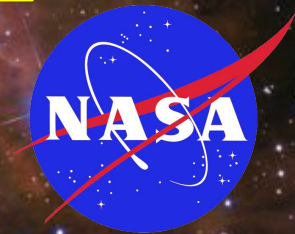


Development & Characterization of 2x2 Array Novel Pixel Sensor AstroPix

Abhradeep Roy*,

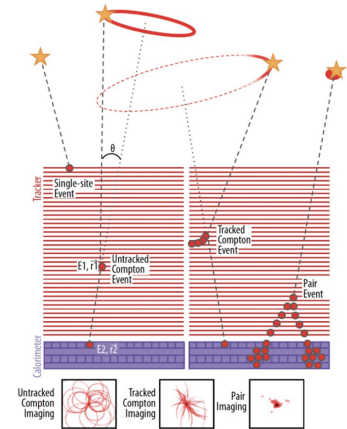
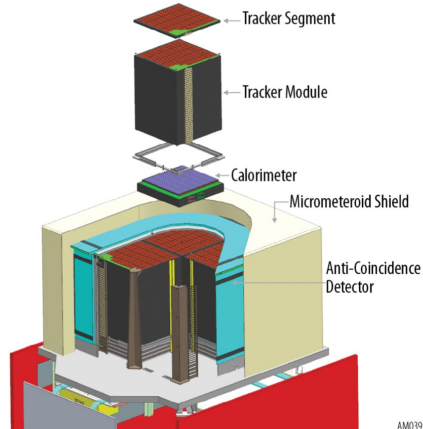
Yusuke Suda, Yasushi Fukazawa, Norito Nakano (Hiroshima U.),
Regina Caputo, Daniel P. Violette, Adrien Laviron (NASA/GSFC),
Manoj Jadhav (ANL), Nicolas Striebig (KIT),
Hiroyasu Tajima, Kushima Shin (ISEE, Nagoya U.)



Introduction

AMEGO-X (Caputo et al. 2022)

- Next-generation MeV gamma-ray satellite telescope
- Energy range: 25 keV – 1 GeV
- Large effective area, Less power consumption, good resolutions



AM039

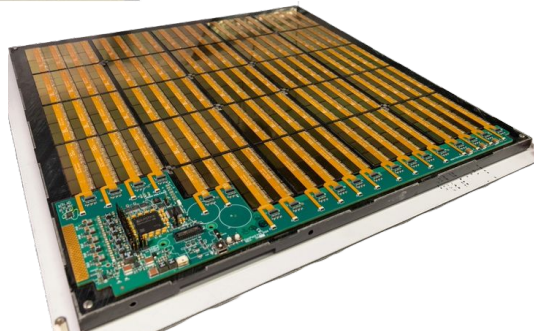
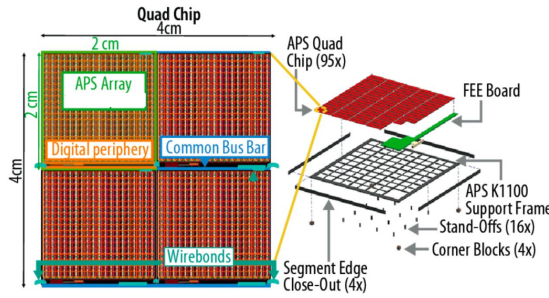
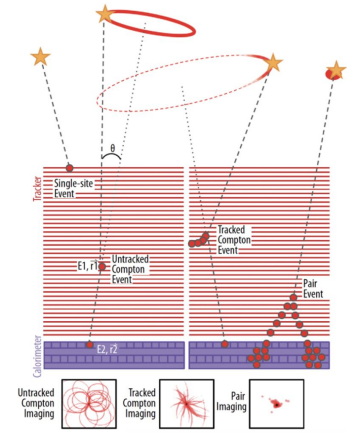
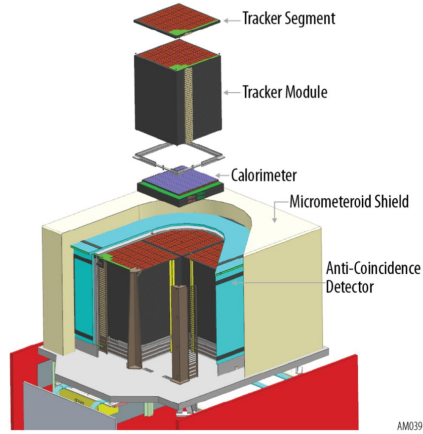
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AstroPix (Steinhebel et al. 2025)

- HV-CMOS pixel sensor: Monolithic active pixels
- Charge collection/amplification/readout co-integrated in pixel – No analog readout required
- Goal:
 - Pitch- 500 x 500 μm^2
 - Depletion depth- 500 μm
 - Dynamic range- 25 – 700 keV
 - Energy resolution- 10% at 122 keV
 - Power- <1.5 mW/cm²
- Quad-chip: 2 x 2 AstroPix array
- Si-tracker: array of quad-chips



Introduction

AMEGO-X (Caputo et al. 2022)

