Quantum-Enhanced Axion Searches Using Josephson Junction-Based Circuits

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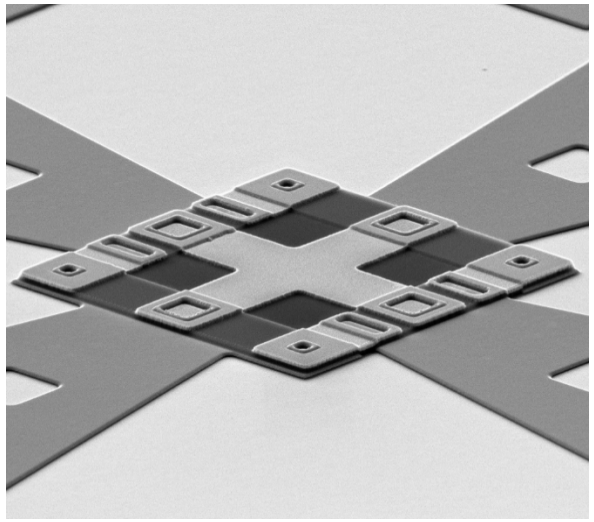

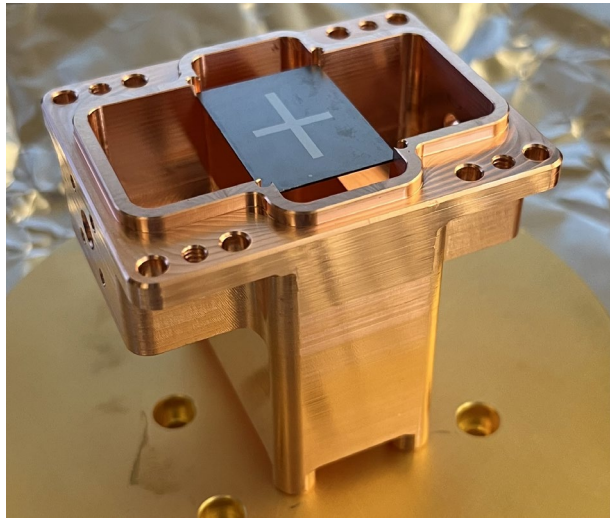

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CU Boulder and NIST

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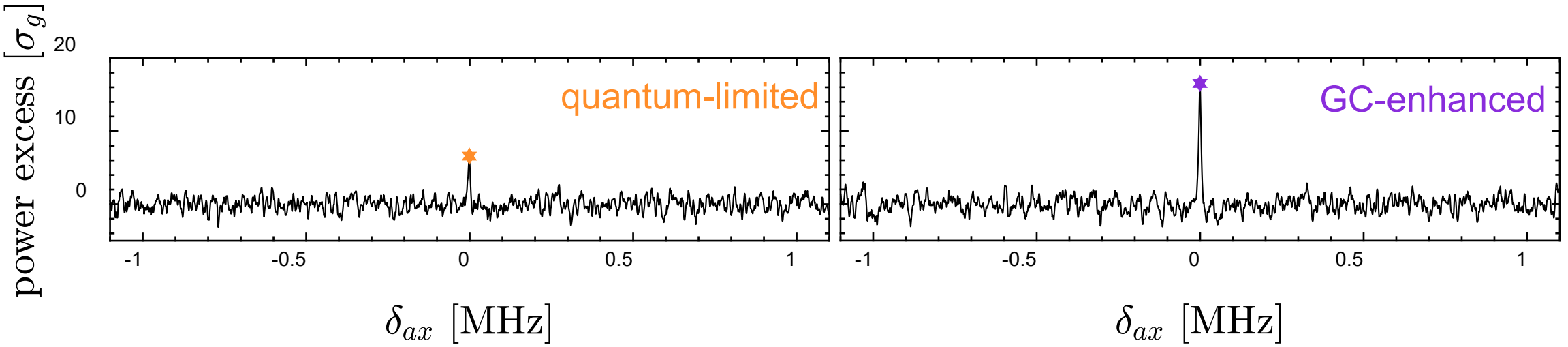
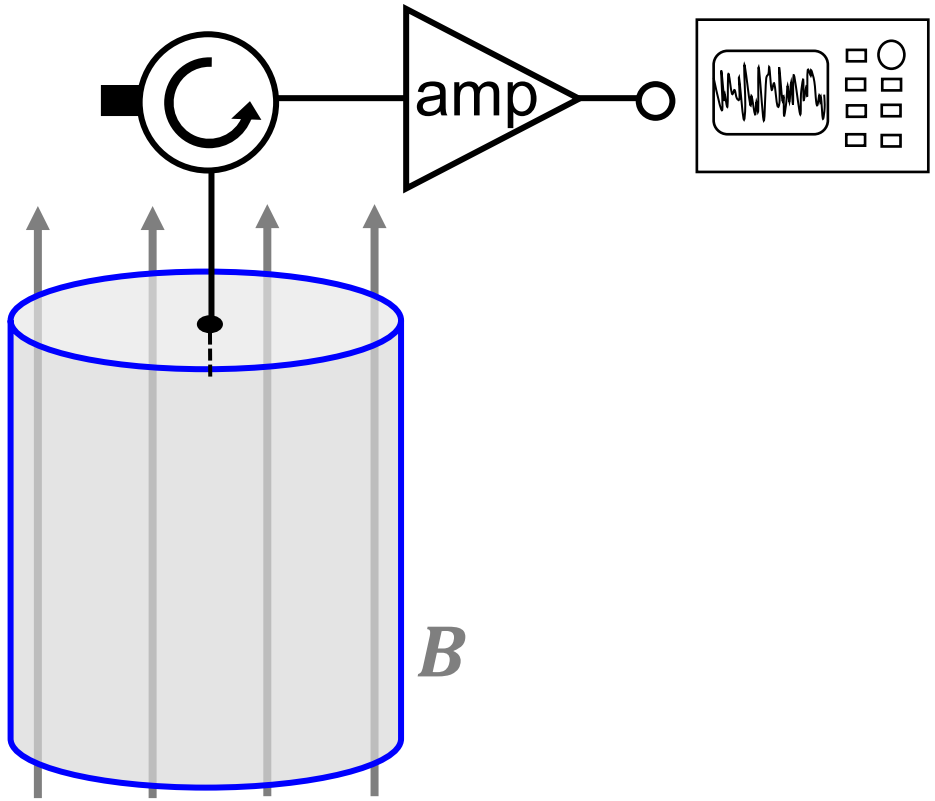
Accelerate axion search with entanglement (G) and swapping (C)

Jiang, Ruddy, *et al.,* PRX Quantum 4 (2), 020302 (2023)

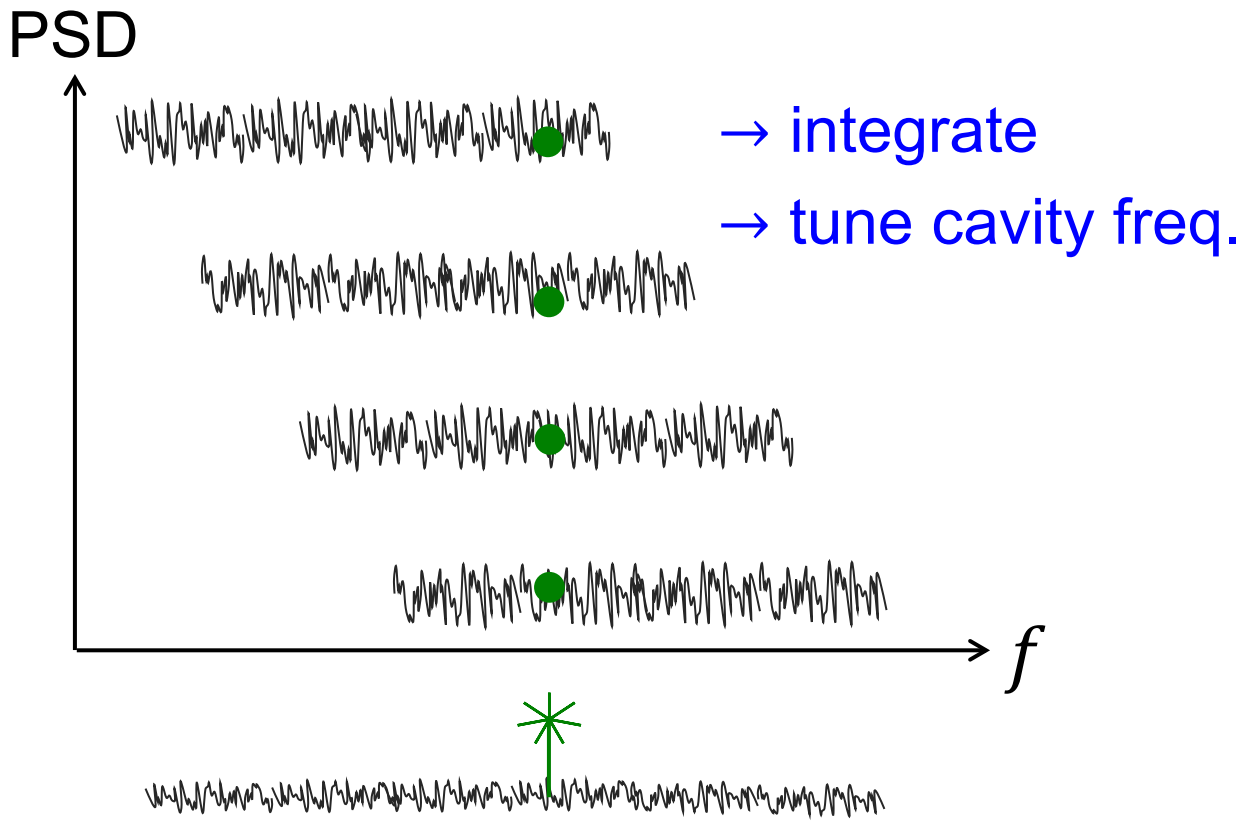


Haloscope: search for axion induced power excess

axion: weak signal, unknown freq.

