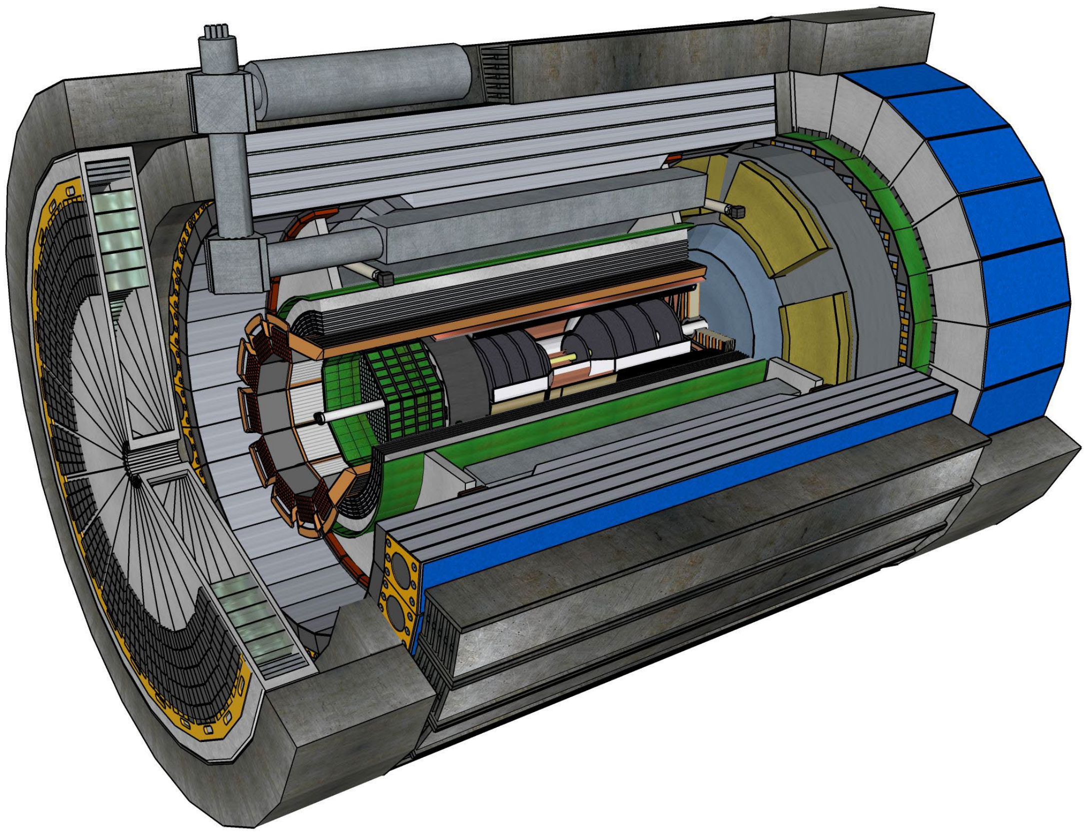
The ePIC Experiment



John Lajoie

Iowa State University

STATE

ePIC

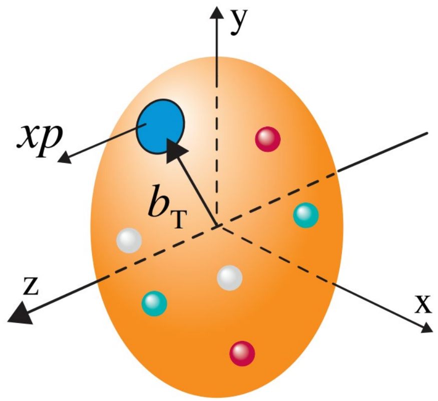
U.S. DEPARTMENT OF ENERGY

Office of Science

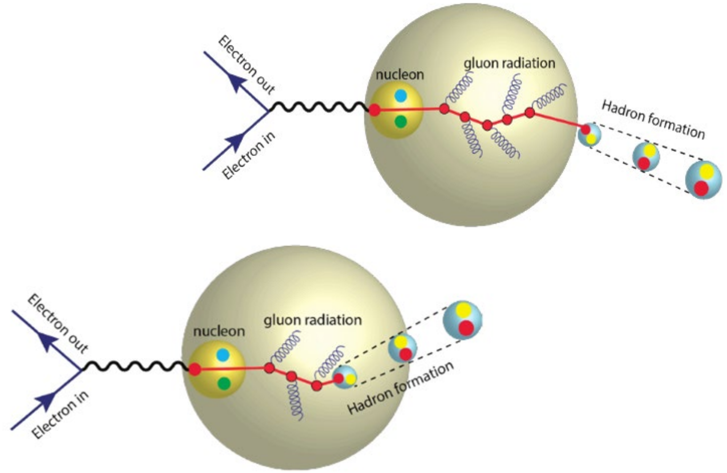
JLUO Annual Meeting 2023

The EIC Science Mission

- How do the **nucleon properties like mass and spin emerge** from quarks and their interactions?

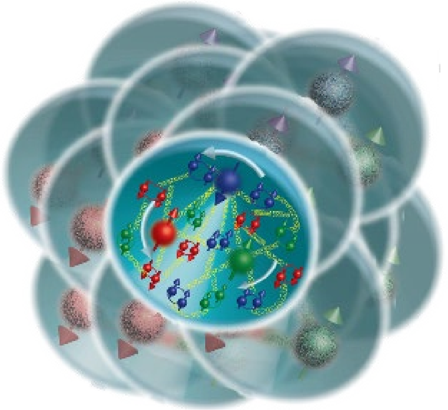


- How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?



- In what manner do color-charged quarks and gluons, along with colorless jets, interact with the nuclear medium? And how do the confined hadronic states emerge from these quarks and gluons?

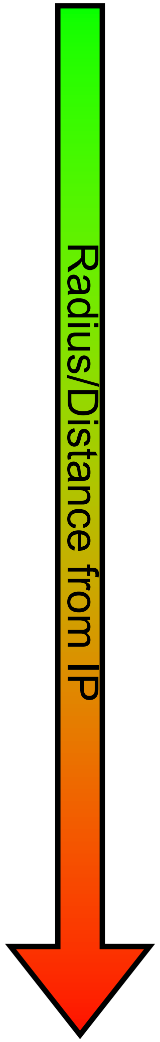
- What is the mechanism through which quark-gluon interactions give rise to nuclear binding?



- What impact does a high-density nuclear environment have on the interactions, correlations, and behaviors of quarks and gluons?

- Is there a **saturation point** for the density of gluons in nuclei at high energies, and does this lead to the **formation of gluonic matter** with universal properties across all nuclei, including the proton?

EIC Detector Requirements



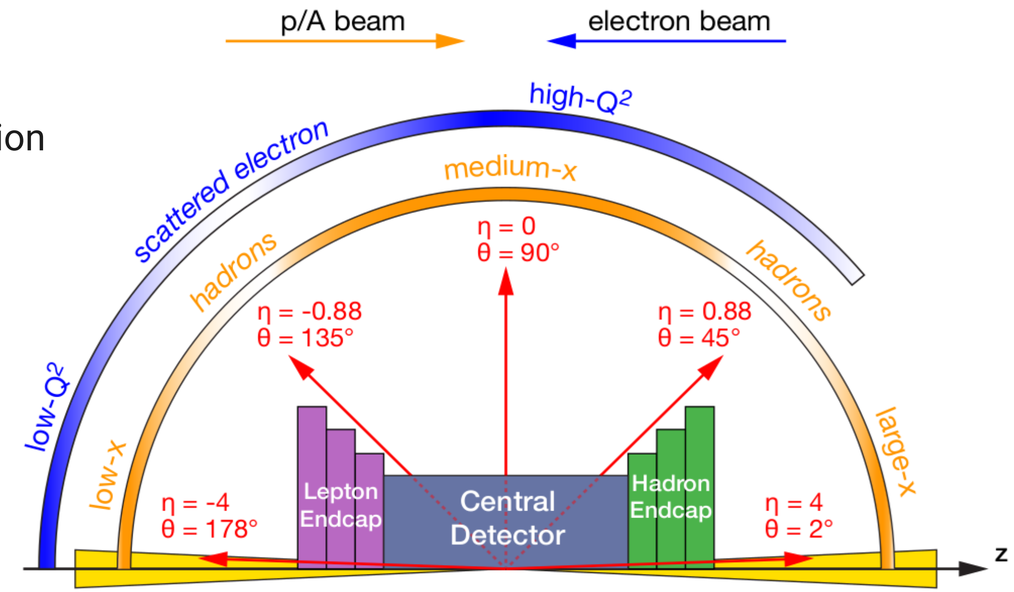
Vertex detector → Identify primary and secondary vertices,
- Low material budget: 0.05% X/X_0 per layer
- High spatial resolution: 20 μm pitch CMOS Monolithic Active Pixel Sensor

Central and Endcap tracker → High precision low mass tracking
- MAPS – tracking layers in combination with micro pattern gas detectors

Particle Identification → High performance single track PID for π, K, p separation
- RICH detectors (RICH, DIRC)
- Time-of-Flight high resolution timing detectors (HRPPDs, LGAD)
- Novel photon sensors: MCP-PMT / HRPPD

Electromagnetic calorimetry → Measure photons (E, angle), identify electrons
- $PbWO_4$ Crystals (backward), W/ScFi (forward)
- Barrel Imaging Calorimeter (Si + Pb/ScFi)

Hadron calorimetry → Measure charged hadrons, neutrons and K_L^0
- Achieve ~70%/√E + 10% for low E hadrons (~ 20 GeV)
- Fe/Sc sandwich with longitudinal segmentation



Very forward and backward detectors → Large acceptance for diffraction, tagging, neutrons from nuclear breakup
- Silicon tracking layers in lepton and hadron beam vacuum
- Zero-degree high resolution electromagnetic and hadronic calorimeters

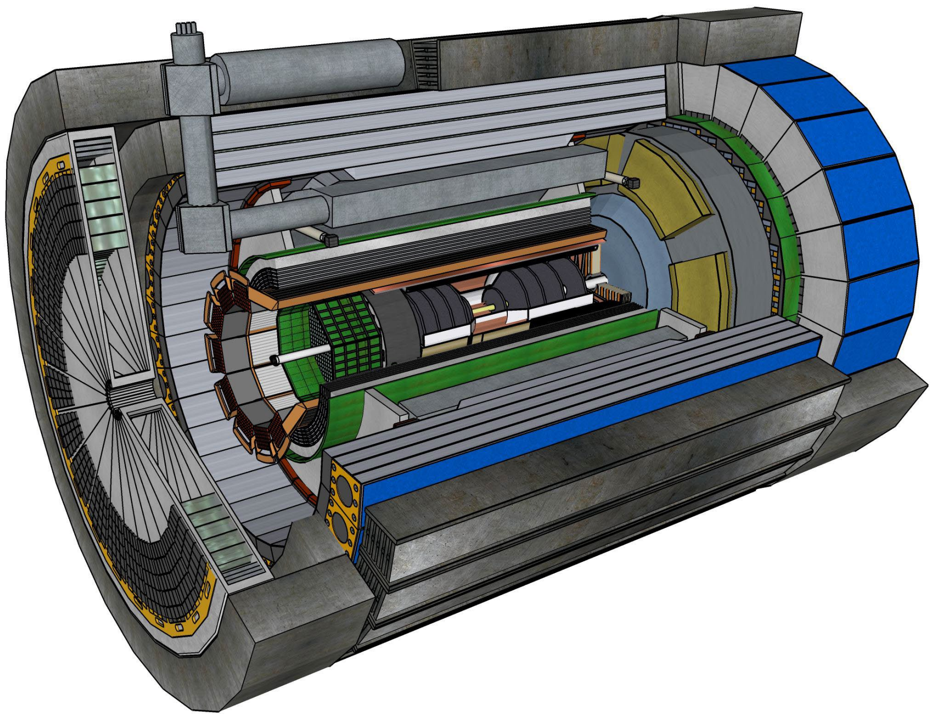
DAQ & Readout Electronics → trigger-less / streaming DAQ, Integrate AI into DAQ

Detector Design Process Timeline

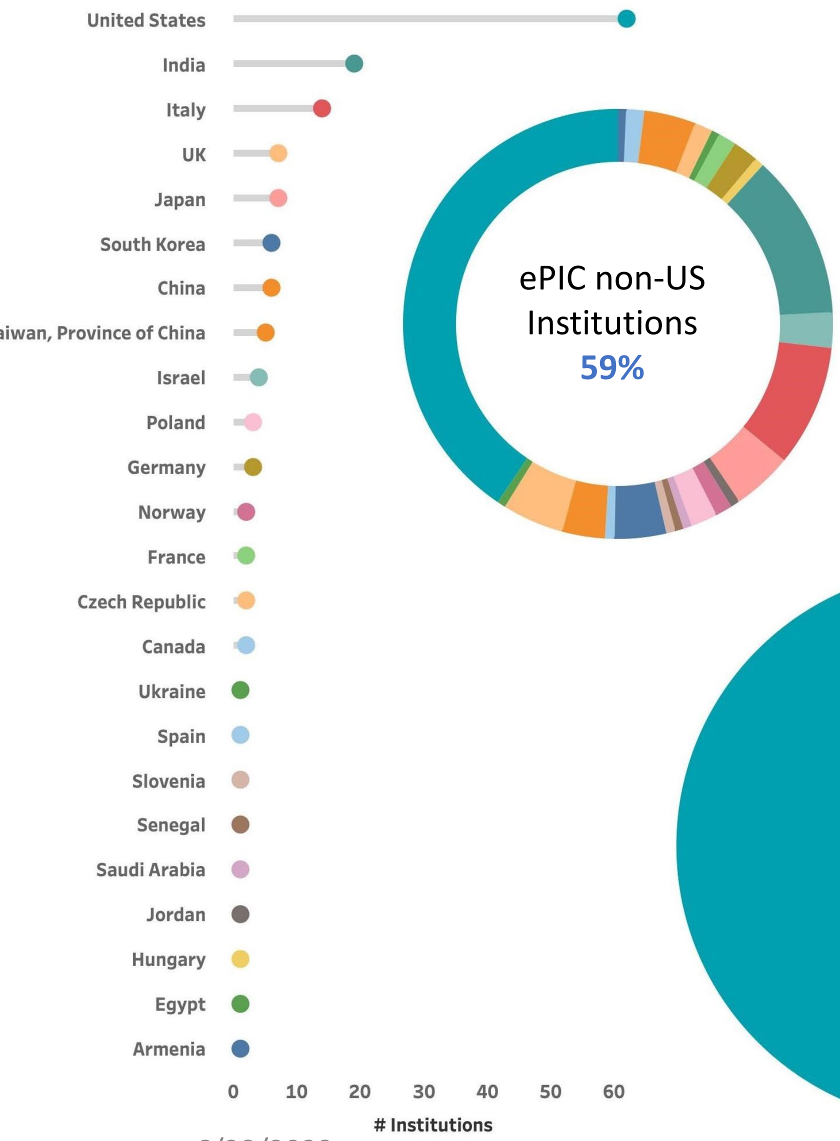
2012 **2015** **2017** **2020**

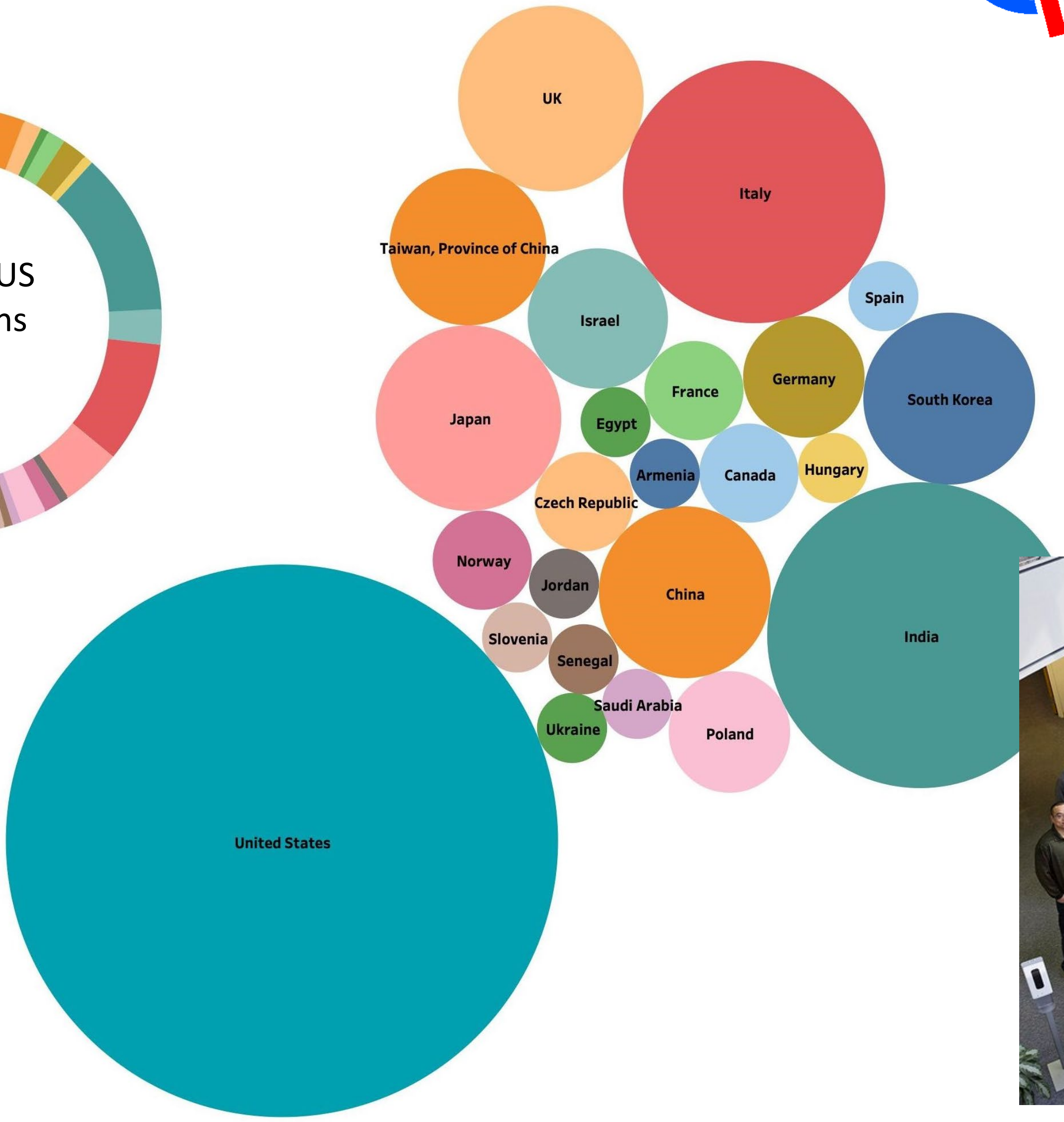
Detector and machine design parameters driven by physics objectives

