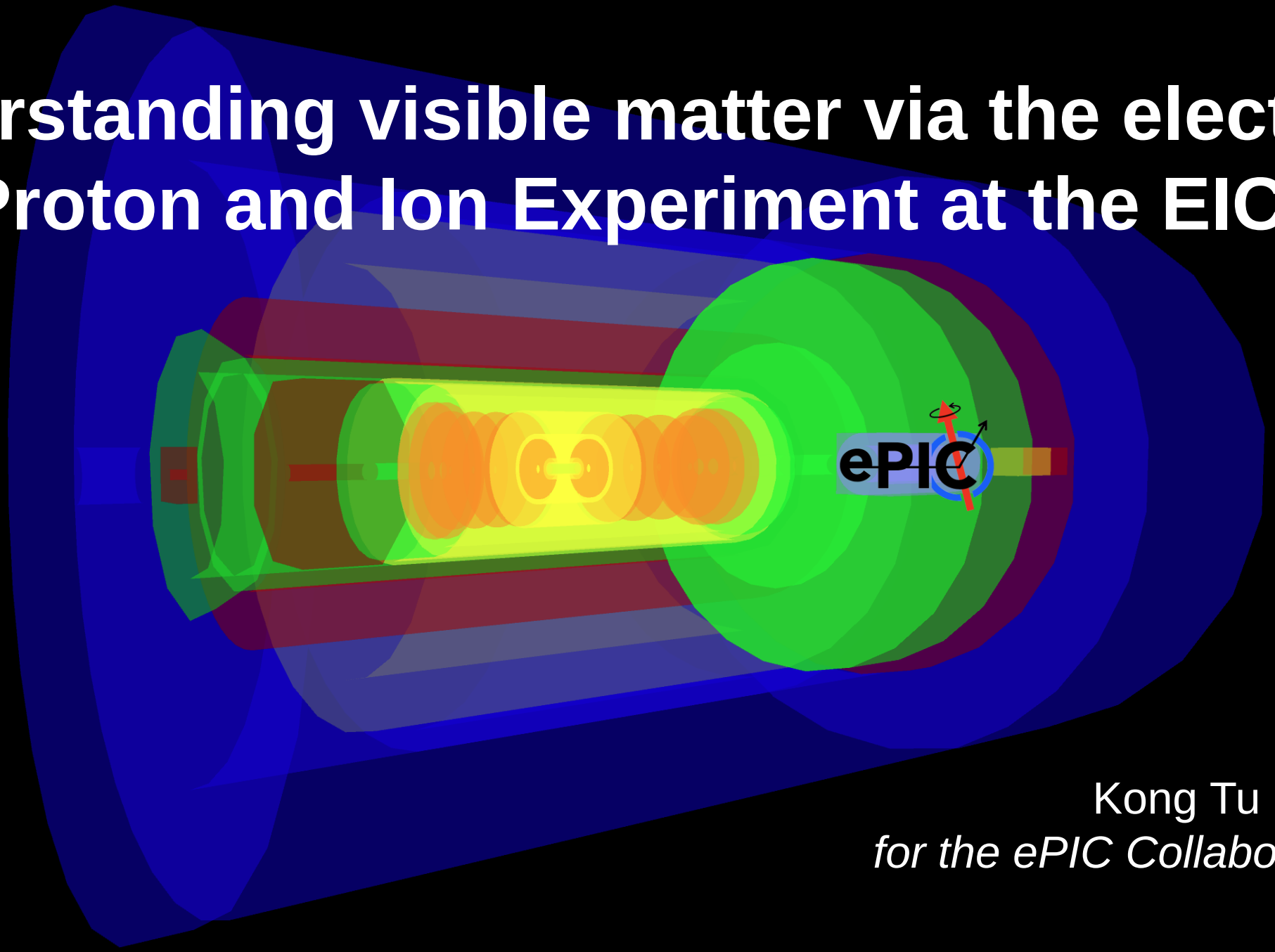
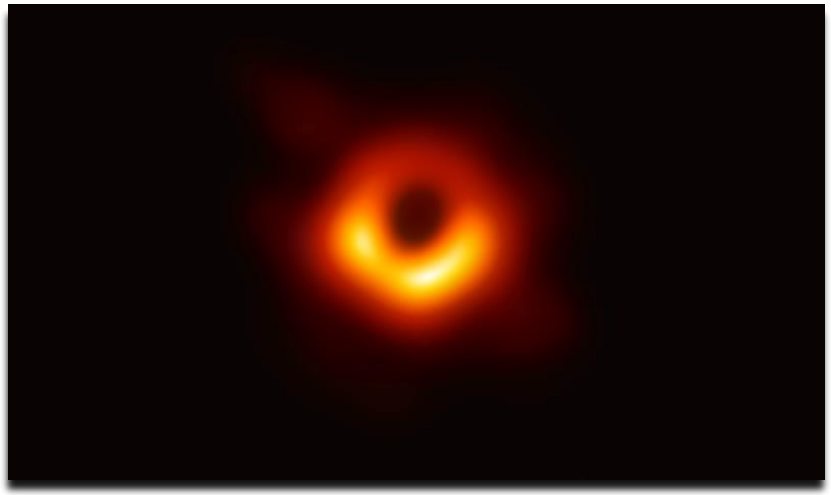
Understanding visible matter via the electron-Proton and Ion Experiment at the EIC



Kong Tu (BNL)
for the ePIC Collaboration

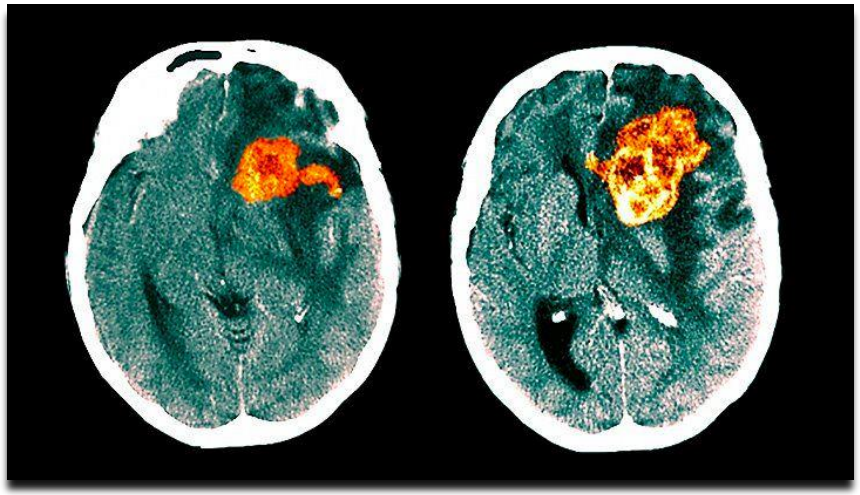
Seeing is believing – the power of imaging

38 billion km (~10^{12}m)



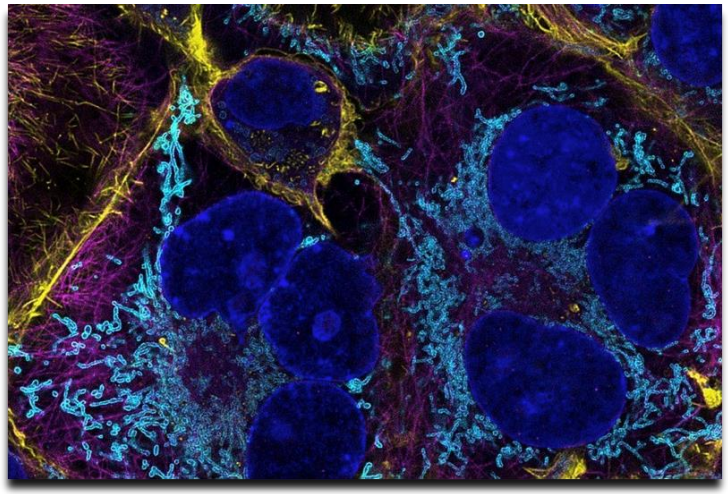
First-ever image of a black hole - *Event Horizon Telescope*

a few centimeter (~10^{-2} m)



CT scan sequence of a patient with a *glioblastoma*.

10-100 nanometer (~10^{-9} m)

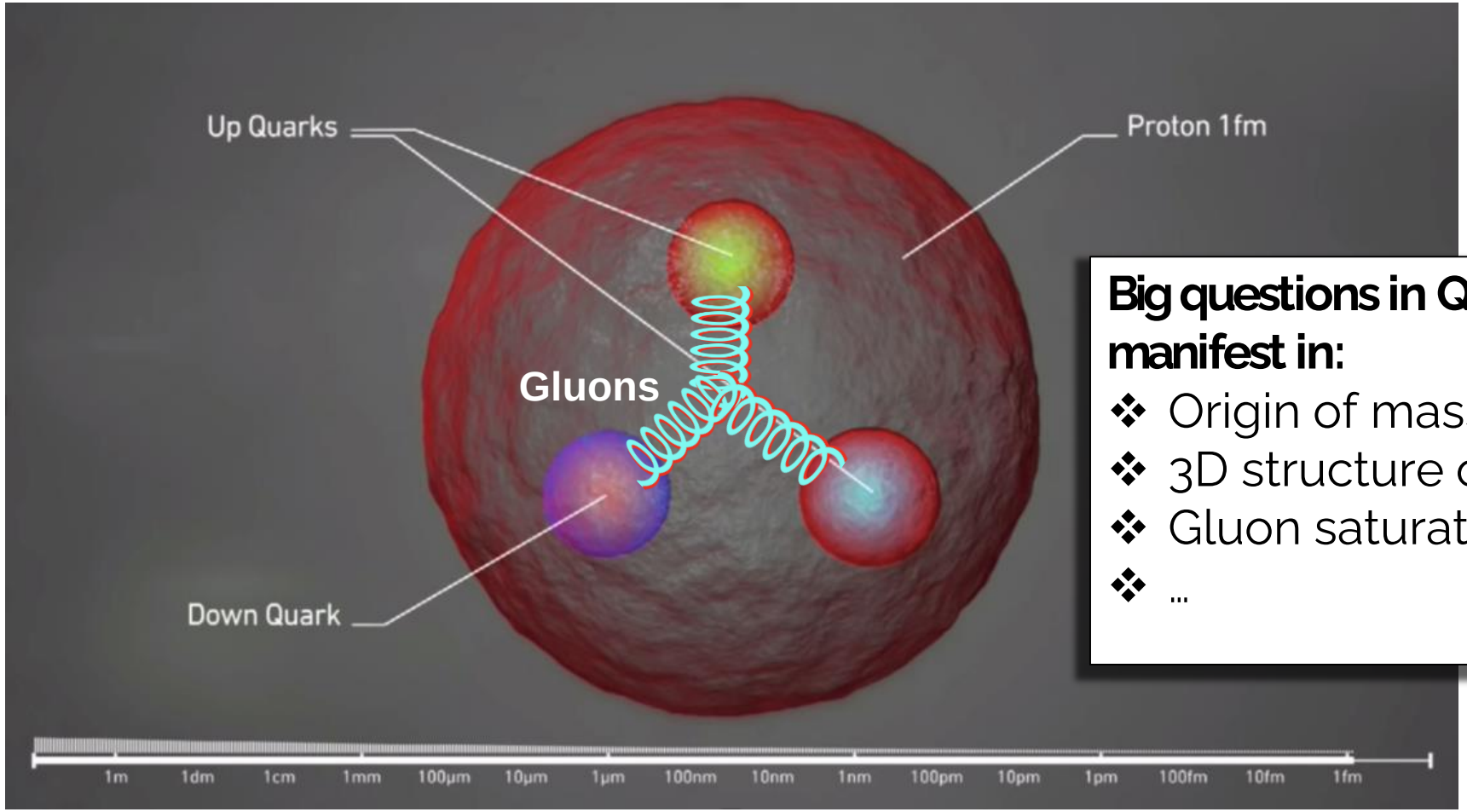


3D images of myelin - the insulation coating our nerve fibres

Astronomical scale → microscopic scale

Imaging: one of the most convincing scientific methods to understand our nature!

