AstroPix: Pixels in Space

Regina Caputo (PI) NASA/GSFC
on behalf of the AstroPix team

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Karlsruher Institut für Technologie

Argonne NATIONAL LABORATORY

NASA

Overview

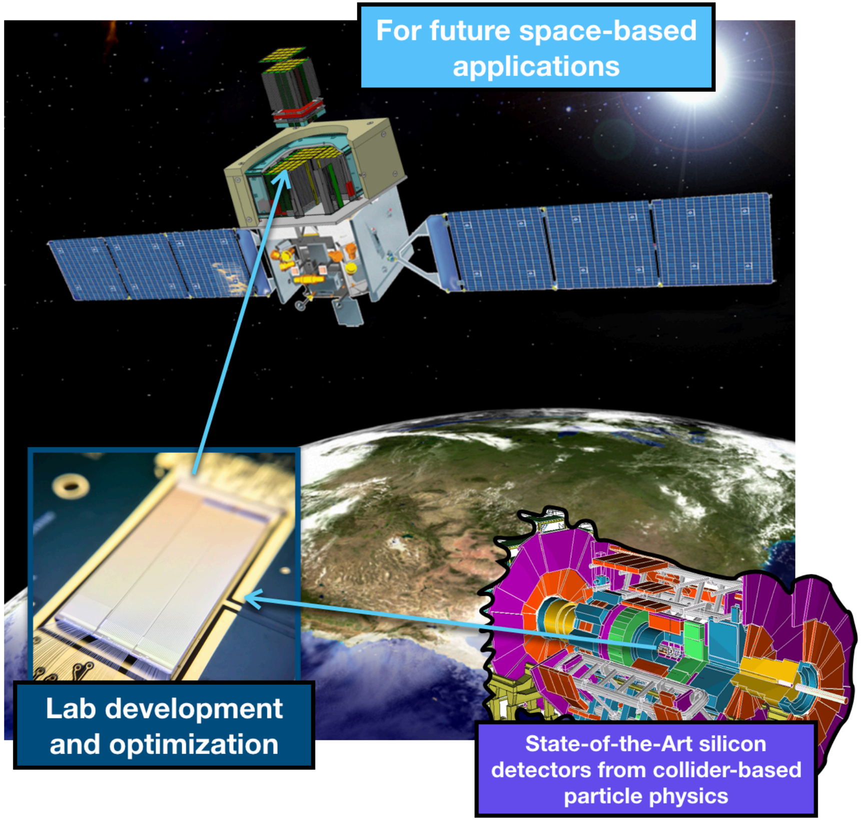
Develop silicon pixel detectors for use in space

- replace double sided silicon strip detector technology
- ATLASPix is a foundation (HV CMOS, monolithic)

Determine what needs/can be optimized for gamma-ray instruments ← Astro2020 Decadal Priority (next generation wide-field gamma-ray explorer)

Design, fabricate, test AstroPix

Test performance, determine suitability for space use



ASTROPIX

Why AstroPix?

The future is CMOS!

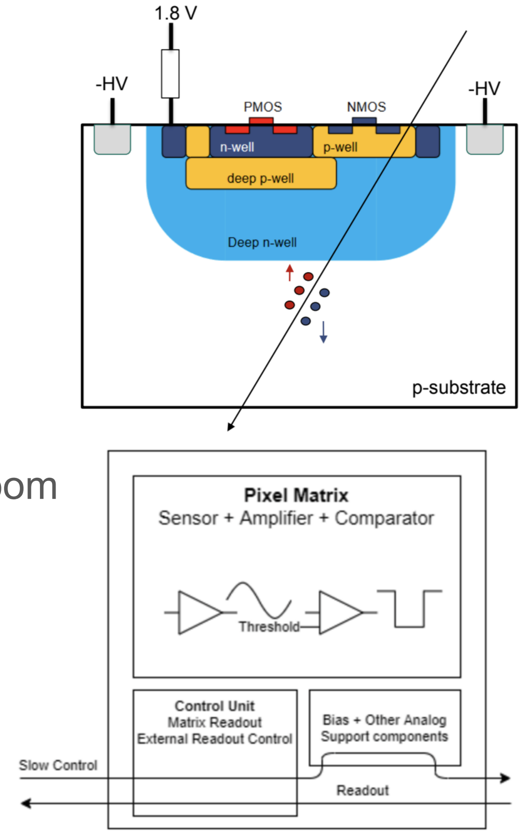
Join functionalities: charge collection/ amplification/readout co-integrated in substrate in pixel matrix

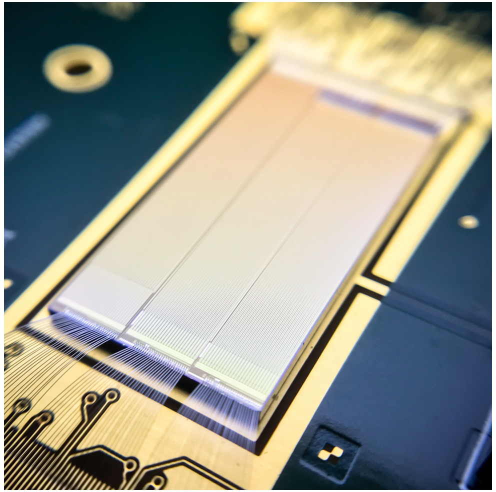
Benefits over current technology

Lower cost: CMOS processes are mass produced, silicon is cheap operates at ~room temp, fewer steps of integration

Less power for same channel count

Lower energy thresholds than strip detectors!





