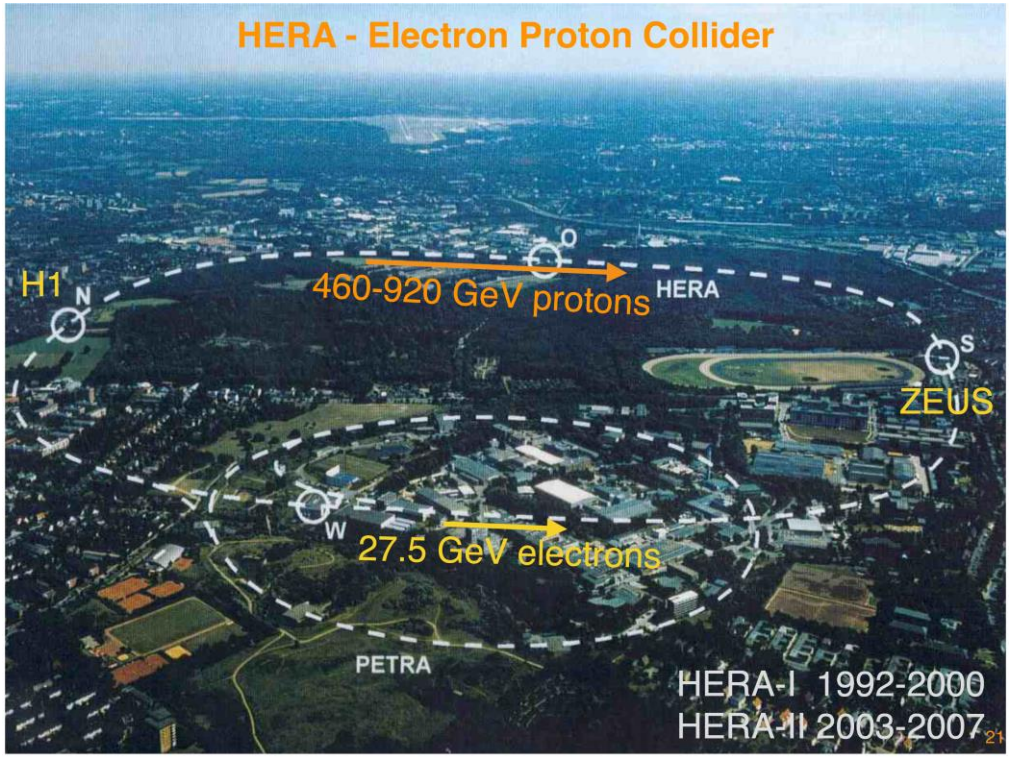
Updates on EIC Projects

TIDC Annual Meeting
Novembre 25, 2023

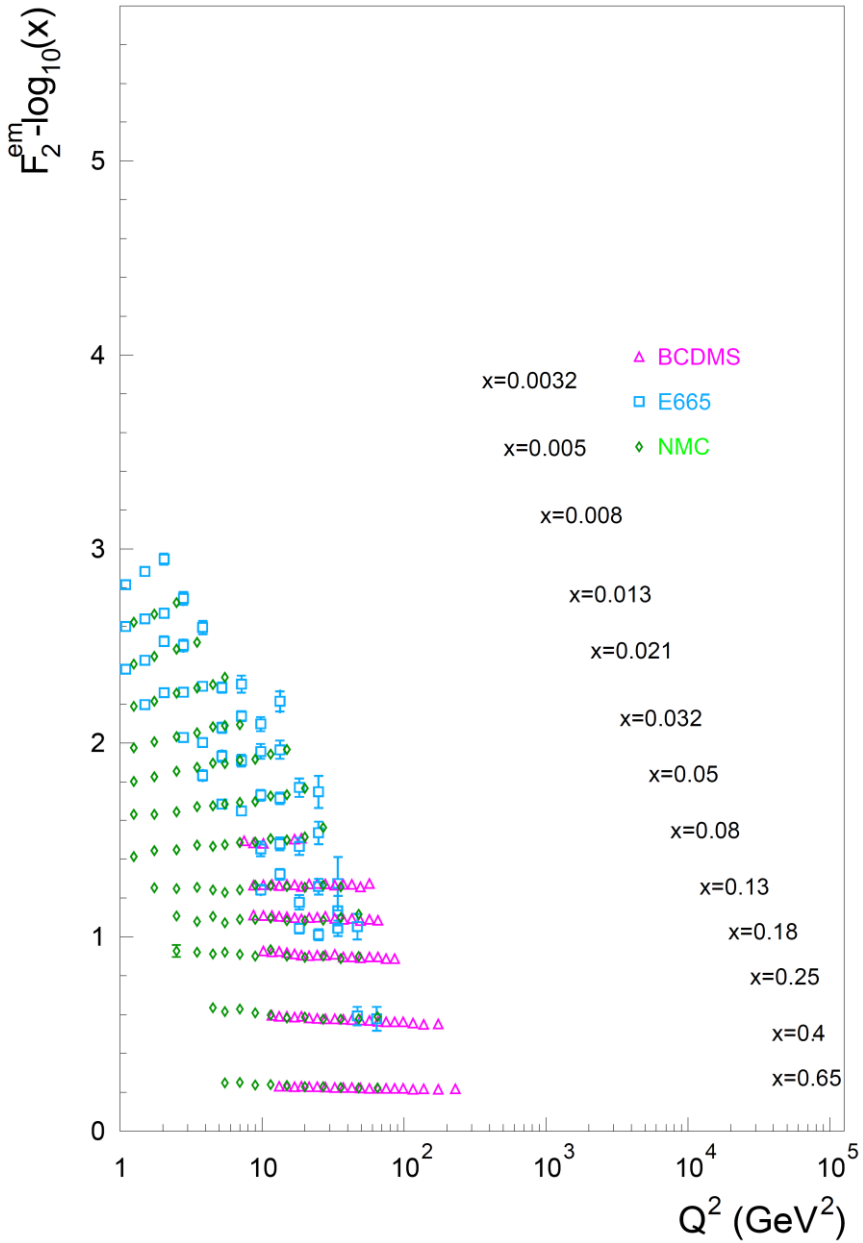
Po-Ju Lin
National Central University

Study Hadron Substructure by Collider

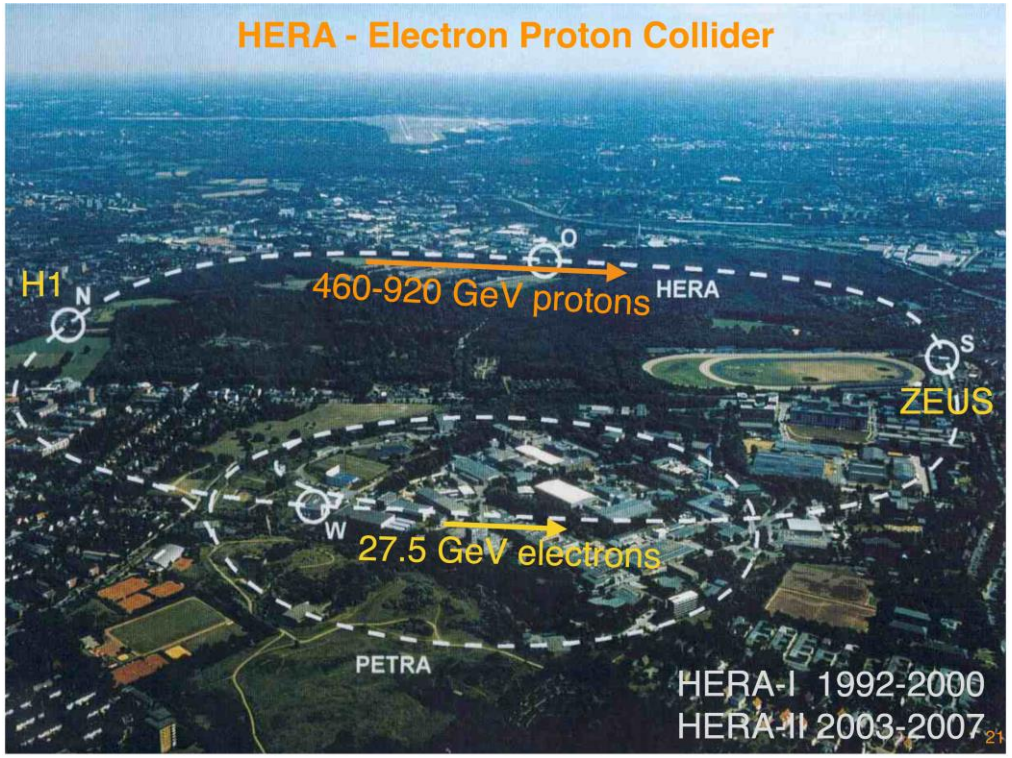


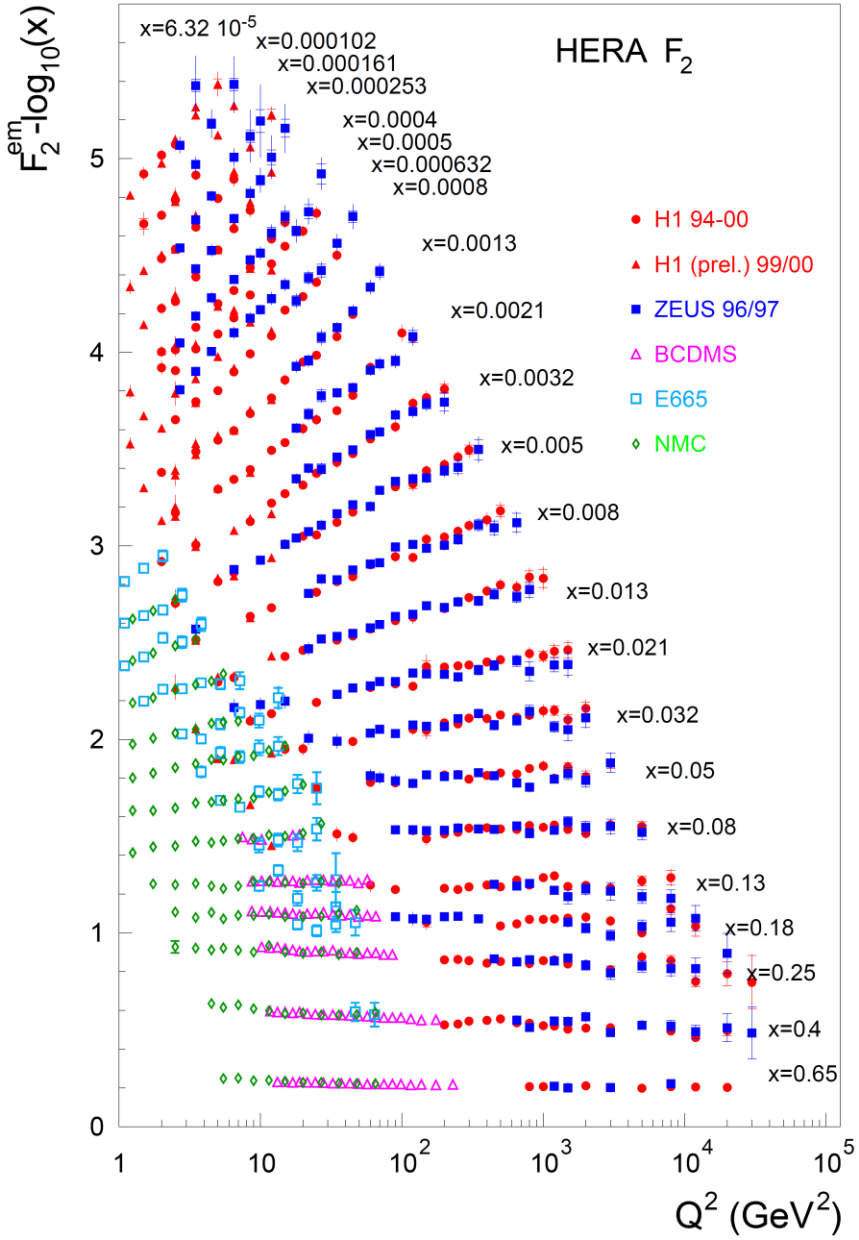
$e^{\pm}$ **27.5 GeV** → ← **920 GeV** p

