Parameteric (Quanutm) Amplifiers for Detectors

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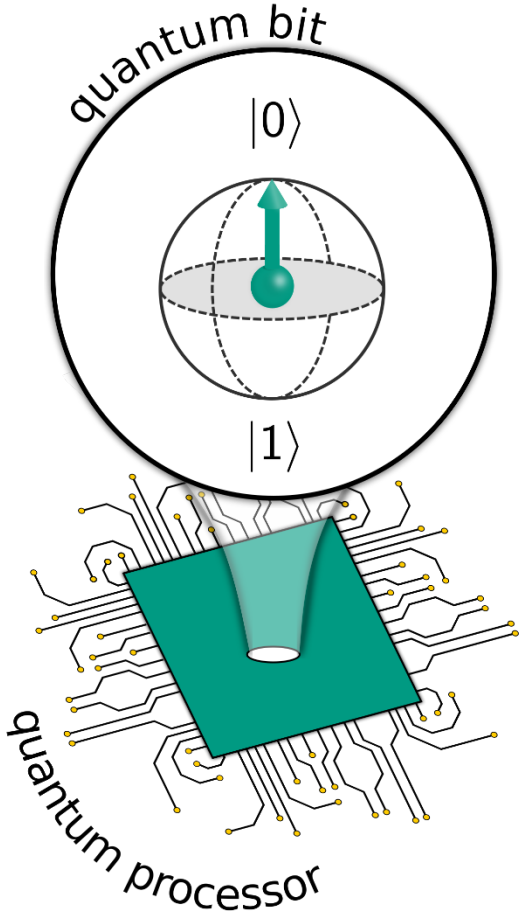
Alexander von Humboldt

Why use a
quantum amplifier ?



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“Quantum Future Award” finals (2021) https://youtu.be/J78UjJ1oUCo?t=5341

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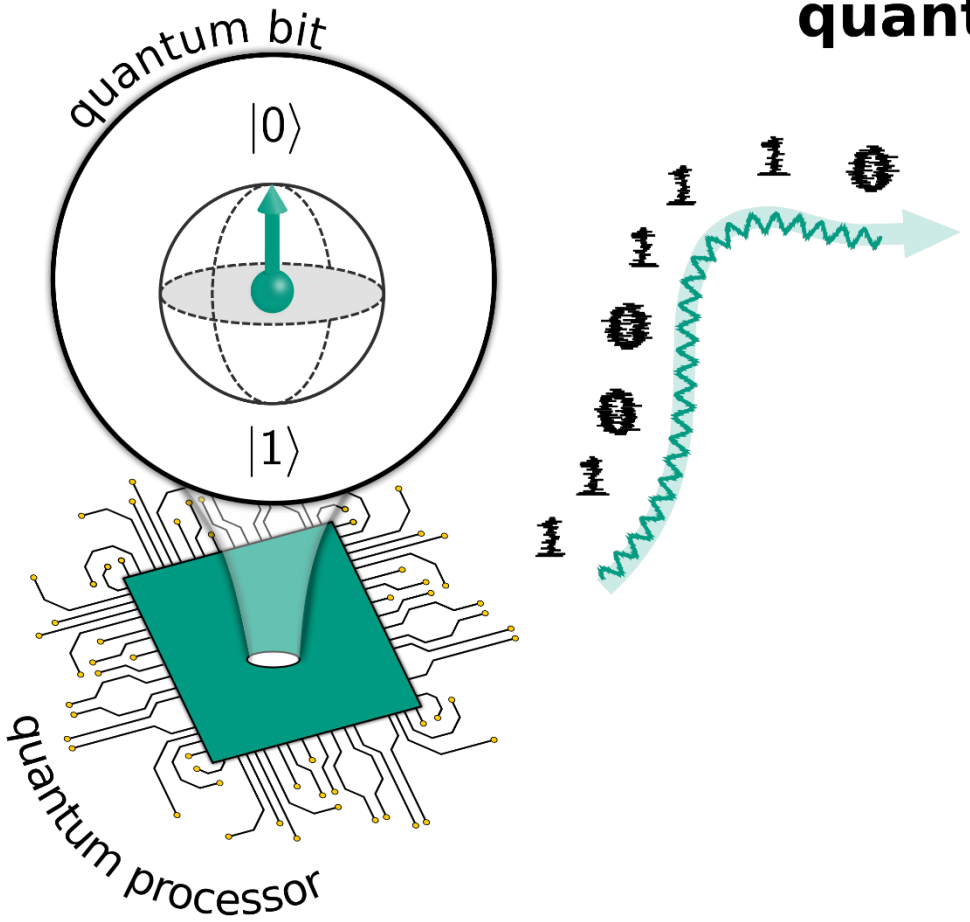

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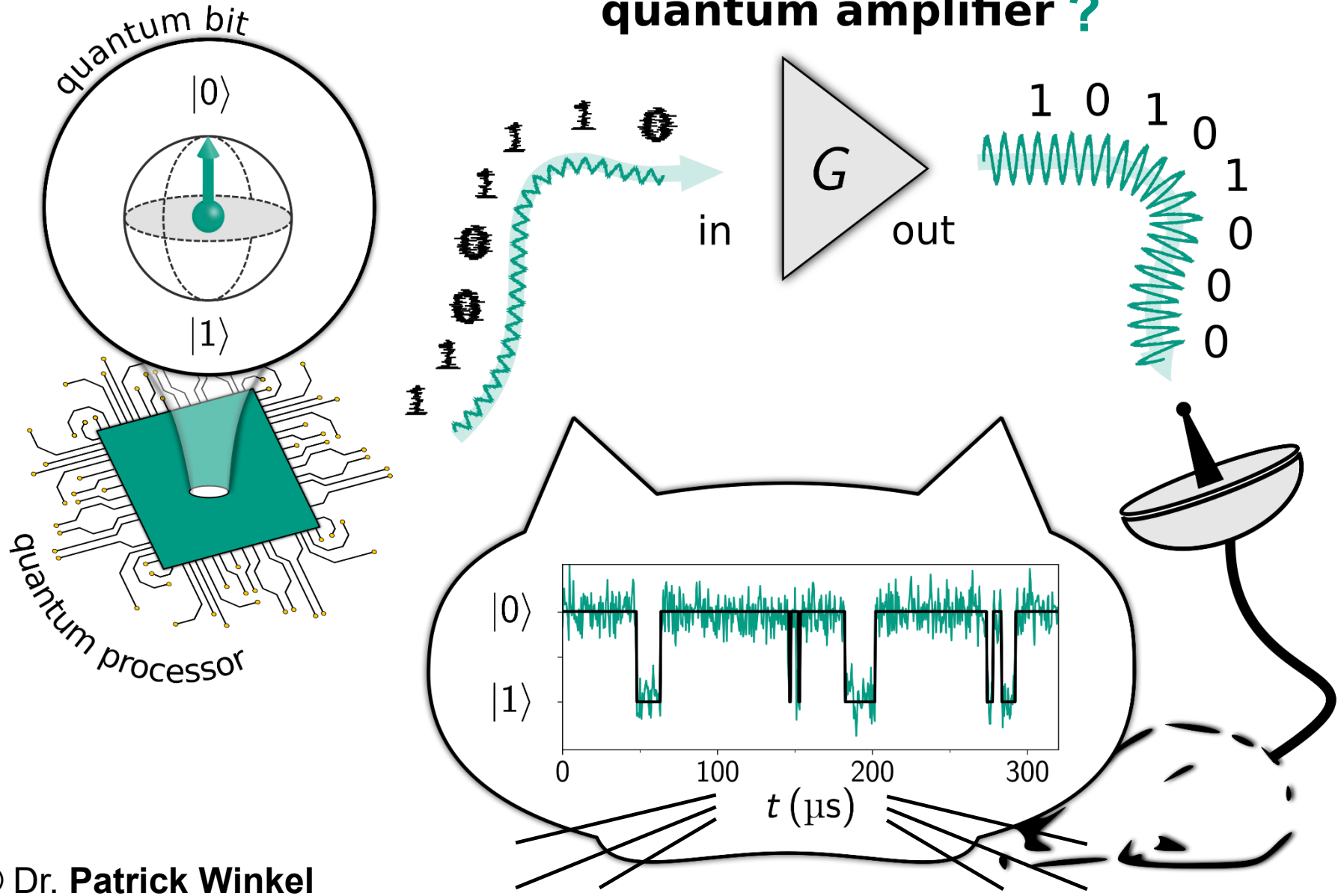

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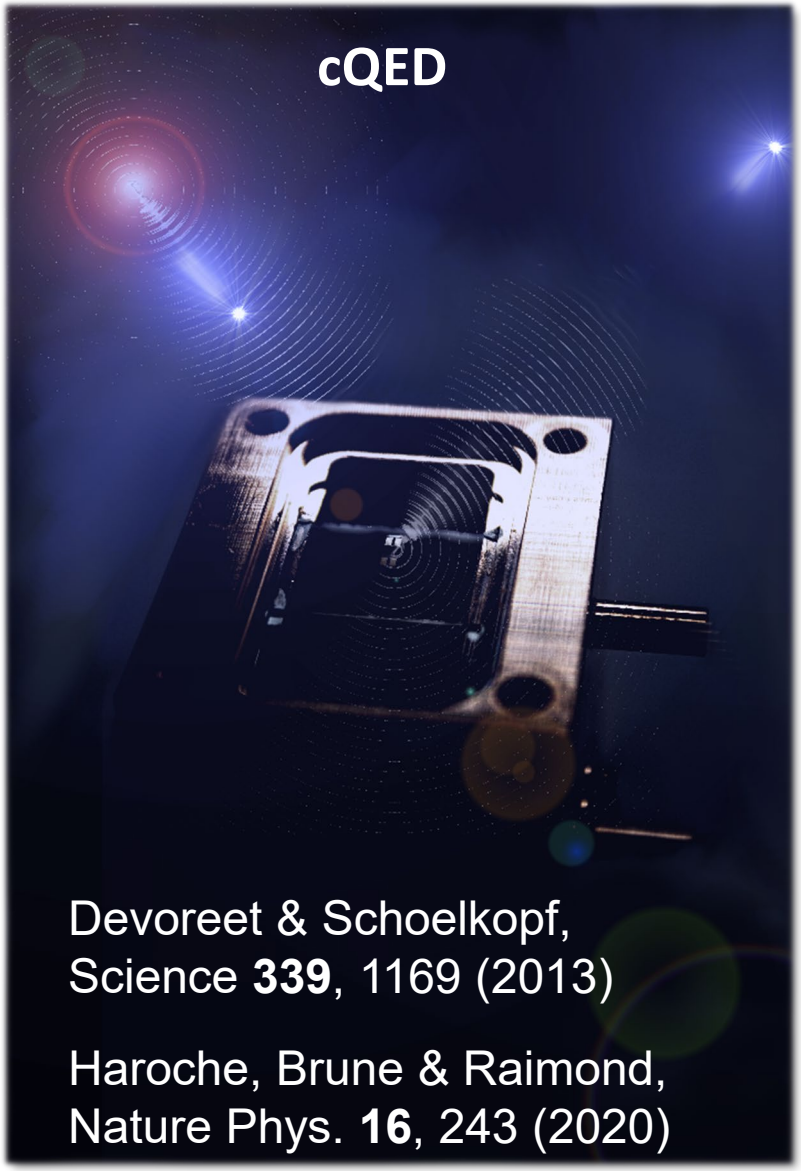
Why do we need amplifiers in cQED?



