Search for Hidden Photon Dark Matter(HPDM) using Dish Antenna in Millimeter-wave region

Yoshiki Okesaku[1]

T. Yamazaki[2], S. Knirck[3], T. Inada[2], T. Idehara[4]

[1]Graduate School of Science, The University of Tokyo(UTokyo)

[2]International Center for Elementary Particle Physics(ICEPP), UTokyo

[3]Institute for Theoretical Physics, University of Heidelberg

[4]Research Center for Development of Far-Infrared Region, University of Fukui

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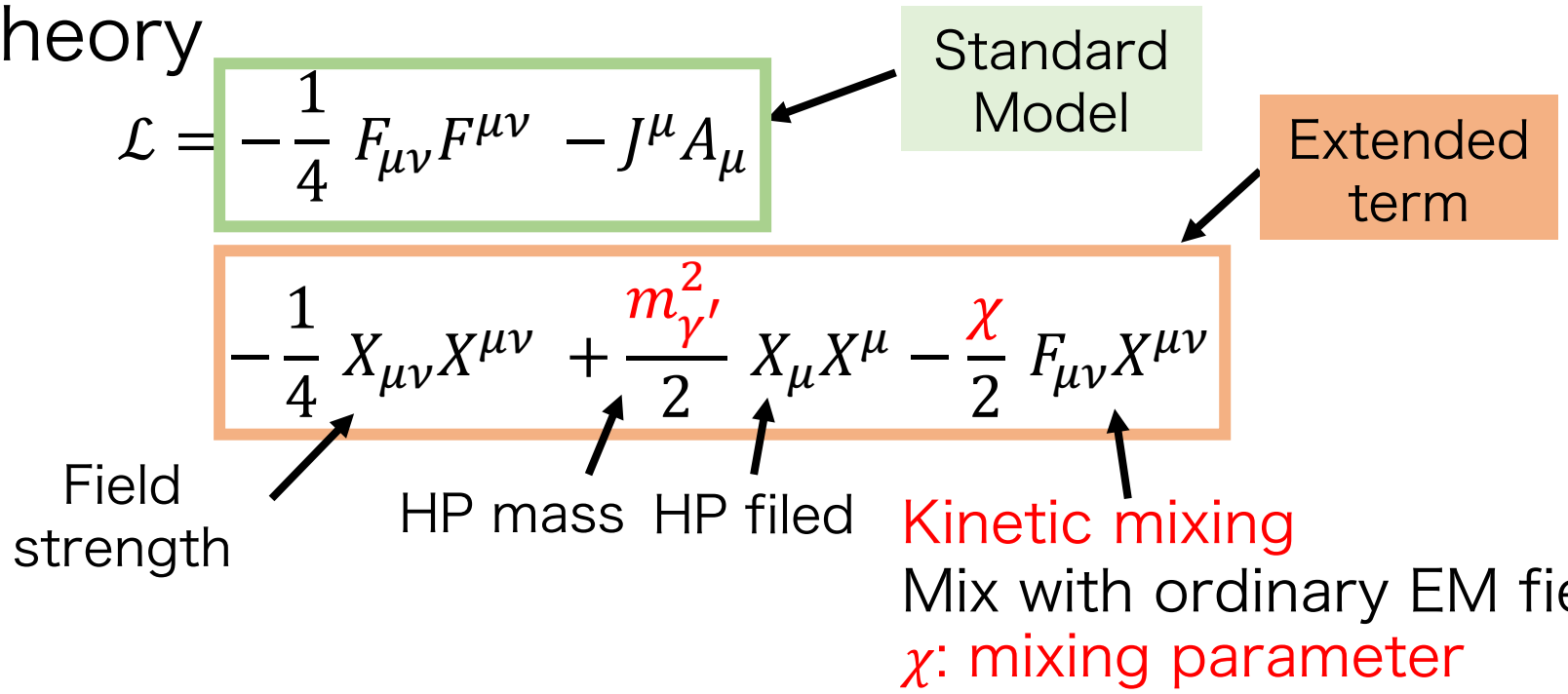
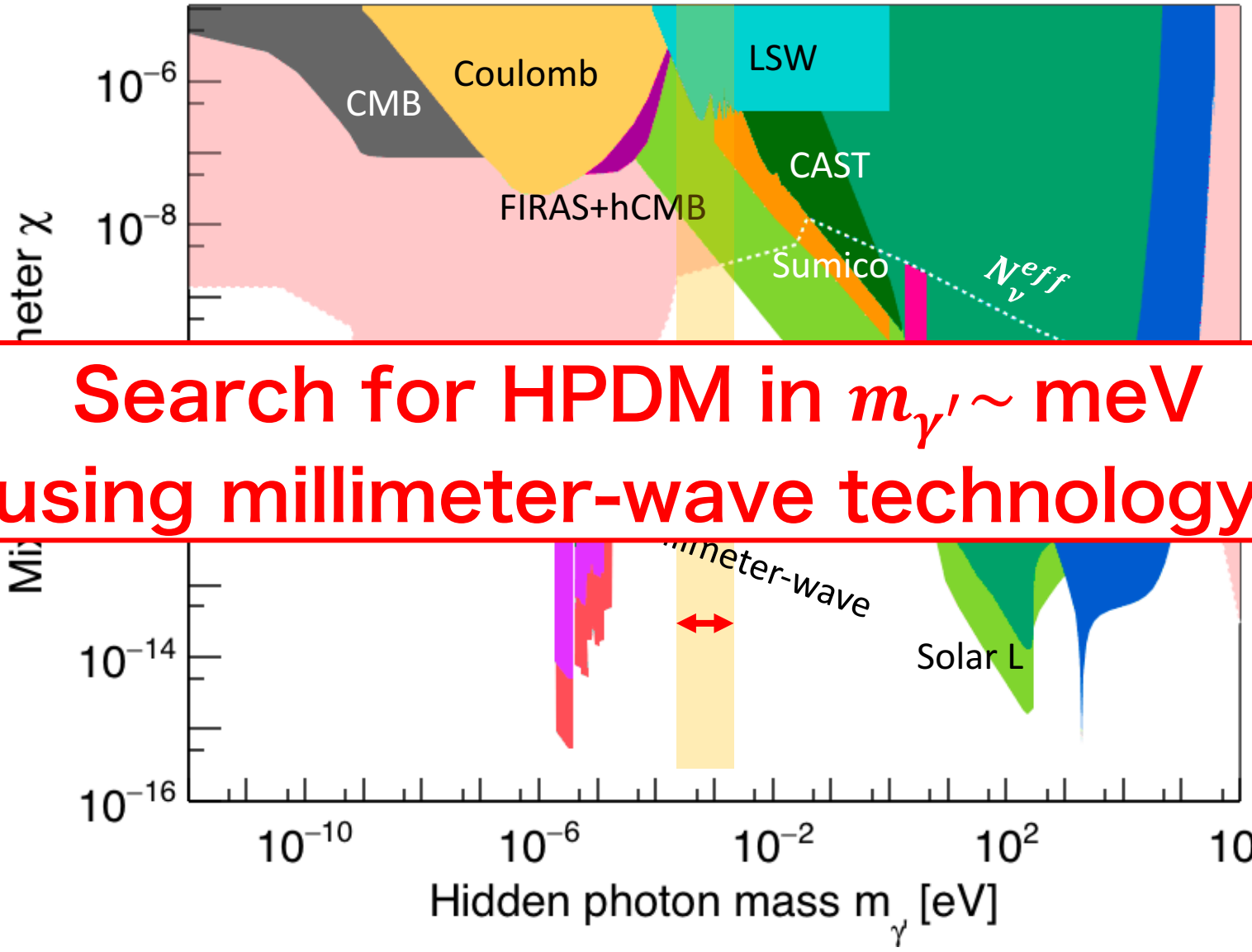
Hidden Photon Dark Matter(HPDM)