$\sqrt{s}$ = 320 GeV



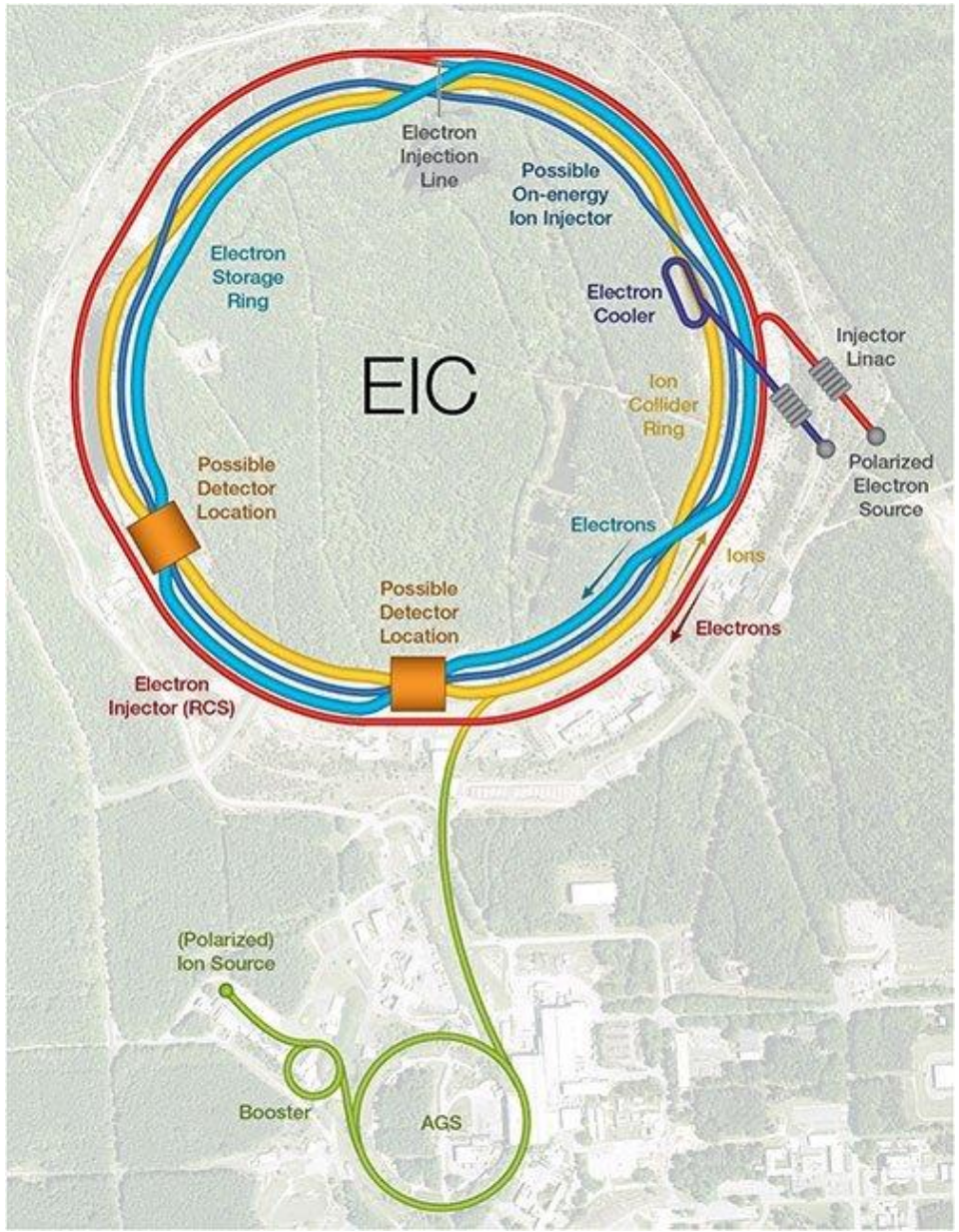
Study Hadron Substructure by Collider





- A great insight of the parton distribution in proton has been provided by the $e^{\pm}$p collider HERA!

The Electron Ion Collider



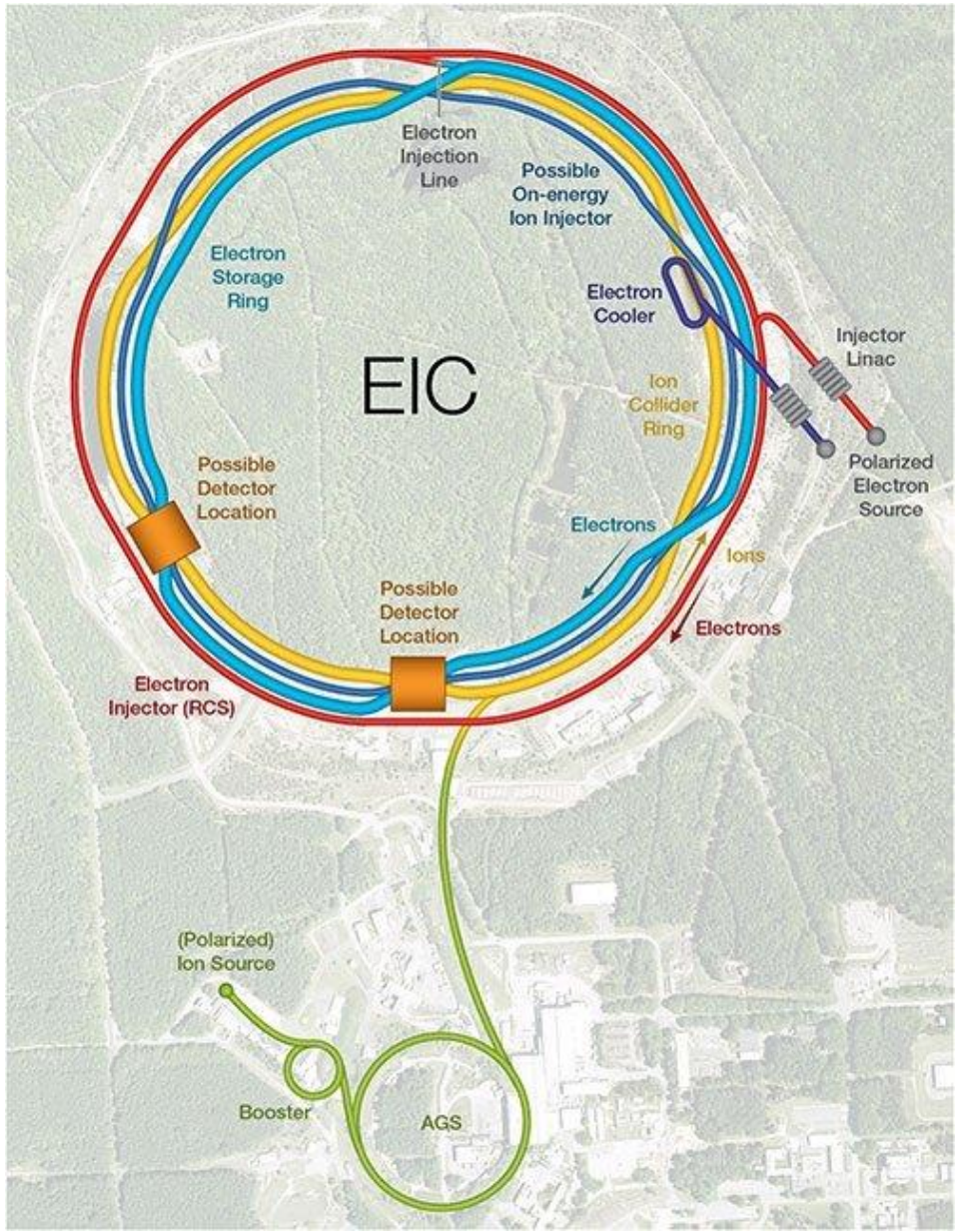
➢ **First - eA collider**

- High luminosity ep collider

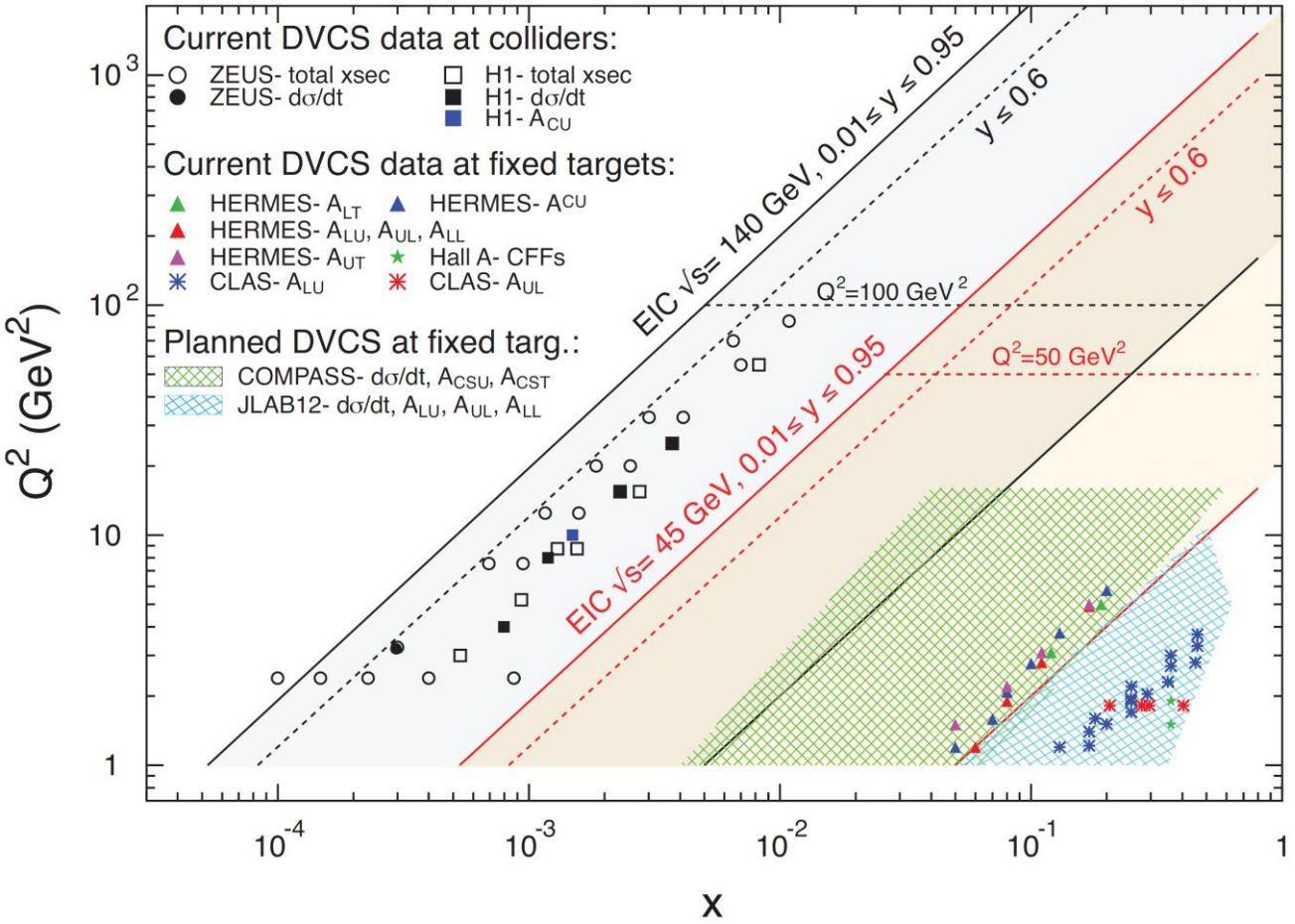
- Polarized target collider

- **For e-N collision at EIC:**
  - Polarized beams: e, p, d/^{3}He
  - e beam 5 – 18 GeV
  - Luminosity $L_{ep} \sim 10^{33\text{-}34}\ cm^{-2}s^{-1}$
  - 30 – 140 GeV variable CoM
- **For e-A collision at EIC:**
  - Wide range of nuclei
  - Luminosity per nucleon same as e-p
  - Variable CoM energy

