths of the investigated particles are in the order of 0.3-5 pm. This is significantly smaller than any molecular extension (nanometers) or the delocalization length in our interferometer (hundreds of nanometers). Many vibrational and rotational states are populated since the molecules are thermally highly excited (300-1000 K). And yet, high-contrast quantum interference patterns could be observed. The visibility and position of these matter-wave interference patterns is highly sensitive to external perturbations. This sensitivity has opened the path to extensive studies of the influence of internal molecular properties on the coherence of their associated matter waves. In addition, it enables a new approach to quantum-assisted metrology. I describe how KDTL interferometry can be used to investigate a number of different molecular properties, including electric moments [4] and optical absorption cross sections [5].

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Matter-wave interference enhanced metrology on biomolecules

Presenter: Lukas Mairhofer
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Matter-wave interferometry is a powerful tool for the study of quantum properties of molecules (Berninger, PRA 76, 2007, Eibenberger, Phys. Rev. Lett. 112, 2014). It has been demonstrated for up to 10.000 amu (Eibenberger, PCCP 15, 2013). As amplitude and phase of the fringe pattern are extremely sensitive to external forces matter-wave interference enhances the spatial resolution of deflectometry by a factor of 10^4 compared to ballistic deflectometry. This has been successfully conducted for electric deflection (Eibenberger, New J. Phys. 13, 2011). Thus matter-wave interferometry enhanced deflectometry makes high precision measurements on complex biomolecules feasible. The determination of their magnetic, electric and optical properties allows the investigation of their structure, of photo-induced conformational changes and of photochemistry in the gas phase. Additional water- bonds mimic the molecule's natural environment and allow us to study the transition from gas-phase to in-vivo-behaviour. We will present a geometry for deflection in magnetic fields suitable for interferometry which requires a homogenous force over the extension of the beam. Furthermore we will introduce a source for beams of internally cold, neutral and intact biomolecules up to 4000 amu that are sufficiently slow and intense for interference experiments. Finally we report on recent progress in our research on biomolecules.

Measurement of operational quasi-probabilities for qubits

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We demonstrate the negativity of operational quasi-probability, recently proposed in [Phys. Rev. A 88, 052123 (2013)], by using the linear optical elements. To compare quantum statistics with classical one, Wigner function has been employed to represent a joint distribution of position and momentum in phase space. Contrary to the classical statistics, it is not straightforward to define a joint probability distribution in quantum statistics due to the uncertainty relation between position and momentum; in quantum physics, when two observables are mutually complementary, one observable cannot be measured without disturbing the other. Due to the complementarity (or uncertainty) principle, the Wigner function is not always positive semi-definite and may be negative valued for some quantum states. Since it is not allowed by any classical probability distribution, the negativity is regarded as a signature of the nonclassicality. In addition, Quantum mechanics does not allow any noninvasive measurements in general. A direct observation of the noninvasive measurability is possible if taking an operational approach to define a commensurate quasi-probability function (CQF), which is positive semi-definite for every macro-realistic model. We propose an optical experiment of a single polarization qubit to study such a nonclassicality in terms of CQF. The experimental results are consistent with the quantum theory. They also confirm that the negativity depends on both quantum state and observable.

Measurement-Assisted Quantum Communication in Spin Channels with Dephasing

Presenter: Yasser Omar
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We propose a protocol for countering the effects of dephasing in quantum state transfer over a noisy spin channel weakly coupled to the sender and receiver qubits. Our protocol, based on performing regular global measurements on the channel, significantly suppresses the nocuous environmental effects and offers much higher fidelities than the traditional no-measurement approach. Our proposal can also operate as a robust two-qubit entangling gate over distant spins. Our scheme counters any source of dephasing, including those for which the well established dynamical decoupling approach fails. Our protocol is probabilistic, given the intrinsic randomness in quantum measurements, but its success probability can be maximized by adequately tuning the rate of the measurements. Work by A. Bayat and Y. Omar.

Measurements of non-locality and phase coherence in Bose-Einstein condensates

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Atomic Bose-Einstein condensates (BECs) are highly controllable isolated quantum systems with long coherence times, and offer applications in metrology and quantum information processing. We experimentally prepare two-component Rubidium-87 BECs, consisting of a few hundred atoms, on an atom-chip [1]. Using state-selective potentials to tune the collisional interactions (one-axis twisting dynamics), we prepare many-particle non-classical states [2] that we analyze by quantum state tomography.

By observing non-locality, it is possible to demonstrate that a system cannot be described by a local (classical) theory, even if the underlying local variables are hidden [3]. As a consequence, provably secure randomness can be extracted from any non-local system. We present a robust experimental technique for detecting non-locality in a two-mode BEC, and the most recent experimental results.

In finite-temperature BECs, interactions with the non-condensed fraction are predicted to limit the phase coherence [4]. We experimentally study the decoherence dynamics and its fundamental limits by performing Ramsey spectroscopy with BECs of different temperatures and densities, which are prepared by controlled shaking of the trap.

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Measuring time with physical clocks: loss of coherence due to gravitational interaction

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In general relativity, the picture of space-time assigns an ideal clock to each space-time point. Being ideal, gravitational effects due to these clocks are ignored and the flow of time according to one clock is independent of the flow of time according to any other. However, if time is defined operationally, as a pointer position of a physical clock that obeys the laws of quantum mechanics and general relativity, such a picture is at most a convenient fiction. We show that the requirement that a clock is dynamical (i.e. is in an energy superposition) and the mass-energy equivalence imply gravitational interaction between the clocks, which entangles them through time dilation effect and leads to a loss of coherence of a single clock. Hence, the time as measured by a single clock is not well-defined. However, the general relativistic notion of time is recovered in the classical limit of clocks.

Memory Cost for Simulating Sequential Quantum Correlations

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It is well known that contextual properties of quantum measurements cannot be reproduced by classical models. But in an implementation with sequential measurements, it may still be possible to achieve the task by using some classical, deterministic automatons with internal memory. The particular model we use are Mealy machines. We thus characterize contextuality by the number of internal states needed by the machine to reproduce quantum predictions. Following this line, we calculate the amount of memory for the scenario of the Peres-Mermin square.

In the analysis so far, the only requirement on the automaton was that it merely must not produce events that are forbidden according to QM. One could expect that it is much more expensive to reproduce the exact probabilities. We find that this is not the case: mixtures of deterministic automata with three internal states are sufficient to simulate all quantum correlations.

Mesoscopic quantum superposition using a single NV- centre in a diamond nanoparticle

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Recently the spin of a nitrogen vacancy (NV-) centre has been proposed as a probe to demonstrate the superposition of spatially separated centre-of-mass (CM) states of a mesoscopic diamond bead levitated in an optical trap in high vacuum [1]. This scheme relies on ms=±1 spin states of the NV-centre for the creation of CM superposition and for the spatial separation of the CM states in an inhomogeneous magnetic field. Further, in this proposal for the demonstration of the superposition, the intensity modulation of the fluorescence from the NV - centre due to gravity induced phase difference between the spatially separated coherent states has been exploited [1].
Towards the implementation of this proposal, we levitate diamond beads containing NV - centres and measure trap frequencies. In the axial direction trap frequency is 15-30 kHz while in the radial directions it is 100-200 kHz. Whilst detecting fluorescence from trapped diamond particles with NV- centres, we find that it is heavily quenched by the trapping laser (1064 nm). We believe that absorption by impurities in diamond [3], multi-photon absorption by the diamond matrix [4], and transition to a dark to state due to 1064 nm laser [2] are among the possible reasons for fluorescence quenching. To rectify this problem, we modulate our trap by an acousto optic modulator to facilitate efficient heat release. Further, to reduce the impact of impurities in diamond, we are making purer diamond nanoparticles from chemical vapour deposited bulk diamond instead of the existing high temperature high pressure diamond. We believe that these measures will rectify the problem of fluorescence quenching from NV- centres and will enable us to demonstrate mesoscopic quantum superposition.

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Mobile polaronic impurities in quasi-one-dimensional Bose-Einstein condensates

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In recent years considerable research efforts have been expended towards understanding the behavior of polarons that result from immersing mobile (bosonic) impurities in Bose-Einstein condensates (BECs). The interaction between such impurities and Bogoliubov phonons of the host condensate is described by a Froehlich-type Hamiltonian. The impurity degrees of freedom can be removed from this Hamiltonian by means of the Lee-Low-Pines (LLP) canonical transformation, at the expense of generating a quartic bosonic term that describes the impurity-mediated interaction between different phonon modes.
We investigate the resulting interacting-boson problem in a quasi-one dimensional BEC by going beyond the mean-field treatment, i.e., taking into account fluctuations around the saddle-point (mean-field) configuration. We make use of the flow-equation (continuous unitary transformation) approach, adopting as our point of departure the Hamiltonian that results from the LLP and mean-field-shift canonical transformations applied to the original Froehlich-Bogoliubov Hamiltonian of the system. By solving the ensuing systems of coupled flow equations, we obtain the ground-state energy of the system and other relevant quantities, such as the total number of phonons in the polaron cloud. We compare the results obtained for different values of the system parameters (the impurity-boson mass ratio, the conserved total momentum of the system, etc.) to those found using the mean-field- and momentum-shell renormalization-group treatments. Finally, we also discuss the implications of our results for ongoing experiments.

Necessary and sufficient conditions for macroscopic realism from quantum mechanics

Presenter: Lucas Clemente
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Macroscopic realism, the classical world view that macroscopic objects exist independently of and are not influenced by measurements, is usually tested using Leggett-Garg inequalities. Recently, another necessary condition called no-signaling in time (NSIT) has been proposed as a witness for non-classical behavior. Here we show that a combination of NSIT conditions is not only necessary but also sufficient for a macrorealistic description of a physical system. Any violation of macroscopic realism must therefore be witnessed by a suitable NSIT condition. Subsequently, we derive an operational formulation for NSIT in terms of positive-operator valued measurements and the system Hamiltonian. We argue that this leads to a suitable definition of "classical" measurements and Hamiltonians, and apply our formalism to some generic coarse-grained quantum measurements.

POSTER CONTRIBUTIONS

Tuesday, 19 May 2015

Arcades, University of Vienna, Universitätsring 1, 1010 Vienna

Sorted alphabetically by poster title

Determination of new operational entanglement measures for bipartite and multipartite quantum states

Presenter: David Sauerwein
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In [1] we introduced new classes of operational entanglement measures that are defined for pure and mixed states describing arbitrary quantum systems. One class quantifies the set of states into which a quantum state can be converted using local operations and classical communication (LOCC), while the other class measures the set of states from which a given state can be obtained via LOCC. Here, we determine these novel measures for pure bipartite states of any local dimensions and for pure four-qubit states. We provide a clear geometrical picture of the underlying sets of states that is used in order to compute the new quantities. Moreover, we show how the new measures can be employed to characterize the entanglement contained in these bipartite and multipartite quantum states.