- Hidden Photon: extra U(1) gauge boson predicted in beyond the Standard Model theory

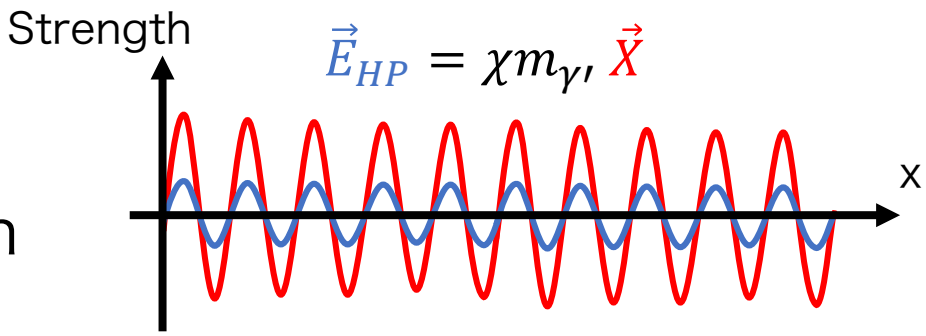


- HP can be Cold Dark Matter(CDM) via misalignment mechanism

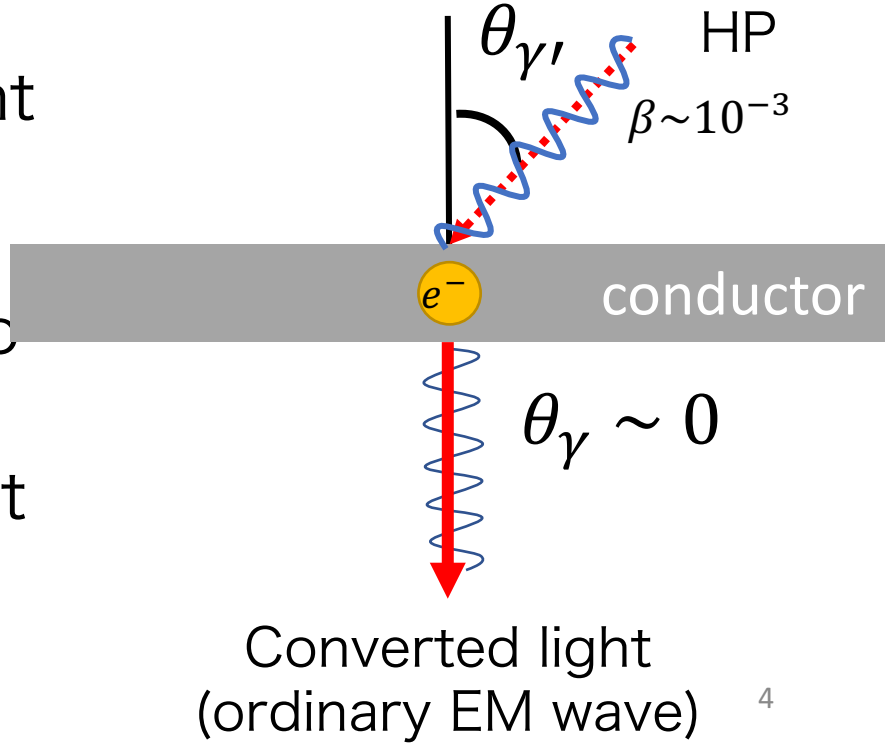
Search region



Method ①



- By kinetic mixing, HP can have ordinary EM filed
  $\vec{E}_{HP} = \chi m_{\gamma'} \vec{X}$ ← HP vector field
- $\vec{E}_{HP}$ oscillates free electrons in conductor, they emits converted light
- Converted light released perpendicular to the conductor surface due to boundary condition
- Energy of Converted light = mass of HP



Method ②

- Focus converted light with a parabolic mirror, measure power spectrum
- Focused power is

