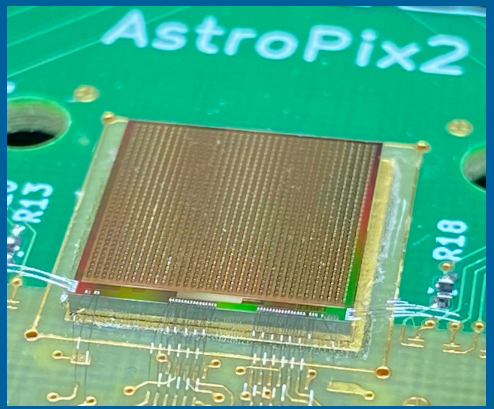
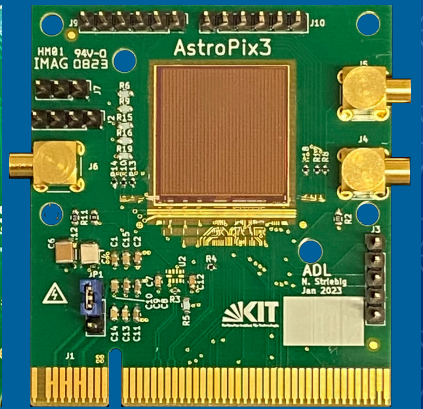
Barrel Imaging Calorimeter Meeting

June 12-16, 2023

AstroPix Test Results at ANL





Manoj Jadhav
Argonne National Laboratory

Jun 16, 2023

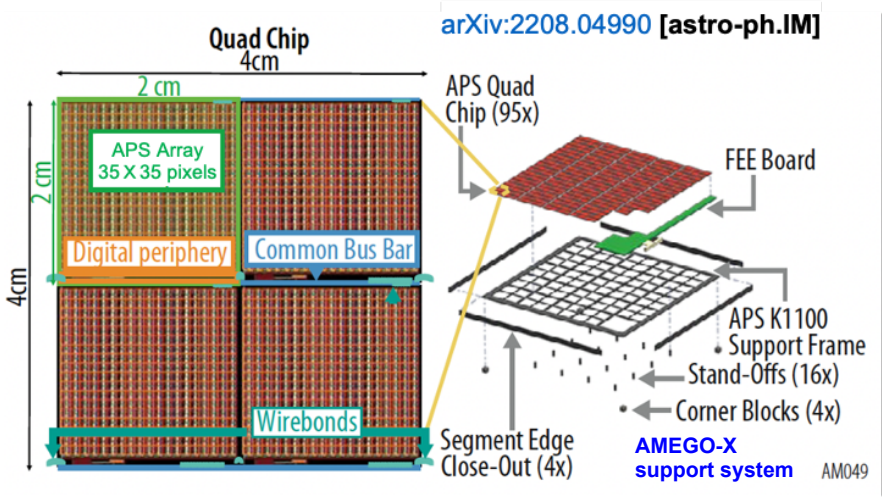
ePIC

Argonne NATIONAL LABORATORY

AstroPix

Imaging layers based on AstroPix sensors

- 180nm HV-CMOS MAPS sensor
- Developed for AMEGOX NASA mission
- Based on ATLASpix3 arXiv:2109.13409 [astro-ph.IM]



Key features:

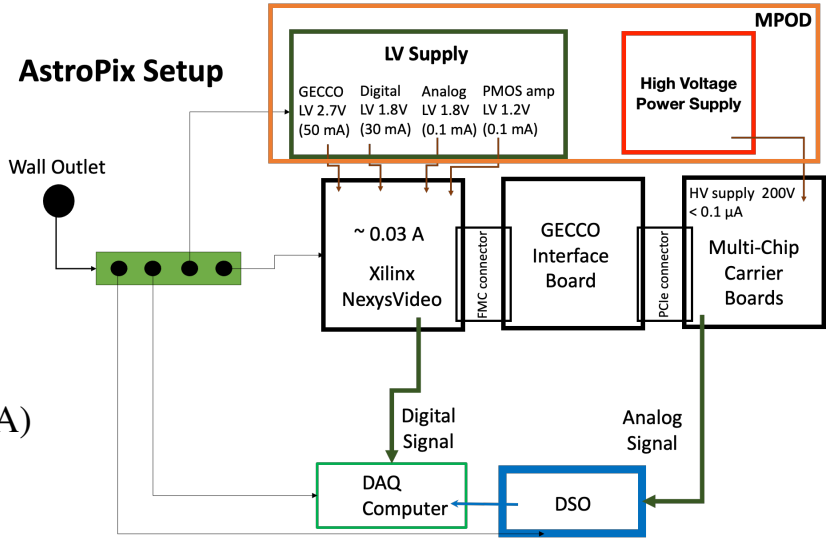
- Very low power dissipation < 1.5 mW/cm^2
- The good energy resolution (<10% @ 60 keV)
- 500 µm X 500 µm pixel size
- Sensor thickness of 700 µm
- Time resolution ~ 3.25 ns (V4)

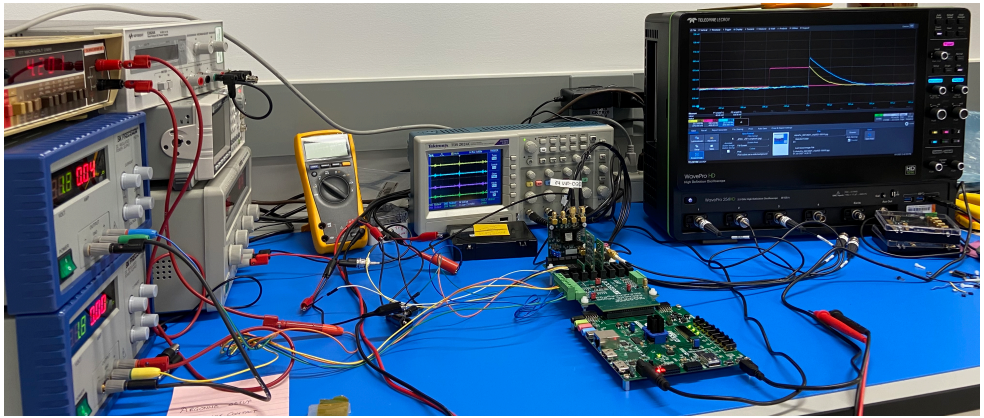
Testbeam Goal

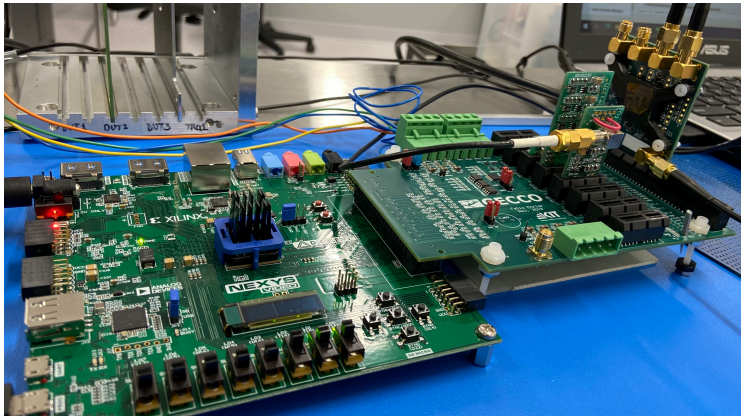
- Assess the feasibility of AstroPix sensor in testbeam environment for tracking performance.
- Testing AstroPix sensor for an imaging electromagnetic calorimeter environment.
  - Is the chip readout scheme optimal for calorimetry? → Tests of chip responses to electromagnetic and hadronic showers in the beam environment
  - How radiation hard is the chip? → Irradiation tests in a high-intensity proton beam

