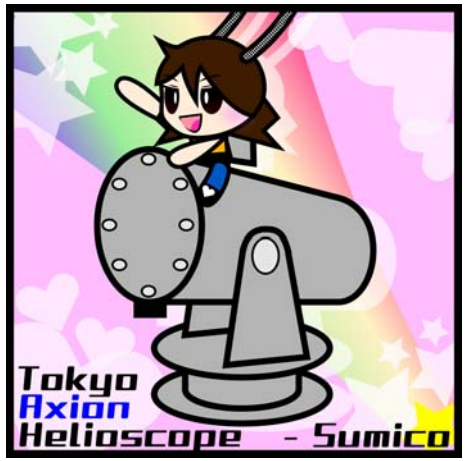
Prospects of search for solar axions with mass over 1 eV and hidden sector photons



Ryosuke Ohta

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

Collaborators

- University of Tokyo
  - M. Minowa
  - Y. Inoue
  - Y. Akimoto
  - R. Ohta
  - T. Mizumoto
  - S. Sakoda
- KEK
  - A. Yamamoto

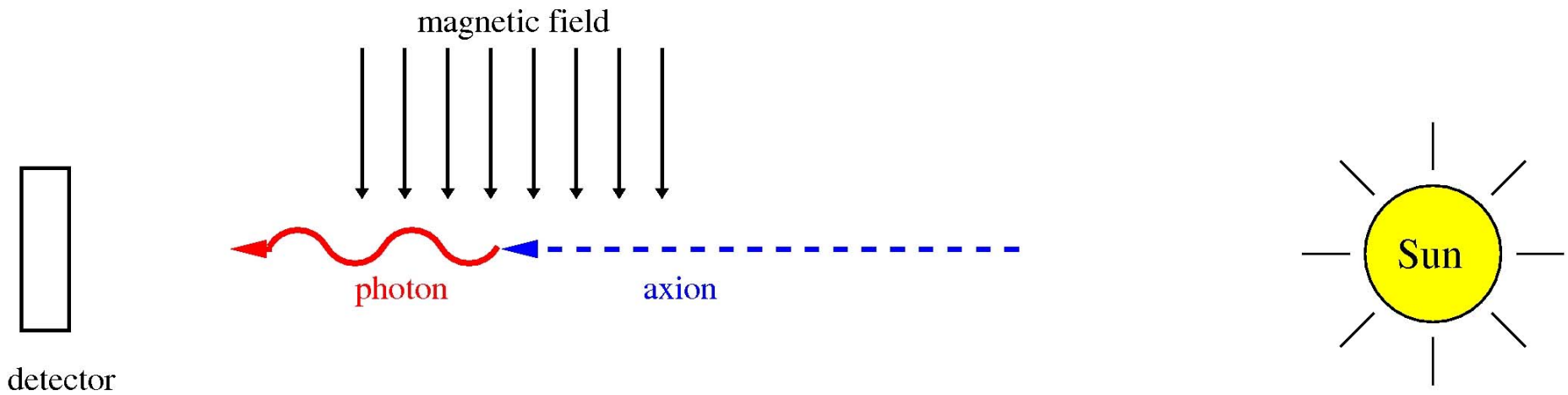
Invisible particles from the Sun

- Axion

- Hidden sector photon

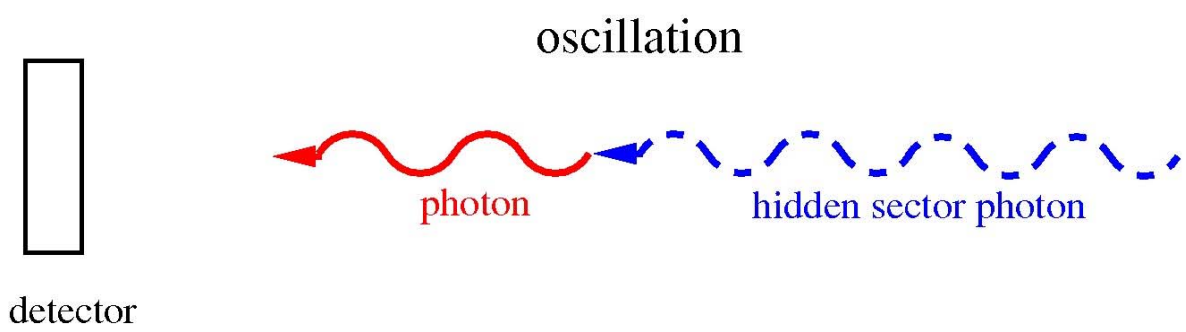
Invisible particles from the Sun

- Axion
  - Primary purpose of our group
  - Coupling with two photons
- Hidden sector photon



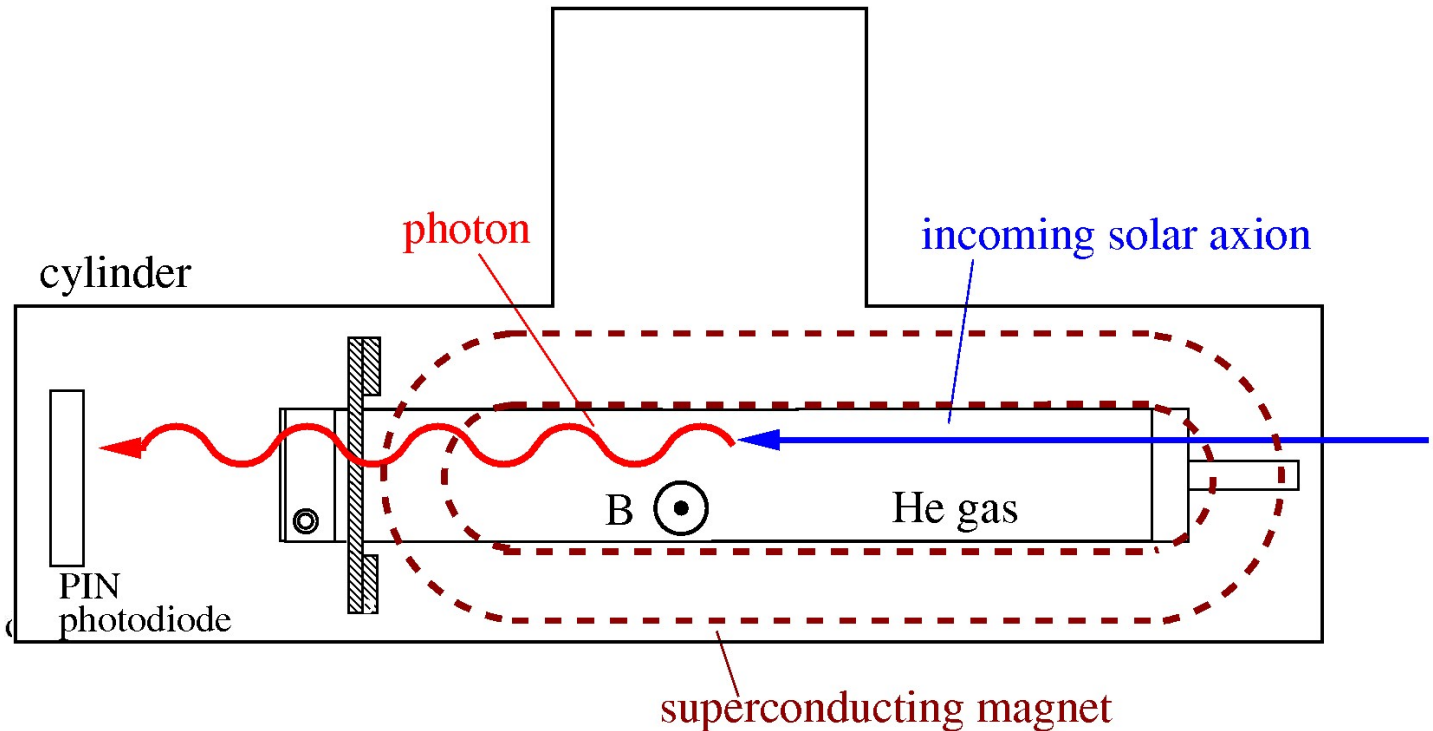
Invisible particles from the Sun

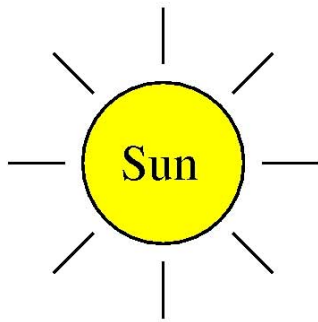
- Axion
  - Primary purpose of our group
  - Coupling with two photons
- Hidden sector photon
  - Mixing with a photon



