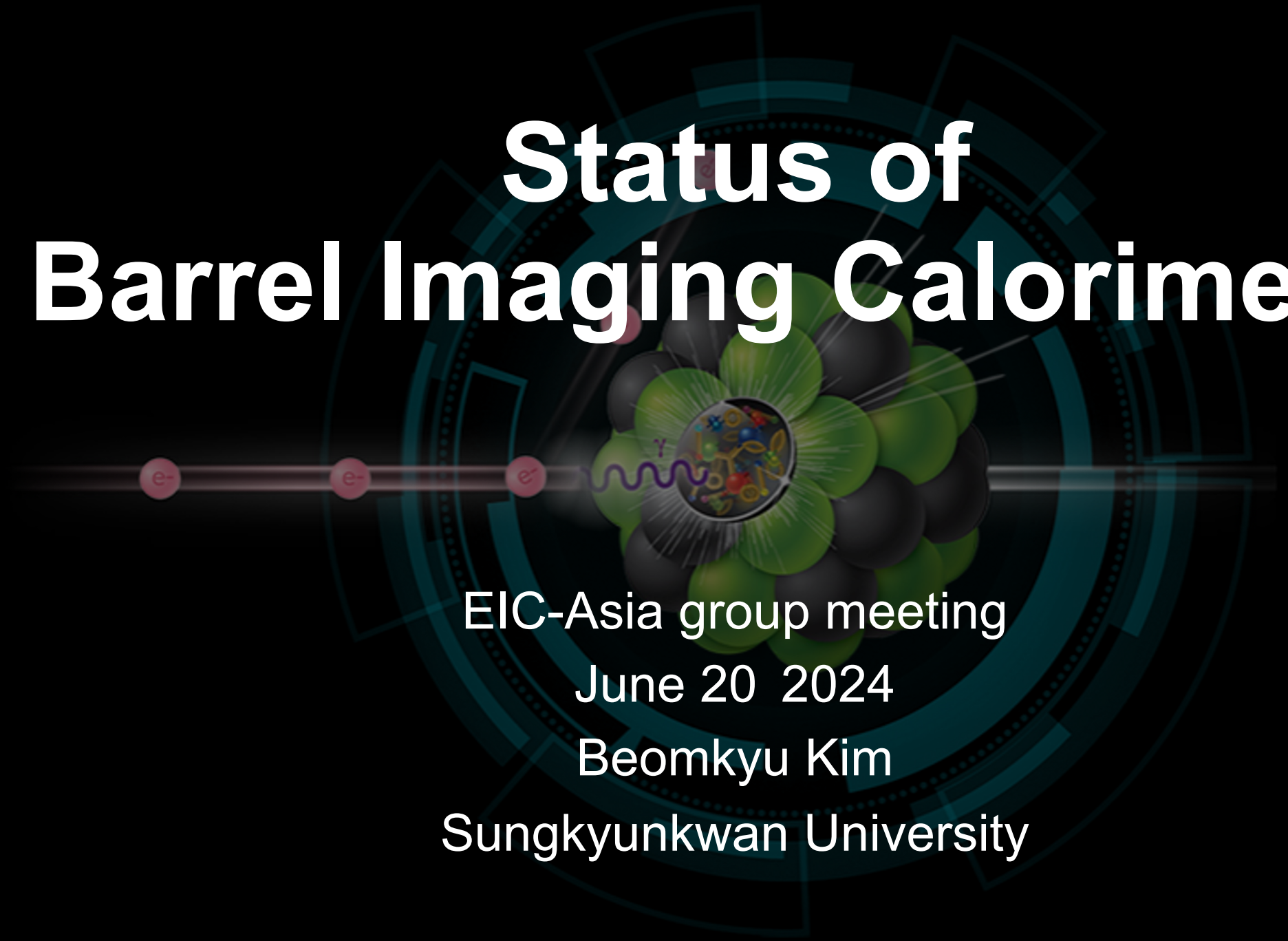
Status of Barrel Imaging Calorimeter



EIC-Asia group meeting

June 20 2024

Beomkyu Kim

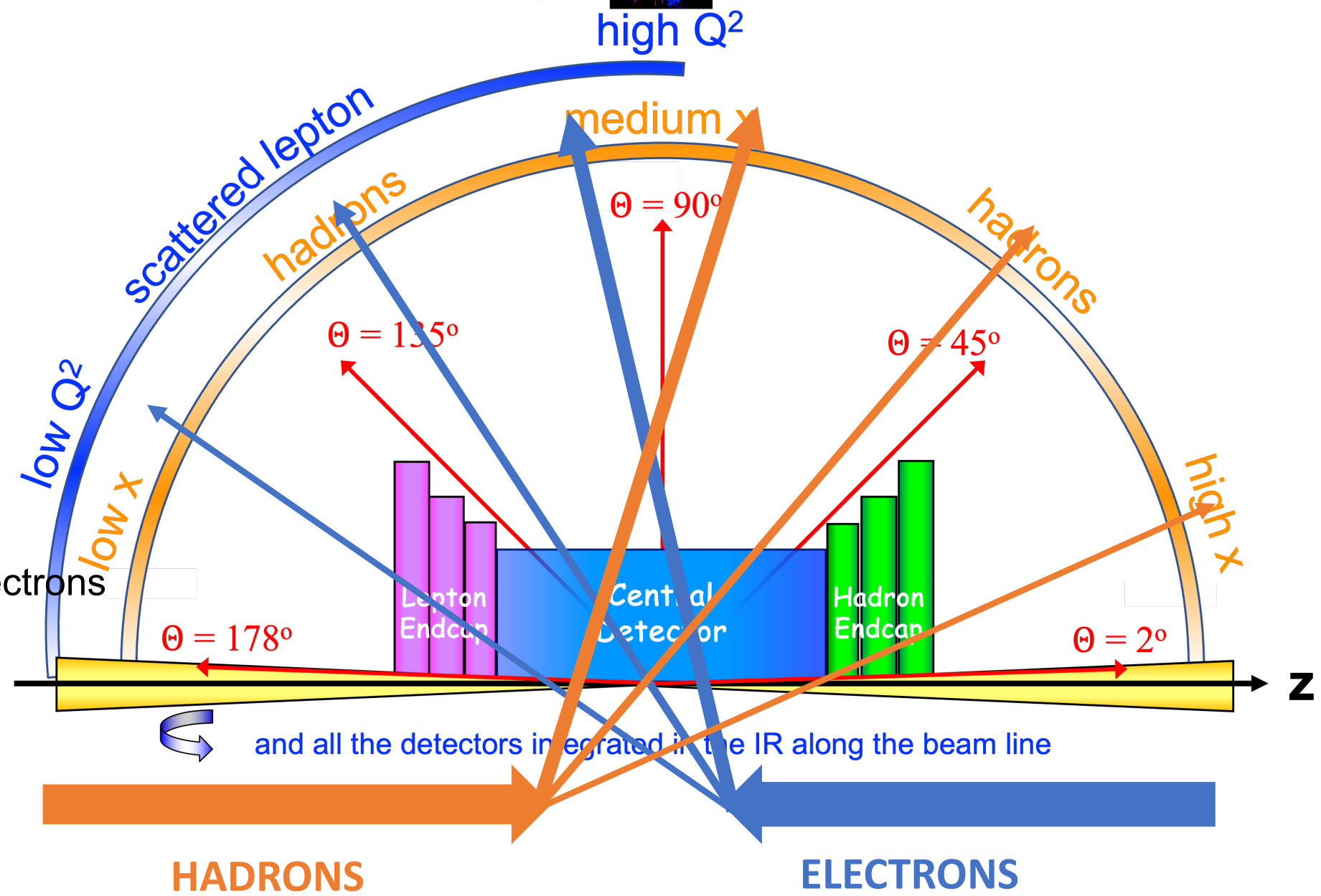
Sungkyunkwan University

Outline

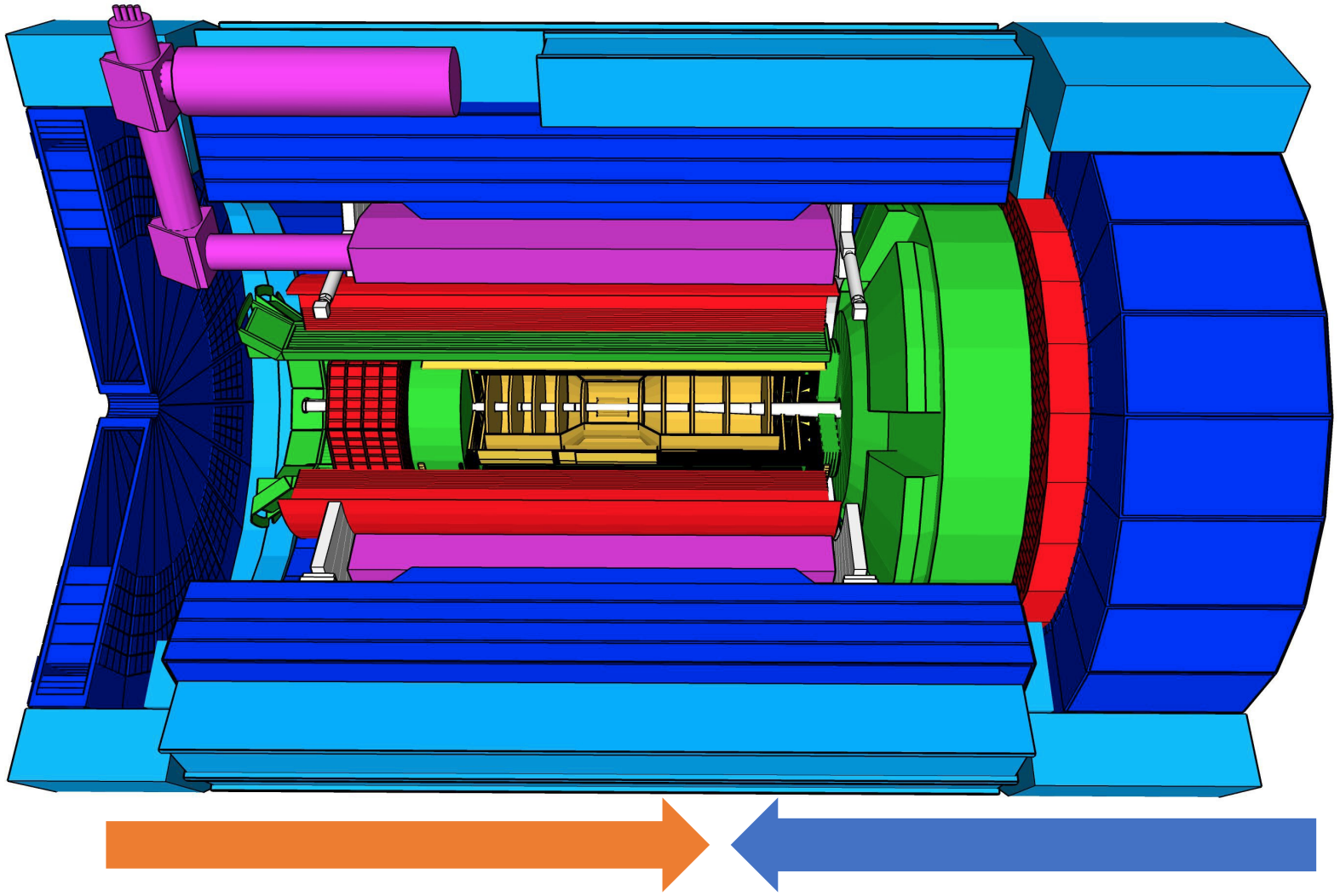
- ePIC Experiment
- Barrel Imaging Calorimeter (BIC) Requirement
- Physics potential with the BIC
- BIC coordination and schedule
- Prototype production
- Beam test
- Summary

EIC General Purpose Detector: Concept

Low Q^2
scattered electrons



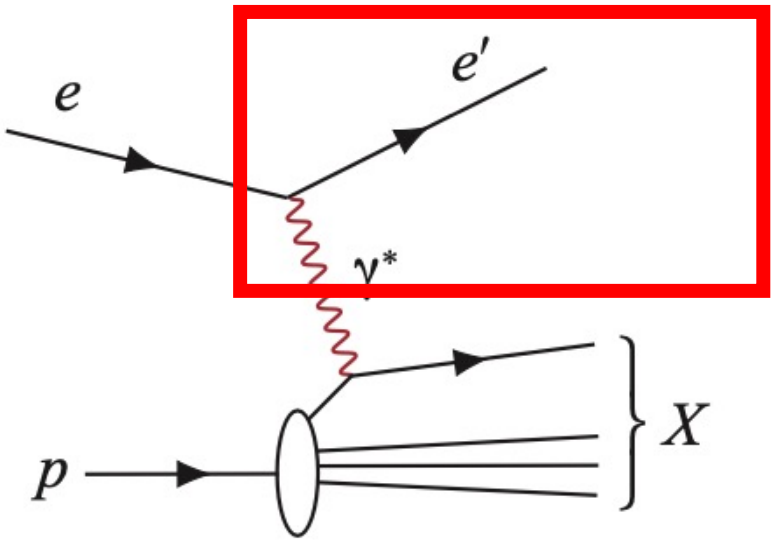
Detectors for ePIC



Magnet
Tracking
Particle Identification
Electromagnetic Calorimeter
Hadronic Calorimeter