- Call for proposals issued jointly by BNL and JLab in **March 2021** (Due Dec 2021)
  - ATHENA, CORE and ECCE proposals submitted
- DPAP closeout **March 2022**
  - ECCE proposal chosen as basis for first EIC detector reference design
- **Spring/Summer 2022** – ATHENA and ECCE form joint leadership team
  - Joint WG's formed and consolidation process undertaken
  - Coordination with EIC project on development of technical design
- Collaboration formation process started **July 2022**
- Charter ratified & elected ePIC Leadership Team **February 2023**
- **Working towards TDR and CD-3A and CD-2/3**



The ePIC Collaboration



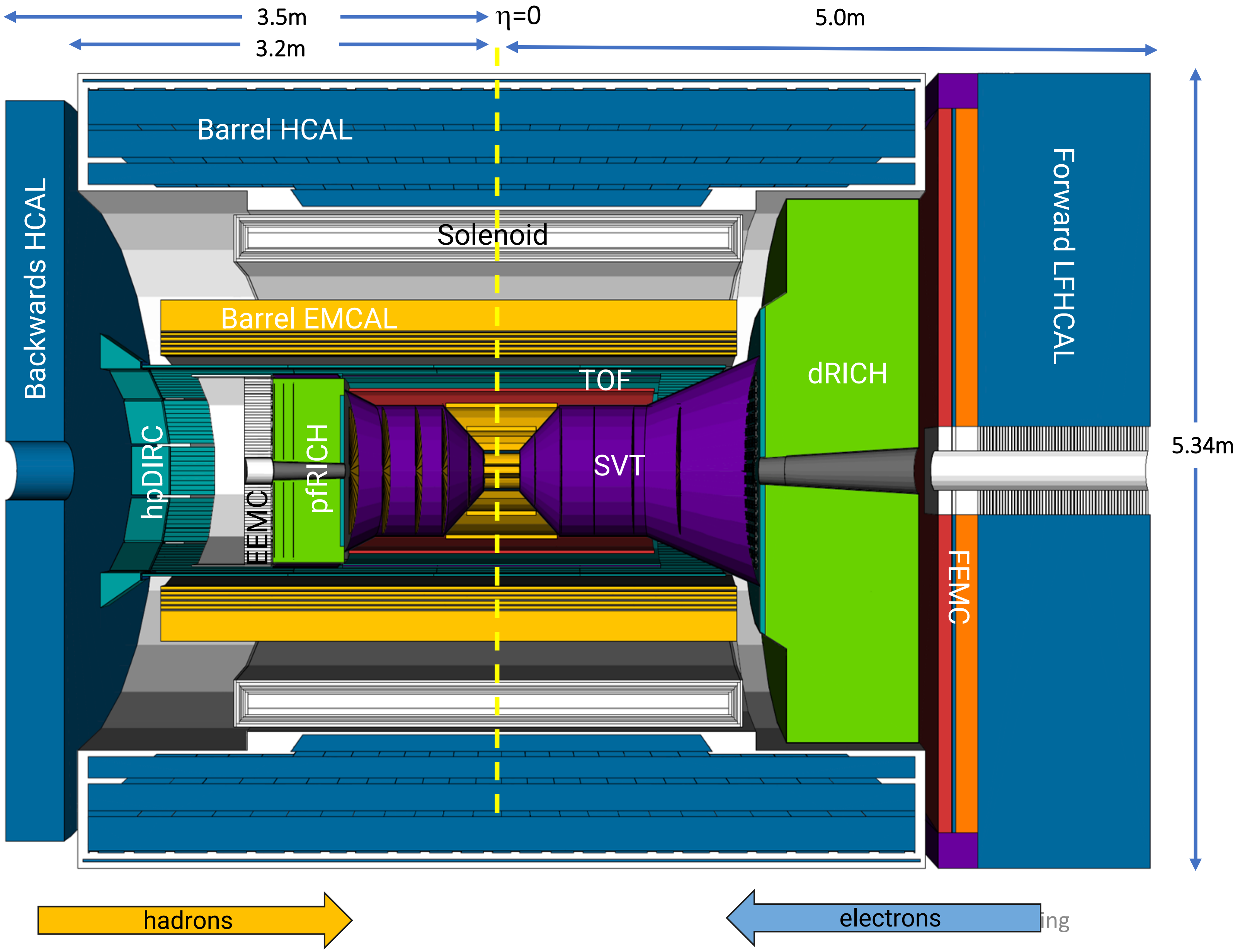


160+ institutions
24 countries

500+ participants

A truly global pursuit for a new experiment at the EIC!

ePIC Detector Design



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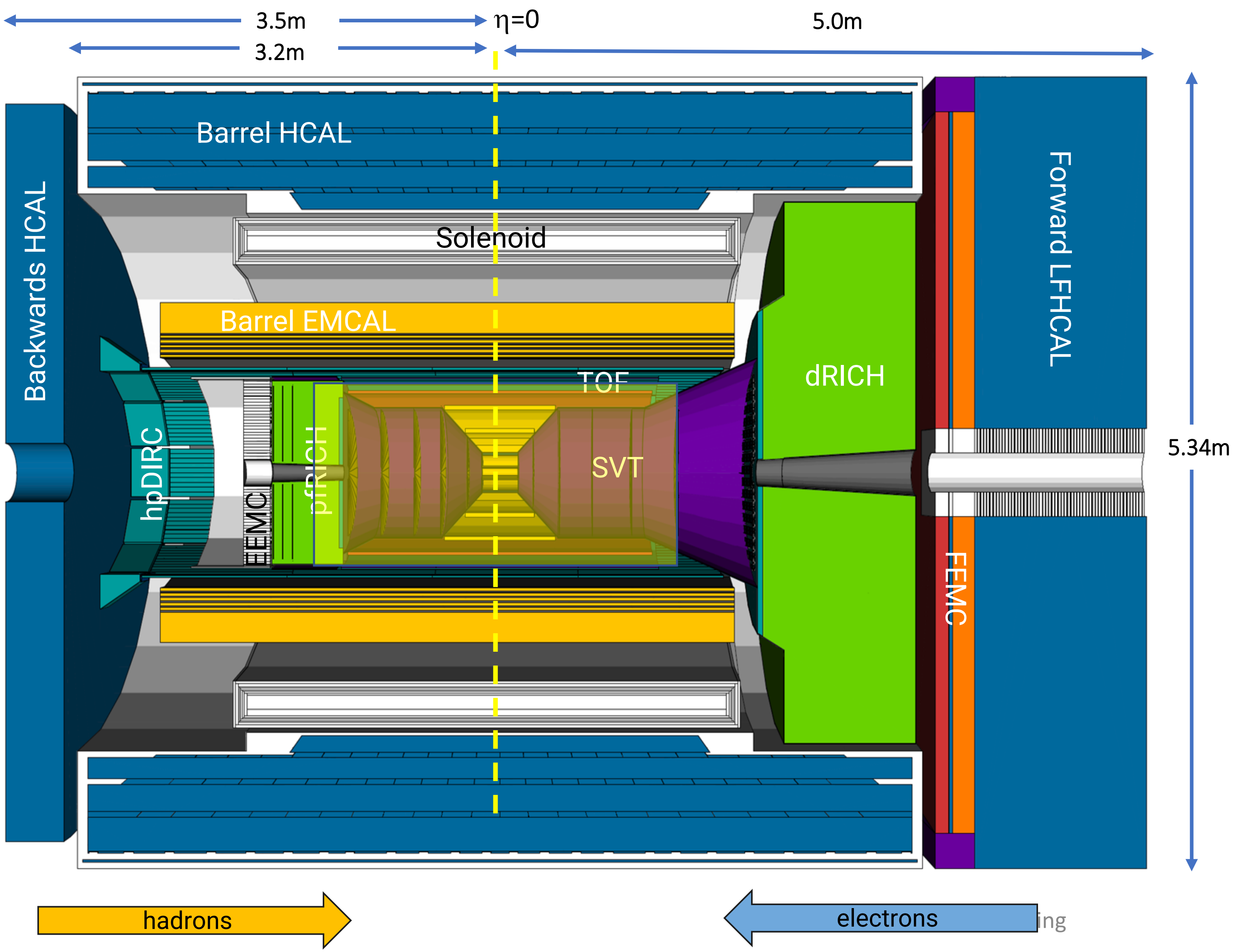
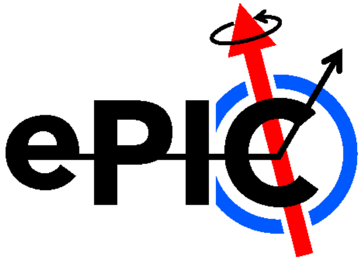
ePIC Detector Design

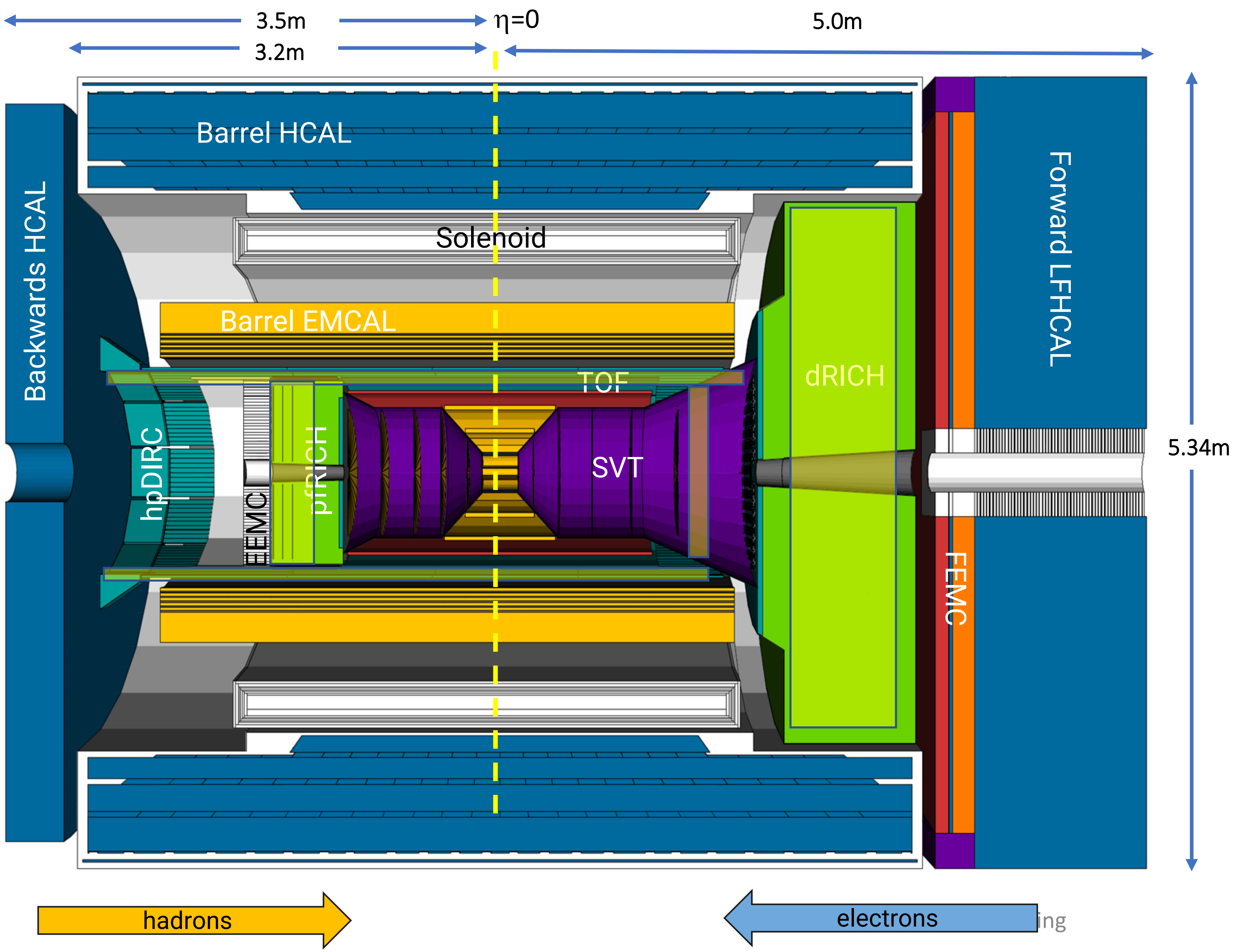




Tracking:

- New 1.7T solenoid
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

ePIC Detector Design



Tracking:

- New 1.7T solenoid
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- MPGDs (μRWELL/μMegas)

PID:

- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

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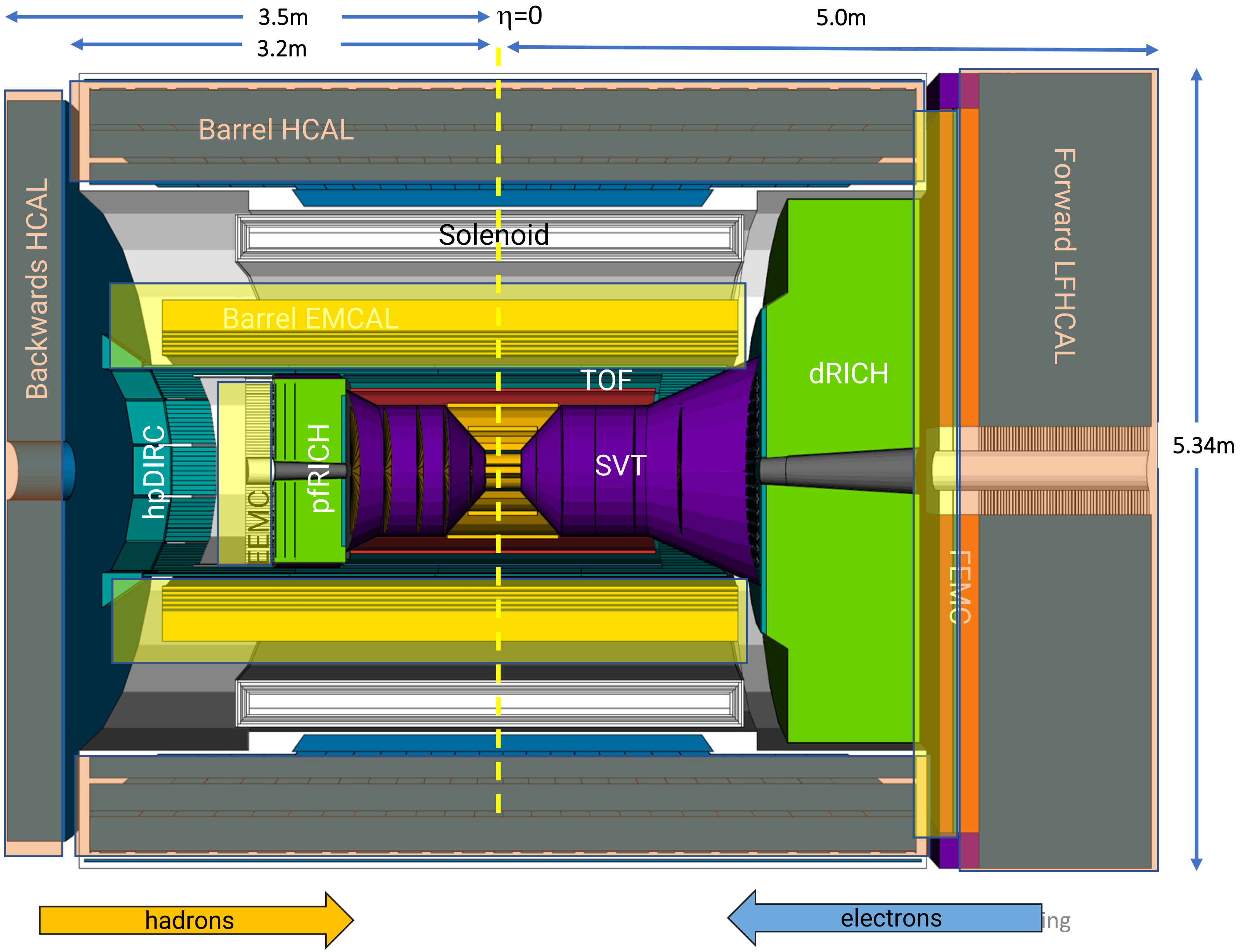
ePIC Detector Design



