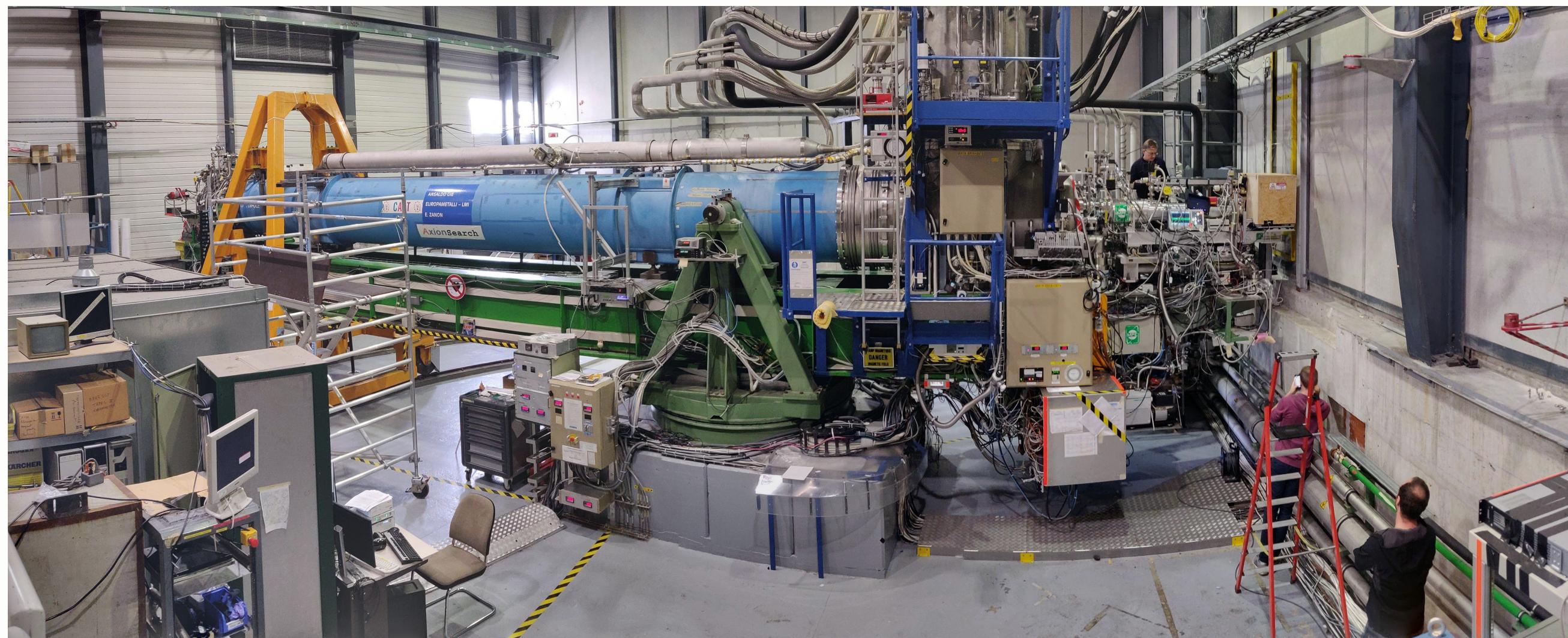


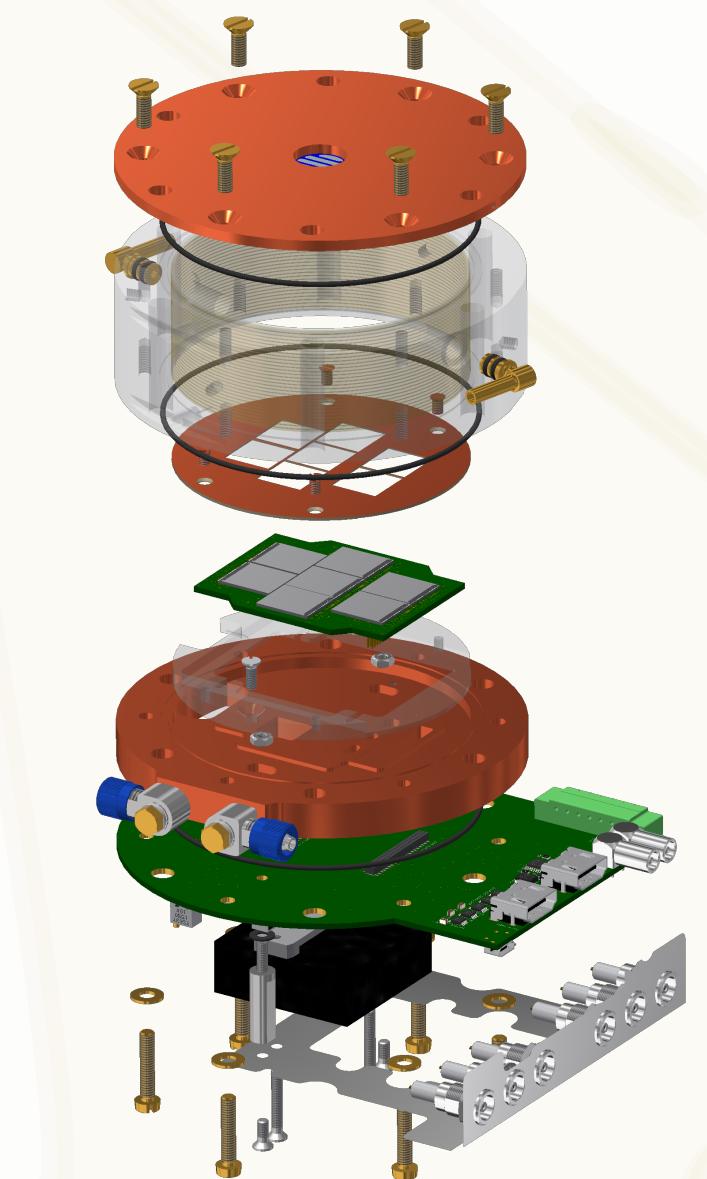
# ⚡ Generic axion limit method for GridPix & expected limits ⚡

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Code Code Code Code Code Code Code Code

Limit(s) ! (methods)

Why is there empty space here?

Generic axion limit method for GridPix & expected limits

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**CERN Axion Solar Telescope**

- second generation axion helioscope
- using a 9.25 m long LHC dipole prototype magnet with  $B = 9$  T
- behind solar helioscopes to compute background on the axion ALP conversion process
- data taking between 2003 and 2021
- solar axions converted in transverse magnetic field to  $\gamma$  via inverse Primakoff effect
- X-ray telescope (NiStar-like optic) focuses X-rays onto small spot
- multiple detector technologies used over years
- GridPix detectors installed in 2014/15 (single GridPix) and 2017/18 (7 GridPix & veto)

We present a generic limit calculation method for GridPix detectors installed behind solar helioscopes to compute background on the axion ALP conversion process. Required are a raytracing model of the expected signal, the set of candidates and a background hypothesis. The specific example given is for the axion-electron coupling using the CAST dataset from 2017/18.

**Data taking campaigns at CAST**

- Run-2 October 2017 - March 2018
- Run-3 October 2018 - December 2018
- solar tracking - background calibration
- Run-2 240 h 200 h 207 h
- Run-3 180 h 1125 h 87 h 984 h
- Total 3528 h

**Septboard detector**

- 256x256 pixel ASIC (Timepix I)
- one hole per pixel
- single electron efficiency
- each Timepix 1.4-1.4 m<sup>2</sup>

**Typical events recorded with a GridPix detector and data reconstruction**

**X-ray**      **Background**

**Event types distinguishable based on geometric properties**

**How to compute background rate?**

Background rejection method

Likelihood  $\mathcal{L}(f, t, \theta)$  of geometric properties

Define likelihood  $\mathcal{L}$  for signals  $\mathbf{s}$  & background  $\mathbf{b}$  where  $\mathcal{L}(\mathbf{s}, \theta, E, t) = \mathcal{L}(\mathbf{s}, t) \cdot \mathcal{L}(\mathbf{s}, \theta, E)$

Signal candidates observed during tracking

Background: detector background based on non-tracking data

• both only cluster after likelihood cut & vetos!

