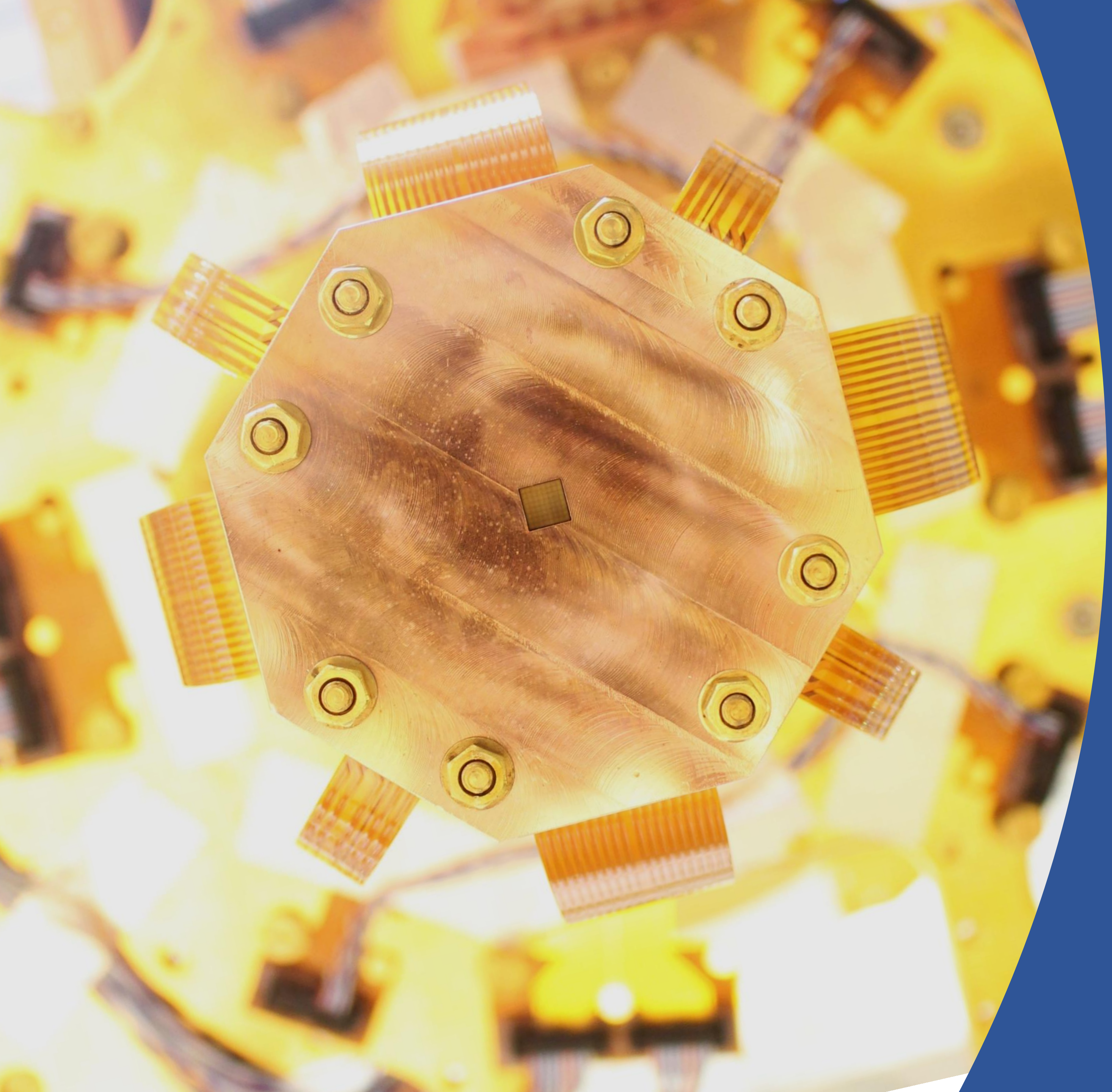

MMCs for IAXO

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D. Hengstler and L. Gastaldo

Kirchhoff-Institute for Physics
Heidelberg University

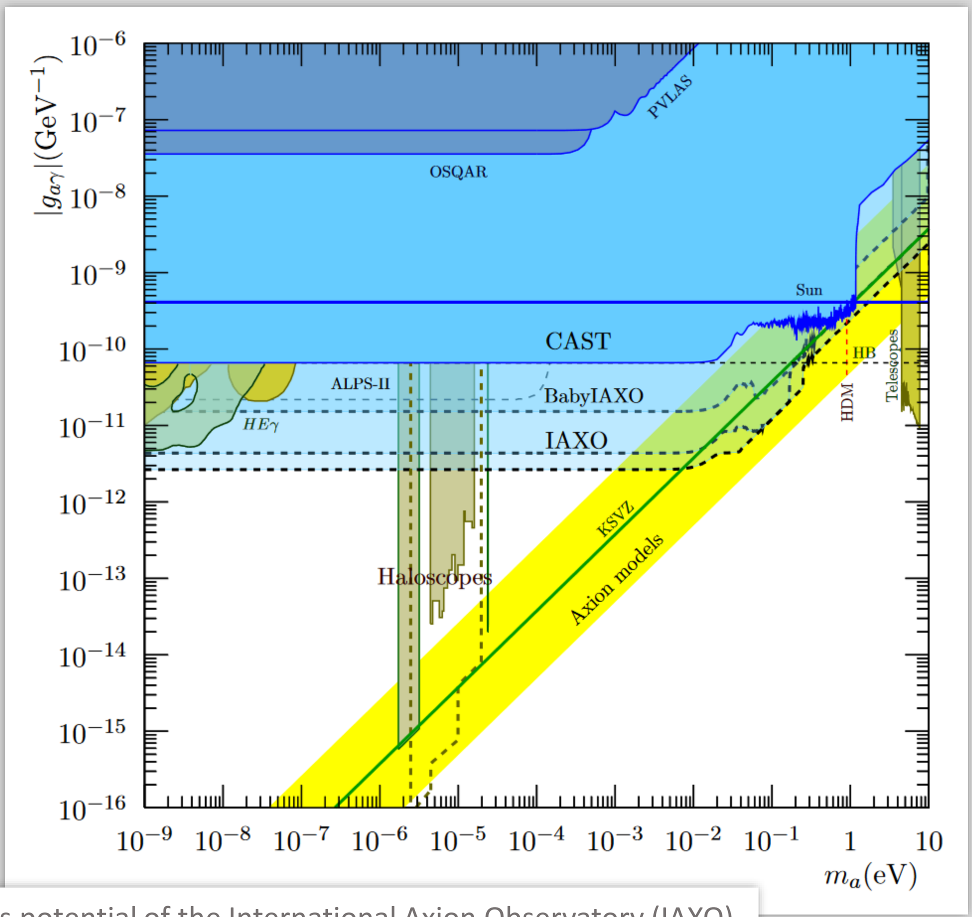
14 October 2020

Axion & ALP Search

- Axion: Possible solution to strong CP problem

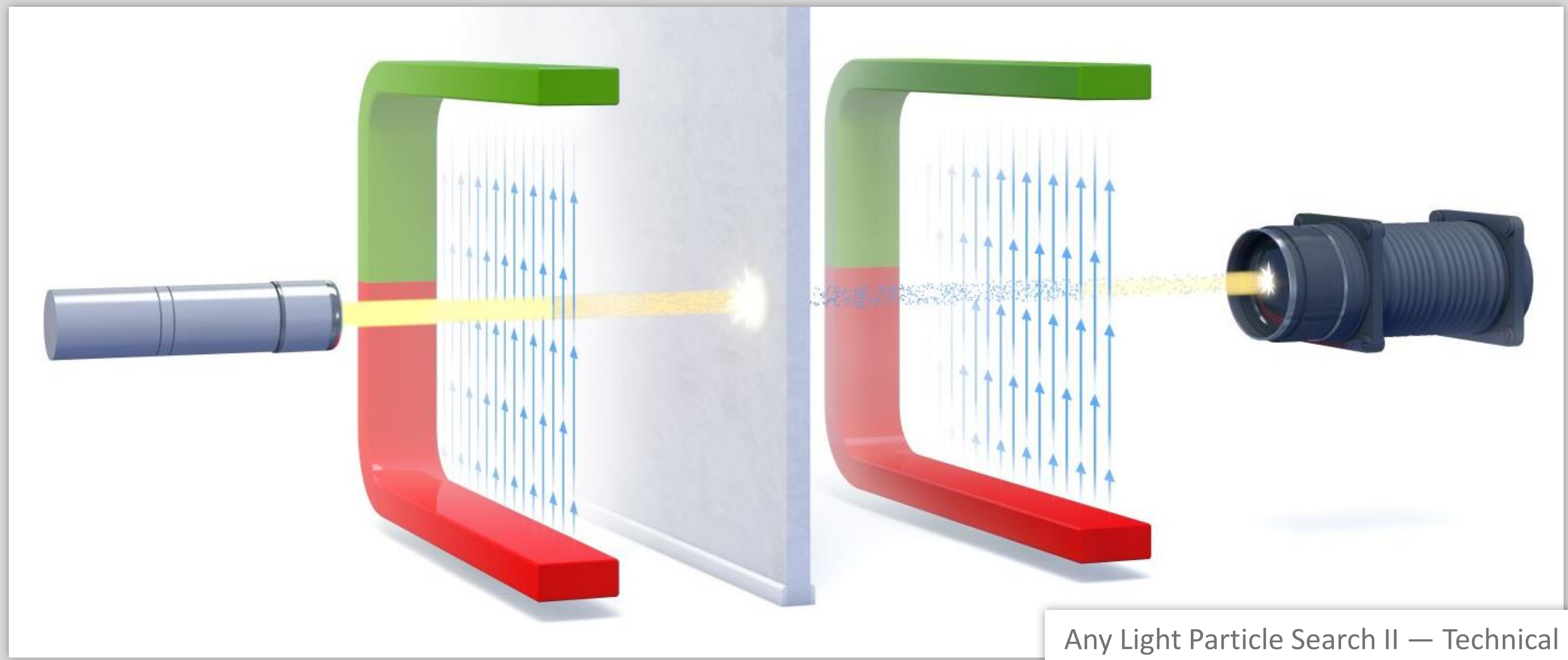
  Why does QCD seem to preserve CP-symmetry?

