Quantum Energetic Advantage in Boson Sampling

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Understanding the energetic efficiency of quantum computers is essential for their scalability and implementation. While the computational advantage of quantum computers has been widely studied and has motivated their development, the concept of a **quantum energetic advantage**—where a quantum computer completes tasks using less energy than the best classical counterparts—has recently emerged, adding a new layer of motivation for advancing quantum technologies [1].

In this work, we examine the energy cost required by a photonic quantum computer to solve the boson sampling problem. Boson sampling involves generating samples from the output distribution of indistinguishable photons passing through a linear optical network – a problem that quickly becomes intractable for classical computers, and showcases a quantum computational advantage. Using the Metric-Noise-Resource (MNR) framework -- a systematic approach to quantify and optimize resource consumption of quantum devices [1] -- we identify the control parameters, performance metric, noise processes and resource consumption of the problem, and perform a quantitative analysis of the trade-off between the quality and quantity of the photons. Moreover, we compare the energetic cost per sample for classical and quantum implementations, see Fig. 1. Using state of the art classical algorithms [2] and supercomputers [3] as a baseline for classical energy consumption, we show the existence of a quantum energetic advantage of photonic computers for boson sampling, even before the regime of computational advantage (grey area in Fig. 1).

This study underscores the importance of integrating energy efficiency into the design of quantum technologies. Demonstrating the potential for a quantum energetic advantage in boson sampling extends the value of quantum computation beyond mere speed-up, emphasizing energy efficiency as a critical factor in the future of scalable quantum systems. As quantum devices evolve toward practical applications, energy considerations should play a pivotal role in their development and optimization.

References

[1] M. Fellous Asiani et al, PRX Quantum 4, 040319 (2023) page
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[3] TOP500 ''23rd Green500 List'' (2024)

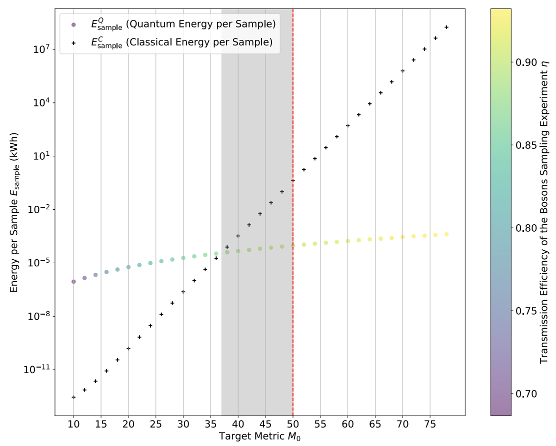

Figure 1: Energy cost per sample for a photonic quantum computer vs a state of the art classical super-computer. The red line marks the threshold for quantum computational advantage: for values of the metric larger than 50 photons, quantum computers are currently believed to outperform classical ones for boson sampling.