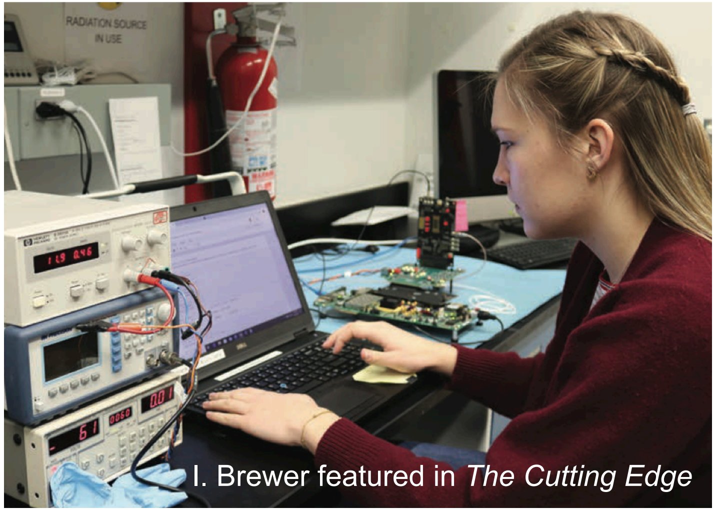
ATLASPix

AstroPix

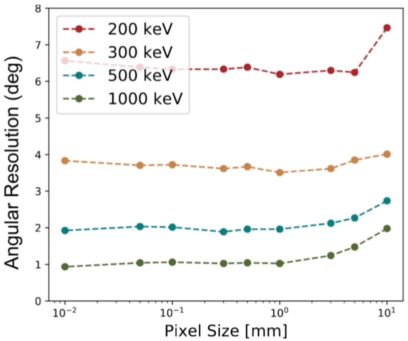
ATLASPix to AstroPix

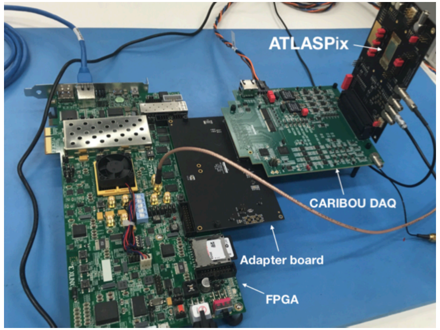
At GSFC: Analysis of ATLASPix
Simulations to optimize pixel parameters for large scale instrument.

Strategy: incremental changes relative to ATLASPix, submit several versions. At KIT: AstroPix_v1 is designed and sent to TSI foundry



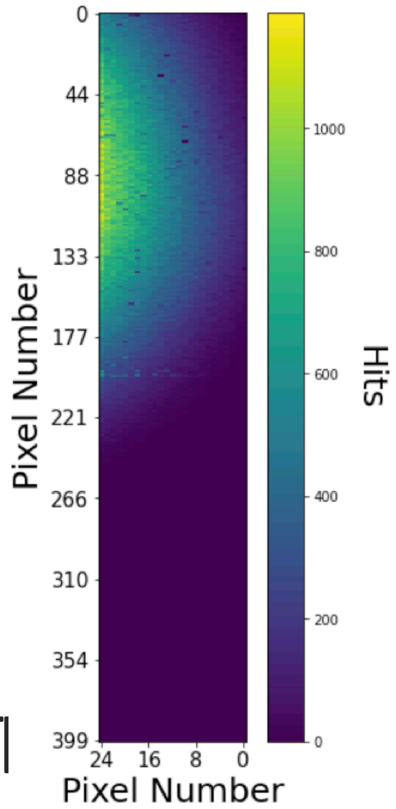
I. Brewer featured in *The Cutting Edge*





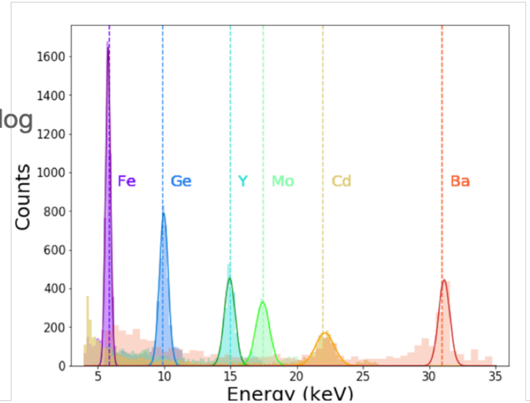
Parameter	Goal
E_{Res}	<10% at 60 keV
Power Usage	<1 mW/cm^2
Passive Material	<5% on the active area of Si
Pixel Size	500 × 500 μm^2
Si Thickness	500 μm
Time Tag	~1 μs

