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@DESY

Tokyo Axion Helioscope

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Axion

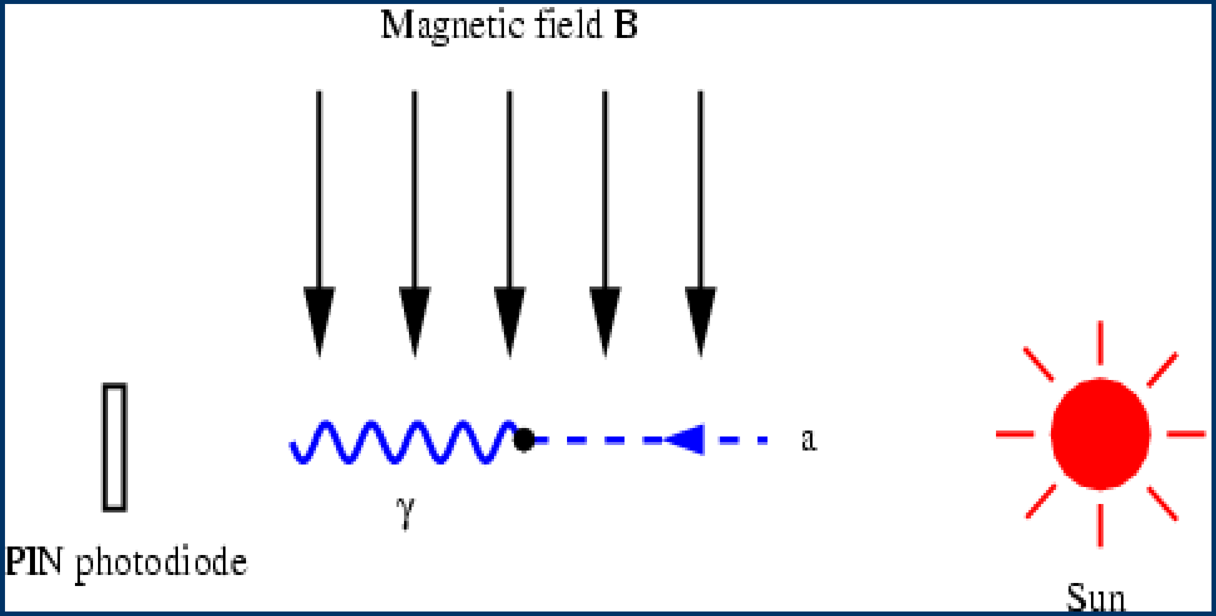
What is the Axion?

- 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: $\Omega_a < 1$

Solar axion, principle of the detection

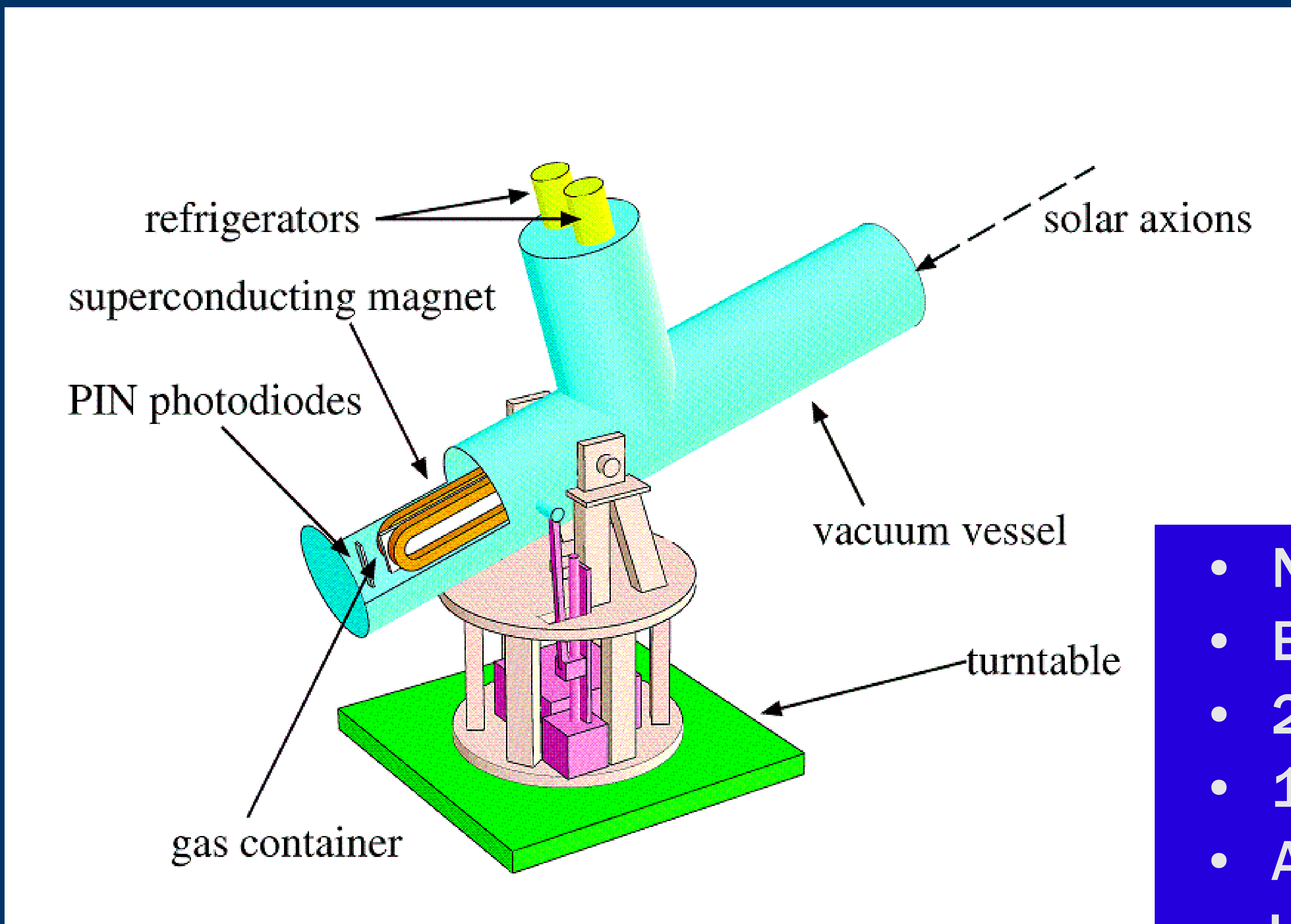


$$p_{a\to\gamma} = \left(\frac{g_{a\gamma\gamma}B}{q}\sin\frac{qL}{2}\right)^2 = \frac{g_{a\gamma\gamma}{}^2 B^2 L^2}{4}$$

