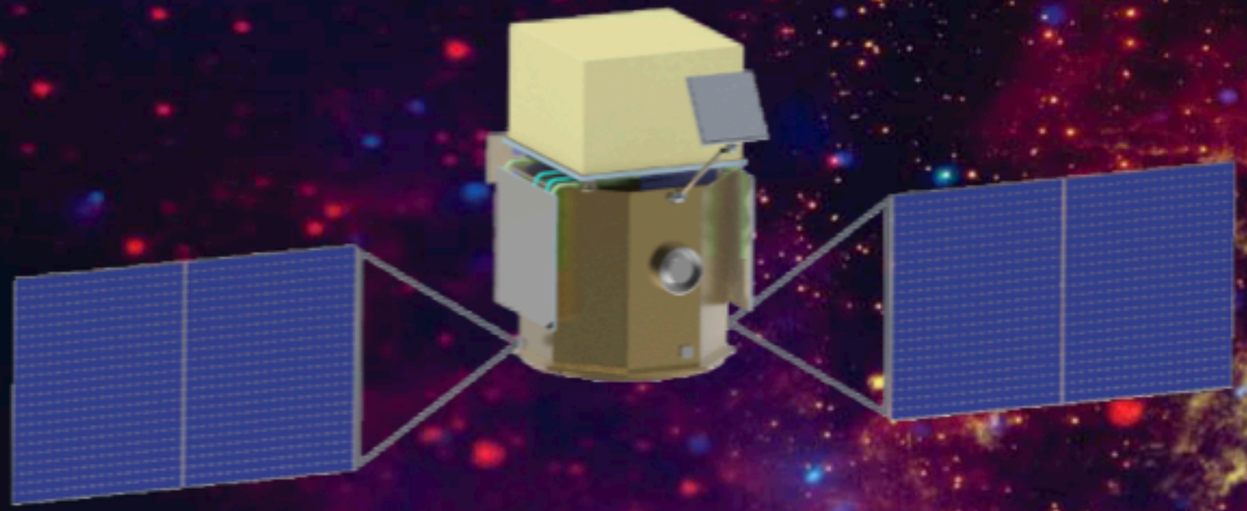
AMEGO-X

ALL-SKY MEDIUM ENERGY GAMMA-RAY OBSERVATORY EXPLORER

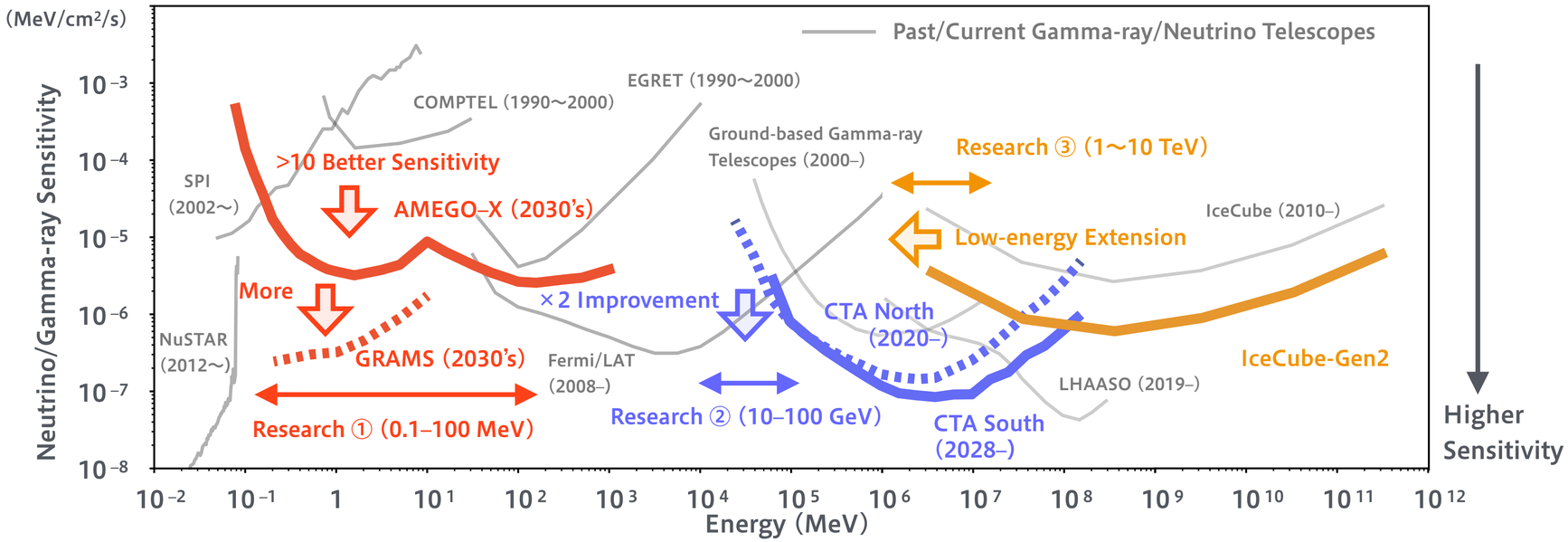


B01: AMEGO-X

Yusuke Suda and Yasushi Fukazawa
Hiroshima University

Wide High-Energy Coverage by "Particles"

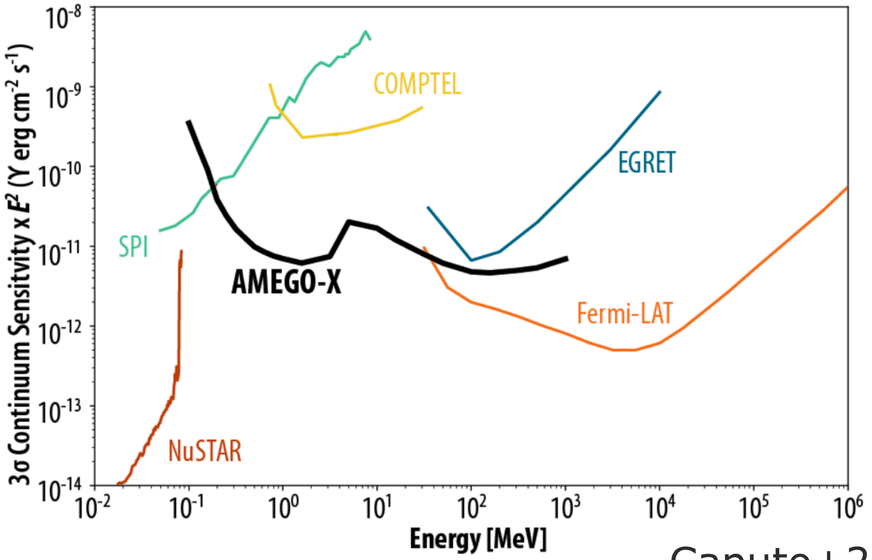
Akira's slide from last year



- **Neutral** keV/MeV/GeV/TeV/PeV regions are covered by different techniques and by gamma rays and neutrinos
- Res. (1) MeV Gamma (Fukazawa@Hiroshima), (2) CTA LST (Okumura@Nagoya), and (3) IceCube (Tsunesada@OMU)
- Need to **fill the sensitivity gaps** and to **extend the energy coverages** for future multimessenger astrophysics (2030–)