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Molecular beam methods for matter wave interferometry

Presenter: Ugur Sezer
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Matter wave interferometery with complex molecules and nanoparticles require an interdisciplinary expertise in fundamental physics, quantum optics and physical chemistry[1]. Such experiments have two key motivations: on the one hand they allow us to explore the transition from quantum physics to classical observations. On the other hand quantum assisted molecular metrology provides new insight into the internal properties and dynamics of molecules [2-4]. Further progress depends significantly on appropriate molecular sources[5]. Here we tackle this challenge along three new avenues:

a) Laser induced acoustic desorption (LIAD) of natural and functionalized chromophores.

We show that LIAD allows one to volatilize fragile, heavy and intact molecules with low forward velocities, down to 20 m/s. This is of particular interest for quantum assisted deflectometry[3] and precision spectroscopy[4].

b) Laser desorption of peptides and proteins into a buffer gas.

Since biomolecules are known to be thermally labile and cannot simply be evaporated, we here present how to laser inject molecules into a pulsed noble gas beam. We show this for large peptides such as indolicidin (ca. 1’900 amu) and even large protein complexes like the perdinin chlorphyll protein complex (ca. 33’000 amu).

c) Laser assisted evaporation of perfluoroalkylated silver nanoparticles.

In recent experiments we were able to show that tailored organic molecules up to 25’000 amu can be synthesized and launched with properties suitable for matter wave interferometery[6], however typically in low quantity. A new synthetic approach is based on functionalizing silver nanoparticles with perfluoroalkyl chains. The size of the metal core can be tuned to high masses and the ligands increase their volatility. We show that perfluoroalkylated silver nanoparticles can be intactly evaporated and subsequently photoionized with VUV light at 157 nm.

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Molecular matter-wave-diffraction at a single sheet of atoms

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Diffraction experiments with matter-waves rely on the performance of the beam splitter employed. While closed optical transitions in atoms are used to realize large momentum transfer beam splitters made of light [1,2] the complex energy structure of polyatomic molecules renders this approach difficult. Material gratings have the advantage that, to first order, they are independent of the matter-waves' internal properties, which makes them useful for a wide class of particles.[3] However, the attractive van der Waals interactions leads to a substantial phase shift of the diffracted molecules and may even prevent them from traversing the grating.[4] In order to reduce this interaction, we have minimized the thickness of the grating material to its physical limit.[5]
We have observed matter-wave diffraction of organic molecules (>500 atomic mass units) at gratings milled into a free-standing membrane of single and double layer graphene. Furthermore, gratings made of carbon nanoscrolls and written into a 1 nm thin insulating biphenyl membrane were tested. From the population of high diffraction orders we deduce a minimal van der Waals interaction for single layer graphene. This paves the way for new quantum experiments with material gratings.

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Monogamy of correlations in the quantum world

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Correlations, classical as well as quantum, present in quantum systems play a significant role in quantum physics. Monogamy forms a connecting theme in the exquisite variety in the space of quantum correlation measures. In simple terms, monogamy dictates that if two quantum systems are highly quantum correlated with respect to some quantum correlation measure, then they cannot be significantly quantum correlated with a third party with respect to that measure.

We begin by discussing how different quantum correlation measures exhibit disparate properties with respect to their monogamy and violation of the same. In particular, we discuss the monogamy of quantum discord which is an information-theoretic quantum correlation measure, and the possibility of beating a monogamy-related no-go–type restriction by introduction of quenched disorder in a paradigmatic quantum spin model.

We then show that themes binding such disparate results have begun to emerge. In particular, we show that all quantum correlations are either already monogamous or can be made so by considering monotonically increasing functions of it, and that all quantum correlations become monogamous for almost all quantum states of a moderately large number of parties.

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arXiv: 1312.6640; arXiv:1406.7239 (to appear in New J. Phys.);
arXiv:1412.6519.

Nano-mechanical quantum states in a circuit quantum electrodynamics device

Presenter: Mehdi Abdi
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Co-Authors: Pernpeintner, Matthias; Gross, Rudolf (Technische Universität München, Garching); Huebl, Hans (Walther-Meißner-Institut, Garching, Germany); Hartmann, Michael J. (Heriot-Watt University, Edinburgh)

Mechanical resonators in their quantum regime are of fundamental and technical interest. However, having a full quantum behavior on these harmonic oscillators requires strong coupling between them and another controllable quantum system, e.g. photons or qubits.

Here, we introduce and study a hybrid system with quantum mechanical interactions between photons, phonons, and excitations of a superconducting qubit. The interactions happen in a circuit QED device featuring a transmon qubit with a mechanical resonator mounted in its shunt capacitor. This system offers a strong nonlinear transmon–mechanical interaction. Moreover, when combined with a strong cavity–transmon interaction, it allows for a wide range of manipulations of the system due to the anharmonicity of the transmon qubit. We will show that in terms of polaritons (a hybridization of the microwave excitations in the resonator and the transmon qubit) two kinds of three-body interactions in the strong coupling regime between the mechanics and the polaritons emerge: One couples the number of polariton quanta to the mechanical position and the other couples a conversion between two polariton types to the position of the mechanical resonator. An important innovation of the architecture is the combination of strong three-body coupling and the anharmonicity of the polaritonic modes that provides for exquisite control of the mechanical mode.

In a few examples we will exploit the advantages of these features. In particular, the interactions can be employed for cooling the mechanical mode to its ground state and preparing it in non-classical states of different categories. Examples therefore are mechanical Fock and cat states, non-Gaussian optomechanical, and hybrid tripartite entangled states. Therefore, we believe that the setup proposed here offers a quantum toolbox for broad control of the mechanical resonator.

Narrow-band Polarization Entangled Photon Pairs Source Resonant to Cs Atoms

Presenter: Giulia Rubino
Affiliation: University of Vienna

Co-Authors: Moqanaki, Amir; Walther, Philip (University of Vienna)

Photonic waveguide chips are a promising platform for miniaturizing and implementing complex photonic networks. Though, lack of strong non-linearities poses a big obstacle for building functional quantum photonic devices since non-linear interactions are an essential ingredient for many applications (e.g. quantum memories, two qubit gates, etc.).
The QuILMI consortium (Quantum Integrated Light and Matter Interface) is aimed at creating an integrated platform for light-matter interactions. This is realized by inserting cold atoms in waveguide networks, as they can potentially provide very high non-linearities.
Our group at the University of Vienna, as a member of QuILMI, is developing a source of polarization entangled photon pairs tuned to the atomic transitions (Cs D2 line, 852 nm) and optimized for coupling into the waveguides. This narrow-band photon source is based on spontaneous parametric down conversion (SPDC) in an optical resonator to actively filter and narrow down the photons bandwidth to that of the Cs atoms (~ 32 MHz).

No External Randomness is Needed to Send Private Messages

Presenter: Edgar Aguilar Lozano
Affiliation: University of Gdansk

Co-Authors: Ramanathan, Ravishankar (University of Gdansk, Poland); Kofler, Johannes (Max Planck Institute of Quantum Optics, Garching); Pawlowski, Marcin (University of Gdansk, Poland)

Randomness is a highly valuable resource which is difficult to come by, especially in a world where we regard everyone as an adversary. Recent advances in the field of Randomness Extraction and Expansion have given the needed mathematical tools to prove that it is possible for two parties to establish a secret cryptographic key when randomness is not available as a resource. Instead of requiring the parties to have initial random seeds, we are able to show that it is sufficient for the message they want to communicate to be (partially) unknown to the adversaries. Hence, this article minimizes the assumptions needed to perform secure Device Independent Quantum Key Distribution (DIQKD).

Noise resistance of the violation of local causality for pure three-qutrit entangled states

Presenter: Wieslaw Laskowski
Affiliation: University of Gdansk

Co-Authors: Ryu, Junghee; Zukowski, Marek (University of Gdansk, Poland)

Bell's theorem started with two qubits (spins 1/2). It is a 'no-go' statement on classical (local causal) models of quantum correlations. After 25 years, it turned out that for three qubits the situation is even more astonishing. General statements concerning higher dimensional systems, qutrits, etc, started to appear even later, once the picture with spin (higher than 1/2) was replaced by a broader one, allowing all possible observables.
This work is a continuation of the Gdansk effort to take advantage of the fact that Bell's theorem can be put in the form of a linear programming problem, which in turn can be translated into a computer code. Our results are numerical and classify the strength of the violation of local causality by various families of three-qutrit states, as measured by the resistance to noise. This is previously uncharted territory. The results may be helpful in suggesting which three-qutrit states will be handy for applications in quantum information protocols. One of the surprises is that the W state turns out to reveal a stronger violation of local causality than the GHZ (Greenberger-Horne-Zeilinger) state.

On the possible emergence of locality from dynamics.

Presenter: Fabio Michele Costa
Affiliation: University of Vienna, VCQ

Locality is a common feature of all known fundamental interactions: the degrees of freedom associated with a given region of space can only interact with neighbouring regions through the common boundary. This property is defined on the basis of a preassigned division of space into regions, which corresponds to a division of sate space into subsystems at the kinematic level. One can ask if the opposite rationale is possible: can one define regions of space as those subsystems for which the dynamics appears local? Here we find that, in general, such an identification is not possible: there exist Hamiltonians (in fact, the overwhelming majority), which appear non-local with repsect to any decomposition in subsystems. However, if only an appropriately small low-energy subspace is accessible, it becomes possible to find a decomposition in subsystem such that an arbitrary Hamiltonian, when restricted to that subspace, appears local.

Operational multipartite entanglement measures

Presenter: Katharina Schwaiger
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Co-Authors: Sauerwein, David; Cuquet, Martí (University of Innsbruck); de Vicente, Julio (Universidad Carlos III de Madrid); Kraus, Barbara (University of Innsbruck)

We introduce two operational entanglement measures which are applicable for arbitrary multipartite (pure or mixed) states. One of them characterizes the potentiality of a state to generate other states via local operations assisted by classical communication (LOCC) and the other the simplicity of generating the state at hand. We show how these measures can be generalized to two classes of entanglement measures. Moreover, we compute the new measures for few-partite systems and use them to characterize the entanglement contained in a three-qubit state. We identify the GHZ- and the W-state as the most powerful three-qubit states regarding state manipulation.