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- hpDIRC
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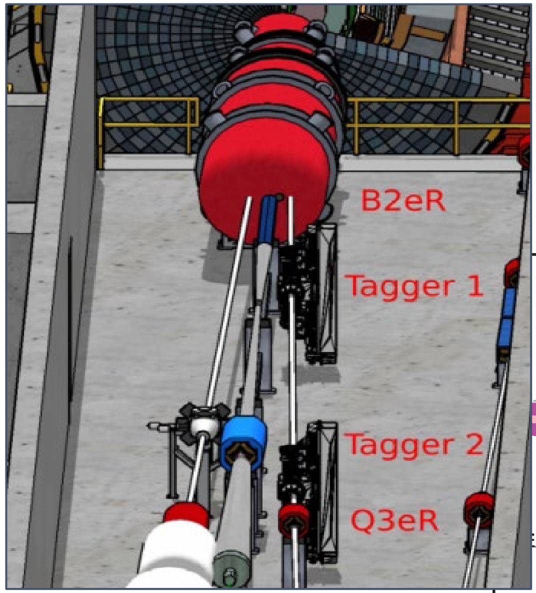
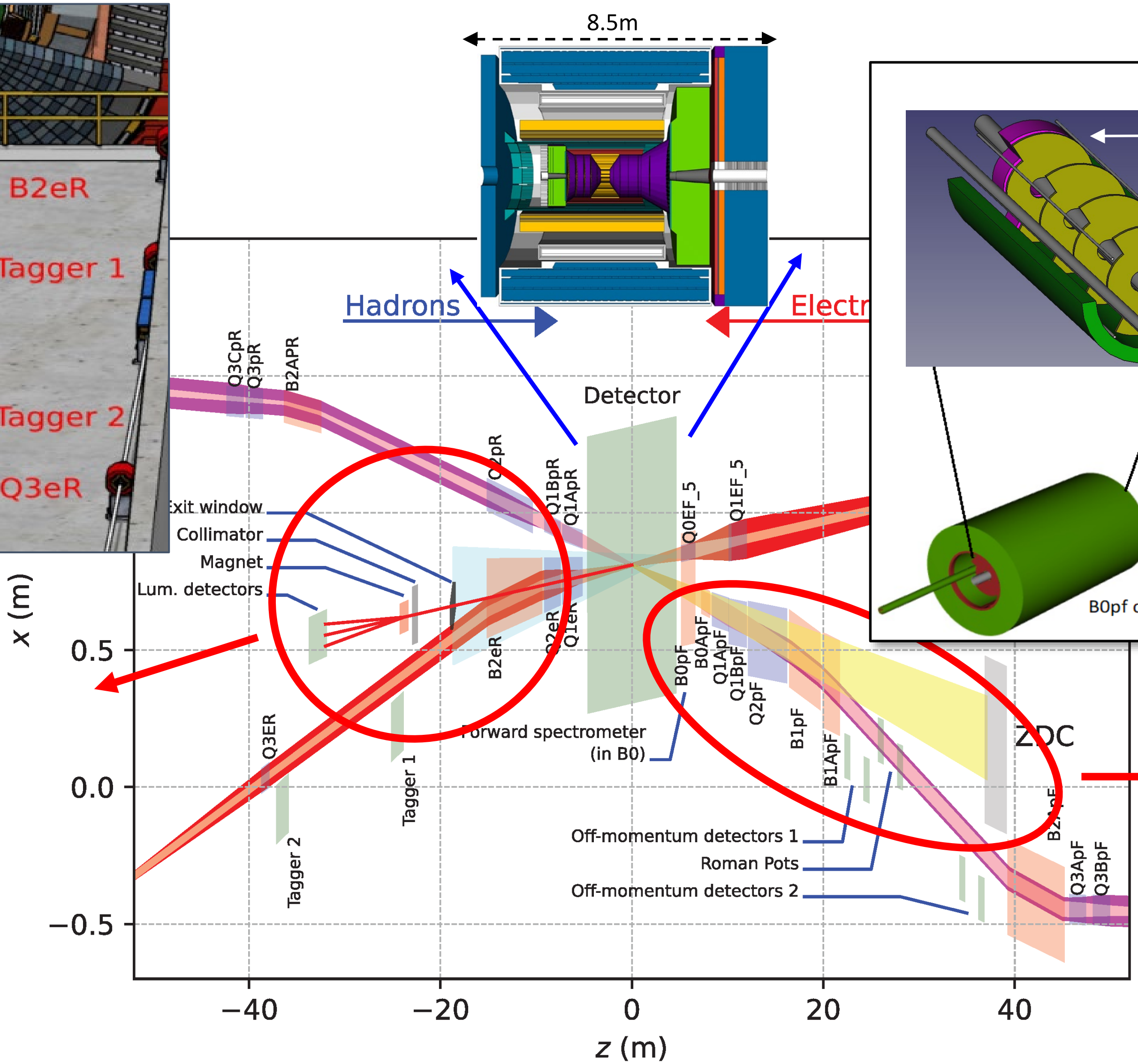
- AC-LGAD (~30ps TOF)

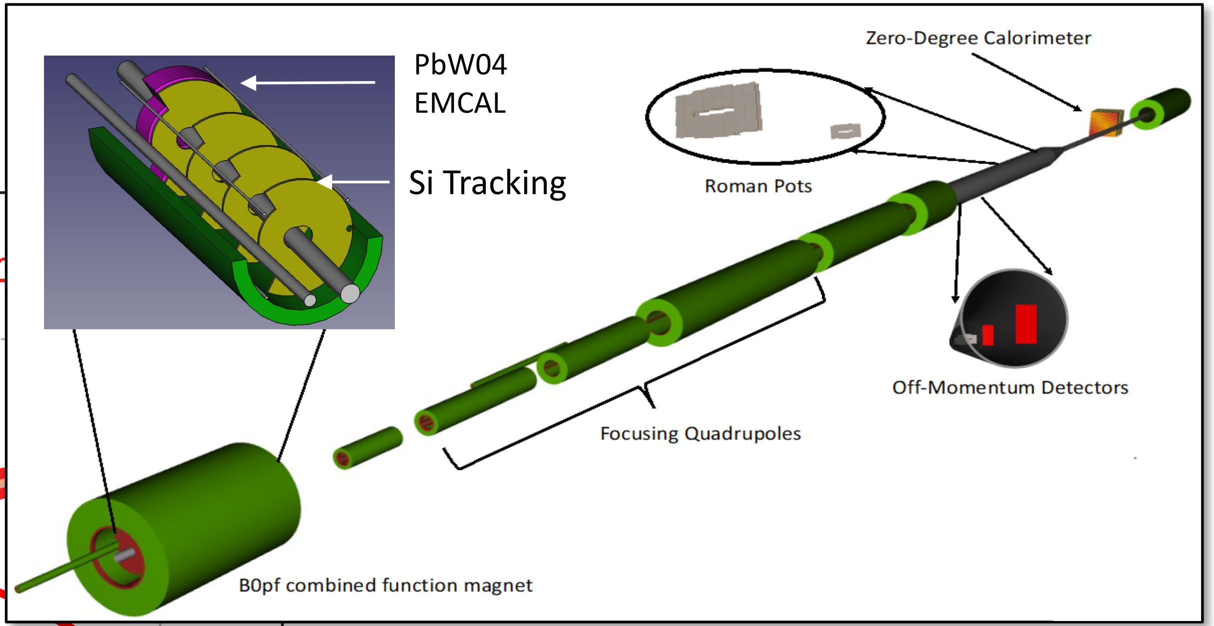
Calorimetry:

- Imaging Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal +HCal in forward direction
- Outer HCal (sPHENIX re-use)
- Backwards HCal (tail-catcher)

Far-Forward and Far-Backward Detectors







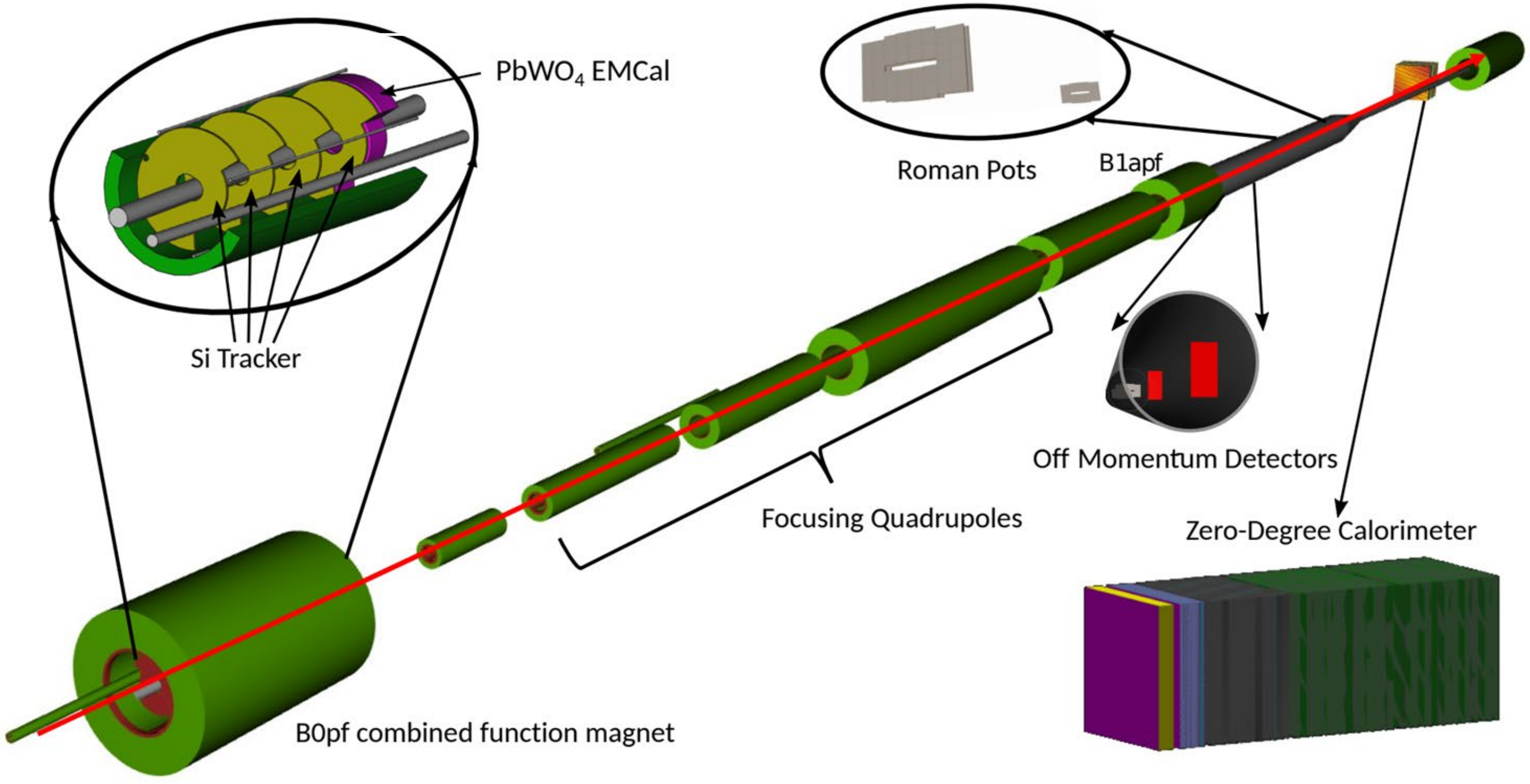
Far-Backward Detectors

- Luminosity monitor
- Low-Q^2 Tagging Detectors

Far-Forward Detectors

- B0 Tracking and Photon Detection
- Roman Pots and Off-Momentum Detectors
- Zero-Degree Calorimeter

Far-Forward Detectors

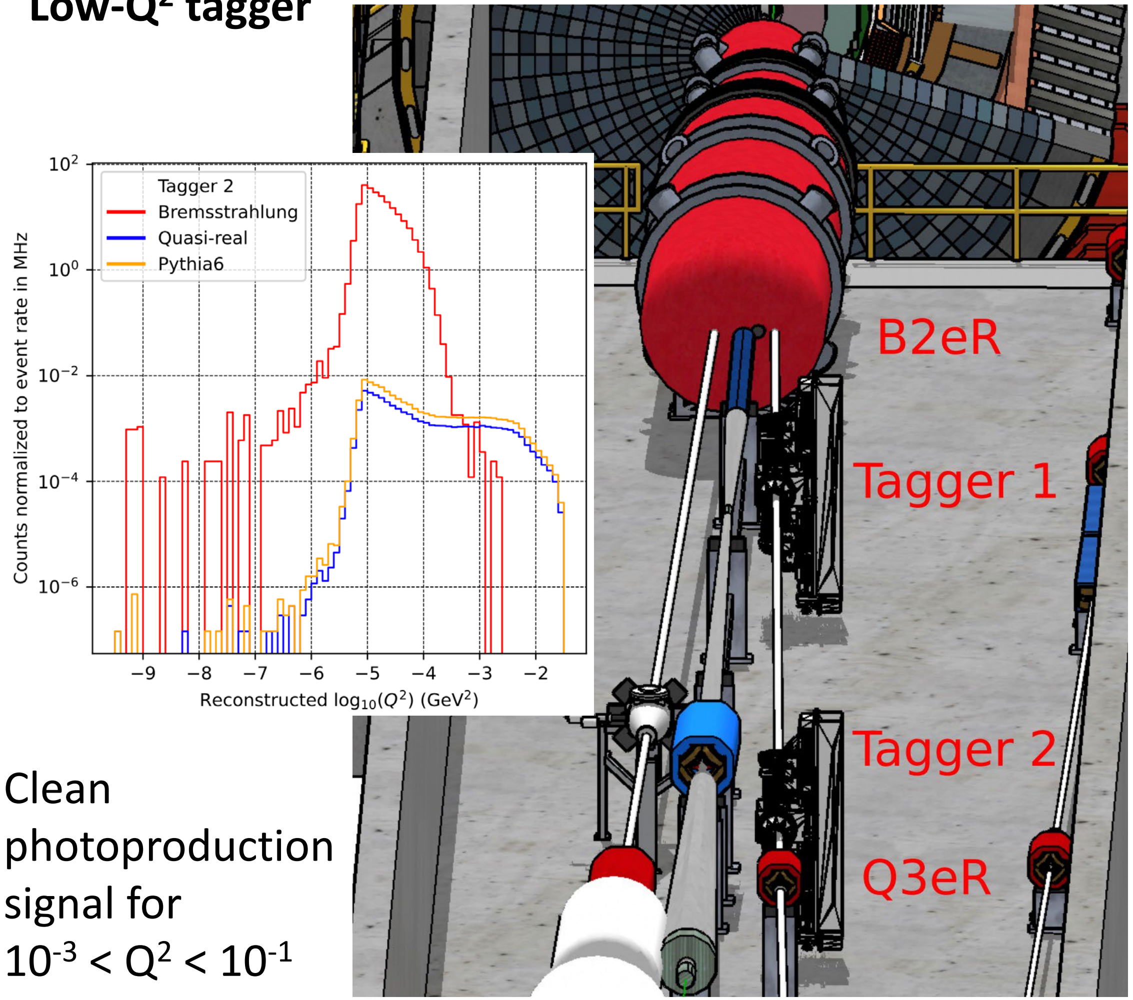


Detector	Acceptance
Zero-Degree Calorimeter (ZDC)	$\boldsymbol{\theta}$ < 5.5 mrad (η > 6)
Roman Pots (2 stations)	0.0 < $\boldsymbol{\theta}$ < 5.0 mrad (η > 6)
Off-Momentum Detectors (2 stations)	$\boldsymbol{\theta}$ < 5.0 mrad (η > 6)
B0 Detector	5.5 < $\boldsymbol{\theta}$ < 20.0 mrad (4.6 < η < 5.9)

- **B0 system:** Measures charged particles in the forward direction and tags neutral particles
- **Off-momentum detectors:** Measure charged particles resulting from, e.g., decays and fission
- **Roman pot detectors:** Measure charged particles near the beam
- **Zero-degree calorimeter:** Measures neutral particles at small angles