- Model independent coupling to photons
- Axion-like particles (ALPs) have similar properties: Generic photon coupling, very light and barely interacting
- Several hints for ALPs
  - Dark matter candidate
  - Stellar cooling anomalies
  - Transparency of the universe



Physics potential of the International Axion Observatory (IAXO)
J. Cosmol. Astropart. Phys. 2019 (2019) 047 [arXiv:1904.09155]

Detection Methods



Any Light Particle Search II — Technical Design Report
J. Instrum. 8 (2013) T09001 [arXiv:1302.5647]

Light-shining-through-a-wall: ALPs in the laboratory

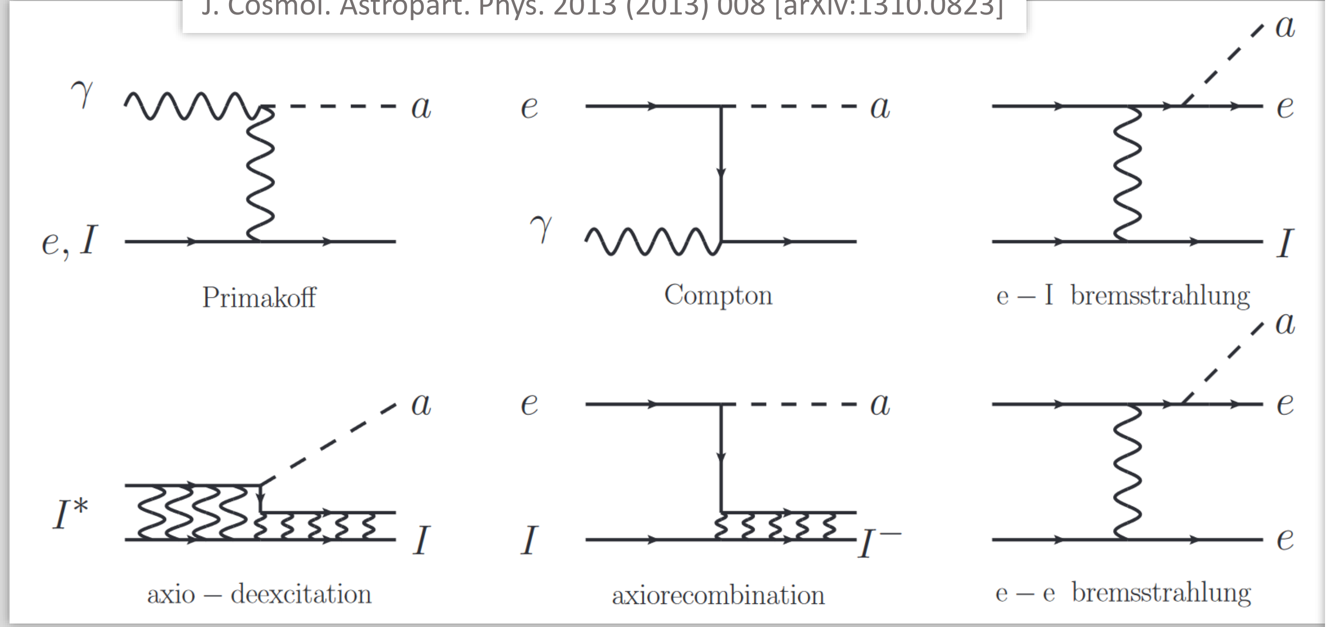
Haloscopes: ALPs as dark matter halo of our galaxy

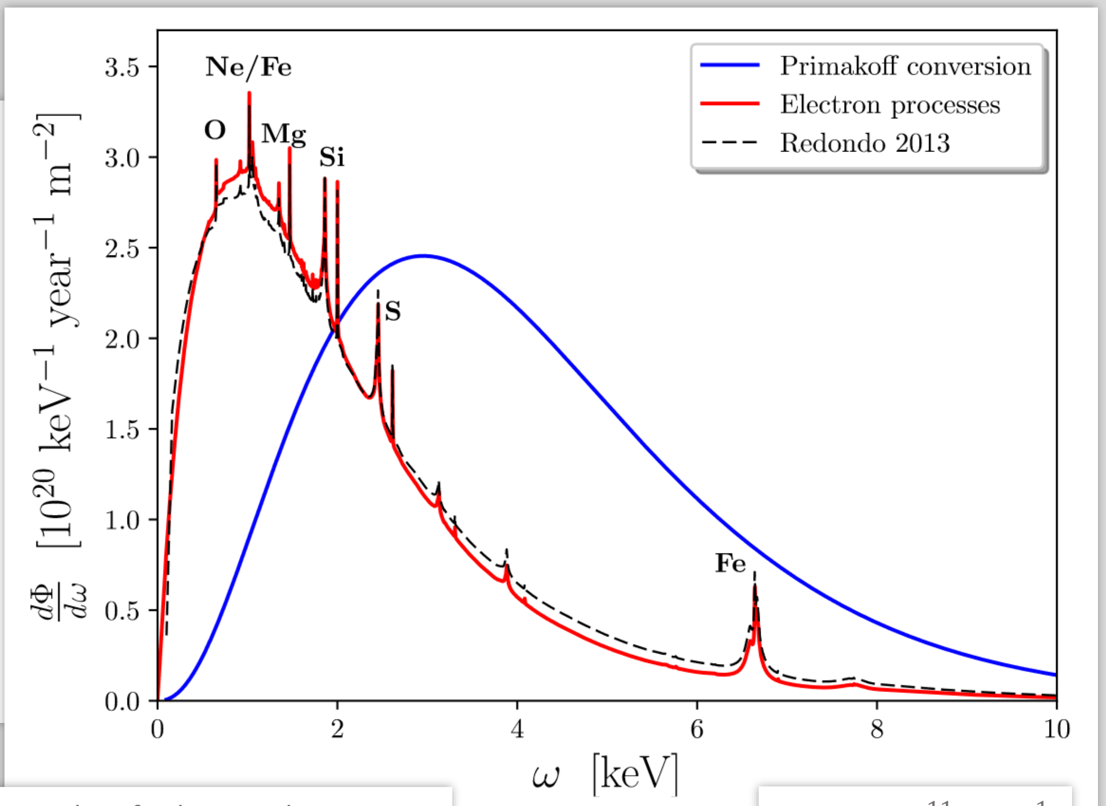
Helioscopes: ALPs from the Sun

Natural source of axions

Solar ALP Flux

Solar axion flux from the axion-electron coupling
J. Cosmol. Astropart. Phys. 2013 (2013) 008 [arXiv:1310.0823]



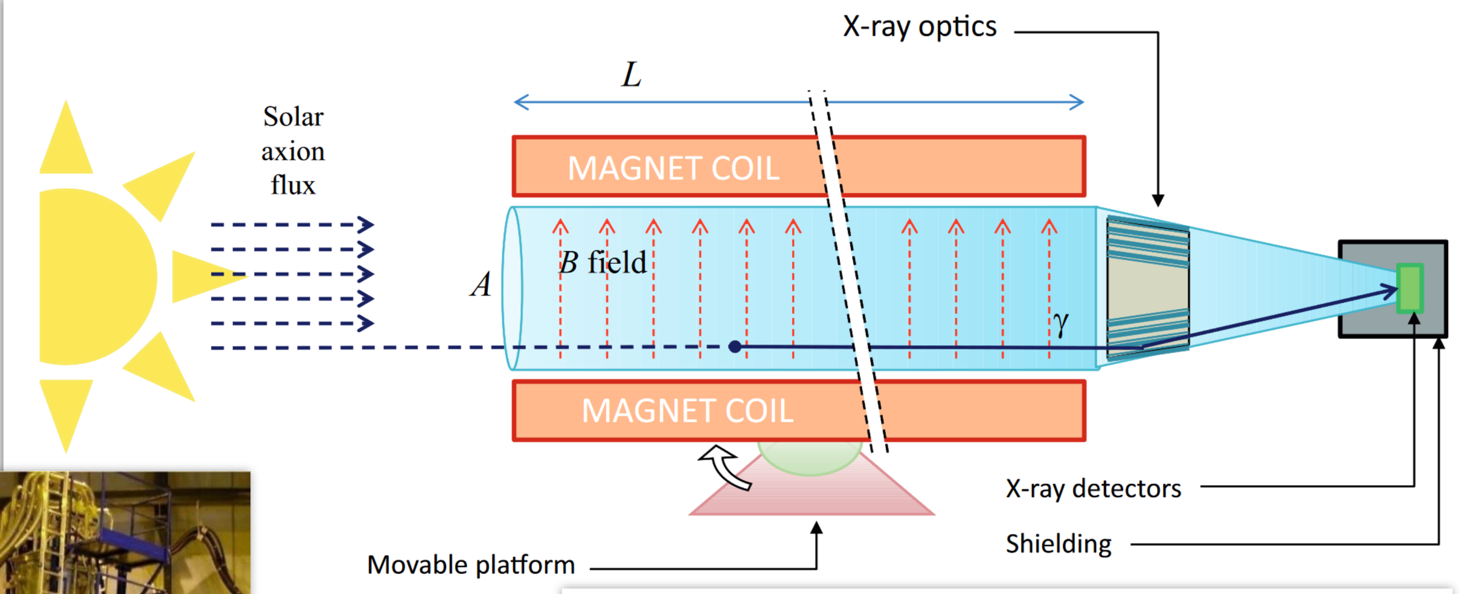


Axions as a probe of solar metals
Phys. Rev. D100 (2019) [arXiv:1908.10878]

$g_{a\gamma} = 10^{-11}\ \mathrm{GeV}^{-1}$
$g_{ae} = 10^{-13}$

Helioscopes & CAST

Concept of helioscopes →



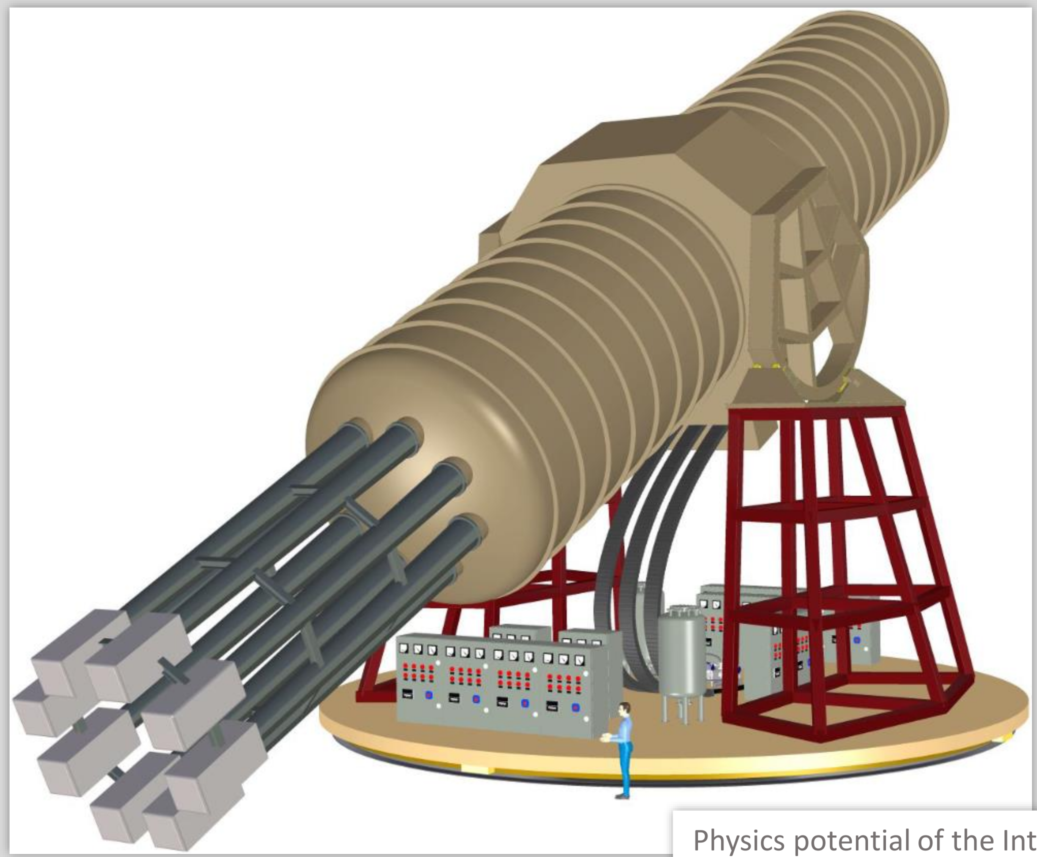
Conceptual Design of the International Axion Observatory (IAXO)
J. Instrum. 9 (2014) T05002 [arXiv:1401.3233]

