Development of Superconducting Tunnel Junction Photon Detector with SOI Preamplifier board to Search for Radiative decays of Cosmic Background Neutrino

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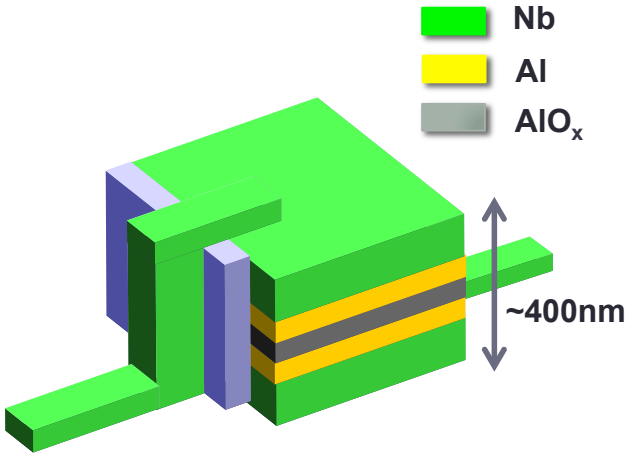
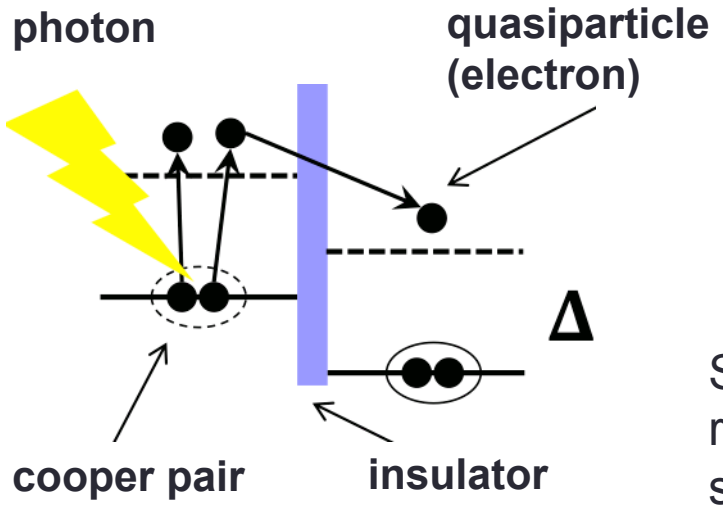
STJ Detector



We are developing STJ photon detector for neutrino decay search (as Dr. Takeuchi slide) aiming at detecting single far infrared(50um) photon

STJ(Superconducting Tunnel Junction) detector is superconducting photoelectric detector that composed of **Superconductor / Insulator /Superconductor**

Incident photons break up cooper pairs in STJ, the electrons from the broken cooper pairs tunnel through the insulator layer