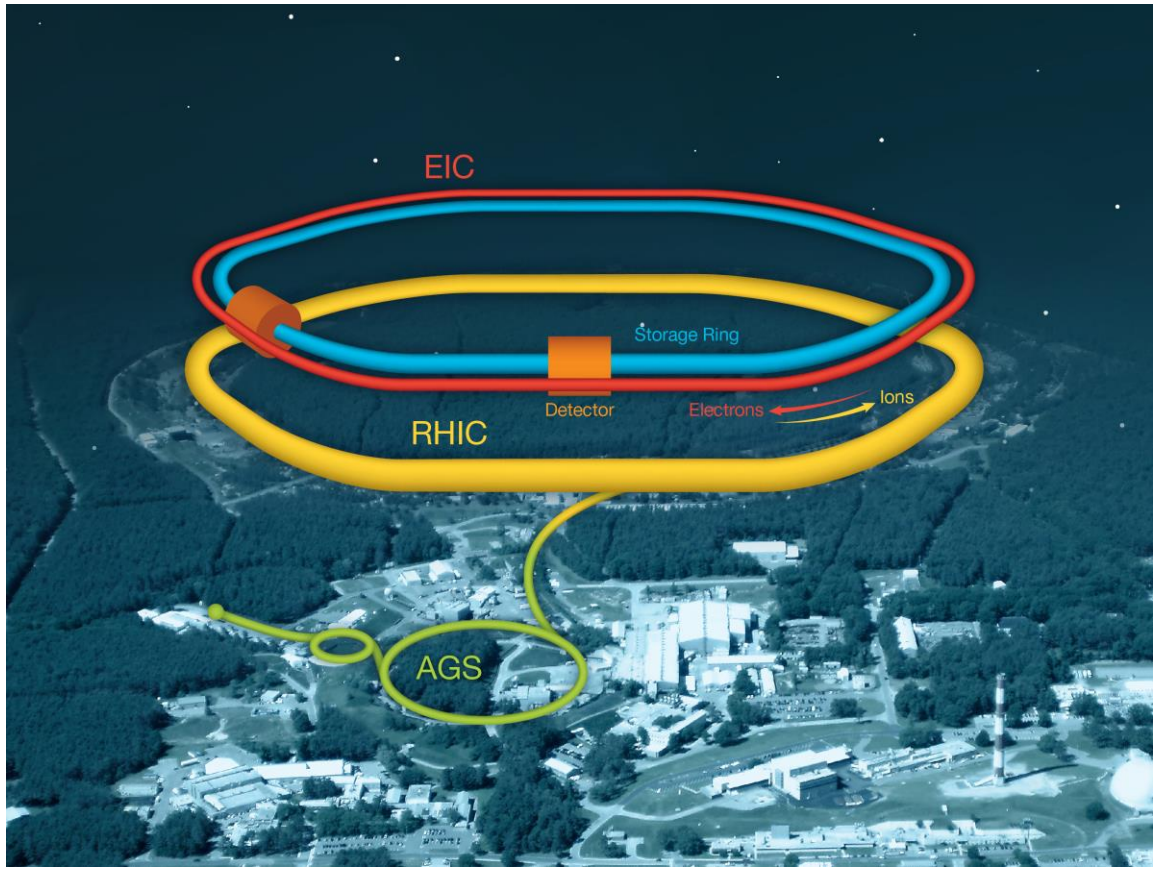
“Seeing” the fundamental structure of matter



Big questions in QCD confinement and its manifest in:

- Origin of mass and spin
- 3D structure of nucleon and nuclei
- Gluon saturation at high energy
- …

The Electron-Ion Collider will probe the fundamental structure of matter with unprecedented precision

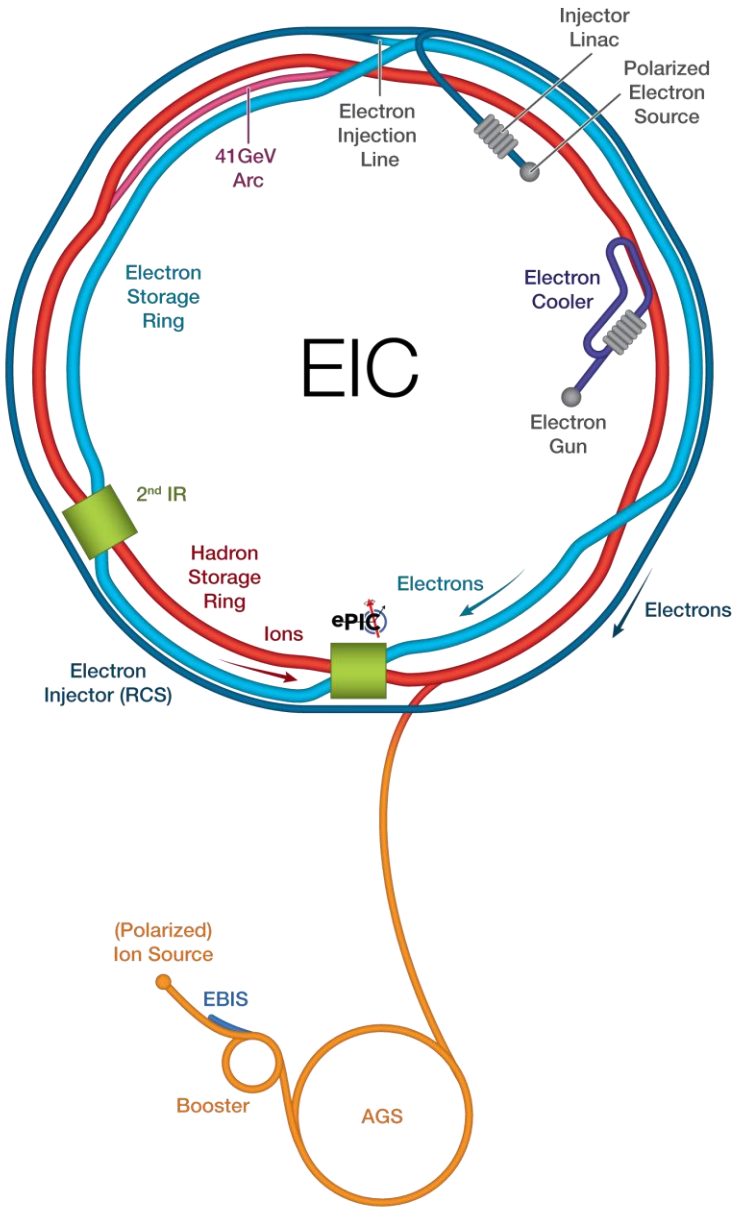


RHIC tunnel will be reused by the EIC and become the first electron-ion collider.

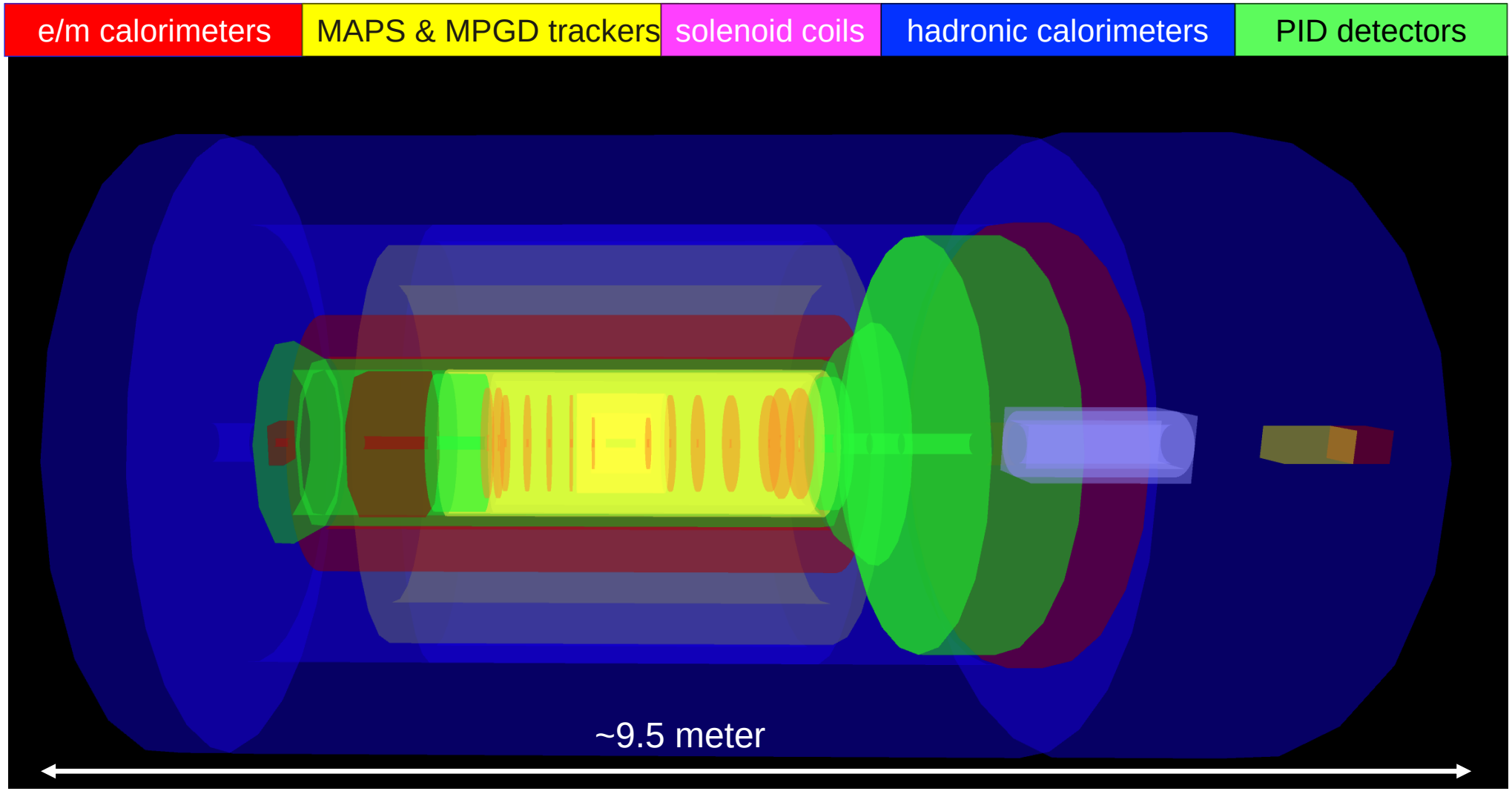
- $\sqrt{s} \Rightarrow$ 20 – 141 GeV
- $\mathcal{L}_{max} \Rightarrow 10^{34}$ cm^{-2} s^{-1}
- Electron, proton, and light nuclei beams can be polarized.

ePIC experiment

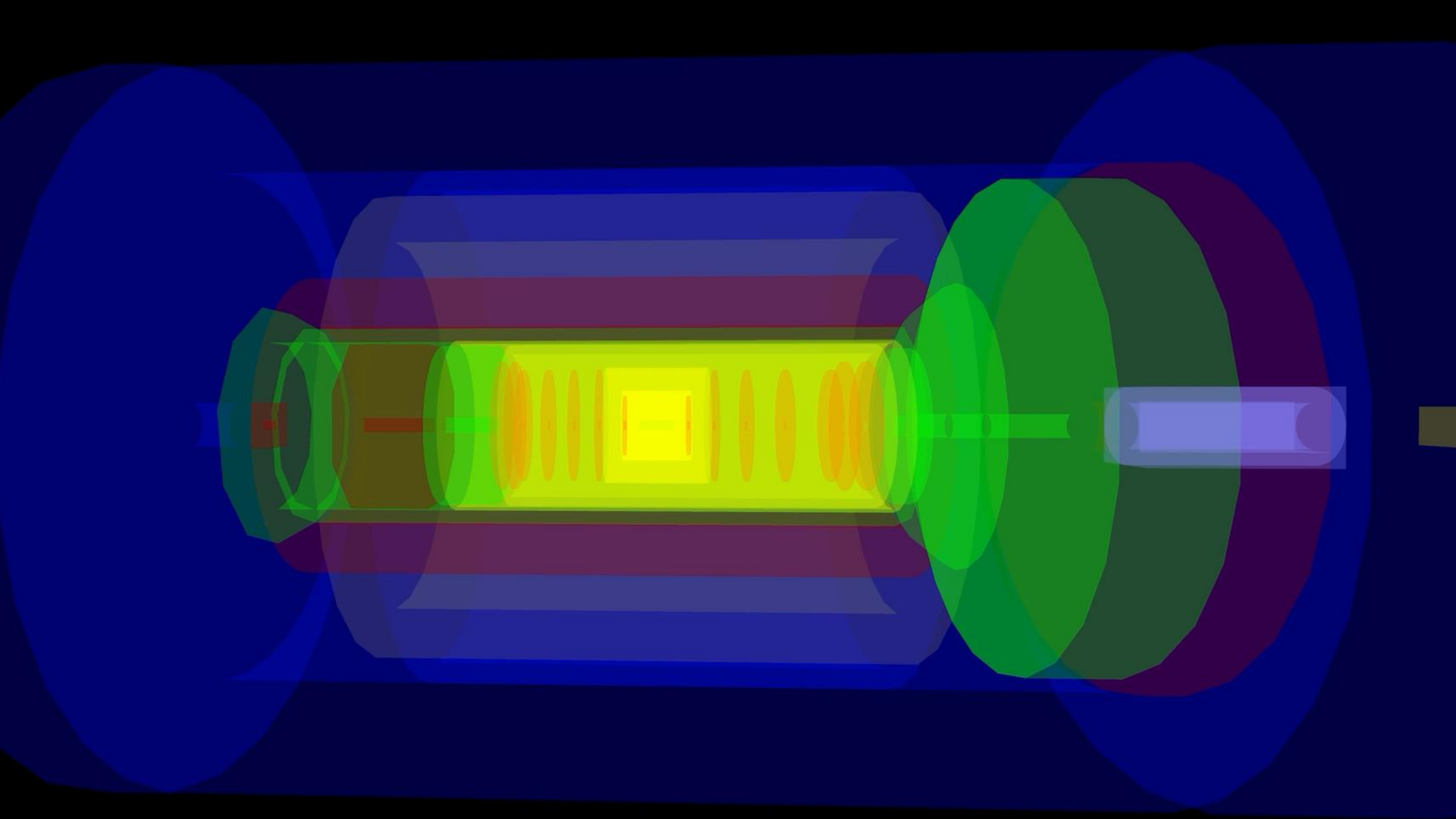
- electron-Proton-Ion Collider experiment (ePIC) is at IP6.
- ePIC experiment is designed to fulfill the requirements of the EIC Yellow report and the NAS report.



