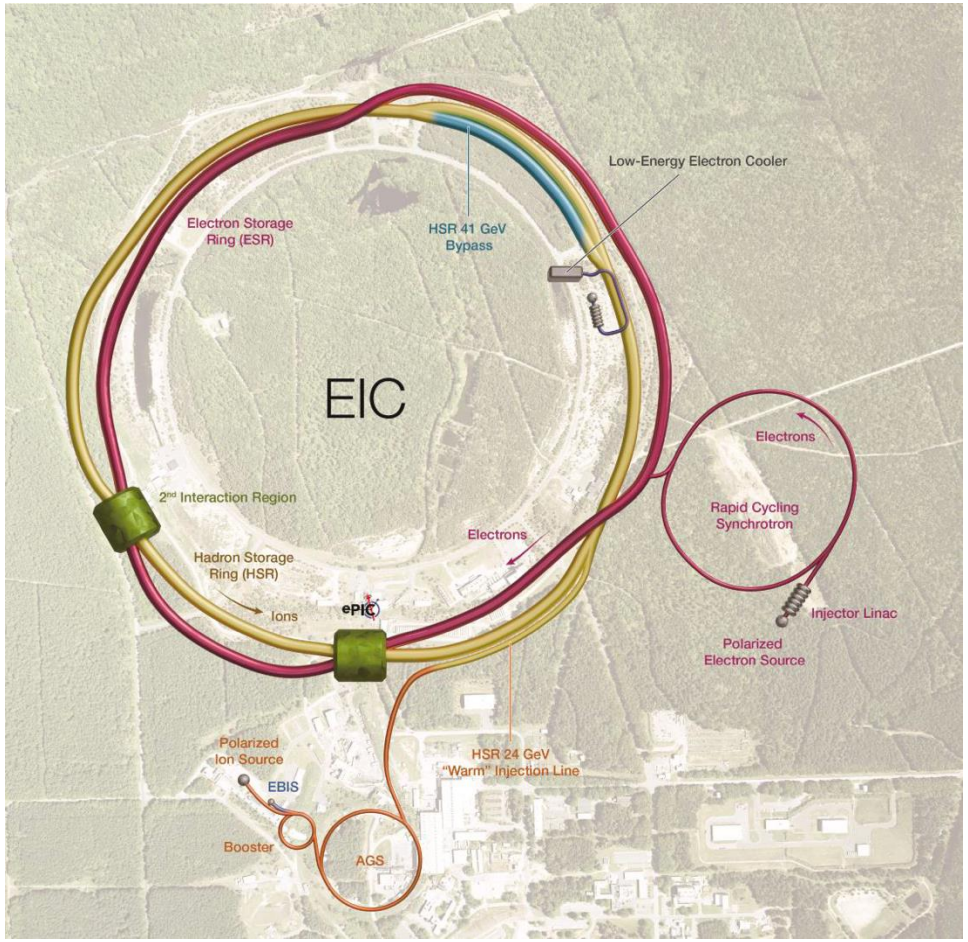
Status of Barrel Imaging Calorimeter in Korea for the Electron-Ion Collider

The 29th International Nuclear Physics Conference (INPC 2025)
May 27th 2025

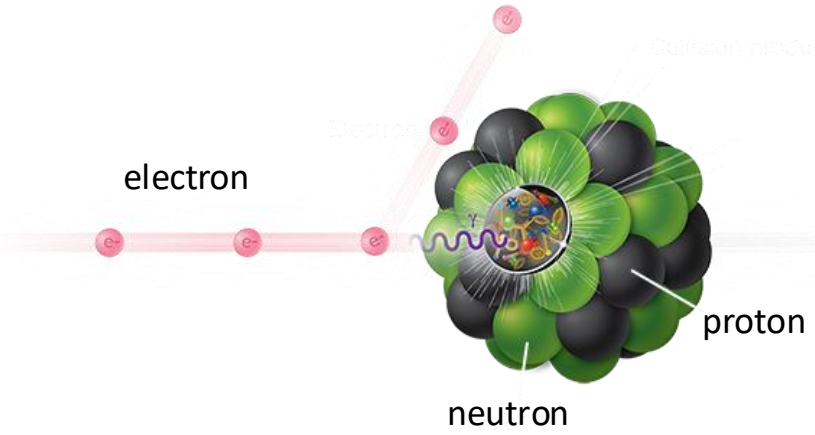
Jeongsu Bok (Pusan National University)

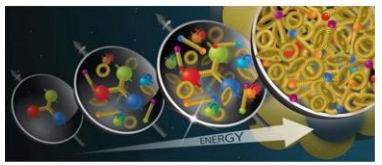
INPC 2025
May 25-30, 2025
DCC, Daejeon, Korea

The Electron-Ion Collider (EIC)



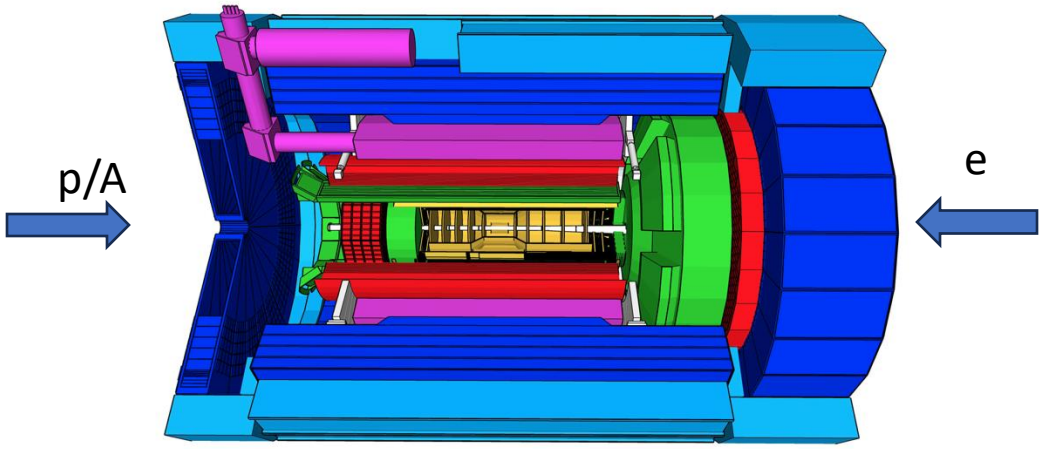
- Science Goal: How do quarks and gluons make up nearly all of the visible matter in the universe?
  - Precision 3D imaging of protons and nuclei
  - Proton spin, mass
  - Quarks and gluons in nuclei
- Based on RHIC, use the existing hadron storage ring. 41–275 GeV. Add an electron storage ring in the RHIC tunnel. 5–18 GeV
- Polarization ~ 70%
- $e^{\uparrow}$ + $p^{\uparrow}$, $d^{\uparrow}$, $He^{\uparrow}$, unpolarized ions up to U.
- $\mathcal{L} = 10^{33-34}\text{cm}^{-2}\text{s}^{-1} \leftrightarrow \mathcal{L}_{\text{int}} = 10-100\ \text{fb}^{-1}/\text{year}$





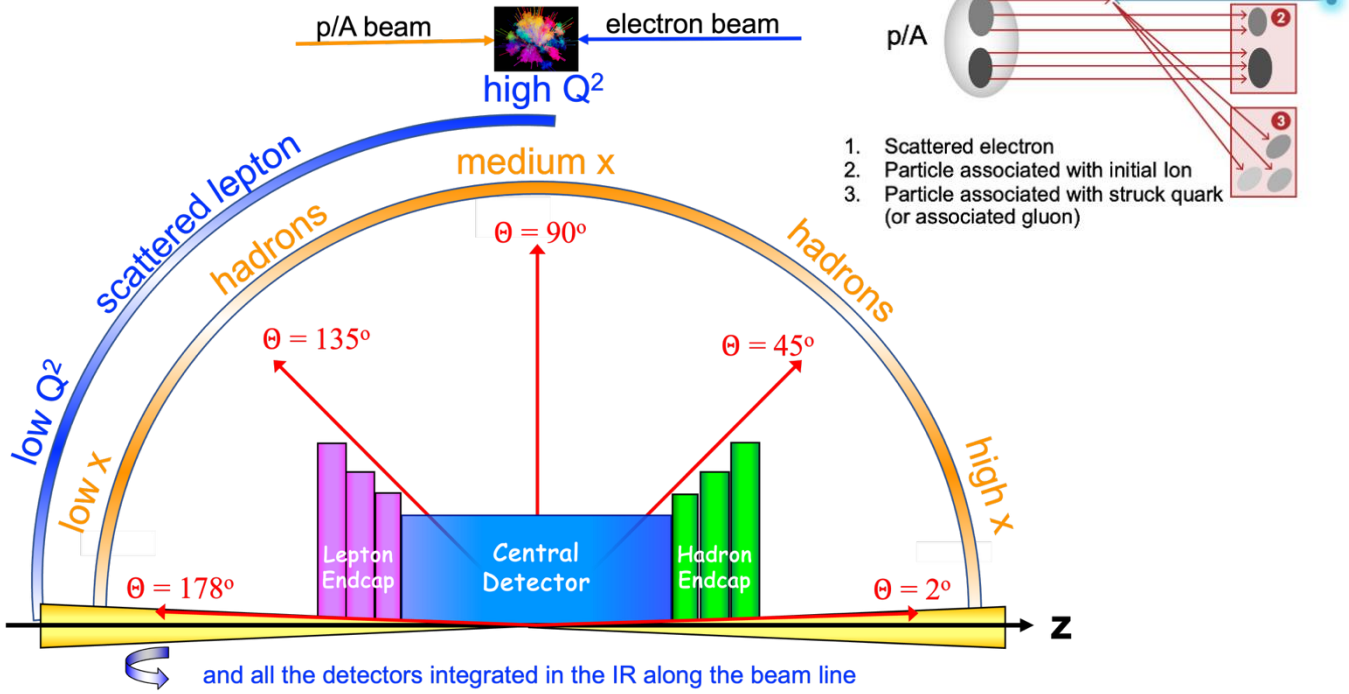
EIC General Purpose Detector: Concept

Magnet
Tracking
Particle Identification
Electromagnetic Calorimeter
Hadronic Calorimeter



