Superconducting Qubit Advantage for Dark Matter (SQuAD)

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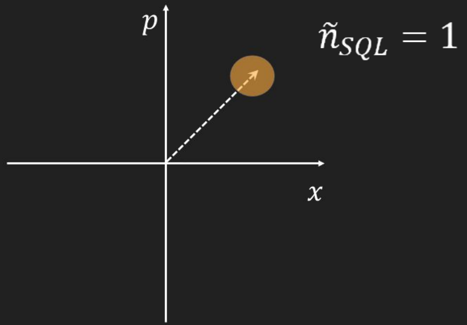
Motivation

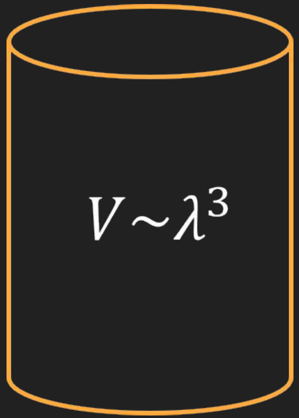
Dark matter searches in the GHz region encounter two main challenges

Quantum noise associated with state of the art linear amplifiers



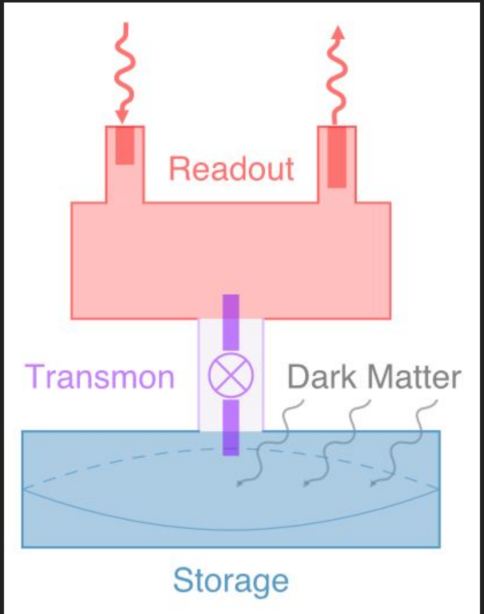
Parametric amplifiers

Signal scales with volume of cavity, volume shrinks with increase in frequency



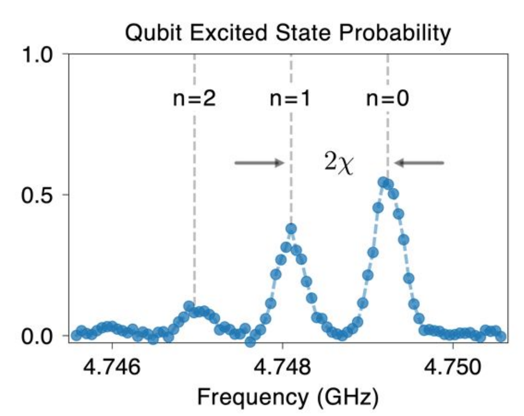
Single Photon Counter

- Superconducting qubit coupled to a high-Q storage cavity
- Photon occupation number imprinted on the qubit frequency



Jaynes-Cummings Hamiltonian

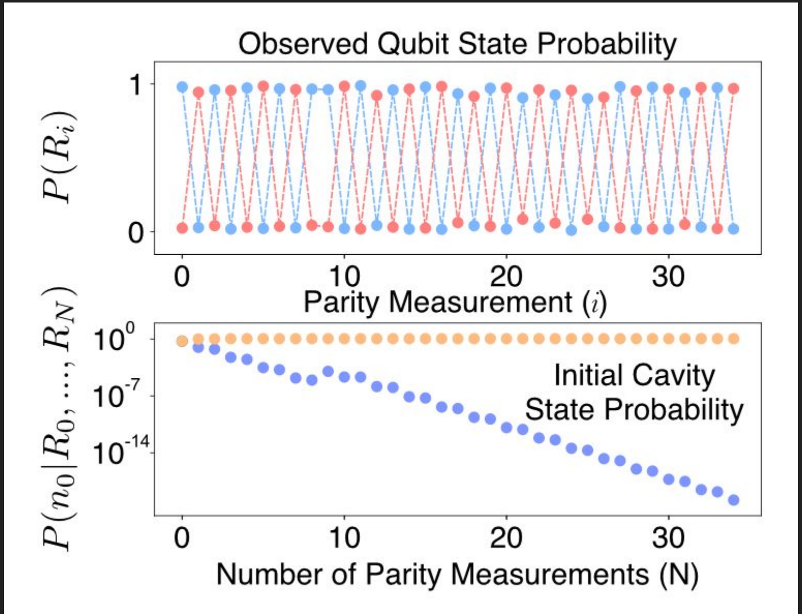
$$\hat{\mathcal{H}} = \omega_c a^\dagger a + (\omega_q + 2\chi a^\dagger a)\frac{\sigma_z}{2}$$