Far Backwards Detectors

Low-Q^2 tagger



Clean photoproduction signal for $10^{-3} < Q^2 < 10^{-1}$

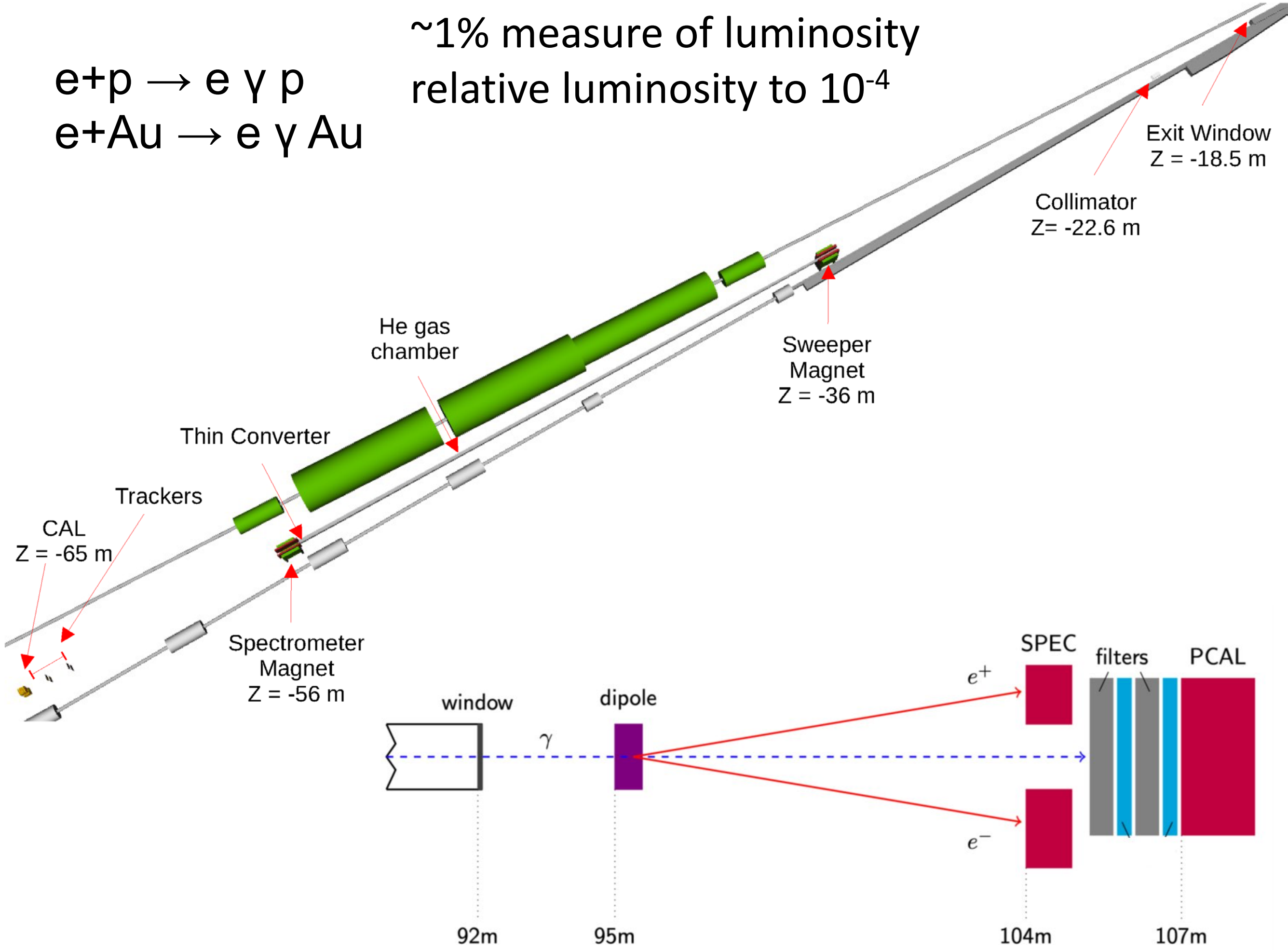
Luminosity Spectrometer

$e+p \rightarrow e\ \gamma\ p$

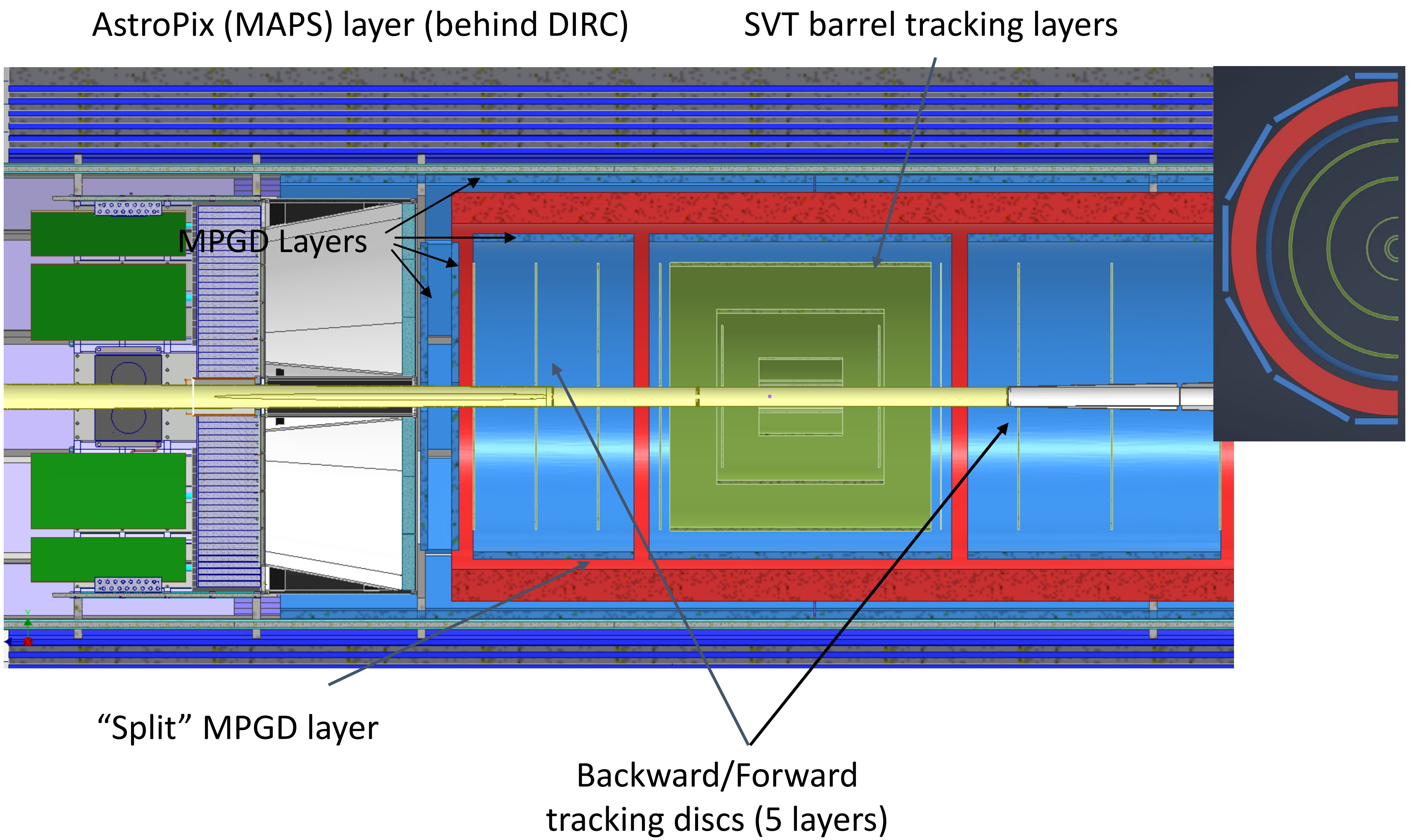
$e+Au \rightarrow e\ \gamma\ Au$

~1% measure of luminosity

relative luminosity to 10^{-4}



Tracking Design Optimization



- **Inner two vertex layers** optimized for beam pipe bakeout and ITS-3 sensor size
- Third layer dual-purpose (vertex + sagitta) - **5 layers total**
- **Five discs in forward/backwards** direction (ITS-3 based large area sensor design EIC LAS)
- **MPGD's** provide pattern recognition redundancy
- **1st AstroPix layer of Barrel ECal** provides ring seed direction, space point for pattern recognition

Tracking Performance

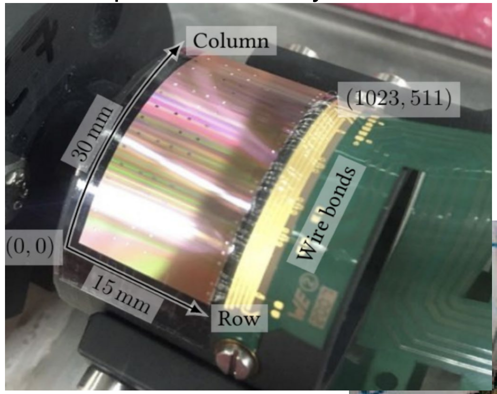
Technology

ITS3 MAPS based Si-detectors:
- O(20μm) pitch, $X/X^0 \sim 0.05 - 0.55\%$/ layer

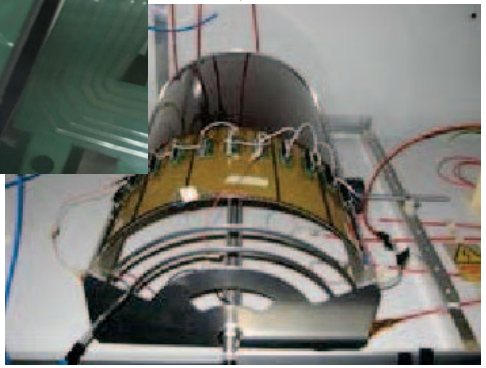
Gaseous tracker:
- $\sigma = 55\ \mu m$, $X/X_0 \sim 0.2\%$/layer

AstroPix outer tracker layer:
- 500μm pixel pitch ($\sigma = 144\ \mu m$)

First "μITS3" assembly at CERN

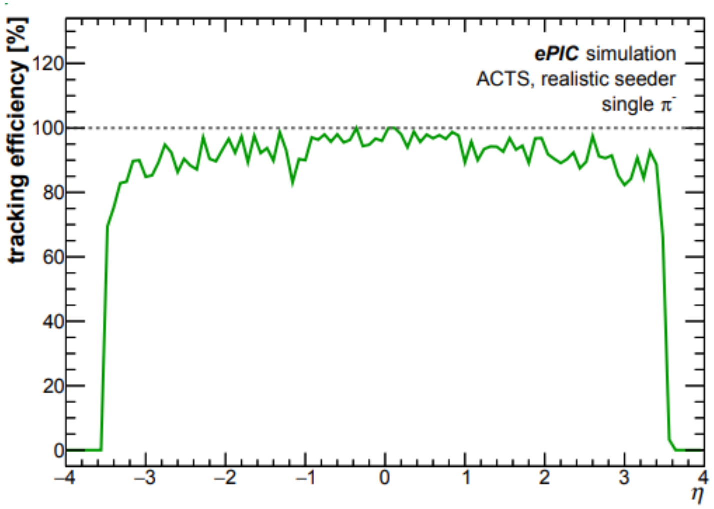


Cylindrical μMega



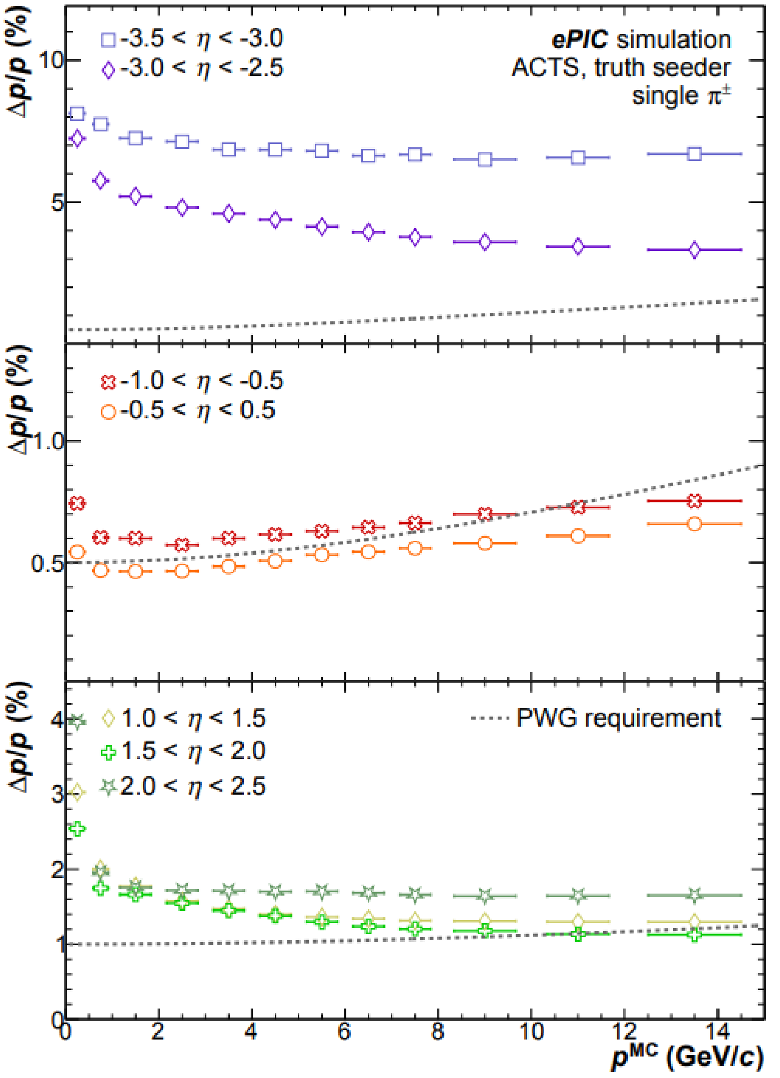
Simulated performance

F. Bock, Hard Probes 2023



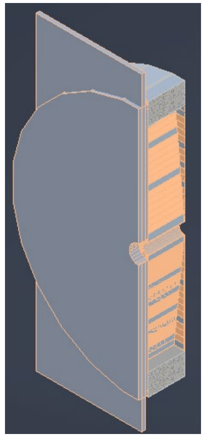
- Meets EICUG Yellow Report design requirements
- Backward momentum resolution complemented by calorimetric resolution

F. Bock, Hard Probes 2023

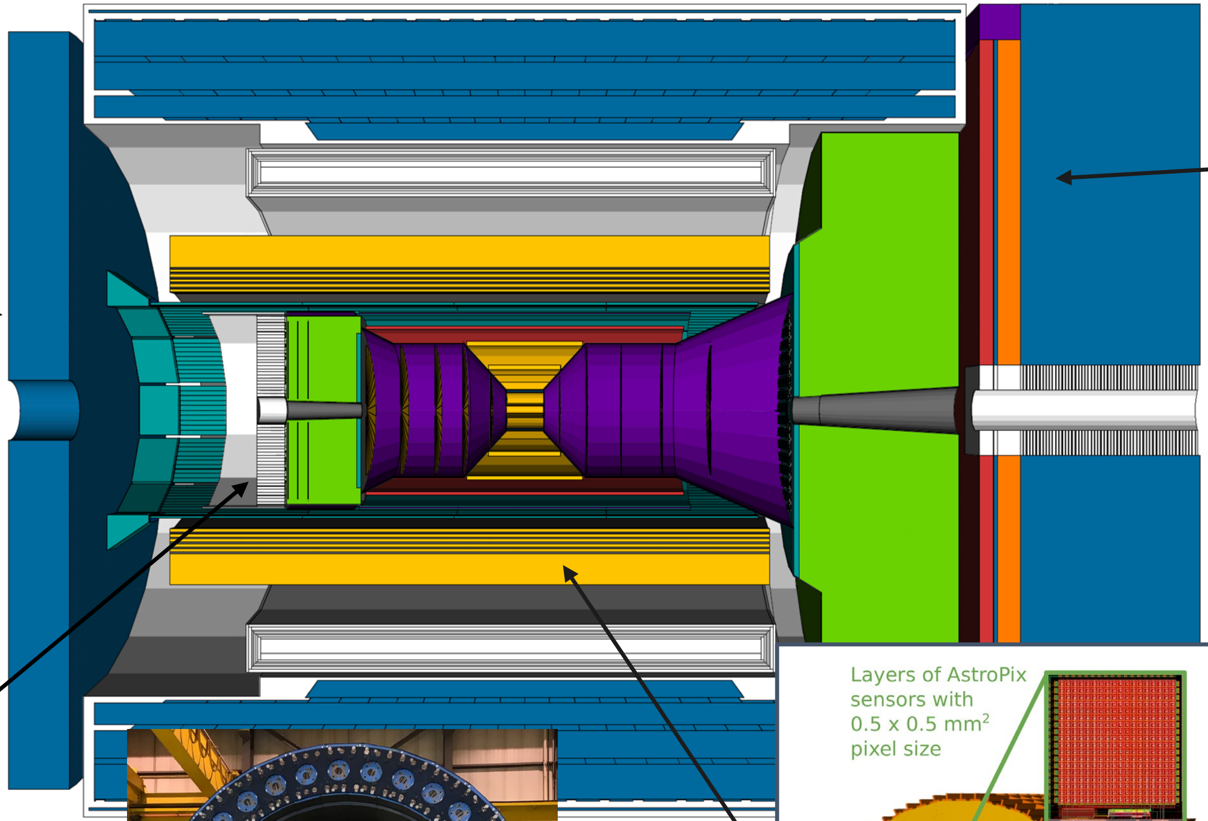


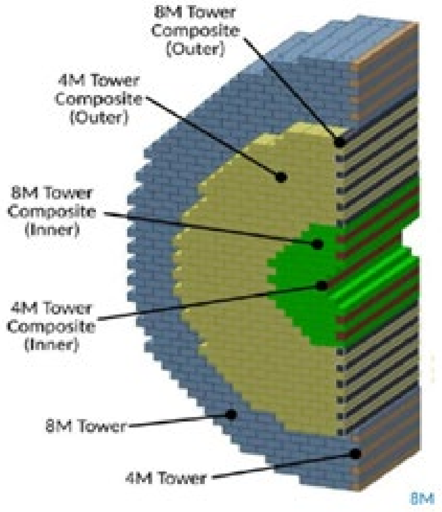
E. Yeats, R. Cruz-Torres, N. Schmidt, S. Maple

Calorimetry

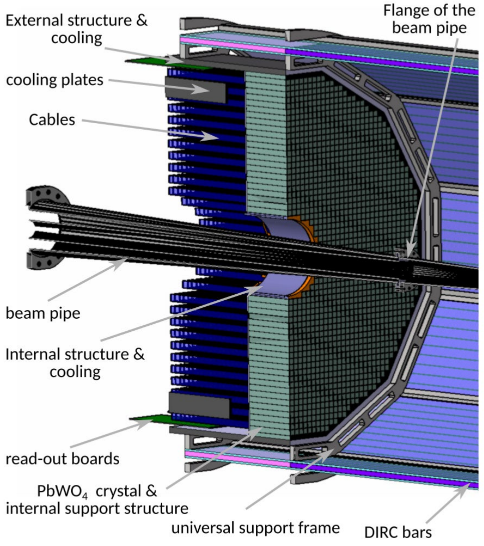


Backwards HCal Steel/Sc Sandwich tail catcher



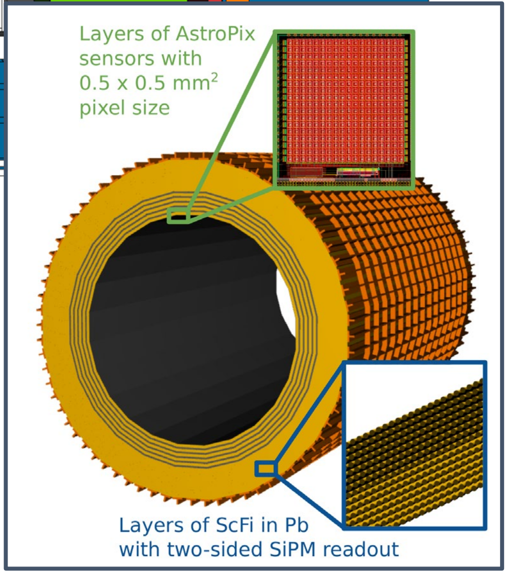


High granularity W/SciFi EMCal
Longitudinally separated HCAL with high-η insert



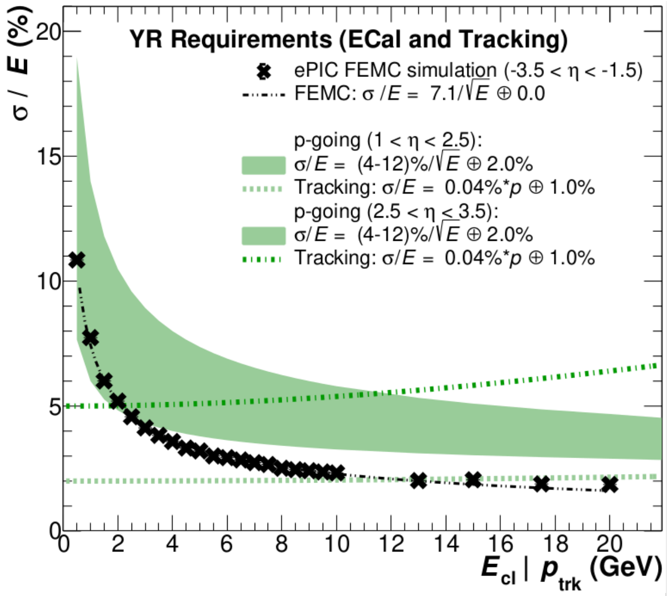
Backwards EMCal PbW04 crystals

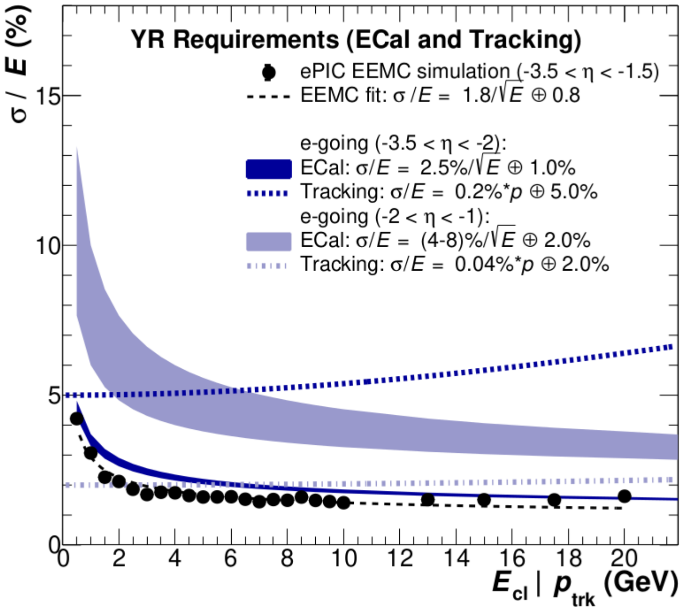
Barrel HCAL (sPHENIX re-use)