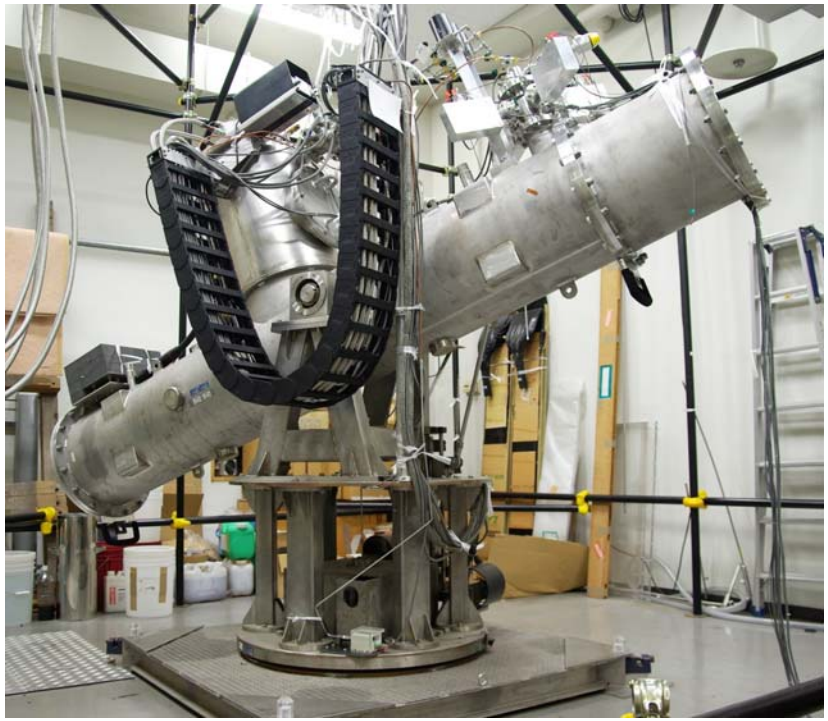
Axion

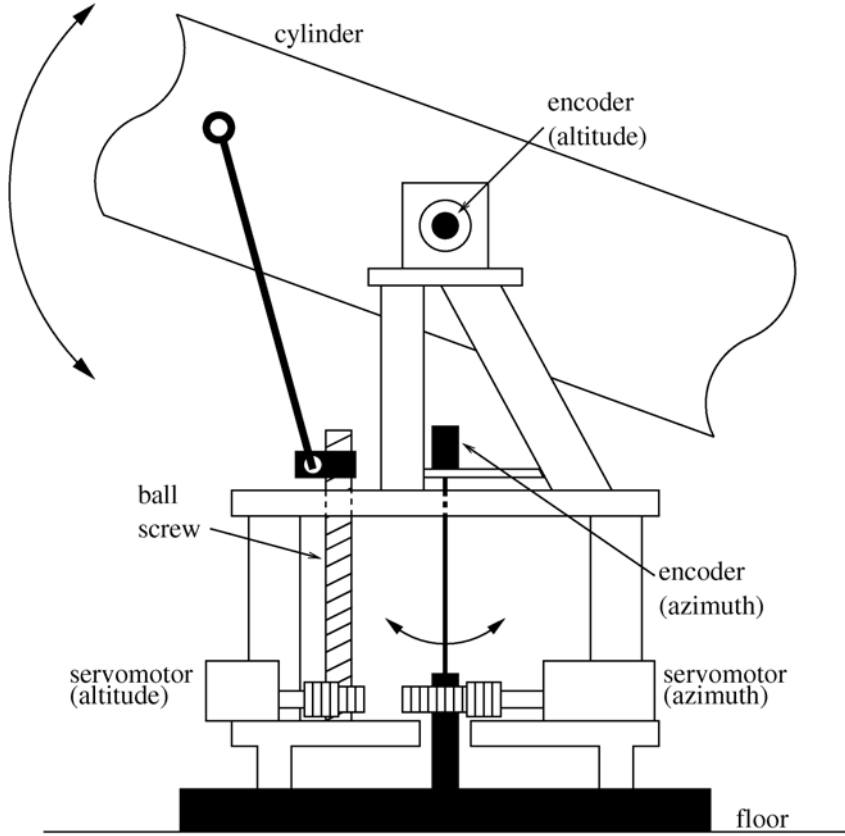
- Introduced to solve strong CP problem
- Transformed into photon via inverse Primakoff conversion





Tokyo Axion Helioscope aka Sumico

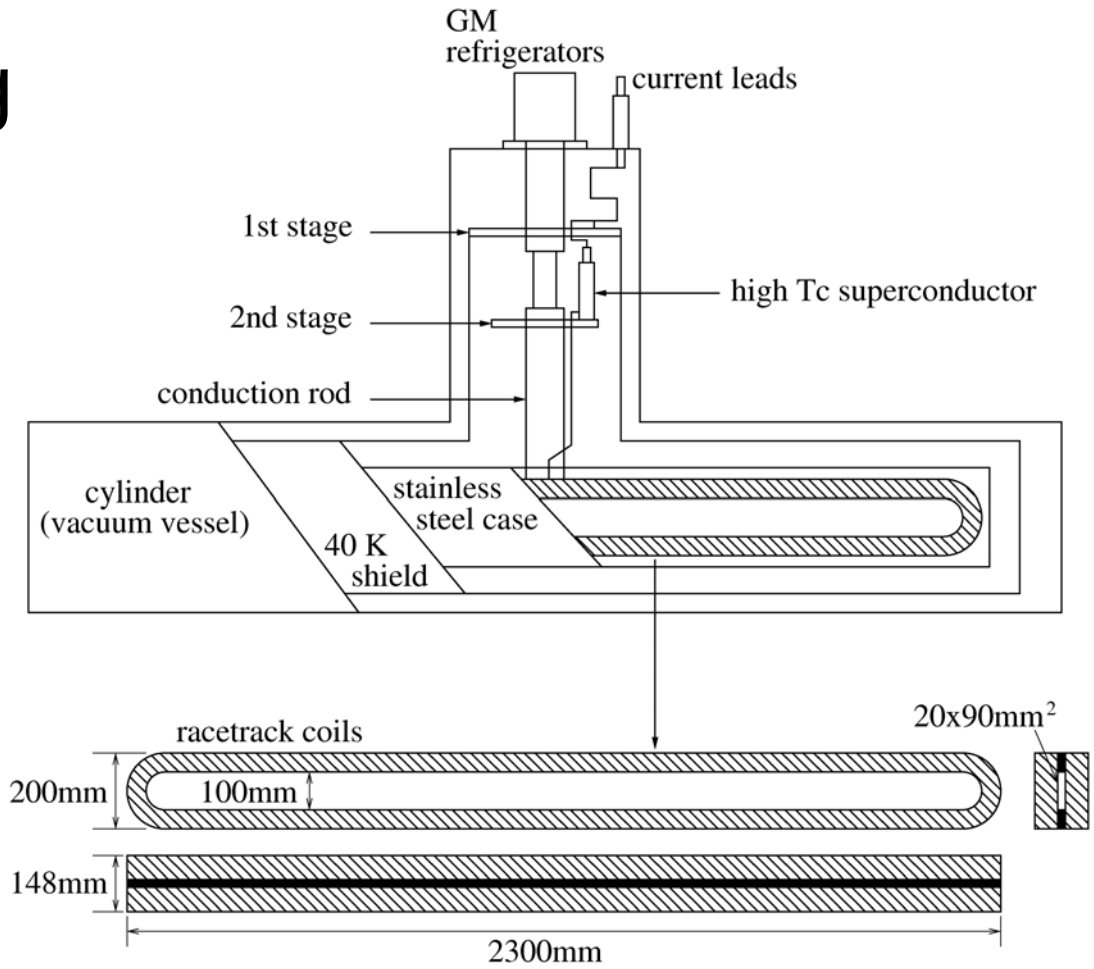




- Azimuth: 360º
- Altitude: ±28º
- Driving system with AC servomotors
- NOVAS-C for calculating position of celestial object
- Case of tracking the Sun: 12 hours/day on average

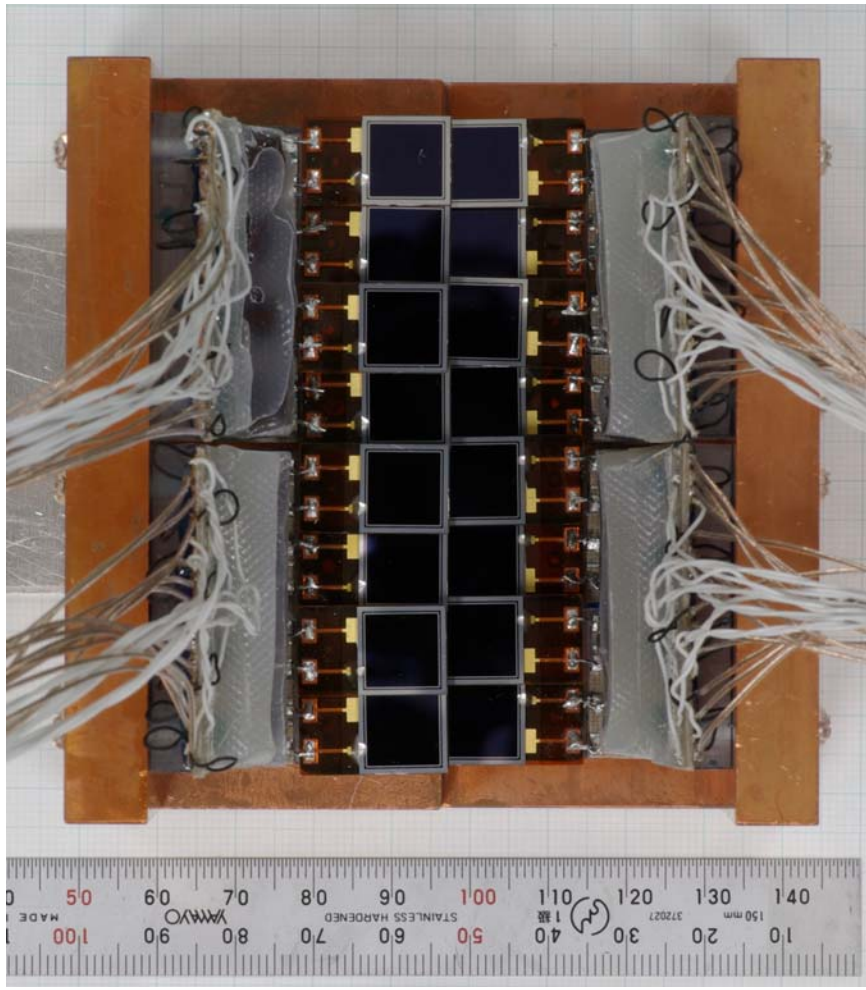
Magnet

- Superconducting magnet (4T 2.3m)
- Two GM refrigerators
  - No liquid He



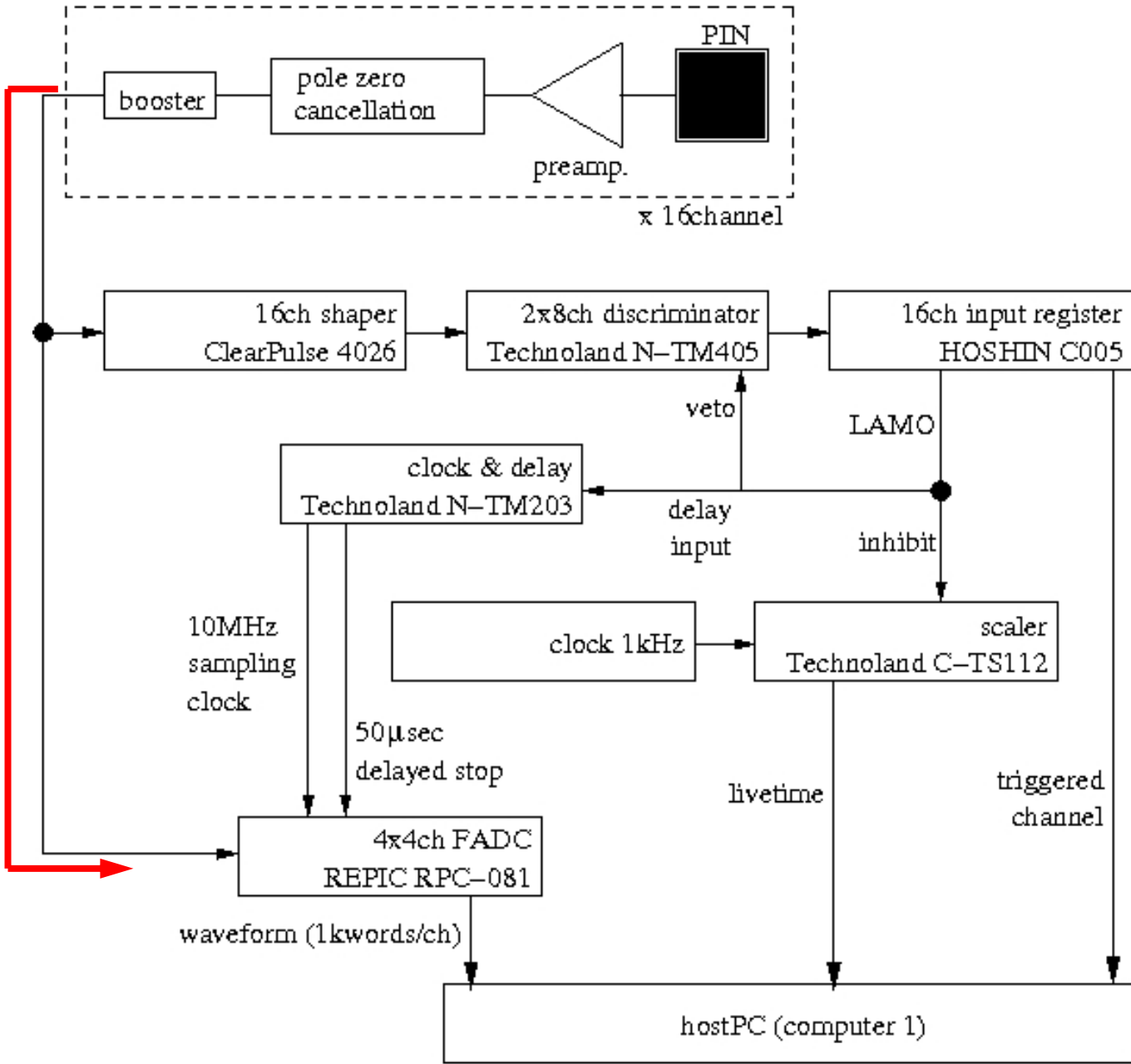
X-ray detector

- 16 PIN photodiodes (Hamamatsu S3590-06-SP)
- High efficiency for X-ray
- Operation at 100K
- Kapton base for low radioactivity
- Resistance to magnetic field



