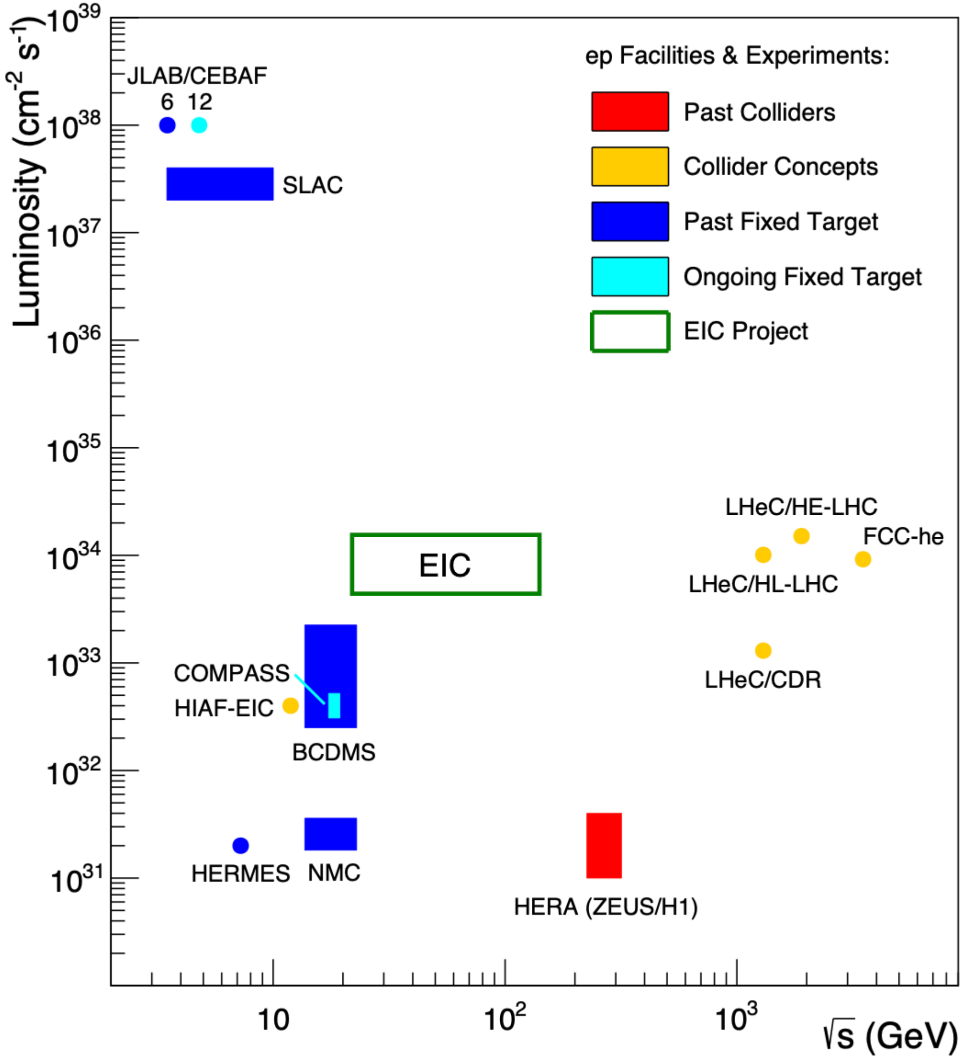
The ePIC detector at the Electron-Ion Collider

Barak Schmookler (UC Riverside)

The Electron-Ion Collider (EIC)



The EIC will be the first

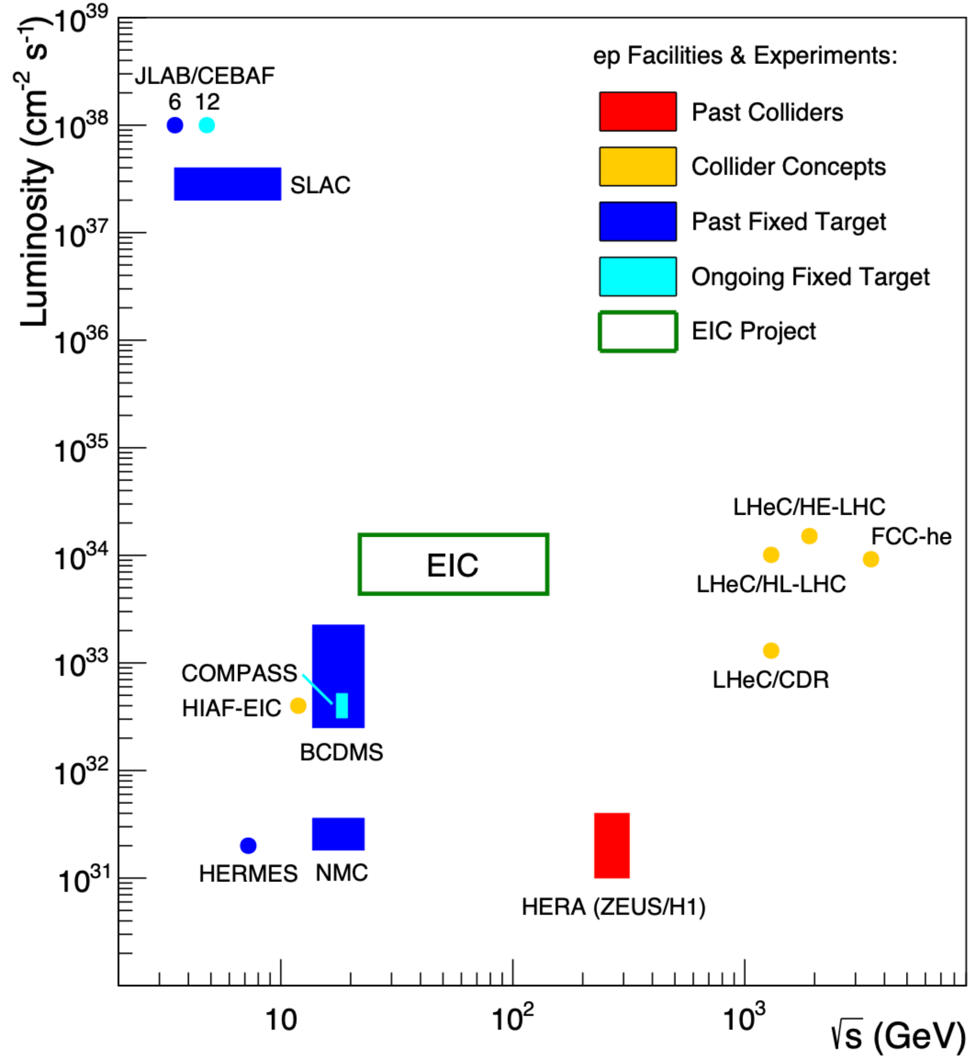
- High-luminosity e-p collider
- Polarized target collider
- Electron-nucleus collider

EIC energy range: $29 < \sqrt{s} < 141\ GeV$

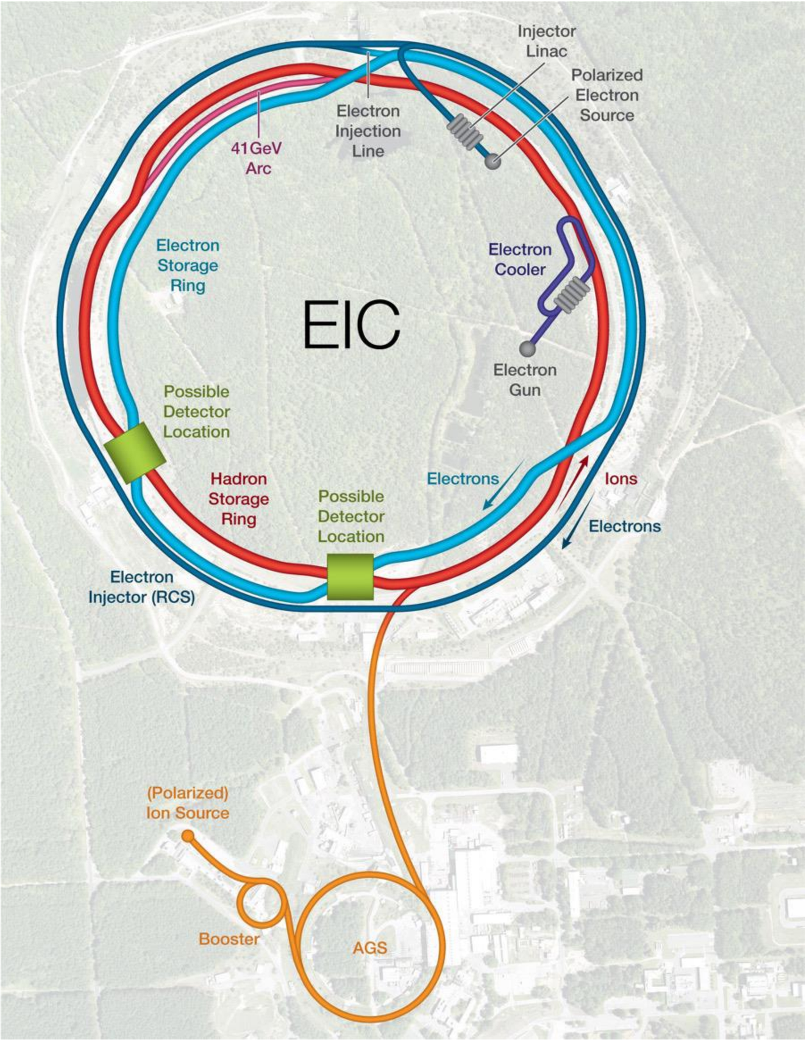
<u>Main physics topics to be explored at the EIC</u>

