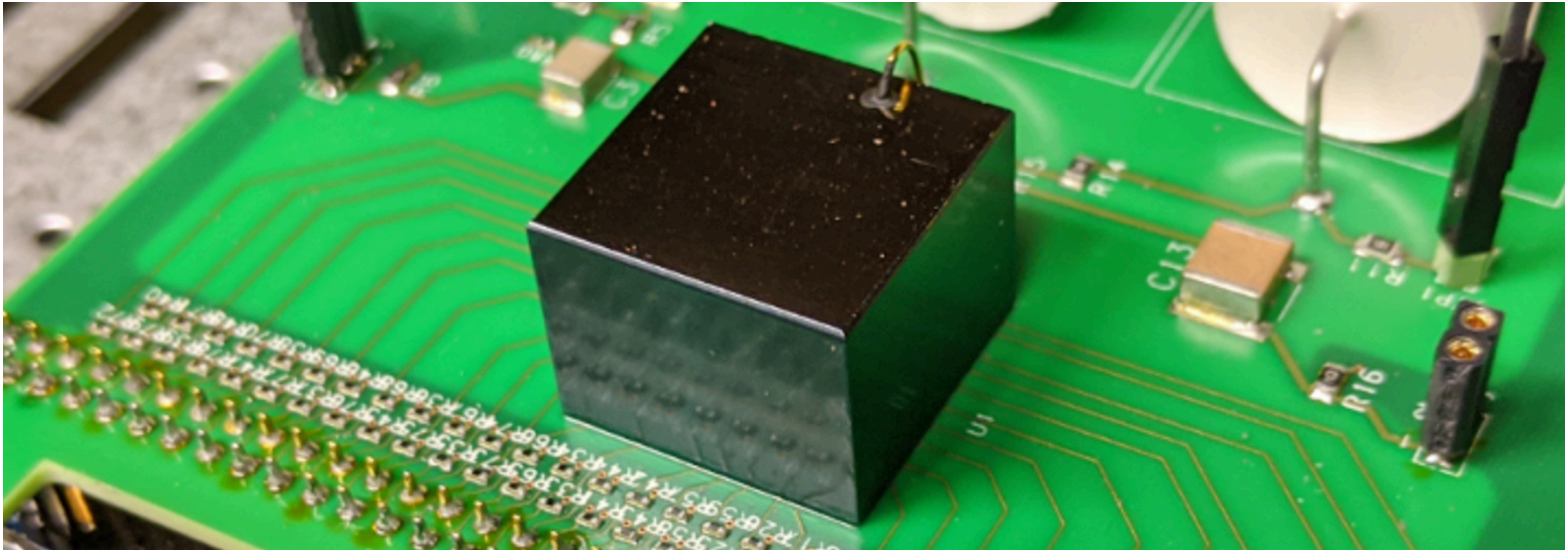
Performance measurements of CdZnTe detectors
for the MeVCube project.



Markus Ackermann, Giulio Lucchetta, DTS-ST3 meeting, 16.03.2022

The MeVCube project

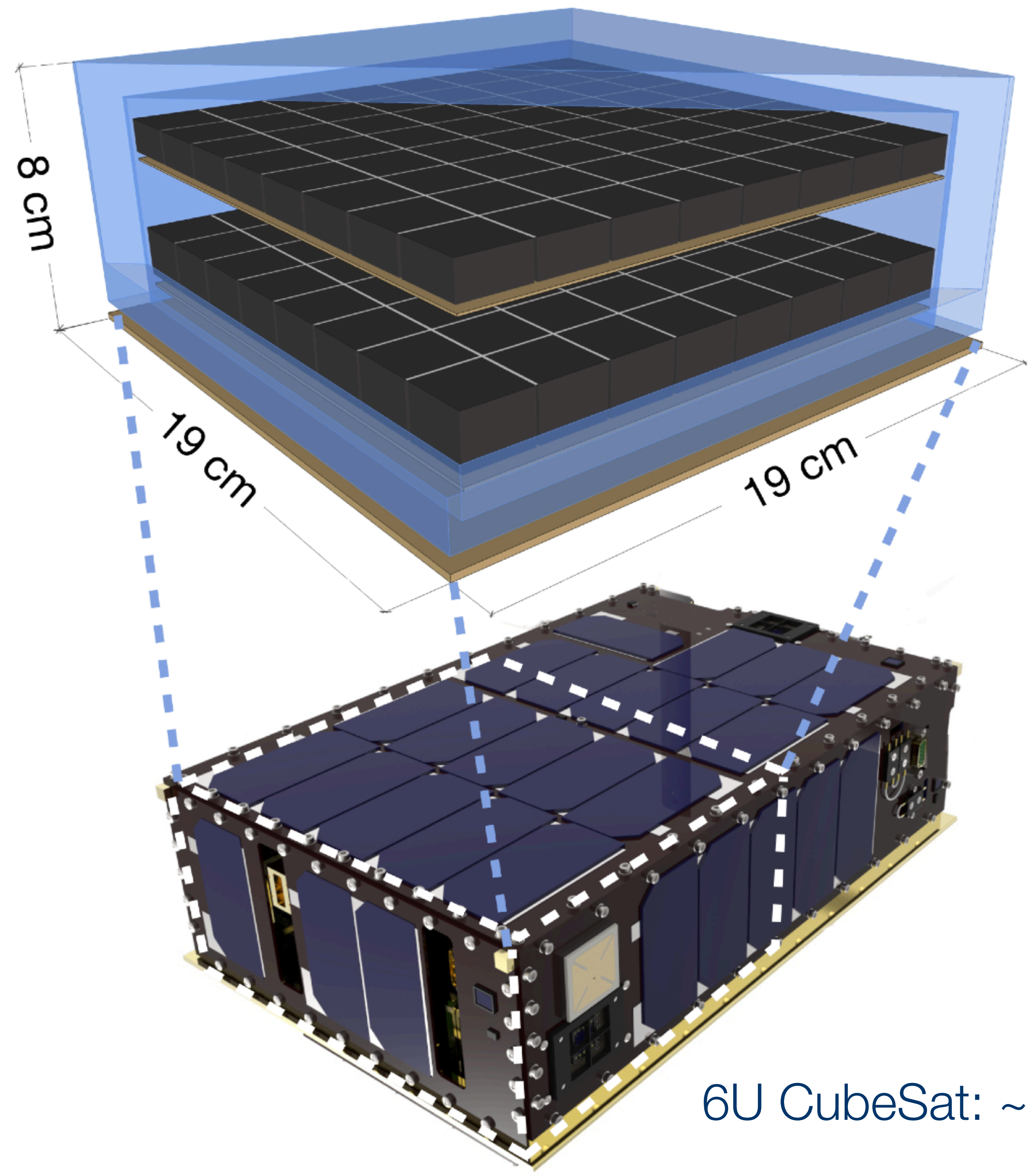
Development of an ultracompact Compton camera for CubeSats

COMPTEL (1991 - 2000)

Weight: 1460 kg
Dimensions: 2.6 m x 1.8 m
Power: 200 W
Energy range: 0.8 - 30 MeV
Energy resolution: 5 - 8% (FWHM)
Angular resolution: 1.7 - 4.4 deg
Effective area: 5 - 30 cm^2
Field-of-view: 1 sr

- Phase 1: R&D project to test feasibility of approach (funded by DSF)