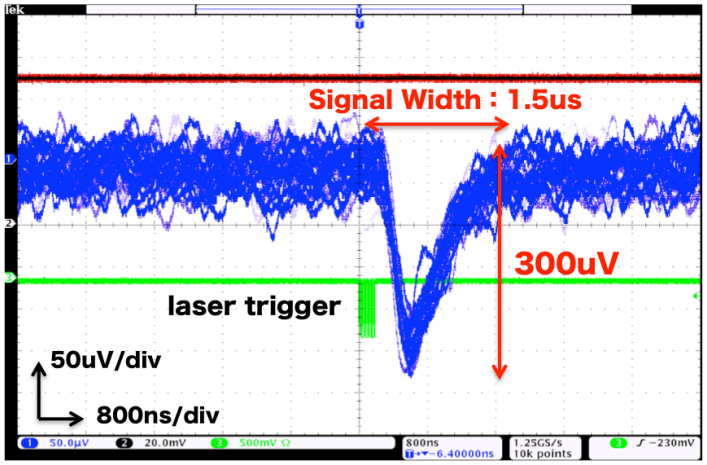


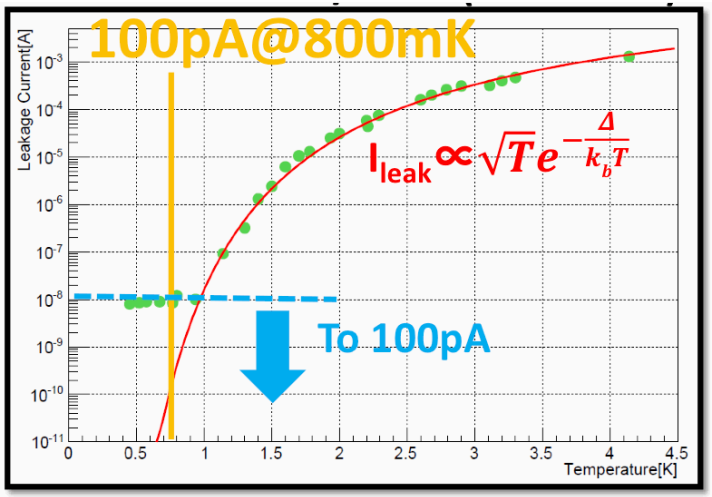
	Si	Nb	Al
Tc [K]		9.23	1.20
Δ [meV]	1100	1.550	0.172

Since energy gap of Nb is ~1meV (Si:~1eV), the energy resolution of STJ can be much better than semiconductor detector.

Nb/Al-STJ

Nb/Al-STJ is one of the candidate detector for neutrino decay search





Temperature dependence of leakage current with Nb/Al-STJ(100 x100um^2)

The signal to infrared(1310nm) laser
Typical signal width is about 1us

Because of this signal width

Requirement for leakage current of Nb/Al-STJ to detect single far infrared photon is below 100pA.

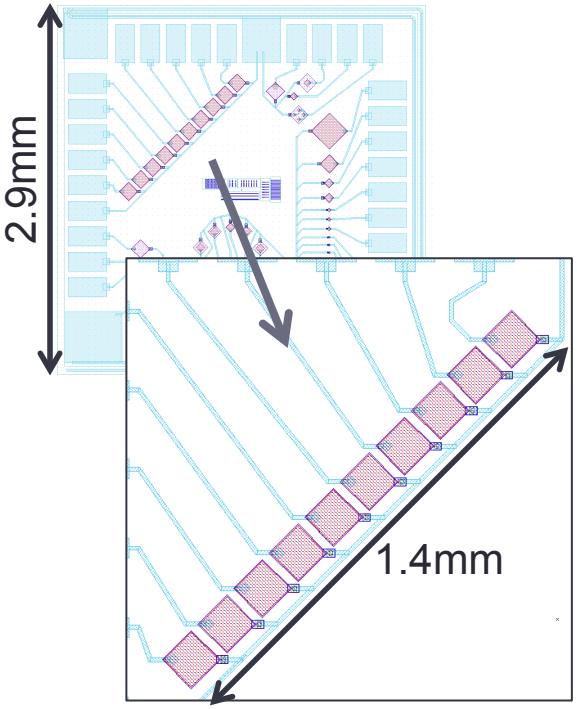
But we haven't achieved such leakage current yet…

To achieve leakage current below 100pA…

- **use better quality STJ or smaller STJ**
- **operate STJ below 800mK**

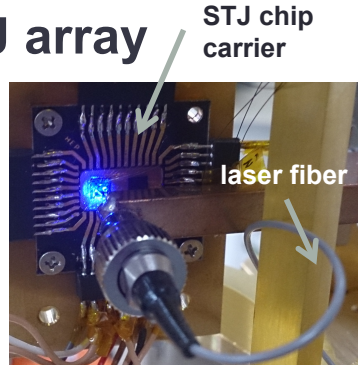
STJ array prototype for Neutrino decay search

We processed STJ at AIST and KEK,
and **measured distribution of infrared(1310nm) laser with STJ array**



