# Reports on IDM 2024

Hinata Takidera (D1)
Department of Physics, The University of Tokyo

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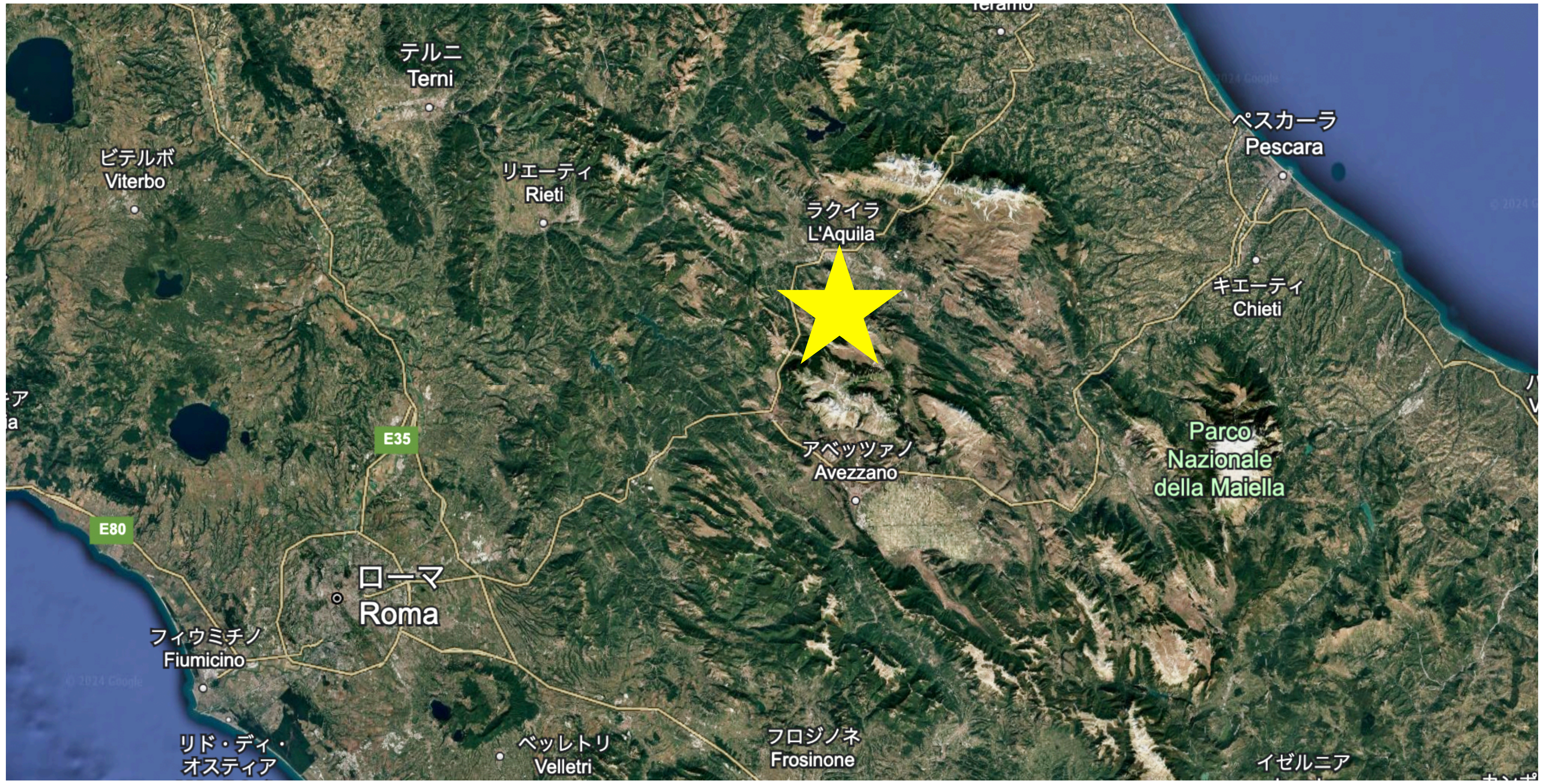
# Contents

# IDM 2024

**IDM 2024 (Identification of Dark Matter 2024)**

- Aim to draw a complete picture of the status of dark matter searches
- July 8th - 12th, 2024
- L’Aquila, Italy
- Hold once every 2 years



# IDM 2024




CONSIGLIO REGIONALE


15TH
JUL 8TH–12TH 2024
L'AQUILA, ITALY
INTERNATIONAL WORKSHOP ON THE IDENTIFICATION OF DARK MATTER
IDM 2024
SALVE
ALOHA
WILLKOMMEN
WELCOME
BENVENUTO
BONVENON
BON BINI

# References



LIDA

- J. Heinze *et al*., First Results of the Laser-Interferometric Detector for Axions (LIDA), Phys. Rev. Lett. **132**, 191002 (2024).

DarkGEO

- J. Heinze *et al*., DarkGEO: a large-scale laser-Interferometric axion detector, New J. Phys. **26**, 055002 (2024).

CAST

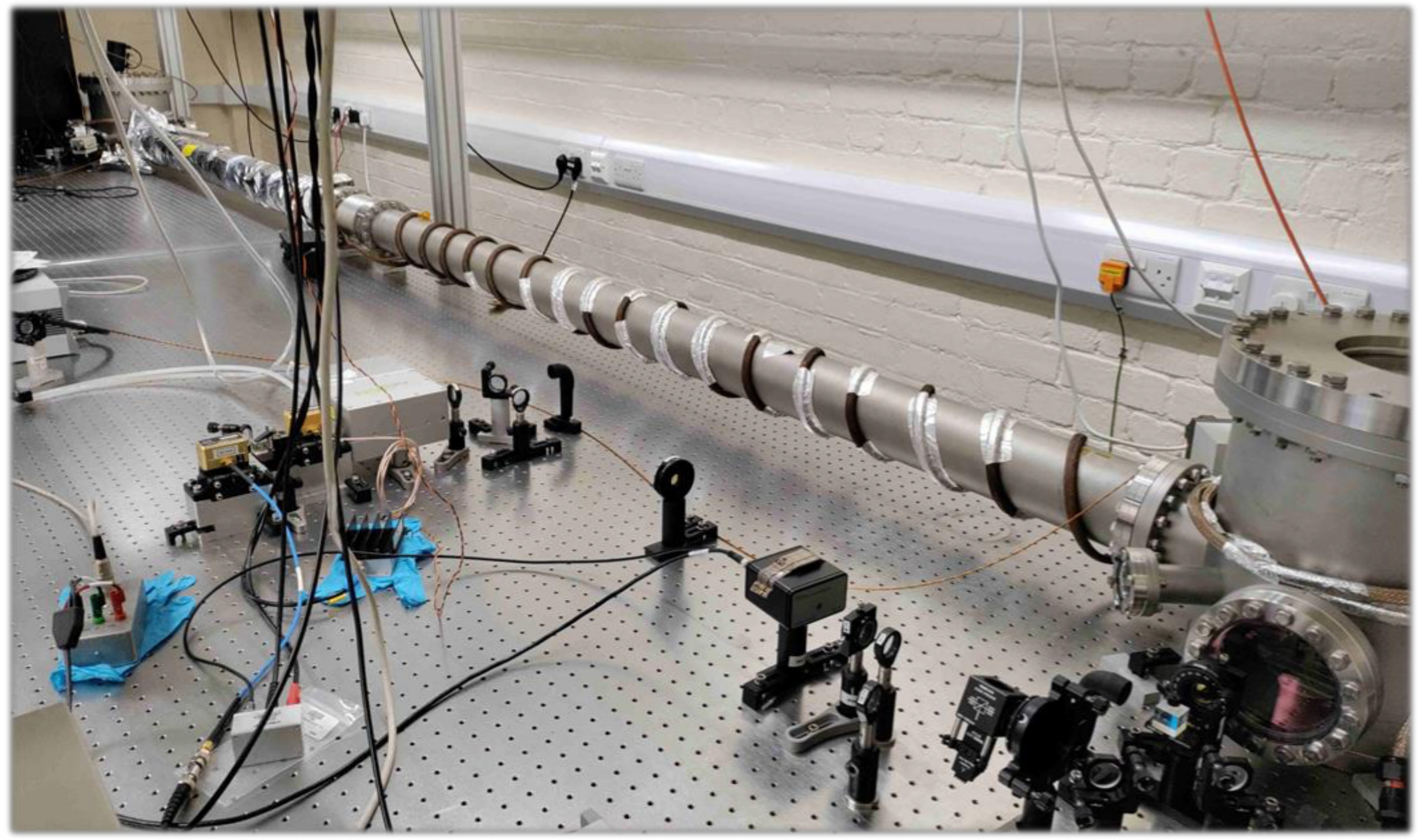
- CAST Collaboration, New CAST limit on the axion-photon interaction, Nat. Phys. **13**, 584 (2017).
- CAST Collaboration, A new upper limit on the axion-photon coupling with an extended CAST run with a Xe-based Micromegas detector, arXiv:2406.16840.

