Developments of Micromegas detectors for BabyIAXO

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X-DEP – X-ray DEtector Technologies for Physics, 05-feb-2024

Content

IAXO/BabyIAXO detector requirements

Micromegas detectors

- Microbulk Micromegas detector
- **BabyIAXO Microbulk**
- **Detector shielding**
- **Electronic readout**

BabyIAXO micromegas prototypes

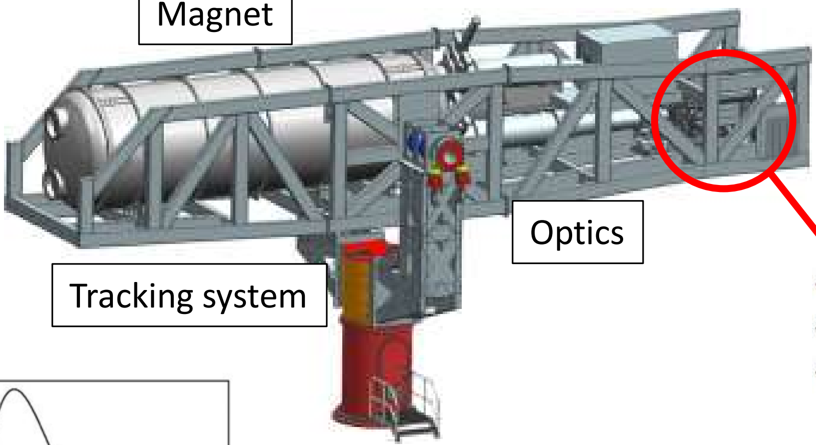
- IAXO-D0 at the University of Zaragoza
- IAXO-D1-LSC at Canfrant Underground Laboratory
- **IAXO-D1-Saclay at CEA-Saclay**

Summary

BabyIAXO experiment

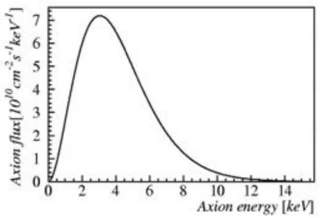
Magnet

Detectors

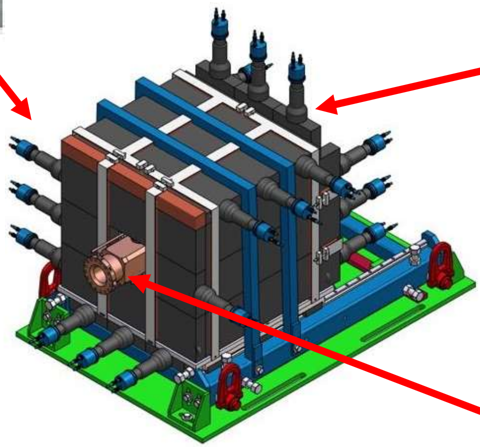


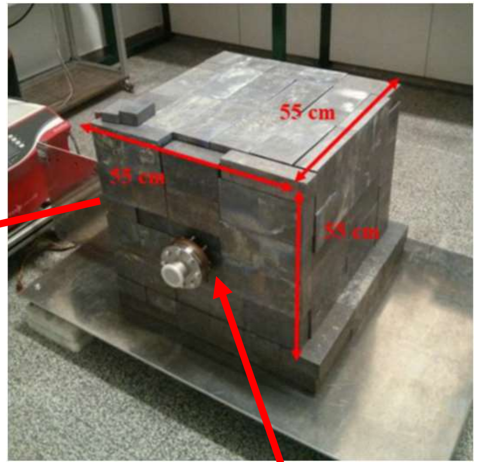
Optics

Tracking system

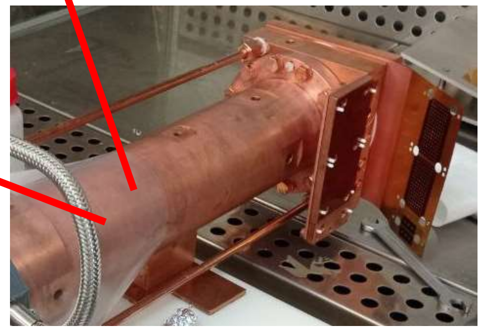


Expected solar axion flux





Passive shielding: several centimeters of lead around the detector

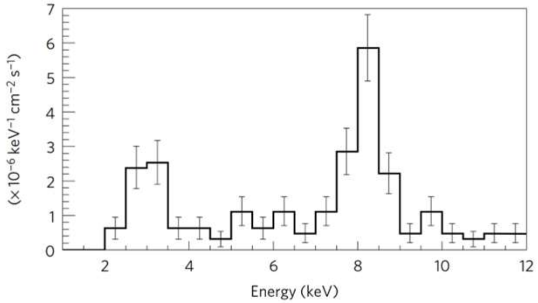


Active shielding: plastic scintillator as a cosmic muon veto.

IAXO collaboration, *Conceptual design of BabyIAXO, the intermediate stage towards the International Axion Observatory*, JHEP 05 (2021) 137 [2010.12076].

