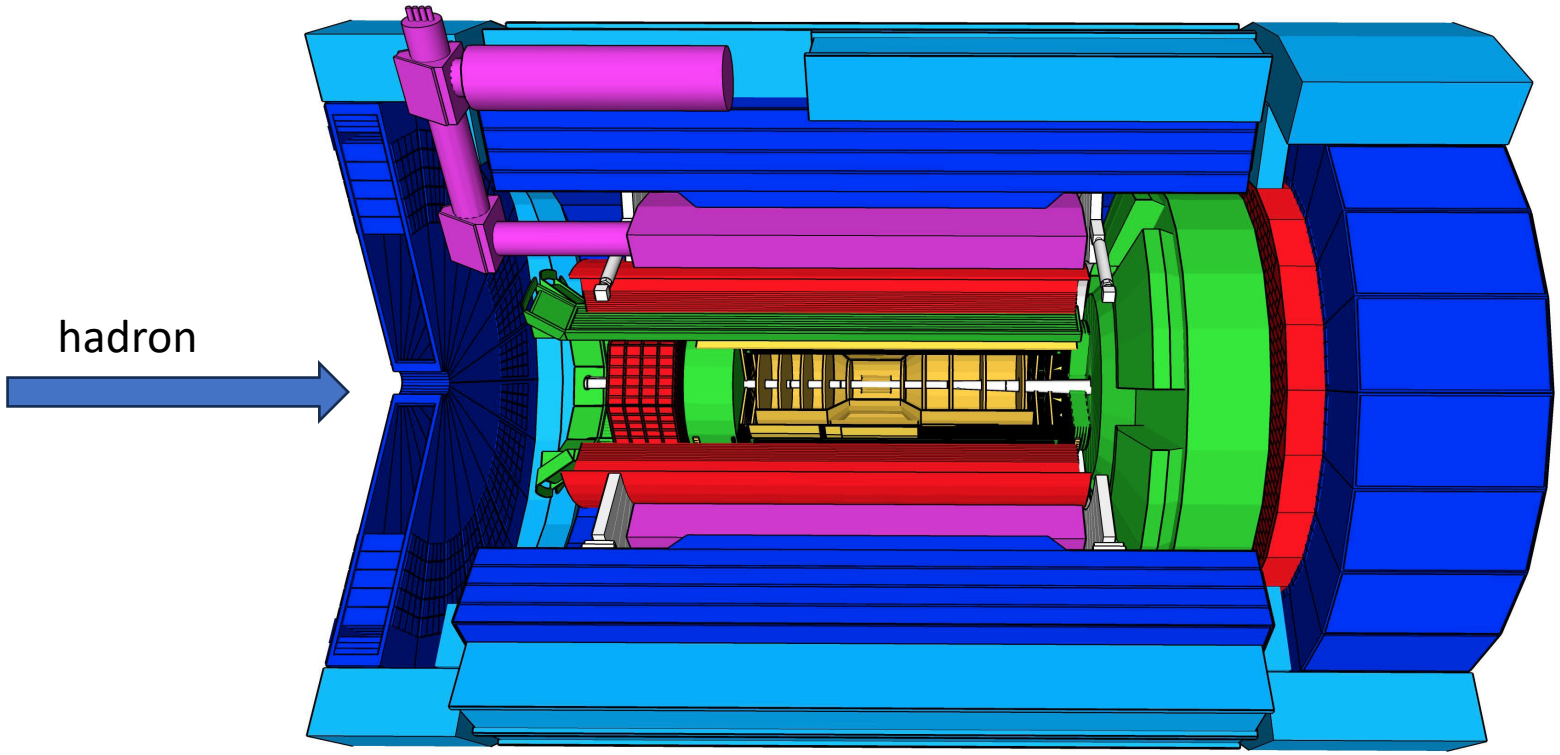
Recent development of the Barrel EMCal for the ePIC

The 4th EIC-Asia Workshop

July 2nd 2024

Jeongsu Bok (Pusan National University)

Detectors for ePIC



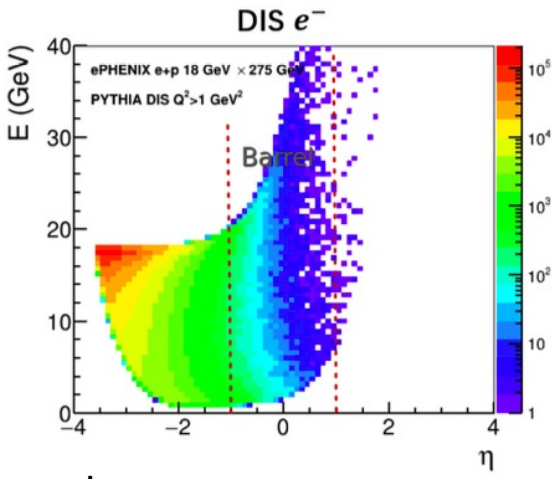
Magnet
Tracking
Particle Identification
Electromagnetic Calorimeter
Hadronic Calorimeter

Coverage

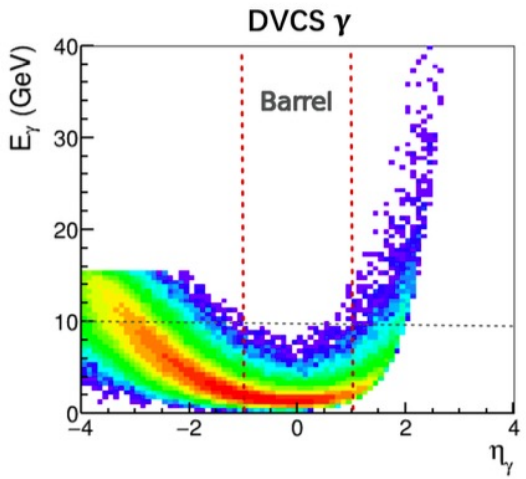
ϕ:360° 2°<θ<178° -4<η<4

EIC Calorimeter requirements

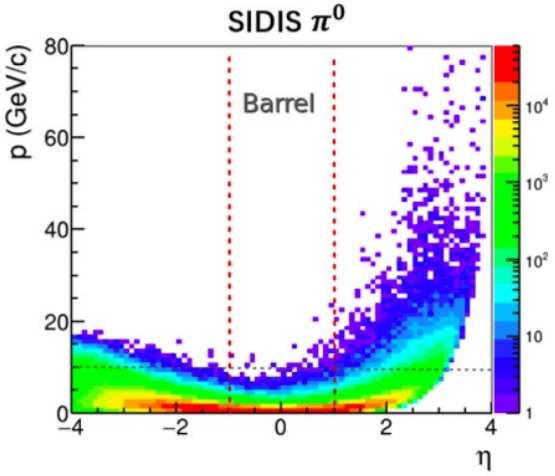
- EIC Yellow Report requirements for Barrel EM Calorimeter
  - Detection of electrons/photons to measure energy and position
  - Require moderate energy resolution $(7-10)\%/\sqrt{E} \oplus (1-3)\%$
  - Require electron-pion separation up to 10^4 at low momenta in combination with other detectors
  -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