← CERN Axion Solar Telescope (CAST)

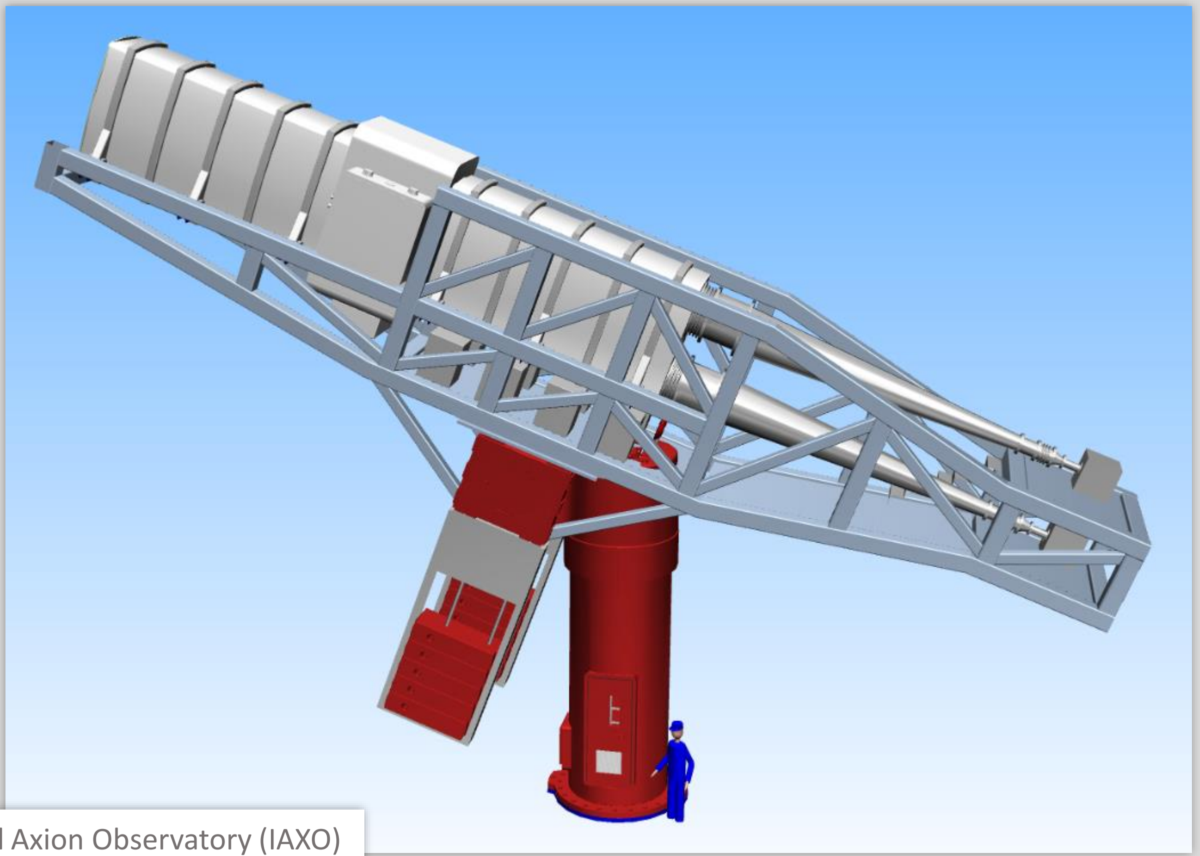
Micromegas for axion search and prospects
J. Phys. Conf. Ser. 65 (2007) 012010

IAXO & BabyIAXO

↓ International Axion Observatory (IAXO)



BabyIAXO — intermediate step towards IAXO ↓



Physics potential of the International Axion Observatory (IAXO)
J. Cosmol. Astropart. Phys. 2019 (2019) 047 [arXiv:1904.09155]

Detektor Requirements

Rare event search: Very low background and high efficiency

- TPCs with Micromegas (used in CAST) are considered as baseline technology for IAXO

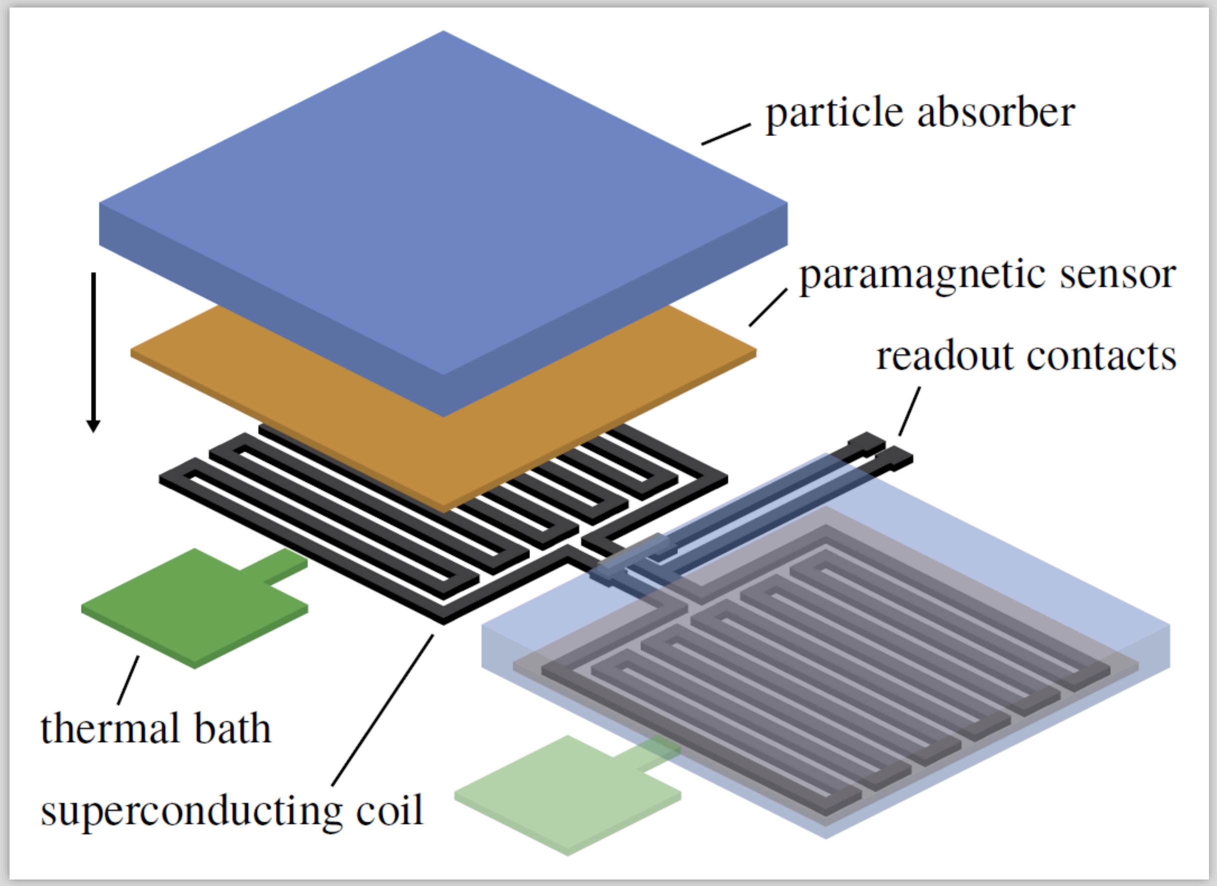
Goal: Background less than $10^{-7}\,\frac{\text{counts}}{\text{keV}\cdot\text{cm}^2\cdot\text{s}}$

- IAXO optics: Round focal spot $\sim 20\ \text{mm}^2$ and up to $1\ \text{mm}$ deviation on the position

After discovery: Study axion spectrum

Good energy resolution & Low energy threshold : Extract ALP properties & information about our Sun