Devoreet & Schoelkopf,
Science **339**, 1169 (2013)

Haroche, Brune & Raimond,
Nature Phys. **16**, 243 (2020)

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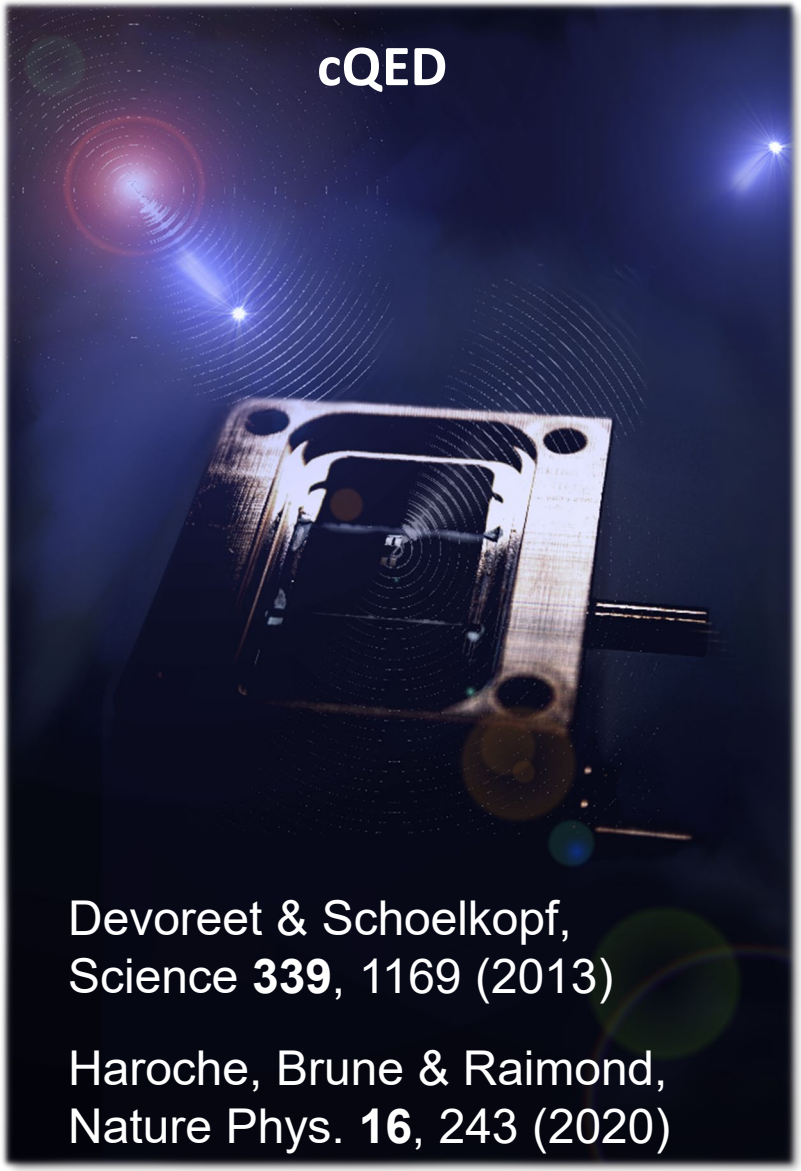

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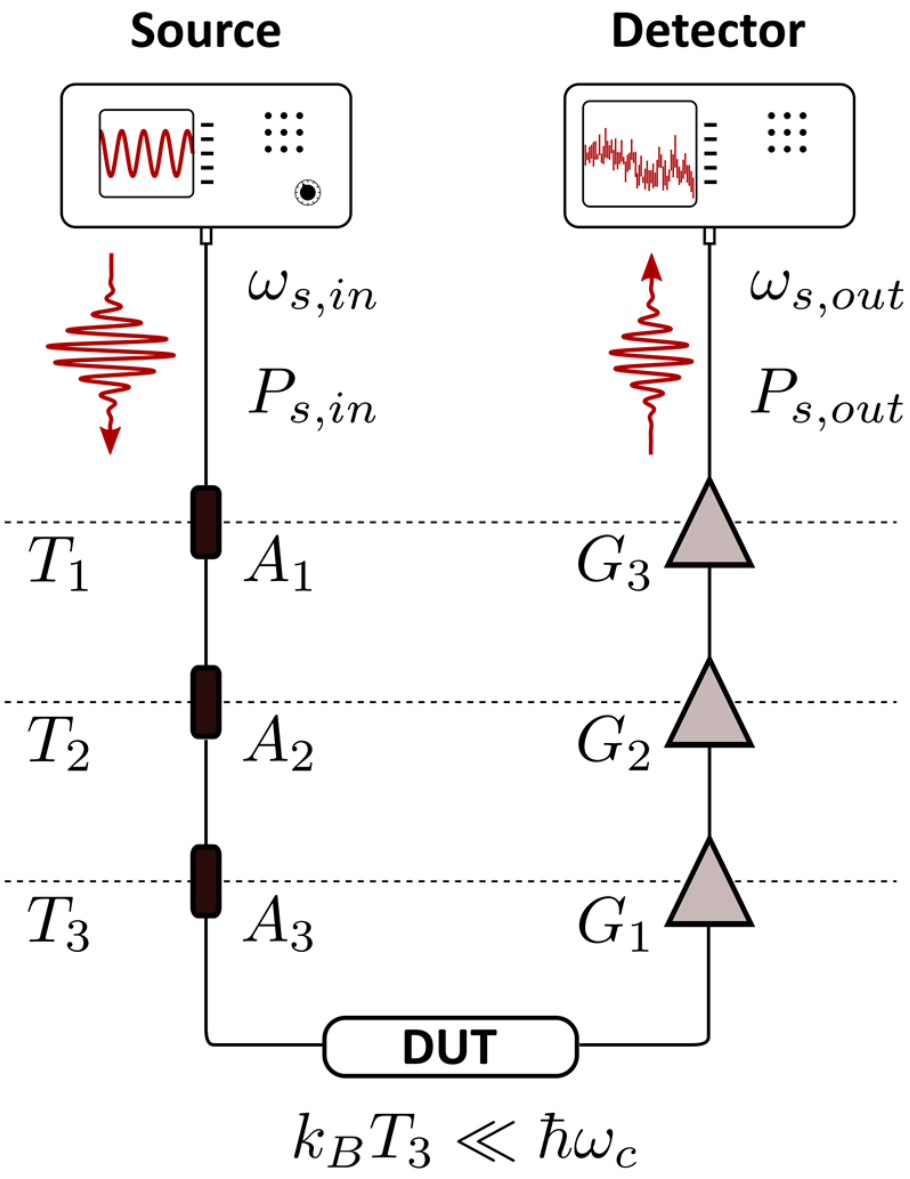
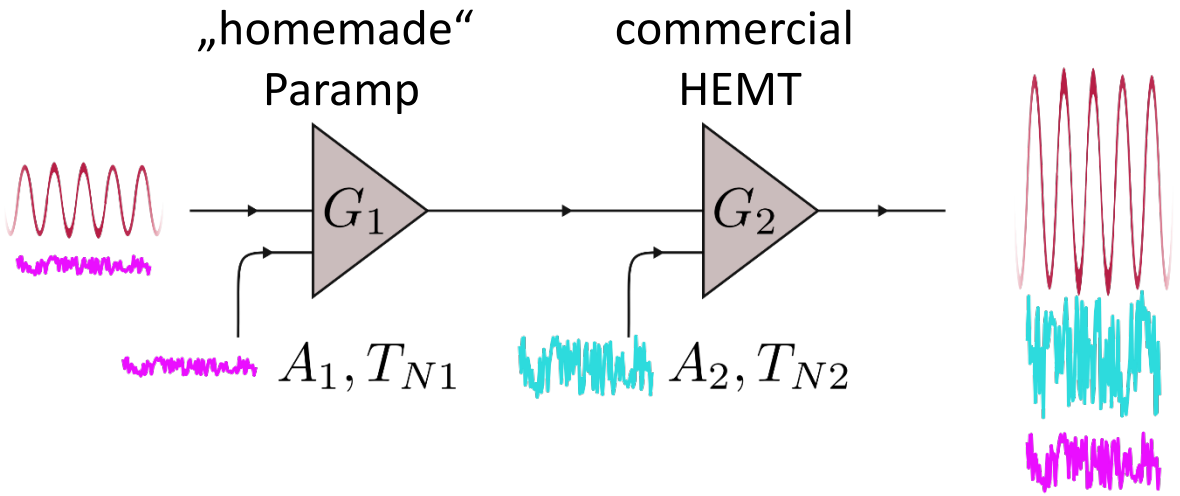
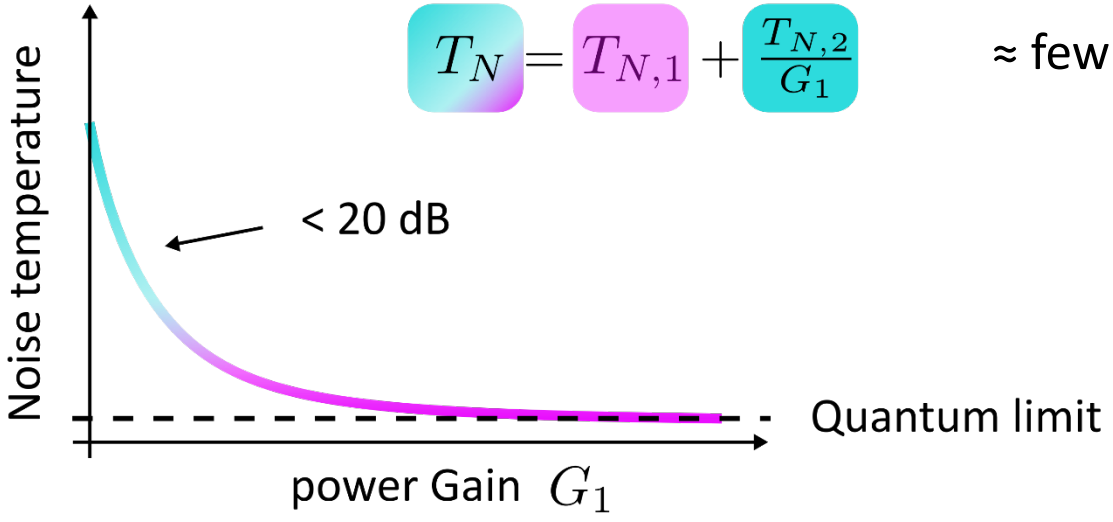