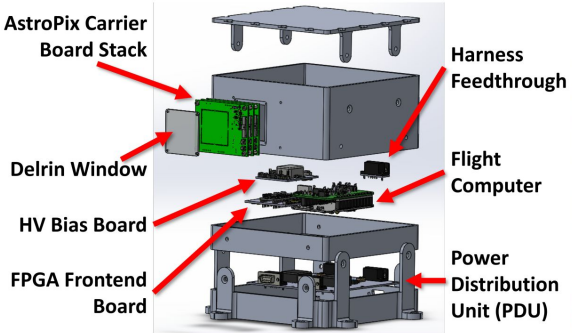
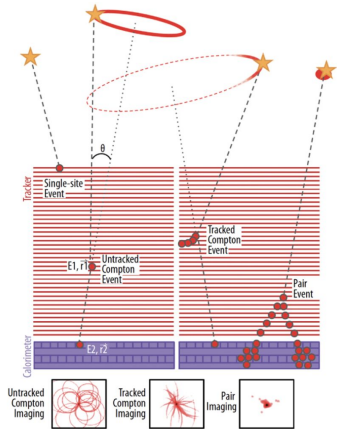
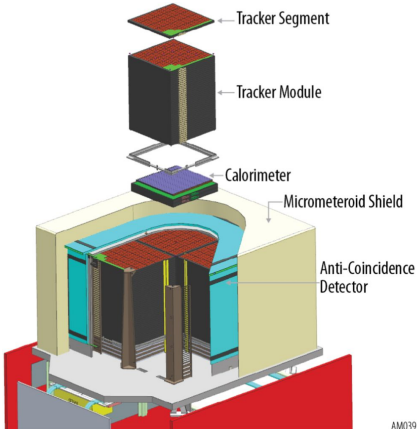
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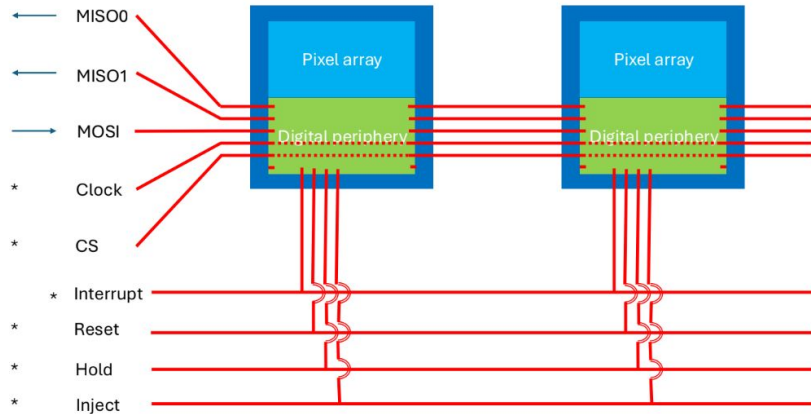
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A-STEP (Violette et al. 2024)

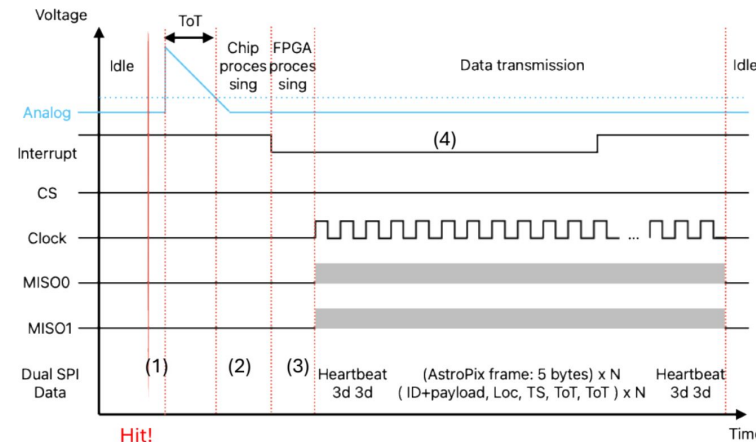
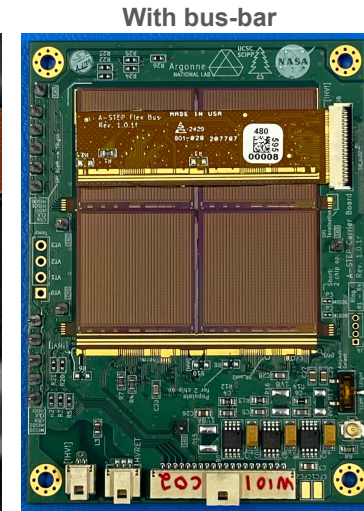
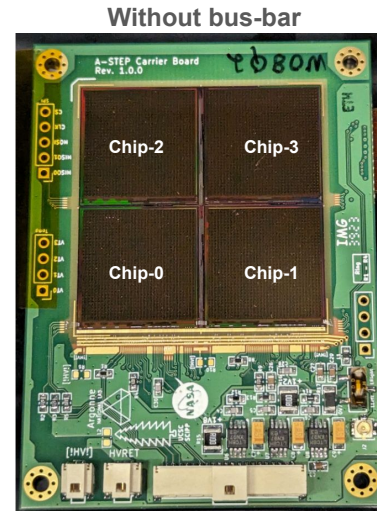
- Flight onboard sounding rocket to test readiness of space operation
- 3 layers of single quad-chips – mini tracker
- Launch from Wallops Flight Facility in 2026



