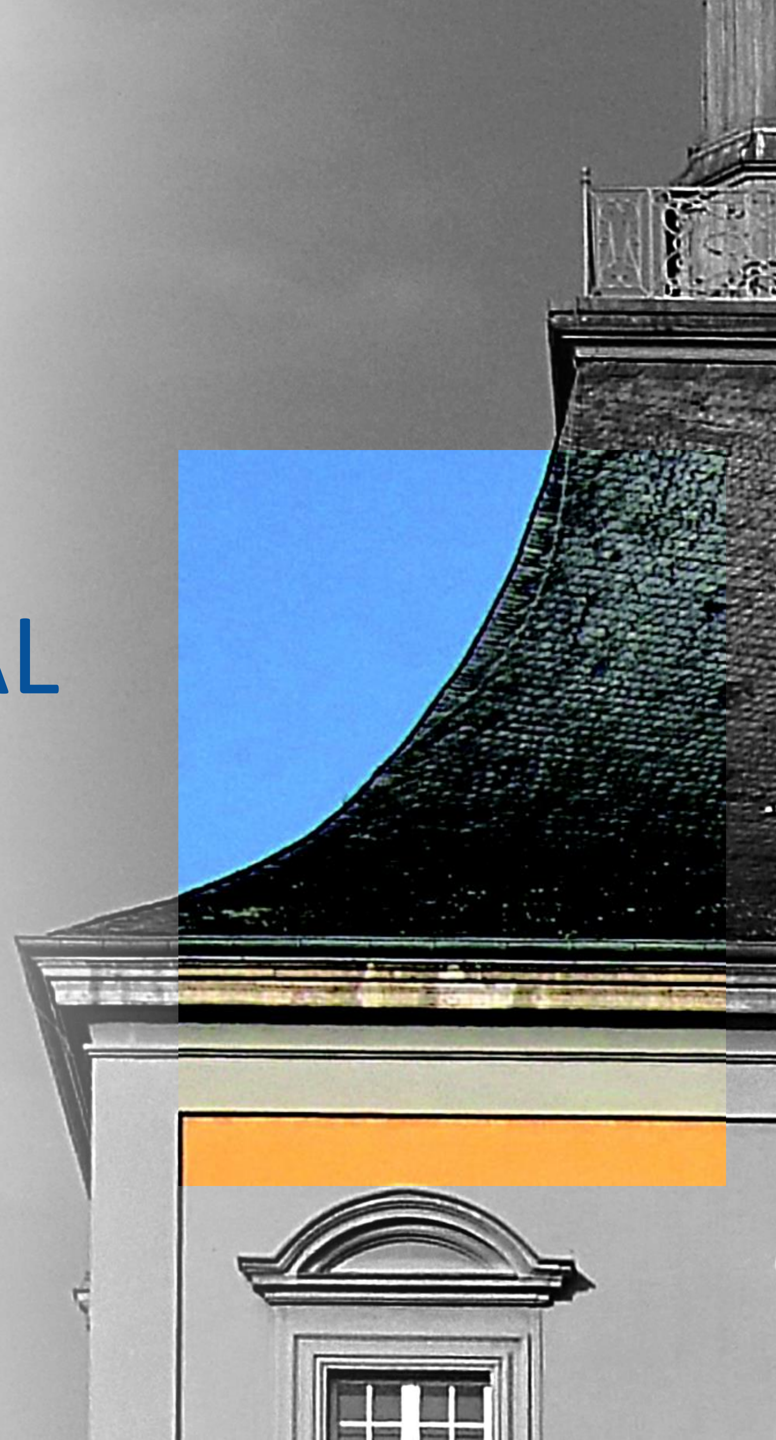
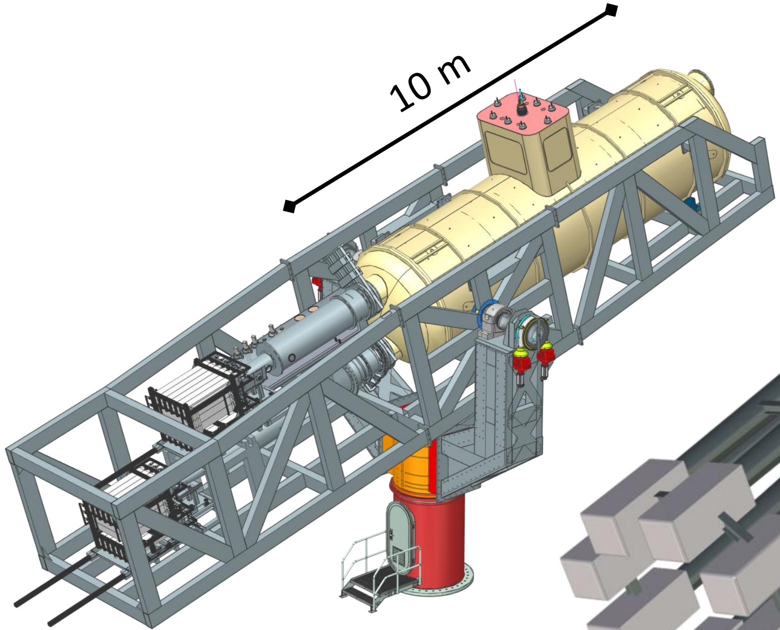
DEVELOPMENT OF A GRIDPIX DETECTOR FOR THE INTERNATIONAL AXION OBSERVATORY

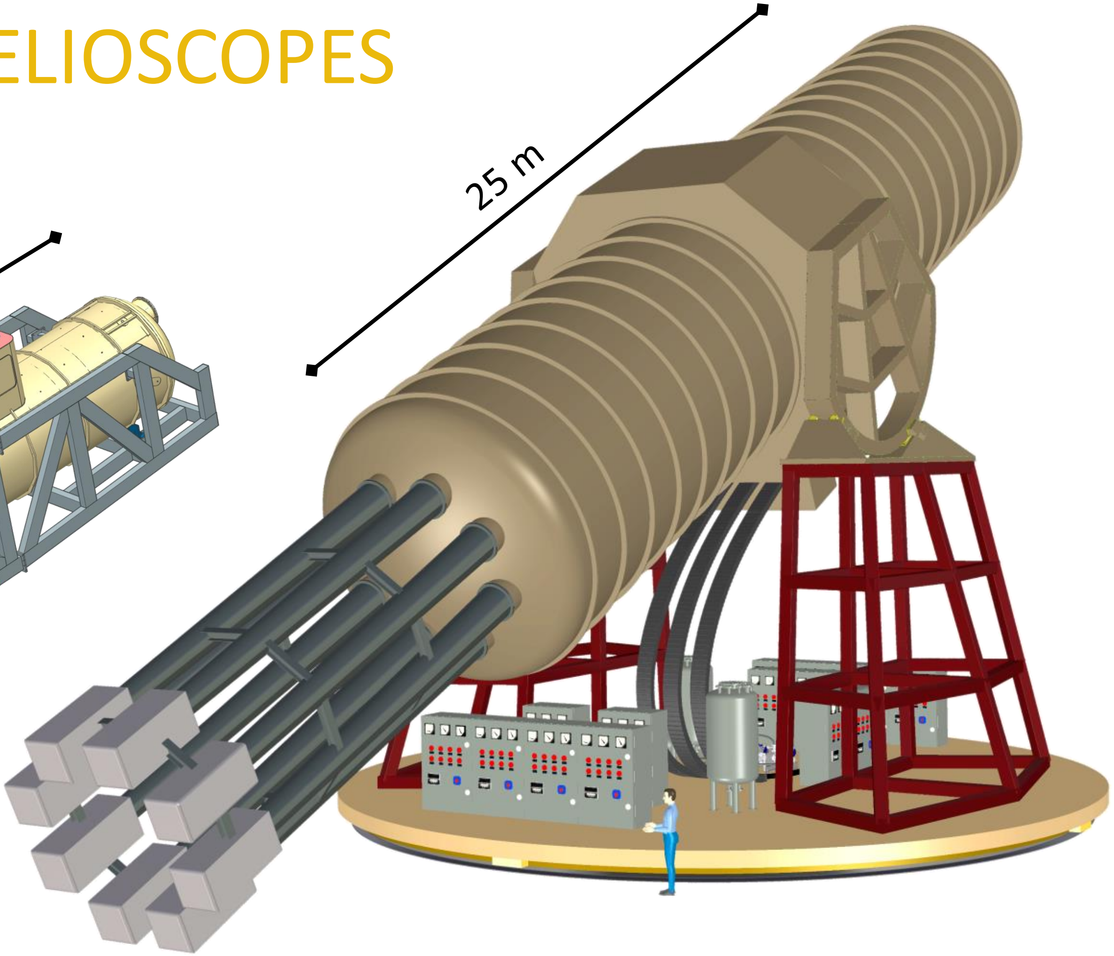
Johanna von Oy, Klaus Desch,
Jochen Kaminski, Tobias Schiffer,
Sebastian Schmidt, and Markus Gruber

