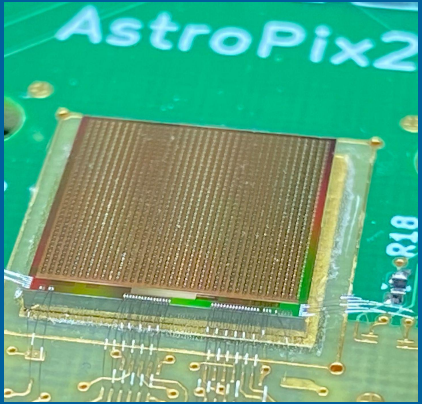
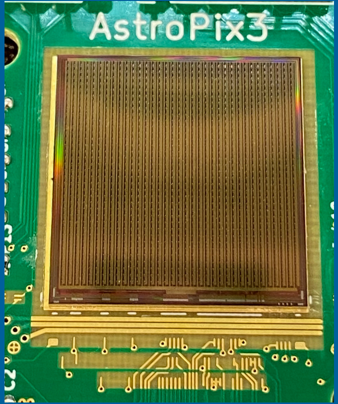
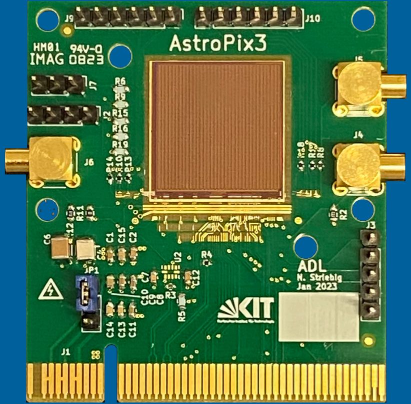
ePIC Collaboration Meeting - Jan 2024 (ANL)

AstroPix v3







Manoj Jadhav
Argonne National Laboratory

Jan 10, 2024

Argonne NATIONAL LABORATORY

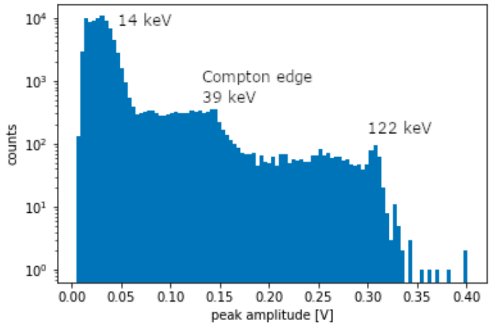
AstroPix Developments

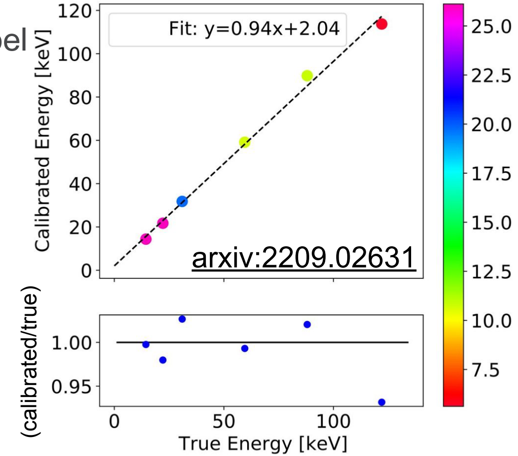
Amanda Steinhebel

arxiv:2302.00101

AstroPix v1 - 0.45 cm × 0.45 cm chip

- 18 × 18 pixel matrix, 175 µm pitch
- Tested for analog output



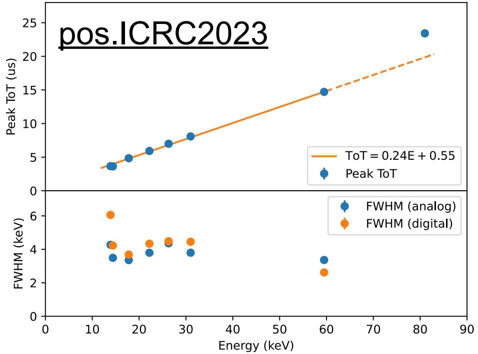


Energy Calibration using analog data

AstroPix v2 - 1 × 1 cm2 chip (MPW)

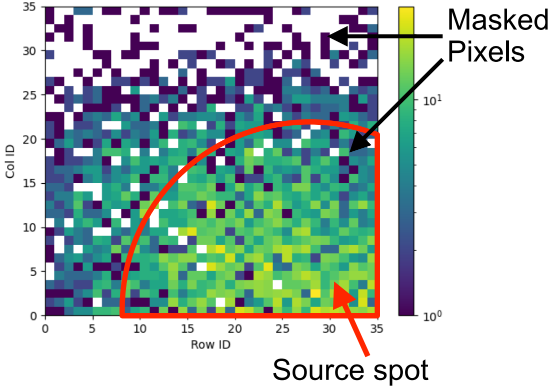
- 35 × 35 pixel matrix, 250 µm pitch
- Row/Column hit identification
- Analog + digital output