- Nucleon structure – full three-dimensional momentum and spatial structure, as well as spin structure
- Origin of nucleon (hadron) mass – how is the nucleon's mass generated by the underlying internal partonic interactions
- Dense partonic systems in nuclei
- Science beyond the 2018 National Academies of Science (NAS) report

The Electron-Ion Collider (EIC)

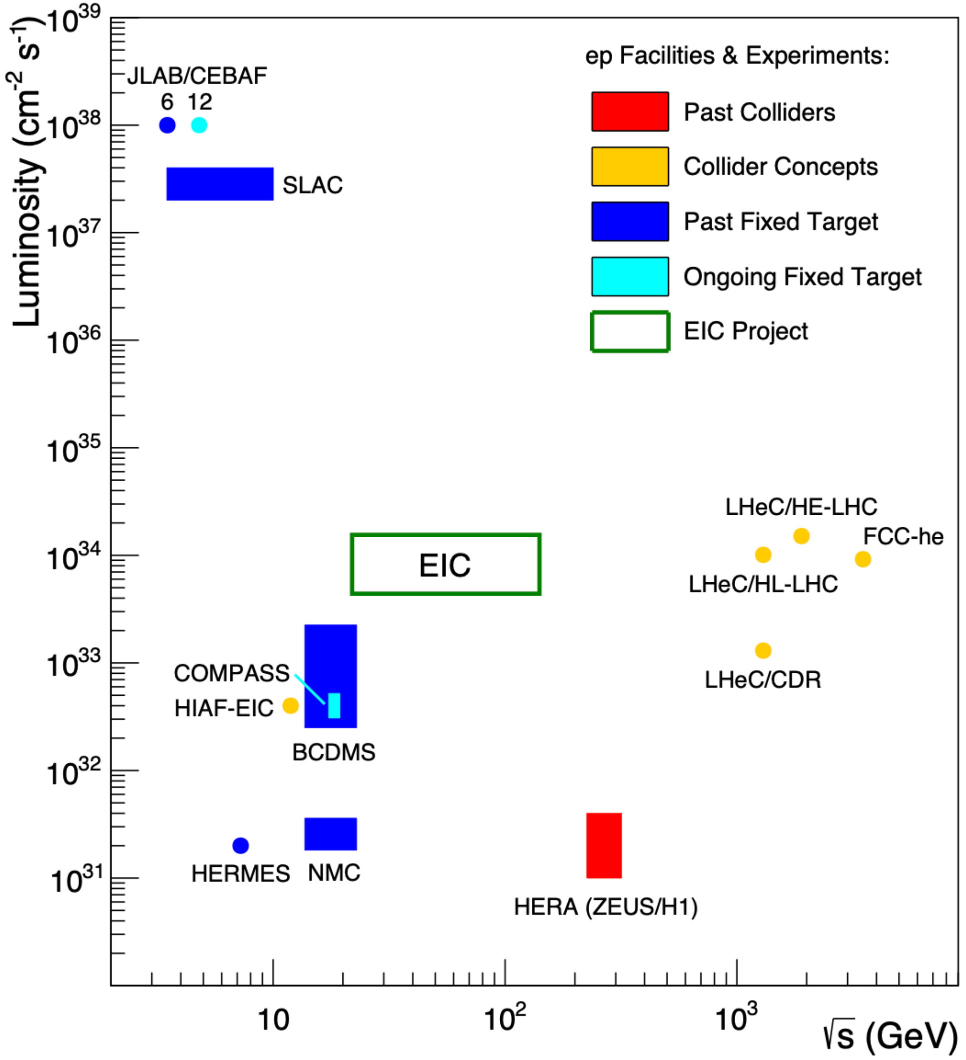


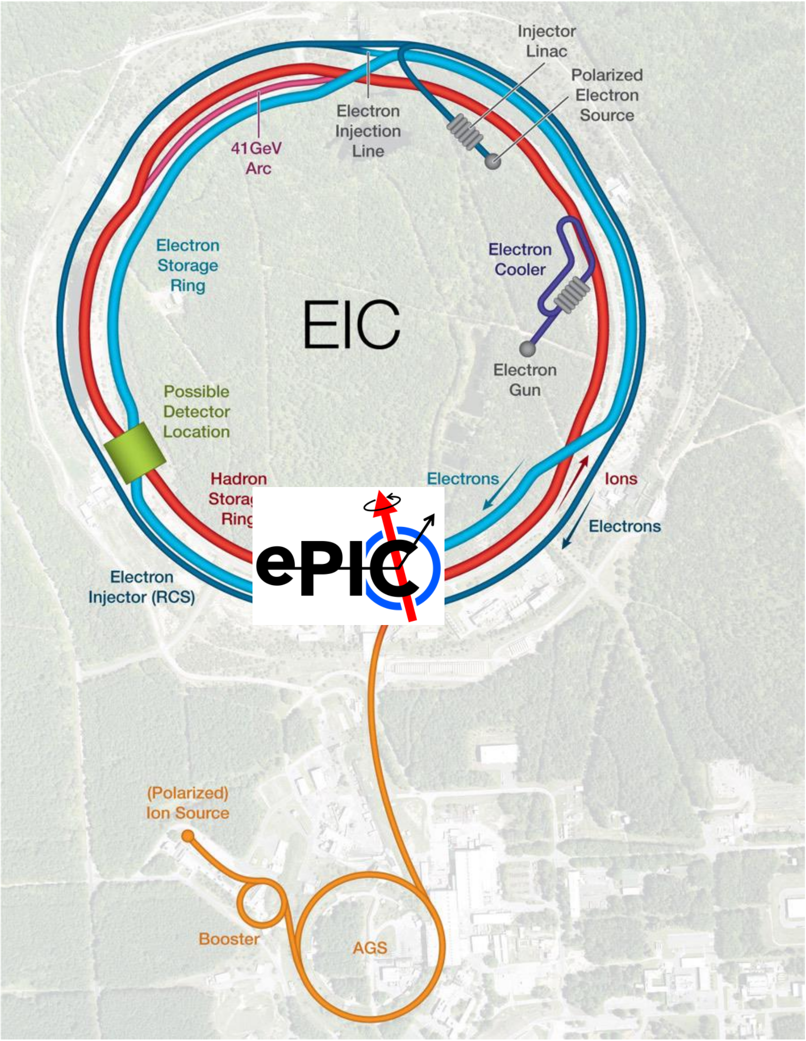
Start date: Early 2030s
Location: BNL
Budget: ~$2.4 billion



See presentation tomorrow by C. Montag for EIC status

The Electron-Ion Collider (EIC)

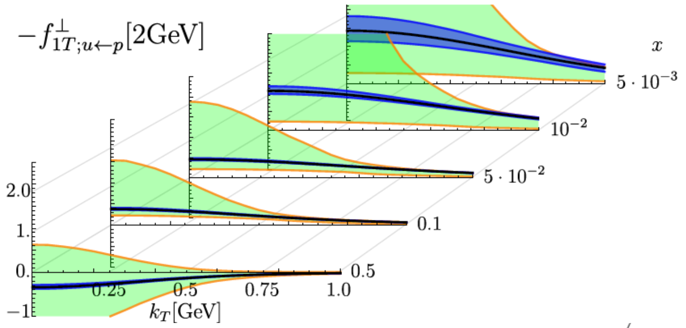


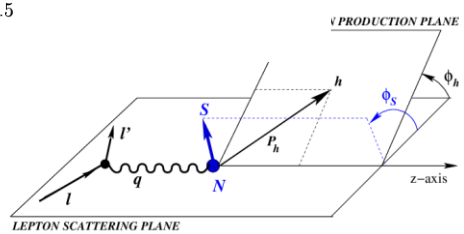


Focus of this talk will be on the physics and status of the **E**lectron-**P**roton/**I**on **C**ollider (ePIC) Experiment

