

# 全天MeVガンマ線衛星用

## HV-CMOSピクセルセンサAstroPixの開発 (3)

Development of an HV-CMOS active pixel sensor  
AstroPix for all sky MeV gamma-ray telescopes (3)



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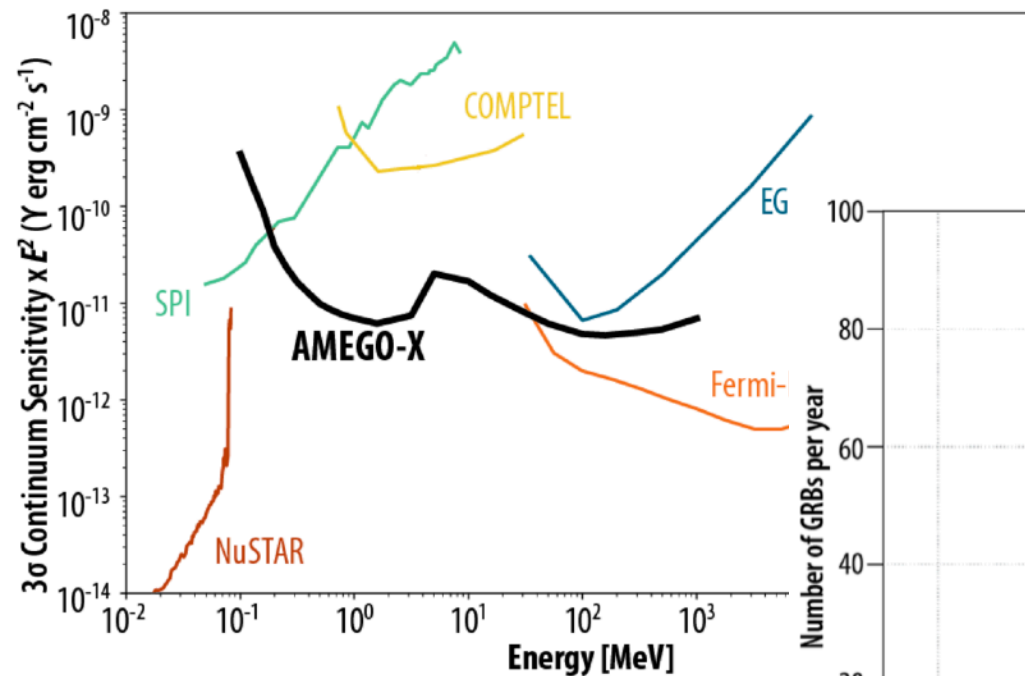
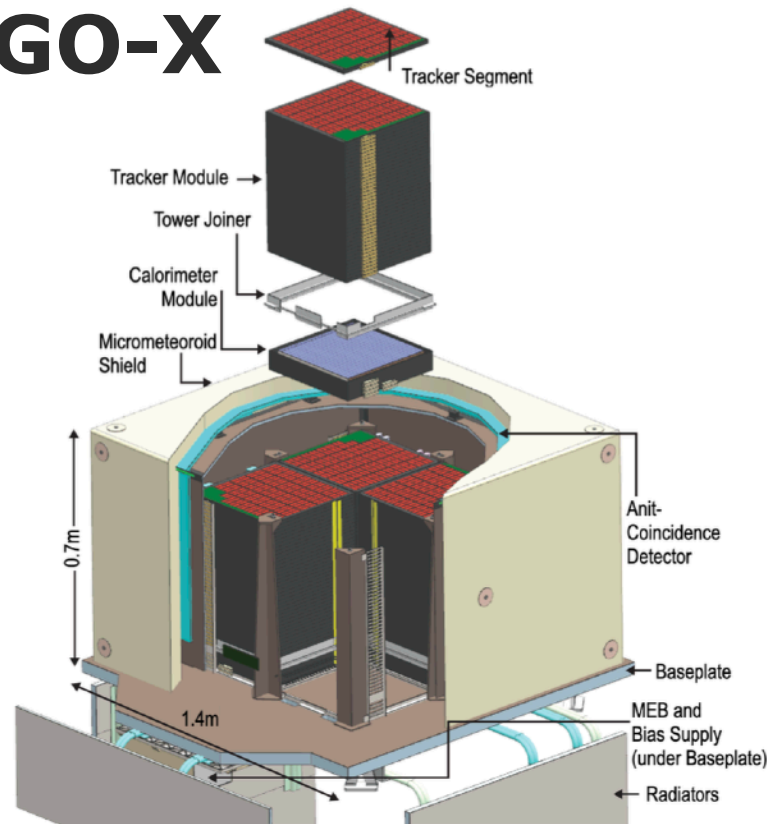


