A low-background Micromegas detector for IAXO and BabyIAXO

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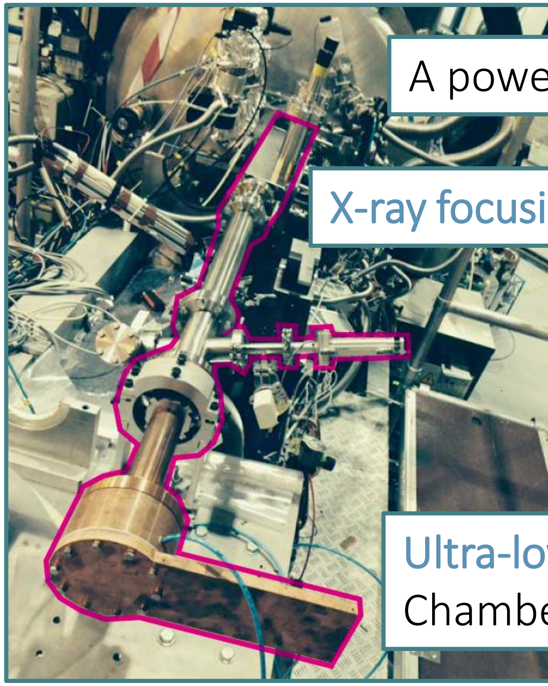
State of the art: IAXO pathfinder - CAST

T. Dafni talk



A powerful and large dedicated magnet

X-ray focusing optics optimized for axion spectrum

Ultra-low background detectors: Time Projection Chamber (TPC) with Micromegas (MM) readout

Enhanced helioscope

First time a Micromegas detector is operated with an x-ray telescope

Optics: Wolter I x-ray telescope → 5cm diameter; 1.5m focal-length

Detector: Shielded Microbulk Micromegas placed at the focal point

Performance:

8 months of operation in data-taking conditions → Best signal-to-noise ratio

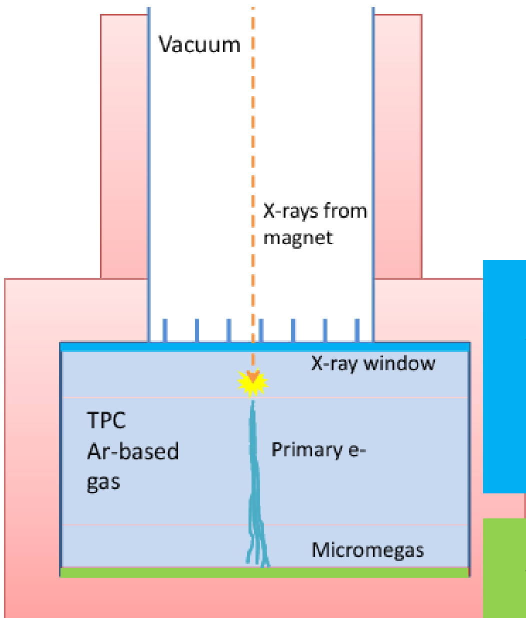
Results published: NPHYS4149

Ultra-low background detector

Time projection chamber (TPC)

+

Step 1: Conversion region



Cathode:
Thin x-ray window
→ Gas tight
→ x-ray transparent

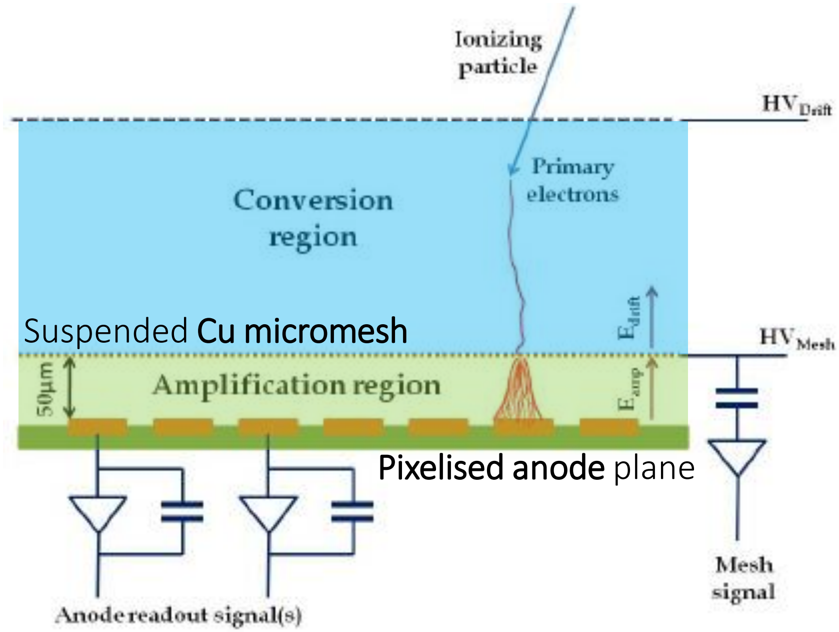
Anode:
Micromegas readout

TPC working principle:

1. Ionizing radiation creates primary charges
2. Primary charges drift towards the anode
   → enter the amplification region

Micromegas Readout

Step 2: Amplification region



Micromegas working principle:

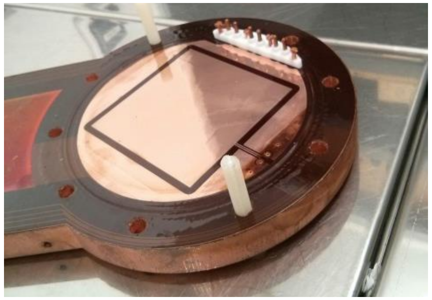
1. Primary e⁻s go through mesh holes
2. Trigger an e⁻ avalanche in the gap
   → detectable signals @ mesh and anode

