

2026 EIC User Group Early Career Workshop

Recent Developments of the AstroPix Imaging Layers for the ePIC Barrel Imaging Calorimeter

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U.S. DEPARTMENT
of ENERGY

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Detector Requirements for Barrel EM Calorimeter

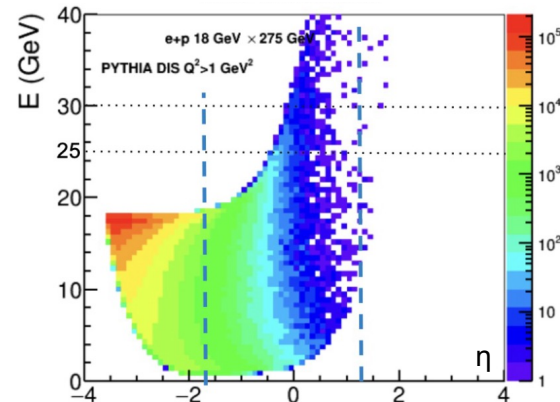


Identify scattered electrons and measure their energy, in high Q^2 events, also decay electrons, e.g. from vector or heavy flavor meson decays, and to measure DVCS photons and decay photons

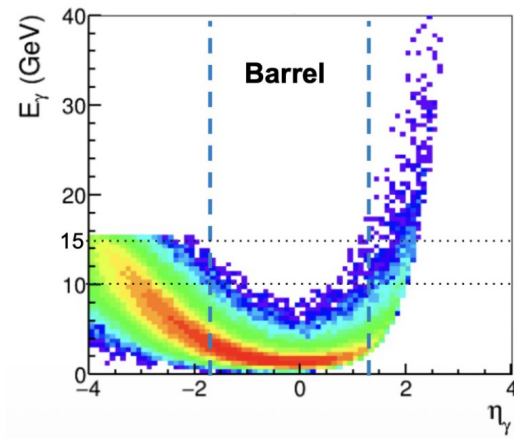
- **Electron ID up to 50 GeV** and down to 1 GeV and below
- Energy resolution $< 10\%/\sqrt{E} + (2-3)\%$
- High power for **e/π separation down to 1 GeV/c**
- **Photon measurements up to 10 GeV**
- **γ/π^0 separation up to 10 GeV**
- Assist with muon identification
- Sufficient dynamic range to **detect MIP signals** in all layers

<https://eic.jlab.org/Requirements/>

Deep Inelastic Scattering electrons



Deeply Virtual Compton Scattering photons



Barrel Imaging Calorimeter

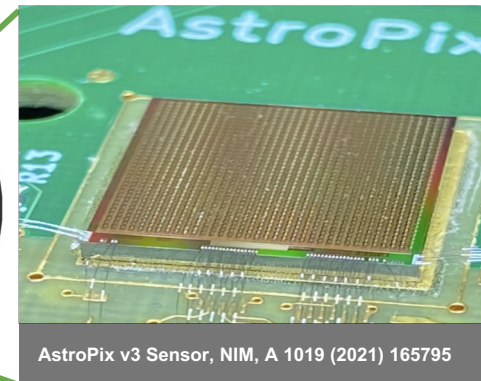
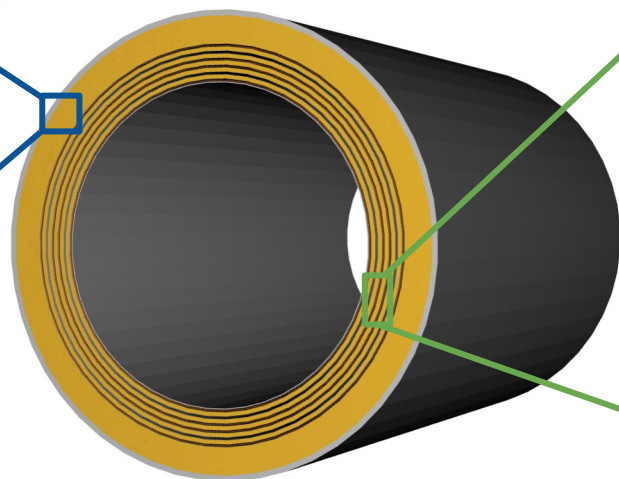
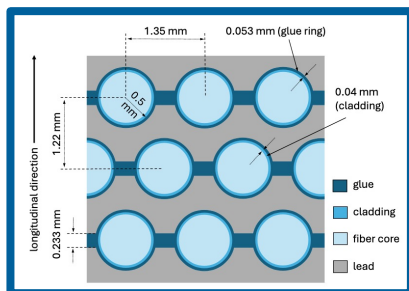
Combination of a high-performance sampling calorimeter with silicon sensors for EM shower profiling

Pb/SciFi sampling calorimeter with two-sided SiPM readout

Mature technology based on the GlueX/KLOE barrel calorimeters, with demonstrated detector performance

→ Energy resolution at GlueX: $\sigma = 5.2\% / \sqrt{E} \oplus 3.6\%$ [\[NIMA 896 \(2018\) 24\]](#)

→ 1.1cm/ $\sqrt{E}$ position resolution in z-direction [\[NIMA 596 \(2008\) 327\]](#)



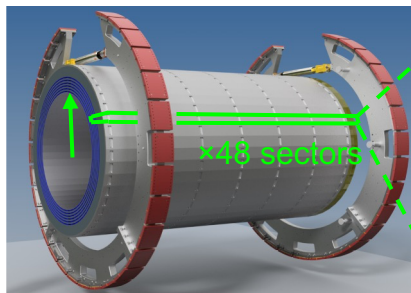
Imaging layers with **AstroPix** MAPS (Monolithic Active Pixel Sensor) in the first half of the calorimeter to capture a **3D image of the developing shower**

→ Developed for NASA AMEGO-X space mission [arXiv:2109.13409](#)

→ 500 μm pixel pitch ($\sim 144 \mu\text{m}$ intrinsic position resolution in z-direction)