JPS 2024 Autumn Meeting, Hokkaido University  
September 16, 2024

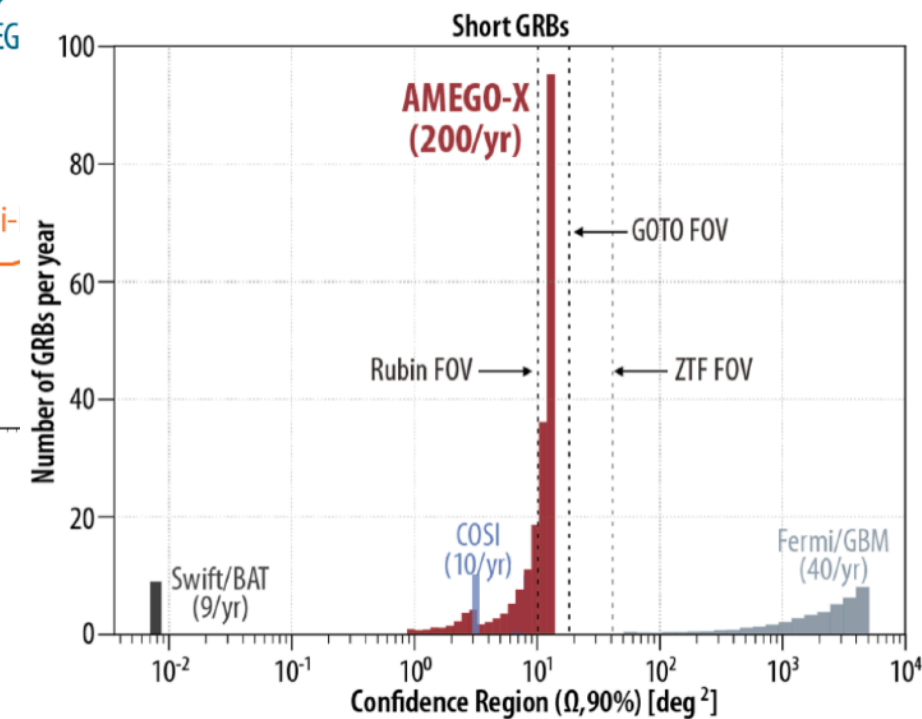
# All-Sky MeV Gamma-Ray Telescope

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## AMEGO-X



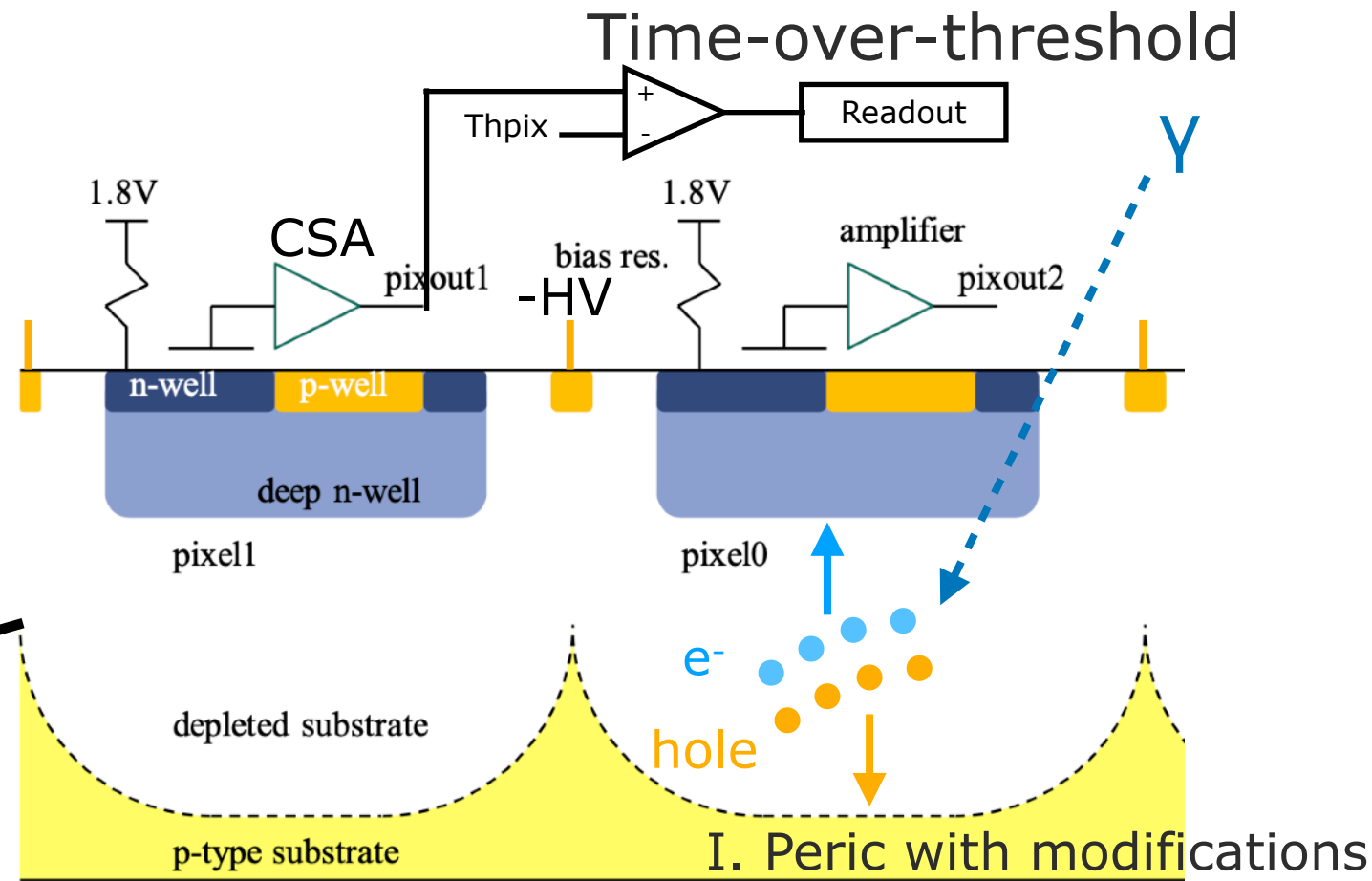
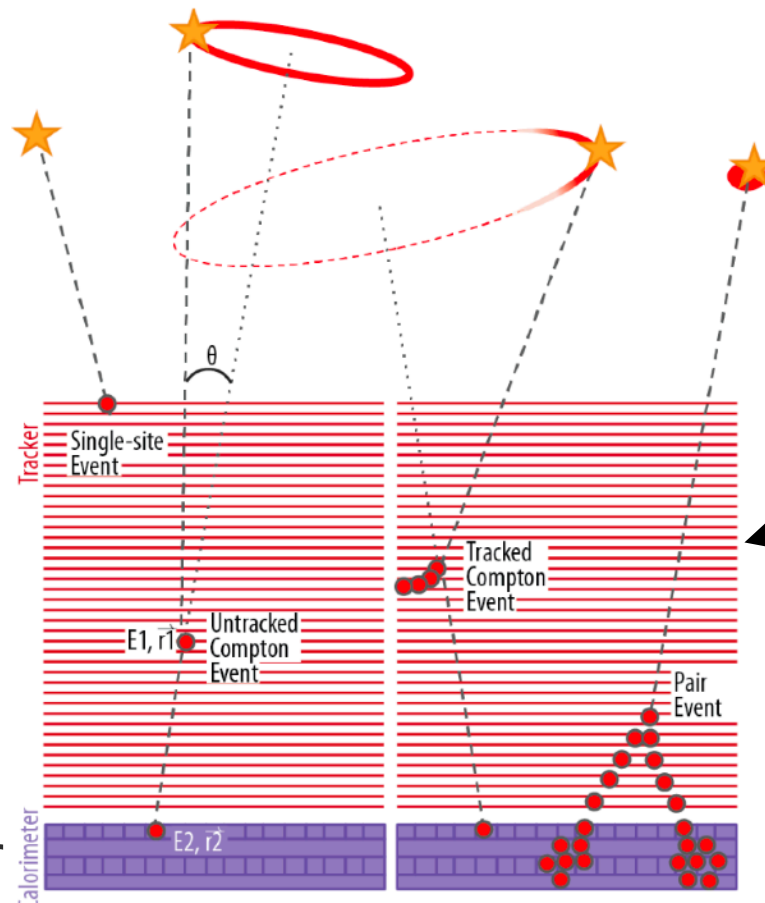
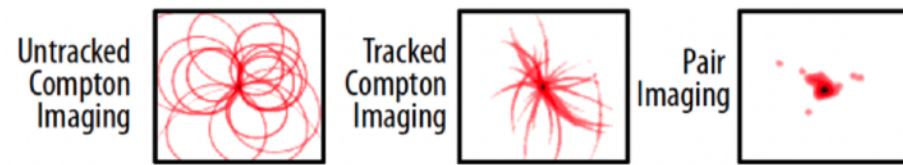
Caputo+22 JATIS



- **All-sky Medium Energy Gamma-ray Observatory eXplorer** (PI: R. Caputo GSFC/NASA) is a proposed MeV mission to study the engines of extreme explosions and extreme accelerators
- Game-changer in high-energy/multi-messenger astronomy
- Not selected in NASA MIDEX2021 due to missing key developments (AstroPix, event reconstruction)
- Aim to resubmit in next MIDEX call  $\sim 2027$