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

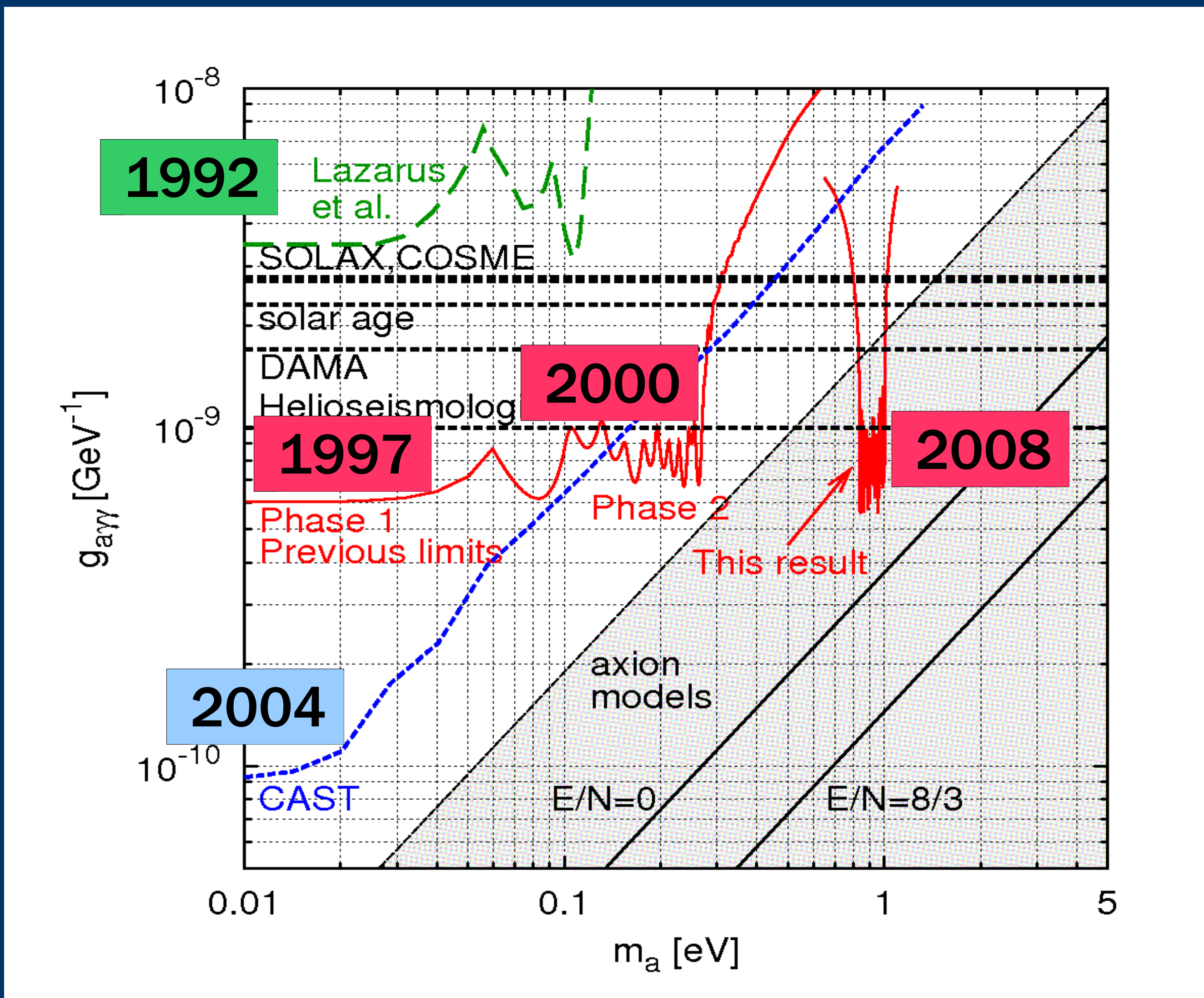
$$m_\gamma = \left(\frac{4\pi\,\alpha\,N_e(z)}{m_e}\right)^{1/2}$$

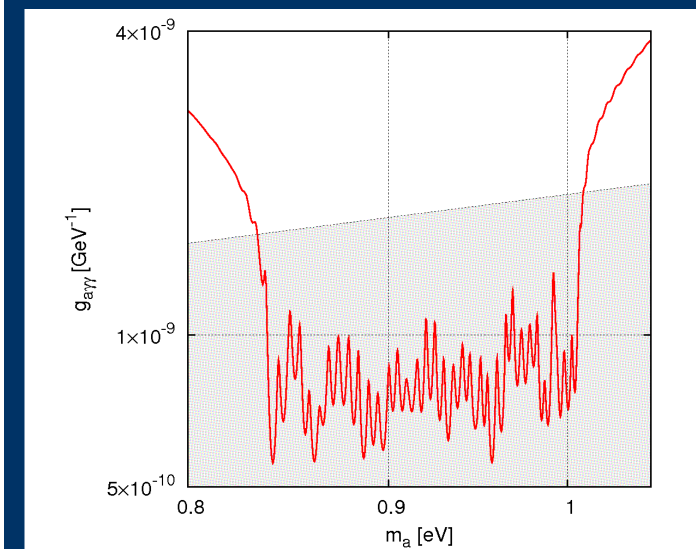
Tokyo Axion Helioscope aka Sumico



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

Results and history

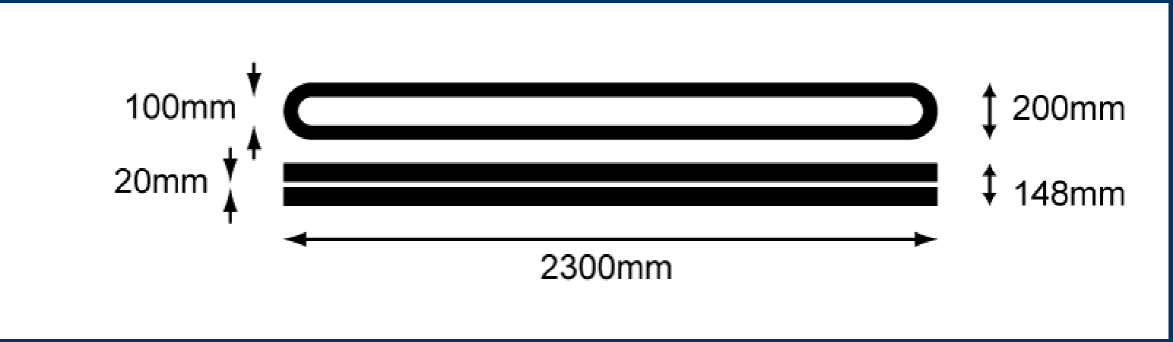




Theory of detection:
1983 P. Sikivie
Proposal:
1989 K. van Bibber et al.