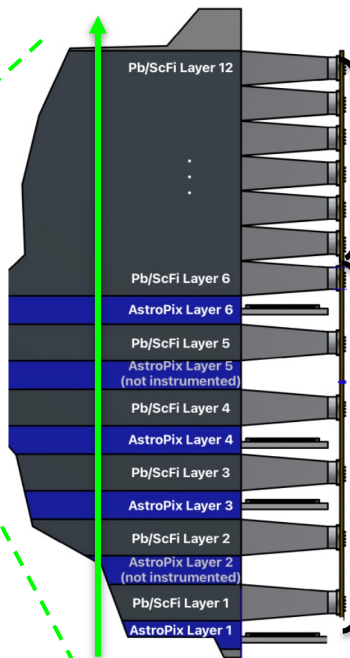
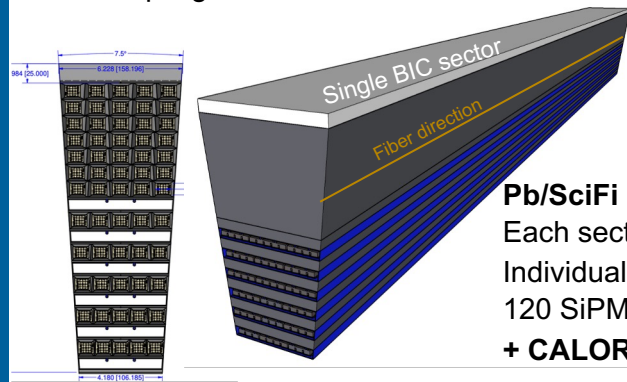
→ Good energy resolution (10% at 112 keV) and low power consumption

BIC Structure



BIC Detector Geometry

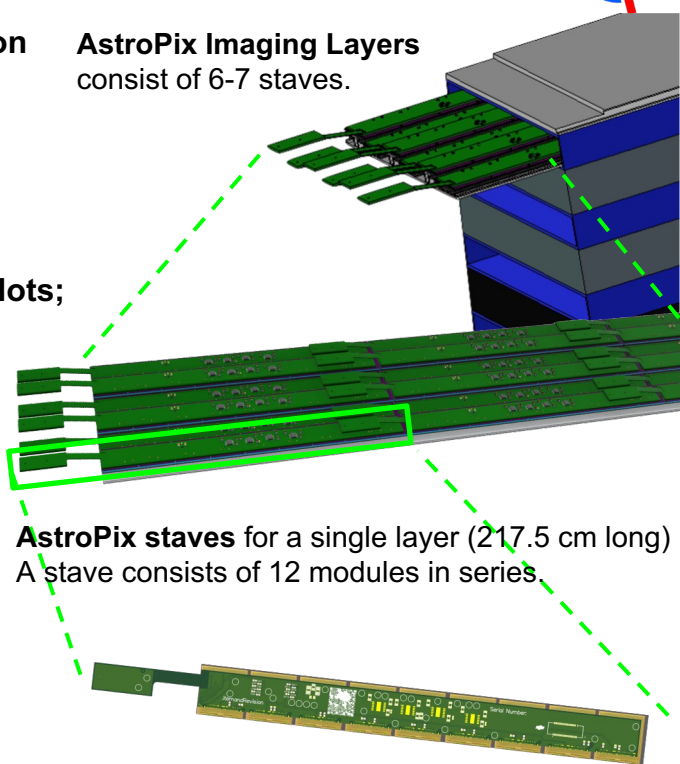
- Active Length: 435 cm
- Inner Radius: 82 cm
- η Range: $-1.71 < \eta < 1.31$
- Total thickness $> 17.1 X_0$ ($\eta=0$)
- Sampling fraction $\sim 10\%$



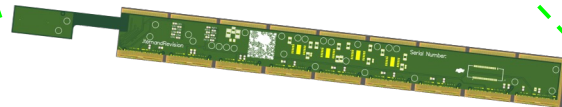
Large back section
of Pb/SciFi

6 imaging layer slots;
4 imaging layers
with AstroPix
interleaved with
5 Pb/SciFi layers

AstroPix Imaging Layers
consist of 6-7 staves.



AstroPix staves for a single layer (217.5 cm long)
A staff consists of 12 modules in series



AstroPix Module

9 AstroPix chips daisy-chained
on AstroLinx readout PCB

+ETC + FELIX

(End of Tray Card for AstroPix Readout)

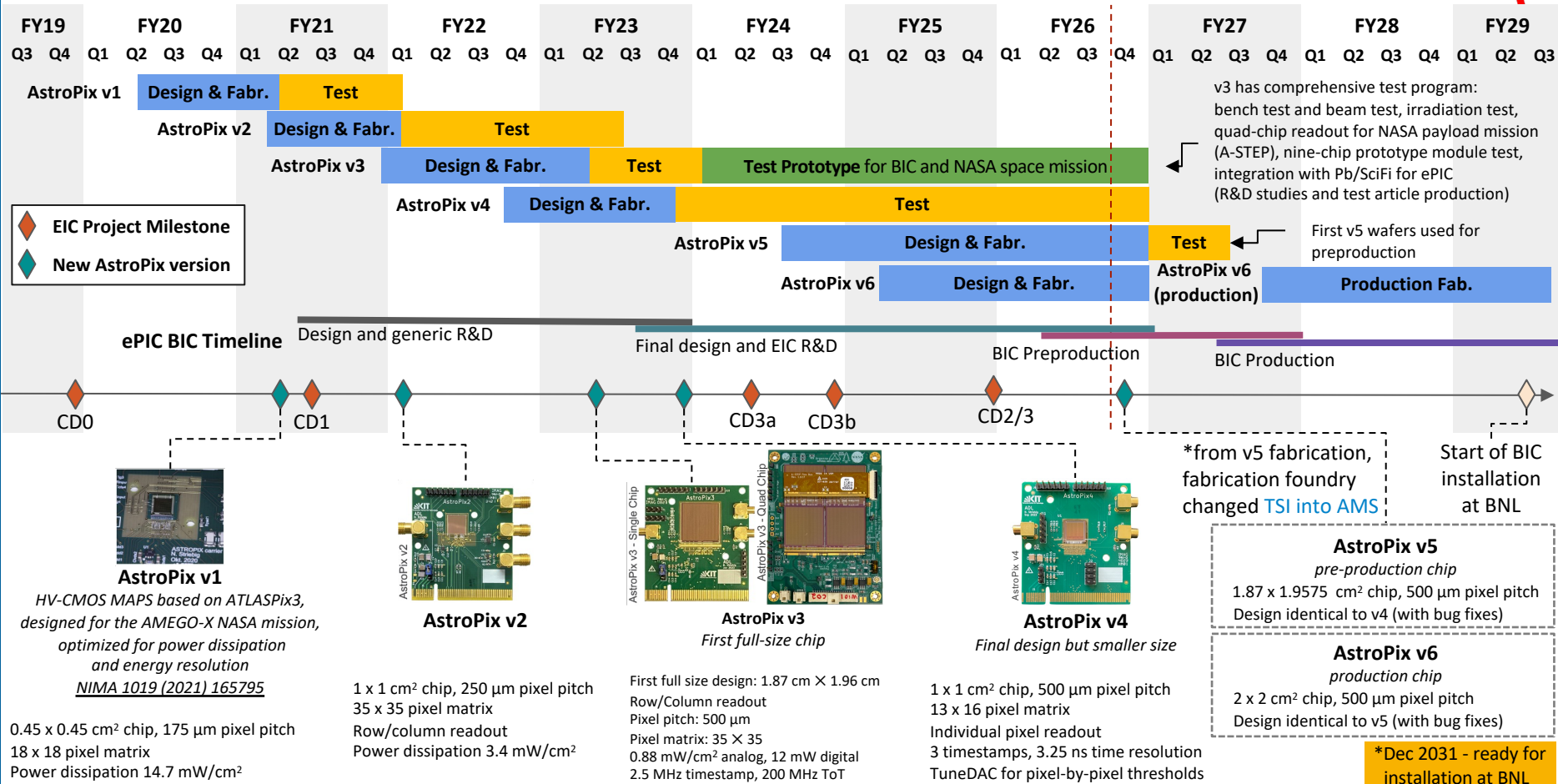


AstroPix Development Timeline

Not shown:

Early CD4 (Oct 2032)

CD4 (Oct 2034)



AstroPix Key Performance



For Final Chip Version in AMEGO-X and BIC

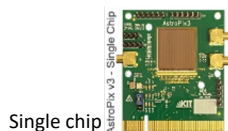
	AstroPix for AMEGO-X requirements [arXiv:2208.04990]	BIC requirements	Status (AstroPix v3)
Pixel pitch	500 μm x 500 μm		.
Power usage	< 1.5 mW/cm ²	~ 2 mW/cm ² in v5 acceptable	4.1 mW/cm ²
Energy resolution	< 10% (FWHM) @ 112 keV		.
Dynamic range	25 - 700 keV		25-200 keV
Passive material	< 5% on the active area of Si	not applicable	
Time resolution	1 μs	20 ns (in v5 acceptable)	
Si Thickness	500 μm Fully depleted		~ 130 μm depleted

AstroPix Imaging Layer R&D Milestones



- AstroPix chip performance characterization
- AstroPix Multilayer/Multichip demonstration
- First beam-test operation of the 9-chip AstroPix prototype module (AstroLinux mock-up)
- Integration between H2GCROC (Calorimeter readout) and A-STEP board (AstroPix readout) using external common clock

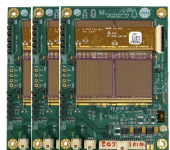
AstroPix v3



Single chip



Quad-chip

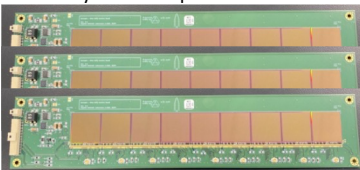


Three-layer of
quad-chips

9-chip prototype PCB module



Three-layer of 9-chip PCB modules



AstroPix v4



AstroPix v5: Chip delivery is expected in Oct. after the fabrication process.
+ ETC (Final AstroPix readout system)

Configuration of AstroPix v4	AstroPix readout	#.Chip	Status
Single chip	GECCO board	1	✅ bench/beam tests (KEK, Dec.2025)
Configuration of AstroPix v3	AstroPix readout	#.Chip	Status
Single chip	GECCO board	1	✅ bench/beam tests (FNAL, Jun.2024) arXiv:2602.06084
Three-layer of single-chips	Three GECCO boards + customized DAQ	1x3	✅ beam tests (CERN & KEK, 2025 summer) by Korean team arXiv:2605.07681
Quad-chip	A-STEP FPGA board	2x2	✅ bench/beam tests (KEK, Dec.2025)
Three-layer of quad-chips	A-STEP FPGA board	3x(2x2)	✅ bench/beam tests (KEK, Dec.2025)
9-chip prototype PCB module	A-STEP FPGA board	1x9	✅ bench test/beam tests (KEK, May.2026)
Three-layer of 9-chips	A-STEP FPGA board	3x(1x9)	Ready to test; (beam test in Aug.2026)
Three-layer of quad-chips + Three-layer of 9-chips	Two A-STEP FPGA boards + external clocks	3x(2x2) 3x(1x9)	Ready to test; (beam test in Aug.2026)

AstroPix Imaging Layer R&D Milestones

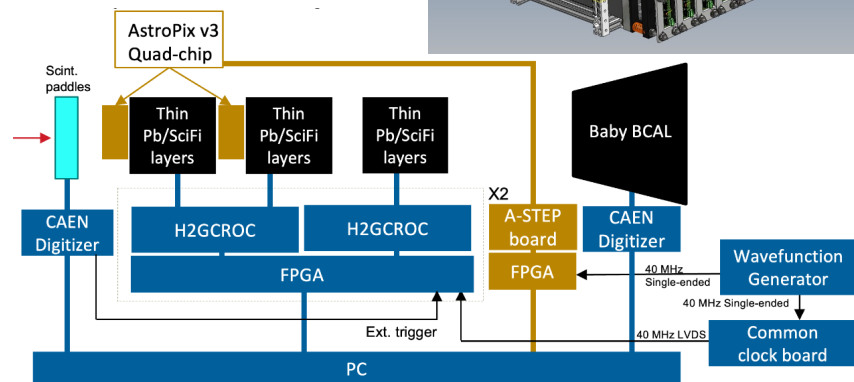
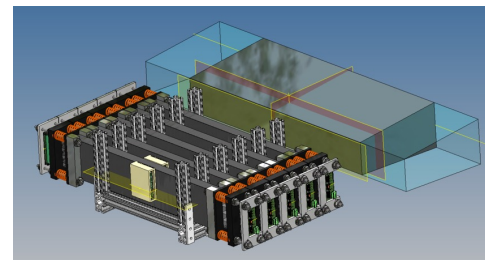
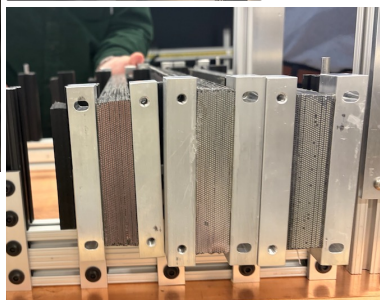
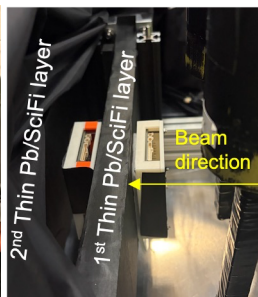
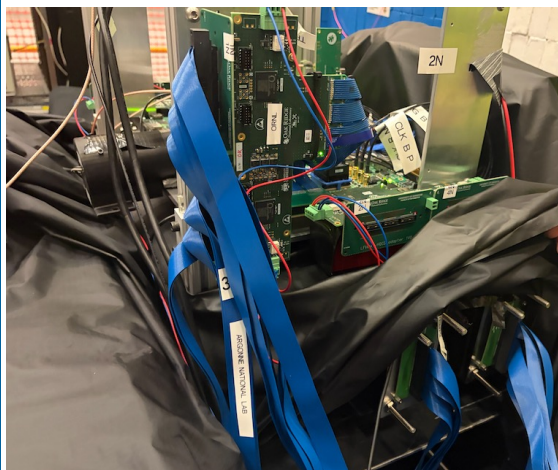


- AstroPix chip performance characterization
- AstroPix Multilayer/Multichip demonstration
- First beam-test operation of the 9-chip AstroPix prototype module (AstroLinux mock-up)
- Integration between H2GCROC (Calorimeter readout) and A-STEP board (AstroPix readout) using external common clock

System Integration

- Synchronization of H2GCROC/CALOROC and A-STEP/ETC readout systems
- Common-clock operation for calorimeter and AstroPix readout using FPGA timestamps for event synchronization.