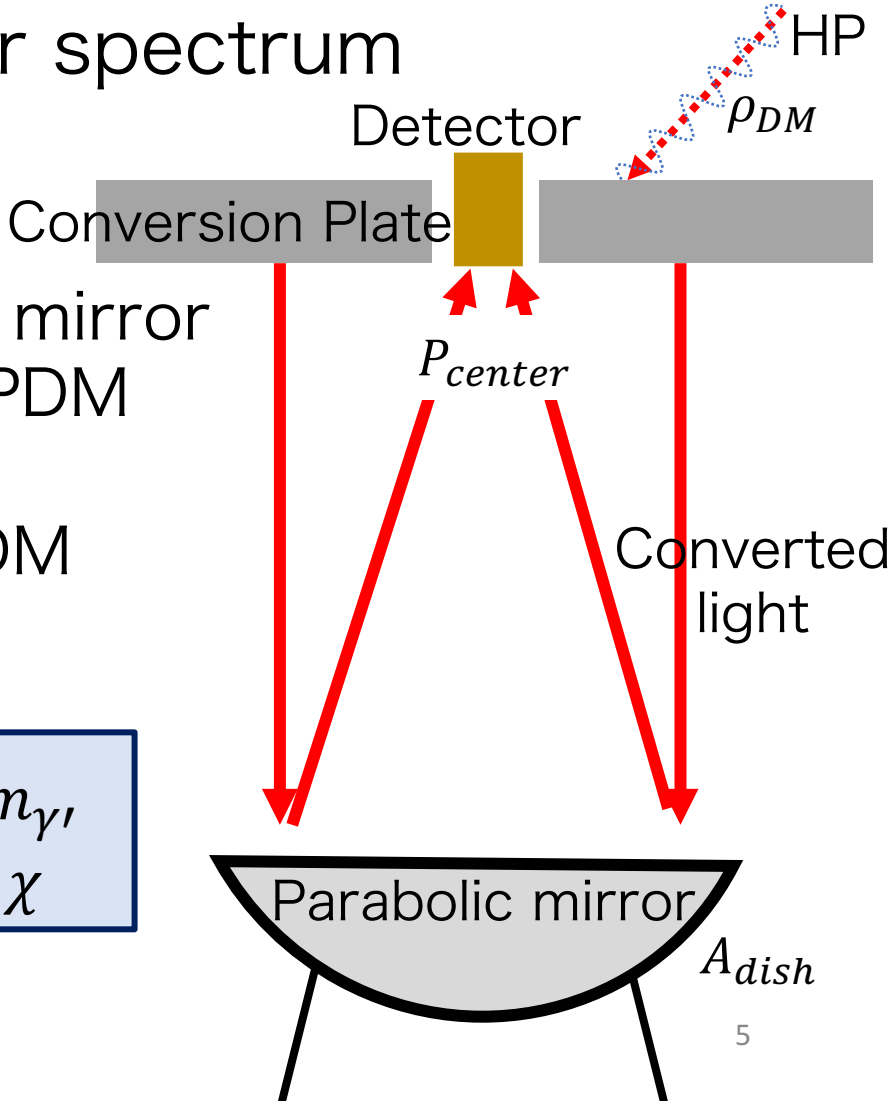
$P_{center} \sim \chi^2 A_{dish}\, \rho_{DM}$

