GREENHORN 2025

Saarbrücken

program booklet

Contents

About

Greenhorn 2025

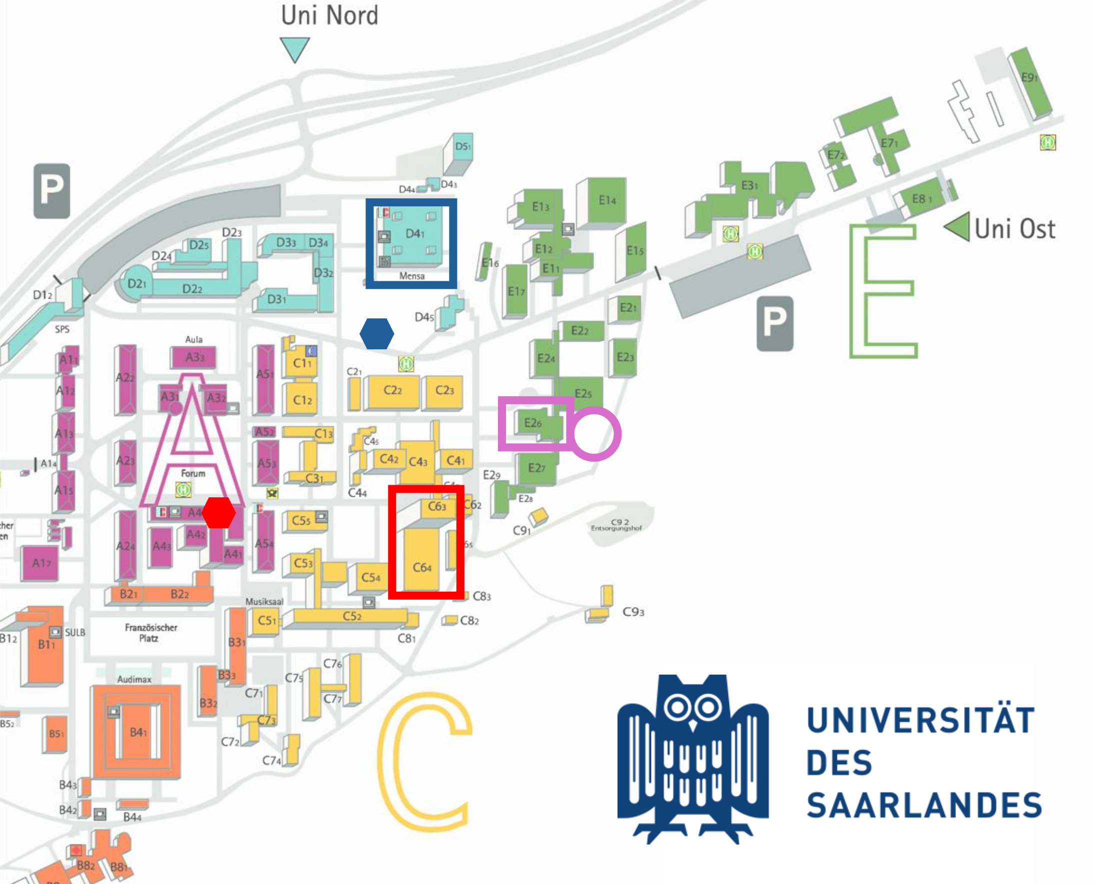
The Greenhorn Meeting is an annual meeting organized by and for young researchers in the fields of quantum optics, nano-optics, atomic physics and ultracold atomic gases. Those in the first half of their PhD or in the last year of their masters are welcome to present their ongoing research, share and discuss ideas, and network with other young scientists.

The Greenhorn 2025 Team

For this year's Greenhorn Meeting, PhD students from the quantum photonics group of Prof. Dr. Jürgen Eschner and the quantum optics group of Prof. Dr. Christoph Becher are happy to invite you to the Saarland University in Saarbrücken. The team includes:

Pascal Baumgart
Lara Becker
Jolan Costard
Akriti Raj
Marlon Schäfer

Location



Bus stop „Universität Campus“

„Physics tower“ C63 & C64
Location of talks (HS II) & poster sessions (hallway)

Bus stop „Universität Mensa“

Mensa D41

Building E26
Breakfast & Lab tours on Tuesday 5pm

BBQ place
BBQ on Tuesday 6pm

Program

Monday – 22.09.2025

18:00	**Get-together at the pub**	t.b.a.

Tuesday – 23.09.2025

8:30 – 9:20	**Registration & Breakfast**	E26, Room E.04
9:30 – 11:30	**Opening & Talks 1** ▪ **Pascal Baumgart,** *Introduction to the Greenhorn Meeting 2025* ▪ **Micha Kappel,** *Design of a tweezer setup for rearrangement and addressing of single atoms in an optical cavity* ▪ **James Rumbold,** *Laser addressing and detection system for a 10-qubit quantum computer* ▪ **Till Schacht,** *Architecture for arbitrary addressing of neutral ytterbium Atoms in a 2D optical tweezer array* ▪ **Ben Michaelis,** *Laser noise reduction for enhanced gate fidelity in neutral atom quantum computers* ▪ **Paula Bañuls Saiz,** *Experimental Study of the combination of addressing and shuttling architecture of an ion trap quantum computer* ▪ **Marius Thomas,** *Clock spectroscopy on the ionic core of alkaline-earth circular Rydberg atoms*	C62, Hörsaal II
11:30 – 12:00	**Coffee break**	C62, hallway

12:00 – 13:00	**Talks 2: Research group presentations** ▪ **Max Bergerhoff,** *Introduction to the lab tours: Quantum photonics group of Prof. Dr. Jürgen Eschner* ▪ **David Lindler,** *Introduction to the lab tours: Quantum optics group of Prof. Dr. Christoph Becher*	C62, Hörsaal II
13:00 – 14:00	**Lunch**	D41, Mensa
14:00 – 16:00	**Poster session 1**	C62, hallway
16:00 – 17:00	**Break**	
17:00 – 18:00	**Lab tours** Guided tours through the laboratories of the quantum photonics group of Prof. Dr. Jürgen Eschner and the quantum optics group of Prof. Dr. Christoph Becher	E26, Room E.04
18:00	**BBQ**	E26, BBQ place

