Search for Weakly Interacting Undiscovered Particles using Sub-THz Gyrotron

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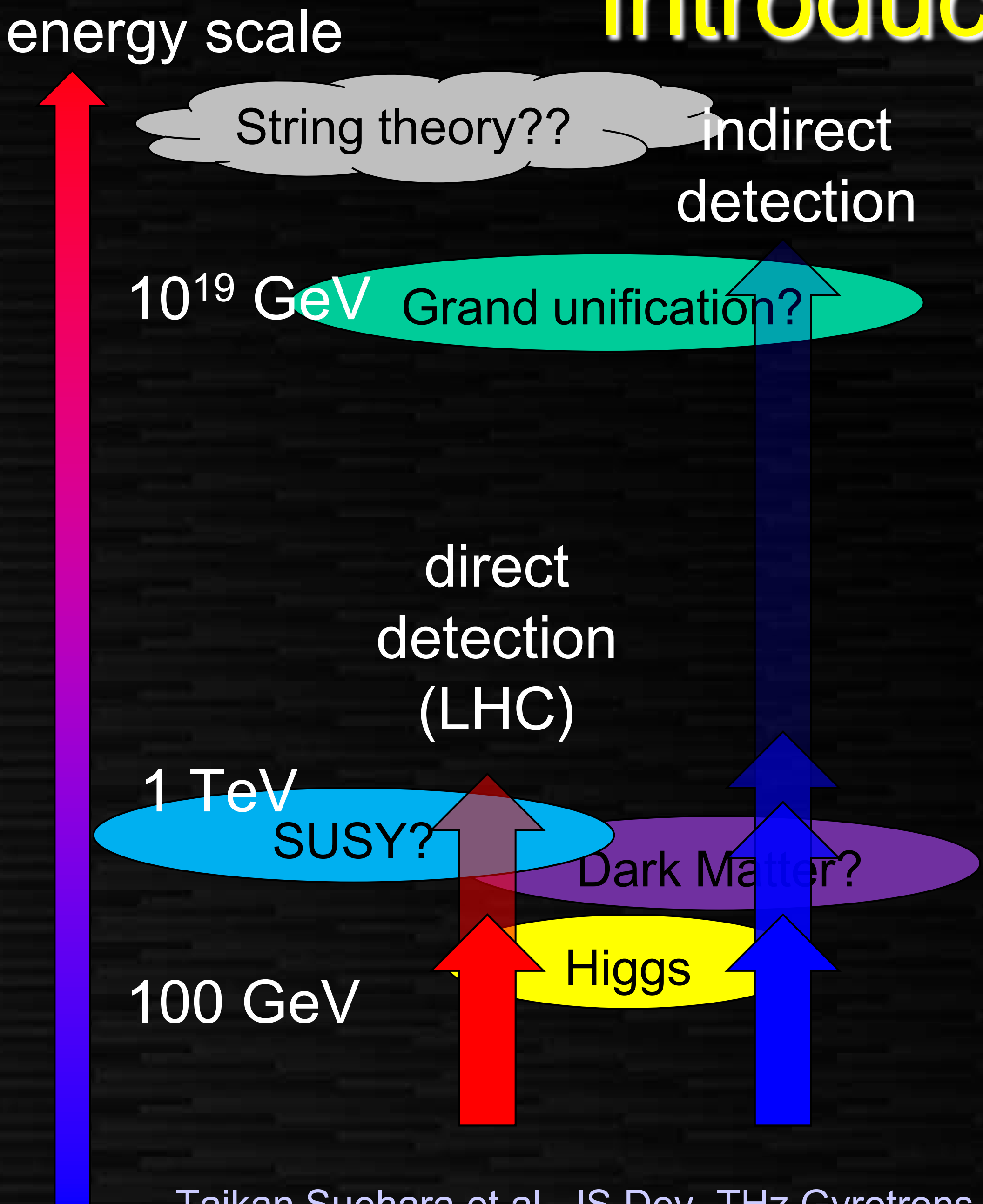
Introduction



Fundamental questions

- How universe began?
- How matter created?
- How 4-forces unified in the "ultimate theory"?
- What is Dark Matter?

etc…

Particle Physics' approach

Fundamental things are "hidden" in higher-energy world! Need to investigate

- Directly, or
- Indirectly

Introduction

energy scale

String theory??

Direct detection

10^{19} GeV Grand unif

direct detection (LHC)

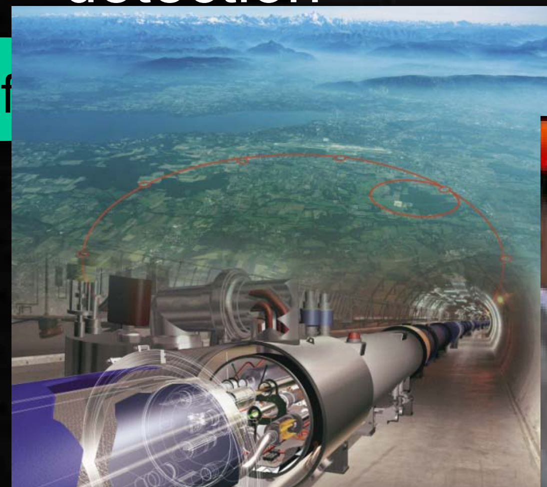
1 TeV

SUSY?

Dark Ma

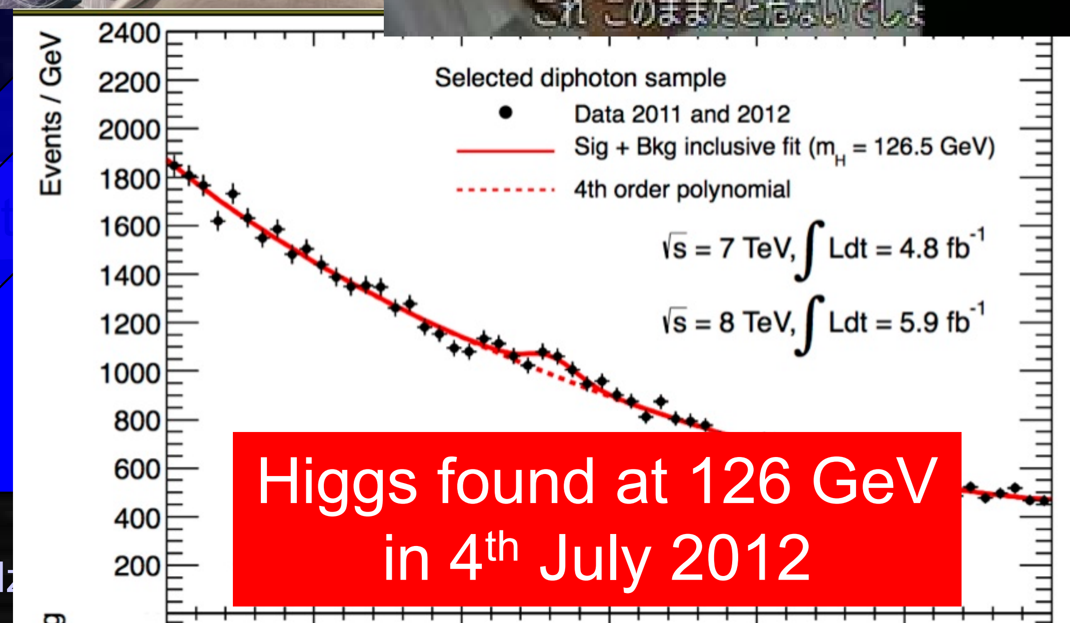
Higgs

100 GeV



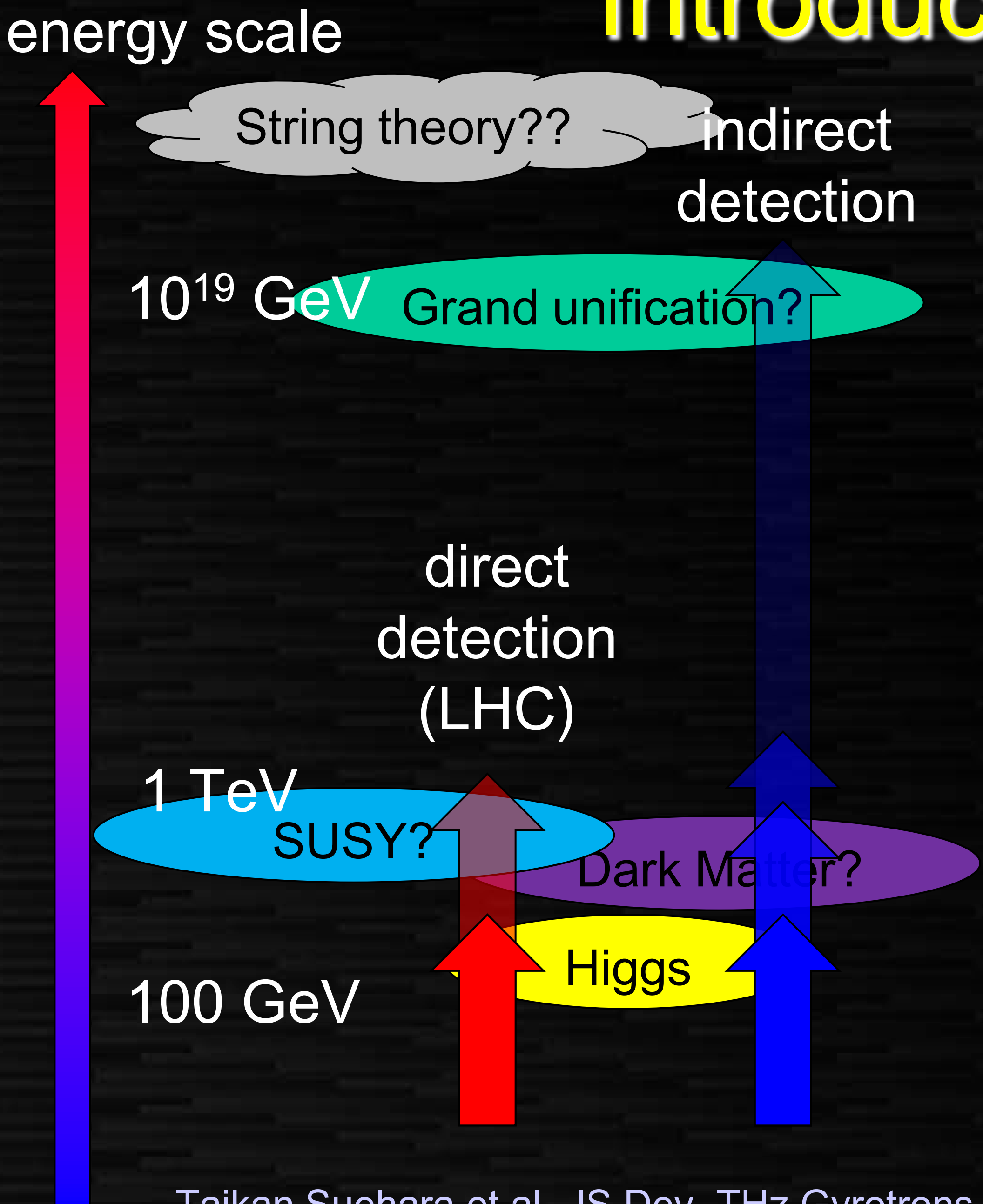
energy frontier collider (LHC)
create particle up to TeV
directly by 8 TeV collision