MeVCube



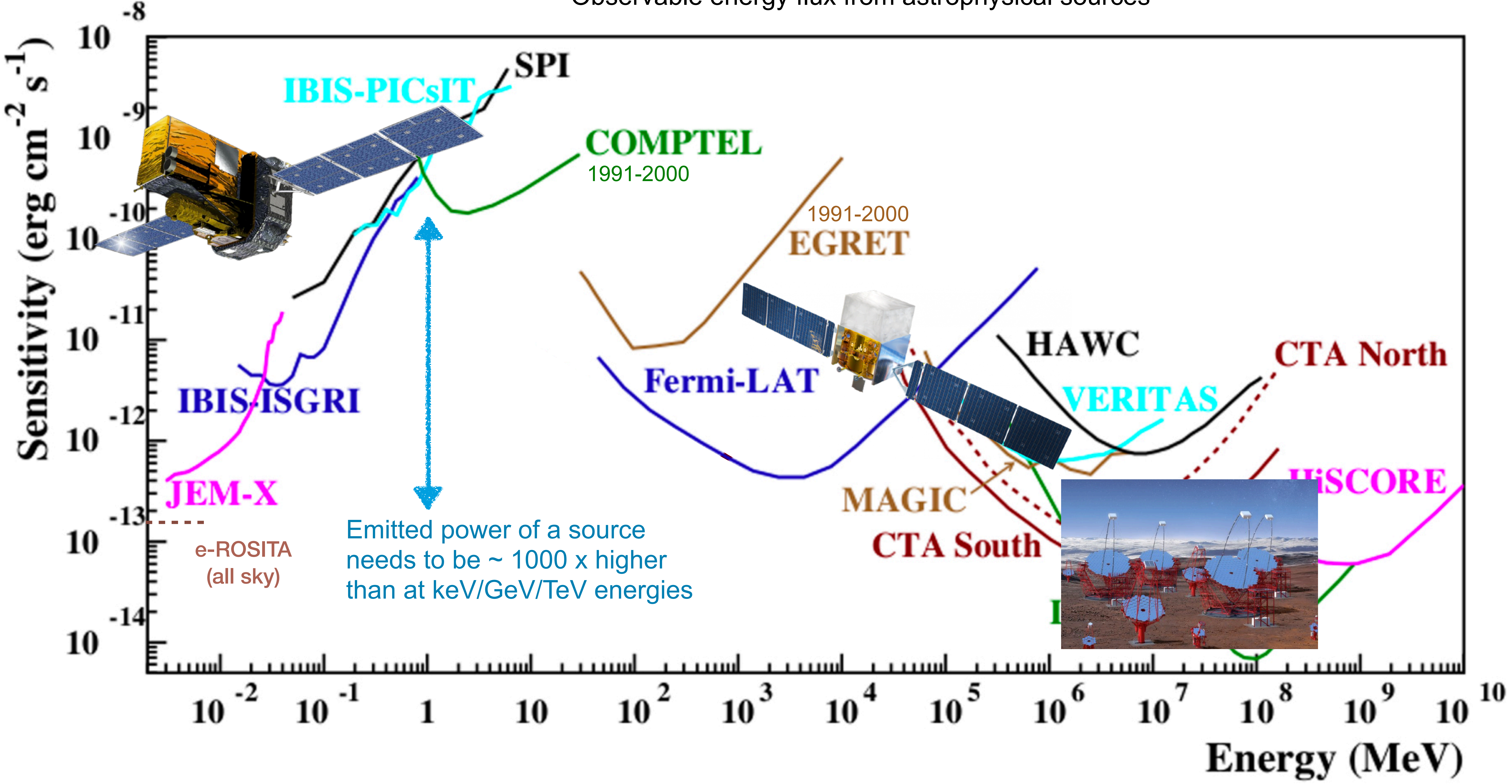
6U CubeSat: ~ 30 cm x 20 cm x 10 cm

- Based on CdZnTe semiconductor detectors
- Each layer consists of a matrix of detector crystals
- Crystal size: 2 x 2 x 1.5 cm^3
- 64 pixels / detector
- Total power: < 5 W

Motivation

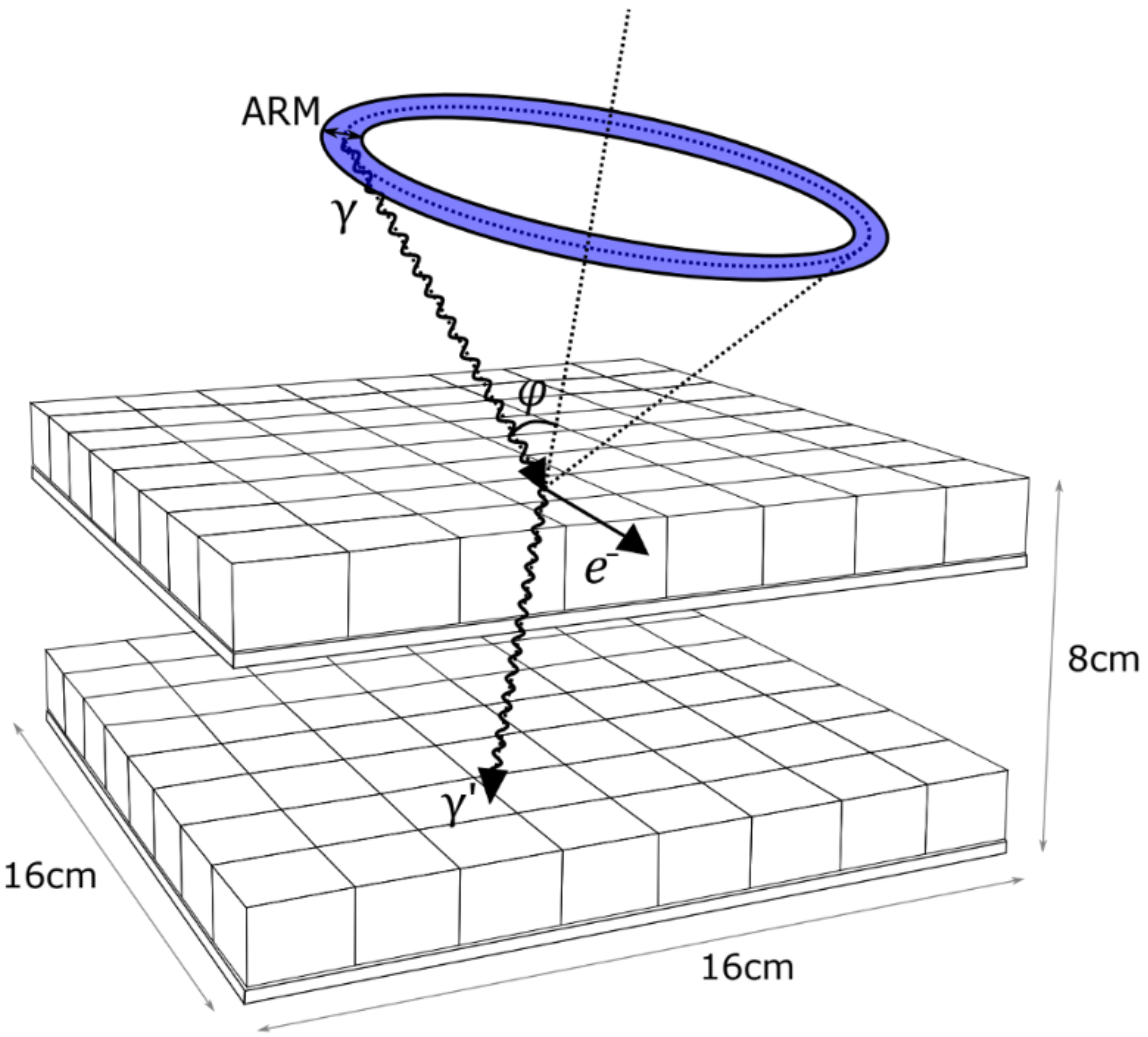
The sensitivity gap at MeV energies

Observable energy flux from astrophysical sources



- Multi-wavelength and multi-messenger observations of astrophysical phenomena need broad coverage of the electromagnetic spectrum
- Spectral lines from radioisotope decays are unique to the high-keV / low-MeV energy range