Wednesday – 24.09.2025

8:30 – 9:20	**Breakfast**	E26, Room E.04
9:30 – 11:30	**Talks 3** ▪ **Sushree Swateeprajnya Behera,** *Towards two-photon interference with color centers in silicon carbide* ▪ **Alicia Robles Pérez,** *Design and characterization of core/ shell InGaAs/ InAlAs nanowires for telecom-wavelength lasing* ▪ **Max Heimann,** *Adiabatic fiber coupling to diamond sawfish cavities* ▪ **Lucca Valerius,** *Addressing fabrication challenges in photonic crystal cavities for diamond color centers* ▪ **Sambit Satapathy,** *Development of a pump-probe optically pumped magnetometer with inexpensive VCSEL diodes for motorized archaeological prospection* ▪ **Clara Baenz,** *Deep Learning Strategies for Stabilizing NV Center Emission Spectra* ▪ **Fabian Scheidler,** *Nanoscale free-electron dynamics in plasmonic nanostructures*	C62, Hörsaal II
11:30 – 12:00	**Coffee break**	C62, hallway

12:00 – 13:00	**Talks 4** ▪ **Simon Brunner,** *Simulating gauge fields in curved spacetime* ▪ **Jurek Eisinger,** *Variational quantum simulation of the interacting Schwinger model on a trapped-ion quantum computer* ▪ **Maharshi Pran Bora,** *Characterizing continuous quantum phase transitions using Kibble Zurek mechanism by using a reverse quench protocol* ▪ **Özgün Ozan Nacitarhan,** *Bohmian trajectories in a double slit experiment*	C62, Hörsaal II
13:00 – 14:00	**Lunch**	D41, Mensa
14:00 – 16:00	**Poster session 2**	C62, hallway
16:00 – 18:00	**Break**	
18:00	**Dinner**	t.b.a.

Thursday – 25.09.2025

8:30 – 9:20	**Breakfast**	E26, Room E.04
9:30 – 10:00	**Invited talk: Toptica**	C62, Hörsaal II

10:00 – 11:30	**Talks 5** ▪ **Finn Lubenau,** *Tuneable light fields for modular quantum simulation* ▪ **Tim Jeglortz,** *Active magnetic field stabilization for an ultracold quantum gas experiment* ▪ **Oskar Sund,** *Spin noise spectroscopy of hot rubidium vapor under two-photon excitation* ▪ **Hans Leonard Michel,** *Vortices in a 2D fermionic superfluid* ▪ **Fabian Bennati,** *Photon-mediated atom-pair creation in momentum states of a BEC* ▪ **Robin Krill,** *Quantum Monte Carlo simulations of hardcore bosons with repulsive density-density interactions on two-dimensional lattices*	C62, Hörsaal II
11:30 – 12:00	**Coffee break**	C62, hallway
12:00 – 13:00	**Talks 6** ▪ **Tizian Schmidt,** *Implementation and characterization of a free-space quantum key distribution system* ▪ **Tom Hobbs,** *Experimental quantum cryptography and the Bell polytope* ▪ **César Bertoni Ocampo,** *Advances in modules for the MultiQomm project* ▪ **Keshav Venkataraman,** *Amplitude amplification using a Floquet system*	C62, Hörsaal II
13:00 – 14:00	**Lunch**	D41, Mensa
14:00	**Closing**	E26, Room E.04

Poster sessions

Tuesday – 23.09.2025 – Poster session 1

Participant	Topic
Clara Baenz	Deep Learning Strategies for Stabilizing NV Center Emission Spectra
Sushree Swateeprajnya Behera	Towards two-photon interference with color centers in silicon carbide
Maharshi Pran Bora	Characterizing continuous quantum phase transitions using Kibble Zurek mechanism by using a reverse quench protocol
Simon Brunner	Simulating gauge fields in curved spacetime
Jurek Eisinger	Variational quantum simulation of the interacting Schwinger model on a trapped-ion quantum computer
Max Heimann	Adiabatic fiber coupling to diamond sawfish cavities
Tom Hobbs	Experimental quantum cryptography and the Bell polytope

Participant	Topic
Özgün Ozan Nacitarhan	Bohmian trajectories in a double slit experiment
César Bertoni Ocampo	Advances in modules for the MultiQomm project
Alicia Robles Pérez	Design and characterization of core/ shell InGaAs/ InAlAs nanowires for telecom-wavelength lasing
Sambit Satapathy	Development of a pump-probe optically pumped magnetometer with inexpensive VCSEL diodes for motorized archaeological prospection
Fabian Scheidler	Nanoscale free-electron dynamics in plasmonic nanostructures
Tizian Schmidt	Implementation and characterization of a free-space quantum key distribution system
Lucca Valerius	Addressing fabrication challenges in photonic crystal cavities for diamond color centers

Wednesday – 24.09.2025 – Poster session 2

Participant	Topic
Fabian Bennati	Tunable symmetry breaking in a quantum gas
Tim Jeglortz	Active magnetic field stabilization for an ultracold quantum gas experiment
Micha Kappel	Design of a tweezer setup for rearrangement and addressing of single atoms in an optical cavity
Robin Krill	Quantum Monte Carlo simulations of hardcore bosons with repulsive density-density interactions on two-dimensional lattices
Finn Lubenau	Tuneable light fields for modular quantum simulation
Ben Michaelis	Laser noise reduction for enhanced gate fidelity in neutral atom quantum computers
Hans Leonard Michel	Vortices in a 2D fermionic superfluid
James Rumbold	Laser addressing and detection system for a 10-qubit quantum computer
Paula Bañuls Saiz	Experimental Study of the combination of addressing and shuttling architecture of an ion trap quantum computer
Till Schacht	Architecture for arbitrary addressing of neutral ytterbium Atoms in a 2D optical tweezer array
Oskar Sund	Spin noise spectroscopy of hot rubidium vapor under two-photon excitation
Marius Thomas	Clock spectroscopy on the ionic core of alkaline-earth circular Rydberg atoms
Keshav Venkataraman	Amplitude amplification using a Floquet system

Abstracts

Design of a tweezer setup for rearrangement and addressing of single atoms in an optical cavity

Micha Kappel, Raphael Benz, Sebastián Alejandro Morales Ramirez, and Stephan Welte

5. Physikalisches Institut, Universität Stuttgart

Neutral atoms coupled to an optical cavity are a promising platform for implementing quantum network nodes. To realize network nodes with multiple stationary atomic qubits, it is crucial to position and address the atoms precisely within the cavity mode. We present an optical de- sign utilizing two two-dimensional acousto-optical deflectors to create optical tweezers capable of trapping arrays of Rubidium atoms inside the cavity. This setup not only facilitates precise atom trapping but also enables individual addressing and rearrangement of the atoms.