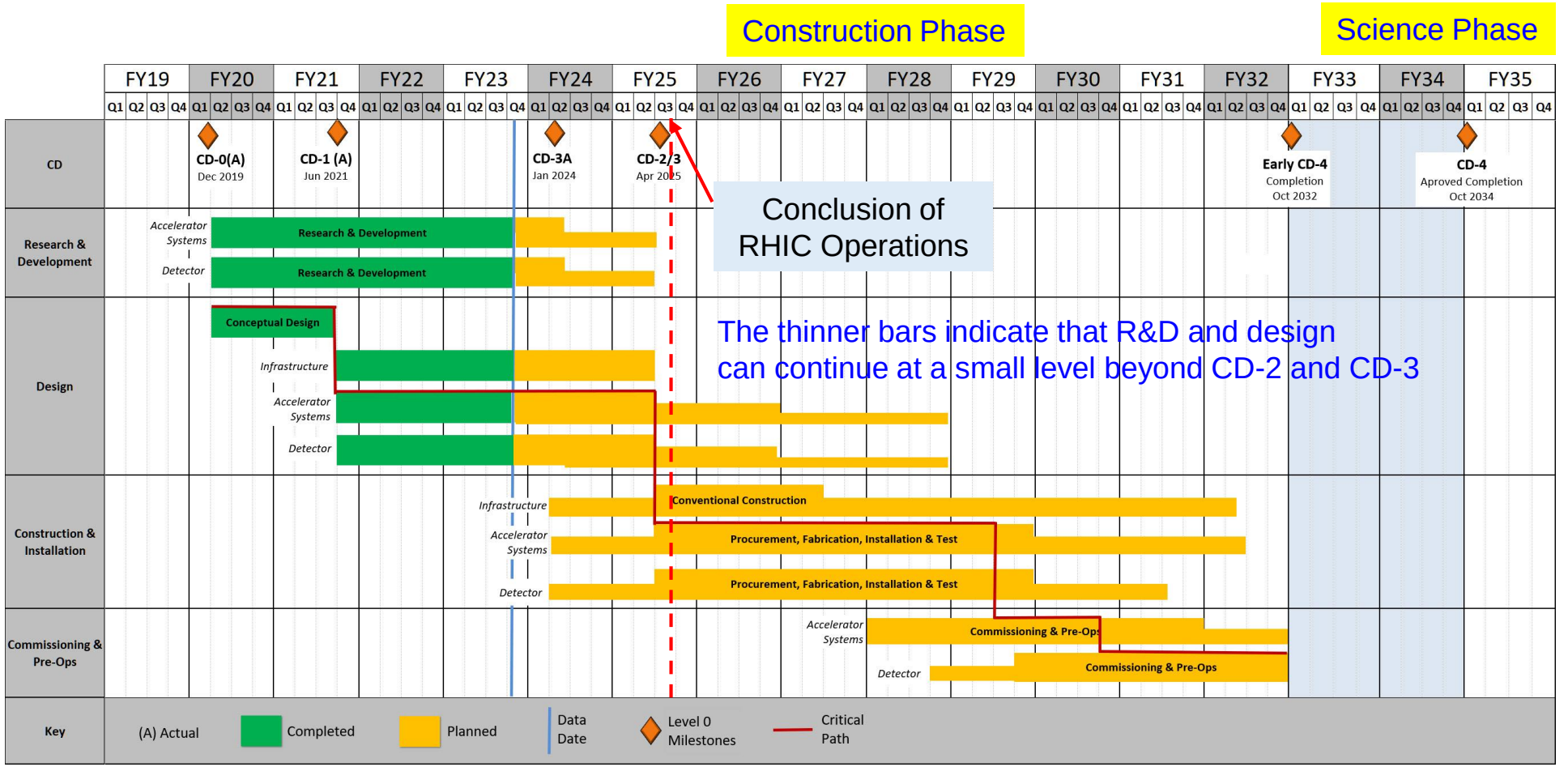
The Electron Ion Collider



- **First - eA collider**
  - **High luminosity ep collider**
  - **Polarized target collider**



EIC High Level Project Schedule



The 1st Detector Collaboration: ePIC

- The ECCE and ATHENA Collaborations were merged.

hadronic calorimeters

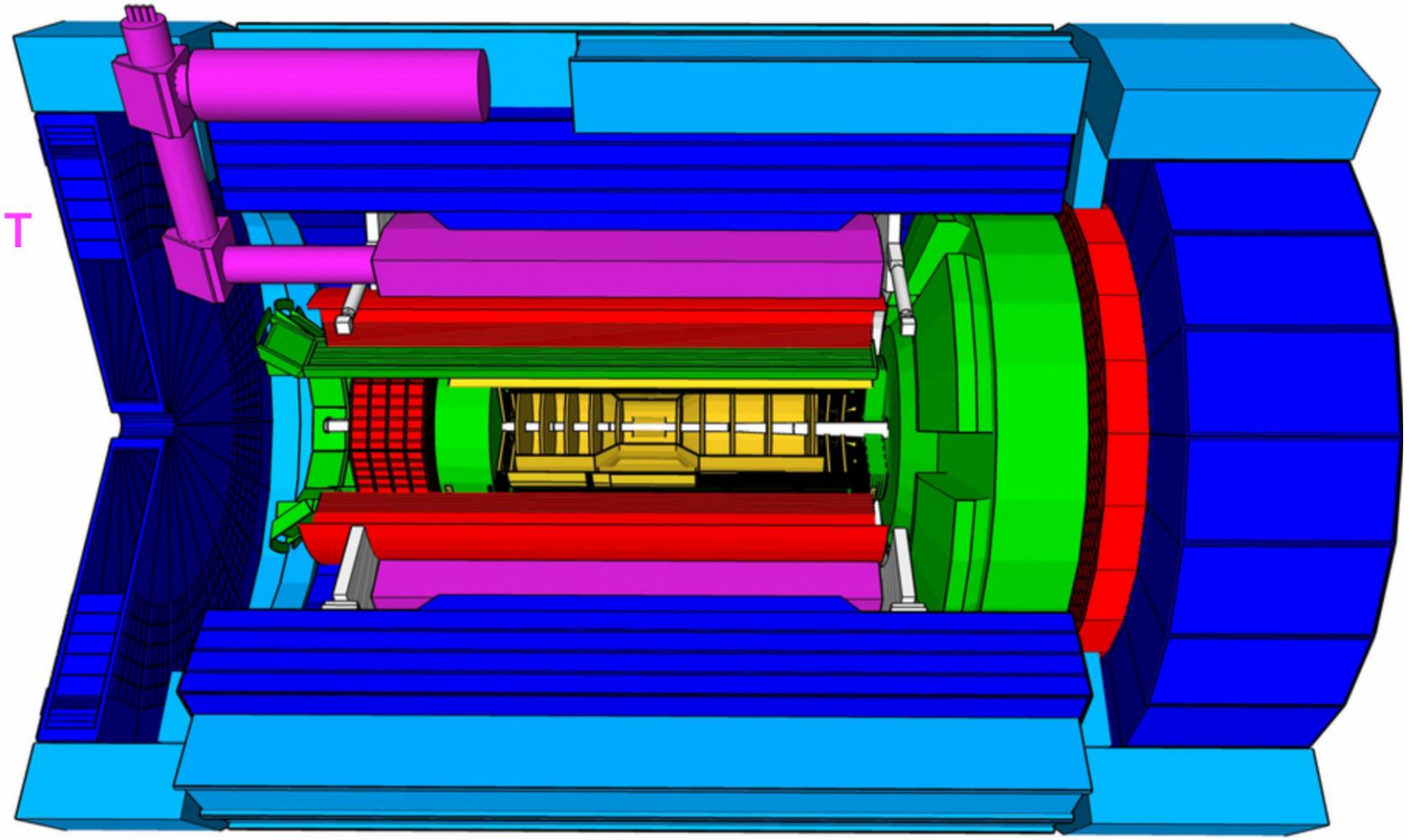
Solenoidal Magnet 1.7 T

e/m calorimeters (ECal)