Quad-chip: Introduction

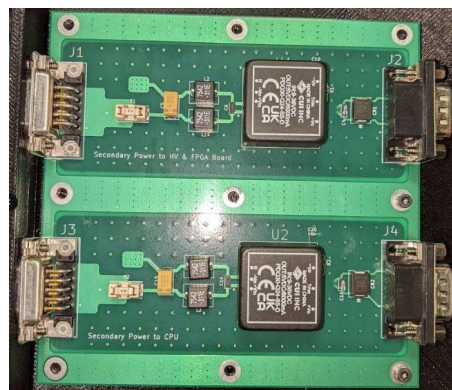
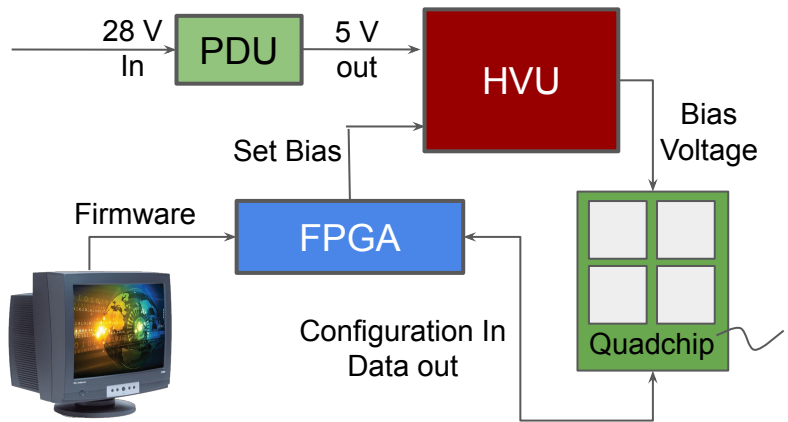
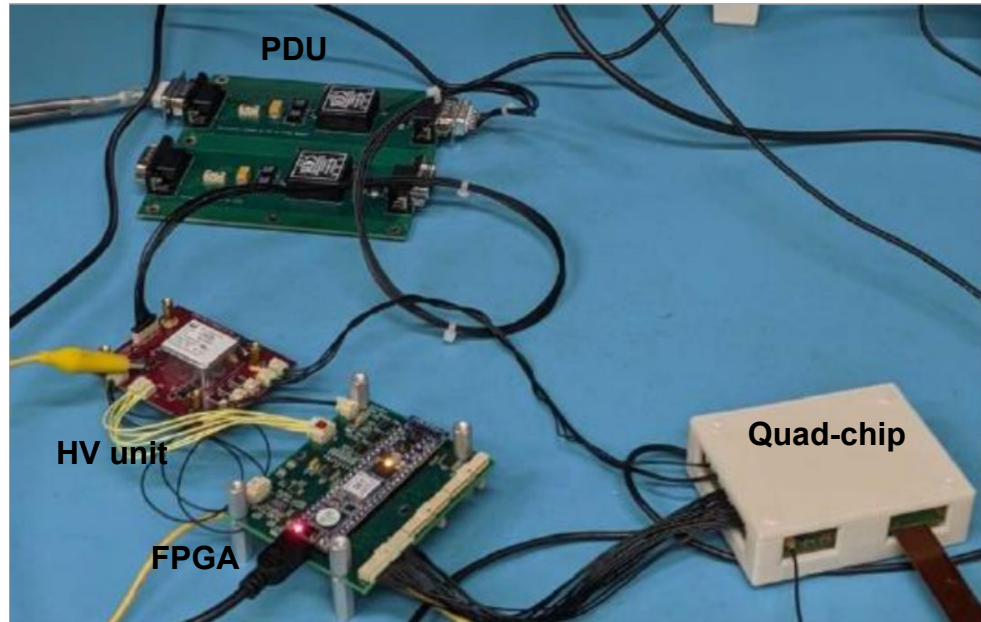


- 2 x 2 array of AstroPix v3 (35 x 35 pixels each with 500 x 500 μm^2 pitch)
- Single SPI line to control 4 chips (Daisy-chained)
- MOSI line: configure chips using FPGA
- MISO lines: carry data to FPGA
- Output: Time-over-threshold (ToT)
- Analog output from pixels of first row for test purpose
- Depends on external clocks—
 - SPI clock: data transfer
 - TS clock for event timestamp
 - ToT clock for ToT measurement
- Power consumption: 4 mW/cm²



Quad-chip: Test Setup

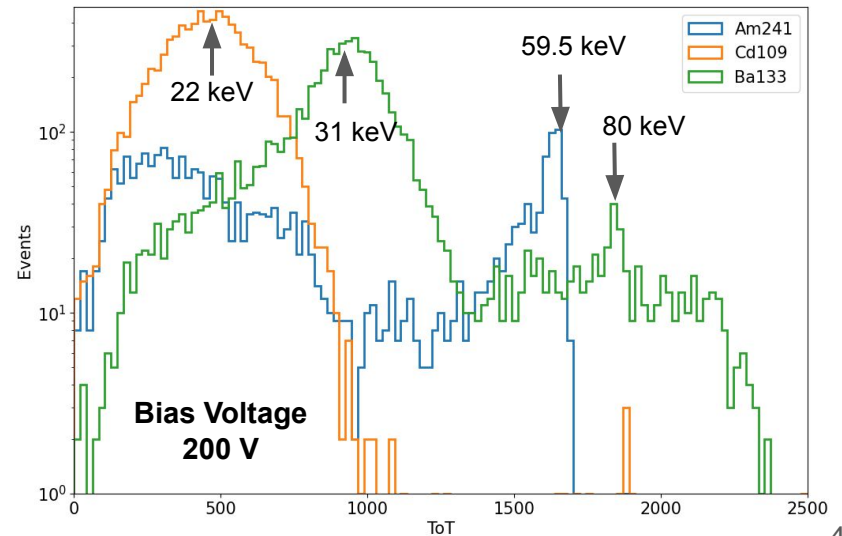
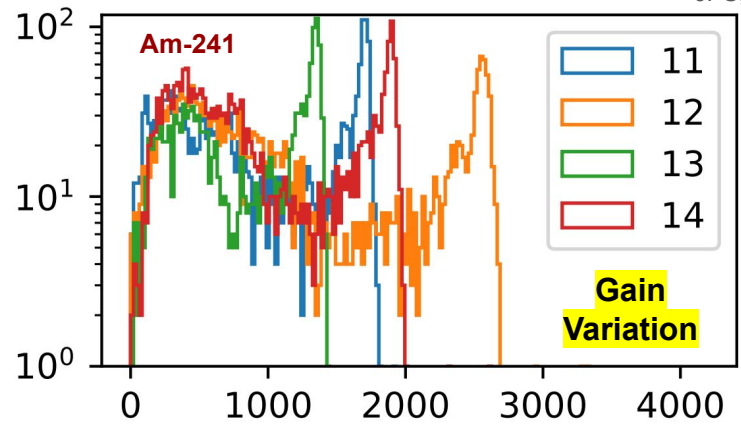
- Same setup as **A-STEP** with a single quad-chip without bus-bar
- A Power-Distribution Unit (PDU)
 - Input = 28 V
 - Output = 5 V to the High Voltage (HV) Unit
- High Voltage unit
 - Can provide bias voltage to 3 quad-chips
 - Bias voltage controlled by FPGA
- [A-STEP firmware](#) is installed in FPGA.