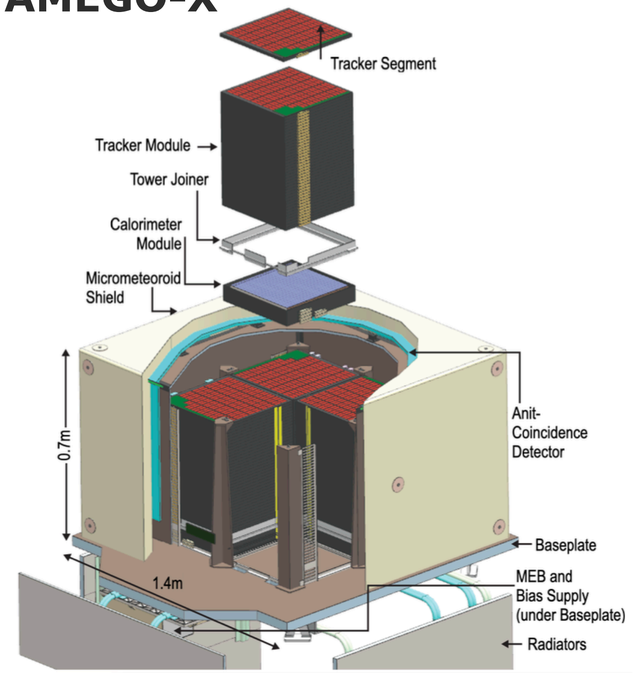
AMEGO-X: All-sky MeV satellite

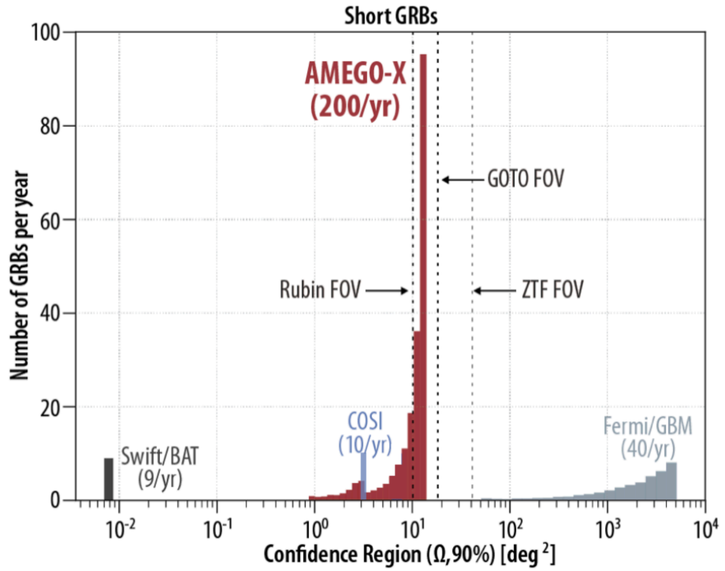
"MeV Gap"



Caputo+22 JATIS

AMEGO-X

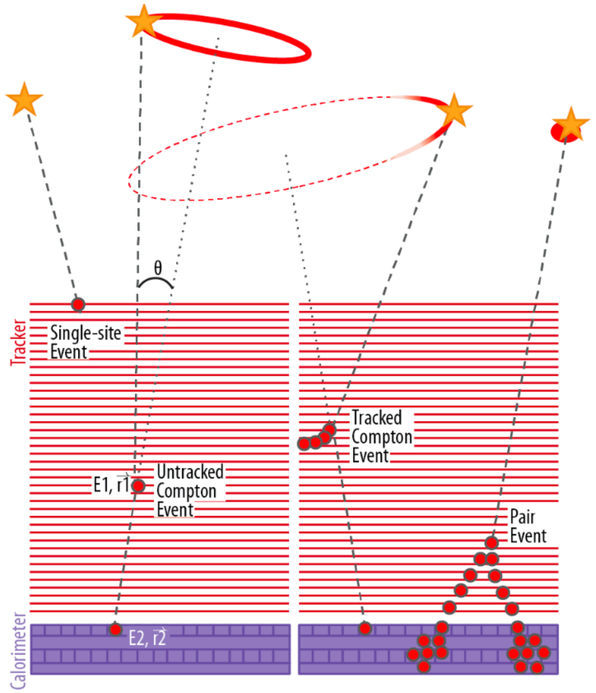


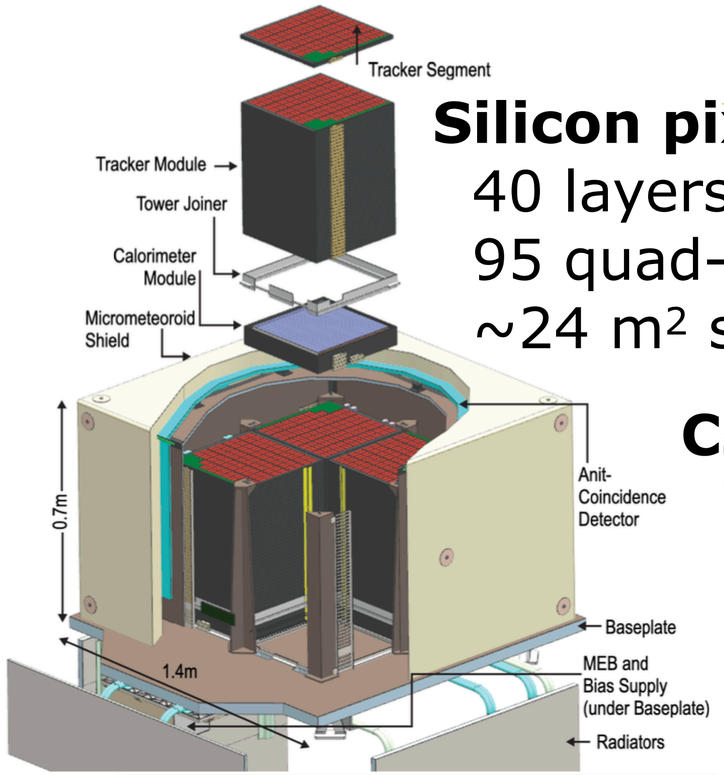


- AMEGO-X (PI: R. Caputo GSFC/NASA) is a proposed MeV mission to study the engines of extreme explosions and extreme accelerators
- Game-changer in high-energy/multi-messenger astronomy

