



# ePIC: A General Purpose Detector for the EIC

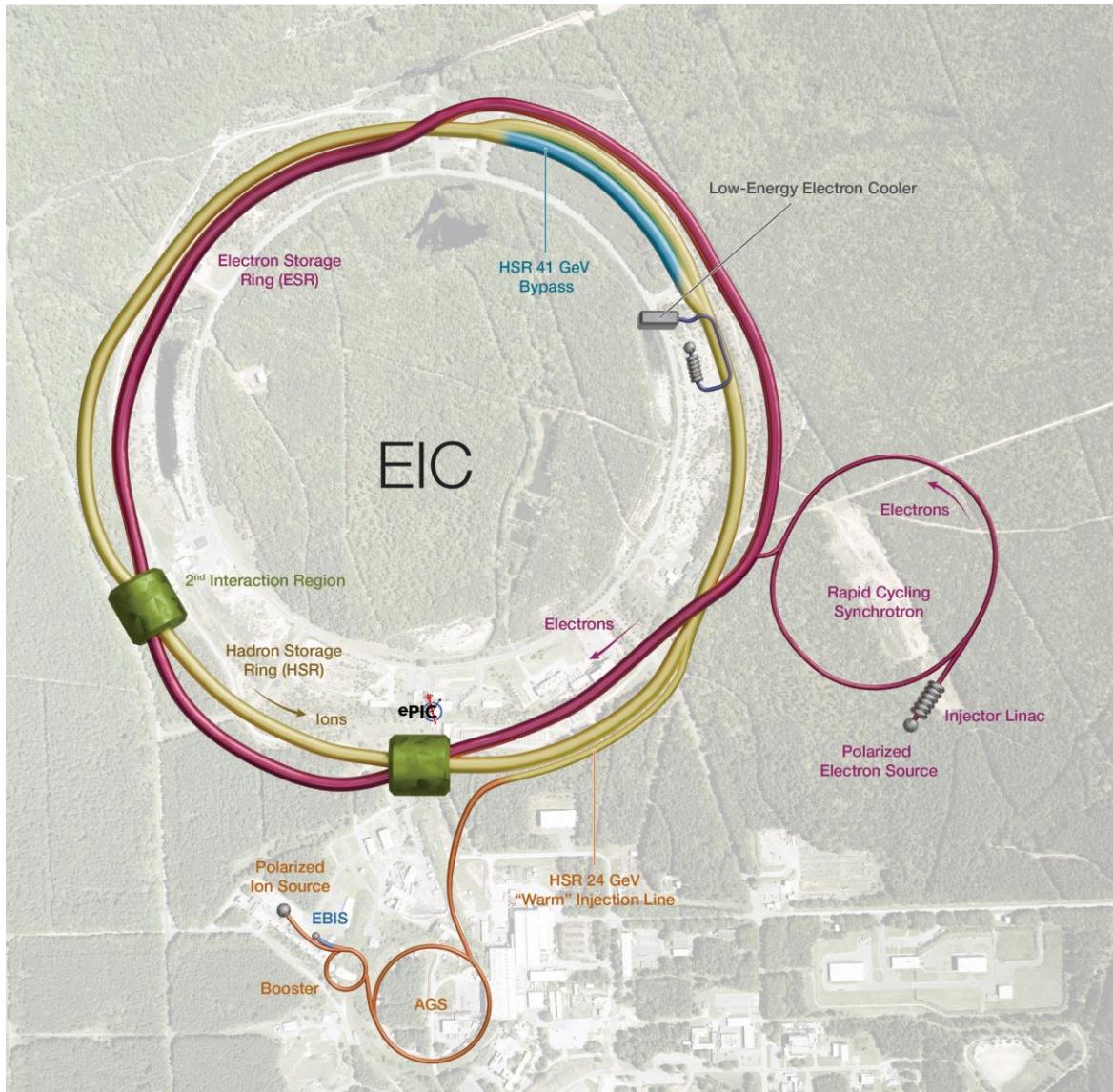
Brian Page

Synergies Between the EIC and the LHC

September 22 – 24, 2025



# The Electron Ion Collider (EIC)



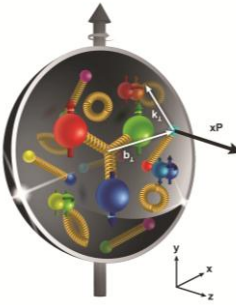
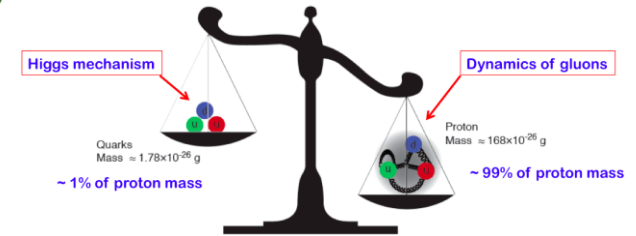
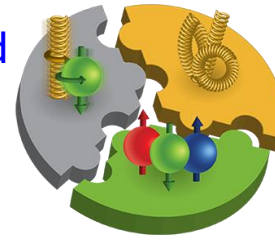
## EIC Capabilities

- ❑ Large center of mass energy range
  - ep: 28 – 141 GeV
  - eA: 28 – 63 GeV
  
- ❑ High luminosity
  - $10^{33} - 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
  - 10 – 100 fb<sup>-1</sup> / year
  
- ❑ Electron / proton (and light ion) beam polarization
  
- ❑ Large range in ion species: proton - Uranium

# The EIC Physics Pillars

How are the sea quarks and gluons, and their spins, **distributed in space and momentum** inside the nucleon?

How do the **nucleon properties emerge** from them and their interactions?



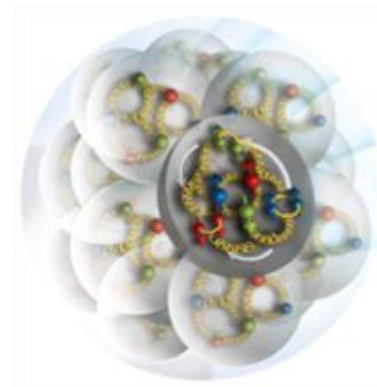
How do color-charged quarks and gluons, and colorless jets, **interact with a nuclear medium**?

How do the **confined hadronic states emerge** from these quarks and gluons?

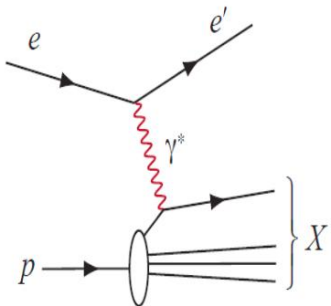
How do the quark-gluon **interactions create nuclear binding**?

How does a **dense nuclear environment affect** the quarks and gluons, their correlations, and their interactions?

What happens to the **gluon density in nuclei**? Does it **saturate at high energy**, giving rise to a **gluonic matter with universal properties** in all nuclei, even the proton?

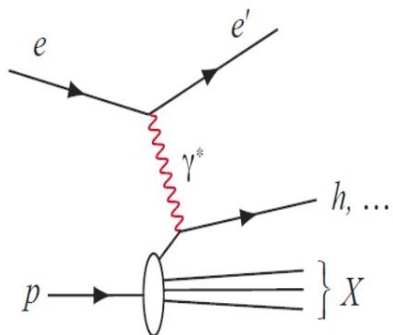


# Physics Informs Design



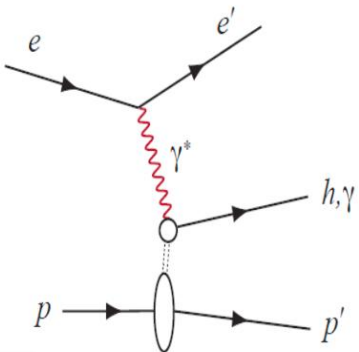
- ❑ Inclusive DIS
  - Fine binning in  $x$  and  $Q^2$

- ❑ Large coverage ( $|\eta| < 3.5$ ) to maximize phase-space reach
- ❑ High-resolution EM calorimetry and PID for  $e/\pi$  separation
- ❑ Low mass, high momentum resolution tracking



- ❑ Semi-inclusive DIS
  - 5-D binning in  $x$ ,  $Q^2$ ,  $z$ ,  $p_T$ , and  $\phi_h$

- ❑ Fine  $p_T$  (tracking) resolution
- ❑ Extensive PID coverage for hadron identification
- ❑ Hadron calorimetry for jet measurements (neutral hadron ID) and muon ID

