Low-Background *X-Ray Detectors for the Next Generation of* ***Solar Axion*** *Searches*

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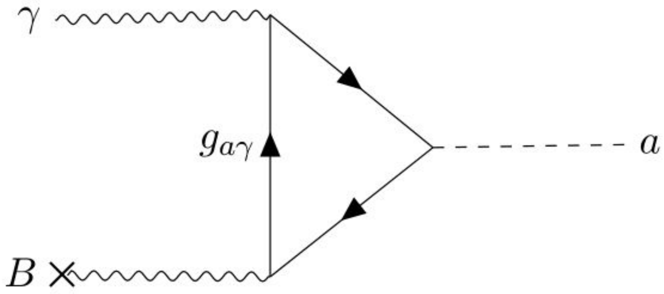
Max Planck Institute for Nuclear Physics (MPIK)
TeV Particle Astrophysics, 31.08.2026

Axions

- hypothetical particles proposed to **solve strong CP problem**
- double as **cold dark matter** candidate
- **axion-like particles (ALPs)** generated in many extensions to Standard Model
- detection possible via **Primakoff effect**



Axions

- hypothetical particles proposed to **solve strong CP problem**
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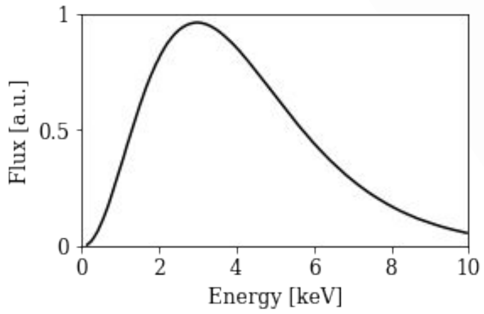
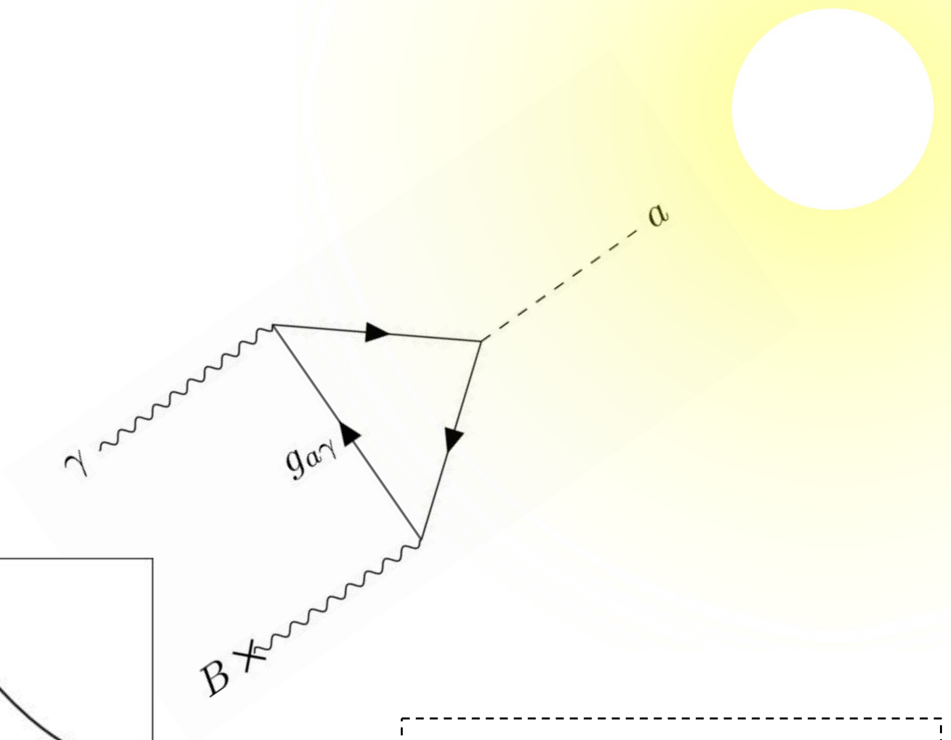
- detection possible via **Primakoff effect**
- **sun** produces axions
  → **Primakoff spectrum**