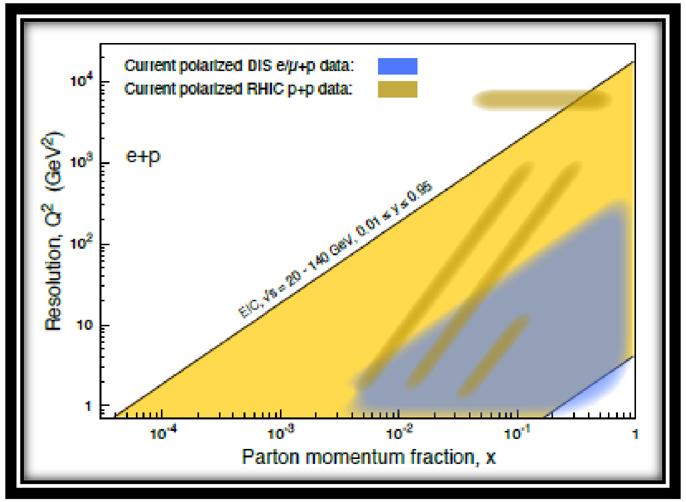
Spin physics at the EIC

Nucl Phys A, Volume 1026, 2022, 122447

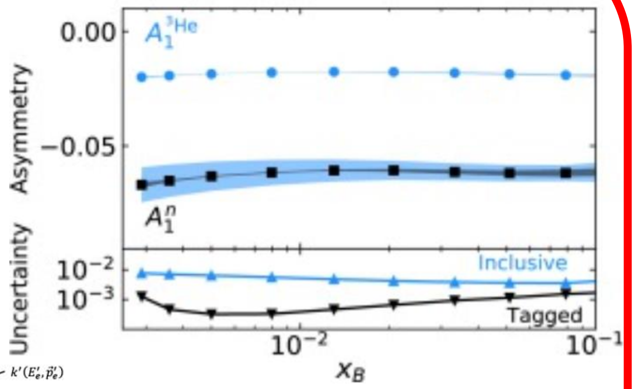


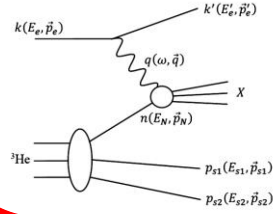


SIDIS



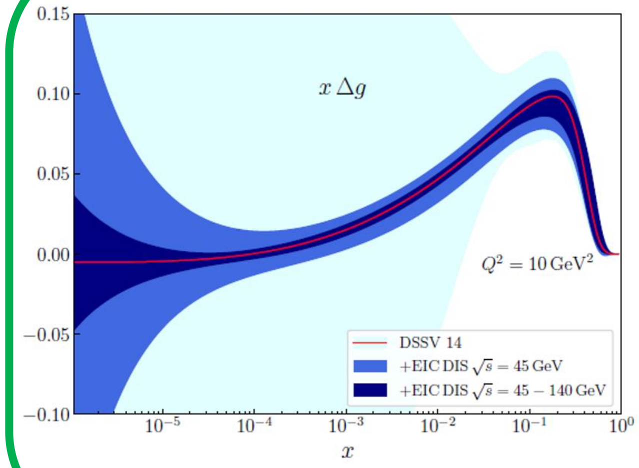
Phys.Lett.B 823 (2021) 136726



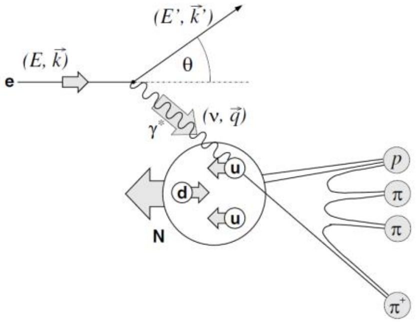


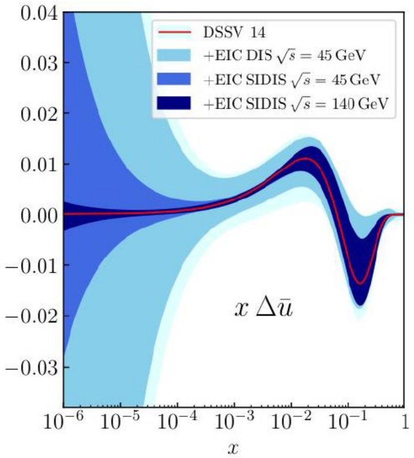
Spectator tagging

Many details in talk by M. Zurek on Monday



(SI)DIS

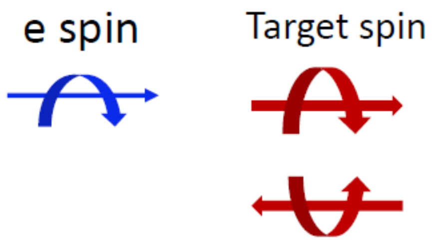




Phys. Rev. D 102 (9) (2020), 94018

Inclusive NC cross section with Longitudinally Polarized protons

At high Q^2, for electron-proton scattering:



$$\Delta\sigma = \frac{d^2\sigma}{dxdQ^2}(\lambda_n = -1, \lambda_l) - \frac{d^2\sigma}{dxdQ^2}(\lambda_n = +1, \lambda_l) = \frac{4\pi\alpha^2}{Q^4 x}\left[-Y_+ g_4 + Y_- 2x g_1 + y^2 g_L\right]$$

$$g_1 = -\lambda g_1^{\gamma} + \eta_z\left(\lambda_l g_v^e - g_A^e\right) g_1^{\gamma z} + \eta_z^2\left[-\lambda_l\left((g_v^e)^2 + (g_A^e)^2\right) + 2 g_A^e g_v^e\right] g_1^z$$

For non-zero electron beam polarization, this term dominates

$$g_{4,5} = \eta_z\left(g_v^e - \lambda_l g_A^e\right) g_{4,5}^{\gamma z} + \eta_z^2\left[-(g_v^e)^2 - (g_A^e)^2 + 2\lambda_l g_A^e g_v^e\right] g_{4,5}^z$$

$$Y_\pm = 1 \pm (1-y)^2$$

$$g_L = g_4 - 2x g_5$$

Prog. Theor. Exp. Phys. 2020, 083C01 (2020)

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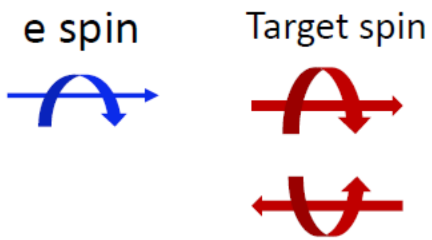


$$\Delta\sigma = \frac{d^2\sigma}{dxdQ^2}(\lambda_n = -1, \lambda_l) - \frac{d^2\sigma}{dxdQ^2}(\lambda_n = +1, \lambda_l) = \frac{4\pi\alpha^2}{Q^4 x}\left[-Y_+ g_4 + Y_- 2x g_1 + y^2 g_L\right]$$

$$\approx \frac{4\pi\alpha^2}{Q^4 x}\left(Y_- 2x g_1^\gamma\right)$$

$$A_{||} = \frac{\sigma(\lambda_n = -1, \lambda_l = -1) - \sigma(\lambda_n = +1, \lambda_l = -1)}{\sigma(\lambda_n = -1, \lambda_l = -1) + \sigma(\lambda_n = +1, \lambda_l = -1)} \approx \frac{Y_-}{Y_+} A_1$$

$$\left\{ A_{\gamma * p} = A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{g_1^\gamma}{F_1^\gamma} \right.$$

Prog. Theor. Exp. Phys. 2020, 083C01 (2020)

Extraction of polarized PDFs from g_1

$$g_1^{\gamma}(x,Q^2) = \sum_{i=q,g} C_i \otimes \Delta f_i$$

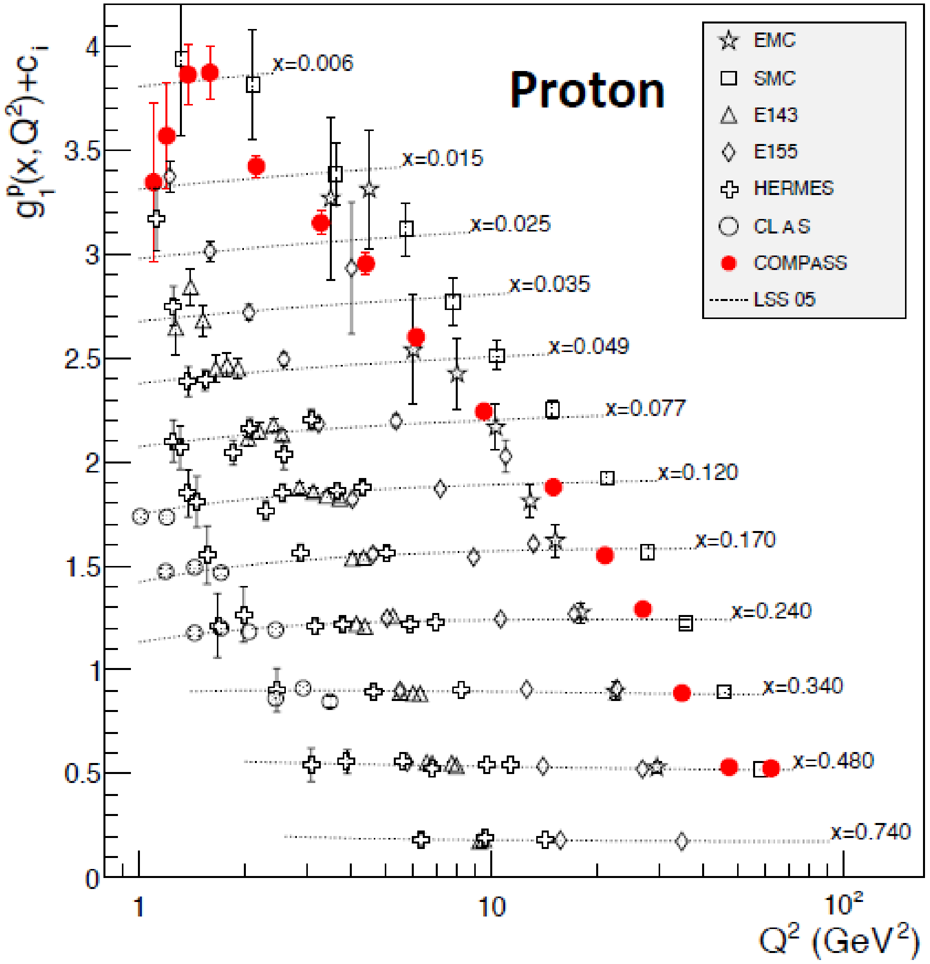
$$= \frac{1}{2}\sum_q e_q^2 \left[\Delta q(x,Q^2) + \Delta\bar{q}(x,Q^2)\right] \quad \textbf{at LO}$$

$$\frac{\partial \Delta f_{i=q,g}}{\partial\, lnQ^2} = \sum_j P_{i,j} \otimes \Delta f_j$$

