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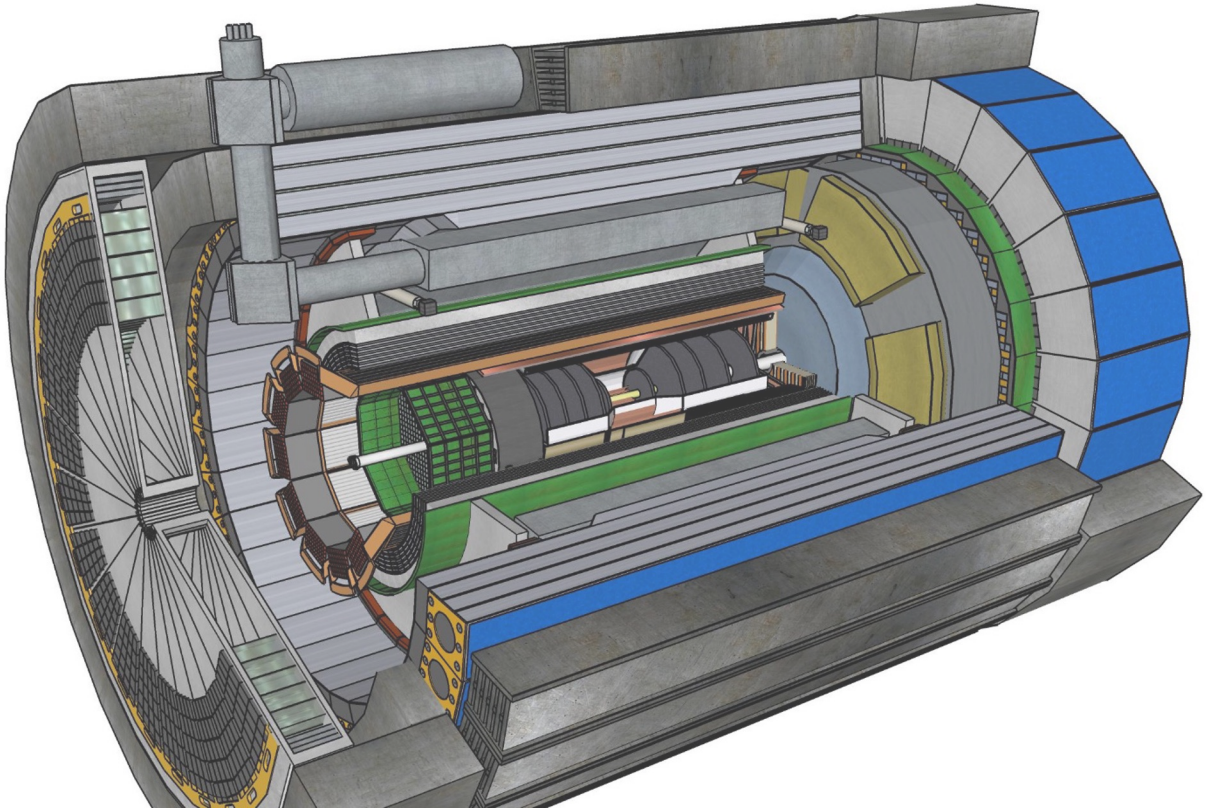
U.S. DEPARTMENT OF ENERGY
Office of Science

ePIC Detector Overview



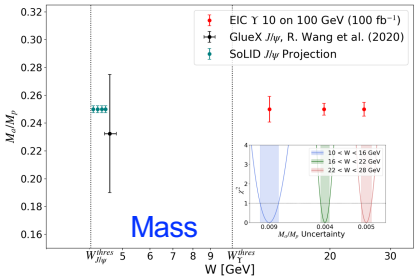
Shujie Li
on behalf of the ePIC Collaboration

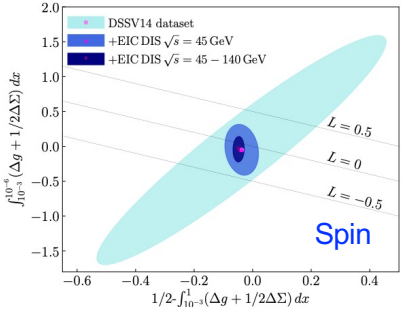
DIS2024@Grenoble, France
April 10, 2024

Electron-Ion Collider: The Next QCD Frontier

see Cristine Aidala's talk on April 12

Proton:

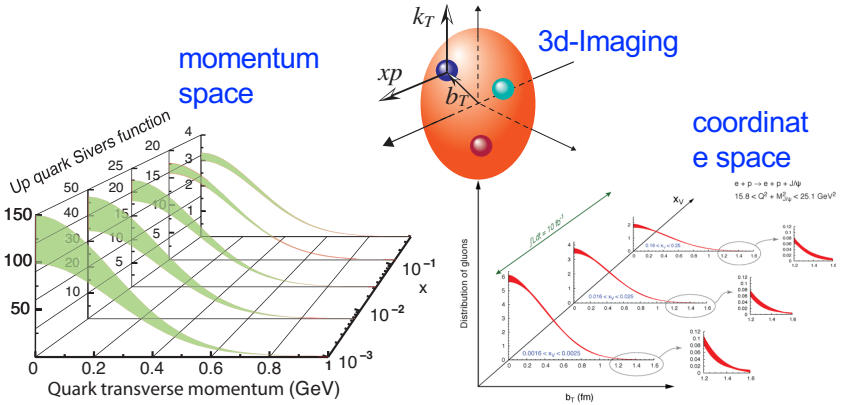




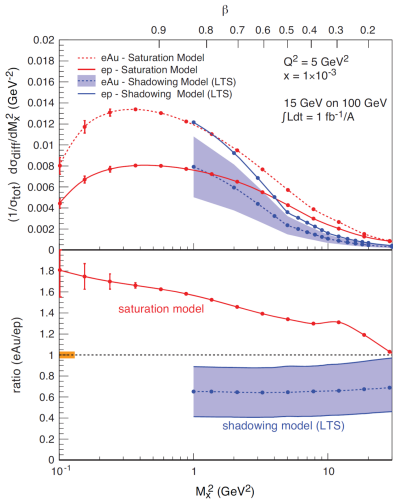
momentum space

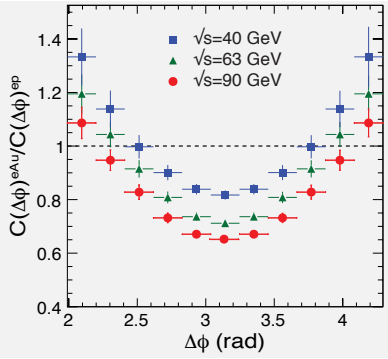
3d-Imaging

coordinate space



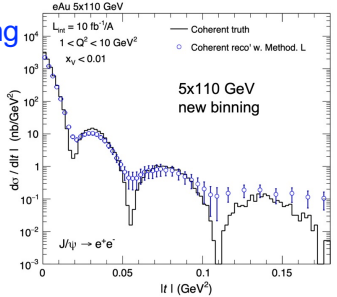
Nuclei:





non-linear QCD effects → Saturation

3d-Imaging of nuclei



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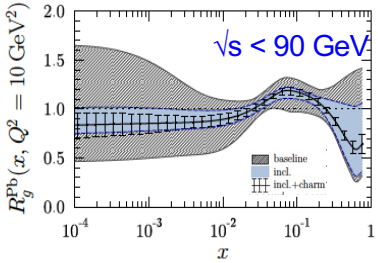
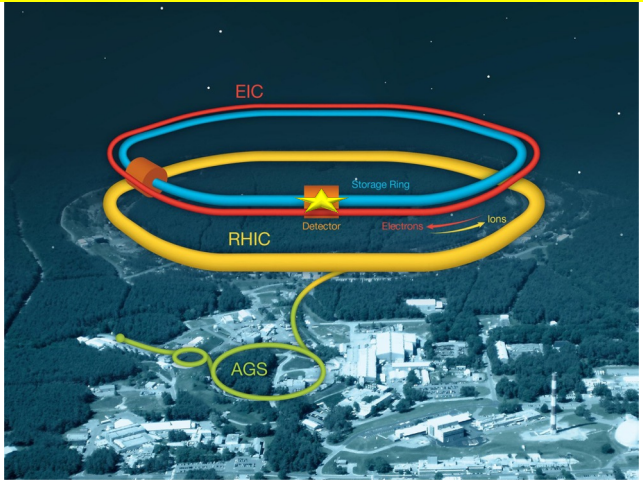


ePIC: the Detector and Collaboration

2nd detector at IP8: see Pawel Nadel-Turonski's talk today



EIC Critical Decision Plan

CD-0/Site Selection	December 2019 ✓
CD-1	June 2021 ✓
CD-3A	Early 2024
CD-3B	**October 2024**
CD-2/3	**April 2025**
early CD-4	October 2032
CD-4	**October 2034**

2020: detector conceptual design in yellow report

2021: call for detector proposal (ATHENA, CORE, ECCE)

2022: ECCE as the reference design → ATHENA+ECCE → project detector

2022.7: detector 1 collaboration formed, name voted: **ePIC**

2023: charter ratified and leadership elected. Technology selections.

