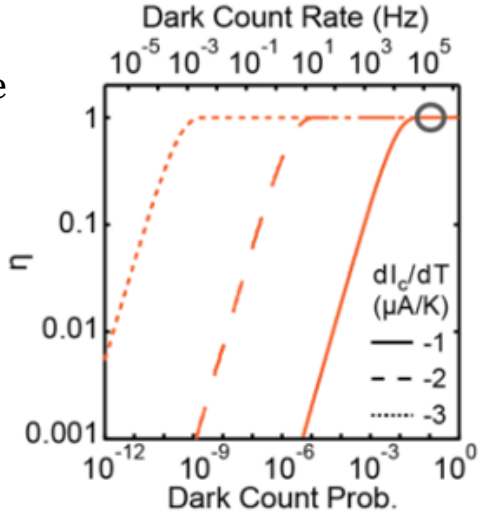
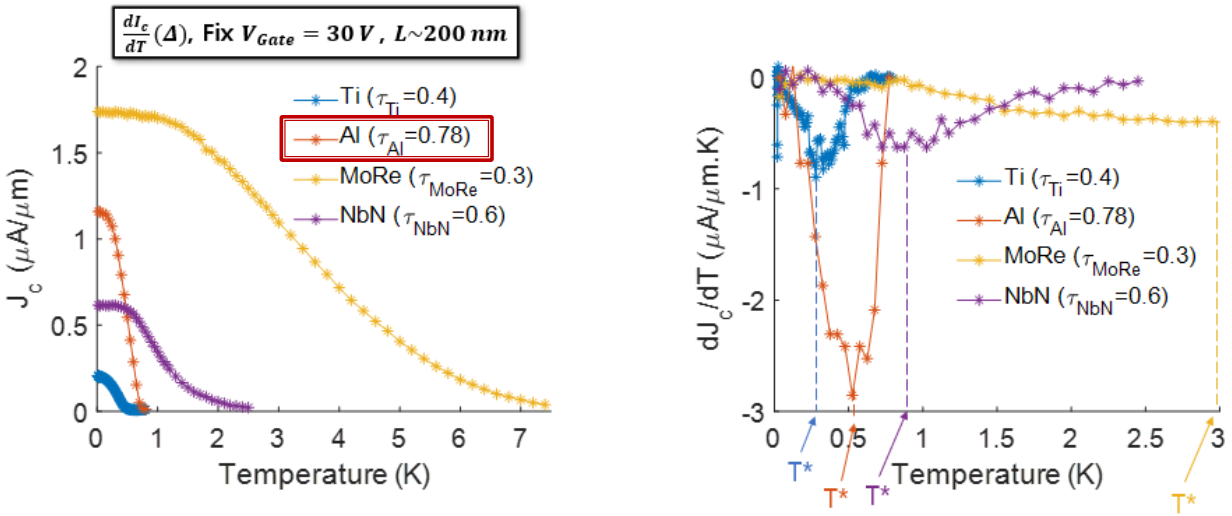
Optimization of $|dI_c/dT|$ for GJJ

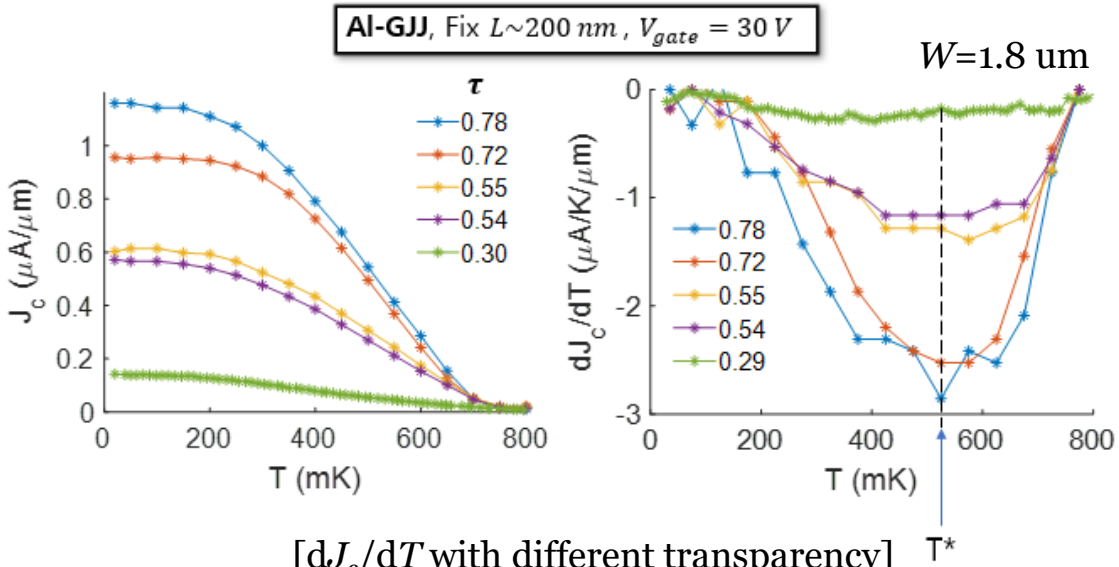
- ✓ $|dI_c/dT|$ ↑ ➔ Detection efficiency ↑ & Dark count rate ↓
- ✓ Lower T_c of $J_c(=I_c/W)$ & larger J_c at low temperature ➔ Aluminum
- ✓ Contact transparency (τ)↑ ➔ $|dJ_c/dT|$ ↑
- ✓ For Al & τ=0.78, $|dI_c/dT|$ ~ 5 μA/K (@ T=500 mK) is realized.