→ First integration of the Pb/SciFi and AstroPix readout systems under beam conditions at the [2026 Hall D beam test](#).



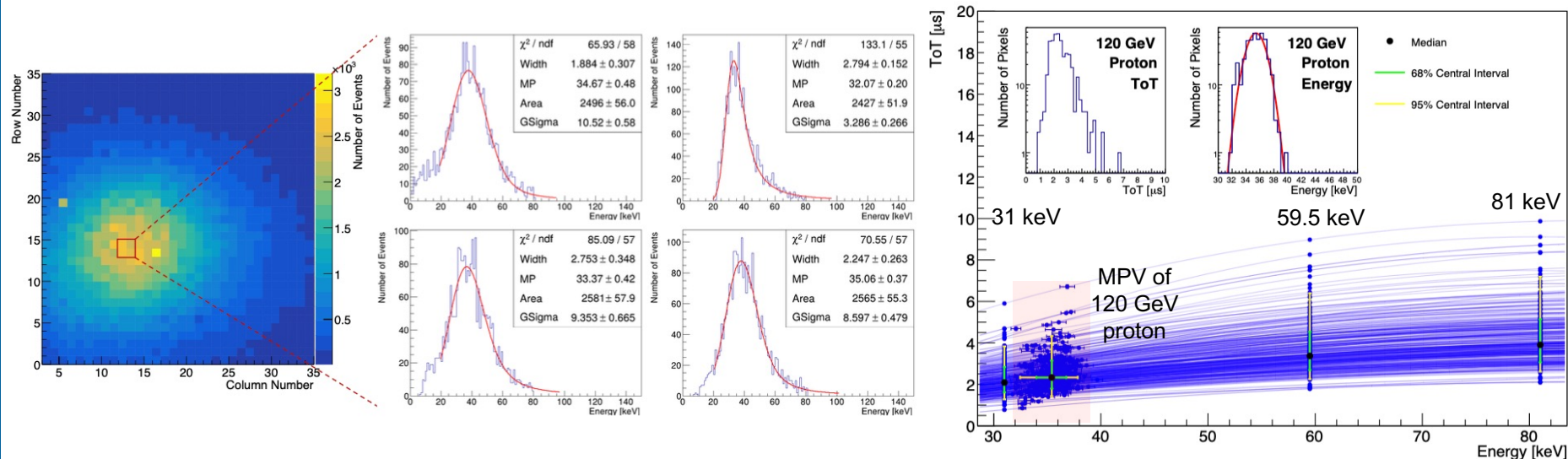
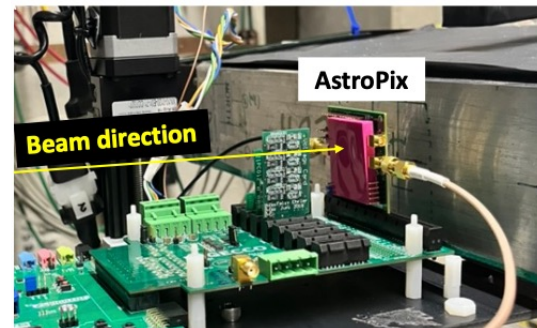
Beam Test Result at FTBF 2024

AstroPix v3 single chip with 120 GeV proton beam

B. Kim, ArXiv: 2602.06084,
Accepted to NIMA (Jul. 9, 2026)



- First 120 GeV proton response
- MIP response within dynamic range (25 keV~200 keV)
- All distributions are well described by a Landau–Gaussian convolution
- MPV of MIPs across all pixels = 34 ± 1.9 keV,
corresponding to the effective depletion depth $\sim 128 \pm 8$ μm

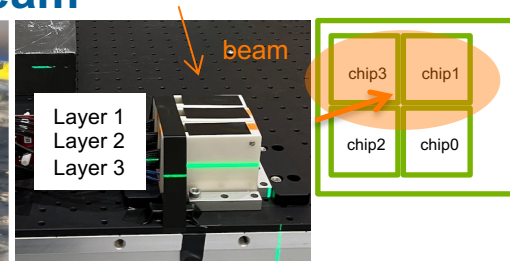


→ AstroPix v3 meets EIC requirement for MIP detection with sufficient dynamic range.

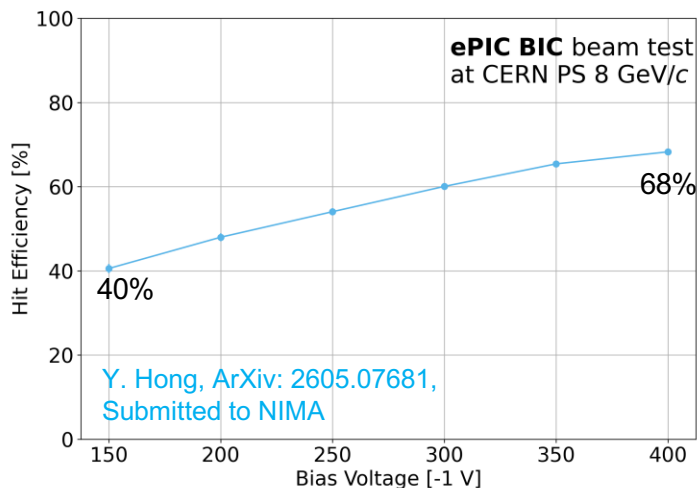
Beam Test Result at KEK/CERN 2024/2025



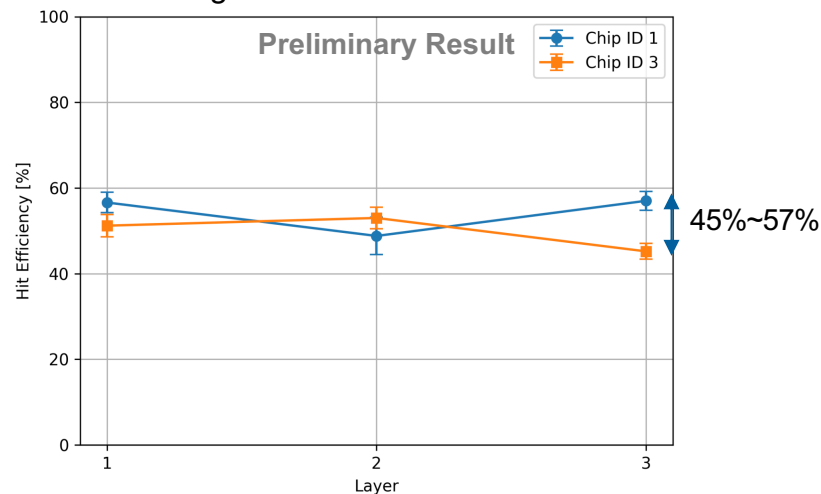
Three AstroPix v3 single chips and quad-chips with e- beam