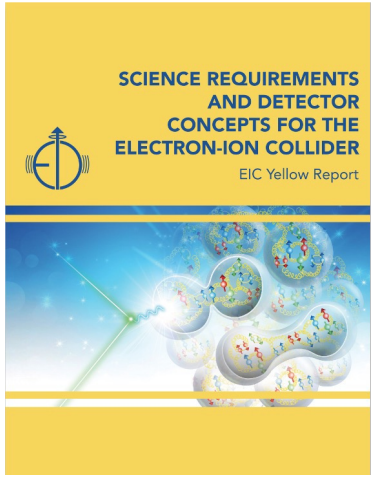
electron measurement in DIS process



γ measurement in DVCS process



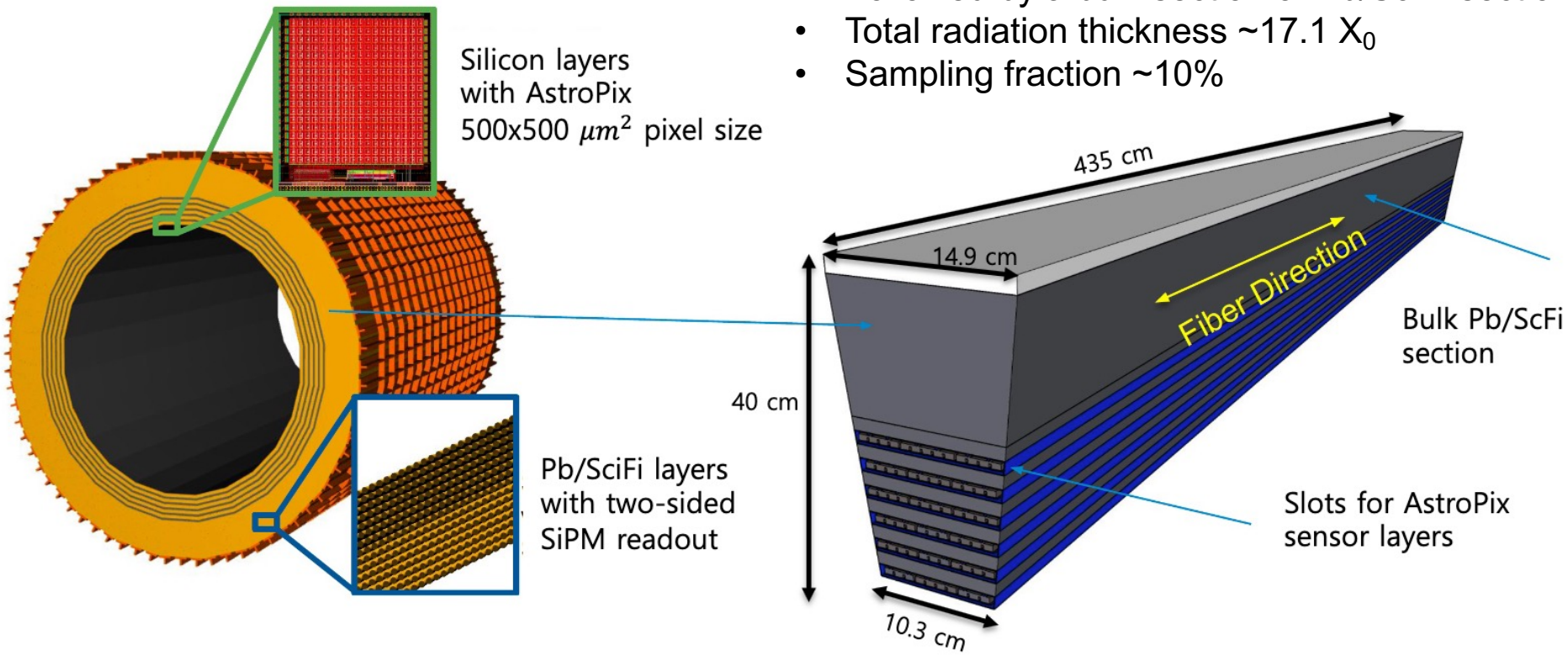
π^0 measurement in SIDIS process



Nucl.Phys.A 1026 (2022) 122447

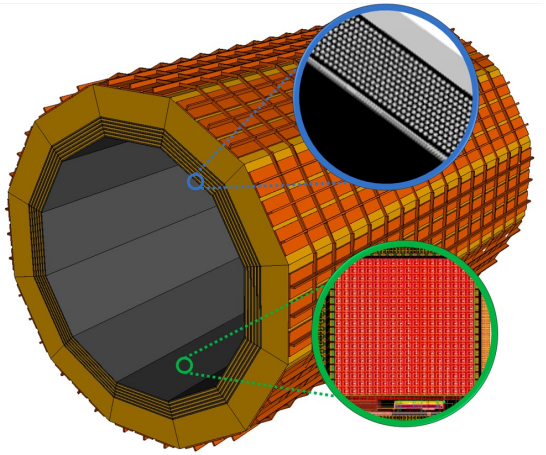
Barrel Imaging Calorimeter: Overview

- 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%

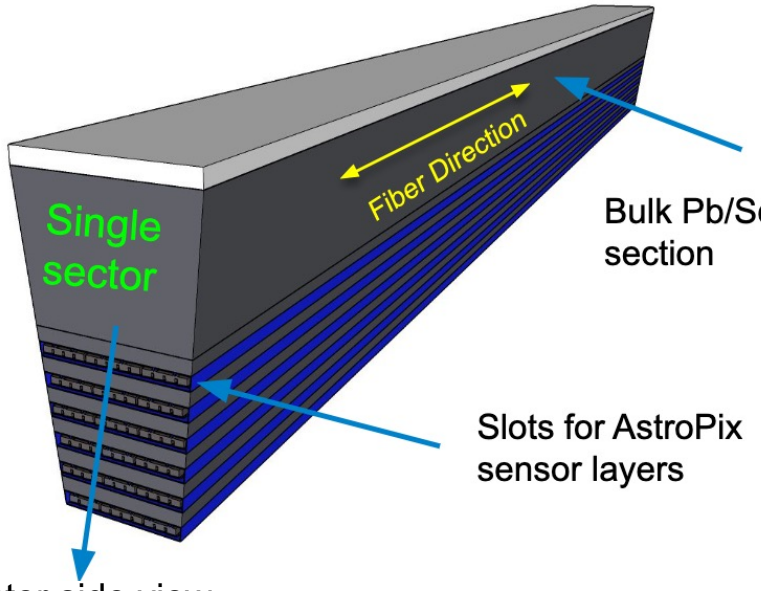


- Energy resolution: Primarily from Pb/SciFi layers (+ Imaging pixels energy information)
- Position resolution: Primarily from Imaging layers (+ 2-side Pb/SciFi readout and radial segmentation)

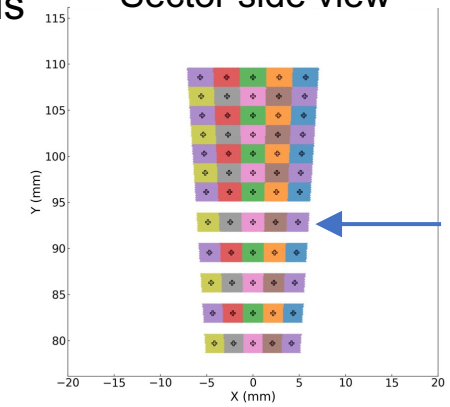
Detector Structure: Imaging Layer



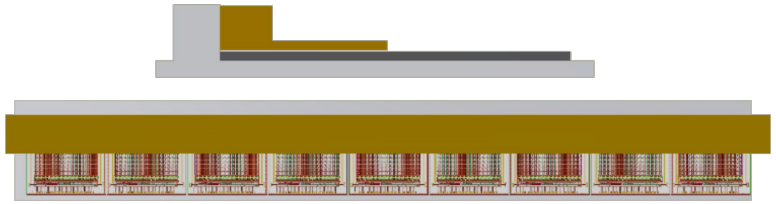
- Length: 432.5 cm
- Radius: ~ 80 cm radius
- Structure: 48 sectors
- -1.71 < η < 1.31



Sector side view



- Pb/SciFi Layer - 12 layers per sector
- Structure: 5 readout cells (one light-guide per readout cell)



Imaging Layer (Silicon Pixel)

- Module – Several AstroPix chips daisy-chained together on Flex PCB
- Length ~16 cm, Width ~2 cm
- Gaps < 200 μm
- Structure: ~ 8 chips/module

- AstroPix tracking layers to capture 3D image of shower development

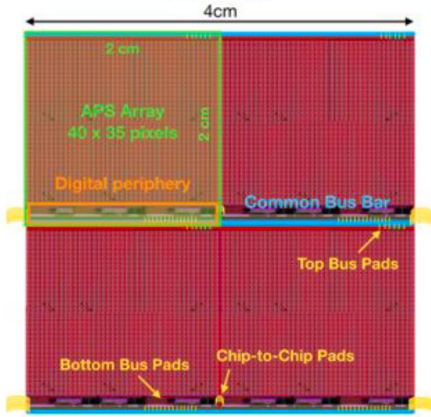
Imaging Layer: AstroPix

- Imaging layers based on AstroPix sensors
  - Developed for AMEGO-X NASA mission
  - CMOS sensor based on ATLASpix3 (arXiv:2109.13409)
- Key features:
  - Very low power dissipation
  - 500 μm pixel size
  - Time resolution ~3.25 ns

AstroPix chip R&D:

- v1 (4.5×4.5 mm2, 200 μm pixel)
  - Early prototype
- v2 (1×1 cm^2, 250 μm pixel)
  - Tested with ɣ, β sources, and 120 GeV proton beam
- v3 (2×2 cm^2, 500 μm pixel, quad chip)
  - Ongoing bench and beam test
  - Main prototyping with this chip version
- v4 (1×1 cm^2, 500 μm pixel)
  - better noise/threshold performance
- v5 (1.87x1.96 cm^2, 500 μm pixel)
  - Final production version for BIC

Quad chip v3



v3 carrier board

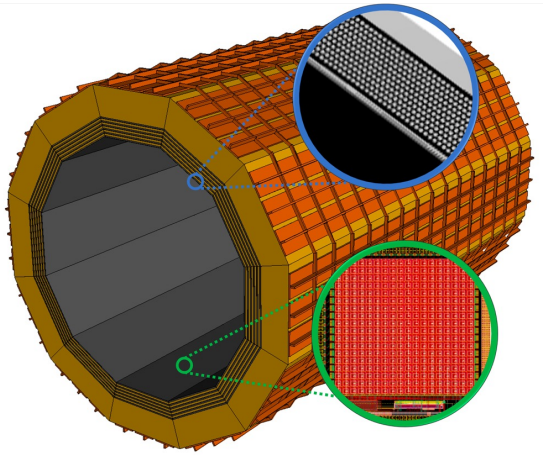
arXiv:2208.04990 **[astro-ph.IM]**

Targeted AstroPix performance goals

Pixel size	$500\,\mu m \times 500\,\mu m$
Power usage	< 1 mW/cm^2
Energy resolution	10% @ 60 keV (based on the noise floor of 5 keV)
Dynamic range	~ 700 keV
Passive material	$< 5\%$ on the active area of Si
Time resolution	25 ns
Si Thickness	$500\,\mu m$

