BabyIAXO Micromegas detectors

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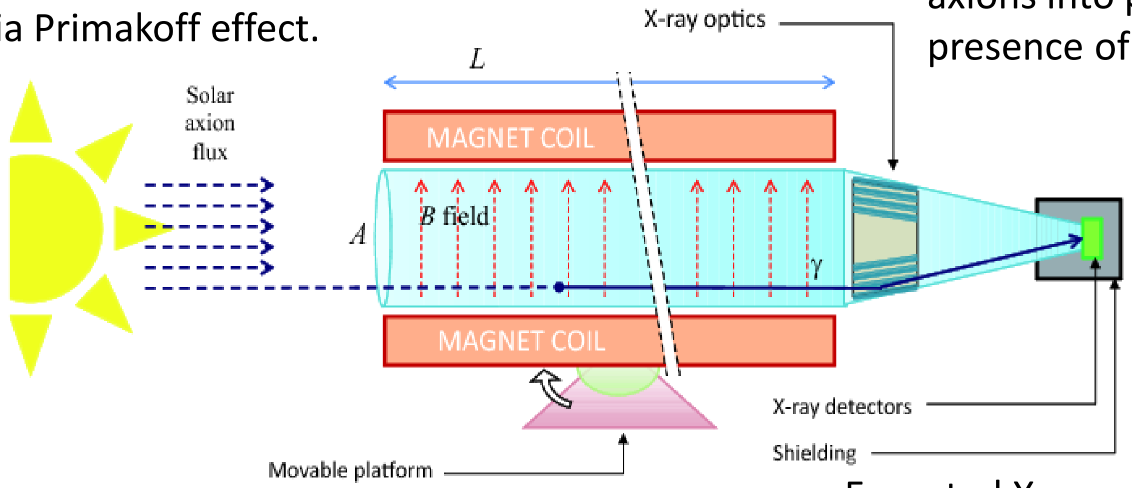
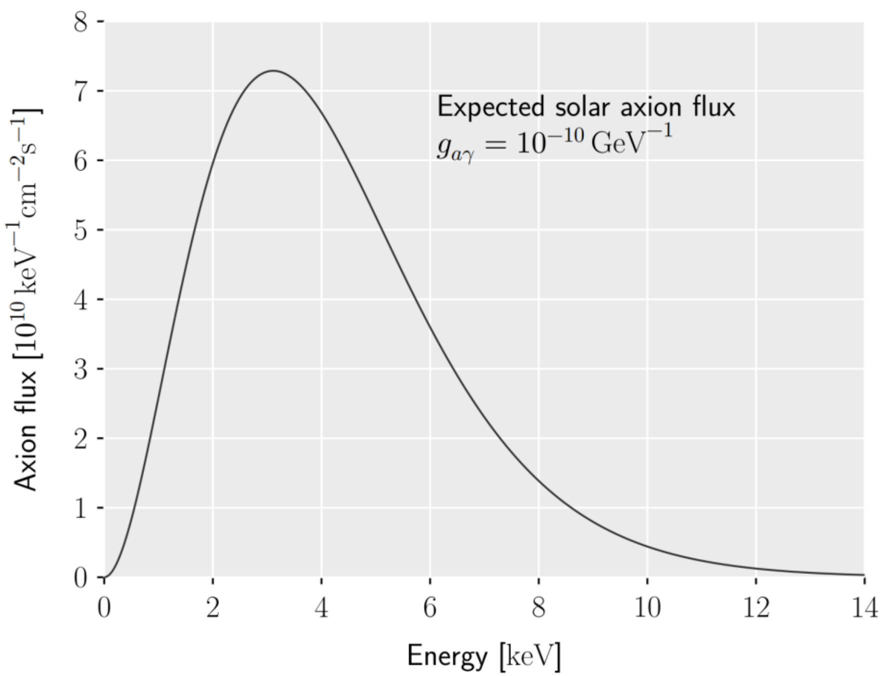
XV CPAN days, 2-6 October 2023
Santander - Spain

Production: stars produce axions from thermal photons via Primakoff effect.

Detection: conversion of axions into photons in the presence of a magnetic field.



Expected X-ray excess when the magnet points to the Sun.



Layout description:

- A powerful and large dedicated magnet
- X-ray focusing optics optimized for axion spectrum
- Ultra-low background x-rays detectors

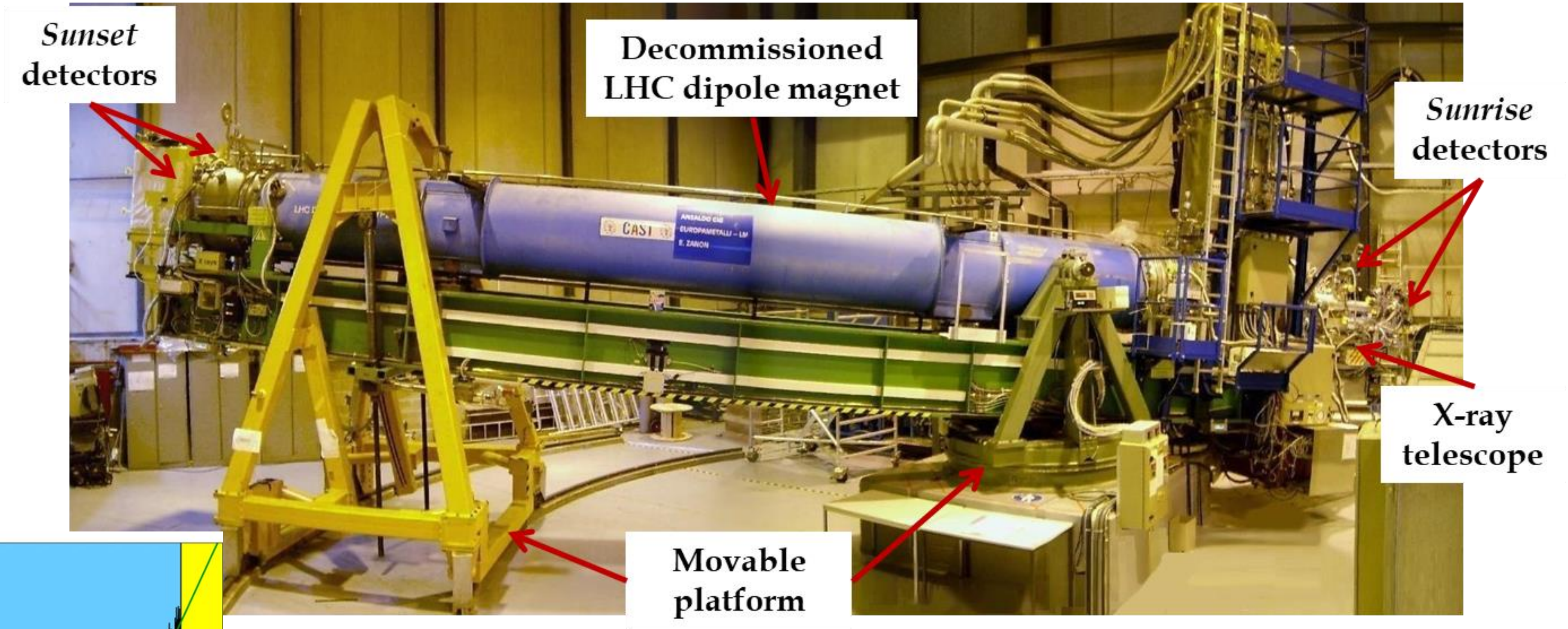
Diagram of the Primakoff effect (a-γ coupling)

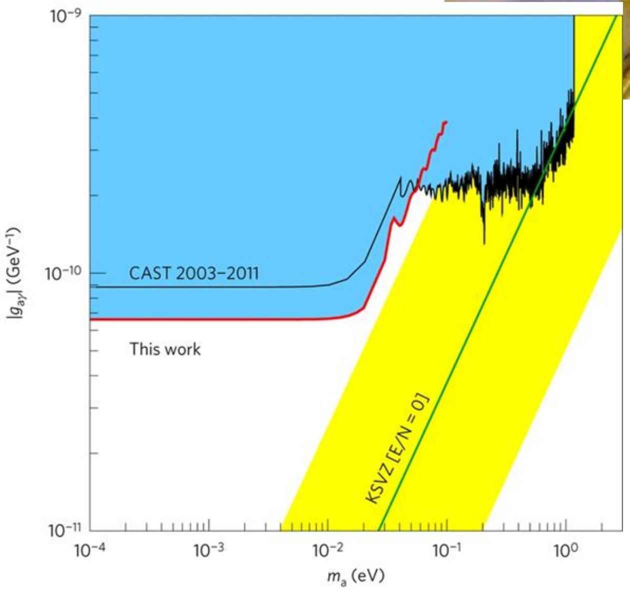
magnet
optics

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

detectors
time

CAST is the most sensitive helioscope so far…

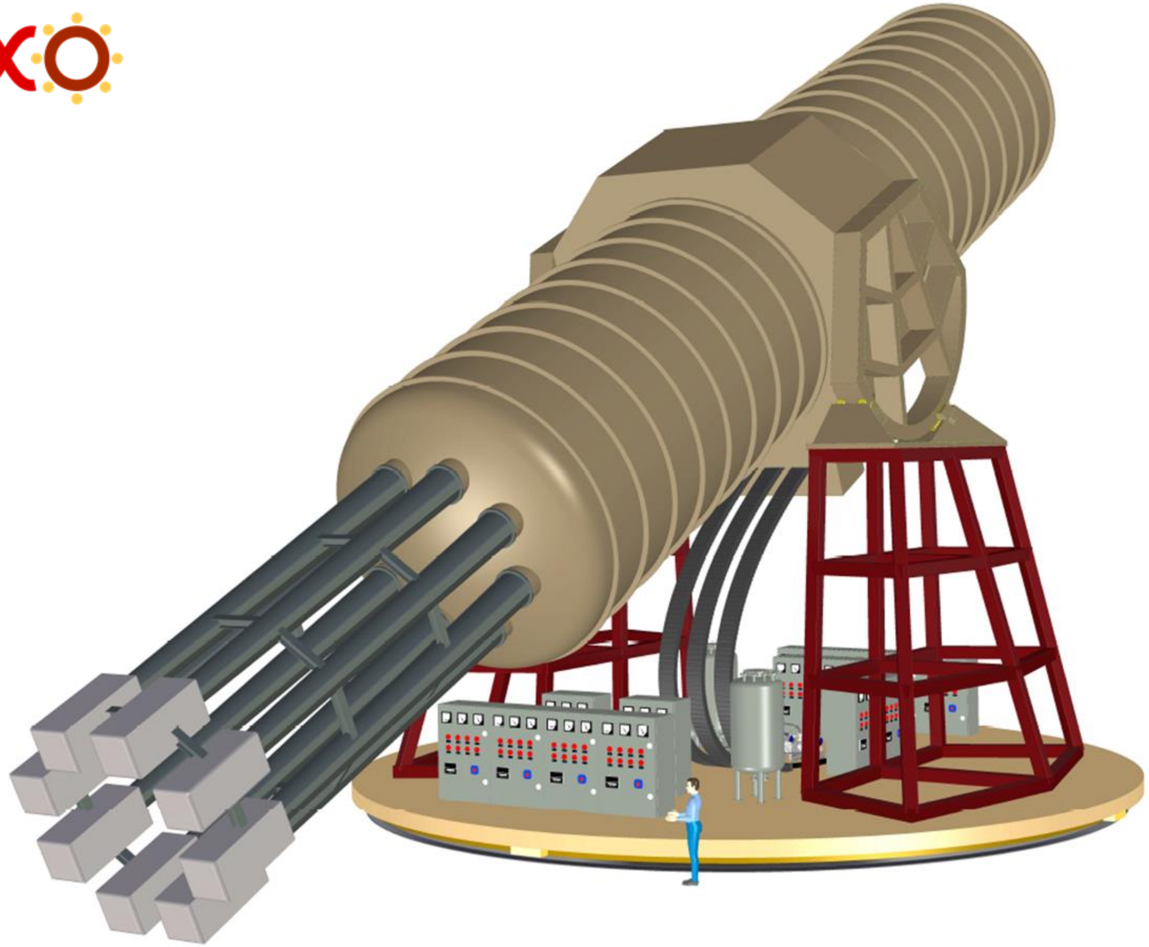




Coupling limit m_a < 0.01 eV
$|g_{a\gamma}| < 0.66 \times 10^{-10}$ [GeV^{-1}] (95% C.L.)