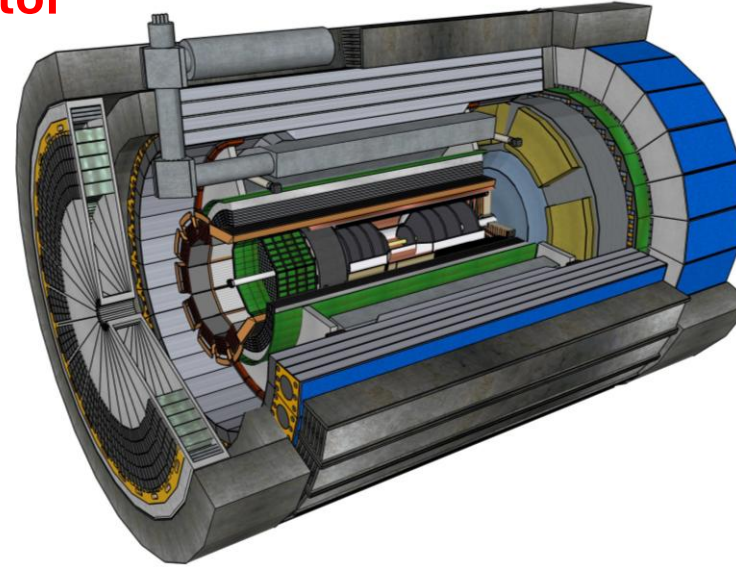
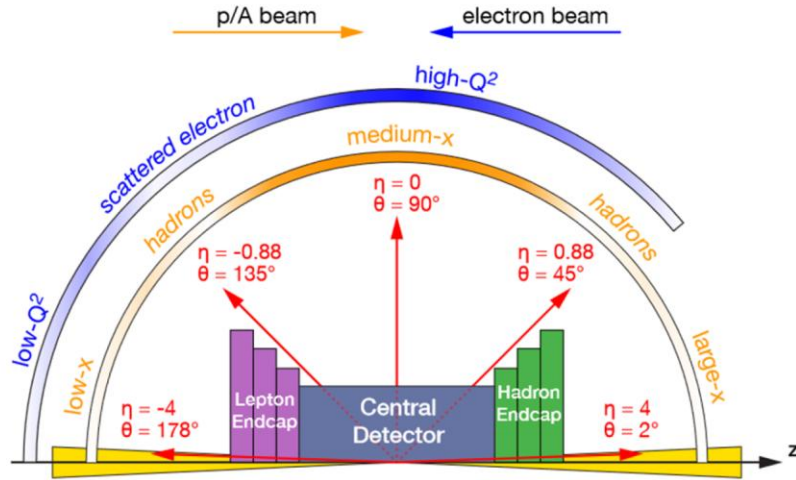


- ❑ Exclusive processes
  - 4-D binning in  $x$ ,  $Q^2$ ,  $t$ , and  $\phi_h$

- ❑ Extended acceptance at very small angles (IR integration and magnet design)
- ❑ Extensive beam-line instrumentation
- ❑ Good vertex resolution
- ❑ EM calorimetry for  $\gamma/\pi$  separation

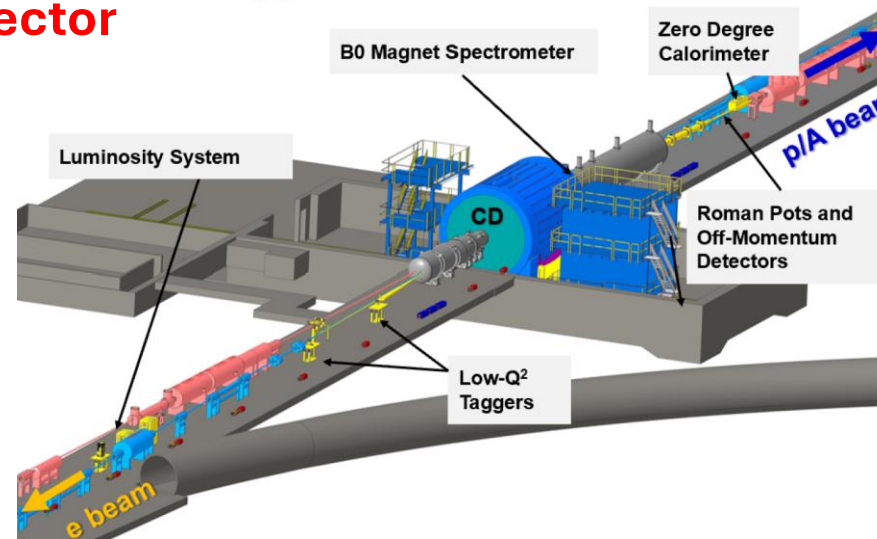
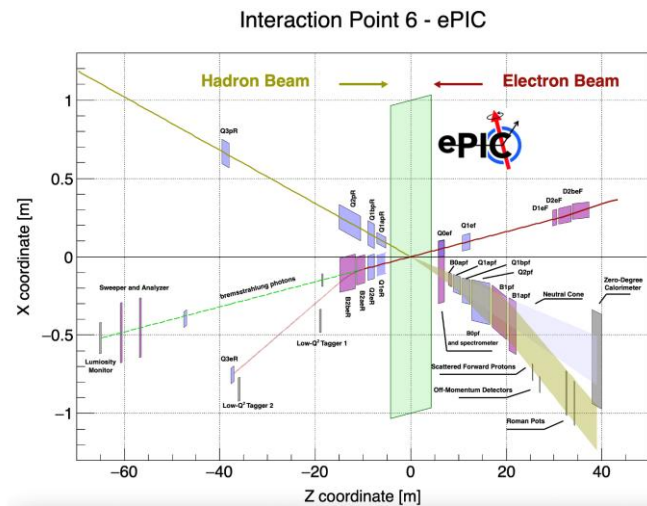
# Full Detector Overview

## Central Detector



- ❑ Central detector follows familiar HEP detector layout: tracking, PID, EM and hadron calorimetry
- ❑ Asymmetric from forward to backward rapidity reflecting different beam energies

## Full Detector



- ❑ Extensive forward and backward instrumentation: lumi, polarimetry, roman pots, ZDC, etc
- ❑ Highly integrated with IR and machine lattice -> full detector is ~90 m