A_{dish}: Effective area of the mirror

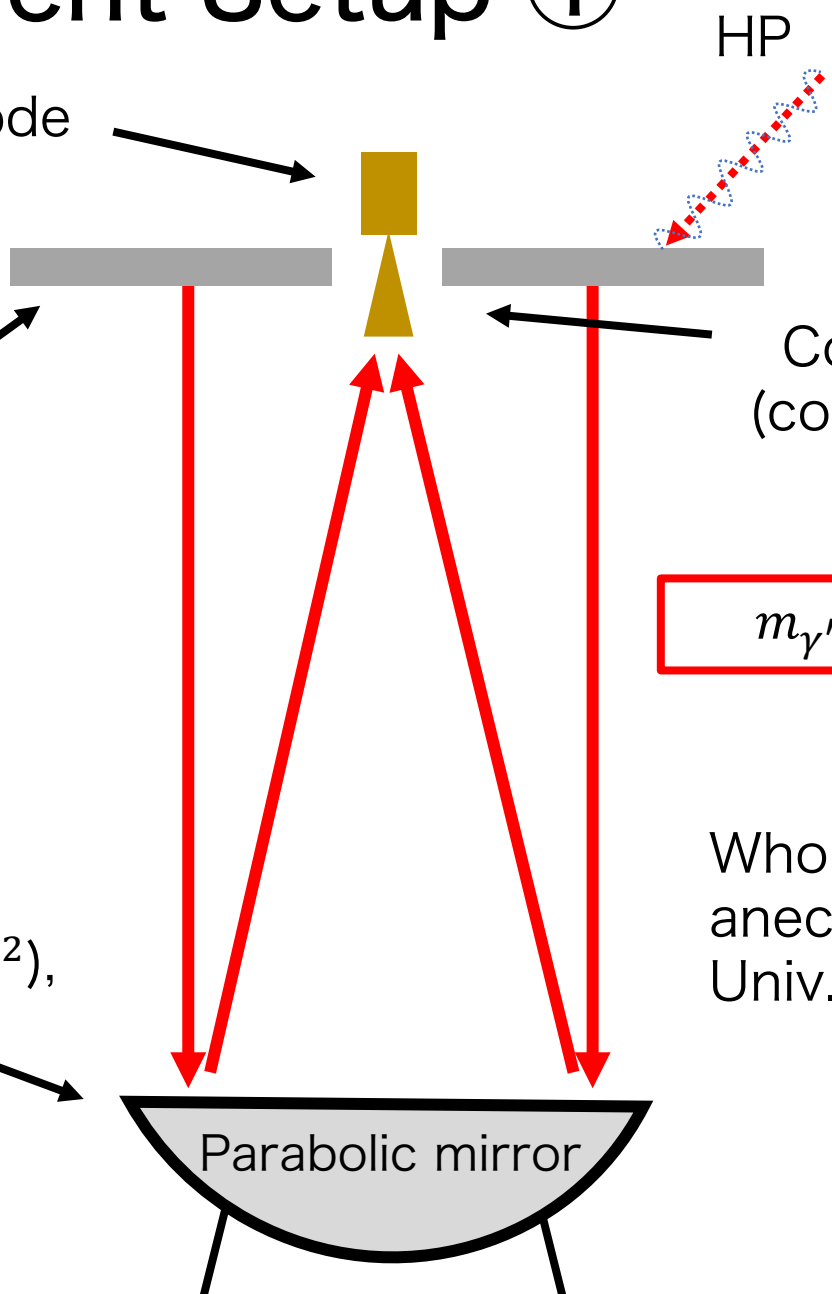
ρ_{DM}: Energy density of HPDM

Search for signal from HPDM

Frequency of signal	→	$m_{\gamma'}$
Power of signal	→	χ



Experiment Setup ①

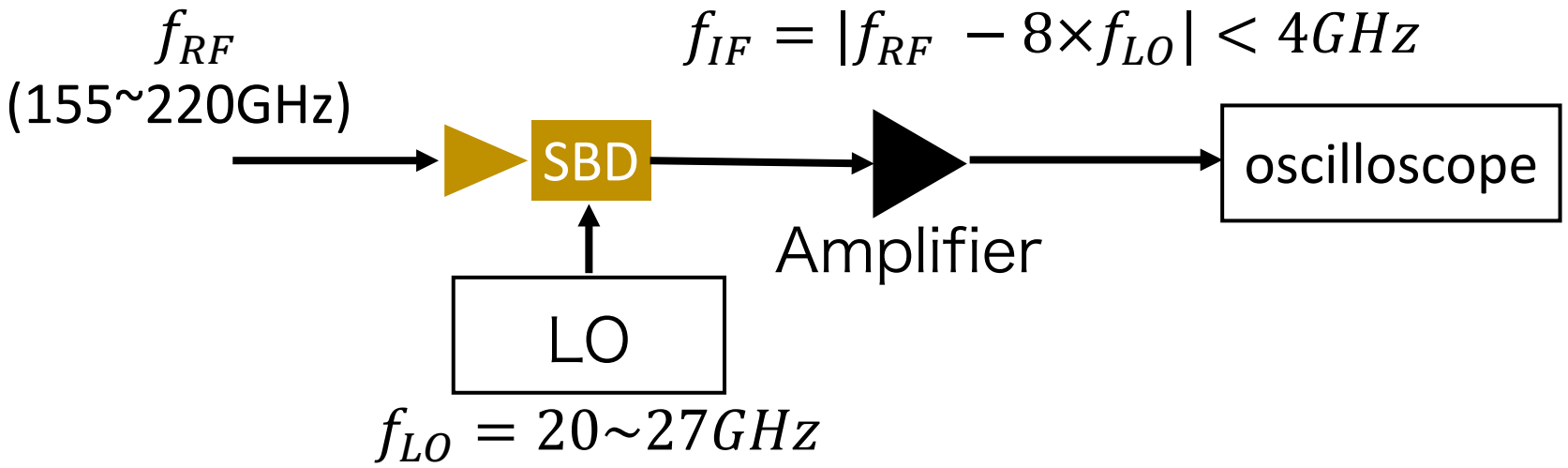


$m_{\gamma'} = 0.6 \sim 0.9\ meV$

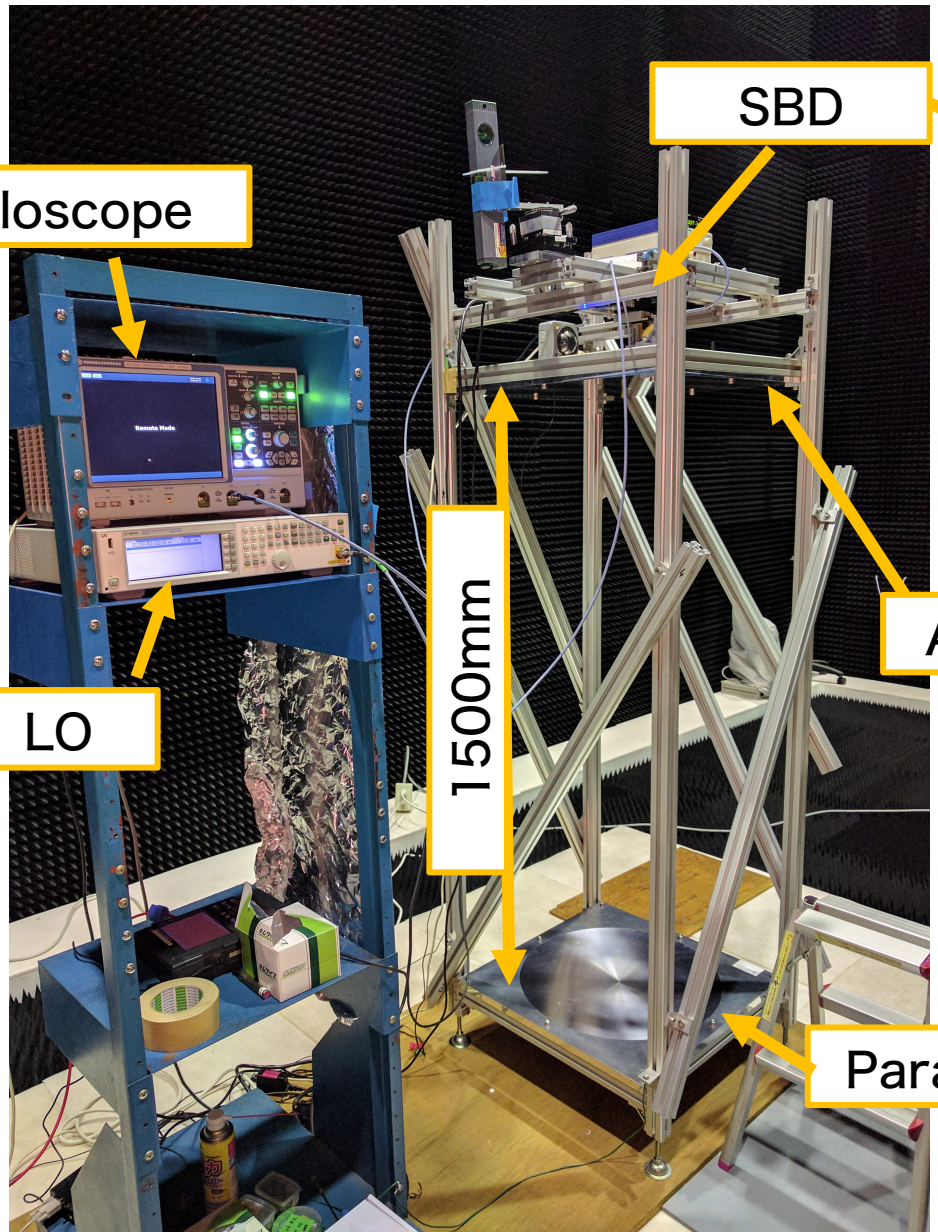
Parabolic mirror
Φ500mm(area: $0.2m^2$),
f=1500mm, Al