Yusuke Suda



Energy Calibration using digital data

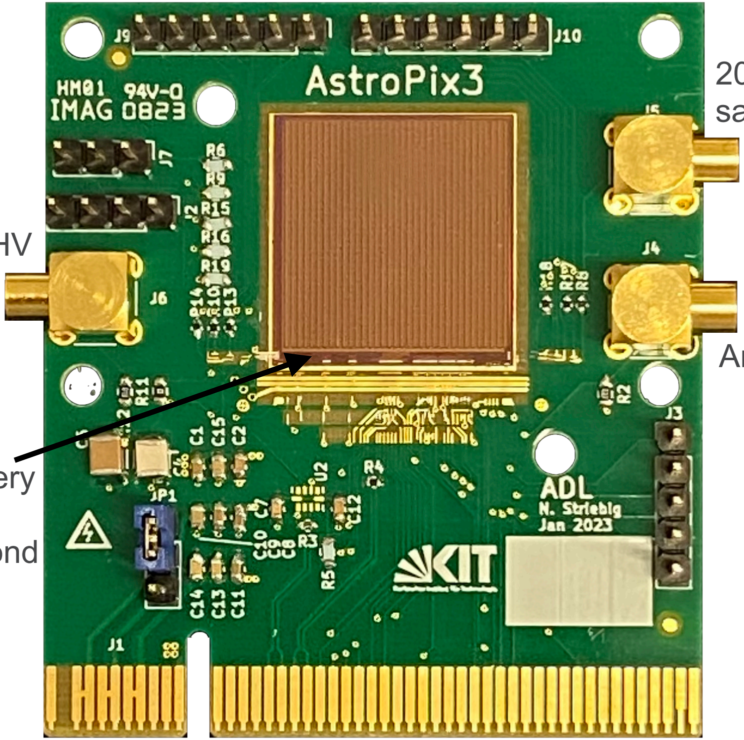
^{90}Sr Source - bench test



AstroPix v3 Specifications

AstroPix v3

- 2 × 2 cm^2 full-size chip with 35 × 35 pixel matrix
- 300 µm pixel size, 500 µm pixel pitch
- Increased spacing between the outer pixel n-well and the chip edge
- Timestamp clock 2.5MHz, ToT clock 200 MHz
- 10-byte data frame per hit
- Chip-generated injection signal
- The first 3 columns are implemented with PMOS amplifier



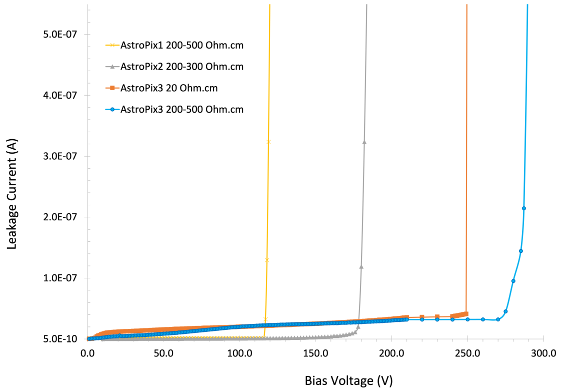
AstroPix v3 - Single Chip

AstroPix v3 Measurements

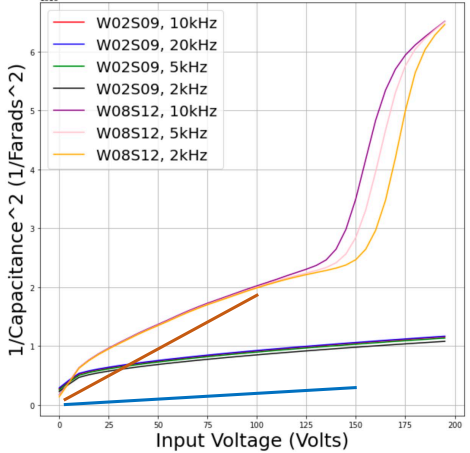
Full-size chip (ongoing testing)

- Sensor characterization
  - IV/CV measurements
  - TCT measurements
- Test bench validation and optimazation
- FTBF testbeam performance studies
- Active and passive irradiation **~10^{15} $n_{equivalent}/cm^2$**
- **Quad-chip readout** (under testing) for NASA's hosted payload mission (A-Step) - **(Taylor's talk)**
- Integration with Pb/SciFi **(Henry's talk)**

