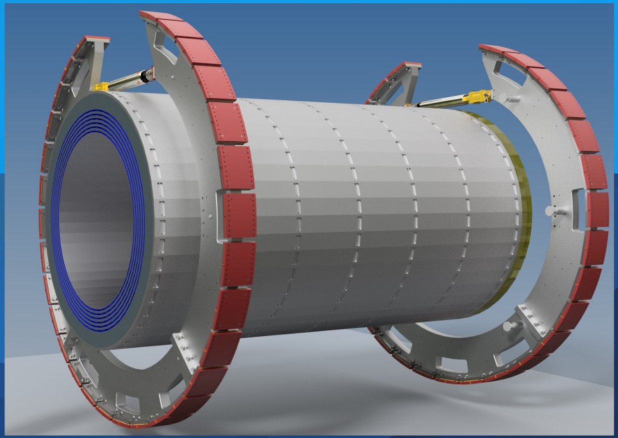
BIC Status Update



Sanghoon Lim
Pusan National University

BIC Project Phases

PED: Preliminary Design → PED: Final Design → Preproduction → Production

Preliminary Design Review
Sept 17/18 2025

Final Design Review
Spring/Summer 2026

Need CD3 approval to start production articles
2027/2028 Production Readiness Review

Ready for installation
~Dec 2031

- Preliminary Design Review, 60% design completion
- AstroPix v3 (and v4)
- BabyBCal & Lanky BCal
- Individual components
- First (second) test articles

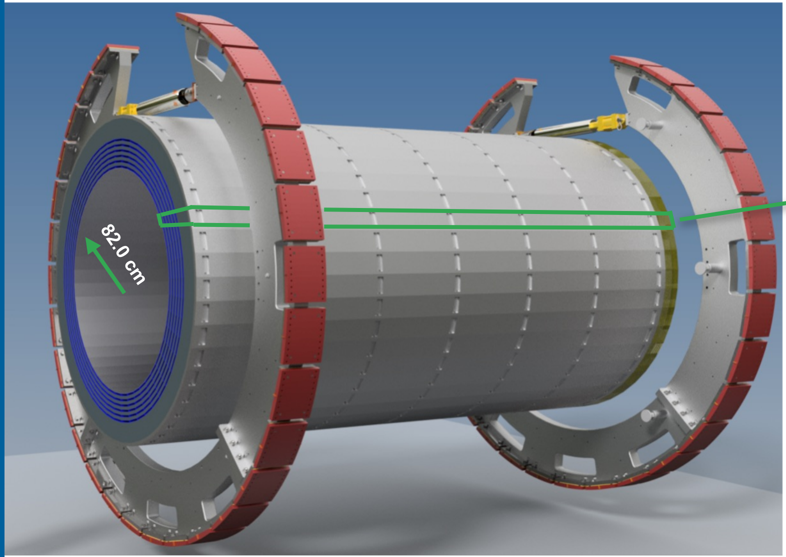
- AstroPix v5
- One full sector
- Final designs (90%)
- Production style procedures
- AstroPix v6 validation tests

- AstroPix v6
- 48 sectors

2

Barrel Imaging Calorimeter

Sector Mechanics

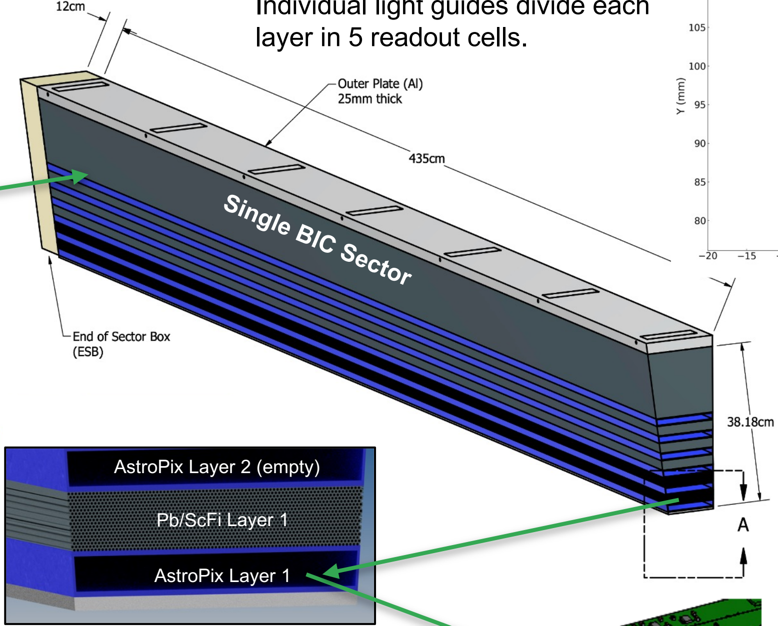


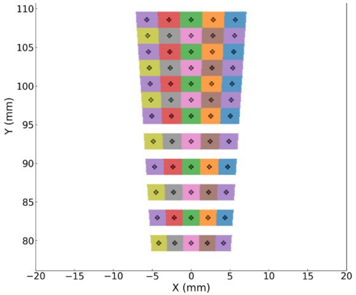
Total BIC weight ~42.5 US tons

Pb/SciFi Layers - 17 rows of fiber between corrugated lead.

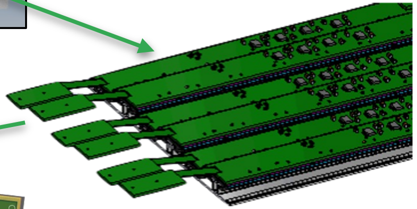
Each sector has 12 Pb/ScFi layers.

Individual light guides divide each layer in 5 readout cells.





SiPMs - 5 per layer x 12 layers = 60 (Hamamatsu S14161-3050)

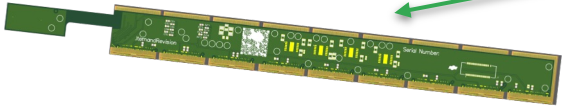


Tray - Structure holding the AstroPix staves for a single layer (217.5 cm long).

AstroPix Module - Nine AstroPix sensors daisy-chained together on Flex PCB.

A stave consists of 12 modules.

A tray contains of 6-8 staves.



Summary of Design and Test Articles Status

BIC Design Completion		Concept	Preliminary Design	First Test Article	Final Design
Sector Mechanics	Scintillating Fibers (CD3a/b)	✓	✓	✓	✓
	Pb/SciFi Matrix Construction	✓	✓	✓ Short matrix	End of 2025
	Carbon Fiber Frames	✓	✓	Short Frame Oct 2025	
	Sector Construction	✓	✓	Short Multi-layer Nov’25	
	Tracker Tray	✓	✓	Dec 2025	
	Tracker Module Base	✓	✓	✓	
Tracker: AstroPix Modules	AstroPix	✓	✓	✓ (v3)	✓ (v5)
	Wafer/chip probing	✓	✓	December 2025	Summer 2026
	AstroLinx	✓	✓	October 2025	
	AstroPix Module	✓	✓	Nov 2025	
	Stave/Tray	✓	✓	Apr 2026	
End-of-Sector Box (ESB) & DAQ	Lightguides	✓	✓	✓	
	SiPM's (CD3a/b)	✓	✓	✓	✓
	CALOROC readout	✓	✓	✓ (H2GCROC)	(CALOROC) 2027
	End-of-Tray Card	✓	✓ (ComPair FPGA)	Contract delay	
	Electrical Services	✓	November 2025	March 2026	Spring 2026
	Cooling	✓	November 2025	February 2026	
	ESB Test Article	✓	✓	April 2026	
System Test	Integrated System Tests	✓	✓	✓ (BabyBCal + SFILs + Chip/Module)	Summer 2026

Sectors and Mechanics

Design constraints defined and mostly frozen; geometries and envelopes documented; BIC and Project engineers aligned.

Design challenges: self-supporting sector with ePIC integration; FEA in progress using delamination data at CF–Pb and Pb/SciFi interfaces.

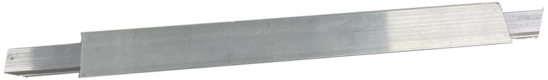
Sector test articles:

- 0.5 m GlueX-style matrix reproduction completed, critical equipment commissioned. SciFi QC procedure established.
- Short bulk Pb/SciFi with GlueX fibers and CF-frame integration ongoing
- Long 3 m article next; full-scale 4.35 m sector for preproduction targeted for 2026

AstroPix tracker mechanics: staves integrated into trays → modules slide onto trays → trays slide into sector drawer/slot.

- First extruded-aluminum mechanical article built and tested for tolerances and stability

Pb/SciFi matrix build and tested at ANL



First tracker test article - module base with stave like railing

Upgraded swager inherited from U. Regina fully operational

Press frame @ Argonne in our new sector production space (5500 sq ft)

Mechanical risks are under active test with a defined path to full-scale sector in 2026. First test articles of tracker support and SciFi matrix tested.

Wafers and Modules

Chip testing scope

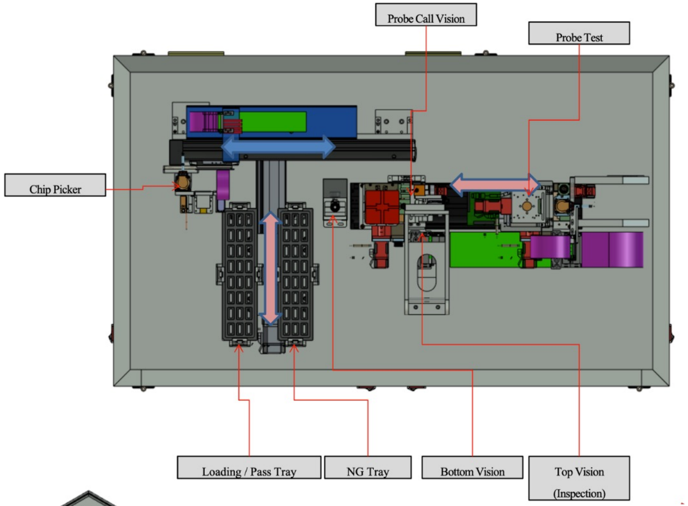
- **Scale:** 31,104 modules, 279,936 AstroPix chips.
- **Need:** automated chip-level testing before module assembly with established QC procedures.
  QC coverage: sensor bias with HV, analog and digital checks, injection scans for relative energy calibration.