Whole setup is in anechoic chamber at Univ. of Fukui

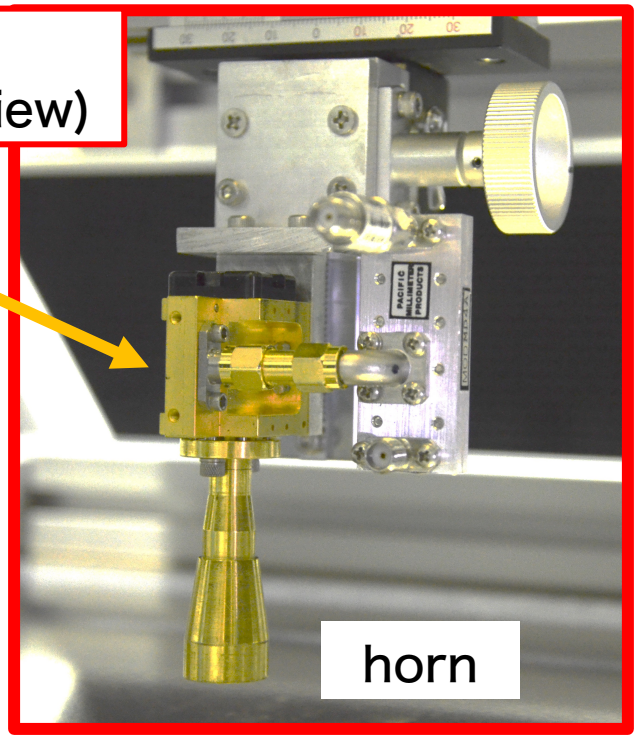
Experiment Setup ②



- Corrugate Horn
  (Coupling with condensed signal ~ -2dB)
- SBD mixes millimeter-wave(f_{RF}) with local oscillator signal(f_{LO}), downconverts to f_{IF}(conversion loss ~ -40dB)
- Amplify SBD output(~36dB×2, total gain: ~ 72dB)
- After amplified, FFT by oscilloscope (region: 0~4GHz)

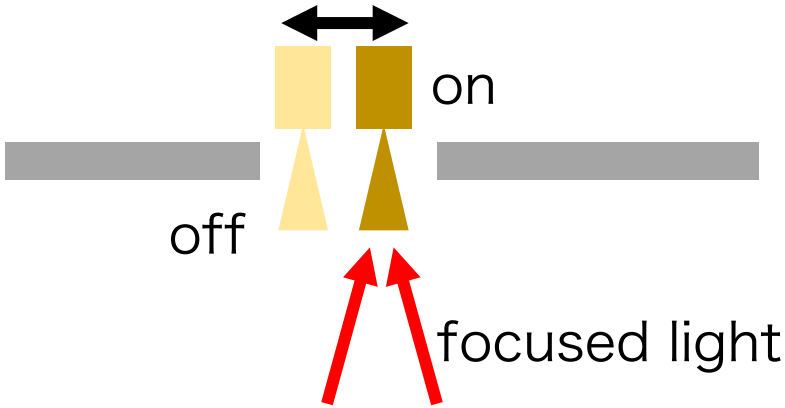


SBD
(large view)



Status of Data Acquisition

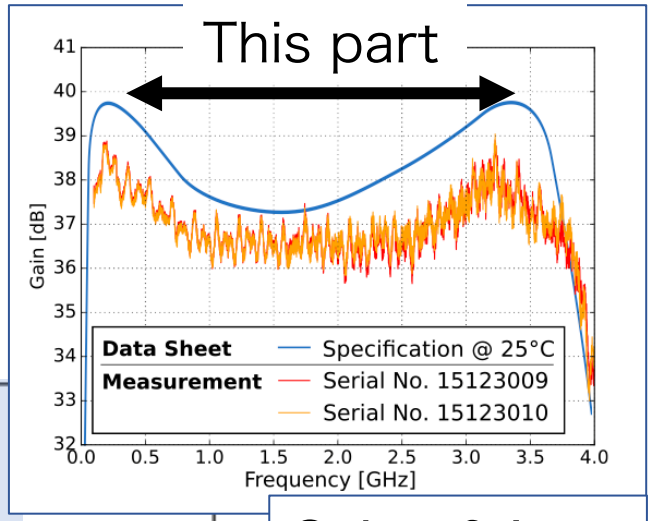
- Data acquisition: from end of Dec. 2016 to end of Mar. 2017
  - ➢Need to measure wide range (155~220GHz)
    - ✓Change f_{LO} 20.00, 20.25,…,27.25GHz
  - ➢On/off measurement
    - ❖Move SBD on/off focal point of parabolic mirror
    - →Signal & BG spectrum