Coverage

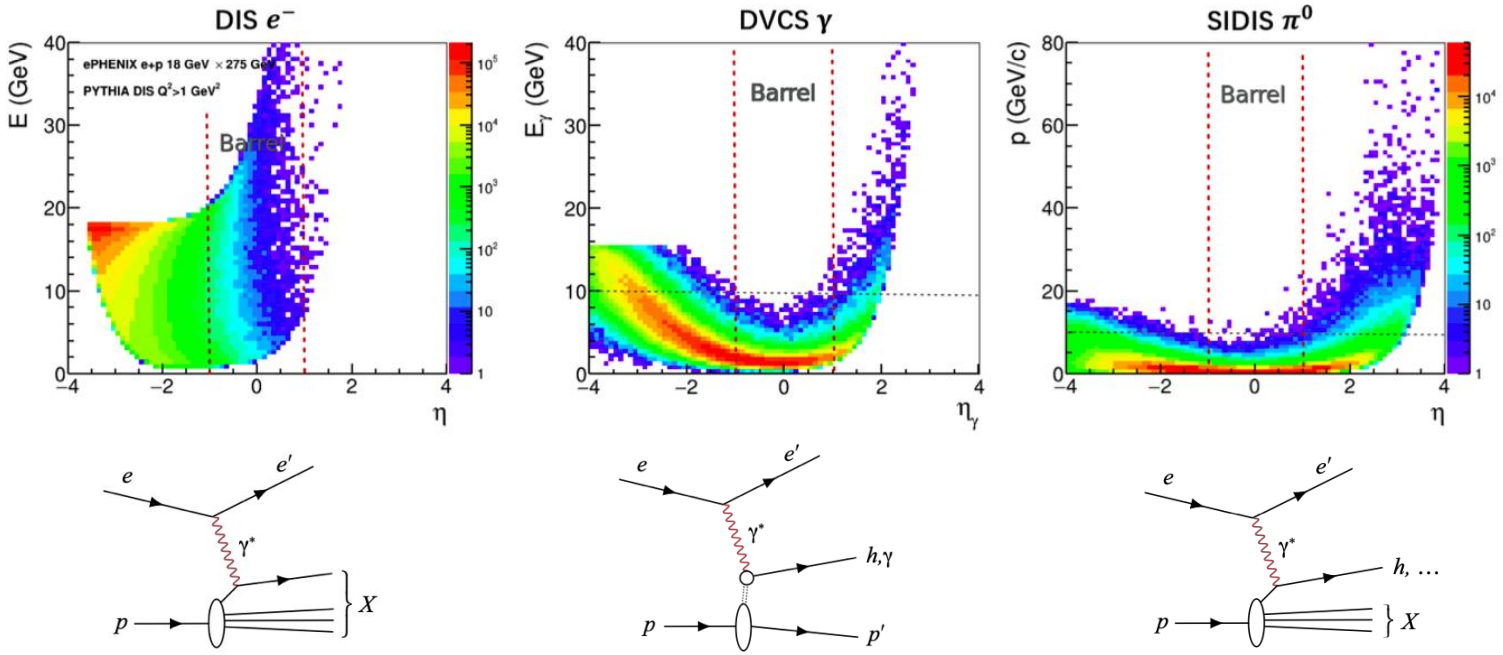
ϕ:360° 2°<θ<178° -4<η<4

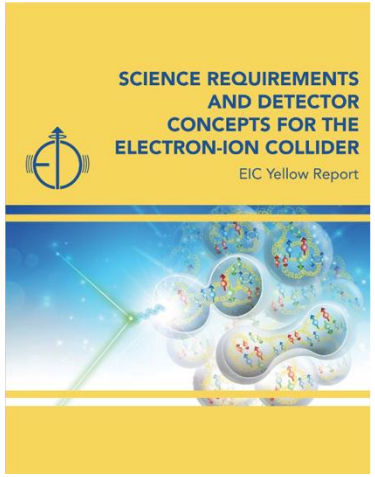


EIC Barrel EMCal Requirements

EIC Yellow Report requirements for Barrel EM Calorimeter

- Detection of electrons/photons to measure energy and position
- Require moderate energy resolution $(7-10)\%/\sqrt{E} \oplus (1-3)\%$
- Require electron-pion separation up to 10^4 at low momenta with other detectors
- Discriminate between π^0 decays and single γ up to ~10 GeV
- Low energy photon reconstruction ~100 MeV

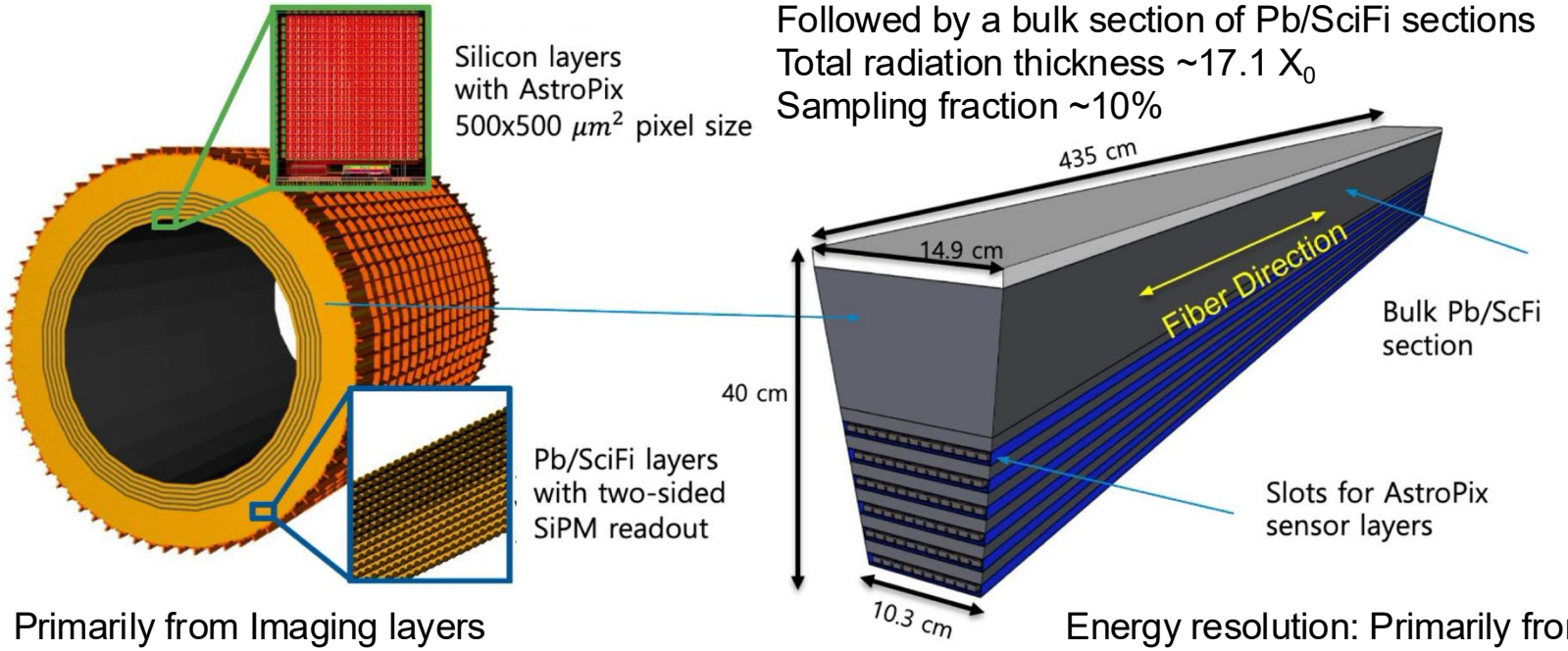


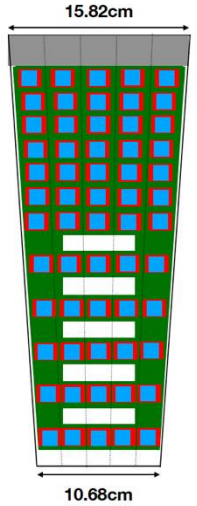


Nucl.Phys.A 1026 (2022) 122447

Barrel Imaging Calorimeter: Overview

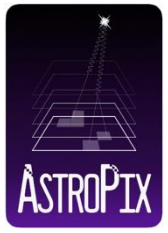
4(+2) layers of imaging Si sensor interleaved with 5 Pb/SciFi layers
Followed by a bulk section of Pb/SciFi sections
Total radiation thickness ~17.1 X_0
Sampling fraction ~10%