[Detector performance with different dI_c/dT]



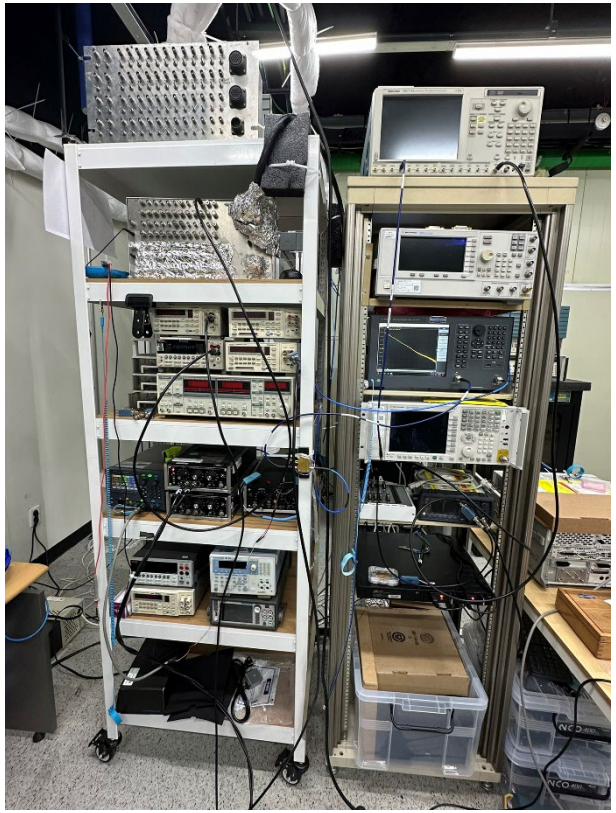


[dJ_c/dT of GJJ with various superconductors]



[dJ_c/dT with different transparency]

