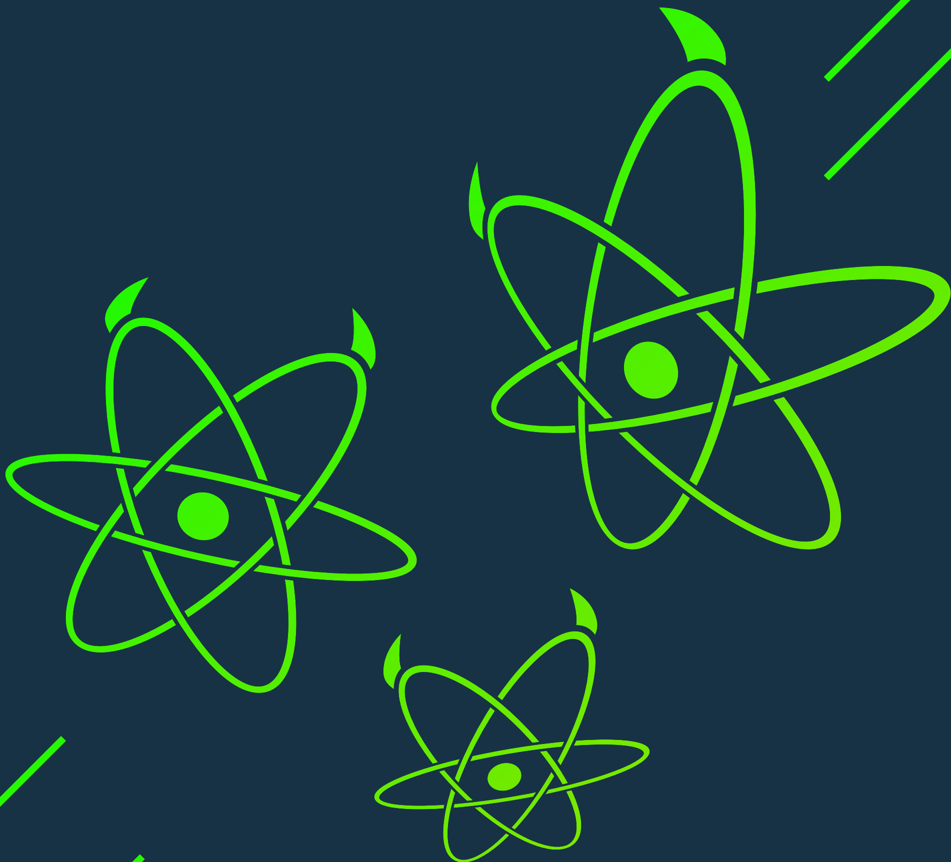
PROGRAMME



GREENHORN

2024

Contents

About

Greenhorn 2024

The Greenhorn Meeting 2024 team is glad to welcome you in Siegen!

In recent years, the Greenhorn Meeting of Young Physicists has established itself as a permanent event. Young scientists are invited to present their research in the fields of optics, photonics, atomic physics and quantum processing, discuss the newest ideas and make new contacts. In this year, the group of Nano-optics — Prof. Mario Agio — and the group of Experimental Quantum Optics — Prof. Christof Wunderlich — welcome you.

We hope that you can use the Greenhorn meeting to get ideas, share knowledge and exchange expertise with other students.

We wish you an inspiring and cheerful time in Siegen!

Organizing committee

Daniel Busch
Markus Nünnerich
Benjamin Bürger
Amr Farrag
Saptarshi Biswas
Laurin Göb

List of Participants

Participant	Affiliation
Sahnawaz Alam	Politechnika Wrocławska
Pascal Baumgart	Universität des Saarlandes
Lara Becker	Universität des Saarlandes
Santiago Emilio Bogino	Universität Mainz
Saloni Chourasiya	Universität Innsbruck
Jolan Costard	Universität des Saarlandes
Daniel Ehrmanntraut	Universität Bonn
Pat Yin (Lavender) Foo	Imperial College London
Ilija Funk	Leibniz Universität Hannover
Maximilian Futterknecht	Universität Ulm
Akhil Gupta	Ludwig-Maximilians-Universität München
Ernst Alfred Hackler	Universität Siegen
Minjae Hong	Max Planck Institute for the Science of Light
Andre Jakubowski	Universität zu Köln
Bartosz Kasza	Uniwersytet Warszawski
Florian Kofler	Universität Innsbruck
Kunyuan Li	Université de Technologie de Troyes
Maximilian Luka	Leibniz Universität Hannover
Zeeshan Rashid	Università degli Studi di Napoli Federico II
Sophie Reißig	Technische Universität Darmstadt
Christoph Rützel	Technische Universität Darmstadt
Fabian Scheidler	Universität Würzburg
Tom Schubert	Technische Universität Wien

Timetable

Time/Date	09.09.24	10.09.24	11.09.24	12.09.24
08:45 - 09:30		Registration & Breakfast	Breakfast	Breakfast
09:30 - 10:00		Opening	External talk	External talk
10:00 - 11:30		Talks 1	Talks 3	Talks 5
11:15 - 11:45		Coffee break	Coffee break	Coffee break
11:45 - 13:15		Talks 2	Talks 4	Talks 6
13:15 - 14:15		Lunch@mensa	Lunch@mensa	Lunch@mensa
14:15 - 16:00		Posters 1	Posters 2	Closing
16:00 - 17:00				
17:00 - 18:00	Arrival	Lab tours@ENC		
18:00 - open end	Pub crawl	BBQ@ENC	Joint dinner	

Tuesday - 10.09.24

08:45 - 09:30	**Registration & Breakfast**
09:30 - 10:00	**Opening**
10:00 - 11:30	**Pascal Baumgart**, *Generation of indistinguishable single photons from a single 40Ca^{+}-ion using short laser pulses* **Lara Becker**, *Transportable quantum communication node based on a cavity ion trap* **Saloni Chourasiya**, *Vibration damping system for integrated cavity-tweezer quantum simulator* **Florian Kofler**, *Modulated gates for improved ion control*
11:15 - 11:45	**Coffee break**
11:45 - 13:15	**Daniel Ehrmanntraut**, *Photon Bose-Einstein-Condensates in Coupled Lattice Potentials* **Andre Jakubowski**, *Open-Source Software for Real-Time Analysis in Super-Resolution Microscopy* **Tom Schubert**, *Programmable Optical Lattices for Quantum Simulation Experiments* **Santiago Emilio Bogino**, *Design and development of X junctions for three dimensional segmented ion traps*
13:15 - 14:15	**Lunch@mensa**
14:15 - 16:00	**Posters 1**
17:00 - 18:00	**Lab tours@ENC**
18:00 - open end	**BBQ@ENC**

