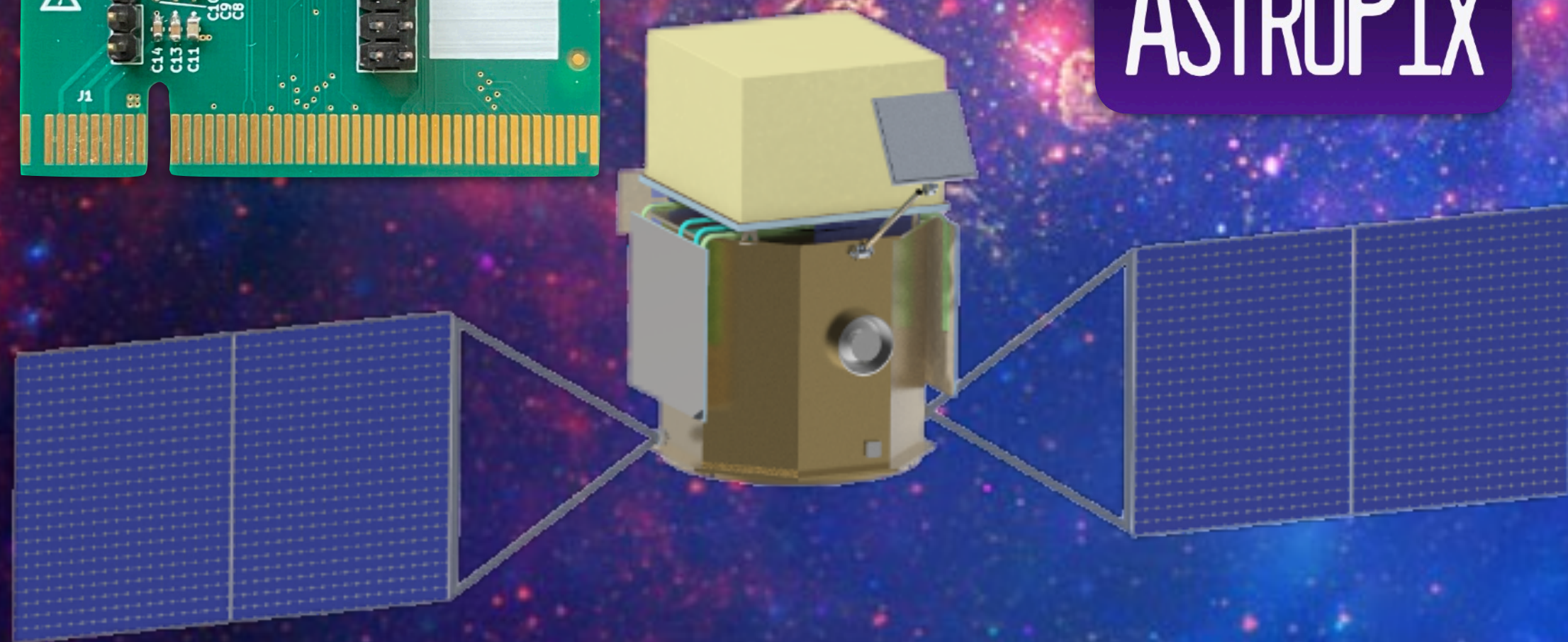
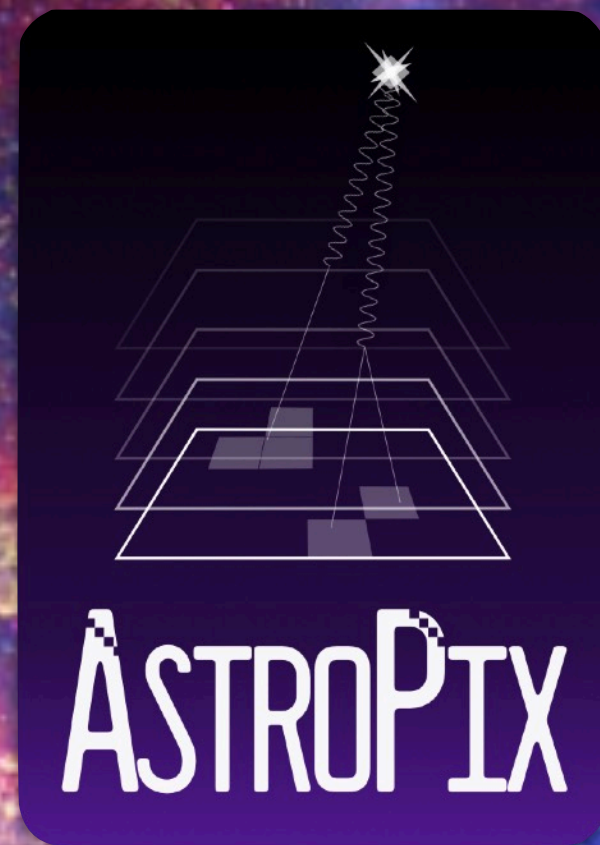
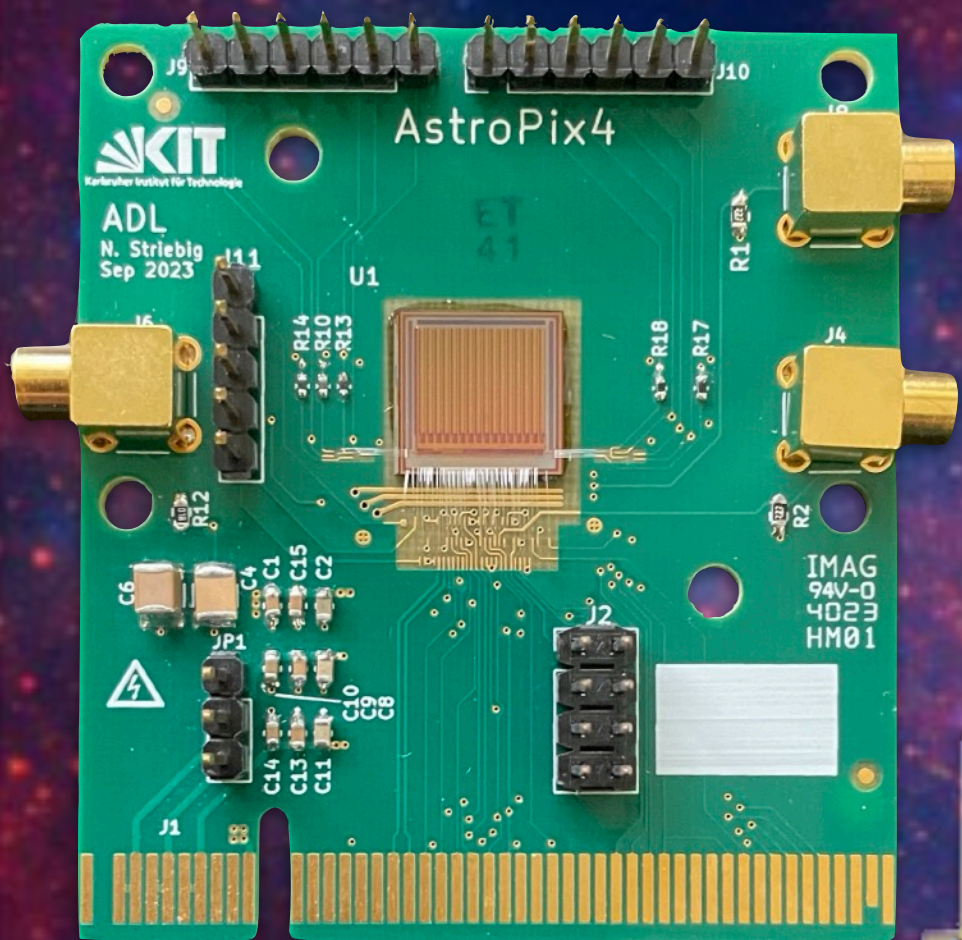


AstroPix: High-voltage monolithic active pixel sensors for space-based experiments

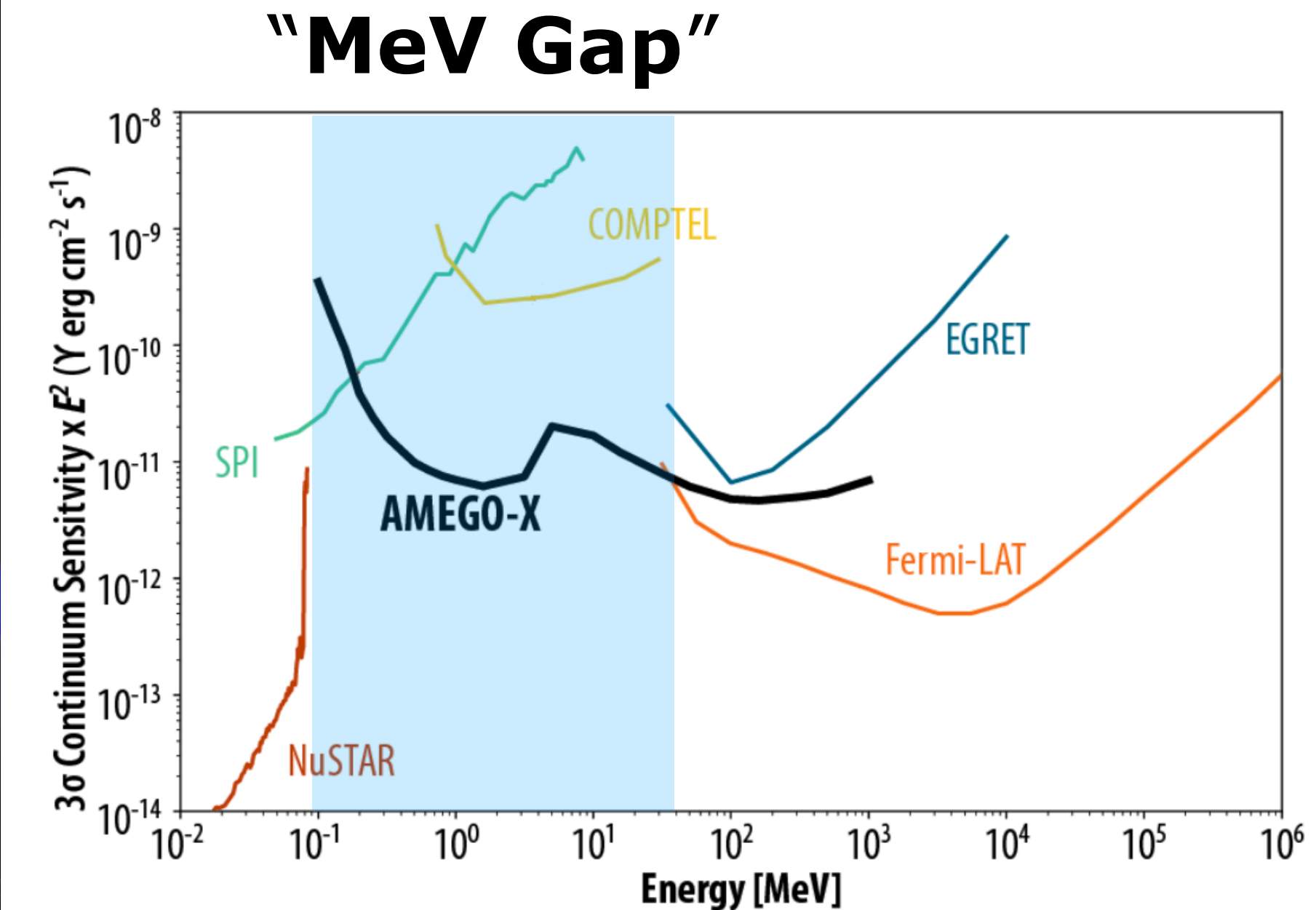
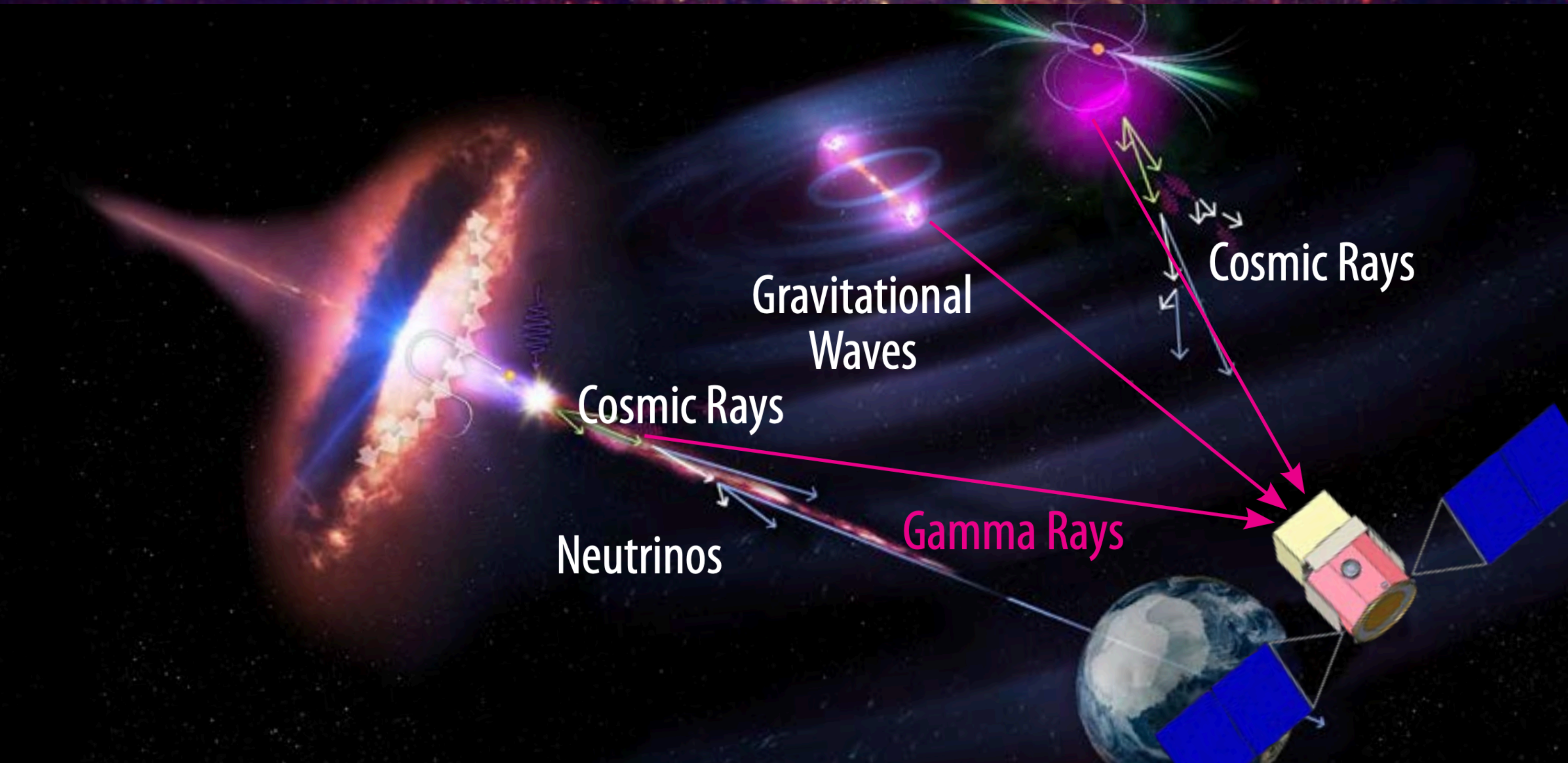


Yusuke Suda (Hiroshima U.),
R.Caputo, D.P.Violette, A.Laviron, K.Kumar,
G.Sommer, C.Kierans, J.S.Perkins (GSFC/NASA),
M.Jadhav, B.Kim, J.Metcalfe (ANL),
T.Shin, V.Fadeyev (UCSC),
N.Striebig, R.Leys, I.Peric (KIT),
N.Nakano, A.Roy, Y.Fukazawa (Hiroshima U.),
S.Kushima, H.Tajima (Nagoya U.)

HSTD14
Academia Sinica, Taiwan
Nov 20, 2025

AMEGO-X: All-Sky MeV Gamma Satellite

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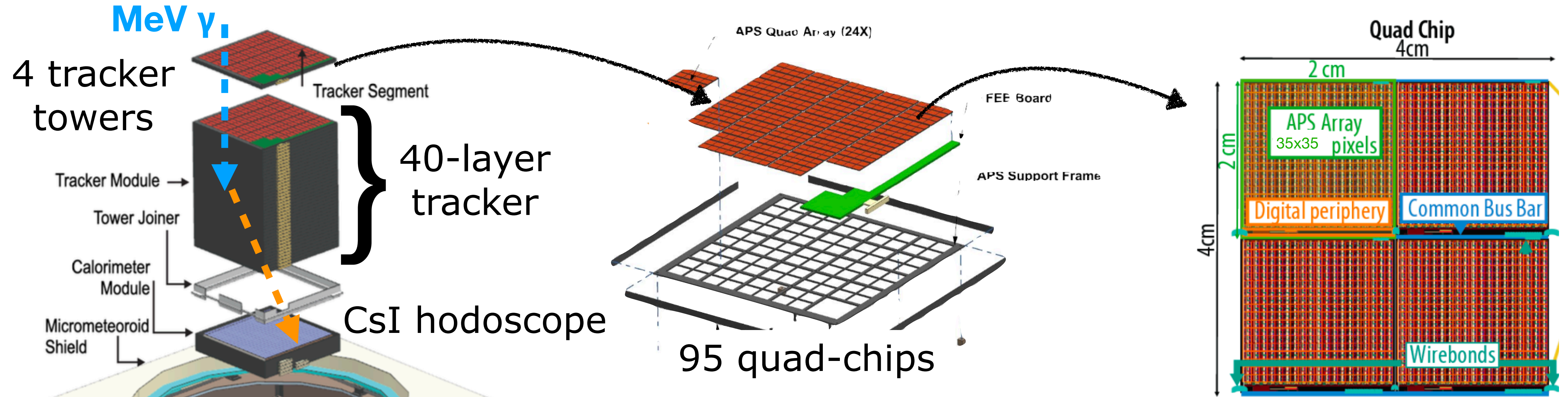


R. Caputo+ 2022

- **All-sky Medium Energy Gamma-ray Observatory eXplorer** (PI: R. Caputo, GSFC/NASA) is a proposed MeV gamma-ray mission
- Supermassive black holes: ~ 150 blazar flares/year
- Neutron star mergers: > 200 short gamma-ray bursts per year
- Galactic cosmic ray origin, multi-messenger astronomy, etc.

AMEGO-X Gamma-Ray Telescope

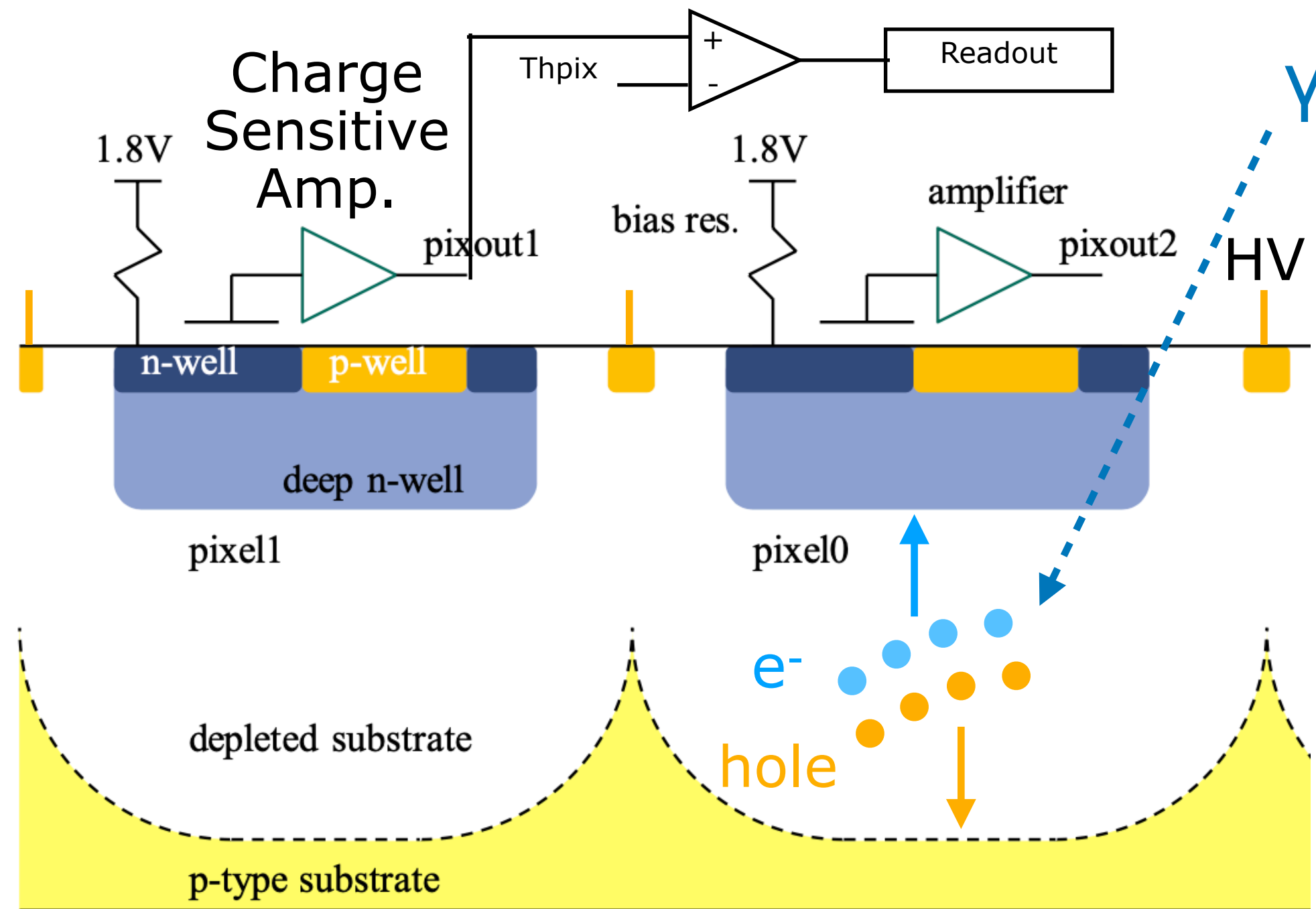
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- Si pixel sensors for Compton camera
→ **Fully depleted thick sensor**
Low noise
Low passive material quantity
- Huge silicon area in space (24 m², 74M pixels)
→ **Low power**
Low cost