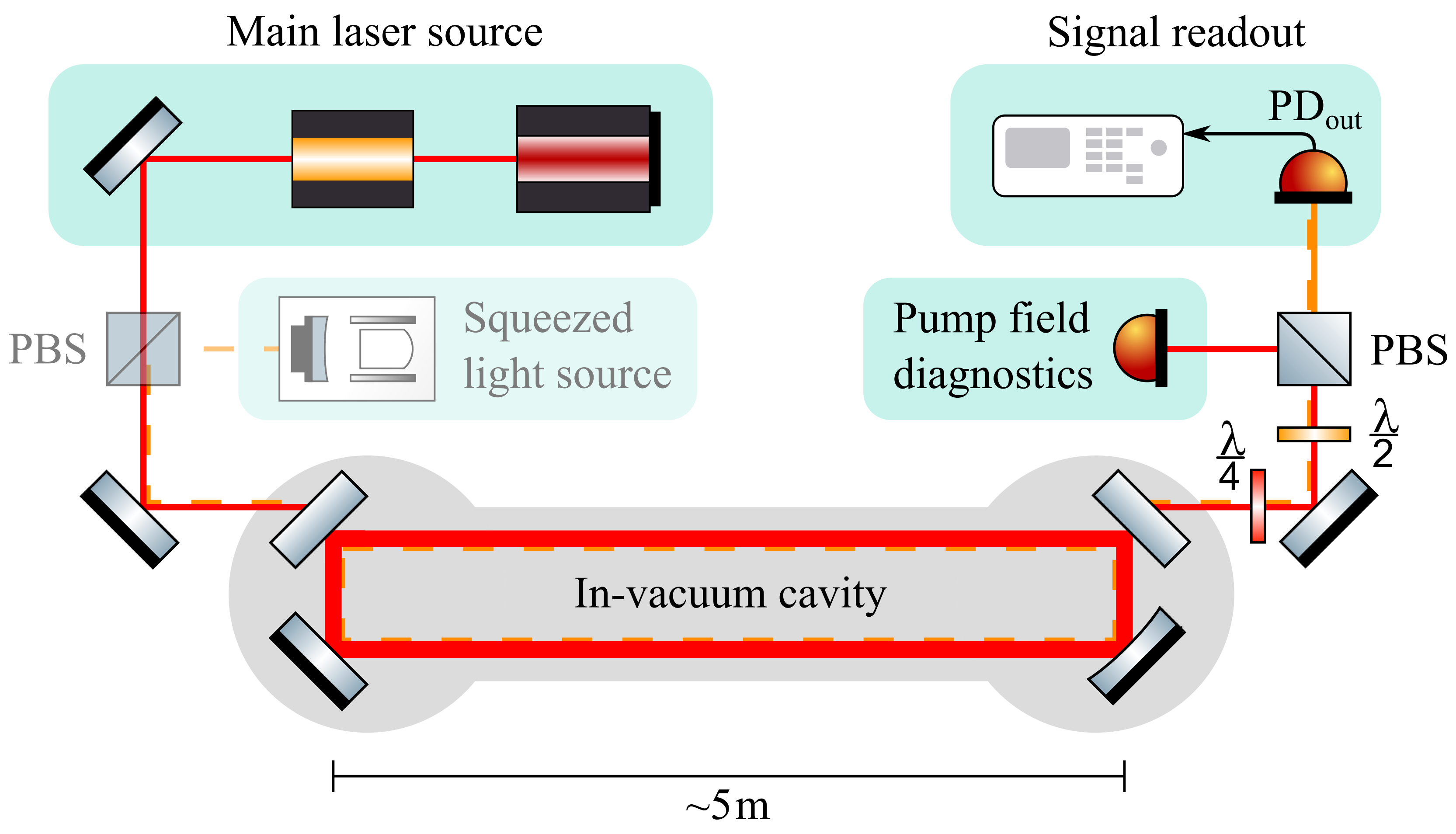
# LIDA

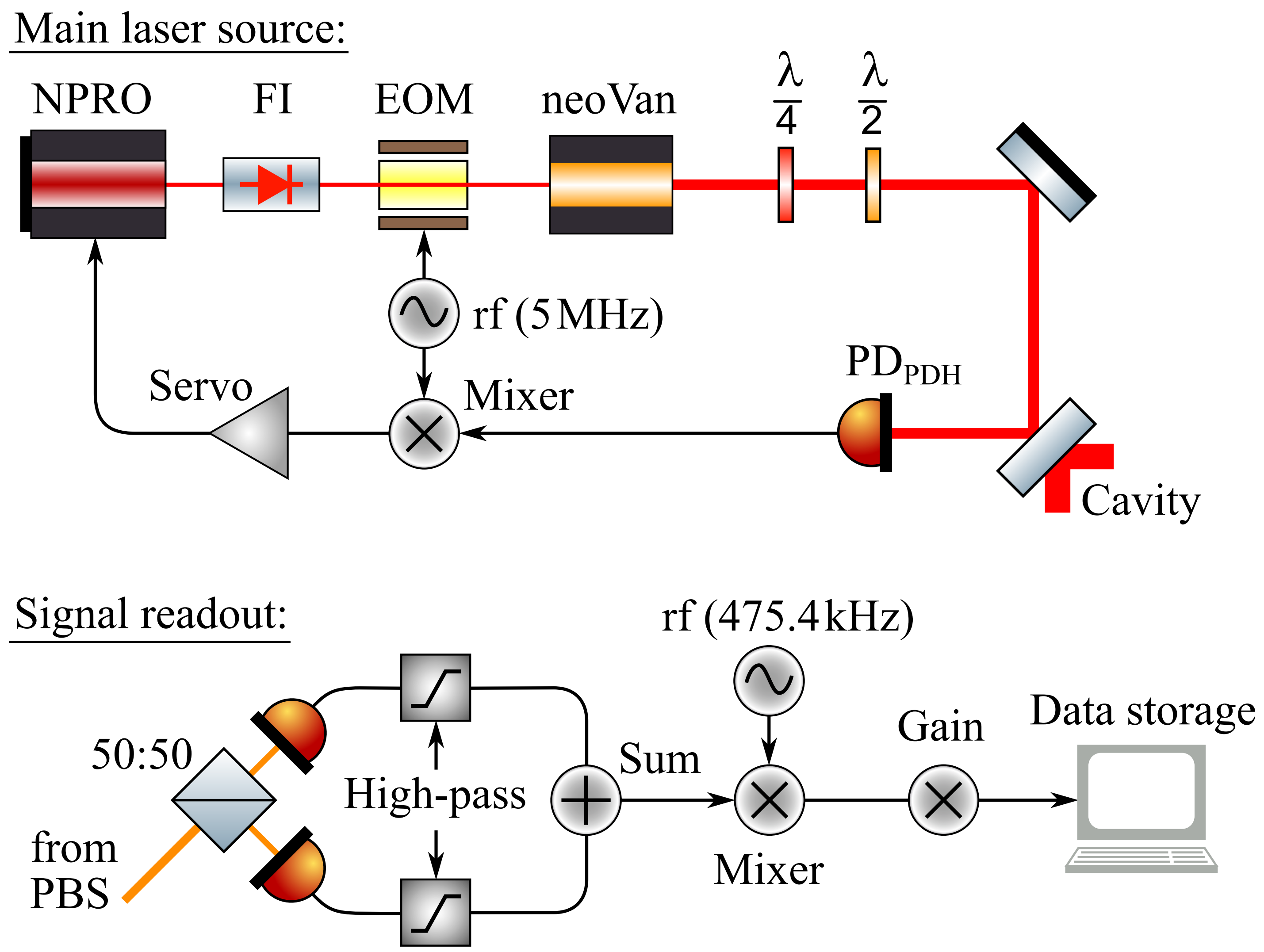


**LIDA (Laser-Interferometric Detector for Axions)**

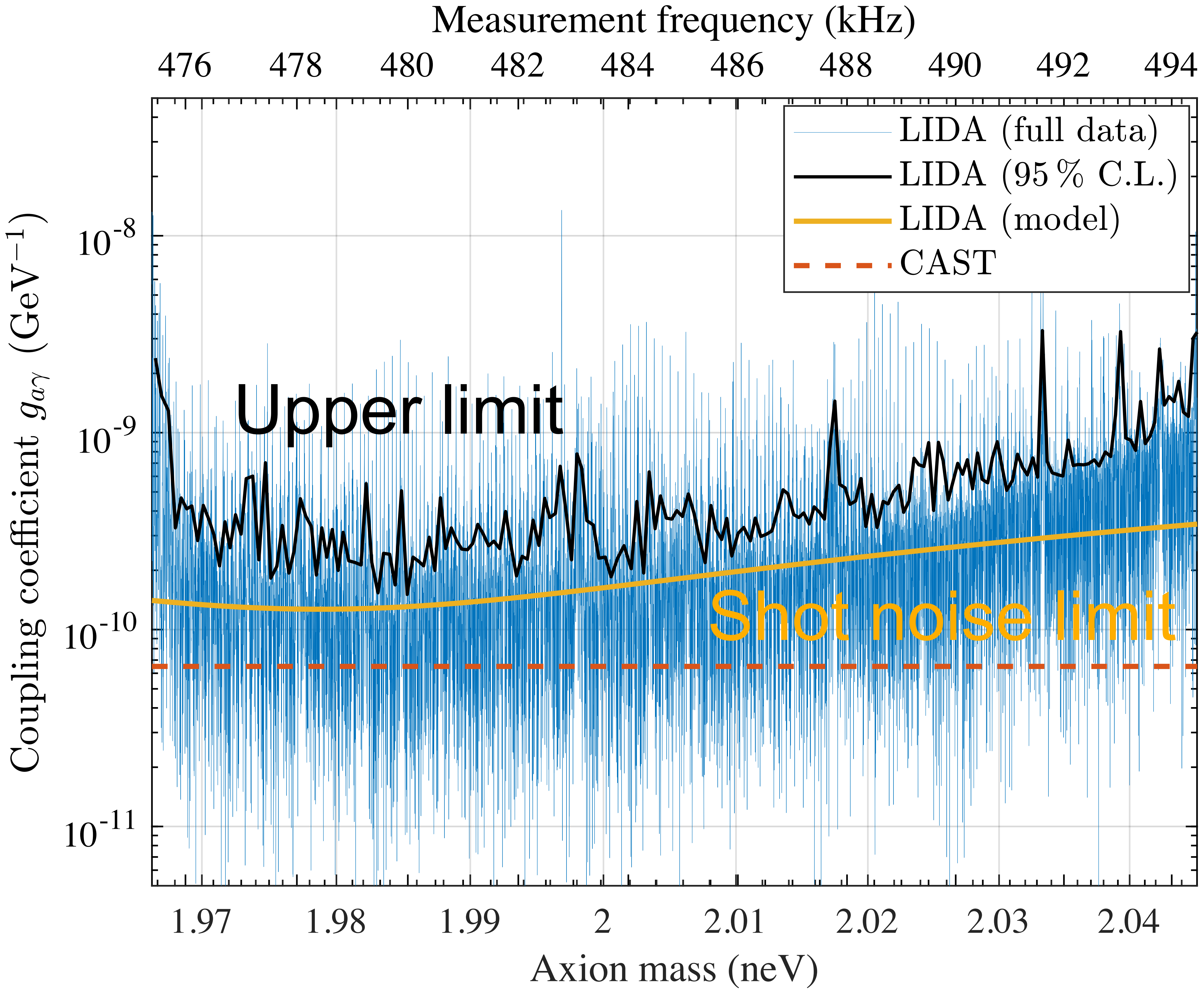
- Dark matter axion search with laser interferometer technique
- Linear polarization
- Aim to detect p-polarization (Axion signal)