Wednesday - 11.09.24

08:45 - 09:30	**Breakfast**
09:30 - 10:00	**External talk**
10:00 - 11:30	**Jolan Costard**, *Integration of a fiber Fabry-Pérot cavity in a linear Paul trap* **Maximilian Futterknecht**, *Using a shelving state of an ion to probe atom-ion spin exchange collisions* **Akhil Gupta**, *Optical system for bi-directional tracking in free-space quantum key distribution link* **Maximilian Luka**, *High brightness single photon sources based on a single DBATT molecule*
11:15 - 11:45	**Coffee break**
11:45 - 13:15	**Zeeshan Rashid**, *Optical Properties of NV Centers Activated by Proton Implantation* **Christoph Rützel**, *Quantum-Processing Architecture with Rydberg-Interacting Neutral-Atom Arrays* **Fabian Scheidler**, *Enhanced Second Harmonic Generation from Silver Nanoantennas* **Ernst Alfred Hackler**, *Double imaging and stray light suppression for a multi species Paul trap for quantum computing*
13:15 - 14:15	**Lunch@mensa**
14:15 - 16:00	**Posters 2**
18:00 - open end	**Joint dinner**

Thursday - 12.09.24

08:45 - 09:30	**Breakfast**
09:30 - 10:00	**External talk**
10:00 - 11:30	**Minjae Hong**, *Towards photon triplet states with a tapered optical fibre* **Bartosz Kasza**, *Fourier mode decomposition approach to Floquet-Liouville problem for unclosed atomic loop transitions* **Sophie Reißig**, *Trapping of Bose-Einstein condensates in a three-dimensional dark focus generated by conical refraction and creation of a 3D lattice of bottle beams*
11:15 - 11:45	**Coffee break**
11:45 - 13:15	**Sahnawaz Alam**, *Characterizing Strain in Laser-Written Diamond Waveguides Using Zero-Field ODMR Spectra of NV− Center Ensembles* **Pat Yin (Lavender) Foo**, *Phase stabilizing multiple standing waves to achieve fast entangling gates for trapped ion quantum computing* **Ilija Funk**, *The Bell Polytope from an Experimentalist's View* **Kunyuan Li**, *Fabrication and Characterization of Silicon Nitride Ring Resonators and Exploration of Titanium Dioxide for Nonlinear Optics*
13:15 - 14:15	**Lunch@mensa**
14:15 - 16:00	**Closing**

Poster Sessions

There will be two poster sessions during the meeting, one on Tuesday and one on Wednesday. These will be held at Seminarzentrum Unteres Schloss, where also the rest of the conference will take place. Each session will last for 105 minutes, so there will be plenty of time to discuss. The posters should be hung up before the start of the session, ideally already in the morning, and taken down afterwards. We will provide the poster walls and pins. During the poster session, the authors should be prepared to answer questions and discuss their work with the participants. Snacks and drinks will exist. In the following you can find the list of posters that will be presented during the two sessions.

Tuesday - 10.09.24 - Poster Session 1

Participant	Topic
Lara Becker	Transportable quantum communication node based on a cavity ion trap
Saloni Chourasiya	Vibration damping system for integrated cavity-tweezer quantum simulator
Maximilian Futterknecht	Using a shelving state of an ion to probe atom-ion spin exchange collisions
Akhil Gupta	Optical system for bi-directional tracking in free-space quantum key distribution link
Maximilian Luka	High brightness single photon sources based on a single DBATT molecule
Zeeshan Rashid	Optical Properties of NV Centers Activated by Proton Implantation
Christoph Rützel	Quantum-Processing Architecture with Rydberg-Interacting Neutral-Atom Arrays
Fabian Scheidler	Enhanced Second Harmonic Generation from Silver Nanoantennas
Bartosz Kasza	Fourier mode decomposition approach to Floquet-Liouville problem for unclosed atomic loop transitions
Sophie Reißig	Trapping of Bose-Einstein condensates in a three-dimensional dark focus generated by conical refraction and creation of a 3D lattice of bottle beams
Pat Yin (Lavender) Foo	Phase stabilizing multiple standing waves to achieve fast entangling gates for trapped ion quantum computing

Wednesday - 11.09.24 - Poster Session 2

Participant	Topic
Pascal Baumgart	Generation of indistinguishable single photons from a single $40Ca^{+}$-ion using short laser pulses
Florian Kofler	Modulated gates for improved ion control
Daniel Ehrmanntraut	Photon Bose-Einstein-Condensates in Coupled Lattice Potentials
Andre Jakubowski	Open-Source Software for Real-Time Analysis in Super-Resolution Microscopy
Tom Schubert	Programmable Optical Lattices for Quantum Simulation Experiments
Jolan Costard	Integration of a fiber Fabry-Pérot cavity in a linear Paul trap
Minjae Hong	Towards photon triplet states with a tapered optical fibre
Sahnawaz Alam	Characterizing Strain in Laser-Written Diamond Waveguides Using Zero-Field ODMR Spectra of NV− Center Ensembles
Ilija Funk	The Bell Polytope from an Experimentalist's View
Kunyuan Li	Fabrication and Characterization of Silicon Nitride Ring Resonators and Exploration of Titanium Dioxide for Nonlinear Optics
Ernst Alfred Hackler	Double imaging and stray light suppression for a multi species Paul trap for quantum computing
Santiago Emilio Bogino	Design and development of X junctions for three dimensional segmented ion traps

Abstracts

Characterizing Strain in Laser-Written Diamond Waveguides Using Zero-Field ODMR Spectra of NV− Center Ensembles

Sahnawaz Alam

Institute of Theoretical Physics, Politechnika Wrocławska, Poland

The negatively charged nitrogen-vacancy center (NV^{-}) in diamond has shown great potential in nanoscale sensing and quantum information, based on its field-sensitive ground spin states. These states are detected by the optically detected magnetic resonance (ODMR), which depends on efficient fluorescence detection. Laser-written waveguides in diamond have recently been used to improve the coupling of NV^{-} centers to light, hence enhancing fluorescence signal [1]. However, in the waveguides, the ODMR spectra are consistently asymmetric. Here, we show that this asymmetry is caused by strain induced by the laser-writing of the waveguide. We exploit this fact to characterize strain across the structure based on zero-field ODMR spectra. We find a dominant compressive axial component transverse to the waveguide, with smaller vertical and shear strain components. To understand the impact of strain on ODMR spectra features, we first simulate a single microwave-driven NV^{-} center and check how its optical response is tuned by specific strain components. We then model the experimental spectra from ensembles of NV^{-} centers, assuming an even distribution of the four NV^{-} orientations in the crystal. We exploit the translational symmetry of the waveguide structure, which reduces the number of relevant strain components to three. Based on numerically calculated four NV^{-} centers' eigenstates and corresponding excitation probabilities for microwave-driven transitions, we compose a simulated ODMR spectrum from pairs of weighted Lorentzians for each NV^{-} orientation. Finally, we extract the strain components by fitting the model to experimental data [3]. Our results reasonably quantify the strain distribution in the studied waveguide structures with results comparable to polarized micro-Raman spectroscopy results [2] but provided via a more accessible experimental method.

