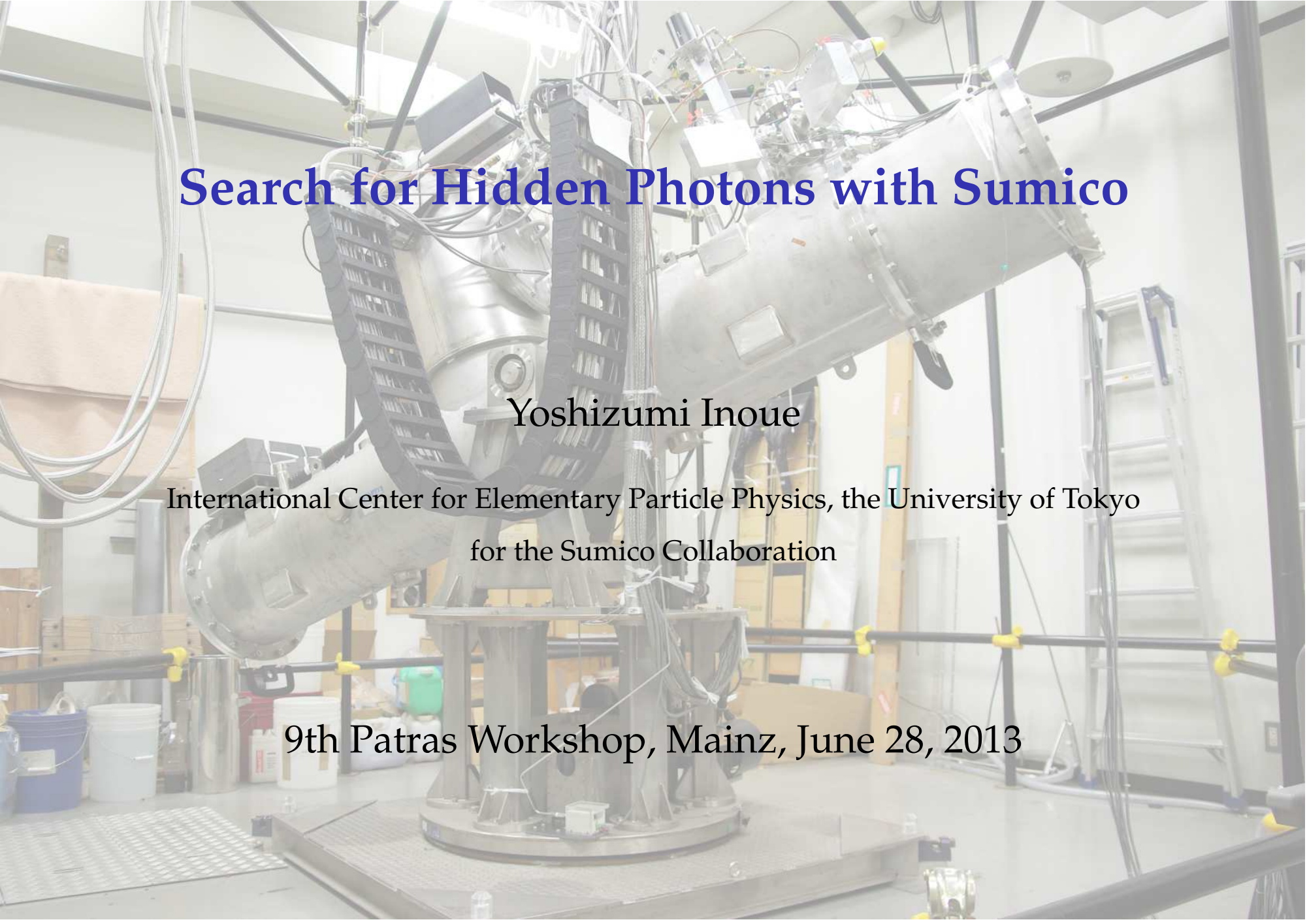


Search for Hidden Photons with Sumico

Yoshizumi Inoue

International Center for Elementary Particle Physics, the University of Tokyo

for the Sumico Collaboration

9th Patras Workshop, Mainz, June 28, 2013

Collaborators

M. Minowa, T. Horie, J. Suzuki, T. Mizumoto, R. Ohta

Department of Physics, School of Science, The University of Tokyo

Y. Inoue

International Center for Elementary Particle Physics, The University of Tokyo

A. Yamamoto

High Energy Accelerator Research Organization (KEK)

⟵ Logo designed by Yuki Akimoto

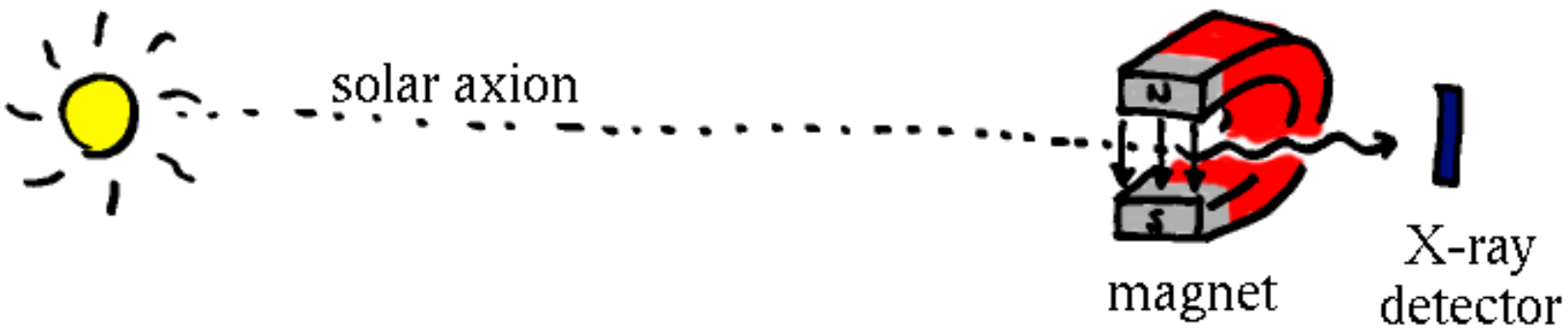
Outline

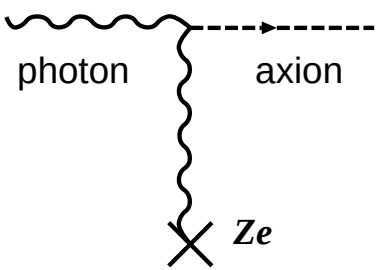
- Sumico
- Solar hidden-photon search
- Longituidinal solar hidden photon (cf. Josef Pradler's talk)
- Hidden-photon dark matter search
- Summary

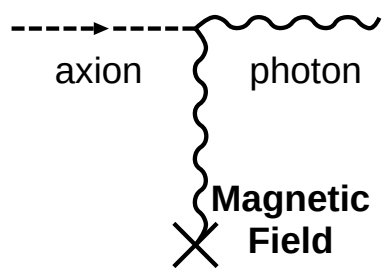
Axion helioscope

[P.Sikivie, PRL51, 1415(1983)]

