Title　: Neutrino Decay Search

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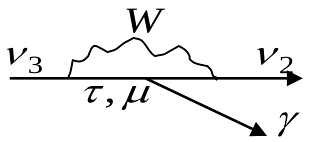
Institutions: University of Tsukuba

Outline

- Purpose
  - Motivation for neutrino decay search
- Method
  - Feasibility of neutrino decay search
  - Rocket experiment with STJ detector
- Status and Plan

Purpose

- **Why three generations ? Why such mass hierarchy with large mass differences ?**
  Only neutrino masses are not measured . To determine the neutrino mass itself is an important subject.
  Neutrino decay observation can determine the neutrino mass.



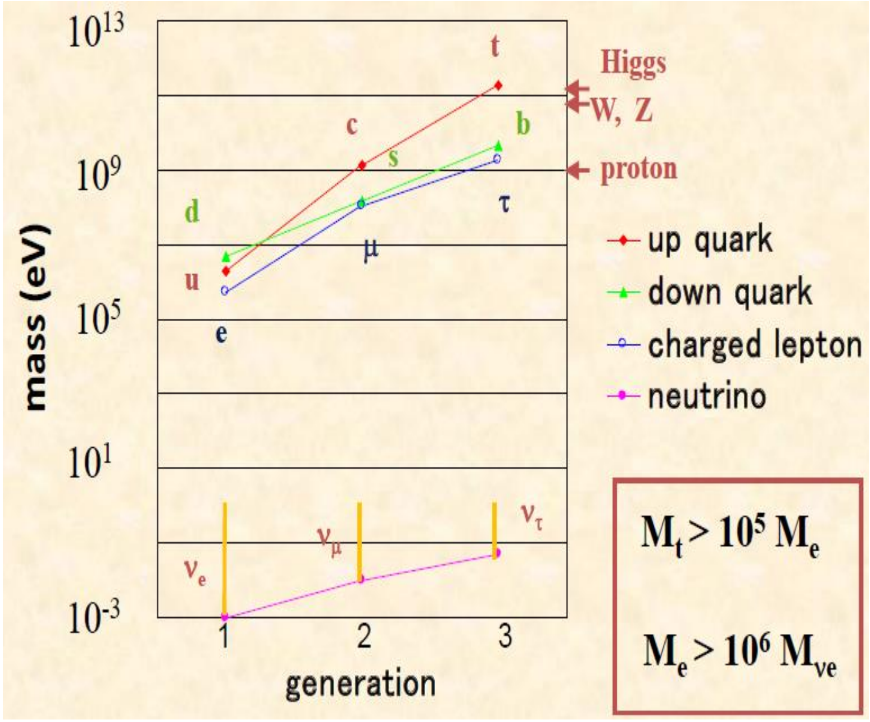
$$\nu_3 \rightarrow \nu_2 + \gamma$$

$$E_\gamma = \frac{m_3^2 - m_2^2}{2m_3} = \frac{\Delta m_{23}^2}{2m_3}$$

Using $\Delta m_{23}^2 = (2.43 \pm 0.09) \times 10^{-3} \mathrm{eV}^2$

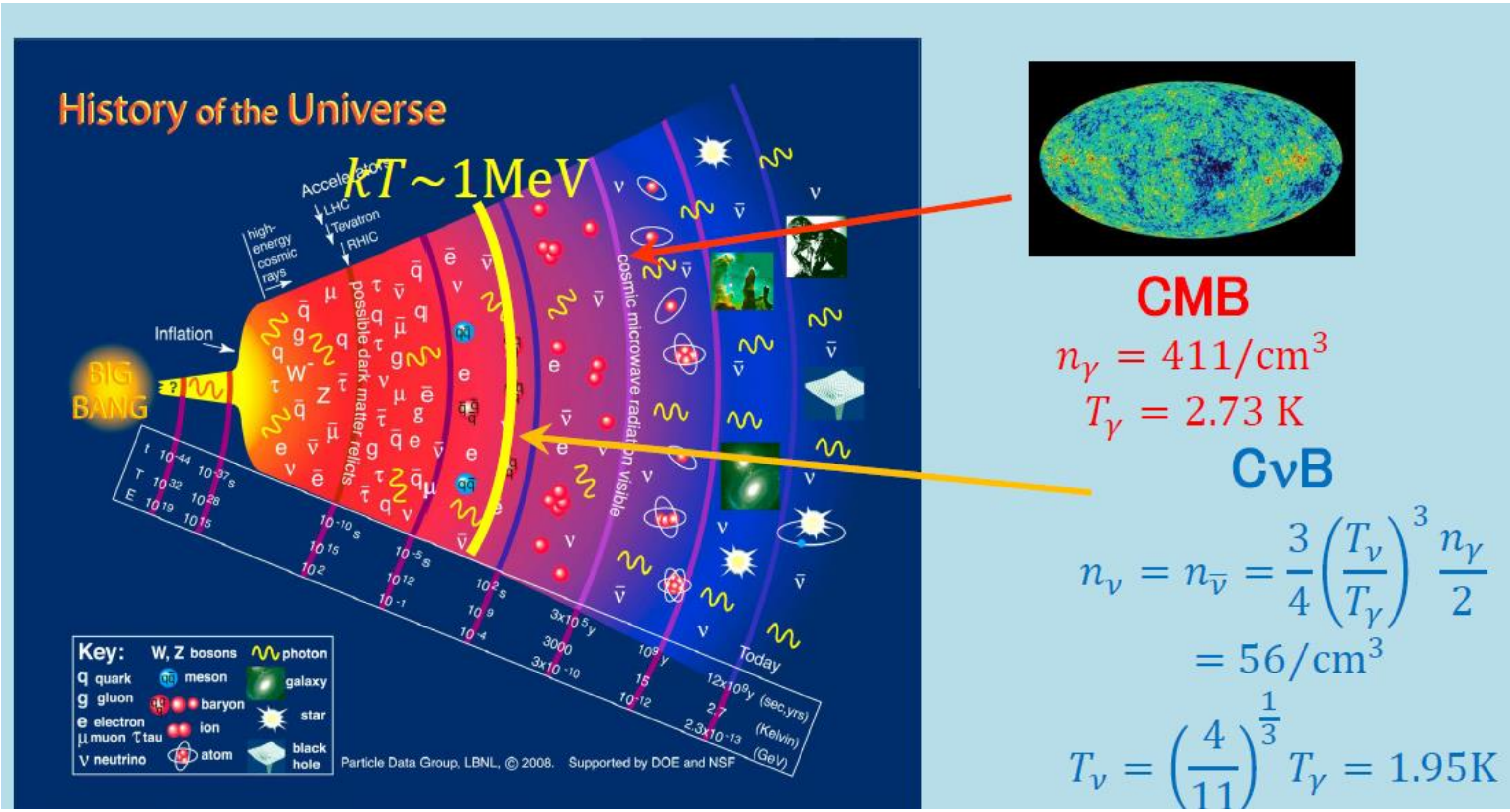
$E_\gamma = 10 \sim 25$ meV at ν_3 rest frame.