Overview of Our Measurement Set-up



Arbitrary Waveform Generator

Analog Signal Generator

Vector Network Analyzer

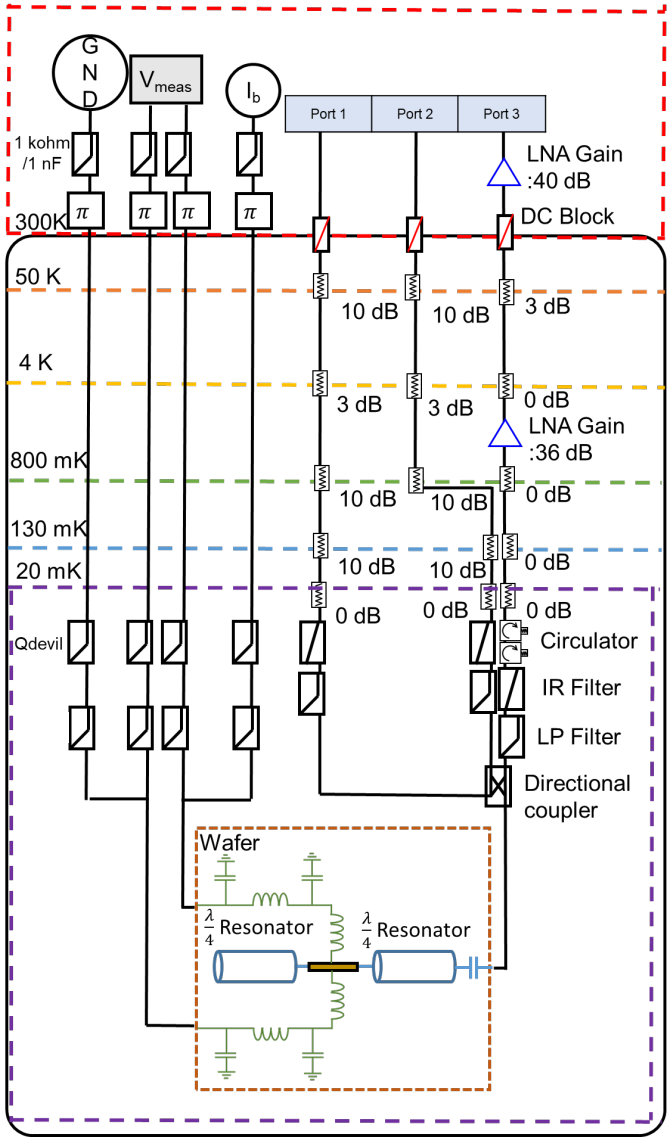
Spectrum Analyzer

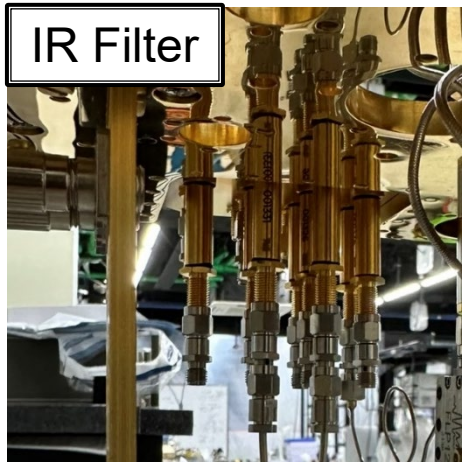
❖ Dedicated Dilution refrigerator

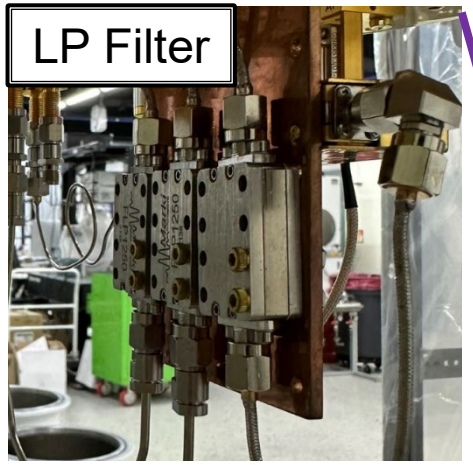
DC Instrument

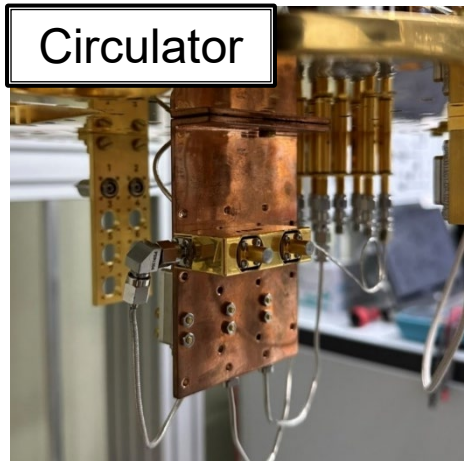
RF Instrument

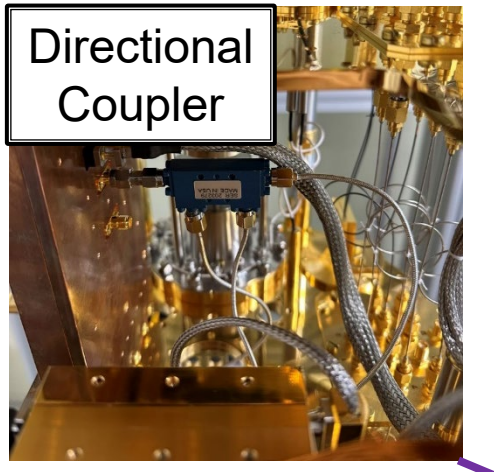
Our Measurement Set-up (RF)

