Dark matter search with single-photon resolution Quantum Capacitance Detectors (QCDs)

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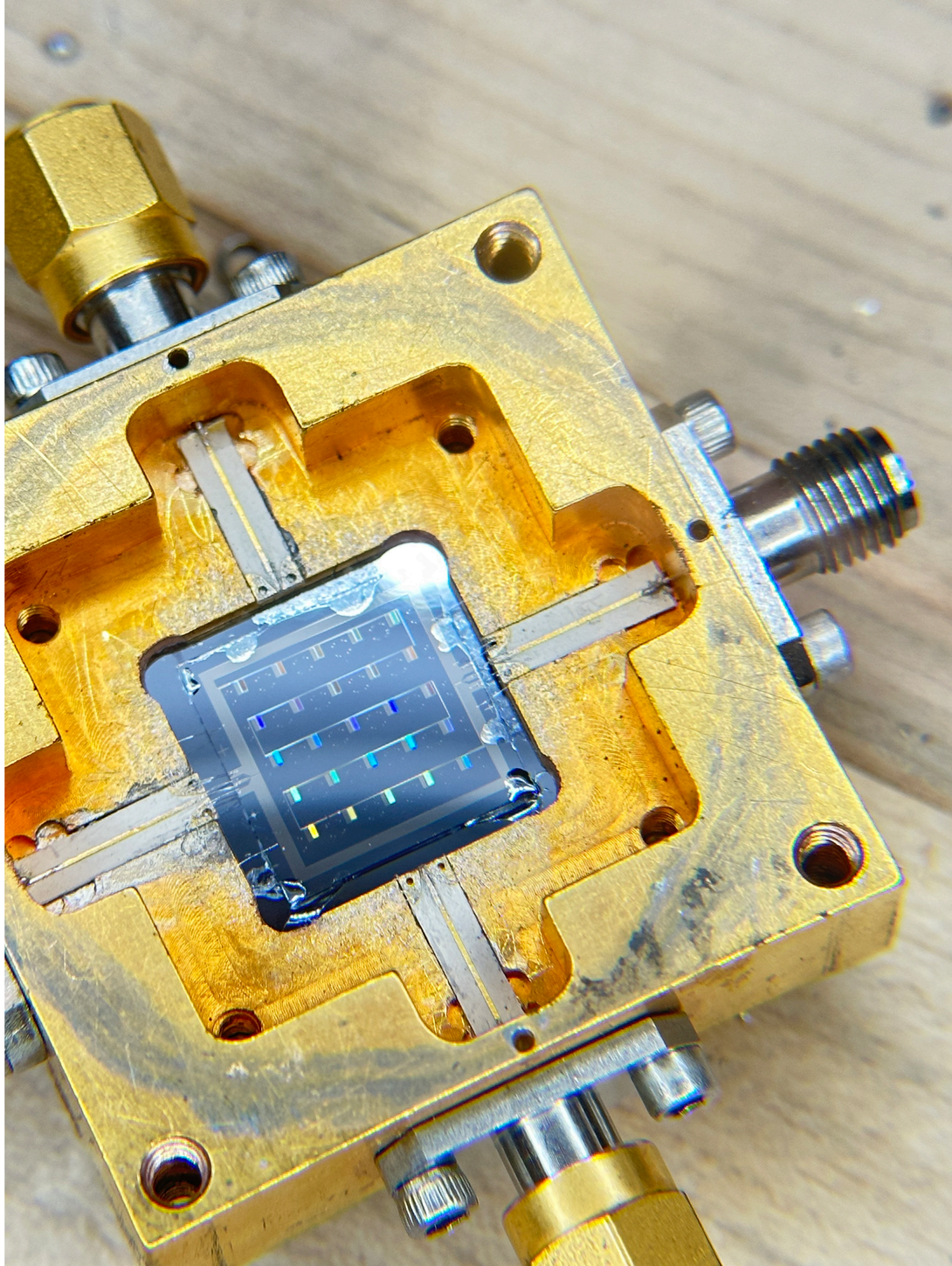
CPAD2023



Fermilab ILLINOIS TECH QuantiSED

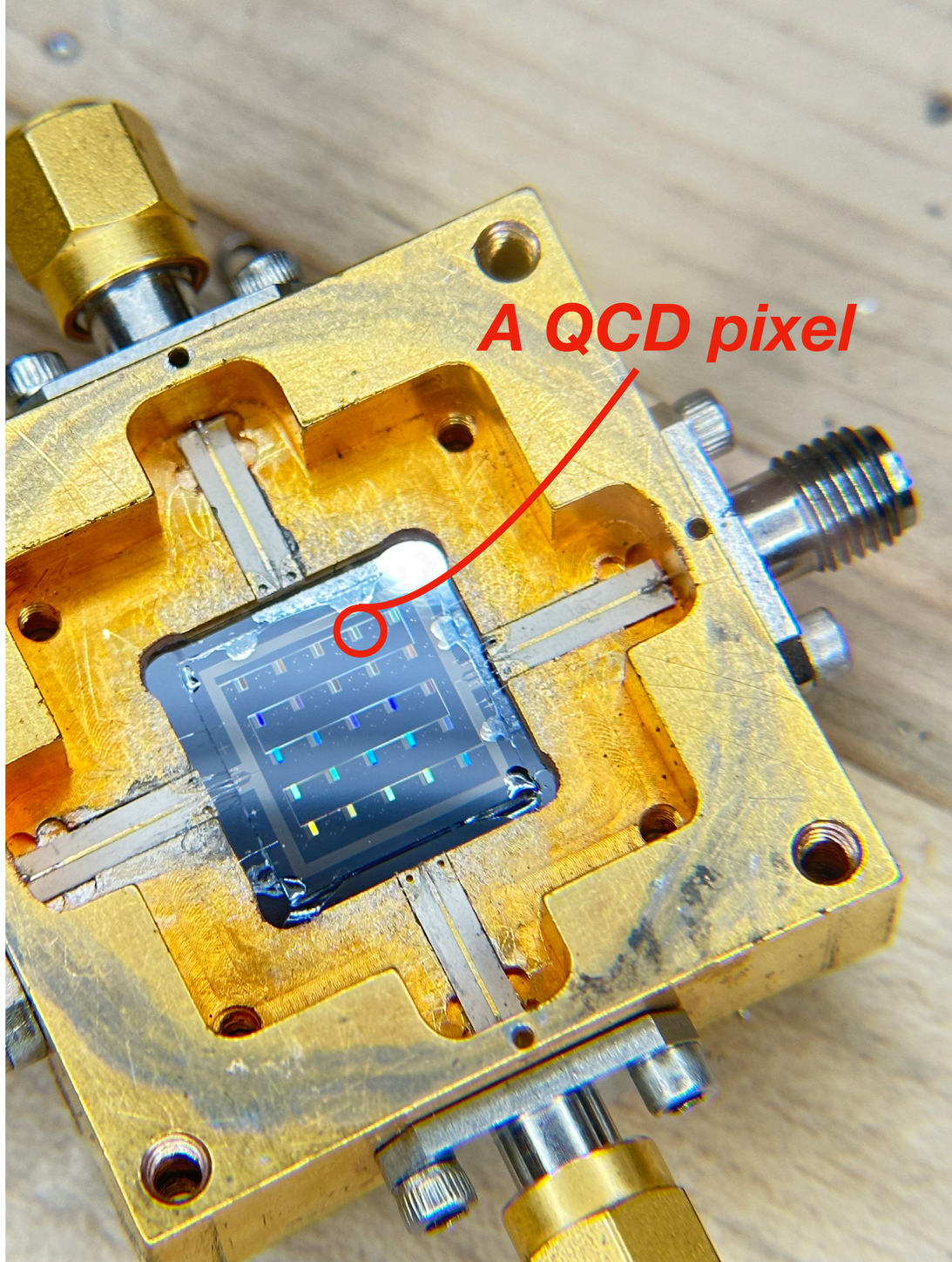
FERMILAB-SLIDES-23-353-ETD

What is : Quantum Capacitance Detector(QCD) ?