ATLASPix: first photon measurements

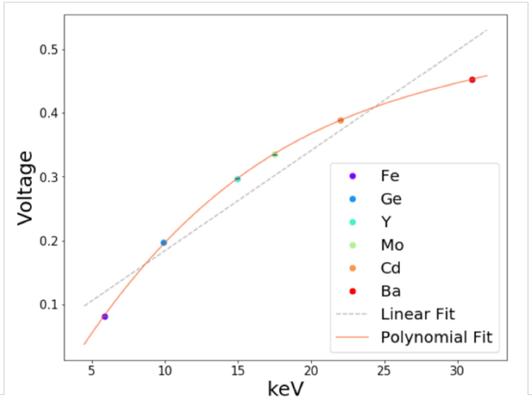


Energy measurement

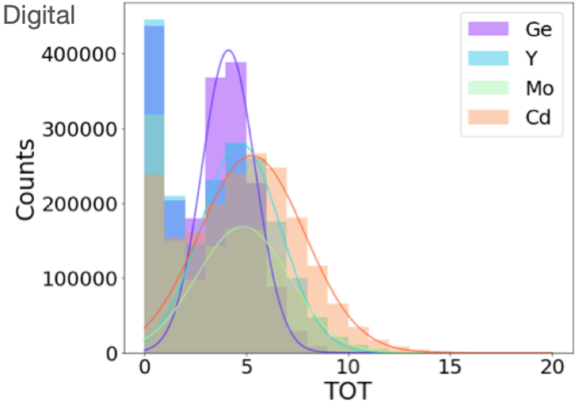
Analog

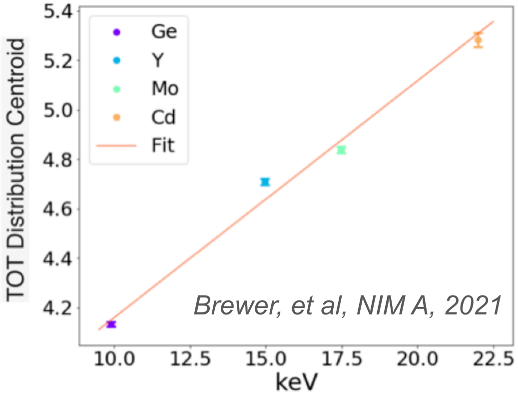


Energy calibration



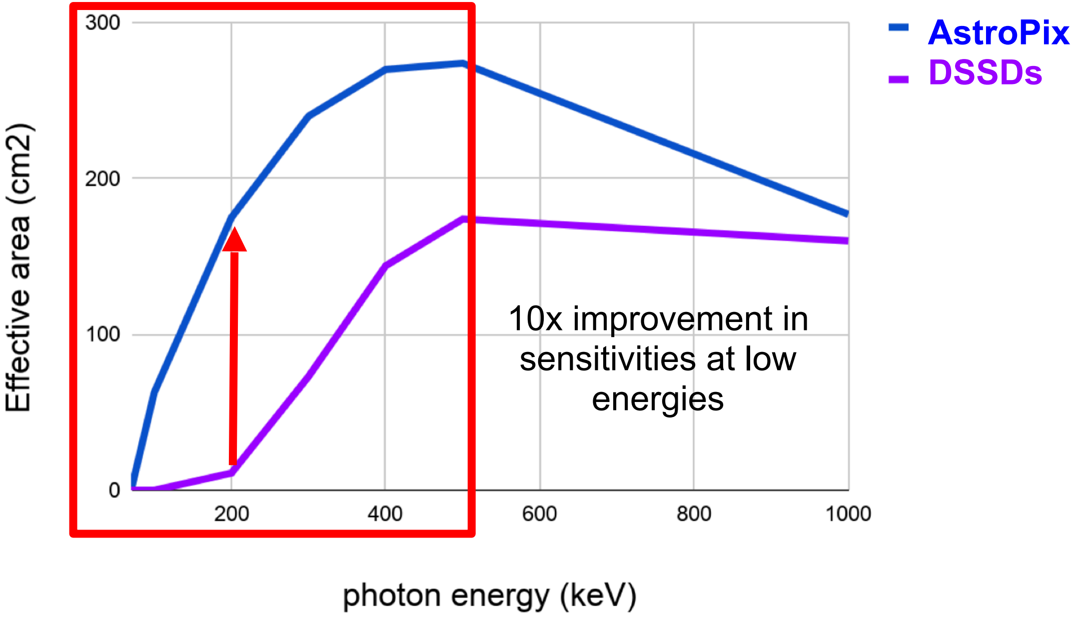
Digital





Brewer, et al, NIM A, 2021

Enabling Technology



Implemented AstroPix in 2021 MIDEX concept: AMEGO-X

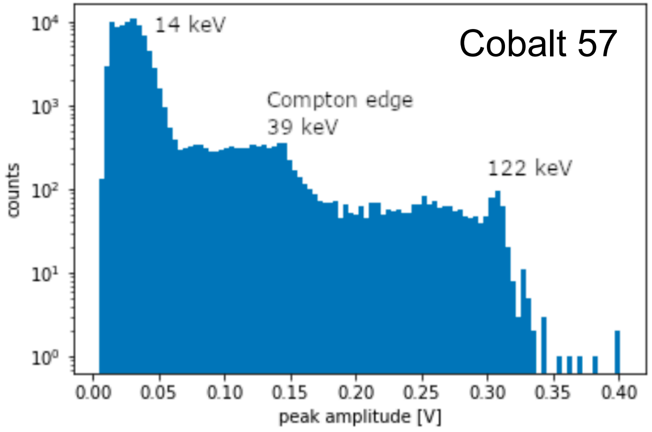
AstroPix v1: Design, Fabrication, and Testing