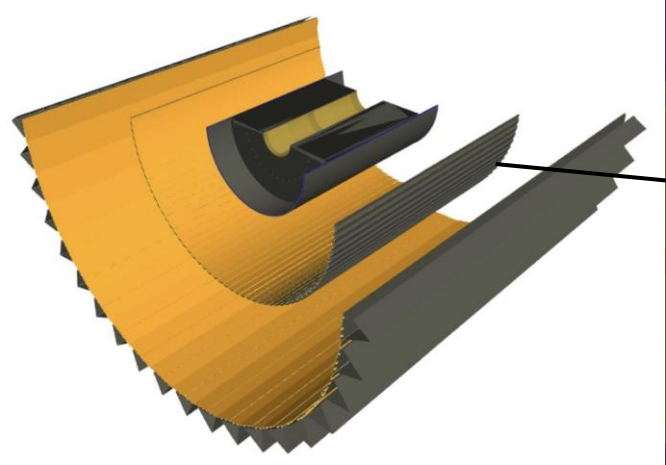
ePIC detector subsystem overview



1.7 T solenoid magnet



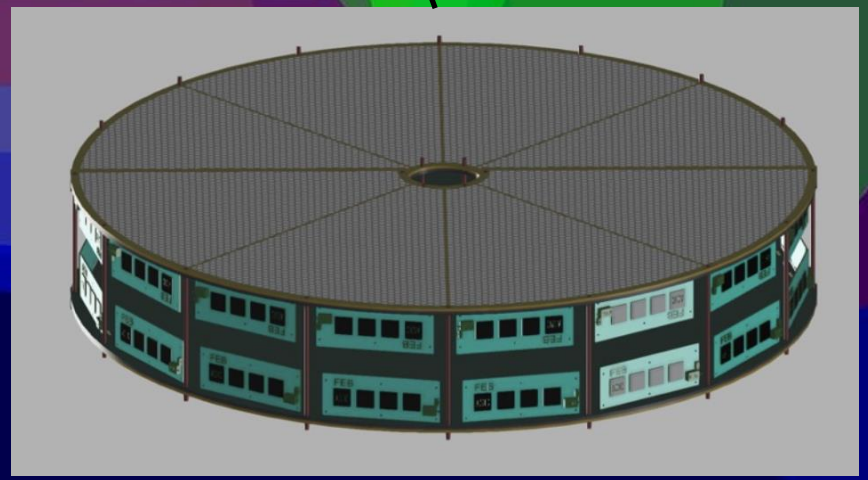
MAPS and MPGD trackers



Silicon Vertex Tracker (SVT):

- Monolithic Active Pixel Sensor (MAPS): ~20x20um
- 3 vertex barrels: ITS3 curved wafer-scale sensor, 0.05% X/X0
- 2 outer barrels: ITS3 based Large Area Sensors (EIC-LAS), 0.55%X/X0
- 5 disks (forward/backward), EIC-LAS, 0.25% X/X0

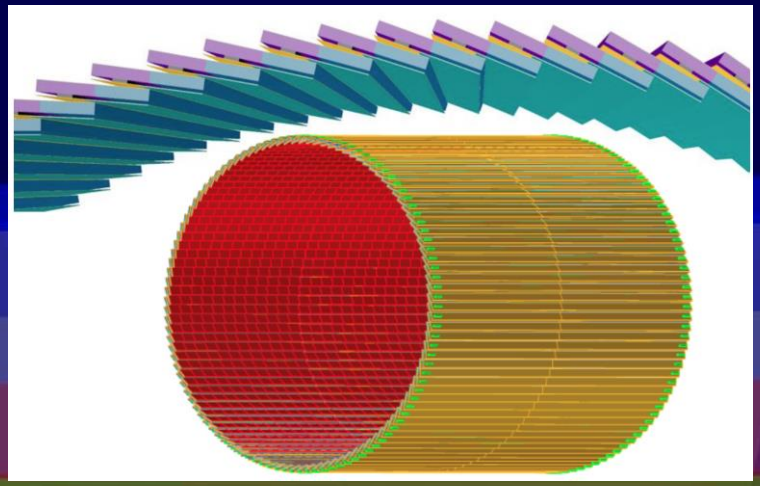
MAPS and MPGD trackers

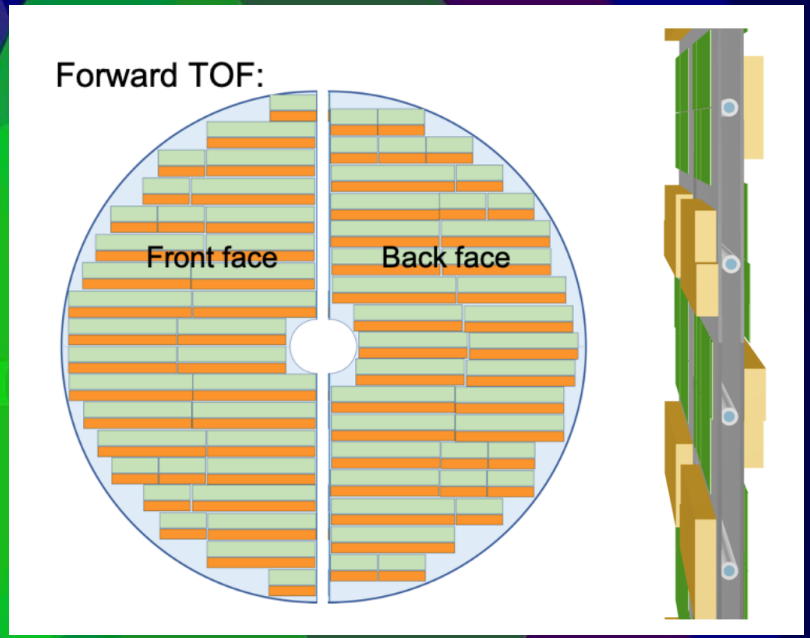


Multi Pattern Gas Detectors (MPGD):
10 ns time resolution,150 um spatial resolution

- 2 GEM-microRwell endcaps (forward/backward) with 1-2% X/X0.
- Inner Micromegas barrel with 0.05% X/X0.
- Outer GEM-microRwell planar layer

AC-LGAD TOF barrel and forward endcap



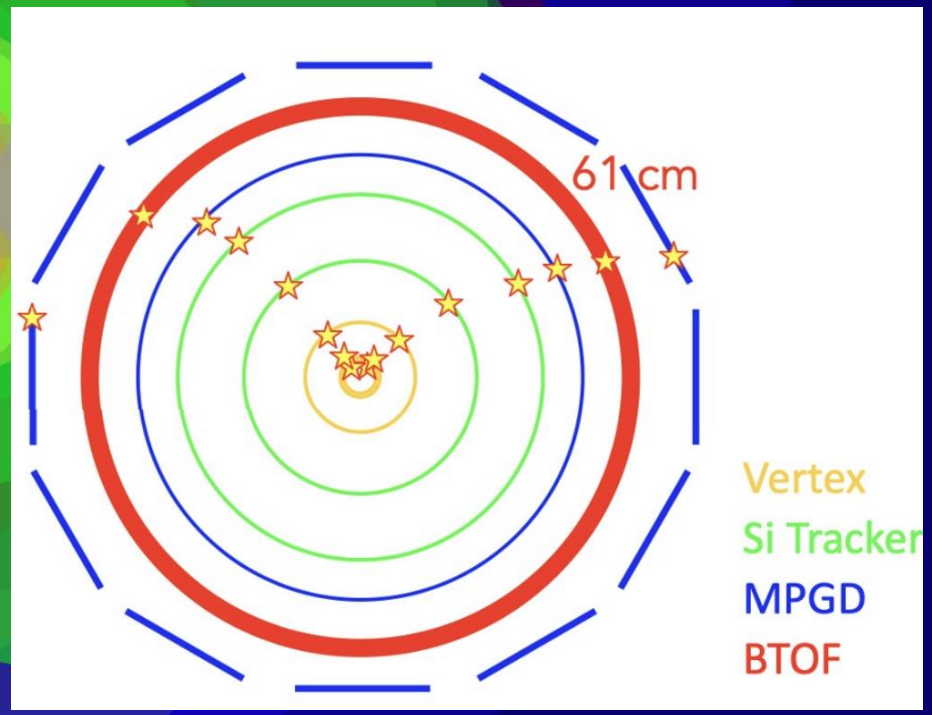


AC-coupled Low Gain Avalanche Diode (AC-LGAD)

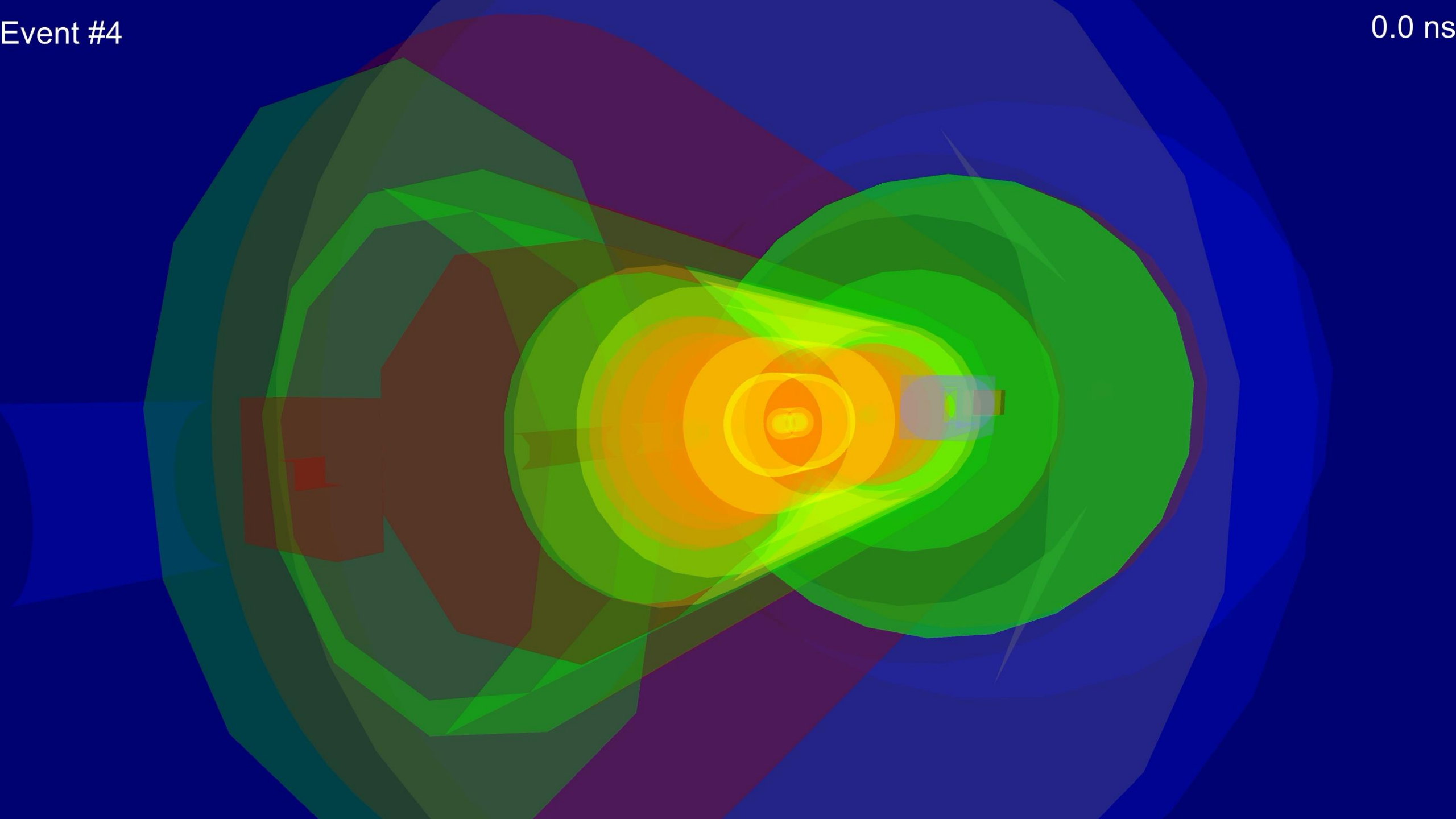
- A PID Time of Flight detectors to cover PID at low pT
- Also provide time and spatial info for tracking
- Resolution: ~30 ps, 30 um (with charge sharing)