DAQ diagram

- Waveform recording by FADC
- Offline shaping



Search for solar axions with mass

$$< A(z) \mid a(0) > = \frac{g_{a\gamma\gamma} B}{2} \exp\left(-\int_0^z dz' \ \Gamma / 2 \right)$$

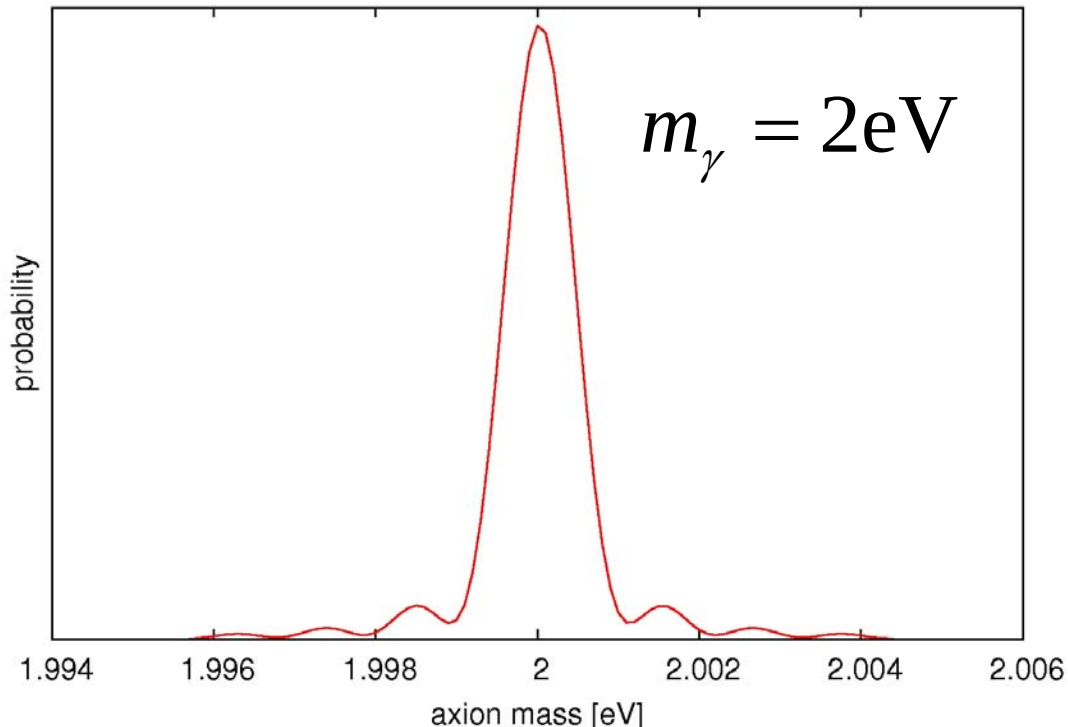
$$\times \int_0^z dz' \exp\left(i \int_0^{z'} dz' \ ' \left(q - i\Gamma/2 \right) \right)$$

$$q = \frac{m_\gamma^2 - m_a^2}{2E_a}$$

$$m_\gamma = \sqrt{\frac{4\pi\alpha N_e}{m_e}}$$

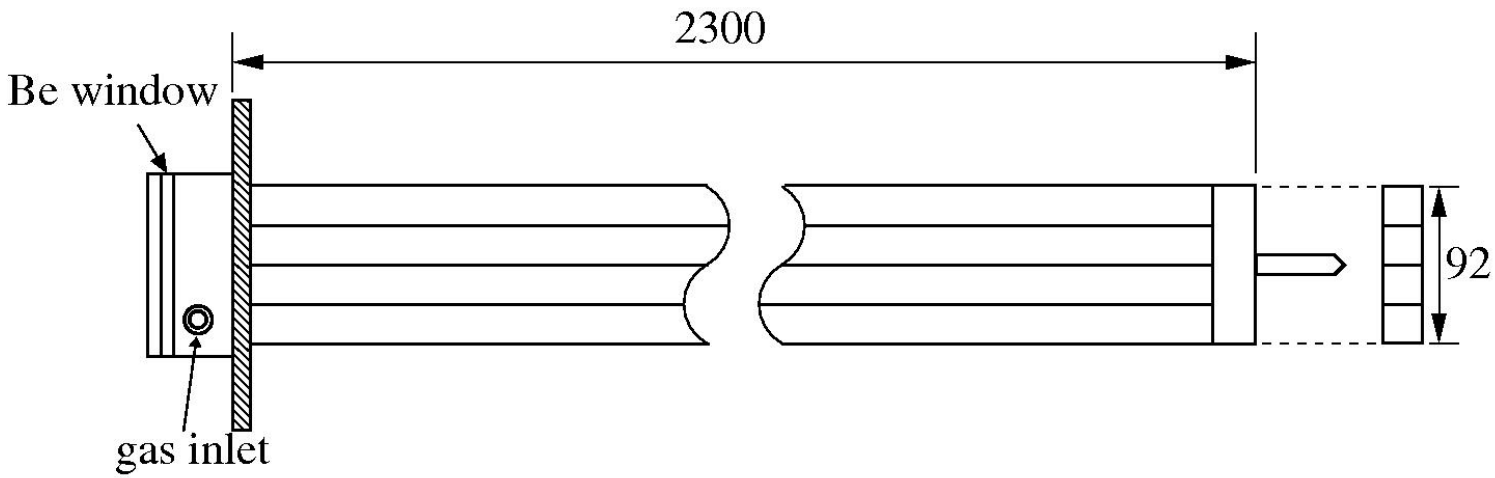
N_e : electron density

$\Leftrightarrow$ He gas density



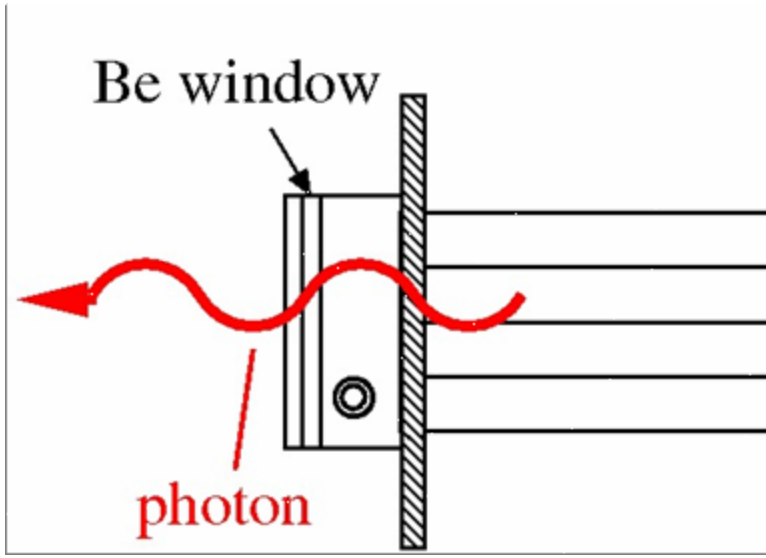
He gas container

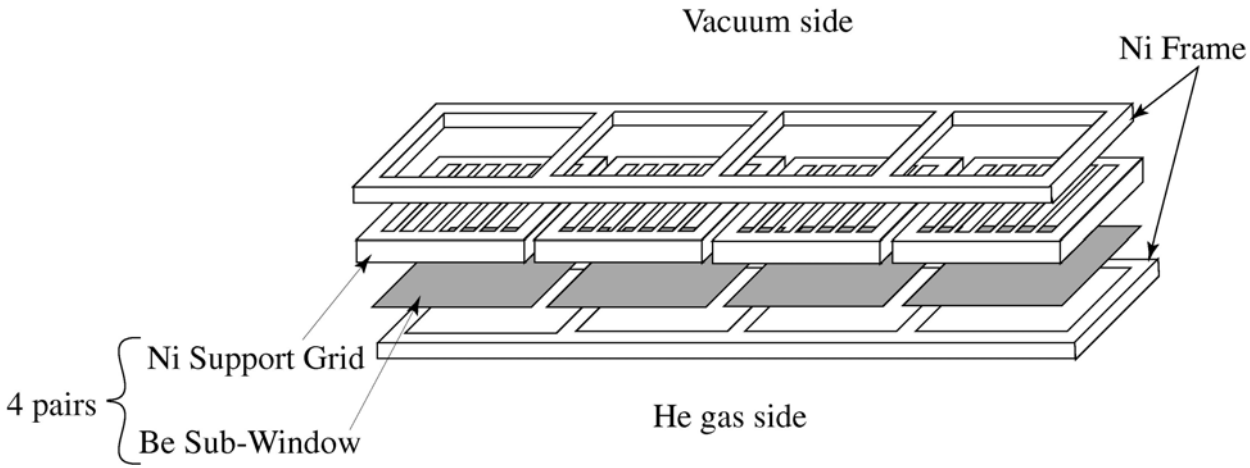
- 4 stainless steel pipes covered with high purity(5N) Al sheet
- One end: supported by 3 Kevlar cords
- Other end: connected to thermal exchanger
- High thermal Uniformity