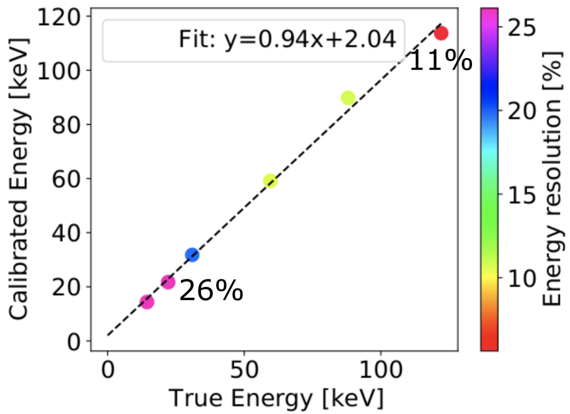
Part of MPW run led by Heidelberg/KIT

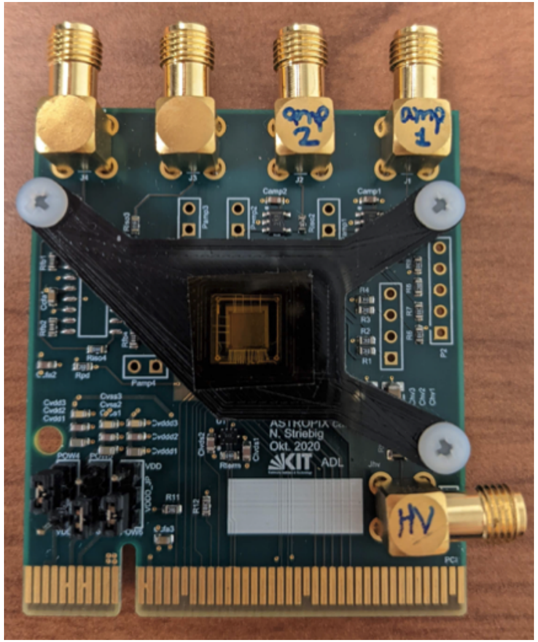
Matrix 4.5 x 4.5 mm² chip area; 18x18 pixels

Changes: Reduce timing requirement (25 ns → 10 us), increase pixel size to 175 x 175 um, 500 um thick, on-chip noise-reducing components, improve Eres

Issue with oscillations in the digital readout

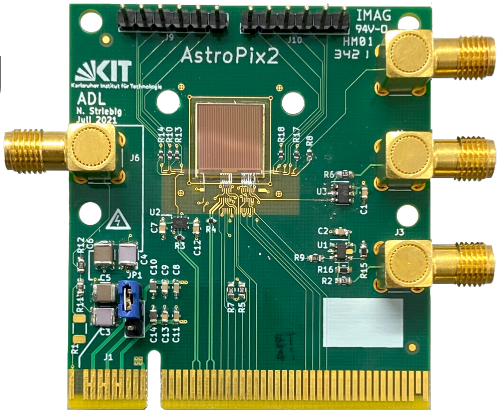






A. Steinhebel, et al, SPIE 2022

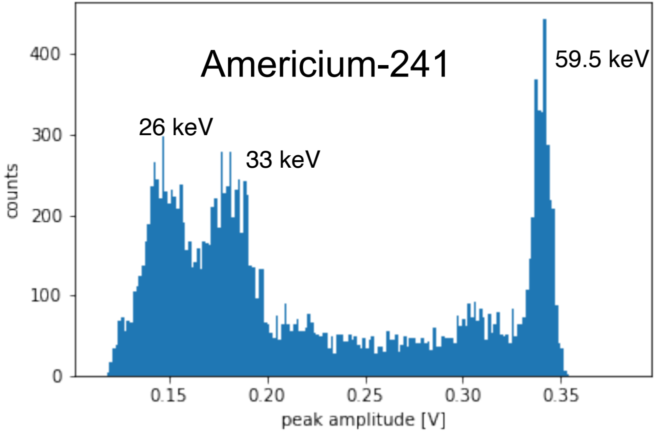
AstroPix v2: Design, Fabrication, and Testing

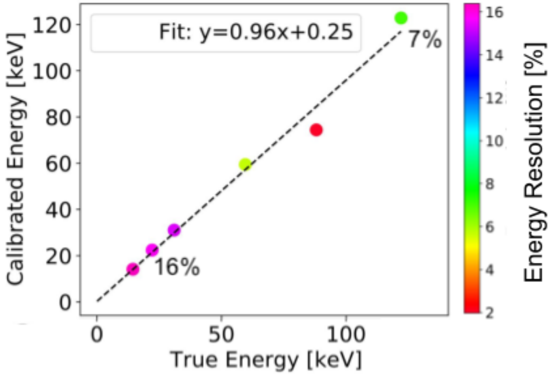


Part of MPW run led by Heidelberg/KIT

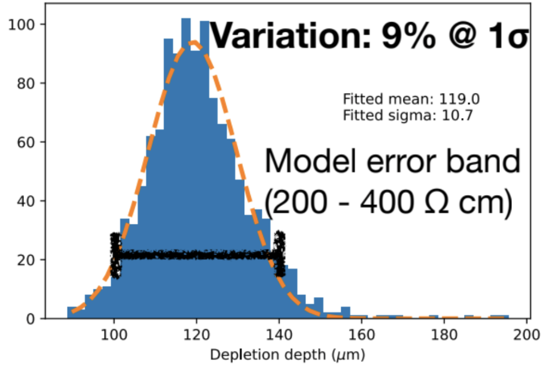
Matrix 1 x 1 cm² chip area; 35 x 35 pixels; 700 um thick wafer

Changes: increase pixel size to 250 x 250 um, update guard ring for higher depletion voltage, reduce analog power 12 uW → <2.8 uW