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[1] M. Hoese et al., Phys. Rev. Applied 15, 054059 (2021).
[2] B. Sotillo et al., Appl. Phys. Lett. 112, 031109 (2018).
[3] M. S. Alam et al., arXiV :2402.06422 (2024) (accepted in Phys. Rev. Applied).

NOTES

Generation of indistinguishable single photons from a single $40Ca^{+}$-ion using short laser pulses

Pascal Baumgart

Universität des Saarlandes, Germany

Quantum networking applications involving entanglement swapping operations require the ability to generate indistinguishable single photons capable of HOM interference [1,2]. A commonly used method to create single photons from trapped ions via continuous excitation of a Λ-type Raman transition renders indistinguishability difficult, as spontaneous scattering events lead to the creation of temporally mixed Raman photons [3]. An alternative approach is excitation by short laser pulses with pulse lengths in the order of the excited state lifetime. Using a Raman transition in a single trapped $40Ca^{+}$-ion with an excited state lifetime of 7 ns, we investigate the feasibility of this approach. We present an experimental setup to generate few-nanosecond laser pulses at the excitation wavelength of 393 nm, and we examine the dependence of the photon purity on the pulse length and amplitude. An additional application of the pulse generation setup, for quantum key distribution based on atom-photon-entanglement, is also presented. Here, the reduced temporal extent of the generated photons is expected to lead to an increased secret key rate compared to continuous excitation.

[1] P. van Loock et al., Advanced Quantum Technologies 3 (2020)
[2] S. L. Braunstein et al., Phys. Rev. A 51 (1995)
[3] P. Müller et al., Phys. Rev. A 96 (2017)

NOTES

Transportable quantum communication node based on a cavity ion trap

Lara Becker

Institut für Experimentalphysik, Universität des Saarlandes, Germany

The range of quantum communication is limited by the propagation loss of light in glass fibers. Quantum repeaters contribute to overcome these distance limitations and to realize quantum networks [1]. In our present ion trap, we have implemented a quantum repeater cell [2, 3] based on two free-space coupled 40Ca^{+} ions [4]. However, the generation efficiency of entangled photon pairs has yet to be enhanced for the application on the 14-km fiber link traversing the city of Saarbrücken [5]. To increase the generation efficiency, a new ion trap with an integrated fiber cavity is set up. In the new setup, the ions are trapped in a multi-segment Paul trap formed by two fiber ferrules, which are machined and metal-coated to provide the electrode configuration. The fiber cavity mirrors are inserted into the ferrule, thereby integrating the sub-mm cavity into the trapping electrodes. With its compact design, the cavity ion trap including the vacuum chamber, control electronics, ablation laser and photoionization laser will be stored in a single transportable rack.

[1] H.-J. Briegel, et al., Quantum Repeaters: The Role of Imperfect Local Operations in Quantum Communication, Phys. Rev. Lett. 81, 5932 (1998)

[2] D. Luong, et al., Overcoming lossy channel bounds using a single quantum repeater node, Appl. Phys. B 122, 96 (2016)

[3] P. van Loock, et al., Extending Quantum Links: Modules for Fiber- and Memory-Based Quantum Repeaters, Adv. Quantum Technol. 3, 1900141 (2020)

[4] M. Bergerhoff, et al., Quantum repeater node with free-space coupled trapped ions, preprint posted on arXiv : 2312.14805 [quant-ph] (2023)

[5] S. Kucera, et al., Demonstration of quantum network protocols over a 14-km urban fiber link, preprint posted on arXiv : 2404.04958 [quant-ph] (2024)

NOTES

Design and development of X junctions for three dimensional segmented ion traps

Santiago Emilio Bogino

Johannes Gutenberg-Universität Mainz

In order to scale current hardware for trapped ion Quantum computers, it is imperative to go from the widely used one dimensional schemes (linear traps) to bi-dimensional schemes. A straightforward starting point is to implement lattices of linear traps, but they need to be efficiently connected between each other with some kind of junction, whether X, Y or T shaped. In order to connect ions from different linear traps, efficient and coherent transport through the junction is required. In our work, the design and development of X junctions is carried out. With the aim of addressing subtle geometry variations that might lead to noticeable improvements in the junction performance, a closed-loop, feedback-driven design and simulation workflow is being developed. Parameterized X junction models are designed and iteratively tested by characterizing their performance for different geometry parameter sets. The designs are first tested by characterizing their trapping ponderomotive pseudopotential due to RF biased electrodes. A key part of the development process is the ion transport algorithm, that needs to characterize the transport performance of different junction models in term of their geometry parameters. The transport happens in a bidimensional path, which puts on a new challenge with respect to transport in linear traps. For each instance of the parameter sets, the optimal RF pseudo potential, which is responsible for the radial confinement within each linear trap segment, is firstly obtained. Then, the DC electrode voltages waveforms are computed to maximize the transport performance across the junction. A proof-of-concept model is also presented, to test the fabrication process and address technical problem that might arise here. In a following step we do not just blindly sweep through parameters, but use the transport performance results as feedback to change the set of geometric parameters towards further improvements. We also improve on the closed-loop optimization, by taking advantage of machine learning tools for reinforced learning to learn from the transport characterization results. In conclusion, our research focuses on the simulation and development of X junctions, which are crucial for the implementation of two dimensional scalable ion traps.

NOTES

Vibration damping system for integrated cavity-tweezer quantum simulator

Saloni Chourasiya

Universität Innsbruck, Austria

In the realm of Cavity Quantum Electrodynamics (QED), natural acoustical disturbances pose a significant challenge. These disruptions can hinder the optimal performance of a high finesse cavity, necessitating the need for a controlled environment free from such interferences. To tackle this issue, we focused on designing and testing a specialized Vibration Isolation and damping platform. This platform aims to shield the cavity from external vibrations within its main chamber, ensuring undisturbed operation. Through practical experimentation, the effectiveness of this platform will be evaluated, with the goal of enhancing the reliability of Cavity QED setups.