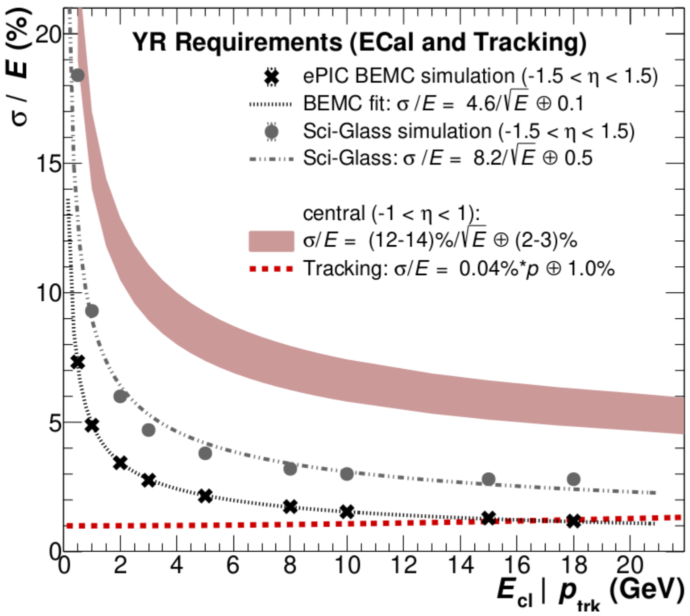


Calorimetry Performance

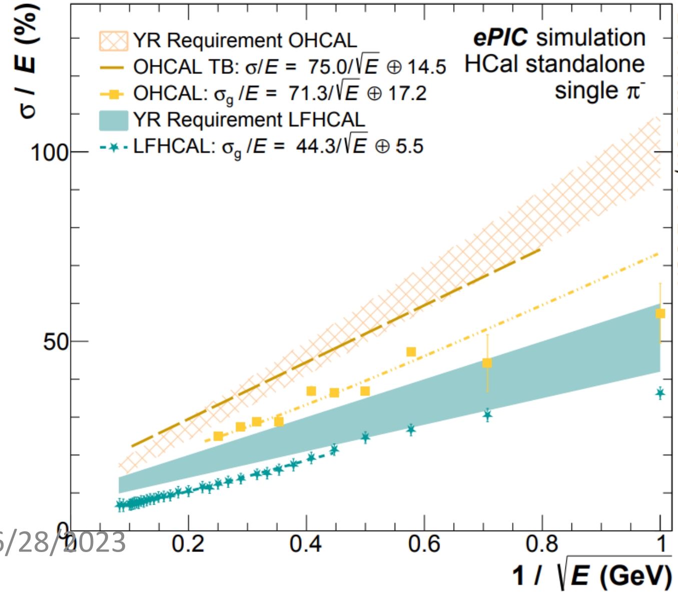
plots by N. Schmidt







F. Bock, Hard Probes 2023



D. Anderson, F. Bock

Performance on energy resolution and matching

- Technologies fulfill YR requirements on energy resolution
- Ongoing simulation studies related to overlaps between different η regions for calorimetry and reconstruction algorithms

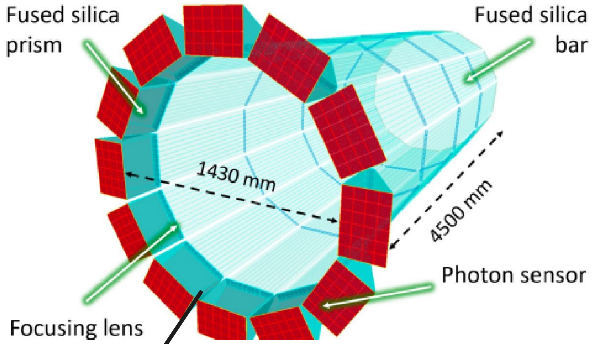
Ongoing work on Monte-Carlo validation

- Validation for high Z absorbers

Particle ID

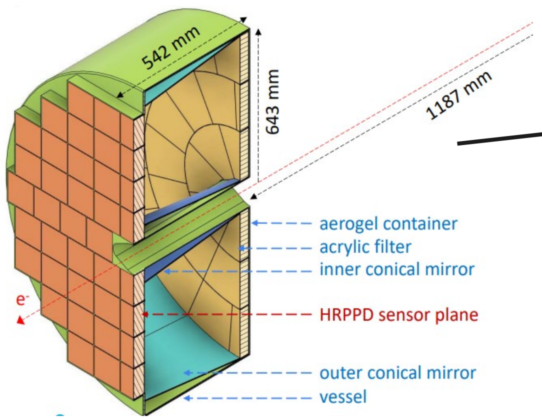
High-Performance DIRC

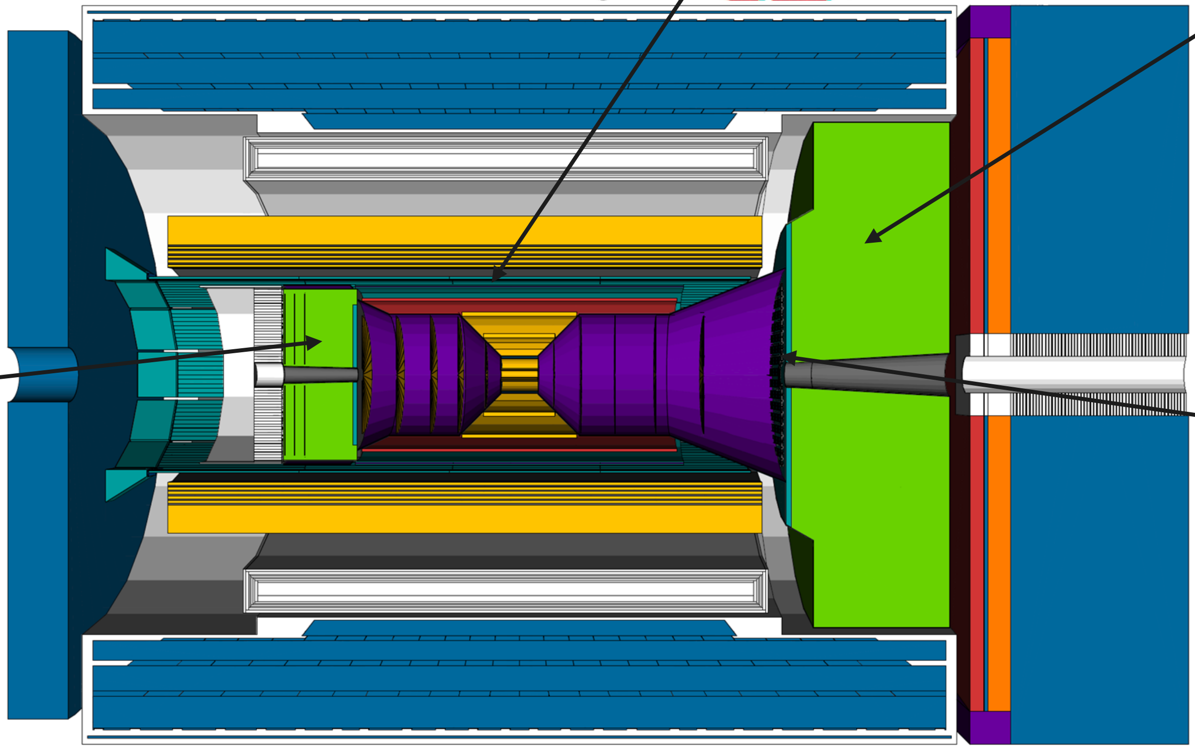
- Quartz bar radiator (BaBAR bars)
- light detection with MCP-PMTs
- Fully focused
- π/K 3б separation at 6 GeV/c



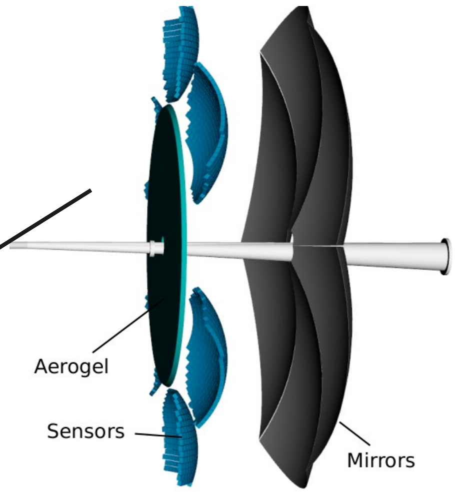
Proximity Focused (pfRICH)*

- Long proximity gap (~40 cm)
- Sensor: LAPPDs
- up to 9 GeV/c 3б π/K sep.



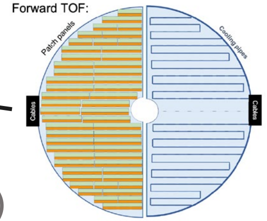


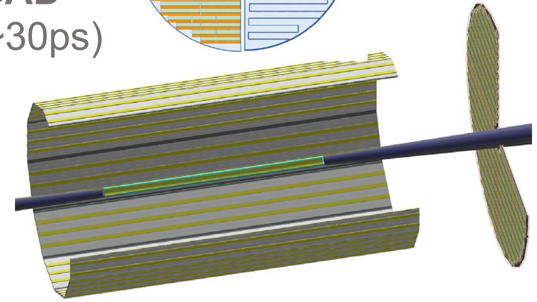
Dual-Radiator RICH(dRICH)



- C_2F_6 Gas Volume and Aerogel
- Sensors tiled on spheres (SiPMs)
- π/K 3σ sep. at 50 GeV/c

AC-LGAD TOF (~30ps)





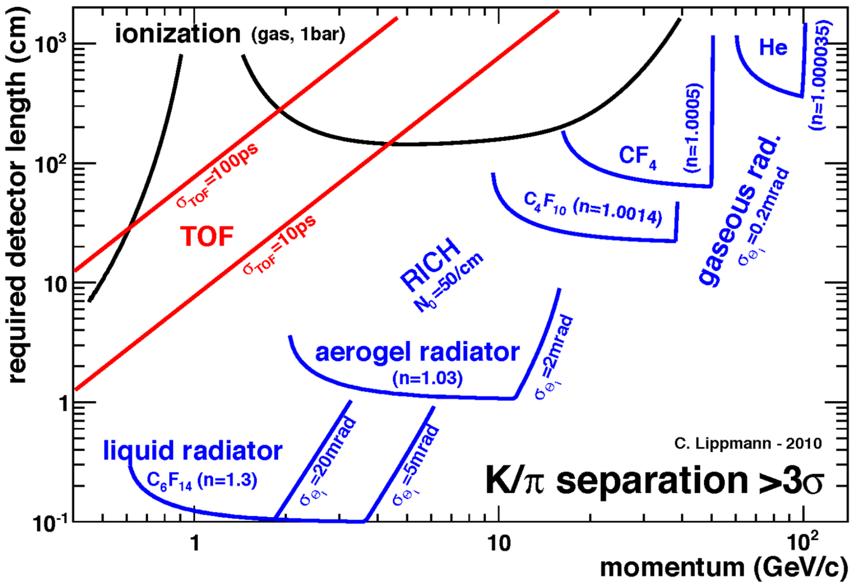
- Accurate space point for tracking
- forward disk and central barrel

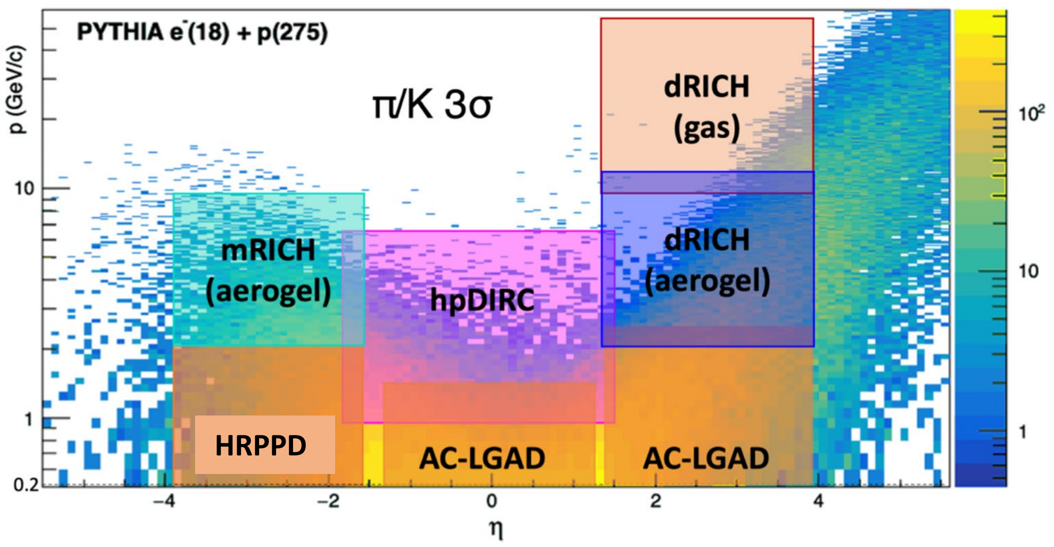
Particle ID

Particle IDentification needs

- Electrons from photons ⟶ **4π coverage in tracking**
- Electrons from charged hadrons ⟶ **mostly provided by calorimetry and tracking**
- Charged pions, kaons and protons from each other on track level ⟶ **Cherenkov detectors**
  - Cherenkov detectors, complemented by ToF

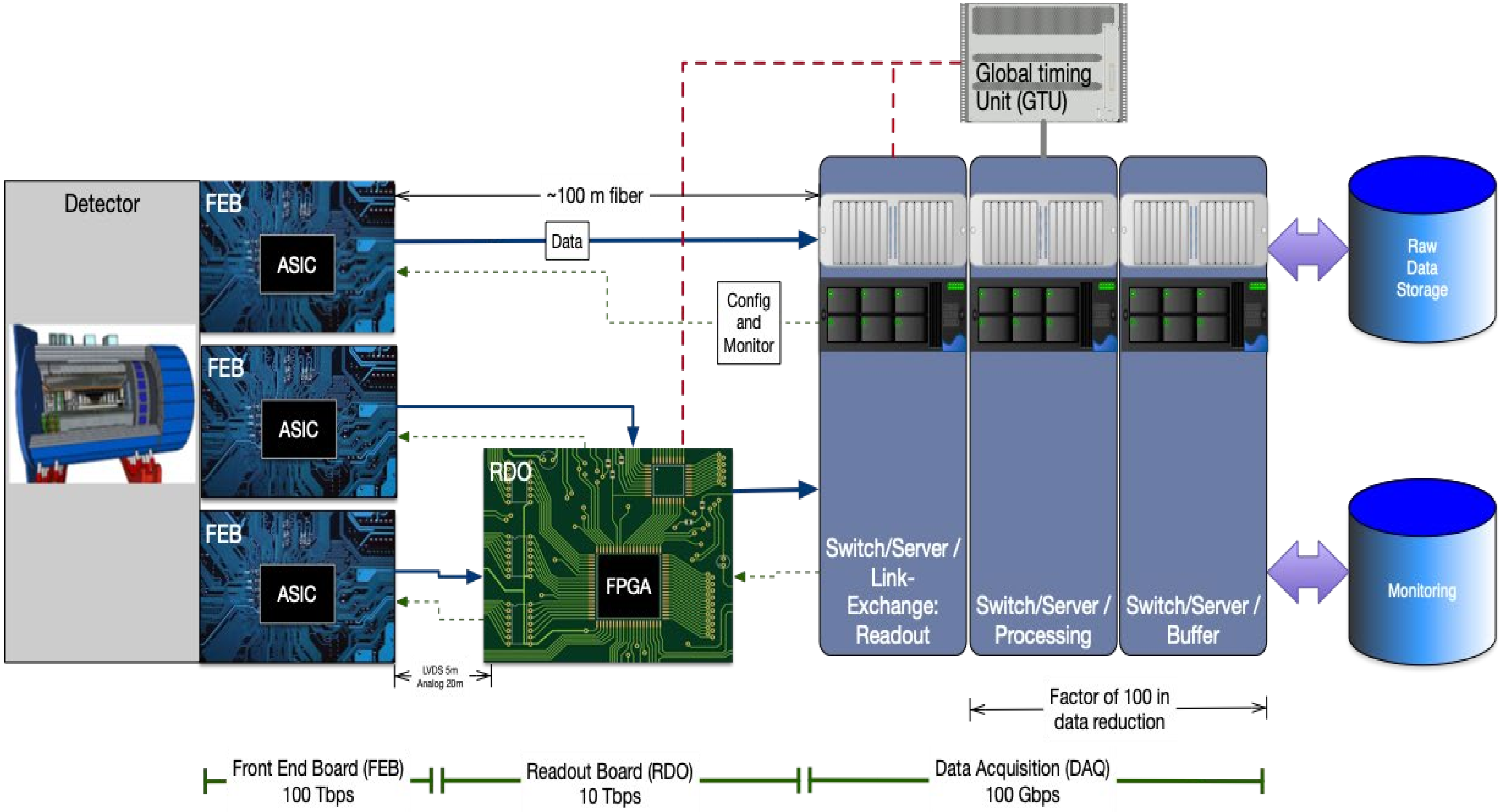
Rapidity	π/K/p and π^0/γ	e/h	Min p_T (E)
-3.5 – -1.0	7 GeV/c	18 GeV/c	100 MeV/c
-1.0 – 1.0	8-10 GeV/c	8 GeV/c	100 MeV/c
1.0 – 3.5	50 GeV/c	20 GeV/c	100 MeV/c