X-ray window

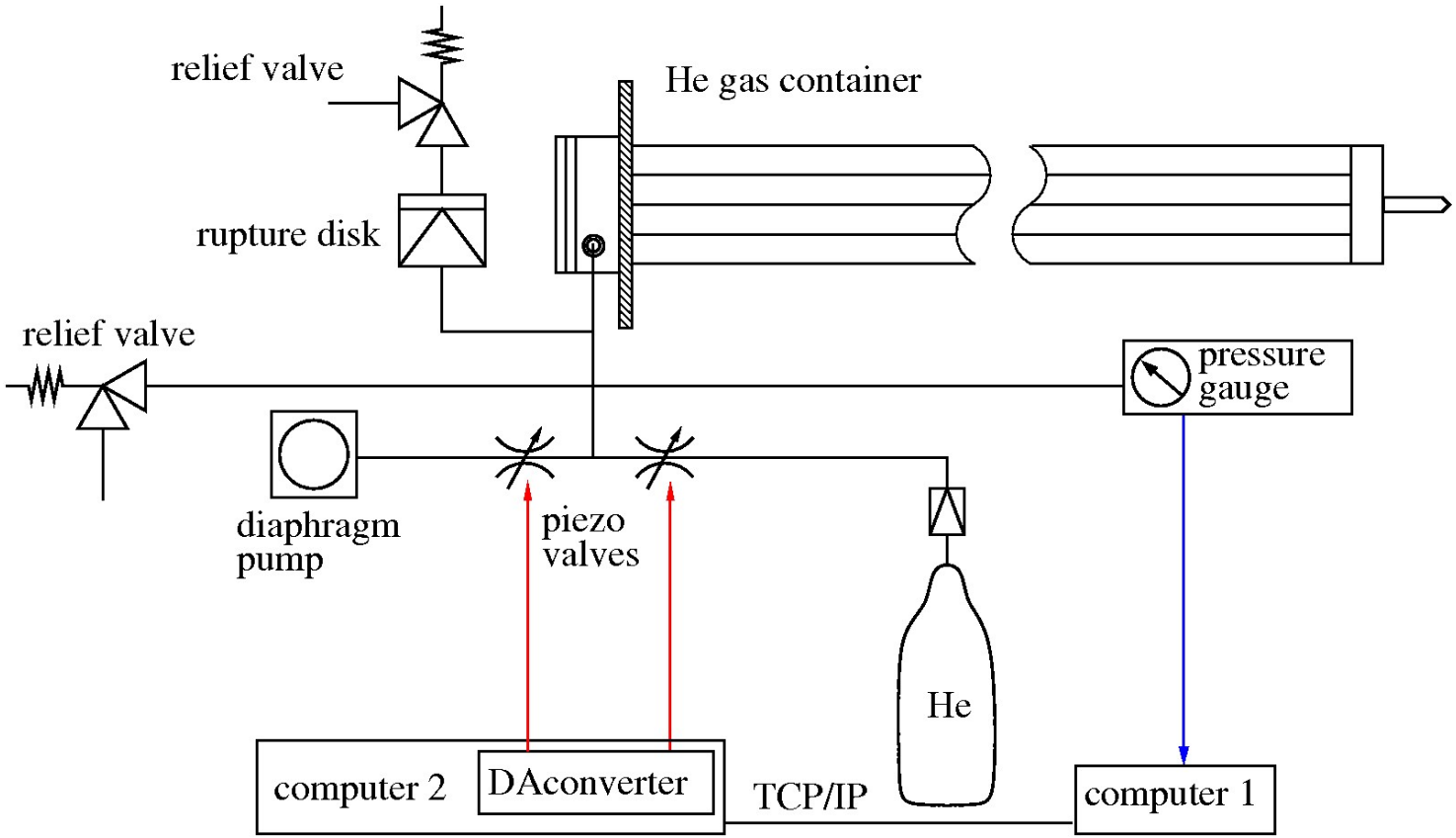
- Transparency > 80% ($E_{x\text{-}ray}$>3keV)
- Endurance up to 0.3 MPa



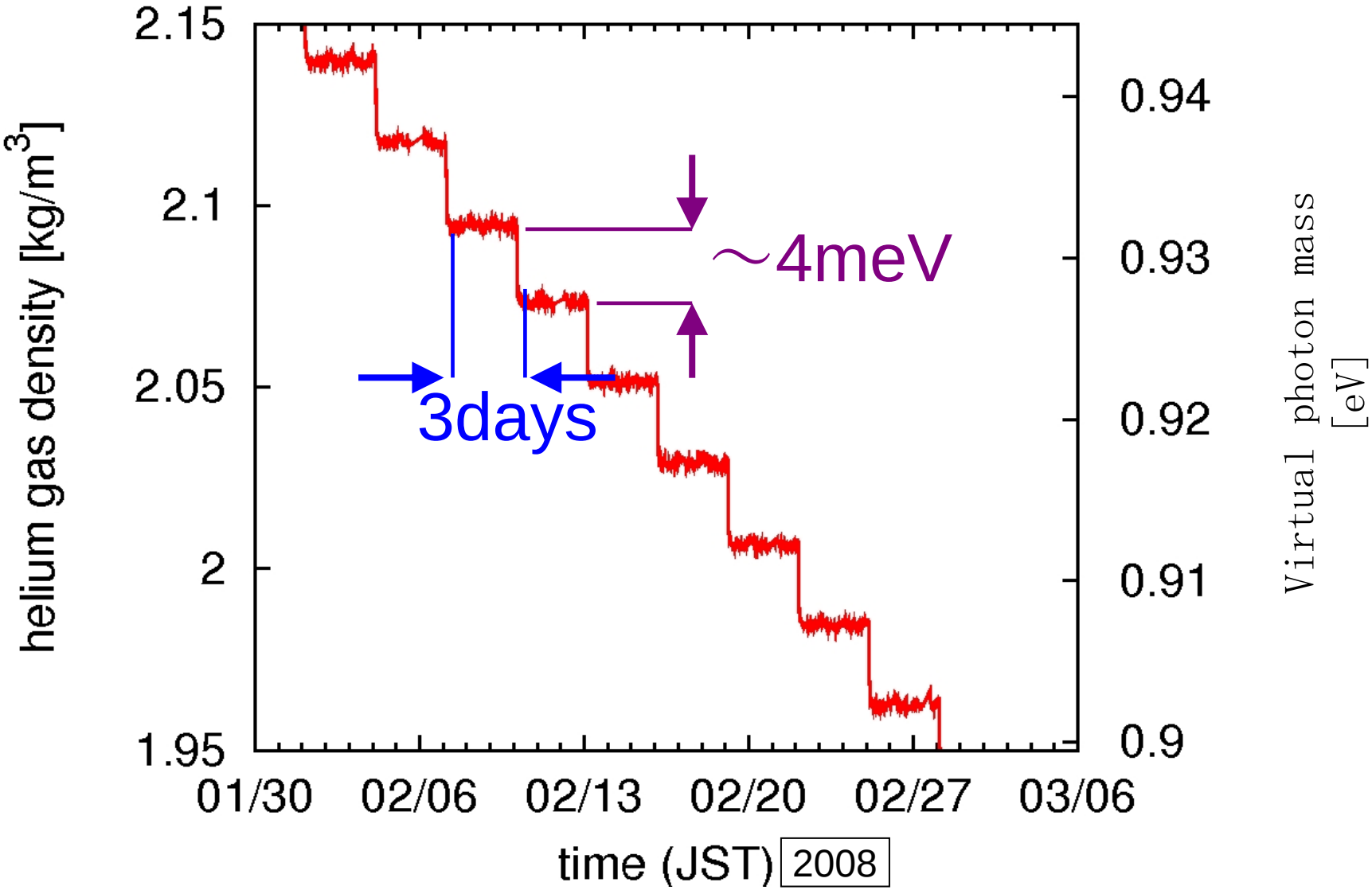


Gas handling system

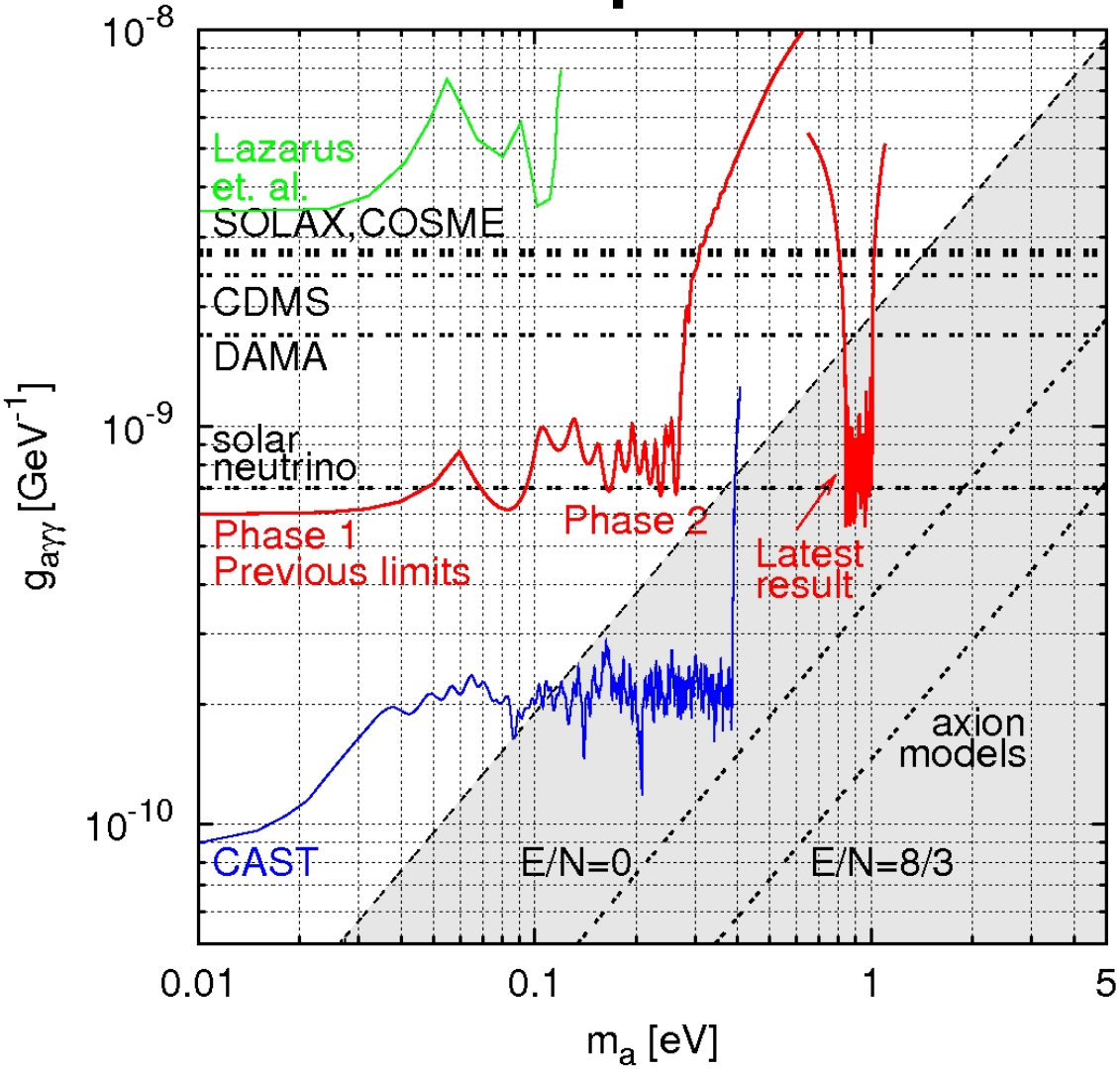
- Piezo valves regulated by PC to control gas flow
- Pressure gauge to monitor pressure in the container