MeVCube design / performance requirements

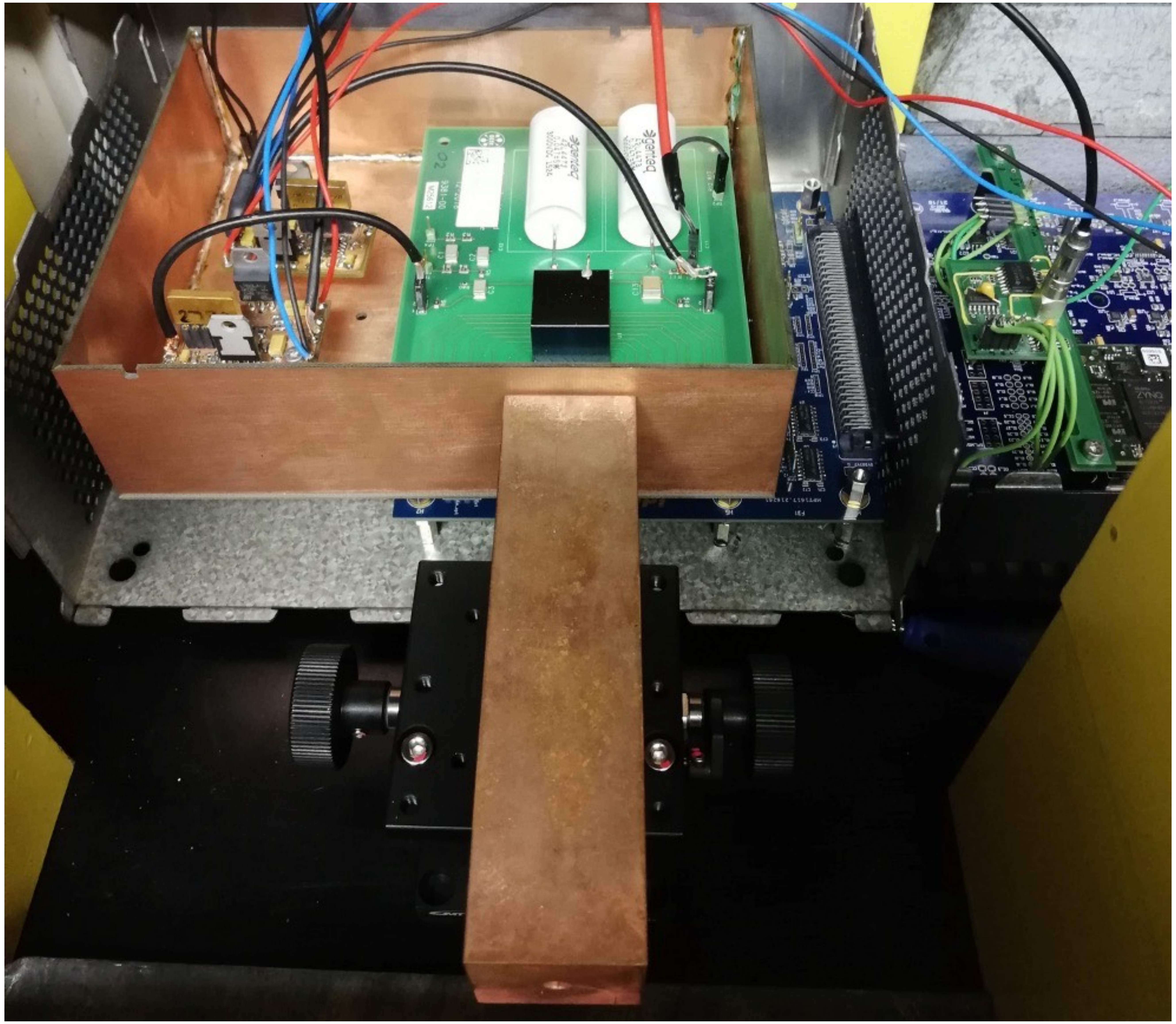


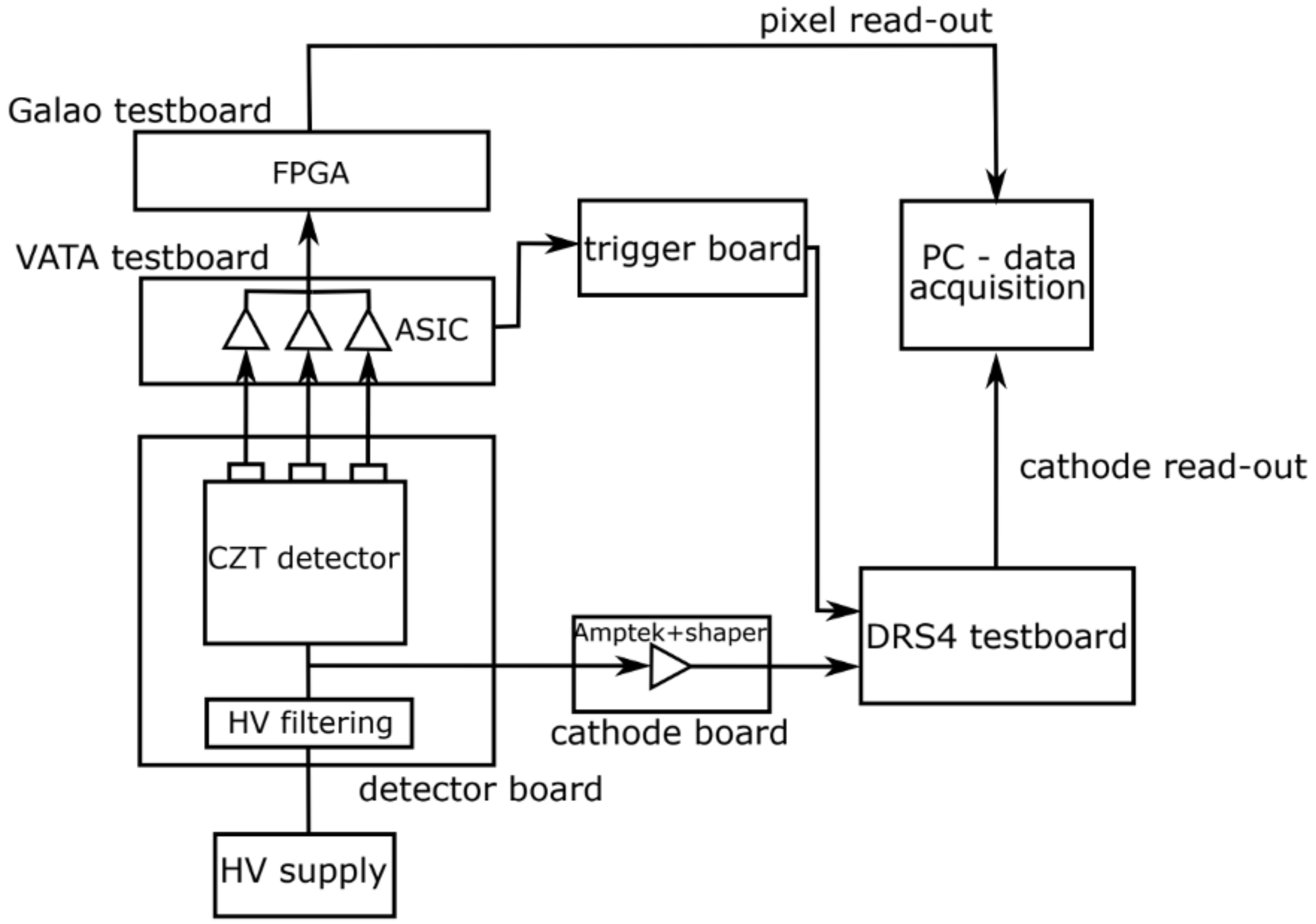
Phase 1: Verify the design requirements in the laboratory

- Cadmium-Zinc-Telluride (CdZnTe or CZT) semiconductor detectors, arranged on two layers
- High atomic number, density and stopping power
- Good spectral and imaging performance

Parameter	Design value
CubeSat model	4 U scientific payload, 6 U complete satellite
Orbit	Low Earth Orbit (LEO), ~ 550 km altitude, $\leq 5°$ inclination
Number of CdZnTe detectors	128 (8x8 pixels each)
CdZnTe detector size	2.0 cm $\times$ 2.0 cm $\times$ 1.5 cm
Pixel pitch	2.45 mm
Pixel size	2.25 mm $\times$ 2.25 mm
Depth resolution (FWHM)	~ 1.8 mm
Energy resolution (FWHM)	$\sim 6.5\%$ at 200 keV, $\sim 2.8\%$ at 662 keV, $\lesssim 2.0\%$ at > 1 MeV
Read-out electronics	VATA450.3 (250 μW / channel)
Total power consumption	< 5 W

Test setup

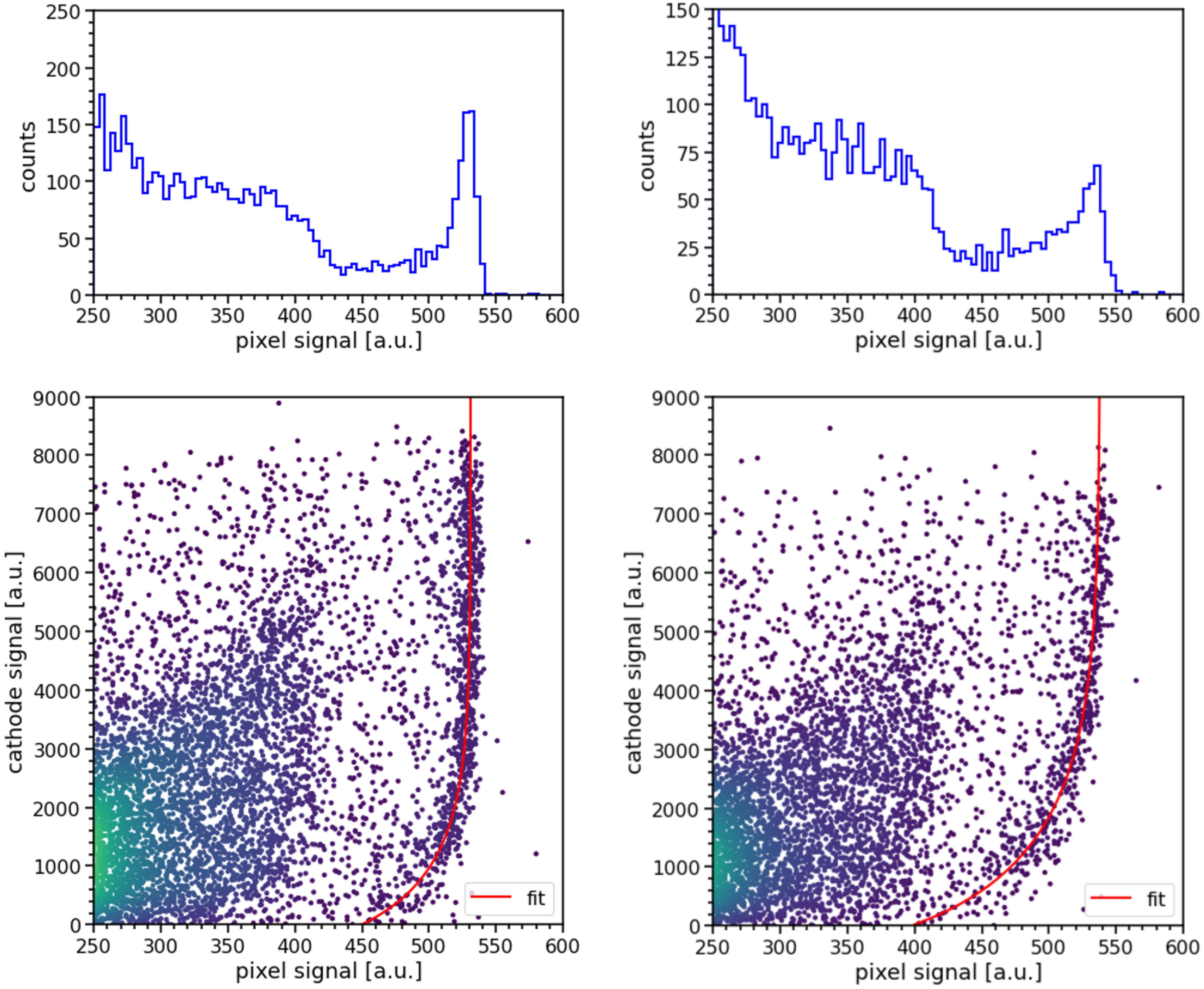




- 64-channel pixel readout with VATA450.3 ASIC (IDEAS)
- Cathode readout with discrete pre-amplifier/ shaper + sampling with DRS4
- Response measurements with Ba-133, Cs-137 and Co-60 radioisotopes
- Copper collimator for depth-of-interaction measurements