(Far - Infrared region $\lambda = 50 \sim 125\ \mu$)



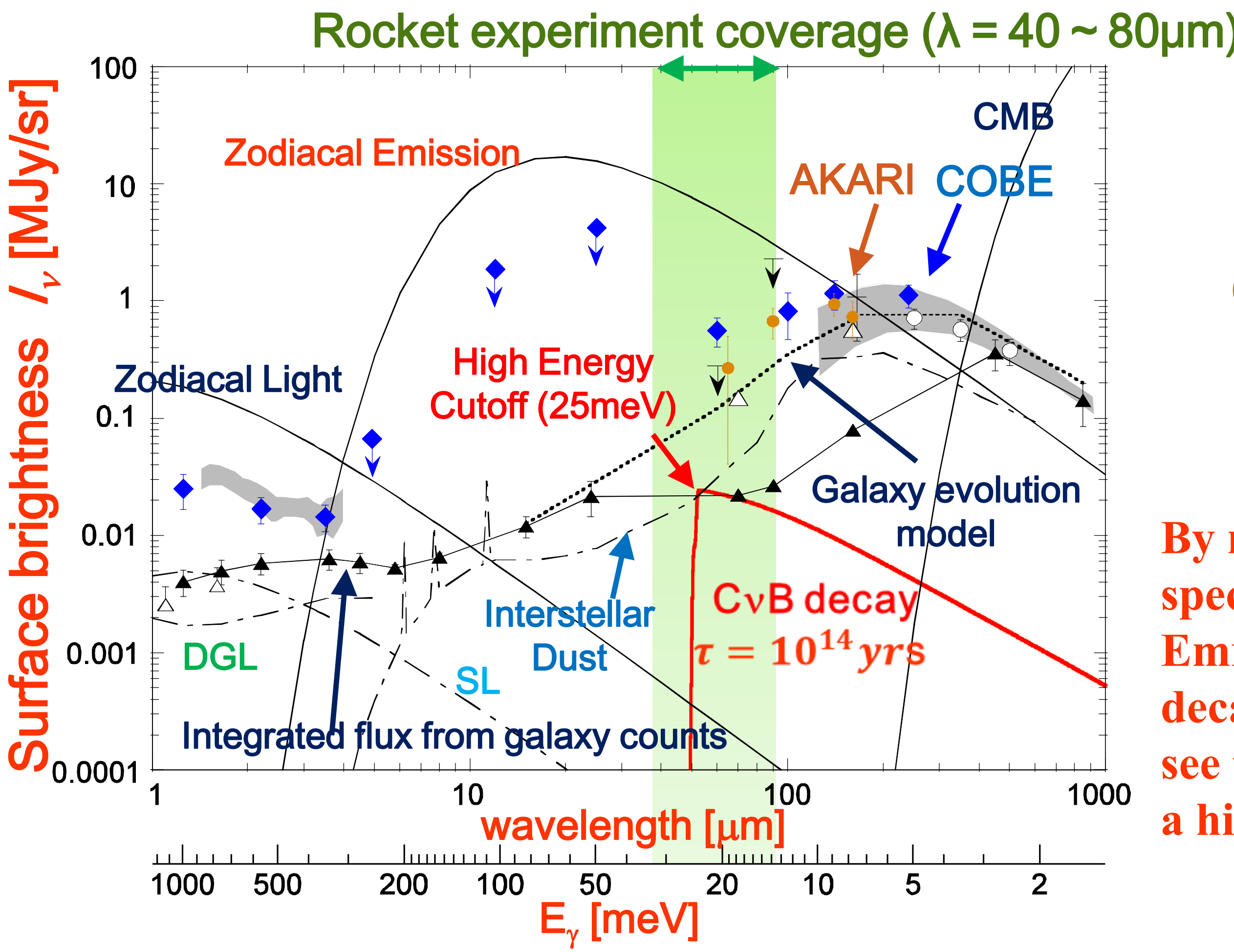
- **As the neutrino lifetime is very long, we need use cosmic background neutrino to observe the neutrino decay. To observe this decay of the cosmic background neutrino means a discovery of the cosmic background neutrino predicted by cosmology.**
- **Measured neutrino lifetime limit $\tau > 3 \times 10^{12}$ year.**
  Left-Right symmetric model predicts the neutrino lifetime larger than 10^{17} year.
  MSSM extension model with vector-like lepton generation predicts 10^{12} - 10^{14} year.

Big-Bang Cosmology and Cosmic Background Neutrino (CνB)



- **A few seconds after Big Bang → Cosmic Background Neutrino (CνB) became free.**
- **300,000 years after Big Bang → Cosmic Microwave Background (CMB) became free.**

Signal of Cosmic Background Neutrino Decay and its Backgrounds



Cosmic Infrared Background (CIB) measurements (● AKARI, ◆ COBE)

By measuring the energy spectrum of the Zodiacal Emission with the CνB decay continuously, we can see the CνB decay signal as a high energy cutoff.

Requirements for the detector

- Continuous spectrum of photon energy around $E_\gamma \sim 25\ \mathrm{meV} (\lambda = 50\mu\mathrm{m})$
- Energy measurement for single photon with better than 2% resolution for $E_\gamma = 25\mathrm{meV}$ to identify the sharp edge in the spectrum
- Rocket and/or satellite experiment with this detector

Method

- We measure the continuous energy spectrum of cosmic infrared photon to search for the neutrino decay signal with rocket and satellite experiments.
- For these experiments, we develop Superconducting Tunnel Junction (STJ) far-infrared photon detector.

COBAND (COsmic BAckground Neutrino Decay Search) Experiment

Rocket Experiment Plan: 5minutes data acquisition at 200 km height in 2021-22.

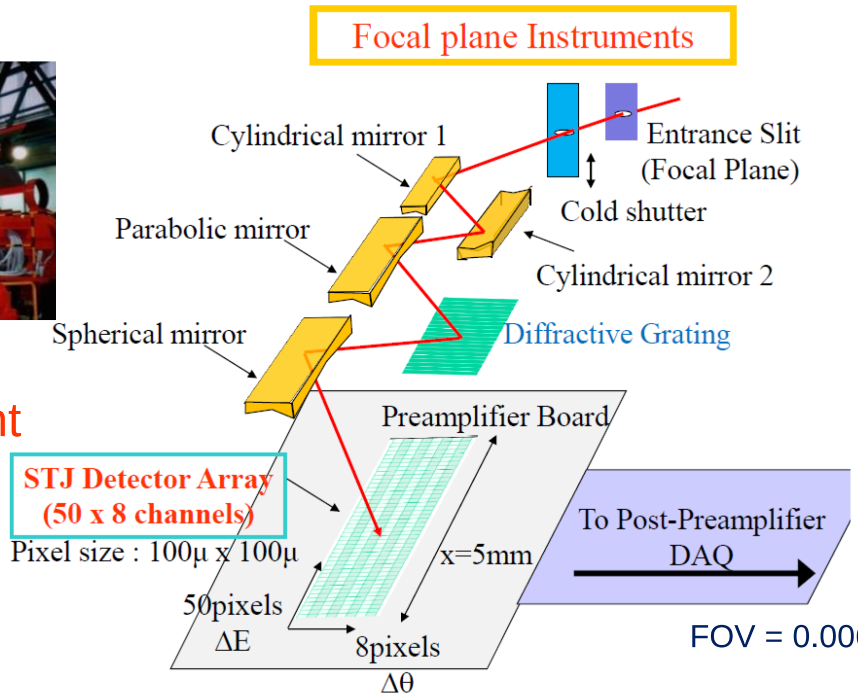
Improve the current limit of lifetime $\tau(\nu_3)$ by two orders of magnitude (~10^{14}years).