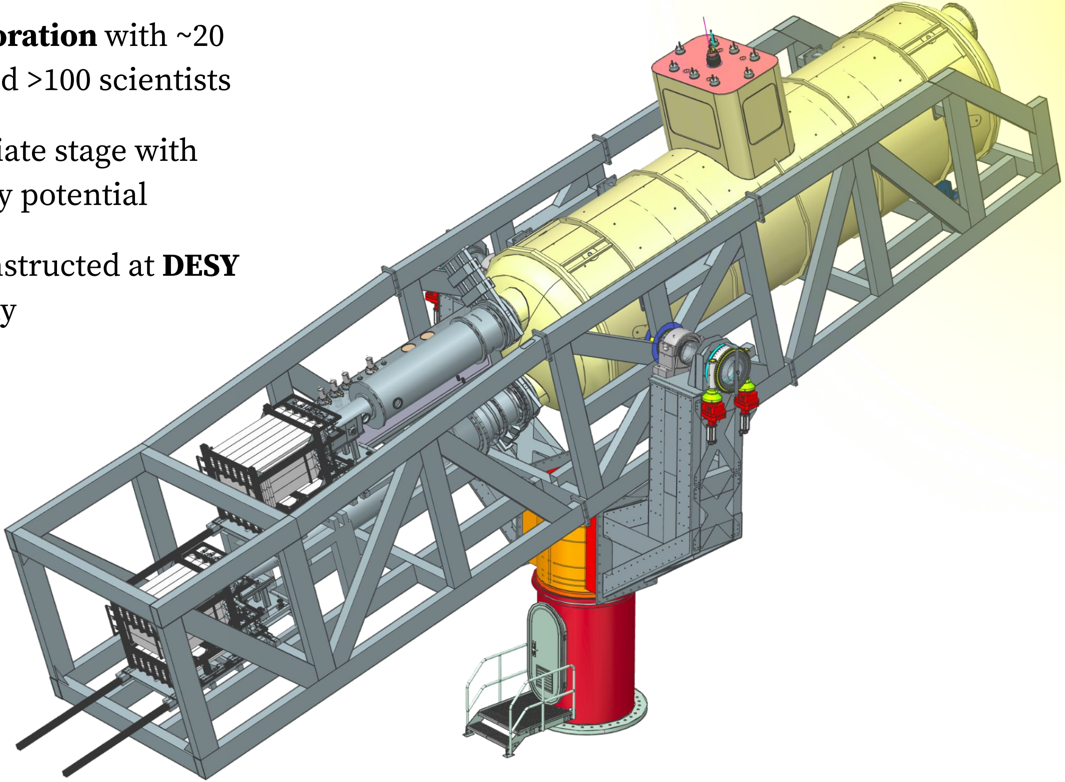
→ **helioscopes:** experiments looking for solar axions

Phys. Rev. Lett. 52, 695 (1984)

IAXO – *the Next-Gen Helioscope*

- **international collaboration** with ~20 member institutes and >100 scientists
- **BabyIAXO:** intermediate stage with new physics discovery potential

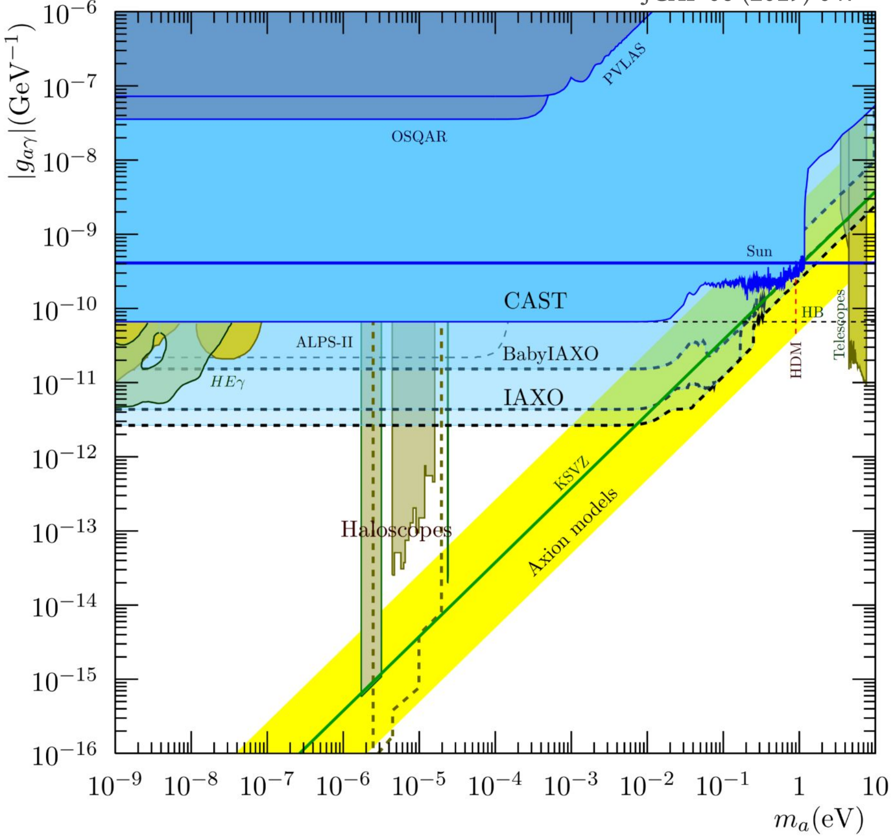
→ currently being constructed at **DESY** in Hamburg, Germany



Helioscope Sensitivity

- **CAST:** State-of-the-art, ran for almost 20 years at CERN
- **IAXO:** aiming for order of magnitude higher sensitivity to $g_{a\gamma}$ over CAST
- **improvements** from CAST to (Baby)IAXO:
  - higher **sun-tracking** time
  - custom **magnet**
  - custom **optics**
  - improved **detectors**