Optical isolation based on chiral interaction of light and matter in a nanophotonic waveguide

Presenter: Jürgen Volz
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Co-Authors: Sayrin, Clément; Albrecht, Bernhard; Schneeweiss, Philipp; Rauschenbeutel, Arno (VCQ, Vienna University of Technology)

Nanophotonic components confine light at the wavelength scale and enable the control of the flow of light in an integrated optical environment. Such strong confinement leads to an inherent link between the local polarization of the light and its propagation direction [1-3]. We employ this effect to demonstrate low-loss nonreciprocal transmission of light at the single-photon level through a silica nanofiber in two different experimental schemes. We either use an ensemble of spin-polarized atoms weakly coupled to the nanofiber-guided mode [2] or a single spin-polarized atom strongly coupled to the nanofiber via a whispering-gallery-mode resonator [1]. We observe a strong imbalance between the transmissions in forward and reverse direction of 8 dB and 13 dB for the atomic ensemble and the resonator-enhanced scheme, respectively. At the same time, the forward transmissions still exceeds 70%. The resulting optical isolators exemplify a new class of nanophotonic devices based on chiral interaction of light and matter, where the state of individual quantum emitters defines the directional behavior.

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Optical Nanofiber cavity on an Atom Chip

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Atom chips are versatile tools for the trapping, cooling and transport of atoms. Magnetic fields generated by current-carrying structures can be used to confine cold atoms to submicron volumes and to transport them with nanometre precision. We use magnetic structures to deliver laser-cooled atoms to a nanofiber near a silicon surface. The waist of the nanofiber has a diameter of 400nm, leading to a substantial evanescent component of the guided light field. The refractive index of the optical fiber is modulated outside the waist of the nanofiber to form an optical cavity containing the evanescent field. We demonstrate enhanced interaction of magnetically delivered atoms with the evanescent field of the nano-cavity.
The experiment will allow the controlled interaction of one-dimensional quasi-condensates with the enhanced one-dimensional light field of the nanofiber cavity. The system is unique compared to other atom-cavity systems in that it posesses a narrow waist which is not limited by diffraction. The system therefore offers remarkable opportunities for the study of light-matter interactions.

Optimal purification of displaced thermal states

Presenter: Xiaobin Zhao
Affiliation: Tsinghua University

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A central goal of quantum communication networks is the implementation of high f idelity transmission, manipulation, and storage of quantum states [1]. On the way to this goal, the presence of noise represents the main hurdle, affecting the distance over which quantum communication is reliable, the accuracy of gate operations, and the lifetime of quantum memories. Many techniques have been developed in order to reduce the detrimental effects of noise, both for qubit systems and for continuous variable states of light and atoms [2-5]. One such technique is purification [2, 3], which attempts to reduce the noise in a teleportation channel by transforming multiple copies of a bipartite mixed state into a smaller number of copies of a state that is closer to an EPR state. Thanks to purification, one can increase the transmission fidelity and potentially build a larger and more robust system. Purification can be applied not only to the entangled states used as a resource for teleportation, but also to the states that emerge from a noisy communication channel. For example, one can imagine the scenario where multiple qubits pointing in the same direction are sent through a depolarizing channel and the goal of purification is to produce a smaller number of qubits pointing in the same direction, but with a longer Bloch vector [4, 5]. In this work we focus on the purification of displaced thermal states, which are generated by thermal noise acting on input coherent states. Assuming that the input states are Gaussian-modulated, we establish the ultimate quantum limit for the pu- rification fidelity, treating separately the case of deterministic protocols and that of protocols using postselection. We show that, in a suitable regime, postselection can give significant improvements in the quality of purification, at the price, of course, of a reduction of the probability of success of the protocol. The advantage of posts-election is a genuine consequence of the finite width of the Gaussian modulation—in other words, it is a consequence of the availability of a non-trivial prior information about the state that one wants to purify. In the limit of infinite modulation (i.e. for uniformly distributed displacement), the fidelity gap between deterministic and probabilistic protocols disappears. In addition to purification, we consider also the possibility of amplifying the signal carried by the input states, identifying the ultimate fidelity and the optimal quantum protocols for this task. With respect to previous works [6-8], a key improvement consists in the ability to deal with a non-uniform (Gaussian) distribution over the displacement, which, besides being more realistic, allows us to observe the difference between deterministic and probabilistic protocols. Finally, we provide quantum benchmarks that can be used to certify that a real- istic implementation of a purification protocol cannot be simulated by performing a measurement on the input thermal state and subsequently preparing a pure state. Interestingly, unlike the optimal quantum value, the value of the fidelity that has to be achieved by an experiment in order to pass the benchmark is the same both for deterministic and probabilistic processes.

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Optimal super-replication of states and unitaries from no-signagling.

Presenter: Pavel Sekatski
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Co-Authors: Skotiniotis, Michalis; Dür, Wolfgang (University of Innsbruck)

It has been shown recently that probabilistic quantum cloning can largely over-perform the deterministic one [G. Chiribella et al. Nat. Comm. 4 (2013)]. In the same lines we demonstrate how one can deterministically generate out of N copies of an unknown unitary operation up to N2 almost perfect copies [W. Dür et al PRL 114, 120503 (2015)]. Then we use the no-signaling principle to derive tight upper-bounds for both tasks, proving the optimality of the two protocols [P. Sekatski et al. arXiv:1412.3361]. Similarly we show how no-signaling leads to the Heisenberg limit in the context of quantum metrology. Finally we discuss the relation between deterministic and probabilistic quantum tasks and the correspondence between asymptotic phase-covariant cloning and phase estimation for different figures of merit.

Pairing in a system of a few attractive fermions in a harmonic trap

Presenter: Tomasz Sowinski
Affiliation: Institute of Physics of the Polish Academy of Sciences

Co-Authors: Gajda, Mariusz; Rzazewski, Kazimierz (Polish Academy of Sciences, Warsaw, Poland)

We study a strongly attractive system of a few spin-1/2 fermions confined in a one-dimensional harmonic trap, interacting via two-body contact potential. Performing exact diagonalization of the Hamiltonian we analyze the ground state and the thermal state of the system in terms of one- and two-particle reduced density matrices. We show how for strong attraction the correlated pairs emerge in the system. We find that the fraction of correlated pairs depends on temperature and we show that this dependence has universal properties analogous to the gap function known from the theory of superconductivity. In contrast to the standard approach based on the variational ansatz and/or perturbation theory, our predictions are exact and are valid also in a strong attraction limit. Our findings contribute to the understanding of strongly correlated few-body systems and can be verified in current experiments on ultra-cold atoms.

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Parallel Lives

Presenter: Paul Raymond-Robichaud
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According to standard quantum mechanics, the density matrix formalism provides a complete description of any physical system in the sense that it can be interpreted to provide the expected statistical results of every possible experiment performed on the system. Furthermore, the density matrix can be used to determine the future predictions of an evolving isolated system: given the density matrix of an isolated system at time t1 and the law of evolution of this system from time t1 to time t2 , the density matrix of the system at time t2 is uniquely determined. From our perspective, the purpose of a physical theory is to establish a correspondence between the physical world and the world of our perceptions and thoughts. We can ask the following question about any physical theory: “does the symbolism within that theory represent the real world (ontic), or is it only what can be known about the real world (epistemic)?”. In the case of the density matrix formalism of quantum mechanics, this question becomes: “Do density matrices represent the world as it is, or are they just states of knowledge about the world?”. Consider now an entangled system shared between two locations. According to the formalism of quantum mechanics, the density matrix of each subsystem is determined by the density matrix of its parent system via partial tracing. However, given the density matrices of the subsystems, it is generally impossible to amalgamate them and reconstruct the density matrix of the whole. Said otherwise, the global density matrix contains more information than its partial traces. Everything written above reflects standard quantum mechanics and should therefore have caused no surprise (but perhaps some boredom) to our readers. The question of interest to us is: “Is the whole really greater than the parts?”. Said otherwise, is the Quantum truly holistic or could it be reductionist? Standard quantum mechanics is intrinsically holistic and this viewpoint is fully appropriate for a “Shut up and calculate" approach. Nevertheless, one may wonder whether the density matrix was the right description of reality all along. Again, the issue with density matrices is that while they make it possible to trace out subsystems, the latter cannot be joined back together in order to recreate the state of the composite system. This begs the following fundamental question: would it be possible to rebuild quantum mechanics in a way that the state of any composite system is nothing more than the state of the subsystems composing it? Better, can we evolve the state of subsystems in a purely local manner in such a way that the global state of the composite system can still be determined from the local state of the evolved subsystems? In this work, we show how such a vision is indeed possible thanks to our notion of "evolution matrices". Furthermore, we formalize all the aforementioned metaphysical concepts. Density matrices, which still describe all the locally accessible information, can be derived from the evolution matrices. However, the evolution matrices contain additional information, which is key to a reductionist explanation for the underlying reality. Note that additional information is required in any reductionist theory, which makes the density matrix necessarily epistemic. We hold a vision in which measurements do not exist but parallel lives are very real. In terms of interpretation, ours is related to the Church of the Larger Hilbert Space. Nevertheless, we depart from the standard Everettian belief that the state of the universe is fully described by its wavefunction. On the contrary, we prove that any such approach would have to be holistic rather than reductionist. From this perspective, a world identified to the universal wavefunction is but a shadow of the real world…

Probabilistic quantum machines: A complete geometric view

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Parametric amplification of the readout process in Raman atomic memory

Presenter: MichalDabrowski
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On-demand retrieval of pre-stored photons can be accomplished using quantum memories. This is an indispensable technique for long distance quantum communication networks and for the enhanced generation of multi-photon states. Such states find applications in a linear quantum computing scheme or quantum simulators using linear optics. Implementations of quantum memories in room-temperature setups are among the most auspicious in terms of possible future applications due to their robustness. Until now room-temperature quantum memories have been realized in solid state systems and in warm atomic ensembles such as gradient echo memory, Raman memory or EIT memory. Here we demonstrate experimentally the theoretical concept of ``Hamiltonian engineering''. We design the Hamiltonian at the readout from Raman atomic memory in warm Rb-87 vapors. In such memory photons are stored in atomic collective excitations called spin-waves. They are interfaced to photons via off-resonant Raman transitions. Ideal readout from Raman atomic memory relies on a pure anti-Stokes scattering process which maps the spin-wave state onto photons state. In real systems additional Stokes scattering at the readout is virtually inevitable and it is a source of extra noise. By modifying the interaction Hamiltonian we are able to control the relative contributions of anti-Stokes and Stokes scattering processes. In the particular setting of our experiment this enables parametric amplification of the readout, albeit with extra noise. We use simple theoretical model describing the coaction between anti-Stokes and Stokes scattering in readout. Previous approaches to describe theoretically the readout of spin-wave excitations in Raman scattering were focused only on a pure anti-Stokes process. Theoretical descriptions of readout from Raman-type memory have already been given for a number of cases, including spatio-temporal evolution with losses, temporal eigen-modes, optimized retrieval, and spatial modes. However, in those aproaches emphasis was put on the pure anti-Stokes scattering. In the present work we use the extended description of the readout process, taking into account the four-wave mixing that includes the Stokes scattering. In the experiment we detect scattered light with spatial resolution and temporal gating using intensified sCMOS camera. This enables directly relating the experimental results to the theoretical predictions for temporal evolution of scattered light. Stokes and anti-Stokes light contributions can be distinguished through intensity correlation measurements and quantified via careful post-processing. Our results can be useful for suppressing unconditional noise floor in readout of Raman-type quantum memories at the single photon level. When anti-Stokes scattering is used to map the spin-wave states onto the states of light, the accompanying Stokes scattering creates unwanted random photons and atomic excitations. Our results show that, though inevitable, this contribution can be estimated by our model and suppressed by adjusting the coupling light frequency to the other side of the atomic resonance. There is also an optimal duration for the anti-Stokes interaction. Beyond the optimum, the spontaneous noise contribution increases.

