TAXO
A low-background SDD for solar axion searches with LAXO

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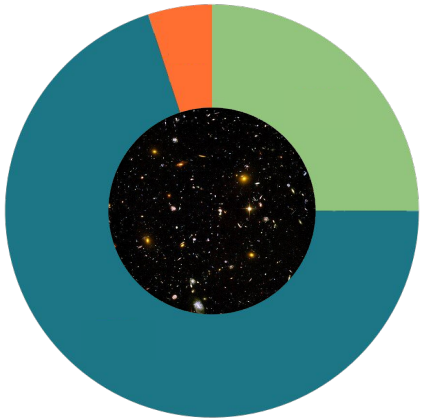
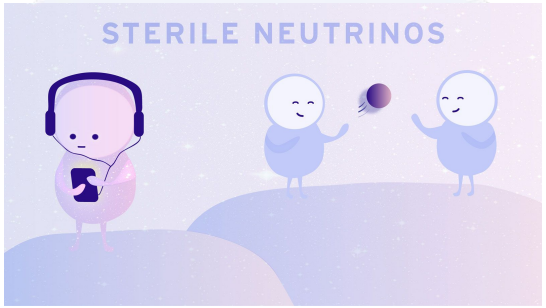
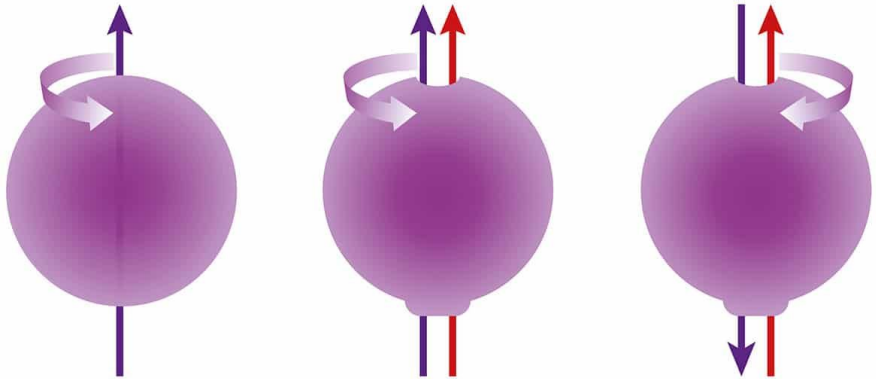
Axions



μeV meV eV keV MeV



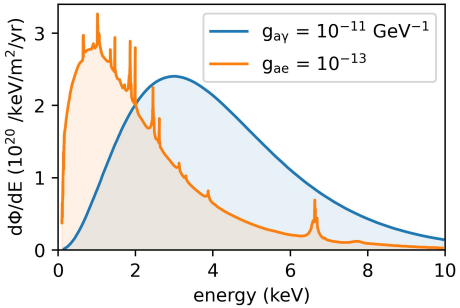
- light, cold **dark matter** candidate
- potentially solve **strong CP problem**
- **conversion to photons** in B-field
  = **Primakoff effect**

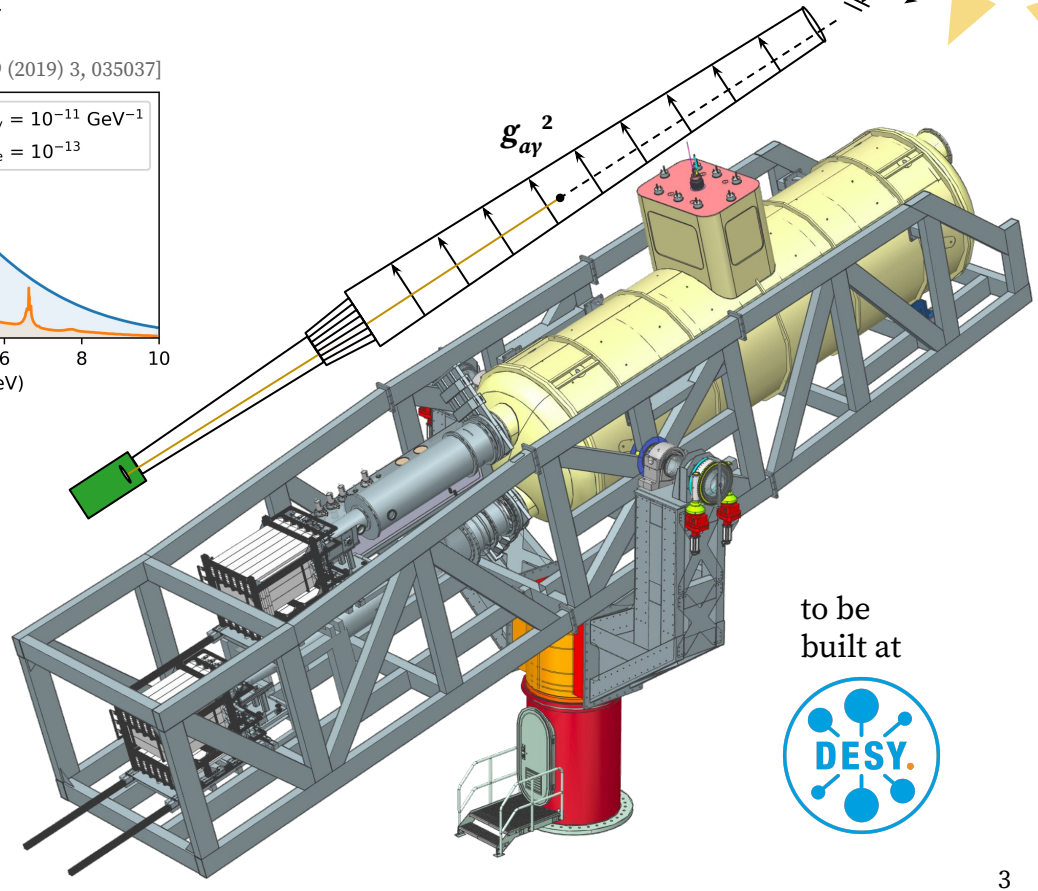


the next-gen helioscope

- search for **solar-axion induced X-rays**

[Dafni et al., PRD 99 (2019) 3, 035037]





to be built at

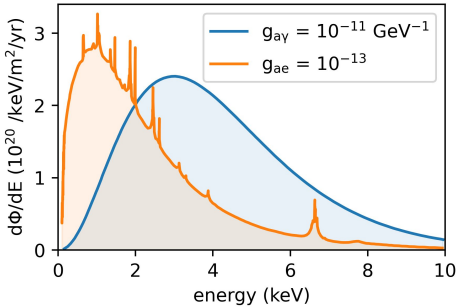
DESY.