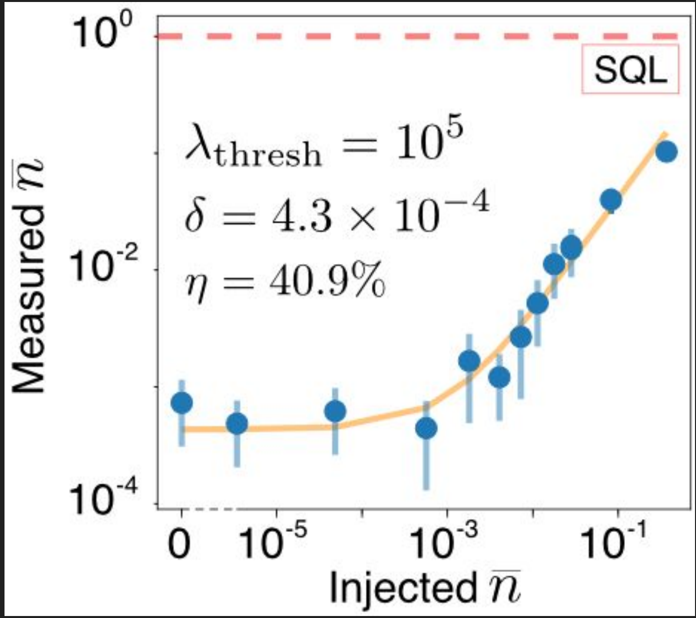


Photon Counting

- Repeated quantum non-demolition measurements suppress detector errors
- Demonstrated noise 15.7 dB below quantum limit
- 1300 x speed up in dark matter search

Dixit et al., Phys. Rev. Lett. 126, 141302

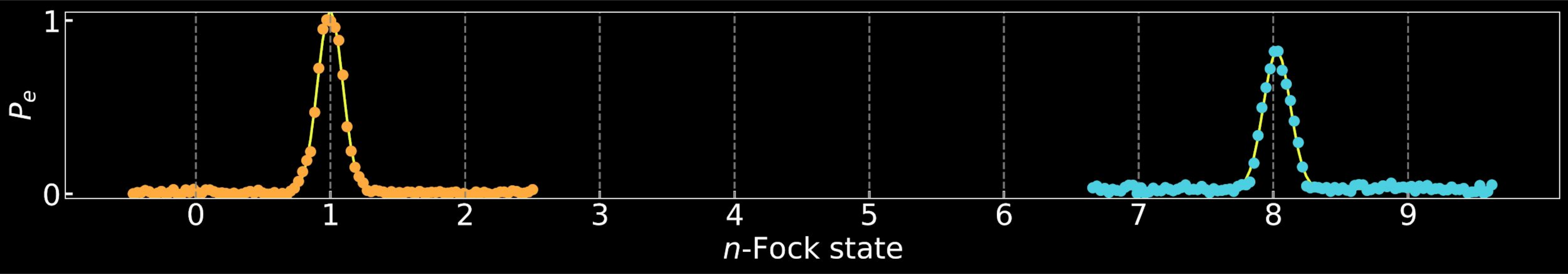




Stimulated Emission

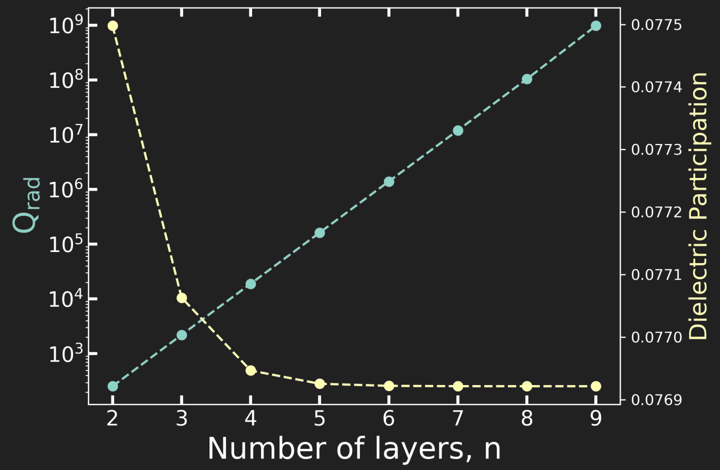
$$\left|\langle n+1|\hat{D}(\alpha)|n\rangle\right|^2 \propto (n+1)$$

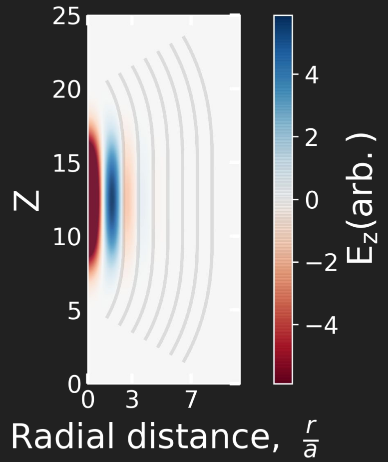
- Initializing the cavity in a Fock state enhances the signal by ***(n+1)*** factor
- Quantum optimal control pulses used to generate Fock states in the cavity

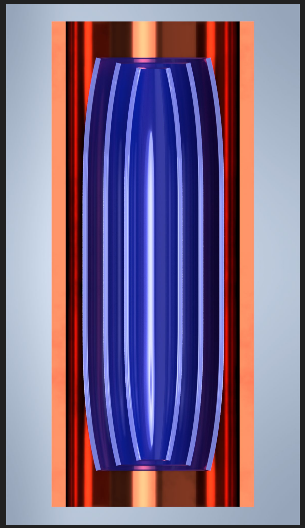


High-Q Photonic Bandgap Cavity

Periodic arrangement of dielectric shells







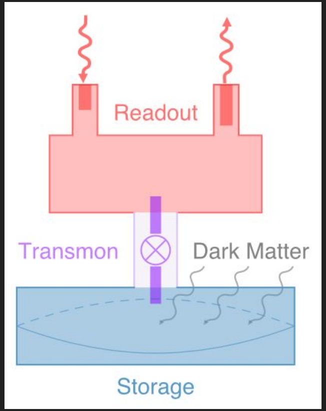
Adding more layers reduces loss along the radial direction

Tapered structure reduces Ohmic losses along the axial direction

Copper helps with thermalization and radiation loss

Conclusion

- Noise suppressed by 15.7 dB with qubit based photon counting



- Signal improvement with high-Q PBG cavity

- Further signal enhancement with stimulated emission