A low background setup for low energy X-ray detection in the context of the BabyIAXO / IAXO axion searches

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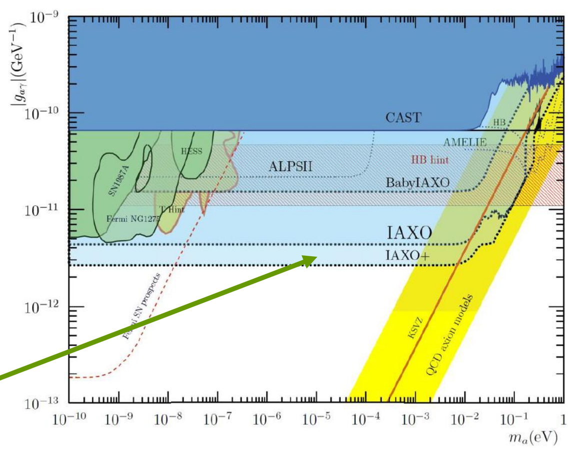
Aims:

- Development of low energy threshold, low background **X-ray detectors** for **axion search** in the BabyIAXO / IAXO projects
- Comparison of different detector types: MicroMegas, TES, **MMC**, SDD

Axions:

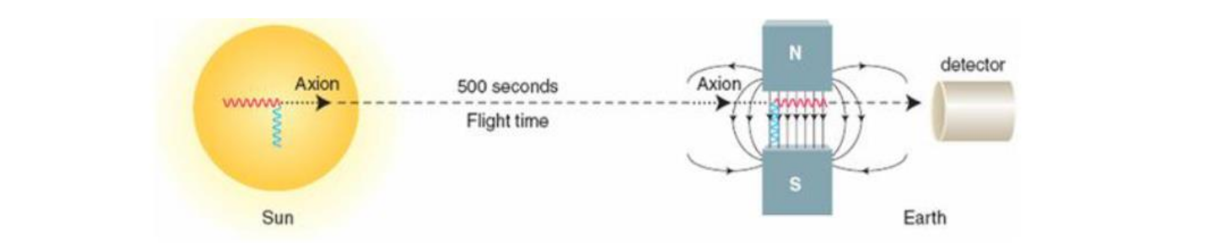
- Proposed as a solution of the strong CP problem of the standard model
- Primordial axions would be a natural dark matter candidate
  - ➡ Search (in tunable microwave cavities) extremely challenging
- Axions should be copiously produced in stellar cores, e. g. in the sun
  - ➡ **Discovery of axions** within a substantial part of the relevant parameter space **in reach for IAXO**



DALPS – ANR project 2020-2024

Detectors for axion-like particle searches

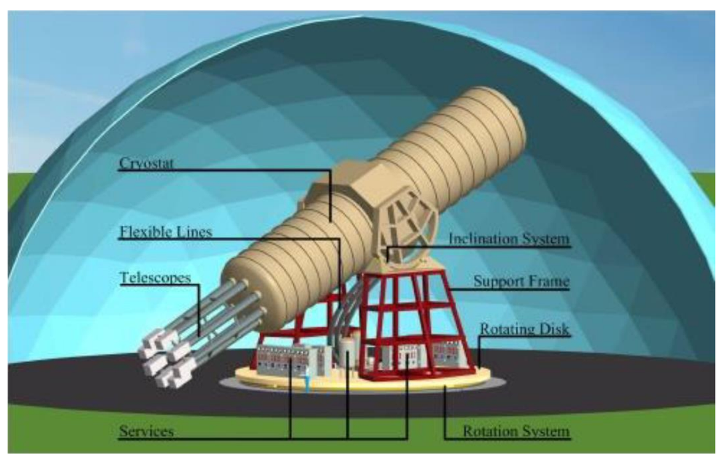
Search for solar axions in BabyIAXO / IAXO