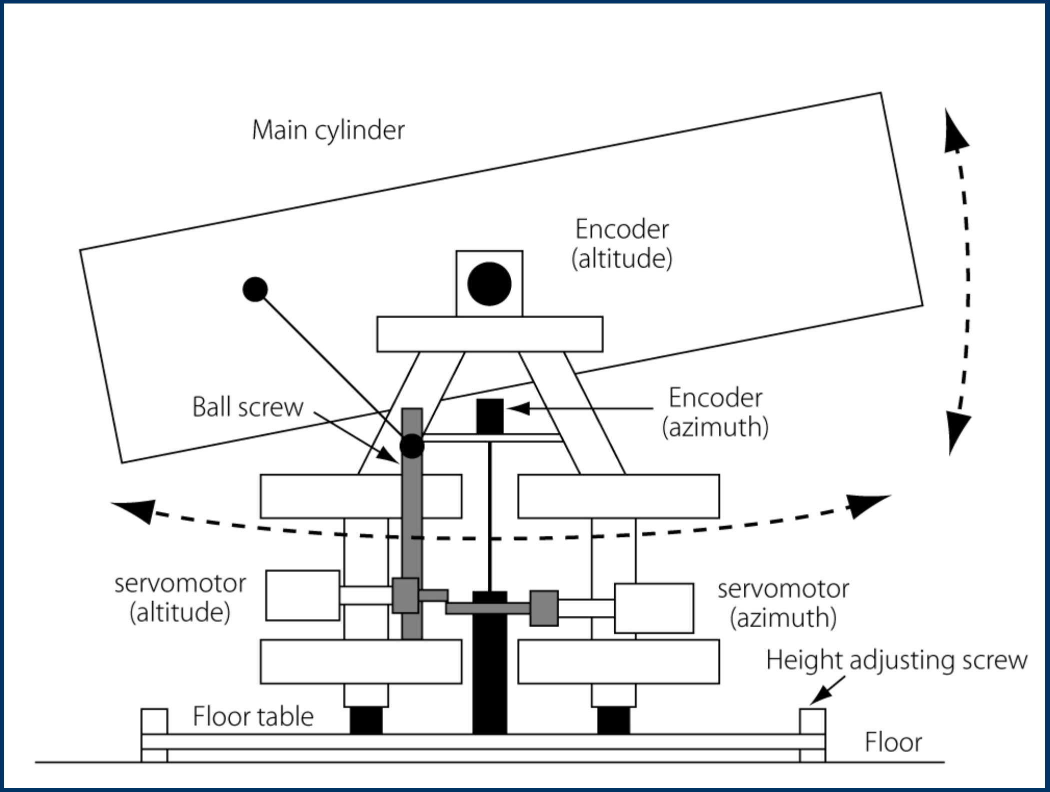
Details of the Helioscope

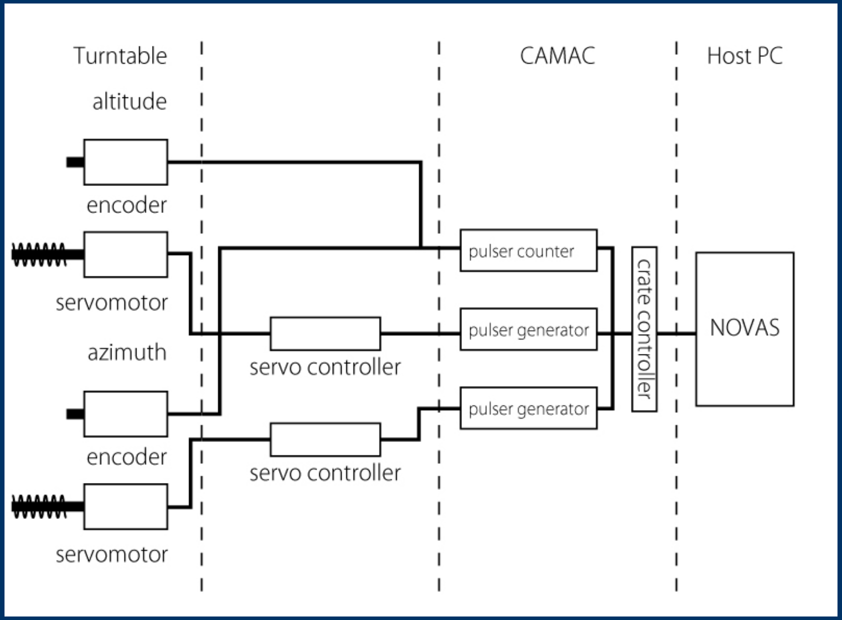
Superconducting magnet and refrigerators



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

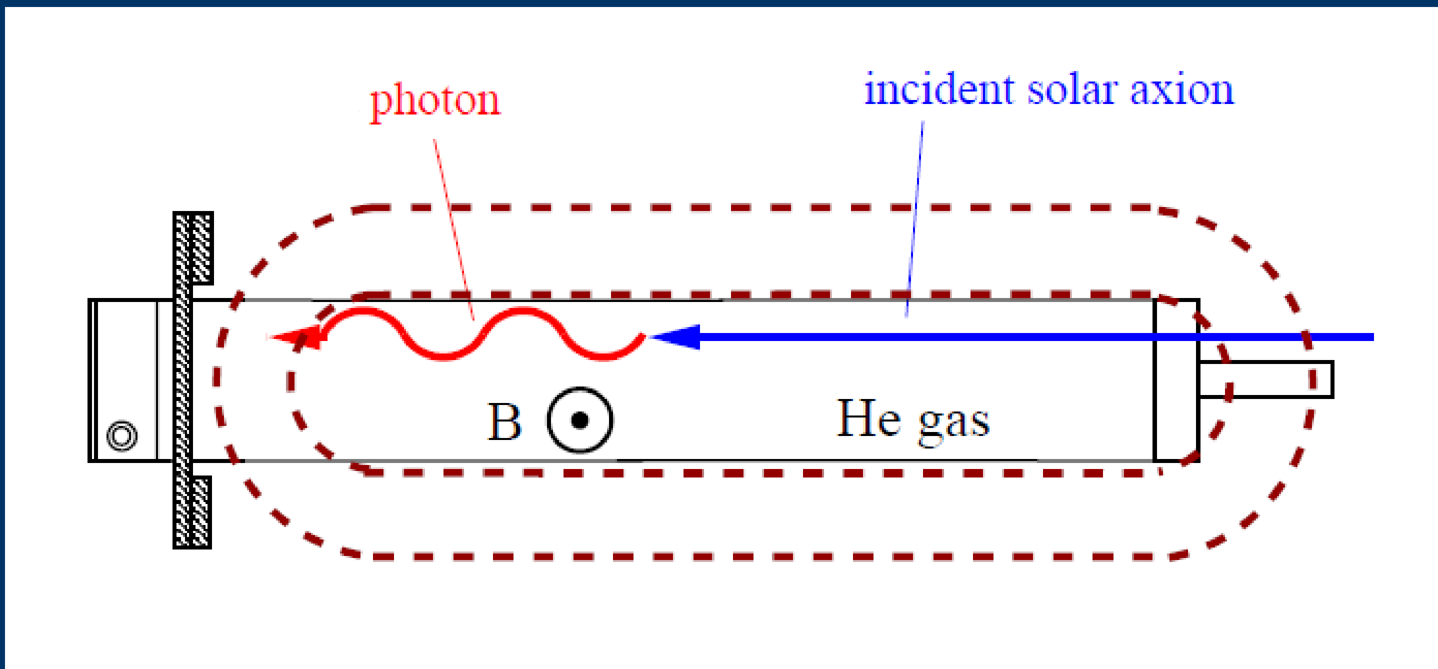
altazimath mount





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

buffer gas



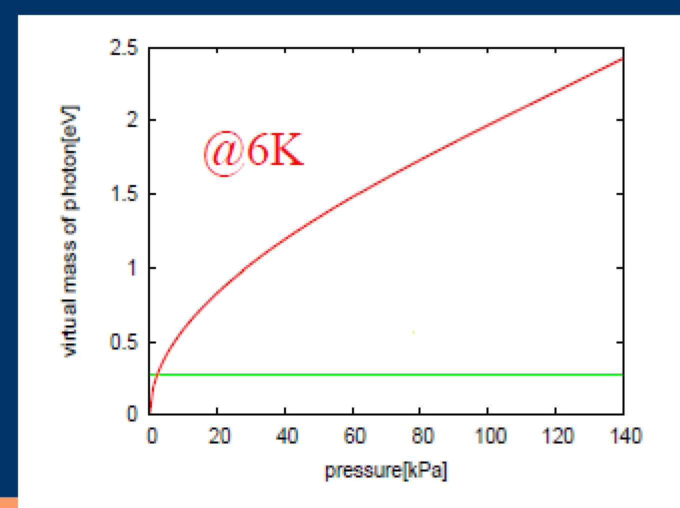
Helium-4 does not liquefy @1atm, 6K.