To mitigate the inevitable atom losses during operation, we propose the inclusion of a reservoir containing additional atoms in a tweezer array outside the cavity mode. These extra atoms can be used to replenish lost atoms within the cavity. We describe our optical setup and discuss experimental techniques and challenges.

Laser addressing and detection system for a 10-qubit quantum computer

James Rumbold, Ferdinand Schmidt-Kaler

Johannes Gutenberg University of Mainz

Professor Ferdinand Schmidt-Kaler's Quantum Information Group at the Johannes Gutenberg University of Mainz aims to implement quantum algorithms on 10 qubits in our latest setup. To achieve high-fidelity quantum gates, and thus successfully enact a multi-qubit algorithm, the laser addressing system must be well optimised. In particular, the waist size of the laser at the ion position should be as small as possible to both reduce crosstalk between neighbouring ions, as well as to increase the intensity of the beam. The spin qubit of the $4S_{1/2}$ state in $^{40}Ca^{+}$ is chosen, requiring high-power Raman transitions to facilitate quantum gates. To enable beam steering along the ion chain whilst retaining the same laser frequency, two crossed AODs are implemented. In our design, the laser addressing and ion imaging is together combined through the use of a dichroic mirror, which possesses a sharp cutoff in transmission between the addressing wavelength at 400 nm and the emitted 397 nm light. This approach minimizes the optical space but requires a careful consideration of the optical equipment to ensure both systems are well optimised. In my talk and poster, I will present these considerations, the simulated results and computer design, as well as any experimental characterisations.

Architecture for arbitrary addressing of neutral ytterbium atoms in a 2D optical tweezer array

Till Schacht[1], Tobias Petersen[1], Nejira Pintul[1], Jonas Rauchfuß[1], Clara Schellong[1], Ben Michaelis[1], Carina Hansen[1], Felix Rönne[1], Frederik Mrozek[1], Alexander Ilin[1], Felix Klein[1], Klaus Sengstock[1,2], and Christoph Becker[1,2]

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Neutral atoms in optical tweezers are emerging as a powerful platform for quantum computing, simulation, and metrology. Key recent developments — including improved qubit coherence, mid-circuit readout, and error correction — are bringing fault-tolerant quantum computation within reach. A critical requirement for scaling these systems is the ability to individually and dynamically address atoms in large 2D arrays. Typical approaches use pairs of crossed acousto-optic deflectors (AODs) to create single-site optical addressing. However this method only allows addressing of arbitrary patterns in a sequential manner, which limits the scalability and speed of operations.

We present a hybrid approach that combines a spatial light modulator (SLM) for flexible static beam shaping with a digital micromirror device (DMD) for fast, reconfigurable temporal modulation. This setup enables microsecond-scale, site-selective illumination with arbitrary patterns across the tweezer array, offering a pathway toward scalable and programmable quantum control.

We also report on the current status of our Ytterbium-171 tweezer experiment, including the successful trapping and imaging of single atoms, setting the stage for implementing quantum control protocols in this system.

Laser noise reduction for enhanced gate fidelity in neutral atom quantum computers

Ben Michaelis[1], Tobias Petersen[1], Nejira Pintul[1], Jonas Rauchfuß[1], Clara Schellong[1], Till Schacht[1], Carina Hansen[1], Felix Rönne[1], Frederik Mrozek[1], Alexander Ilin[1], Felix Klein[1], Klaus Sengstock[1,2], and Christoph Becker[1,2]

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In recent years, neutral atoms have emerged as one of the most promising platforms for quantum computing and quantum simulation, characterized by scalability long coherence times, high-fidelity single atom control as well as engineerable strong long-range interactions.

In our project we use the alkaline-earth-like element ytterbium, whose fermionic isotope ^{171}Yb features a rich level structure, which offers metastable states, for the realisation of sophisticated qubit schemes facilitating mid-circuit read-out and advanced error correction schemes and furthermore allows for optical trapping and manipulation of Rydberg states.

A key factor in the development of a fault tolerant quantum computer is achieving high gate fidelities. Laser noise at the Rabi frequency is one of the big impediments in reaching that goal. Although lasers are commonly stabilized using techniques such as the Pound-Drever-Hall (PDH) method, these methods also lead to servo-induced laser noise that impacts gate performance.

Here we present experimental results for effectively suppressing servo noise by more than 20 dB in a frequency quadrupled UV-laser driving Rydberg excitations at our experiment. Our scheme is based on cavity filtering and fast feedforward. Additionally we show simulations indicating that this improvement reduces the infidelity of π-pulses by up to two orders of magnitude.

Quantitative characterisation of crosstalk in a trapped-ion quantum computer setup

Paula Bañuls Saiz, **Ferdinand Schmidt-Kaler**

Johannes Gutenberg Universität Mainz

The goal of the project is to quantitatively characterise crosstalk in a trapped-ion quantum computing setup, a key factor limiting gate fidelity in multi-qubit systems. The system under study employs $^{40}Ca^{+}$ ions, with qubit encoding in the $^{4}S_{1/2}$ ground state, and laser-driven Raman transitions for single gate operations. Accurate control of individual qubits requires precise laser addressing; however, residual illumination on neighbouring ions — i.e., crosstalk — can introduce unwanted errors during quantum operations. In this study, we focus on characterizing this crosstalk, by measuring and analysing the spatial and intensity profiles of the addressing beam at the target ion, as well as its effects on neighbouring ions during single gate sequences. Specifically, we analyse the Rabi oscillations induced on each ion when a Raman beam is applied to a selected target ion. By extracting the Rabi frequencies across the ion chain, we are able to measure the level of crosstalk depending on the ion position. These measurements are complemented by variations in beam waist, helping to identify the main optical contributions to the observed crosstalk. This characterisation provides essential feedback for the optimisation of the addressing system and sets a benchmark for improving gate fidelity in future multi-qubit experiments.

Clock spectroscopy on the ionic core of alkaline-earth circular Rydberg atoms

M. Thomas, A. Götzelmann, E. Pultinevicius, A. Humić, M. Renz, F. Thielemann, C. Hölzl, and F. Meinert

5th Institute of Physics, University of Stuttgart, Germany

In recent years, highly excited Rydberg atoms have emerged as a promising platform for quantum simulation and computing. However, they come with fundamental restrictions, such as lifetime limited coherence times. We tackle this challenge by exciting neutral ^{88}Sr atoms to long-lived circular Rydberg states (CRS). At maximum orbital momentum, fewer decay channels exist, and these can even be suppressed using a resonator made from indium tin oxide (ITO). This results in CRS with lifetimes in the millisecond-range, even at room temperature [1].