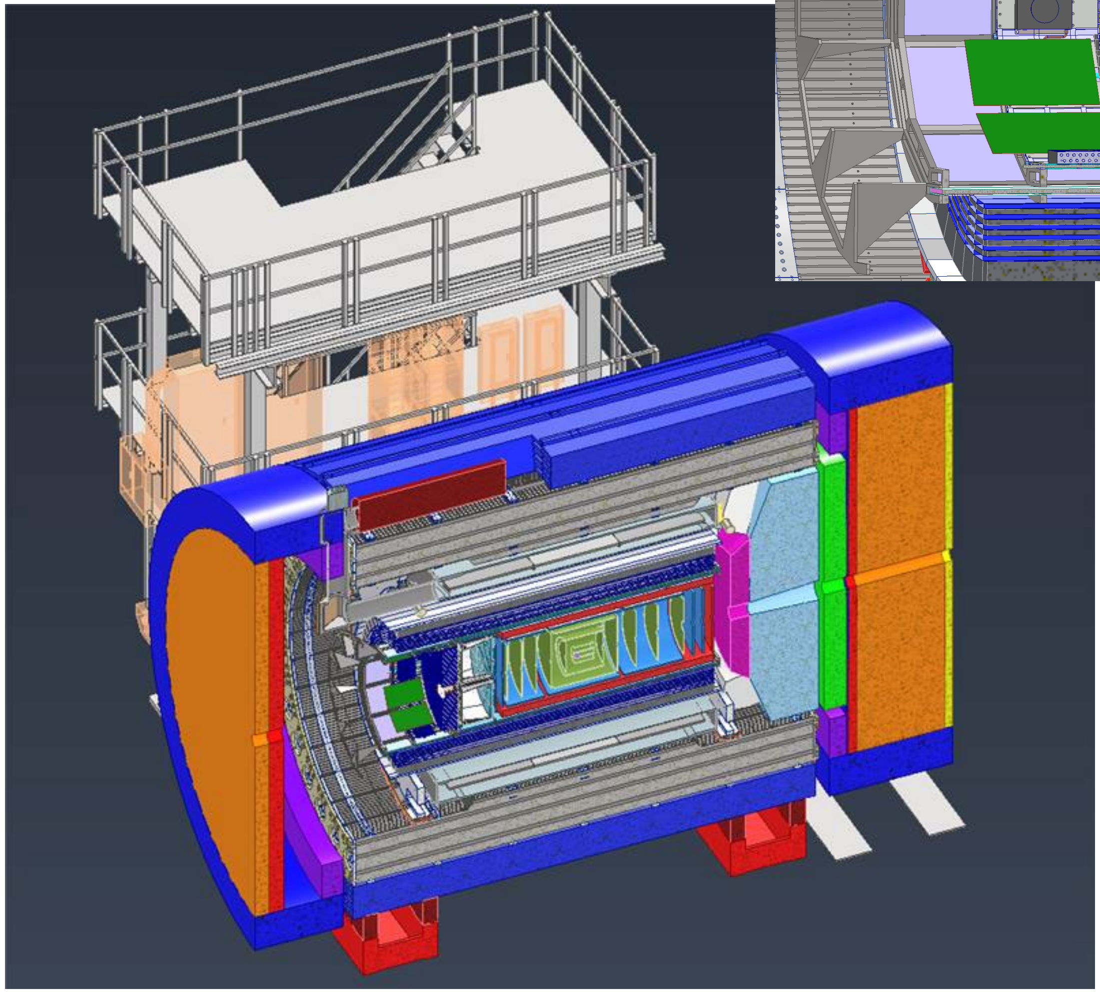
Need more than one technology to cover the entire momentum ranges at different rapidities

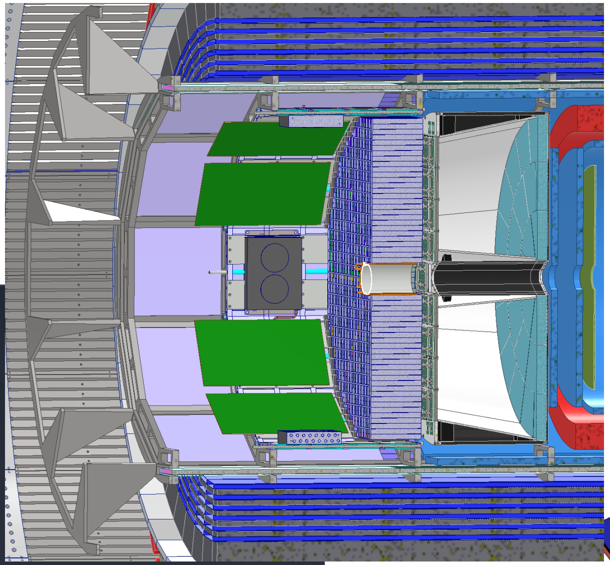
ePIC Streaming DAQ



- No External trigger
- All collision data digitized but aggressively zero suppressed at FEB
- Low / zero deadtime
- Event selection can be based upon full data from all detectors (in real time, or later)
- Collision data flow is independent and unidirectional-> no global latency requirements
- Avoiding hardware trigger avoids complex custom hardware and firmware
- Data volume is reduced as much as possible at each stage

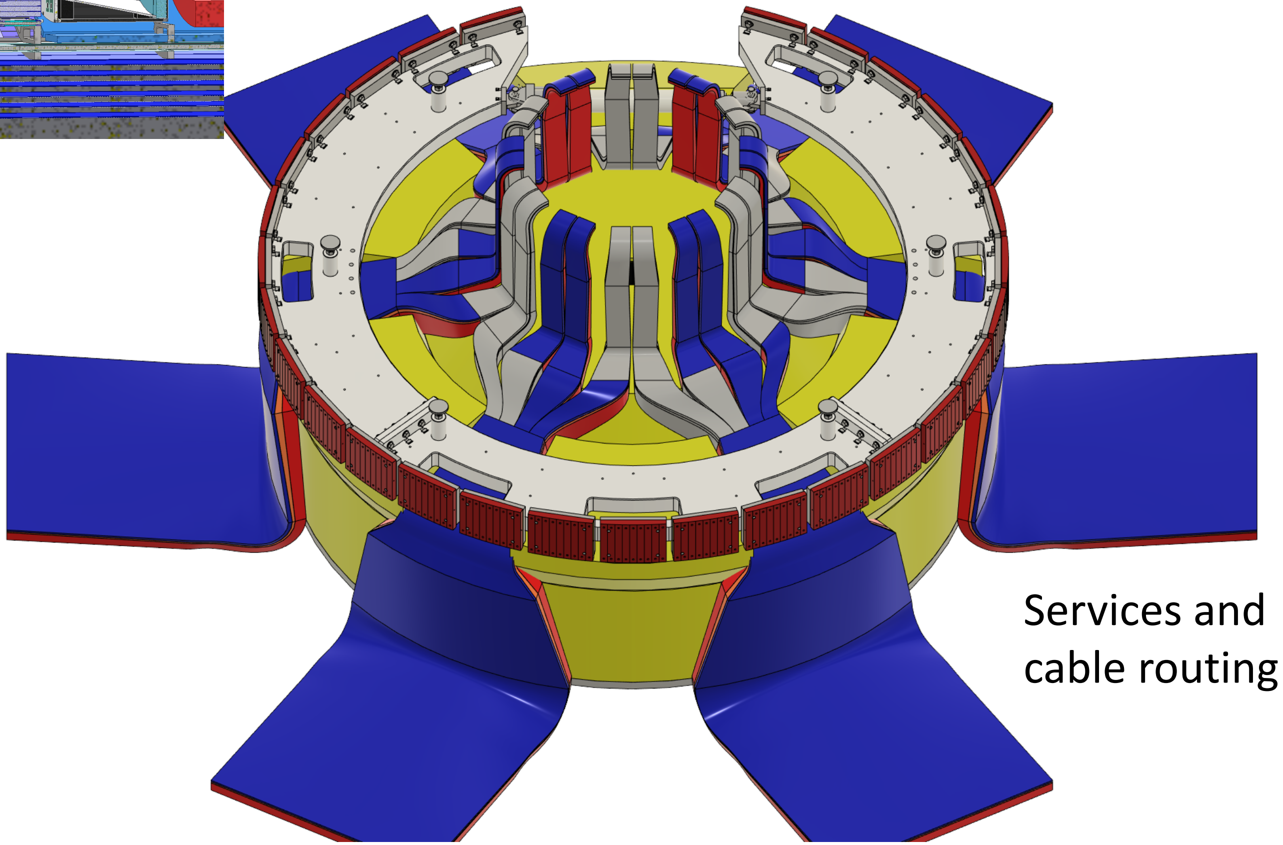
Integration





Backwards detector optimization

dRICH vessel, end rings, and services paths

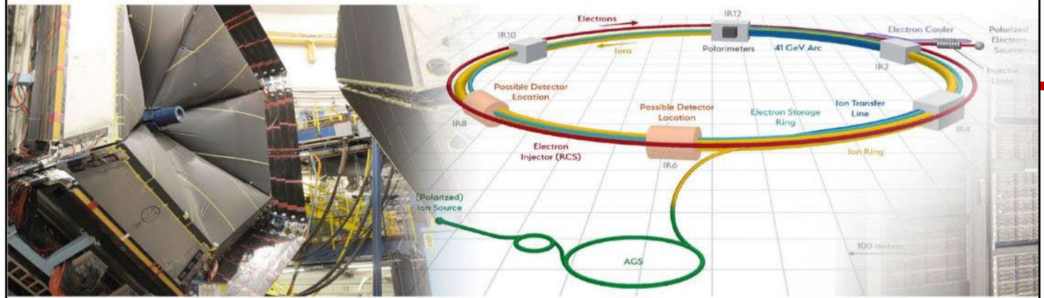


Services and cable routing

The EIC and Jefferson Lab

From Stuart Henderson's talk (Monday)

Jefferson Lab's Science and Technology Vision



Nuclear Physics at CEBAF

Vibrant 12 GeV research program, operating >30 weeks/yr, supporting 1,900 annual users

MOLLER Project & SoLID proposal

Future opportunities with an upgraded CEBAF

Theory and computation supporting NP goals

Electron-Ion Collider

Partnering with BNL in the management, design, and construction of the Electron-Ion Collider Project

Leadership in EIC scientific program

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S. Henderson – June 26, 2023

5

The Jefferson Lab Of The Future

- We are entering **a new era at Jefferson Lab. We are reinventing Jefferson Lab** to take on a more significant role with a diversified mission – with a goal of delivering **even greater impact for the Nation**
- **We are facing a time of change, opportunity and challenge, unprecedented since the Lab's founding**
- This transformation requires
  - Staffing up to fulfill the mission
  - Improving our processes to ensure scalability
  - Developing new skills and talent pipelines
  - Designing organizations that scale with growing portfolios
  - Scaling-up Mission Support capabilities to enable this growth in scope, staff, budget, expectations and risks
- **This reinvention is underway**

It is a time of change and opportunity for Jefferson L

S. Henderson – June 26, 2023

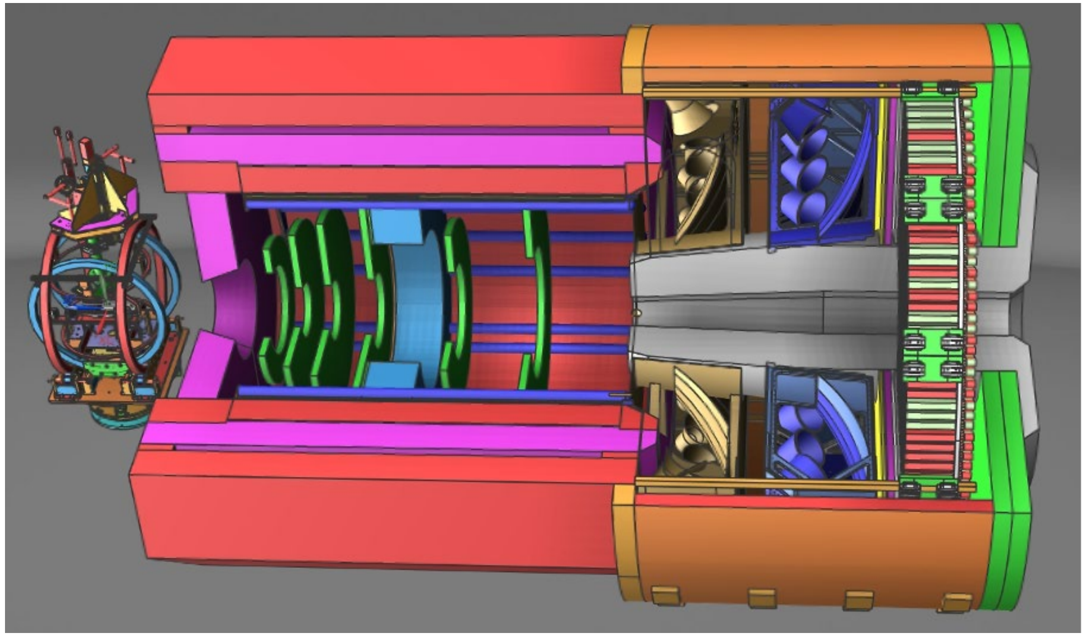
6

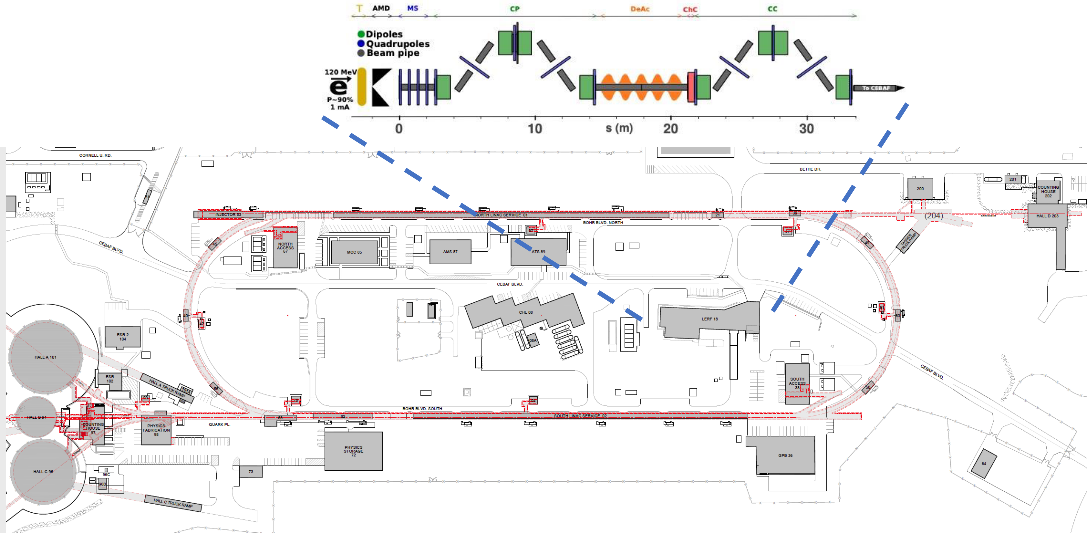
EIC and the Future at Jefferson Lab

- SoLID

See talk by Xiaochao Zheng

  - TMD structure of nucleon (valence region)
  - Near-threshold J/Ψ production
  - Parity-violating asymmetries





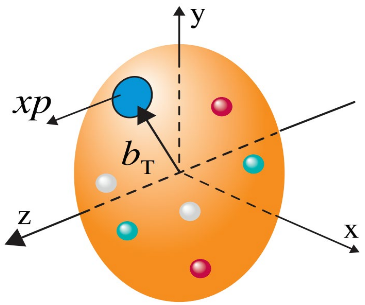
- Positrons @ JLab

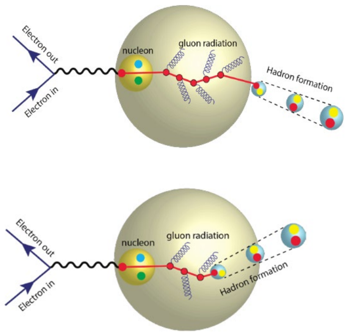
See talk by Eric Voutier

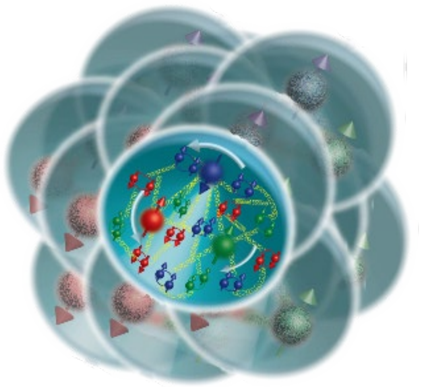
  - Unique capability
  - Beam charge dependence for 3D imaging
  - First step to potential EIC upgrade

Conclusions

- The EIC is a new QCD laboratory designed to elucidate:
  - Origin of Nucleon Mass & Spin
  - Confinement
  - Nucleon / Nuclear Femtography
  - Dense Gluon States
  - BSM physics







- The EIC science goals are a natural extension of QCD studies at JLab and RHI, and there is complementarity between the future programs at the EIC and JLab

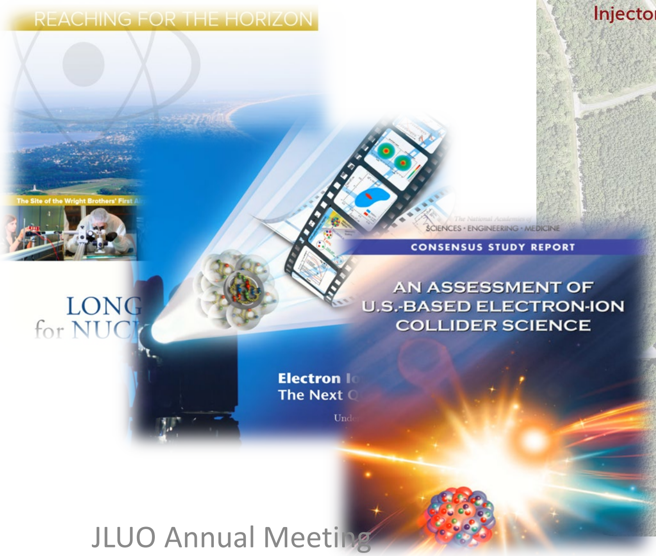
- The ePIC Detector is maturing into a detailed technical design to pursue the EIC science program
  - EIC detectors are an enormous undertaking that will require participation and expertise from both the RHIC and JLab communities, as well as key international contributions!

