Friday Contributed Sessions (FRI)

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Overview of Sessions

(Lecture halls ZHG001, ZHG002, ZHG003, ZHG004, ZHG006, ZHG007, ZHG008, ZHG009, ZHG101, ZHG103, ZHG104, and ZHG105)

Sessions

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FRI 2.1–2.6	Fri	10:45–12:15	ZHG002	**Many-Body Quantum Dynamics III**
FRI 3.1–3.5	Fri	10:45–12:00	ZHG003	**Quantum Chaos**
FRI 4.1–4.7	Fri	10:45–12:30	ZHG004	**Foundational / Mathematical Aspects – Alternative Views**
FRI 5.1–5.8	Fri	10:45–12:45	ZHG006	**QIP Implementations: Solid-State Devices II**
FRI 6.1–6.5	Fri	10:45–12:00	ZHG007	**Quantum Error Mitigation**
FRI 7.1–7.6	Fri	10:45–12:15	ZHG008	**Entanglement and Complexity: Contributed Session to Symposium III**
FRI 8.1–8.6	Fri	10:45–12:15	ZHG009	**Quantum Detectors in Optics and Particle Physics**
FRI 9.1–9.3	Fri	10:45–11:30	ZHG101	**Fundamental Quantum Tests**
FRI 10.1–10.8	Fri	10:45–12:45	ZHG103	**Foundational / Mathematical Aspects – Unconventional Approaches**
FRI 11.1–11.7	Fri	10:45–12:30	ZHG104	**Quantum 2D-Moiré and Rhombohedral van-der-Waals Systems: Contributed Session to Symposium**
FRI 12.1–12.7	Fri	10:45–12:30	ZHG105	**Quantum Phenomena in Solid-State Devices**

FRI 1: Quantum Information: Concepts and Methods II

Time: Friday 10:45–12:30 Location: ZHG001

FRI 1.1 Fri 10:45 ZHG001

Metainformation in quantum guessing games — •Teiko Heinosaari and Hanwool Lee — Faculty of Information Technology, University of Jyväskylä, Finland

Quantum guessing games form a framework for analyzing quantum information processing tasks, where information is encoded into quantum states and retrieved through measurements. Classical side information is partial knowledge about the input. It can significantly influence the guessing strategy and earlier work has shown that the timing of such side information, whether revealed before or after the measurement, can affect the structure of optimal strategies and success probabilities. We go beyond this established distinction by introducing the concept of metainformation. Metainformation is information about information, and in our context it is knowledge that additional side information of certain type will become later available, even if it is not yet provided. We show that this seemingly subtle difference between having no expectation of further information versus knowing it will arrive can have operational consequences for the guessing task. Our results demonstrate that metainformation can, in certain scenarios, enhance the achievable success probability up to the point that post-measurement side information becomes as useful as prior-measurement side information, while in others it offers no benefit. By distinguishing metainformation from actual side information, we uncover a finer structure in the interplay between timing, information, and strategy, offering new insights into the capabilities of quantum systems in information processing tasks.

FRI 1.2 Fri 11:00 ZHG001

From bosons and fermions to spins: A multi-mode extension of the Jordan-Schwinger map — Benoît Dubus[1], •Tobias Haas[1,2], and Nicolas J. Cerf[1] — [1]Centre for Quantum Information and Communication, Université libre de Bruxelles — [2]Institut für Theoretische Physik, Universität Ulm

The Jordan-Schwinger map is widely employed to switch between bosonic or fermionic mode operators and spin observables, with numerous applications ranging from quantum simulation and ultracold quantum gases to quantum optics. While the construction of observables obeying the algebra of spin operators across multiple modes is straightforward, a mapping between bosonic or fermionic Fock states and spin states has remained elusive beyond the two-mode case. Here, we generalize the Jordan-Schwinger map by algorithmically constructing complete sets of spin states over several bosonic or fermionic modes, allowing one to describe arbitrary multi-mode systems faithfully in terms of spins. We discuss our method's potential for efficiently simulating complex many-body dynamics with spin systems.

FRI 1.3 Fri 11:15 ZHG001

Optimising measurement of correlators for fermionic quantum simulators — •Ahana Ghoshal[1], Carlos de Gois[1], Kiara Hansenne[1,2], Otfried Guehne[1], and Hai-Chau Nguyen[1] — [1]Naturwissenschaftlich-Technische Fakultat, Universitat Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany — [2]Université Paris-Saclay, CEA, CNRS, Institut de Physique Théorique, 91191 Gif-sur-Yvette, France

Simulating many-body fermionic systems on conventional quantum computers poses significant challenges due to the overheads associated with the encoding of fermionic statistics in qubits, leading to the proposal of native fermionic simulators as an alternative. This raises the question of characterising the state of a fermionic simulator, which often boils down to measuring certain overlapping sets of few-point correlators from the output of the quantum simulation. We present a systematic framework for optimising the measurement of two- and four-point correlators in fermionic simulators based on their native fermionic gates.This is obtained by developing a graph representation for the set of correlators to be measured, which is then overlaid by a graph describing the constraints from the fermionic gates. Optimising measurement settings is then mapped to graph theoretical problems, for which various algorithms can be applied. We illustrate our methods for the recently proposed fermionic simulators with various sets of two- and four-point correlators as examples.

FRI 1.4 Fri 11:30 ZHG001

Lindblad engineering for quantum Gibbs state preparation under the eigenstate thermalization hypothesis — •Eric Brunner[1], Luuk Coopmans[1], Gabriel Matos[1,2], Matthias Rosenkranz[1], Frederic Sauvage[1], and Yuta Kikuchi[3,4] — [1]Quantinuum, London SW1P 1BX, United Kingdom — [2]Quantinuum, Oxford OX1 2NA, United Kingdom — [3]Quantinuum K.K., Tokyo, Japan — [4]iTHEMS, RIKEN, Wako, Saitama 351-0198, Japan

Building upon recent progress in Lindblad engineering for quantum Gibbs state preparation algorithms, we propose a simplified protocol that is shown to be efficient under the eigenstate thermalization hypothesis (ETH). The ETH reduces circuit overheads of the Lindblad simulation algorithm and ensures a fast convergence toward the target Gibbs state. Moreover, we show that the realized Lindblad dynamics exhibits an inherent resilience against stochastic noise, opening up the path to a first demonstration on quantum computers. We complement our claims with numerical studies of the algorithm's convergence in various regimes of the mixed-field Ising model. In line with our predictions, we observe a mixing time scaling polynomially with system size when the ETH is satisfied. In addition, we assess the impact of algorithmic and hardware-induced errors on the algorithm's performance by carrying out quantum circuit simulations of our Lindblad simulation protocol with a local depolarizing noise model. This work bridges the gap between recent theoretical advances in dissipative Gibbs state preparation algorithms and their eventual quantum hardware implementation.

FRI 1.5 Fri 11:45 ZHG001

Discrete Quantum Walks with Near-Term Neutral Atom Hardware Error Modelling — •Stephanie Foulds and Vivien Kendon — University of Strathclyde, Glasgow, UK

Quantum walks, the quantum analogue to the classical random walk, have been shown to be able to model fluid dynamics [1,2]. Neutral atom hardware is a promising choice of platform for implementing quantum walks due to its ability to implement native multiqubit gates and to dynamically re-arrange qubits [3]. Using error modelling for multiqubit Rydberg gates via two-photon adiabatic rapid passage [4], we present the gate sequences and final state fidelities for some toy quantum walks, including 'lazy' quantum walks.

[1] S.Succi et al., EPJ Quantum Technol. 2, 12 (2015).
[2] S. Hatifi et al., arXiv:2503.05393v2.
[3] K. McInroy et al., arXiv:2402.02127v1.
[4] G. Pelegrí et al., Quantum Sci. Technol. 7 (2022) 045020.

FRI 1.6 Fri 12:00 ZHG001

Universal dissipators for driven open quantum systems and the correction to linear response — •Lorenzo Bernazzani, Balázs Gulácsi, and Guido Burkard — University of Konstanz, D-78457 Konstanz, Germany

We investigate in parallel two common pictures used to describe quantum systems interacting with their surrounding environment, i.e., the stochastic Hamiltonian description, where the environment is implicitly included in the fluctuating internal parameters of the system, and the explicit inclusion of the environment via the time-convolutionless projection operator method. Utilizing these two different frameworks, we show that the dissipator characterizing the dynamics of the reduced system, determined up to second order in the noise strength or bath-system coupling, is universal. That is, it keeps the same form regardless of the drive term, as long as the drive is weak. We thoroughly discuss the assumptions on which this treatment is based and its limitations. By considering the first non-vanishing higher-order term in our expansion, we also derive the linear response correction due to memory-mediated environmental effects in driven-dissipative systems. We demonstrate this technique to be highly accurate for the problems of dephasing in a driven qubit and for the theory of pseudomodes for quantum environments [1].

[1] L. Bernazzani, B. Gulácsi, G. Burkard. arXiv:2505.19262 (2025).

FRI 1.7 Fri 12:15 ZHG001

Turning qubit noise into a blessing: automatic state preparation and long-time dynamics for impurity models on quantum computers — •Corentin Bertrand[1], Pauline Besserve[1,2,3], Michel Ferrero[2,3], and Thomas Ayral[1] — [1]Eviden Quantum Lab,

78340 Les Clayes-sous-Bois, France — [2]Collège de France, Université PSL, 11 place Marcelin Berthelot, 75005 Paris, France — [3]CPHT, CNRS, Ecole Polytechnique, Institut Polytechnique de Paris, 91128 Palaiseau, France

Noise is often regarded as a limitation of quantum computers. In this work, we show that in the dynamical mean field theory (DMFT) approach to strongly-correlated systems, it can actually be harnessed to our advantage. Indeed, DMFT maps a lattice model onto an impurity model, namely a finite system coupled to a dissipative bath. While standard approaches require a large number of high-quality qubits in a unitary context, we propose a circuit that harvests amplitude damping to reproduce the dynamics of this model with a blend of noisy and noiseless qubits. We find compelling advantages with this approach: a substantial reduction in the number of qubits, the ability to reach longer time dynamics, and no need for ground state search and preparation. This method would naturally fit in a partial quantum error correction framework.

FRI 2: Many-Body Quantum Dynamics III

Time: Friday 10:45–12:15 Location: ZHG002

FRI 2.1 Fri 10:45 ZHG002

Geometric speed limit of state preparation and curved control spaces — Maximilian Goll[1,2] and •Robert H. Jonsson[2] — [1]Freie Universität Berlin, Germany — [2]Nordic Institute for Theoretical Physics, Stockholm University, Sweden

The preparation of quantum many-body systems faces the difficulty that in a realistic scenario only few control parameters of the system may be accessible. In this context, an interesting conjecture was put forward by Bukov et al. in 2019, that the minimal length of any accessible state preparation protocol, as measured by the Fubini-Study metric, may lower bound the integrated energy fluctuation during any state preparation protocol.

We show that the conjecture holds if the accessible parameter space has no extrinsic curvature, when embedded into the space of all dynamically accessible states. However, we construct counter examples to the general form of the conjecture for qubits and harmonic oscillators.

[1] arXiv:2504.15175

FRI 2.2 Fri 11:00 ZHG002

Quantum phase transitions and collective excitations in long-range interacting spin XX models with superconducting qubits — •Benedikt J.P. Pernack, Mikhail V. Fistul, and Ilya M. Eremin — Theoretische Physik III, Ruhr-Universität Bochum, Bochum 44801, Germany

We investigate the emergence of collective quantum phases in coherent networks of superconducting qubits described effectively by interacting spin XX models with both short- and long-range couplings, subject to tunable local longitudinal and transverse magnetic fields. The spin interactions are engineered via the direct embedding of π-Josephson junctions in dissipationless transmission lines, enabling precise control over the interaction range and local field strengths [1]. Using advanced numerical techniques, including density matrix renormalization group (DMRG) analysis, we map out the phase diagram and identify quantum phase transitions between distinct ground states. Analytically, we employ a hard-core boson approach to characterize the ground state properties, order parameters, and the spectrum of Bogoliubov collective modes. Our results reveal a rich landscape of quantum phases, including paramagnetic, compressible superfluid, and weakly compressible superfluid states, and provide insight into the interplay between interaction range, local fields, and collective excitations in engineered quantum systems.

