2008-08-30 RECEU 2008
@浅虫温泉

暗黒物質・太陽アクシオン実験

みのわまこと

Department of Physics
and
RESCEU
The University of Tokyo

Tokyo Axion Helioscope

Collaborators

University of Tokyo

M. MINOWA

Y. Inoue

Y. Akimoto

R. Ohta

T. Mizumoto

KEK

A. Yamamoto

Axion

What is the Axion?

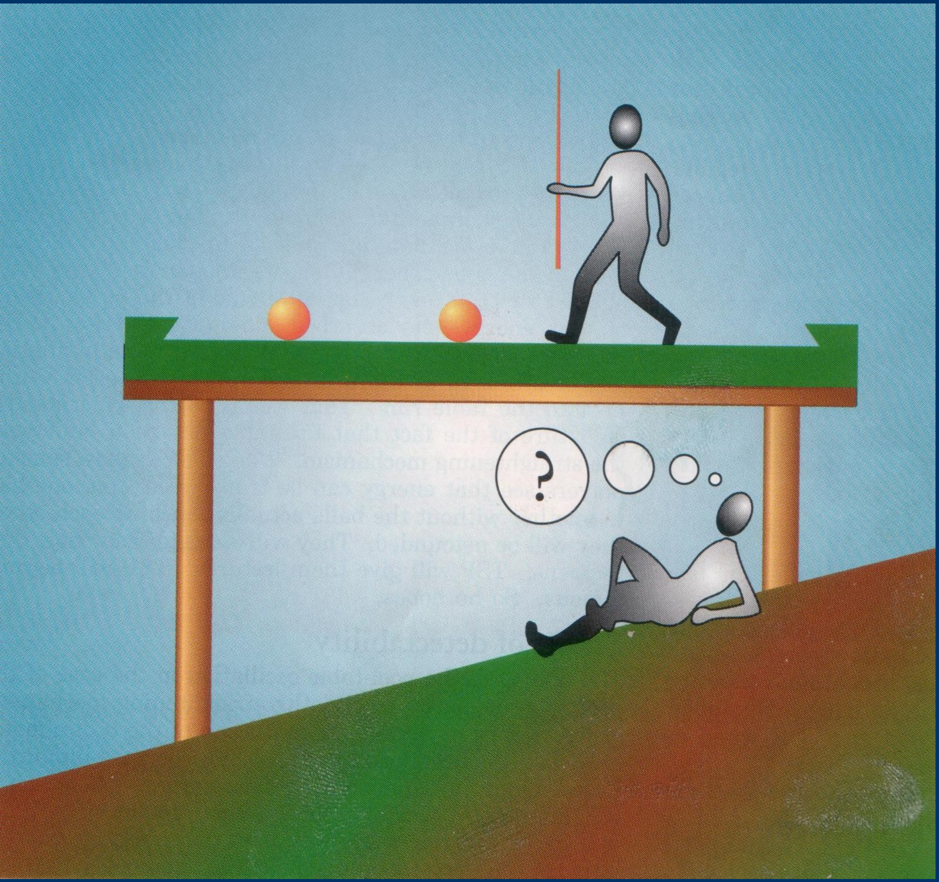
- QCD $\rightarrow \theta$ vacuum $\rightarrow$ Strong CP problem (eg. neutron EDM)
- Peccei–Quinn mechanism:
  global chiral U(1) + SSB
  $\rightarrow \underline{\text{NG boson}} + \underline{(1/32\pi^2 f_a) a F_a \tilde{F}_a}$

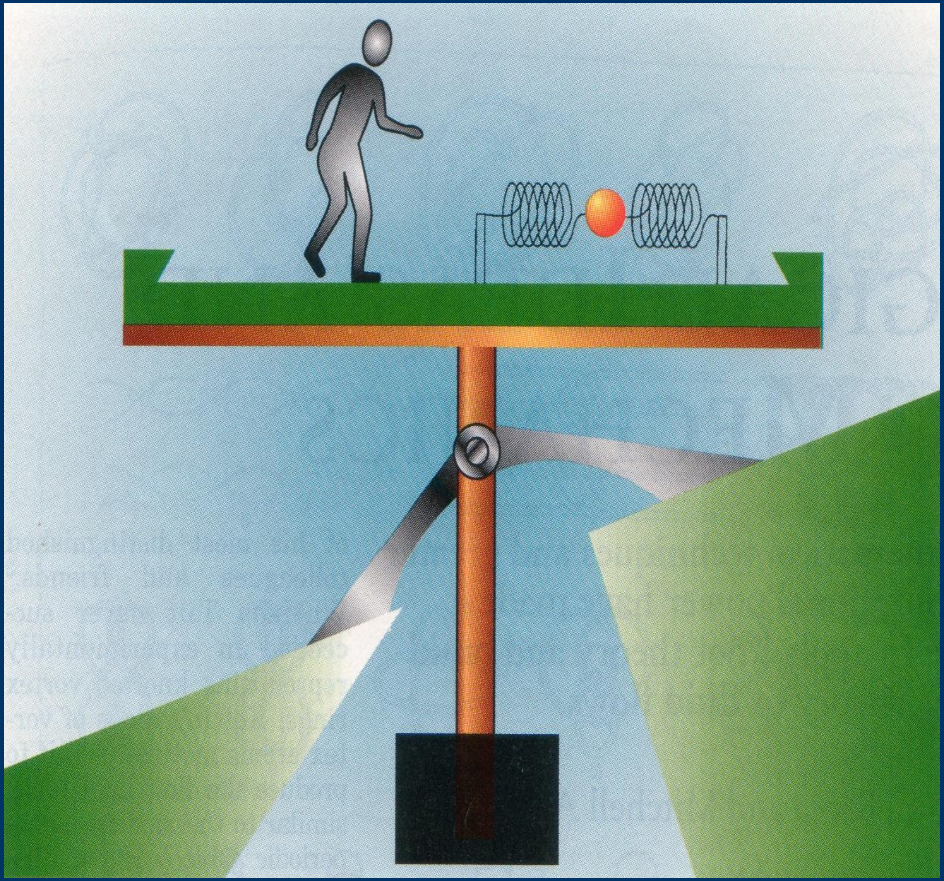
  $\downarrow$ axion; $\downarrow$ resolves Strong CP

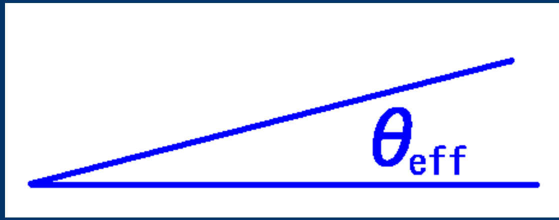
Searches/Limits:

- Experiments: Accelerator, Reactor, Nuclear transition, Telescope, Solar axion, Laser, Microwave cavity, ...
- Astrophysics: Solar axion, Red giants, SN1987A
- Cosmology: $\Omega_a < 1$

An analogy,
P. Sikivie, Phys. Today 49 (1996) 22.







Axion mass and $g_{a\gamma\gamma}$

$$m_a = 0.6\left(\frac{10^7\,\mathrm{GeV}}{f_{\mathrm{PQ}}}\right)\mathrm{eV}$$

$$g_{a\gamma\gamma} = \frac{\left|E/N - 1.92\right|}{8/3 - 1.92} \times 1.45\left(\frac{m_a}{1\mathrm{eV}}\right) \times 10^{-10}\,\mathrm{GeV}^{-1}$$

ただし、 DFSZ model の *E/N* は比較的自由

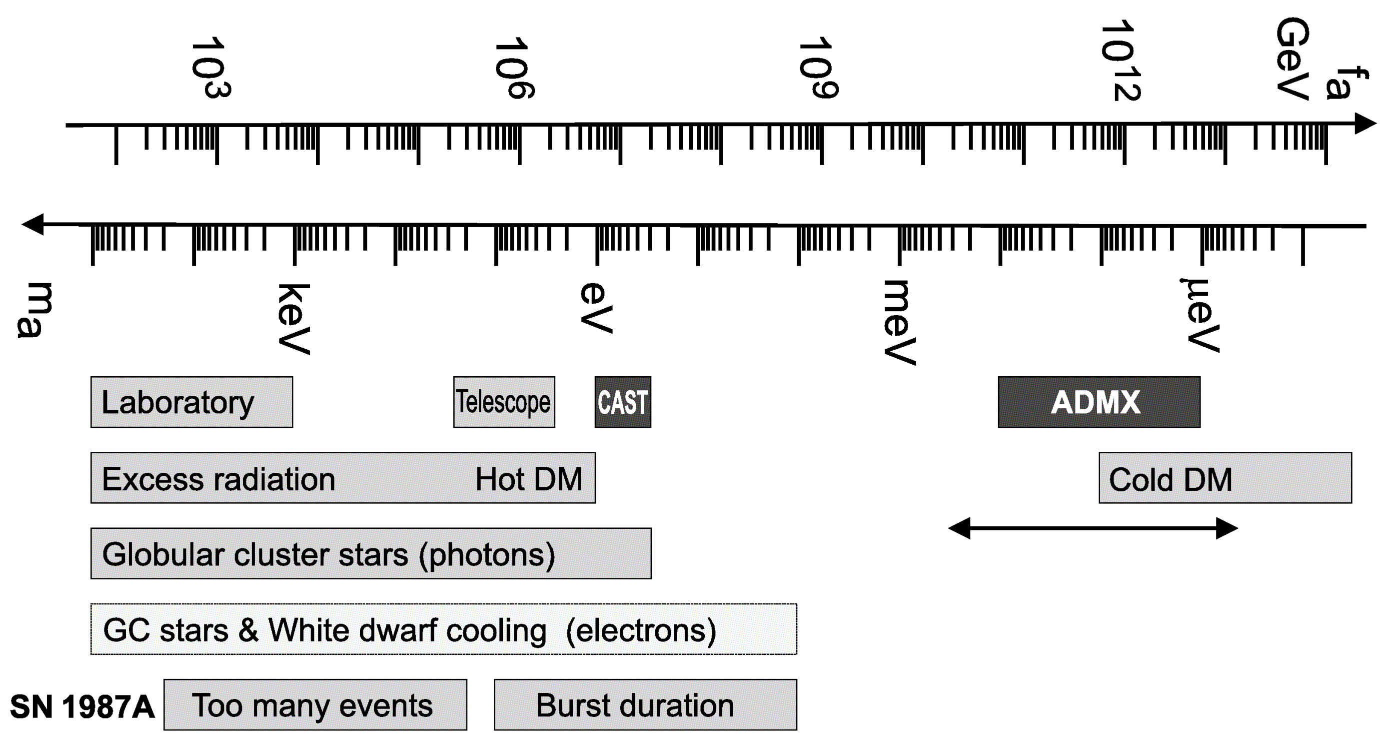
GUT model, DFSZ model(GUT を仮定) : E/N=8/3