Asai on NHK



Higgs found at 126 GeV in 4th July 2012

Introduction



Indirect detection

Observing “rare phenomena” in lower energy particles to look at effects from “higher” scale

ex.1) b-factory @KEK

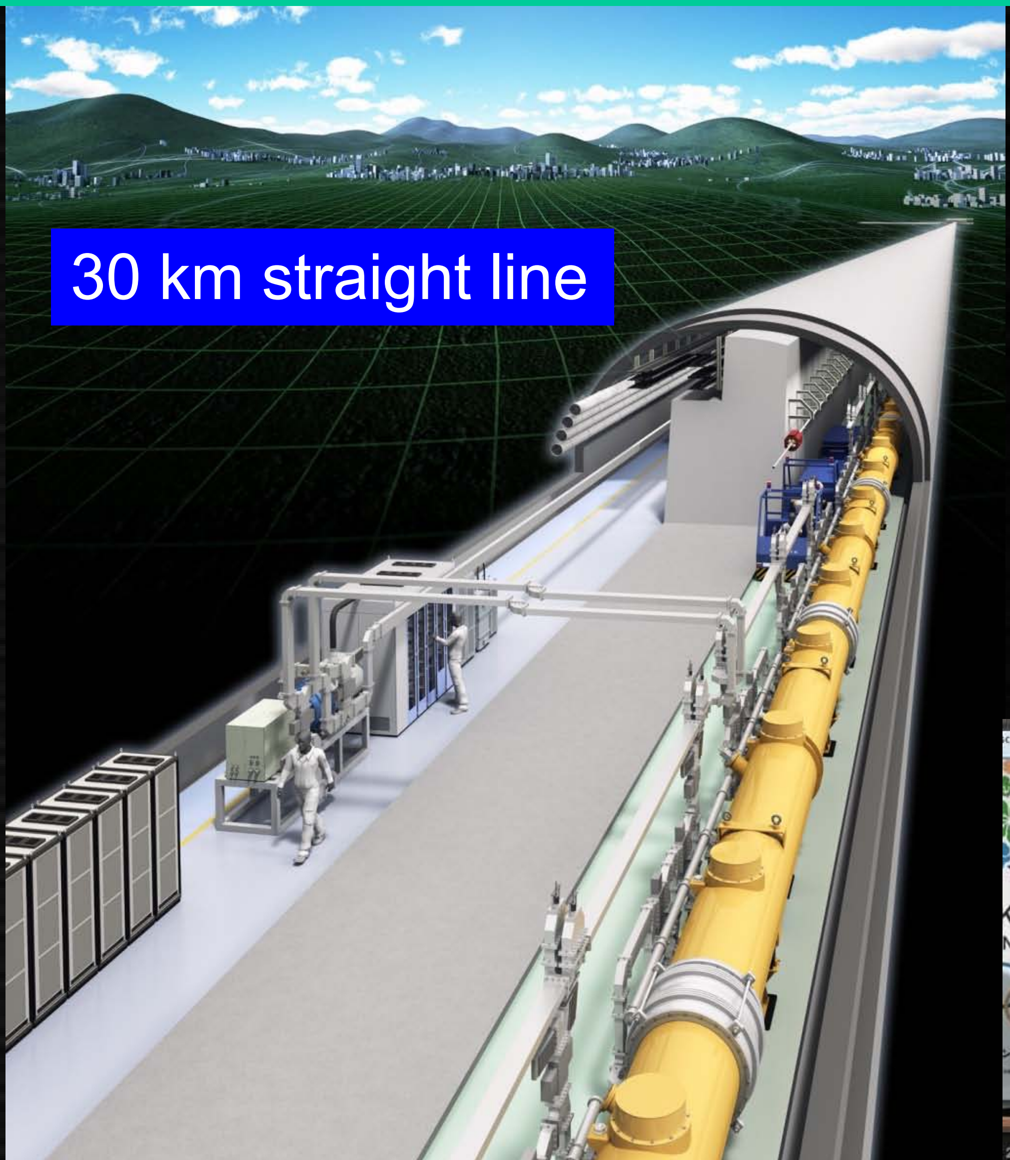
observing rare b-meson (~5 GeV) interaction to look for new physics

Japanese novel prize winners on b-physics

Introduction

energy scale

ex.2) International Linear Collider



30 km straight line

Indirect detection

Observing “rare phenomena”
in lower energy particles
to look at “higher” scale

0.5 – 1 TeV e+ e- collider
to be built until mid 2020s
(10 years construction)

“Higgs factory” -
precise measurements of
Higgs for new physics

Japanese minister of science stated promotion of ILC, Jan 2013

Introduction

energy scale

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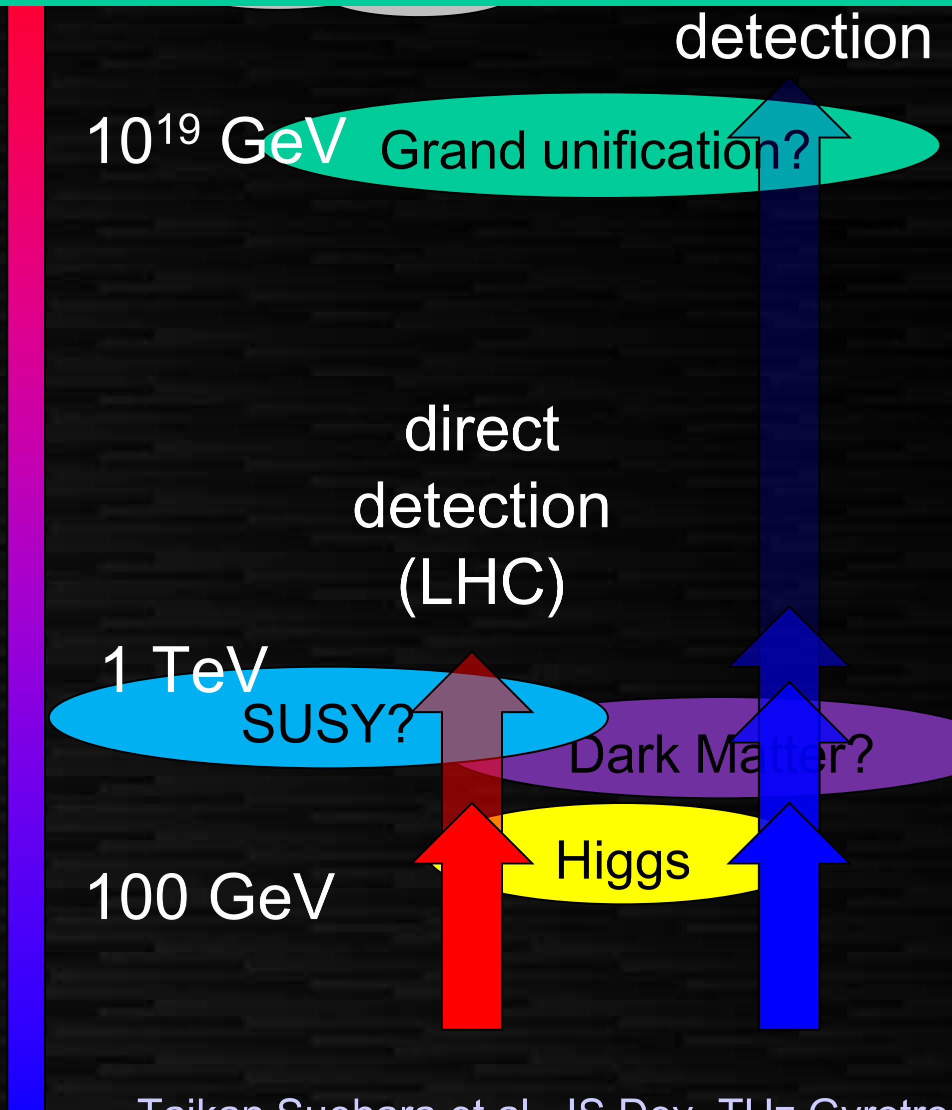

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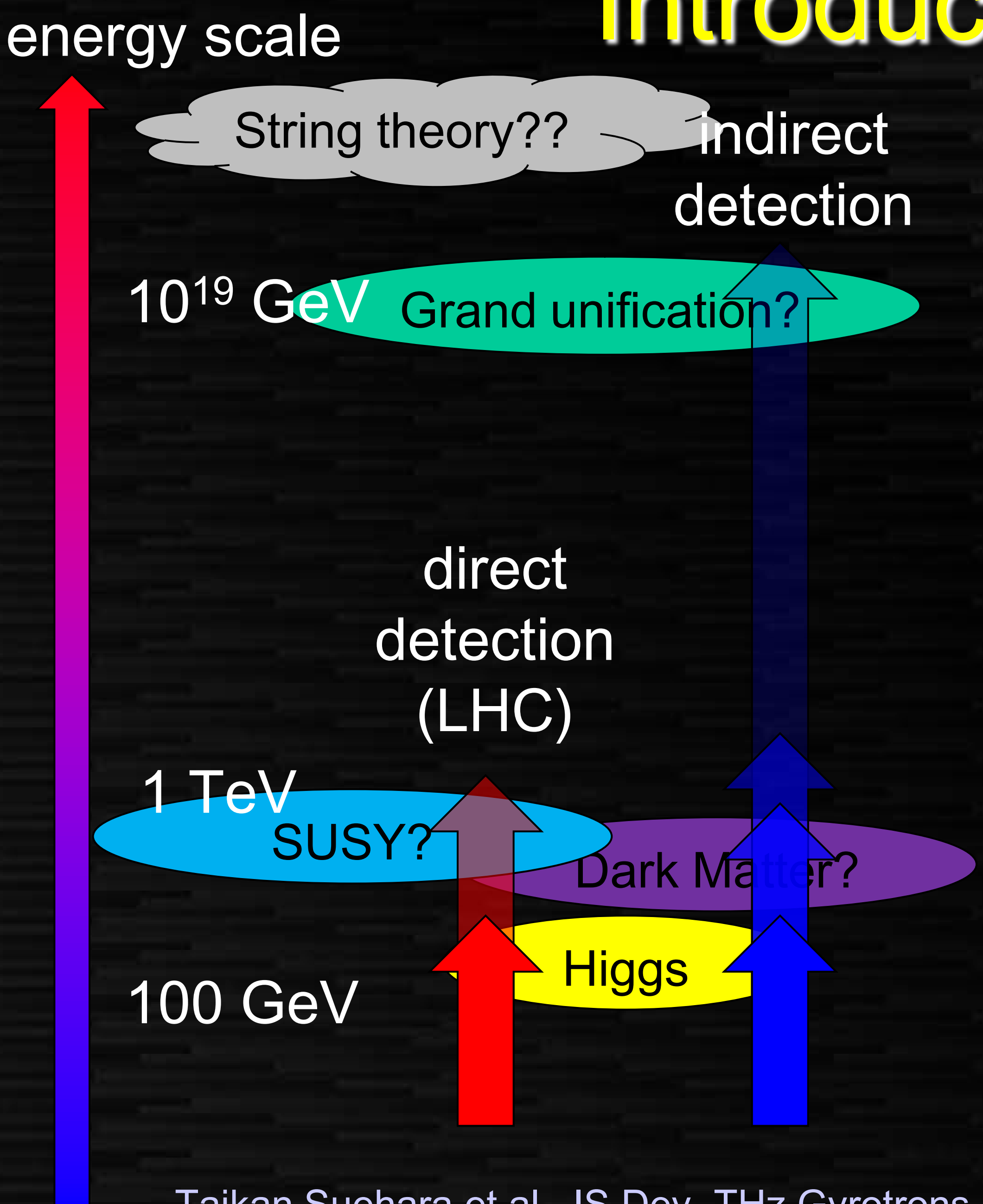