# 1st science run

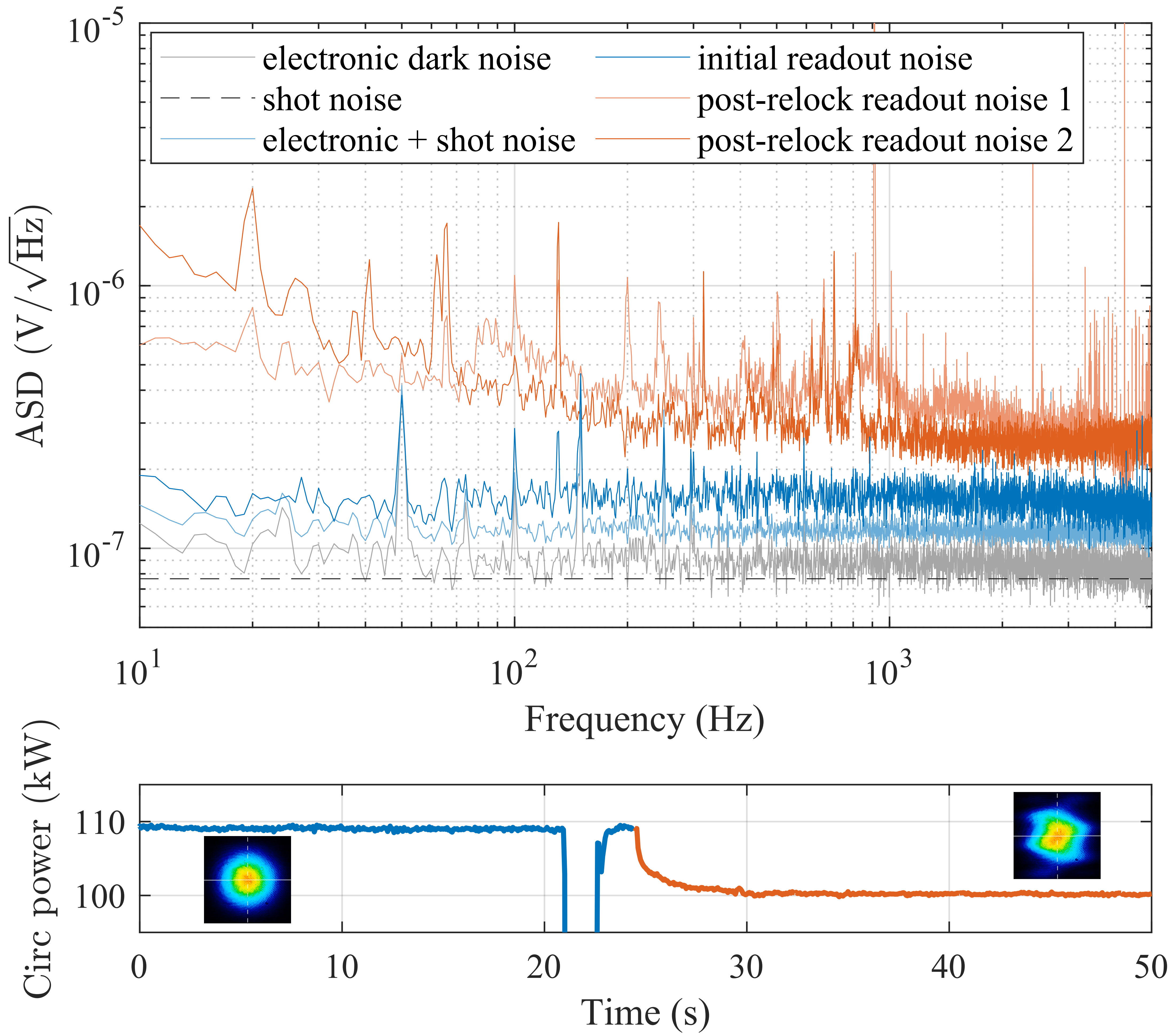



| | |
|---|---|
| Input pump power | 12 W |
| Intra-cavity power | 118 kW |
| Measurement time | 85 h |
| Detuning | 478 kHz |
| Finesse (s-pol.) | 74220 |
| Finesse (p-pol.) | 2220 |

Peak sensitivity $g_{a\gamma} = 1.51 \times 10^{-10}\ \mathrm{GeV}^{-1}$ for $m_a = 1.985\ \mathrm{neV}$ (95% C.L.)

# Discussion






Sensitivity is limited by

- electronic dark noise
- shot noise
- technical laser noise

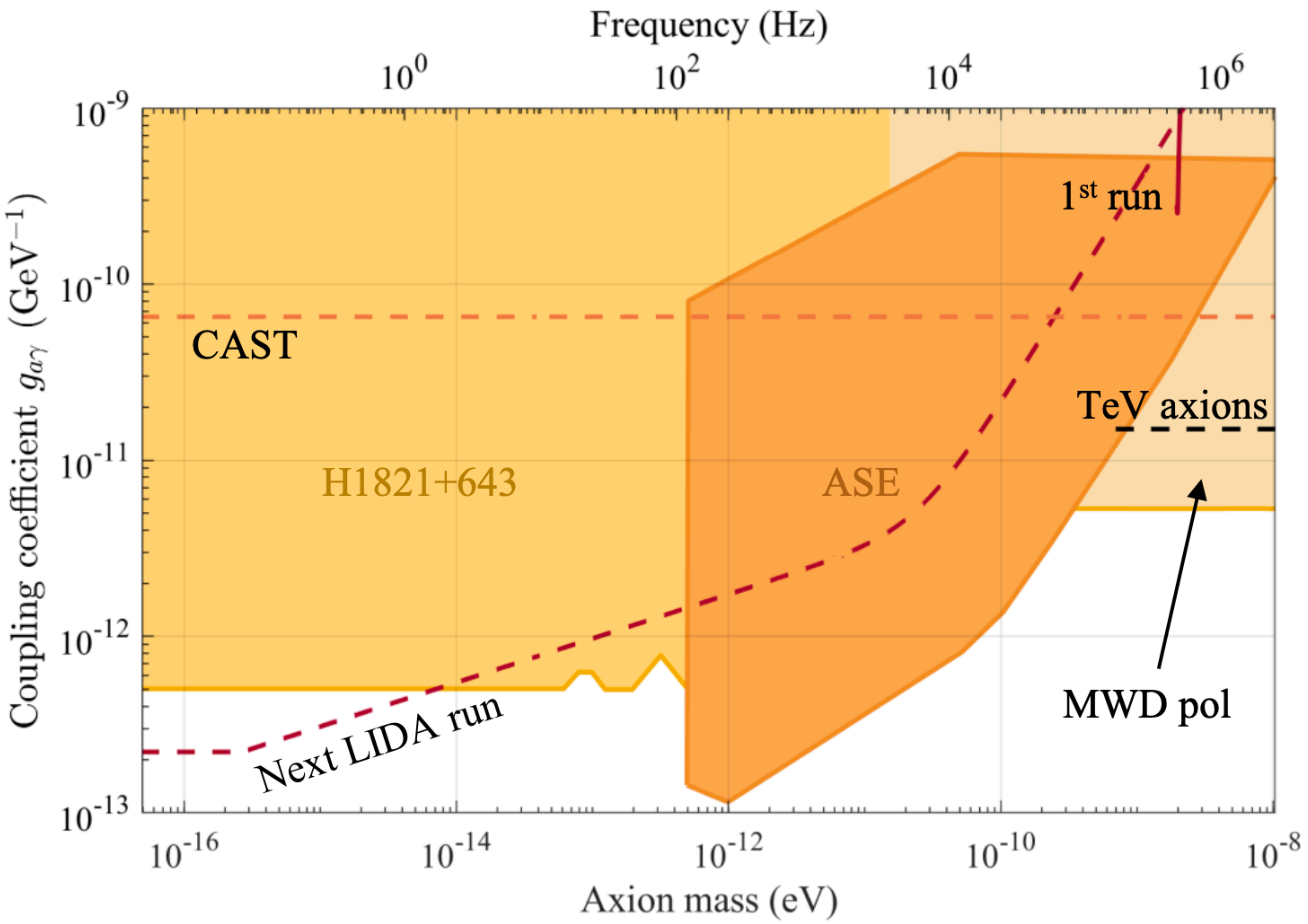
If disturbed, the cavity changes its state correlating with

- a reduction in circulating power
- a distortion of the transmitted field
- higher readout noise