R. Caputo+ 2022

HV-CMOS pixel sensor



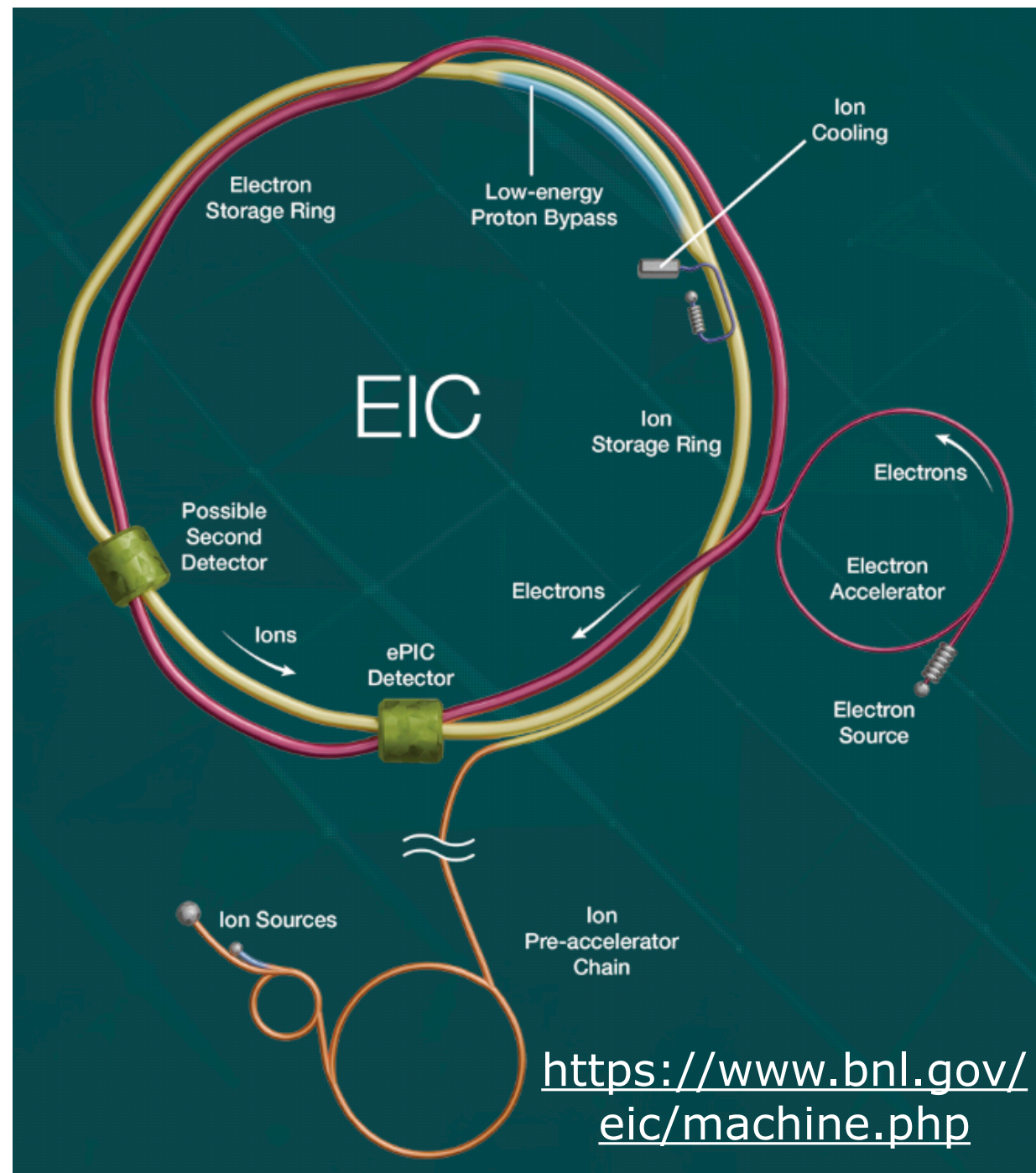
I.Peric+'07 with modifications

- Monolithic active pixel sensor (MAPS) = Detector + CMOS
 - In-pixel charge amplification and on-chip digitization
 - **Low noise**
 - **Low passive** material quantity
 - Typical CMOS wafer process & high yield
 - **Low cost**
- HV-CMOS MAPS
 - **Fully depleted thick sensor**
- Low pixel density allowing a large pixel pitch
 - **Low power**
- Time-over-Threshold measurement
 - Energy & timing

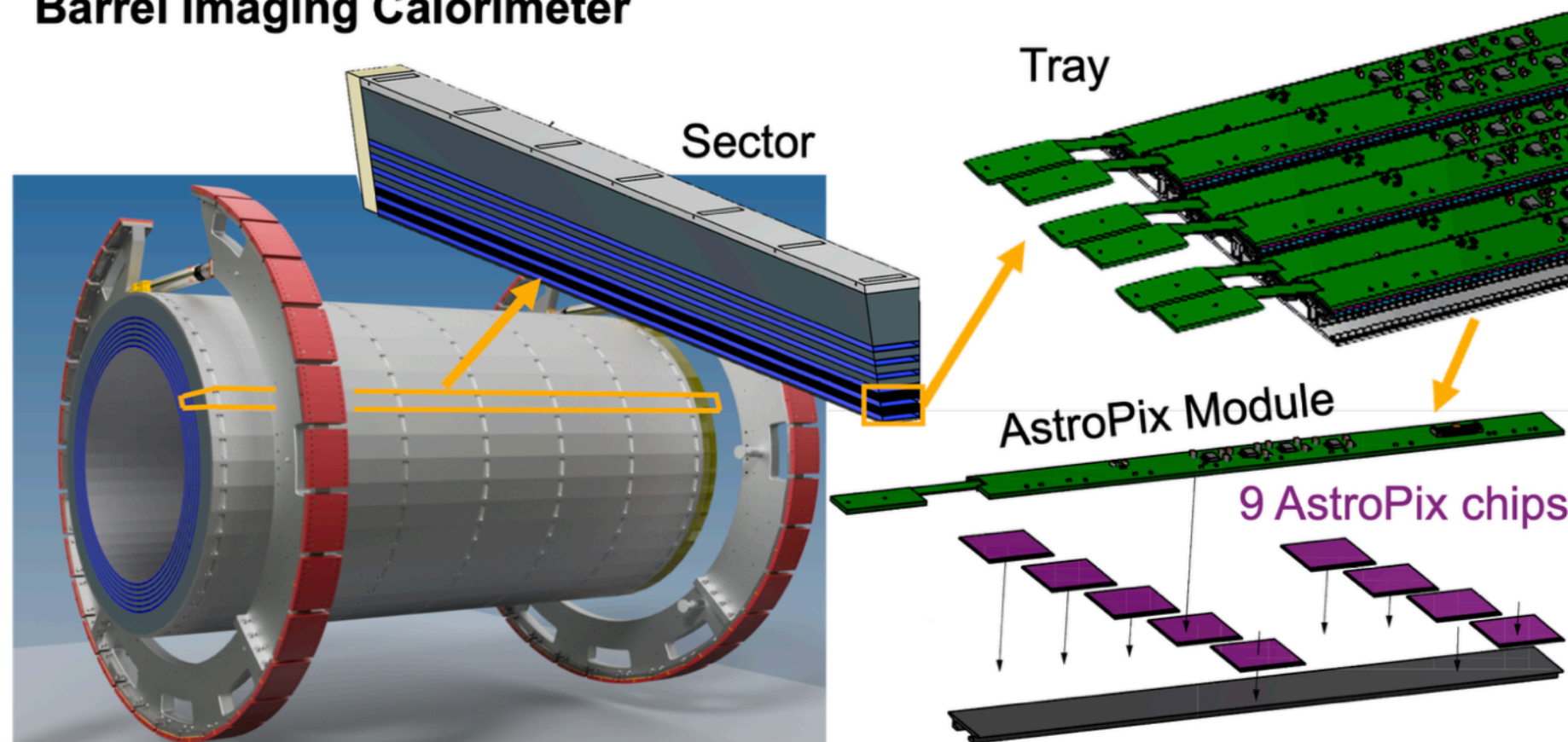
	Pixel pitch	Full depletion	Dynamic range	Energy resolution (FWHM at 122 keV)	Power
Goal	500 × 500 μm^2	500 μm	25 - 700 keV	12.2 keV	< 1.5 mW/cm ²

AstroPix @ Electron-Ion Collider

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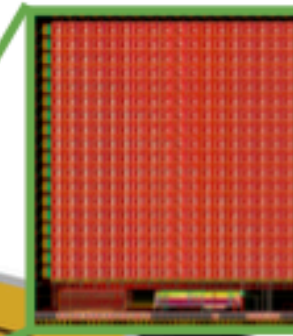


Barrel Imaging Calorimeter

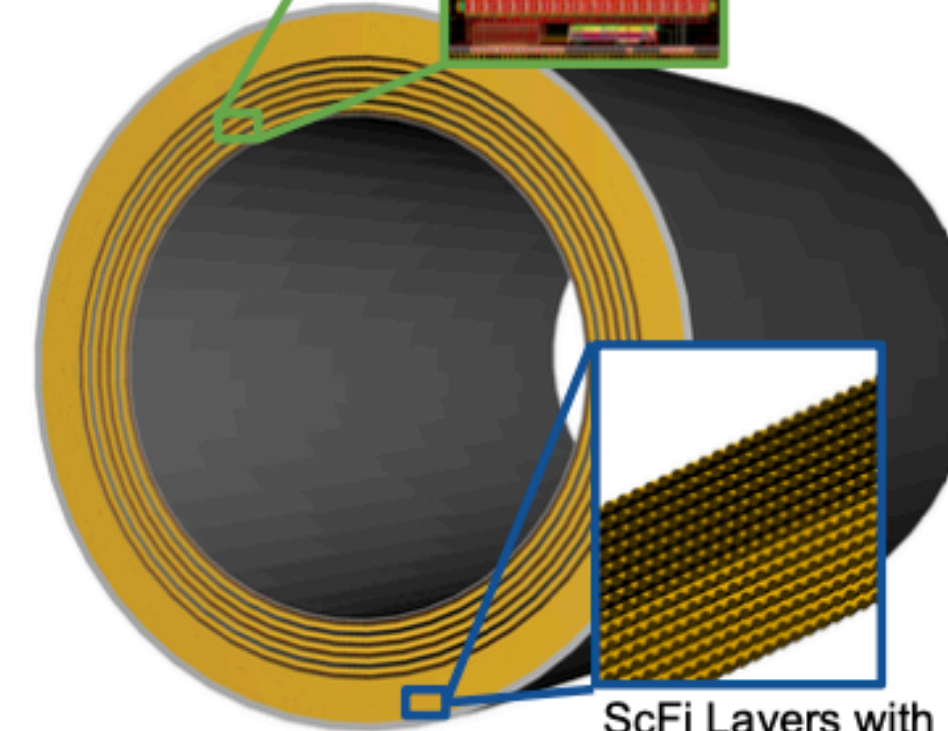


The ePIC Barrel Imaging Calorimeter (BIC)

AstroPix: silicon sensor with $500 \times 500 \mu\text{m}^2$ pixel size



The electromagnetic calorimeter is the main detector for **electron-pion separation**. The inclusive physics program requires up to 10^4 pion suppression at low momenta in the barrel



ScFi Layers with two-sided SiPM readout

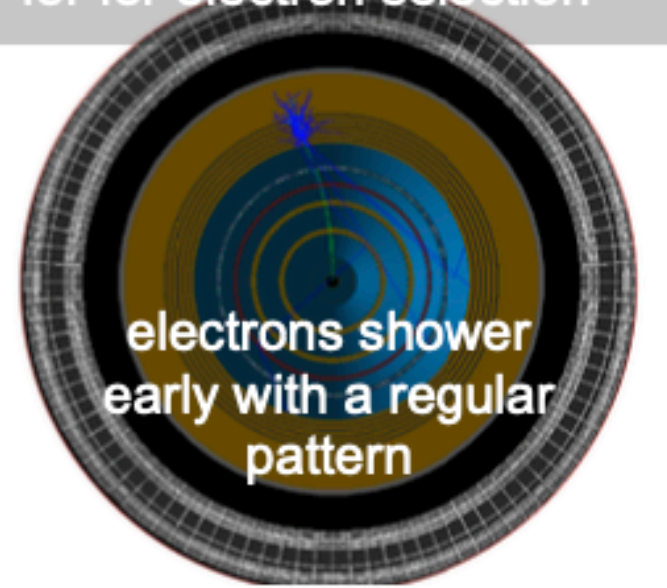
Total thickness $> 17.1 X_0$

Sampling fraction $\sim 10\%$

Large back section of Pb/ScFi

4(+2) planes of AstroPix sensors interleaved with 5 Pb/ScFi layers

Example: 3D Shower Imaging for electron selection



Energy resolution - Primarily from Pb/ScFi layers (+ AstroPix energy information)

Position resolution - Primarily from Imaging Layers (+ 2-sided Pb/ScFi readout and ϕ -R segmentation)

M.Jadhav (ANL) @ PIXEL 2024

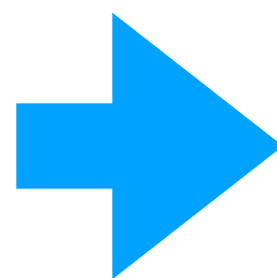
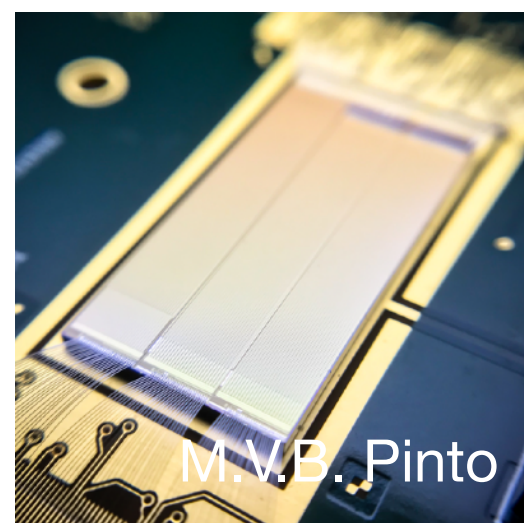
B.Kim+2025, PoS(VERTEX2025)

AstroPix Series

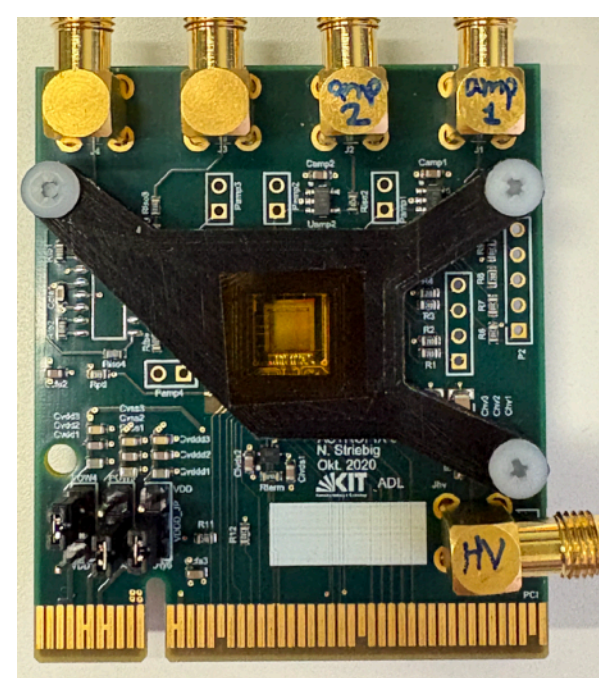
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MuPix