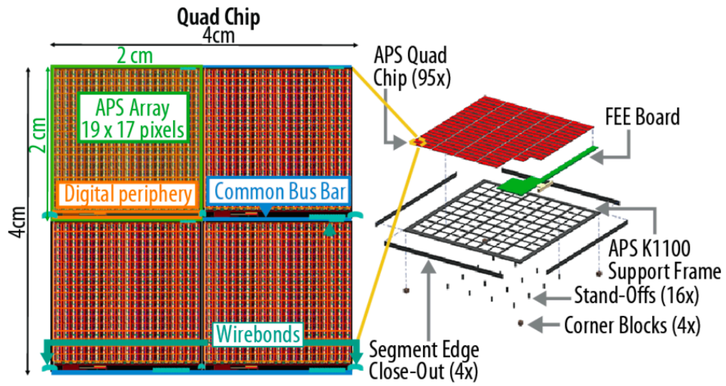
Parameter	
Energy Range	25 keV – 1 GeV
Energy Resolution	5% FWHM at 1 MeV, 17% (68% containment half width) at 100 MeV
Point Spread Function	4° FWHM at 1 MeV, 3° (68% containment) at 100 MeV
Localization Accuracy	transient: 1° (90% CL radius), persistent: 0.6° (90% CL radius)
Effective Area	1200 cm^2 at 100 keV, 500 cm^2 at 1 MeV, 400 cm^2 at 100 MeV
Field of View	2π sr (<10 MeV), 2.5 sr (>10 MeV)

AMEGO-X Instrument

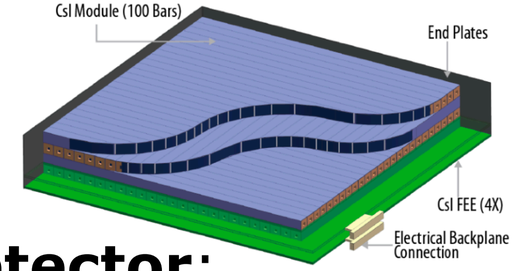


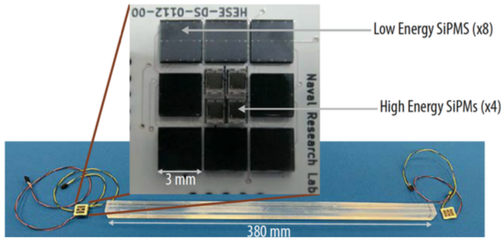


Silicon pixel tracker:
40 layers
95 quad-chips/layer
~24 m² silicon area



CsI Calorimeter: 4 layers
25 bars/layer read out by SiPMs



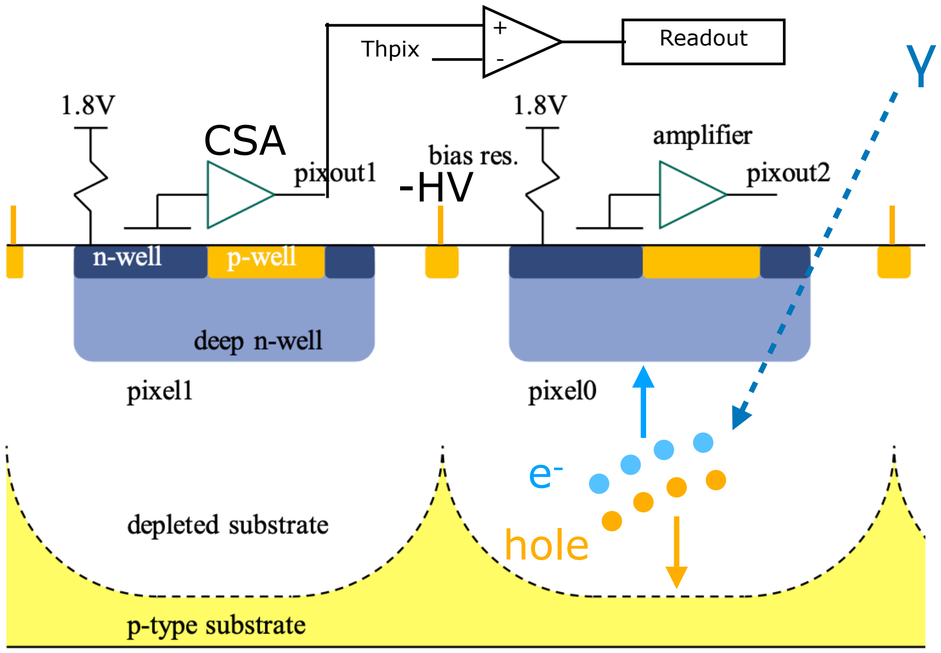


Anti-Coincidence Detector:
5 scintillator panels

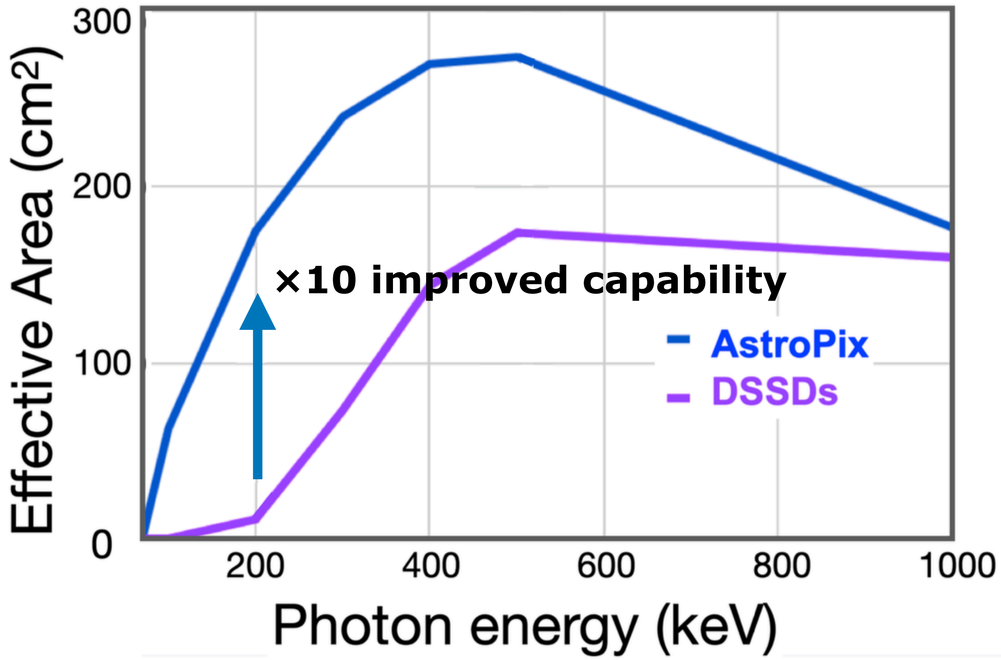
- Not selected in NASA MIDEX2021 due to missing key developments
- Key developments for success:
  a new pixel silicon sensor “AstroPix”, event reconstruction

AstroPix: Novel Pixel Sensor

HV-CMOS pixel sensor



I.Peric+'07 with modifications

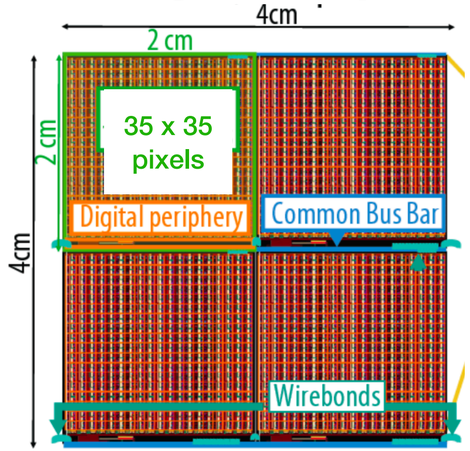


- Lower energy thresholds than strip detectors
- Less passive materials in the telescope
- Less power for same channel count
- Lower cost: CMOS processes are mass produced, fewer steps of integration