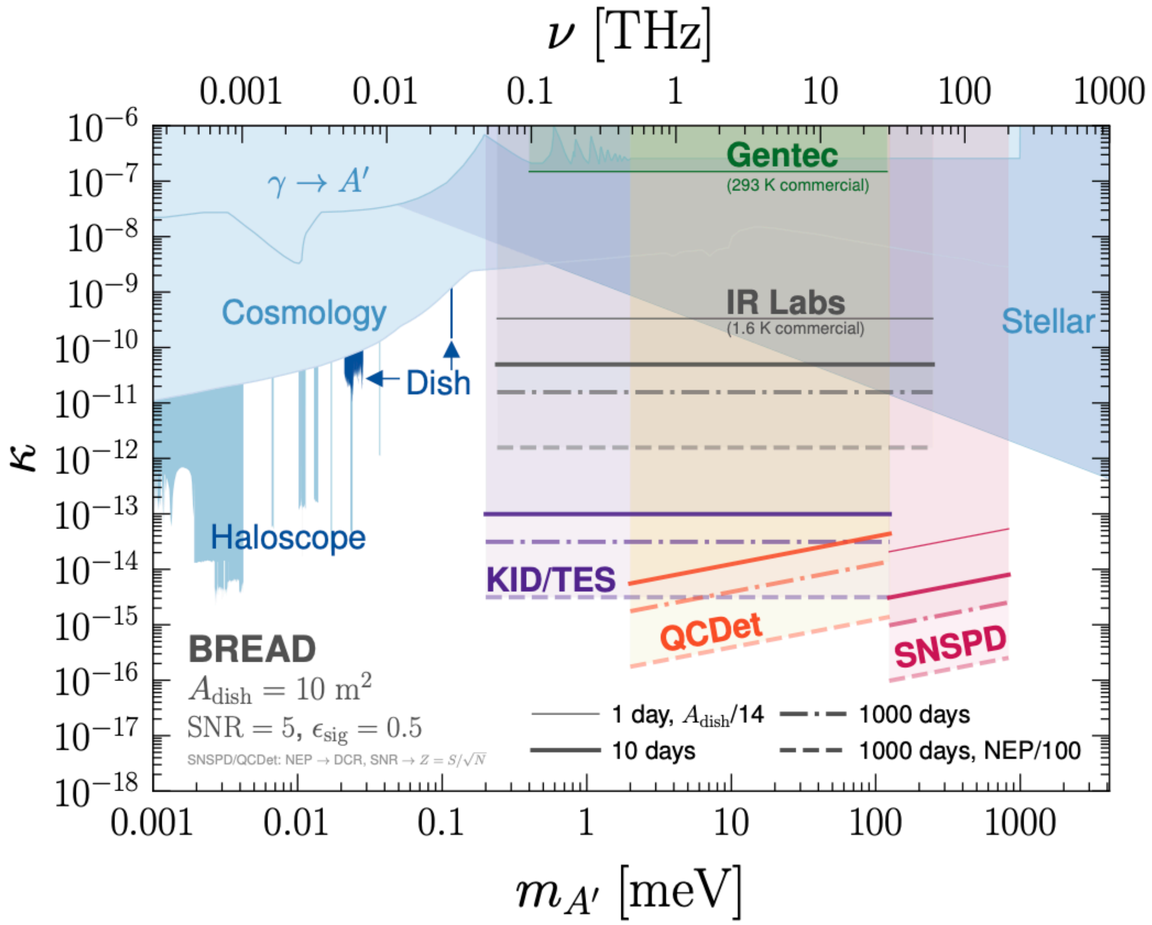
- A superconducting **quantum detector** based on **charge qubit**
- Fabricated by **JPL/NASA** for far-infrared spectroscopic mission
- The most sensitive **far-infrared (1.5THz) single photon detector.**
- Has low Noise Equivalent Power :

$$NEP < 10^{-20} W/Hz^{1/2}$$

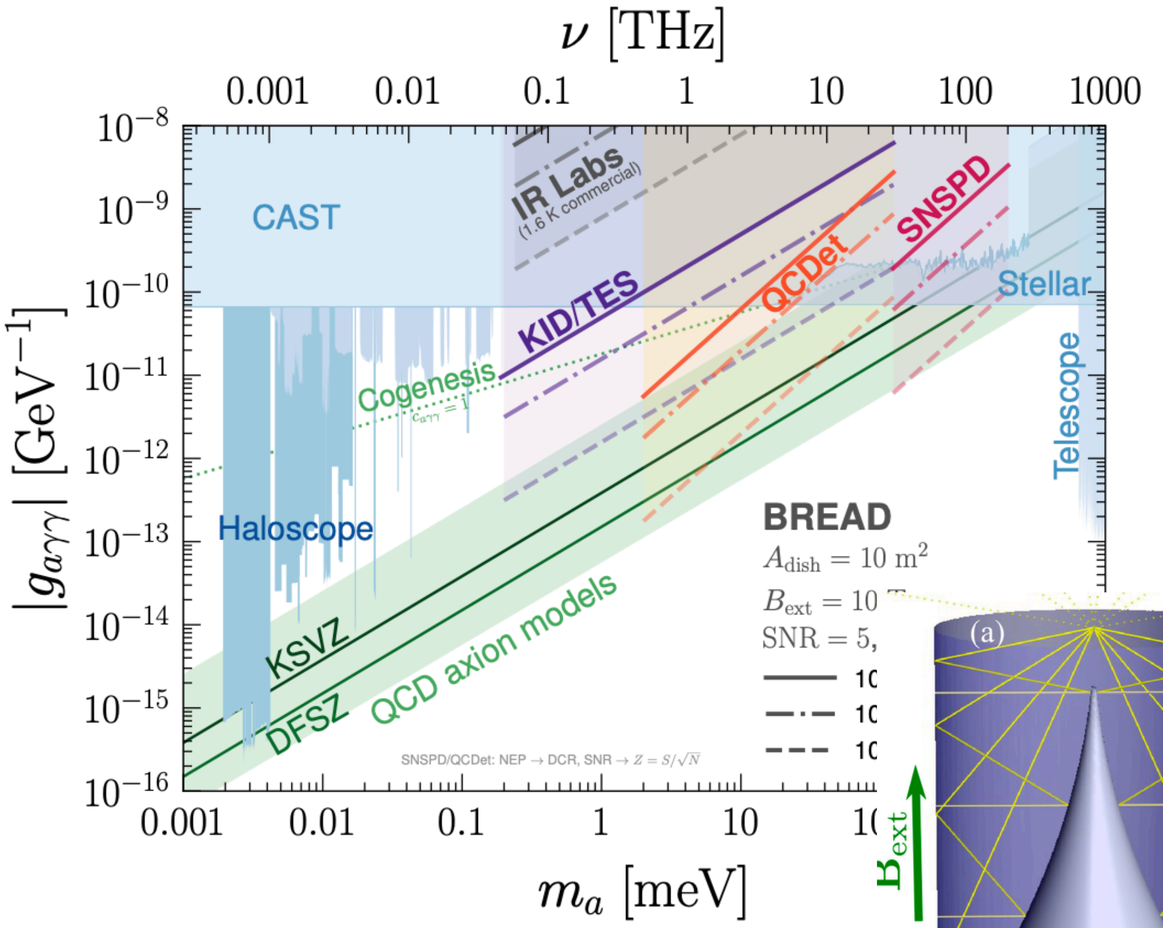
- See Pierre's Echternach's Poster (id#52)