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

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

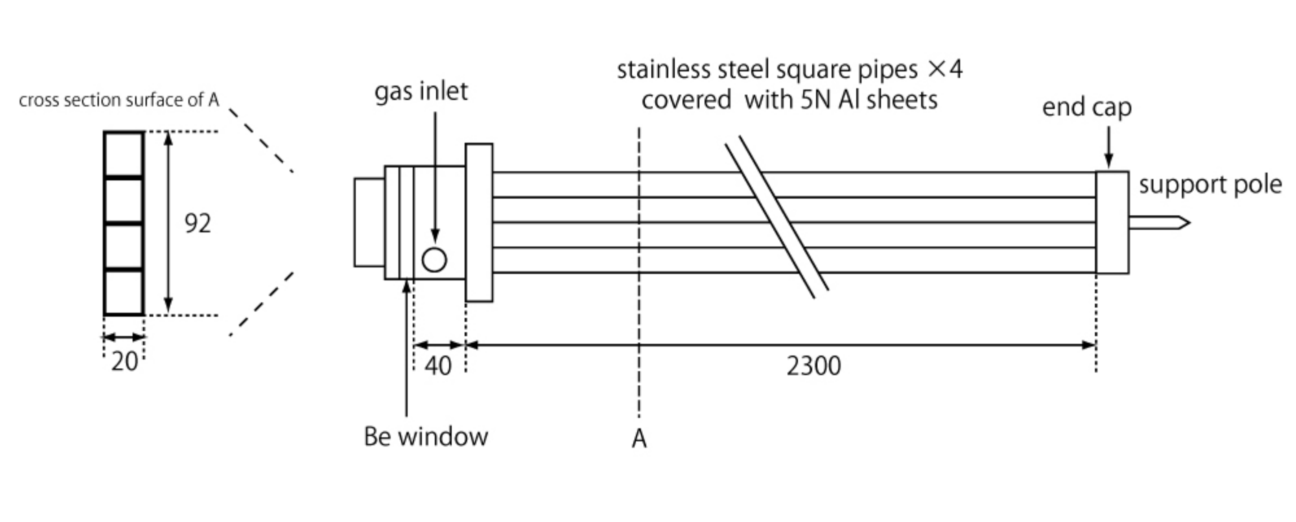
$$q = \frac{\left| m_\gamma^2 - m_a^2 \right|}{2\omega}$$

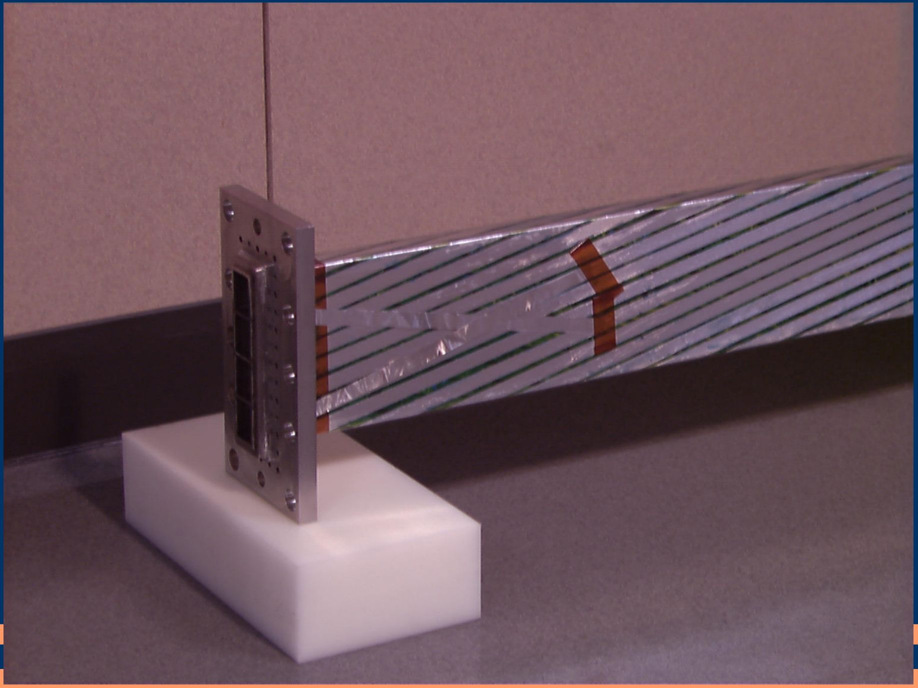
$$m_\gamma = \left(\frac{4\pi\, \alpha\, N_e(z)}{m_e} \right)^{1/2}$$