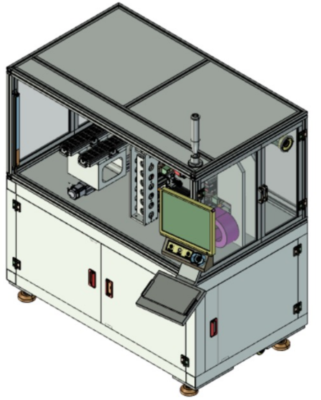
v3 Pilot (this fall → 2025 Q4)

- **Probe card:** simple v3 card for the carrier board, built with a Korean manufacturer; uses validated GECCO + FPGA setup; leverages ALICE experience
- **Throughput target:** validate the QC flow on ~80 v3 chips this fall
- **Automation:** single-chip v3 test machine from C-ON Tech due 2025 Q4 to run initial validation, refine the test flow, document the full chain, and deliver qualified v3 chips for prototype modules

Preproduction (v5/v6, FY26-FY27)

- **Design update:** v5 ready in FY26 for preproduction
- **Process readiness:** finalize procedures and acceptance criteria





Single-chip v3 test machine is under production by C-ON tech in Korea

We are moving from a validated v3 pilot to a preproduction workflow for v5/v6, establishing throughput, traceability, and acceptance criteria needed to de-risk delivery of 280k+ chips for 31k modules.

Wafers and **Modules**

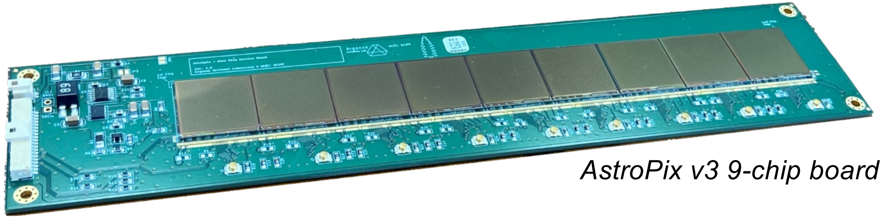
Scope: single-flavor module for more than 30,000 units

AstroLinx (PCB): optimized for module performance, meets required operation specs; first design completed and reviewed. Expected this fall; another iteration anticipated.

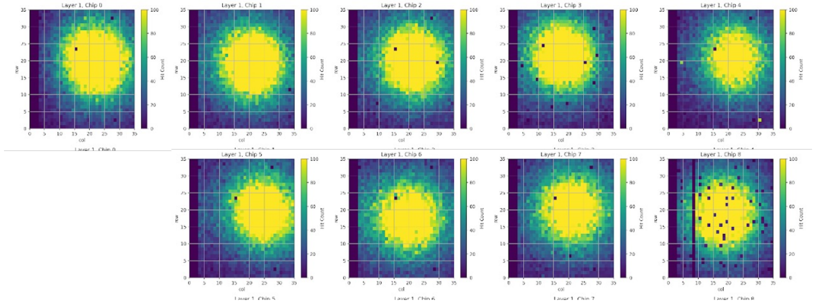
9-chip PCB test article: In hand to mock up AstroLinx, verify power-distribution stability and daisy-chain readout. Successfully tested on a bench with sources.

Module builds: plan to assemble about six prototypes this fall using an extruded aluminum base, AstroPix v3, and AstroLinx; test PCB designed to validate electrical performance; initial base-plate prototype produced to define assembly steps.

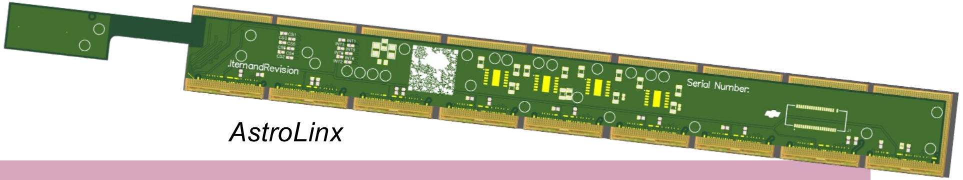
Open design items: base-plate locking mechanism, adhesive selection, flex-PCB connector finalization



AstroPix v3 9-chip board



Daisy chain readout through 9 chips with source scan



AstroLinx

AstroLinx has been reviewed and the 9-chip PCB validated with sources; we are proceeding to module test articles to lock performance and assembly while closing the few remaining design choices for preproduction.

ESB (End of Sector Box) and DAQ

Function: on-detector power distribution and data collection. Encloses cooling and provides mechanical protection.

Interfaces with ePIC: integration procedure nearly final; service requirements provided (electrical cabling, cooling, DAQ).

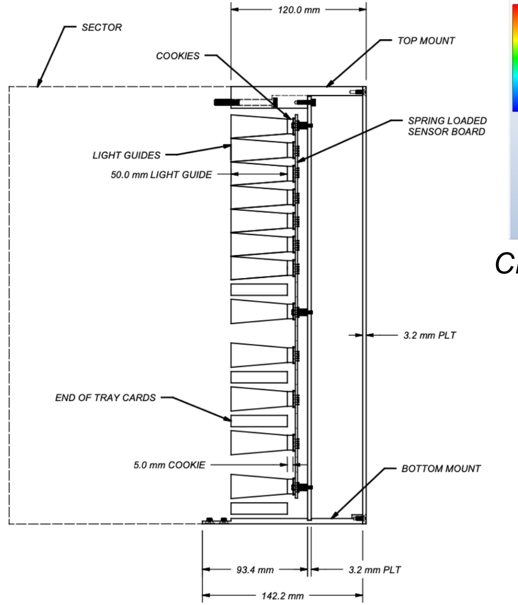
Thermal/mechanical validation: Ongoing: development and construction of PCB (thermal) test article to validate CFD calculations.

SiPM readout path: CALOROC → common RDO → FELIX.

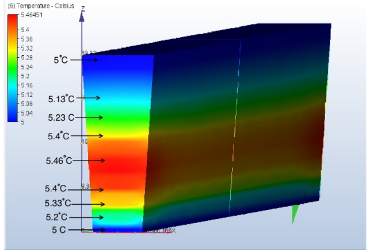
- Lightguides design complete, geometry fixed.
- CALOROC design under submission; evolution of HGCROC with CMS and ALICE heritage.
- SiPMs passed FDR at CD-3a/3b.

AstroPix readout path: End-of-Tray Card (ETC) → FELIX.

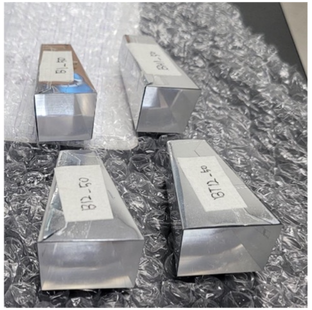
- ETC to be designed by NASA GSFC; start pending contract processing; leverages existing AstroPix FPGA board designs.



ESB Envelope



CFD Calculations Performed



LG test articles validated

ESB envelope and interfaces nearly finalized; CALOROC at submission; ETC awaits contract start, with existing designs reducing risk. SiPM design completed. Lightguides and cookies nearly finalized.

System Testing

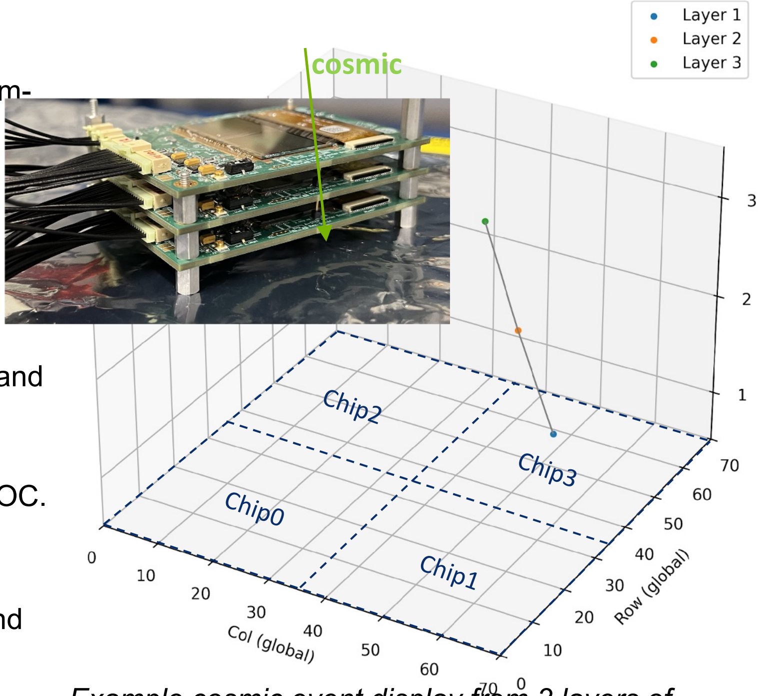
Function: validate system-level performance and design, establish system-level QC/QA procedures.

AstroPix imaging layers: multichip and multilayer test articles to demonstrate daisy-chaining, synchronization, and energy, position, and timing response; bench and beam tests completed.

Pb/SciFi calorimetry: Bulk (~15.5 X_0) and SFILs (~1.5 X_0) tested with e and π beams, validating energy response and e/π separation in the Pb/SciFi section; simulations benchmarked.

- **ANL-built SFILs:** first units show good MIP response with HGCROC.

Large-scale integration (PED, PREP): readout and large-test-article integration underway to validate system-level performance, calibration, and QC/QA at the AstroPix Tray and Sector levels; outputs will also inform component-level QC procedures.



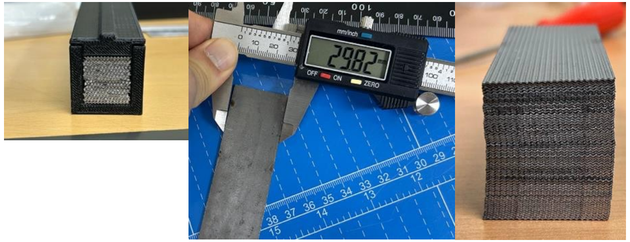
Example cosmic event display from 3 layers of daisy-chained AstroPix v3 quad chips

The testing program de-risks the design and defines system QC/QA for production; current validations confirm calorimeter energy performance and rate capability, and validate the simulation against data.

