Hidden Particle Search using Sub-THz Gyrotron

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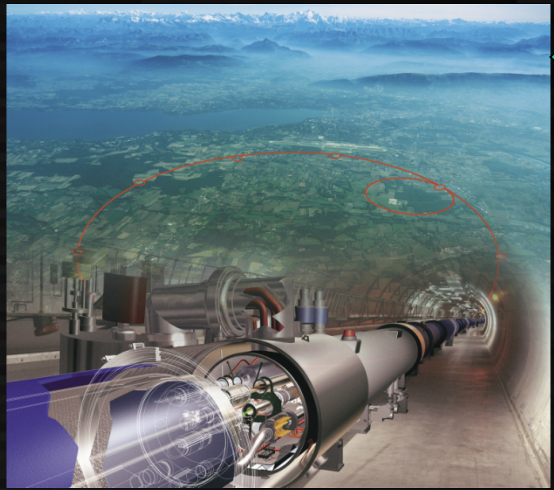
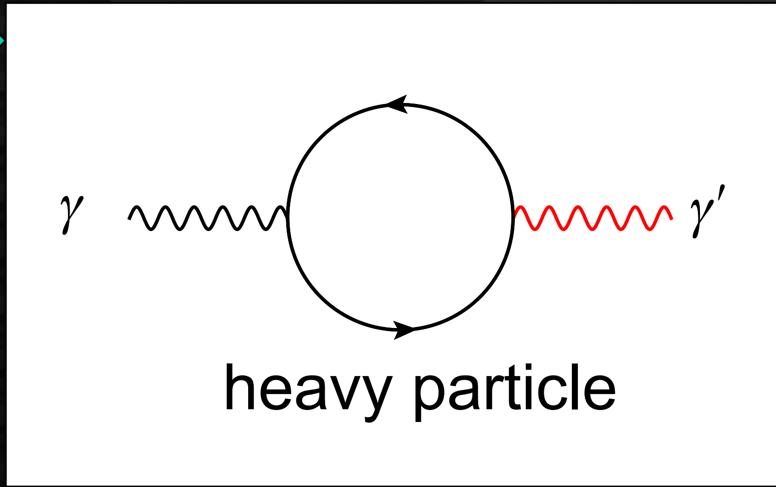
High Energy vs. Weak Coupling



complemental



high energy colliders (LHC etc.) searching for TeV particles

Searching for weak couplings involving heavy particles

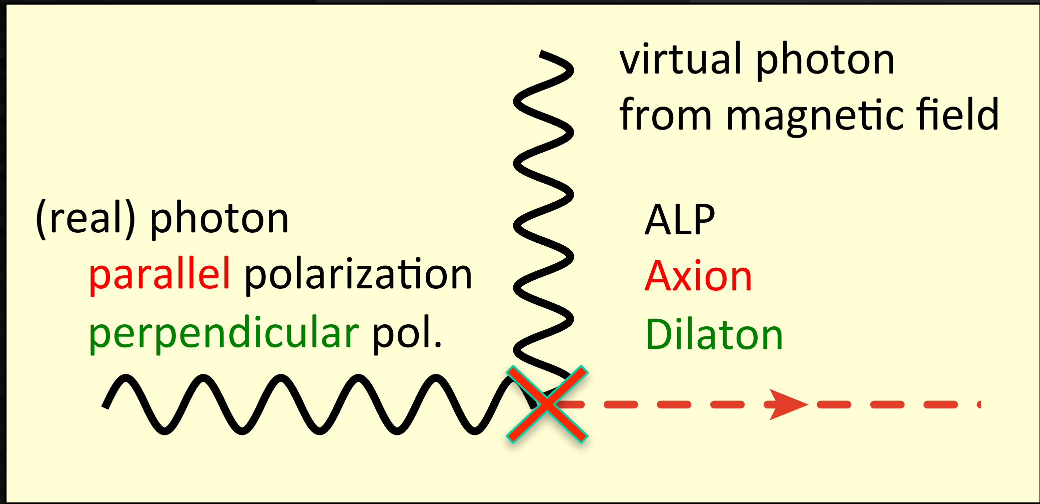
TeV (or higher) scale physics

- Dark matter
- Dark energy
- Baryogenesis
- Hierarchy

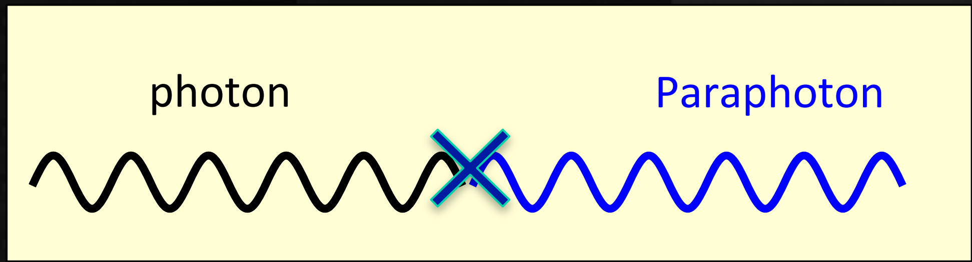
etc.