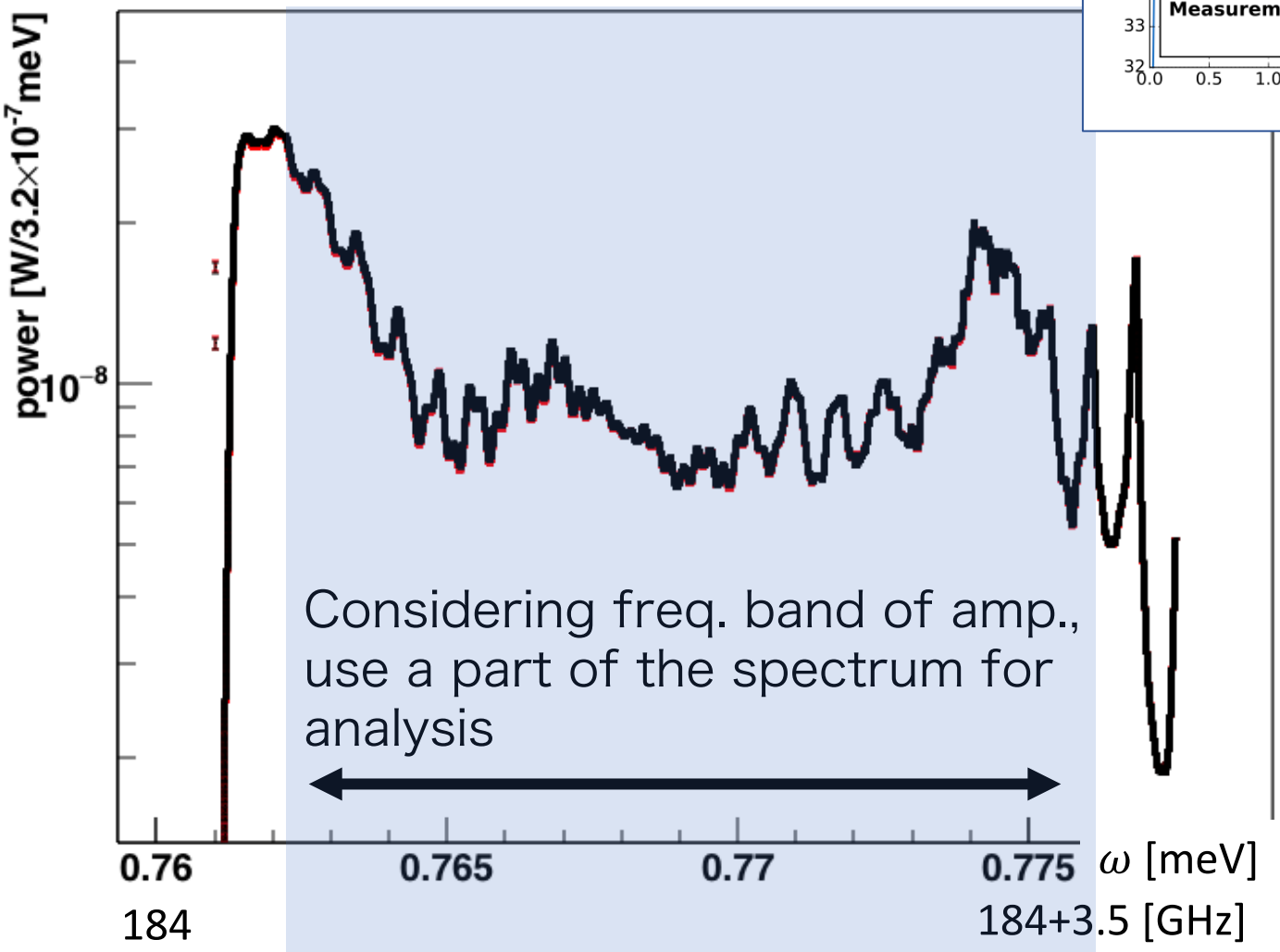
Spectrum shape

LO=23GHz→f_{RF}=184~188GHz

Red:on focal point　Black:off focal point



Gain of Amp.



BG: thermal noise of SBD

Peak Search

- HPDM signal reflects its velocity distribution(Maxwell-Boltzman dist.)

$$F(\omega) = P_0\theta(\omega - m_{\gamma'})\times 2\sqrt{\frac{\omega - m_{\gamma'}}{\pi}}\,\omega_0^{-\frac{3}{2}}\exp\left(-\frac{\omega - m_{\gamma'}}{\omega_0}\right) + a\omega^2 + b\omega + y_0$$

BG

P_0: Power of HPDM signal

θ: Step function

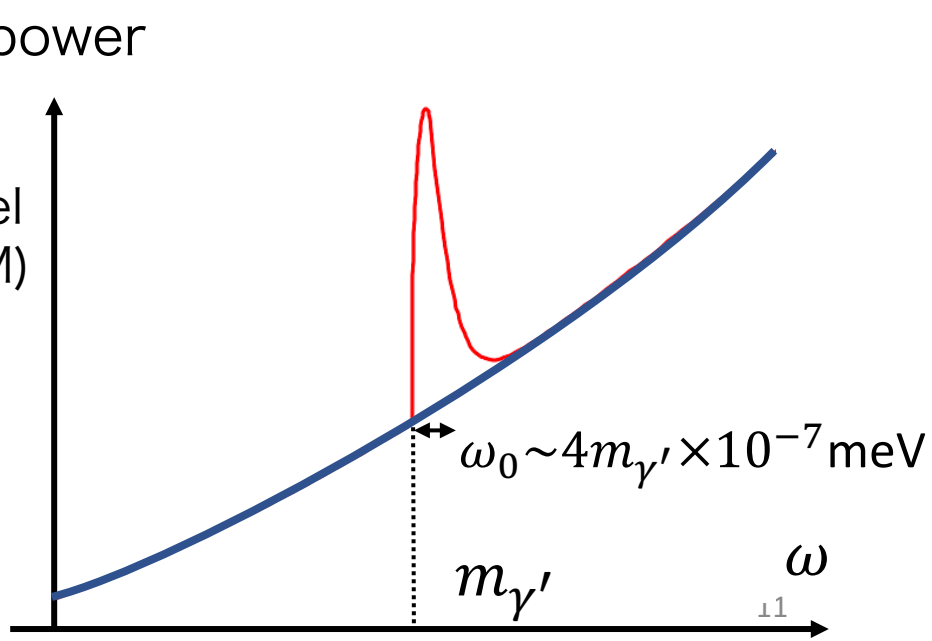
ω_0: dispartion const. ($m_{\gamma'}$×4e-7)