[1] B.J.P. Pernack, M.V. Fistul, I.M.Eremin, Phys. Rev. B 110, 184502 (2024)

FRI 2.3 Fri 11:15 ZHG002

Computational fluid dynamics simulation of dipolar gases in the hydrodynamic regime — •Michael Mayle[1], Reuben R. W. Wang[2,3], and John L. Bohn[4] — [1]Fakultät Angewandte Mathematik, Physik und Allgemeinwissenschaften, Technische Hochschule Nürnberg Georg Simon Ohm, Nürnberg, Germany — [2]ITAMP, Center for Astrophysics | Harvard & Smithsonian, Cambridge, Massachusetts 02138, USA — [3]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA — [4]JILA, NIST, and Department of Physics, University of Colorado, Boulder, Colorado 80309, USA

In a recent theoretical effort, a hydrodynamic model of ultracold, but not yet quantum condensed, dipolar gases has been derived. Within this model, the dipolar scattering results in an anisotropic viscosity tensor. Effects of the anisotropy have been predicted to be observable in the weltering motion, i.e., the collective oscillations of a dipolar Fermi gas, as well as in its acoustic behavior.

In this contribution, we approach dipolar fluids from a computational fluid dynamics (CFD) perspective. To this end, previously derived analytic expressions of the anisotropic viscosity tensor are implemented in the finite-element software COMSOL Multiphysics. This allows us to investigate a whole spectrum of fluid flow situations but now including the inherent anisotropy of dipolar scattering. We present first results of such CFD simulations with an emphasis on effects attributable to the special characteristics of the anisotropic viscosity tensor.

FRI 2.4 Fri 11:30 ZHG002

Fully numerical Hartree-Fock calculations for atoms and small molecules with quantics tensor trains — •Paul Haubenwallner and Matthias Heller — Fraunhofer Institut für Graphische Datenverarbeitung IGD, Darmstadt, Deutschland

We present a fully numerical framework for the optimization of molecule-specific quantum chemical basis functions within the quantics tensor train format using a finite-difference scheme. The optimization is driven by solving the Hartree*Fock equations (HF) with the density-matrix renormalization group algorithm on Cartesian grids that are iteratively refined. In contrast to the standard way of tackling the mean-field problem by expressing the molecular orbitals as linear combinations of atomic orbitals (LCAO) our method only requires as much basis functions as there are electrons within the system. Benchmark calculations for atoms and molecules with up to ten electrons show excellent agreement with LCAO calculations with large basis sets supporting the validity of the tensor network approach. Our work therefore offers a promising alternative to well-established HF-solvers and could pave the way to define highly accurate, fully numerical, molecule-adaptive basis sets, which, in the future, could lead to benefits for post-HF calculations.

FRI 2.5 Fri 11:45 ZHG002

Long-range polarization models for reactive molecular systems. — •Shuran Xu and Stefan Ringe — Department of chemistry, Korea University, Seoul, Republic of Korea.

The combination of the molecule-based many-body expansion (MBE) with machine learning interatomic potentials (MLIP) has proven highly potent in generating surrogate potential energy surfaces for fast computational sampling of condensed phases. Key to accurate MBE-MLIP potentials is an accurate description of long-range electrostatics which requires the definition of element-specific fixed atomic parameters such as atomic charges and polarizabilities. In the case of reactive systems, such a treatment falls short due to significant charge transfer generating atomic environment-dependent atomic charges and polarizabilities. In this work, we systematically investigate this problem at the example of protonated water clusters and discuss possible solution strategies from Thole-type polarization models up to MBE-corrected models.

FRI 2.6 Fri 12:00 ZHG002

Role of many-body electronic structure effects on carbon monoxide surface distribution and dynamics on copper — •Seungchang Han and Stefan Ringe — Korea University, Seoul, Republic of Korea

Electrochemical CO2 reduction offers a promising and sustainable approach to producing valuable chemicals and fuels. Copper (Cu) stands out as the sole catalyst capable of yielding substantial quantities of higher reduced products such as ethylene, ethanol, and methane. The complex nature of the active site environment, including facet, site, and coverage dependencies of the central carbon monoxide (CO) intermediate, is known to influence product selectivity significantly. To investigate these adsorption phenomena and their energetic profiles, studies often use the Perdew-Burke-Ernzerhof (PBE) functional based on the generalized gradient approximation (GGA). Although widely used, this approach relies on error compensation, which can limit its applicability to systems for which the error is unknown. It also leads to an inconsistent prediction of adsorption trends across different surface facets and adsorption sites. Applying many-body corrections based on the random phase approximation (RPA) has been shown to improve the prediction of facet- and site-dependent stability significantly. In this study, we investigate the initial relationships between facet and site dependencies that affect adsorption energies, incorporating results derived from the RPA. Additionally, we elucidate coverage-dependent adsorption energy trends to deepen understanding of surface interactions.

FRI 3: Quantum Chaos

Time: Friday 10:45–12:00 Location: ZHG003

FRI 3.1 Fri 10:45 ZHG003

Chaos and integrability in partially distinguishable fermions on a lattice — •Caroline Stier, Edoardo Carnio, Gabriel Dufour, and Andreas Buchleitner — Albert-Ludwigs-Universität Freiburg

We study the fermionic many-body quantum dynamics generated by a Hubbard-like Hamiltonian with nearest neighbour interaction and a continuously tunable level of distinguishability of the particles. For not strictly indistinguishable fermions, distinct invariant symmetry sectors of the many-body Hilbert space are populated, with tangible impact on the many-body dynamics. For indistinguishable fermions, the dynamics is integrable; for partially distinguishable fermions, however, numerical results show the emergence of chaotic dynamics. We explain the breakdown of integrability with analytical arguments, in tandem with simulations of the dynamics within specific symmetry sectors.

FRI 3.2 Fri 11:00 ZHG003

High dimensional hyperbolic motion is maximally quantum chaotic — •Gerrit Caspari, Fabian Haneder, Juan Diego Urbina, and Klaus Richter — University of Regensburg

The Maldacena-Shenker-Stanford (MSS) bound is a condition on a system's quantum Lyanpunov exponent, defined as the growth rate of the regularized out-of-time-order correlator (OTOC) with respect to a thermal state. It states that the exponent is bounded by the system's temperature T, with maximally chaotic quantum systems, e.g. black holes, being defined by its saturation. Thus, it is expected that non-gravitational, maximally chaotic systems should have a gravitational dual.

In this contribution, we study the OTOC of a particle on a hyperbolic surface in arbitrary dimensions. Using the Wigner-Moyal formalism and a saddle-point approximation based on exact results for the mean level density given by the Selberg trace formula we show compliance to the MSS bound for low temperatures and finite dimensions and the asymptotic approach to a saturation formally obtained for infinite dimensions. To this end, a controlled asymptotic analysis of the interplay between dimensionality, temperature and quantum corrections is mandatory and nicely displays a transition from a sqrt(T) behavior into a T behavior of the quantum Lyapunov exponent. Together with the previous analysis of previous works, our results strongly indicate that high-dimensional hyperbolic motion admits an effective description in terms of emergent gravitational degrees of freedom.

FRI 3.3 Fri 11:15 ZHG003

Controlling Many-Body Quantum Chaos — •Lukas Beringer[1], Mathias Steinhuber[1], Juan Diego Urbina[1], Klaus Richter[1], and Steven Tomsovic[1,2] — [1]Institut für Theoretische Physik, Universität Regensburg, Regensburg, Germany — [2]Department of Physics and Astronomy, Washington State University, Pullman, WA USA

Controlling chaos is a well-established technique that leverages the exponential sensitivity of classical chaotic systems for efficient control. This concept has been generalized to single-particle quantum systems [1] and, more recently, extended to bosonic many-body quantum systems described by the Bose-Hubbard model [2]. In direct analogy to the classical paradigm, a localized quantum state can be transported along a specific trajectory to a desired target state. In the bosonic many-body case, this approach reduces to time-dependent control of the chemical potentials, making it suitable for rapid and customizable state preparation in optical lattice experiments. We discuss how this protocol can serve as a toolbox for studying many-body interference and present recent progress on preparation protocols for entangled states.

[1] S. Tomsovic, J. D. Urbina, and Klaus Richter, Controlling Quantum Chaos: Optimal Coherent Targeting, PRL 130.2 (2023): 020201.

[2] L. Beringer, M. Steinhuber, J. D. Urbina, K. Richter, S. Tomsovic, Controlling many-body quantum chaos: Bose-Hubbard systems, New J. Phys (2024): 26 073002.

FRI 3.4 Fri 11:30 ZHG003

Non-Markovianity in Chaotic Subsystem Evolution — •Zhuo-Yu Xian[1], Shao-Kai Jian[2], and Greg White[3,4,5] — [1]Department of Physics, Freie Universität Berlin, Arnimallee 14, DE-14195 Berlin, Germany — [2]Department of Physics and Engineering Physics, Tulane University, New Orleans, Louisiana, 70118, USA — [3]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [4]School of Physics and Astronomy, Monash University, Clayton, VIC 3800, Australia — [5]School of Physics, University of Melbourne, Parkville, VIC 3010, Australia

The process tensor captures how an environment influences a system across multiple time intervals, and its multi-time mutual information furnishes a measure of non-Markovianity. We examine the non-Markovianity of a subsystem's dynamics embedded in various unitary evolutions of the global system, described by random matrices, various Sachdev-Ye-Kitaev models, and holographic conformal field theories. This non-Markovianity arises from two distinct mechanisms: (i) interaction-induced temporal correlations, which appear already at early times, and (ii) entanglement phase transition, which appears at the Page time of a finite environment. We further show that the process-tensor mutual information coincides with the timeline pseudoentropy when the subsystem is depolarized and establishes its holographic correspondence in the dual black hole spacetime. Our results on non-Markovianity connect the fields of quantum chaos, many-body dynamics, and the black hole information problem.

FRI 3.5 Fri 11:45 ZHG003

Statistical Hadronization of Loosely Bound Nuclei — •Hjalmar Brunssen — Physikalisches Institut, Universität Heidelberg

It has been shown that the statistical hadronization model (SHM) yields an excellent description of hadron and light-nucleus yields in heavy-ion collisions at the LHC. While the yields of hadrons are in general well understood, the hadronization of nuclei is a very active research topic. In particular, the hypertriton, whose wavefunction is similar in size to the entire fireball, represents an ideal probe to test the production mechanism of nuclei.

This talk presents an approach for incorporating the size of loosely bound nuclei into the SHM calculation of production yields, focusing on hypertriton, deuteron and helium-3 nuclei. For this, the finite spatial extent of the wavefunction is considered, which leads to a significant correction relative to a point-like treatment, especially in small collision systems. We test the approach by comparing its predictions with data from ALICE and STAR.

