Speaker: Vasco Cavina (Scuola Normale Superiore, Pisa)

Title: *Exact requirements for battery-assisted qubit gates*

Abstract:

Identifying the fundamental energetic constraints of quantum computation is one of the central challenges in modern quantum technologies. In this talk, we show that gate implementation precision is intrinsically limited by the lack of energetic and coherent resources. Adopting a resource-theoretic perspective, we model the implementation of a non-energy-preserving gate (NEPG) $\mathcal{V}$ on a qubit system S via an energy-preserving operation acting jointly on S and a battery B, as outlined in Fig. 1.

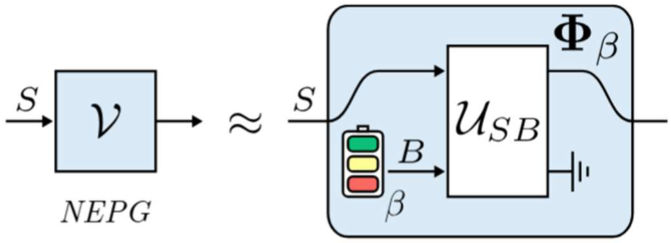

***Figure 1**: Schematic representation of the approximated implementation of a non-energy-preserving gate (NEPG) on the system S through a joint total-energy-preserving unitary transformation U_{SB} with the battery B initialized in the input state β.*

We aim to obtain a resulting map $\mathbf{\Phi}_\beta$ as close as possible to the desired gate $\mathcal{V}$. Quantifying the error in terms of channel distances, we derive a simple expression as a function of the battery state, which we call the *Unitary Defect*. Remarkably, the unitary defect is independent of the specific gate being implemented, highlighting a universal property of the battery itself.

Using this result, we identify optimal battery states that achieve the highest precision under constraints on the average energy, energy variance, number of energy levels, and quantum Fisher information. For instance, we prove that when the system is driven by an oscillatory pulse of frequency ω, the implementation error ϵ_C (interpreted as the inverse of the precision) of a qubit gate with off-diagonal element V_{01} is constrained by the average energy and energy variance of the pulse (below, $\eta \approx 1.374$)

$$\langle E \rangle \geq \eta \frac{\omega |V_{01}|^2}{\sqrt{\epsilon_C}} + o\left(\frac{1}{\sqrt{\epsilon_C}}\right) \qquad \langle E^2 \rangle \geq \frac{9}{4} \frac{\omega^2 |V_{01}|^2}{\epsilon_C} + o\left(\frac{1}{\epsilon_C}\right)$$

By establishing fundamental limits on the precision achievable for any given battery preparation (and hence for any specific driving protocol), our framework can help experimentalists distinguish which part of the observed error originates intrinsically from the pulse design and which arises from extrinsic factors such as noise and hardware limitations.

[1] ArXiv preprint arXiv:2506.11855 – Riccardo Castellano, VC, Martí Perarnau-Llobet, Pavel Sekatski and Vittorio Giovannett