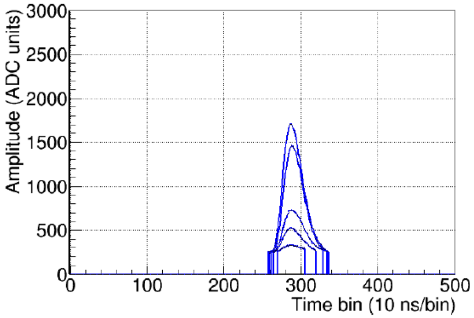
Ultra-low background detector

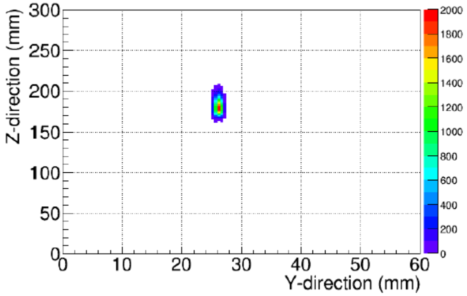
JCAP 1601 (2016) 033
JCAP 1601 (2016) 034

Useful features for axion searches

- **Solid structure and consolidated manufacture** *(2010 JINST 5 P02001)*
  systematic reliable performance *(JINST 7 (2012) P04007)*
- **Low intrinsic radioactivity** *(Astropart. Phys 34 (2011) 354-359)*
  made out of Kapton and copper
- **Good energy resolution** *(JCAP 1512 (2015) 008)*
  13% FWHM at 5.9 keV
- **Low energy threshold** *(2014 JINST 9 P01001)*
  < 0.5keV already achieved
- **Topological information** *(2013 JINST 8 C12042)*
  high power to discriminate x-rays signals from background
- **Proven performance by IAXO pathfinder (CAST)** *(2017 NPHYS4149)*
  Combination of X-Ray optics + Micromegas detectors
  Best signal-to-noise ratio







Ultra-low background

Background improvements

- Radiopurity

  Non-radiopure components replaced

- Readout patterned with high granularity

  Identify signals & reject background

  Offline rejection algorithms

- Shielding

  Active shielding: muon vetos

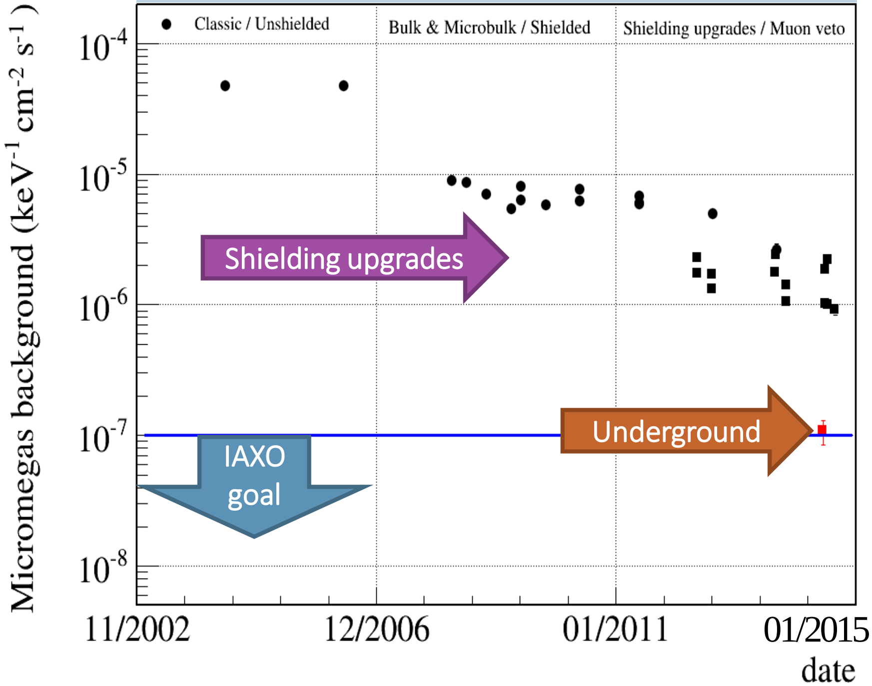
  → **scintillators** covering the maximum solid angle for cosmics

  Passive shielding: external gamma coverage

  → detector chamber and tubes made out of **electroformed copper**

  → **pure lead shielding** around the detector

Background evolution at CAST



Background achieved in CAST

(0.83 ±0.03) x 10^{-6} counts keV^{-1} cm^{-2} s^{-1}

Background in LSC (underground)

~ 10^{-7} counts keV^{-1} cm^{-2} s^{-1}

IAXO goal

10^{-7}-10^{-8} counts keV^{-1} cm^{-2} s^{-1}

The IAXO-D0 setup at Zaragoza

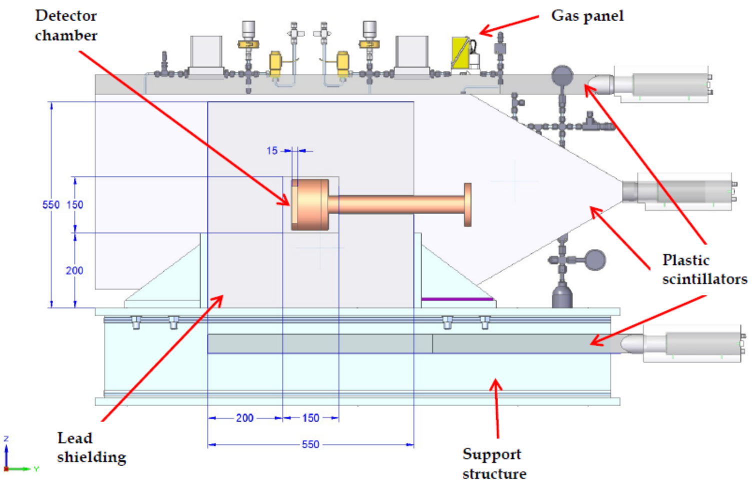
IAXO detector prototype

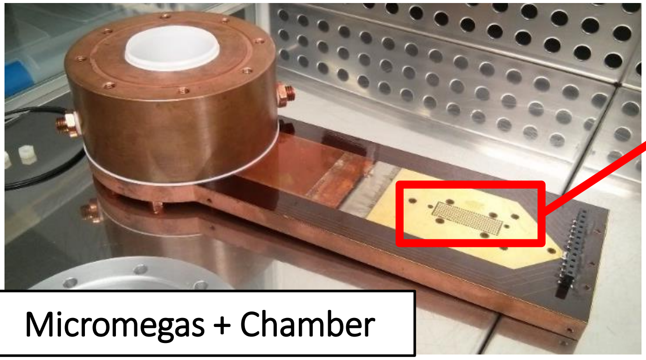
Goals

- Background level: 10^{-7}-10^{-8} counts keV^{-1} cm^{-2} s^{-1}
- Energy threshold: ~0.1 keV