Weakly Interacting Sub-eV Particles (WISPs)

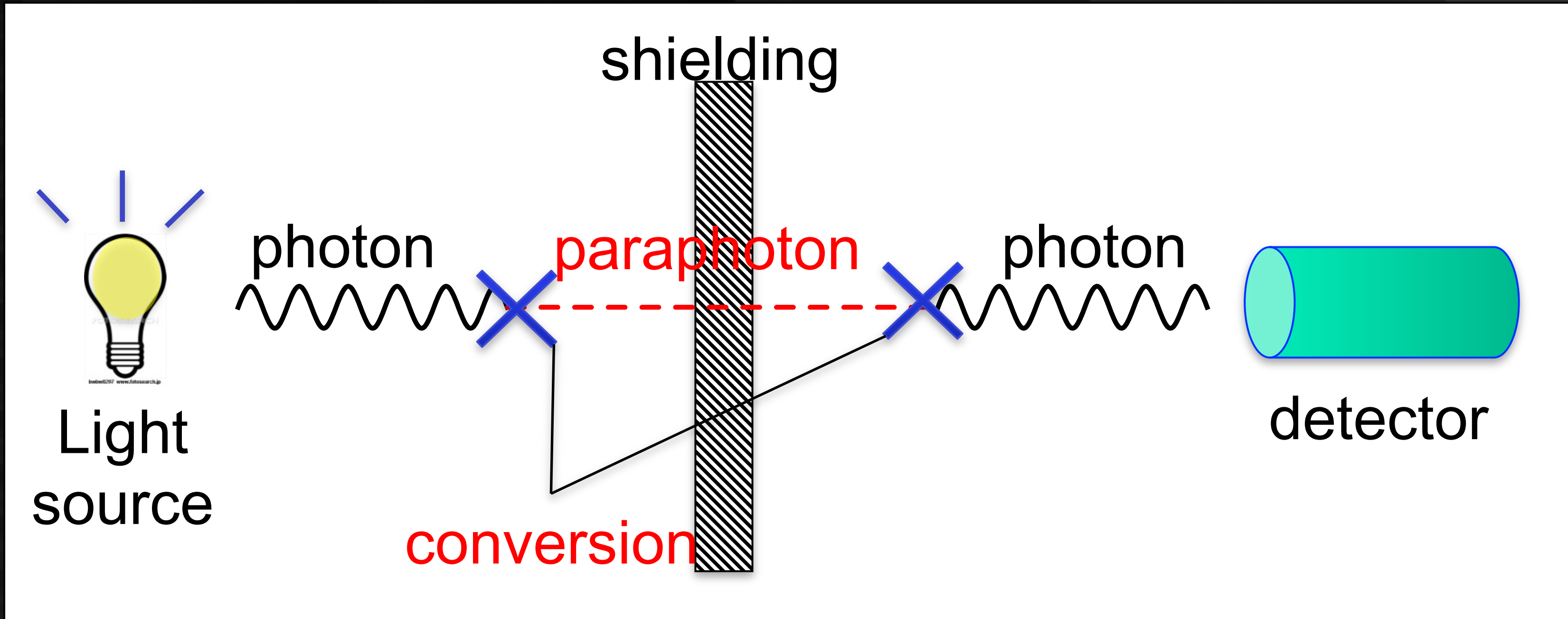
1. ALP (Axion-like particle)
   - Axion (pseudo-scalar)
     CP problem in QCD
   - Dilaton (scalar)



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



‘Light Shining through a Wall’ (LSW)