Barrel (BTOF): 0.05 x 1 cm strip, 1% X/X0

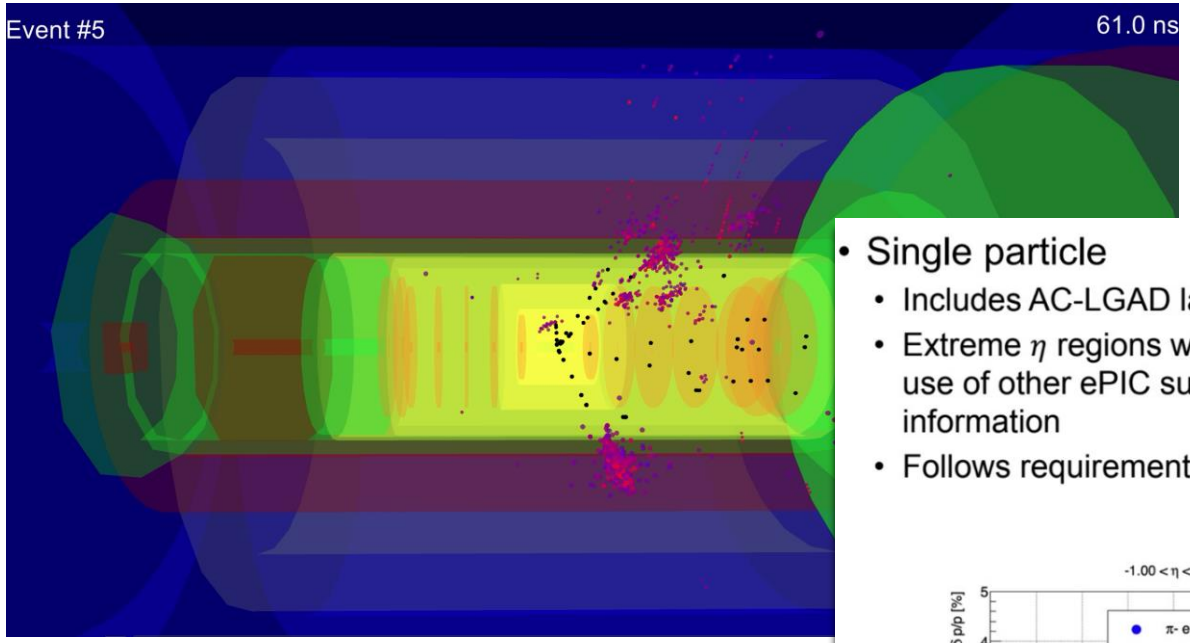
Forward disk (FTOF) : 0.05 x 0.05 cm pixel, 2.5% X/X0



The tracking system from inside out: vertex, Si Tracker, MPGD, BTOF


Event #4
0.0 ns

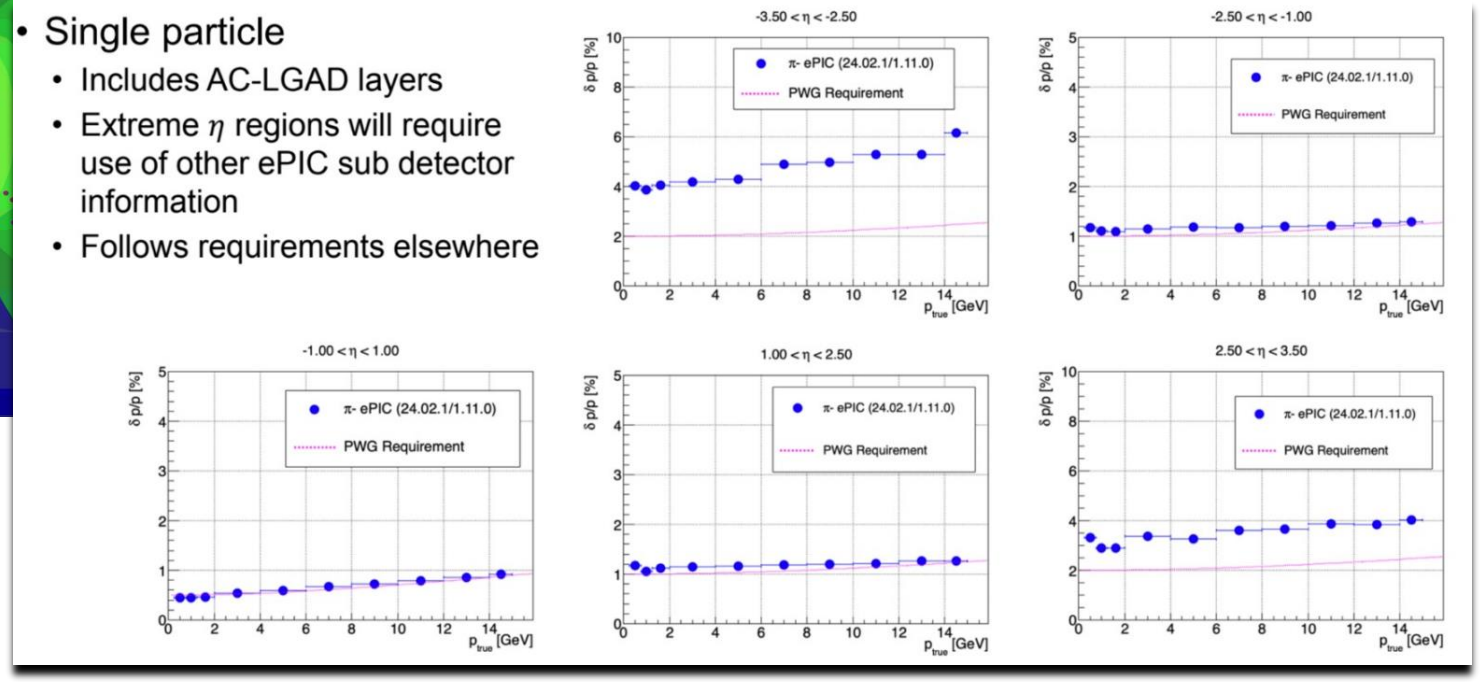
Tracking is the core of ePIC



Forward and backward regions are challenging to meet the requirement alone by tracking; will need help from other subsystems.

Tracking performance based on single particle studies

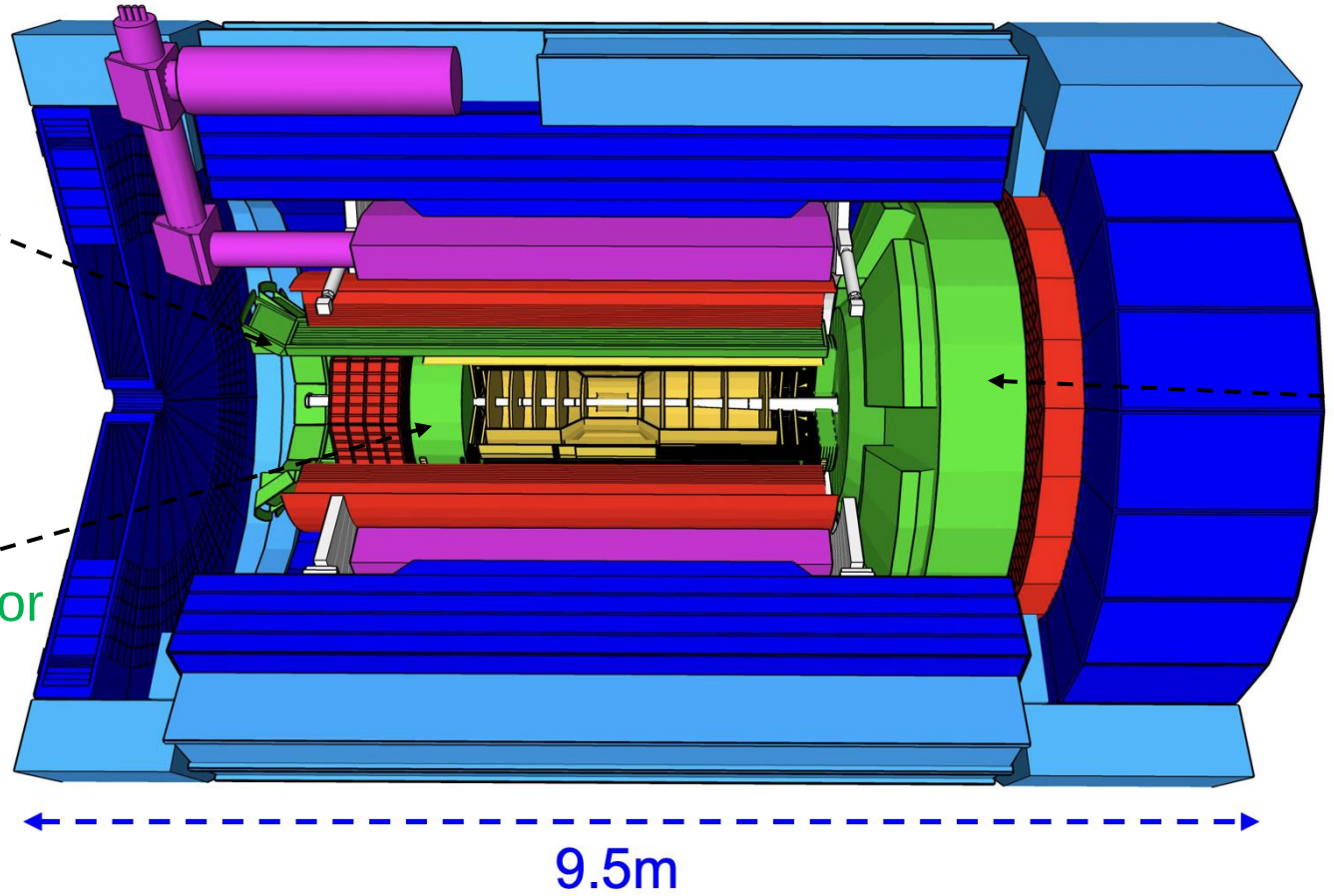
- Single particle
  - Includes AC-LGAD layers
  - Extreme η regions will require use of other ePIC sub detector information
  - Follows requirements elsewhere



Particle Identification Detectors in ePIC

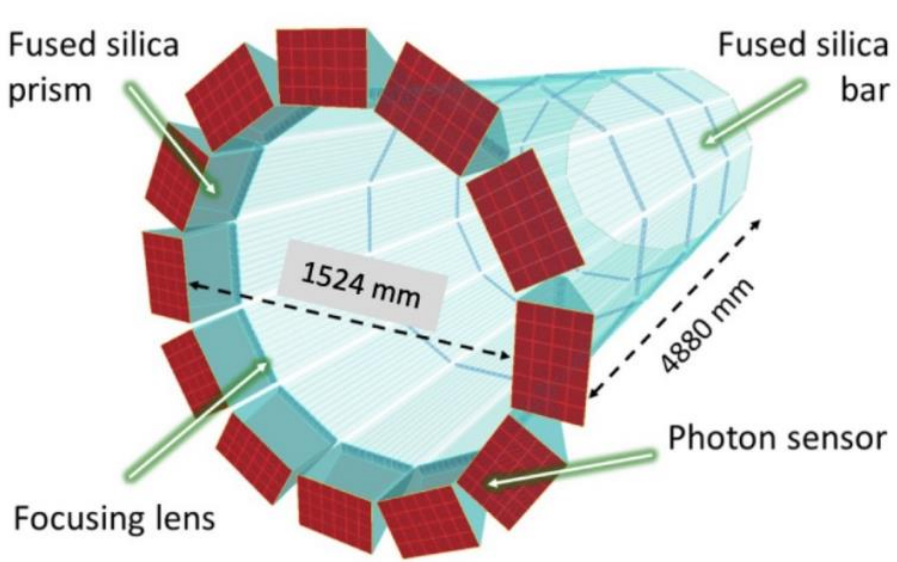
High-performance
Detection of Internally Reflected Cherenkov light (**hpDIRC)**