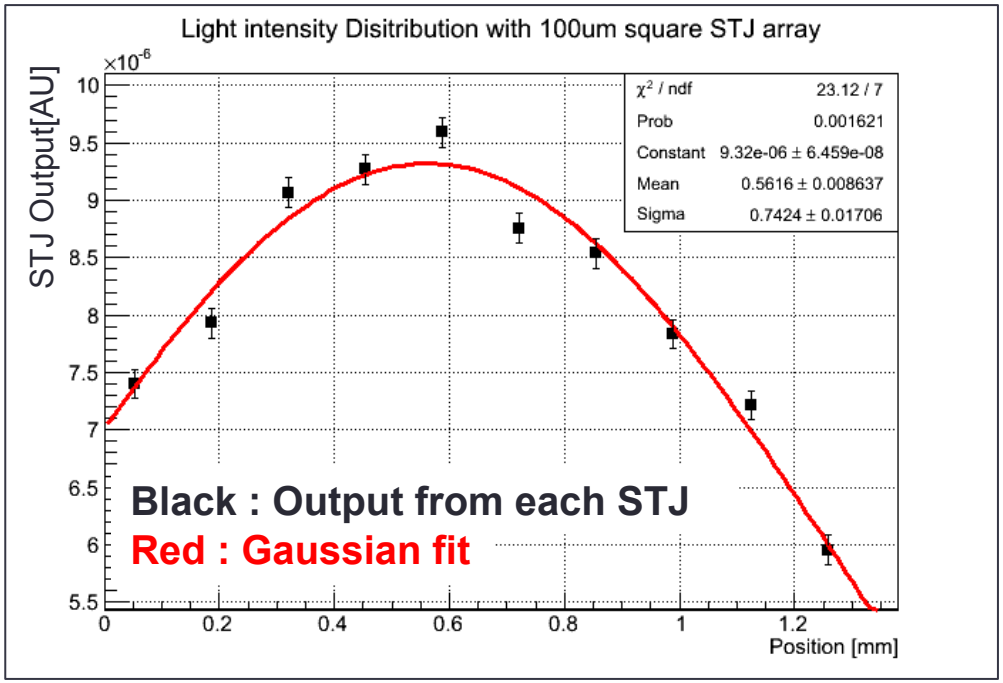
STJ array on the chip
The number of STJs : 10
The size of each STJ : 100um x100um

The distribution of laser from fiber is expected to be Gaussian



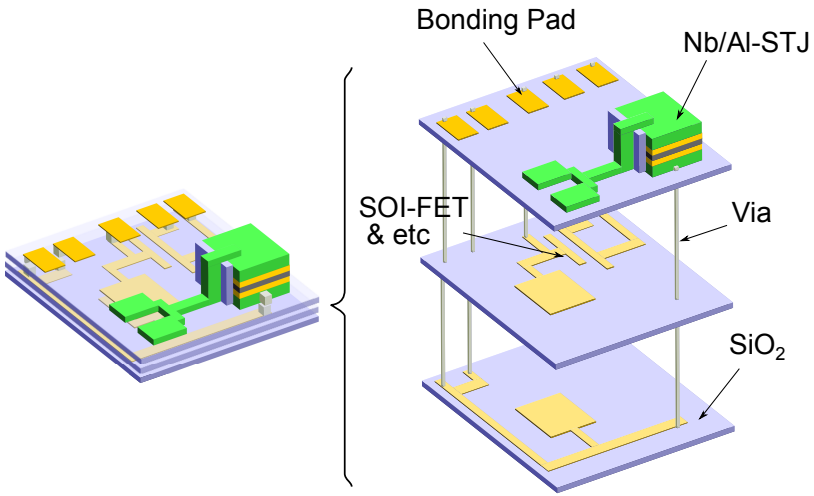
STJ illuminated with blue laser

The distribution of infrared light with STJ array



SOI-STJ

We are also developing a new detector :SOI-STJ



Silicon On Insulator (SOI)

Processing LSI on SiO_2 insulator

- Low Power to be operated
- high speed
- can operate at a few Kelvin

SOI-FET is suitable for amplifier for STJ signal

+

STJ

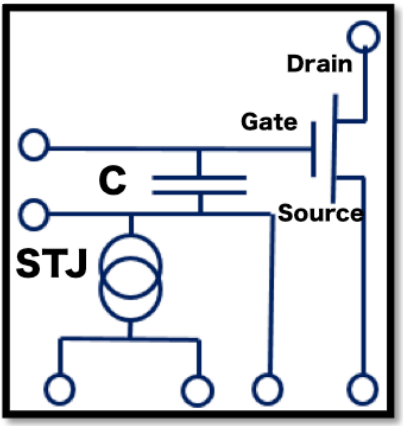
has high energy resolution

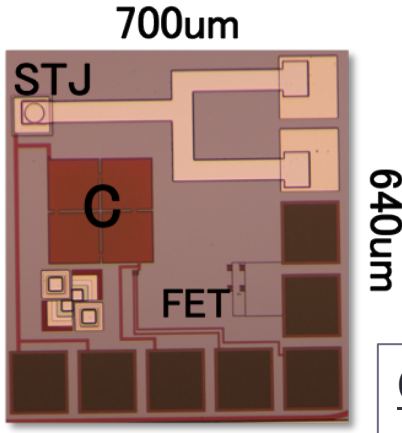
=

SOI-STJ

Processing STJ directly on a SOI preamplifier board to make the detector compact ,low noise and easy to be multipixel detector.