Metallic Magnetic Calorimeters



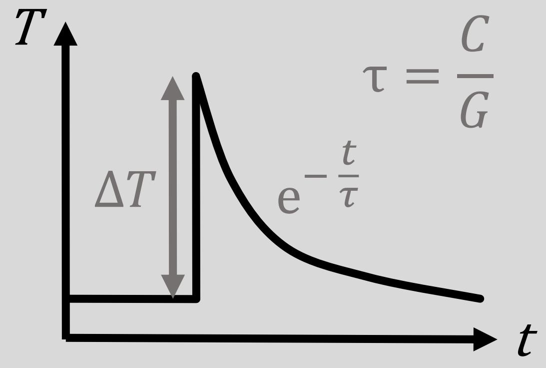
$$C = C_{abs} + C_{sen}$$

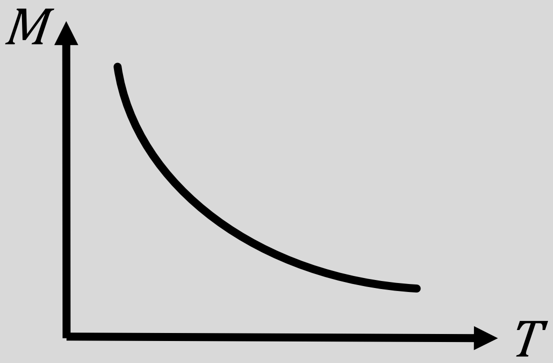
$$\Delta T \cong \frac{E}{C}$$

$$\Delta M \cong \frac{\partial M}{\partial T} \Delta T$$

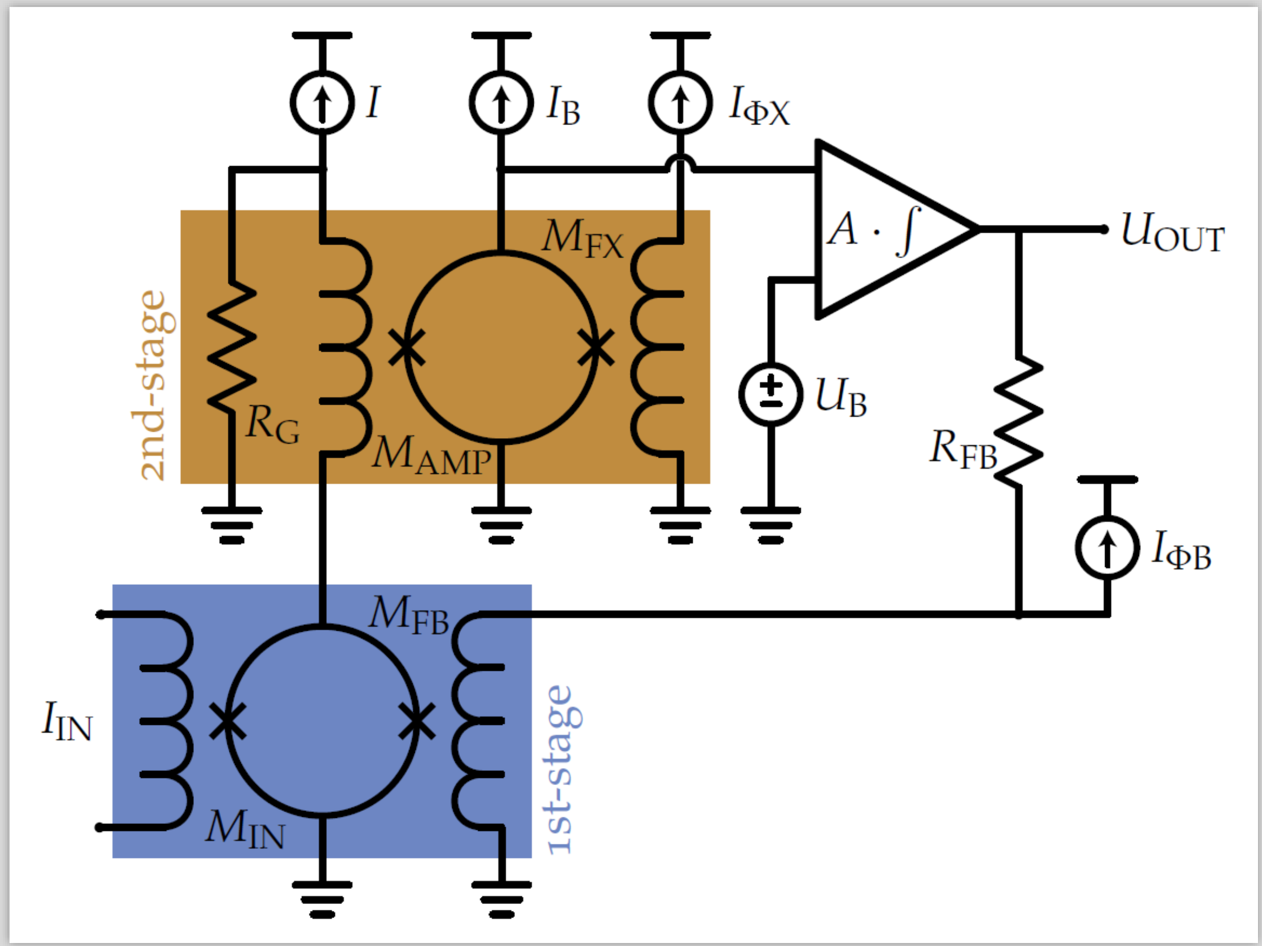
$$\Delta \phi \propto \Delta M$$

$$\Rightarrow \Delta \phi \propto \frac{\partial M}{\partial T} \frac{E}{C}$$





Two-Stage SQUID Readout



- SQUID: Sensitive magnetometer
  — but not well defined!
- Flux-locked-loop operation to convert and amplify flux to voltage
- Low noise and large bandwidth flux amplifier

$$u_{OUT} = -\frac{M_{IN}}{M_{FB}} R_{FB}\, i_{IN}$$

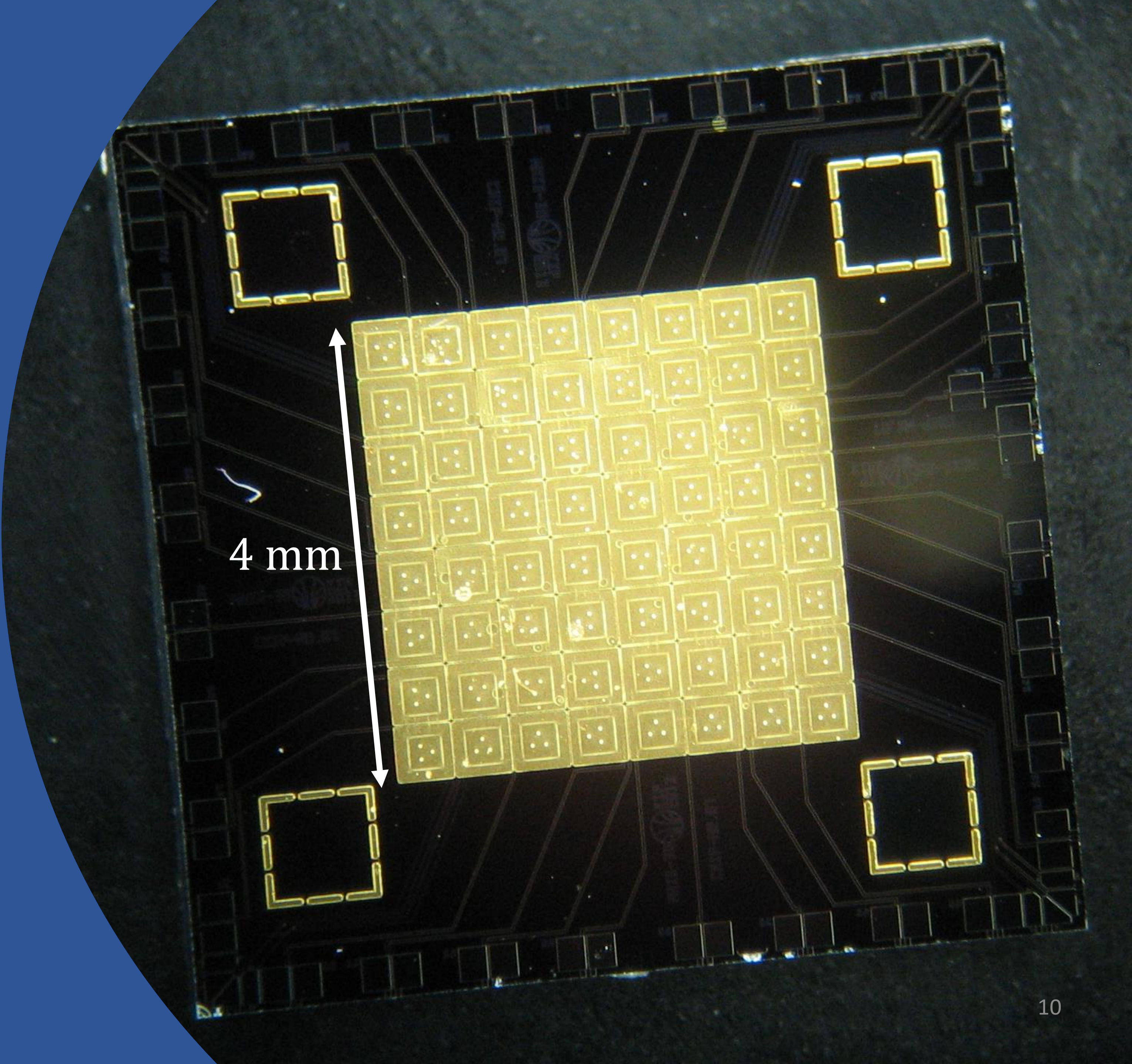
$$u_{OUT} \propto i_{IN}$$

maXs30 Detector

64-pixel detector
16 mm^2 active area

$\Delta E_{\mathrm{FWHM}} = 8\ \mathrm{eV}$

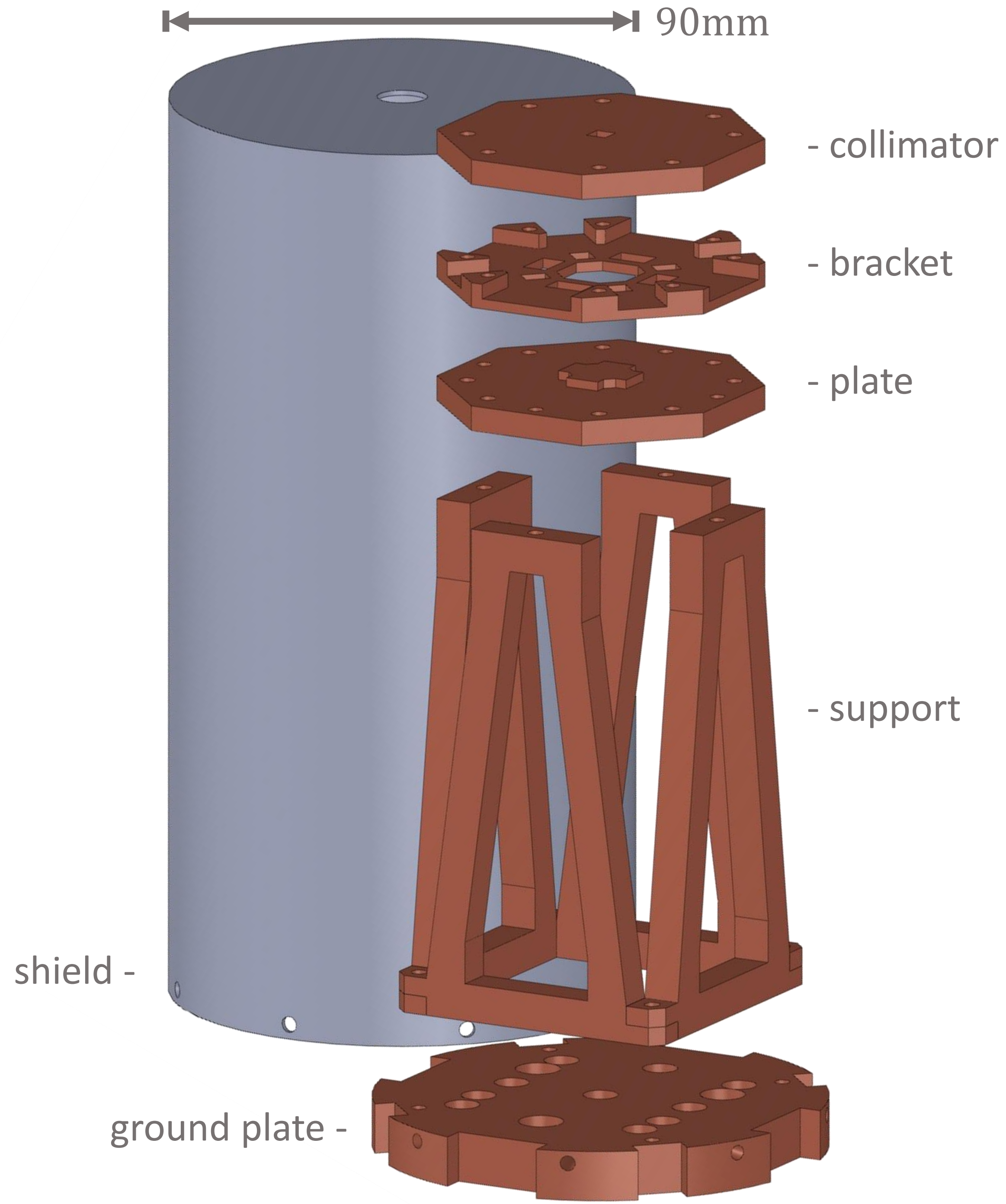
Operated at 25 mK
Filling factor of 93 %
Low energy thresholds
High linearity