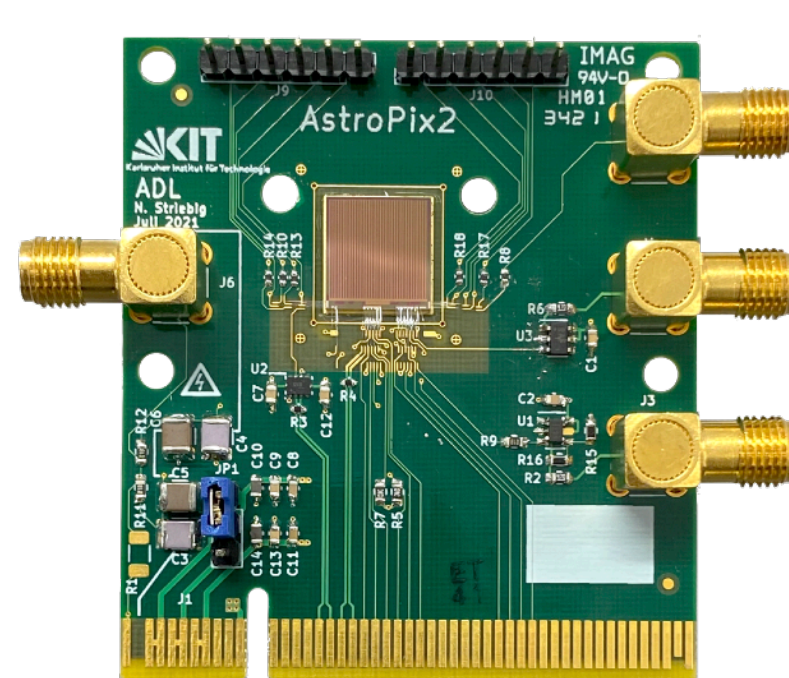
ATLASPix



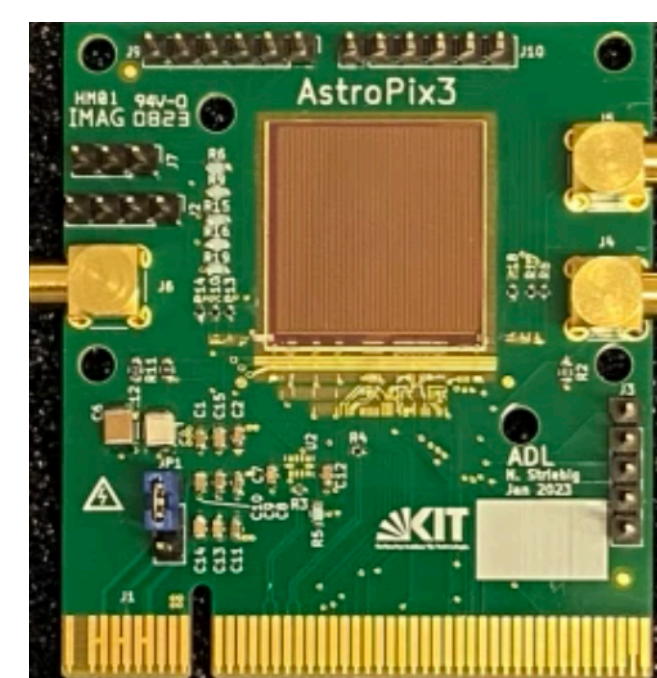
AstroPix v1



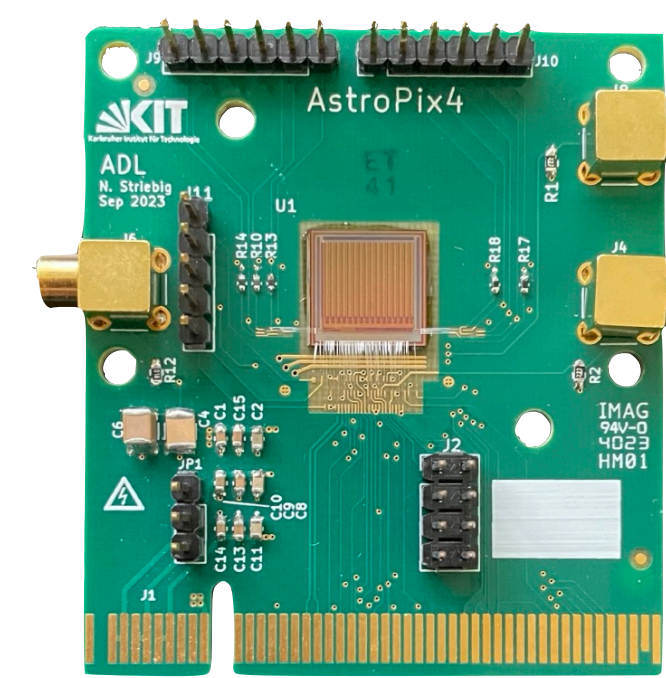
v2



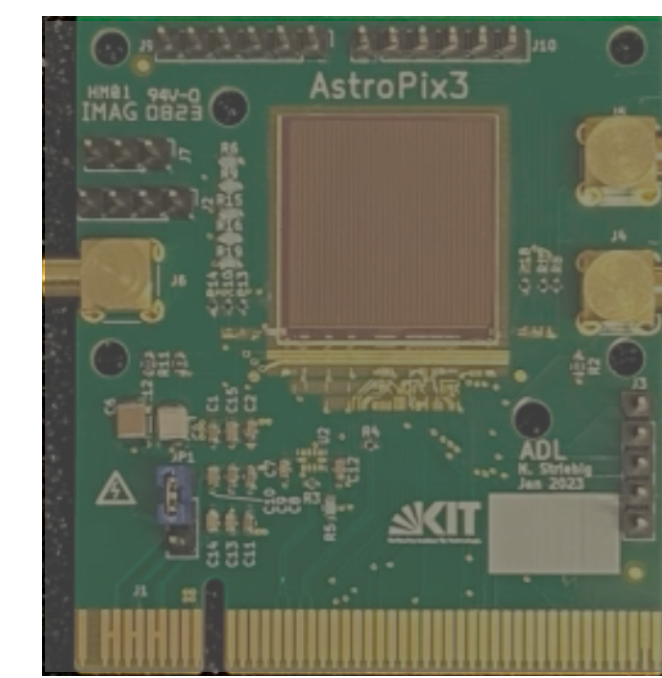
v3



v4



v5



Pitch: 150 x 50 μm

175 x 175 μm

250 x 250 μm

500 x 500 μm

500 x 500 μm

Power: 160 mW/cm²

24.6 mW/cm²

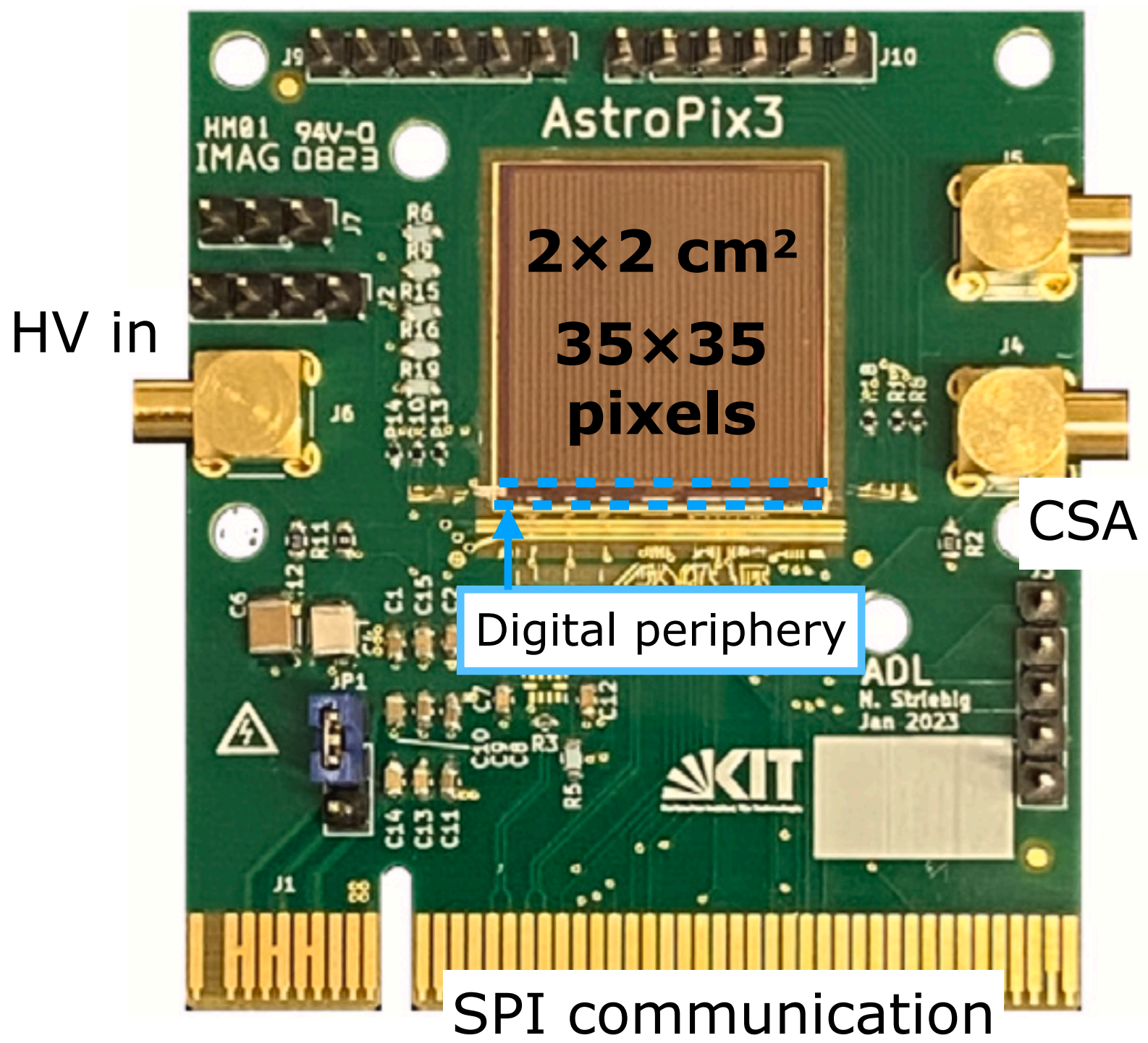
7.2 mW/cm²

4.1 mW/cm²

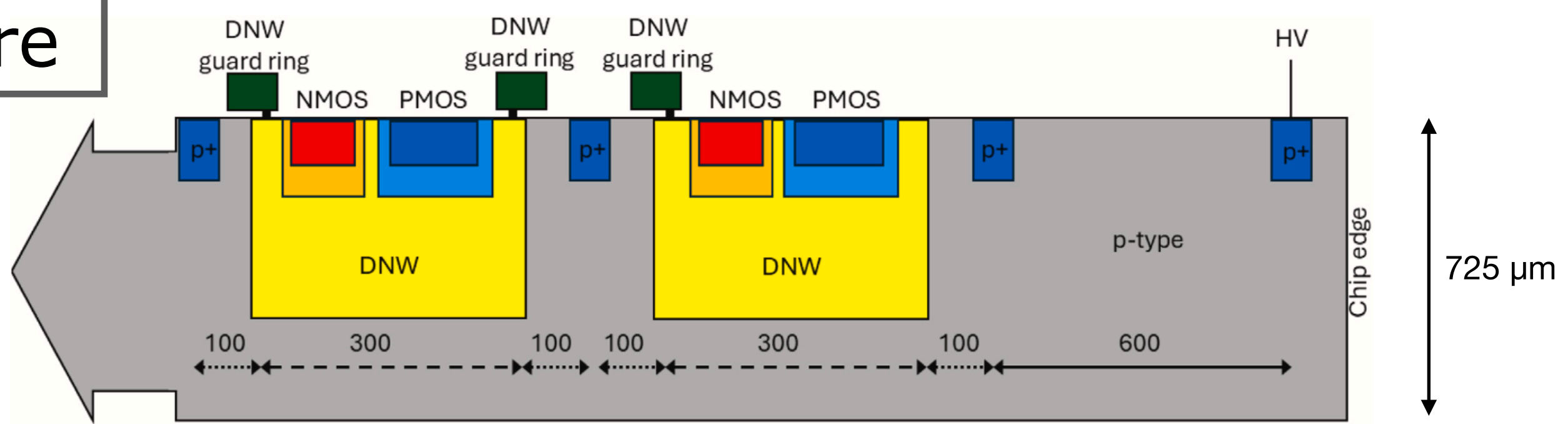
2 mW/cm²

- PI: R. Caputo (GSFC/NASA)
- Design: Karlsruhe Institute of Technology based on ~20 years of experience in HV-MAPS
- AstroPix1: First prototype. Analog readout only
- AstroPix2: Digital readout capability
- AstroPix3: Full reticle chip, 2 x 2 cm². Large pixel pitch, 500 μm
- AstroPix4, AstroPix5, ...

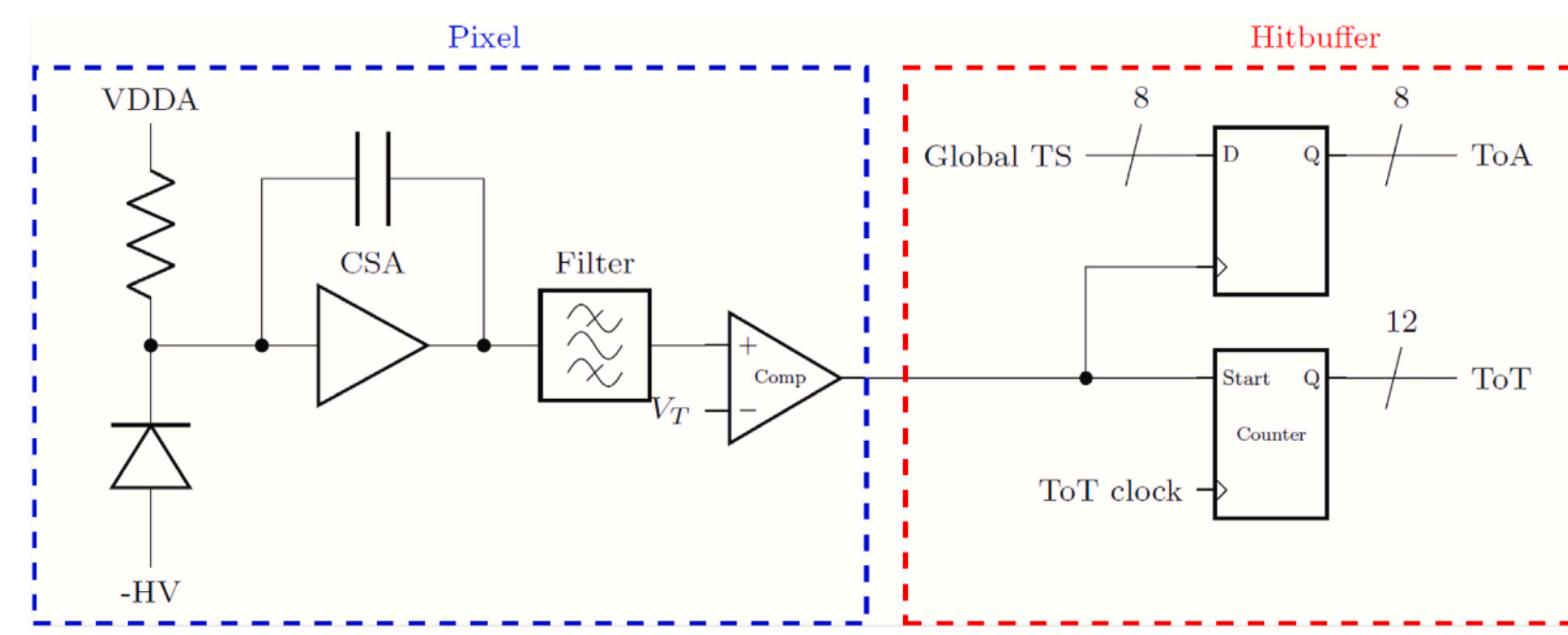
AstroPix3



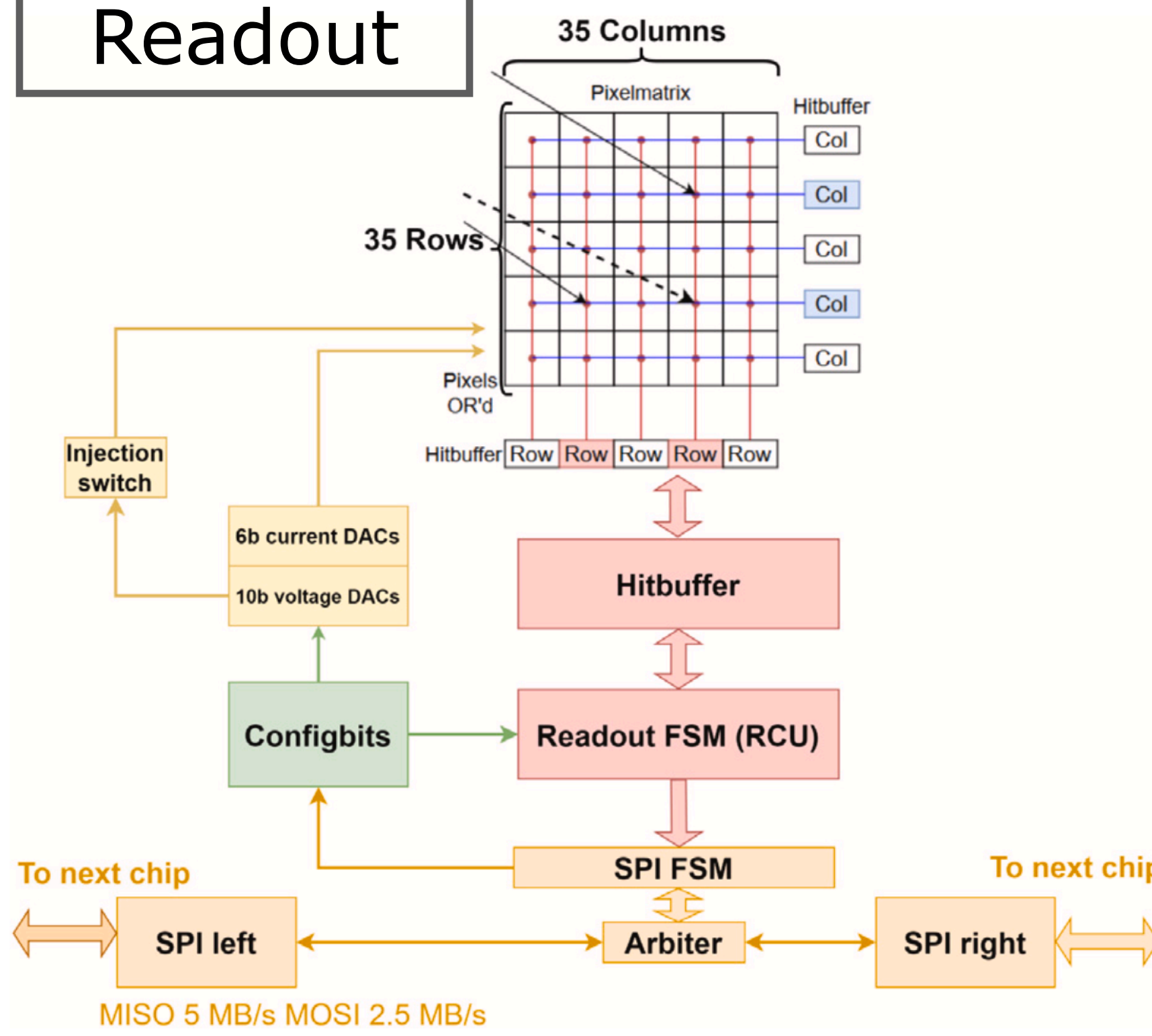
Structure



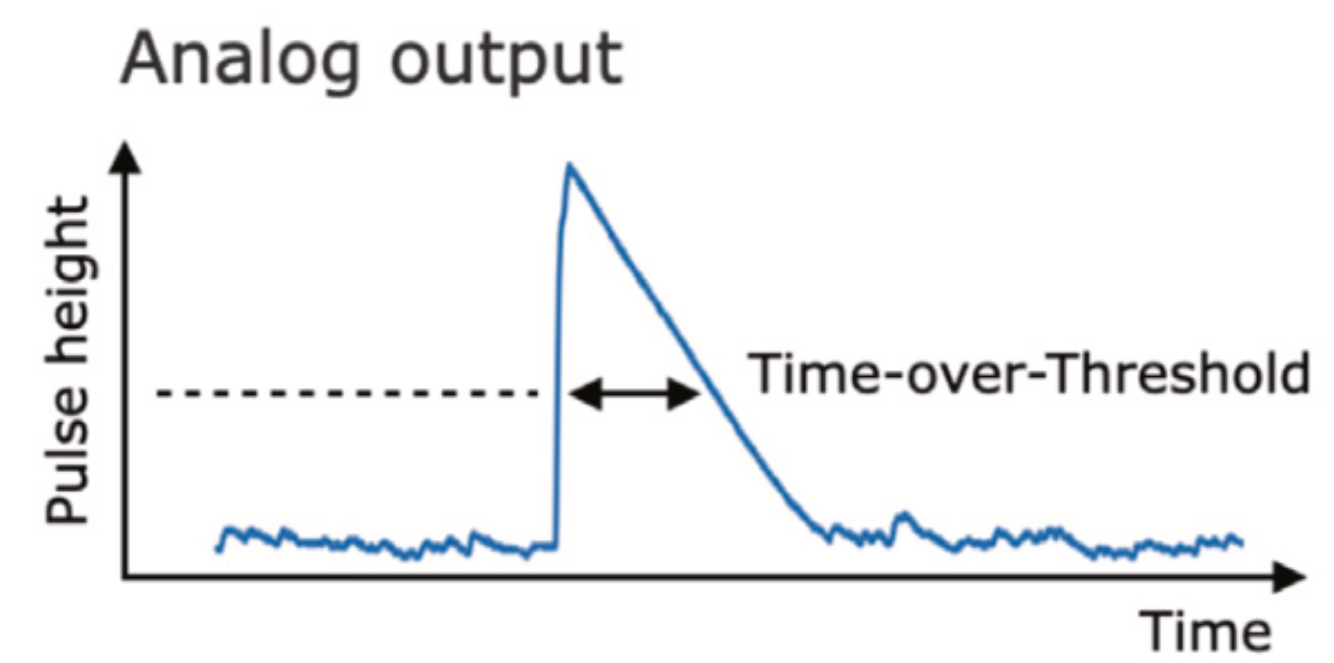
Electronics



Readout

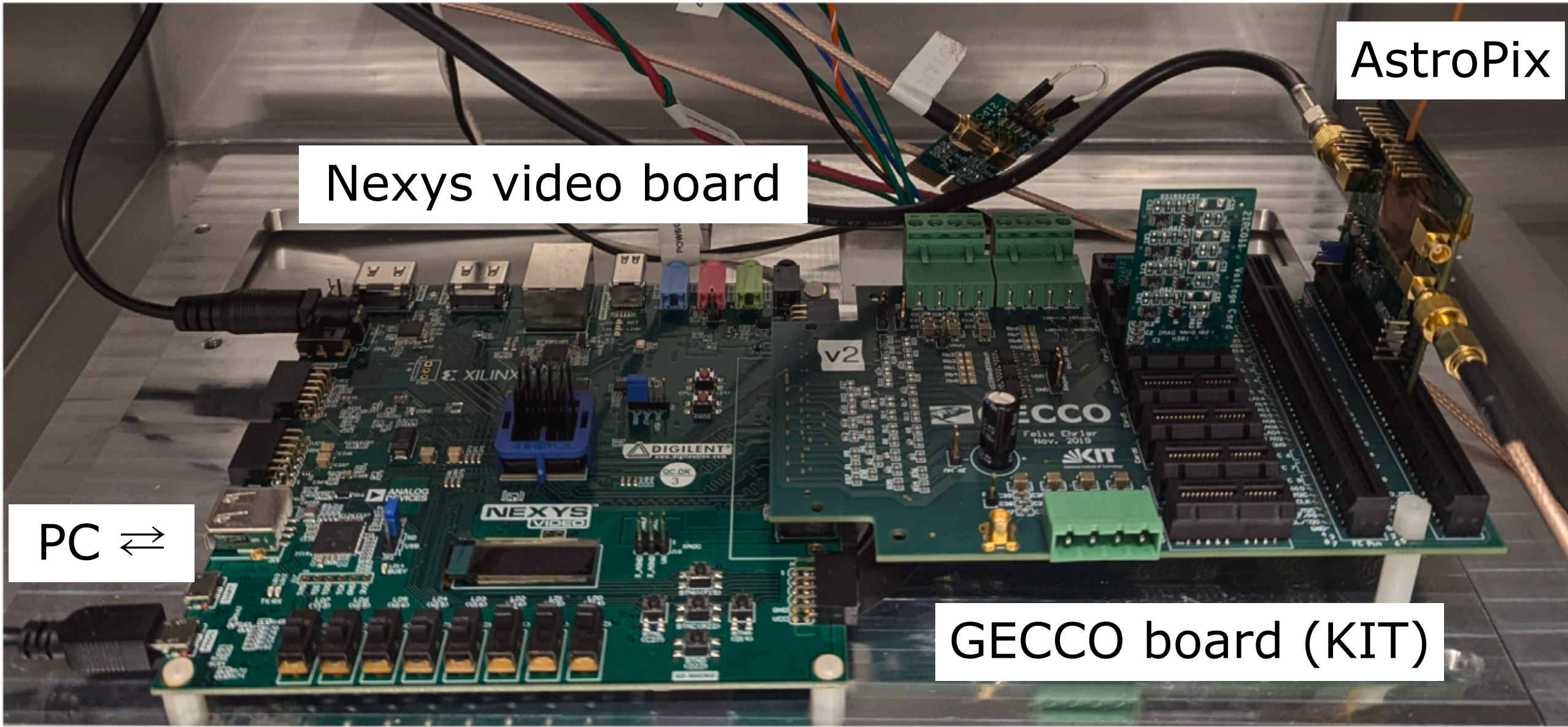


	ATLASPix [5,6]	v1 [7]	v2 [7,8]	v3 [9-11]	Goal [12]
E_{res} [keV]	$7.3 \pm 1.2\%$	$20 \pm 7.4\%^*$	$15 \pm 3\%$	$10.4 \pm 3.2\%^\diamond$	10%
(FWHM)	at 30.1	at 30.1	at 30.1	at 59.5	at 122
Pitch [μm]	150×50	175×175	250×250	500×500	500×500
Thick [μm]	100	725	725	725	525
Dep. [μm]	48 [■]	N.M.	N.M.	$94 \pm 6^\Delta$	500
Range [keV]	5-32	14-122	14-80	22-200	25-700
Analog [mW/cm ²]	120	14.7	3.4	1.06	1.0
Digital [mW/cm ²]	40	9.9	3.75	3.06	0.5