SOI-STJ can be new novel detector!



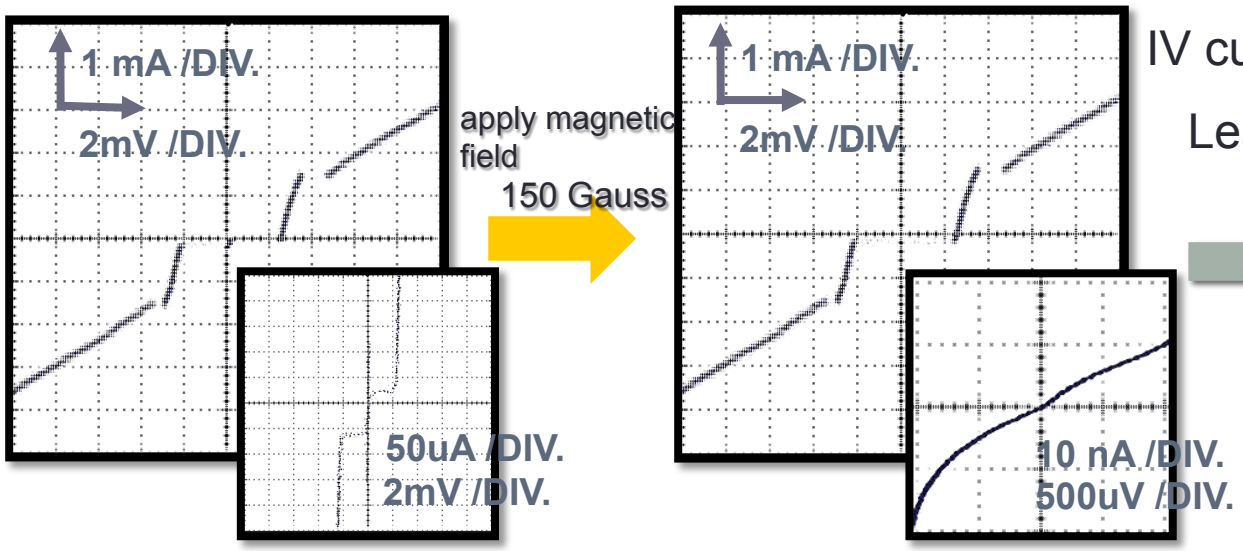


STJ processed on SOI and schematic of prototype

Question

- Is SOI caused any damage by processing STJ?
- Can Nb/Al-STJ be processed on SOI board ?

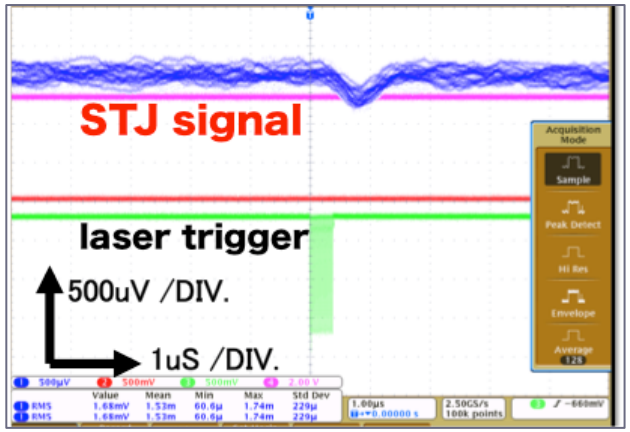
STJ processed on SOI board



IV curve of the STJ on SOI board

Leakage current : 6nA @0.5mV

We can process good STJ on SOI board !