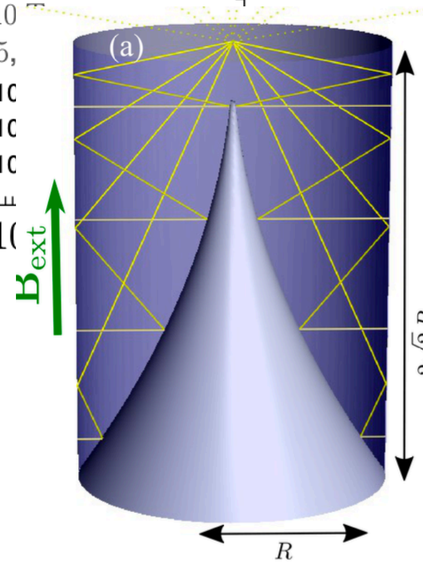
Projected sensitivity to dark matter using QCD



Hidden photon dark matter

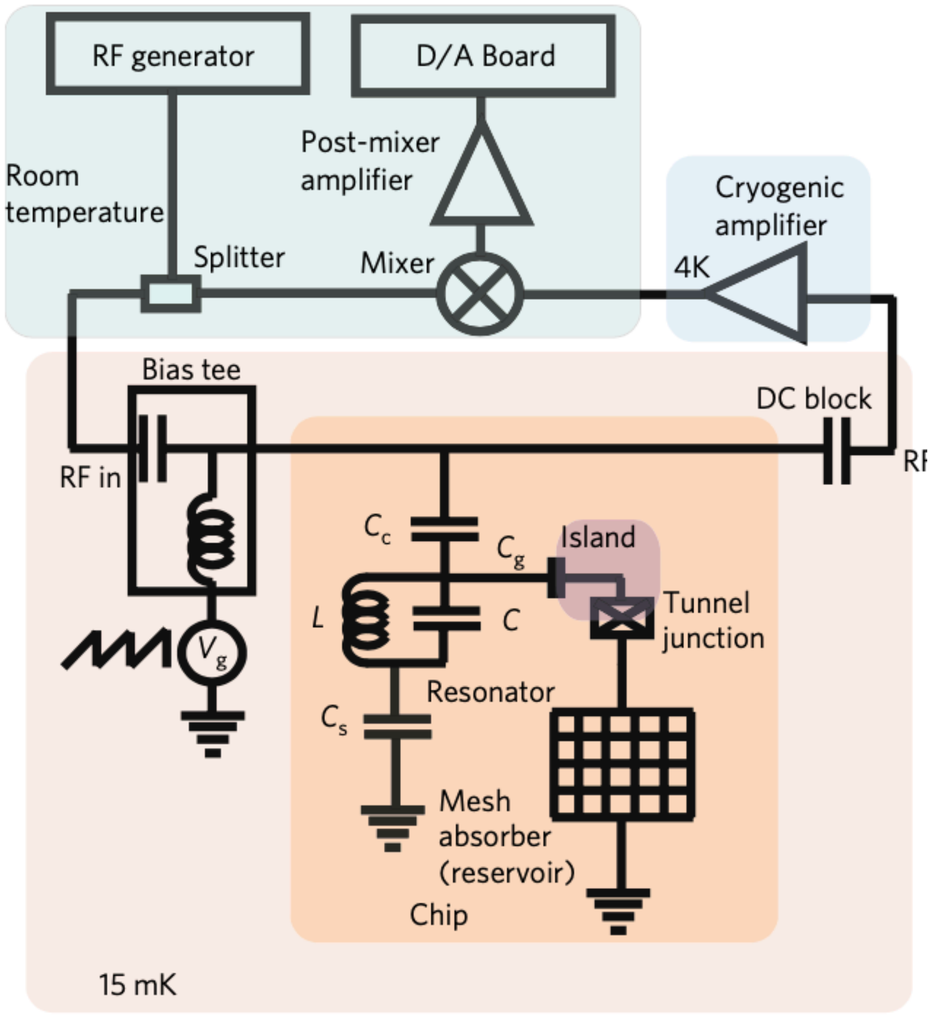


Axion dark matter

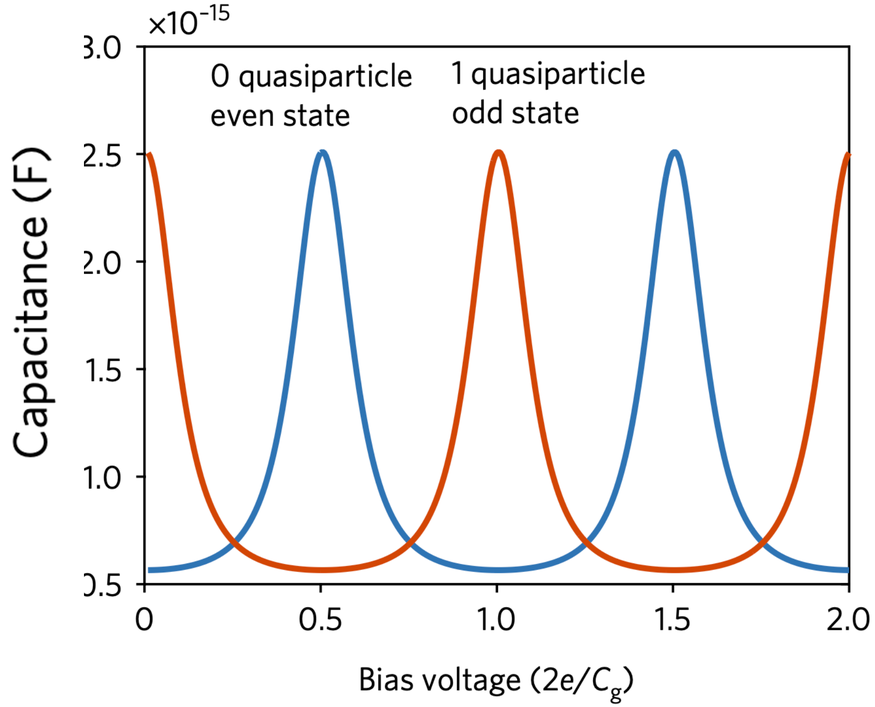


Liu, Jesse, et al. *Physical Review Letters* 128.13 (2022): 131801.