IV measurements for different versions



APXV3 W02S09 at 2-20kHz and W08S12 at 2-10kHz CV



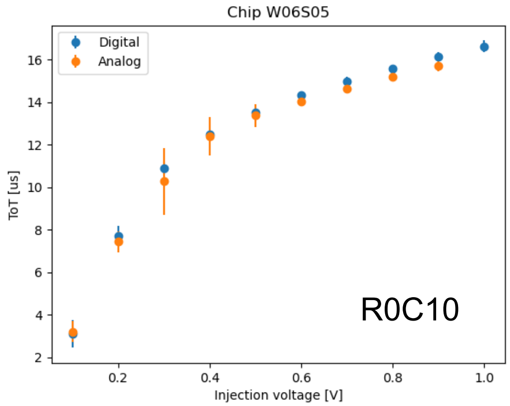
W02 - 20 Ohm.cm
W08 - 200-500 Ohm.cm

UCSC group

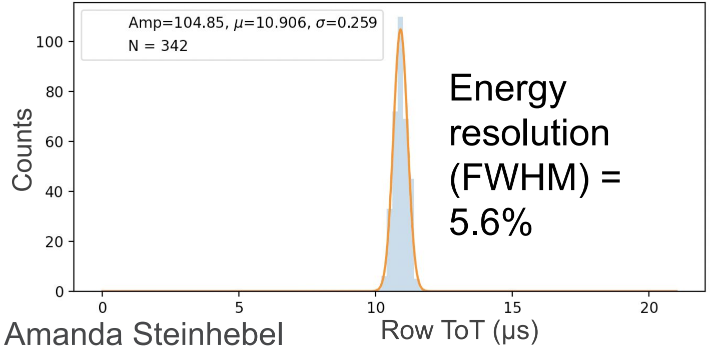
AstroPix v3 Results

Test Bench Measurements

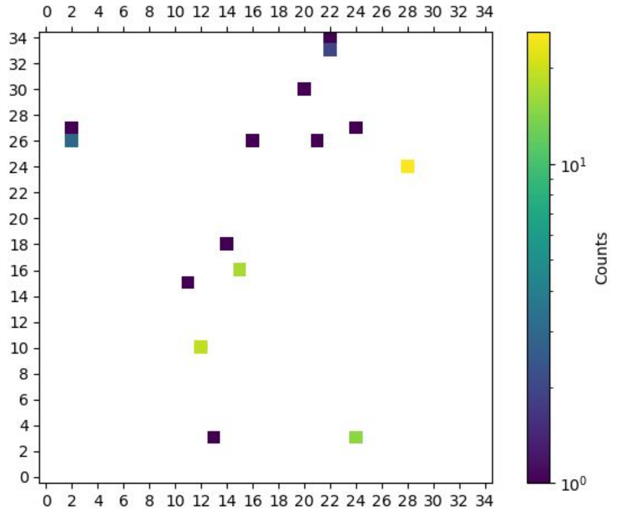
- Injection voltage scan shows that the analog and digital ToT agree well
- The energy resolution of 5.6% is measured using an injected pulse
- Noise scan shows <1% of noisy pixels
  - resolves issue with noisy pixels observed with v2
- Noisy pixels can be masked by disabling the comparator



Amanda Steinhebel



Amanda Steinhebel



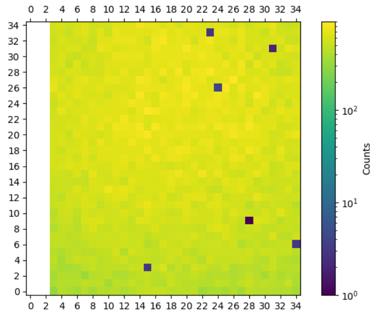
Amanda Steinhebel

AstroPix v3 Results

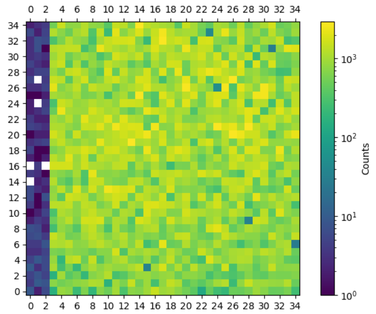
Source Scan Measurements

- Ba133, 30min, ~8 nCi
- Am241, 10min, ~106 nCi
- 200 mV threshold, delta(TS)<=1
- First 3 cols (PMOS) disabled
- Ba133, 5min, ~8 nCi, enabling PMOS amplifier col
  - higher hit rate in PMOS cols