The amplification of readout signal by Stokes scattering may be very useful in some applications especially if extra noise is not crucial. This is the case when we use detectors of small quantum efficiency or we are focused on other properties of retrieved light e.g. in retrieval of stored images. For instance the amplification in the readout can be utilized as a robust single-shot projective test to see whether the atomic memory is in the ground (empty) state. The facility to continuously tune the Hamiltonian coefficients sets the scene for developing new quantum protocols in room-temperature atomic memories.

Partial separability and multipartite entanglement measures (poster)

Presenter: SzilárdSzalay
Affiliation: MTA Wigner Research Centre for Physics

The main concern of this poster is how to define proper measures of multipartite entanglement for mixed quantum states. Since the structure of partial separability/entanglement is getting complicated if the number of subsystems exceeds two, one cannot expect the existence of an ultimate scalar entanglement measure which grasps even a small part of the rich hierarchical structure of multipartite entanglement, and some higher order structure characterizing that is needed. In this poster we show some results from a forthcoming paper [1] making some steps towards this direction.

First, we reveal the lattice-theoretic structure of the partial separability classification, introduced earlier [2] as a complete extension of preceding works on the classification problem [3,4]. It turns out that the structure of the entanglement classes is the up-set lattice of the structure of the different kinds of partial separability/entanglement, which is the down-set lattice of the lattice of the partitions of the subsystems.

Second, we introduce the notion of multipartite monotonicity, expressing that a given set of entanglement monotones, while measuring the different kinds of entanglement, shows also the same hierarchical structure as the entanglement classes. Then we construct such hierarchies of entanglement measures, and propose some physically well-motivated ones, based on the notion of statistical distinguishability.

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Planar antenna for 99% efficiency in collecting photons

Presenter: Xiao-LiuChu
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A single photon source with well-defined photon arrival times in well-defined modes is a highly desirable resource for various applications, including quantum communication, quantum cryptography and sub-shot-noise detection. In these applications, performance is quickly compromised by losses. In quantum key distribution, for example, low losses are desirable both for increased data transmission rates and higher security of the connection.

In this work, we fabricate and characterize a planar antenna which serves to direct the emission from an arbitrarily oriented single quantum emitter with 99% efficiency [1][2][3]. The antenna design composes of a multilayered architecture with stepwise change in the refractive index across the structure. Single non-blinking colloidal quantum dots (CdS/CdSe) serve as the single-photon source. The stream of single photons emitted by a quantum dot sandwiched between the thin polymer films (PMMA/PVA) are channeled into the high index substrate (sapphire) and collected by a standard microscope objective.

We demonstrate the performance of the antenna by investigating the angular emission pattern from a single quantum dot. The experimental results show a remarkable agreement with the theoretical design, which predicts collection efficiencies greater than 99% [3]. Such an antenna provides a crucial building block of an ultra-bright single-photon source that can deliver up to several tens of millions of photons per second at deterministic times.

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Practical and efficient experimental characterization of multiqubit stabilizer states

Presenter: Marie-ChristineRoehsner
Affiliation: University of Vienna

Co-Authors: Philip Walther, University of Vienna

Vast developments in quantum technology have enabled the preparation of quantum states with more than a dozen entangled qubits. The full characterization of such systems demands distinct constructions depending on their specific type and the purpose of their use. Here we present a method that scales linearly with the number of qubits for characterizing stabilizer states. Our approach is based on the concept of Identity Products (IDs) and allows simultaneous extraction of information about the fidelity, the entanglement, and the nonlocality of the state and thus is of high practical relevance. We demonstrate the efficient applicability of our method by performing an experimental characterization of a photonic four-qubit cluster state and three- and four-qubit Greenberger-Horne-Zeilinger states. Our scheme can be directly extended to larger-scale quantum information tasks.

Practical Measurement Device Independent Entanglement Witness

Presenter: EphanielleVerbanis
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Co-Authors: Rosset, Denis; Martin, Anthony; Lim, Charles C. W.; Thew, Robert (GAP, University of Geneva)

Entanglement is one of the quintessential characteristics of quantum physics and is a valuable resource in emerging quantum technologies.A reliable verification and characterization of entanglement is therefore critical for many applications and protocols. Various methods have been proposed to demonstrate entanglement. One of them uses a so called entanglement witness to distinguish entangled states from separable ones. An entanglement witness is defined such that for a given quantum state ρ and an hermitian operator W, the state is said to be entangled if $\mathrm{Tr}[\rho\, W] < 0$, otherwise it is separable. This standard entanglement witness relies on a perfect implementation of the measurements. Importantly, if there are errors in the implementation of the measurements, then one cannot faithfully witness entanglement. Approaches based on Bell inequalities have been proposed to overcome this problem of device dependency. The violation of Bell inequalities, which guarantees the presence of entanglement, is completely independent of the measurements or the internal workings of the measuring devices. However, these methods require the detection loophole to be closed to ensure that fair sampling has been restricted and one has reliably witnessed entanglement.
A novel solution to this was recently proposed by Branciard {\it et al.}, whereby instead of using classical inputs to perform a Bell test, quantum states inputs are sent to the participating parties -an approach arising out of work on nonlocal games by Buscemi. In this scenario, an entanglement witness which is robust to measurements imperfection can be derived. This measurement-device-independent entanglement witness (MDIEW) provides a new entanglement detection scheme which is tolerant to losses and does not require to trust the detecting devices. Here we introduce a variation of the MDIEW protocol that exploits another recent idea of detector device independent QKD. Instead of preparing ancilla qubits to probe the entangled state, a qubit state is encoded in an extra degree of freedom, via a simple linear circuit. In doing this we greatly simplify the experimental overhead to perform MDIEW. Previous demonstrations about MDIEW have required 6 photon experiments; two entangled photons and two heralded photon sources for the local quantum states to probe the entanglement. With our practical two-photons implementation, we characterized the entanglement in SPDC sources, using untrusted detectors and facing high losses. In MDIEW protocols, the requirement to trust measurements is replaced by the requirement to trust the inputs generation. In principle, the input qubit must be prepared exactly as specified in the assumptions. Experimentally, it is often impossible to achieve perfect qubit preparation. Here, we also investigate the impact on the entanglement characterization of systematic and fluctuating errors in the input qubit preparation.

Projective simulation with generalization

Presenter: Alexey Melnikov
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Co-Authors: Makmal, Adi; Dunjko, Vedran; Briegel, Hans (University of Innsbruck)

The capacity to generalize is an important feature of any intelligent agent. It empowers the agent to cope with large amount of data and allows to handle previously unencountered perceptual stimuli. We present a dynamic and autonomous machinery that enables projective simulation agent to meaningfully generalize. Both projective simulation, a novel physical approach to artificial intelligence based on stochastic processing of data, and the presented generalization machinery are based on very simple principles. This simplicity allows us to provide an extensive analytical analysis of the agent's performance.

Propagation of nanofiber-guided light through an array of atoms

Presenter: Le KienPham
Affiliation: Vienna Center for Quantum Science and Technology

Co-Authors: Rauschenbeutel, Arno (Vienna Center for Quantum Science and Technology)

We study the propagation of nanofiber-guided light through an array of atomic cesium, taking into account the transitions between the hyperfine levels $6S_{1/2}$ F=4 and $6P_{3/2}$ F'=5 of the D_2 line. We derive the coupled-mode propagation equation, the input-output equation, the scattering matrix, the transfer matrix, and the reflection and transmission coefficients for the guided field in the linear, quasistationary, weak-excitation regime. We show that, when the initial distribution of populations of atomic ground-state sublevels is independent of the magnetic quantum number, the quasilinear polarizations along the principal axes *x* and *y*, which are parallel and perpendicular, respectively, to the radial direction of the atomic position, are not coupled to each other in the linear coherent scattering process. When the guided probe field is quasilinearly polarized along the major principal axis *x*, forward and backward scattering have different characteristics. When the array period is far from the Bragg resonance, the backward scattering is weak. Under the Bragg resonance, most of the guided probe light can be reflected back in a broad region of field detunings even though there is an irreversible decay channel into radiation modes. When the atom number is large enough, two different band gaps may be formed, whose properties depend on the polarization of the guided probe field.

Proposal of creating spin cat states in Bose-Einstein condensates

Presenter: Hon WaiLau
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Lots of efforts are currently made in many areas to bring quantum effects to the macroscopic level. A particularly dramatic class of macroscopic superposition states are the so-called cat states, which has been demonstrated in experiment with over one hundred microwave photons. In our recent works, we have proposed an experimental scheme to create spin cat states in Bose-Einstein condensates (BEC) with the possibility of cat sizes of hundreds of atoms based on detailed study of atom loss [Lau et. al, PRL 113, 090401 (2014)]. Our scheme relies purely on the Kerr nonlinearity due to atomic collisions in BEC with two different hyperfine states. We show that with suitable choice of system, magnetic field and high trapping strength, it is possible to significantly increase the Kerr effect while suppressing the two-body loss. This results in small overall loss and fast cat time, hence, a large spin cat state. The existence of cat states can be proved by the homodyne detection on the optical readout. Our analysis also includes the effects of higher-order nonlinearities, atom number fluctuations, and limited readout efficiency.

Protected Subspace Ramsey Spectroscopy

Presenter: LaurinOstermann
Affiliation: Institute for Theoretical Physics, University of Innsbruck

Co-Authors: Plankensteiner, David; Ritsch, Helmut; Genes, Claudiu (Institute for Theoretical Physics, University of Innsbruck, Austria)

The present poster introduces the concept of asymmetric Ramsey spectroscopy, where collective dipole-dipole interaction is exploited to increase the sensitivity of a Ramsey experiment instead of being an unwanted source of noise. Employing two extra (local) operations on the individual atoms, one before and one after the period of free evolution, allows for the collective state to exhibit a minimal total dipole, thus protecting it from environmental decoherence and decay. The poster will focus on recent results in extended 2D- and 3D-systems and provide examples as to how such a technique could be implemented using today's experimental methods.