KSVZ model : E/N=0

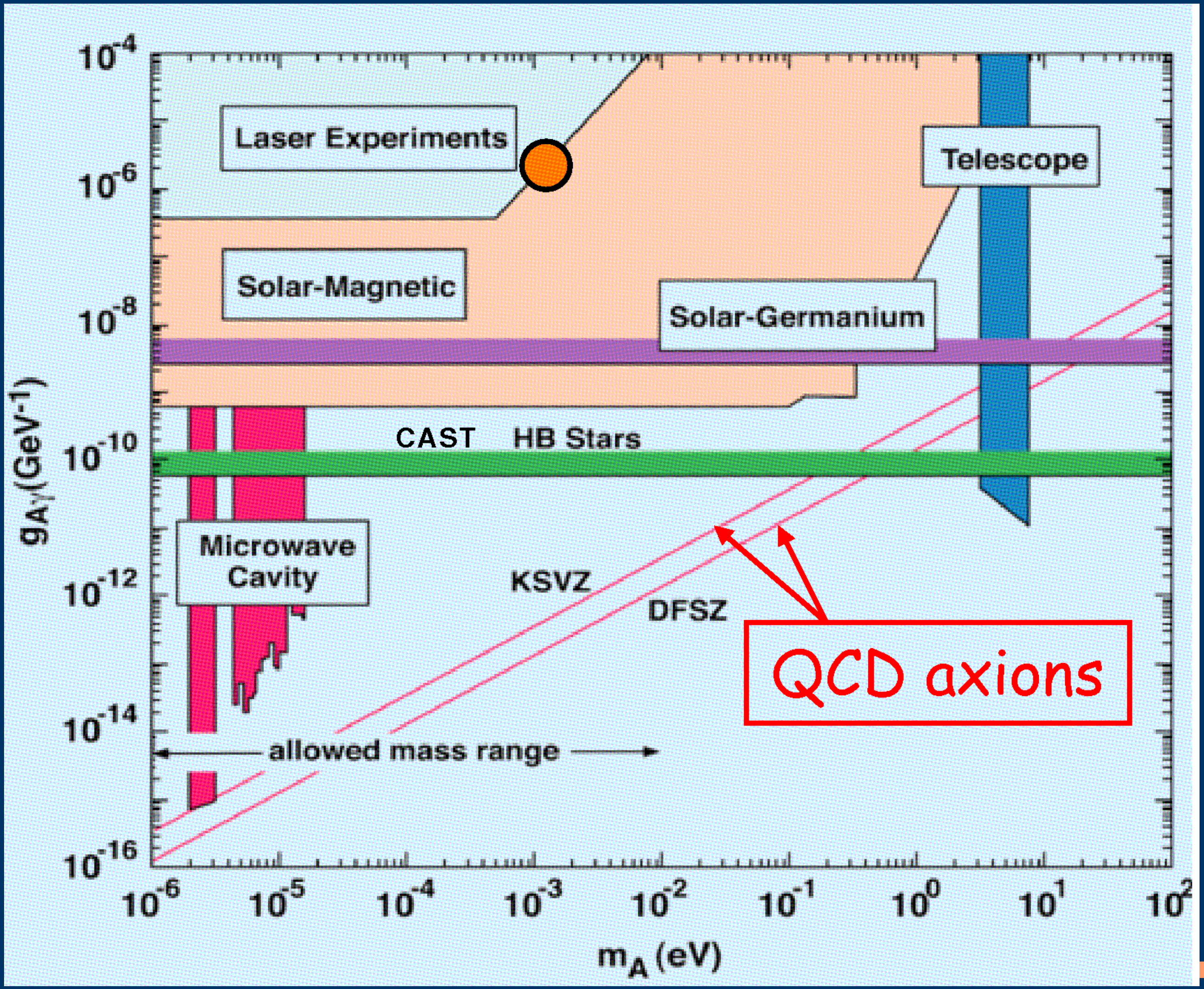
(*E/N* : the ratio of the electromagnetic and color anomalies)

Axion constraints

2008 Review of Particle Physics



Axion searches

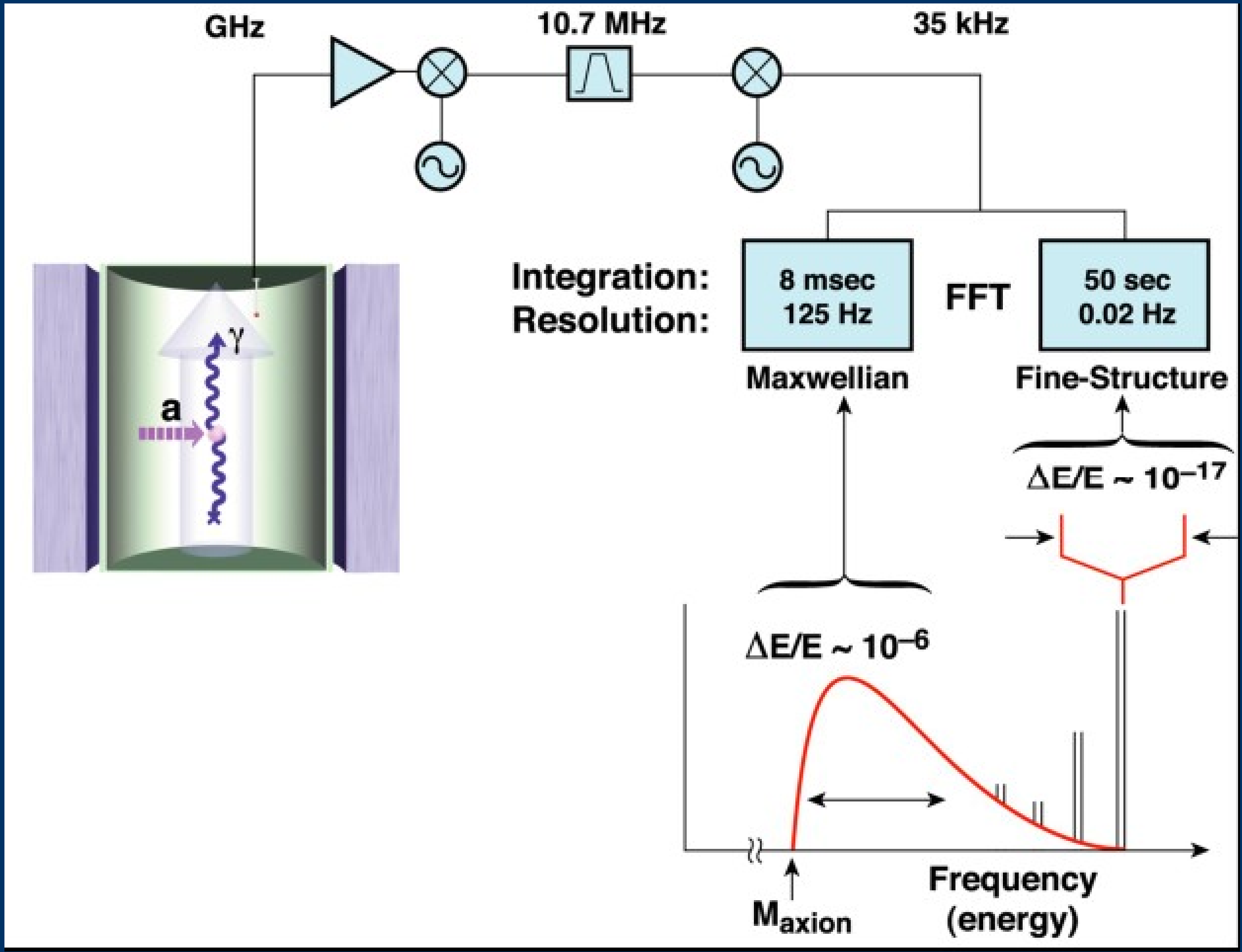


W. Wester
PATRAS 4
2008

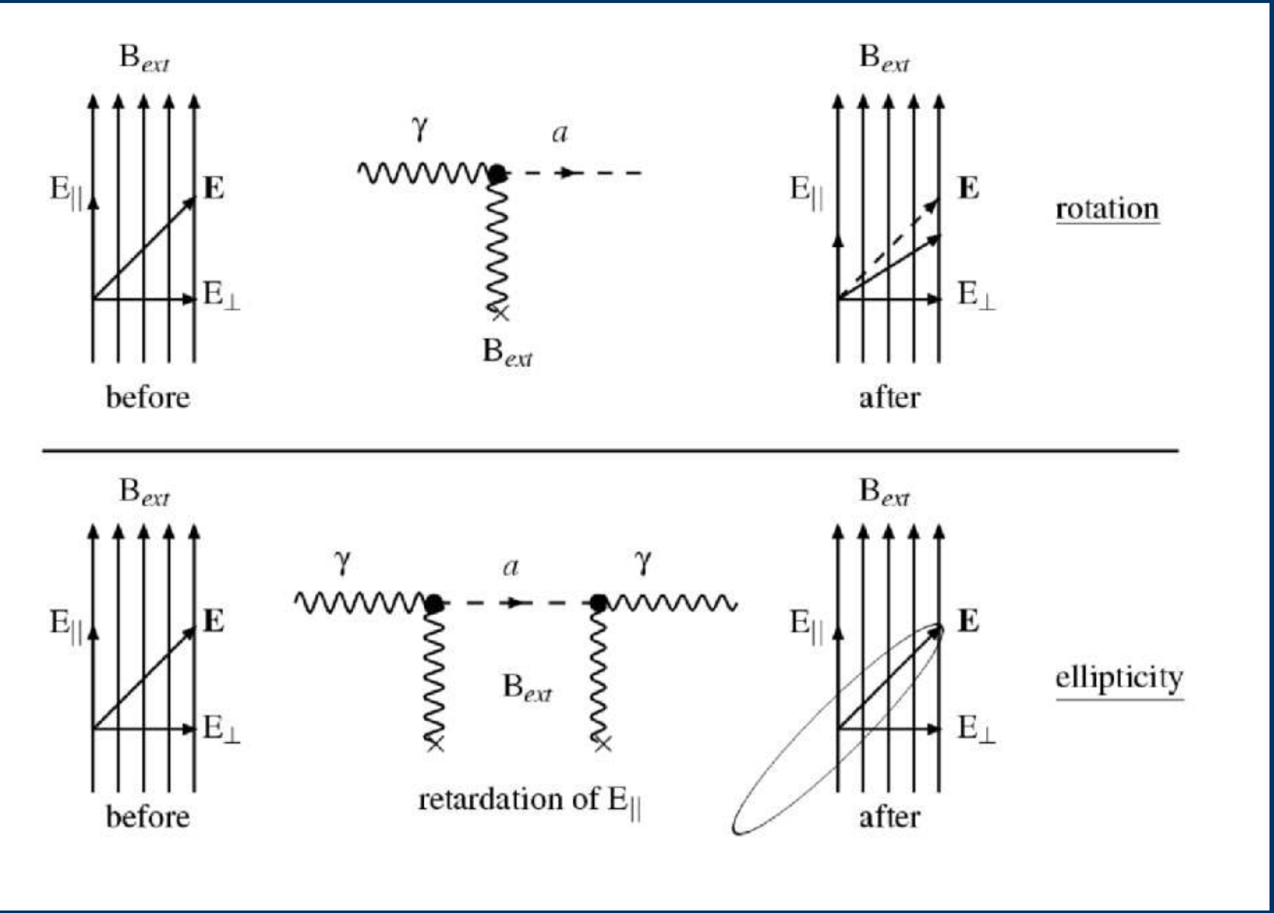
Axion experiments around the world

- Dark matter axion searches – microwave cavity
  - ADMX /US
  - CARRACK /Kyoto
- Solar axion searches – magnetic
  - Tokyo Axion Helioscope aka Sumico /RESCEU
  - CAST /CERN
- LASER experiments
  - PVLAS /Italy – photon polarization
    - Anomaly claimed and disclaimed later
  - Follow-up experiments excluded the anomaly – photon regeneration, shining thru a wall

