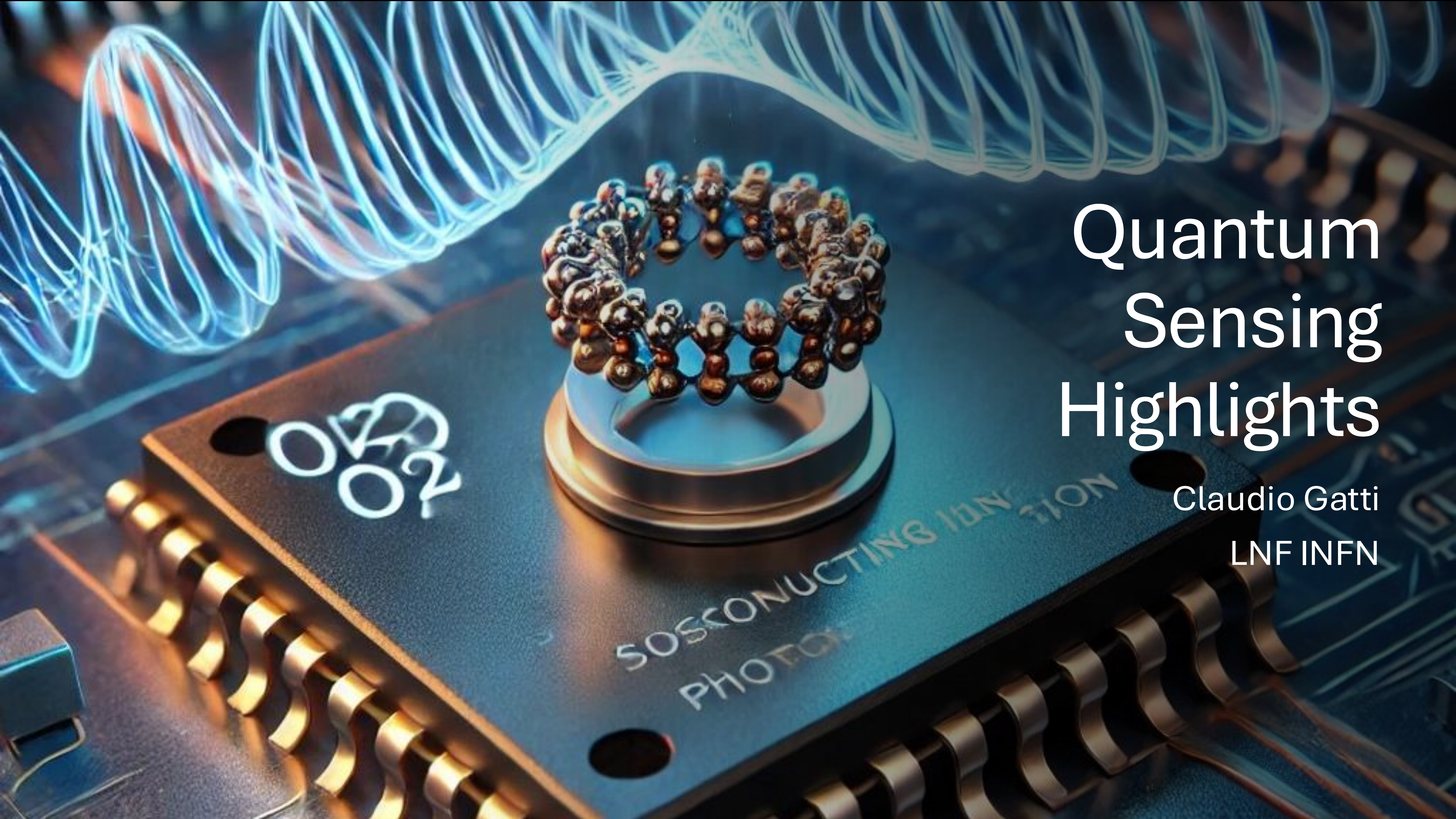
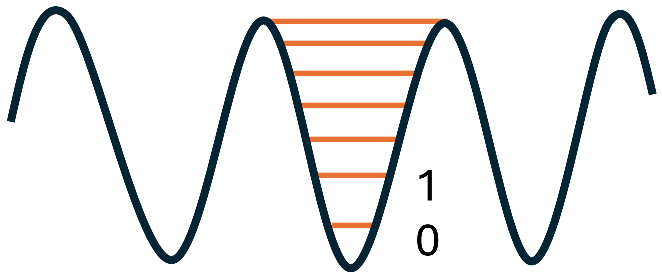