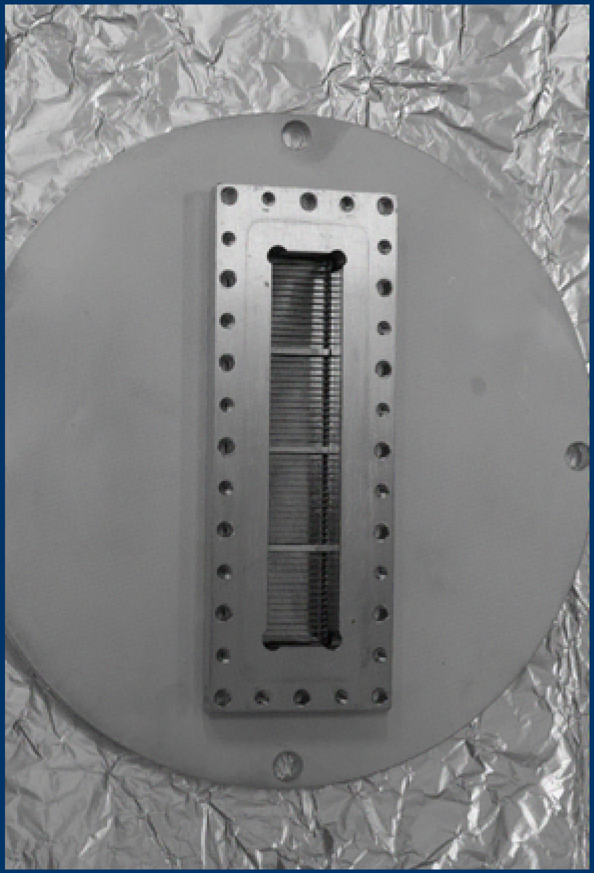
buffer gas container

- Stainles 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

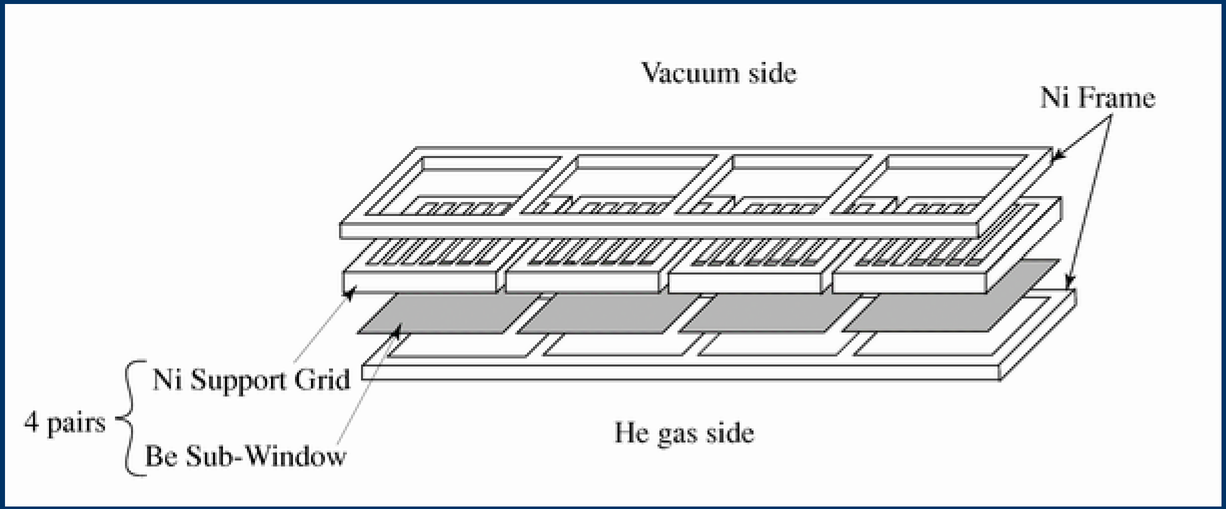




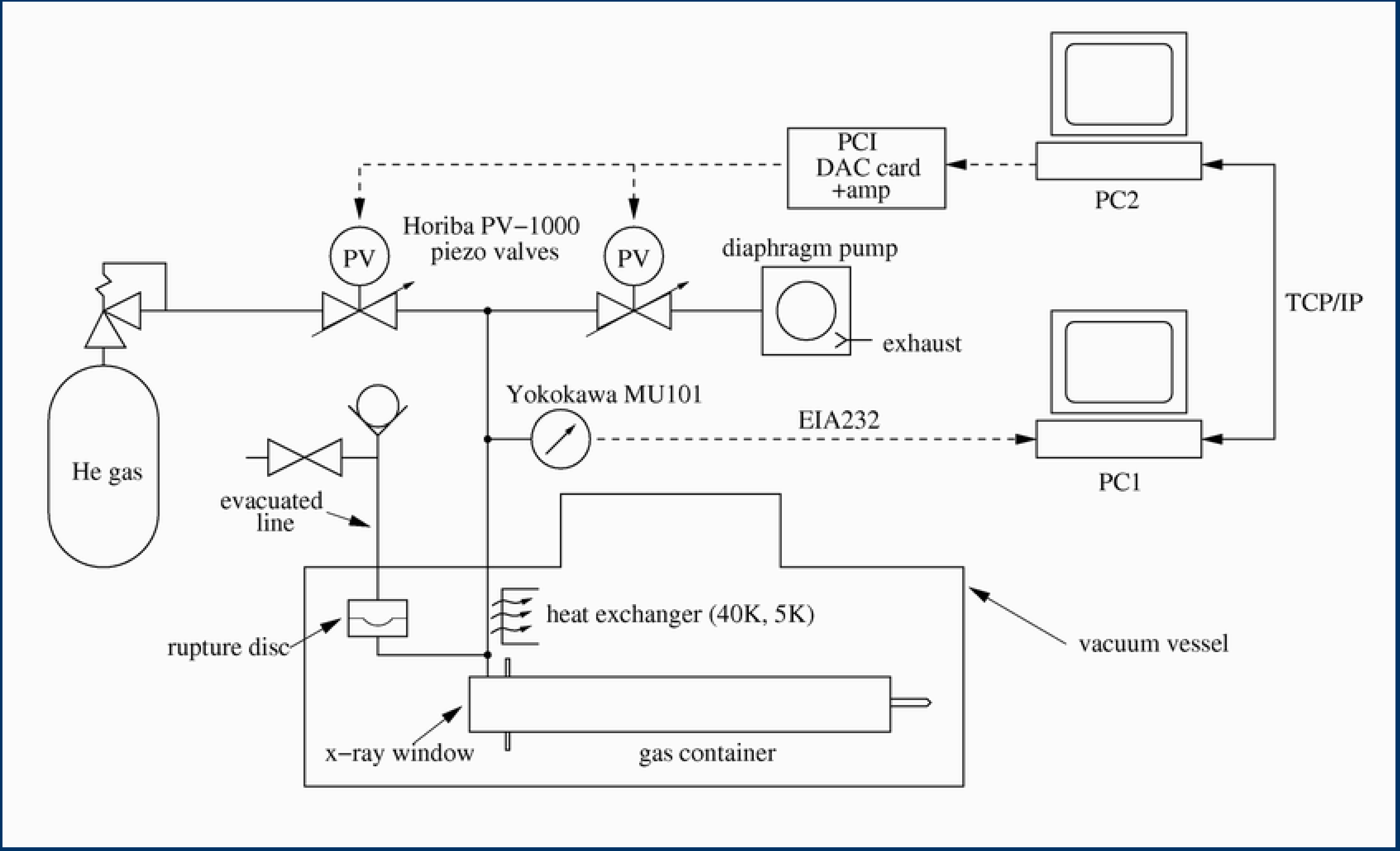
X-ray window



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

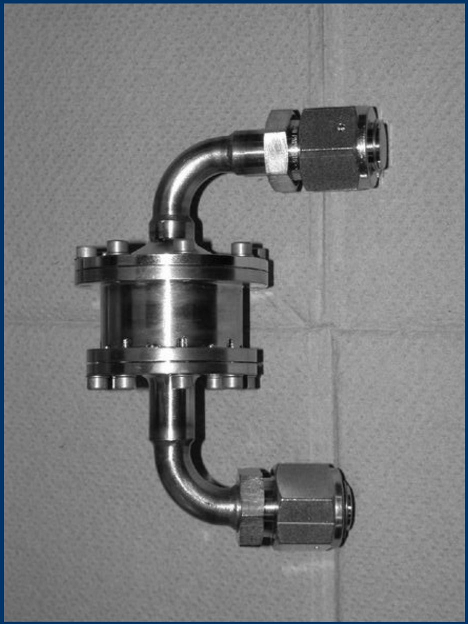


gas handlig system

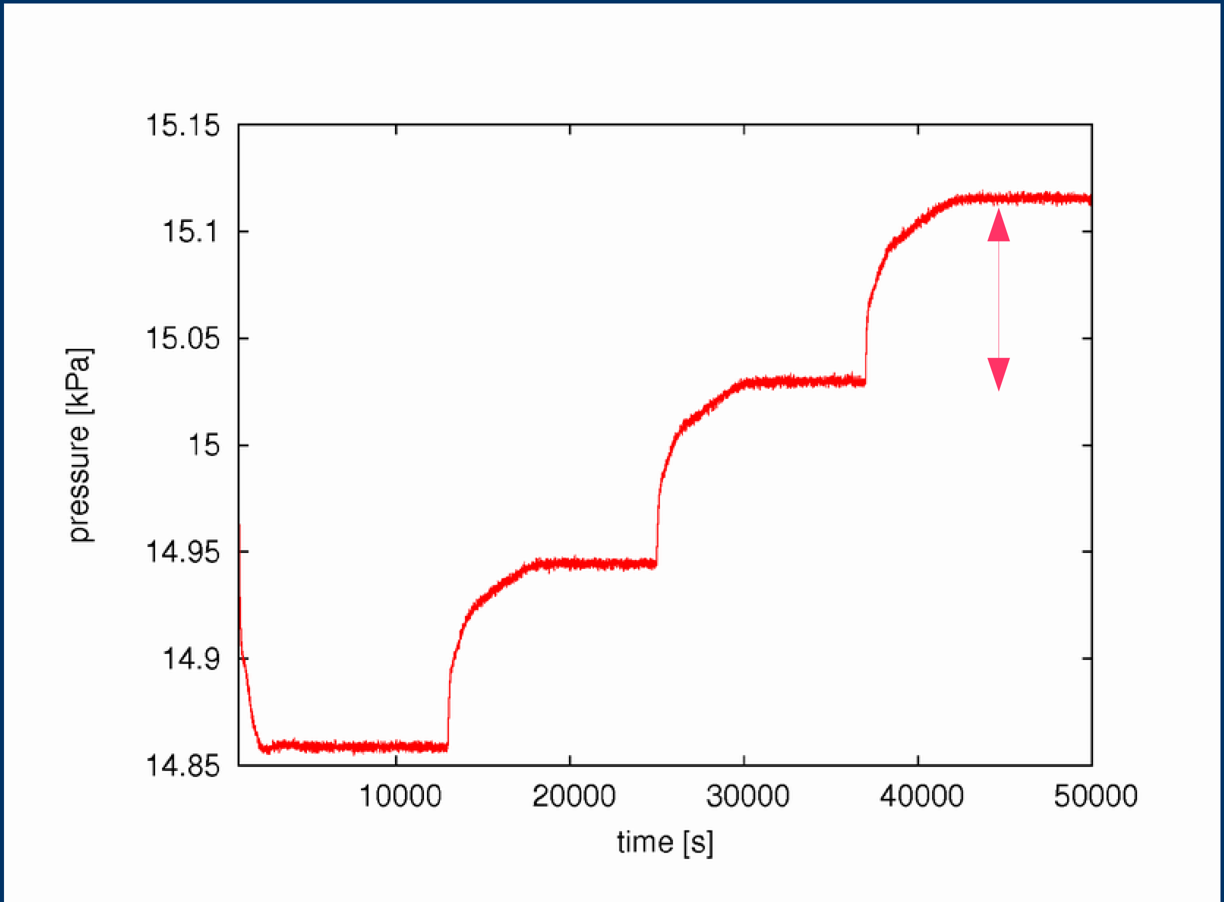


rupture disk

- 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