Total number of 2x2 cm^2 chips: 249,600 **~100 m^2**

Detector Structure: Pb/SciFi Layer



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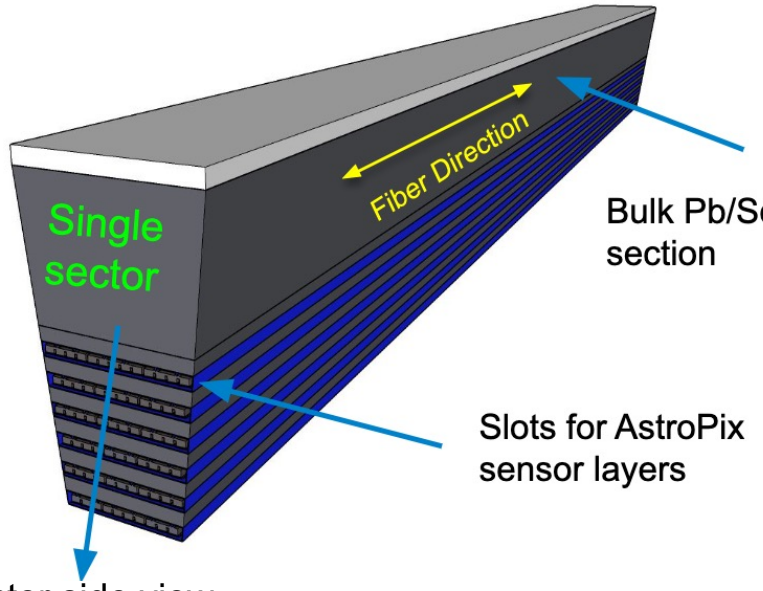
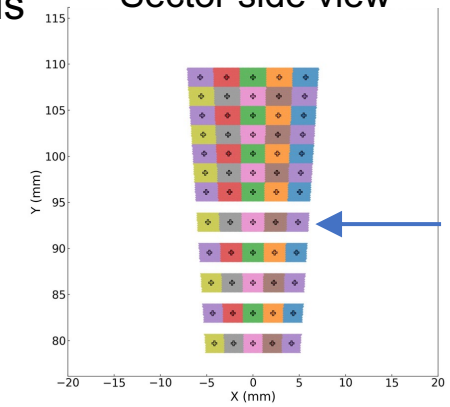
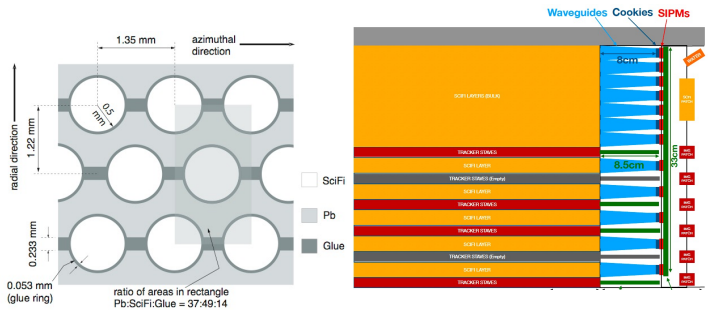
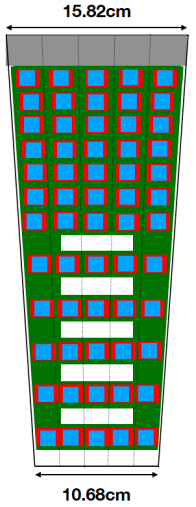


Sector side view



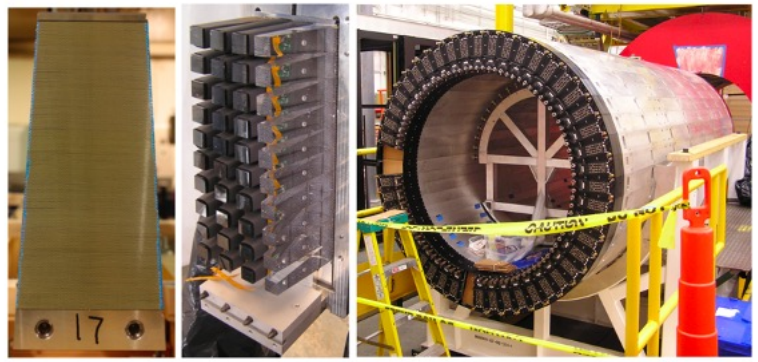
- Pb/SciFi Layer - 12 layers per sector
- Structure: 5 readout cells (one light-guide per readout cell)
- Construction: 17 rows of fiber





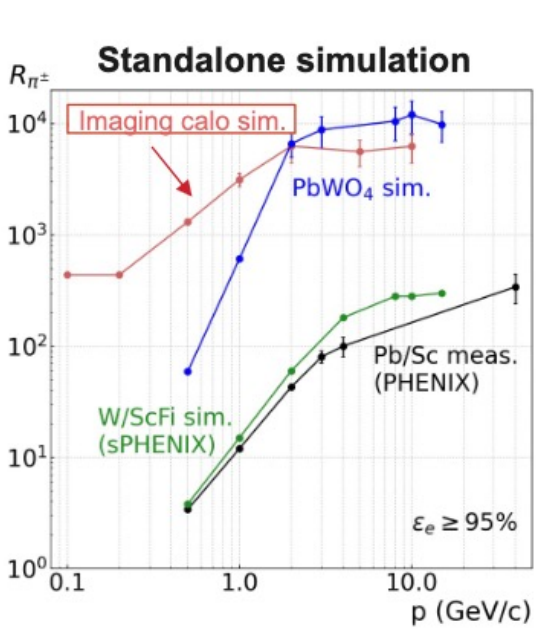
Pb/SciFi Layer

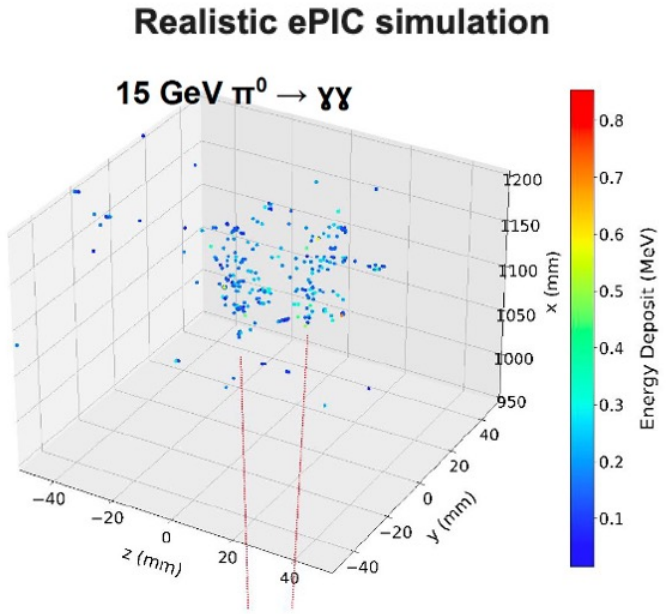
- 2-sided SiPM readout
- Lightguides on sector sides
  - inner surface ~2×2 cm^2
  - output face 1.3×1.3 cm^2
- 12 layers x 5 cells x 2 sides x 48 sectors = 5760 channels

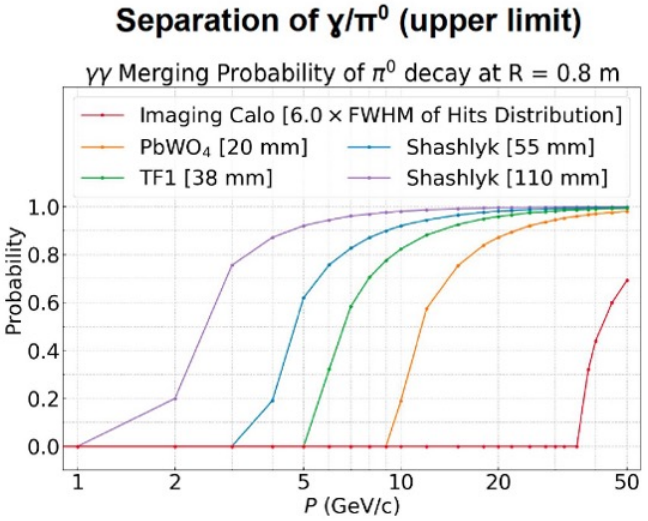


GlueX Pb/SciFi sampling calorimeter

BIC Performance

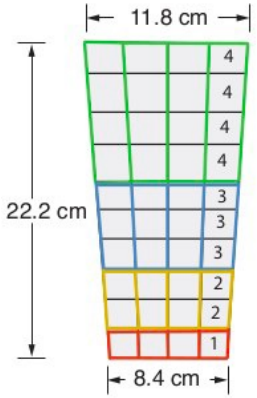


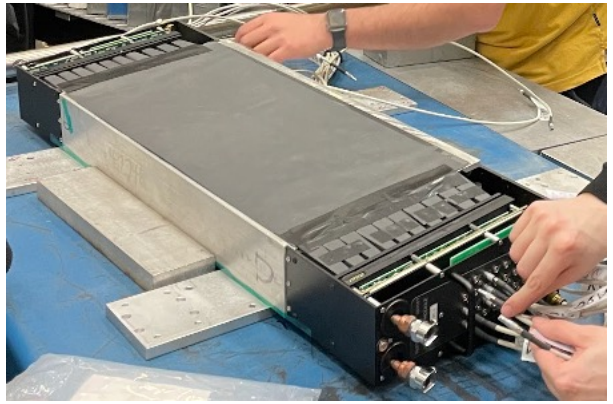


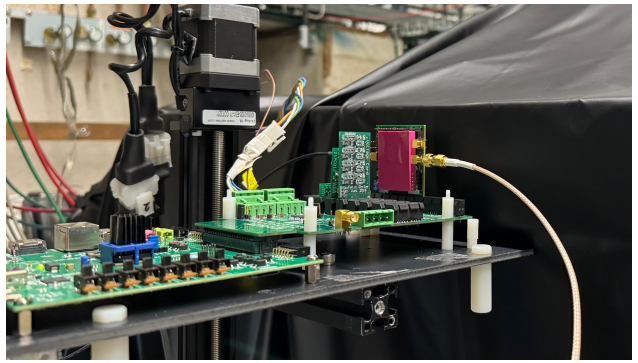


- Separation of electrons from background in Deep Inelastic Scattering processes
  - Method: E/p cut (Pb/ScFi) + Neural Network using 3D position and energy info from imaging layers
- Discriminate between π^0 decays and single γ from DVCS, identification
  - Precise position resolution allows for excellent separation of γ/π^0 based on 3D shower profile
  - Separation of two γ from π^0 well above required 10 GeV