AstroPix Setup

- AstroPix version tested - 1 to 3
- NexysVideo FPGA (Xilinx Artrix-7), GECCO
  - Vivado Design Suite HLx to program chip
  - Analog (DSO) and Digital data acquisition
- V_{BD} = ~ 180V (for v2) and ~ > 250V (for v3)
- LV supply
  - Digital 1.8V (~ 30 mA) and Analog 1.8V (~ 0.1 mA)
  - GECCO 2.7V (~50 mA) and
  - for v3: PMOS amplifier 1.2V (~ 0.1 mA)

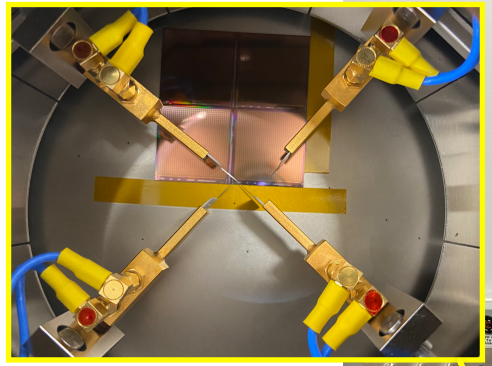


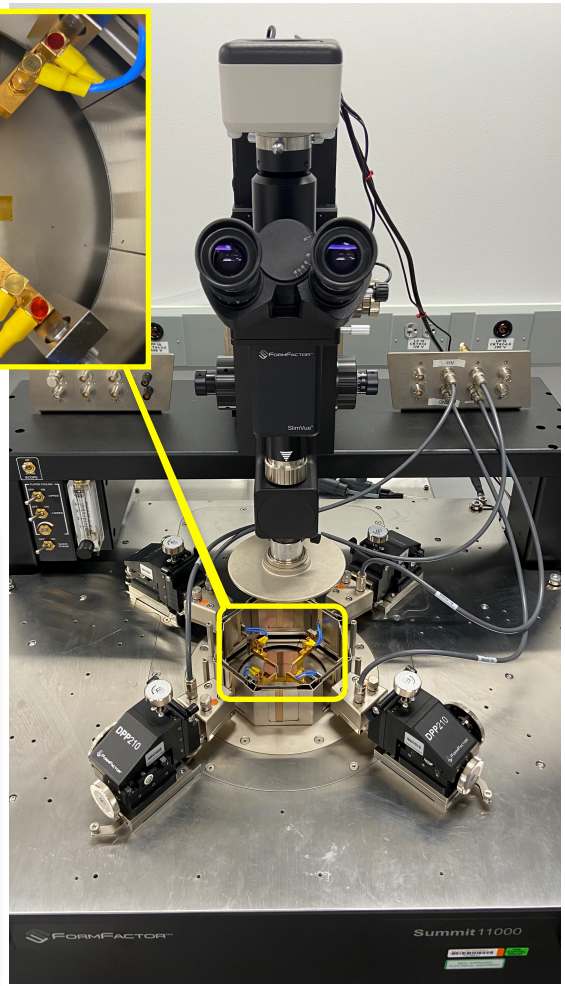


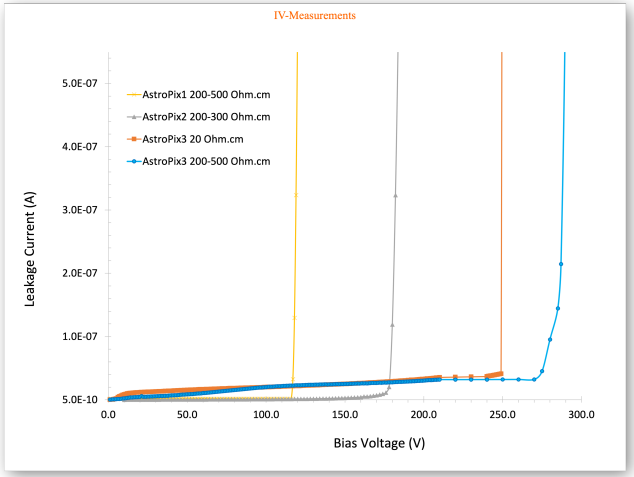


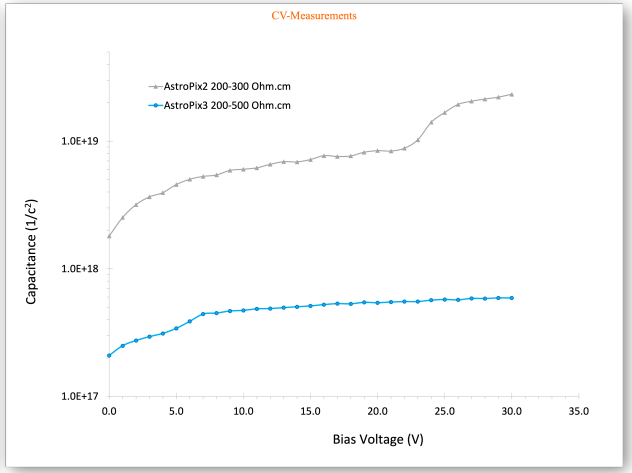
AstroPix Characterization

- IV and CV measurements
- FormFactor Summit 11000
  - Keithley 2400 SCS and CAEN DT1471ET
- high breakdown voltage
- Leakage current < 40 nA, Capacitance ~ 1 nF
- Edge-Transient Current Techniques (TCT) measurements under investigation
  - Depletion Depth and charge sharing