Dedicated Background Analysis

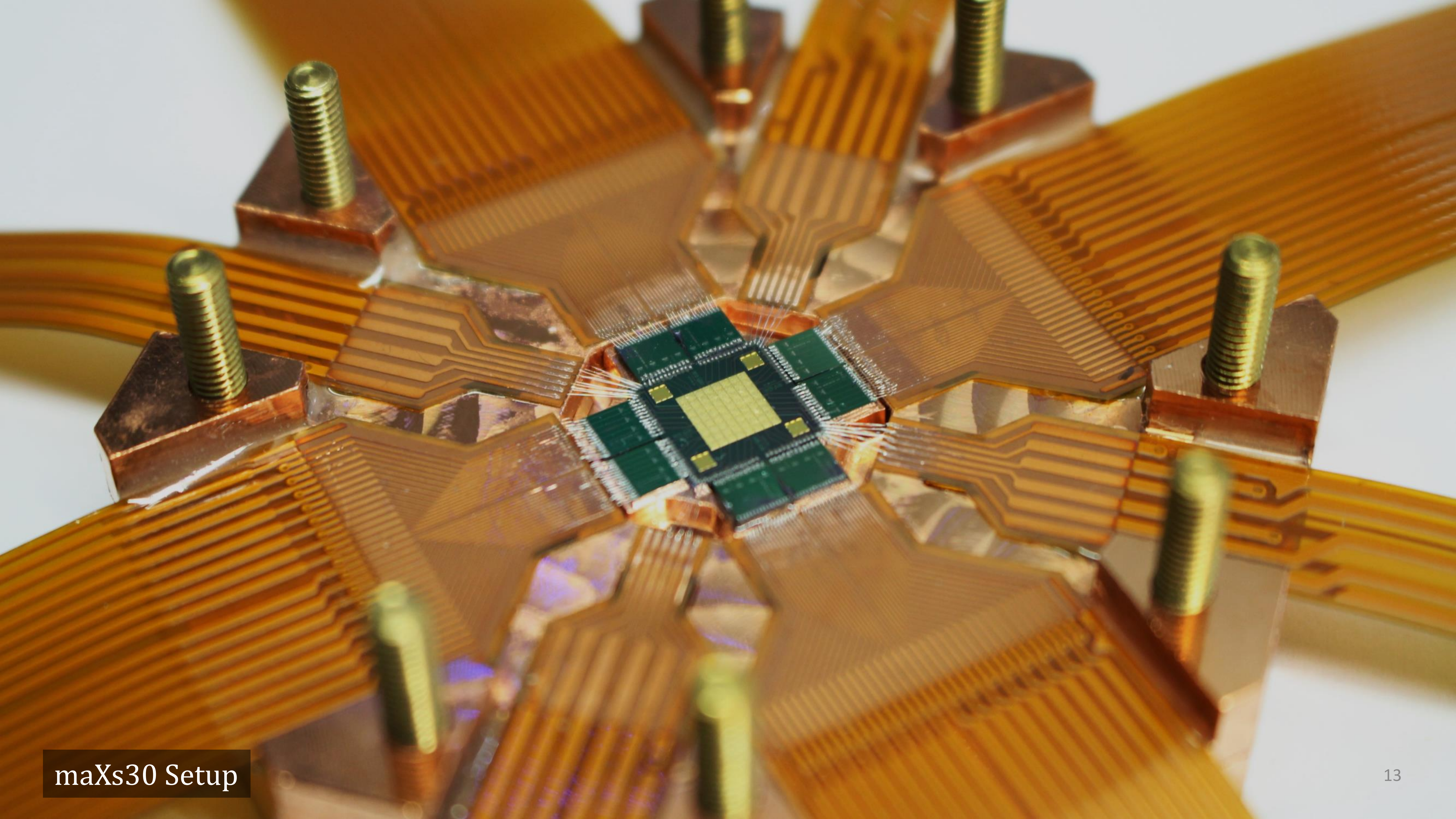
MMC fulfil all requirements – but background needs to be investigated:

1. Design of a new multi-purpose radiopure setup
2. Chip testing and setup assembly
3. Long term background measurement
4. Background analysis and source identification

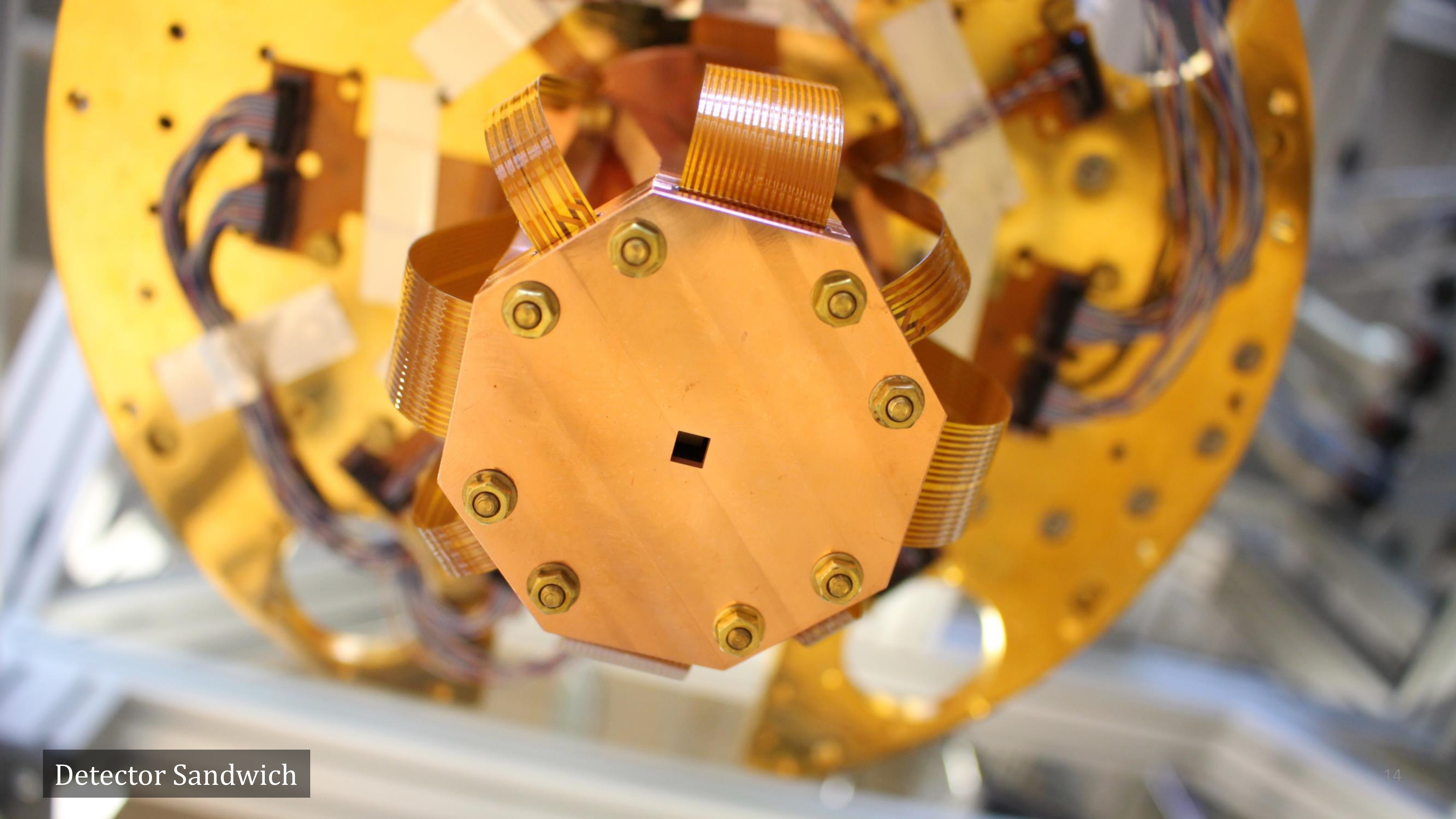


Setup Design

- Only radiopure materials
- Multipurpose platform
  - For different detectors dimensions up to 24 mm × 24 mm chip size
  - Allows different SQUID attachment
- Good thermalisation
  - Large contact area between parts
  - Triangle shapes reduce vibrations
- Modular design
  - Easy to adjust in the future