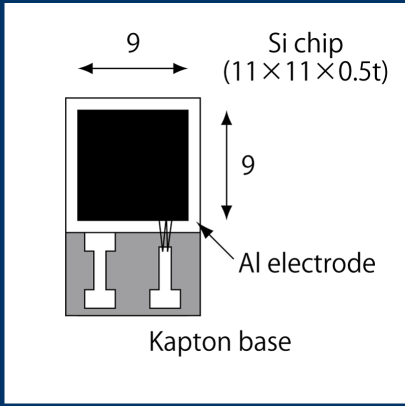


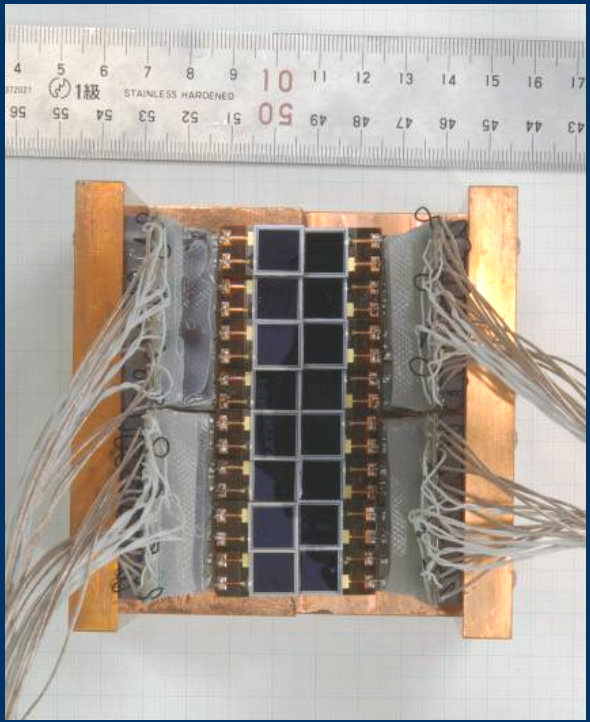
T=5.75K

Δm_γ = 2 meV

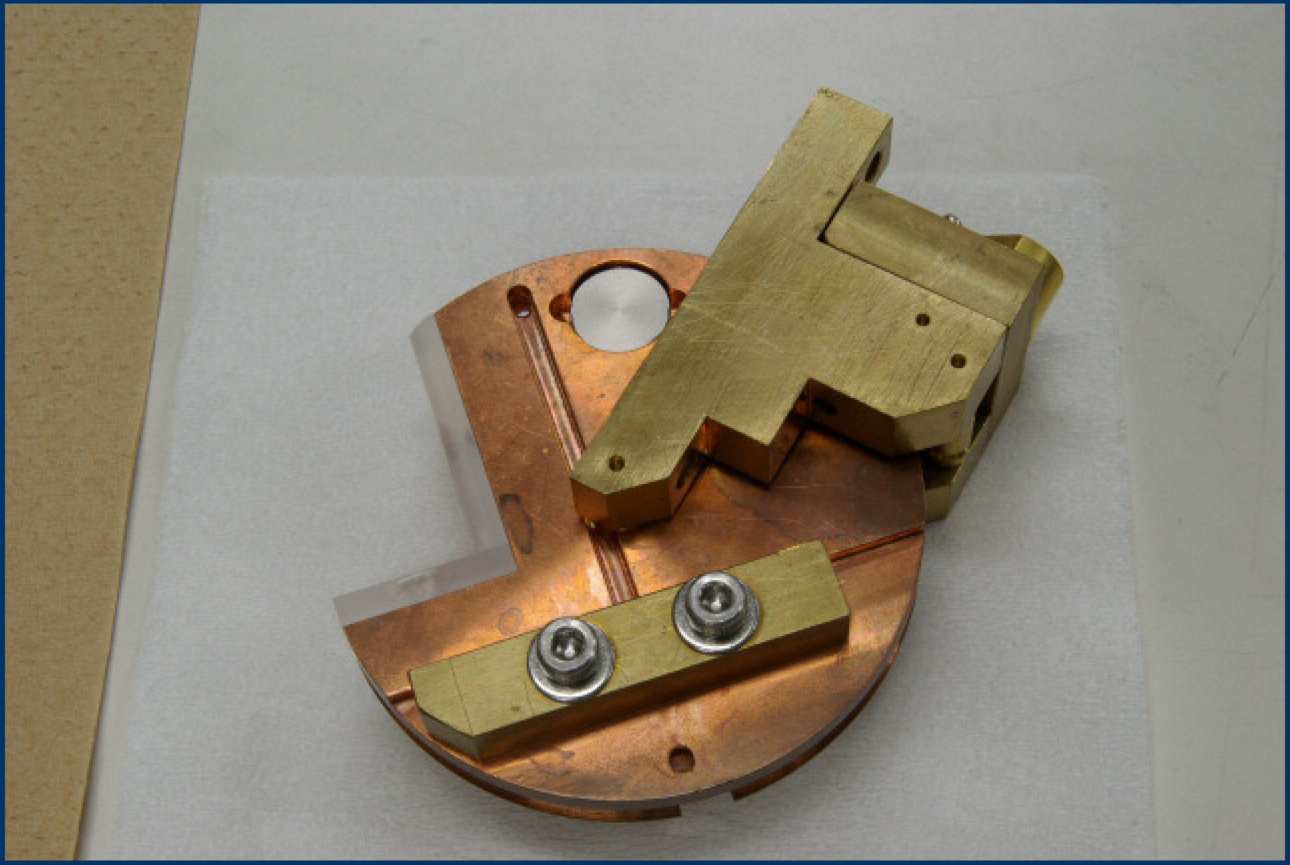
PIN photodiodes as X-ray detectors

- 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

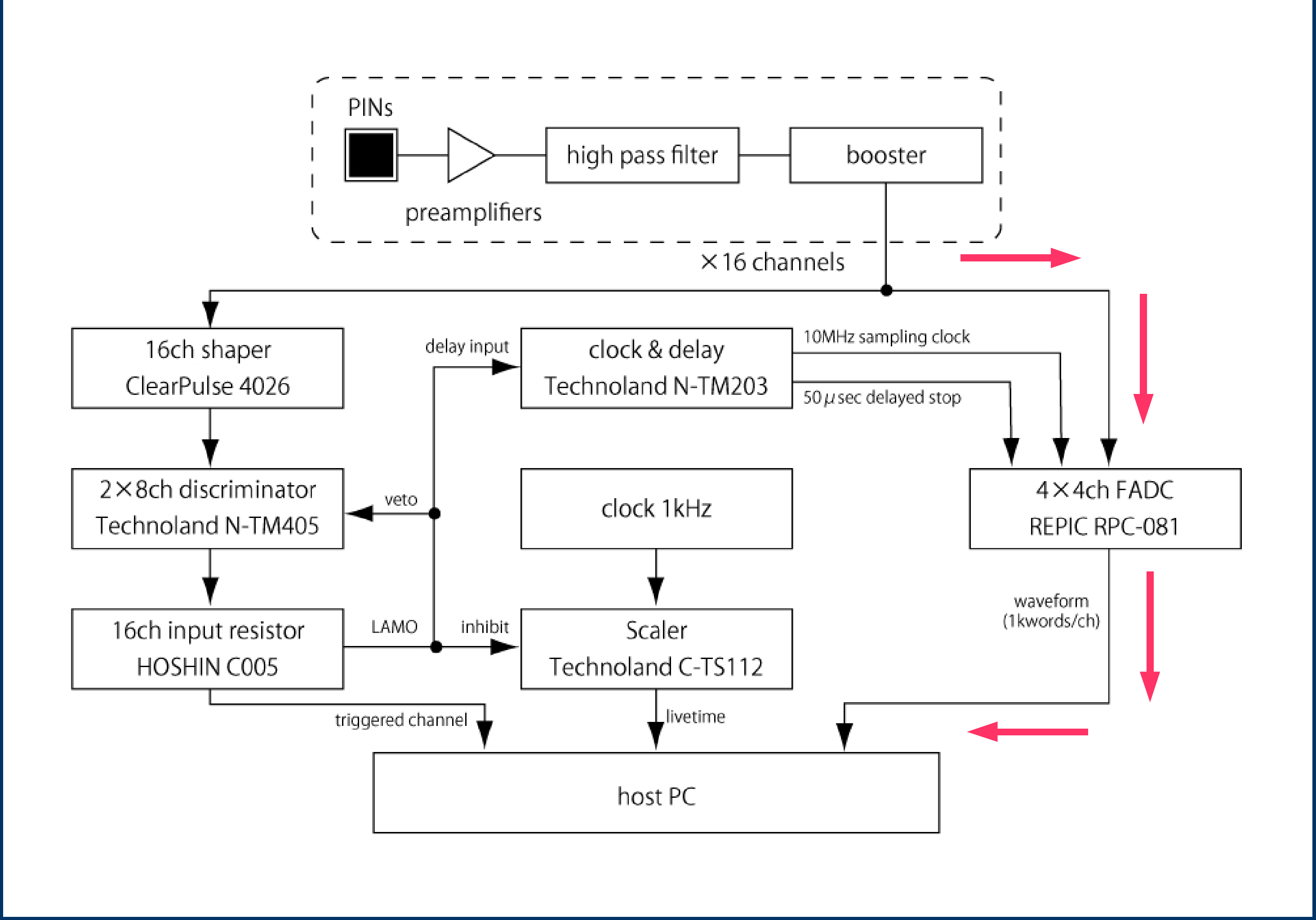




calibration system with ^{55}Fe

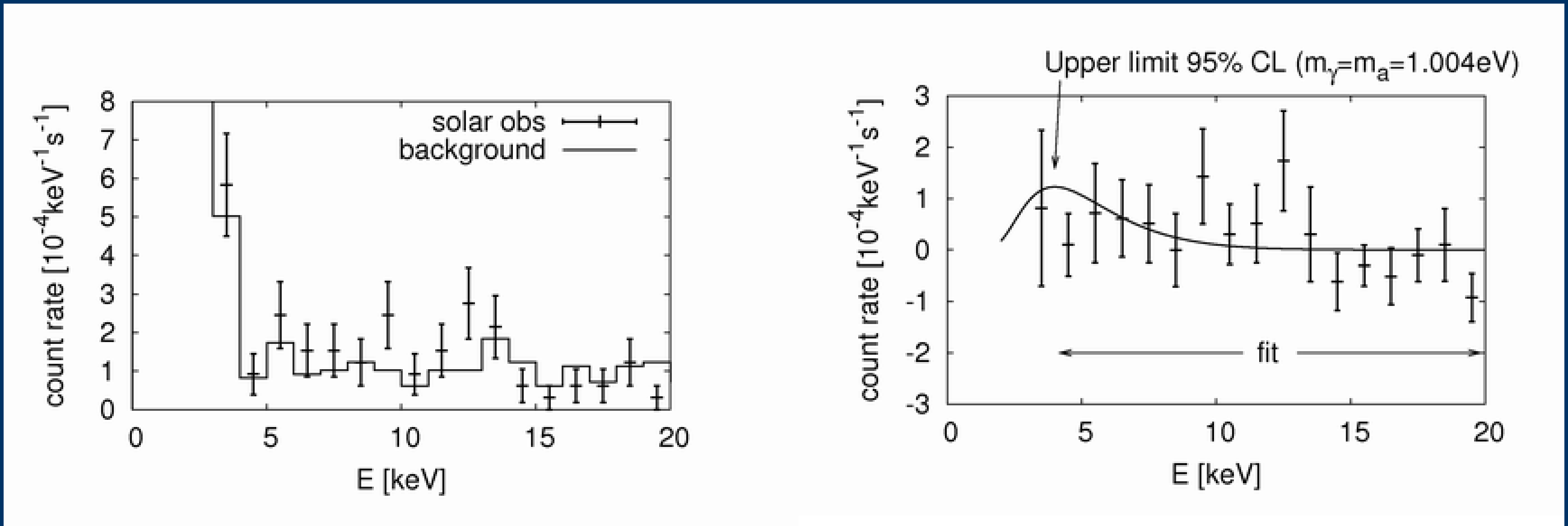


DAQ



- Waveform recording
- Offline shaping

Spectrum



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