NOTES

Integration of a fiber Fabry-Pérot cavity in a linear Paul trap

Jolan Costard

Universität des Saarlandes, Germany

In the field of quantum communication and quantum processing, the development of quantum repeaters has become crucial as the communication range is limited by losses [1]. In our experiment, this quantum network node is realized with two calcium ions in a linear Paul trap. Only a small percentage of the light from free-space emission of the excited ion is captured. However, our objective is to couple most of these photons into a single optical mode of a fiber. Therefore, if a well-calibrated optical resonator is placed around the ion, one can enhance the spontaneous emission rate of a photon by the Purcell factor [2]. In our experiment, we integrate a high-finesse fiber cavity into the linear Paul trap with sub-mm spacing. This allows us to optimize the collection efficiency and the generation rate of photons entangled with the ion, thus improving the communication rate.

[1] H.-J. Briegel, W. Dür, J. I. Cirac, and P. Zoller, Quantum Repeaters: The Role of Imperfect Local Operations in Quantum Communication, Phys. Rev. Lett. 81, 5932 (1998)

[2] E. Purcell, Spontaneous emission probabilities at radio frequencies. Phys. Rev. 69, 681 (1946)

NOTES

Photon Bose-Einstein-Condensates in Coupled Lattice Potentials

Daniel Ehrmanntraut

Institut für angewandte Physik, Universität Bonn, Germany

Inspired by the experimental observation of Bose-Einstein condensation (BEC) in ultracold atomic gases, researchers subsequently also turned to study Bose condensation phenomena in other physical systems, e. g. exciton-polaritons, magnons or photons. Photon BECs, which were realised for the first time by our group at the University of Bonn [1], are of particular interest because the platform enables quantum gas experiments at room temperature and with a high level of experimental control. One such example for controllability is the possibility to introduce variable potentials for the optical quantum gas and study the collective behaviour in large arrays of coupled condensates in one or two-dimensional systems. In my presentation, I will discuss our work on the realisation of lattices of coupled photon BEC potentials. The condensates are trapped inside a high-finesse optical microcavity filled with a liquid dye solution. Repeated absorption and emission of photons inside the cavity thermalises the photon gas. By structuring one of the cavity mirrors with surface profiles, we implement micro-potentials which spatially localise the BECs and allow for interactions between photon condensates at neighbouring sites assisted by photon tunnelling [2, 3]. In particular, I will discuss our approach to dynamically correct residual variations of the potential energy at individual lattice sites. Precise control over the energy levels is vital for future studies on topological defects, turbulent dynamics and XY model simulations with light.

[1] J. Klaers et al., Nature 468, 545-548 (2010)
[2] D. Dung et al., Nat. Photonics 11, 565-569 (2017)
[3] C. Kurtscheid et al., EPL 130, 54001 (2020)

NOTES

Phase stabilizing multiple standing waves to achieve fast entangling gates for trapped ion quantum computing

Pat Yin (Lavender) Foo

Imperial College London, University of Oxford, United Kingdom

Trapped ions serve as a promising platform for constructing quantum devices due to their long coherence times and ability for high-fidelity gate operations [1,2]. Developing fast entangling gates in many-ion crystals is beneficial in reducing qubits' exposure to environmental noise and hence susceptibility to errors. However, coherent errors begin to dominate as gate duration decreases. In the case of Mølmer–Sørensen (MS) gates, a speed limit arises due to the increasingly significant effect of a non-commuting off-resonant carrier term. Recent results have demonstrated the technique of phase controlling optical fields at the positions of ions using standing waves [3]. By placing ions at the antinodes of the standing wave, the error due to carrier term is suppressed, thus overcoming the speed limit in MS gates without sacrificing fidelity [4]. To generate beams with high light intensities and narrow waists required for fast gate operations at each qubit, we describe our current progress of developing a system with two phase-stabilized optical standing waves, enabling individual-ion addressing in a chain. In the set-up, two beams are steered using crossed acoustic-optic deflectors (AODs) and form an interferometer with counter-propagating beams. Drifts in optical path lengths due to air currents, temperature, or vibrations may cause standing wave antinodes to deviate from the positions of ions. We will explore strategies for implementing feedback loops to perform phase corrections for each of the standing waves, through varying the phase of the radio-frequency field driving the AODs. We will integrate this system into a chain of $40Ca^{+}$ ions with quadrupole transition at 729 nm for implementing scalable high-speed entangling gates.

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[1] J. Benhelm, G. Kirchmair, C. F. Roos, and R. Blatt, "Towards fault-tolerant quantum computing with trapped ions," Nature Physics, vol. 4, no. 6, pp. 463–466, Apr. 2008

[2] C. J. Ballance, T. P. Harty, N. M. Linke, M. A. Sepiol, and D. M. Lucas, 'High-Fidelity Quantum Logic Gates Using Trapped-Ion Hyperfine Qubits', Phys. Rev. Lett., vol. 117, p. 060504, Aug. 2016.

[3] C. T. Schmiegelow et al., 'Phase-Stable Free-Space Optical Lattices for Trapped Ions', Phys. Rev. Lett., vol. 116, p. 033002, Jan. 2016.

[4] S. Saner and O. Băzăvan et al., 'Breaking the Entangling Gate Speed Limit for Trapped-Ion Qubits Using a Phase-Stable Standing Wave', Phys. Rev. Lett., vol. 131, p. 220601, Dec. 2023

NOTES

The Bell Polytope from an Experimentalist's View

Ilija Funk

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From an experimental viewpoint, the Bell polytope (also named local set or local polytope) is a geometrical structure within the space of measurement outcomes of an experiment. Its volume contains all possible measurement outcomes that can be fully explained with local hidden variable theories. The boundaries of this volume define the Bell inequalities. One experiment with true quantum behaviour is polarization-based entanglement from a spontaneous parametric down-conversion (SPDC) source. However, based on its experimental parameters, the results still can lie either within or outside the Bell polytope. Slight adjustments of the parameters lead to different locations in this polytope space. We investigate mathematically and experimentally how the experimental parameters of an SPDC source (e.g. alignment, the orientation of compensation crystals, orientation of the measurement basis, polarization control within the fibers) influence the location of the measurements result in the polytope space. This will provide insight into the experimental accessibility of all locations in the Bell polytope as well as aid the alignment process in a systematic way.

NOTES

Using a shelving state of an ion to probe atom-ion spin exchange collisions

Maximilian Futterknecht

Institut für Quantenmaterie, Universität Ulm, Germany

I am setting up an experiment for investigating spin exchange collisions between a Doppler-cooled, single ion in a linear Paul trap and a cloud of ultracold Rubidium atoms. To detect a spin exchange event between the species, we plan to use a long-lived, meta-stable shelving state of the Barium ion. The corresponding optical quadrupole transition is driven by a 1762 nm cavity-stabilized diode laser. For efficiently measuring spin exchange, the optical transitions between two Zeeman levels of the ground state and the shelving state need to be resolved and the excitation rate must be temporarily stable. The detection efficiency is affected by background magnetic fields, which determine the Zeeman splitting and hence the transition frequency. Zeeman spectra, including all allowed shelving transitions, are measured and studied and the temporal stability of the transition frequencies is investigated. Eventually, drifts of background fields will be compensated to prepare the experimental requirements for successfully measuring spin exchange.