BabyIAXO detector requirements

- High detection efficiency in the RoI: **1-10 keV.**
- Very low background (<10 keV): **10^{-7} c/keV/cm²/s.**
  - + Radiopurity: inner components.
  - + Passive shielding: lead shell.
  - + Active shielding: muon vetos (PMT scintillators).
  - + Event discrimination strategies: G4 simulation and prototype measurments.



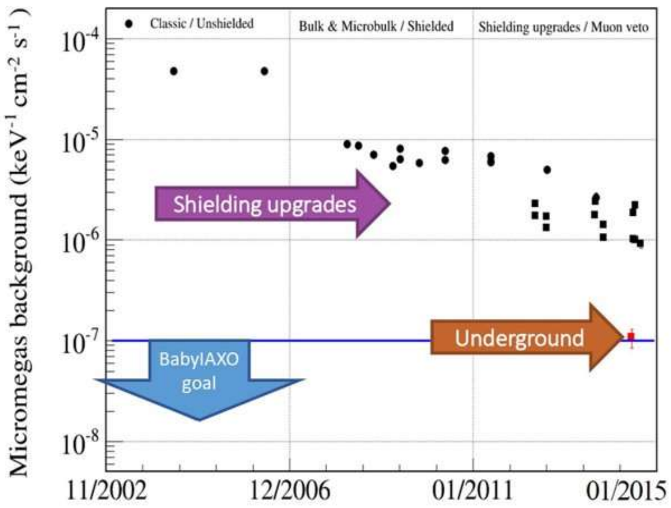
CAST background measurement, NATURE PHYSICS (2017)

Figure of Merit (FoM): $g_{a\gamma}^4 \sim B^2 L^2 A \quad \epsilon_d b^{-1/2} \quad \epsilon_o \alpha^{-1/2} \quad \epsilon_t^{-1/2} t^{-1/2}$

magnet, detectors, optics, time

IAXO is based on the experience acquired during the CAST experiment

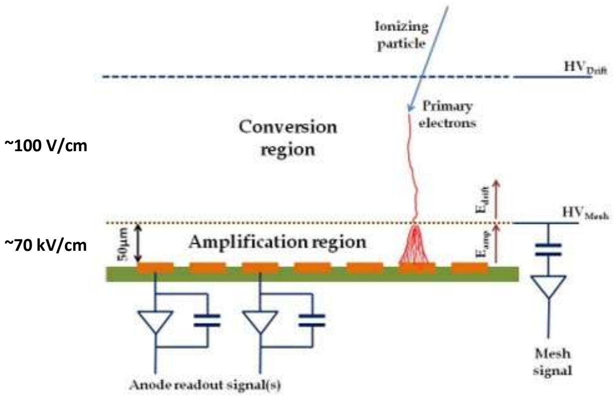
Background evolution in CAST

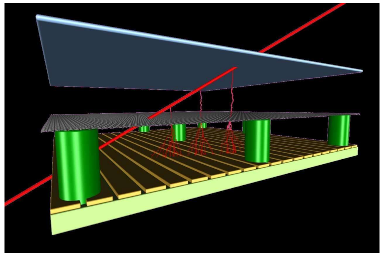


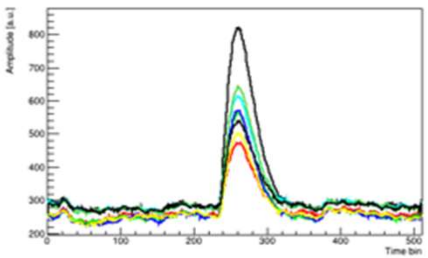
Microbulk Micromegas detectors

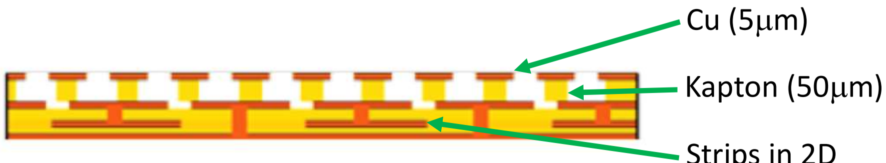
Micromegas:

- Conversion region: X-rays ionize the gas creating electrons that drift towards the amplification region.
- Amplification region: electrons pass through mesh holes due to a high field and are amplified. Electron-ion movement induce signals in both mesh & strips.
- Gas mixture: Ar + Isobutane (Xe/Ne + ISO)