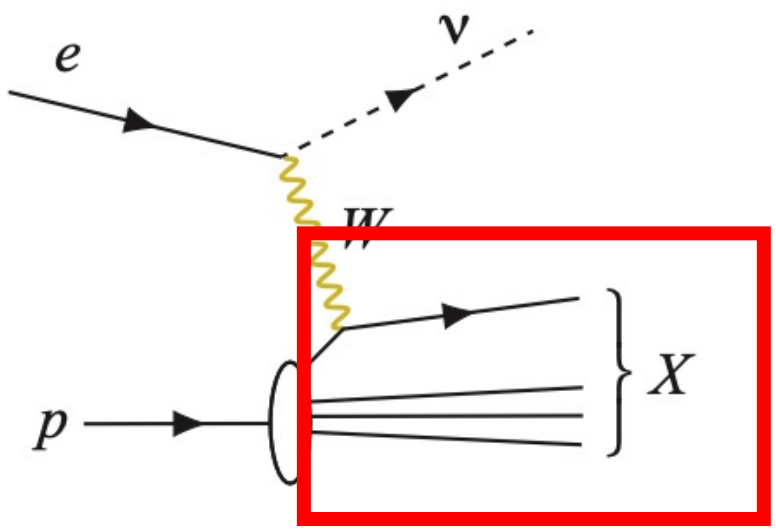
Coverage
ϕ:360° 2°<θ<178° -4<η<4

Barrel Calorimeter Requirement



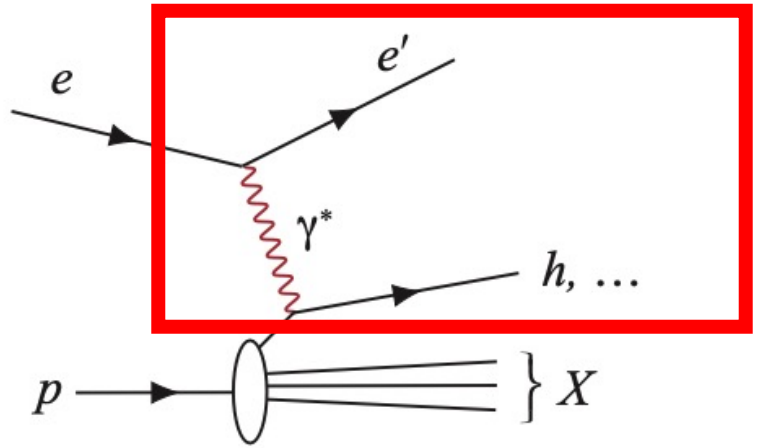
Neutral-current Inclusive DIS

$e + p/A \rightarrow e' + X$



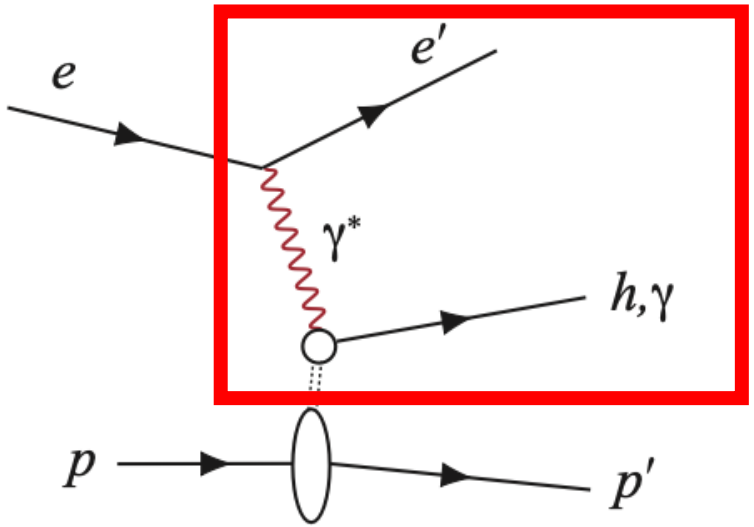
Charged-current Inclusive DIS

$e + p/A \rightarrow \nu + X$



Semi-Inclusive DIS

$e + p/A \rightarrow e' + h^{\pm,0} + X$

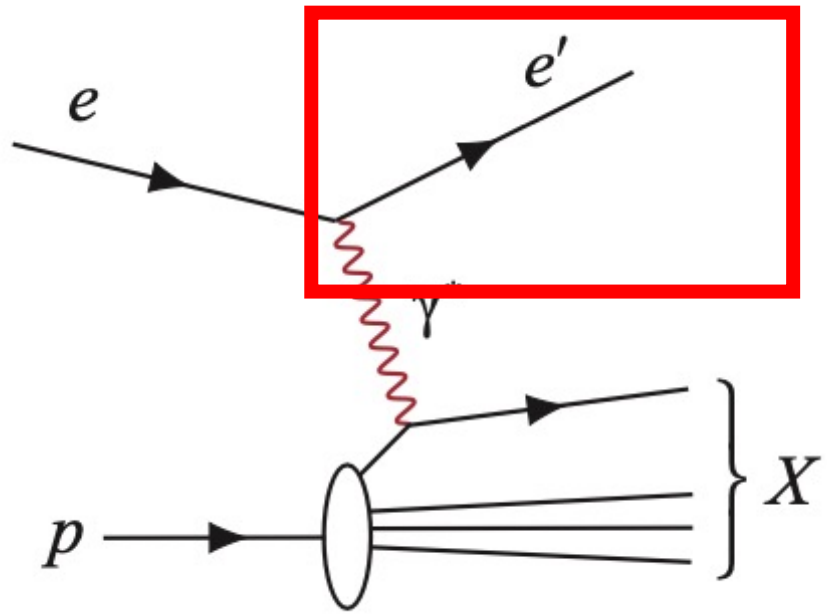


Exclusive DIS

$e + p/A \rightarrow e' + p'/A' + \gamma/h^{\pm,0}$

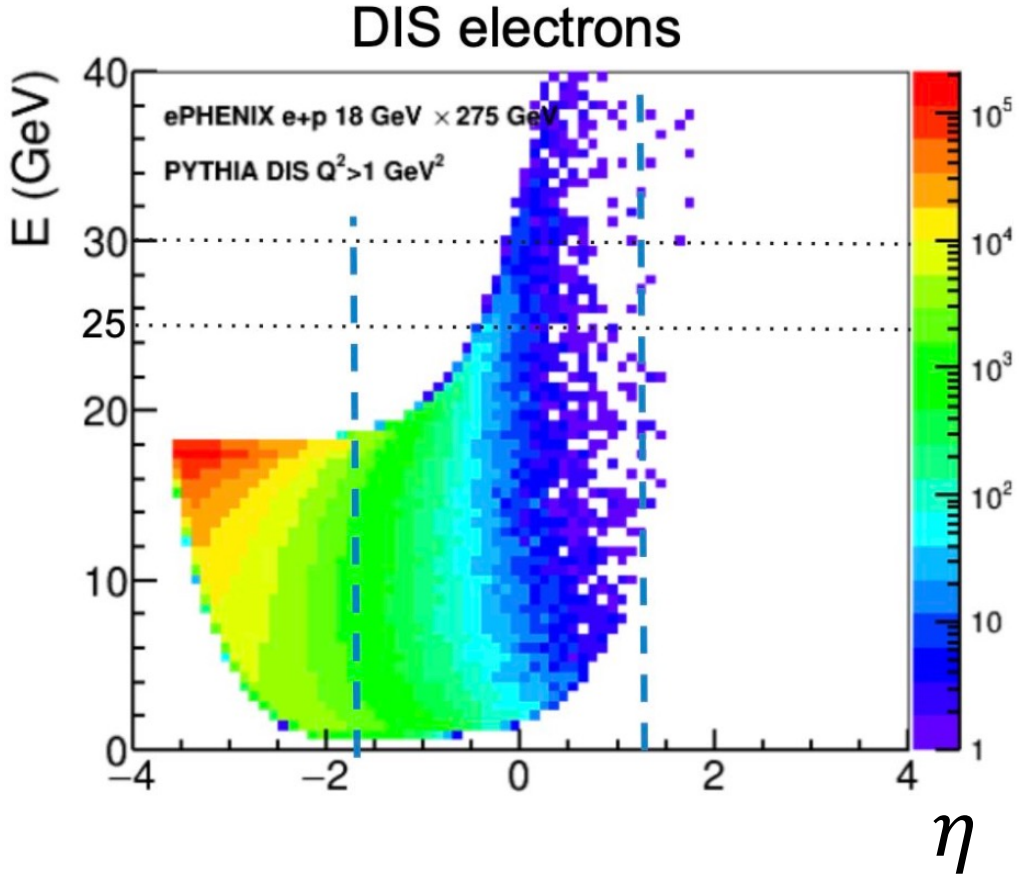
Barrel Calorimeter Requirement

- Inclusive DIS
  - Up to 10^4 π^- background suppression at low momenta in the barrel
- General: $100\ \mathrm{MeV} < \gamma\ \mathrm{energy} < 10\ \mathrm{GeV}$



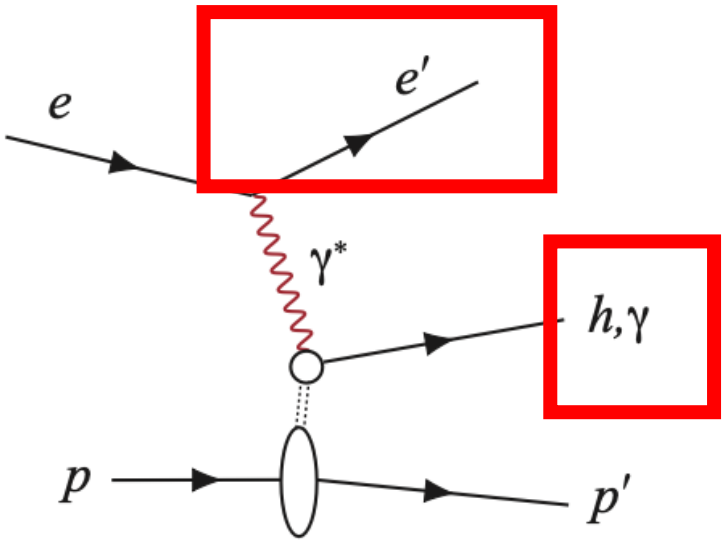
Neutral-current Inclusive DIS

$$\mathrm{e} + \mathrm{p/A} \rightarrow \mathrm{e}' + X$$



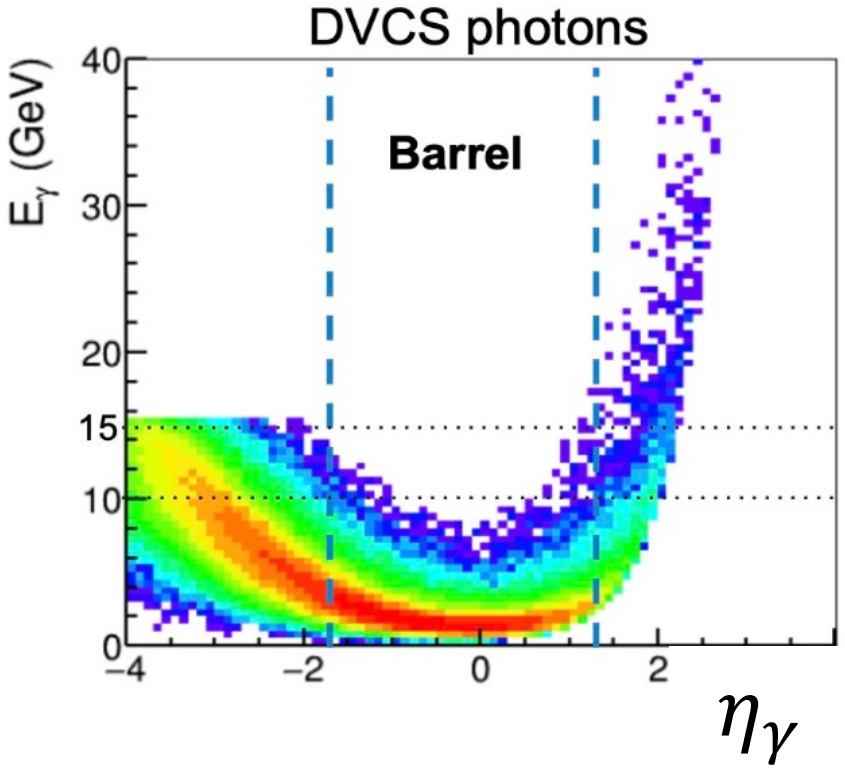
Barrel Calorimeter Requirement

- Exclusive DIS (DVCS)
  - Up to 10^4 π^- background suppression at low momenta in the barrel
  - Good energy resolution (<7-10%/$\sqrt{E}$ $\oplus$ (1-3%)
  - Fine granularity for good π^0/γ separation up to 10 GeV

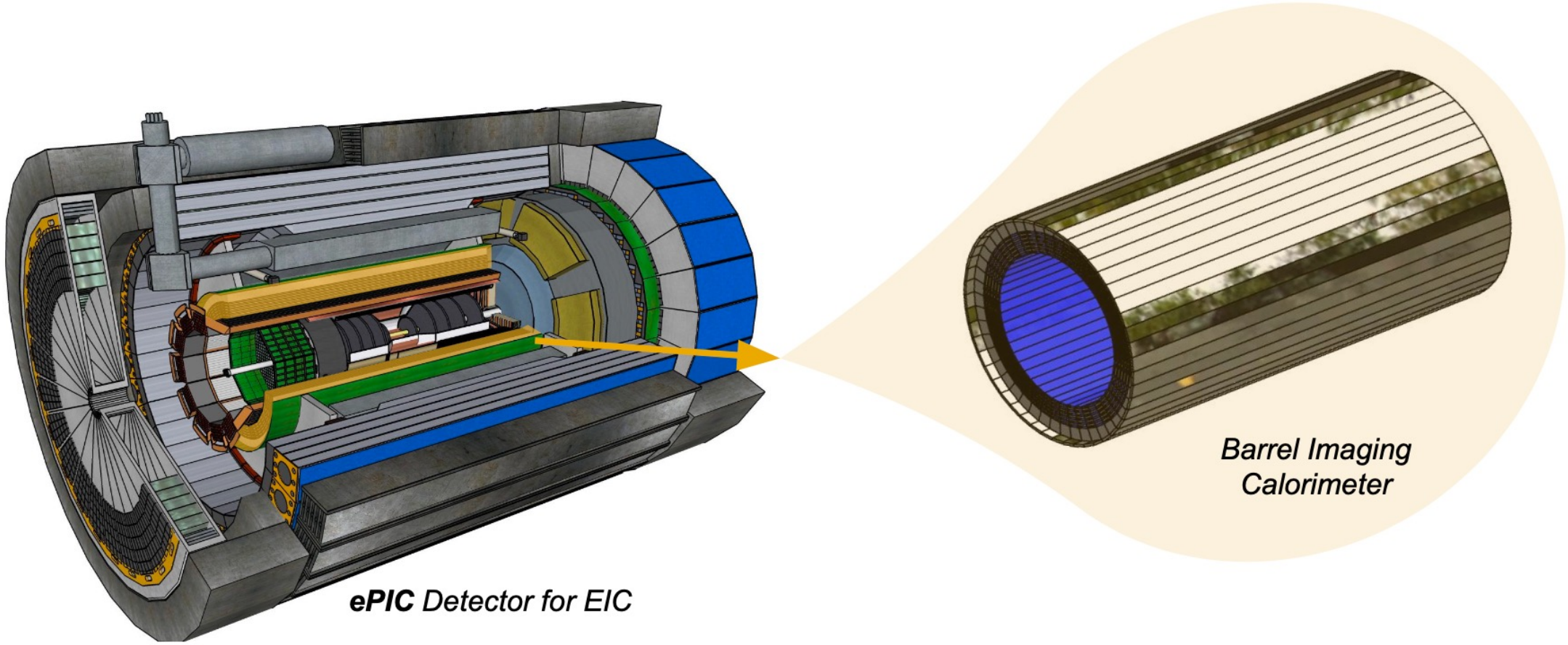


Exclusive DIS

$e + p/A \rightarrow e' + p'/A' + \gamma/h^{\pm,0}$



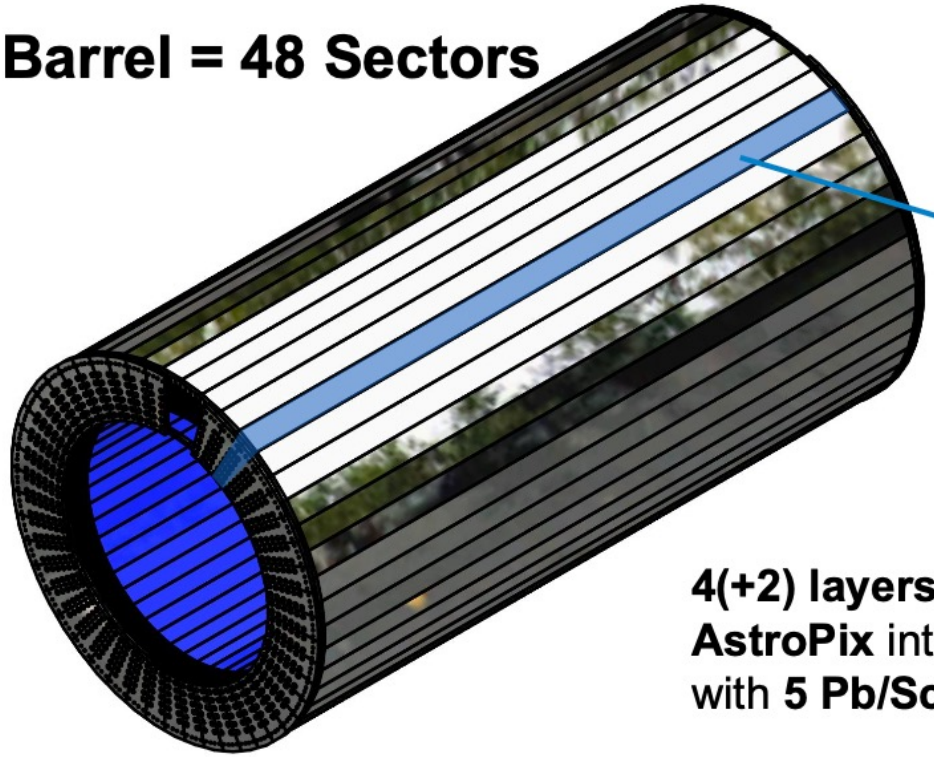
Barrel Imaging Calorimeter



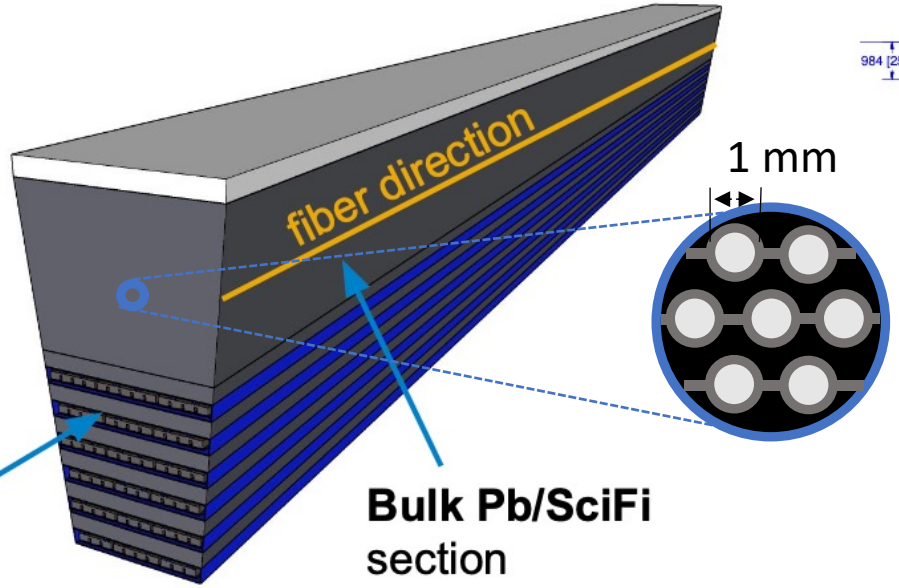
Solution: Hybrid SciFi/Pb calorimeter with a silicon tracker to precisely measure 3D image of electromagnetic shower

Barrel Imaging Calorimeter

Barrel = 48 Sectors



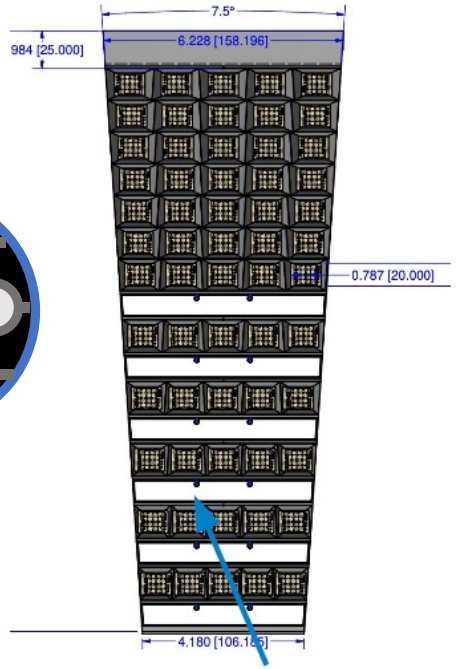
Sector



4(+2) layers of AstroPix interleaved with **5 Pb/ScFi layers**

Bulk Pb/SciFi section

Sector End View



Length: ~435 cm

Radius: ~ 82 cm

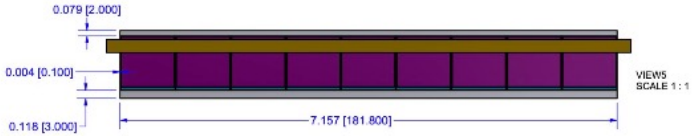
η Coverage: -1.71 < η < 1.31

Depth: 17.1X0 at η = 0

Sampling fraction ~ 10%

AstroPix layers built from

Modules



Module - 9 AstroPix chips daisy chained together

Pb/SciFi Layer (1.4X0)

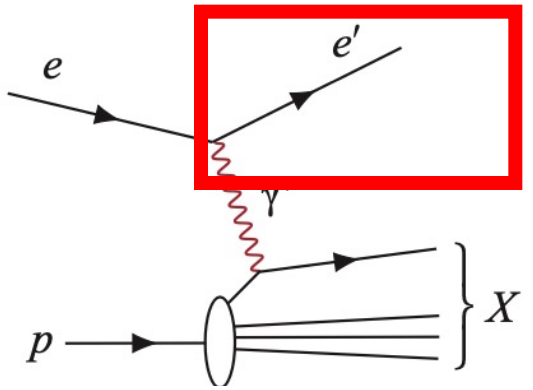
- 5 readout cells per layers
- 1 light-guide per cell