FRI 4: Foundational / Mathematical Aspects – Alternative Views

Time: Friday 10:45–12:30 Location: ZHG004

FRI 4.1 Fri 10:45 ZHG004

Three Steps Turn Euclidean Relativity Into a Pillar of Physics — •Markolf H. Niemz — Heidelberg University, Germany

In special relativity (SR), there is coordinate time t and proper time τ. Two facts deserve reflection: (1) Clocks measure τ, but the construct t is more common in the equations of physics than natural τ. (2) Cosmology is aware of the Hubble parameter H_θ, but the parameter τ is preferred to $\theta = 1/H_\theta$ in both SR and general relativity (GR). **We show:** Euclidean relativity (ER) describes nature exclusively in natural concepts. Three steps make ER work: (1) The new time coordinate is τ. (2) The new parameter is θ. (3) An observer's reality is a projection from 4D Euclidean space (ES). Because of the different concepts, ER neither conflicts with nor requires SR/GR! All energy moves through ES at the speed c. Absolute ES is experienced as a relative Euclidean spacetime: Each object experiences its 4D motion as its proper time and the other three axes as its proper space. Both the Lorentz factor and gravitational time dilation are recovered in ER. Thus, ER predicts the same relativistic effects as SR/GR. In ER, τ is the length of a 4D Euclidean vector "flow of proper time" $\boldsymbol{\tau}$. Gravity makes its comeback as a force. Any acceleration rotates an object's $\boldsymbol{\tau}$ and curves its worldline in ES. $\boldsymbol{\tau}$ is crucial for objects that are very far away or entangled. Information hidden in θ and in $\boldsymbol{\tau}$ is not available in SR/GR. ER solves the wave–particle duality and explains entanglement without postulating non-locality. Entangled objects have never been spatially separated in their view, but their proper time flows in opposite 4D directions. https://www.preprints.org/manuscript/202207.0399

FRI 4.2 Fri 11:00 ZHG004

On Schrödinger's requirements for space functions — •Dieter Suisky — Berlin (suisky5@aol.com)

It will be demonstrated that the wave function and the energy of the ground state of a quantum mechanical system can be derived from the requirements which had been posed by Schrödinger in the First Communication in 1926: In order to substitute the traditional quantum conditions Schrödinger looked for real, single-valued in the whole configuration space, finite and twice continuously differentiable functions. From these requirements alone and the theorem of Rolle it follows that there is such function which (1) is symmetric and zero in the end points, (2) has one maximum and two turning points, (3) the position of the maximum is at x =0. Furthermore, a differential equation of 1st order can be established from which the wave function of the ground state can be calculated. The coordinates of the turning points can be obtained by the differential equation of 2nd order which follows straightforwardly from the previously derived differential equation of 1st order if the condition for all turning points of the twice differentiable space function f(x) is taken into account. Moreover, the energy value of the lowest state can be calculated too and is different from zero, E > 0, which is typical for the quantum mechanical systems. The procedure fits for the quantum mechanical harmonic oscillator. The differential equation of 2nd order is nothing else the well-known Schrödinger equation, which is now already obtained from a differential equation of 1st order. The analysis of the relations between differential equations of different orders can be traced back to Euler.

FRI 4.3 Fri 11:15 ZHG004

How come the quantum? Testing a proposal for the origin of Planck's quantum of action — •Christoph Schiller — Motion Moutain

The answer to Wheeler's question "How come the quantum?" given by Kauffman is presented and explored. The answer, going back to an approach by Dirac, proposes a topological origin of Planck's quantum of action. The proposal is checked against all quantum effects, including non-commutativity, spinor wave functions, entanglement, Heisenberg's indeterminacy relation, and the Schrödinger and Dirac equations. The principle of least action is deduced. The spectra of elementary particles, the gauge interactions, and general relativity are derived. Estimates for elementary particle masses and for coupling constants, as well as numerous experimental predictions are deduced. Complete agreement with observations is found. The derivations also appear to eliminate alternatives and thus provide arguments for the uniqueness of the proposal.

Details, publications and preprints at https://motionmountain.net/strands

FRI 4.4 Fri 11:30 ZHG004

A Fresh Geometric Perspective of an Electron and its Waves — •Fong Yang — Minnesota, United States

Matter consists of particles and waves. Every day we interact with particles while essentially disregarding waves. Quantum mechanics mathematically describe matter from the waves perspective while disregarding particles. This description does not reflect our everyday experience with matter.

The double slit experiment shows that electrons inherently have wave properties. Quantum mechanics can predict time-elapsed double slit experiment results using wave mechanics. But it is unable to explain how electrons interact with the macroscopic environment within this experiment.

My theoretical research illustrates how electrons interact with its macroscopic environment using basic geometry and algebra, and the conservation of energy concept.

Theoretical research begins with a suggested first-person perspective of a traveling electron and its waves. The physical restrictions of the double slit experiment setup, the mathematical geometrics of the electron's waves, and the conservation of energy concept, together constrains the electron to certain locations in space until its interaction with the macroscopic environment. Basic algebra is then used to translate the geometric perspective into two distinctive wave properties. These properties are at a minimum a 99% match compared to double slit experiment calculations derived from conventional trigonometric perspective of the electrons' waves.

FRI 4.5 Fri 11:45 ZHG004

Superposition and Entanglement of Polarized Photons without Hidden Variables — •Eugen Muchowski — Primelstraße 10, 85591 Vaterstetten

Superposition and mixtures of indistinguishable photon beams are equivalent under certain conditions. This idea explains the correlations of entangled photons as well as entanglement swapping and teleportation without using hidden variables. This sheds new light on the Einstein-Bohr debate. The superposition of indistinguishable photon beams can be experimentally demonstrated with a Mach-Zehnder interferometer.

FRI 4.6 Fri 12:00 ZHG004

Particle masses generated by mass quanta and elementary charges circulating in individual eigenspaces of particles, not embedded in space-time. — •Herrmann Hans-Dieter — Berlin

Intrinsic properties of particles such as invariant mass, spin, magnetic dipole moment and Compton wave length are modelled assuming an extra space fixed to the structure of an individual particle. The particle appears as composited and extended in its eigenspace. The eigenspace resembles the space spanned by body-fixed coordinates of a spinning top, a satellite or a drone. The structural building stones of particle models are so called rotons with D=3+1 dimensions. The biroton with D=5+1 dimensions represents the minimum structure of a lepton model or a quark-equivalent. The meson model consists of a biroton and an anti-biroton with D=9+1 dimensions. A baryon model needs D=25+1 dimensions, it consists of six birotons with quarter-valued spins. This model structure provides mass values, spin and magnetic momenta in reasonable agreement with the experiment.

The mass quantum mQ approx.= 1/32 of the muon mass is calculated using muon data as input and serves as a universal constant. It may have both signs in the eigenspace, such that the small electron mass and the vanishing neutrino masses can be modelled as differences between positive and negative partial masses. The partial masses of a particle may be located at different positions in space-time, this could explain quantum nonlocality as well as nonlocal gravity.

FRI 4.7 Fri 12:15 ZHG004

The alleged necessity of quantum mechanics — •Albrecht Giese — Taxusweg 15, 22605 Hamburg

To what extent is quantum mechanics unavoidable for describing elementary particles? Historically the existence of quantization occurred in the investigations of the energy levels of atoms. Atoms are oscillators and these oscillators are subject to specific constraints. It is a physical fact that certain constraints permit only specific oscillation energies. However, the development of QM has since led to the assumption that most physical quantities are subject to quantization. Is this a reasonable or necessary development?

We have examples of specific facts about elementary particles that can be better, or even only, explained classically. A striking example is the development of inertia, where the classical derivation yields precise results, whereas the accepted Higgs model does not give us any. There are other examples where known rules have been successfully postulated in quantum mechanics but can instead be *derived using classical methods. A prominent example is the Planck relation E = h*ny.

We will recommend a discussion on the conclusions that can be drawn from this fact.

FRI 5: QIP Implementations: Solid-State Devices II

Time: Friday 10:45–12:45 Location: ZHG006

FRI 5.1 Fri 10:45 ZHG006

The challenges of developing electronic design automation tools for quantum technology — Karen Bayros[1], Martin Cyster[1], Jackson Smith[1], Jesse Vaitkus[1,2], Nicolas Vogt[1,2], Salvy Russo[1], and •Jared Cole[1] — [1]Theoretical, Computational and Quantum Physics group, School of Science, RMIT University, Melbourne, Australia — [2]HQS Quantum Simulations GmbH, Karlsruhe, Germany

Large-scale quantum computing requires extremely high precision qubits, with long coherence times, accurately calibrated control and free from unpredictable parameter drift.

Equivalent constraints have been addressed in conventional semiconductor electronics and other branches of engineering, often with the help of advanced computer simulation tools - referred to as Electronic Design Automation (EDA). For quantum technology, we are facing entirely new difficulties in terms of the scale and precision required for creating quantum EDA tools.

I will discuss the fundamental challenges in developing EDA tools for quantum technology, specifically those relevant to superconducting and semiconducting qubits. These challenges ultimately stem from the fundamental structure of quantum physics, which is ironic given that we need to solve quantum physics problems to build a quantum computer, in order to efficiently solve those quantum physics problems!

In discussing these issues, I will present our recent efforts to develop proof-of-principle multi-scale quantum EDA tools.

FRI 5.2 Fri 11:00 ZHG006

Semiconductor quantum dots in fiber-based microcavities — •Jonas Grammel[1], Nam Tran[2], Simone Luca Portalupi[2], Peter Michler[2], and David Hunger[1] — [1]Physikalisches Institut, Karlsruher Institut für Technologie — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart

Semiconductor single photon sources are fundamental building blocks for quantum information applications. The current limitations of such quantum dot sources are the emitting wavelength and insufficient collection efficiency in fiber-based implementations. In the project *Telecom Single Photon Sources* we aim to realize high brightness, fiber coupled sources of single and indistinguishable photons at the telecom wavelength for the upcoming realization of fiber-based quantum networks. We employ open cavities realized with fiber-based mirrors, in combination with InGaAs quantum dots emitting in the telecom O-band and C-band. To achieve Fourier-limited photons we utilize the lifetime reduction of the emitters via the Purcell effect. We optimize the mode matching between the cavity mode and the guided fiber mode by introducing a fiber-integrated mode-matching optics that can basically reach near-unity collection efficiency. Fundamentally new is also the combination of Fabry-Perot micro-cavity modes with lateral micro- and nanostructures to reduce the cavity mode volume and thereby boost the emission enhancement and efficiency of the single photon emitters.

FRI 5.3 Fri 11:15 ZHG006

Two-photon spectrum and dynamics of a quantum dot under phonon-assisted excitation — •Lennart Jehle[1], Lena Maria Hansen[1], Thomas Sando[1], Patrik Isene Sund[1], Raphael Joos[2], Simone Luca Portalupi[2], Mathieu Bozzio[1], Peter Michler[2], and Philip Walther[1] — [1]University of Vienna, Faculty of Physics, Vienna Center for Quantum Science and Technology (VCQ), 1090 Vienna, Austria — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, University of Stuttgart, 70569 Stuttgart, Germany

Quantum dots promise to emit with high probability exactly one photon when pumped by a short laser pulse. However, there exists a finite chance of exciting the quantum dot twice within the duration of a single laser pulse, leading to the consecutive emission of two photons and imposing a fundamental limit on the multiphoton probability. Here, we resolve the distinct temporal shape of each of the photons' wavepackets using fast coincidence detection and report an asymmetric two-photon spectrum unique to phonon-assisted excitation. We demonstrate how this two-photon process provides insights into the emission dynamics and enables a direct measurement of the effective Rabi frequency, thus allowing us for the first time to extract the Rabi frequency of a non-resonantly driven quantum dot. By extending the temporal and spectral analysis further, we uncover correlations between the emission time and wavelength. Finally, we use this new understanding of the re-excitation process to maintain a low multiphoton probability regardless of the laser pulse length and thus improve the performance for quantum cryptography and quantum computing.