# Central Detector Summary

hadronic calorimeters

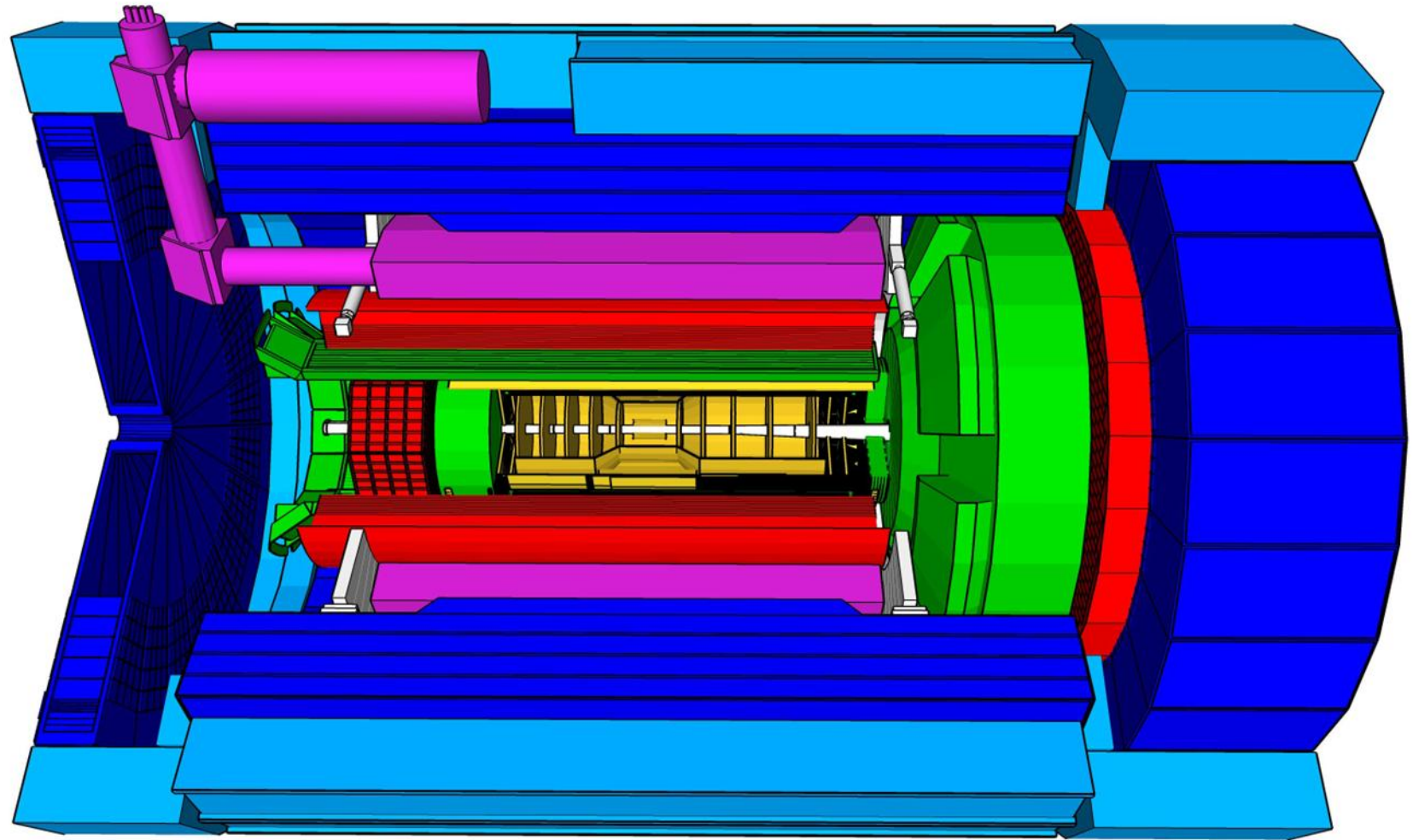
Solenoidal Magnet

e/m calorimeters  
(ECal)

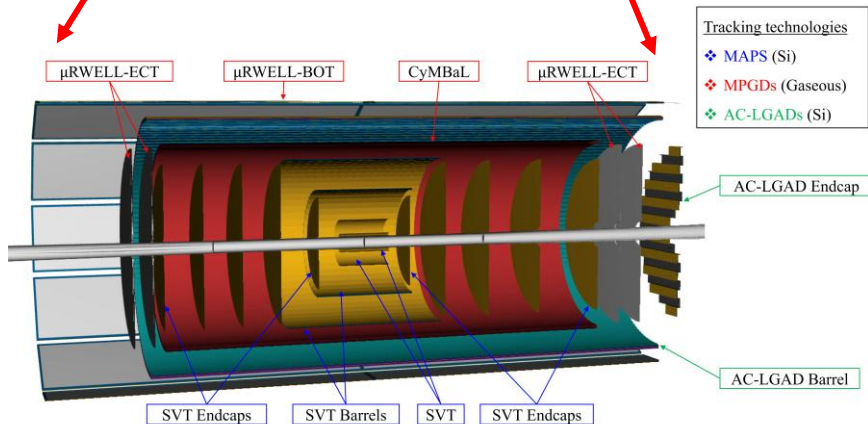
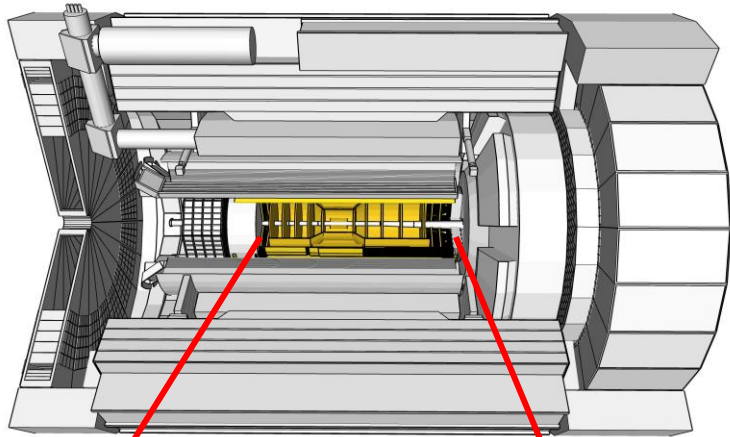
Time of Flight,  
DIRC,  
RICH detectors

MPGD trackers

MAPS tracker



# Trackers



## General Requirements for trackers

- Excellent momentum resolution ( $dp/p(\%)$  up to  $0.05 \cdot p + 0.5$  at mid-rapidity)
- High spatial resolution ( $20 \mu\text{m}/p_T + 5 \mu\text{m}$  at mid-rapidity)
- Low material budget
- Timing resolution adequate to resolve 10 ns beam bunch spacing

## Detector Solutions

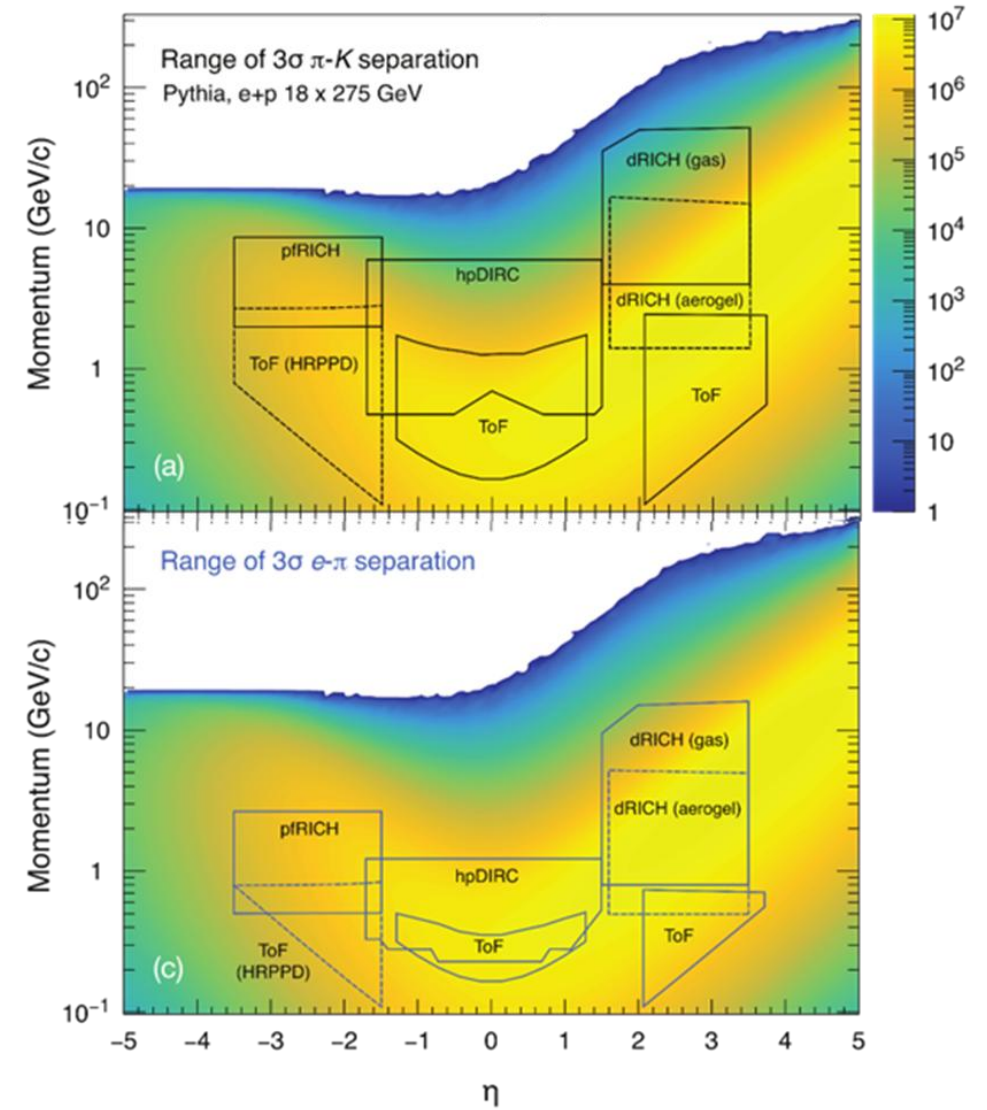
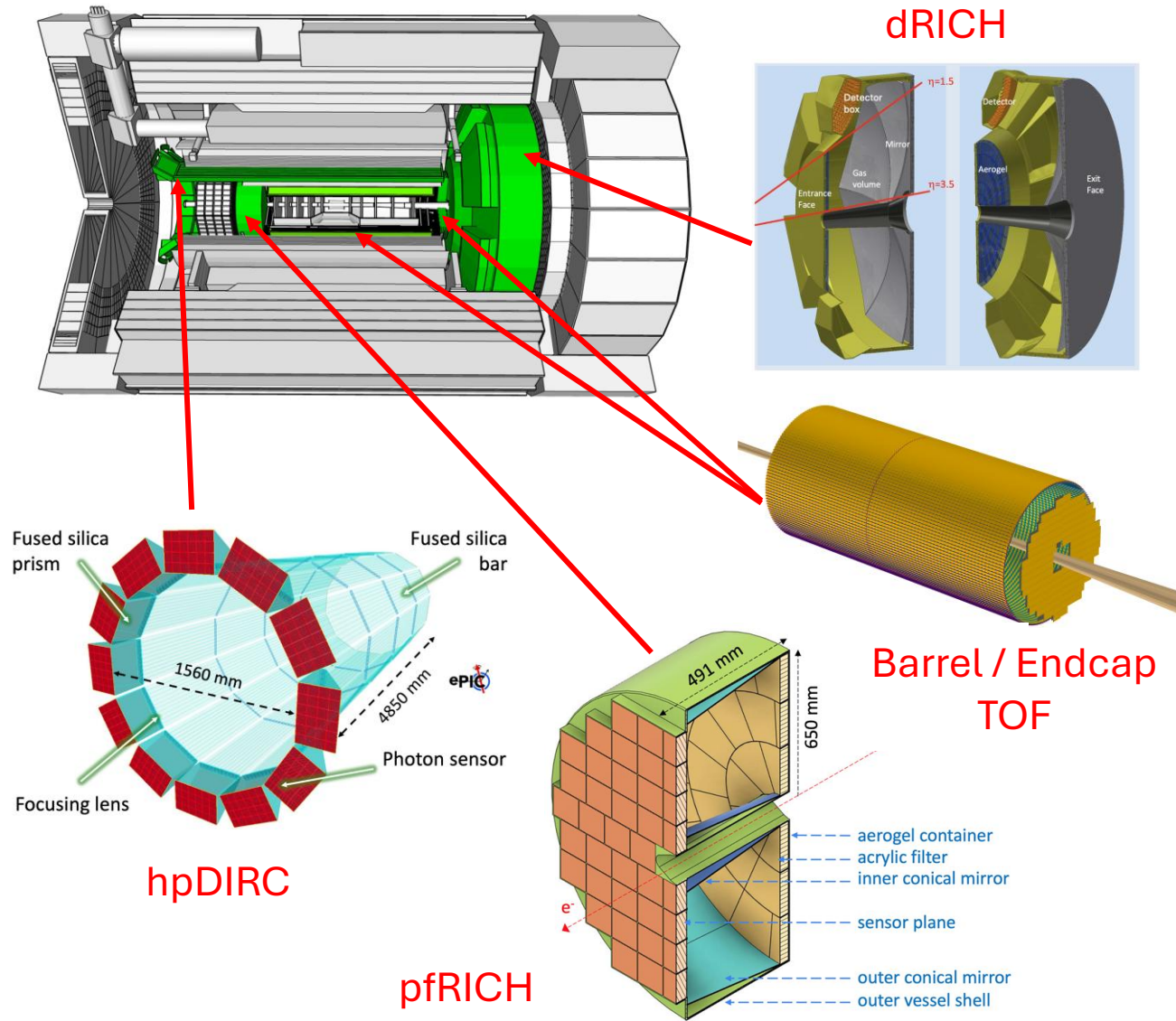
### ❑ Silicon Vertex Tracker ([Synergy with ALICE ITS3 development](#))

