Q 3: Quantum Computing and Simulation (joint session Q/QI)

Time: Monday 11:00–13:00 Location: E214

Q 3.1 Mon 11:00 E214

An energy estimation benchmark for quantum computers — •Andreas J C Woitzik[1], Edoardo Carnio[1,2], and Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg im Breisgau, Federal Republic of Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg im Breisgau, Federal Republic of Germany

While quantum-mechanical measurements yield intrinsically stochastic outcomes, the fluctuations in the output of current noisy intermediate-scale quantum (NISQ) devices are caused, for the large part, by imperfections in the hardware components and operations. We propose a simple energy estimation benchmark and use it to gauge noise-induced fluctuations in the output of IBM Quantum System One in Ehningen. We find that the errors we measure in our benchmark correlate only weakly with the reported calibration data of the machine. Moreover, a time-resolved analysis of the benchmark measure reveals periodic oscillations and unpredictable outliers that cannot be mildened by measurement error mitigation. We conclude that we cannot rely on single realizations of circuit outcomes, but rather on appropriately sampled ensembles.

Q 3.2 Mon 11:15 E214

Effects of particle losses in two photon quantum walks — •Federico Pegoraro, Philip Held, Sonja Barkhofen, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS) Warburger Str. 100, 33098, Paderborn, Germany

In real photonic quantum systems losses are an unavoidable factor limiting the scalability to many modes and particles, restraining their application in fields as quantum information and communication. A considerable amount of engineering effort has been taken in order to improve the quality of particle sources and system components. At the same time, data analysis and collection methods based on post-selection have been used to mitigate the effect of particle losses. This has allowed for investigating experimentally multi-particle evolutions where the observer lacks knowledge about the system's intermediate propagation states. Nonetheless, the fundamental question how losses affect the behaviour of the surviving subset of a multi-particle system has not been investigated so far. For this reason, with this contribution we study the impact of particle losses in a quantum walk of two photons reconstructing the output probability distributions for one photon conditioned on the loss of the other in a known mode and temporal step of our evolution network. We present the underlying theoretical model that we have devised in order to model controlled particle losses, we describe a platform capable of implementing our theory and in the end we show how localized particle losses change the output distributions without altering their asymptotic spreading properties.

Q 3.3 Mon 11:30 E214

Realization of a photonic ultra-fast free space discrete-time quantum walk. — •Jonas Lammers, Syamsundar De, Nidhin Prasannan, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Recent developments in quantum systems based on time-multiplexed techniques have shown high potential for quantum communication and information processing protocols. The time-multiplexed architecture has already been used in experiments demonstrating exponential increase in GHZ state generation and quantum advantage based on Gaussian boson sampling. Here we demonstrate an ultra-fast free space discrete-time quantum walk. With the newest generation of SNSPDs enabling higher than ever timing resolutions, we were able to overcome the need for long optical delay paths - typically optical fibers - in time-multiplexed systems. The resulting free space architecture enables us to increase measurement repetition rates by multiple orders of magnitude and promises increased stability. Furthermore, we can expect an increase in efficiency which would lead to an exponential increase in observable step numbers. We performed a full polarization resolved quantum walk characterization using coherent light and heralded single photons, observing up to twenty quantum walk steps with high similarity to theory. The demonstrated ultra-fast quantum walk is a promising platform for quantum simulations and opens up a path for large-scale quantum photonic networks utilizing time-multiplexing.

Q 3.4 Mon 11:45 E214

Multiphoton entangled graph states from a single atom — •Philip Thomas, Leonardo Ruscio, Olivier Morin, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching

Optical photons interact very weakly with their environment, making them robust qubit carriers suitable for numerous protocols in quantum information science. Many experiments on photonic entanglement that were carried out over the last decades relied on the well-established toolbox of non-linear optics. However, the underlying process is intrinsically probabilistic and thus poses a practical limit on the size of entangled states one can generate. In order to avoid this obstacle, we use a single Rubidium atom in an optical cavity as an efficient photon source [1]. Single photons are emitted sequentially while the atomic spin qubit mediates entanglement between them. We show that by tailored single-qubit operations on the atomic state we generate Greenberger-Horne-Zeilinger (GHZ) states of up to 14 photons and linear cluster states of up to 12 photons. A combined source-to-detection efficiency of 43% leads to coincidence rates orders of magnitude higher than the previous state-of-the-art [2]. Our work represents a step towards scalable measurement-based quantum computing and communication.