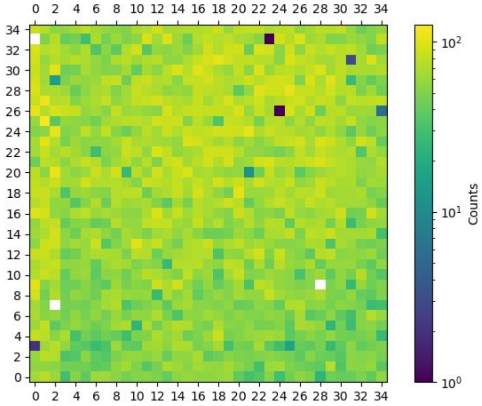
Ba133 - 93.6% of hits paired

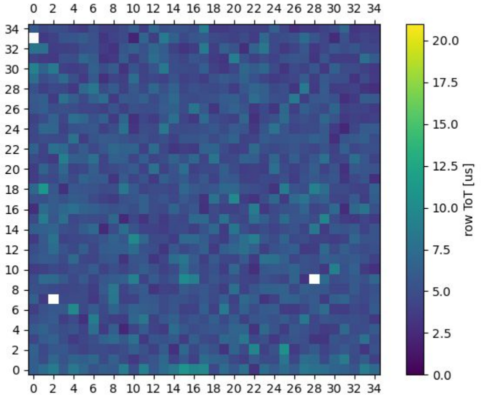


Am241 - 82.1%% of hits paired

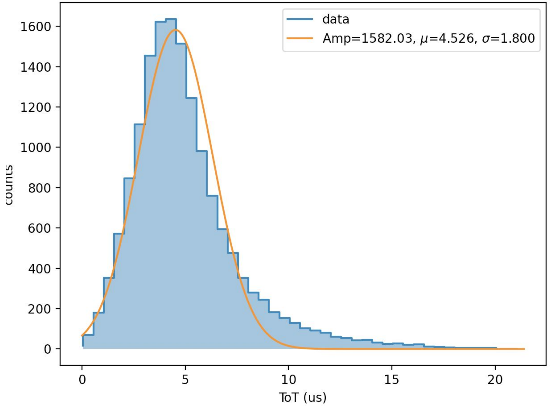


Ba133

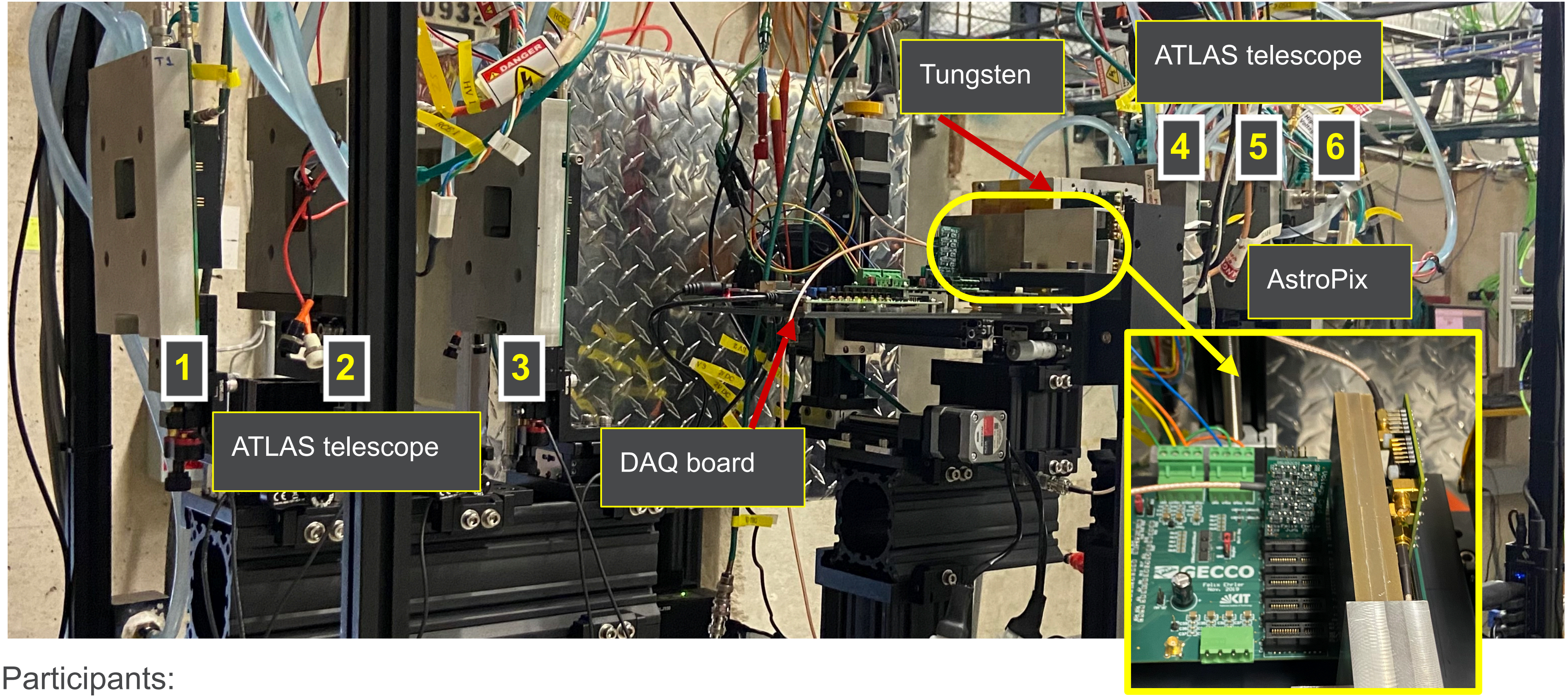




Mean ToT distribution



AstroPix v3 TestBeam



Participants:
Jihee Kim, Maria Zurek, Manoj Jadhav, Jessica Metcalfe

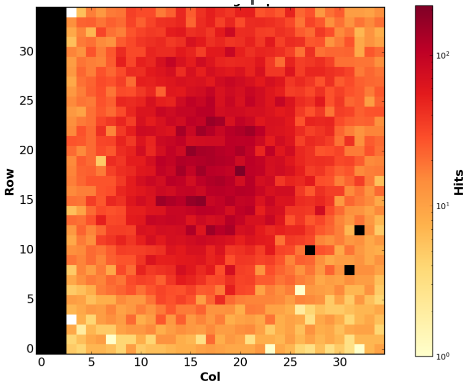
AstroPix v3 TestBeam Results

120 GeV Proton Low intensity beam

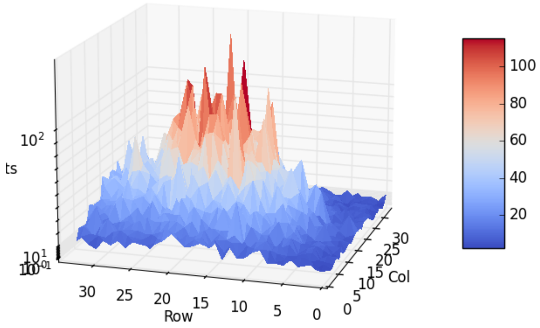
- 120 GeV Proton
  - 5000 protons/spill
  - 4.7 mm × 4.8 mm beam spot
- Data acquisition
  - Total 8 hours
  - 300 mV threshold
  - HV bias voltage 150 V
- Total 37,472 raw events
  - 96.67 % of events were decodable
  - 44,742 pixels* were fired
  - Among 91.1 % of active pixels, 91.02 % of pixels were fired
- Uniform pixel response for Minimum Ionizing Particle

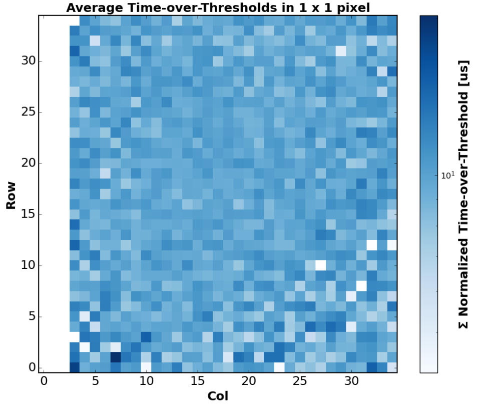