Example of gas handling

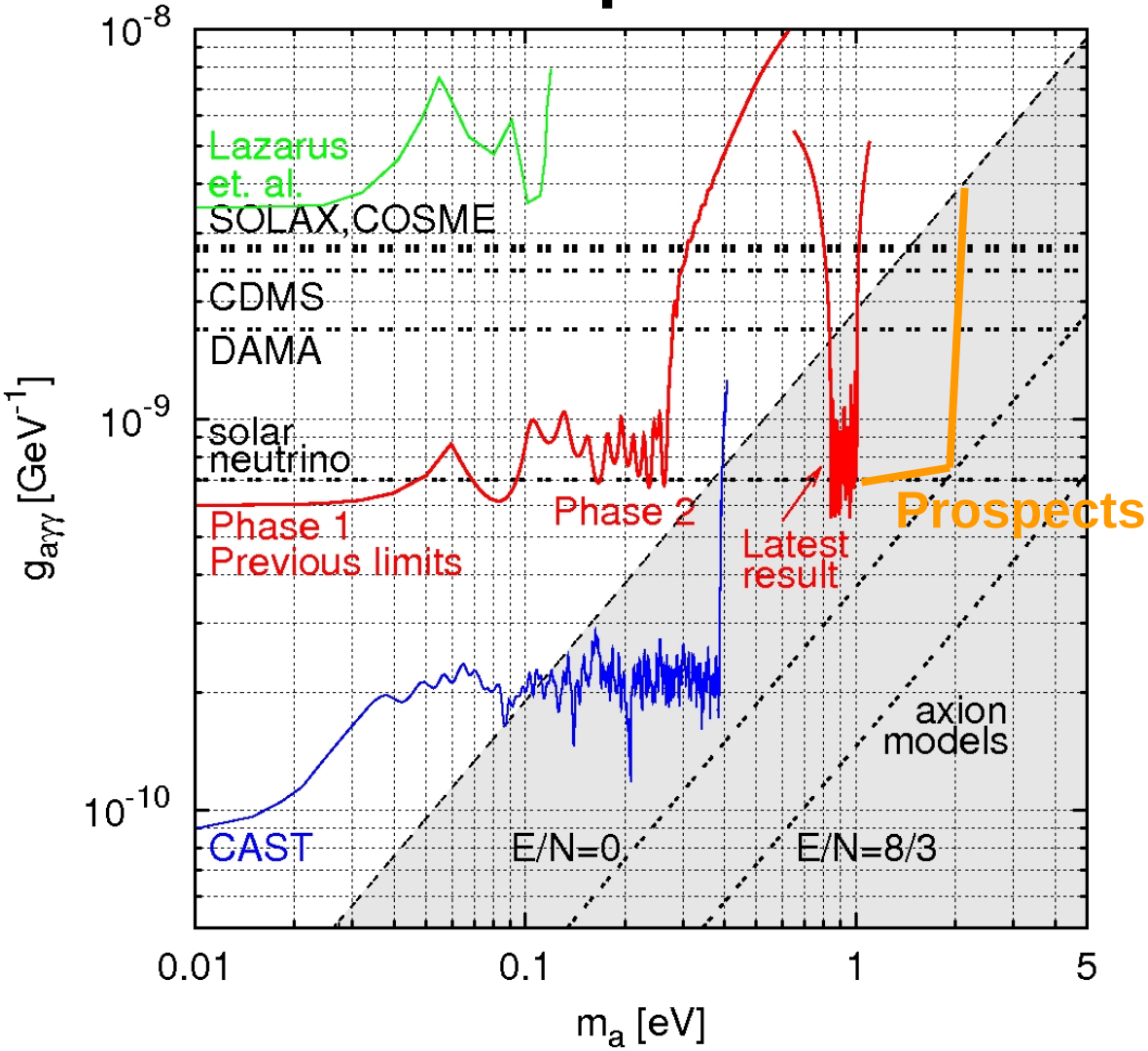


Prospects



Ref: Y. Inoue et al., Physics Letters B 668 (2008) 93

Prospects



Ref: Y. Inoue et al., Physics Letters B 668 (2008) 93

Hidden sector photon

- Extensions of the Standard Model:
  - Additional U(1) gauge symmetry
- Mixing with a photon

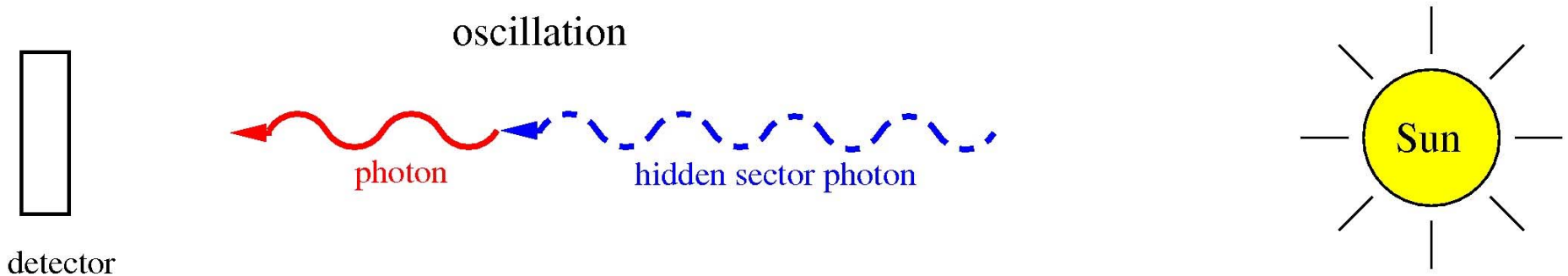
$$L_{\text{int}} = -\frac{1}{2}\chi F_{\mu\nu} B^{\mu\nu}$$

χ : mixing strength

$F^{\mu\nu}$: photon field strength

$B^{\mu\nu}$: hidden photon field strength

Ref: S. N. Gninenko et al., Phys. Lett.B 664 (2008) 180



Hidden sector photon

- In vacuum

$$P_{\gamma' \to \gamma}(\omega) = 4\chi^2 \sin^2\left(\frac{\Delta q\, l}{2}\right)$$

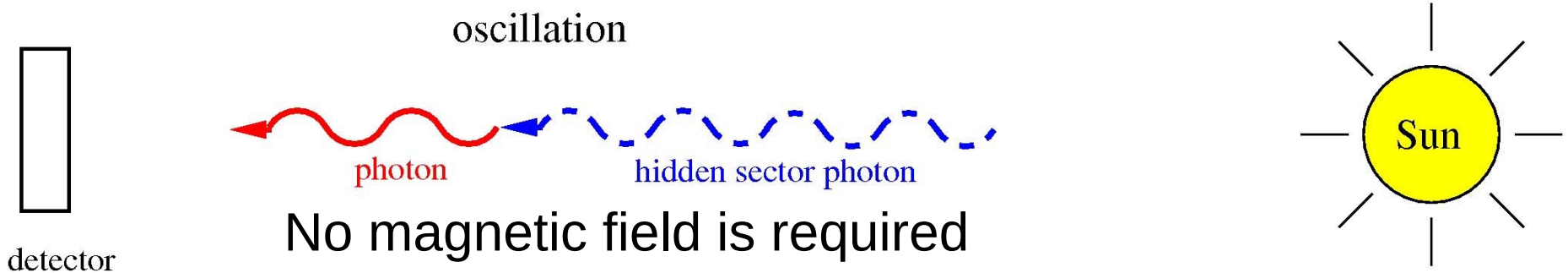
l : vacuum region length

ω : photon energy

$m_{\gamma'}$: hidden photon mass

$$\Delta q = \omega - \sqrt{\omega^2 - m_{\gamma'}^2} \approx \frac{m_{\gamma'}^2}{2\omega} \quad (\text{for } m_{\gamma'} << \omega)$$

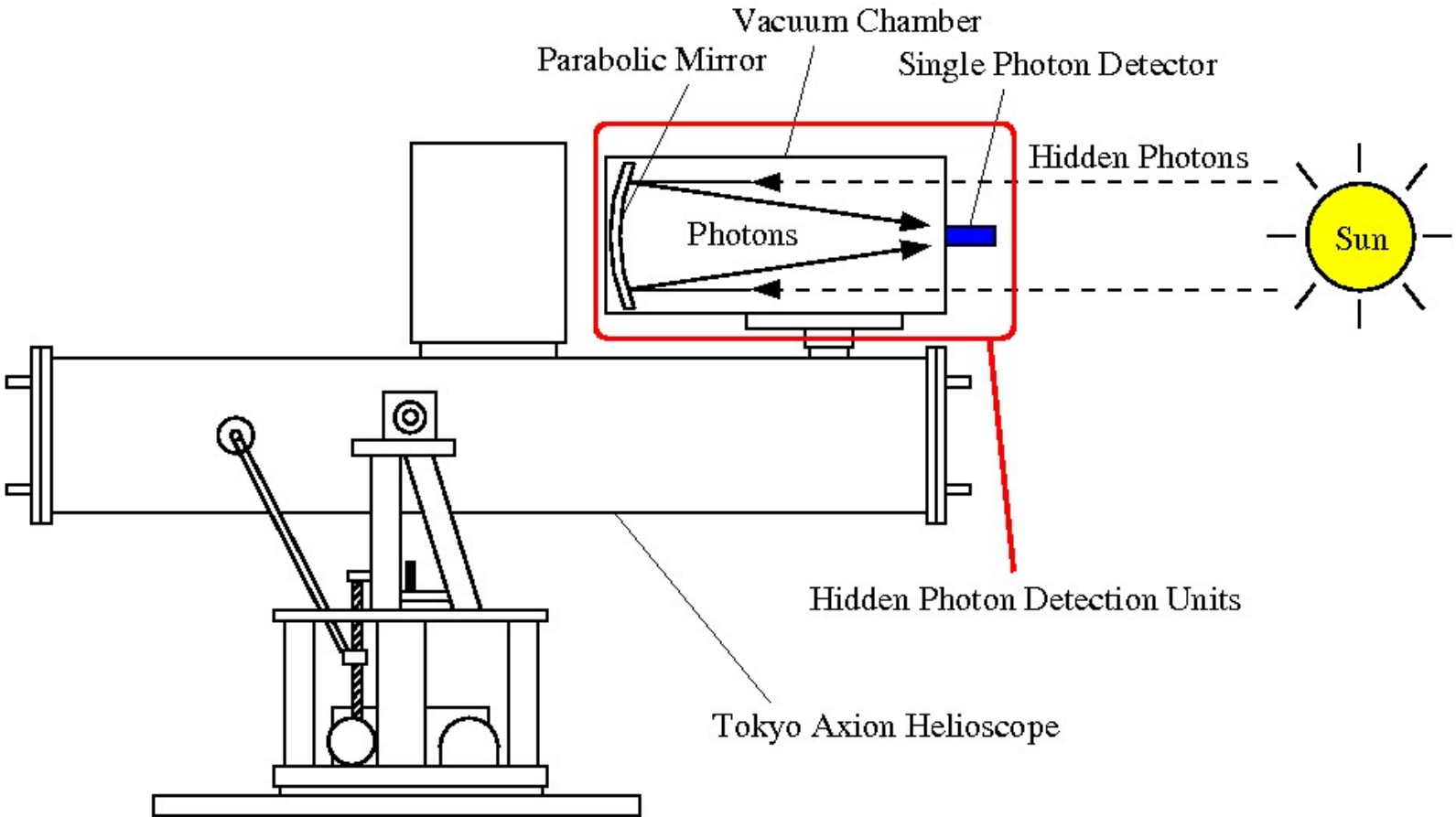
Ref: S. N. Gninenko et al., Phys. Lett.B 664 (2008) 180