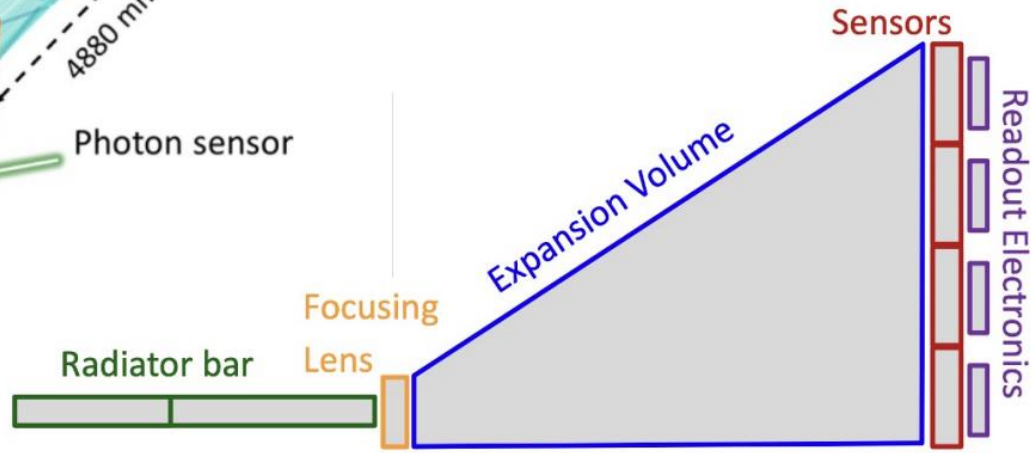
Proximity-focusing
Ring Cherenkov detector **(pfRICH)**



Dual radiator RICH (dRICH)

Barrel PID detector - hpDIRC

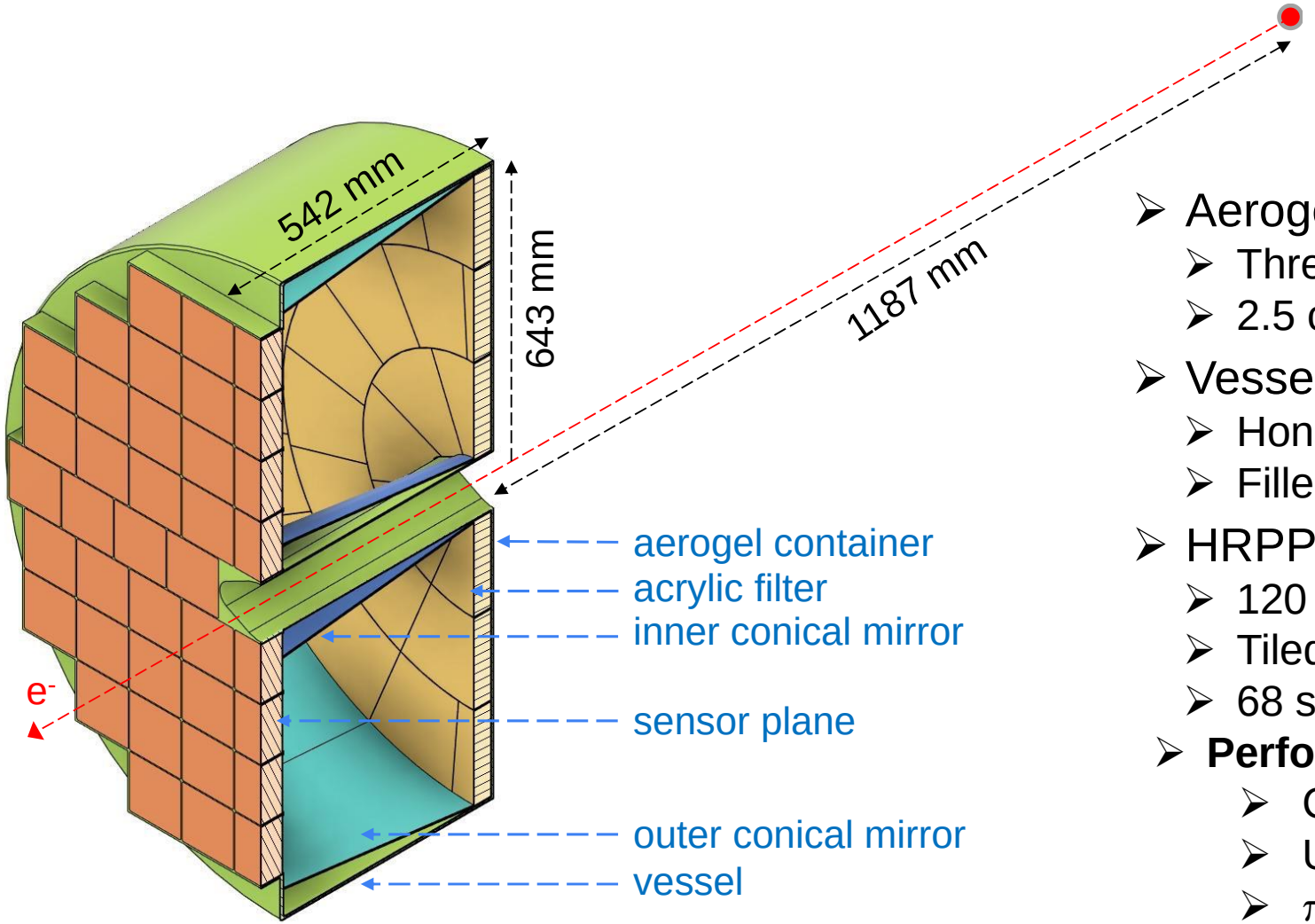




hpDIRC

- 10 long bars
- flat mirrors on far end
- MCP-PMT Sensors
- Reconstruction based on geometrical and/or time info (TOF from AC-LGAD)
- >3sigma pi/k separation power

Backward electron-going PID detector - pfRICH

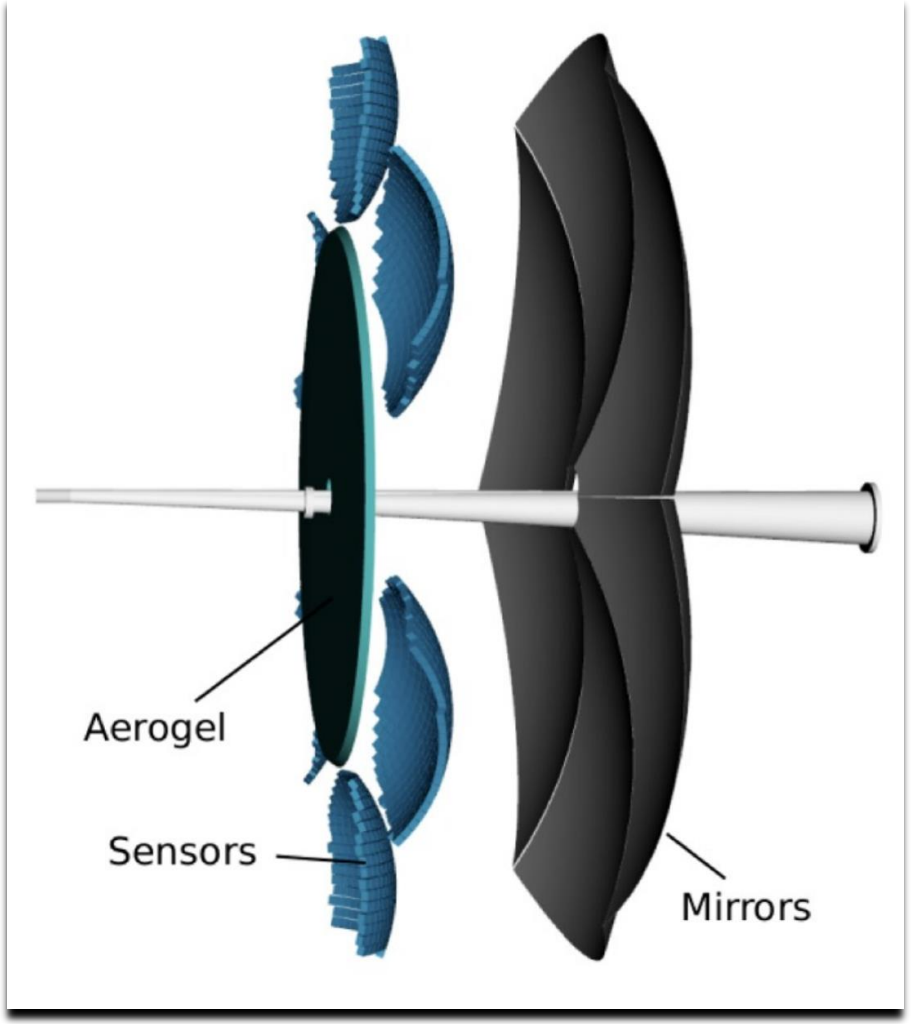


- Aerogel
  - Three radial bands; Opaque dividers
  - 2.5 cm thick, 42 tiles total
- Vessel
  - Honeycomb carbon fiber sandwich
  - Filled with nitrogen
- HRPPD photosensors with timing capability
  - 120 mm size
  - Tiled with a 1.5mm gap
  - 68 sensors total
- **Performance:**
  - Coverage: $-3.5 < \eta < -1.5$
  - Uniform performance in $\{\eta,\phi\}$ range
  - π/K separation: above 3σ up to 9.0 GeV/c

Forward hadron-going PID detector - dRICH

dRICH:

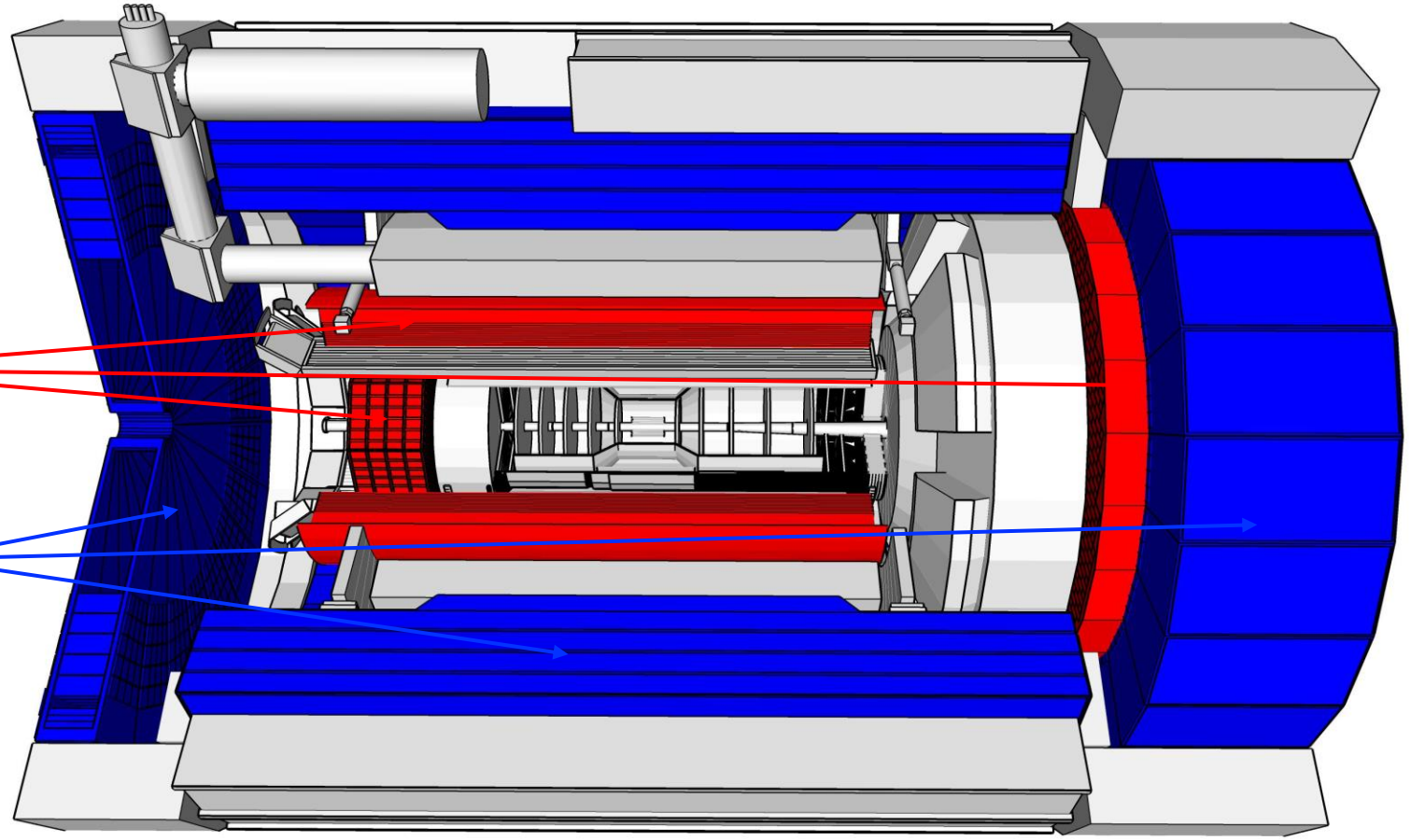
- for high momentum PID at forward region ~ 50 GeV/c for pi/K separation.
- $1.5 < \eta < 3.5$ coverage
- 4cm aerogel + C2F6 gas
- 6 spherical mirrors to focalize photons
- SiPM based sensors for photon detection