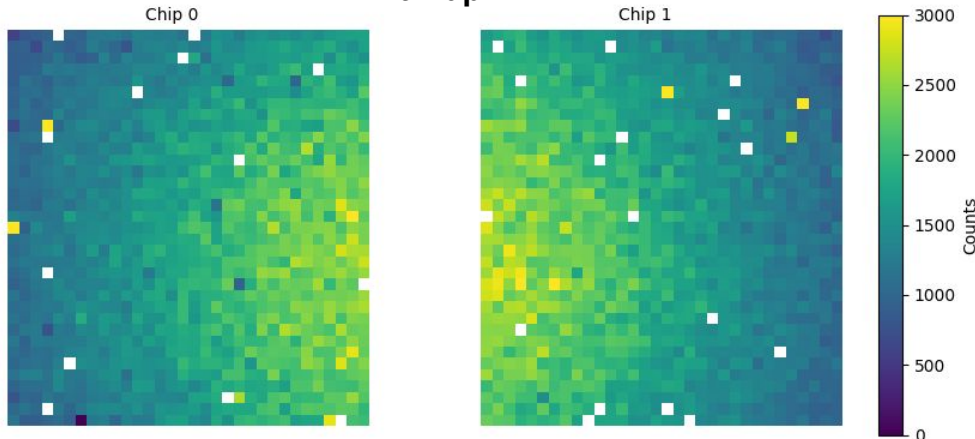
Quad-chip: ToT Spectra

Aim:

- Energy calibration of quad-chip (without busbar) made of AstroPix-v3.
- Radioisotopes: ^{109}Cd (22 keV), ^{133}Ba (31 keV, 80 keV), ^{241}Am (59.5 keV).
- About 10-15 noisy pixels per chip – masked.
- Variation of gains among pixels.
- Expected hitmap observed using ^{133}Ba .
- Estimation of the depletion depths of Si sensors using radioisotope spectra.

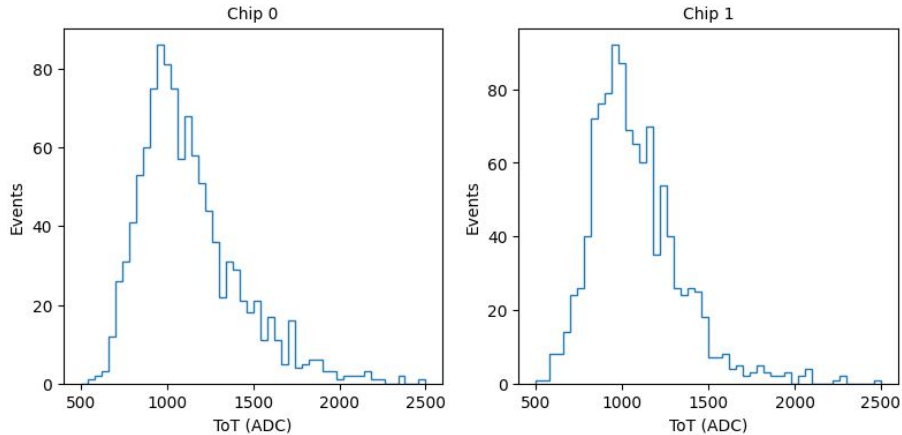
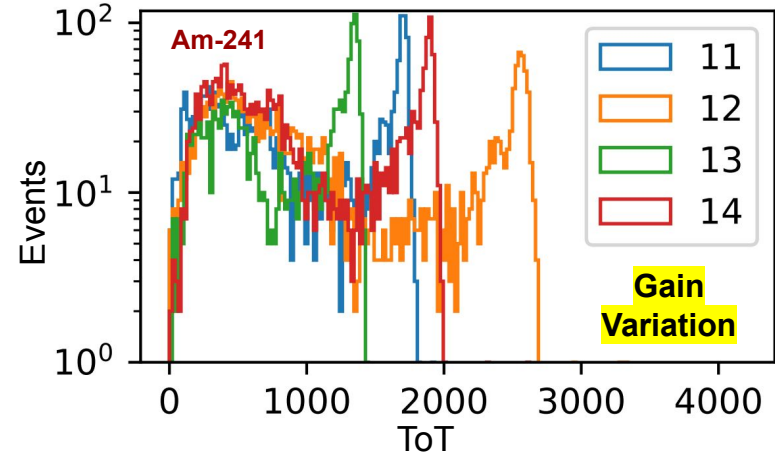
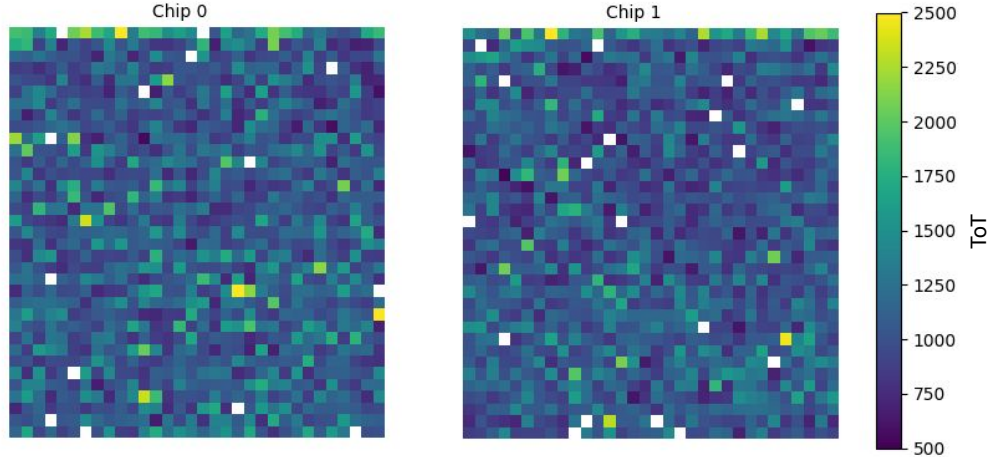