Transmitted light is elliptically polarized, if s-polarization is injected

# Next run



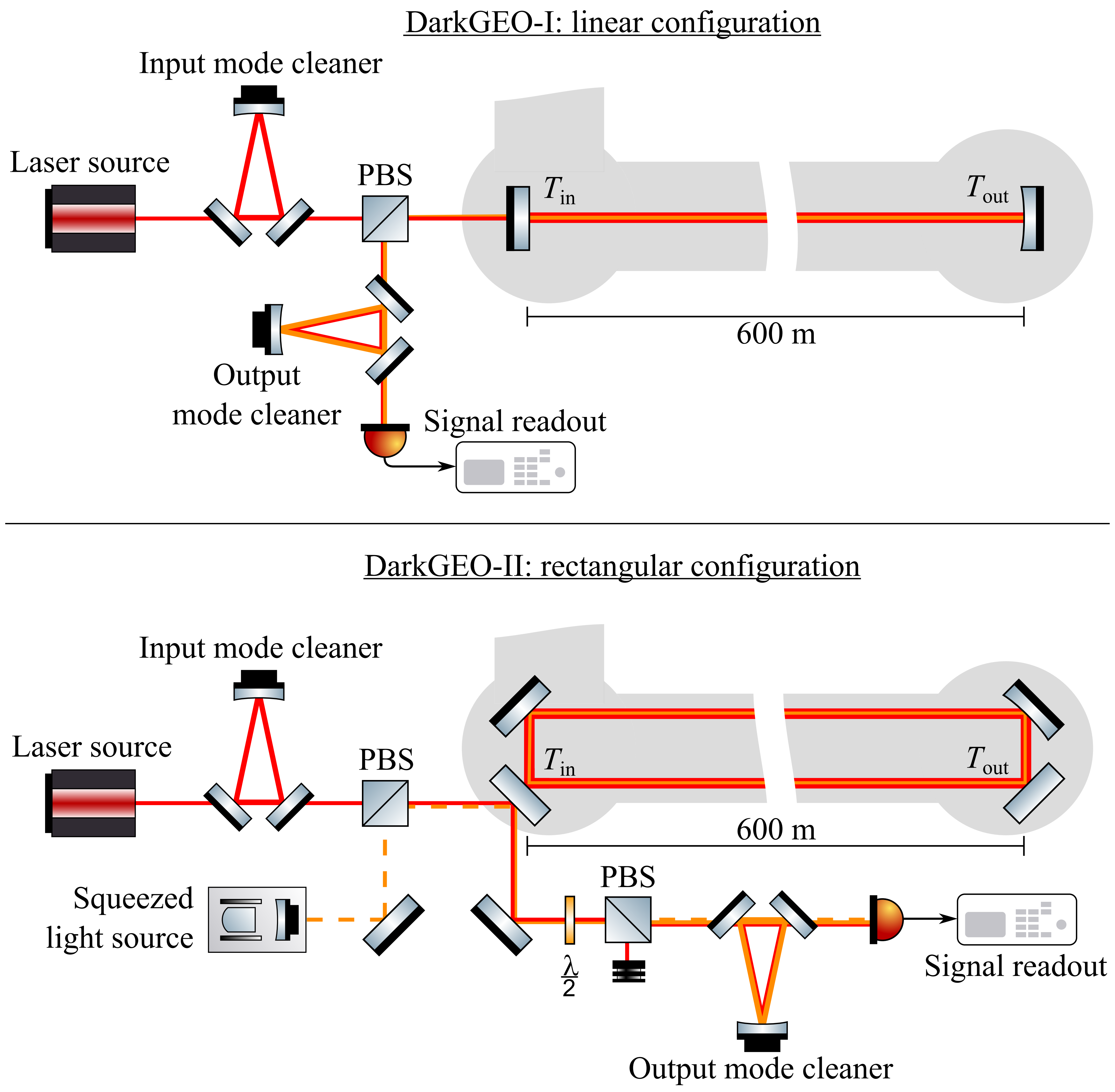


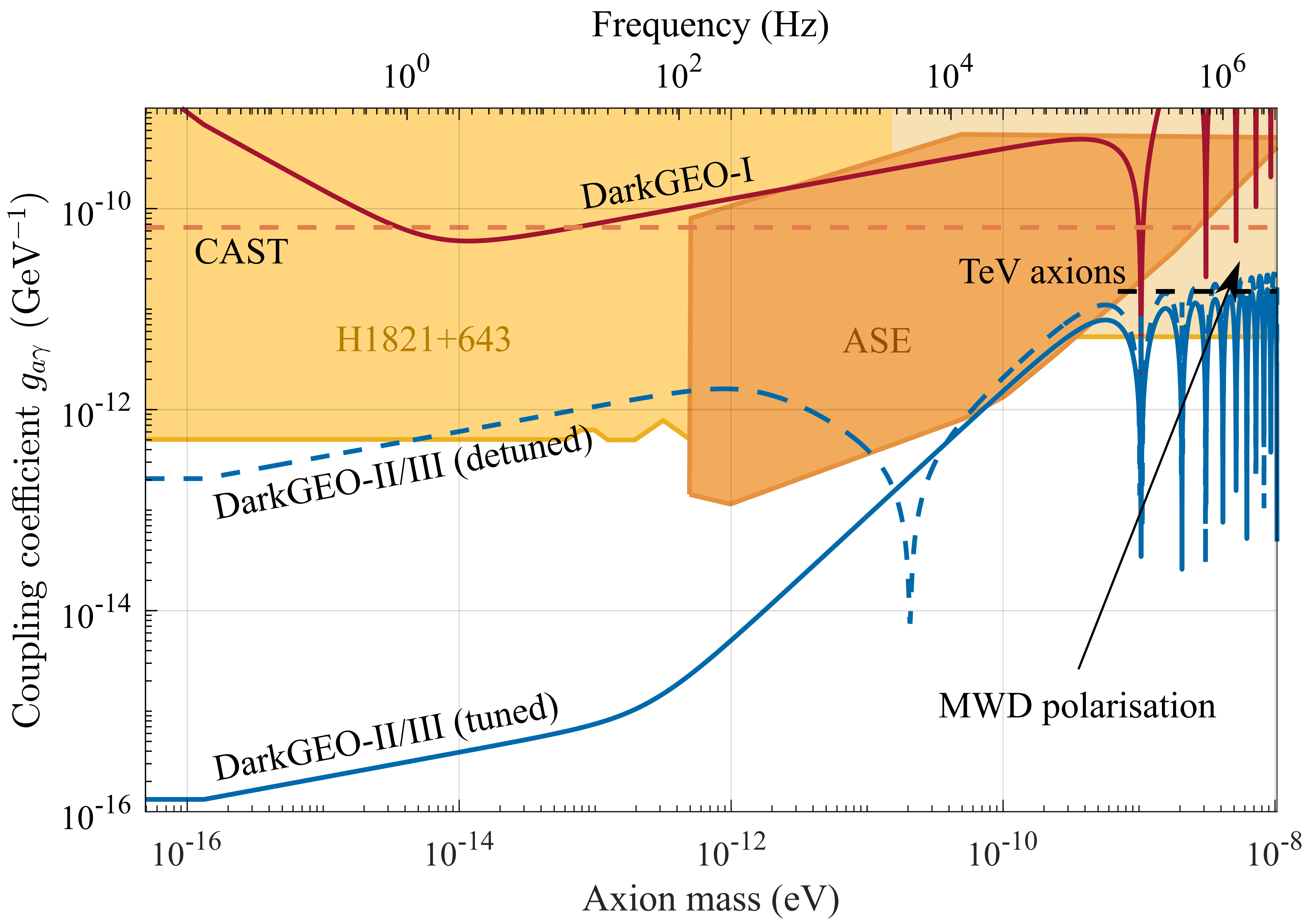

| | 1st run | Next run |
|---|---|---|
| Intra-cavity power | 118 kW | 200 kW |
| Measurement time | 85 h | 6 months |
| Squeezing level | - | 10 dB |
| Detuning | 478 kHz | 0 kHz |

- Preparing squeezing light
- Adjusting resonant frequency difference by tuning angle of the mirrors with pico-motor

# DarkGEO

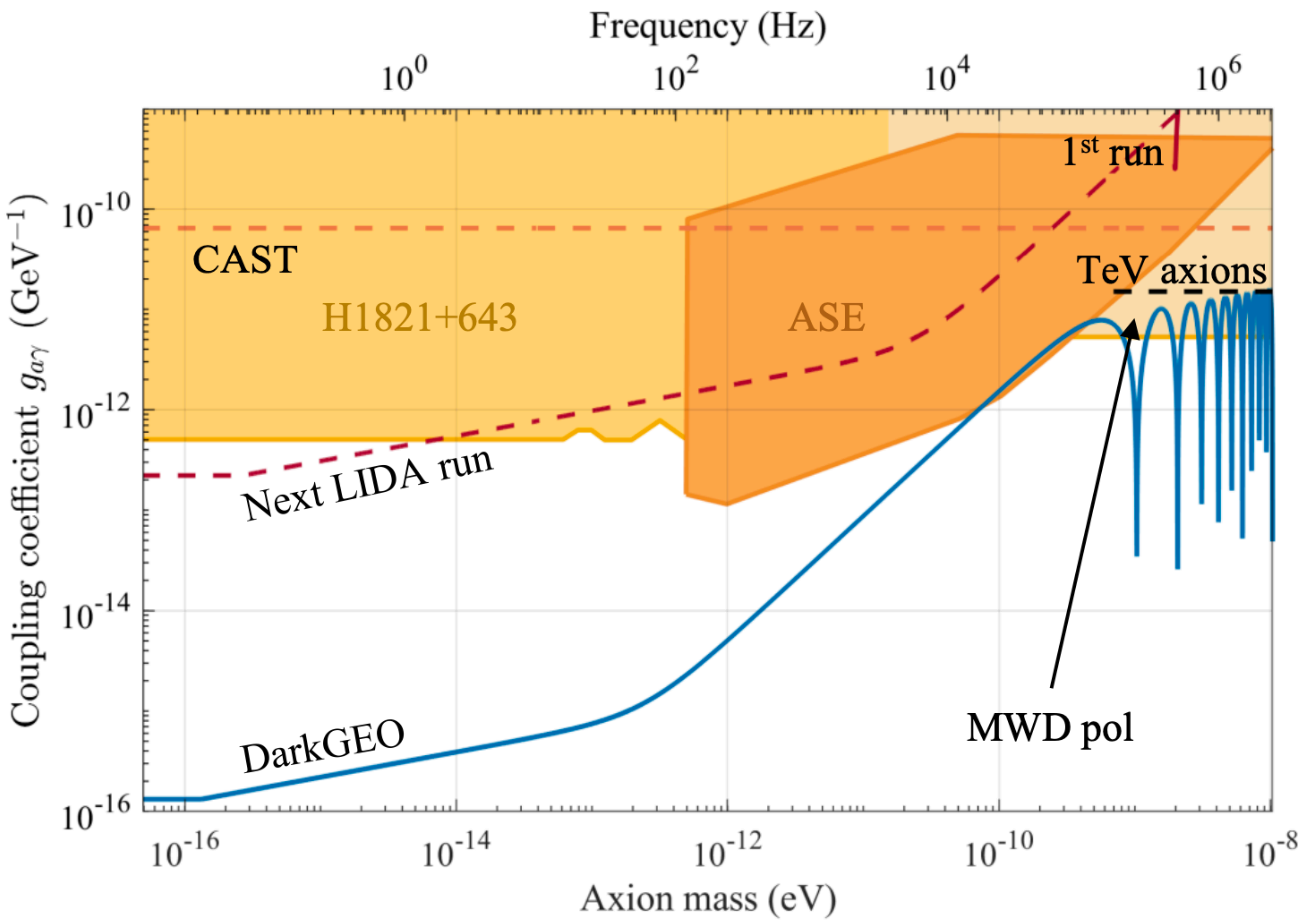



DarkGEO-I: linear configuration
Input mode cleaner
Laser source
PBS
$T_{in}$
$T_{out}$
600 m
Output
mode cleaner
Signal readout
DarkGEO-II: rectangular configuration
Input mode cleaner
Laser source
PBS
$T_{in}$
$T_{out}$
600 m
Squeezed
light source
PBS
$\frac{\lambda}{2}$
Output mode cleaner
Signal readout