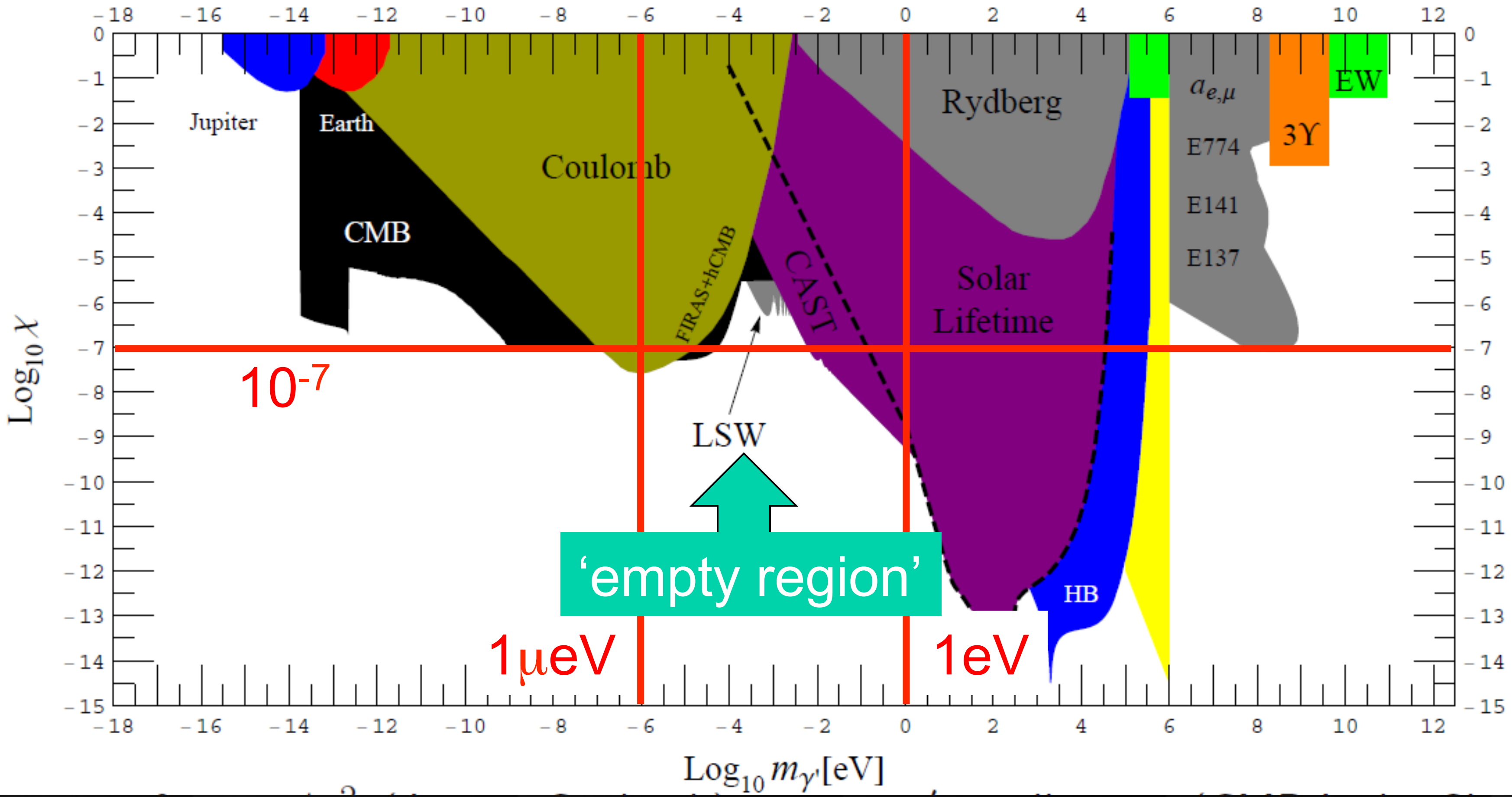


- Strong light source and sensitive detector are keys
- Searchable paraphoton mass depends on photon E