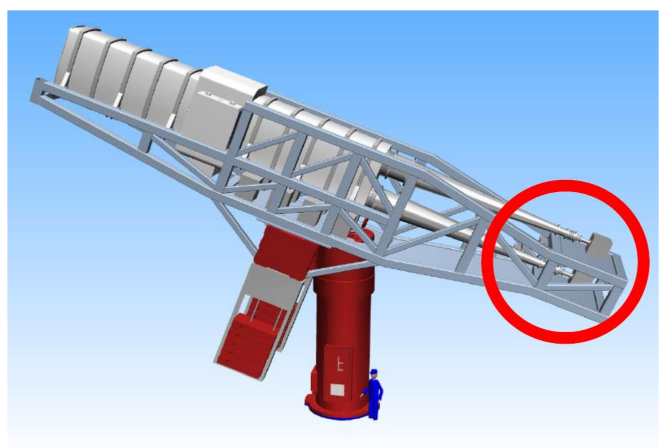
Production in the Sun
Conversion of thermal photons into axions via Primakoff effect in the solar core

Detection in the helioscope
Conversion of axions into photons via the inverse Primakoff effect in a strong magnetic field

IAXO:
Full-scale experiment with 8-bore magnet
Will be hosted at DESY



BabyIAXO:
Smaller 2-bore magnet
Fully funded, under construction



Experimental challenge

Low energy threshold (~ 0.5 keV), very low background X-ray detectors

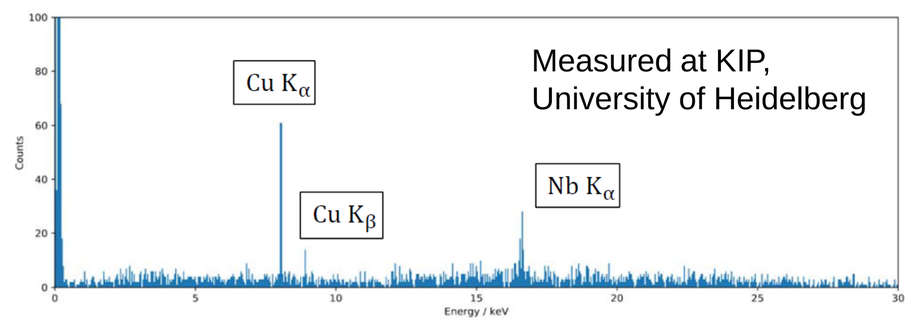
Test program at CEA-LNHB

Determine the intrinsic background of an MMC based X-ray detector array

Requirement: ~ 10^{-8} counts/keV/cm²/s

Actual level:

Background spectrum (one month, no special shielding, no muon veto)

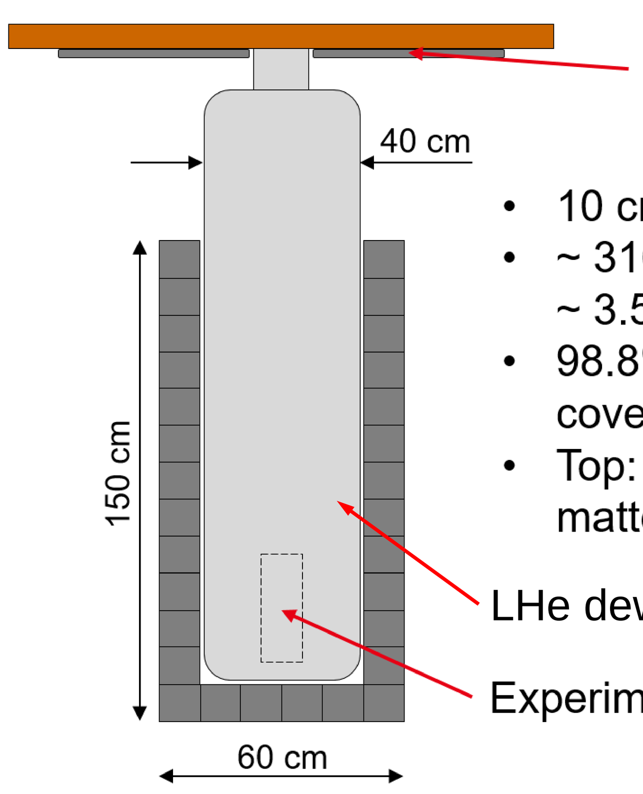


First background estimation: $2 \cdot 10^{-4} \frac{\text{counts}}{\text{keV cm}^2\text{ s}}$ (from 0 to 10 keV)