Hit Map



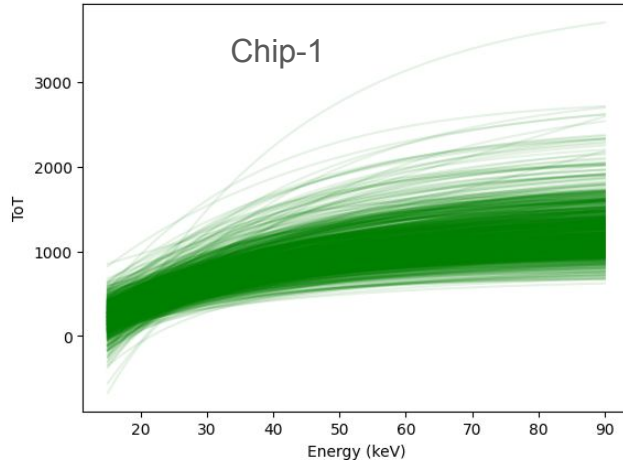
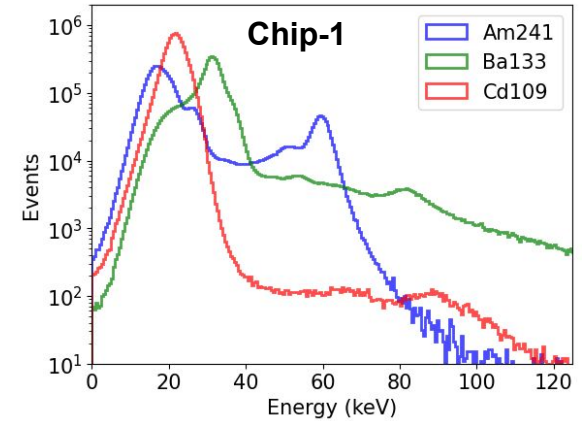
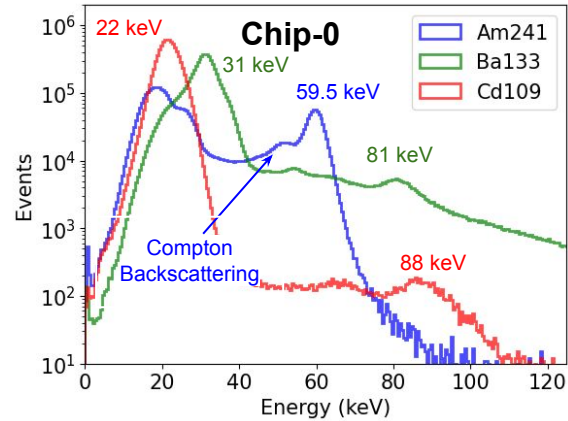
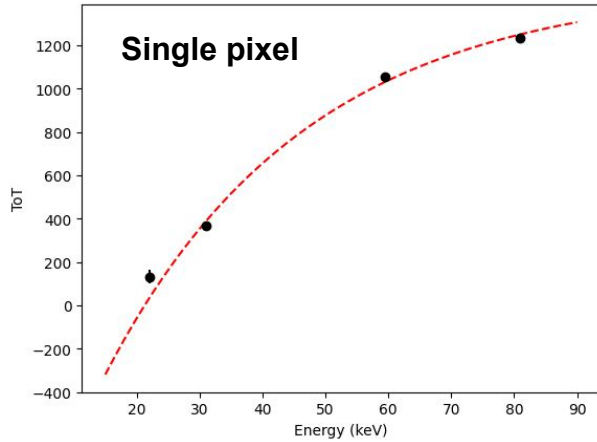
Quad-chip: ToT Spectra

59.5 keV Peak Position



- ToT peak position is correlated with pixel gain
- Observed variation in gain is mostly random

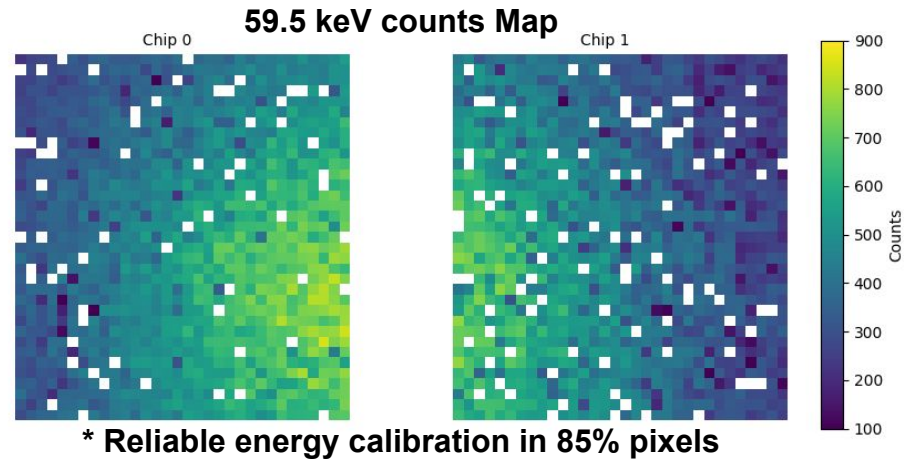
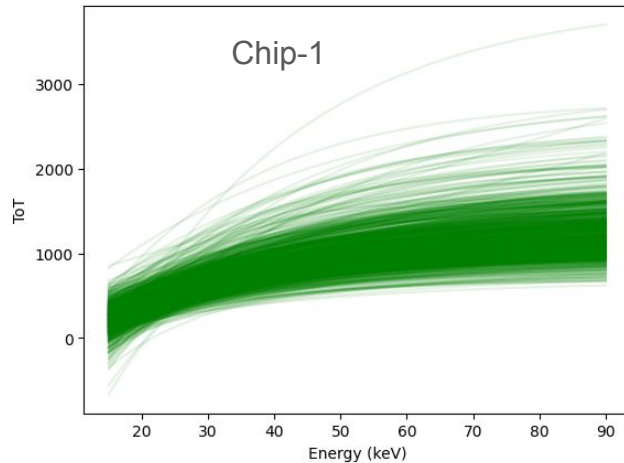
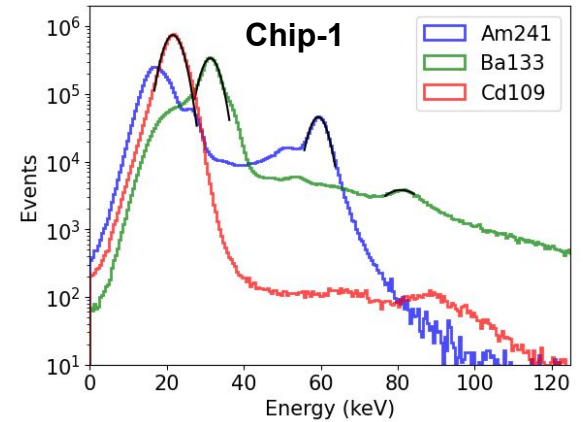
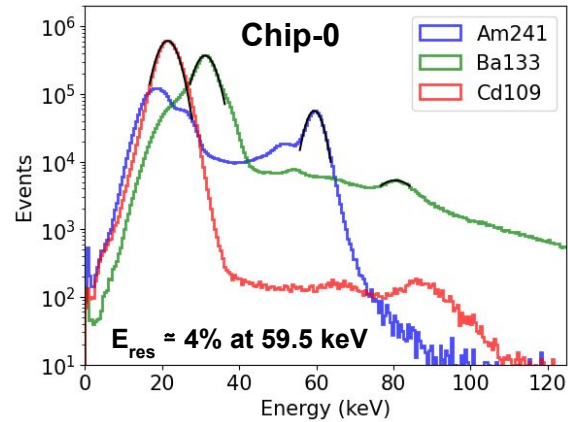
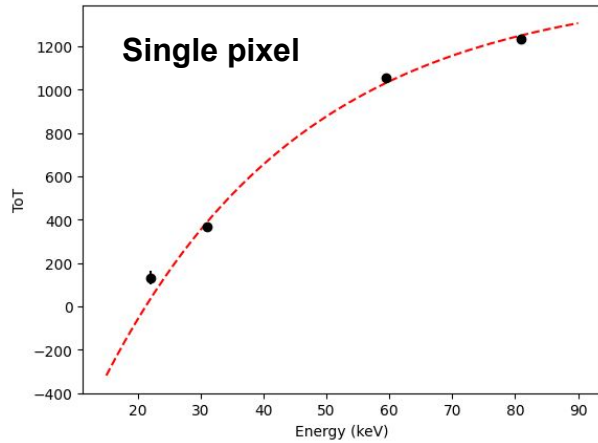
Quad-chip: Energy Calibration