DPG Göttingen 2025



GENERATIONS OF HELIOSCOPES





IAXO collaboration 2014, arXiv:1401.3233v1

Previous experiments

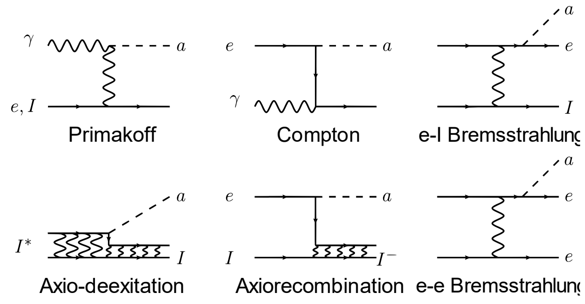
CAST

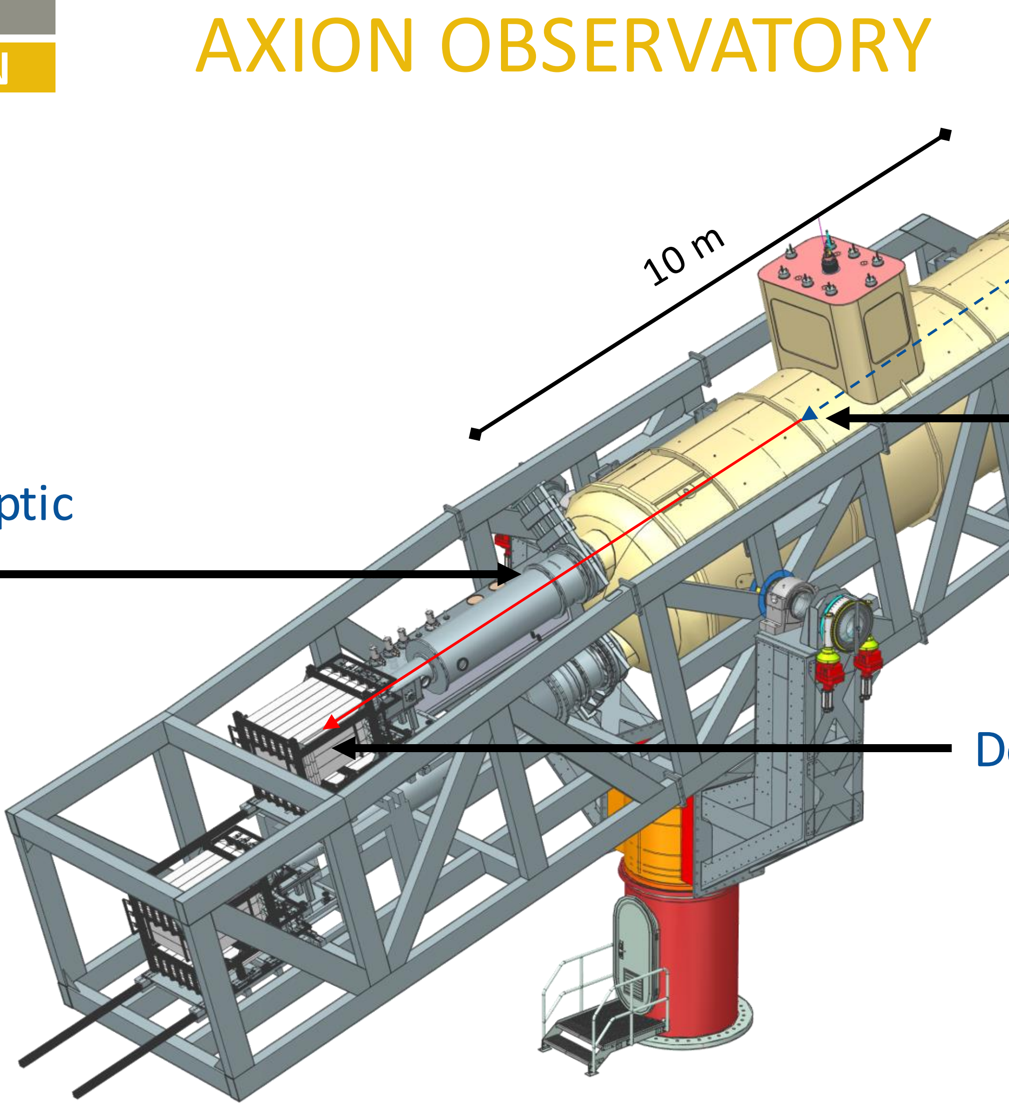
BabyIAXO

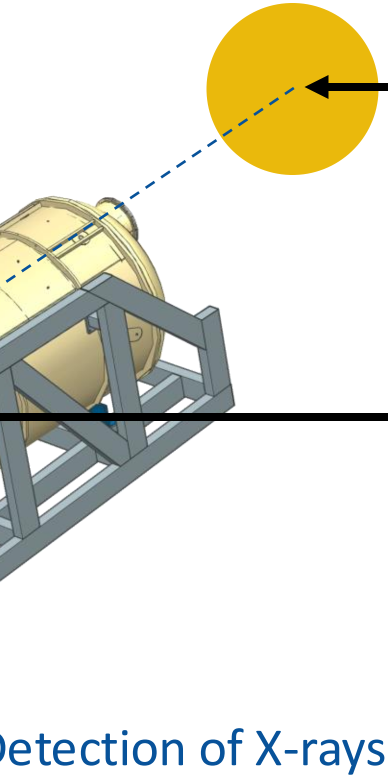
IAXO

THE (BABY) INTERNATIONAL AXION OBSERVATORY

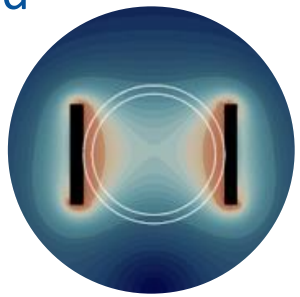
Axion production in the sun





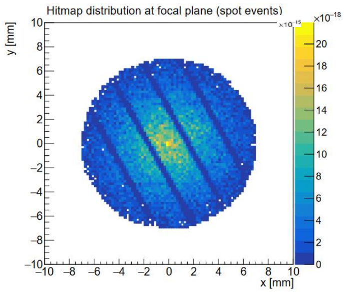


Axions couple to photons in magnetic field



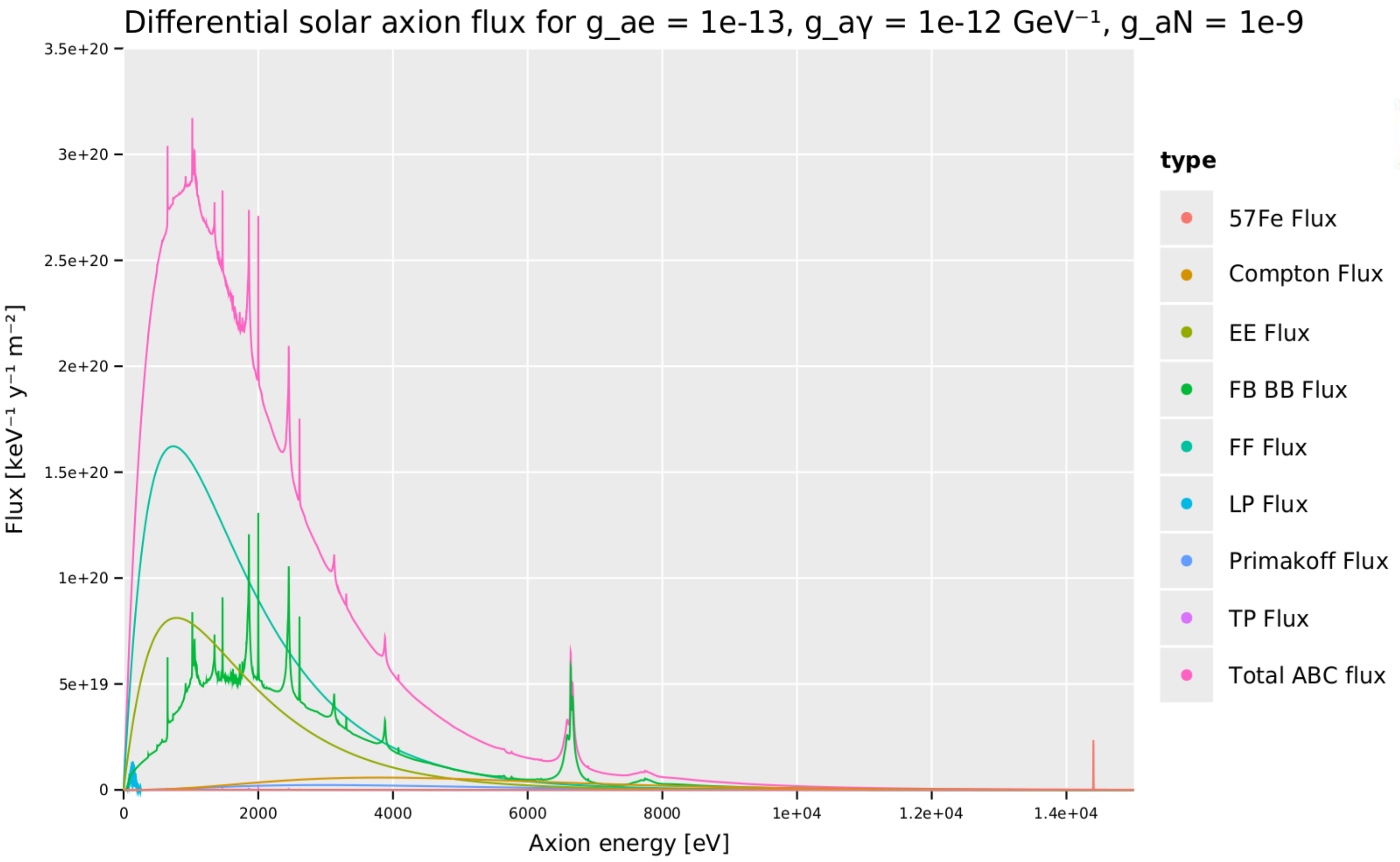
Focus of X-rays in optic

Detection of X-rays

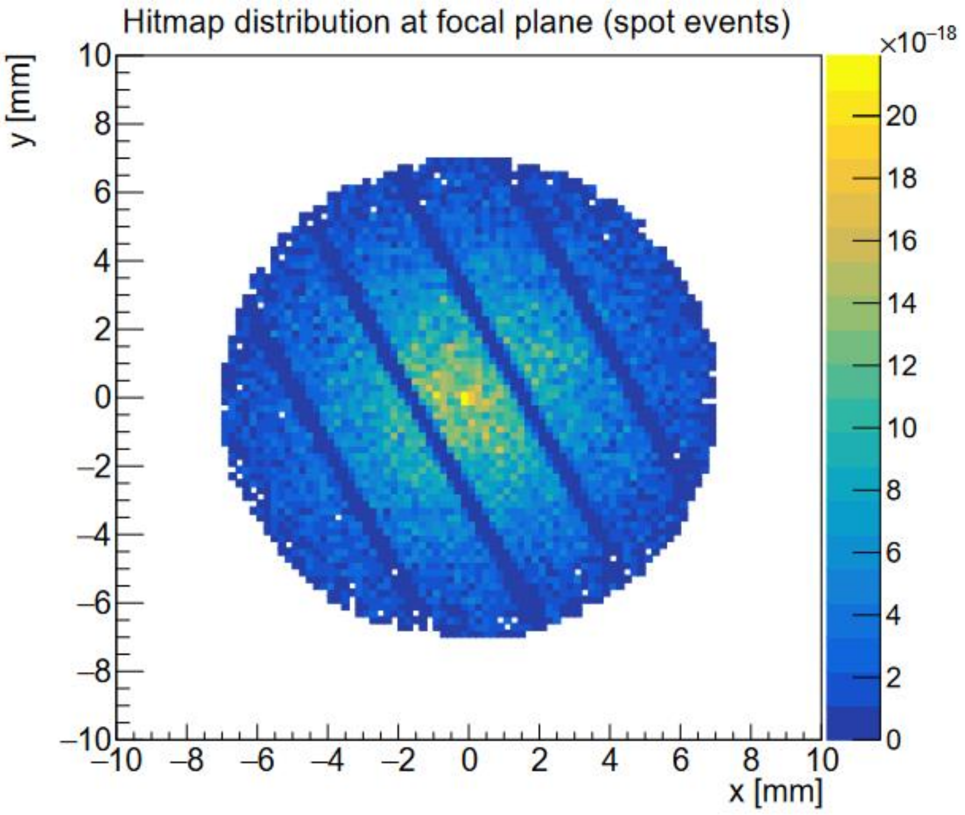


DETECTOR CHALLENGES FROM SIMULATIONS

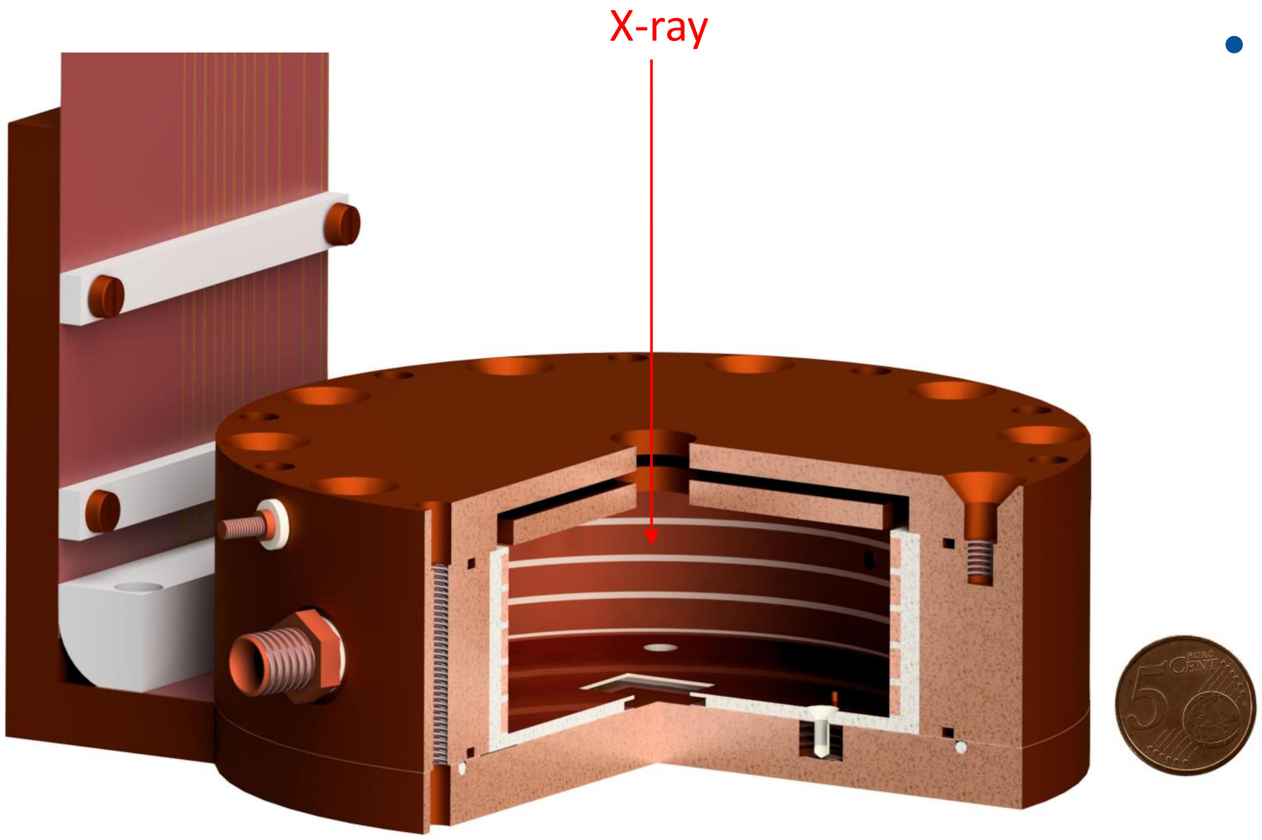
Low energy X-rays



Low signal count

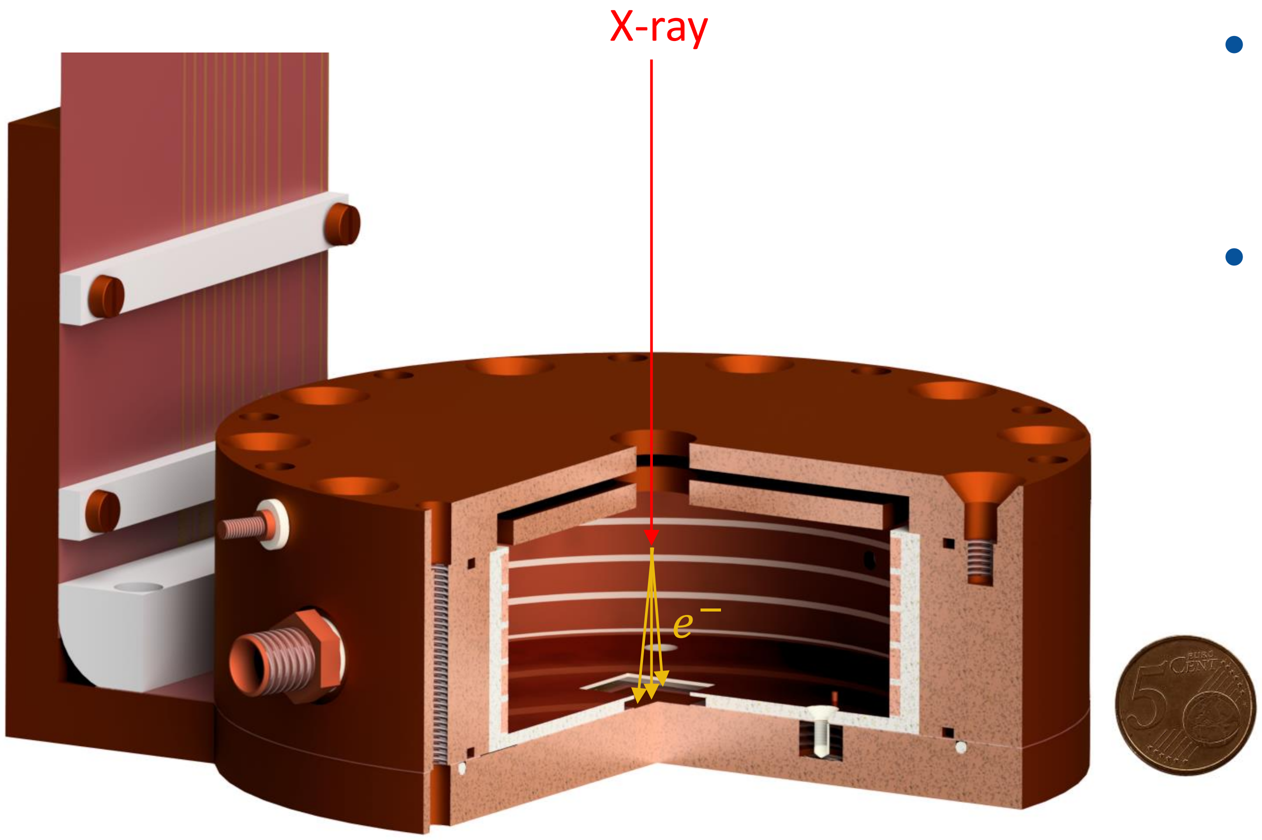


DETECTOR PRINCIPLE



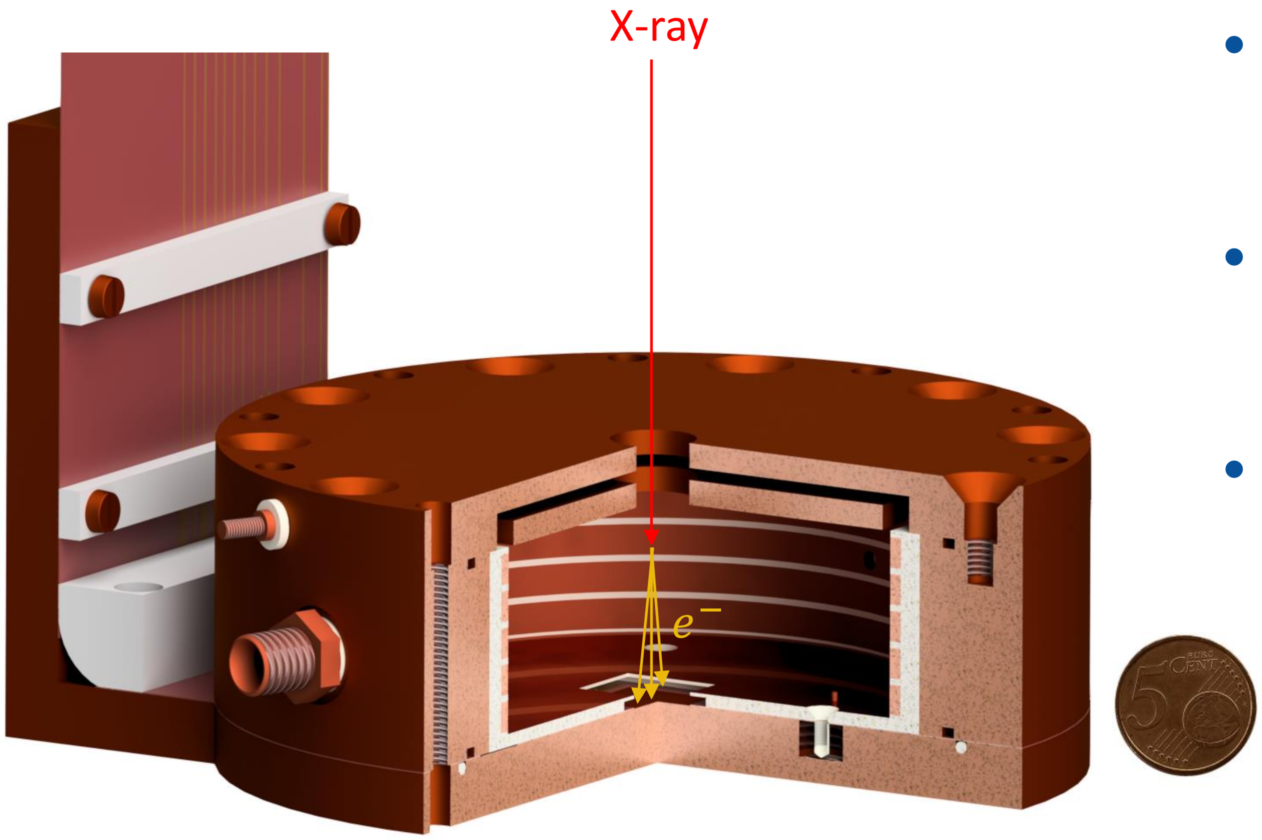
- X-rays travel through ultra thin window

DETECTOR PRINCIPLE



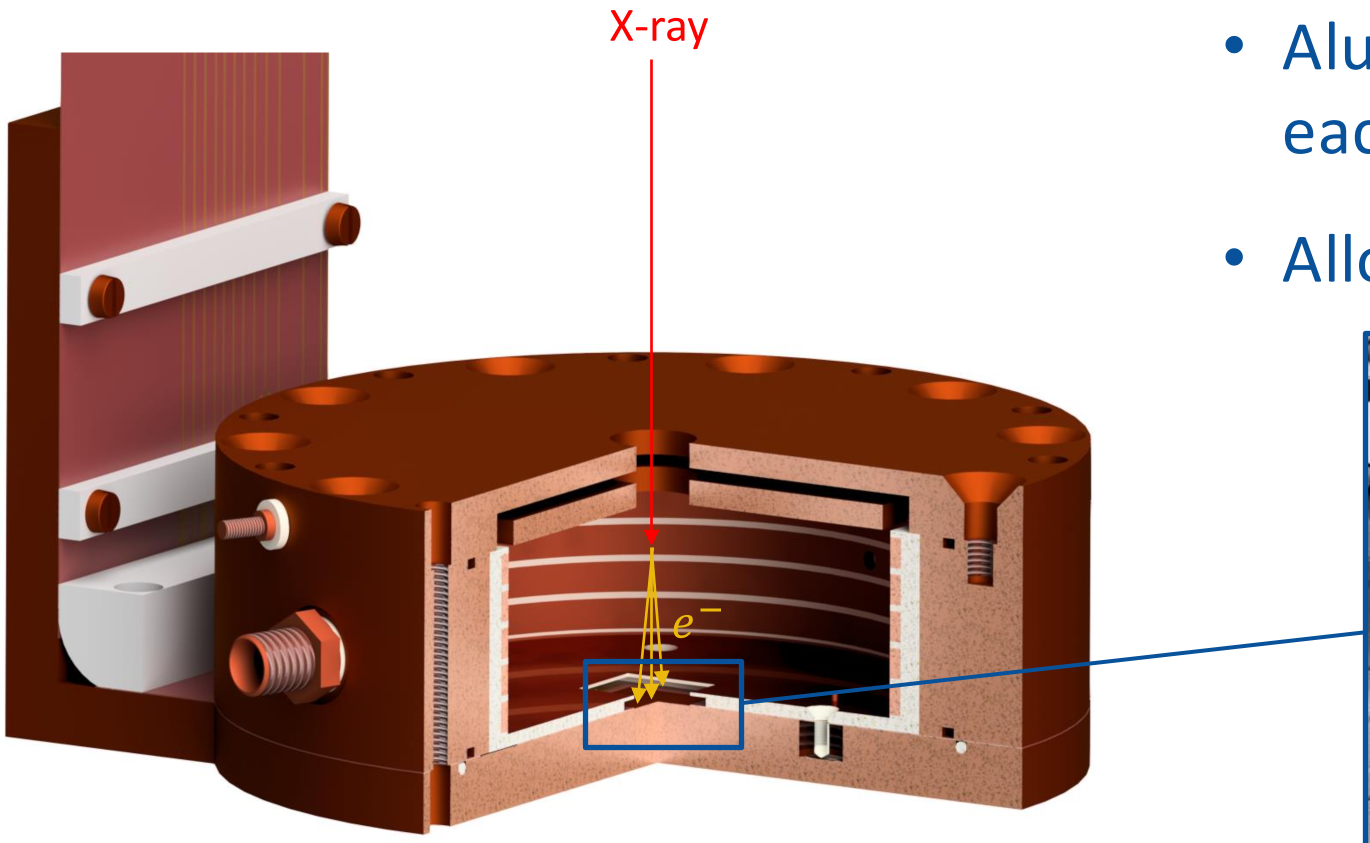
- X-rays travel through ultra thin window
- Ionize atoms in argon isobutane mixture

DETECTOR PRINCIPLE

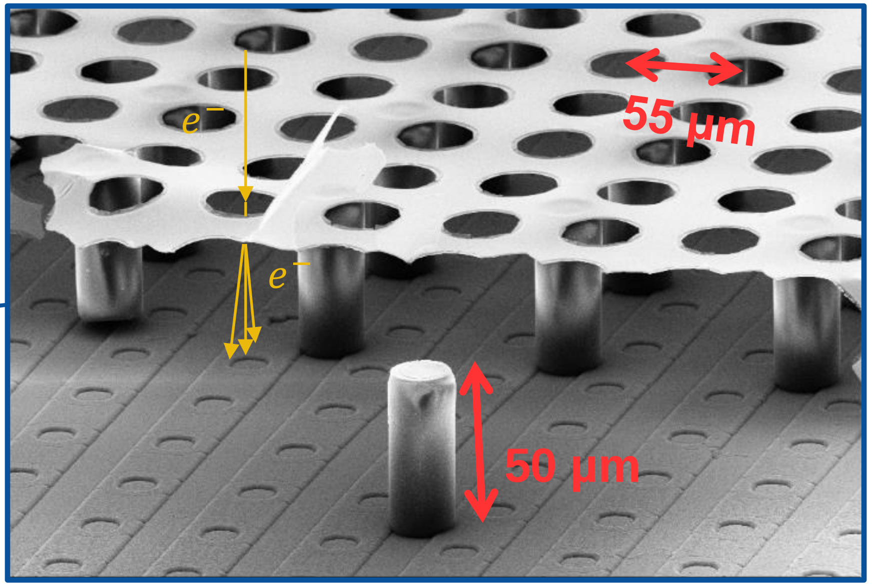


- X-rays travel through ultra thin window
- Ionize atoms in argon isobutane mixture
- Electrons are accelerated in electric field towards detection chip

DETECTOR PRINCIPLE

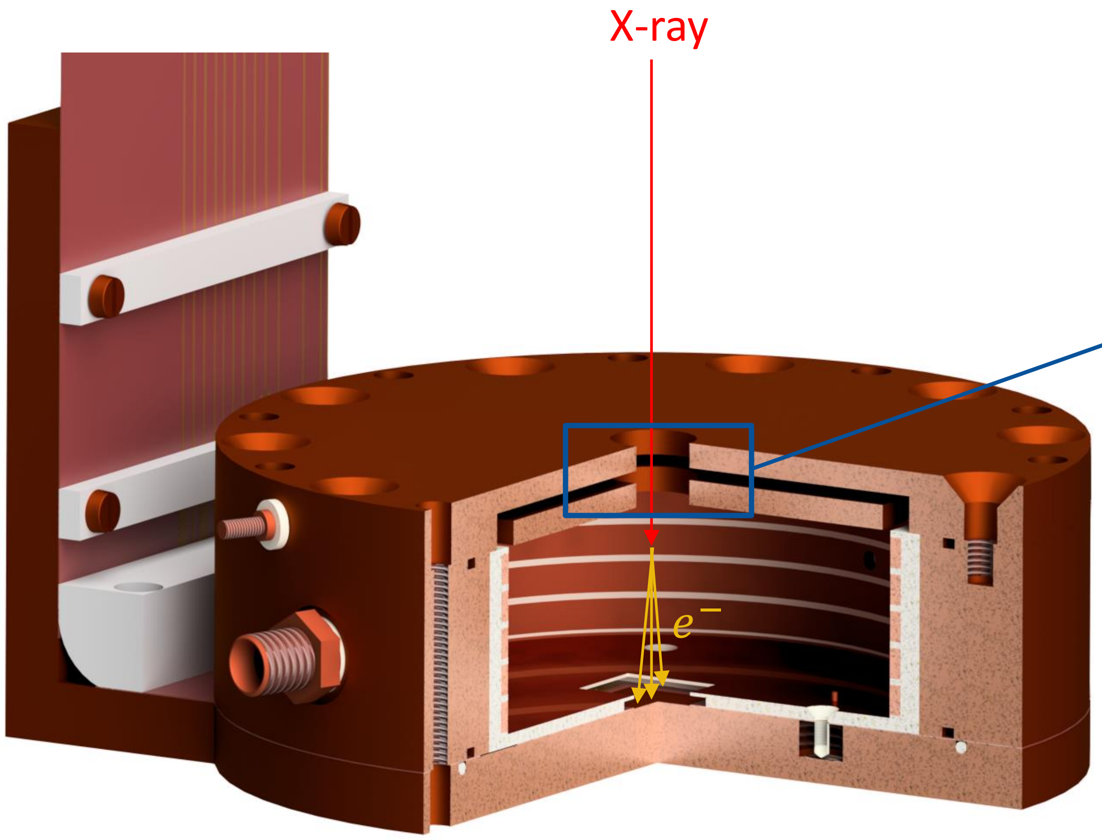


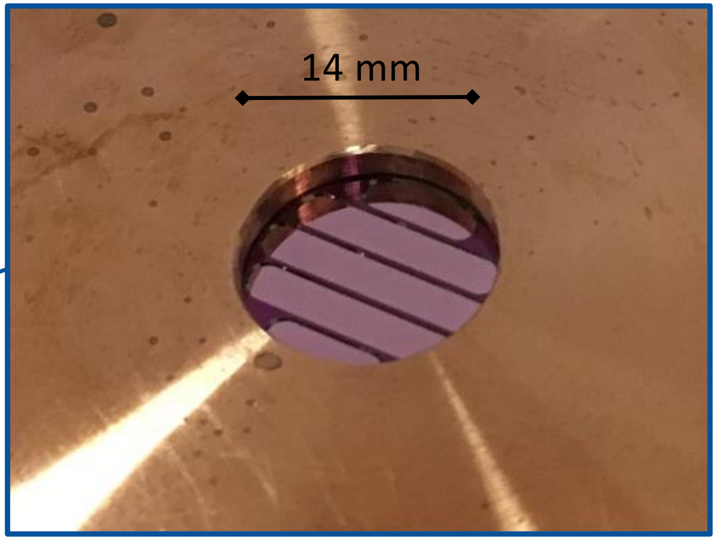
- Aluminium grid with one hole above each pixel of the Timepix3 chip
- Allows single electron detection



→ T 71.5 talk by Sabine Hartung

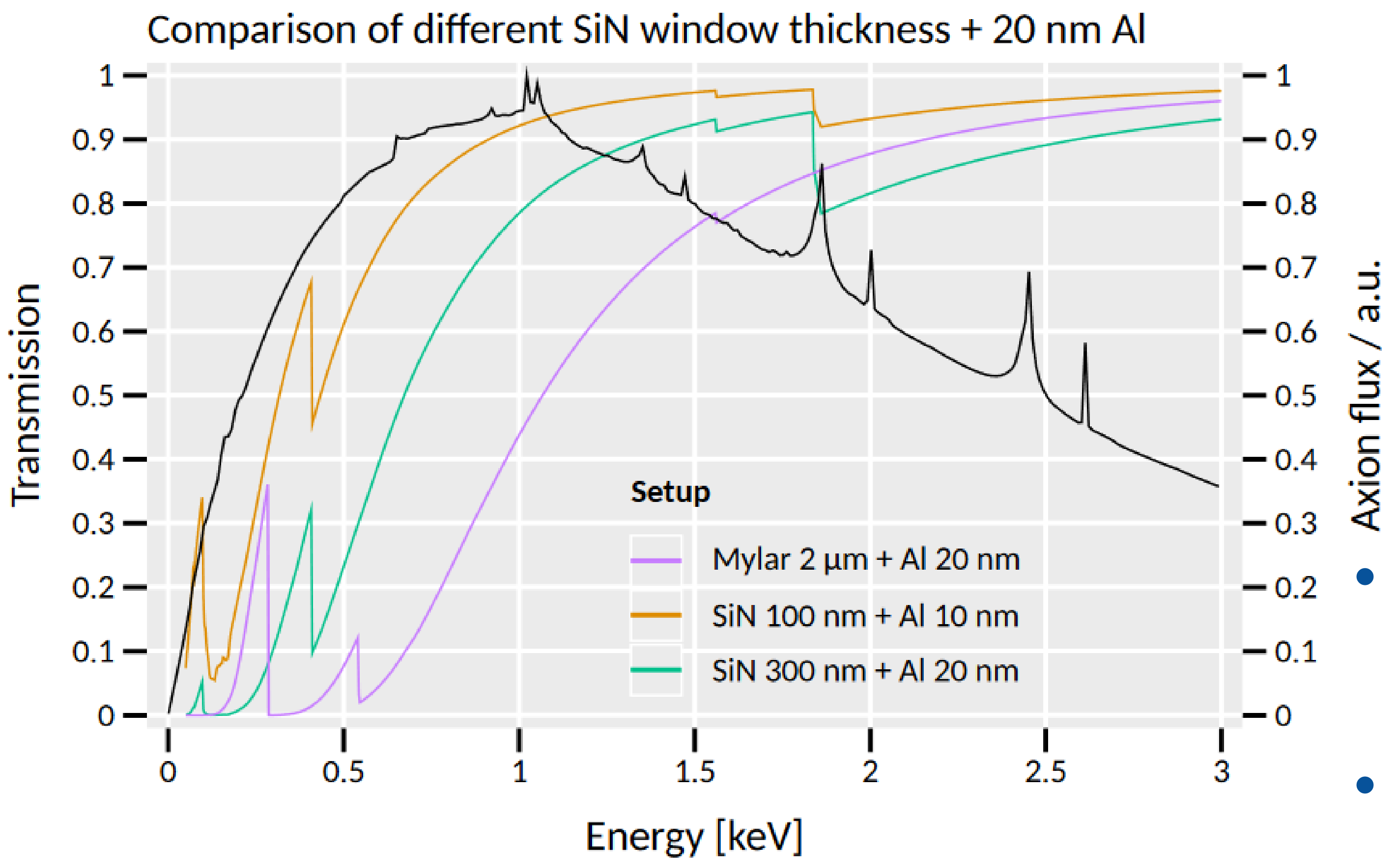
DETECTOR PRINCIPLE - ULTRA THIN WINDOWS

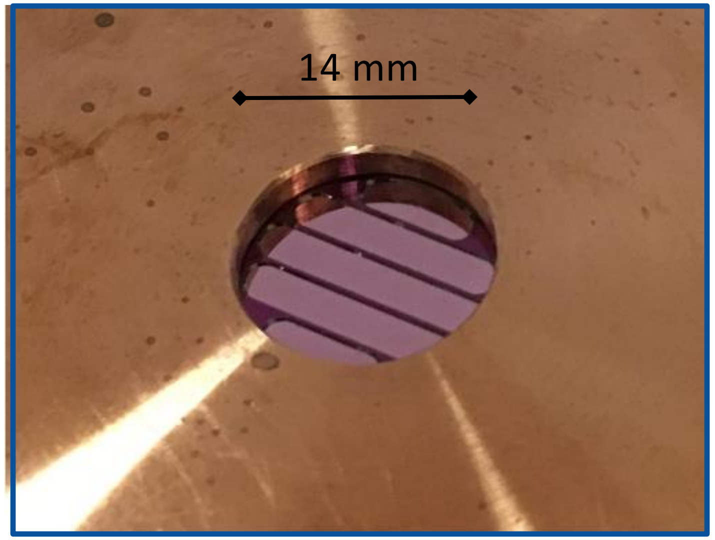




- Silicon nitride window supported by silicon strips
- Withstands a pressure difference of up to 1.5 bar