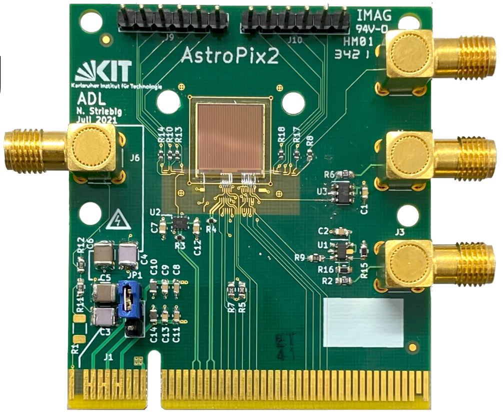


Depletion depth/pixel

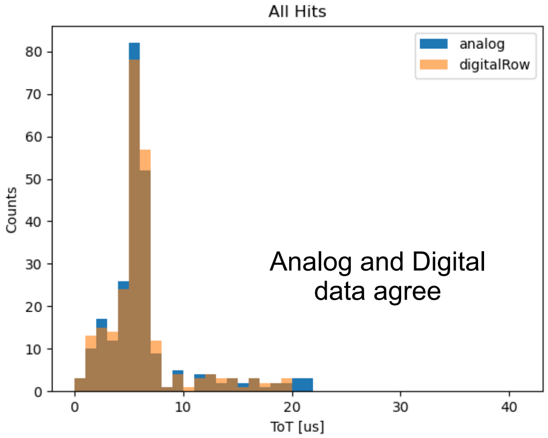


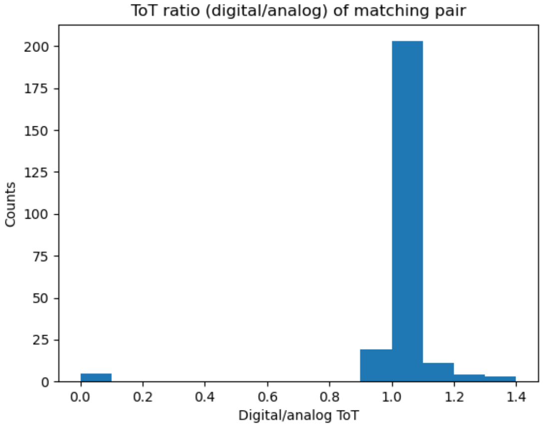
Am-241 Source, bias 160 V,
200 mV threshold

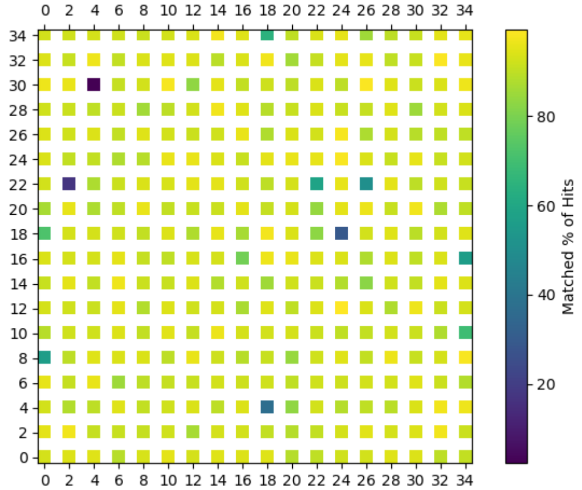
AstroPix v2: Design, Fabrication, and Testing



Consider only digital and analog hits from same pixel that are coincident in time (paired with a measurement made with the other strategy)







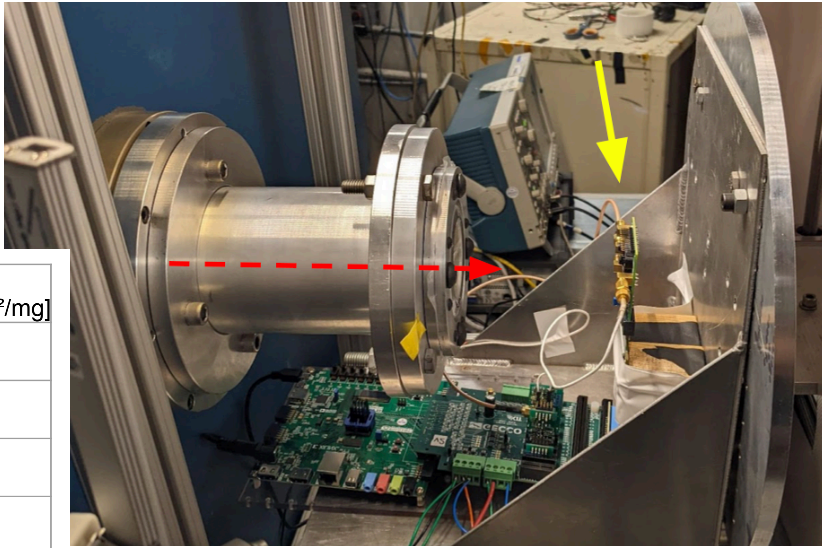
AstroPix v2: Radiation testing

***4 separate* beam tests**

2 Heavy Ion campaigns at LBNL; 2 at Fermilab with 120 GeV protons ran by ANL

Proved resistant to catastrophic latch-up up to Linear Energy Transfer (LET)=65

Single event upset testing lead to improved data collection software. Still analyzing most recent HI campaign