Activities in Korea

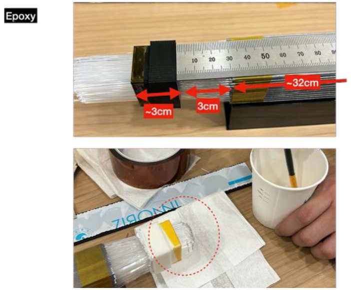
Pb/SciFi Prototype Module Production

1) Pb plate preparation

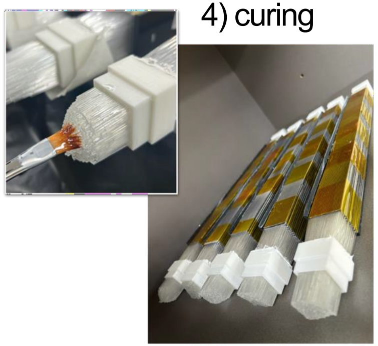


2) Stacking with fiber

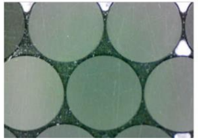
3) Cutting fiber



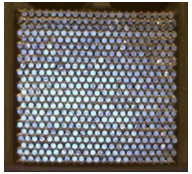
4) curing

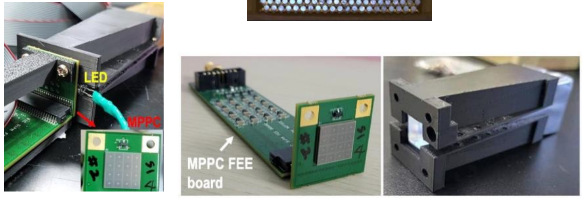


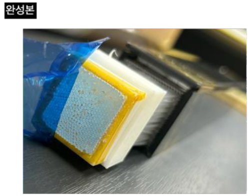
5) polishing

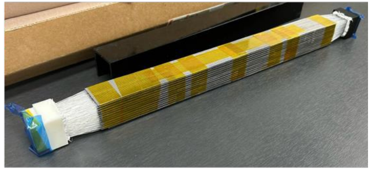


Produced 33 of 32x3x3 cm^3 unit modules for beam test

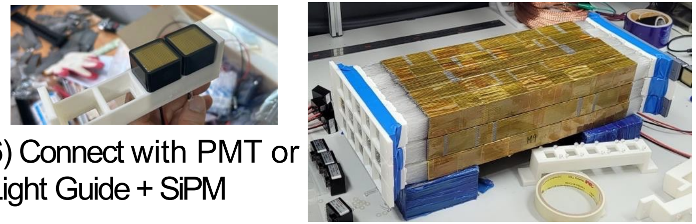






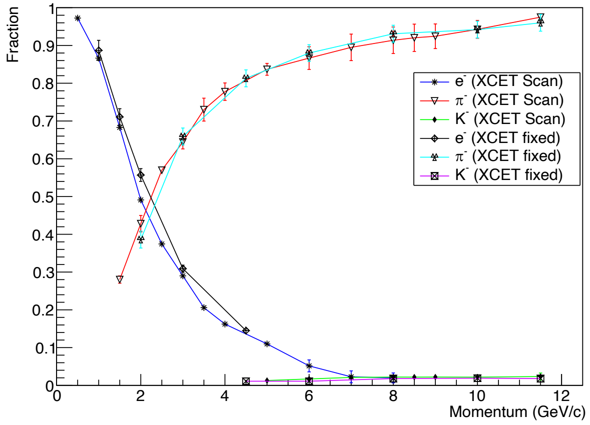


6) Connect with PMT or Light Guide + SiPM

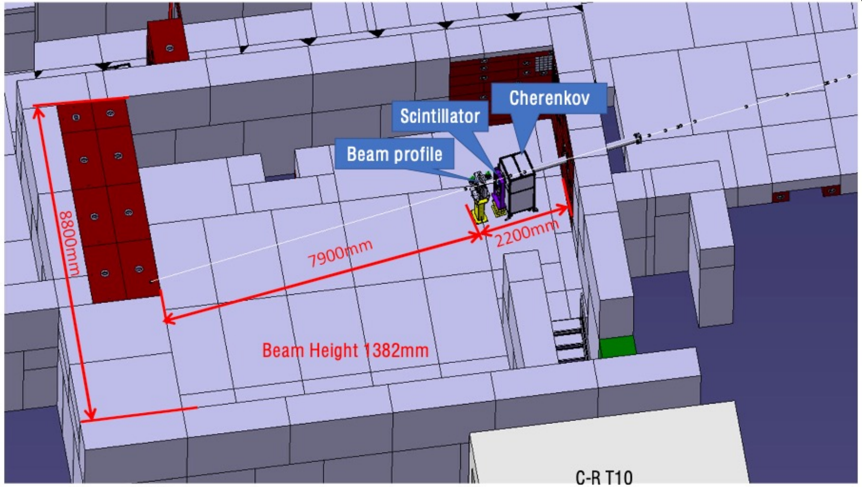


Recent beam test at CERN PS T10 in July 2025

Parameter	T09 Target	T10/T11 Target	
Beam Line	T09	T10	T11
Secondary beam Max Momentum (GeV/c)	15	11.5	3.5
Δp/p (%)	±0.7 to ± 15.0	±0.7 to ± 15.0	±0.7 to ± 15.0
Maximum intensity/spill (hadrons/electrons)	$\sim 10^6$	$\sim 10^6$	$\sim 10^6$
Available particle types	Pure electrons (T09) or mixed/pure hadrons or pure muons		

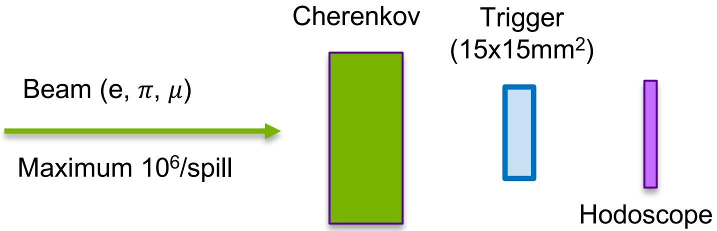


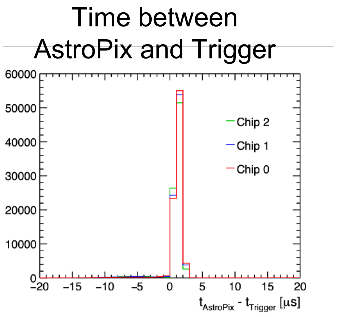
T10 (neg) beam composition (arXiv: 2507.02567)

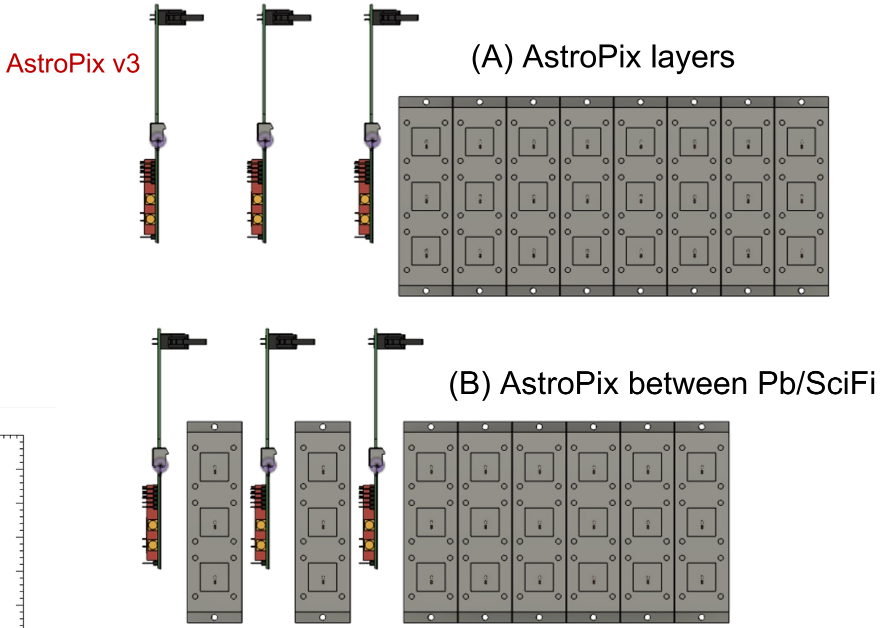


Mixture of electron, pion, etc., fraction changes in momentum
Muon beam available.
Particle identification with two Cherenkov Counters
An expert can adjust focus and rate.
At T10 in July 2025, the trigger (10x10mm) rate was 2.7kHz during the BIC beam test.