Noise temperature

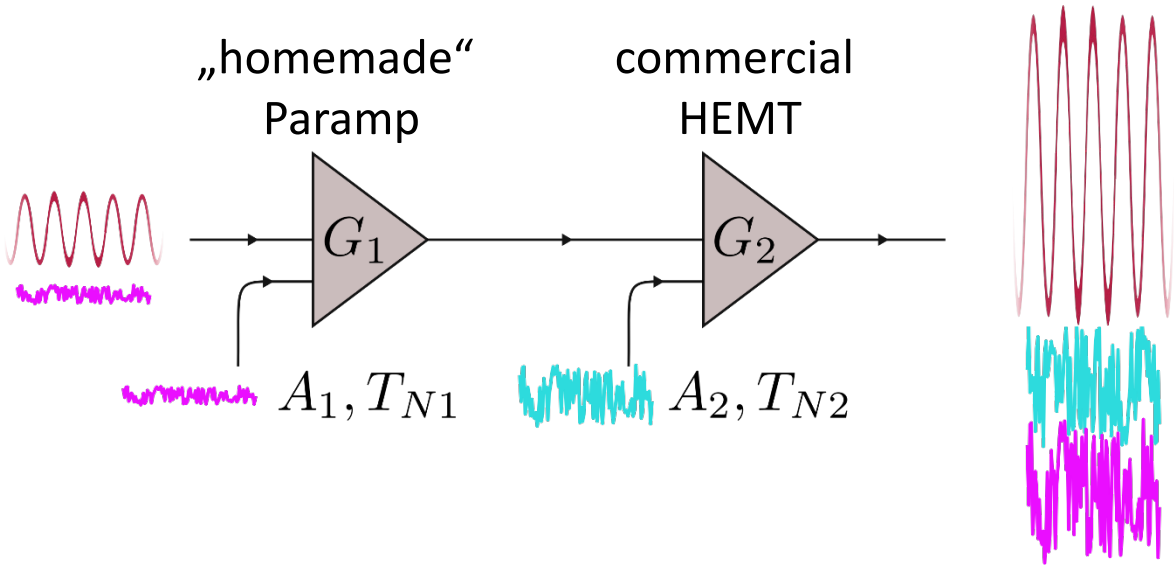


$$T_N = T_{N,1} + \frac{T_{N,2}}{G_1}$$

≈ few 1 K

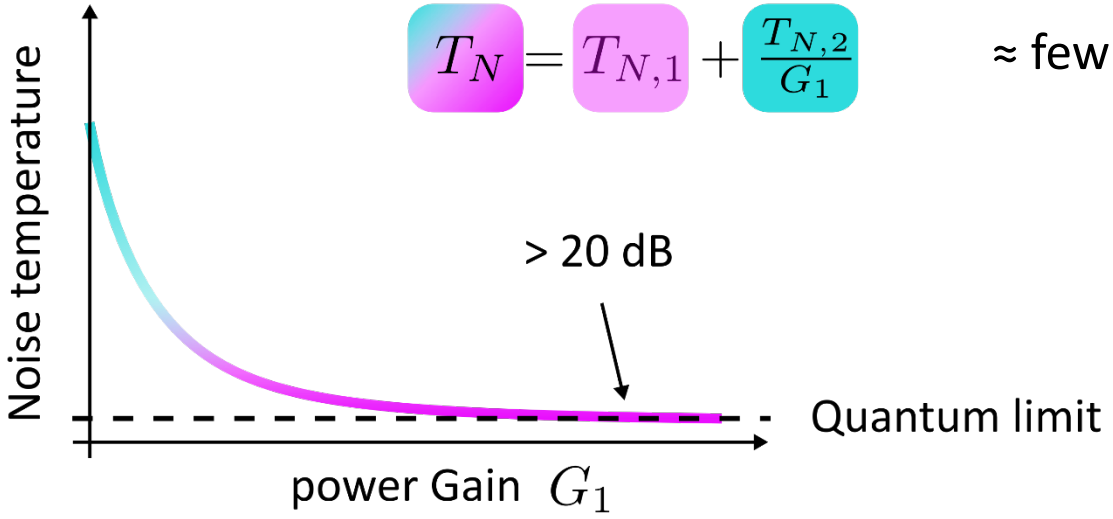


Noise temperature



$$T_N = T_{N,1} + \frac{T_{N,2}}{G_1}$$

≈ few 0.1 K



So, why do we need amplifiers in cQED?

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Quantum systems are fragile =>
single photon readout signals

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But detectors are not that “fragile”
So, do we need parametric amplifiers for detectors?

Let‘s take a look at RF resonators (detectors) readout

Increase kinetic inductance:

⇒ increase responsivity $\Re \sim \alpha = L_K/(L_K+L_G)$

Valenti et al. Phys. Rev. Applied 11, 054087 (2019)

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(Maleeva *et. al.*, Nat. Comm. 9:3889, 2018)

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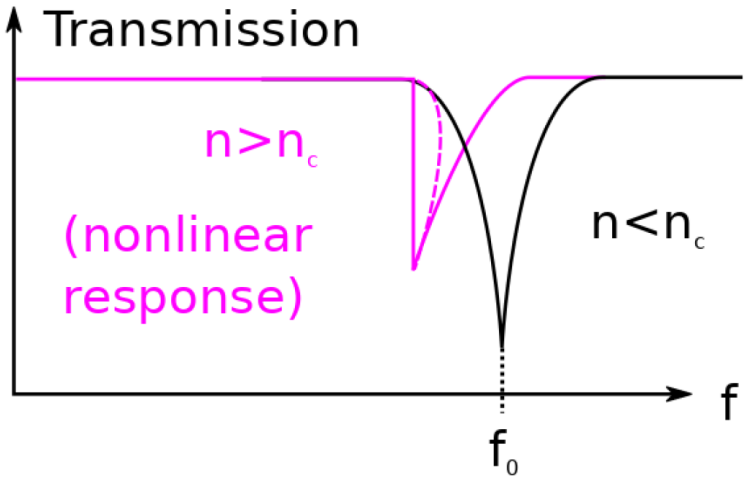

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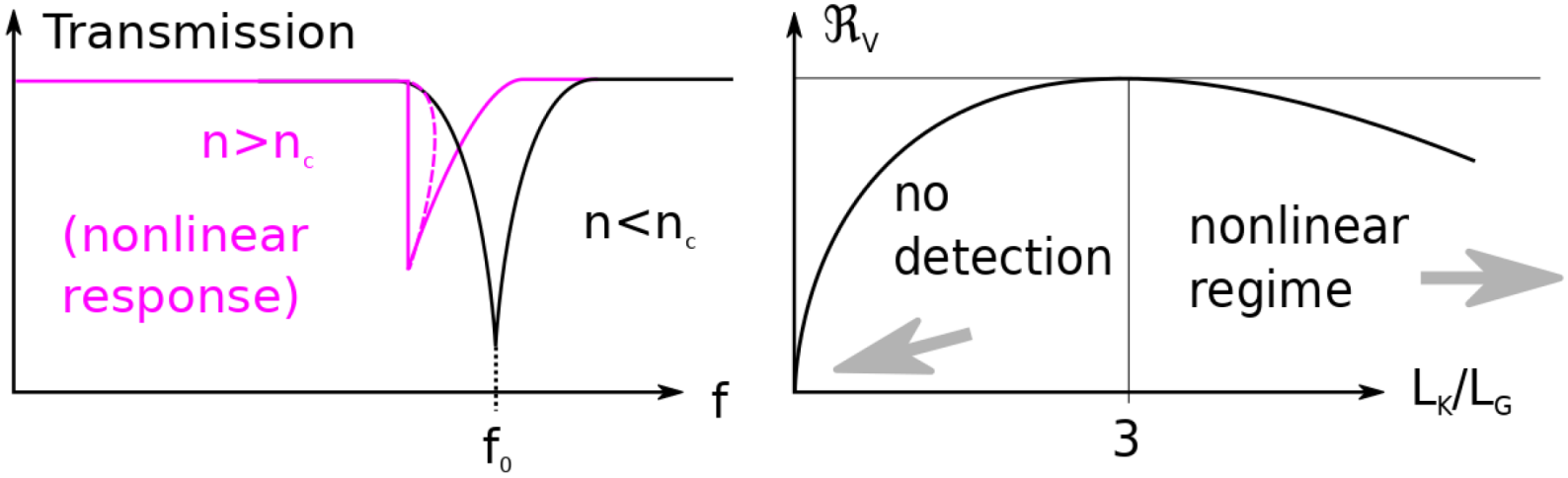
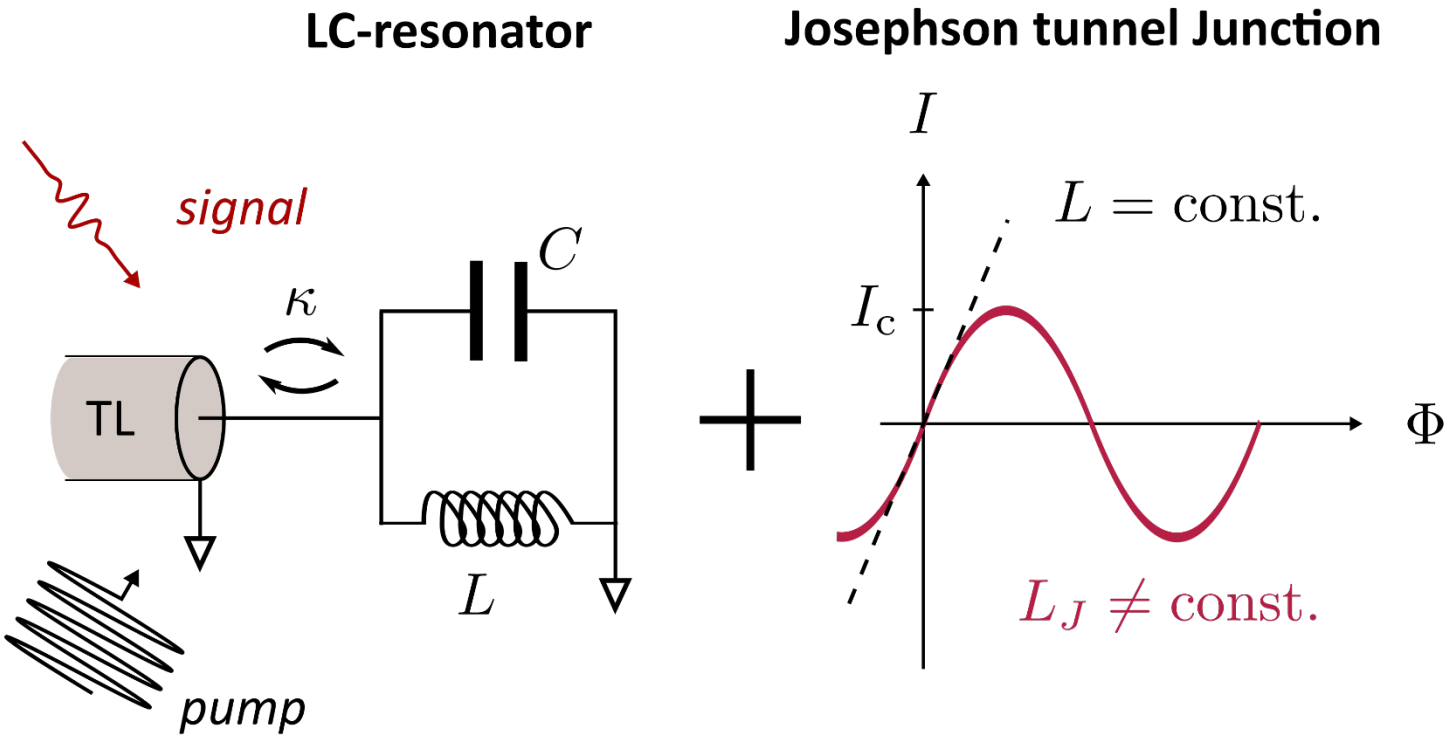


Encode interplay in **voltage responsivity**:

$$\Re_V = \alpha \times n_c^{1/2} \Rightarrow \text{maximum at } \alpha = 3/4$$

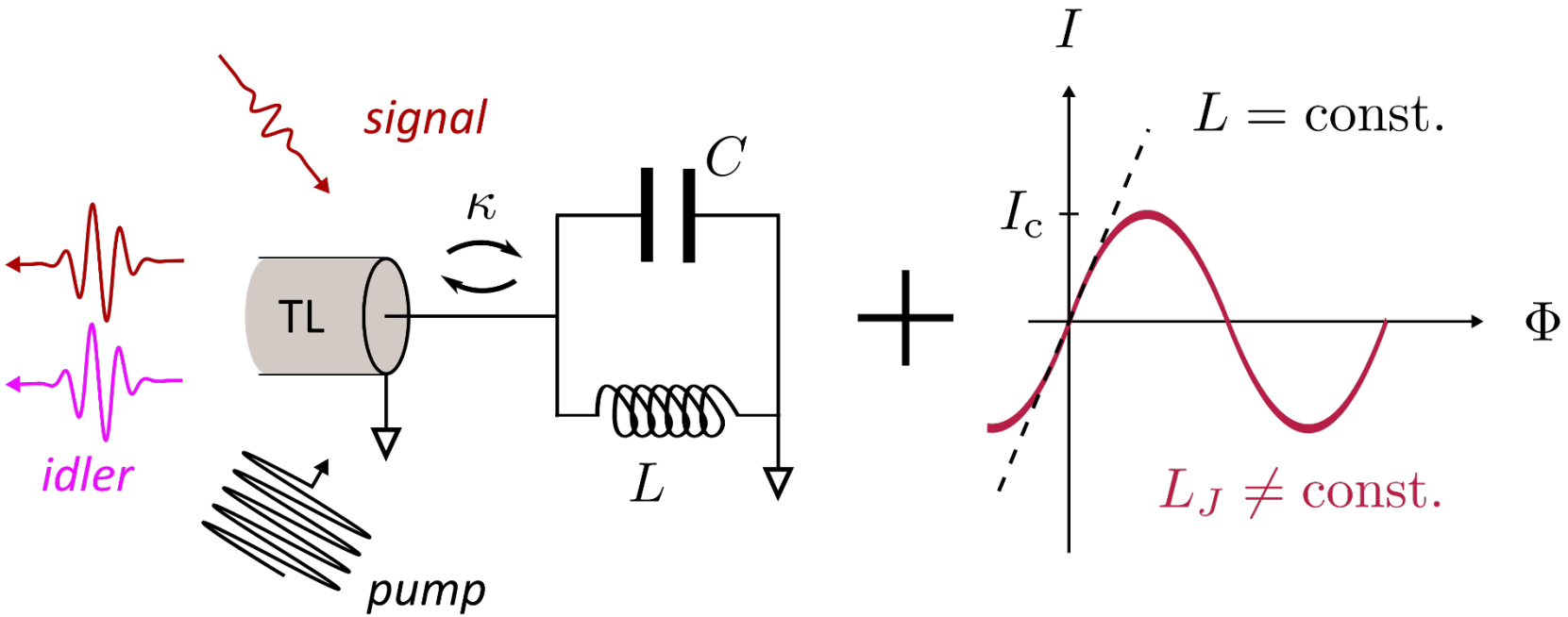
Valenti et al. Phys. Rev. Applied 11, 054087 (2019)