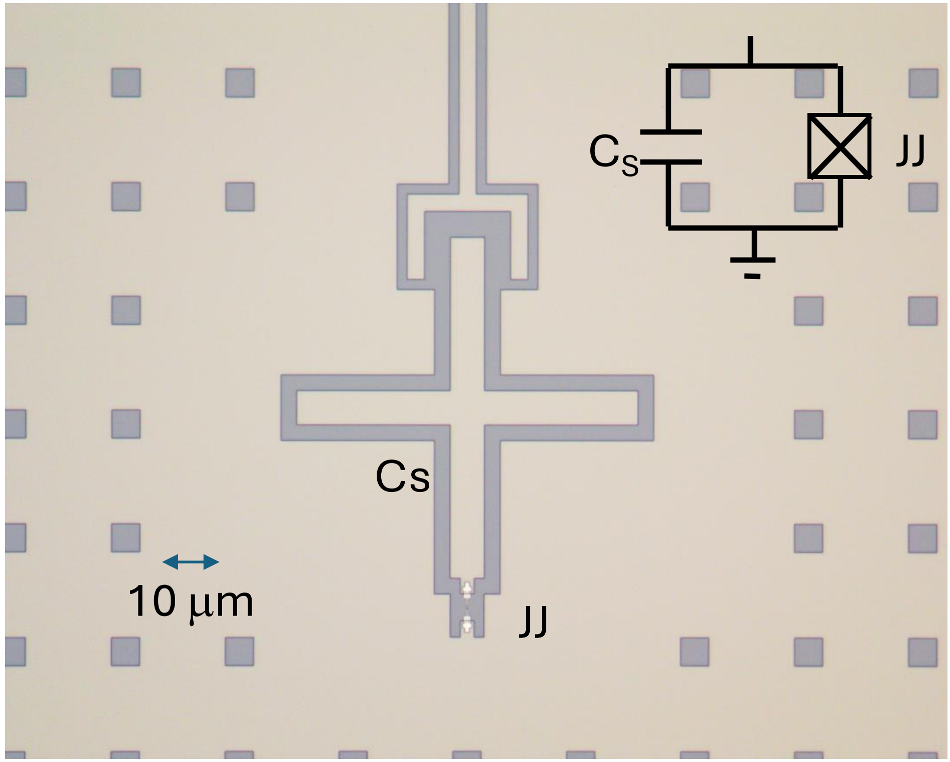
Quantum Sensing Highlights

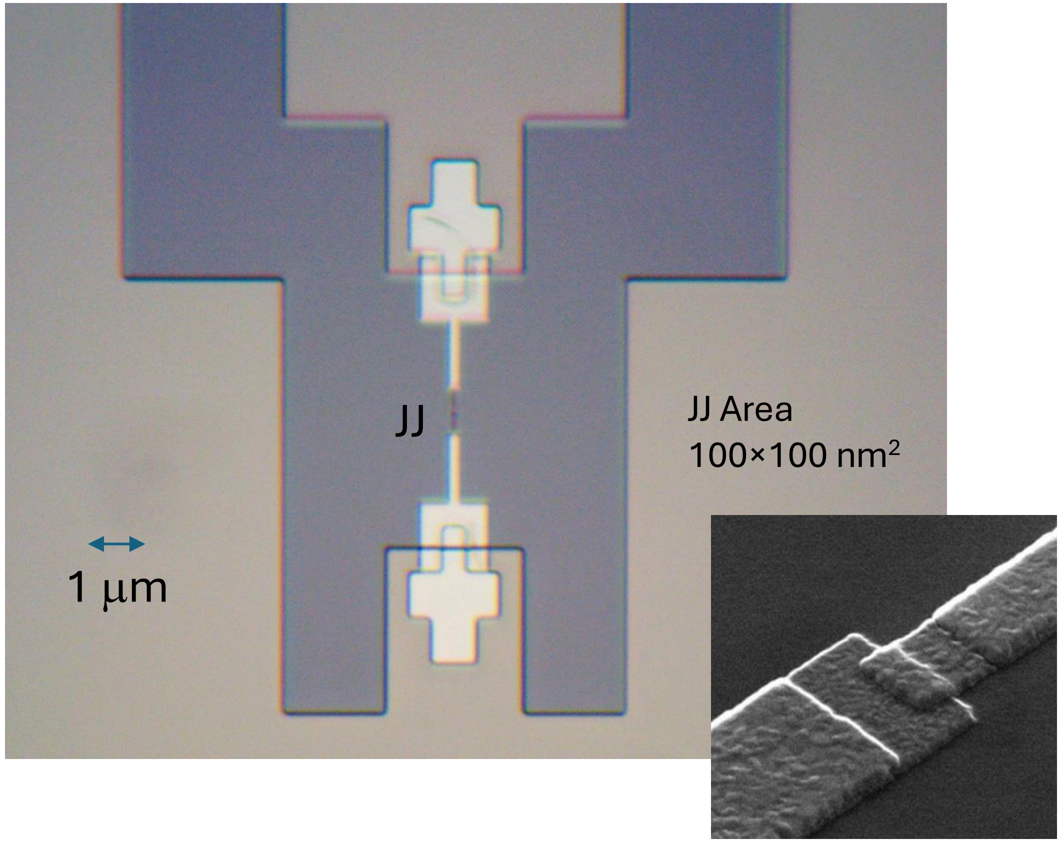
Claudio Gatti

LNF INFN

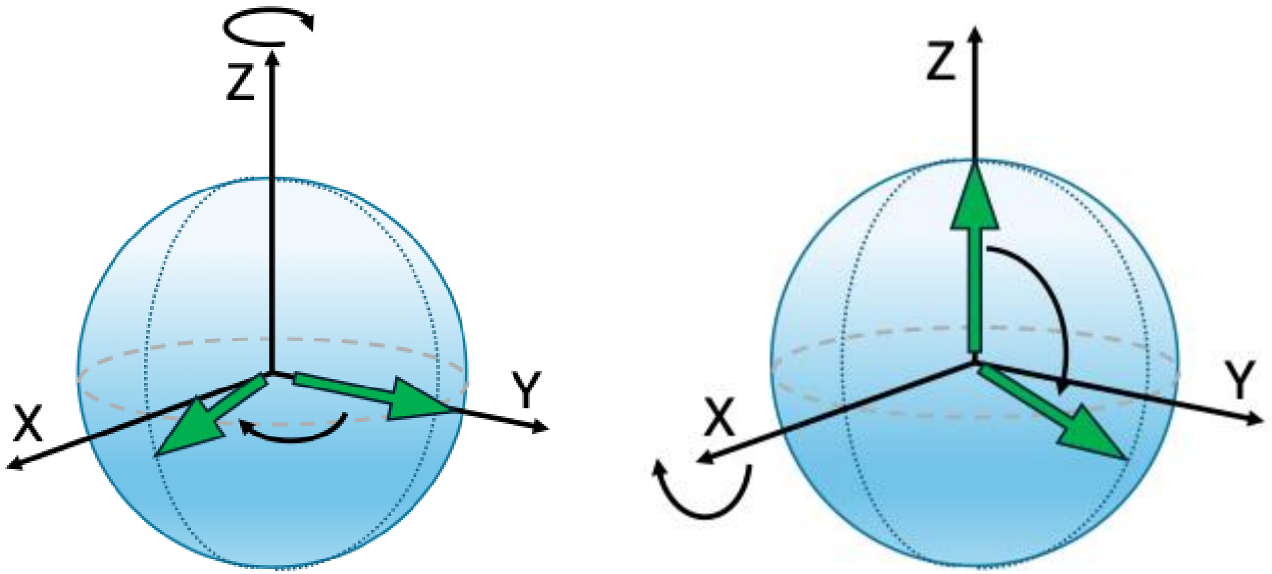
Superconducting Qubits







Single Qubit Sensors

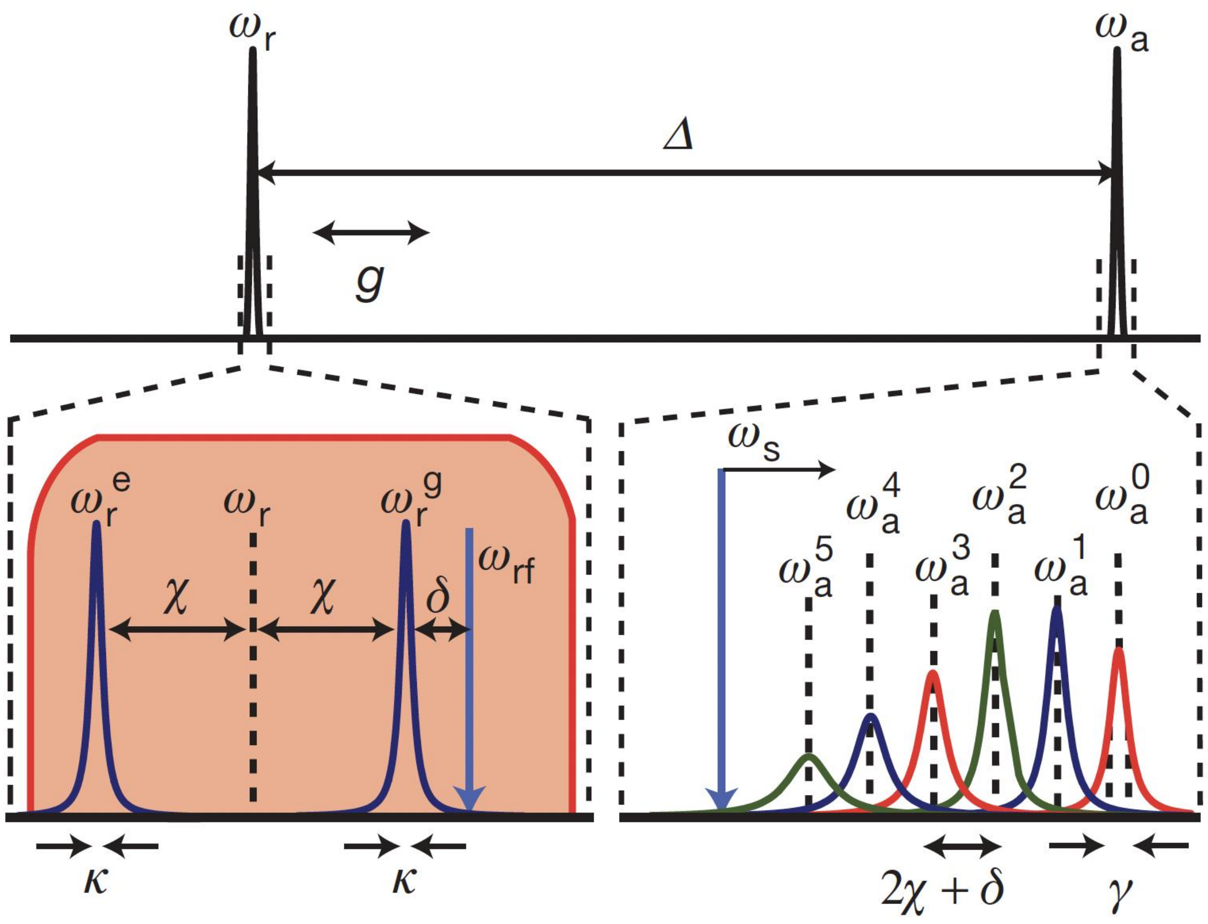


$$\begin{cases} H_{int} = \epsilon\sigma_x \\ H_{int} = \epsilon\sigma_z \end{cases}$$

$H_{int} = \epsilon\sigma_x$ → Excitation

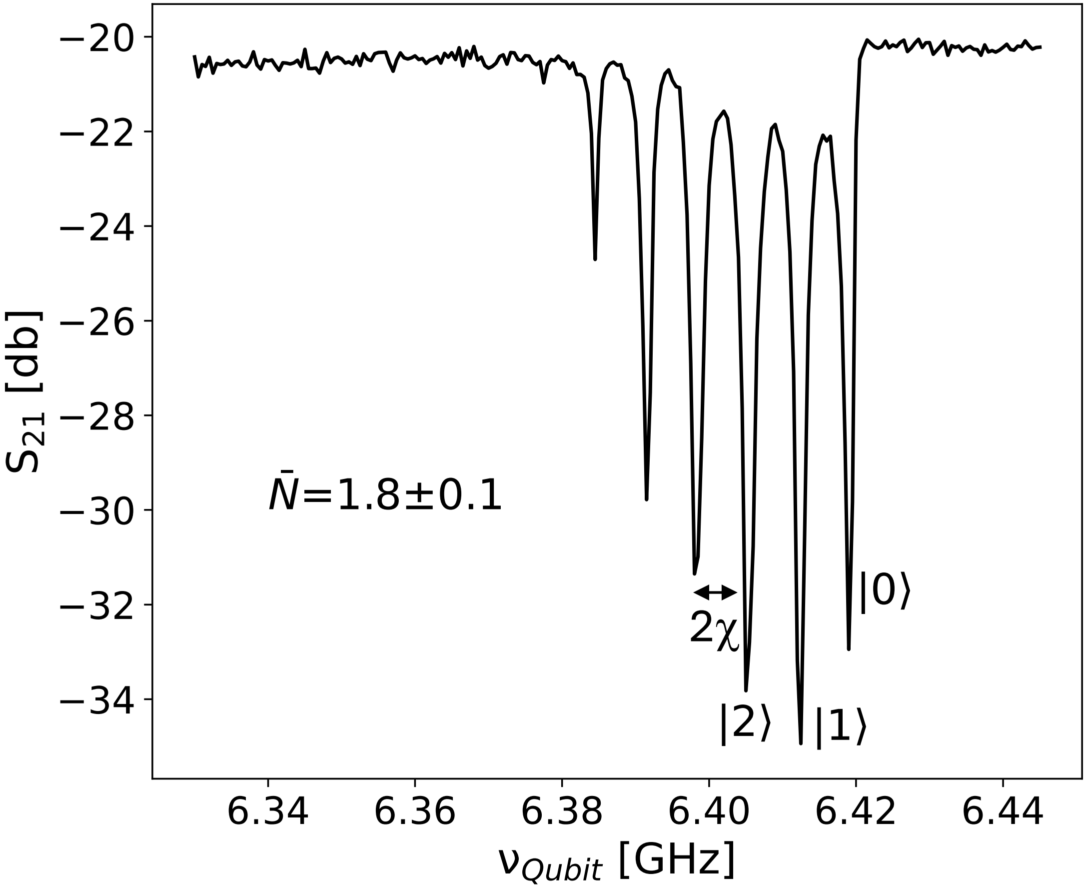