No magnetic field is required

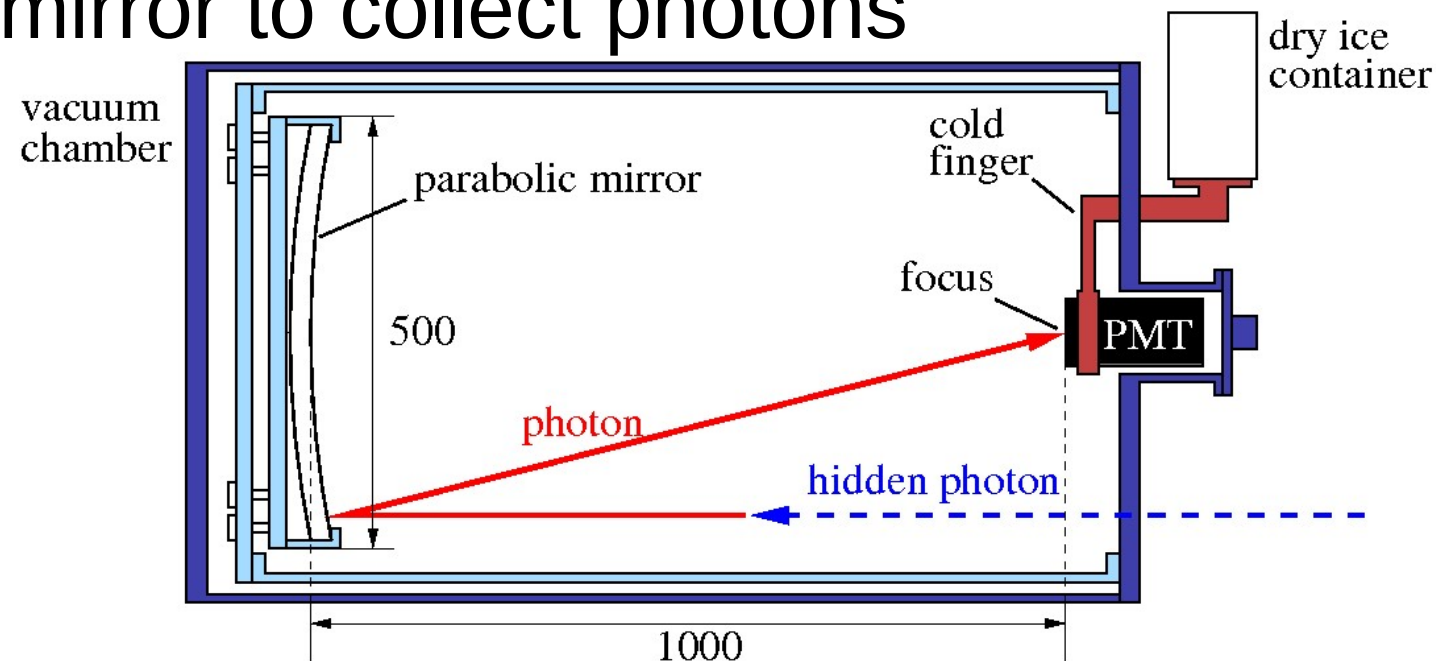
Search for hidden sector photons

- Using the tracking system of Sumico
- Additional detection unit
  - Vacuum chamber, mirror, photomultiplier

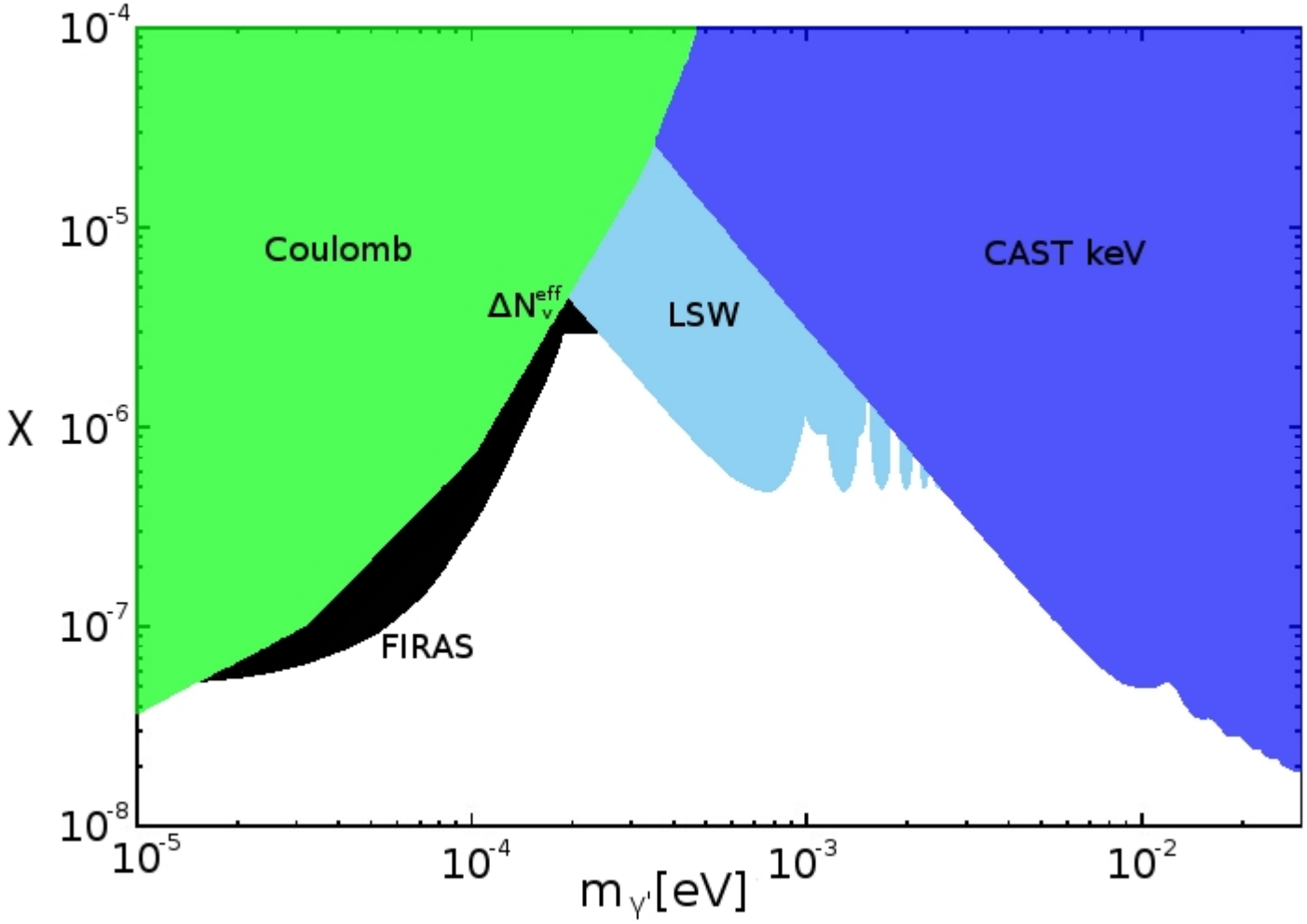


Outline

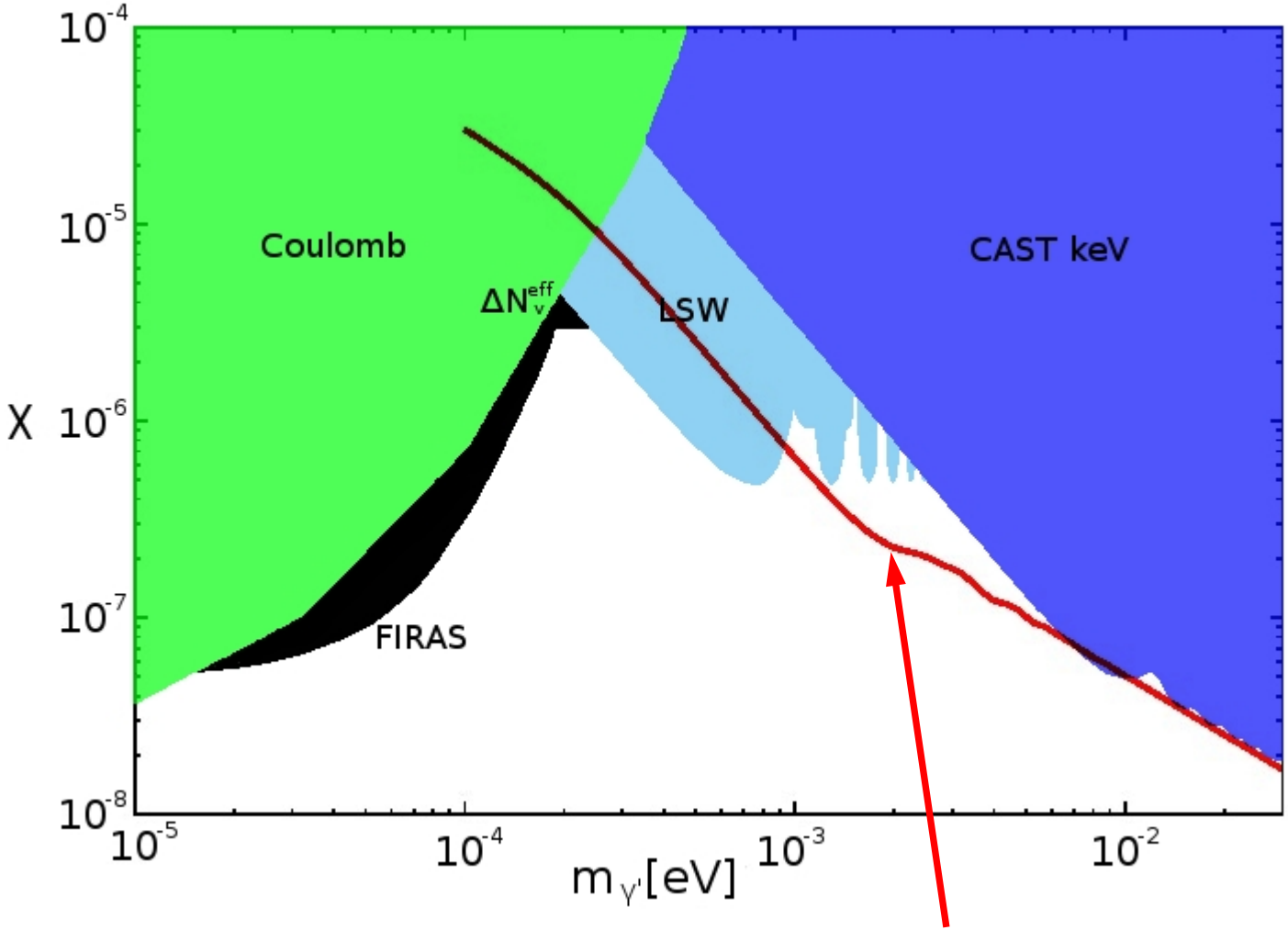
- PMT operated at low temperature to reduce dark current
  - Example: Hamamatsu R329-02 @ -30°C
    - Dark current ~ 10 Hz
      (Several times smaller than dark current at room temperature)
- Parabolic mirror to collect photons