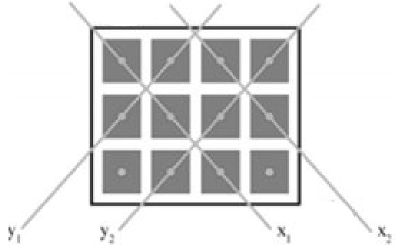


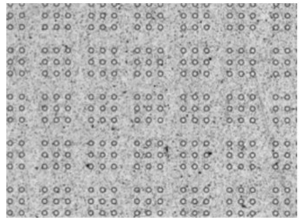






S. Andriamonje et al. JINST 2010 5 P02001





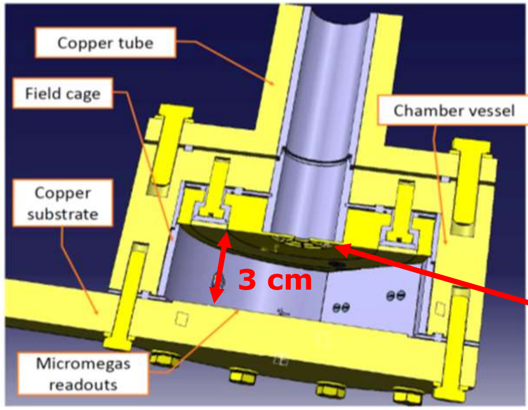
Micromesh grid

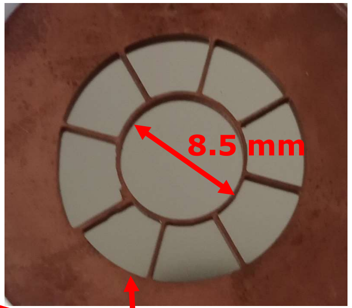
Microbulk:

- Intrinsic radiopurity.
- Very homogeneous amplification gap, uniform gain.
- Good energy resolution @5.9keV (^{55}Fe peak).
- Pixelized readout gives topological information.
- High power to discriminate X-rays signal from background events.

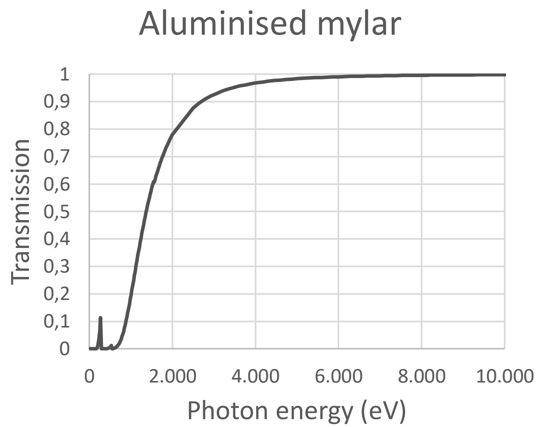
BabyIAXO Microbulk detector

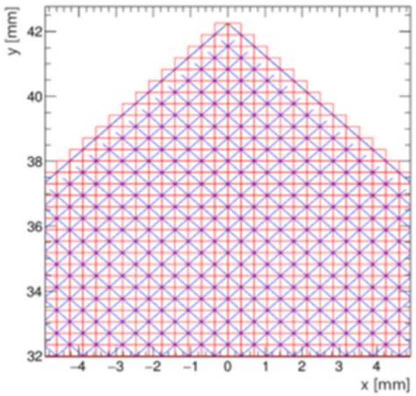
- TPC (Time projection chamber) made of copper with 3 cm drift.
- Microbulk readout with 50 μm of amplification region.
  - 120 x 120 strips
  - Pitch = 0.5 mm
  - 6 x 6 cm^2
- Mylar window: high transmission in the ROI (1-10 keV).



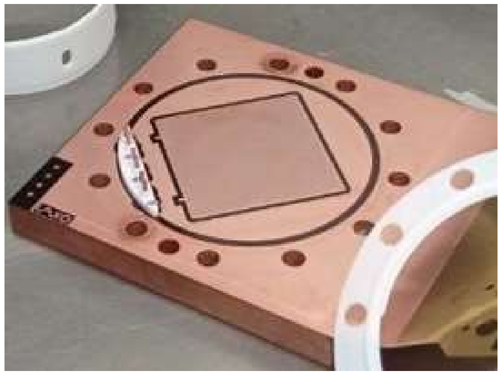


mylar window





2D strips microbulk



Prototypes:

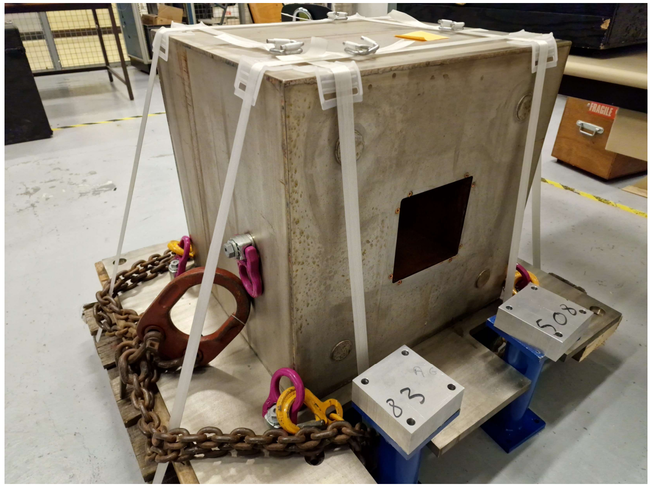
IAXO-D0 → IAXO-D1 → Saclay / Zgz / LSC

(IAXO CAST pathfinder at Zaragoza)