IAXO detector requirements

- search for **solar-axion induced X-rays**

1) sufficient **energy threshold** and **resolution**

[Dafni et al., PRD 99 (2019) 3, 035037]

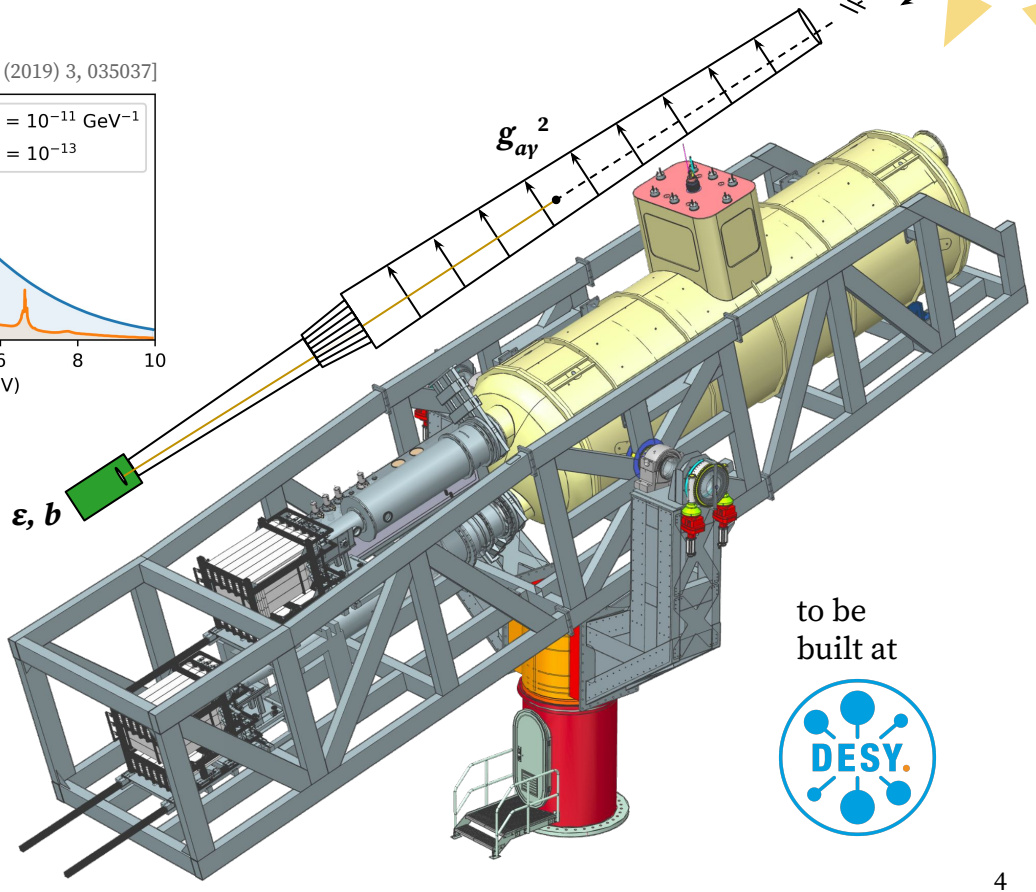


- **sensitivity** scales with $g_{aγ}^{-4} \propto \varepsilon / b^{1/2}$

2) high X-ray **detection efficiency** (***ε***)

3) **ultra-low background** (***b***)

   - babyIAXO goal **10^{-7} cts/keV/cm^2/s**
   - IAXO goal **10^{-8} cts/keV/cm^2/s** *(single events per year)*



to be built at DESY.

Silicon drift detectors (SDDs)

- tiny read-out electrode, **low capacitance**

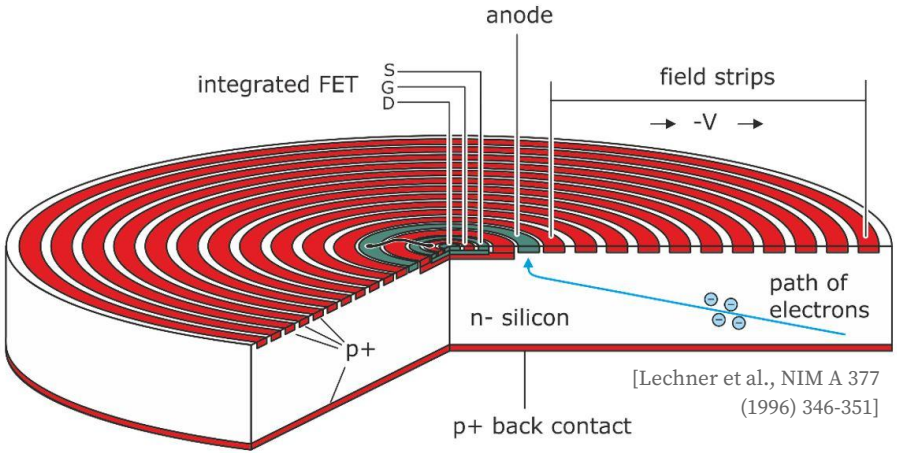
➔ low **energy threshold** (< 1 keV)
and good **resolution** (< 200 eV FWHM at 6 keV)

- thin deadlayer (< 100 nm), **no entrance window**

➔ high X-ray **detection efficiency** in [1, 10] keV

- **semiconductor-grade materials**, little auxiliaries

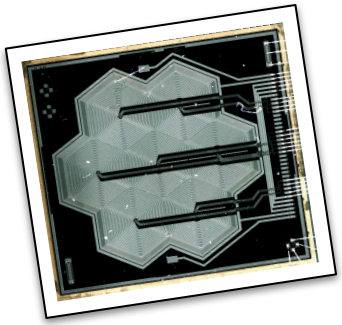
➔ great potential for **low-background** operations



[Lechner et al., NIM A 377 (1996) 346-351]

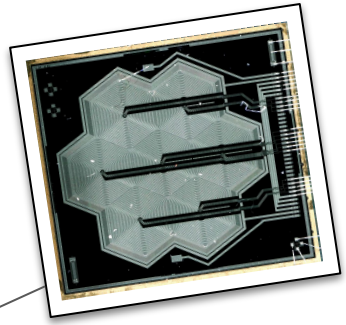
MAX PLANCK SEMICONDUCTOR LABORATORY

7x3-mm pixel **TRISTAN** prototype
SDD array with integrated JFET



TRISTAN SDD for
IAXO = **TAXO**

Detection efficiency



- depends on **geometry**

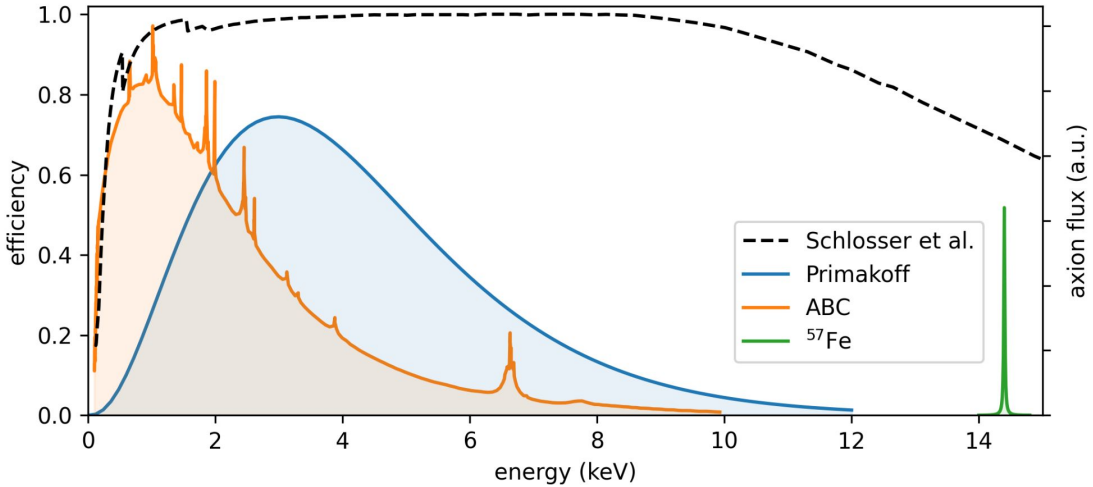
  → **450-µm SDD** with **50 nm dead layer**, no entrance window