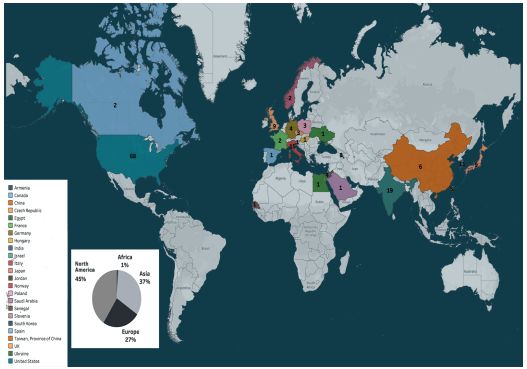
2024: working towards TDR…

https://wiki.bnl.gov/EPIC/index.php
https://www.bnl.gov/eic/epic.php

Collaboration meetings:

2023.7 @ Warsaw
2024.1 @ ANL
2024.7 @ Lehigh U.
2025.1 @ TBD

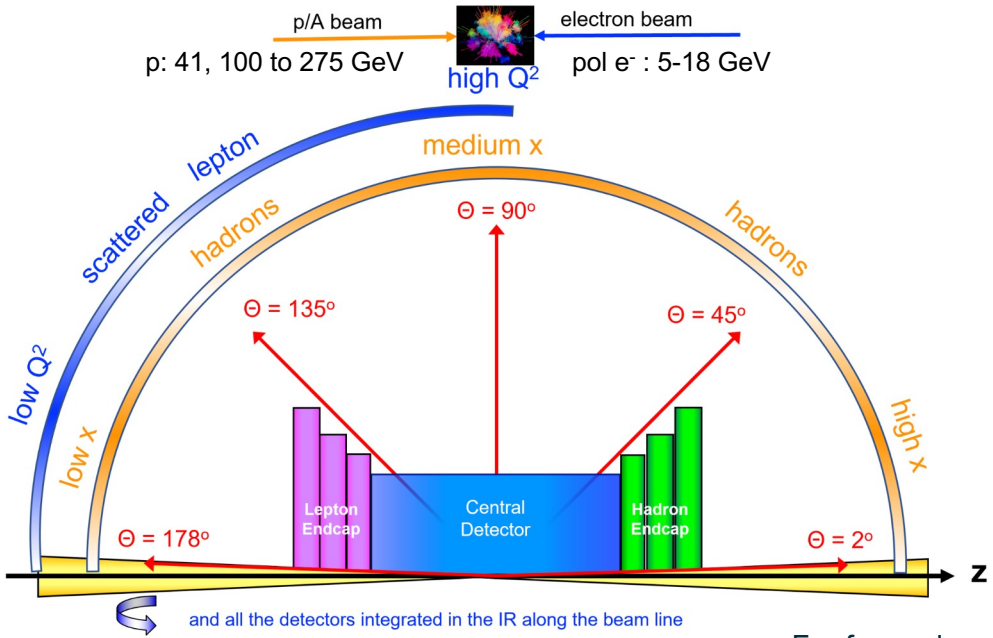
170+ institutions, 24 countries



Detector Design Concepts

Luminosity: 10^{33} - 10^{34} $cm^{-2}s^{-1}$

Center-of-mass energy: 28 - 140 GeV



luminosity detector
low Q^2 tagger

Far-forward: particle from nuclear breakup and exclusive process

ep and **eA** collision**:**

- PID
- various beam background (beam gas, synchrotron radiation,etc)

asymmetric beam energies

- asymmetric detector design
- large η coverage: -4 to 4 (central)

10ns **beam bunch** spacing:

- fast (stream) readout

25 mrad **crossing angle**:

- acceptance effect

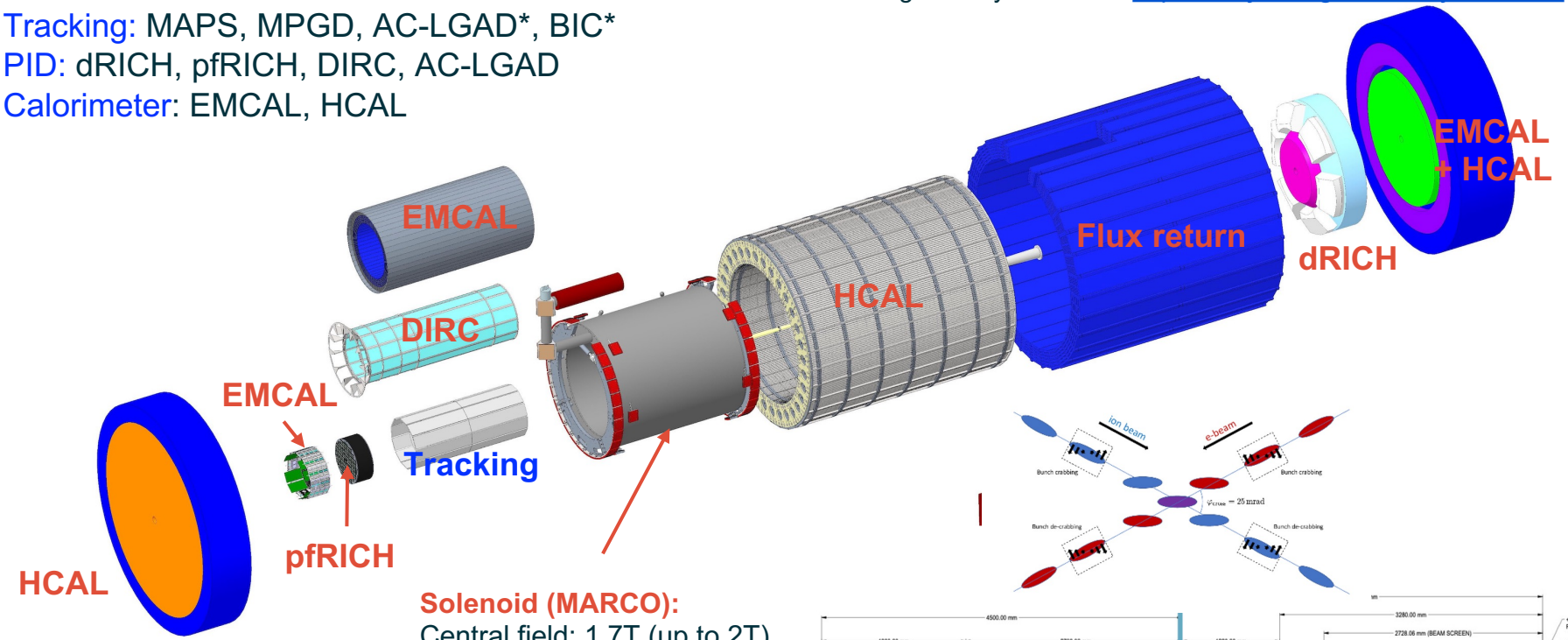
…

Central Detector Package

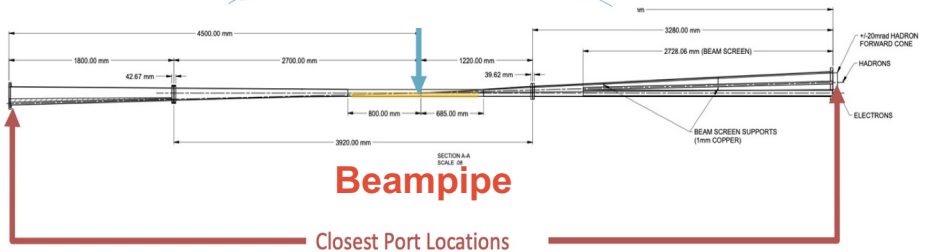
Length x Radius = 9.5m x 3.3m

ePIC detector geometry database: https://eic.jlab.org/Geometry/Detector/

Tracking: MAPS, MPGD, AC-LGAD*, BIC*
PID: dRICH, pfRICH, DIRC, AC-LGAD
Calorimeter: EMCAL, HCAL



Solenoid (MARCO):
Central field: 1.7T (up to 2T)
Bore diameter: 2.84m

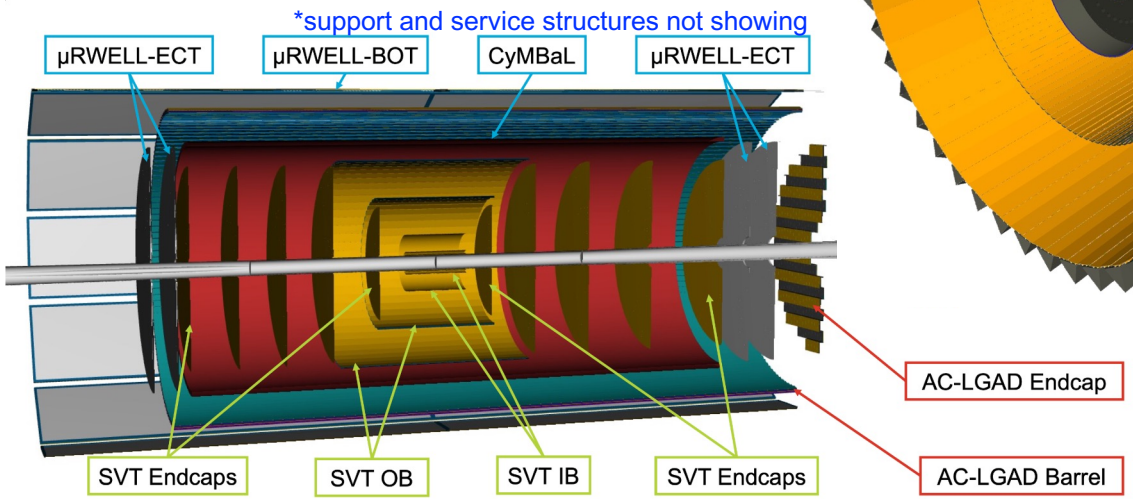


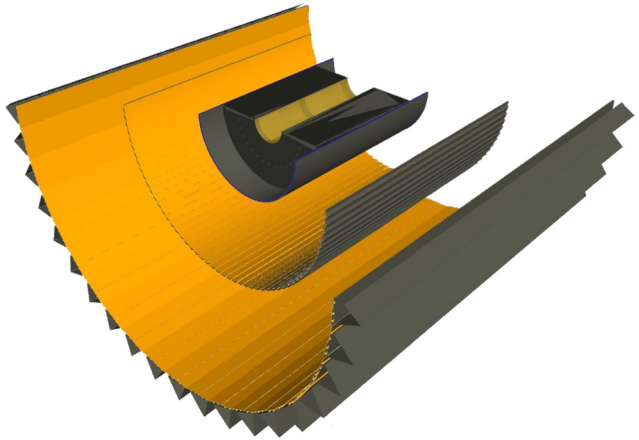
Tracking System

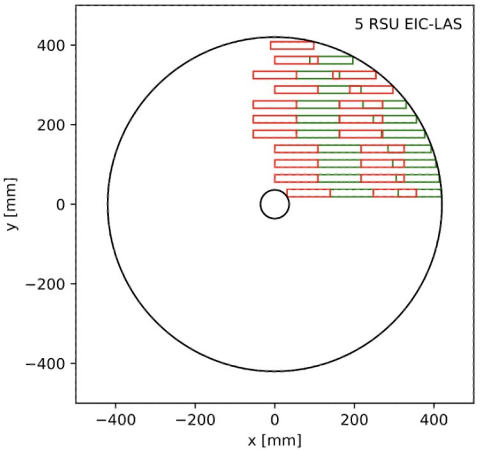
See Gian Michele Innocenti's talk today

Requirements:

- High pattern recognition efficiency
- High spatial resolution
- Low material budget
- Good time resolution







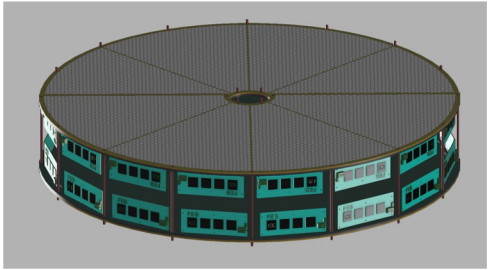
Silicon Vertex Tracker (SVT):

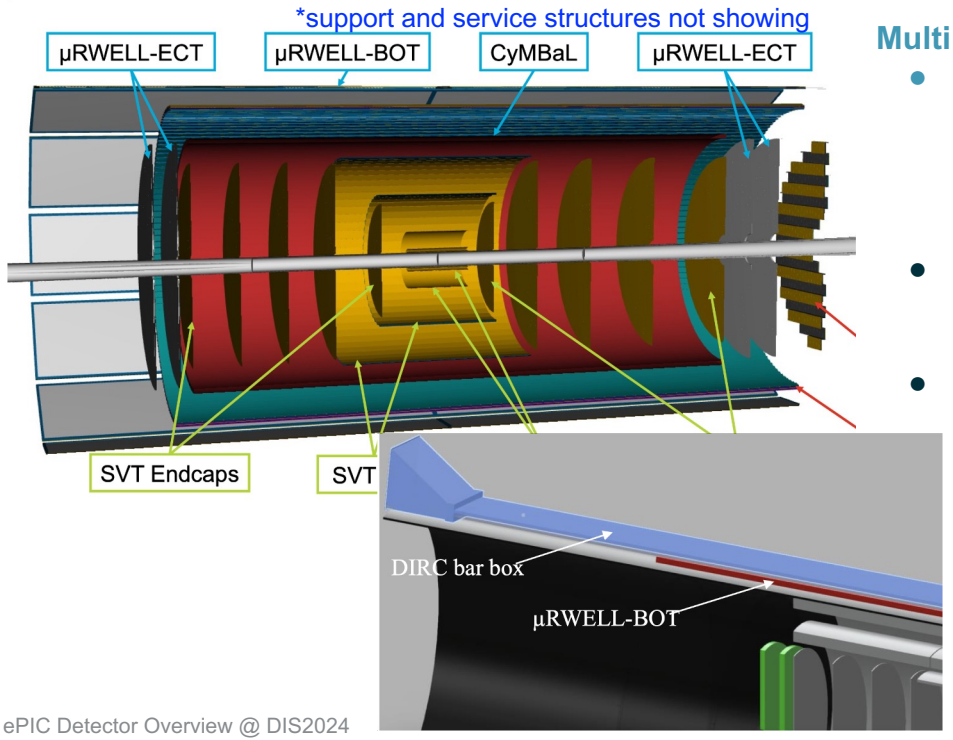
- Monolithic Active Pixel Sensor (MAPS): ~20x20um
- 3 vertex barrels: ITS3 curved wafer-scale sensor, 0.05% X/X_0
- 2 outer barrels: ITS3 based Large Area Sensors (EIC-LAS), 0.55% X/X_0
- 5 disks (forward/backward), EIC-LAS, 0.24% X/X_0

Tracking System

Requirements:

- High pattern recognition efficiency
- High spatial resolution
- Low material budget
- Good time resolution





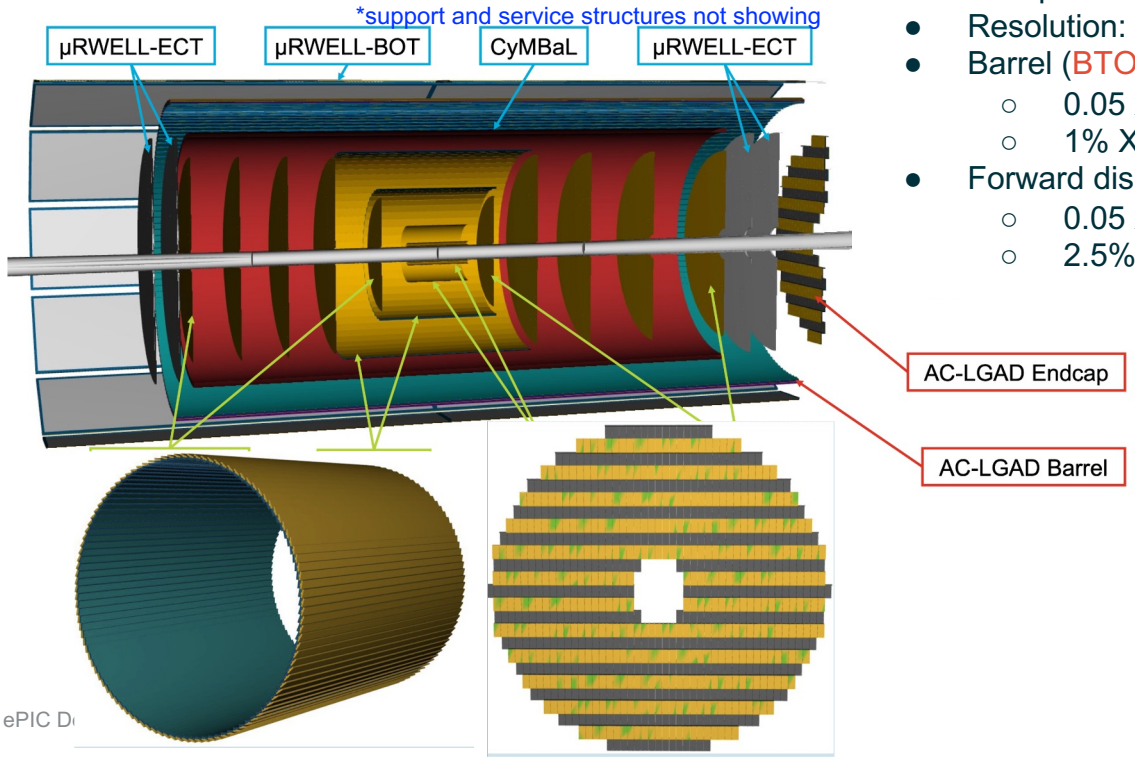
Multi Pattern Gas Detectors (MPGD):

- 2 GEM-μRwell endcaps (forward/backward):
  - provide additional hits for pattern recognition
  - 10 ns time resolution
  - 150 um spatial resolution
  - 1-2% X/X_0
- Inner Micromegas barrel:
  - Cylindrical Micromegas Barrel Layer (CyMBaL)
  - 0.5% X/X_0
- Outer GEM-μRwell planar layer:
  - Barrel Outer MPGD Tracker (BOT)
  - improve angular and space point resolution on hpDIRC

Tracking System

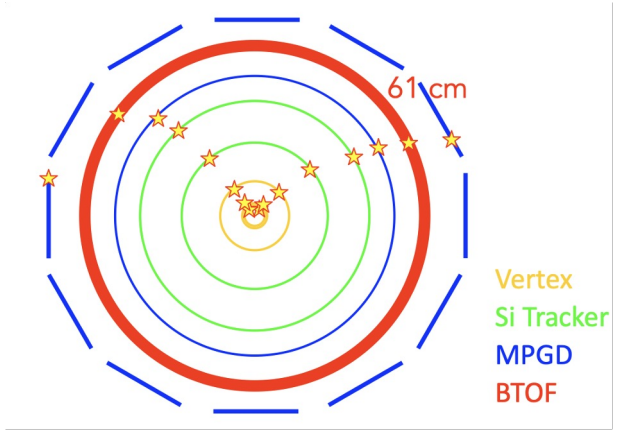
Requirements:

- High pattern recognition efficiency
- High spatial resolution
- Low material budget
- Good time resolution



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

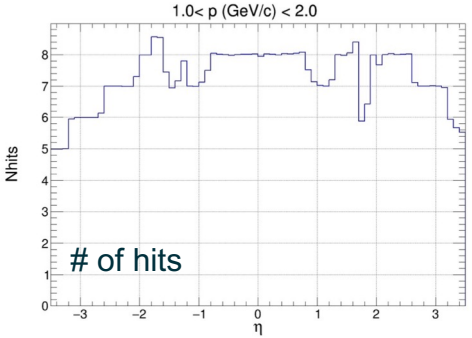
- A PID Time of Flight detectors to cover PID at low pT
- Also provide time and spatial info for tracking
- Resolution: ~30 ps, 30 um (with charge sharing)
- Barrel (BTOF):
  - 0.05 x 1 cm strip
  - 1% X/X0
- Forward disk (FTOF) :
  - 0.05 x 0.05 cm pixel
  - 2.5% X/X0