- Monolithic Active Pixel Sensors (MAPS) using 65 nm CMOS process
- 3 inner layers utilizing ALICE ITS3 curved MAPS –  $20 \mu\text{m}$  pixel pitch  $0.05\% X/X_0$
- 2 outer layers and 5 forward/backward disks using ITS3-based EIC Large Area Sensor  $\leq 0.55\% X/X_0$

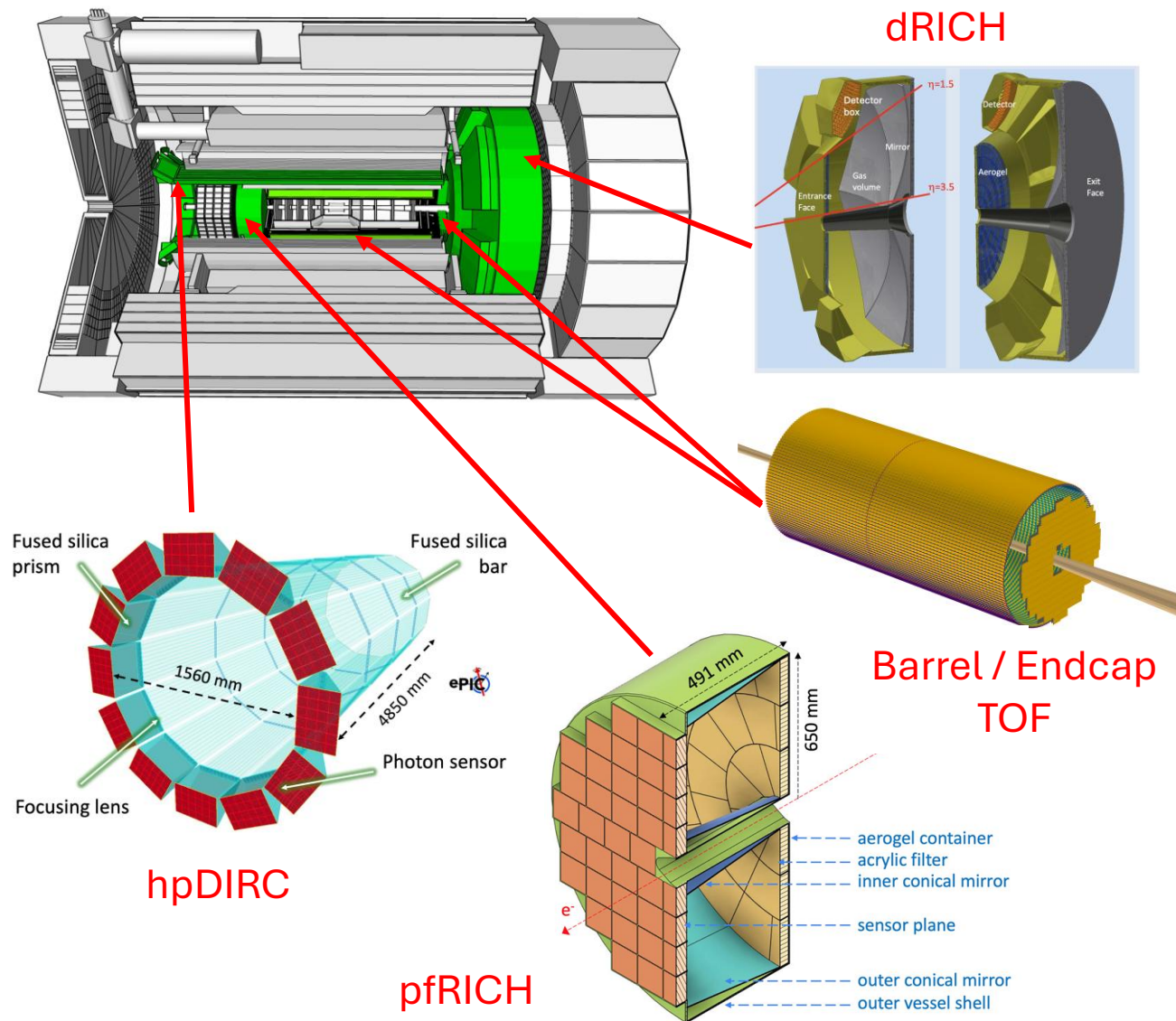
### ❑ MPGD – based Trackers

- Provide additional hit points and fast ( $O \sim 10$  ns) timing capability
- Cylindrical Micromegas Barrel Layer (CyMBaL)  $X/X_0 \sim 1\%$
- $\mu$ RWELL Barrel Outer Tracker provides space point directly in front of hpDIRC  $X/X_0 \sim 1.5\%$  (central region)
- GEM- $\mu$ RWELL endcap disks provide extra hit points where background interference is highest

# Particle Identification



# Particle Identification



## Dual Radiator Ring Imaging Cherenkov (dRICH)

- Aerogel +  $C_2F_6$  gas for PID up to 50 GeV/c
- First-ever use of SiPMs in a RICH (Possible for LHCb)