- Hit efficiency as a function of bias voltage (-150 to -400 V) with three AstroPix single-chips



- Hit efficiency per layer using three AstroPix quad-chips
Bias voltage = -150V

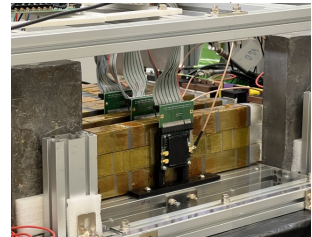


→ AstroPix v3 shows hit efficiencies of 40–68%, and further improvements are expected in AstroPix v5.

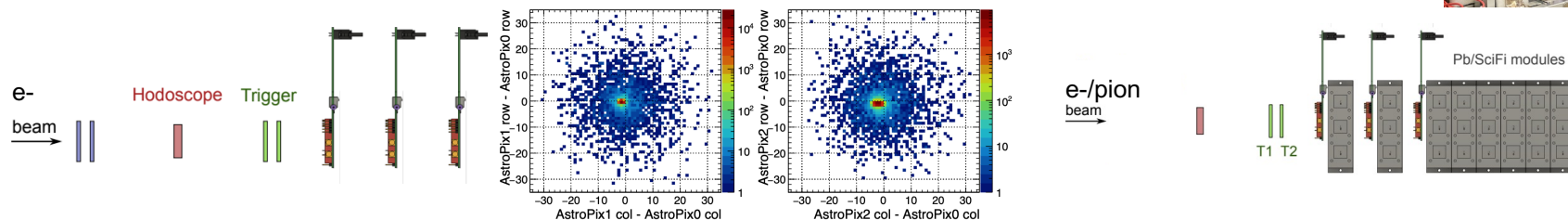
Beam Test Result at KEK/CERN 2025

Y. Hong, ArXiv: 2605.07681,
Submitted to NIMA

Three AstroPix v3 single chips interleaved Pb/SciFi modules

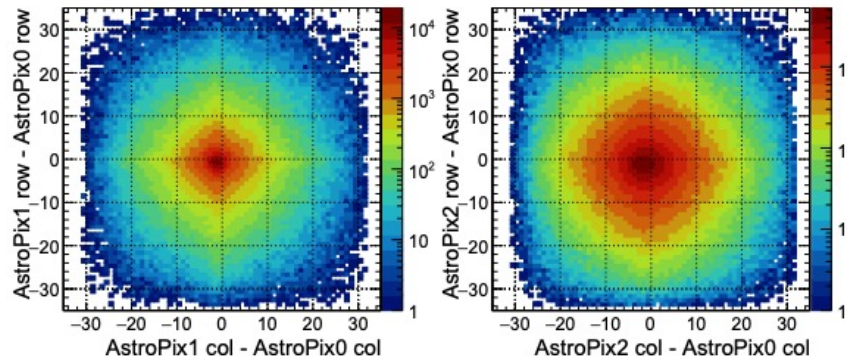


- Goal: investigated the capability of AstroPix to measure EM shower development

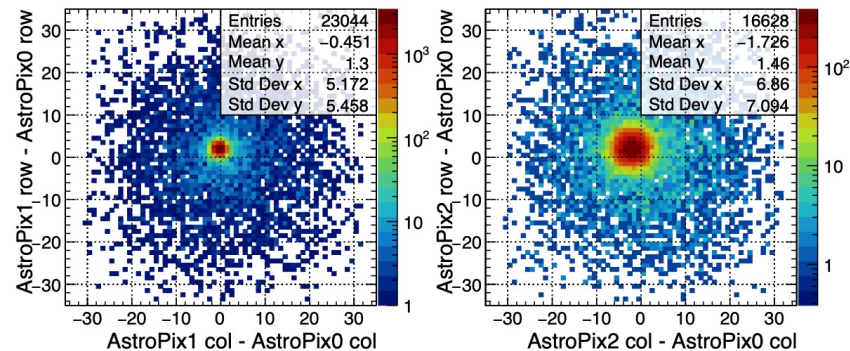


- Position residuals between the first (reference) AstroPix-v3 layer

AstroPix+Calo@4.5GeV electron beam



AstroPix+Calo@2GeV only hadrons



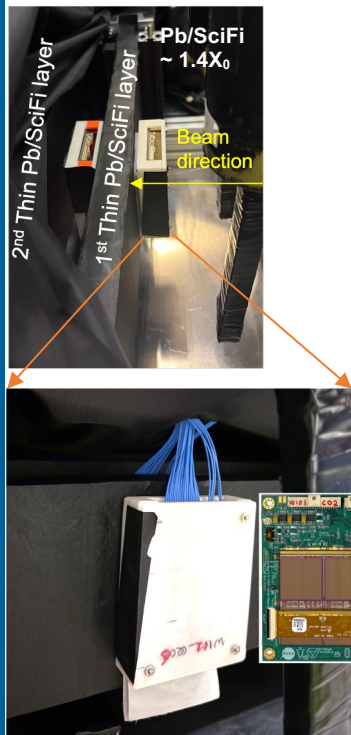
→ AstroPix measurements provide a quantitative characterization of EM shower development.

→ Distinct position residual patterns are observed for electrons and pions, providing discrimination power between them.