Quantum Cheshire Cats and Uncertainty Relations studied with Neutrons

Presenter: StephanSponar
Affiliation: Technische Universität Wien

Co-Authors: Denkmayr, Tobias; Geppert, Hermann; Demirel, Bülent; Hasegawa, Yuji (Vienna Univ. of Technology)

Neutron interferometry [1,2], where an interference effect of matter-waves passing through a perfect silicon-crystal interferometer is observed, and neutron polarimetry (also referred to as spin-interferometry) have established as a powerful tool for investigations of fundamental quantum mechanical concepts using massive particles. The former technique enabled several textbook experiments, such as demonstrations of the 4π spinor symmetry of spin-1/2 particles, spin superposition, gravitational and topological phase effects, as well as studies of intra-partite entanglement, i.e., entanglement between different degrees of freedom. The latter was utilized for demonstration of anti-commuting properties of Pauli spin matrices, topological phase measurements, and tests of alternative theories of quantum mechanics.
Heisenberg's uncertainty principle is probably the most famous statement of quantum physics and its essential aspects are well described by formulations in terms of standard deviations. However, a naive Heisenberg-type error-disturbance relation (EDR) is not valid in general. An improved error-disturbance uncertainty relation, proposed in 2003 by Ozawa [3]. My poster will present an overview of our neutron optical approaches for investigations of error-disturbance uncertainty relations via a successive measurement of non-commuting neutron spin observables [4]. The disturbance on one spin observable is induced by a prior measurement of another incompatible spin observable. Though universally valid, Ozawa's relation is not optimal. Recently, Branciard has derived a tight EDR, describing the optimal trade-off relation between error and disturbance. Our experimental results clearly demonstrate the validity of Ozawa's and Branciard's EDR and that the original Heisenberg EDR is violated throughout a wide range of experimental parameters [5]. Nevertheless, Branciard's relations can be considerably strengthened for measurements for mixed states. In a recent experiment we demonstrate tightness of a stronger error-disturbance relations for mixed states using a neutron polarimetric setup. This new relations will play an important role in applications to state estimation problems including quantum cryptographic scenarios.
In addition, a new counter-intuitive phenomenon, the so-called quantum Cheshire Cat which was proposed by Aharonov and his co-workers in [6], is demonstrated in a neutron interferometric experiment [7] by applying so-called weak-measurements [8]: If a quantum system is subject to a certain pre- and post-selection, it can behave as if a particle and its property are spatially separated. In our neutron interferometer experiment weak values of the neutron's path and spin are determined, suggesting that for the successfully post-selected ensemble the neutrons go through one beam path of the interferometer, while their spin travels along the other - a disembodiment of a quantum particle from its properties.

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Quantum controlled-Z gate for weakly interacting qubits

Presenter: Michal Micuda
Affiliation: Palacky University

Co-Authors: Starek, Robert; Straka, Ivo; Mikov a, Martina; Dusek, Miloslav; Jezek, Miroslav; Filip, Radim; Fiurasek, Jaromir (Palacky University, Olomouc, Czech Rep.)

We propose and experimentally demonstrate a scheme for conditional implementation of a maximally entangling quantum controlled-Z gate between two qubits whose coupling can be arbitrarily weak. We show that the weak inter-qubit coupling can be enhanced by quantum interference. Both before and after the interqubit interaction, one of the qubits is coherently coupled to an auxiliary quantum level, and finally it is projected back onto the qubit subspace. This procedure enhances the inter-qubit interaction strength although the coupling to auxiliary quantum level can be considered as a local bypass that allows the qubit to partly avoid the interaction with the other qubit. We experimentally demonstrate our scheme using a linear optical setup with weak interferometric coupling between single-photon qubits. In our experiment, we utilize time-correlated photon pairs generated in the process of spontaneous parametric downconversion and we exploit their polarization and spatial degrees of freedom to implement the quantum bypass. We characterize the performance of our scheme by measuring the Hofmann lower bound on quantum gate fidelity for various strengths of coupling to the auxiliary mode. At the optimal operating point where the fidelity and success probability are maximized we perform a full quantum process tomography of the quantum CZ gate. This yields a gate fidelity F=0.846, which is consistent with a theoretical model of our experiment.

Quantum parameter estimation using multi-mode Gaussian states

Presenter: DominikSafranek
Affiliation: University of Vienna

Optimal estimation of physical parameters from quantum states is becoming one of the crucial steps towards the new-era quantum technologies. Progress in this field will lead to the detectors and sensor with precision far beyond what we can do now, with both commercial and fundamental applications. Most of the experimental setups now use a special kind of states called Gaussian states. However, current mathematical formalism for estimation of parameters from Gaussian states is particularly ineffective. We derive formulae for the optimal estimation of parameters using two- and multi-mode Gaussian states in the so-called phase-space formalism, which allows for an effective study of the precision limits in the detectors particular implementation.

Quantum Randomness Certified by the Uncertainty Principle

Presenter: GiuseppeVallone
Affiliation: University of Padova

Random numbers are of fundamental importance for scientific and practical applications. On the last years, great effort has been devoted to Quantum Random Number Generators (QRNG), based on the intrinsic randomness of the quantum measurement process. Recently, Device Independent (DI) protocols showed the possibility to generate secure random numbers that are certified by the violation of a Bell inequality. The disadvantage of such protocols lies in the fact that they are difficult to implement because loophole-free violations of Bell inequalities are required.

Here we present a method, based on the Uncertainty Principle, to estimate the amount of true randomness that can be obtained by a given source. The advantage of the presented method resides on its simplicity: no Bell inequality violation is required but it is only necessary to measure the system in two conjugate bases. With an initial seed of true randomness, our protocol is able to expand the randomness by taking into account all possible side quantum information possessed by an adversary.

We now describe in detail our method. A general QRNG works as follows: given a d-level quantum system A prepared in a state ρA, the random variable Z is obtained by measuring the state ρA with a d outcome measurement Z: each outcome z is obtained with a given probability Pz. If the state ρA is pure, the number of true random bits that can be extracted from each measurement is quantified by the classical min-entropy H(Z) = −max z(log2 Pz). If the state ρA is mixed, the system A is correlated with another quantum system, denoted by E. In this case, the amount of true random bits that can be extracted from the random variable Z, if one requires uniformity and independence from the environment system E, is given by the conditional min-entropy $H_{min}(Z|E)$ [1].

Our method allows to estimate the conditional min-entropy and then the amount of true randomness that can be obtained by a given source by exploiting the Uncertainty Principle. Indeed, by measuring the system in conjugate observables Z and X, it is possible to obtain the following bound on the conditional min-entropy [2]

Hmin(Z|E) ≥ log2(d) − H1/2(X),

where d is the dimension of the Hilbert space and H1/2(X)=2 log2 Σx (px)1/2 the max-entropy of the X outcomes. The measurement Z is used to generate the random sequence Z, while the measurement X is used to quantify the amount of true-randomness contained in Z. In our protocol we do not use any assumption on the source ρA: an adversary, called Eve can have full control on the source and the environment E. The bound is achieved by only assuming trusted measurements device, meaning that Eve has no access to it and that the device performs a given POVM that are only sensitive to a subspace of dimension d. To test the protocol, we experimentally implemented QRNGs employing both qubits and ququarts (4-level system). We asymptotically obtained 0.8583 secure random bits per measurement in the qubit case, and 1.685 secure random bits per measurement in the ququart case. The experimental demonstration shows that the method is very efficient and very robust with respect to the increasing of the dimension d of the system.

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Quantum silicon photonics

Presenter: Xiao-songMa
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Co-Authors: Guo, Xiang; Schuck, Carsten; Fong, King Y. (Department of Electrical Engineering, Yale University, New Haven, USA); Jiang, Liang (Department of Applied Physics, Yale University, New Haven, USA); Tang, Hong X. (Department of Electrical Engineering, Yale University, New Haven, USA)

The advantages of single photons at the optical frequency make them not only the workhorse of testing the foundations of quantum physics against the classical interpretation of nature, but also suitable for various tasks in quantum information processing. In order to realize these tasks, one needs a scalable platform for building up multiple quantum logic gates with complex quantum optical circuitries. Silicon and other CMOS compatible material are the ideal candidates due to their chip-scale footprint, well-established fabrication techniques and compatibility to exotic material (superconductors for instance) enabling measurement-induced nonlinear interaction between photons.
I will cover our recent endeavors in quantum sensing as well as quantum logic operations with silicon photonic platform. I will first present our demonstration of on-chip interaction-free measurements via the quantum Zeno effect. By taking the inherent advantages of the lithographically written waveguides, we employ wave-particle duality of single photons and the quantum Zeno effect to sense the presence of absorbers even if the photons and the absorbers haven’t interacted. Second, I will present the results of on-chip quantum interference realized with SiN waveguides, which is the key building block of linear optical quantum computation.

Quantum time

Presenter: LorenzoMaccone
Affiliation: Universita' di Pavia

Co-Authors: Vittorio Giovannetti, Seth Lloyd

We give a consistent quantum description of time, based on Page and Wootters' conditional probabilities mechanism, that overcomes the criticisms that were raised against similar previous proposals. In particular we show how the model allows to reproduce the correct statistics of sequential measurements performed on a system at different times.

Random correlations detect and characterise quantum entanglement

Presenter: WieslawLaskowski
Affiliation: University of Gdansk

Co-Authors: Tran, Minh Cong (Nanyang Technological University, Singapore); Dakic, Borivoje (University of Vienna); Arnault, Francois (Universite de Limoges); Paterek, Tomasz (Nanyang Technological University, Singapore)

We show that expectation value of squared correlations measured along random local directions is a quantifier of quantum entanglement in pure states which can be directly experimentally assessed by a measurement on two copies of the state. Entanglement can therefore be measured by parties who do not share a common reference frame and do not even possess a well-defined local reference frame. We show that already a single-qubit-per-party reference and rotationally invariant measurements are sufficient to quantify entanglement and violate a Bell inequality. We also provide an entanglement witness solely in terms of random correlations, capable of detecting entanglement in mixed states, and emphasise how data gathered for a single measurement setting reliably detects entanglement.

Real-time optimal state estimation for cavity optomechanical systems

Presenter: JasonHoelscher-Obermaier
Affiliation: VCQ, University of Vienna

Co-Authors: Markus Aspelmeyer, University of Vienna

We demonstrate optimal state estimation in real time for a cavity optomechanical system through Kalman filtering. By taking into account nontrivial experimental noise-sources, such as colored laser noise and spurious mechanical modes, we implement a realistic state-space model that allows to predict the conditional system state, i. e., conditioned on previous measurements, with minimal least-square estimation error. We apply this method for estimating the mechanical state as well as optomechanical correlations both in the weak and strong coupling regime. The level of accuracy in state estimation provided by Kalman filtering is an important next step for achieving optimal (classical and quantum) control of cavity optomechanical systems.

Relaxation of plasma oscillations in a bosonic Josephson junction

Presenter: Marie Bonneau
Affiliation: Atominstitut TU Wien

In plasma oscillations (also called Josephson oscillations) two conjugate variables oscillate in phase quadrature. Such oscillations are triggered when one variable is set out-of-equilibrium, which induces a variation of the conjugate variable.