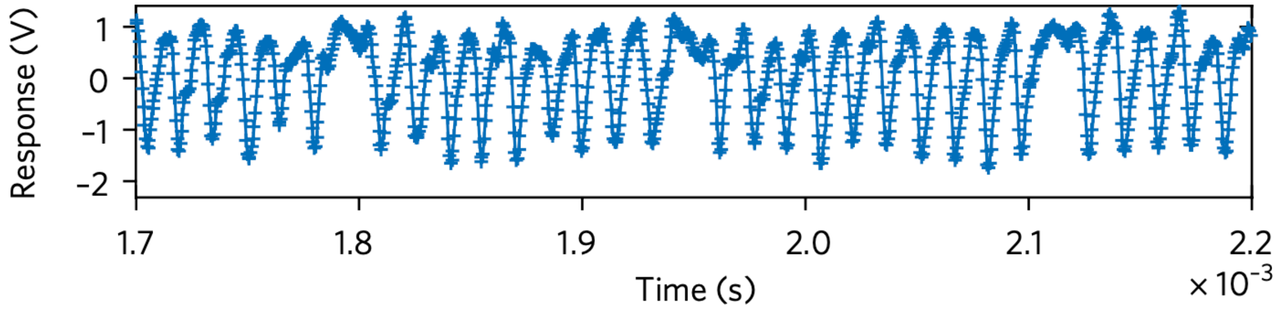
How does QCD work?



Schematic of a QCD circuit



Simulated quantum capacitance trace

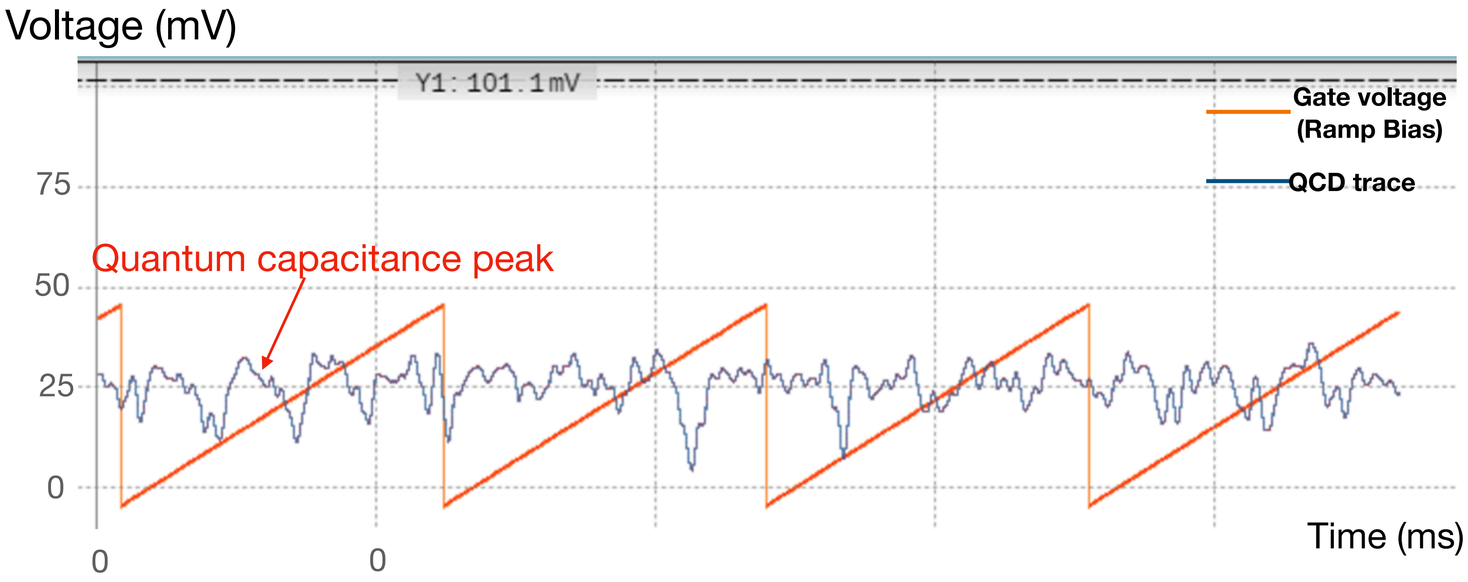


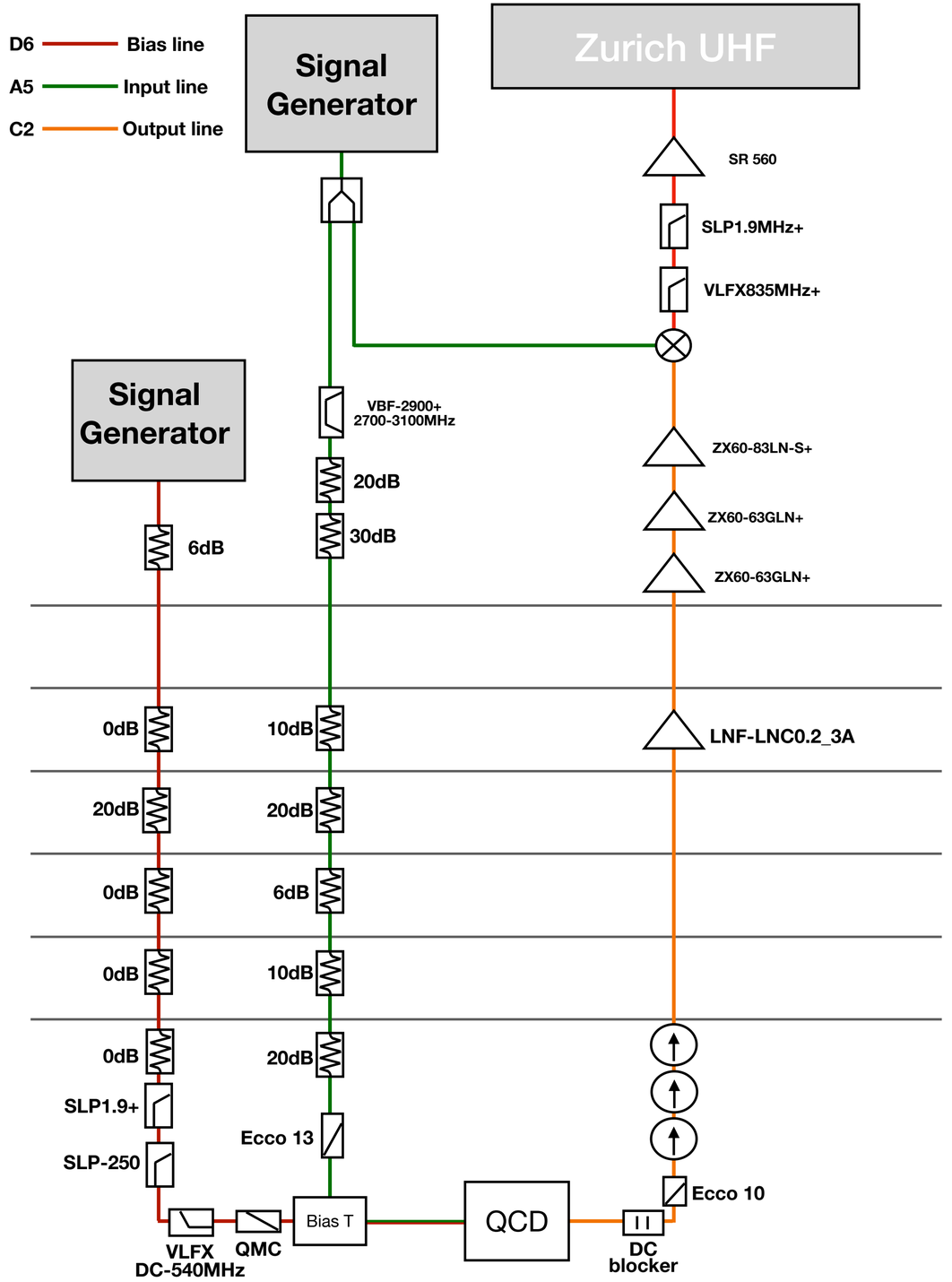
Real time data

Echternach, P. M., et al. *Nature Astronomy* 2.1 (2018): 90-97.