# AstroPix: Novel Pixel Sensor

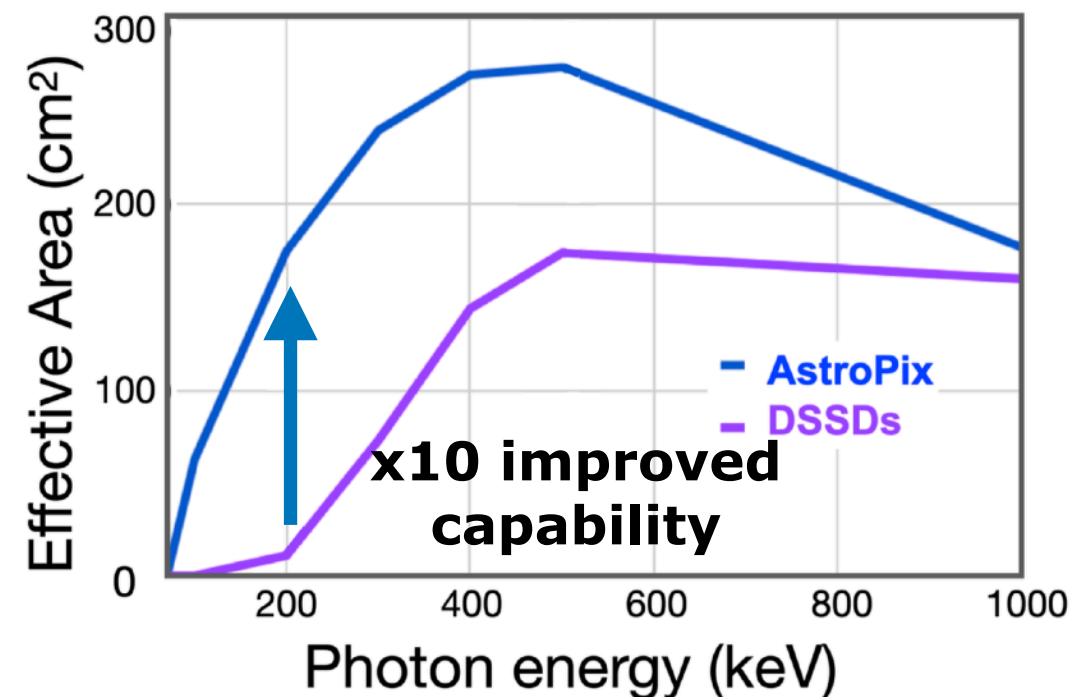
3



Tracker

Calorimeter

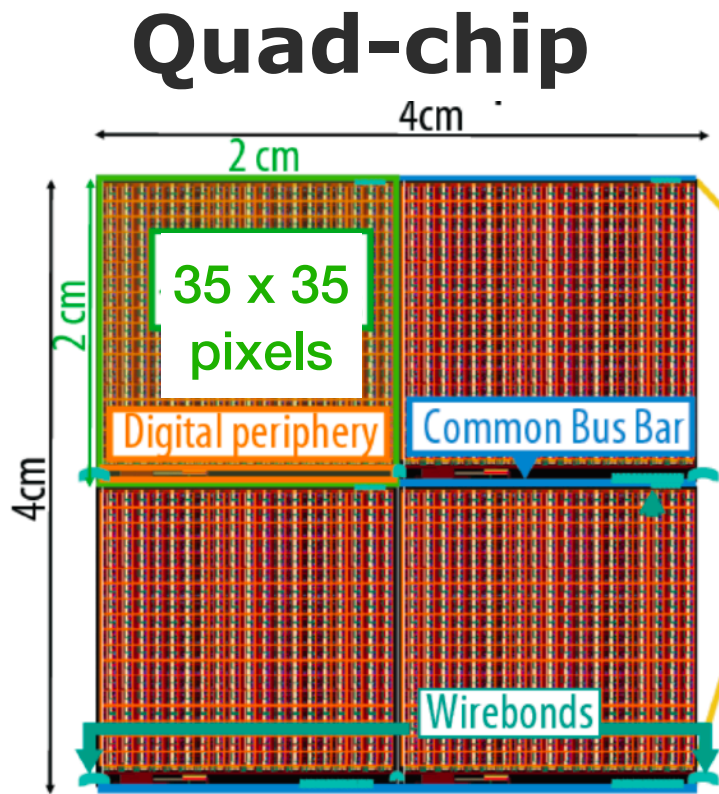
- New HV-CMOS active pixel sensor
- HV → Large sensitive layer
- CMOS → Low noise readout
- Low power consumption





# AstroPix Development

## Goal



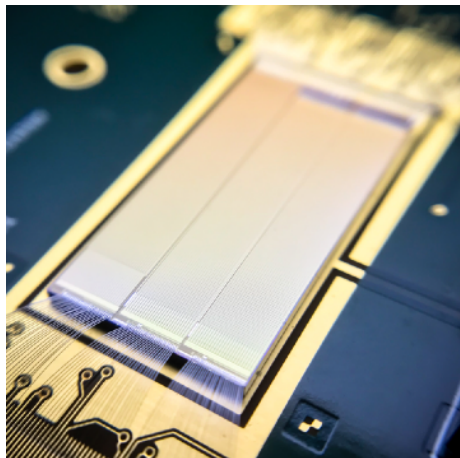
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Power consumption	<1.5 mW/cm <sup>2</sup>
Pixel pitch	500 × 500 μm <sup>2</sup>
Thickness	500 μm
Dynamic range	25 keV–700 keV
Energy resolution	<10% (FWHM) at 60 keV

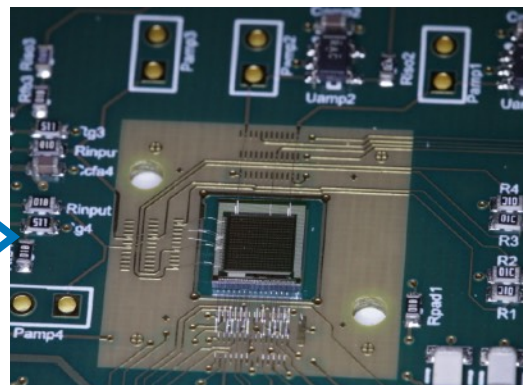
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→ **AMEGO-X, ePIC at EIC**

## ATLASPix

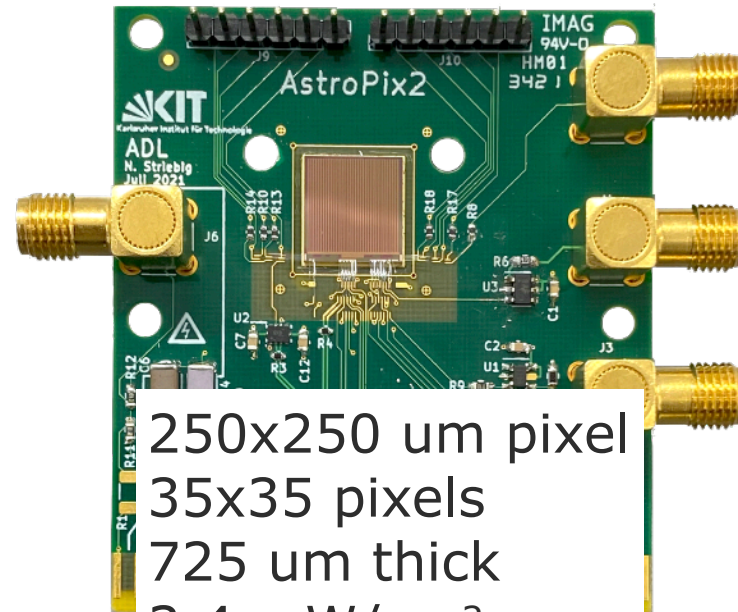


## AstroPix1



175x175 μm pixel  
18x18 pixels  
725 μm thick  
14.7 mW/cm<sup>2</sup>

## AstroPix2



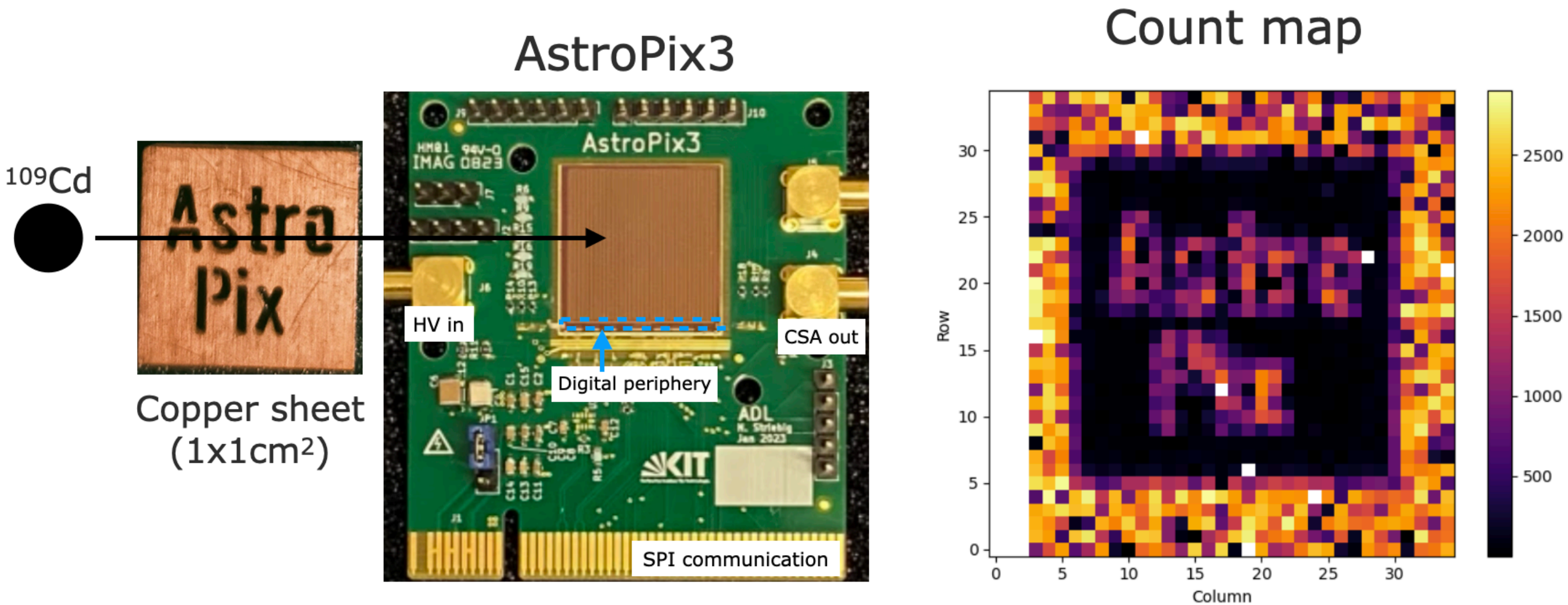
250x250 μm pixel  
35x35 pixels  
725 μm thick  
3.4 mW/cm<sup>2</sup>