DGLAP evolution

Need measurements at a wide variety of x values and scales (Q^2 values) to constrain the polarized quark and gluon PDFs

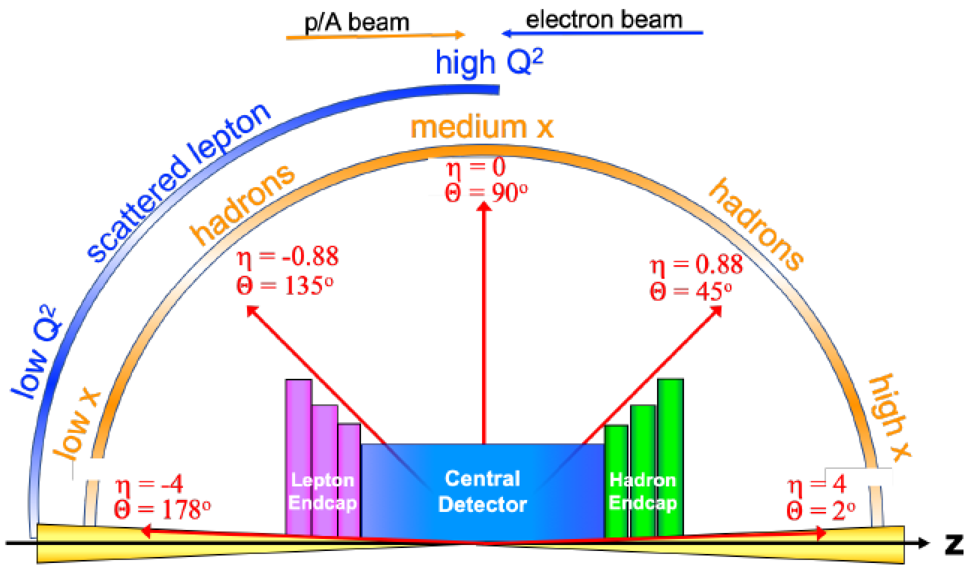
Aidala et al.1209.2803v2



Prog. Theor. Exp. Phys. 2020, 083C01 (2020)

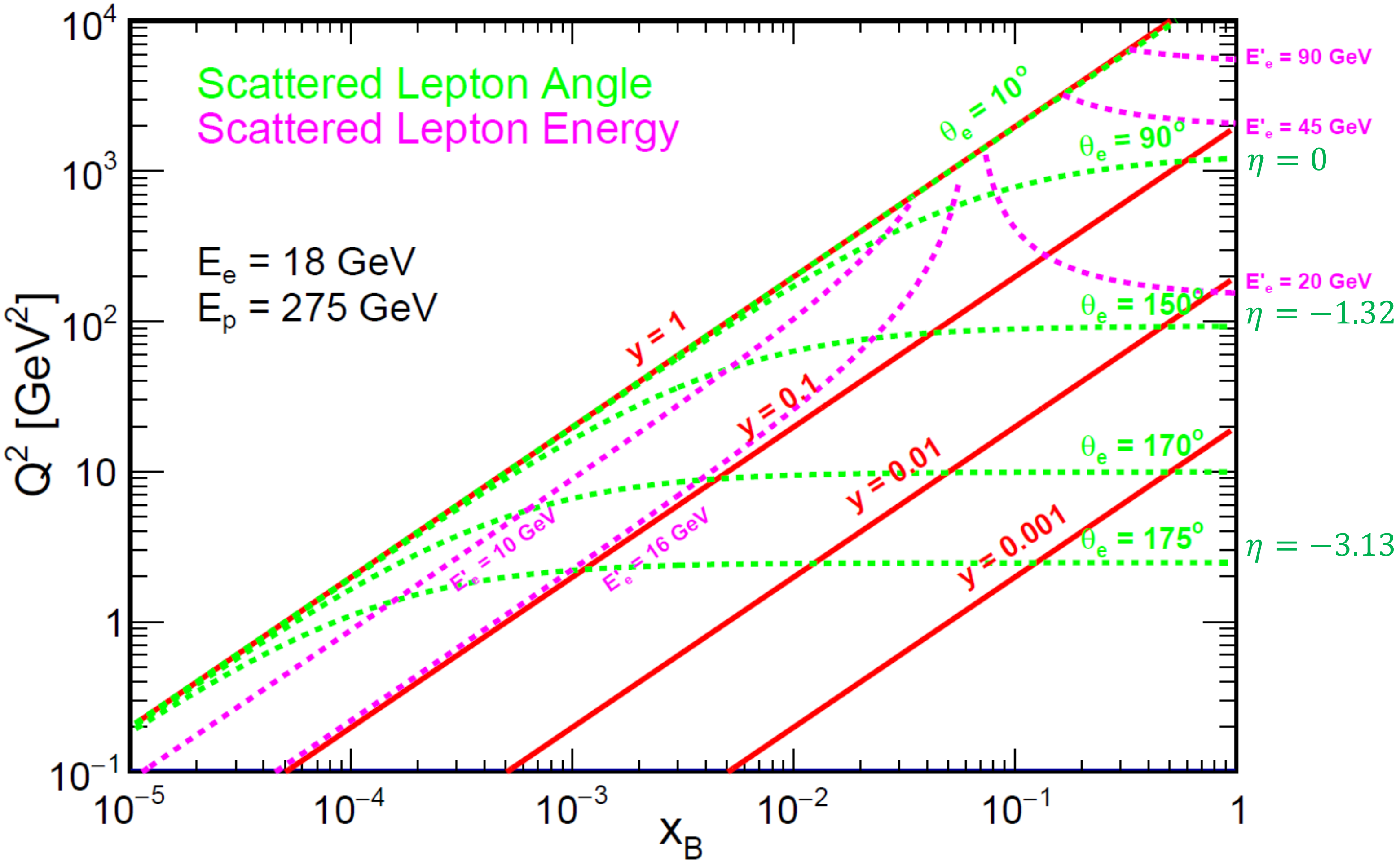
What are the general EIC detector requirements to make good measurements for the observables shown above?

Detector requirement	Associated challenge
Hermetic coverage for the scattered electron	Leave no gaps in EMcal coverage while also incorporating PID readout
Good momentum resolution over the entire detector acceptance, including for the endcap regions	Design trackers to optimize momentum resolution when the particle has a large component parallel to the solenoid field
High scattered electron purity in the backwards direction and barrel	Require high-precision EMcals and additional detectors for low momentum
PID for π/K/p separation down to very low momenta	Combine multiple technologies to obtain continuous coverage from high to low momentum
Good forward calorimetry and PID	Need good energy resolution for hadronic final state; space is constrained for PID detector placement



