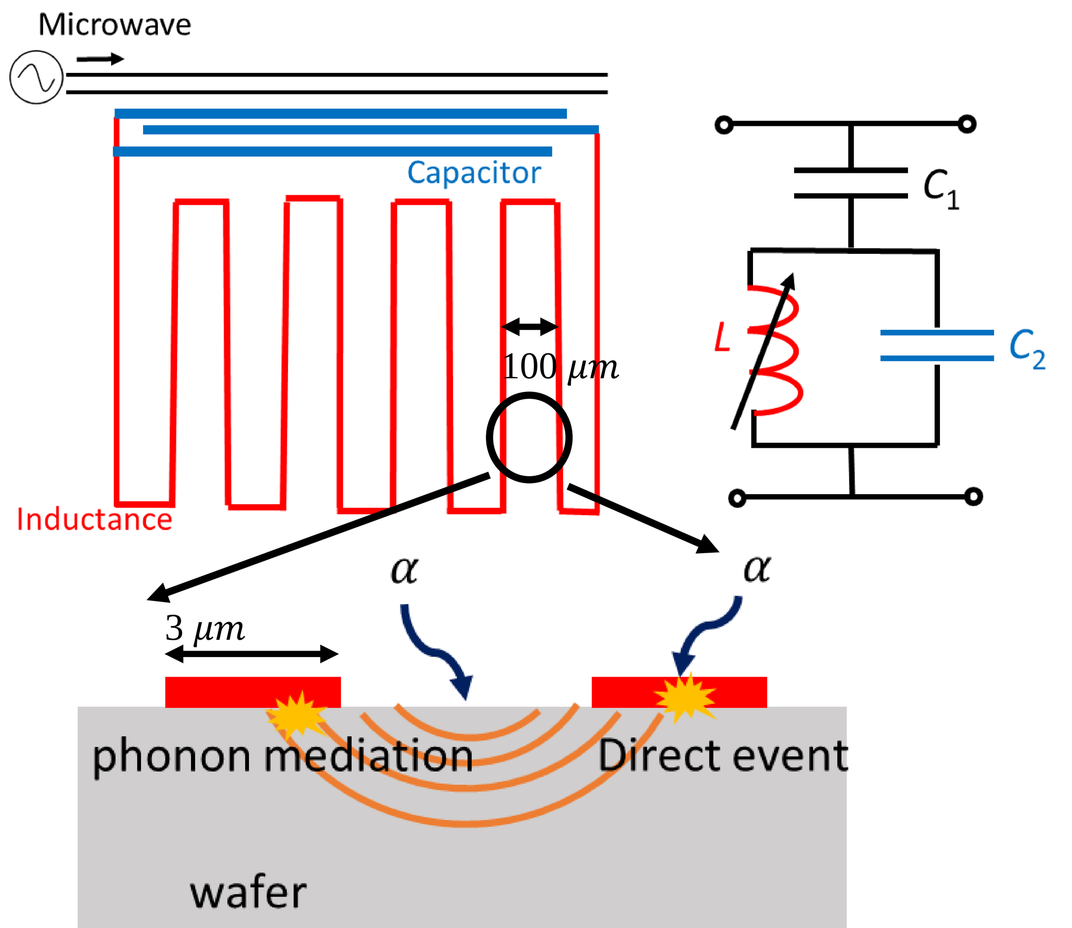
47-347

Alpha line detection with Nb based and YBCO based superconducting resonators

*M. Naruse, T. Ando, M. Kuwata, Y. Waga, T. Taino, H. Myoren
Graduate School of Science and Engineering, Saitama University
**naruse@super.eees.saitama-u.ac.jp*

Abstract: For high-energy particle detection, we investigated two materials: niobium (Nb) and a high-temperature superconductor, $YBa_2Cu_3O_{7-\delta}$ (YBCO). Lumped element kinetic inductance detectors are fabricated with both superconducting films. The alpha line (5.49 MeV emitted by Am-241) is irradiated from the top side of the devices. When we submitted the abstract, we thought that YBCO-KIDs detected the alpha line, but after further investigation, we found that the signal was fake. Although the quality factor and the noise level of the YBCO-based device were comparable with that of the Nb-base KID, the signal suppressed due to the large gap energy and short quasiparticle lifetime. The performance of the Nb-KIDs was an excellent agreement with the expectations; the energy resolution was 25, and the decay time was approximately 1 μs. We distinguished the direct absorption events and the phonon mediated events. By decreasing the filling factor of the inductance line, the phonon originated events suppressed, and the energy resolution improved.