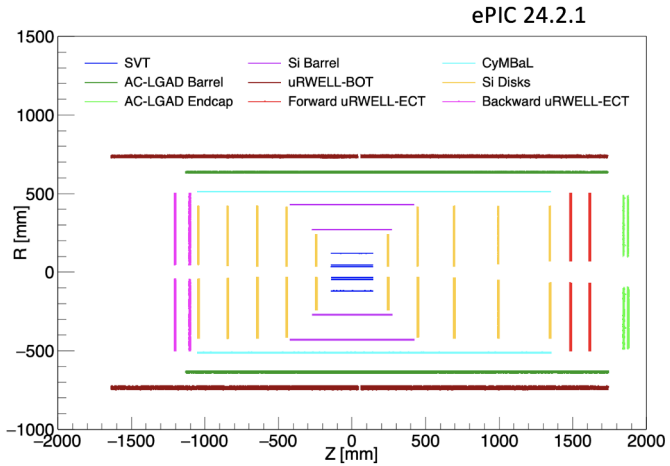


Tracking Performance

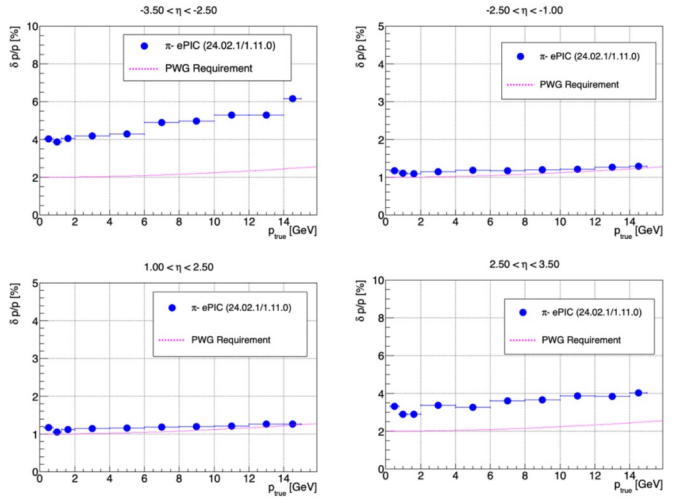
Requirements: https://eic.jlab.org/Requirements/index.html

	Momentum Resolution	Spatial Resolution
Backward (-3.5 to -2.5)	~0.10%×p⊕2.0%	~ 30/pT μm ⊕ 40 μm
Backward (-2.5 to -1.0)	~ 0.05%×p⊕1.0%	~ 30/pT μm ⊕ 20 μm
Barrel (-1.0 to 1.0)	~0.05%×p⊕0.5%	~ 20/pT μm ⊕ 5 μm
Forward (1.0 to 2.5)	~0.05%×p⊕1.0%	~ 30/pT μm ⊕ 20 μm
Forward (2.5 to 3.5)	~0.10%×p⊕2.0%	~ 30/pT μm ⊕ 40 μm





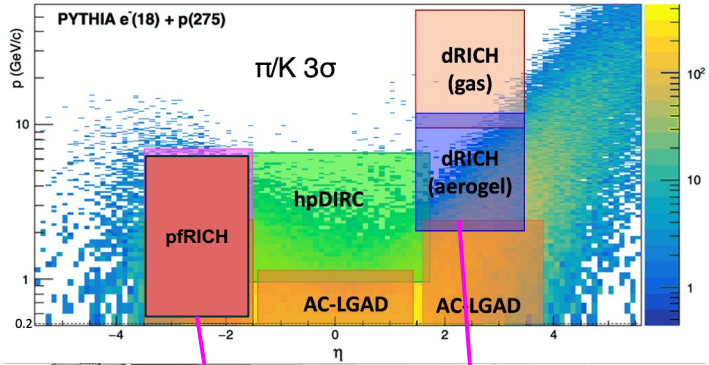
- Single particle
  - Includes AC-LGAD layers
  - Extreme η regions will require use of other ePIC sub detector information
  - Follows requirements elsewhere

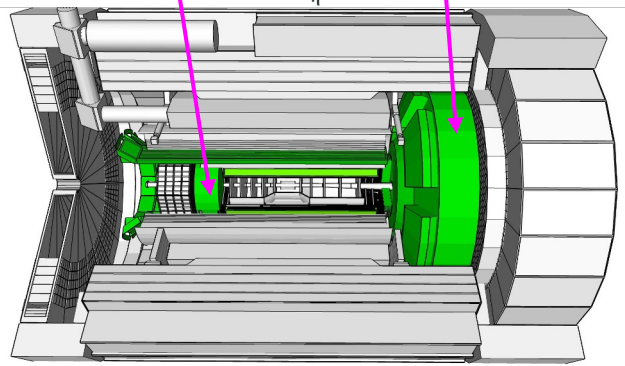


See Chandradoy Chatterjee's talk today

Particle Identification (PID)

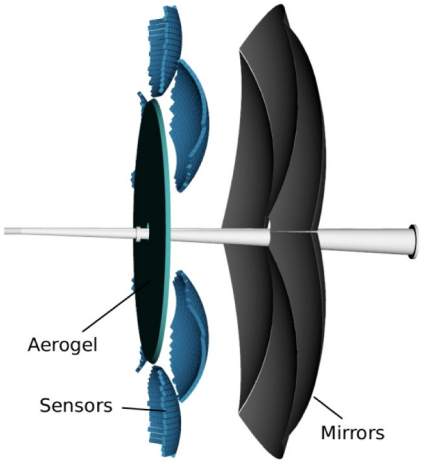
e/γ: tracking
e/h: calorimetry
π/K/p: Cherenkov + AC-LGAD

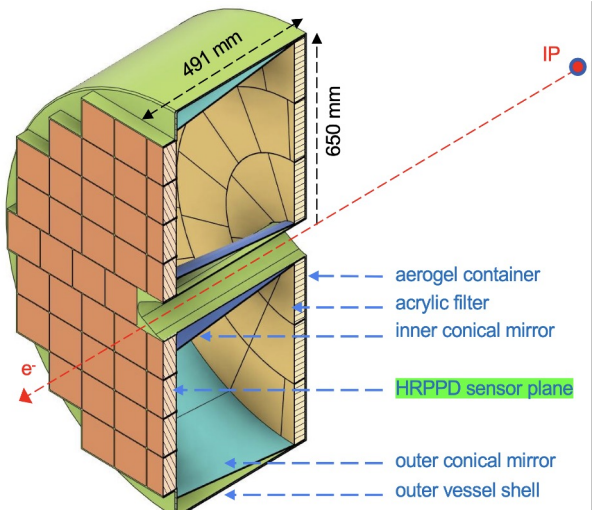




Dual Radiator Ring Cherenkov detector (dRICH):

- for high momentum PID at forward region
- 4cm aerogel + C_2F_6 gas
- 6 spherical mirrors to focalize photons
- SiPM based sensors for photon detection



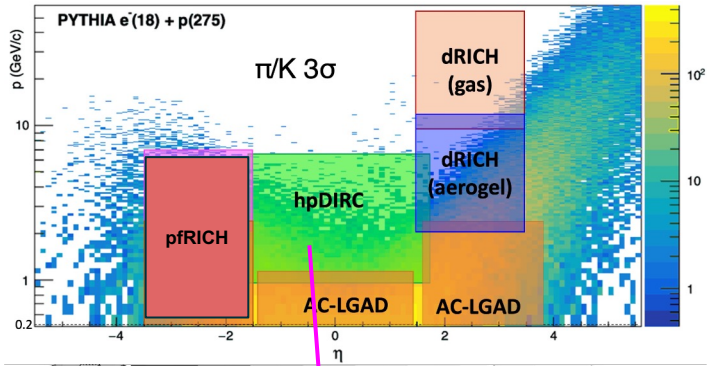


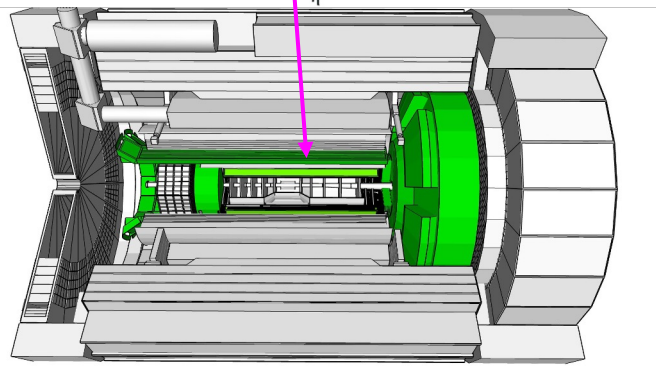
Proximity focusing RICH (pfRICH):

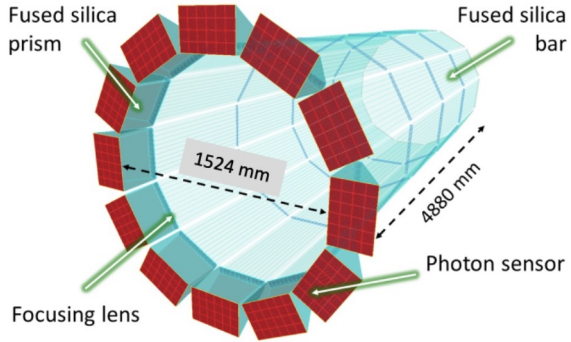
- High Rate Picosecond Photodetector (HRPPD) sensors → can also provide reference time (~20pm) for ToF
- π/K up to 7 GeV/c
- Almost uniform acceptance in η, ϕ