ADMX, DM axion search with a cavity

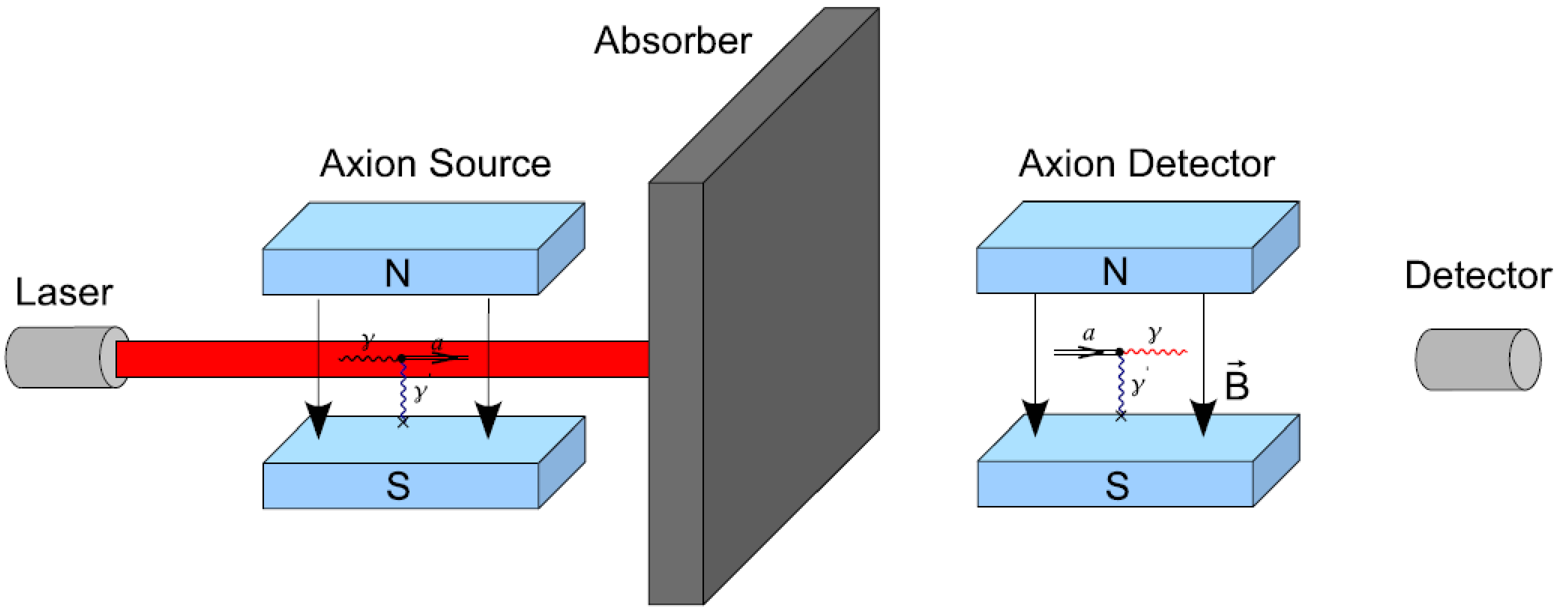


PVLAS, LASER photon polarization

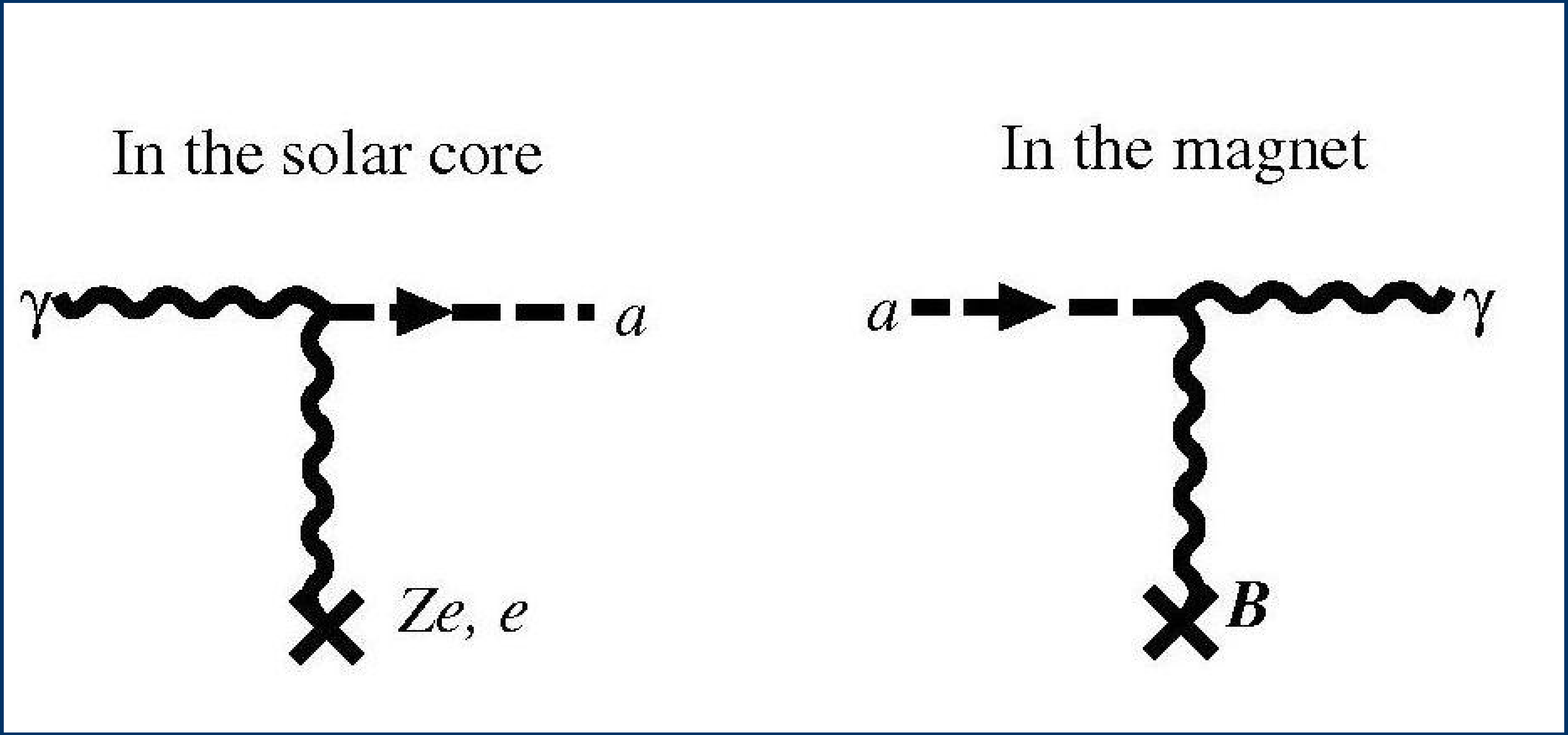


$$\mathcal{L}_{\text{int}} = g_{a\gamma\gamma} a \mathbf{E} \cdot \mathbf{B}$$

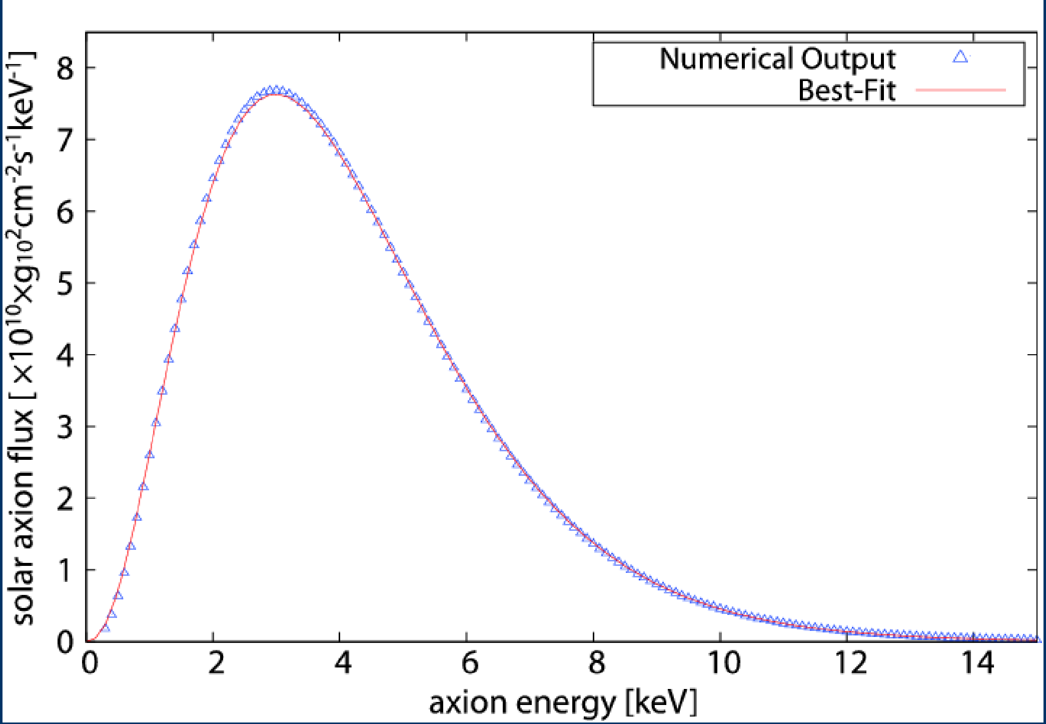
Photon regeneration, shining thru a wall



Solar axion, production and detection



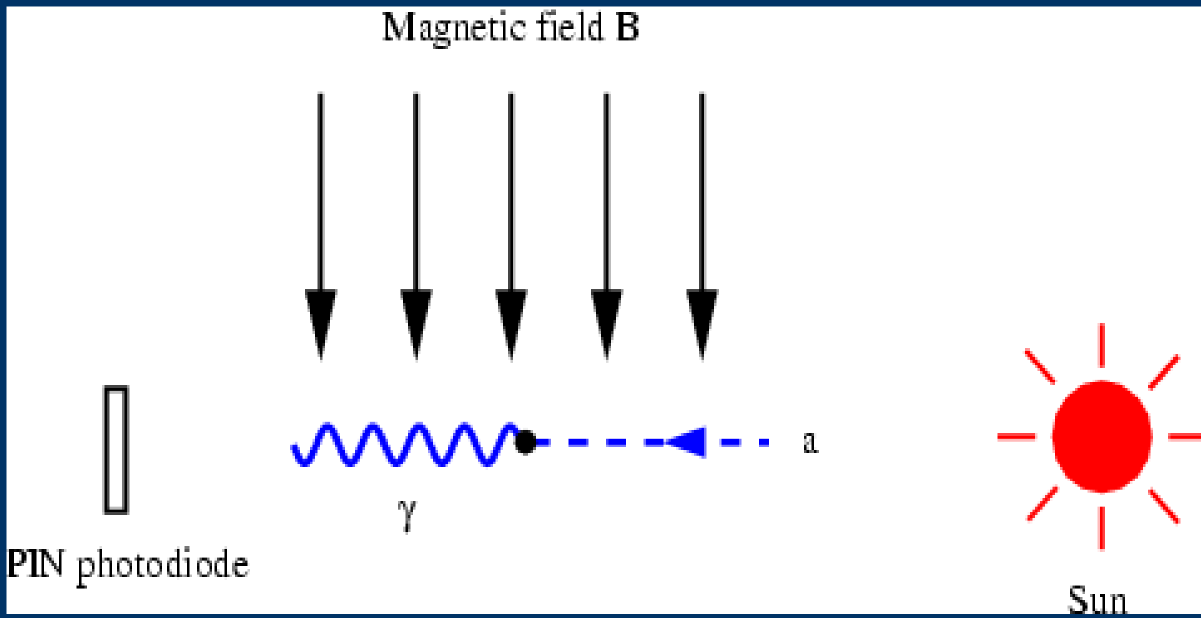
Energy of solar axion



solar axion spectrum
(G.G.Raffelt, 2005)

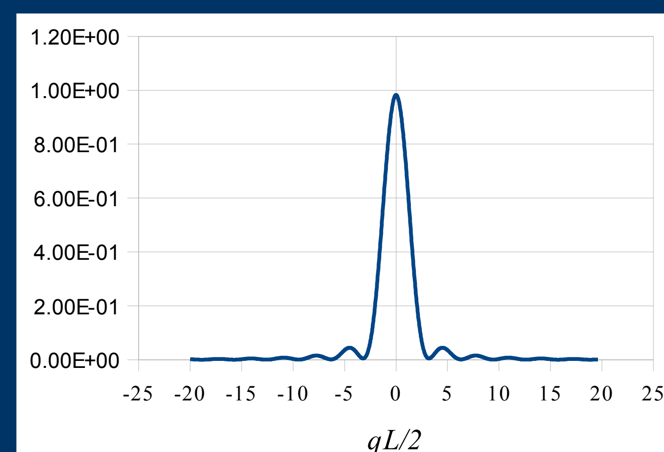
$$\frac{d\Phi_a}{dE} = 6.020\times 10^{10} g_{10}^2 \mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{keV}^{-1}\left(\frac{E}{\mathrm{keV}}\right)^{2.481}\exp\left(-\frac{E}{1.205\mathrm{keV}}\right)$$

Principle of detection

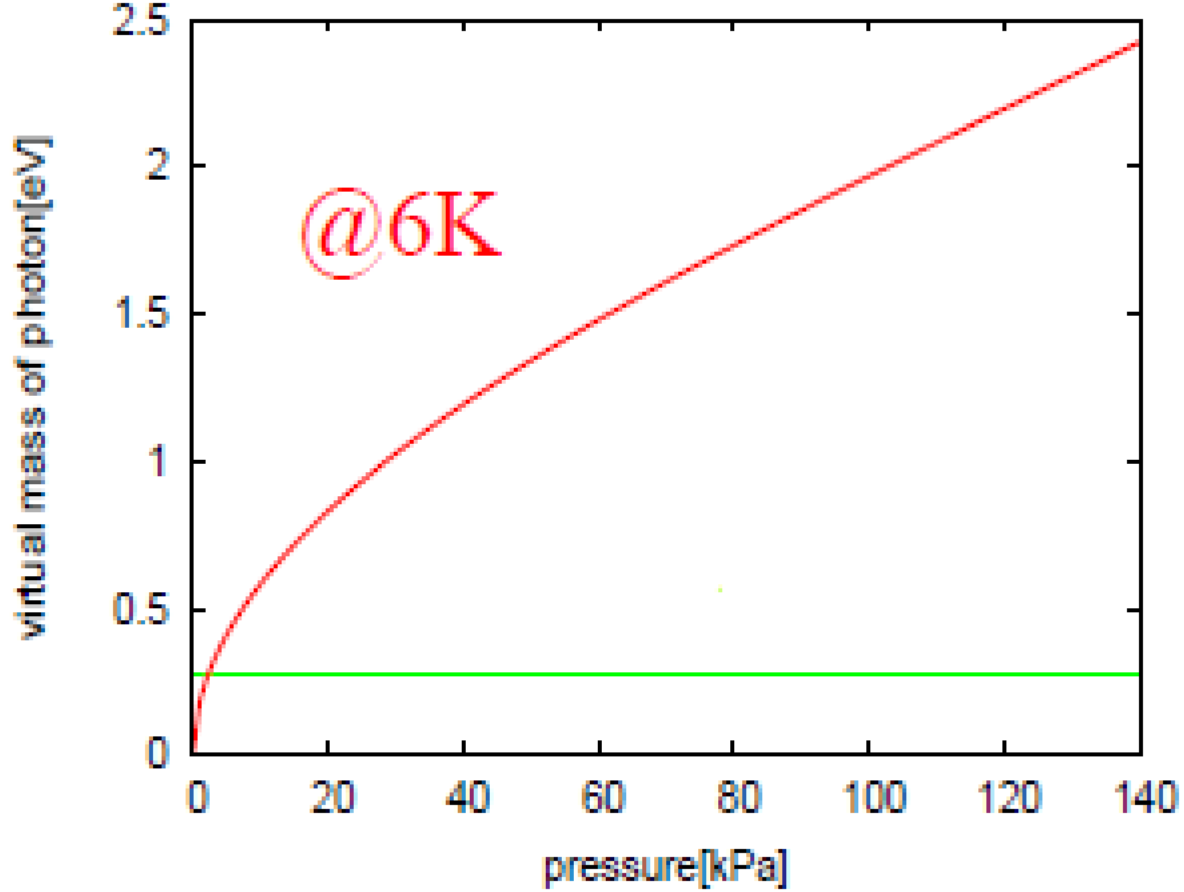


$$p_{a\to\gamma} = \left(\frac{g_{a\gamma\gamma} B}{q} \sin \frac{qL}{2} \right)^2$$