## Proximity Focusing RICH (pfRICH)

- Aerogel radiator for  $\pi/k$  separation up to  $\sim 8$  GeV/c at  $3\sigma$
- Novel photosensor solution: HRPPDs (under consideration for LHCb upgrade)
- Excellent time resolution ( $< 30$  ps) allows integrated ToF capability

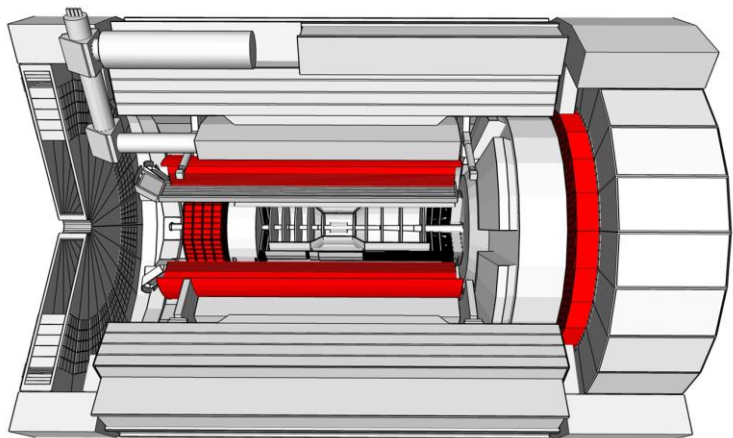
## High-Performance DIRC (hpDIRC)

- Quartz bar radiators running length of ePIC barrel -  $\pi/k$  separation up to 6 GeV/c at  $3\sigma$
- 3-layer spherical lens system reduces photon loss between bars and expansion prism
- Pixelized MCP-PMTs as photosensors – possibility to use HRPPDs in synergy with pfRICH

## Time-of-Flight Barrel and Forward Endcap (BTOF and FTOF)

- AC-LGAD sensors provide 20-35 ps time resolution
- $\pi/k$  separation at  $3\sigma$  for  $p_T < 1.2$  GeV/c and  $p < 2.5$  GeV/c for BTOF and FTOF, respectively

# Electromagnetic Calorimetry

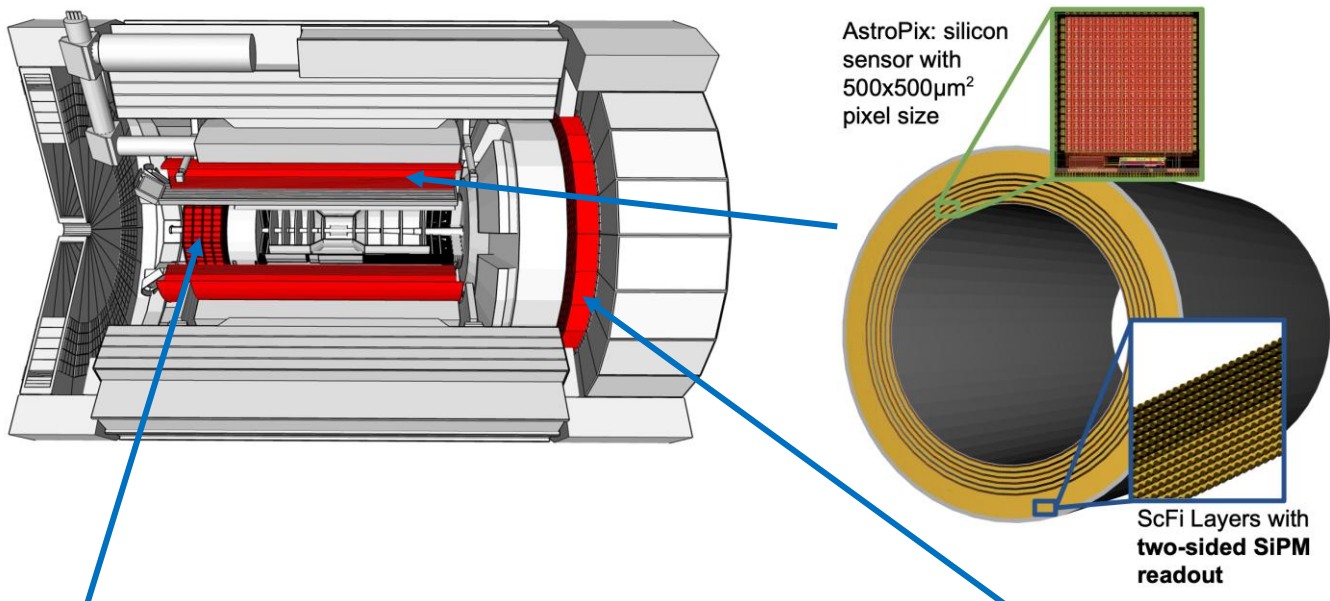


## General Electromagnetic Calorimetry Considerations

- ❑ Electron-Going Endcap Calorimeter
  - Excellent energy resolution for precision determination of kinematics from scattered electron
  - Electron-hadron discrimination (with other subsystems) up to  $10^4$
  
- ❑ Barrel Calorimeter
  - Electron identification and hadron suppression for high  $Q^2$  events and electrons from vector meson decay
  - Excellent spatial resolution to discriminate DVCS photons from  $\pi^0$  decays
  - Large dynamic range to measure MIPs initiated from muons
  
- ❑ Hadron-Going Endcap Calorimeter
  - Large area coverage for jet measurements
  - Spatial resolution to discriminate DVCS photons and  $\pi^0$ s
  - Performance to high energies for particles boosted by hadron beam

	$\sigma_E/E$	E Range [GeV]
E-Endcap	$(2-3)\%/\sqrt{E} + (1-2)\%$	0.1 – 18
Barrel	$10\%/\sqrt{E} + (2-3)\%$	0.1 – 50
H-Endcap	$12\%/\sqrt{E} + 2\%$	0.1 – 100

# Electromagnetic Calorimetry

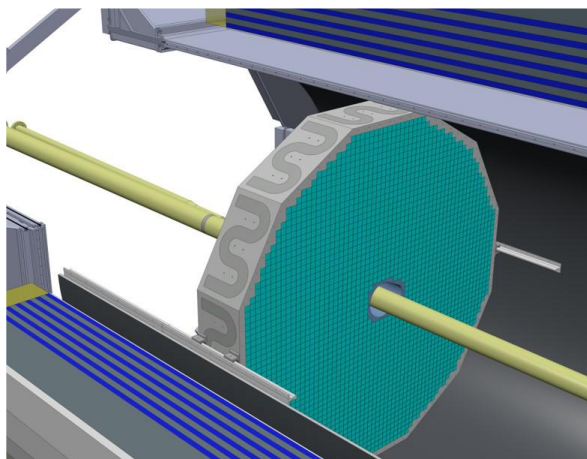


## Barrel Imaging Calorimeter (BIC)

- Hybrid calorimeter: 6 layers of AstroPix (4 instrumented) interleaved with 5 Pb/ScFi layers, followed by bulk Pb/ScFi
- Pb/ScFi sections based on GlueX design – SiPM readout at either end of barrel
- AstroPix: MAPS sensors with 500 μm pixel pitch and ~3.2 ns time resolution

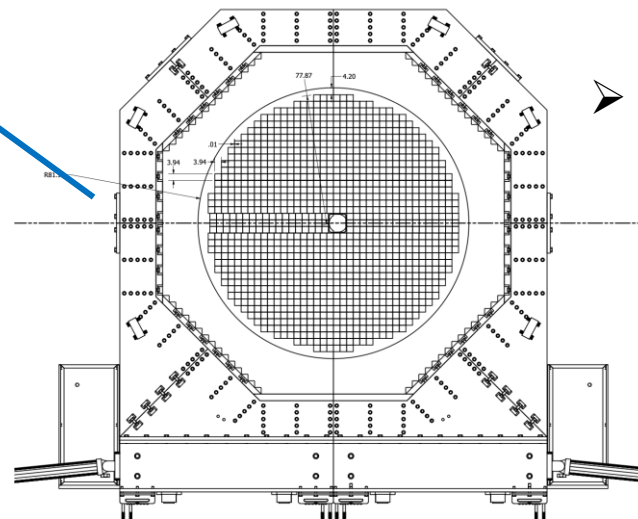
## Hadron-Endcap Ecal

- Tungsten/SciFi SPACAL design with SiPMs
- Utilized in sPHENIX barrel EMCal

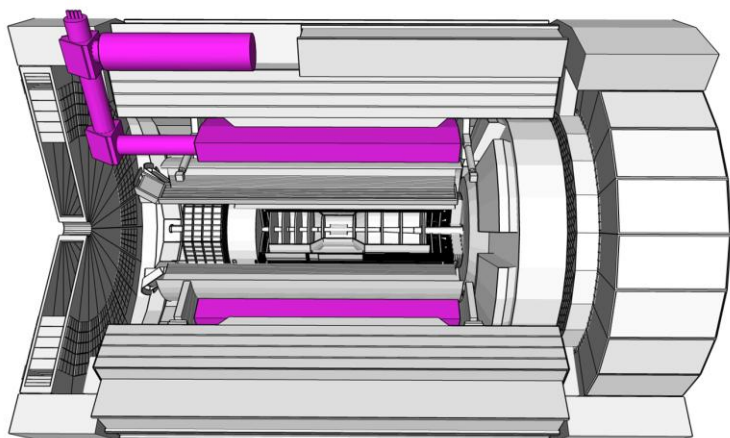


## EEEMCAL

- High-precision  $\text{PbWO}_4$  crystal calorimeter
- First use of SiPMs in a crystal calorimeter