Josephson Parametric Amplifier (JPA)



Josephson Parametric Amplifier (JPA)

LC-resonator **Josephson tunnel Junction**



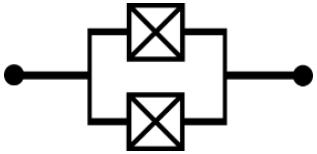
$$\omega_s + \omega_i = 2\omega_p$$

Parametric amplifier check list

- ***Enhance saturation power***

C. Eichler *et al.*, EPJQT (2014)

- ***Cover a large frequency band***

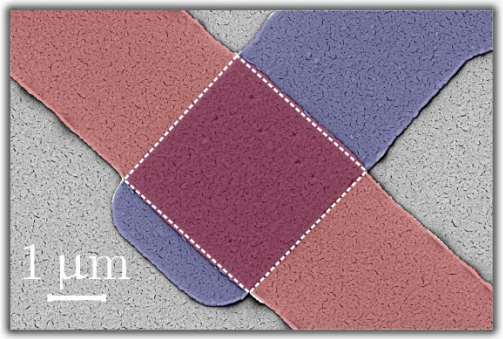


- ***Pump – signal separation in frequency***

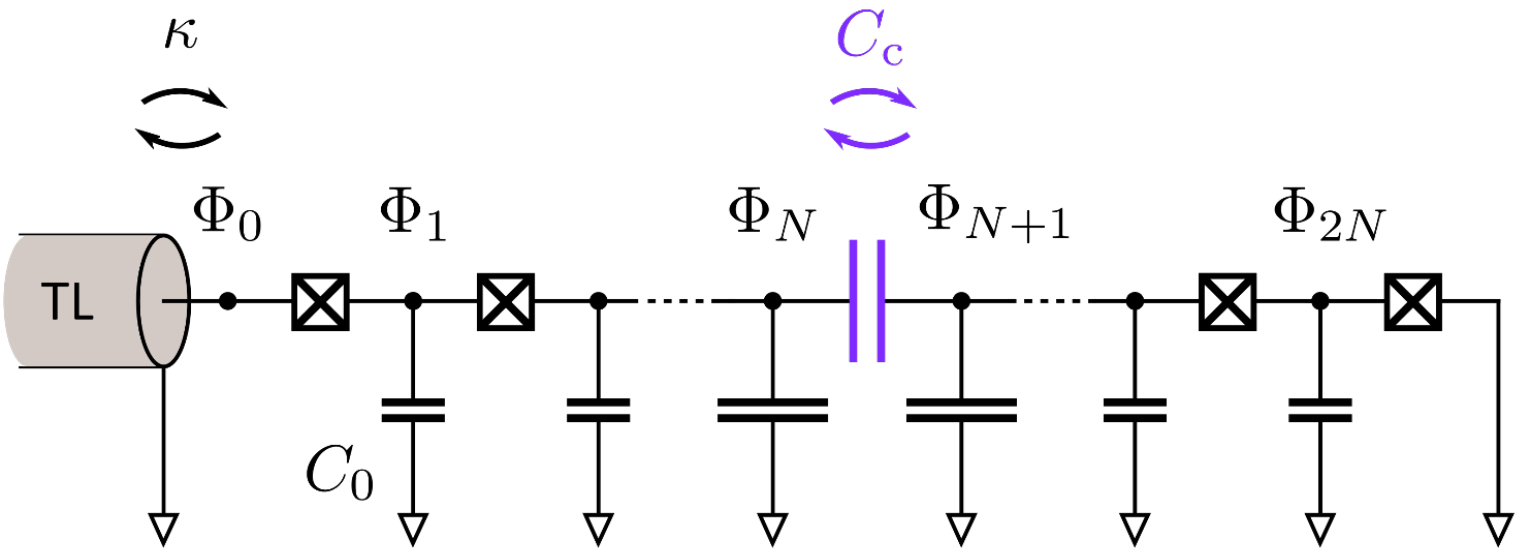
A. Roy, M. Devoret, CRP (2016)

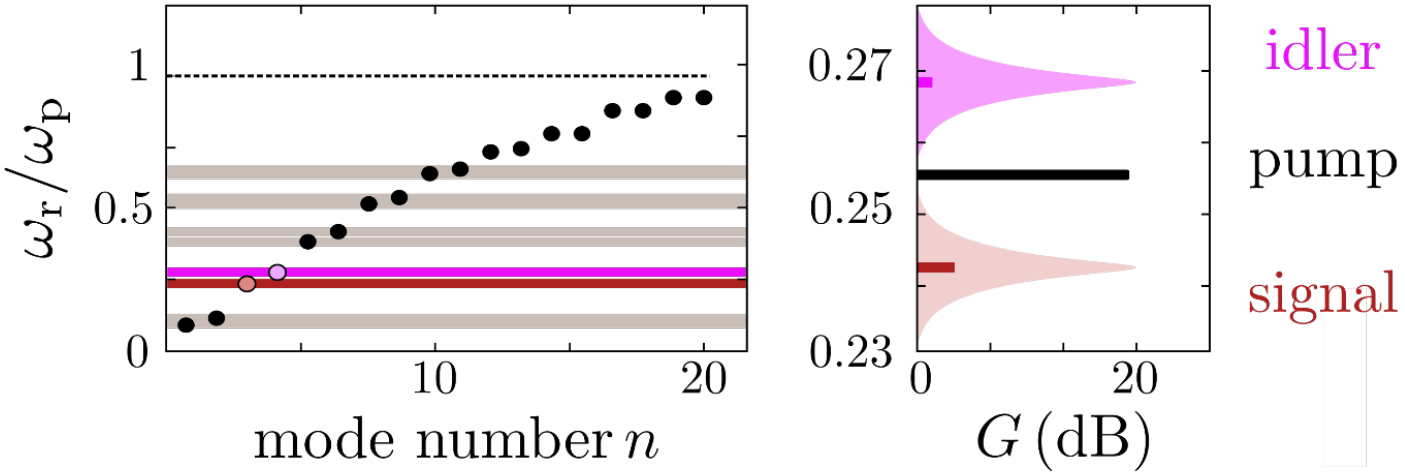
- ***Simple and cheap fabrication***

L. Grünhaupt *et al.*, APL (2017)



Dimer-Josephson-Junction-Array-Amplifier (DJJAA)





Winkel, Takmakov et al. Phys. Rev. Applied 13, 024015 (2020)

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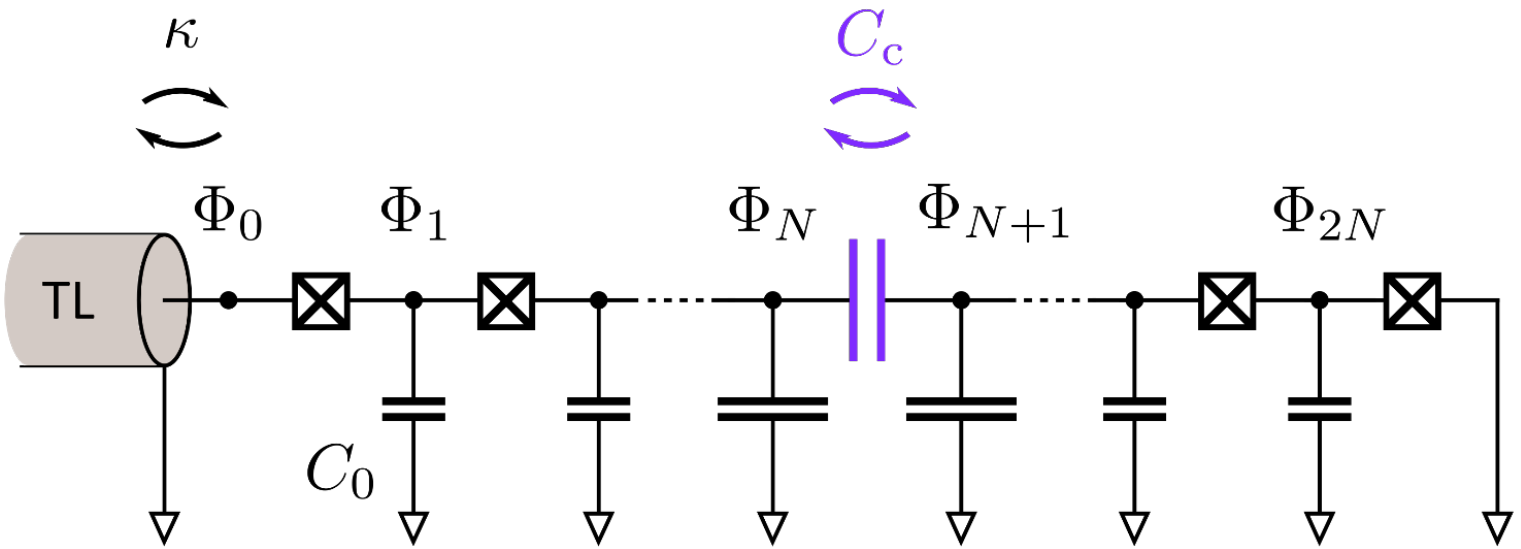