*Matching hits with exact time timestamp + ToT matching

Hit map

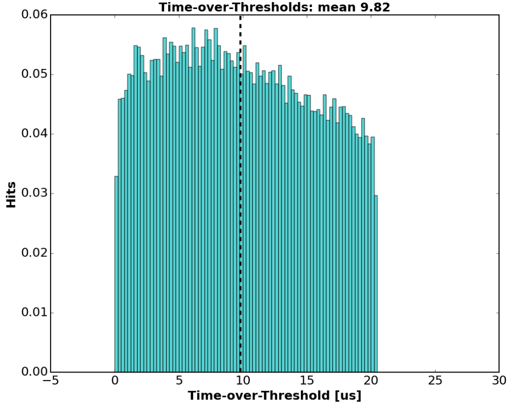


Hit map 3D





Average ToT in Pixel array



ToT distribution

Software and Firmware Development

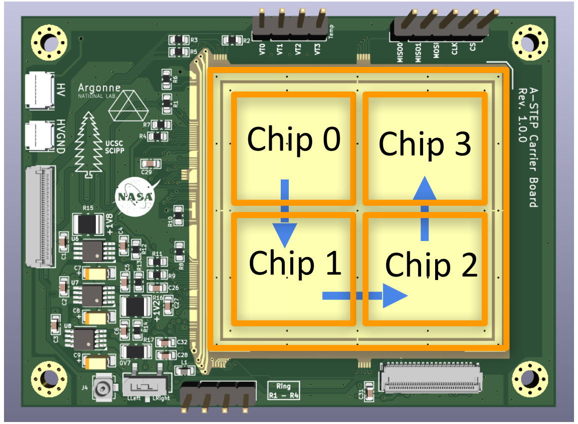
SW led by N. Striebig (KIT) and A. Steinhebel (GSFC), FW led by R. Leys and N. Striebig (KIT)

- FW-driven SPI readout to reduce deadtime
  - The self-trigger readout when there is data in buffers without SW check
  - Sensor data frame detection, IDLE discard, Tagging/reframing, routing to single Readout Buffer
- FW Scale-ability
  - Read through the daisy chain in FW rather than SW
  - Up to 20 daisy-chained SPI inputs have their own interfaces, which feed into the global buffer
- SW speedup to match FW
  - Reduce the chance of incomplete data return
  - Speed-up in analysis scripts, esp. when probing every pixel individually