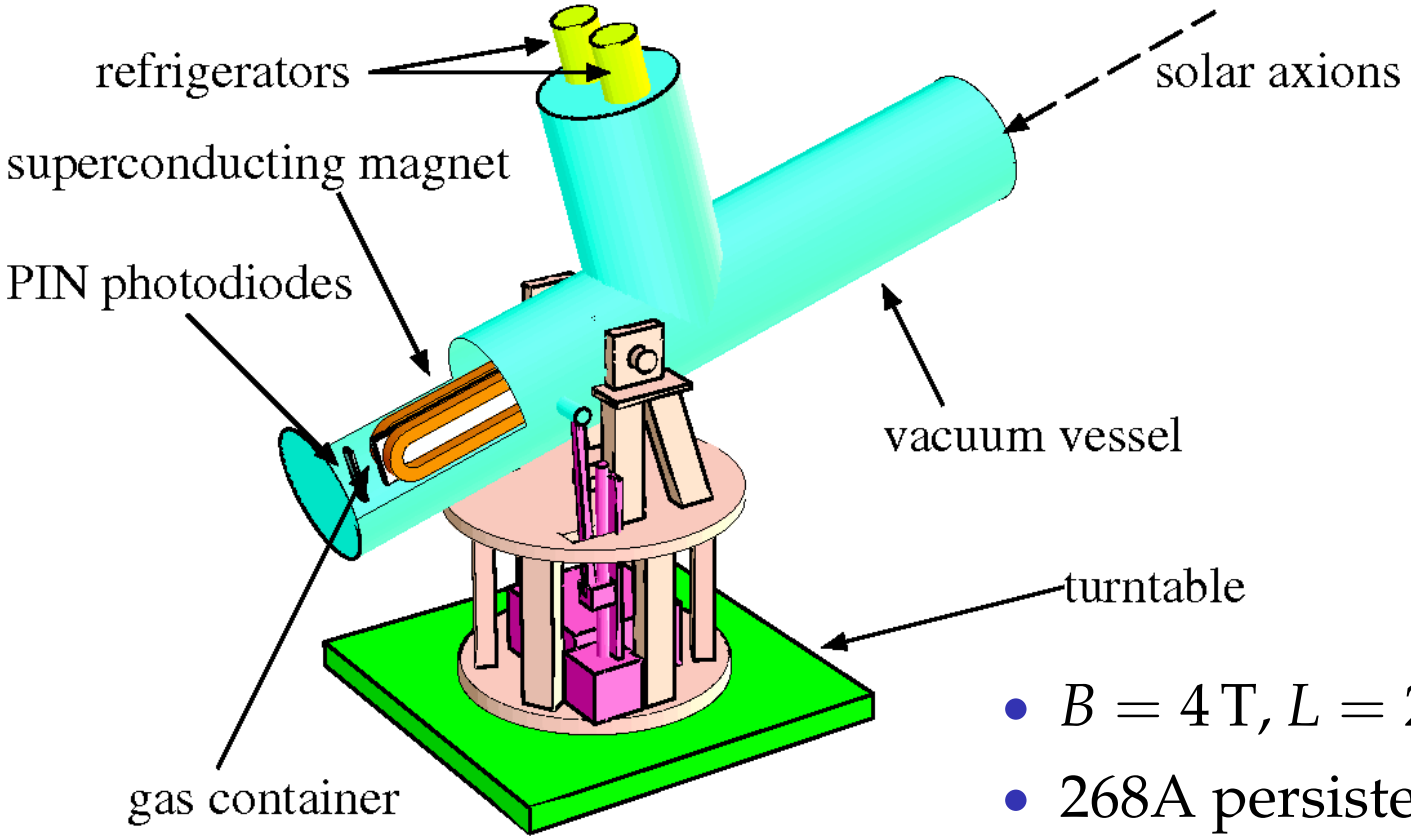
$$\mathscr{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}\partial_\mu a \partial^\mu a + \underline{g_{a\gamma\gamma} a \vec{E}\cdot\vec{B}} + \cdots$$





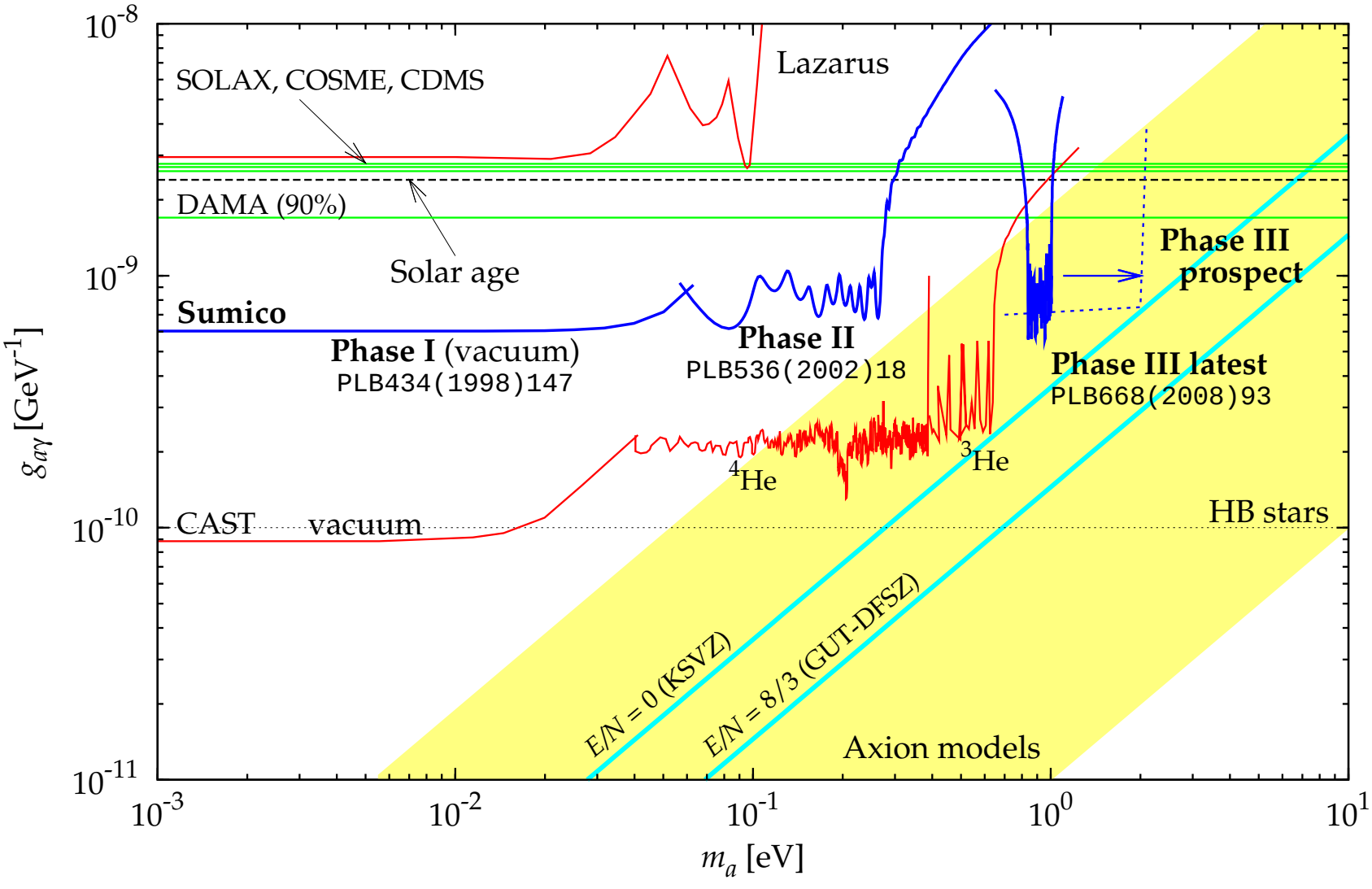


Sumico detector



- $B = 4\,\mathrm{T}$, $L = 2.3\,\mathrm{m}$
- 268A persistent current
- 16 PIN photodiodes
- Track the sun $\sim 12\,\mathrm{hours/day}$