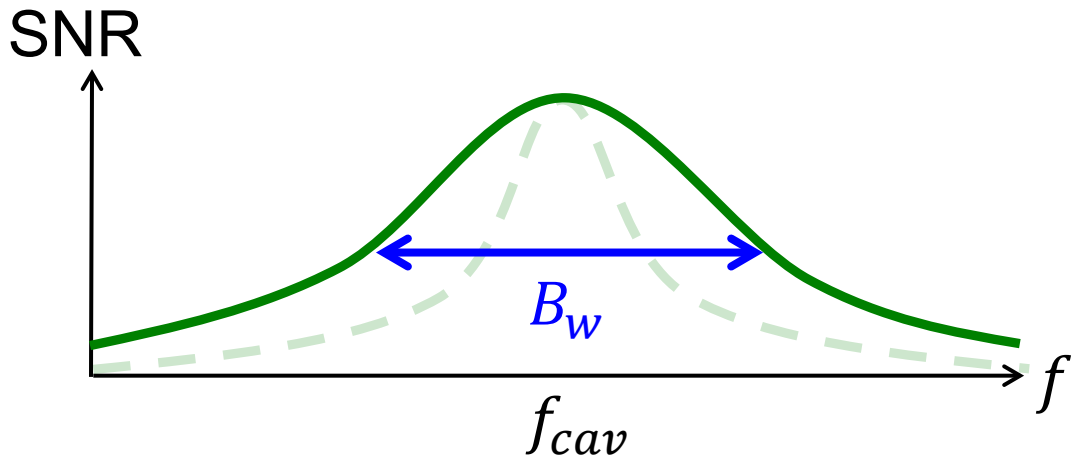


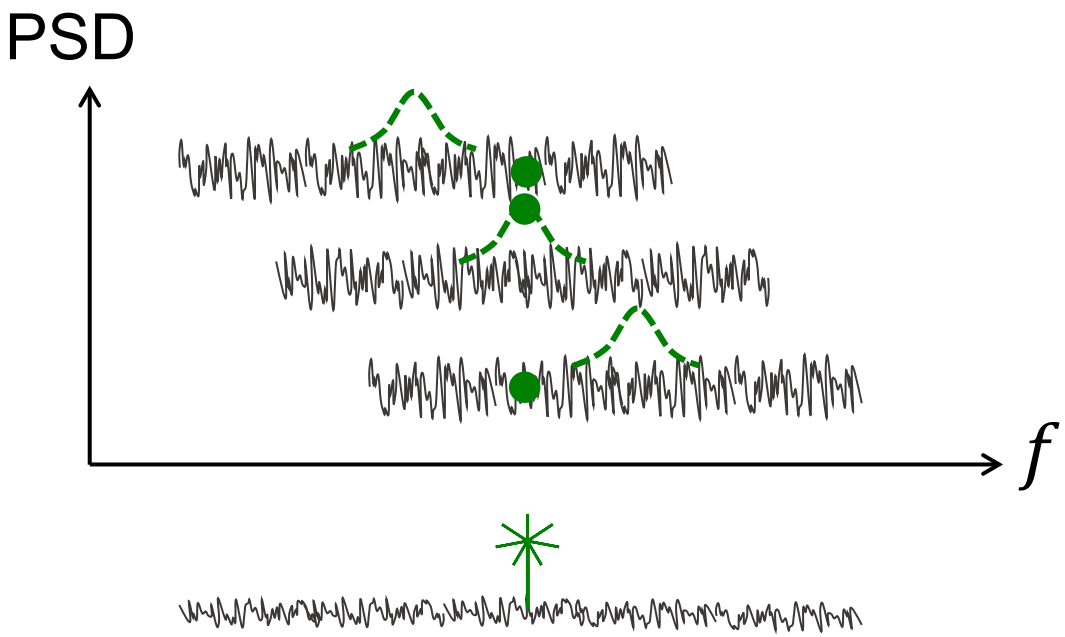
cavity (tunable)

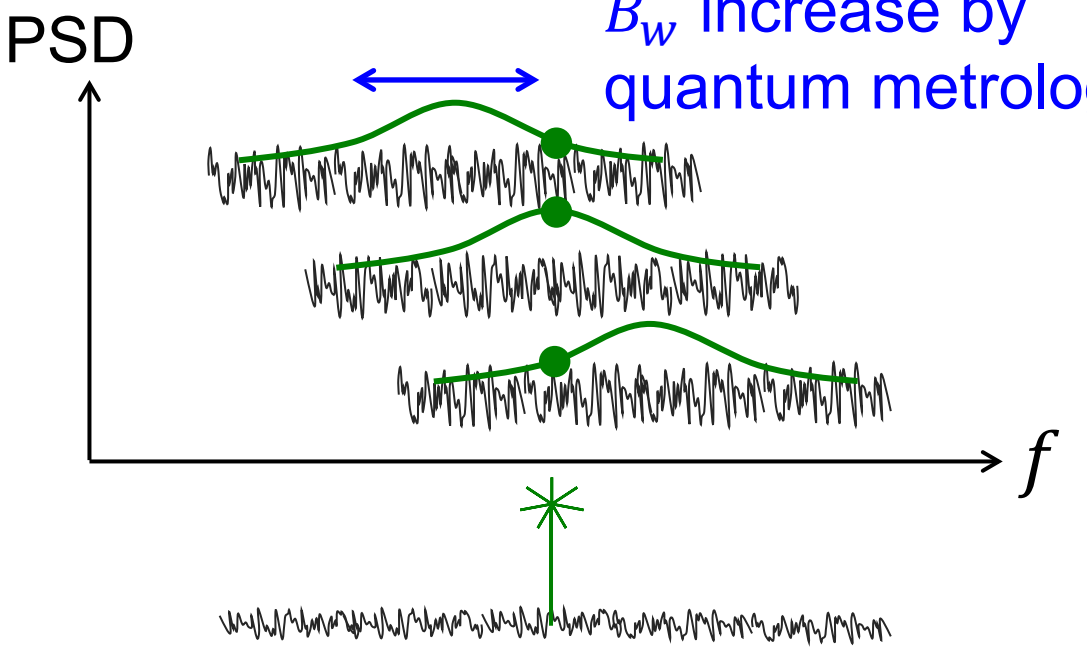


Sikivie, P., *Phys. Rev. Lett.* **51,** 1415 (1983)

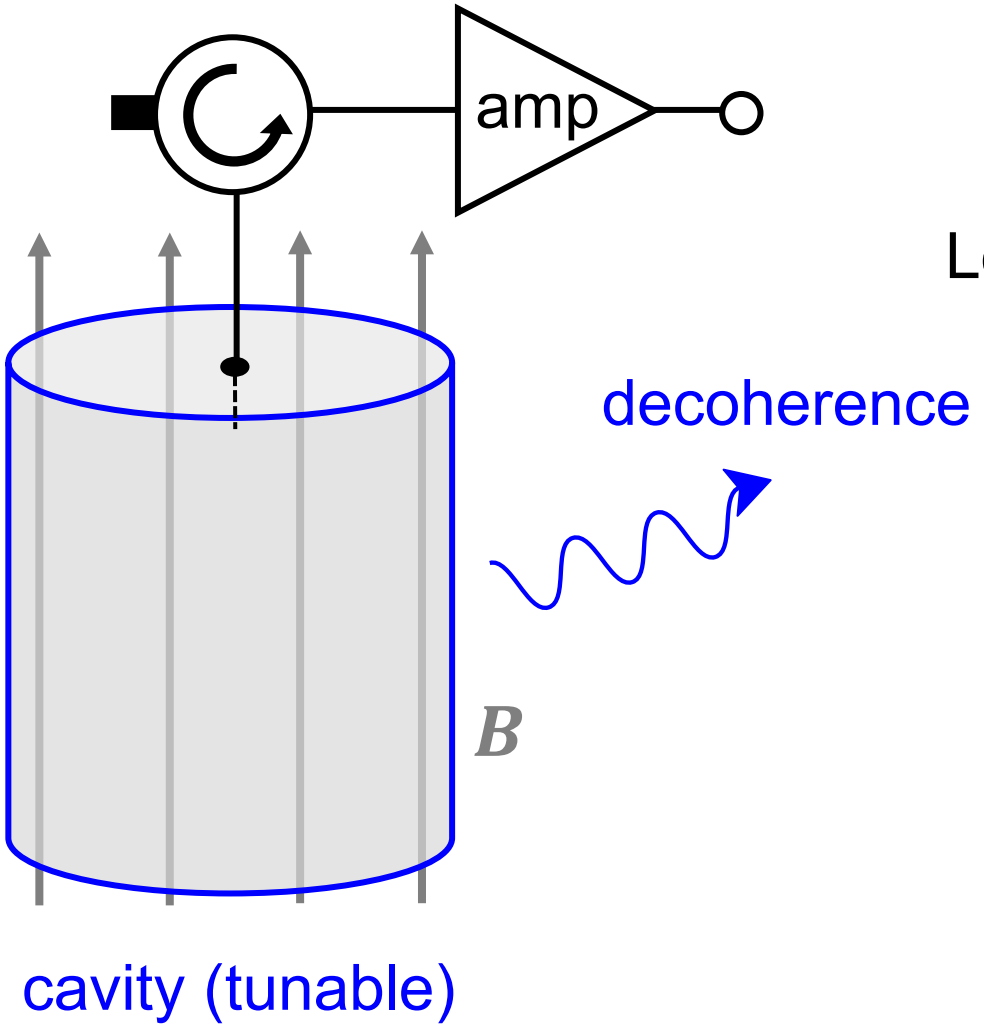
Resolving the signal faster by increasing visibility bandwidth