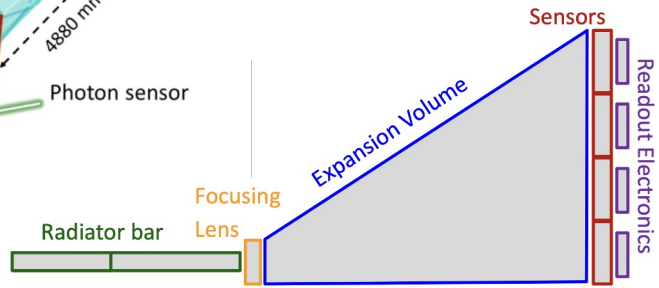
Particle Identification (PID)

e/γ: tracking
e/h: calorimetry
π/K/p: Cherenkov + AC-LGAD









High performance Detection of Internally Reflected Cherenkov light (hpDIRC)

- 10 long bars
- flat mirrors on far end
- MCP-PMT Sensors
- Reconstruction based on geometrical and/or time info
- >3σ π/K separation power

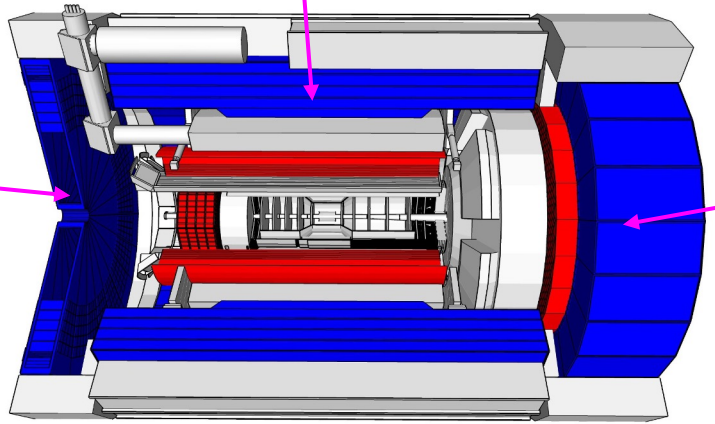
Calorimeter

See Henry Klest's talk today

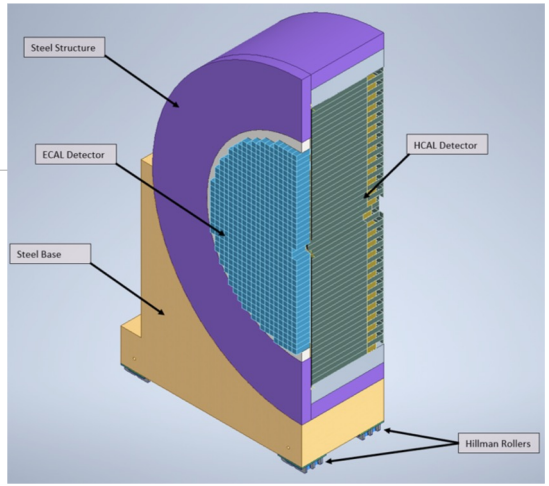
Backward HCAL:

- similar to **LFHCAL** design
- Steel/Sc W/Sc bars with SiPM embeded
- Tail catcher for EMCAL
- Low energy neutron detection
- Good spatial resolution for hadrons

Barrel HCAL: reuse from sPHENIX



Longitudinal Forward Hadronic Calorimeter (LFHCal)

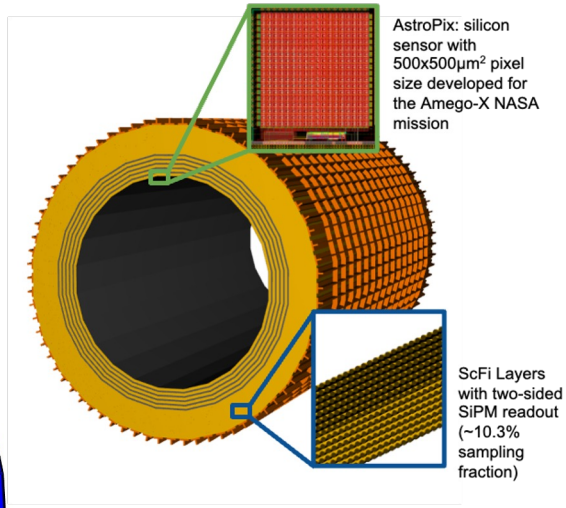


Calorimeter

See Henry Klest's talk today

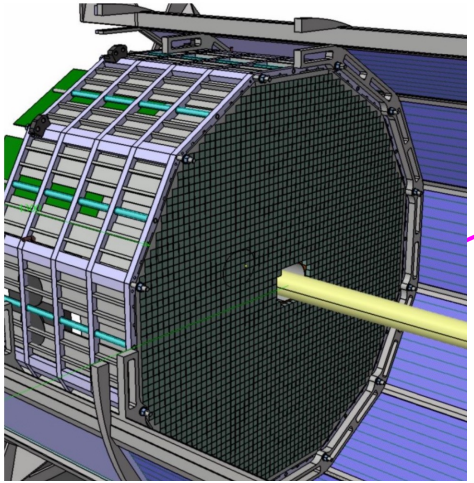
Barrel Imaging Calorimeter (BIC, BeCAL):

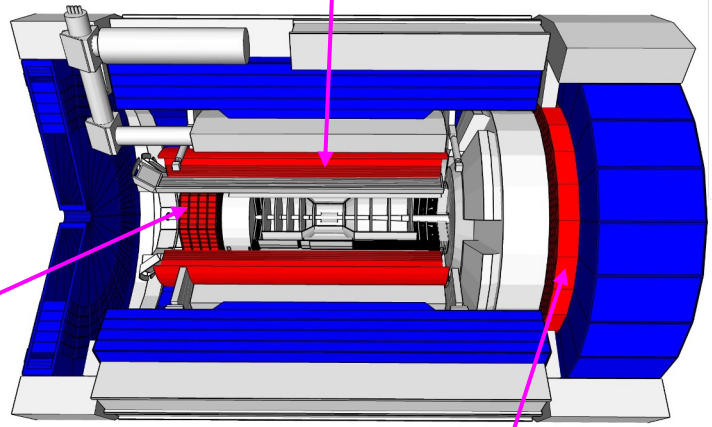
- 6 layers of imaging Si sensors (AstroPix) interleaved with 5 SciFi/Pb layer
- Followed by a large section of SciFi/Pb



Backward ECAL:

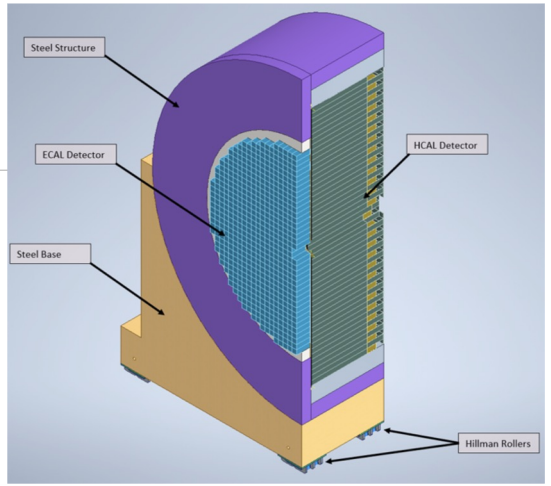
- $PbWO_4$ crystals
- excellent energy resolution and high pion suppression for electron reconstruction



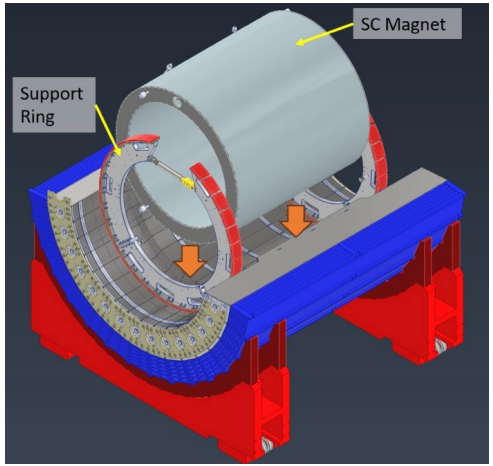


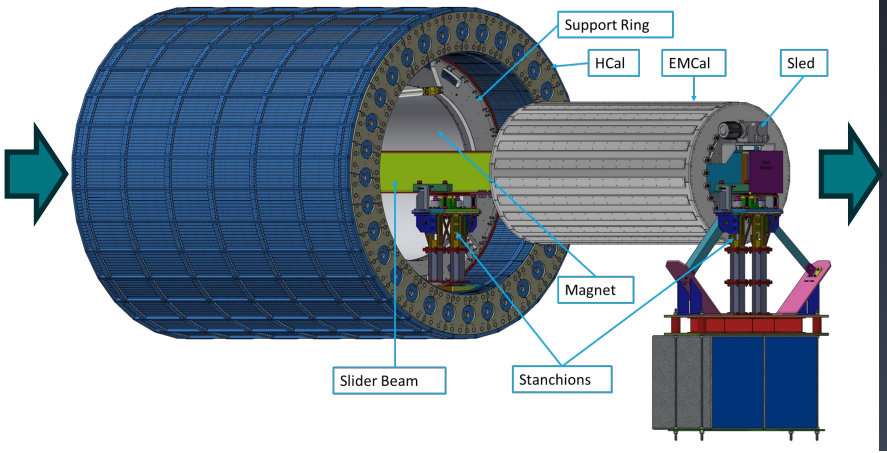
proton-going Electromagnetic Calorimeter (pECal):

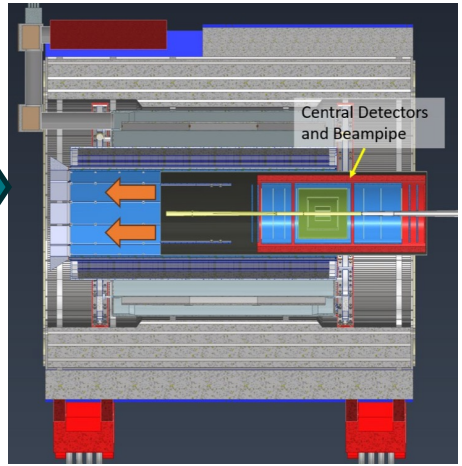
- W/ScFi blocks beehive with fiber
- good π/γ separation
- tracking+pECal+LFHCAL for optimized HF jets
- SiPMs as photonsensors