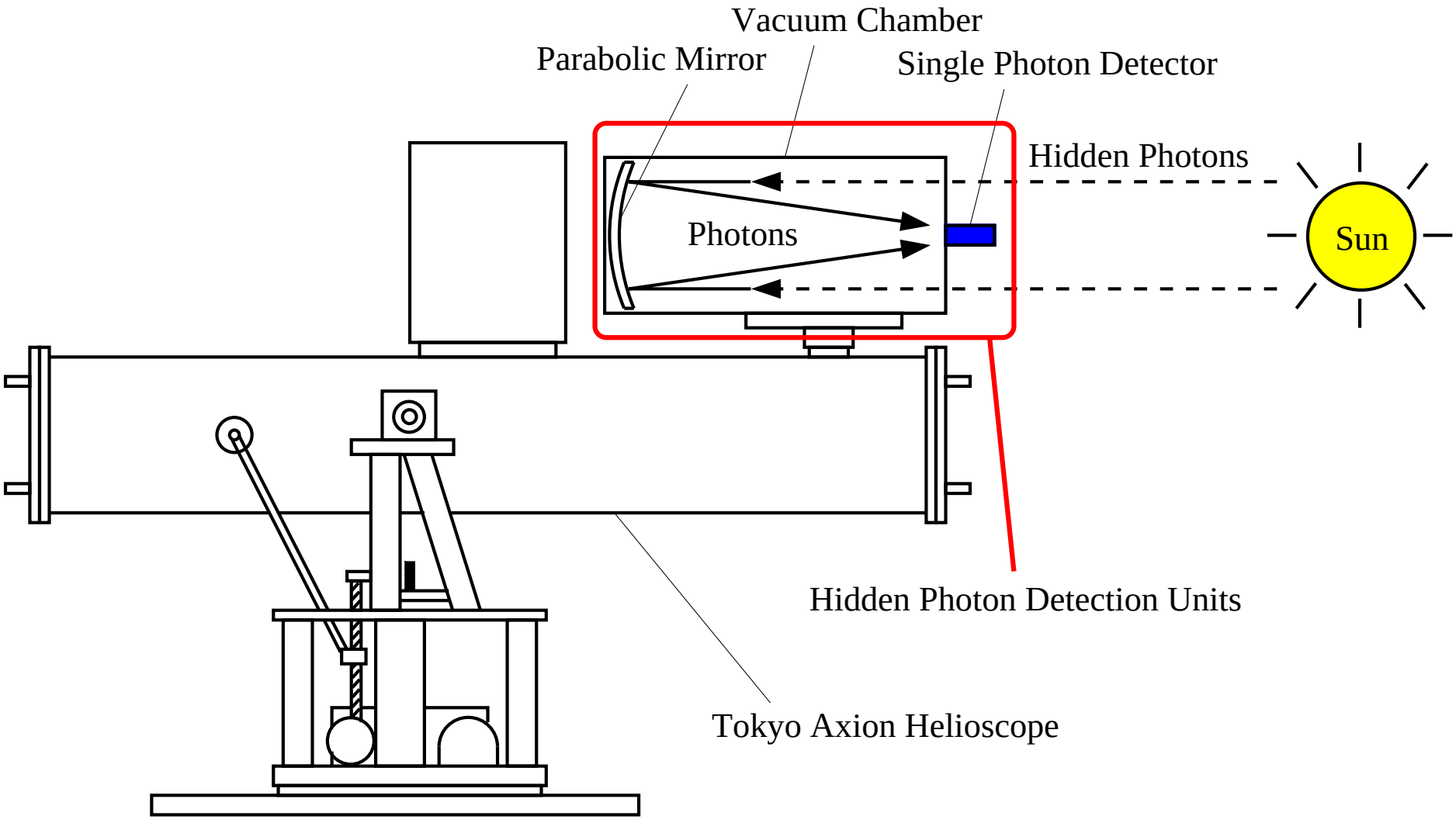
Axion search result



Current status of solar axion search

- Trying to explorer higher mass region ($m_\gamma > 1\,\mathrm{eV}$)
- Thermal non-uniformity at higher ρ_{He}.
  - $\rightarrow$ Not settled yet.
- G.-M. friges can not cool the superconducting magnet to its operating temperature, $T_{\mathrm{mag}} \lesssim 5.7\,K$.
  - $\rightarrow$ Unknown heat injection? Friges deteriorated?
  - $\rightarrow$ Under investigation...

Solar hidden-photon search



Hidden-sector photon

[S.Gninenko, J.Redondo, PLB664(2008)180]

$U(1)_h$ gauge boson (γ') in the Hidden sector.

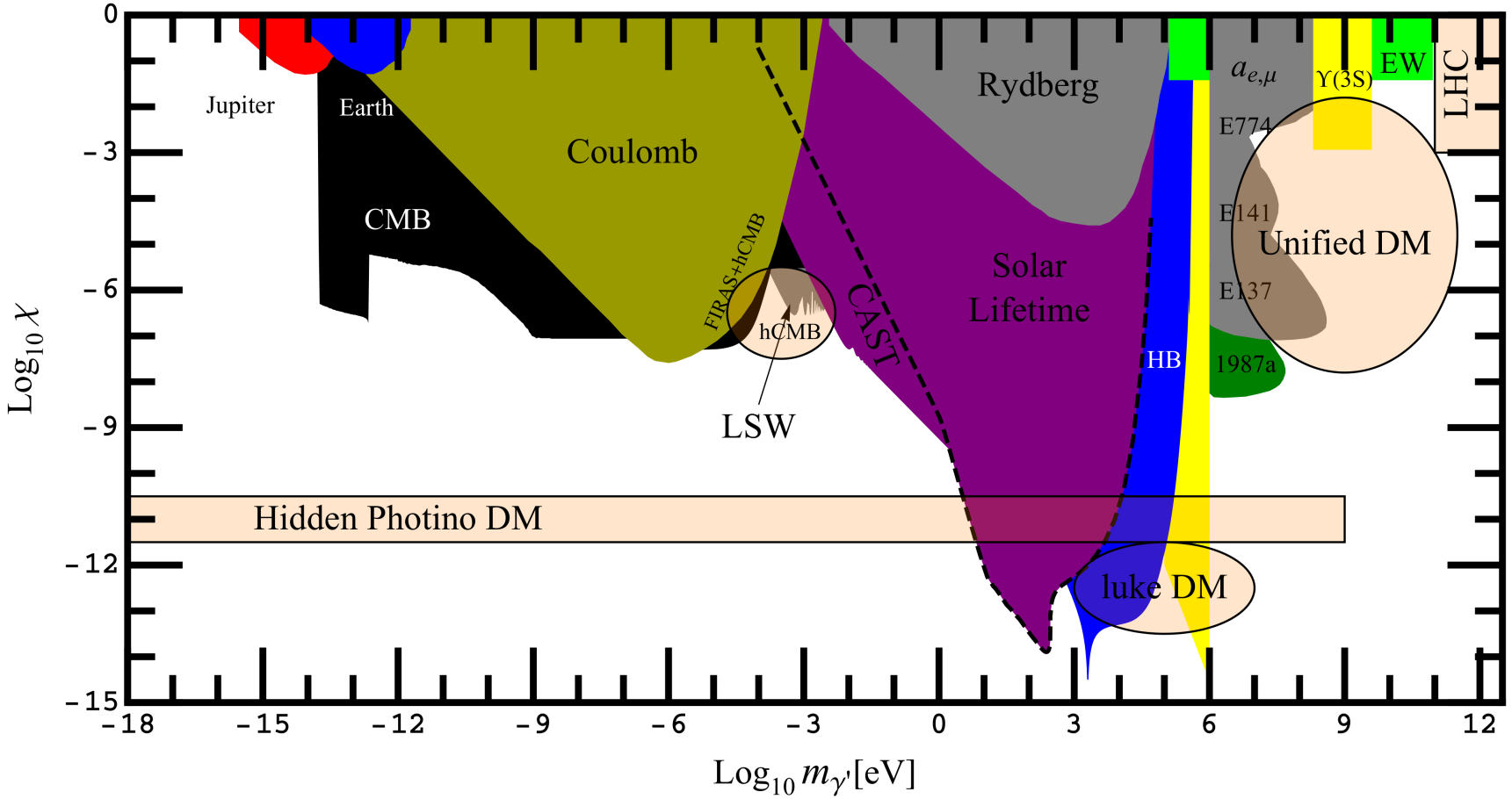
$$\mathscr{L} = -\frac{1}{4}A_{\mu\nu}A^{\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} \underbrace{-\frac{\chi}{2}A_{\mu\nu}B^{\mu\nu} + \frac{m_{\gamma'}^2}{2}B_\mu B^\mu}$$

$\rightarrow \gamma$–γ' mixing / γ–γ' vacuum oscillation

They can be observed!

- Deviations of Coulomb's law
- Light shining through walls
- CMB spectrum
- Stellar cooling
- Hidden-photon helioscope

Limit on hidden-photon parameters



[J.Jaeckel & A.Ringwald, Annu. Rev. Nucl. Part. Sci. 2010.60:405-437, `arXiv:1002.0329v1`]

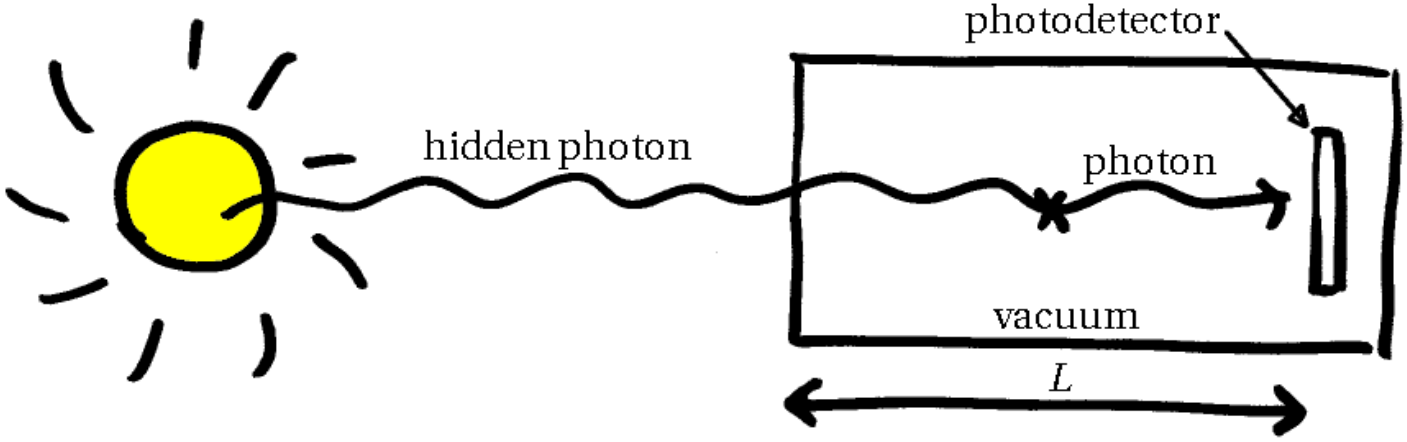
Hidden-photon helioscope

$\gamma' \leftrightarrow \gamma$ vacuum oscillation probability:

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

γ' flux at Earth (conservative):

$$\frac{\mathrm{d}\Phi_{\gamma'}}{\mathrm{d}\omega} \gtrsim \chi^2 \left(\frac{m_{\gamma'}}{1\,\mathrm{eV}}\right)^4 \frac{10^{32}}{\mathrm{eV\,cm^2 s}} \qquad \begin{pmatrix} 1 < \omega < 5\,\mathrm{eV}, \\ 10^{-4} < m_{\gamma'} \ll 1\,\mathrm{eV} \end{pmatrix}$$