Recent beam test at CERN PS T10 in July 2025

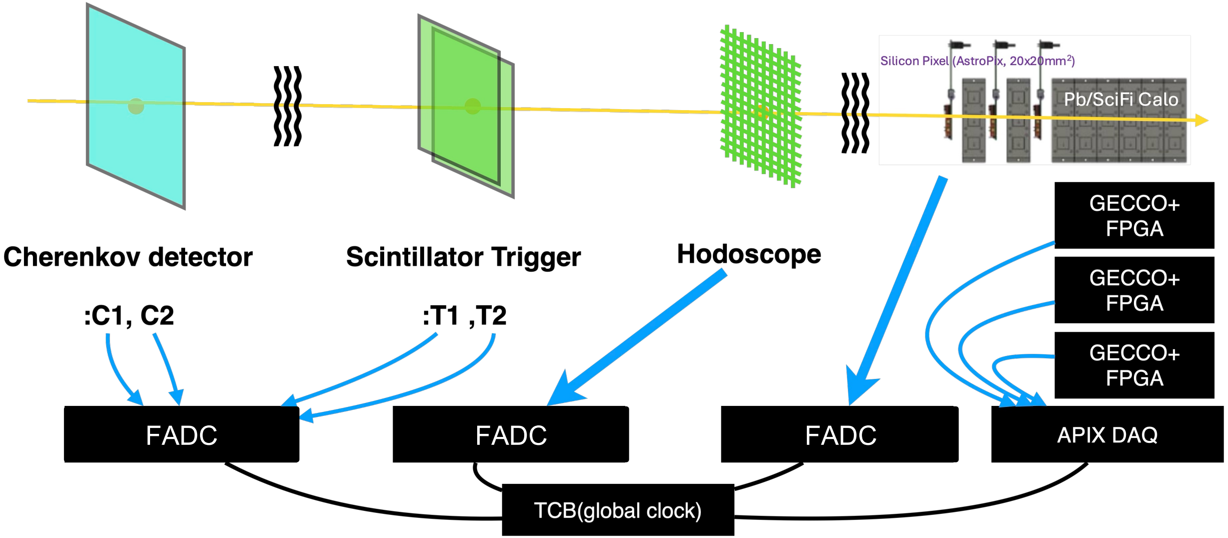


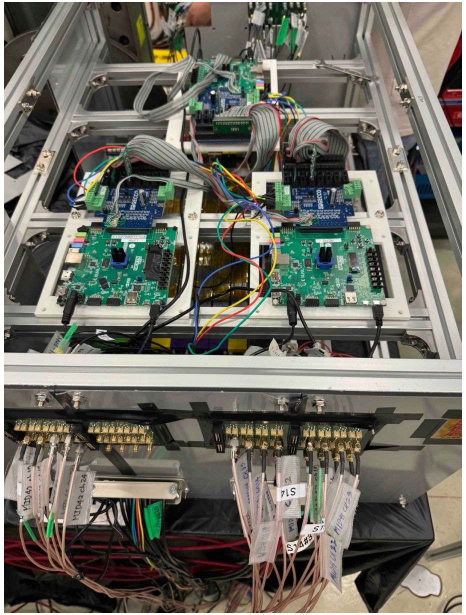




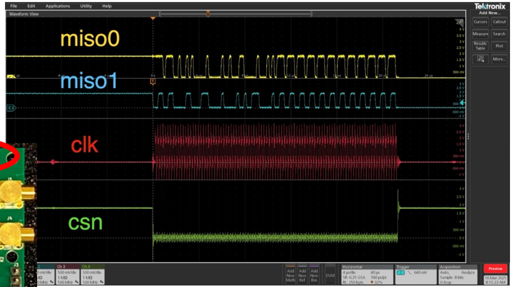
Goal: Proof-of-principle imaging of electrons and pions using a synchronized setup of AstroPix in the beam environment, using synchronized data taking between AstroPix and Pb/SciFi

DAQ integration



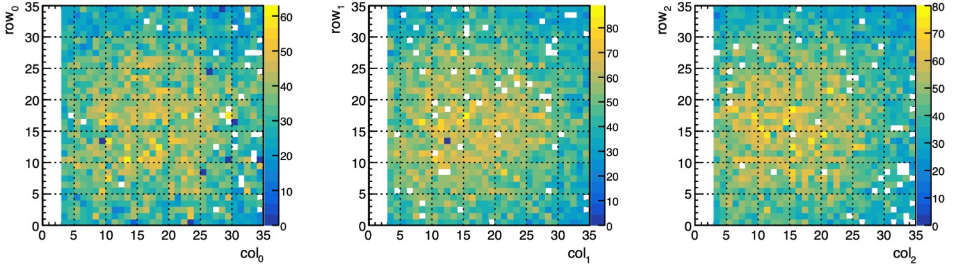


TCB provides the global clock for multiple DAQ modules
A trigger signal (via NIM) initiates three DAQs to record their analog signals & timestamp
Custom DAQ device to collect data from AstroPixs with their external timestamp
(No trigger mode for AstroPix readout)

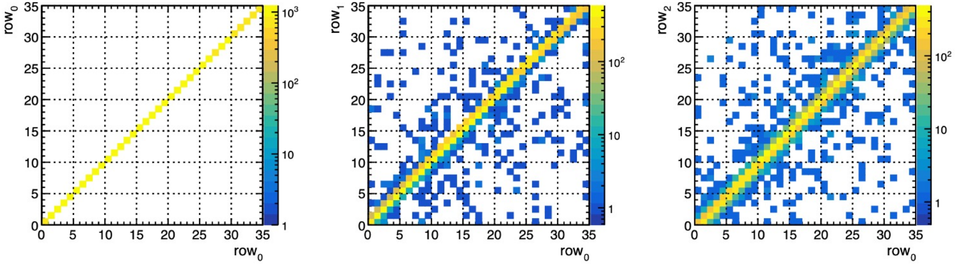


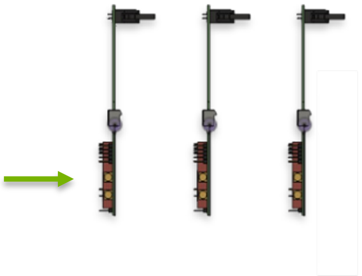
Synchronization of three layers of AstroPix v3

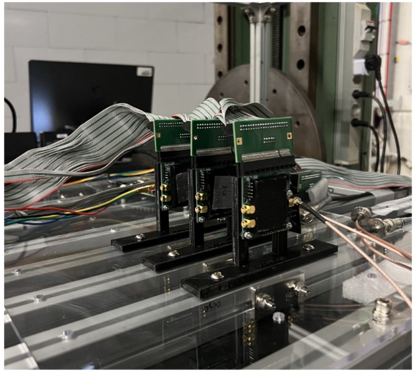
Hitmap



Correlation to the upstream chip

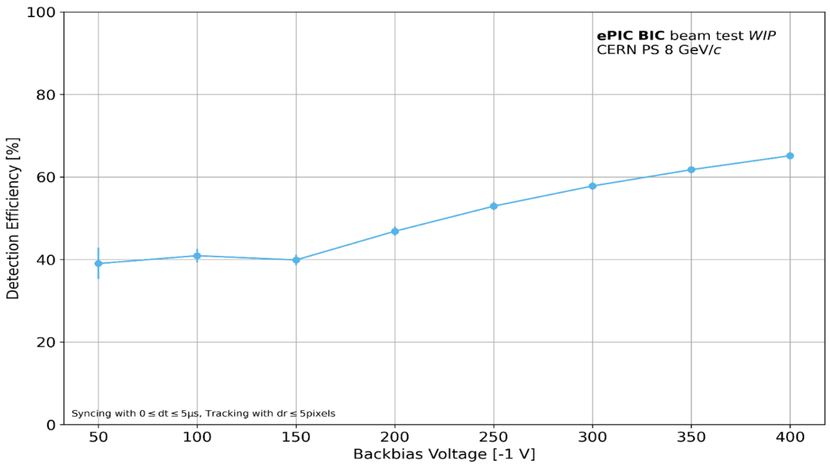




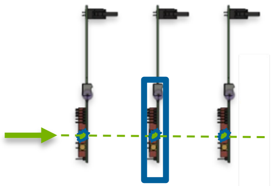


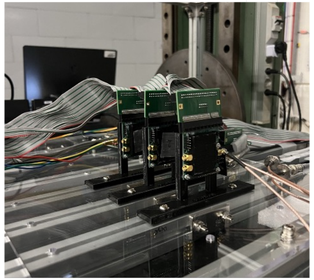
- Three AstroPix v3 layers are tested using the electron/pion beam at CERN PS.
- Correlations to the upstream show good alignment and data synchronization between AstroPix.
- The integrated system works well at a 2.7 kHz trigger rate on the beam. (BIC rate < 1 kHz/chip)

AstroPix v3 chip tracking efficiency (Shallow depletion depth)



Detection efficiency in percentage as a function of bias voltage

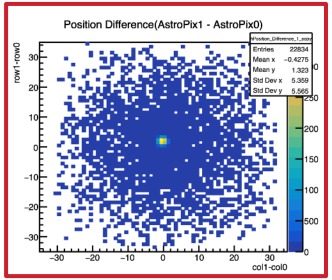




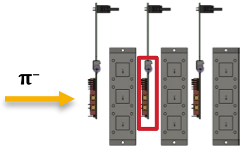
- Proof-of-principle for a method to measure tracking efficiency of AstroPix v3 under beam conditions.
- It is calculated as the probability of having a hit on the position estimated from hits on the first & third chips.
- The shallow depletion of v3 was known and is addressed in v5 with increased depletion.

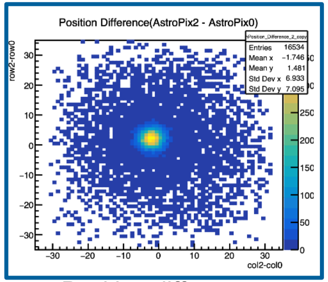
Different shower profiles of electrons and pions

Pions

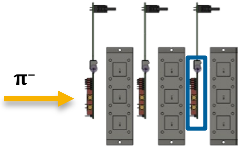


Position difference
between 1st-2nd layer

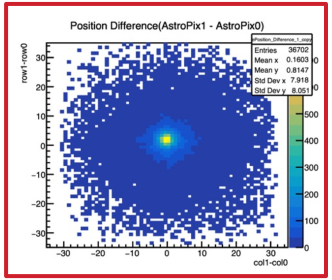




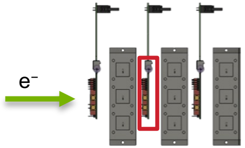
Position difference
between 1st-3rd layer

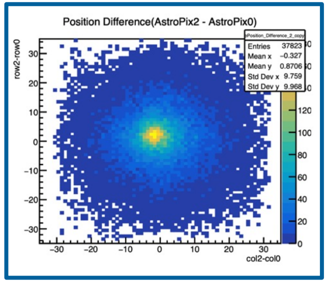


Electrons

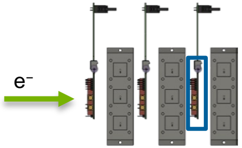


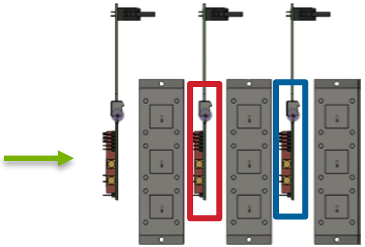
Position difference
between 1st-2nd layer