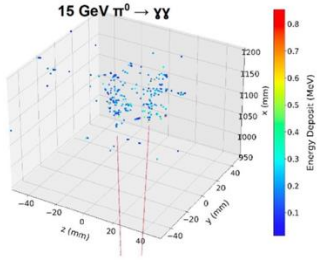


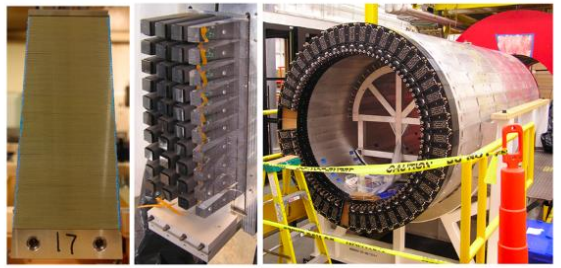


Position resolution: Primarily from Imaging layers
(+2-side Pb/SciFi readout and radial segmentation)

Energy resolution: Primarily from Pb/SciFi layers
(+ Imaging pixels energy information)



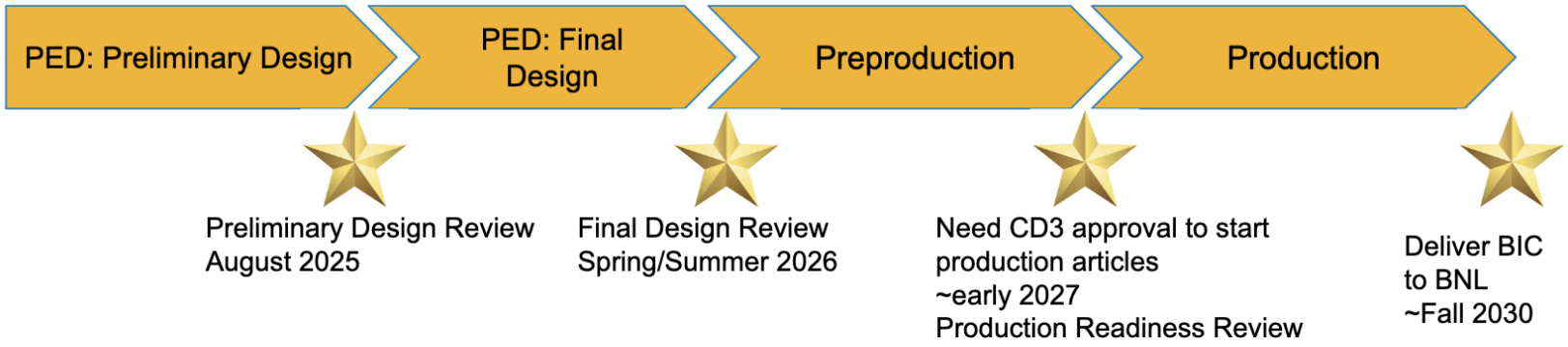


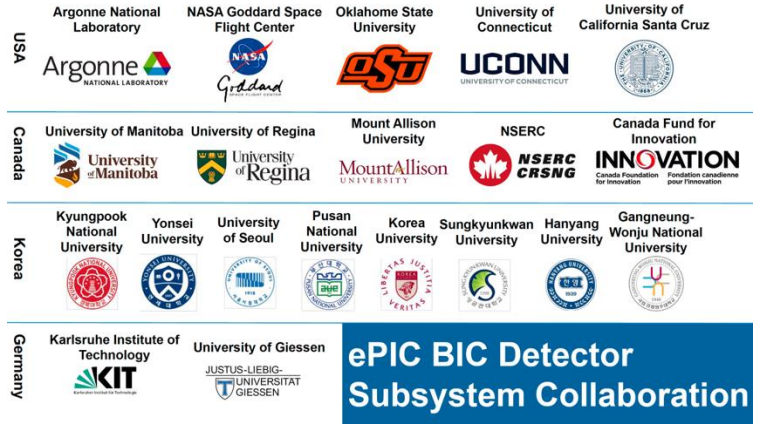


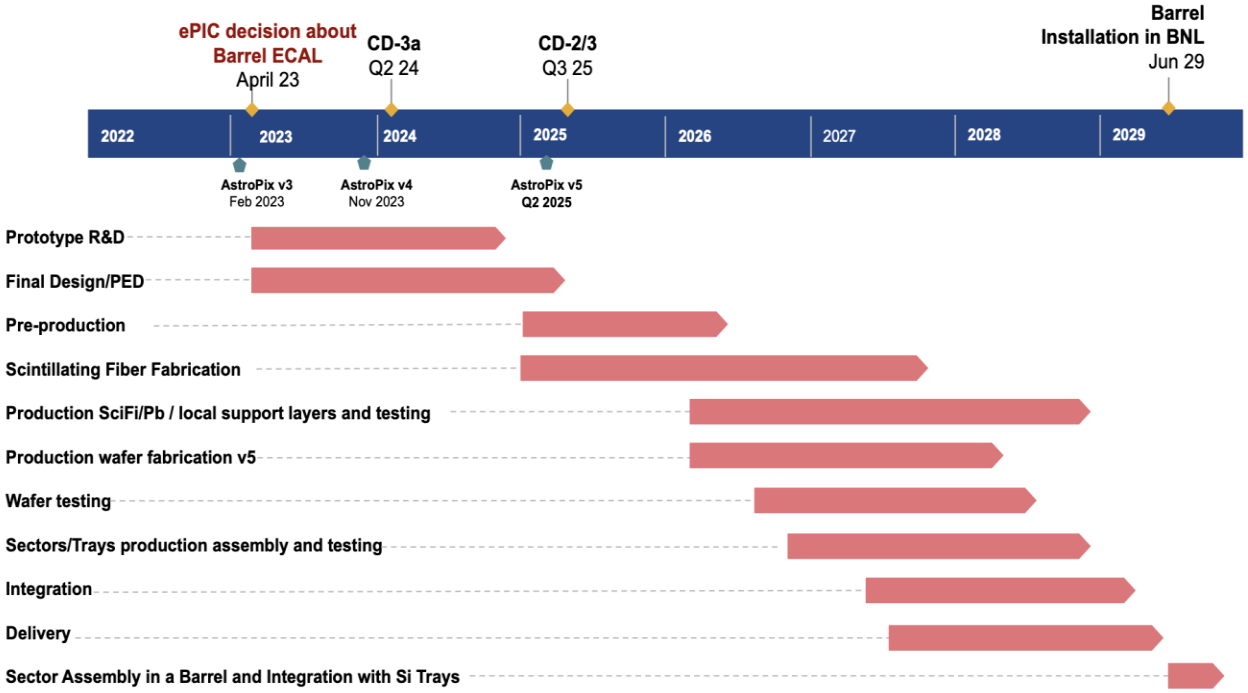
AstroPix tracking layers to capture 3D image of shower development
NASA AMIGO-X mission
Total number of 2x2 cm^2 chips for BIC: 249,600 ~100 m^2