In the case of the alkaline-earth species ^{88}Sr, the excitation of the first valence electron to the CRS exposes the second valence electron near the core. This provides access to a range of new tools – including trapping and cooling of the CRS. For sideband cooling, for example, narrow optical transitions are required. The ionic $^{88}Sr^+$ core offers a clock transition that meets this requirement. In my Master's Thesis, I focus on driving this $^2S_{1/2}$ - $^2D_{5/2}$ clock transition of the second valence electron and performing spectroscopy on it. This is the first step of implementing resolved sideband cooling of Rydberg atoms. It can also be used for state detection and for local addressing due to the interaction between the $^2D_{5/2}$ state and the CRS electron [2]. To resolve the resulting energy shift and to exploit all the possibilities of the transition, a narrow-linewidth Hz-laser has been set up. In my contribution, I will focus on the idea of the experiment, its setup, and on what this experiment enables in the future.

[1] C. Hölzl et al., Physical Review X **14**, 021024 (2024).
[2] M. Wirth et al., Physical Review Letters **133**, 123403 (2024).

Towards two-photon interference with color centers in silicon carbide

Sushree Swateeprajnya Behera[1,2], **Nien-Hsuan Lee**[1,2], **Jonas Schmid**[1,2], **and Leonard K.S. Zimmermann**[1,2], **Jonah Heiler**[1,2], **Flavie Davidson-Marquis**[1,2], **Stephan Kucera**[1], **Florian Kaiser**[1,2]

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Color centers in wide-bandgap semiconductors are emerging as promising platforms for quantum photonic technologies, including quantum memory and processing capabilities

Considering that most quantum experimental implementations require costly cryogenic systems, it is instrumental in reducing the cost-per-system, e.g., by densely integrating multiple quantum systems on one photonic chip.

Here, I present my thesis project towards a scalable architecture for multiplexing divacancy color centers in a silicon carbide photonic chip. Our overall goal is to demonstrate on-chip two-photon Hong-Ou-Mandel interference between two waveguide-integrated separated divacancy centers. A crucial step towards this goal is to maximize the photon collection efficiency from the chip into optical fibers. I will present our latest advances towards high-efficiency coupling from silicon carbide waveguides into optical fibers. Since our approach is based on evanescent light coupling from tapered waveguides into tapered optical fibers, we achieve a surprisingly robust interface, which is beneficial for upscaling. I will also briefly sketch the next steps, which include setting up the cryo-optic microscopy setup.

We believe that our approach can contribute toward building multiplexed, chip-integrated quantum networks and scalable quantum communication systems.

Design and characterization of core/shell InGaAs/InAlAs nanowires for telecom-wavelength lasing

A. Robles Pérez, B. Haubmann, J. J. Finley, and G. Koblmüller

Walter Schottky Institut, School of Natural Sciences, and MC-QST, Technische Universität München, Garching, Germany

Semiconductor nanowires are promising candidates for nanoscale light sources operating in the telecom wavelength range, owing to their tunable optical properties and versatile geometries. In this work, we investigate core/shell InGaAs/InAlAs nanowires with the goal of achieving lasing near telecom wavelengths ($\sim$ 1.3–1.55 μm). To identify the optimal Indium content and nanowire dimensions, we combine numerical simulations with experimental characterization. COMSOL is employed to calculate the effective refractive index, the confinement factor, and to analyze mode cut-off conditions, while Lumerical simulations are used to determine the reflectivity of the nanowire facets. Together, these simulations provide the necessary parameters for calculating the threshold gain, enabling us to optimize key nanowire dimensions, particularly the diameter, for lasing performance. Experimentally, nanowires are grown via molecular beam epitaxy (MBE). High-resolution X-ray diffraction (HRXRD) confirms the achieved Indium composition, while scanning electron microscopy (SEM) is used to measure the nanowire geometry. Photoluminescence (PL) spectroscopy assesses the optical properties and lasing behavior of the fabricated nanowires. Currently, our focus is on achieving lasing in bulk nanowires. In future work, we plan to explore the integration of quantum dots as zero-dimensional gain media within the nanowire structure to potentially enhance lasing characteristics.

Adiabatic fiber coupling to diamond sawfish cavities

Max Heimann[1], Pascal Frehle[1,2], Marco Stucki[1,2], Julian M. Bopp[1,2], Tommaso Pregnolato[1,2], Maarten H. van der Hoeven[1] and Tim Schröder[1,2]

[1] *Department of Physics, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany*
[2] *Ferdinand-Braun-Institut (FBH), Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany*

Color centers in diamond are promising candidates for many applications in the field of quantum information [1]. To harness their full potential, it is essential to couple these color centers to cavity modes. When the cavity resonance coincides with the zero-phonon line of the chosen color center, it can enhance the spontaneous emission rate of single photons via the Purcell effect [2]. To enable long-distance interconnection of color centers with other devices it is necessary to efficiently couple the cavities to an optical fiber – a key requirement to utilize them as components in quantum networks. A scalable method for the fabrication of these cavities remains an unresolved challenge. Here, we present the successful coupling to a half open Sawfish photonic crystal cavity etched into diamond [3, 4] with resonances near the zero-phonon line of the tin-vacancy center at 619nm. The cavity mode is converted into a waveguide mode, which is subsequently transferred adiabatically to a tapered optical fiber fabricated through hydrofluoric acid etching [4]. The taper profile was optimized for minimal length to mitigate losses due to surface roughness and improve mechanical stability. Through numerical simulations, we demonstrate how these optimizations leverage the confinement of the light within the fiber core allowing for a steep removal of the cladding. In our work we showed adiabatic fiber coupling to Sawfish photonic crystal cavities in diamond hosting color centers. Additionally, we implement novel approaches in controlling the shape of a tapered fiber for adiabatic coupling to ensure efficiency and mechanical stability.

[1] M. Ruf, et al. Journal of Applied Physics. 130 (2021), 070901.
[2] R. E. Evans, et al. Science. 362 (2018), 662-665.
[3] J. M. Bopp, et al. Adv. Optical Mater. 12 (2024), 2301286.
[4] T. Pregnolato, et al. APL Photonics 9 (2024), 036105.
[5] M. Burek, et al. Phys. Rev. Appl. 8 (2017), 024026.