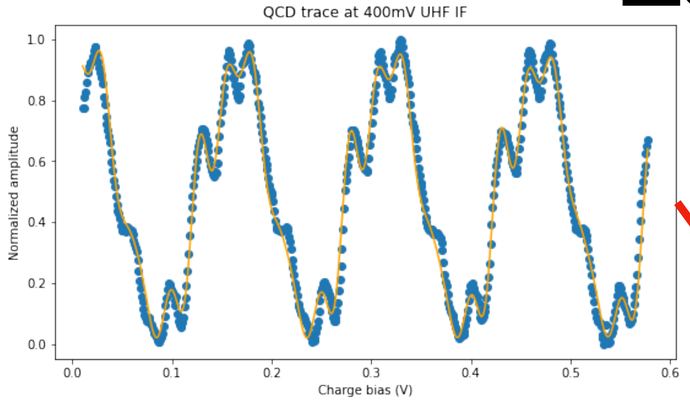
QCD Readout

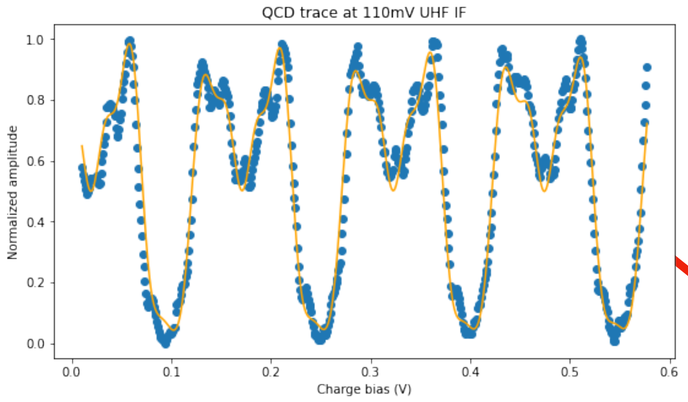
- Sweep the gate voltage that spans a few quantum capacitance peaks.
- Counting the missing peaks (tunneling event)
- Missing peak rate shows that the dark count rate is high at this point