Beam Test Result at Hall D 2026

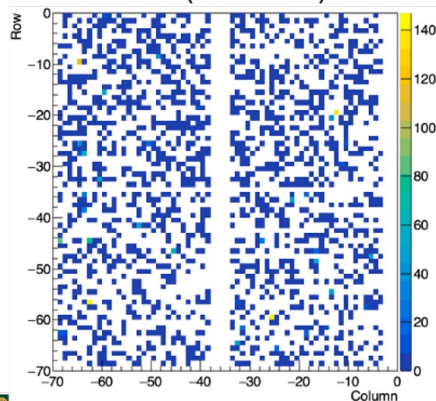
Two AstroPix v3 quad chips interleaved Pb/SciFi modules

- Confirmed the stable operation up to ~ 1.2 kHz beam rate at KEK beam test last year; **promising stable operation under Hall D beam conditions.**

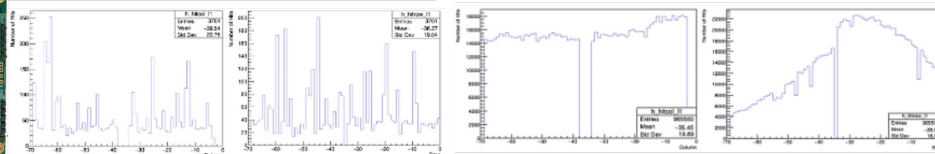
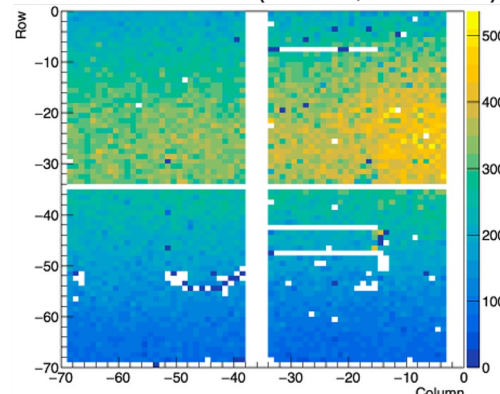


- 1st layer of AstroPix quad-chip: beam profile

- No beam (cosmic run)



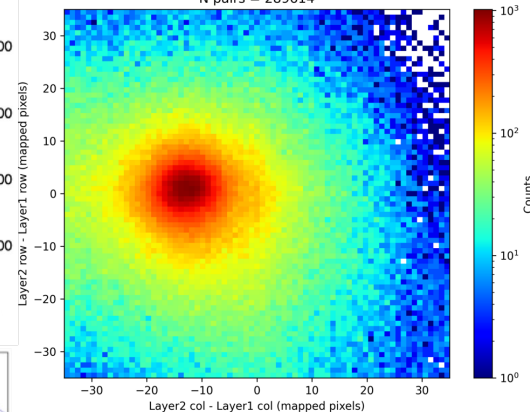
- Run1318 – 1324 (Total 61,416 events)



- Position residual plot

500 MeV electron @ hall D

Combined Layer2 - Layer1 Position Residual
TOT ≥ 100 , [timestamp diff] ≤ 1 , $0 \leq dt_cfpga < 20.0$ us
N pairs = 289614



Work In Progress

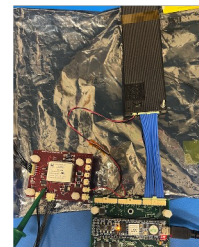
→ The quad-chips shows a position residual pattern consistent with the single-chip measurements.

9-chip Module: Bench Test Result

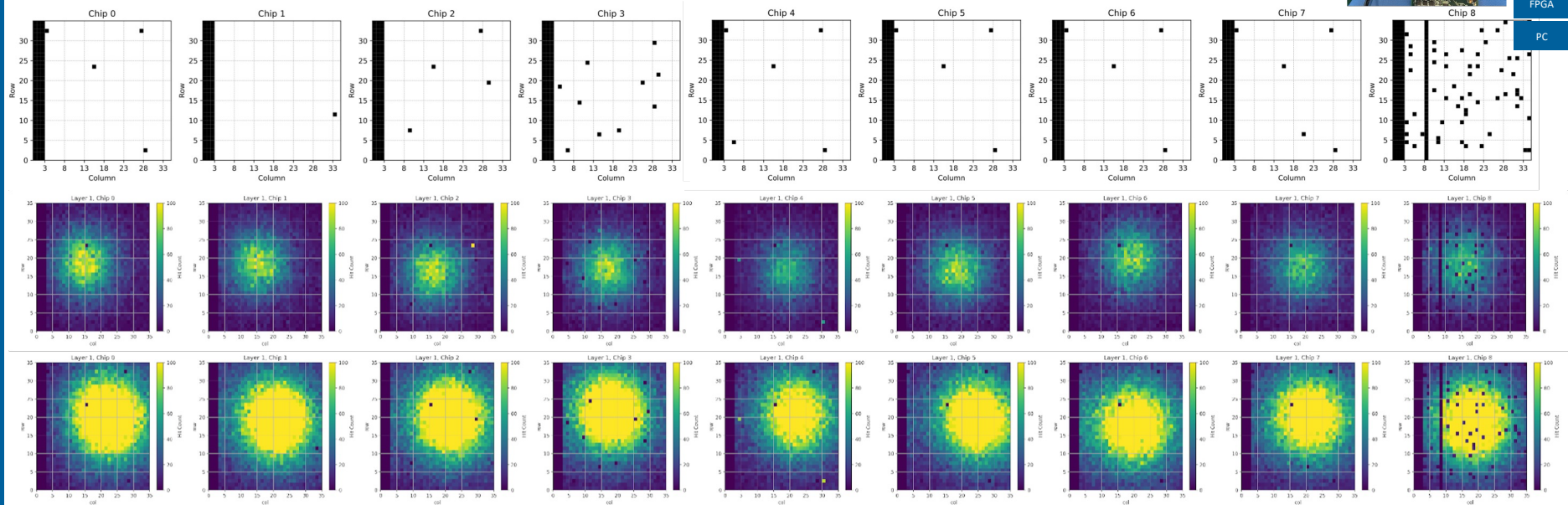
B.Kim,
PoS(VERTEX2025) 031, 2025



- Benchmarking electric design of AstroPix Module for BIC: proof of concept with module readout design (mock up of AstroLinx)
- Noise scan** - pixels with noise rate ≥ 1 Hz were masked
 - Achieved 99% active pixel yield** for all chips (except chip 8: 91.9%)
- Source test with Sr-90**
 - Results consistent with v3 single-chip performance, confirming proper operation



ASTEP
-HW
FPGA
PC

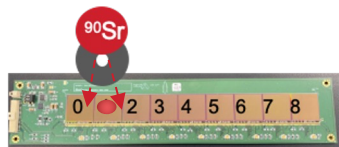


→ Demonstrated stable operation and validated daisy-chained readout of the prototype module.