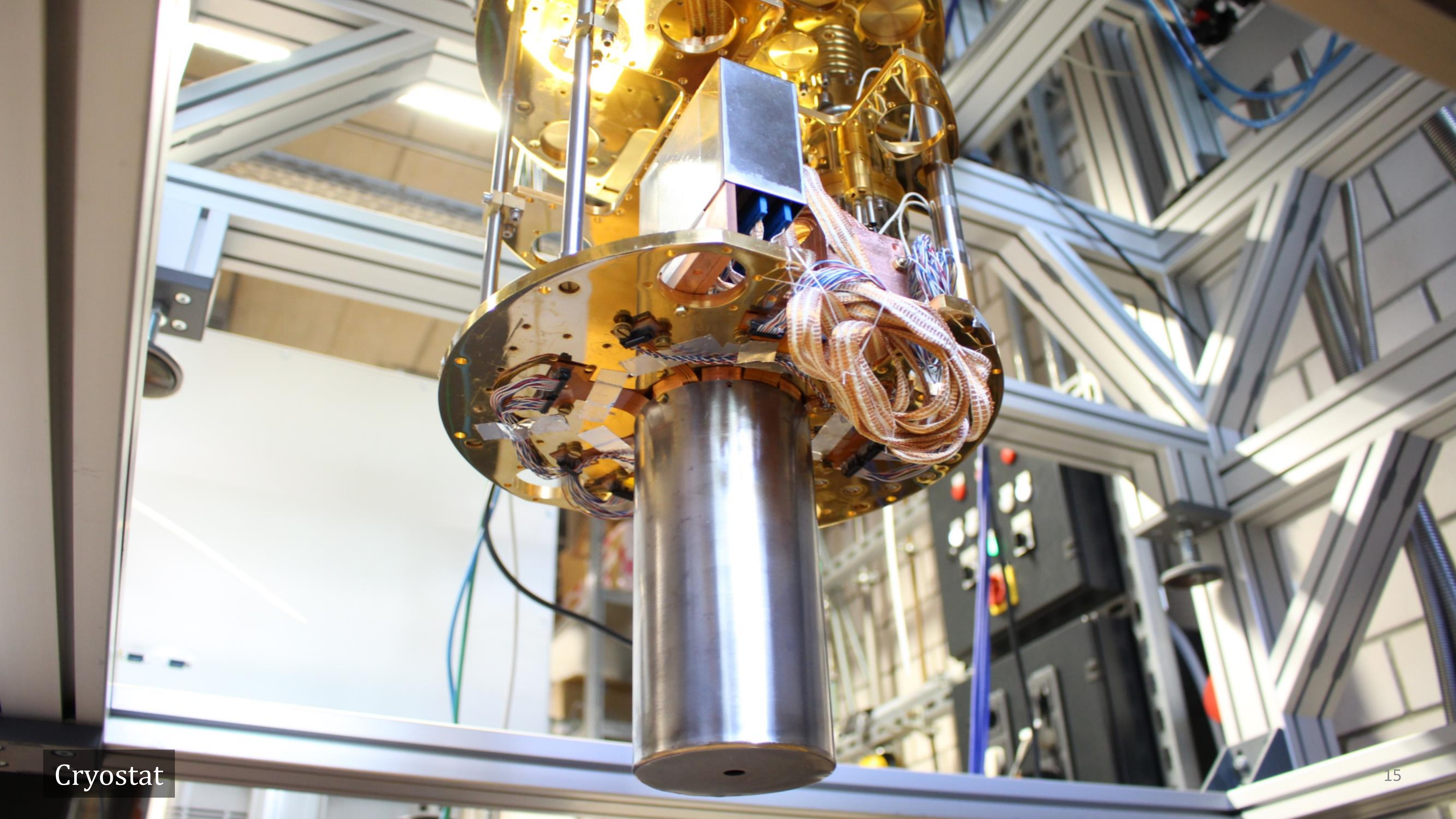


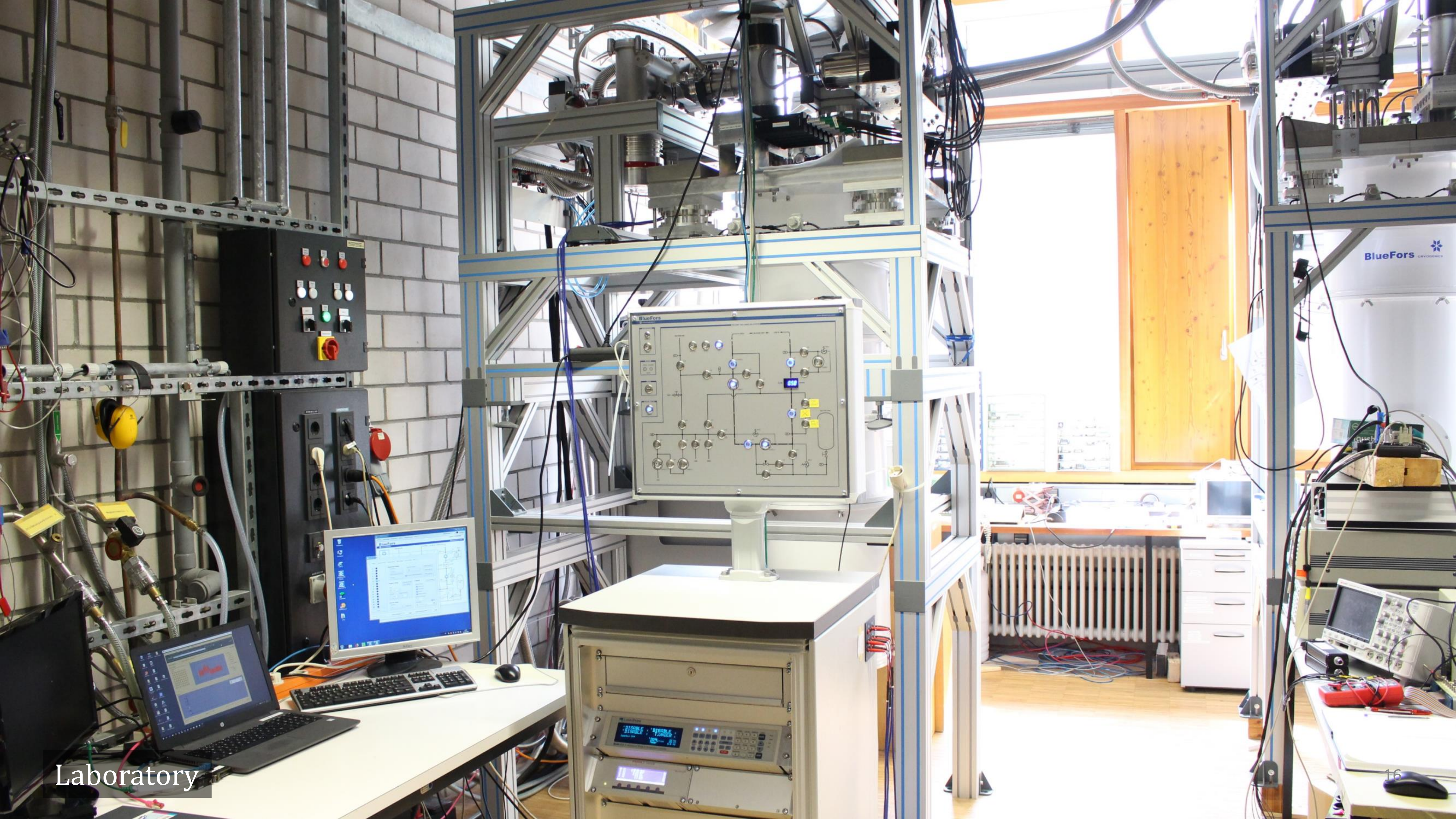
maXs30 Setup



Detector Sandwich

Cryostat

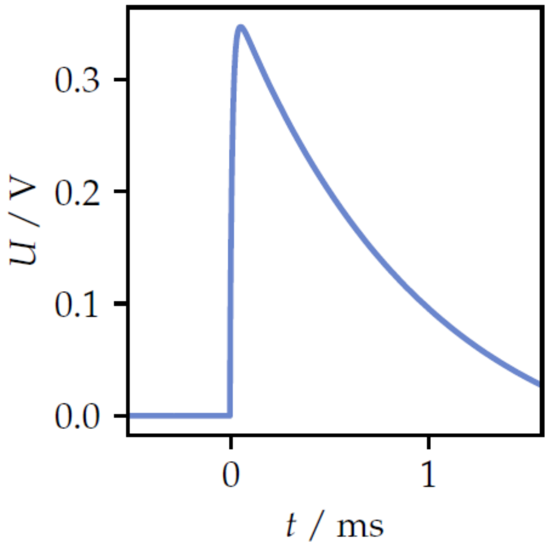




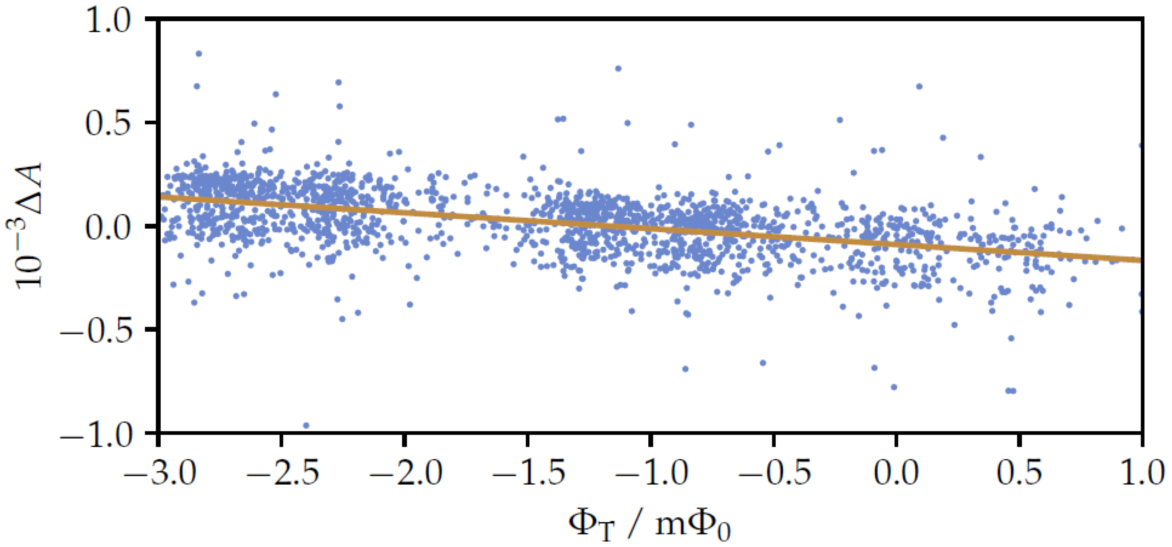
Laboratory

Data Analysis

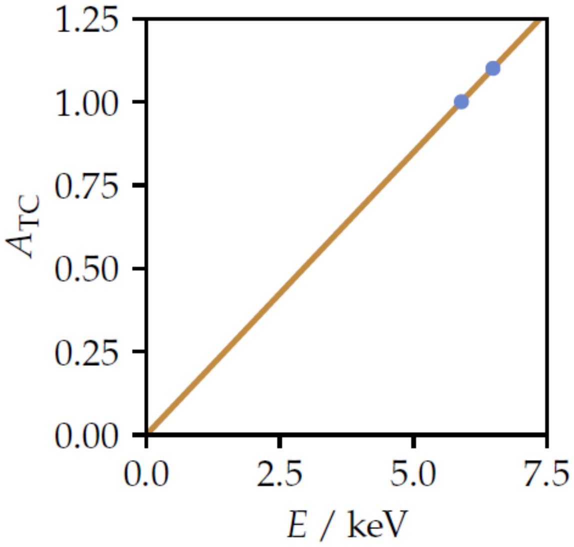
Template pulse



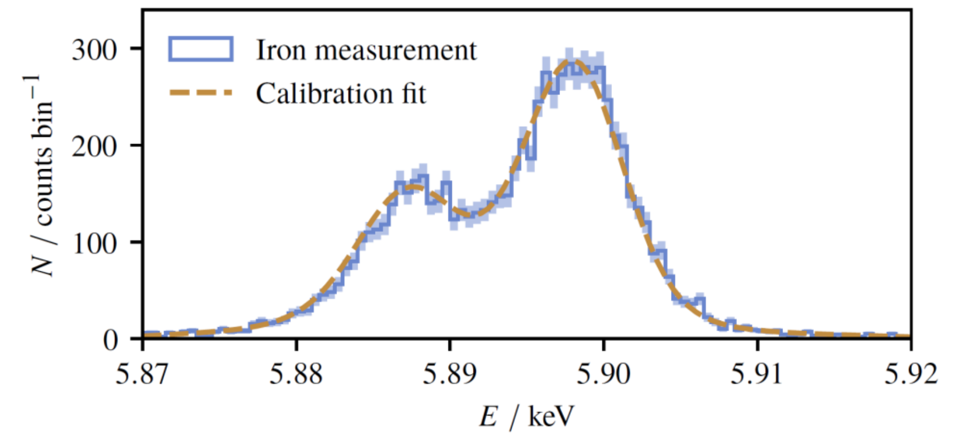
Temperature correction



Non-linearity correction



Necessary for good energy resolution ⇒



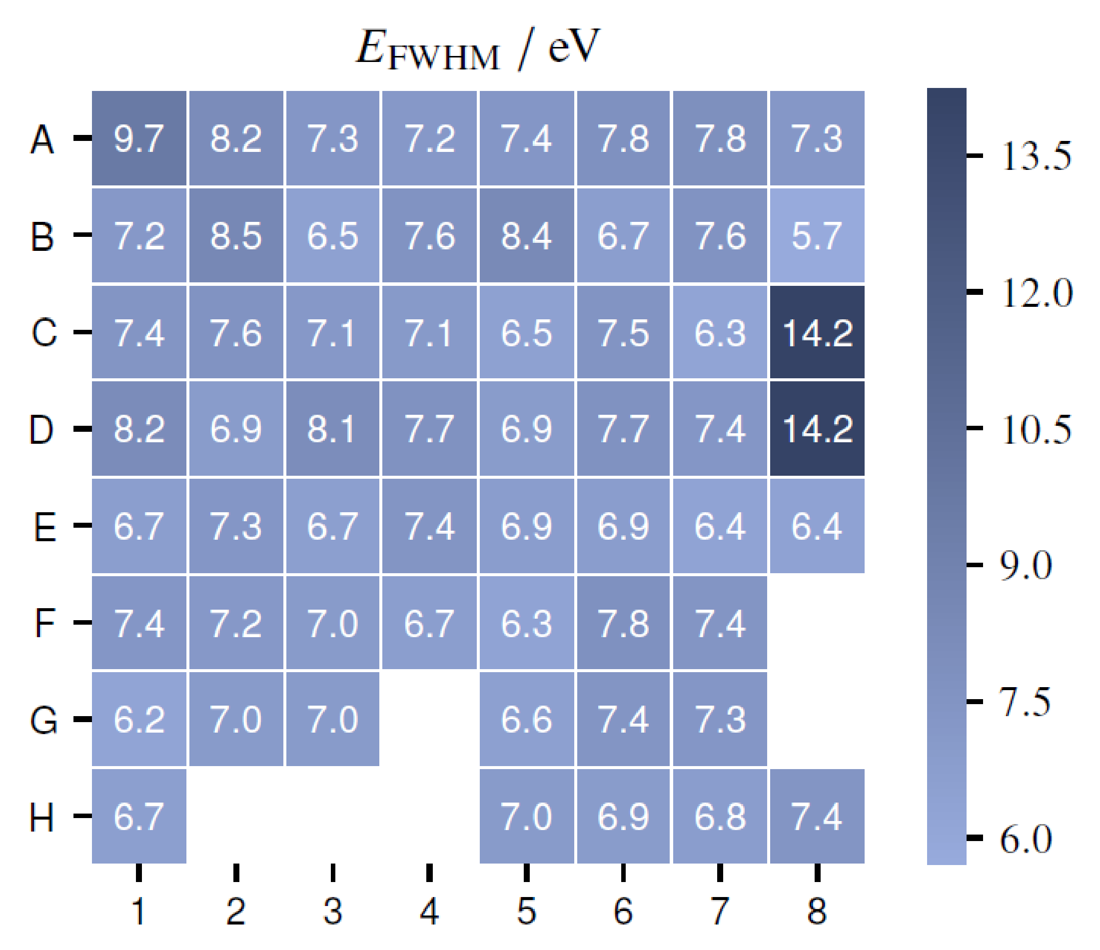
Detector Performance

- Average energy resolution:

$$E_{\mathrm{FWHM}} = 6.1\ \mathrm{eV}\quad @\ 0\ \mathrm{eV}$$

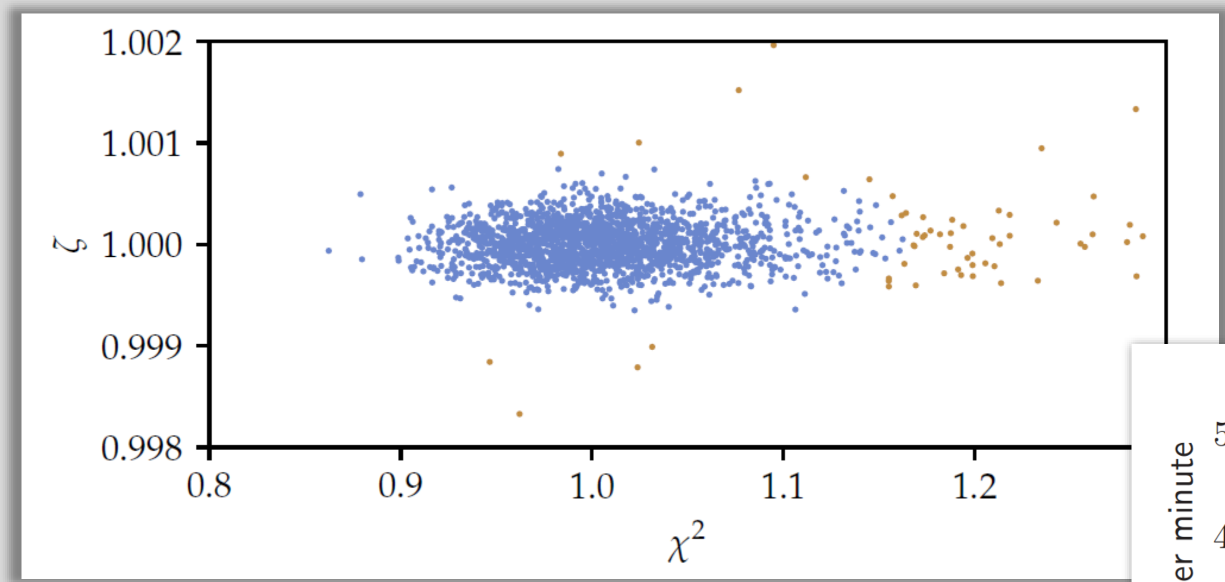
$$E_{\mathrm{FWHM}} = 7.2\ \mathrm{eV}\quad @\ 5.9\ \mathrm{keV}$$

- 31 detector channels are working
  - Scratch over one readout channel
- Best performing detector setup yet



Energy resolution @ 5.9 keV

Data Reduction

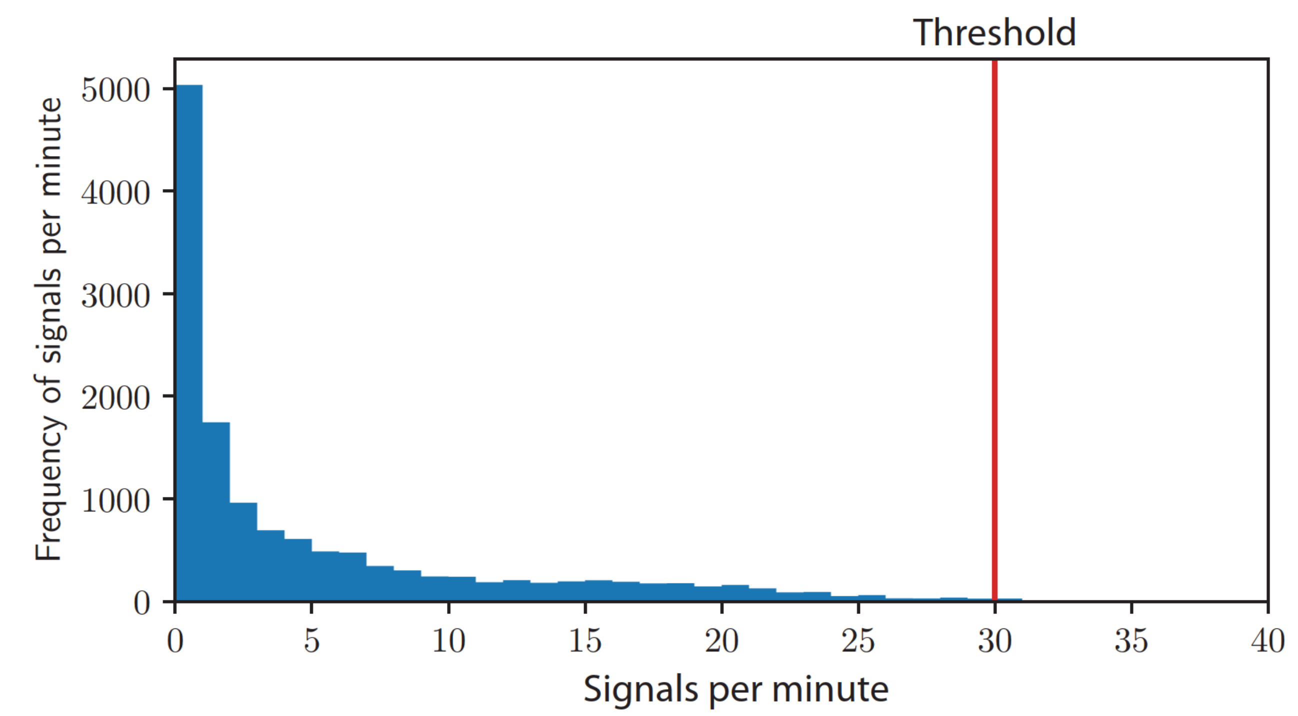


Ellipse cut

(identifies deviations in the pulse shape)

Burst cut

(identifies noise bursts)

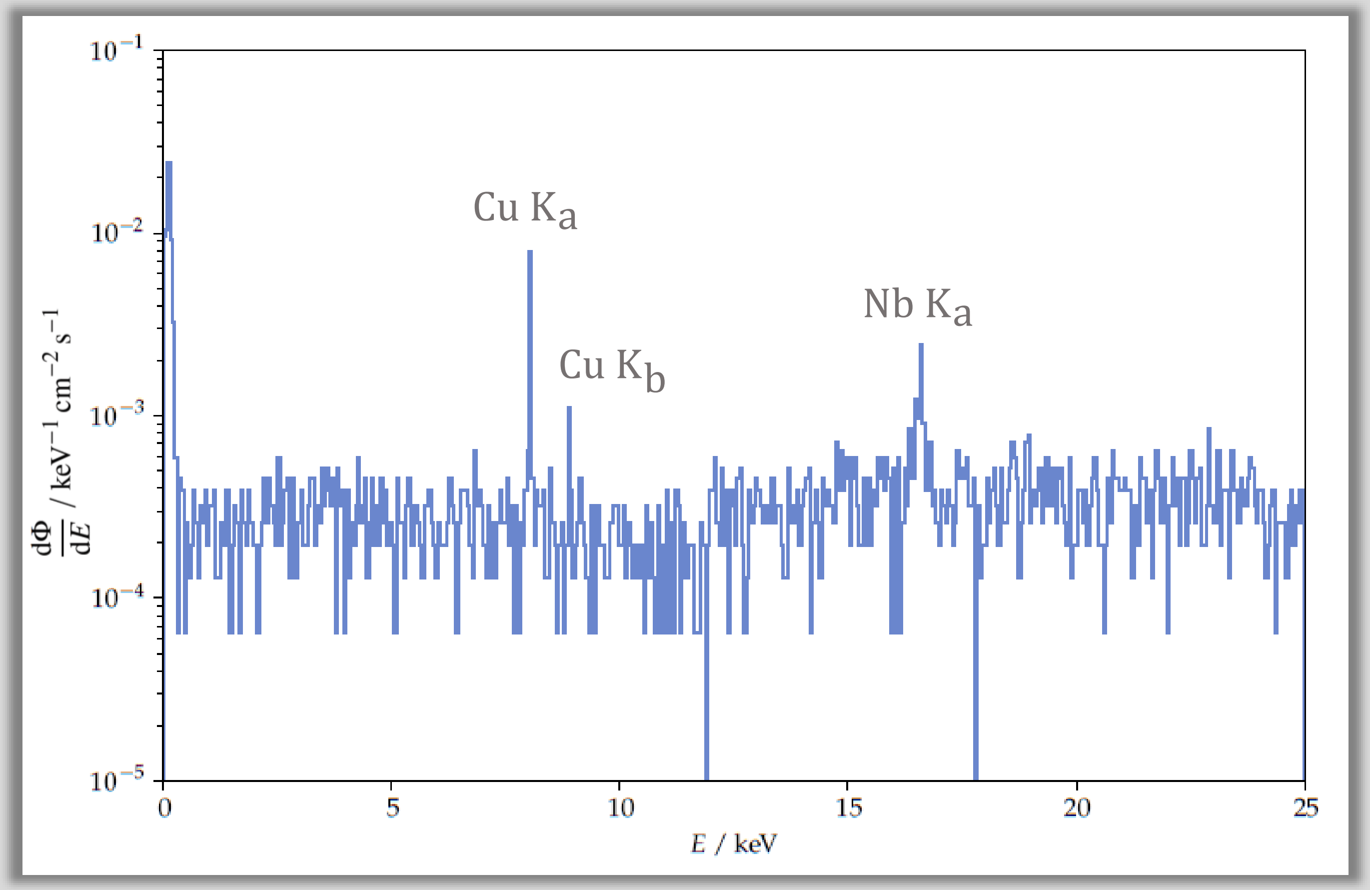


First Background Spectrum

- One month of background
- Neither active nor passive shielding

$$3.2\ (1) \cdot 10^{-4} \frac{\text{counts}}{\text{keV} \cdot \text{cm}^2 \cdot \text{s}}$$

- Niobium shielding is contaminated with radioactive ^{94}Nb ($33\ \frac{\text{mBq}}{\text{kg}}$)
- White background presumably due to contamination
- Fluorescence lines due to muons