Slide from Amanda’s Talk in TIC

Next Steps

- Energy calibration of AstroPix v3
- Optimize configuration settings
- Depletion depth measurements are ongoing
  - TCT data collected by Amanda with the help of UCSC colleagues
- Irradiated AstroPix v3 with different 400 MeV Proton dose
  - Data analysis and sensor characterization of irradiated samples
- AstroPix v3 quad-chip development
  - Carrier board if designed by Taylor (check his talk this afternoon)
  - We have assembled the first few boards
  - They are under testing
- Module-like board design with 8 single chips is undergoing



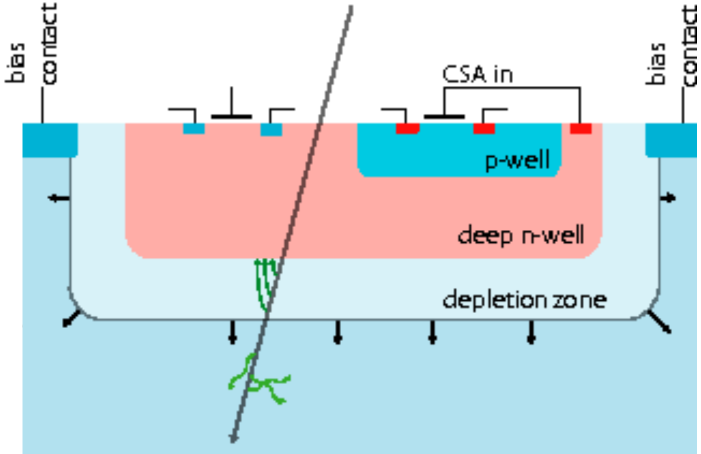
AstroPix v3 quad-chip carrier board
- Demonstrate required services
- Daisy chaining

Thank you

AstroPix

HV-CMOS Monolithic Active Pixel Sensor (MAPS):

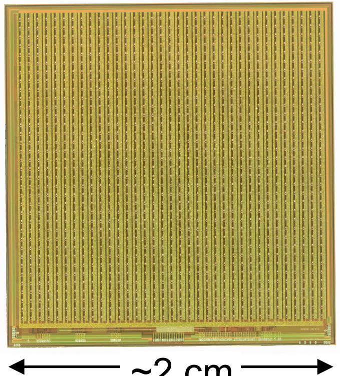
- Combination of silicon pixel and front-end ASIC
- On-pixel charge amplification and digitization
- The technology uses more typical CMOS wafer processing for cost-effective mass production
- Fabrication on a single wafer enables a shorter design cycle
- No need to bump-bond to each pixel - improves yield



AstroPix (based on **ATLASPix3** **arXiv:2109.13409**)

- 180 nm HV-CMOS MAPS sensor
  designed at KIT (also designed ATLASPix, MuPix, etc.)
- Developed for AMEGO-X GSFC/NASA mission
  (Upgrade to the Fermi's LAT)

AstroPix v3 (Under test)



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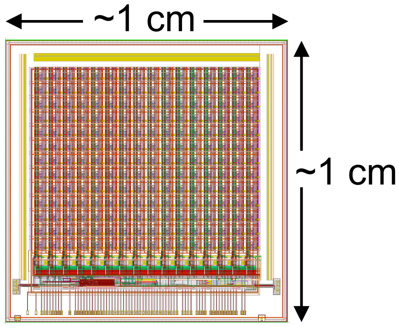
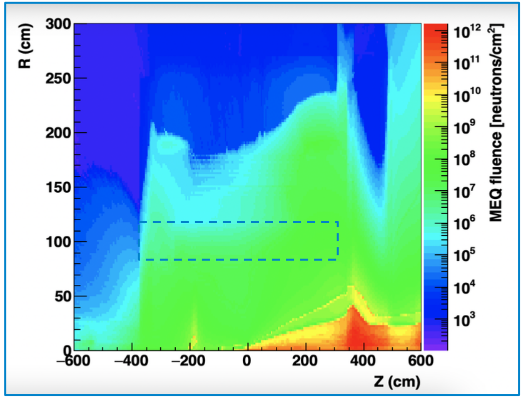


AstroPix v4
(Ready to test,
Nicolas' Talk)

AstroPix v3 Iradiation

- IV and CV measurements performed for the v2/v3 chips before irradiations
  - Same measurements will be repeated post irradiation
- 9 v2 & 6 v3 chips irradiated for Passive Irradiation (Al-foil dosimetry)
- Active Irradiation for Latch-up (and SEE) is planned - week of 26th May