$H_{int} = \epsilon\sigma_z$ → Phase Rotation

Resolving photon number states in a superconducting circuit



doi:10.1038/nature05461

Resolving photon number states in a superconducting circuit

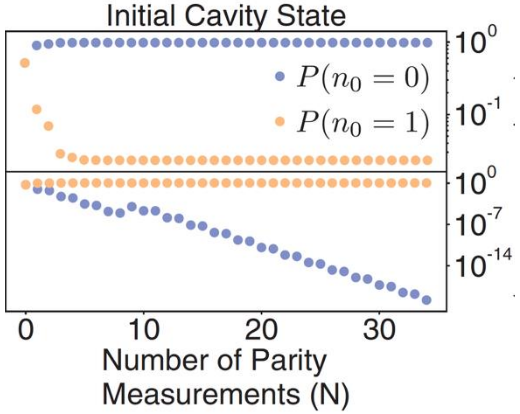


$$\omega'_q = \omega_q + 2n_\gamma \chi$$

Photon number in resonator

Appl. Sci. 2024, 14(4), 1478

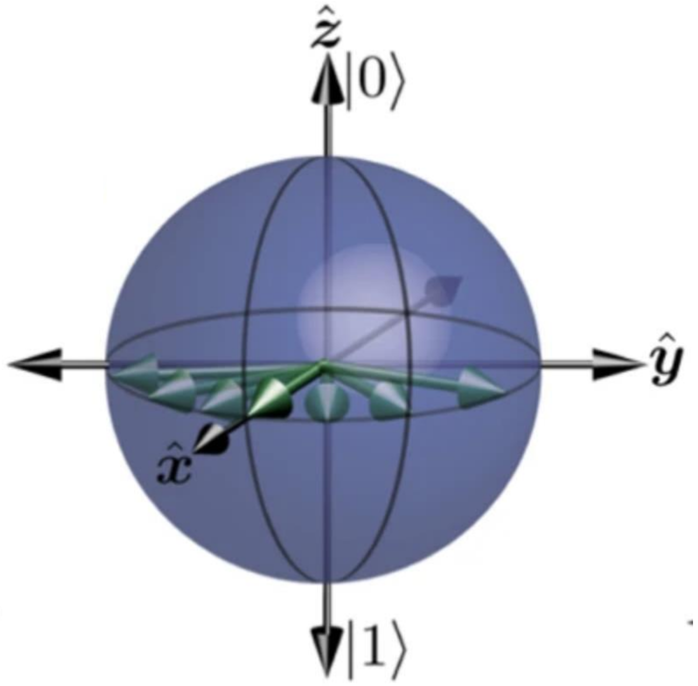
Searching for Dark Matter with a Superconducting Qubit