AstroPix Development

Goal

Quad-chip

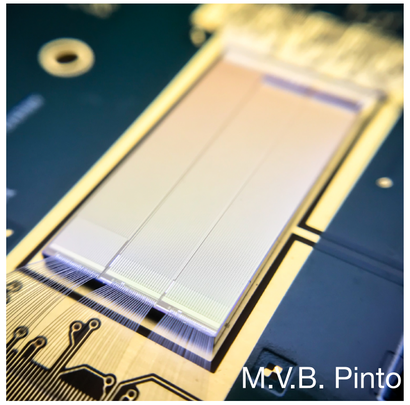


Power consumption	<1.5 mW/cm^2
Pixel pitch	500 × 500 μm^2
Thickness	500 μm
Dynamic range	25 keV–700 keV
Energy resolution	<10% (FWHM) at 60 keV

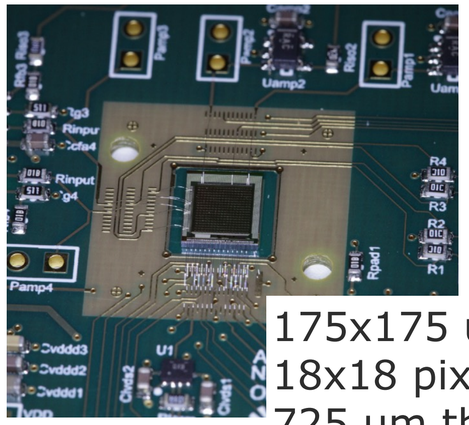
→ **AMEGO-X, ePIC at EIC**

AstroPix Team
PI: R. Caputo (NASA/GSFC)
Design: N. Striebig (KIT)
GSFC, ANL, KIT, UCSC,
Nagoya U, Hiroshima U

ATLASPix

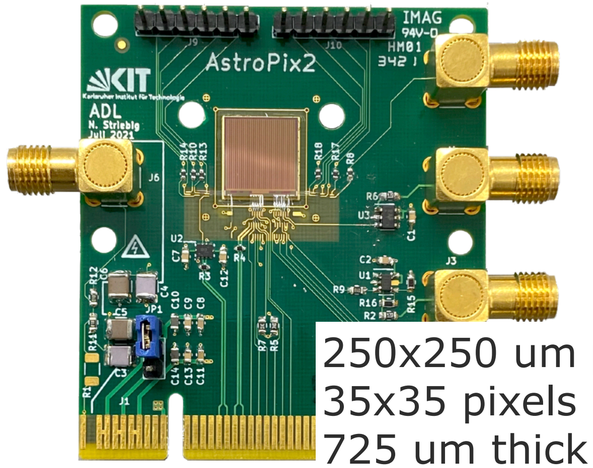


AstroPix1



175x175 um pixel
18x18 pixels
725 um thick
14.7 mW/cm^2

AstroPix2



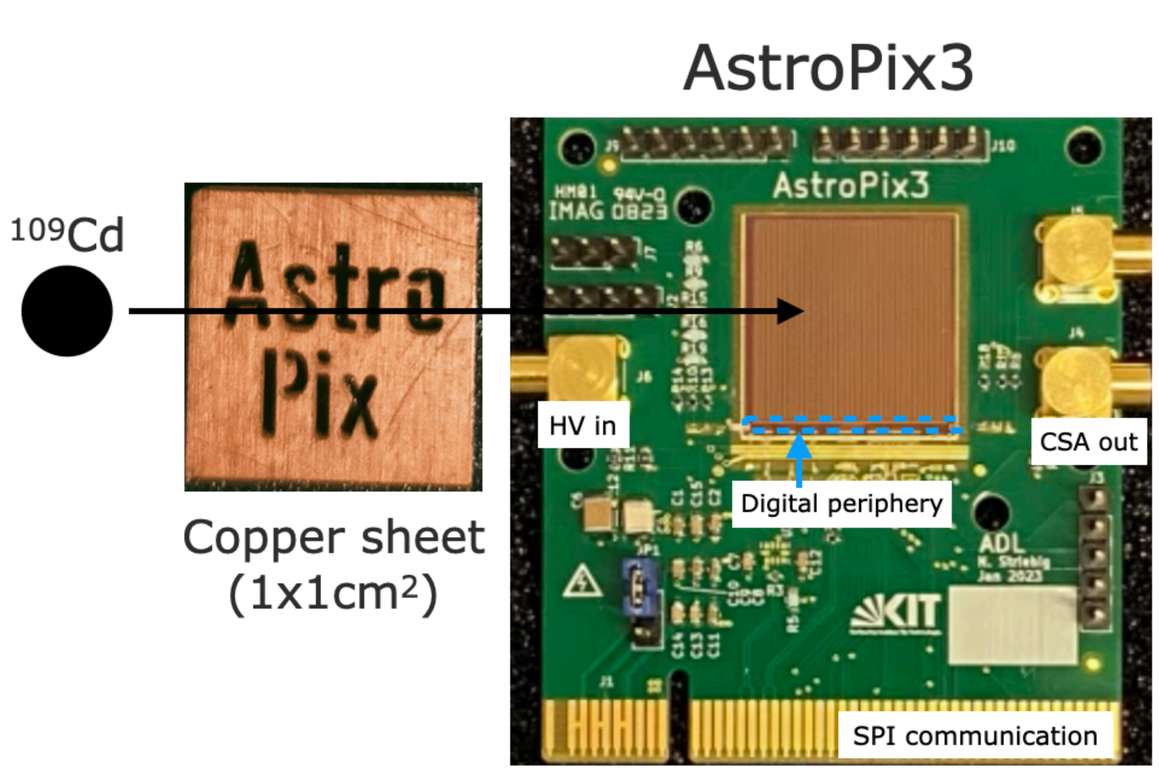
250x250 um pixel
35x35 pixels
725 um thick
3.4 mW/cm^2