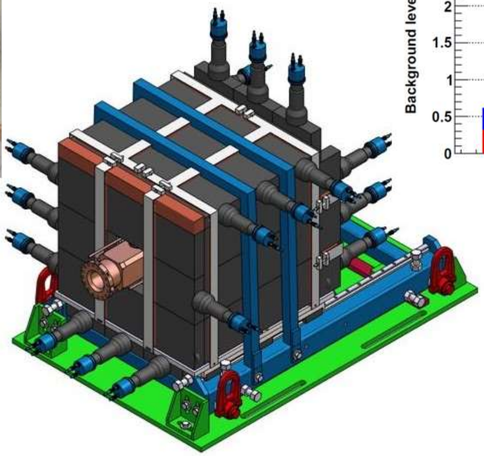
IAXO-D1
- Radiopurity of chamber
- Connections
- Future radiopure electronics

Detector shielding

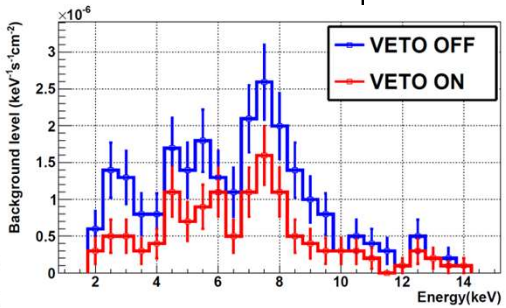
Passive shielding:
- 20 cm of lead (Z = 82).
- ~4π coverage (weak spot on the pipe hole).
- Blocks eviromental/cosmic gamma radiation.
- Chamber, pipe, … made of radiopure copper to block possible lead radiation.



Active shielding:
- Large plastic scintillator coupled to low-noise photomultipliers (PMTs)
- Shields from cosmic rays: especially the muon induce events.
- ~4π coverage (~100% geometrical efficiency).



Effect of two veto setup at CAST



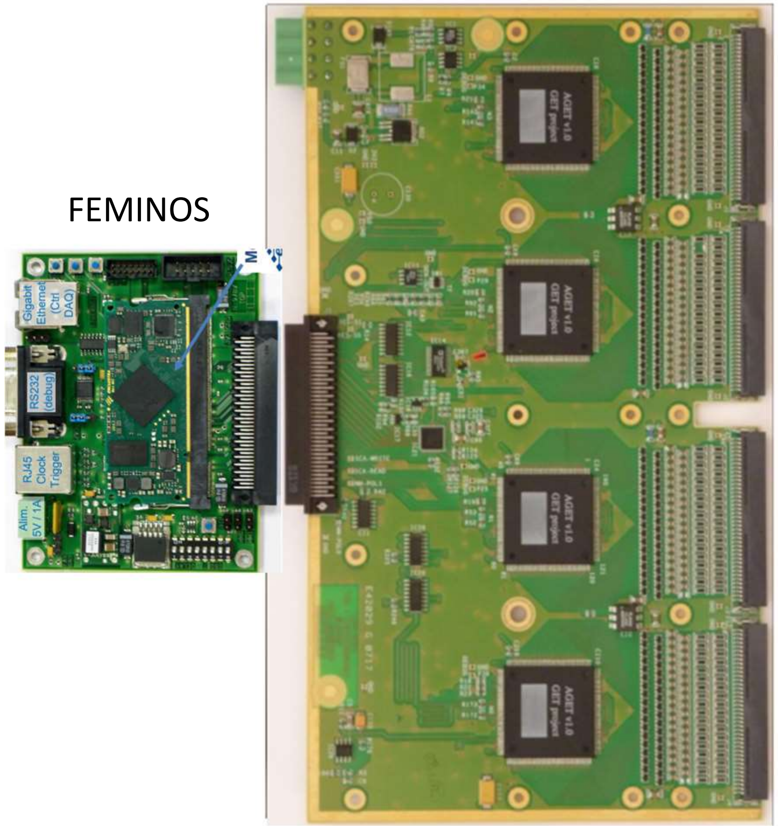
Electronic readout (present)

- BabyIAXO Micromegas electronics based on the a AGET chip (ASIC for Generic Electronic system for TPCs)
- The 64-channel ASIC performs the amplification, detection and analog storage of the shaped detector signal before its digitization by an external 12-bit ADC
- Large flexibility in sampling frequency (100 MHz max.)
- Peaking time (16 values from 50 ns to 1 /ls)
- Gain (4 ranges from 120 fC to 10 pC per channel)
- Resolution < 850 e- (Gain: 120 fC; Peaking Time: 200 ns; Cdetector < 30 pF)

