- **Energy consumption comparison for different quantum computing platforms**

Authors: Antoine Pignalosa, Ata Krichene, Yuchen Lu

The ongoing miniaturization in classical microelectronics, once guided by Moore's Law, has reached physical and energetic constraints that motivate the exploration of fundamentally new computing paradigms. Among them, quantum computing emerges as a promising solution, not only for achieving computational speed-ups but also for addressing the escalating energy consumption in large-scale simulations and artificial intelligence tasks. This presentation focuses on the energy profile of quantum computers, with an emphasis on superconducting ,photonic and trapped ions platforms, currently among the most mature and scalable architectures.
Superconducting quantum processors operate at ultralow temperatures (~20 mK) using dilution refrigerators, enabling initialization in the quantum ground state and suppression of thermal noise. However, this comes at the cost of significant cryogenic power overhead, particularly due to the need for thermal attenuation along microwave lines and the multi-stage cooling of control electronics. We analyze the energy requirements for performing basic quantum gates such as the X-gate, where the interplay between Rabi frequency, gate duration, and decoherence dictates both power consumption and fidelity.

Then, we'll move on to photonic quantum computers. A photonic quantum computer is a type of quantum computer that uses photons as carriers of quantum information. It performs computations by manipulating the quantum states of photons using optical components such as beam splitters, phase shifters, and detectors. Photonic systems are particularly promising due to their low noise and ability to operate at room temperature.This presentation will focus on the energy consumption involved in operating such a platform. Three main components will be examined. First, the photon source will be analyzed, as it acts as a pump to enable operations on a photonic chip. Then, although it does not directly consume energy, some basic photonic chip operations will be presented to illustrate the power required for computation. Finally, photo-detection will be analyzed along with the cryogenics it requires, which represent the most energy-consuming part of this type of computer.

Finally, trapped-ions platform will be studied. Trapped-ion quantum computers leverage chains of laser-cooled ions confined in radio-frequency Paul traps, using narrow optical or Raman transitions to implement high-fidelity single- and multi-qubit gates via carrier and sideband Rabi drives that couple each ion's internal states to a shared vibrational "bus" mode.[1]
Although the intrinsic energy per qubit flip is only on the order of picojoules[2], the full experimental setup—including RF trap amplifiers, laser heads and modulators, vacuum pumps, control electronics, and environmental stabilization—draws on the order of one to two kilowatts continuously[3]. State preparation (cooling and optical pumping), coherent control (Raman or optical gates plus error-correction overhead), and state readout (fluorescence detection and associated hardware) each contribute several hundred watts, with overall dissipation dominated by trap RF and vacuum infrastructure. When compared with superconducting and photonic platforms, trapped ions exhibit very low pulse-energy requirements but incur higher system-level overhead.

Sources:

Superconducting platforms:

- Optimising Cryogenic Wiring for Superconducting Qubit Processors in a Dilution Refrigerator A. T. Di Lonardo, J. P. Dehollain, N. K. Langford
- Optimizing Resource Efficiencies for Scalable Full-Stack Quantum Computers Marco Fellous-Asiani , Jing Hao Chai, Yvain Thonnart , Hui Khoon Robert S. Whitney , and Alexia Auffèves

Photonic platforms:

- Quantum circuits with many photons on a programmable nanophotonic chip, Xanadu Toronto Canada: https://arxiv.org/pdf/2103.02109

-13dB Squeezed Vacuum States at 1550nm from 12mW external pump power at 775nm Axel Schönbeck, Fabian Thies, Roman Schnabel : https://arxiv.org/abs/2005.09891?

- High-efficiency Thermo-optical Phase Shifter using Wave-vector and Polarization Multiplexing. Zhen Wang, Qihang Shang, Yong Zhang, Yikai Su : https://otip.sjtu.edu.cn/publication/Conference/2021-ACP-ZhenWang-High-efficiency Thermo-optical Phase Shifter using.pdf

Trapped ions platforms:

- [1] Bernardini, Francesco, Abhijit Chakraborty, and Carlos R. Ordóñez. "Quantum computing with trapped ions: a beginner's guide." European Journal of Physics 45, no. 1 (2023): 013001.
- [2] Bruzewicz, Colin D., John Chiaverini, Robert McConnell, and Jeremy M. Sage. "Trapped-ion quantum computing: Progress and challenges." Applied physics reviews 6, no. 2 (2019).
- [3] Fellous-Asiani, Marco, Jing Hao Chai, Yvain Thonnart, Hui Khoon Ng, Robert S. Whitney, and Alexia Auffèves. "Optimizing resource efficiencies for scalable full-stack quantum computers." PRX Quantum 4, no. 4 (2023): 040319