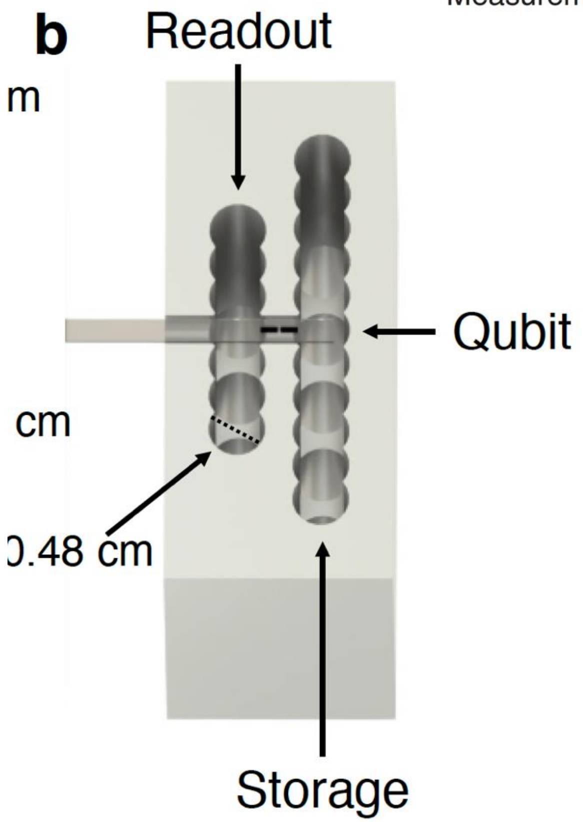


Photon detection by repeated phase-rotation (parity) measurements with Ramsey protocol

$$\Delta\omega_q = 2n_\gamma\chi$$

$$\bar{S}_x = cos\Delta\omega_q t$$
$$\bar{S}_y = sin\Delta\omega_q t$$

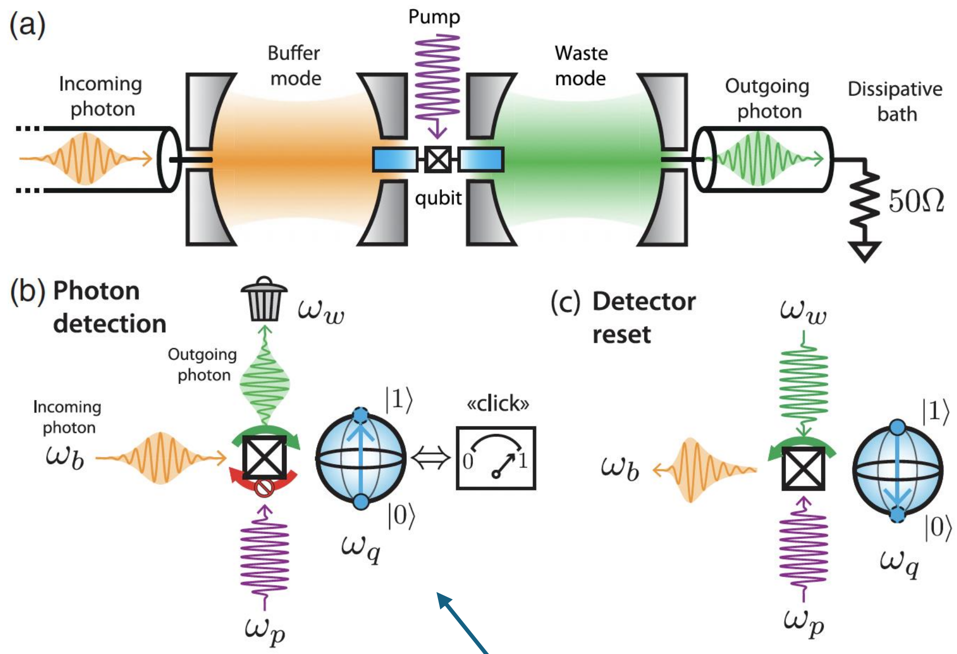




PHYSICAL REVIEW LETTERS 126, 141302 (2021)

Irreversible Qubit-Photon Coupling for the Detection of Itinerant Microwave Photons – Search for Axions

Itinerant photon



$$\omega_p = \bar{\omega}_q + \omega_w^e - \omega_b^g$$

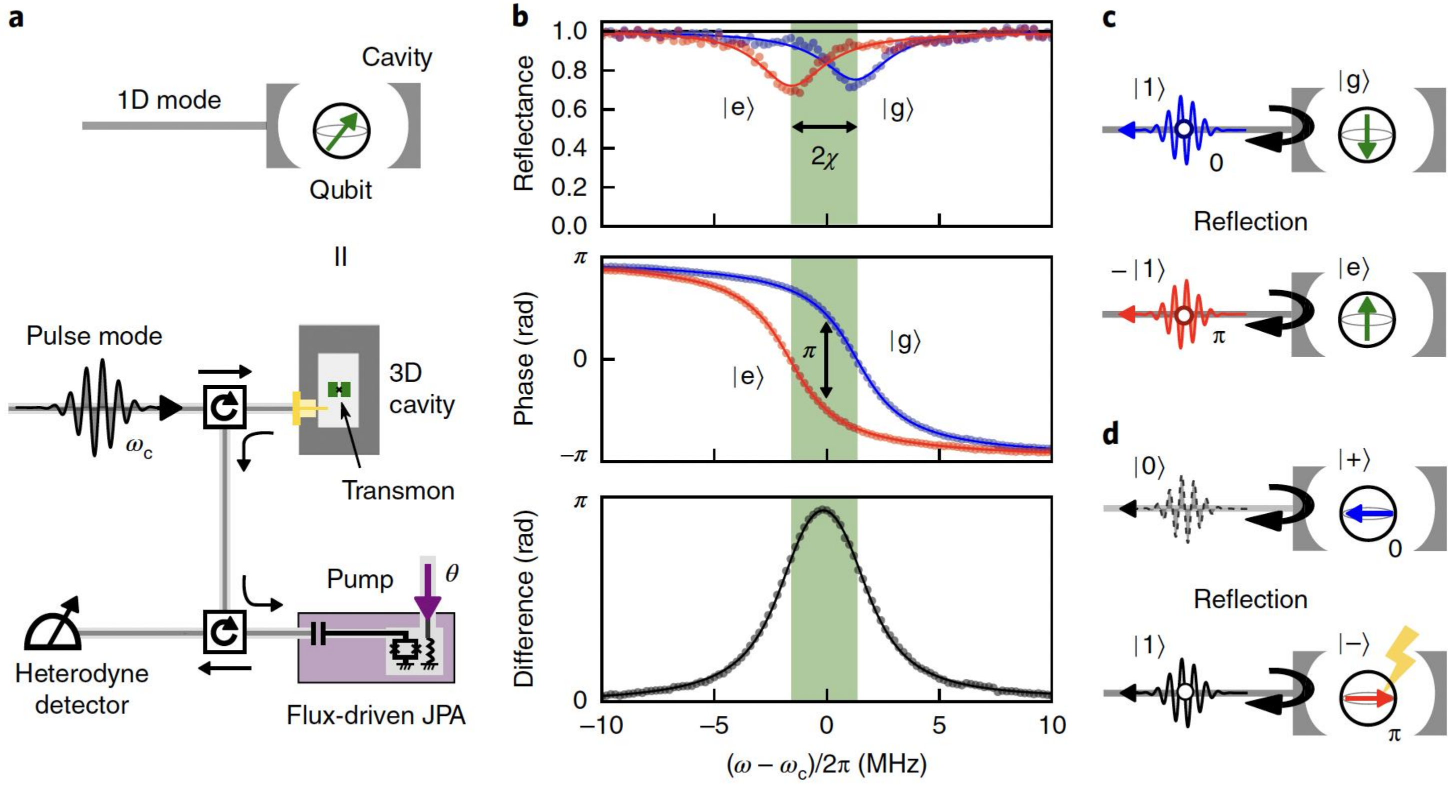
Irreversible process, no photon reflection