Time.of.Flight, DIRC, RICH detectors

MPGD trackers

MAPS tracker



9.5 m

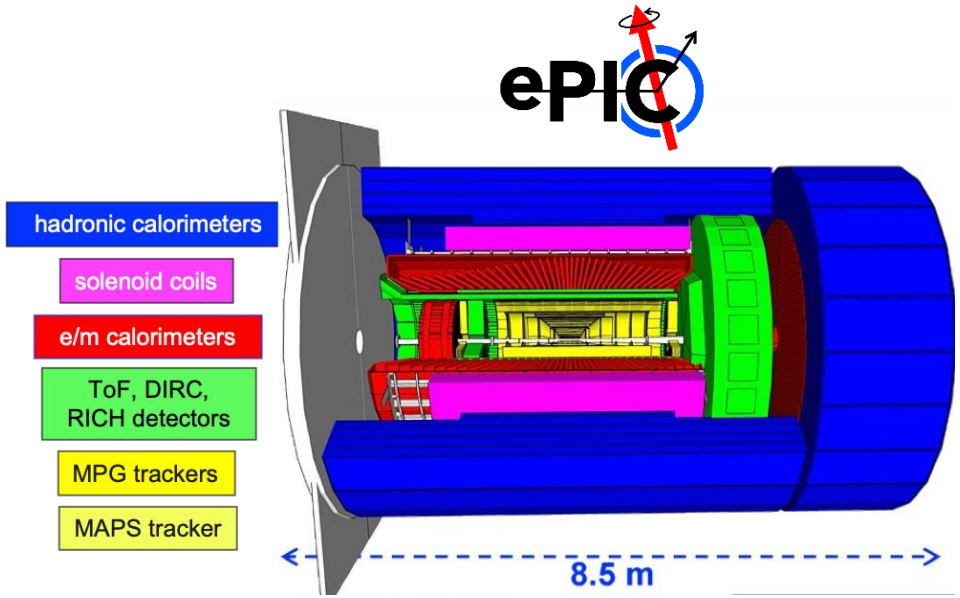
Hadron beam

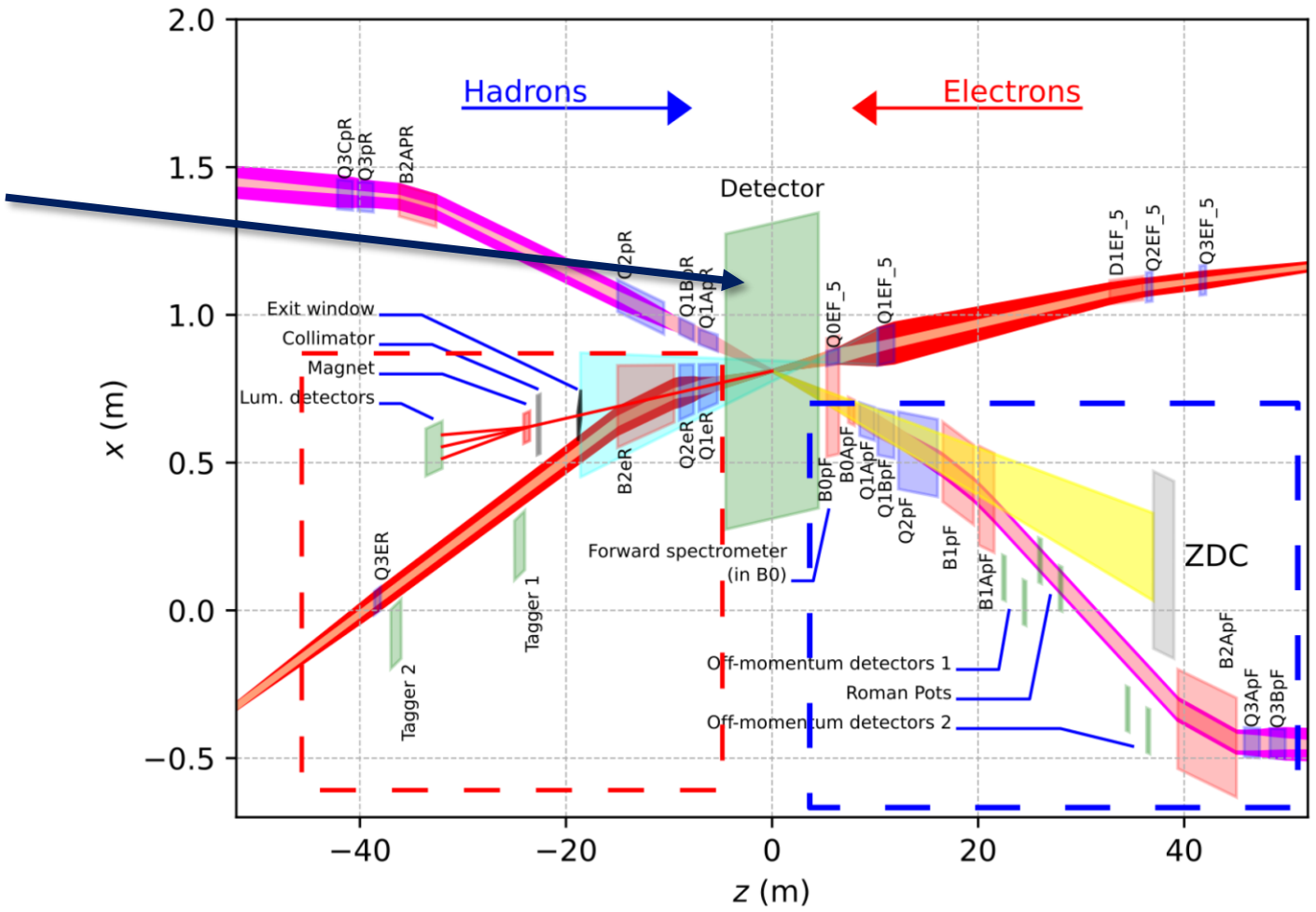
p: 100-275 GeV

Electron beam

e: 5-18 GeV

The 1st Detector Collaboration: ePIC

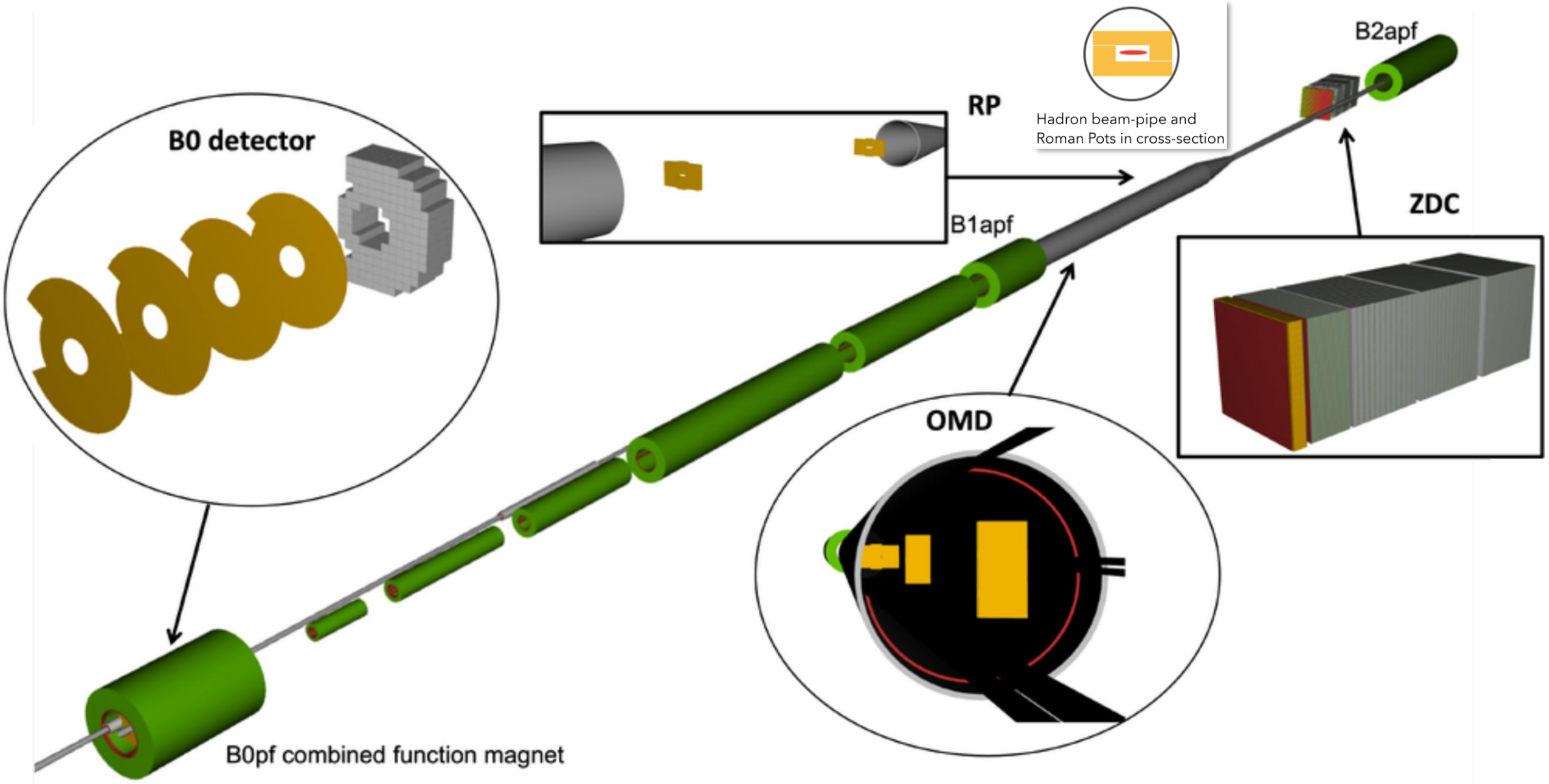




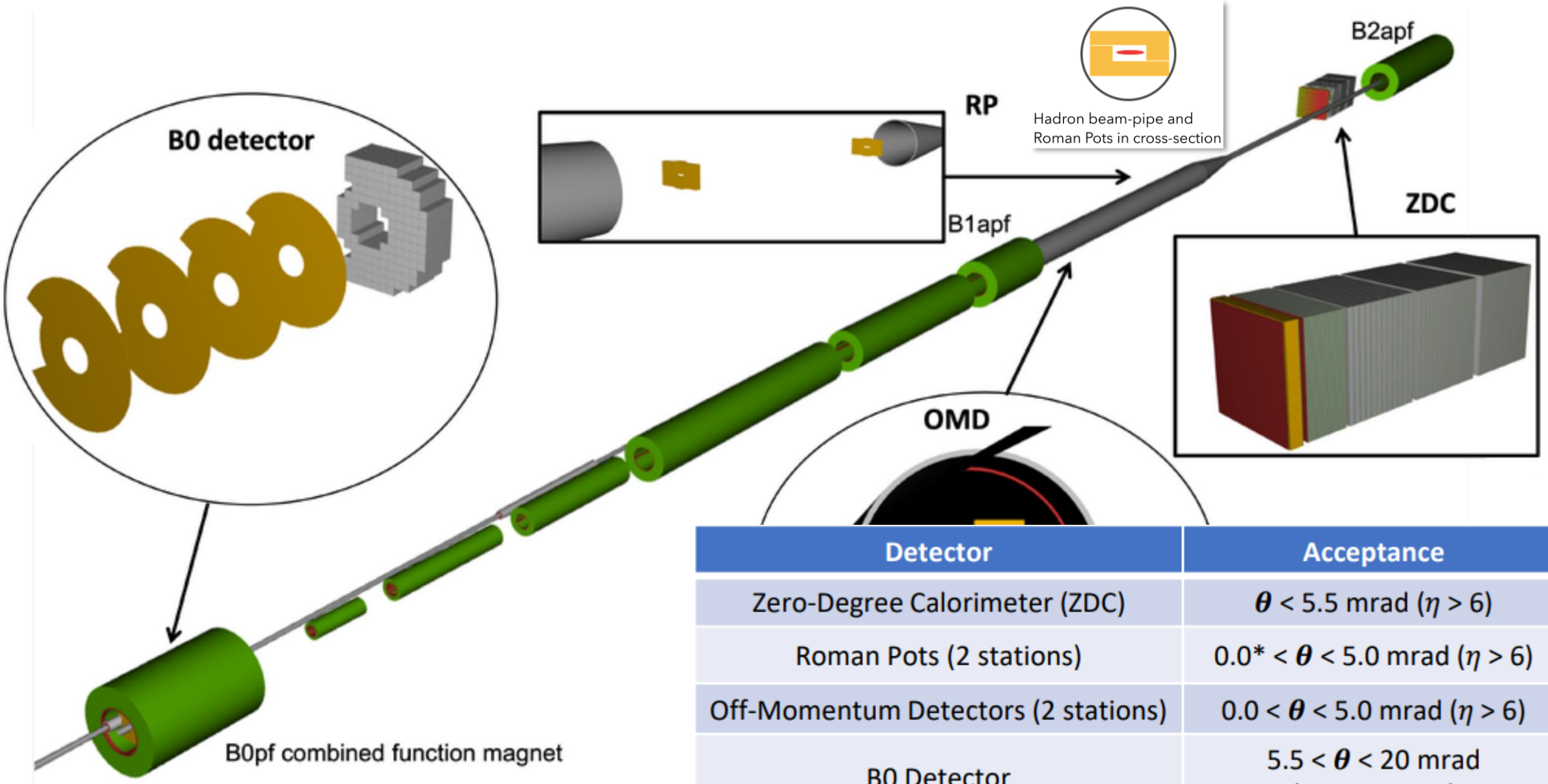
- Auxiliary detectors needed to tag particles with very small scattering angles both in the outgoing lepton and hadron beam direction.

- Far forward and backward detectors provide vital information for the reaction kinematics of the colliding systems.