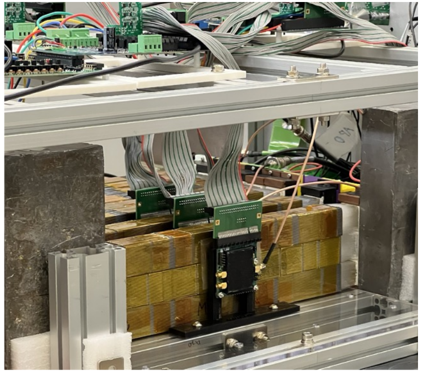




Position difference
between 1st-3rd layer

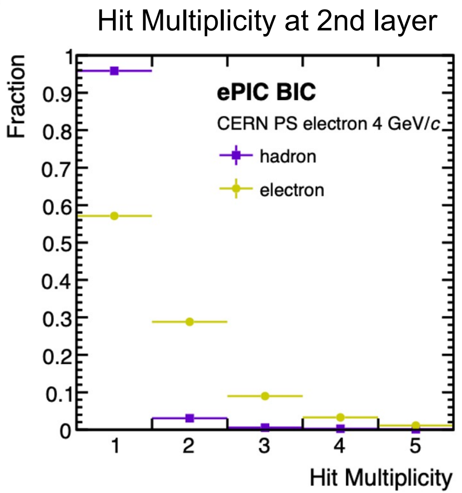


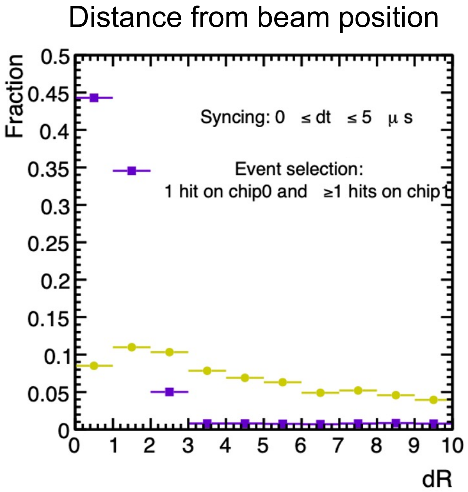


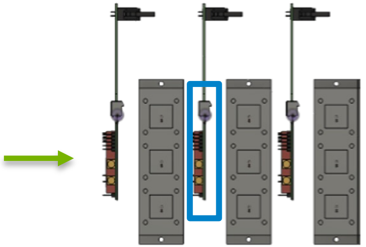


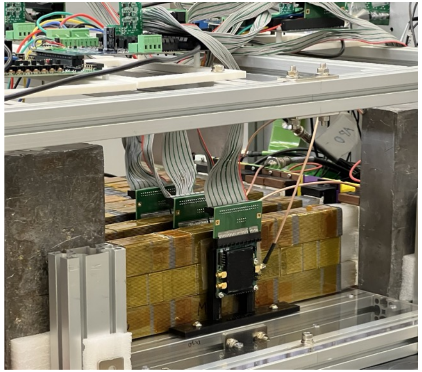
Proof-of-principle imaging of electrons and pions was performed using a synchronized AstroPix setup in the beam environment.

Different shower profiles of electrons and pions



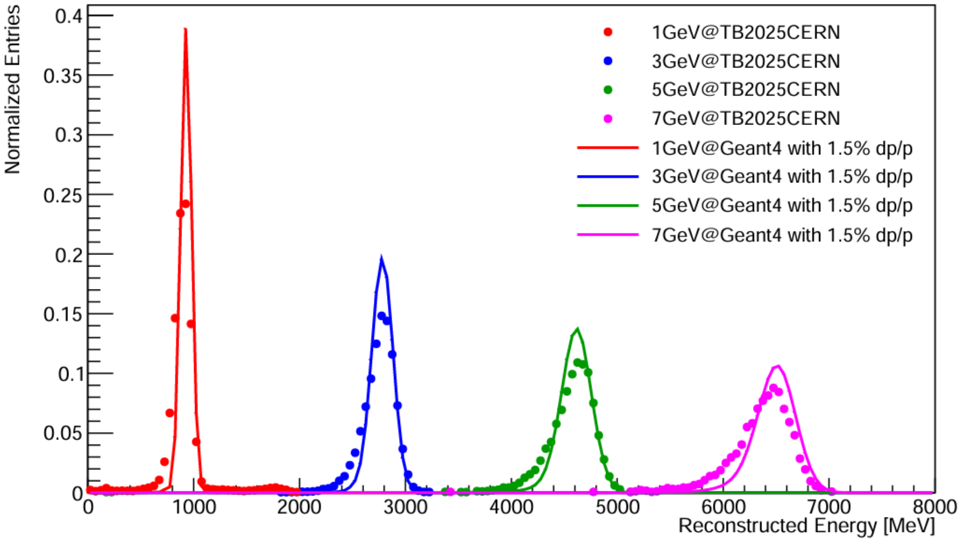






- The hit multiplicity and distance from the beam position at the second AstroPix v3 chip differ for electrons and pions.
- The electron/pion separation power in the beam test condition will be enhanced by AstroPix information on shower shape.

Electron energy measurement



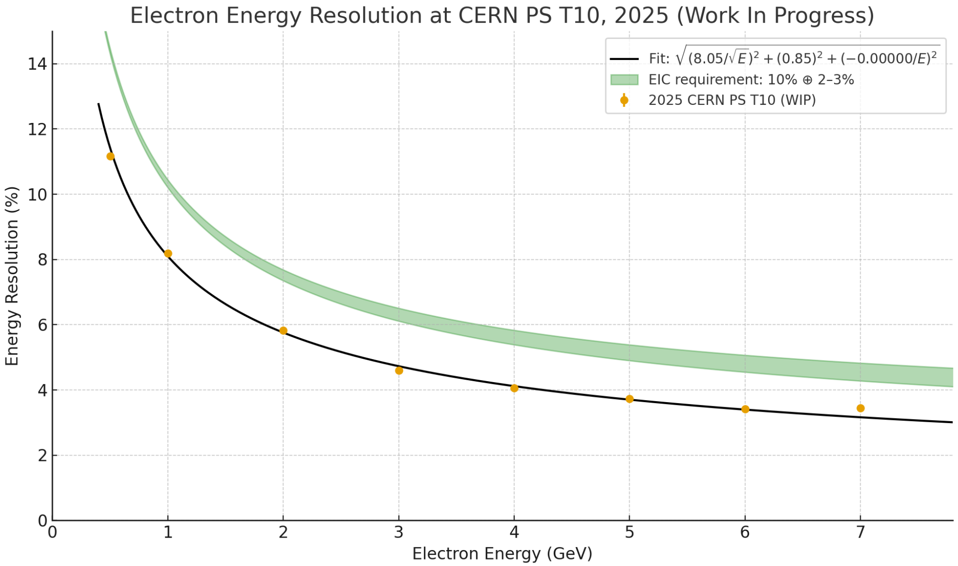
Applying beam momentum spread (dp/p) to simulation

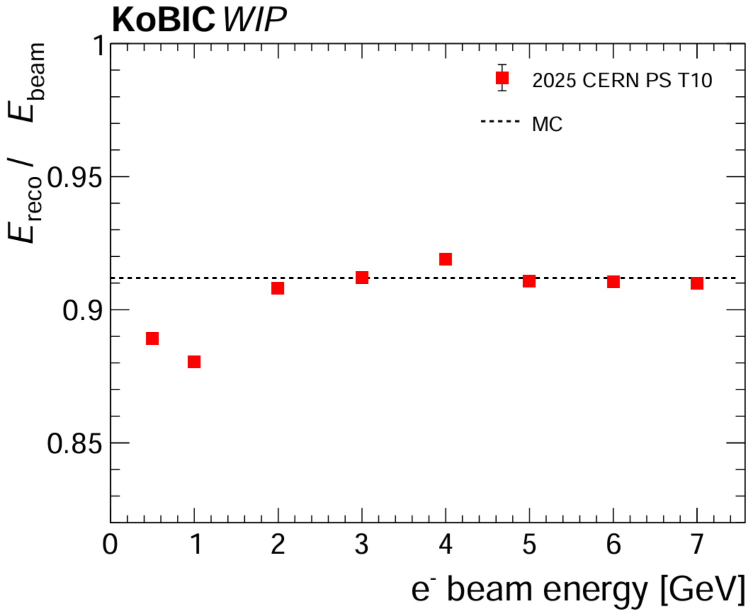
$$\sigma_{\text{total}} = \sqrt{\sigma^2_{\text{original}} + \sigma^2_{\text{spread}}}$$

***1.5% dp/p :** Expected momentum spread for the 3 mm collimator setup

- According to the GEANT4 simulation, energy resolution is affected by the beam momentum spread.
- At CERN PS T10, the beam momentum spread is 0.6~15%, depending on the collimator setup. (arXiv:2507.02567)
- With an additional momentum spread of 1.5%, the resolution in the simulation is shown with the data.

Energy Resolution & Linearity





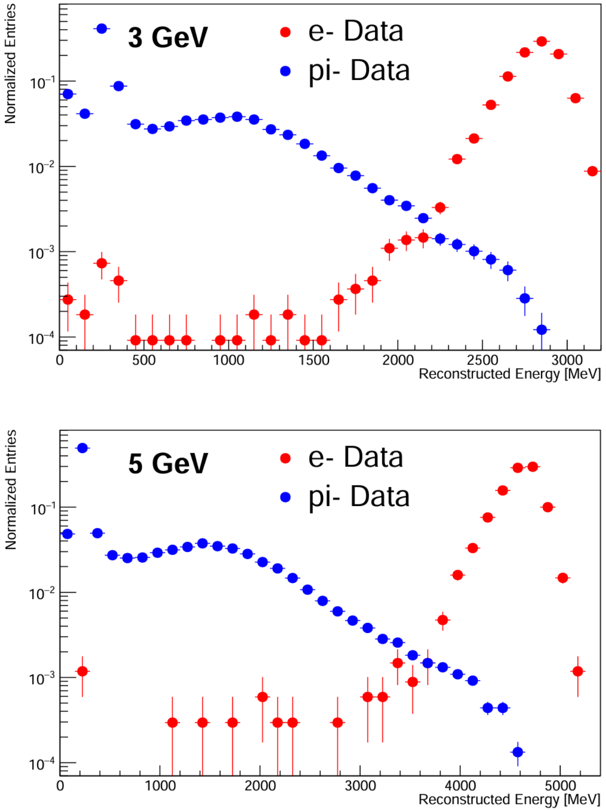
Resolution : (Stochastic) 8.05 %, (Constant) 0.85 %, (Noise) 0.00 %

$$\boxed{\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b \oplus c/E}$$

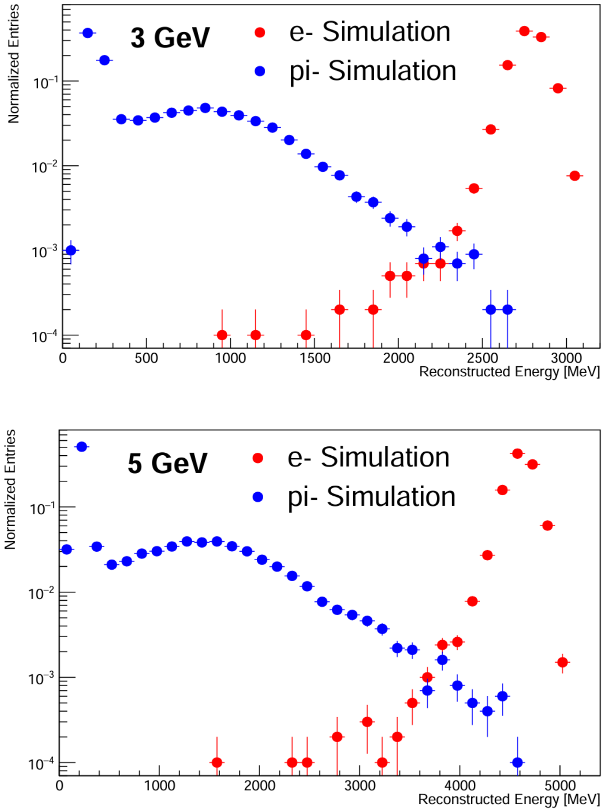
- The energy resolution has been progressively improved, achieving the best performance in this beam test.