FRI 5.4 Fri 11:30 ZHG006

Deterministic single-step fabrication of quantum dot-circular Bragg grating resonators with high process yield — •Avijit Barua[1], Kartik Gaur[1], Léo J. Roche[1], Suk In Park[2], Priyabrata Mudi[1], Sven Rodt[1], Jin-Dong Song[2], and Stephan Reitzenstein[1] — [1]Institut für Physik und Astronomie, Technische Universität Berlin (TUB), Berlin, Germany — [2]Korea Institute of Science and Technology (KIST), Seoul, Republic of Korea

The integration of quantum dot (QD) single-photon emitters into photonic structures is pivotal for the establishment of hybrid quantum networks. Here, we use the deterministic, single-step in-situ electron-beam lithography (i-EBL) for integrating QDs into circular Bragg grating (CBG) resonators with high accuracy and scalability. Notably, devices with two/three rings deliver photon extraction efficiencies comparable to structures with more rings, enabling faster fabrication, reduced device footprint, and compatibility with electrical contacting. To demonstrate scalability, we report on the fabrication of several hundred QD-CBG devices across multiple sessions and samples. The devices exhibit bright, narrow-linewidth single-photon emission with excellent optical quality. To evaluate QD placement accuracy, we perform cathodoluminescence mapping along with scanning electron microscopy, and the statistical analysis of these devices shows that our i-EBL concept allows for sub-40 nm alignment accuracy and >80% process yield across various CBG geometries. Our findings highlight a reliable route toward scalable, high-performance QD-based single-photon sources for future integration in hybrid quantum photonic networks.

FRI 5.5 Fri 11:45 ZHG006

Spectroscopy and coherent nuclear spin manipulation of Eu-based molecular systems — •Evgenij Vasilenko[1], Vishnu Unni C.[1], Barbora Brachnakova[1], Weizhe Li[2], Nicholas Jobbitt[1], Senthil Kuppusamy[1], Mario Ruben[1], and David Hunger[1] — [1]Karlsruhe Institute of Technology — [2]FAU Erlangen

Rare-earth ions in solid-state hosts are promising spin qubit candidates due to their excellent optical and spin coherence properties. Recent work on Eu^{3+}-based molecular materials has demonstrated exceptional optical coherence [1], showing that ligand fields can be chemically engineered to improve both optical and spin properties for quantum applications. We investigate Eu^{3+}-doped molecular crystals and powders that exhibit long spin lifetimes and narrow homogeneous linewidths at 4.2 K [1,2]. In a single macroscopic crystal of $[Eu(Ba)_4(pip)]$, we observe inhomogeneous linewidths of 1.95 GHz, homogeneous linewidths of 120 kHz, spin $T_{1,\mathrm{sp}}$ on the order of hours, and photon echo decays around 3 μs at 4.2 K, representing an improvement over previous results [1]. A complete spin characterization was performed on the same molecular complex, including both hyperfine transitions. Spin echo experiments revealed a coherence time of 613 μs, extended to 2 ms via

CPMG dynamical decoupling. We also demonstrate the integration of these molecular crystals into open-access Fabry-Pérot fiber cavities to enhance emission via the Purcell effect [3].

[1] Serrano et al., Nature, 603, 241-246 (2022)
[2] Kuppusamy et al., J. Phys. Chem. C 127, 22 (2023)
[3] Hunger et al., New J. Phys 12, 065038 (2010)

FRI 5.6 Fri 12:00 ZHG006

Superconducting parallel-plate resonators for the detection of single electron spins — •André Pscherer, Jannes Liersch, Patrick Abgrall, Hélène Le Sueur, Emmanuel Flurin, and Patrice Bertet — Quantronics Group, Université Paris-Saclay, CNRS, SPEC, 91191 Gif-sur-Yvette Cedex, France

Solid-state spins have been explored as a resource for quantum sensing, computation and communication using mostly optical transitions to control and read out single spins [1]. Even though detecting spins via their spin-flip transition in the microwave frequency range would extend the palette of usable spins to those without optical transitions, this path seems impractical for single spins due to their vanishingly low radiative decay rates. Only recently, our group demonstrated the microwave-only detection of a single spin [2], enabled by a superconducting resonator with a Purcell factor of 10^{14} and a single-microwave-photon detector [3]. In this talk, I will explain the design of the currently used resonator and our progress towards a significantly improved resonator, which will shorten the spin lifetime to $\sim 10\,\mu$s.

[1] D. Awschalom *et al.*, Nature Photonics, 12(9), 516-527 (2018)
[2] Z. Wang, L. Balembois *et al.*, Nature, 619, 276-281 (2023)
[3] R. Lescanne *et al.*, PRX 10, 021038 (2020)

FRI 5.7 Fri 12:15 ZHG006

Influence of dephasing on the indistinguishability of 2D and bulk-embedded semiconductor quantum emitters — •Steffen Wilksen, Alexander Steinhoff, and Christopher Gies — Institute for Physics, Faculty V, Carl von Ossietzky University Oldenburg, 26129 Oldenburg, Germany

The generation of high-quality single photons is an important prerequisite for a multitude of quantum applications, including linear (photonic) quantum computing and quantum communication. While antibunching has been demonstrated in many cases, limitations of the Hong-Ou-Mandel (HOM) indistinguishability, quantifying the ability of emitted photons to interfere with each other, remain an open research question especially in single-photon sources based on 2D van der Waals materials.

In this talk, we analyze the influence of the coupling to acoustic phonon modes on the photon indistinguishability in two types of semiconductor-based single-photon sources, i.e. quantum dots in transition-metal dichalcogenides (TMDs), and III-V quantum-dot molecules. We simulate the HOM experiment and determine the indistinguishability by numerically computing two-time correlation functions. Results are obtained using an exact diagonalization approach, taking into account both markovian and non-markovian contributions. An optical cavity is considered for altering the recombination rate via the Purcell effect. Our results reveal fundamental limitations of HOM indistinguishability in TMD-based single-photon sources, rooted in the two-dimensional nature of the phonons.

FRI 5.8 Fri 12:30 ZHG006

Two-photon polymerization of strip-loaded thin-film lithium niobate waveguides for high-efficient photon pair sources and quantum circuits — •Alexandra Rittmeier[1,2], Muhamed A. Sewidan[2,3], Elisavet Chatzizyrli[1,2], Philipp Gehrke[1,2], Laura Bollmers[4], Silia Babel[4], Laura Padberg[4], Christof Eigner[4], Christine Silberhorn[4], Douglas Bremner[5], Anna Karoline Rüsseler[1,2], Andreas Wienke[1,2], Dietmar Kracht[1,2,3], Moritz Hinkelmann[1,2], and Michael Kues[1,2,3] — [1]Laser Zentrum Hannover e.V., Germany — [2]PhoenixD, LUH, Germany — [3]Institute of Photonics, LUH, Germany — [4]Paderborn University, Germany — [5]Alter Technology, Livingston, UK

Advancements in integrated photonics are essential for future chip-scale photonic systems and depend on new materials and fabrication methods. Lithium niobate (LN) is highly attractive due to its strong nonlinearity and excellent electro-optical properties. We introduce an etchless fabrication method for strip-loaded thin-film LN waveguides using two-photon polymerization (2PP), achieving low propagation losses of 0.15 dB/cm and rapid production cycles. The approach enables LN substrate reuse, promoting sustainable manufacturing. Using this fabrication approach, we realized a photon pair source with a 201 MHz pair generation rate and a coincidence-to-accidental ratio of 379, outperforming platforms fabricated via etching methods. In addition, we realized key components such as grating and directional couplers, demonstrating the potential of 2PP-fabricated optical components on LN for scalable, high-performance quantum photonic circuits.

FRI 6: Quantum Error Mitigation

Time: Friday 10:45–12:00 Location: ZHG007

FRI 6.1 Fri 10:45 ZHG007

Error Mitigation for Time-Evolution Approach for Greens Functions on Quantum Computers — •Jannis Ehrlich[1] and Daniel F. Urban[1,2] — [1]Fraunhofer-Institut für Werkstoffmechanik IWM, Freiburg, Germany — [2]Freiburger Materialforschungszentrum, Universität Freiburg, Germany

The computation of Greens functions plays a central role in many-particle physics, as they are directly connected to the energy of the system and the spectral function. Their calculation with classical computers is challenging due to the explicit treatment of electron interactions, especially in the case of strong correlation effects. We present a time-evolution approach for extracting the Greens function by simulating the quantum system on a quantum computer. We explicitly investigate the influence of errors on the results and proper error mitigation strategies as well as the effect of symmetry protection for simulations on current quantum devices.

FRI 6.2 Fri 11:00 ZHG007

Coherently mitigating boson samplers with stochastic errors — Deepesh Singh[1], Ryan J Marshman[1], •Nathan Walk[2], Jens Eisert[2,3], Timothy C Ralph[1], and Austin P Lund[1,2] — [1]University of Queensland — [2]Freie Universität Berlin — [3]Helmholtz-Zentrum Berlin

Sampling experiments provide a viable route to show quantum advantages of quantum devices over classical computers in well-defined computational tasks. However, devices such as boson samplers are susceptible to various errors, including stochastic errors due to fabrication imperfections causing the implemented unitary operations to deviate randomly from their intended targets. Whilst full-scale quantum error correction remains challenging, quantum error mitigation schemes have been devised to estimate expectation values, but it is unclear how these would work for sampling experiments. Here, we adopt the unitary averaging protocol which employs multiple stochastic boson samplers to generate a distribution that better approximate the ideal distribution as the number of samplers increases. We derive rigorous upper bounds on the trace distance between the output probability distributions induced by invertible vacuum-heralded networks based on the Schur-Weyl duality. More broadly, these results suggests a path towards understanding error mitigation for sampling experiments and developing analysis tools for photonic circuits incorporating measurements and feed-forward. Other applications include the implementation of linear combination of unitaries and fabrication benchmarking.

FRI 6.3 Fri 11:15 ZHG007

Quantum error mitigation combining subspace and probabilistic techniques — Prachi Sharma[1], João C. Getelina[2], Thomas Iadecola[2,3], Yong-Xin Yao[2,3], and •Peter P. Orth[1] — [1]Department of Physics, Saarland University, 66123 Saarbrücken, Germany — [2]Ames National Laboratory, Ames, Iowa 50011, USA — [3]Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011, USA

As quantum computing advances toward real-world applications, mitigating errors remains a critical challenge, particularly when determining ground state energies of many-body models on noisy quantum hardware. To address this, synergistic approaches to quantum error mitigation are necessary, combining the strengths of multiple techniques to ensure more reliable quantum operations. In this work, we integrate quantum subspace expansion methods with probabilistic error reduction techniques to address these challenges. We apply this framework to ground state energy calculations of a 16-site mixed field Ising model on IBM quantum hardware and noisy simulators using the Variational Quantum Eigensolver (VQE) [1]. Our results demonstrate a two order-of-magnitude improvement in the accuracy of the ground state energy on IBM's noisy backend simulators, highlighting the effectiveness of this approach in systematically enhancing the reliability of quantum computations.

[1] J. Getelina et al., APL Quantum 1, 036127 (2024).

FRI 6.4 Fri 11:30 ZHG007

Mitigation of correlated readout errors without randomized measurements — •Adrian Aasen[1,2], Andras Di Giovanni[3], Hannes Rotzinger[3], Alexey Ustinov[3], and Martin Gärttner[2] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Heidelberg, Germany — [2]Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena, Jena, Germany — [3]Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Germany

Quantum simulation, the study of strongly correlated quantum matter using synthetic quantum systems, has been the most successful application of quantum computers to date. It often requires determining observables with high precision, for example when studying critical phenomena near quantum phase transitions. Thus, readout errors must be carefully characterized and mitigated in data post-processing, using scalable and noise-model agnostic protocols. We present a readout error mitigation protocol that uses only single-qubit Pauli measurements and avoids experimentally challenging randomized measurements. The proposed approach captures a very broad class of correlated noise models and is scalable to large qubit systems. It is based on a complete and efficient characterization of few-qubit correlated positive operator-valued measures (POVMs), using overlapping detector tomography. To assess the effectiveness of the protocol, observables are extracted from simulations involving up to 100 qubits employing readout errors obtained from experiments with superconducting qubits.

