TUE 5: QIP Certification and Benchmarking

Time: Tuesday 14:15–16:00 Location: ZHG006

TUE 5.1 Tue 14:15 ZHG006

Photonic Fidelity Witnesses — •Riko Schadow[1], Naomi Spier[2], Stefan N van den Hoven[2], Malaquias C Anguita[2], Redlef B G Braamhaar[2], Sara Marzban[2], Jens Eisert[1], Jelmer J Renema[2], and Nathan Walk[1] — [1]Freie Universität Berlin — [2]University of Twente

Certification and benchmarking represent a key challenge across all platforms for quantum information science and technology. A fundamental task in this regard is the verifiable creation of a particular quantum state. This can be accomplished via a fidelity witness - an empirical procedure that verifies with high probability that the experimentally prepared state has at least a certain fidelity with a desired target state. A promising avenue for experiments and applications is photonics, specifically the manipulation of photon number states through linear optics, which can directly demonstrate a quantum computational advantage via BosonSampling and, combined with adaptivity, universal, fault-tolerant quantum computation. Here, we design several sample-complexity efficient fidelity witnesses tailored to photonic systems and implement them on multi-photon entangled states generated by spontaneous parametric down-conversion sources injected into an integrated waveguide chip. We compare the witnesses in terms of required assumptions, closeness to the true fidelity and overall experimental effort. Using the best witnesses we certify sufficiently fidelities with highly entangled target states to verify the generated entanglement structure. We expect these tools to have further applications for quantum communication, computation and metrology.

TUE 5.2 Tue 14:30 ZHG006

Characterizing multimode linear optical devices via Scattershot Boson Sampling — •Cheeranjiv Pandey[1], Robert Schade[2], Jan-Lucas Eickmann[1], Jonas Lammers[1], Florian Lütkewitte[1], Fabian Schlue[1], Kai Hong Luo[1], Simone Atzeni[1], Mikhail Roiz[1], Christian Plessl[2], Benjamin Brecht[1], Michael Stefszky[1], and Christine Silberhorn[1] — [1]Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS) Warburger Str. 100, 33098, Paderborn, Germany — [2]Paderborn Center for Parallel Computing, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany

Photonics has recently emerged as a promising platform for implementing various quantum computational and communication schemes. At the heart of many such schemes lie multimode linear optical devices, composed of integrated arrays of beam splitters and phase shifters. Previous work has demonstrated that any arbitrary unitary matrix can be decomposed into an array of these components. Consequently, these devices can implement any unitary transformation between their input and output channels by precisely controlling the beam splitter transmissivities and phase shifter values. However, real devices often deviate from their ideal behavior due to fabrication imperfections and thermal cross-talk, making accurate device characterization essential. We showcase our ongoing research focused on developing characterization techniques that will allow us to reconstruct the unitary matrix implemented by such devices using data obtained from Scattershot Boson Sampling (SBS) experiments.

TUE 5.3 Tue 14:45 ZHG006

Probing Continuous Variable Quantum Interference with Photon Counting — •Fabian Schlue[1], Patrick Folge[1], Takefumi Nomura[2], Philip Held[1], Federico Pegoraro[1], Michael Stefszky[1], Benjamin Brecht[1], Stephen M. Barnett[3], and Christine Silberhorn[1] — [1]Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Paderborn University, Paderborn, Germany — [2]Department of Applied Physics, School of Engineering, The University of Tokyo, Tokyo, Japan — [3]School of Physics and Astronomy, University of Glasgow, Glasgow G4 8QQ, UK

The interference of squeezed quantum states on a balanced beam splitter is the most fundamental element in hybdrid photonic quantum computing circuits such as Gaussian boson sampling, where photon counting is deployed at the output of the circuit.

We demonstrate the generation of two independent single-mode squeezed states from the interference of two modes of a two-mode squeezed state from a dispersion-engineered parametric down-conversion source on a balanced beam splitter. We measure the joint photon-number statistics by using photon-number resolved coincidence detection. If the two modes are indistinguishable, the photon statistics become decorrelated, which we prove with different statistical measures. On the other hand, partial distinguishability gives rise to a richer structure that cannot be explained in a standard single-mode picture anymore.

Our investigations shed important insight into the inner workings of hybrid quantum photonic networks with many photons.