Example: scattered electron reconstruction

$Q^2 = sxy$



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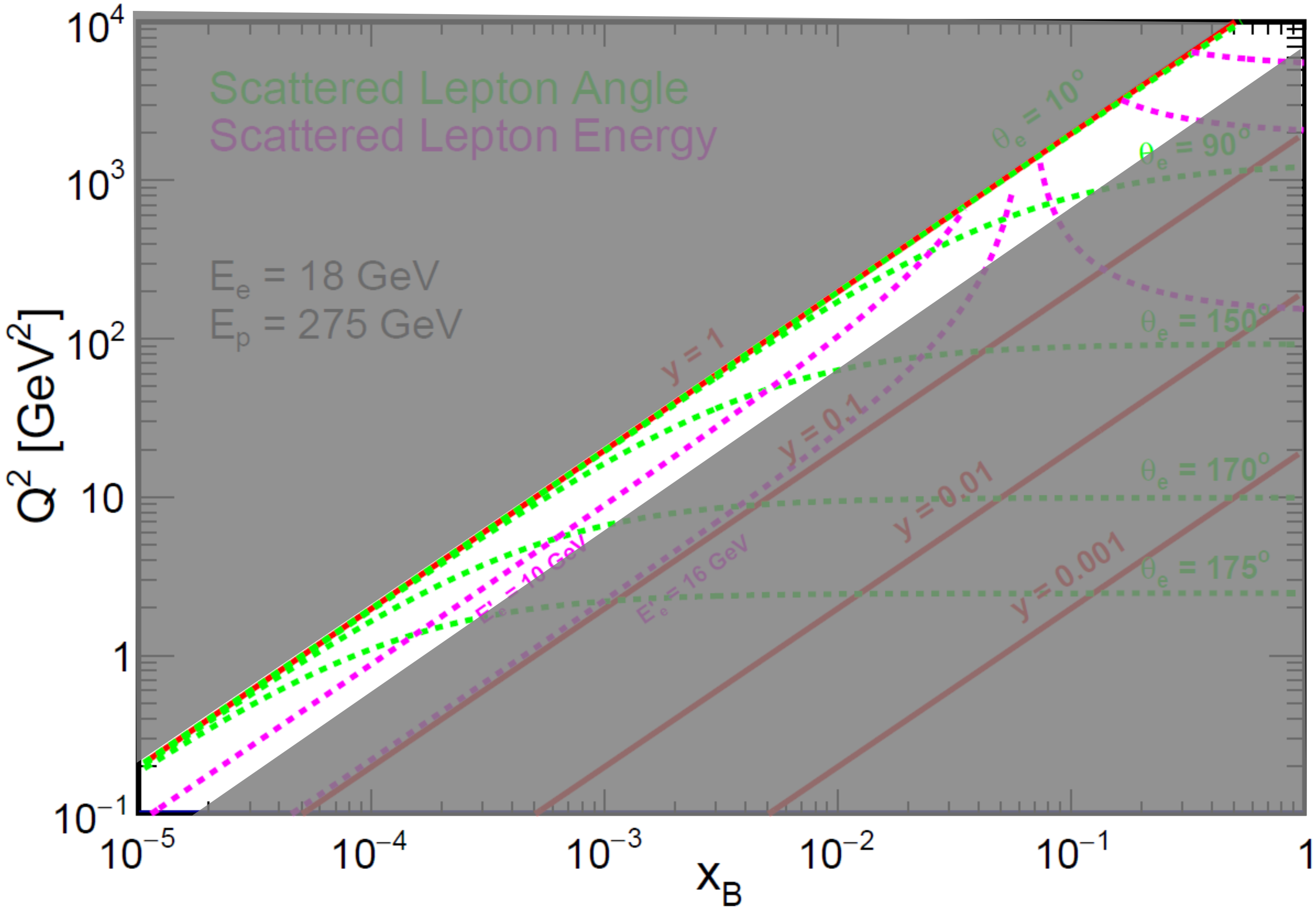


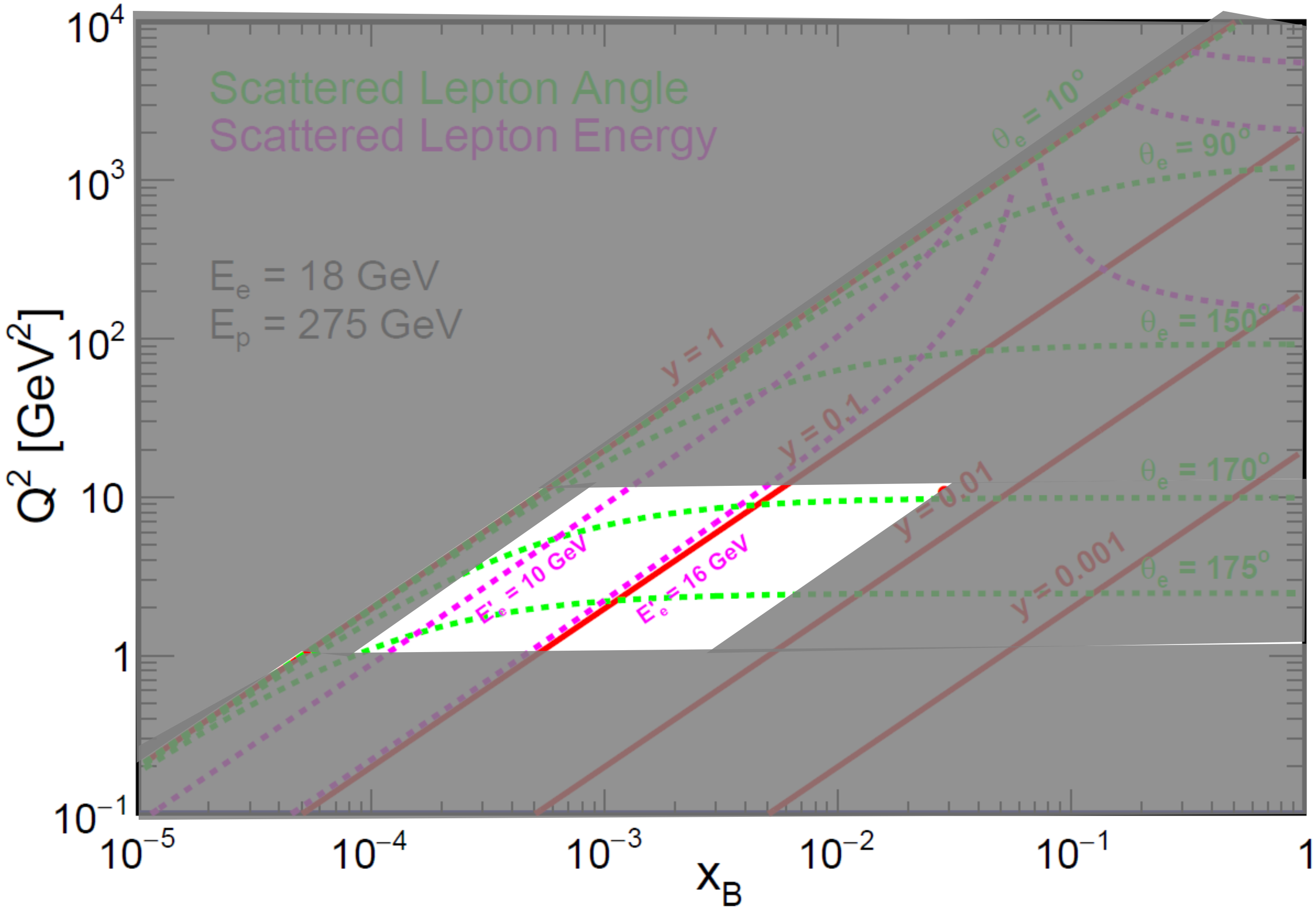
<u>High y region</u>

Problem: large amount of photoproduction background to the DIS electron and large QED radiative corrections.

The detector needs very good electron identification at low to moderate momenta, as well as the ability to reconstruct the total $E - p_z$ for the event.

Example: scattered electron reconstruction

$$Q^2 = sxy$$



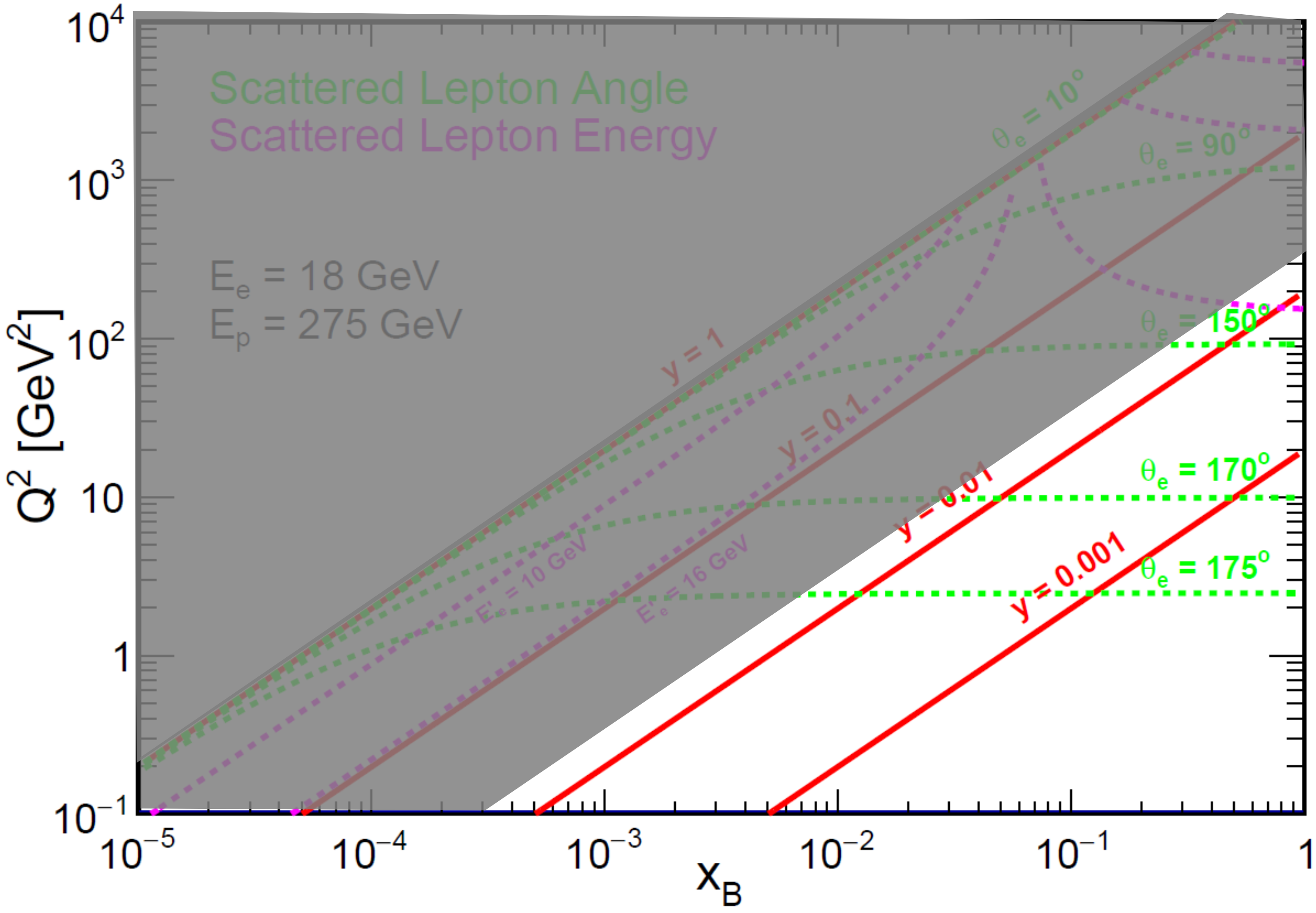
Intermediate y / lower Q^2 region

Problem: the scattered electron goes into the electron endcap – that is, it has a small scattering angle w.r.t. the electron beam – and has a large momentum.