Barrel Imaging Calorimeter Technical Drawings
T. O'Connor, K. Bailey

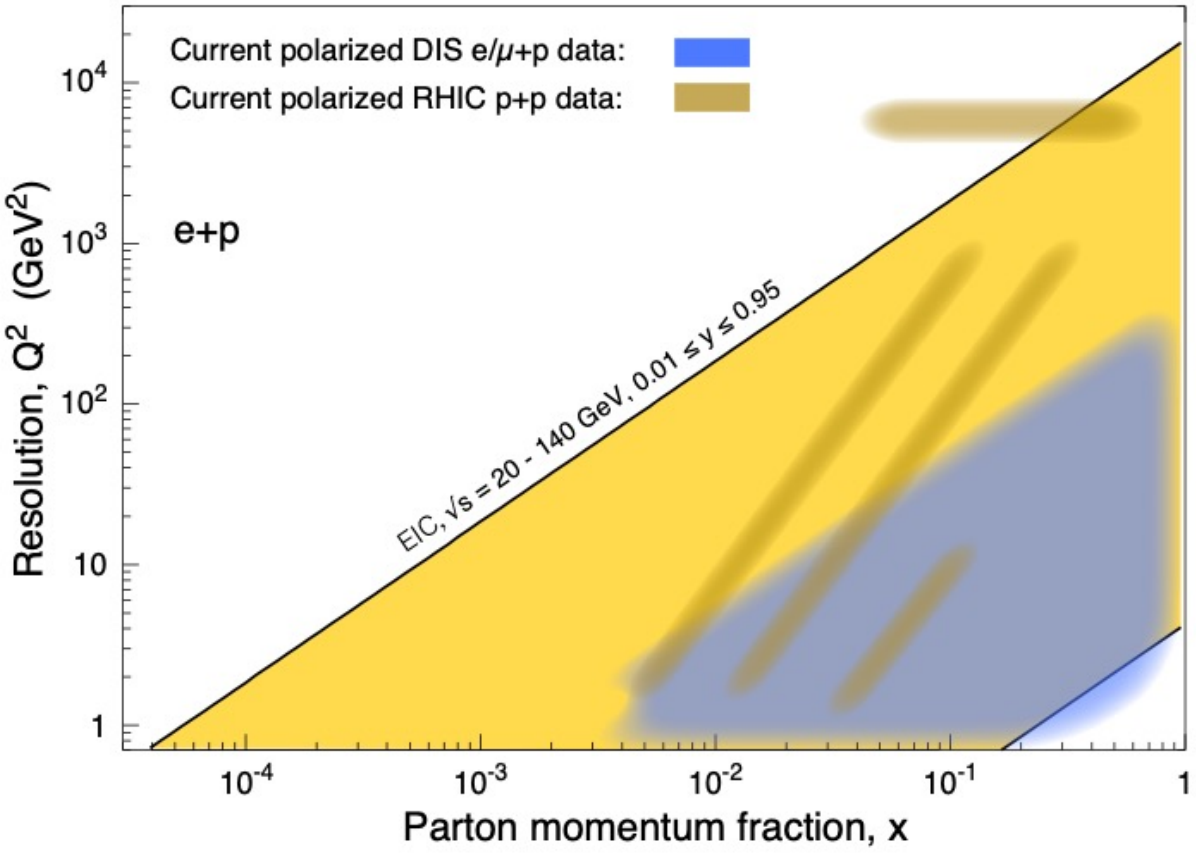
Physics potential with BIC

Neutral-current Inclusive DIS

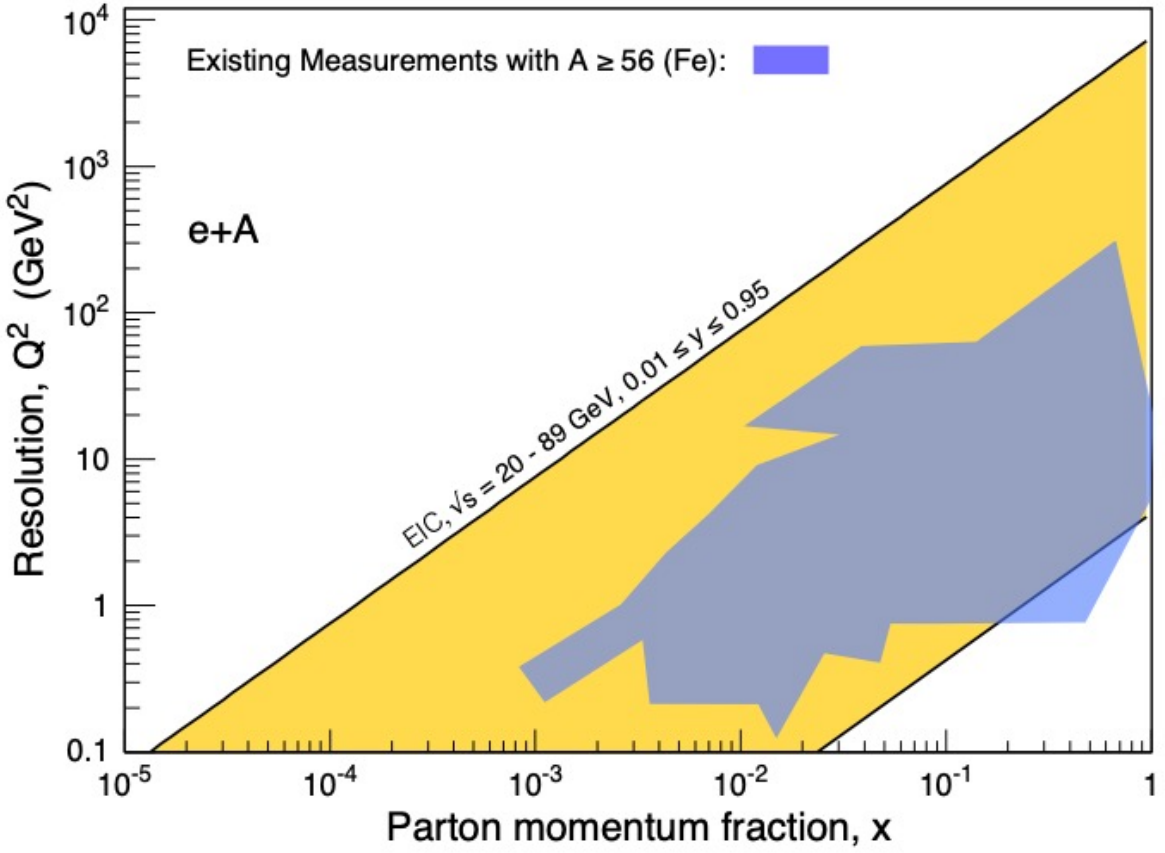
$$e + p/A \rightarrow e' + X$$



BIC Requirement: 7-10%/$\sqrt{E} \oplus$ (1-3)%



BLUE: CERN, DESY, Jlab, SLAC



BLUE: World data

Physics potential with BIC

Wigner function → QCD genetic map

$W(x,b_T,k_T)$

Momentum space

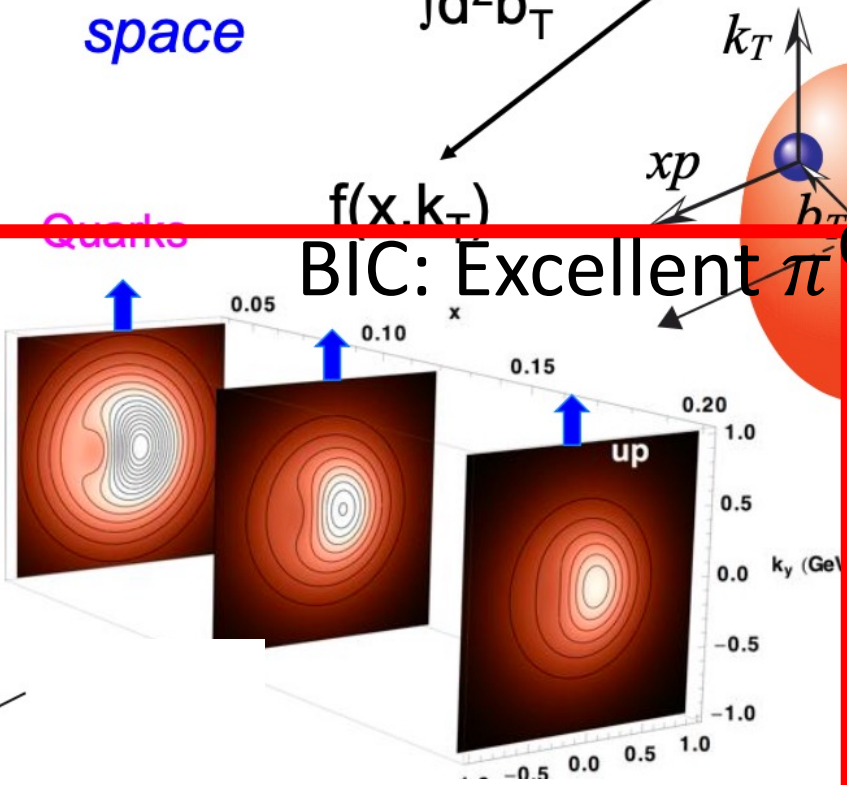
$\int d^2b_T$

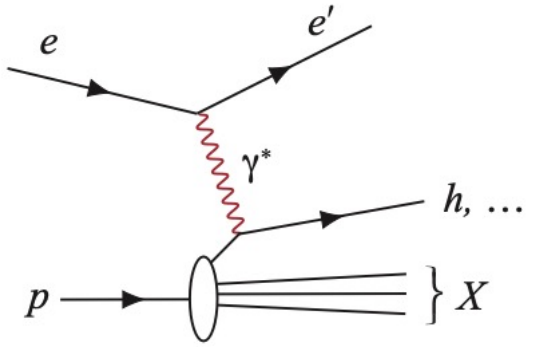
$f(x,k_T)$

$\int d^2k_T$

$f(x,b_T)$

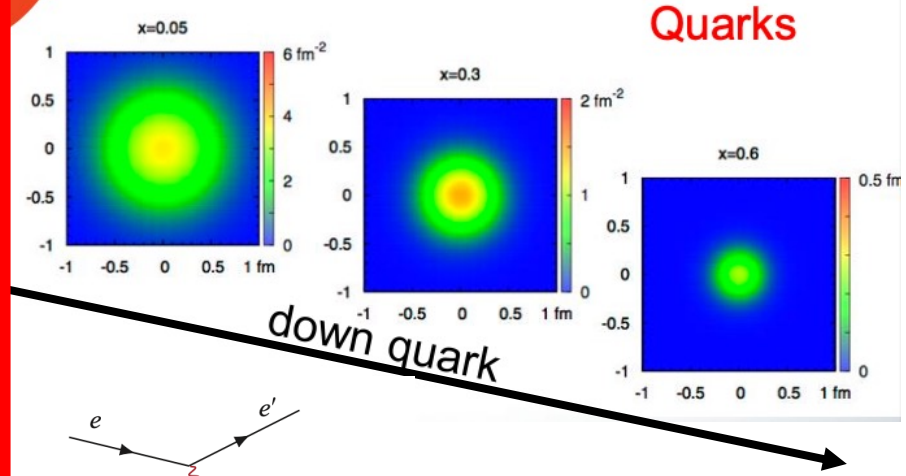
Coordinate space

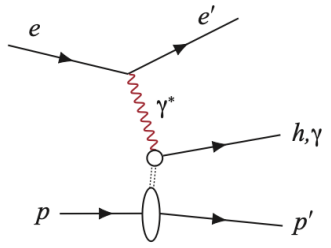




Semi-Inclusive DIS

$e + p/A \rightarrow e' + h^{\pm,0} + X$





Exclusive DIS

$e + p/A \rightarrow e' + p'/A' + \gamma/h^{\pm,0}$

BIC: Excellent π^0 /gamma seperation

Physics potential with BIC

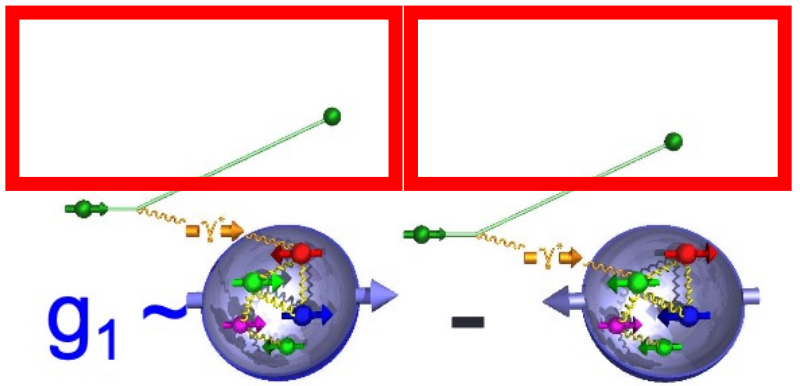
$$\frac{1}{2} = \left[\frac{1}{2}\Delta\Sigma + L_Q\right] + [\Delta g + L_G]$$

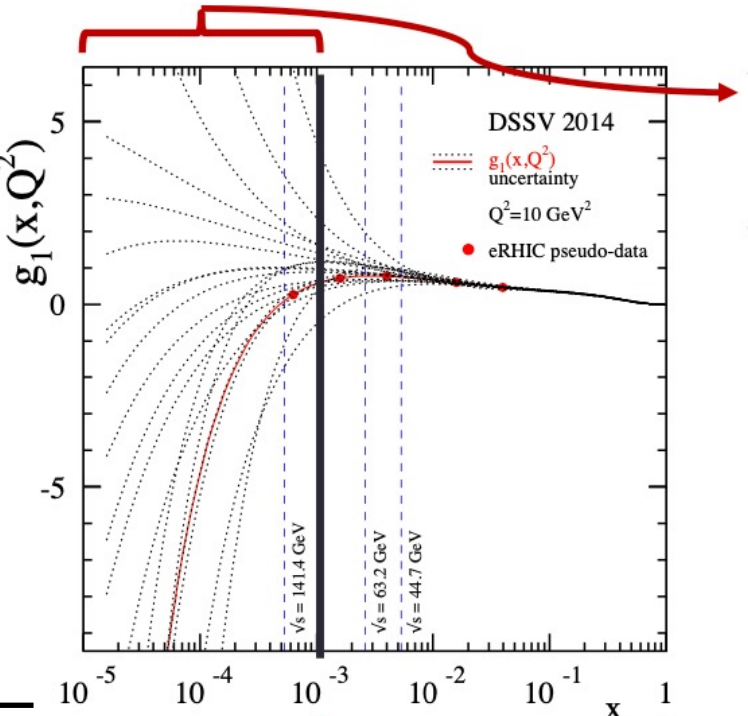
~ 0.12 +/-0.02 ~ 0.20 +/- 0.10

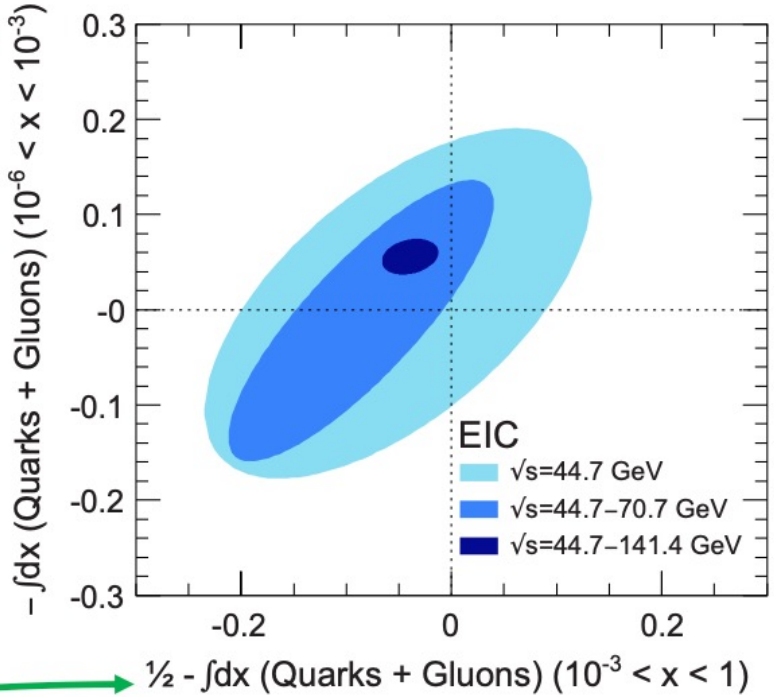
$\Delta\Sigma/2$ = Quark contribution to Proton Spin
Δg = Gluon contribution to Proton Spin
L_Q = Quark Orbital Ang. Mom ??
L_G = Gluon Orbital Ang. Mom ??

Spin structure function g_1 needs to be measured over a wide range in x-Q^2
Especially low-x

Precision in $\Delta\Sigma$ and Δg ➔ A clear idea
Of the magnitude of $L_Q+L_G = L$
Lattice Calculations : comparison