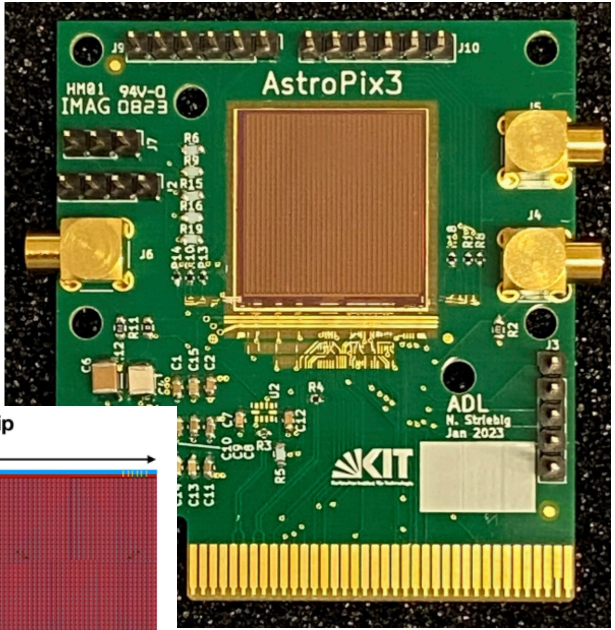


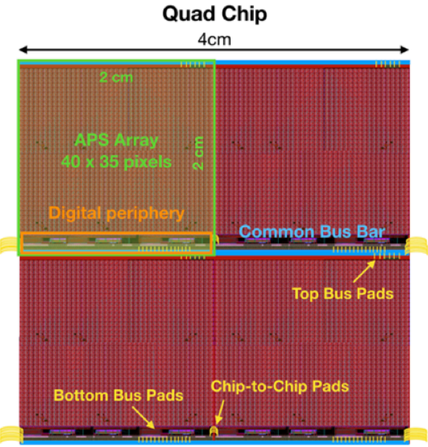
Ion	**LET**$_{[\mathrm{MeV*cm^2/mg}]}$
Argon	8
Copper	19
	21
Krypton	28
	31
Xenon	47
	65

AstroPix v3: Design and Fabrication

Pixel Matrix:

- 500um² Pixel Pitch, 300um² Pixel Size
- 35 x 35 pixels
- first 3 cols PMOS amplifier others NMOS
- Pixel Comparator Outputs Row/ Column OR wired
- Goal:
  - Pixel Dynamic Range 20keV - 700keV
  - Noise Floor 5 keV (2%@662keV)





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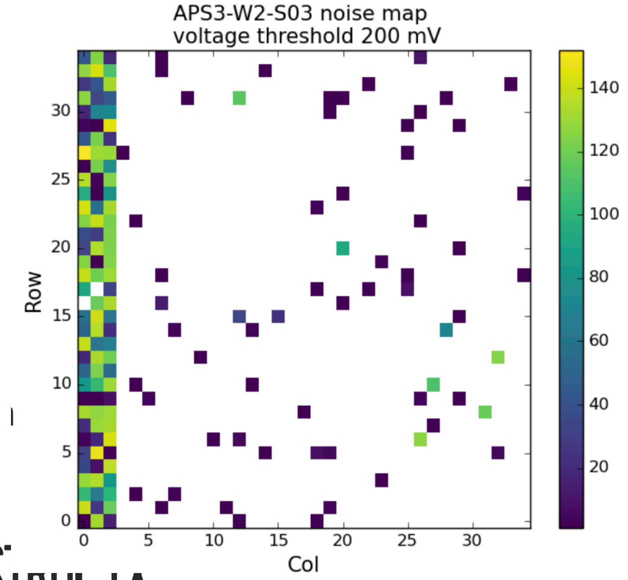
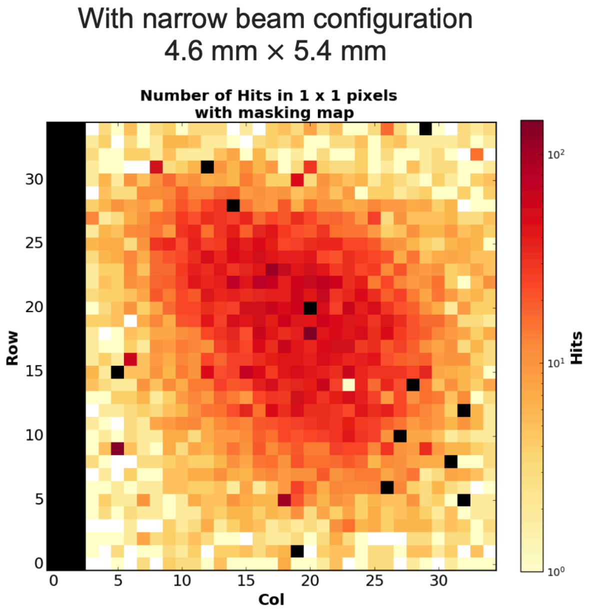
AstroPix v3: Testing

Underway at GSFC, ANL (J. Kim - see below) and Hiroshima





(Left) Noise map

Beam test (one example):
3h run time; 250 mV threshold, 150 V bias

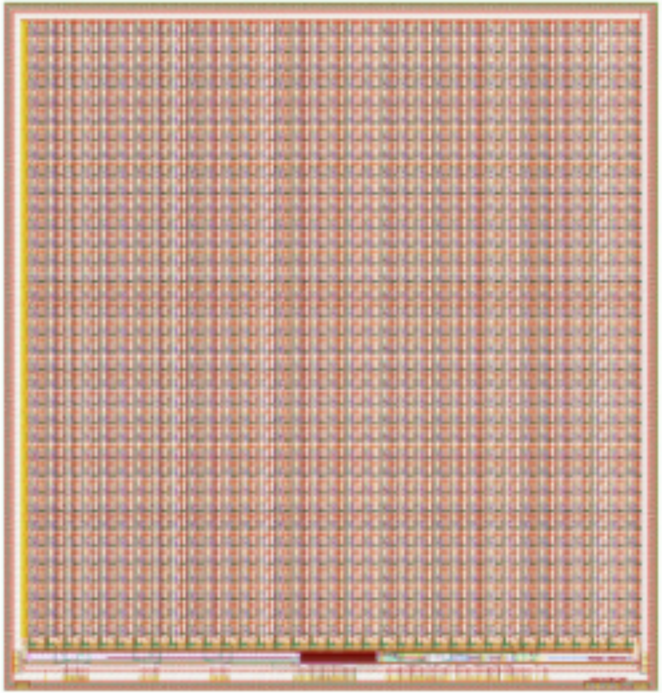
90% active pixels; 87% fired

Still characterizing

AstroPix v4: Design, Fabrication, and Future

Pixel Matrix:

- 500um^2 Pixel Pitch, 300um^2 Pixel Size
- 16 x 16 pixels (1cm^2 chip)
- New:
    - Tune each pixel (TuneDACs);
    - Individual hit buffers
        - Row/column not or-ed
        - 3 timestamps yield a 3.125 ns resolution for Timing and ToT
- Design to TSI in April 2023, approved for fabrication this week



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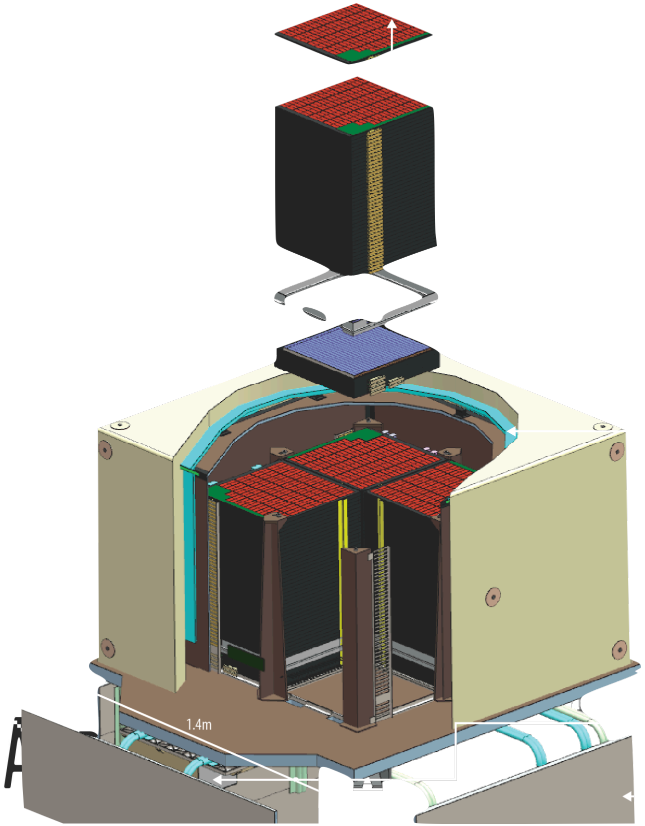
AMEGO-X: AstroPix implemented in gamma-ray telescope



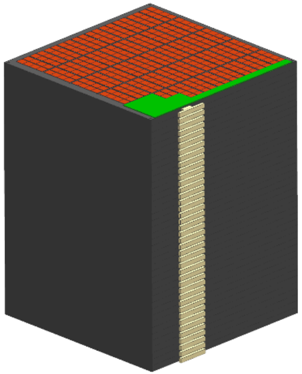
Medium sized explorer mission (~$300M)

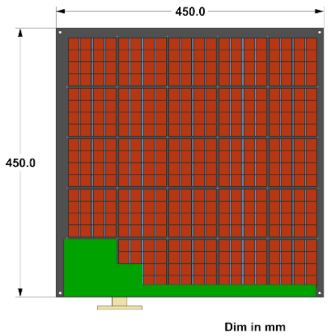
AstroPix based tracker: 40 layers with 95 quad chips per layer

CsI hodoscopic calorimeter (similar to Fermi-LAT)

Anticoincidence detector (Plastic scintillator)

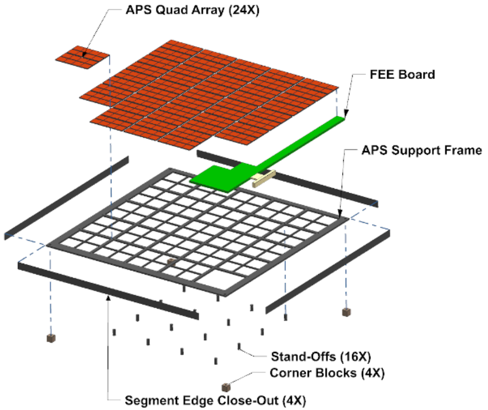
AMEGO-X: AstroPix tracker

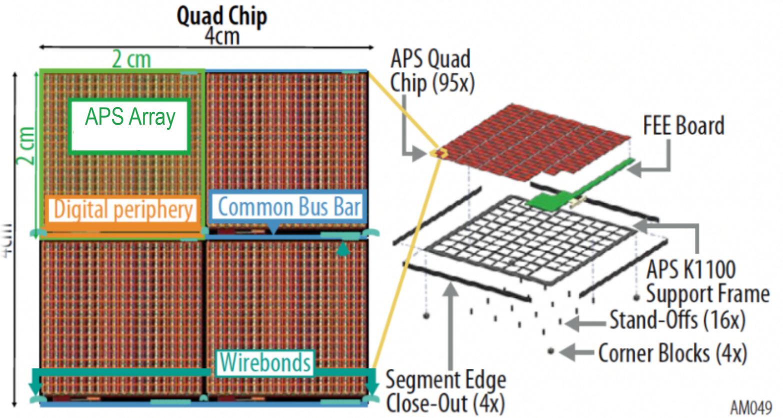




4 towers; 40 layers per tower, 10 x 10 “quad chips” per layer

- ~40m² AstroPix
- Green: FPGA to aggregate signals from chips in layer





AstroPix Workshop: August 1-5, 2022

5 day workshop with >20 international collaborators in person and virtual

Interdisciplinary - contributions from X-ray astronomers, particle collider detector developers, high energy particle physicists, and radiation/electrical engineers