GlueX Pb/SciFi sampling calorimeter

BIC schedule



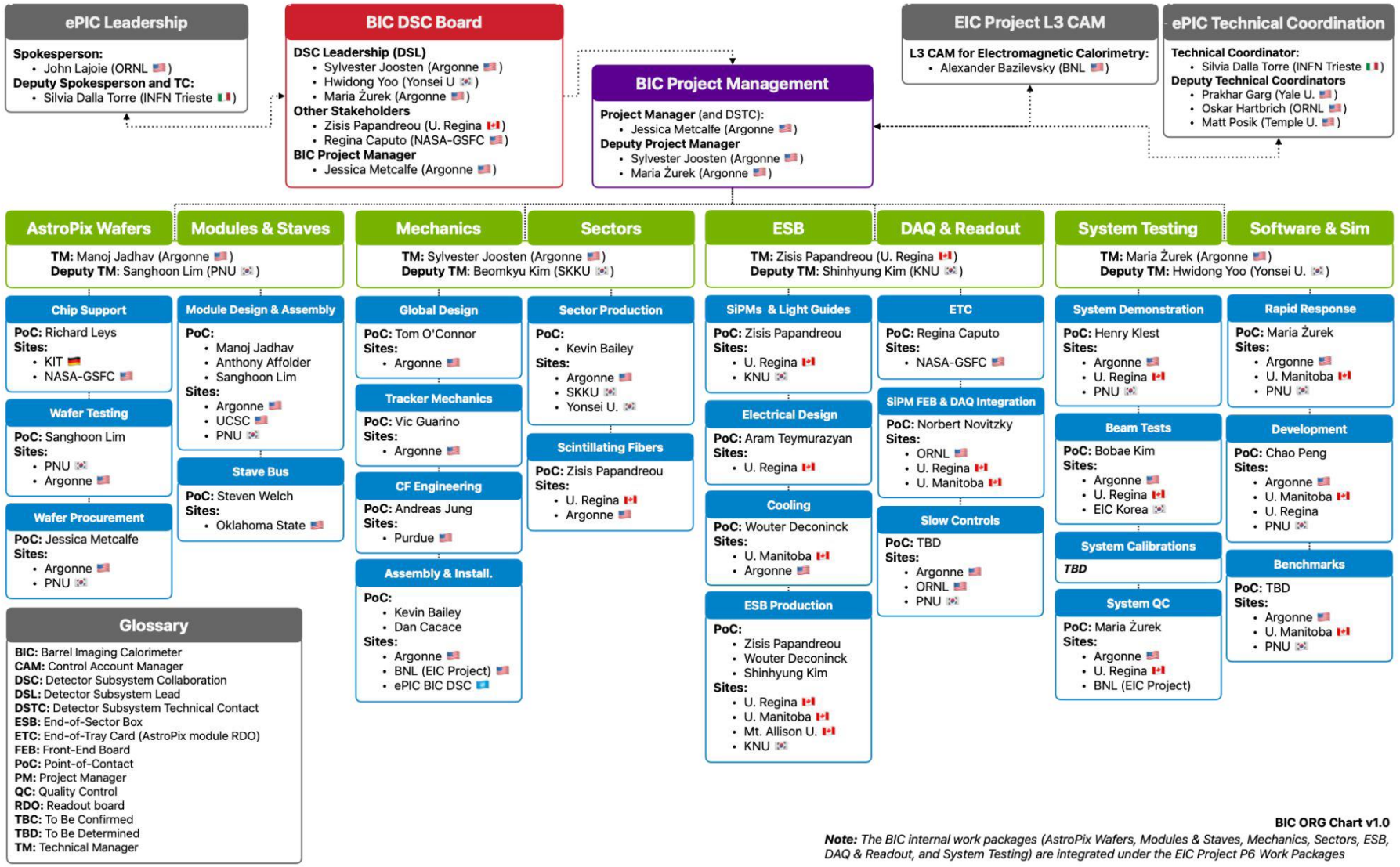




Contribution in Korea

AstroPix chip test, module assembly
Pb/SciFi sector production
Readout Box
System Test
Simulation

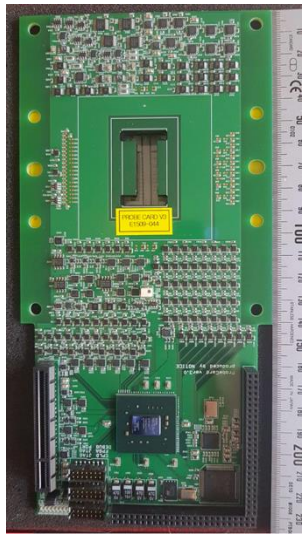
BIC Organization



BIC ORG Chart v1.0

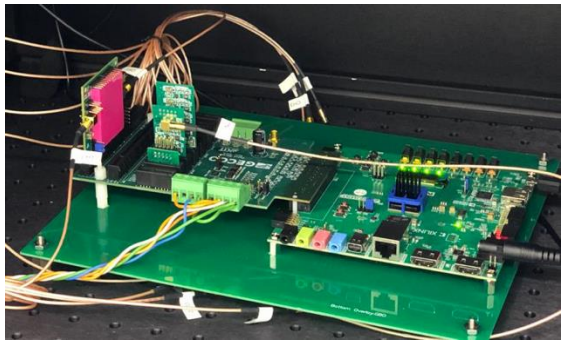
Note: *The BIC internal work packages (AstroPix Wafers, Modules & Staves, Mechanics, Sectors, ESB, DAQ & Readout, and System Testing) are integrated under the EIC Project P6 Work Packages*

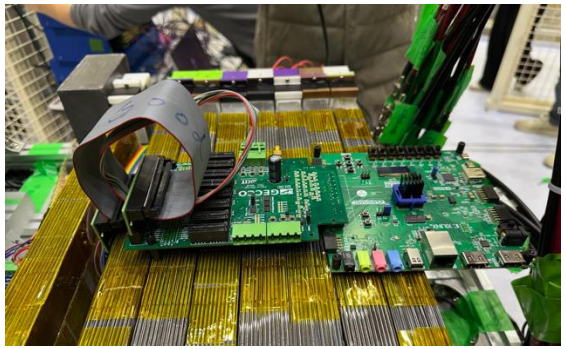
Silicon pixel chip test and wafer level test



Probe card for ITS2

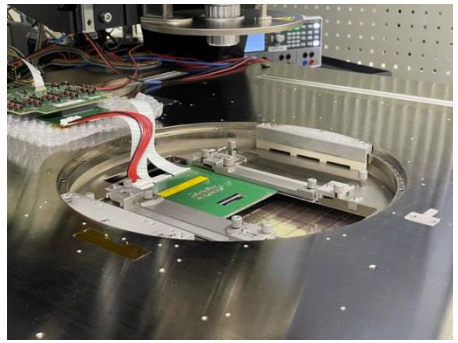
AstroPix single chip setup

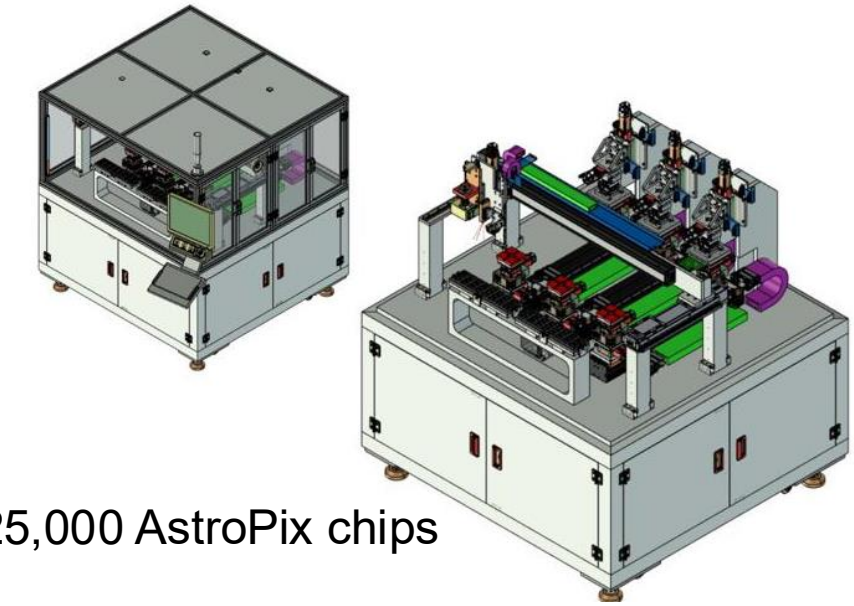




AstroPix single chip setup with flexible cable in the recent beam test

Wafer testing system for ITS3





Total area of ~100m^2, over 25,000 AstroPix chips

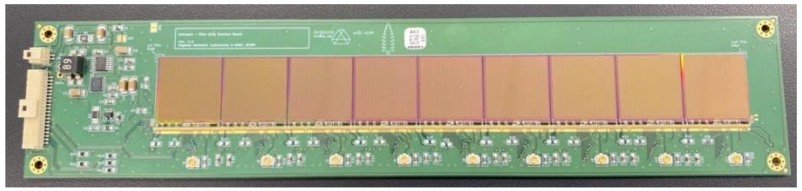
Probe card:

Connection with a flexible cable has been tested for the test beam at KEK (2025 March)

Test system:

Preparing to establish chip characterization method.