»Superconducting Tunneling Junction (STJ) detectors in development

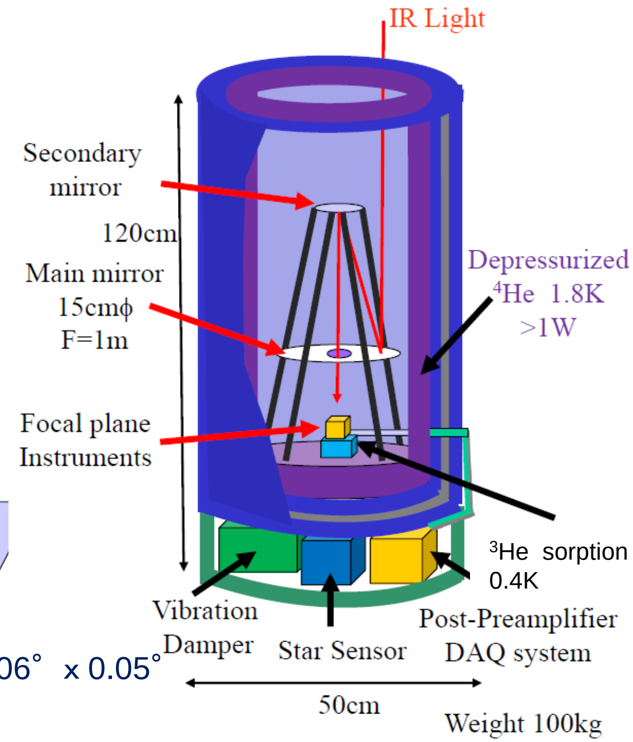
> Array of 50 Nb/Al-STJ pixels with diffractive grating covering $\lambda = 40 - 80\mu m$

JAXA Rocket
CIB Experiment

（Feb 2, 1992）



FOV = 0.006° x 0.05°



Satellite experiment after 2025 → **sensitivity of $\tau(\nu_3)$ ~10^{17}year**

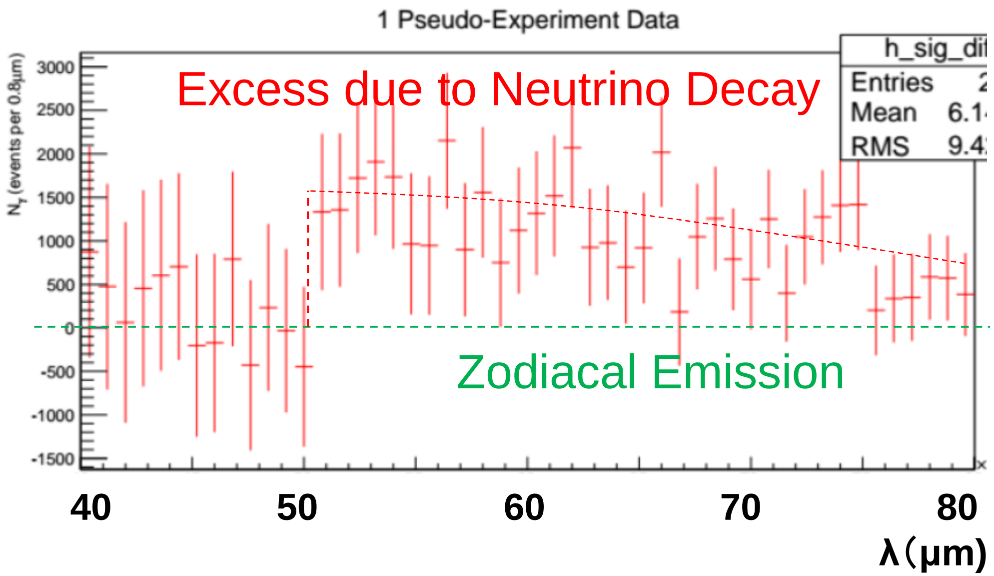
> STJ using Hafnium: Hf-STJ for satellite experiment (S. H. Kim et al. JPSJ 81,024101 (2012))

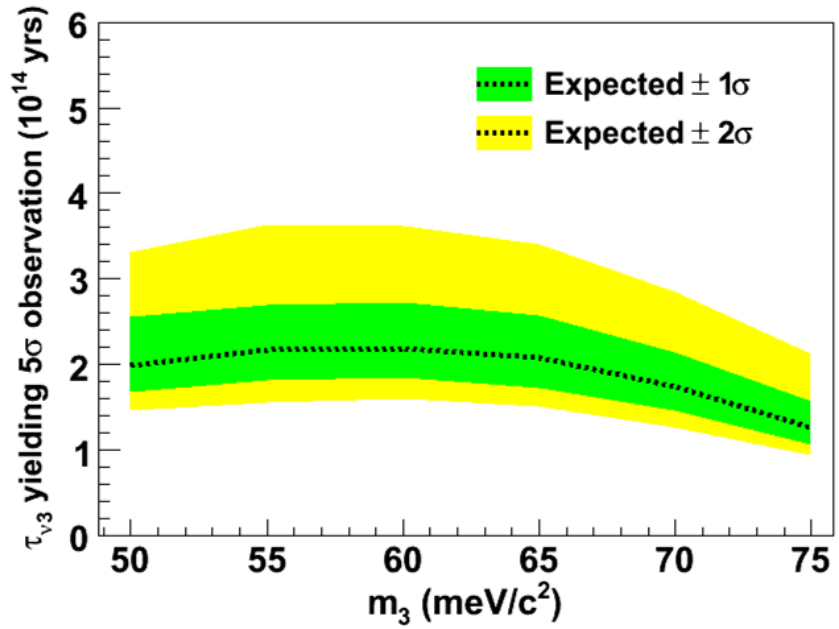
- $\Delta = 20\mu eV$: Superconducting gap energy for Hafnium
- $N_{q.p.} = 25meV/1.7\Delta = 735$ for 25meV photon: $\Delta E/E < 2\%$ if Fano-factor is less than 0.3

Sensitivity to Neutrino Decay

Parameters in the rocket experiment simulation

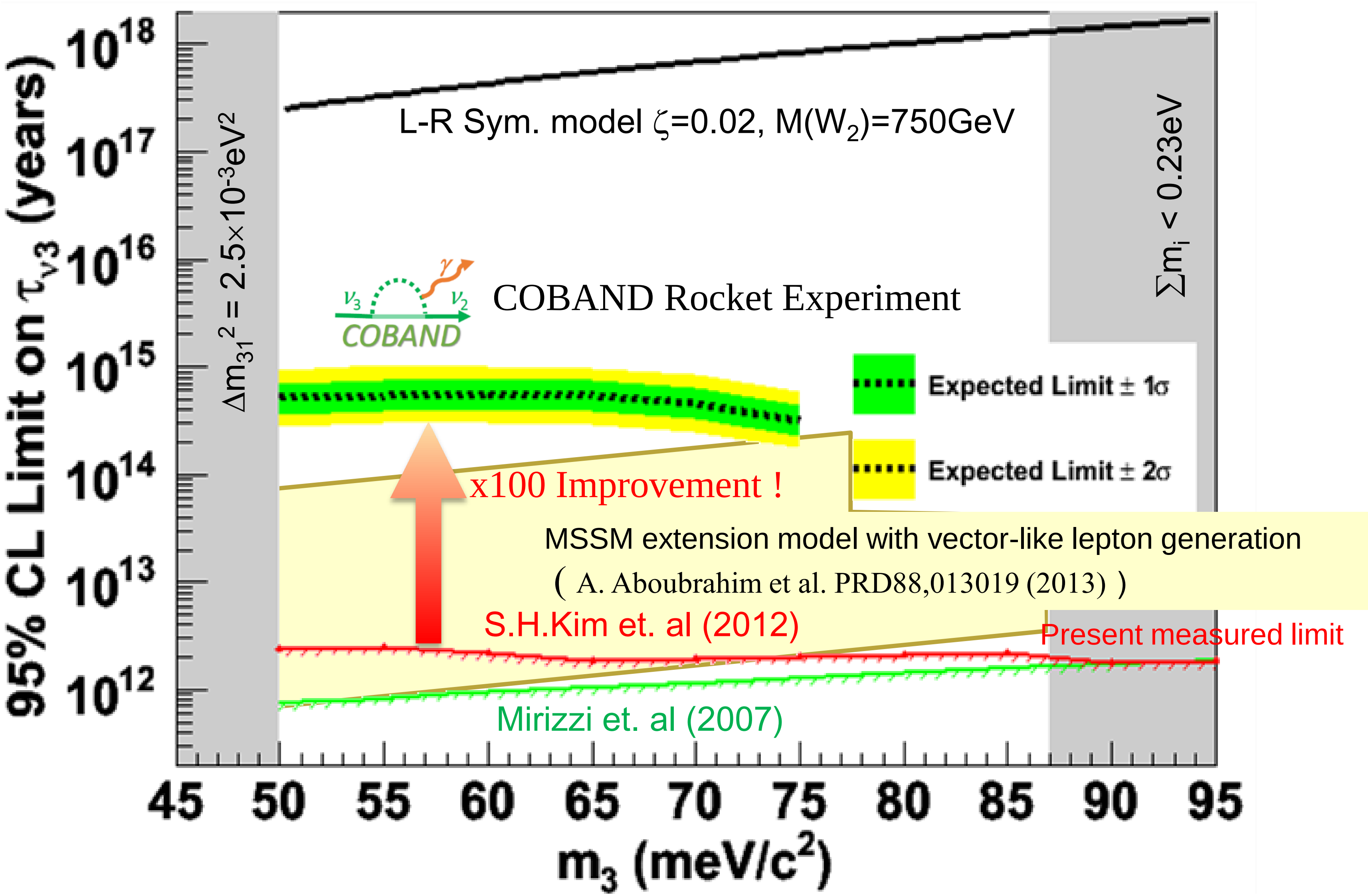
- telescope diameter: 15cm
- 50-column (λ: 40μm – 80 μm) × 8-row array
- Viewing angle per single pixel: 100μrad × 100μrad
- Measurement time: 200 sec.
- Photon detection efficiency: 100%