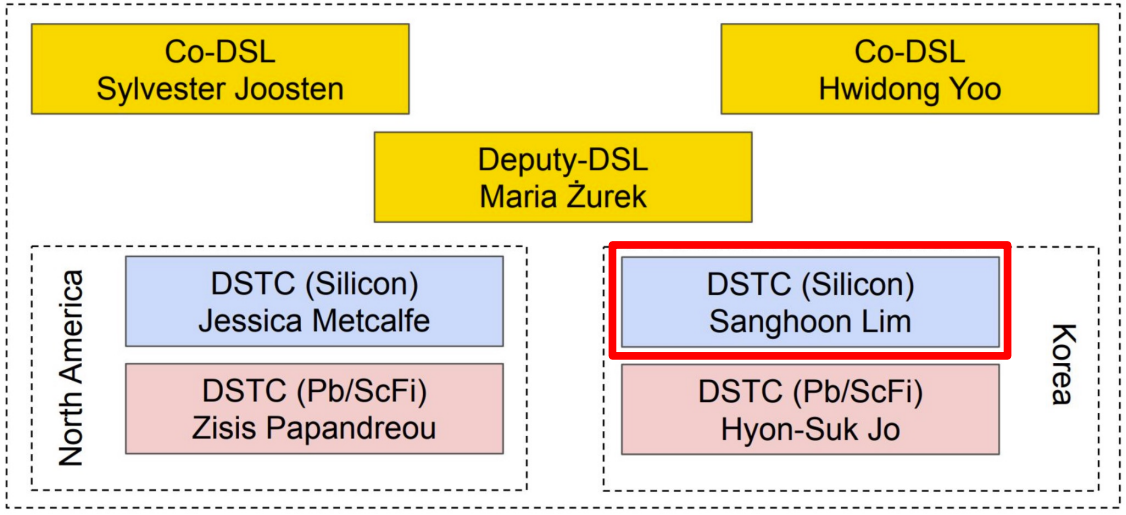


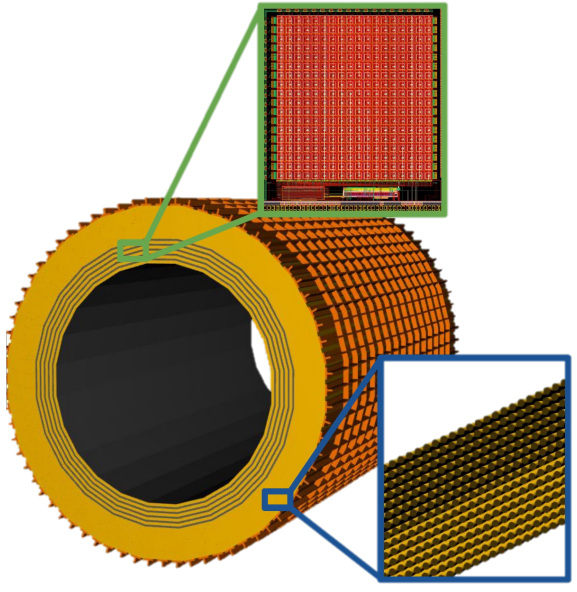


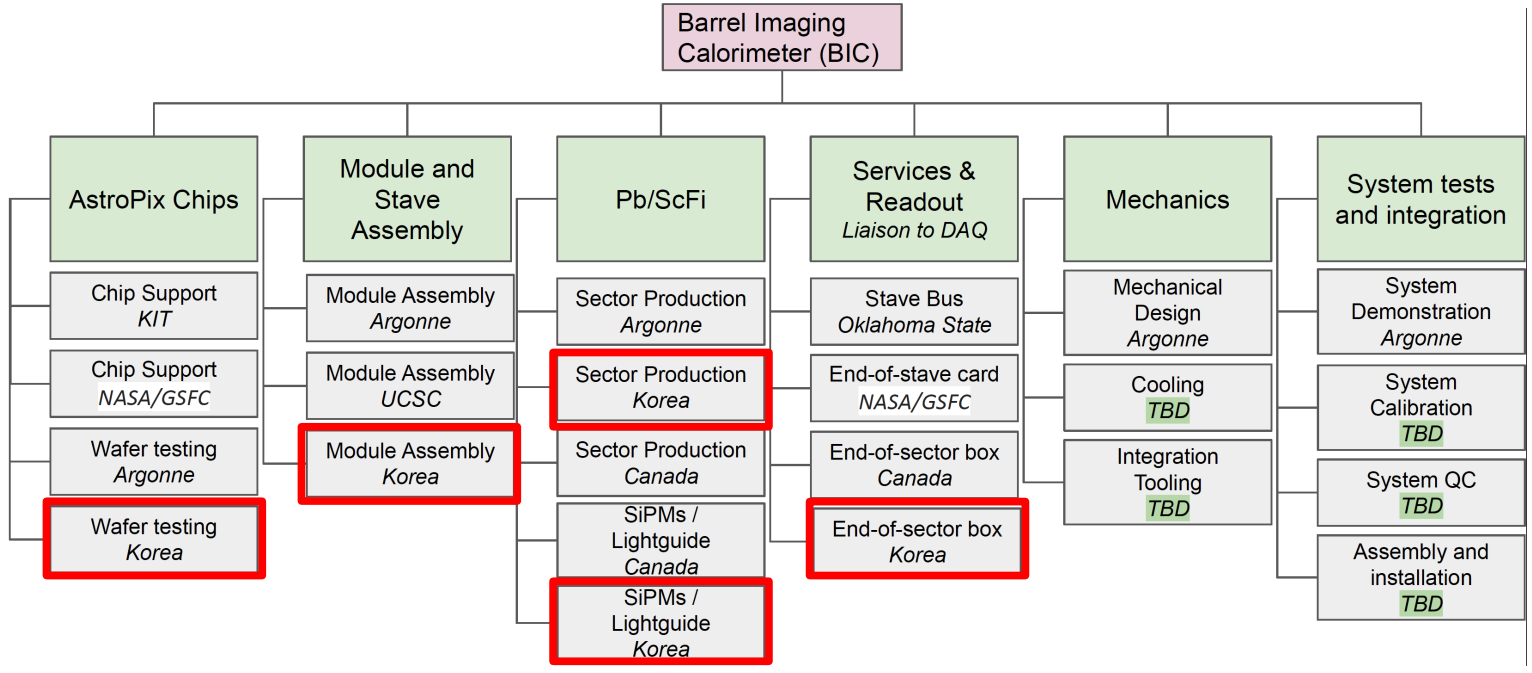


BIC Requirement: 7-10%/$\sqrt{E}$ $\oplus$ (1-3%

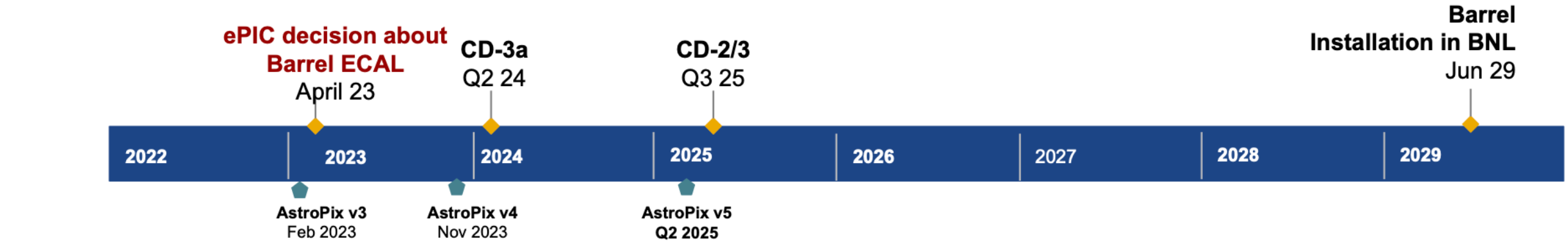
Coordination

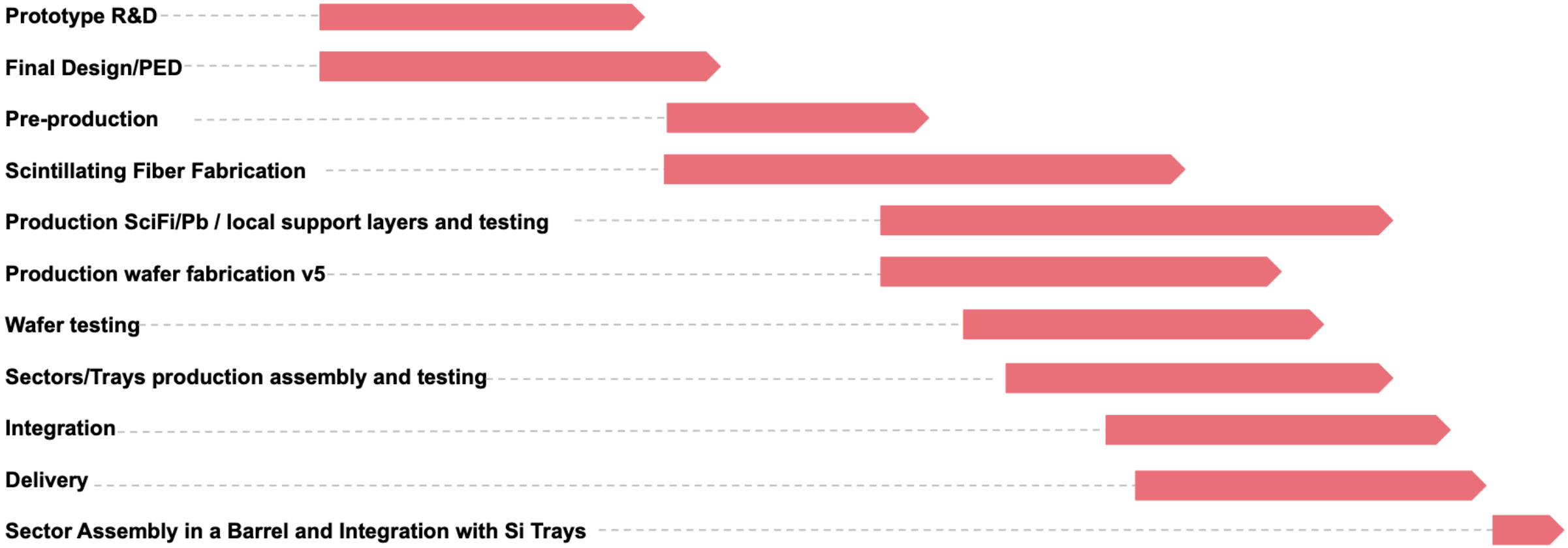






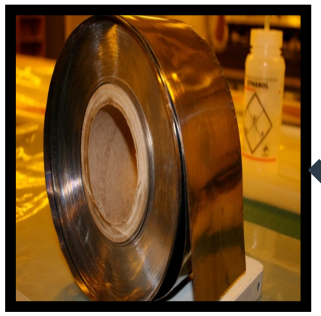
High Level Schedule

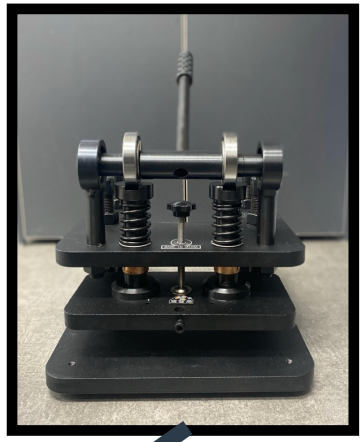


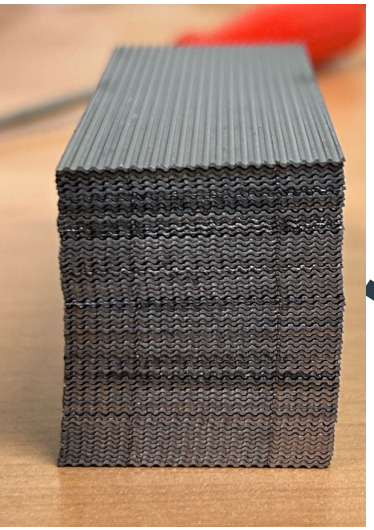


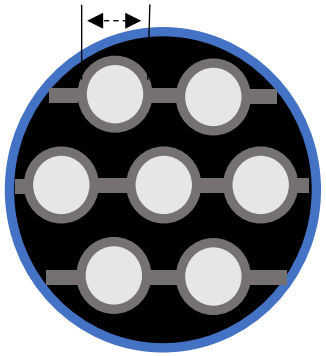
Prototype production of SciFi/Pb

PRESS

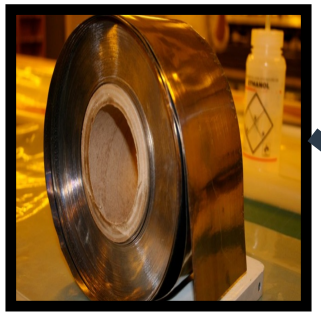


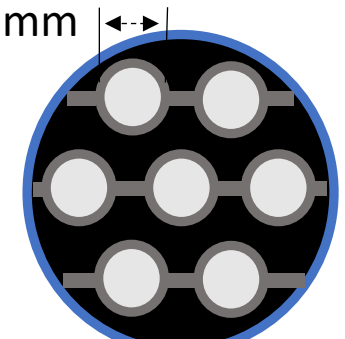




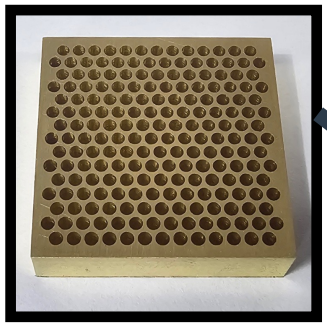


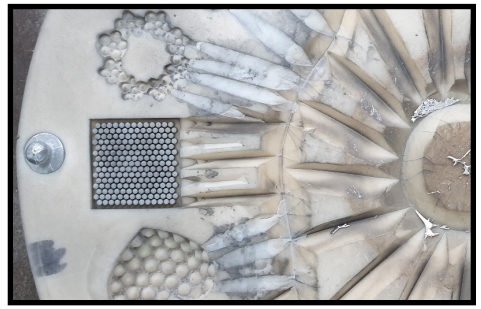
ROLLER

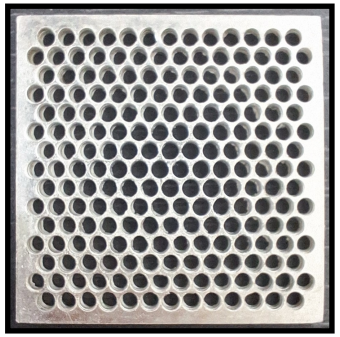




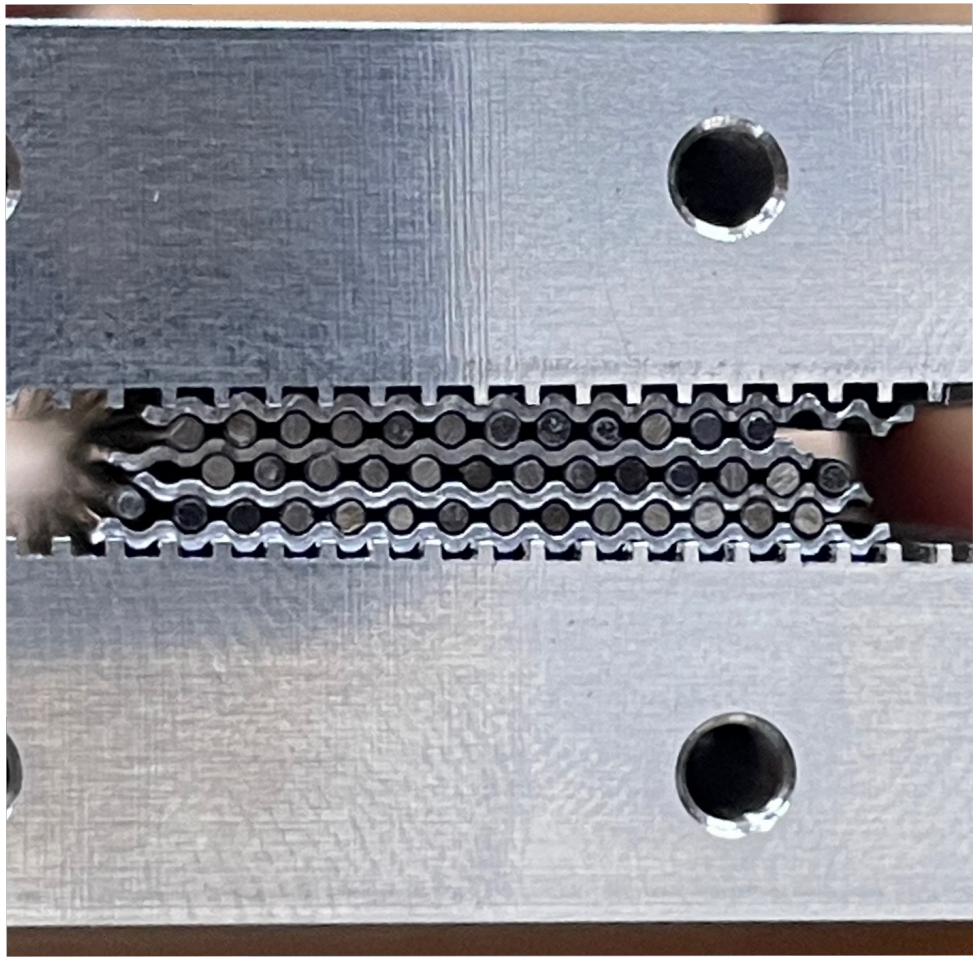
CASTING

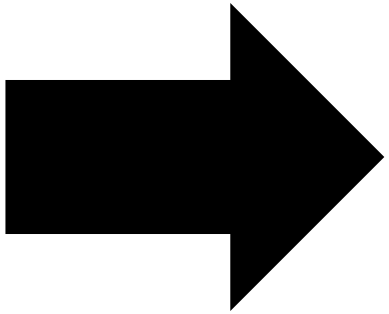