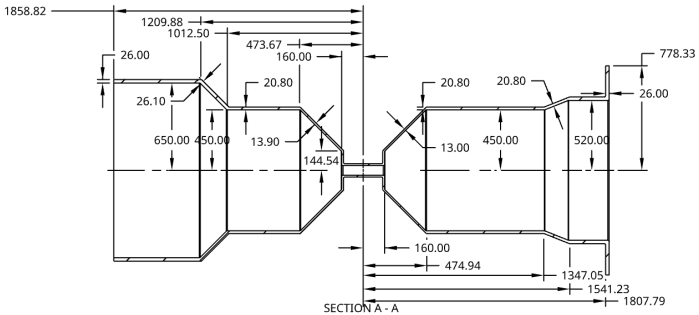
Integration and Installation

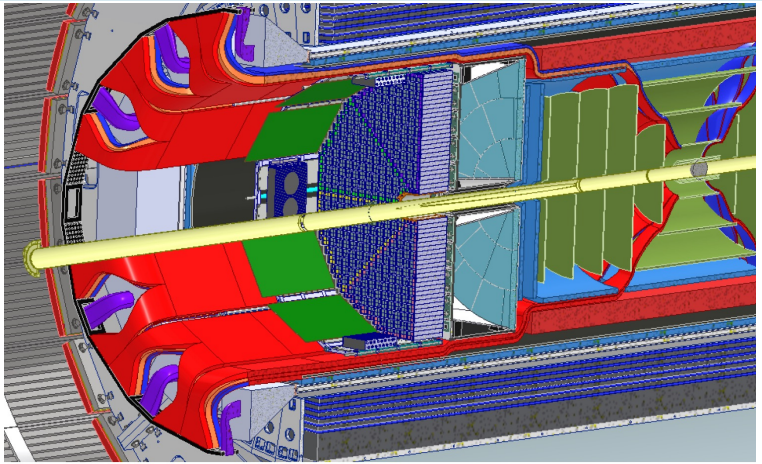






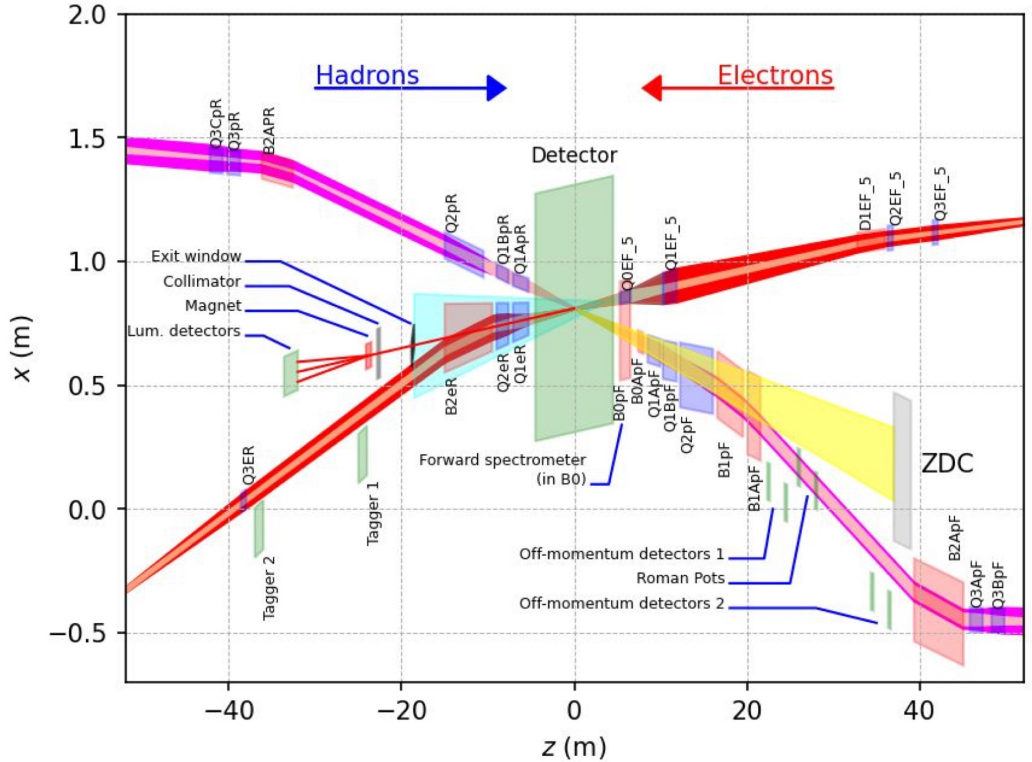
Service (cables and cooling) and support structures:





Far-forward/backward Systems

see Michael Pitt's talk today



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

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

Far-backward:

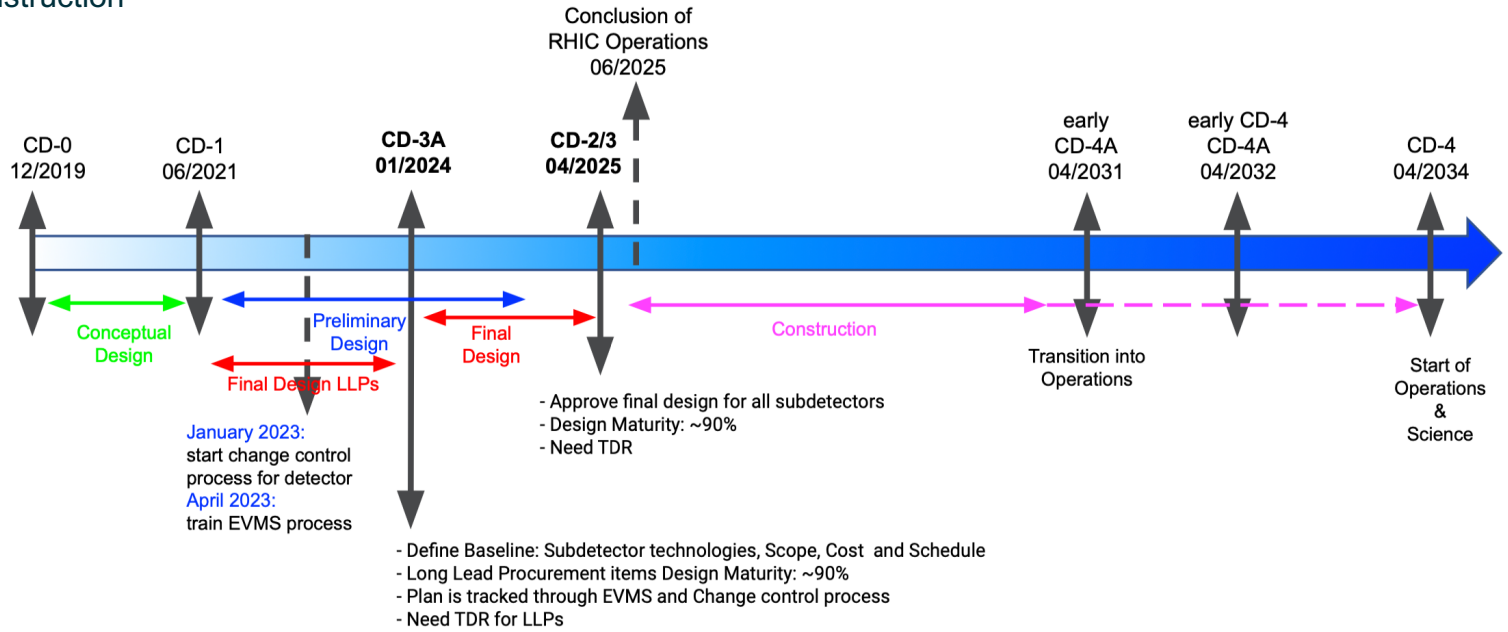
- Two low Q^2 electron taggers
- luminosity monitor