Far-Forward Detectors



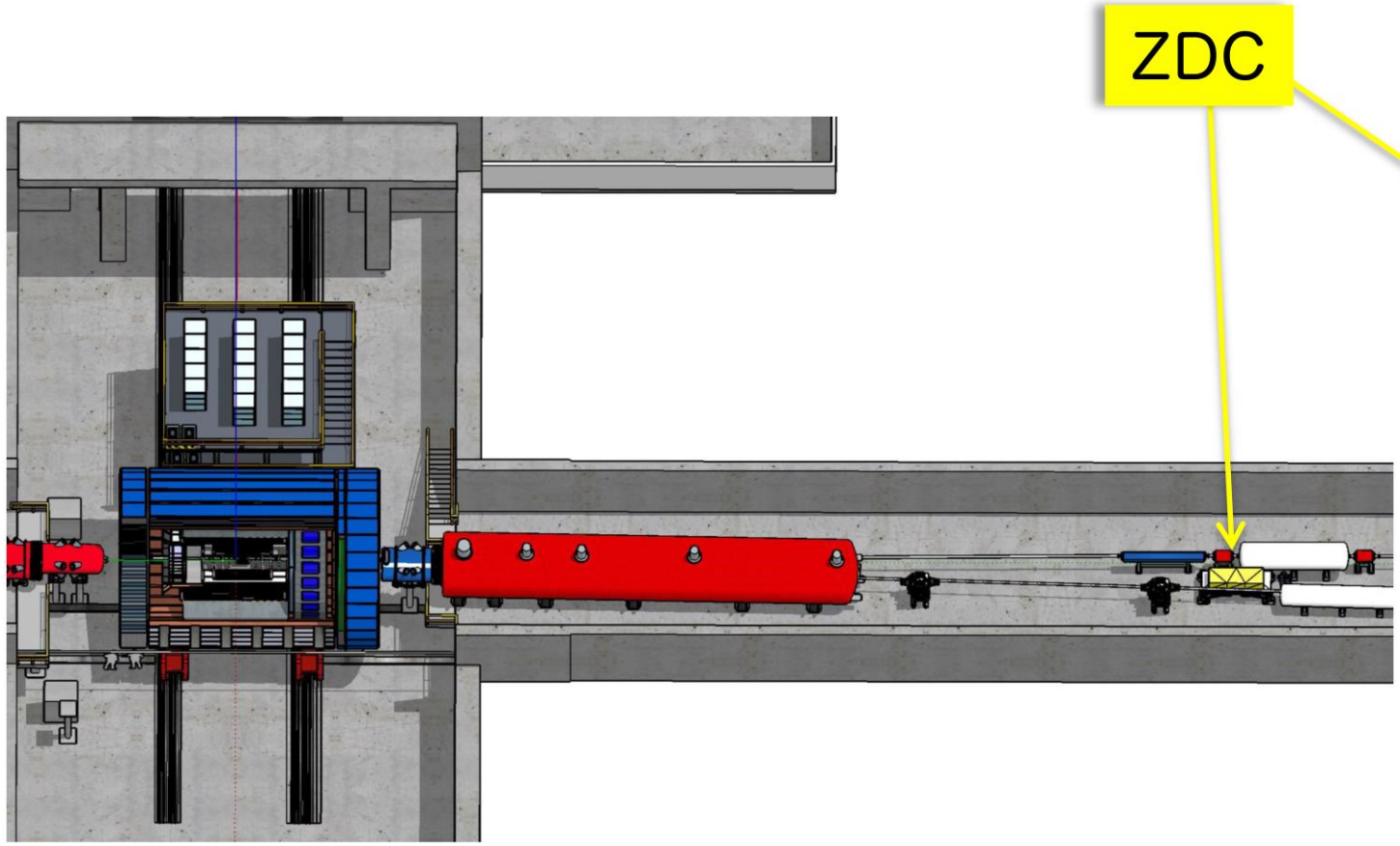
Far-Forward Detectors

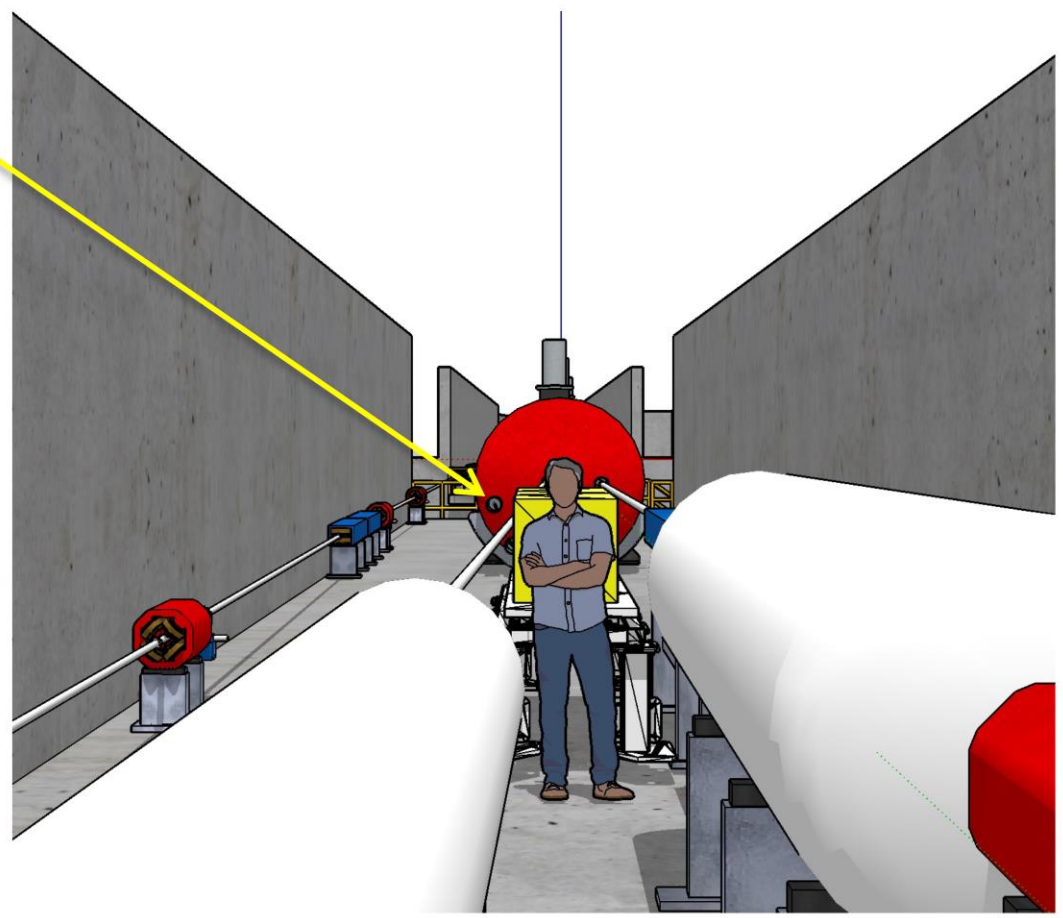


Detector	Acceptance
Zero-Degree Calorimeter (ZDC)	$\theta < 5.5$ mrad ($\eta > 6$)
Roman Pots (2 stations)	$0.0^* < \theta < 5.0$ mrad ($\eta > 6$)
Off-Momentum Detectors (2 stations)	$0.0 < \theta < 5.0$ mrad ($\eta > 6$)
B0 Detector	$5.5 < \theta < 20$ mrad ($4.6 < \eta < 5.9$)

Zero Degree Calorimeter (ZDC)

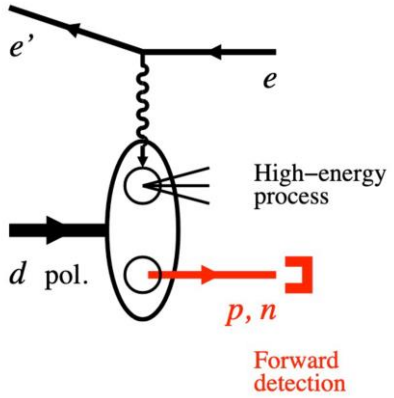
A calorimeter for measuring photons and neutrons.
ZDC sits at about 30m from the interaction point.

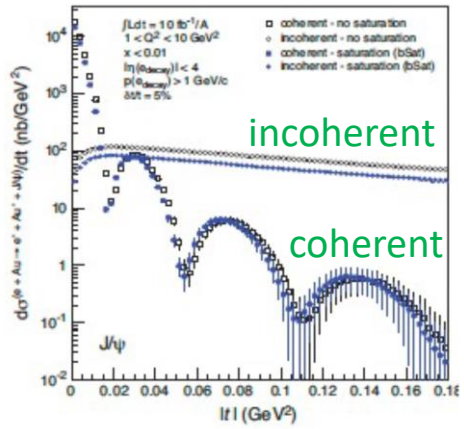


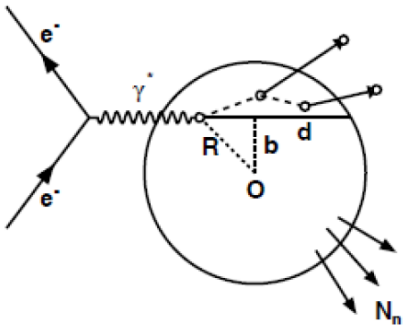


Physics Related to ZDC

- Spectator tagging in $e + d/^3He$ collisions
  - Neutron structure, spin structure
  - Proton by B0/Roman pots and neutron by ZDC





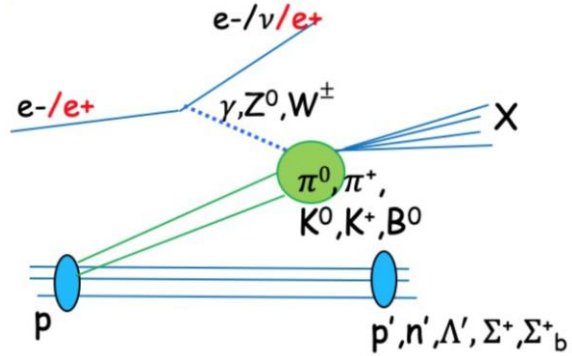


Intra-nuclear cascading increases with d (forward particle production)

Leads to evaporation of nucleons from excited nucleus (very forward)

- $e + A$ collision at small angle
  - Determination of excited nucleus breakup
    - Veto with evaporated neutrons and photons from de-excitation
  - Collision geometry characterization in $e + A$ collisions
    - Correlated to neutron multiplicity
    - Study of nuclear matter effect

- Meson structure via Sullivan Process
  - Measure neutron or $\Lambda(\rightarrow n + 2\gamma)$ in far-forward region
    - Structure of π, K, etc.



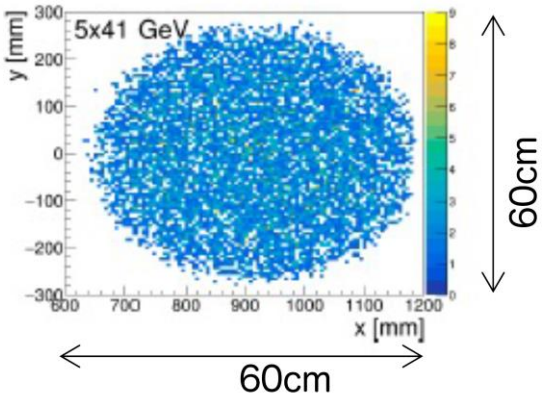
- And more…

Performance Requirements

- Large acceptance: $60cm \times 60cm$ front surface → From meson structure measurement
- Measurement of GeV photons and neutrons
- Detection of soft photons, with efficiency $> 90\%$

YR Fig. 8.104

Neutrons from e+p→ e'+X+n



	Energy range	Energy resolution	Position resolution
Neutron	~ 275 GeV (up to beam energy)	$\frac{50\%}{\sqrt{E}} + 5\%$	$\frac{3 \text{ mrad}}{\sqrt{E}}$
Photon	$O(100)$ MeV	$20\sim30\%$	
	$20\sim40$ GeV	$\frac{35\%}{\sqrt{E}}$	$0.5\sim1$ mm

→ Pion structure may require 1mm pos. resol.

→ Veto in $e + Pb$ exclusive J/ψ production

→ u-channel exclusive π^0

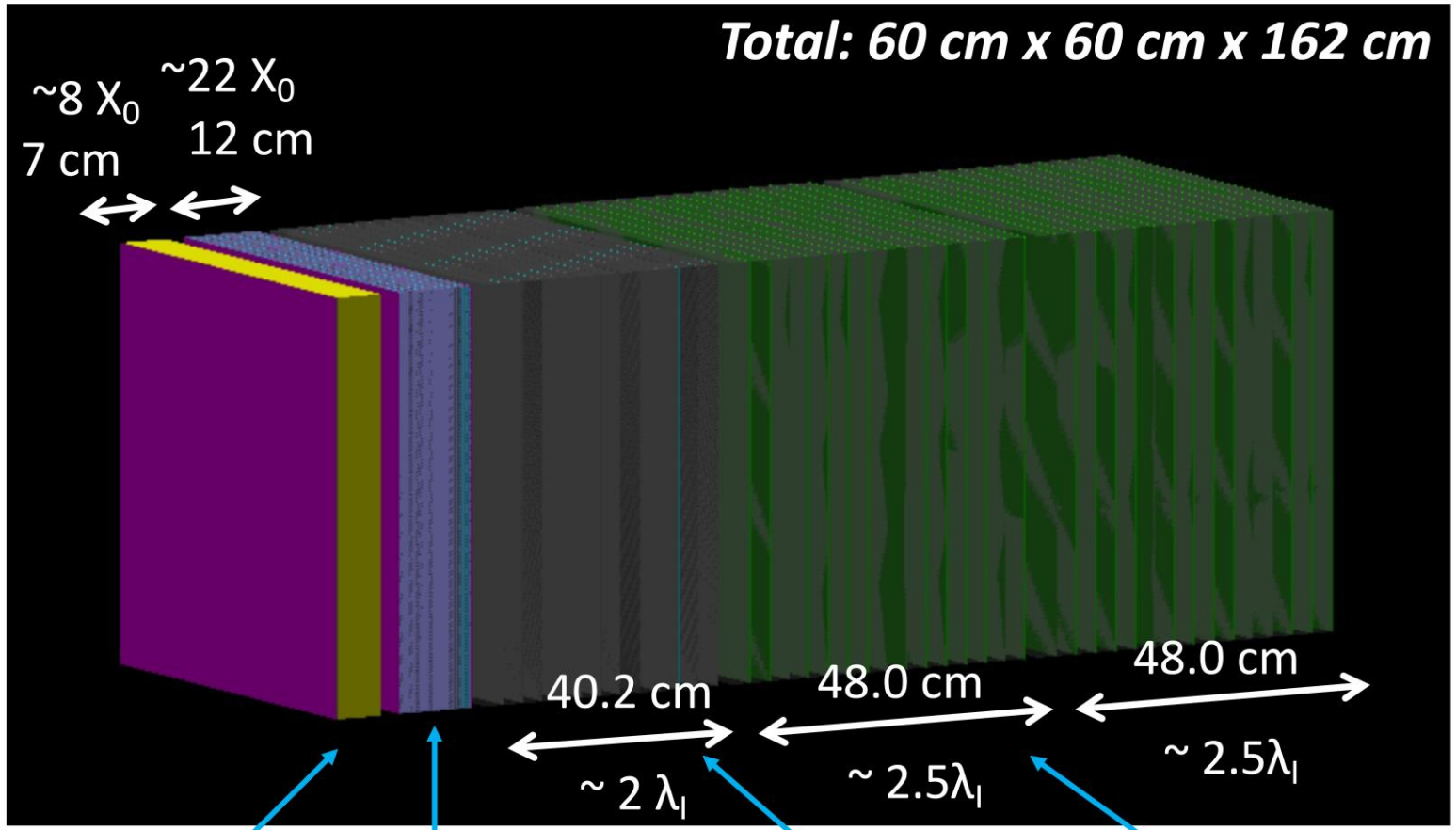
→ Kaon structure requires tagging n and 2 or 3 γ (Λ or Σ)