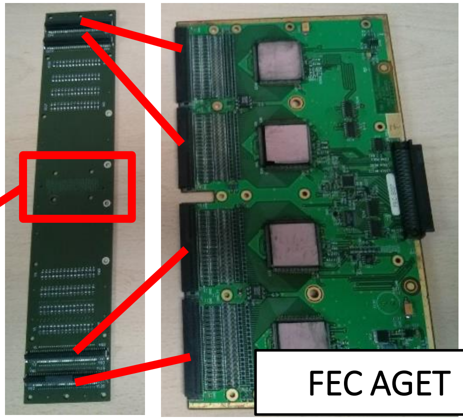
Experimental setup

- Detector: same design as CAST XRT-MM
  excellent performance
- AGET-based electronics
  auto-trigger for every readout channel





Micromegas + Chamber



FEC AGET

IAXO-D0 Micromegas

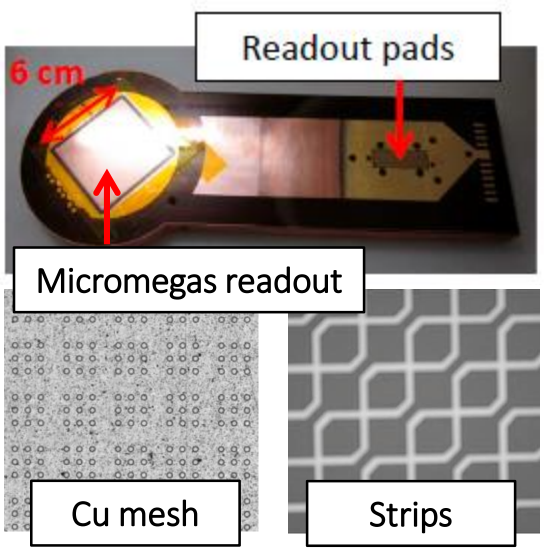
Detector characteristics

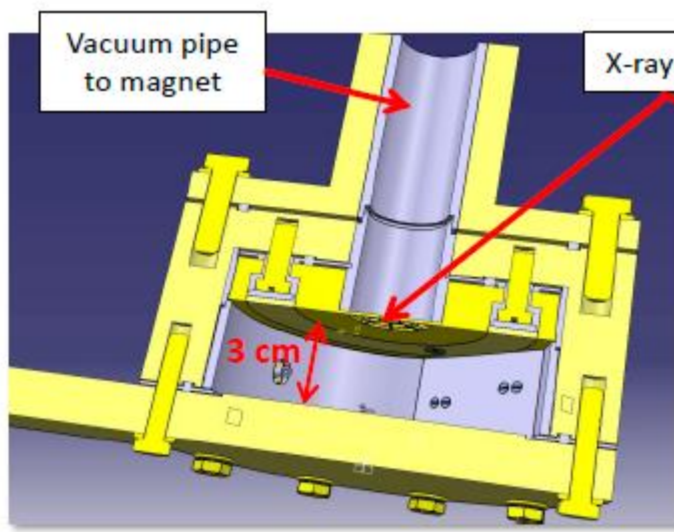
TPC drift: Electroformed Cu chamber = 3cm
1.4bar (Ar+2% Isobutane)

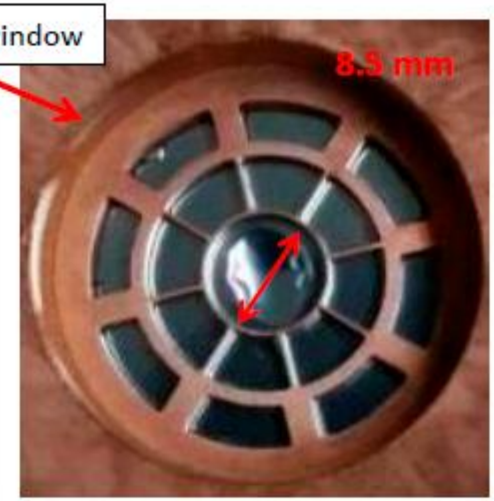
Readout: Strip pattern pitch = 500µm
Active area = 6 x 6 cm^2
} 120 strips per axis

X-ray window: 4µm aluminized mylar (gas-tight & transparent to x-rays)

Strongback cathode: Spider-web design







IAXO-D0 shielding

Passive shielding

Lead shielding

- 20cm of lead, 4π coverage
- Properly stop gamma radiation

Electroformed Cu chamber and pipes

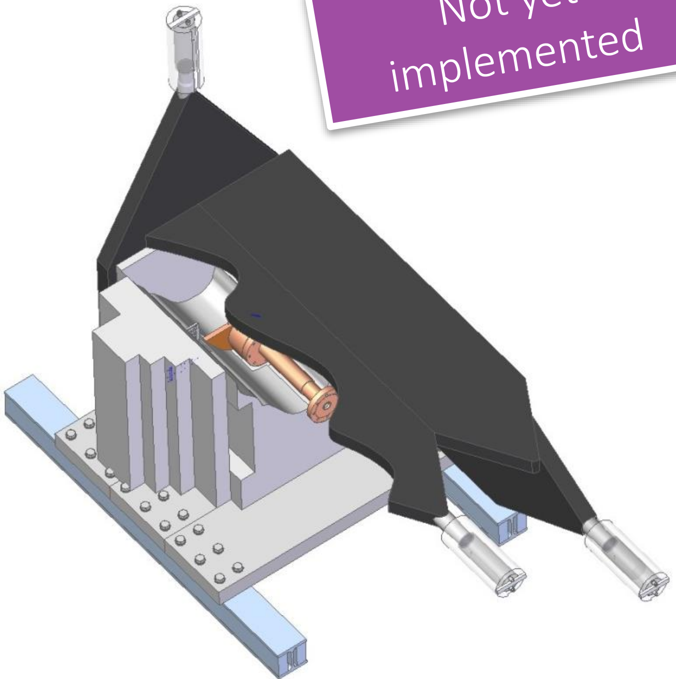
- Innermost shielding for possible lead radiation