$$= \frac{g_{a\gamma\gamma}{}^2 B^2 L^2}{4}$$



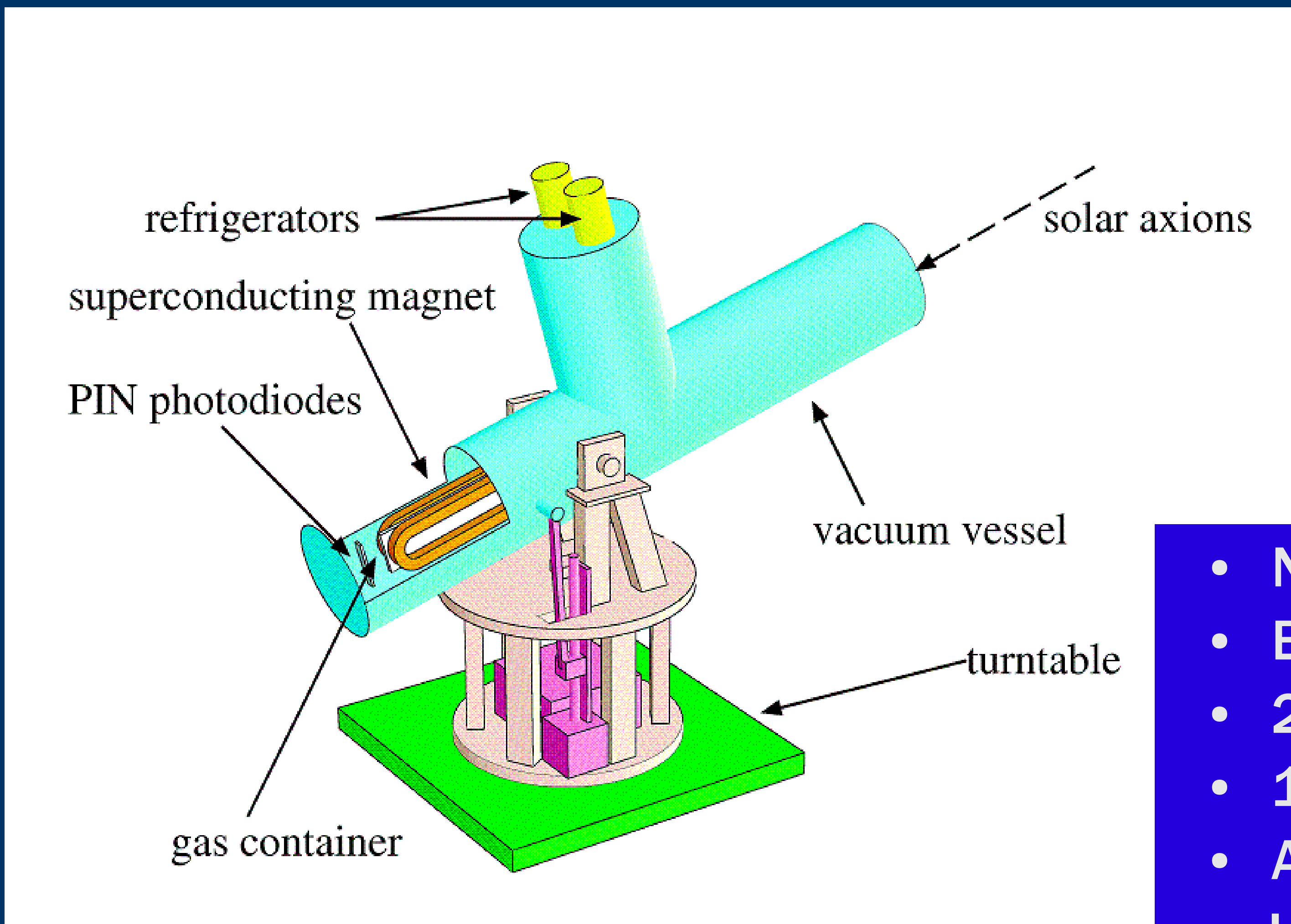
Virtual photon mass in ^{4}He gas



$$q = \frac{\left|m_\gamma^2 - m_a^2\right|}{2\omega}$$

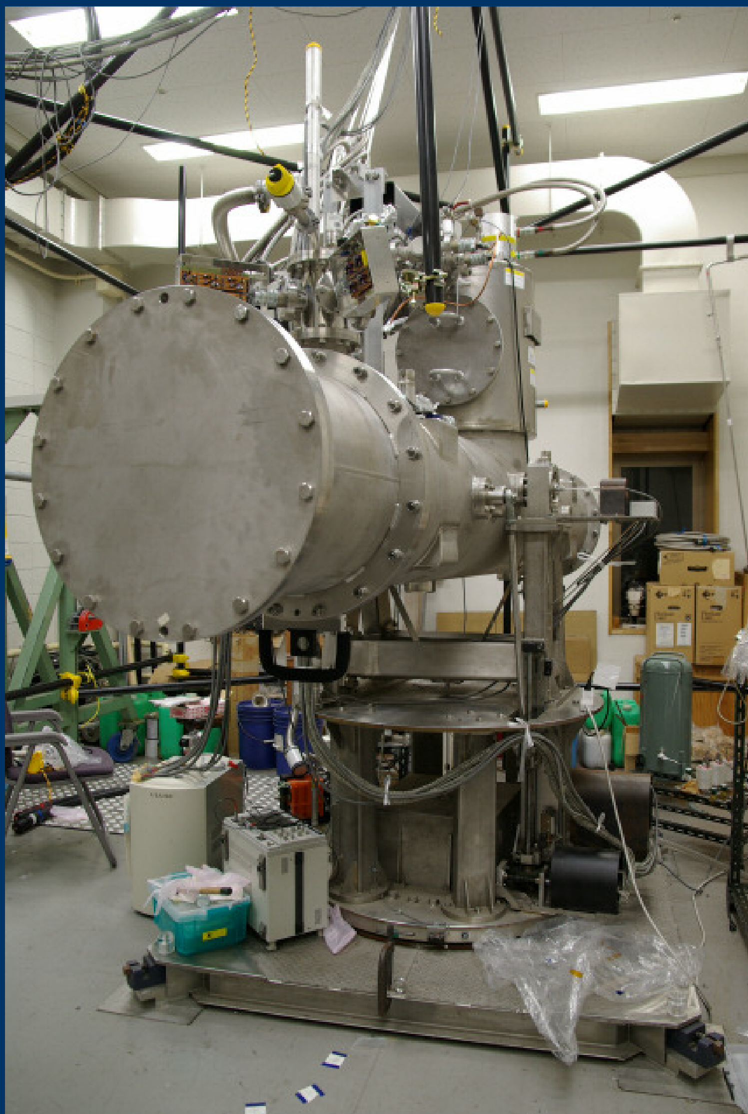
$$m_\gamma = \left(\frac{4\pi\,\alpha\,N_e(z)}{m_e}\right)^{1/2}$$

Tokyo Axion Helioscope aka Sumico



- No Liq. He
- B=4T, L=2.3m
- 268A persistent current
- 16 PIN photodiodes
- Altazimuth:
  Horiz. 360°, vert. ±28°

Sumico in Hongo campus

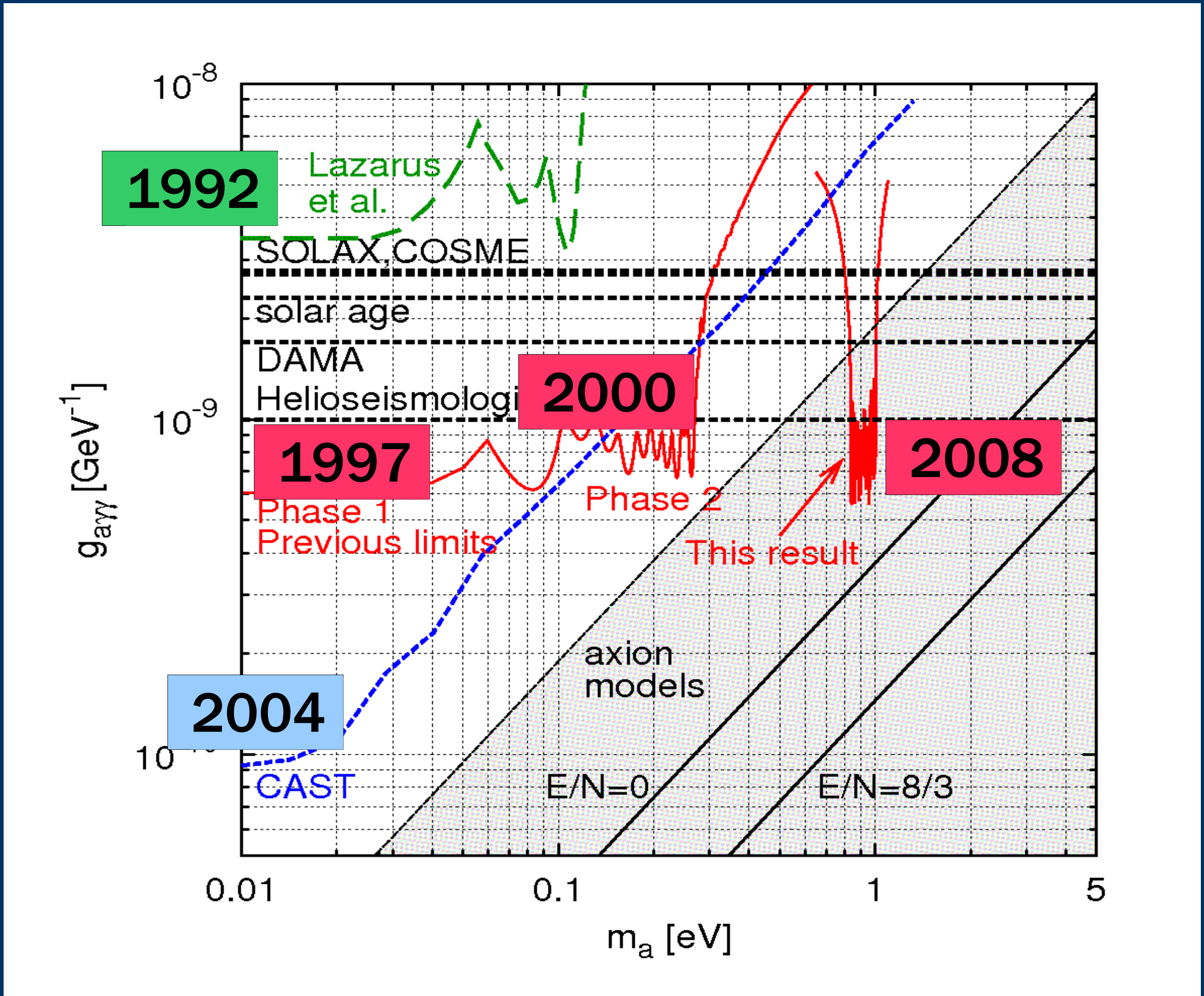


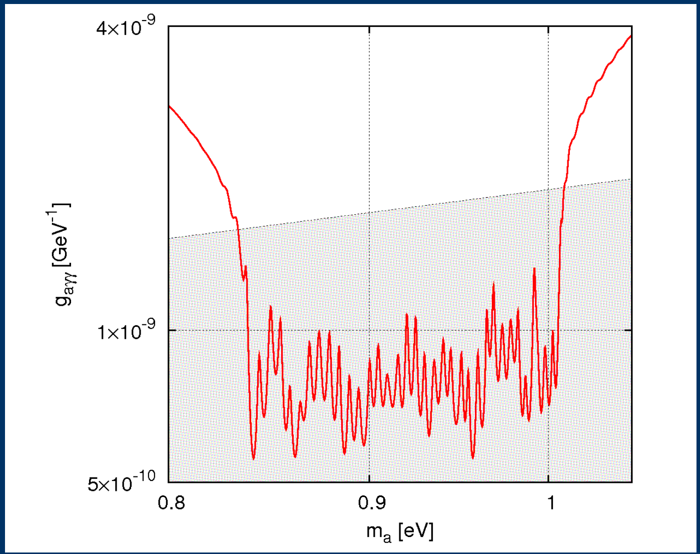
- Phase 1 : 1997
  m_a < 0.03 eV
  no buffer gas