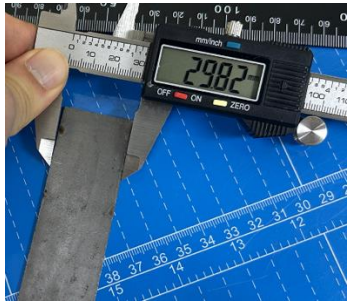
Developing a multi-line single-chip test system. Depending on the test procedure and time, one chip handler can cover multiple test stations



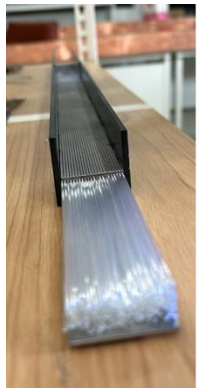
AstroPix Module with 9 AstroPix sensors daisy-chained together on Flex PCB

Pb/SciFi Prototype Module Production

1) Pb plate preparation

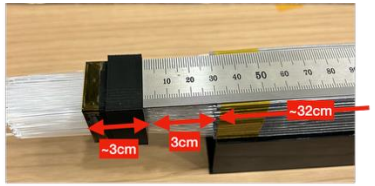


2) Stacking with fiber

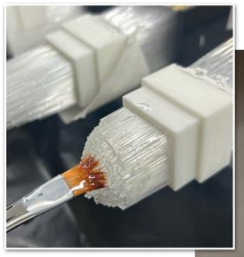


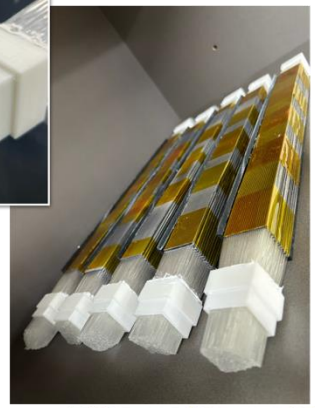
3) Cutting fiber

Epoxy

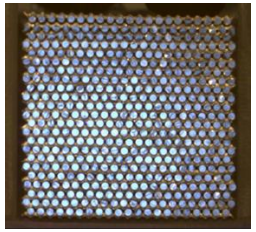


4) curing

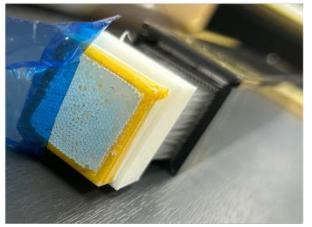


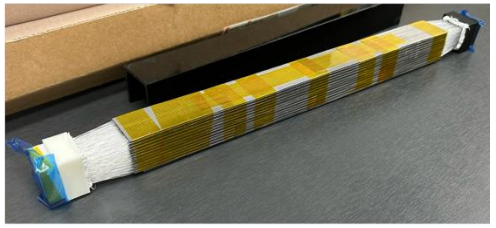


Produced 33 of 32x3x3 cm^3 unit modules for beam test including one for light guide
Details will be introduced by Sangwoo Park (SKKU)

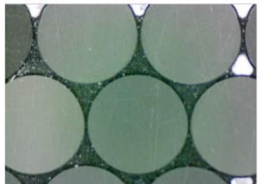


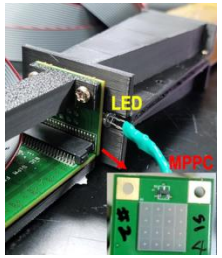
완성본

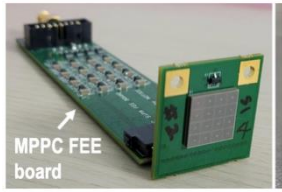


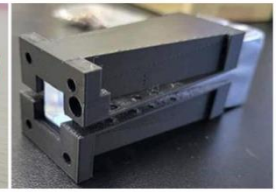


5) polishing





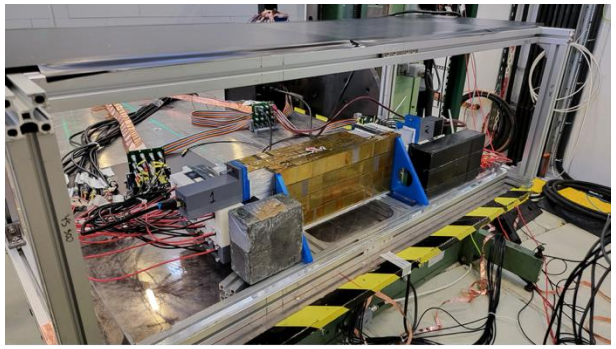


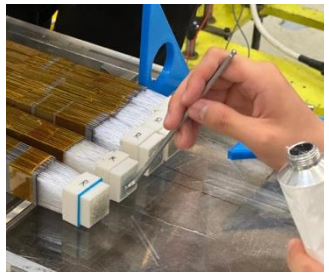


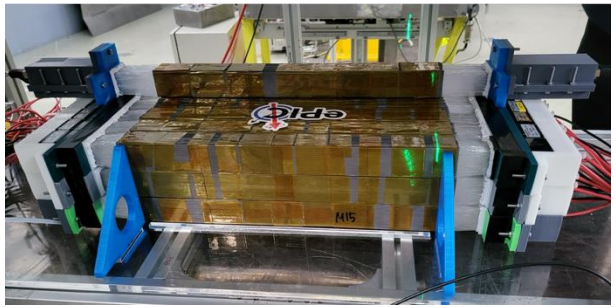
6) Connect with PMT or Light Guide + SiPM

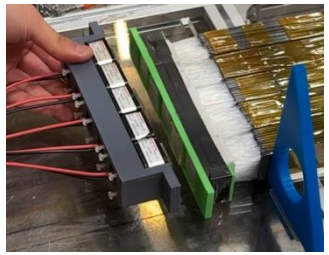
First beam test in Aug 2024 at CERN PS T10