Addressing fabrication challenges in photonic crystal cavities for diamond color centers

Lucca Valerius[1,2], Marco E. Stucki[1,2], Tommaso Pregnolato[1,2], and Tim Schröder[1,2]

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[2] *Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin*

Color centers in diamond are a promising platform for quantum communication, providing a spin-photon interface suitable for quantum networks. Embedding these centers in photonic crystal cavities (PhCCs) enhances emission into the zero-phonon line via the Purcell effect, enabling the efficient generation of photon entanglement. However, fabricating diamond-based PhCCs using reactive ion etching remains a major challenge. With feature sizes often below 100 nm, imperfections such as rough sidewalls, micromasking, and etch variability can significantly alter performance and yield. A critical factor is the hard mask material used during oxygen plasma etching, which strongly influences pattern transfer fidelity. In this work, we present an overview of our fabrication approach and development of new methods, including a systematic analysis of common sources of uncertainty and loss in diamond nanofabrication. Our aim is to identify and mitigate key challenges in order to advance reliable, high-performance spin-photon interfaces. By refining fabrication techniques, we contribute to improving the scalability and robustness of diamond-based quantum photonic devices.

Development of a pump-probe optically pumped magnetometer with inexpensive VCSEL diodes for motorized archaeological prospection

Sambit Satapathy[1], **Sven Linzen**[1], **Theo Scholtes**[1], **Florian Wittkämper**[1], **Aaron Jaufenthaler**[2], **and Ronny Stolz**[1,3]

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[2] *Leopold-Franzens-University of Innsbruck, Austria*
[3] *Technische Universität Ilmenau, Germany*

The Mongol period holds immense cultural significance for human civilization, profoundly influencing the present age. Archaeological exploration of settlement remains from this era is of immense significance, not only for the Mongol state but also for humanity as a whole, providing valuable insights into human-environment interactions under challenging climatic conditions, resource utilization, and our shared history. Over recent decades, SQUID (Superconducting Quantum Interference Device) magnetometers have enabled the discovery of significant artifacts in large-scale archaeological surveys [1]. However, despite their high sensitivity (in the pT to fT range), they are bulky and require expensive cryogenic cooling.

Optically pumped magnetometers (OPMs), which provide comparable sensitivities, have emerged as promising alternatives since they do not require cryogenic cooling and allow for more compact sensor designs. However, earlier OPM systems with sufficient sensitivity were fiber-coupled and lacked readiness for field applications.

Here, we present a novel OPM based on cesium (Cs) atoms in a microfabricated cell, operating slightly above room temperature. This compact system leverages low-cost, commercially available Vertical Cavity Surface Emitting Laser (VCSEL) diodes and employs a Free Spin Precession (FSP)-based detection scheme [2]. The Cs ensemble is optically pumped to a large spin polarization from a single laser pulse in the microsecond scale, thereby eliminating the need for a Larmor-feedback operation, allowing for simplified read-out and minimizing systematic errors. Further development aims to make the system fully mobile in the near future. The prototype has demonstrated a sensitivity of approximately 5 $\mathrm{pT}/\sqrt{\mathrm{Hz}}$, showcasing its potential for archaeological and geophysical surveys, with room for significant improvements.

This advancement paves the way for the development of a multi-channel magnetometer array capable of large-scale, motorized, or drone-based magnetic surveys. Beyond archaeology, the system holds promise for diverse applications in biomagnetism, geophysics, and fundamental physics explorations.

[1] S. Reichert, N. Erdene-Ochir, and S. Linzen, 'Overlooked—Enigmatic— Underrated: The City Khar Khul Khaany Balgas," *Journal of Field Archaeology*, vol. 47, no. 6, pp. 397–420, 2022.
[2] Zoran D. Grujić, Peter A. Koss, Georg Bison, and Antoine Weis, 'A sensitive and accurate atomic magnetometer based on free spin precession," *The European Physical Journal D*, vol. 69, no. 5, p. 135, 2015.

Deep learning strategies for stabilizing NV center emission spectra

Clara Zoé Baenz[1], **Gregor Pieplow**[1], **Kilian Unterguggenberger**[1], **Laura Orphal-Kobin**[1], **and Tim Schröder** [1,2]

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Spectral diffusion poses a major challenge for integrating quantum emitters into photonic networks. In this work, we investigate the use of deep learning methods, specifically recurrent neural networks with Long Short-Term Memory (LSTM) architecture, to model spectral fluctuations in nitrogen–vacancy (NV) centers in diamond. The networks are trained on time-series data of the optical transition frequency to learn temporal correlations in the dynamics of the zero-phonon line (ZPL). Such trained models may aid in the forecasting of spectral shifts and provide a basis for compensating such fluctuations through predictive modelling. We present a preliminary study using negatively charged NV centers in diamond nanopillars, where we find initial indications that this approach may be viable for improving the spectral stability of solid-state quantum emitters.

Nanoscale free-electron dynamics in plasmonic nanostructures

<u>Fabian Scheidler</u>, Jessica Meier, Luka Zurak and Bert Hecht

Nano-Optics Biophotonics Group, Experimental Physics 5, University of Würzburg, Am Hubland, 97074 Würzburg, Germany

Intense laser pulses give rise to strong-field phenomena, where the external electromagnetic field exceeds the binding field of electrons in matter [1]. In atomic gases this results in high-harmonic generation which is typically described by a three-step recollision model involving laser-induced ionization, free acceleration, and recombination. At sharp metallic nanotips, a similar process leads to a nonlinear photocurrent driven by multiphoton and strong-field photoemission [2], which has been applied for high quality pulsed electron beam sources, e.g. for ultra fast electron microscopy [3].

Plasmonic nanoantennas fabricated by focused helium ion beam milling from monocrystalline gold microplatelets provide large field enhancements stemming from both an asymmetric nanotip-shaped gap and plasmonic hotspots [4]. Such structures have been shown to yield a geometry-dependent photocurrent across small gaps.

Our goal is to obtain a local electron source based on plasmonic nanoantennas. This source will subsequently be used to control electron motion at the nanoscale by utilizing plasmonic near fields driven by a femtosecond Ti:Sa laser in the visible to infrared spectral regime. To describe the free-electron dynamics, we develop a semi-classical simulation scheme to analyze free-electron motion in plasmonic near fields.

[1] Dombi, P. et al. *Rev. Mod. Phys* **2020**, 92, 025003.
[2] Krüger, M. et al. *Journal of Physics B: Atomic, Molecular and Optical Physics* **2018**, 51, 172001.
[3] Park, H. S. et al. *Nano Letters* **2007**, 7, PMID: 17622176, 2545-2551.
[4] Meier, J. et al. *Advanced Optical Materials* **2023**, 11, 2300731.