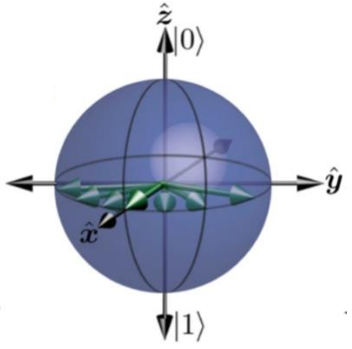
PHYSICAL REVIEW X 10, 021038 (2020)

Axion serach in arXiv:2403.02321

Quantum non-demolition detection of an itinerant microwave photon

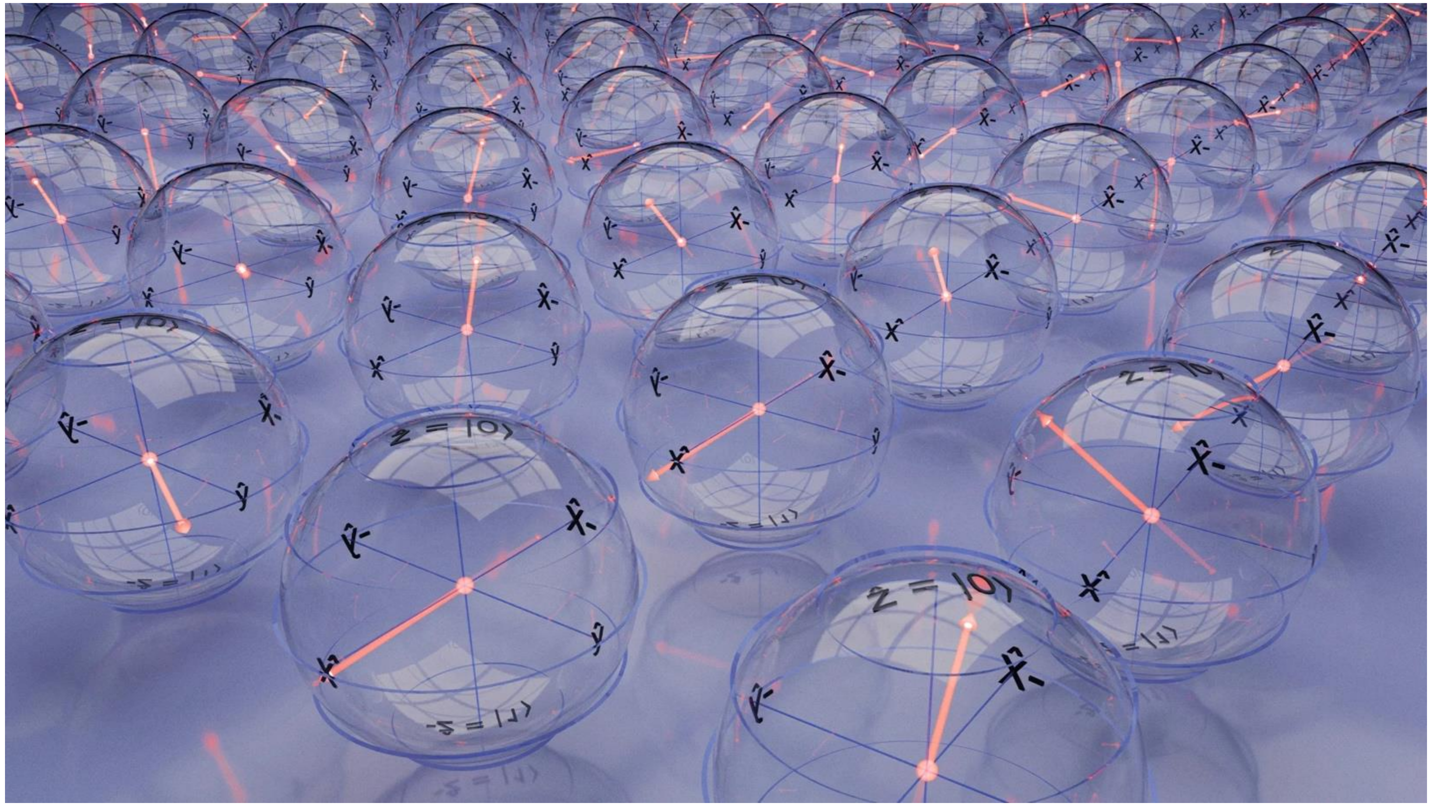
Itinerant photon