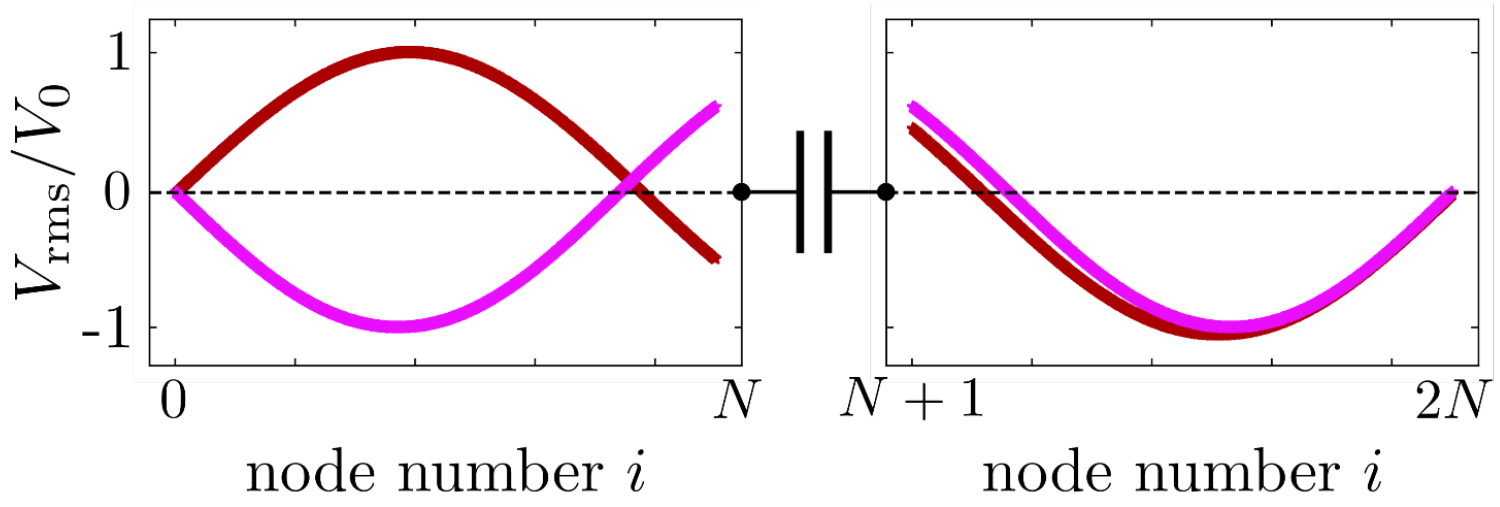

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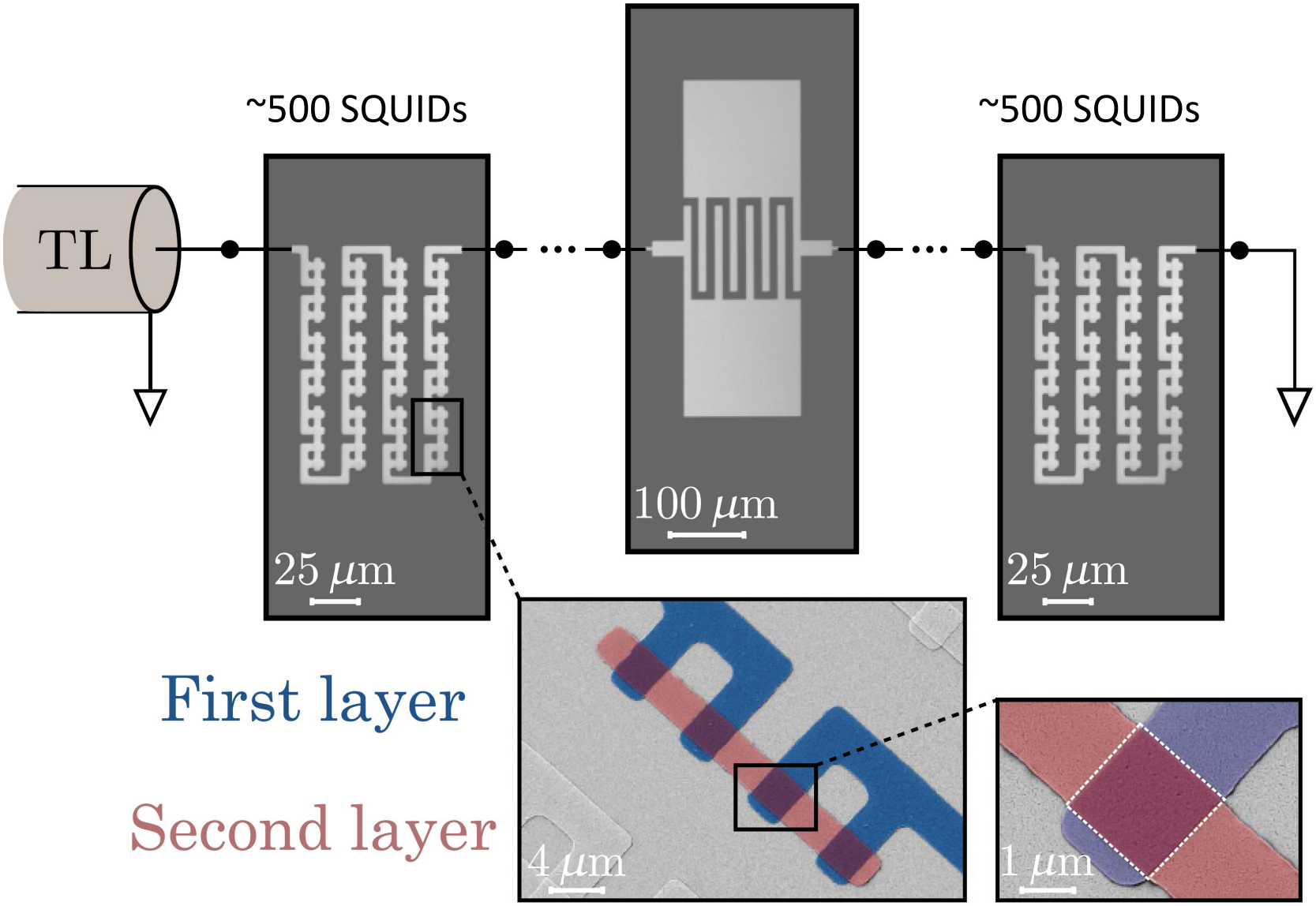
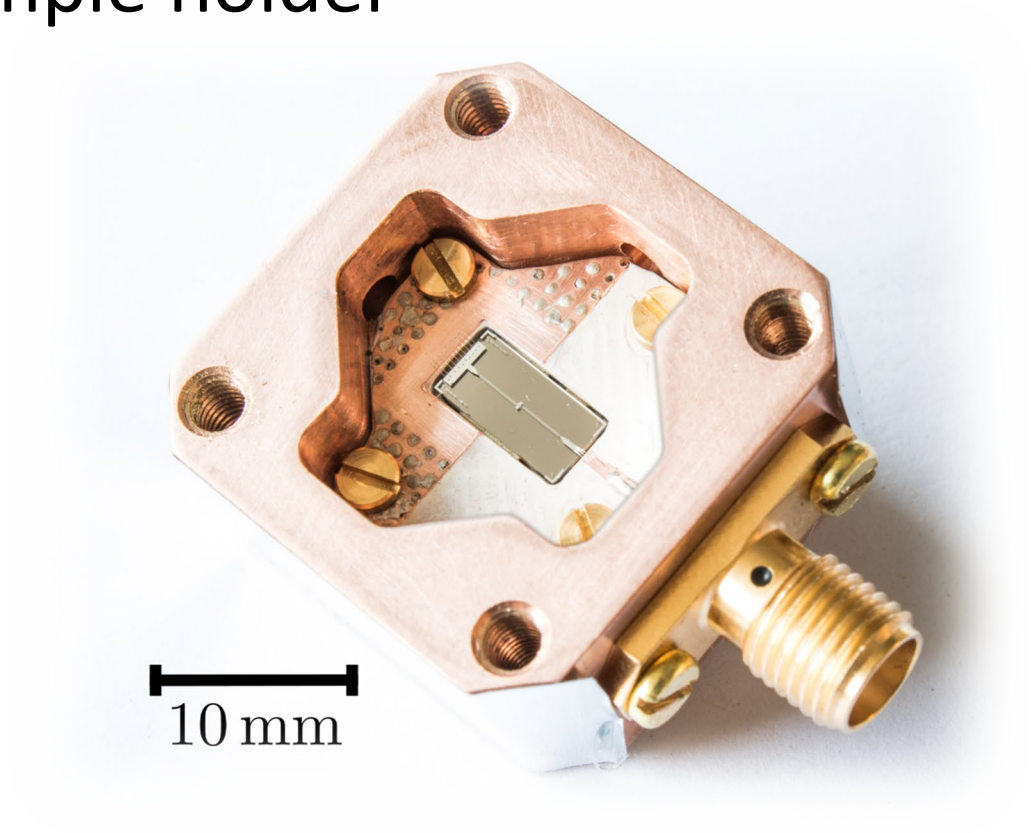
DJJAA Circuit design



Winkel, Takmakov et al. Phys. Rev. Applied 13, 024015 (2020)

Sample holder



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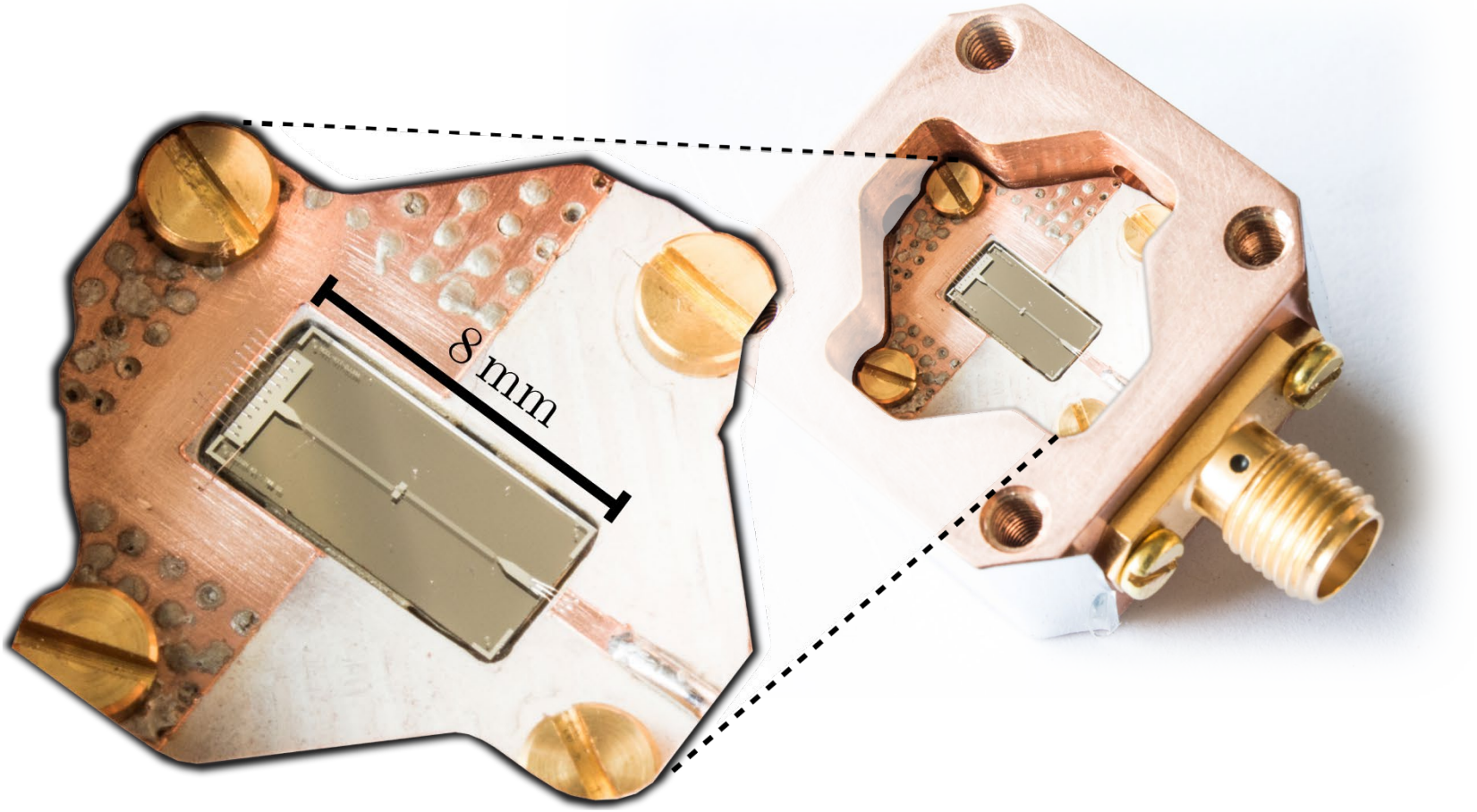