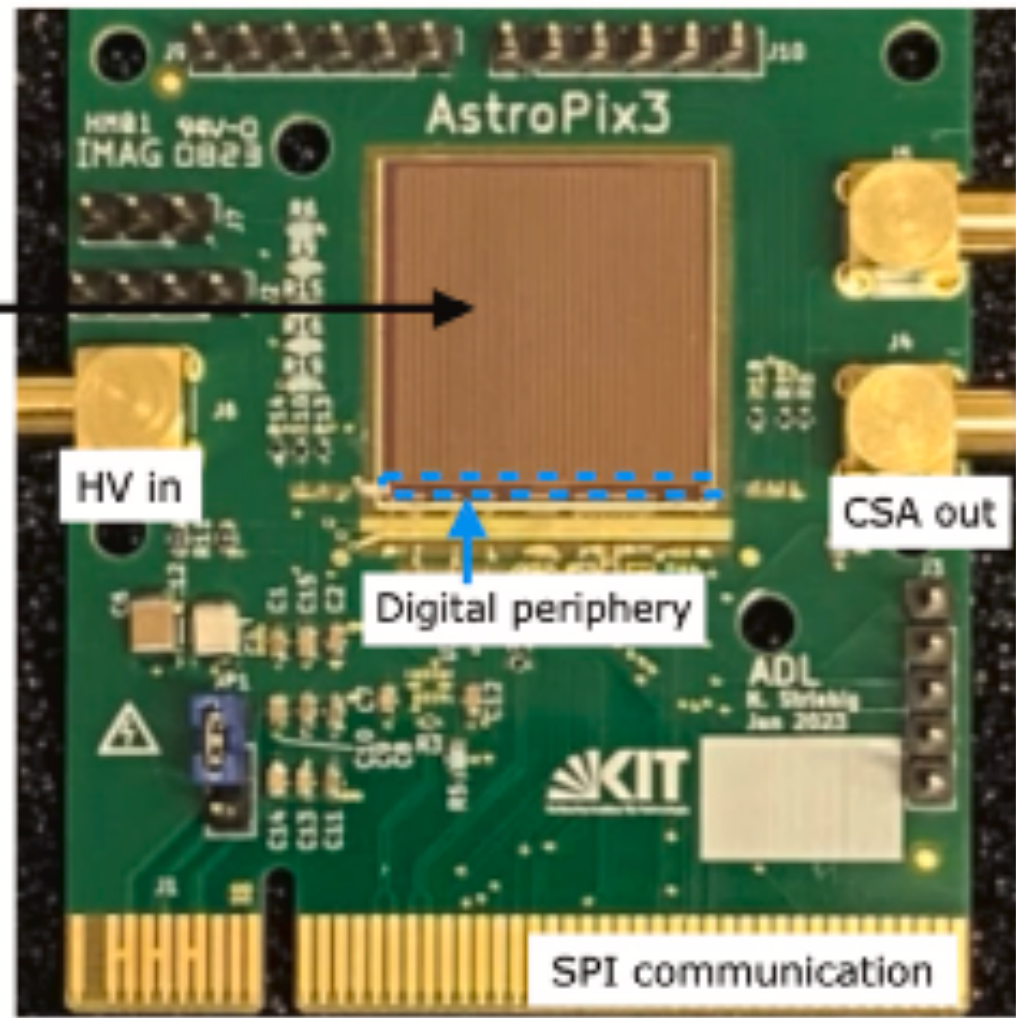
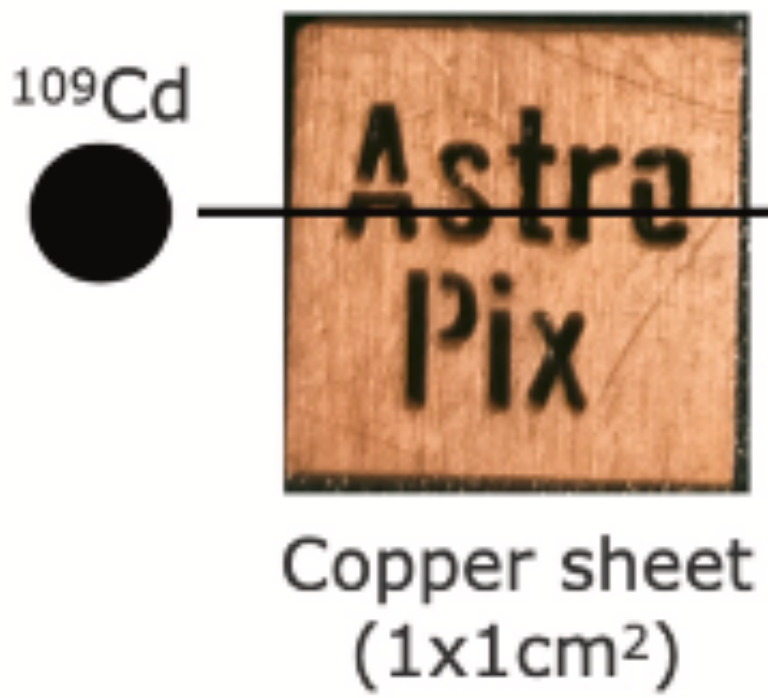
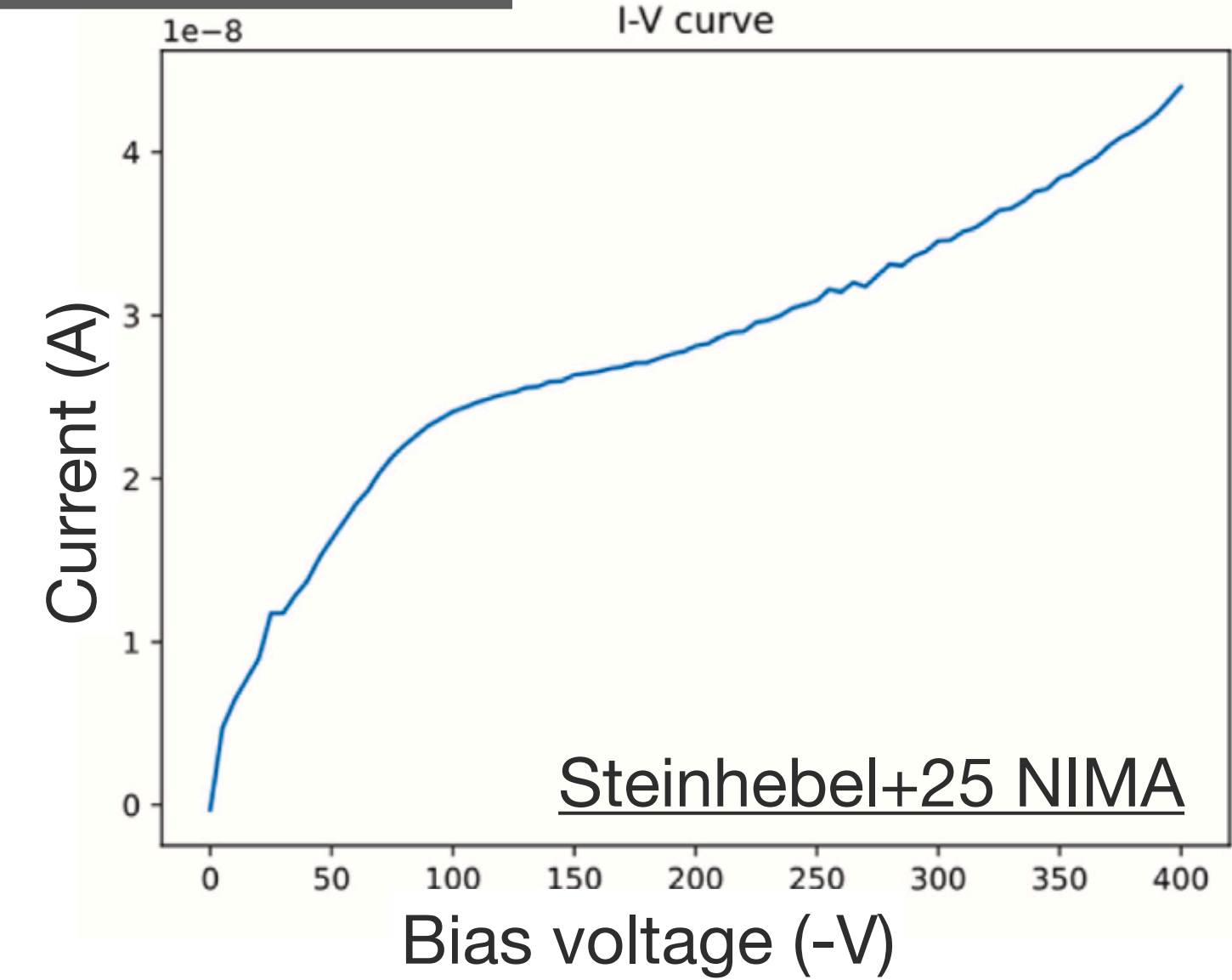


Steinhebel+25 NIMA

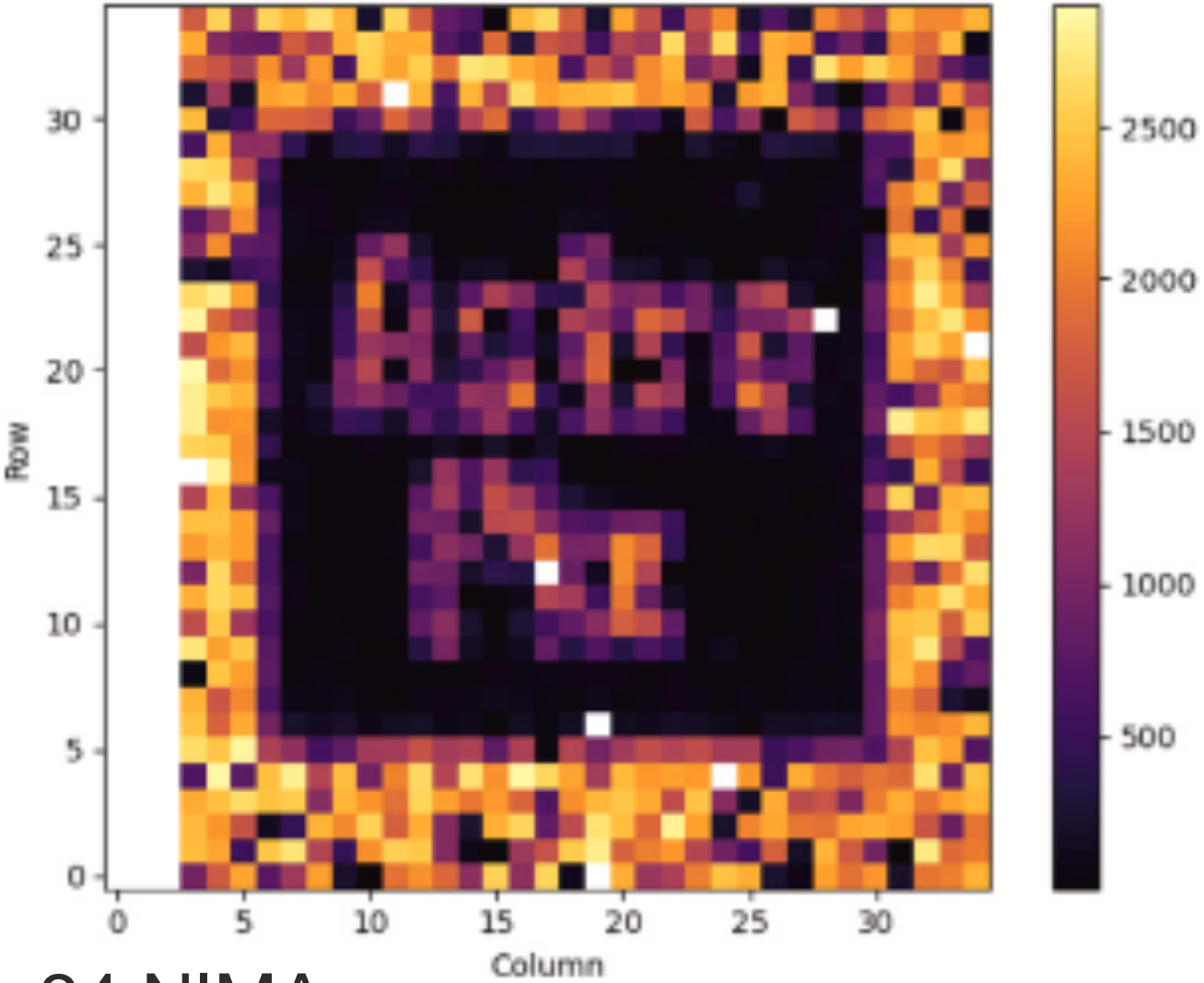
Setup



I-V curve



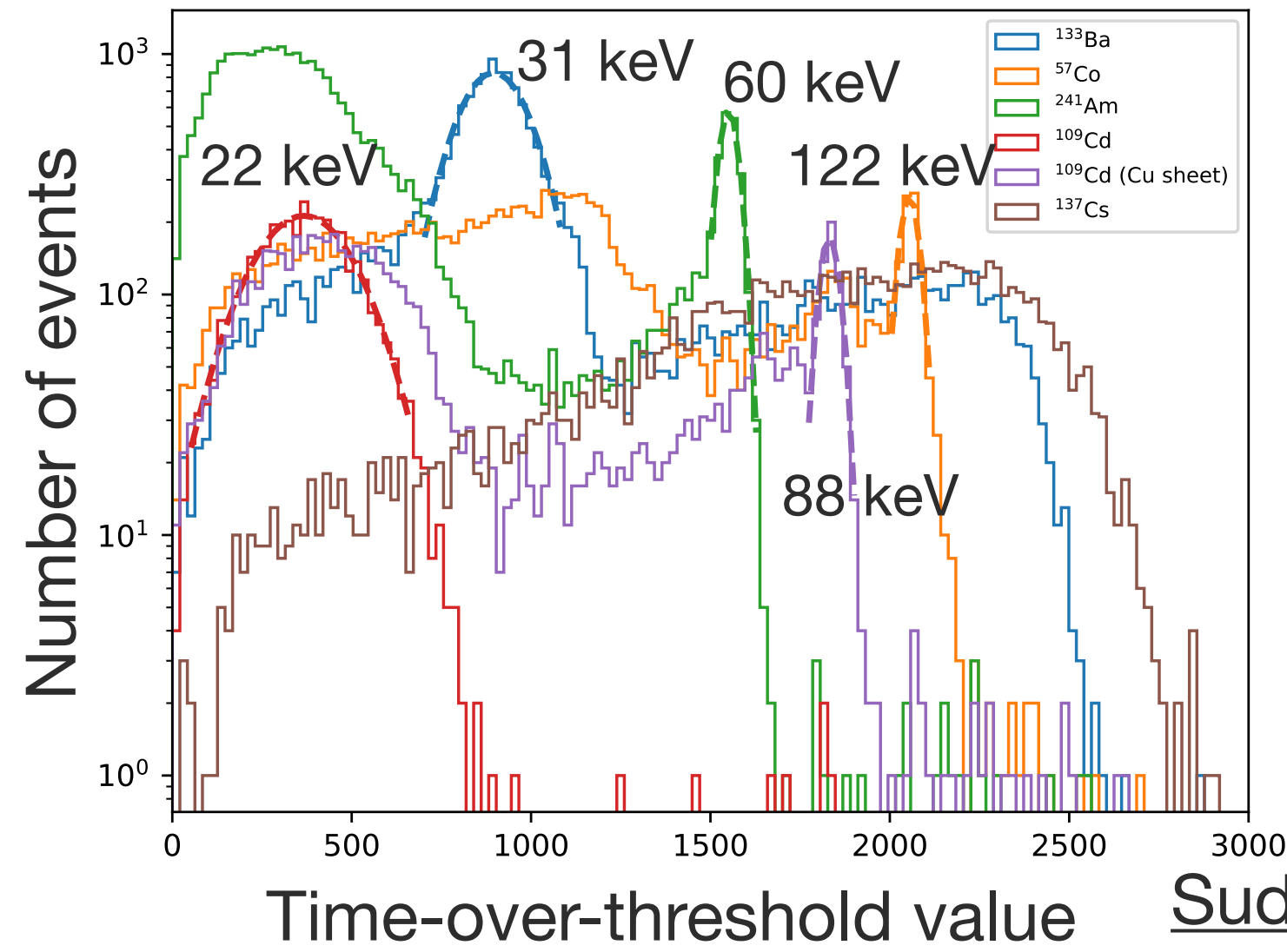
Imaging



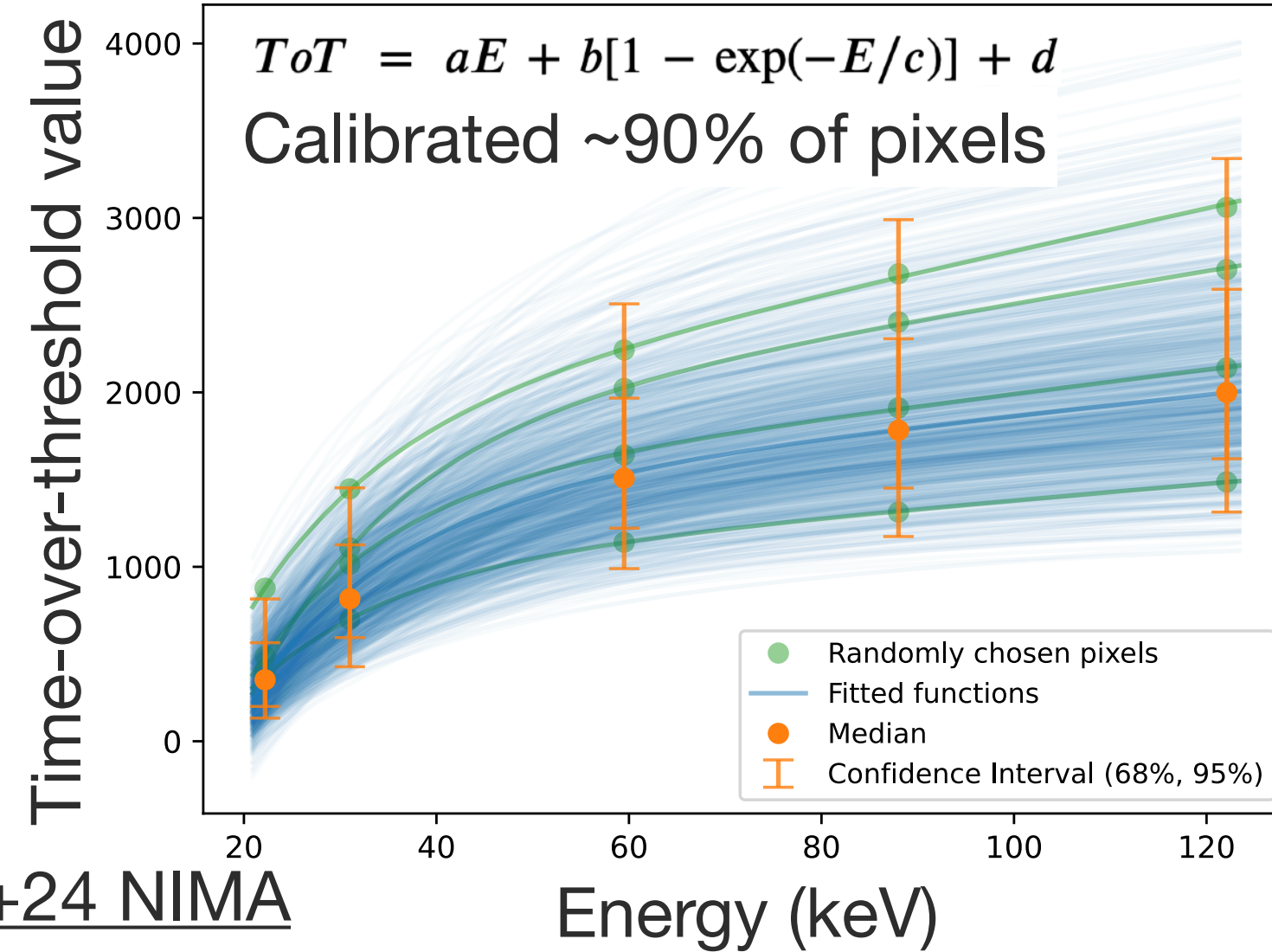
AstroPix3: Performance

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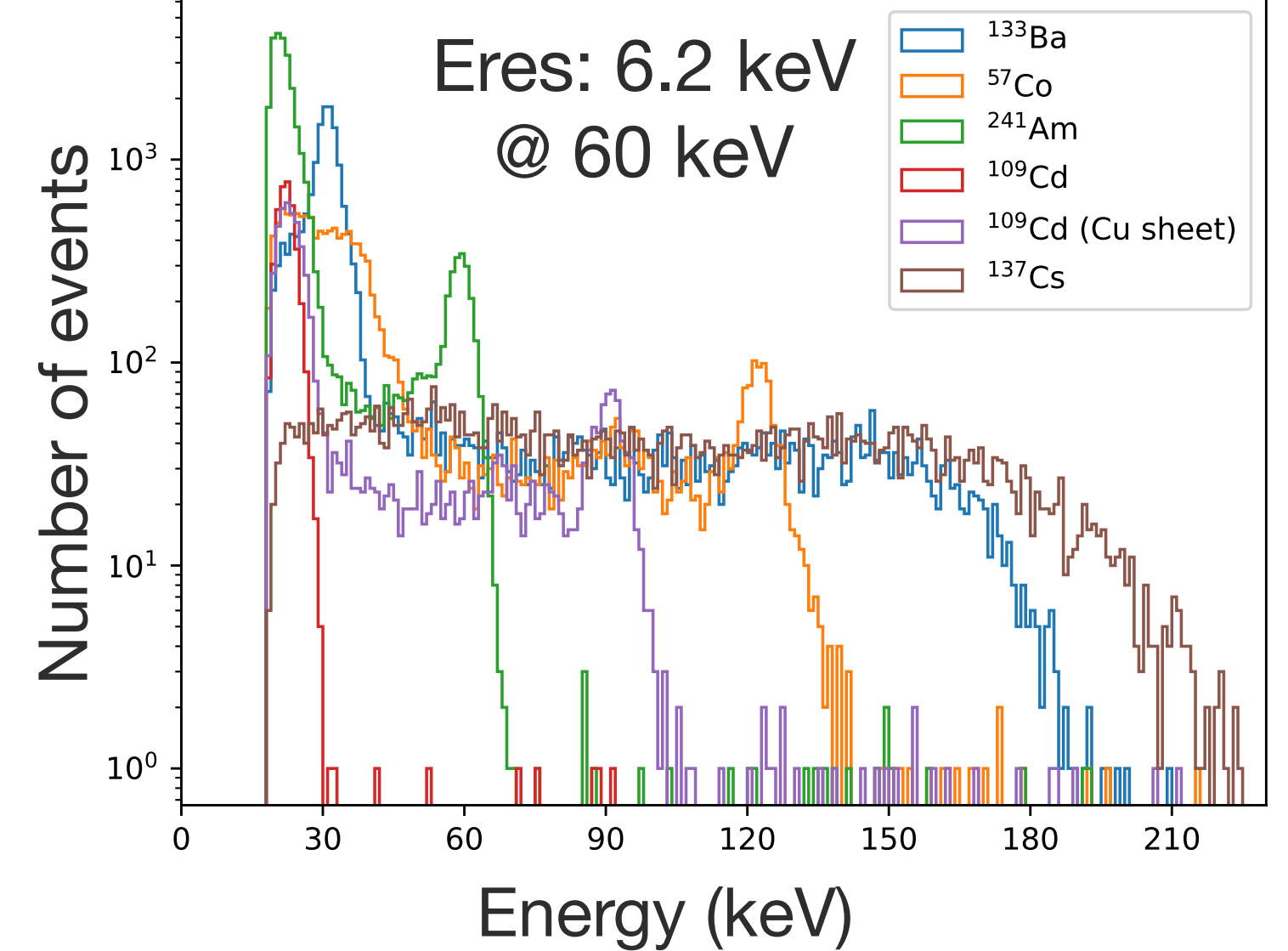
ToT spectra