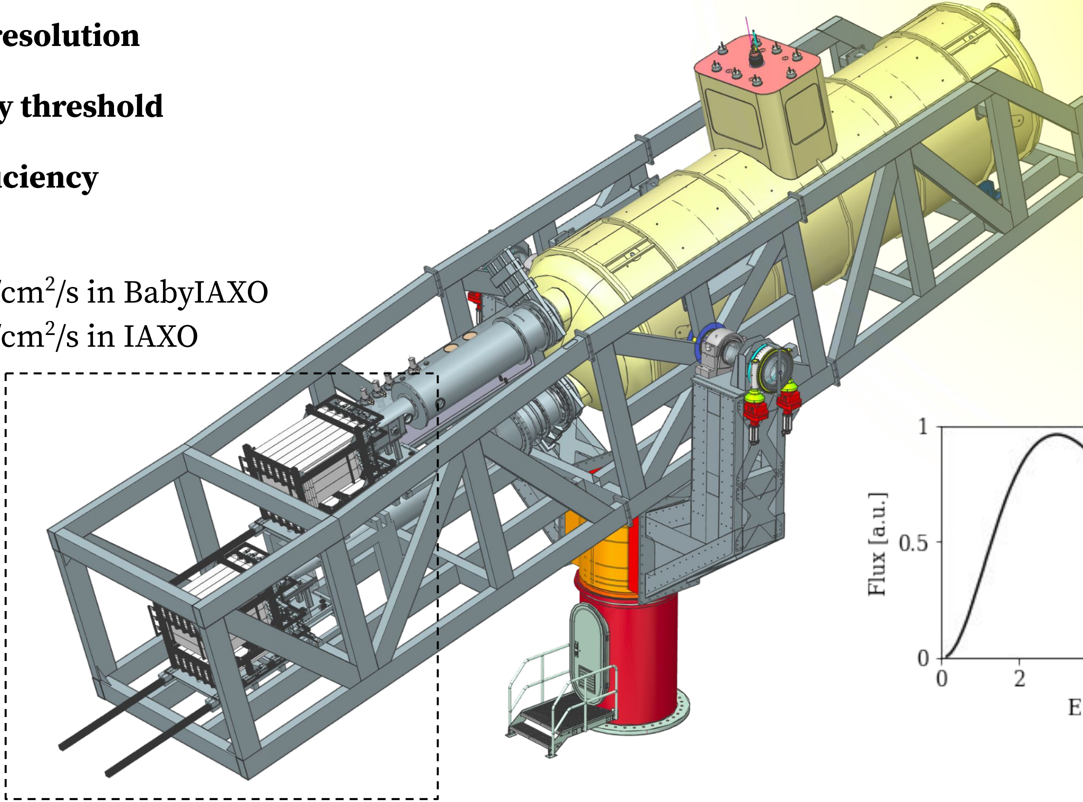
JCAP 06 (2019) 047

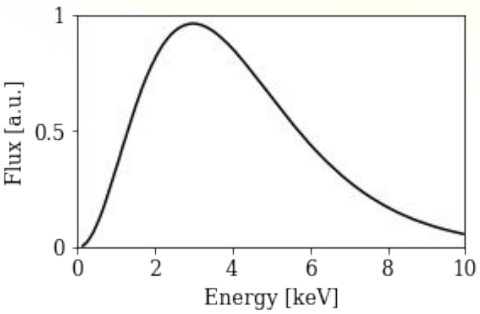


Detector Requirements

- sufficient **energy resolution**
- low enough **energy threshold**
- high **detection efficiency**
- low **background**:
    - 10^{-7} cts/keV/cm^2/s in BabyIAXO
    - 10^{-8} cts/keV/cm^2/s in IAXO

→ typical challenges to dark matter / CEνNS / 0νββ experiments, but **above ground**



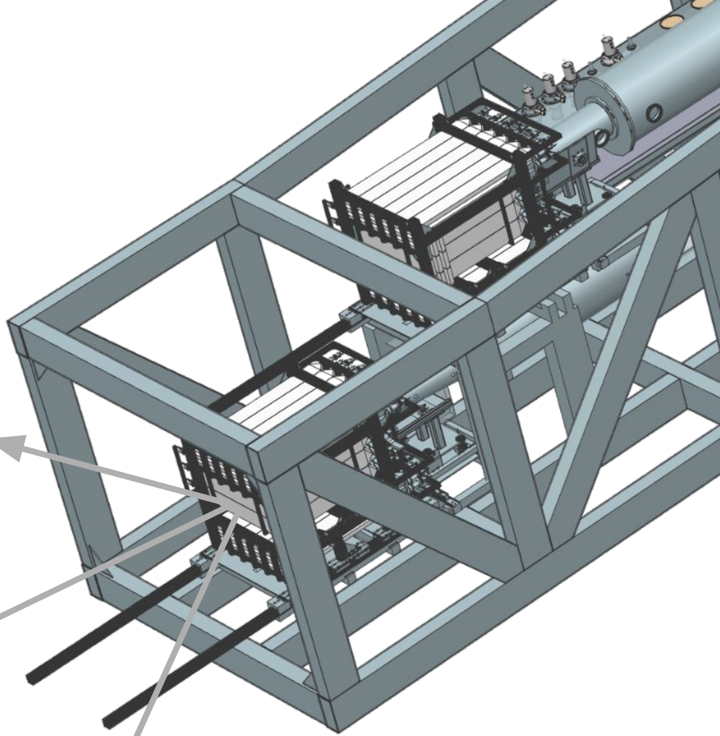


BabyIAXO Detectors

two beamlines and **modular** construction → can use **different detectors**

various **technologies** are in development:

gaseous detectors:
Micromegas, GridPix



semiconductor detectors: SDD

cryogenic detectors:
TES, MMC

common low-background strategies:

- small sensitive volume
- radiopure materials
- passive shielding
- active veto systems

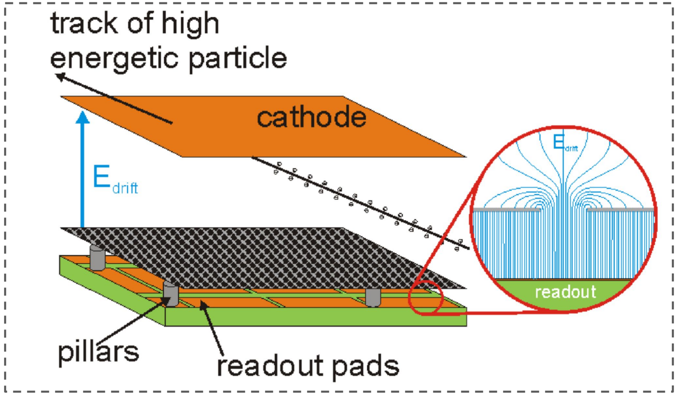
main challenges:

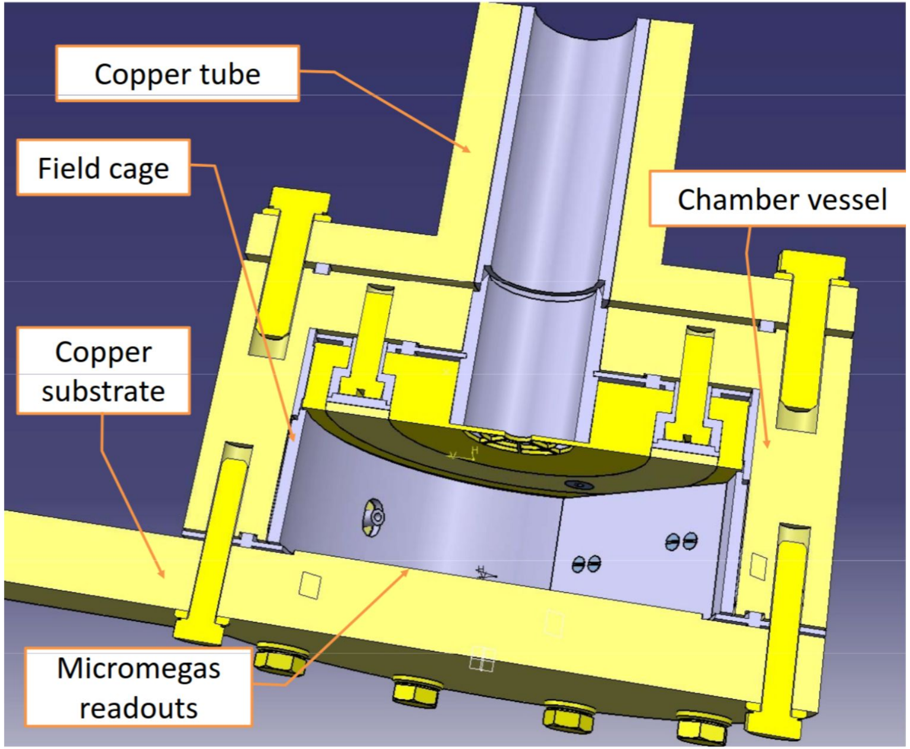
- radioimpurities
- cosmic neutrons

Micromegas

JINST 18 (2023) C10003
Nucl. Instrum. Meth. A 376 (1996) 29-35
JINST 9 (2014) T05002

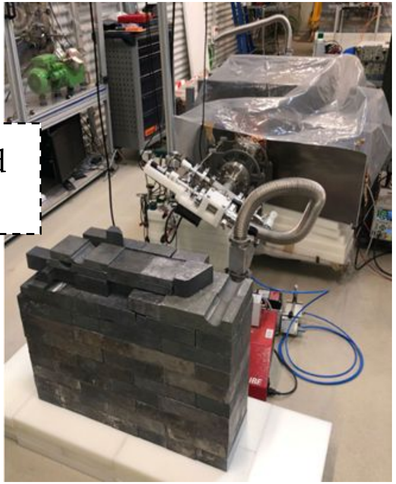
- **Micro-Me**sh **Gas**eous Structure
- **time projection chamber** filled with argon-isobutane or xenon-neon-isobutane mix
- **well-established** technology, baseline detector operated in CAST for a long time