DETECTOR PRINCIPLE – ULTRA THIN WINDOWS

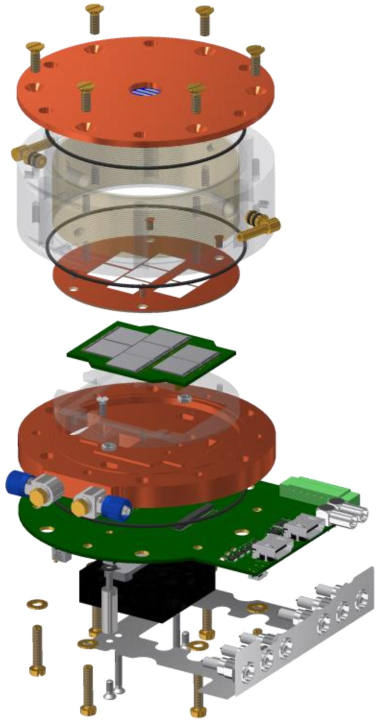


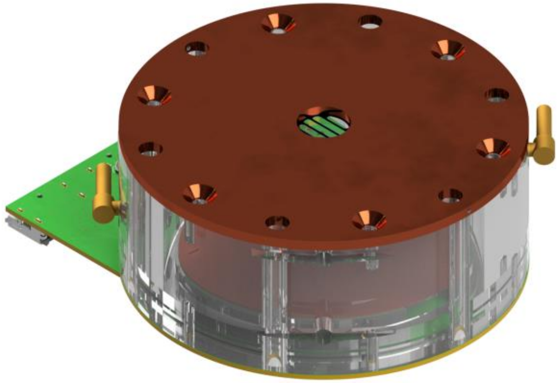


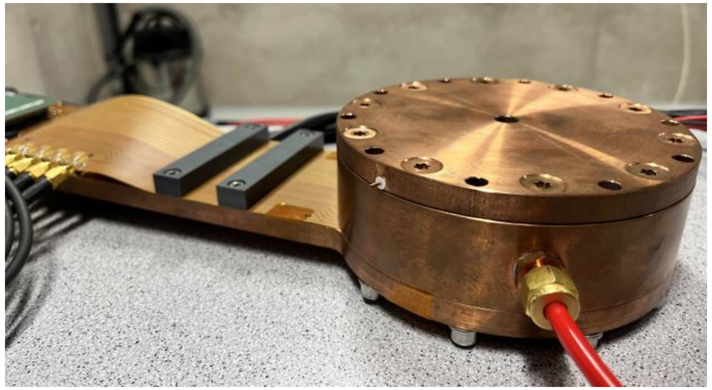
- Silicon nitride window supported by silicon strips
- Withstands a pressure difference of up to 1.5 bar

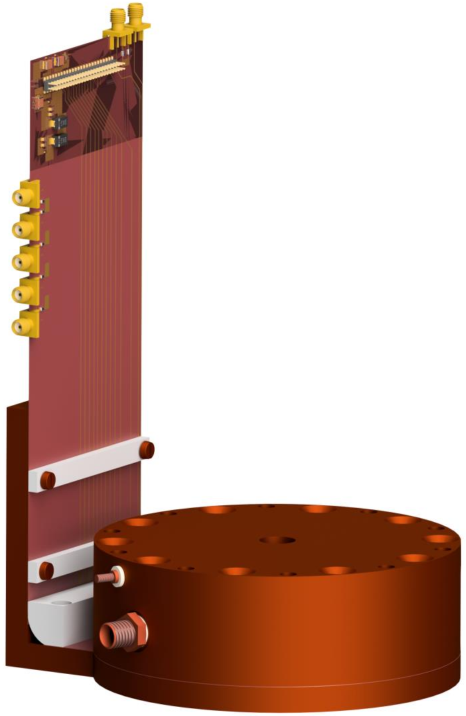
GENERATIONS OF GRIDPIXES FOR HELIOSCOPES

Sebastian Schmidt 2024, https://doi.org/10.48565/bonndoc-303









CAST 7 Chip
Detector

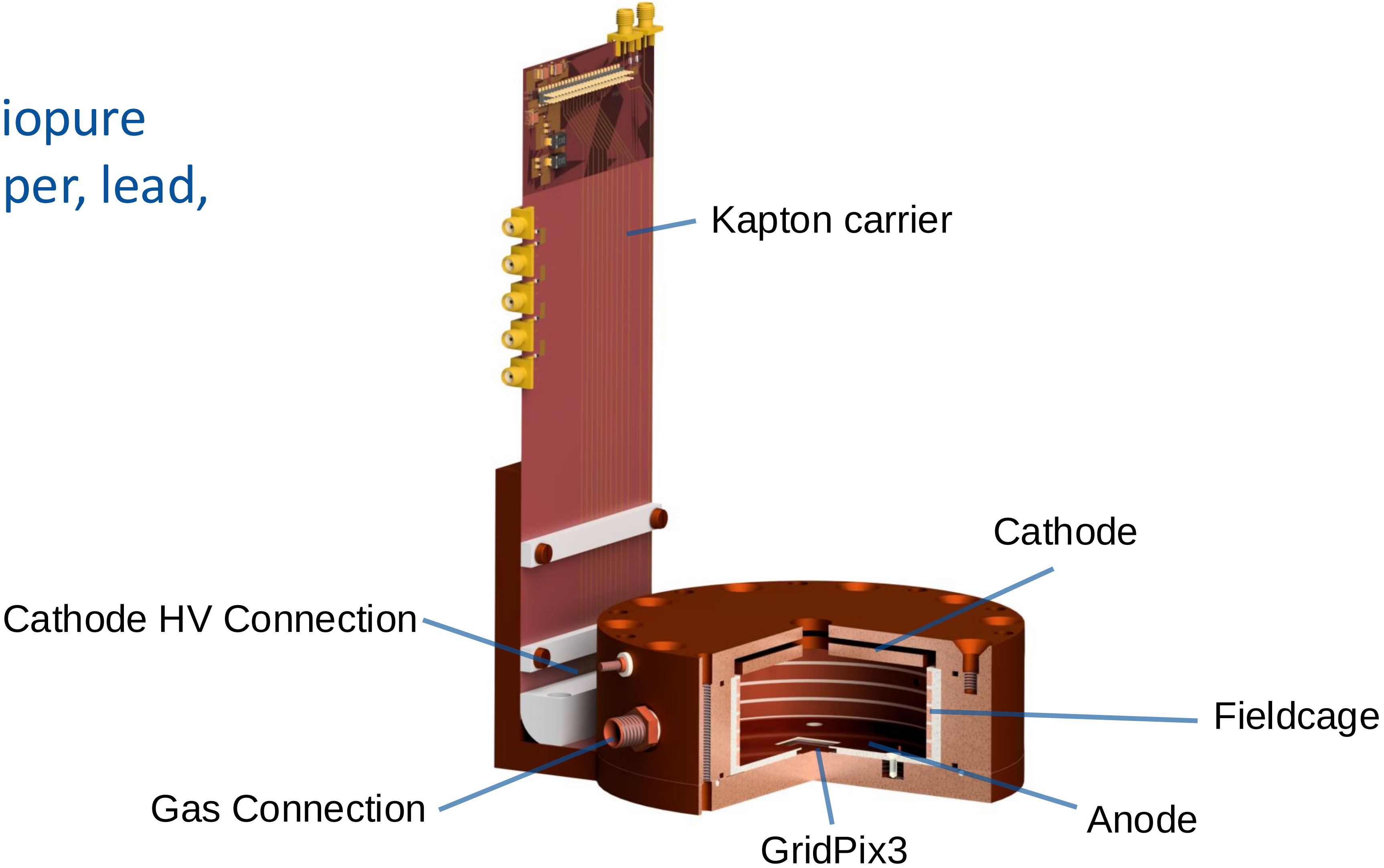
First
GridPix3 Detector

Prototype
IAXO Detector

Radiopure
IAXO Detector

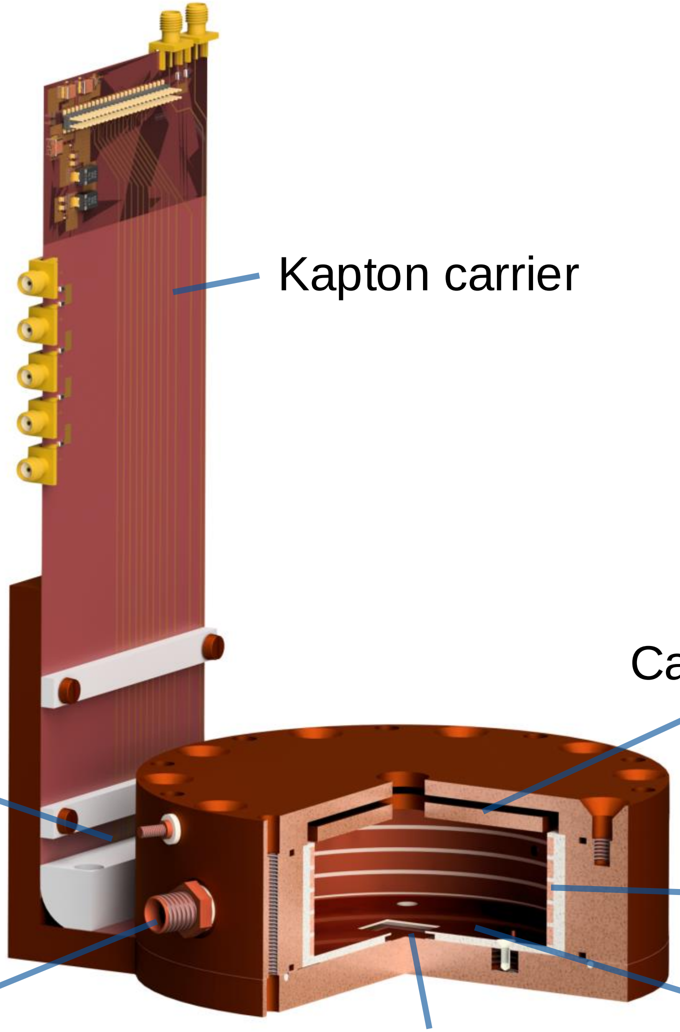
RADIOPURE DETECTOR CONCEPT

- Low signal calls for radiopure materials like pure copper, lead, teflon or kapton



RADIOPURE DETECTOR CONCEPT

- Low signal calls for radiopure materials like pure copper, lead, teflon or kapton
- Move away as many electronic parts as possible



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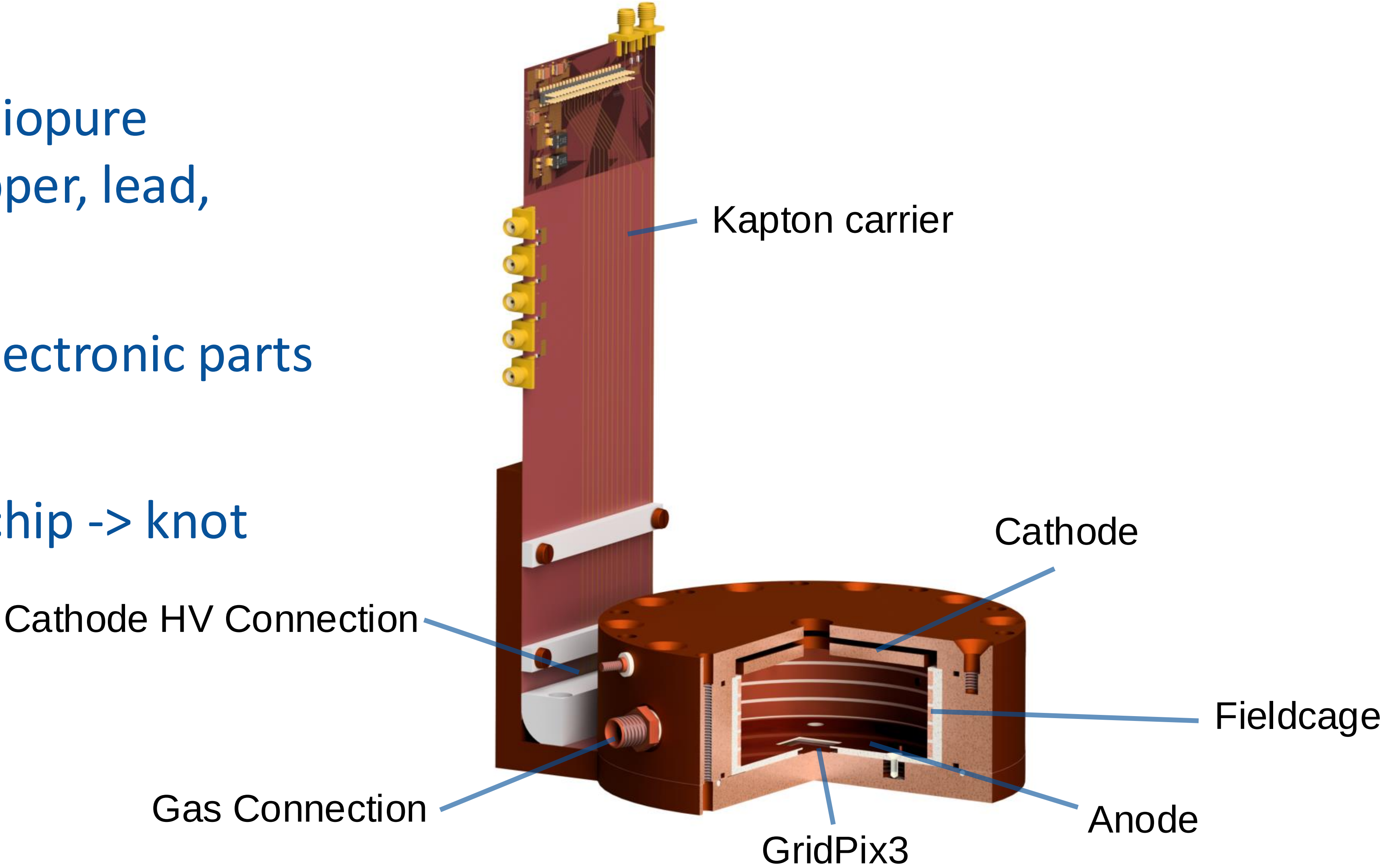
- No soldering close to chip -> knot copper wires



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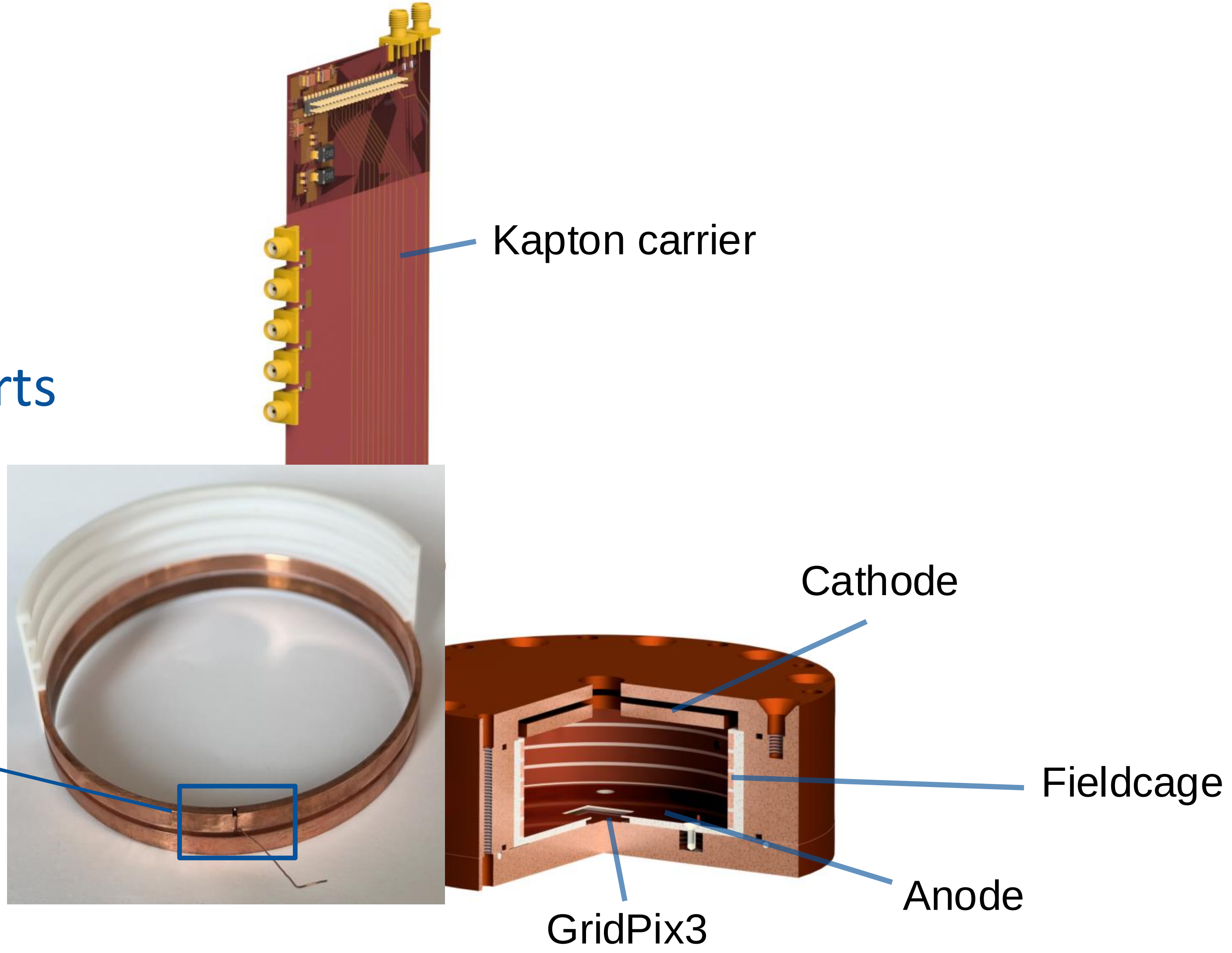
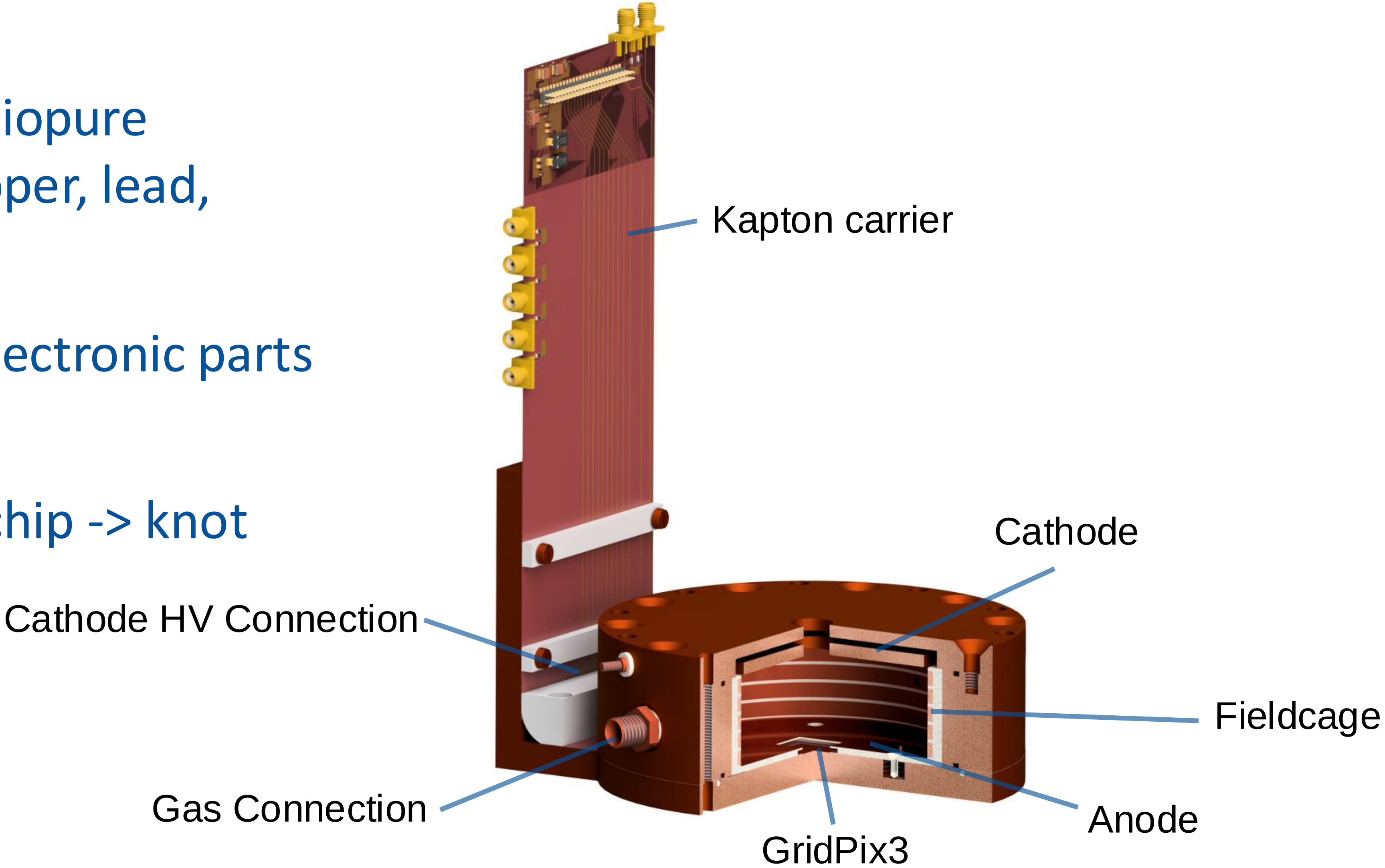


