Q 44: Quantum Information II

Time: Thursday 11:00–13:00 Location: HS 1199

Q 44.1 Thu 11:00 HS 1199

A fine structure qubit encoded in metastable strontium trapped in an optical lattice — •Sebastian Pucher[1,2], Valentin Klüsener[1,2], Jan Geiger[1,2], Felix Spriestersbach[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2,3] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology, 80799 München, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany

The development of scalable, high-fidelity qubits is a key ongoing research challenge in quantum information science, with neutral atoms trapped in optical lattices being a promising candidate. Here, we present spectroscopy of a new Raman qubit using long-lived metastable states in Sr. This architecture enables fast single- and two-qubit gates. We coherently transfer the atoms from the ground state to the metastable $^3P_2$ state and couple this state to the $^3P_0$ state using a two-photon Raman transition. We demonstrate high-fidelity Rabi oscillations of atoms trapped in an optical lattice and study the coherence times in our system. This work establishes metastable Sr as a promising candidate for realizing quantum computing.

Q 44.2 Thu 11:15 HS 1199

Optimization of Optical Spin Gates for negatively charged Group-IV Colour Centers in Diamond — •Yannick Strocka, Gregor Pieplow, and Tim Schröder — Humboldt-Universität zu Berlin, Department of Physics, Berlin, Germany

The control of the spin of negatively charged Group-IV colour centers in diamond plays an important role in various applications such as quantum computers and quantum repeaters. These applications require high fidelity control of the spin qubit, which is formed by the two lowest lying energy eigenstates of the system. Typically a microwave control is used to manipulate the qubit. In this work, however, we theoretically study the control using optical means. The optical control is composed of two laser pulses, whose frequencies are detuned from the transition between the lowest lying ground and excited state. This way a, so called, Raman spin gate is created. Optical pulses have the advantage that they allow the control over a much larger range of splittings. Under idealized assumptions perfect gates are in theory possible. The details of the color centers, however, are such that fast phononic decay greatly impacts the gate fidelity: Spurious population in the highest lying states, reduce the fidelity of the Raman spin gates due to spontaneous phononic relaxation. In order to counteract that decoherence effect any population in the levels affected must be minimized. In this work we combine gradient-free optimization such as the Nelder-Mead algorithm and gradient-based methods like Grape and Krotov to achieve this goal

Q 44.3 Thu 11:30 HS 1199

Enhancing the purity of single photons in parametric down-conversion through simultaneous pump-beam and crystal-domain engineering — •Baghdasar Baghdasaryan[1,2], Fabian Steinlechner[1,2,4], and Stephan Fritzsche[1,3,5] — [1]FSU Jena — [2]IAP Jena — [3]HI Jena — [4]Fraunhofer IOF, Jena — [5]TPI, Jena

Spontaneous parametric down-conversion (SPDC) has shown great promise in the generation of pure and indistinguishable single photons. Photon pairs produced in bulk crystals are highly correlated in terms of transverse space and frequency. These correlations limit the indistinguishability of photons and result in inefficient photon sources. Domain-engineered crystals with a Gaussian nonlinear response have been explored to minimize spectral correlations. Here, we study the impact of such domain engineering on spatial correlations of generated photons. We show that crystals with a Gaussian nonlinear response reduce the spatial correlations between photons. However, the Gaussian nonlinear response is not sufficient to fully eliminate the spatial correlations. Therefore, the development of a comprehensive method to minimize these correlations remains an open challenge. Our solution to this problem involves simultaneous engineering of the pump beam and crystal. We achieve purity of single-photon state up to 99 % without any spatial filtering. Our findings provide valuable insights into the spatial waveform generated in structured SPDC crystals, with implications for applications such as boson sampling.

Q 44.4 Thu 11:45 HS 1199

Phase compensation for free space continuous variable quantum key distribution using unscented Kalman filter — •Wenjia Elser[1,2], Stefan Richter[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nürnberg, Germany

Continuous variable quantum key distribution (CV-QKD) is typically conducted in a very low signal to noise ratio (SNR) regime associated with the quantum signal. As a result, the tracking and compensation of laser phase noise is critical to reducing excess noise in the signal. This work concerns the phase compensation of our experiment data over an urban free-space CV-QKD link. Implementing time-division multiplexed reference pulses to provide a sufficiently high SNR reference for laser phase tracking, we apply an unscented Kalman filter (UKF) on the phase estimation and investigate its effect on the quantum signal excess noise.