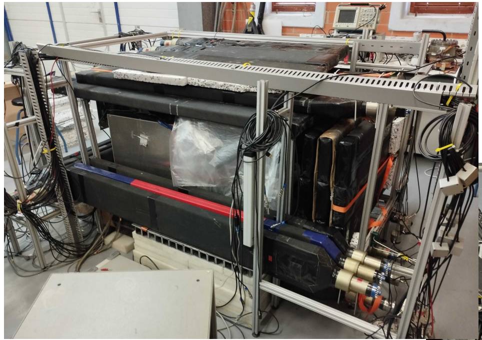


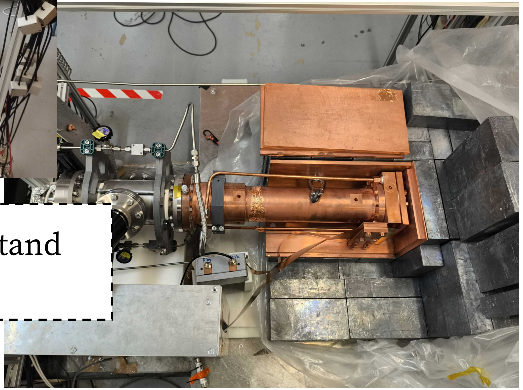
Micromegas

- ongoing measurements: optimization of **gas mixture**, characterization and reduction of **background**
- **functional setup** incl. shielding already at DESY
- investigation of active **neutron veto**
- ongoing background and veto **simulations**

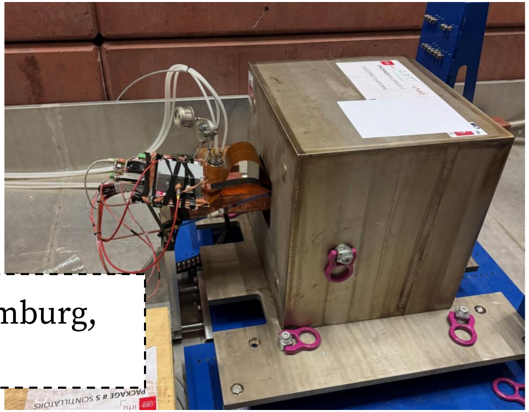


deep-underground teststand in Canfranc, Spain





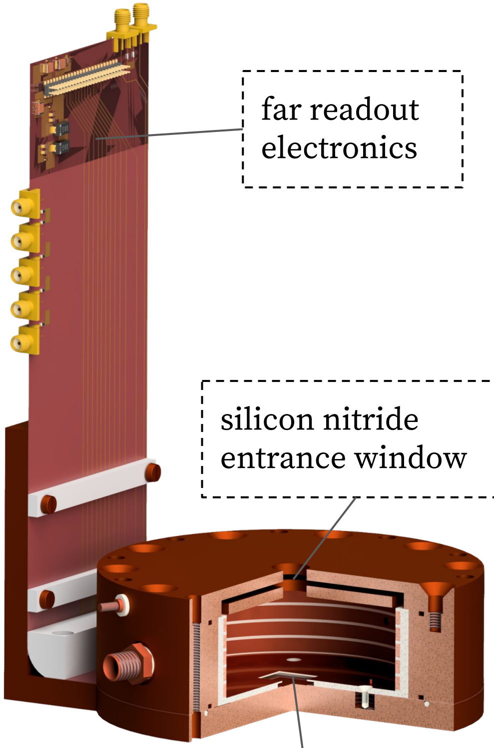
above-ground teststand in Zaragoza, Spain

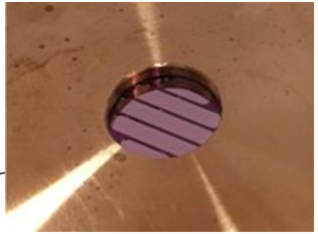


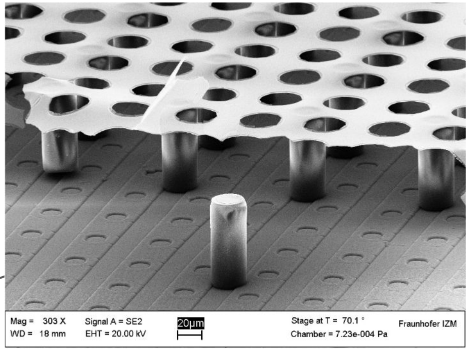
full setup in Hamburg, Germany

GridPix

- based on Micromegas, with **different readout chip**
- operated with argon-isobutane gas mix
- **single-electron** detection, lower **energy threshold**