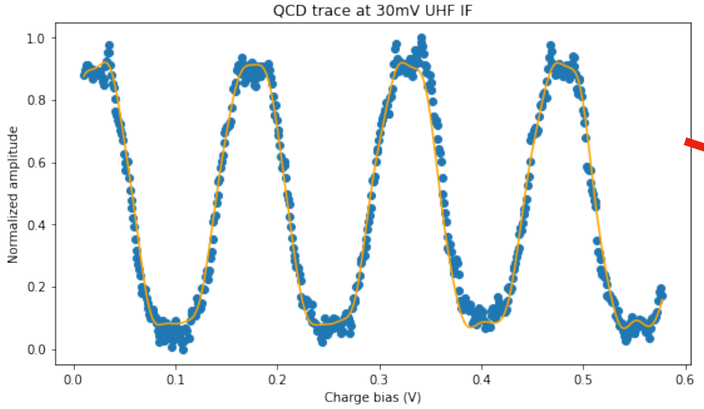


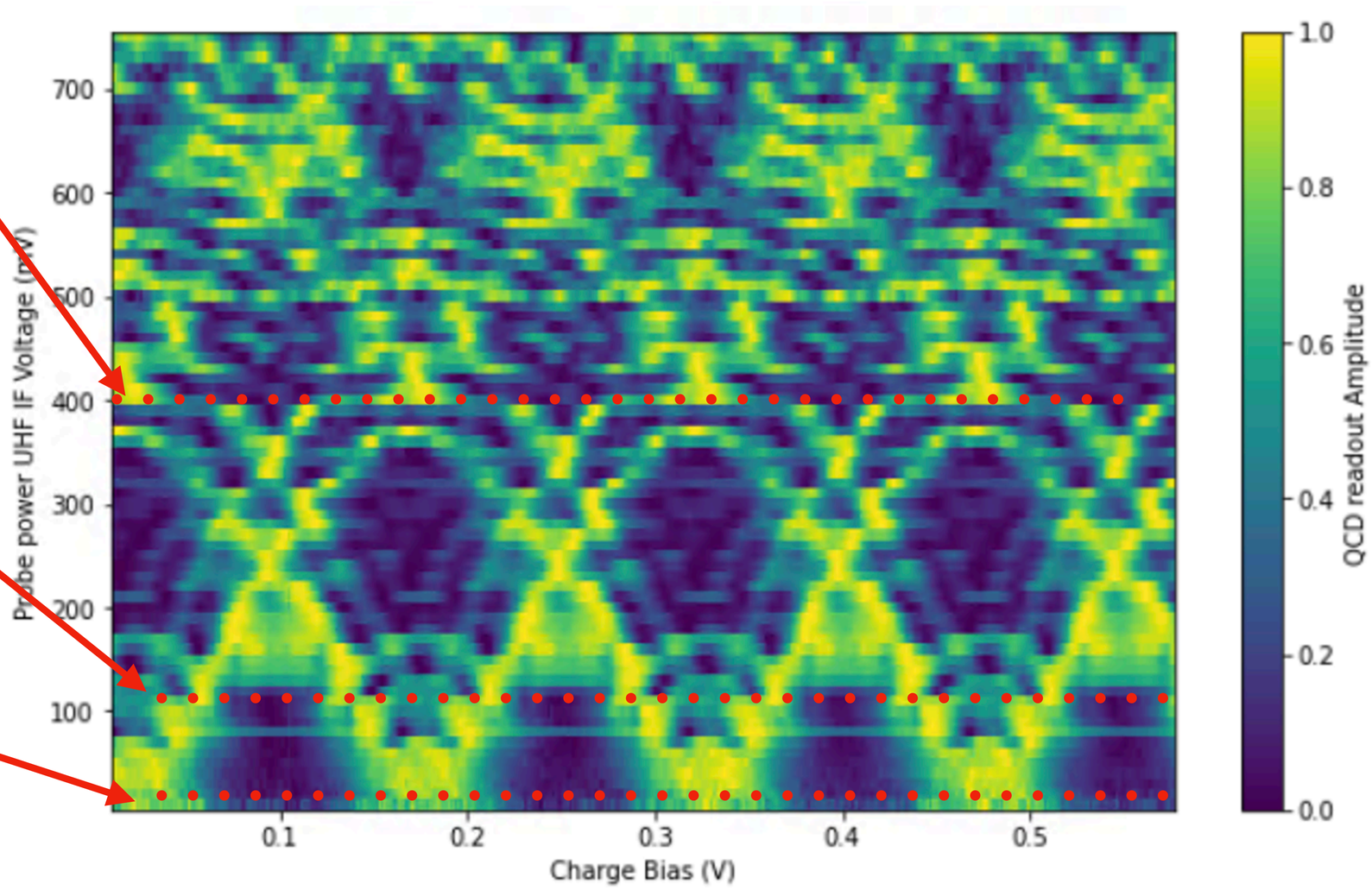


Landau Zener transition





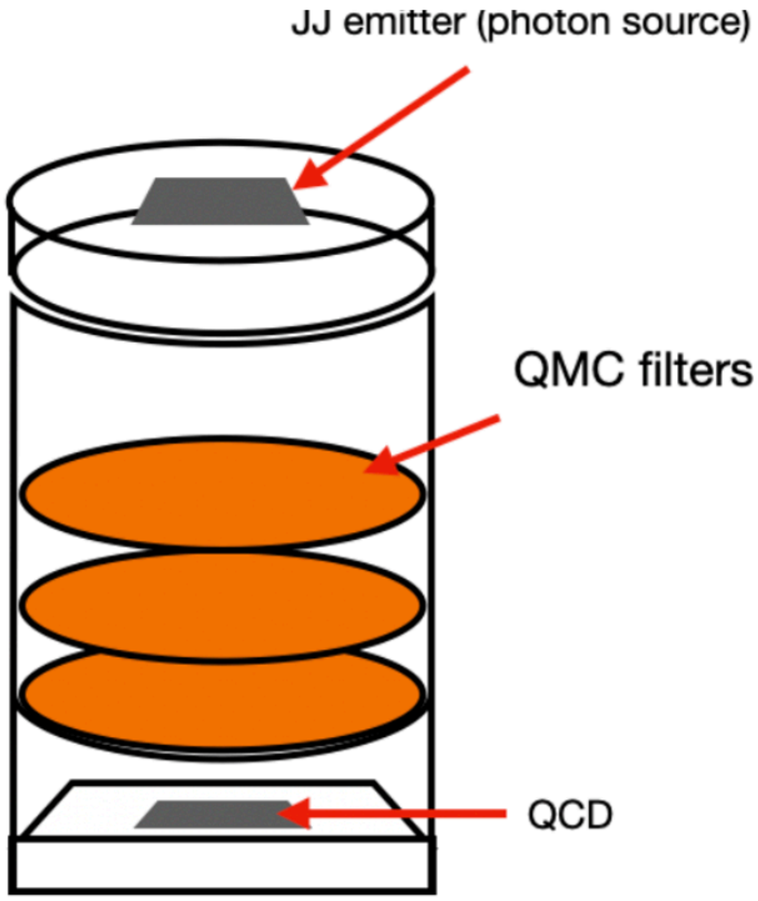




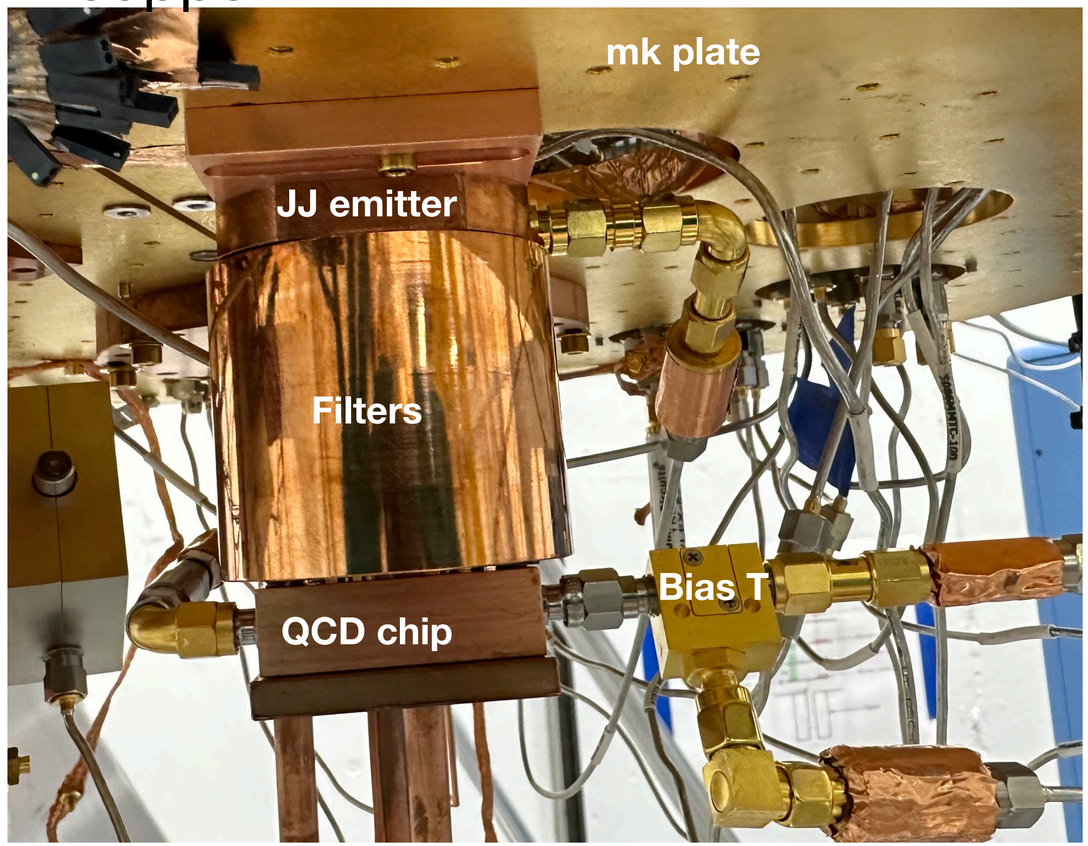
Detector Assembly

Designed and fabricated at Fermilab

- Using a Josephson radiator as photon sources
- QMC filter with 0.1THz passband around 1.5THz
- Enclosure made up of OFHC copper



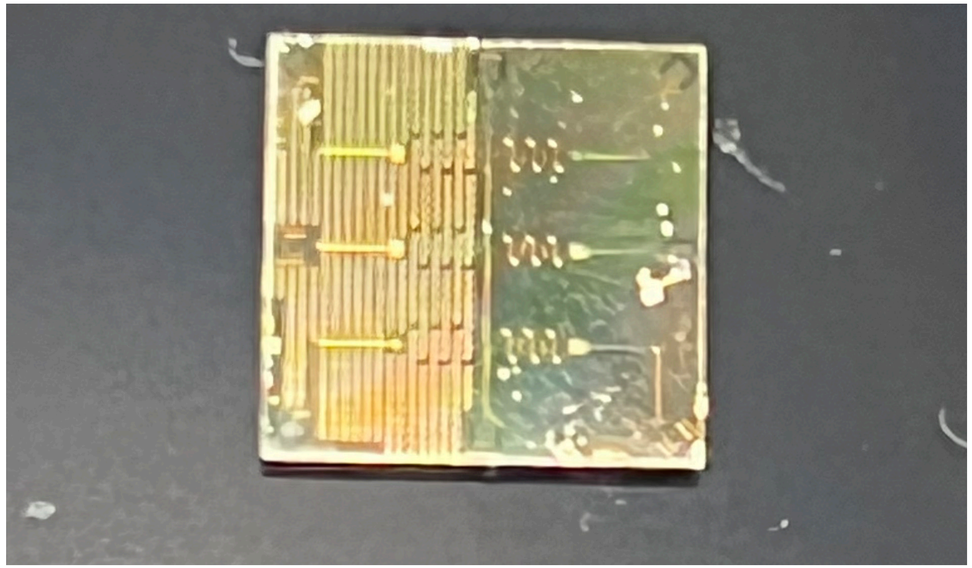
Design with filters and emitter



Assembly inside QuantiSED fridge

Josephson radiator/photon source:

*Fabricated by McDermott group at University of Wisconsin Madison.