- Challenge: large energy coverage, detailed reconstruction of photon and neutron showers

Preliminary ZDC Design

- A composition of four different calorimeter configurations

*note: space for readout may extend the longitudinal length.



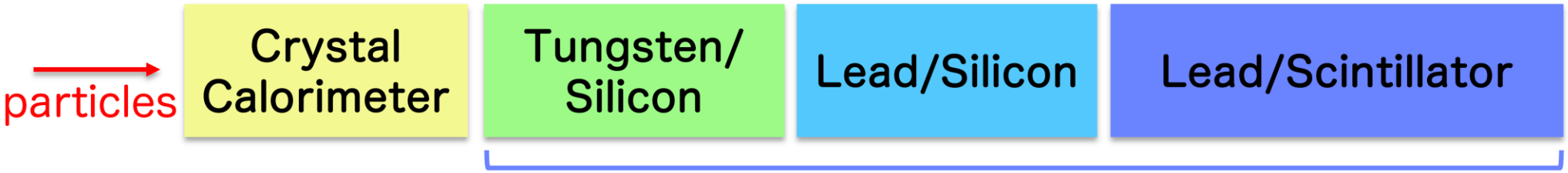
Crystal ($PbWO_4$) + Silicon Pixel layer

W/Si calo. 3 Pixel layers are inserted.

Pb/Si calo.

Pb/Sci. calo.

Design Concept: Full Shower Reconstruction



Meas. of O(100) MeV photons

Meas. of GeV-photons, shower, and position
ALICE FoCal-E type calorimeter
←Expected energy resolution: 25%/√E+2%

Meas. of hadron shower (Si for rad-hard.)

Meas. of hadron energy

Transverse granularity

Crystal
3cm x 3cm

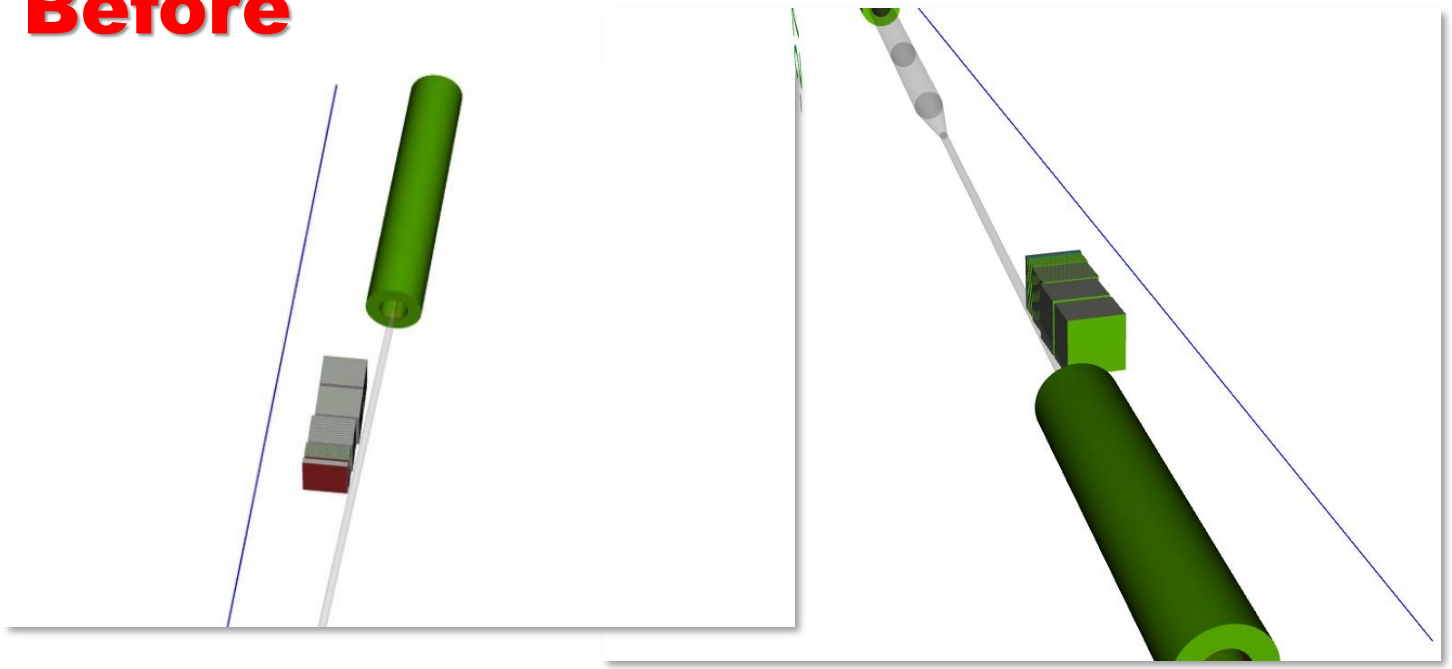
Silicon
Pad layer 1cm x 1cm
Pixel layer 3mm x 3mm

Scintillator
10cm x 10cm

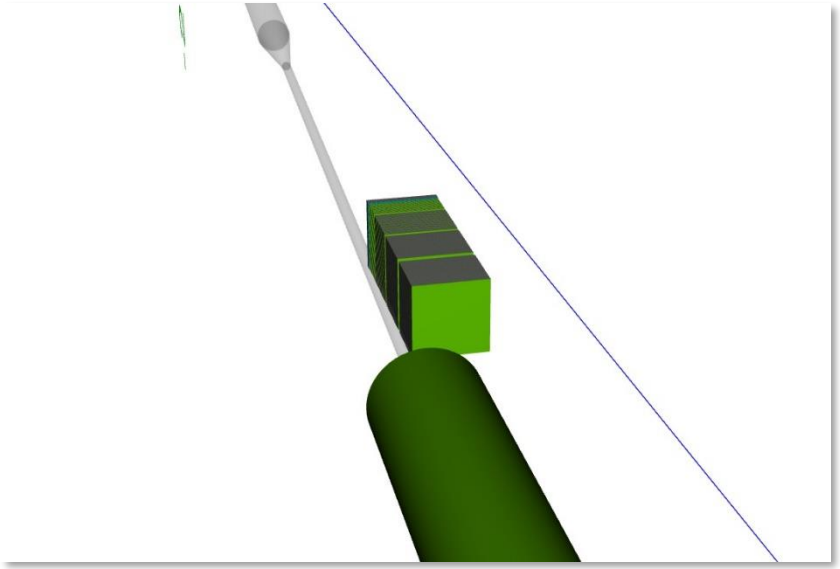
Monte Carlo Implementation

- **History…**
  - Athena: DD4hep, ECCE: Fun4All
  - EPIC has chosen DD4hep for MC development – update to ECCE/EPIC-style required
  - Fixed bugs in the initial implementation