Hidden-photon flux from the Sun

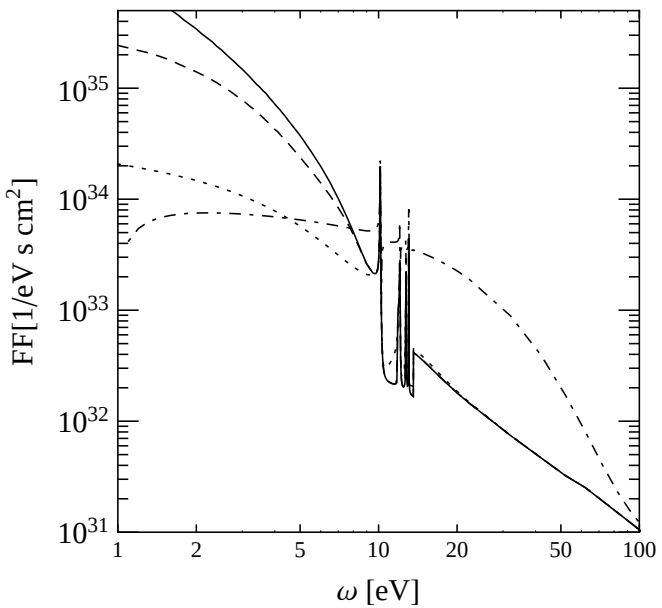
Transverse γ' flux at Earth:

$$\frac{d\Phi_{\gamma'}}{d\omega} = \int_0^{R_\odot} \frac{r^2 dr}{(1\,\mathrm{AU})^2} \frac{\omega^2}{\pi^2} \frac{\Gamma}{e^{\omega/T}-1} \underbrace{\frac{\chi^2 m_{\gamma'}^4}{(m_\gamma^2 - m_{\gamma'}^2)^2 + (\omega\Gamma)^2}}$$

$$\equiv \chi^2 \left(\frac{m_{\gamma'}}{\mathrm{eV}}\right)^4 FF.$$

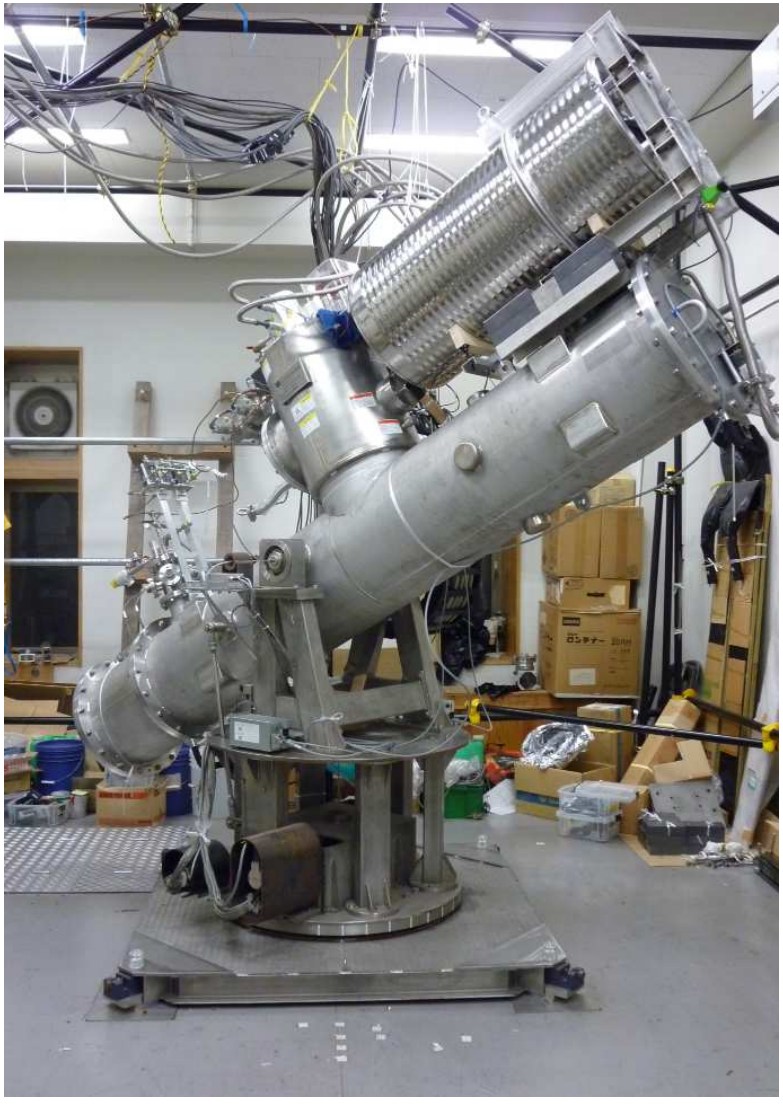
Resonant at $m_\gamma^2 = m_{\gamma'}^2$,

$$m_\gamma^2 = \omega_\mathrm{P}^2 = \frac{4\pi n_e}{m_e}.$$



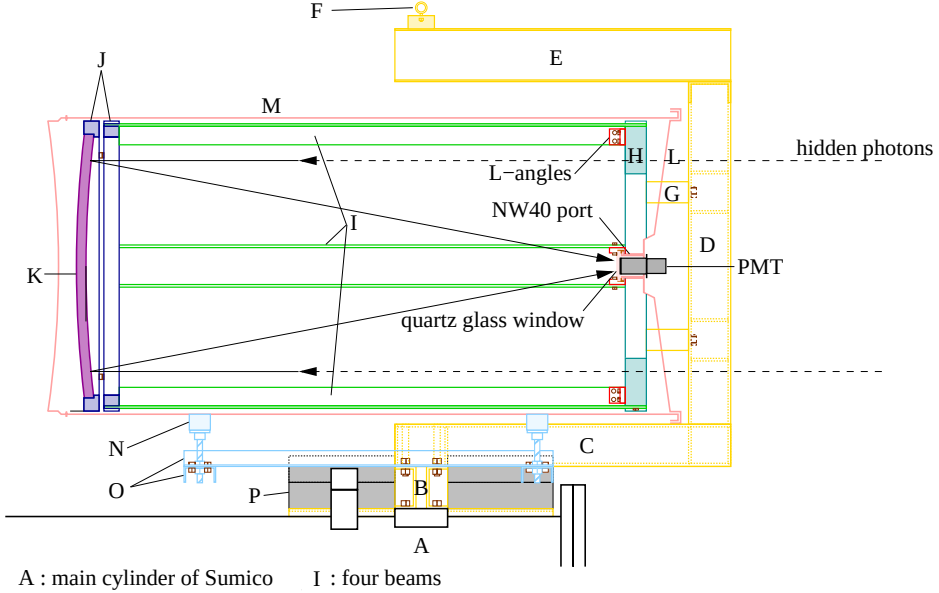
[J.Redondo, `arXiv:1202.4932`]

Piggyback hidden-photon detection unit



Low-cost parabolic mirror:
$D = 0.5\,\mathrm{m}, \quad L \simeq f = 1\,\mathrm{m}$