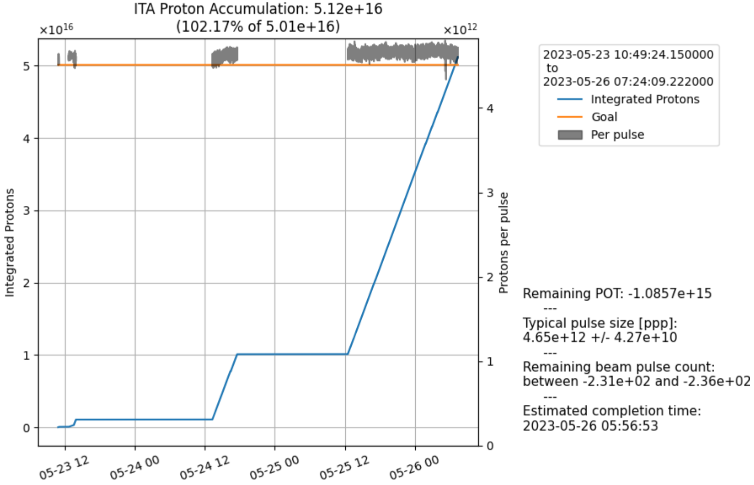


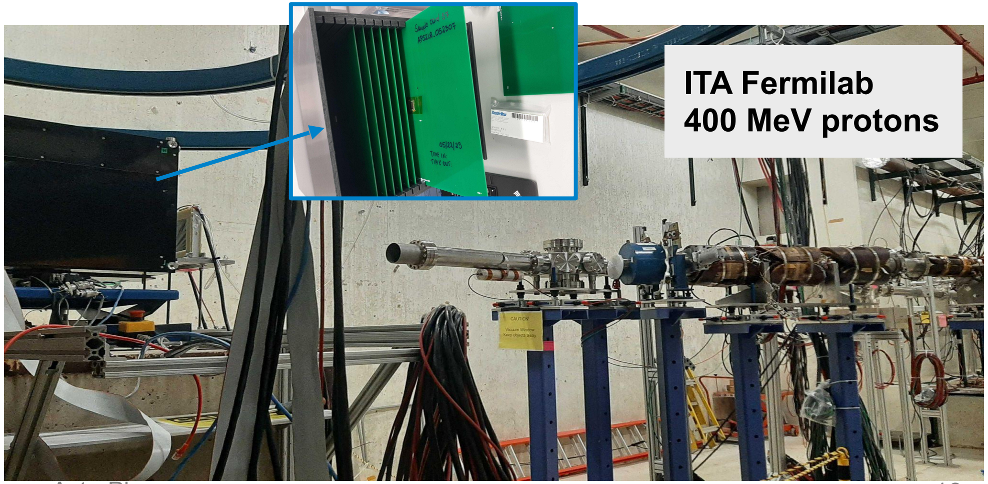
V2 Irradiation

Nb of samples	Doses (400 MeV protons)
3	4.50E+13
3	1.08E+15
2	1.01E+16
1	5.02E+16

V3 Irradiation (low and high ResChips)

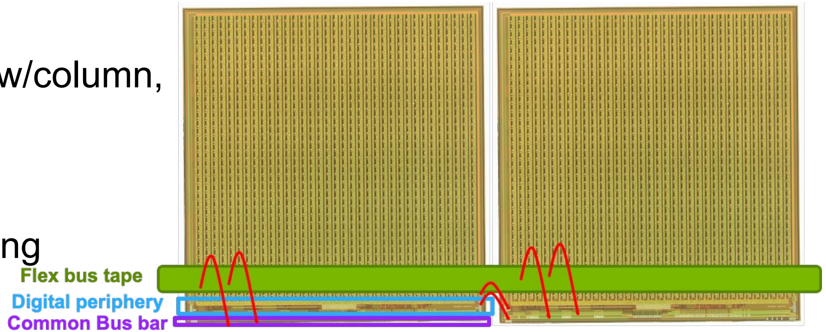
Nb of samples	Doses (400 MeV protons)
2	4.50E+13
1	5.04E+15

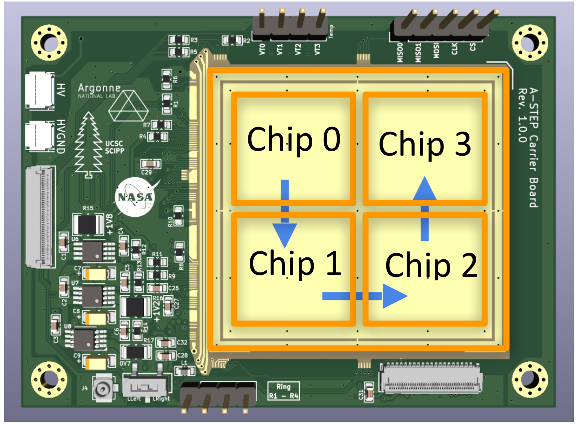




AstroPix Readout

- 10 bytes of data per hit - header (chipID, payload), row/column, timestamp, ToT
- SPI I/O daisy chained - chip-to-chip signal transfer
  - signals are digitized and routed out to the neighboring chip using 5 SPI lines via wire bond
- Power/Logic I/O distribution on the module (through a bus tape)
  - 4 power lines (LV, HV), ~20 Logic I/O (SPI, clk, timestamp, interrupt, digital Injection, etc.)
  - HV, VDDA/VDDD(1.8V), VSSA(1.2V), Vminuspix(0.7V)
  - power distribution can be controlled using voltage regulators
  - mostly part of the end of the stave services
- Data will be received by FPGA at the end of the stave
  - FPGA aggregates data before sending off-detector
- Low heat load at chip, only cooling of end of the stave card
- The operational temperature for AstroPix is at room temperature and considered to be operated at 22 °C