[10.1038/nphys4109](https://doi.org/10.1038/nphys4109)

IAXO-The International Axion Observatory



- Super toroidal magnet
  - 20 meters long
  - Magnetic field up to 5.4 T
  - 8 bores of 60 cm Ø
- Dedicated X-ray optics
  - 0.2 cm^2 focal spot
- Tracking system
  - Based on gamma ray telescopes
  - 50% of Sun-tracking time
- X-ray detector technologies
  - Micromegas
  - GridPix
  - Metallic Magnetic Calorimeters (MMC)
  - Transition Edge Sensors (TES)
  - Silicon Drift Detectors (SDD)

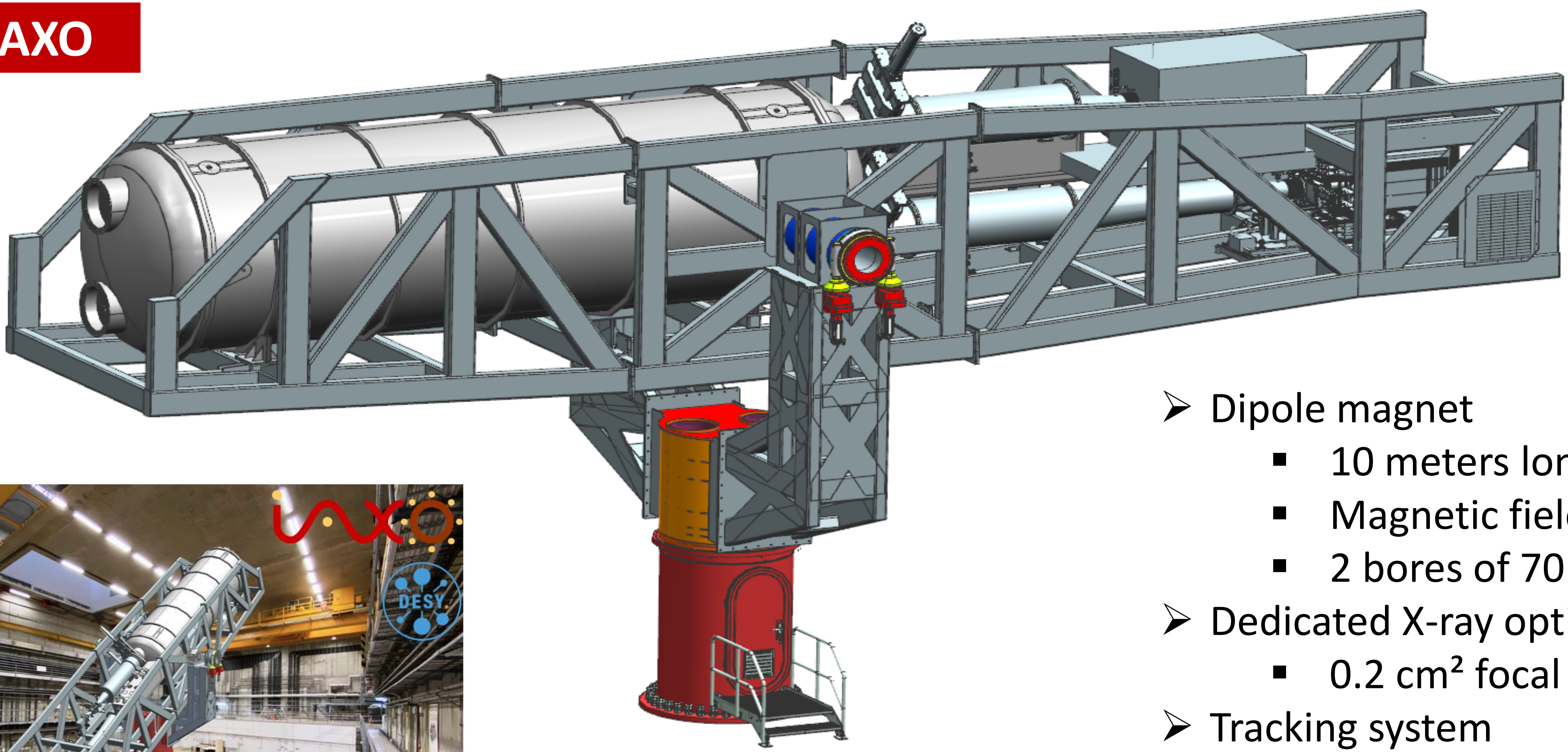
CERN-SPSC-2013-022

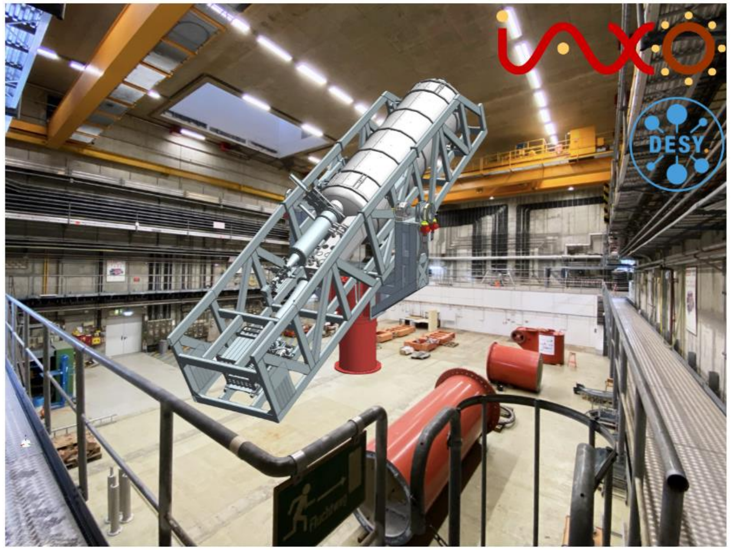
IAXO aims to improve CAST sensitivity to solar axions in 1 order of magnitude!

BabyIAXO helioscope

BabyIAXO is currently under construction and DESY!

BabyIAXO





[10.1007/JHEP05(2021)137](https://doi.org/10.1007/JHEP05(2021)137)

- Dipole magnet
  - 10 meters long
  - Magnetic field ~2 T
  - 2 bores of 70 cm Ø
- Dedicated X-ray optics
  - 0.2 cm² focal spot
- Tracking system
  - Based on gamma ray telescopes
- X-ray detector technologies
  - Micromegas (baseline)

Sentitivity prospects

Parameter space showing the sensitivity of the experiments in the $g_{a\gamma}$- m_a plane

- Coupling constant to photons $g_{a\gamma}$
- Axion mass m_a

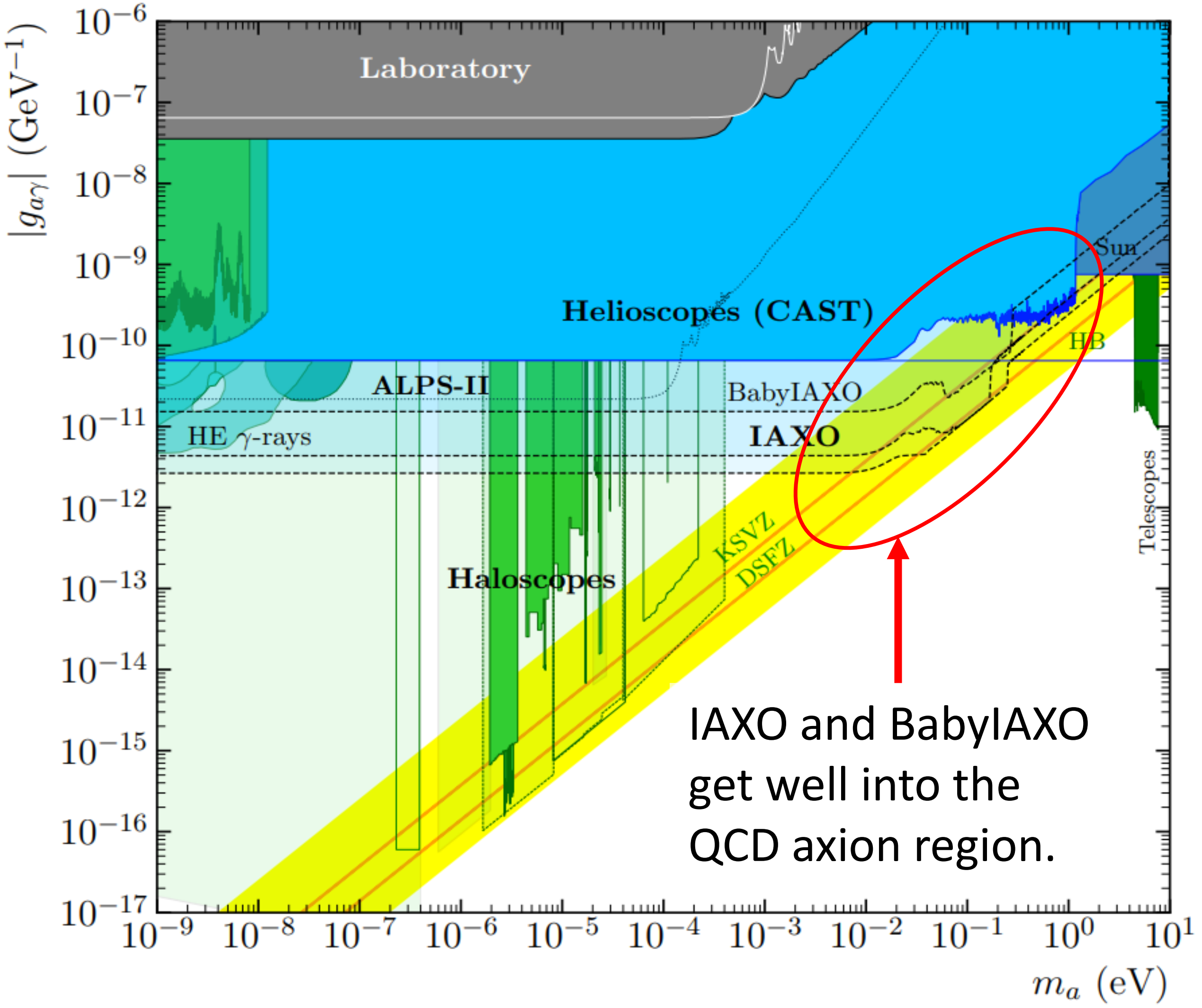
CAST has reached similar levels to the most restrictive astrophysical bounds.
Nature Physics 4109 (2017)

BabyIAXO:

- Probes part of the QCD band
- Improves signal-to noise ratio (SNR) by a factor >10^2 that of CAST

IAXO:

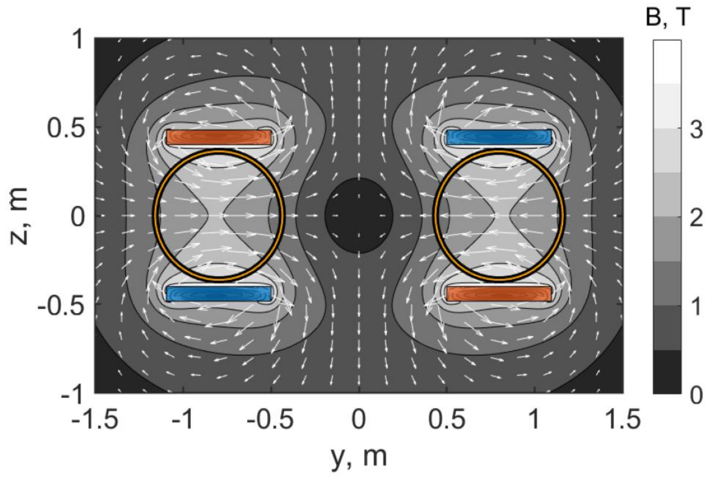
- Probes large generic unexplored ALP space, QCD axion models in the meV to eV mass band and astrophysically hinted regions.
- Improves SNR by a factor > 10^4 and sensitivity in $g_{a\gamma}$ by > 1 order of magnitude