- Identified prominent ToT peak positions for known energies and fitted ToT vs Energy plot using:

$$\text{ToT}(E) = a + b(1 - \exp[-E/c])$$
- Applied the inverse function to convert ToT spectra to energy spectra.
- Stacked energy spectra for all pixels in each chip

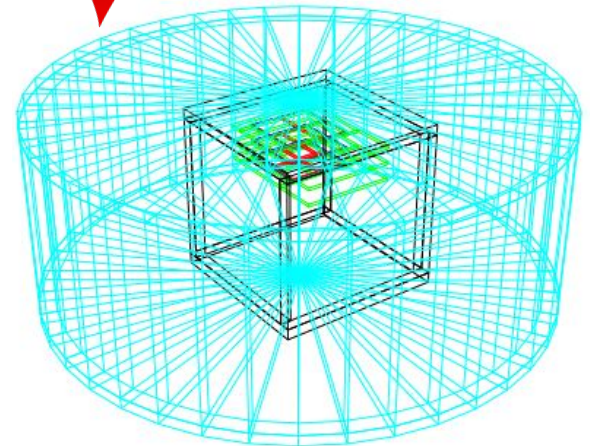
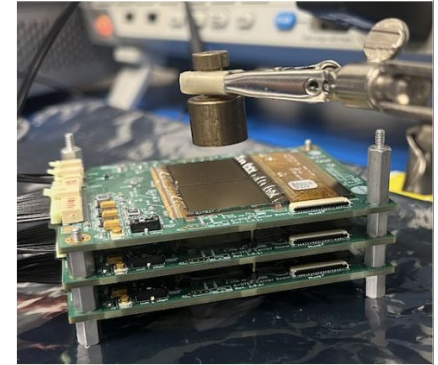
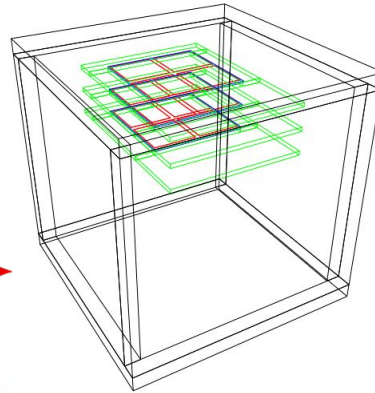
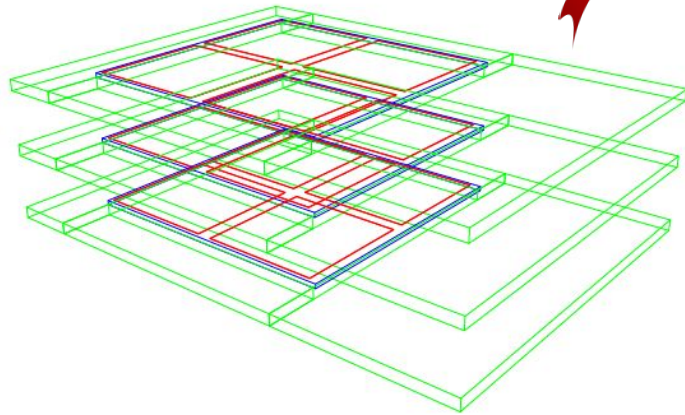
Quad-chip: Energy Calibration