Active shielding

Muon vetoes

- 5 plastic scintillators + PMTs
- Designed to cover a solid angle of 4π for cosmic muons

Not yet implemented



REST: acquisiton and analysis software

Rare Event Searches with TPCs

Collaborative framework
→ C++
→ ROOT
→ Others (GEANT4, magboltz)

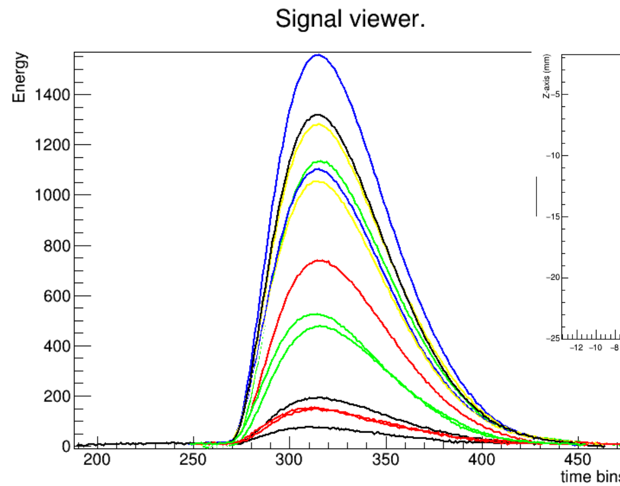
Acquisition + analysis + simulations

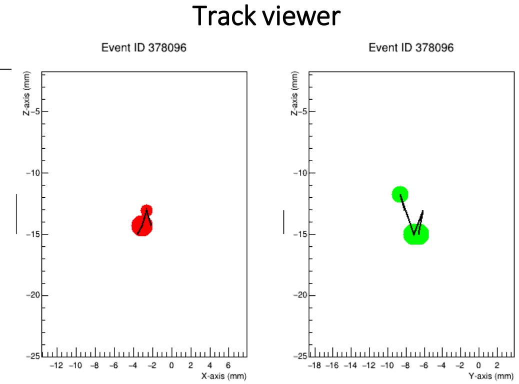
Analysis steps

- Signal analysis
- Hit analysis
- Track analysis

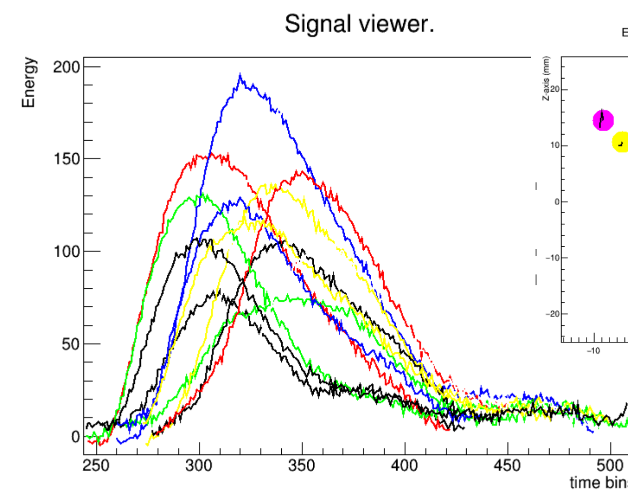
Discrimination capabilities

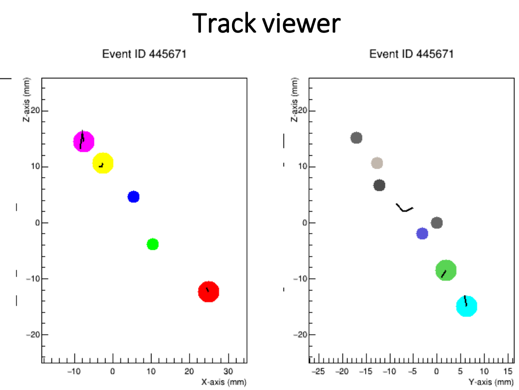
- Topological information
- Observables → event selection