prospects


Coulomb
ΔN_ν^{eff}
LSW
CAST keV
FIRAS
X
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
$m_{\gamma'}$[eV]

prospects



BG = 10Hz, p << 10Pa, S = 0.2m^2 ,
L = 1m, R = 90%, t = 10^6 s

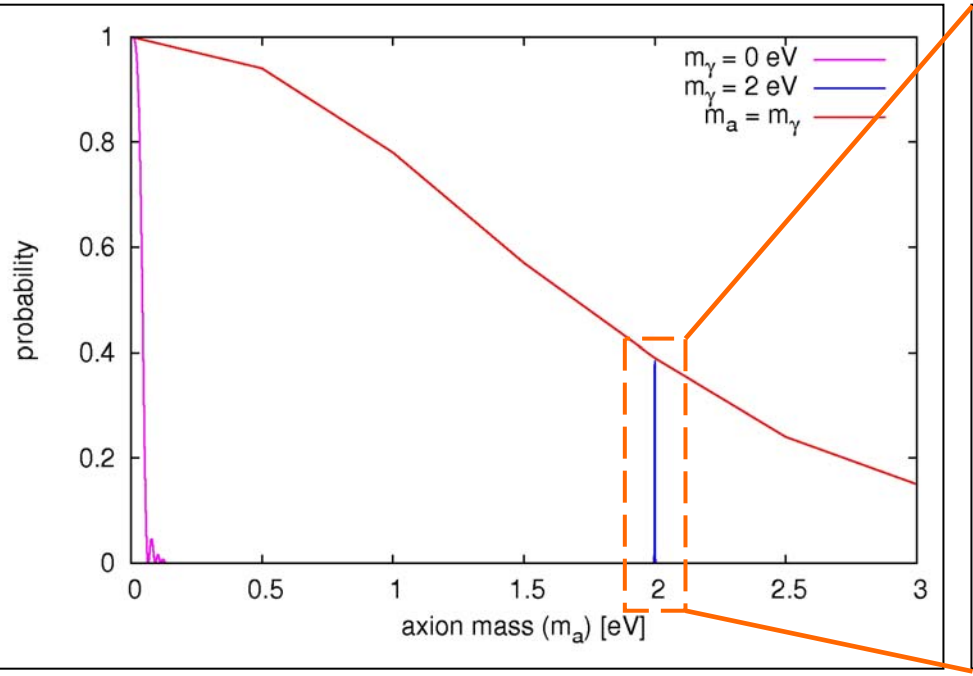
Summary

- The Search for solar axions with mass over 1 eV is almost ready.
- Next plan is the search for hidden sector photons. Some additional equipments are under preparation.

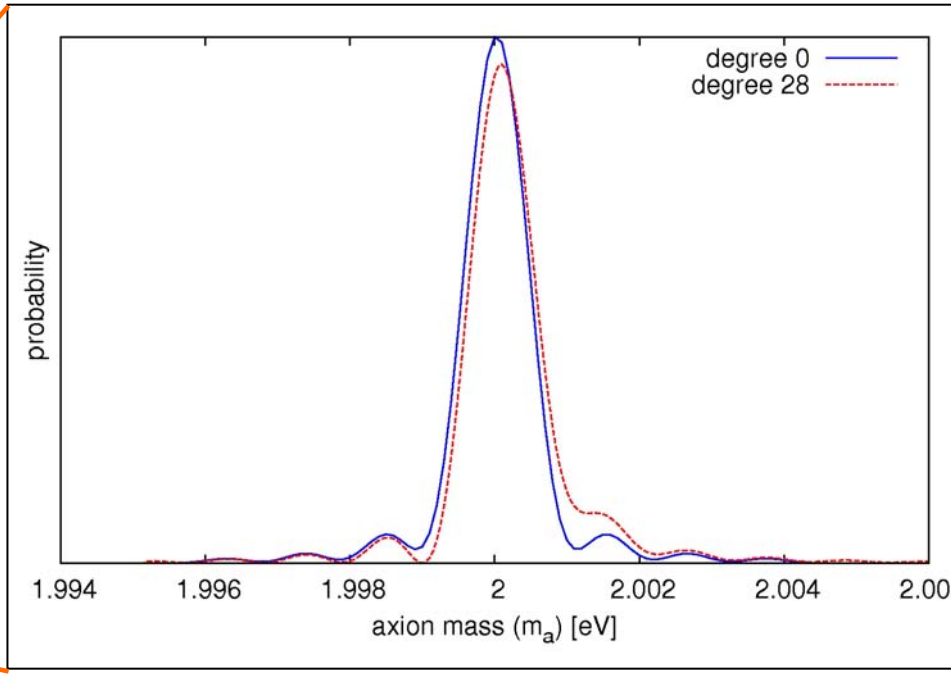
Thank you.

Effects of gas

Damping



Density gradient



- Sensitivity decreases with denser gas because of X-ray absorption
- Sensitivity is also affected by gravity because of density gradient

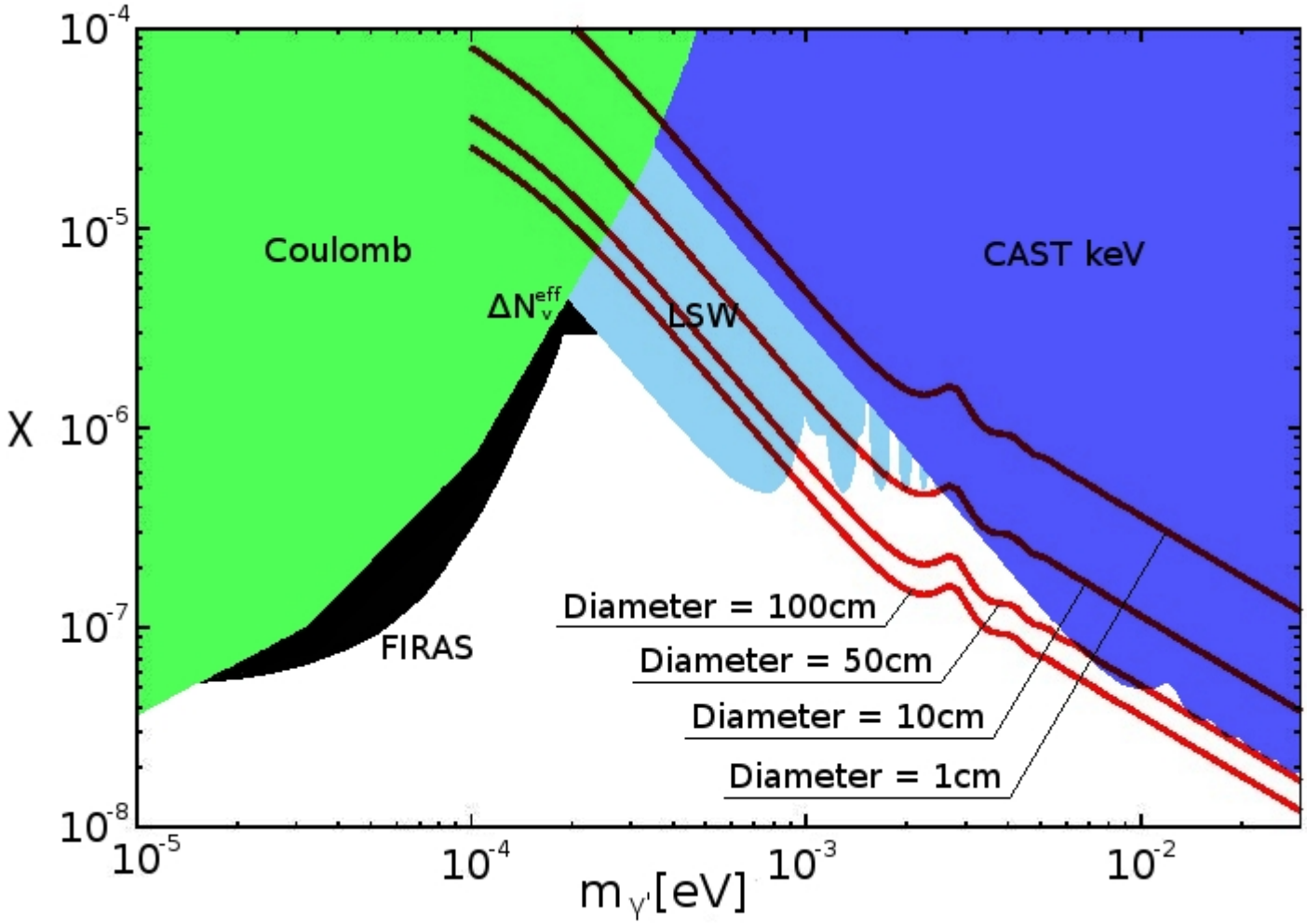
Contribution of parameters

$$\frac{\mathrm{d}\Psi_{\mathrm{x}}}{\mathrm{d}E} = \frac{\mathrm{d}\Phi_{\mathrm{a}}}{\mathrm{d}E} \times P_{a\to\gamma} \times \varepsilon \times S \times T$$