FEMINOS: digital board to read out a front-end card equipped with AGET chips

Front End Card AGET

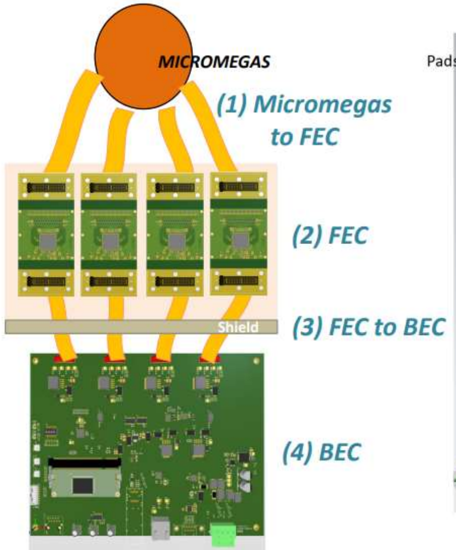
FEMINOS

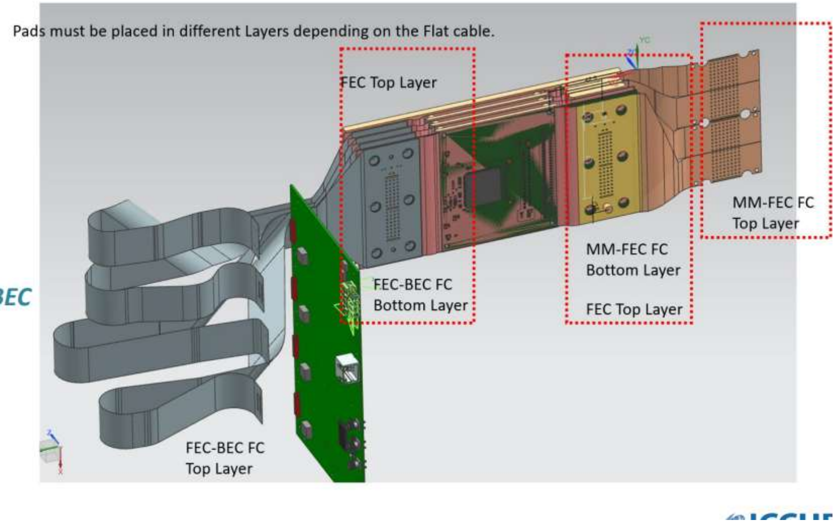


AGET: S. Anvar et al., AGET, the get front-end asic, for the readout of the time projection chambers used in nuclear physic experiments, IEEE Nucl. Sci. Symp. Conf. Rec. (2011)
FEMINOS: Anvar et al., "The readout electronics and data acquisition system of the MINOS vertex tracker," 2014 19th IEEE-NPSS Real Time Conference, Nara, Japan, 2014, pp. 1-5, doi: 10.1109/RTC.2014.7097530.

Electronic readout (future)

- Readout noise as low as possible for low energy threshold
- New architecture of the existing system in order to improve the electronic noise: approach the front end cards (FEC) to the detector and improve the radiopurity of the components
- Optimization of the FEC locations to study the electronics effect on the background of the detector





In construction now
To be tested in 2024

IAXO-D0 at the University of Zaragoza

Goal of IAXO-D0 measurements:
- ❖ Study background discrimination techniques.
- ❖ Effect of a multi-layer veto system to tag cosmogenic neutrons (in addition to muons).

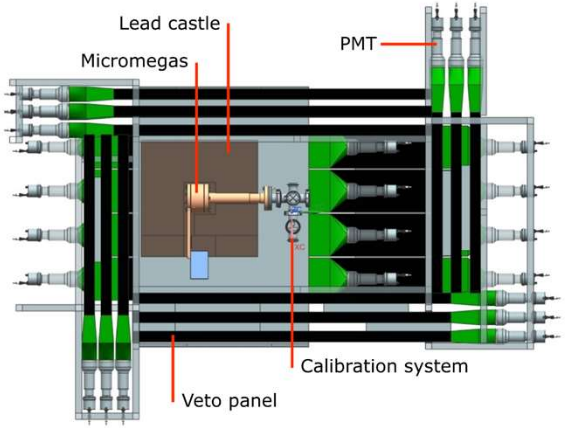
Set-up:
- ❖ At surface level at the University of Zaragoza.
- ❖ Detector: microbulk from CAST using Xe(48,85%)-Ne(48,85%)-ISO(2,3%) gas mixture.
- ❖ Veto system: 57 panels with a 4π coverage.
- ❖ Electronic readout: 4 AGET ASICs for micromegas and vetoes (veto readout trigger by micromegas).

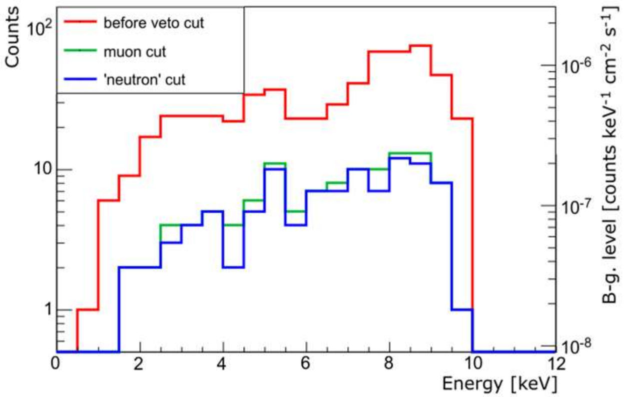
Background discrimination (data processing with REST-for-physics*):
- ❖ Micromegas data: energy and topological information.
- ❖ Veto system: multiplicity and energy.

Results:
- ❖ $(8.56 \pm 1.22) \times 10^{-7}$ counts keV^{-1} cm^{-2} s^{-1} (~80% of software effieciency @6 keV).