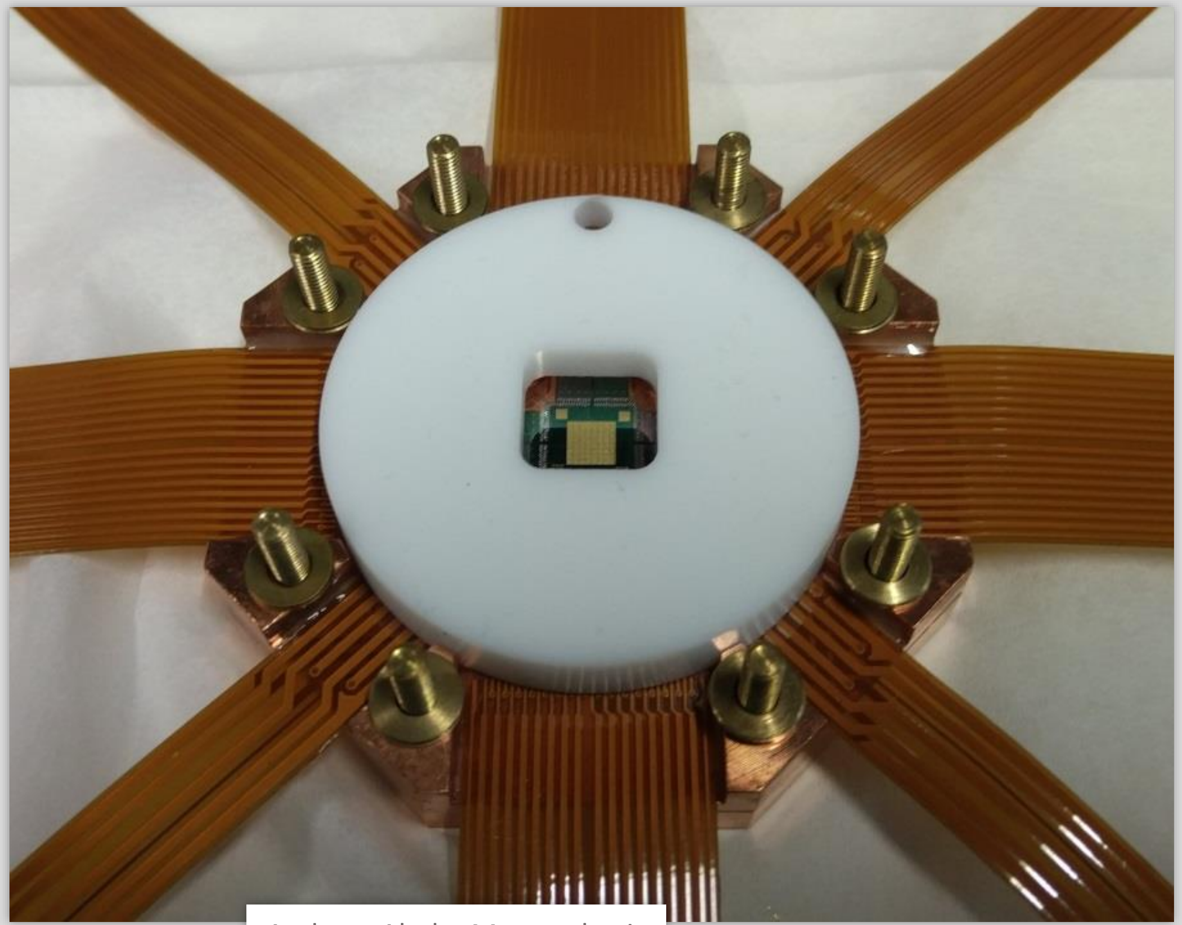


Additional PFTE shield

- Test of existing PFTE (Teflon) shield in the characterized setup
- 20 days of background

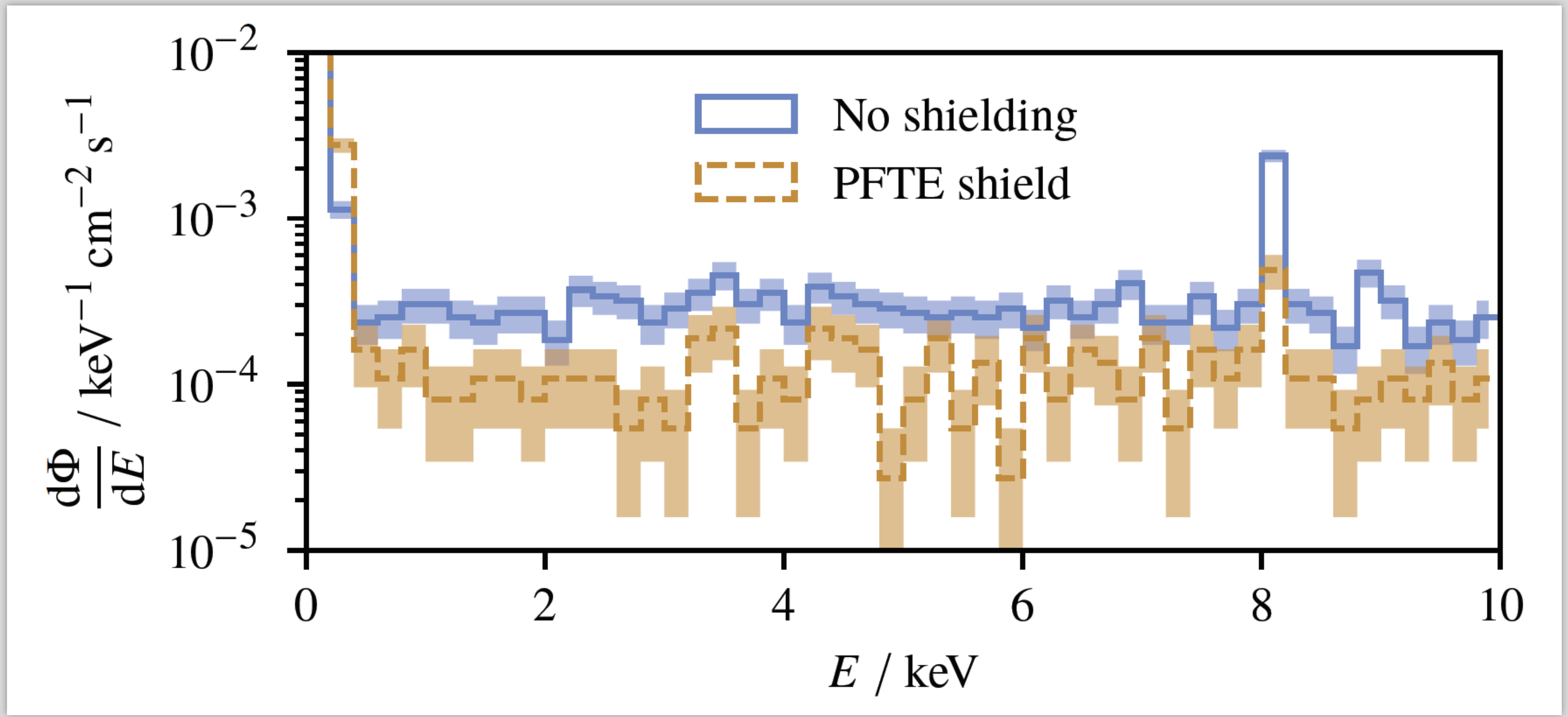
$$1.20\,(8) \cdot 10^{-4}\,\frac{\text{counts}}{\text{keV} \cdot \text{cm}^2 \cdot \text{s}}$$

- Background reduced by 63 %
- Matches expected reduction by the effective shielded solid angle



Andreas Abeln, Master thesis

Background Spectrum



Further Background Reduction

- Expected muon flux: $\sim 1.4 \cdot 10^{-2} \frac{1}{\text{cm}^2 \cdot \text{s}}$
- Direkt muon hits can be idenified — but not secondary events!

Muon veto necessary

- New superconducting shield: Copper plated with superconductor
- Several shields for a step-by-step reduction of external radiation

Lead shield
Copper shields
PFTE shield

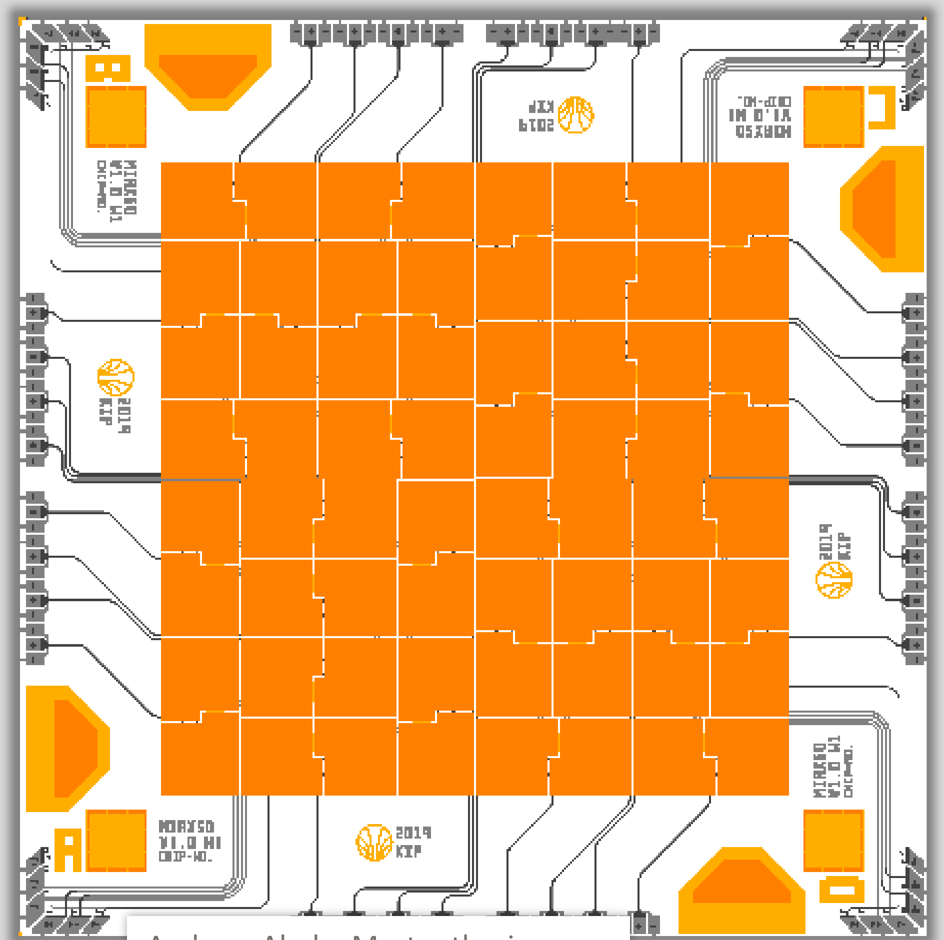
Onion design

New Detector: maXs-IAXO

- Based on maXs100
- Very large, 1 cm^2 absorber
- Matching the BabyIAXO X-ray optics
- Simulated energy resolution:

$$E_{\mathrm{FWHM}} = 11\ \mathrm{eV}$$

Design finished, production starts soon!



↕1 mm

Andreas Abeln, Master thesis

Summary

- First MMC-based low-background prototype for IAXO developed
- maXs30 MMC array fully characterized - best performing detector setup yet
- Methods to reduce background sources identified

Current developments:

- maXs-IAXO to mach the IAXO X-ray optics
- Background reduction via active and passive shields

⇒ Solid basis for future IAXO setups