Energy resolution measurements

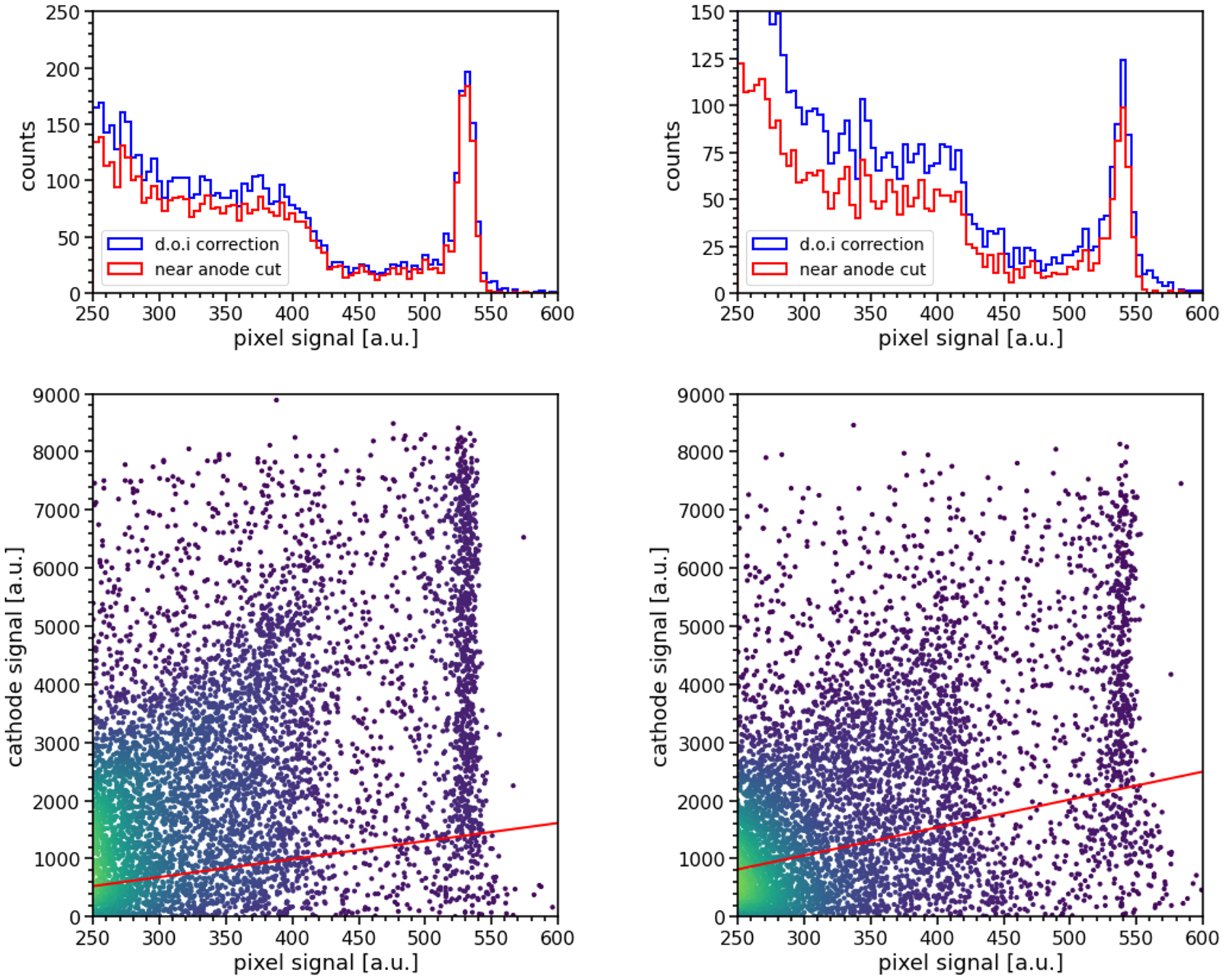
Depth-of-interaction correction



- Measurement of photo-peak of Cs-137 (662 keV)
- Cathode signal proportional to depth-of-interaction
- Non-linear response of pixel signal for interactions in the anode region
- Cathode signal can be used to correct non-linearities and improve energy resolution.