e^-/π^- Separation in Beam Test Data

<Data> (Log scale y)

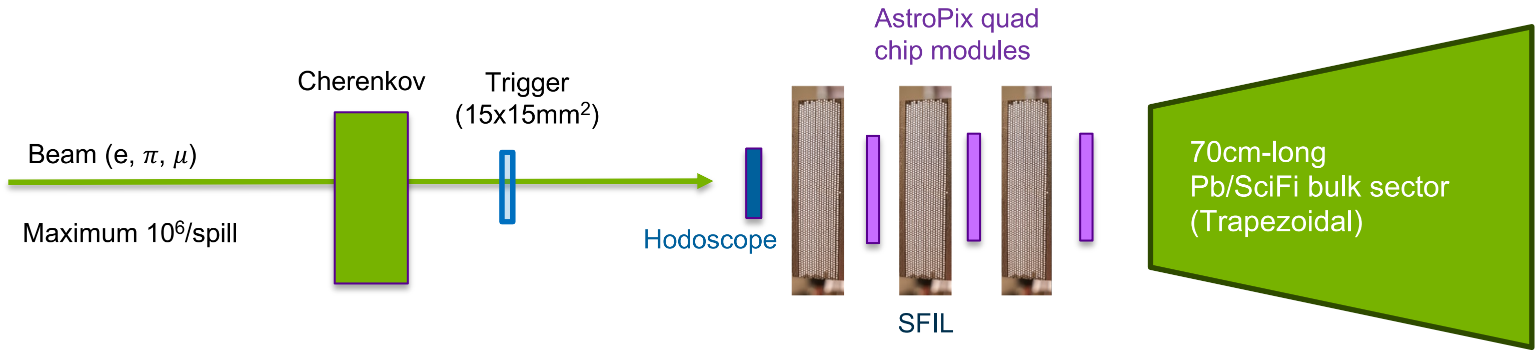


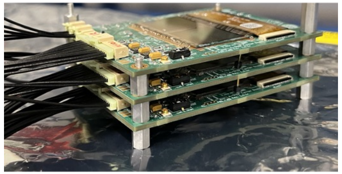
<Simulation> (Log scale y)

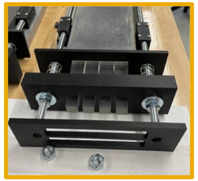


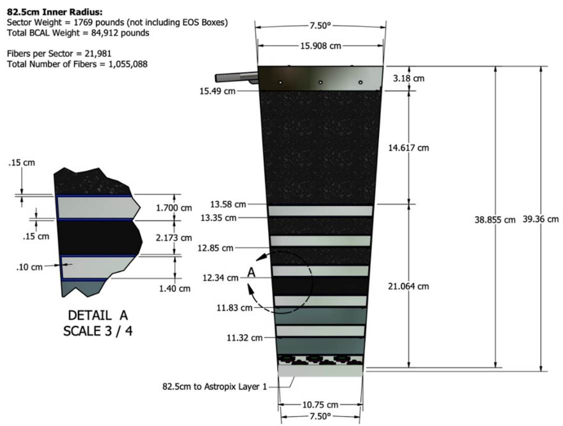
- Separating pions from electrons in data using a Cherenkov counter.
- Electron and pion energy distributions in data and simulation show good agreement.
- E/p allows discrimination between electrons and pions entering the calorimeter.

Next CERN beam test proposal




AstroPix quad chip modules


50cm-long SFIL at ANL



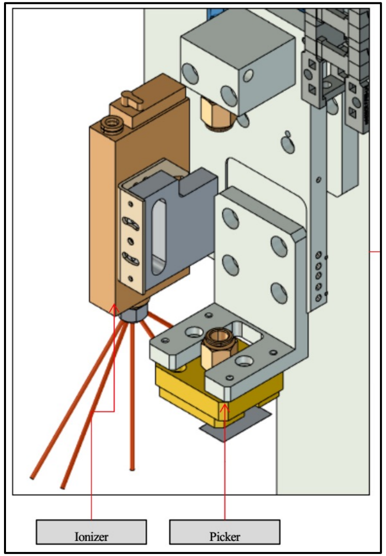
BIC sector dimension

(1) Test each AstroPix / Pb/SciFi
(2) Astropix-intervened setup

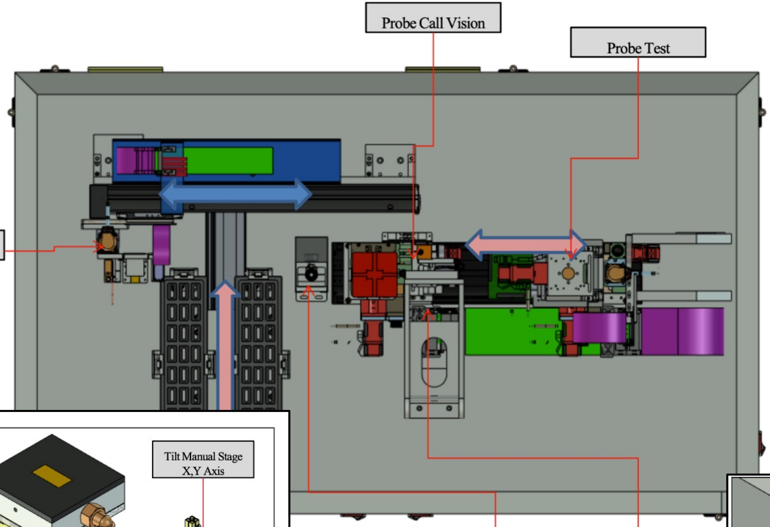
Detector preparation:

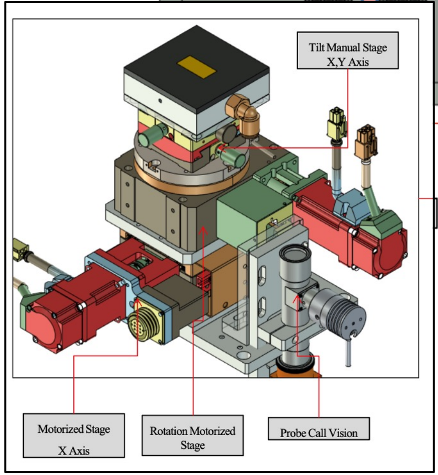
- 3 AstroPix quad chips are already available.
- Readout box with SiPM+LG will be built.
- HGCROC readout is a key item.
- Bulk sectors and SFIL will be built at ANL and the Korean institutions