- Phase 2 : 2000
  m_a < 0.27 eV
  ^{4}He of safe pressure

- Phase 3 : present result
  0.84 eV < m_a < 1.00 eV
  ^{4}He of higher pressure

Results and history

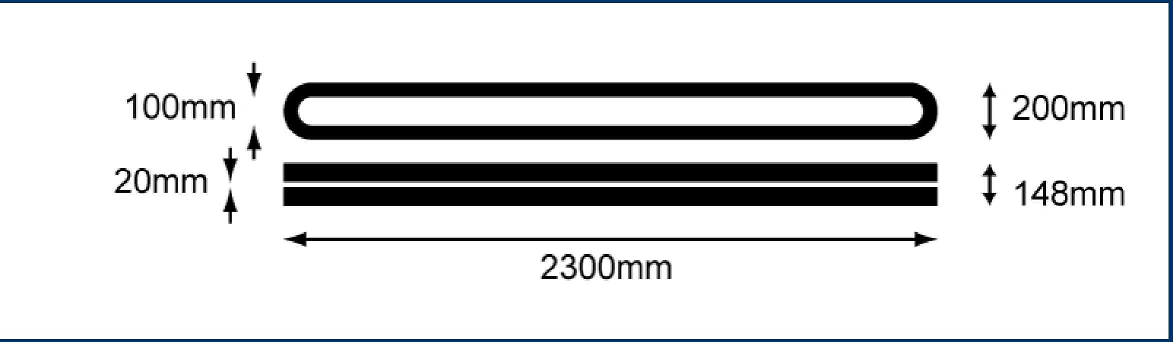




Theory of detection:
1983 P. Sikivie
Proposal:
1989 K. van Bibber et al.

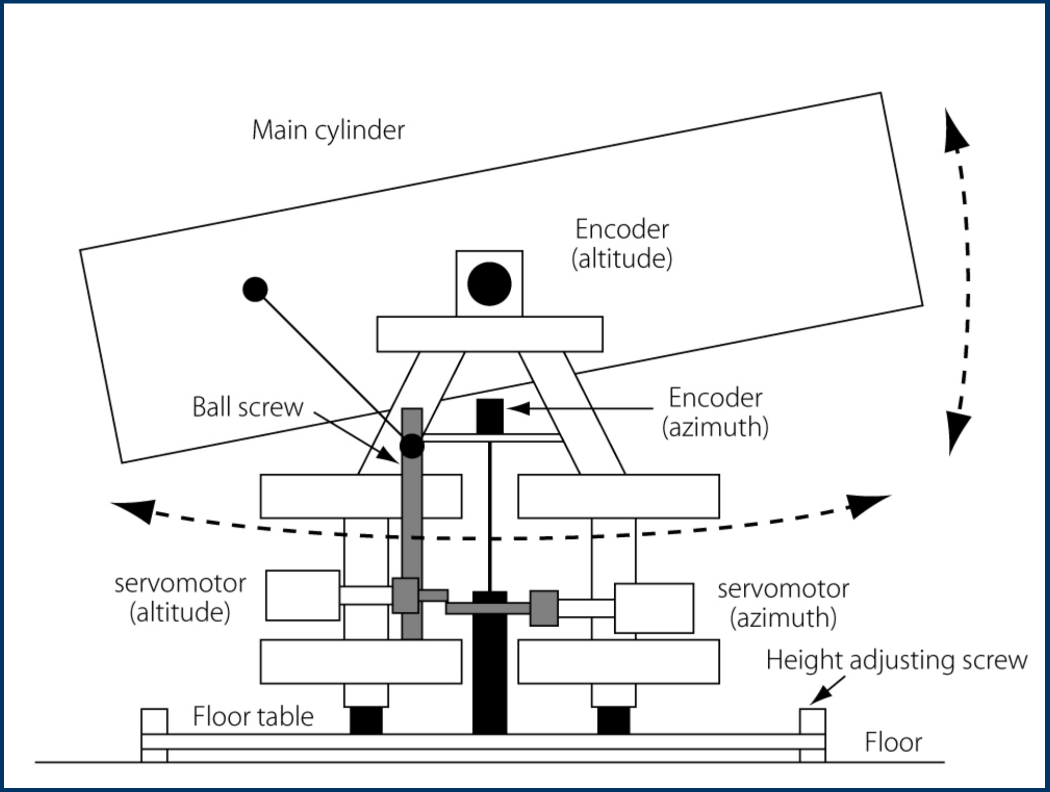
Details of the Helioscope

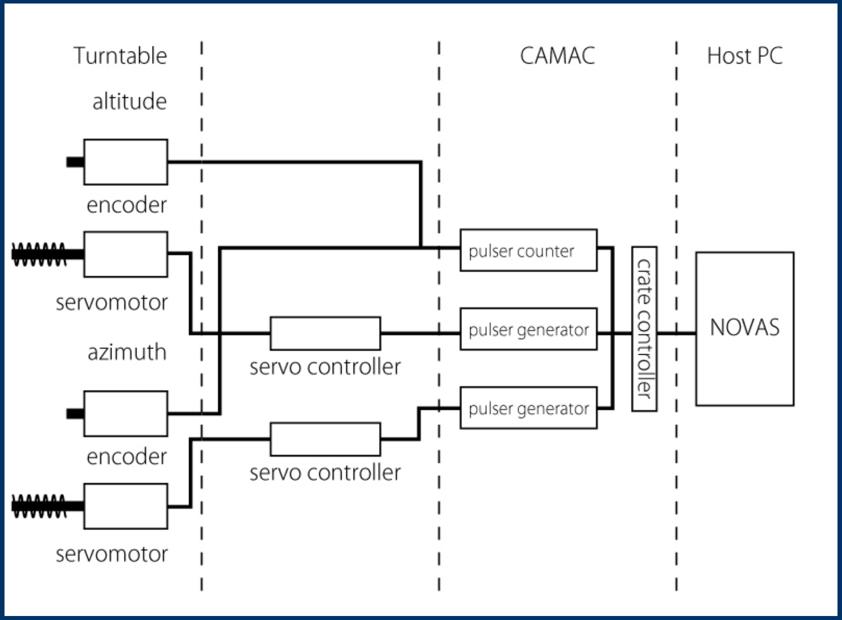
Superconducting magnet and refrigerators



- 2x Gifford-McMahon refrigerators, no liq. helium
- T=5 – 6K
- 268 A persistent current
- B=4T

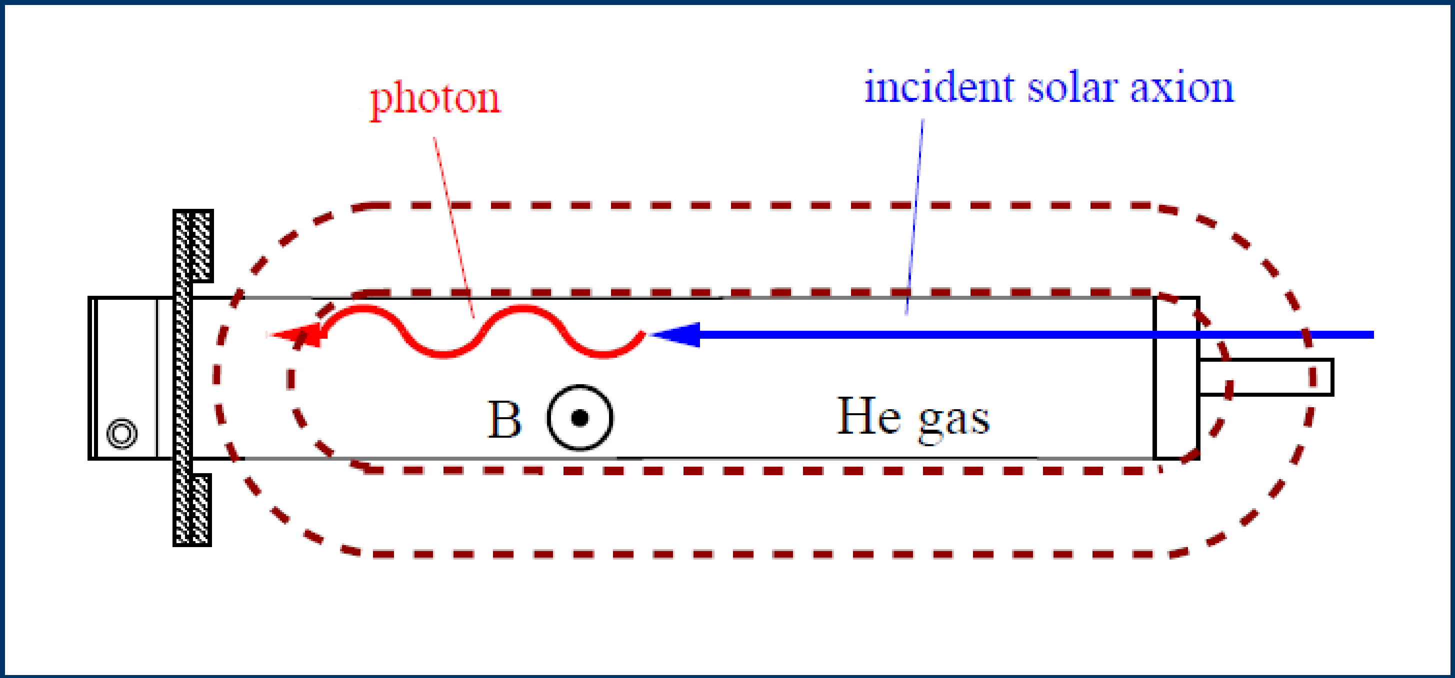
altazimuth mount





- 2 servomotors and 2 rotary encoders for altitude and azimuth
- Horiz. 360°, vert. ±28°
- NOVAS-C program for the tracking

buffer gas

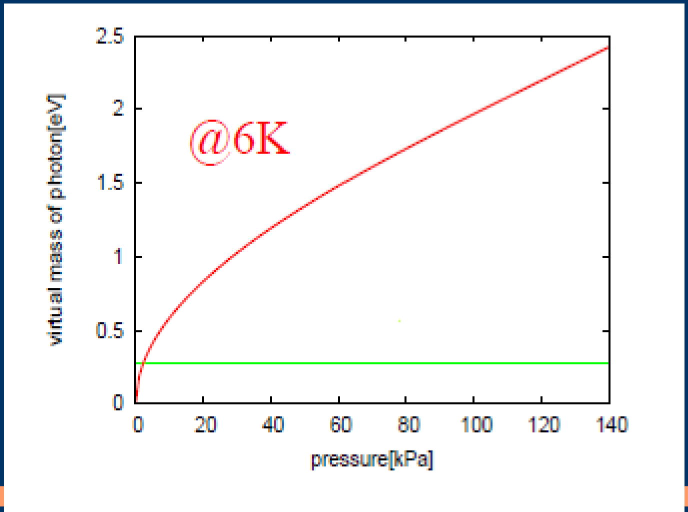


Helium-4 does not liquefy @1atm, 6K.