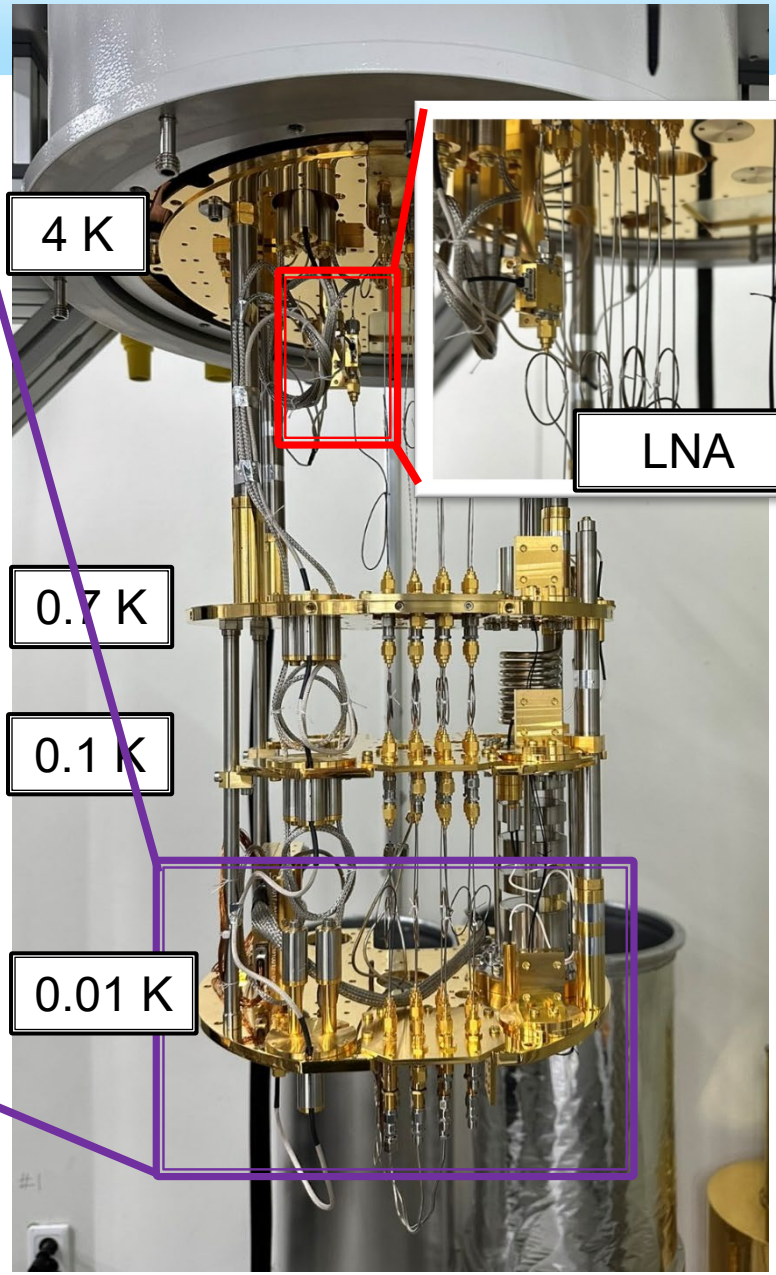












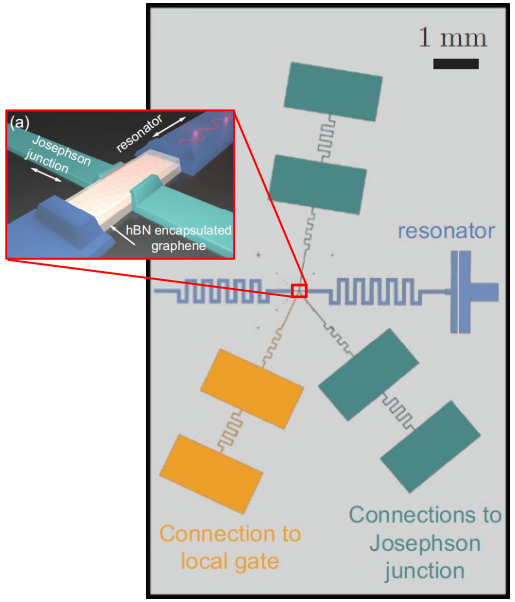
Calibration*

*No O(THz~meV) single-photon sources

➔ **How can we check the response of our detector to DM scattering?**

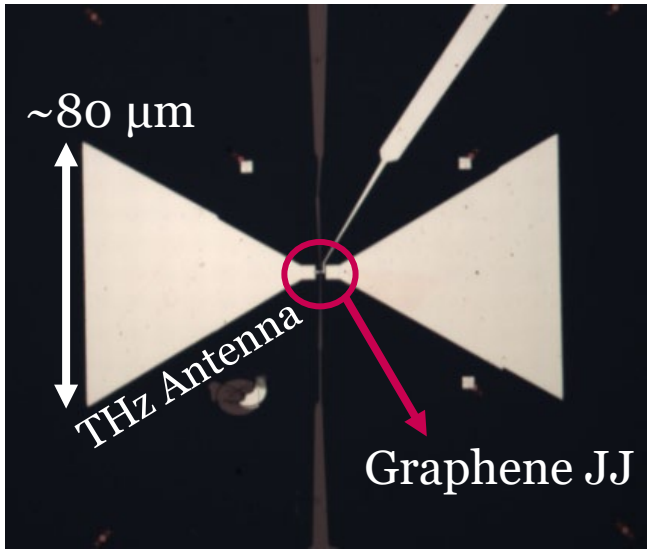
How to Calibrate Detector

Microwave (μW)



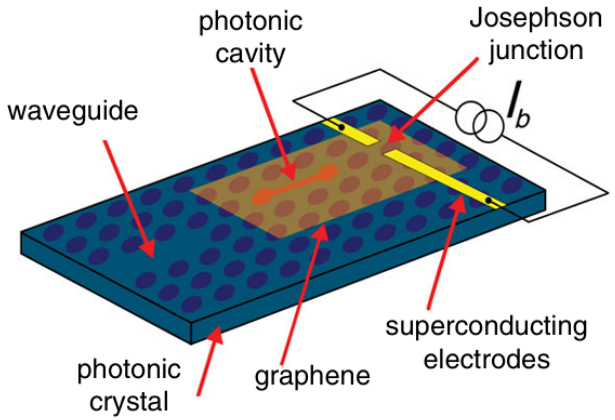
Photon energy E= **0.1 meV**
Wavelength λ=1 cm

Terahertz (THz)