The detector needs an optimal tracking layout in the electron endcap. The EMCal in the endcap must also have a very good energy resolution, allowing the tracker momentum and the calorimeter energy measurements to complement one other.

Example: scattered electron reconstruction

$Q^2 = sxy$



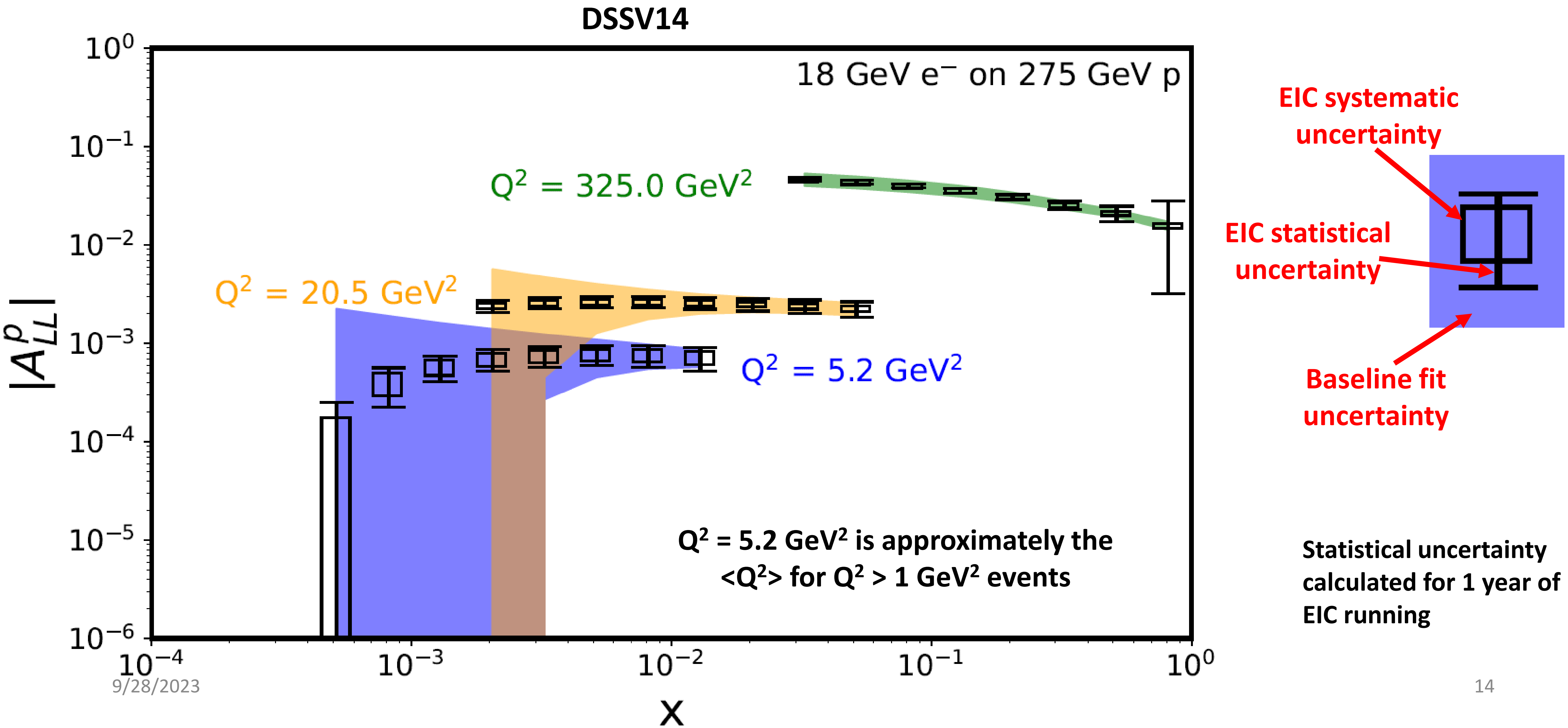
<u>Low y region</u>

Problem: reconstruction of x_B using the scattered electron becomes impossible (due to 1/y dependence).

The detector needs to use information from the hadronic final state to reconstruct x_B. This requires good energy and P_T resolution in the hadronic endcap.

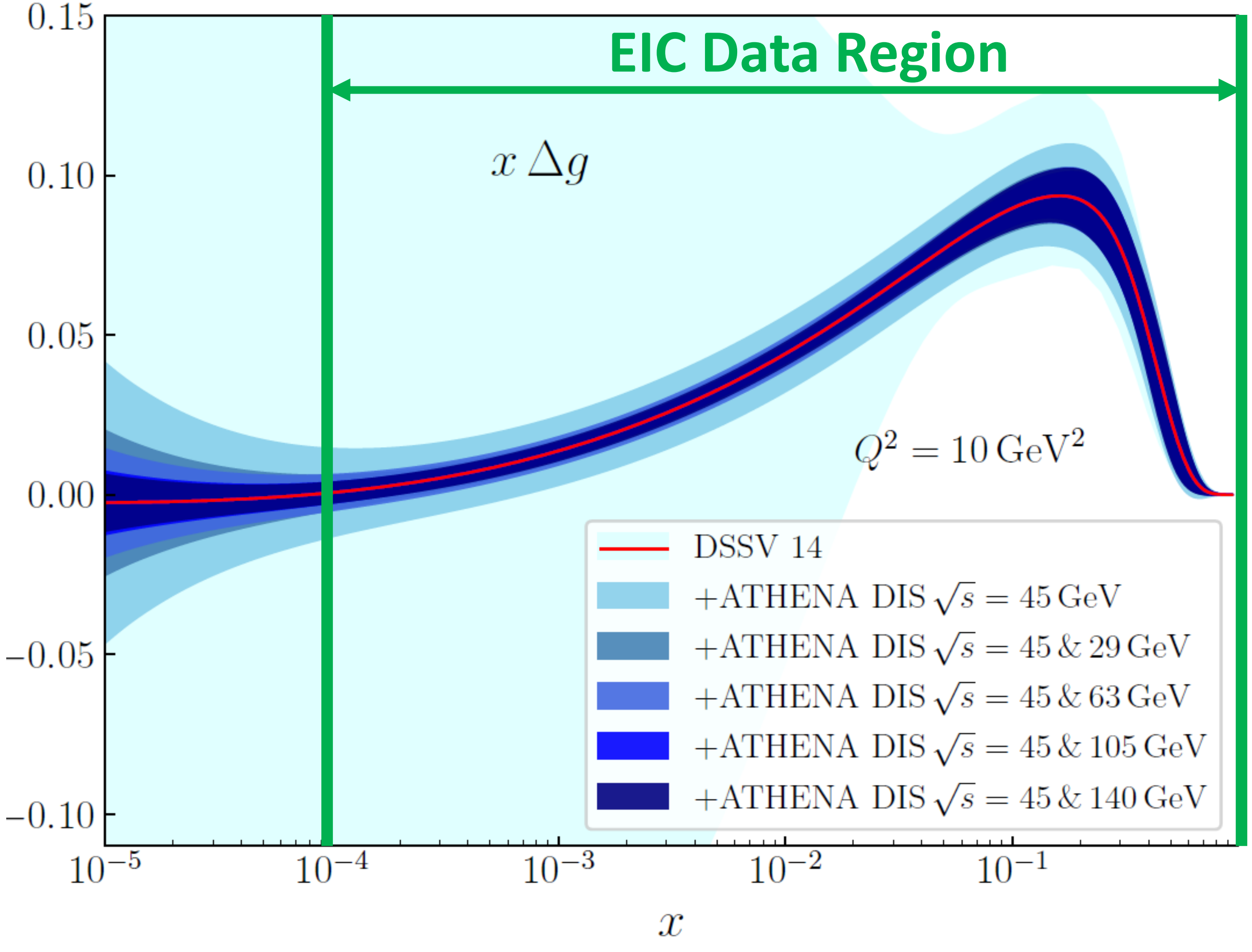
Alternatively for many measurements it is often easier to rely on overlaps between data at different $\sqrt{s}$. This requires the detector to be optimized for scattered electron kinematics at different beam energies.