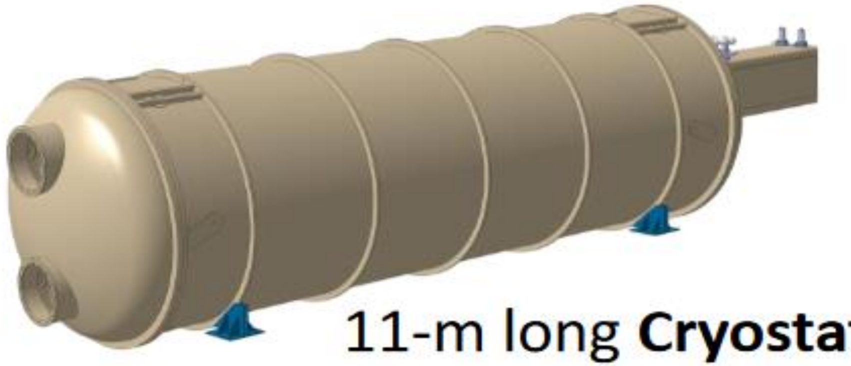


Review of Physics potential of IAXO JCAP (2019) 06 047

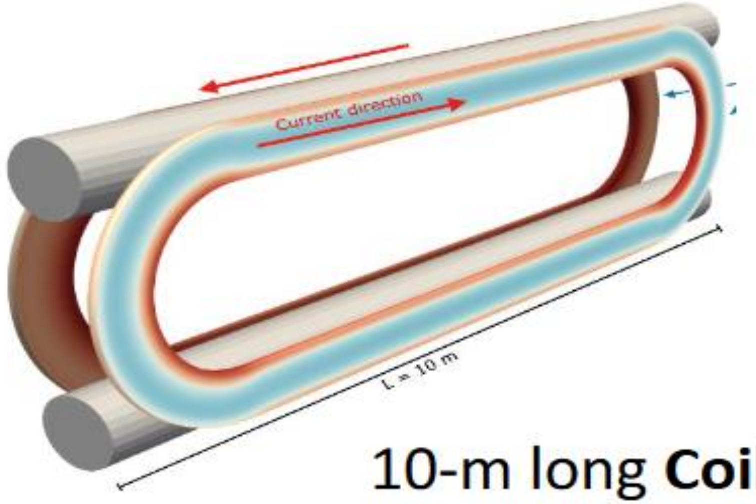
Superconducting magnet

- 2 parallel flat coils: 10m long.
- Conductor: standard Rutherford cable with 30-40 strands of NbTi/Cu
- 2 bores: 70 cm diameter; vacuum & buffer gas
- Optimized layout: maximum magnetic field at bores
- Cold mass at 4.5 K
- Minimal risk: straightforward and robust design choices





11-m long **Cryostat**



10-m long **Coils**

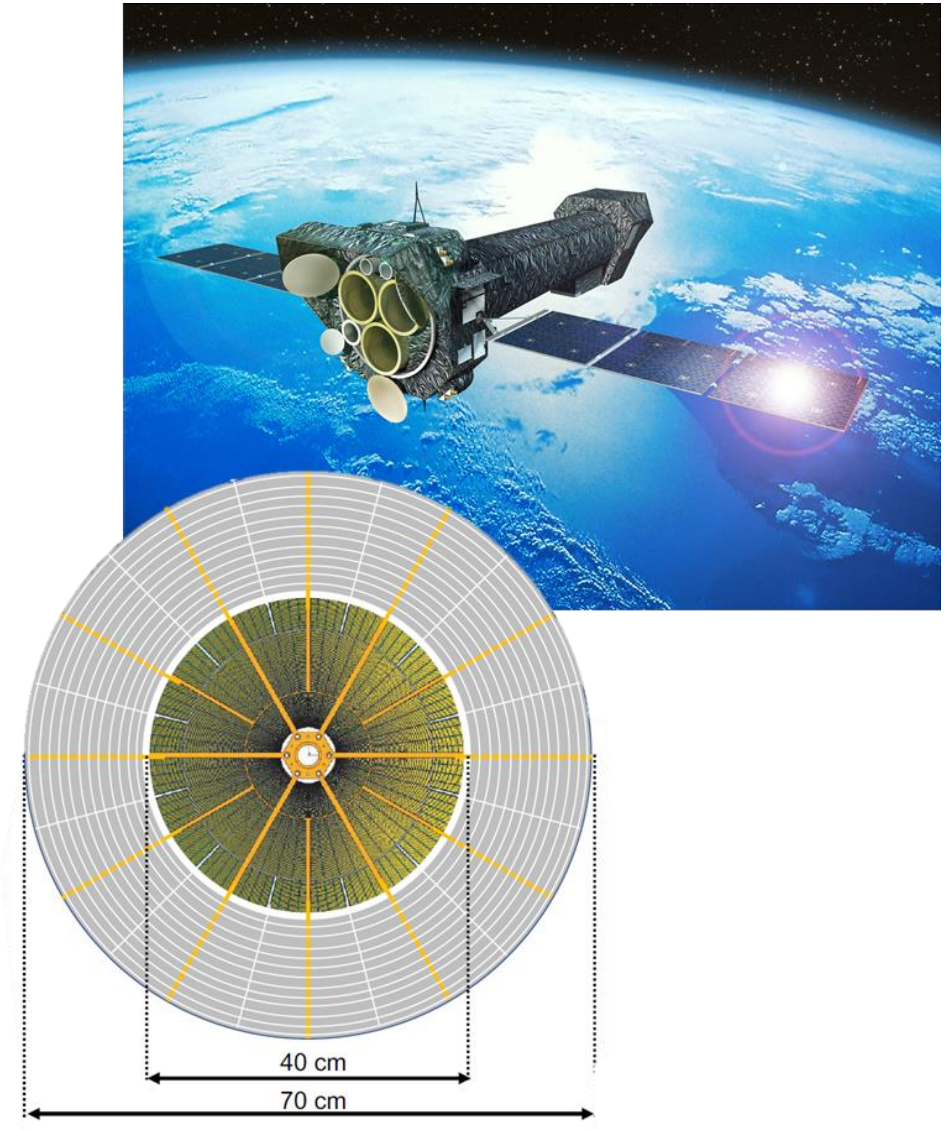
~35 km **Superconductor**

Dedicated X-ray optics

- Multilayer-coated segmented-glass Wolter-I optics
- Signal from the 0.7 m diameter bore focused to 0.2 cm^2 area
- Mature technology based on NASA's NuSTAR telescopes

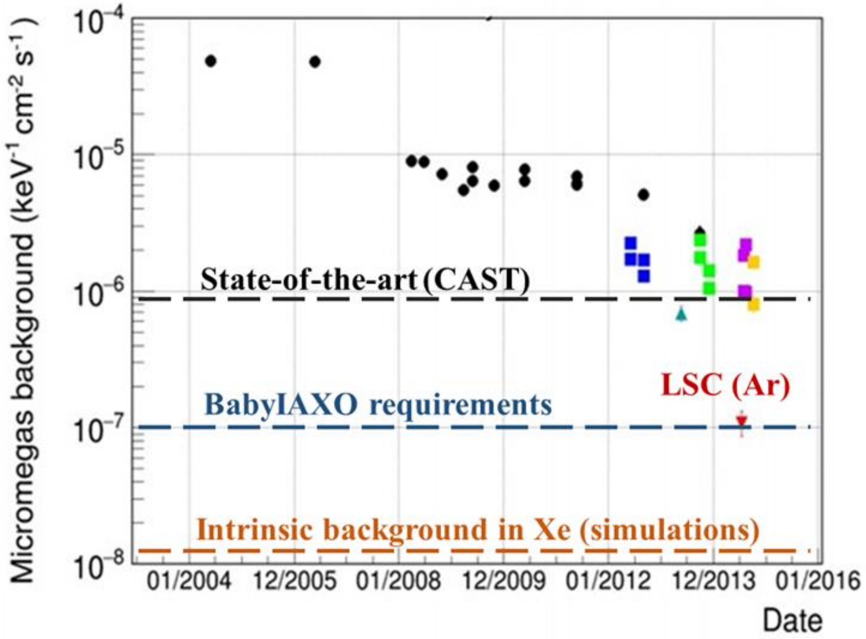
Two different telescopes:

- Custom made telescope
  - 5 m focal length
  - Hybrid approach with different inner and outer optics to increase the diameter and cover the bore
- XMM flight spare
  - 7.5 m focal length
  - Already available and compatible with BabyIAXO

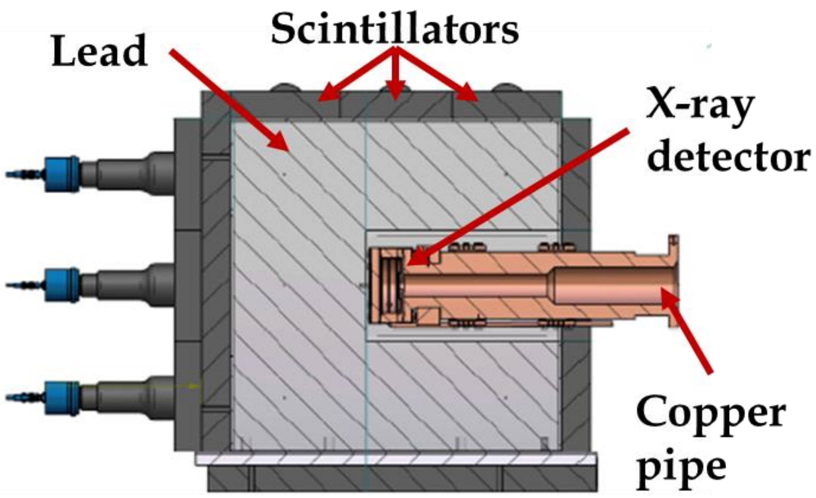


Ultra-low background X-ray detectors:

- Required to distinguish axion signal above the nominal background of the detector.
- Required background level 10^{-7} c keV^{-1} cm^{-2} s^{-1} in the RoI [0-7] keV
- Current baseline is Micromegas, but other technologies (GridPix, MMC, TES and SDD) are under study.



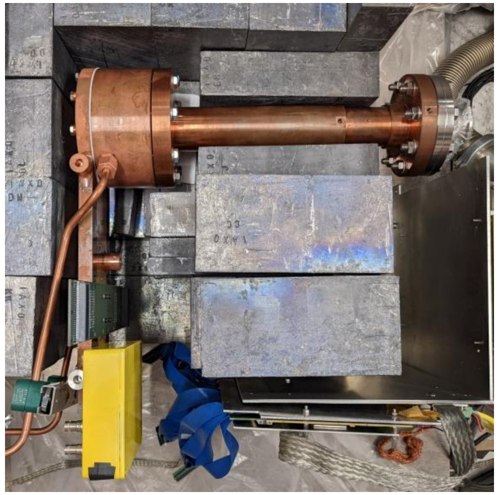
State of the art on low-background techniques:

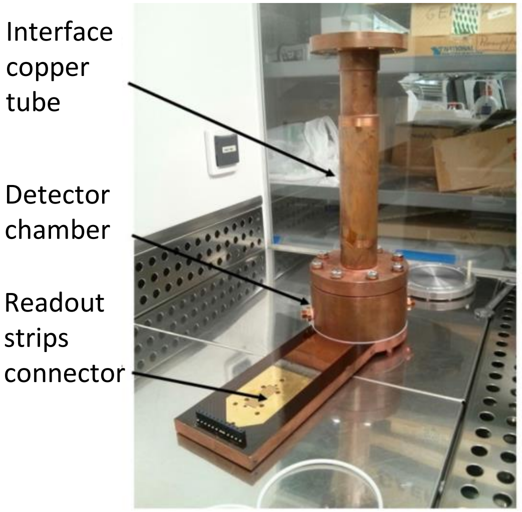


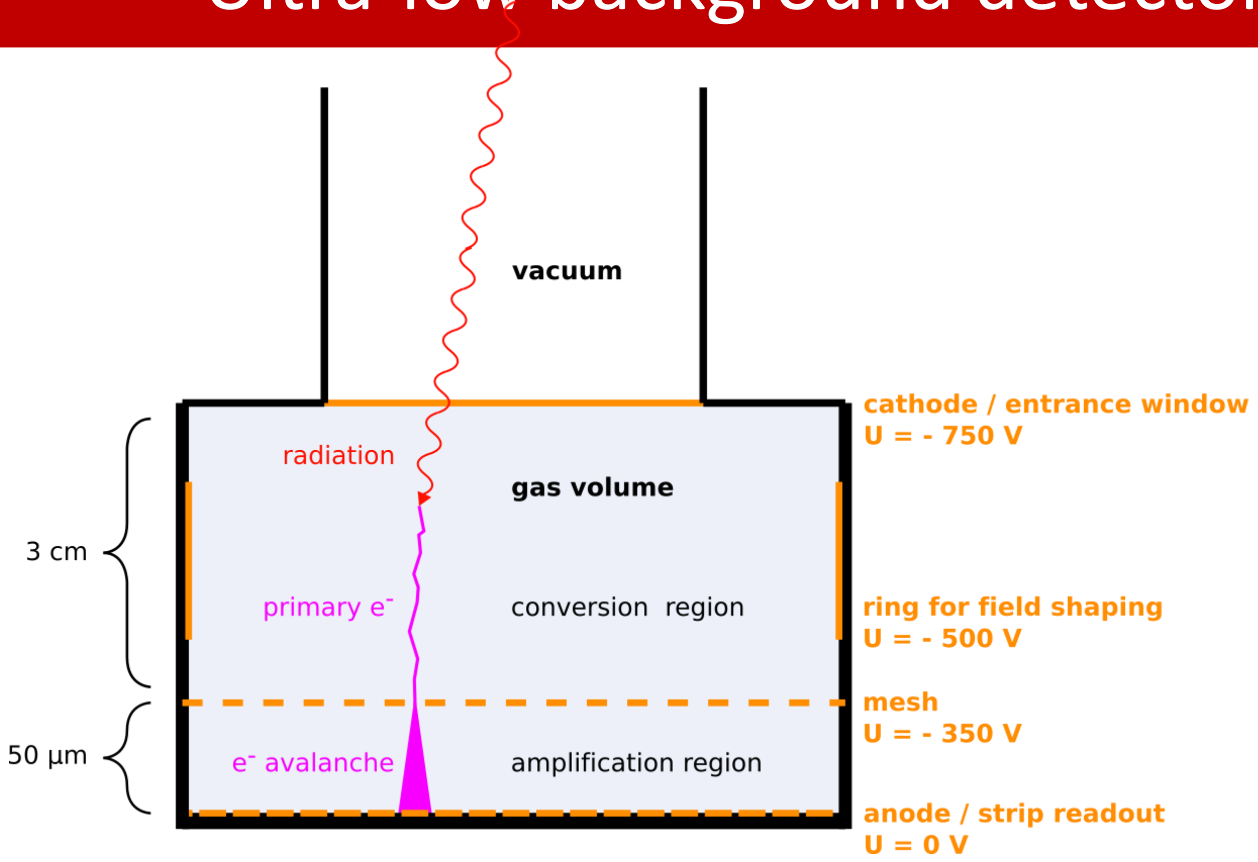
- Intrinsic radiopurity of the X-ray detector (measured at the LSC)
- Event discrimination (X-ray like events)
- Shielding strategies:
  - Radiopure copper
  - Lead shielding (20 cm)
  - Active muon veto (cosmic rays and secondaries)