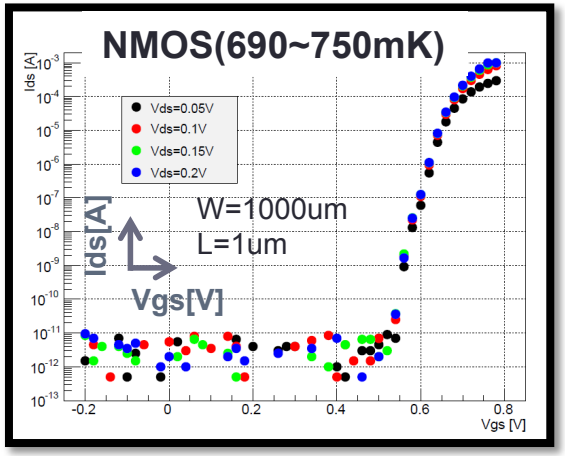


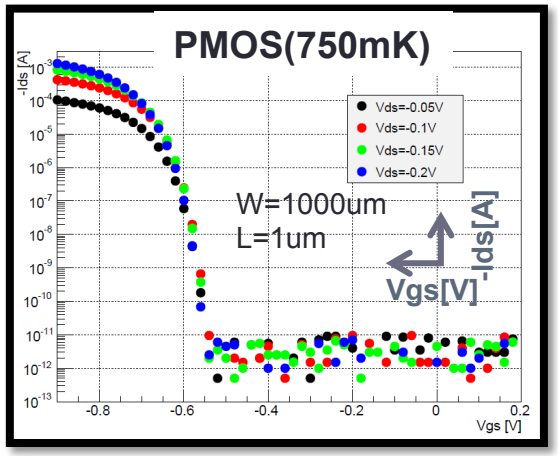
Signal of Nb/Al-STJ processed on SOI board to 465nm light

We observed typical STJ signal from STJ on SOI board !

We confirmed STJ processed on SOI board has no problem!

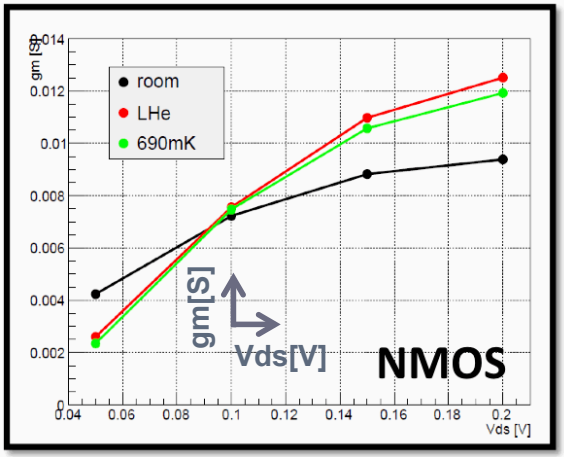
SOI-FET after processing STJ at Low Temperature

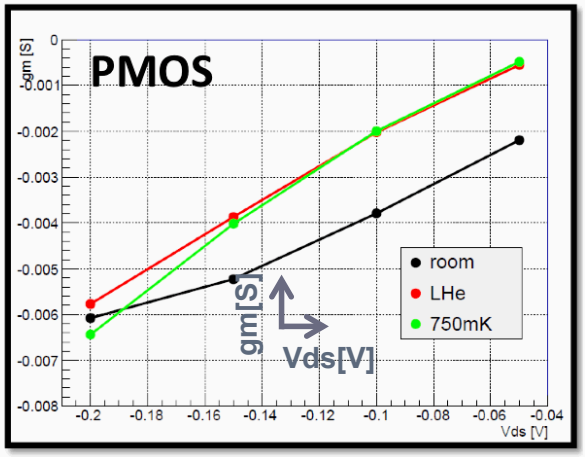




I-V curve of SOI-FETs after processing Nb/Al-STJ.

- Both of NMOS and PMOS can be operated below 800mK.
- Trans-conductance "gm" is not varied drastically for each temperature at operation voltage(0.2V).





SOI-FET with STJ processed has excellent performance below 800mK.