Indirect detection

Observing "rare phenomena"
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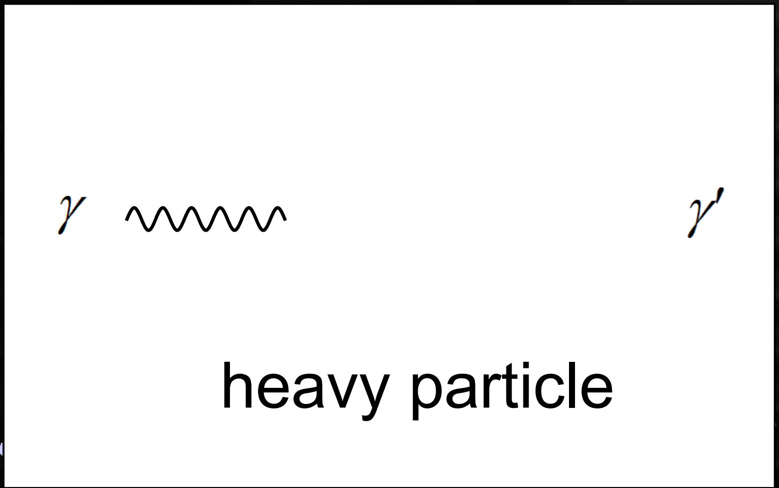
Our experiment

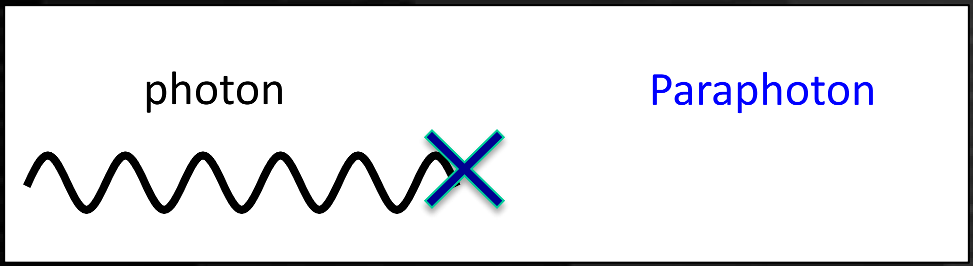
observing rare
conversion involving
heavy particle using
high-intensity photons



Paraphoton and ALPs

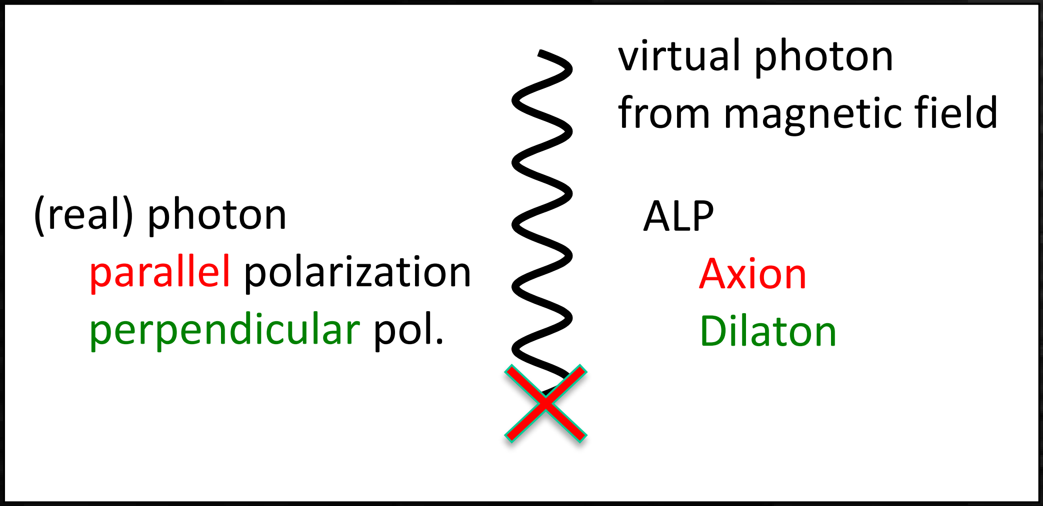
first target

1. Paraphoton (hidden photon)
   Extra U(1) Gauge Boson
   photon ↔ paraphoton osc.



Looking for rare conversion between photons & paraphotons

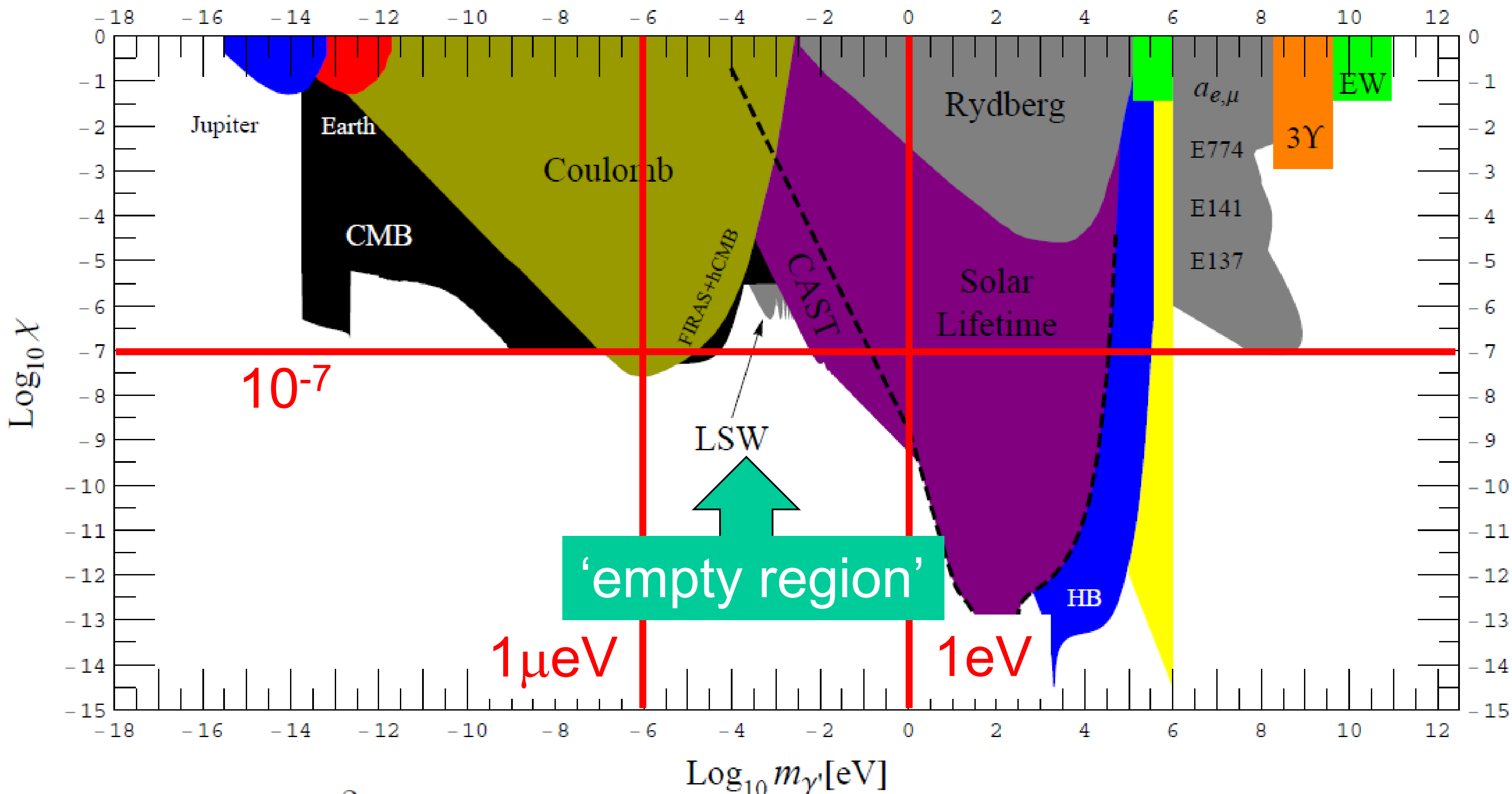
2. ALP (Axion-like particle)
   - Axion (pseudo-scalar)
     CP problem in QCD
   - Dilaton (scalar)



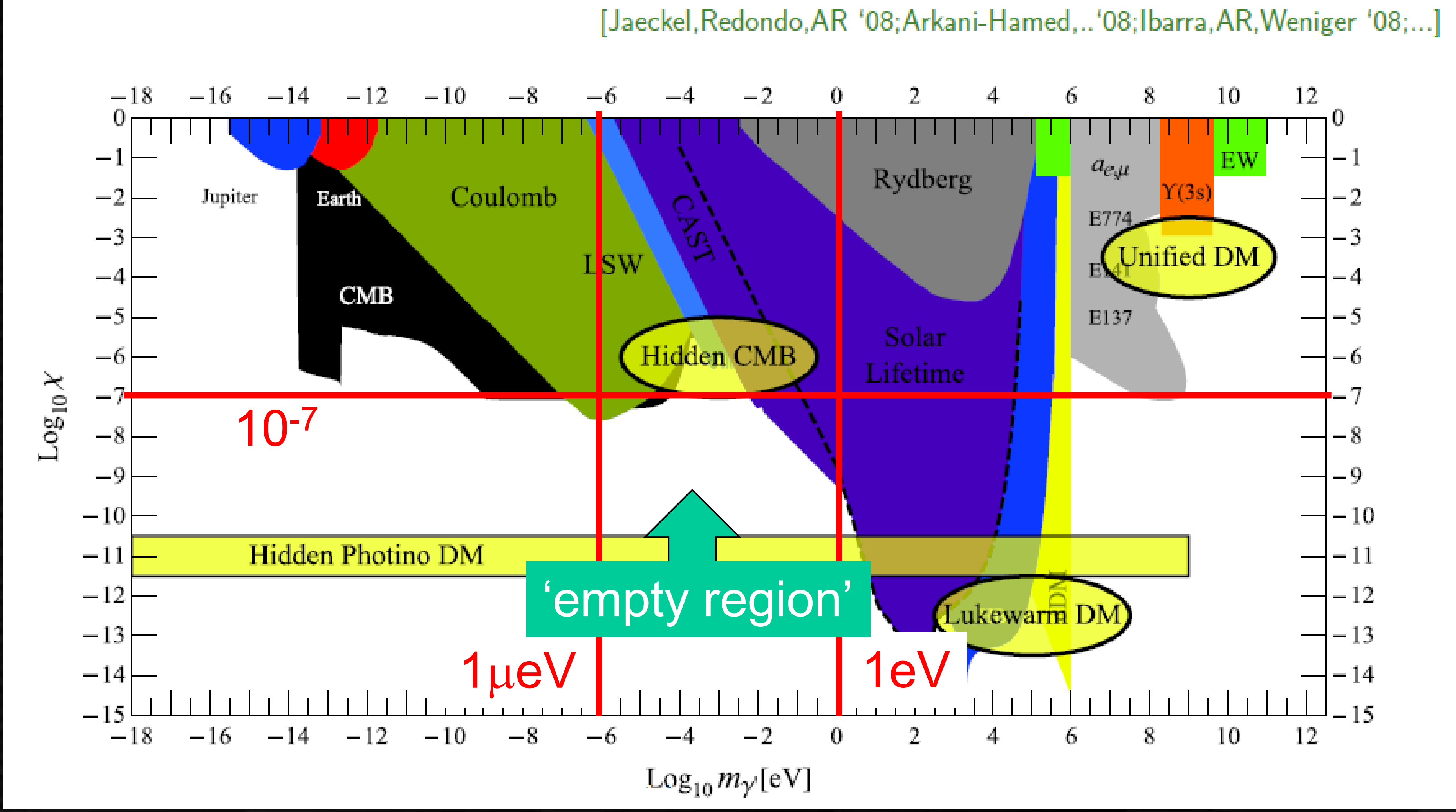
Looking for rare conversion within strong magnetic field