## AstroPix3 tested

**AstroPix4**  
under test

**AstroPix5**  
To be submitted

# AstroPix3

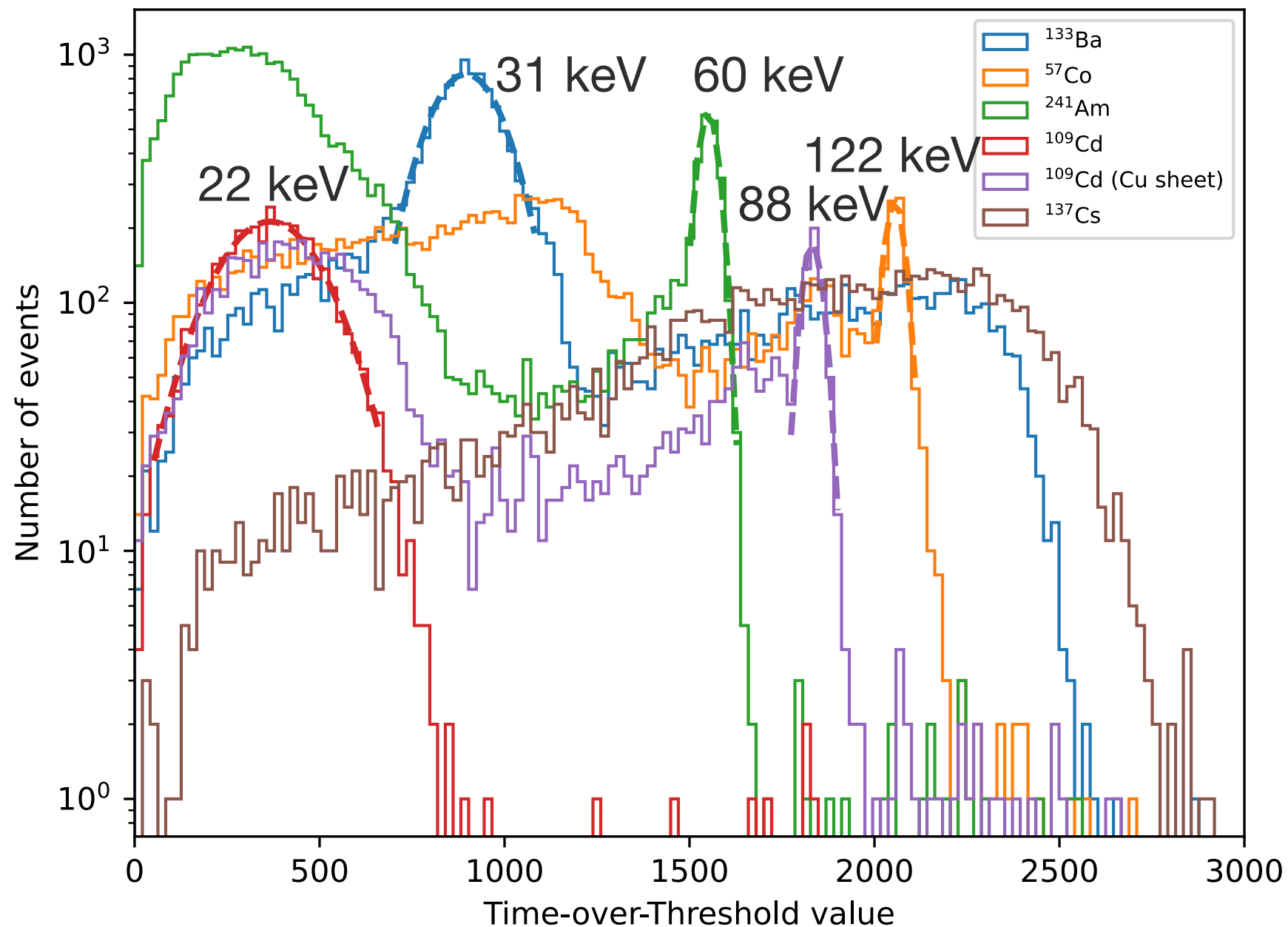


- Full reticle chip: 2 x 2 cm<sup>2</sup>. 725 um thick
- Matrix: 35 x 35 pixels
- Pixel pitch: **500 um** (pixel size 300 um to reduce capacitance)
- Power consumption: 4.12 mW/cm<sup>2</sup>
- Full digital readout capability

Suda+24 NIMA

# Energy Spectra in ToT

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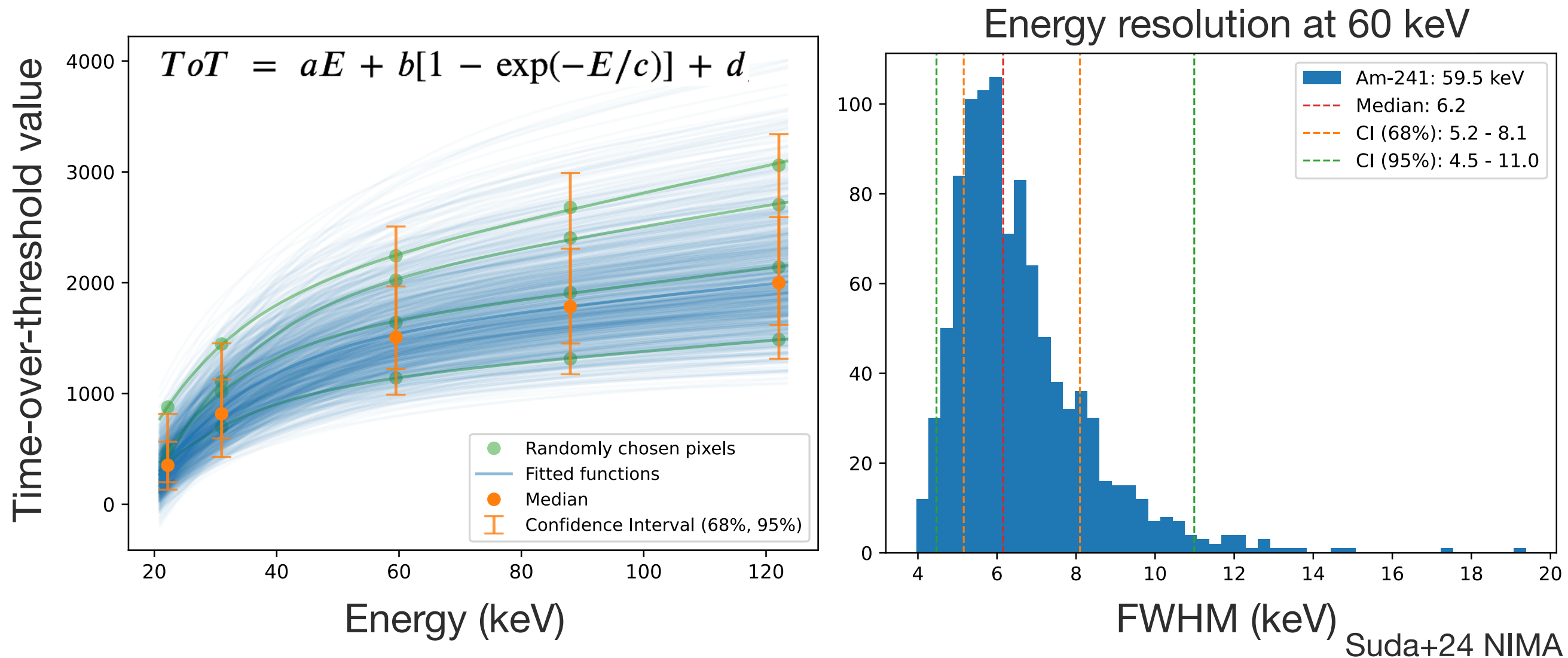


Suda+24 NIMA

- Photopeaks can be seen in 22 - 122 keV range
- 92% of the tested pixels show 22 keV peak  
→ Lower limit of the dynamic range (25 keV) is satisfied