Simulating Gauge Fields in Curved Spacetime

Simon Brunner

University of Innsbruck

Phononic excitations in a Bose-Einstein condensate (BEC) exhibit dispersion relations analogous to those of relativistic scalar fields and it has been demonstrated that these fluctuations can be engineered to serve as quantum simulators for scalar fields in Friedmann - Lemaître– Robertson– Walker cosmologies. We propose utilizing a BEC interacting with the degenerate transverse cavity modes of a confocal cavity as a platform to simulate gauge fields in curved spacetime. Starting from the action describing a double pumped two-level atomic gas confined in a confocal cavity, we derive an analytical framework for long-wavelength excitations above the ground state. In this acoustic regime, we identify a mapping between the emergent phononic dynamics and a relativistic gauge field on a cosmological spacetime. This work lays the groundwork for experimental detection of cosmological particle production of gauge field quanta by tuning the effective metric via experimentally accessible parameters.

Variational quantum simulation of the interacting Schwinger model on a trapped-ion quantum computer

Jurek Eisinger[1], Christian Melzer[1], Stephan Schuster[2], Diego Alberto Olvera Millan[1], Janine Hilder[1], Ulrich Poschinger[1], Karl Jansen[3,4], Ferdinand Schmidt-Kaler[1]

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Simulations in high-energy physics are currently emerging as an application of noisy intermediate scale quantum (NISQ) computers. We explore the multi-flavor lattice Schwinger model – a toy model inspired by quantum chromodynamics – in one spatial dimension and with nonzero chemical potential by means of variational quantum simulation on a shuttling-based trapped-ion quantum processor. This fermionic problem becomes intractable for classical numerical methods even for small system sizes due to the sign problem arising in Quantum Monte Carlo methods, caused by integration over highly oscillatory functions representing observables. We employ a parameterized quantum circuit executed on our quantum processor to identify ground states in different parameter regimes of the model, mapping out a quantum phase transition, which is the hallmark feature of the model. The resulting states are analyzed via quantum state tomography, to reveal how characteristic properties such as correlations in the output state change across the phase transition. Moreover, we use the results to determine the phase boundaries of the model.

Characterizing continuous quantum phase transitions using Kibble Zurek mechanism by using a reverse quench protocol

Maharshi Pran Bora, E. Braun, D. Rubin, M. Cartier, G. Zürn, and M. Weidemüller

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The Kibble Zurek mechanism encapsulates the relation between quench time of phase transition to the topological defects produced in the process [1]. It has been widely studied for a wide variety of systems. Implementation of the Kibble Zurek mechanism in an isolated quantum system could give insight into the universality class of the phase transition by determining the critical exponent of the transition [2] .

In our system, we have a Rydberg quantum simulator where the spin states are encoded in the Rydberg states manifold in Rubidium-87 atoms trapped in an optical dipole trap. The spin interactions are mediated by the van der Waals and the resonant dipole interaction depending on the states selected. The system also has an advantage of introducing disorder in the interactions given by the randomized position of the atoms. A microwave field couples the two Rydberg states. The system is initialized in the paramagnetic regime and then ramp through a supposed phase transition. Depending on the speed of the ramp, topological defects appear in the final state.

Numerical simulations have shed light on the possibility of accessing these defects through a global measurement of the system, in this case the magnetization rather than looking at individual defects. Instead of ramping through the phase transition once using the control parameter, our approach would be to start from an initial paramagnetic regime, go through the supposed phase transition and back into the ferromagnetic state and back to the paramagnetic state. This will lead to the mapping of the defects onto the global magnetization, thus giving insight into the nature of the possible phase transition.

[1] Reichhardt, C. J. O., Del Campo, A., & Reichhardt, C. (2022). Kibble-Zurek mechanism for nonequilibrium phase transitions in driven systems with quenched disorder. Communications Physics, 5(1).
[2] Keesling, A., Omran, A., Levine, H., Bernien, H., Pichler, H., Choi, S., Samajdar, R., Schwartz, S., Silvi, P., Sachdev, S., Zoller, P., Endres, M., Greiner, M., Vuletić, V., & Lukin, M. D. (2019). Quantum Kibble–Zurek mechanism and critical dynamics on a programmable Rydberg simulator. Nature, 568(7751), 207–211.

Bohmian trajectories in a double slit experiment

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This project investigates Bohmian Mechanics as an alternative interpretation of quantum theory, focusing on its application to the double-slit experiment. Unlike the standard Copenhagen interpretation, Bohmian Mechanics introduces deterministic particle trajectories guided by a wave function, offering a solution to the measurement problem without invoking wave function collapse.

We present an experiment that visualizes these trajectories using birefringent crystals to mimic a double-slit setup. The observed interference patterns and direct phasefront measurements reveal behavior consistent with Bohmian predictions, while also addressing criticisms such as the so-called "surreal trajectories." Adjustments in the experimental setup further improve the clarity and accuracy of the results.

The findings contribute to the ongoing discussion about the interpretation of quantum mechanics and demonstrate the potential of Bohmian Mechanics to provide a coherent, realist framework for quantum phenomena.

Tuneable light fields for a modular quantum gas platform

Finn Lubenau, Tobias Hammel, Maximilian Kaiser, Daniel Dux, Matthias Weidemüller and Selim Jochim

Physikalisches Institut, Universität Heidelberg

We are presenting our Heidelberg Quantum Architecture, a modular quantum gas experiment, that combines individual modules into a single platform, allowing for quick upgrades, exchanges, and debugging of each module.

Currently, the core modules consist of a cold atom source that allows for very fast cycle time, dipole traps and optical tweezers, high fidelity single atom and spin resolved imaging and confinement to a 2D plane using an optical accordion.

Here, we will present the progress on implementing a spatial light modulator (SLM) module to create tuneable light fields in a precise and reproducible way, including the ability to correct for optical aberrations, by using Phase Shift Interferometry (PSI) with the atoms acting as the wavefront sensor [1].

Using this module, we aim to create an optical dipole trap at 812 nm, with the ability to shift the energy of the $2P \leftrightarrow 3S$ transition in Lithium-6 via the AC Stark Shift created by this potential. As the $2S \leftrightarrow 2P$ transition at 671 nm is used for imaging, this would effectively shield the atoms by shifting the transition away from the resonance of the imaging light. Using this, local measurements might be performed without affecting the remaining system, giving the ability to gain valuable insights into the processes present in ultracold quantum gases.