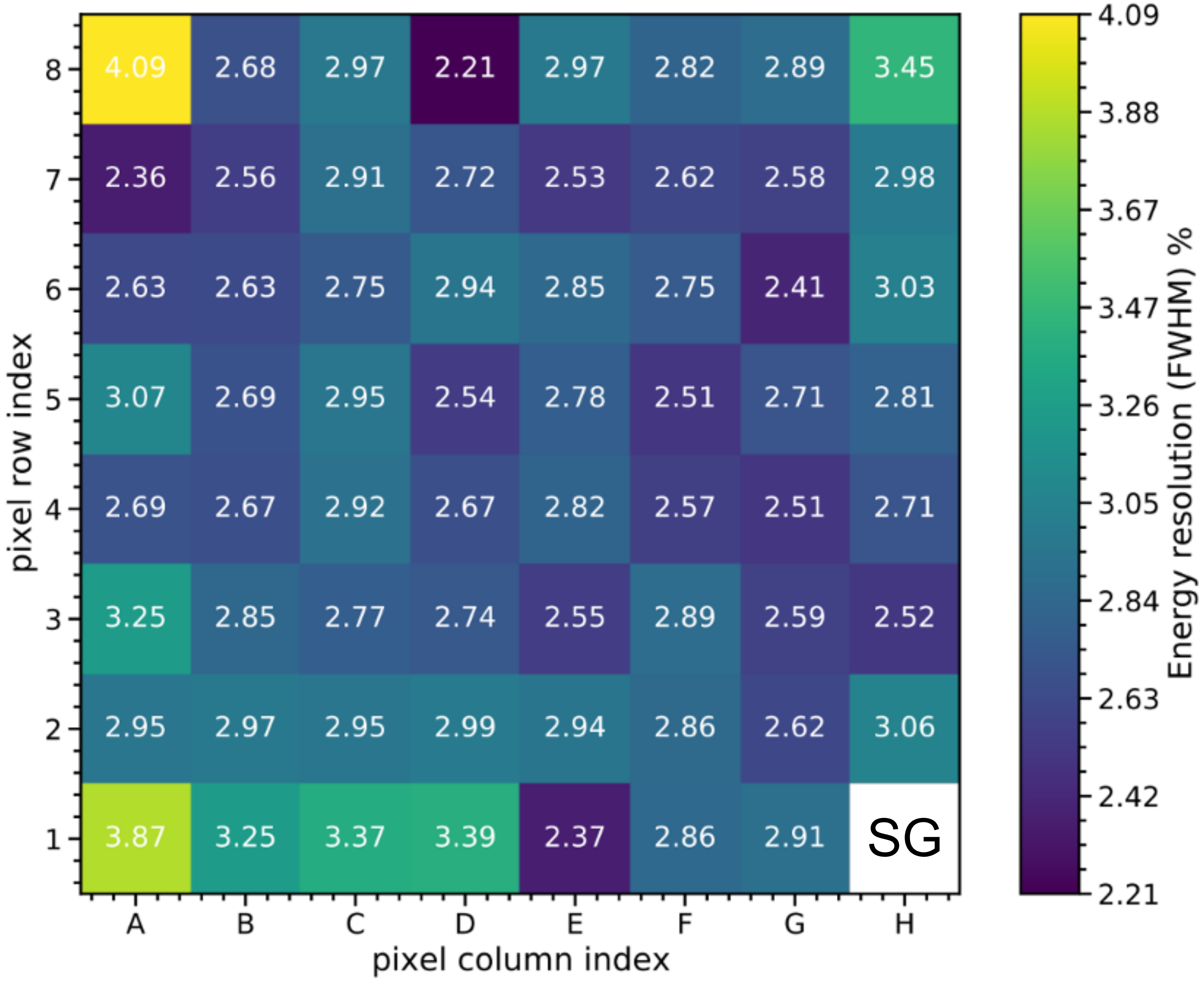
Energy resolution measurements

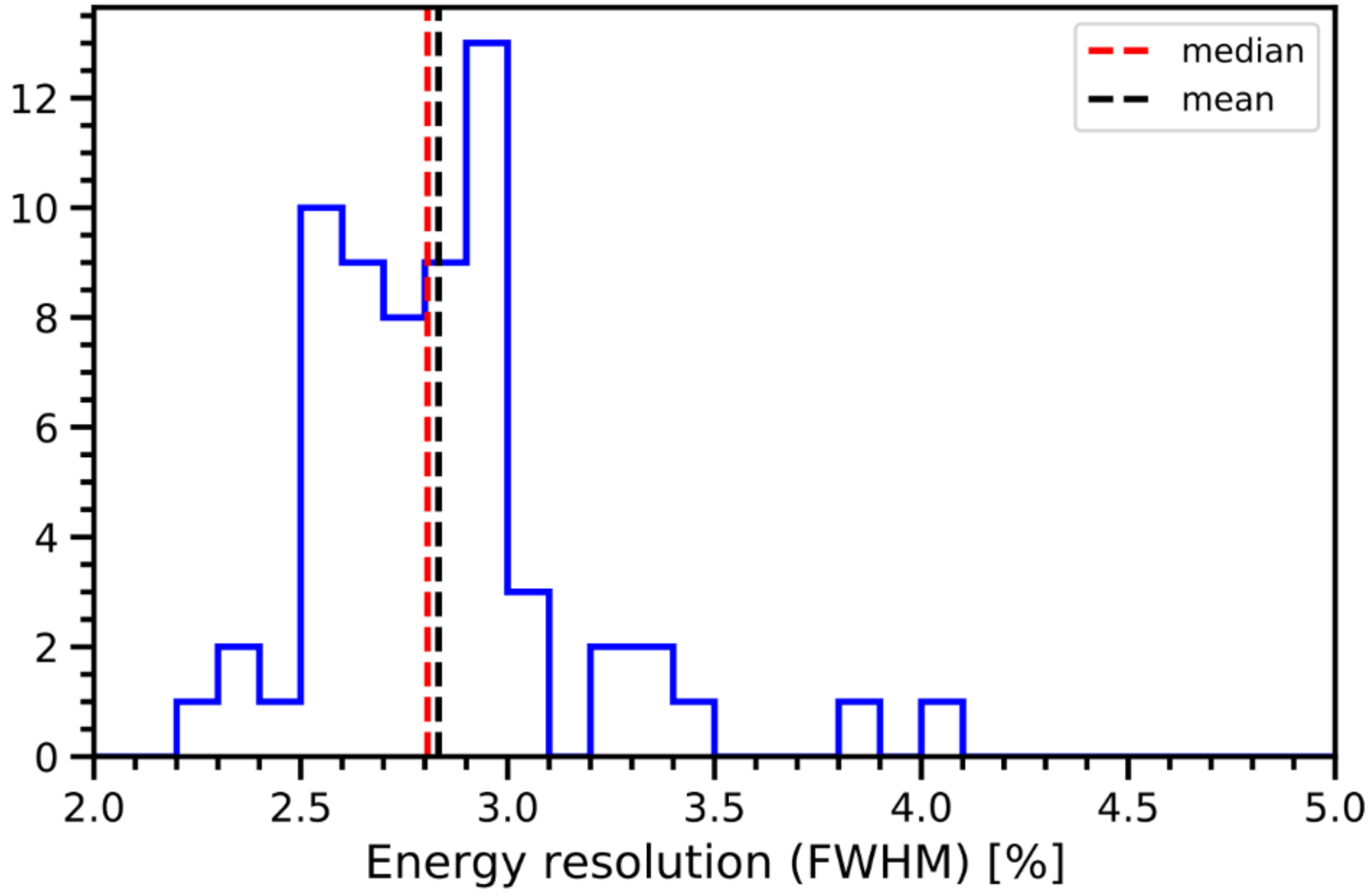
Depth-of-interaction correction

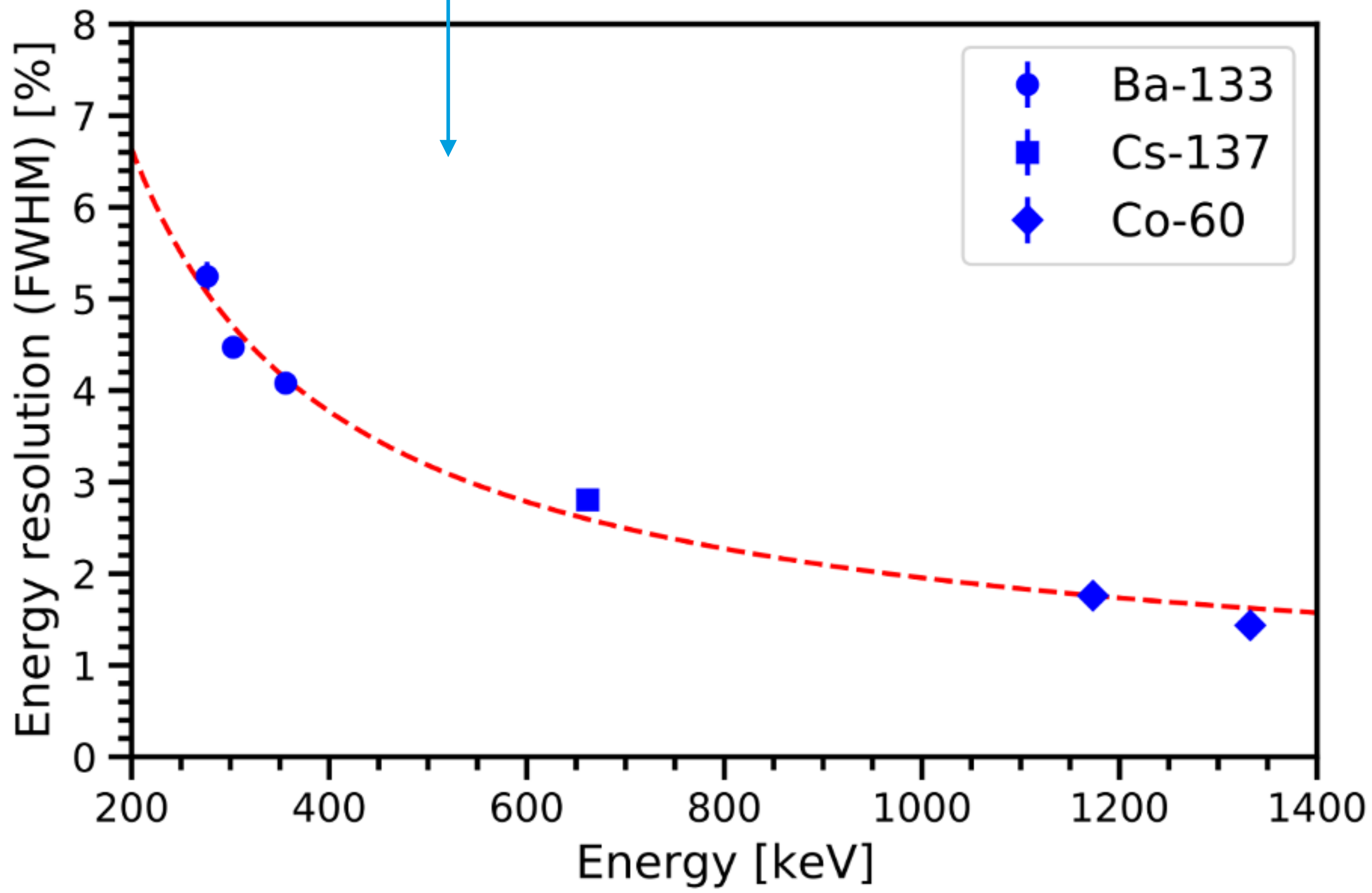


- Measurement of photo-peak of Cs-137 (662 keV)
- Cathode signal proportional to depth-of-interaction
- Non-linear response of pixel signal for interactions in the anode region
- Cathode signal can be used to correct non-linearities and improve energy resolution.
- Removal of near-anode events (10%-20%) further improves the line resolution.