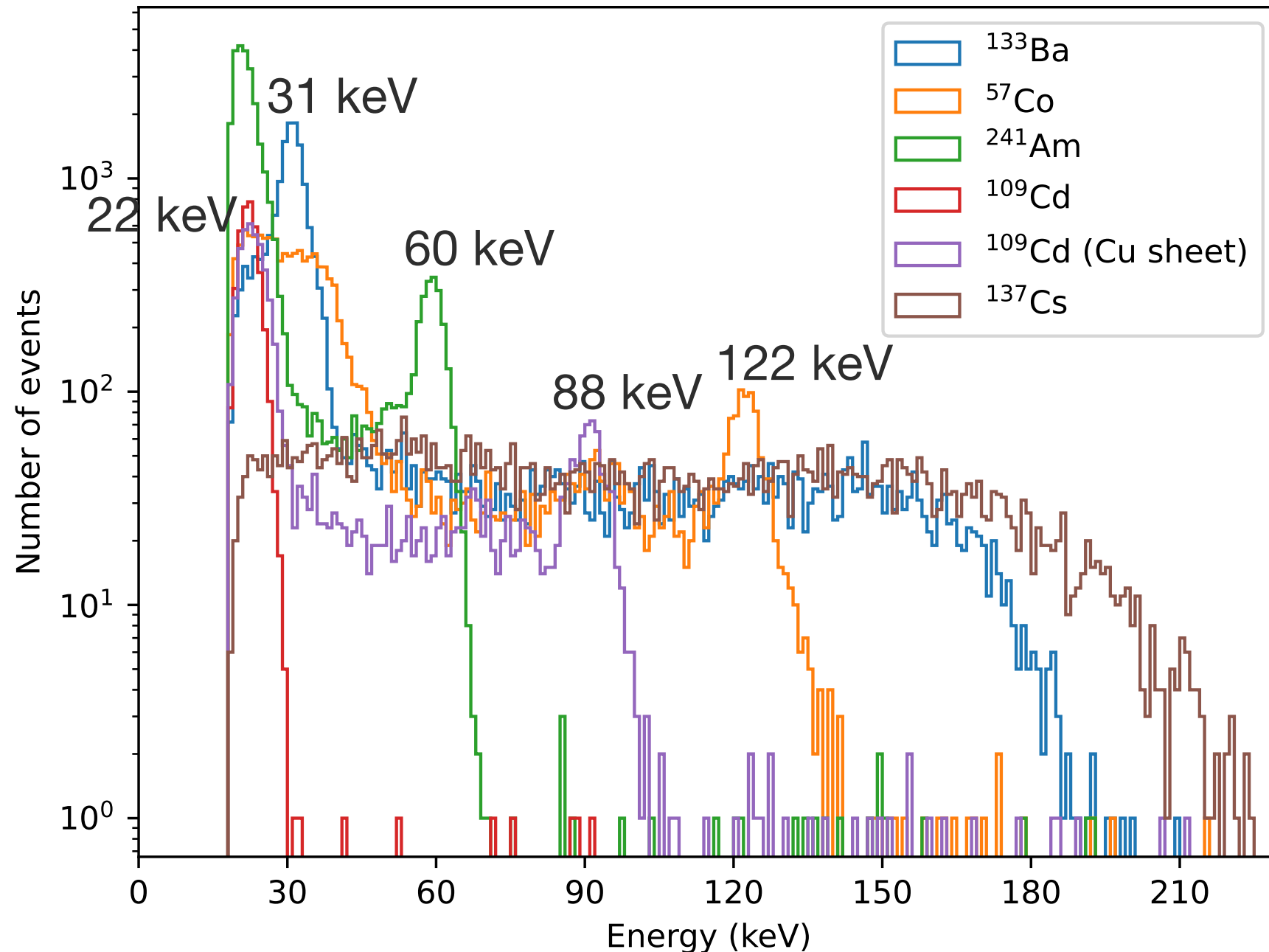
# Energy Calibration



- Energy calibration over the full sensor
  - 90% of the tested pixels are calibrated
- Energy resolution (FWHM) @ 60 keV: 6.2 keV
  - 44% of the calibrated pixels satisfy the requirement

# Calibrated Energy Spectra

8



Suda+24 NIMA

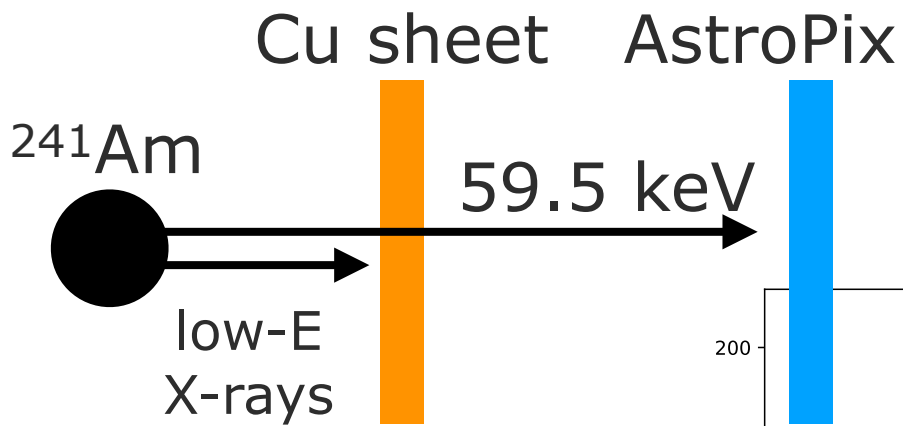
- The high energy component in  $^{133}\text{Ba}$  could be Compton edge for higher energy photons, such as 302.9 keV and 356.0 keV (the Compton edges for those photons are 164.3 keV and 207.3 keV, respectively)
- Dynamic range: 22 - 122 keV or  $\sim 200$  keV, assuming the calibration curves are also applicable at energies above 122.1 keV



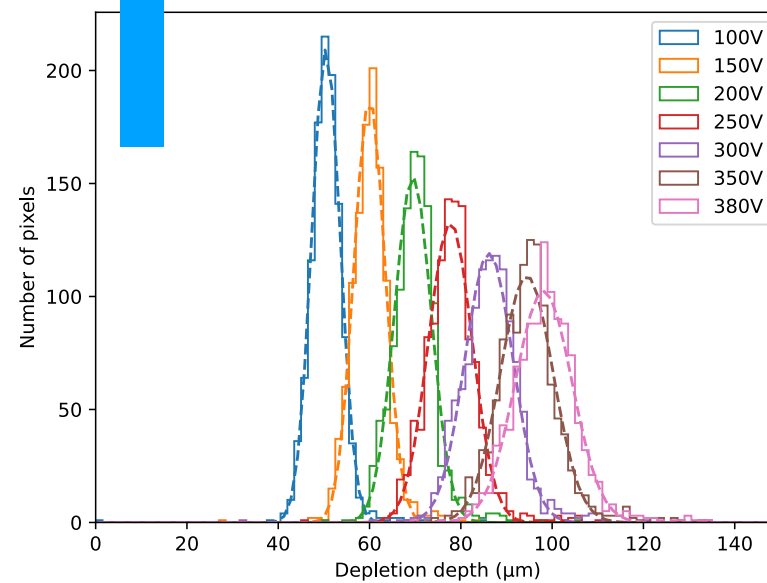
# Depletion Depth Measurements

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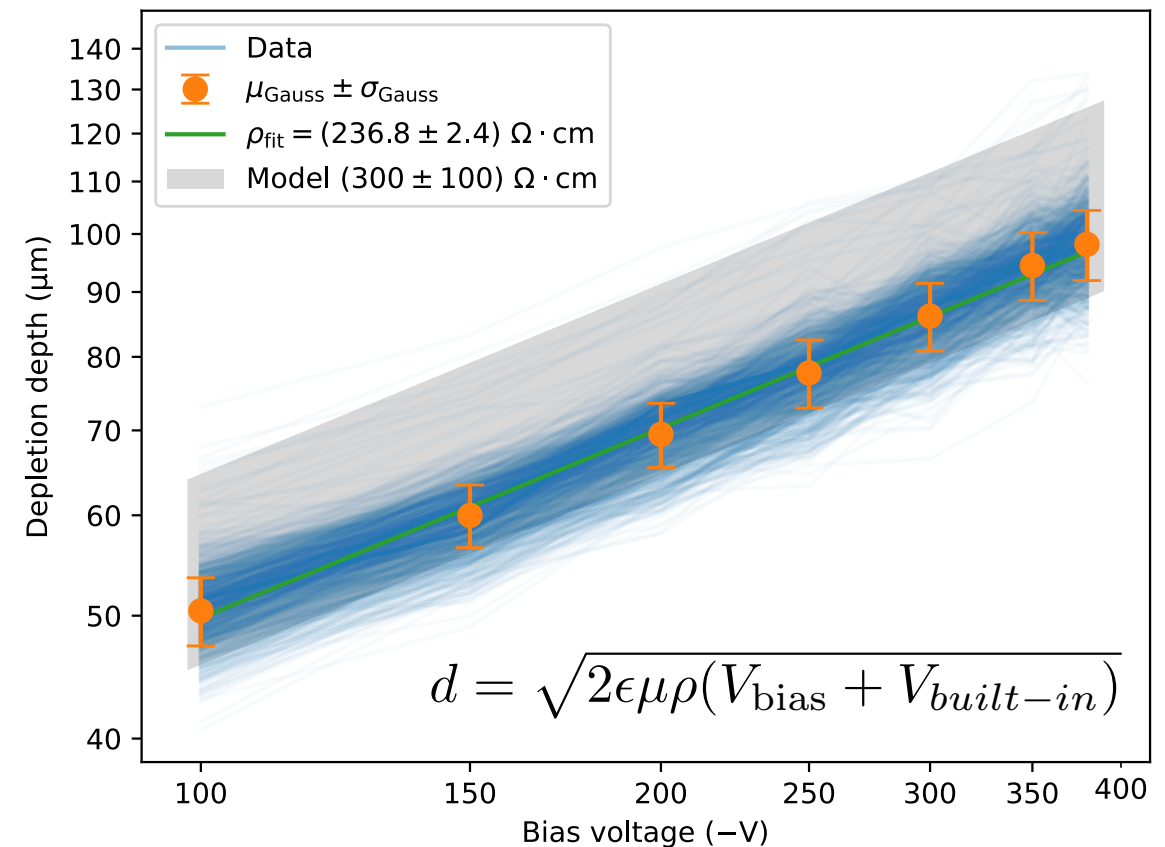
Setup