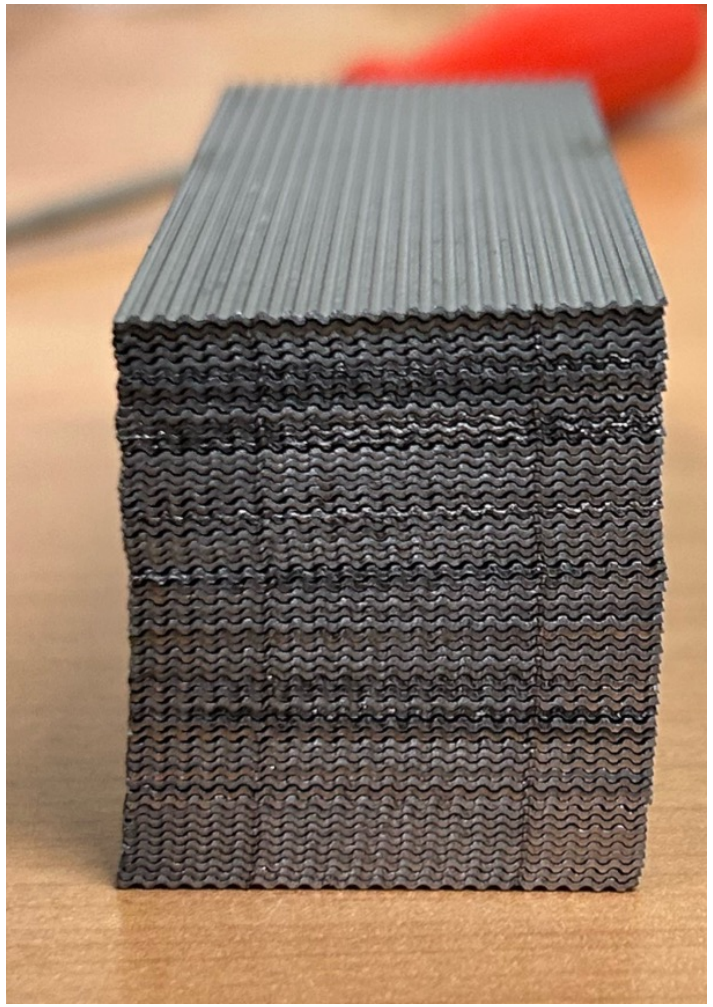




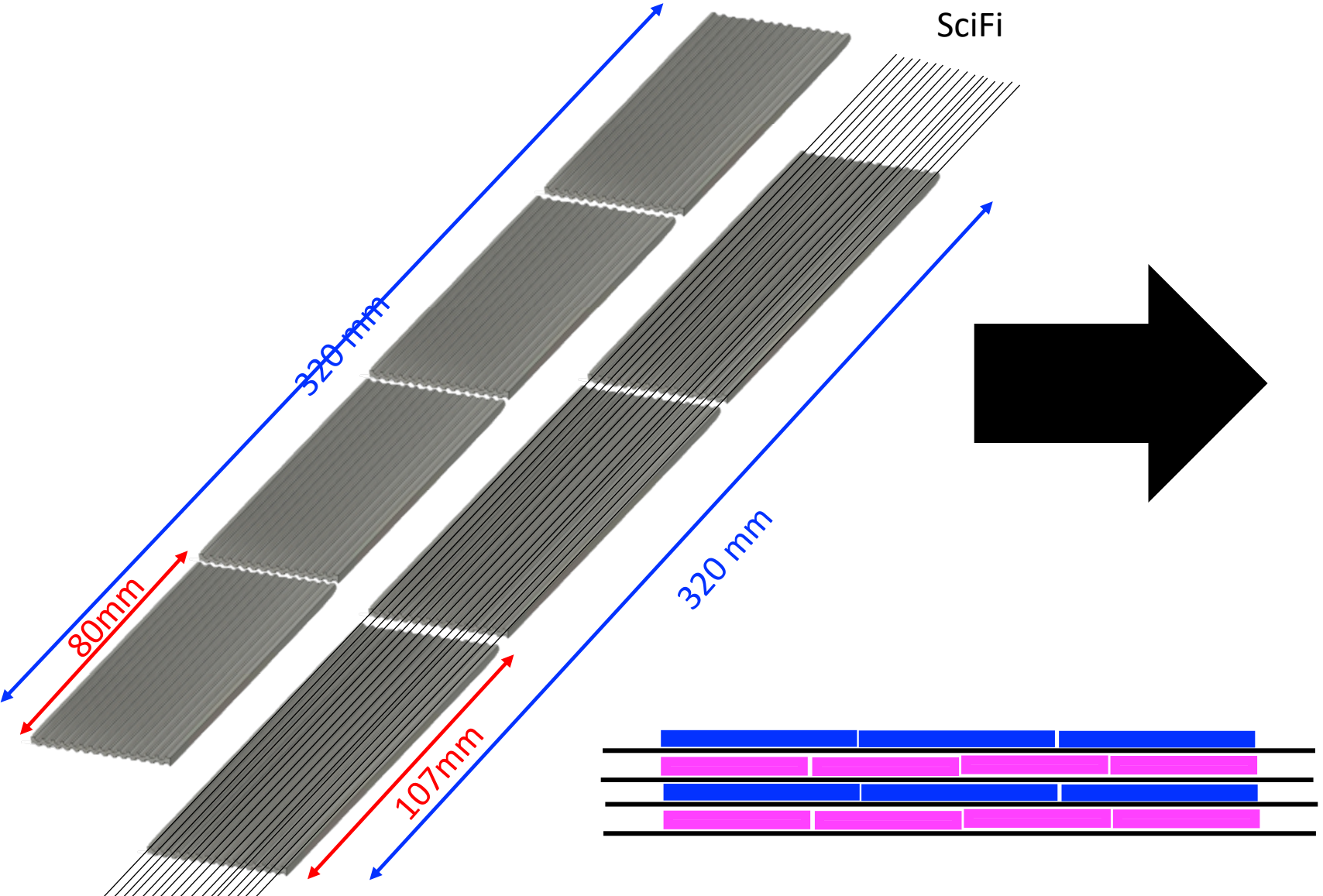
Pb sheet forming by pressing method

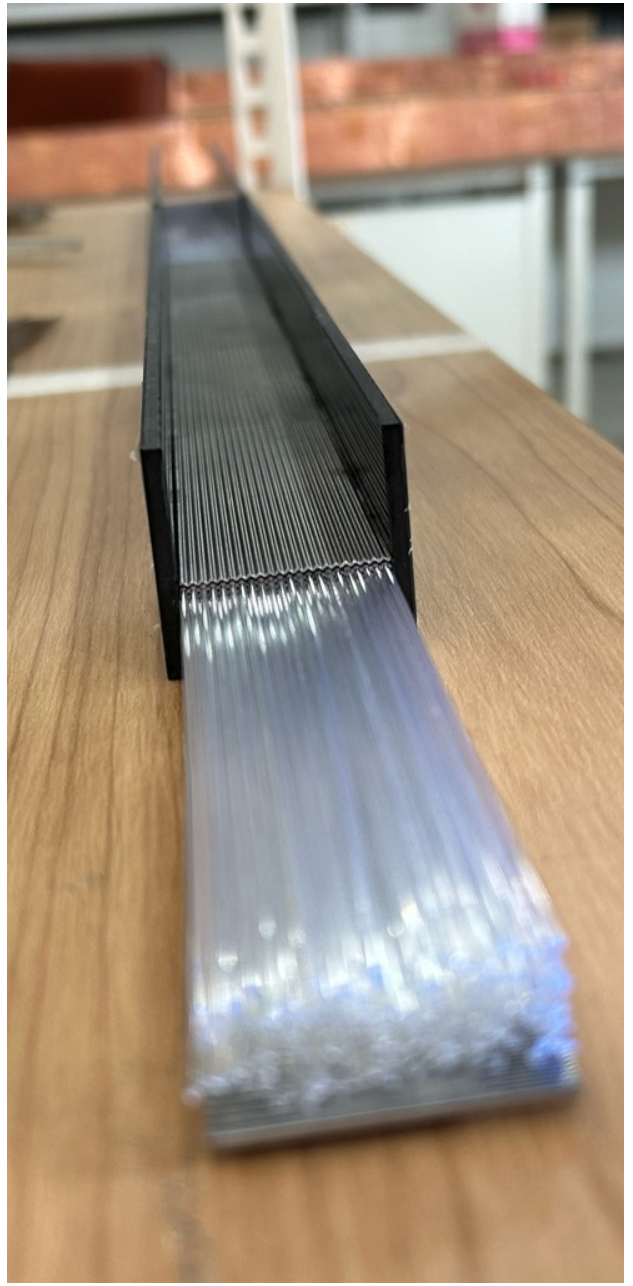






Proto-type production

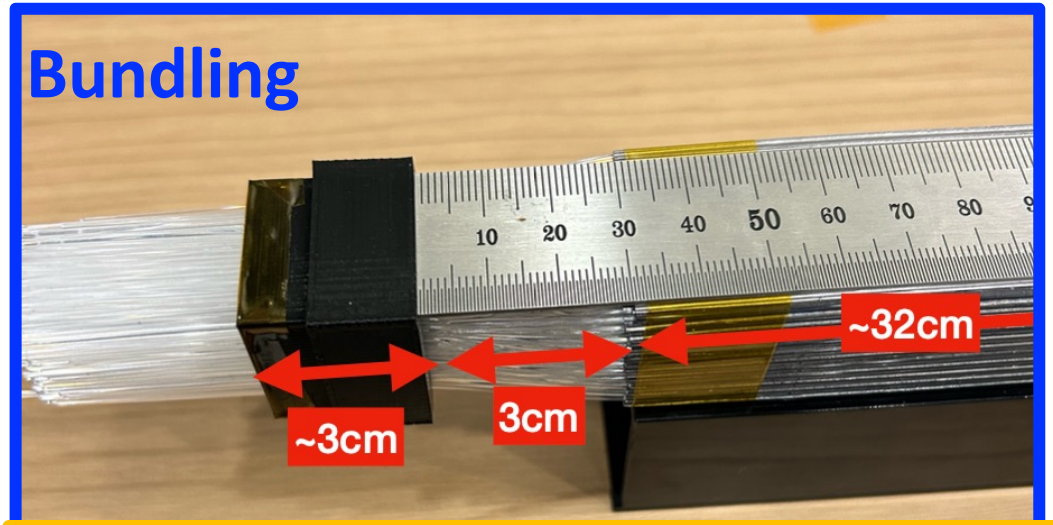




Proto-type production

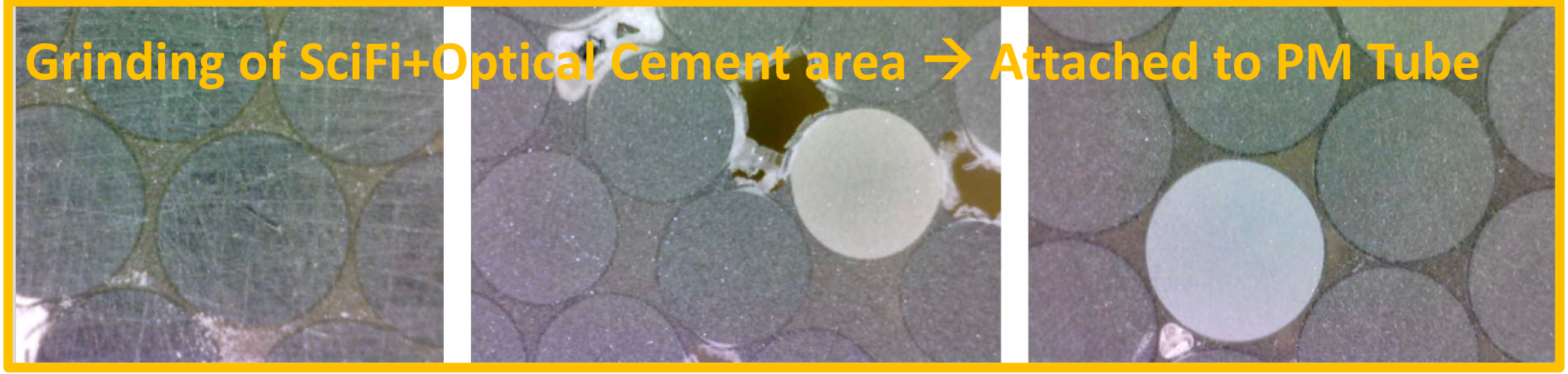
Stacked Pb/SciFi

Bundling

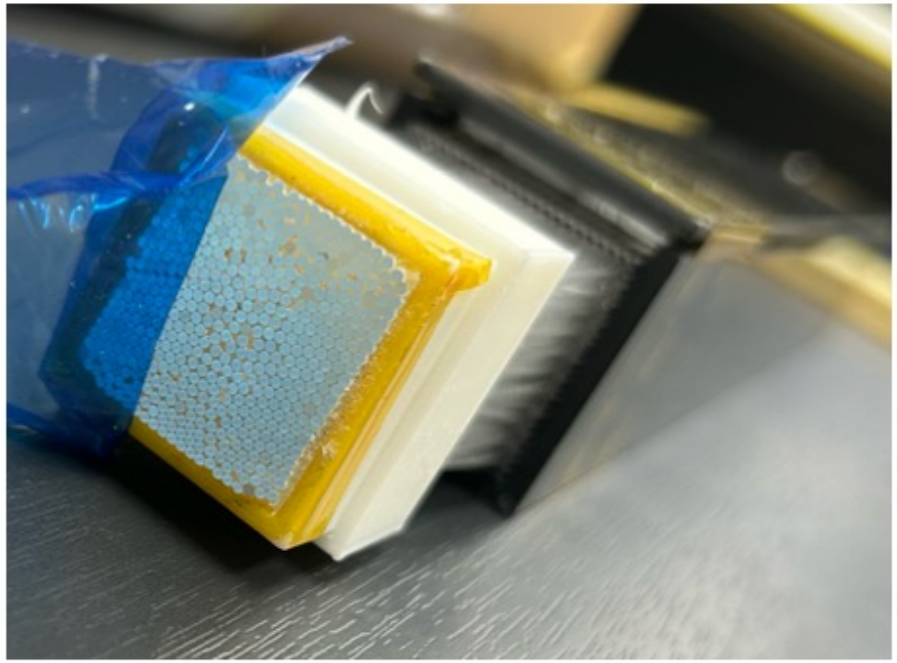


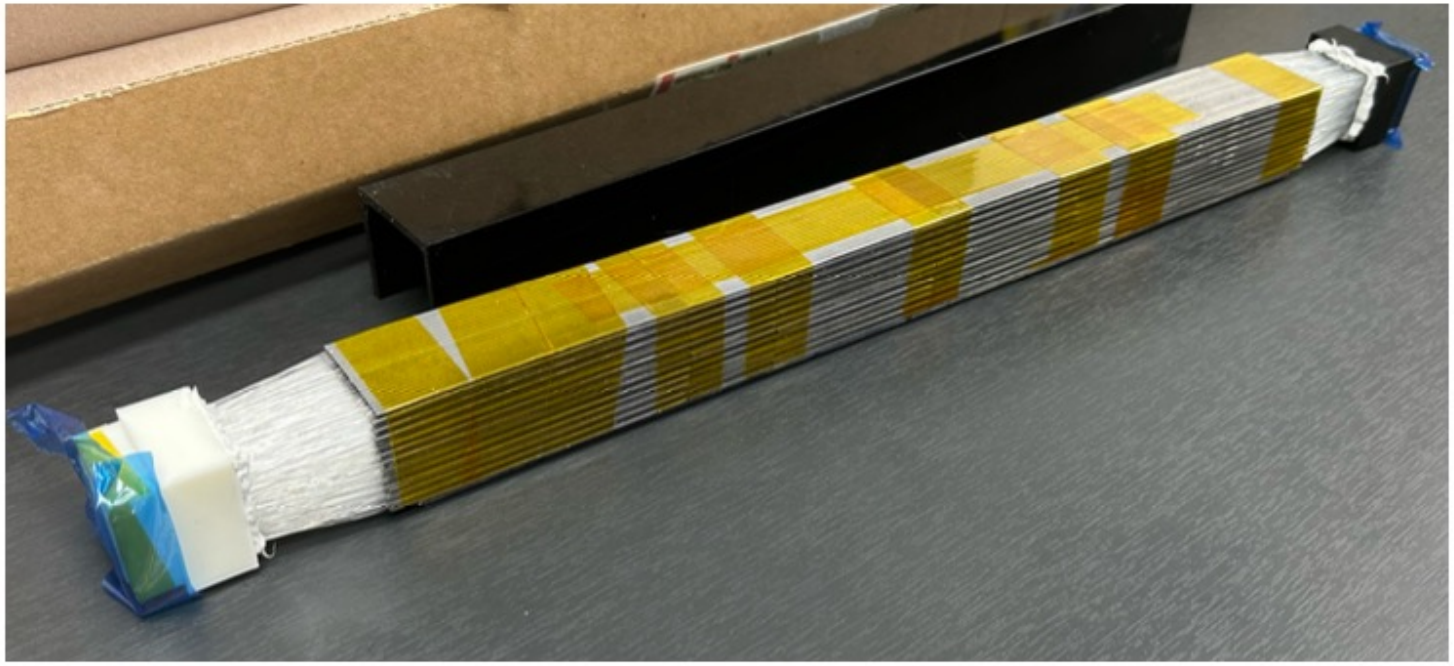
Optical Cement Bonding

Grinding of SciFi+Optical Cement area → Attached to PM Tube



Proto-type production





One module Dimension: 3cm×3cm×32cm

# of lead sheets: 80mm×4×13cm: 52ea, 107mm×3×13cm: 39ea

# of SciFi: 40cm×520ea

Super-module (4x4 modules) configuration

PMT Bundle

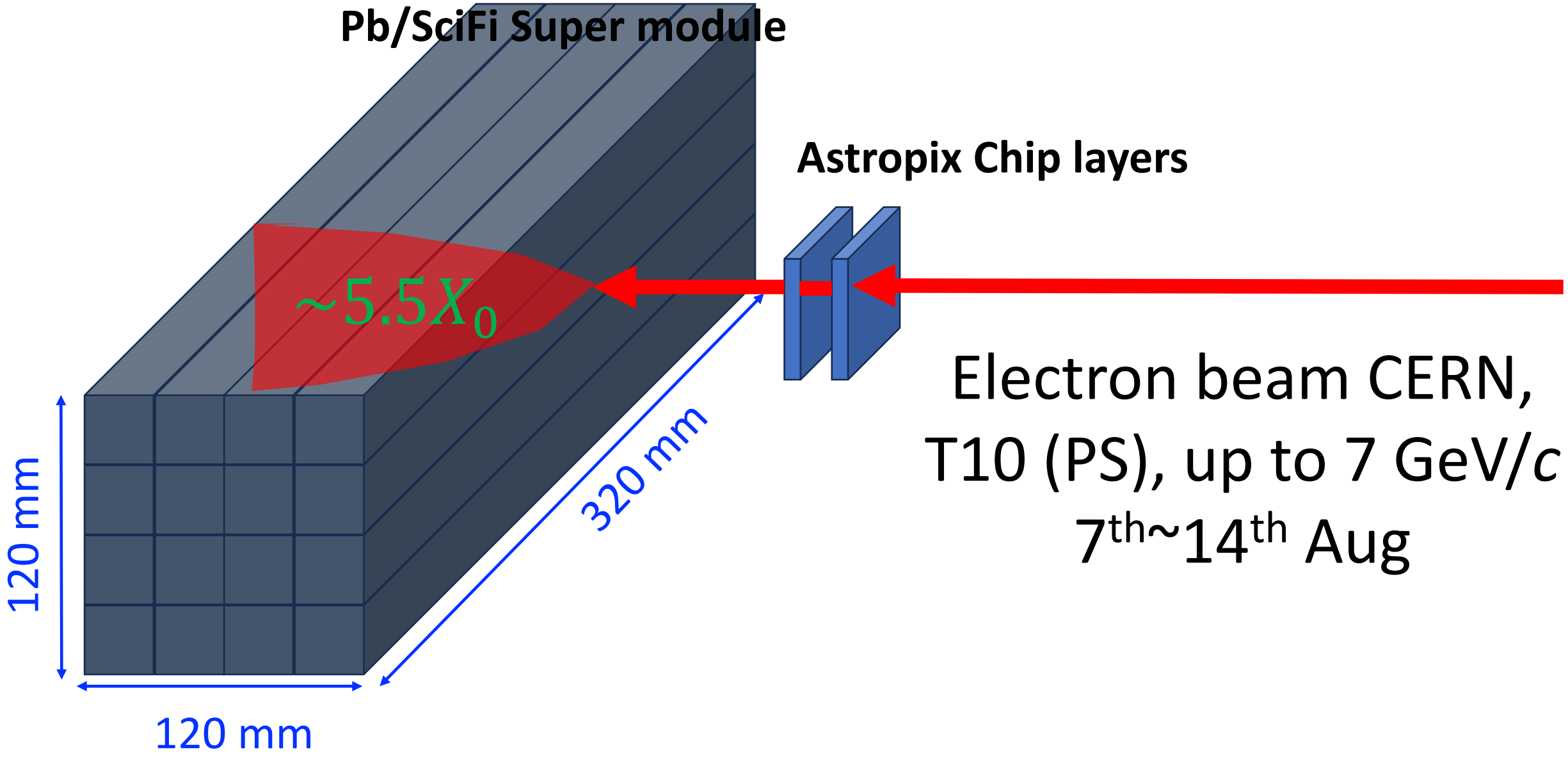
Real configuration

R11265U-100

- Photomultiplier tube (PMT)
- Outer shell : $30mm \times 30mm$
- Active area : $23mm \times 23mm$