**REST-for-Physics, a ROOT-based framework for event oriented data analysis and combined Monte Carlo response*, Comput. Phys. Commun. 273 (2022) 108281 [2109.05863]

IAXO-D0 at the University of Zaragoza





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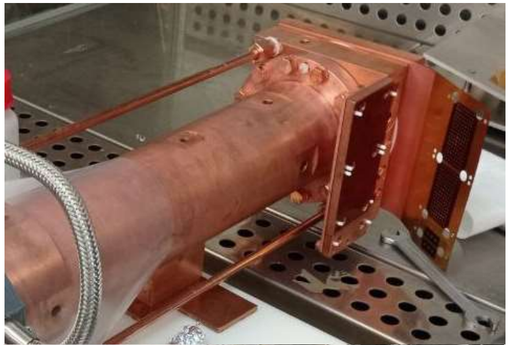
Results:
- $(8.56 \pm 1.22) \times 10^{-7}$ counts keV^{-1} cm^{-2} s^{-1} (~80% of software effieciency).
- Lowest surface level background with this type of detector.

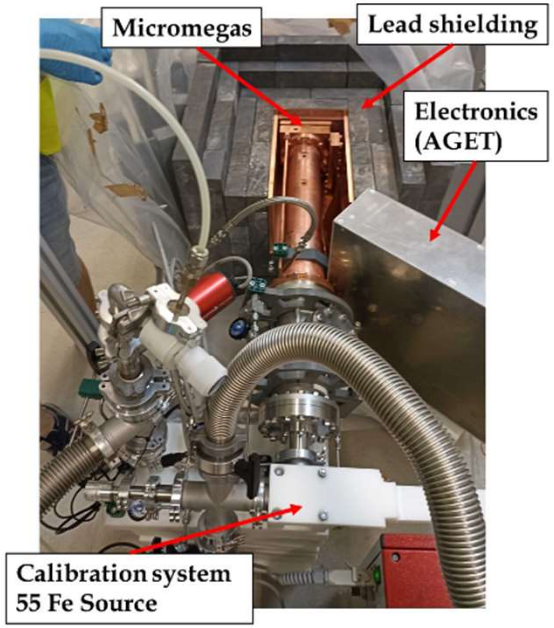
IAXO-D1 at LSC (Canfranc Underground Laboratory)

Goal of IAXO-D1-LSC prototype:
- ❖ Study the potential of this technology in "absence" of cosmics.
- ❖ Test of different gas mixtures: Ar-ISO and Xe-Ne-ISO.

Set-up:
- ❖ At the Underground Laboratory of Canfranc (Spanish Pyrenees), were the cosmic muon is a factor 10^4 less.
- ❖ Detector: new microbulk (IAXO-D1) with 20 cm thick lead shielding .
- ❖ Electronic readout: 4 AGET chips. Connected through a flat cable.

Background data taking over view:
- ❖ Xe-Ne-ISO mixture recirculating (January - May 2023).
- ❖ Ar-ISO(1%) on open loop (May 2023 - ongoing).