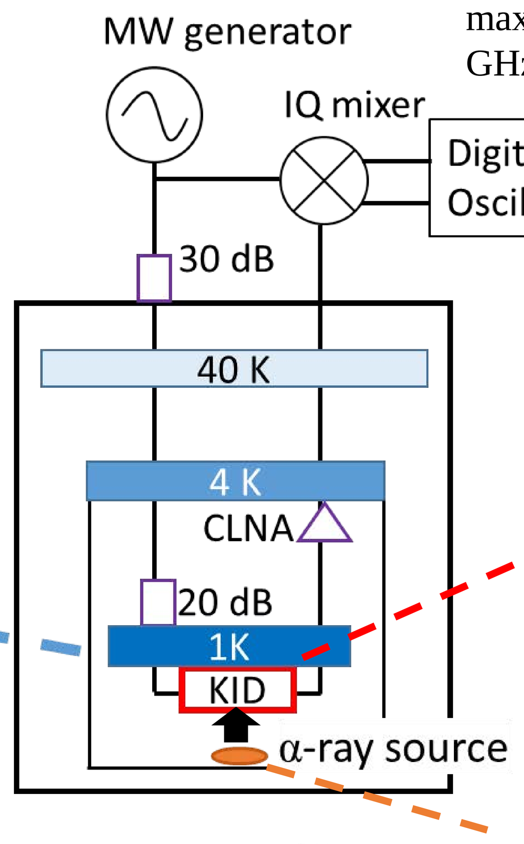
LeKID as α-line detector

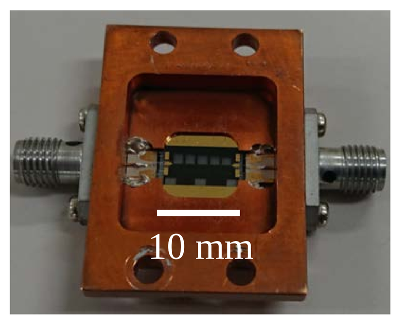


(top) Schematic drawing of Lumped element Kinetic Inductance Detector (LeKID) and Equivalent circuit of LeKID. (bottom) Alpha particles emitted from Am241 enter the top side of the device.

Measurements in 1 K cryostat

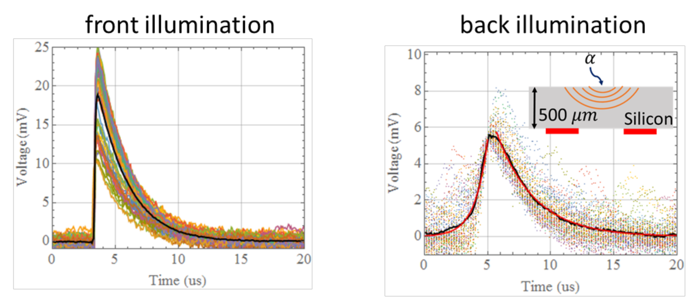
For fast sampling (>15 MHz), we also used the oscilloscope whose maximum rate is 1.25 GHz.





Am^{241}
5.49 MeV (84.5 %)
5.44 MeV (13%)

Phonon mean free path in silicon



- Our device detected the phonon created at the backside of a silicon wafer even though the wafer thickness was 500 μm.
- Since the decay time of the back-absorbed signal was a few μs and comparable with that of the front-absorbed signal, the detector responded to phonon.