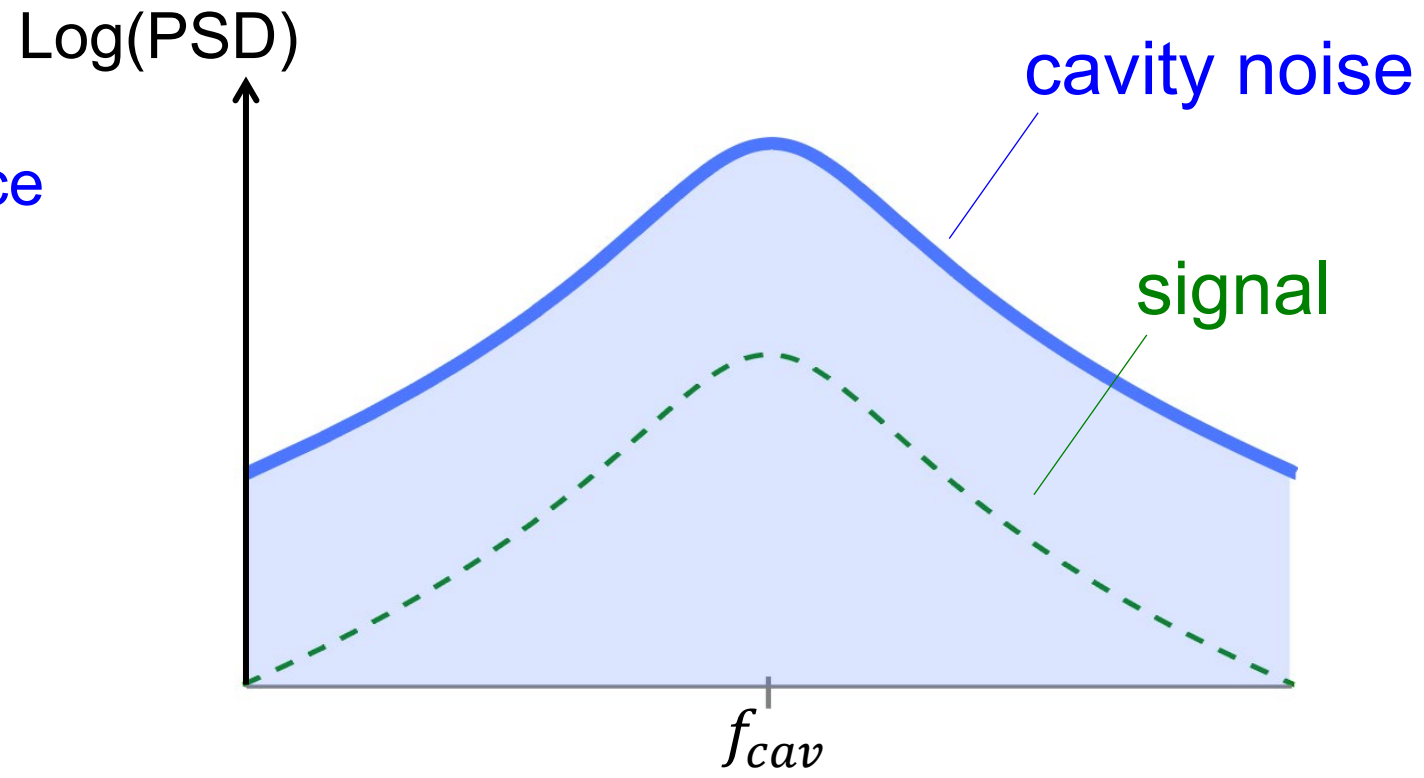




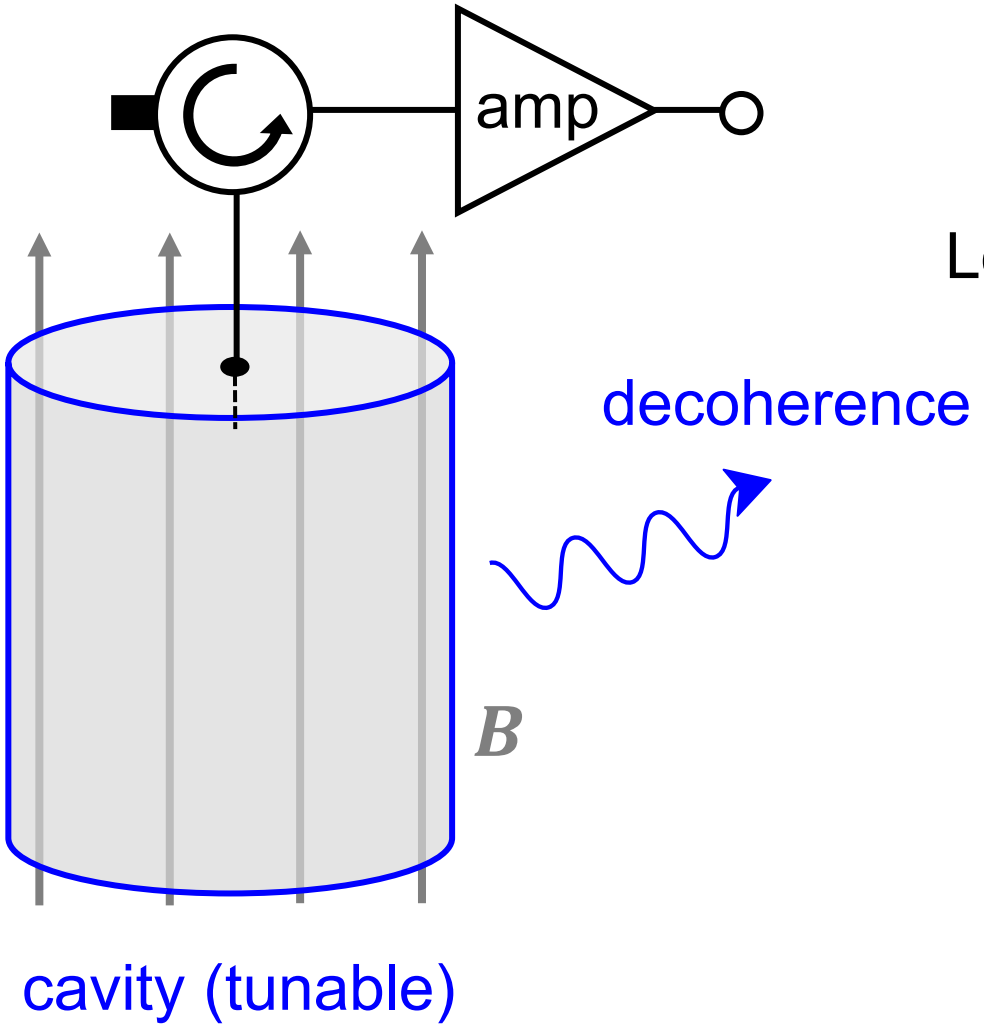


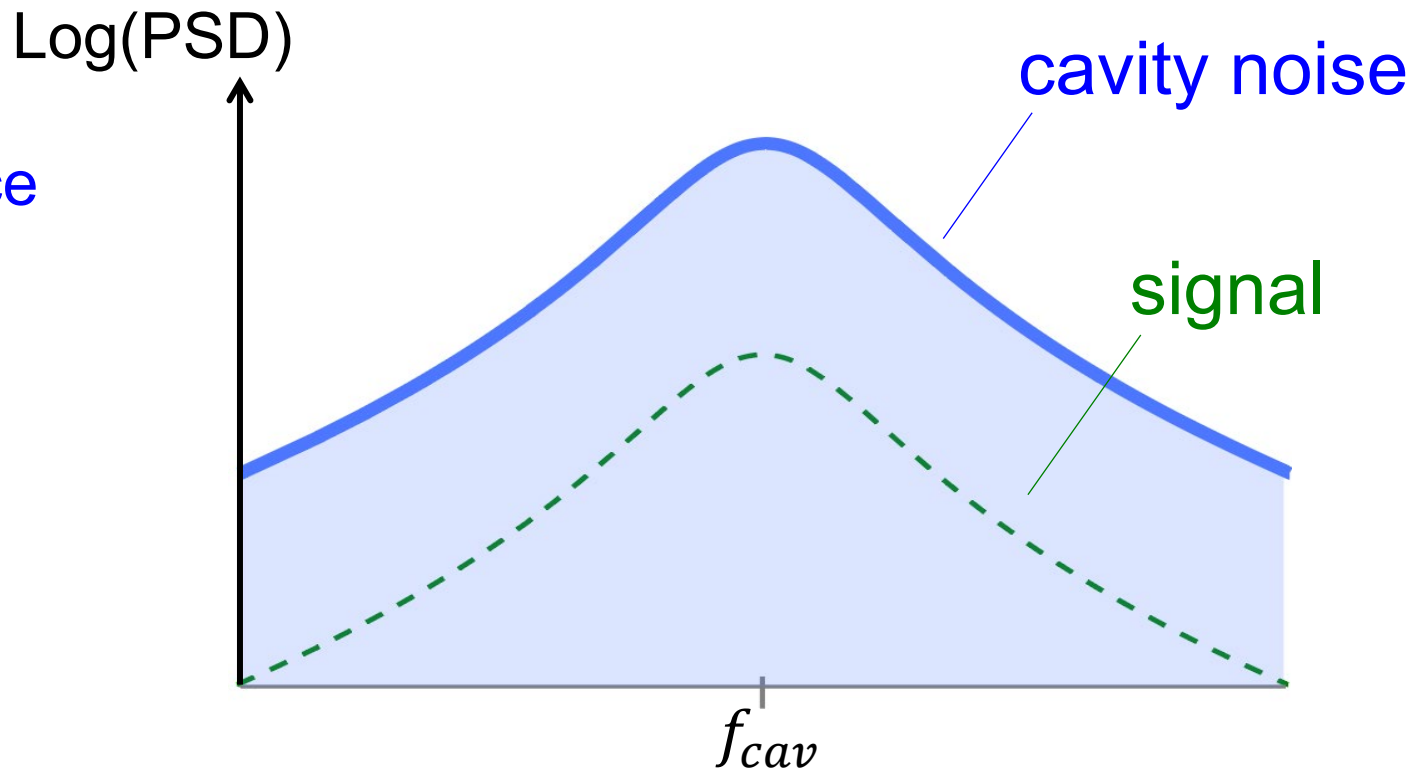
visibility bandwidth is set by two sources of quantum noise