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

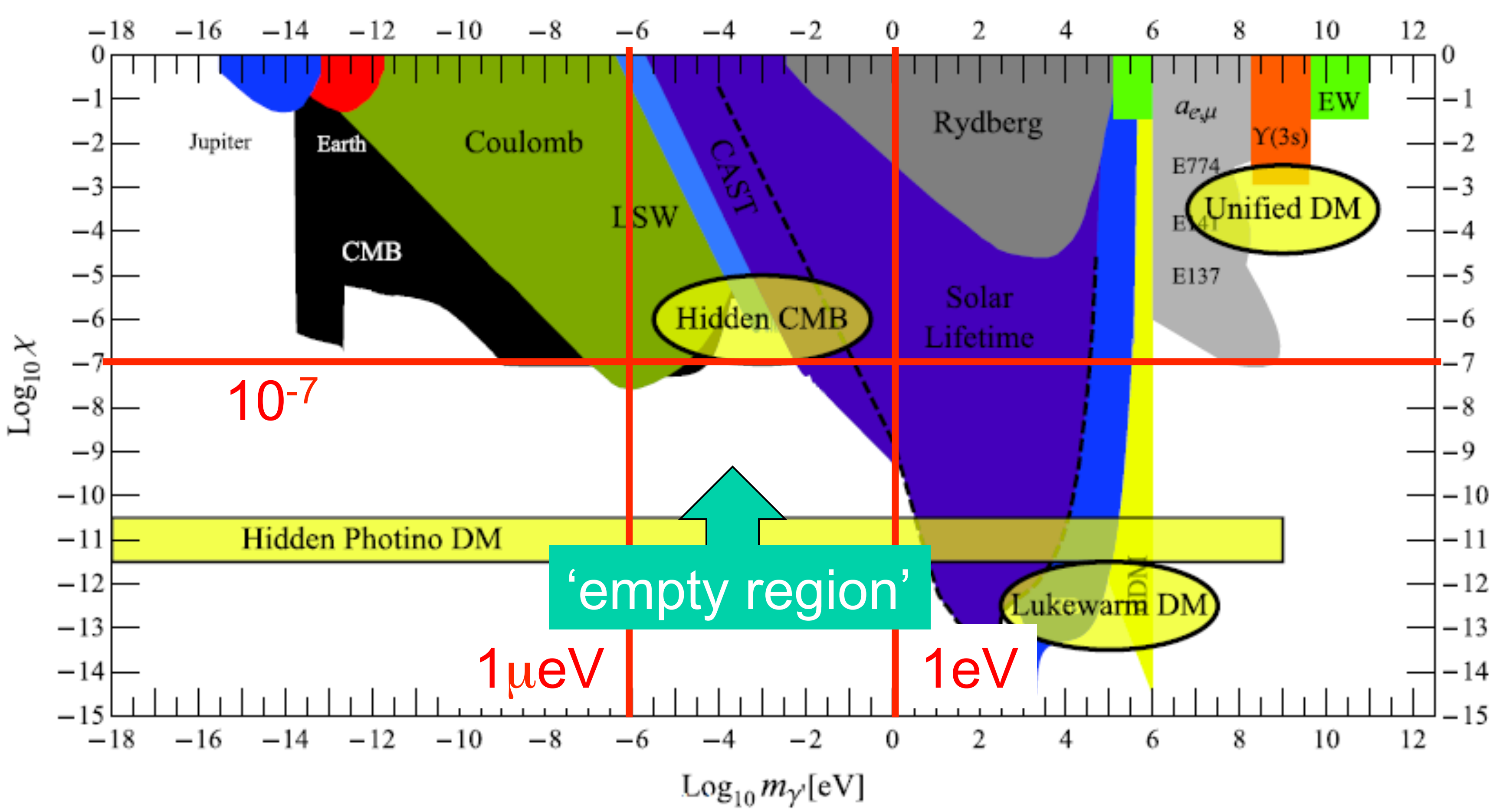
Current Limit for Paraphoton

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

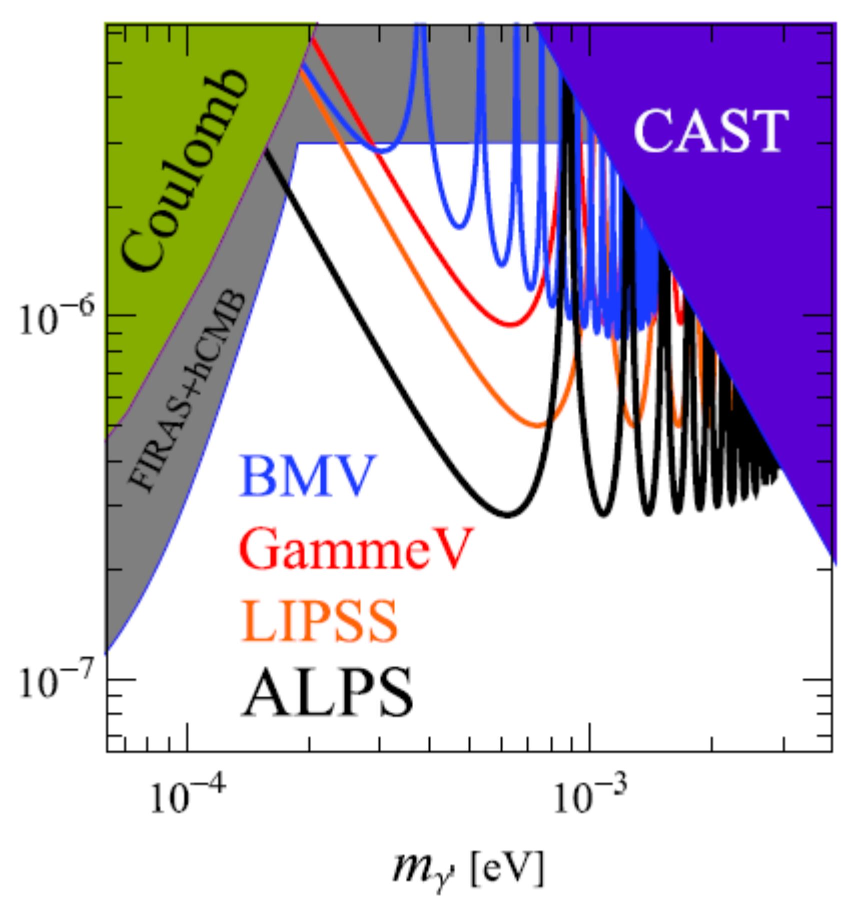


Current Limit for Paraphoton

[Jaeckel,Redondo,AR '08;Arkani-Hamed,..'08;Ibarra,AR,Weniger '08;...]



Magnified View (~ meV)



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

meV (THz) photons!

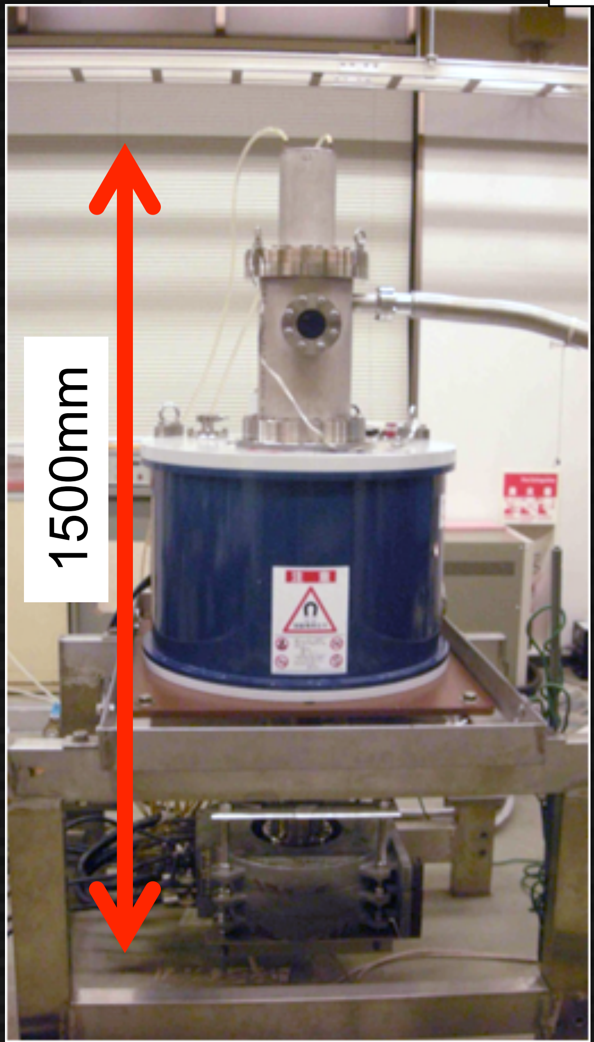
$$P_{\gamma\gamma'} = 16\chi^2 \left(\sin \frac{m_{\gamma'}^2 L}{4\omega} \right)^2$$