AstroPix test system

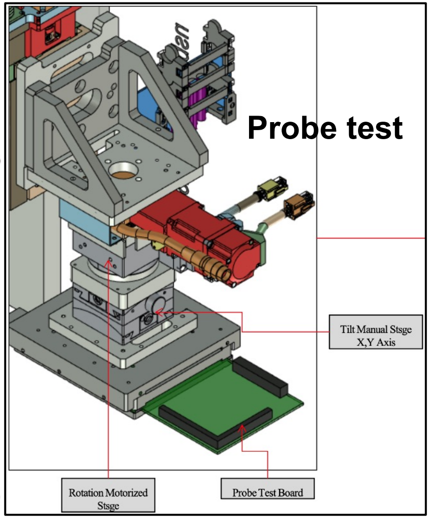


Sensor picker

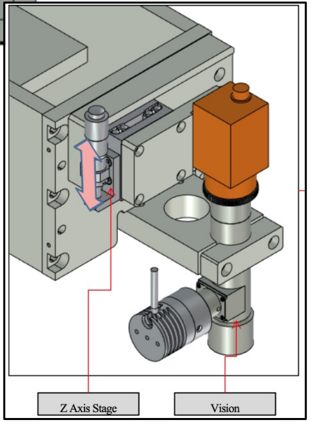




Working stage



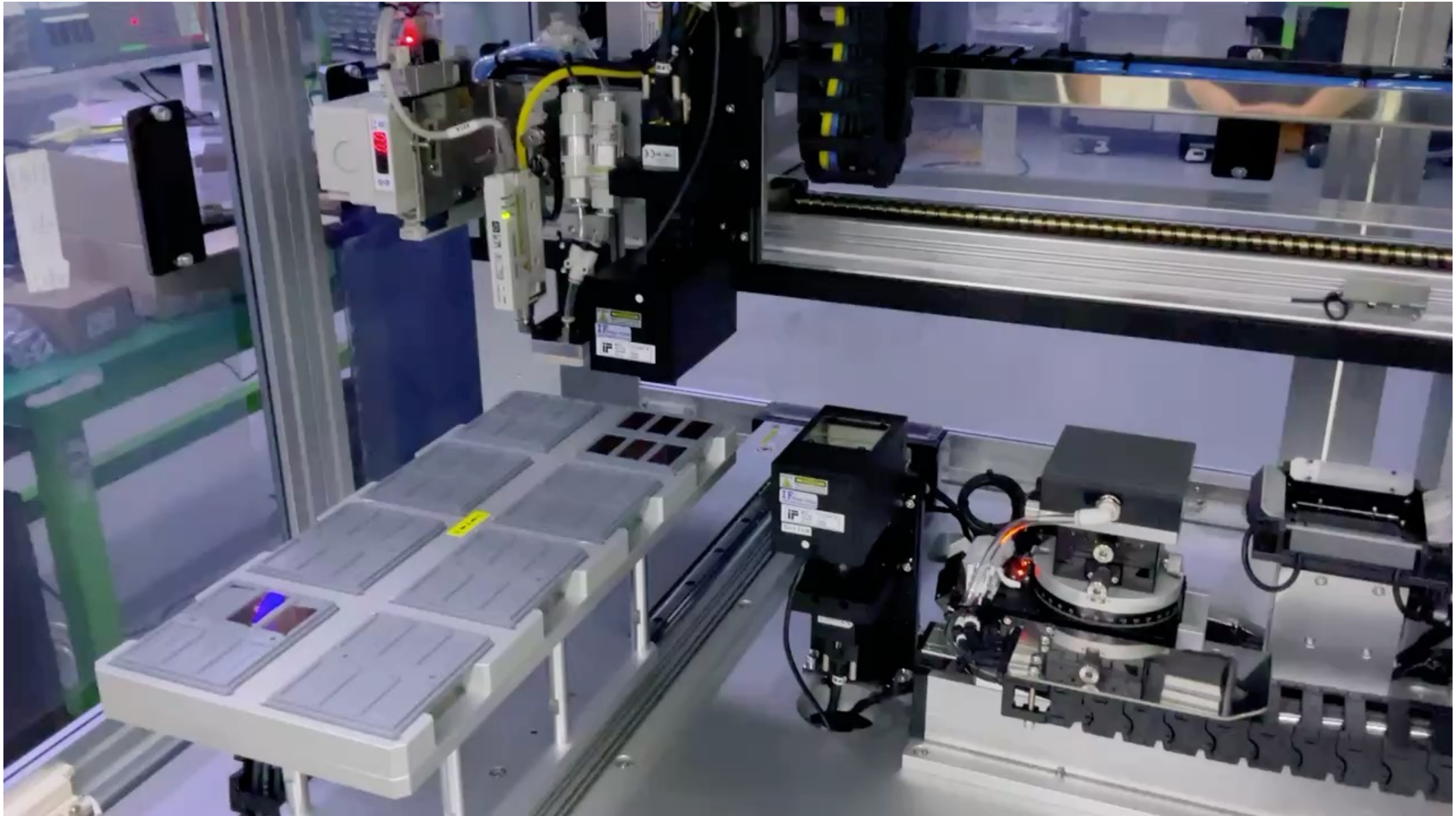
Probe test



Vision inspection

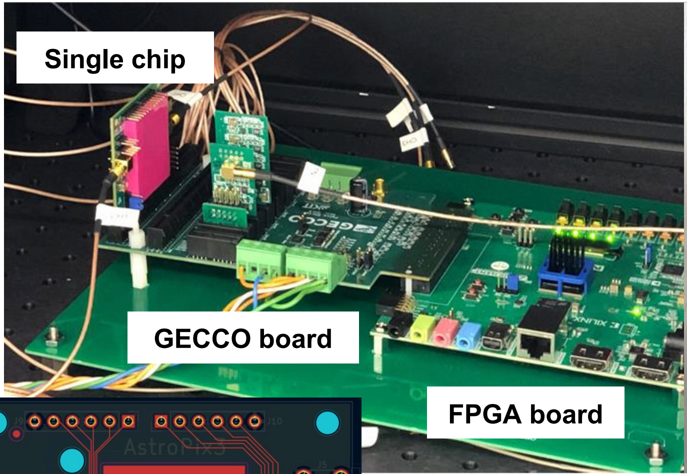
23

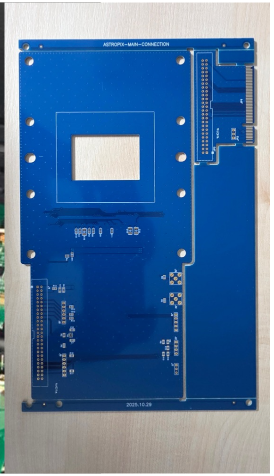
AstroPix test system

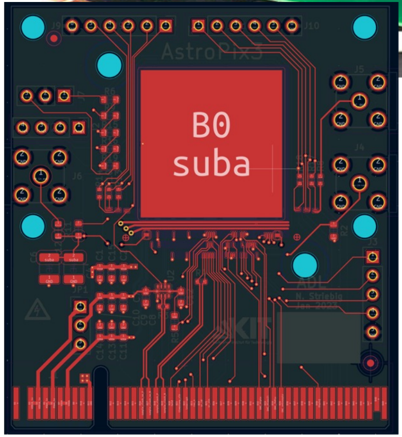


AstroPix test system

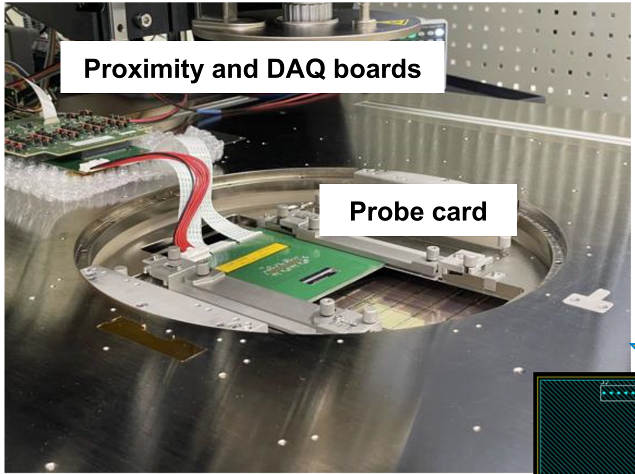
AstroPix v3 lab measurement setup



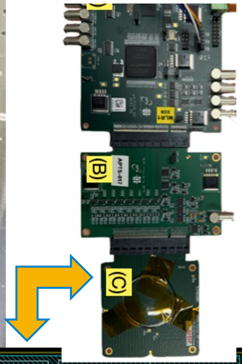


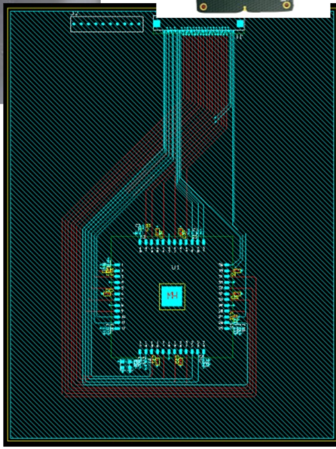


ALICE ITS3 ER1 wafer probing system



Testbench

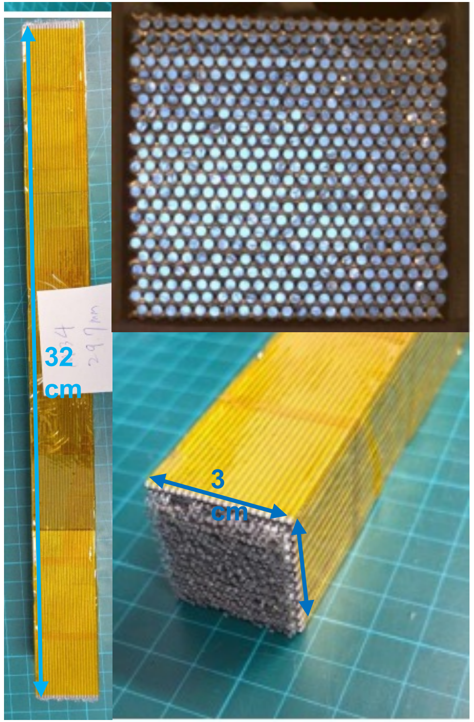




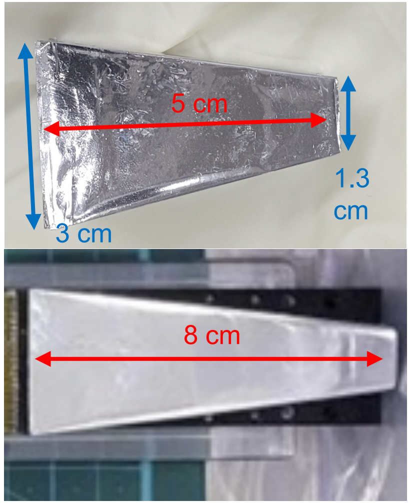
- Initial version of probe card for AstroPix v3: a simple version for the chip carrier board.
- Uses already validated GECCO and FPGA board setup, which will be connected with flexible cables
- Recently, the probe card design for v3 has been done by a local manufacturer in Korea

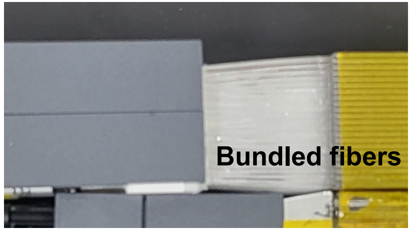
25

Development of the readout system

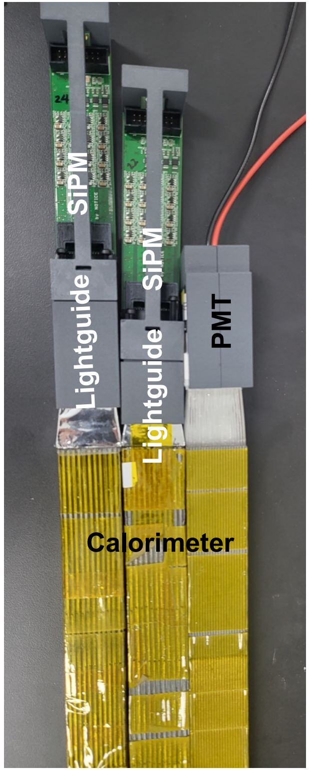


+





+



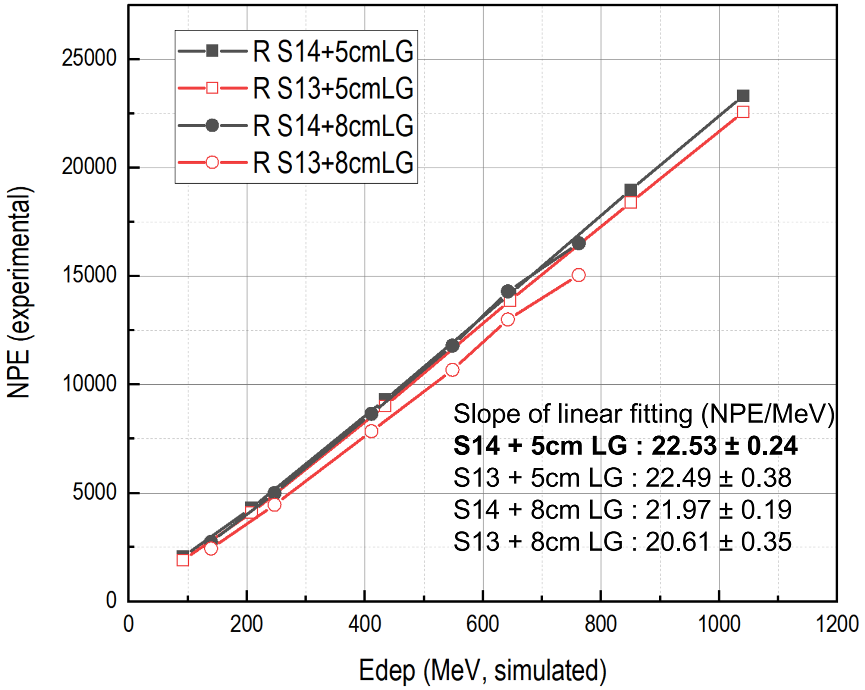
1. Calorimeter
Pb plates & Scintillating fibers