Frequency (Hz)
$10^0$
$10^2$
$10^4$
$10^6$
Coupling coefficient $g_{a\gamma}$ (GeV$^{-1}$)
$10^{-10}$
$10^{-12}$
$10^{-14}$
$10^{-16}$
CAST
DarkGEO-I
TeV axions
H1821+643
ASE
DarkGEO-II/III (detuned)
DarkGEO-II/III (tuned)
MWD polarisation
$10^{-16}$
$10^{-14}$
$10^{-12}$
$10^{-10}$
$10^{-8}$
Axion mass (eV)

# DarkGEO prospects






| | 1st run | Next run | DarkGEO |
|---|---|---|---|
| Intra-cavity power | 118 kW | 200 kW | 10,000 kW |
| Measurement time | 85 h | 6 months | 1 year |
| Squeezing level | - | 10 dB | 10 dB |
| Detuning | 478 kHz | 0 kHz | 0 kHz |

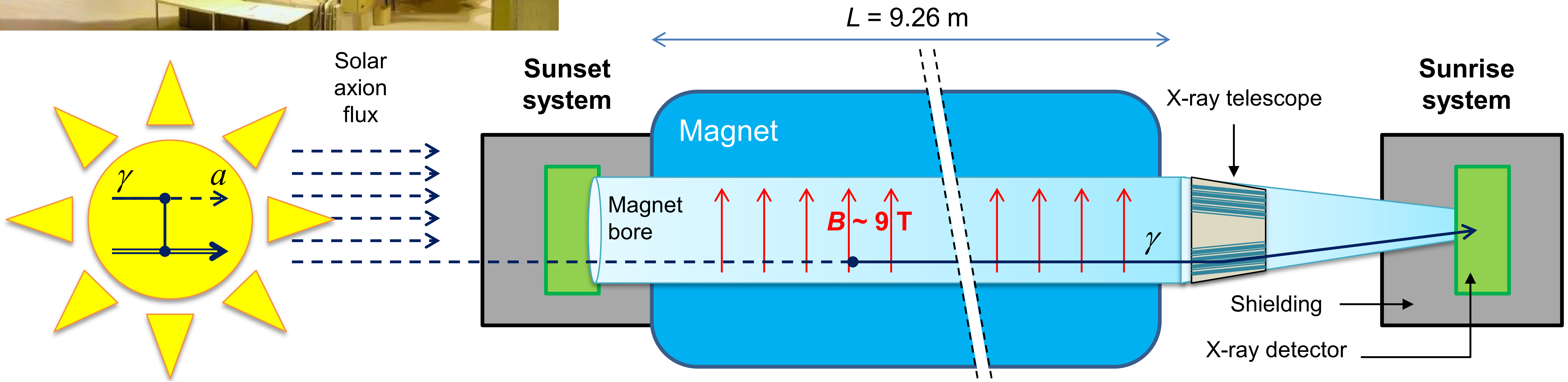
# CAST



**CAST (SERN Axion Solar Telescope)**

- A powerful axion helioscope
- Decommissioned prototype LHC dipole magnet
- Solar tracking possible during sunrise and sunset (2 × 1.5 h per day)

Use magnet directed at the Sun to convert solar axions to X-rays



# How to obtain upper limit



Differential solar axion flux

$$\frac{d\Phi_a}{dE} = 6.02 \times 10^{10} \left( \frac{g_{a\gamma}}{10^{-10}\ \mathrm{GeV}^{-1}} \right)^2 E^{2.481} e^{-E/1.205}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{keV}^{-1}$$

Likelihood function

$$\ln \mathcal{L} = -R_T + \sum_i^n \ln R\left(E_i, \boldsymbol{x}_i\right)$$

$R_T$: Expected number of signal and background counts

$R\left(E_i, \boldsymbol{x}_i\right)$: Expected rate

$$R\left(E_i, \boldsymbol{x}_i\right) = s\left(E_i, \boldsymbol{x}_i\right) + b\left(E_i\right)$$

$s\left(E_i, \boldsymbol{x}_i\right)$: Signal rate (Expected rate from axion conversion)

$b\left(E_i\right)$: Background rate

$$s\left(E_i, \boldsymbol{x}_i\right) = \frac{d\Phi_a}{dE} P_{a\rightarrow\gamma} \epsilon\left(E, \boldsymbol{x}_i\right)$$

$P_{a\rightarrow\gamma}$: Axion-photon conversion probability

$\epsilon\left(E, \boldsymbol{x}_i\right)$: Detector response

Upper limit is set by integrating the following posterior probability from 0 to 95 %

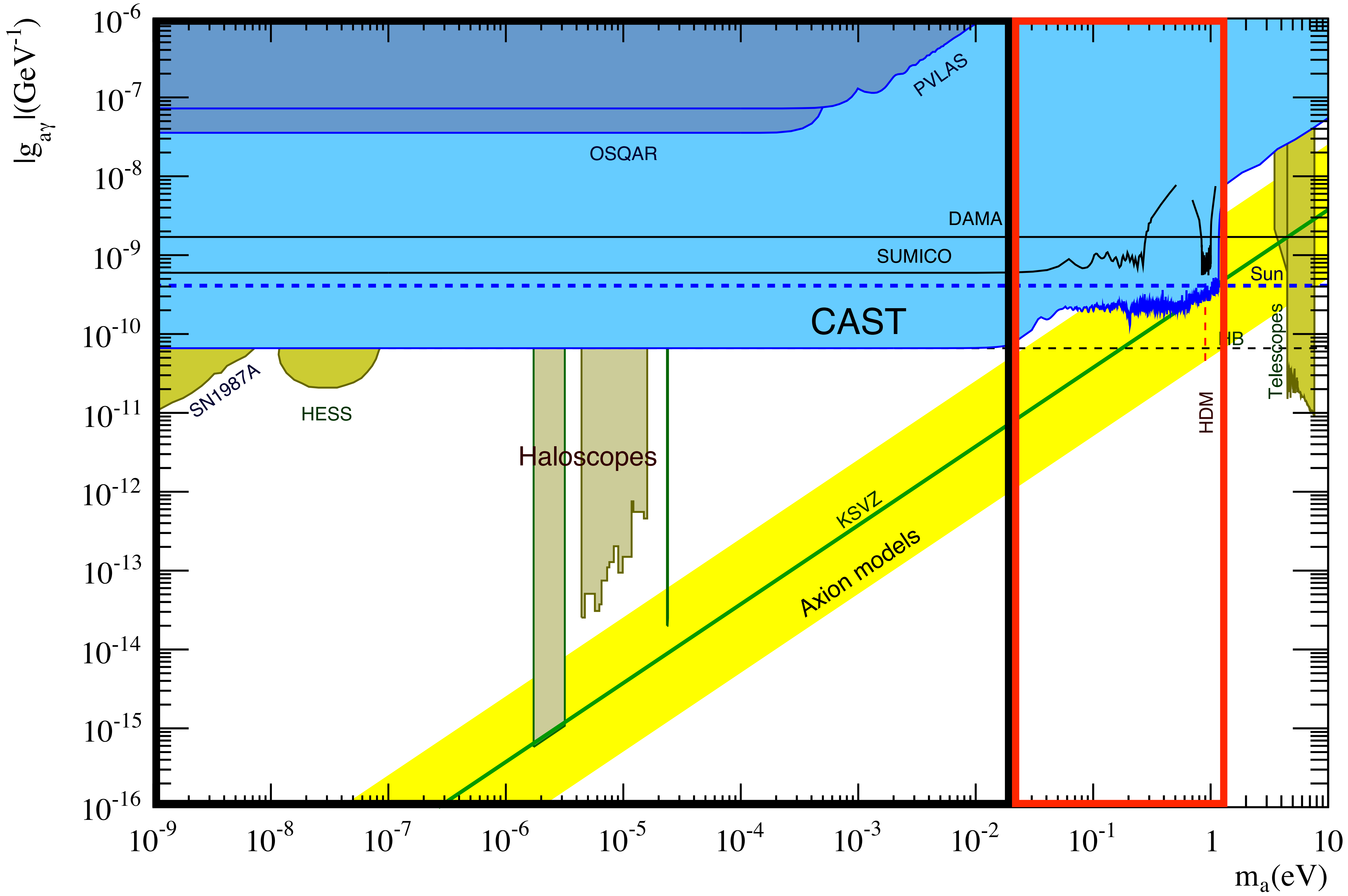
$$\mathcal{P} = \mathcal{L} \times \Pi$$

$\mathcal{P}$: Posterior probability

$\Pi$: Prior probability

# CAST upper limit

Vacuum phase　　Gas phase




**Axion-photon conversion probability**

Vacuum phase

Axion-photon coupling

Magnetic field

Axion mass

$$P_{a\rightarrow\gamma} = \left(\frac{g_{a\gamma}BL}{2}\right)^2 \left(\frac{\sin(qL/2)}{qL/2}\right)^2 \qquad q = \frac{m_a^2}{2E}$$