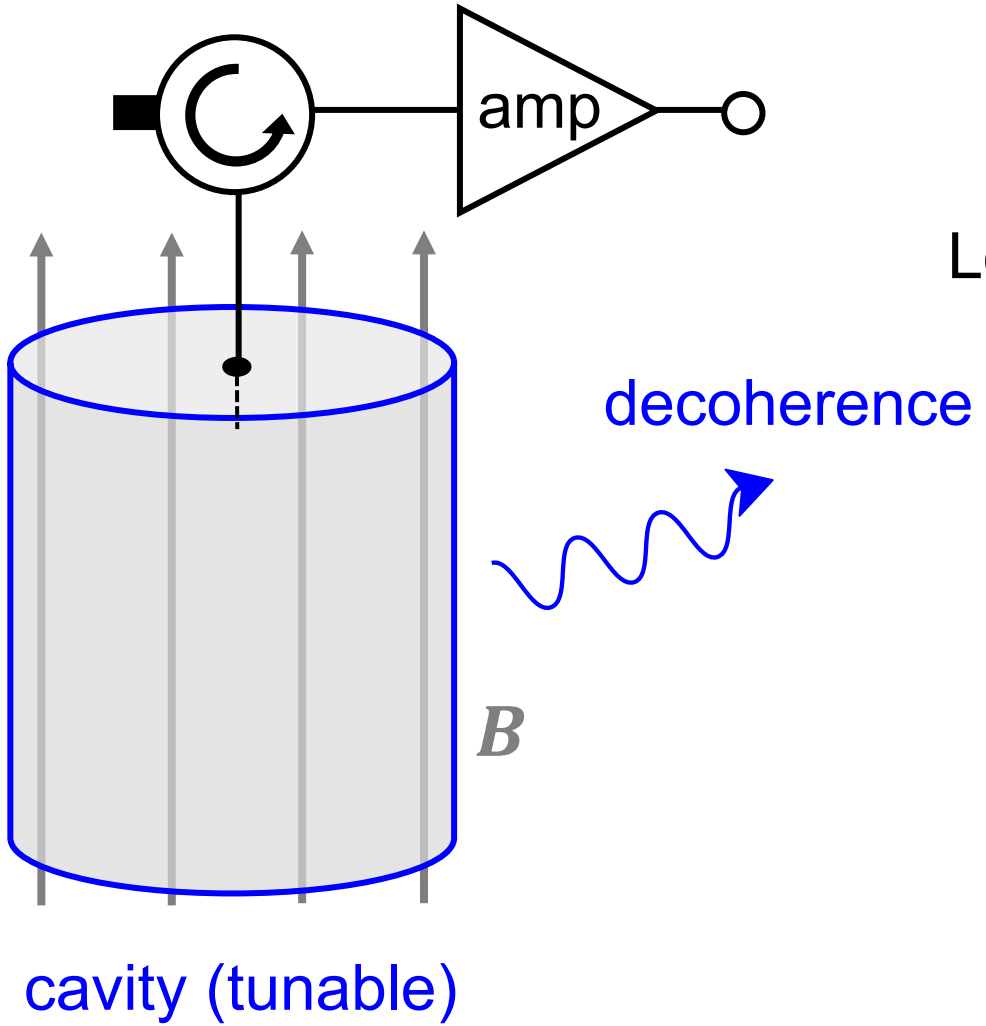


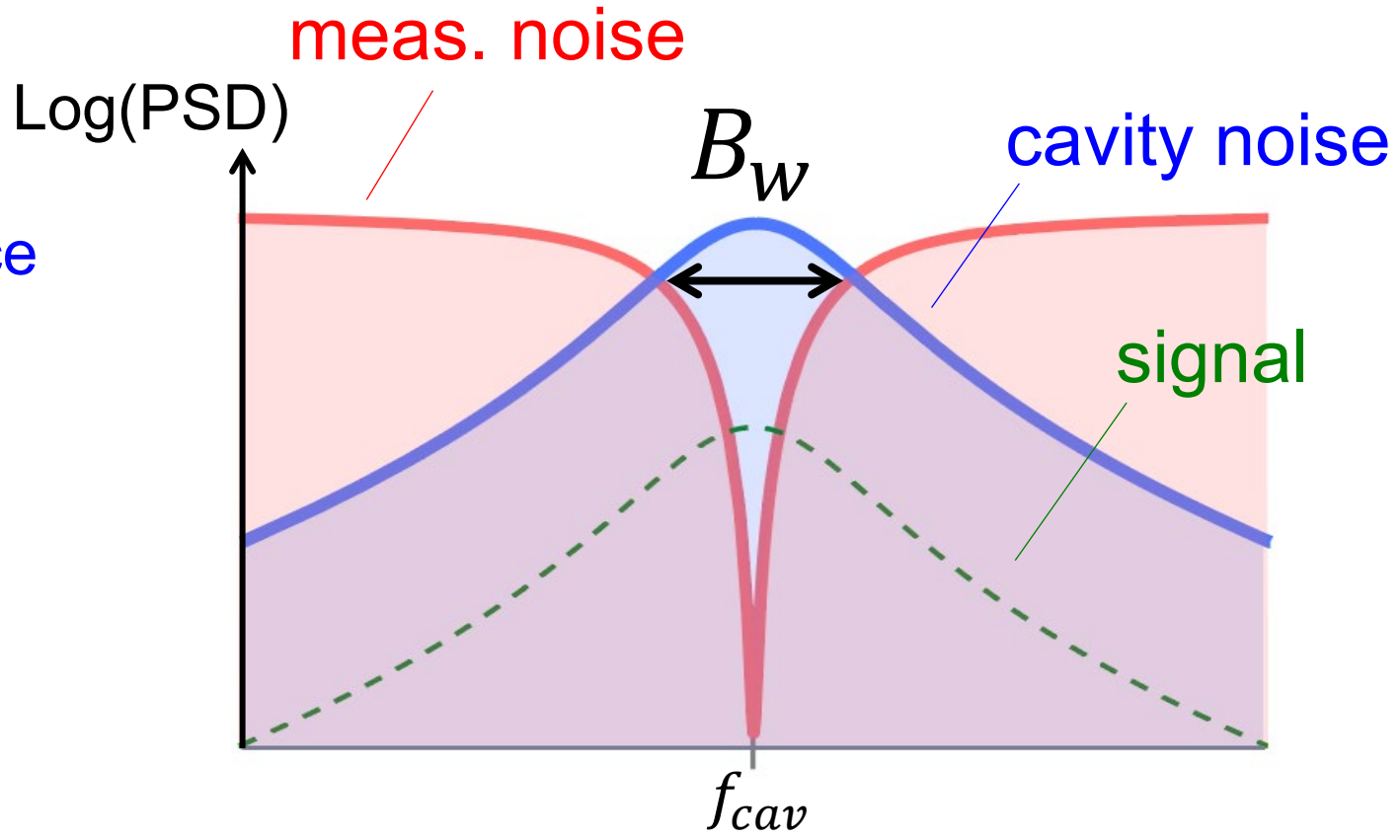
visibility bandwidth is set by two sources of quantum noise



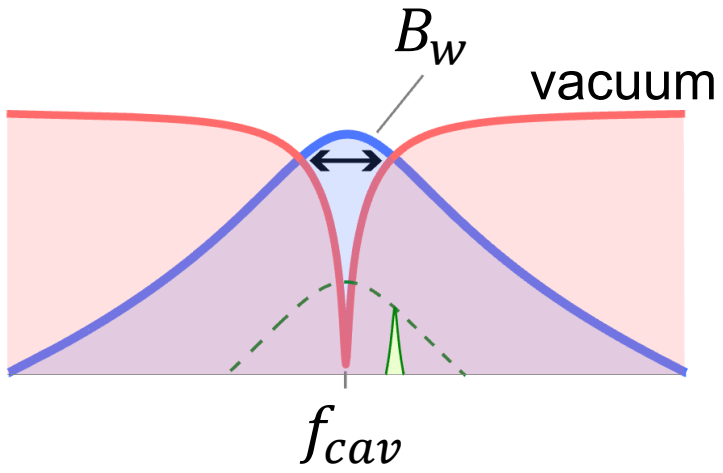


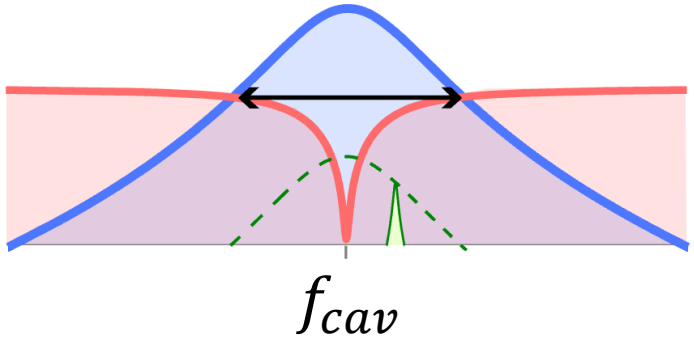
visibility bandwidth is set by two sources of quantum noise





Bandwidth increase using quantum technology

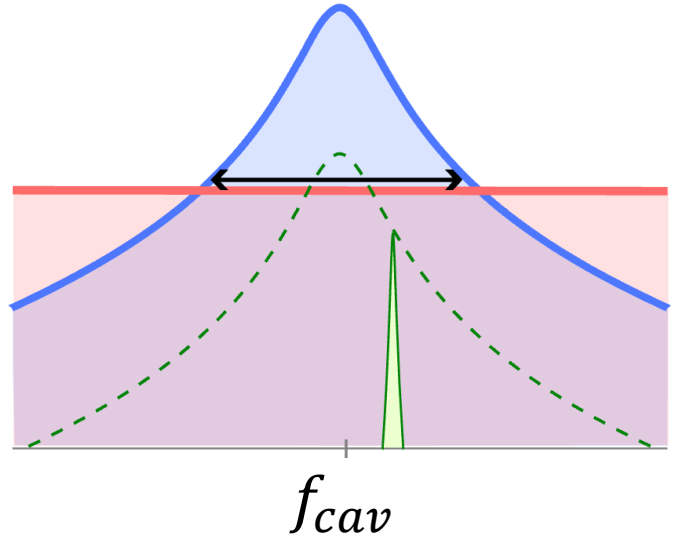




× 2

MM, DAP *et al.*, ***PRX*** (2019)

KMB, DAP *et al.*, ***Nature*** (2021)



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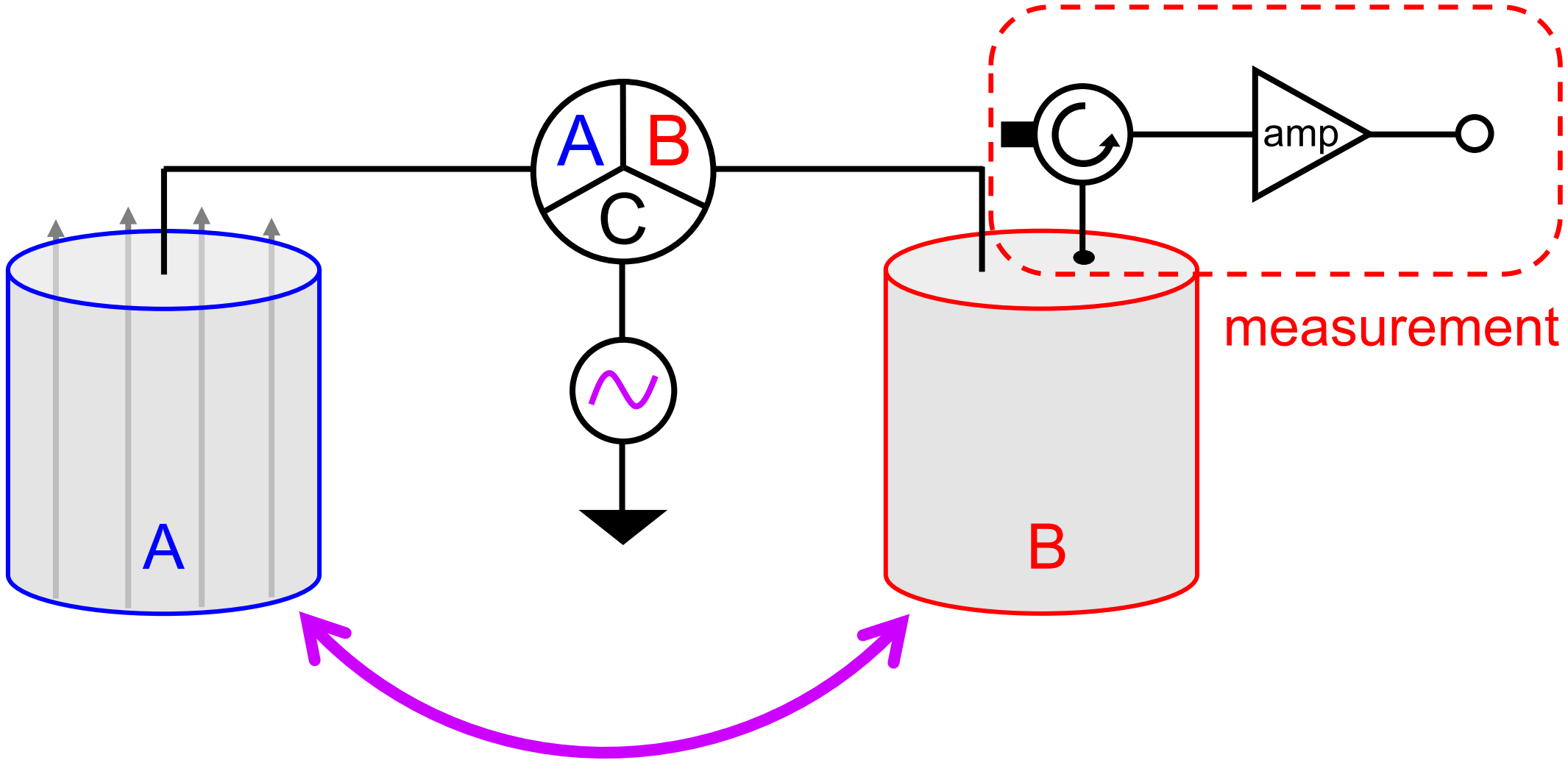
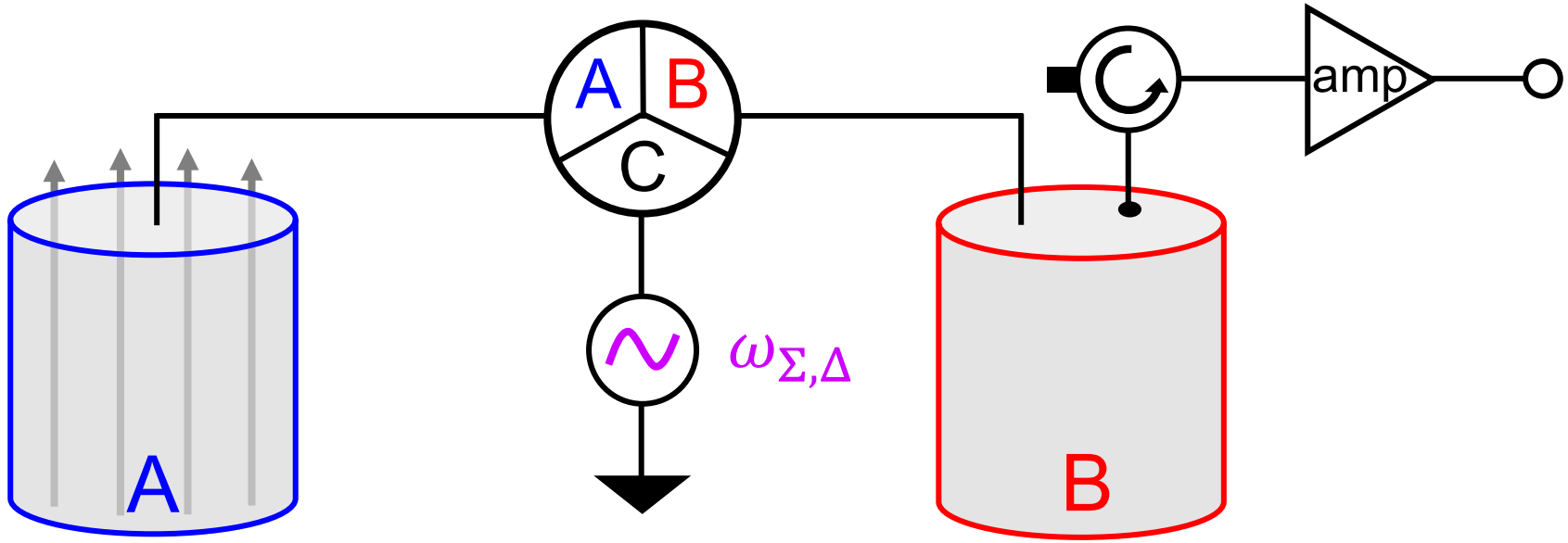
theory: KW, BMB, **YJ** *et al.*, ***PRX Quantum*** (2021)