Beam Test at FTBF

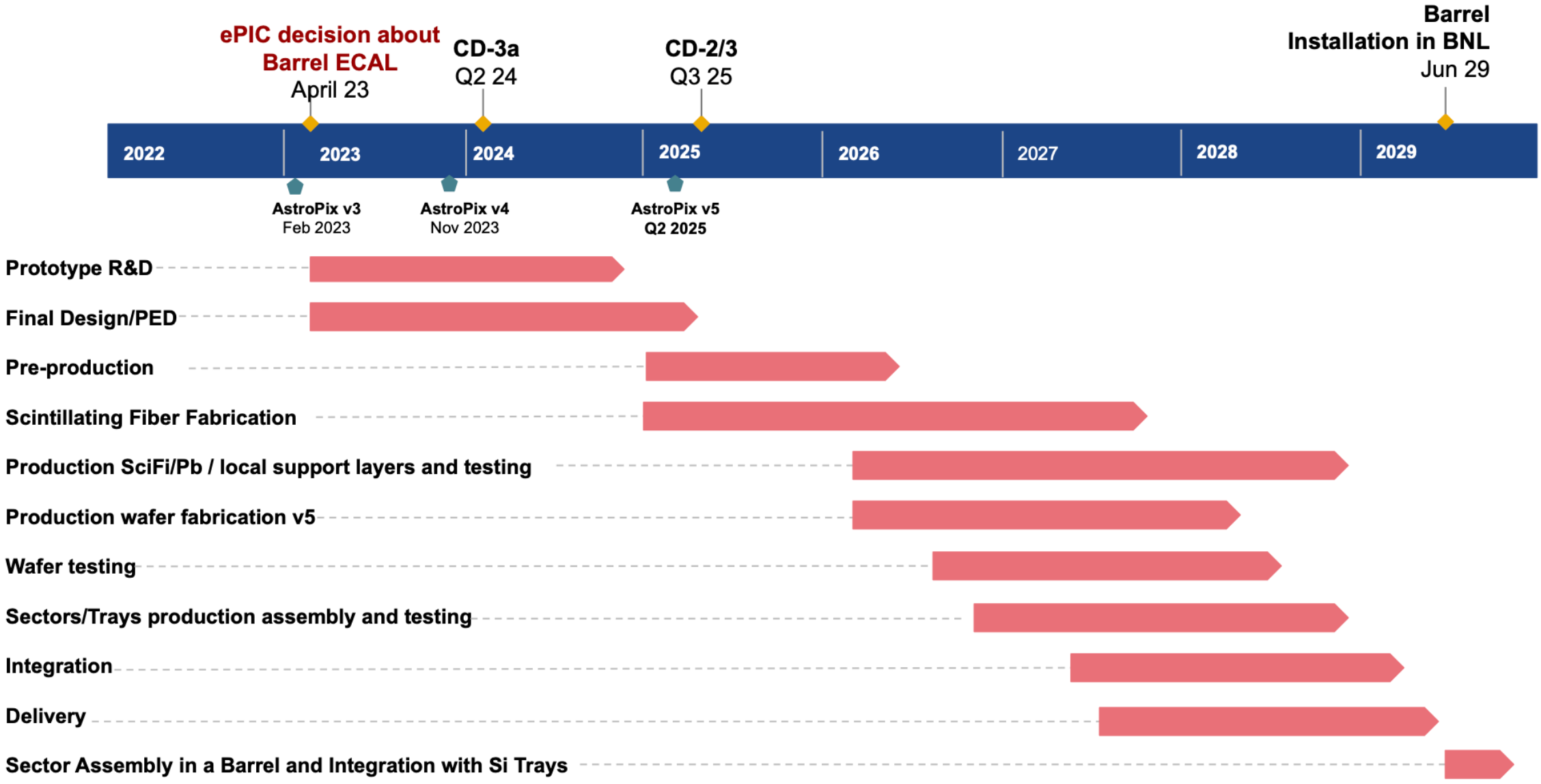






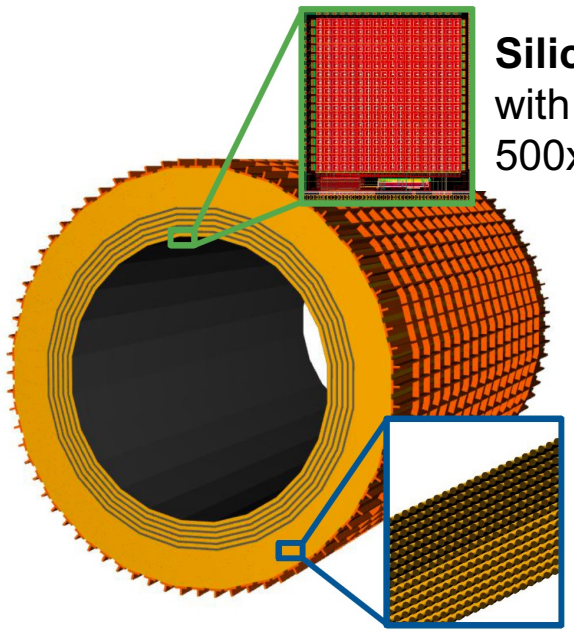
June 2024
AstroPix + BabyBcal
120 GeV proton beam at Fermilab

BIC: Schedule



BIC activity in Korea

Korean institutions for the BIC



Silicon layers
with AstroPix
500x500 μm^2 pixel size

Pb/SciFi layers
with two-sided
SiPM readout

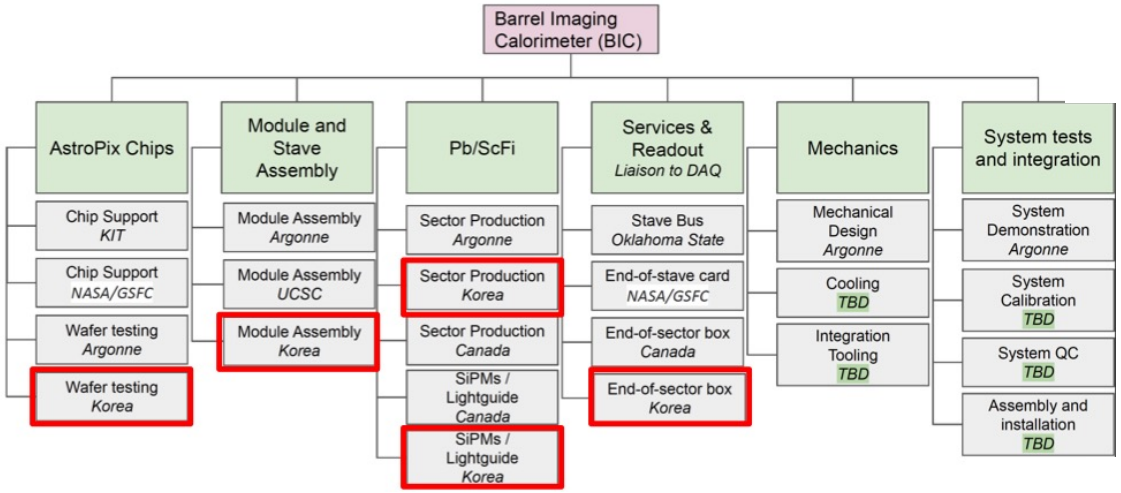
USA
- Argonne National Laboratory
- NASA Goddard Space Flight Center
- Oklahome State University
- University of Connecticut
- University of California Santa Cruz

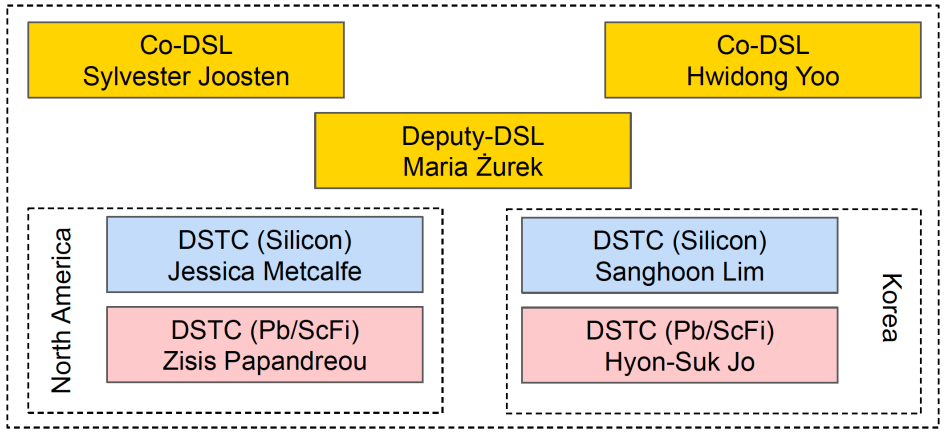
Canada
- University of Manitoba
- University of Regina
- Mount Allison University
- NSERC
- Canada Fund for Innovation

Korea
- Kyungpook National University
- Yonsei University
- University of Seoul
- Pusan National University
- Korea University
- Sungkyunkwan University
- Hanyang University
- Gangneung-Wonju National University

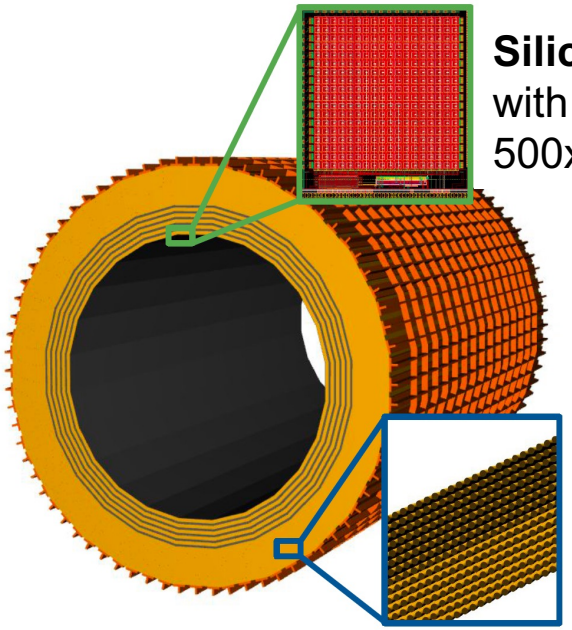
Germany
- Karlsruhe Institute of Technology
- University of Giessen

ePIC BIC Detector Subsystem Collaboration



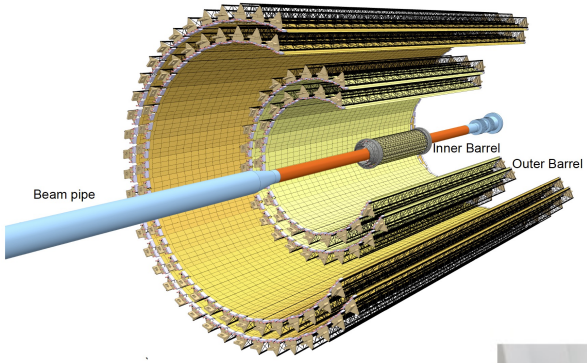


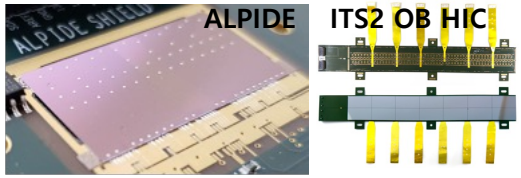
Korean institutions for the BIC: Silicon