E= **10 meV**
λ=100 μm

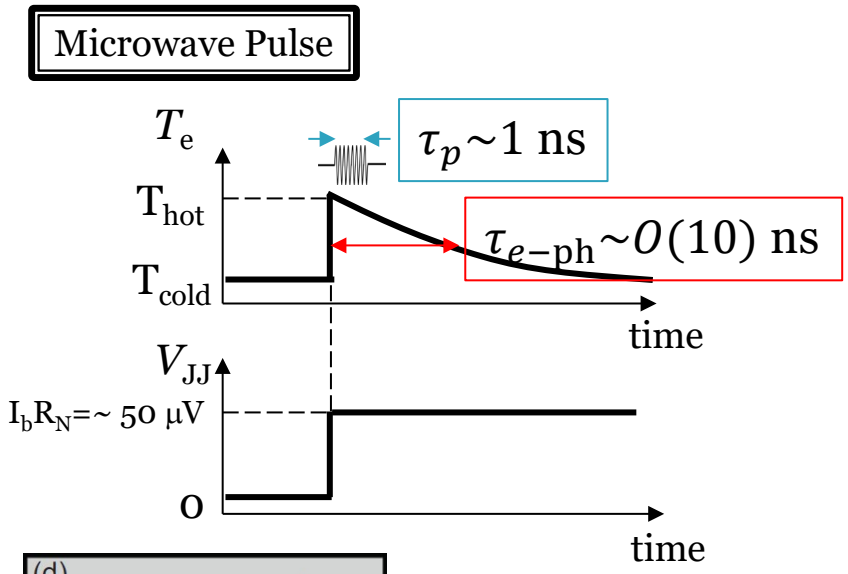
Infrared (IR)

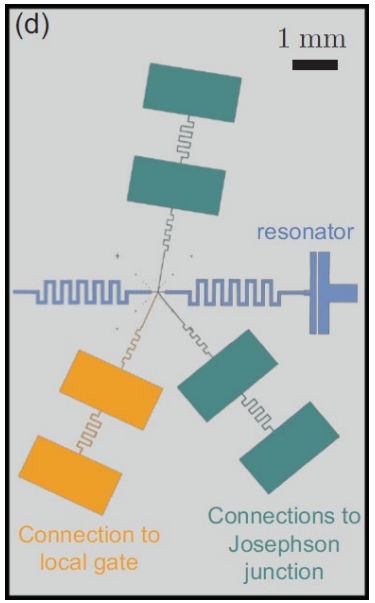


E= **1 eV**
λ=1 μm

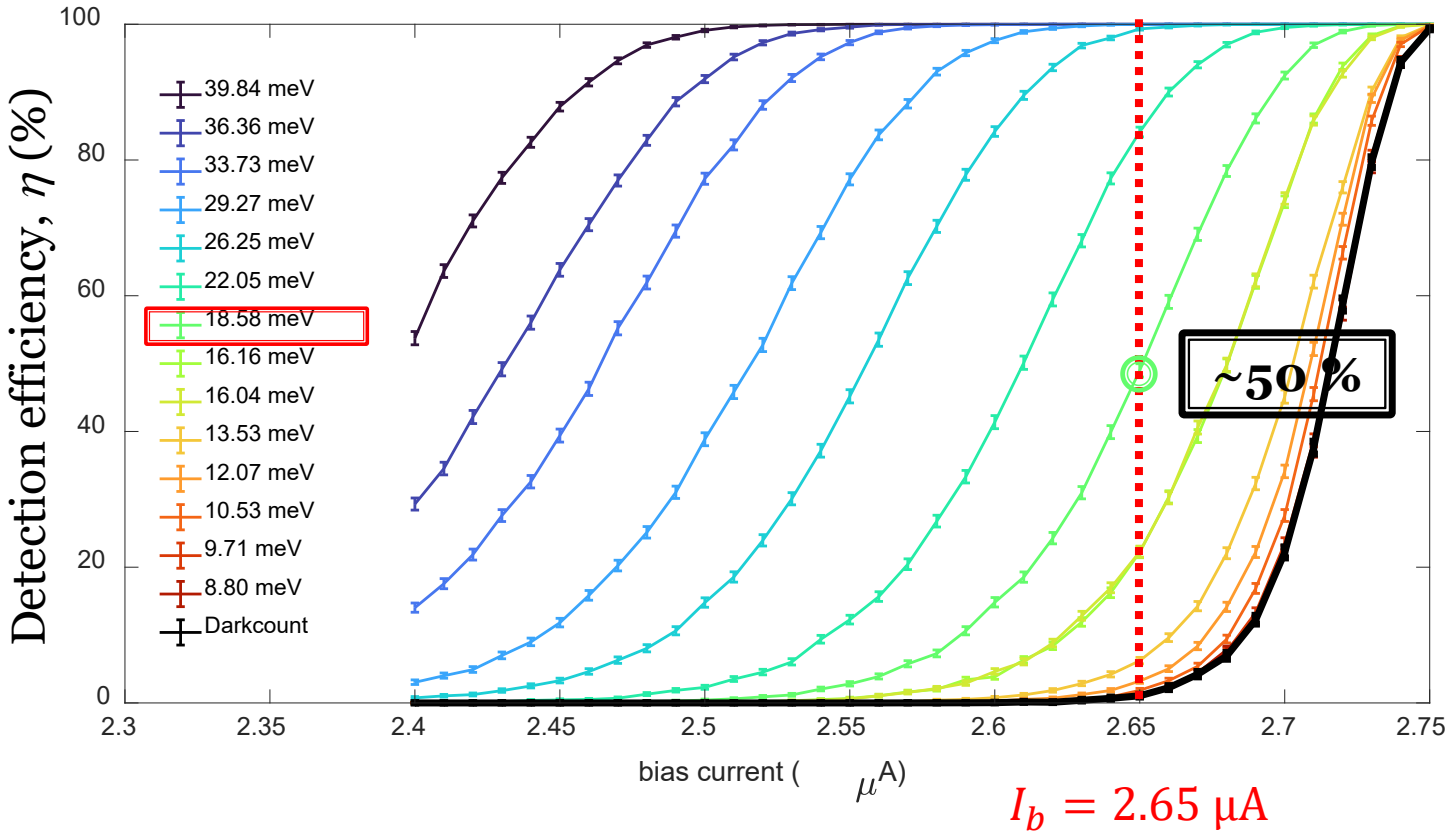
Different energy of photons requires different coupling scheme.