Microbulk Micromegas gaseous detectors

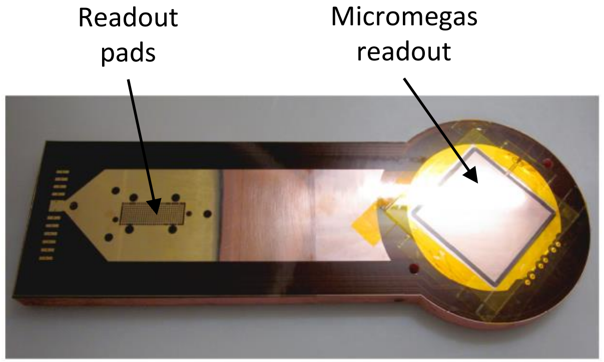
- Very homogeneous amplification gap, uniform gain.
- Intrinsically radiopure.
- Good energy and spatial resolution.
- Pixelized readout gives topological information.







Performance tested in CAST

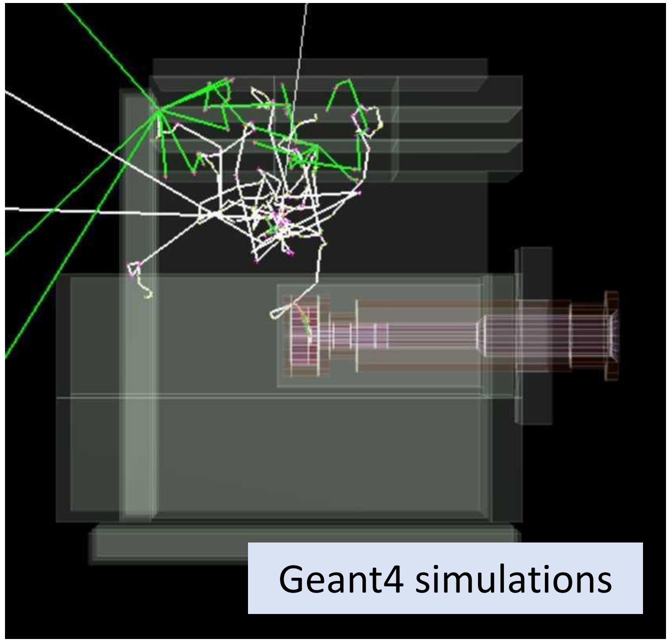


- Signal reaches the active volume through a mylar window.
- X-rays ionize the gas in the conversion region and the produced signal is read by the Micromegas.
- Data is analyzed with the REST-for-Physics framework (github.com/rest-for-physics).

Background measurements at surface

Tests at surface UNIZAR with IAXO-D0

- Implementation of 4π muon veto.
- Testing if neutrons can be efficiently tagged.



Geant4 simulations

Simulations

- Background might be limited by cosmic neutrons
- Hypothesis to be confirmed by IAXO-D0/IAXO-D1
- Cosmic neutron tagger is being designed and will be implemented in the simulations

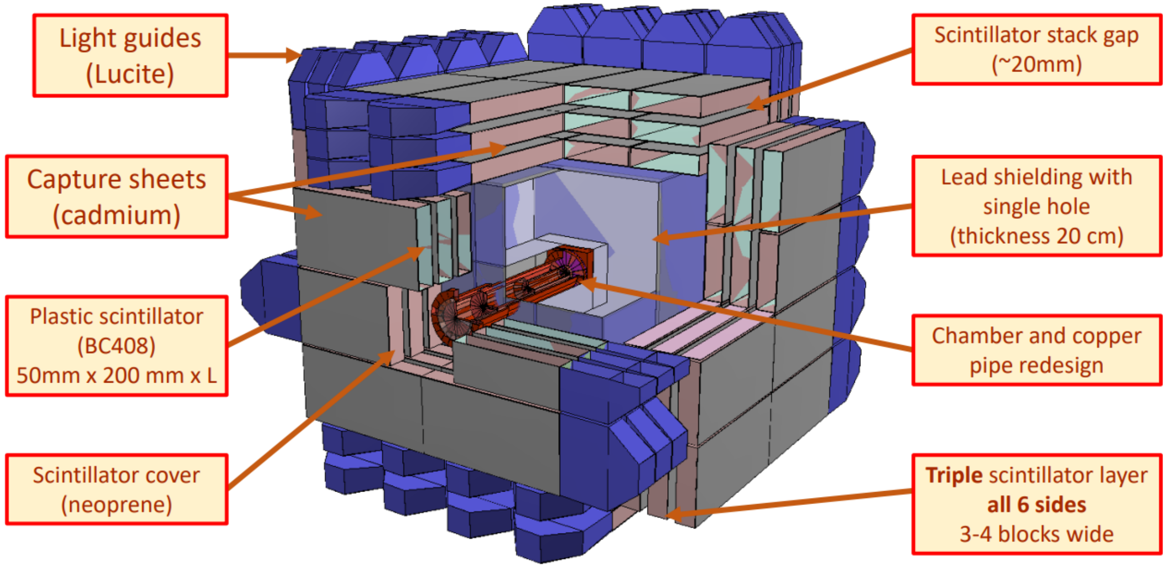
Measurements at Canfranc Underground Lab (LSC)

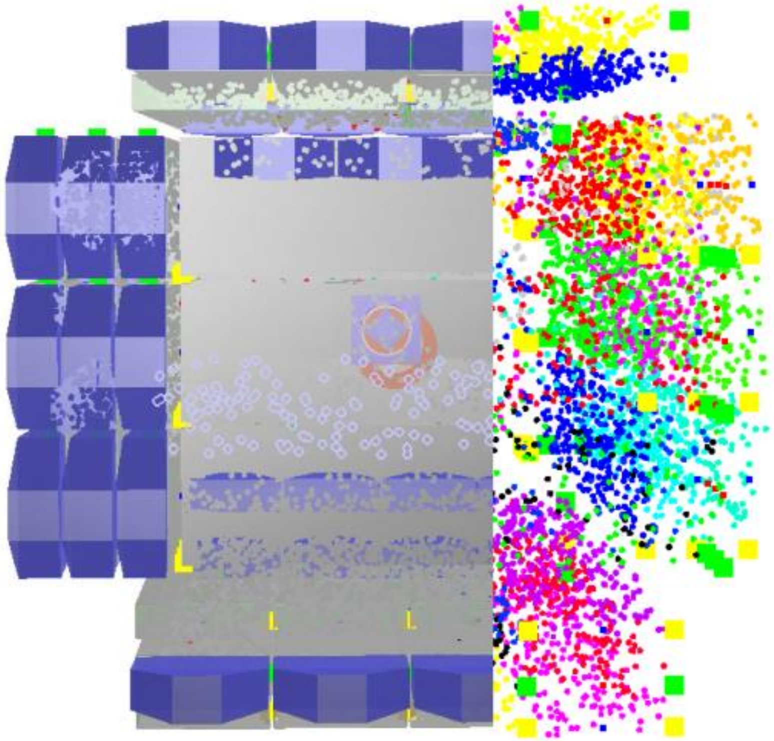
Underground tests with IAXO-D1

- Determine part of intrinsic and cosmic induced events

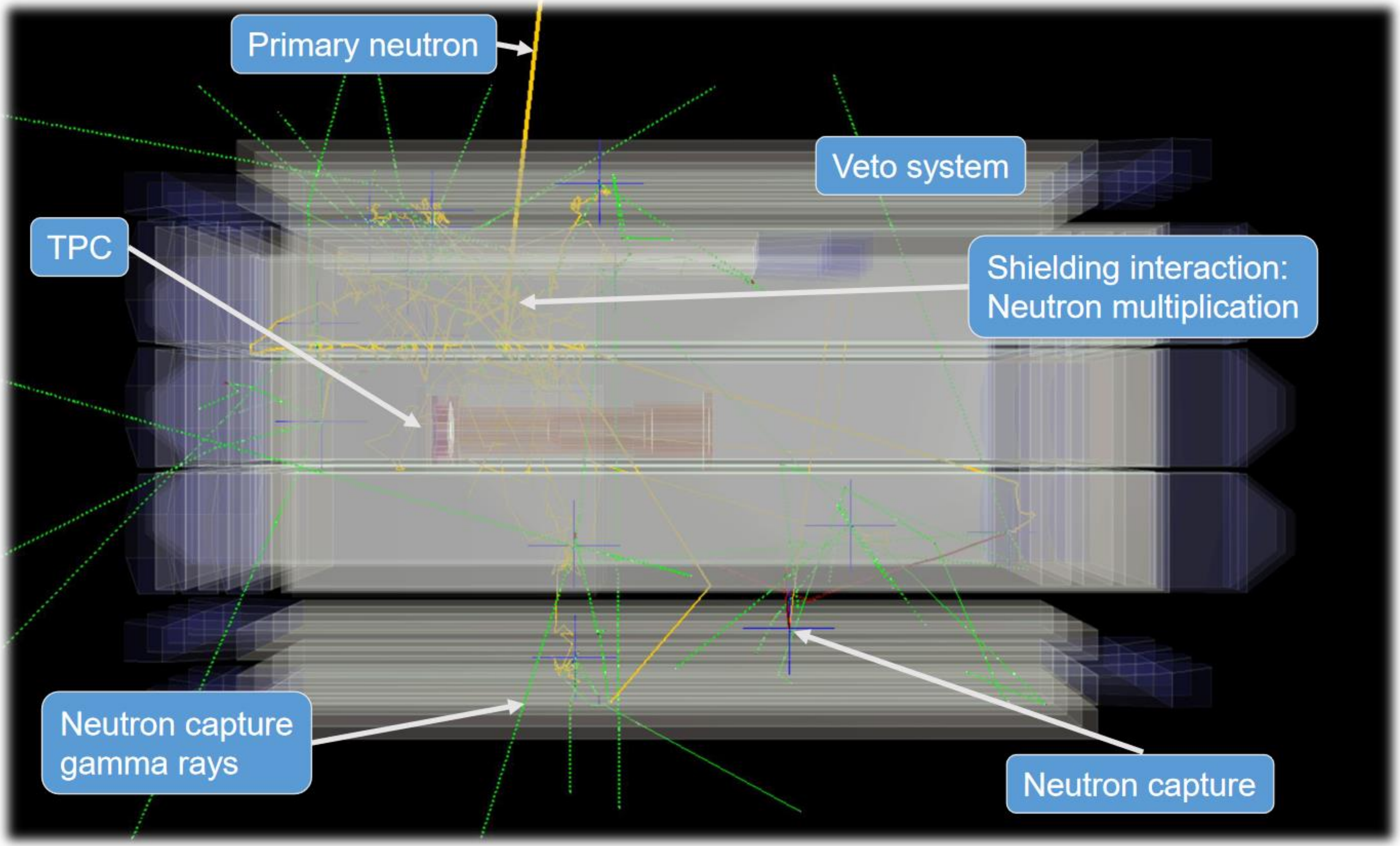
Veto system simulation

- Micromegas detector with vacuum pipe
- Lead shielding
- Three veto layers (scintillation plastics)
- Cadmium sheets for neutron capture
- Geant4 and Rest-for-Physics sofware
- Focused in muons and cosmic neutrons