Expected EIC experimental precision



Statistical uncertainty calculated for 1 year of EIC running

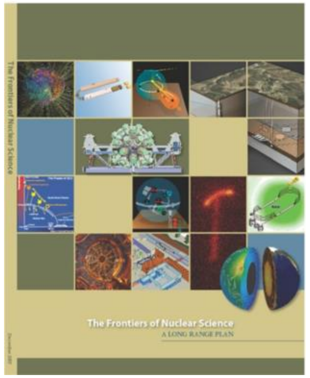
Impact of EIC on helicity PDFs

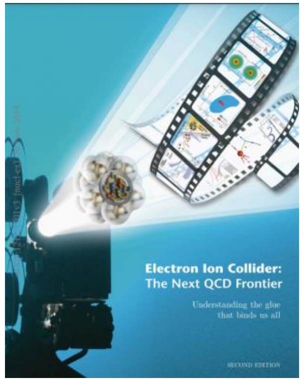


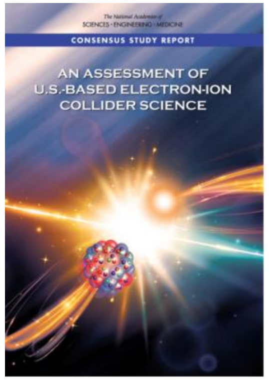
e-beam E	p-beam E	$\sqrt{s}$ (GeV)	inte. Lumi. (fb^{-1})
18	275	140	15.4
10	275	105	100.0
10	100	63	79.0
5	100	45	61.0
5	41	29	4.4

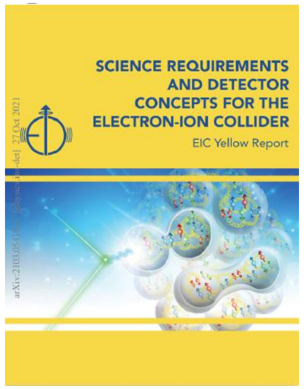
Detector proposals

EIC physics goals and detector requirements – 2007-2020

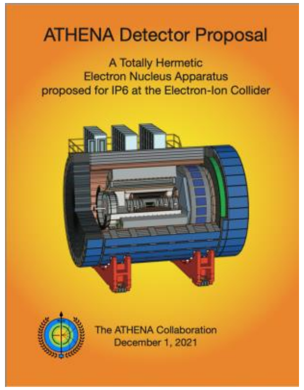


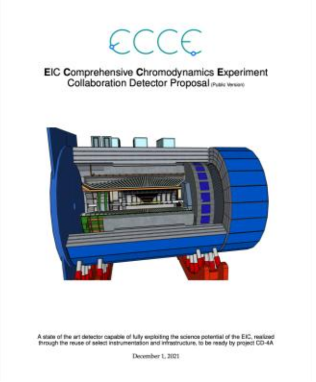






Detector proposals – Dec. 2021





Timeline

- January 2020: BNL site selection
- EIC Yellow report outlines detector requirements
- March 2021: Call for detector proposals
- December 2021: Detector Proposal Advisory Panel (DPAP) begins review of three proposals: ATHENA, CORE, and ECCE
- March 2022: ECCE adopted as reference design for first detector, collaborations merge
- July 2022: ePIC collaboration

ePIC detector design

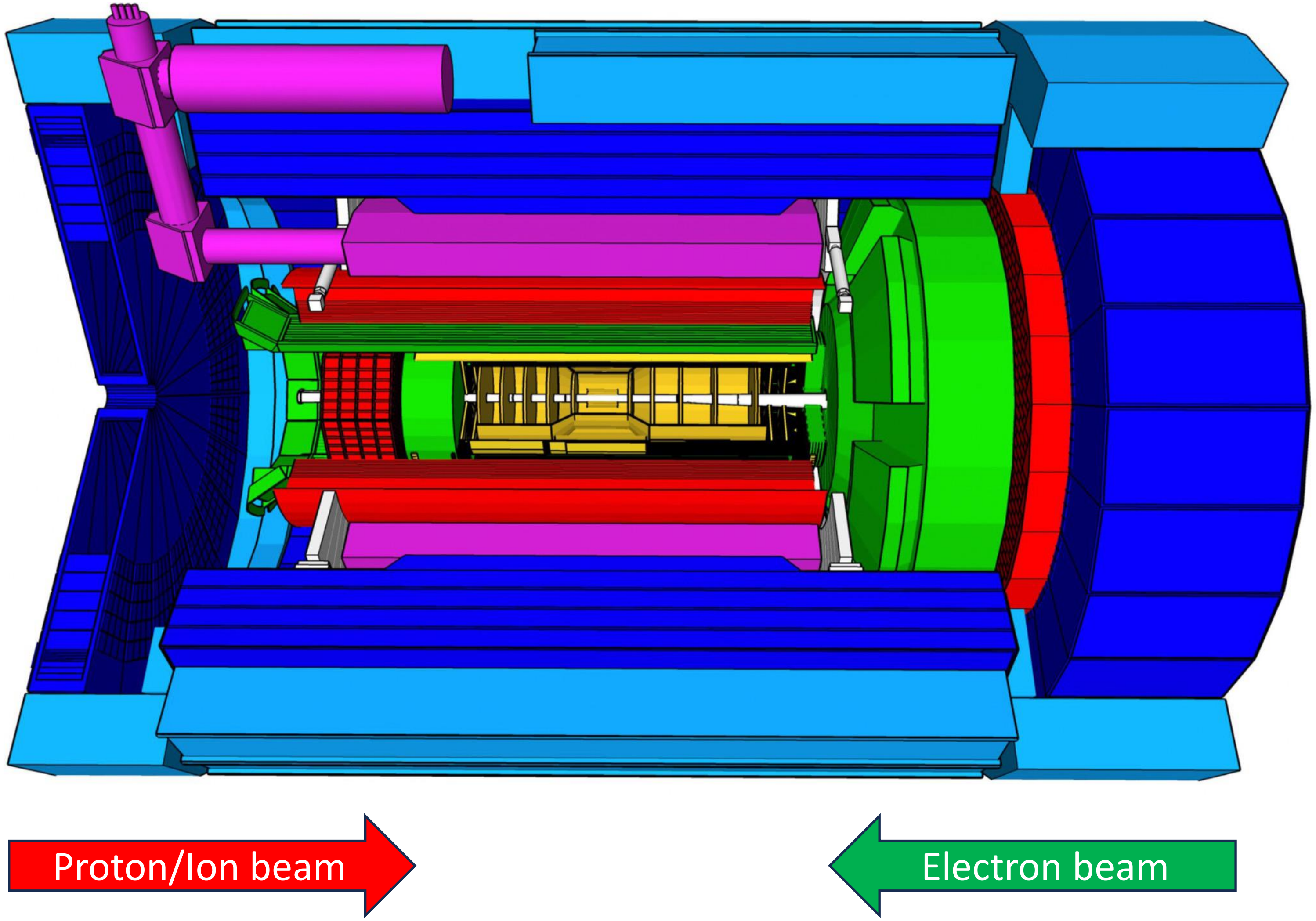
Magnet
- New 1.7 T SC solenoid, 2.8 m bore diameter

Tracking
- Si Vertex Tracker MAPS wafer-level stitched sensors (ALICE ITS3)
- Si Tracker MAPS barrel and disks
- Gaseous tracker: MPGDs (μRWELL, MMG) cylindrical and planar

PID
- high performance DIRC (hpDIRC)
- dual RICH (aerogel + gas) (forward)
- proximity focussing RICH (backward)
- ToF using AC-LGAD (barrel+forward)

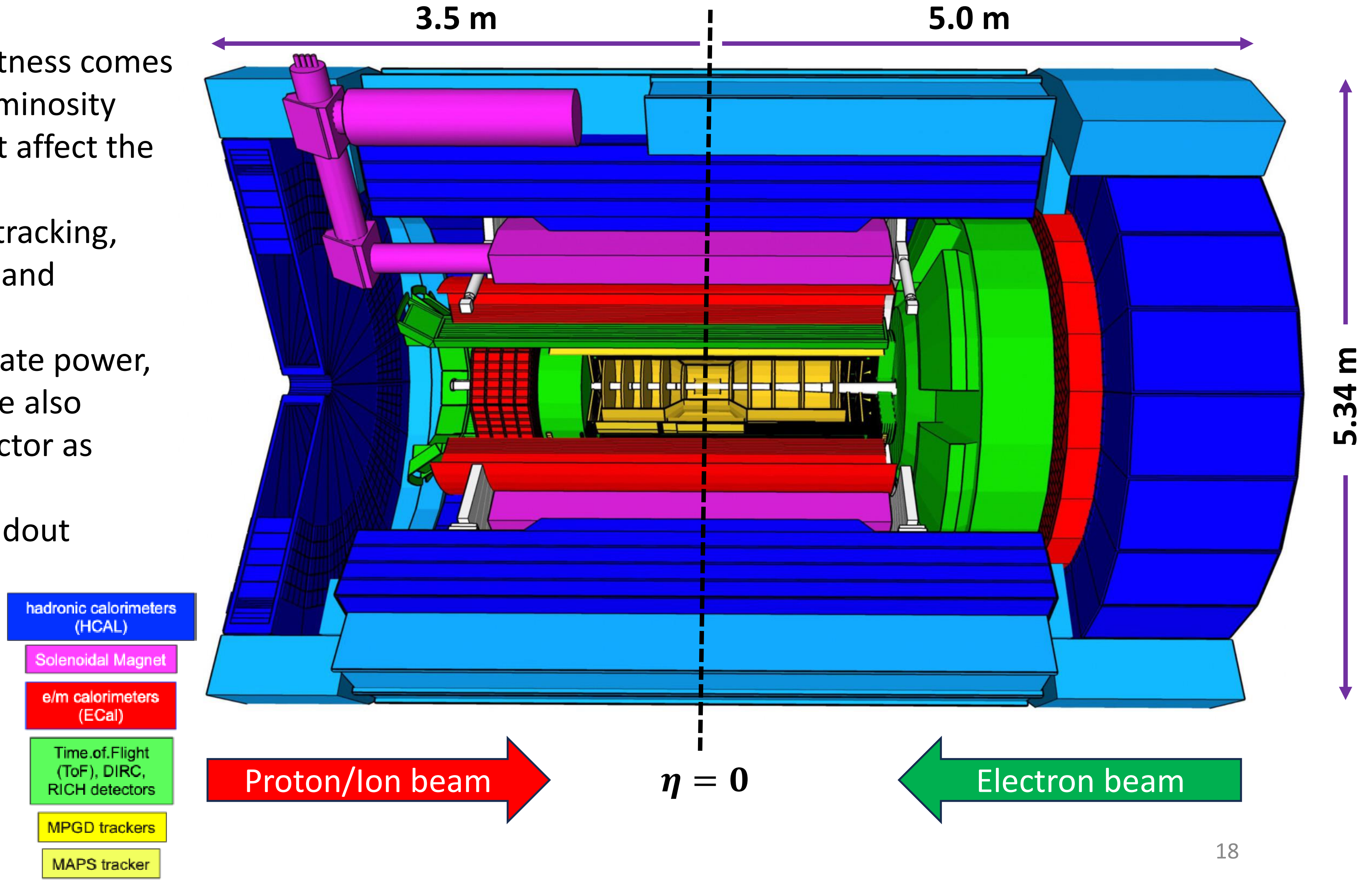
EM Calorimetry
- imaging EMCal (barrel)
- W-powder/SciFi (forward)
- $PbWO_4$ crystals (backward)