Detector Calibration Scheme





- ✓ Using **microwave pulse** as a fake signal
- ✓ Microwave pulse duration (τ_p~1 ns) is set shorter than cooling time (τ_{e-ph}~O(10) ns).

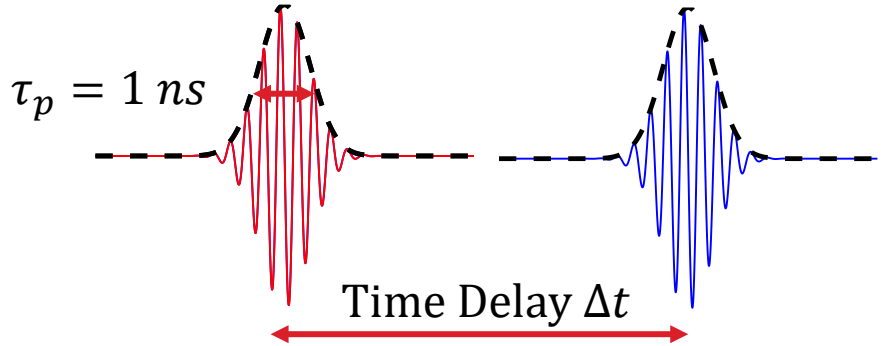


I_b = 2.65 μA

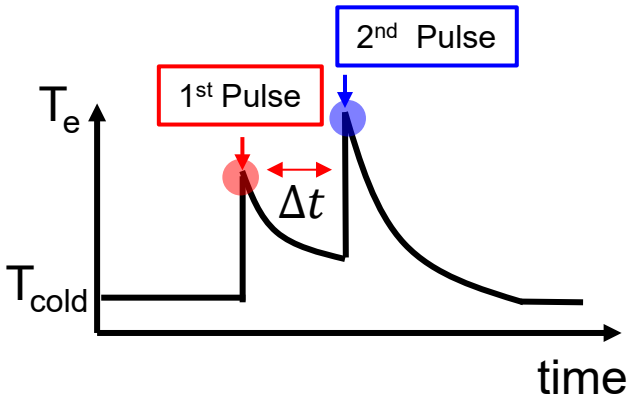
Threshold E ~ 20 meV

Thermal Relaxation Time Measurement Scheme

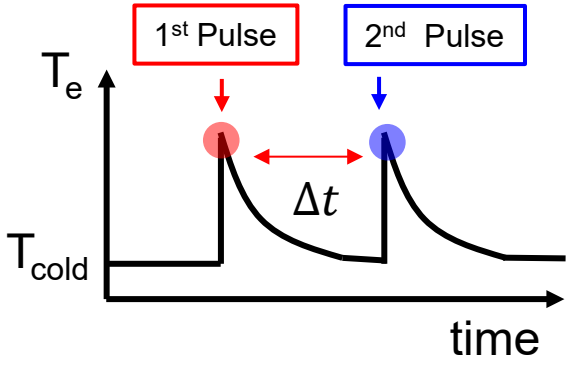
Two-pulse sequency



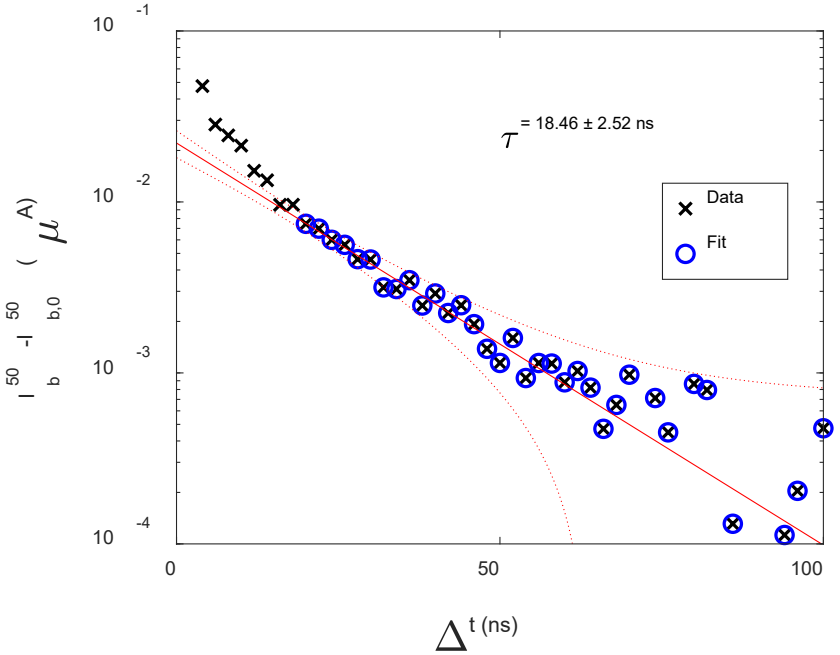
Case 1, $\Delta t \ll \tau_{th}$



Case 2, $\Delta t \gg \tau_{th}$