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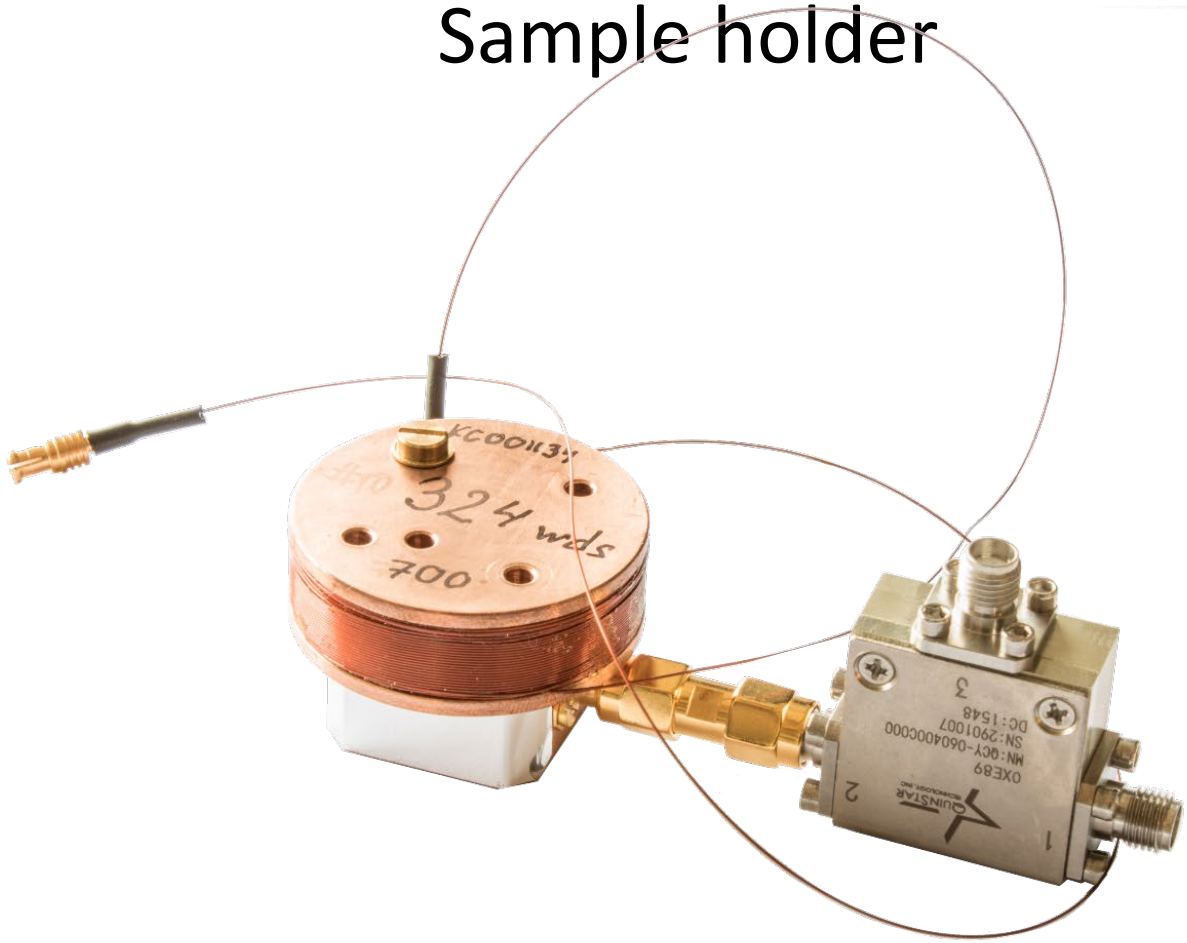

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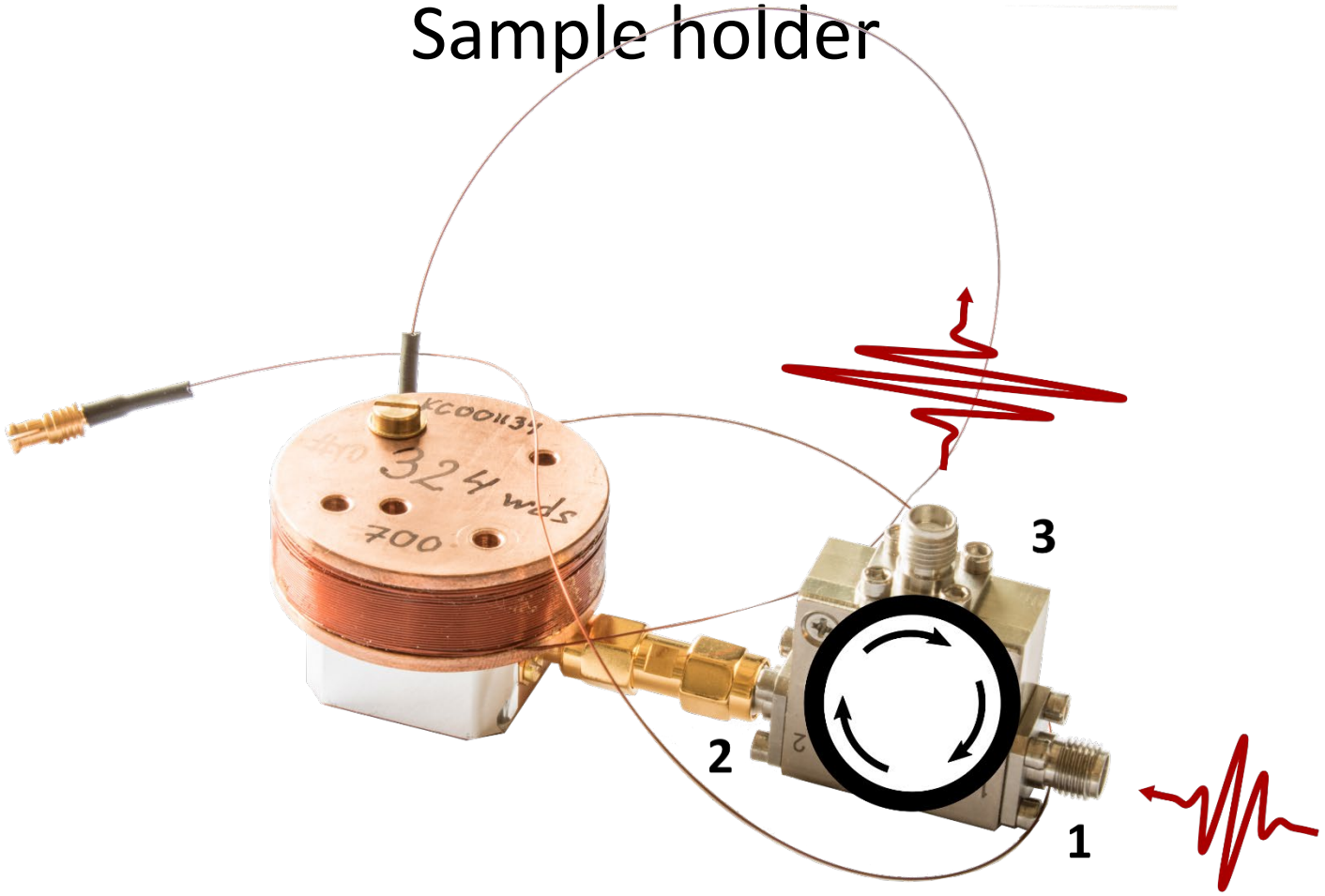
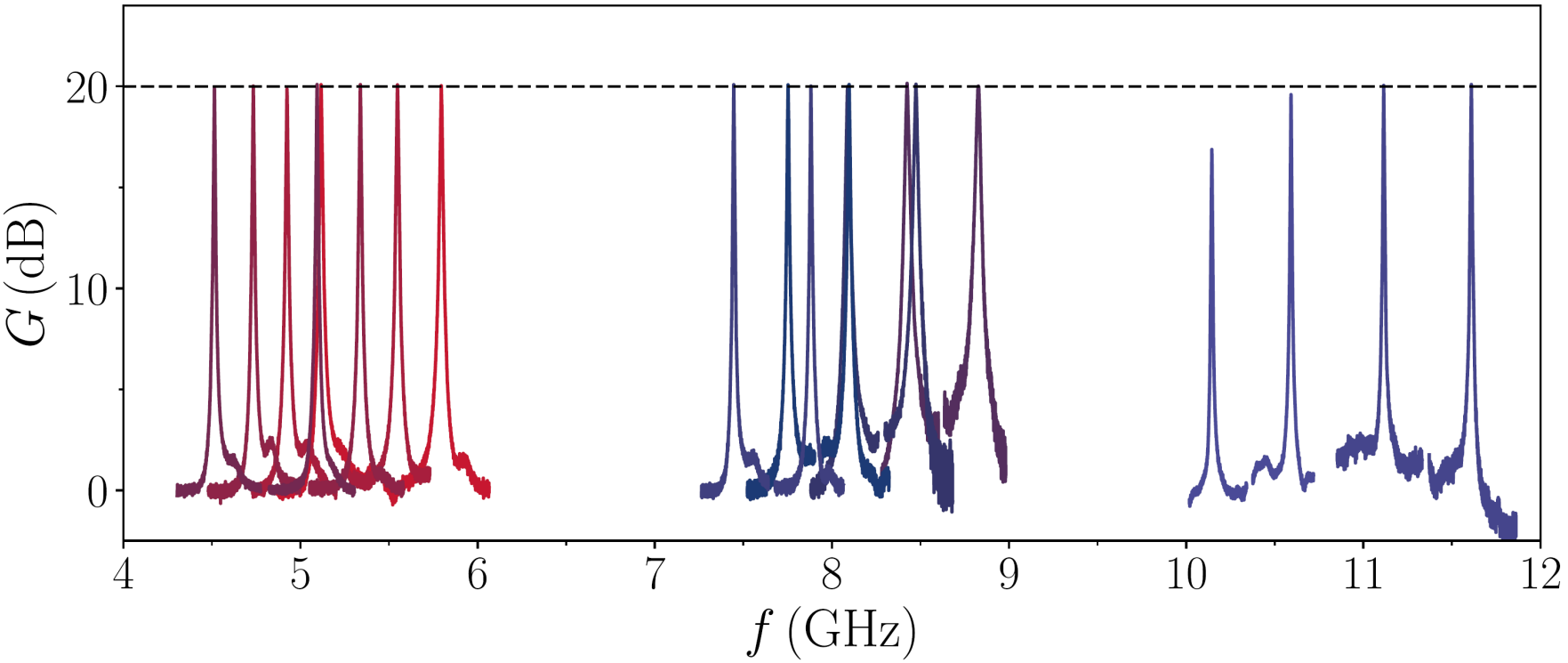
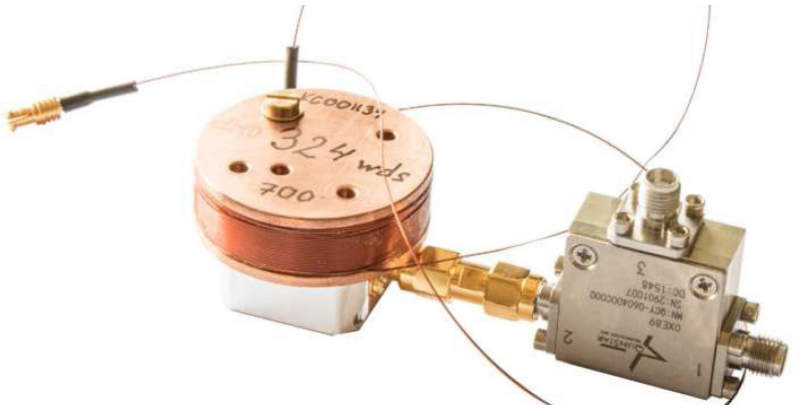


Winkel, Takmakov et al. Phys. Rev. Applied 13, 024015 (2020)