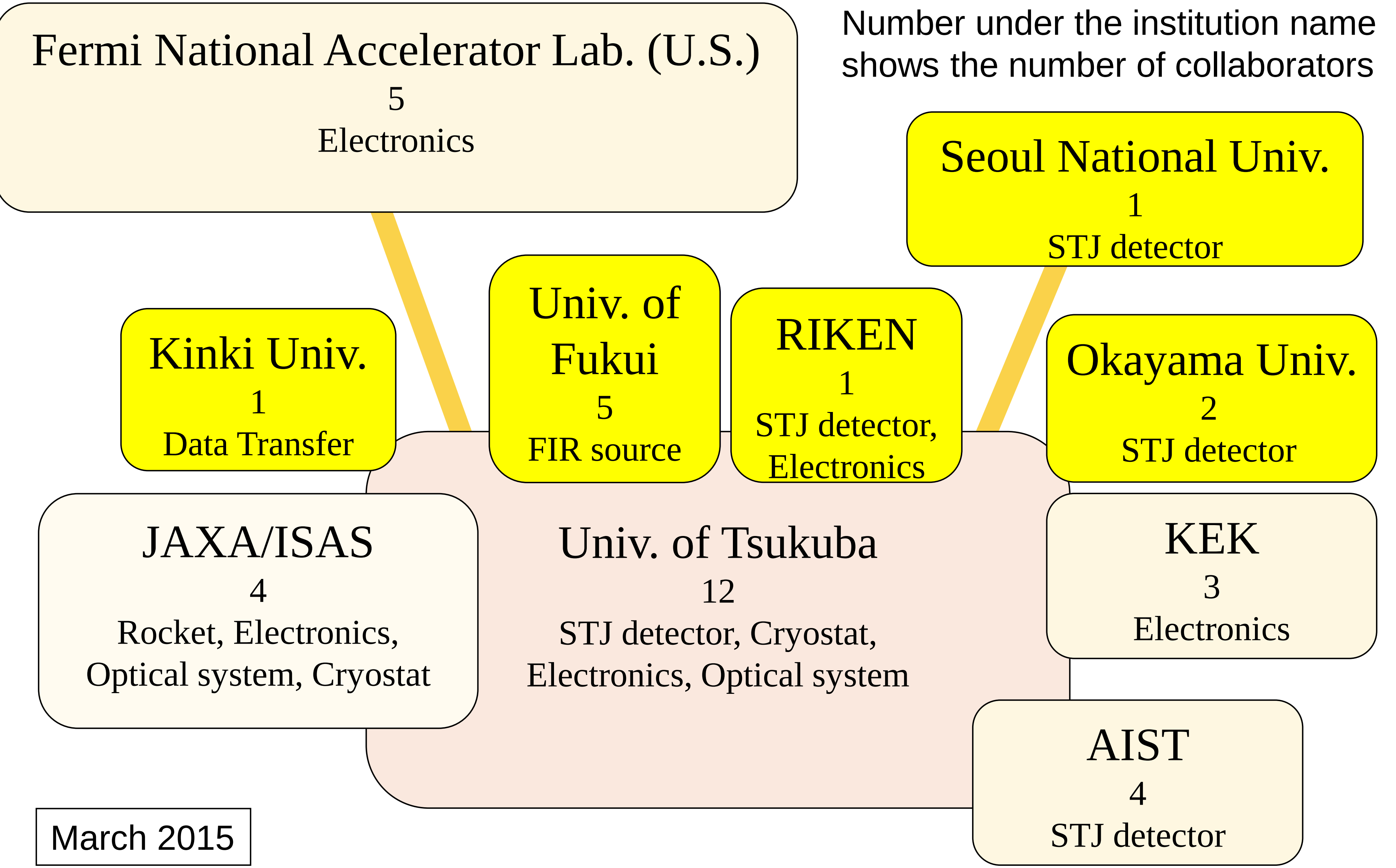


- If ν_3 lifetime were 2×10^{14} yrs, the signal significance is at 5σ level

COBAND Experiment Sensitivity to Neutrino Decay



Contribution of Japan and U.S



March 2015

Project Status

- Nb/Al-STJ

  Leakage current of STJ satisfied the experimental requirement less than 100pA.

- SOI-STJ

  We made Nb/Al-STJ on the SOI cryogenic amplifier board. The SOI cryogenic amplifier worked at 350mK. The STJ signal for visible laser pulse light was observed.