Measure the switching probability varying ***Δt***
→ calculate the **thermal relaxation time**



$$\tau_{th}^{*} = 18\ \text{ns} >> \tau_p = 1\ ns$$

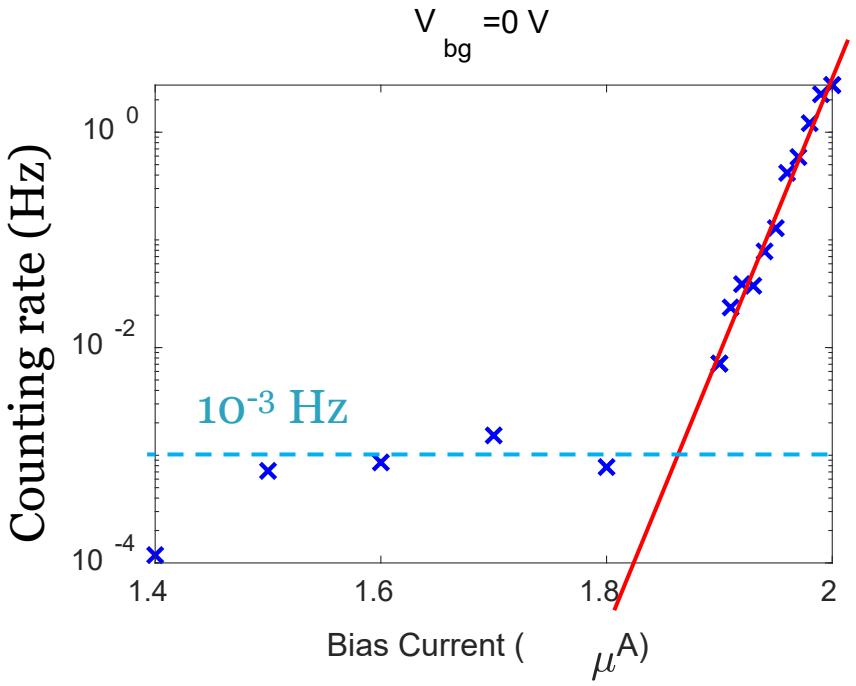
LEE*

*Low energy excess

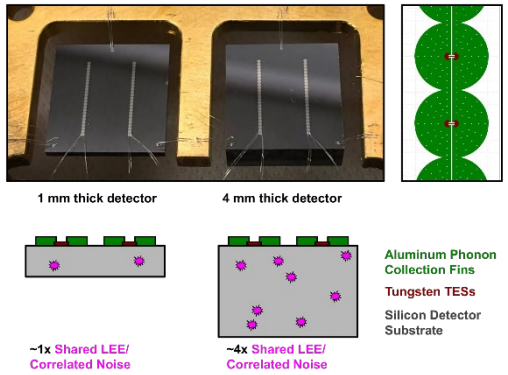
Low Energy Excess (LEE) in GJJ Detector

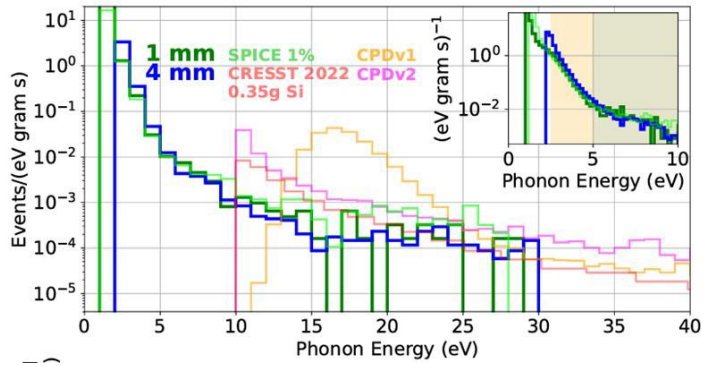
- Dark matter search was performed at various bias currents.
- Counting rate saturates around 10^{-3} Hz, which is too high to be due to dark matter.