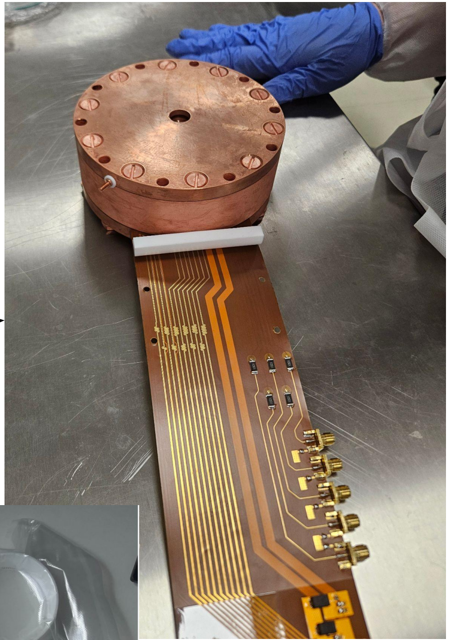
Nucl. Instrum. Meth. A 556 (2006) 490-494
Nucl. Instrum. Meth. A 845 (2017) 233-235

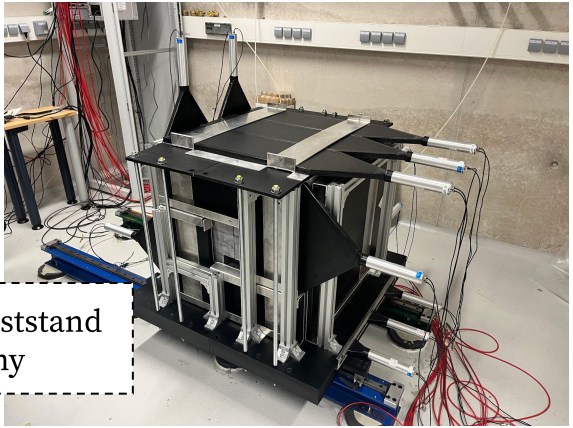
GridPix

- background measurements **above-ground** with non-radiopure materials **concluded**
- **radiopure** GridPix assembled & functional
- **teststand at shallow depth** fully commissioned

→ **background measurement**

assembly of
radiopure GridPix

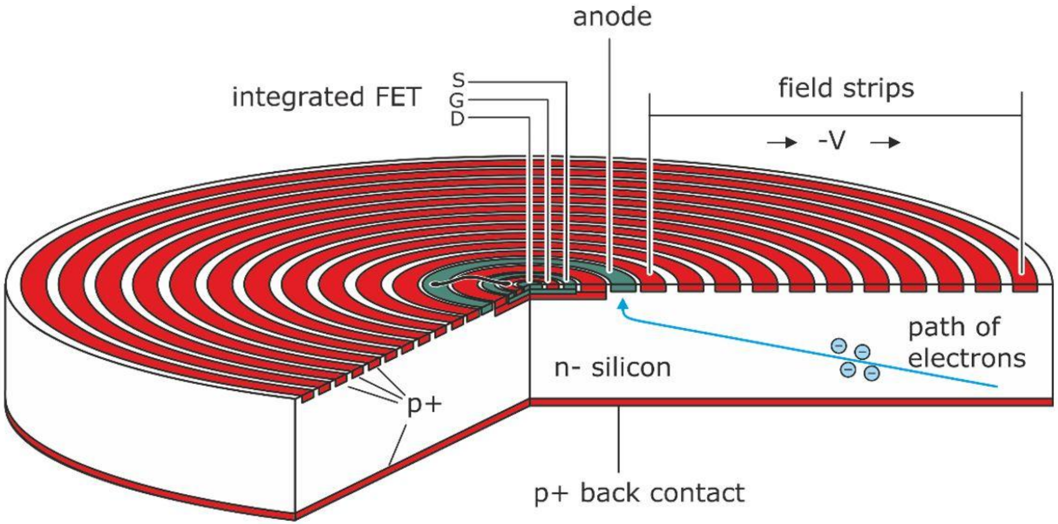




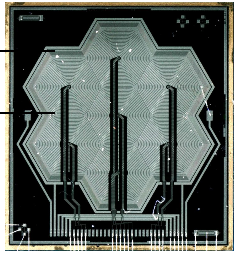
shallow-depth teststand
in Bonn, Germany

SDD

- **S**ilicon **D**rift **D**etector
- good **energy resolution**, high **X-ray detection efficiency** and **no entrance window**
- great **low-background potential**