(Calculate from standard Halo model velocity dist. of HPDM)

$m_{\gamma'}$: mass of HPDM

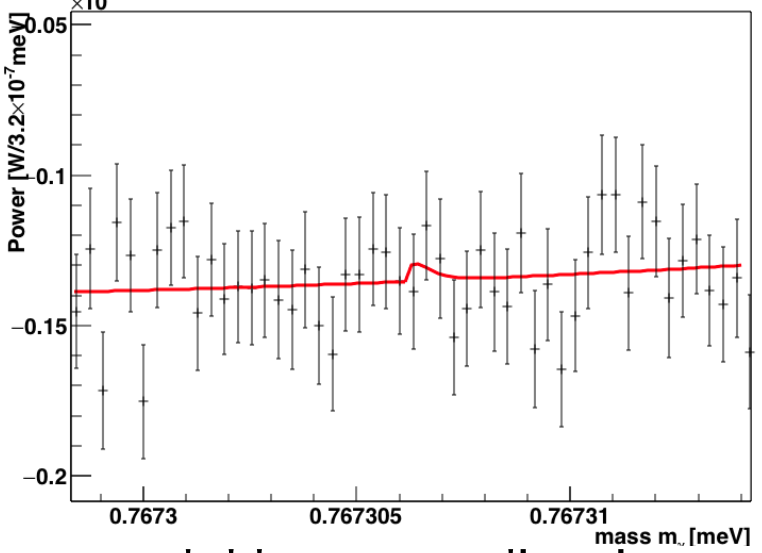
Peak search for each $m_{\gamma'}$ using $F(\omega)$

(P_0, a,b, y_0:fitting parameters)



Limit to HPDM

- Parameter P_0 is power detected by oscilloscope. Convert into power of converted light(P_{hp}) coming from conversion plate



(SBD conversion loss, gain of amp., are measured. Horn coupling is calculated from expected focused light)

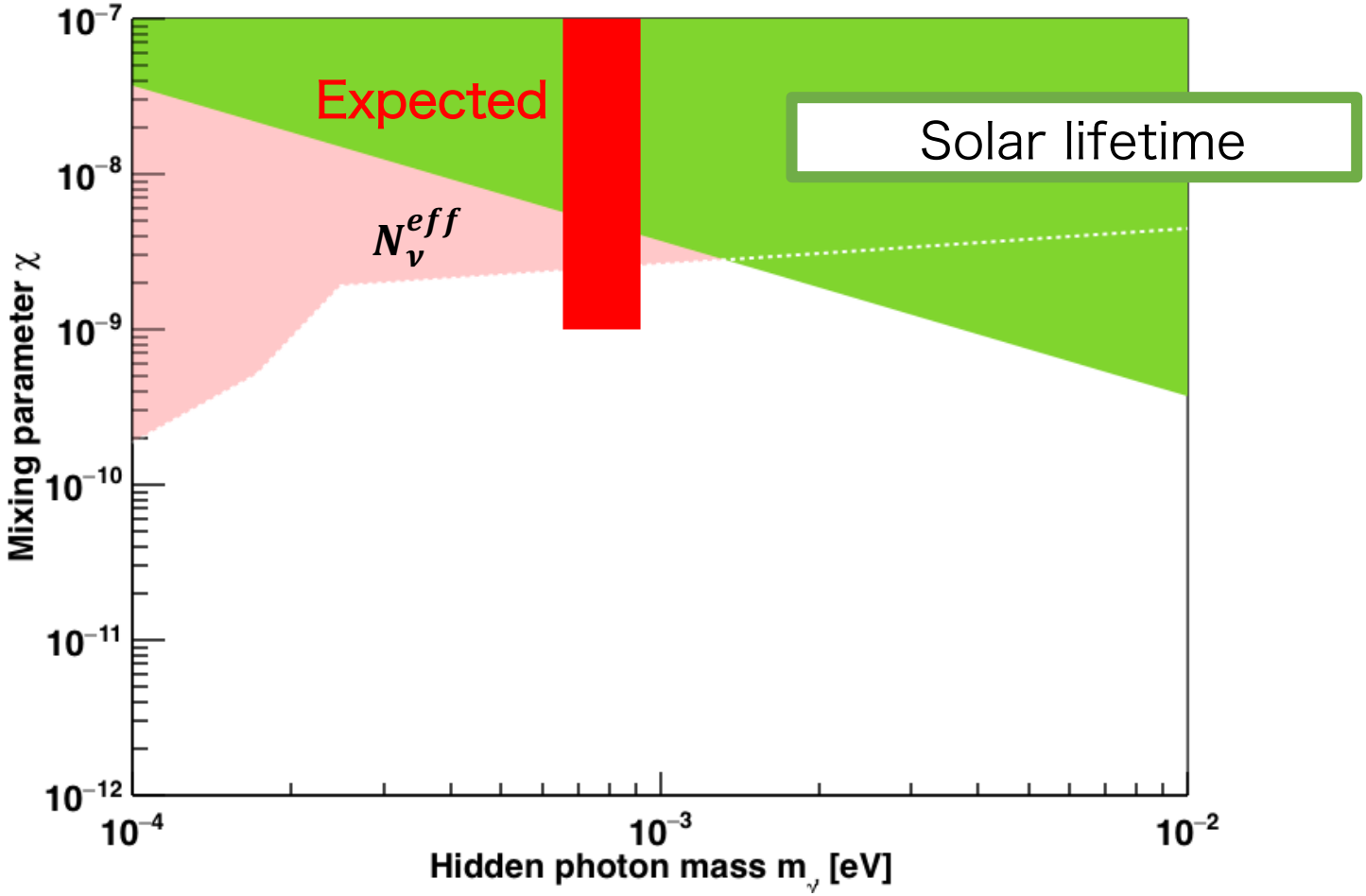
$$P_{hp} \pm \Delta P_{hp} = \frac{P_0 \pm \Delta P_0}{\text{ConversionLoss} \times \text{Gain} \times \text{Coupling}}$$