Detailed method in  
[Suda+24 NIMA](#)

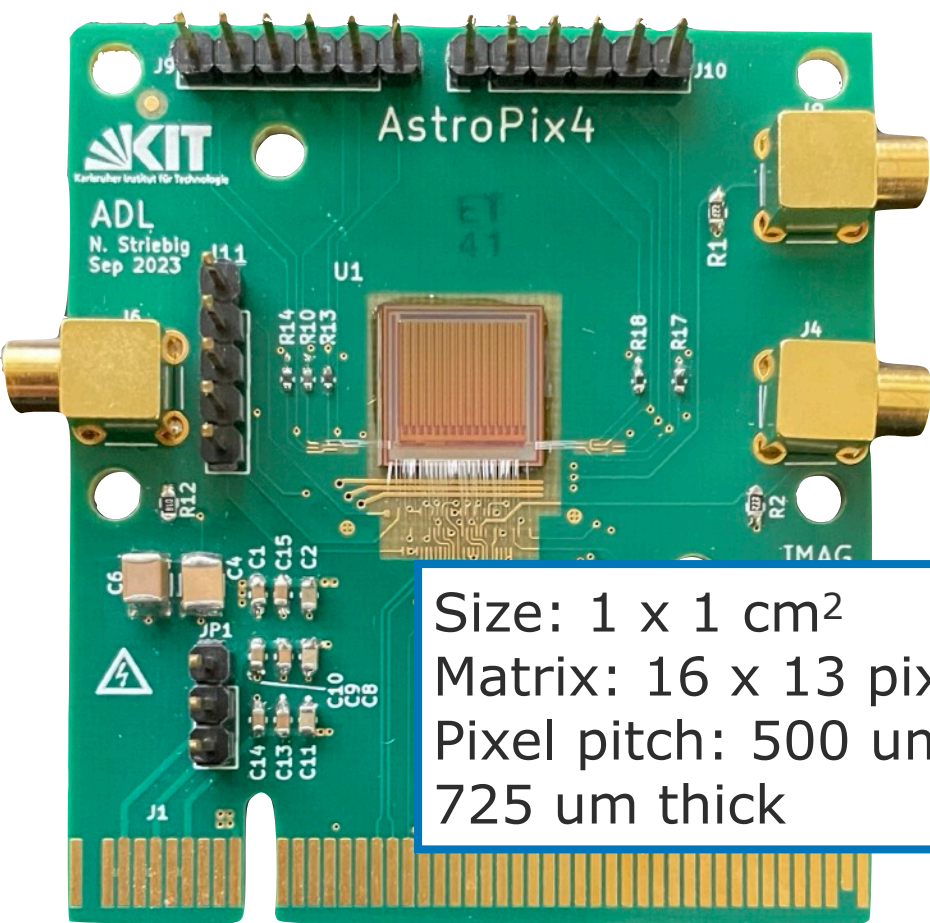


Depletion depth vs. Bias voltage

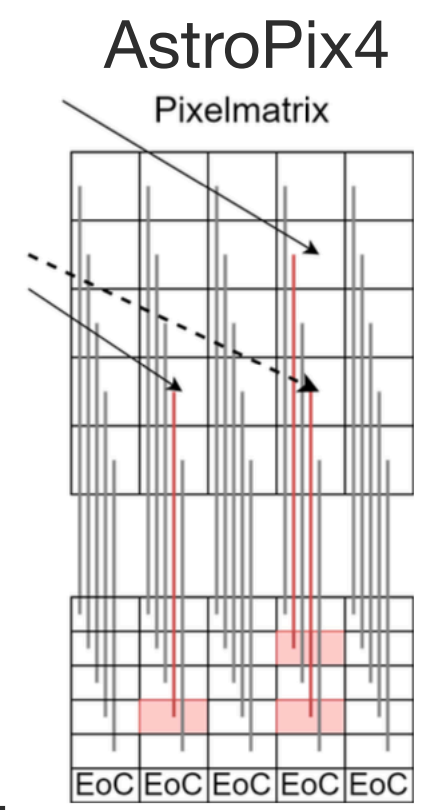
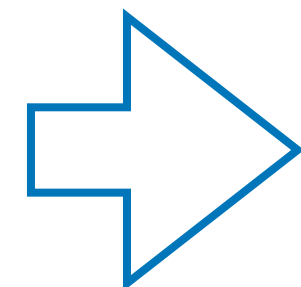
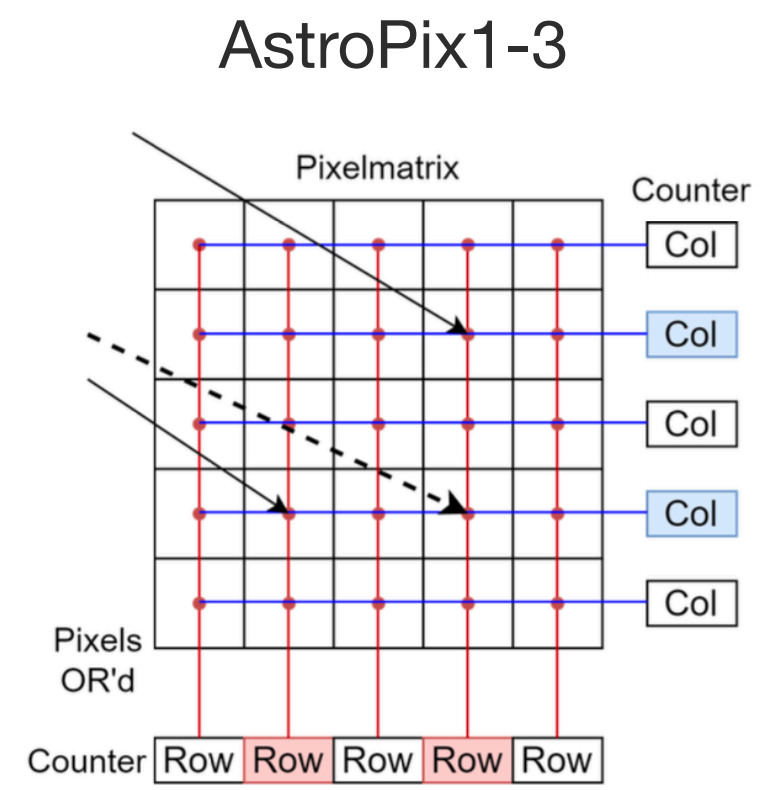


- Estimate from the detection rate of  $^{241}\text{Am}$  59.5 keV events
  - Extract photopeak events from the fitted spectrum
- Measured depths follows the PN junction model curve
- Depletion layer develops as expected
- Higher resistivity chips is necessary to achieve full depletion