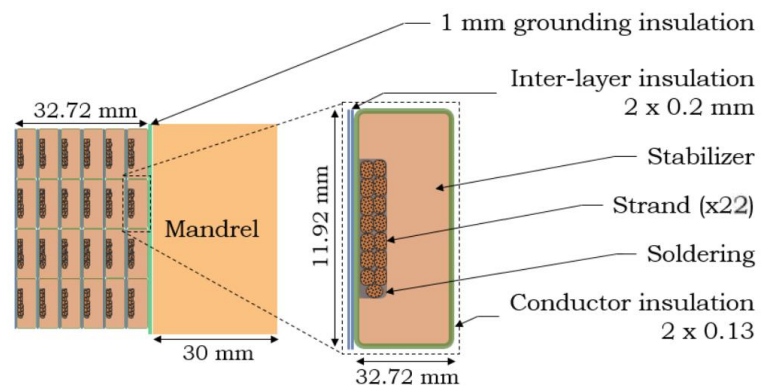
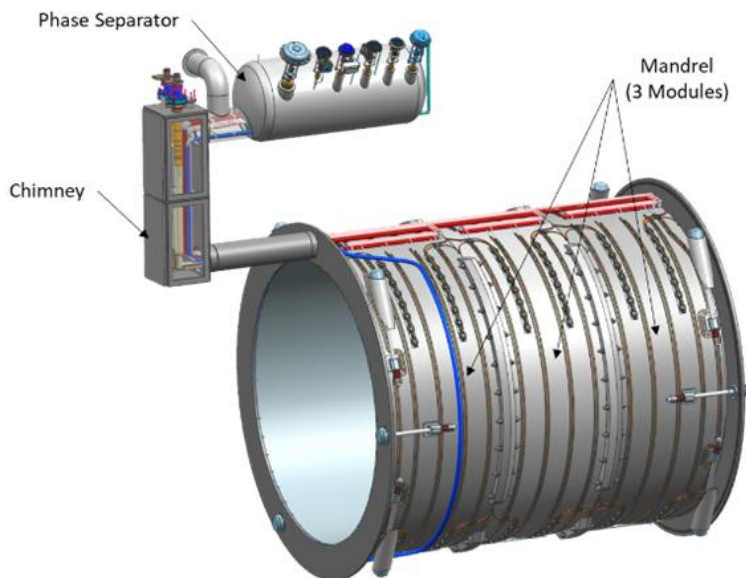
# MARCO Magnet



$B_0$	1.5 T	1.7 T	2.0 T	Units
Current	2942	3335	3924	A
$T_{op}$	4.7	4.7	4.7	K
$B_{peak}$	2.00	2.27	2.67	T
Temp. margin	3.06	2.82	2.45	K
Load line margin	59.6	54.2	46.1	%
$I / I_c(T, B_{peak})$	17.9	22.1	29.3	%

1.7 T nominal field  
2.0 T possible

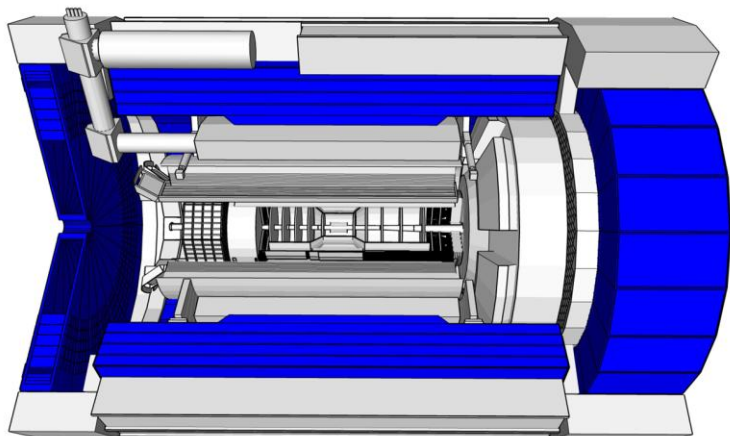
## Magnet with Renewed Coils (MARCO)



## Rutherford In Copper Channel (RICC) Conductor

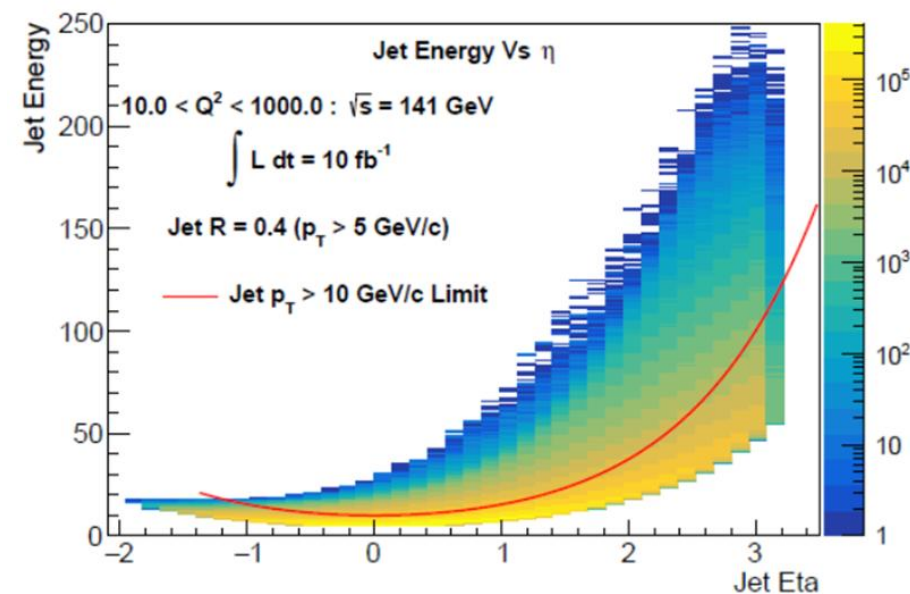
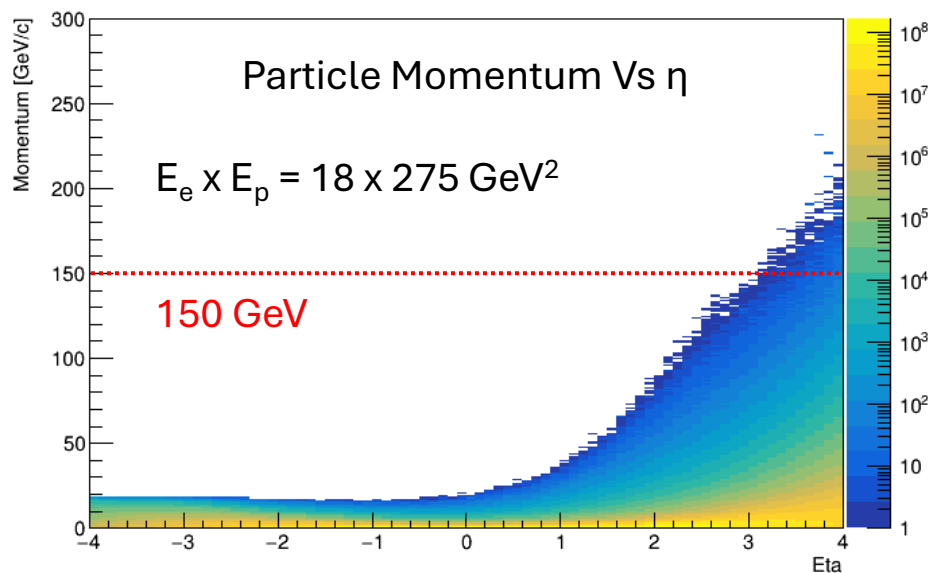
- ❑ Solenoidal field supplied by new large-bore MARCO magnet
  - Bore Radius = 1420 mm
  - Cryostat OR = 1770 mm
  - Cryostat Length = 3850 mm
- ❑ 3 modules with 6 conductor layers each
- ❑ Steel return yoke designed to reduce fringe fields and provide projectivity in RICH region
- ❑ 2 and 3D mechanical analysis done on all components – all stresses and displacements within acceptable limits