Cd109 calibration



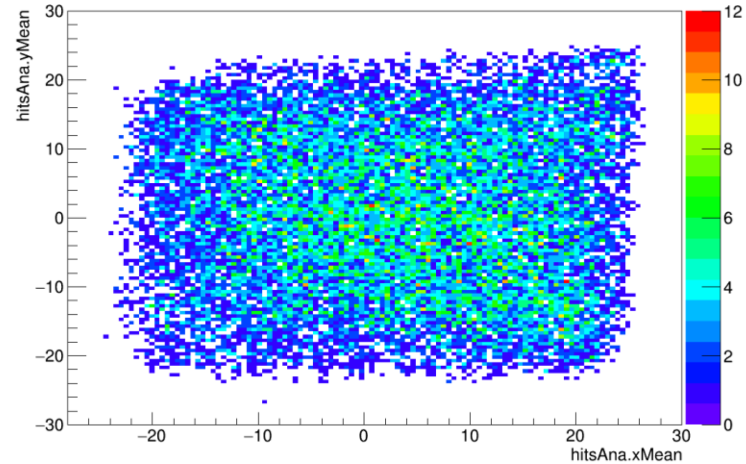


Background

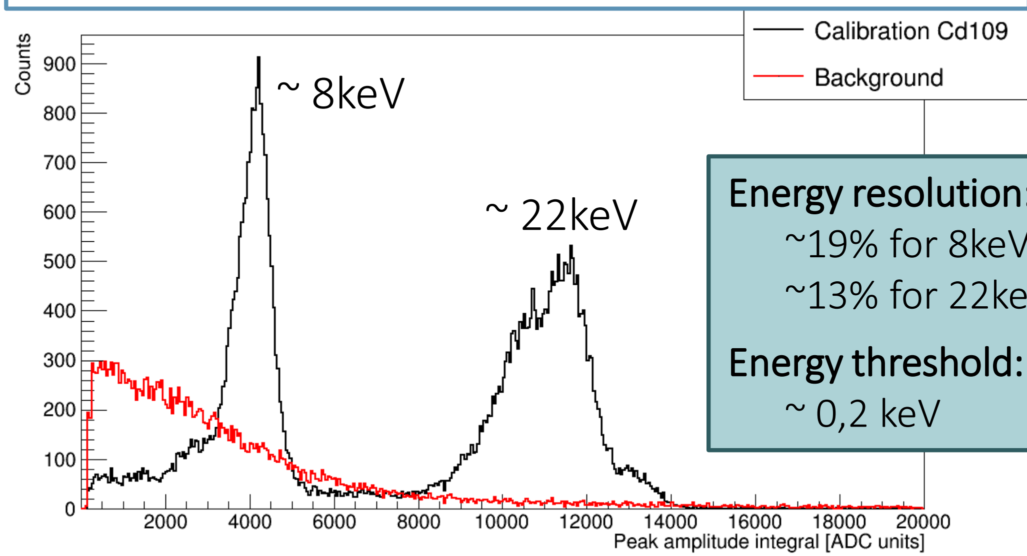
First IAXO-D0 data-taking campaign: Ar+2%Iso

- 16/07/2018 – 21/08/2018 → 37 days
  - ~406h of background
  - 20-23h background runs
  - 20min Cd109 calibrations between background runs

Background run



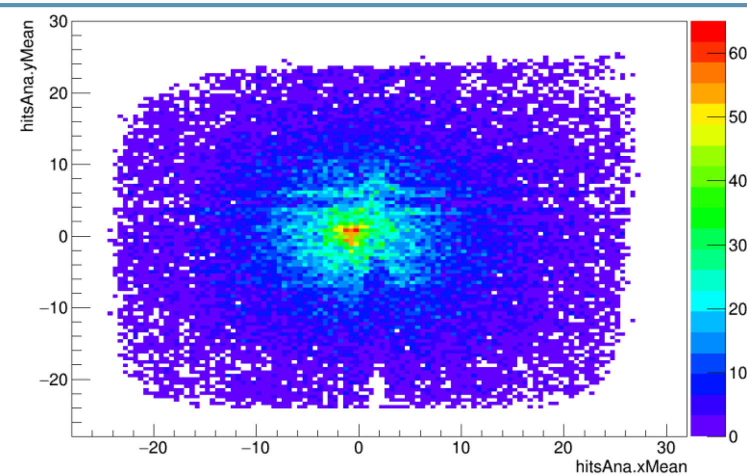
Raw energy spectum



Energy resolution:
~19% for 8keV
~13% for 22keV

Energy threshold:
~ 0,2 keV

Cd109 calibration run



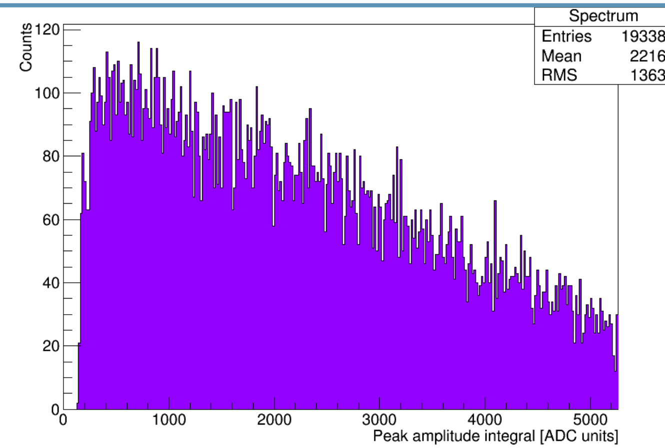
Background discrimination with REST

- Characterization of x-rays with REST observables
  - **1 track**
  - 2 tracks (99% of the total energy)
  - **Small, punctual and symmetric energy depositions**
  - **Centre of the readout** (fiducial cut)

- *Preliminary* background level
  - 1,3 · 10^{-4} counts/keV/cm^2/s
  - Too high but still room to improve
    - Better cuts
    - Less noise
    - Muon vetoes

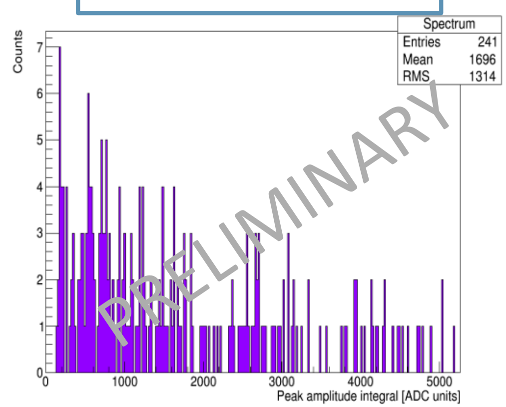
work in progress!!

Raw background energy spectum [0,10] keV (23h)