- **99% absorption efficiency** for Primakoff flux (**weighted average**, 300 eV threshold)

also

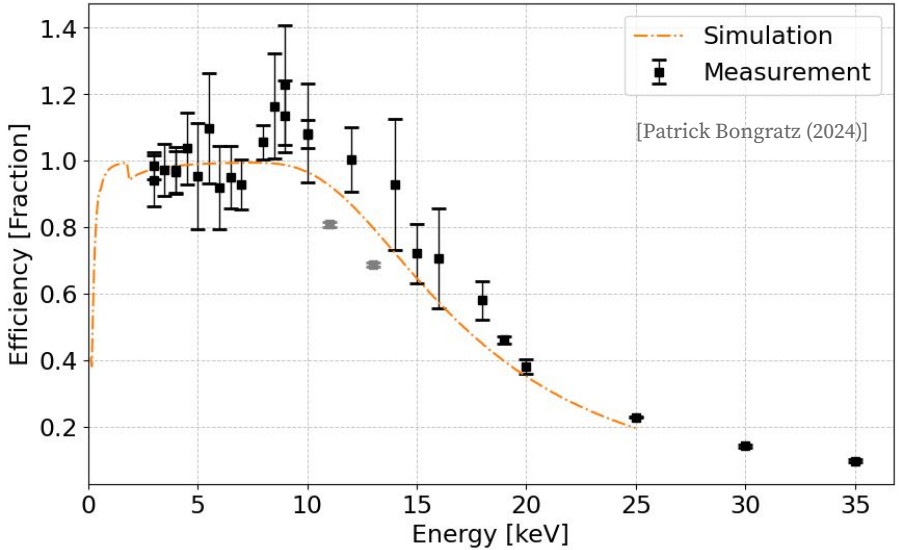
- **92%** for ABC flux (-"-)
- **68%** for ^{57}Fe flux (at 14.4 keV)

[Schlosser et al., NIM A 624 (2010); Dafni et al., PRD 99 (2019)]

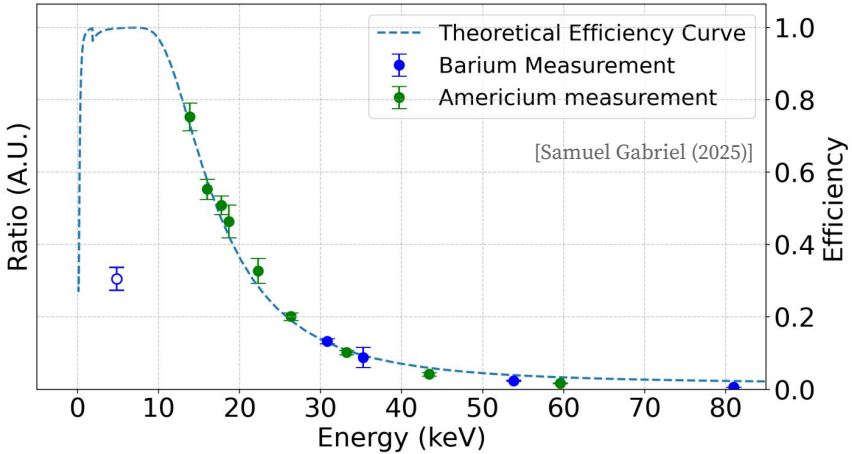


Detection efficiency

- direct measurement at SOLEIL SYNCHROTRON **synchrotron**:
  - photodiode as reference
  - **data matches simulation**



- qualitative measurement with **radioactive sources**:
  - using intensities of **Am241** and **Ba133** spectral peaks (gammas & X-rays)
  - **follows shape of theory curve**



Background challenge

babyIAXO goal **10^{-7} cts/keV/cm^2/s**

IAXO goal **10^{-8} cts/keV/cm^2/s**

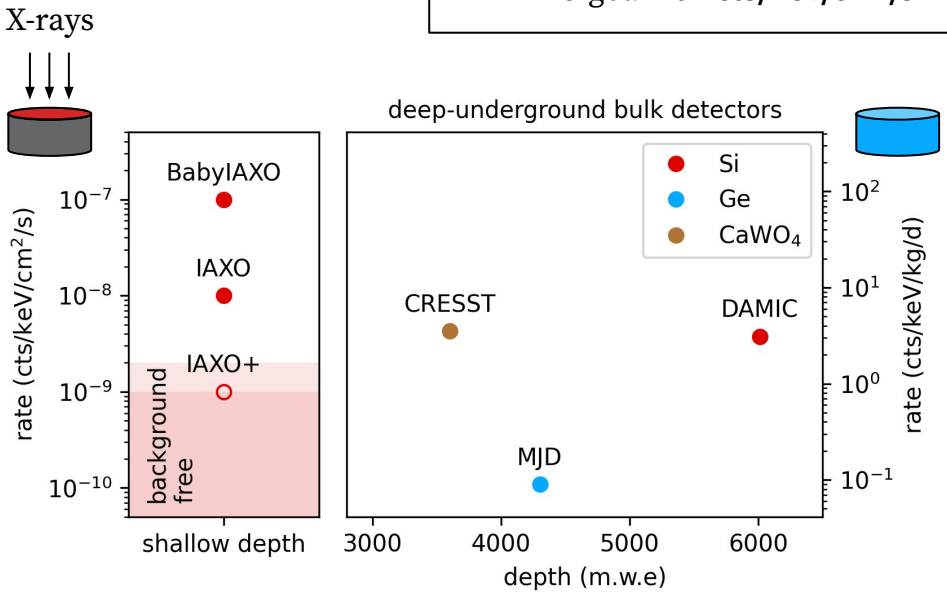
- **similar to** other rare-event searches, e.g. **CEνNS**, **WIMP**, **0νββ decay** searches

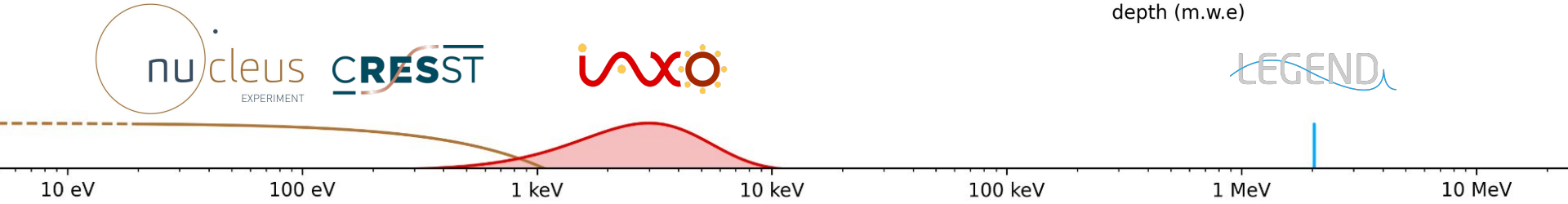
➔ radiopurity, **background mitigation**

but

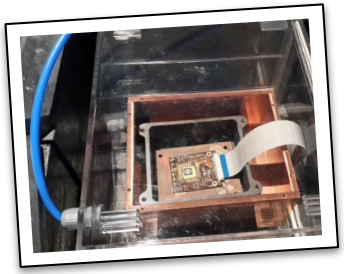
- deep-underground like performance **at shallow depth**