➡ **Shielding**
➡ **Muon veto**

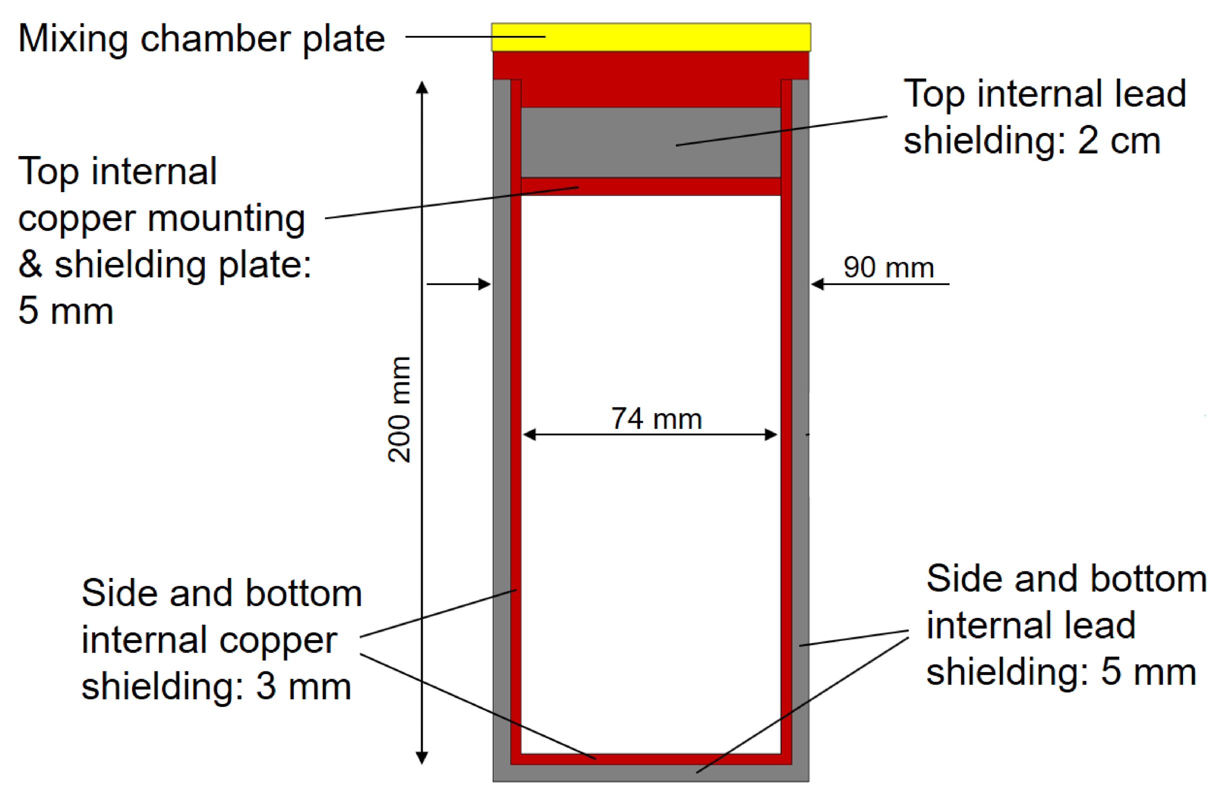
Concept of low background setup

External lead shielding

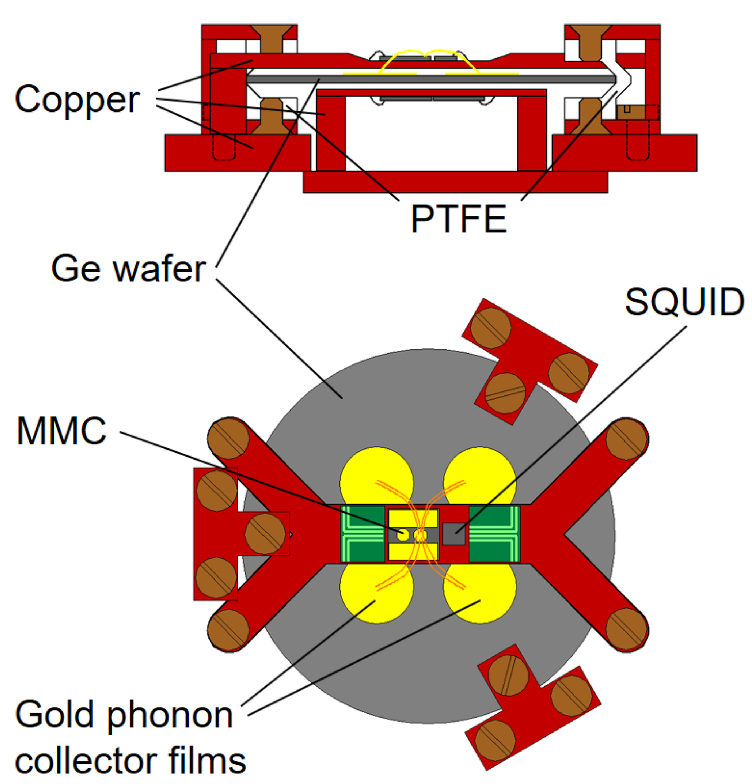


- 10 cm Pb shield
- ~ 316 lead bricks
- ~ 3.5 tons
- 98.8% solid angle coverage
- Top: flexible lead mattes available