Length of magnet

Energy

Momentum transfer between axion and photon

Coherence condition
$qL/2 \ll 1$

$$P_{a\rightarrow\gamma} = \left(\frac{g_{a\gamma}BL}{2}\right)^2$$

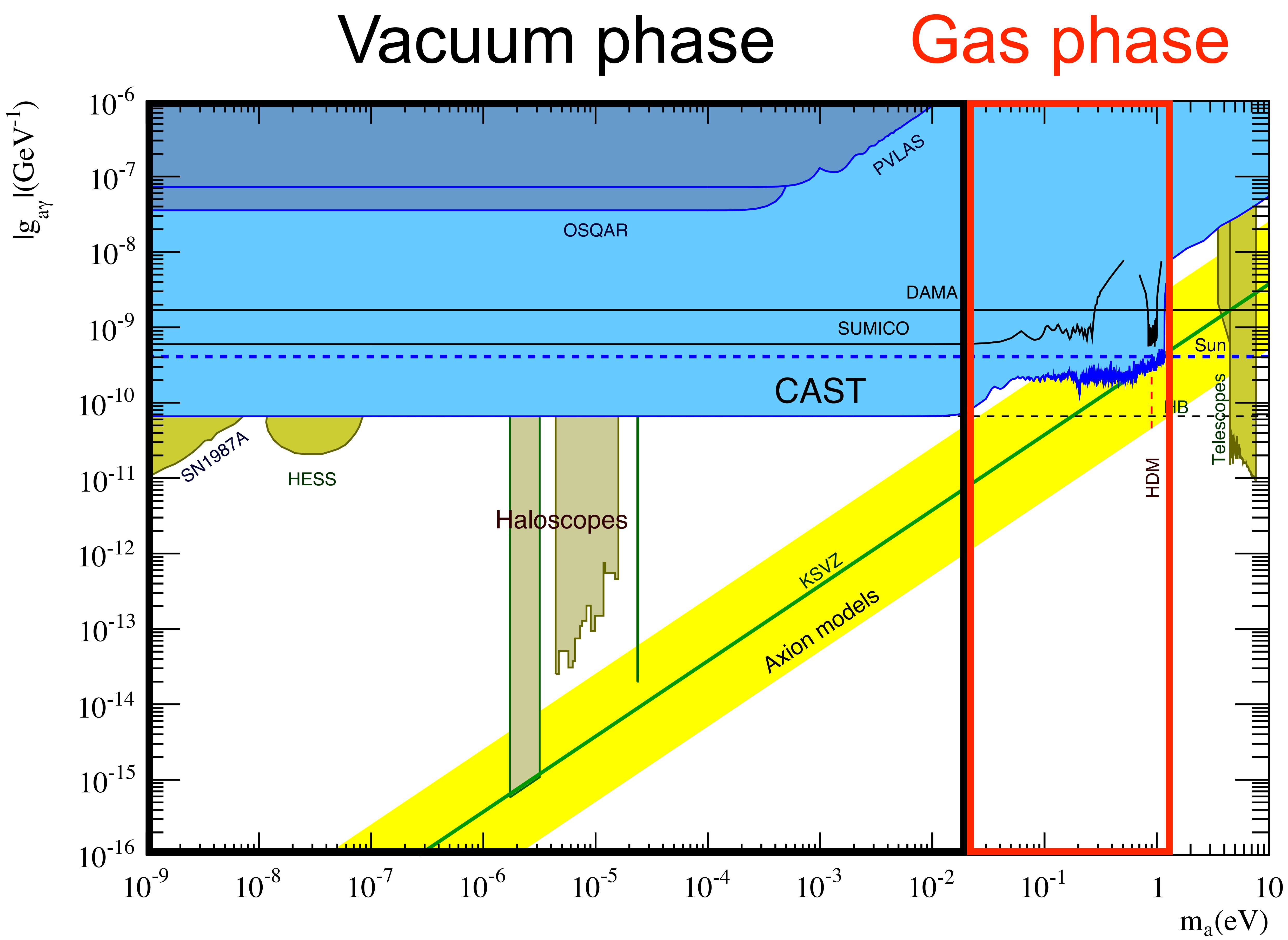
Vacuum $m_a < 0.02$ eV

$^4$He $0.02 < m_a < 0.39$ eV

$^3$He $0.39 < m_a < 1.17$ eV

The expected signal is mass-independent because the axion-photon oscillation length far exceeds the length of the magnet

# CAST upper limit




Vacuum $m_a < 0.02\ \mathrm{eV}$

$^4$He $0.02 < m_a < 0.39\ \mathrm{eV}$

$^3$He $0.39 < m_a < 1.17\ \mathrm{eV}$

## Axion-photon conversion probability

### Gas phase

$$P_{a\to\gamma} = \left(\frac{g_{a\gamma}B}{2}\right)^2 \frac{1 + e^{-\Gamma L} - 2e^{-\Gamma L/2}\cos(qL)}{q^2 + \Gamma^2/4}$$

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

Inverse absorption length for photons in a gas

Photon refraction mass

The axion-photon momentum mismatch will reduce the sensitivity

→ Match photon refraction mass determined by buffer gas density to axion mass

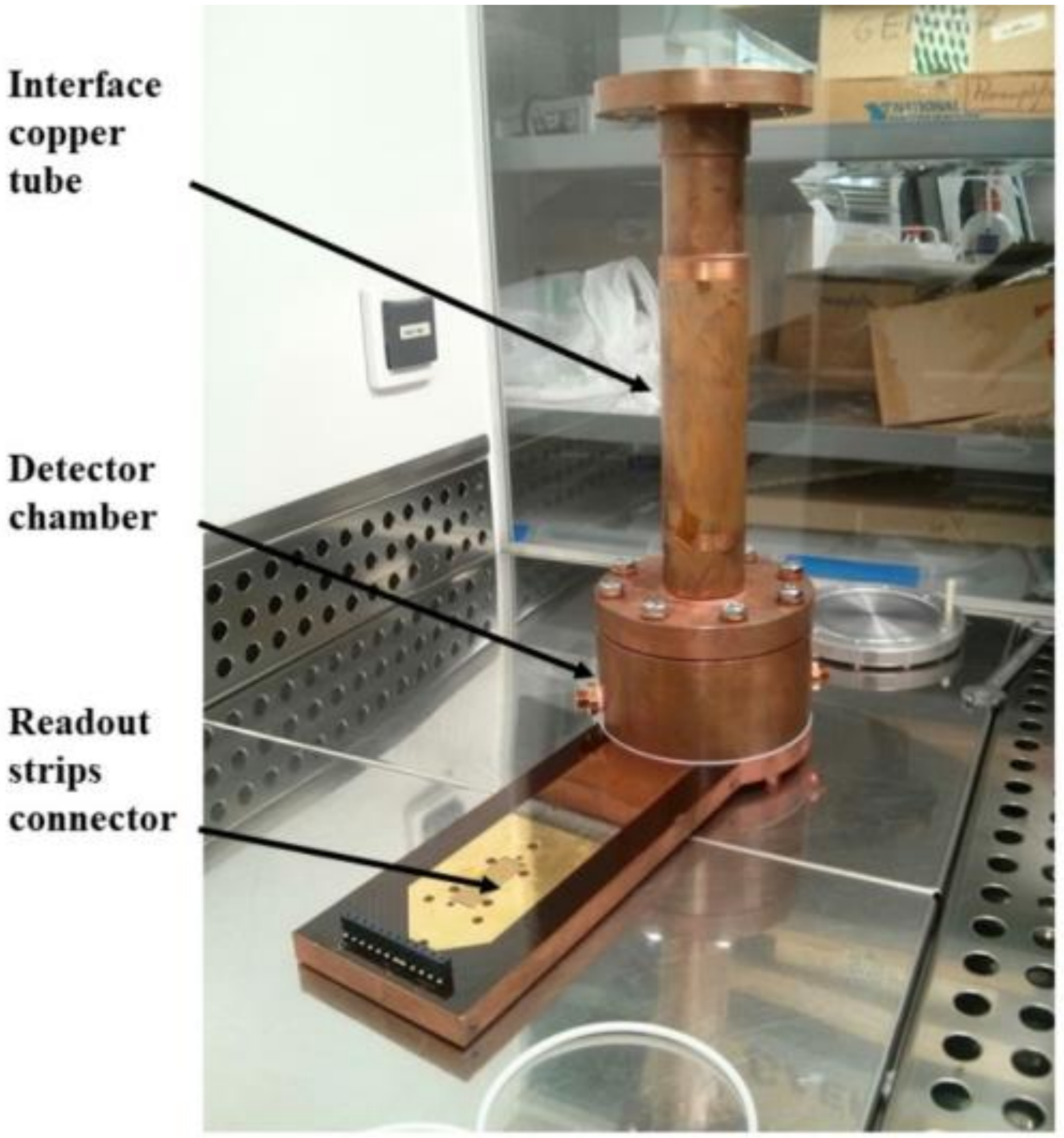
CAST Collaboration, J. Cosmol. Astropart. Phys. 02 (2009) 008.
CAST Collaboration, Phys. Rev. D **92**, 021101 (2015).
CAST Collaboration, Phys. Rev. Lett. **107**, 261302 (2011).
CAST Collaboration, Phys. Rev. Lett. **112**, 091302 (2014).