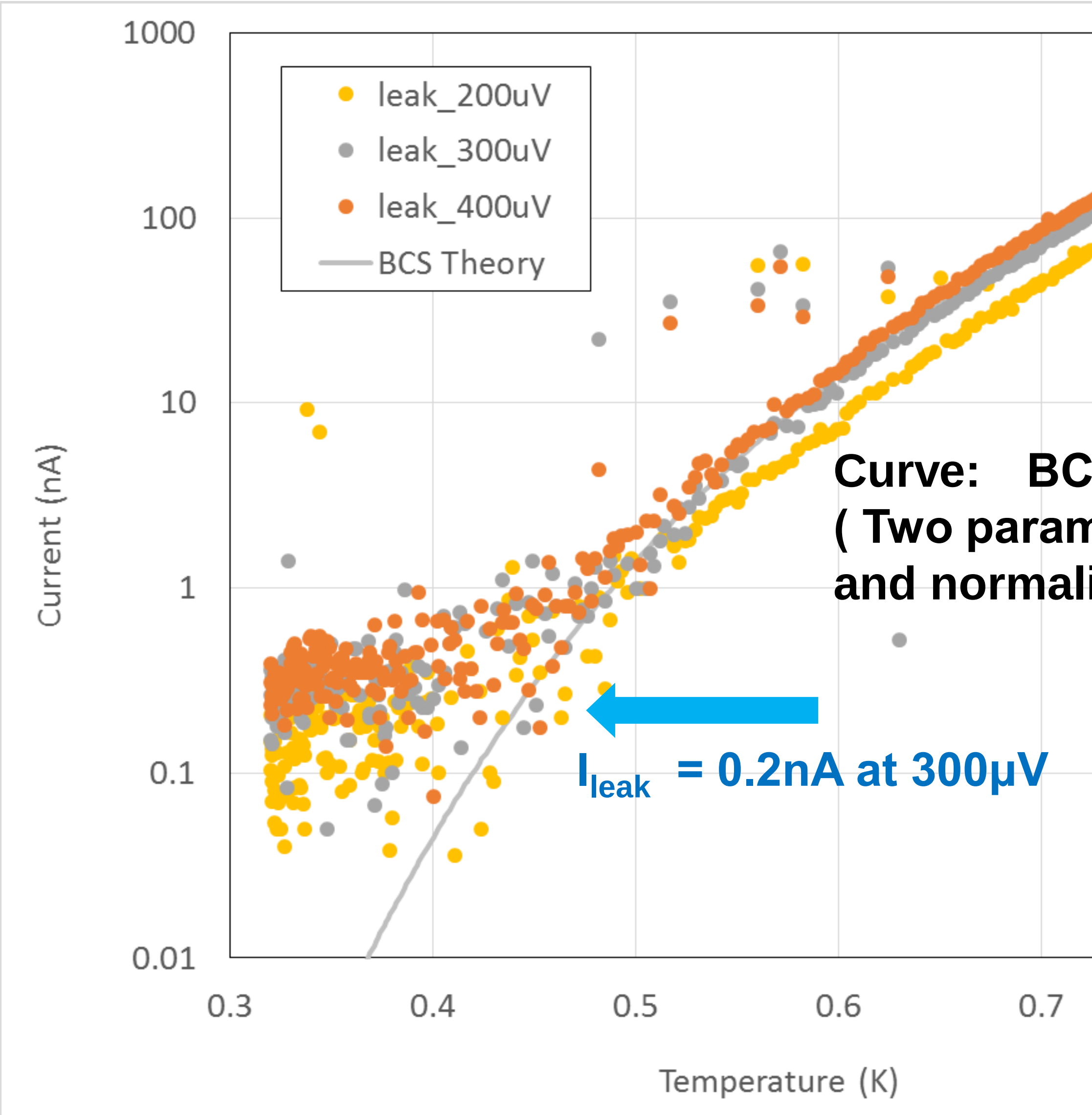
- Hf-STJ

  DC response of Hf-STJ to visible laser light was observed.

Leakage Current of Nb/Al-STJ made at AIST CRAVITY

T. Fujii (AIST)

Leakage Current at 200, 300 and 400uV vs. Temperature **50μm-sq. Nb/Al-STJ**



Curve: BCS theory prediction at 300μV (Two parameter fit of the energy gap Δ and normalization → Δ= 0.57meV)

Leakage current has satisfied our requirement of 0.1nA for 20μm-sq. STJ .

STJ size	# of samples	I_{leak} at 0.3mV
50 x 50μm^2	18	224±29 pA
20 x 20 μm^2	7	**39±13 pA**
10 x 10 μm^2	20	**14±7 pA**

R&D at Fermilab

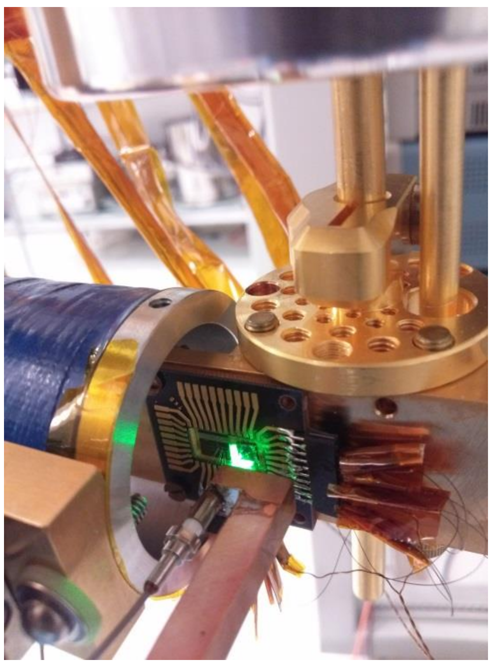
Test of Nb/Al-STJ＋HEMT cryogenic preamplifier (made at Fermilab)

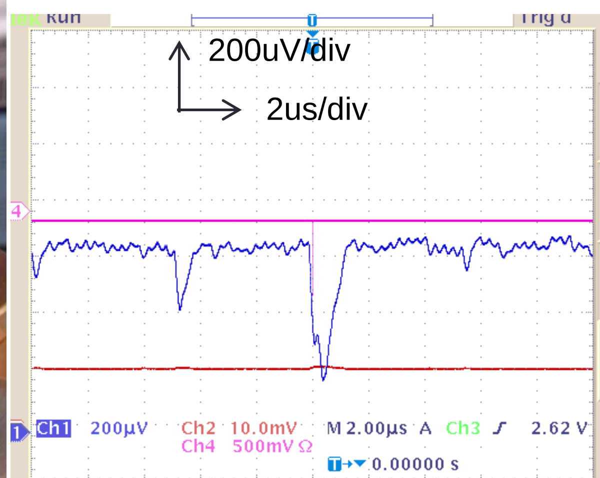
2013/8/1〜14, 8/26〜9/15（ Japan: 5, US:5）

STJ Test at 2K

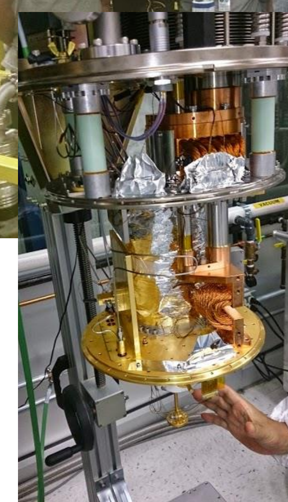
2014/2/13〜3/6（ Japan: 7, US:6）, 2014/8/26〜9/12（ Japan: 6, US:6）