Relaxation time of the signal

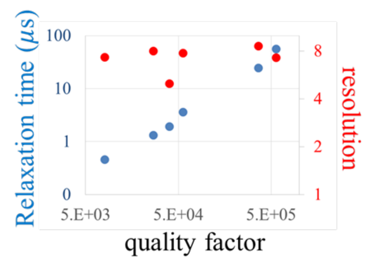
Relaxation time of quasiparticles (τ_{qp})in niobium and YBCO is much shorter than that of resonators (τ_r).

$$\tau_{qp-Nb} \sim 10^{-9}\ s \text{ at 1K}$$

$$\tau_{qp-YBCO} \sim 10^{-12}\ s \text{ at T<<Tc}$$

$$\tau_r \sim \frac{Q}{\pi f_0} = 1\ \mu s$$

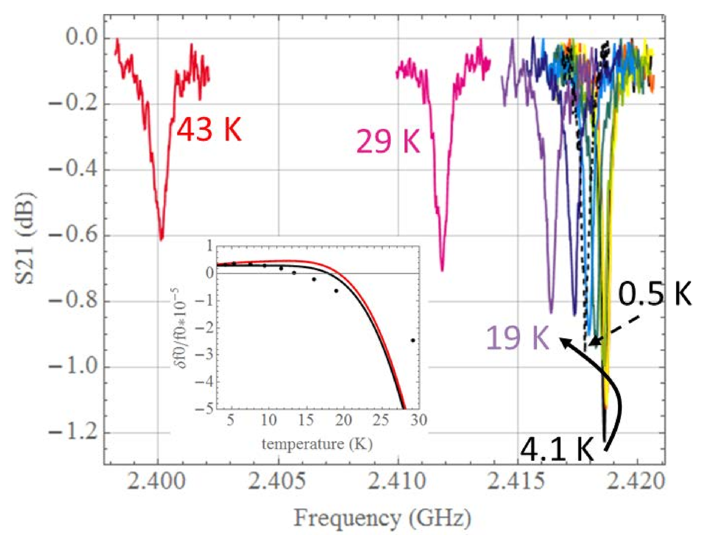
$$(Q = 10000, f_0 \sim 3 * 10^9)$$

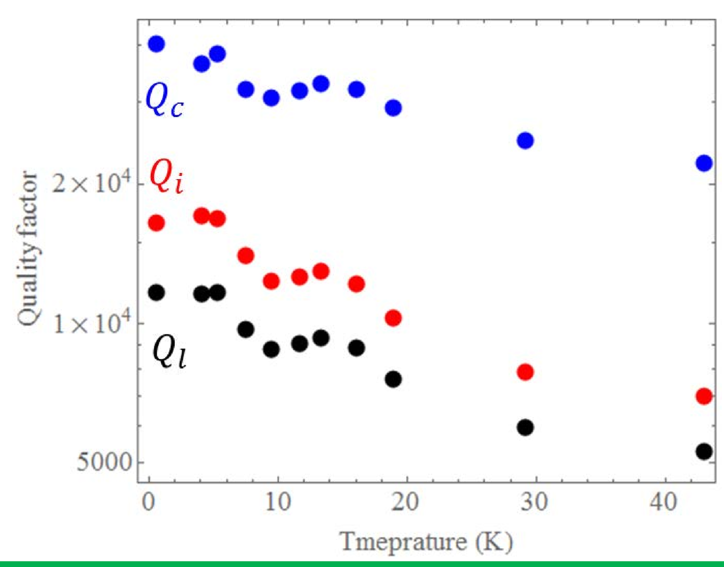


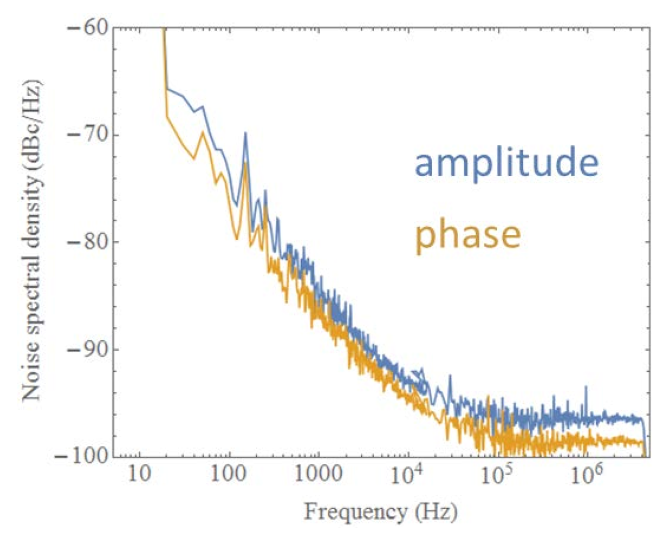
The higher Q resonator has longer pulse but has equivalent energy resolution.