Status updates from all collaborators, definition of goals and priorities, coordination of tasks to achieve these goals

Organized by A. Steinhebel

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Next Steps

- Continued improvements to chip design
  - v4 is the dream, funded for v5
- Multilayer AstroPix setup for a beam test
  - Done at ANL
- Sounding rocket payload
  - Early 2025
- AMEGO-X prototype
  - Selected APRA 22 proposal
  - Resubmit AMEGO-X mission proposal ~2026

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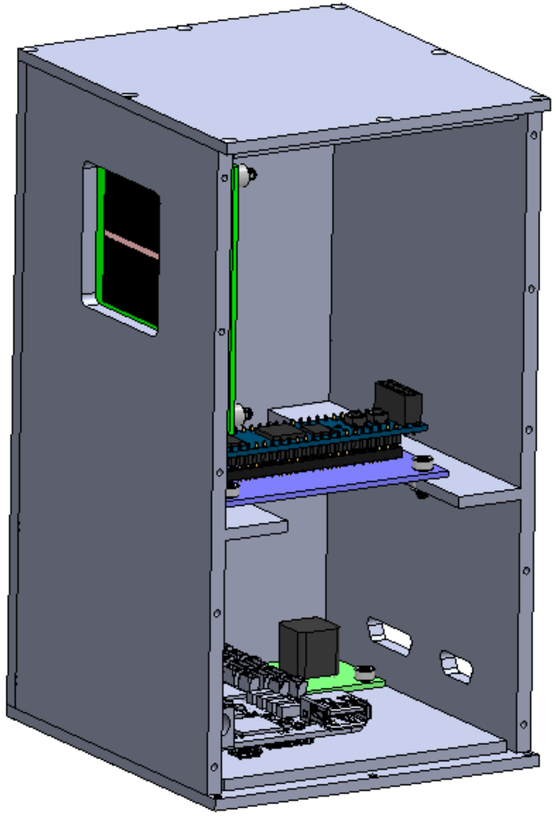
Sounding Rocket Payload: A-STEP

Plan for flight prototype (see right) and hosted payload

Coordinating with Sounding Rocket Program Office (SRPO) + Wallops Flight Facility for engineering support

Kickoff October 2022. Fly early 2025

Demonstrate detectors work in relevant environment. Reconstruct charged particle tracks



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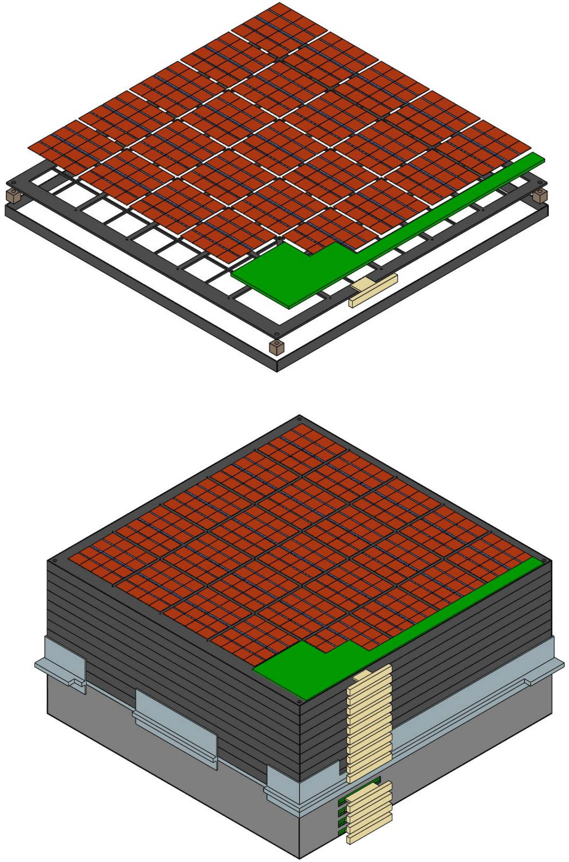
Next Steps: AMEGO-X prototype

Combination of ~5 APRA efforts

- AstroPix tracker
- CsI Calorimeter
- Compton Event reconstruction improvements

Demonstrate system works in relevant environment



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Publications

AstroPix specific:

- I. Brewer, et al, SPIE 2020: https://arxiv.org/abs/2101.02665
- I. Brewer, et al, NIM A, 2021: https://arxiv.org/abs/2109.13409
- A. Steinhebel, et al, SPIE 2022: https://arxiv.org/abs/2209.02631
- A. Steinhebel, et al, PIXEL 2022: https://arxiv.org/abs/2302.00101

Utilizing AstroPix technology:

- I. Martinez-Castellanos, H. Fleischhack, et al, AJ, 2022: https://arxiv.org/abs/2111.09209
- R. Caputo, et al, JATIS 2022: https://arxiv.org/abs/2208.04990

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AstroPix: Summary