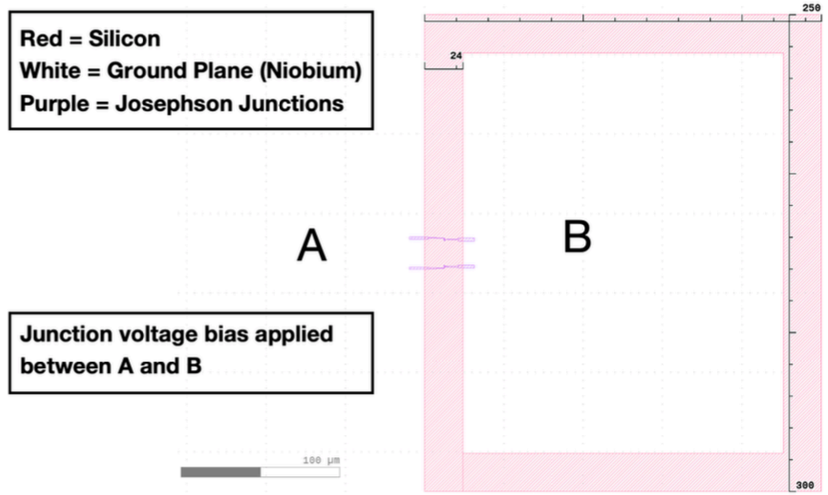
Josephson radiator chip

Josephson radiator is

- A **photon source**
- Using **AC Josephson effect** as a current source

$$I = I_c sin(wt) \quad w = K_j V_{DC}$$

- The structure has a radiation impedance that matches with the junction impedance to emit photons at frequency w.



Structure of Josephson radiator

Black body source

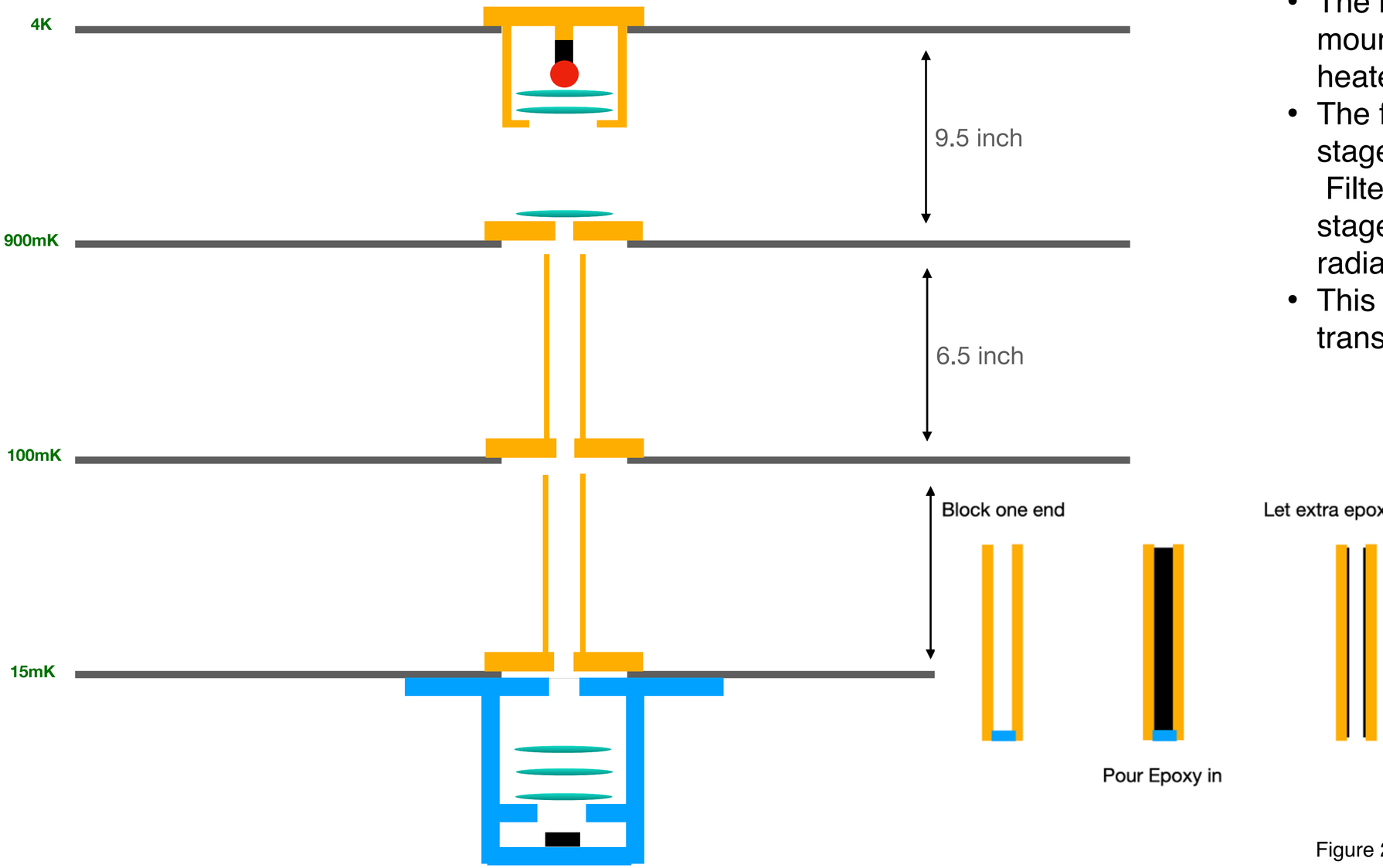


Figure 1. Current black body design

- The black body source will be mounted on 4K stage since it will be heated up to 27K.
- The first IR filter will be place in 4k stage to see a higher cooling power. Filter is also required on 900mK stage so it will block most unwanted radiation from 4K.
- This design is using copper tube to transfer photons in free space.