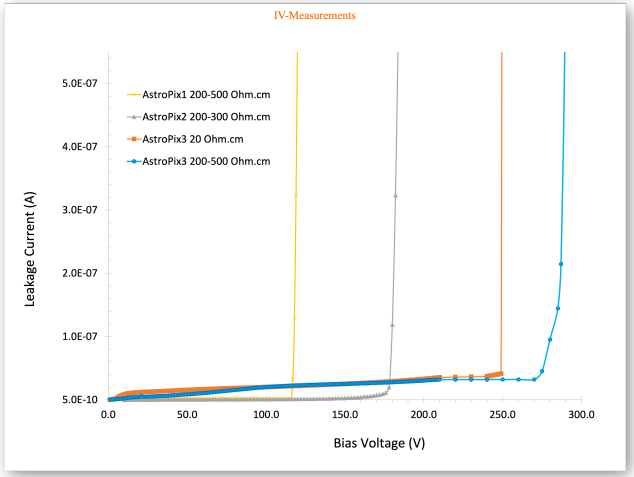


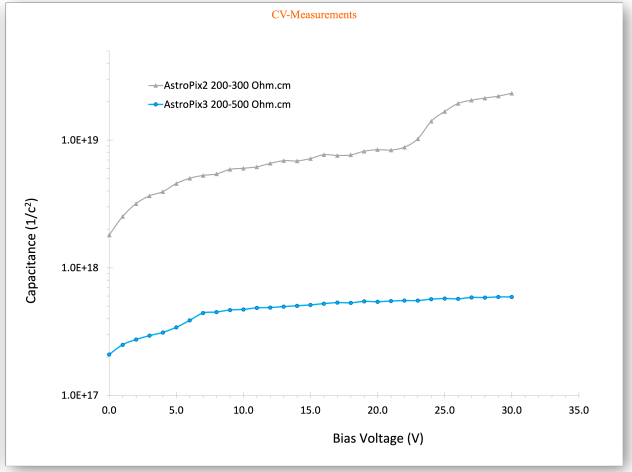


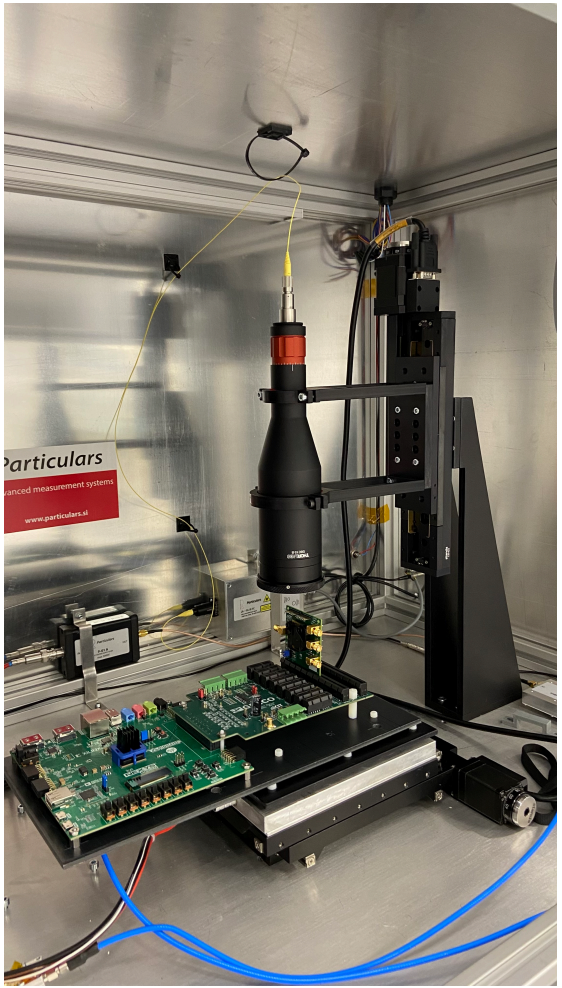


AstroPix Characterization

- IV and CV measurements
- FormFactor Summit 11000
  - Keithley 2400 SCS and CAEN DT1471ET
- high breakdown voltage
- Leakage current < 40 nA, Capacitance ~ 1 nF
- Edge-Transient Current Techniques (TCT) measurements under investigation
  - Depletion Depth and charge sharing







Imaging layers R&D

AstroPix sensor validation testing

- Bench tests with **AstroPix v2**
  - Energy resolution studies
  - Noise measurements
  - Digital data acquisition
  - Sensor characterisation (IV, edge-TCT, depletion depth)

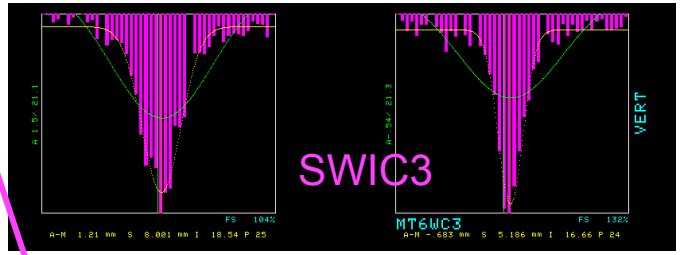
- **Testbeam campaign at Fermilab FTBF**
  - Feb&Apr 2023 - v2 testing; May 2023 v3 testing
  - Validate detector performance at **120 GeV proton** beam
  - **Intergration of AstroPix with ATLAS telescope**
  - **AstroPix telescope tracker (4 layers of AstroPix)**
  - **Feasibility with Calorimeter environment** with **pions/electron beam** at FTBF with tungsten radiator, readout aspects (ANL LDRD grant)

- **Irradiation test**
  - 400 MeV proton (minimum 4.5E12 protons/min) at the FNAL ITA Facility
  - Latch-up tests by NASA with heavy ions (from Argon to Xenon with an atomic tune of 16 MeV/a.m.u.) at LBNL (BASE) - No Latch-up at 65 LET

FTBF Testbeam

< 7 kHz per chip @ FNAL
~83 Hz per chip @ EIC Barrel region
08:43:10
(based on 36 kHz per 2×216 cm²)
Very high rate @ FNAL

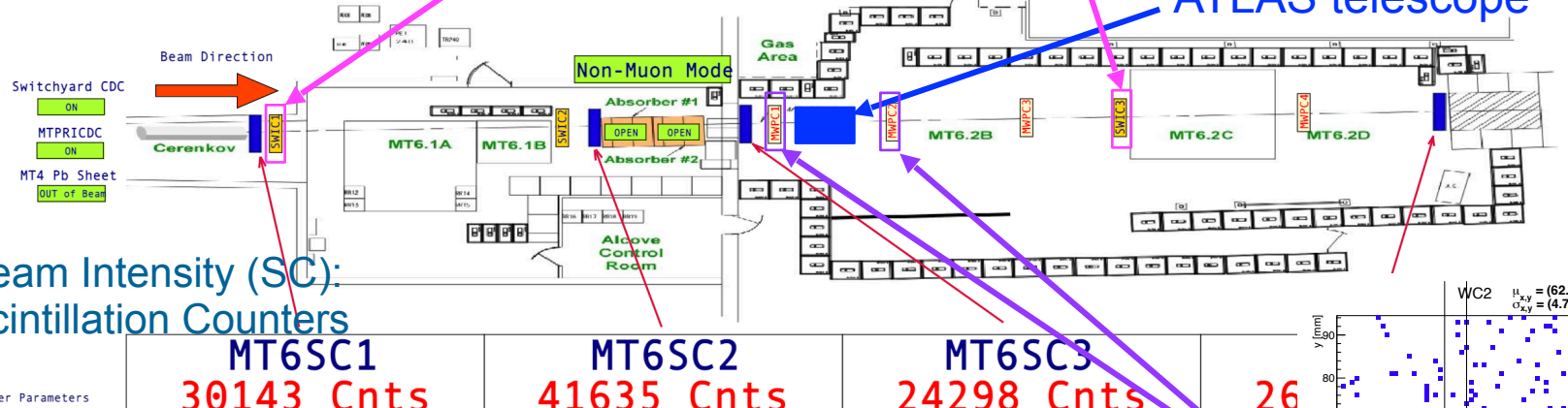
Beam Profile (SWIC): Segmented Wire Ionization Chambers



FTBF Status

Mtest Energy: 120 GeV
MTest Mode: Proton

ATLAS telescope



Beam Intensity (SC): Scintillation Counters

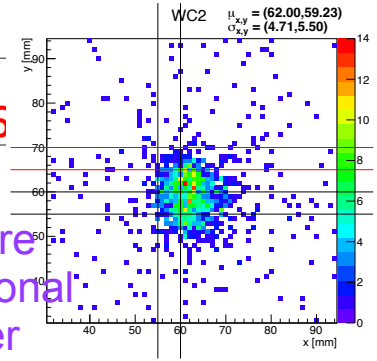
MT6SC1	MT6SC2	MT6SC3	
30143 Cnts	41635 Cnts	24298 Cnts	26

Other Parameters
- Scintillator Counters
- Cherenkov Parameters
- Pinhole Collimators
- Mtest - 17
- TTL Timing
- NIM Timing Marks
- MT6 Environment
- MCenter Environment