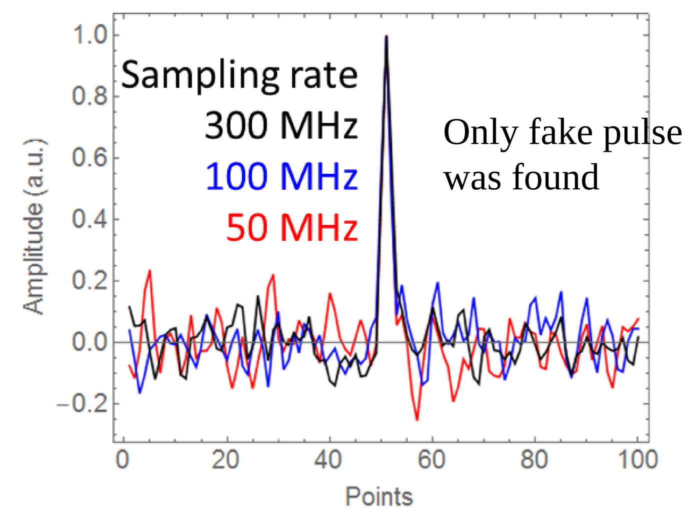
YBCO

- 200-nm thick film covered by in-situ Au deposited on MgO.
- Tc was degraded by processes, but still above 75 K.
- Device was patterned by wet etching in twice. First is for removing the Au coat and second is for pattering YBCO.
- Width of Inductance is 5 μm.
- Good Quality factors (>15000) below 6 K.