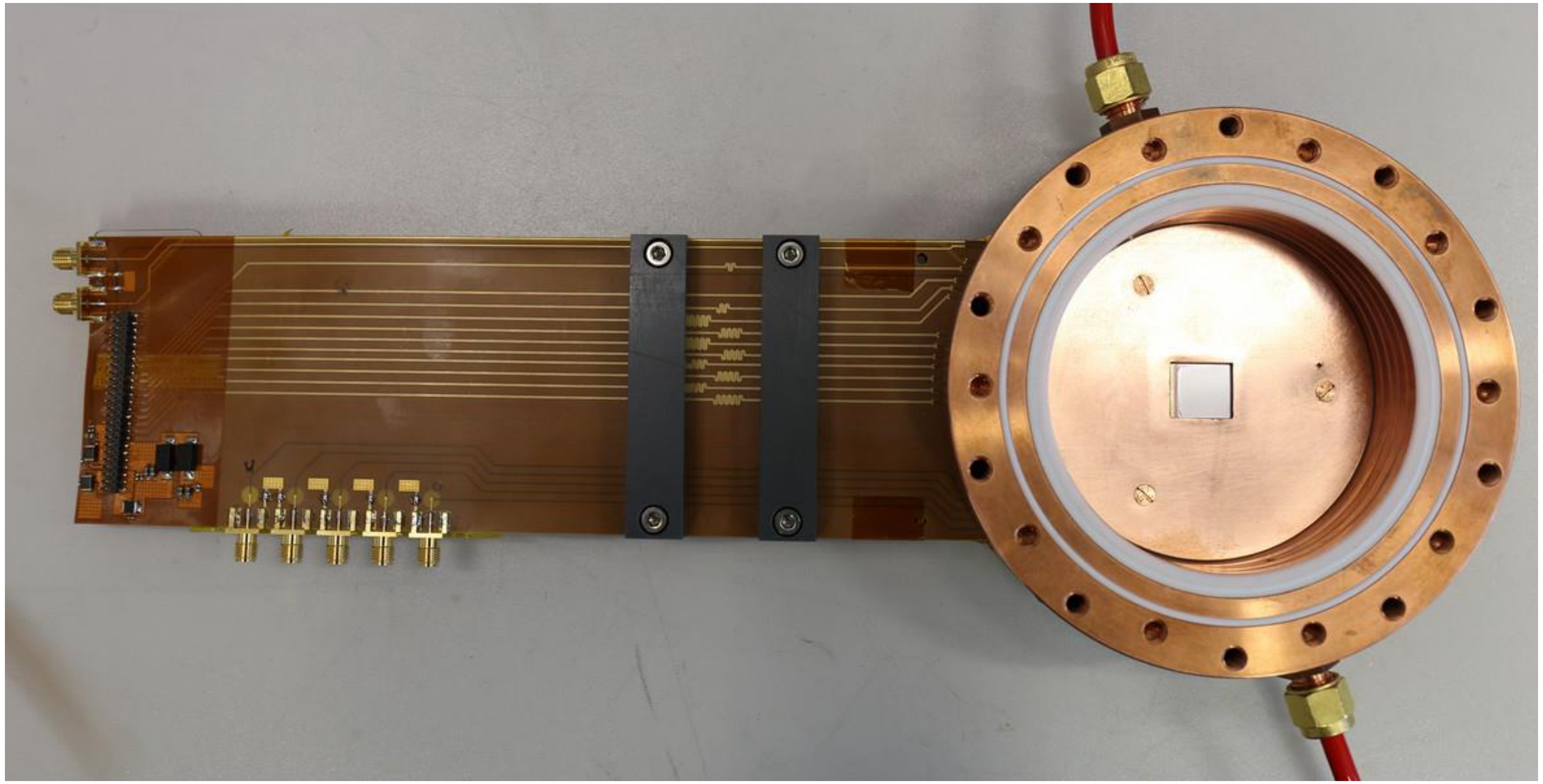
RADIOPURE DETECTOR CONCEPT

- Low signal calls for radiopure materials like pure copper, lead, teflon or kapton
- Move away as many electronic parts as possible
- No soldering close to chip -> knot copper wires
- Clean all pieces before assembly

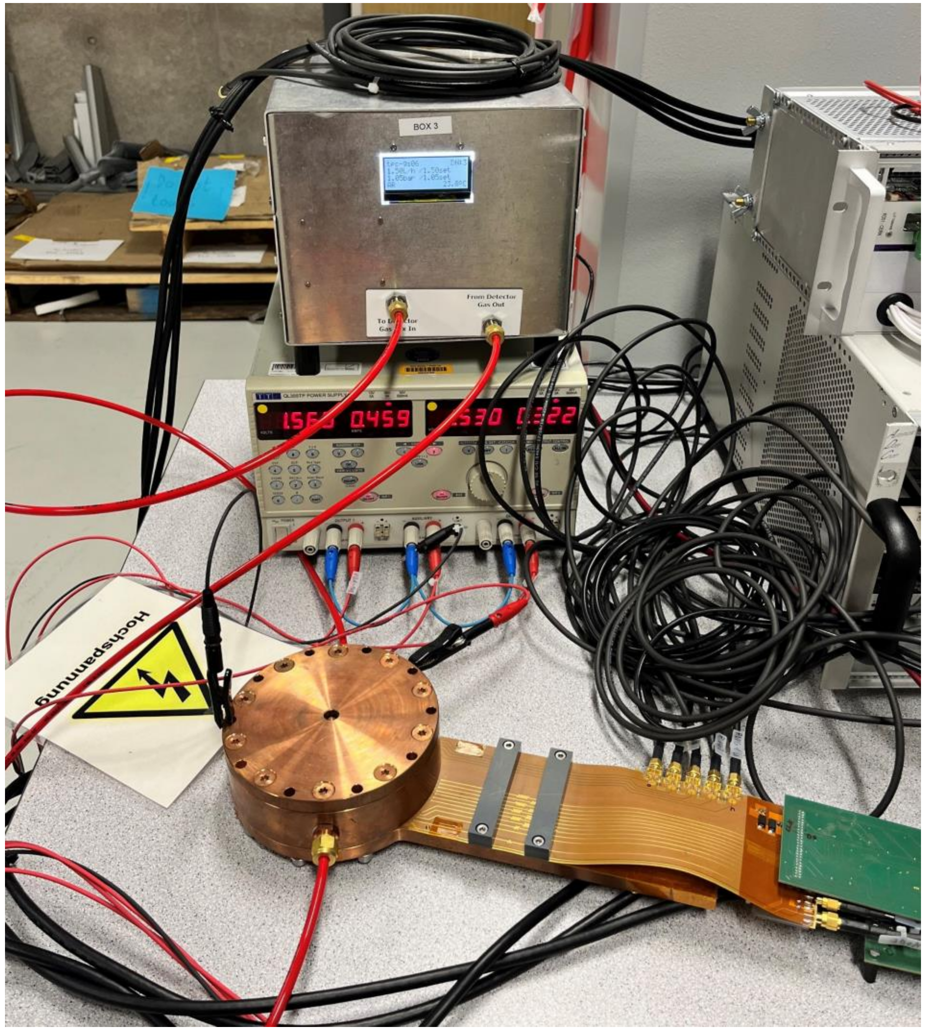


PROTOTYPE IAXO DETECTOR TESTS

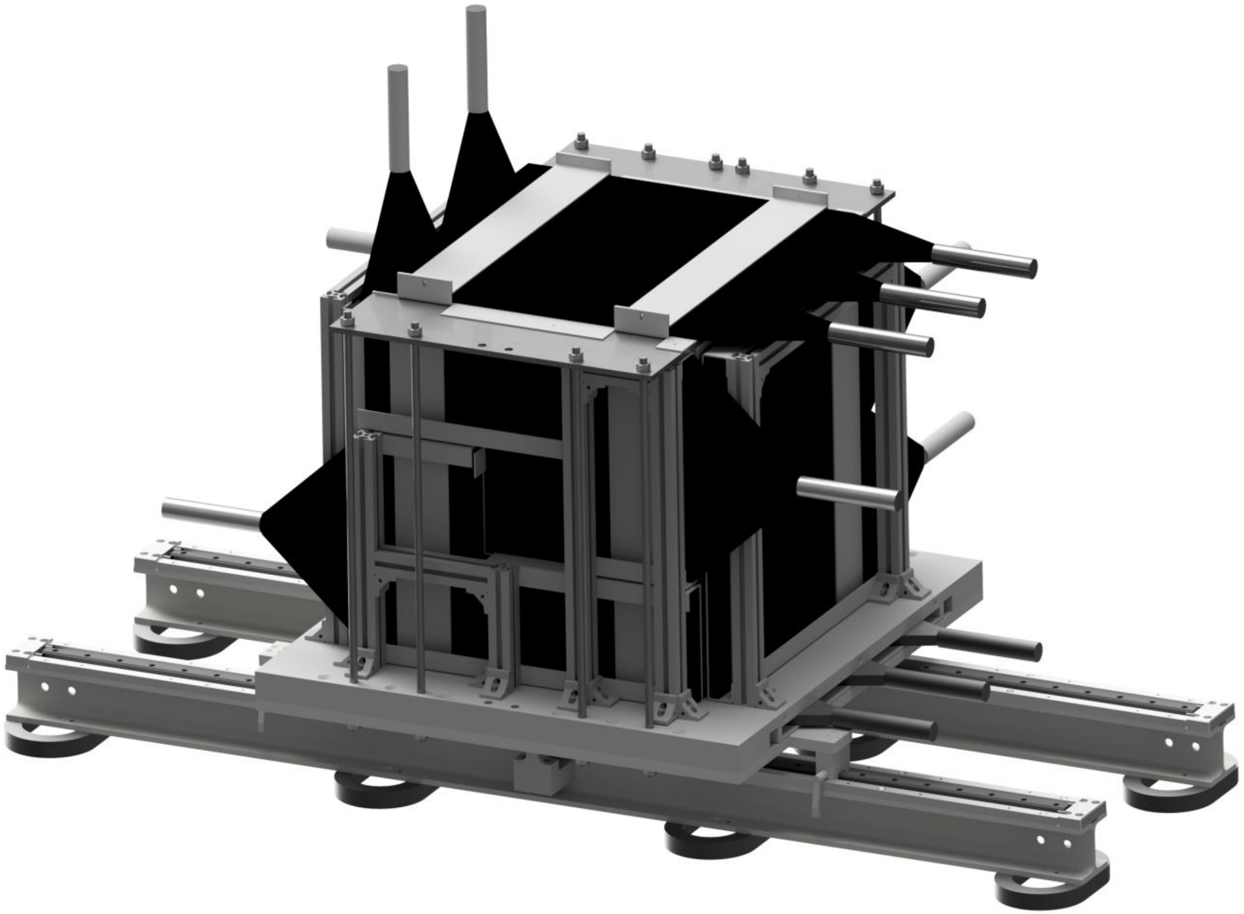
- First prototype out of non-radiopure versions of materials
- Confirm design and assembling
- Background tests at surface level and in underground lab

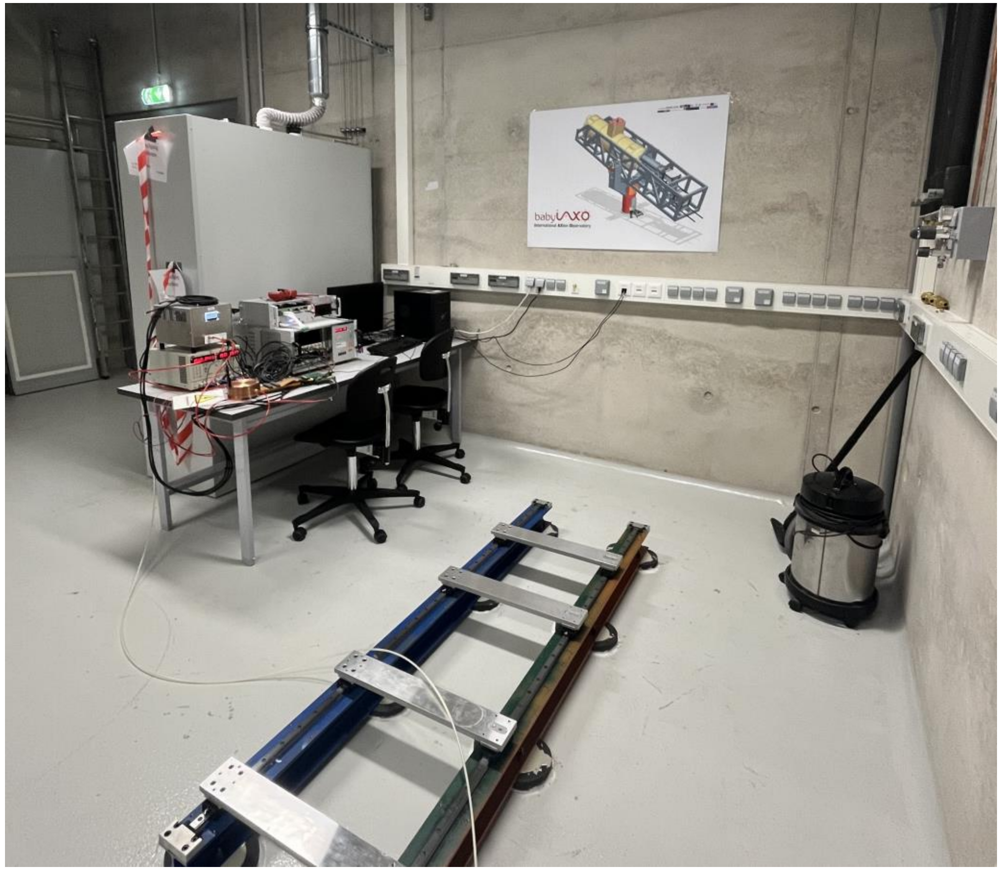


TEST SETUP IN THE UNDERGROUND LAB



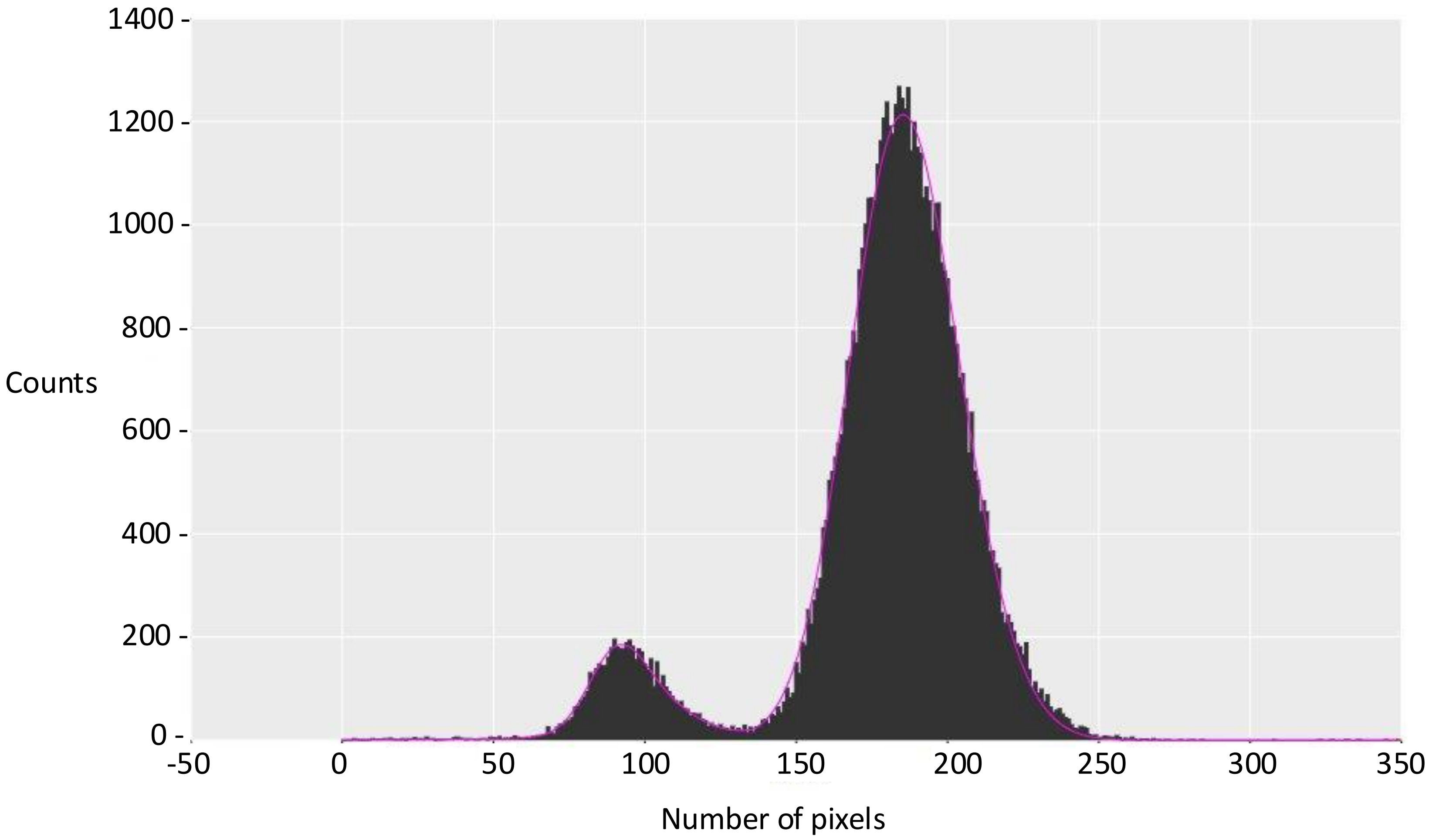
TEST STAND PLANS IN FTD UNDERGROUND LAB



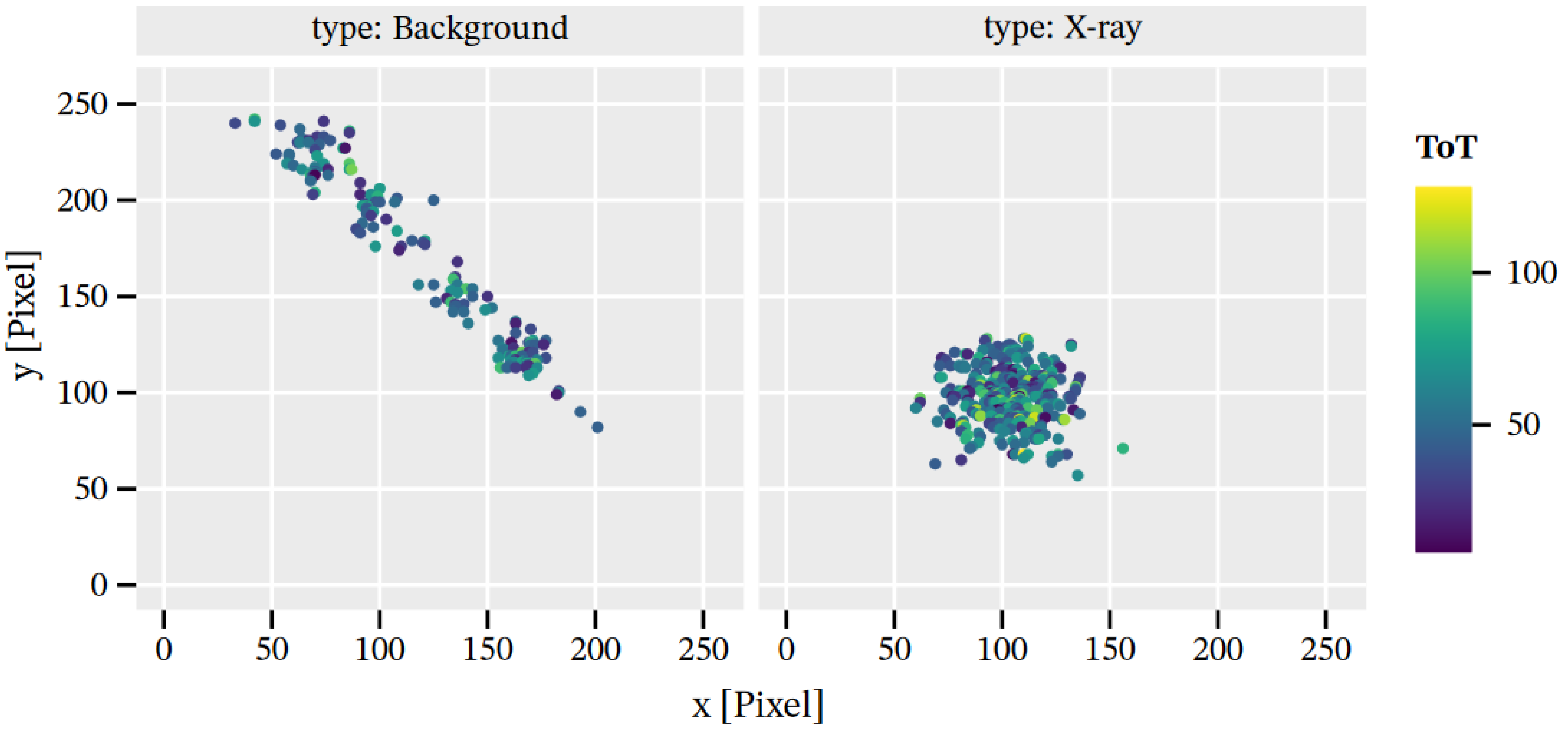


DETECTOR CALIBRATION WITH ^{55}FE

- Data taking for over 1000 h
- Runs with ^{55}Fe source in between background runs
- Shows iron peak as expected around 220 pixels per event