Current Limit for Paraphoton

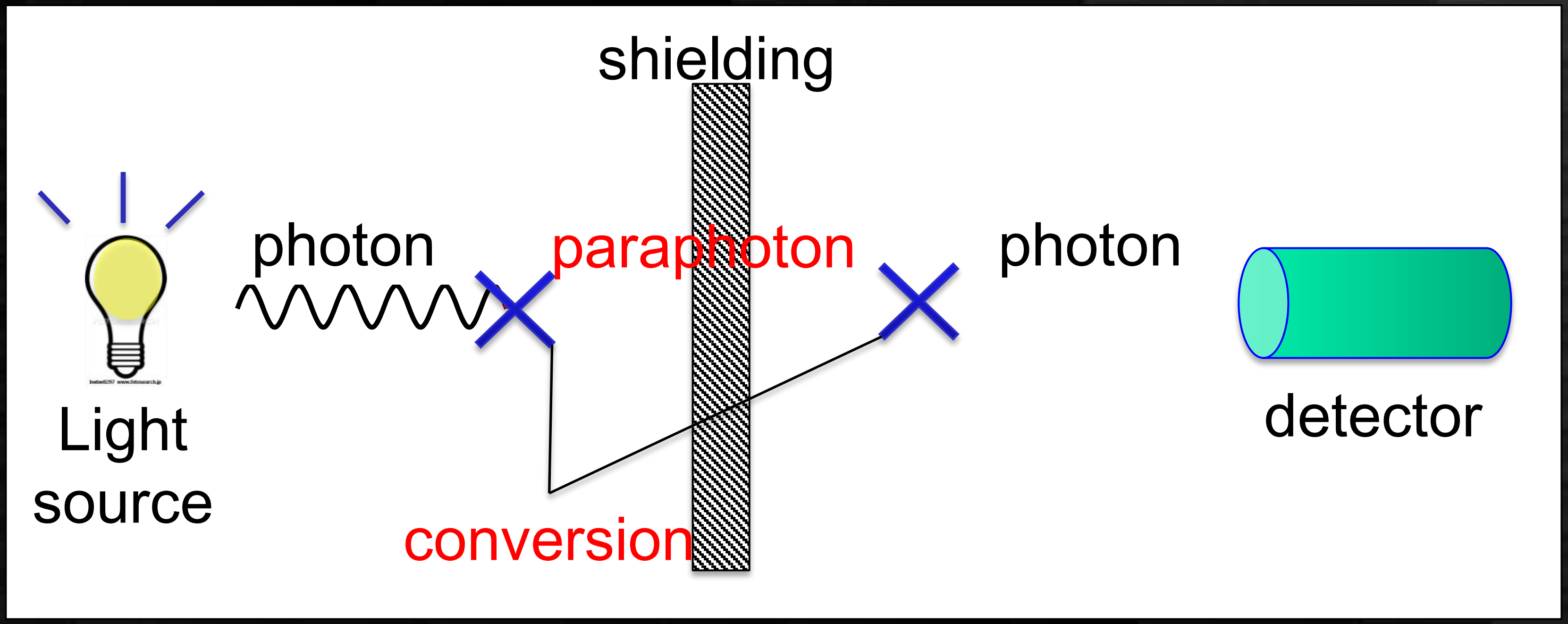
[Bartlett,..'88; Kumar,..'06; Ahlers,..'07; Jaeckel,..'07; Redondo,..'08;Postma,Redondo '08;Bjorken,Essig,Schuster,Toro'09;...]



Current Limit for Paraphoton



‘Light Shining through a Wall’ (LSW)



- Strong light source and sensitive detector are keys
- Searchable paraphoton mass depends on photon E

paraphoton mass

conversion length

$$P_{\gamma\gamma'} = 16\chi^2 \left(\sin \frac{m_{\gamma'}^2 L}{4\omega} \right)^2$$

$(\omega >> m_{\gamma'})$

conversion prob.

photon energy

LSW with laser: ALPS@DESY

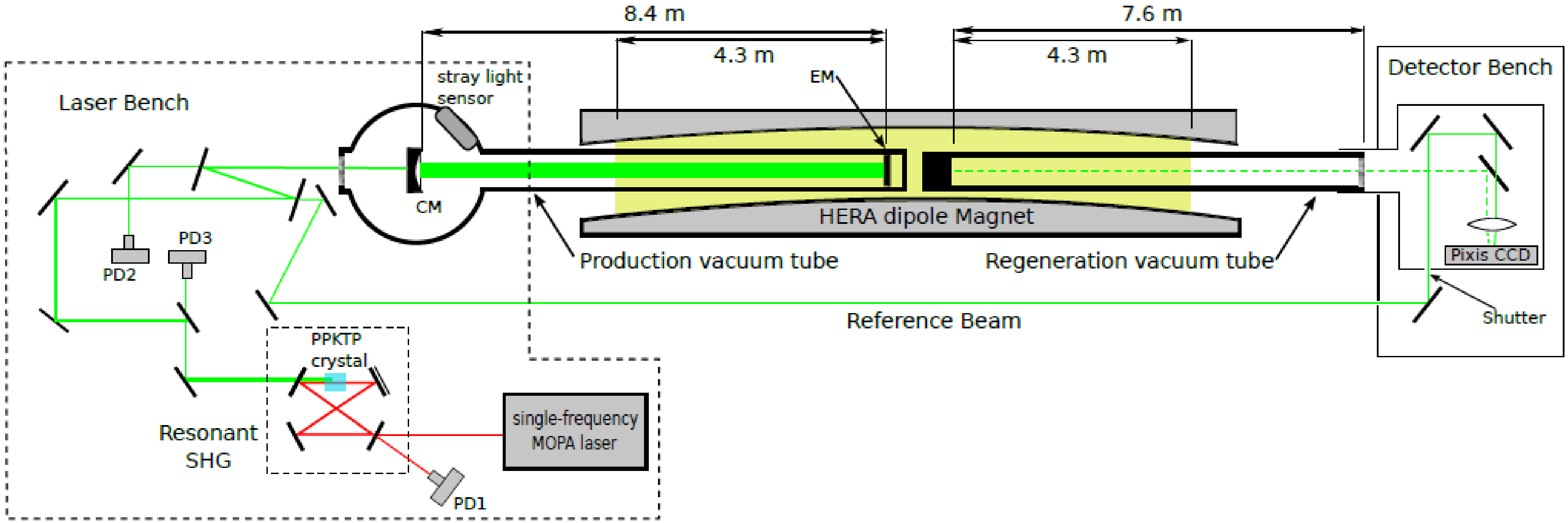
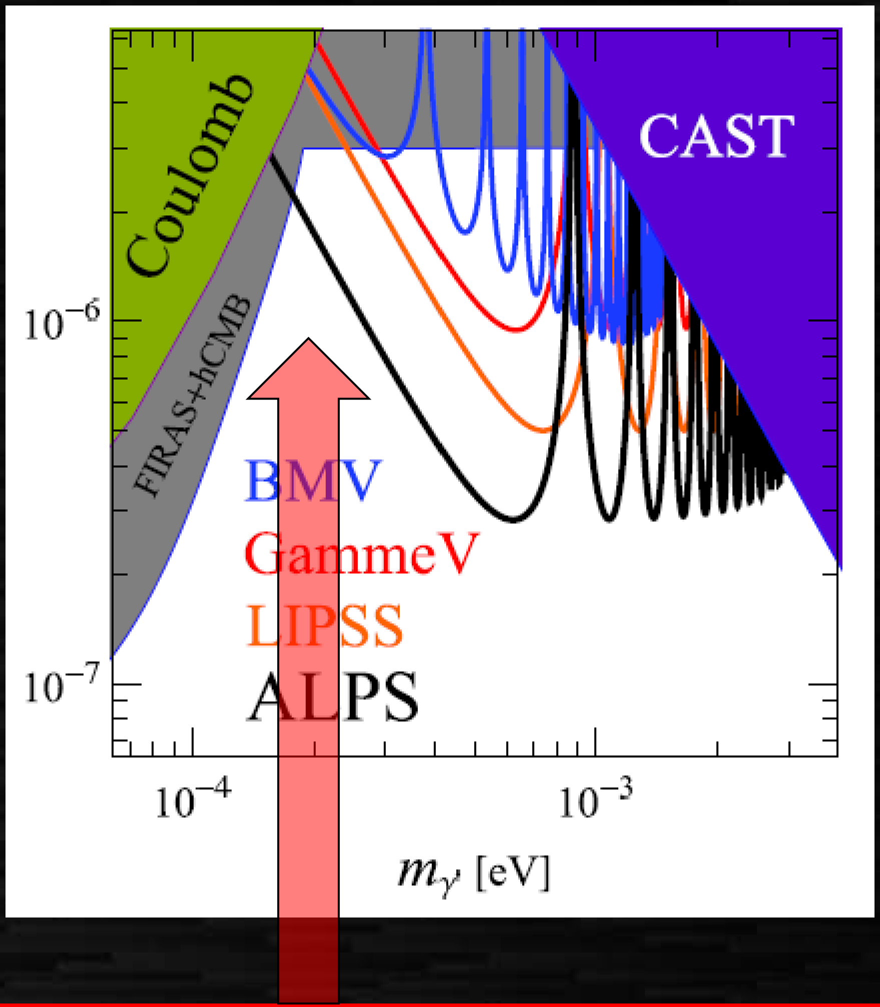


Figure 1: Schematic view of the ALPS LSW experiment. See the text for a description.

- Laser (532 nm) + Fabry-Perot cavity
  - 1.2 kW accumulation
- Magnet for ALP search(5T x 8.8m)
- Cooled CCD detector (single photon detection)

Magnified View (~ meV)



Laser LSW
sensitive at > 0.5 meV
'pit' at 0.1 meV

meV (THz) photons!