➔ **cosmic-ray** induced backgrounds





TAXO development steps

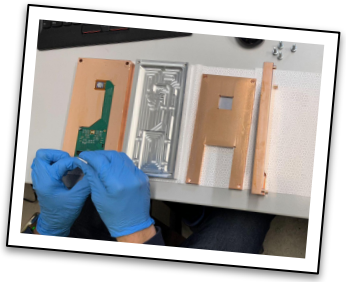


SDD **pathfinder**

material insufficiencies, close-by electronics

➔ **$(1.9 \pm 0.2) \cdot 10^{-5}$ cts/keV/cm^2/s** at shallow depth

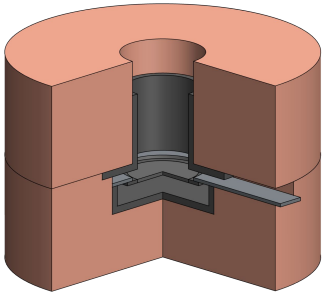
[Houdy et al., 2019]



TAXO **demonstrator**

consequent **low-background** approach, **far electronics**

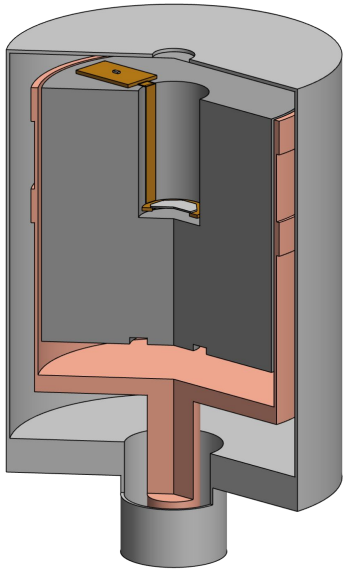
➔ demonstrate **O(10^{-7}) cts/keV/cm^2/s**



babyTAXO

dedicated SDD production, improved **passive shield**

➔ target **< 10^{-7} cts/keV/cm^2/s** at shallow depth



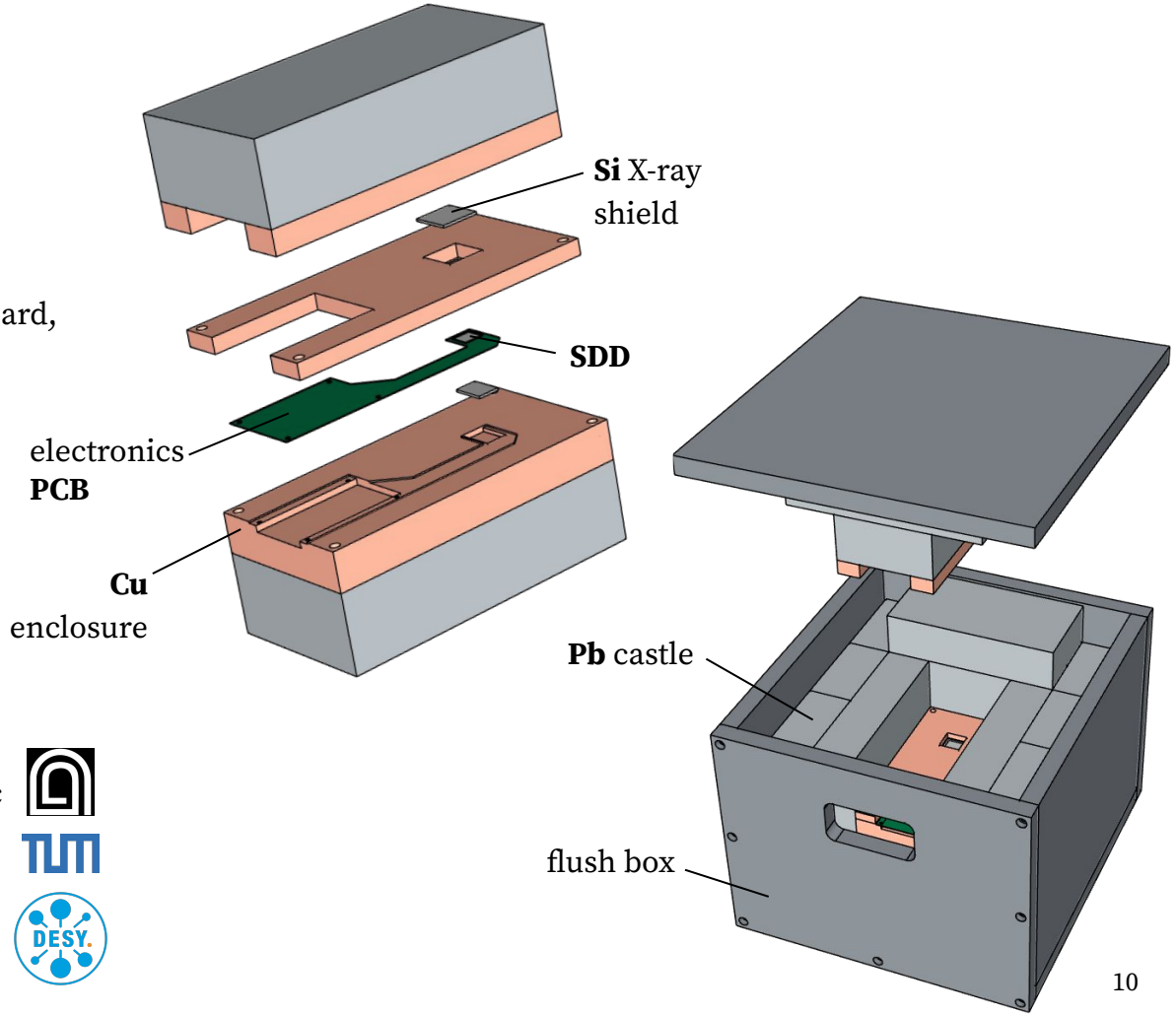
TAXO

all-semiconductor **active shield** SDD-in-HPGe detector

➔ target **< 10^{-8} cts/keV/cm^2/s** at shallow depth

TAXO demonstrator

- **passive shield** setup with
  - prototype **SDD** on polyimide board, far electronics
  - **Si** X-ray shield, radiopure **Cu** enclosure
  - compact **Pb** castle, flush box