BACKGROUND REDUCTION THROUGH SHAPE



Use likelihood method to cut out clusters that are not signal shaped

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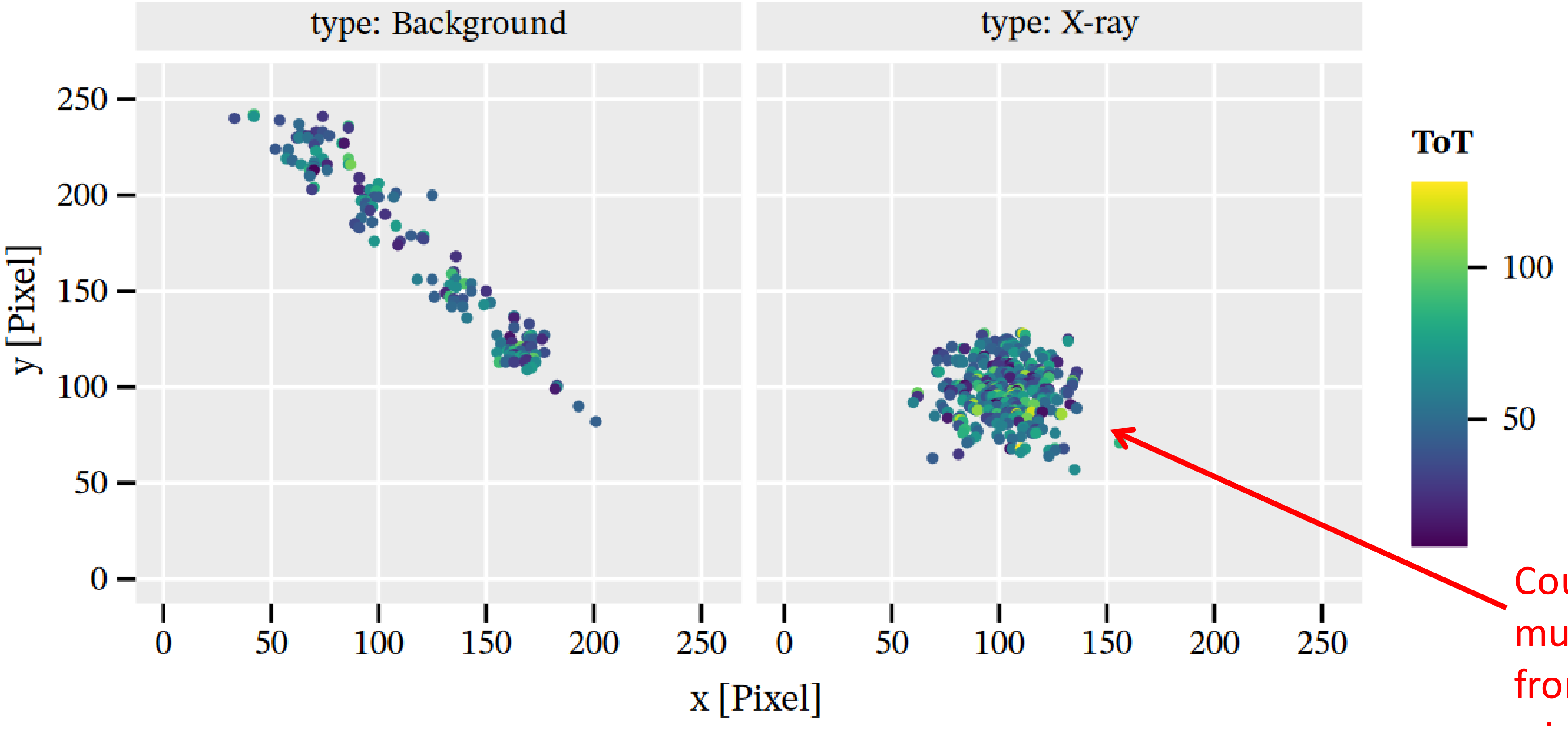
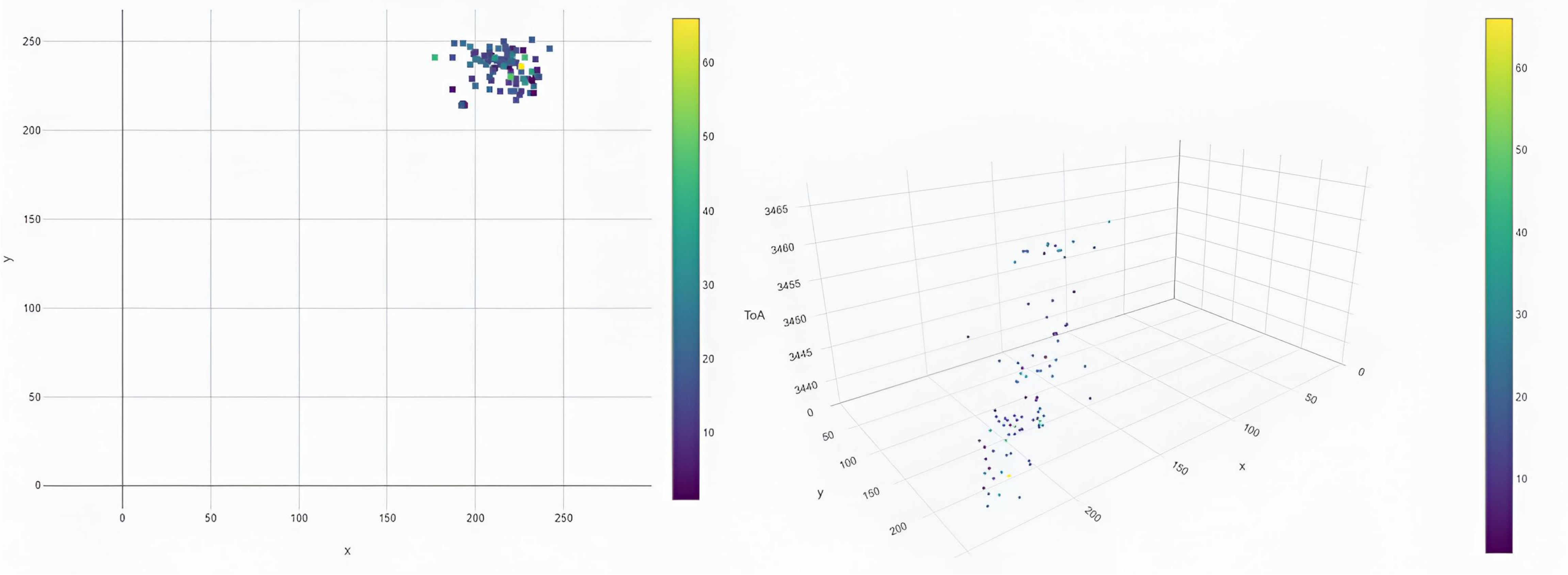


Could also be a muon coming from the window side

Use likelihood method to cut out clusters that are not signal shaped

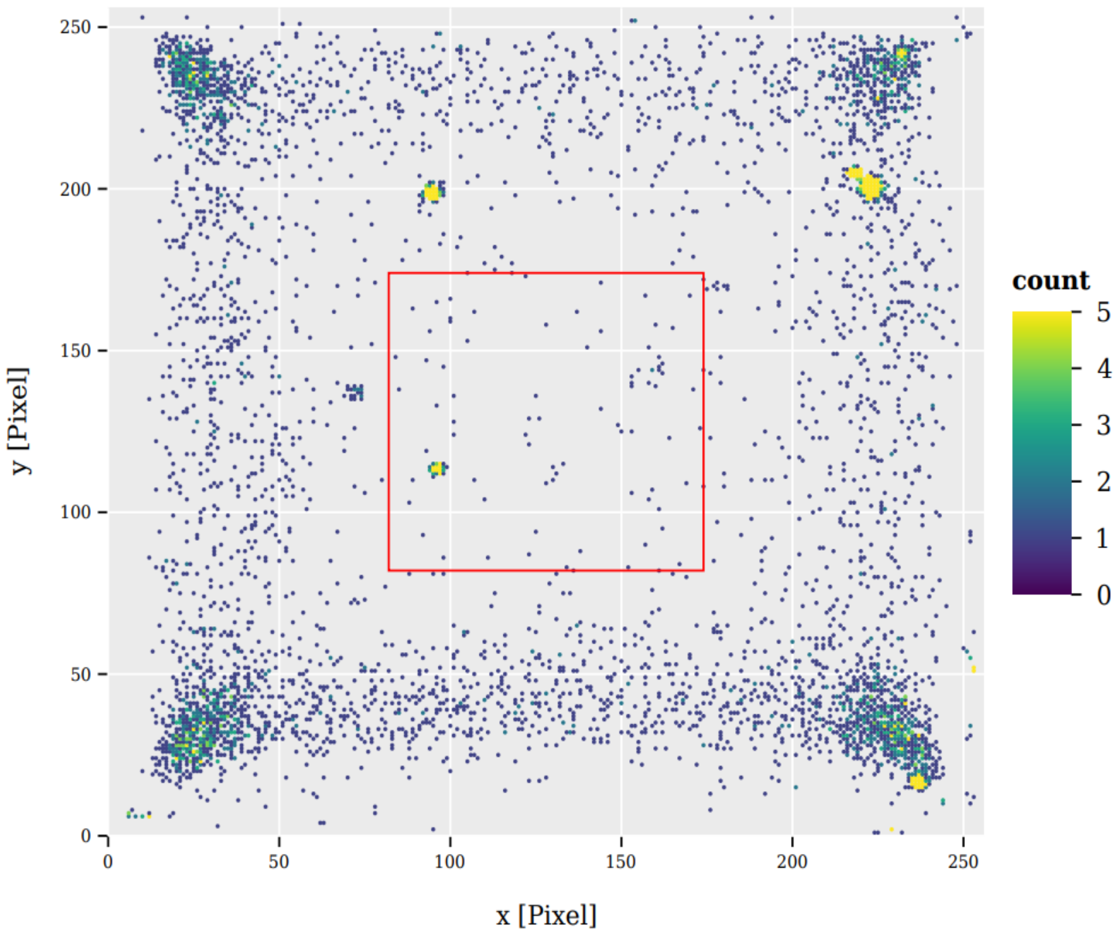
TOA FOR BACKGROUND REDUCTION



New background reduction with Timepix3:
ToA (Time of Arrival) is more spread out for muon events

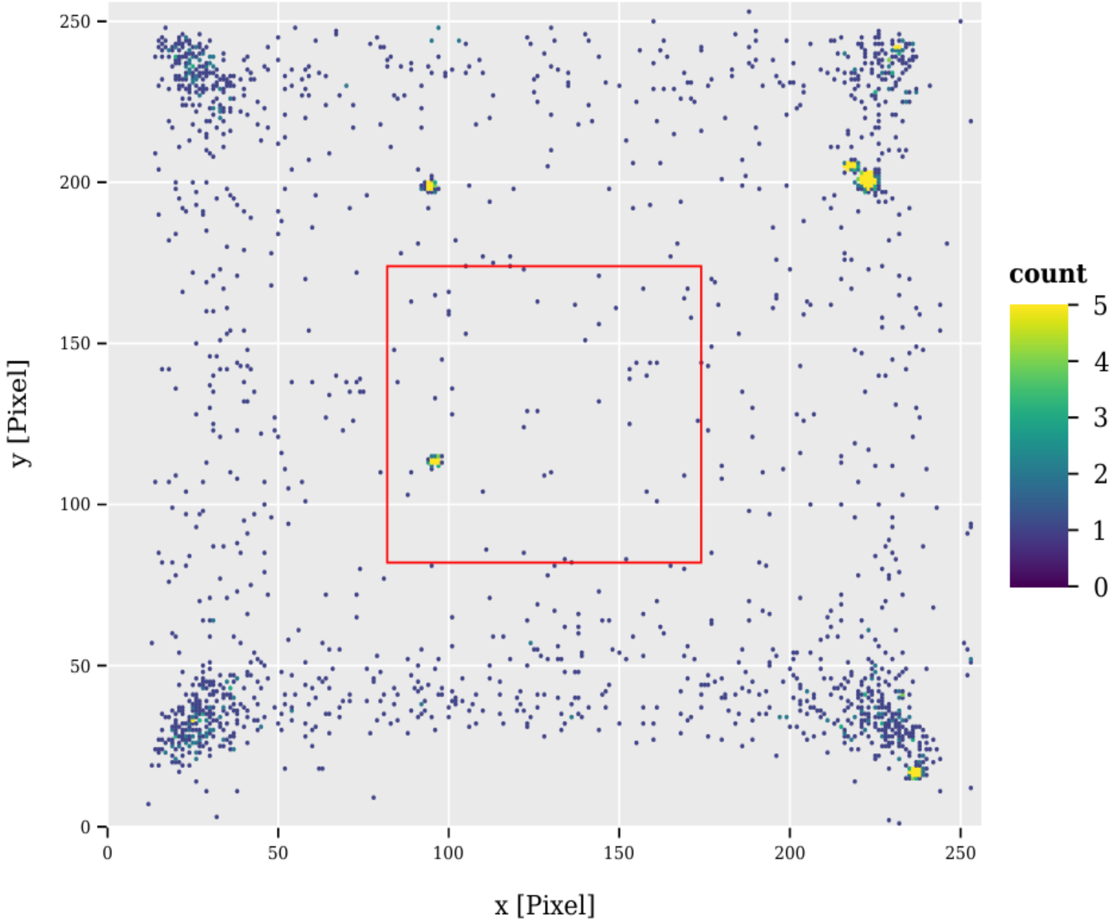
BACKGROUND RUN SPATIAL RESOLUTION

- Centers of round events displayed on the chip dimensions
- Already cut non-round background events
- Defects visible



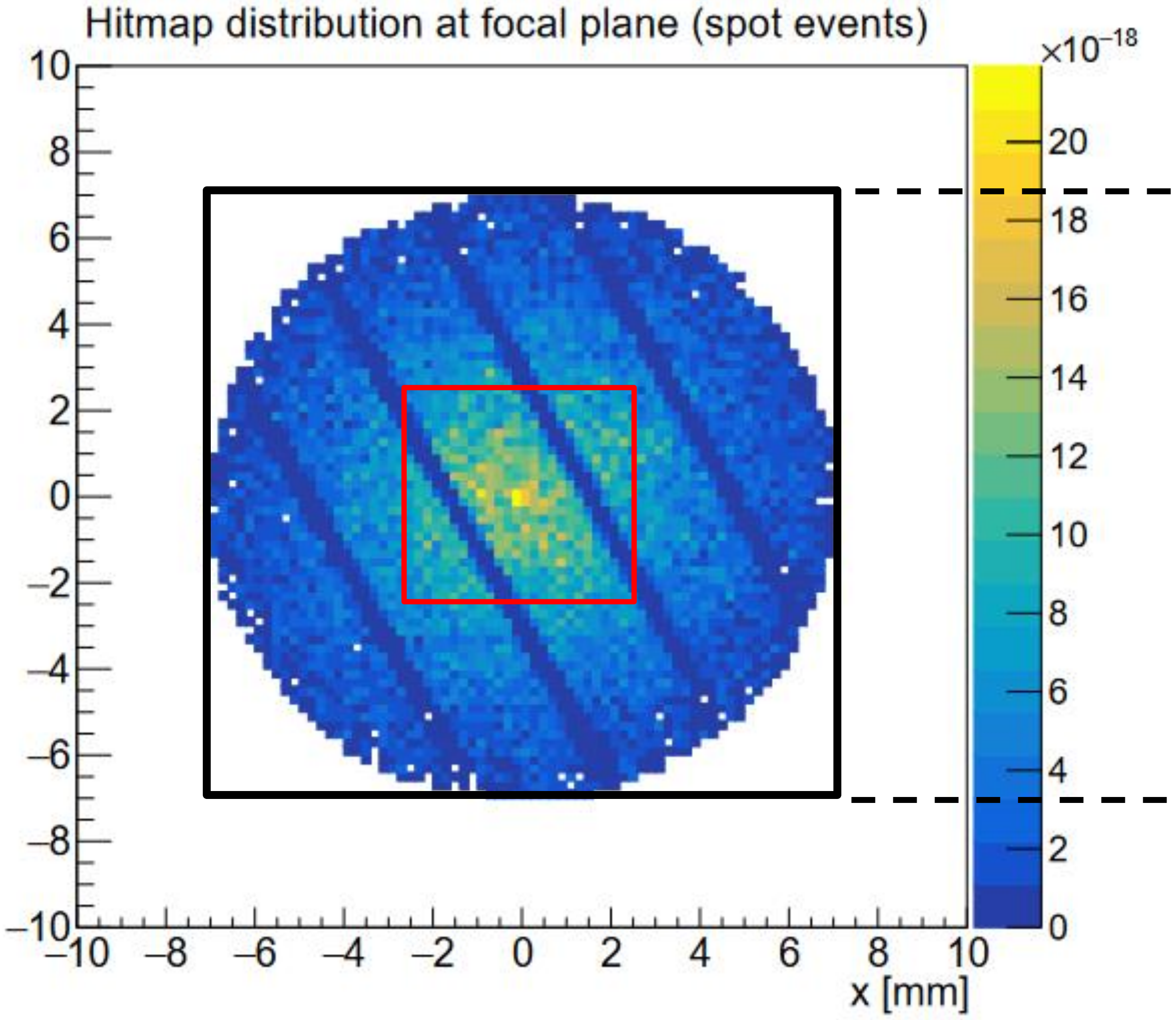
BACKGROUND RUN SPATIAL RESOLUTION TOA

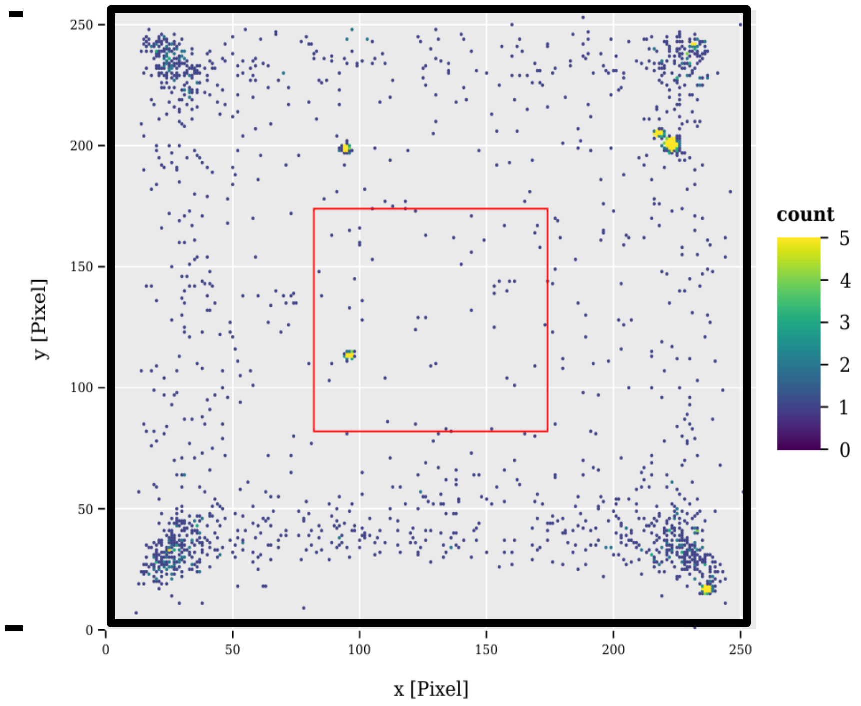
- Centers of round events displayed on the chip dimensions
- Events cut by shape and ToA in likelihood
- Defects visible



BACKGROUND RUN SPATIAL RESOLUTION

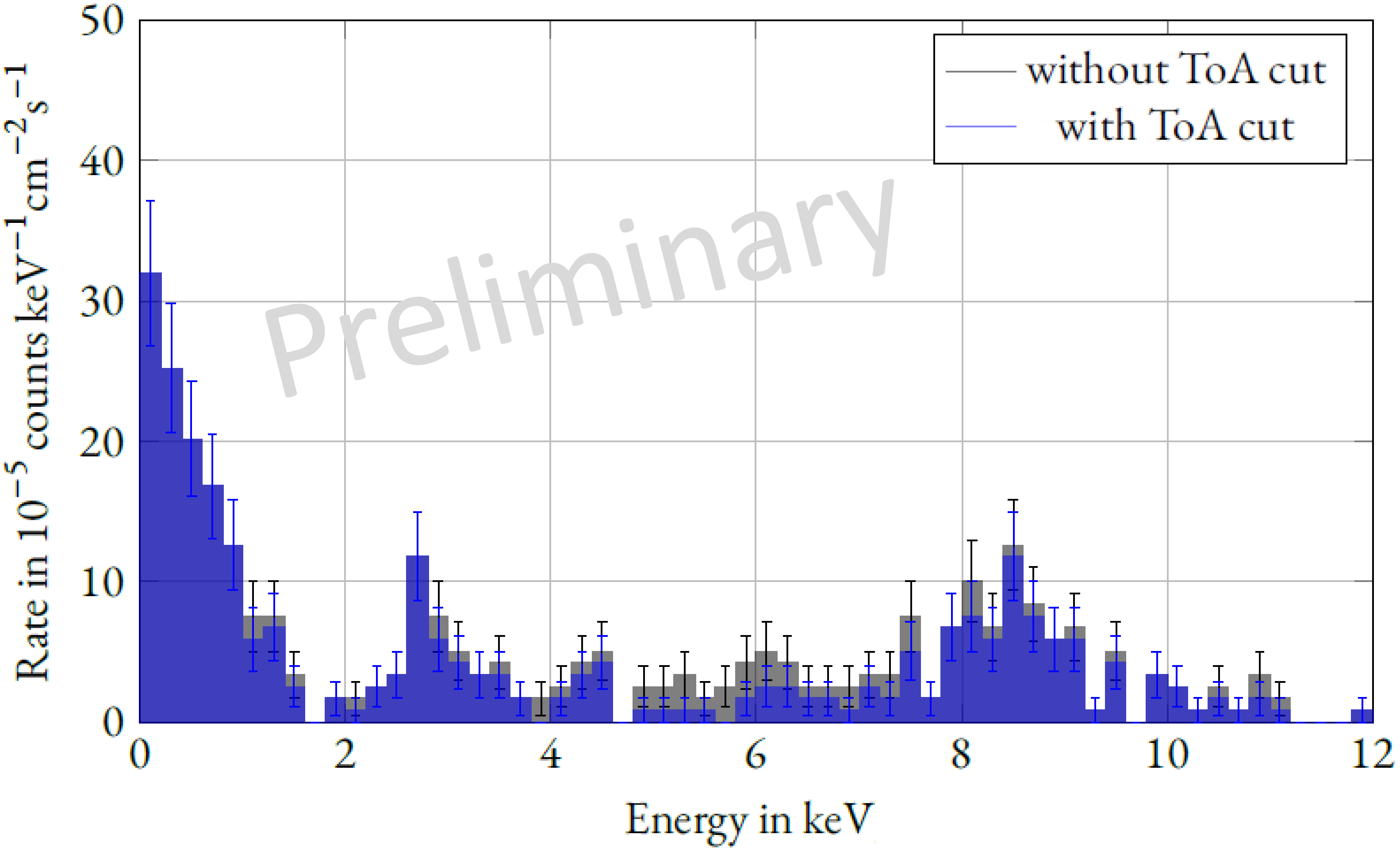
Simulation: Primakoff, XMM, GridPix with REST v2.4.1