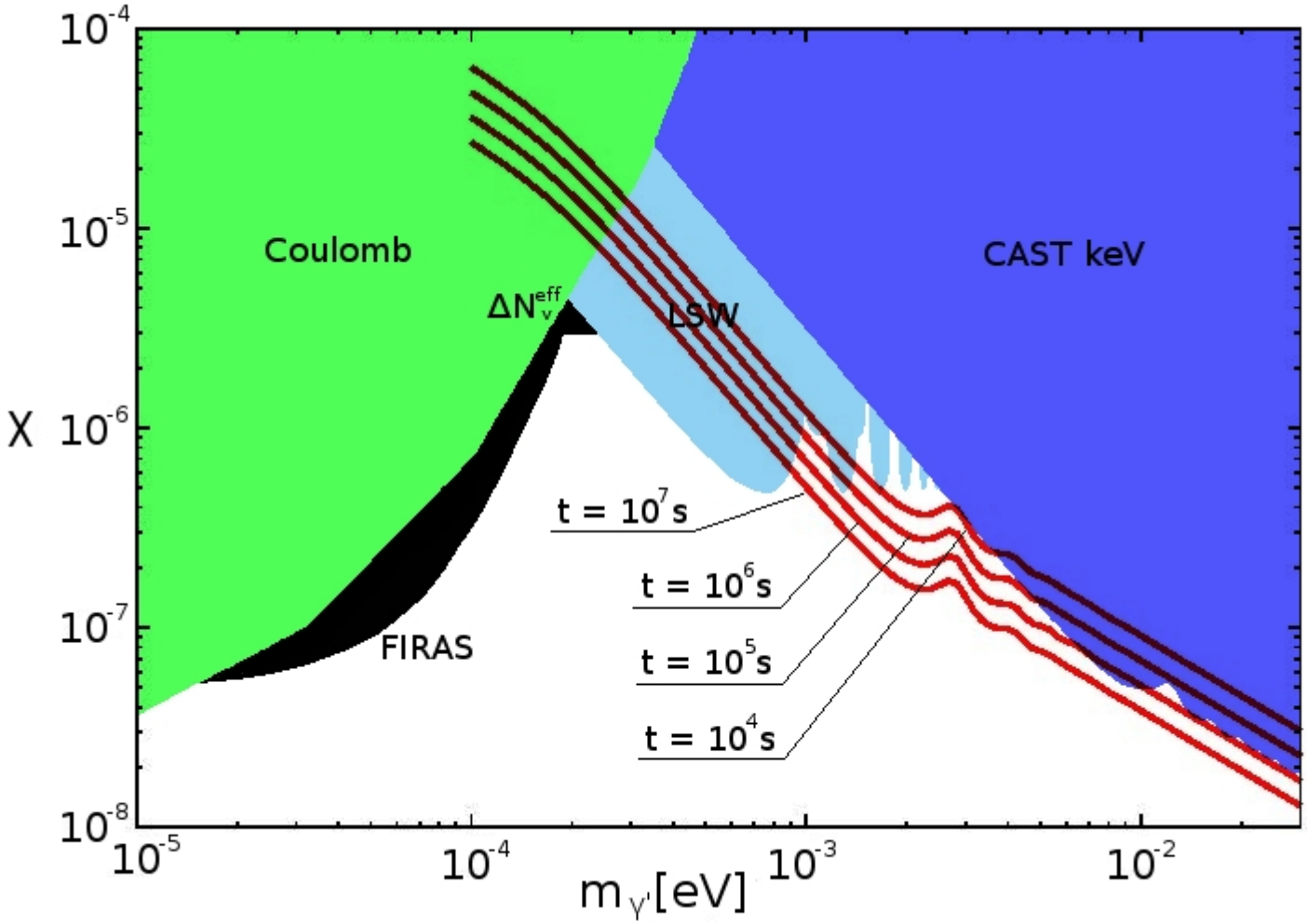
$$\frac{\mathrm{d}\Phi_{\mathrm{a}}}{\mathrm{d}E} \propto g_{a\gamma\gamma}^{2} \qquad P_{a\to\gamma} \propto (g_{a\gamma\gamma} BL)^{2}$$

$$g_{a\gamma\gamma} < (BL)^{-\frac{1}{2}} (ST)^{-\frac{1}{4}} N^{\frac{1}{8}}$$

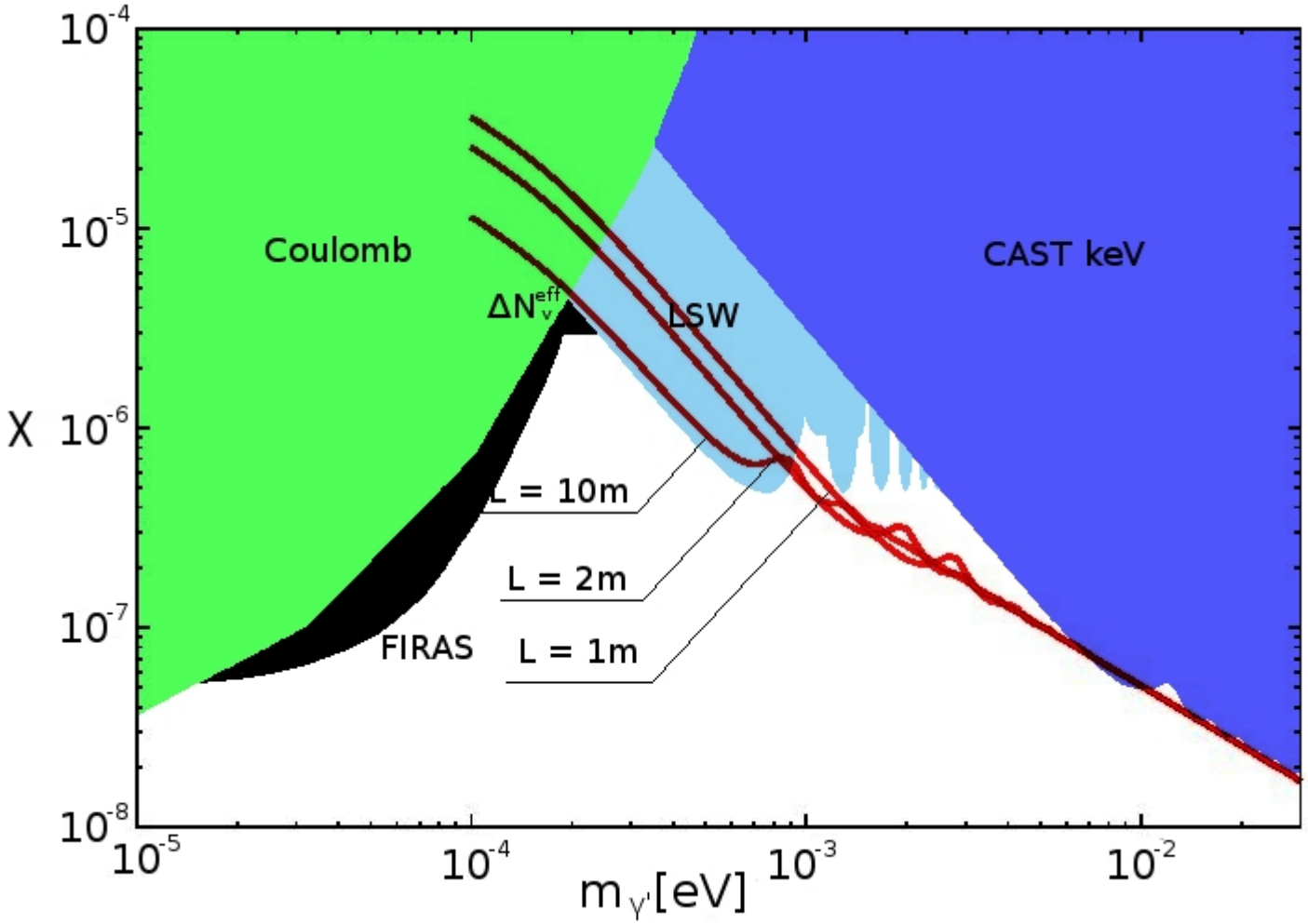
Various dependence



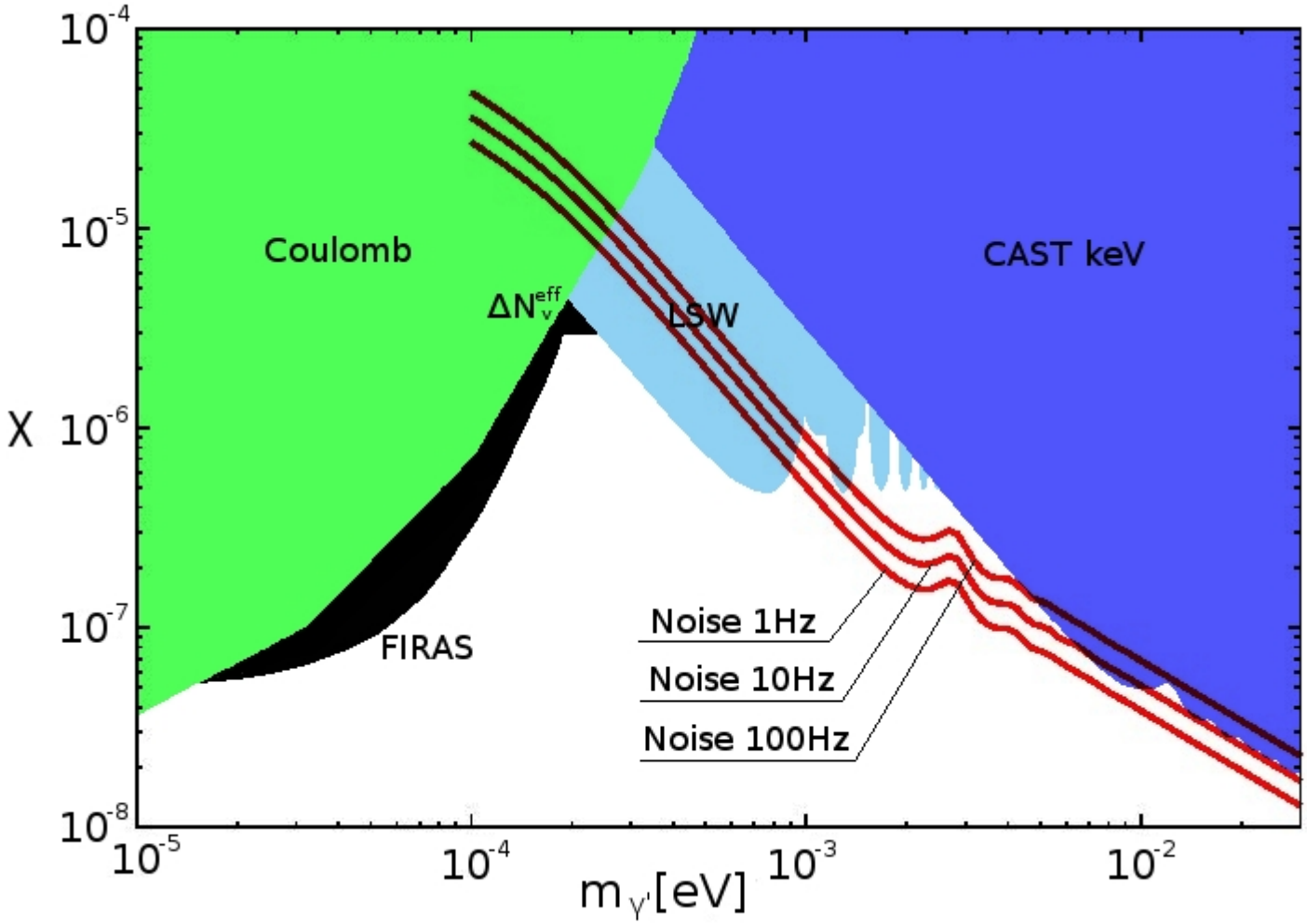
Various dependence



Various dependence



Various dependence



Various dependence