In our system, the bosonic Josephson junction is formed by two coupled degenerate 1D Bose gases trapped in a double-well potential [1]. The conjugated variables are the relative phase and the population imbalance between the two wells. The plasma frequency is varied by tuning the tunnel coupling between the wells.

We prepare a phase imbalance and measure the resulting plasma oscillations. We observe a damping of these oscillations in a few periods. On the timescale of our measurement, the system always relaxes towards the same state, with zero relative phase and zero population imbalance. Furthermore, even if the initial relative phase exhibits large fluctuations, its standard deviation decreases during the relaxation process and converges to a low value, while the standard deviation of population imbalance stays low.

Damping of plasma oscillations was already reported in [2], but no explanation was given for it.We study here this effect in a systematic way. We first investigated the influence of tunnel coupling: We saw as expected a clear effect on the plasma oscillation frequency, but no variation of the final state and of the relaxation timescale. When varying the atom number from 1000 to 3000, we again only observed an effect on the oscillation frequency. We also observed the final state and the relaxation timescale to be independent of the initial phase. Finally, we saw that, while temperature affects the global amplitude of the plasma oscillations, it does not change the decay timescale. This precise characterization should allow determination of the relaxation mechanism taking place in our system.

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Rydberg Excitation of Trapped Strontium Ions

Presenter: Markus Hennrich
Affiliation: Experimental Physics, University of Innsbruck

Co-Authors: Higgins, Gerard; Pokorny, Fabian; Maier, Christine; Haag, Johannes; Kress, Florian; Colombe, Yves (Experimental Physics, University of Innsbruck)

Trapped Rydberg ions are a novel approach for quantum information processing |1,2]. This idea joins the advanced quantum control of trapped ions with the strong dipolar interaction between Rydberg atoms. For trapped ions this method promises to speed up entangling interactions and to enable such operations in larger ion crystals.
In this presentation we will show our progress in realizing this novel quantum system. Just recently, we have for the first time observed trapped strontium Rydberg ions. The ions were excited to the 26S Rydberg state using a two-photon excitation with 243nm and 304-309nm laser light. Both UV lasers were overlapped in a hydrogen-loaded photonic crystal fiber [3] and together focused down to approximately 10µm beam waist on the ion. The tunability of the 304-309nm laser should enable us to excite our strontium ions to even higher Rydberg levels. Such highly excited levels are required to achieve a strong interaction between neighboring Rydberg ions in the trap.

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Searching for Nonlinearities in Graphene at the Single-Photon level

Presenter: Irati Alonso Calafell
Affiliation: University of Vienna, Faculty of Physics

Co-Authors: Rozema, Lee; Procopio, Lorenzo; Walther, Philip (University of Vienna)

Single-photon sources are an essential tool for experiments in quantum information, and it is known that nonlinear effects can be used to create such a source. To date, however, available optical materials require high intensities and long interaction times to induce strong enough nonlinearities.

In this poster, we introduce a theoretical proposal in which nanostructured graphene shows strong nonlinear effects at the single photon level. In this proposal, graphene's strong nonlinear effects are used to implement the photon blockade. The predicted anti-bunched emission indicates that graphene could be an extraordinary candidate to produce high quality single photons with an extremely high efficiency. However, the predicted wavelength of the single photons is longer than 2um – much beyond the range of current single photon detectors. In addition to presenting an overview of the quantum picture of light, and the Hanbury Brown-Twiss interferometer, this poster will discuss our efforts to implement super-conducting nanowire detectors for very long wavelength single photons in order demonstrate this exciting effect.

Shot-by-shot imaging of Hong-Ou-Mandel interference with an intensified sCMOS camera

Presenter: Michal Jachura
Affiliation: University of Warsaw

Co-Authors: Chrapkiewicz, Radoslaw (University of Warsaw)

Recent advances in single-photon-sensitive cameras such as electron multiplying and intensified charged coupled devices (EMCCD and ICCD) have substantially stimulated the exploration of optical phenomena at the low-intensity levels. Nevertheless, a vast majority of experiments still typically operate in the regime of several to hundreds of photons per camera frame. The observation of truly single pairs of photons have been virtually out of the grasp of the cameras due to their slow frame rate and high noise. Hence the methods for realizing spatially resolved coincidence measurements are usually based on scanning single-pixel detectors or detector arrays reaching a dozen of pixels. Here we show that by overcoming aforementioned limitations, camera detectors can be effectively employed to detect truly single pairs of photons. Specifically, we present the first successful recording of Hong-Ou-Mandel (HOM) interference of photons generated in a spontaneous parametric down-conversion (SPDC) process obtained with the state-of-the-art intensified sCMOS camera system of our design [1,2]. The camera system begins with the image intensifier where each photon that induces a photoelectron emission produces a macroscopic charge avalanche resulting in a bright flash at the output phosphor screen. The flashes are imaged with a high numerical aperture relay lens on the fast, low-noise sCMOS sensor and detected as 25-pixel Gaussian spots which can be easily discriminated from the low-noise background [1]. Their central positions are retrieved from each captured frame with a sub-pixel resolution, by a real-time software algorithm which provides full information about transverse coordinates of each registered coincidence events [3]. High visibility of the recovered HOM dip yielding 96.3% stays in a perfect agreement with the independent measurement performed using a standard APDs setup, which confirms the excellent signal-to-noise ratio of our detection system. Thanks to its high resolution, we are able to spatially resolve coalesced photons within the transversal mode they occupy. This photon-number-resolving capability allowed us to quantify the number of coalesced pairs, which has been performed so far using the ultra-low-temperature transition-edge superconducting detectors [4] . Finally we propose an extended version of a coincidence imaging scheme based on spatially resolved detection of two mutually heralding photons and perform its proof-of-principle demonstration for retrieving the spatial modes of both interfering photons.

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Single photon transistor based on an impedance-matched circuit QED system

Presenter: Oleksandr Kyriienko
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Co-Authors: Sørensen, Anders S. (Niels Bohr Institute, University of Copenhagen)

Circuit quantum electrodynamics (cQED) represents a rapidly evolving field of quantum optics, where high-quality superconducting microwave cavities combined with Josephson junction-based artificial atoms enable strong photon-atom coupling at the single photon level. It has recently emerged as highly promising platform for quantum computer realization, thus posing the challenge of proposals for practical implementations of quantum information processing devices. One example is a single photon transistor (SPT), which represents a device where a single photon control pulse triggers a transmission of strong coherent probe, being a quantum analog of a field effect transistor in conventional electronics [1]. The operation of SPT device is typically based on a strong effective photon-photon nonlinearity, which can be introduced by the coupling to an atom trapped in the vicinity of a probe waveguide. In this vein, several schemes for cQED-based single photon transistors were proposed [2, 3]. However, they ultimately rely on the active time-control of single photon control pulse and probe signal, complicating the integration of devices in general computational schemes.

Here we propose a single photon transistor which can operate under continuous wave probe signal condition, with a single photon signal pulse on-demand shuttering. It represents a passive device which does not require signal and probe timing, largely simplifying its future implementation. The generic idea relies on the exploitation of the impedance matching condition, where reflection of a single control photon from a one-sided microwave cavity is strongly suppressed when its input/output coupling constant is equal to the effective decay rate to a metastable state of an embedded artificial atom. We devise a particular realization using a three level superconducting qubit, which is coupled to two separate microwave cavities, both coupled to waveguide channels. The first microwave cavity perturbatively couples to lowest levels of a superconducting qubit, while the second cavity mode is strongly coupled to the upper transition, which is additionally hybridized by the qubit drive. The relevant subspace of states contains the ground state, the first cavity excited state, and the subspace of highly mixed metastable states. By the control of drive strength and coupling parameters, the effective total decay rate to metastable states can be made equal to coupling to first waveguide, leading to full absorption of single photon pulse. Next, the presence of radiative decay between these states leads to appearance of photon flux leaving the second cavity through a separate input/output port conditioned on arrival of single photon, finalizing the SPT duty cycle. The system can serve as highly efficient single photon detector or quantum computational logic gate.

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Squeezed-entangled states significantly enhance precision in optical quantum metrology

Presenter: Paul Knott
Affiliation: University of Sussex

Quantum metrology aims to harness the power of quantum mechanics to make sub-classical-precision measurements. A crucial advantage of quantum metrology is that it provides high precision with a significantly lower particle flux. This is an important requirement for many applications such as biological sensing, where disturbing the system can damage the sample, or gravitational wave detection, where the lasers in the interferometer interact with the mirrors enough to degrade the measurement. The most commonly used optical quantum states employ either squeezing or entanglement to enhance measurements, but here we utilise both these techniques to create squeezed-entangled states, and use the quantum Fisher information to show that substantial improvements can be gained over states that use squeezing or entanglement in isolation. We then show how the squeezed-entangled states can be created and measured using present day, or near future, technology. Finally, we simulate an experiment to show that these states can be used to measure a phase with sub-classical precision, even in a lossy interferometer. Our results extend the capabilities of practical quantum metrology schemes and highlight the significant improvements exhibited by states that combine both squeezing and entanglement to enhance phase measurements.

State-Transfer Simulation in Integrated Waveguides Circuits

Presenter: Ludovico Latmiral
Affiliation: Imperial College London

Co-Authors: Di Franco, Carlo; Kim, Myungshik (Imperial College, London)

The spin-chain model has many applications in quantum information and communication, particularly if we consider the transmission of quantum states and the implementation of quantum computing [1,2]. The influence that the dynamics of a particular element exerts on other parties during the time evolution of quantum many-body systems was named information flux [3]. Given a certain Hamiltonian and the distribution of coupling strengths, we can control the information flux and thus the dynamics by operating on the initial state of the system.

Exploiting a map from fermion to boson chains, we present in this poster the generalization of the state transfer to the case of a three-level quantum state, allowed by the larger Hilbert space of the single elements of our chain. The bosonic nature of the systems has substantial effects on the efficiency of the protocol for the transmission of information that requires more than a single qubit for its encoding [4]. Moreover, we show that, from an experimental point of view, boson chains are less error sensitive and more robust: e.g. in case of a non-perfect initialization of the the medium used for state transfer when there are more excitations than expected.

Eventually, we highlight that the information flux can provide a bound for the correction on transfer fidelity which does not depend on the state we want to transfer or the initialization of the medium.

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Stochastic variational approach for investigation of quantum dynamics in light harvesting complexes

Presenter: Vladimir Chorosajev
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Co-Authors: Abramavicius, Darius (Vilnius University)

Light harvesting is an essential process in plants and photosynthetic bacteria, in which the solar photons are absorbed by antenna complexes, inducing the formation of coherent excitons. The energy is then transferred with a high efficiency to pigment-protein complexes and reaction centers. The dynamics occur on very short timescales (hundreds of femtoseconds to picoseconds) and require to account for multiple effects when constructing a theoretical model; namely the strong interaction with the protein/solvent environment (leading to polaron formation and decoherence) and the resonant coupling between constituent pigments (leading to coherent energy transfer). In the intermediate regime where both couplings are of the same order one can not efficiently use perturbative methods to analyze the quantum dynamics of such a system.