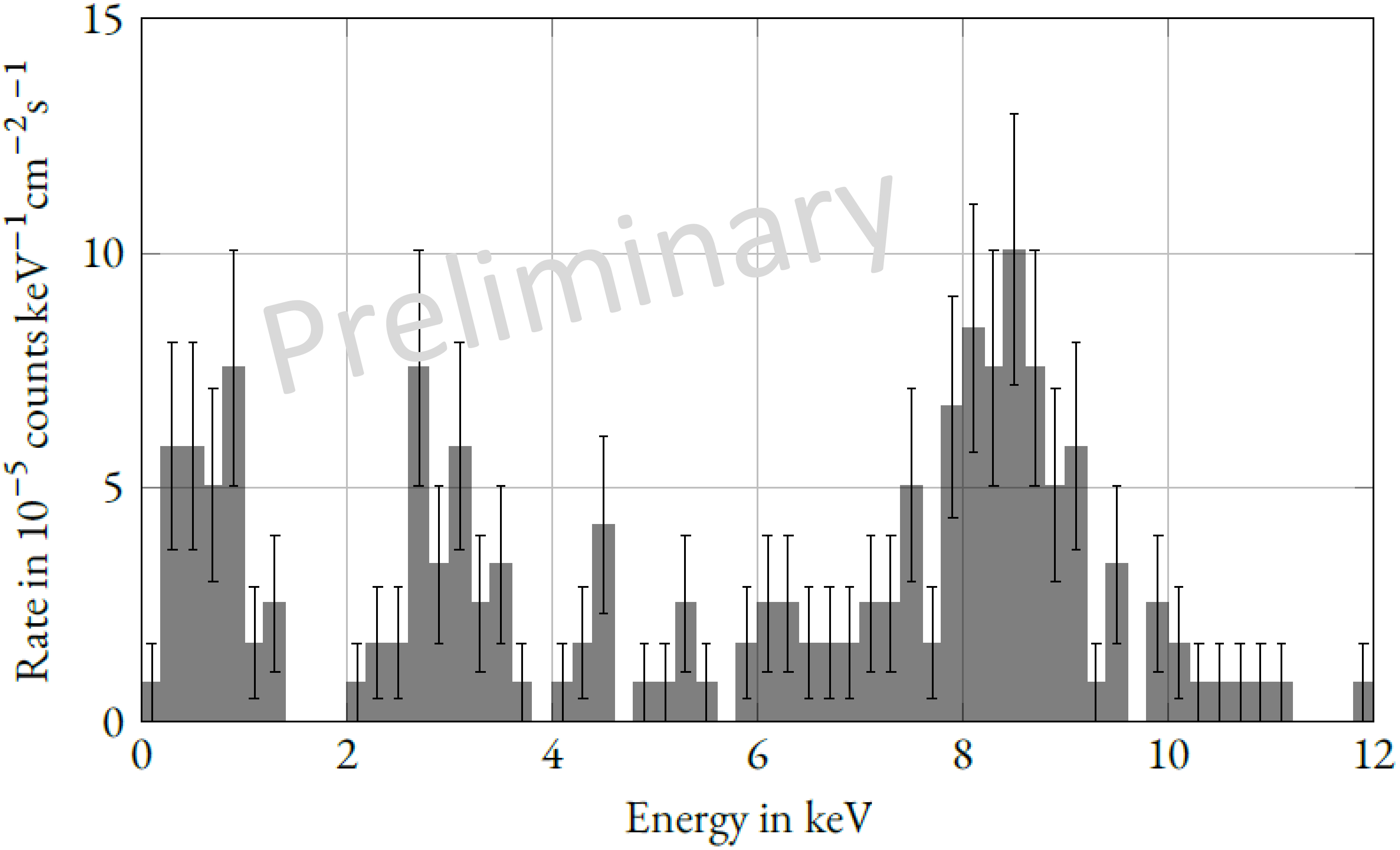
SURFACE LEVEL BACKGROUND RATE

- Background rate with simulation as calibration
- Simple cut on ToA length already reduces background
- Goal for BabyIAXO: $< 10^{-7}\ keV^{-1}cm^{-2}s^{-1}$

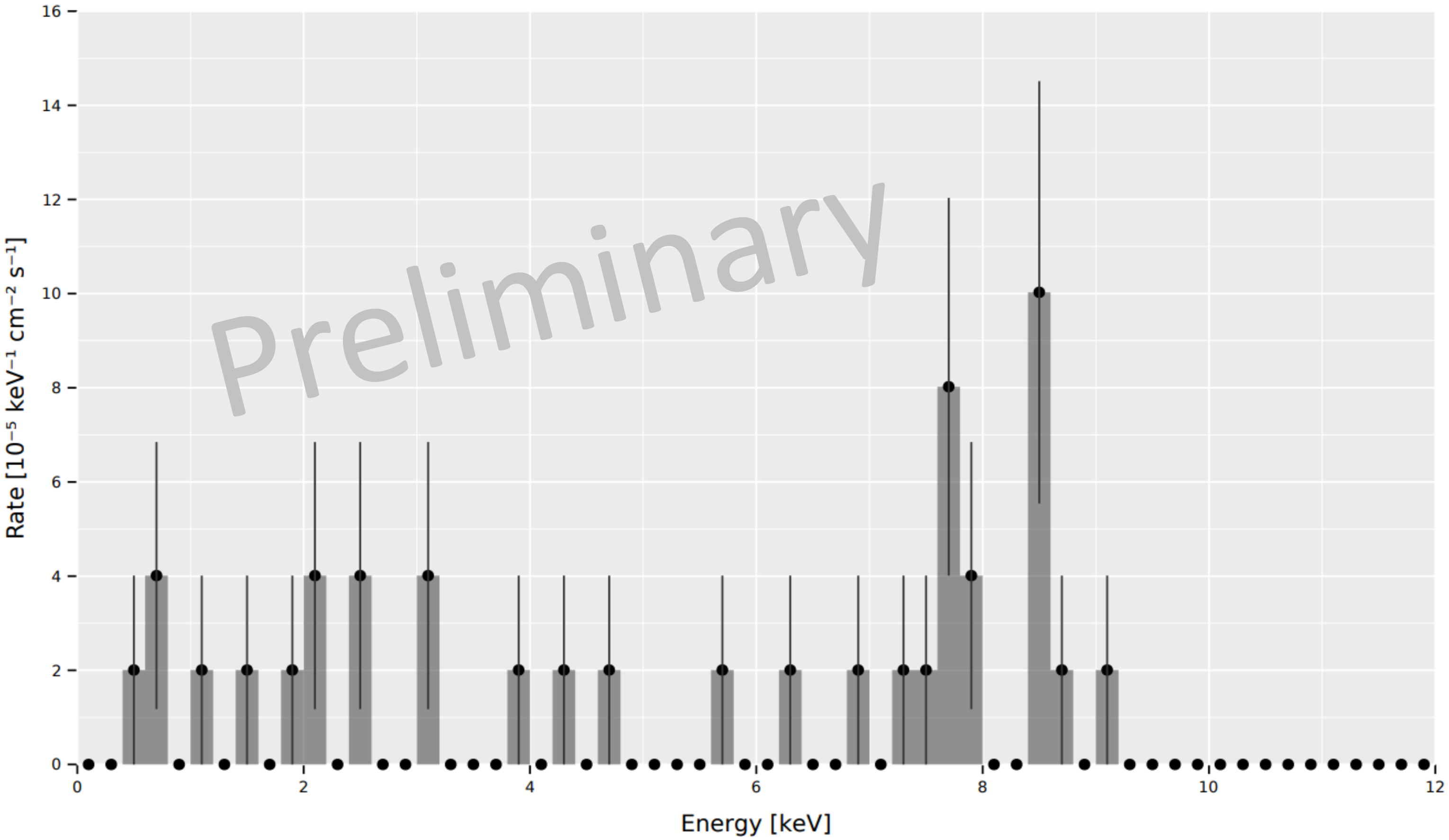


SURFACE LEVEL BACKGROUND RATE

- More background reduction through ToA in likelihood
- Goal for BabyIAXO: $< 10^{-7}\ keV^{-1}cm^{-2}s^{-1}$

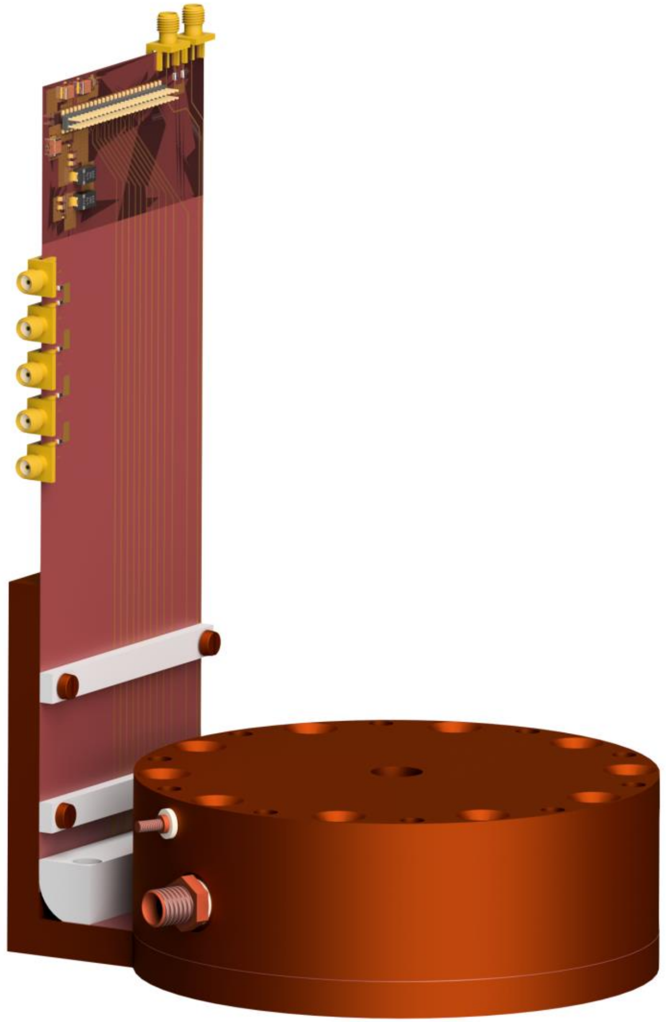


UNDERGROUND LAB BACKGROUND RATE



CONCLUSION AND OUTLOOK

- Axion detection challenges approached with a GridPix detector with:
  - Radiopure materials
  - Ultra thin windows



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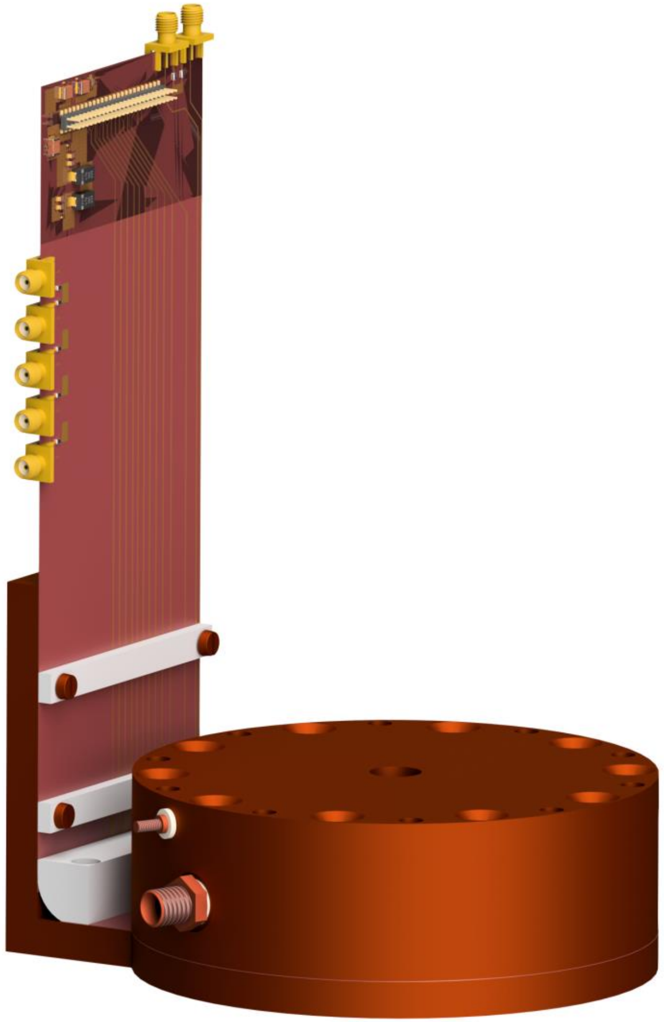

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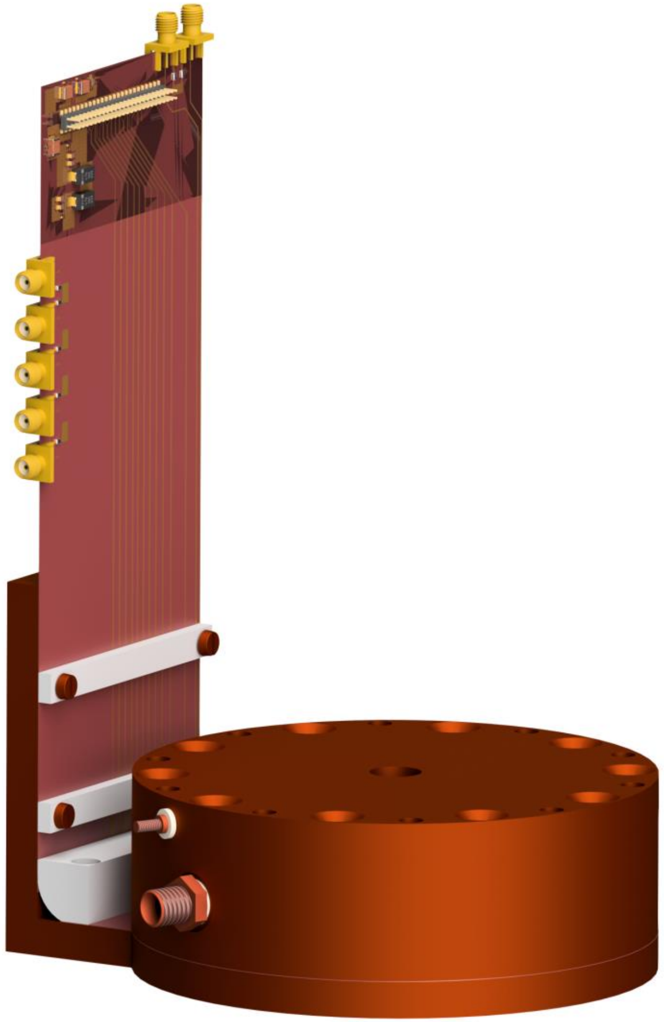

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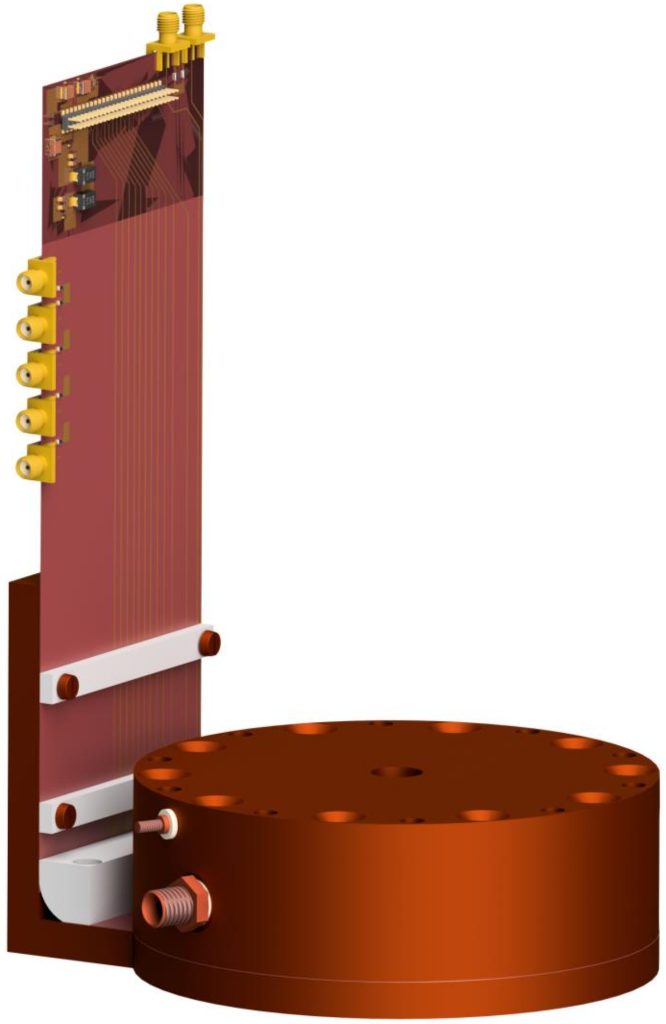
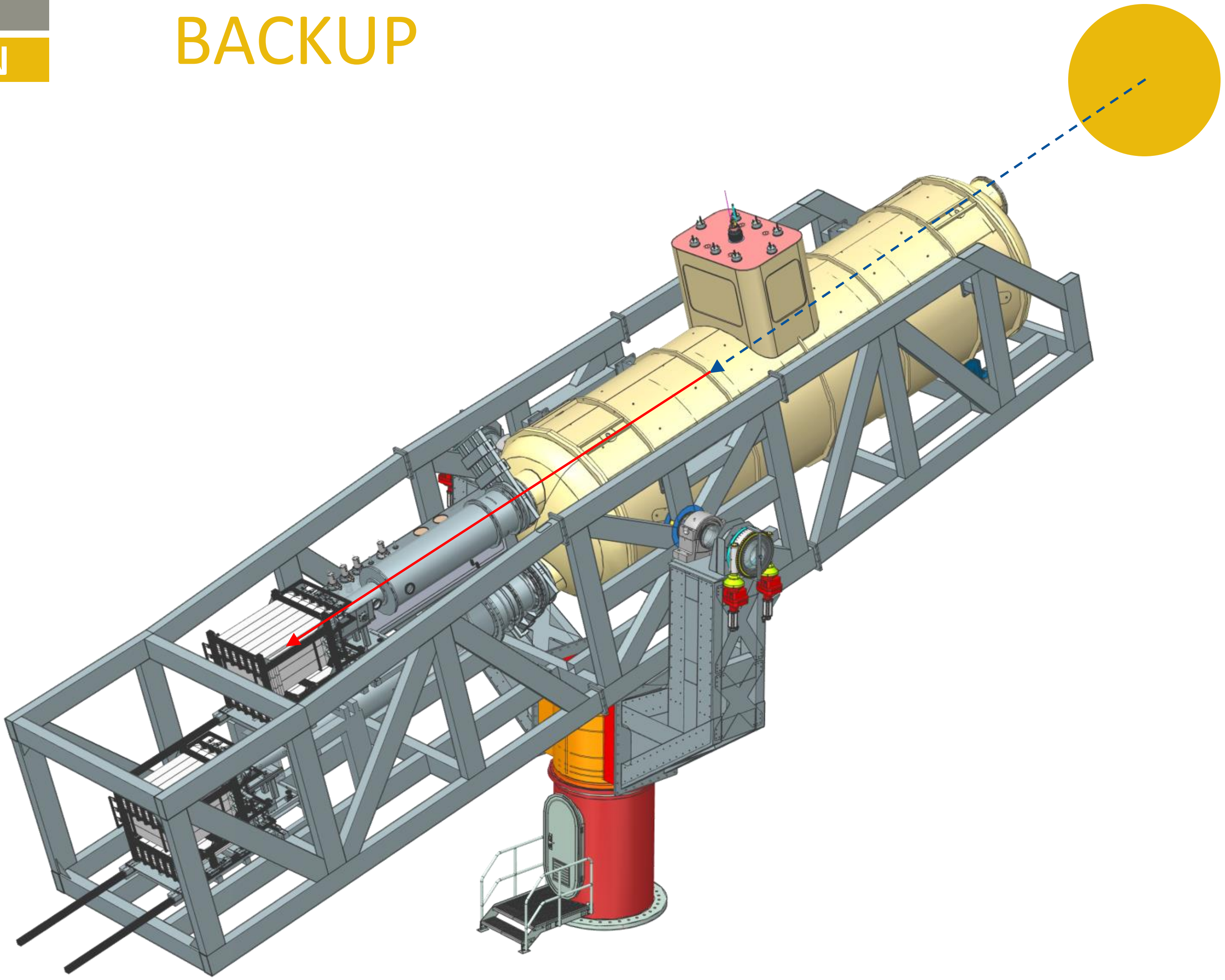
- Build second detector from radiopure Cu-OFE and PTFE and test stand in Bonn