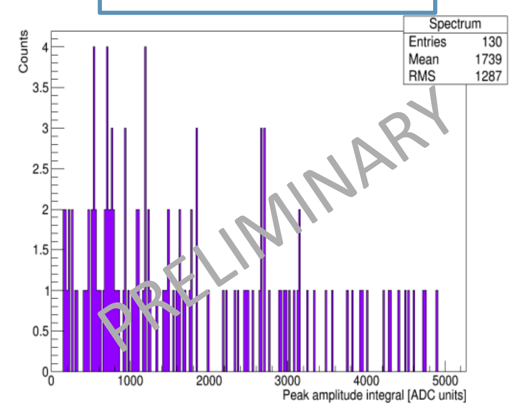


Background energy spectum [0,10] keV: X-ray + fiducial cuts

1,5 x 1,5 cm^2



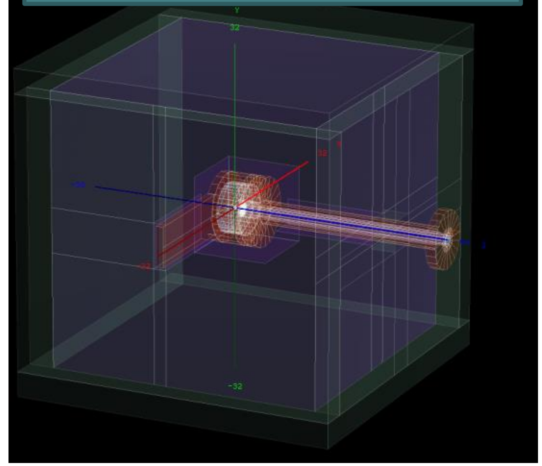
0,85 x 0,85 cm^2



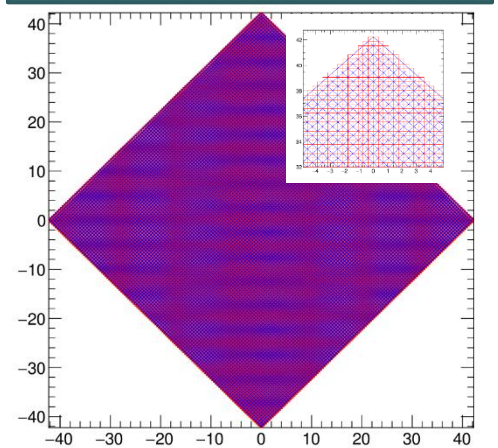
Background model simulation with REST

Step 1: IAXO-D0 geometry and readout implementation (Ar + 2% Iso)

Geometry



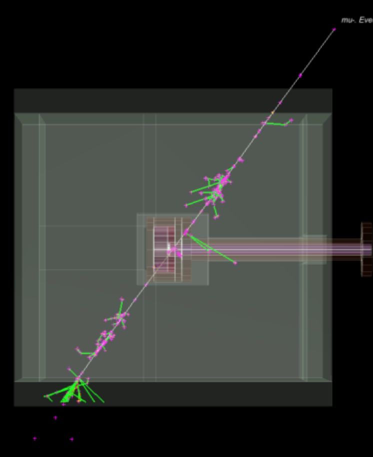
Readout



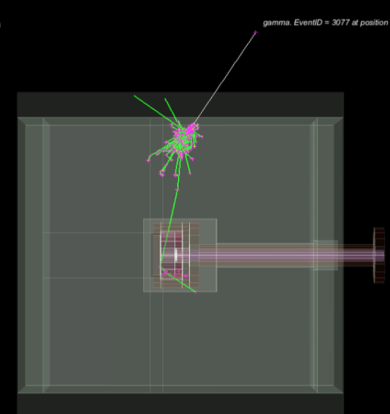
Step 2: simulation of the individual contributions

- **Cosmic muons**
- **Cosmic gammas**
- **Cosmic neutrons**
- Environmental gammas
- Radioactivity neutrons
- Material contaminations
- Ar39 from the gas

Cosmic muons



Cosmic gammas



Cosmic neutrons

Background model simulation with REST

Step 3: analysis with REST

Simulation → experimental-like energy hits → tracks

1. Characterization of x-rays and definition of discriminants
2. Discrimination of background
3. Combination of all the background components
4. Background model for Ar+2%Isobutane

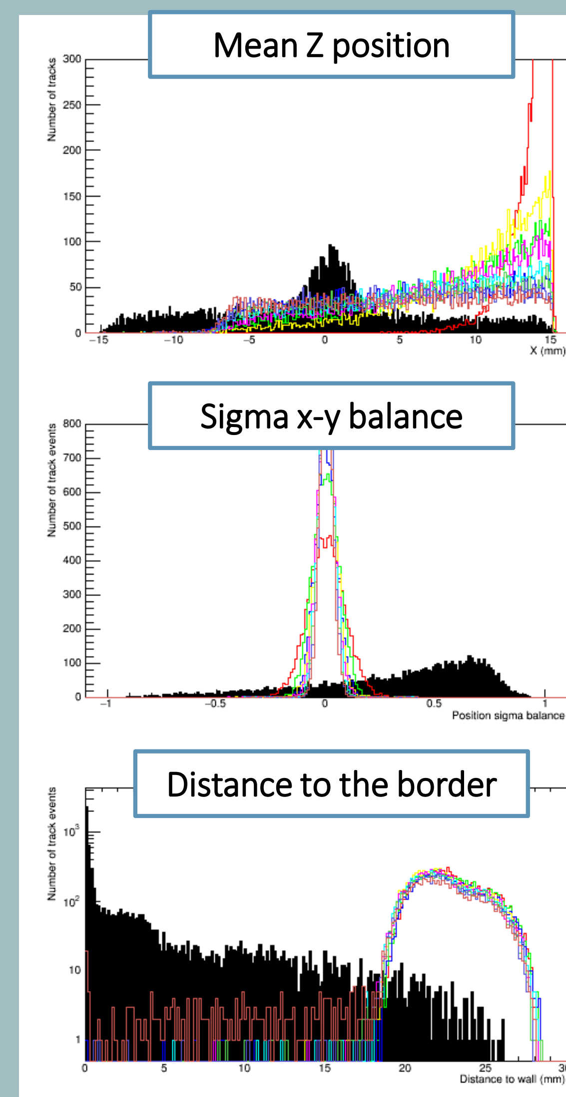
work in progress!!