NOTES

Optical system for bi-directional tracking in free-space quantum key distribution link

Akhil Gupta

Ludwig-Maximilians-Universität München, Germany

Quantum key distribution (QKD) is emerging as a secure alternative to current mathematical complexity based cryptographic algorithms generating shared secret keys. QKD leverages fundamental principles of quantum physics to securely exchange keys between communicating parties. With the appropriate post-processing steps, any eavesdropping attempt can be detected successfully. Quantum Key Distribution (QKD) can be implemented using either fiber-based or free-space channels. Free-space communication offers several advantages over fiber-based systems: it is more compact, easier to install, and significantly cheaper. This work primarily focuses on ground-to-ground free-space communication. We aim to design a secure ground-to-ground communication link and demonstrate its feasibility over a distance of three kilometers using simple systems. Telescopes play a crucial role in free-space communication, as they are essential for transmitting and receiving photons between the sender and receiver units. We are developing a symmetrical telescope design that functions both as a sender and receiver for the free-space link, optimized for two wavelengths: an 850 nm source as the QKD signal and a 1550 nm beam as a beacon for tracking, synchronization and classical communication. Their bidirectional stability and low-loss transmission in free-space settings are key factors for successful quantum communication.

NOTES

Double imaging and stray light suppression for a multi species Paul trap for quantum computing

Ernst Alfred Hackler

Universität Siegen, Siegen

Multi-species ion crystals are useful, for example, for quantum information processing with trapped ions or for quantum logic spectroscopy. Here, we report on the development and performance of an imaging system for mixed ion crystals of Barium and Ytterbium ions. Since the wavelengths of the resonance fluorescence of these two ion species are far apart (369 nm and 493 nm, respectively), dispersion in a refractive imaging system has to be considered. To image both species simultaneously, a double imaging system was designed and built, taking into account dispersion and chromatic aberrations. At the same time, this set-up efficiently suppresses stray light. In this poster, I present the simulation and measurement results that were used to quantify the performance of this set up.

NOTES

Towards photon triplet states with a tapered optical fibre

Minjae Hong

Department für Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Max-Planck-Institut für die Physik des Lichts Erlangen, Germany

Quantum entanglement photons has been applied to various fields, such as quantum communication, cryptography, and imaging. Traditional two-photon entanglement is achieved via spontaneous parametric down-conversion (SPDC) [1] but producing multiple photon entanglement states can offer higher degrees of freedom for more efficient applications in quantum technology [2, 3]. Third Order Spontaneous Parametric Down Conversion (TOSPDC) is a nonlinear quantum process, where a highenergy pump photon is converted into three lower-energy signal photons. The generation of triplet states through TOSPDC is based on $\chi^{(3)}$ susceptibility.Optical fibres provide a promising platform [4] to observe these effects. They offer long interaction length to balance the relatively low nonlinearity of silica providing that phase matching is fulfilled. In the present case, we plan to use tapered fibres. The phase matching can be achieved by adjusting the radius of the tapered fibre. The tapering radius can be determined through solving the waveguide eigenvalue equation for specific target wavelengths. Furthermore, TOSPDC must obey the energy and momentum conservation. When pump photons with the frequency ω_p is converted into three signal photons with the frequencies ω_1, ω_2, and ω_3, the energy conservation is: $\omega_1 + \omega_2 + \omega_3 - \omega_p = 0$, and momentum conservation is described with the propagation constants of each photons: $\beta_1 + \beta_2 + \beta_3 - \beta_p = 0$. Thus, we calculated the diameter for 532 nm pump photon producing 1596 nm signal photons of degenerated TOSPDC case ($\omega_1 = \omega_2 = \omega_3$), which the most efficient scenario. Although the aim of the project is to generate triplet photon state, this is a very challenging task that exhibits a very low efficiency. It is very important to fulfill the phase-matching condition for the degenerate case to enhance the weak phenomena. Since TOSPDC shares the same phase-matching conditions with third harmonic generation (THG), it is easier to determine and check the phasematching properties operating in the THG regime [6]. The exact diameter of the tapered fibre can be estimated by measuring the wavelength of signal photons generated using a pulsed pump with a rather broad spectrum and calculate the diameter from the phase-matching conditions [7]. In the first part of my work, I conducted third harmonic generation (THG) starting from a 1550nm pump laser. The laser delivers pulses that are 66 fs long with an energy per pulse up to 792 nJ. The propagation of the input pulses in the untampered fibre yields spectral broadening due to self-phase modulation. Due to the chromatic dispersion, the intermodal phase matching should be satisfied in the fibre. We produced HE12 (LP02) mode with 517 nm signal photons from the fundamental mode of pump photons at 1551 nm. Considering the phase matching conditions, we estimated the diameter of the tapered fibre to 767 nm, which is relatively closed to the target diameter (790 nm for the triplet generation 532 nm $\rightarrow$ 1596 nm). The experimental data fitting shows RTHG $\propto$ p3.1 dependency, as expected from the theory. Using tapered fibres, it is very important to adjust the transition from the untapered fibre to the tapered region so as to transfer the desired mode with minimal loss. For the targeted process, the pump at λ_p is in the visible region and in a high-order transverse mode and the generated photons at $3 \times \lambda_p$ are in the fundamental spatial mode of the fibre. Not only the visible HE12 mode must be carefully prepared, but also adiabatically coupled in the tapered region, while maintaining minimal transition losses for the IR fundamental mode. The coupling loss is minimized under the adiabatic criterion, described by [5]:

$$\frac{dr}{dz} = \frac{r}{2\pi}(\beta_i - \beta_j)$$

($\beta_i - \beta_j$). Here, r is the radius of the fibre at position z, β_i and β_j are the propagation constants of mode i and j. Because of the number of spatial modes involved in the process, the shape of the transition is rather complicated. In parallel, we need to prepare the spatial mode of the pump in the visible region. In this case we used long period grating (LPG), These are known to allow mode-conversion [8]. Since LP01 mode cannot be directly converted into LP02 mode due to the broken fibre symmetry, it will be done through a twostep process. We calculated the grating periods by finding the propagation constants of each mode, β_{01}, β_{11}, and β_{02}, and by solving the equation: $\Lambda_i \rightarrow j = 2\,|\beta_i - \beta j|$. The project aims to directly generate and characterize the triplet state, using TOSPDC in a tapered optical fibre, overcoming limitations of low third-order nonlinear susceptibility and phase mismatching challenges in conventional methods. Tapered fibres are a promising platform, and we now can produce reliably tapered fibre with the right range of diameter to fulfill the necessary phase-matching conditions for the process. The preparation of the right spatial mode is also possible through long-period grating. These are the necessary first steps toward the generation of photon triplet states.