Please request intensity from the MCR using F:MTSCL5

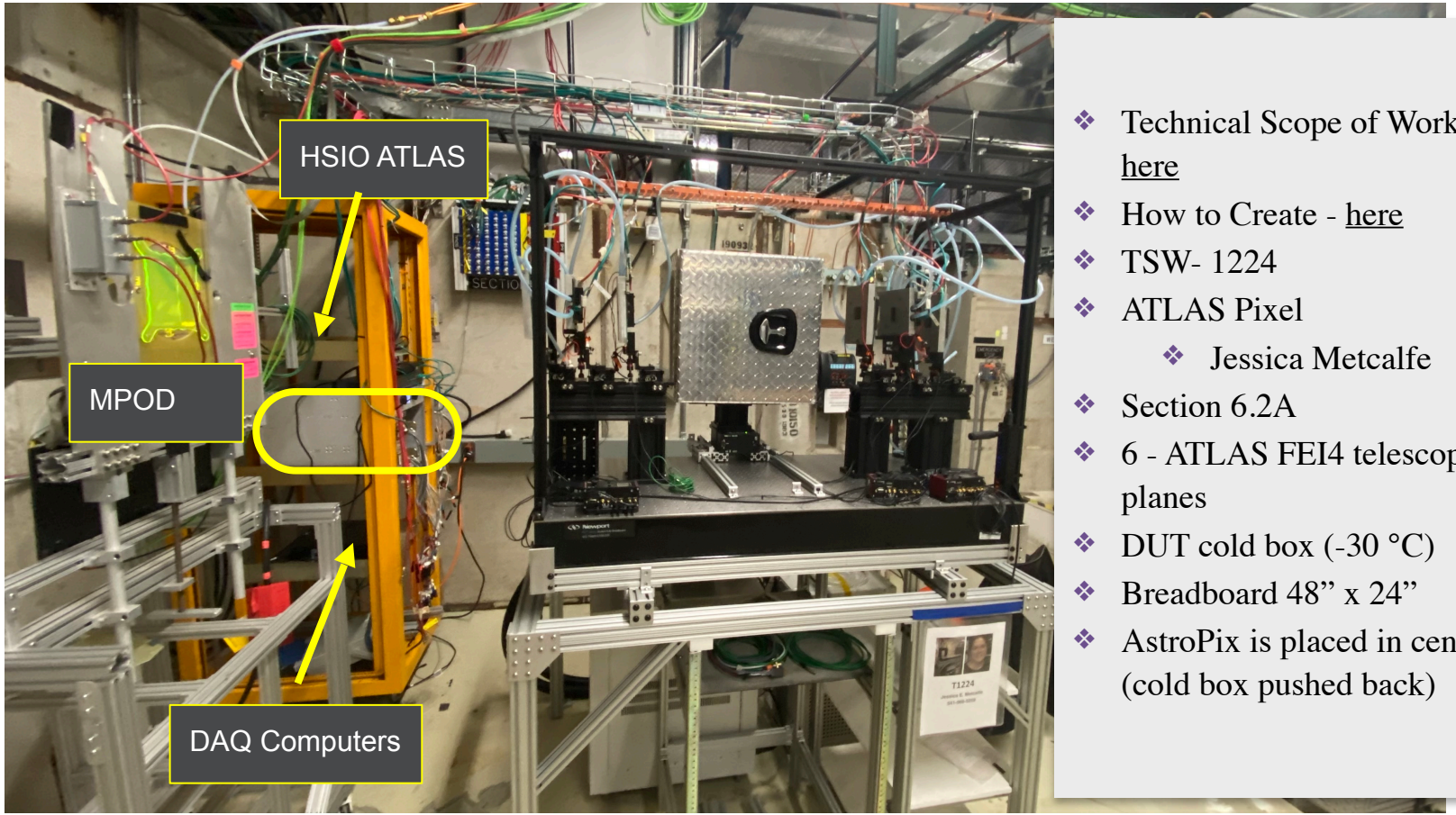
SC1+SC2+SC3+Spill (F:MTSCL5)	19094 Cnts
MWPC Triggers	0 Cnts
Experiment Triggers	0 Cnts
Next Spill	53 Sec

Multi-Wire Proportional Chamber (MWPC)



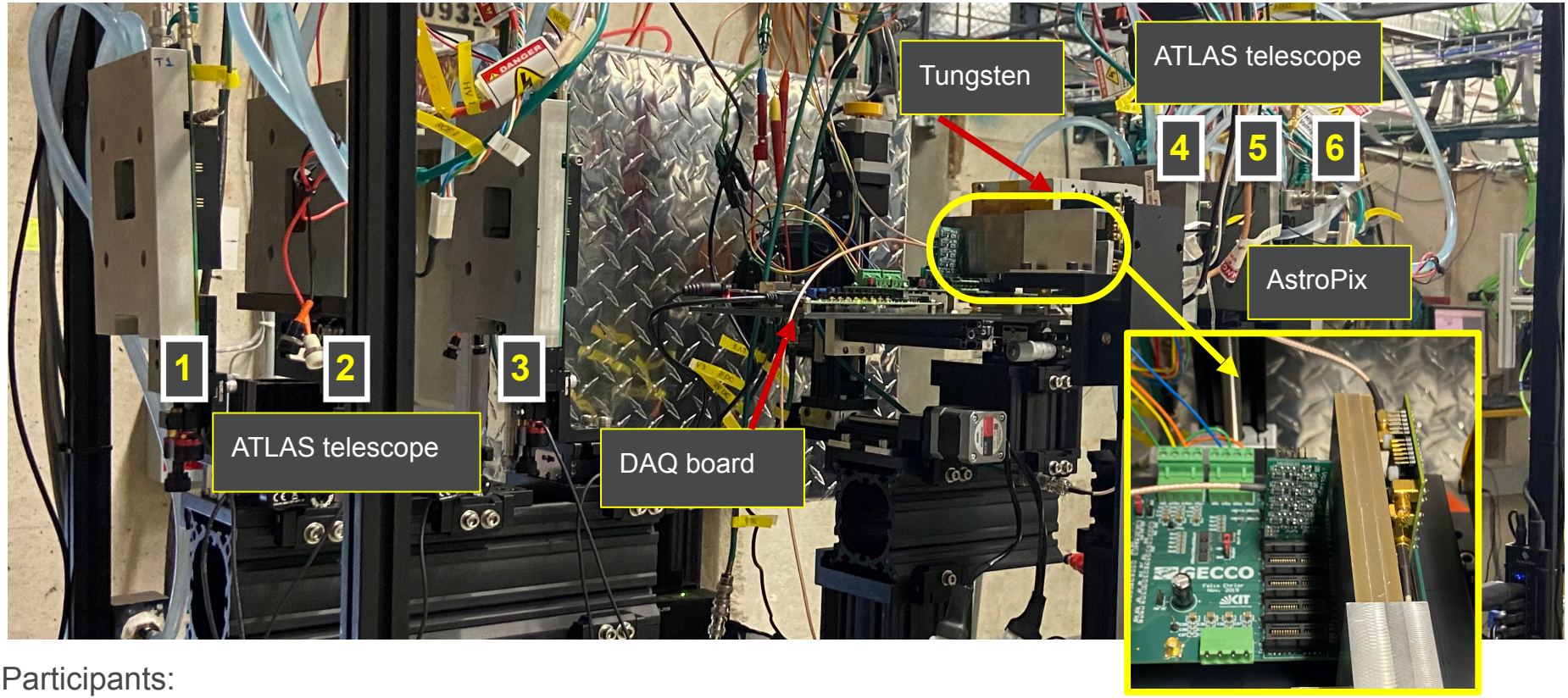
4 seconds spill per minute

AstroPix FTBF Setup



- Technical Scope of Work - here
- How to Create - here
- TSW- 1224
- ATLAS Pixel
  - Jessica Metcalfe
- Section 6.2A
- 6 - ATLAS FEI4 telescope planes
- DUT cold box (-30 °C)
- Breadboard 48” x 24”
- AstroPix is placed in center (cold box pushed back)