Internal high purity Pb & Cu shielding

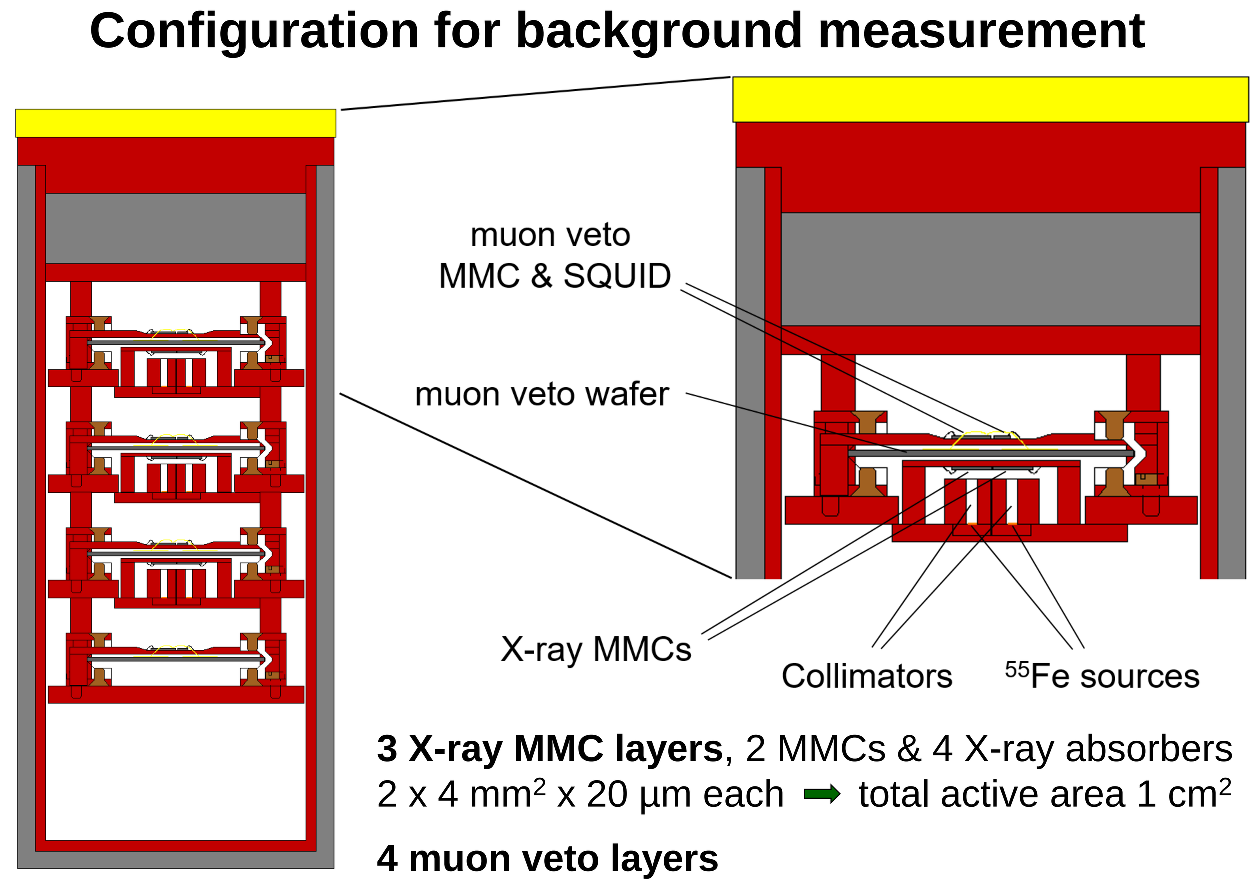


Internal muon veto



- **Ge wafer**, 50.8 mm (2″) diam., 1 mm thick
- Atmospheric muons: *E* deposit ≳ few keV
- C_{Ge} = 48.5 pJ/K @ 20 mK;
- Gold phonon collector films 4 x ϕ7 mm, 200 nm C_{Au} = 41.4 pJ/K @ 20 mK
- Gold wire bonds to MMC sensor C_{wires} ≈ 4.0 pJ/K @ 20 mK
- $\mathbf{C_{veto}}$ **≈ 94 pJ/K @ 20 mK**
- Expected count rate: ~ 0.5 s^{-1}
- One MMC, one SQUID channel

Configuration for background measurement

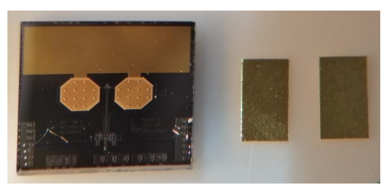


3 X-ray MMC layers, 2 MMCs & 4 X-ray absorbers 2 x 4 mm² x 20 µm each ➡ total active area 1 cm²

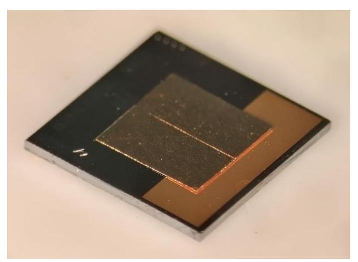
4 muon veto layers

- Internal copper shielding cylinder: high-purity CuC2 OFHC copper
- All other copper pieces: CuC1, left-over from EDELWEISS DM search
- Internal lead shielding: semi-ancient (~ 100 y) lead, (2.27 ± 0.69) Bq/kg