Calorimeter

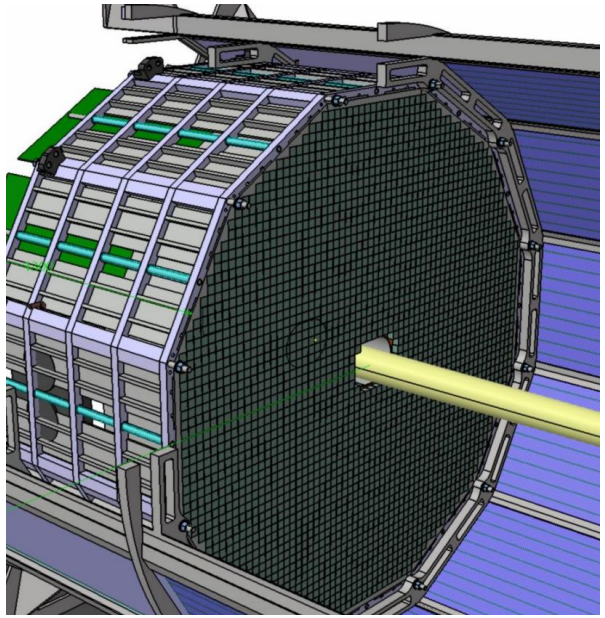
Calorimeters with wide range of acceptances(**backward, barrel, forward**) and different technologies:

- **Electromagnetic Calorimeter.**
- **Hadronic Calorimeter.**



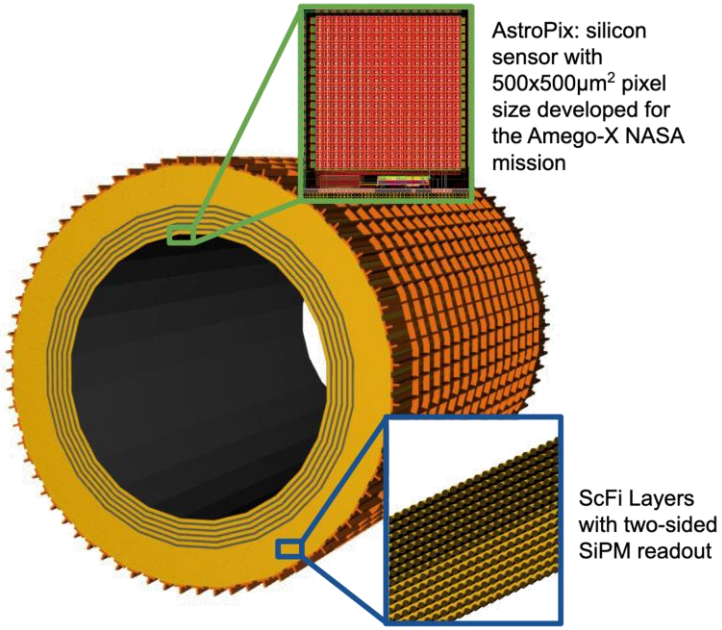
EM Calorimeter

Backward



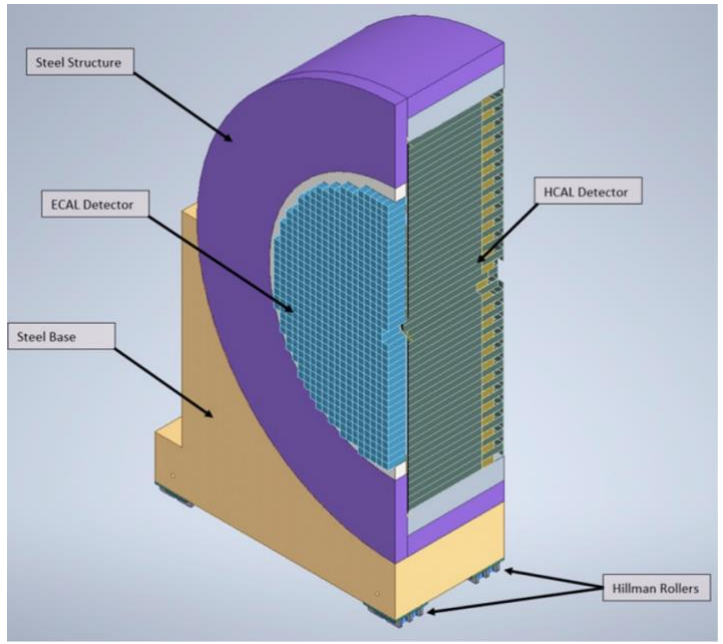
- PbWO4 crystals
- excellent energy resolution and high pion suppression for electron reconstruction

Barrel



- 6 layers of imaging Si sensors (AstroPix) interleaved with 5 SciFi/Pb layer
- Followed by a large section of SciFi/Pb

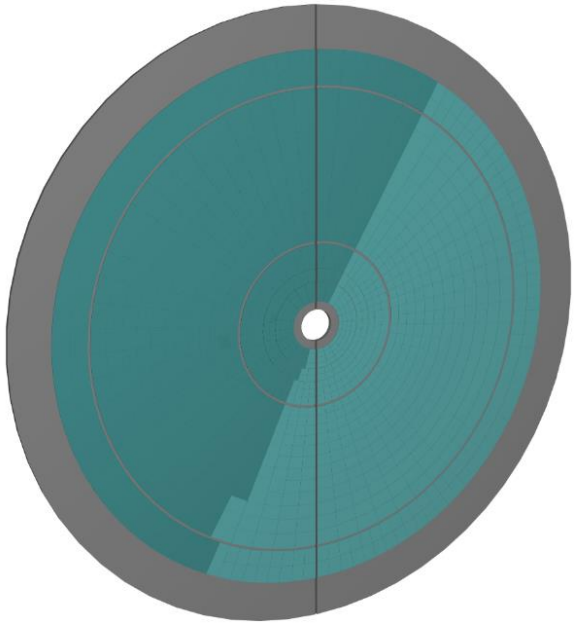
Forward



- W/ScFi blocks beehive with fiber good pi/gamma separation
- Tracking+pECal+LFHCAL for optimized HF jets
- SiPMs as photonsensors

Hadronic Calorimeter

Backward

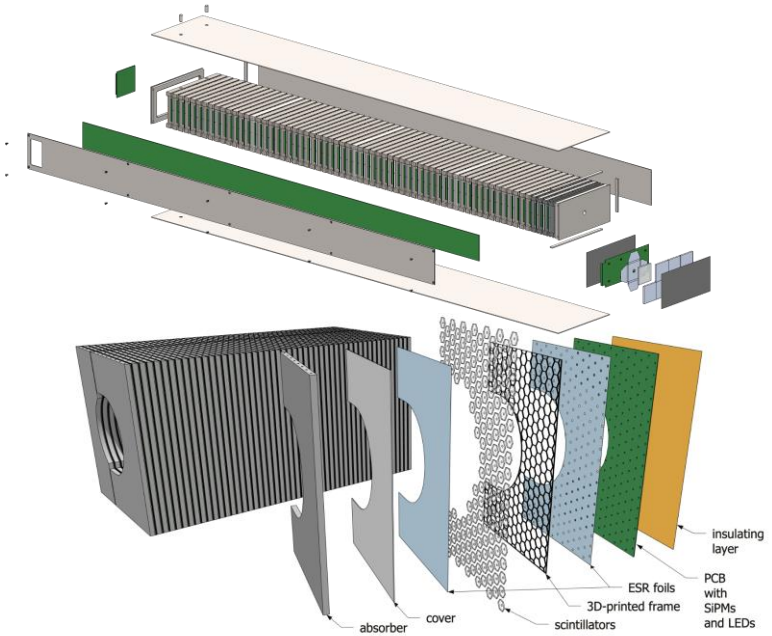


- Low-x hadronic final state important for gluon saturation, typically backward-going
- Exact design still in progress

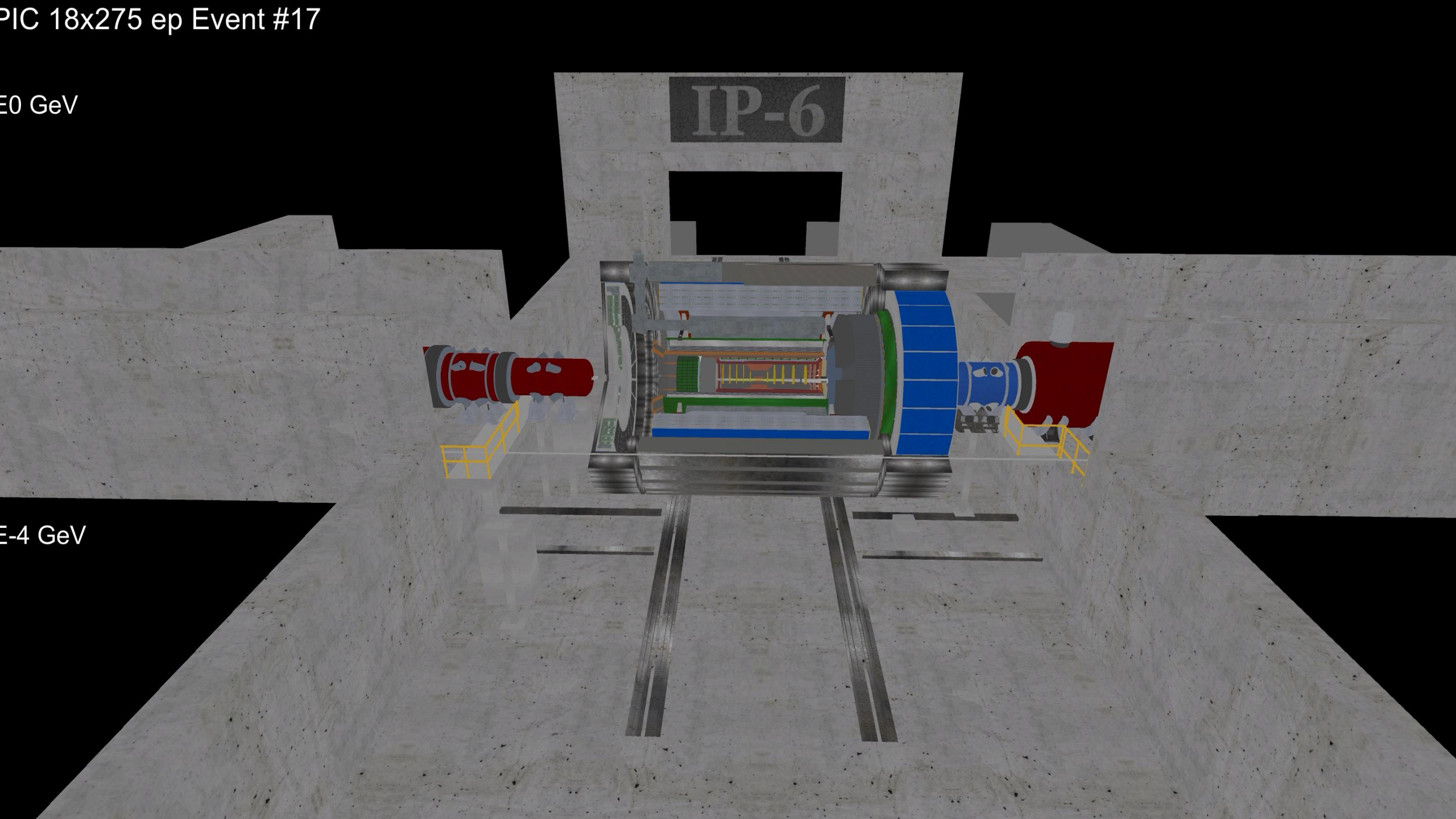
Barrel

- **Reuse from sPHENIX**
- Upgrade electronics to HGCROC
- Increase segmentation by reading out each tile individually