AstroPix FTBF Setup

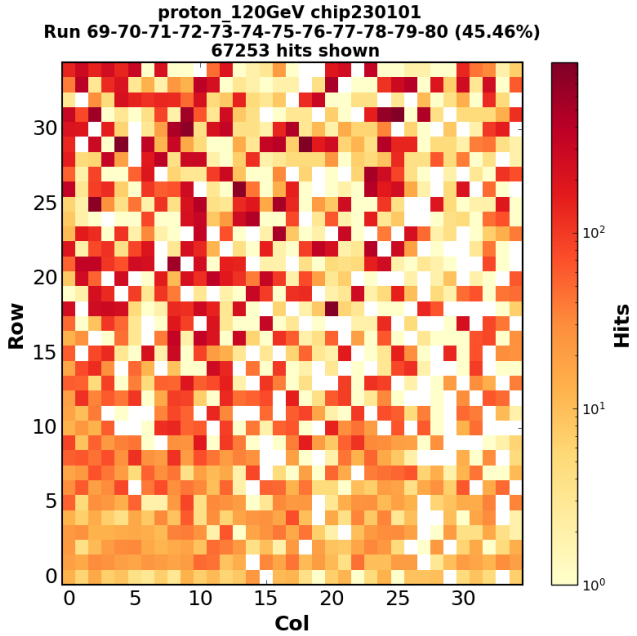


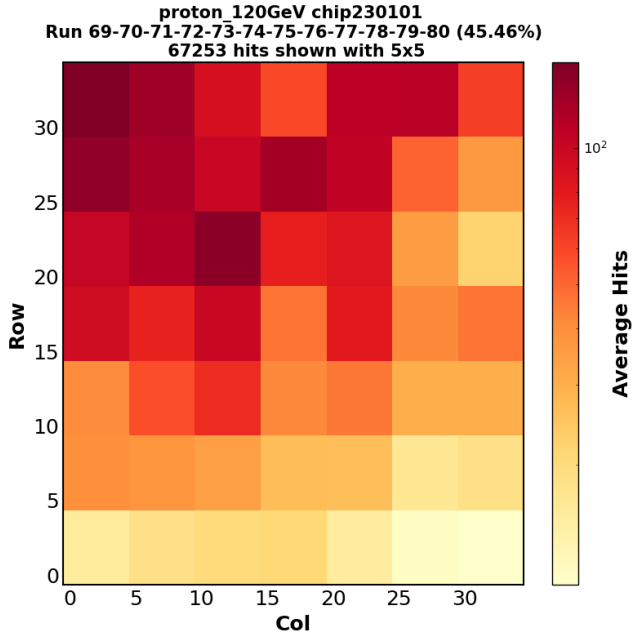
Participants:
Jihee Kim, Doyeon Kim, Maria Zurek, Manoj Jadhav, Junqi Xie, Jessica Metcalfe
2022@ Ricardo Lutz, Amanda Steinhebel

AstroPix v2 FTBF

- Beam position information
  - Started with v2 chip testing in 2022
  - AstroPix v2 chip was tested during Feb 2023 and Apr 2023
  - high threshold at 400 mV, **masked pixels** as white blocks, Total **85 % active pixels**
  - Beam is located at upper left corner

5×5 grid

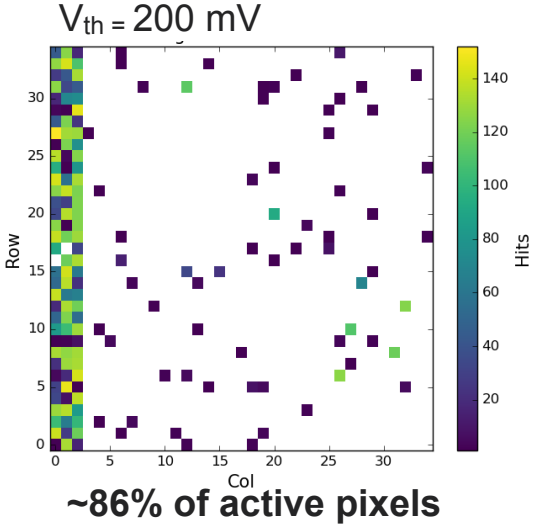




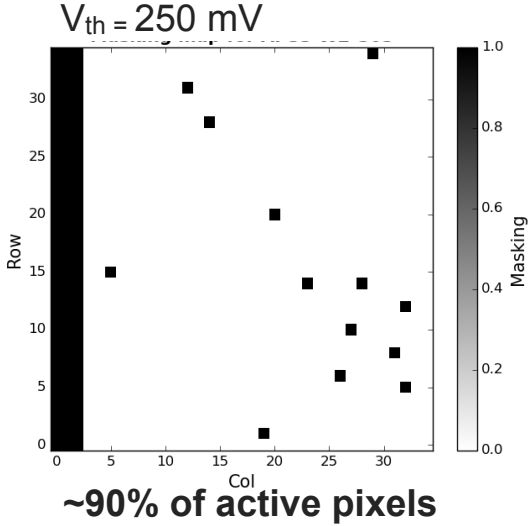
AstroPix v3 FTBF

APS3-W2-S03 - noise scan

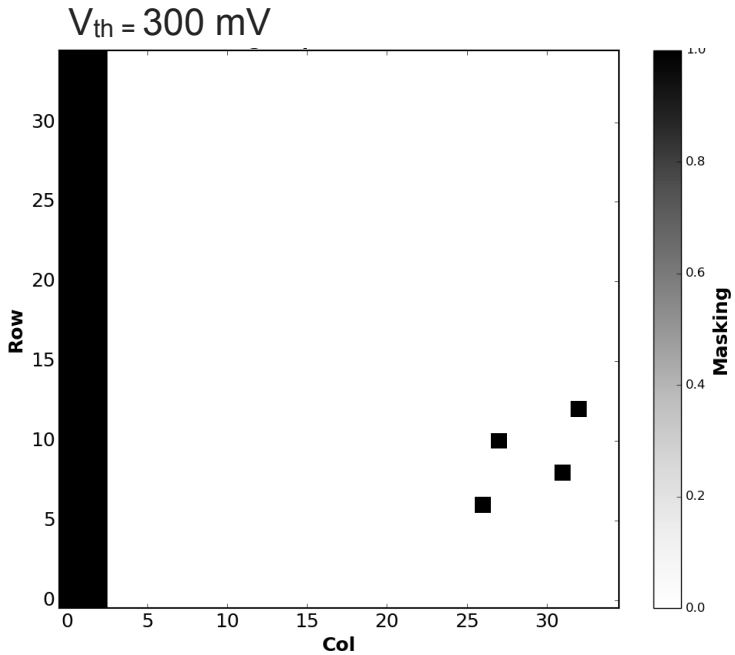
- Time window: 5 secs
- First 3 columns masked, Reduced masked pixels from v2 to v3
- Selected higher threshold for MIPs
  - Maximum number of active pixels
  - Reduce the rate of hits



~86% of active pixels



~90% of active pixels



~91% of active pixels

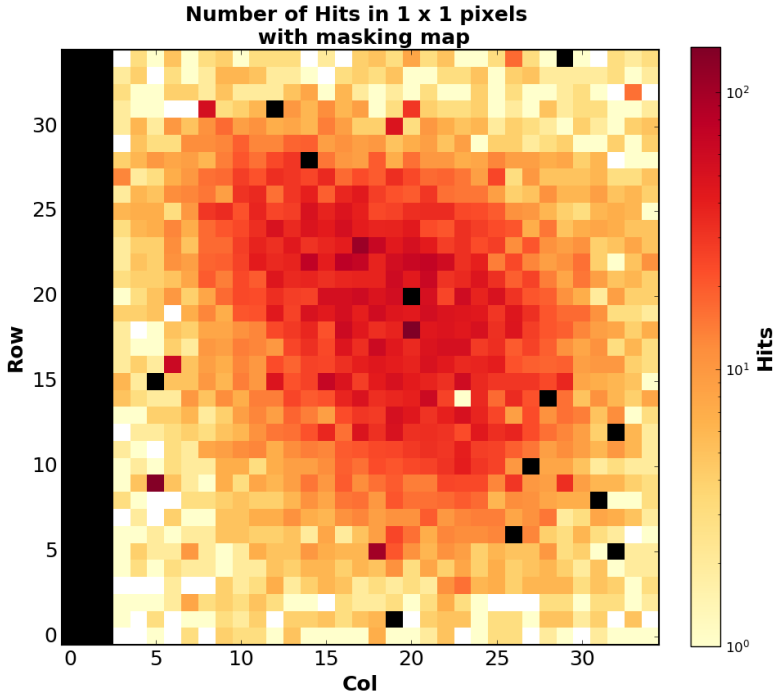
AstroPix v3 FTBF

APS3-W2-S03 - 120 GeV Proton

- 120 GeV Proton
  - 20000 protons/spill
  - 4.6 mm × 5.4 mm
- Data acquisition
  - Total **3 hours**
  - **250 mV** threshold
  - HV bias voltage 150 V
- Total 16,629 raw events
  - **63.28 % of events were decodable**
  - 15,339 hits* were fired
  - Among 90.37 % of **active** pixels, **86.94 % of pixels were fired**