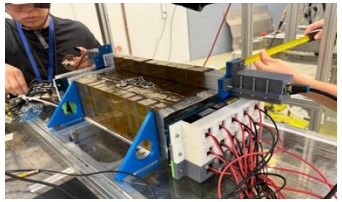
Pb/SciFi module assembly

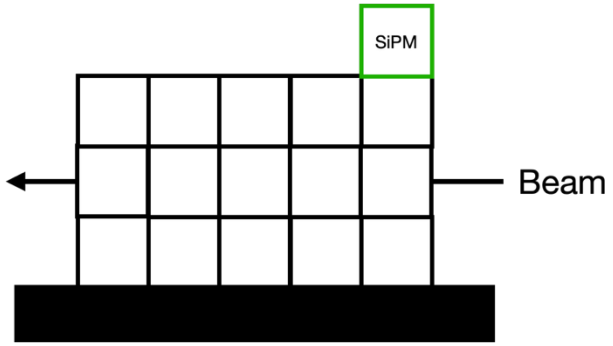


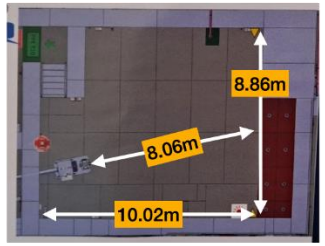


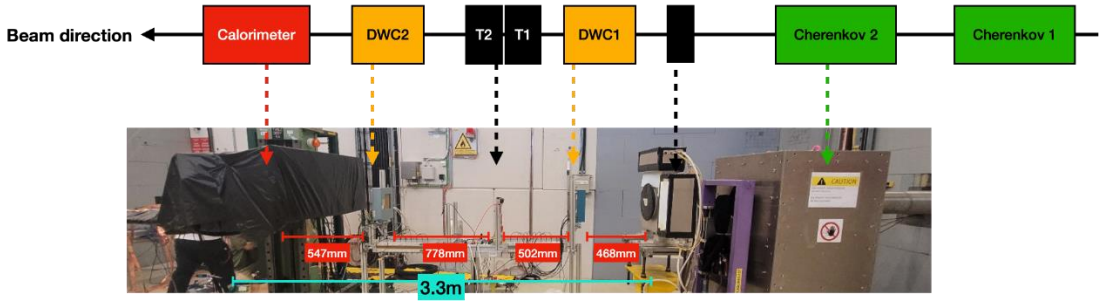




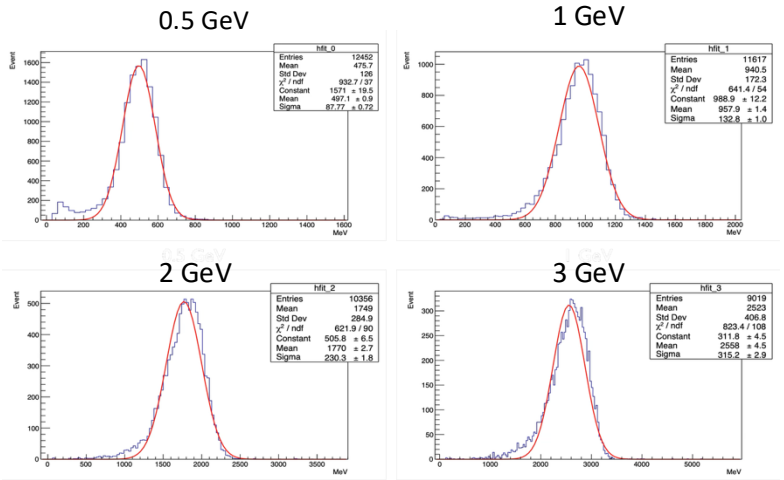




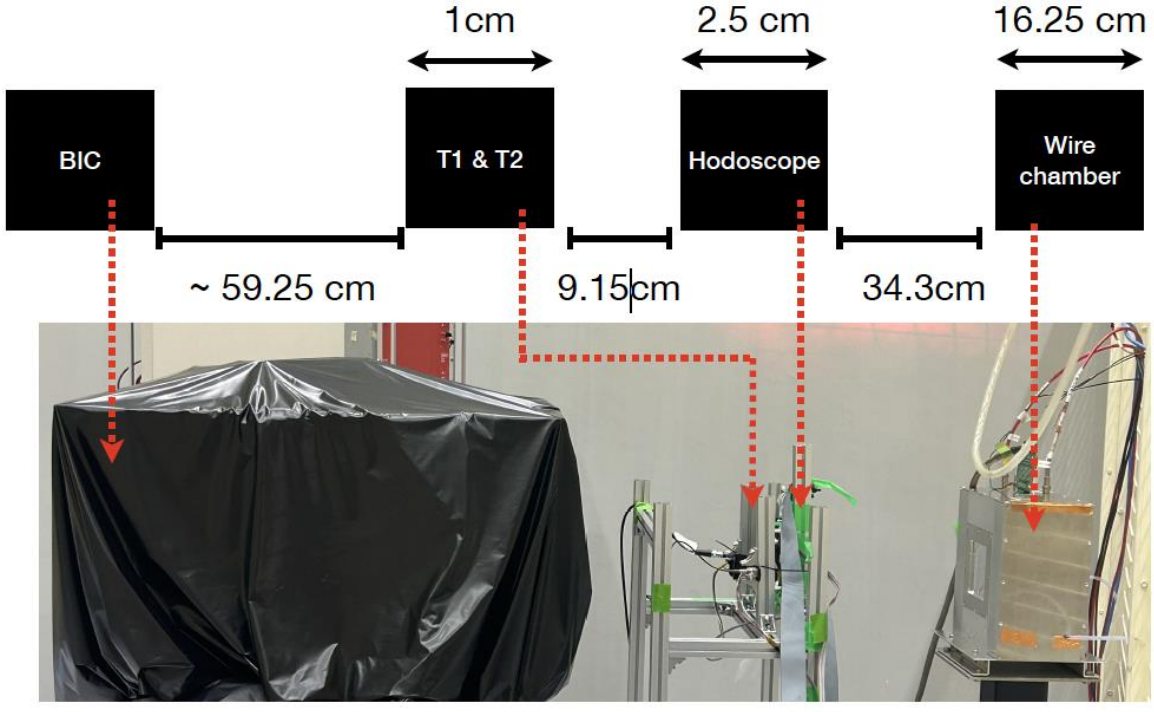


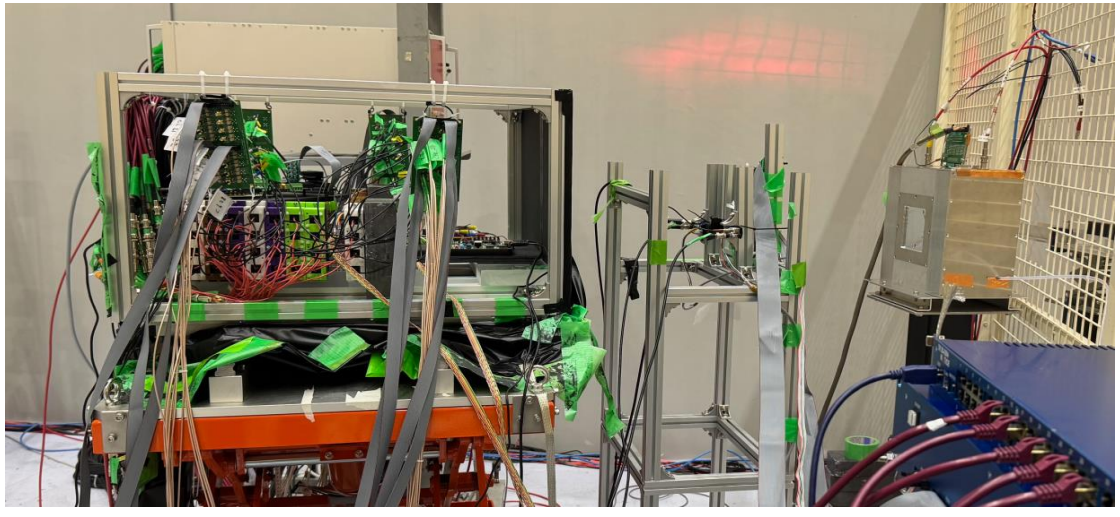


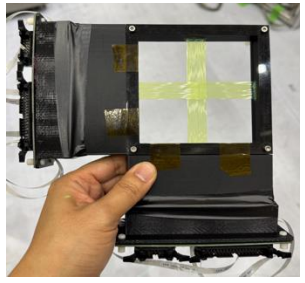
Successfully collected data from the prototype produced in Korea using our DAQ system for 0.5,1,2,3 GeV electron beams
17 participants from 5 institutions

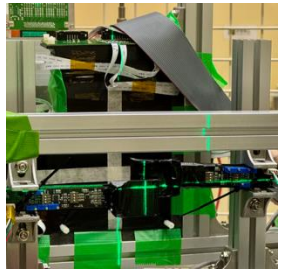


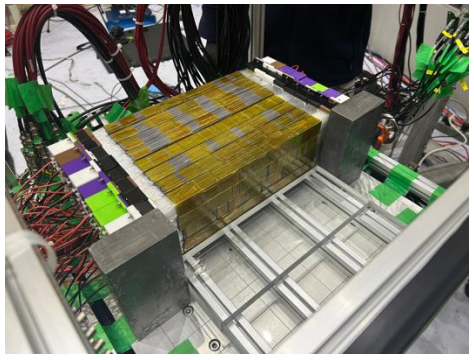
Second beam test in Mar 2025 at KEK PF-AR