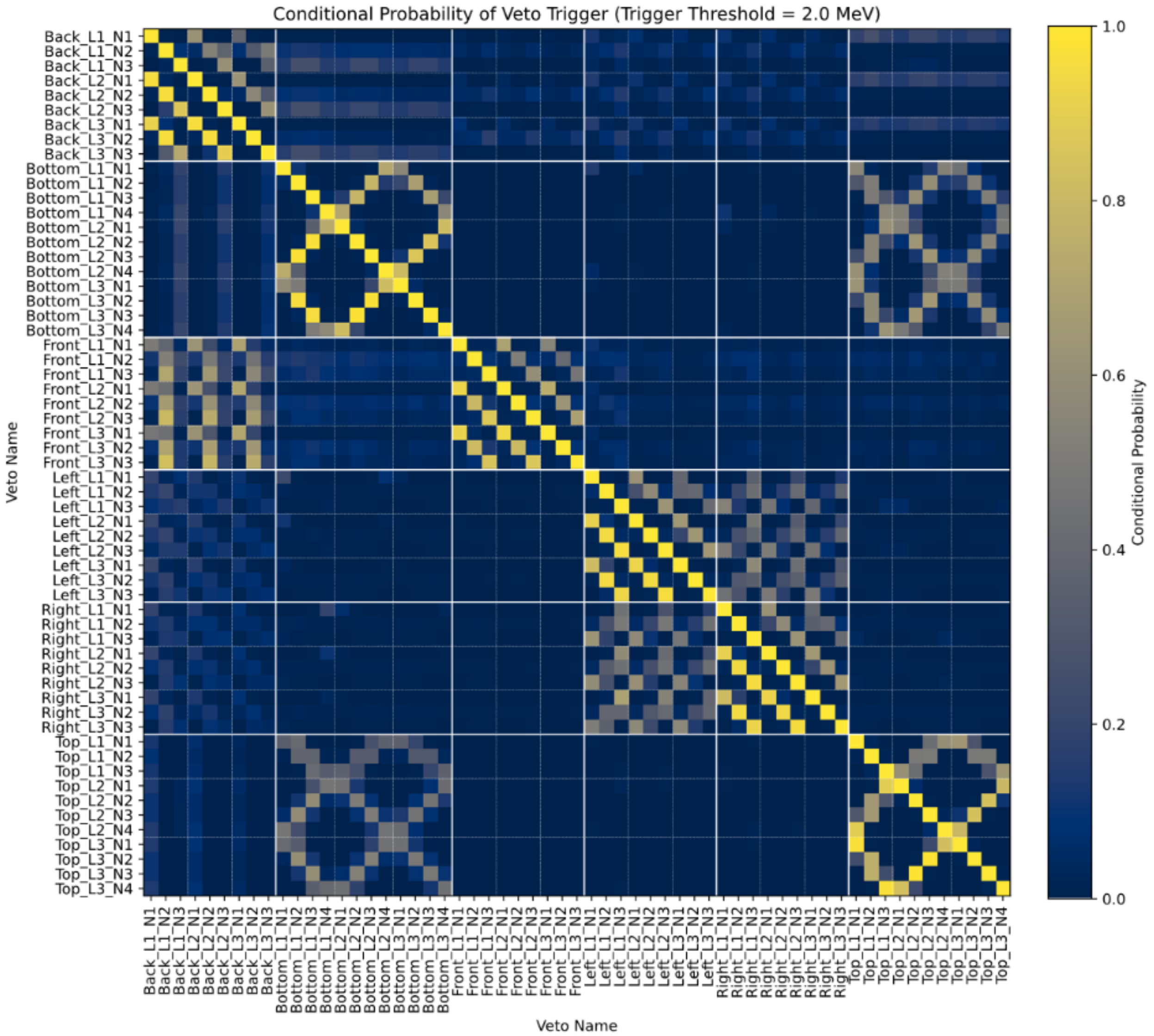


- Geant4: simulate events
- Rest-for-Physics: analyse data and produce realistic signals

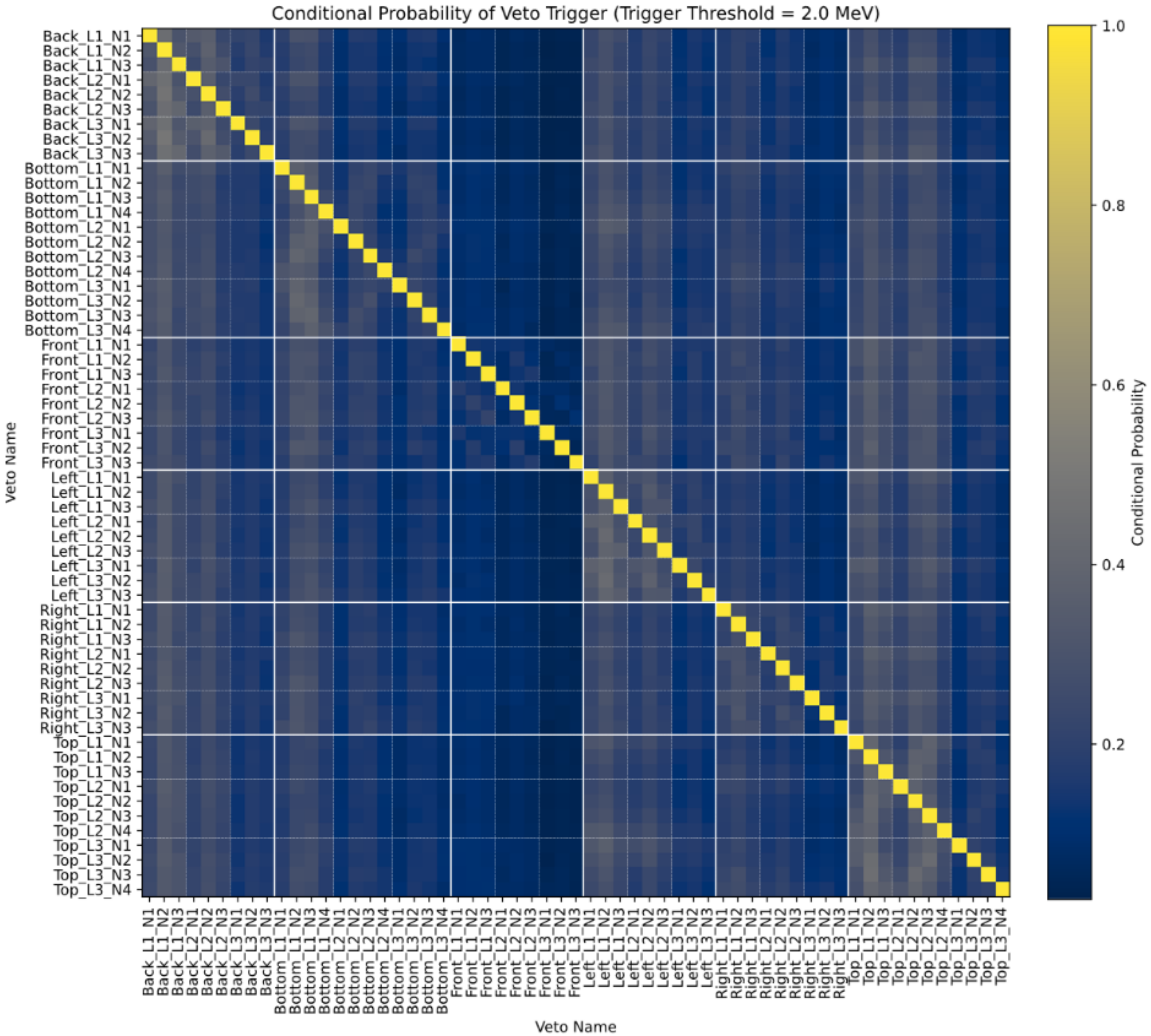

Primary neutron
Veto system
TPC
Shielding interaction:
Neutron multiplication
Neutron capture
gamma rays
Neutron capture

Geometrical correlation between vetoes

Muons

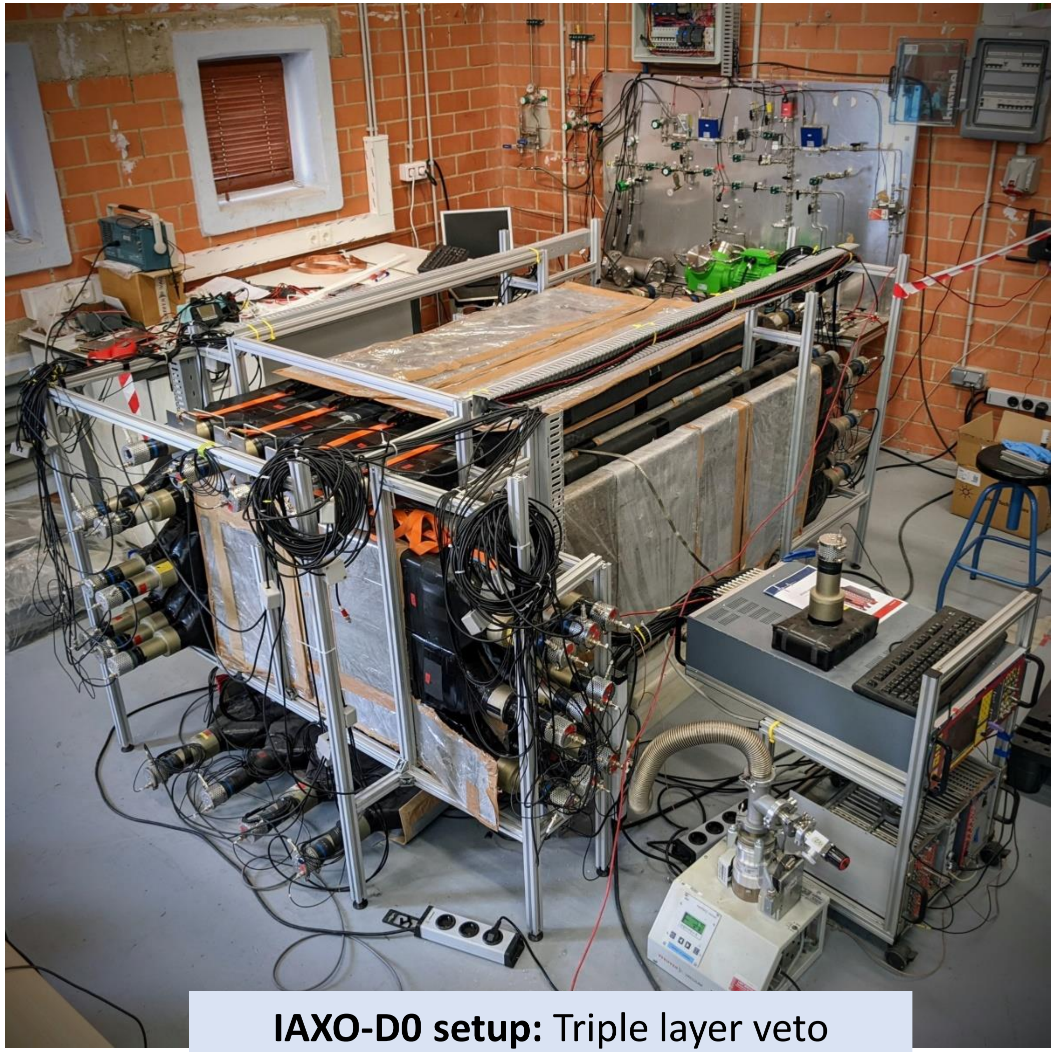


Neutrons



IAXO-D0 detector with veto system in Zaragoza

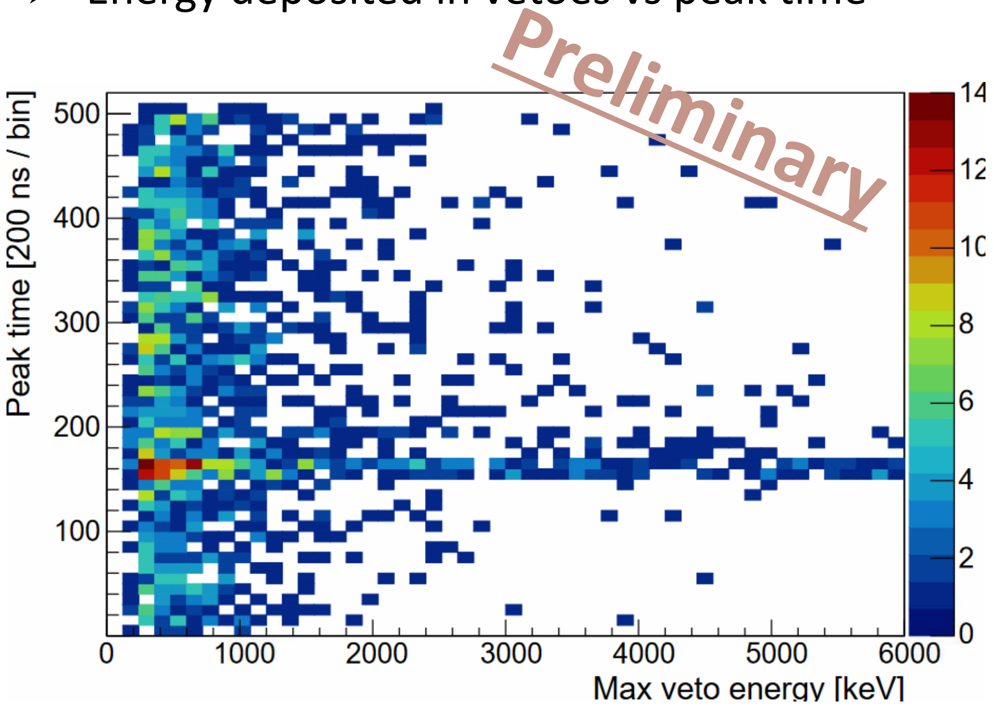
- Micromegas detector
  - 6x6 cm surface
  - 120 channels
  - Several detectors tested
- Calibration sources
  - 55Fe
  - UV lamp (Cu [8keV], Ti [4.5keV])
- 4π veto system
  - Plastic scintillators with light guides and photomultipliers (54 vetoes)
  - Cadmium sheets for neutron capture
- Gases
  - Argon + 1% Isobutane
  - Xenon(48.85%) + Neon (48.85%) + C4H10 (2.3%)
- Slow control and gas panel
  - Remote control (calibrations, gas pressure...)
  - Open loop or recirculation mode