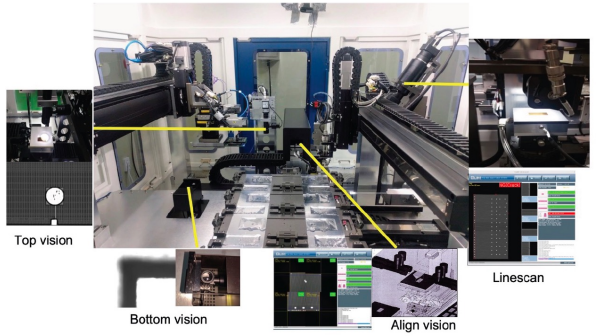


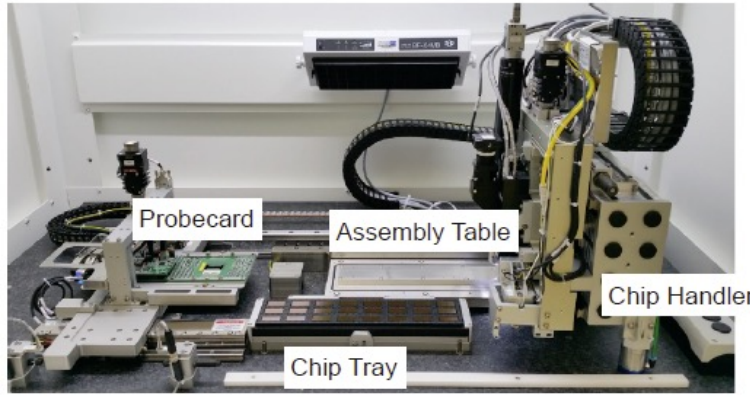
Silicon layers
with AstroPix
500x500 μm^2 pixel size

Pb/SciFi layers
with two-sided
SiPM readout





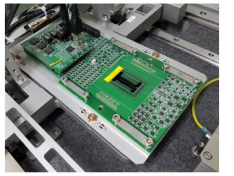


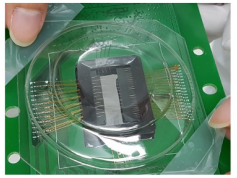


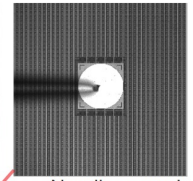
Expertise in Silicon Detector R&D

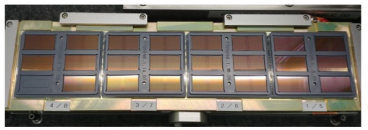
Silicon trackers for ALICE

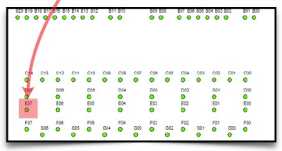
Mass chip test and module production for ALICE ITS2
Continue in ITS3 and ALICE3


Probecard

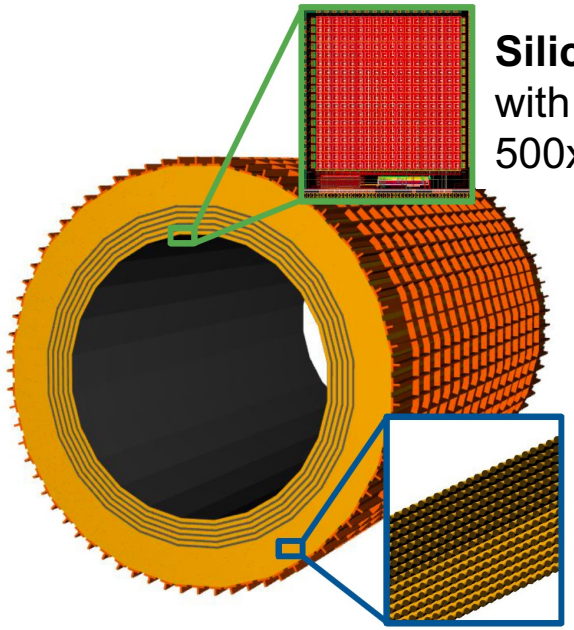

Needles of Probecard
67 needles to contact


Needle on pad


23 of ALPIDE Chips in Tray

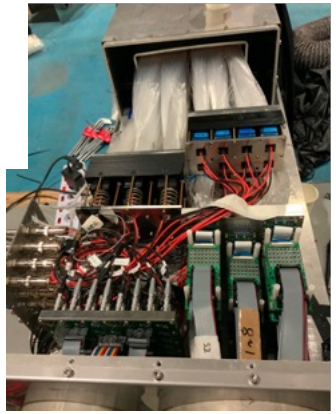

Pads on ALPIDE

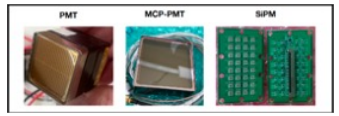
Korean institutions for the BIC: Calorimeter



Silicon layers
with AstroPix
500x500 μm^2 pixel size

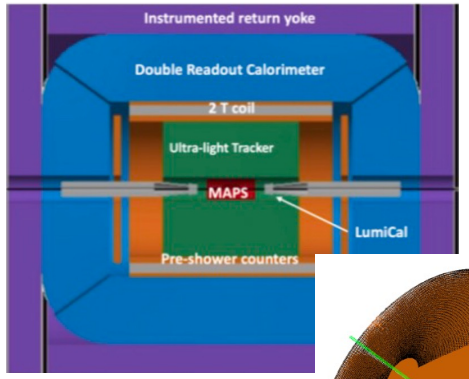
Pb/SciFi layers
with two-sided
SiPM readout

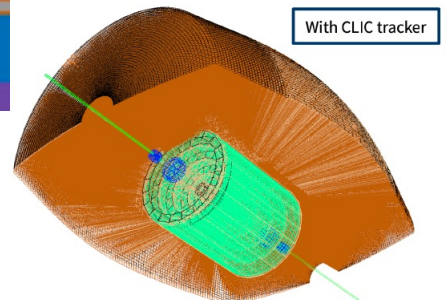


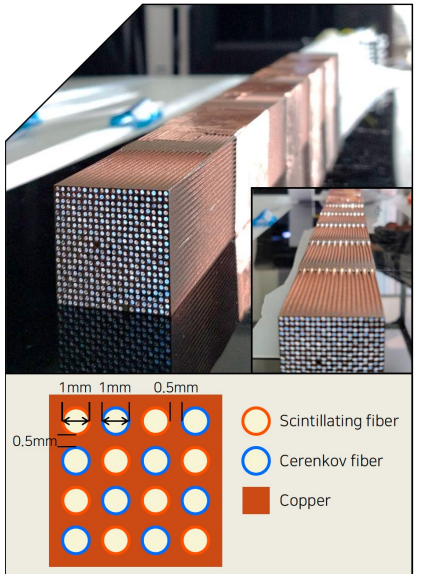


Testbeam with various module types:
2022 (CERN SPS), 2023 (CERN PS),
2024 (CERN SPS)

Dual-Readout Calorimeter



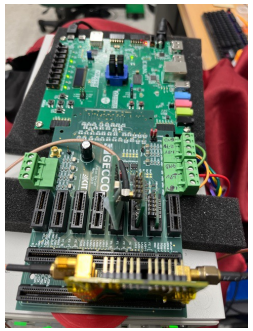


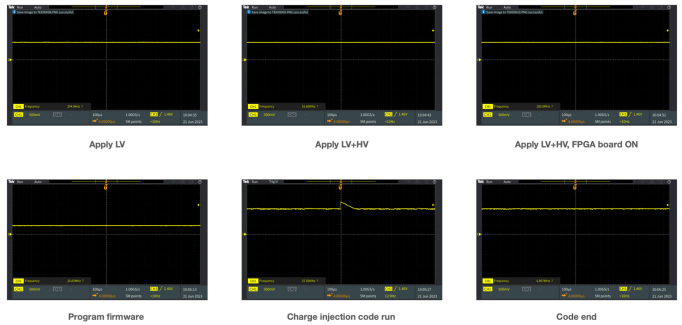


Expertise in Calorimeter

Dual-Readout Calorimeter
Scintillating + Cherenkov Fiber

BIC in Korea: Silicon



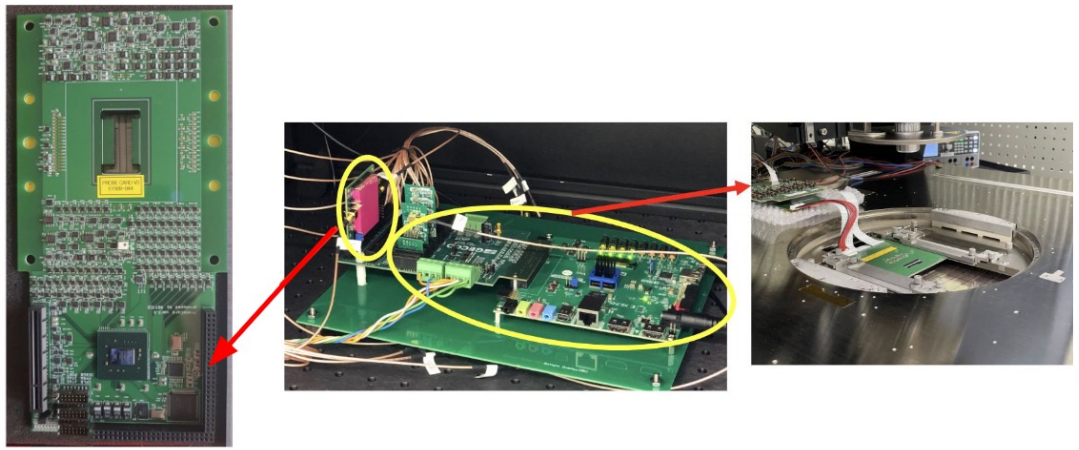


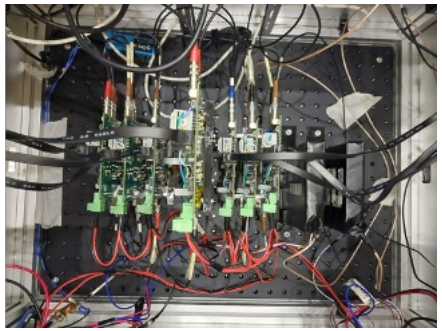
Chip test

- Initial discussion with C-ON Tech and NOTICE
- Based on the design files of the single-chip carrier board of AstroPix v3, a probe card design begins
- Plan to make a probe card for AstroPix chip as the exact dimension of ITS2 ALPIDE to utilize the probe station
- Plan for wafer-level chip test for the BIC AstroPix