[1] P. Thomas *et al.*, Nature **608**, 677-681 (2022).
[2] H.-S. Zhong *et al.*, Phys. Rev. Lett. **121**, 250505 (2018).

Q 3.5 Mon 12:00 E214

Multi-photon coherence and interference — •Sholeh Razavian[1,2], Klaus Mølmer[3], Jasmin Meinecke[1,2], and Harald Weinfurter[1,2] — [1]Department fur Physik, Ludwig-Maximilians-Universitat, Munich, Germany — [2]Max-Planck-Institute for quantum optics, Garching, Germany — [3]Niels Bohr Institute, Copenhagen, Denmark

The Hong-Ou-Mandel(HOM) effect is a prime example of photon interference in quantum optics and forms the basis for many quantum applications. While HOM interference is a two-photon effect, we are lifting it to the general case, considering multi-photon interference including decoherence effects.

Here we are analyzing polarized photons propagating in integrated waveguide arrays with polarization dependent coupling. With two observables, one for path and one for polarization. The output is a superposition of all the different configurations in a possibly non-classical state.

We analyze multiphoton coincidence measurements and samples from the probability distribution in order to investigate polarization-dependent decoherence of the total quantum state.

Q 3.6 Mon 12:15 E214

Physical computing with a superfluid — Maurus Hans[1], •Elinor Kath[1], Marius Sparn[1], Nikolas Liebster[1], Felix Draxler[2], Helmut Strobel[1], and Markus Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Germany — [2]Interdisziplinäres Zentrum für Wissenschaftliches Rechnen, Universität Heidelberg, Germany

We report on the implementation of a hybrid neural network with a physical system. As a proof-of-concept we implement the regression and interpolation of a non-linear, one-dimensional function. A digital micromirror device is used to prepare an elongated atomic cloud and encode input values by imprinting a phase profile onto the superfluid. Its non-linear response is detected by the observation of the density distribution, from which the output value is generated by a trained linear layer. We compare the performance of this hybrid neural network for different parameters and give an outlook for further directions.

Q 3.7 Mon 12:30 E214

A novel quantum simulation platform for ultracold ytterbium atoms using hybrid optical potentials — •Etienne Staub[1,2], Tim O. Höhn[1,2], Guillaume Brochier[1,3], Clara Z. Bachorz[1,2,4], David Gröters[1,2], Bharath Hebbe Madhusudhana[1,2,5], Nelson Darkwah Oppong[1,2,6], and Monika Aidelsburger[1,2] — [1]Ludwig-Maximilians-Universität München, München, Germany — [2]Munich Center for Quantum Science and Technology, München, Germany — [3]École normale supérieure de Lyon, Lyon, France — [4]Max-Planck-Institut für Quantenoptik, Garching, Germany — [5]Los Alamos National Laboratory, Los Alamos, USA — [6]JILA, University of Colorado at Boulder, Boulder, USA

We report on our recent progress constructing a novel experimental platform for ytterbium atoms. Our approach combines optical lattices and optical tweezers, providing a versatile, robust and scalable environment for both analog and digital quantum simulation. A central ingredient of our implementation are optical potentials at the magic and tune-out wavelengths for the ground and meta-stable clock state of ytterbium. Leveraging high-resolution optical clock spectroscopy, we present preliminary results from our efforts to experimentally determine two new magic wavelengths and the ground-state tune-out wavelength near the narrow cooling transition at 556nm. Furthermore, we demonstrate loading, cooling and imaging of individual atoms in our tweezer array. Possible avenues of research include the simulation of lattice gauge theories and the implementation of quantum computing schemes by means of collisional gates.

Q 3.8 Mon 12:45 E214

Robust localization effects in dipolar systems with positional disorder — •Adrian Braemer and Martin Gärttner — University Heidelberg, Germany

We study a Heisenberg XXZ model with disordered couplings arising from power-law interactions between randomly positioned sites. This type of system is realized naturally in a large range of quantum simulation platforms. We numerically find indications of a localization transition and derive a simple, effective model for the local integrals of motion based on strongly interacting pairs. By systematically taking into account higher order resonances, we find a strong renormalization flow towards a pure Ising model. This might explain the numerically observed robustness of the localization transition, which in this system does not drift towards strong disorder strength as the system size is increased. One may even conjecture that the localized phase could be stable in this type of systems.