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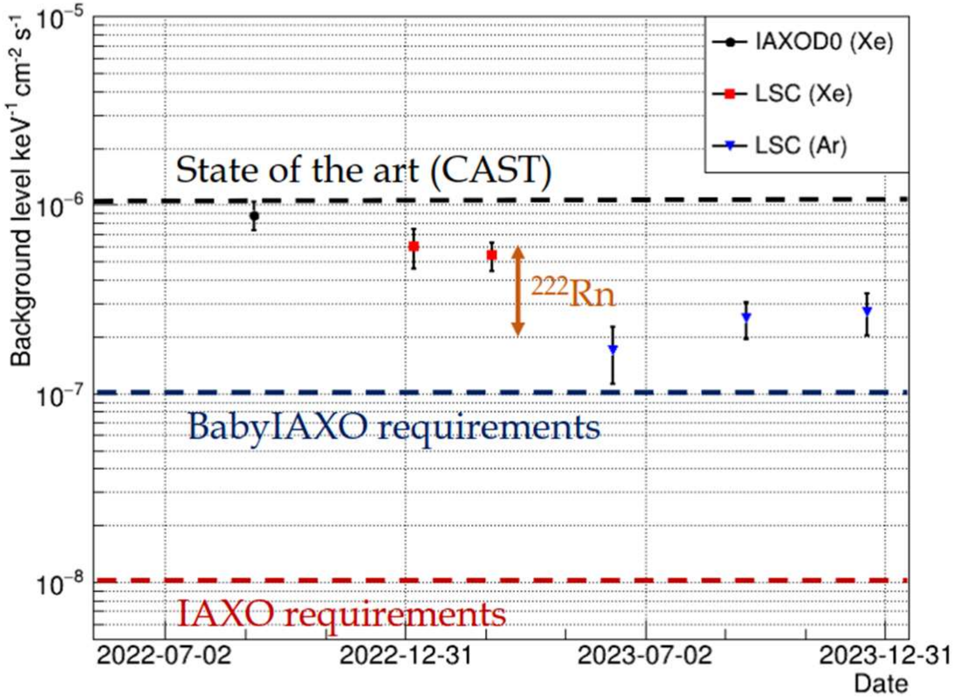
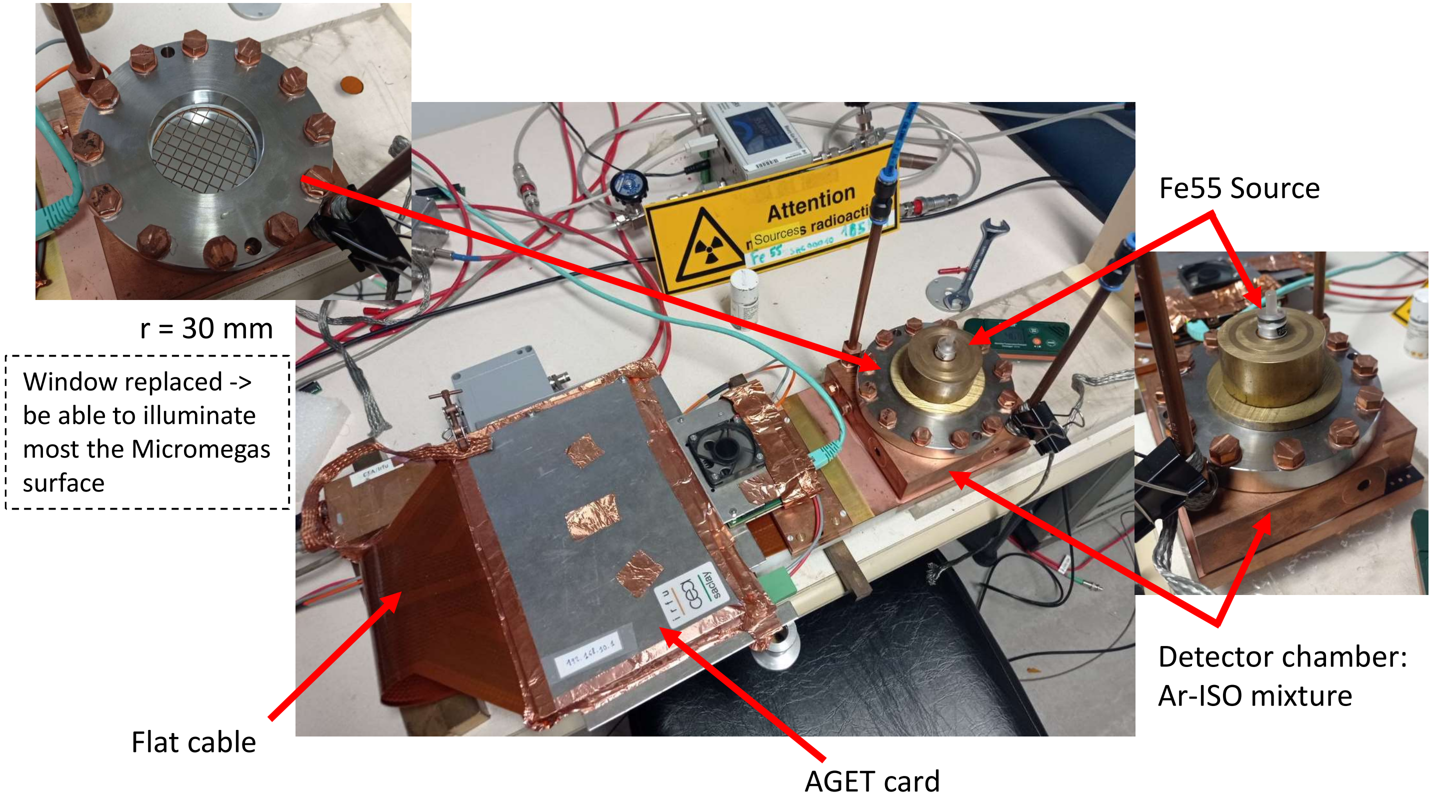
Goal of IAXO-D1-LSC prototype:
- ❖ Study the potential of this technology in "absence" of cosmics.
- ❖ Test of different gas mixtures: Ar-ISO and Xe-Ne-ISO.

Set-up:
- ❖ At the Underground Laboratory of Canfranc (Spanish Pyrenees), cosmic muon flux reduced by factor ~60000.
- ❖ Detector: new microbulk (IAXO-D1) with 20 cm thick lead shielding .
- ❖ Electronic readout: 4 AGET chips. Connected through a flat cable.

Background data taking over view:
- ❖ Xe-Ne-ISO mixture recirculating the gas (January - May 2023).
  - ~ 5-6 × 10^{-7} counts keV^{-1} cm^{-2} s^{-1} (~80% of software eff.)
- ❖ Ar-ISO(1%) on open loop (May 2023 - ongoing).
  - ~ 2 × 10^{-7} counts keV^{-1} cm^{-2} s^{-1} (~80% of software eff.)



IAXO-D1 at CEA-Saclay



Goal of IAXO-D1-Saclay prototype:

- Optimization of background rejection techniques.
- Study the evolution of the background with the different shieldings.