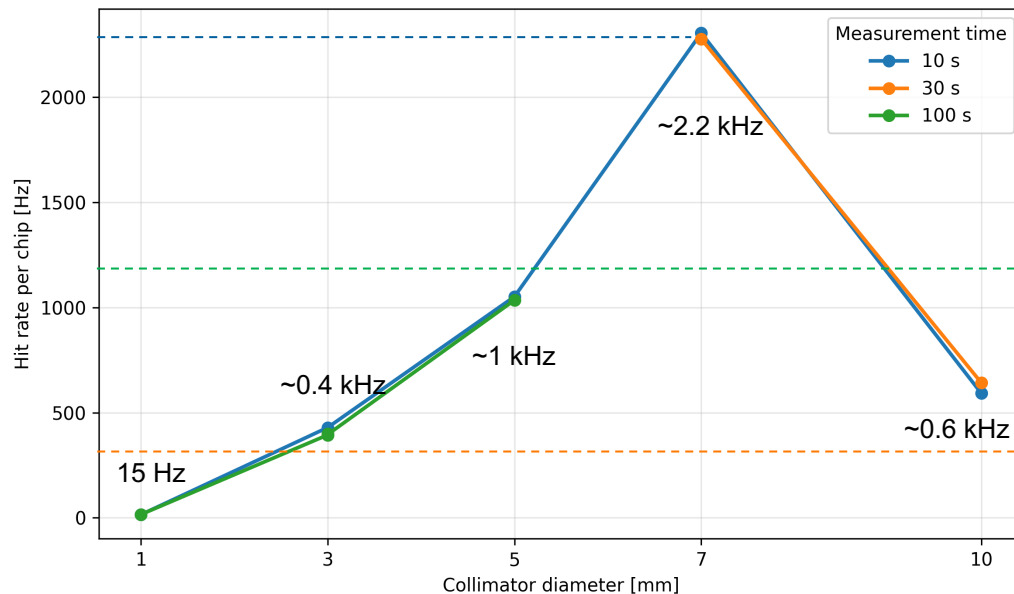
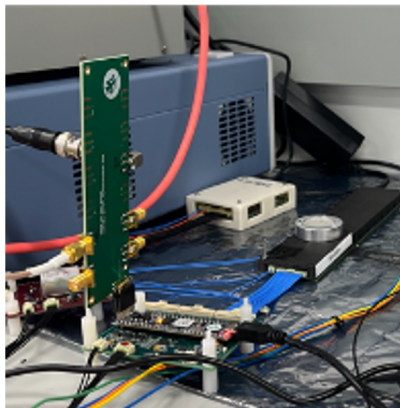
9-chip Module: Data Rate Results

- Goal: Validate the capability to read out data from the 9-chip prototype with the current setup (w. larger buffering margin)
- Maximum hit rate with the current setup:
 - **Per 9 chips:** ~2.5 kHz
 - **Per chip:** ~2.2 kHz

Saturation limit with collimators > 7 mm,
where stable data-taking is no longer possible.



Collimator: 3/5/7/10/16 mm diameters



~1.18 kHz per chip:
Max. expected data rates
for imaging layers,
taking into account DIS,
electron, and proton beam
backgrounds

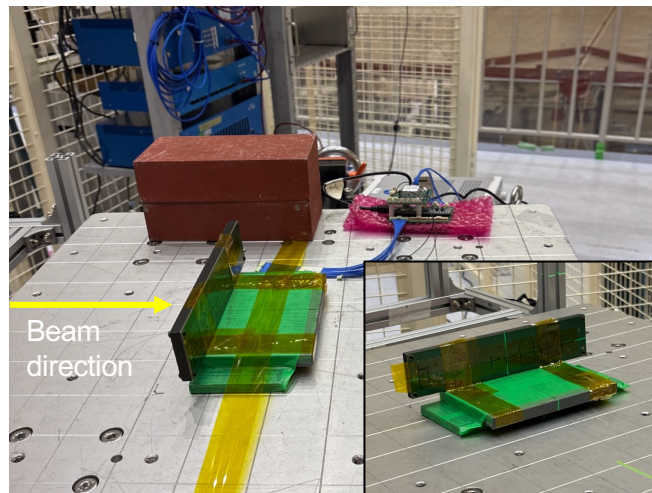
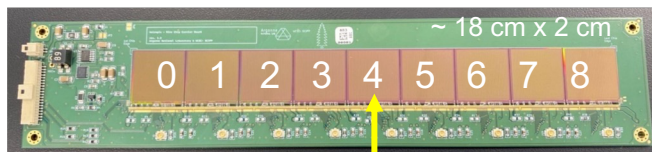
~285 Hz per chip:
Avg. expected data rates
for imaging layers

- The per-chip measurement on the 9-chip prototype, under the current setup, meets imaging-layer data-rate.
- Operation in realistic beam conditions is promising: ~2.2 kHz per chip is expected on ~2–3 chips.

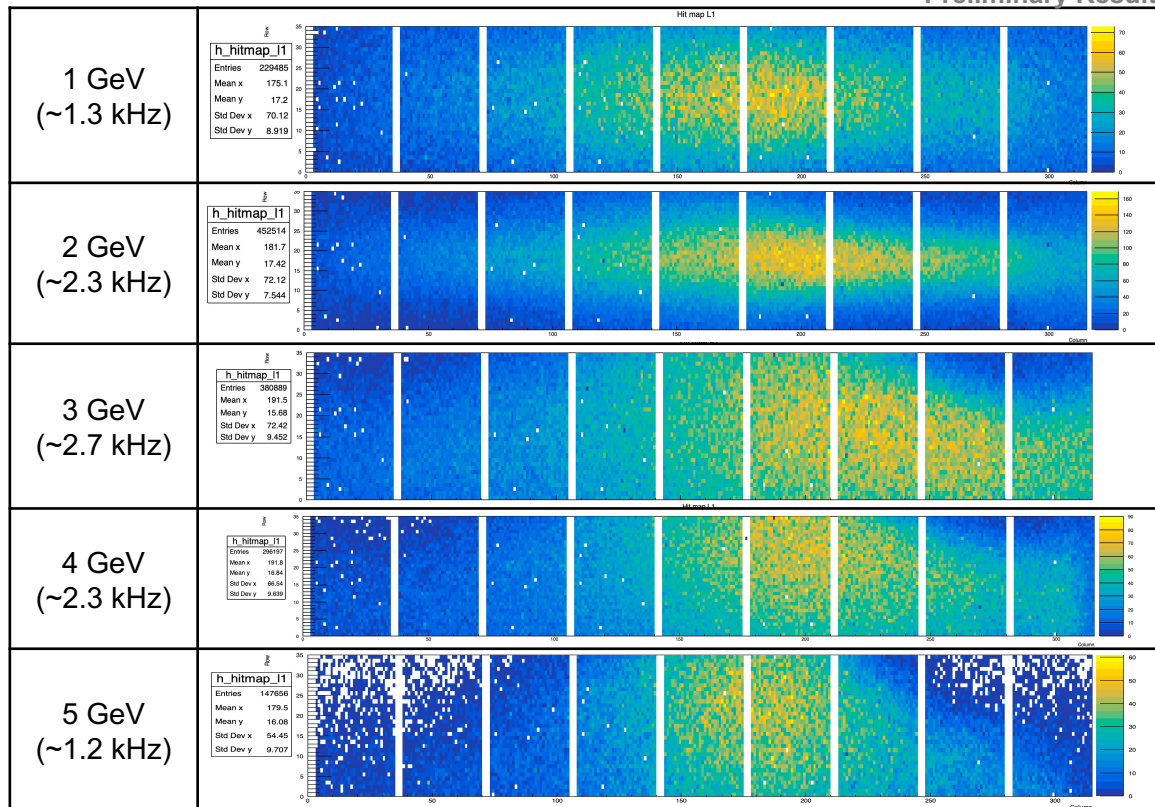
9-chip Module: Beam Test Result at KEK 2026