# Hadronic Calorimetry

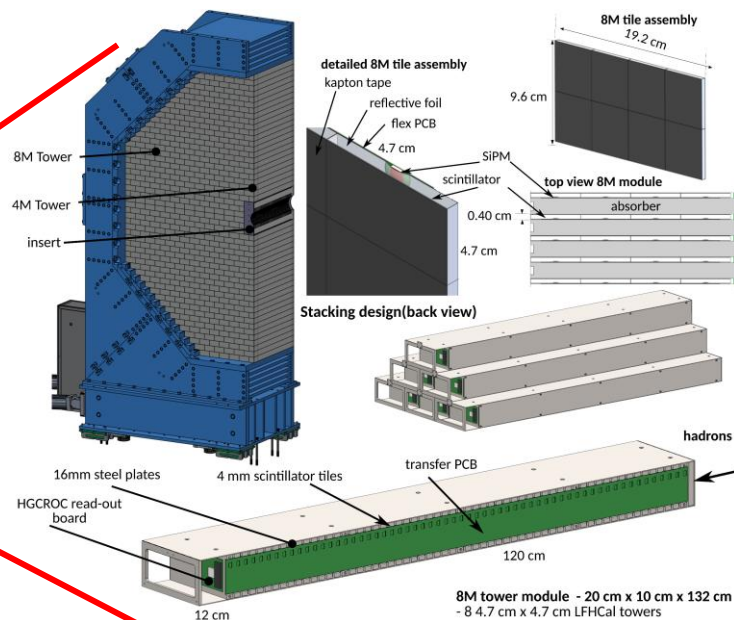
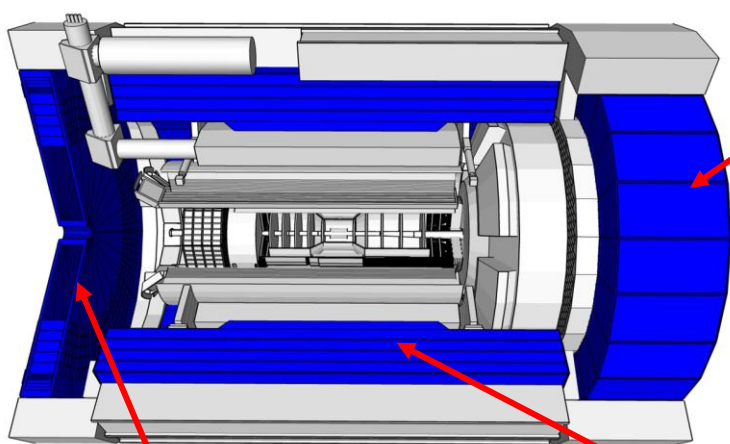


## General Hadronic Calorimetry Considerations

- ❑ Particles in forward direction boosted to high energies (up to  $\sim 150$  GeV) by hadron beam energy
- ❑ Tracking momentum and angular resolution degrades for  $> 3$  so finely segmented good resolution hadronic calorimetry needed for jet measurements and kinematics determinations
- ❑ Calorimetry in mid and backward rapidity needed for neutrals detection, tail catching, and muon identification



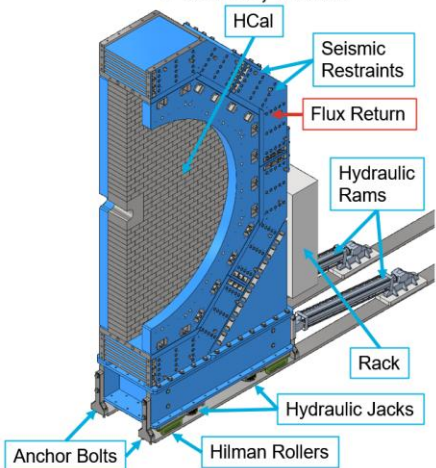
# Hadronic Calorimetry



## Forward HCal (LFHCal)

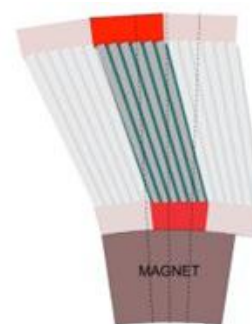
- Longitudinally segmented steel + scintillator SiPM-on-tile design
- 8752 towers x 7 individual longitudinal readout groupings ~6 interaction lengths
- High-granularity insert close to beam pipe
- CALICE-like design optimized for particle flow reconstruction

## Backward Endcap (BE) 11'x4'x25', 125ton



## Negative HCal

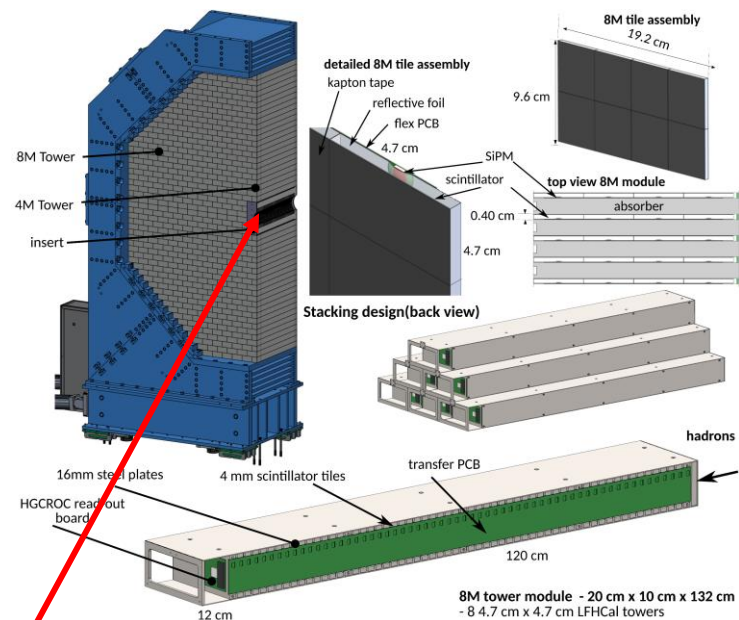
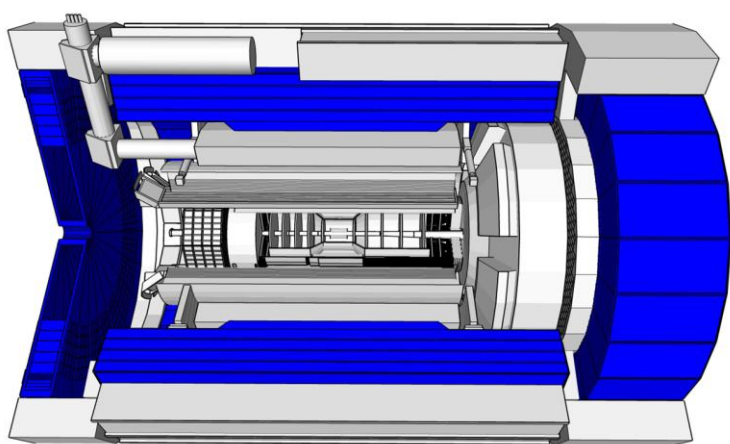
- Similar layout to forward HCal
- Tail catcher for identifying neutral components of jets
- Muon ID