experiment: **YJ**, EPR *et al.*, ***PRX Quantum*** (2023)



quantum non-demolition (QND)

Entanglement (G) and swapping (C) yield quantum non-demolition

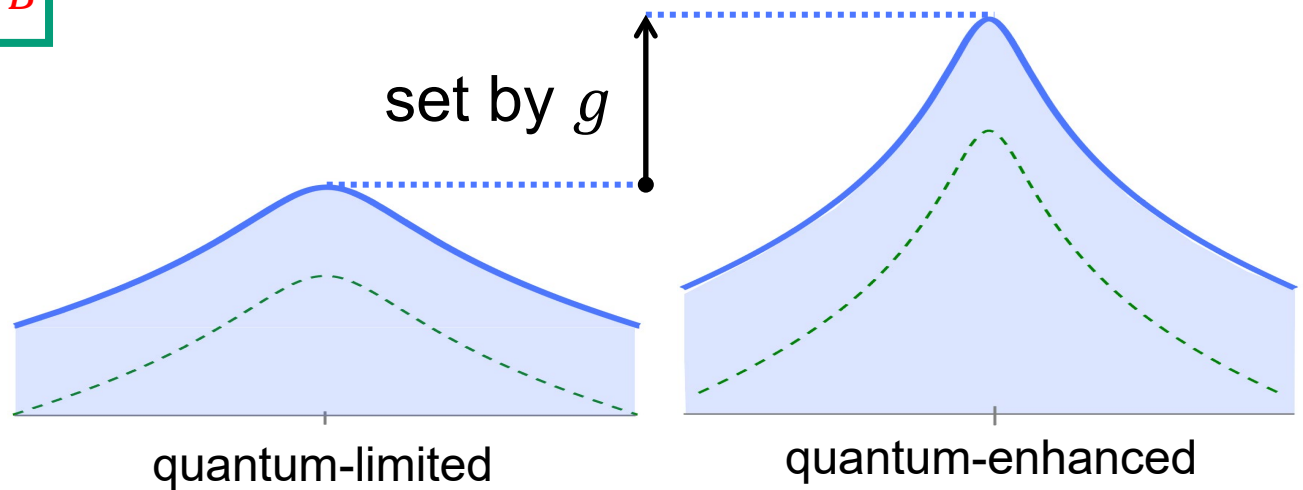


$$\hat{H}_{\mathrm{QND}} = g\hat{A}^{\dagger}\hat{B}^{\dagger} + g\hat{A}\hat{B}^{\dagger} + \mathrm{h.c.} = g\hat{X}_A\hat{X}_B$$

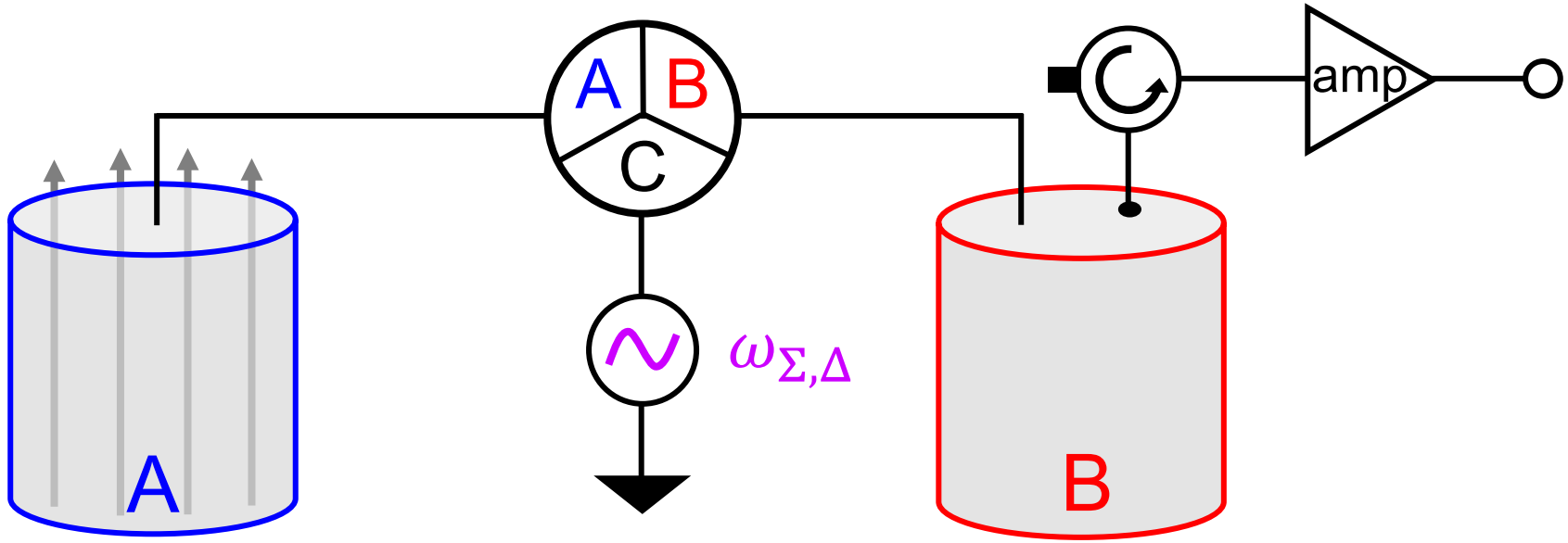
(ω_Σ: G) (ω_Δ: C)

$$\frac{d\hat{Y}_B}{dt} = -2g\hat{X}_A \qquad \frac{d\hat{X}_A}{dt} = 0$$

amplified signal QND



Combine two interactions yields quantum non-demolition

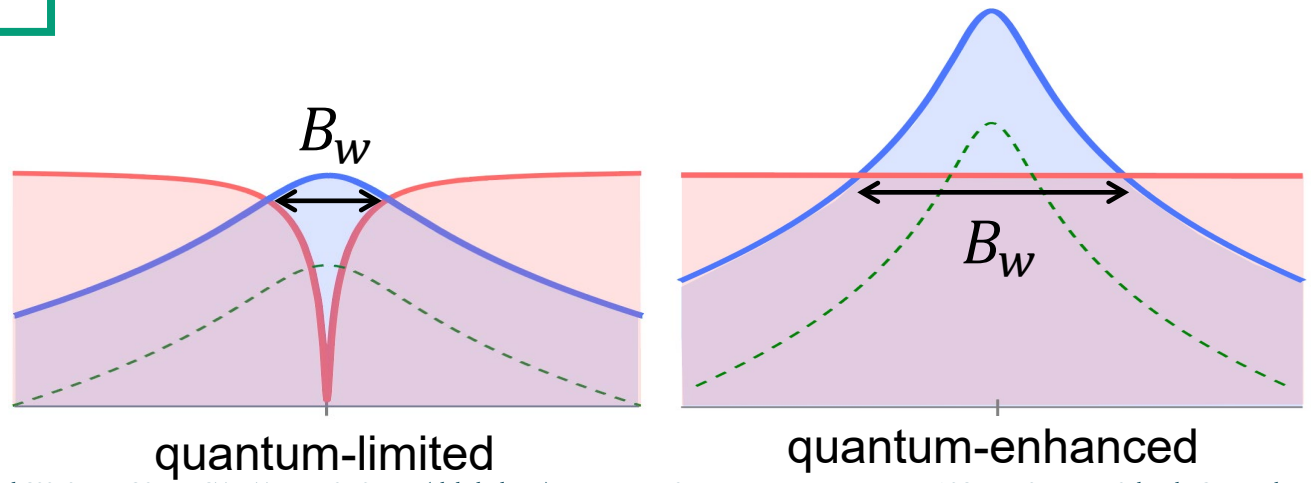


$$\hat{H}_{\mathrm{QND}} = g\hat{A}^{\dagger}\hat{B}^{\dagger} + g\hat{A}\hat{B}^{\dagger} + \mathrm{h.c.} = g\hat{X}_A\hat{X}_B$$

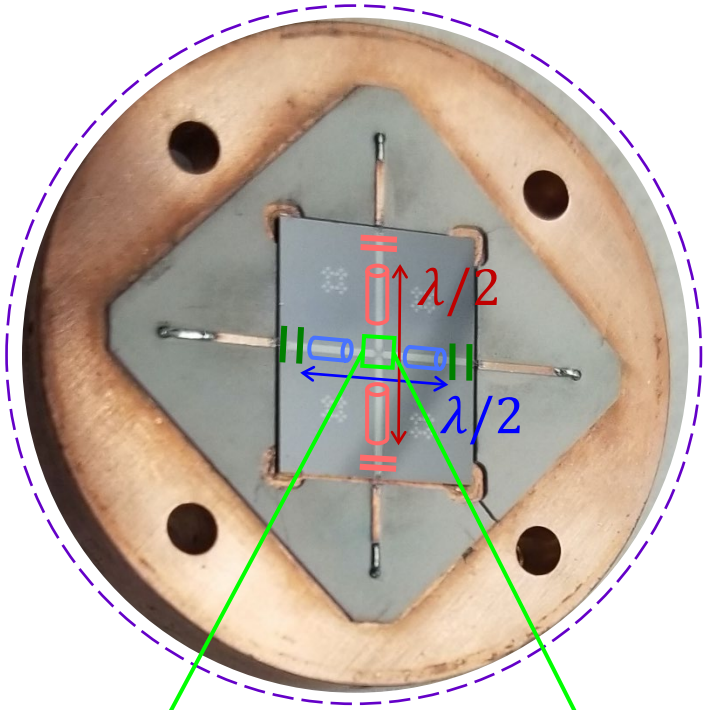
(ω_Σ: G) (ω_Δ: C)