FRI 6.5 Fri 11:45 ZHG007

Revealing correlated noise with single-qubit operations — •Balázs Gulácsi, Joris Kattemölle, and Guido Burkard — University of Konstanz

Spatially correlated noise poses a significant challenge to fault-tolerant quantum computation by breaking the assumption of independent errors. Existing methods such as cycle benchmarking and quantum process tomography can characterize noise correlations but require substantial resources. We propose straightforward and efficient techniques to detect and quantify these correlations by leveraging collective phenomena arising from environmental correlations in a qubit register. In these techniques, single-qubit state preparations, single-qubit gates, and single-qubit measurements, combined with classical post-processing, suffice to uncover correlated relaxation and dephasing. Specifically, we use that correlated relaxation is connected to the superradiance effect which we show to be accessible by single-qubit measurements. Analogously, the established parity oscillation protocol can be refined to reveal correlated dephasing through characteristic changes in the oscillation line shape, without requiring the preparation of complex and entangled states.

FRI 7: Entanglement and Complexity: Contributed Session to Symposium III

Time: Friday 10:45–12:15 Location: ZHG008

FRI 7.1 Fri 10:45 ZHG008

Entanglement theory with limited computational resources — Lorenzo Leone, Jacopo Rizzo, Jens Eisert, and •Sofiene Jerbi — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Germany

The precise quantification of the ultimate efficiency in manipulating quantum resources lies at the core of quantum information theory. However, purely information-theoretic measures fail to capture the actual computational complexity involved in performing certain tasks. In this work, we rigorously address this issue within the realm of entanglement theory. We consider two key figures of merit: the computational distillable entanglement and the computational entanglement cost, quantifying the optimal rate of entangled bits (ebits) that can be extracted from or used to dilute many identical copies of n-qubit bipartite pure states, using computationally efficient LOCC. We demonstrate that computational entanglement measures diverge significantly from their information-theoretic counterparts. While the von Neumann entropy captures information-theoretic rates for pure-state transformations, we show that under computational constraints, the min-entropy instead governs optimal entanglement distillation. Meanwhile, efficient entanglement dilution requires maximal ($\tilde{\Omega}(n)$) ebits even for nearly unentangled states. Our results establish a stark, maximal separation of $\tilde{\Omega}(n)$ vs o(1) between computational and information-theoretic entanglement measures. Finally, we find new sample-complexity bounds for measuring and testing the von Neumann entropy, efficient state compression, and efficient LOCC tomography protocols.

FRI 7.2 Fri 11:00 ZHG008

Quantum Magic and Entanglement in Nuclear Many-Body Systems — •Federico Rocco[1], James W. T. Keeble[1], and Caroline Robin[1,2] — [1]Fakultät für Physik, Universität Bielefeld, D-33615 Bielefeld, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, D-64291 Darmstadt, Germany

Concepts of quantum information science shed light on the complexity of quantum many-body systems, providing new insights into the structure of matter and emergence of degrees of freedom. Non-stabilizerness, or magic, is related to the amount of non-Clifford resources required to perform a quantum simulation and has emerged as a central quantity in the study of quantum complexity. Beyond that, estimates of non-local magic between different partitions of the nuclear system can uncover many-body correlations not captured by entanglement. In this talk, I will discuss investigations of magic and non-local magic based on stabilizer Rényi entropies in atomic nuclei, as well as the connection between quantum complexity, emergent collective behavior and shape deformation.

FRI 7.3 Fri 11:15 ZHG008

Revealing continuous-variable entanglement through derivatives of phase-space distributions — •Elena Callus[1], Martin Gärttner[1], and Tobias Haas[2] — [1]Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena — [2]Institute of Theoretical Physics, Universität Ulm

The Peres–Horodecki, or positive partial transpose, criterion is a necessary condition for bipartite separability, and its violation is sufficient to certify the presence of entanglement. In this work, we explore the implication of this criterion on phase-space distributions of separable states. More specifically, we show that one can formulate separability criteria in terms correlations of phase-space distributions, together with their spatial derivatives, at arbitrary points in phase space. This approach complements work on certification of nonclassicality by means of such distributions [1]. We demonstrate the versatility of this approach by considering the relevance of low-ordered criteria in certifying entanglement in important classes of states. Finally, we also discuss possible experimental approaches in order to access these entanglement witnesses.

[1] M. Bohmann, E. Agudelo, and J. Sperling, "Probing nonclassicality with matrices of phase-space distributions", Quantum 4, 343 (2020).

FRI 7.4 Fri 11:30 ZHG008

Demonstration of verified BosonSampling — •Naomi Spier[1], Redlef B G Braamhaar[1], Riko Schadow[2], Sara Marzban[1], Jens Eisert[2], Nathan Walk[2], and Jelmer J Renema[1] — [1]University of Twente — [2]Freie Universität Berlin

Sampling from random quantum circuits has been proposed as a first demonstration of a concrete computational advantage for special purpose, non-universal quantum processors. Whilst ideal sampling implementations have extremely strong complexity theoretic arguments for their classical intractability, real sampling devices are vulnerable to the potential existence of efficient, classical simulation algorithms and the status of many claimed advantage demonstrations remains contested. The original sampling proposal, BosonSampling, involves the propagation of single photon states through a random linear optical interferometer and has received significant attention, especially due to the rapid increase in the size, quality and configurability of integrated photonic waveguides. Whilst photon loss errors are immediately apparent from the data, errors due interferometer imperfections and photon distinguishability can also destroy quantum advantage but are more challenging to quantify. In this work, utilising recently developed photonic fidelity witnesses, we carry out a proof-of-principle, efficient verification of a BosonSampler using an integrated, reconfigurable interferometer. The verification is shown to detect errors due to interferometer noise, distinguishability and Poissonian photon sources.

FRI 7.5 Fri 11:45 ZHG008

Purification of Noisy Measurements and Faithful Distillation of Entanglement — •Jaemin Kim, Jiyoung Yun, and Joonwoo Bae — School of Electrical Engineering, Korea Advanced Institute of Science and Technology (KAIST), 291 Daehak-ro, Yuseong-gu, Daejeon 34141, Republic of Korea

We consider entanglement distillation with noisy operations in which quantum measurements that constitute a general quantum operation are particularly noisy. We present a protocol for purifying noisy measurements and show that imperfect local operations can distill entanglement. The protocol works for arbitrary noisy measurements in general and is cost-effective and resource-efficient with single additional qubit per party to resolve the distillation of entanglement. The purification protocol is feasible with currently available quantum technologies and readily applied to entanglement applications.

FRI 7.6 Fri 12:00 ZHG008

Entangled subspaces through algebraic geometry — •Masoud Gharahi[1] and Stefano Mancini[2] — [1]University of Trieste, Trieste, Italy — [2]University of Camerino, Camerino, Italy

We propose an algebraic geometry-inspired approach for constructing entangled subspaces within the Hilbert space of a multipartite quantum system. Specifically, our method employs a modified Veronese embedding, restricted to the conic, to define subspaces within the symmetric part of the Hilbert space. By utilizing this technique, we construct the minimal-dimensional, non-orthogonal yet Unextendible Product Basis (nUPB), enabling the decomposition of the multipartite Hilbert space into a two-dimensional subspace, complemented by a Genuinely Entangled Subspace (GES) and a maximal-dimensional Completely Entangled Subspace (CES). In multiqudit systems, we determine the maximum achievable dimension of a symmetric GES and demonstrate its realization through this construction. Furthermore, we systematically investigate the transition from the conventional Veronese embedding to the modified one by imposing various constraints on the affine coordinates, which, in turn, increases the CES dimension while reducing that of the GES.

FRI 8: Quantum Detectors in Optics and Particle Physics

Time: Friday 10:45–12:15 Location: ZHG009

FRI 8.1 Fri 10:45 ZHG009

Laser-Doppler-Vibrometer mit quetschlichtverbesserter Auflösung — •Mengwei Yu[1], Pascal Gewecke[2], Roman Schnabel[2] und Christian Rembe[1] — [1]Institut für Elektrische Informationstechnik, TU Clausthal, 38678 Clausthal-Zellerfeld — [2]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg

Das heterodyne Laser-Doppler-Vibrometer (LDV) detektiert kleinste Schwingungsamplituden bei mechanischen Strukturen mit einer Auflösung im Sub-Picometerbereich und ist typischerweise durch Photonenschrotrauschen beschränkt. Kennzeichnend für das heterodyne LDV ist, dass das Fotodetektorsignal einen Träger bei der Differenzfrequenz zwischen Mess- und Referenzlicht hat. Korrelierte Photonen überwinden als sogenanntes Quetschlicht die Schrotrauschgrenze von optischem Messverfahren. Durch das Einkoppeln von vakuumquetschtem Licht in den Messstrahl eines LDVs kann entweder das Amplituden- oder das Phasenrauschen des Lichts effektiv unterdrückt werden. Die Reduzierung des Phasenrauschens führt zu einer Verbesserung des Träger-Rausch-Verhältnisses und folglich zu einer verbesserten Amplitudenauflösung bei der Schwingungsmessung. In dieser Studie wird ein heterodynes LDV vorgestellt, das die Einspeisung von Quetschlicht mit synchroner Abtastung und Demodulation kombiniert. Die digitale Vibrationsamplitudenauflösung wird in diesem Beitrag von einem durch Schrotrauschen limitierten Wert von 6 $\mathrm{fm}/\sqrt{\mathrm{Hz}}$ auf ein sub-Schrotrauschen-Niveau von 4 $\mathrm{fm}/\sqrt{\mathrm{Hz}}$ verbessert, was das Potenzial quantenbasierter Technologien in hochpräzisen optischen Messsystemen aufzeigt.

FRI 8.2 Fri 11:00 ZHG009

Dynamics of quantum mixtures in microgravity — •Lakshmi Priyanka Guggilam, Jonas Böhm, and Dorthe Leopoldt — Institut für Quantenoptik, Leibniz Universität Hannover

The MAIUS (Matter wave interferometry under microgravity) project aims to demonstrate atom interferometry in weightlessness as a promising tool for precision measurements, e.g., of Einstein*s equivalence principle (EEP), with accuracies that couldn*t be achieved with classical tests. With the launch of MAIUS-1, it was possible to create the first BECs in space using Rb-87 atoms and performing interference experiments with these macroscopic quantum objects. In MAIUS-2, we focus on understanding the dynamics of K-41 and Rb-87 quantum mixtures in microgravity to pave the wave for long-time dual species atom interferometry. This talk is focused on the preparation of K-41 and Rb-87 quantum mixtures in the Einstein Elevator, an active drop tower providing 4 s of microgravity time every 4 minutes. In addition, the simultaneous transport of both species to weaker traps using Shortcut To Adiabaticity (STA) protocols and their resulting dynamics will be discussed. These techniques are important prerequisites to perform EEP tests with BECs created on an atom chip under microgravity. The MAIUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number: 50WP1431.

FRI 8.3 Fri 11:15 ZHG009

Gravitational wave-induced photon superradiance in atoms — •Navdeep Arya and Magdalena Zych — Stockholm University, Stockholm, Sweden

The effects of spacetime curvature on atoms are typically very small. However, we argue that spontaneous buildup of quantum coherence enables atoms in an array to cooperate and amplify their response to gravitational waves. This cooperation manifests as gravitational wave-induced photon superradiance—delayed, intense, and directional emission of photons at frequencies shifted by the gravitational wave frequency. This effect arises in a regime distinct from flat-spacetime superradiance, which allows gravitational effects to dominate the collective atomic response. The effect persists despite common experimental challenges like position disorder and partial filling, highlighting coherent atom arrays as potential candidates for broadband gravitational wave detection. Our findings demonstrate a coupling interface between general relativistic gravity and quantum matter under laboratory settings in a many-body system, with implications for both fundamental science and practical applications.