## Barrel HCal

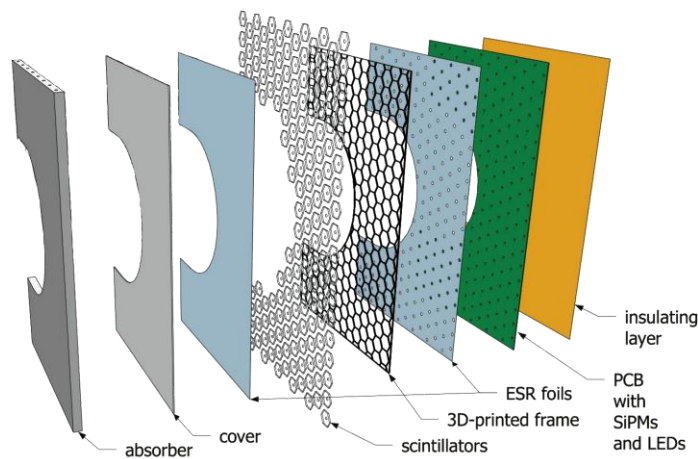
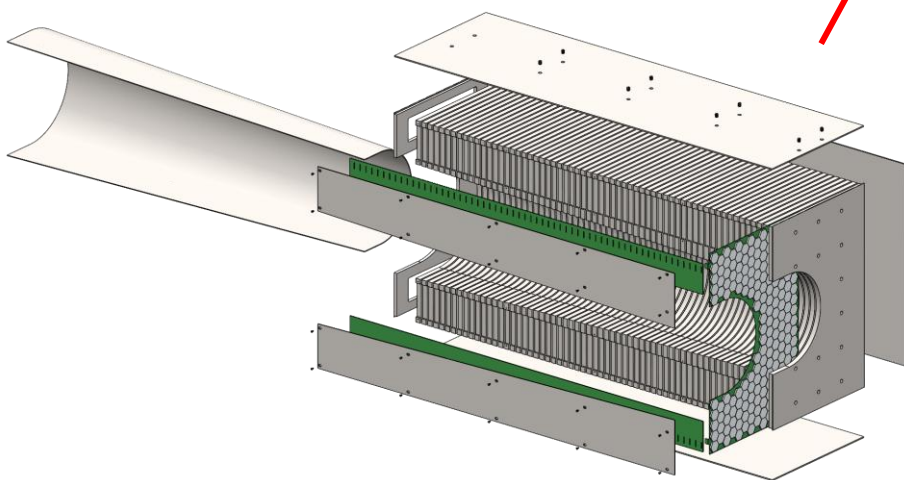
- Steel + scintillator design – tilted vertical plates
- Reuse of sPHENIX calorimeter
- Tail catcher and muon ID

# Hadronic Calorimetry



## Forward HCal (LFHCal)

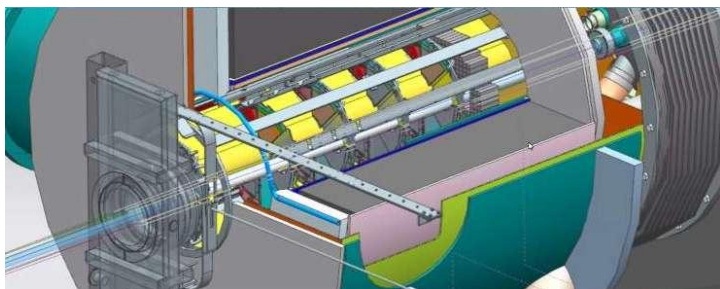
- Longitudinally segmented steel + scintillator SiPM-on-tile design
- 8752 towers x 7 individual longitudinal readout groupings ~6 interaction lengths
- High-granularity insert close to beam pipe
- CALICE-like design optimized for particle flow reconstruction



## High-Granularity Insert

- Beam pipe shape is non-trivial in forward endcap region
- Machine each layer to match beam pipe envelope to maximize acceptance
- SiPM-on-tile with hexagonal segmentation
- Hexagons offset layer-to-layer to improve shower reconstruction

# Far-Forward & Far-Backward Instrumentation

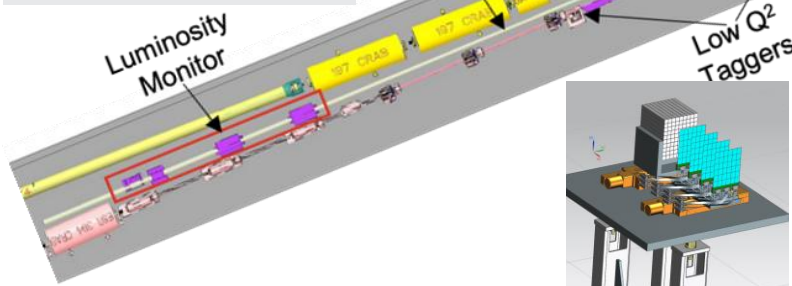
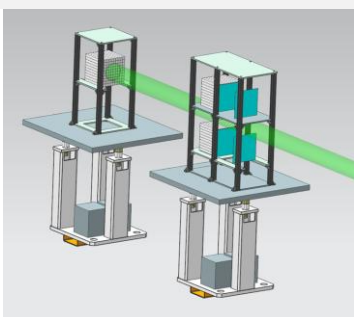


## B0 Magnet Spectrometer

- detection of forward scattered protons and  $\gamma$
- 4 tracking layers each of AC-LGAD / EICROC (500x500  $\mu\text{m}^2$  pixel) – Synergy with forward ToF
- EMCAL: 2x2x20  $\text{cm}^3$   $\text{PbWO}_4$  calorimeter – Synergy with backward ECal

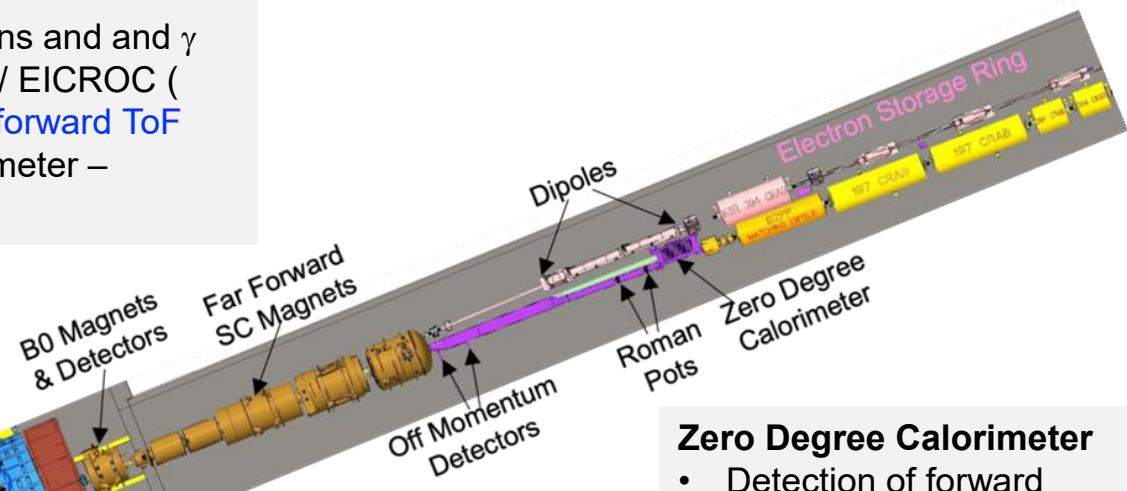
## Luminosity System

- Measure bunch-by-bunch luminosity through Bethe-Heitler process
- Pair-spectrometer: each with 2 tracking layers of AC-LGAD / FCFD – Synergy with Barrel-ToF
- Calorimeter: Tungsten-powder + SciFi SPACAL – Synergy with forward ECal



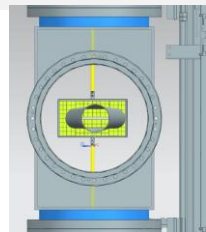
## Low- $Q^2$ Taggers

- detection of scattered electrons
- 2 stations with 4 tracking layers each (16x18 $\text{cm}^2$ ) Si / Timepix4
- Calorimeter: Tungsten-powder + SciFi SPACAL – Synergy with forward ECal



## Roman Pots and Off-Momentum Detectors

- Detection of forward scattered protons and nuclei
- 2 stations with 2 tracking layers each
- AC-LGAD / EICROC (500x500  $\mu\text{m}^2$  pixel) – Synergy with forward ToF



## Zero Degree Calorimeter

- Detection of forward scattered neutrons and  $\gamma$
- EMCAL: 2x2x20  $\text{cm}^3$   $\text{PbWO}_4$  calorimeter – Synergy with backward ECal
- HCAL: Steel-SiPM-on-Tile – Synergy with forward HCal



# Summary

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- ❑ The Electron-Ion Collider will be the ultimate machine for the exploration of QCD and will likely be the only novel collider build in the next few decades
- ❑ The ePIC detector is designed to be a precision QCD experiment that will fully address the extensive physics program at the EIC
- ❑ ePIC is a complex detector with over 20 individual subsystems utilizing both established and novel technologies to provide tracking, PID, EM and hadronic calorimetry and near-beam detection capability over a wide acceptance
- ❑ Many opportunities for synergistic development and implementation of detector technologies as well as related needs like streaming readout / DAQ and even magnet construction