Here we propose a stochastic method based on the Dirac-Frenkel time-dependent variational principle to investigate the evolution of the wavefunction of an optically excited molecular aggregate, taking into account the interaction with the environment having an arbitrary spectral density function at both zero and finite temperatures. Excitonic polaron formation (the effect of the optical excitation on the properties of local environment and protein vibrational modes) is also present in the model.

The approach gives detailed evolution of the wavefunctions, for which the initial conditions are randomly sampled. Averaging over the ensembles one obtains the usual expected effects of decoherence and polaron formation, when more detailed dynamics can be extracted for any single realization. Measurable observables such as the absorbtion spectrum agree with the experimental data for the LH2 light harvesting complex, found in purple bacteria. Complex temperature-dependent dynamics are found, displaying exciton self-trapping at low temperatures and thermally induced state delocalization at high temperatures.

Stopping Quantum Zeno's arrow

Presenter: Isabel Gonzalo
Affiliation: Universidad Complutense de Madrid

Co-Authors: Porras, Miguel A. (Universidad Politécnica de Madrid); Luis, Alfredo (Univerisdad Complutense de Madrid)

We report on the Zeno dynamics of a freely moving quantum particle whose position in space is frequently measured. Although the quantum Zeno effect takes its name from Zeno's arrow paradox, the effect of position measurements on the motion of the free particle has not received the attention that it would deserve given its fundamental character.

We find that the probability that the particle remains the region of space where it is originally found increases with the frequency of the measurements, i. e., measurements tend to stop the particle, reaching unity in the limit of continuous measurements. For macroscopic particles, however, measurements are found to be less effective in stopping the particle, thus recovering the expected fatuousness of stopping a classical object by simple observation. We distinguish between the limit of continuous measurements and of very frequent measurements (the measurement repetition time is much shorter than the typical evolution time of the quantum wave packet). In the limit of continuous measurements, the particle is trapped with probability unity in an infinite potential well, as can be expected from [1]. This effective potential is caused by the constant observation, which, as a result, causes the particle to bounce back and forth within it. This means that the particle is not stopped, but moves in the original direction or backward alternately. On the contrary, with very frequent measurements, the particle is stopped with high probability (but less than unity) in a highly non-classical quantum state of zero expected value of the momentum where the particle moves both forward and backward at the same time [2]. This is a net example of a quantum Schrödinger cat state --a quantum Schrödinger arrow state so to say.

This Zeno dynamics is seen to be equivalent to the well-known dynamics of the formation of high-order diffraction modes of an open Fabry-Pérot resonator when light bounces back and fro between its mirrors [3]. This analogy allows us to obtain simple analytical expressions, brought from Optics, that explain the above facts and the disappearance of the Zeno effect in the limit of macroscopic particles.

In an alternate approach, we find that the Zeno dynamics of the freely moving particle with certain kinetic energy subjected to very frequent position observations is equivalent to the non-observed dynamics of a particle with the same kinetic energy located initially within a potential barrier occupying the region of position measurements and of height proportional to the frequency of the measurements. Approaching the limit of continuous measurements, the ever higher barrier is equivalent to the infinite potential well that limits the dynamics to the subspace defined by the position measurement region [1].

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Storage of hyperentanglement in a solid-state quantum memory

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Two photons can simultaneously share entanglement between several degrees of freedom such as polarization, energy-time and spatial modes. This resource is known as hyperentanglement, and it has been shown to be an important tool for optical quantum information processing. Here we demonstrate the quantum storage and retrieval of photonic hyperentanglement in a solid-state quantum memory prepared using the atomic frequency comb protocol. A pair of photons entangled in polarization and energy-time is generated such that one photon is coherently stored in the quantum memory, while the other photon has a telecommunication wavelength suitable for transmission in optical fiber. We measured violations of a Clauser–Horne–Shimony–Holt Bell inequality for each degree of freedom, independently of the other one, which proves the successful storage and retrieval of the two bits of entanglement shared by the photons. Our scheme is compatible with long-distance quantum communication in optical fiber, and is in particular suitable for linear-optical entanglement purification for quantum repeaters.

Storage of light in a nanofiber-trapped atomic ensemble

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The storage of a classical optical pulse is an important capability for the realization of all-optical signal processing schemes. Simple optical buffers can be extended to work as optical quantum memories, in which quantum states of light can be stored and retrieved. Such quantum memories are crucial elements of a global quantum optical network.

The storage of light has been achieved with several systems, e.g., in ensembles of cold or ultracold atoms. However, the realization of efficient, long-lived fiber-integrated optical memories, as desirable for applications in optical fiber networks, is still subject to active research.

Here, we report on the progress of a novel implementation of an optical quantum memory. We use a nanofiber-based experimental platform for trapping and optically interfacing laser-cooled cesium atoms [1]. The nanofiber is realized as the waist of a tapered optical fiber. The atoms are trapped about 250 nm above the nanofiber surface. The long atomic ground state coherence times [2] and the good coupling of the trapped atoms to fiber-guided fields make this system a promising candidate for the realization of a fiber-coupled quantum memory.

We demonstrate the storage of weak optical pulses in a nanofiber-coupled ensemble of laser-cooled cesium atoms. Using the effect of electromagnetically induced transparency (EIT) we are able to drastically slow down fiber-coupled light pulses. We also experimentally show the storage and retrieval of fiber-guided light with a high overall efficiency and a largely improved characteristic memory lifetime compared to previously demonstrated fiber-integrated optical memories. Our results are an important step towards fully fiber-based quantum networks.

Superconducting Lumped-element Resonator Arrays for Analog Quantum Simulations

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Superconducting circuits operated at microwave frequencies are one of the most promising platforms for the development of quantum technologies, such as quantum computers, ultra-sensitive measurement setups based on quantum-limited amplifiers, and analog quantum simulators. Especially the latter ones have recently attracted much attention as the field of circuit Quantum Electrodynamics (circuit QED) is at the stage where scaling up of the number of nonlinear resonators or artificial atoms is achievable and at the same time considerably simpler than scaling up of multi-purpose quantum computers. Analog quantum simulators, based on a specific microwave circuit with linear and nonlinear elements, have many potential applications. Theoretical proposals span from localized and delocalized phases of light described by the Bose-Hubbard Hamiltonian, to simulating dynamical quantum Hall effect, and observing topological states such as Majorana particles. Successful realization of analog quantum simulators relies on the construction of large number of nonlinear resonators with highly controllable parameters placed on a chip. To address these challenges we explore quasi-lumped element LC-based resonators, whose smallest size is not limited by the wavelength, as unit elements for analog quantum simulators. Our findings allow an accurate mapping of the quasi-lumped element design to an equivalent circuit and the system's Hamiltonian. In this way we are able to reverse engineer and find a design that yields the desired Hamiltonian. We test our approach on three coupled resonators.

The maximally entangled set of three- and four-qubit states and some applications

Presenter: Cornelia Spee
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Spatially separated parties are constrained to Local Operations and Classical Communication (LOCC). Entanglement is a resource to overcome this constraint and studying deterministic LOCC transformations allows to obtain a (partial) order of the states with respect to their entanglement. In the bipartite case the maximally entangled state is well known. It is the state which allows to obtain all other states via LOCC but cannot be obtained from any other state via non-trivial deterministic LOCC transformations. As there exists no single state with this property in the multipartite case, we introduced in [1] the Maximally Entangled Set, which is the minimal set of pure n-partite states such that any other pure fully entangled n-partite state can be obtained via LOCC from a state in this set.

We studied the MES for three- and generic four-qubit states and showed that the MES for three qubits is of measure zero, whereas for four qubits almost all states are in the MES. Moreover, we determined the LOCC convertible states in the MES for three- and generic four-qubit states, which are for both cases of measure zero. As these state are the only relevant ones concerning deterministic entanglement manipulation, they are promising candidates to discover new applications of multipartite entanglement.

We also investigated the deterministic preparation of arbitrary (pure or mixed) states via LOCC in the bipartite, three-qubit and four-qubit case [2]. In particular, we showed that in the bipartite- and in the three-qubit case the MES does not only contain the most useful states among pure states but also among mixed states of the same dimension. Moreover, we showed that any pure or mixed three-qubit (four-qubit) state can be obtained deterministically via LOCC transformations from a specific six-qubit (23-qubit) state respectively.

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[2] C. Spee, J. I. de Vicente and B. Kraus, arXiv:1504.02643 [quant-ph].

The Maximally Entangled Set of Tripartite Qutrit States

Presenter: Martin Hebenstreit
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The Maximally Entangled Set (MES) introduced in [1] generalizes the idea of maximally entangled states from the bipartite to the multipartite setting. In the bipartite setting there exists a so-called maximally entangled state with the property, that this state cannot be reached from any other state via Local Operations and Classical Communication (LOCC). However, any other state can be obtained from the maximally entangled one. In the multipartite setting, however, there is no such state, but the property can be generalized to a set of states, the MES. We expect that studying the MES will enhance our understanding of quantum entanglement. The MES has been characterized for three and four qubit states in the past. Here, the notion of the MES will be reviewed and results on the characterization of the MES for tripartite qutrit states will be presented. We show the similarities and the differences to the MES for generic four qubit states.

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The Quantum Dimension of the Electromagnetic Field

Presenter: Jan Naudts
Affiliation: Universiteit Antwerpen

With a few modifications Quantum Electro Dynamics (QED) can be turned into a mathematically consistent theory. The formalism involves reducible representations of the Canonical Communication Relations. Wave functions can be defined and describe electromagnetic fields interacting with electron fields.

The modifications to the theory are kept as minimal as possible. Famous expressions are still recognizable. Never the less some changes are striking. Eye catching is the shift of integrations over momentum space from operator expressions to evaluations of quantum expectations. More important is that the normalization of functions is imposed for each wave vector separately. The temporal gauge is used because it simplifies the formalism. The problem of redundant degrees of freedom of the electromagnetic field is eliminated. Dirac's equation looks familiar. Both scattering states and bound states can be studied.

Some examples are worked out up to second order in the coupling constant.

The role of Gaussian distance in entropic uncertainty for continuous variables

Presenter: Wonmin Son
Affiliation: Sogang Univ.

The Gaussian distribution is known to maximize the Shannon entropy at fixed variance. Applying this observation to a pair of canonically conjugate quantum observables $\hat{x}$ and $\hat{p}$, we rewrite the entropic uncertainty relation in a suggestive form, where the standard deviations σ_x and σ_p are featured explicitly. From this, it follows in a transparent manner that: (i) The entropic uncertainty relation implies the Kennard-Robertson uncertainty relation $\sigma_x \sigma_p \geq \hbar/2$; (ii) the gap between the two inequalities is exactly quantified by the non-Gaussianity of the probability distributions of the two observables.