- Calculate upper limit(95%C.L.) of P_{hp} from $P_{hp} \pm \Delta P_{hp}$
- $\chi_{95\%CL} =$

$$4.5\times10^{-14} \left(\frac{P_{hp95\%}}{10^{-23}\text{W}} \times \frac{1\text{m}^2}{\underbrace{A_{dish}}_{0.20\ m^2}} \times \boxed{\frac{0.3\text{GeV/cm}^3}{\rho_{DM}}} \right)^{\frac{1}{2}} = 1$$

Expected Result

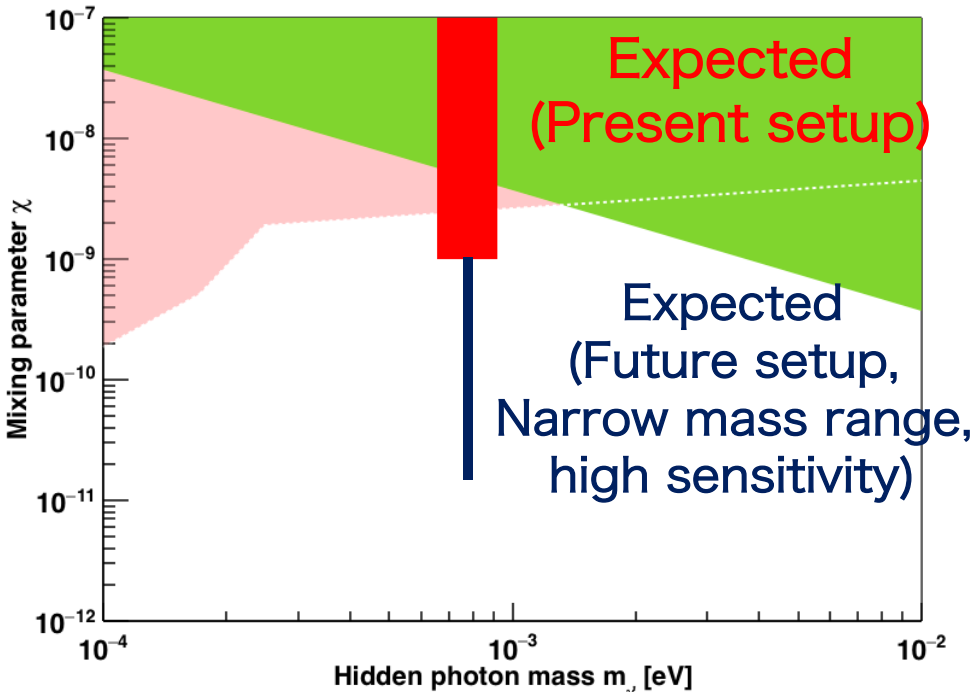
- Calculate the reaching sensitivity with all 3-month data

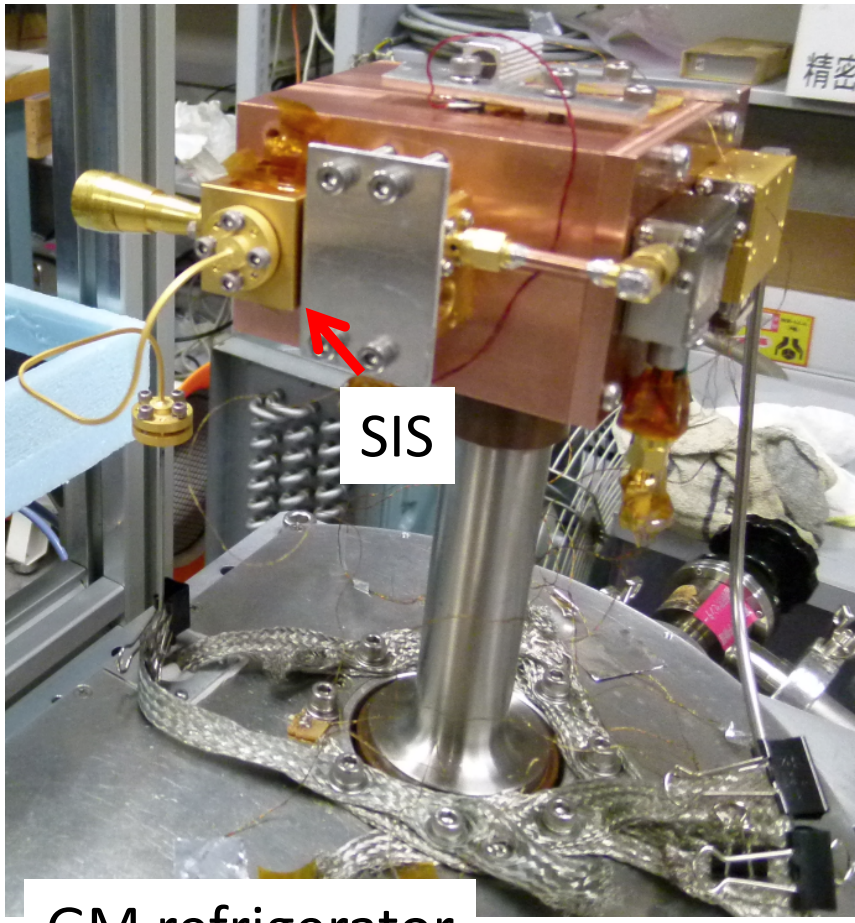


- Analysis in progress: New result will come out soon.

Future plan

- SIS mixer
  - Conversion Loss ~ -10dB
  - Thermal noise
    1/1000 of SBD
  - 2 order high sensitive search is possible!





GM refrigerator

Summary

1. Search for Hidden Photon Dark Matter predicted in beyond Standard Model

2. Combine Dish antenna method with millimeter-wave technology, HPDM of mass $0.6\sim0.9$ meV can be searched

3. We already have finished taking 3 month data, and data analysis is in progress. Sensitive to unsearched $\mathrm{m}_{\gamma'} = 0.6\sim0.9$ meV region

4. For future improvement, using low conversion loss and low noise SIS mixer, 2 orders of magnitude higher sensitivity search is possible