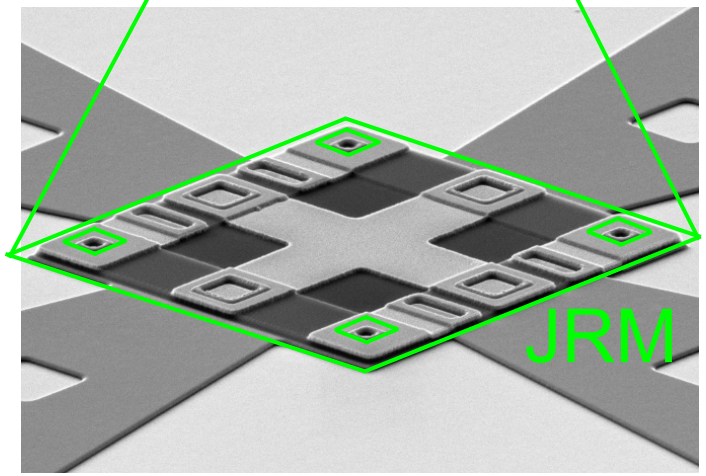
$$\frac{d\hat{Y}_B}{dt} = -2g\hat{X}_A \qquad \frac{d\hat{X}_A}{dt} = 0$$

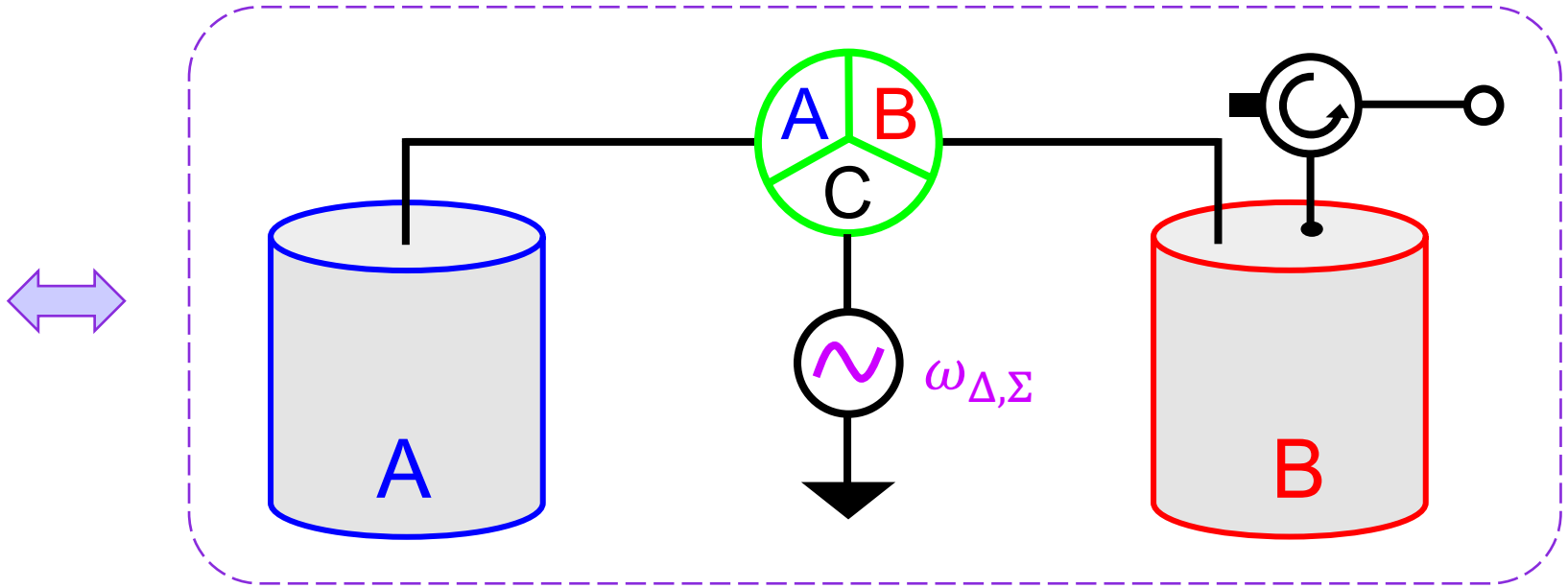
amplified signal QND

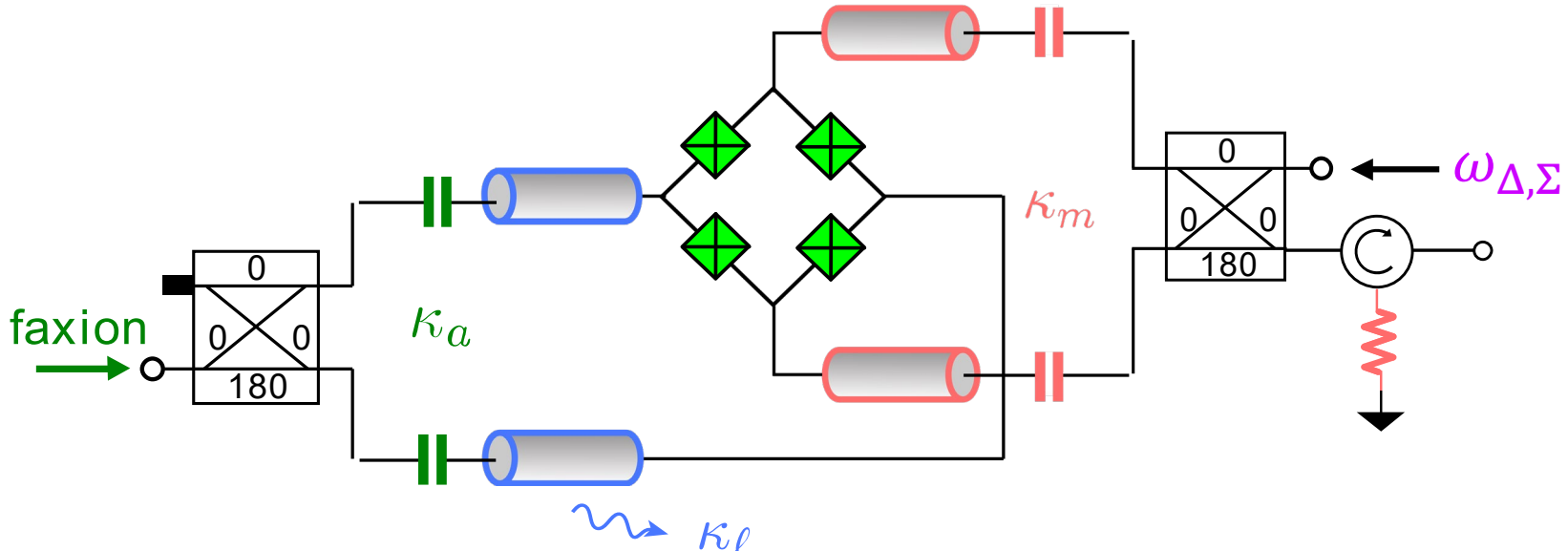


Josephson circuits for prototype demonstration

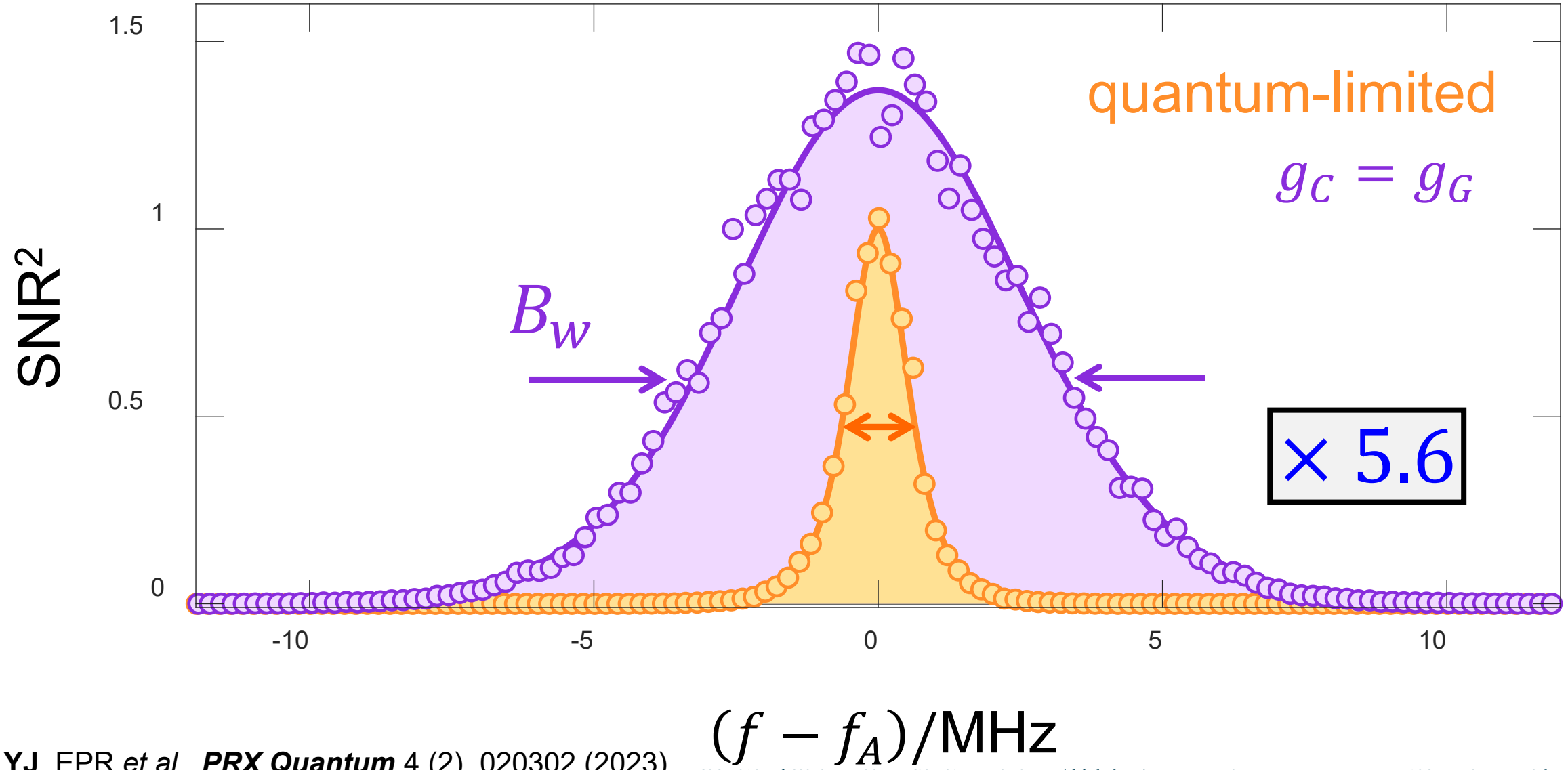








Quantum non-demolition interaction yields bandwidth increase



YJ, EPR *et al.*, ***PRX Quantum*** 4 (2), 020302 (2023)