The simplest causal games

Presenter: Mateus Araújo
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Since causality plays an essential role in the formulation of the laws of nature, a fundamental explanation of this role is called for. It is also called for to describe physical regimes where the causal structure is itself not well-defined, such as in quantum gravity.
Oreshkov, Costa and Brukner [Nat. Comm. 3:1092] showed that the local validity of (causally ordered) quantum mechanics is not sufficient to enforce the existence of a global causal order between events, by constructing probability distributions compatible with local quantum mechanics but incompatible with a the existence of a global causal order.
Here we pursue the study of probability distributions compatible with a global causal order, which we show to form a convex polytope, defined by "causal inequalities", which we propose to interpret as "device-independent causal games", much as Bell inequalities can be viewed as "device-independent nonlocal games". We construct the simplest nontrivial causal polytope for two events, and the corresponding causal games, which are significantly simpler than the one presented in Oreshkov et al. We also derive the correlations which maximally violate the simplest causal inequalities under the constraint that locally, quantum mechanics holds.

Towards a Quantum Network with Trapped Ions in Optical Cavities

Presenter: Florian Ong
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Optical cavities can be used as efficient quantum interfaces between photons and atoms to realize a quantum network [1,2]. In such a network, photonic channels link quantum nodes containing one or several quantum emitters. The technical requirements for the building blocks of a quantum network are demanding because coherent effects should dominate the system's dynamics. Here we report on the development of a two-node elementary quantum network based on calcium ions trapped in separate optical cavities.

One node is based on a 2 cm long cavity and is already up and running. It operates in the intermediate coupling regime of cavity QED where coherent and dissipative processes have similar rates. This node was used to demonstrate fundamental quantum network protocols including deterministic single-photon generation [3], tunable entanglement between an ion and a photon [4] and heralded entanglement of two ions [5].

The second node is under development [6] and relies on a so-called fiber-cavity, i.e., an optical cavity defined between the coated facets of two optical fibers [7]. The facets are machined by CO_2 laser ablation and coated with a high-reflectivity dielectric multilayer stack. The short cavity length, typically a few hundreds of micrometers, is designed for strong coupling. In this regime the coherent interaction between the ion and the cavity field dominates over dissipative processes. This should result in higher fidelities and efficiencies for the network protocols already available at the first node. This poster will describe the latest advancements of the fiber-cavity setup.

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Towards Nanofiber based Quantum Networks

Presenter: Adarsh Prasad
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In a new project, we plan to establish nanofiber-based atom-light interfaces as quantum-enabled fiber-optical components for quantum information processing and communication. The key ingredient is a nanofiber-based optical dipole trap which stores cold atoms in the evanescent field around the nanofiber [1,2]. In this evanescently coupled atom-waveguide-system, even a few hundred atoms are already optically dense for near-resonant photons propagating through the nanofiber. The first goal of this project is to realize efficient quantum memories which allow one to directly store and retrieve the quantum state of fiber-guided photons [3]. Furthermore, nanofiber-coupled atoms can provide a strong optical non-linearity. The second goal of this project is to explore and to maximize this non-linearity until it prevails down to the single photon level. This would then enable optical quantum switches and photon-photon quantum gates which are essential for implementing deterministic optical quantum computation. The final goal is to interconnect these components in order to demonstrate different quantum network applications, such as highly efficient photon counting, heralded entanglement of two fiber-coupled quantum memories, and a non-linear interaction between two single-photon pulses.

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Towards phase measurement and quantum back-action in a double-well system

Presenter: RuGway WU
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Output coupling atoms and detecting them in time of flight will allow to make minimum invasive measurements on trapped ultracold gases. In particular we plan to apply this technique to study quantum gases trapped in a double-well on the atomchip. Starting with two independently created BECs, we will investigate the formation of a relative phase between through the action of the measurement. Repeated measurement on a coherently split BEC will allow us to characterize measurement back-action through the subsequent phase diffusion. Here we describe the first steps towards implementation.

Towards resolving photon number distribution in a cavity with a single ion

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The discreteness of photons has played a central role in quantum optics, leading to important observations such as antibunched light and photon blockade. Cavity quantum electrodynamics is an ideal setting in which to explore the granular feature of photons, as the interaction between atoms and photons is greatly enhanced. Discrete number distributions have previously been measured in microwave cavities using Rydberg atoms and superconducting qubits [1,2]. However, observations of intracavity photon number distributions have not yet been reported in the optical domain.

Here, we present an experimental strategy for resolving the photon number distribution in an optical cavity using a single ion. We consider a single 40Ca+ ion that is dispersively coupled to a high-finesse cavity. The cavity will be driven by a weak laser beam to populate the cavity with a mean photon number between one and ten. The ion will experience a photon-number-dependent ac-Stark shift. We will perform high-precision spectroscopy on the qubit transition to identify the modified atomic energy-level structure. This measurement is expected to demonstrate a nondestrutive detection of intracavity optical photons. The scheme may open up possibilities to measure fragile nonclasscial photon states, including Fock states and Schrodinger's cat states in an optical cavity.

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Towards the spin-wave storage of entangled photons in a solid state quantum memory

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To establish remote quantum networks, the distribution of entanglement over long distances is required. In order to overcome transmission loss in quantum channels (e.g. optical fibers), quantum repeater architectures have been proposed [1]. The availability of single photons at telecom wavelength entangled with photons stored in long-lived quantum memories for synchronization issues [1,2] is a crucial resource in this context. In this contribution, we will describe our efforts towards the demonstration of entanglement between a telecom photon and a long-lived spin wave solid-state quantum memory.

We have developed an ultra-narrow band photon pair source [3], with one photon at telecom wavelength and its time-correlated photon compatible with a rare earth doped crystal ideally suited for a spin state storage [4]. A pump laser at 426 nm wavelength generates widely non degenerate photon pairs at 606 nm (signal) and 1436 nm (idler) wavelengths inside a periodically poled lithium niobate crystal (PPLN) using spontaneous parametric down conversion. The PPLN crystal is surrounded by a bow-tie cavity which is resonant to both, signal and idler, wavelength. The non-degenerate double resonance leads to a reduction of the number of spectral modes and an enhancement of the output rate (spectral brightness). The source is designed such that the signal photons matches the frequency of the 3H4-1D2 transition in a praseodymium doped crystal (Pr3+ : Y2SiO5), with a bandwidth of 3 MHz which is lower than the hyperfine structure splitting in the 1D2 state. The idler photons herald the arrival of the signal photons at the solid state memory, which are then mapped onto optical atomic excitations in the crystal for a fixed storage time up to 4.5 μ s, using the atomic frequency comb (AFC) scheme [4]. Pr3+ : Y2SiO5 provides a three fold ground state which can be addressed by transfer pulses and makes it an ideal candidate for spin-wave storage, enabling longer storage times and on-demand read-out of the stored quantum information. Recently the storage of weak coherent pulses at the single photon level in the spin state of the Pr3+ : Y2SiO5 crystal has been shown in our group [5].

Our ongoing work aims at the storage of single photons in the spin state of the praseodymium ions. A crucial requirement to reach the quantum regime is to achieve a high signal to noise ratio with the incoming quantum field. For this purpose, the source properties such as spectral brightness, and heralding efficiency have been significantly increased. The long term stability of the photon pair source as well as the storage efficiency have also been improved. In addition we want to show frequency-bin entanglement between the photon pairs, taking advantage of four spectral modes emitted by the cavity [3]. In order to verify the entanglement, we use electro optical phase modulatorsand appropriate spectral filtering, enabling the violation of one Bell inequalities [6].

Such a setup with photons at telecom wavelength, non- classically correlated with photons stored in the spin states of a solid state quantum memory with on demand read-out would be a building block for a quantum repeater and paves the way for large quantum networks.

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Universal entanglement decay of photonic orbital angular momentum qubit states in atmospheric turbulence

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The orbital angular momentum of light (OAM) has attracted a lot of attention in the field of (quantum) communication due to its, in principle, infinite-dimensional Hilbert space.
However in the case of free-space quantum communication, wave front errors introduced by atmospheric turbulence can deteriorate the information since the wave front is responsible for the OAM of the photons.
In this contribution, we consider the entanglement decay of two entangled OAM photonic qubits both propagating through weak atmospheric turbulence. It has been known, but not well-understood, that qubits with higher OAM preserve their entanglement better also for stronger turbulence. To explain this effect we introduce a characteristic length scale of the OAM wave front profile, the so-called phase correlation length. Furthermore, we show that the entanglement decay is determined by a sole parameter - the ratio of the newly introduced phase correlation length and the Fried parameter, defining the turbulence correlation length [1].

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Weak Values, Contextuality, Pigeonholes, and the Mean King

Presenter: Mordecai Waegell
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The Kochen-Specker (KS) theorem shows that noncontextual hidden variable models of reality with random choice are inconsistent with quantum mechanics. Such noncontextual models predict certain outcomes for specific experiments that are never observed in practice, and this is how the theorem is proved. A realist model, consistent with the Aharonov-Bergmann-Lebowitz formulation of quantum mechanics, is introduced to explain why those outcomes are never observed. This model requires independent truth-value assignments to each observable, just as the KS theorem, but now allows that the entire assignment is dependent on both the pre-selected and post-selected quantum states in a time-symmetric manner. The truth-values assigned to the observables of this model are at least partially consistent with the weak values of those observables. Using sets that prove the KS theorem, we find a particular logical inconsistency within the truth-value assignment which has a corresponding signature in the weak values of the set. This inconsistency is never in the pre-selected or post-selected quantum state, which is why it is never observed, but its signature can be revealed through weak measurements. We also show that for specific cases where the logical inconsistency is in a `classical basis,' this gives rise to the quantum pigeonhole effect. As a loosely related issue, we show using weak values that any KS set can be used to foil the Mean King's trick.

Witnessing causal nonseparability

Presenter: Mateus Santos
Affiliation: University of Vienna, VCQ

Processes are generalizations of quantum channels that do not assume the existence of a global causal structure but are still compatible with the validity of quantum mechanics locally. The processes that are not compatible with a global causal structure are called causally nonseparable. However, it was still unknown whether these causally nonseparable processes were a mathematical curiosity or something that could actually be physically implemented.

Here we show that the quantum switch -- a new resource for quantum computation that has been experimentally demonstrated -- is in fact an example of such a nonseparable process, and we derive witnesses that can be used to demonstrate its nonseparability. However, we show that the quantum switch cannot violate any causal inequality -- which are constraints on probabilities derived from the assumption of a definite causal structure. These causal inequalities can, nevertheless, be violated by other nonseparable processes whose physical implementability is unknown. This opens up the question about the relationship between causal nonseparability, physical implementability, and violation of the causal inequalities.

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