  ➔ Low Energy Excess (LEE)
- Cosmic ray may cause such dark counts.

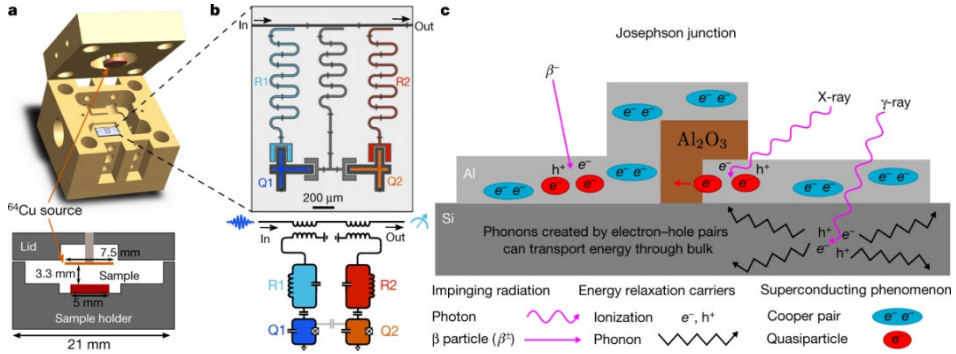


Counting rate of GJJ vs. Bias current





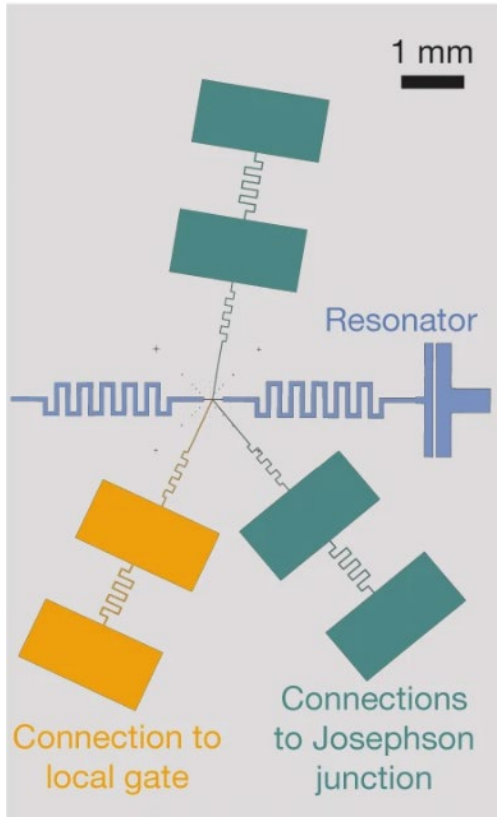
Substrate volume ↑, DCR ↑ [arXiv:2505.16092]

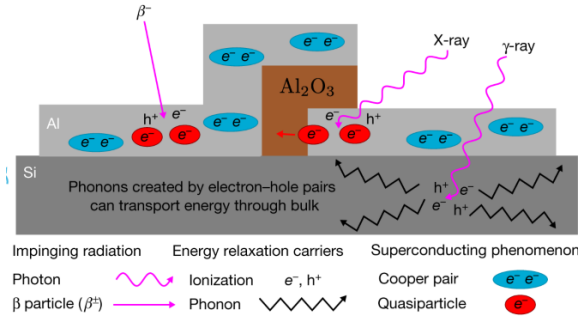


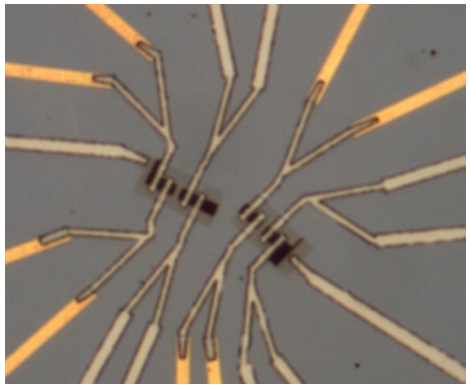
[Nature 584, 551–556 (2020)]

Investigating LEE in GJJ Detector

- To avoid LEE and search for dark matter, we need to investigate the origin of LEE.
- Currently, we are comparing devices with different areas of superconducting electrodes.
- We plan to compare devices with different volume of subsrates.







Large area of SC electrode

Minimal area of SC electrode