ABSTRACT

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Photonic platforms offer unique advantages compared to other physical platforms, making them highly interesting for quantum information processing. On this account, I will present the three different lines of research I have been following for exploiting photonic architectures, such as quantum foundation tasks, linear-optical entanglement generation, and quantum computational advantage.

In the first research line, resulting in the papers [5] and [2], we propose and test families of coherence and contextuality witnesses, with experiments carried out with single photon states processed by a programmable integrated device. In addition, we test quantum information advantage for the task of quantum interrogation, theoretically and experimentally verifying that the advantage achievable by quantum theory cannot be explained by non-contextual models. Finally, we show theoretically, numerically, and experimentally that the family of inequalities introduced in [4] is such that their violations witness not only coherence inside the interferometers, but also the dimensionality of the information encoded. In particular, we show that it has violation only for coherent qudits.

In a second research line, we address the issue of generating photonic entangled states using only linear optics. Implementing large-scale linear-optical photonic quantum computing is challenging due to inherent difficulties, such as the probabilistic nature of entangling gates for photonic qubits. The known entanglement generation schemes have low success probabilities, but current state-of-the-art architectures require small entangled states, such as Bell and GHZ states, as the main resource for the computation, making urgent the development of improved protocols for entanglement generation. Following the approach proposed in [1], we propose a scheme to generate qutrit Bell-pairs using only 6 single photons, a linear interferometer, and 6 photodetector. Qutrit Bell states play an important role in quantum computation due to their unique properties and potential applications. This is an on-going work, but we believe that, although the generation probabilities are small, enabling access to active feed-forward operations might boost these probabilities.

The third research line focuses on the task of demonstrating quantum advantage with Boson Sampling architectures. This work is a newly-started collaboration with the authors of a new Boson Sampling validation technique [3]. They show via theoretical arguments and simulations that binned-mode photon number distributions can be used in practical scenarios to efficiently distinguish ideal boson samplers from those affected by realistic imperfections. We are currently working on the technical details of an experimental implementation of this method. In addition, we are trying to fix the algorithm for simulating it, since it does not work in the case of Gaussian Boson Sampling (GBS). This last part is significant, as GBS is the state-of-the-art Boson Sampling technique to prove quantum advantage.

[1] Sara Bartolucci et al. “Creation of entangled photonic states using linear optics”. In: (2021). arXiv: `2106.13825v1 [quant-ph]`.

[2] Taira Giordani et al. “Experimental certification of contextuality, coherence, and dimension in a programmable universal photonic processor”. In: *Science Advances* 9.44 (2023), eadj4249.

[3] Benoit Seron et al. “Efficient validation of Boson Sampling from binned photon-number distributions”. In: (2022). arXiv: `2212.09643v1 [quant-ph]`.

[4] Rafael Wagner, Rui Soares Barbosa, and Ernesto F Galvão. “Inequalities witnessing coherence, nonlocality, and contextuality”. In: (2022). arXiv: `2209.02670v1 [quant-ph]`.

[5] Rafael Wagner, Anita Camillini, and Ernesto F. Galvão. “Coherence and contextuality in a Mach-Zehnder interferometer”. In: (2022). arXiv: `2210.05624v1 [quant-ph]`.