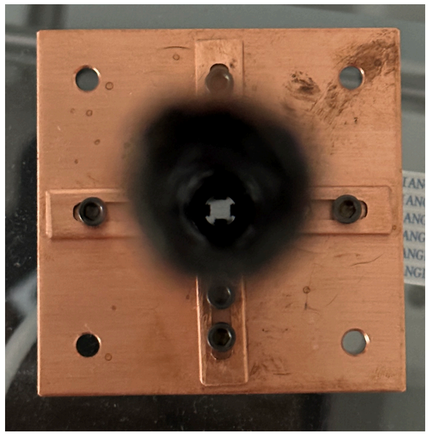


Figure 2. Black coating for copper tube

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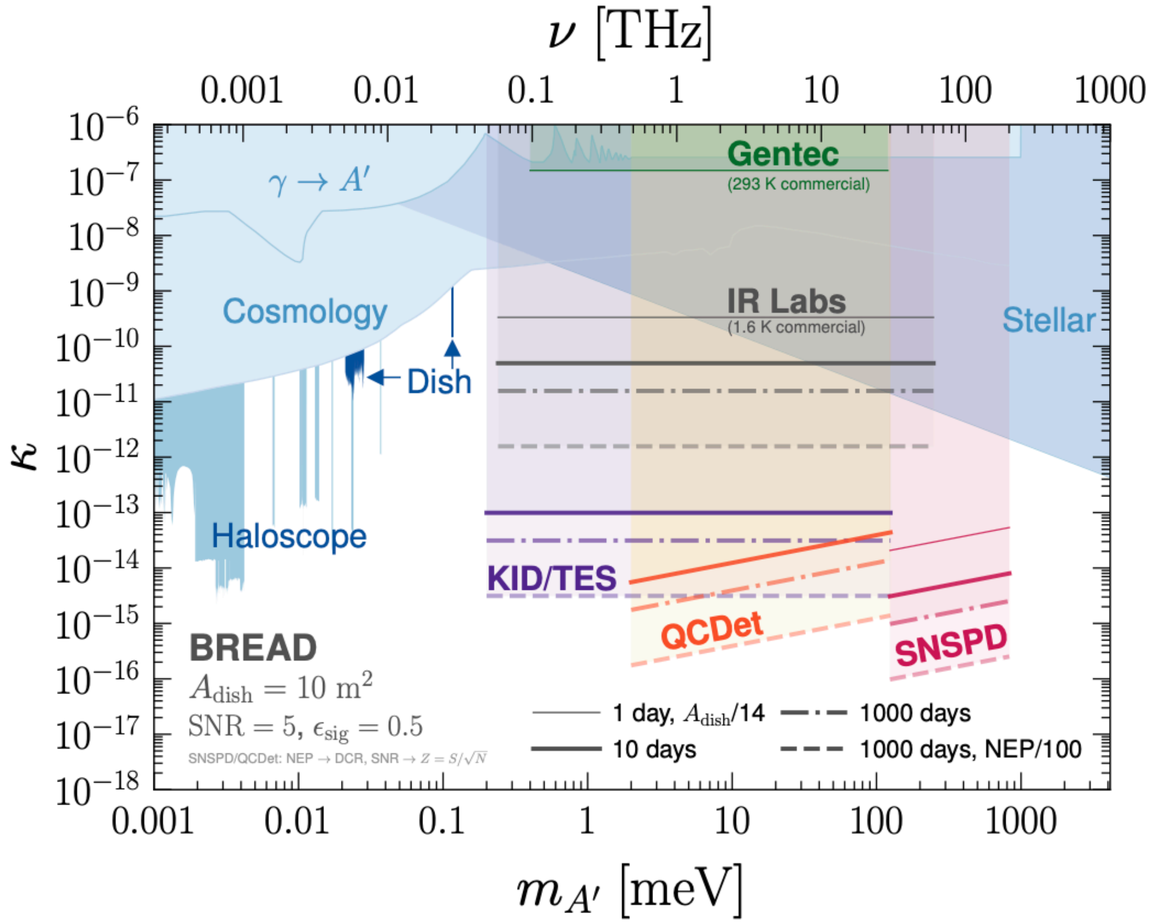

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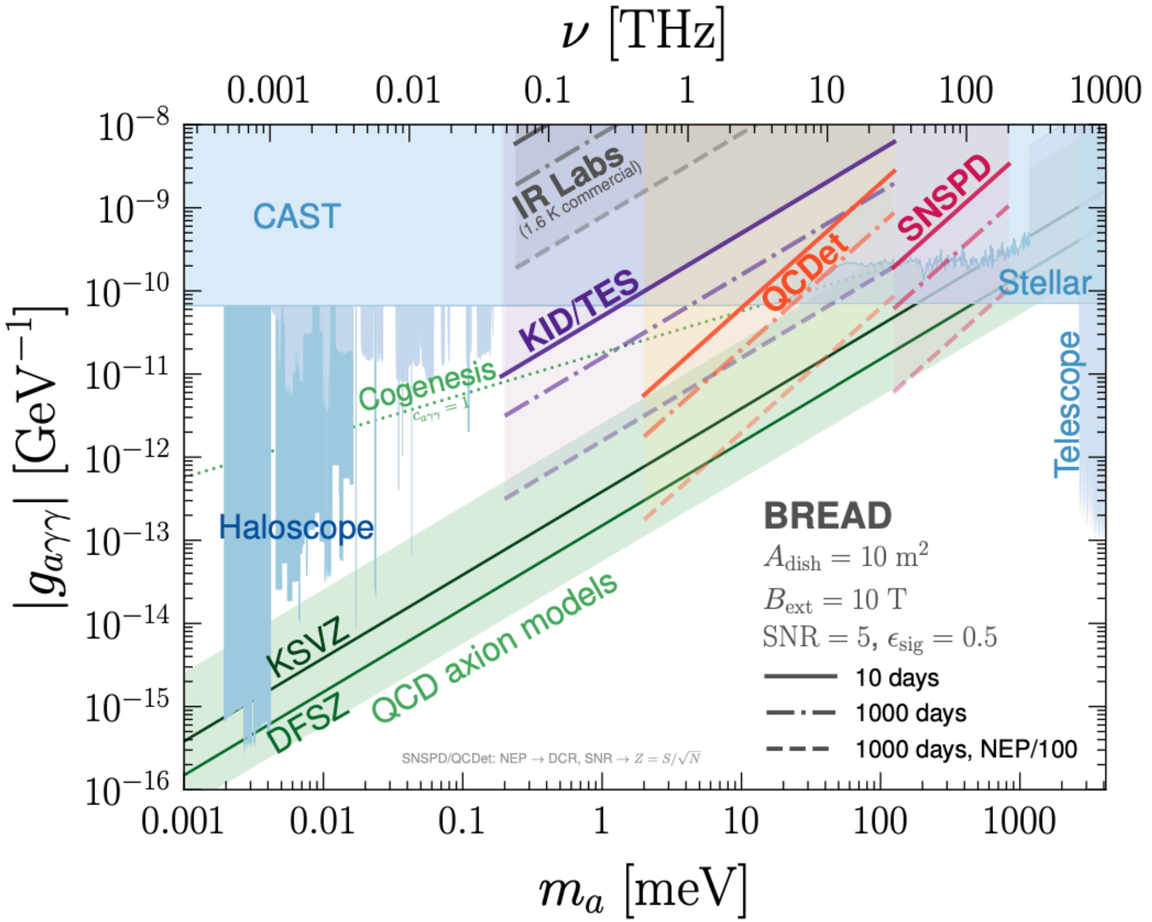

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Acknowledgement

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