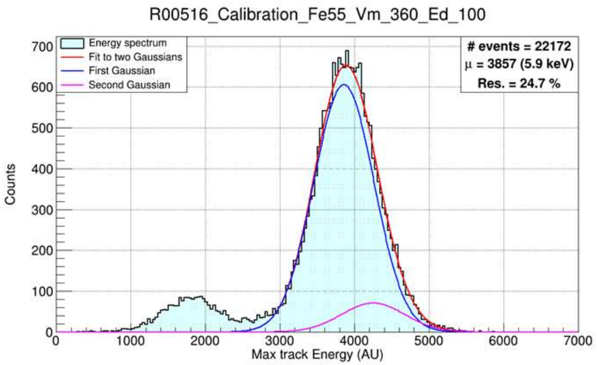
Set-up:

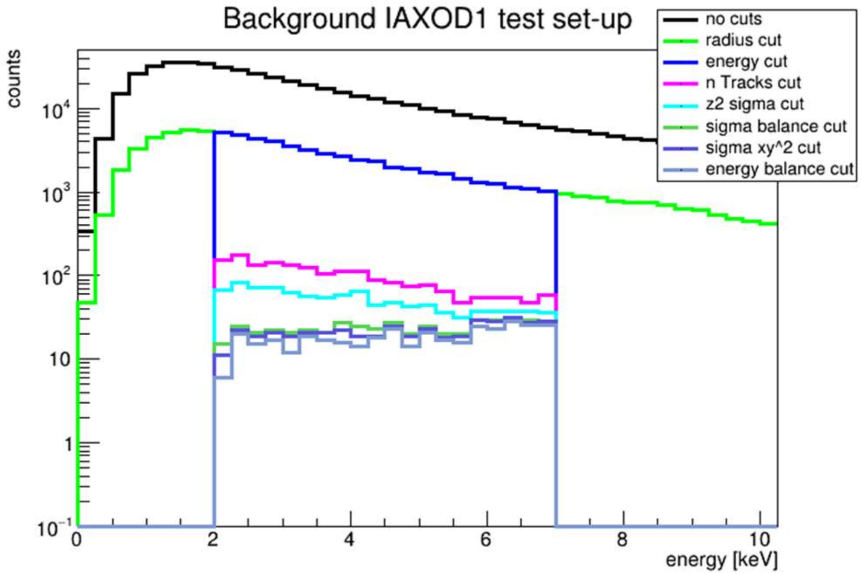
- At surface level at CEA-Saclay.
- Detector: new microbulk (IAXO-D1) without any shielding.
- Electronic readout: 4 AGET chips. Connected using a flat cable.

Background data taking:

- First preliminary measurement without any shielding and non radiopure window: ~ 2×10^{-5} counts keV^{-1} cm^{-2} s^{-1} (compatible with firsts CAST background).

IAXO-D1 at CEA-Saclay





17 days
(1.95 +/- 0.11) × 10^{-5} c/(s keV cm^2)

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Set-up:

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Background data taking:

- ❖ First preliminary measurement without any shielding and non radiopure window: ~ 2 × 10^{-5} counts keV^{-1} cm^{-2} s^{-1} (compatible with firsts CAST background).

Summary

Summary:

- Axions searches with helioscopes requires **ultra-low background** x-ray detectors (10^{-7} counts/(s keV cm^2)) -> **Microbulk Micromegas**

- There are different set-up to test this technology at **LSC**, the **University of Zaragoza** and **CEA-Saclay**, to explore the necessary techniques to reach the required background levels.

Prospects and future improvements:

- Shielding and veto configuration optimization.
- Gas optimization with Xe (or Ar).
- Comparison between background data and simulations.
- Radiopure electronics to be tested.
- Measurements at DESY underground lab (location of BabyIAXO) in 2024-25.

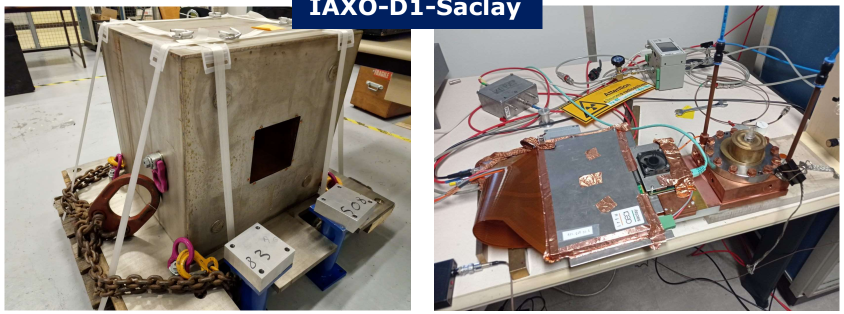
IAXO-D0/IAXO-D1-Zgz

Xe: $(8.56 \pm 1.22) \times 10^{-7}$ c keV^{-1} cm^{-2} s^{-1}

IAXO-D1-LSC

Xe: $(5.41 \pm 0.94) \times 10^{-7}$ c keV^{-1} cm^{-2} s^{-1}
Ar: $(2.42 \pm 0.99) \times 10^{-7}$ c keV^{-1} cm^{-2} s^{-1}

IAXO-D1-Saclay



Thanks for your attention