Testbench with AstroPix

- Built a testbench and performed a basic operation with charge injection

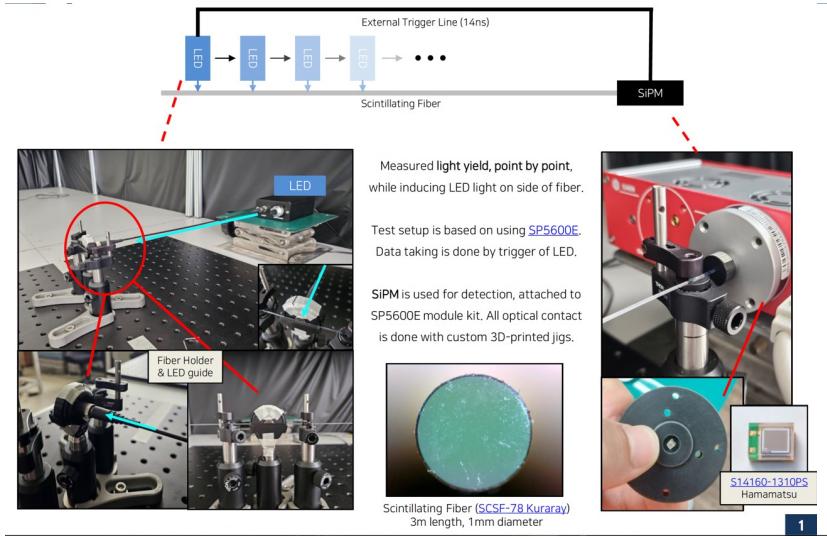


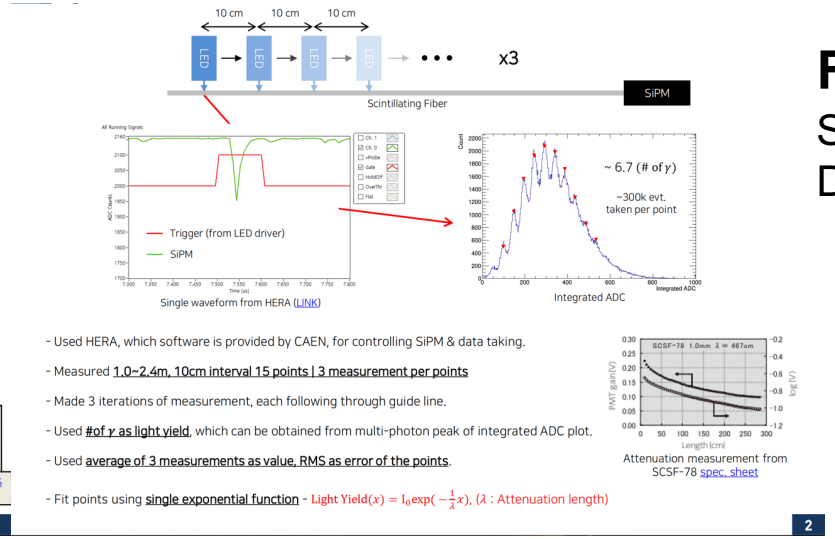


Testbeam with ALPIDE telescope

- 6 ALPIDE layers for reference tracks: Excellent tracking with position resolution of 5um
- DUT (AstroPix v3 or v4): Position resolution and hit efficiency

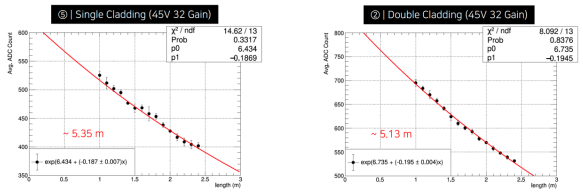
BIC in Korea: Pb/SciFi





Fiber Attenuation Measurement

Single and double cladding
Developing automated process

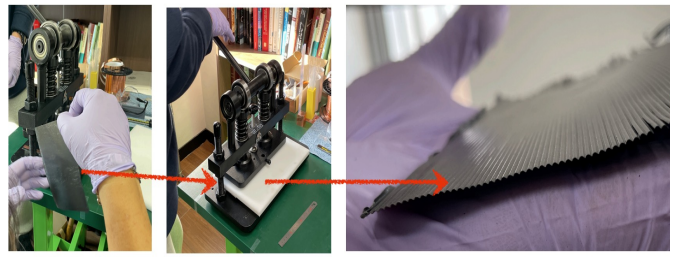


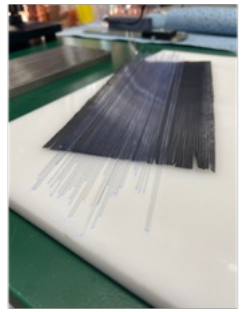
	SC	DC
Avg.	5.19 m	4.87 m
Stdev.	0.45 m (~9%)	0.18 m (~4%)

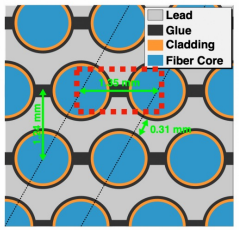
Measured Attenuation length

Prototype Pb/SciFi production

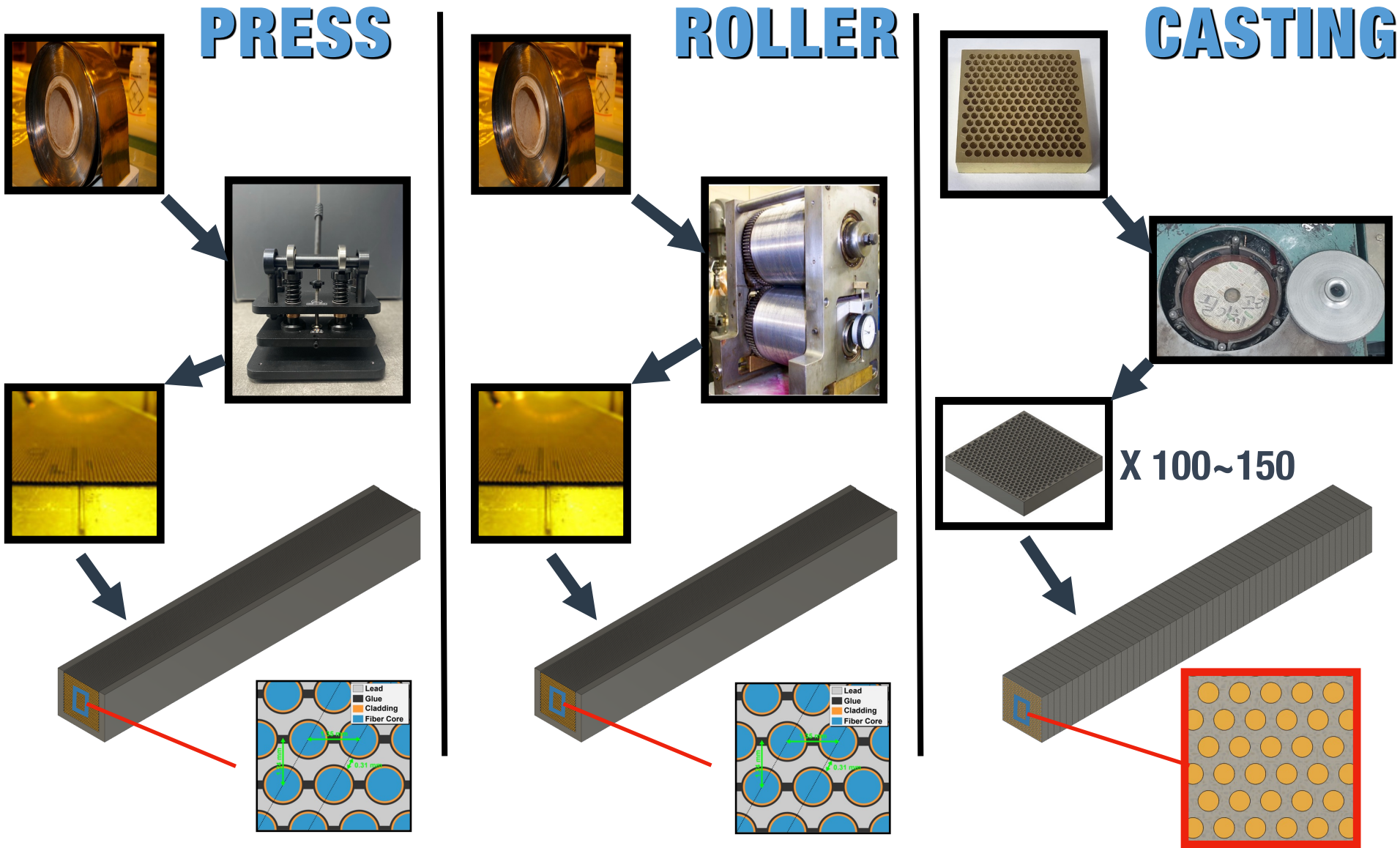
A similar design to the GlueX prototype
Under development of processing Pb layers
Prototype can be used for further developing read-out box and testing with silicon layers