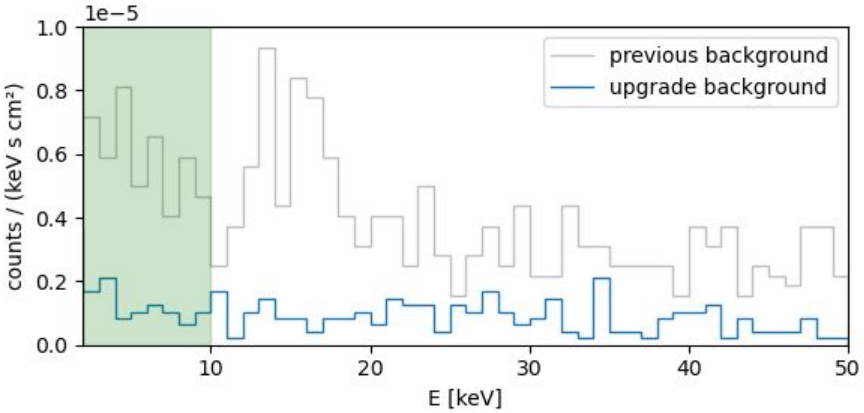
➔ demonstrate **O(10^{-7}) cts/keV/cm^2/s**

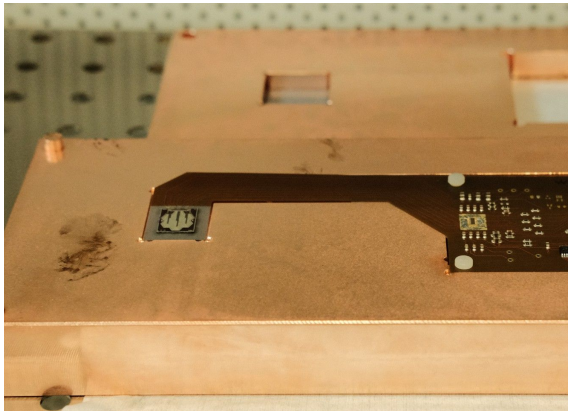
1) **deep underground** at Canfranc
2) **surface level** at TUM
3) **shallow depth** at DESY

TAXO demonstrator at Canfranc

- installed in Lab2500 (**2450 m.w.e.**)
- second measurement campaign with **5-fold improvement** of background
- over 150 days of live time, background index

  $(1.2 \pm 0.2) \cdot 10^{-6}$ cts/keV/cm^2/s in **[2, 10] keV**

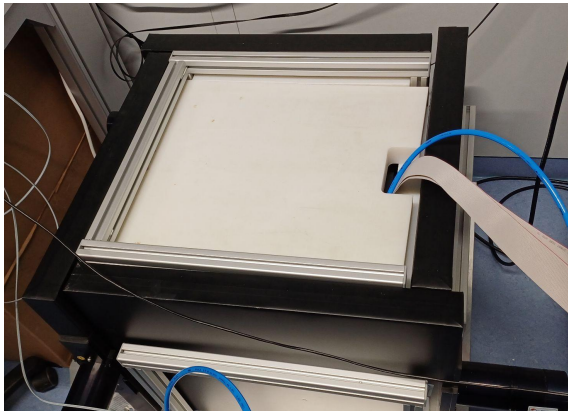


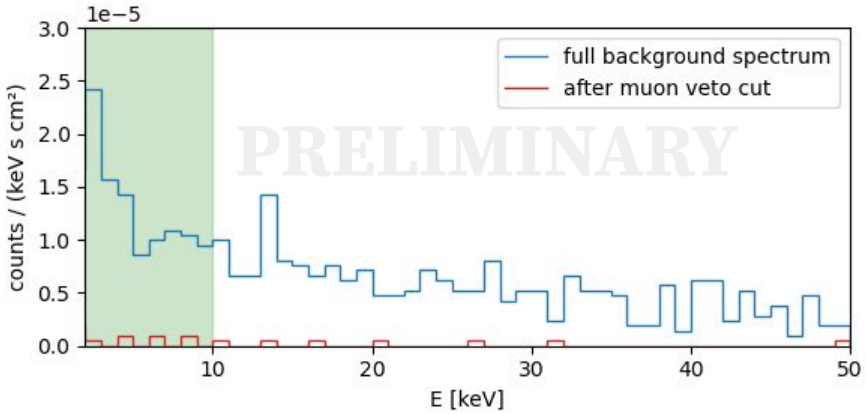


TAXO demonstrator at TUM

- **twin** of Canfranc demonstrator with **muon veto** & **neutron shield**
- first campaign at TUM **ongoing**, move to DESY in the future
- over 50 days of live time, background index

  $(4 \pm 2) \cdot 10^{-7}$ cts/keV/cm^2/s in **[2, 10] keV**

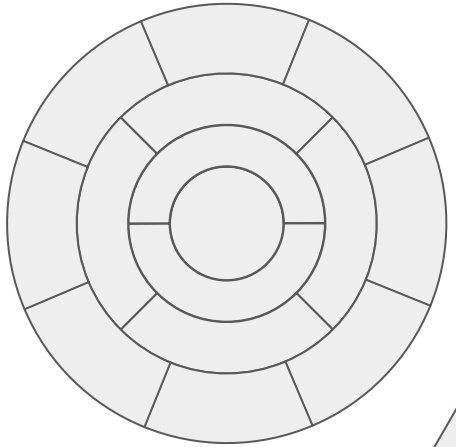


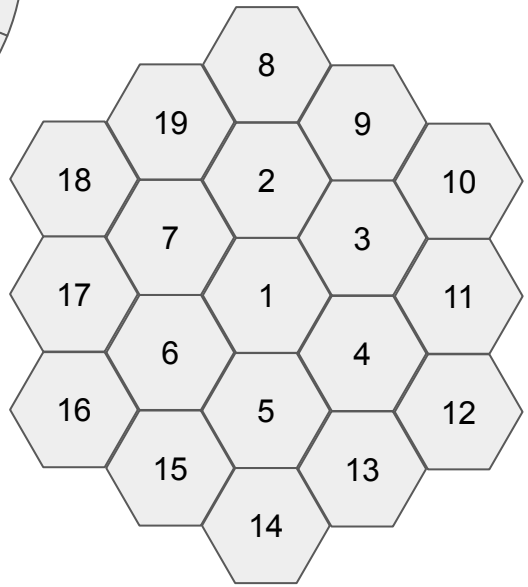


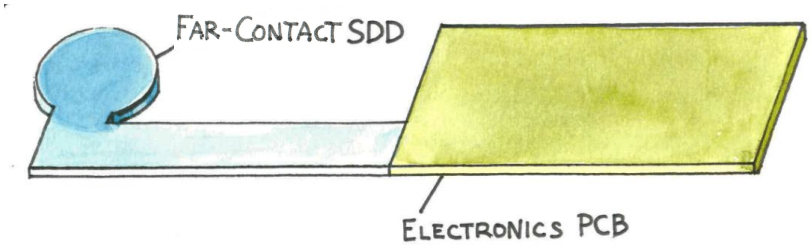
SDD in babyIAXO

SDD concept:

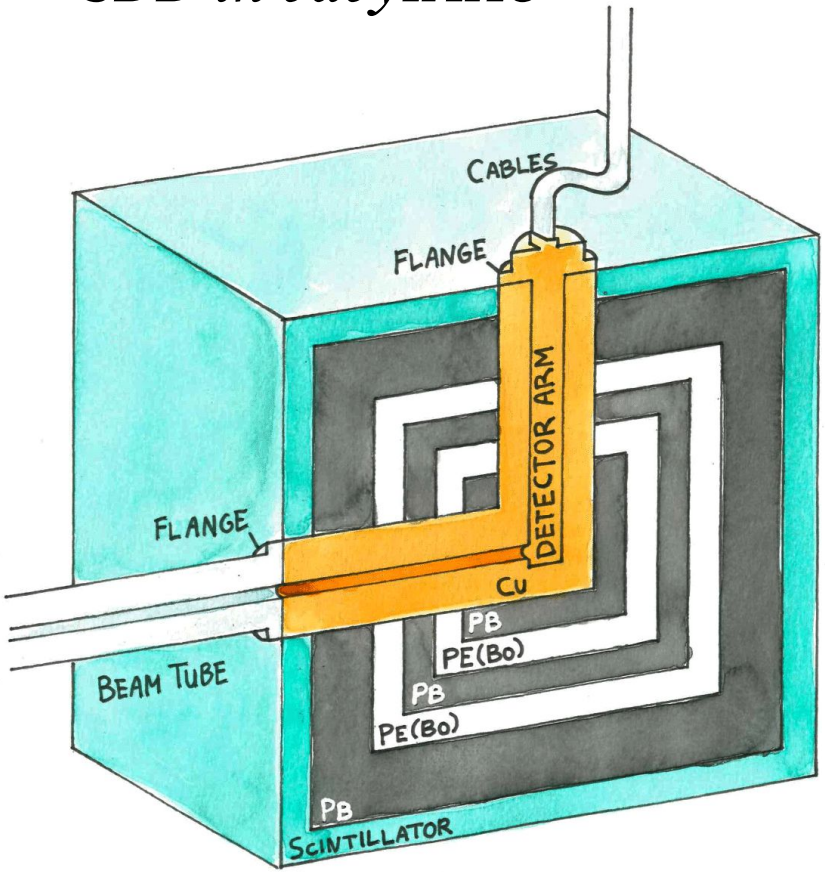
- different **pixelation** ideas under investigation
- **distant contacts** to reduce close-by activity
- collaboration with **Max Planck Semiconductor Lab (HLL)**



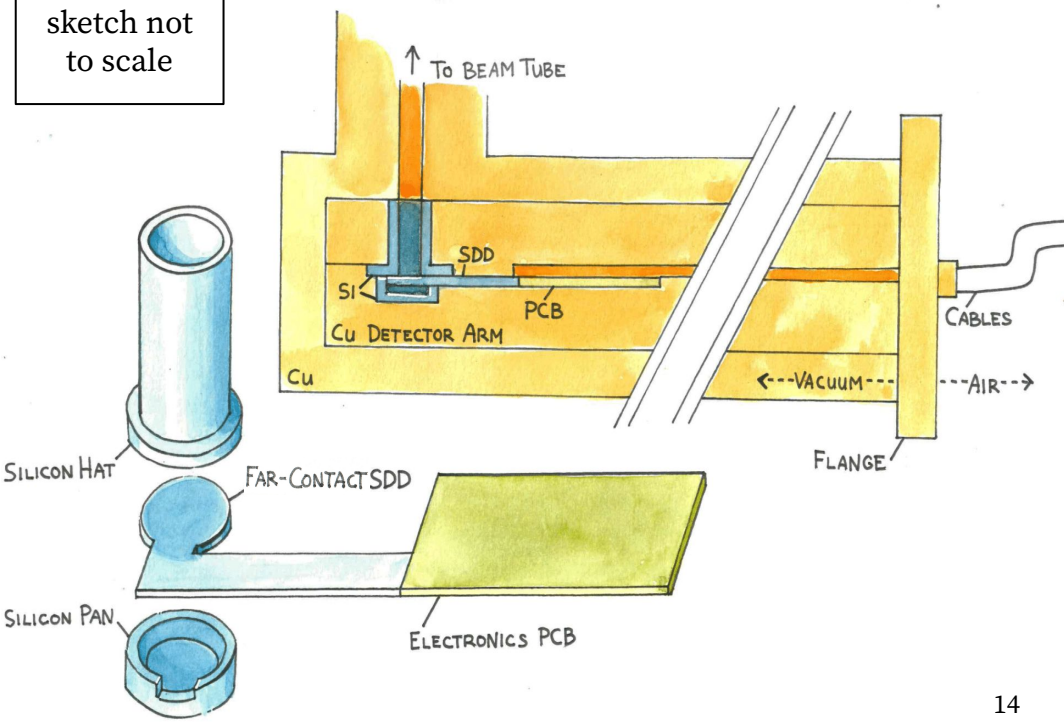




SDD in babyIAXO

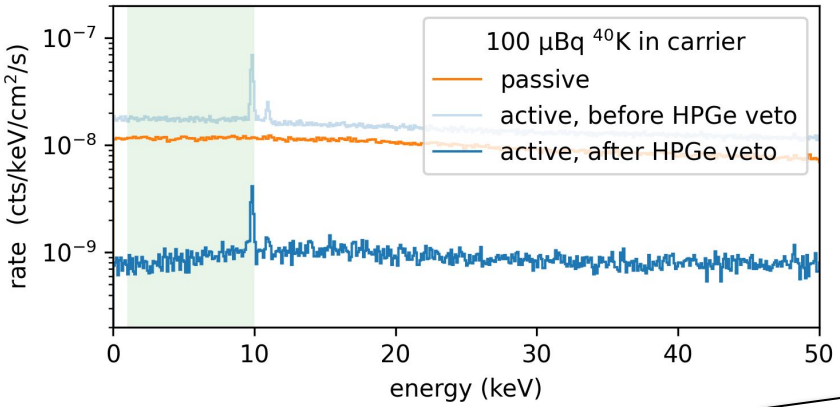


sketch not to scale



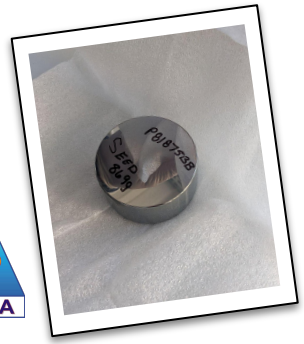
SDD-in-HPGe detector

- all-semiconductor **active-shield design**, ultra-pure **~4π veto**



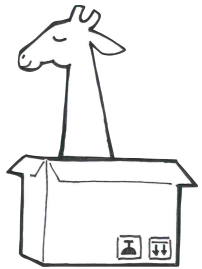
- well-type HPGe detector **prototype, proof-of-principle** preparation ongoing

➔ target **< 10^{-8} cts/keV/cm²/s,** potential detector for LEGEND



Conclusion

- **TAXO** SDD development to meet challenging IAXO X-ray detector requirements with a
  - conventional **passive shield** setup
  - novel all-semiconductor **SDD-in-HPGe active-shield** design
- theoretical **detection efficiency** verified in two experiments
- **background exploration** deep-underground and at shallow depth **ongoing**
- SDD and shielding **design for babyIAXO** shifting into focus



Thank you for your attention!