Energy resolution summary



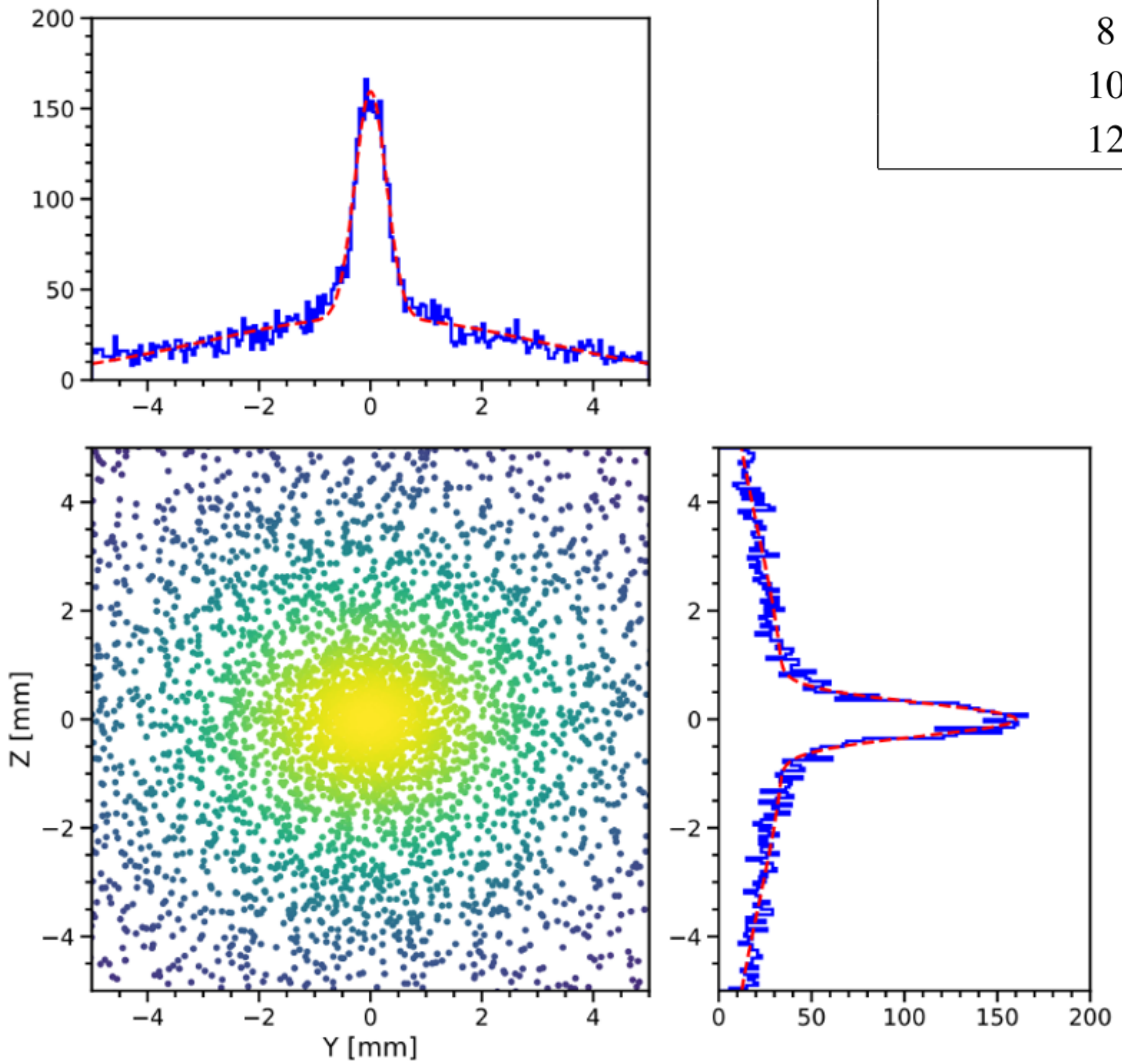


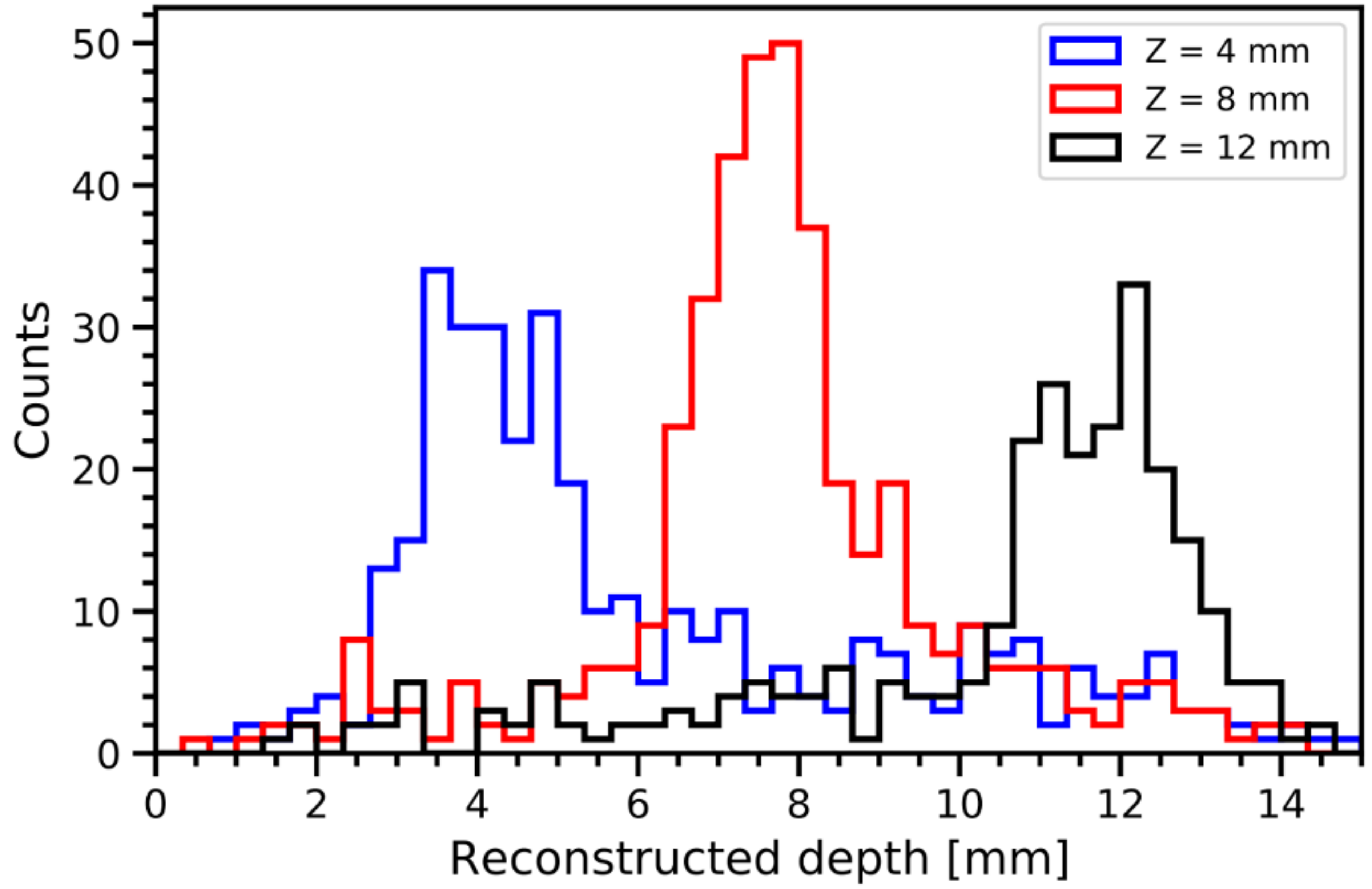


- Energy resolution <3% FWHM at 662 keV for a large majority of pixels (median resolution: 2.8%)
- Energy dependence: 6.5% @ 200 keV, < 2% @ 1 MeV

Spatial resolution

Collimator position [mm]	Reconstructed depth [mm]	R_{tot} [mm] (FWHM)	R_{det} [mm] (FWHM)
4	4.16 ± 0.12	2.10 ± 0.61	1.97 ± 0.64
6	5.89 ± 0.11	2.07 ± 0.54	1.95 ± 0.58
8	7.73 ± 0.08	1.79 ± 0.40	1.65 ± 0.43
10	10.04 ± 0.07	1.88 ± 0.35	1.75 ± 0.38
12	12.12 ± 0.08	2.05 ± 0.31	1.92 ± 0.33





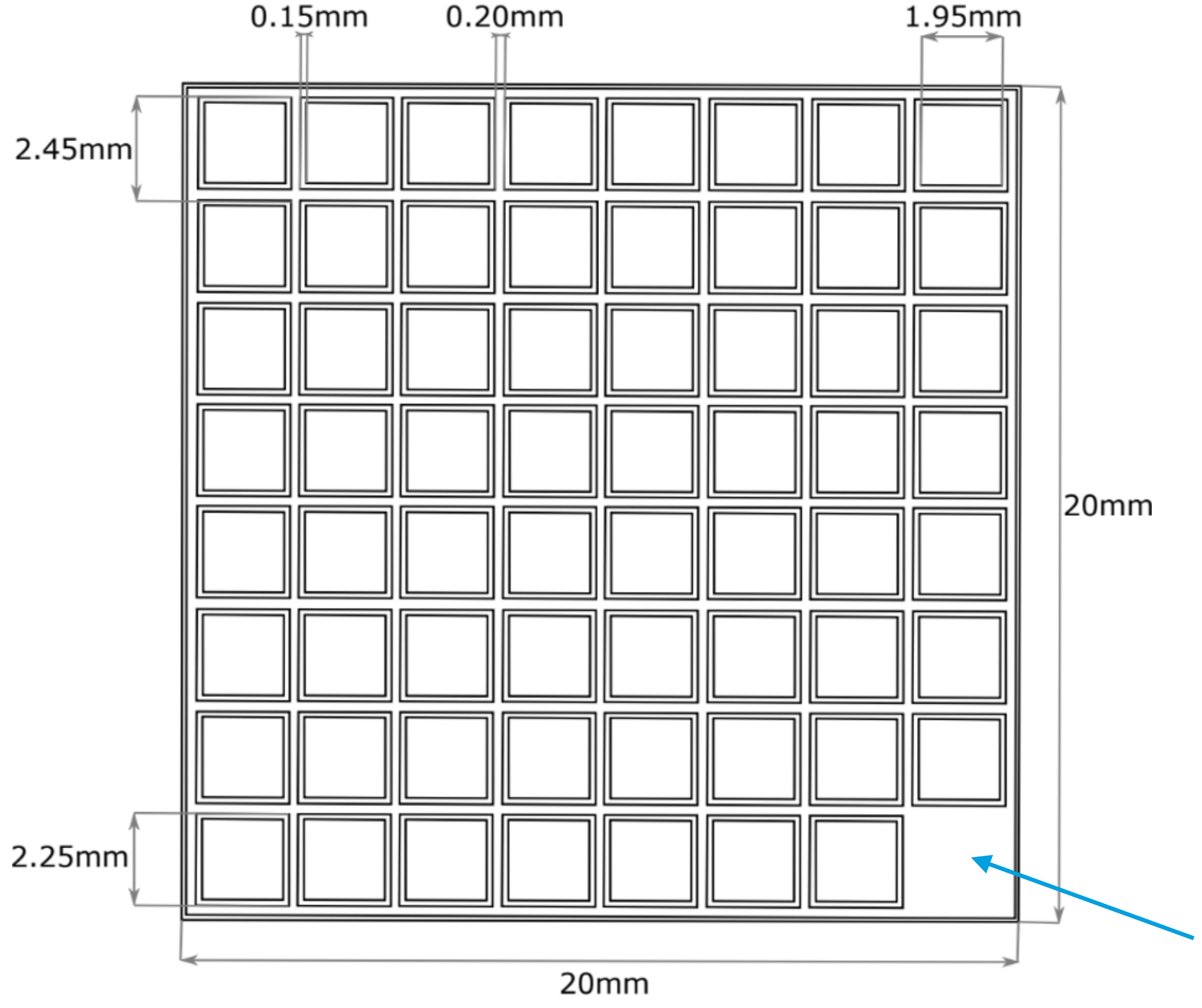
- Measurement with Cs-137 source
- Depth resolution < 2 mm (FWHM)

- Collimator: Cu, 10 cm, 0.5 mm diameter drill hole
- Geant4 Simulation of “illumination” spot