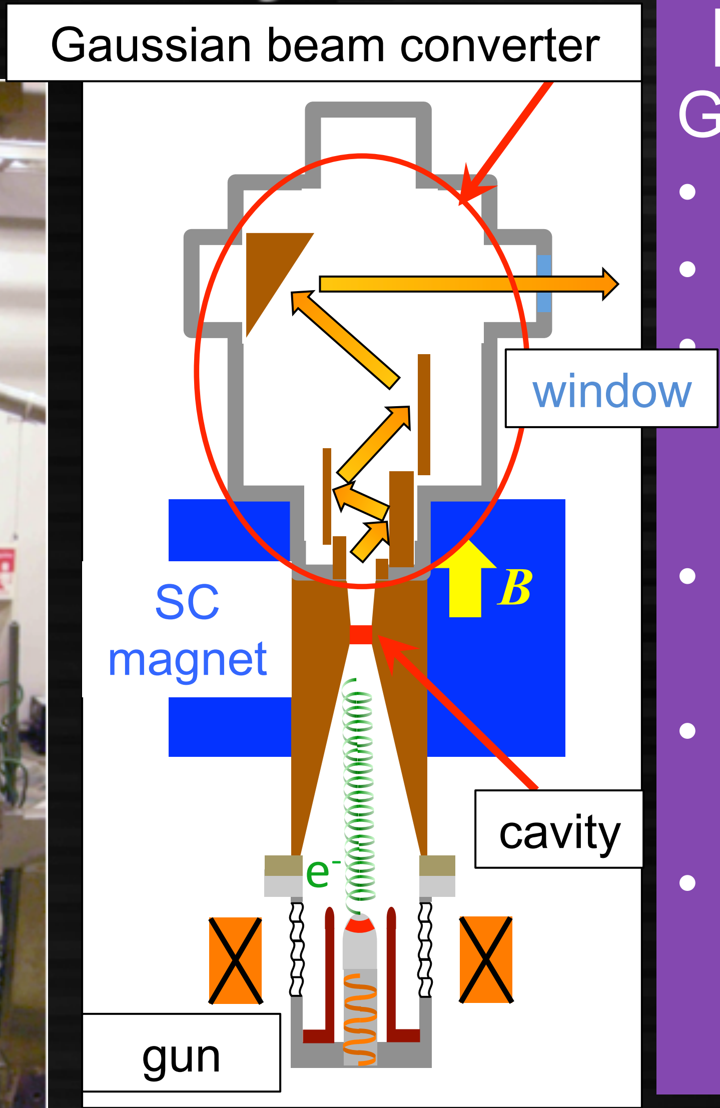
LSW with THz photons can cover the 0.1 meV region!

Plan for LSW exp. with THz

- 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 (SIS etc.)

Gyrotron



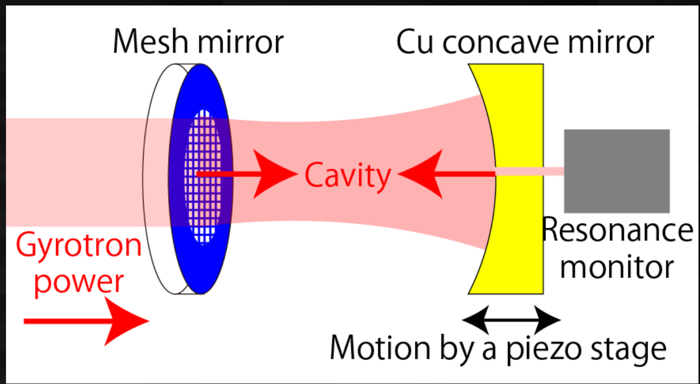


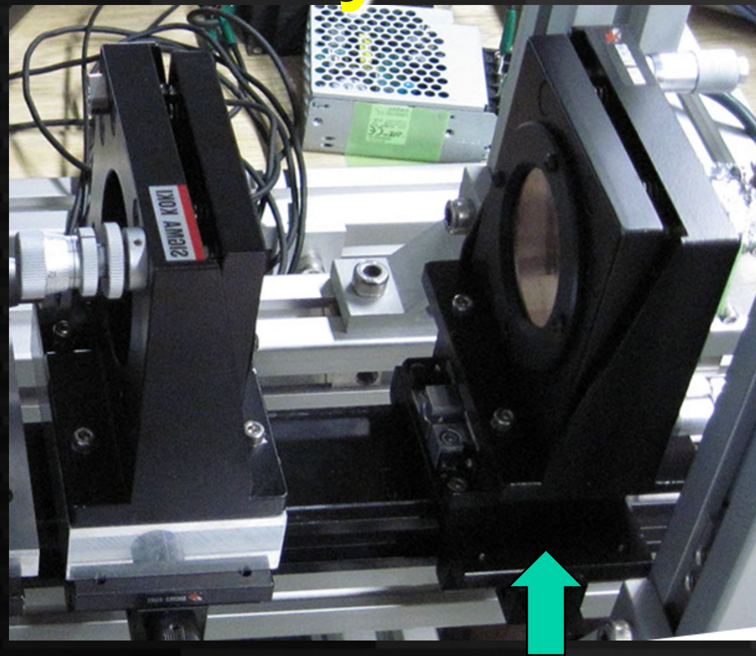
【Gyrotron FU CW GI】
- developed in Fukui
- 201-206 GHz
- 300 W Gaussian with internal mode converter
- line width: ~1MHz (good condition)
- duty up to 50% up to 20 Hz
- assembled for positronium exp. (see Yamazaki's talk on Friday)

Fabry-Perot Cavity

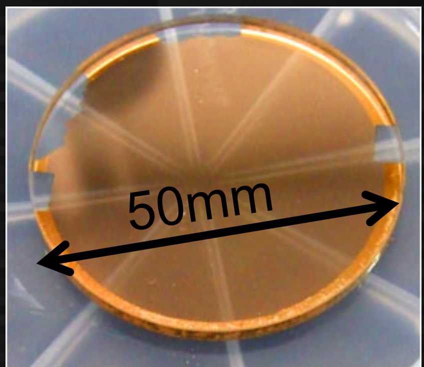
One-dimensional cavity

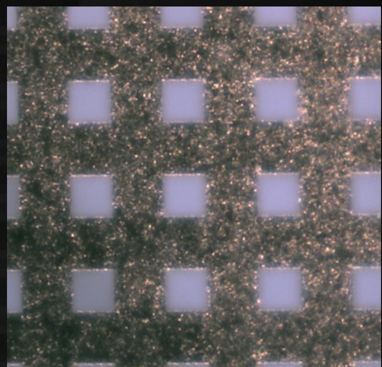
- high density (optical confinement)
- free cavity length