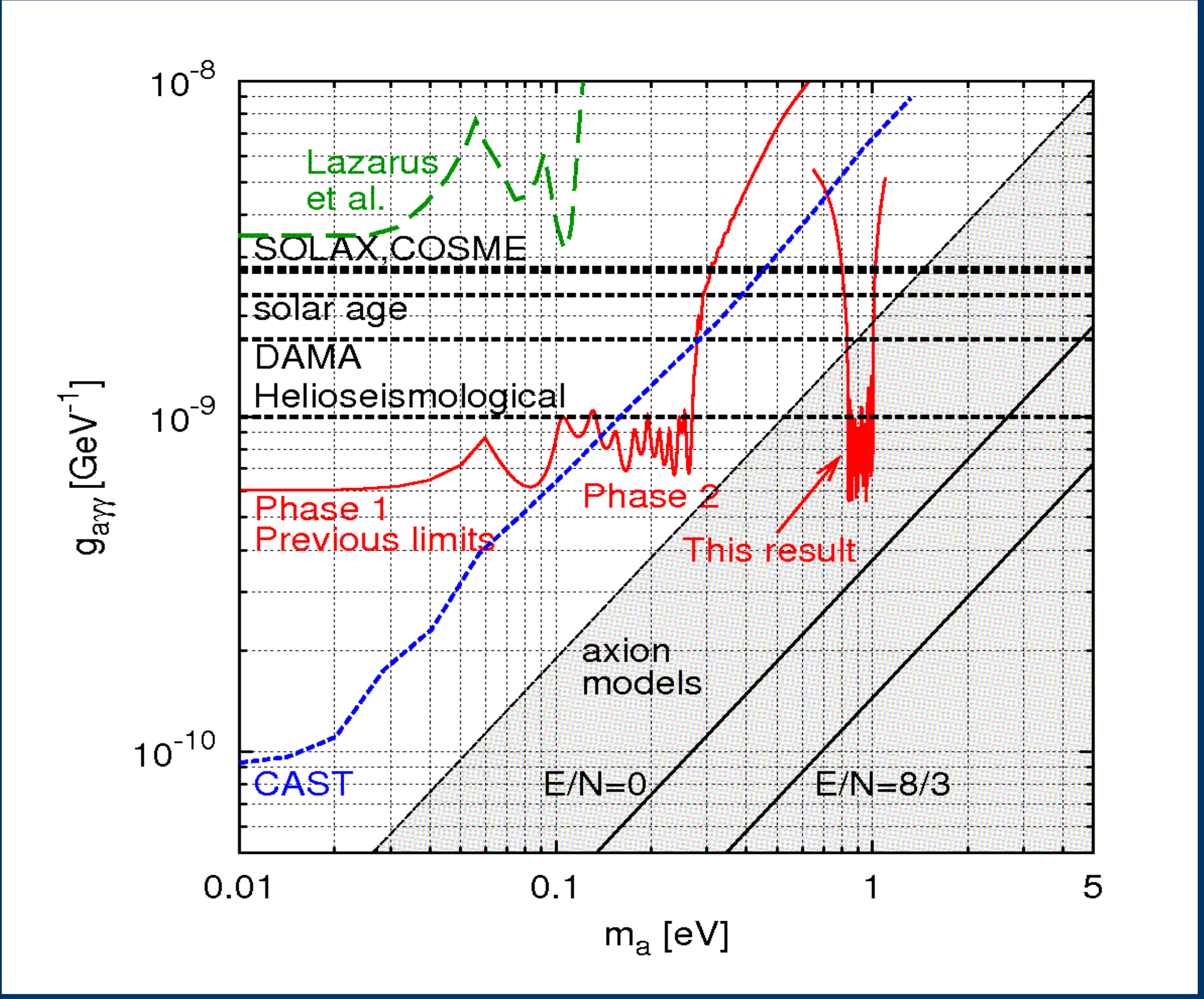
y_{ij}: count rate

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

	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

Sumico vs. CAST to scale

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 might survive in 1 < m_a < 2 eV.

Something yet to be completed

- No liquid helium and no current leads do not mean cable free.
- There are hoses for the refrigerators and cables for detectors and control.