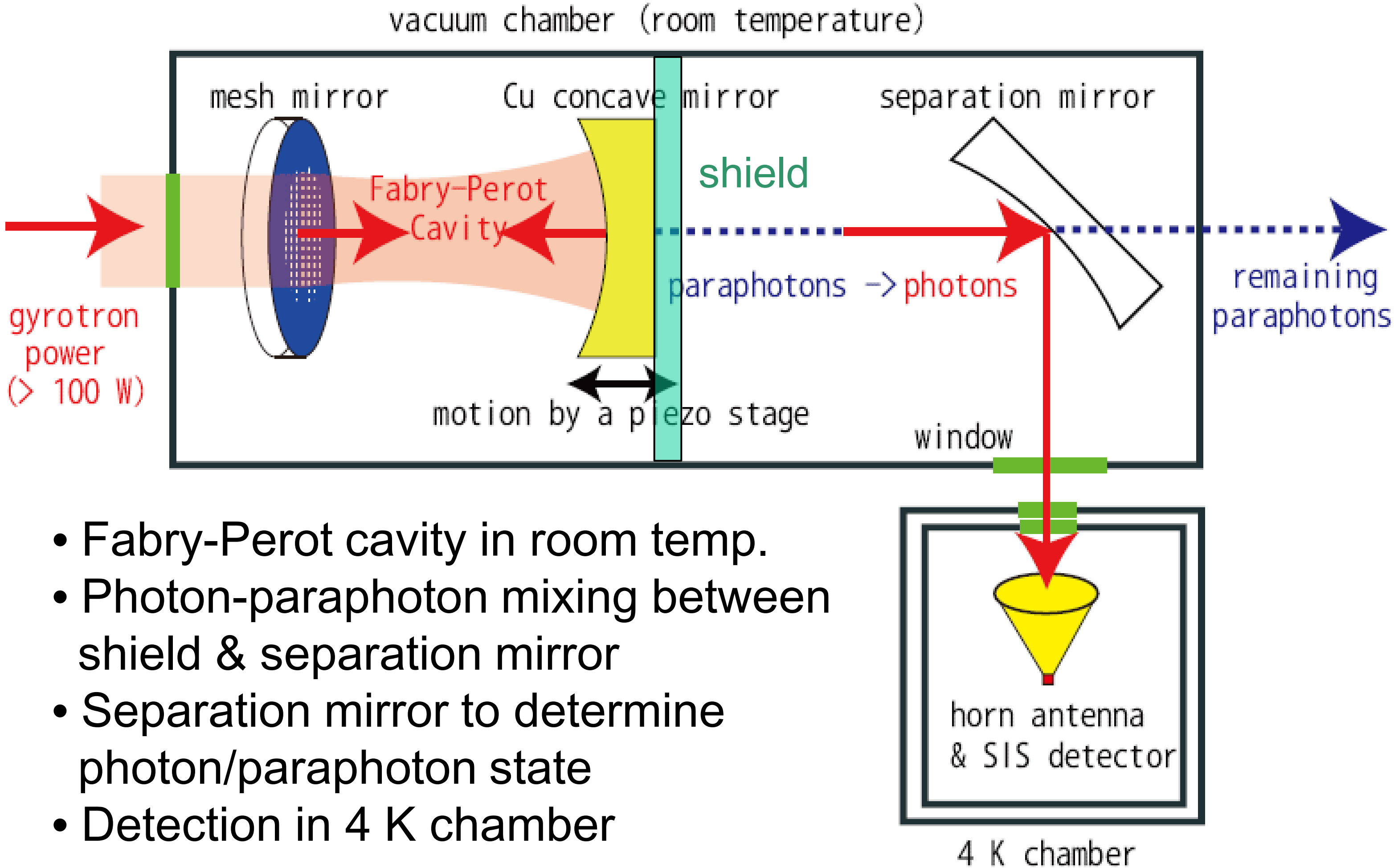
$$P_{\gamma\gamma'} = 16\chi^2 \left(\sin \frac{m_{\gamma'}^2 L}{4\omega} \right)^2$$

LSW with THz photons can cover the 0.2 meV region!

Key components for THz-LSW

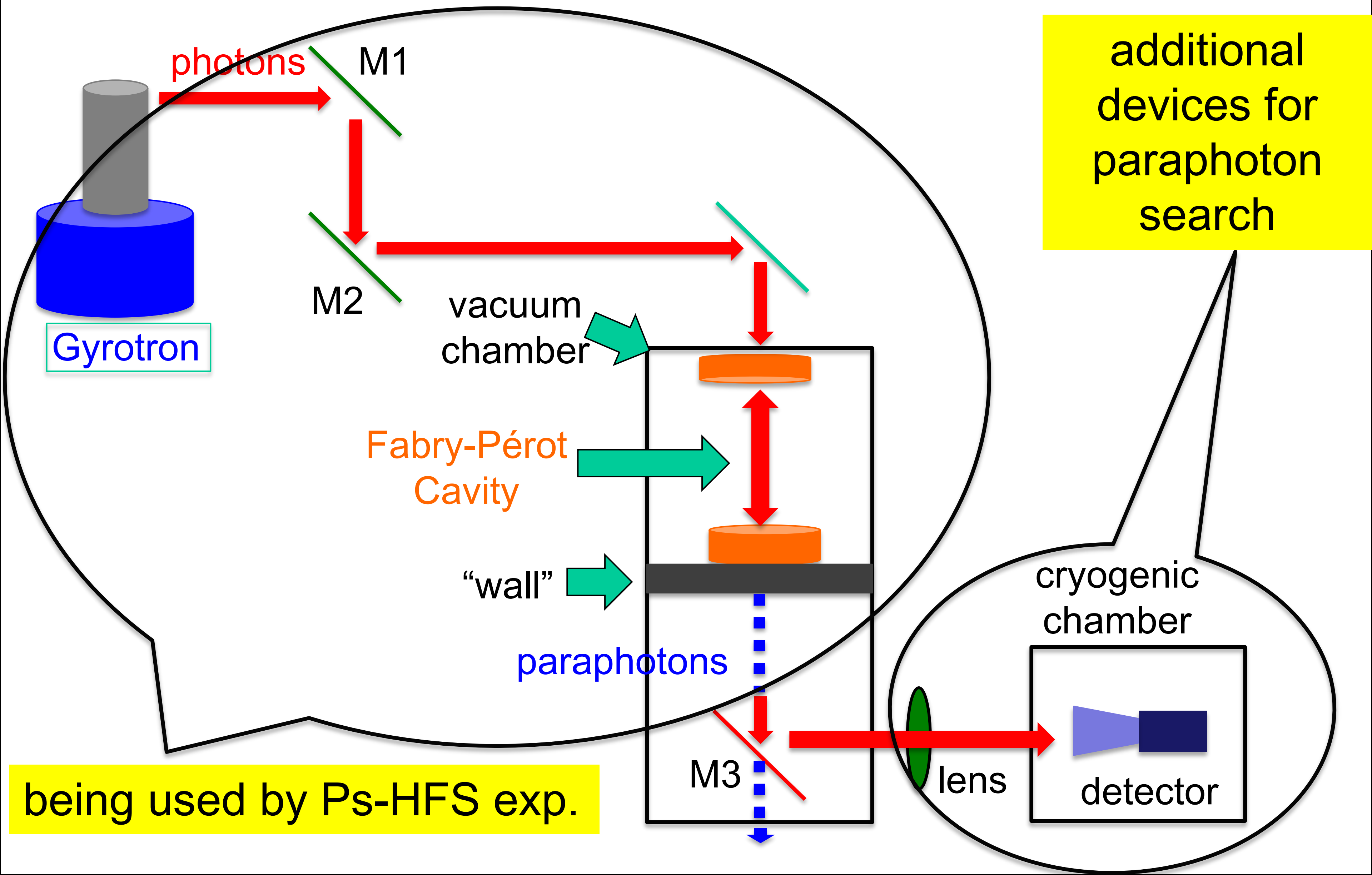
- Strong light source in THz
  - Gyrotron with Fabry-Perot cavity
  - Number of photons at the same power is 1000 times larger in THz photons than in visible photons
- Sensitive detector
  - More difficult than visible photons because of lower energy
  - Superconducting detector

Setup of THz-LSW exp.

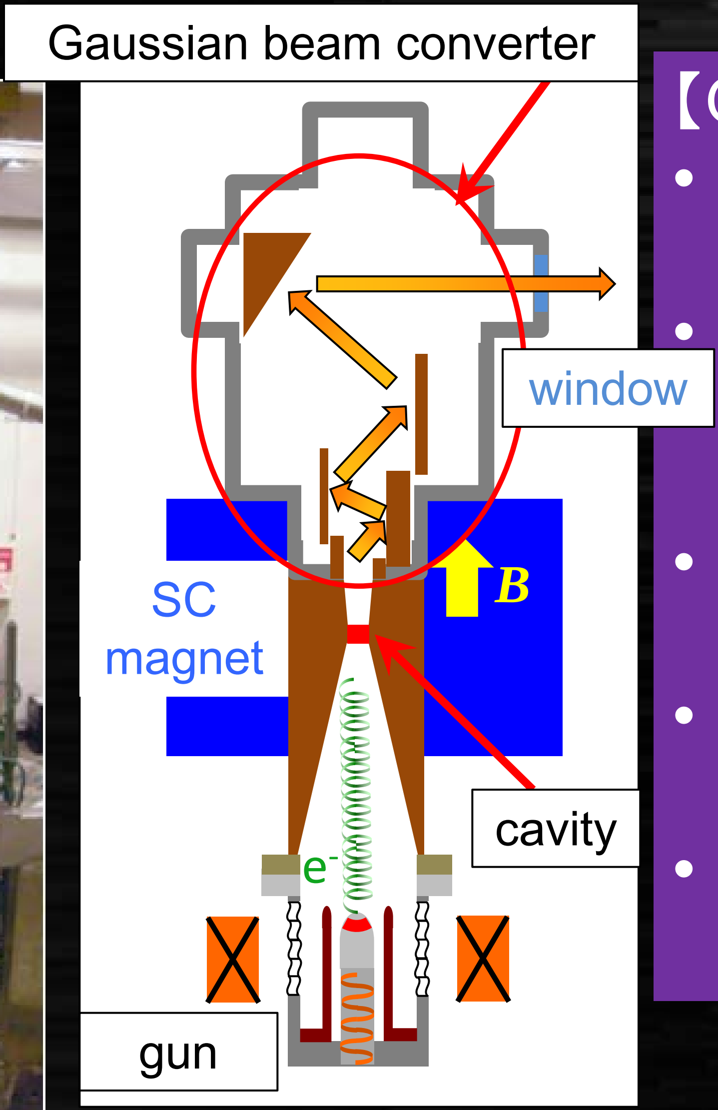


- Fabry-Perot cavity in room temp.
- Photon-paraphoton mixing between shield & separation mirror
- Separation mirror to determine photon/paraphoton state
- Detection in 4 K chamber

Setup shared with Ps-HFS exp.



Gyrotron

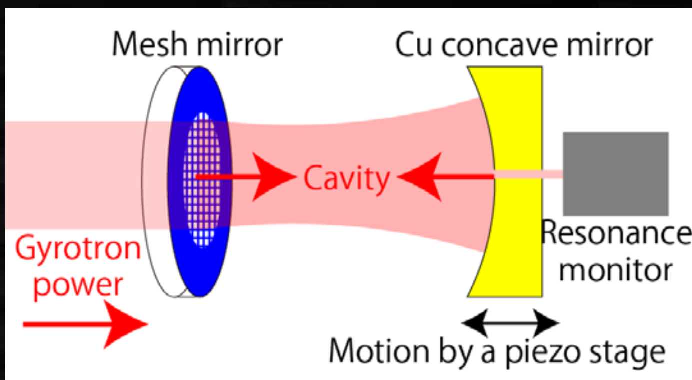


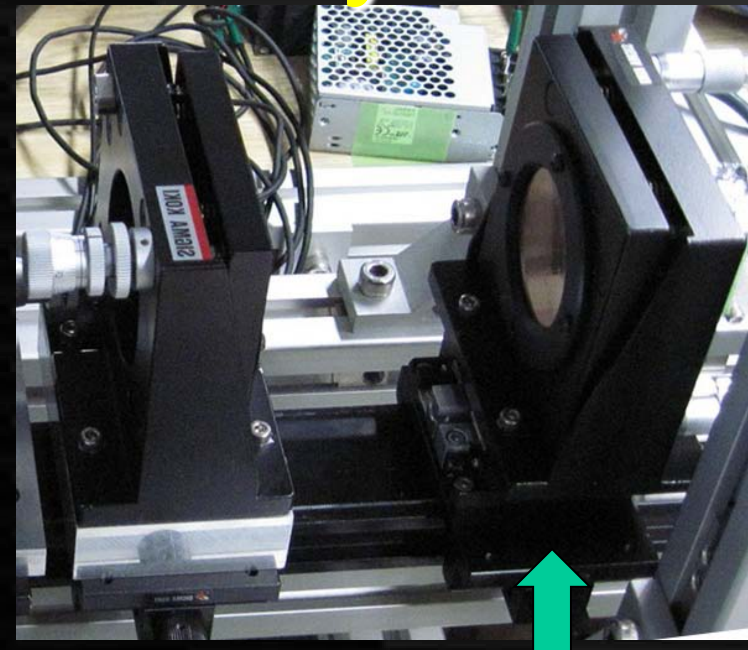
【Gyrotron FU CW GI】
- 201-206 GHz
  (cavity replaceable)
- ~300 W Gaussian with internal mode converter
- line width: ~1MHz
  (at good condition)
- duty up to 50%
  up to 20 Hz
- assembled for Ps-HFS exp.