FRI 8.4 Fri 11:30 ZHG009

Label-free mid-IR imaging with undetected photons — •Marlon Placke[1], Chiara Lindner[2], Felix Mann[1], Inna Kviatkovsky[1], Helen Chrzanowski[1], Frank Kühnemann[2], and Sven Ramelow[1] — [1]Institute for Physics, Humboldt-Universität zu Berlin, Germany — [2]Fraunhofer Institute for Physical Measurement Techniques IPM, Freiburg, Germany

Sensing with undetected photons has become a distinct research field with numerous demonstrated applications, often dedicated to mid-infrared wavelength regions. Since these spectral bands entail molecule specific absorbance signatures also referred to as their fingerprints, sample compositions may be probed spectroscopically. To sidestep the challenges associated with camera sensors and low noise and broadband illumination sources for low-energy mid-infrared photons, we utilise a nonlinear interferometer in a widefield imaging arrangement with around 3500 resolved spatial modes and broadband signal and idler emission around 800 and 3800 nm, respectively. To importantly combine this with high-resolution spectral information, we employ Fourier

transform infrared spectroscopy by scanning the interferometric delay and analysing the resulting interferogram for each illuminated camera pixel. Finally, we demonstrate the practicality of our novel hyperspectral technique for applications such as microplastics detection and bio-imaging tasks. Accordingly, this quantum imaging method holds good potential for applications relying on compact, cost-effective, and label-free analysis near the intrinsic performance limit of the probe light itself.

FRI 8.5 Fri 11:45 ZHG009

Optimisation of TES design for the CRESST experiment — •Colin Moore — Max-Planck-Institut für Physik

The Cryogenic Rare Event Search with Superconducting Thermometers (CRESST) experiment aims at the direct detection of sub-GeV dark matter particles via elastic scattering off nuclei in a variety of target crystals at cryogenic temperatures. Located at the underground Laboratori Nazionali del Gran Sasso (LNGS) in Italy, CRESST operates cryogenic calorimeters consisting of an absorber crystal equipped with a tungsten Transition Edge Sensor (W-TES).

The W-TES developed in CRESST are composed of a tungsten thin film serving as the sensitive part of the thermometer, a gold thermal link connecting the sensor to the heat bath, and aluminum phonon collectors which increase the collection area of the sensors. Additionally, each W-TES is equipped with a heater which stabilises the sensors within their superconducting transition.

The technology utilised by CRESST allows for a leading energy threshold. Nevertheless, continuous R&D efforts are underway to further improve signal to noise ratio and overall sensitivity. Optimising the TES design is a non-trivial task, owing to the complex interdependence of the properties of the absorber and sensor. To address these challenges, we have conducted detailed studies targeting specific aspects of the TES design and carried out comparative evaluations of various sensors configurations.

In this contribution, we present the outcomes of these optimisation studies and their impact on the performance of CRESST detectors.

FRI 8.6 Fri 12:00 ZHG009

COMPASSO mission and its quantum optical clock — •Johanna Popp[1], Frederik Kuschweski[1], Jan Wüst[1], Markus Oswald[1], Tim Blomberg[1], Jonas Pollex[2], André Bussmeier[1], Niklas Röder[1], Issaree Khattiwiriyapinyo[1], Thilo Schuldt[1], and Claus Braxmaier[1,3] — [1]DLR Institute of Quantum Technologies — [2]DLR Institute of Space Systems — [3]Institute of Microelectronics, University of Ulm

Quantum optical clocks are high-performance devices in terms of frequency stability and accuracy and are therefore important instruments in research of fundamental and applied physics, such as in geodesy and navigation with the Global Navigation Satellite System (GNSS). The established microwave clock technologies on GNSS satellites are one limititation for geolocation with cm precision. Hence national and international space agencies are aiming to replace these systems with next-generation technologies. In the DLR COMPASSO mission, a quantum optical clock based on modulation transfer spectroscopy of iodine will be deployed to the ISS as a technology demonstrator [1]. In this contribution, we present the mission architecture and highlight the key part of the optical clock: the iodine-based optical frequency reference reaching a fractional instability down to 10^{-15}.

[1] Kuschewski, F. et al. GPS Solut 28, 10 (2024).

FRI 9: Fundamental Quantum Tests

Time: Friday 10:45–11:30 Location: ZHG101

FRI 9.1 Fri 10:45 ZHG101

Optically Hyperpolarized Materials for Levitated Optomechanics - Testing the Nuclear Einstein de-Haas and Barnett Effect — •Marit O. E. Steiner, Julen S. Pedernales, and Martin B. Plenio — Institute of Theoretical Physics, Ulm University, Germany

Levitated solids with controllable spins offer a new platform for exploring spin-mechanical interactions in the solid state. Nuclear spin hyperpolarization enables investigation of the weak couplings between nuclear spins and rotational degrees of freedom, which have so far eluded experimental observation.

I will explore the potential of levitating solids embedded with optically controllable electron spins, which can hyperpolarize their nuclear spin environment. Pentacene-doped naphthalene serves as a leading example. Leveraging photo-excited triplet states in pentacene, this system achieves nuclear spin hyperpolarization in naphthalene with demonstrated polarization rates up to 80%, significantly enhancing spin-dependent forces and sensitivity to spin-rotational couplings.

I then investigate the use of hyperpolarized naphthalene to probe the nuclear Einstein-de Haas and Barnett effect. These theoretically predicted effects have not yet been observed in solids due to weak spin-mechanical coupling. By combining polarized hydrogen nuclear spins with controllable particle rotation, we propose a protocol to enable their first detection in the solid state.

FRI 9.2 Fri 11:00 ZHG101

99 years old and going stronger than ever: the molecular hydrogen ion — Stephan Schiller[1], •Soroosh Alighanbari[1], Magnus Schenkel[1], Vladimir Korobov[2], and Jean-Philippe Karr[3] — [1]Heinrich-Heine-Universität Düsseldorf — [2]Joint Institute for Nuclear Research, Dubna — [3]LKB, Sorbonne Université; Université d' Evry-Val d' Essonne

At the end of 1926, the same year that Schrödinger presented his wave equation, it was applied for the first time to a molecule, the molecular hydrogen ion (MHI) by Burrau. Even famous physicists (Pauli, Teller, Herzberg, Dehmelt, Lamb) worked on the topic at some time. Nevertheless, for the first 70 years, it did not appear that this family of three-body systems would become of much relevance to fundamental physics - it was too difficult to handle, experimentally and computationally. However, thanks to the efforts of a few reserach teams, today the precision physics of the MHI is entering center stage. MHIs are beginning to contribute to the determination of fundamental constants, tests of quantum physics, and the search for new interparticle forces. Furthermore, the perspective of comparing vibrational transitions in H_2^+ and its antimatter counterpart could lead to novel and ultra-accurate tests of CPT invariance.

MHIs are today studied with some of the most advanced techniques, such as sympathetic laser cooling, rotational laser cooling, quantum logic spectroscopy, Penning-Malmberg traps, frequency-comb-based optical metrology, cw-optical parametric oscillators. A bright future of high-accuracy results still lies ahead.

FRI 9.3 Fri 11:15 ZHG101

Multi-Path and Multi-Particle Tests of Complex versus Hyper-Complex Quantum Theory — Ece Ipek Saruhan, Joachim von Zanthier, and •Marc-Oliver Pleinert — Quantum Optics and Quantum Information Group, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 1, 91058 Erlangen, Germany

The axioms of quantum mechanics provide limited information regarding the structure of the Hilbert space, such as the underlying number system. The latter is generally regarded as complex, but generalizations of complex numbers, so-called hyper-complex numbers, cannot be ruled out in theory. Therefore, specialized experiments to test for hyper-complex quantum mechanics are needed. To date, experimental tests are limited to single-particle interference exploiting a closed phase relation in a three-path interferometer called the Peres test. The latter distinguishes complex quantum mechanics from quaternionic quantum mechanics. Here, we propose a general matrix formalism putting the Peres test on a solid mathematical ground. On this basis, we introduce multi-path and multi-particle interference tests, which provide a direct probe for any dimension of the number system of quantum mechanics.

[Phys. Rev. Lett. 134, 060201 (2025)]

FRI 10: Foundational / Mathematical Aspects – Unconventional Approaches

Time: Friday 10:45–12:45 Location: ZHG103

FRI 10.1 Fri 10:45 ZHG103

Particle-wave duality and quantization: Self-organisation of particle movement in zero-point field — •Christian Jooss — Institute of Materials Physics, University of Goettingen, Friedrich-Hund-Platz 1, 37077 Goettingen, Germany

The Göttingen physicist Friedrich Hund gave a fitting definition of quantum theory, namely as 'The theory of the role that h plays in nature'.[1] In this contribution, I discuss the Planck constant h as being an emergent quantity, reflecting the threshold between energy and momentum conserving random motions of particles in the Lorentz-invariant zero-point field and the lasting energy / momentum changes of quantum states. The analysis builts up on the analysis of the stochastic effects of a real zero-point field on particle motion[2], distinguishing reversible fluctuations which underly detailed energy balance and abrupt lasting changes in quantum state determined by h. Based on simple models of these processes, the emergence of particle-wave duality can be understood in terms of a self-organization effect, where the effect of the zero-point field on particle motion and its back reaction on zero-point fluctuations gives rice to the emergence of matter waves. Thus, existence of the quantum of action is interpreted as an expression of an organizational law[3]. The impact of this analysis on the realistic interpretation of quantum mechanics is discussed. References: [1] F. Hund, Geschichte der Quantentheorie, BI Wissenschaftsverlag 1975. [2] L. de la Pena and A. M. Cetto, The quantum dice: An introduction to stochastic electrodynamics, Kluwer Academic Publishers, 1996. [3] Ch. Jooss, Self-organization of Matter, de Gruyter 2020.

FRI 10.2 Fri 11:00 ZHG103

Quantum randomness revisited: simulating quantum measurement as a unitary time evolution — •Thomas Dittrich, Oscar Rodríguez, and Carlos Viviescas — Departamento de Física, Universidad Nacional de Colombia, Bogotá D.C., Colombia

Quantum measurement is usually regarded as incompatible with unitary time evolution, since the collapse of the wave packet breaks time reversal invariance. We challenge this view, studying quantum measurement as a unitary time evolution of the measurement object coupled to an environment that represents the meter and the apparatus. Modelled as a heat bath comprising only a finite, if large, number of boson modes, it is fully included in the time evolution of the entire system. We perform unitary numerical simulations of projective measurements of σz in spin-1/2 particles. They are prepared in a neutral pure state, the environment in a product of coherent states with centroids chosen at random from a thermal distribution. Initially, the spin gets entangled with the heat bath and loses coherence, reproducing the collapse. For large times and most of the initial states of the environment, the spin returns to a pure state, either spin up or spin down with equal probability, as definite outcome of the measurement. Unitarity allows us to run the simulations backwards from final state to preparation, undoing the measurement and tracing its result back to those initial conditions of the heat bath that entailed this result. That reveals the observed randomness as amplified quantum and thermal noise of the macroscopic environment. Extending our approach to an EPR setup is sketched as work in progress.

FRI 10.3 Fri 11:15 ZHG103

A heuristic solution to the time of arrival problem via mathematical probability theory — •Maik Reddiger — Anhalt University of Applied Sciences

There does currently not exist any scientific consensus on how to predict the probability that a single quantum particle impinges on an ideal detector in a given interval of time. The apparent simplicity of the problem is overshadowed by the deep conceptual discrepancies, which are exposed by the multitude of solutions proposed so far. Ab initio approaches need to model the ideal detector in such a manner, that it is compatible with quantum dynamics. A corresponding boundary condition for the Schrödinger equation was suggested by Werner in the 1980s, yet there is reason to question the physical validity of this detector model. In this talk I present an approach via mathematical probability theory and a physically natural adaption of the Madelung equations, which assures that the detector is perfectly absorbing. The presented solution is heuristic in the sense that a full solution would require a well-posedness result for the Cauchy problem of the corresponding system of PDEs for sufficiently regular initial data.

This solution of the time of arrival problem is obtained within the more general framework of geometric quantum theory. Geometric quantum theory is a novel adaption of quantum mechanics, which makes the latter consistent with mathematical probability theory.