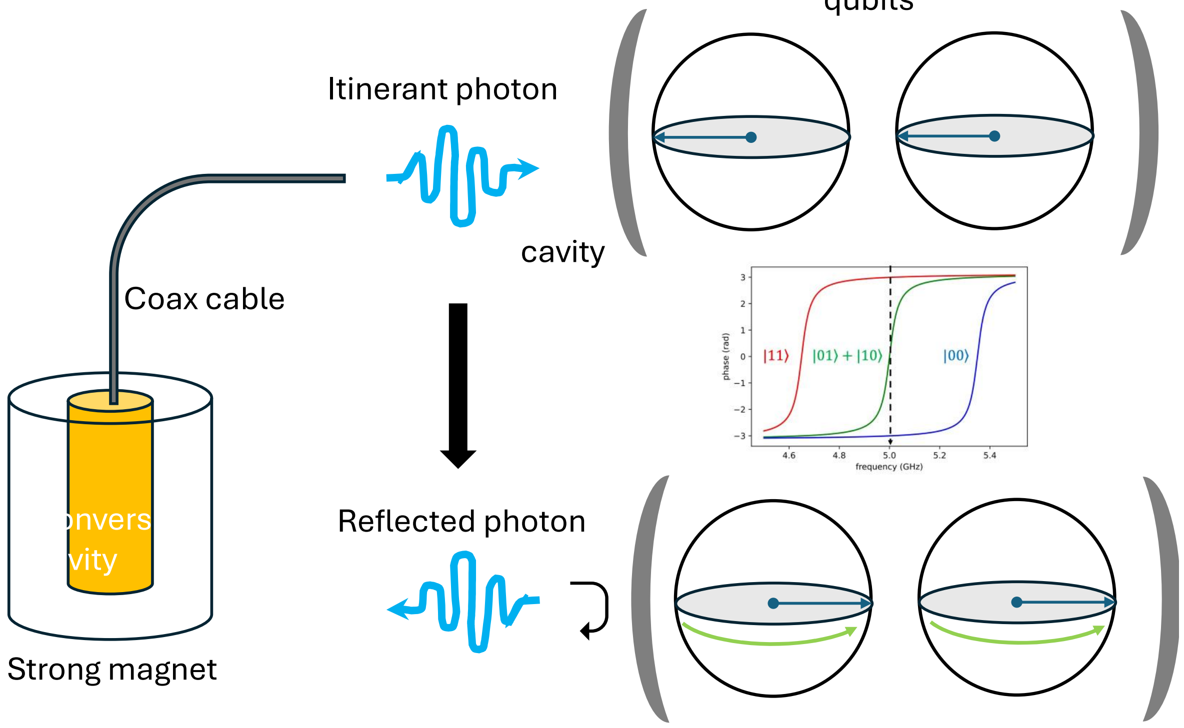


https://doi.org/10.1038/s41567-018-0066-3

Multi Qubit Sensors

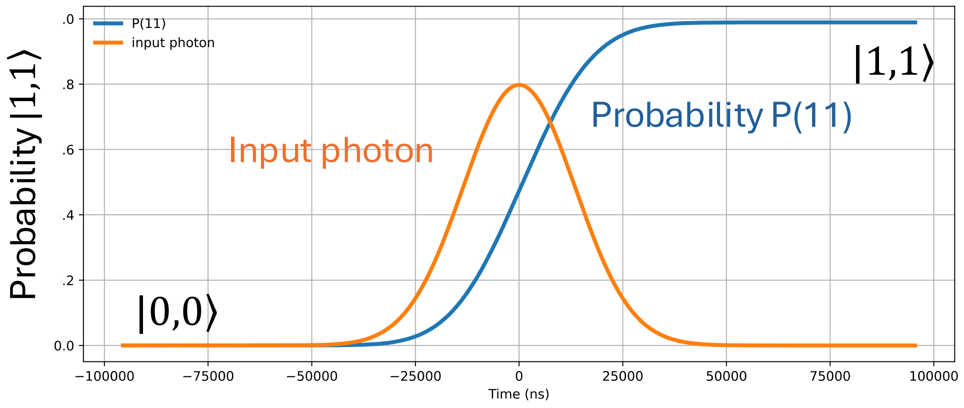


Error Correction with Two Qubits



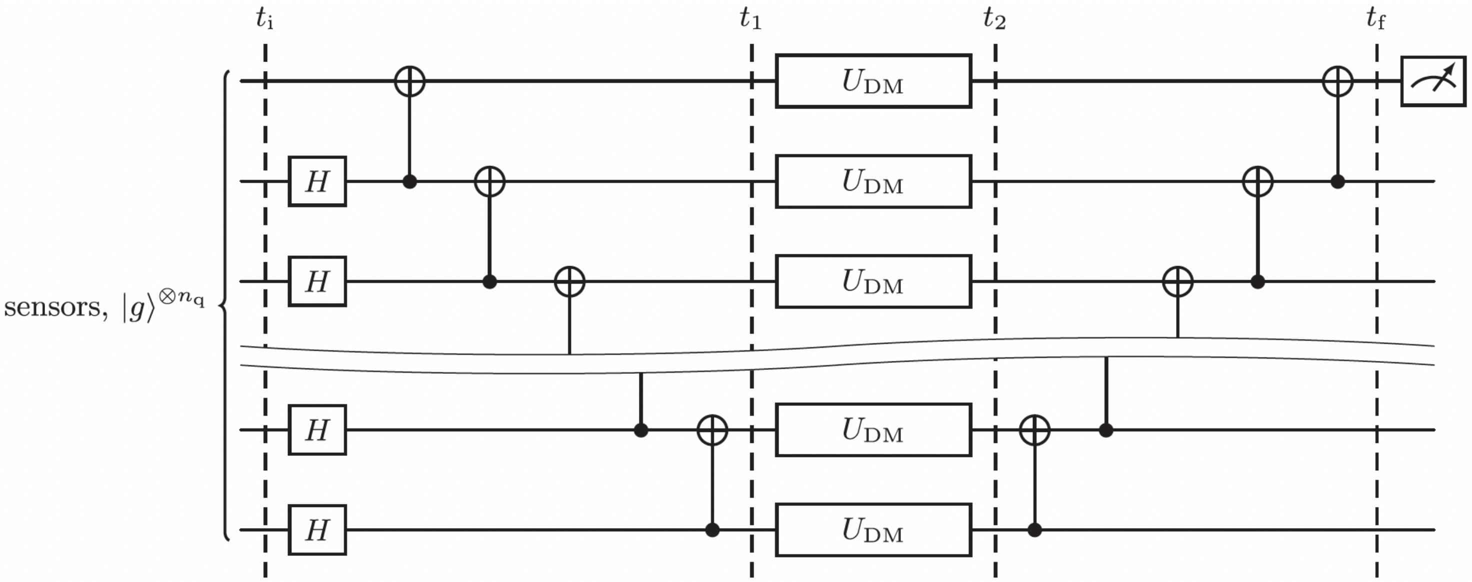
Reduced dark counts:

$$Error\ rate \propto p(1|0)^2$$



Appl. Sci. 2024, 14(4), 1478
https://doi.org/10.1016/j.nima.2024.170010

Quantum Enhancement in Dark Matter Detection with Quantum Computation



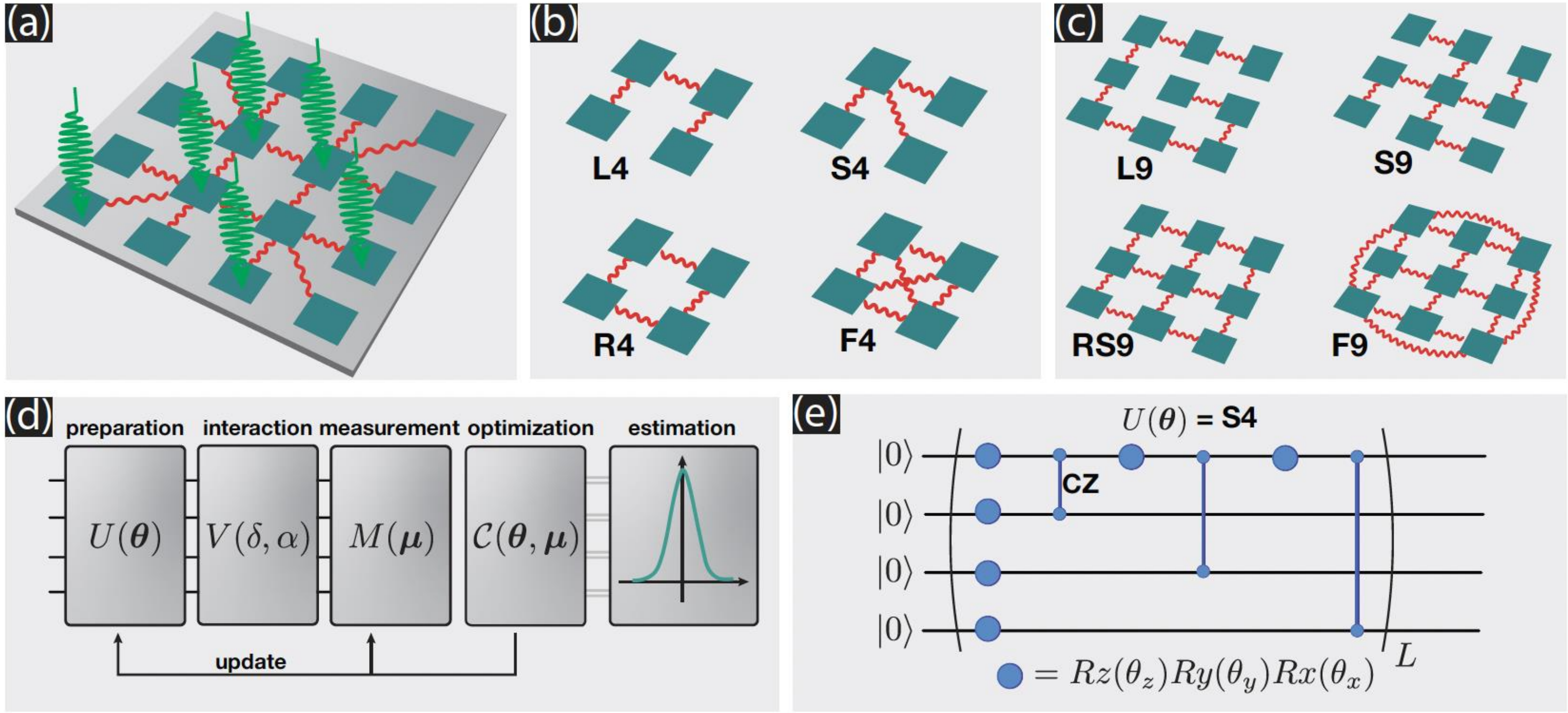
Use n_q entangled qubit state to enhance dark matter sensing by $n_q^{\,2}$

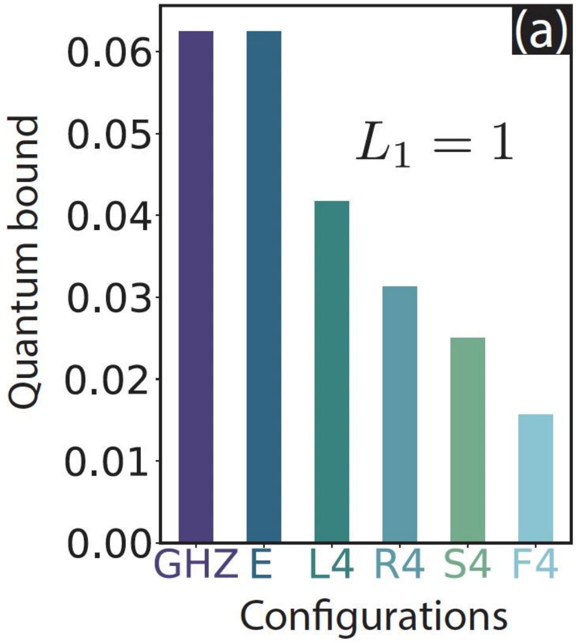
$$P_{g\to e}^{(\alpha=0)} = \sin^2(n_\mathrm{q}\delta) \simeq n_\mathrm{q}^2\delta^2$$

PHYSICAL REVIEW LETTERS 131, 211001 (2023)

PHYSICAL REVIEW LETTERS 133, 021801 (2024)