Nb/Al-STJ+ HEMT cryogenic preamplifier at 0.9K with MilliKelvin Facility ADR

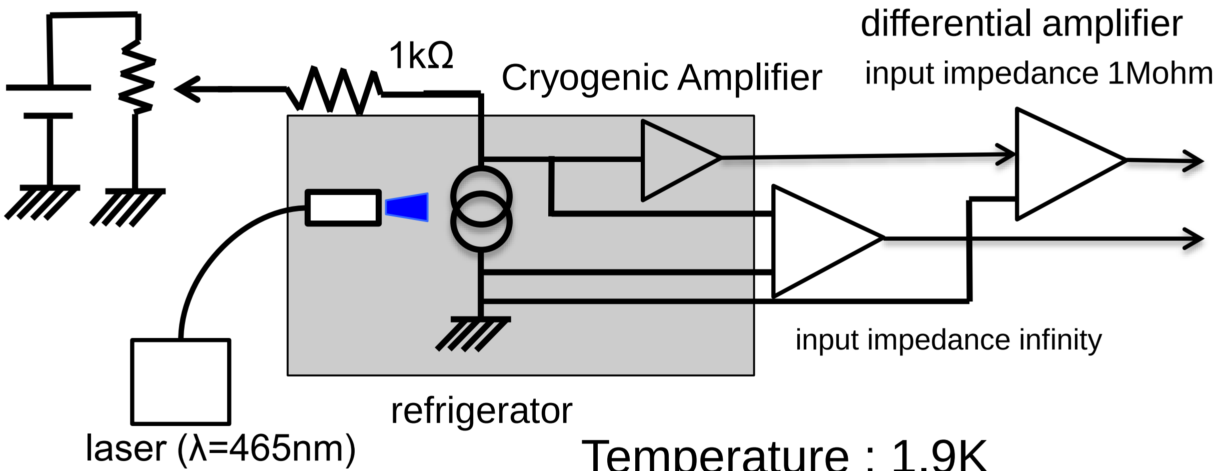




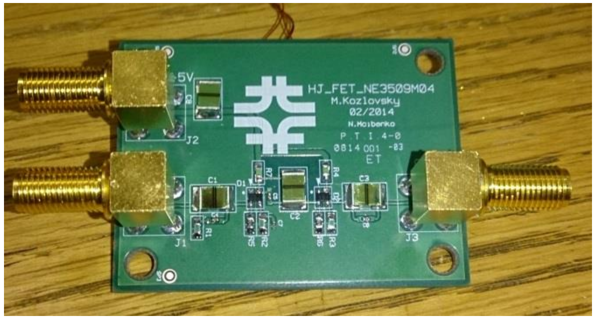
We obtained the response to the laser light (465nm) with the newly designed Al/Nb-STJ (20um x 20um). No cryogenic amplifier this time.



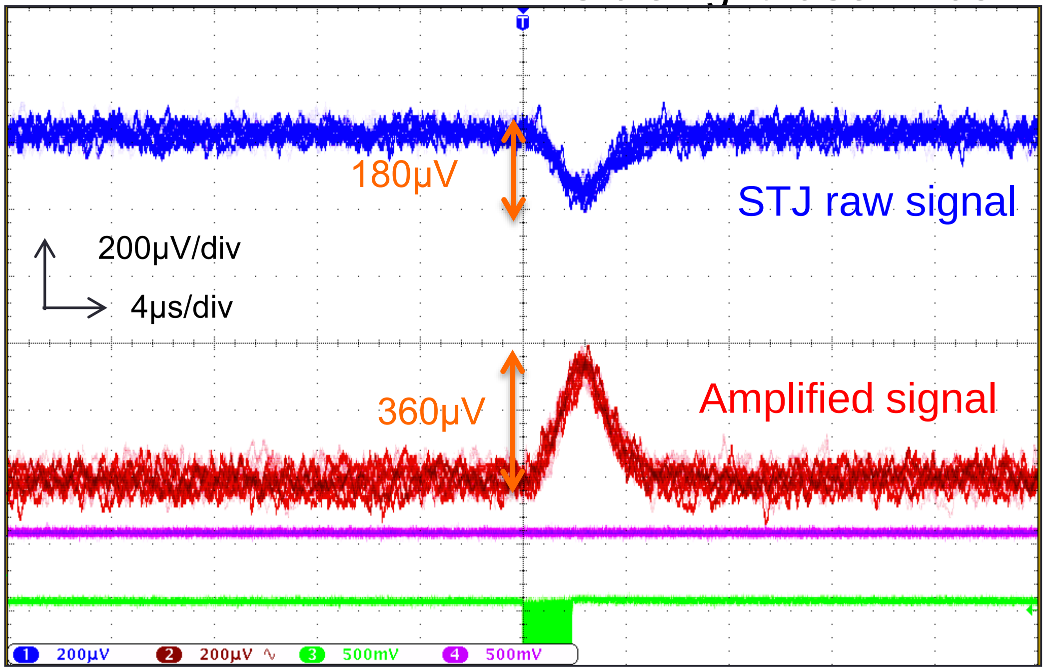
STJ signal amplified with a cryogenic HEMT amplifier made by Fermilab group



Cryogenic amplifier made by Fermilab group



Temperature : 1.9K
Visible light laser 465nm



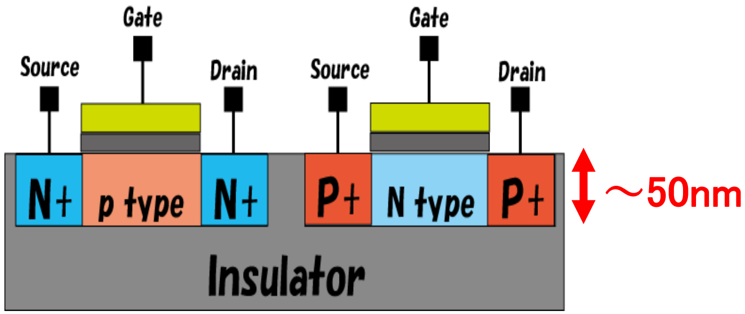
STJ signal was amplified with this cryogenic amplifier. Developing higher gain amplifier.

Fermilab group also joined the R&D of the SOI cryogenic amplifier.

R&D of SOI-STJ Detctor

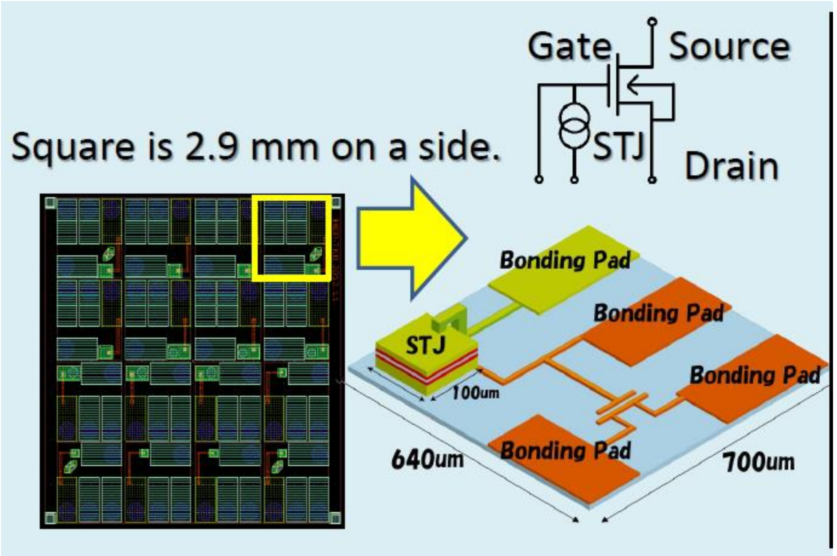
FD-SOI (Silicon-On-Insulator) device was proved to operate at 4K by a JAXA/KEK group (AIPC 1185,286-289(200 FD-SOI 9)). It has the following characteristics:
low-power consumption, high speed, easy large scale integration and <u>suppression of charge-up by high mobility carrier due to thin depletion layer(～50nm).</u>

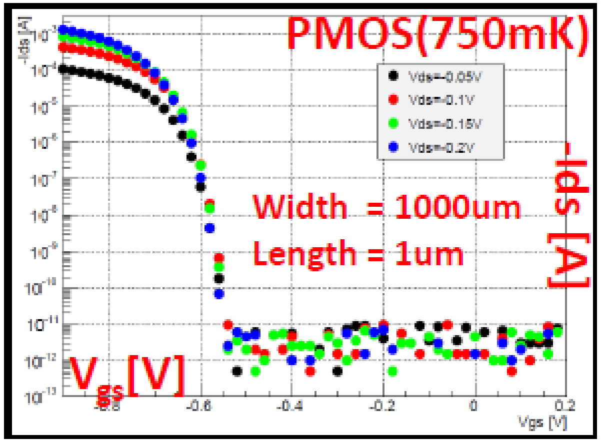
FD-SOI -MOSFET



To improve the signal-to-noise ratio and to make multi-pixel device easily, we made a SOI-STJ detector where we processed Nb/Al-STJ on a SOI transistor board.