Fabry-Perot Cavity

One-dimensional cavity

- high density (optical confinement)
- free cavity length

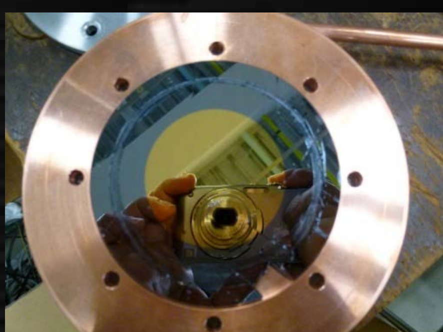


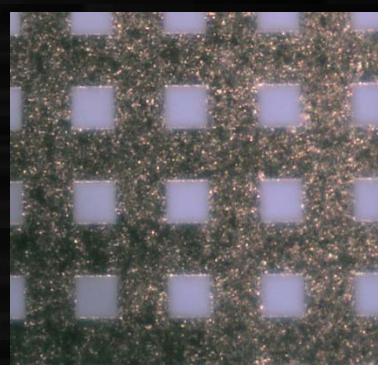


Maintain resonance by controlling cavity length with a piezo stage (< 100nm resolution)

20-30kW accumulated (water cooled silicon)

mesh melted at 20KW with quartz



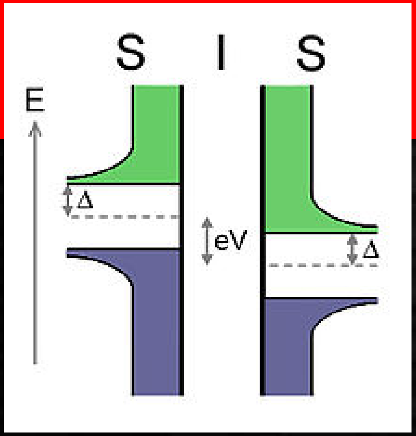


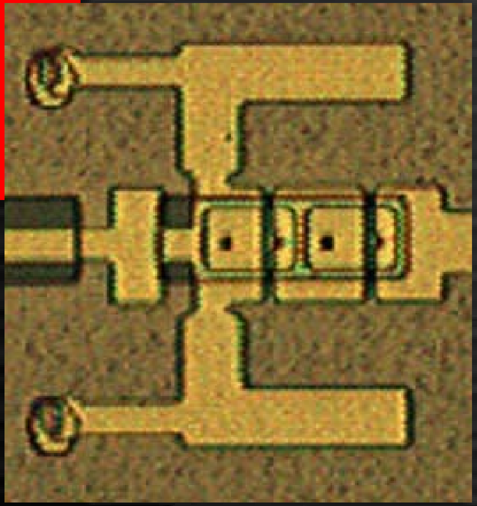
Au mesh (200μm width, 360μm period, 1μm thick) depleted on quartz or silicon

99% reflection, ~0.7% transmission @ 203 GHz

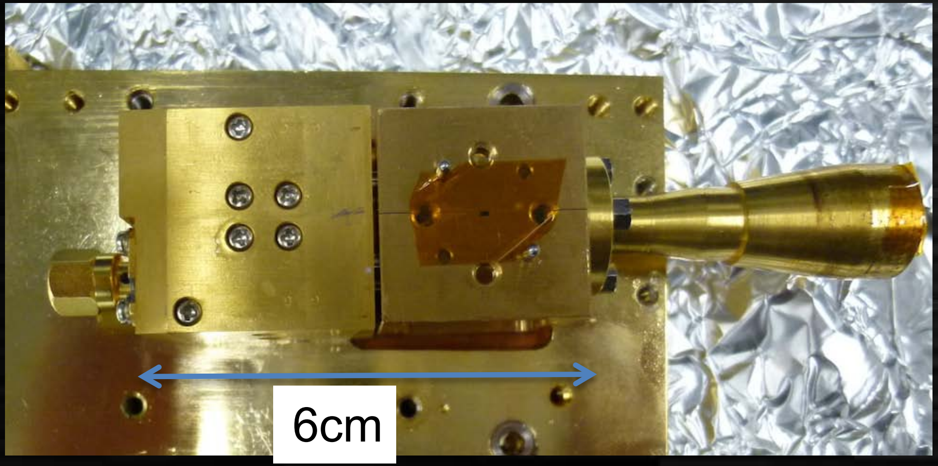
Superconducting Detector

Superconductor-Insulator-Superconductor tunnel junction detector (SIS or STJ)

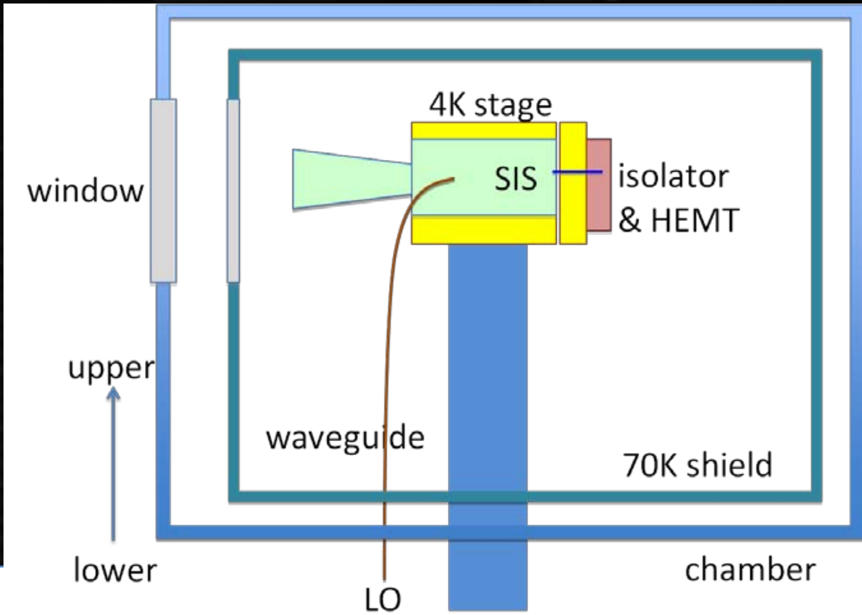


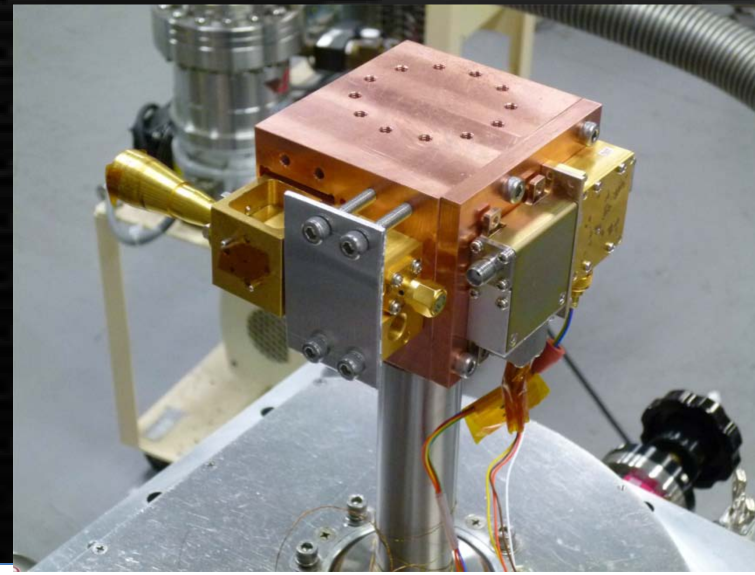


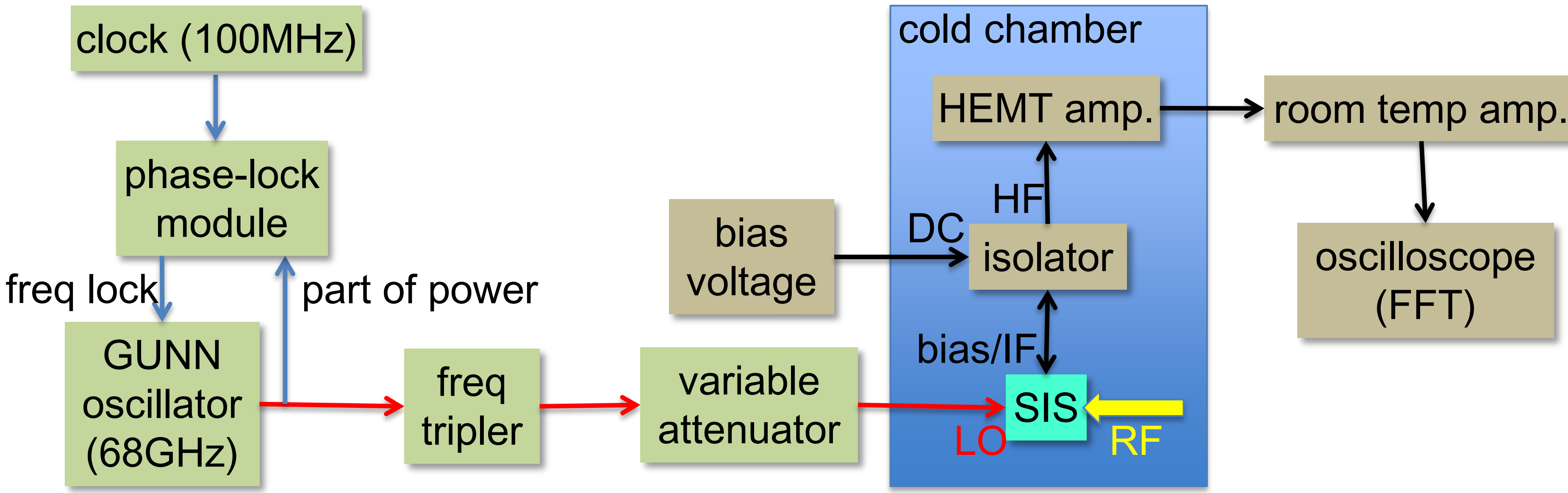
- Used in radio-astronomy
  - Nobeyama observatory (tuned to 230 GHz)
- Nb superconductor
  - 4K operation
- Heterodyne detection
  - Fundamental mixer
  - Suitable for narrowband feature of gyrotron