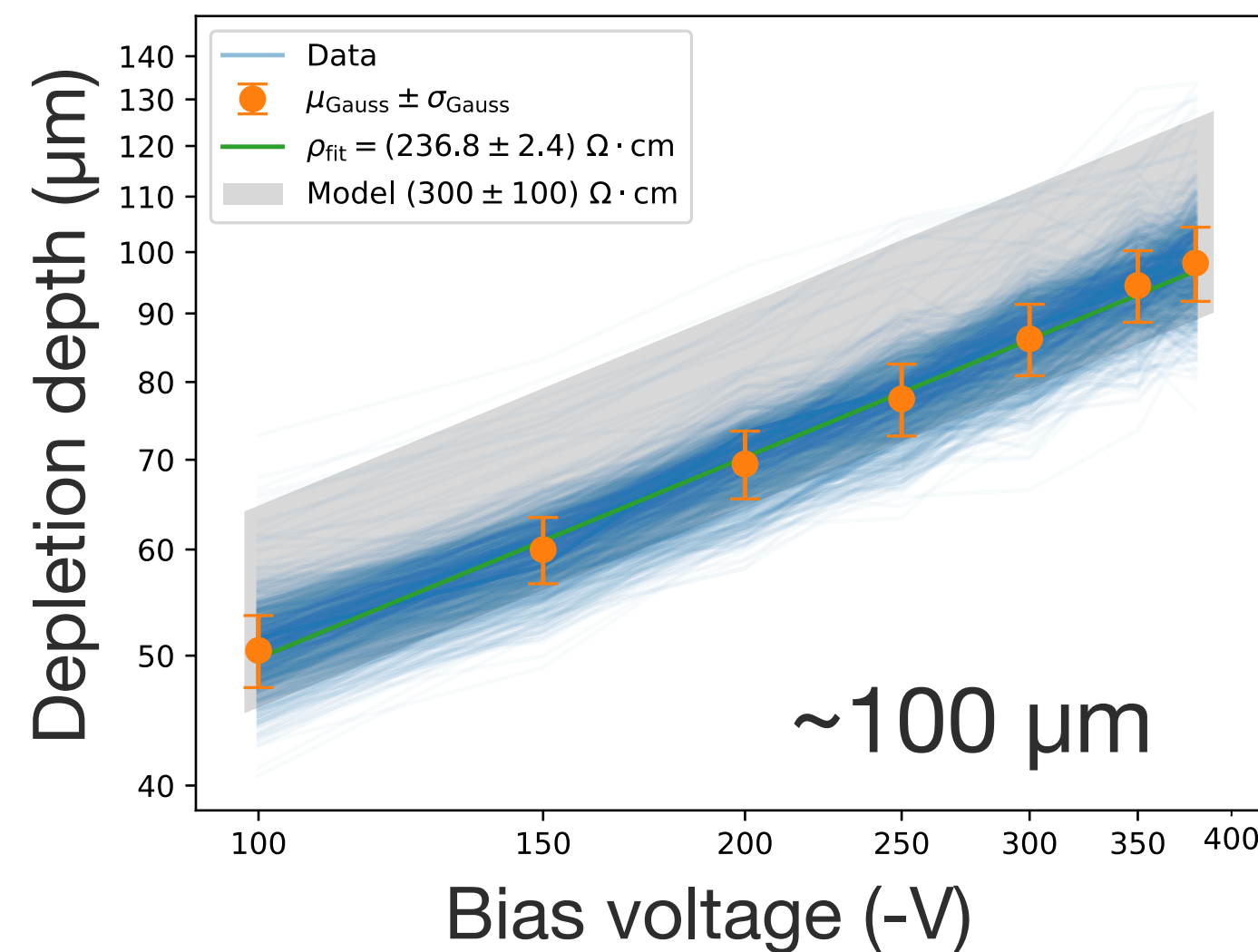
Calibration curves



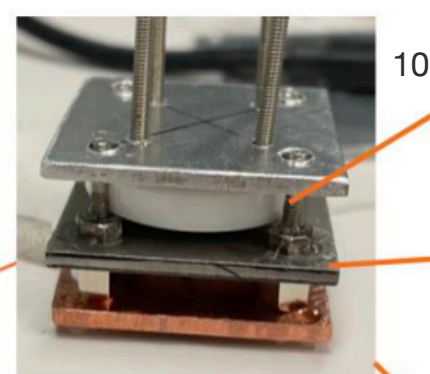
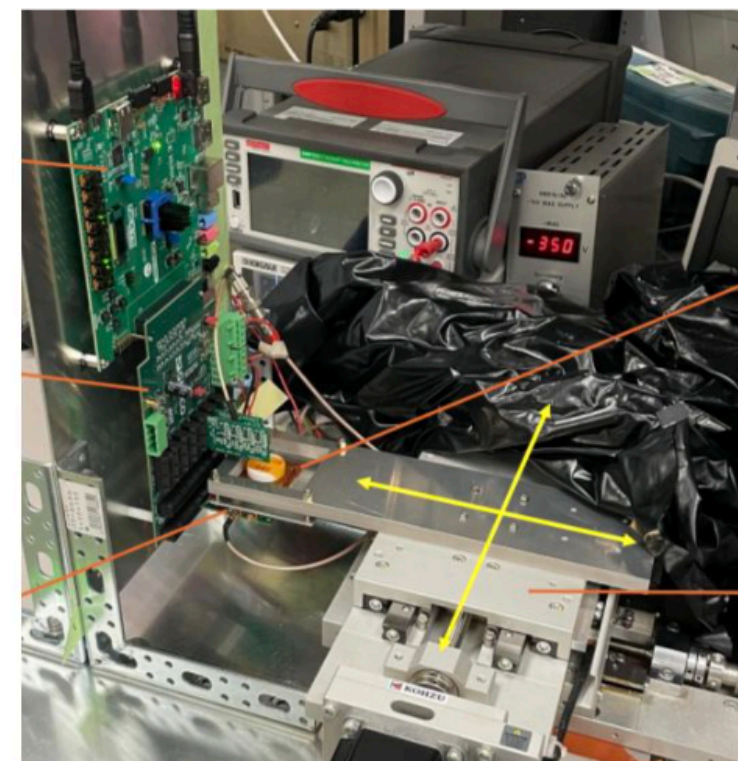
Energy spectra



Depletion depth

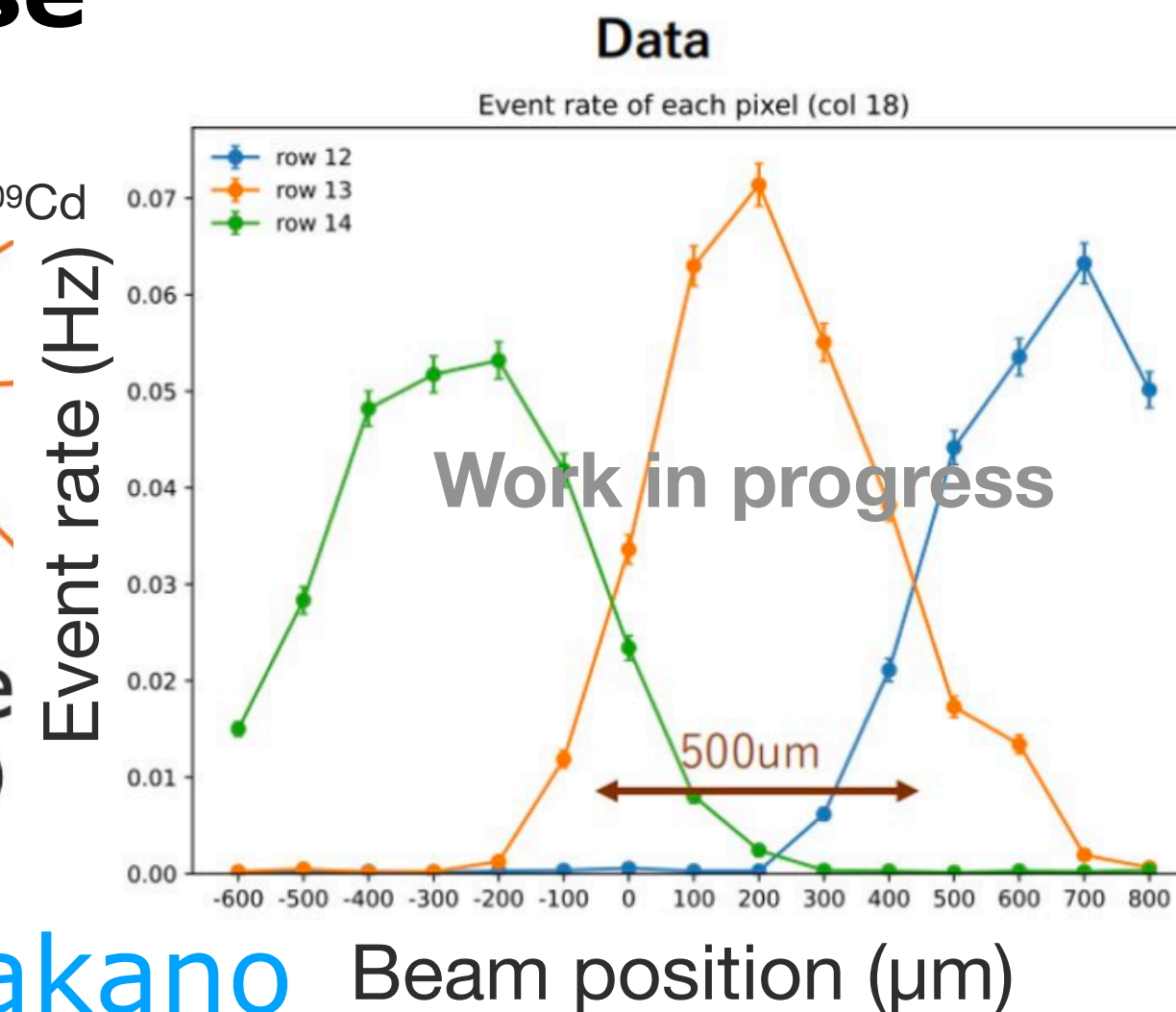


Sub-pixel response



XY stage
(1 $\mu\text{m}/\text{step}$)

109Cd
Event rate (Hz)



→ Poster by N.Nakano

Beam position (μm)

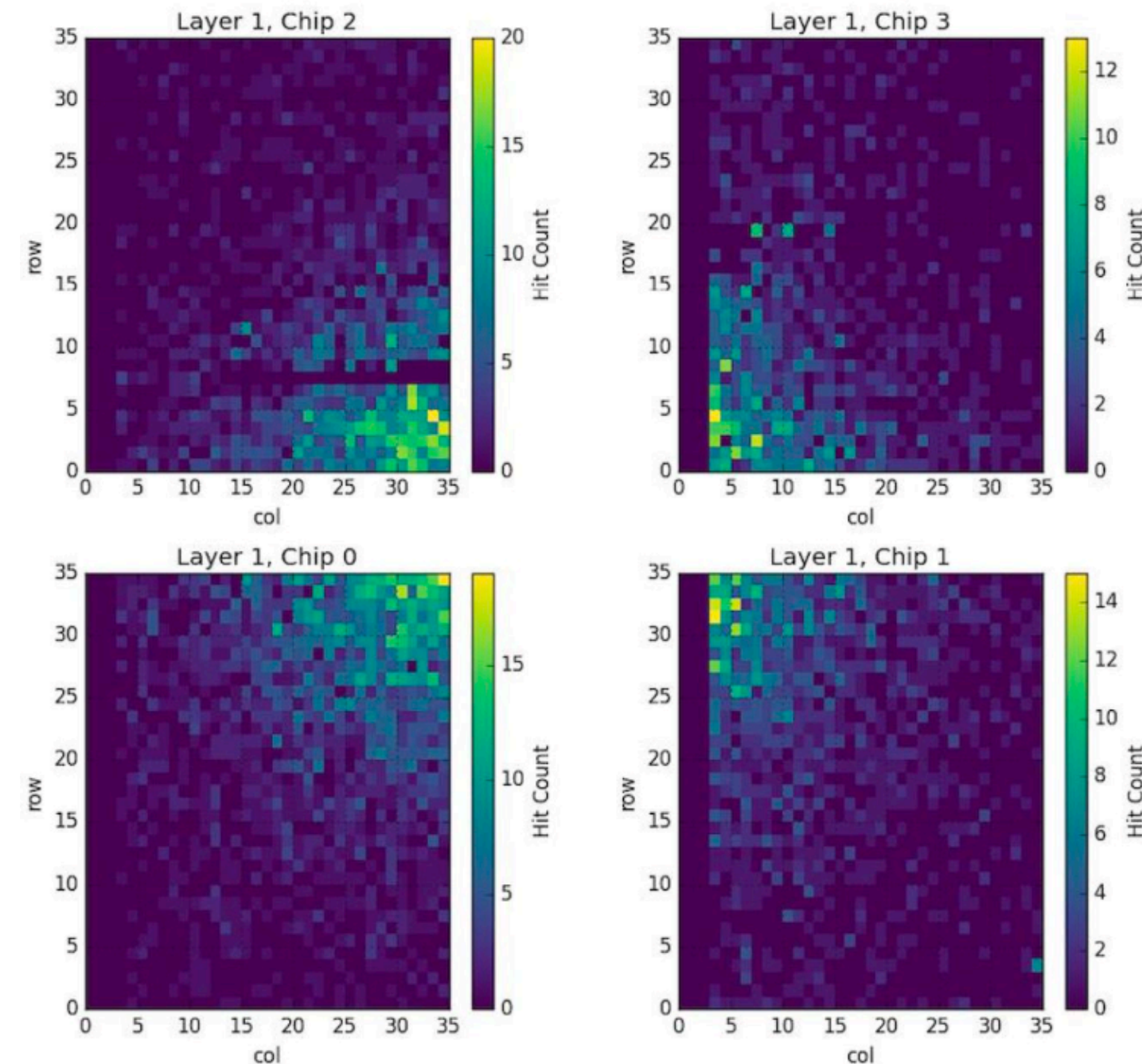
Beam position (μm)

AstroPix3: Quad-Chip

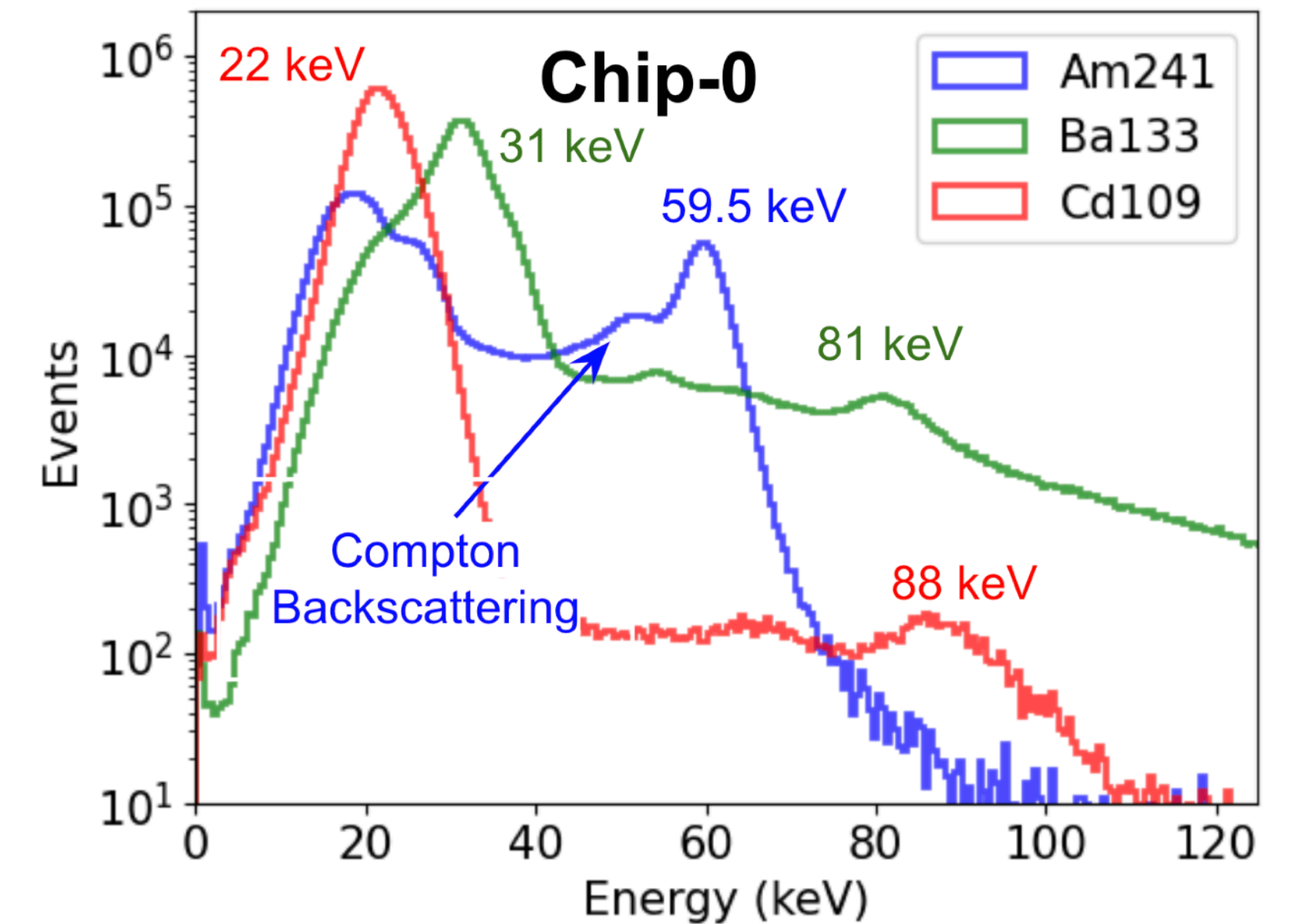
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Source scan with Sr-90