We confirmed that both Nb/Al-STJ detector and SOI MOSFET worked normally at 750mK.

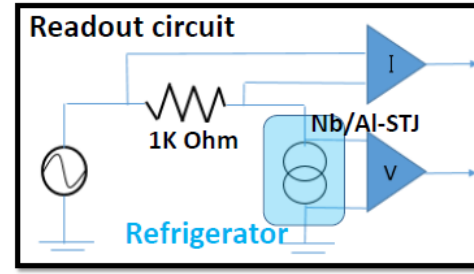




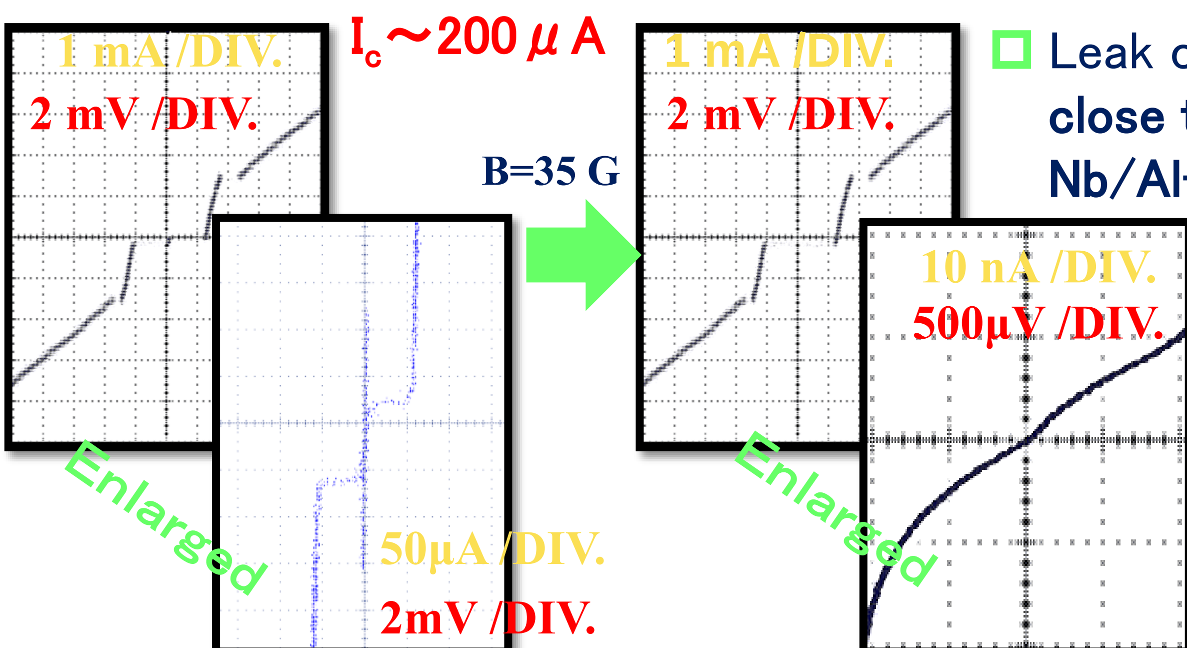
Performance of Nb/Al–STJ in SOI–STJ Detector

We measured the I–V curve of the Nb/Al–STJ (50 x 50 μ m^2 junction) processed on the SOI wafer

at **700mK** with a dilution refrigerator.

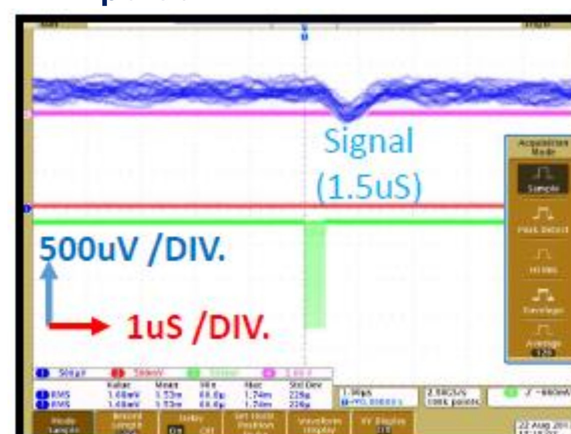


- **I–V curve of Josephson Junction**



- Leak current @ 0.5mV is **6nA. It is close to our best record of normal Nb/Al–STJ(100um x 100um) 10nA**.

- **Signal of Nb/Al–STJ in SOI–STJ for 465nm laser pulse.**



- Quality Factor ($R_{dynamic}$/R_{normal})　　**On Si wafer : 5 x 10^5**
  On SOI wafer : 3 x 10^5

R&D of Superconducting Tunnel Junction (STJ) Detctor

Hf-STJ

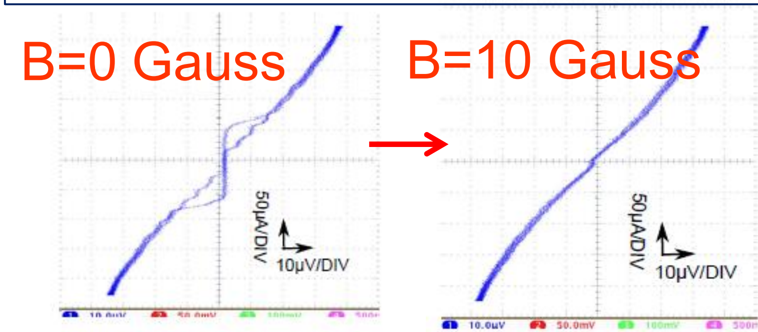
Goal: Measure energy of a single far-infrared photon for neutrino decay search experiment within 2% energy resolution.

Micro-calorimeter: Hf-STJ can generate enough statistics of quasi-particles from cooper pair breakings to achieve 2% energy resolution for photon with $E_\gamma = 25$ meV.

Material	$T_c(K)$	Δ(meV)
Niobium	9.20	1.550
Aluminum	1.14	0.172
Hafnium	0.13	0.021

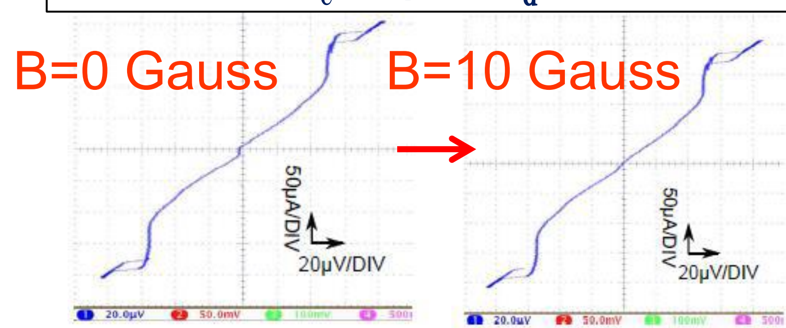
I-V curve of Hf-STJ (**200x200μm²**)

- T~80mK, I_c=60μA, **R_d=0.2Ω**



I-V curve of Hf-STJ (**100x100μm²**)

- T~40mK, I_c=10μA, **R_d=0.6Ω**



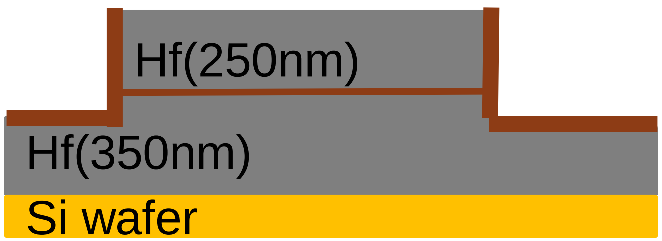
Hf-STJ (100x100μm²) shows smaller leakage current than **Hf-STJ (200x200μm²)** which we have established to work as a STJ in 2011.