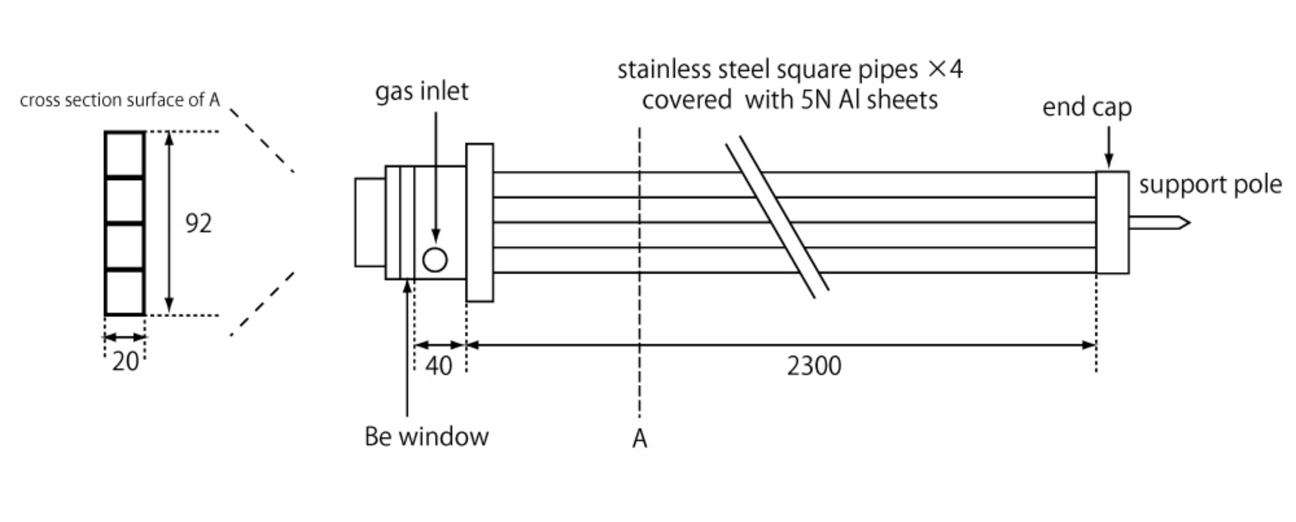
$$p_{a\to\gamma} = \left(\frac{g_{a\gamma\gamma} B}{q} \sin \frac{qL}{2} \right)^2 = \frac{{g_{a\gamma\gamma}}^2 B^2 L^2}{4}$$

$$q = \frac{\left| m_\gamma^2 - m_a^2 \right|}{2\omega}$$

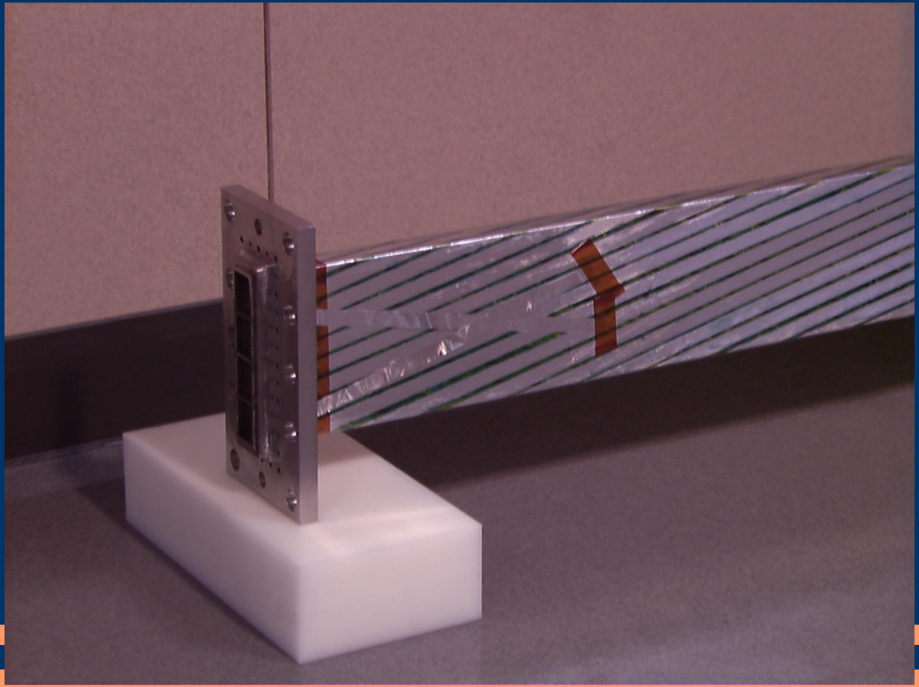
$$m_\gamma = \left(\frac{4\pi\alpha N_e(z)}{m_e} \right)^{1/2}$$



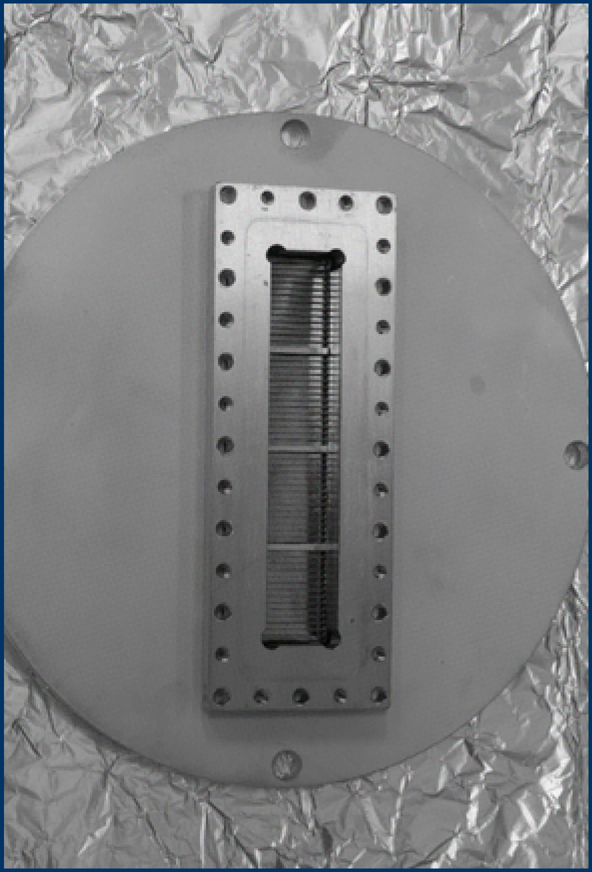
buffer gas container



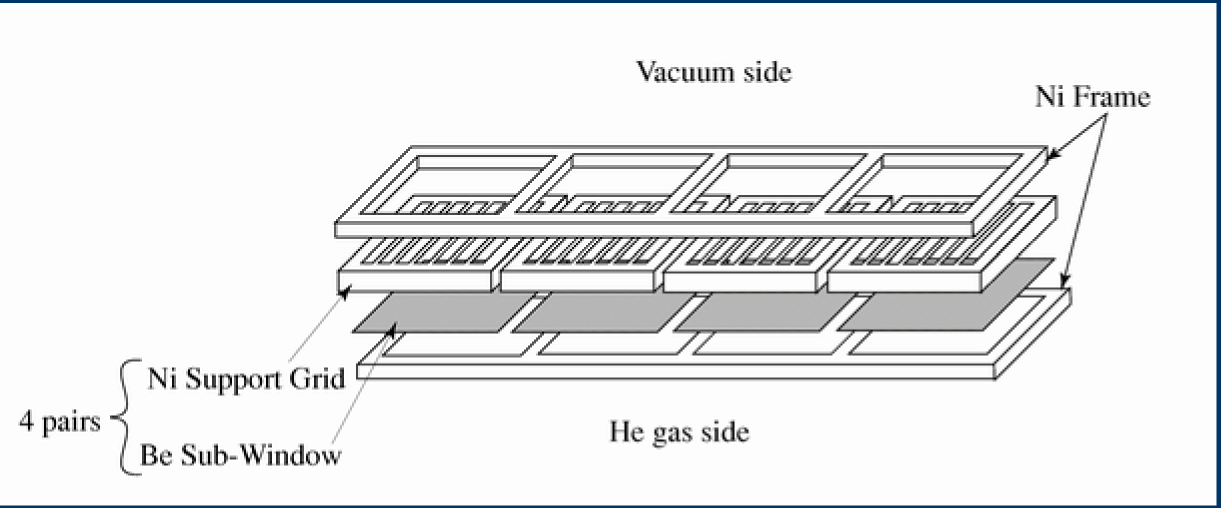
- Stainless steel square pipes wrapped with 2 layers of 0.1-mm thick 99.999%-pure Al sheet
- Thermal contact only at one end.
- Uniform temperature along the container
- X-ray window on one end



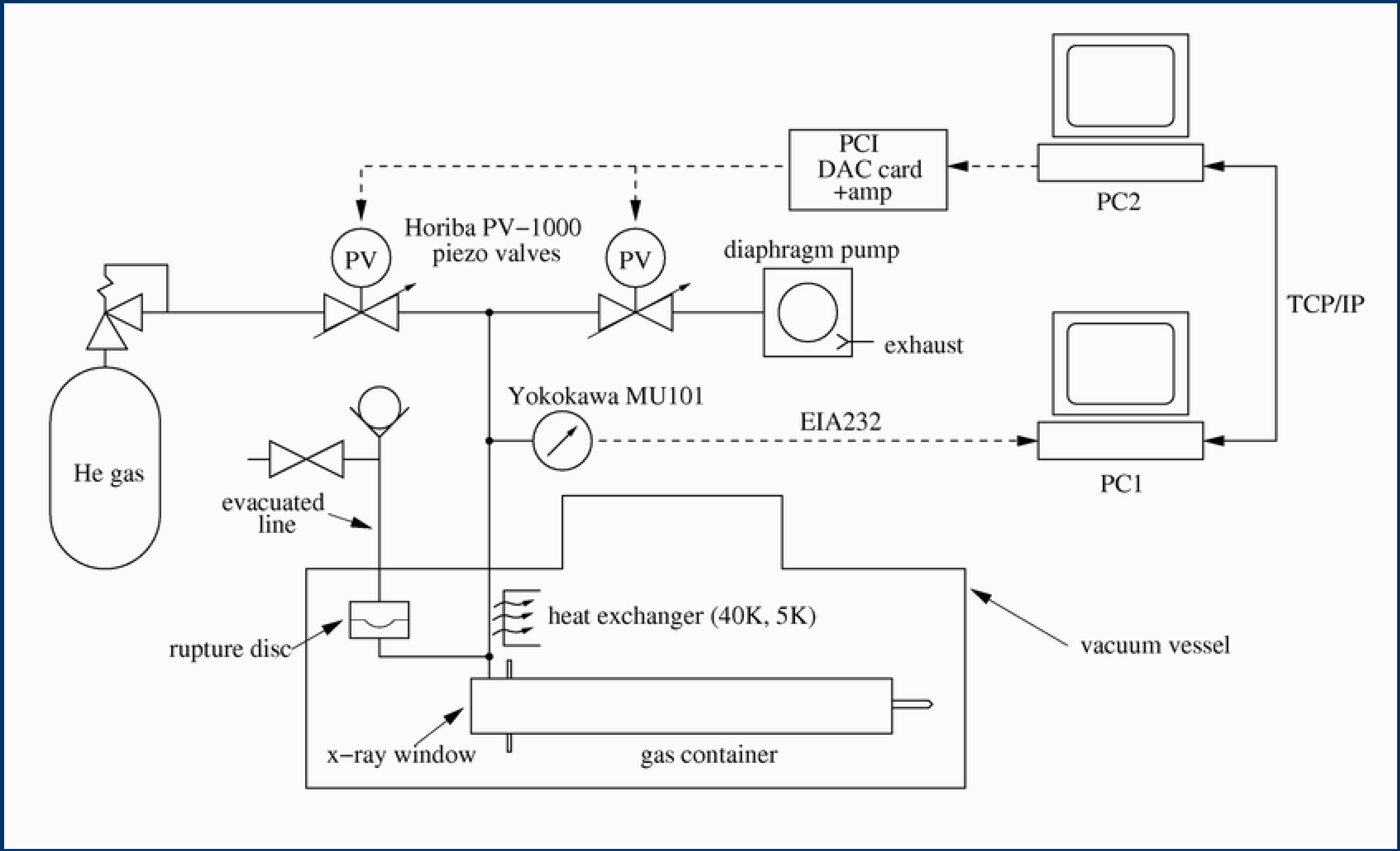
X-ray window



- 25μm-thick Be
  with 1μm-thick polyimide coating
  and Ni frames
- withstands 0.3 Mpa
- Transmissivity 81.4% @2.98 keV