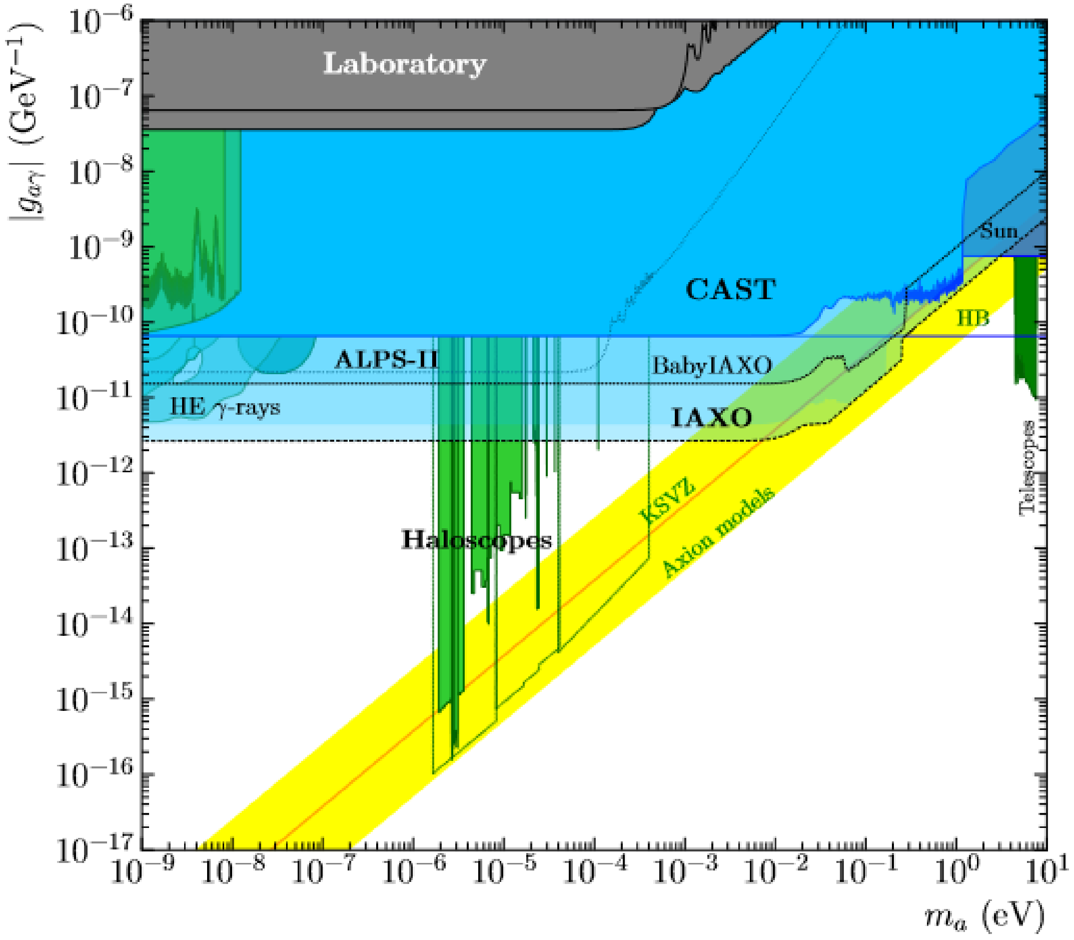
UNIVERSITÄT BONN

BACKUP



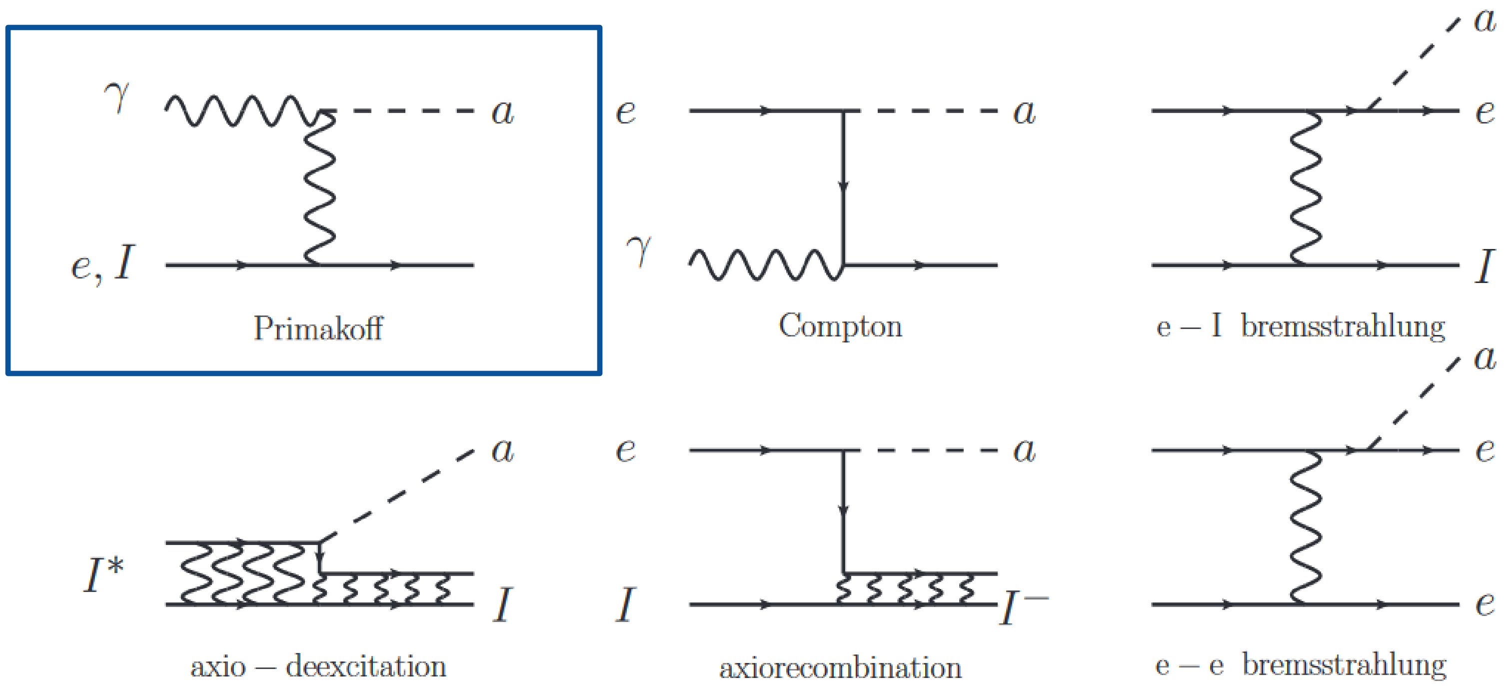
THE AXION

- Motivated by being able to solve the strong CP problem:
  - ➢ CP violation is not observed in strong interactions
- Candidate for light dark matter
- Weakly interacting due to small coupling strengths



IAXO collaboration 2020, arXiv:2010.12076

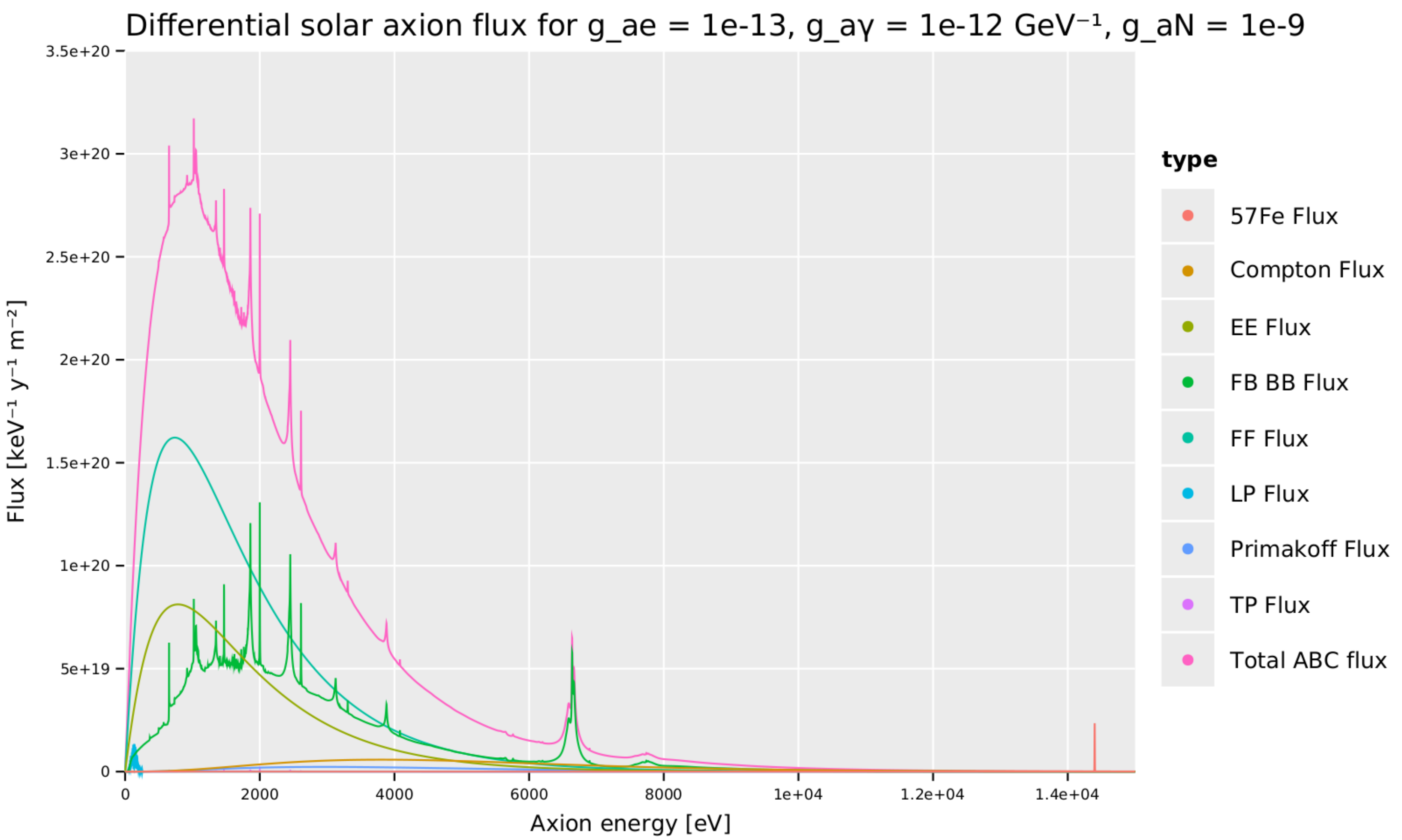
OTHER AXION COUPLING MECHANISMS



- Other production mechanisms similar to SM processes are possible
- Different mechanisms influence the expected axion spectrum

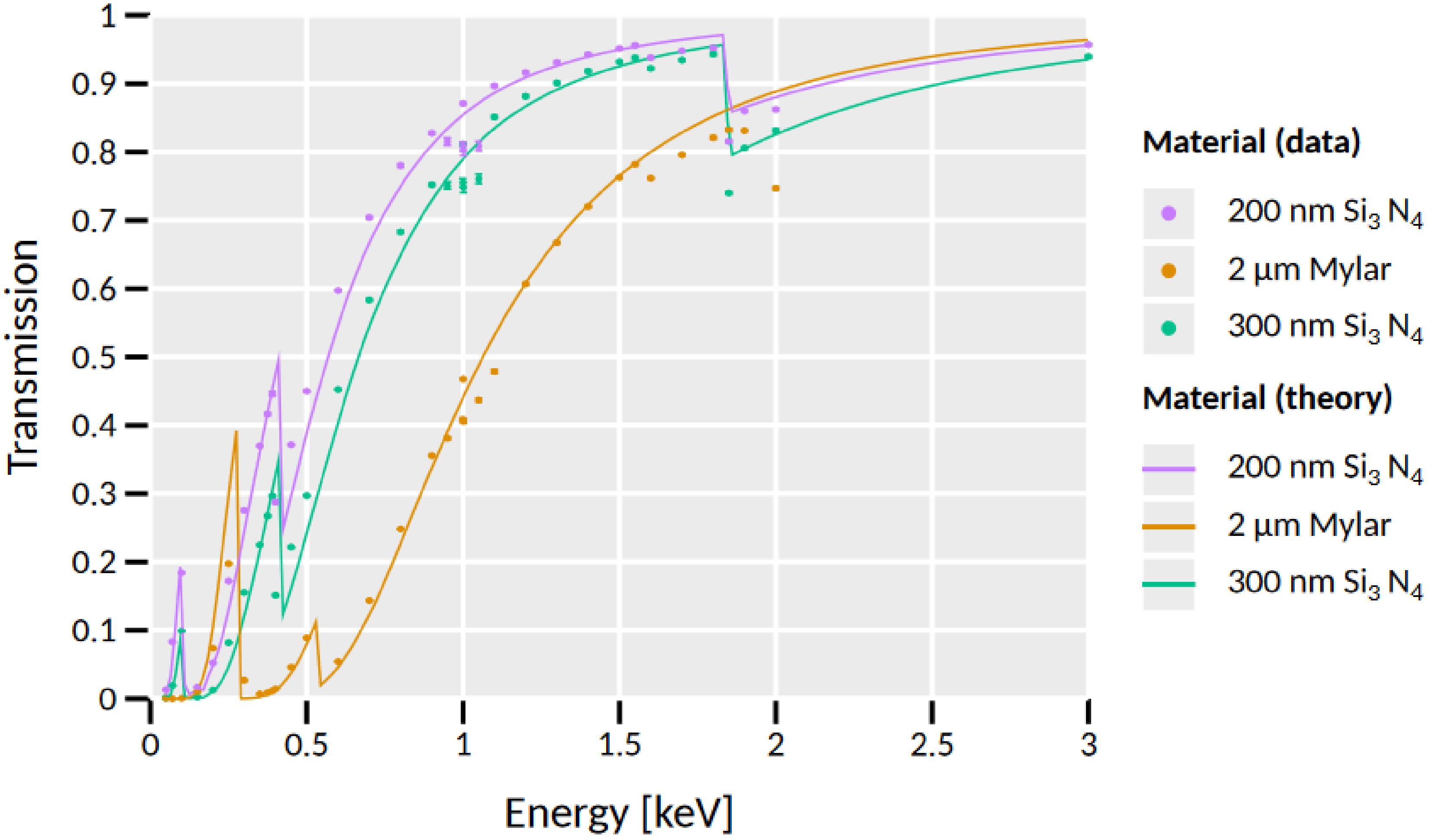
THE AXION ENERGY SPECTRUM

- Coupling strengths $g_{a\gamma}$, g_{ae} and g_{aN} depend on axion model
- After inverse Primakoff: photons inherit energy spectrum



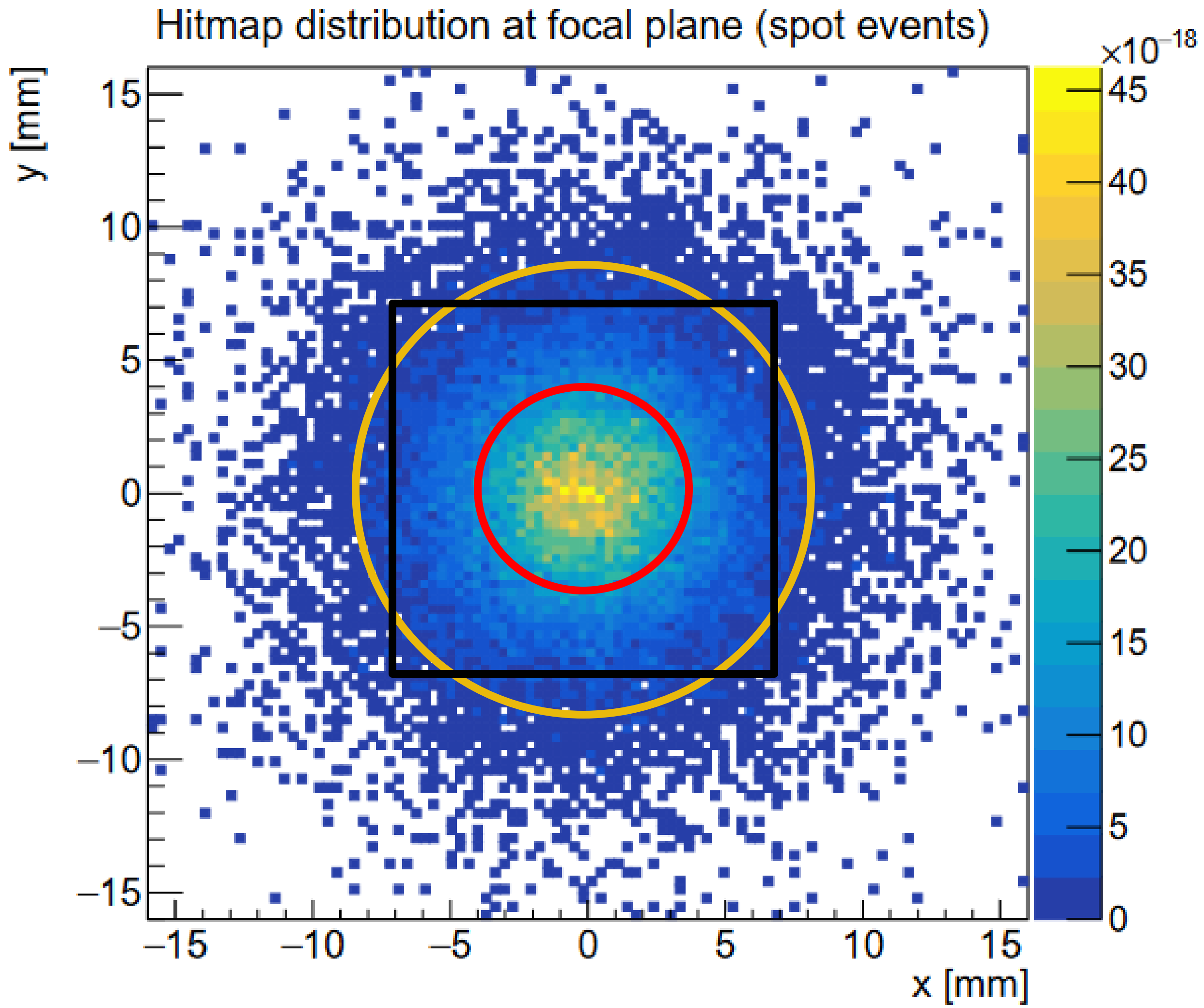
DETECTOR PRINCIPLE – ULTRA THIN WINDOWS

Window measurements at SOLEIL



FOCAL DISTRIBUTION BEFORE WINDOW

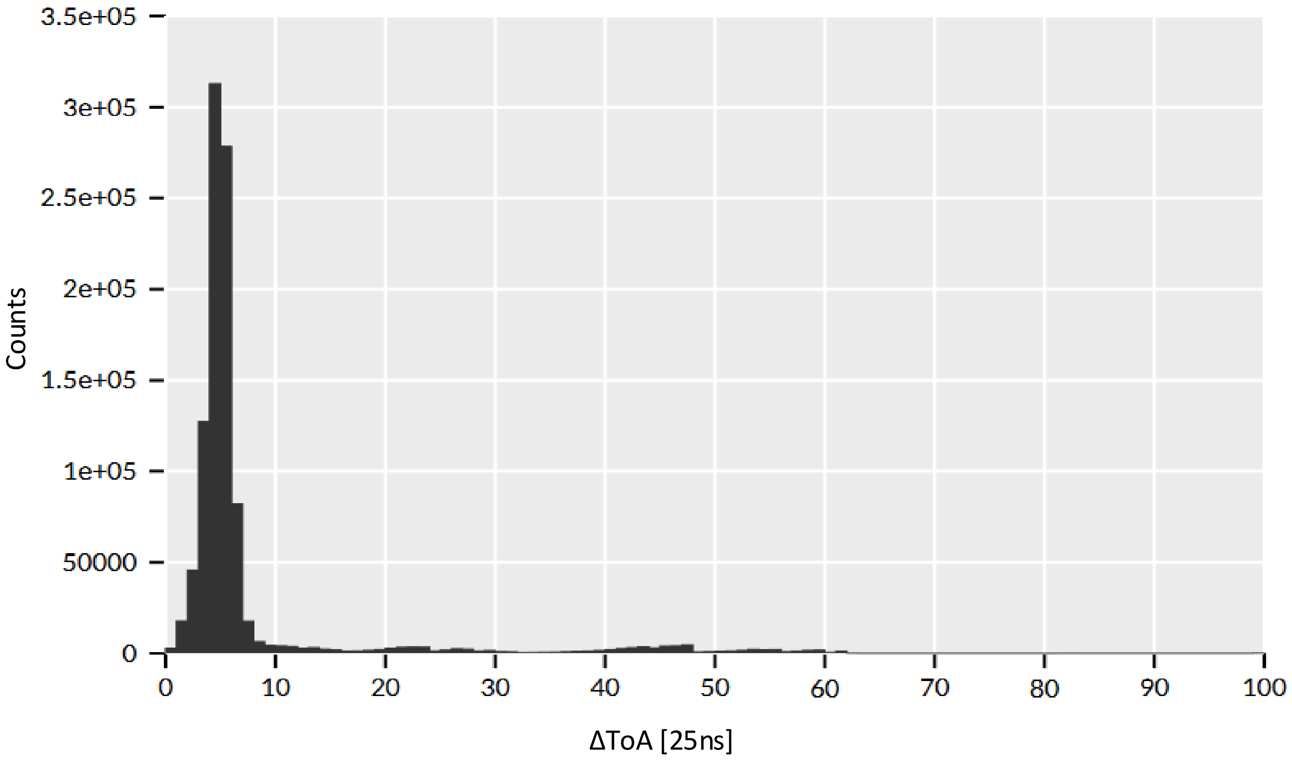
Simulation: Primakoff, XMM with REST v2.4.1