FRI 10.4 Fri 11:30 ZHG103

Simultaneous processes in mechanics and quantum physics — •Grit Kalies[1] and Duong D. Do[2] — [1]HTW University of Applied Sciences, Dresden, Germany — [2]The University of Queensland, Brisbane, Australia

Processes change the properties of objects. Using examples such as the lifting, acceleration or displacement of a body as well as of a quantum object, we substantiate the plausibility and advantages of replacing 'force is action' with 'process is action'. Since each process with energy transfer describes the change in one property of a macroscopic or microscopic object, simultaneous processes allow for a more detailed energetic analysis than forces. The notion of acting forces and the current general definition of work are interpreted as helpful geometric substitute concepts, which conceal the actual dynamic processes such as the momentum work that takes place at the macroscopic and quantum levels.

FRI 10.5 Fri 11:45 ZHG103

Plasma-like description for quantum particles — •Andrey Akhmeteli — LTASolid Inc., Houston, Texas, USA

A scalar complex wave function can be made real by a gauge transformation (Schrödinger, Nature, 1952). Similarly, one real function is also enough to describe matter in more realistic theories, such as the Dirac equation in an arbitrary electromagnetic (Akhmeteli, J. Math. Phys., 2011, Eur. Phys. J. C, 2024) or Yang-Mills (A., Quantum Rep., 2022) field. As these results suggest some "symmetry" between positive and negative frequencies and, therefore, particles and antiparticles, one-particle wave functions can be described as plasma-like collections of a large number of particles and antiparticles (A., Eur. Phys. J. C, 2013, Entropy, 2022). The similarity of the dispersion relations for the Klein-Gordon equation and a simple plasma model provides another motivation for the plasma-like description of quantum particles.

The criterion for approximation of continuous charge density distributions by discrete ones with quantized charge is based on Gaussian smoothing (A., arXiv:2503.10667). A discrete distribution satisfying this criterion can be found for any smooth distribution. An example mathematical model of the interpretation is proposed.

The plasma-like description can offer an intuitive picture of the uncertainty principle, the double-slit experiment, and negative probabilities. Wave function spreading is not problematic for the model. Any experimental results that can be described using one-particle wave functions can be emulated using the plasma-like description.

FRI 10.6 Fri 12:00 ZHG103

Pinning quantum particles to surfaces and curves: a momentum operator- based approach — •Mohammad Shikakhwa — Department of Basic Sciences, TED University, Ziya Gökalp Caddesi No.48, 06420, Kolej - Çankaya, Ankara, Turkey

A physical, intuitive approach is proposed to confine a spin zero particle in 3D to arbitrary surfaces and curves embedded in the 3D space through the introduction of strong confining potential(s). The idea is to start from the onset with the Hamiltonian expressed in terms of the Hermitian *components* of the momentum operator and achieve confinement to the lower dimensional manifolds by dropping these Hermitian components that are normal to these manifolds along with setting the corresponding normal coordinates to zero. The resulting Hamiltonian, expressed now in terms of the manifold momenta along with a geometrical potential is a Hermitian operator. The resulting manifold momenta are at the kinematical ones proportional to the velocity of the particle on these manifolds.

FRI 10.7 Fri 12:15 ZHG103

Two quantum analogies — •Ryszard Wojnar — Institute of Fundamental Technological Research PAS

In the first analogy, the diffusion equation with an imaginary diffusion coefficient D=ih/2m is considered. The solutions are harmonic functions decaying in time. The disappearance time of a wave packet is proportional to m/h: for an electron of the order of seconds, for a mass of 1 g of the order of 10^10 years.

The second analogy refers to the hexatic transformation. The change in the contact of the particles participating in the transformation leads to either the creation or annihilation of dislocations 5-7, formations distinguished against the background of the hexagonal lattice.

FRI 10.8 Fri 12:30 ZHG103

Volume Portions Provide the Quantum Postulates and Exact Quantum Frames For Space Navigation — •Hans-Otto Carmesin — Universität Bremen, Fachbereich 1, Postfach 330440, 28334 Bremen — Studienseminar Stade, Bahnhofstr. 5, 21682 Stade — Gymnasium Athenaeum, Harsefelder Straße 40, 21680 Stade

A space paradox shows that space is an average of microscopic volume portions. These imply the quantum postulates, as well as gravity and curvature in spacetime. It is very valuable and insightful that the volume portions show how the quantum postulates are derived from spacetime and how they are applied to spacetime: In this manner, exact quantum frames of spacetime are derived and exact space navigation is enabled for the first time (Carmesin 2025). Predictions are derived, have been tested empirically, and can additionally be tested by space flights in various manners.

[1] Carmesin, H.-O. (2025): On the Dynamics of Time, Space and Quanta - Essential Results for Space Flight and Navigation. Berlin: Verlag Dr. Köster.

FRI 11: Quantum 2D-Moiré and Rhombohedral van-der-Waals Systems: Contributed Session to Symposium

Time: Friday 10:45–12:30 Location: ZHG104

FRI 11.1 Fri 10:45 ZHG104

Observation of Floquet states in graphene — •Marco Merboldt[1], Michael Schüler[2], David Schmitt[1], Jan Philipp Bange[1], Wiebke Bennecke[1], Karun Gadge[3], Klaus Pierz[4], Hans Werner Schumacher[4], Davood Momeni[4], Daniel Steil[1], Salvatore R. Manmana[3], Michael Sentef[5], Marcel Reutzel[1], and Stefan Mathias[1] — [1]Georg-August-Universität Göttingen, I. Physikalisches Institut, Germany — [2]Department of Physics, University of Fribourg, Fribourg, Switzerland — [3]Georg-August-Universität Göttingen, Institut für Theoretische Physik, Germany — [4]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [5]Institute for Theoretical Physics, University of Bremen, Bremen, Germany

Floquet engineering – the coherent dressing of matter via time-periodic perturbations – is a mechanism to realize and control emergent phases in materials out of equilibrium. However, the broad applicability of Floquet engineering to quantum materials is in question, especially with respect to (semi-)metals and graphene in particular.

Here, we resolve this long-standing debate by using electronic structure measurements to provide direct spectroscopic evidence of Floquet effects in graphene [1]. We report light-matter-dressed Dirac bands by measuring the contribution of Floquet sidebands, Volkov sidebands, and their quantum path interference to graphene's photoemission spectrum. Fully supported by experiment and theory, we demonstrate that Floquet engineering in graphene is possible.

[1] Merboldt *et al.*, Nature Physics (2025)

FRI 11.2 Fri 11:00 ZHG104

Giant chiral current in gapped graphene at room temperature — •Fanrong Lin[1], Weilong Guo[2], Qingjun Tong[2], and Yanpeng Liu[3] — [1]Georg-August-University of Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany — [2]Hunan University — [3]Nanjing university of aeronautics and astronautics

Nonlinear electrical signals serve as a complementary probe for investigating intrinsic quantum geometric properties while also revealing unconventional charge transport phenomena in systems with specific band topologies. A paradigmatic example is the chiral charge transport observed in gapped monolayer graphene, where the chiral Bloch electrons undergo unidirectional skew scattering. However, these nonlinear signals are typically exceedingly weak, necessitating either intrinsic topological band structures or extrinsic circuit enhancements to achieve detectable magnitudes. Here, we introduce a linear projection method that amplifies nonlinear physical, yielding a dramatically enhanced signal even at room temperature. Using this approach, we observe a robust unidirectional skew-scattered current, exhibiting a signal of several microvolt at room temperature. Furthermore, this chiral current exhibits dual tunability via external gate and DC bias voltages, enabling control over both the majority carrier type and the skew conductivity. Finally, we demonstrate nonlocal transport mediated by this tunable chiral current, generating a substantial nonlocal signal in remotely gated Hall bar pairs with a geometric factor of 4. This unconventional charge transport mechanism opens a pathway for long-range control in next-generation electronic devices.

FRI 11.3 Fri 11:15 ZHG104

Thermoelectric Transport Measurements in Dual-Gated Bernal Bilayer Graphene — •Moritz Knaak[1], Martin Statz[1], Kenji Watanabe[2], Takashi Taniguchi[3], and Thomas Weitz[1] — [1]1. Institute of Physics, Faculty of Physics, University of Göttingen, Göttingen, Germany — [2]Research Center for Functional Materials, National Institute for Materials Science, Tsukuba, Japan — [3]International Center for Materials Nanoarchitectonics, National Institute for Materials Science, Tsukuba, Japan

In dual-gated, hexagonal boron-nitride(hBN) encapsulated Bernal bilayer graphene(BLG) devices a cascade of correlated phases have been identified by magnetoconductance measurements. The correlated phases emerge close to Lifshitz-transitions. There, the density of states(DOS) is high and the kinetic energy gets quenched. While conductance measurements alone can be used to study correlated phases, it is difficult to precisely connect the DOS with said phases. The Seebeck coefficient, extracted from thermoelectric transport measurements provides a more direct probe of the DOS. It is defined as the ratio of the thermal voltage to its inducing temperature difference. We demonstrate measurements of the Seebeck coefficient at 4 K up to a calibration factor. For the measurements we employed an on-chip heater next to an hBN-encapsulated BLG device with graphite contacts and dual graphite gates to simultaneously tune the Fermi-level and an out-of-plane electric field. The source-drain contacts were simultaneously used as quasi-4-point-probe on-chip resistance thermometers to determine the local temperature differences between them.

FRI 11.4 Fri 11:30 ZHG104

Two-particle spin and valley blockade in graphene double quantum dots — •Christian Volk[1,2], Samuel Möller[1,2], Luca Banszerus[1,2], Katrin Hecker[1,2], Hubert Dulisch[1,2], Kenji Watanabe[3], Takashi Taniguchi[4], and Christoph Stampfer[1,2] — [1]JARA-FIT and 2nd Institute of Physics, RWTH Aachen University — [2]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich — [3]Research Center for Functional Materials, NIMS, Tsukuba, Japan — [4]International Center for Materials Nanoarchitectonics, NIMS, Tsukuba, Japan

Double quantum dots (DQDs) are promising building blocks for spin or valley qubits. The weak hyperfine interaction and the weak spin-orbit interaction in bilayer graphene (BLG) promise long spin coherence times. Additionally, the well tunable valley degree of freedom offers the possibility to create valley-based qubits in BLG DQDs. Efficient readout requires a spin- or valley-to-charge conversion, often provided by Pauli blockade. Thus, a comprehensive understanding of the limits and the tunablility of spin and valley blockade in BLG DQDs is necessary for evaluating their potential for hosting qubits.

Here, we show spin and valley blockade in two-electron BLG DQDs. Magnetotransport measurements reveal a rich level spectrum and we observe a magnetic field tunable spin and valley blockade, which is limited by the orbital splitting, the strength of the electron-electron interaction and the difference in the valley g-factors between the symmetric and antisymmetric two-particle orbital states. Our findings are supported by transport simulations following a rate equation approach.

FRI 11.5 Fri 11:45 ZHG104

Electronic Transport in Twisted Bilayer Graphene: Towards

Quantum Moiré-tronics — •Thomas Stegmann — Instituto de Ciencias Físicas, Universidad Nacional Autónoma de México

We investigate electronic transport in twisted bilayer graphene (TBLG) at small - though not magic - twist angles. In the first part of the talk, we propose a device in which the direction of the current flow can be steered by the twist between the layers. The observed current steering angle exceeds significantly the twist angle itself and arises over a broad range of experimentally accessible parameters. This behavior is attributed to the trigonal warping of the energy bands beyond the van Hove singularity, induced by the moiré pattern. Since the shape of these bands depends on the valley degree of freedom, the resulting current is partially valley-polarized, highlighting potential applications in valleytronics [1]. In the second part, we report anomalous edge states in TBLG at a twist angle of 1.696°. These edge states support electronic transport with conductance values near the conductance quantum and give rise to a nonlocal resistance. Notably, this nonlocal effect is not due to chiral edge transport, but due to the fact that these states are localized only at certain edges of the system, depending on how the nanoribbon has been cut from the bulk [2]. Finally, we discuss briefly how the electronic transport in graphene can be guided along atomically thin current paths through the engineering of Kekulé distortions, offering yet another route toward nanoscale current steering [3].