[1] Hill et al., 2024

Active magnetic field stabilization for an ultracold quantum gas experiment

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We aim to experimentally investigate theoretically predicted excitations of a dipolar quantum gas of dysprosium atoms in a toroidal trap. In particular, we focus on the emergence of Higgs modes across the transition from a superfluid to a supersolid as an indicator of spontaneous symmetry breaking. Precise control of the magnetic field is crucial, as the excitation occurs near a critical point in the phase diagram, where the relative dipolar strength, serving as the control parameter, is finely tuned via Feshbach resonances. This necessitates sub-mG magnetic field stability. I present the plans for an active magnetic field stabilization setup where I intend to reduce the fluctuations relative to an arbitrary offset magnetic field using an array of fluxgate sensors placed outside the science chamber. A digital compensation loop with field coils allows to infer and control the magnetic field at the site of the atoms and reduce the background noise up to a bandwidth of 1 kHz.

Spin noise spectroscopy of hot rubidium vapor under two-photon excitation

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Spin noise spectroscopy (SNS) probes spontaneous spin fluctuations arising in hot rubidium vapors via measurements of optical Faraday rotation noise. The resulting noise power spectra reveal properties of the atomic spin ensemble, such as the Larmor precession frequency, relaxation times, g-factors, and hyperfine splitting of the ground-state manifold [1].
In this work, we investigate a two-color, two-beam SNS configuration: one laser (795 nm) probes these ground-state spin fluctuations, while a second laser (762 nm) couples the 5S-5D ladder-type two-photon transition, emitting fluorescence at 421 nm [2]. This two-photon transition has recently suggested as an new optical frequency standard due to its Doppler-free narrow linewidth [3]. In contrast to the conventional approach of single-color excitation at 778.1 nm, the two-color approach has gained interest, as it requires significantly lower optical powers and vapor densities while achieving comparable frequency stability [4].

By measuring spin noise on both the probe and coupling beams, as well as their cross-correlation spectra, we investigate how the two-photon excitation modifies ground-state spin fluctuations and whether additional spin noise features or dynamic back-action from excited states can be observed. Such measurements may provide new insights into light-induced shifts, spin dephasing, and nonlinear spin-light interactions.

[1] Crooker, S., Rickel, D., Balatsky, A. et al. Spectroscopy of spontaneous spin noise as a probe of spin dynamics and magnetic resonance. Nature 431, 49–52 (2004)
[2] Prajapati, N., Akulshin, A. M. and Novikova, I. Comparison of collimated blue-light generation in Rb-85 atoms via the D1 and D2 lines. J. Opt. Soc. Am. B 35, 1133–1139 (2018)

[3] Lemke, N. D., Martin, K. W., Beard, R. et al. Measurement of optical rubidium clock frequency spanning 65 days. Sensors 22, 1982 (2022)
[4] Ahern, E. J., Scholten, S. K., Locke, C. et al. Tailoring the stability of a two-color, two-photon rubidium frequency standard. Phys. Rev. Applied 23, 044025 (2025)

Vortices in a 2D fermionic superfluid

Hans Leonard Michel, **Artak Mkrtchyan, Moritz von Usslar, René Henke, Cesar Cabrera, Henning Moritz**

Institut für Quantenphysik, Universität Hamburg

Vortices are widely studied excitations in superfluid systems from superfluid helium to ultracold Bose Einstein Condensates. While many experiments observed vortices in 3D quantum gases, few realisations were made in truly 2D systems. Here I will report on the realisation of vortices in a 2D superfluid made from ultracold ^{6}Li atoms. We freeze out the vertical motion by strong confinement and generate vortices by dragging two repulsive tweezers through the gas, see also [1,2]. The vortices are detected by ramping to a quasi-3D regime and subsequent time of flight imaging. We plan to use this technique to gain insight into superfluidity in 2D systems in the BEC-BCS crossover.

[1] E. C. Samson, K. E. Wilson, Z. L. Newman, and B. P. Anderson, Phys. Rev. A 93, 023603, (2016).
[2] W. J. Kwon et al., Nature 600, 64 (2021).

Tunable symmetry breaking in a quantum gas

F. Bennati Weis, P. Christodoulou, N. Reiter, J. Fricke, N. Montalti, T. Esslinger, and T. Donner

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The symmetry class of a system's Hamiltonian plays a crucial role in determining the collective behavior and phases of the quantum many- body system, from its collective excitations and critical phenomena to universality classes. In the realm of analogue quantum simulations, controlling such symmetry classes is of great interest, yet generally difficult to achieve. In this talk, we explore numerically how a cavity QED system of ultracold atoms coupled to an optical cavity can provide an experimental platform to study such tunable symmetry classes.

We employ simulations of a generalized Gross- Pitaevskii equation (GGPE) [1] to study the dynamics of a BEC dispersively coupled to an optical cavity mode and transversely driven by a running-wave laser drive. We demonstrate how introducing a tunable symmetry- breaking field via a counter-propagating drive enables continuous control over the symmetry class of the system, allowing us to interpolate between Z2- and U(1)- symmetric self-organization transitions [2,3]. These findings not only highlight the power of our GGPE simulations but in particular manifest the role of atomic many- body cQED systems as versatile quantum simulators in which many- body Hamiltonians of different symmetry classes can be engineered within the same physical system. They further will allow us to investigate how symmetry classes of Hamiltonians govern the emergence of macroscopic structures from microscopic fluctuations.

[1] L. Fioroni et al in SciPostPhysCodeb.38 (2024)
[2] K. Baumann et al in Nature 464, 1301 (2010)
[3] J. Leonard et al in Nature 543, 87 (2017)

Photon-mediated atom-pair creation in momentum states of a BEC

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Correlated pairs of particles have proven fundamental in various branches of physics, spanning fields as condensed-matter and cosmology to quantum information. Cavity- quantum- electrodynamics (cQED) experiments with ensembles of ultracold atoms constitute a particularly versatile platform to study the creation of correlated pairs of atoms, with cavity photons mediating infinite-range interactions [1].

Motivated by recent experimental advances in our group [2], we present a numerical approach to study photon-mediated pairing dynamics in a BEC inside a high-finesse optical cavity and transversely illuminated by a running-wave laser drive. Our approach is based on generalized Gross-Pitaevskii-Equation (GGPE) simulations [3] augmented by a truncated-wigner method [4], and allows us to simulate pair-production processes in real- and momentum space. We demonstrate that our approach captures effects beyond mean-field level, i.e. pair-production seeded by quantum fluctuations in the atomic and cavity fields, and features beyond those accessible in semi-analytical few-mode models. We study the emerging quantum statistics of the atomic pairs and investigate how the interplay of fluctuations and building correlations shape the pairs' quantum statistics over time.