Example

Same observables for:

→ Color lines: x-rays [1-10] keV

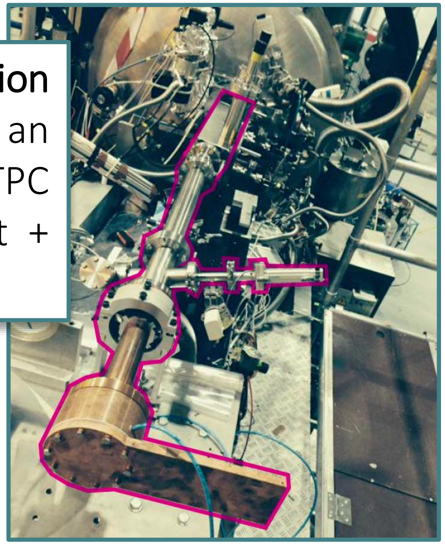
→ Black line: cosmic muons



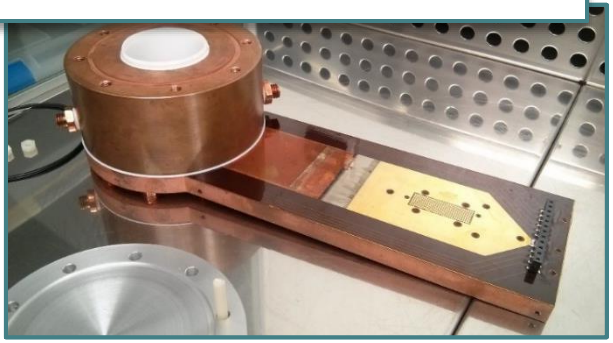
Summary & conclusions

Thanks for your attention!

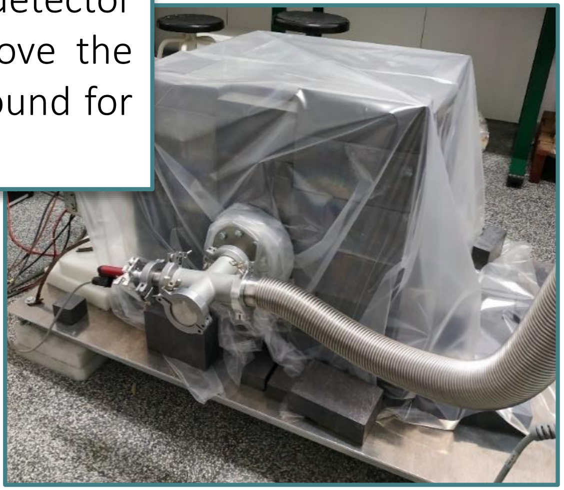
The baseline detection technique for IAXO is an ultra-low background TPC + Micromegas readout + x-ray telescope



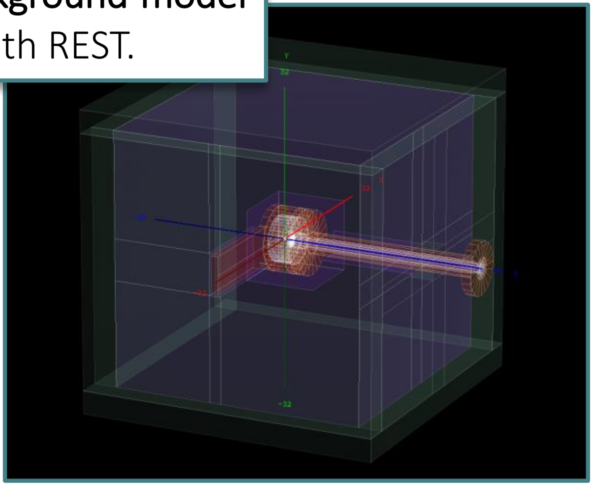
Microbulk Micromegas detectors for axion searches: very stable, good energy resolution in the RoI and low background levels.



IAXO-D0: IAXO detector prototype to prove the levels of background for IAXO.

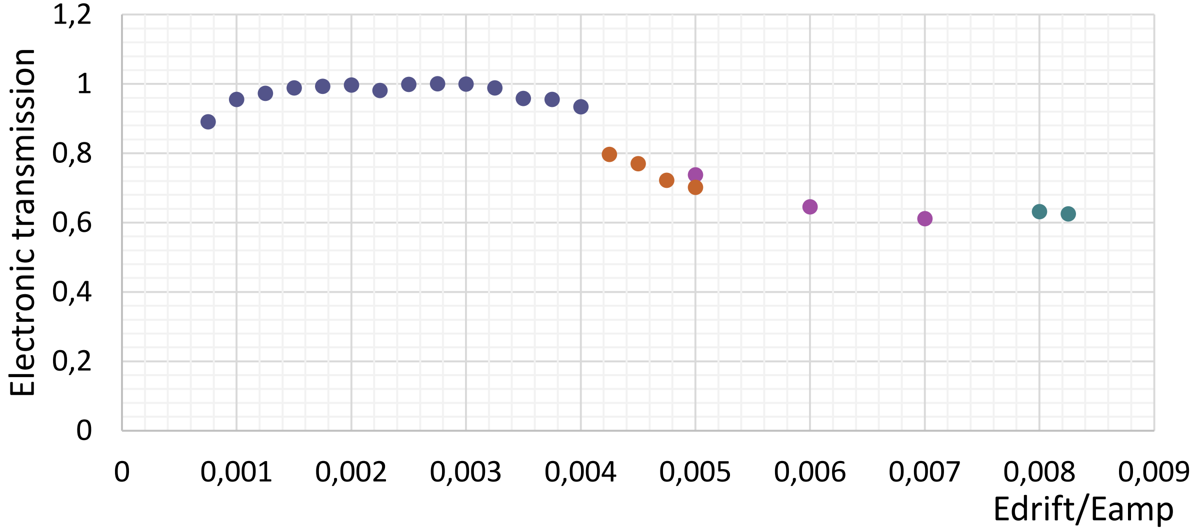


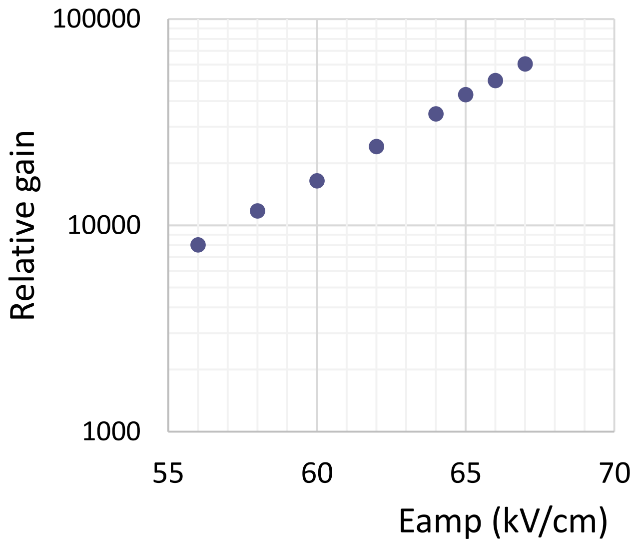
IAXO-D0 background model simulation with REST.