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[2] Zeilinger, Anton, Michael A. Horne, and Daniel M. Greenberger. "Higher-order quantum entanglement." NASA. Goddard Space Flight Center, Workshop on Squeezed States and Uncertainty Relations. 1992.

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NOTES

Open-Source Software for Real-Time Analysis in Super-Resolution Microscopy

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Super-resolution microscopy enables visualization of structures below the diffraction limit, achieving nanometer-scale resolutions. Single-molecule localization microscopy (SMLM) relies on stochastic fluorophore emission and point-spread function deconvolution. We present a novel Python-based software solution for real-time single molecule localization microscopy image analysis and microscopy experiment control, addressing the lack of open-source alternatives to proprietary software. Our software, developed using Python 3, leverages Pylablib, PyQt6, and the Multiprocessing package for parallel processing. The system has been successfully tested with the Andor Zyla 4.2 camera and Coherent OBIS Laser System. The architecture comprises three main components: (1) Acquisition-Experiment-Control, (2) Identification of Regions of Interest, and (3) Data Fitting and Image Rendering. These modules operate concurrently through discrete Multiprocessing processes, overcoming Python General Interpreter Lock (GIL) limitations. A user-friendly graphical interface enhances accessibility and ease of use. We validated the software by imaging nuclear pores using DNA points accumulation for imaging in nanoscale topography (DNA-PAINT), with nuclear pores serving as a reliable reference standard for quantitative super-resolution microscopy. Initially developed for studying macromolecular complexes in biological contexts, the software's applications extend to various scientific disciplines. The work provides value to the general optics community through its flexible, accessible alternative to commercial software. Our work contributes to advancing super-resolution microscopy and related optical imaging techniques.

NOTES

Fourier mode decomposition approach to Floquet-Liouville problem for unclosed atomic loop transitions

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Multi-level atoms, e.g. excited to Rydberg states, present many unique opportunities, but present several challenges for numerical treatment of their interaction with multiple laser fields. In hot-atom systems this is further aggravated by the necessity to include Doppler broadening. Further challenges arise if the system is time-dependent, as the system then doesn't have a strict steady-state solution. Our study presents a numerically efficient approach to solving the Floquet-Liouville problem, focusing on unclosed atomic loops, as exemplified by Rydberg-atom microwave sensing protocols. By manipulating terms within the master equation and applying Fourier decomposition of Floquet-Lindblad modes, we uncover new insights into the control and coherence of atomic states under periodic driving, resulting from uncloseness. The results are particularly relevant for superheterodyne Rydberg sensors [1], where the main question is the efficient transfer of modulation from a weak microwave signal field to light. These findings enhance our understanding of quantum dynamics in Floquet systems and offer potential applications in modelling quantum communication, sensing and transduction protocols [2].

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[2] S. Borówka et al., Continuous wideband microwave-to-optical converter based on room-temperature Rydberg atoms, Nature Photonics, 32-38 (2024).

NOTES

Modulated gates for improved ion control

Florian Kofler

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Quantum systems and their utility for quantum information processing relies critically on our ability to isolate them from the environment while simultaneously admitting desired controls to drive coherent evolution. These two requirements are intrinsically at odds and much effort has been devoted to reconcile the two. In state-of-the-art quantum information processors environmental shielding is now often so well integrated that the main contributors to noise arrive through the control fields themselves. In this work, we apply techniques from optimal control to laser fields that drive coherent evolutions on a quantum system consisting of calcium-40 ions in a linear Paul trap, with the aim of reducing experimental imperfections in this drive. This will be achieved by enabling the control of additional degrees of freedom in the radio-frequency pulse-generation and integrating this functionality into the existing experimental control software using the ARTIQ and Sinara ecosystem. We will apply optimal control techniques in the form of balanced Gaussian amplitude modulation for the two-qubit entangling gate based on the Mølmer-Sørensen interaction, which has previously been shown to reduce the unwanted effects of mode crowding. We will further use concatenated composite pulses for single qubits to mitigate the impact of crosstalk in the single-site addressing. The implementation of these techniques is conducted in a manner that will facilitate the testing of additional optimal control techniques in the future.

NOTES

Fabrication and Characterization of Silicon Nitride Ring Resonators and Exploration of Titanium Dioxide for Nonlinear Optics

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We present our recent advancements in the fabrication and characterization of integrated photonic devices, focusing on silicon nitride (Si_3N_4) ring resonators and the initial exploration of titanium dioxide (TiO_2) as a promising material for nonlinear optics. Our study involves the fabrication of Si_3N_4 ring resonator structures using Electron Beam Lithography (EBL) and Reactive Ion Etching (RIE). We successfully observed resonance phenomena in the waveguide-coupled ring resonators at the 1550 nm wavelength range, a crucial spectral region for quantum optics and telecommunications applications. We investigated the impact of the gap between the ring and the waveguide on the light intensity within the waveguide, providing insights into coupling efficiency and potential applications in quantum information processing. Furthermore, we initiated research on TiO_2 as a material with higher third-order nonlinear coefficients, which could enable more efficient nonlinear optical processes crucial for quantum optics experiments. Our presentation will also address common fabrication challenges encountered during the EBL process, such as stitching errors, and discuss our optimized RIE recipes for etching both Si_3N_4 and TiO_2 materials. This work contributes to the ongoing efforts in developing robust and efficient integrated photonic platforms for quantum optics applications.

NOTES

High brightness single photon sources based on a single DBATT molecule

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Single organic fluorescence molecules under cryogenic temperature are known for spectral stability. This means no blinking and no bleaching occurs. Moreover, their emission flux is high, while they can emit narrowband photons (down to 12 MHz) [1]. Our friend is the molecule dibenzanthanthrene, DBATT, which emits in the visible region of the spectrum, around 589nm. For the innovative use of single photon sources in nanoquantum optics, it is of utmost importance to maximize and effectively detect the single photon stream. A relay lens with high NA is developed to improve light collection. Driving the system resonantly with pulsed excitation an increase in power gives rise to so-called Rabi rotations [2]. These are used to obtain single photons in a "push-button" fashion via short optical π-pulses [3].