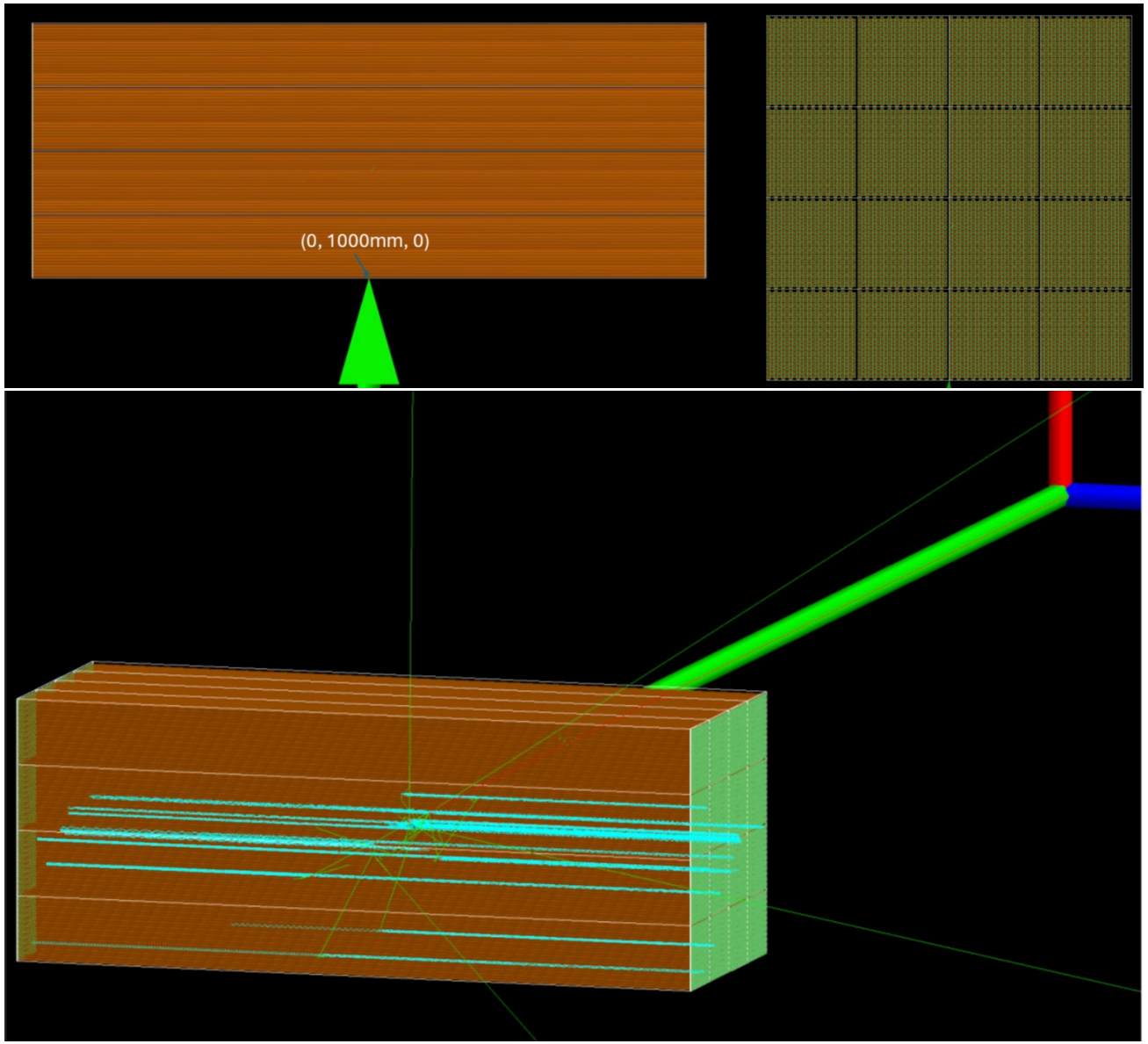
Schematic view

Beam Test

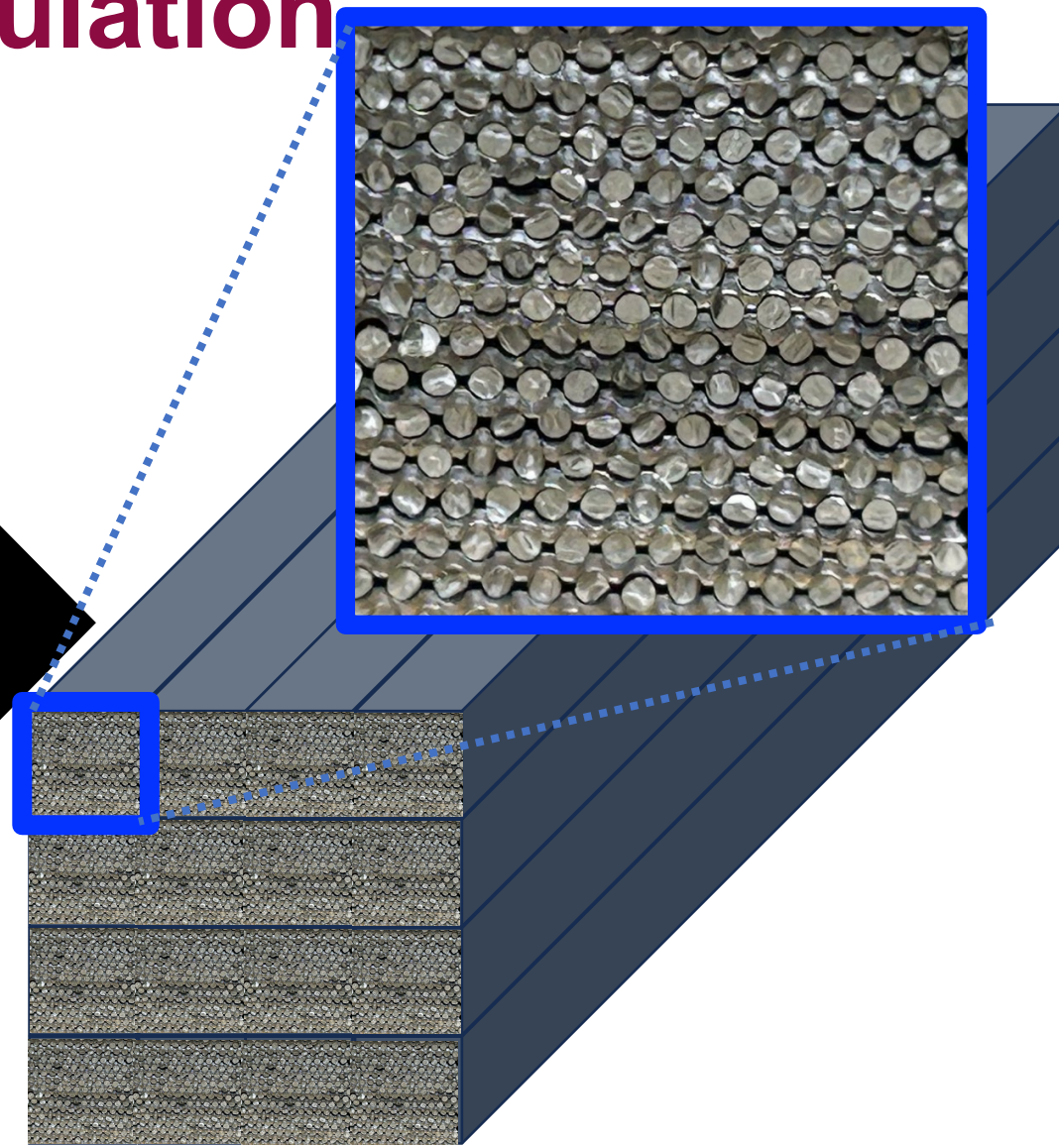


Electron beam CERN,
T10 (PS), up to 7 GeV/*c*
7^{th}~14^{th} Aug

Beam Test Simulation



Dual Readout Calorimeter Simulation



Updating with the Pb/SciFi materials

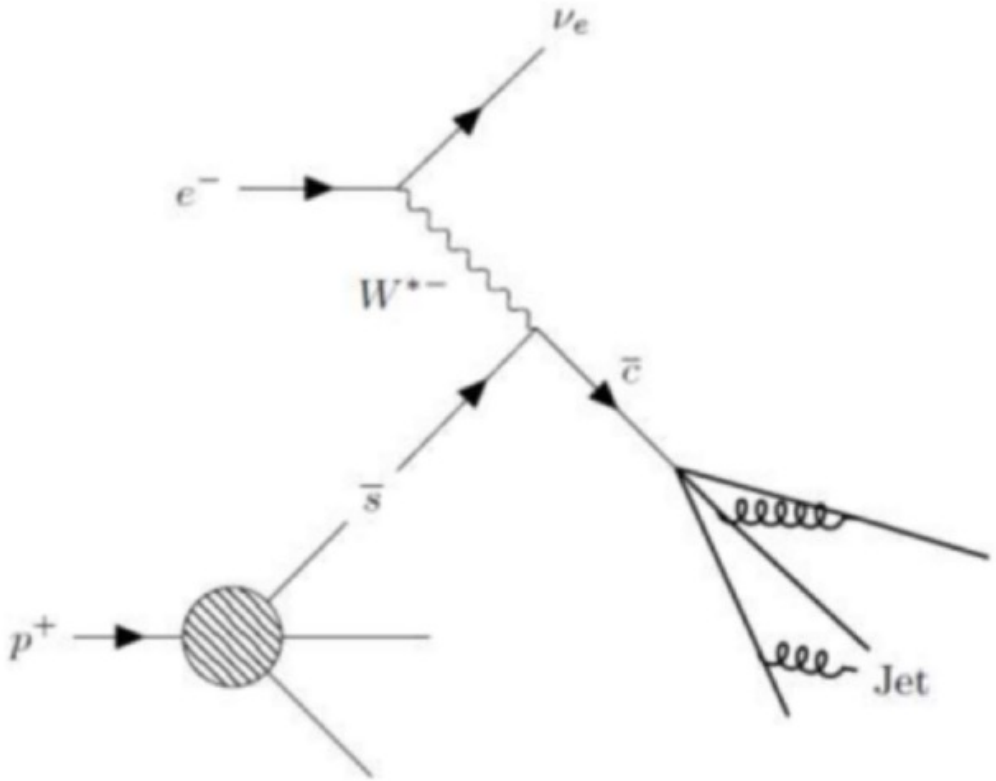
Summary

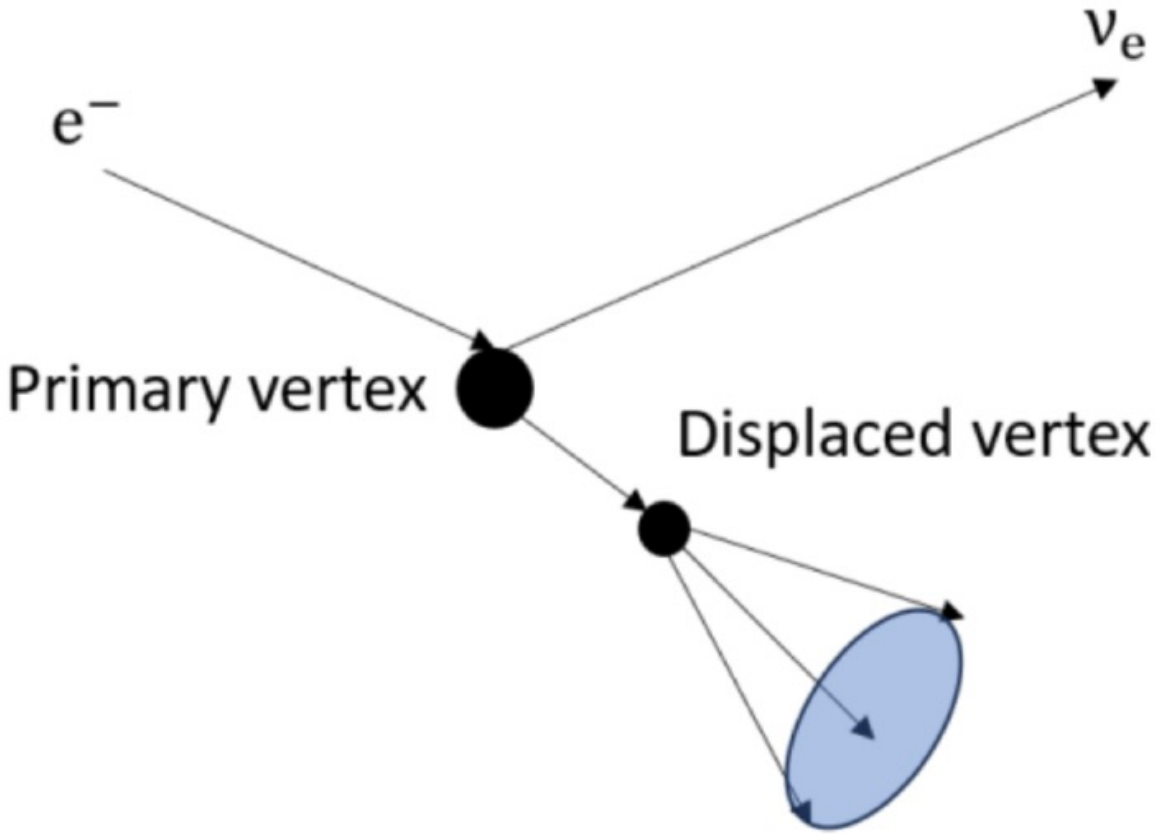
- BIC Requirements
  - 7-10%/$\sqrt{E} \oplus$ (1-3)%,
  - Up to 10^4 π^- background suppression
  - π^0/γ separation up to 10 GeV

  → Barrel Imaging Calorimeter
- BIC Coordination and Collaboration: North America + Korea
- Proto-type module production:
- Beam test: 7th~14th Aug 2024 at T10, CERN

Backup

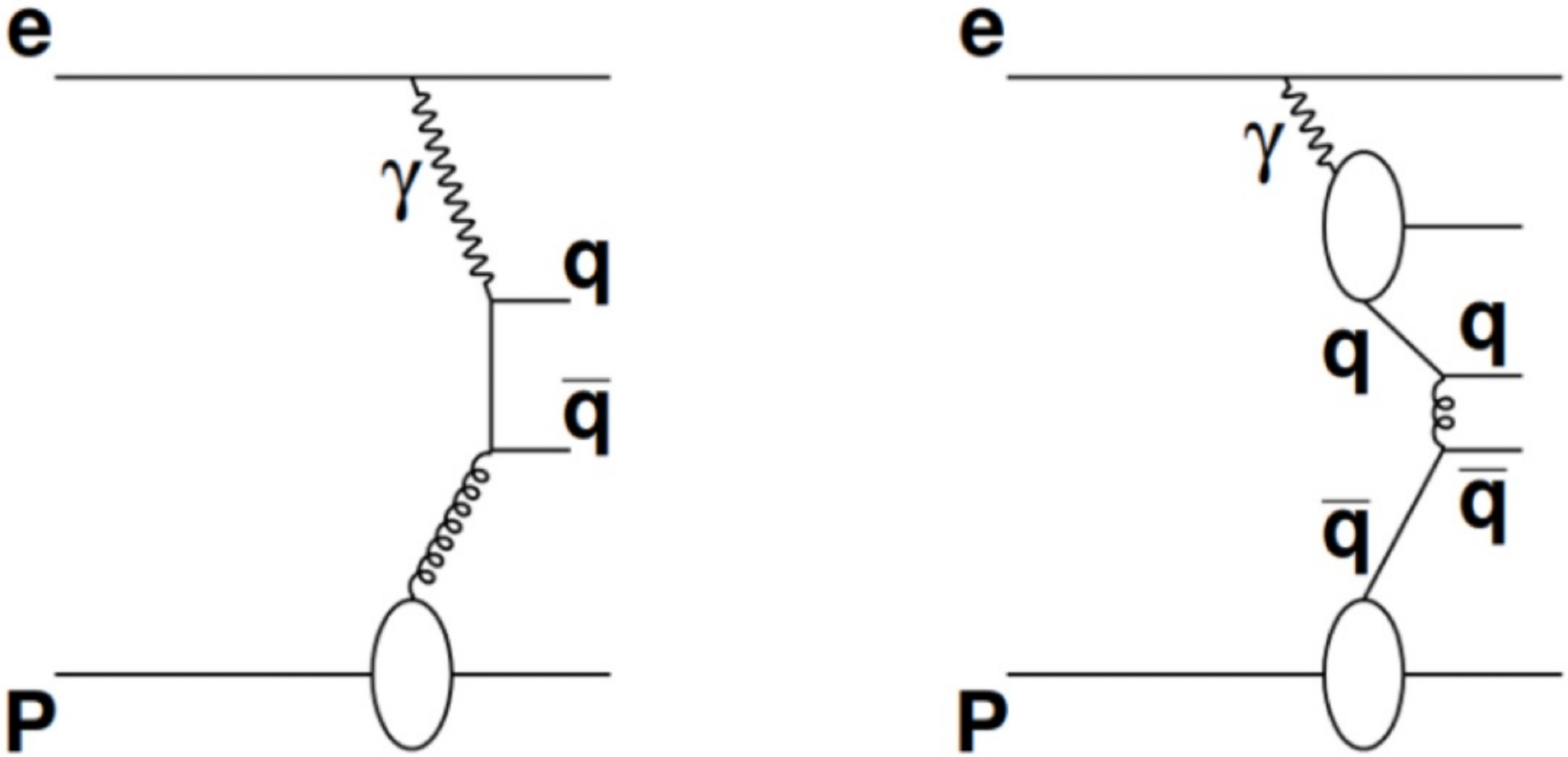
Physics potential with BIC





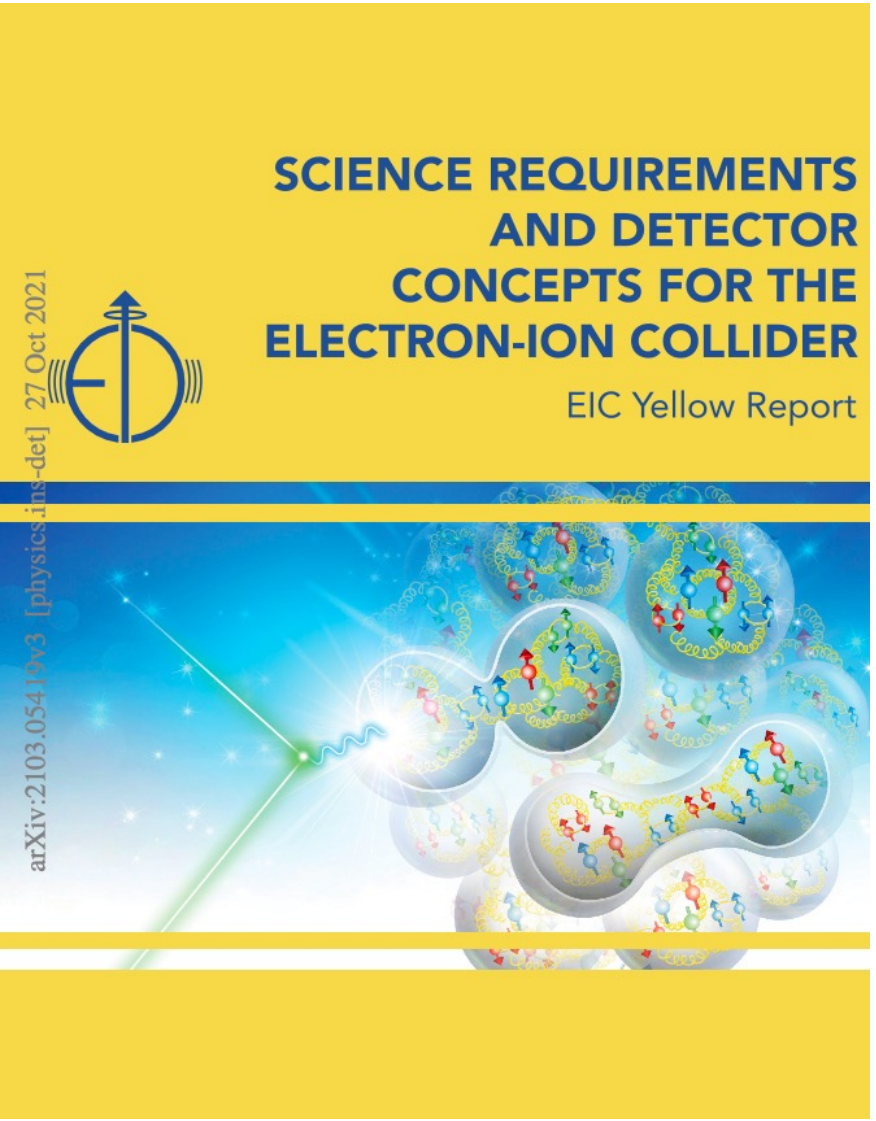
Strange quark parton distribution fuction