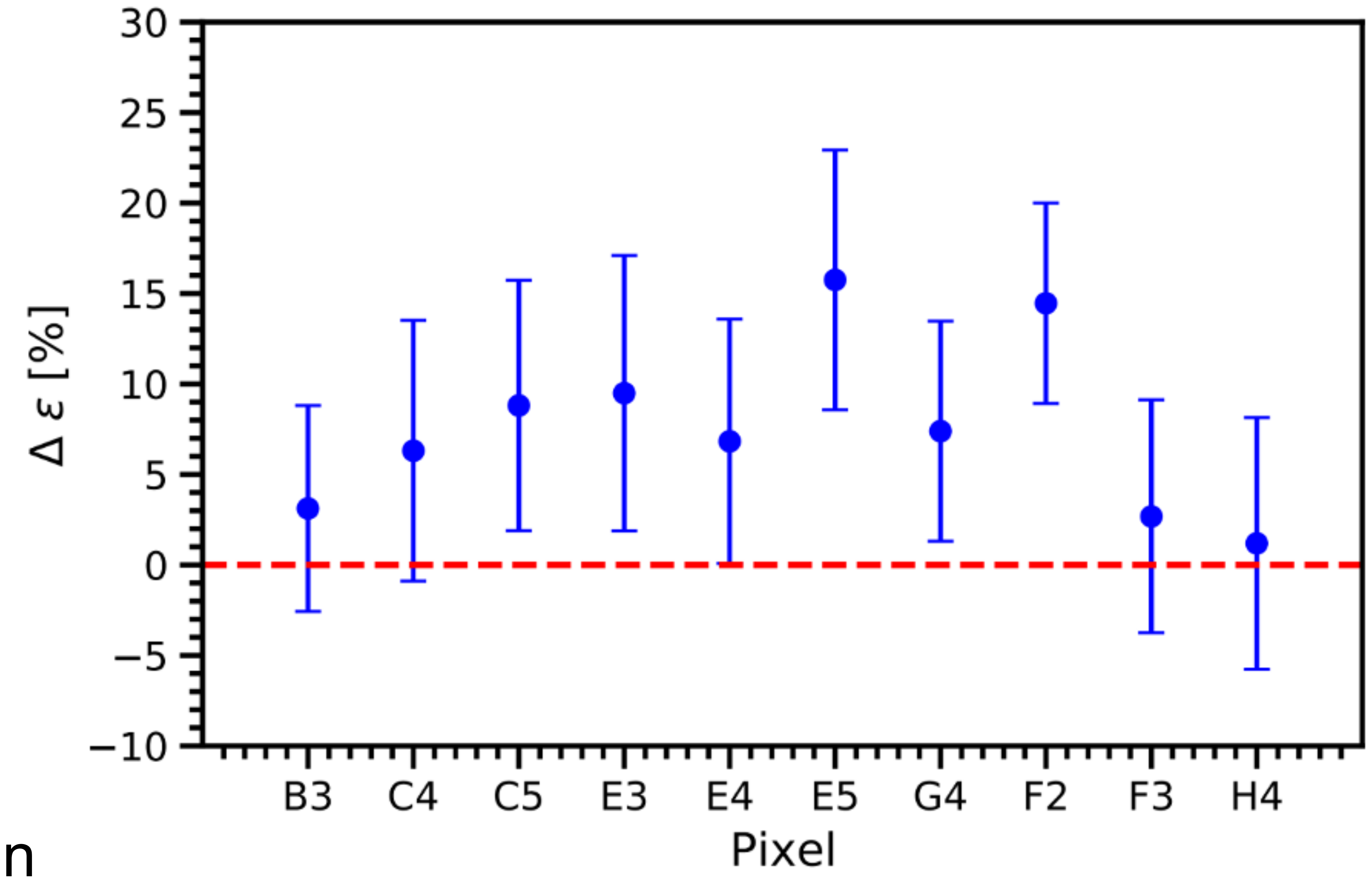
Effects of an anode steering grid

- Pixel H1 is connected to a steering grid that can be biased to facilitate better charge collection in pixels
- Several studies in literature have seen improved efficiency with biased steering grids
- Measurements for several pixels show 0% - 15% improvements
- Efficiency gain is deemed too small to justify the added complexity for the camera design