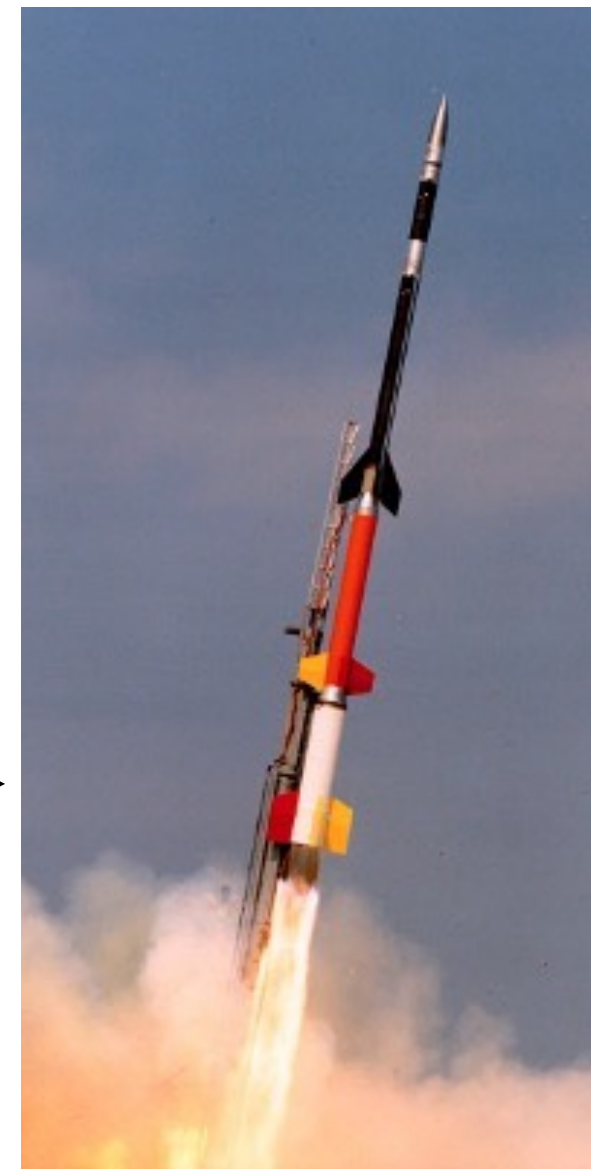
Energy spectra



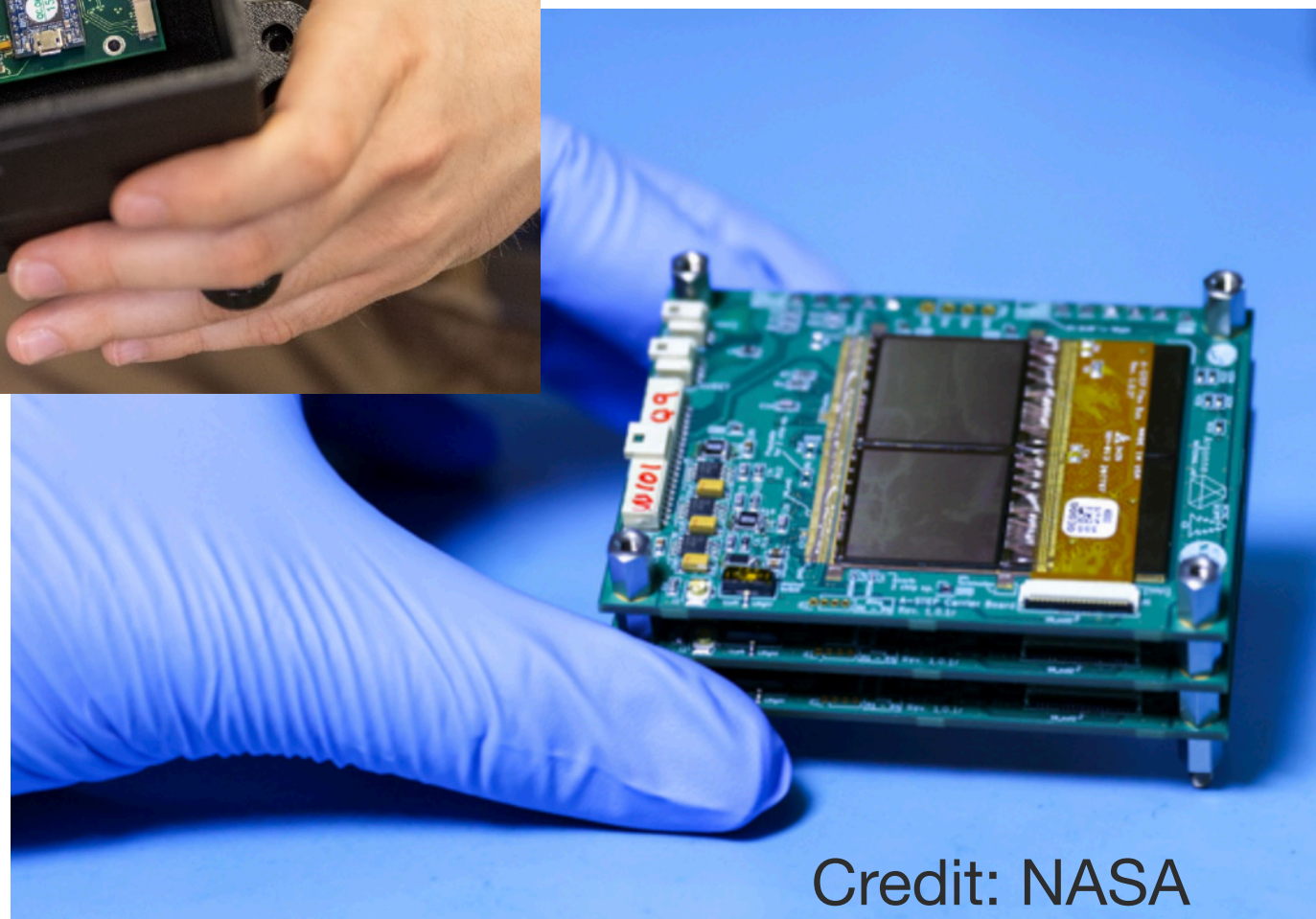
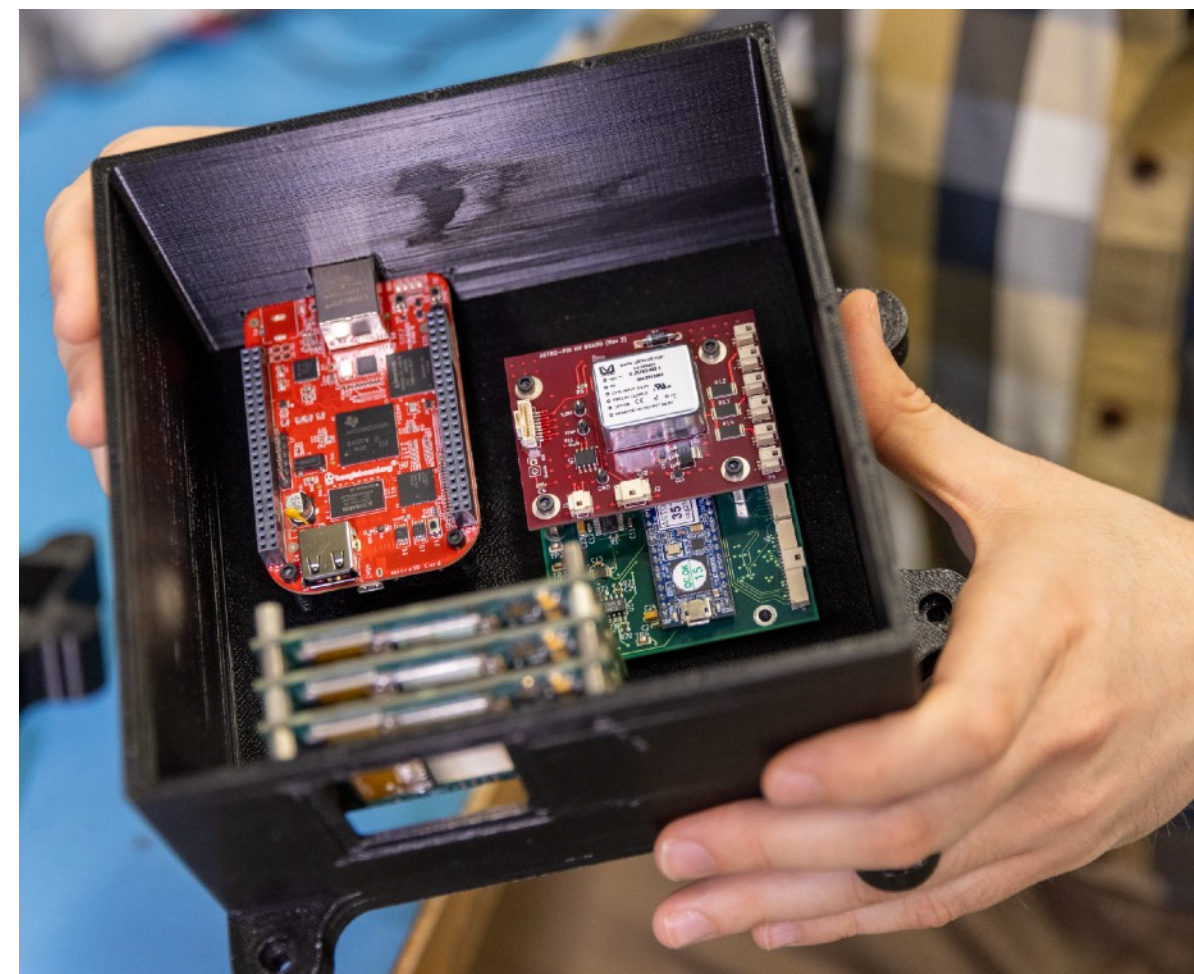
- Quad-chip: Four daisy-chained AstroPix chips
- Minimum component of the AMEGO-X's tracker
- Successfully readout hits from four V3 chips!
- Similar performance as V3 single chip

AstroPix in Space

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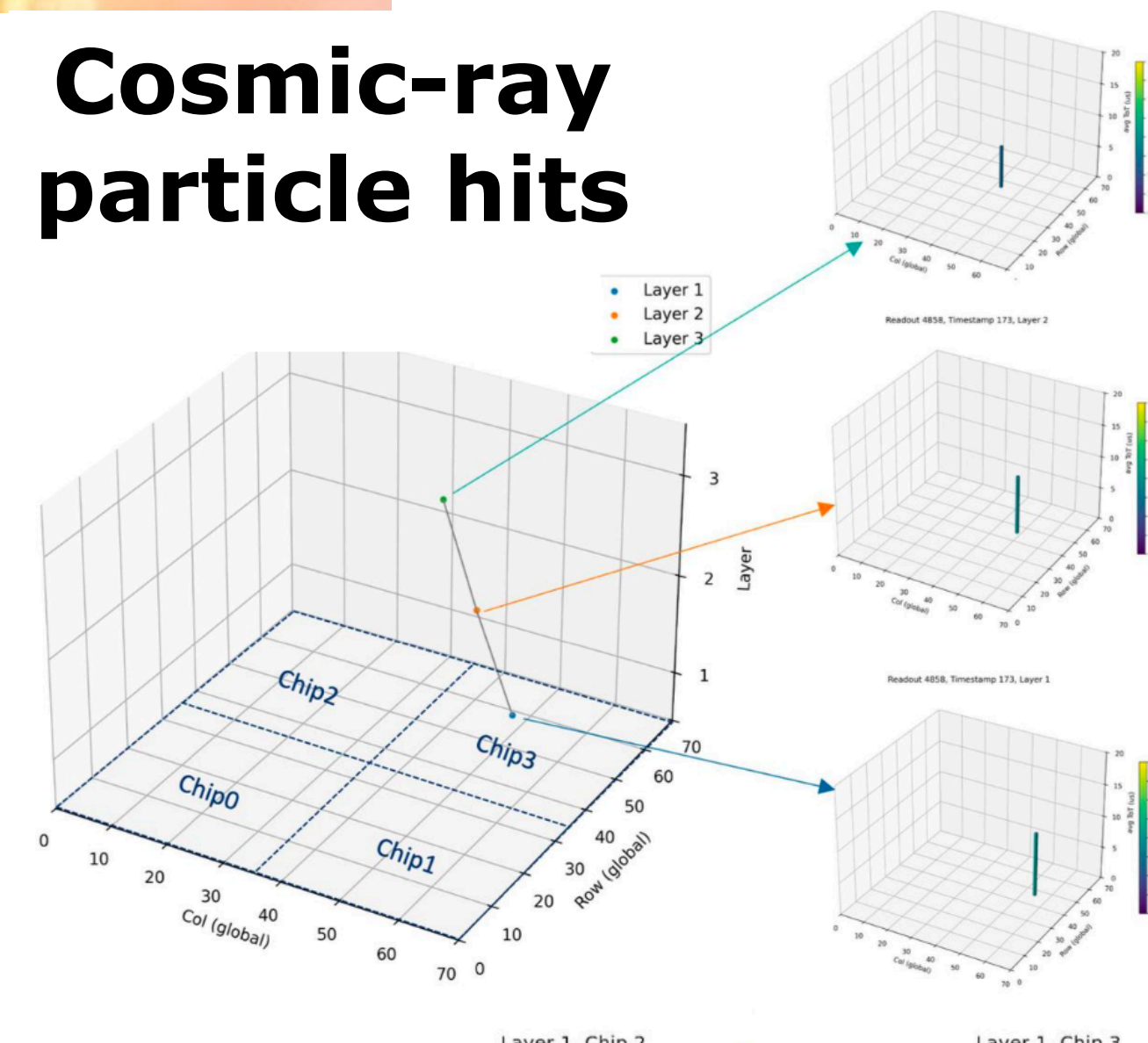


- A-STEP: AstroPix **Sounding Rocket** Technology dEmonstration Payload
- Detector: **3-layer** v3 quad-chips
- To increase the Technical Readiness Level of the AstroPix sensors
- Plan to launch from Wallops Flight Facility in 2026
- Characterization/reconstruction/simulation are ongoing

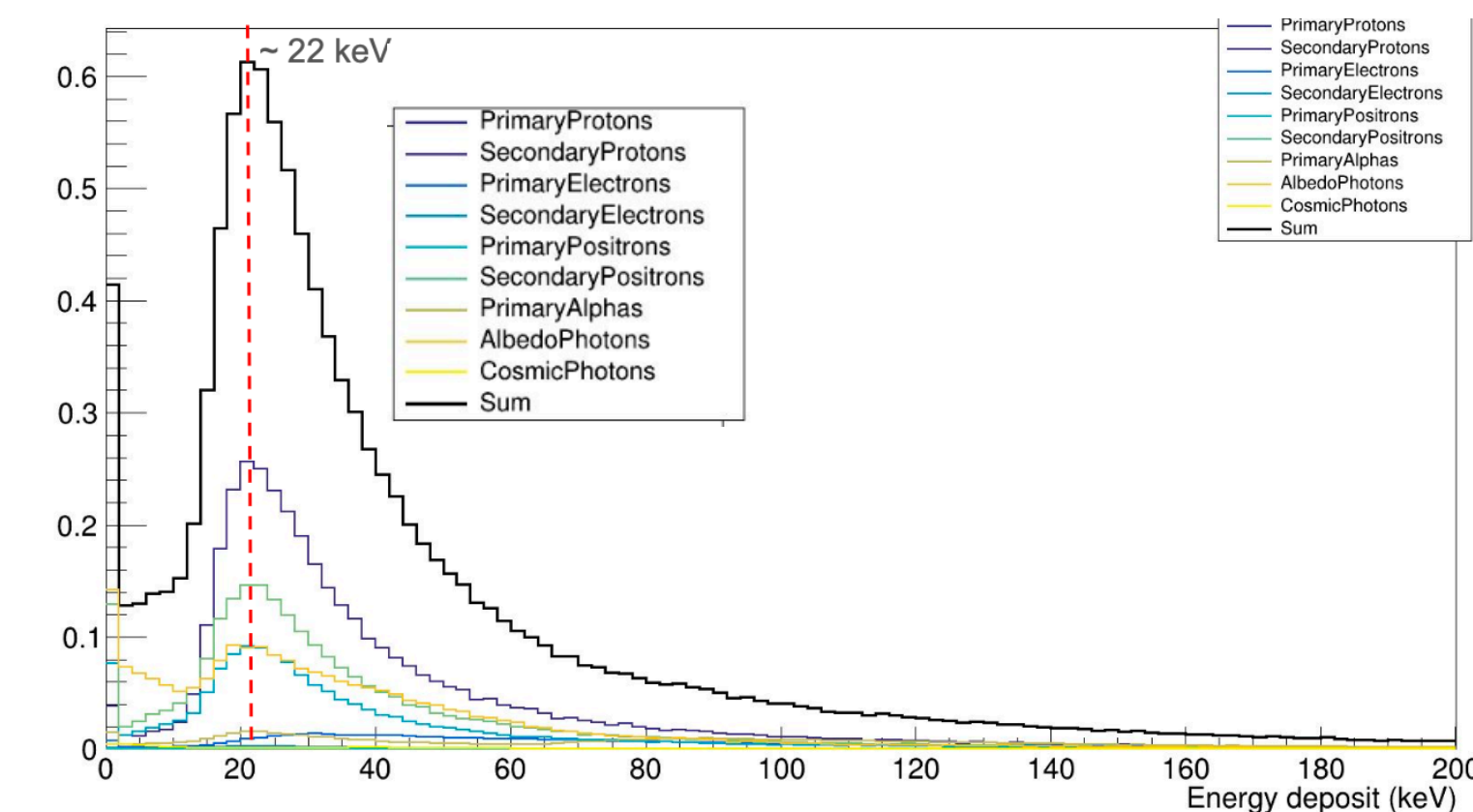


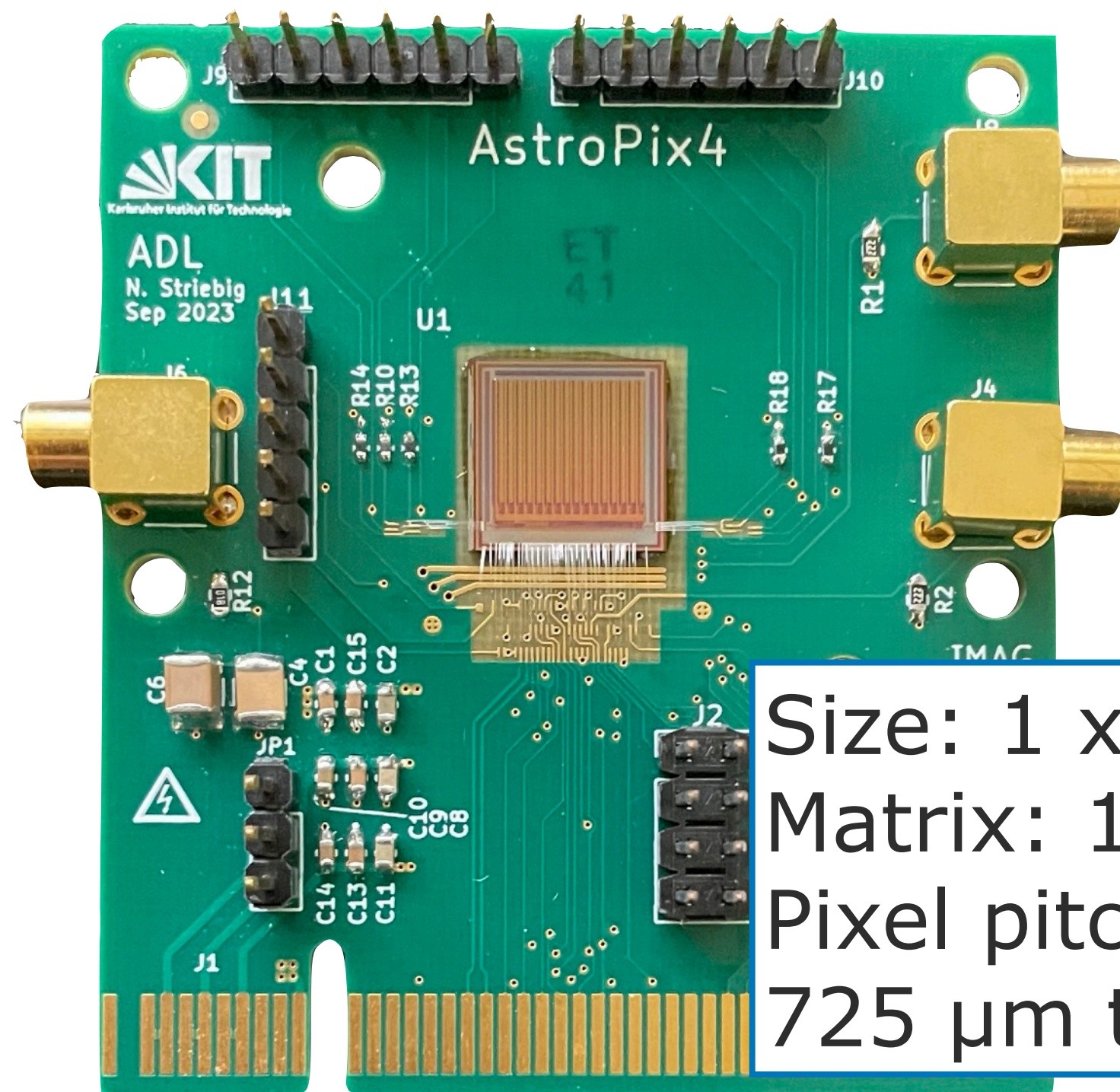
Credit: NASA

Cosmic-ray particle hits

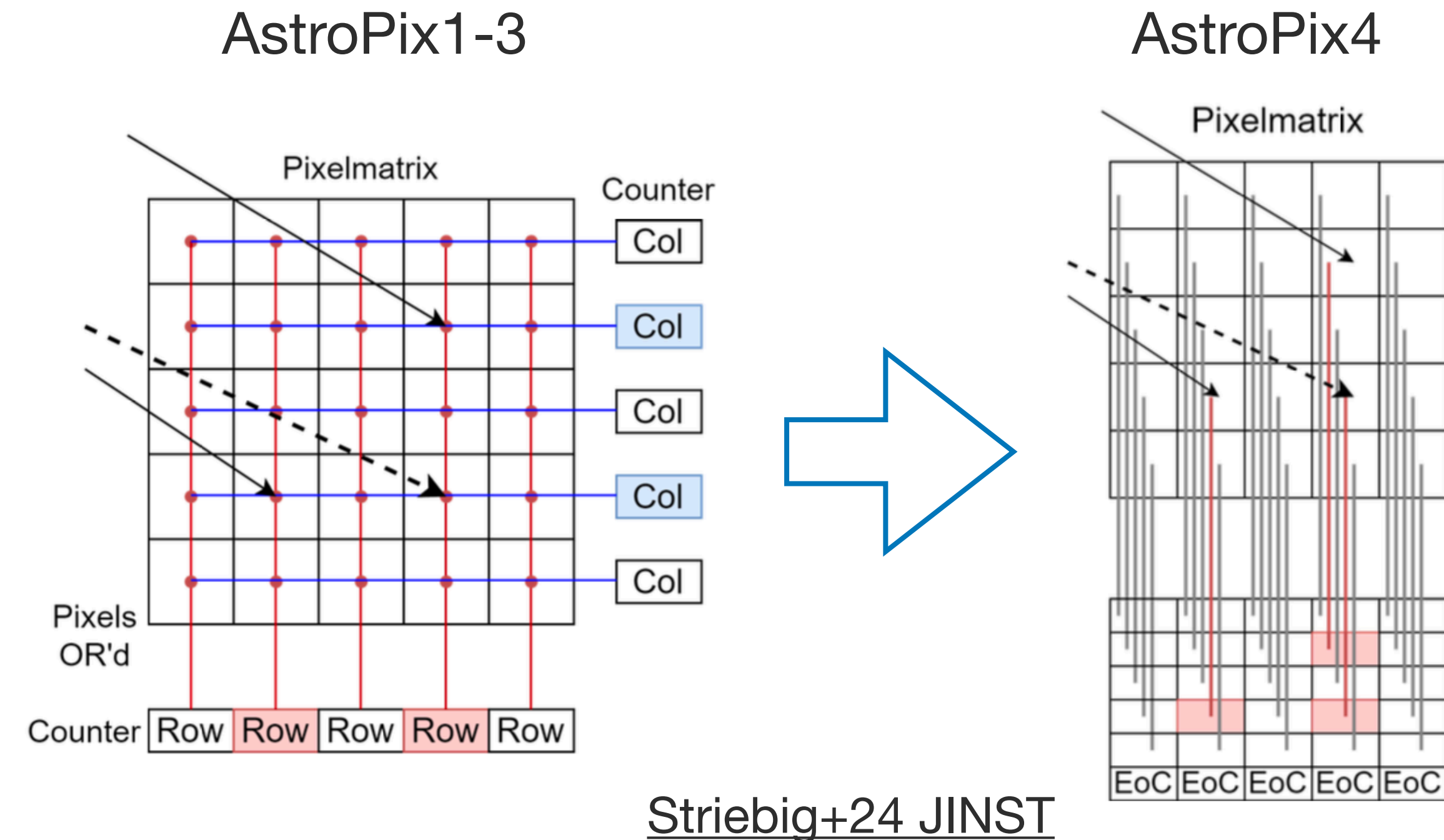


Cosmic-ray simulations





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

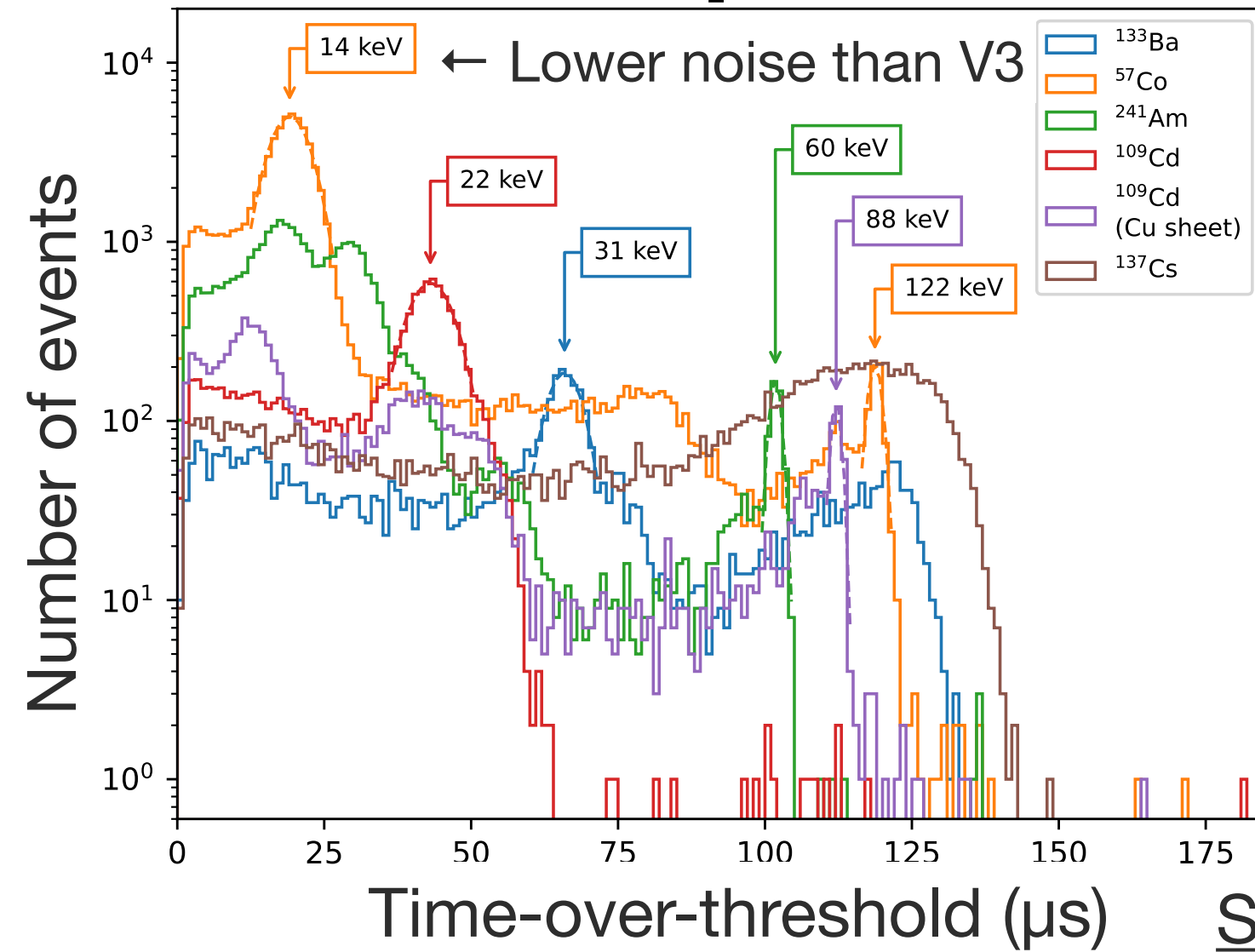


- Reduced input capacitance by optimizing the routing and minimizing the metal-to-n-well capacitance → Lower noise floor and better energy resolution
- Pixel-by-pixel comparator threshold tune → ToT variation to be suppressed
- Individual hit buffer → No identification problem with multiple hits in Row/Col
- Improved time stamp structure → 3 ns for timing and ToT