*Matching hits with
exact time timestamp + ToT difference < 0.5 us

With narrow beam configuration

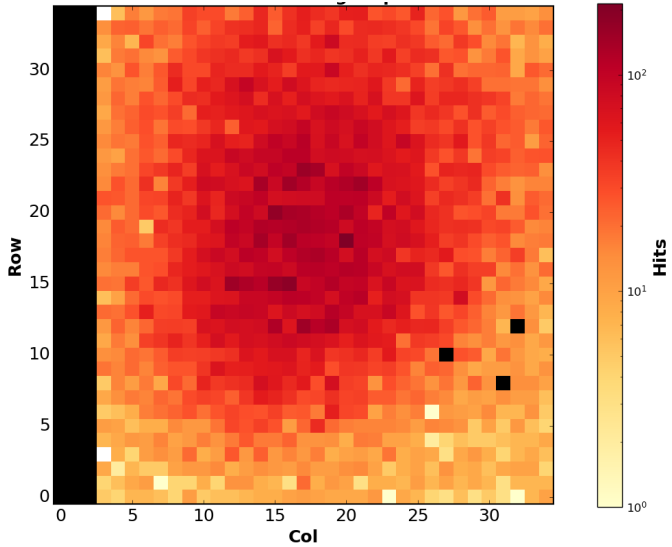


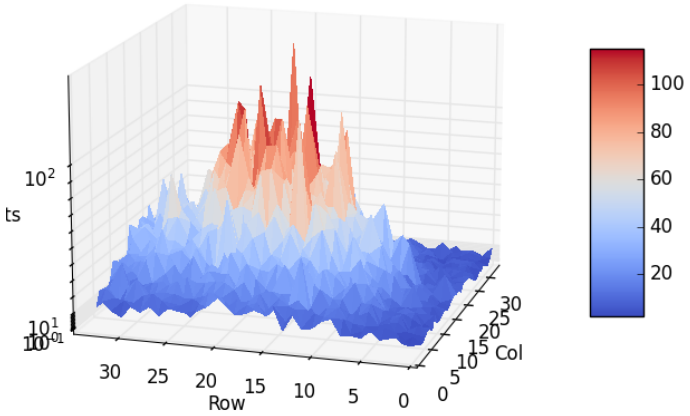
AstroPix v3 FTBF

APS3-W2-S03 - 120 GeV Proton

- 120 GeV Proton
  - 5000 protons/spill
  - 4.7 mm × 4.8 mm
- 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 hits* were fired
  - Among 91.1 % of active pixels, 91.02 % of pixels were fired