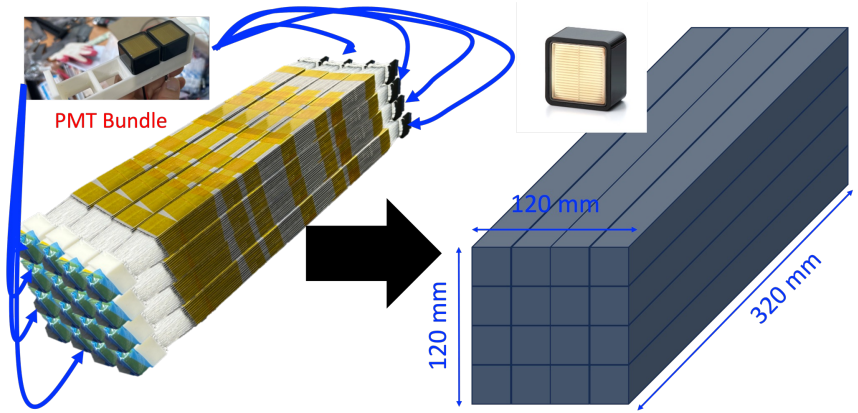




BIC in Korea: Pb/SciFi

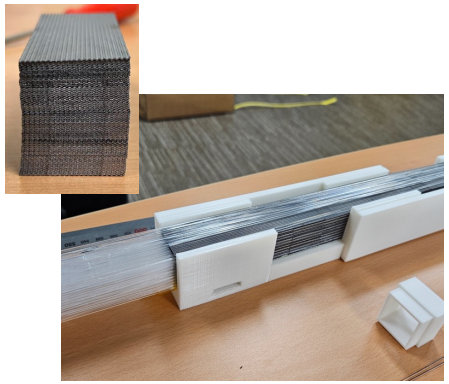


BIC in Korea: Prototype Beamtest

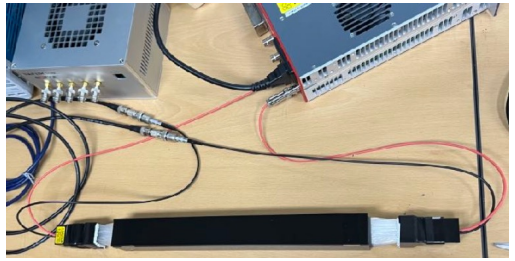


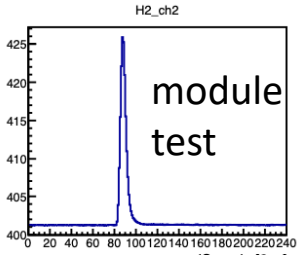
Real configuration

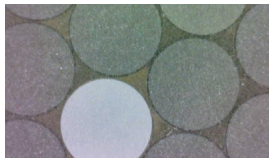
Schematic view



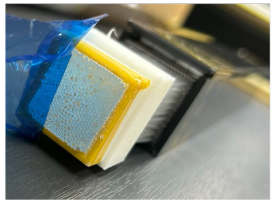
stacking

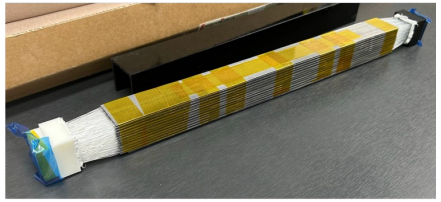




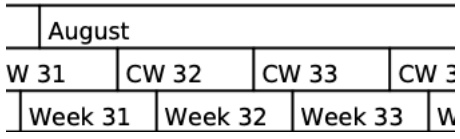


polishing

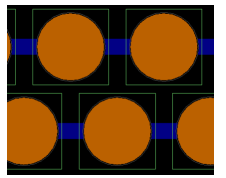


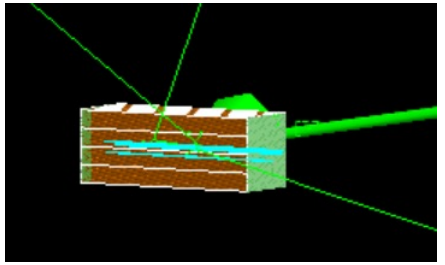


unit module

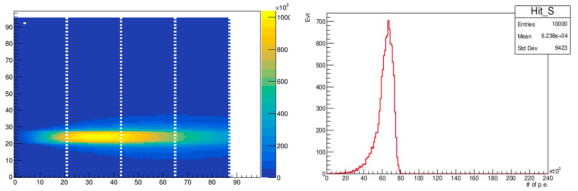


- Beamtest at PS T10 is scheduled in August 7~14th
  - AstroPix & Pb/SciFi + PMT, SiPM readout
- Looking for another opportunity in Fall
  - Starting from 32x12x12 cm^3
  - Eventually, 32x36x36 cm^3 to contain enough fraction of shower





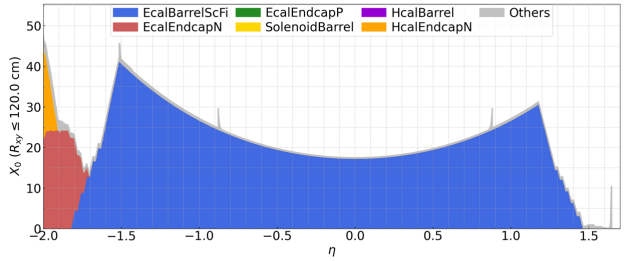
GEANT4 for this prototype



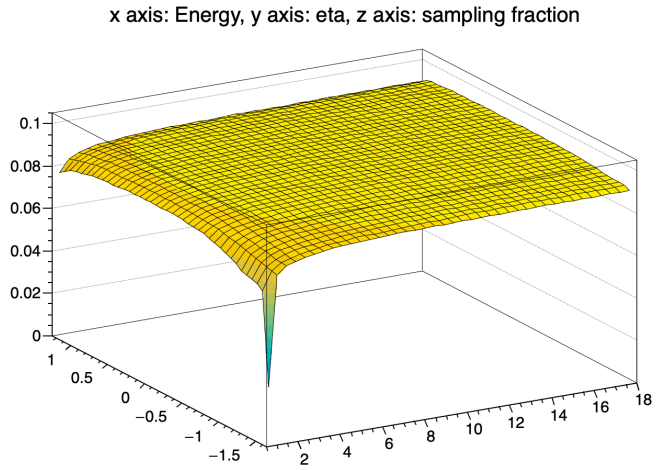
BIC in Korea: Simulation

Simulation development for TDR

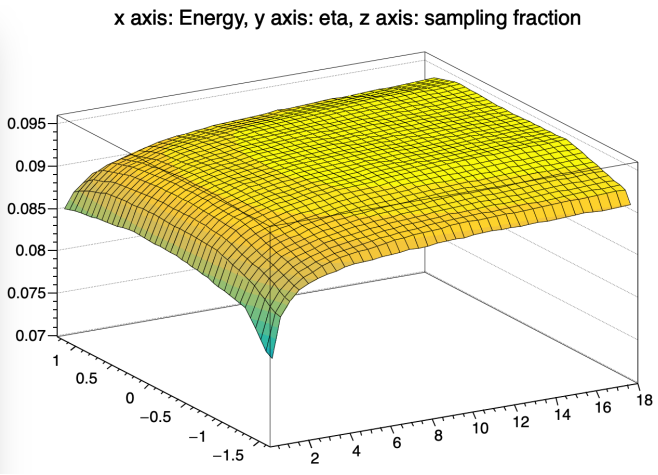
Detailed geometry implementation and performance study
e.g., realistic silicon module, sampling fraction, material scan, light guide…



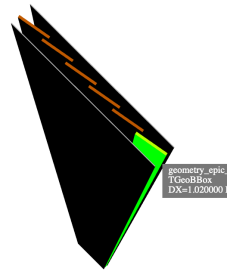
Material scan and overlap check



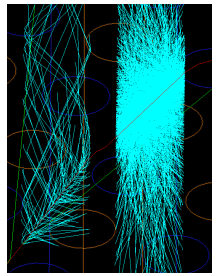
electron



photon



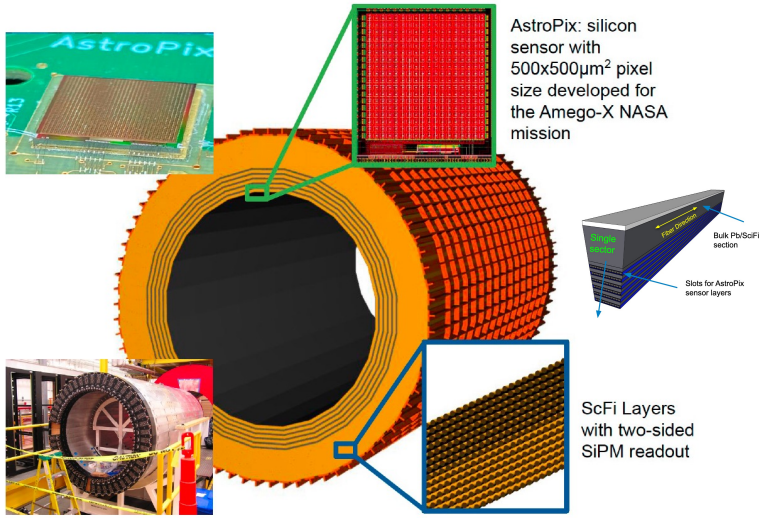
Geometry implementation



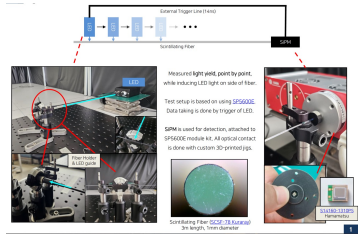
Optical photon simulation in DRC

Summary

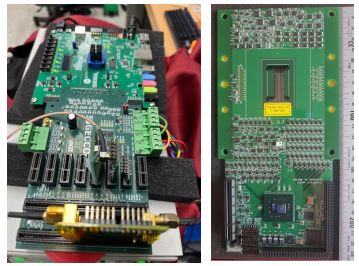
Barrel Imaging Calorimeter



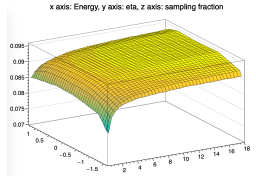
Recent Activity in Korea



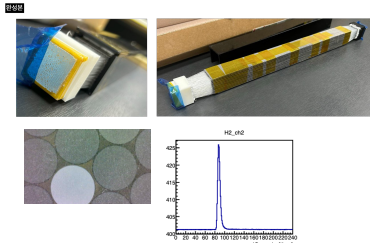
Attenuation length



Chip test preparation



Simulation



Beamtest in Aug.