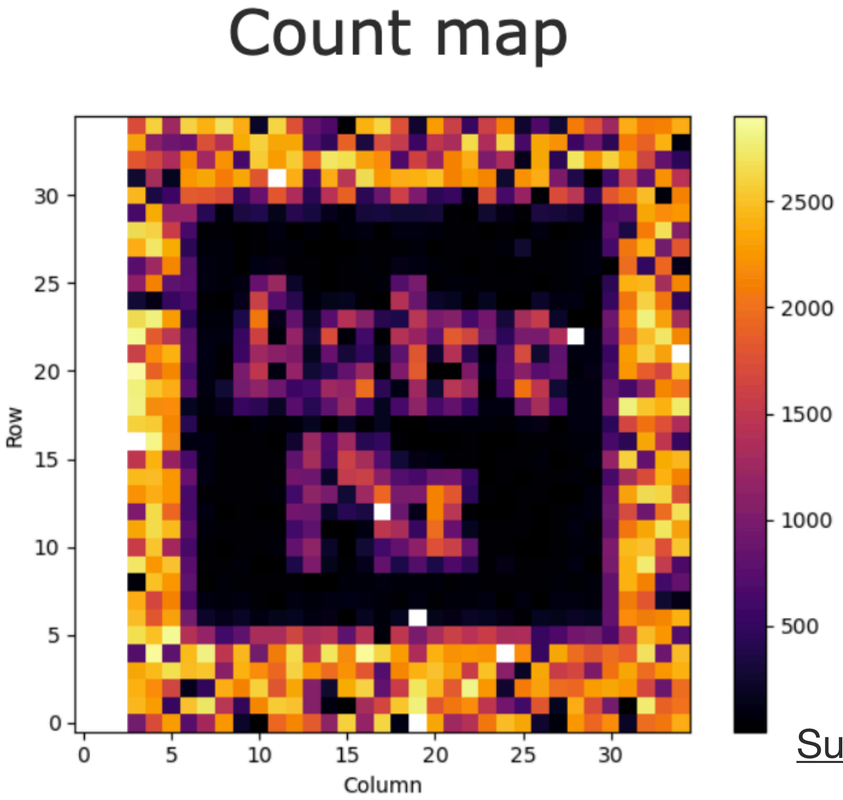
AstroPix3
tested

AstroPix4
under test

AstroPix5
To be submitted

AstroPix3



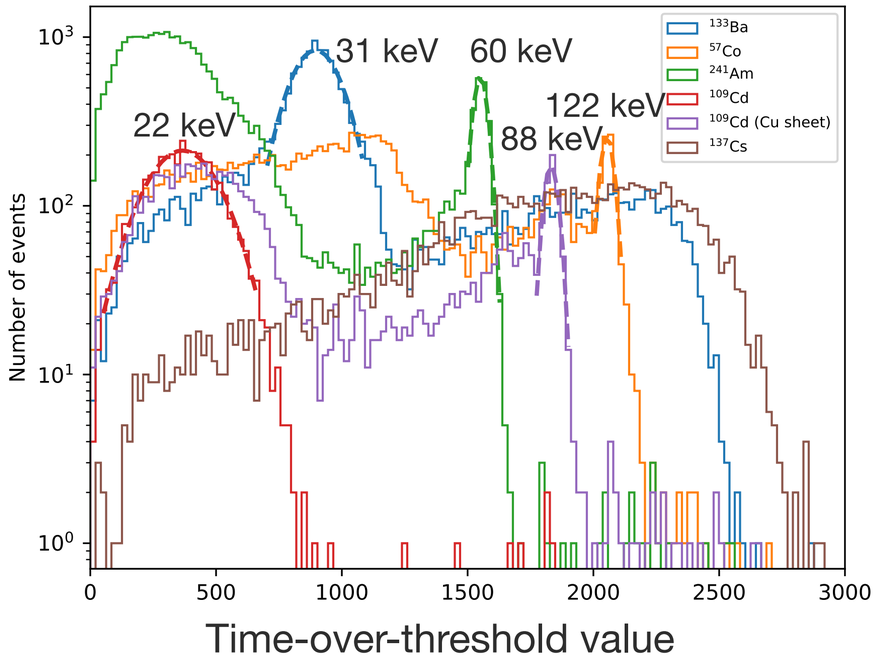


Suda+24 NIMA

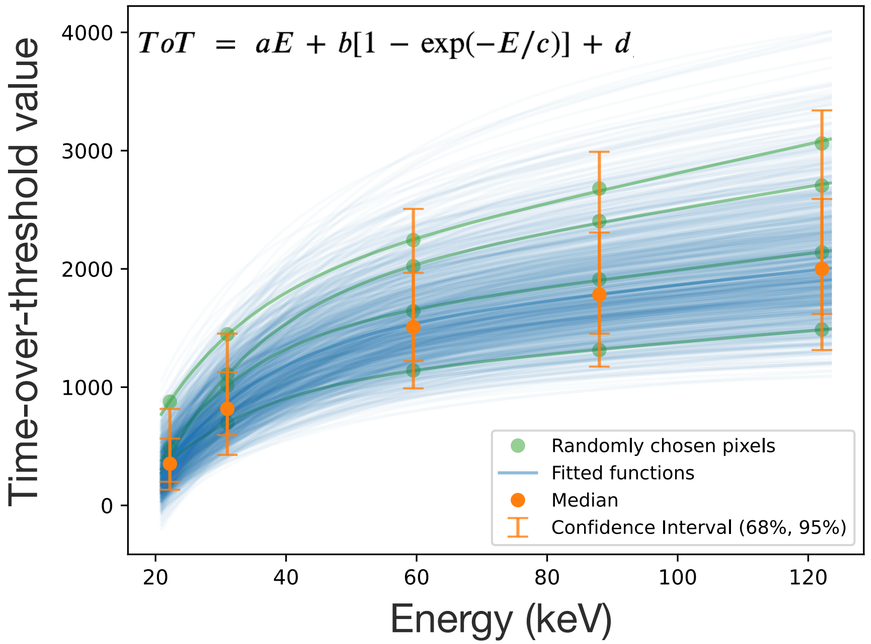
- Full reticle chip: **2 x 2 cm^2**. 725 um thick
- Matrix: 35 x 35 pixels
- Pixel pitch: **500 um** (pixel size 300 um to reduce capacitance)
- Power consumption: 4.12 mW/cm^2
- Full digital readout capability