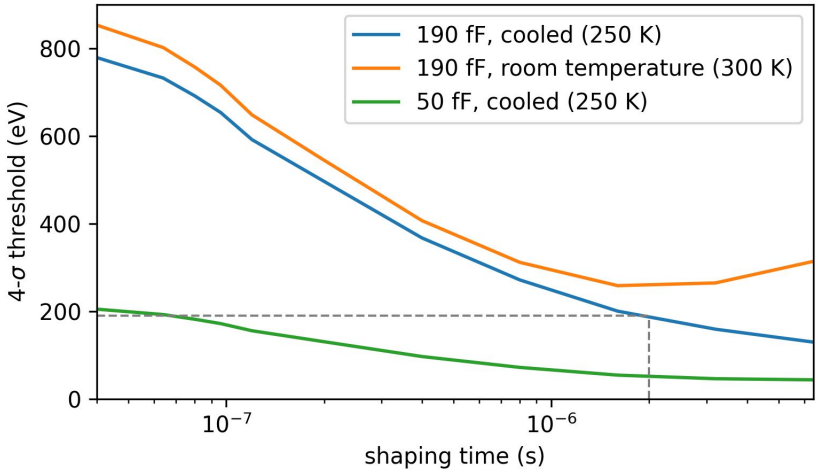
Backup

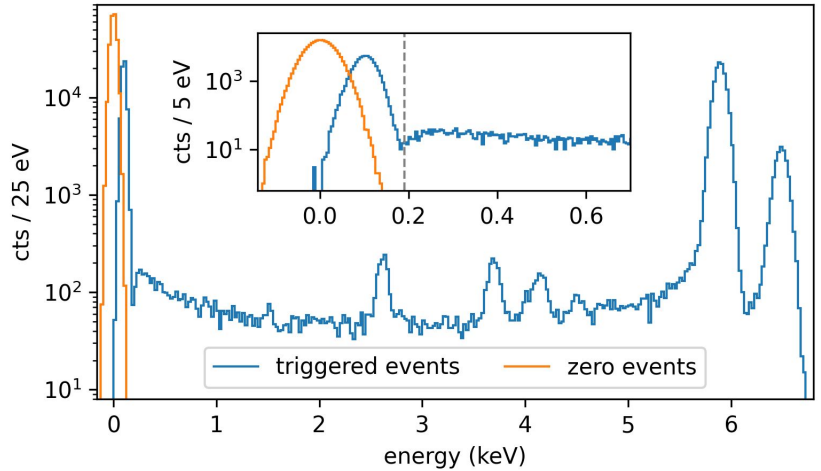
Energy threshold

- depends on **noise performance**
  - read-out capacitance
  - temperature
  - trigger filter (shaping time)

- **200 eV** achieved with TRISTAN SDD (cooled, 2 µs shaping time)
- **25 eV** reported in literature, droplet SDD
  [Strüder et al., Microscopy Today 28 (2020)]

➔ **sub-keV threshold** feasible, but cooling/close-by electronics could alter background performance



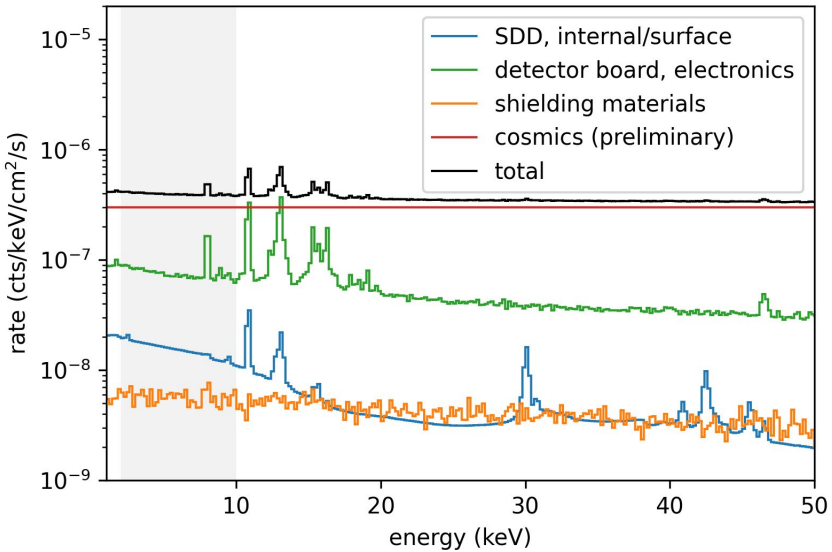


Background projections

- stand-alone **Geant4** application, demonstrator and different shielding geometries implemented

- **radiogenic** backgrounds
  - **assay** results, radiopurity **estimates**
  - cosmogenic **activation** (^{3}H, ^{32}Si)
    [Saldanha et al., PRD (2020) 10, 102006;
    Orrell et al., Astropart.Phys. 99 (2018) 9-20]

- **cosmic** backgrounds
  - full (correlated) above ground **cosmic ray flux**, cosmic ray library (**CRY**)
    [https://nuclear.llnl.gov/simulation/doc_cry_v1.7/cry.pdf]

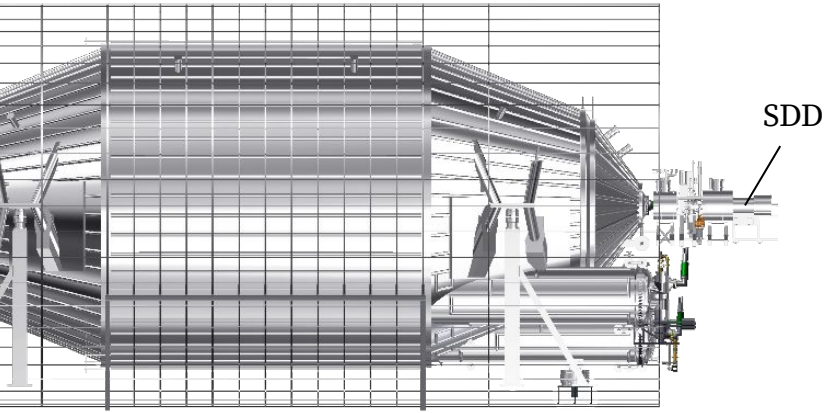


➔ significant **reduction of neutron-induced background** with borated polyethylene

TRISTAN

keV-sterile neutrino search with KATRIN

[Mertens et al., J.Phays.G 46 (2019) 6, 065203]

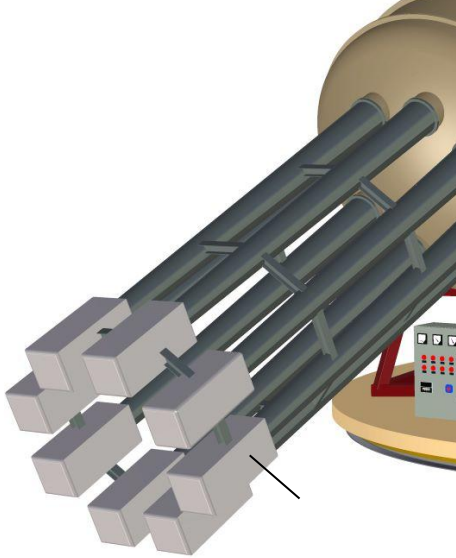


- **high-rate electron spectroscopy**
- ultra-high vacuum compliance, calibration