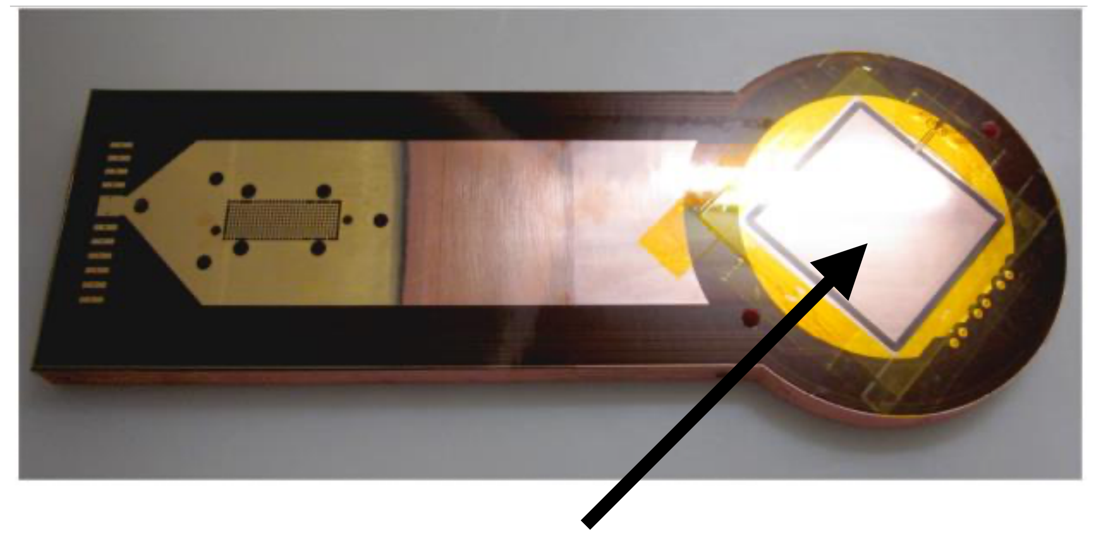
# Principle of detection

**The IAXO pathfinder ultra-low background detector**

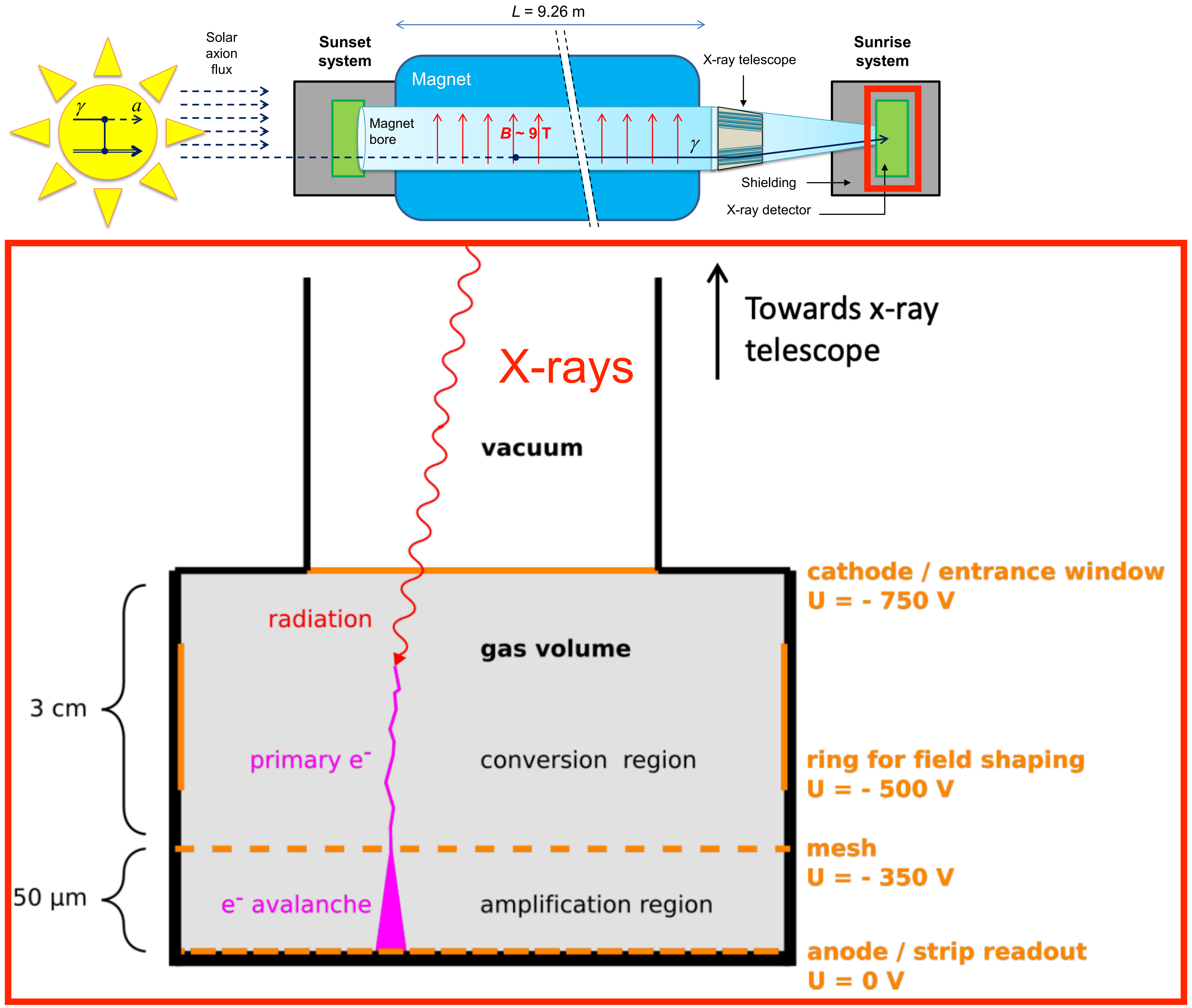
Microbulk Micromegas detectors

- Very homogeneous amplification gap, uniform gain
- Intrinsically radiopure
- Good energy and spatial resolution
- Pixelized readout gives topological information



Micromegas readout

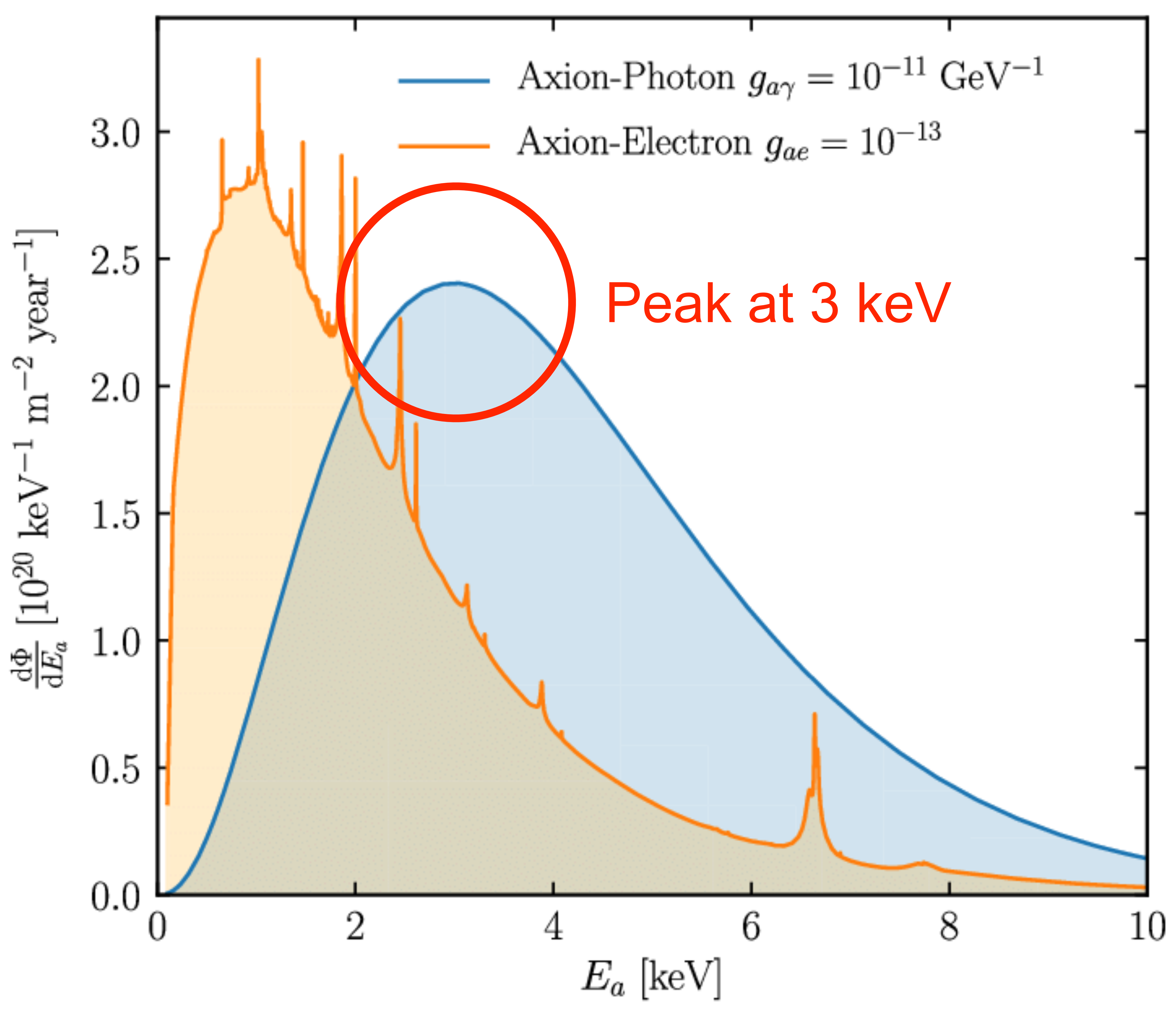



X-rays ionize the gas in the conversion region and the produced signal is read by the Micromegas