Realization



MMC chip w/ 2 Au absorbers
2 x 4 mm² x 20 µm each
16 mm² active area / MMC



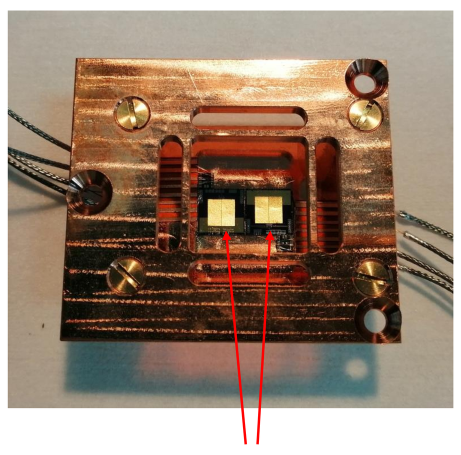
Au absorbers fixed to MMC sensors

1st step:

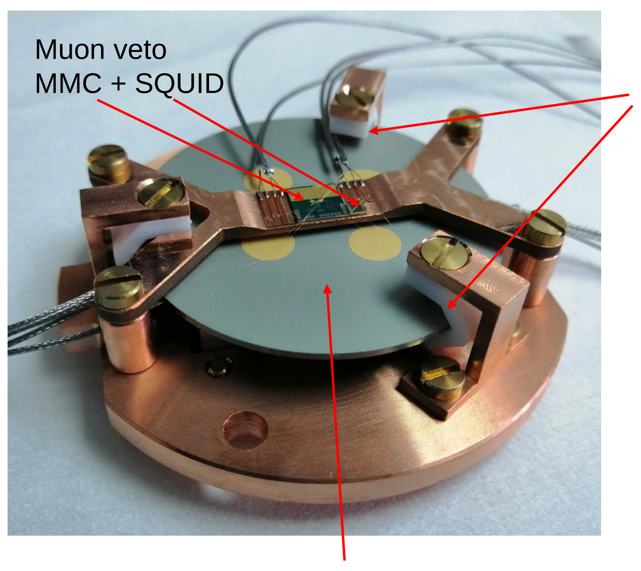
- 1 X-ray MMC layer;
- 1 muon veto layer

Non optimal:

- Standard PbSn solder
- Standard brass screws

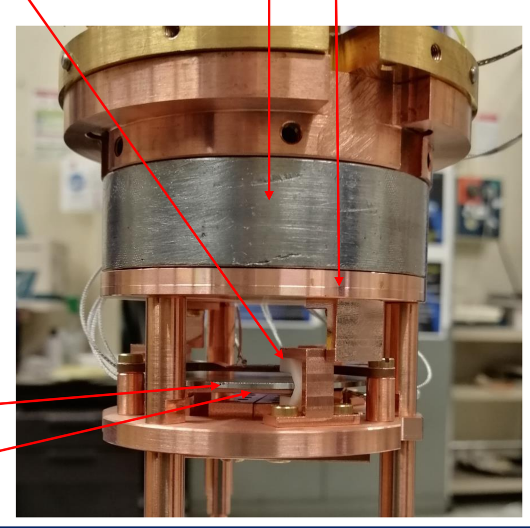


2 X-ray MMCs + SQUIDs in their holder



PTFE wafer holder pieces

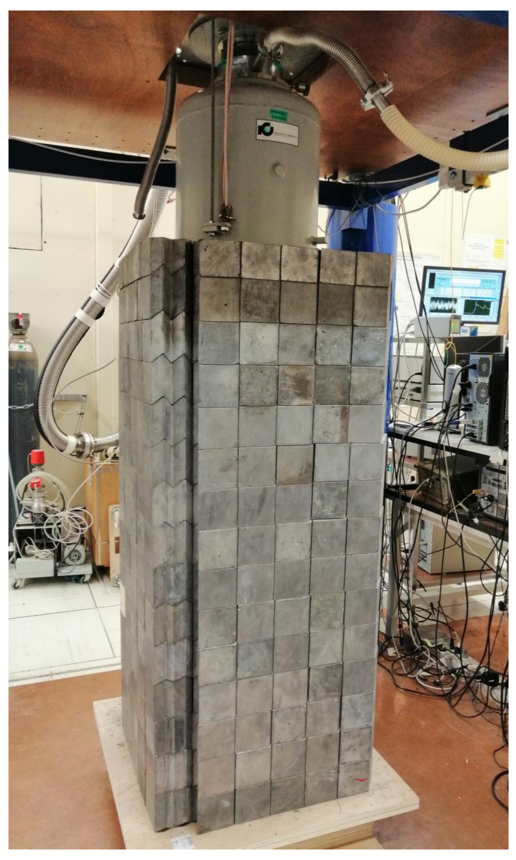
Internal Pb + Cu top shielding



Muon veto Ge wafer w/ Au phonon collector films

X-ray MMCs: just underneath the muon veto

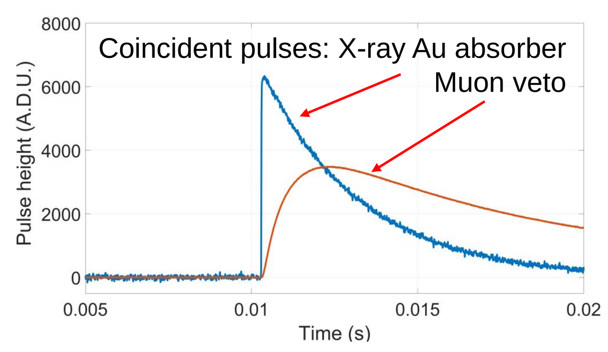
Internal Pb + Cu shielding cylinders

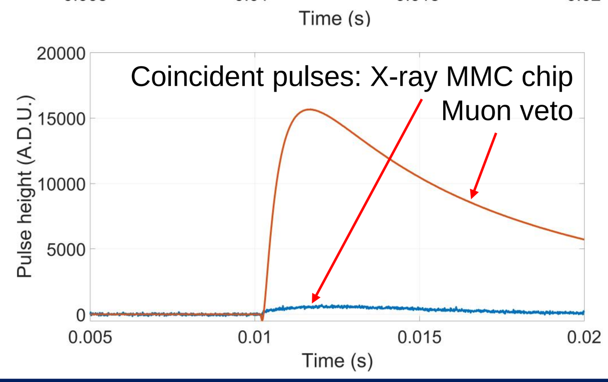


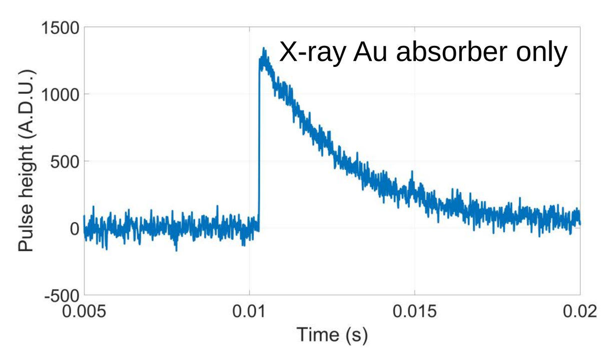
External Pb shielding

Results

- One X-ray MMC (or its immediate surrounding) is contaminated: > 1 c/s
- Second X-ray MMC: ~ 1 count / 3 min
- Muon veto works: most pulses in the "clean" X-ray MMC are in coincidence with the veto.
- Veto-only count rate: ~ 1 count / 3 s
- A few very low energy pulses in the X-ray MMC are not in coincidence with the veto
- ^{55}Fe X-rays not identifiable ➡ no energy scale
- Various problems with data acquisition
  ➡ no exploitable spectra, no background rate







Next steps

- Fix problems with energy calibration
- Fix problems with data acquisition
- Full setup with **3 X-ray MMC layers + 4 muon veto layers**
- **Kapton/copper ribbon cables**
  ➡ no solder inside the internal shielding
- **Copper screws**

Acknowledgment: We acknowledge support from the Agence Nationale de la Recherche (France) ANR-19-CE31-133 0024.