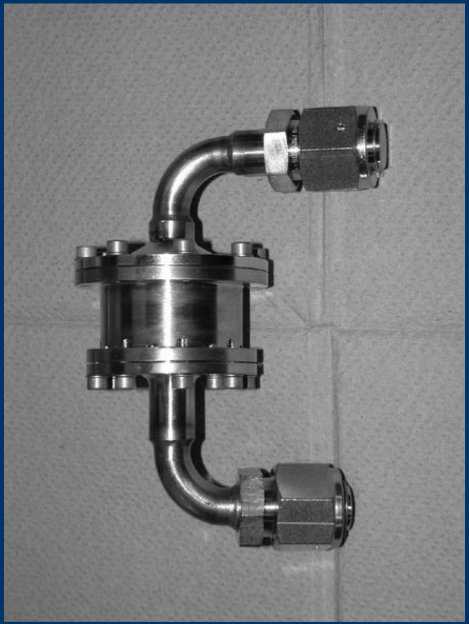


gas handlig system

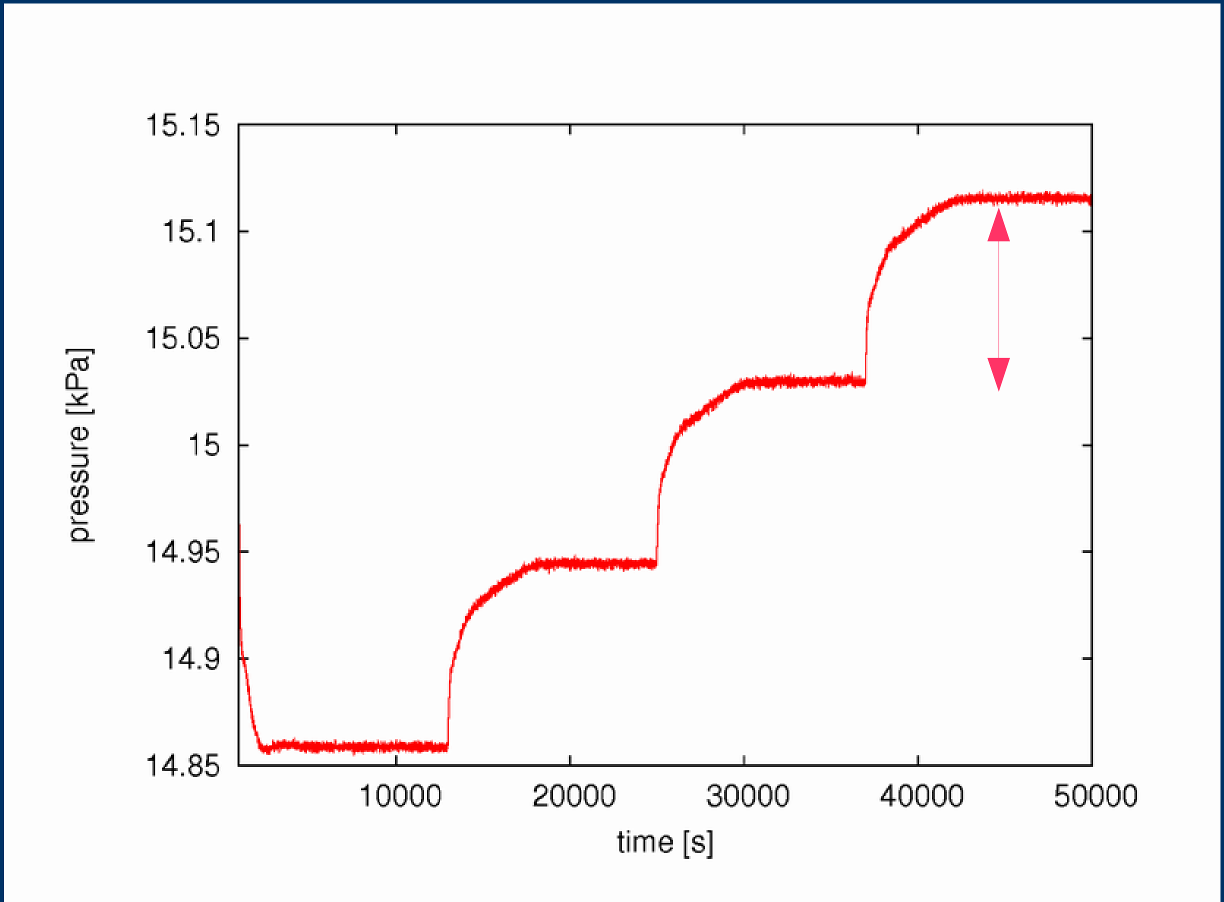


rupture disk

- When the superconducting magnet quenches,
  the temperature rises up to 50 – 60K within a few seconds.
- Pressure change is, however, rather slow.
- A rupture disk is added.
- It breaks at P = 0.248 Mpa before X-ray window explodes.



pressure setting with piezo valves

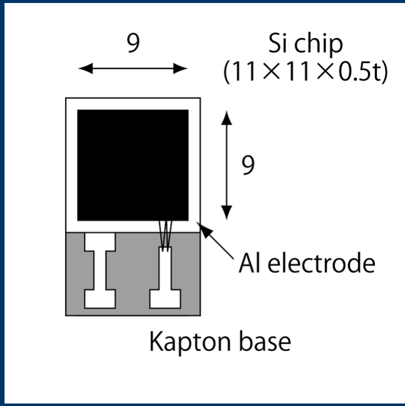


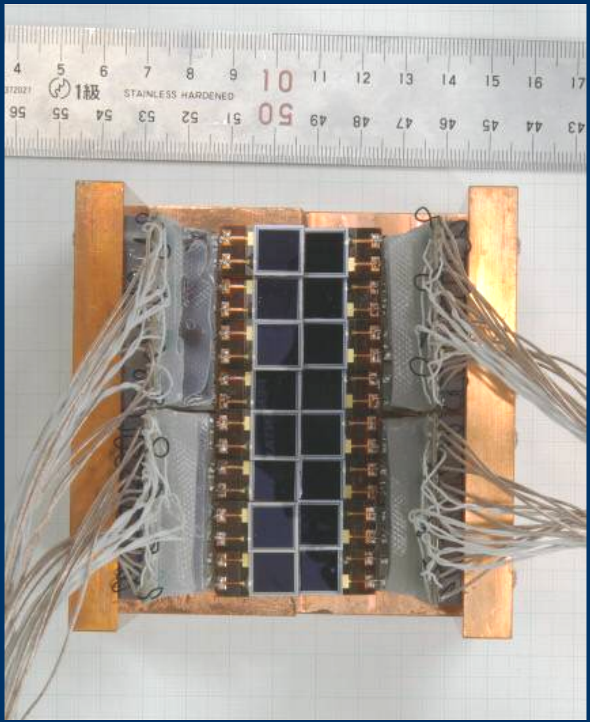
T=5.75K

Δm_{γ} = 2 meV

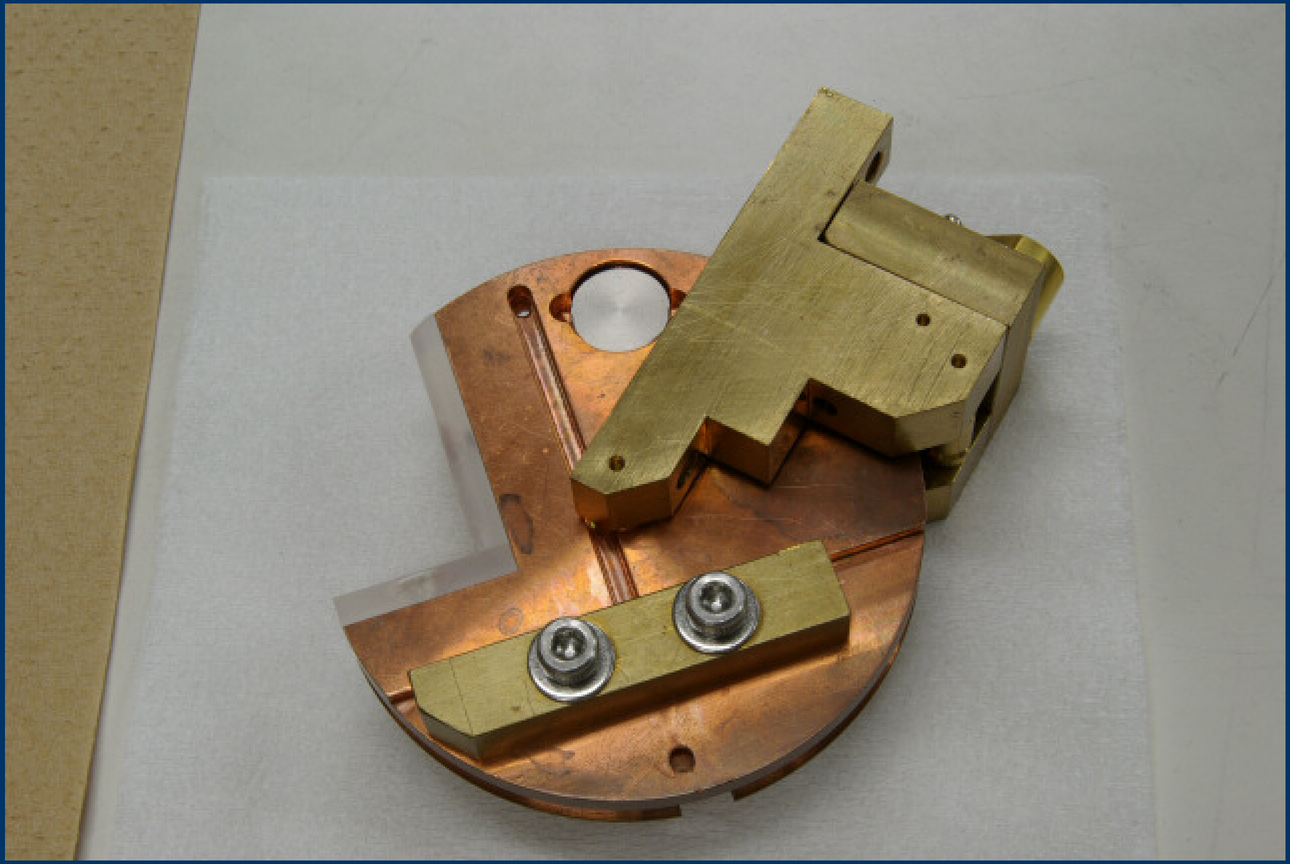
PIN photodiodes as X-ray detectors

- 16 x Hamamatsu S3590-06-SPL
- High efficiency with 0.5 mm thickness
- Only 0.35μm inactive surface layer
- Cold operation at T=60K anchored at the radiation shield