AstroPix3 Performance

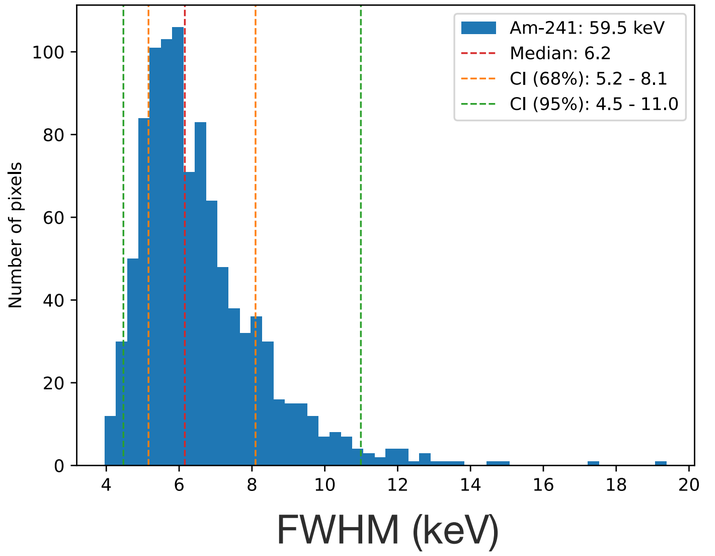
ToT spectra



Calibration curves



Energy resolution at 60 keV



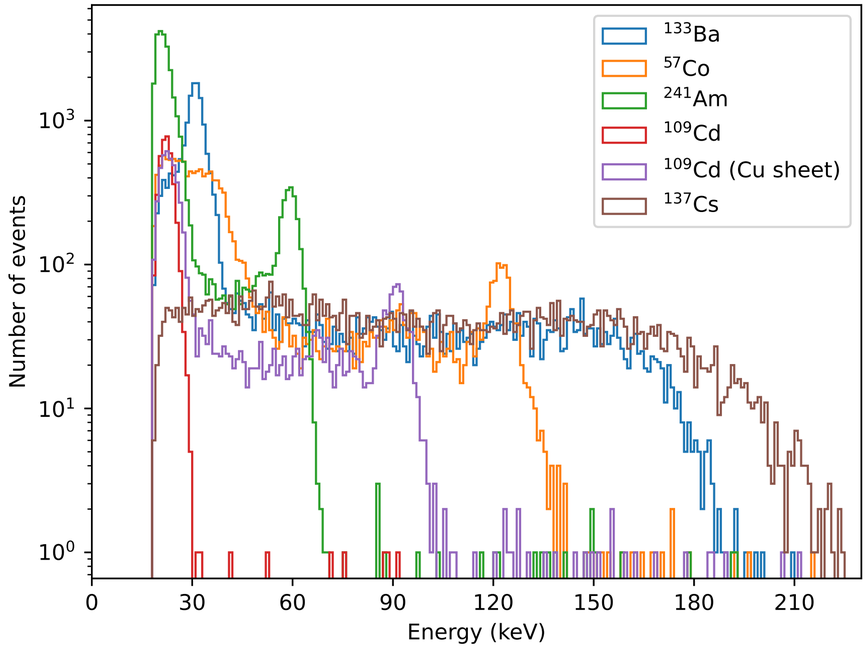
Suda+24 NIMA

- 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

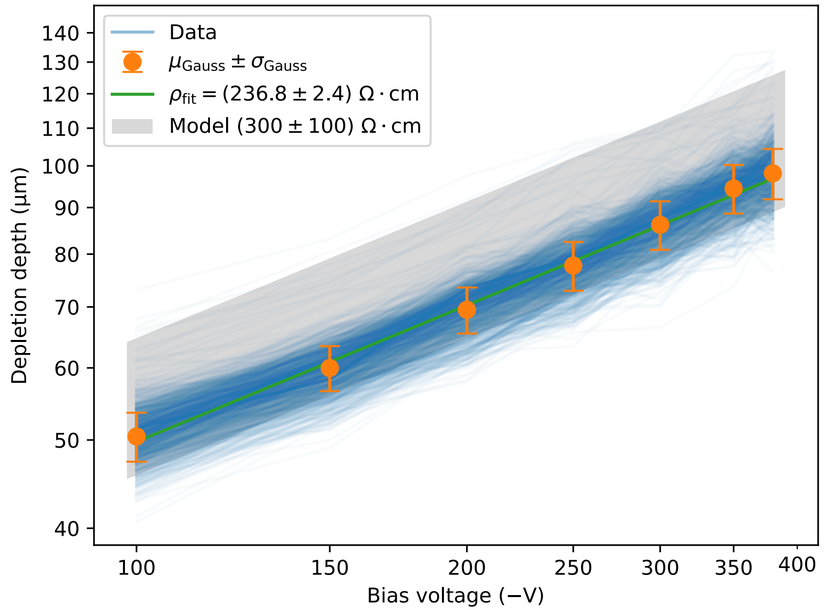
- Energy calibration over the full sensor
  - 90% of the tested pixels are calibrated
- Energy resolution (FWHM) @ 60 keV: 6.2 keV
  - 44% of the calibrated pixels satisfy the requirement