Optimized quantum sensor networks for ultralight dark matter detection

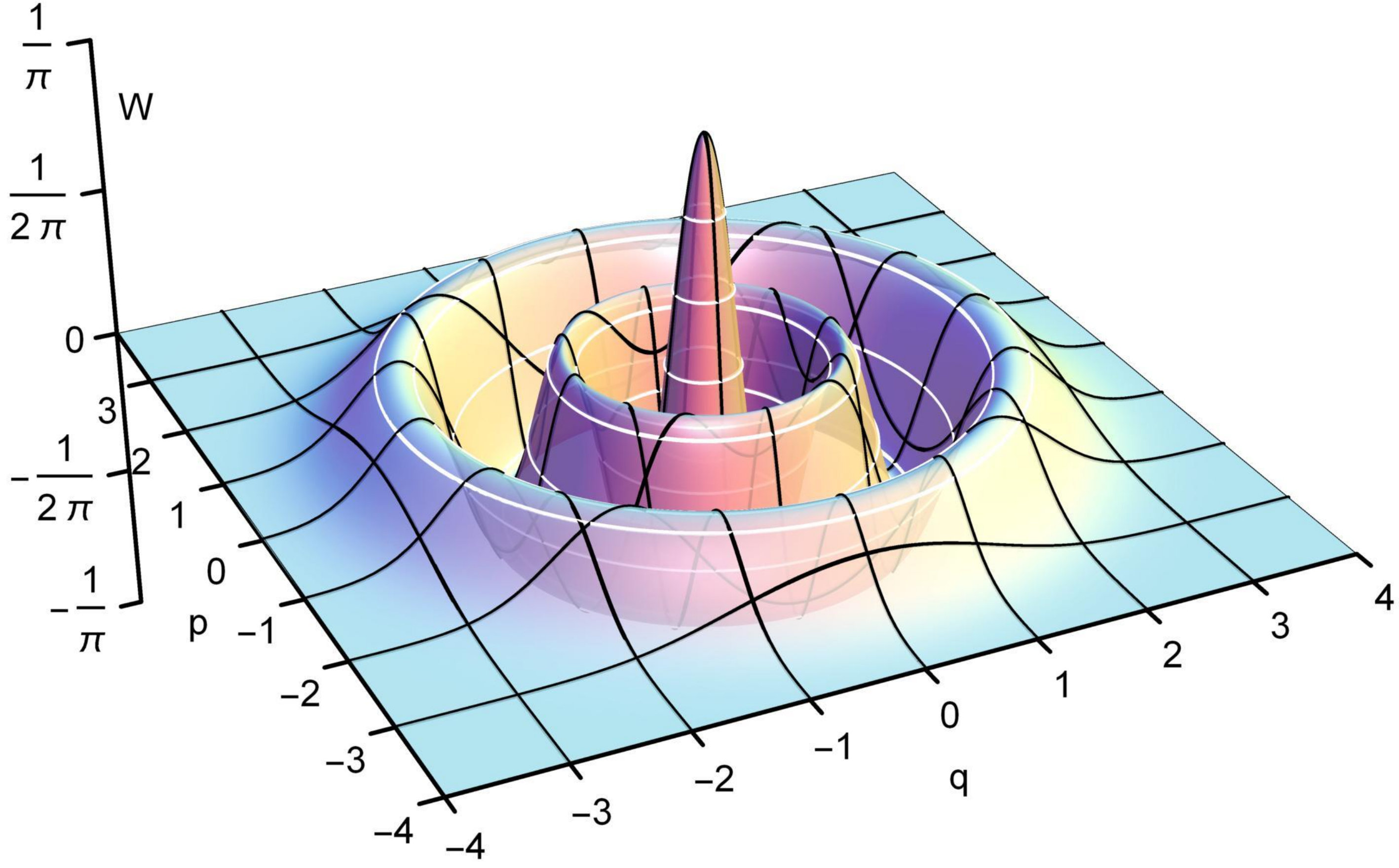




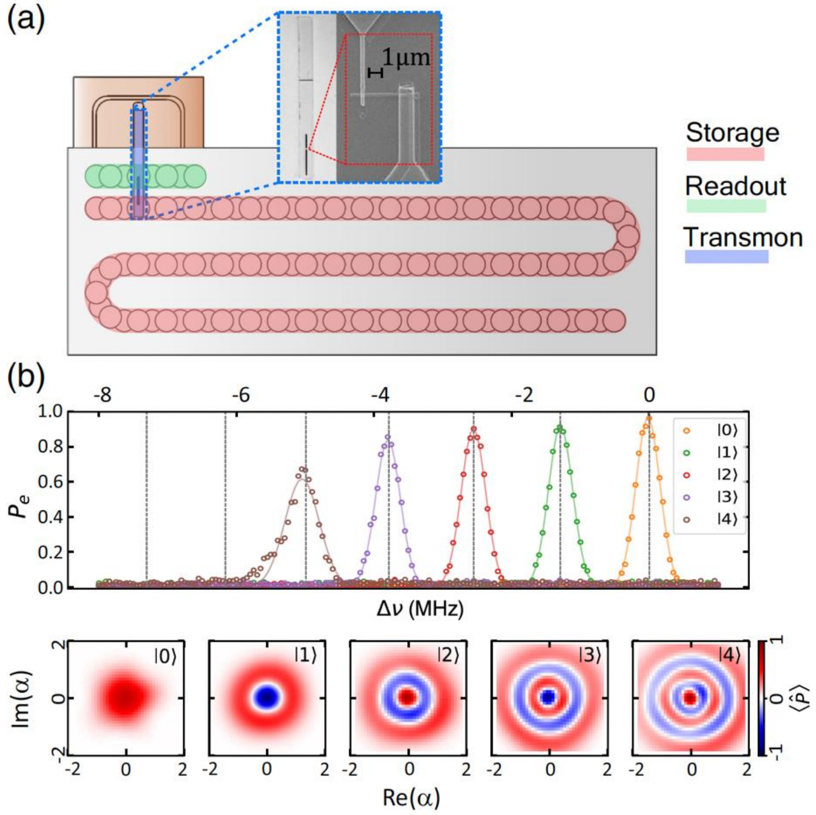
Multi-qubit systems, optimizing both state preparation and measurement using a variational quantum metrology framework

arXiv:2505.2118

Non Classical States



Stimulated Emission of Signal Photons from Dark Matter Waves



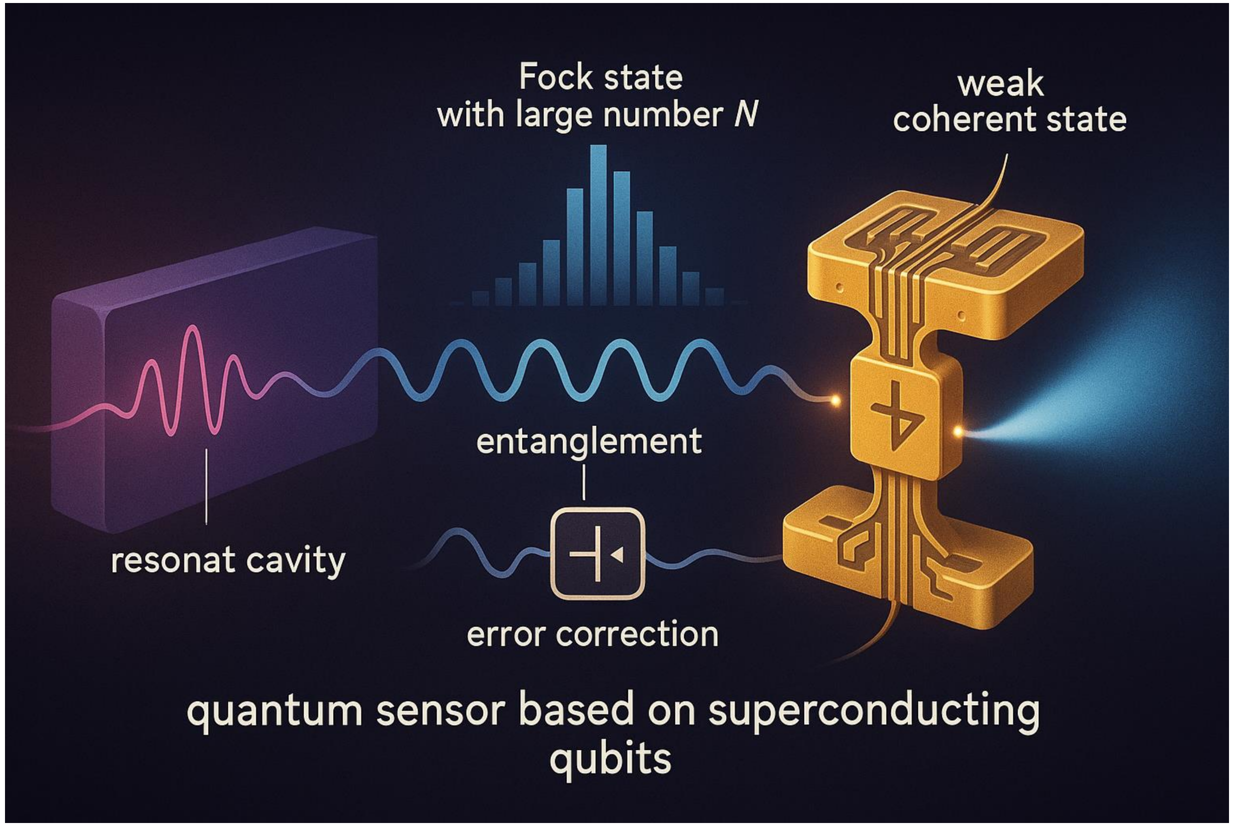
Enhancement of the signal by (n+1)

$$|\langle n+1|\hat{\mathcal{D}}(\alpha)|n\rangle|^2 = |\langle n+1|e^{(\alpha a^\dagger - \alpha^* a)}|n\rangle|^2$$
$$\sim |\langle n+1|\alpha a^\dagger|n\rangle|^2 = (n+1)\alpha^2$$

PHYSICAL REVIEW LETTERS 132, 140801 (2024)

Towards an optimal detector for HFGW

- An advanced quantum sensor leveraging superconducting qubits that utilizes entanglement, quantum error correction, and high-photon-number Fock states (large N) to significantly boost the sensitivity for detecting weak coherent states.



Maybe in 10 years:

Signal $\propto (n_{Fock} + 1) \times n^2_{qubits} \times N^{(2)}_{Detectors} \rightarrow (10 + 1) \times 100 \times 100 = 10^5$