- Azimuthal range is presently restricted to 60° without a human intervention.
- Automated cable handling system would enable complete unmanned operation with full azimuthal range.

Summary

New limit

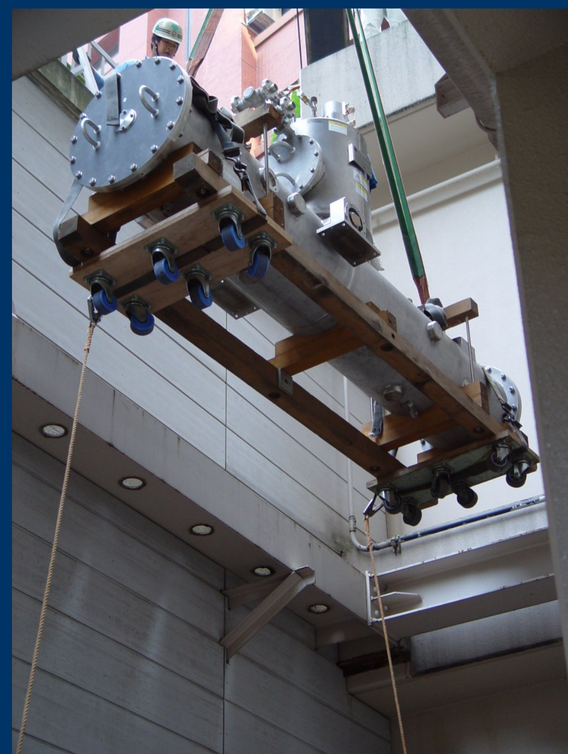
$$g_{a\gamma\gamma} < 5.6 - 13.4 \times 10^{-10}\ \mathrm{GeV}^{-1}$$

$$0.84 < m_a < 1.00\ \mathrm{eV}$$

is set by
the Tokyo Axion Helioscope aka Sumico.

→ arXiv:0806.2230v1 [astro-ph]

Photo gallery



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