*Matching hits with
exact time timestamp + ToT matching

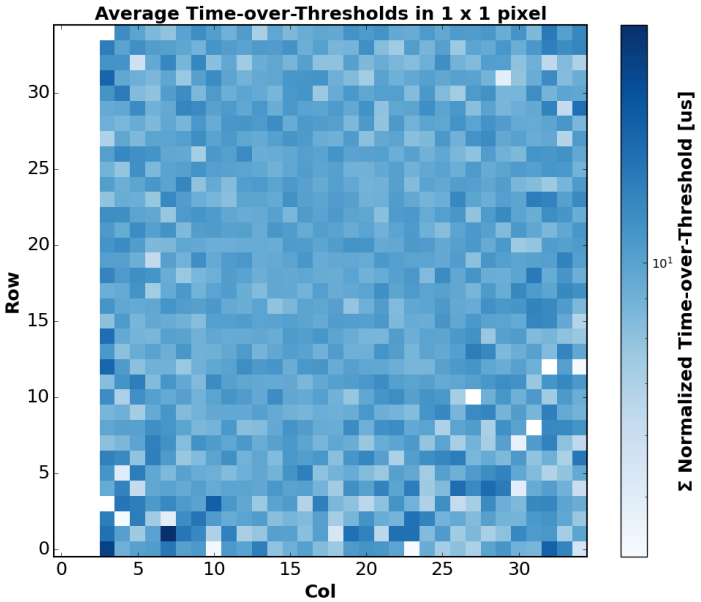




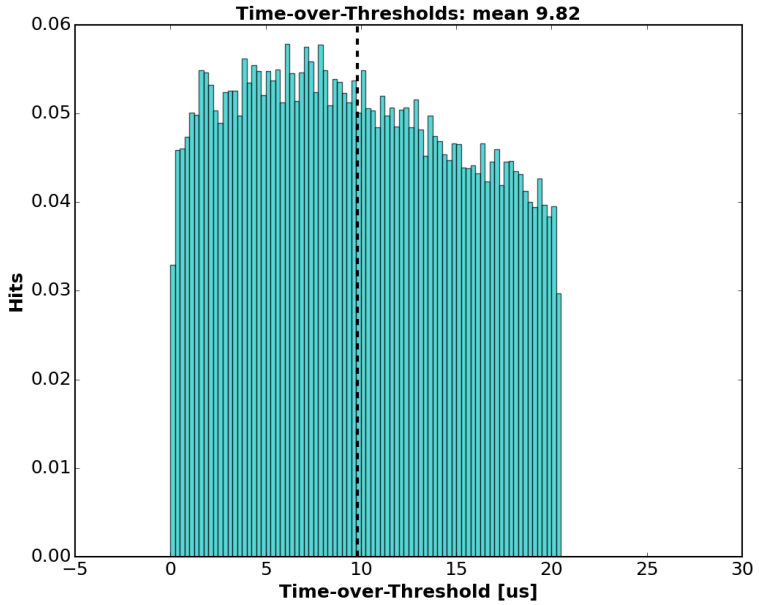
AstroPix v3 FTBF

APS3-W2-S03 - 120 GeV Proton

- Uniform pixel response for Minimum Ionizing Particle



Average ToT in Pixel array



ToT distribution

AstroPix v3 FTBF

APS3-W2-S03 - Voltage Bias Scan

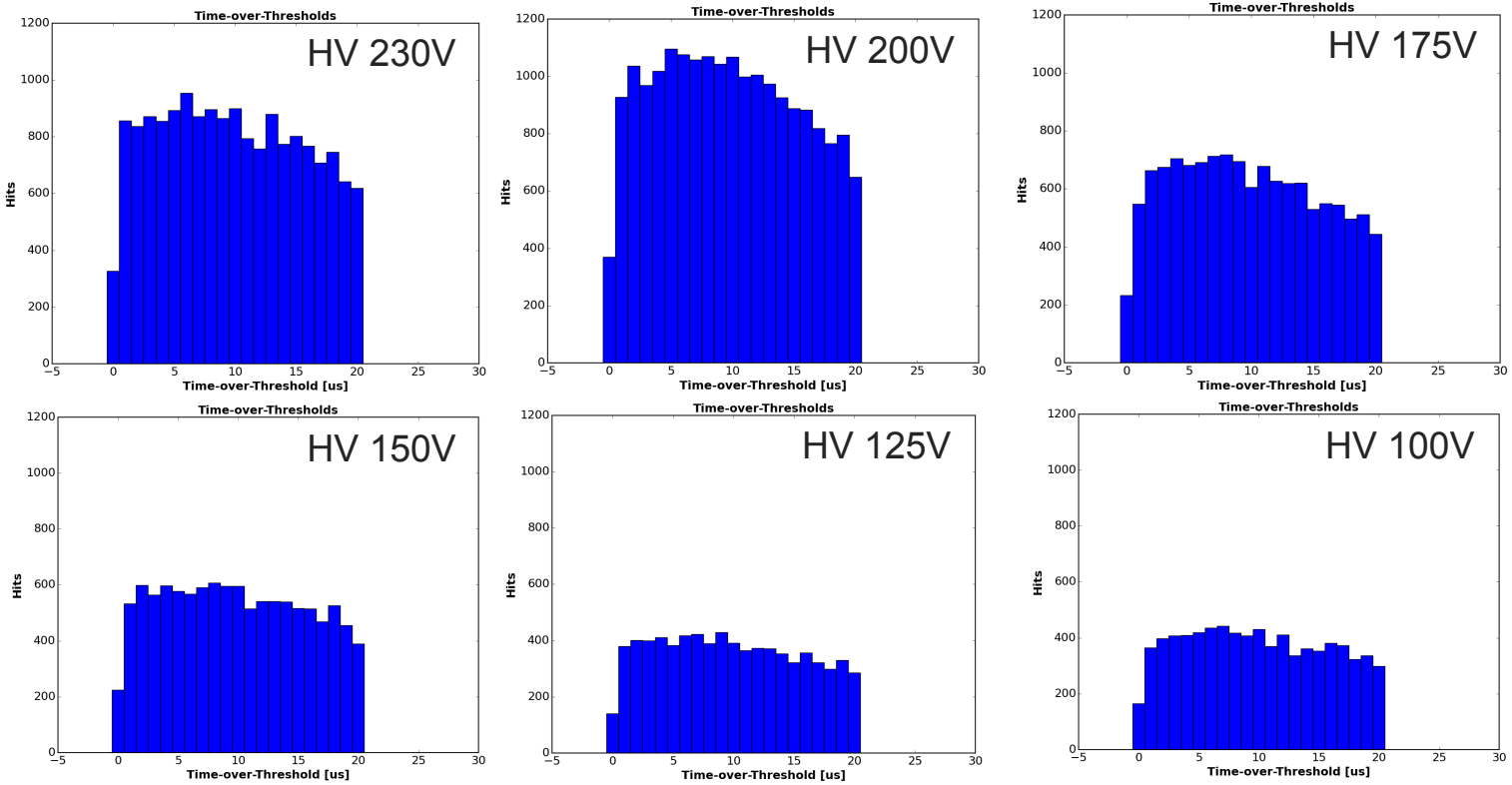
- 2 hours data-taking each scan

HV Bias Voltage [V]	$I_{measured}$ [nA]	Number of events (decodable [%])
230 V run# 74	52.8 nA	20,321 (51.74 %)
200 V run# 75	43.4 nA	14,669 (92.66 %)
175 V run# 76	41.9 nA	10,314 (97.54 %)
150 V run# 70	37.5 nA	9,206 (96.97 %)
125 V run# 77	34.0 nA	6,867 (98.97 %)
100 V run# 78	35.5 nA	7,028 (98.99 %)

AstroPix v3 FTBF

APS3-W2-S03 - Voltage Bias Scan

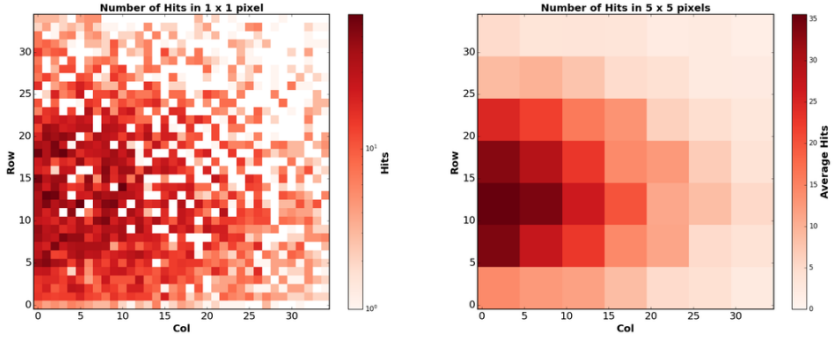
- 2 hours data-taking each scan



AstroPix FTBF

AstroPix v2 and v3 - 120 GeV Proton

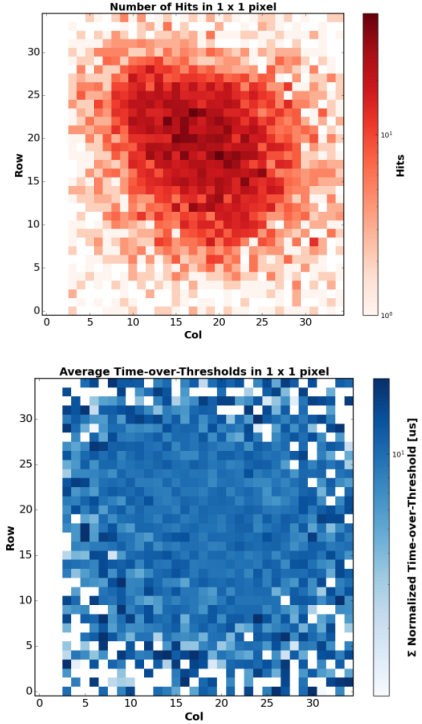
Feb and April 2023 - AstroPix v2 (1×1 cm², 250 µm pixel)



Beam spot hit maps

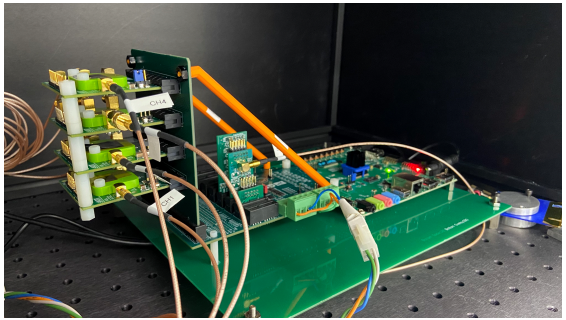
ToT hit maps

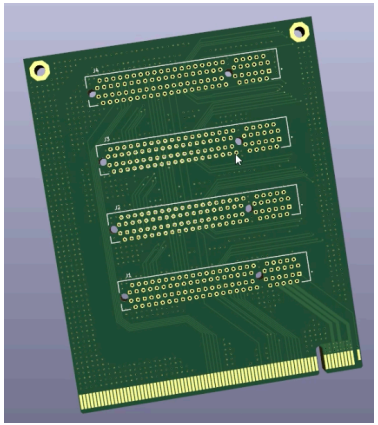
May 2023 - AstroPix v3 (2×2 cm², 500 µm pixel)

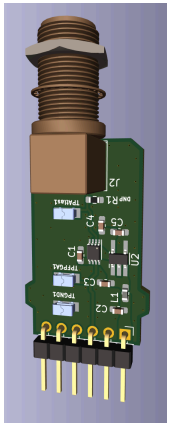


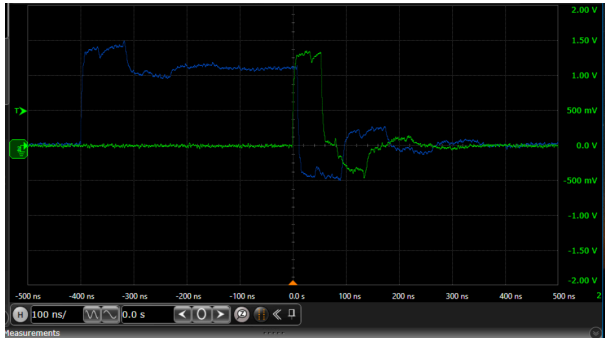
AstroPix FTBF - In Progress

- Goal
  - Trigger integration with ATLAS
  - Multilayer tracker
- Test-beam Campaign
  - Benchmark multi-layer tracker telescope
    - Multi-layer adaptor PCB - link
    - External trigger card - link
    - Firmware update onging