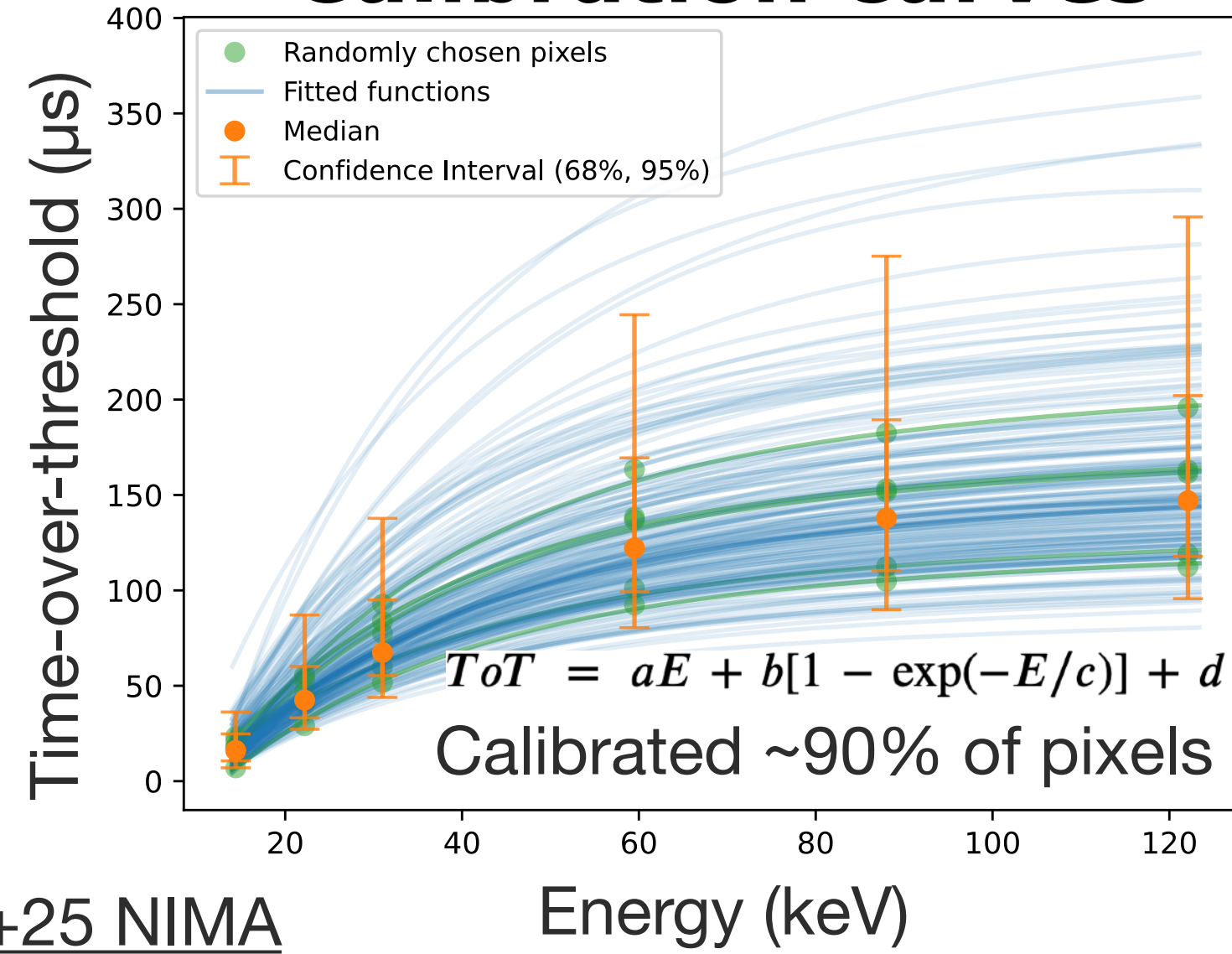
AstroPix4: Performance

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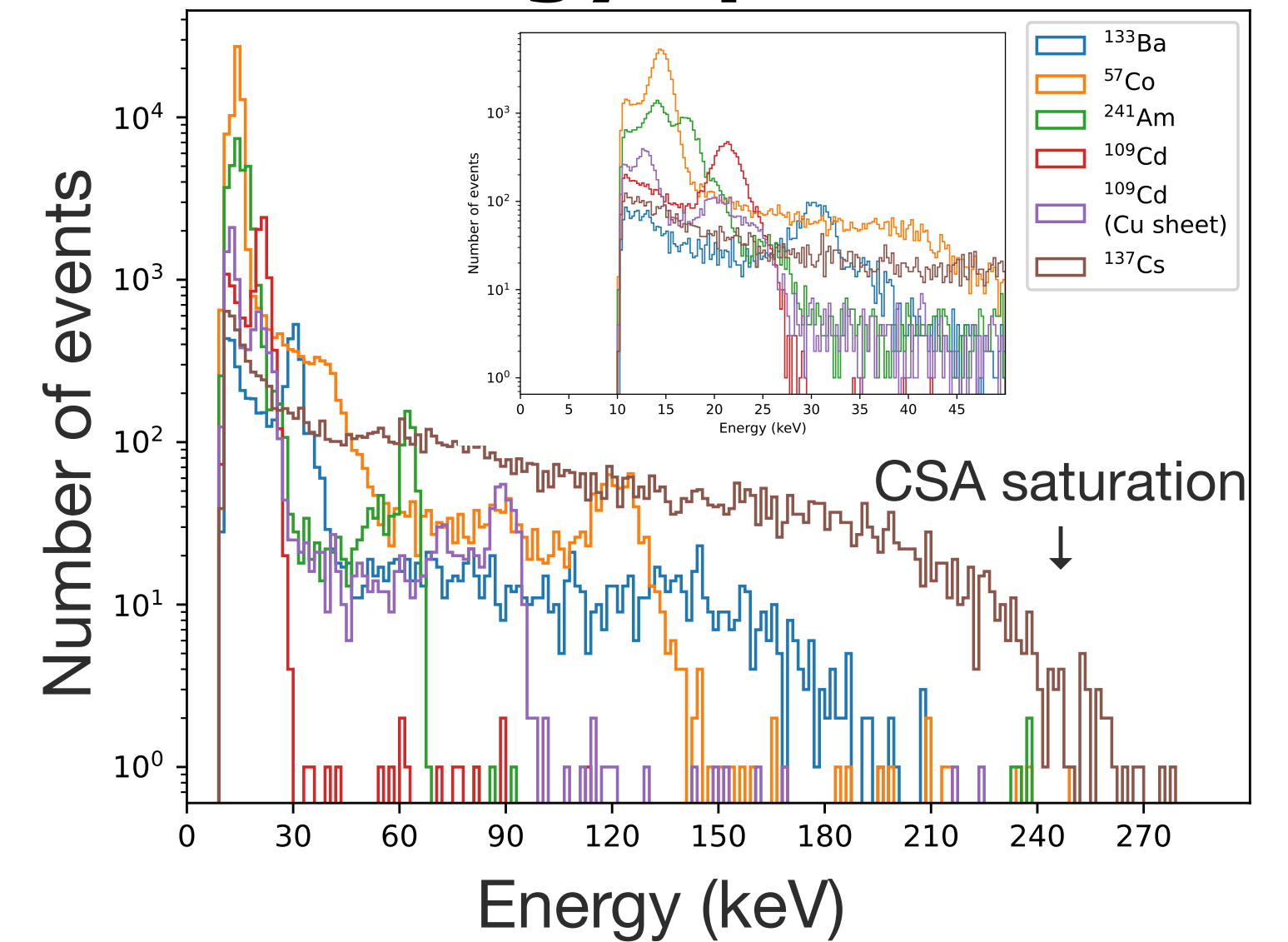
ToT spectra