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





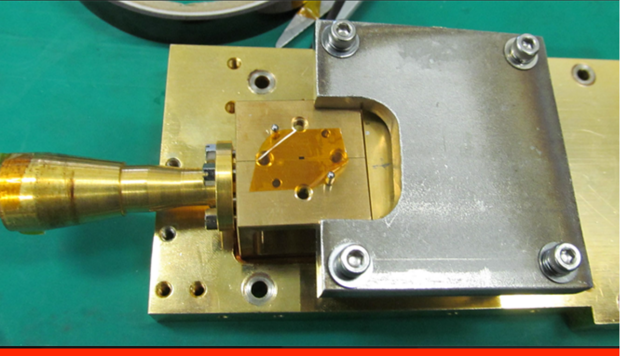
Au mesh (200μm width, 360μm period, 1μm thick) depleted on quartz or silicon
99% reflection, ~0.7% transmission @ 203 GHz

20-30kW accumulated (water cooled silicon)

mesh melted at 20KW with quartz

Superconducting Detector

- SIS Heterodyne (phase I)
  - Eliminating background by selecting gyrotron frequency
  - SIS Detector from Nobeyama
    - Nb SIS, 4K operation, noise level: ~ 100K
  - Originally tuned for 230GHz
    - Now testing performance at < 210 GHz

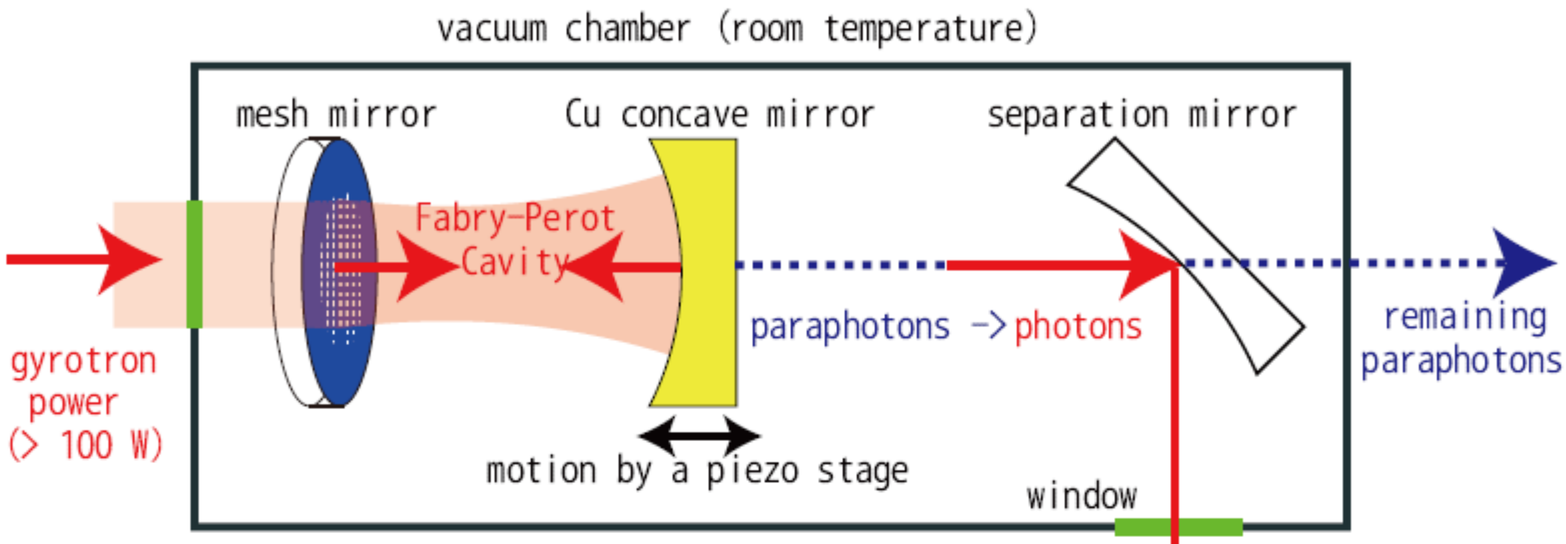


Possible combining existing technologies
Now preparing

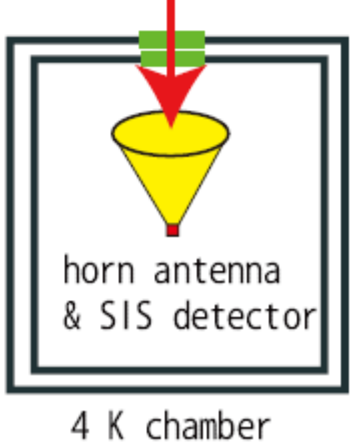
- Direct detection (phase II)
  - Photon counting device will drastically gain sensitivity
  - Candidates: SIS, TES, KIDs
    - Detector speed is essential for photon counting: SIS may be most suitable