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NOTES

Optical Properties of NV Centers Activated by Proton Implantation

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Diamond exhibits various colors due to the active point defects in the crystal lattice. One of them is the nitrogen-vacancy (NV) center, formed by the nitrogen atom and the neighboring vacancy, and its negatively charged species (NV^-) is crucial for quantum communication, quantum metrology, and quantum sensing. The NV^- has triplet ground and excited states and can be optically initialized and read out, while the spin state can be controlled by the microwave (MW) driving field. High photon counts are essential to increase the sensitivity; therefore, samples with a high concentration of NV^- centers are desirable. However, their number is low even in the nitrogen-rich samples. Thus, one regularly uses various techniques, such as electron irradiation or ion implantation, to increase the number of NV centers. We create defects in the diamond lattice by proton implantation. After the annealing process and the NV^- creation, we examine their optical properties in the samples with different nitrogen concentrations. Proton implantation allows us to create well-localized NV centers with a high spatial resolution. Spectral decomposition reveals that most are NV^- centers, not the undesired, neutral species (NV0). Finally, optically detected magnetic resonance (ODMR) confirms that hyperfine splitting persists after proton irradiation. Our findings pave the way to more affordable and compact quantum devices.

NOTES

Trapping of Bose-Einstein condensates in a three-dimensional dark focus generated by conical refraction and creation of a 3D lattice of bottle beams

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Optical trapping and guiding potentials based on conical refraction (CR) in a biaxial crystal present a versatile tool for the manipulation of atomic matter waves in atomtronics circuits. The conversion of a Gaussian input beam to a drak focus beam by CR has an efficiency of close to 100% and the optical setup requires the addition of the biaxial crystal and a circular polarizer only. Based on the conicalrefraction theory, we derive the general form of the potential, the trapping frequencies, and the potential barrier heights. Based on the specific properties of CR, we generate a three-dimensional dark focus optical trapping potential for ultra-cold atoms and Bose-Einstein condensates. This ’optical bottle’ is created by a single blue-detuned laser beam and gives full 3D confinement of a cold atom cloud. We present the experimental implementation of one ’optical bottle’ and give a detailed analysis of the trapping properties. We further investigate the creation of a 3D lattice of bottle beams by exploiting the Talbot effect of a microlens array which is combined with CR

NOTES

Quantum-Processing Architecture with Rydberg-Interacting Neutral-Atom Arrays

Christoph Rützel

Technische Universität Darmstadt, Germany

Quantum computers promise to be able to solve and calculate problems that surpass the limit of processing power that is available with current regular computers. Thus, research of quantum technologies is in high demand in the field of quantum optics as well as modern physics and related fields of engineering in general. For a quantum computer, several criteria need to be fulfilled. These criteria include scalability of the system and obtaining a set of universal quantum gates. While approaches using superconducting circuits and trapped ions often face scalability issues, the approach of using neutral atoms trapped in arrays of dipole traps is advantageous particularly in this respect. By illuminating a microlens array (MLA) with a red detuned laser beam, it is possible to create a two-dimensional array of dipole traps [1] which are extended into the third dimension at no additional cost due to the Talbot effect [2]. By using two MLAs simultaneously in order to generate two trap arrays, it is possible to create configurations with more than 3000 trap sites [1]. On average, 1167 single atoms were trapped in this special trapping structure. By defining one of the two trap arrays as quantum processing unit and supercharging it with atoms from the respective other array, the filling fraction is increased significantly. Defect-free clusters of up to 441 qubits can be realised after further assembly cycles using an additional movable tweezer. A set of universal quantum gates can consist of single-qubit operations together with a two-qubit operation. In order to introduce an interaction between single neutral atoms, the so-called Rydberg blockade can be used [3]. A two-qubit gate uses two atoms, where one is designated as the target atom and the other as the control atom. If the control atom is excited to the Rydberg state, the dipole–dipole interaction between the atoms shifts the Rydberg level of the target atom. This means that the excitation to the Rydberg state is blocked (Rydberg blockade) for the target atom because the transition is out of resonance. Thus, the excitation dynamics and phase of the target atom can be controlled with the state of the control atom. Combining the Rydberg blockade mechanism with a two-photon rotation between states $|0\rangle$ and $|1\rangle$ of the target atom enables the creation of a CNOT gate between two atoms, which, in combination with one-qubit gates, leads to a set of universal quantum gates. As one needs to be able to implement the blockade for all available qubits, the ability to address individual trap sites is necessary. This is realised by additional laser sources that are responsible for the Rydberg excitation and the blockade mechanism that interact with the trapped atoms at their individual locations.

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[2] M. Schlosser et al., Phys. Rev. Lett. 130, 180601 (2023)
[3] M. Schlosser et al., J. Phys. B: At. Mol. Opt. Phys. 53, 144001 (2020)

NOTES

Enhanced Second Harmonic Generation from Silver Nanoantennas

Fabian Scheidler

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Plasmonic gold nanostructures allow to achieve large field enhancement in nanoscale volumes and are therefore appealing to boost nonlinear processes such as second harmonic generation (SHG). Especially intense near-field hot spots emerge in the gaps of symmetric colinear dimer antennas, yet strong SH sources created in the gap region oscillate out-of-phase and thus destructively interfere in the far-field [1]. Introducing local asymmetry by careful design of the antenna gap geometry allows to mitigate the so-called silencing effect and leads to enhanced SHG [2]. In the ultraviolet-visible spectral range, however, the SH efficiency for gold nanoantennas is limited due to high damping below 500 nm. Here we present silver nanoantennas fabricated from epitaxial grown single-crystalline microplate- lets with the aim to boost SHG between 400 nm to 500 nm, where silver shows significantly less absorption losses compared to gold. The antenna design is optimized for SHG taking into account the linear scattering response. To this end we investigate colinear coupled systems, utilizing both capacitive coupling and conductive coupling, to find an antenna design that shows a resonance at the fundamental and the SH frequency.

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NOTES

Programmable Optical Lattices for Quantum Simulation Experiments

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Creating tailored optical potentials on demand is crucial for quantum simulation experiments with ultracold atoms, supporting the exploration of diverse strongly correlated phenomena, such as magnetic frustration or topological order. This project outlines the design and projection of lattice potentials using holographic beam shaping methods, combined with precise corrections of optical aberrations. The corrections and projection of the potentials are achieved by the employment of a Digital Micromirror Device (DMD) and a Spatial Light Modulator (SLM), which provide phase and amplitude modulation by displaying grating-like structures. During the correction process, an iterative phase shift interferometry algorithm is used to reconstruct the complete phase profile which the setup imprints on the beam, enabling phase correction of wavefront aberrations with resolutions on the order of $\lambda/100$. For shaping the corrected beam into the desired optical lattices, we implement different holographic projection methods, including basic Fourier Transform (FT) and the Gerchberg-Saxton algorithm, and analyze their effectiveness. Further a general user software including a graphical user interface is implemented, facilitating manual control of the SLM-DMD structure in real time, creating additional flexibility for future research projects. As a result, we are able to implement a variety of optical lattices, ranging from lattices in box-shape potentials to linearly tilted superlattices. Our results provide a highly versatile toolbox for state-of-the art quantum simulation experiments, laying for instance the foundation, for fractional quantum Hall physics.