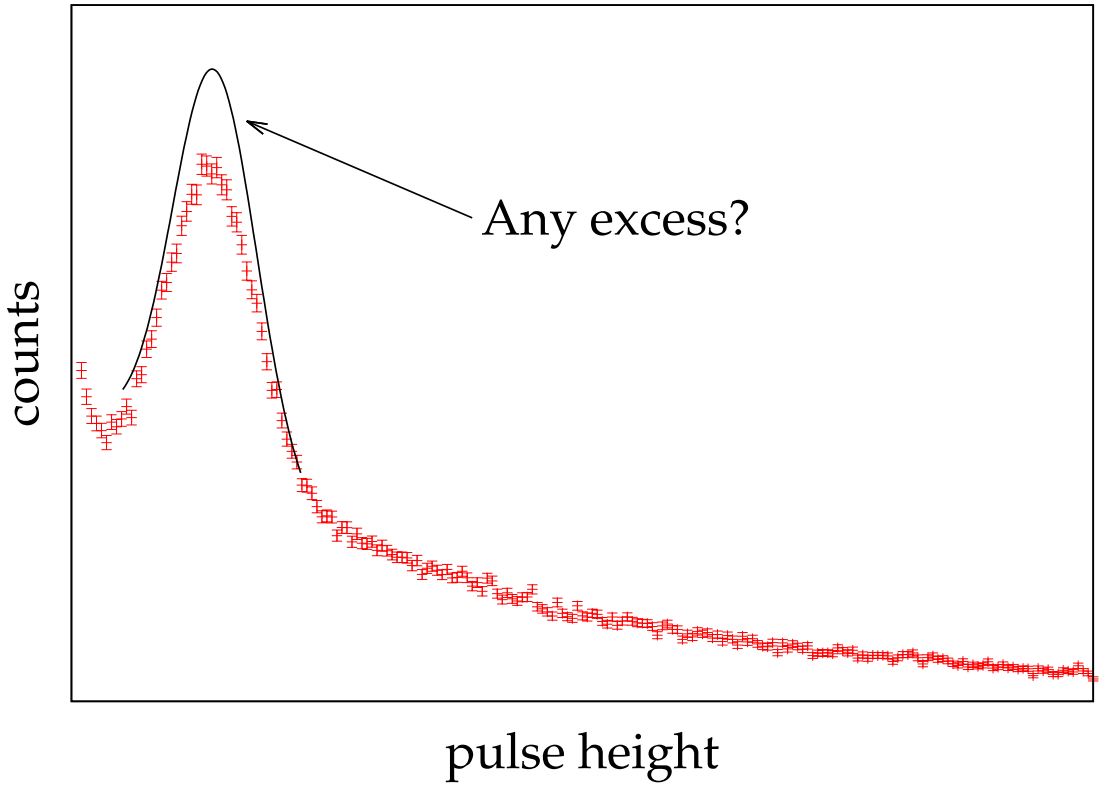
PMT: Hamamatsu R3550P



A : main cylinder of Sumico
B : base
C : beams
D : columns
E : square pipe
F : eyebolt
G : rods
H : duralumin ring
I : four beams
J : mirror holder (two aluminium rings)
K : parabolic mirror
L : lid of the vacuum chamber
M : cylindrical main body of the vacuum chamber
N : wooden sleeper
O : aluminium channel bar
P : lead blocks

Pulse height spectrum from PMT

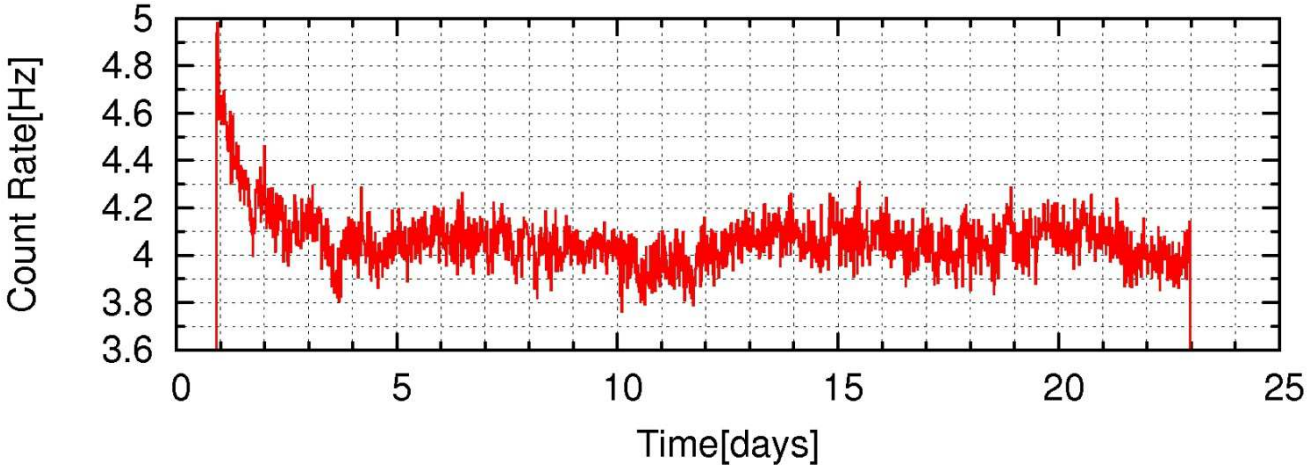
HPs will appear as an *excess* of the *single photon peak*.



Stability of dark count rate

Stability of dark count rate is crucial, but...

- x-axis: lapsed time since Oct. 25, 00:00 JST 2010.