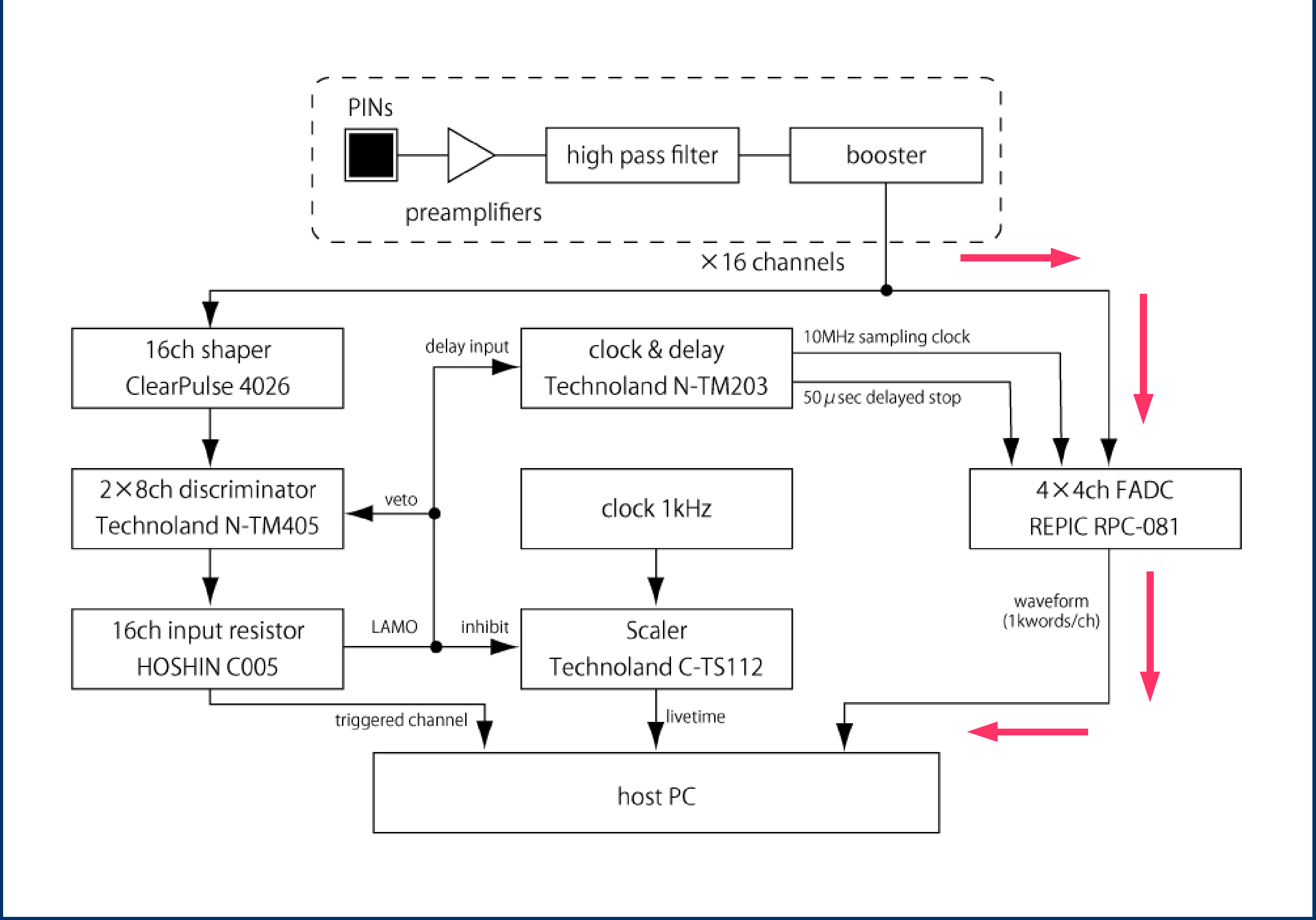




calibration system with ^{55}Fe

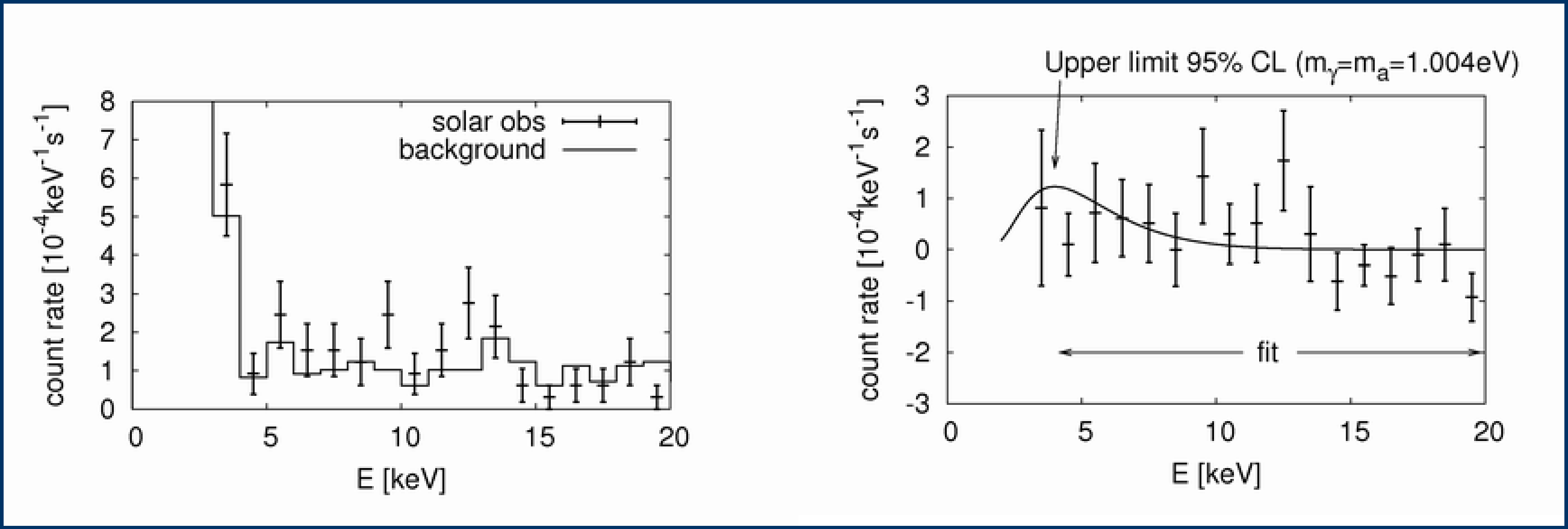


DAQ



- Waveform recording
- Offline shaping

Spectrum



$$\chi^2 = \sum_{i=1}^{n} \sum_{j=4\mathrm{keV}}^{20\mathrm{keV}} \frac{(y_{ij} - p_{ij})^2}{\sigma_{ij}^2}$$

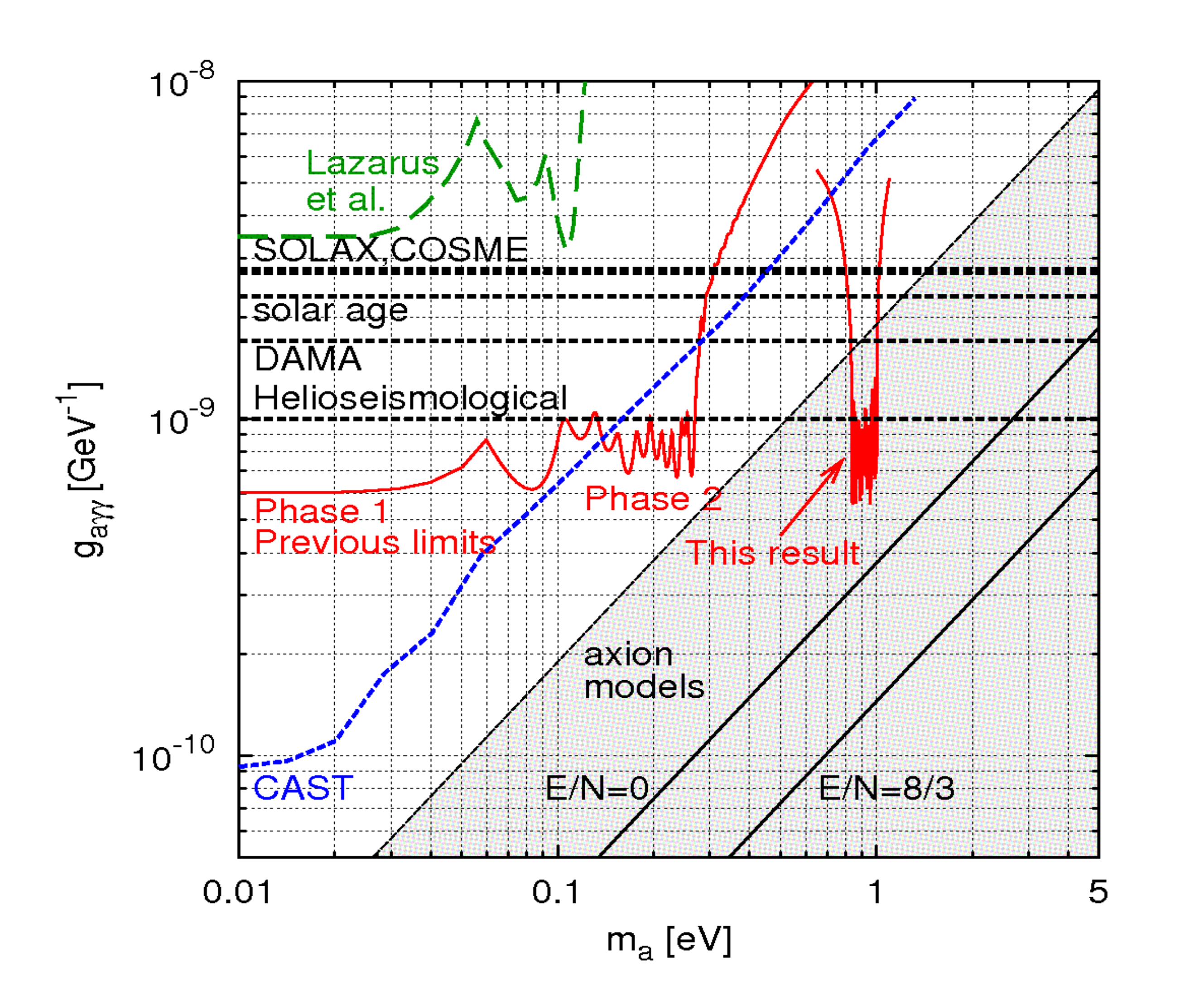
y_{ij}: count rate

p_{ij}: expected count rate

in j-th energy bin

of i-th pressure setting

The result



10^{-8}
10^{-9}
10^{-10}
$g_{a\gamma\gamma}$ [GeV^{-1}]
Lazarus
et al.
SOLAX,COSME
solar age
DAMA
Helioseismological
Phase 1
Previous limits
Phase 2
This result
axion
models
CAST
E/N=0
E/N=8/3
0.01
0.1
1
5
m_a [eV]

Sumico vs. CAST
to scale

Sumico vs. CAST

	Sumico	CAST
BL	4T x 2.3m	9T x 9.26m
T	5 - 6 K	1.8 K
buffer gas	helium-4	helium-4 and -3
cooling	refrigerator	liq. helium
swing	(360°), ±28°	100°, ±8°
detectors	PIN photodiodes	many kinds
running cost	~20kW (¥10k/d)	don't know
# institutes	2	17
# collab.	6	61
size	\small	\Huge

Limitation and Hope

$$g_{a\gamma\gamma}^{\text{limit}} \propto N^{1/8} T^{-1/8} A^{-1/4} B^{-1/2} L^{-1/2}$$

N : background rate
T : running time
A : detector area

Smaller *BL* cannot be compensated by any other factors.

→ CAST wins

X-ray absorption and decoherence due to gravity are not fatal in helium-4 buffer gas even with m_γ=2 eV.

→ Sumico may survive in $1 < m_a < 2$ eV.

Summary

New limit

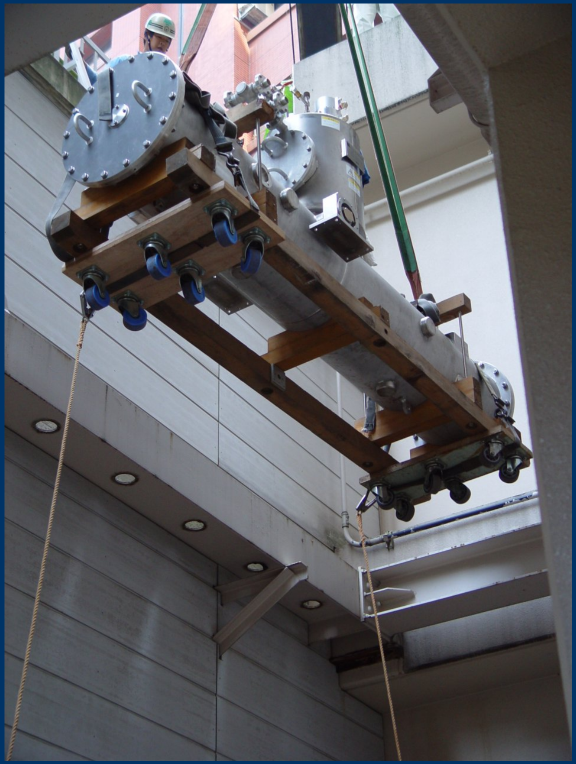
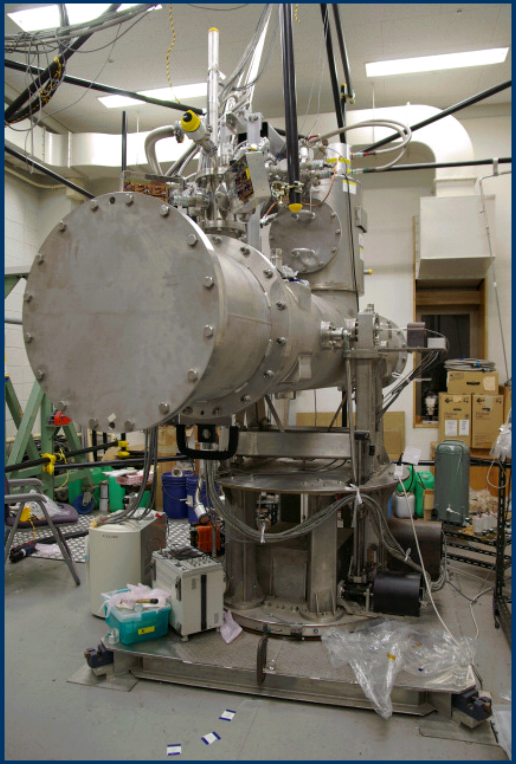
$g_{a\gamma\gamma} < 5.6 - 13.4 \times 10^{-10}$ GeV^{-1}

$0.84 < m_a < 1.00$ eV

is set by
the Tokyo Axion Helioscope aka Sumico.

→ arXiv:0806.2230v2 [astro-ph]
to appear in Phys. Lett. B

Photo gallery

Sumico moved from an old building to a new one in 2002.