IAXO-D0 setup: Triple layer veto system with cadmium sheets to discriminate neutron background

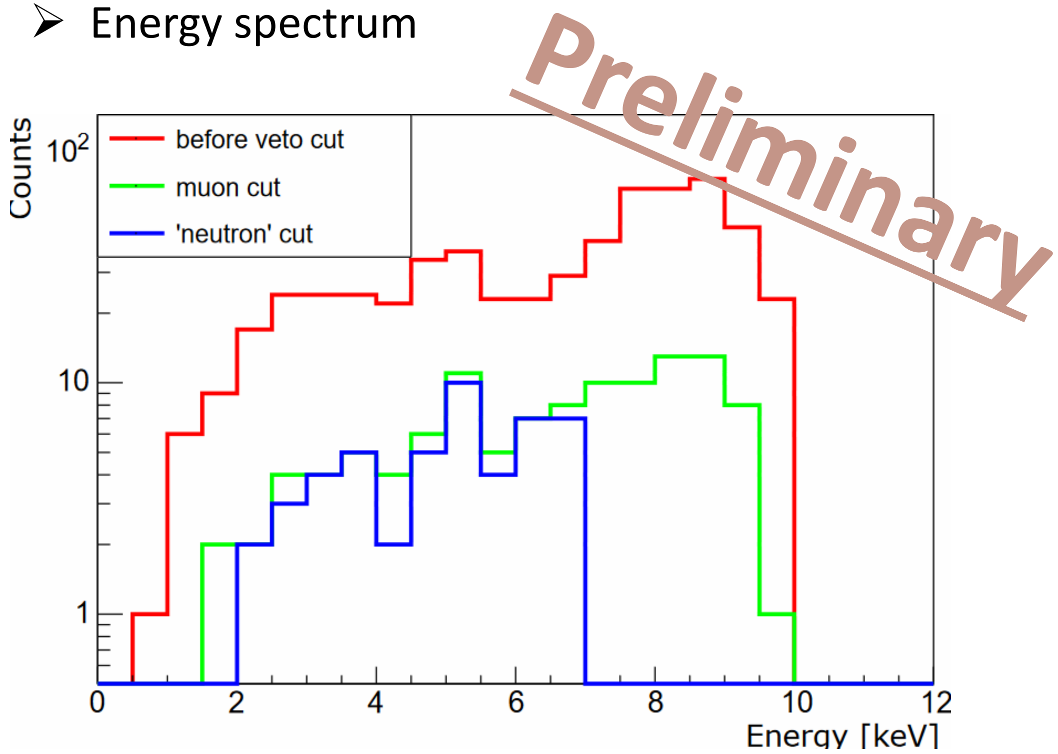
Data analysis

➢ Energy deposited in vetoes vs peak time



- Muons visible in time bin 185, trigger window.
- Delayed events could be neutrons
- Multiplicity cut: neutron events trigger many vetoes

➢ Energy spectrum

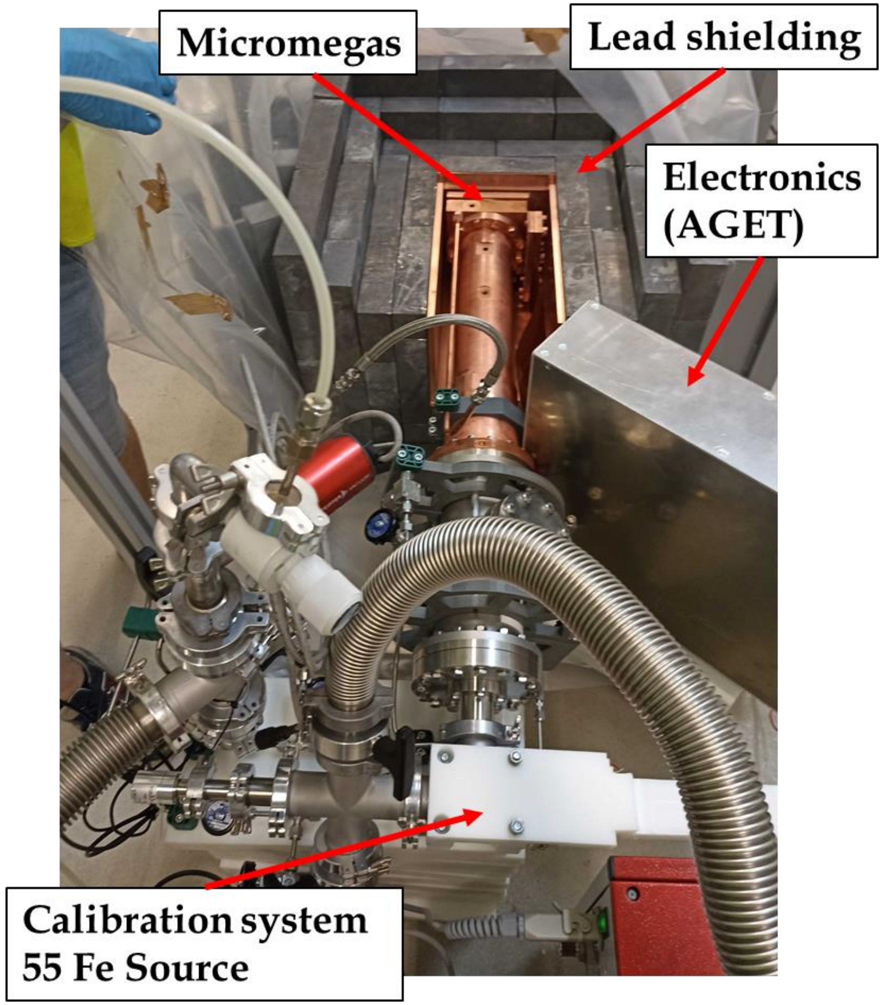


- Region of interest: 2-7 keV
- Fiducial selection: 0.9mm radius
- Muons in time window
- Neutrons-> high multiplicity selection

Background level in 51 days data taking: 49 events → $\mathbf{8.56} \times \mathbf{10^{-7}} counts\ keV^{-1} cm^{-2} s^{-1}$

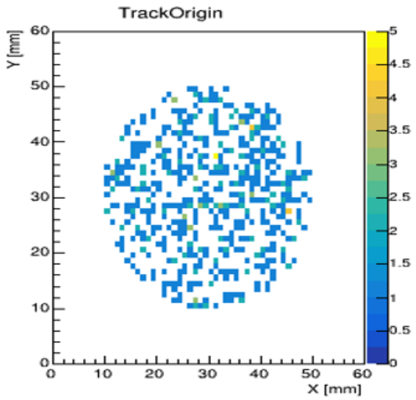
IAXO-D1 detector in the Underground Laboratory of Canfranc (LSC)

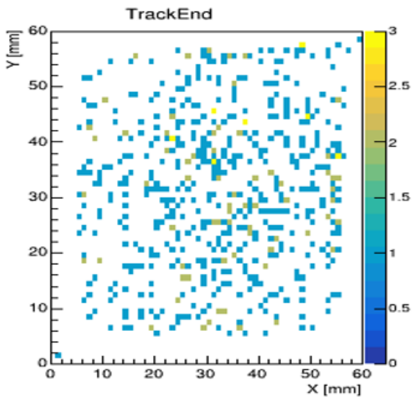
- Micromegas detector
  - Same as IAXO-D0
- Calibration sources
  - 55Fe
- Almost 4π lead shielding
- Gases
  - Argon + 1% Isobutane
  - Xenon(48.85%) + Neon (48.85%) + C4H10 (2.3%)
- Slow control and gas panel
  - Remote control (calibrations, gas pressure...)
  - Open loop or recirculation mode
- Measure intrinsic background