# Update of detector



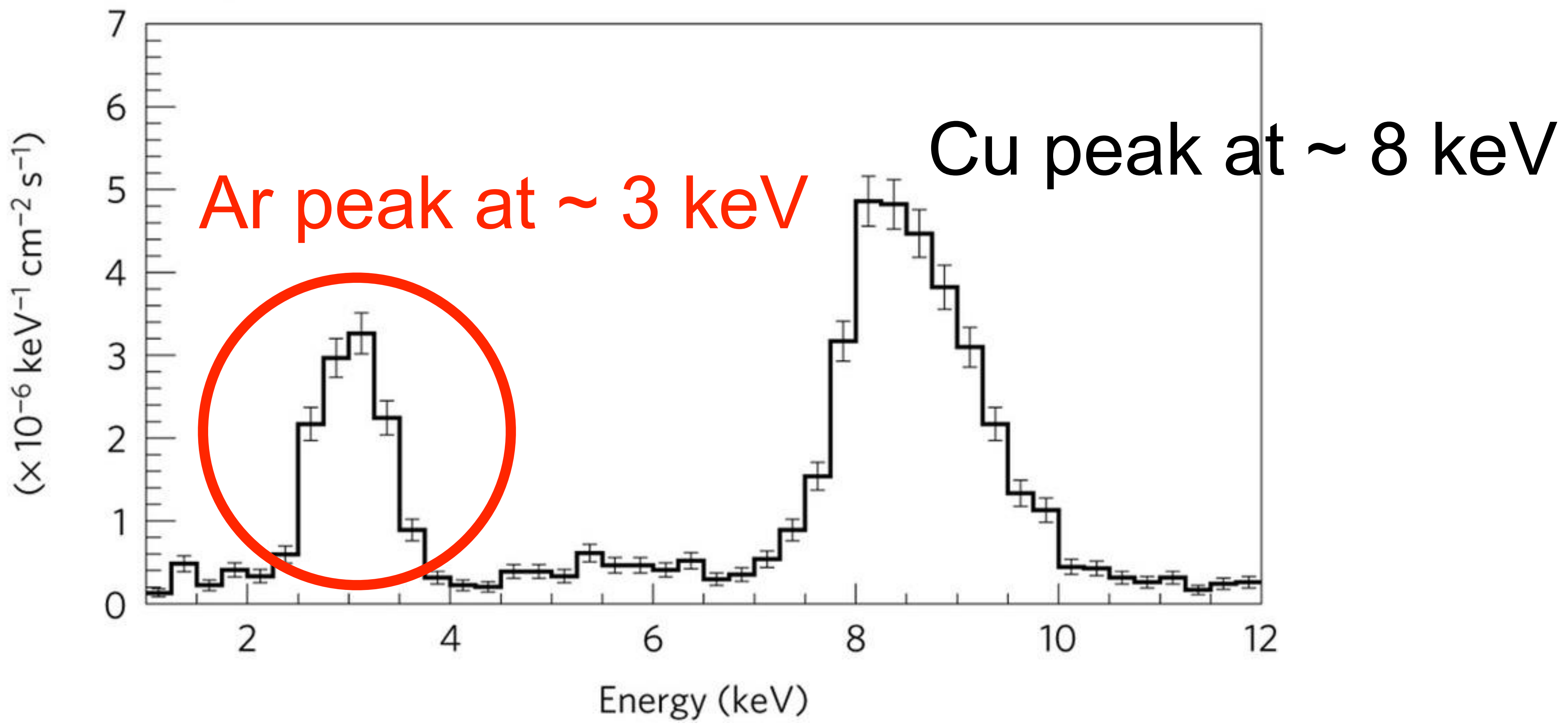
Differential solar axion flux




Toward Xe-based gas mixtures

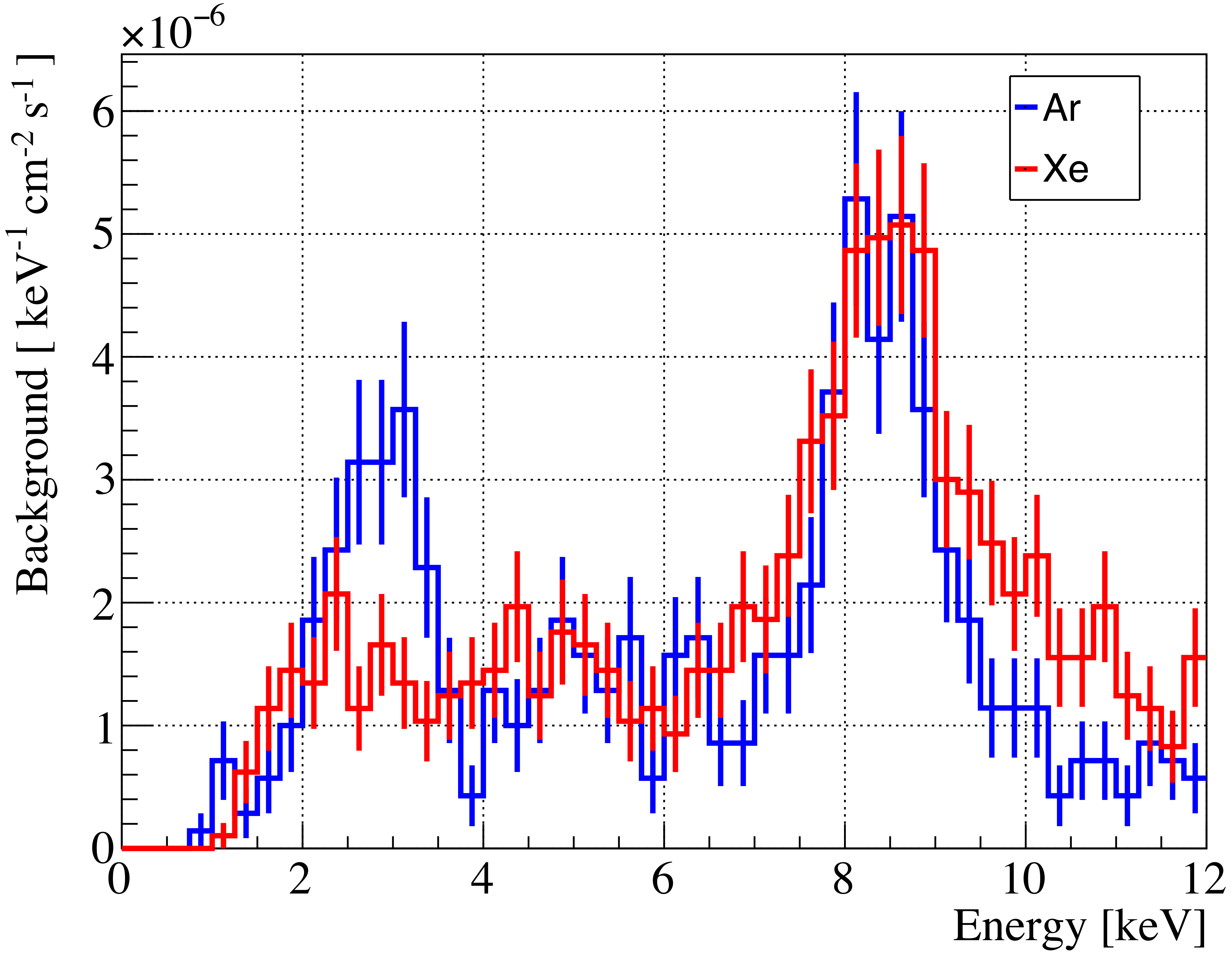
- Typical background spectra with Ar-based mixtures has peak at ~ 3 keV
- Solar axion peak expected at ~ 3 keV
- Need to reduce the background in this range

Measured count rate spectrum of background data in the sunrise detector



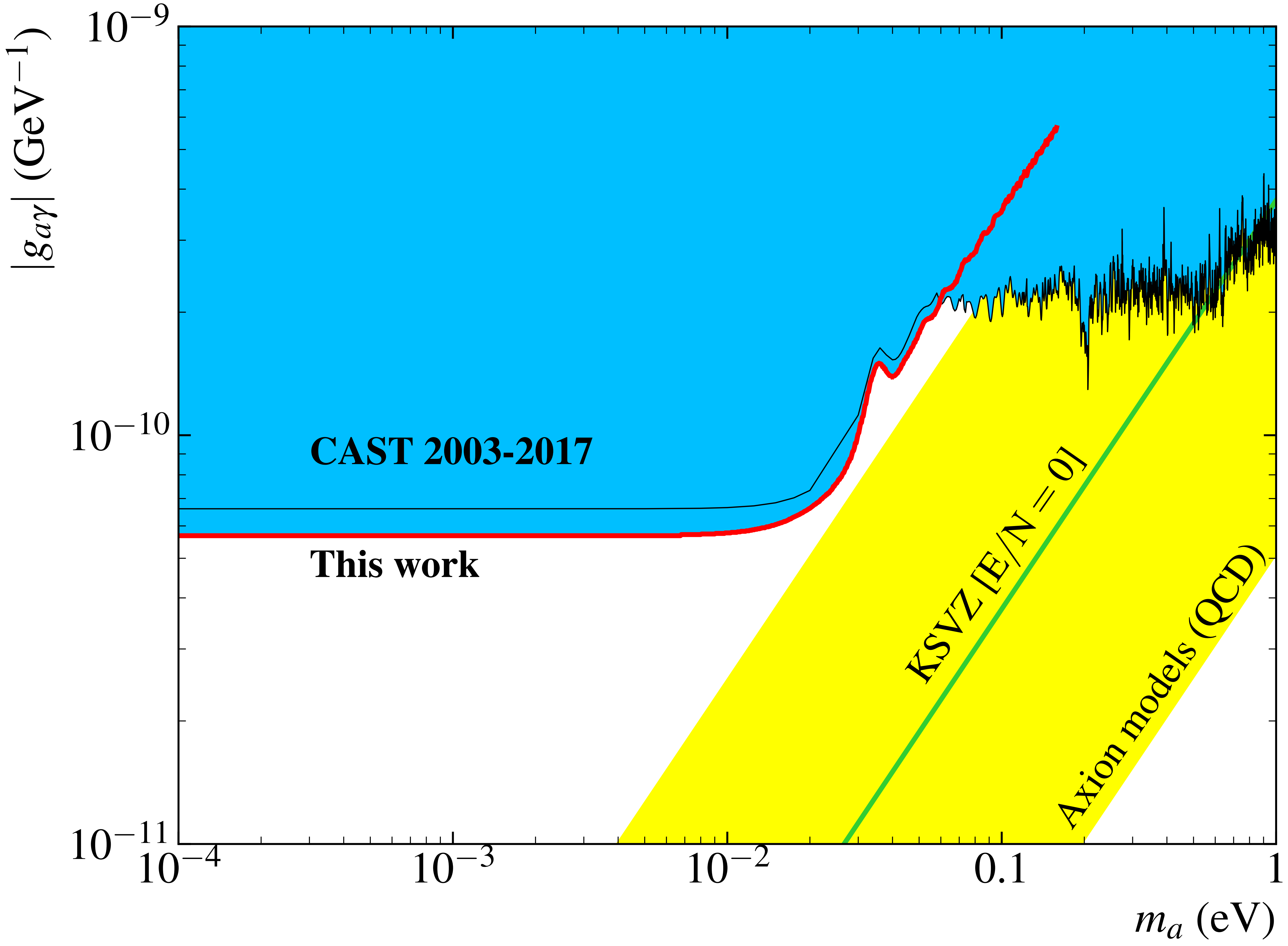
# Update of detector






Succeeded to reduce the background at ~ 3 keV with Xe-based gas mixtures

# New upper limit




CAST 2017 upper limit $g_{a\gamma} < 6.6 \times 10^{-11}\ \mathrm{GeV}^{-1}$ for $m_a < 0.02$ eV (95% C.L.)

New upper limit $g_{a\gamma} < 5.7 \times 10^{-11}\ \mathrm{GeV}^{-1}$ for $m_a < 0.02$ eV (95% C.L.)

# Summary



## LIDA

- One of the most rival experiment for DANCE
- Achieved shot noise at detuned frequency
- Plan to realize simultaneous resonance by tuning angle of mirrors

## CAST

- A powerful axion helioscope
- Updated upper limit
- Developing baby IAXO (next generation detector)