Need detector development & improvement

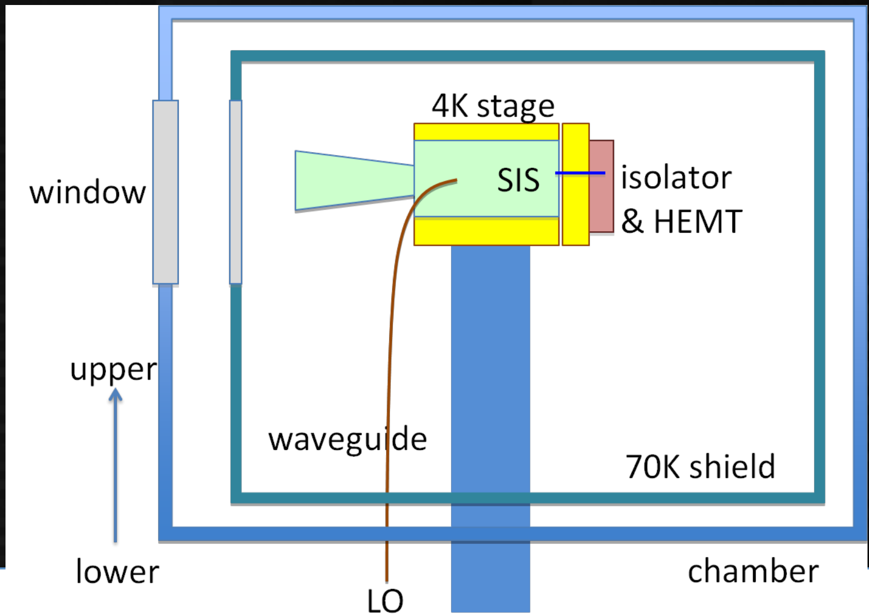
Setup (phase I)

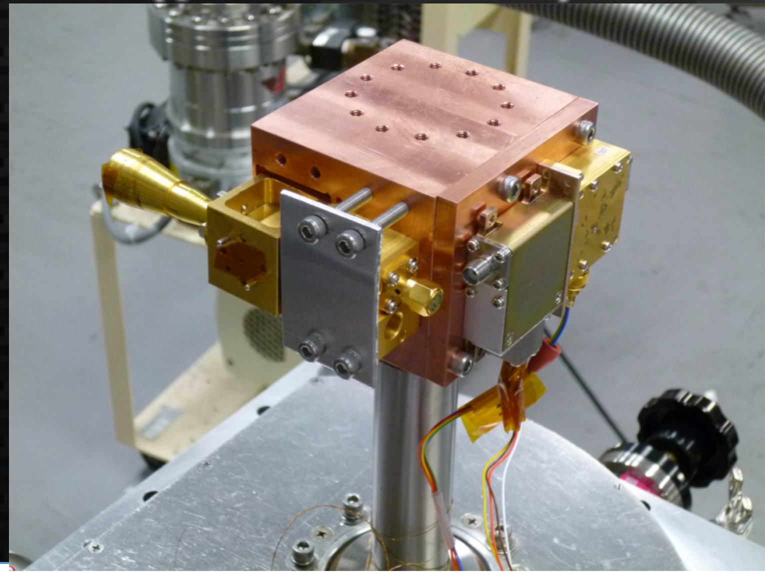


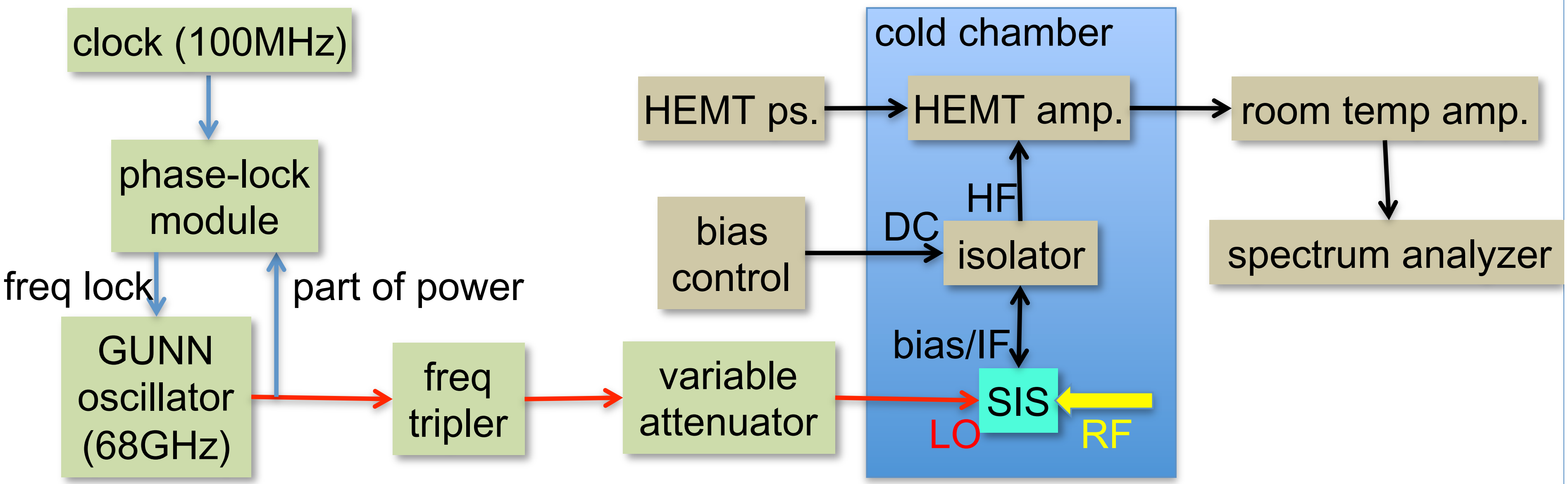
- Fabry-Perot cavity in room temp.
- Photon-paraphoton mixing between Cu mirror & separation mirror
- Separation mirror to determine photon/paraphoton state
- Detection in 4 K chamber