[1] J. Phys: Mater. 5:024003 (2022)
[2] Phys. Rev. B 110:205432 (2024)
[3] Nano Letters 24:2322 (2024)

FRI 11.6 Fri 12:00 ZHG104

Persistent Haldane Phase in Carbon Tetris Chains — •Anas Abdelwahab[1], Christoph Karrasch[2], and Roman Rausch[2] — [1]Leibniz Univesität Hannover, Institut für Theoretische Physik, Hannover — [2]Technische Universität Braunschweig

We introduce the concept of "tetris chains", which are linear arrays of 4-site molecules that differ by their intermolecular hopping geometry. We investigate the fermionic symmetry-protected topological Haldane phase in these systems using Hubbard-type models. The topological phase diagrams can be understood via different competing limits and mechanisms: strong-coupling $U \gg t$, weak-coupling $U \ll t$, and the weak intermolecular hopping limit $t' \ll t$. Our particular focus is on two tetris chains that are of experimental relevance. First, we show that a "Y-chain" of coarse-grained nanographene molecules (triangulenes) is robustly in the Haldane phase in the whole $t' - U$ plane due to the cooperative nature of the three limits. Secondly, we study a near-homogeneous "Y′-chain" that is closely related to the electronic model for poly(p-phenylene vinylene). In the latter case, the above mechanisms compete, but the Haldane phase manifests robustly and is stable when long-ranged Pariser-Parr-Popple interactions are added. The site-edged Hubbard ladder can also be viewed as a tetris chain, which gives a very general perspective on the emergence of its fermionic Haldane phase. Our numerical results are obtained using the density-matrix-renormalization group as well as the variational uniform matrix-product state (VUMPS) algorithms.

FRI 11.7 Fri 12:15 ZHG104

A Wannier approach to electronic structure in twisted van der Waals bilayers — •Ruven Hübner[1], Matthias Florian[2], and Alexander Steinhoff[1] — [1]Institute for Physics, Faculty V, Carl von Ossietzky University Oldenburg, 26129 Oldenburg, Germany — [2]University of Michigan, Dept. of Electrical Engineering and Computer Science, Ann Arbor, MI, USA

Moiré structures in two-dimensional van der Waals materials offer an interesting platform to explore the interplay of quantum phenomena across vastly different length scales—from the atomic scale, on the order of Ångström, to the supercell scale, reaching up to $\sim 40\,\text{nm}$. While DFT calculations have made remarkable progress in handling large systems, they do not readily reveal the dominant mechanisms that govern the electronic structure. In fact, it seems natural to retain much of the electronic structure of the individual monolayers and treat the interlayer interaction as a relatively small perturbation. This view can be well motivated by the model of Koshino, who introduced a tight-binding framework for moiré bilayers where a simple basis transformation reveals dominant interlayer couplings in reciprocal space, enabling a significant reduction in basis states [1]. We take this approach one step further by incorporating the Wannier projection method, based on multiple DFT calculations of untwisted bilayers with different stacking configurations. Besides providing a computationally efficient model, our framework enables analytical insight into moiré band splitting within the original Brillouin zones of the monolayers.

[1] Mikito Koshino 2015 New J. Phys. **17** 015014

FRI 12: Quantum Phenomena in Solid-State Devices

Time: Friday 10:45–12:30 Location: ZHG105

FRI 12.1 Fri 10:45 ZHG105

Probing many-body correlations using quantum-cascade correlation spectroscopy — •Thomas Volz — School of Mathematical and Physical Sciences, Macquarie University, Sydney, Australia

In quantum optics, the radiative quantum cascade is of fundamental importance. Two-photon cascaded emission has been instrumental for example to test Bell inequalities and generate entangled photon pairs. These experiments rely on the nonlinear nature of the underlying energy ladder, which enables the direct excitation and probing of specific single-photon transitions. Here we use exciton-polaritons to explore the cascaded emission of photons in the regime where individual transitions are not resolved. We excite a polariton quantum cascade by off-resonant laser excitation and probe the emitted luminescence using a combination of a narrow spectral filter and a Hanbury-Brown and Twiss setup for measuring the second-order autocorrelation function of the photons. The measured photon-photon correlations exhibit a strong dependence on the polariton energy and therefore on the underlying polaritonic interaction strength, with clear signatures of Feshbach resonances due to two- and three-body excitonic complexes, shedding new light on earlier observations of photon autocorrelations in resonant transmission. We not only establish photon cascade correlation spectroscopy as a highly sensitive tool to study the underlying quantum properties of novel semiconductor materials and many-body quantum phenomena. Our findings also highlight the potential of semiconductor exciton-polariton systems for generating single-photon non-linearities.

FRI 12.2 Fri 11:00 ZHG105

X-ray parametric down-conversion reveals EUV-polariton — •Christina Bömer — Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

Spontaneous parametric down-conversion (PDC) of photons is a gateway into the quantum realm. On the occasion of 100 years of Quantum Physics, we present a study of the effect in the x-ray regime and report the observation of a novel hybrid-state of light and matter that emerges from this fundamental nonlinear process. In our experiment, single x-ray photons are spontaneously converted by a diamond crystal into photon pairs. Of each pair, one photon is tuned to the extreme-ultraviolet (EUV) spectral range, where its coupling to the surrounding diamond is so strong that photonic and electronic properties hybridize: This forms the EUV-polariton. Remarkably, the hybridization occurs without an enhancement cavity, which marks a stark contrast to the prevalent paradigm of strong-coupling in cavities. The EUV-polariton links quantum hybridization in the microscopic domain to meso- and macroscopic length scales via its cavity-free propagation. This offers enticing prospects for studying buried interfaces and nanostructures using the polariton itself as a probe.

FRI 12.3 Fri 11:15 ZHG105

Single polycyclic aromatic molecular emitters embedded in a hexagonal boron nitride stack — •Tianyu Fang, Ricardo Gioia Alvarez, and Daqing Wang — Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, 53115 Bonn, Germany

Single polycyclic aromatic hydrocarbon molecules embedded in solid-state matrices have been proven an excellent platform for narrow-linewidth single-photon emission. We extend this host-guest setting to van der Waals materials to leverage the advantages of flexible hybrid integration. By encapsulating perylene molecules between hexagonal boron nitride stacks, we observe spectrally narrow single-photon emission at cryogenic temperatures. We determine the exact emission origins through vibronic spectra assignment and resolve 0-0 zero-phonon-line linewidths down to the GHz scale.

FRI 12.4 Fri 11:30 ZHG105

Electron-hole quantum dots in bilayer graphene — •Christoph Stampfer[1,2], Katrin Hecker[1], Lars Mester[1], Hubert Dulisch[1], Konstantinos Kontogeorgiou[3], Simone Sotgiu[1], Fabian Hassler[3], and Christian Volk[1,2] — [1]JARA-FIT and 2nd Institute of Physics A, RWTH Aachen University, Aachen, Germany, EU — [2]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, Jülich, Germany, EU — [3]JARA-Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany, EU

Here we show that bilayer graphene allows the realization of electron-hole double quantum dots that exhibit near-perfect particle-hole symmetry, in which transport occurs via the creation and annihilation of single electron-hole pairs with opposite quantum numbers. We demonstrate that particle-hole symmetric spin and valley textures lead to a protected single-particle spin-valley blockade. The latter will allow robust spin-to-charge and valley-to-charge conversion, which are essential for the operation of spin and valley qubits. By time-resolved measurements where we apply a dual pulse between the (0e, 0h) to (1e, 1h) charge configurations we study unconventional higher order tunneling processes which are able to lift the blockade. Extracting the timescales of blockade lifting and investigating the main mechanisms in the strong lead-quantum dot coupled system, allows us to confirm the state degeneracies. Combined with microwave control, the presented spin-valley blockade will enable the study of spin and valley coherence times by electron spin-resonance or electron dipole spin-resonance techniques, and open the door for spin and valley qubit operation.

FRI 12.5 Fri 11:45 ZHG105

Interplay between Hund's rule and Kondo effect in the third shell of a quantum dot — •Olfa Dani[1], Johannes C. Bayer[1,2], Timo Wagner[1], Gertrud Zwicknagl[3], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Institut für Mathematische Physik, Technische Universität Braunschweig, Braunschweig, Germany

We study electron transport in the third shell [1] of a gate-defined quantum dot in a GaAs/AlGaAs two-dimensional electron gas. The device structure allows the precise determination and controlled variation of the number of electrons (N) occupying the quantum dot [2]. We observe zero-bias anomalies (ZBAs) with unexpected large widths for successive filling of the shell of the quantum dot. The ZBAs display a characteristic particle-hole symmetry for the three spin-degenerate orbital states. The broad widths of the ZBAs are attributed not only to the contribution of a Kondo resonance but also to the presence of excited Hund multiplets [3]. The role of Hund's rule exchange is further supported by the triangular trend of the charging energy as function of N in the third shell. The quantum dot is viewed as a multi-orbital Kondo impurity with Hund's interaction and serves as a model system for a Hund's coupled impurity.

[1] L. P. Kouwenhoven, et. al., Rep. Prog. Phys. 64, 701-736 (2001).
[2] T. Wagner, et. al., Nat. Phys.15, 330-334 (2019).
[3] O. Dani, et. al., arXiv: 2505.21675 (2025).

FRI 12.6 Fri 12:00 ZHG105

Hybrid optomechanics with double quantum dots — •Victor Ceban — Institute of Applied Physics, Moldova State University, Chisinau, Moldova

The quantum dynamics of a hybrid optomechanical device made of a double quantum dot (DQD) interacting with phonons and photons had been investigated. The system dynamics is solved for the cases when one bosonic field is multi-mode and the other is single-mode. The contribution of the multi-mode field is treated via the reservoir theory, within the Born and Markov approximations, and a set of corresponding damping terms are introduced into the master equation which describes the system dynamics. The behaviour of different optomechanical devices can be described via the proposed model where the single-mode field describes either photons in an optical cavity or phonons in a nanomechanical resonator, while the contribution of the multi-mode field is given by the electromagnetic vacuum or a thermal phonon bath. Here we present the effect of the environmental (phonon/photon) reservoir on the single-mode (photon/phonon) field due to the interaction with the DQD.

FRI 12.7 Fri 12:15 ZHG105

Atomic-size contacts obtained from lithographically fabricated electrodes using electromigration at room temperature in ambient condition and under vacuum — •Samanwita Biswas[1], Werner Wirges[1], Thomas Hultzsch[1], Marcel Strohmeier[2], Annika Zuschlag[2], Sarah Loebner[1], Dieter Neher[1], Elke Scheer[2], and Regina Hoffmann-Vogel[1] — [1]University of Potsdam — [2]University of Konstanz

Developing tunable yet stable atomic junctions for molecular electronics has always been challenging. The standard electrode material for molecular electronics is Au because of its electronic simplicity and resistance to chemical reaction making it easy to use. Pd, with its d-bands contributing to the charge transport and its relatively low Fermi energy is interesting for establishing good electrical contact to low-dimensional materials. In our study we explore the charge transport of electron beam lithography patterned Pd nanocontacts with a width of about 100nm.Via electromigration (EM) we have further narrowed them down to a cross section of few atoms and eventually reaching also the one atomic contact limit. We have conducted EM in nitrogen atmosphere in a glove box and under vacuum. The experiments under vacuum have been performed using a mechanically controlled break junction setup in combination. Atomic force microscope and scanning electron microscope measurements indicate successful EM. The conductance histograms from both experiments show comparable results.