# AstroPix4

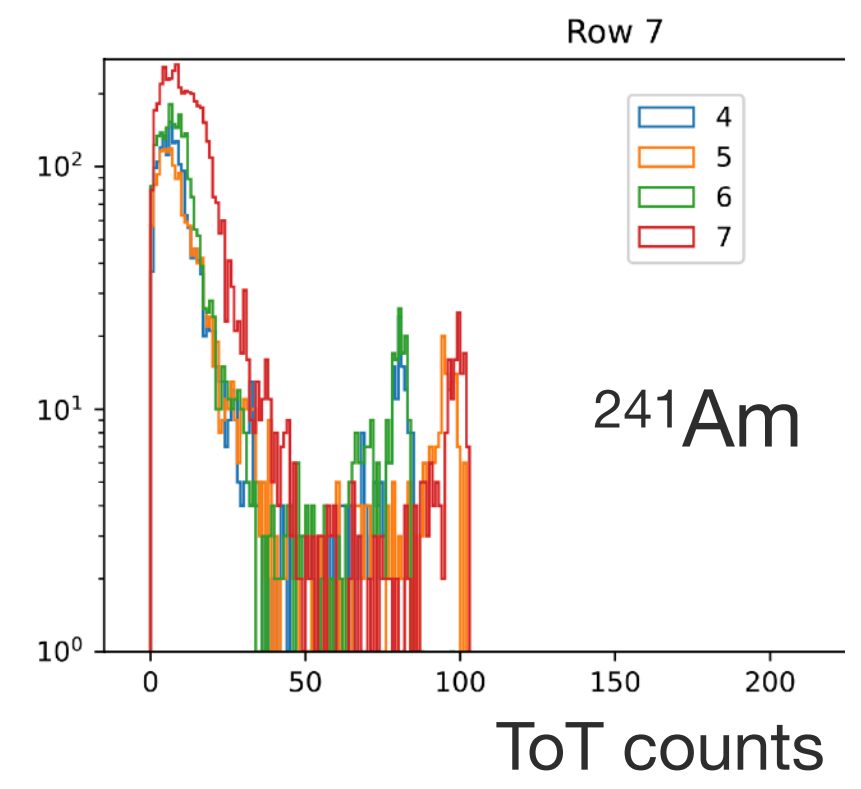


Size: 1 x 1 cm<sup>2</sup>  
Matrix: 16 x 13 pixels  
Pixel pitch: 500  $\mu$ m  
725  $\mu$ m thick



Striebig+24 JINST

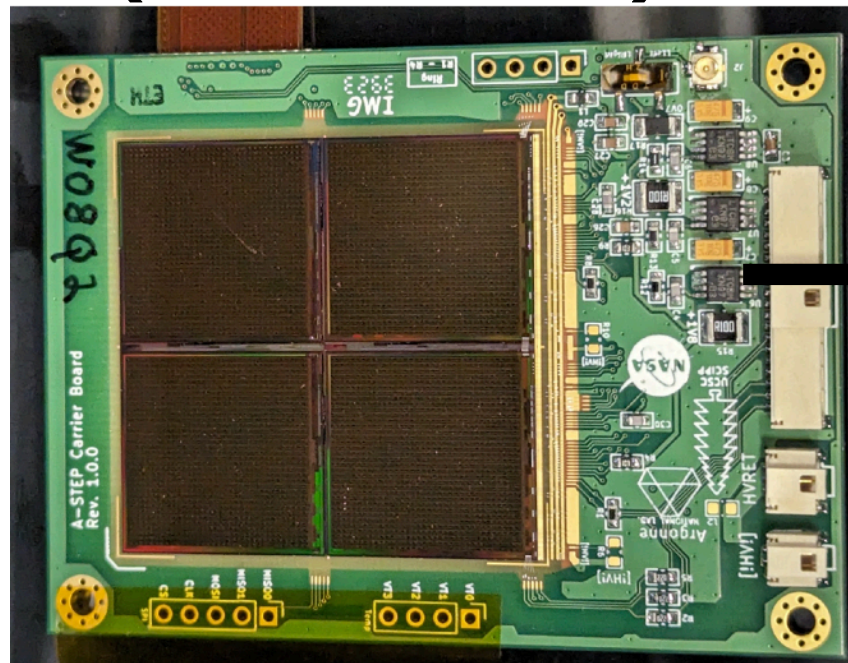
- Pixel-by-pixel comparator threshold tune  
→ ToT variation to be suppressed
- Individual hit buffer  
→ No identification problem with multiple hits in Row/Col
- Improved time stamp structure  
→ 3 ns for timing and ToT (design)



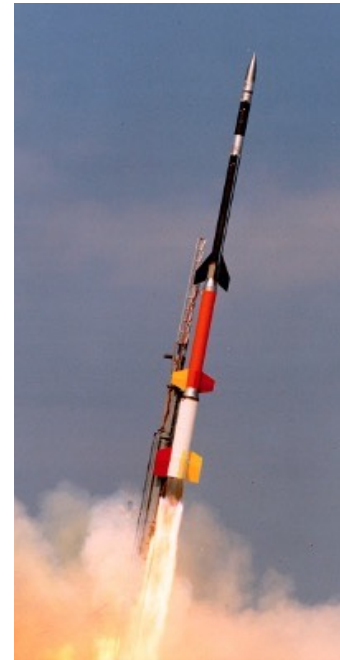
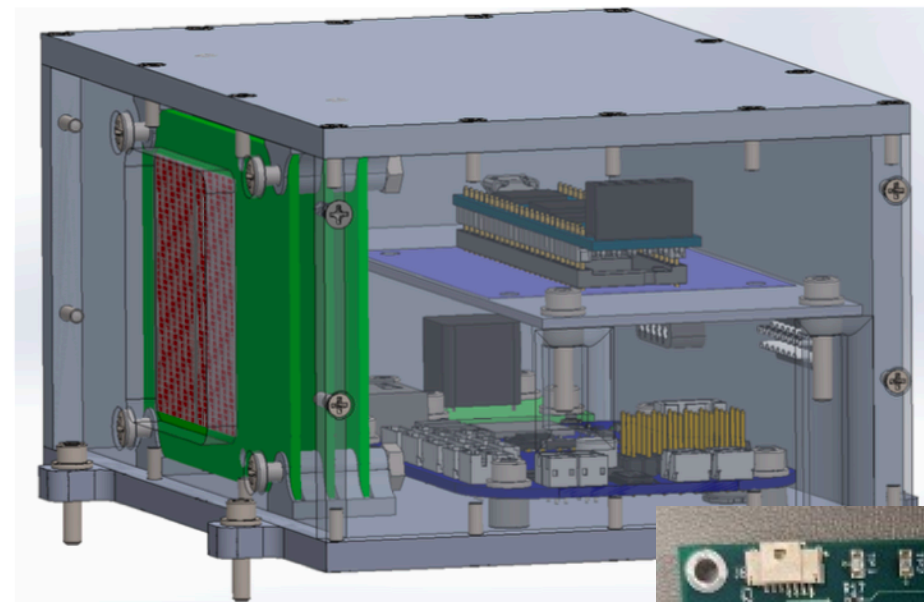


# AstroPix in Space

## Quad-chip (AstroPix3 x4)



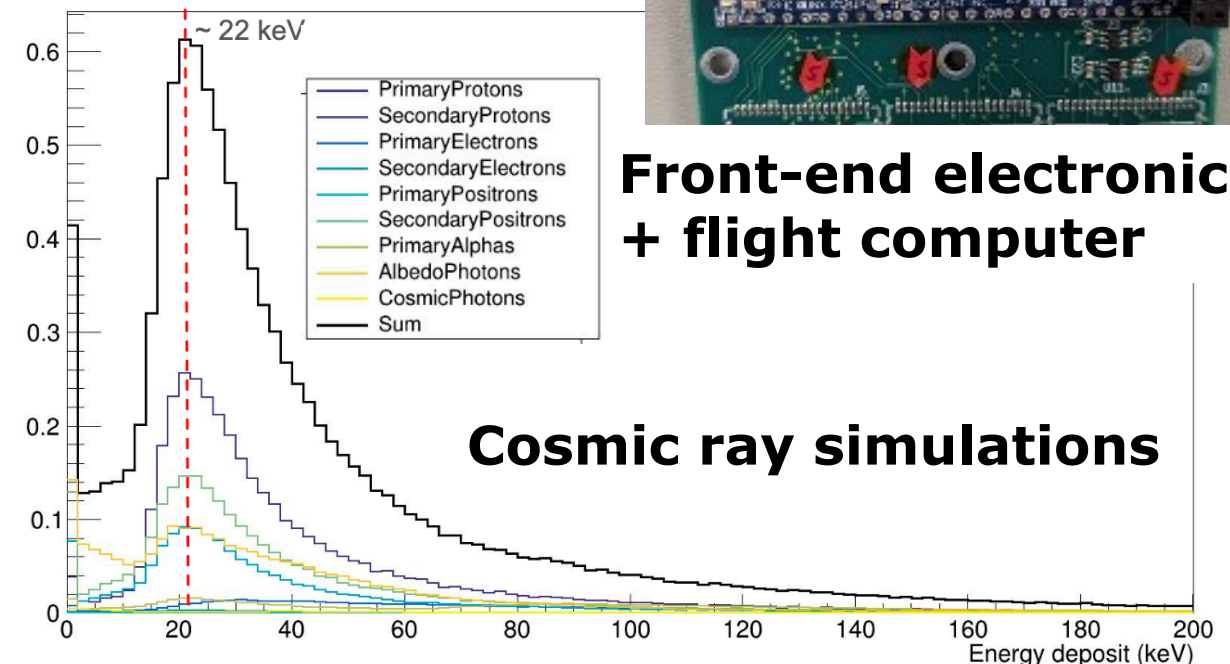
## A-STEP detector



- Quad-chip (4 x 4 cm<sup>2</sup>): Minimum component of the AMEGO-X's tracker
- **Sounding rocket** hosted flight ("A-STEP") is planned in **autumn 2025** to increase the Technical Readiness Level of the AstroPix detectors