Before

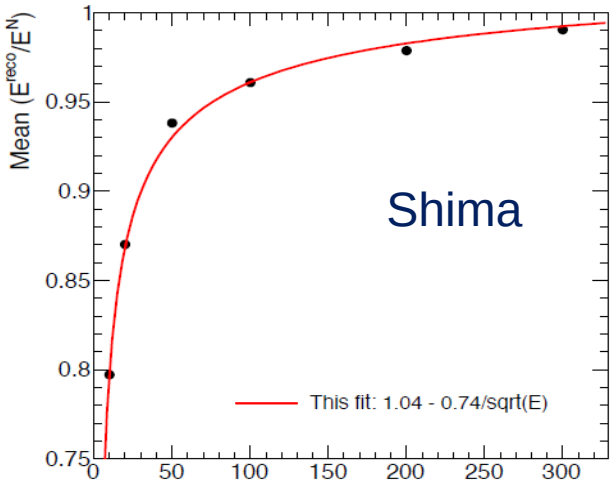


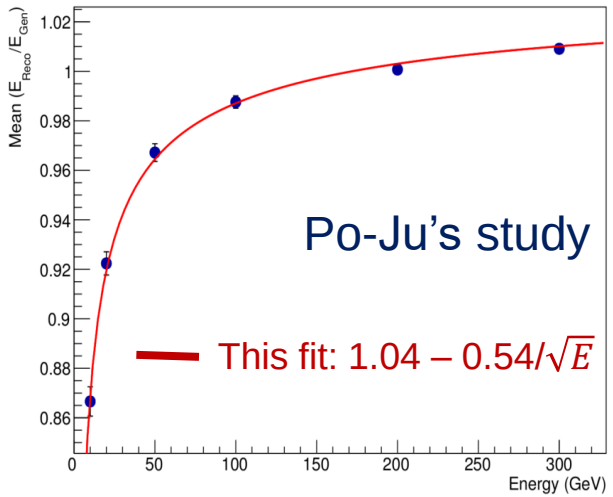
After

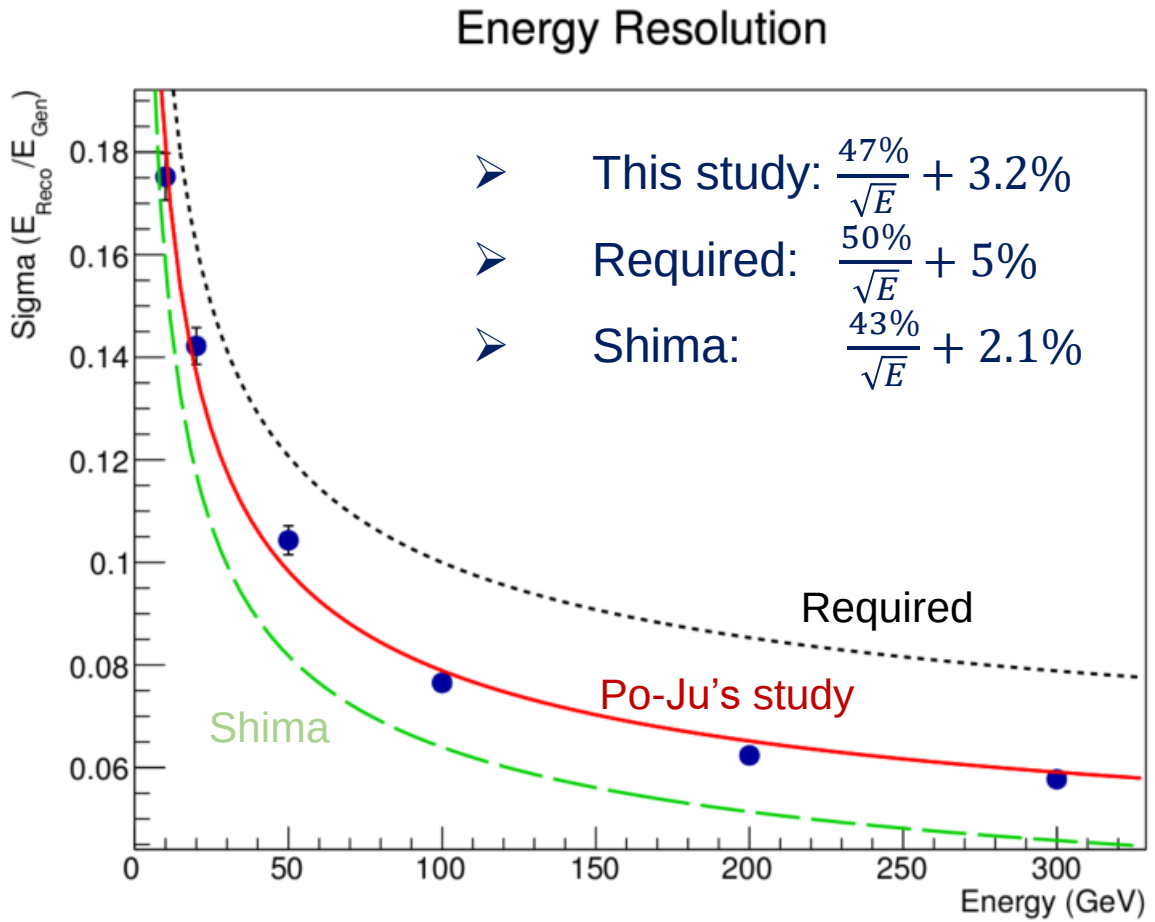


Monte Carlo Studies

- Energy resolution was much worse than the one obtained in Fun4All by Dr. Shima Shimizu
  - Some changes in ZDC setup
  - Energy dependent calibration







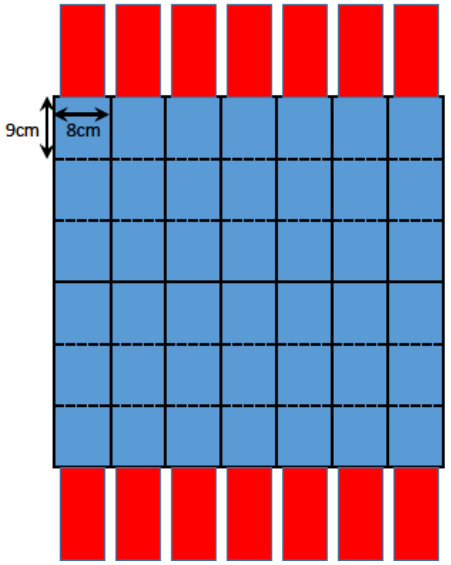
- Result not as good as what Shima had, but acceptable

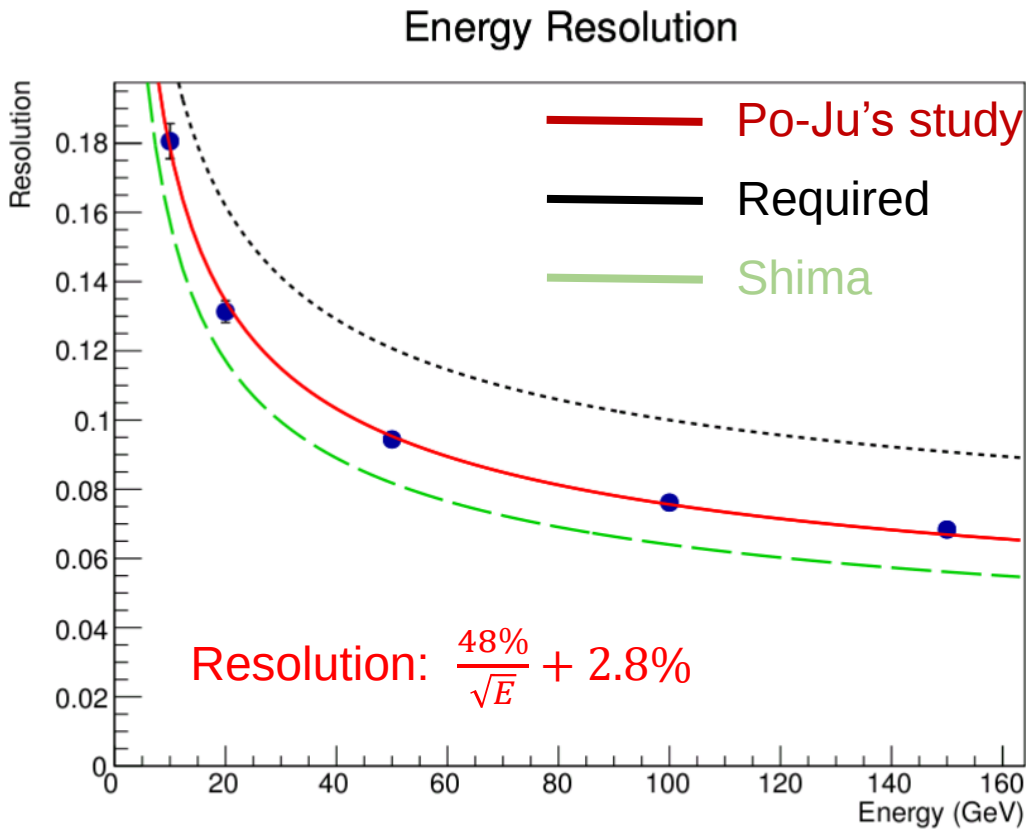
ZDC Monte Carlo Study

1st Silicon & crystal calorimeter

Pb-Scintillator

W-Si imagine calorimeter

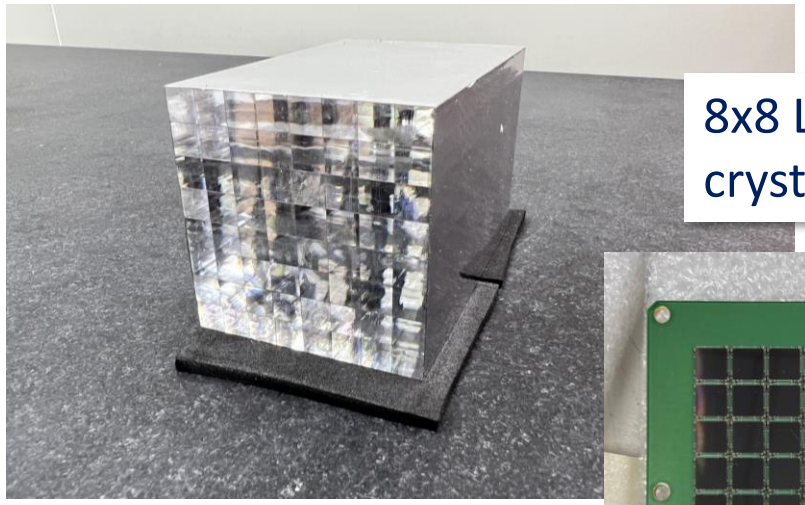




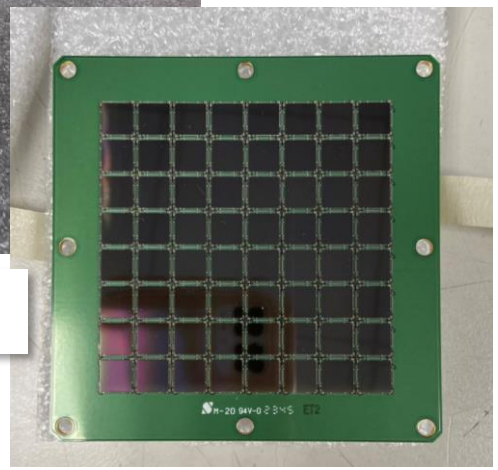
- ZDC simulation updated
  - Upstream modules with smaller lateral size to fit between beam pipes
  - Overall length about 183 cm, within 2m limit
  - More cost effective, Pb-Silicon module removed
  - HCAL resolution improved
- Base design, meets the resolution requirement

ZDC ECAL Prototype with LYSO

	Light Yeild	Cost	Note
$PbWO_4$	Low	Less expansive	
LYSO	High (>100 x $PbWO_4$)	High	Good timing resolution
SciGlass	Better than $PbWO_4$	Not high	Mature (contact CUA?)