Physics potential with BIC



Polarized photon structure using dijets

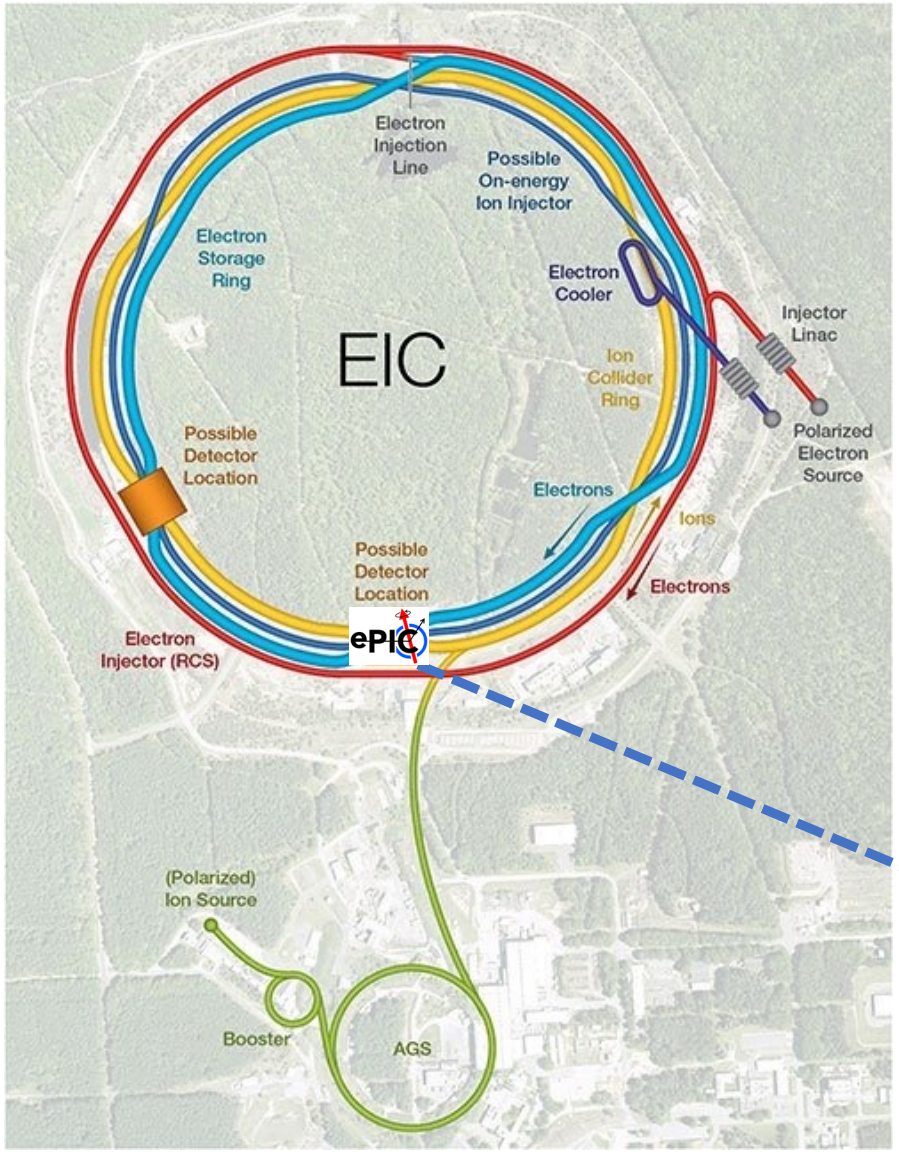
Key science questions



- Emergence of the nucleonic mass/spin

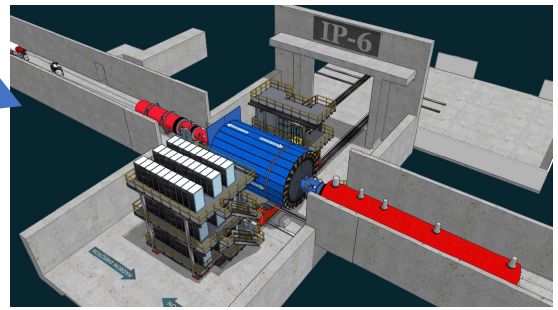
- Parton distributions inside nucleon in
  - momentum and coordinate space
- Gluon saturation
- Nuclear modification of PDF
- Colour charge through Cold Nuclear Matter

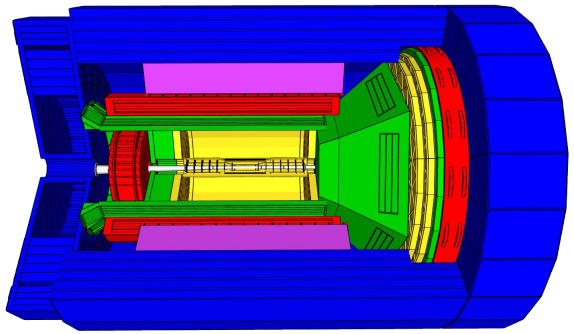
The Electron-Ion Collider (EIC)



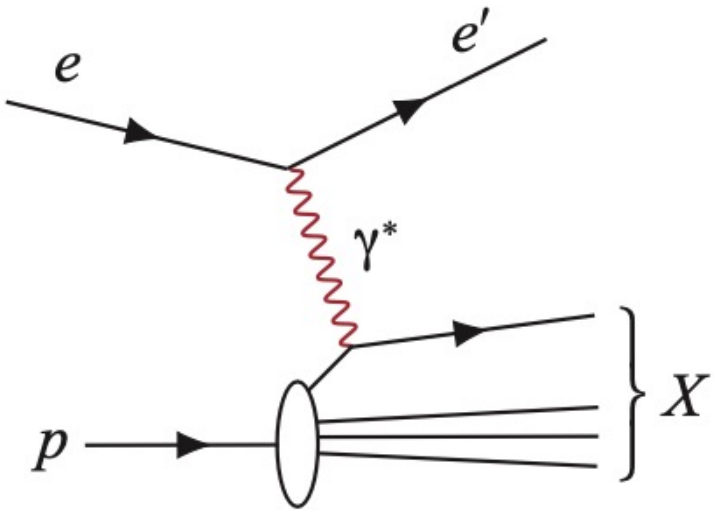
- Polarization ~ 70%
  - $e^{\uparrow}$ + $p^{\uparrow}$, $d^{\uparrow}$, $He^{\uparrow}$
  - $e^{\uparrow}$ + unpolarized ions up to U.
- $\mathcal{L} = 10^{33-34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

  $\leftrightarrow \mathcal{L}_{\mathrm{int}} = 10\text{–}100\ \mathrm{fb}^{-1}/\mathrm{year}$
- h: 41-275 GeV, e: 5-18 GeV
- The first experiment “ePIC”



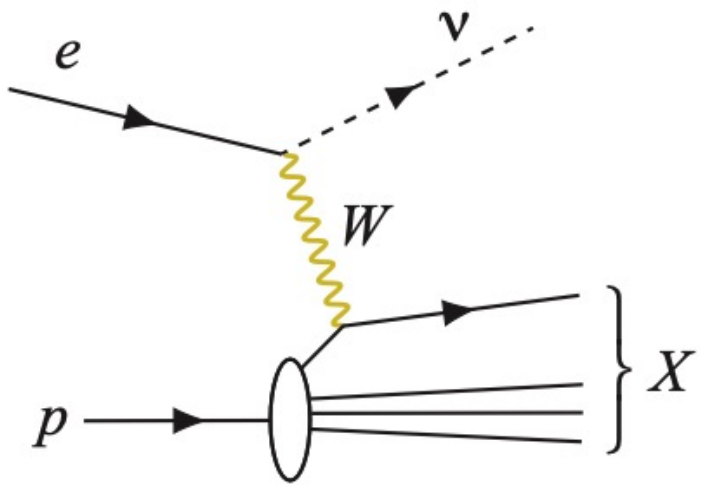


DIS processes



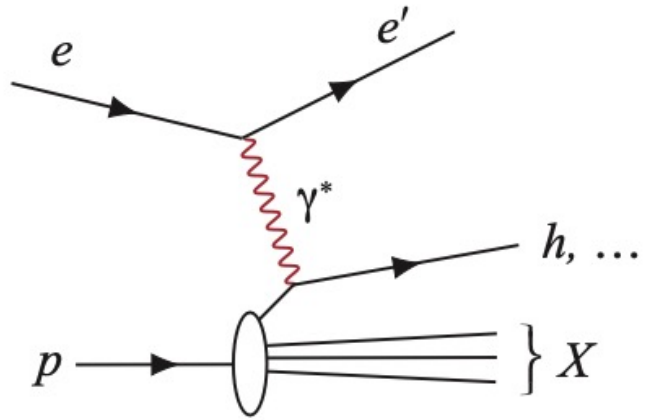
Neutral-current Inclusive DIS

$e + p/A \rightarrow e' + X$



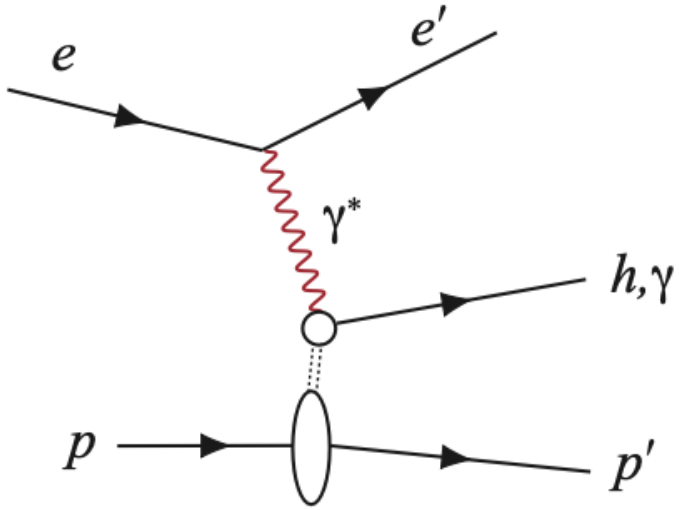
Charged-current Inclusive DIS

$e + p/A \rightarrow \nu + X$



Semi-Inclusive DIS

$e + p/A \rightarrow e' + h^{\pm,0} + X$

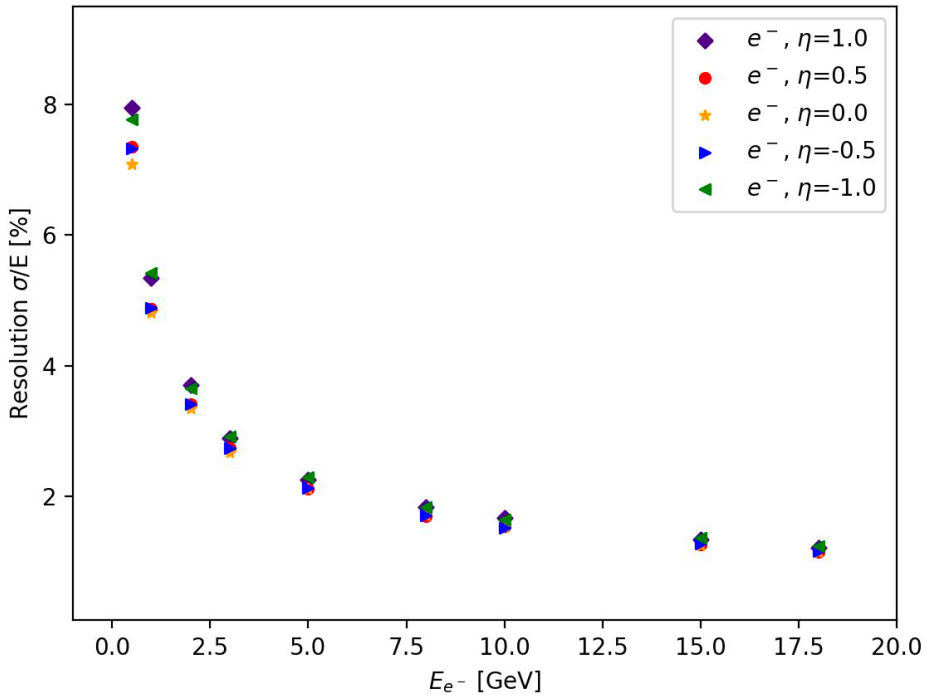


Exclusive DIS

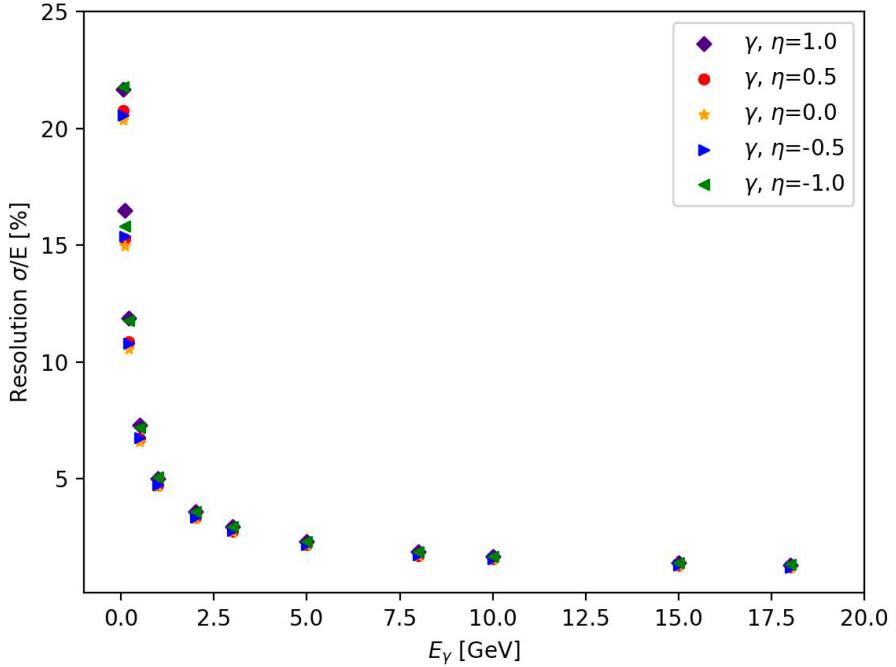
$e + p/A \rightarrow e' + p'/A' + \gamma/h^{\pm,0}$

BIC Performance: Energy Resolution

electron

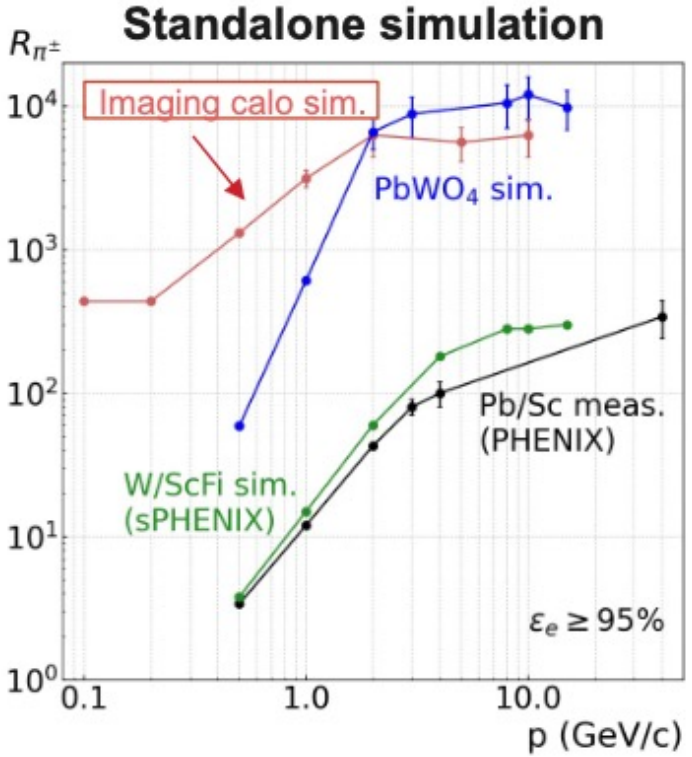


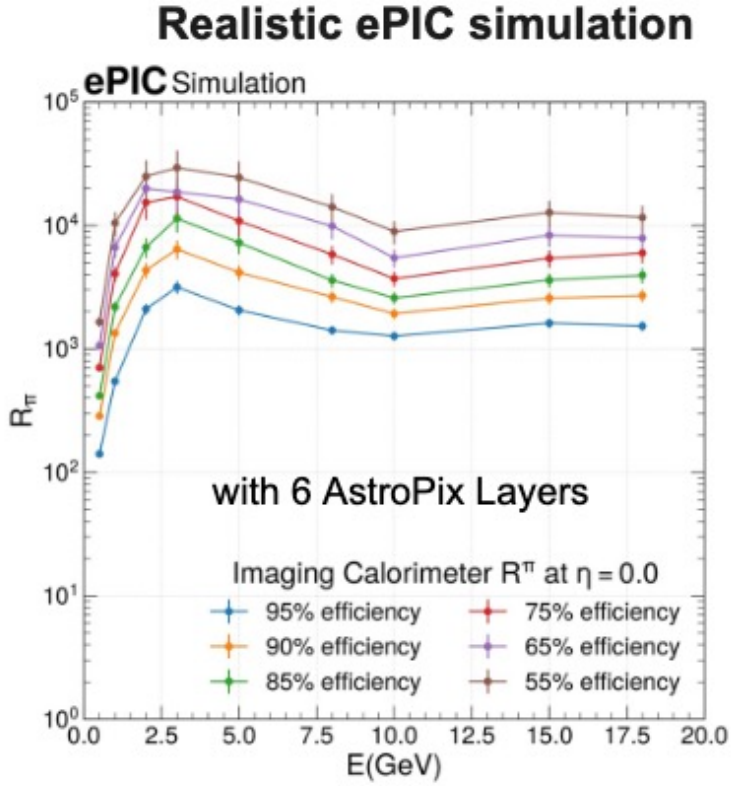
photon

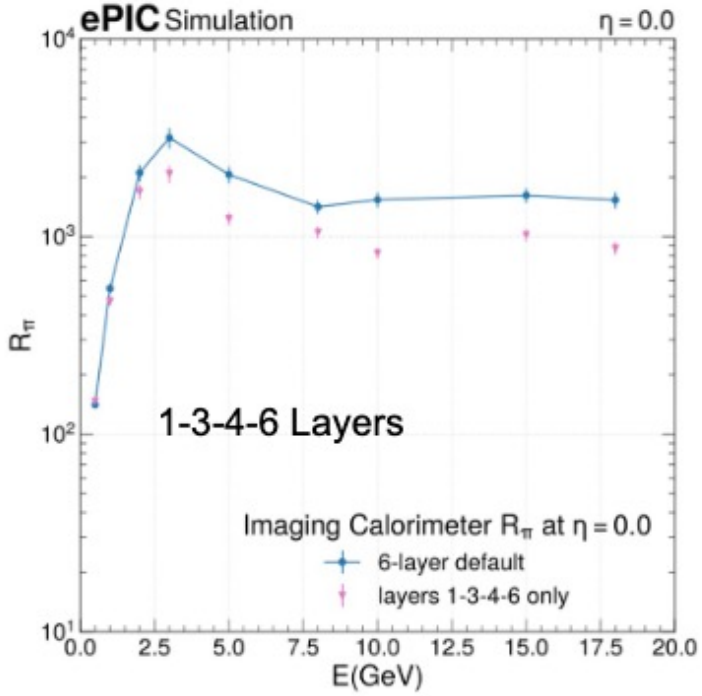


- Resolution extracted from a Crystal Ball fit σ
- GlueX Pb/ScFi ECal: σ = 5.2% /$\sqrt{E}$ ⊕ 3.6% *NIM, A 896 (2018) 24-42*