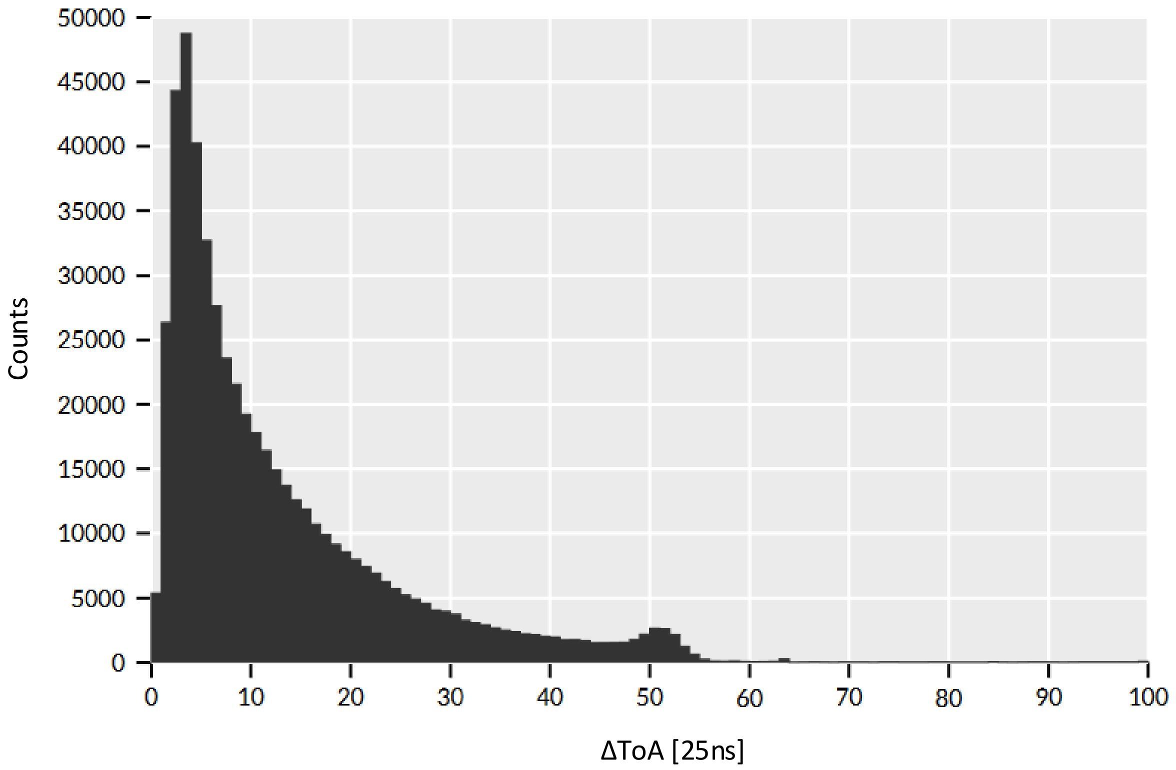
- Red: HEW=7.83mm
- Yellow: W90=16.83mm
- Black: Timepix3 chip size

ΔTOA OF ^{55}FE EVENTS VS BACKGROUND

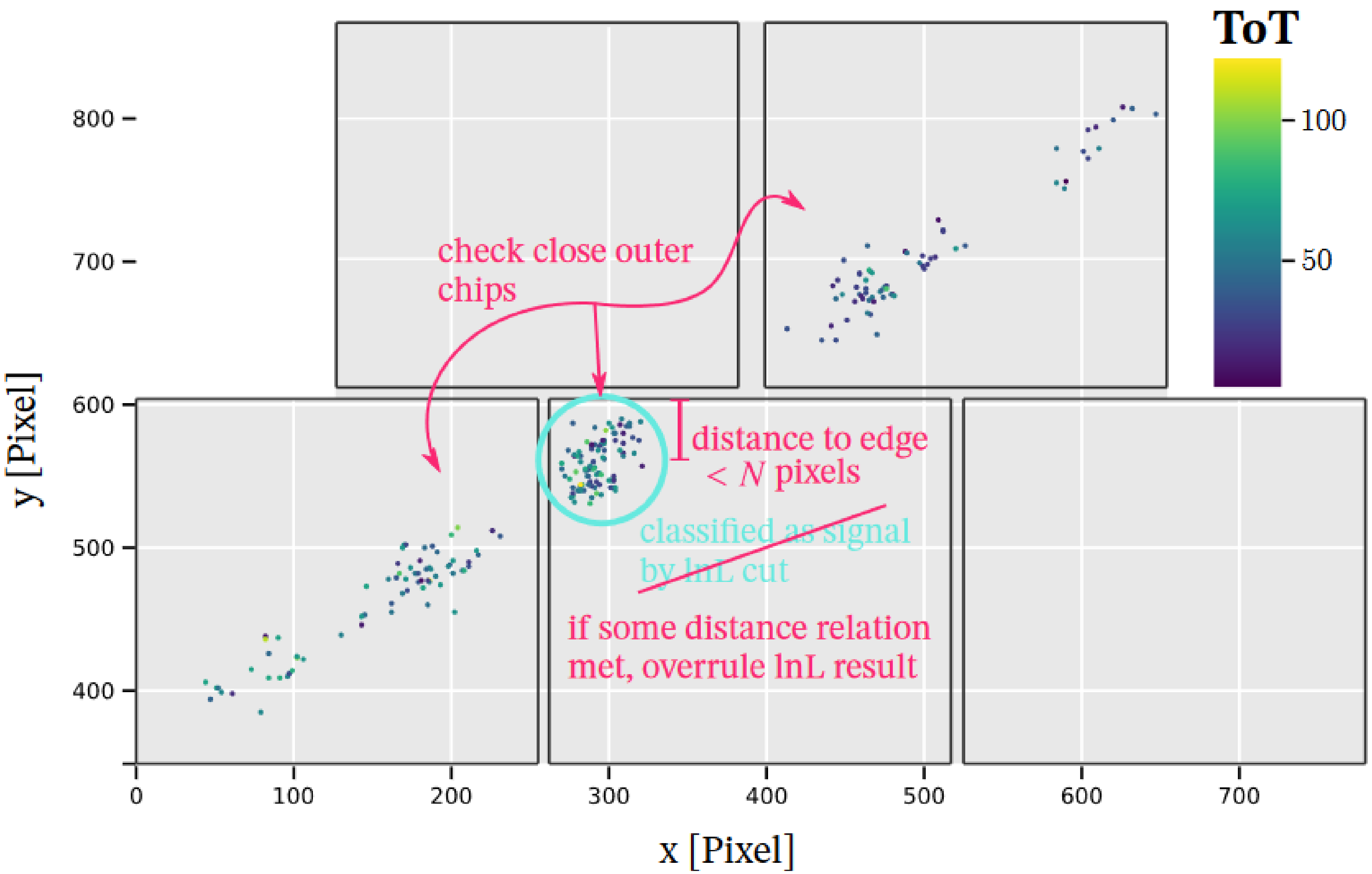
^{55}Fe

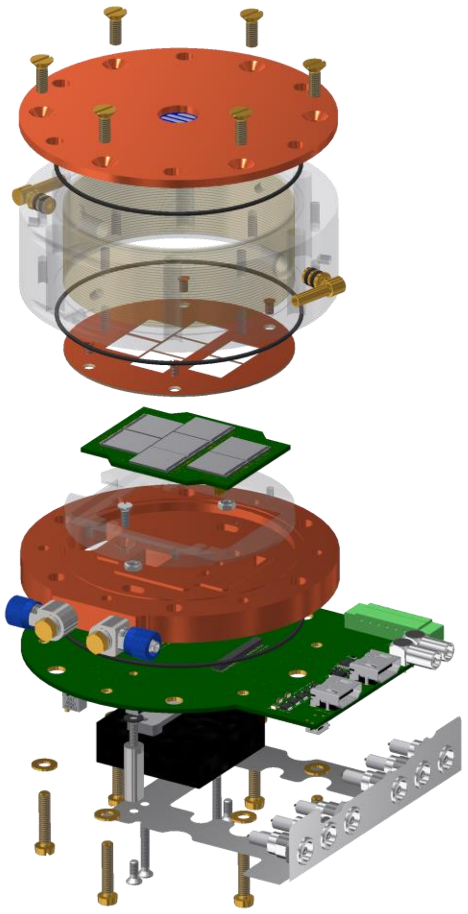


Background



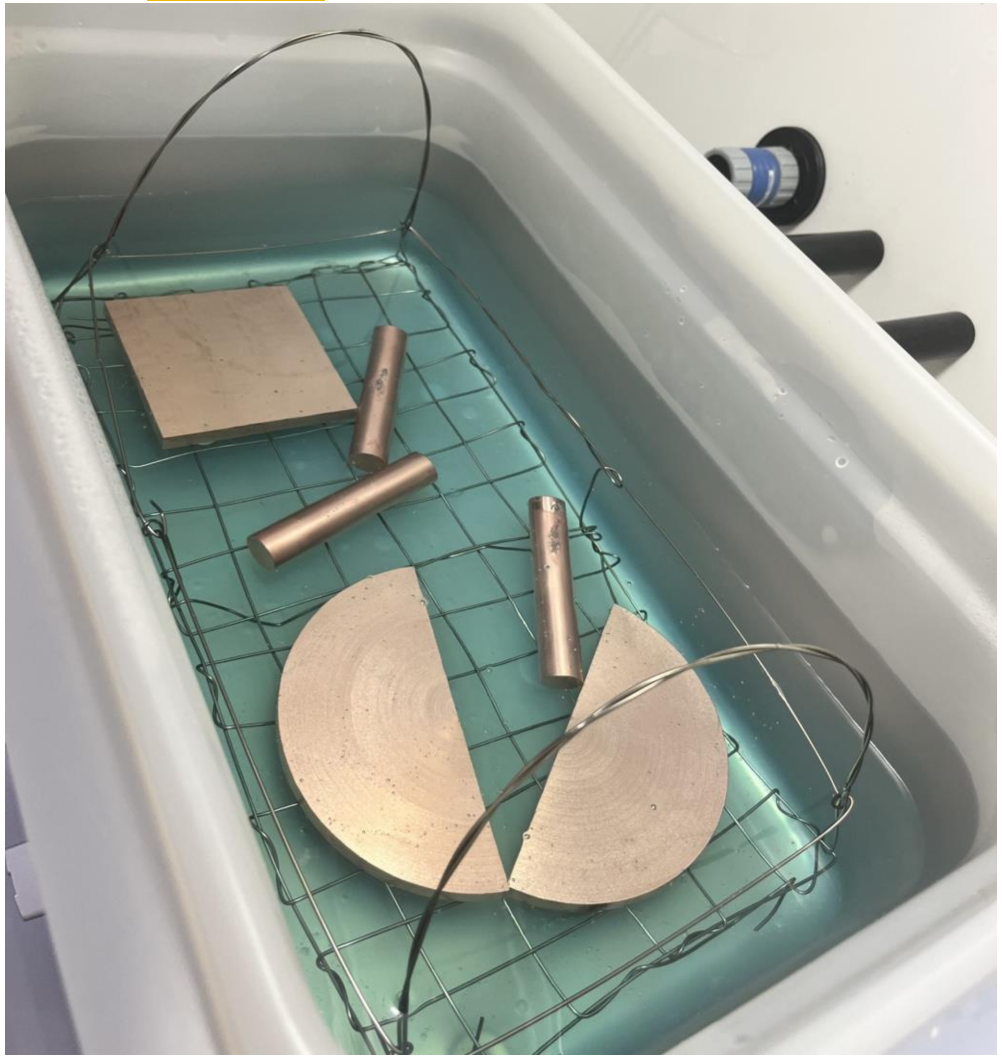
BACKGROUND REDUCTION THROUGH 7 CHIPS





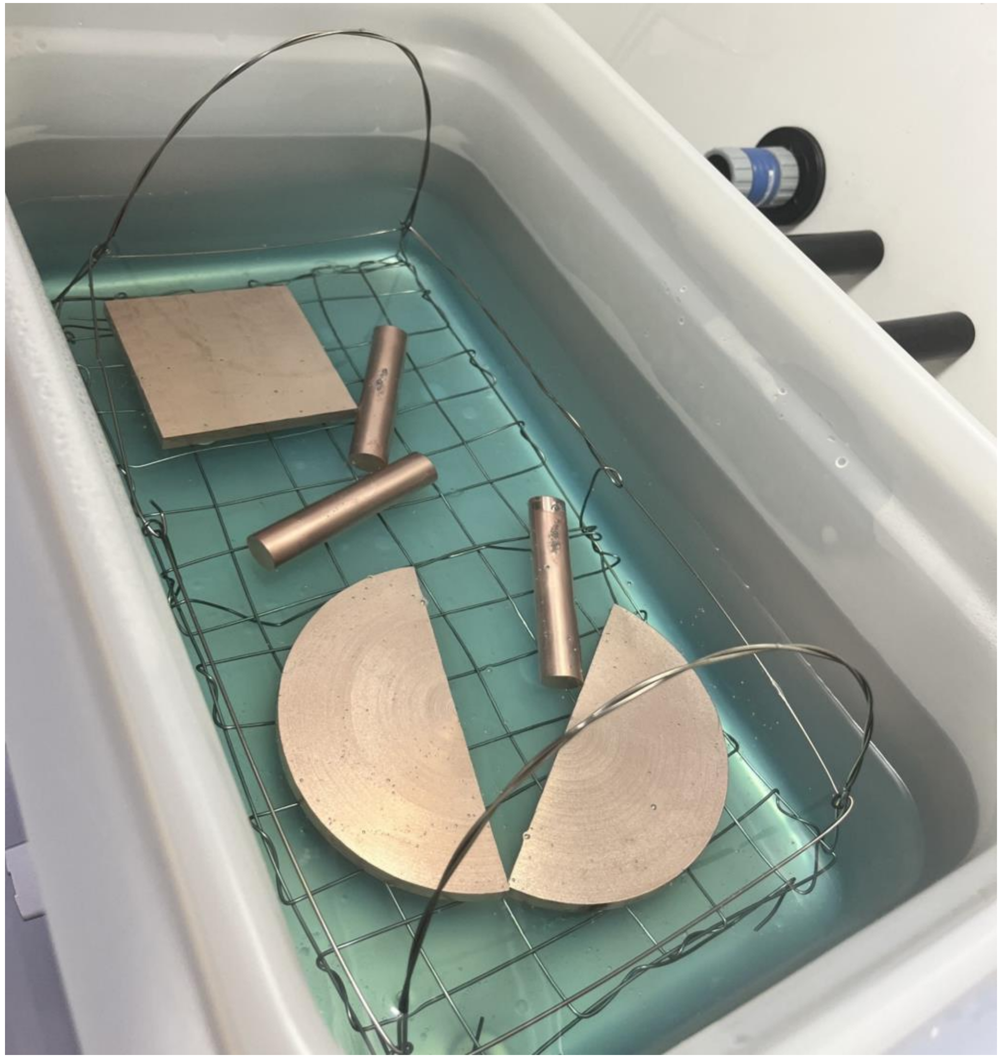
7 chip GridPix detector

TOWARDS A RADIOPURE PROTOTYPE



- Cleaning the radiopure materials to get rid of:
  - ^{40}K from human contact
  - ^{210}Pb from ^{222}Rn from surfaces
  - Oxidation of copper
- Storage in sealed or N_2 flushed areas

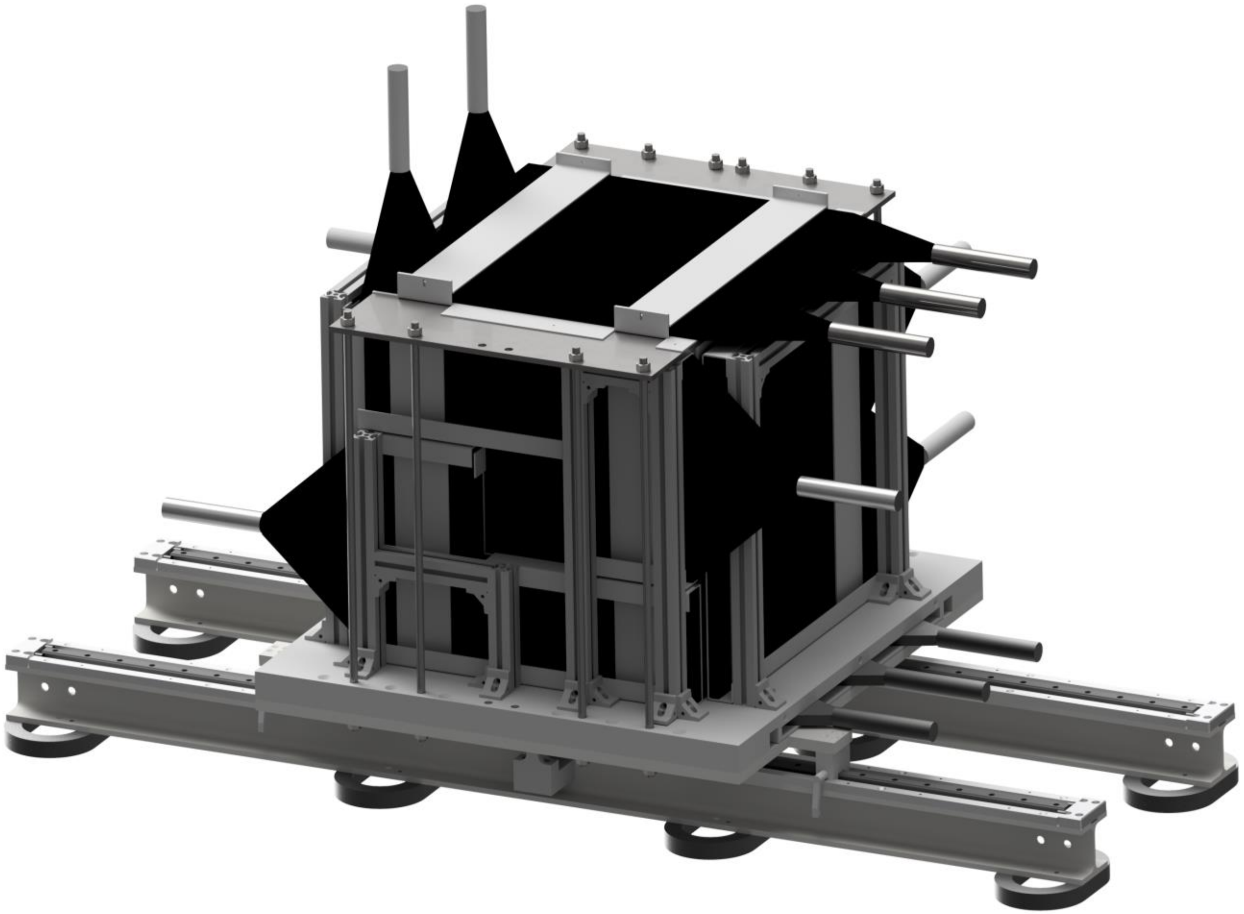
TOWARDS A RADIOPURE PROTOTYPE



Radiopurity measurements with a germanium detector in Canfranc

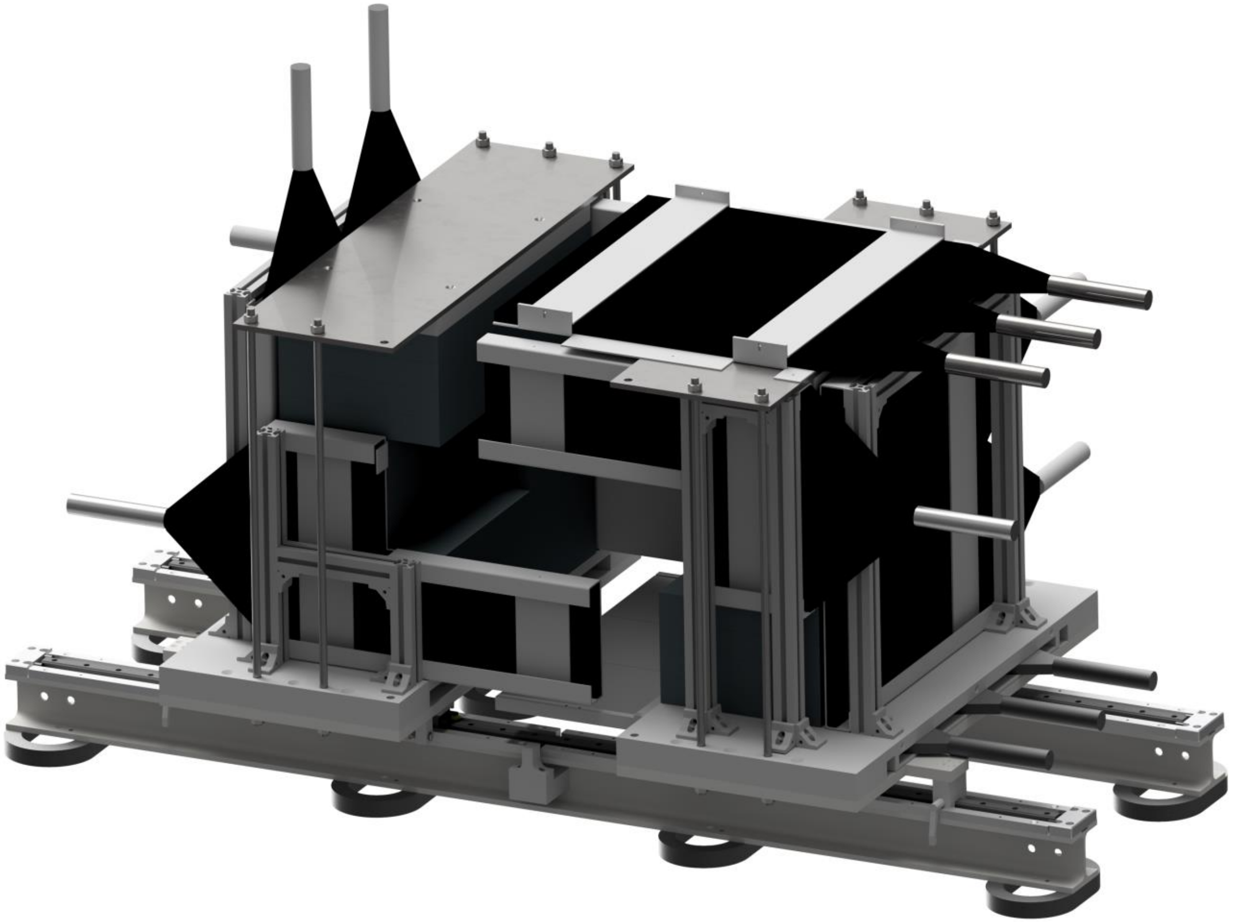
	Isotope	A (mBq/kg)
232Th	228Ac	< 3.4
	228Th	< 2.8
238U	234mPa	< 114
	226Ra	< 5.2
235U	235U	< 2.3
	40K	< 14
	137Cs	< 1.0
	60Co	< 0.82

TEST STAND WITH SHIELDING



- Test stand in FTD basement in Bonn
- Similar to BabyIAXO conditions
- Passive shielding:
  - Concrete
  - Lead castle
- 14 scintillators as active muon veto

TEST STAND WITH SHIELDING



- Test stand in FTD basement in Bonn
- Similar to BabyIAXO conditions
- Passive shielding:
  - Concrete
  - Lead castle
- 14 scintillators as active muon veto
- Slide apart to access detector

TEST STAND WITH SHIELDING