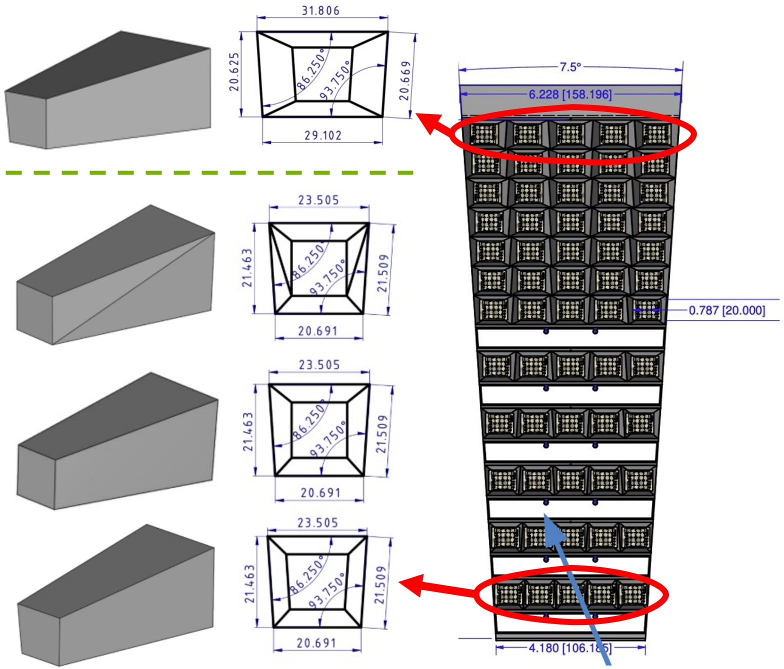
2. Lightguide
Square, acrylic lightguides wrapped with Al Mylar (5, 8 cm)
Bundled fiber for PMT

3. Photon senser (Hamamatsu)
SiPM (S13 & S14)
PMT

26

Development of the readout system



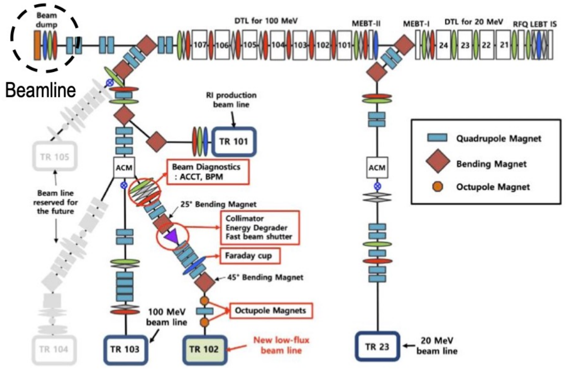


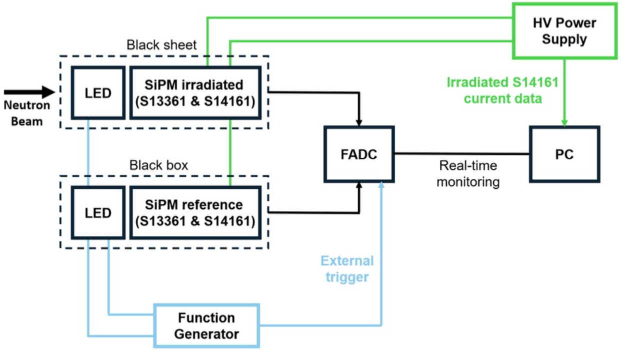
Beam test results
1. Linearity of SiPM readout
2. Small difference in light yield for SiPM readout (< 10%)

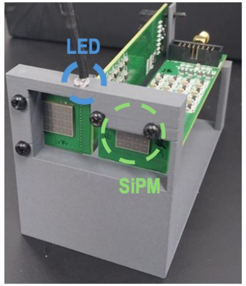
Future plan
Lightguides matching the dimensions for actual deployment will be tested

27

SiPM radiation hardness test



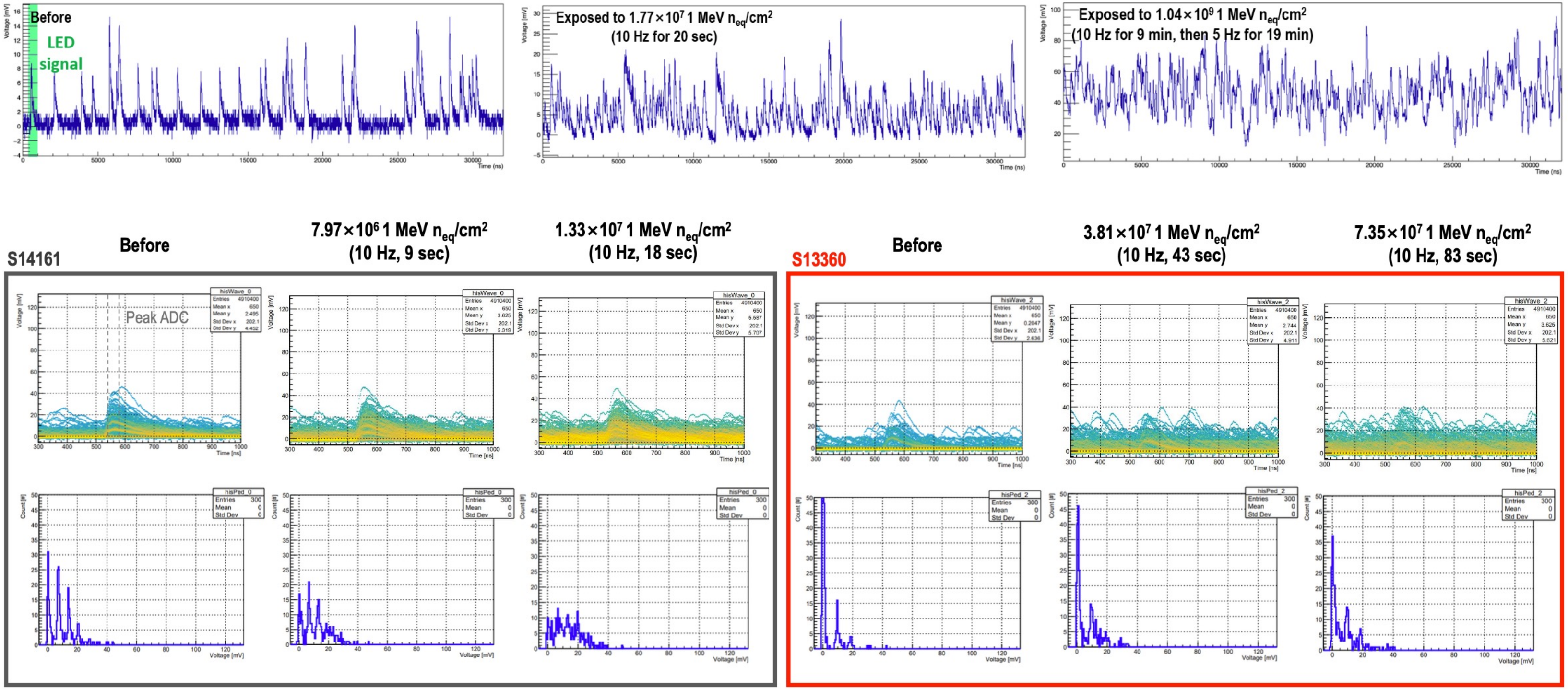




Date	Beam setting	Fluence [1MeV n_{eq}/cm^2]	LED Hz	Remarks
Jun 26	10 Hz × 5 min 10 Hz × 4 min 5 Hz × 19 min	1.04×10^9	100 Hz	Comparison of S13 and S14 S14: higher photon detection efficiency S13: lower dark count rate
Sep 5	1 Hz × 60 min vs 5 Hz × 12 min	6.20×10^8 (each)	100 Hz vs 500 Hz	Two pairs (S14 & S13) Same fluence, test for rate dependence

- Real-time SiPM irradiation monitoring: Two SiPMs (Hamamatsu S13361 and S14161) were irradiated with neutron beams at KOMAC, and monitoring of single-photoelectron response (LED window), dark current rate, and baseline shifts.
- Performance change evaluation: Pre- and post-irradiation IV measurements were performed to quantify leakage-current increases and breakdown-voltage shifts for both devices.

SiPM radiation hardness test



S14161 shows a lower ADC sigma as a noise indicator, while S13361 exhibits lower leakage current and better single-photoelectron peak separation during irradiation.

29

Summary

- Successful PRD in September 2025
  - ~60% design-complete across the BIC

- Past to final design demonstration of all individual test articles
  - Demonstrated now: Pb/SciFi sections; lightguide + SiPM chain; initial chip probing flow; v3 module test article (9-chip pcb), system-level SciFi and AstroPix integrations
  - On track by the end of 2025: carbon-fiber sections; short sector assembly; expanded chip-probe throughput and module pre-series; all components of ESB

- Activities in Korea
  - Test Pb/SciFi module production
  - A series of test beams at KEK PF-AR and CERN PS T10
    Successful data taking with an integrated system of multi-layer AstroPix and Pb/SciFi modules
  - Development of an Automatic AstroPix sensor test machine
  - Study of light guide and SiPM readout

Backup