3 mm

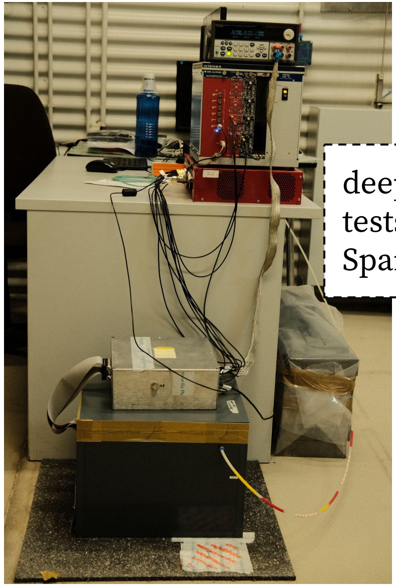


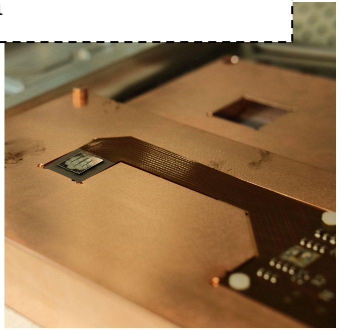
7-pixel prototype SDD

J. Phys. G 48 (2020) 1, 015008
Nucl. Instrum. Meth. A 225 (1984) 608-614
Nucl. Instrum. Meth. A 377 (1996) 346-351

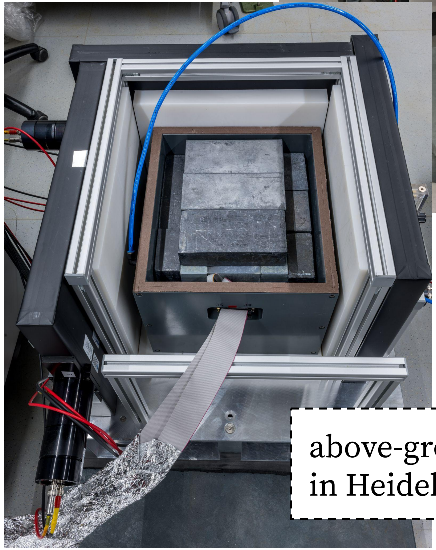
SDD

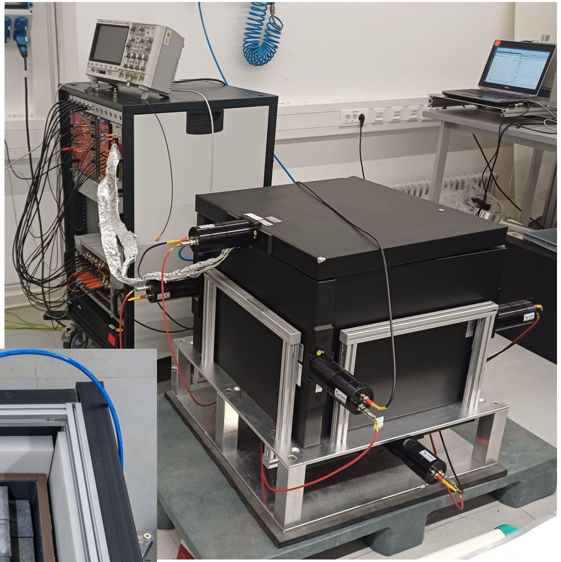
- background measurements **deep underground** concluded
- background measurement **above ground** ongoing





deep-underground teststand in Canfranc, Spain





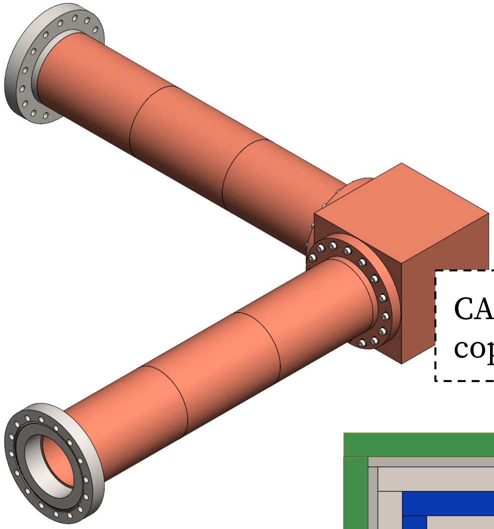
above-ground teststand in Heidelberg, Germany

SDD

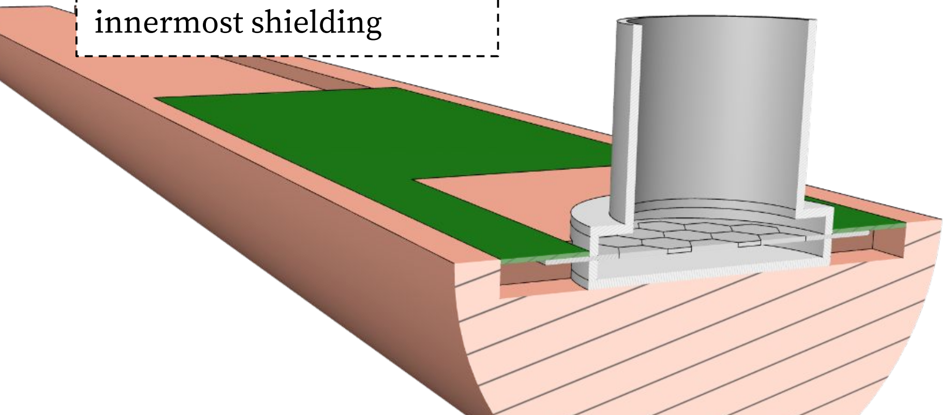
ongoing **simulation and design** efforts to optimize

- **shielding** against radioactive and cosmic background
- **SDD and PCB** design for low background operation