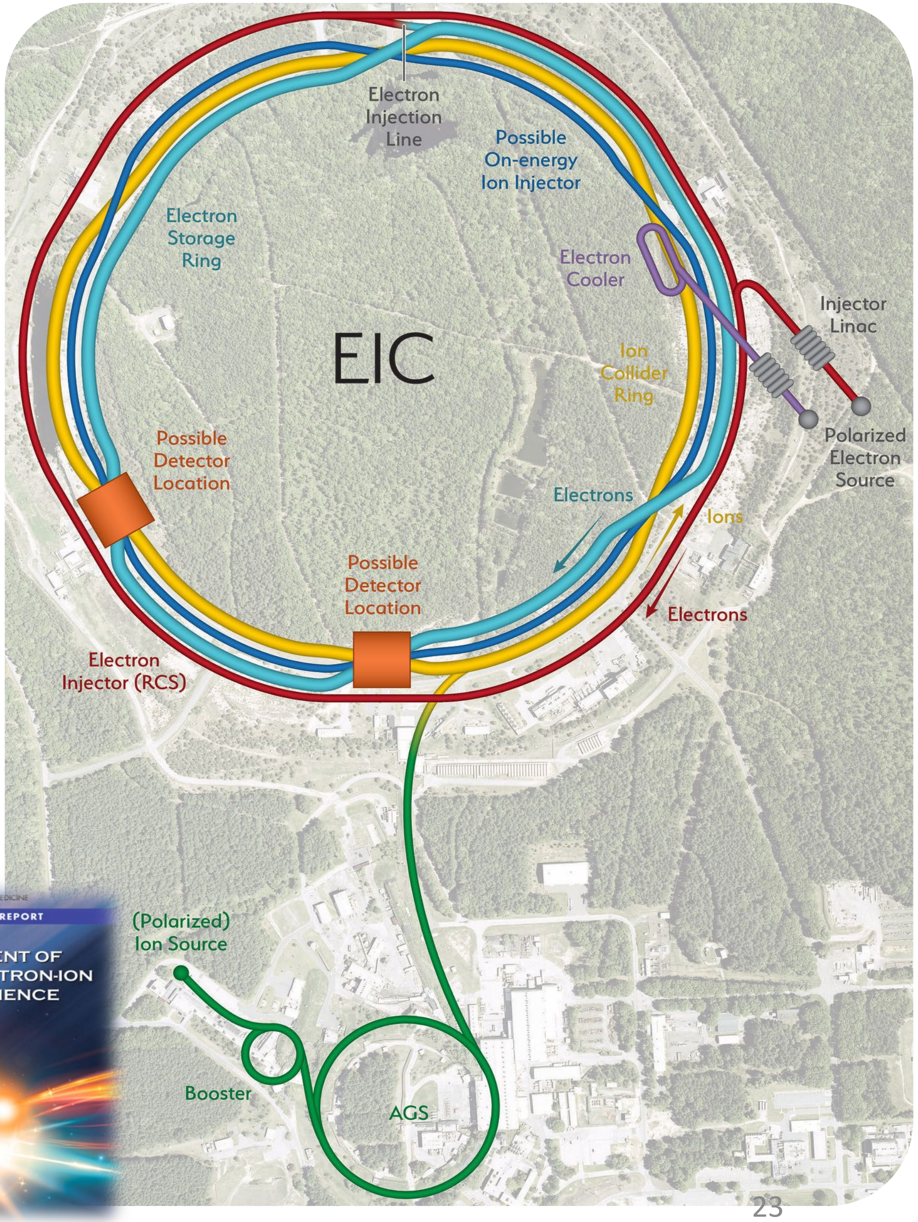

"New directions in science are launched by new tools much more often than by new concepts."
Freeman Dyson


BACK UP

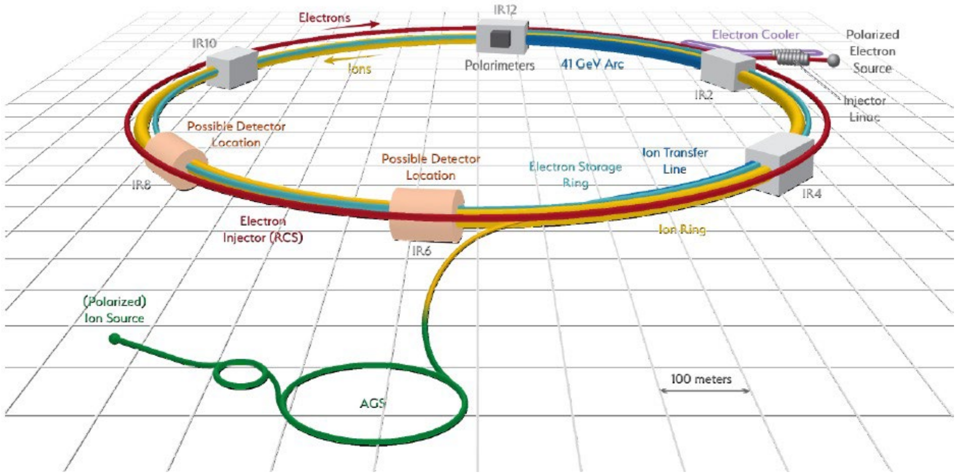
The Electron-Ion Collider (EIC)

- Joint project between Brookhaven National Lab and Jefferson Lab
- $1.7-2.8B investment
  - CD-1 (2021), CD-3A (2024), CD-2/3 (2025)
- Explore the structure of matter via QCD:
  - Origin of Nucleon Mass & Spin
  - Confinement
  - Nucleon / Nuclear Femtography
  - Dense Gluon States
  - BSM
- Operations as soon as 2032

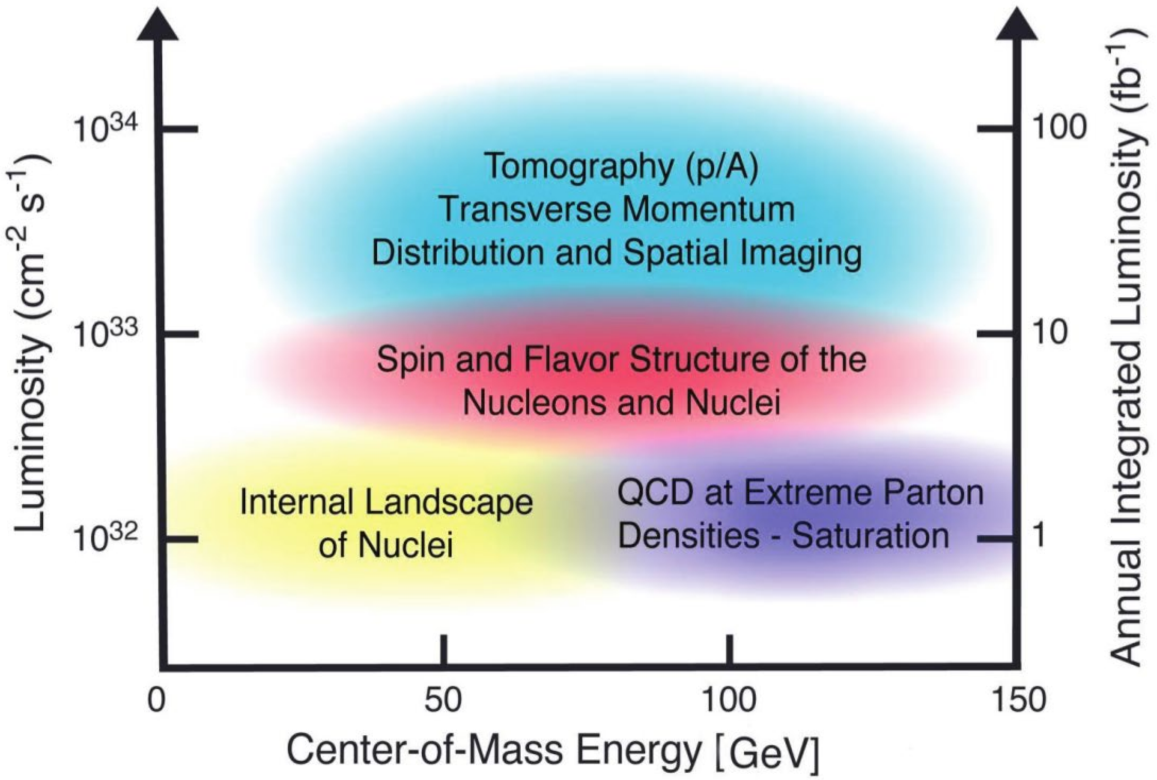




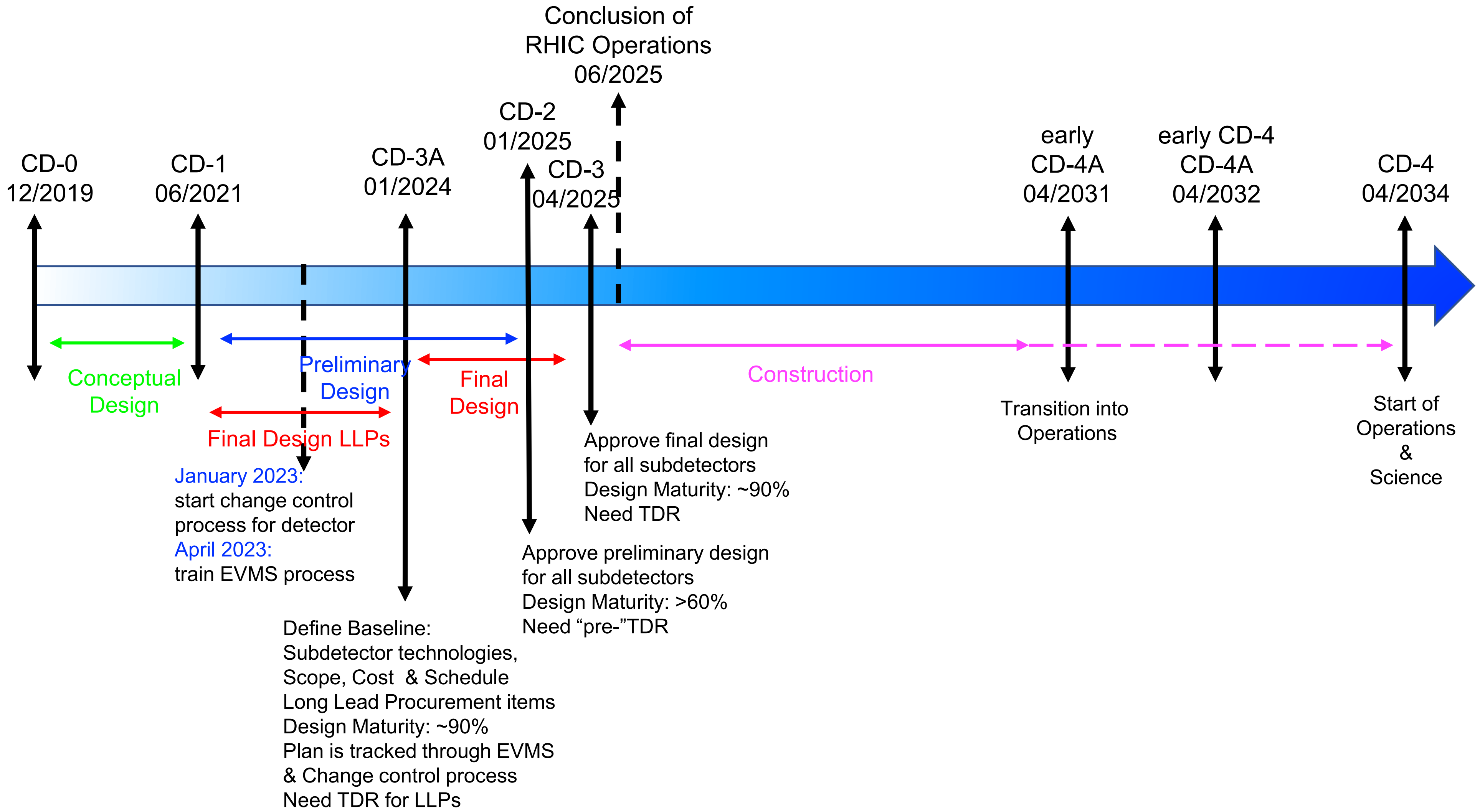
EIC Machine Parameters



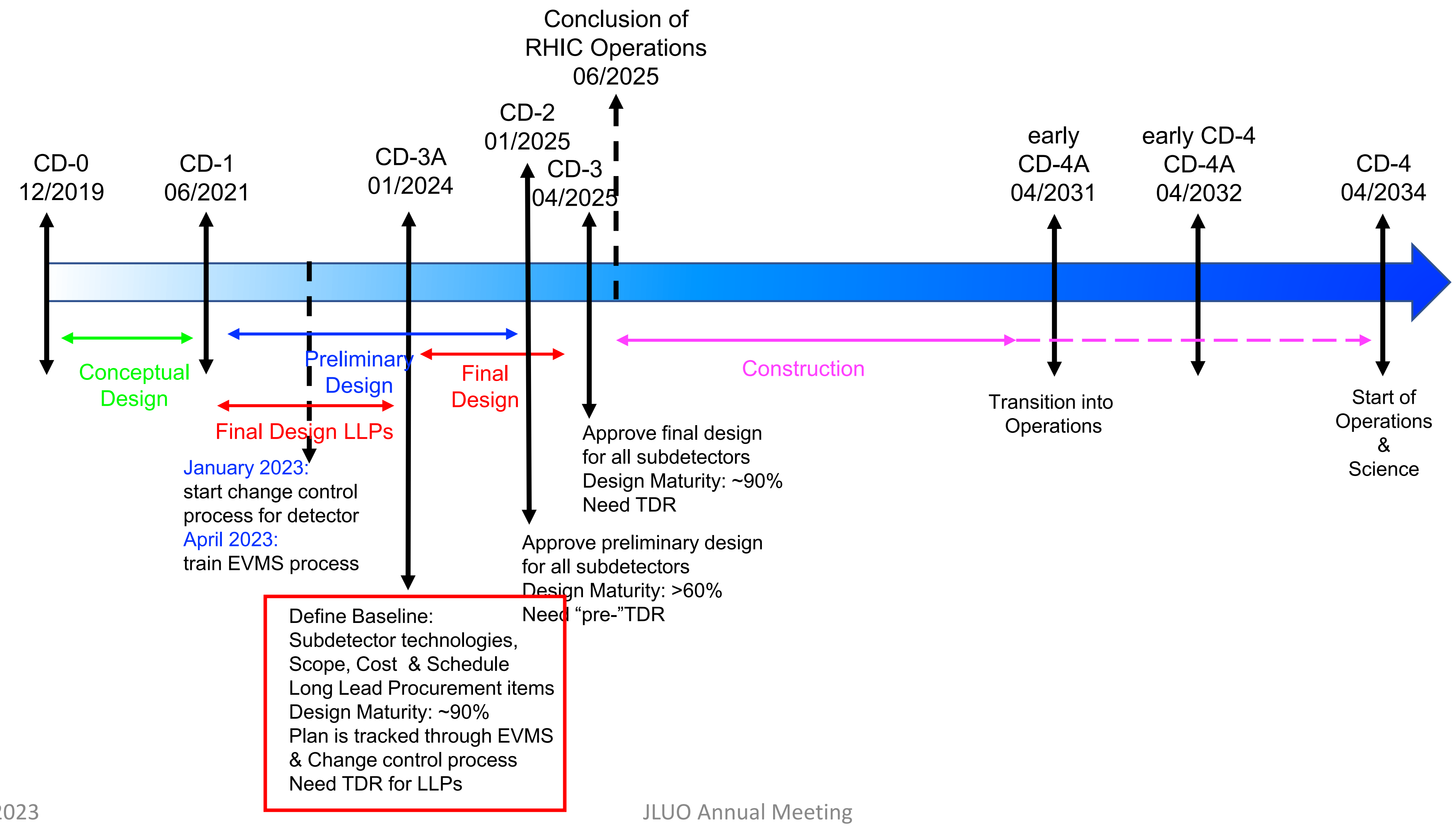
- Center of mass energy: 20 – 140 GeV
  - Electrons: 2.5 – 18 GeV
  - Protons: 40 – 275 GeV (ions: Z/A x E_{proton})
- Luminosity: 10^{34} /cm^2/sec
- Polarization: <70% (both electron and ion)
- Ion Species: proton - Uranium
- Detectors: up to 2 interaction regions with (almost) complete coverage