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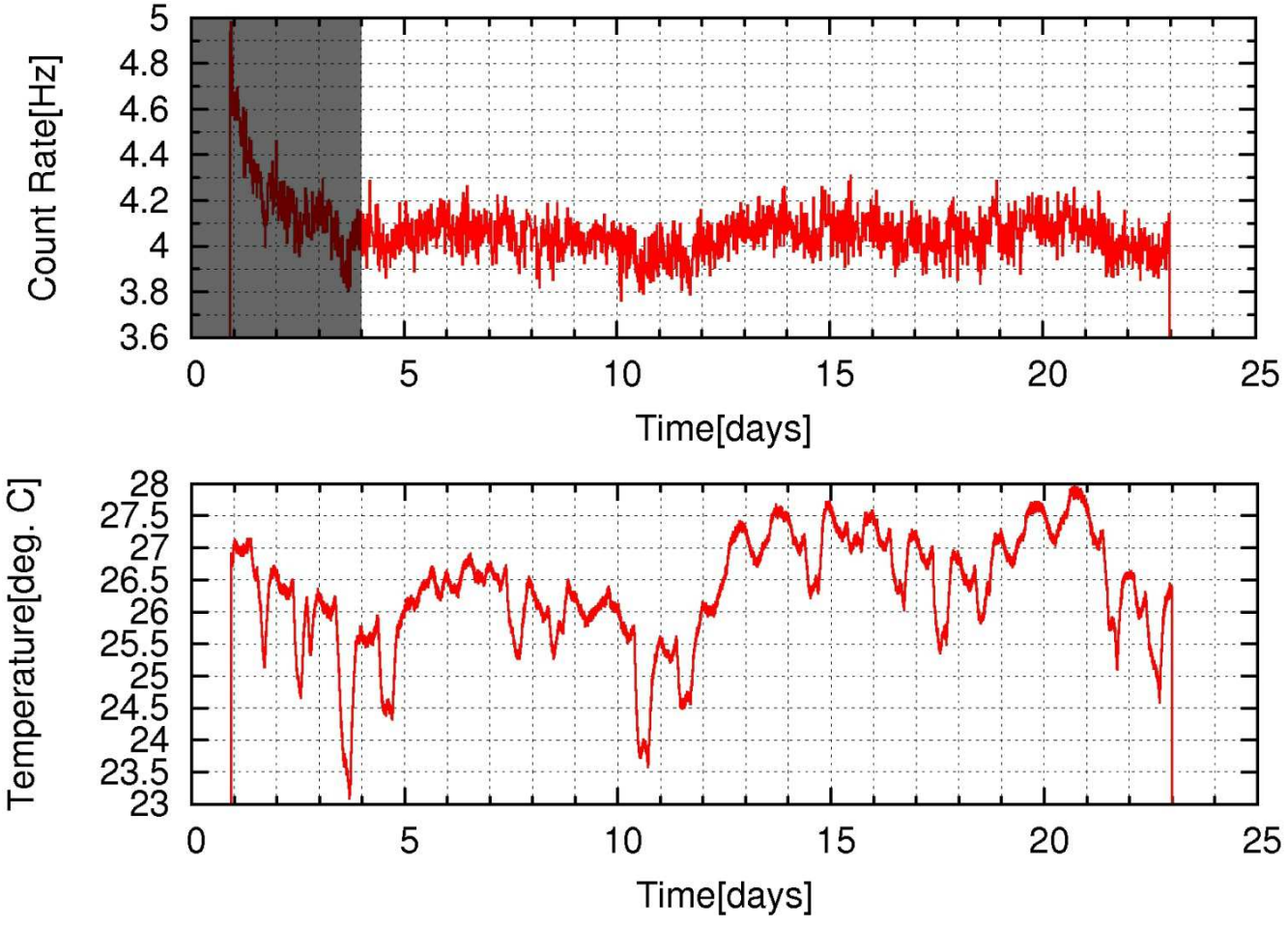
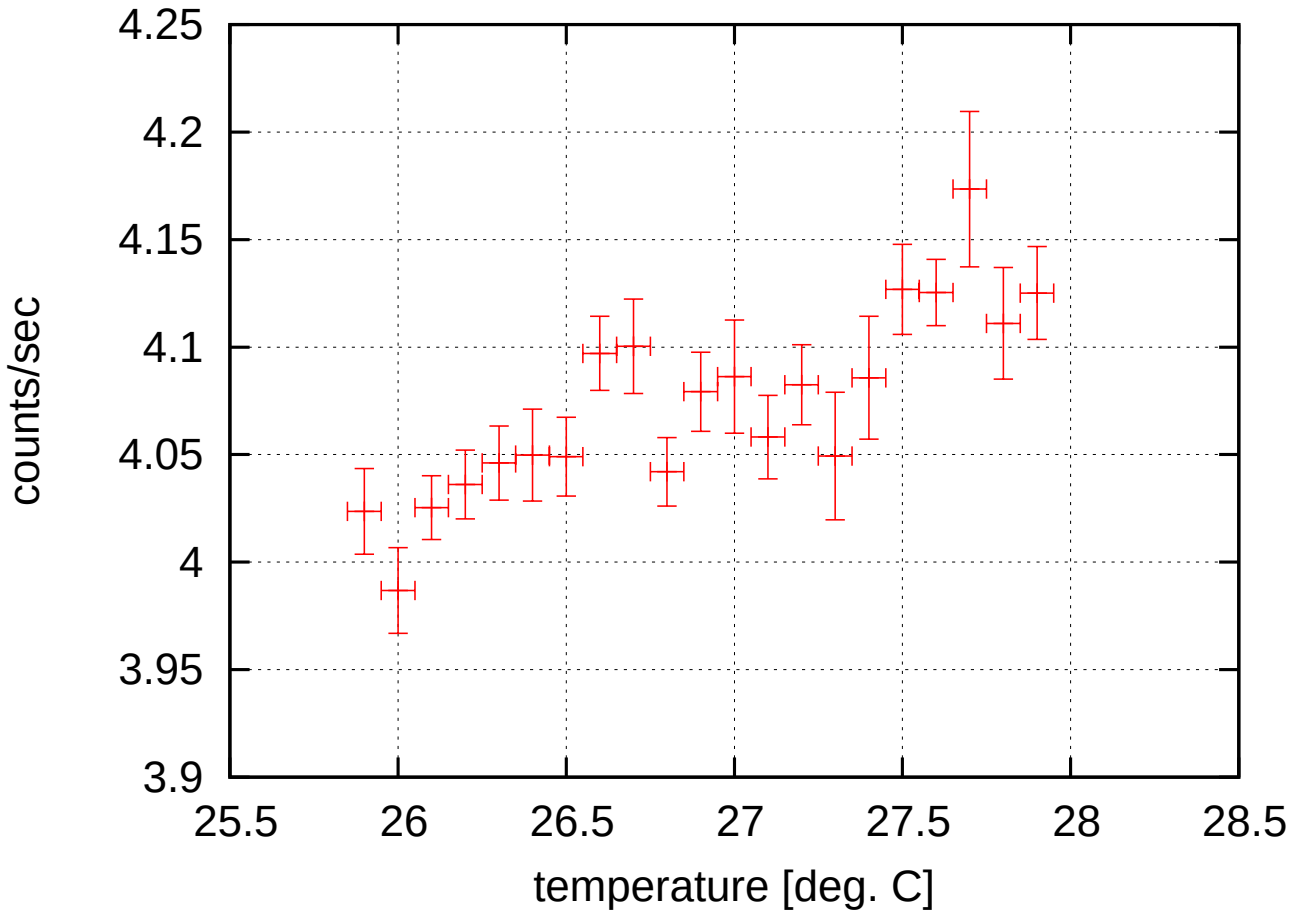
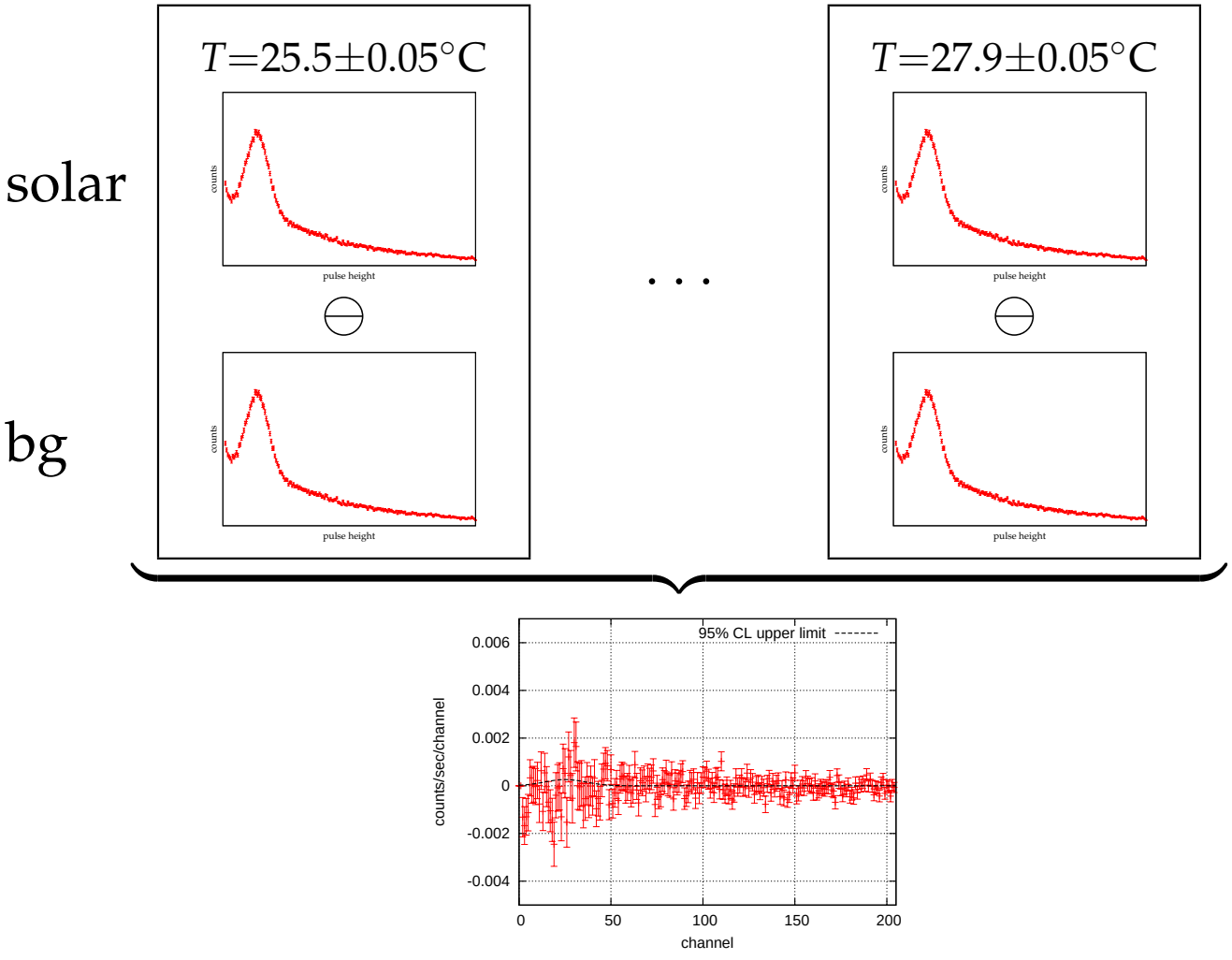


Stability of dark count rate

The temperature dependence of dark count rate:



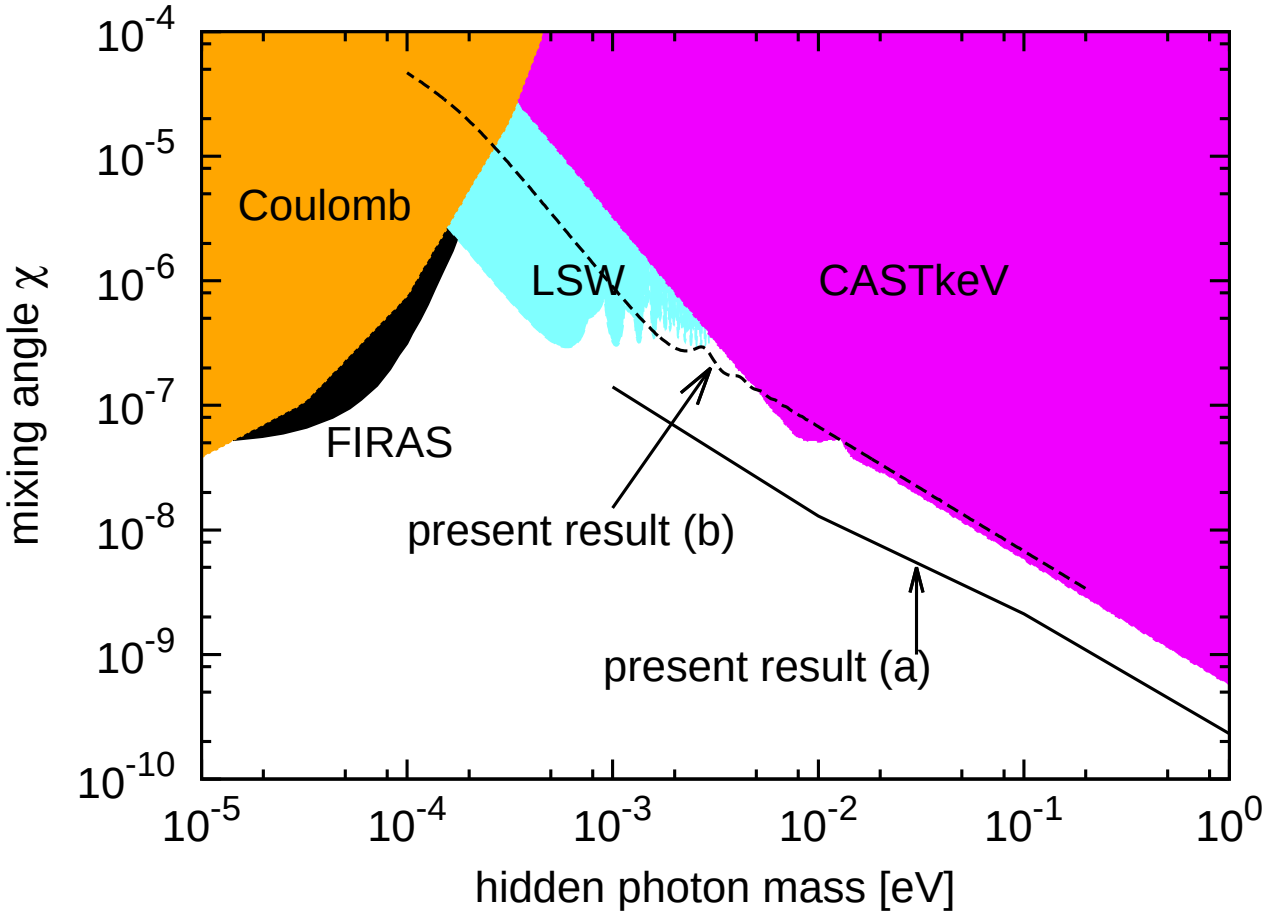
Data analysis



$$N_{\text{fit}} = (-7.9 \pm 6.5(\text{stat.}) \pm 3.4(\text{sys.})) \times 10^{-3}\text{s}^{-1}$$