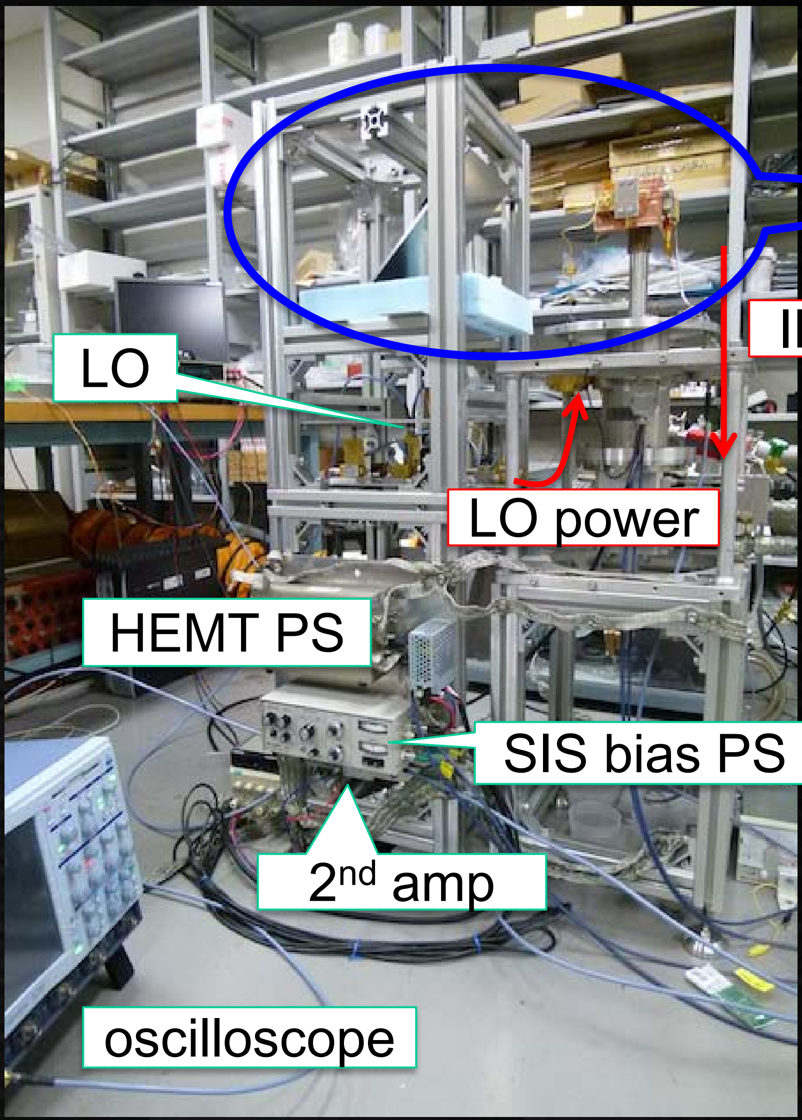
SIS setup / detection system

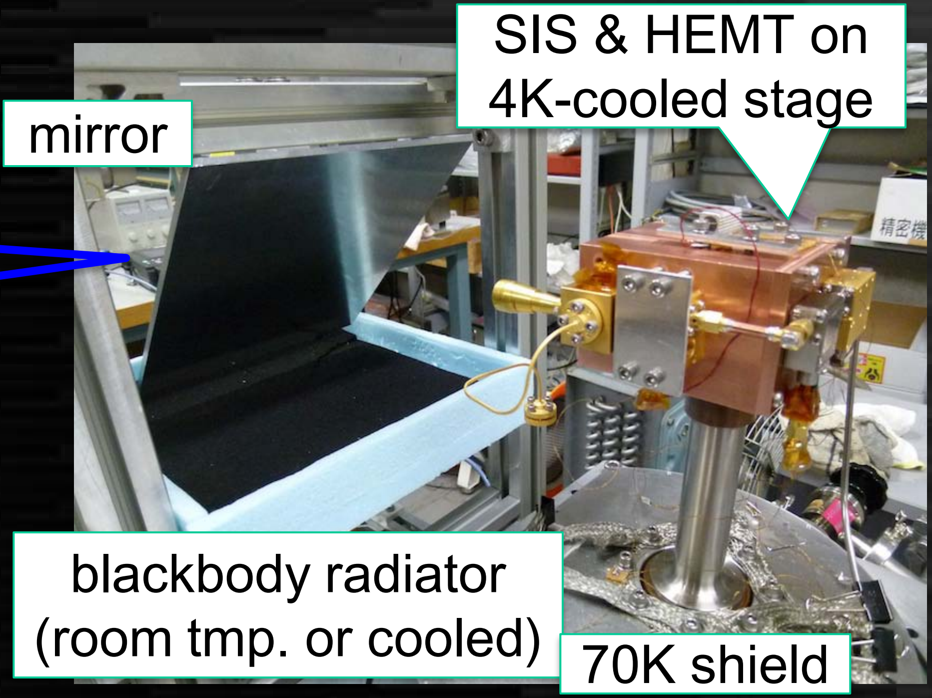






SIS performance test w/ blackbody

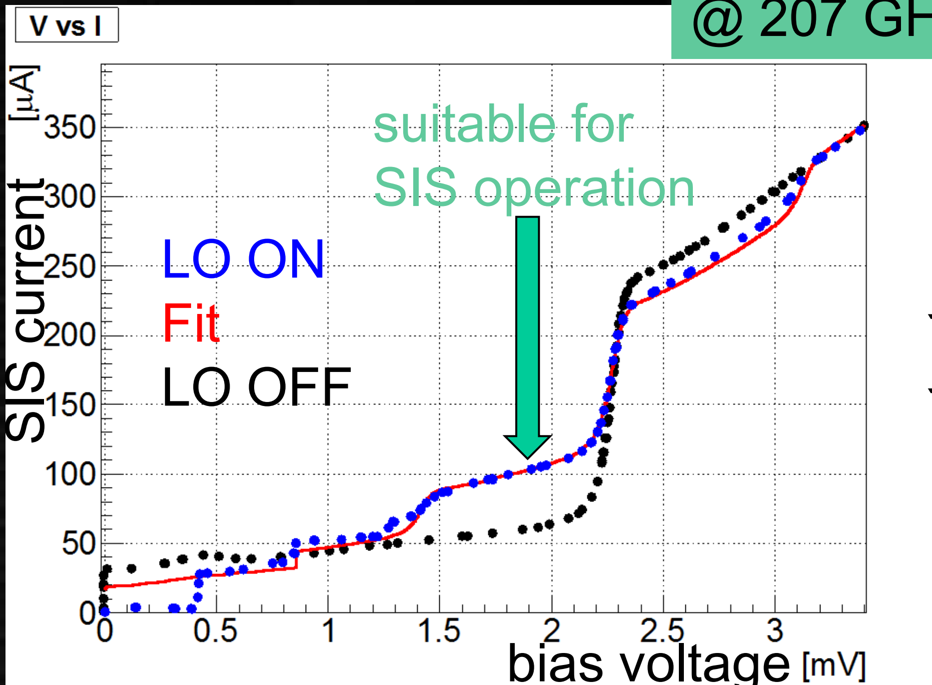




- Using 2-stage GM refrigerator (0.5 W @ 4K stage)
- 70GHz GUNN + tripler used for LO input
- 296K, 194K & 77K blackbody (with coolant under radiator)

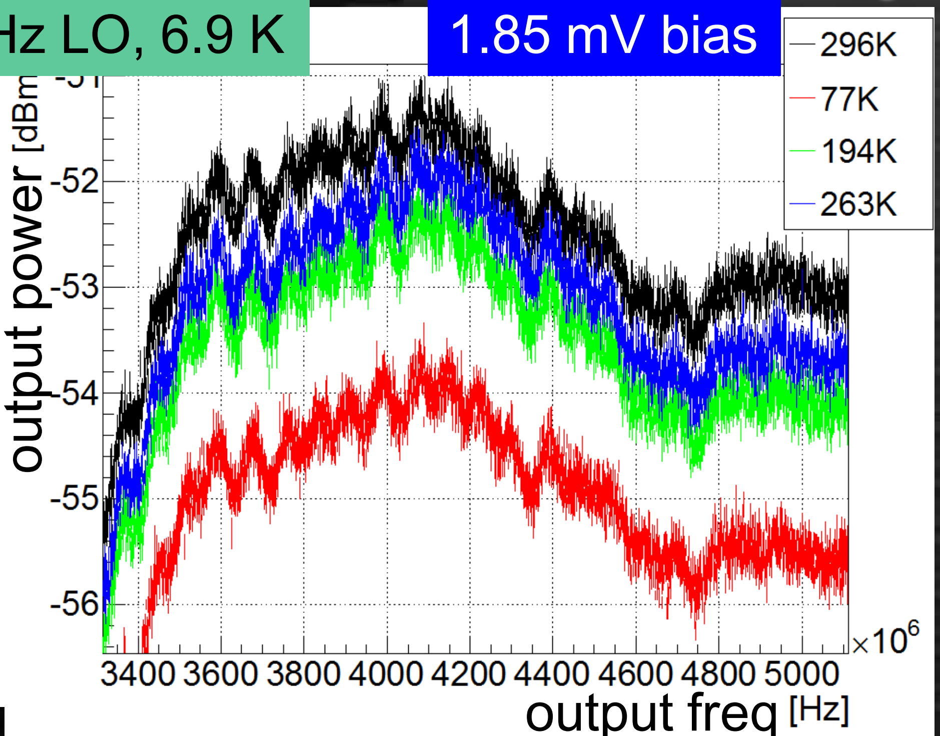
SIS performance test w/ blackbody

@ 207 GHz LO, 6.9 K



DC characteristics

1.85 mV bias

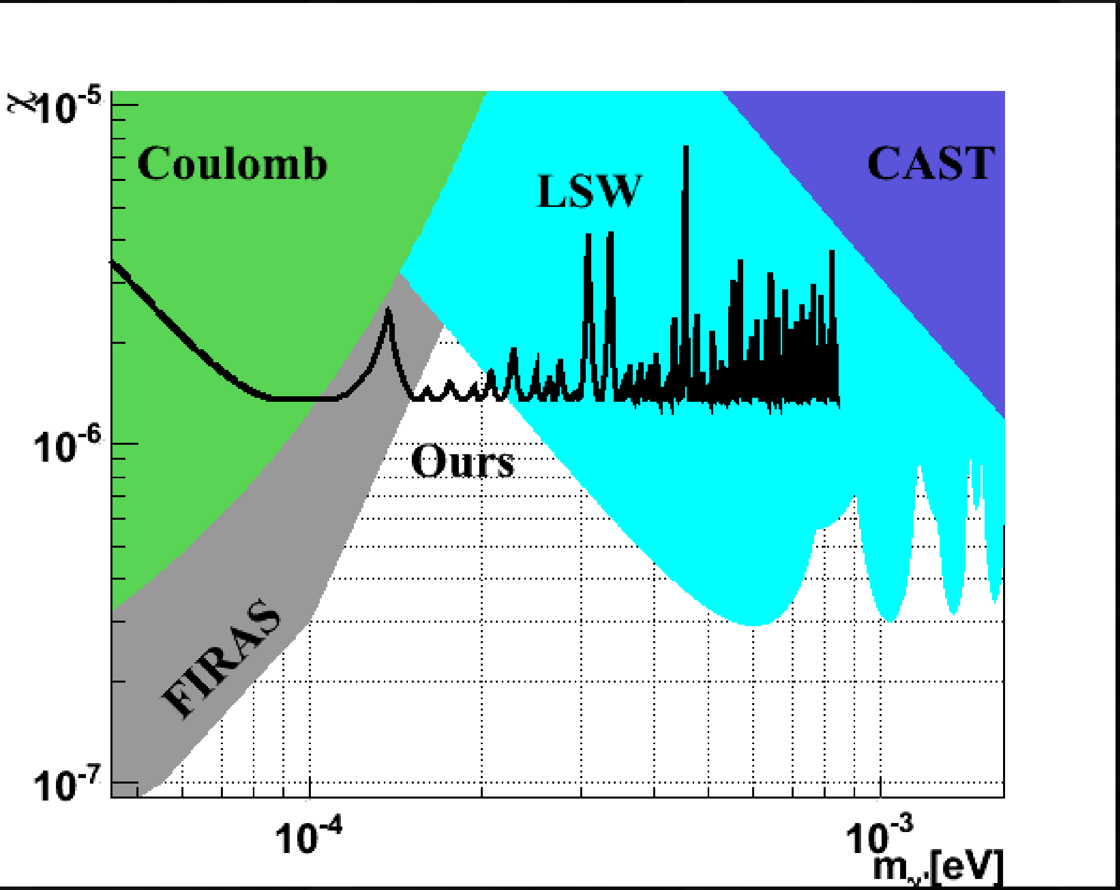


response of blackbody input

- Josephson junction seen (bump at around 2.2 mV)
- Plateau at around 2 mV with LO
- Height of plateau reasonable