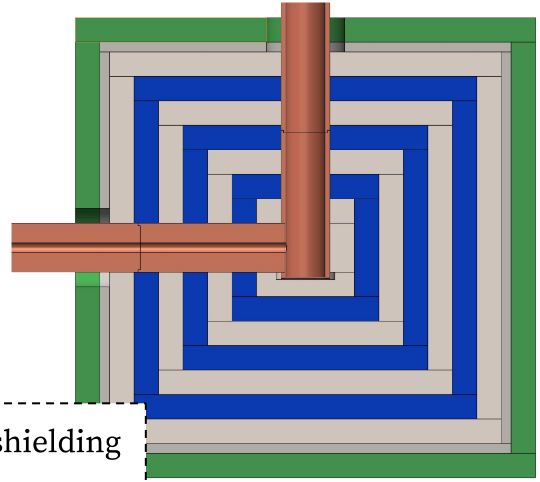
→ **production** will start later this year



CAD model of innermost copper shielding

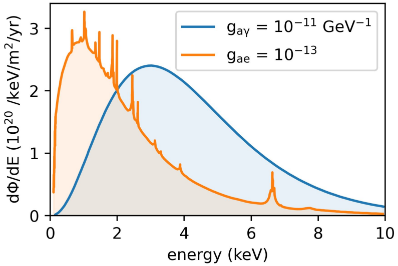


sketch of SDD and PCB in innermost shielding



sketch of shielding design

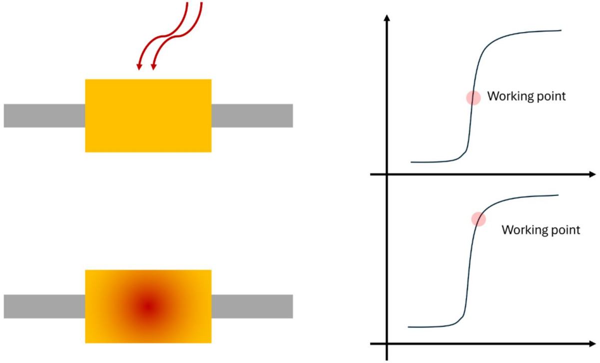
TES & MMC



- **‘beyond-discovery’** technologies with superior **energy resolution** and **-threshold**
- ongoing **R&D** efforts

Transition **E**dge **S**ensor

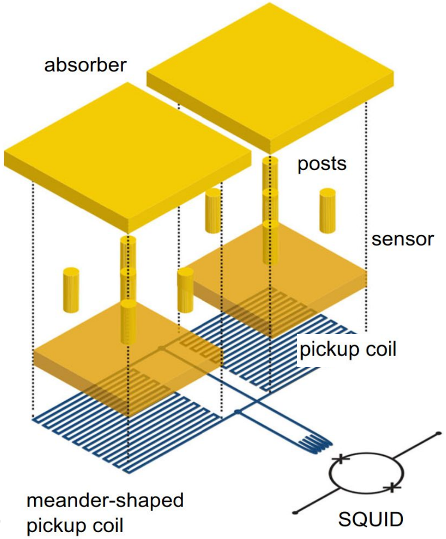
superconductor at critical temperature → energy deposition leads to increased **resistance**



Instruments 2024, 8(4), 47
J. Low Temp. Phys. 222 (2026), 27

Metallic **M**agnetic **C**alorimeters

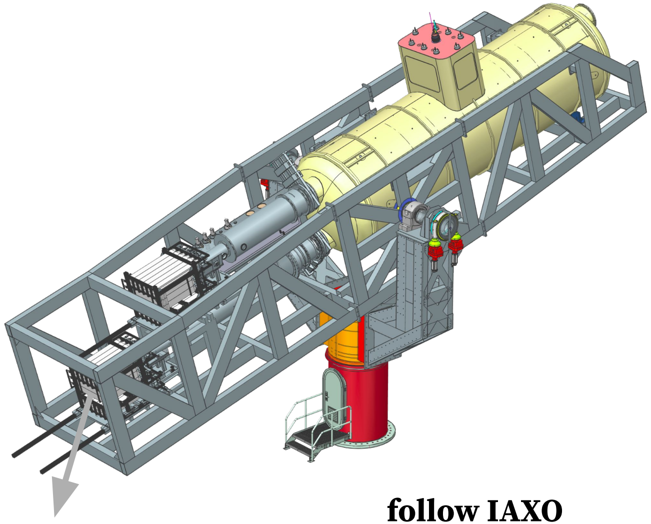
cooled **paramagnetic** sensor → energy deposition leads to change in **magnetisation**



J. Low Temp. Phys. 193 (2018) 3, 365-379
J. Low Temp. Phys. 219 (2025) 2, 21-27

Summary

- **Axions/ALPs** are highly motivated dark matter candidates
- **BabyIAXO** is the next generation helioscope with discovery potential
- requires highly **sensitive low-energy, low-background X-ray** detector
- several technologies in development:
  - gaseous detectors: **Micromegas**, **GridPix**
  - semiconductor detectors: **SDD**
  - cryogenic detectors: **TES**, **MMC**
- design and commissioning currently **ongoing**



Thank you!

follow IAXO

Backup

Background challenge

- similar challenges as **dark matter** / **CEvNS** / **0νββ** experiments

but:

- not a volume detector, **surface normalization**
- deep-underground background level **above ground**