NOTES

Useful Information

The Venue

The meeting will be hosted at Seminarzentrum Unteres Schloss (Obergraben 25), which is located close to the university campus Unteres Schloss. You can reach it by foot from the main station in Siegen in around 7-10 minutes. Here we will have breakfast and host the talks and poster sessions.

Hotels

Hotel Concorde From Hotel Concorde you can take the bus line C111 from Kaisergarten to Kölner Tor, or just walk for 20 minutes along Sandstraße towards Obergraben. You can also take the scenic route via Oberstadt. Just follow the Kampenstraße and later Marburger Tor and Kölner Straße.

Gasthof Meier From Gasthof Meier it is only a 9 minutes walk. Follow Koblenzer Straße in the direction of Siegen City Center, then turn right into Obergraben.

Hotel Holiday Inn Finally from Hotel Holiday Inn you can walk straight along Koblenzer Straße and then turn right into Obergraben. It is a 15 minutes walk. Otherwise, you can take the bus line C100/C101/C102 from Siegen Kreishaus to Siegen Kölner Tor, however you will not save much time.

Hotel Bürger If you stay in Hotel Bürger, it is a longer walk of 30 minutes. You can still walk but there is a bus line (R13/R12) from Siegen Blumenstraße to Siegen Kölner Tor.

Lab Tours and BBQ @ ENC

This year's Greenhorn meeting is hosted by two research groups, the Experimental Quantum Optics group of Prof. Dr. Christof Wunderlich and the Nano-Optics group of Prof. Dr. Mario Agio.

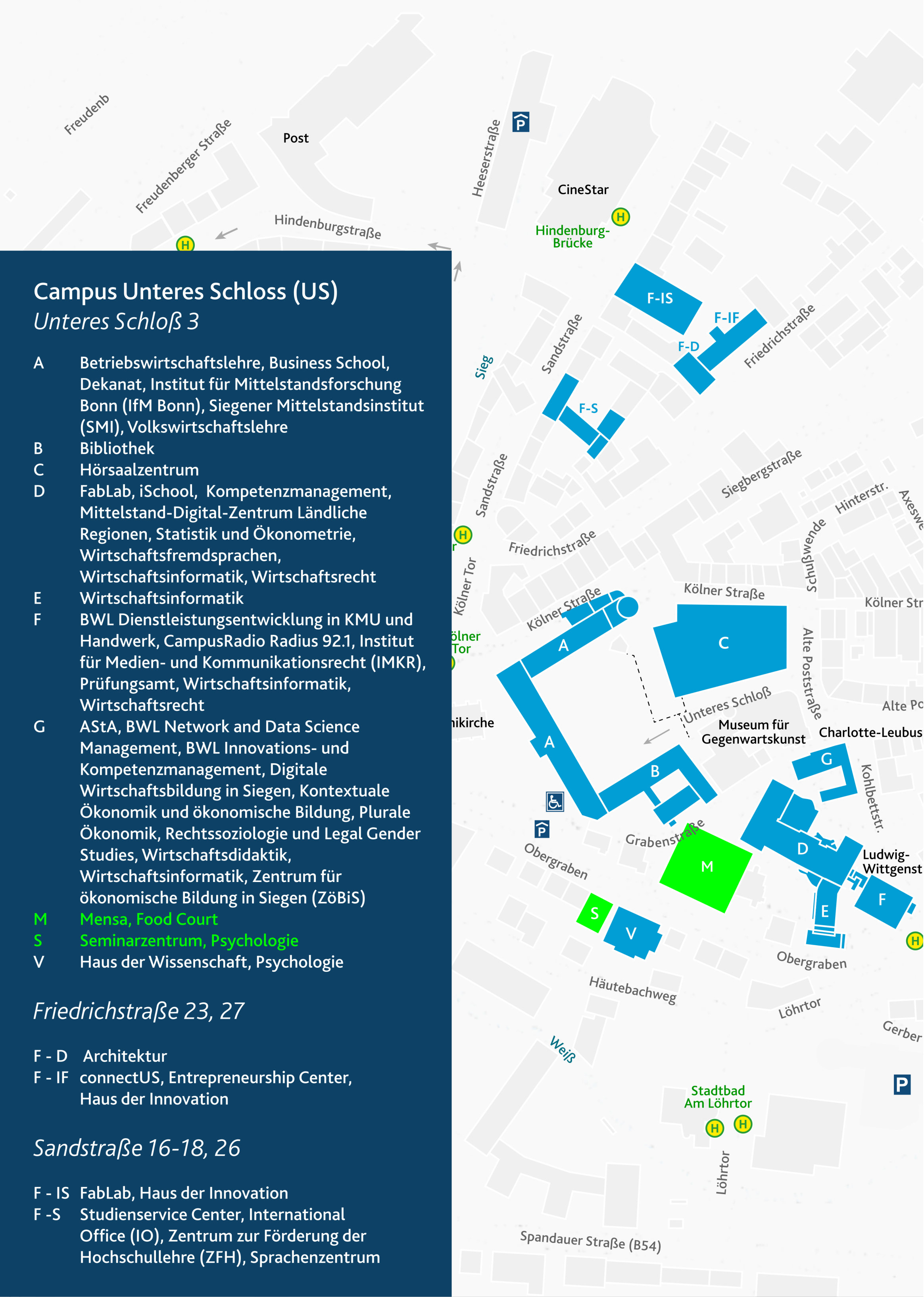
The former concentrates its theoretical and experimental work on the development and exploration of new schemes for quantum information processing using individual atoms and open fundamental questions related to quantum physics. The main focus lies on ion trapping technologies and its applications to topics like quantum simulation or quantum computing.

The latter having its experimental and theoretical research activities in Quantum Nano-Optics, Nano Spectroscopy and Nano Sensing, in tight cooperation with local, national and international research groups. Reseach includes investigating the properties of light beyond the diffraction limit and studying its interaction with nanoscale matter. In particular interrogating single quantum systems and in exploring quantum phenomena that occur at the subwavelength scale.

Both groups are happy to share insights into currently ongoing experiments in their labs. These lab tours will take place on tuesday before having a cozy BBQ at the Emmy-Noether-Campus.

Joint Dinner

On the last evening of the meeting, we would like to invite every participant to a joint dinner. Either to keep discussing all the interesing topics that were presented so far, or just to have some nice food. The exact restaurant will be announced shortly before the event.



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