Current Status: towards CD-2

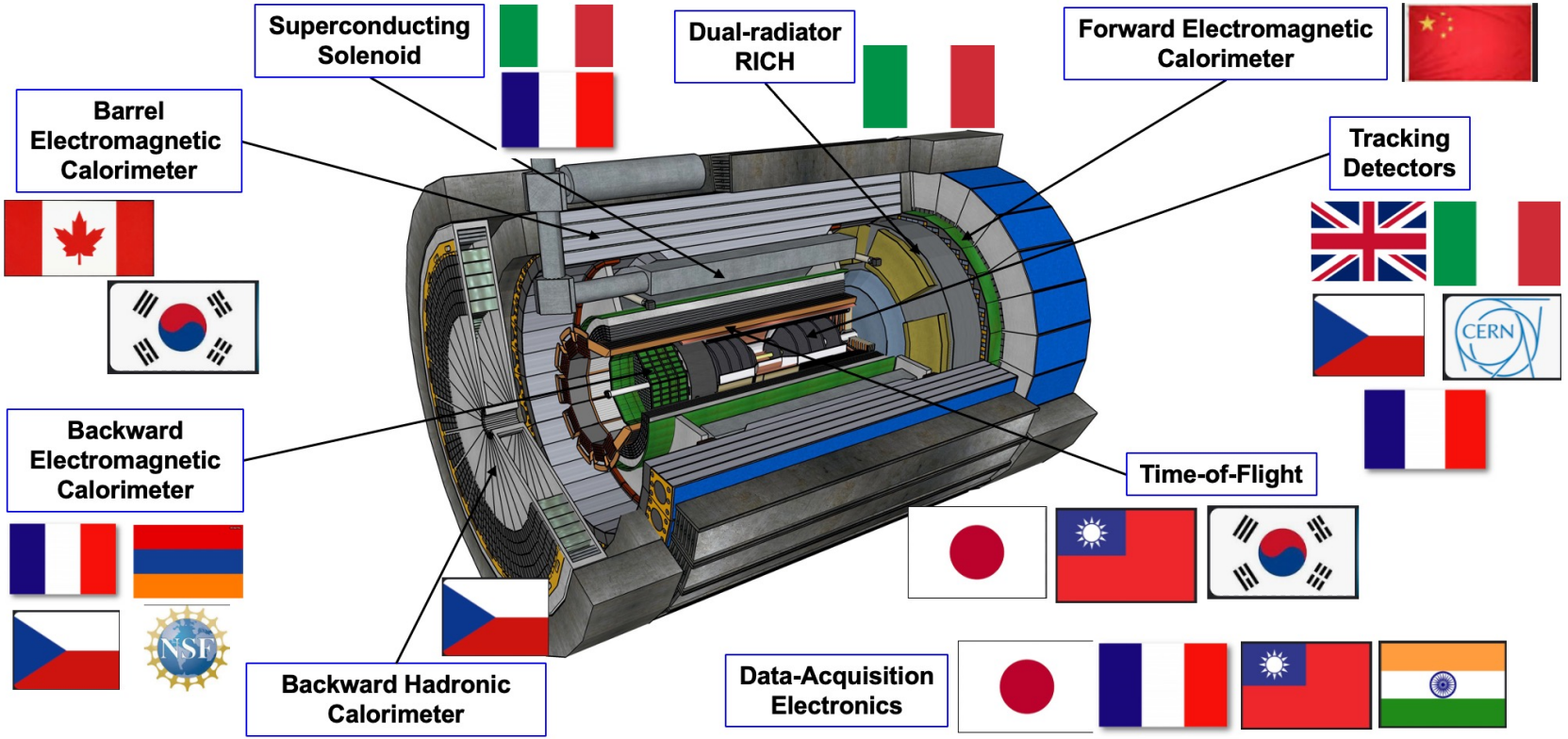
- Generic EIC-related detector R&D
- Beam test
- Readout and database
- Integration
- Simulation with full material, background ,and reconstruction

➔ Subsystem internal review (time, cost, performance)

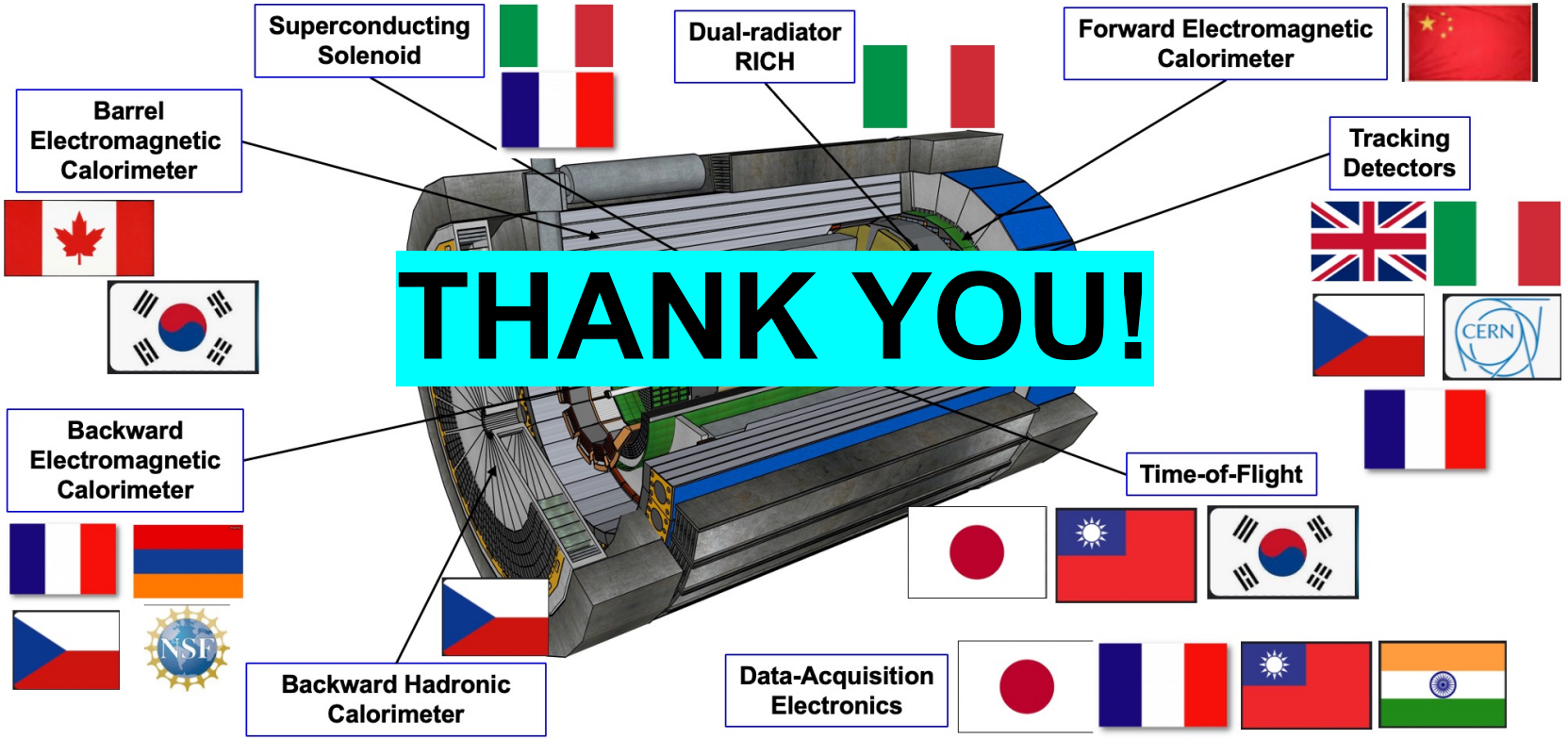
➔ Prepare for Technical Design Report:



International Engagement https://wiki.bnl.gov/EPIC/index.php



International Engagement https://wiki.bnl.gov/EPIC/index.php



Backup

Central Detector Package

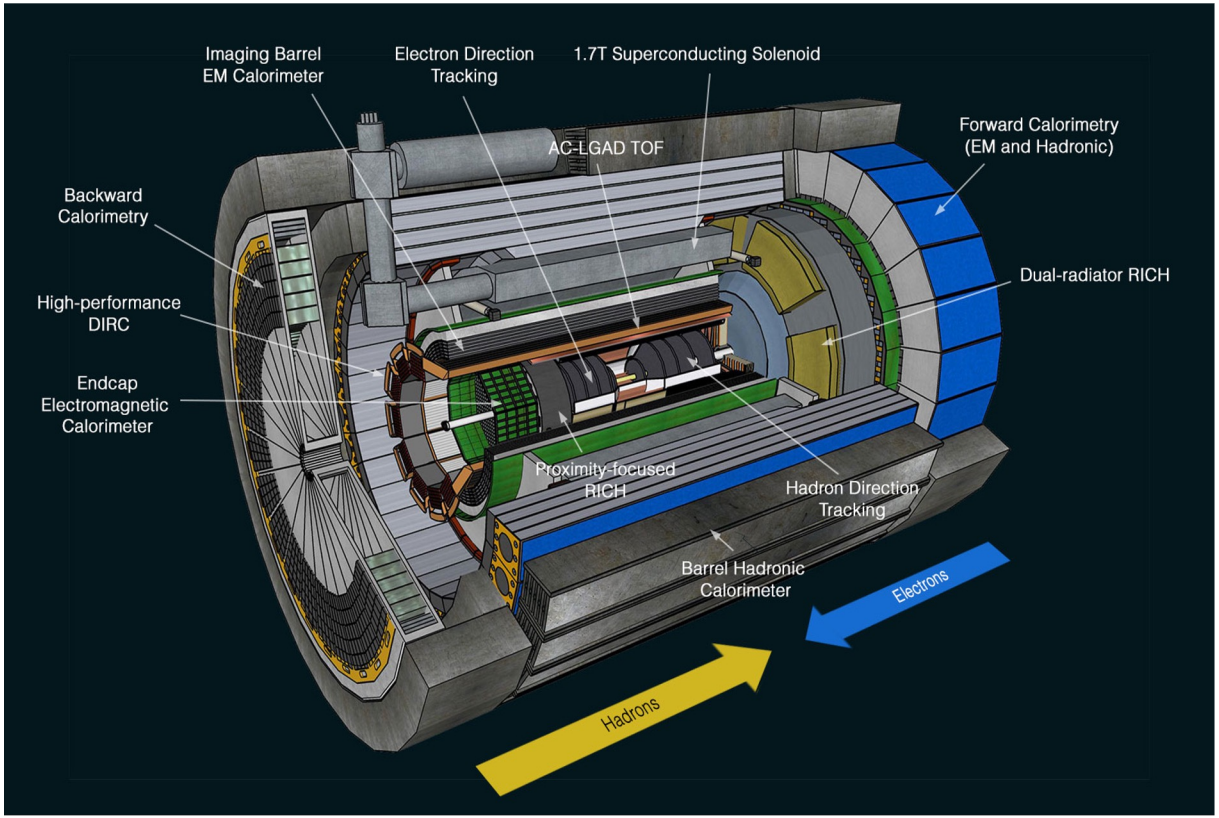
Length x Radius = 9.5m x 3.3m

Tracking: MAPS, MPGD, AC-LGAD*, BIC*

PID: dRICH, pfRICH, DIRC, AC-LGAD

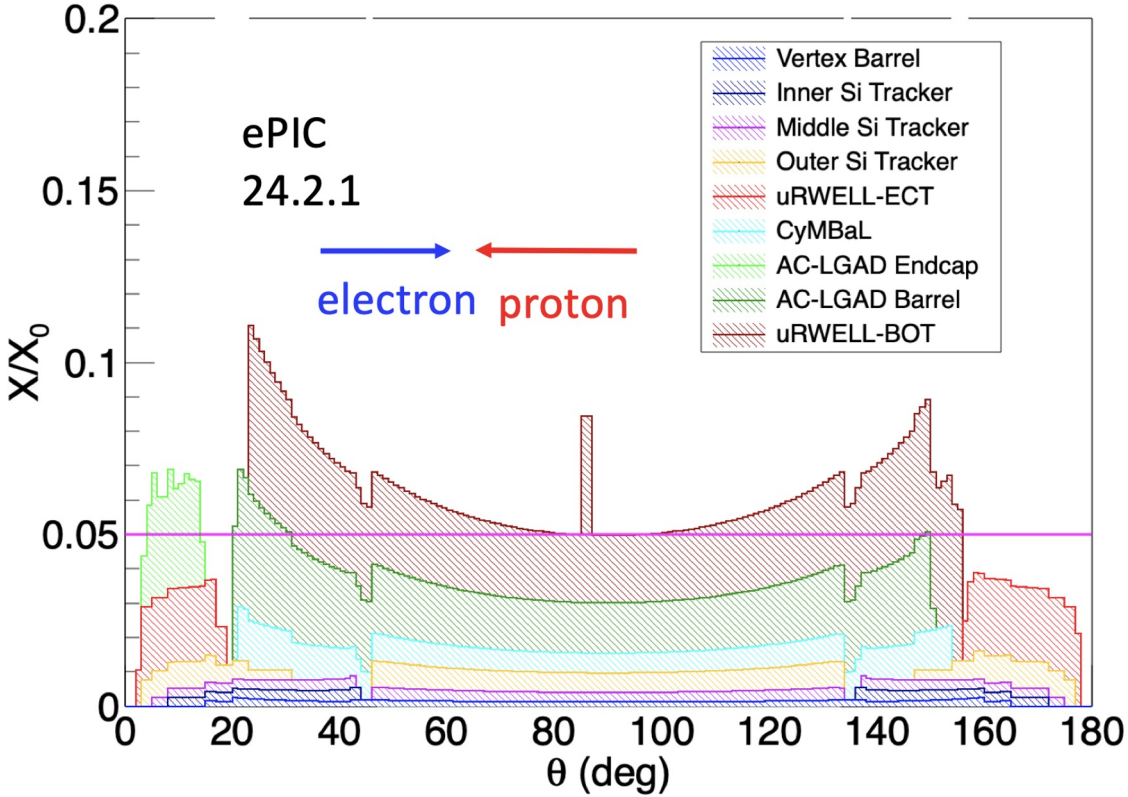
Calorimeter: EMCAL, HCAL

ePIC detector geometry database: https://eic.jlab.org/Geometry/Detector/



EIC – Detector Requirements

η	Nomenclature	Tracking						Electrons and Photons			π/K/p		HCAL		Muons
		Resolution	Relative Momentun	Allowed X/X_0	Minimum-p_T (MeV/c)	Transverse Pointing Res.	Longitudinal Pointing Res.	Resolution σ_E/E	PID	Min E Photon	p-Range	Separation	Resolution σ_E/E	Energy	
< -4.6	Low-Q2 tagger														
-4.6 to -4.0		Not Accessible													
-4.0 to -3.5			Reduced Performance												
-3.5 to -3.0	Backward Detector		σ_p/p ~ 0.1%×p⊕2%	~5% or less	150-300			1%/E ⊕ 2.5%/√E ⊕ 1%	π suppression up to $1:10^{-4}$	20 MeV	≤ 10 GeV/c	≥ 3σ	50%/√E ⊕ 10%	~500MeV	Muons useful for background suppression and improved resolution
-3.0 to -2.5															
-2.5 to -2.0			σ_p/p ~ 0.02% × p ⊕ 1%												
-2.0 to -1.5						dca(xy) ~ 40/p_T μm ⊕ 10 μm	dca(z) ~ 100/p_T μm ⊕ 20 μm	2%/E ⊕ (4-8)%/√E ⊕ 2%	π suppression up to $1:(10^{-3}\text{-}10^{-2})$	50 MeV					
-1.5 to -1.0															
-1.0 to -0.5	Barrel		σ_p/p ~ 0.02% × p ⊕ 5%		400	dca(xy) ~ 30/p_T μm ⊕ 5 μm	dca(z) ~ 30/p_T μm ⊕ 5 μm	2%/E ⊕ (12-14)%/√E ⊕ (2-3)%	π suppression up to $1:10^{-2}$	100 MeV	≤ 6 GeV/c		100%/√E ⊕ 10%		
-0.5 to 0.0															
0.0 to 0.5															
0.5 to 1.0															
1.0 to 1.5	Forward Detectors		σ_p/p ~ 0.02% × p ⊕ 1%		150-300	dca(xy) ~ 40/p_T μm ⊕ 10 μm	dca(z) ~ 100/p_T μm ⊕ 20 μm	2%/E ⊕ (4*-12)%/√E ⊕ 2%	3σ e/π up to 15 GeV/c	50 MeV	≤ 50 GeV/c		50%/√E ⊕ 10%		
1.5 to 2.0															
2.0 to 2.5															
2.5 to 3.0			σ_p/p ~ 0.1%×p⊕2%												
3.0 to 3.5															
3.5 to 4.0	Instrumentation to separate charged particles from photons		Reduced Performance												
4.0 to 4.5		Not Accessible													
> 4.6	Proton Spectrometer														
	Zero Degree Neutral Detection														


ePIC
24.2.1
electron
proton
Vertex Barrel
Inner Si Tracker
Middle Si Tracker
Outer Si Tracker
uRWELL-ECT
CyMBaL
AC-LGAD Endcap
AC-LGAD Barrel
uRWELL-BOT
X/X0
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
120
140
160
180
θ (deg)

Cross Section and Rate Comparisons

cross-section	5x41 GeV	5x100 GeV	10x100 GeV	10x275 GeV	18x275 GeV
Total ep	28.5ub	35ub	41ub	50ub	54ub
hadron beam (p) gas	77.3mb	76.8mb	76.8mb	78.5mb	78.5mb
electron beam gas	622.158 +/- 0.036 mb	622.158 +/- 0.036 mb	699.393 +/- 0.041 mb	699.393 +/- 0.041 mb	768.343 +/- 0.049 mb

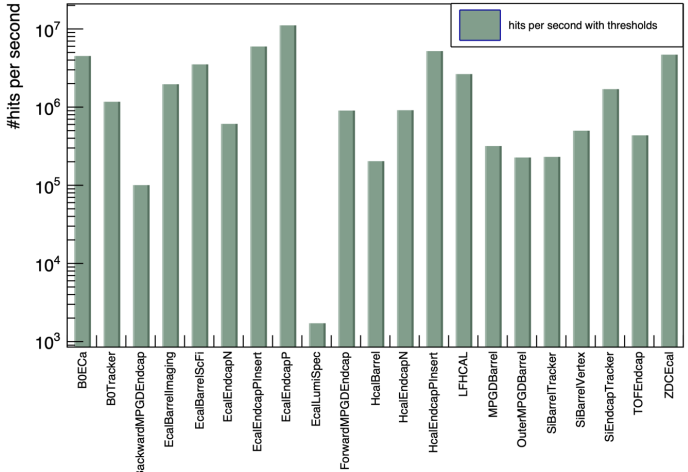
Different to hadron-hadron colliders beam related background cross-sections are larger than signal cross-section

Remember:

- electron beam current and energy impact electron beam gas background and synchrotron radiation
- hadron beam current impacts hadron beam gas

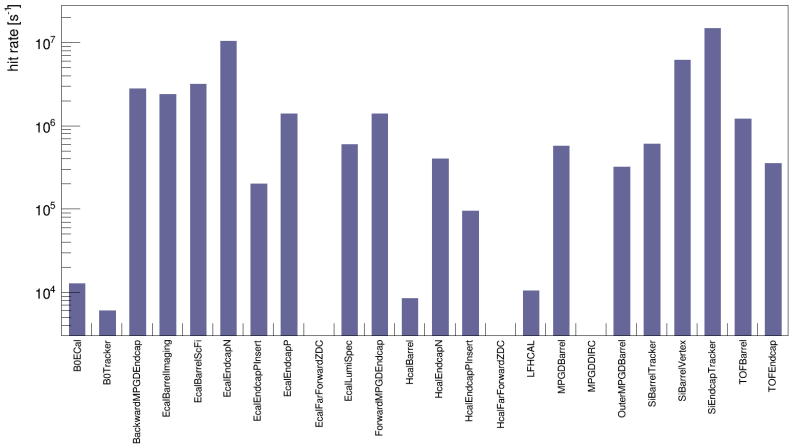
rates in kHz	5x41 GeV	5x100 GeV	10x100 GeV	10x275 GeV	18x275 GeV	Vacuum
Total ep	12.5 kHz	129 kHz	184 kHz	500 kHz	83 kHz	
hadron beam gas	12.2kHz	22.0kHz	31.9kHz	32.6kHz	22.5kHz	10000Ahr
	131.1kHz	236.4kHz	342.8kHz	350.3kHz	241.8kHz	100Ahr
electron beam gas	2181.97 kHz	2826.38 kHz	3177.25 kHz	3177.25 kHz	316.94 kHz	10000Ahr

DIS and Beam Gas Background Rates



DIS ep: 18 GeV x 275 GeV
Luminosity: 1.54×10^{33} $cm^2 s^{-1}$.

Electron Beam Gas
10 GeV
vacuum after 10000 Ah



Hadron Beam Gas
protons: 275 GeV
vacuum after 10000 Ah