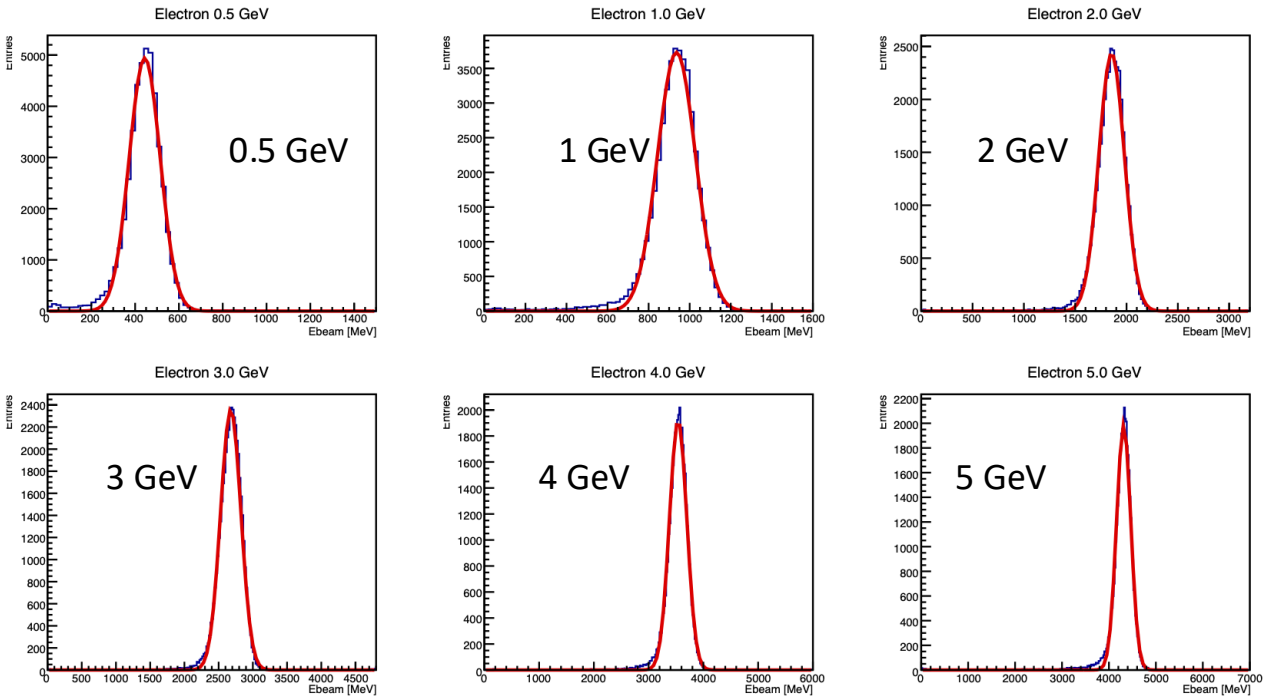
Detector setup

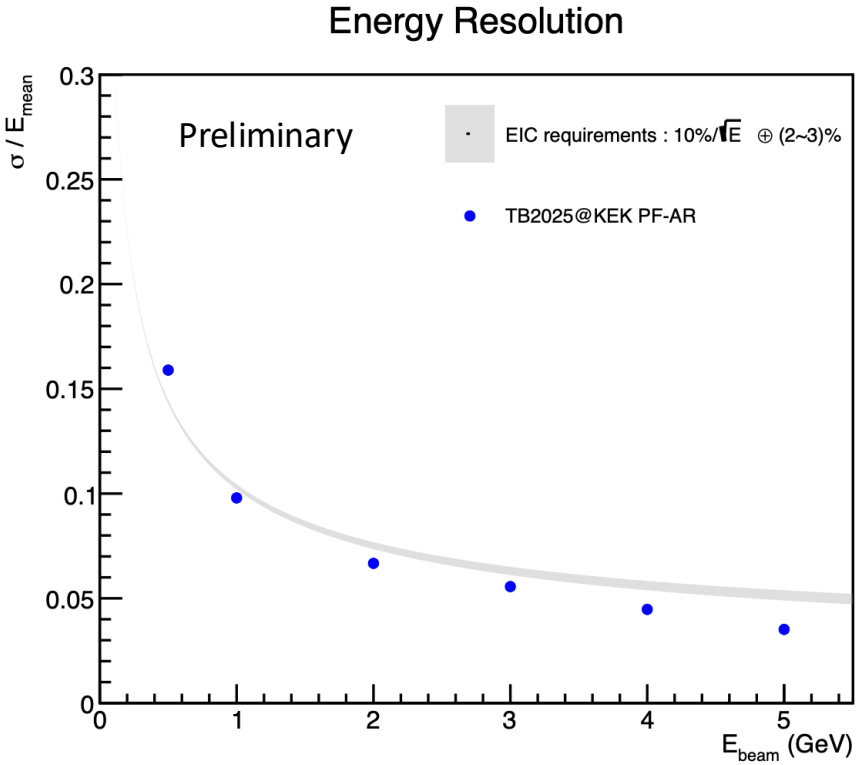
- Wire Chamber
- Hodoscope, Trigger
- Pb/SciFi Calorimeter

Program

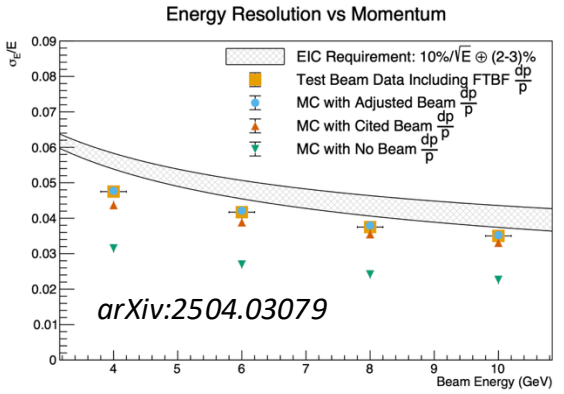
- Horizontal, vertical position scan.
- Calibration
- Energy response
- Position dependent energy response.
- Longitudinal (transverse) shower profile along modules
- Time (position) resolution by horizontal positions scan

Electron energy response of Pb/SciFi prototype

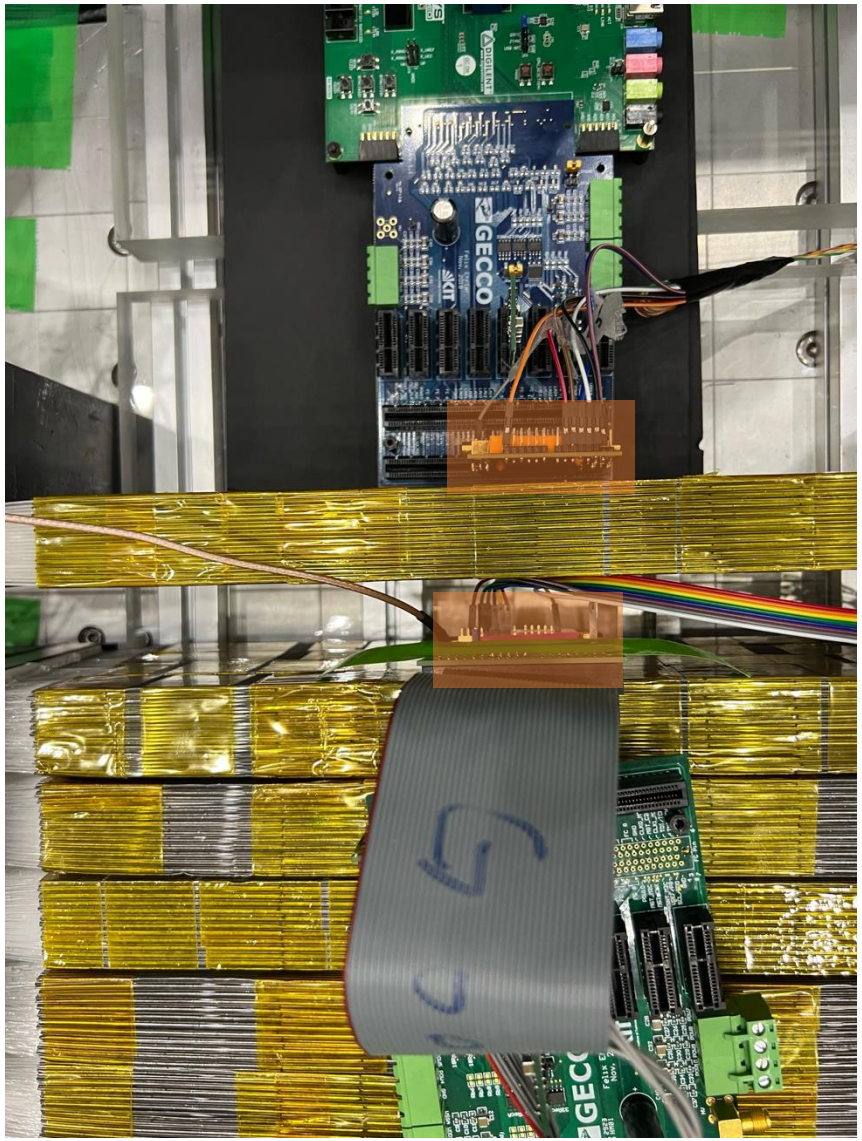


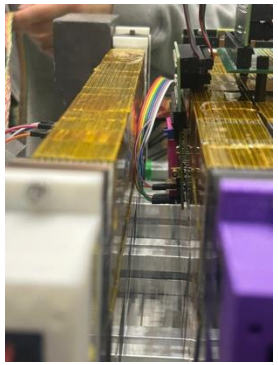


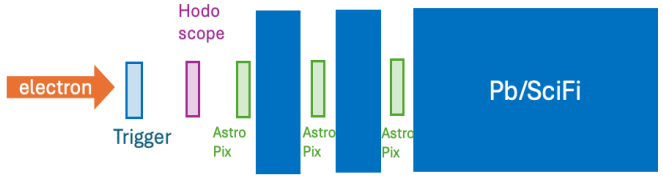
4x7 setup of 32x3x3cm^3 unit modules: 32x12x21cm^3 ~ 15.2X$_0$
Energy resolution below EIC requirement 10%⊕2~3% from 1 GeV
Below 5% at 4 GeV like baby-bcal result (including dp/p) (*arXiv: 2504.03079*)



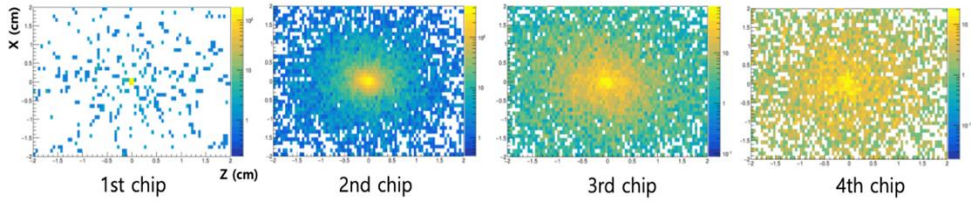
AstroPix data taking between Pb/SciFi layers







First data taking of AstroPix between Pb/Scifi prototype layers for BIC
Data taken using the GECCO + FPGA development board and our DAQ simultaneously



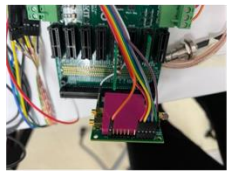
GEANT4 simulation using 0.5 GeV electron for intervened silicon pixel between Pb/SciFi prototype modules.
Detailed GEANT4 simulation will be intoduced in the poster by Changhui Lee (KNU)