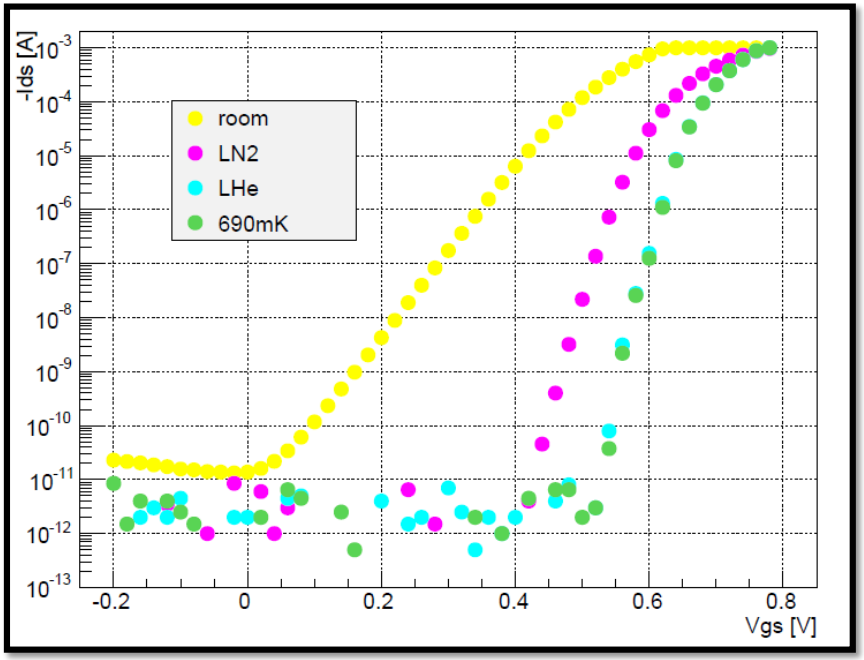
SOI-FET is suitable for cold preamplifier for STJ signal !

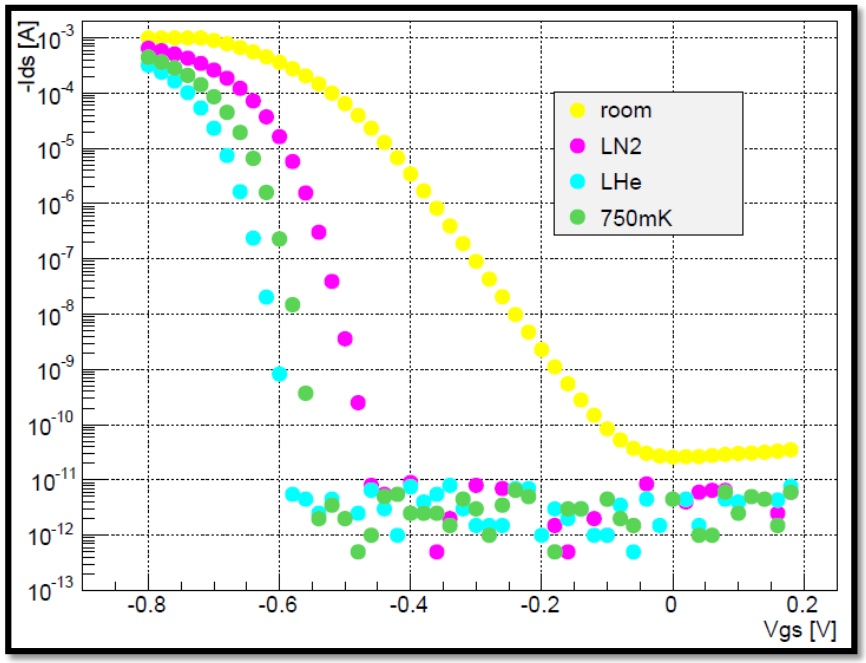
Summary

- **We are developing STJ and SOI-STJ to detect single far infrared photon for neutrino decay search.**
- **We confirmed**
  - ✓ **STJ processed on SOI board has sufficient quality.**
  - ✓ **SOI-FET has no damage by processing STJ**
  - ✓ **SOI-FET has excellent performance below 800mK.**

BUCK UP

Temperature dependence of IV curve





Threshold voltage is changed. But the other properties are almost unchanged.

Requirement for leakage current

When far-infrared single photon incident to the Nb/Al-STJ, Number of created quasi-particle in STJ is around **100e**(assuming Gal = 10).

We want to separate between the signal and pedestal (3 sigma). so requirement for fluctuation of the leakage current of STJ is follow.