The work to reduce a large leakage current of Hf-STJ is underway.

Research Highlight

Hf-STJ Test Result in 2014

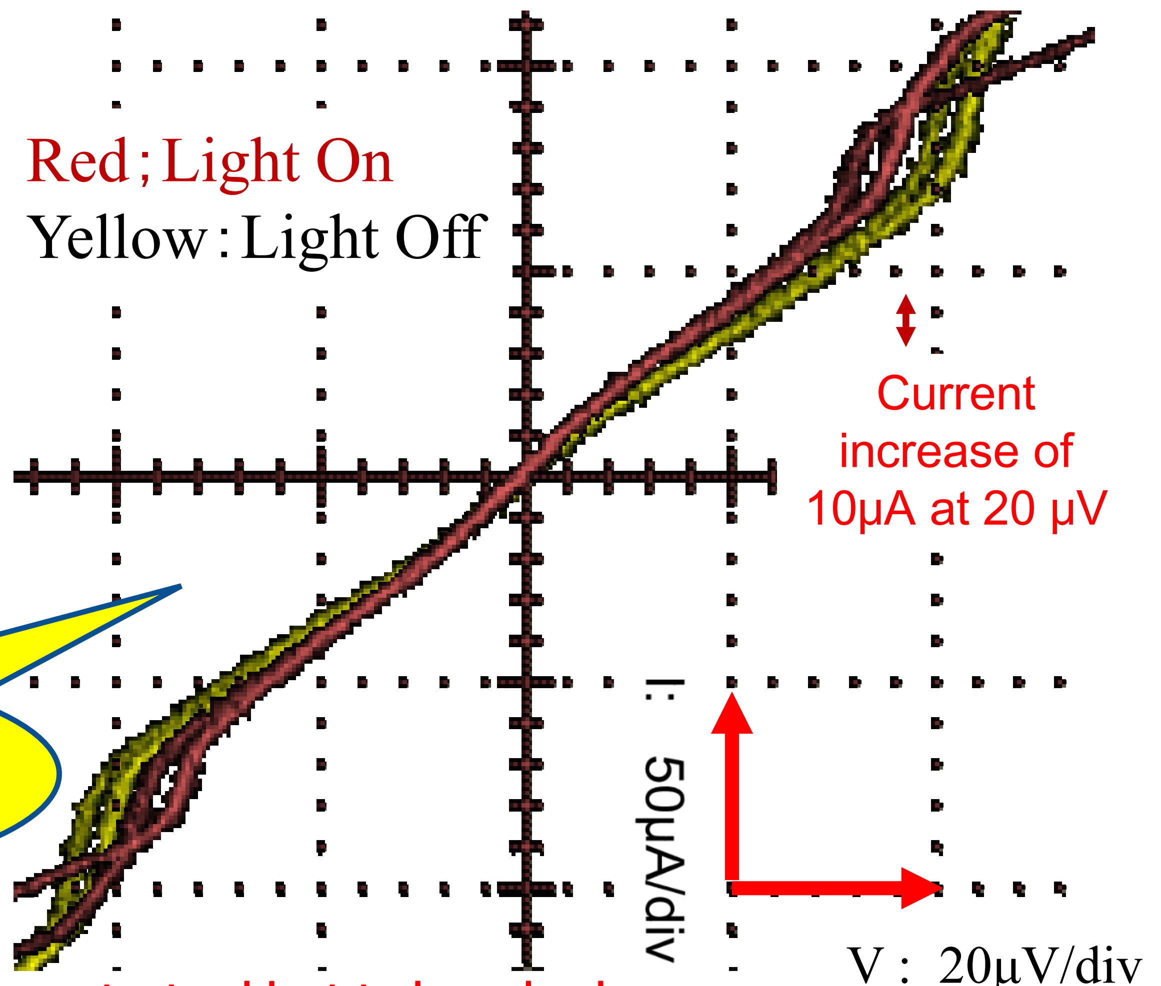
Hf-STJ Response (Visible laser light 456nm 100kHz)



HfOx : 20Torr,1hour 1.5nm
Outside insulater : 45nm

100×100μm²
T=39~53mK
R_d=0.6Ω

First observation of Hf-STJ light response in the world (2014)



Decreasing the leakage current is important subject to be solved.

We are trying to downsizing the STJ.

Future Prospects

- We will complete R&D of Nb/Al-STJ with SOI cryogenic amplifier, readout electronics and cryostat in JFY 2019 and will submit a proposal of neutrino decay search rocket experiment to JAXA/ISAS in JFY 2019.

- We will perform the rocket experiment for neutrino decay search around 2021-22.

- We continue R&D of Hf-STJ, readout electronics and cryostat for a satellite experiment after 2025.

Number of Participants

	2013	2014	2015	2016	2017
日本	23 （10）	32 （12）	（　）	（　）	（　）
米国	5 （0　）	5 （0　）	（　）	（　）	（　）

（　　）: Graduate Students

Number of Persons Acquiring Doctor Degree from FY1979 to FY2017

Permanent academic position	Postdoctoral Fellow	Company
0 （ 0 ）	0 （ 0 ）	0 （ 0 ）

（　　）: from FY2013 to FY2017

Number of Presentations
from FY1979 to FY2017

Refereed Papers	International Conference
9 （ 8 ）	40 （ 29 ）

（ ）: from FY2013 to FY2017

Number of Academic Dissertation from FY2013 to FY2017

Doctor	Master
0	8

Number of Citations from FY1979 to FY2017

（Only Referee Reading）

Average	Over 50	From 20 to 49
4.5 （2.0 ）	0 （ ）	0 （ ）

（ ）: from FY2013 to FY2017

Research Papers Cited over 100 Times

None

Other Important Research Papers (within five titles）

- **"Search for Radiative Decays of Cosmic Background Neutrino using Cosmic Infrared Background Energy Spectrum", S.H. Kim, K. Takemasa, Y. Takeuchi and S. Matsuura, JPSJ 81 (2012) 024101**

- **“Development of superconducting tunnel junction photon detector using Hafnium”, S.H. Kim , H.S. Jeong, K. Kiuchi, S. Kanai, T. Onjo, K. Takemasa, Y. Takeuchi, H. Ikeda, S. Matsuura, H. Sato, M. Hazumi and S.B. Kim, Physics Procedia 37 (2012) 667-674 (Proceedings of TIPP2011)**

- **"Development of Superconducting Tunnel Junction Photon Detectors with Cryogenic Preamplifier for COBAND experiment", S. H. Kim *et al.* (COBAND Collaboration) SPPHY 213, 242 - 248 (2018)**

- **"Development of Superconducting Tunnel Junction Detector Using Hafnium for COBAND Experiment", K.Takemasa *et al.* . (COBAND Collaboration) SPPHY 213, 254 - 258 (2018)**

Comments for the U.S. Japan Program

- U.S. Japan program has been based on the firm U.S.-Japan collaboration. Many people from Japan stayed at the U.S. laboratories who contributed to obtain various valuable physics results. Such real co-operative studies will be important for keeping high energy physics active and international.

- U.S. Japan program has been very useful for the education of graduate students and young postdocs. In this program, these young people should be able to stay at U.S. laboratories for enough period to accomplish their work. In the point of view of graduate student education, the University teams should have a leadership on most experiments in the U.S. Japan program and should have enough travel expenses.