AstroPix3 Performance

Calibrated energy spectra



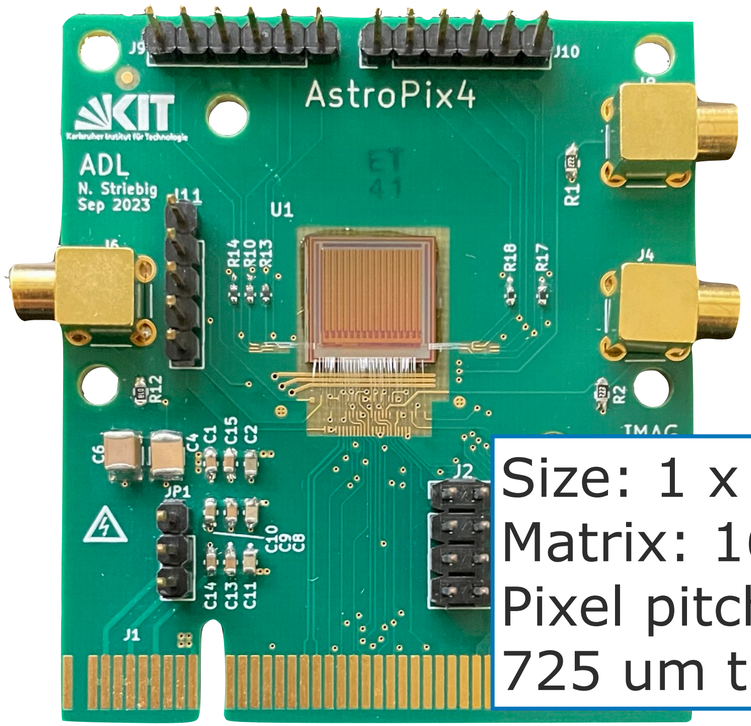
Depletion depth



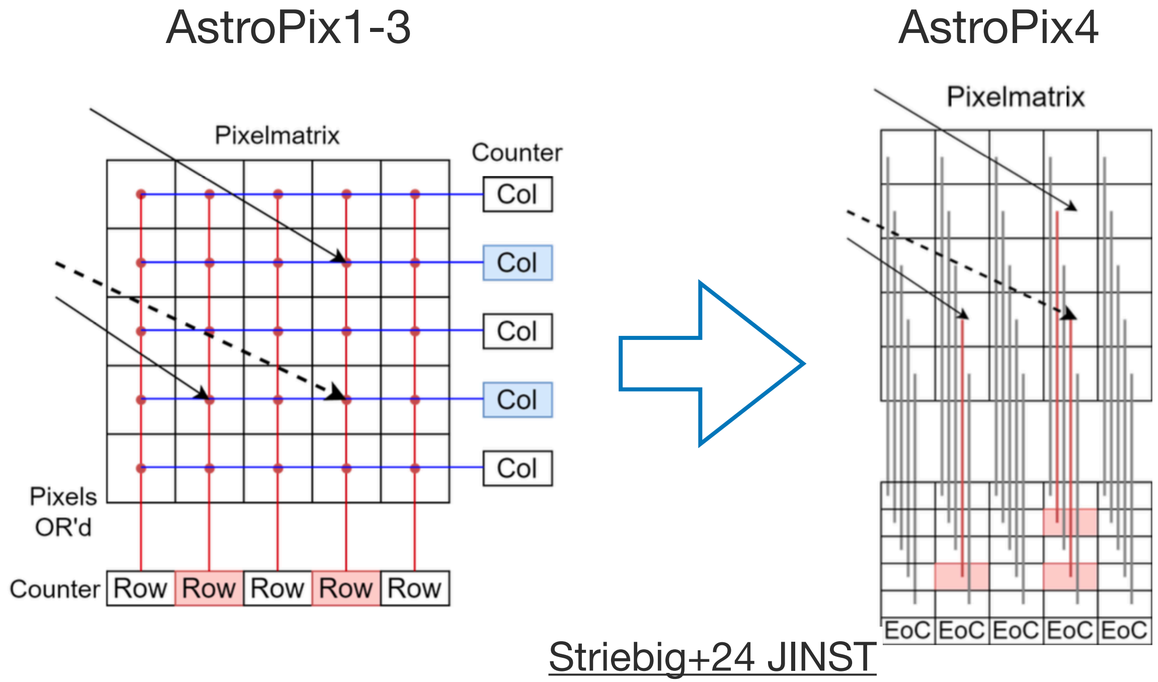
Suda+24 NIMA

	Pixel pitch	Thichness	Dynamic range	Energy resolution (FWHM at 60 keV)	Power
Goal	500×500 μm²	500 μm fully depleted	25 keV - 700 keV	< 6 keV	< 1 mW/cm²
AstroPix3	500×500 μm²	100 μm depletion	22 keV - ~200 keV	6.2 keV	4 mW/cm²

AstroPix4



Size: 1 x 1 cm²
Matrix: 16 x 13 pixels
Pixel pitch: 500 um
725 um thick

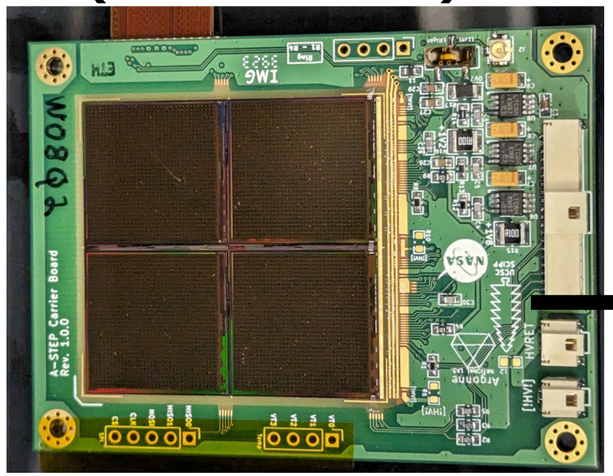


Striebig+24 JINST

- Reduced input capacitance by optimizing the routing and minimizing the metal-to-n-well capacitance → Lower noise floor and better energy resolution
- 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)

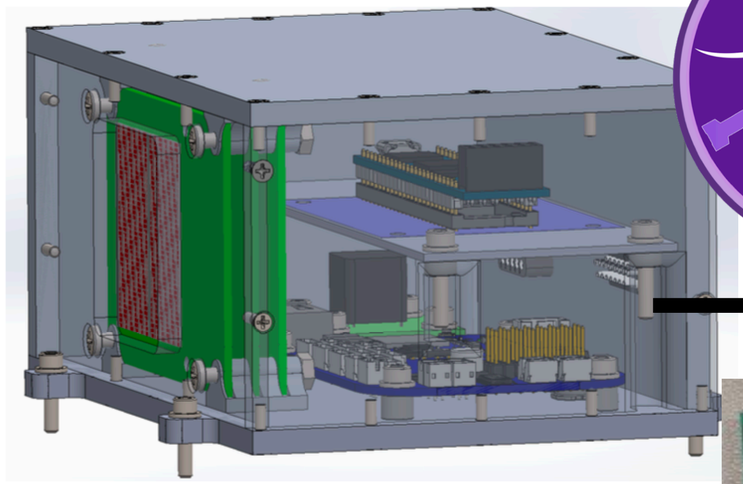
AstroPix in Space

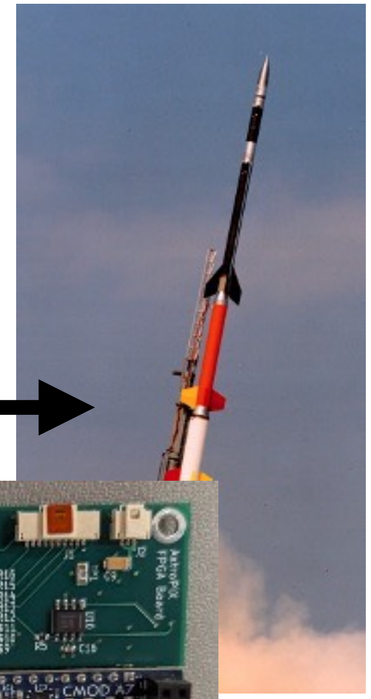
Quad-chip
(AstroPix3 x4)