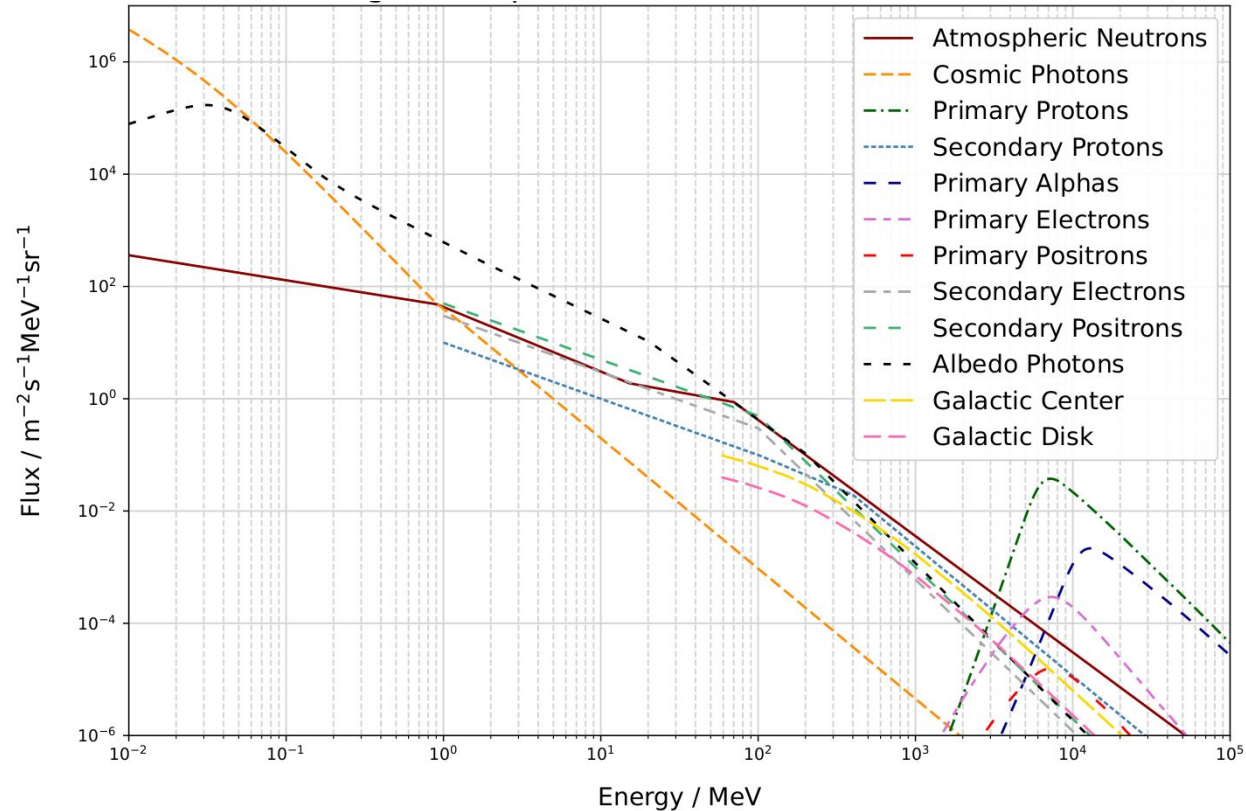
A-STEP: Performance Simulation

- [MEGALib](#): Geant4-based simulation tool.
- Geometry components:
 - silicon: $1.75 \times 1.75 \times 0.007 \text{ cm}^3$ (blue: inactive, red: active)
 - PCB: $5.4 \times 7.399 \times 0.237 \text{ cm}^3$ (green)
 - Aluminium enclosure: $10 \times 10 \times 10 \text{ cm}^3$ (thickness = 0.635 cm)
 - Rocket body (cyan)



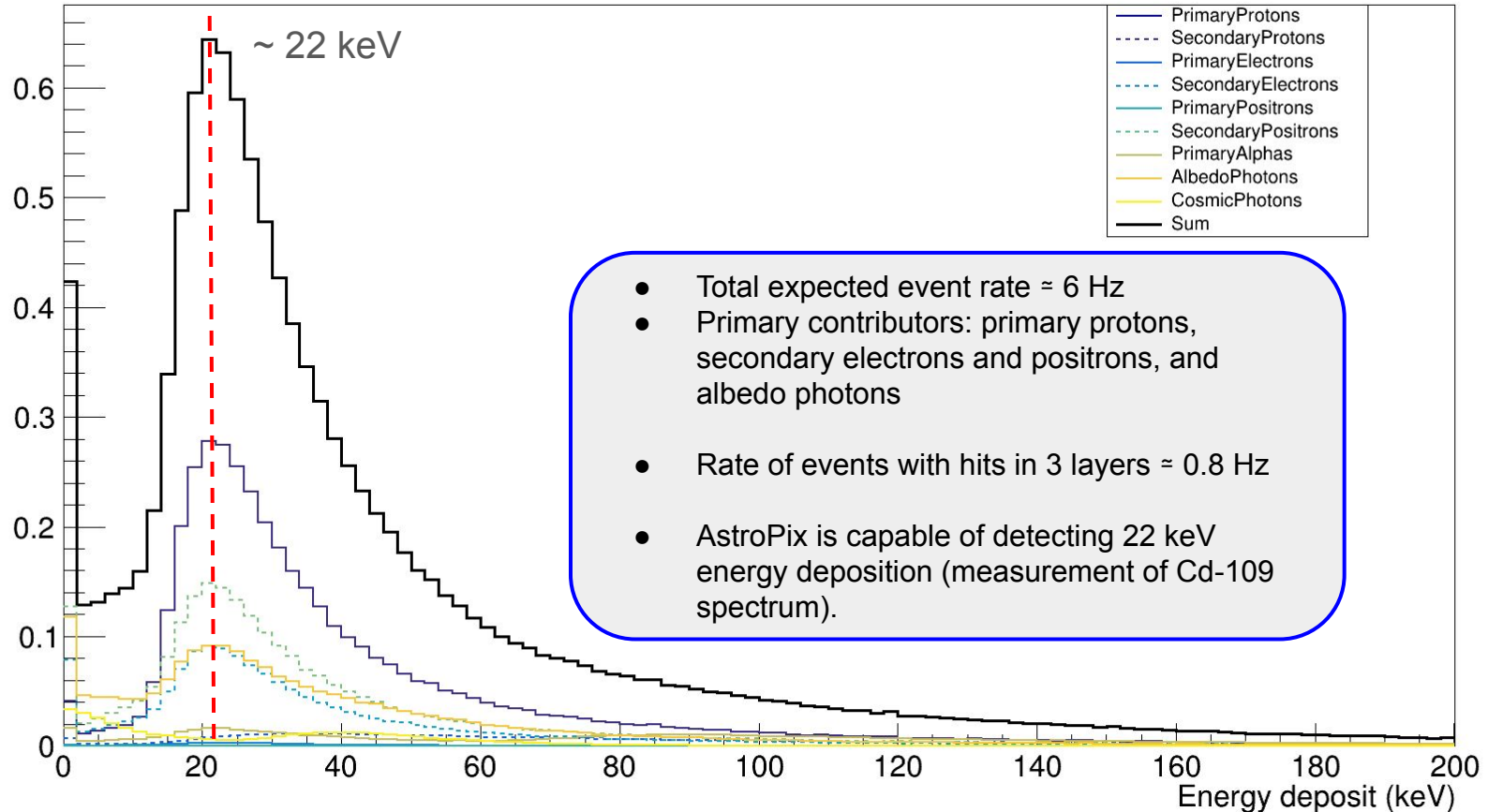
A-STEP: Cosmic Background Model

Background spectrum at 300 km altitude and 30° inclination
<https://github.com/pcumani/LEOBackground>