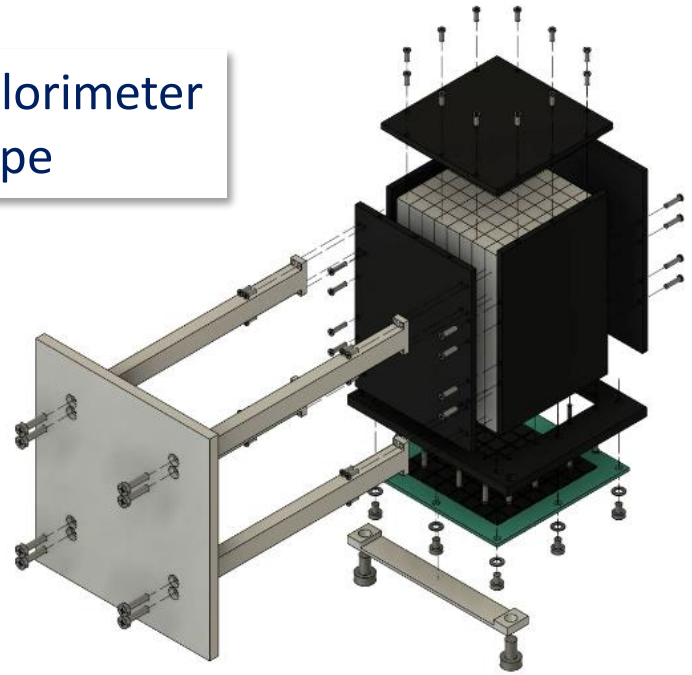


8x8 LYSO crystal array



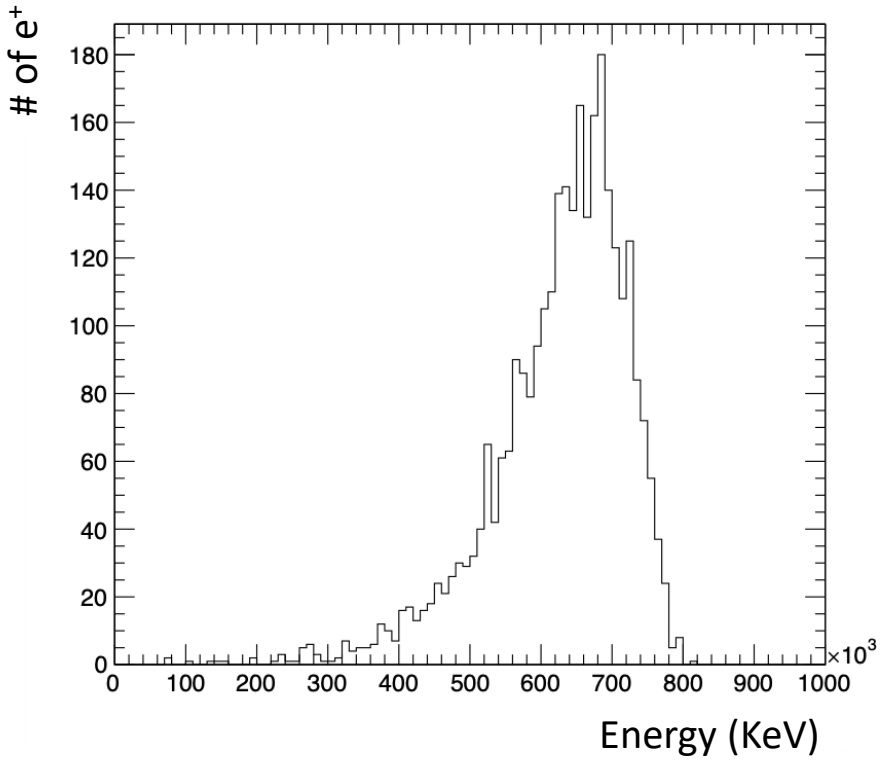
8x8 LYSO SiPM array

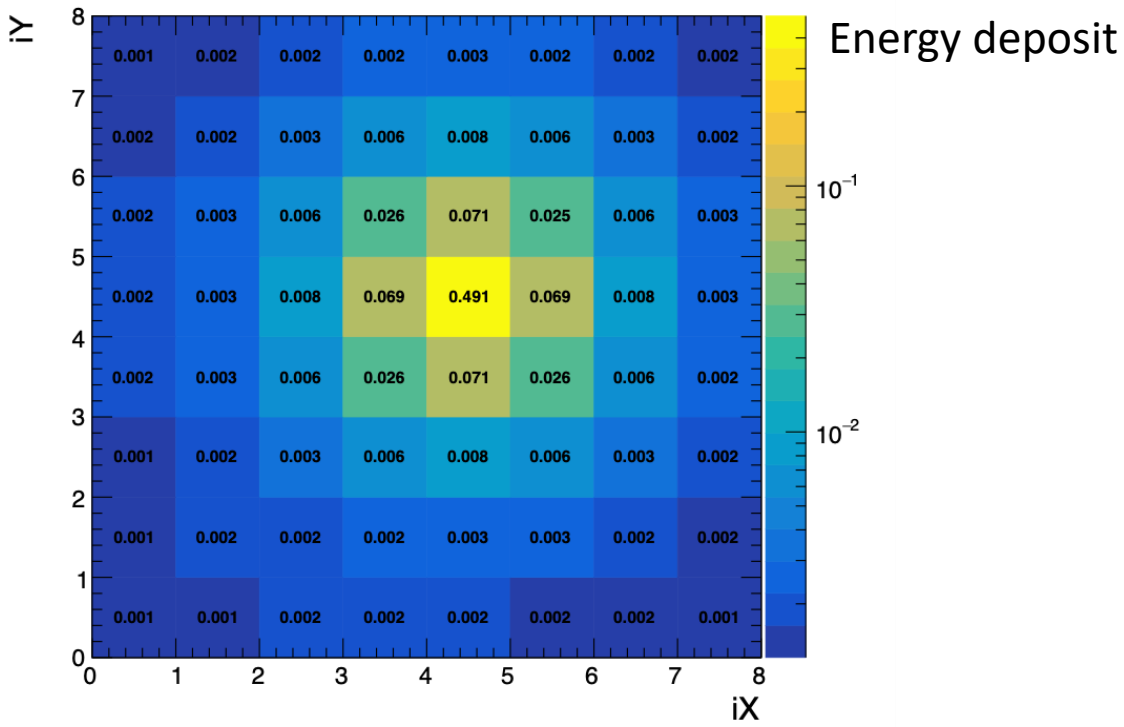
LYSO calorimeter prototype



- Aim to have a beam test at Tohoku University in February 2024 to compare the performance between the LYSO and $PbWO_4$ crystals for 900 MeV positrons

ZDC Monte Carlo Study

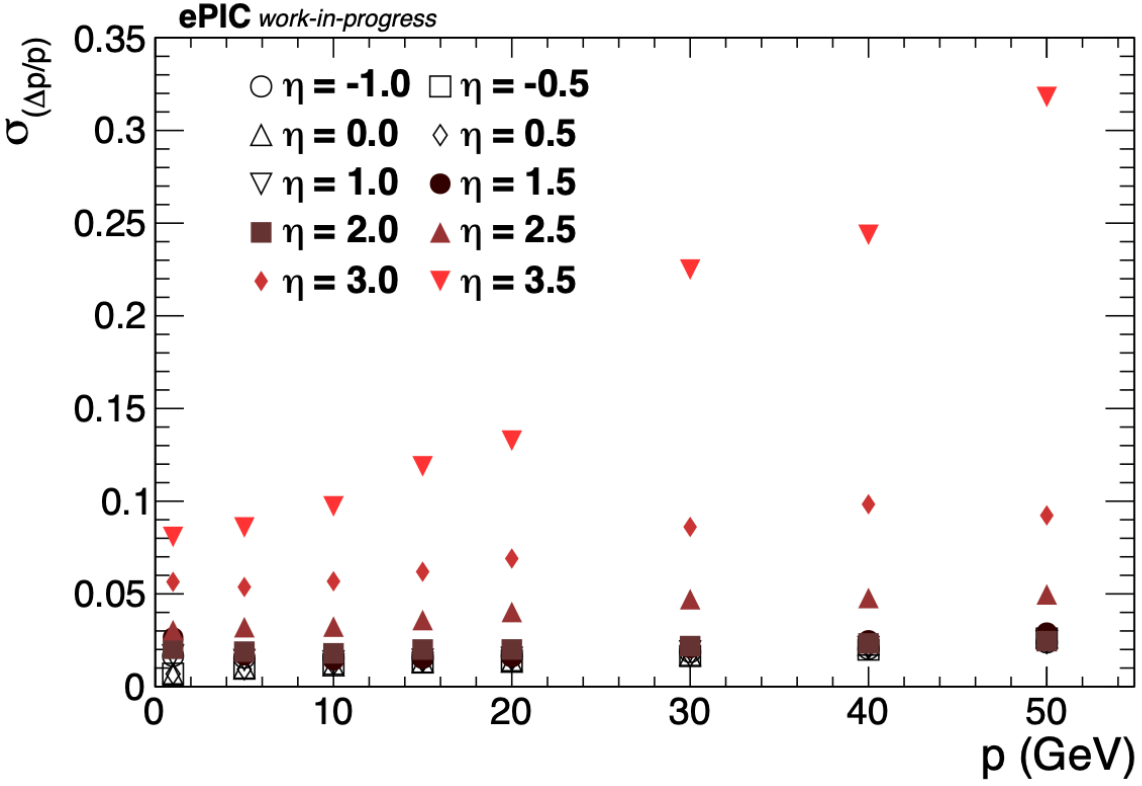


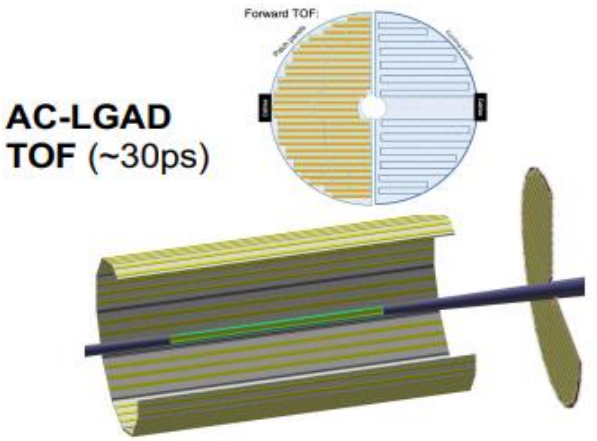


- For the beam test in February 2024
- Various optical properties in the GEANT4 simulation are being studied.
- Future plan: optimizing the ZDC ECAL (homogeneous / sampling / …)

TOF Prerformance Study

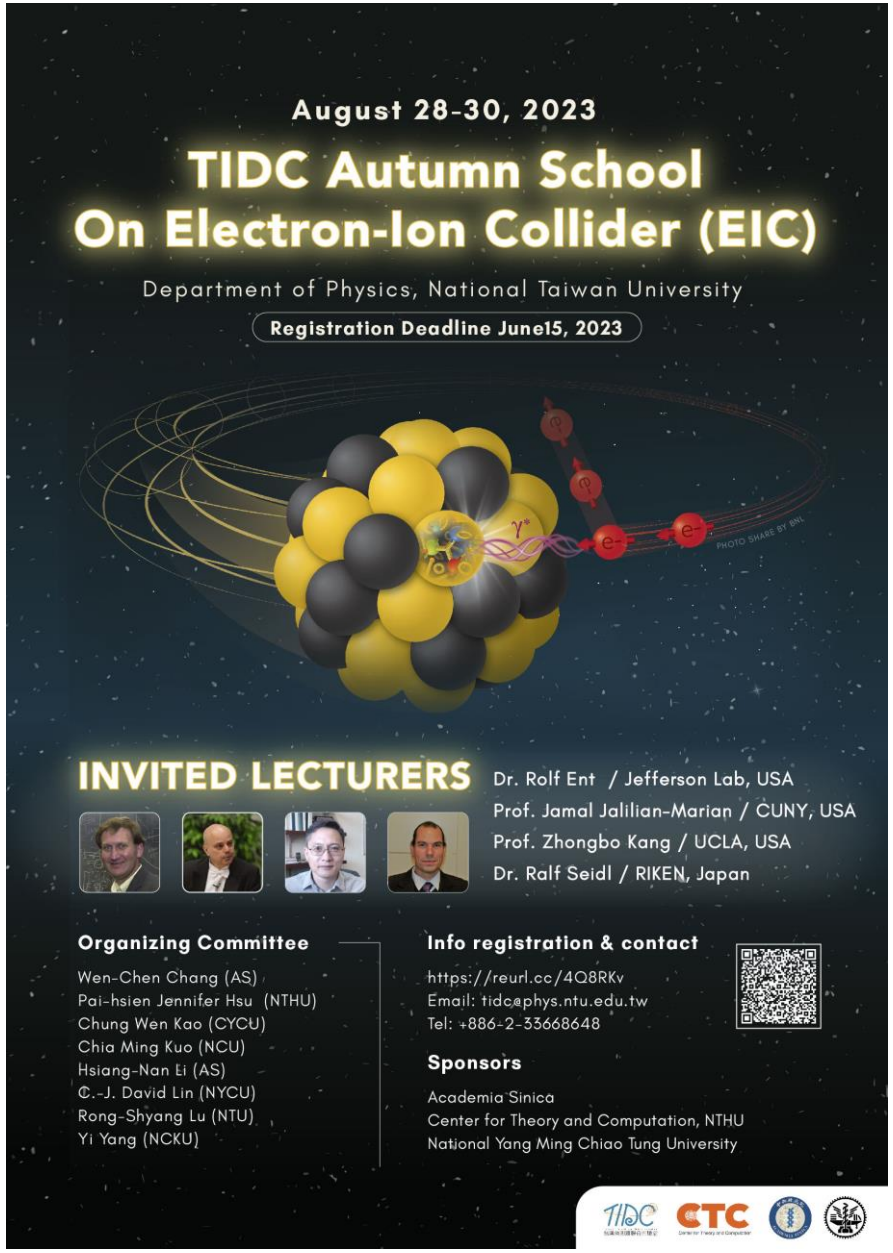
- Started to study the impact of AC-LGAD (Low Gain Avalanche Detectors) on the momentum resolution at ePIC.
- Goal: optimize the pad size of the AC-LGAD sensors

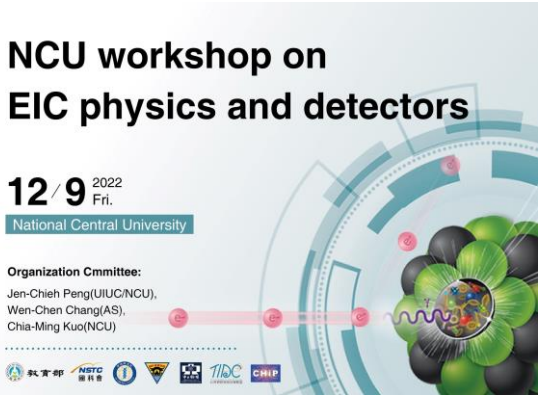




- Simulation with DD4hep and reconstruction
- 1000 π^- using particle gun

Meetings in Taiwan





Initial Stage 2025

Plan to bid for the EIC UG meeting for 2027

Summary

- EIC will provide insights into interesting physics topics, not limited to hadron structure studies.
- Involvement with different projects has been initiated:
  - ZDC simulation
  - Crystal / EMCAL of ZDC
  - TOF performance study
- Exploring other possibilities that groups from Taiwan can contribute