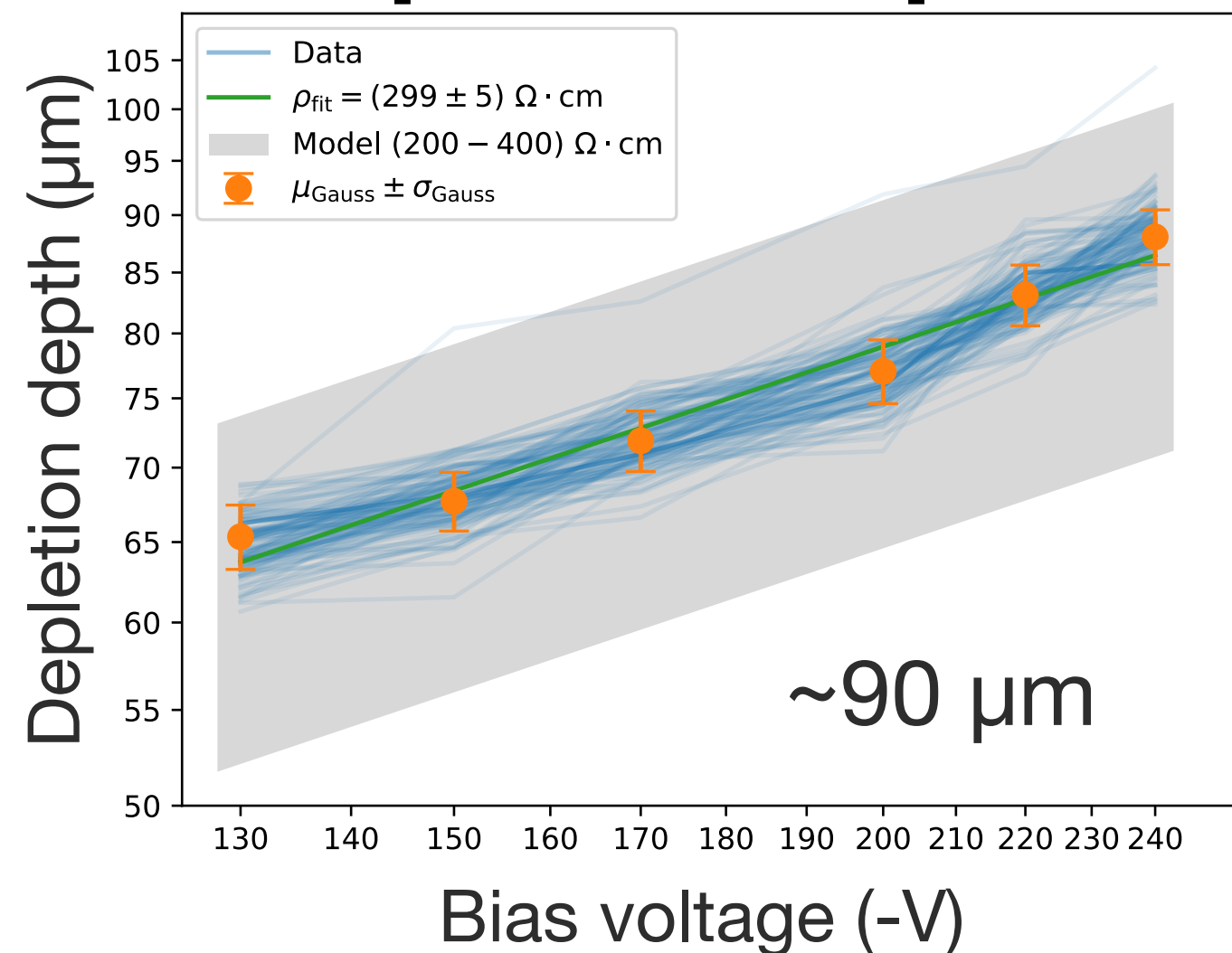
Calibration curves



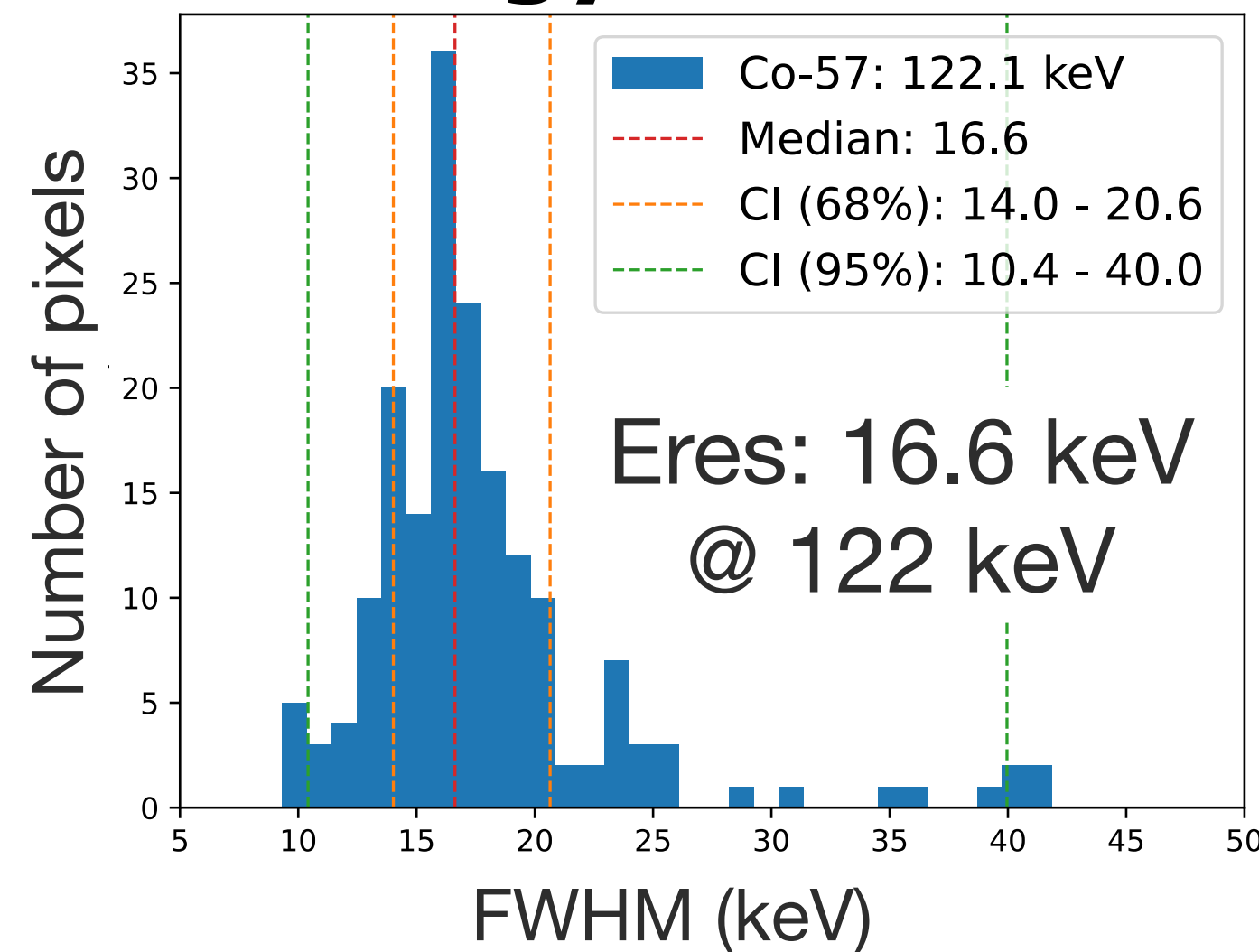
Energy spectra



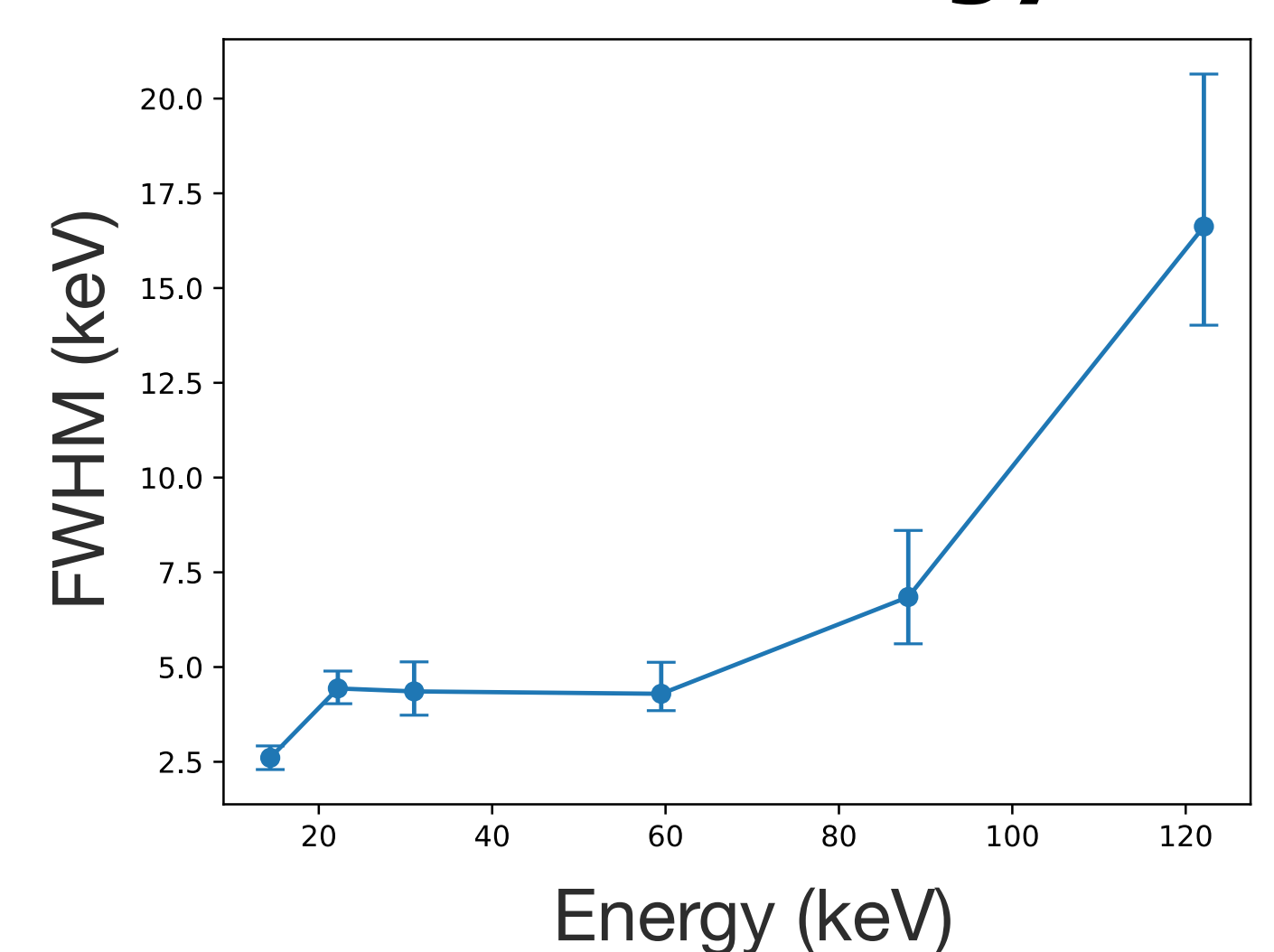
Depletion depth



Energy resolution

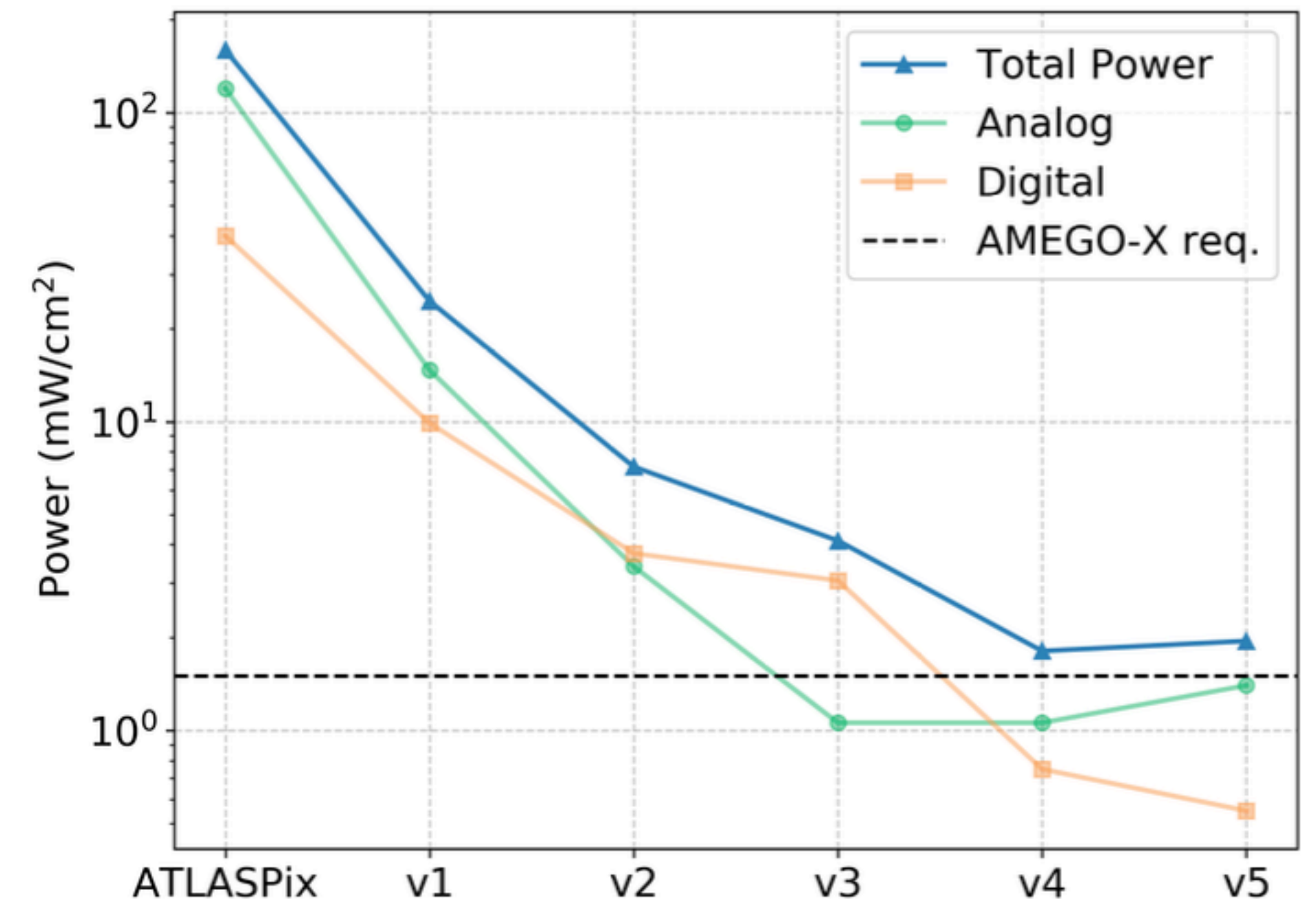


Eres vs. Energy



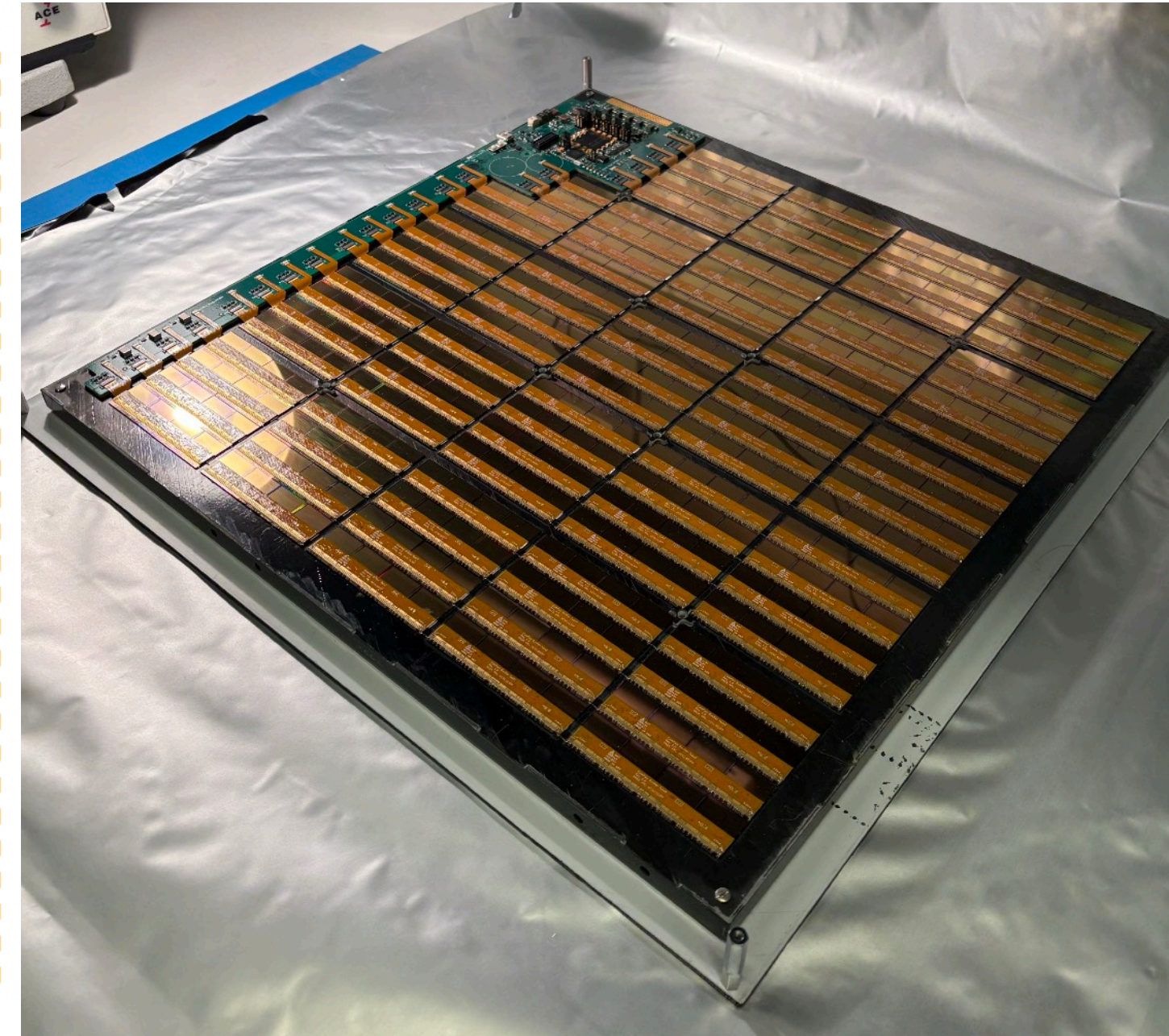
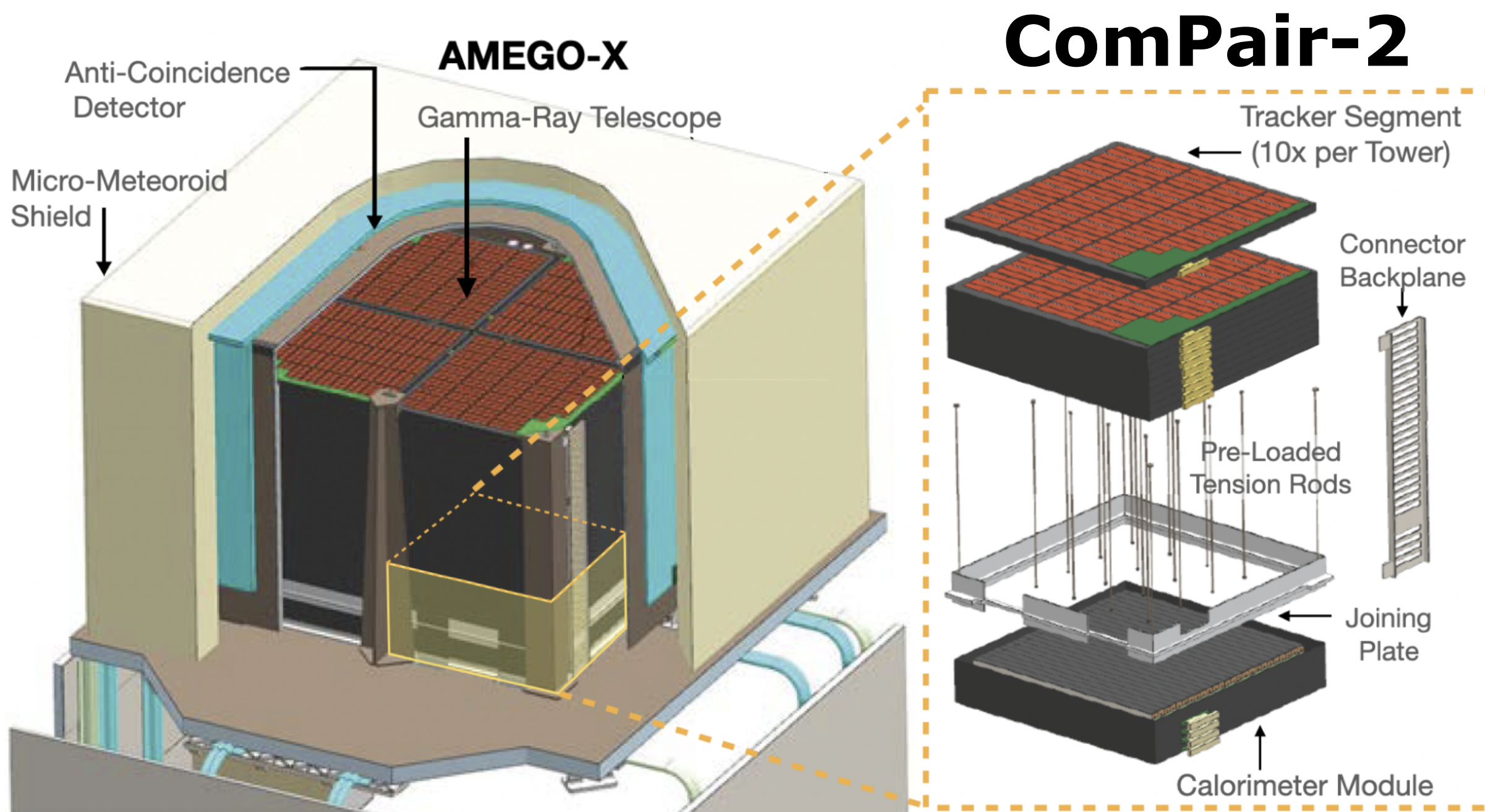
	Pixel pitch	Depletion depth	Dynamic range	Energy resolution (FWHM at 122 keV)	Power
Goal	500×500 μm^2	500 μm	25 - 700 keV	12.2 keV	< 1.5 mW/cm ²
AstroPix4	500×500 μm^2	~90 μm @ 240 V	14 - ~250 keV	17.8 keV	~2 mW/cm ²

- AstroPix5 is submitted. Arrival in spring
- Full 2x2 cm² reticle chip. 36 x 34 pixels
- Updated guard ring design for higher breakdown voltage up to 400-500 V
- Two test columns with high dynamic range CSA that should not saturate until > 700 keV
- Reduced pixel capacitance



Prototype Telescope

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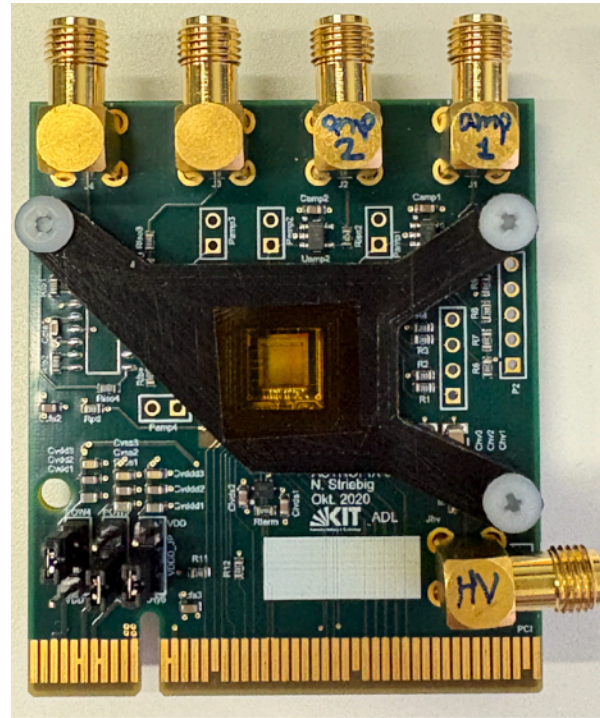


- First prototype tray with 95 quad-chips and FPGA
- Successfully passed environmental (vibration, thermal, vacuum) test
- Custom FEE testing in progress

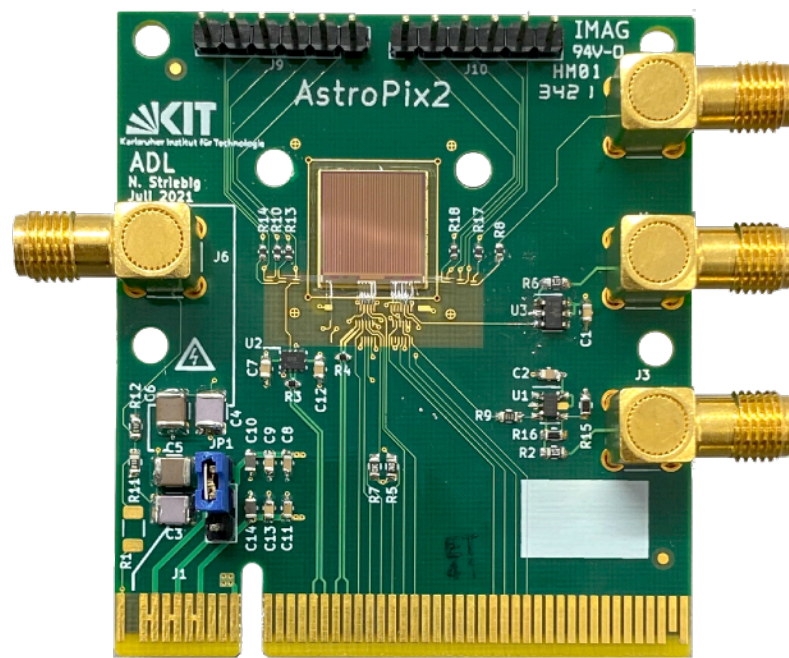
- ComPair-2 (PI: R. Caputo (GSFC/NASA)): AstroPix tracker + CsI calorimeter
 - Demonstration of Compton and Pair reconstructions
- Instrument integration and testing in 2026
- Machine learning approach to improve event classification and reconstruction
- Follow-up funding for balloon flight

Summary

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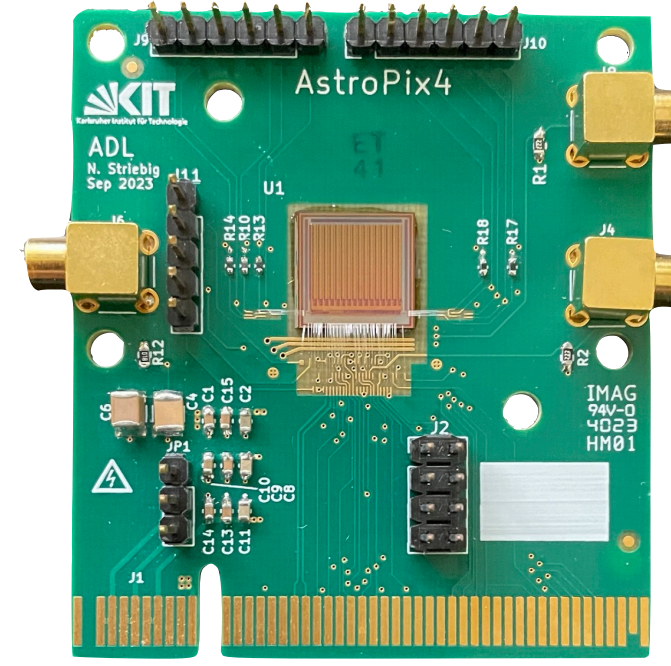
AstroPix1



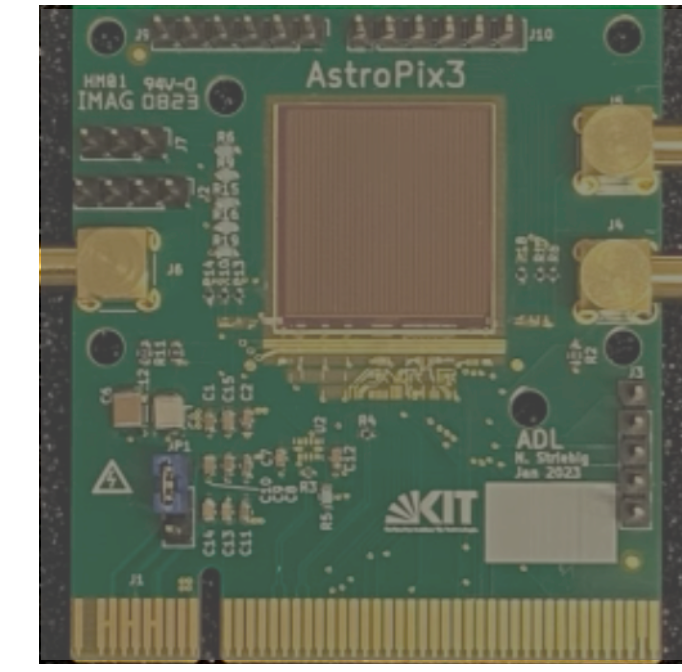
AstroPix2



AstroPix3



AstroPix4



AstroPix5

AstroPix6?

2020

2021

2022

2023

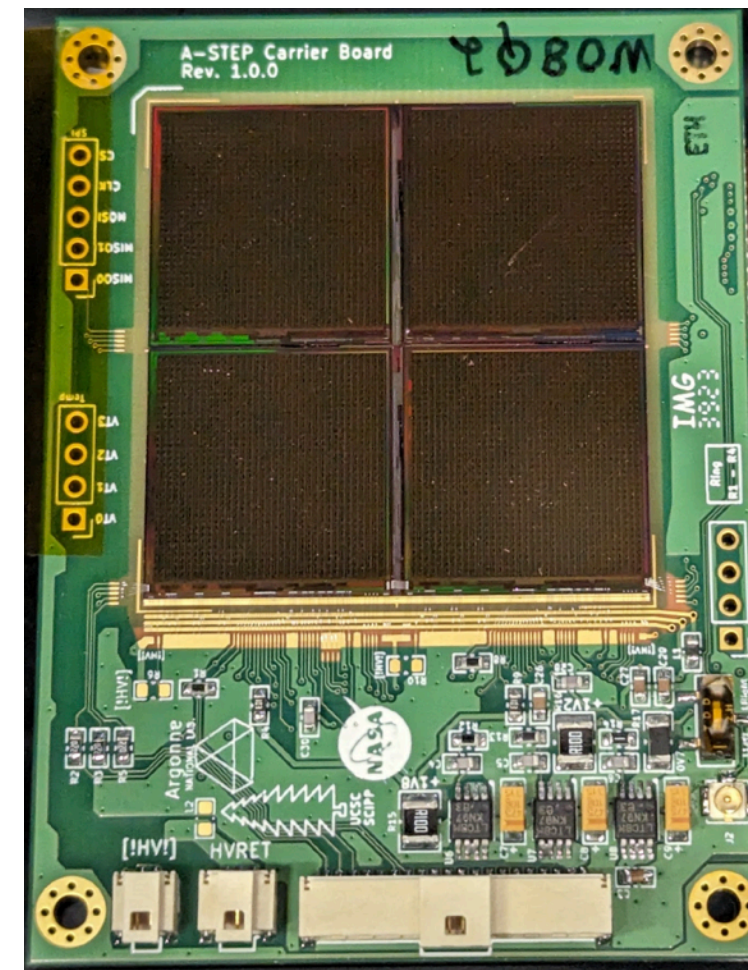
2024

2025

2026

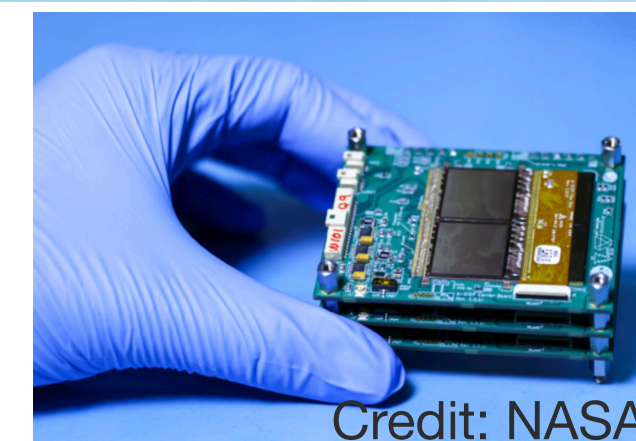
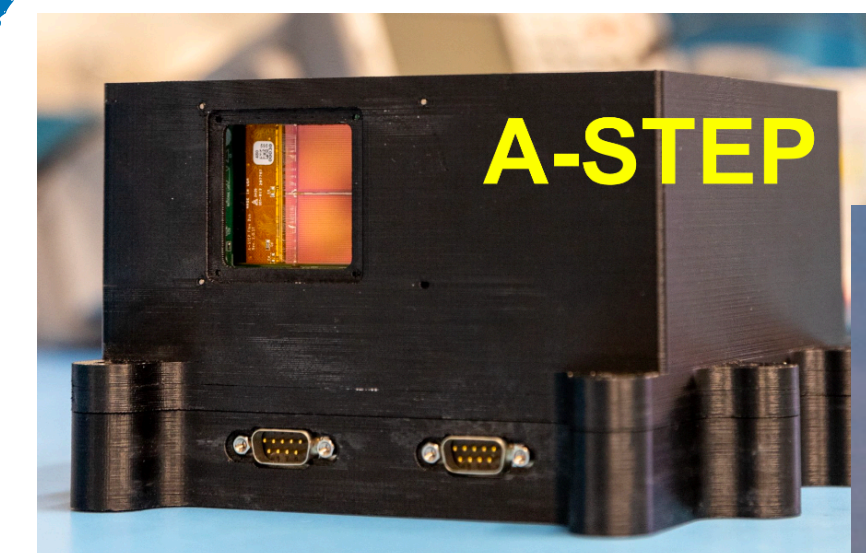
2027

- AstroPix is a newly developed HV-CMOS sensor for a future gamma-ray mission, AMEGO-X
- Latest AstroPix has a low enough noise floor with moderate energy resolutions. However, achieved depletion depth is far from the goal
- Future AstroPix will have a higher breakdown voltage allowing deeper depletion depth



Quad-chip

Sounding rocket



Credit: NASA



ComPair-2