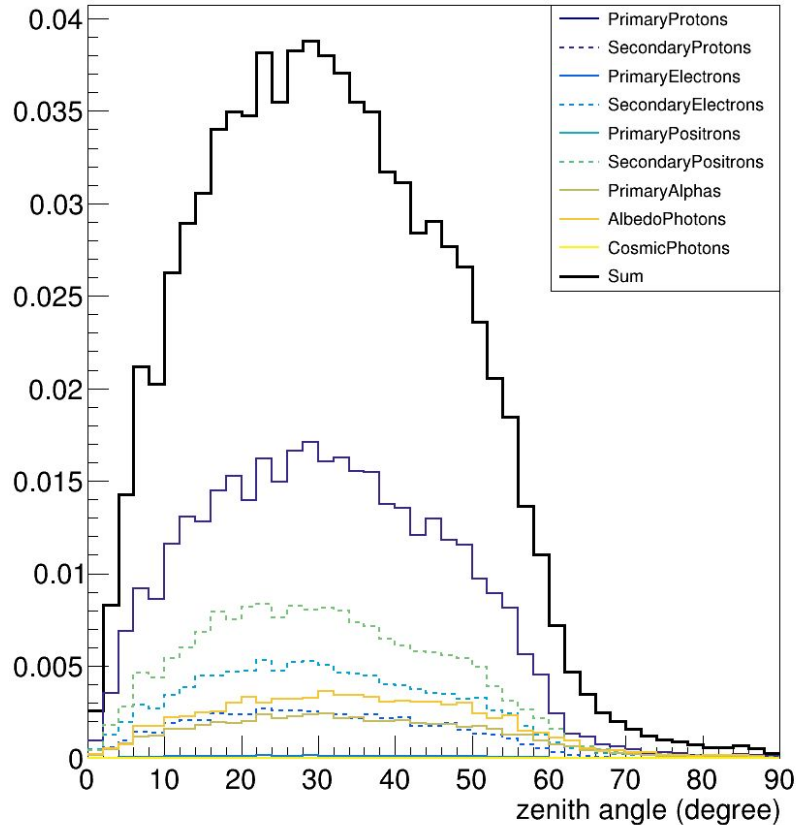
A-STEP: Deposited Energy Spectrum

Cumulative deposited energy spectrum distribution (normalized by trigger rate)

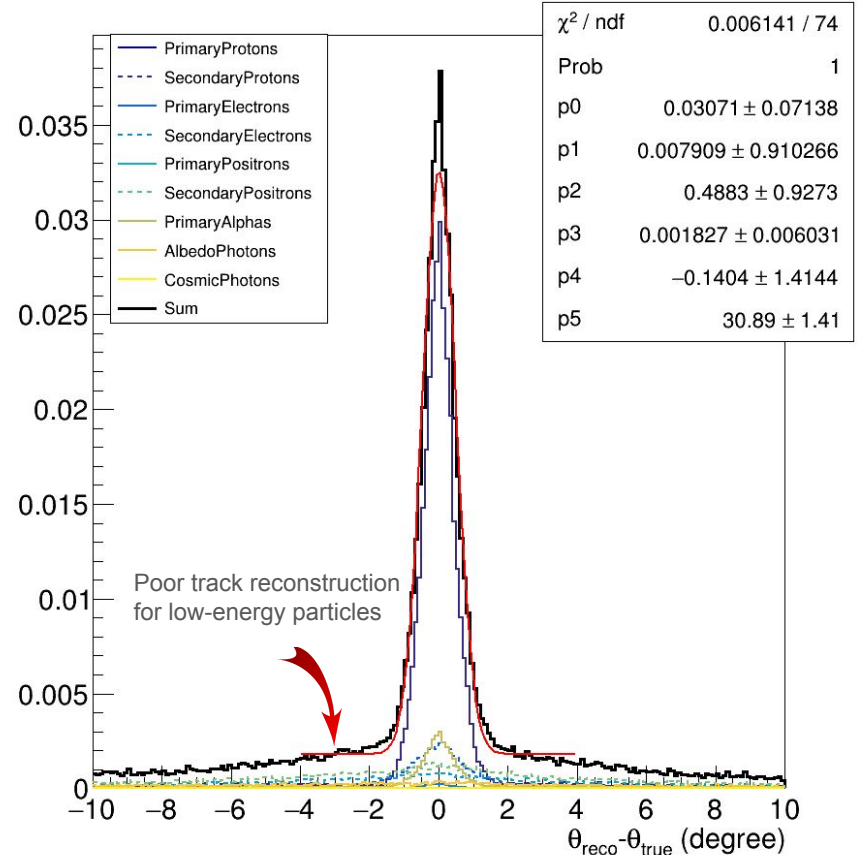


A-STEP: Track Reconstruction

Total reconstructed zenith angle distribution of 3-layered events
(Normalised by trigger rates)



Angular deviation distribution of all reconstructed 3-layered events
(Normalised by trigger rates)



Summary

- Development of AstroPix is progressing well. Sounding rocket test flight of A-STEP will be in 2026.
- Successful connection between two AstroPix v3 chips in the quad-chip. Next step is to test functionality of quad-chip with busbar powering all four chips. Quadchip with busbar and a 9-chip array are being successfully tested by other groups.
- Immediate future plan: measurement of depletion depth of the AstroPix pixels in the quad-chip.
- Low energy threshold (< 22 keV) confirms AstroPix's capability of detecting majority of the events during A-STEP flight.
- MEGAlib simulation predicts an event rate of ~ 6 Hz during A-STEP flight.
- Future plan: Assembly of A-STEP in the laboratory – simulate its performance on the ground level and compare.

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thank you