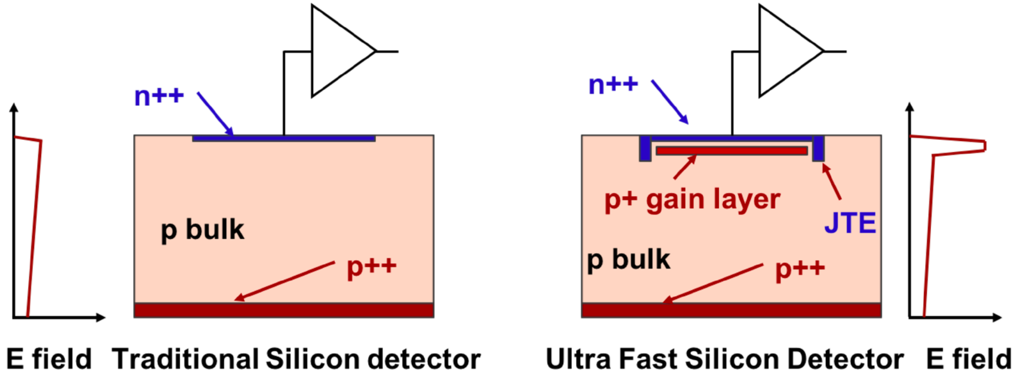
EIC Project Schedule

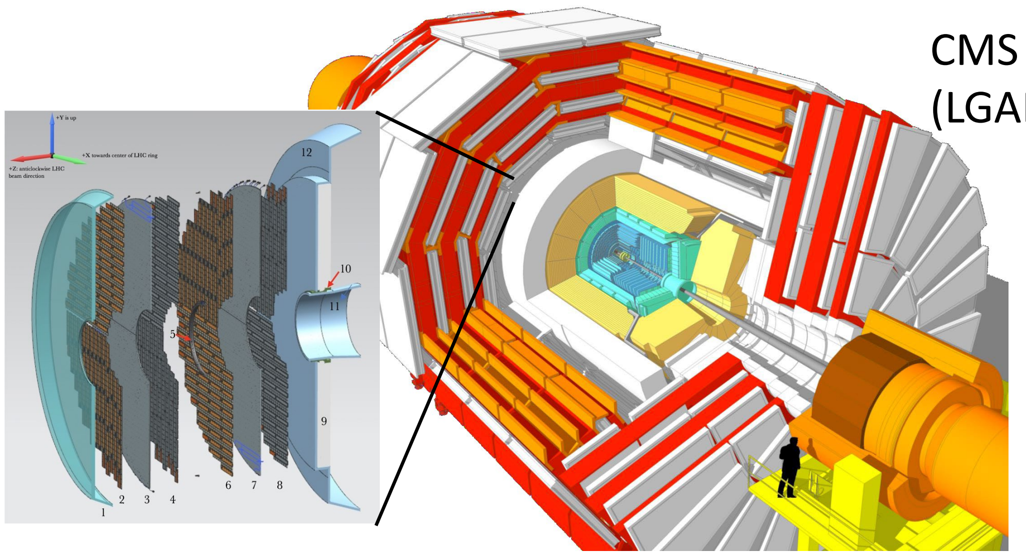


EIC Project Schedule



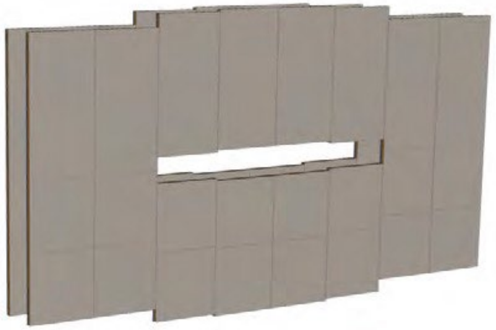
AC-LGAD TOF



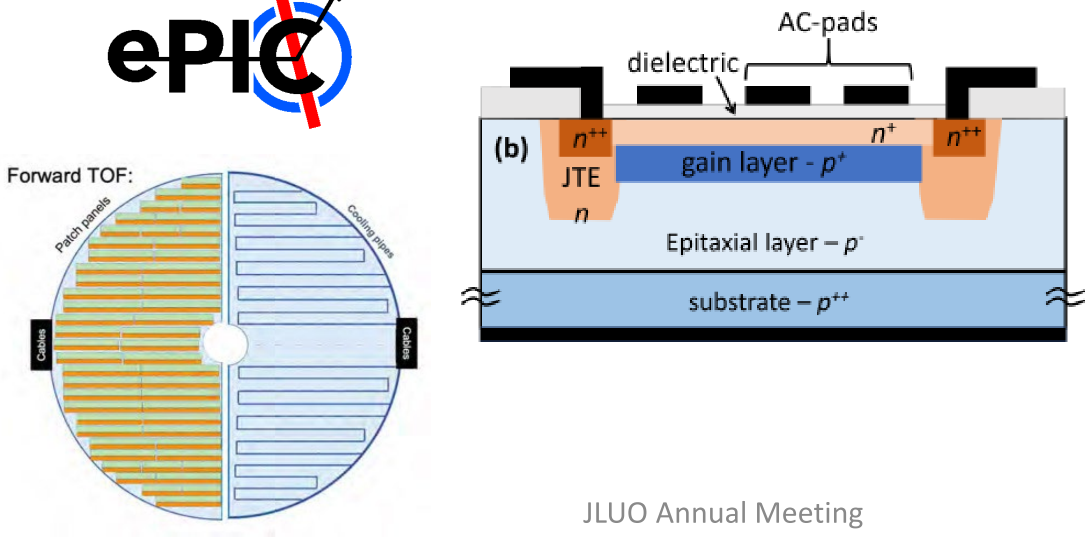


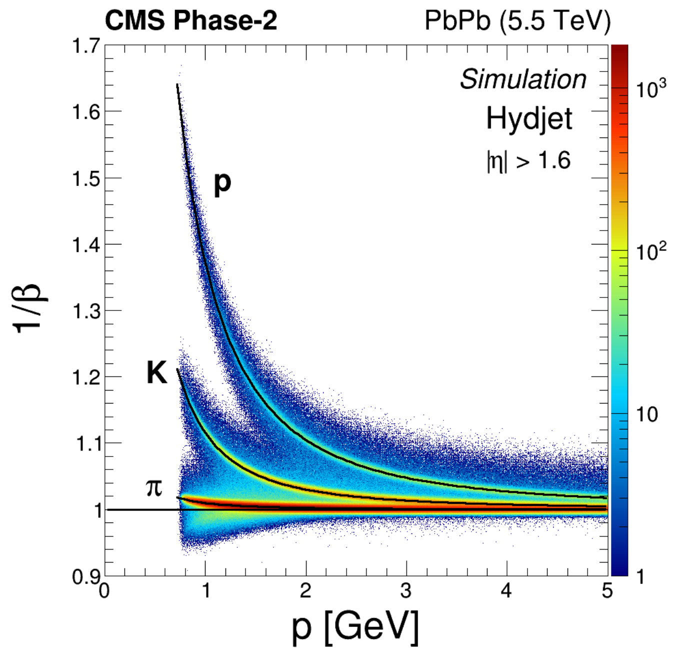
CMS ETL (LGAD)

AC-LGAD detectors add an AC-coupled readout to provide both *fast timing response* and *excellent spatial resolution* (4D).

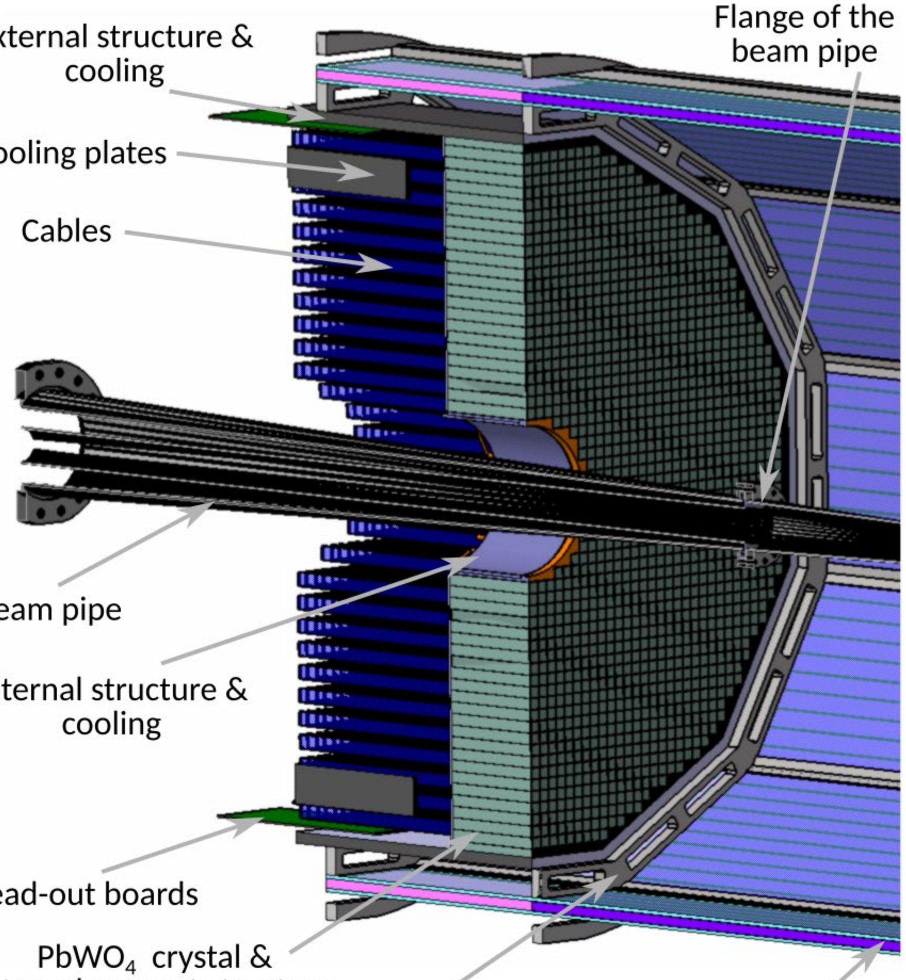


Roman pot arrays





Backward Calorimetry

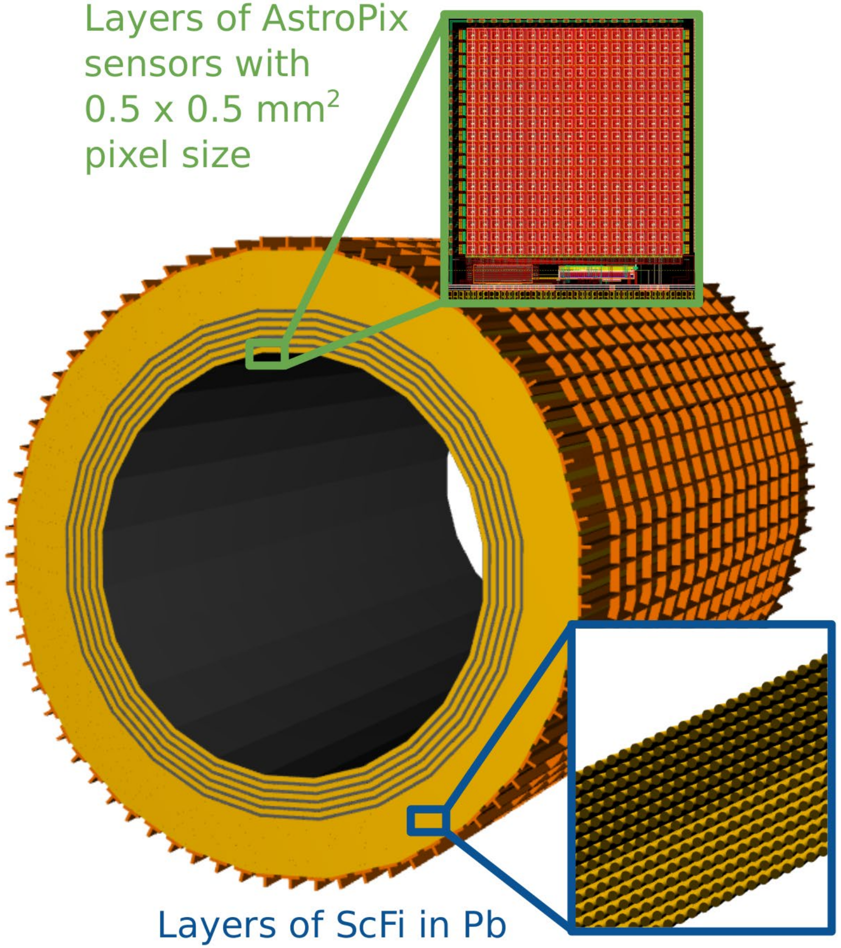


Backward EMCAL

- Non-projective **$PbWO_4$ calorimeter** (EEEMC-Consortium)
  - $2 \times 2 \times 20$ cm^3 crystals
  - Length ~$20X/X_0$, transverse size ~Molière radius
  - Located inside the inner DIRC frame
  - Preferred readout: SiPMs of pixel size 10μm or 15μm
  - Cooling to keep temperature stable within ± 0.1 °C
- Ongoing efforts advancing the design to increase coverage in η ($-3.7 < \eta < -1.5$) with inlay around beampipe

Barrel EM Calorimetry

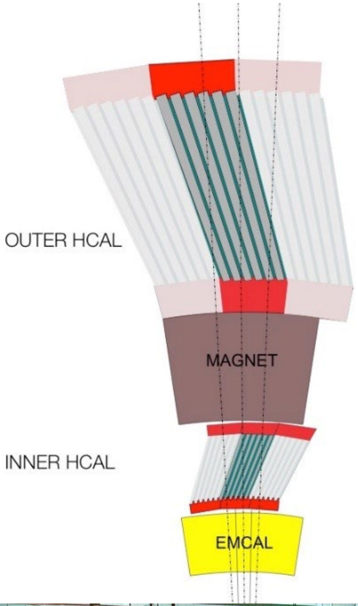
- **Hybrid concept**
  - Imaging calorimetry based on monolithic silicon sensors AstroPix (NASA's AMEGO-X mission) - 500 µm x 500 µm pixels Nuclear Inst. and Methods in Physics Research, A 1019 (2021) 165795
  - Scintillating fibers in Pb (Similar to GlueX Barrel ECal, 2-side readout w/ SiPMs) Nuclear Inst. and Methods in Physics Research, A 896 (2018) 24-42
- 6 layers of imaging Si sensors interleaved with 5 Pb/ScFi layers and followed by a large chunk of Pb/ScFi section (can be extended to inner HCAL)
- Total radiation thickness for EMCAL of ~20 X_0
- Detector coverage: $-1.7 < \eta < 1.3$ which overlaps with "electron-going" side endcap

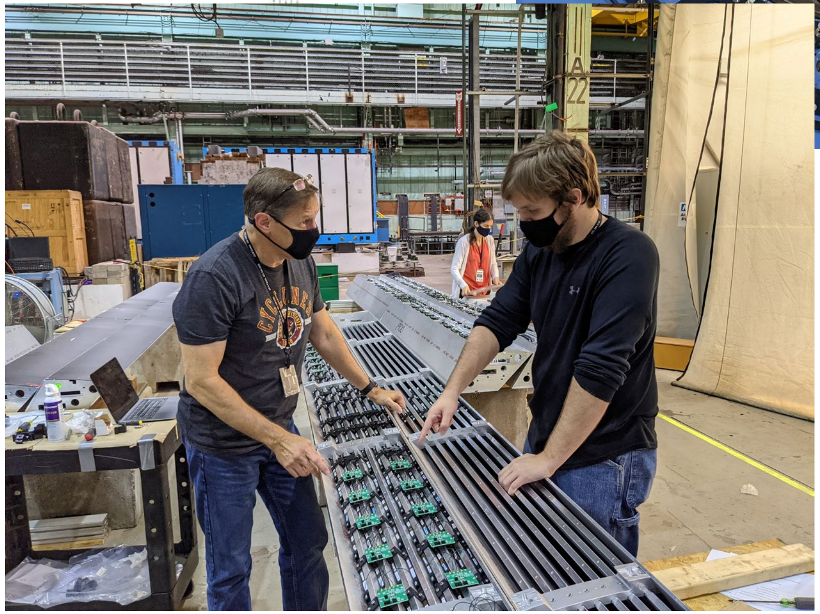


Energy resolution - SciFi/Pb Layers: $5.3\% / \sqrt{E} \oplus 1.0\%$

Position resolution - Imaging Layers (+ 2-side SciFi readout): with 1st layer hit information ~ pixel size

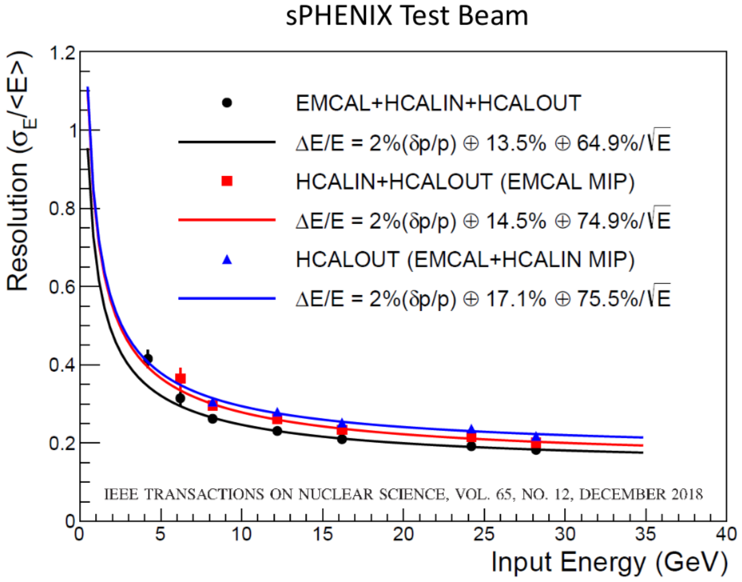
Barrel Hadronic Calorimetry



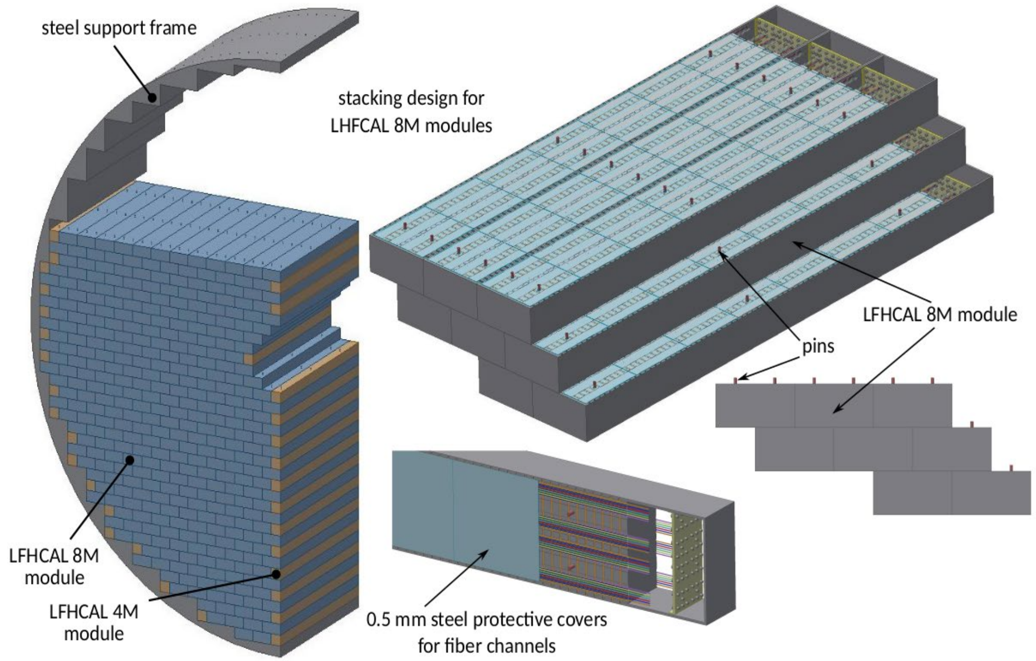


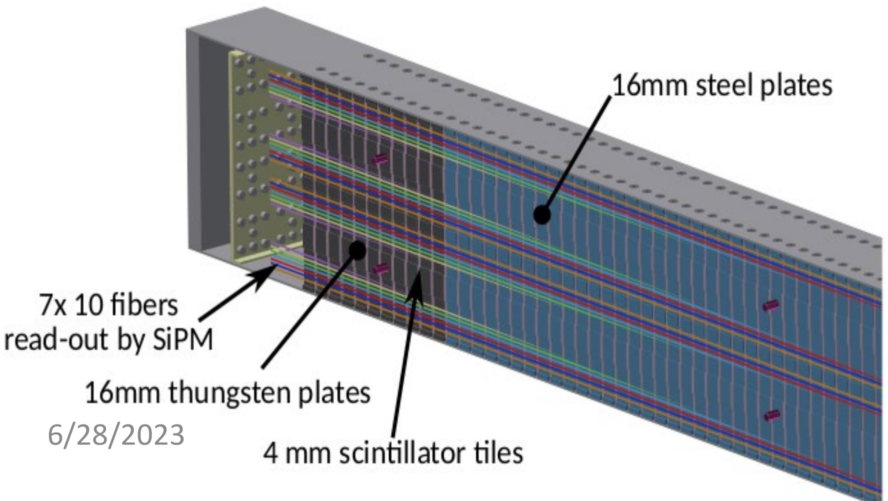
Reuse of sPHENIX outer (outside of the Solenoid) HCal ≈ 3.5λ_I

- Steel and scintillating tiles with wavelength shifting fiber
- $\Delta\eta \times \Delta\phi \approx 0.1 \times 0.1$ (1,536 readout channels, SiPMs)



Forward Hadronic Calorimetry





Design based on longitudinally separated steel and scintillator tiles (ORNL)

- Inspired by Projectile Spectator Detector (CBM)
    - 60 layers of steel-sci plates + 10 layers of W-Sci plates (5 x 5 cm towers)
    - 7 signals per tower (from 10 plates)
    - λ/λ_0 = 6.9 (HCAL only, larger shower containment)

- Ongoing efforts to explore granular inlay around beampipe