DJJAA gain



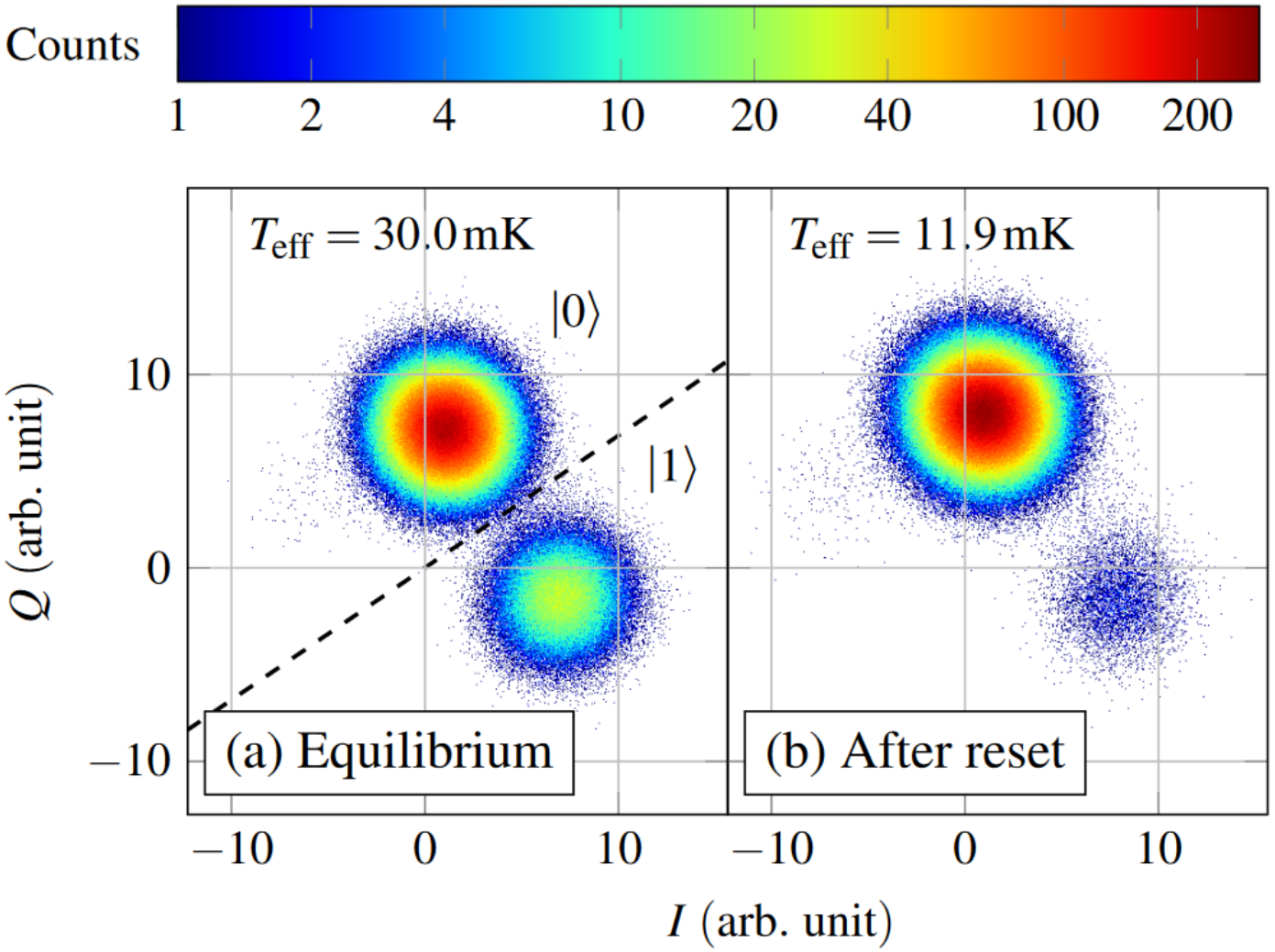


Saturation power:
-95 dBm

Winkel, Takmakov et al. Phys. Rev. Applied 13, 024015 (2020)

DJJAA in action

- using FPGA electronics from AG Sander and Weber (KIT-IPE) -



Richard Gebauer, et al., AIP Conference Proceedings 2241, 020015 (2020)

Conclusions:

- Josephson parametric amplifiers are an essential tool for quantum information processing

- JPAs might become a useful tool for detectors IF

* applications require powers in the -90 dBm range

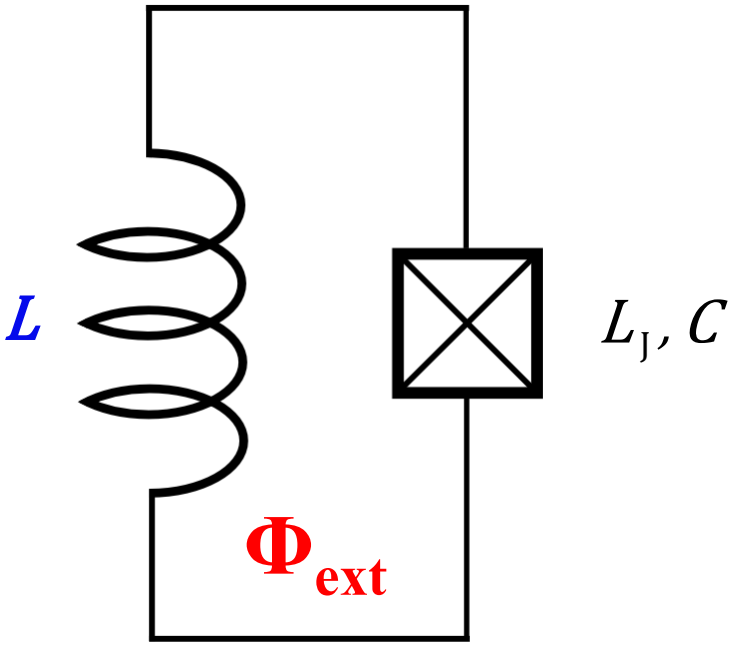
or

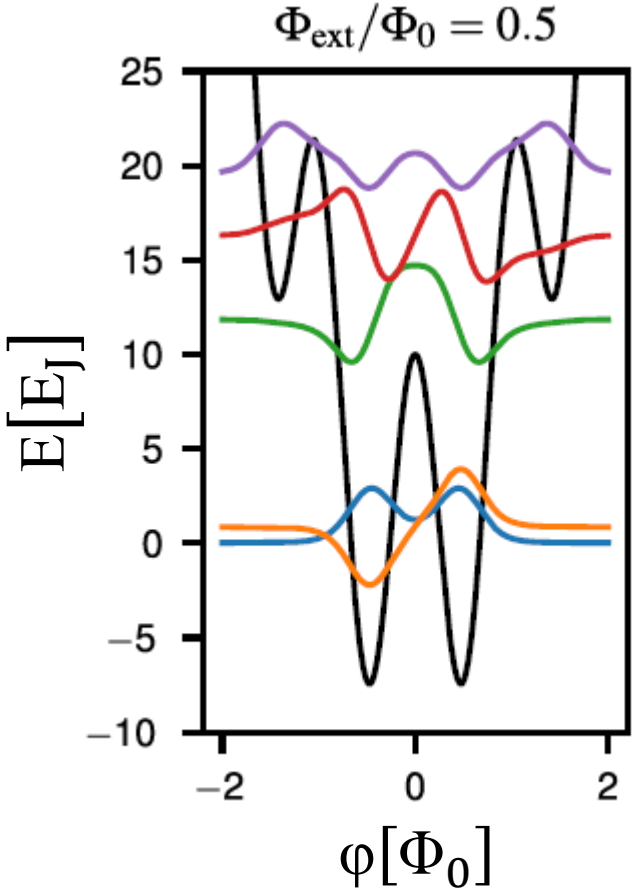
* quantum limited JPAs can exceed -90 dBm

Supplementary info

Fluxonium qubits

Manucharyan et al. Science (2009)





Needs “superinductance”:

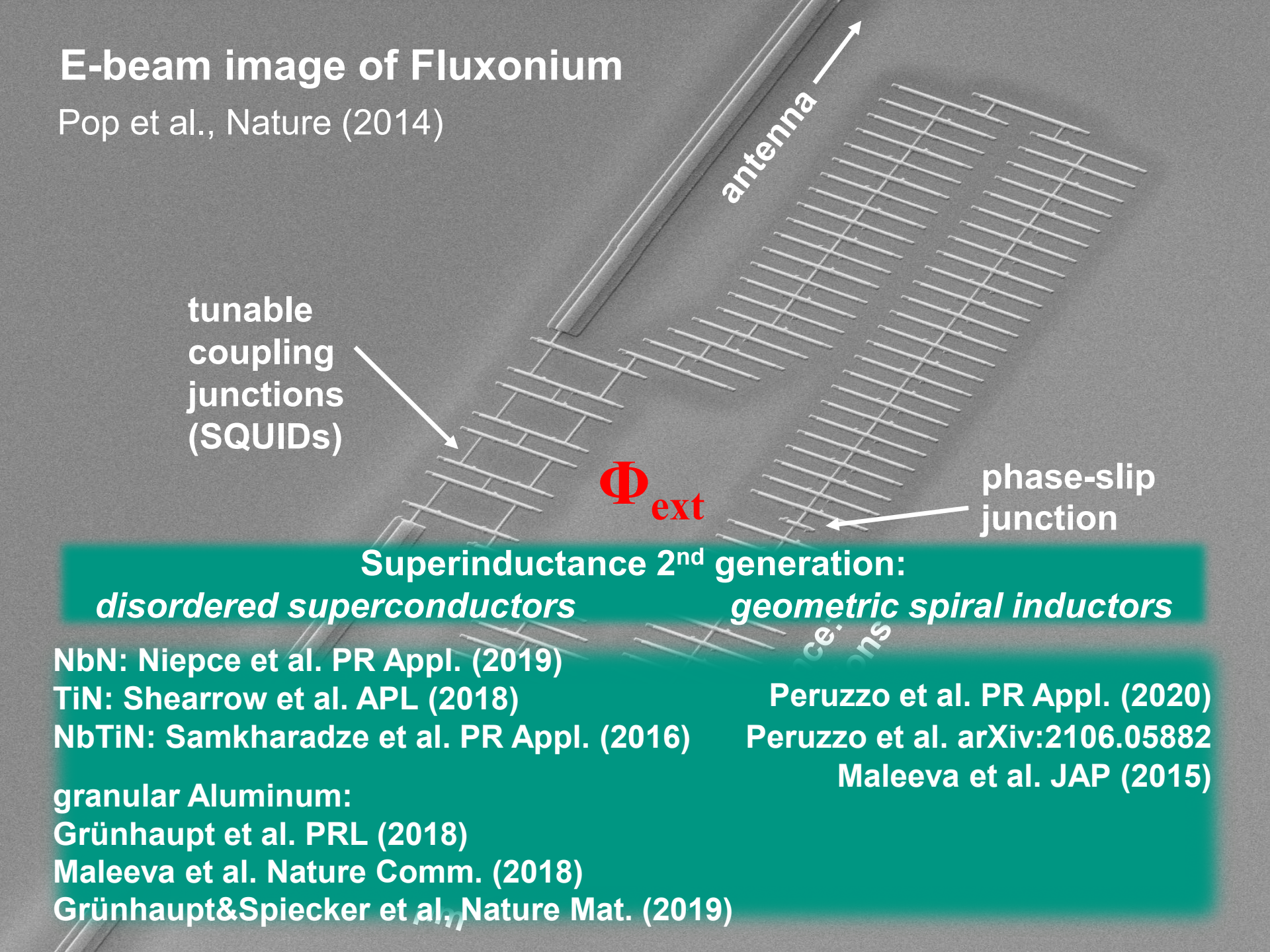
$$L\,\omega\big|_{10\mathrm{GHz}} \gg R_0 = \frac{h}{(2e)^2} = 6.4\ \mathrm{k\Omega}$$

Masluk et al. PRL (2012)
Bell et al. PRL (2012)
Pioneering by P. Delsing and D. Haviland
PRL 67 (1991), PRB 54 (1996), …