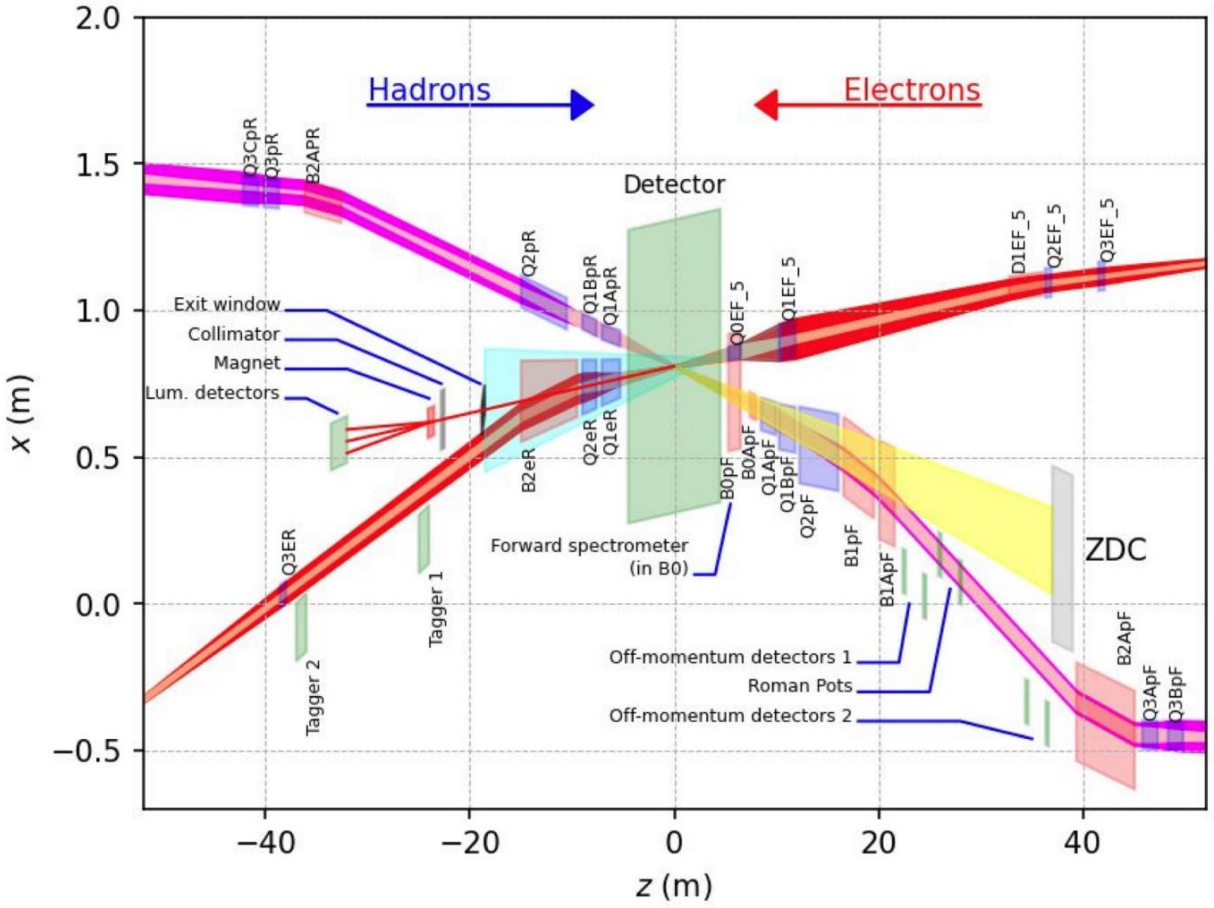
Forward



- Forward Hcal: Steel + Scintillator SiPM-on-tile
- Forward insert calorimeter to further improve acceptance ($3.2 < \eta < 4$)


PIC 18x275 ep Event #17
E0 GeV
E-4 GeV
IP-6

Far-forward and far-backward system



Far-forward: Detect particles from nuclear breakup and exclusive processes

- B0 tracker/Calorimeter
- Roman pots
- off-momentum detector
- Zero-degree calorimeter

Far-backward:

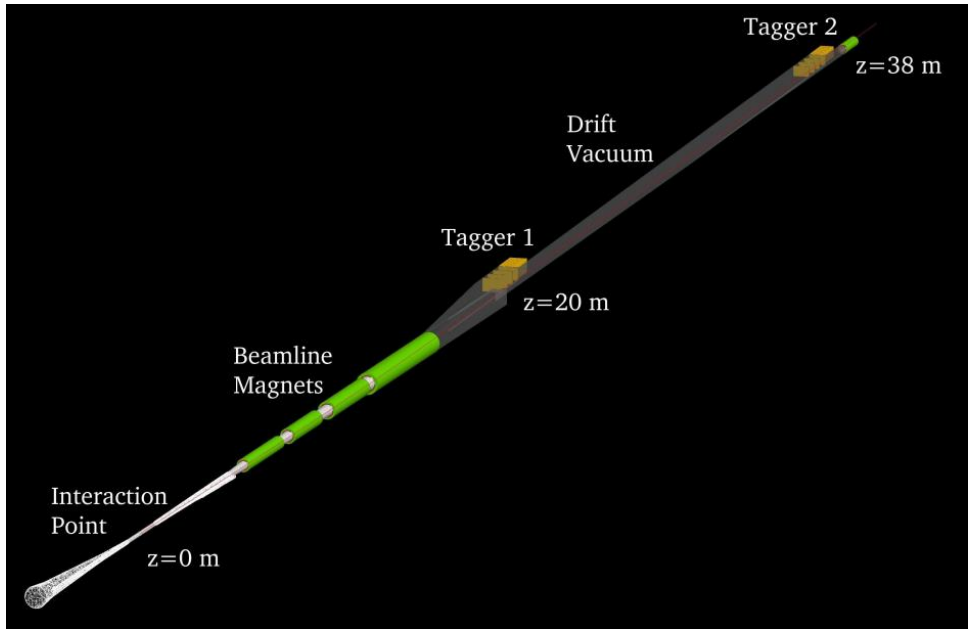
- Two low Q^2 electron taggers
- luminosity monitor

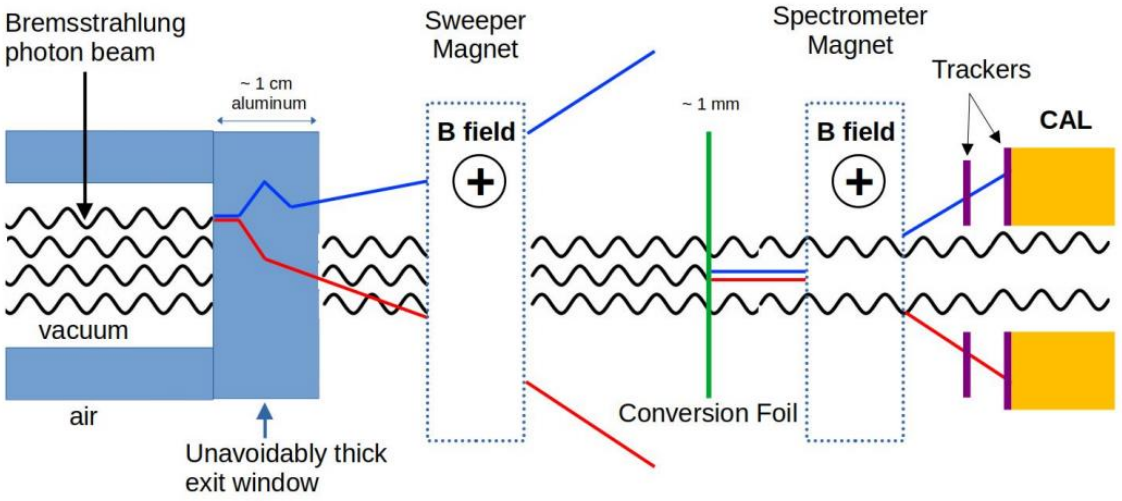
Far-backward detectors

- **Low Q^2 taggers:**
  - ✓ Pixel-based 4 trackers (Timepix4), with rate capability of > 10 tracks per bunch
  - ✓ Calorimeters (for calibration)
- Challenges: high, non-uniform Brem. background

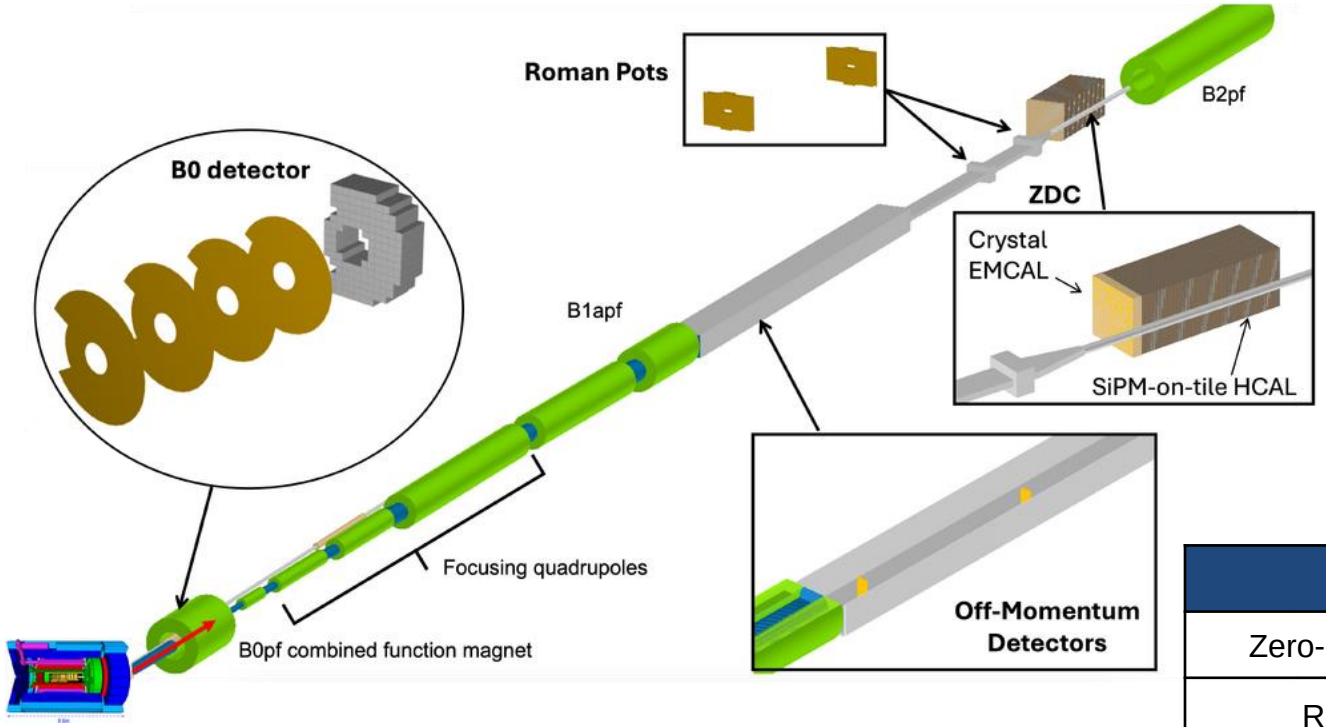
Luminosity monitor:
Precise luminosity determination (<1%), from Bremsstrahlung processes ($ep \rightarrow e\gamma p$)

- ✓ Tracker: AC-LGAD strips with 20um resolution
- ✓ Calorimeter: Scintillating Fiber, $23X_0$