3d data sources:

- X-ray tube: 8 different lines ("geometric" reference data)
- CAST background & tracking (candidate) data

• compute gain G

• photo & escape peak:

- linear fit  $\pi$
- G vs a linear mapping G to energy (eV)

• compute likelihood values for each cluster

• compare with reference at energy & cut

• if not cut: X-ray like & candidate

• outer GridPix: 2 geometric vetoes

connected cluster on outer chip? once cluster passing at center cluster?

**Background rate in center 5.5 m<sup>2</sup>**

Background rejection method

Energy calibration

Septem veto

Line veto

background rate 0.8 keV:  $8.7476 \times 10^{-6} \text{ keV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$

**How to compute a limit?**

Limit inputs

Requires a model for signal at any  $(x, y)$ , total expected flux (based on  $\mathbf{s}$ ) & detection efficiency

Action image on detector (via raytracing)

Combined detection efficiency and total flux

**Bayesian limit approach**

Define Likelihood  $\mathcal{L}$  for signals  $\mathbf{s}$  & background  $\mathbf{b}$  where  $\mathcal{L}(\mathbf{s}, \theta, E, t) = \mathcal{L}(\mathbf{s}, t) \cdot \mathcal{L}(\mathbf{s}, \theta, E, t)$

Signal candidates observed during tracking

Background: detector background based on non-tracking data

• both only cluster after likelihood cut & vetos!

Systematics further add:

$Z_M = \mathcal{L}(\mathbf{s}, \theta, E, t) \cdot N(\theta_s) \cdot N(\theta_b)$

Product over all candidates

$\mathcal{L}_M = \prod_{i=1}^N \left[ \frac{\partial \mathcal{L}}{\partial \theta_i} \right] \exp \left[ \frac{\partial \mathcal{L}}{\partial \theta_i} \right] \frac{\partial \mathcal{L}}{\partial \theta_i} \frac{\partial \mathcal{L}}{\partial \theta_i} \frac{\partial \mathcal{L}}{\partial \theta_i} \frac{\partial \mathcal{L}}{\partial \theta_i} \right] d\theta_1 d\theta_2 d\theta_3 d\theta_4$

Total expected signal

Number of parameter penalty terms

eval.  $\mathcal{L}_M$  vs  $\theta$  vs  $E$  vs  $t$  vs  $\mathbf{s}$

eval.  $\mathcal{L}_M$  vs  $\theta$  vs  $E$  vs  $t$  vs  $\mathbf{s}$

Evaluate using Metropolis-Hastings Markov Chain Monte Carlo

Use MCMC

1 systematics + 4 fold integration

Infeasible for numerical integration for many MCMC samples

For expected limit:

requires set of candidates drawn from background

requires set of candidates drawn on tracking time

candidates observed during tracking

Use MC full for a Monte Carlo simulation of parameters  $(x, y)$  & coupling constant  $\theta_{ae}$

**Expected limit: axion-electron coupling  $\theta_{ae}$**

Uncertainties

- Wavelength: 1.5 nm
- Window thickness: 1.0 mm
- Yield: 0.0007
- Time of year: 0.0007
- Magnet length: 1 m
- Mass: 7.708 × 10<sup>3</sup> GeV<sup>-1</sup>
- with constant: 1.0 × 10<sup>3</sup> GeV<sup>-1</sup>
- Window rotation: 30° ± 0.2°
- Reference dist interp (CDK, morphology): 0.0002
- Alpha: 0.0002
- Detector mounting precision: 0.0002
- Squared sums yield:  $\sigma_a = 0.04583, \sigma_b = 0.00282, \sigma_p = 0.05$

All code written in <https://gitlab.com/vindar/timepixanalysis>  
All results shown preliminary.  
(8): BARTH, K., et al. CAST constraints on the axion-electron coupling. Journal of Cosmology and Astroparticle Physics, 2013, 2013, Jg. Nr. 05, S. 010.

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