TUE 5.4 Tue 15:00 ZHG006

Benchmarking of Large Photonic Systems — •Jan-Lucas Eickmann[1], Jonas Lammers[1], Mikhail Roiz[1], Kai-Hong Luo[1], Simone Atzeni[1], Florian Lütkewitte[1], Fabian Schlue[1], Cheeranjiv Pandey[1], Timon Schapeler[2], Benjamin Brecht[1], Tim J. Bartley[2], Michael Stefszky[1], and Christine Silberhorn[1] — [1]Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Paderborn University, Warburger Str. 100, Paderborn 33098, Germany — [2]Department of Physics & Institute for Photonic Quantum Systems (PhoQS), Paderborn University, Warburger Str. 100, Paderborn 33098, Germany

Photonics is a promising platform for noisy intermediate-scale quantum technologies due to its scalability and room-temperature operation. Taking advantage of deterministic squeezed state generation in parametric down-conversion, Gaussian boson sampling (GBS) has been proven to be a scalable approach towards photonic quantum simulation. The scheme consists of many single-mode squeezed states that are sent into an interferometer, before measuring the photon-number outputs. However, many factors impact the performance, like photon loss, interference quality, and spectral single-modeness of the quantum light source, requiring detailed system characterization. We present methods to characterize large photonic quantum systems, focusing on benchmarking quantum state generation and interference as well as estimating total system efficiency. We apply these methods to characterize the Paderborn Quantum Sampler (PaQS), a 12-mode Gaussian boson sampling device that incorporates many integrated components.

TUE 5.5 Tue 15:15 ZHG006

Certifying Quantum Gates via dimensional advantage — •Anna Schroeder[1,2], Jan Nöller[1], Nikolai Miklin[3], Lucas B. Vieira[1], and Mariami Gachechiladze[1] — [1]Department of Computer Science, Technical University of Darmstadt, Darmstadt, Germany — [2]Merck KGaA, Darmstadt, Germany — [3]Institute for Quantum-Inspired and Quantum Optimization, Hamburg University of Technology, Germany

Certifying individual quantum devices efficiently and with minimal assumptions remains a significant challenge. Traditional device-independent approaches often rely on space-like separation or computational hardness assumptions, which are both difficult to realize in practice. Recently, a robust certification framework,*Quantum System Quizzing (QSQ),*has been introduced under the sole assumption of bounded dimension. This protocol uniquely identifies the underlying quantum model for a universal gate set.*Leveraging concepts from automata theory, we explore the dimension gap between classical and quantum models in deterministic protocols and characterize the classical simulation cost of the observed deterministic*responses. We identify a family of certification schemes that exhibit increasing quantum advantage and analyze their robustness in the presence of noise on quantum hardware.*Our approach shifts the focus from spatial correlations to deterministic tests in temporal scenarios, which are more amenable to implementation on NISQ devices, paving the way for reliable and resource-efficient quantum certification protocols.

TUE 5.6 Tue 15:30 ZHG006

SPAM-free sound certification of quantum gates via quantum system quizzing — •Nikolai Miklin[1], Jan Nöller[2], Martin Kliesch[1], and Mariami Gachechiladze[2] — [1]Hamburg University of Technology — [2]Technical University of Darmstadt

The rapid advancement of quantum hardware necessitates the development of reliable methods to certify its correct functioning. However, existing certification tests often fall short: they either rely on flawless state preparation and measurement, or fail to provide soundness guarantees, meaning that they do not ensure the correct implementation of the target operation by a quantum device. We introduce an approach, which we call quantum system quizzing, for certification of quantum gates in a practical server-user scenario, where a classical user tests the results of exact quantum computations performed by a quantum server. Importantly, this approach is free from state preparation and measurement (SPAM) errors. For a wide range of relevant gates, including a gate set universal for quantum computation, we demonstrate that our approach offers soundness guarantees based solely on the dimension assumption. Additionally, for a highly-relevant single-qubit phase gate - which corresponds experimentally to a pi/2-pulse - we prove that the method's sample complexity scales inverse-linearly relative to the average gate infidelity. By combining the SPAM-error-free and sound notion of certification with practical applicability, our approach paves the way for promising research into efficient and reliable certification methods for quantum computation.

TUE 5.7 Tue 15:45 ZHG006

A digital twin of atomic ensemble quantum memories — •Elizabeth Robertson[1], Benjamin Maass[1], Konrad Tschernig[1], and Janik Wolters[1,2,3,4] — [1]Institute of Space Research, German Aerospace Center, Berlin, Germany — [2]nstitutes of Physics, Technische Universität Berlin, Berlin, Germany — [3]Einstein Center Digital Future (ECDF) Berlin, Germany — [4]AQLS UG Haftungsbeschränkt, Germany

Performance estimation of experimentally demonstrated quantum memories is key for their deployment in quantum communication and quantum computing networks [1]. While existing platforms like Qiskit and Strawberry Fields enable quantum simulations, they do not natively account for the lossy and noisy nature of physical devices. We present a practical framework for modeling ensemble-based atomic quantum memories using the quantum channel formalism. By representing several state-of-the-art experimental memories with Kraus operators, we highlight key performance metrics of each of the memories and enable direct comparison between them. We further demonstrate the utility of this approach by simulating a memory-assisted quantum token protocol for authentication, for different experimentally demonstrated memories [2]. [1] Gündoğan, M. et al. Proposal for space-borne quantum memories for global quantum networking. npj Quantum Inf 7, 128 (2021) [2] Manuscript in preparation.