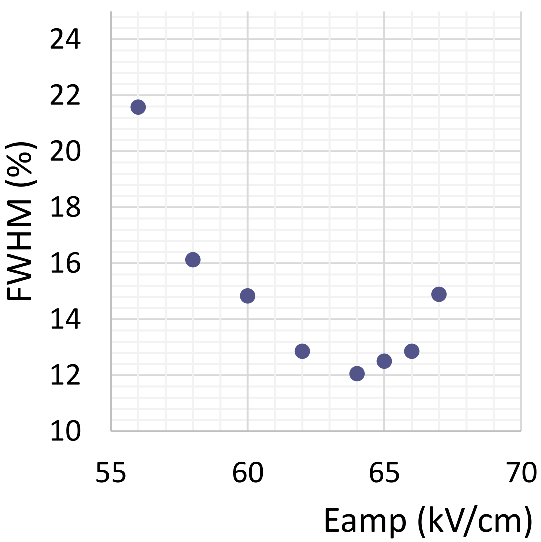


Back-up slides

Micromegas characterization

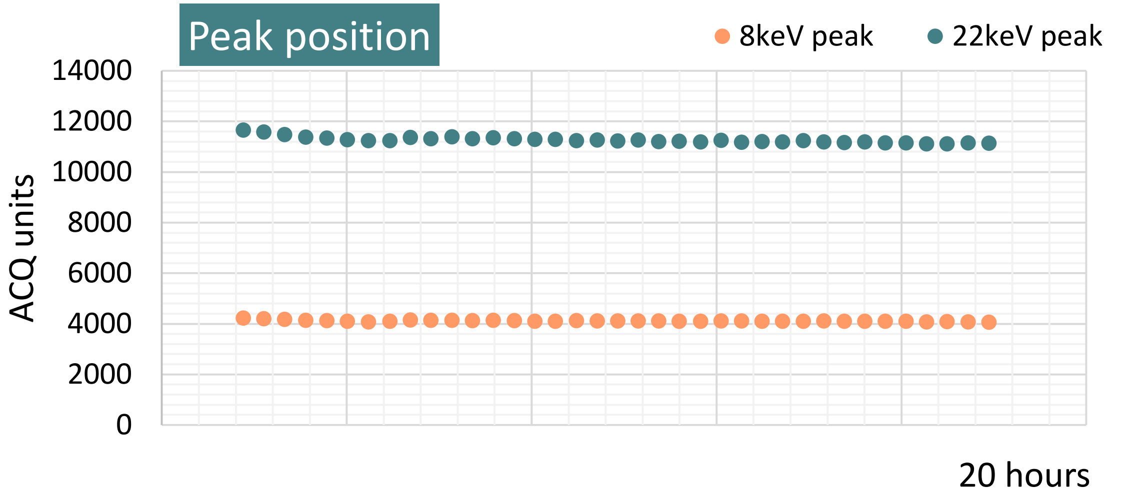


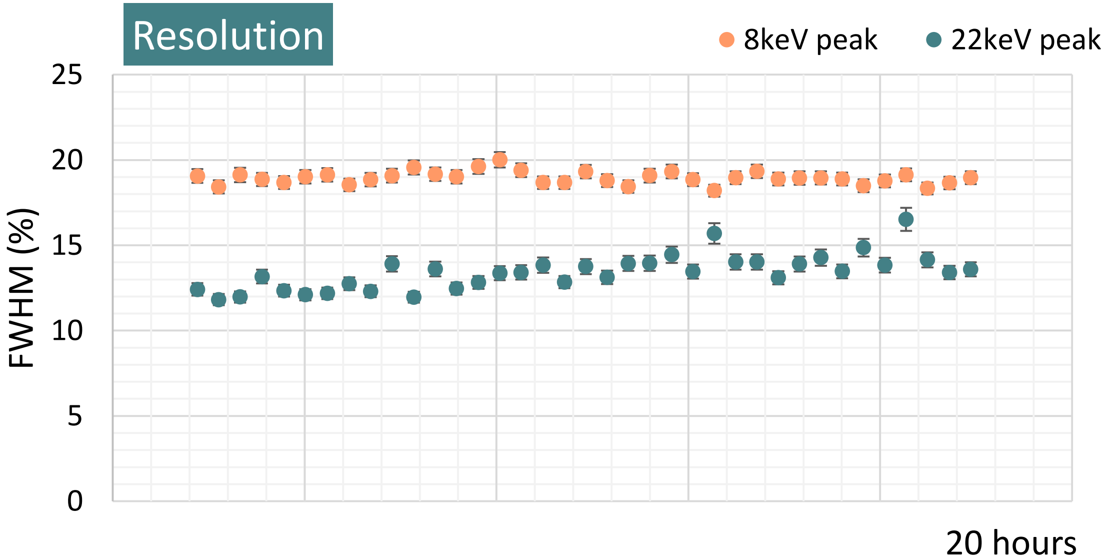




- Data taking conditions
  - Ar+2%Iso @ 1,4bar
  - Gas flux ~ 3 l/h
  - **Cd109 source (22keV)**
  - Vacuum at the pipe
- Best operarion point:
  - V_{mesh} = 320V
  - V_{drift} = 710V
- Expected performance achieved
- Compatible with previous measurements

Micromegas performance over time





- Data taking conditions
  - Ar+2%Iso @ 1,4bar
  - Gas flux ~ 3 l/h
  - Cd109 source (22keV)
  - Vacuum at the pipe
  - V_{mesh} = 320V
  - V_{drift} = 710V
- 20 hours of calibration
- Very stable gain and resolution