Operational verification under beam conditions

Preliminary Result



- Electron beam energies 1–5 GeV
- Stable data-taking up to a **2.7 kHz beam rate**

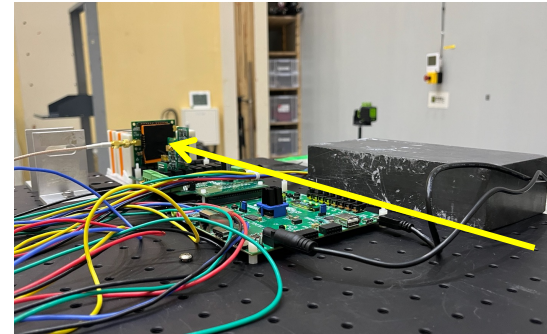


→ The first beam test of the 9-chip prototype module showed stable operation up to 2.7 kHz beam rate.

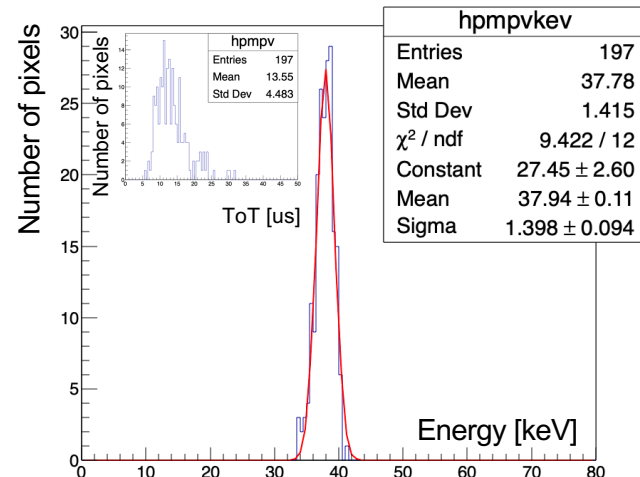
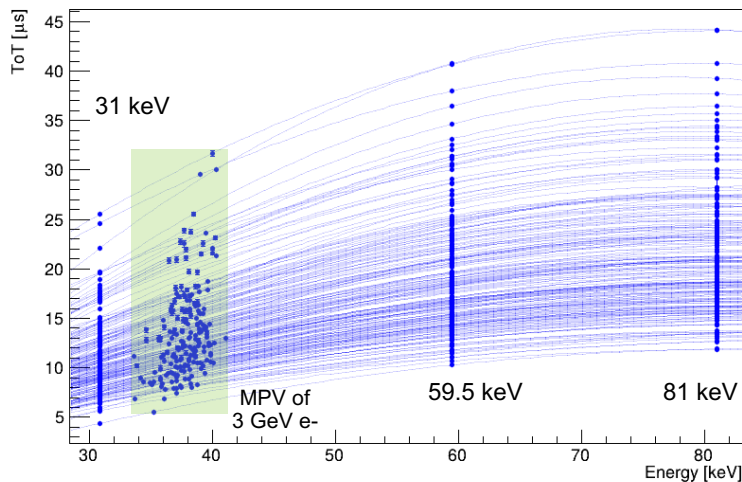
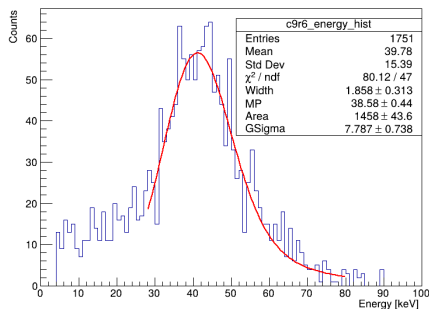
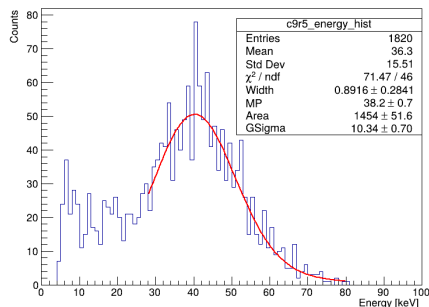
AstroPix v4 Single-chip Test Result

Beam test at KEK in Dec.2025

- **92.8%** pixels of AstroPix v4 sensor: Total 203 pixels (13 x 16 pixel matrix) except for 5 masked pixels
- MIP response within dynamic range using 3 GeV electron beam
- Energy distribution per pixel fitted with Landau convoluted with Gaussian function
- MPV of MIP = 37.9 ± 1.4 keV, corresponding effective depletion depth of 142 ± 5 μm



Manuscript in preparation

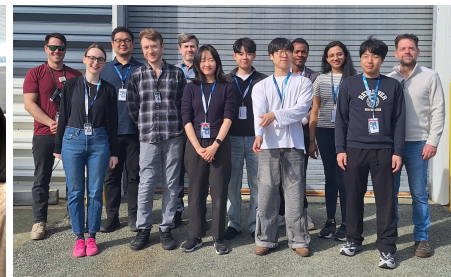


→ AstroPix v4 meets EIC requirement for MIP detection with sufficient dynamic range.

Summary & Plan



- The ePIC BIC **meets EIC requirements** with a **compact, high-performance design**, combining **Pb/SciFi calorimeter** and **AstroPix imaging layers** for **3D shower** imaging, based on mature GlueX and NASA AstroPix technologies.
- Successfully characterized the single-chip performance of both AstroPix v3 and v4 and demonstrated the scalability of the imaging layers through progressively larger multi-chip and multi-layer configurations.
- FY25 PDR successfully completed, with demonstrated Pb/SciFi performance, AstroPix performance, and validated Pb/SciFi + AstroPix system testing.
- For Final Design Review, FY26 beam tests planned at Jefferson Lab Hall D, KEK and CERN.
- System-level beam tests will integrate Pb/SciFi layers with H2GCROC (CALOROC) and multi-chip, multi-layer AstroPix systems with A-STEP (ETC), focusing on synchronization and 3D shower imaging.



Thank you