- Barrel Electromagnetic Calorimeter is an important detector for ePIC
  - Imaging layer with AstroPix sensor and Pb/SciFi layer
- Performance of the Barrel Imaging Calorimeter fulfill the requirement
  - Electron-pion separation, pion/gamma reconstruction, energy resolution
- Korean instutions are actively participating in the BIC R&D.
  - 8 Korean institutions and 10 faculties
  - Expertise in ALICE silicon pixel, Dual Readout Calorimeter
  - Recent activity and Plan: silicon chip test and module assembly, Pb/SciFi R&D, Detector simulation

USA: Argonne National Laboratory; NASA Goddard Space Flight Center; Oklahome State University; University of Connecticut; University of California Santa Cruz

Canada: University of Manitoba; University of Regina; Mount Allison University; NSERC; Canada Fund for Innovation

Korea: Kyungpook National University; Yonsei University; University of Seoul; Pusan National University; Korea University; Sungkyunkwan University; Hanyang University; Gangneung-Wonju National University

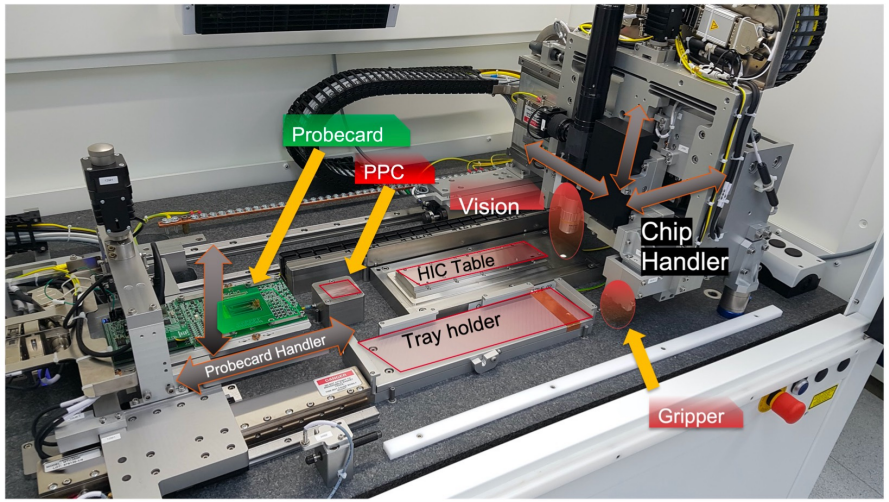
Germany: Karlsruhe Institute of Technology; University of Giessen

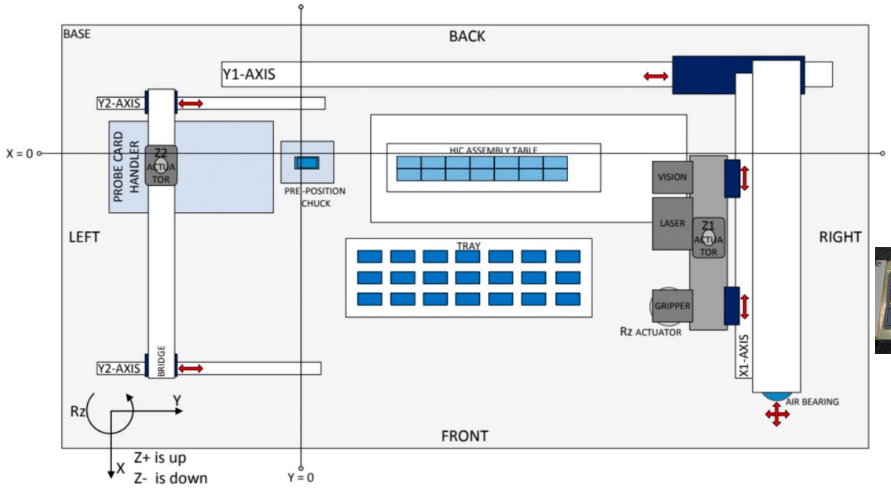
ePIC BIC Detector Subsystem Collaboration

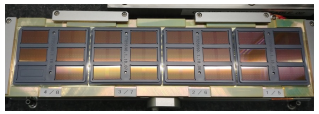
Thank You!

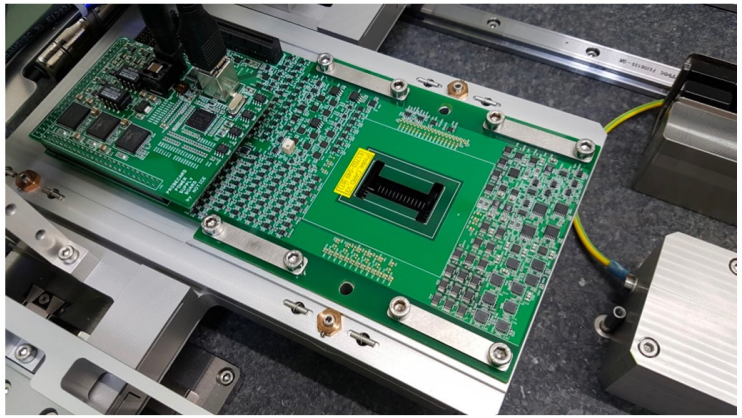
Backup slides

Chip Test Machine (ALICE ITS2, ALICIA)



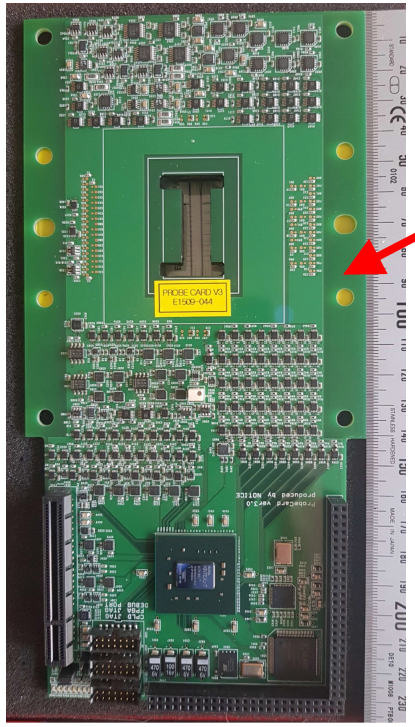




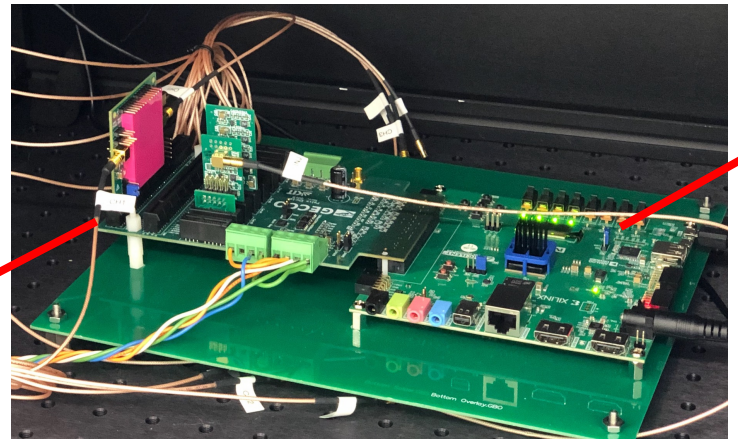


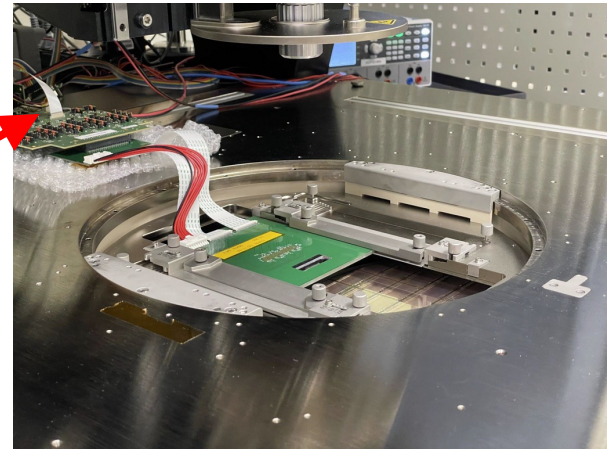
- Dummy AstroPix chips with bonding pads
- With a new tray, the operation of the chip handler can be customized for AstroPix
- Wafer-level chips can be also used for the wafer probe later

Probecard for AstroPix



Probecard for ALPIDE





- Initial version for AstroPix v3: a simple version for the carrier card only
- Considering the same dimension as the ITS2 probe card to utilize the ALICIA machine for the initial test
- GECCO and FPGA development boards can be connected with flexible cables

Wafer Testing for ALICE ITS3