Layout of anode pixels

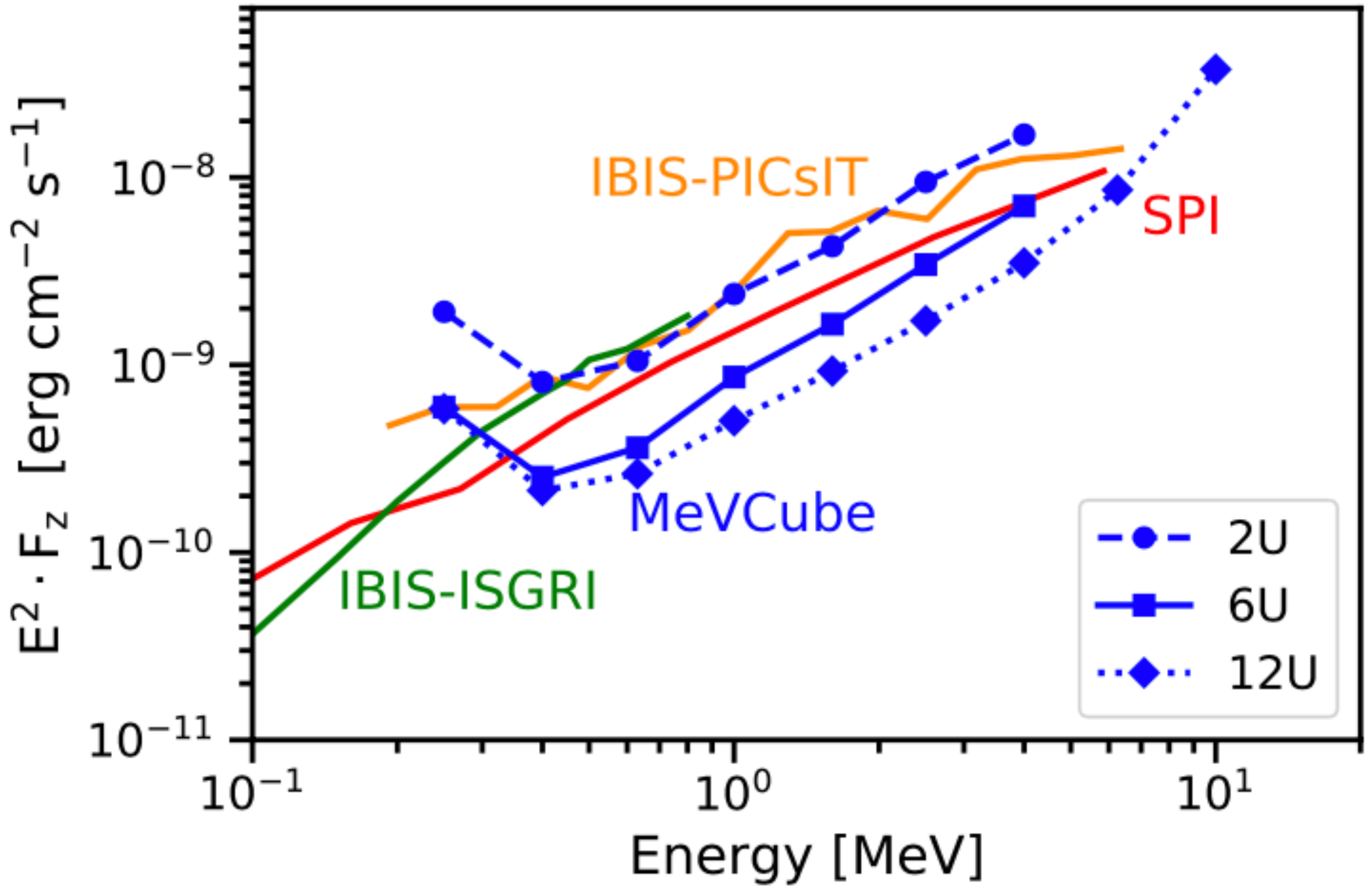


Steering grid connection
Bias voltage: < -100V

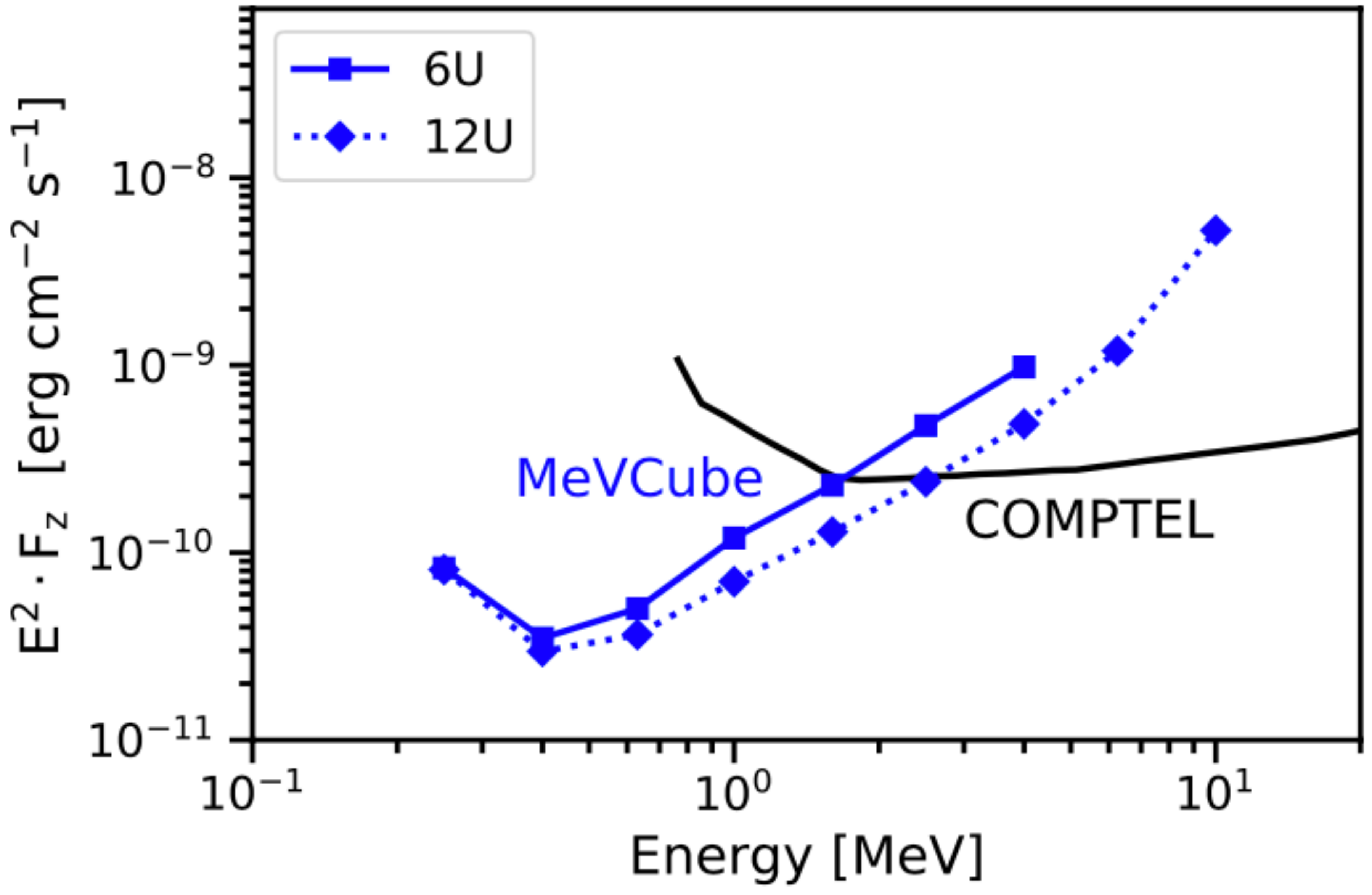


Summary

- We have evaluated the performance of CdZnTe detectors in a laboratory test setup.
- Energy resolution and depth-of-interaction resolution have been measured and are meeting / exceeding the requirements.
- Sensitivities for various CubeSat configurations have been calculated using simulations with input from the measurements.
- The improvements in efficiency from a steering grid are not high enough to justify the added complexity.
- Two papers are (almost) ready for submission.
- Next phase of project has started.



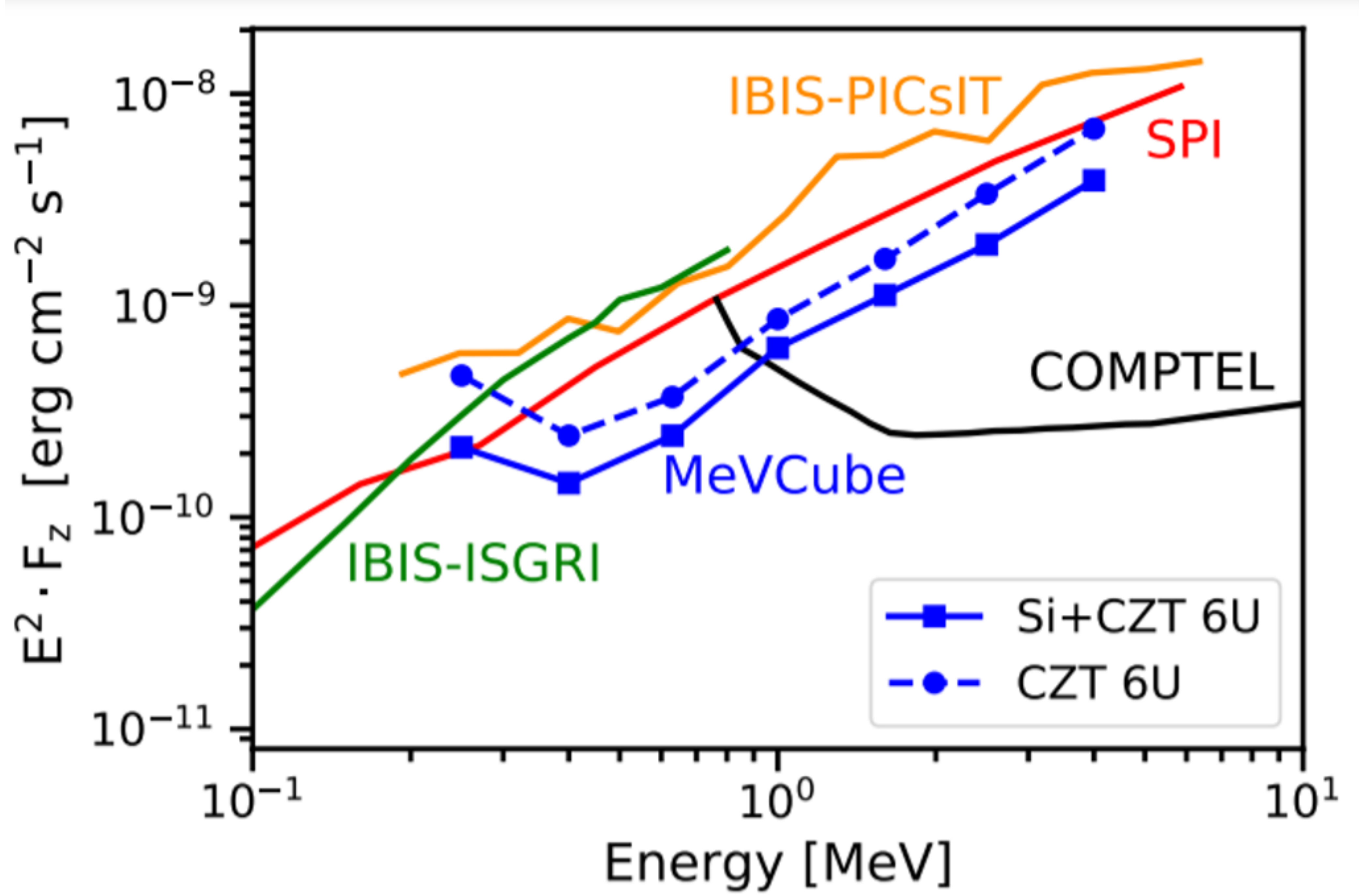
1U = 10 x 10 x 10 cm (CubeSat size)



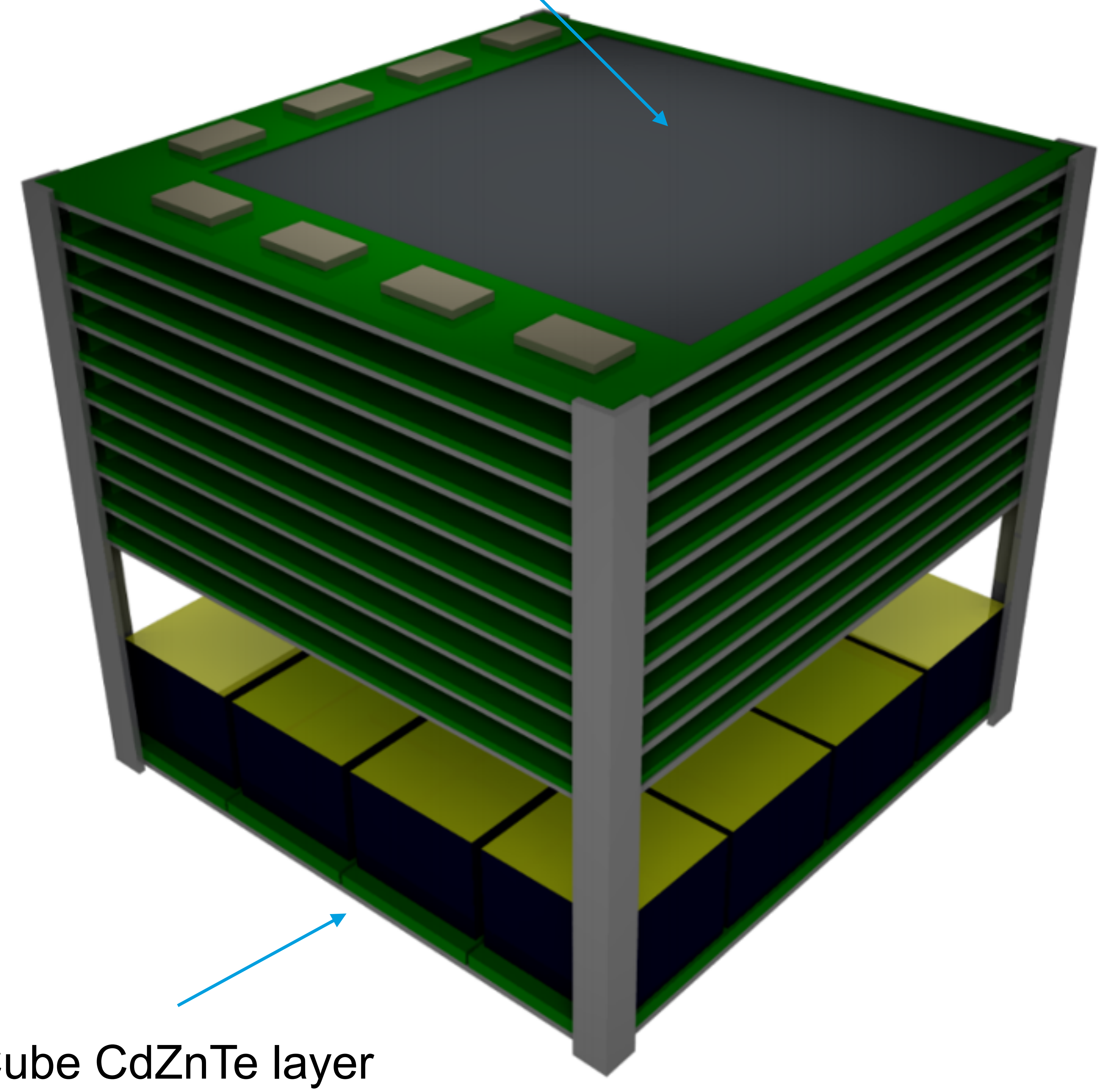
Next step

Phase 2: Development of a full flight-ready camera module

- Successful proposal with IHEP Beijing to DFG and NSFC
- HU/DESY develops the CdZnTe photon absorption layer
- IHEP develops a 10-layer silicon strip detector as interaction layer



Double-sided 500µm silicon strip detectors
7cm x 7cm, 128 strips, VATA 460.3 readout
(Developed at IHEP Beijing)



MeVCube CdZnTe layer