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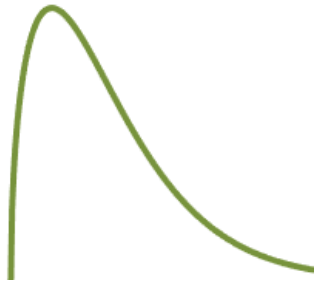
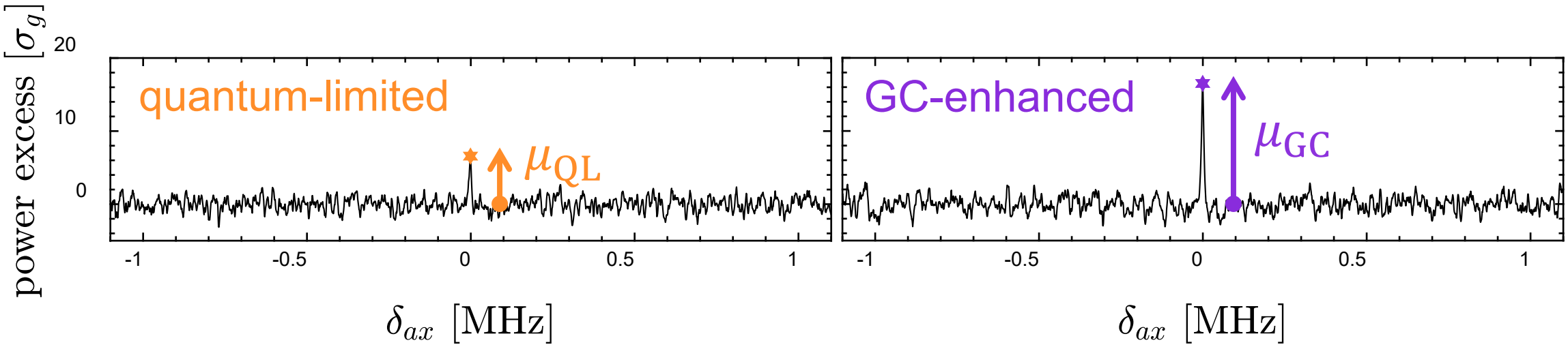
Search for a weak signal at unknown frequency

1%
vacuum PSD



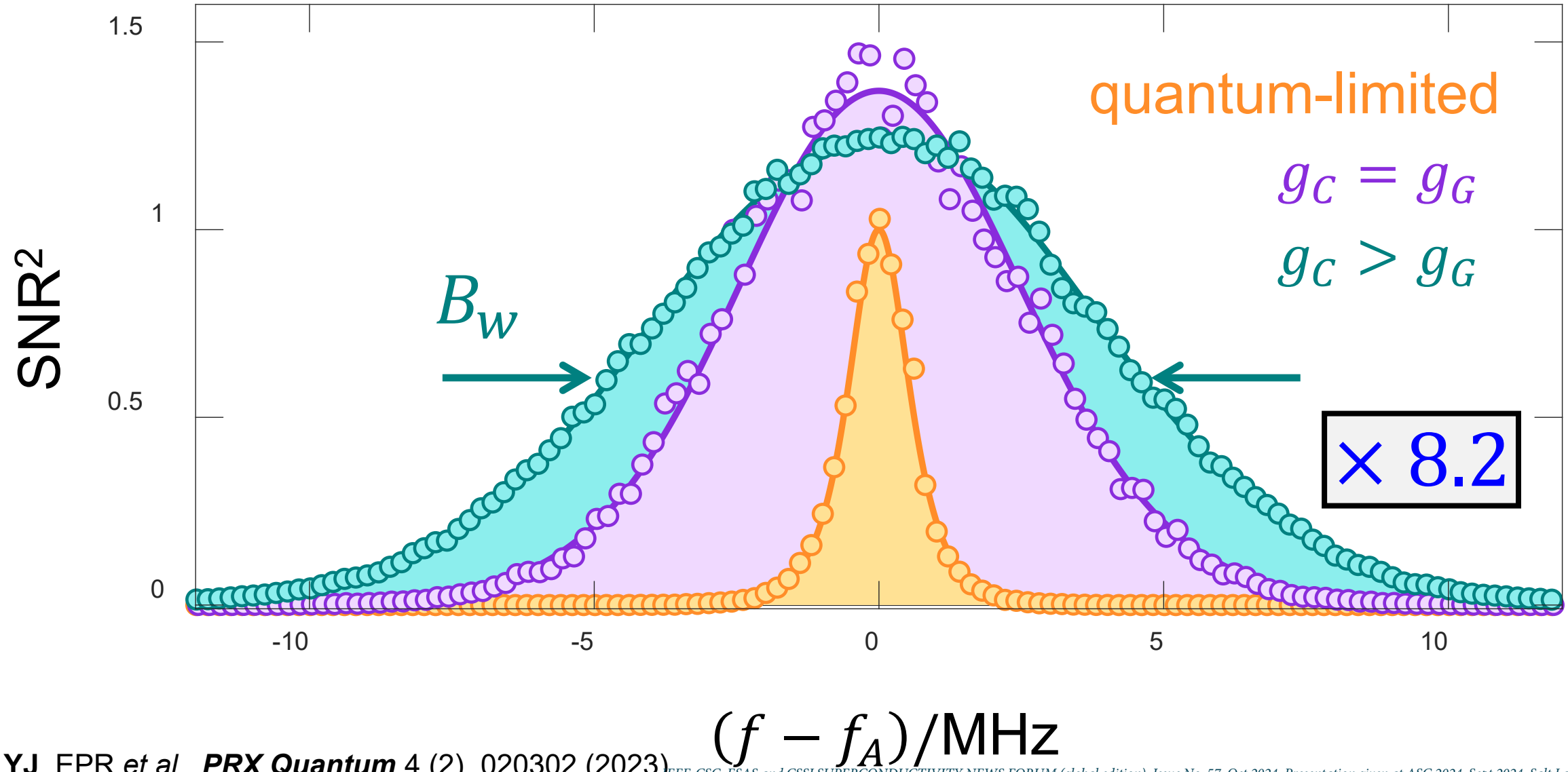
faxion: unknown freq.



$$\mathrm{SRE} = \left(\frac{\mu_{\mathrm{GC}}}{\mu_{\mathrm{QL}}}\right)^2$$

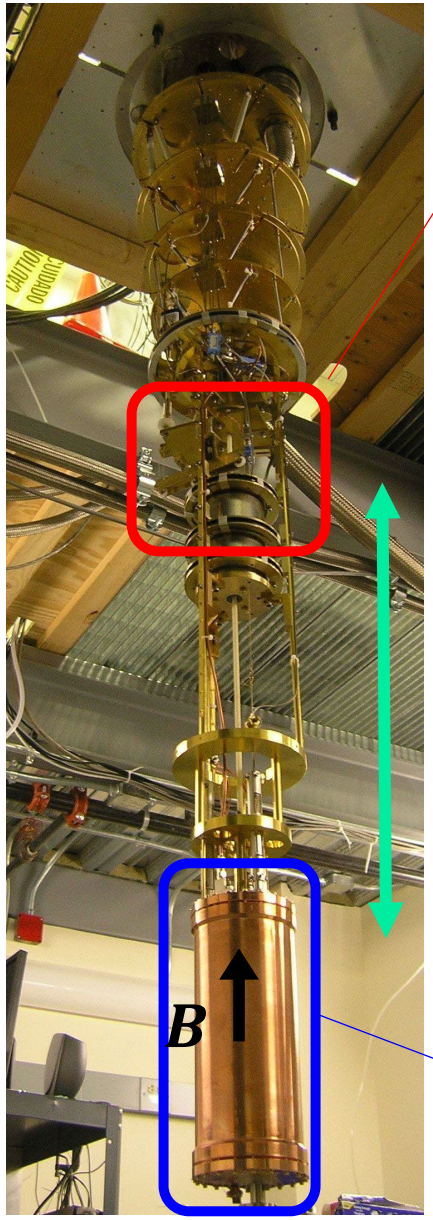
$\times 5.6$

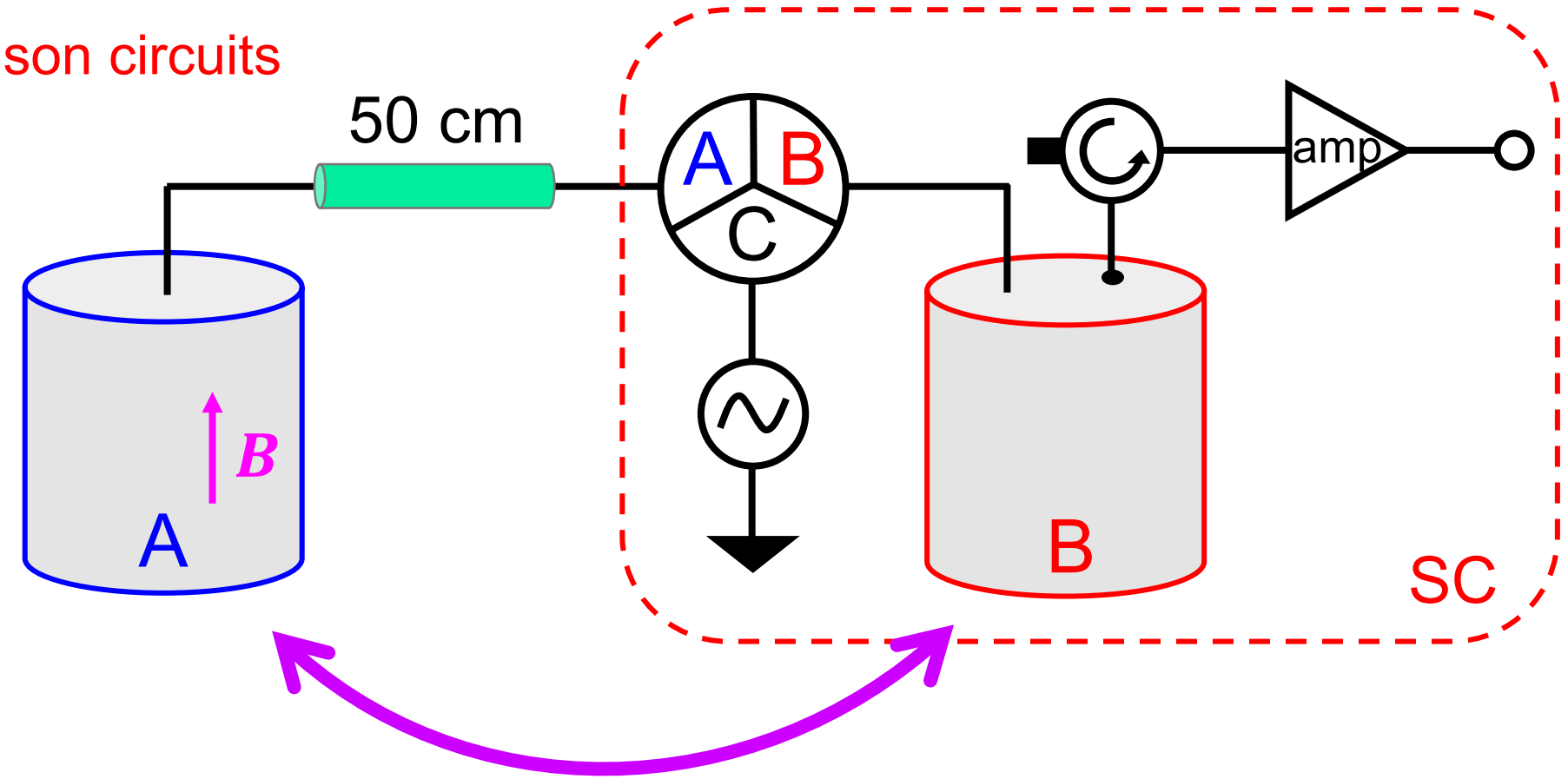
Imbalanced interaction rates result in further speedup