Q 44.5 Thu 12:00 HS 1199

Detection of spin order from collective photon scattering — •Benjamin Zenz[1], Ansgar Schaefer[1], Maurizio Verde[1], Zyad Shehata[2], Stefan Richter[2], Joachim Von Zanthier[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Mainz, Germany — [2]Institut für Physik, Erlangen, Germany

Ion traps are ideal candidate platforms for quantum simulators of interacting spin systems by encoding the effective spins within the internal energy levels of the ions. This talk presents a way to efficiently read out the spin order of an $^{40}Ca^+$ ion crystal in a segmented Paul trap by detecting collective, coherent photon scattering in the far-field. In the past, we employed far-field photon detection to reveal the ion's position [1]. Now, we utilize a two-photon process involving a narrow quadrupole transition near 729 nm and a dipole transition near 854 nm to achieve background-free detection of 393 nm photons. Additionally, this scheme enables a spin-selective detection, such that we can determine the spin order of an ion crystal and investigate it's temporal evolution. Our experimental results are obtained with linear crystals of 3,4 and more ions and fit the theory expectations.

[1] S. Wolf, J. Wechs, J. von Zanthier, and F. Schmidt-Kaler Phys. Rev. Lett. 116, 183002 (2016)

Q 44.6 Thu 12:15 HS 1199

Determination of free-electron density matrices using heterodyne detection and maximum likelihood estimation — •Hao Jeng[1,2], Jan-Wilke Henke[1,2], and Claus Ropers[1,2] — [1]Max Planck Institute for Multidisciplinary Sciences, D-37077 Göttingen, Germany — [2]University of Göttingen, D-37077 Göttingen, Germany

Free electrons interacting with light are known to scatter into superpositions of momentum states [1], but existing methods to determine these density matrices are limited in accuracy [2]. We have developed a reconstruction algorithm based on maximum likelihood estimation that circumvents these issues, and we have used this method to verify the formation of attosecond electron pulses. We have also developed an analogue of optical heterodyne detection for free electrons, which we use to examine the quantum states produced from interactions with light in a waveguide. These techniques greatly simplify the measurement and reconstruction of free-electron states, opening up new routes of investigation into the quantum interaction between free electrons and light.

[1] Feist et al., Nature 521, 200 (2015).
[2] Priebe et al., Nature Photonics 11, 793 (2017).

Q 44.7 Thu 12:30 HS 1199

Free-electron cavity-photon interaction via integrated photonics — •Germaine Arend[1,2], Yujia Yang[3,4], Armin Feist[1,2], Guanhao Huang[3,4], Jan-Wilke Henke[1,2], Arslan Sajid Raja[3,4], F. Jasmin Kappert[1,2], Rui Ning Wang[3,4], Hugo Lourenco-Martins[1,2], Junqiu Liu[3,4], Ofer Kfir[1,2], Tobias J. Kippenberg[3,4], and Claus Ropers[1,2] — [1]Max Planck Institute for Multidisciplinary Sciences, D-37077 Göttingen, Germany — [2]Georg-August-Universität Göttingen, D-37077 Göttingen, Germany — [3]Swiss Federal Institute of Technology Lausanne (EPFL), CH-1015 Lausanne, Switzerland — [4]Center for Quantum Science and Engineering, EPFL, Lausanne, Switzerland

Quantum communication largely relies on the generation of photon pairs as well as their interactions with different quantum systems. Coupling of single photons with free electrons, a potential candidate, has been hampered due to limited control over the optical states and the lack of coincidence detection capabilities. Here, we generate electron-photon pairs by inelastic scattering of free electrons with the evanescent optical field of a Si_3N_4 resonator and detect the generated photons, as well as the corresponding electron energy loss. The temporal correlation of both particles demonstrates a distinct peak of coincidence events, highlighting their common origin [1]. The connection between energy loss and photon number enables post-selection onto single, or even n-photon states. This setup enables the exploration of new experimental concepts in free-electron quantum optics. [1] A. Feist, G. Arend et al., Science 377, 777 (2022)

Q 44.8 Thu 12:45 HS 1199

Mesoscopic quantum dynamic in X-ray waveguides — •Petar Andrejic[1], Leon Lohse[2,3], and Adriana Palffy[4] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg — [2]Deutsches Elektronen-Synchrotron — [3]Georg-August-Universität Göttingen — [4]Julius-Maximilians-Universität Würzburg

Grazing incidence X-ray waveguides have become a well established platform for X-ray quantum optics. In these systems, X-rays are scattered resonantly by Mössbauer transitions in atomic nuclei, leading to a collective interaction between the indistinguishable nuclei and the waveguide field.

We show that driving such X-ray waveguides at forward incidence allows for direct excitation of multiple guided modes, with centimetre scale attenuation lengths [1]. In this regime, the embedded Mössbauer nuclei absorb and emit collectively into a super-position of these modes, with the resultant radiation field displaying pronounced interference beats on a micrometre scale. We show that this interference pattern leads to sub-radiance of the nuclear ensemble, with suppression of the dynamical beat at certain critical waveguide lengths. We also consider structuring the nuclear ensemble into micrometre scaled patches, and show that it is feasible to engineer the resultant internuclear coupling to create mesoscopic and hopping models [2], with potential for applications in quantum simulation and experimental exploration of mesoscopic quantum dynamics and topological physics.

[1] https://doi.org/10.1364/opticaopen.24028686.v2
[2] https://doi.org/10.48550/arXiv.2305.11647