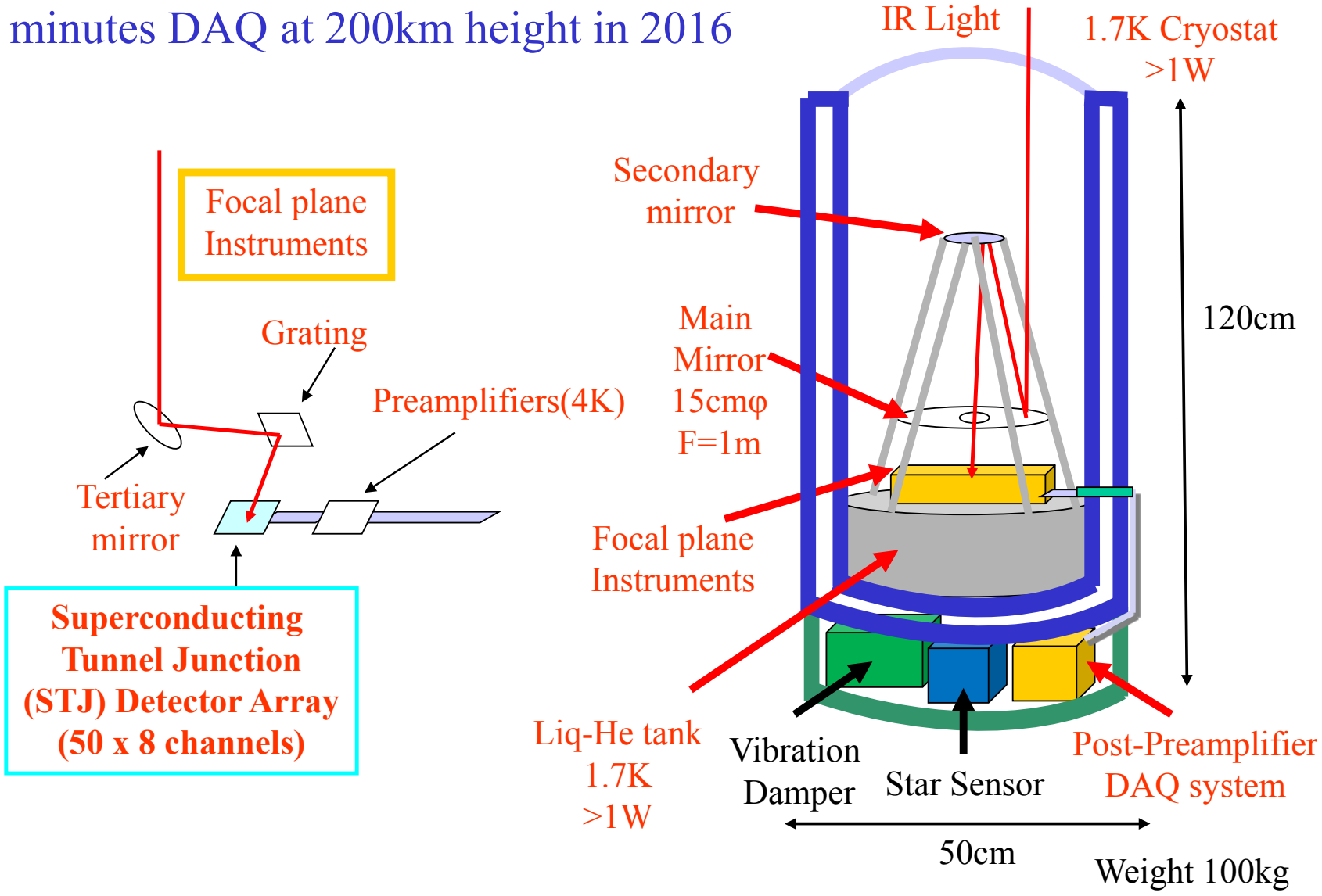
$$\delta N_{qleak} = 33 \text{ e}$$

If we assume that integration width is 1.5 uS, our requirement for the leakage current is…

$$N_{qleak} = 1089 \text{ e}$$

$$I_{leak} = \frac{1089 \times 1.6 \times 10^{-19}}{1.5 \times 10^{-6}} = 108[pA]$$

5 minutes DAQ at 200km height in 2016



Nb/Al-STJ on newly designed chip

Division 1
100um×100um STJ array

Division 2
STJs with dispersed junction

Division 3
STJ array with
different sizes

Division 5
STJs with and without SiO_2
To measure transmittance
of SiO_2

Division 4
STJs with different under layer sizes
(Upper layer sizes are same)
To measure dispersion of quasi particle