$$N \leq 1.02 \times 10^{-2}\text{s}^{-1} \quad (95\%\ \text{CL})$$

Pilot run result



Live time:
ca. 2×10^5s,

Measurement:
Oct. 26 – Nov. 16, 2010.

[T.Mizumoto, *et al.*, `arXiv:1302.1000`, To be published in JCAP]

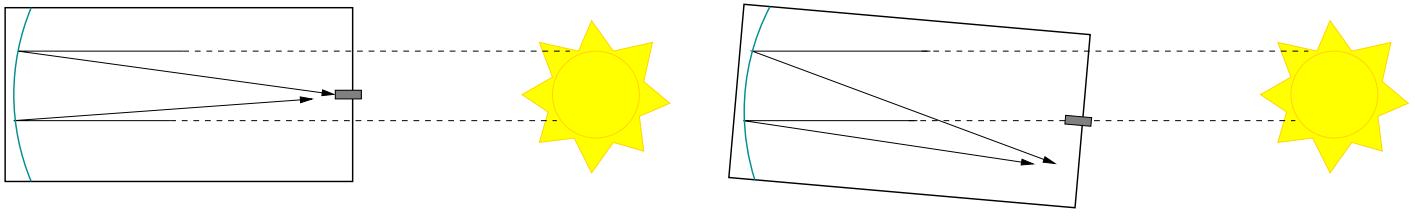
Developments

When solar- and bg measurements could be switched in < 10 min, dark count drift is negligible.

- Shutter

  → ✘ Almost every surface is emitting photons!

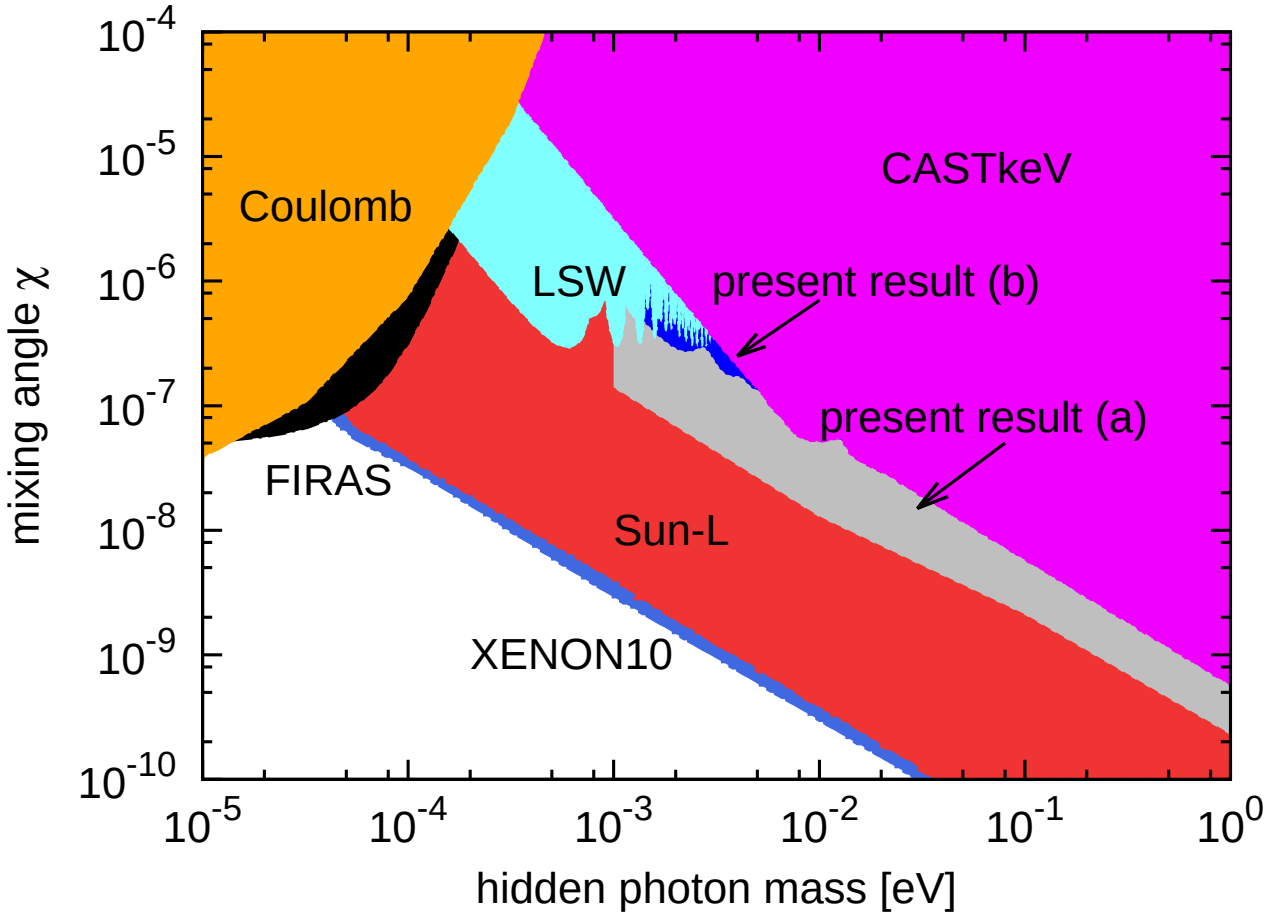
- Look-aside measurement



→ ✓ Worked fine.

L-mode hidden photons

[H.An, M.Pospelov, J.Pradler, arXiv:1302.3884]
[J.Redondo, G.Raffelt, arXiv:1305.2920]