IAXO

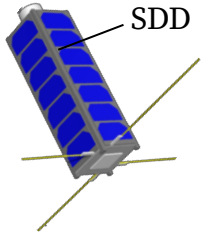
solar axion search

[Armengaud et al., JINST 9 (2014) T05002]



- **rare-event X-ray detection**
- ultra-low background, high-efficiency

ComPol



X-ray polarization measurement of Cygnus X-1

- compact **Compton telescope**, CubeSat mission
- space environment, radiation hardness, remote operation

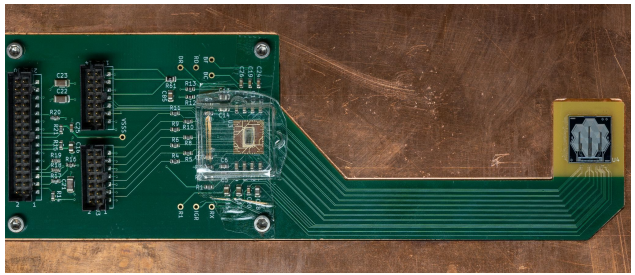
TAXO demonstrator at Canfranc

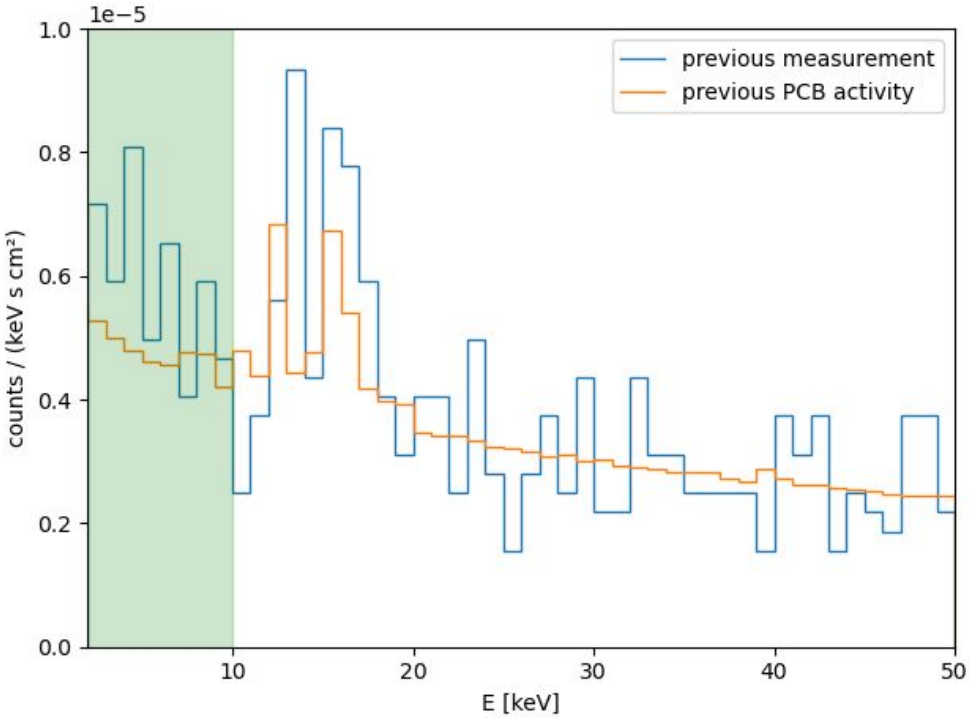
previous measurement campaign 2022-2023:

- “GIRAXO” PCB
- **background** level **higher than anticipated**

  $(5.6 \pm 0.5) \cdot 10^{-6}$ cts/keV/cm^2/s in **[2, 10] keV**

➔ dominated by **radioimpurities in PCB**





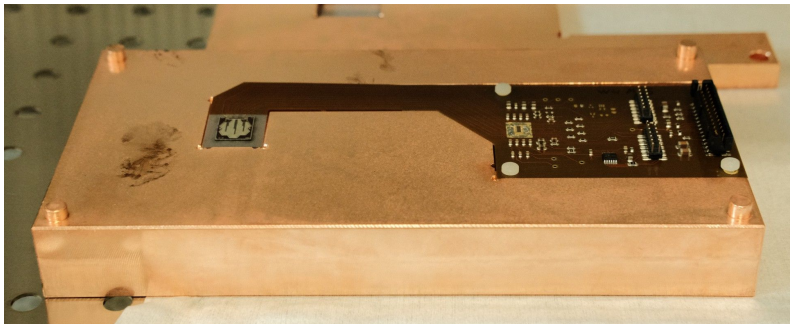
TAXO demonstrator at Canfranc

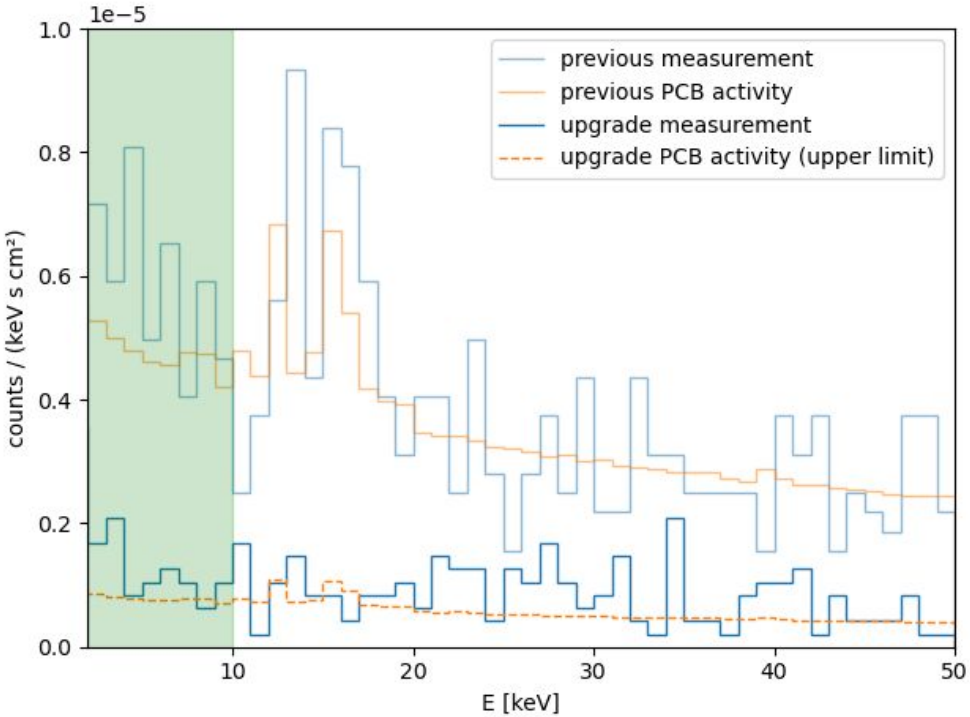
upgrade measurement campaign 2024-today:

- “rigid-flex” PCB
- **background** level **reduced by factor 5**

  $(1.2 \pm 0.2) \cdot 10^{-6}$ cts/keV/cm^2/s in **[2, 10] keV**

➔ radioassay of **radioimpurities in PCB**





TAXO demonstrator at TUM

- **background** index

  $(4 \pm 2) \cdot 10^{-7}$ cts/keV/cm^2/s in **[2, 10] keV**