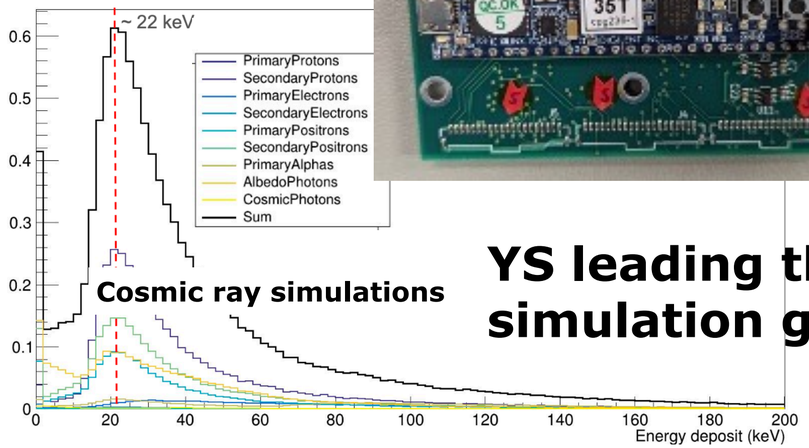
3 layers

A-STEP detector





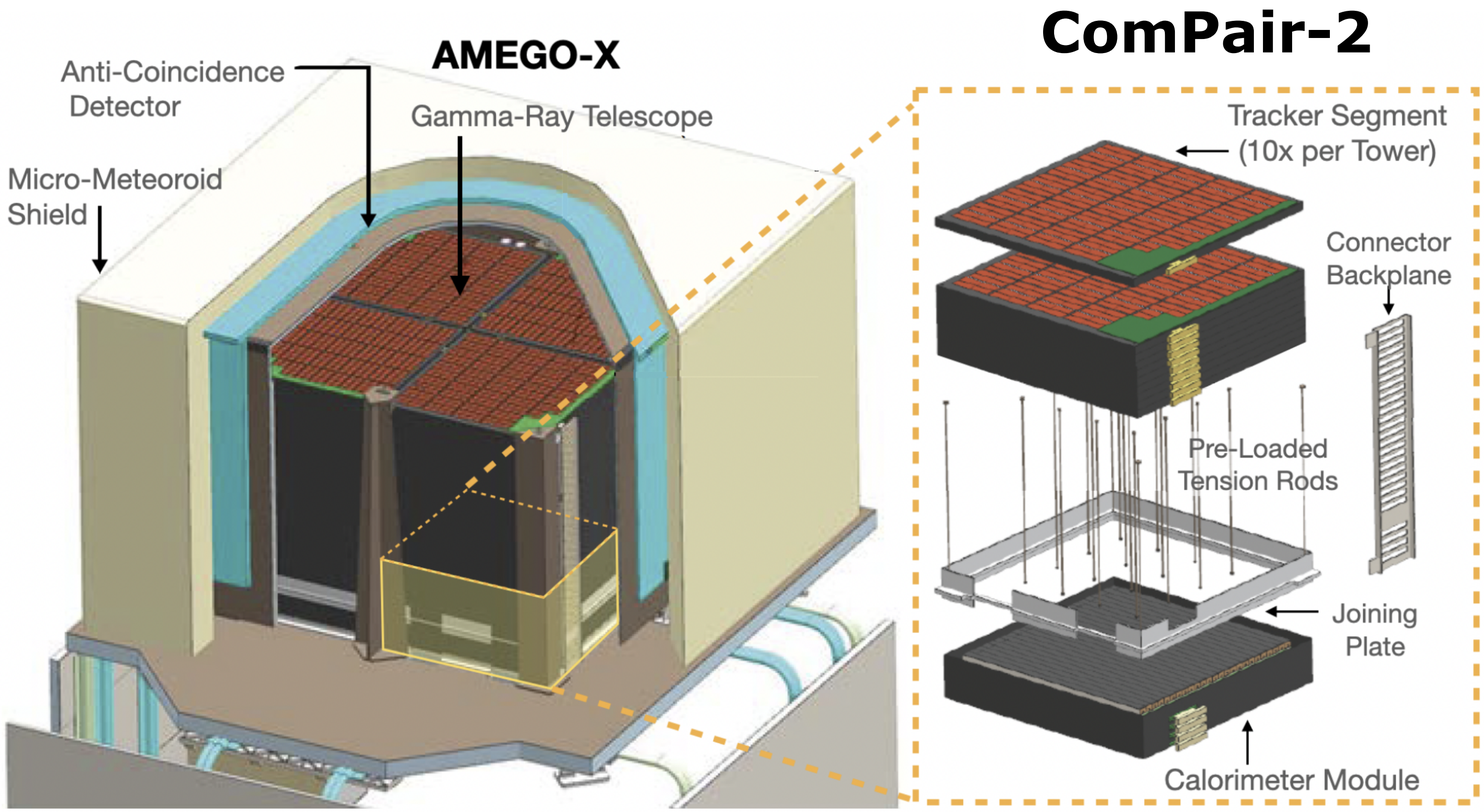
- **Quad-chip**: Minimum component of the AMEGO-X's tracker
- **Sounding rocket** hosted flight ("A-STEP") is planned to launch from Wallops Flight Facility in **autumn 2025** to increase the Technical Readiness Level of the AstroPix sensors



Cosmic ray simulations

YS leading the simulation group

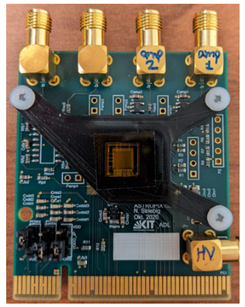
ComPair-2 - Prototype Telescope



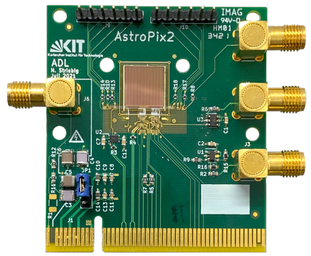
- ComPair-2 (PI: R. Caputo (GSFC/NASA)): AstroPix tracker + CsI calorimeter
  - NASA APRA funded project. Kickoff in Sep. 2023
  - Hiroshima group is involved in the pipeline group
- Instrument integration, environmental testing, and beam test in **2026**
  → Long duration balloon flight

Summary and Future

FY2023 | FY2024 | FY2025 | FY2026 | FY2027

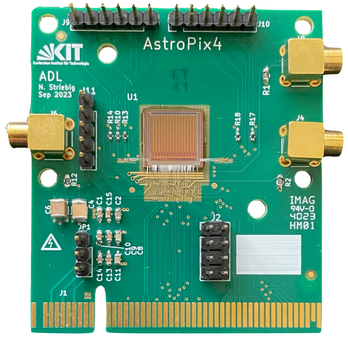


AstroPix1



AstroPix2

AstroPix3

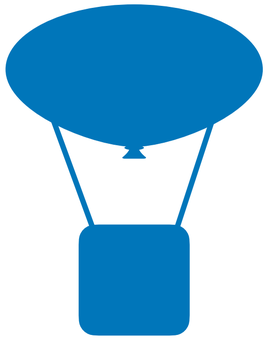


AstroPix4

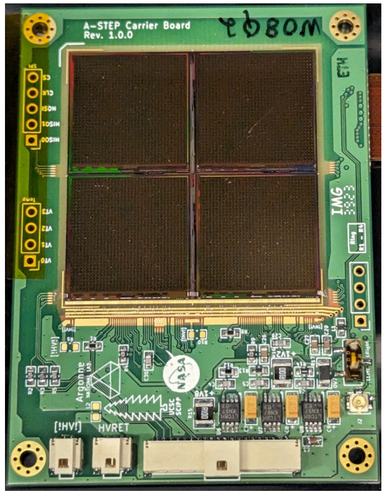
AstroPix5

AstroPix6?

Balloon flight?



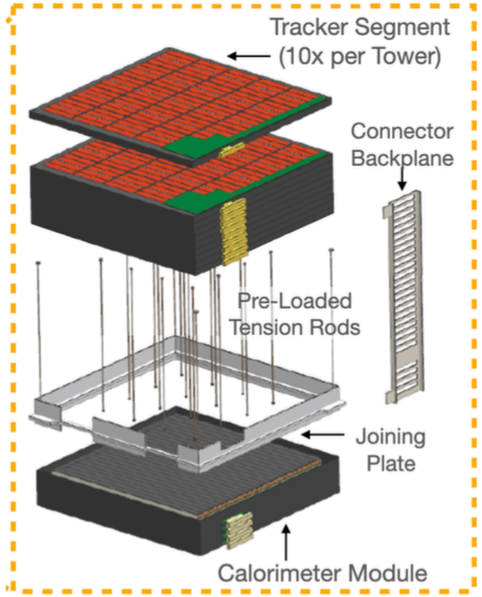
Published a paper:
Suda+24 NIMA



Quad-chip

Sounding rocket

ComPair-2



Beam test

Demonstrate the Compton reconstruction technique with ComPair-2

Resubmit AMEGO-X in next MIDEX call ~2027