[1] F. Mivehvar et al in Advances in Physics, 70(1) (2021)
[2] F. Finger et al in Phys. Rev. Lett. 132 (2024)
[3] L. Fioroni et al in SciPostPhysCodeb.38 (2024)
[4] A. Sinatra et al in J. Phys. B: At. Mol. Opt. Phys. 35 3599 (2002)

Quantum Monte Carlo simulations of hardcore bosons with repulsive density-density interactions on two-dimensional lattices

Robin Krill[1,2], **Jan Alexander Koziol**[2], **Calvin Krämer**[2], **Anja Langheld**[2], **Kai Phillip Schmidt**[2], **and Giovanna Morigi**[1]

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[2] *Friedrich-Alexander-Universität Erlangen-Nürnberg*

We present an extension to the stochastic series expansion quantum Monte Carlo algorithm to account for long range interactions. To test the method, we determine ground-state properties of long-range hardcore Bose-Hubbard lattice models in two dimensions. Recent investigations of such systems with mean-field approaches indicate rich quantum phase diagrams including a devil's staircase of solid phases and a plethora of exotic lattice supersolids [1]. The quantum Monte-Carlo approach allows us to extend this mean-field study by fully incorporating quantum fluc- tuations, and thus to analyse the interplay among frustration, long-range interactions, and quantum fluctuations.

[1] J. A. Koziol, G. Morigi, K. P. Schmidt, SciPost Physics 17.4 (Oct. 10, 2024)

Implementation and characterization of a free-space quantum key distribution system

Tizian Schmidt, and Ilja Gerhardt

Leibniz Universität Hannover

Quantum key distribution (QKD) offers means to transmit data with unprecedented security between two distant parties. The security comes from exploiting the principles of quantum physics. Without having to trust anyone else, an entanglement-based QKD system can be checked for security by measuring the violation of so-called Bell inequalities [1], and/or measuring the Quantum Bit Error Ratio (QBER) [2]. We fully implemented a free space QKD system: from characterizing the source's entanglement, up to the continuous operation outside. A full characterization of the source allows complete knowledge over the degree of entanglement, quantified by a Bell value and Schmidt number. In addition, we fully describe the effect of transmission through the free space channel on the QBER. The post processing steps needed for full security, such as Error Correction and Privacy Amplification, are implemented simultaneously to the experiment. The compactness of the system allows for further experiments with multiple nodes in a network configuration.

[1] Ekert (1991), Quantum Cryptography with Bell's Theorem
[2] Bennett, Brassard & Mermin (1992), Quantum Cryptography without Bell's Theorem
[3] Peloso et. al. (2009), Daylight operation of a free-space, entanglement-based QKD system

Experimental quantum cryptography and the Bell polytope

Tom Hobbs, and Ilja Gerhardt

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Quantum key distribution(QKD) protocols such as E91 or BBM92 allow two distant parties to generate a private key consisting of a long random number based on an initial seed. This can be used to encrypt communications. Implemented correctly, these protocols are provably secure against eavesdropping. However, real-world implementations of these protocols are always imperfect: the entanglement source, quantum channel, and measurement systems will all introduce some noise and losses into the system. These errors can be used by an eavesdropper to gain information about the system, and compromise the security of the key.

The shared quantum state can be visualised by plotting the correlations between the detector outcomes of the two parties; for example, simultaneous clicks on horizontal/horizontal, horizontal/vertical, vertical/vertical channels. In more general terms, such correlations can be represented by so-called Bell polytopes.

We aim to link this theoretical description to our experimental QKD setup, and investigate how each part of the system affects the location of our observed outcomes within the polytope. Non-ideal components are the spontaneous parametric down-converting photon source, the optical fibre or free space channel, and the polarisation analysis and photon detection units. We will measure the transfer matrices which describe the effects of each of these components on the shared quantum state, and investigate how this affects the location of the state within the polytope.

Advances in modules for the MultiQomm project

César Bertoni Ocampo

Universität Münster, Department für Quantentechnologie

I will discuss the progress made in various modules developed for the MultiQomm project. In particular, a low dark count rate detector (DCR-SNSPD), micro-ring-based multiplexing system, and polarisation-sensitive detection module.

Amplitude amplification using the atom-optics kicked rotor

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The atom-optics realisation of the quantum kicked rotor represents one of the most well-studied experimental platforms for simulating the physics of Anderson localization. In this work, we show that the same platform can be used to implement a quantum algorithm to perform quantum amplitude amplification (AA), a generalization of Grover's search algorithm. This is done using the usual kick sequence in combination with the well established technique of Raman velocity selection. We argue that this platform is well suited to implement AA, as its characteristic property of localization can be exploited to enhance the performance of the amplitude amplification algorithm by reducing its average runtime. We also introduce a kick potential which asymptotically leads to the optimal quantum speed up, constituting a complementary approach. Finally, we demonstrate that the scheme is fairly robust to noise in the kicks and discuss the experimental feasibility of each component of our proposal.

Useful information

Lab tours & BBQ

The Greenhorn meeting 2025 is hosted by two experimental research groups from Saarland university: Prof. Dr. Jürgen Eschner's quantum photonics group and Prof. Dr. Christoph Becher's quantum optics group.

The former specializes in quantum communication experiments using single trapped $^{40}Ca^{+}$-ions as quantum memories and single photons as flying qubits. The current main research objectives are the realization of a quantum repeater scheme and various quantum communication protocols, including QKD, over an urban fiber link through Saarbrücken.

The latter works in the fields of optical spectroscopy and quantum optics with color centers in diamond, quantum photonics with microresonators in diamond, and nonlinear optics with single photons with the goal of making color centers in diamond and single photons available for applications in quantum technologies.

Both groups welcome you to a tour through their laboratories for a deeper insight into their ongoing experimental work. The tour will take place on Tuesday, September 23rd and we will meet on the ground floor in building E26. Afterwards, we will close off the first day of the meeting with a BBQ in front of the same building.

Joint dinner

On the evening of the second day, Wednesday September 24th ,we will meet at a restaurant (yet to be announced) for a joint dinner. More info will follow soon.

Presentations

All participants should present a talk (12 minutes + 3 minutes for questions) and a poster. The topics do not have to be the same. The posters should be A0 (841 × 1189 mm, vertical) in size. You can bring a USB stick with your presentation on it (Powerpoint or pdf, recommended to have both) or send us the presentation via mail. In any case, we ask you to provide the file(s) to us until the day before your talk if possible.

Contact

If you have any questions, feel free to reach out to us, either via email or during the conference, just talk directly to us, the organization committee.

Greenhorn Meeting 2025

Website:
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