YJ, EPR *et al.*, ***PRX Quantum*** 4 (2), 020302 (2023)

Josephson circuits are incompatible with magnetic field





axion cavity (A)

remote entanglement (G)
& swapping (C)

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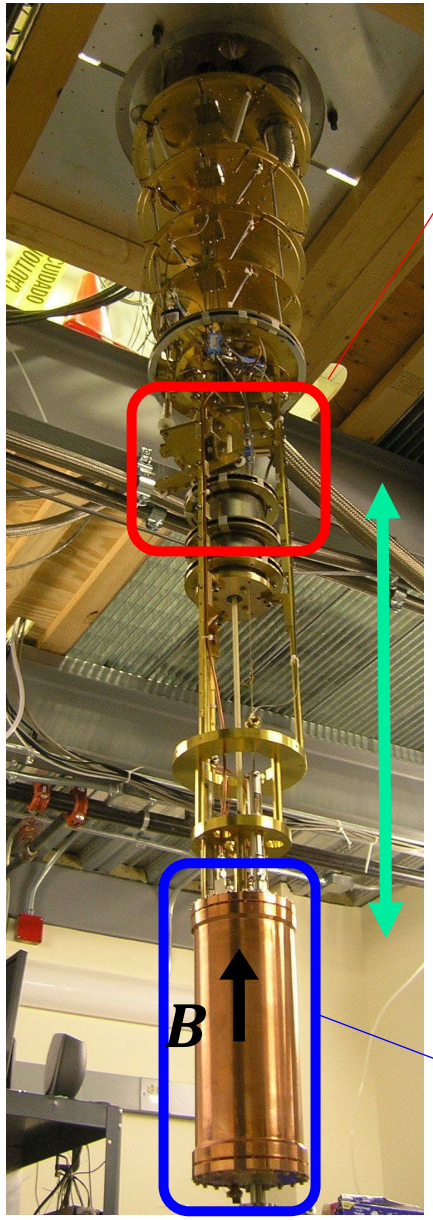
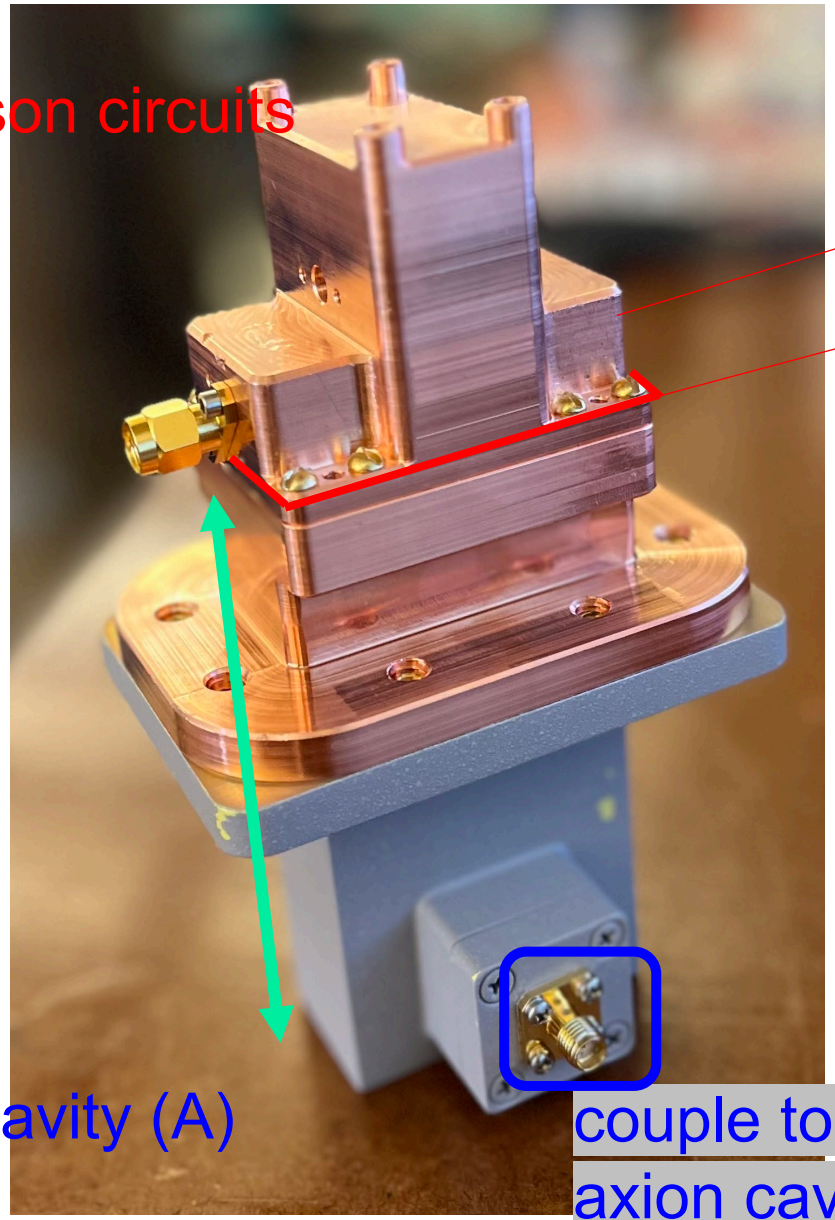
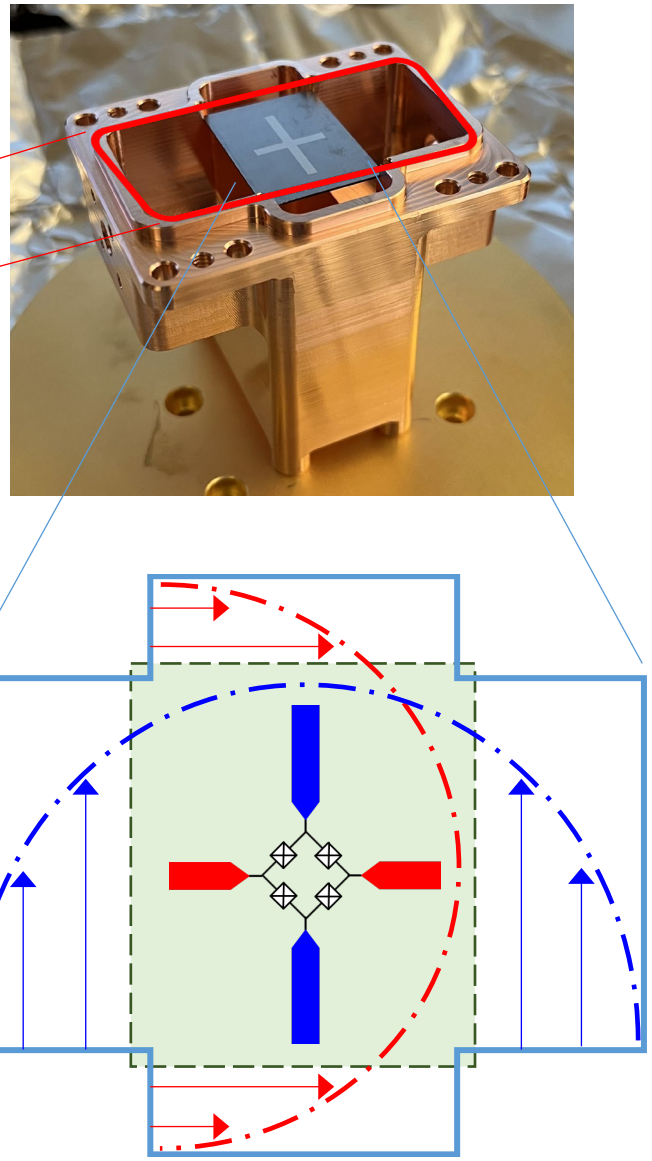
Waveguide Josephson circuits to implement remote GC







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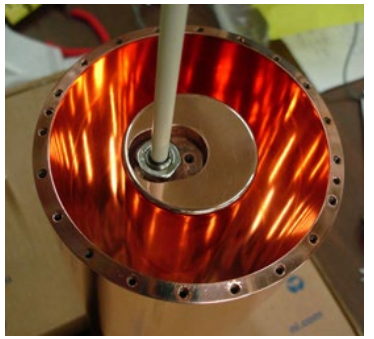
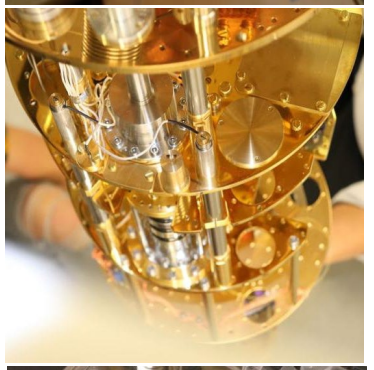
Conclusion

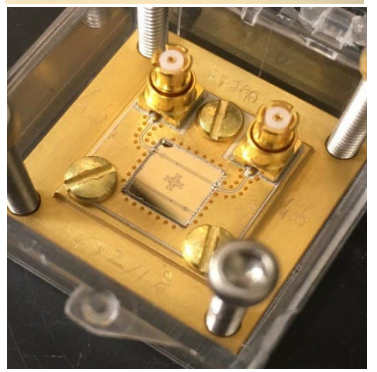
balanced GC – x 5.6

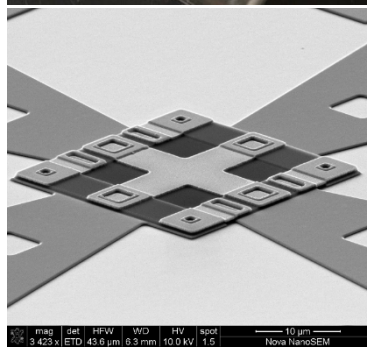
imbalanced GC – x 8.2

on-going progress: remote GC using waveguide JPC









The Haloscope At Yale Sensitive To Axion CDM

HAYSTAC

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