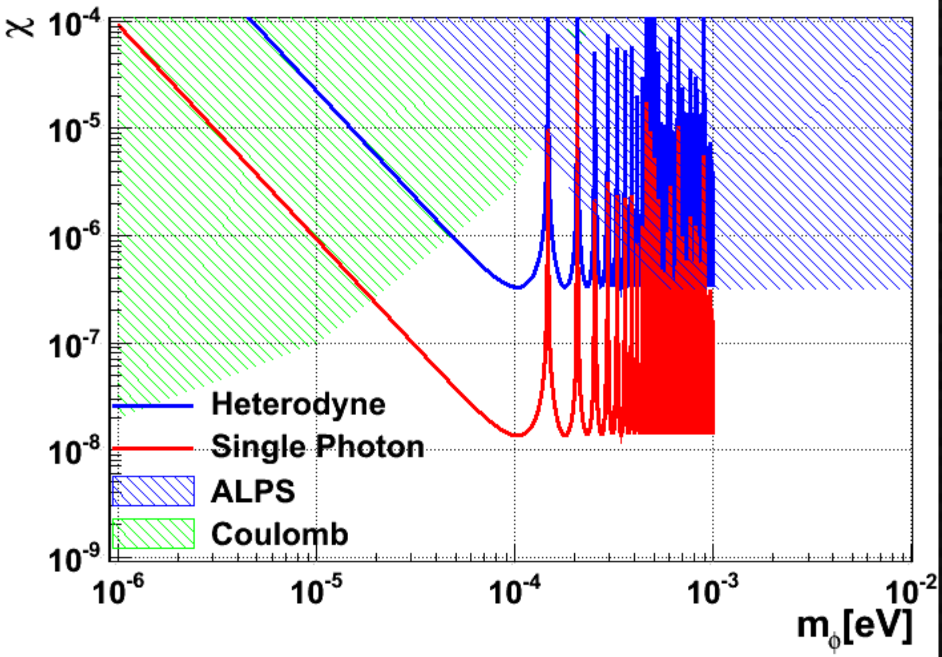
4 K Chamber (phase I)

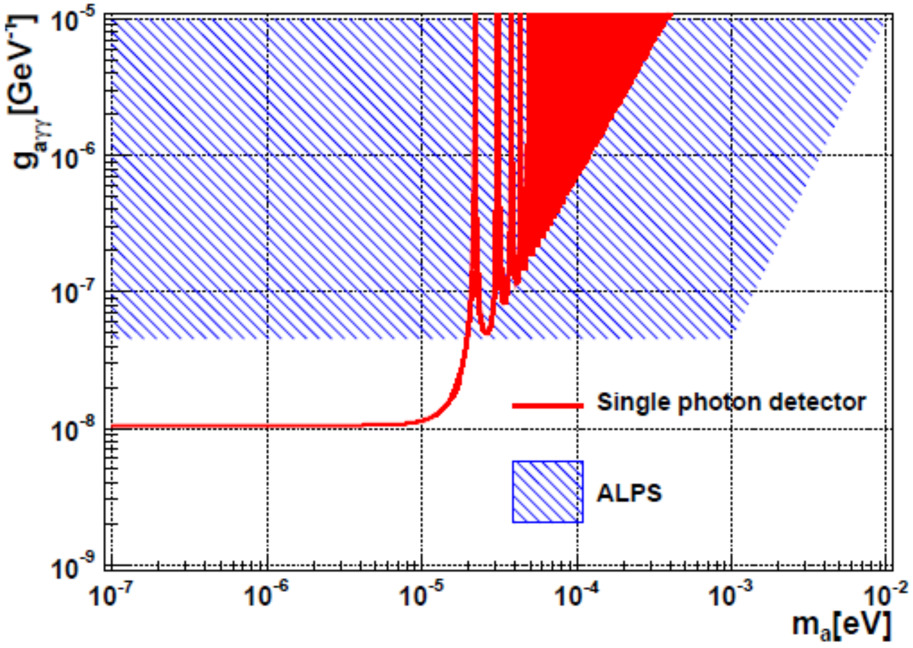






Expected Sensitivity





Phase I (heterodyne): paraphoton only

Aim to cover the pit at $m_{\gamma'} \sim 10^{-4}$ eV

Phase II (direct): paraphoton & ALP (with strong magnet)

~ 10 times lower limits for paraphoton

Summary

- Hidden particle search with THz wave
  - World highest sensitivity for ~0.1 meV paraphoton
- Using a gyrotron as the photon source
  - 300 W, 200 GHz
- SIS heterodyne detection for phase I
  - Single photon detector for phase II
- Plan to finish preparation by end of this year, measurement from early next year
  - Noise reduction is the key
  - About one month measurement for the first result

backup

Assuming conditions

	phase I	Phase II	
target	paraphoton	paraphoton	ALP
power	5 kW		
meas. time	10^6 sec (~ 10 days)		
detection	heterodyne	direct	
det. eff.	10 %		
line width	1 MHz	10 GHz	
noise	50 K	300 mK blackbody only	
conv. length	10 cm		4.3 m
mag. field	-		5 Tesla

THz superconducting detectors

detector	method	priciple of detection	material	temperature	noise level (NEP)	speed	noise source
SIS / STJ (superconductor-insulator-superconductor tunnel junction)	heterodyne	Cooper pair broken -> change in I-V characteristics	Nb	4K	10^{-21} x δf (10^{-15} with 1 MHz width)	slow (msec) Fourier transform	quantum thernal
	direct		Hf etc.	<0.3K	10^{-17}	fast (nsec)	blackbody, leak I
MKID (microwave kinetic inductance detector)		change in kinetic inductance	Al etc.	<1K	10^{-17}	intermediate (μsec)	blackbody, amp noise
TES (transition edge sensor)		bolometer at around Tc	Hf etc.	<0.3K	10^{-17-19}	slow (msec)	blackbody