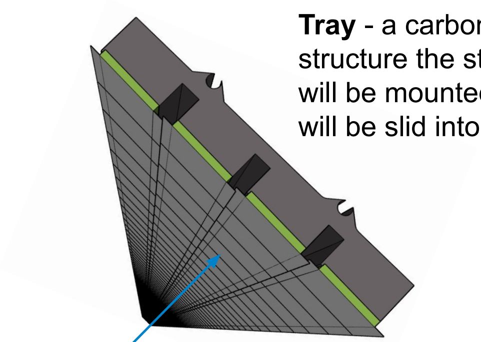


AstroPix v3 quad-chip carrier board
- Demonstrate required services
- Daisy chaining

AstroPix Assembly

AstroPix v5 (Production version)

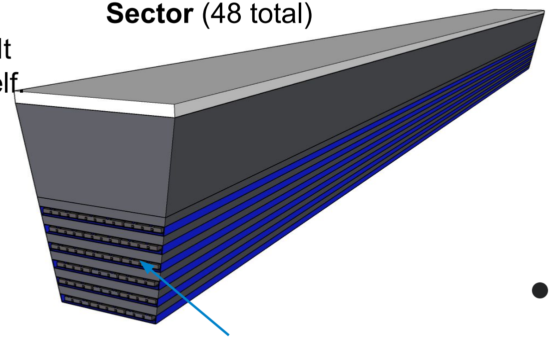
- Full size chip - 2 $\times$ 2 cm^2, pixel pitch 500 μm,
- 35 $\times$ 35 pixel matrix → 1225 hit buffers
- Fix any bug from v4



Tray - a carbon fiber structure the staves will be mounted on. It will be slid into a shelf.

AstroPix **Stave**
Consists of 1 x 108 chips with the support structure, "turbofanned"
AstroPix **Module**
Subset of chips

Sector (48 total)



Shelf - a carbon fiber structure that is glued to the Pb/ScFi layers, that we will slide trays with AstroPix staves on.

*The designs presented on these slides are not final but for illustration only

Module Strategy

- QC testing with wafer probing + Module and stave level QC testing and tuning
- "Baseline" model of Modules on Stave
  - Module - 8 single chips
  - Stave - 13 Modules - 104 chips
  - 12 or 14 Staves per AstroPix layer per Calorimeter Sector
  - Total 249600 chips
- All staves are identical and get combined in a separate production step
- Data is transmitted to the end of the Stave card using flex base tape
- Institutions - ANL, GSFC/NASA, KIT, UCSC, Korea, Oklahoma State

AstroPix Timeline and Production

v3 full size chip (ongoing testing)

- Test bench characterization (ongoing)
- Testbeam performance studies
- Active and passive irradiation **~10^{15} $n_{equivalent}$/cm^2**
- **Quad-chip readout (ready to test)** for NASA's hosted payload mission (A-Step) - **January 2025**
- Integration with Pb/SciFi - FY2024 **(Henry's talk)**

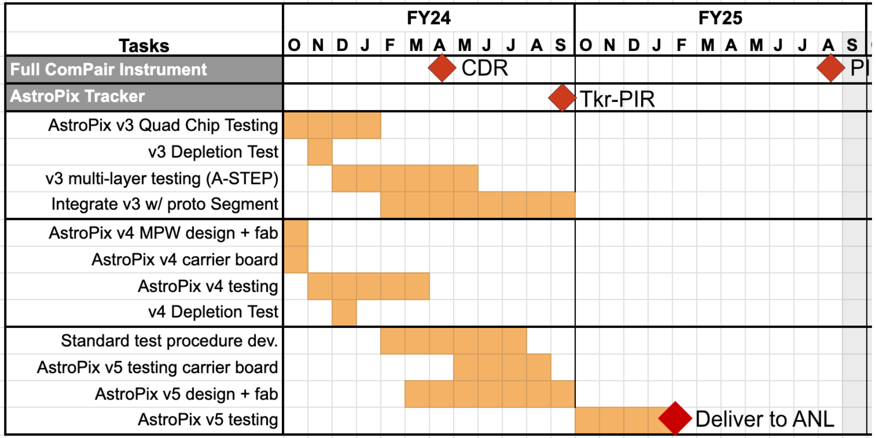
v4 new features for better performance (MWP)

- **Final design version**, smaller chip (1cm × 1cm)
- Fabricated wafers **delivered last week**
- Chip carrier board design for bench test is ready for the PCB fabrication

v5 full size final chip

- Fix any bugs from v4
- v5 chips available **November 2024**

GSFC/NASA ComPair-2 AstroPix timeline



BIC@ePIC Timeline

- **Prototype R&D** (v3) Ongoing - till Nov 24
- Pre-Production (v5) chips starts **Nov 2024**

(More info in Maria's talk)

Production

- Fabrication by TSI - with a large production order, AMS is a backup