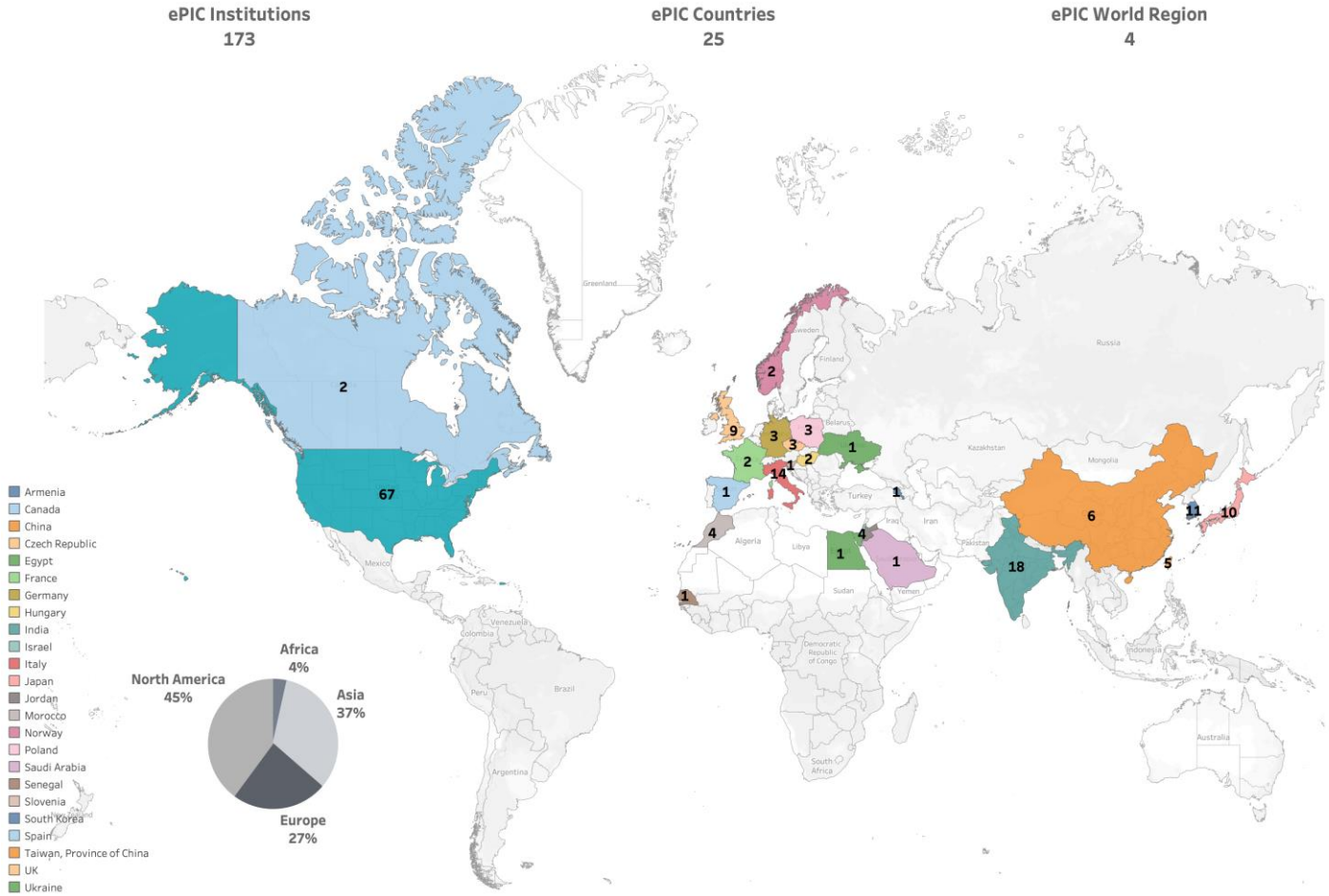
Far-forward detectors



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

ePIC is an international collaboration

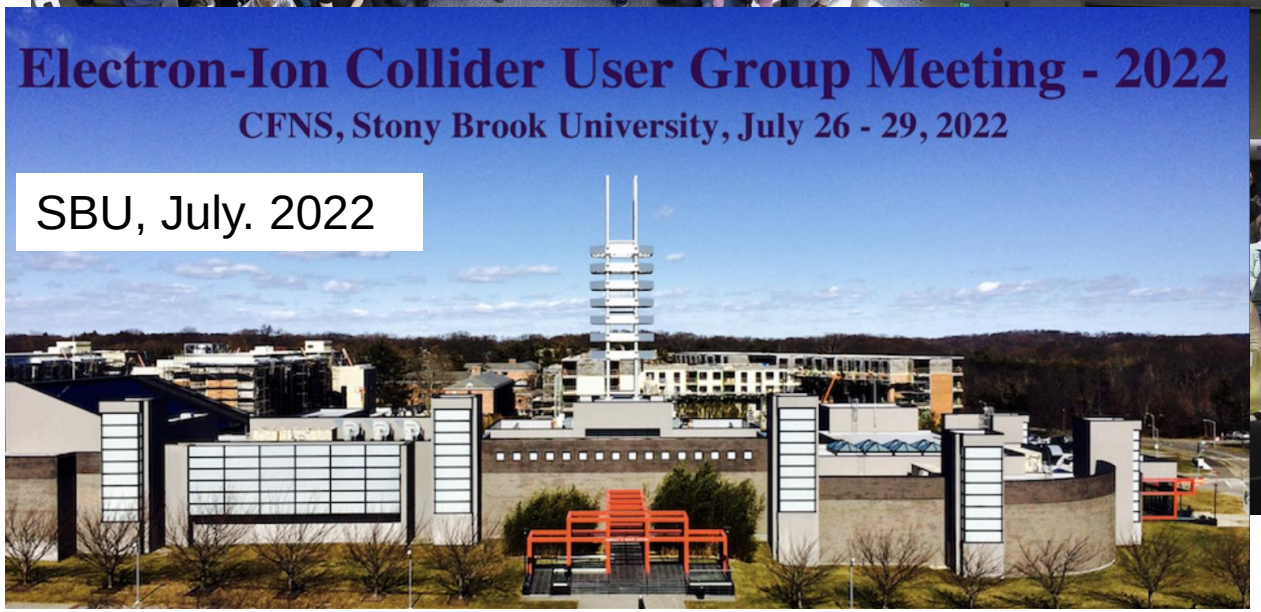
- ePIC Initiated in July 2022
- Currently: >850 collaborators (from 2024 Institutional Survey)
- >650 members active in ePIC activities



4 collaboration meetings so far

JLab, Jan. 2023

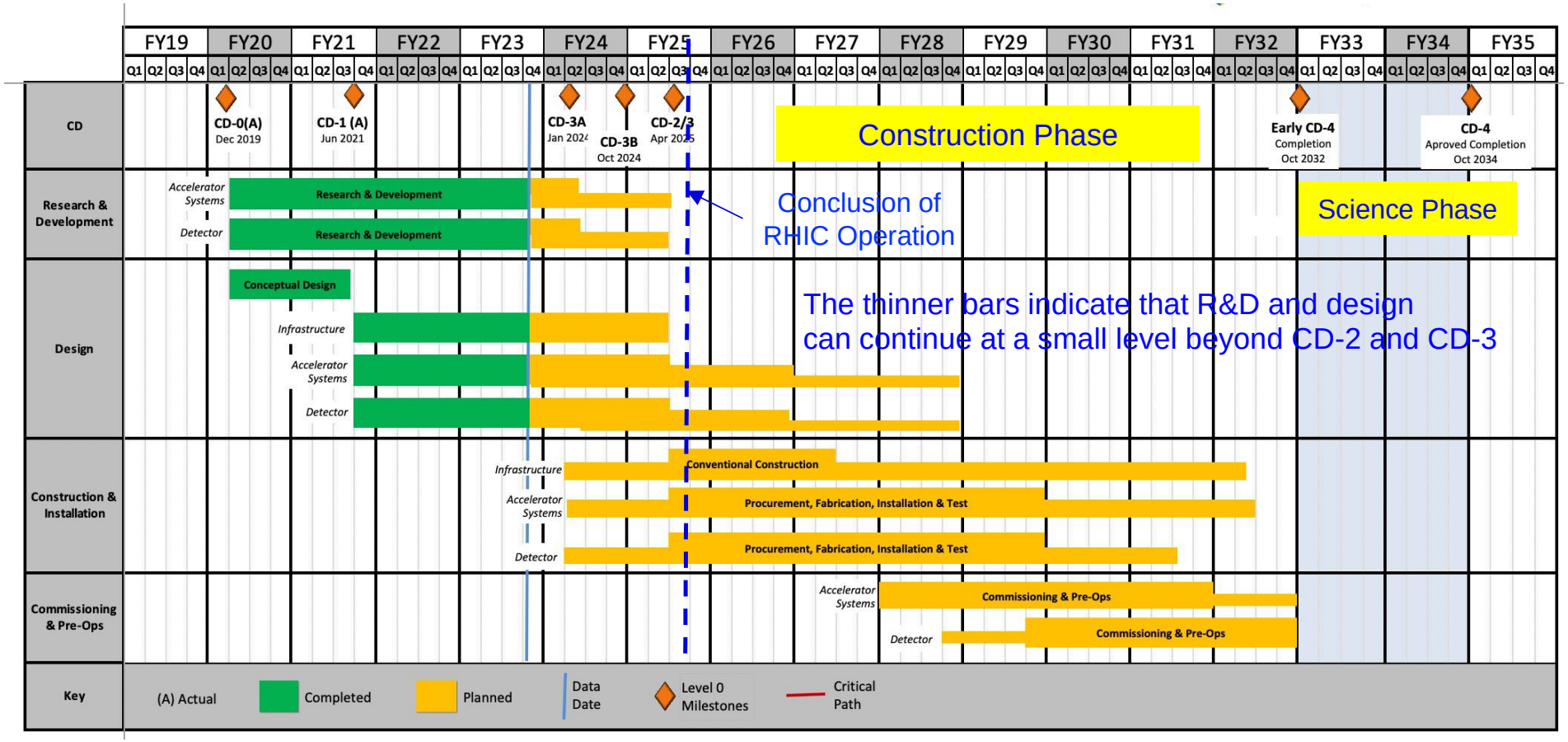
Warsaw, July 2023



SBU, July. 2022

ANL,
Jan. 2024

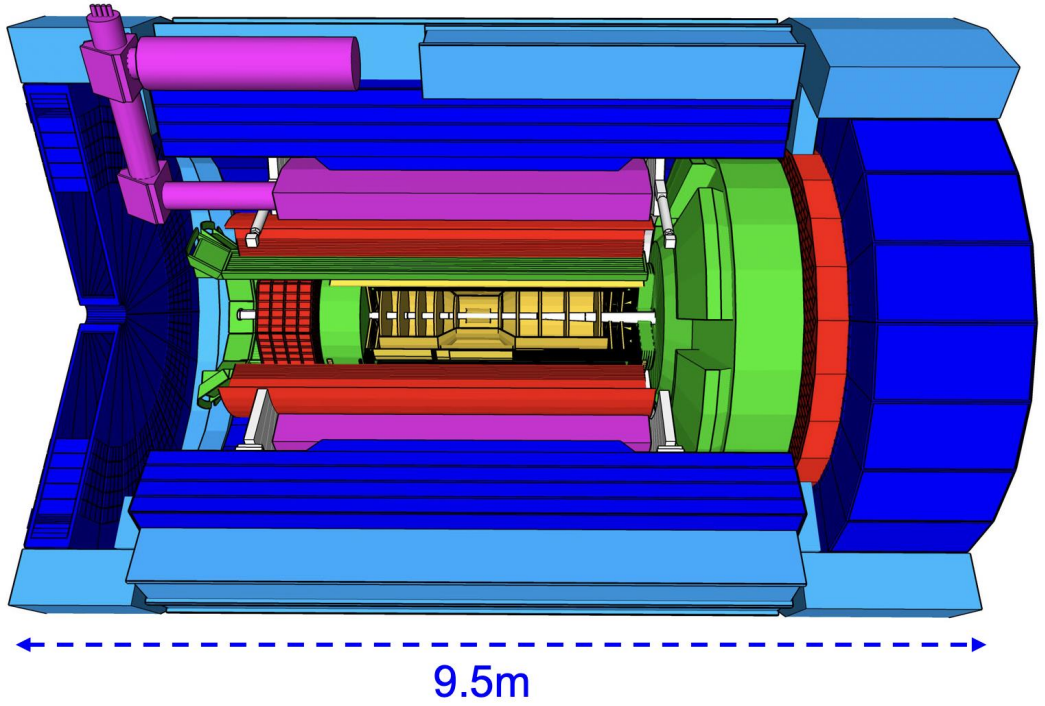
Going full-speed towards the CD-2 (April 2025)

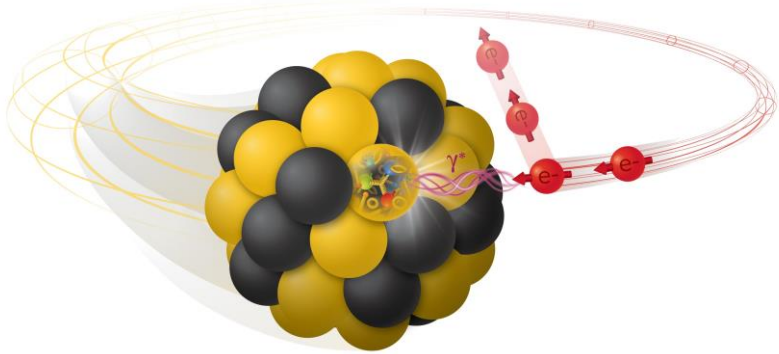


(slide taken from Elke and Rolf)

ePIC experiment – a versatile detector for understanding the visible matter

- ✓ ePIC is the 1st Electron-Ion Collider experiment, sitting at IP6.
- ✓ ePIC is a young but large international collaboration with > 850 members.
- ✓ ePIC is an experiment with state-of-the-art detector technologies.





Acknowledgment

The event display is provided by VIRTUE, which is made by Sean Preins (UCR), https://store.steampowered.com/app/2728380/VIRTUE/

Many thanks to my ePIC colleagues for their discussions and inputs to the slides!

Thank you!

Backup