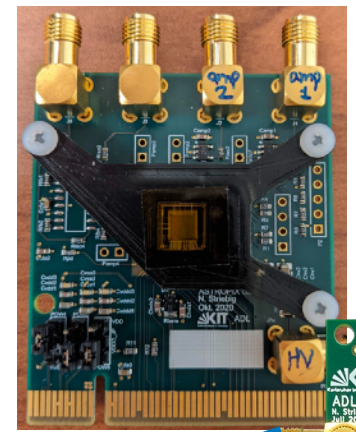
## Front-end electronics + flight computer





# Summary and Future

	Pixel pitch	Depletion depth	Dynamic range	Energy resolution	Power
<b>Goal</b>	500×500 $\mu\text{m}^2$	500 $\mu\text{m}$	25 keV - 700 keV	< 6 keV	1.5 mW/cm <sup>2</sup>
<b>AstroPix3</b>	500×500 $\mu\text{m}^2$	100 $\mu\text{m}$	22 keV - ~200 keV	6.2 keV	4 mW/cm <sup>2</sup>



**AstroPix1**

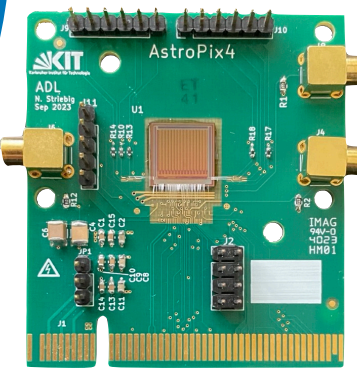
**AstroPix2**



**AstroPix3**



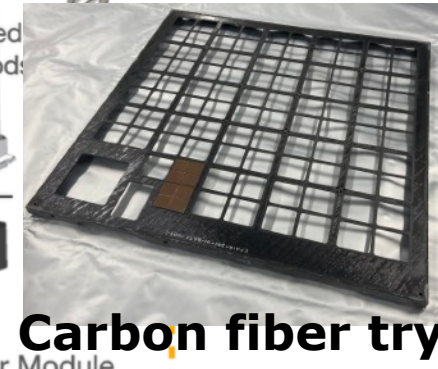
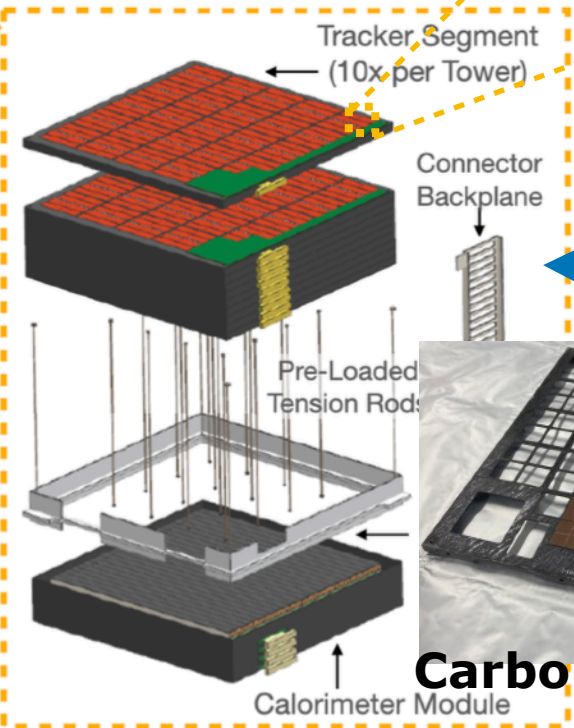
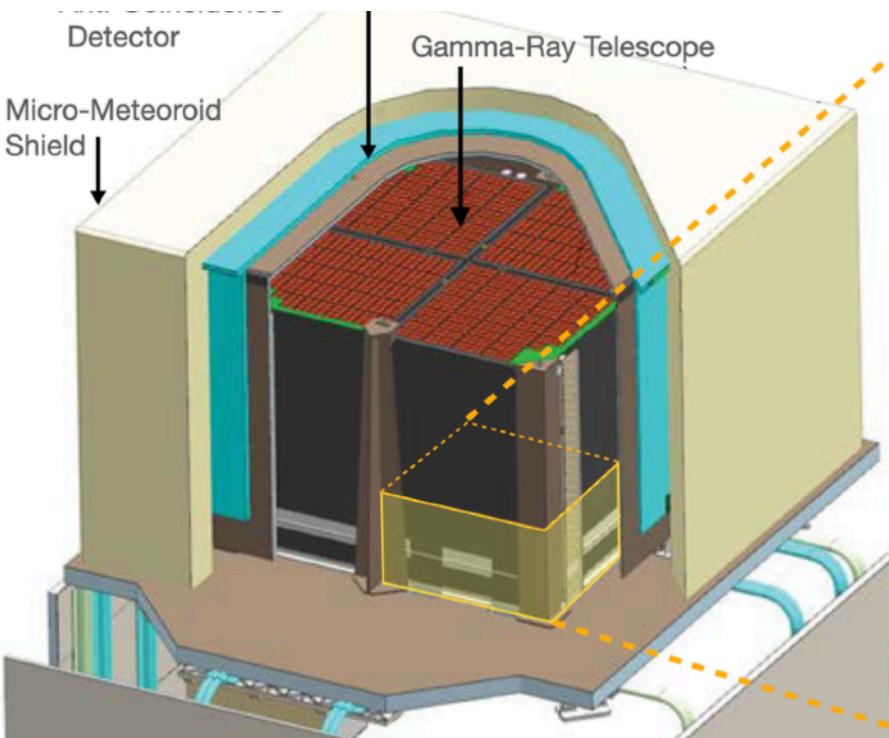
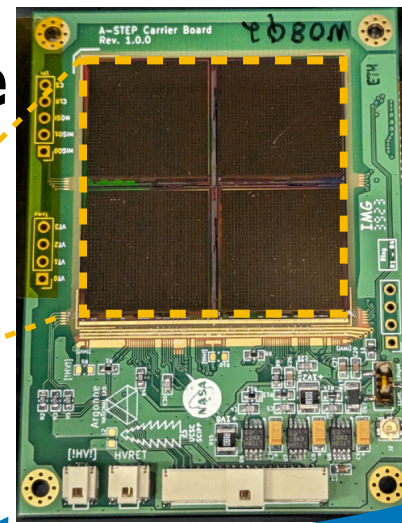
**AstroPix4**



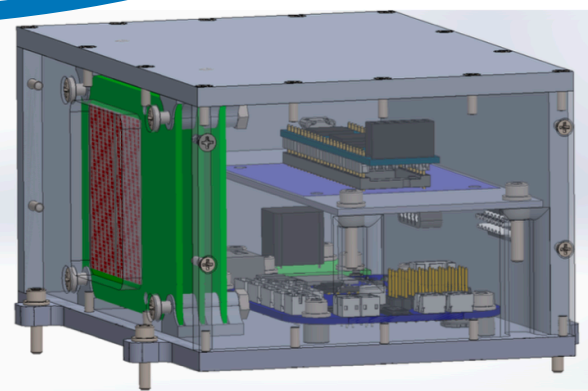
**AMEGO-X**  
Resubmit in next MDEX call ~2027

**Prototype telescope "ComPair-2"**  
2026

**Quad-chip**



**Carbon fiber tray**



**A-STEP 2025**

**AstroPix5**  
2025