Signal from silicon pixel to DAQ, FPGA

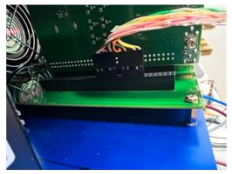
BIC_DAQ

TCB

▲BIC_DAQ & TCB



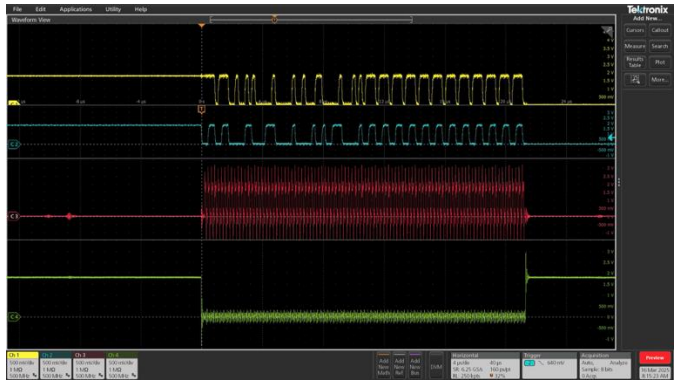
▲SPI pins@AstroPix



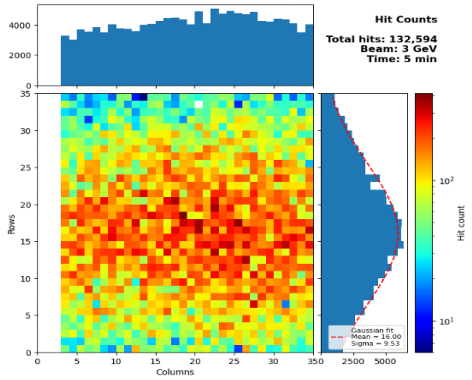
▲SPI ports@BIC_DAQ

FPGA, GECCO

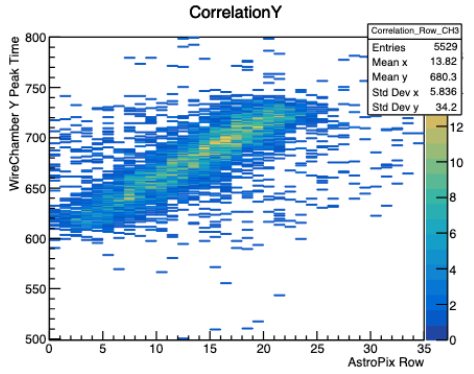
Hits on AstroPix chip were recorded in our DAQ and GECCO+FPGA development board setup simultaneously



Signal in the DAQ from the pins

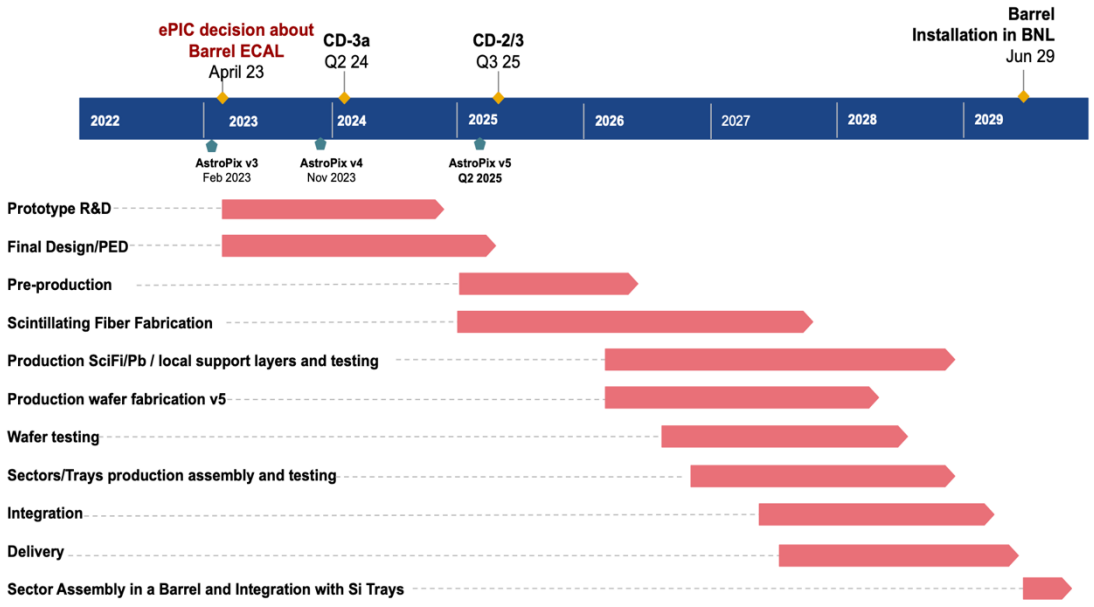


Signal through FPGA (in front of Pb/SciFi)

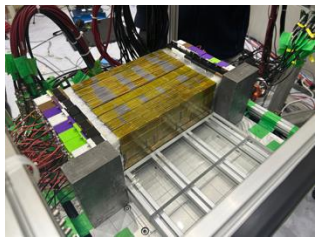


Initial look of correlation of beam position at AstroPix and drift time at Wire Chamber

Beam Test Plan



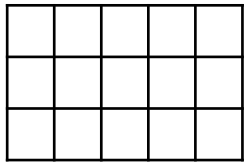
First piece in May 2024

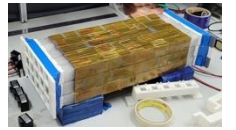


Mar 2025 at KEK

2024

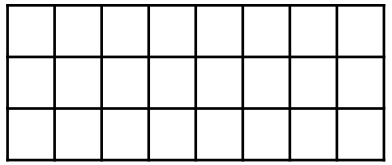
2024 Aug at CERN PS T10

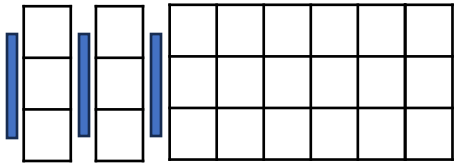




2025

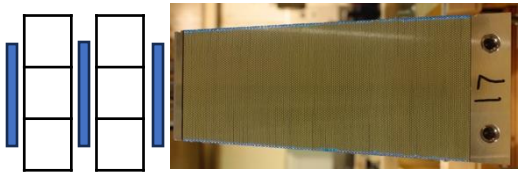
2025 Mar at KEK PF-AR

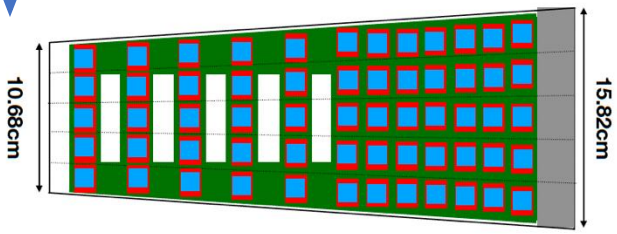




July 2025 at CERN PS T10

2026

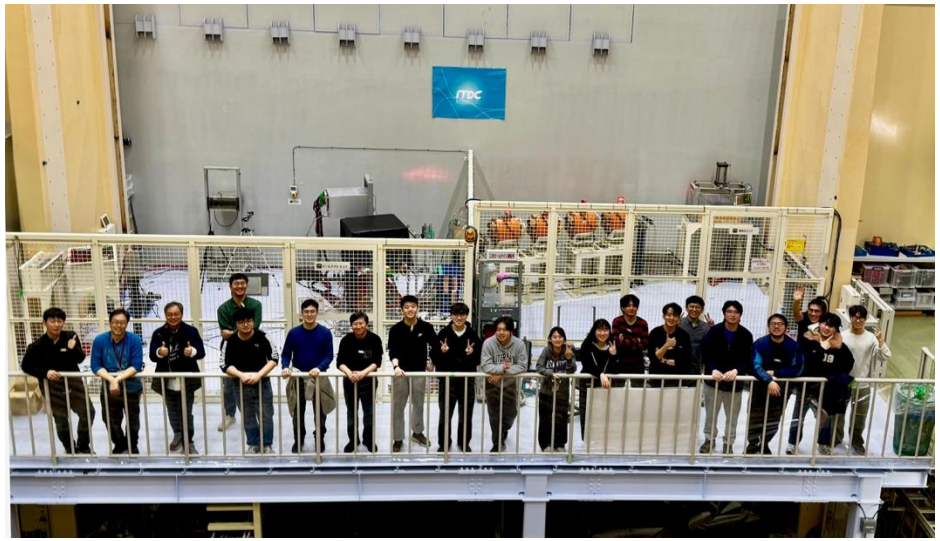




- 2025 and 2026 are critical years for system testing
- Beam test plan in 2025 at KEK, CERN
  - AstroPix+Pb/SciFi integrated system toward 3D shower imaging
  - Electron, Pion, Muon
- Beam test plan in 2026
  - Short (70cm) BIC sector prototype in full depth in preparation
  - HGCROC, Readout Box

Summary

- Barrel Imaging Calorimeter is a crucial detector for ePIC
- Korean group is actively working on AstroPix chip test, preparation for Pb/SciFi sector production, Readout Box, simulation, and system test.
- Korean group built Pb/SciFi prototype and formed a fantastic team through beam tests at CERN in Aug 2024 and KEK in Mar 2025
- Energy response of Pb/SciFi prototype looks good and integrated data actuisition of AstroPix between Pb/SciFi was succesful. We expect important progress in future beam tests.
- Related presentations
  - Talk by Sangwoo Park (SKKU) ‘Production of the prototype Pb/SciFi calorimeter of the Barrel Imaging Calorimeter for the Electron-Ion Collider’
  - Poster by Changhui Lee (KNU) ‘Beam test results and simulations of a prototype detector of the Barrel Imaging Calorimeter for the Electron-Ion Collider’



20 participants from 6 institutions in March 2025 at KEK PF-AR Testbeam