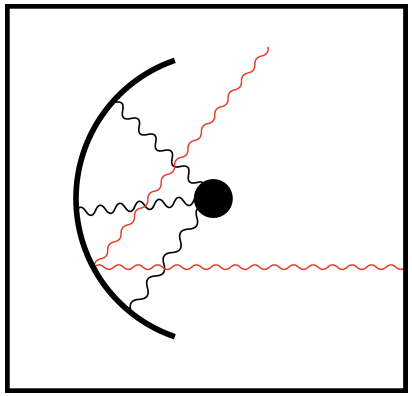


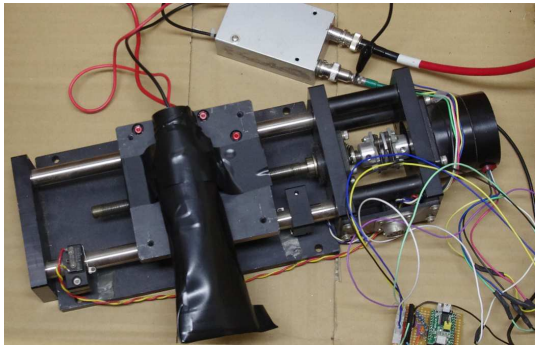
L-mode hidden photons

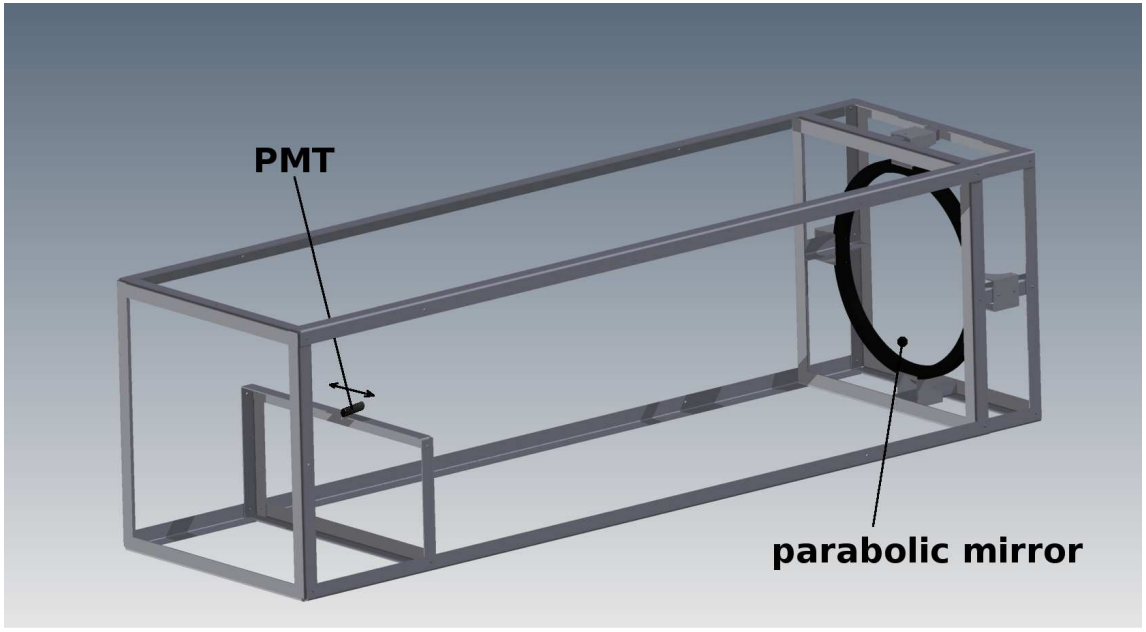
	T-mode	L-mode
solar HP	only heavy HP	dominant!
	$m_{\gamma'} \gtrsim 10\,\mathrm{eV}$	$m_{\gamma'} < 1\,\mathrm{eV}$
vacuum oscillation	✓	✘
DM detector	△	✓

Hidden-photon DM search

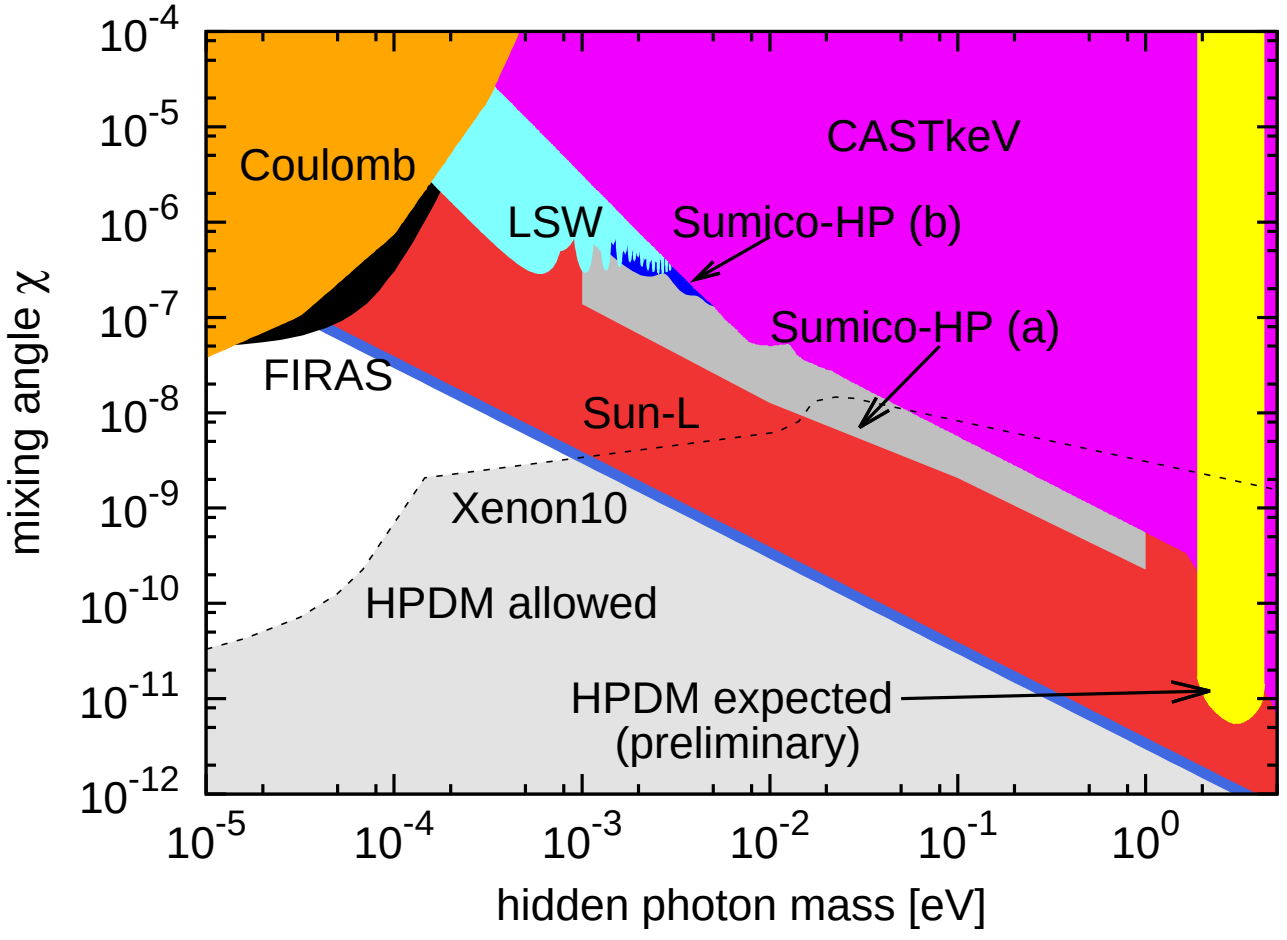
[D.Horns, *et al.*, arXiv:1212.2970]







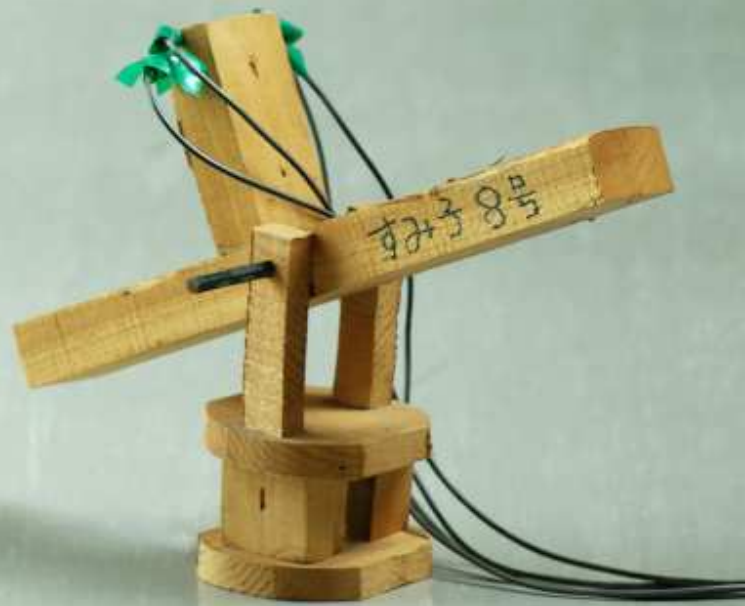
Expected sensitivity



Summary

- Sumico is an axion helioscope.
- Axion search is currently suspended due to a trouble in the cryogenic system.
- Solar hidden photon detector add-on was developed.
- Pilot run yielded a competitive sensitivity.
- However, not competitive against stellar L-mode HP limits.
- Dish anntena HPDM search just launched.

Thank you for your attention!



Dependence of hidden-photon sensitivity

$$\begin{aligned}\chi_{\mathrm{lim}} \quad \leq \quad & 10^{-7} \times \left(\frac{m_{\gamma'}}{\mathrm{meV}}\right)^{-1} \left(\frac{\nu_{\mathrm{dark}}}{\mathrm{s}^{-1}} \frac{100\mathrm{days}}{T}\right)^{1/8} \left(\frac{0.1\,\mathrm{m}^2}{S_{\mathrm{mirror}}}\right)^{1/4} \\ & \times \left(\int \frac{\mathrm{d}\omega}{\mathrm{eV}} \frac{FF\mathrm{eV}\,\mathrm{cm}^2\,\mathrm{s}}{10^{35}} \eta_{\mathrm{mirror}} \frac{\eta_{\mathrm{PMT}}}{0.1} \frac{P_{\gamma'\to\gamma}}{\chi^2}\right)^{-1/4}\end{aligned}$$

γ'-γ oscillation probability in medium

$$P_{\gamma' \leftrightarrow \gamma} =$$

$$\frac{4\chi^2 m_{\gamma'}^4}{(m_{\gamma'}^2 - m_\gamma^2)^2 + 4\chi^2 m_{\gamma'}^4} \sin^2 \left(\frac{L\sqrt{(m_{\gamma'}^2 - m_\gamma^2)^2 + 4\chi^2 m_{\gamma'}^4}}{4\omega} \right),$$

where

$$m_\gamma^2 = \omega^2 - k^2 = -\omega^2(n^2 - 1).$$

Thermal non-uniformity at higher mass