- Difference on blackbody temperature seend
- Noise temp. calculated to be ~ 200K

Expected Sensitivity (1st step)



conditions

25 kW accumulation

2 MHz linewidth

(LO 1.8MHz, Gyrotron1MHz)

225 K noise temp.

10% efficiency

8640 sec x 3 livetime

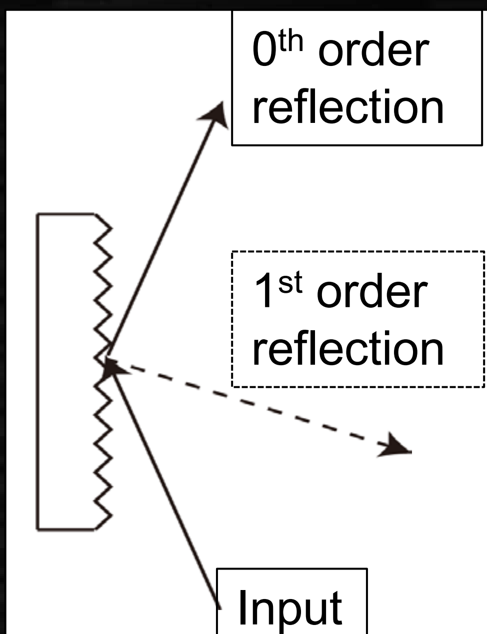
The most powerful measurement around 0.1-0.2 meV (max. factor-2 improvement)

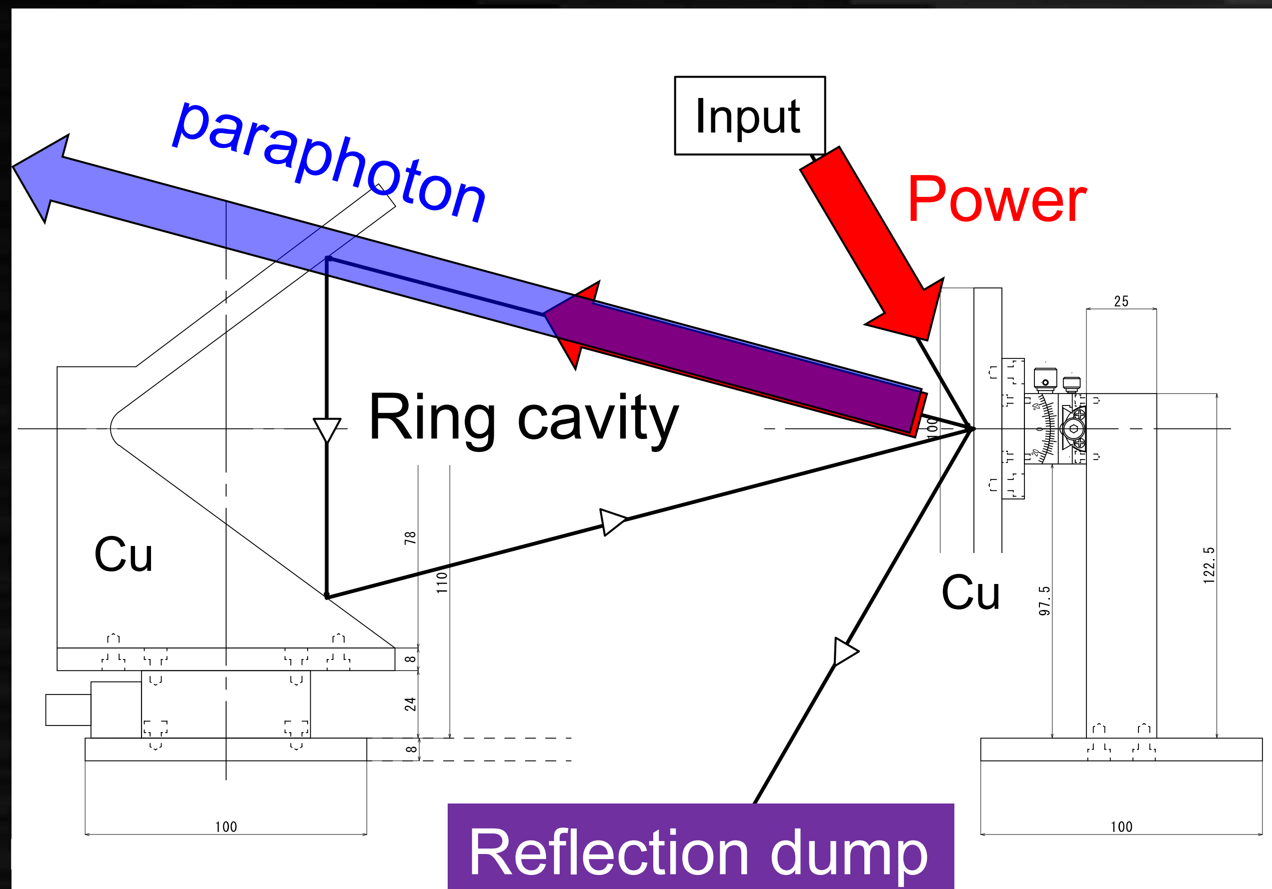
Future plan (1) High-power setup

Using gyrotron with higher power (ex. MW class)

Problems
- Reflection from cavity
- Heat dissipation at cavity

Cu grating!
- Water cooling
- Reflection can be dumped



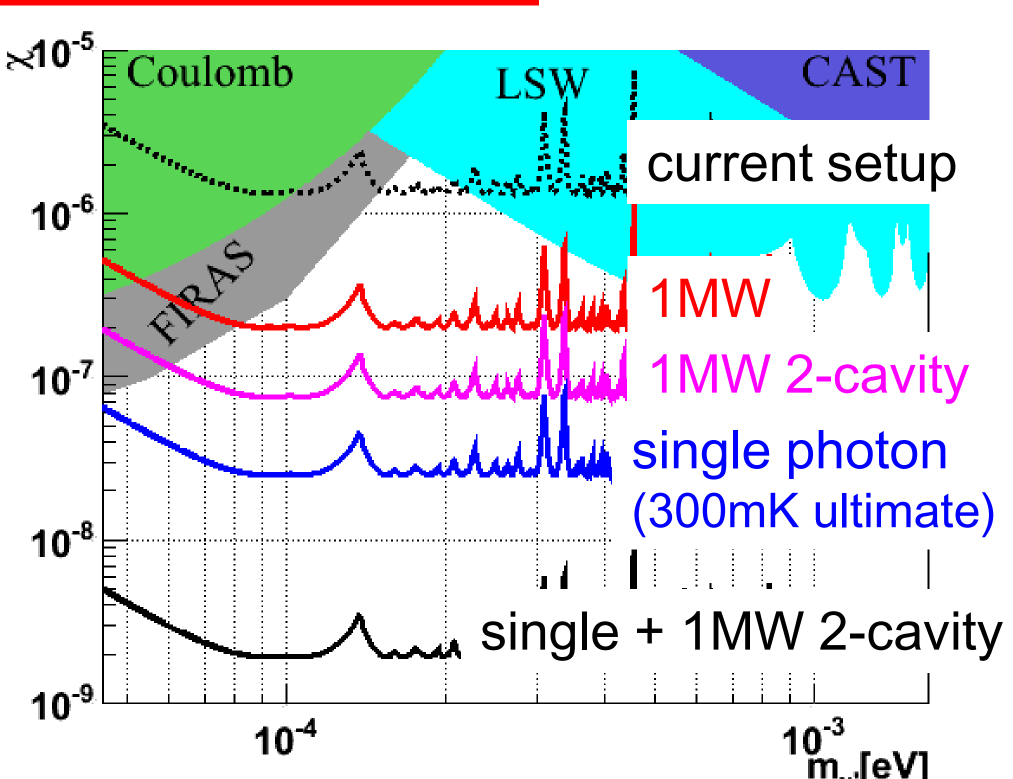


Future plan(2) Single-photon detector

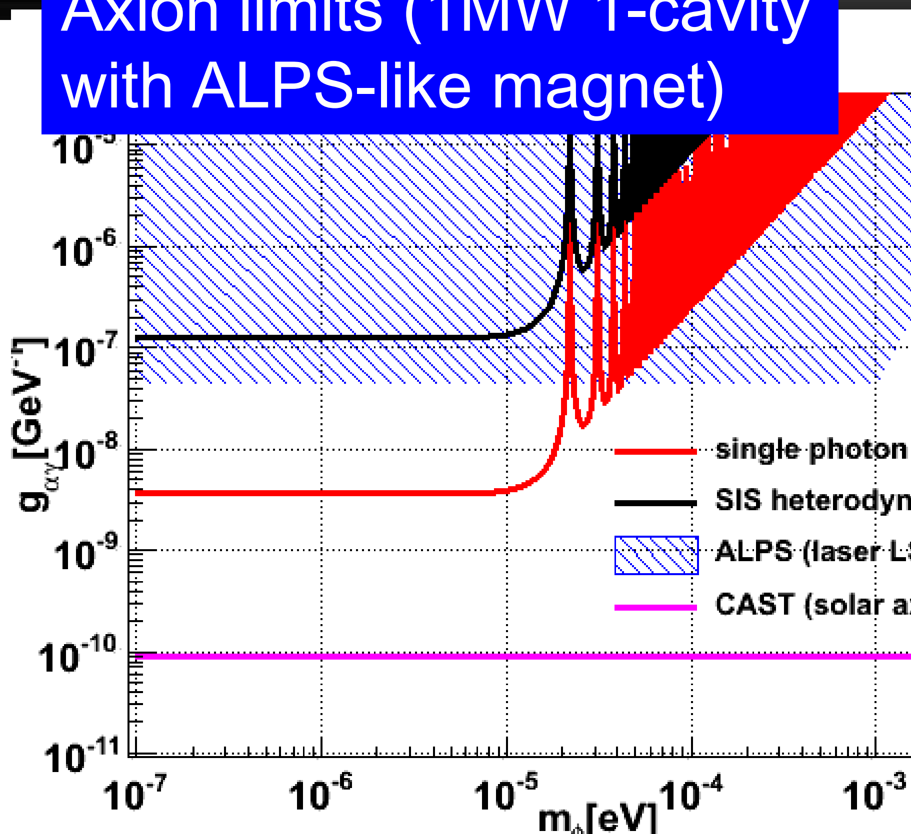
- Sensitivity of heterodyne detectors is limited by shot noise -> direct detection!
- "Single photon detector"
  - fast (nanosec response), relatively broadband
  - lower temperature – 300 mK (pulse-tube cooler) with low-Tc material (Al etc.)
- SIS direct detector is under development (mainly for CMB polarization measurement)
- Ultimate sensitivity – 300mK blackbody (less than 10^{-10} compared to 4K)

Sensitivity of future plans

Paraphoton limits



Axion limits (1MW 1-cavity with ALPS-like magnet)



Big improvements in paraphoton/ALP search seen!
“pit” on paraphoton search fully covered with
1MW gyrotron or single photon detector

Summary

- Hidden particle search with THz wave
  - World highest sensitivity for ~0.2 meV paraphoton
- Using a gyrotron as the photon source
  - 300 W, 200 GHz, 25 kW accumulated in cavity
- SIS heterodyne detection for the first step
  - Result will be seen this summer (hopefully!)
  - Max. factor-2 improvement
- Upgrade of power source or detector will lead to drastic improvement of search power!