BIC Performance: electron/pion separation

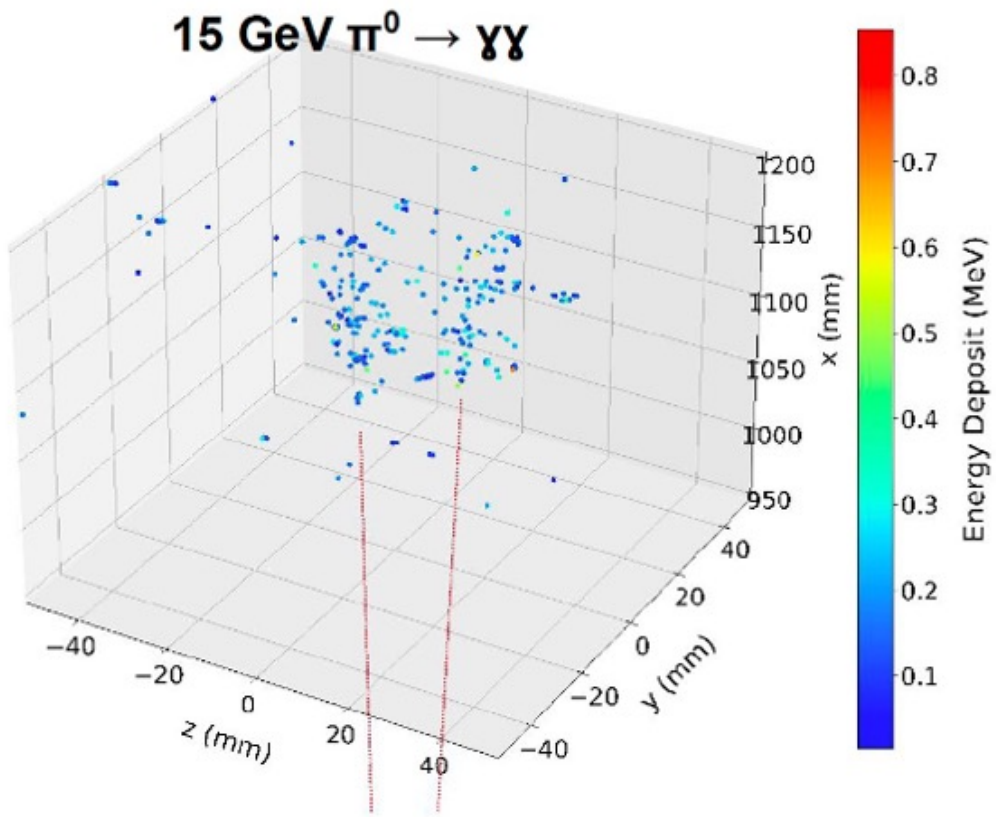


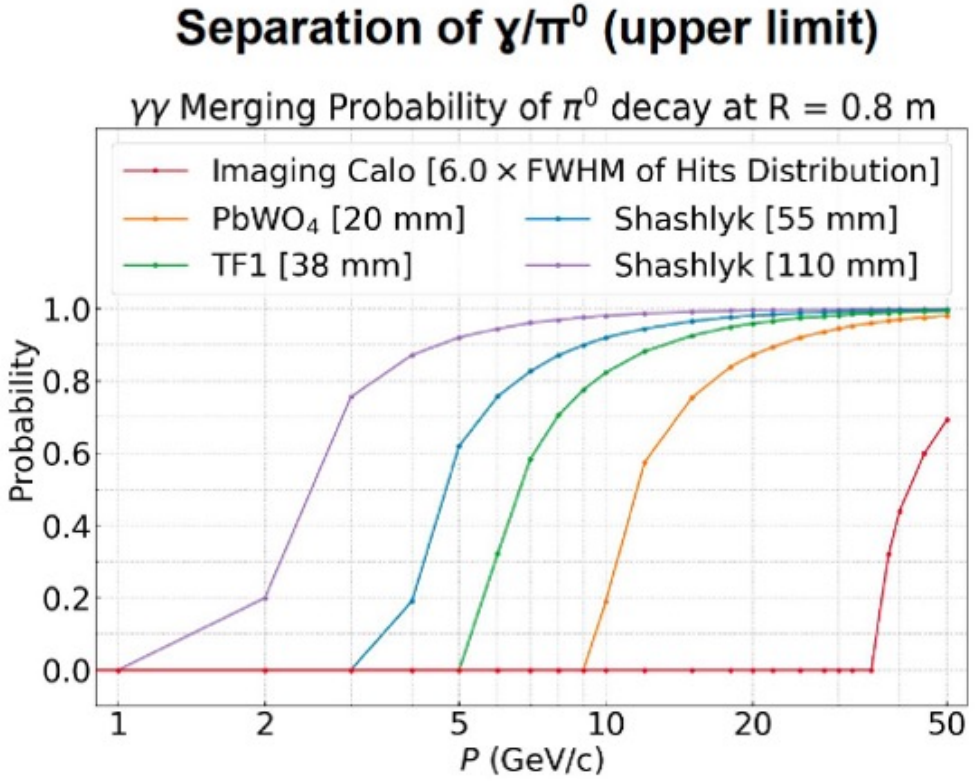




- Separation of electrons from background in Deep Inelastic Scattering (DIS) processes
- Method: E/p cut (Pb/ScFi) + NN using 3D position and energy info from imaging layers
- e-π separation exceeds 10^3 in pion suppression at 95% efficiency above 1 GeV

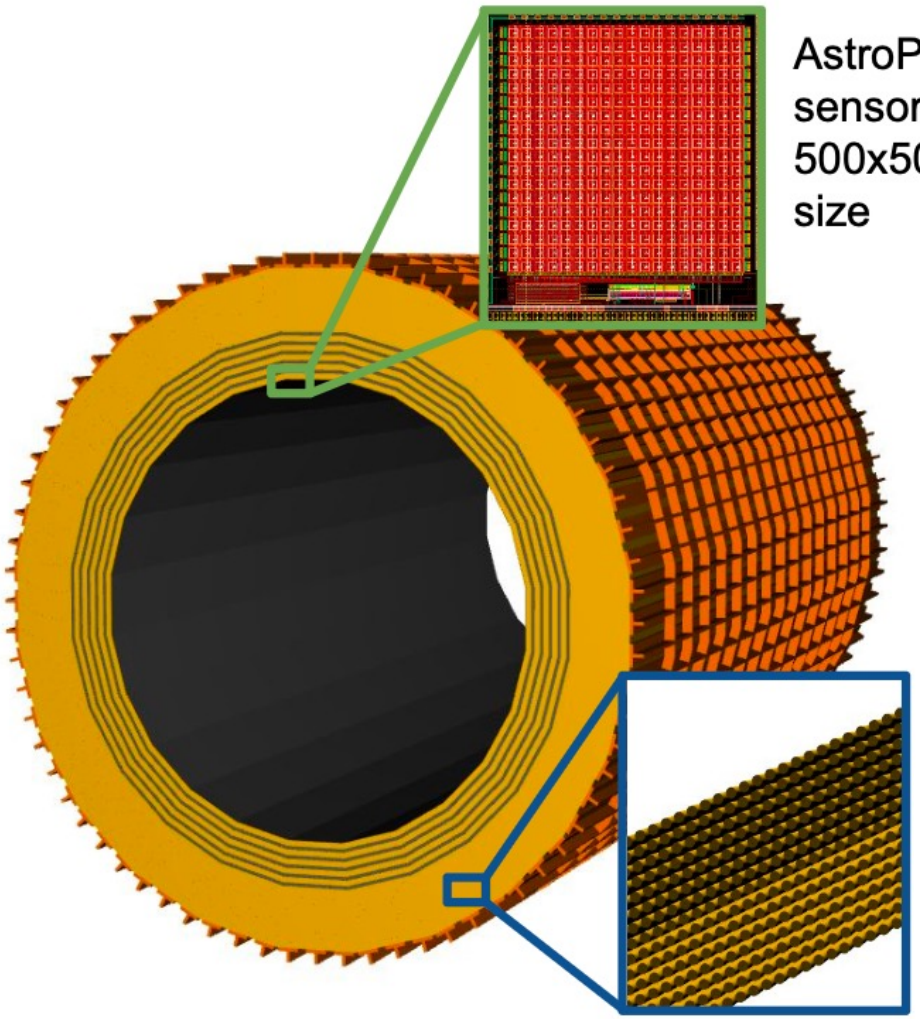
BIC Performance: Neutral Pion Identification



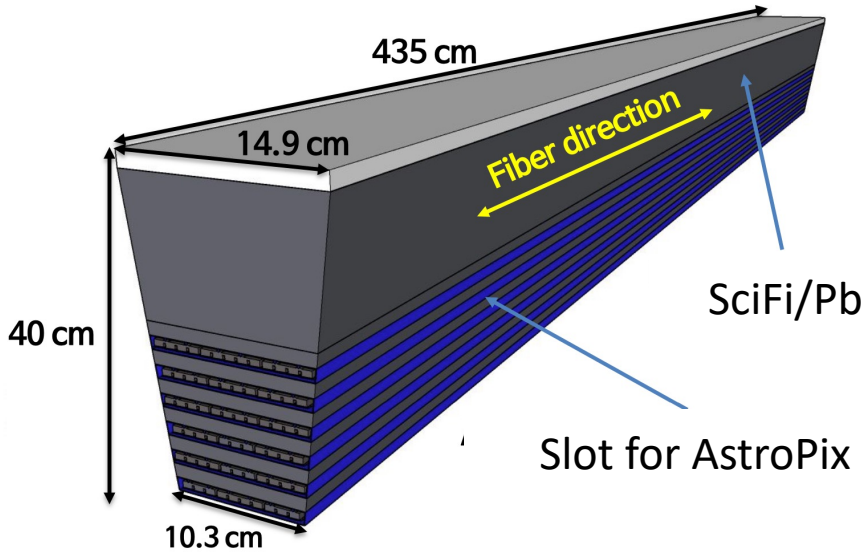


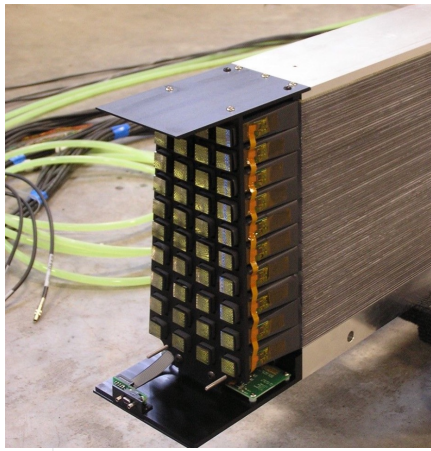
- Separation of two gammas from neutral pion well above required 10 GeV
- Discriminate between π^0 decays and single γ from DVCS, π^0 identification
- Precise position resolution allows for excellent separation of γ/π^0 based on 3D shower profile

Barrel Imaging Calorimeter



AstroPix: silicon sensor with 500x500μm^2 pixel size

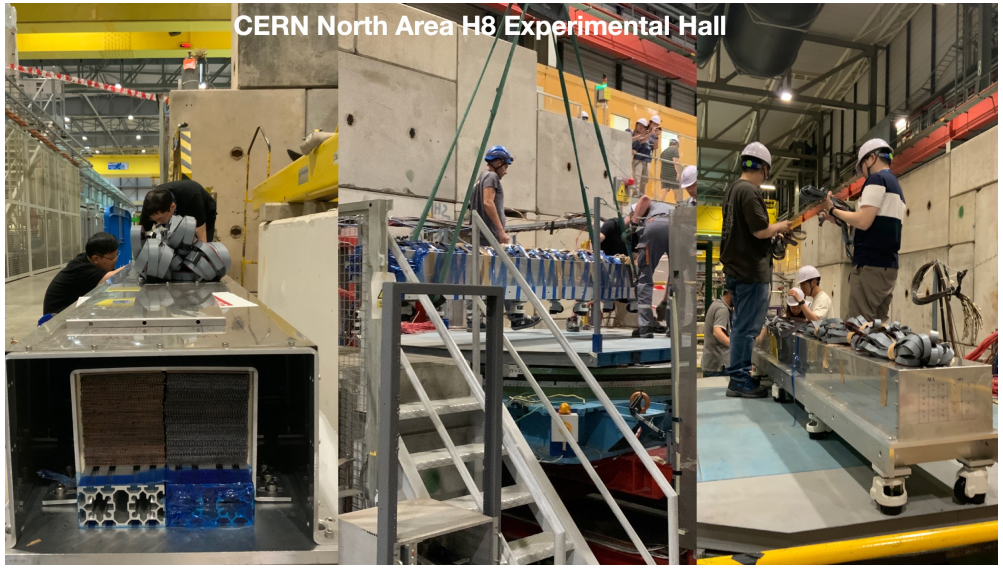




SciFi/Pb layers
With two-sided
SiPM readout

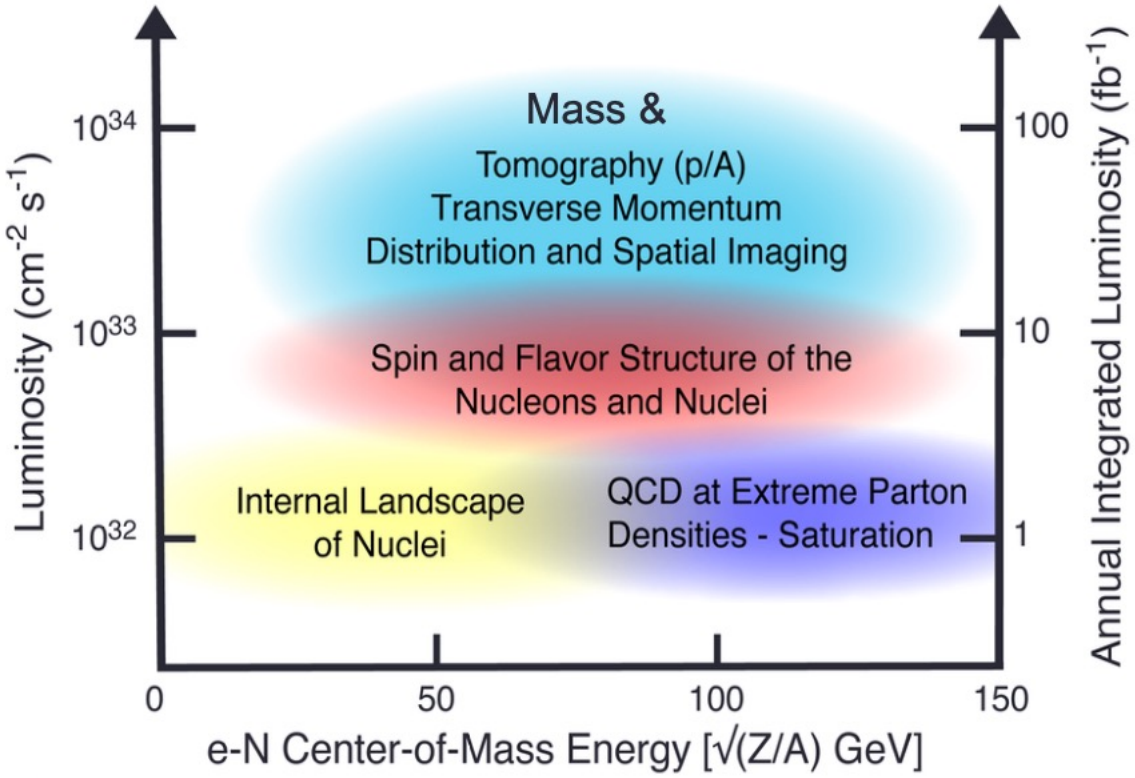
- 48 modules covering 2π in azimuth
- 4(+2) layers of imaging Si sensors interleaved with 5 SciFi/Pb layers
- Followed by a bulk section of SciFi/Pb
- Total radiation thickness $\sim 17.1\ X_0$
- Sampling fraction $\sim 10\%$

- Proto-type modules being prepared for 3 different methods
  - i) Pressing method
  - ii) Rolling method
  - iii) Casting method
- Beam test planned in August with a final goal to see the synced DAQ signal with Astropix chips



Summary

- Origin of Nucleon Spin
  - DIS with polarized electrons and protons for a large range in x and Q^2
  - Good electromagnetic calorimetry at the level of 7-10%/$\sqrt{E}$ $\oplus$ (1-3)%



- Multi-dimensional imaging of the Nucleon
  - Transverse Momentum Distribution measurement by Semi-Inclusive DIS
  - Generalized Parton Distribution measurement by Exclusive DIS
- Nuclear modification of PDF: The same BIC requirement
- Colour charge through Cold Nuclear Matter: Jet Physics