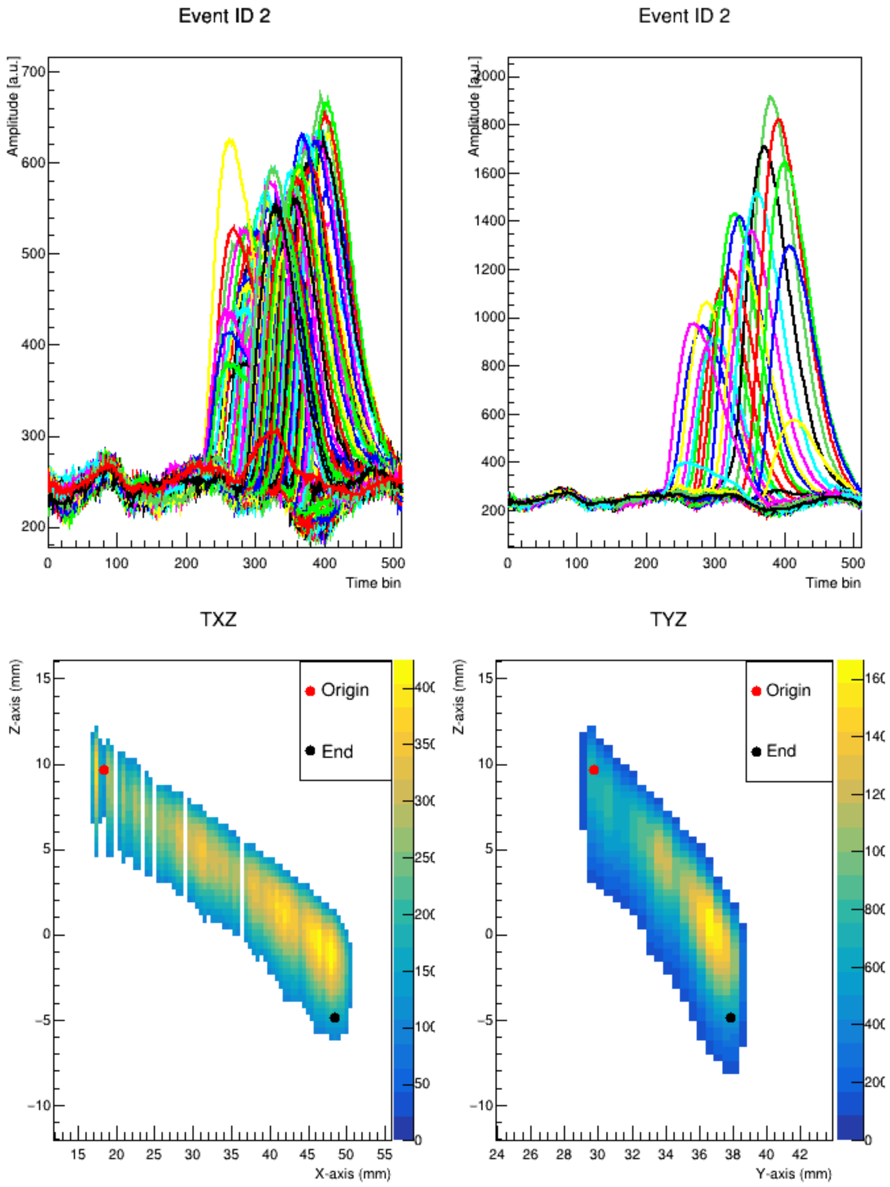


Low gain run for alphas

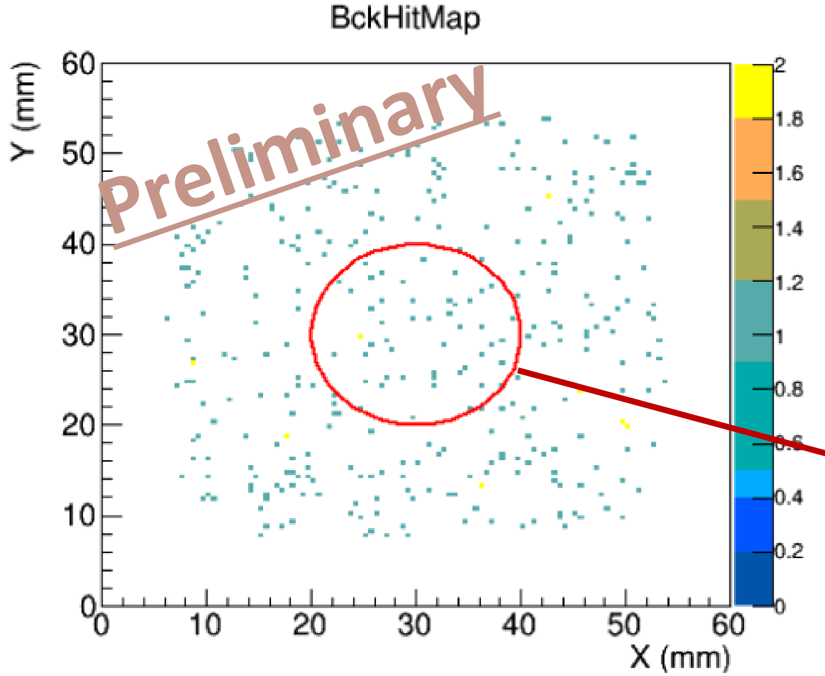
- Data taking conditions:
  - Xe + Ne + Isobutane mixture
  - HVMesh = 230 V
  - HVDrift = 750 V
  - Gas flow 2 l/h (recirculation)
- Using dedicated analysis for the reconstruction of alpha tracks (AlphaCAMM):
  - Detailed reconstruction of origin and end of the tracks
  - Reconstruction of polar angle
- Low gain run results:
  - 608 alphas in 15.3 days inside fiducial area (r<2cm)
  - Extrapolated ^{222}Rn activity [6 – 12] Bq m^{-3}

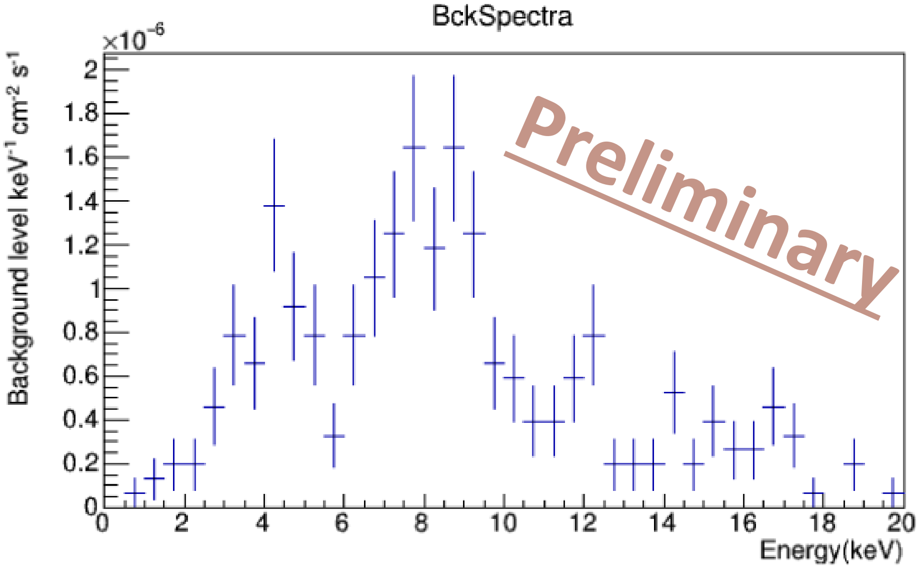


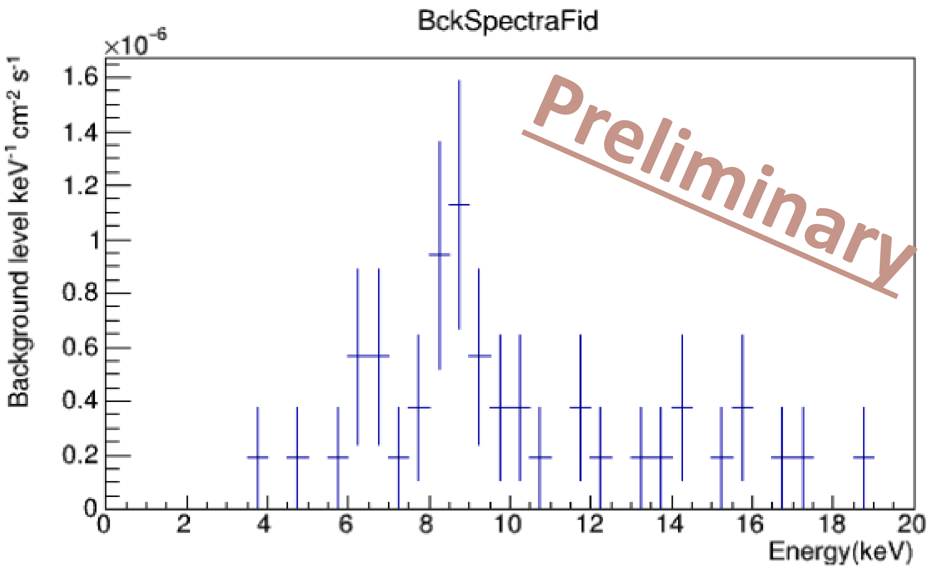




Background run with argon

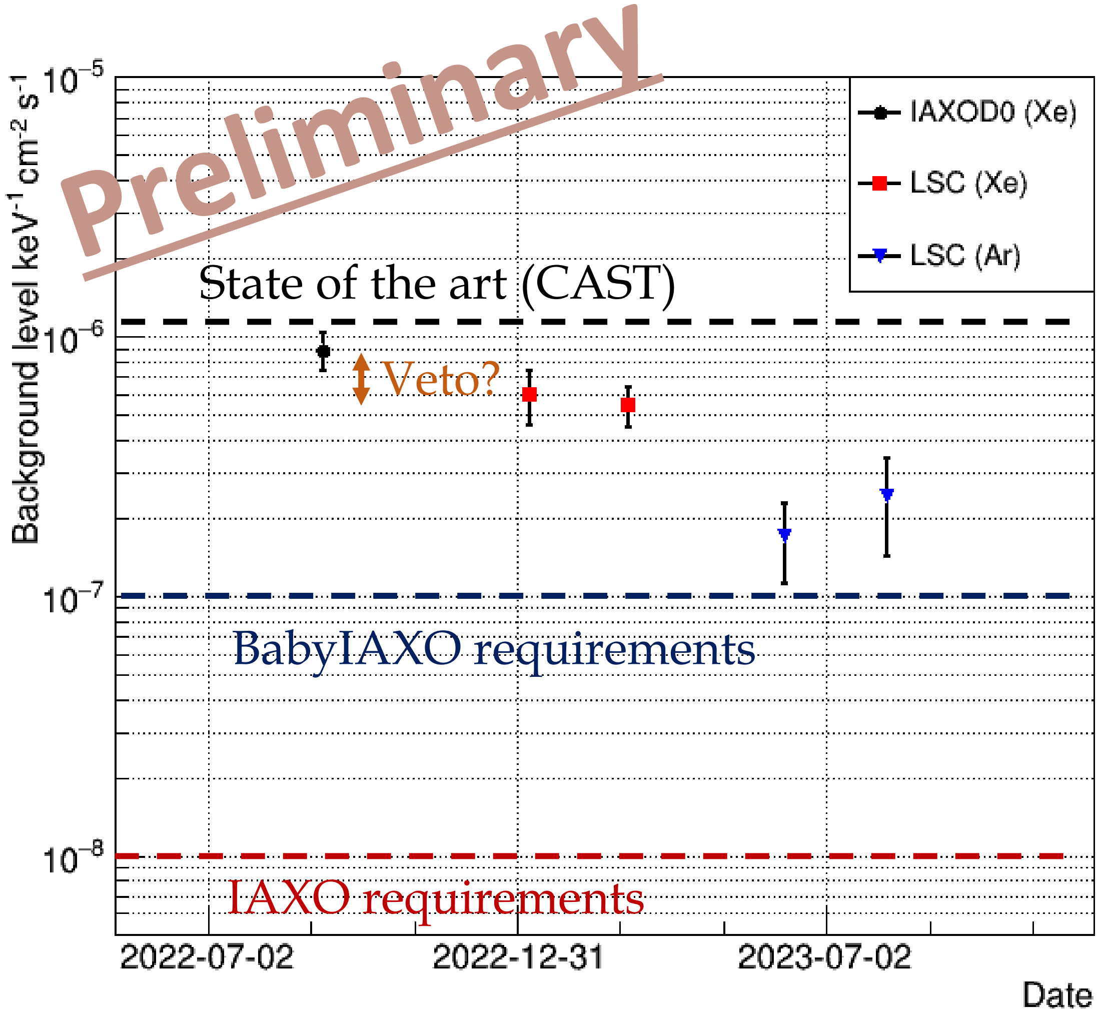






- Background level in 39 days of data king: [2-7] keV (r<1 cm)
  9 counts → **(1.69 +/- 0.56) × 10^{-7}** c keV^{-1} cm^{-2} s^{-1}

Background status

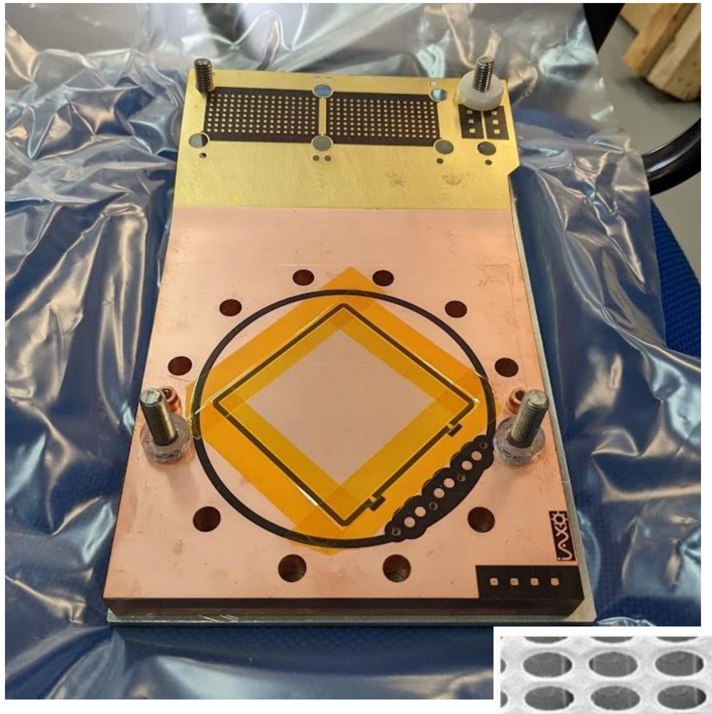


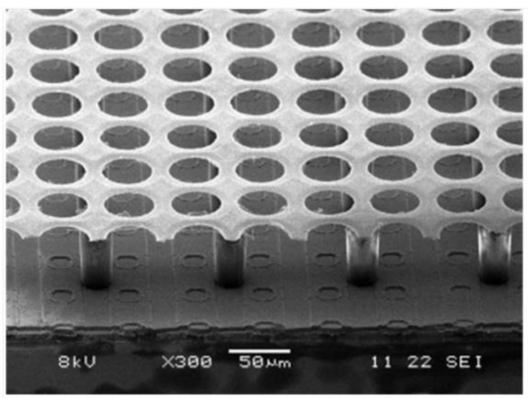
- IAXO-D0 background in Xe with 51 days, [2-7] keV (r<1 cm): **8.56 × 10^{-7}** c keV^{-1} cm^{-2} s^{-1} at surface level
- IAXO-D1 underground background level in Xe with 45 days, [2-7] keV (r<1 cm): 33 counts → **(5.41 +/- 0.94) × 10^{-7}** c keV^{-1} cm^{-2} s^{-1}
- IAXO-D1 underground background level in Ar with 39.15 days, [2-7] keV (r<1 cm) 9 counts → **(1.69 +/- 0.56) × 10^{-7}** c keV^{-1} cm^{-2} s^{-1}

Thank you !!!