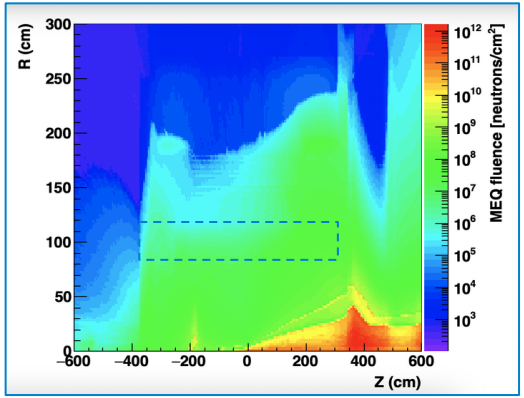






Irradiations Studies

- 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

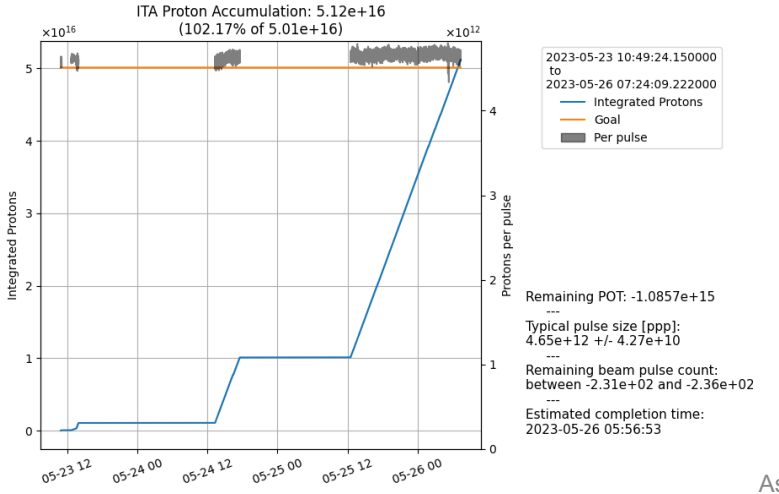


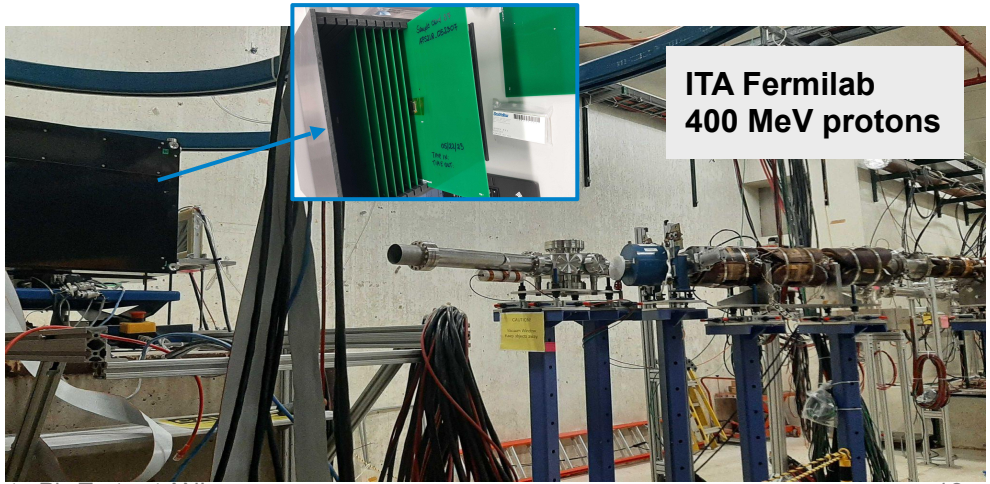
V2 Irradiation

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



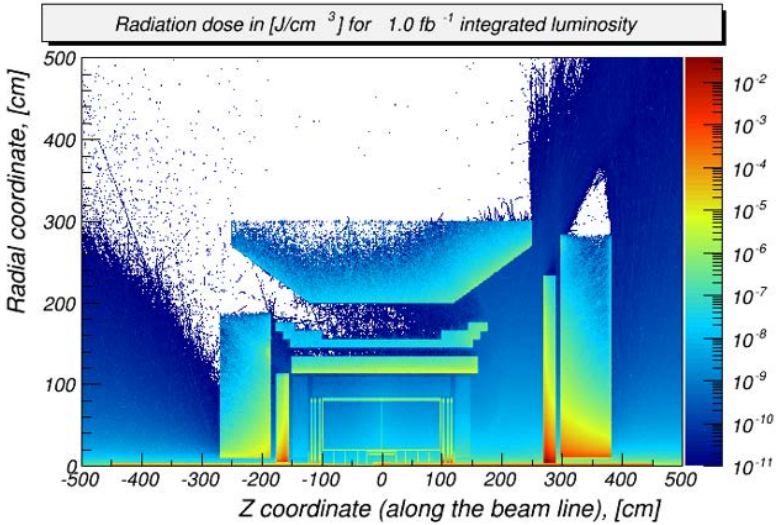


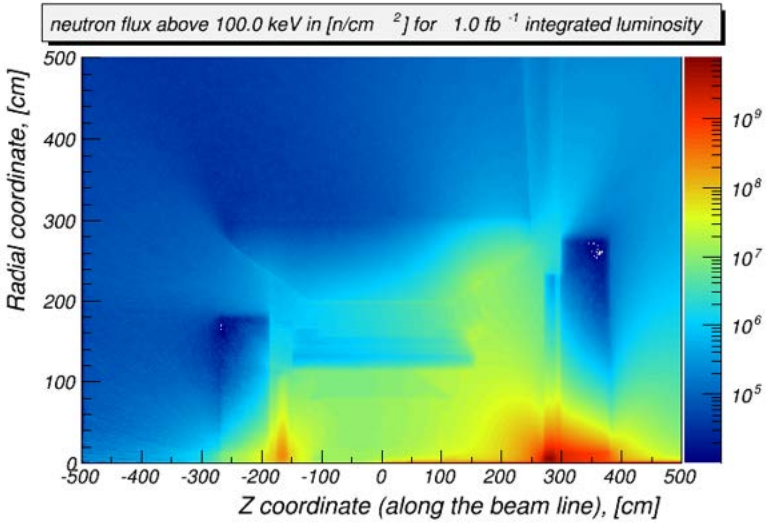
Summary

1. AstroPix chip performance studies with test beam
    1. DAQ with different triggering schemes, a benchmark set for the test with v3 chip ✅
    2. Initial data obtained with single layer setup with and without W-radiator, in self-triggering streaming data mode ✅
    3. Multilayer AstroPix standalone telescope with radiator layer 🚧
    4. External trigger from existing ATLAS telescope to study tracking efficiency, position resolution, etc. 🚧
    5. External trigger and multilayer readouts are being currently tested at FNAL MTest Facility 🚧
2. Irradiation test with v2 and v3 chips, irradiation plan tested
    1. v2 chip pre-irrad characterization and Irradiation performed at different radiation doses ✅
    2. Irradiation beam test Ongoing at FNAL MTA Facility 🚧
        1. Passive Irradiation of v2 chips is completed, v3 chip will be irradiated this week
        2. Active Irradiation of the v3 chip will be performed in the coming weeks

Backup

Ionization radiation and neutron flux





- Maximum ionizing radiation dose from e+p collisions at the highest EIC luminosity ($10^{34}cm^{-2}s^{-1}$): ~1 Rad/year
- Neutron flux: 10^8 neutrons/cm^2 per year at the top luminosity (two order of magnitude lower than the near-beam-line detectors)