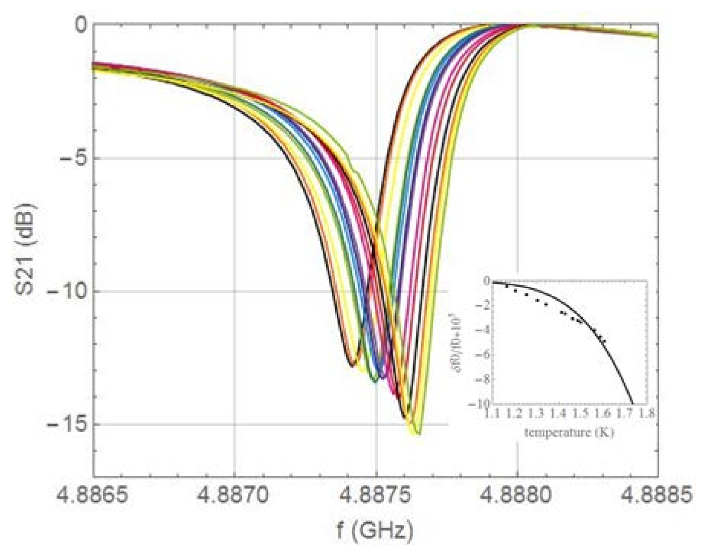


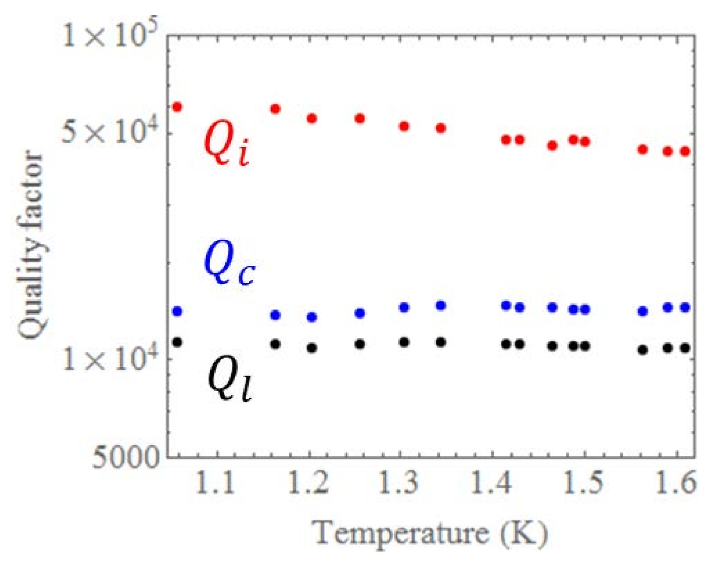


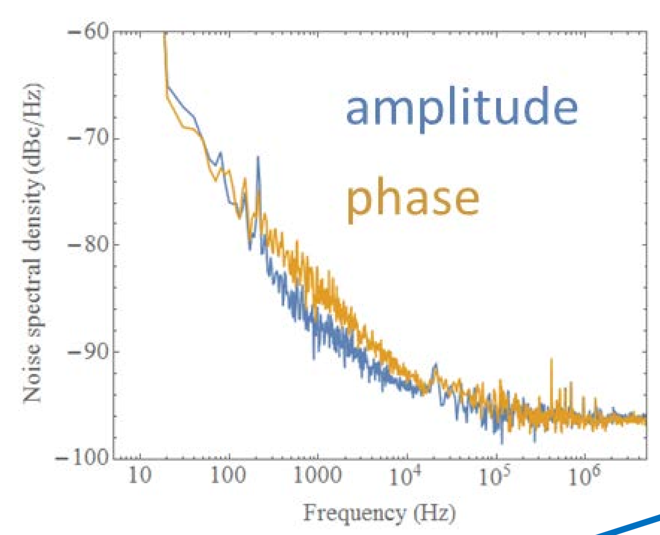


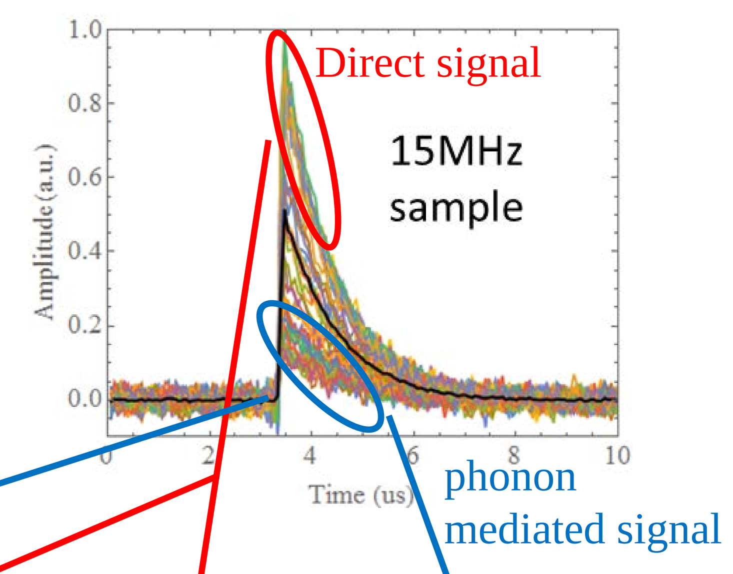
Nb

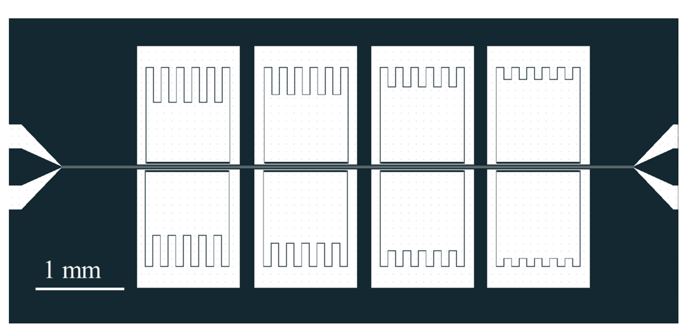
- 100-nm thick film sputtered on high-R Si.
- Tc was 8.7 K.
- Device was patterned by dry etching.
- Inductance width is 3 μm.
- Readout power is applied as high as possible to improve energy resolution, although high power cause the slope of the amplitude noise at low frequency range.
- Two types of the signal were found. Higher pulses correspond to the direct absorption of α-line in niobium film. Lower pulses respond to the phonons created the absorption of α-line in the silicon substrate.
- Decay time of the pulse is around 1 μs and good agreement with the ringing time calculated by the quality factor and the resonant frequency.