Pop et al. Nature (2014)
Earnest et al. PRL (2017)
Nguyen et al. PRX (2019)
Pita-Vidal et al. PRApp (2019)
Pechenezhskiy et al. Nature (2020)
Kalashnikov et al. PRX Q (2020)

E-beam image of Fluxonium

Pop et al., Nature (2014)



Superinductance 2nd generation:

disordered superconductors

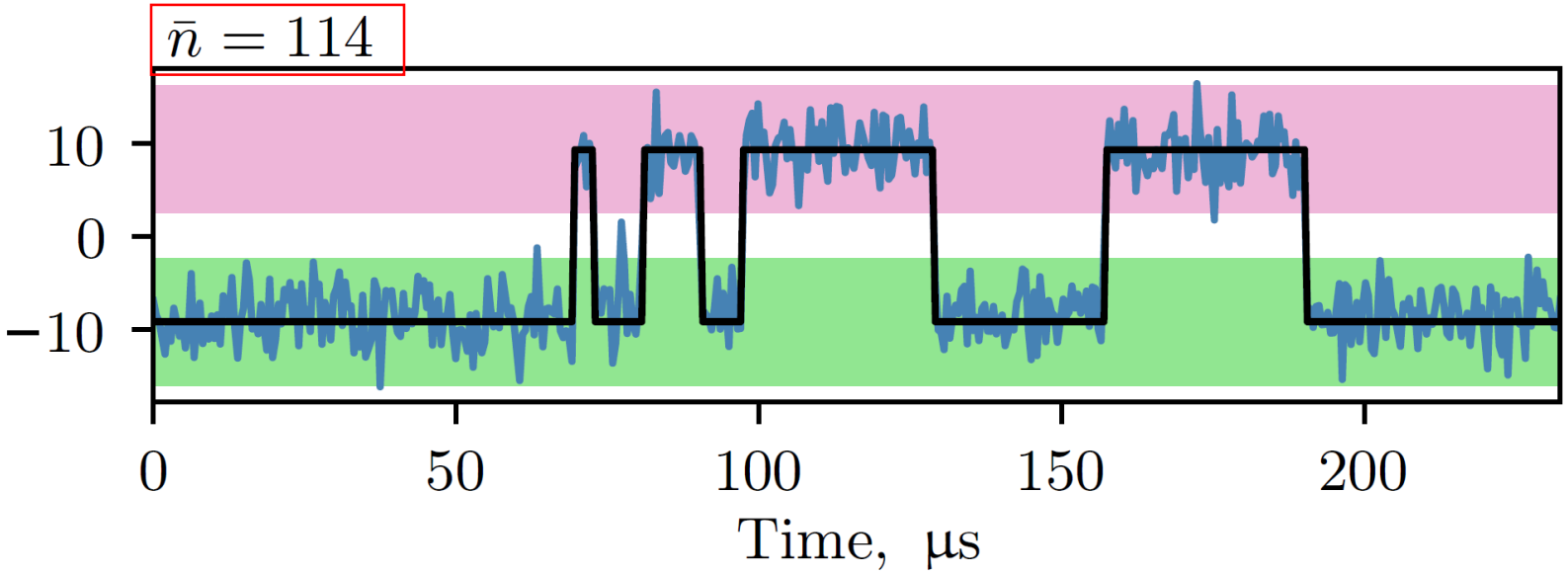
NbN: Niepce et al. PR Appl. (2019)
TiN: Shearrow et al. APL (2018)
NbTiN: Samkharadze et al. PR Appl. (2016)

granular Aluminum:
Grünhaupt et al. PRL (2018)
Maleeva et al. Nature Comm. (2018)
Grünhaupt&Spiecker et al., Nature Mat. (2019)

geometric spiral inductors

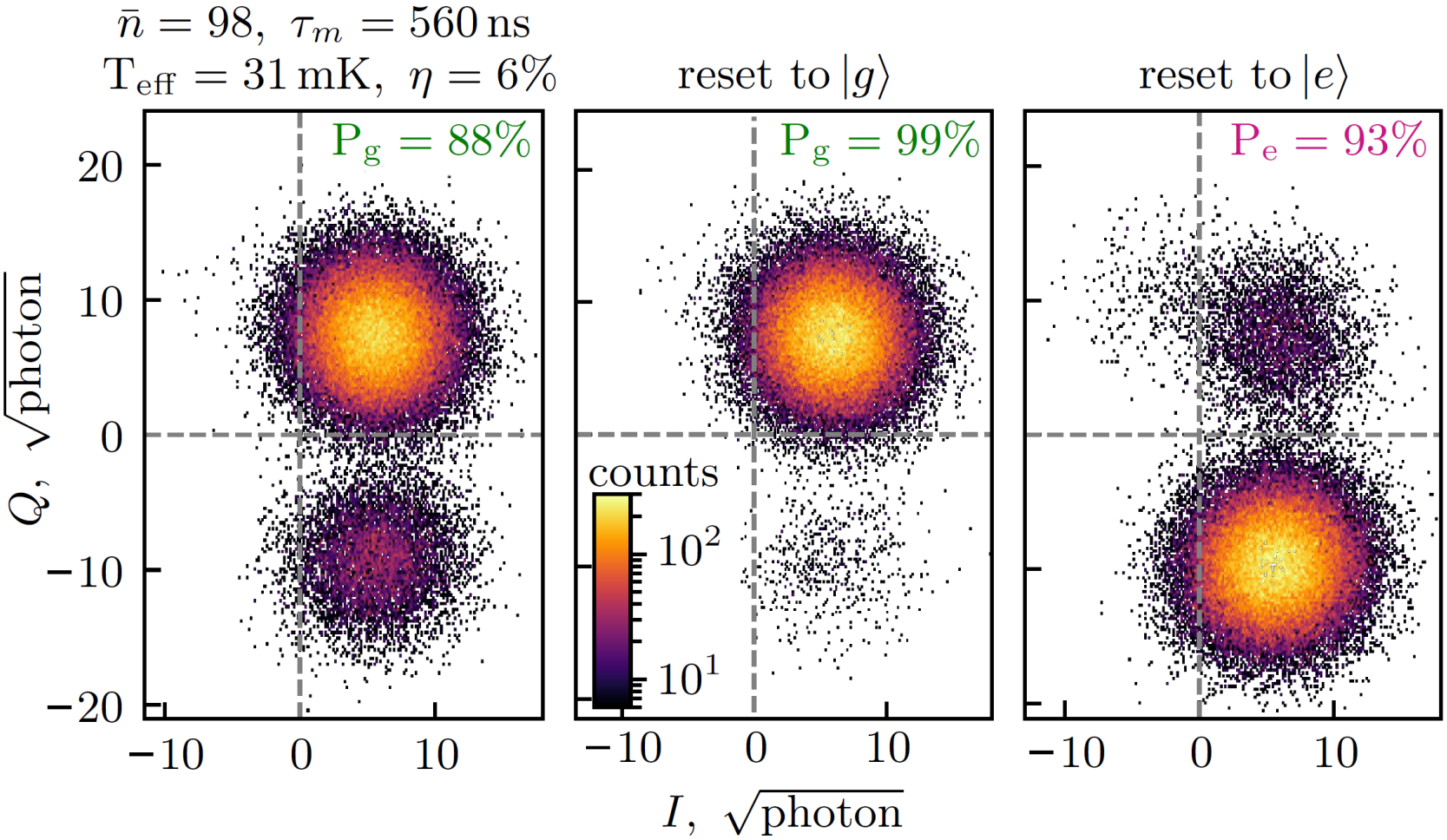
Peruzzo et al. PR Appl. (2020)
Peruzzo et al. arXiv:2106.05882
Maleeva et al. JAP (2015)

GrAl fluxonium: resilience to readout photons



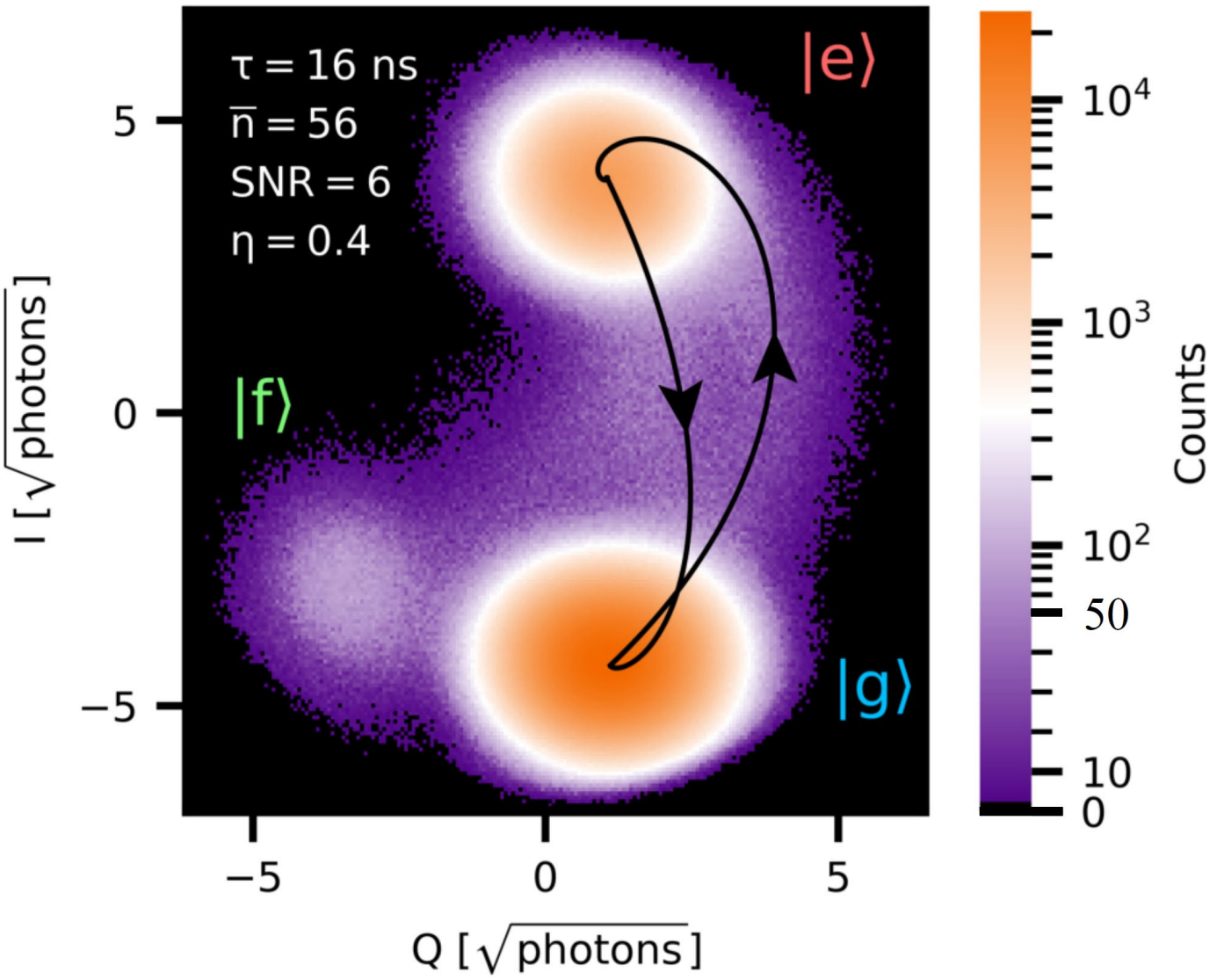
Gusenkova, Spiecker et al., Phys. Rev. Applied 15, 064030 (2021)

GrAl fluxonium: resilience to readout photons



Gusenkova, Spiecker et al., Phys. Rev. Applied 15, 064030 (2021)

GrAl fluxonium + high dynamic range DJJAA



Takmakov, Winkel et al., Phys. Rev. Applied 15, 064029 (2021)