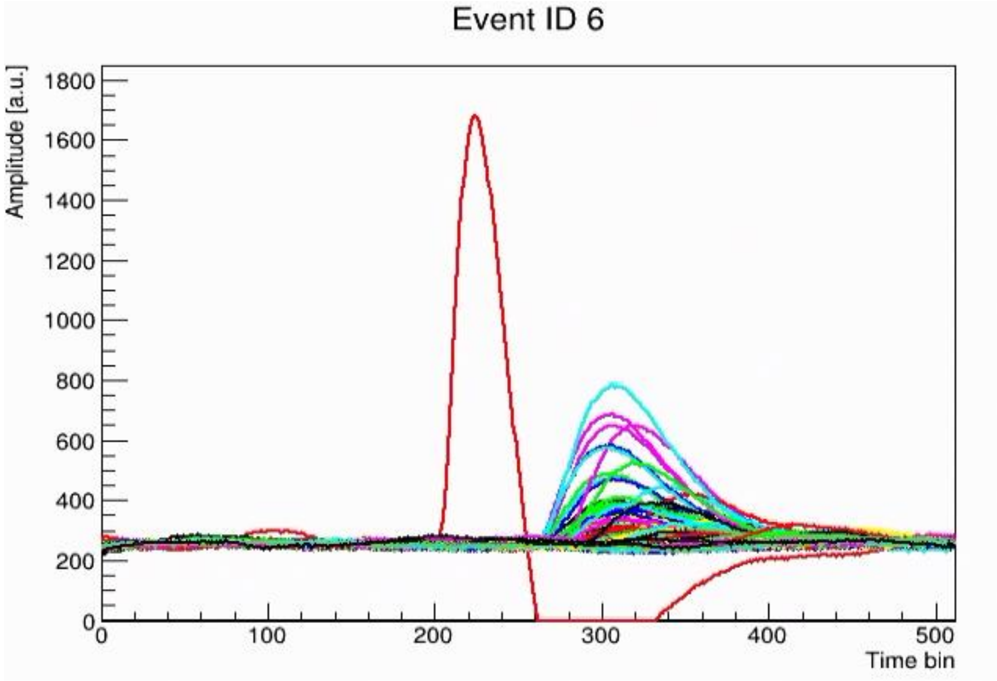
Back up

Micromegas detectors



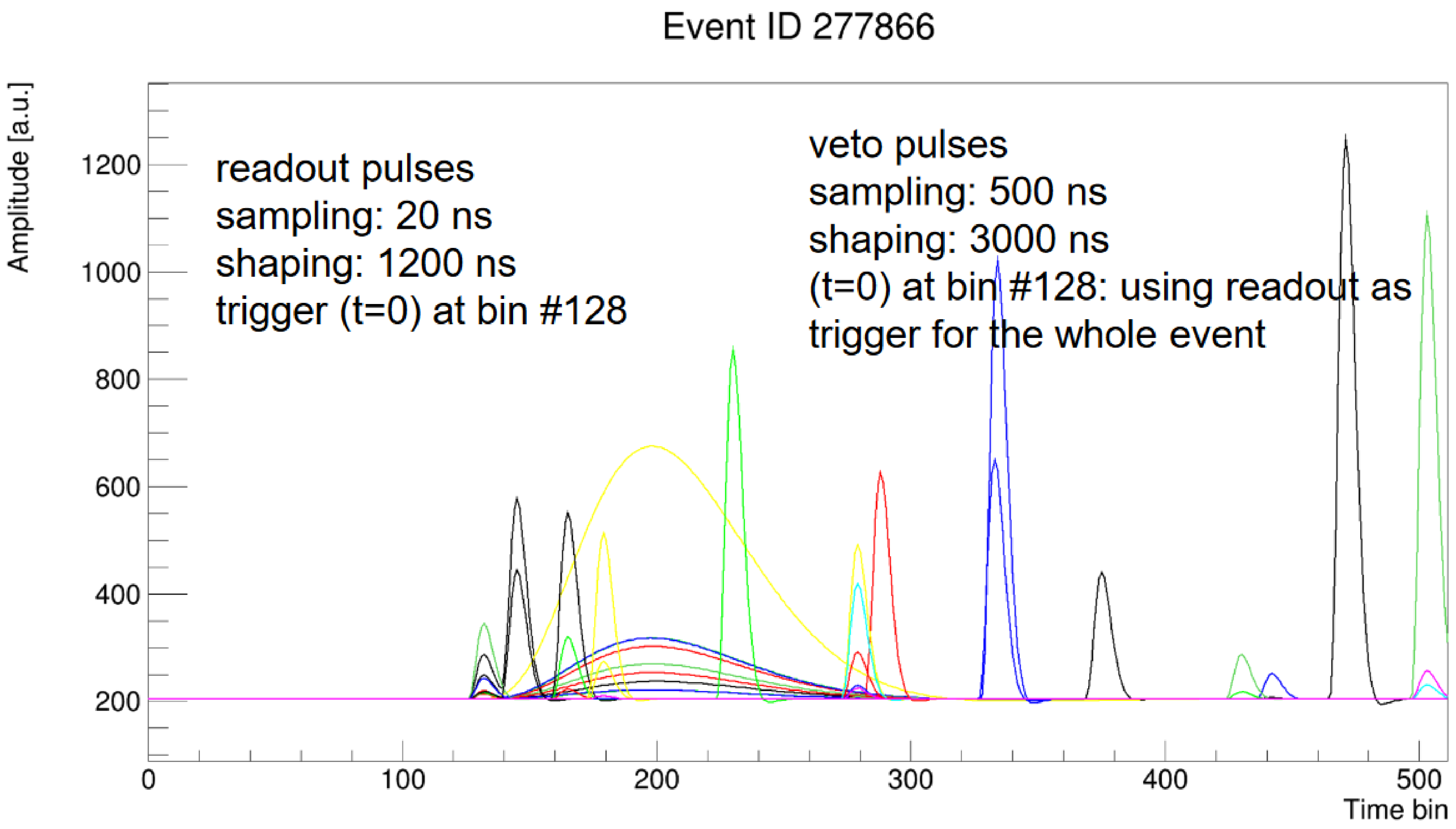


Bulk Micromegas

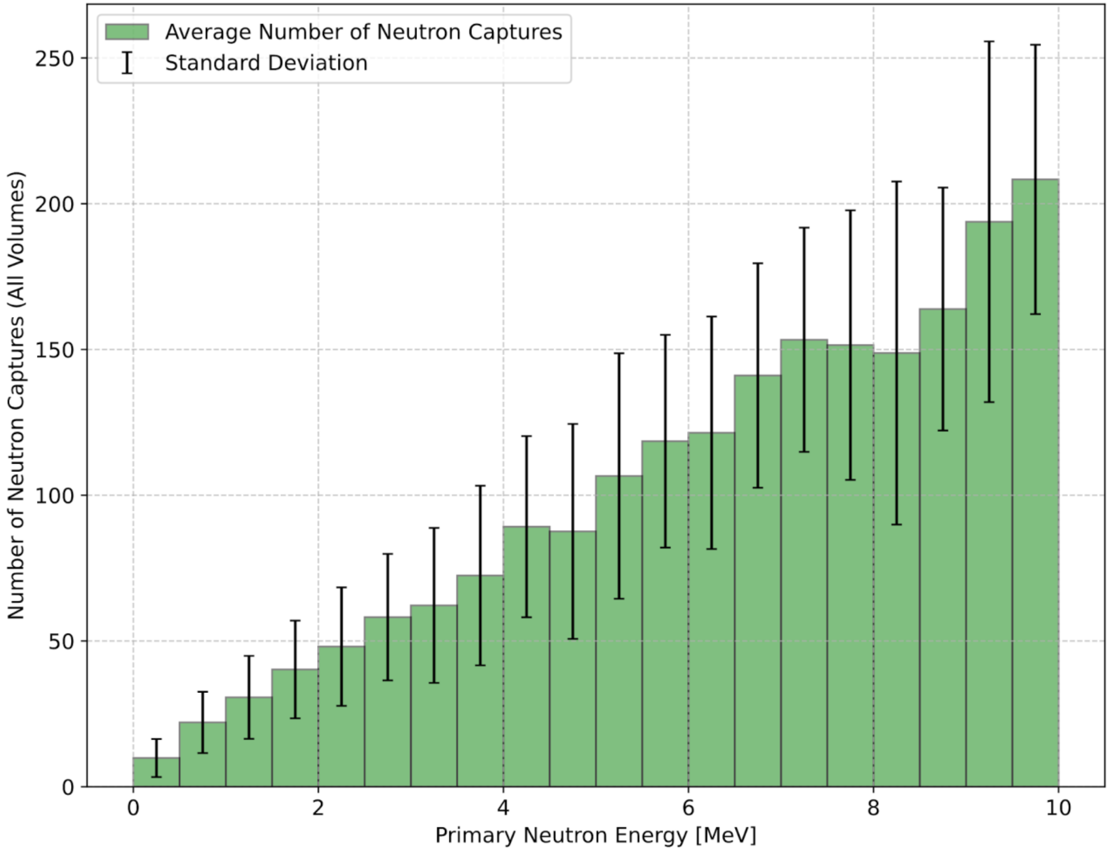


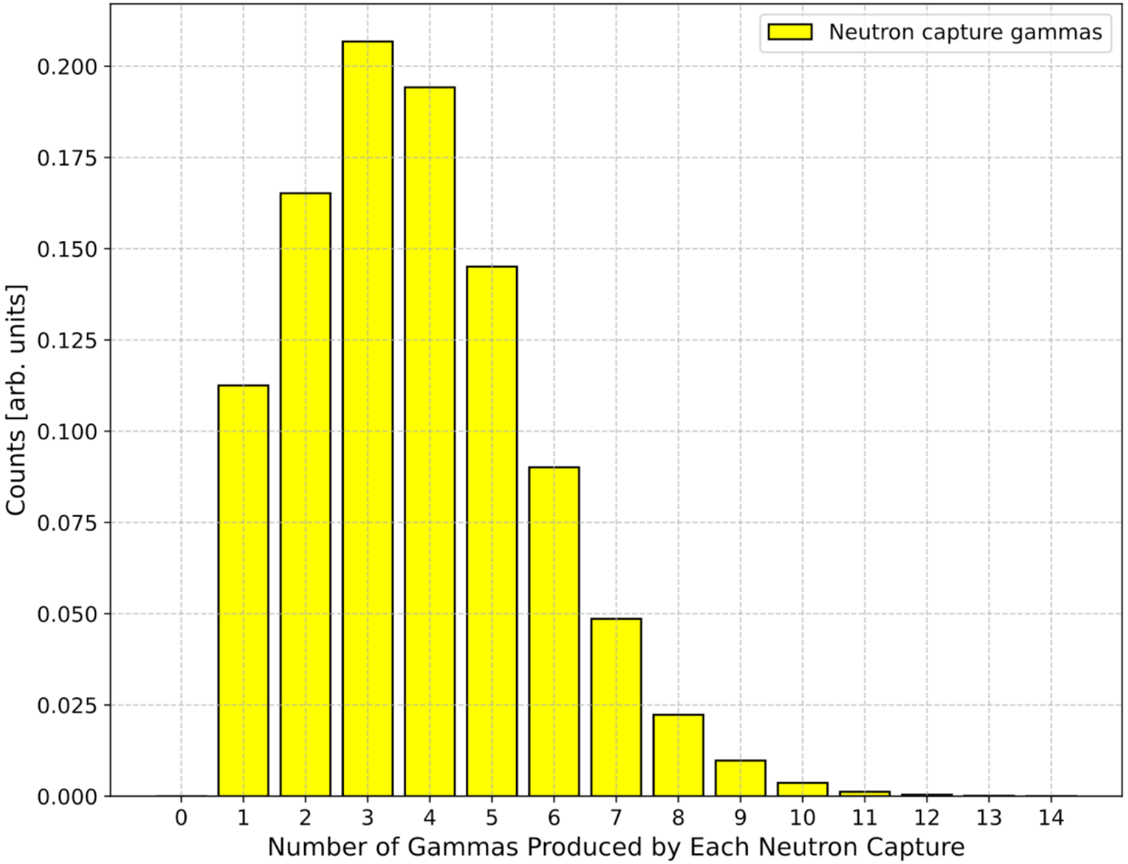
Example of real veto pulse with MM pulses

Pulse simulation on vetoes and detector



Neutron simulations





IAXO-D1 underground measurements

Calibration run with argon

- Data taking conditions:
  - Ar + 1% Isobutane mixture
  - HVMesh = 320 → 315 V
  - HVDrift = 750 V
  - Pressure 1.25 bar
  - Gas flow 2 l/h (open loop)
  - ^{55}Fe calibration source

X-ray window