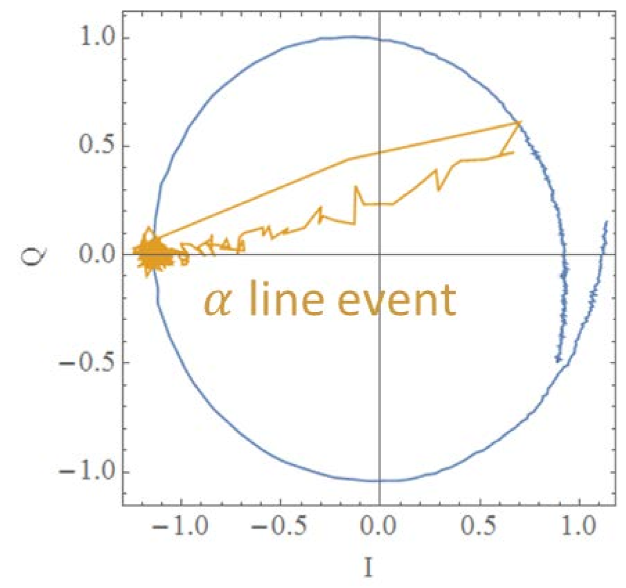


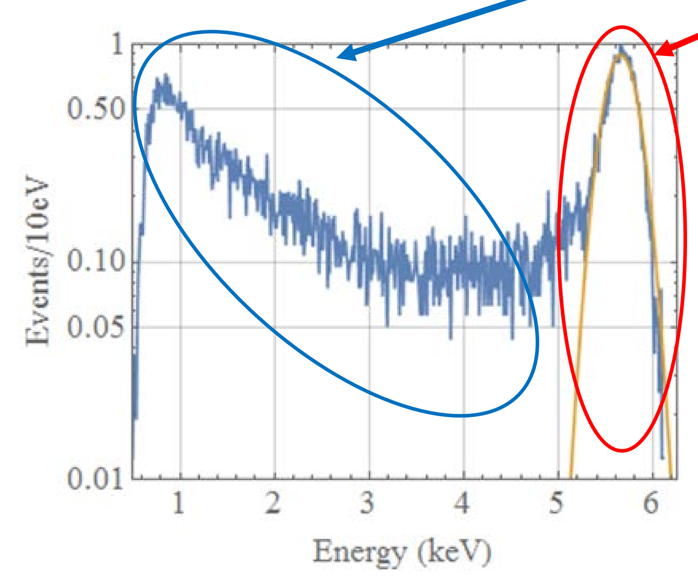


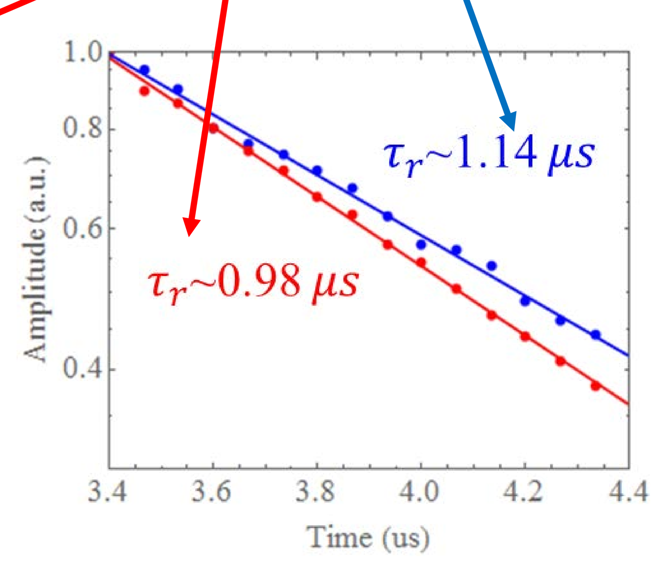












Energy resolution from theory

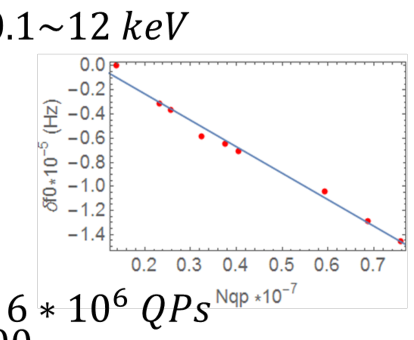
Cardani+ APL 2015

- $\sigma = \frac{\Delta^2 N_0 V}{\eta \alpha S_2 Q}\sqrt{\frac{4Q_c}{Q^2} \cdot \frac{k_b T_n}{P_{in}\tau_{qp}}} \sim 470\ eV$ (assumed η = 0.57)

where Δ: *energy gap*$\sim$1*meV*,
N_0: *single spin density* $1\times10^{10}\ eV^{-1}\mu m^{-3}$,
V: *volume of Lekid* $3\times5000\times0.1$ *in* μm
S_2: *almost unit in amp.readout*
Q: *loaded* $Q \sim 10^4$, Q_c: *coupling* $Q \sim 10^4$
k_b: *boltzman constant*,
T_n: *noise temp.of HEMT*$\sim$7 K
p_{in}: *read out power*~ -60 *dBm*,
τ_{qp}: *QPs life time*$\sim 10^{-9}$
α: *kinetic fraction*$\sim$0.08

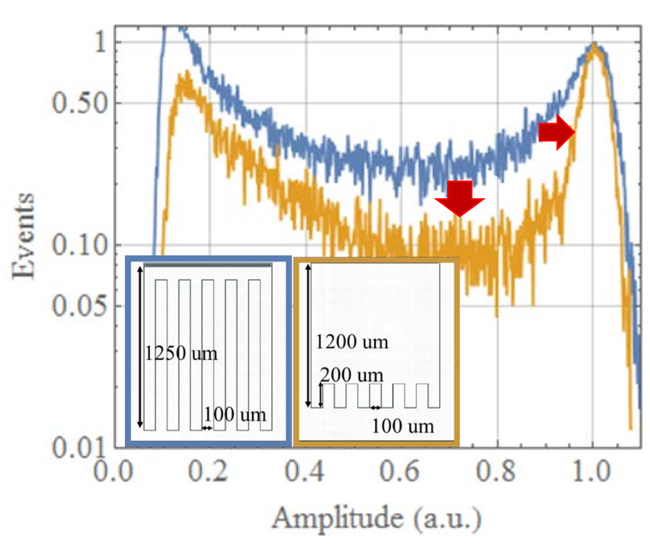
Energy resolution from experiments

- Linear stopping power @ 5.5 MeV in Niobium
$120\ keV\ \mu m^{-1} \times 0.1 \sim 12\ keV$
- $\frac{12\ keV}{\Delta E} \sim \frac{12000}{25} \sim 480\ eV$



Cross check

- The energy of 12 *keV* creates $6*10^6$ *QPs*
$\because \eta\frac{12000}{\Delta_{Nb}} = \eta\frac{12000}{0.0011} = 6*10^6$
- The maximum pulse height indicates that $5*10^6$ *QPs* are excited in the resonator.



Low filling factor of Inductance line reduced the phonon event and improved the resolution.

Conclusion: Alpha lines (5.49 MeV) were irradiated to YBCO-LeKID and Nb-LeKID. Both detectors made pulse responses, but it turned out that the signal with YBCO LeKID was fake. Energy deposited to the 100-nm thick niobium film is 12 keV, and the energy resolution of the Nb-LeKIDs corresponded to 480 eV. This value was close to the prediction. The count rate calculated with the pulse decay time is approximately 500 kHz.