Hadron calorimetry
- FeSc (barrel, re-used from sPHENIX)
- Steel/Scint – W/Scint (backward/forward)



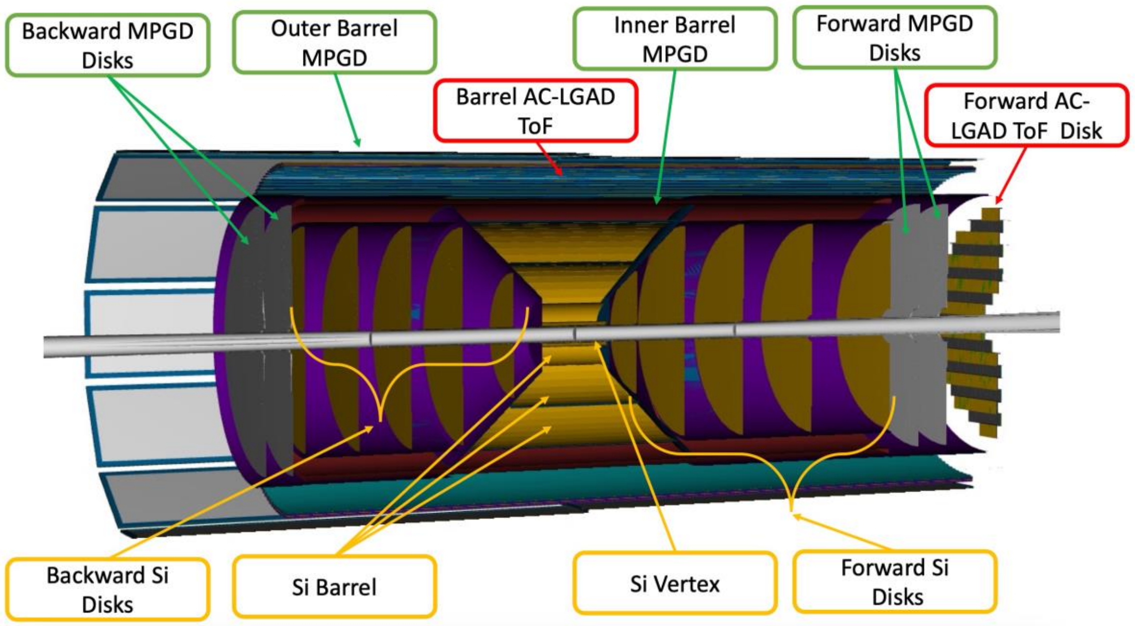
ePIC detector design

- Detector is ~9m long – compactness comes from IR design allowing high luminosity
- Solenoidal field – magnet won't affect the electron beam
- Combines > 16 subsystems for tracking, vertexing, PID, EM calorimetry, and hadronic calorimetry
- Substantial challenges to integrate power, cooling, and data services, while also maintaining as hermetic a detector as possible
- Detector will use streaming-readout approach



ePIC detector design – tracking

Full tracking system: Silicon Vertex Tracker (SVT) + MPGDs + AC-LGAD TOFs detectors

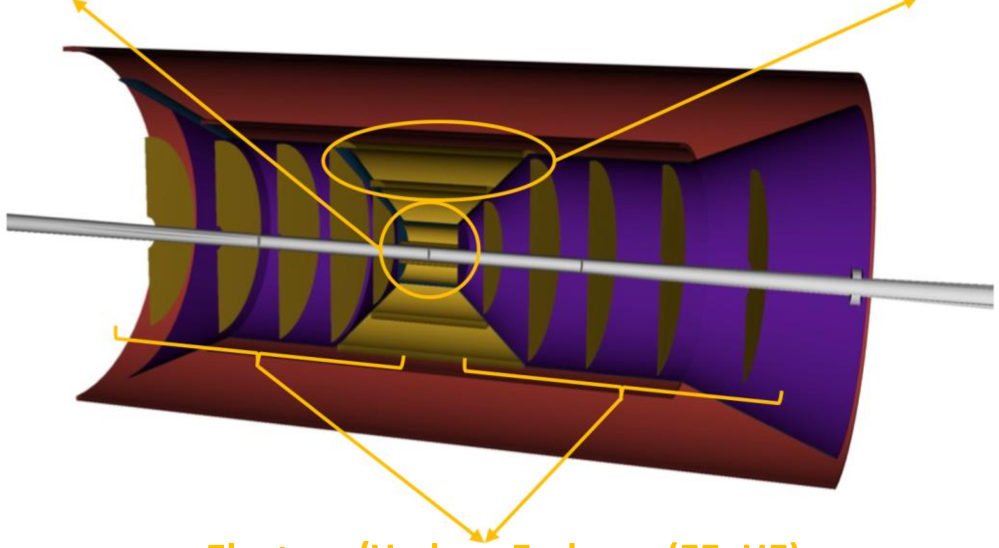


MPGDs and **AC-LGADs** provide
- additional hit points for track reconstruction
- fast timing hits for background rejection (~10-20 ns)

SVT

Inner Barrel (IB)
- Two curved silicon vertex layers
- One curved dual-purpose layer
- 0.05% X/X0 per layer

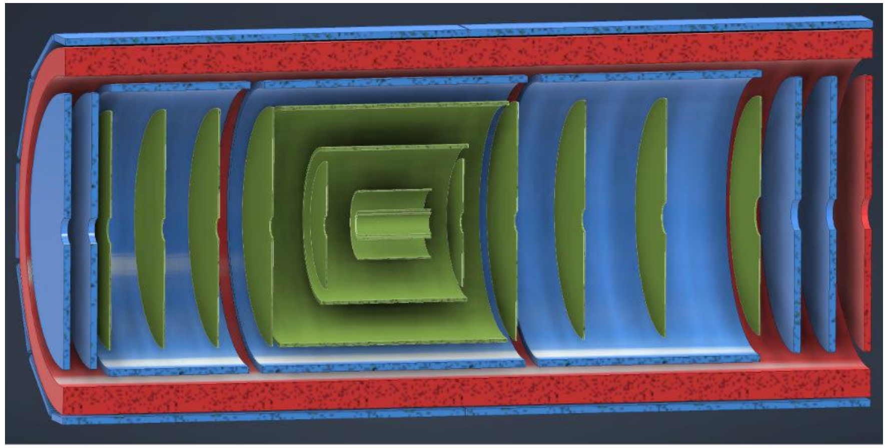
Outer Barrel (OB)
- One stave-based sagitta layer
- One stave-based outer layer
- 0.55% X/X0 per layer



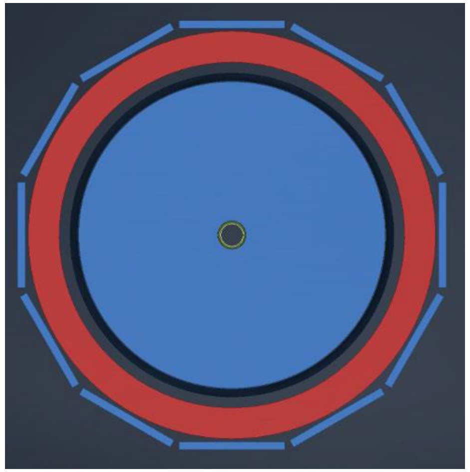
Electron/Hadron Endcaps (EE, HE)
- Five disks on either side of the Interaction Region
- 0.24% X/X0 per layer

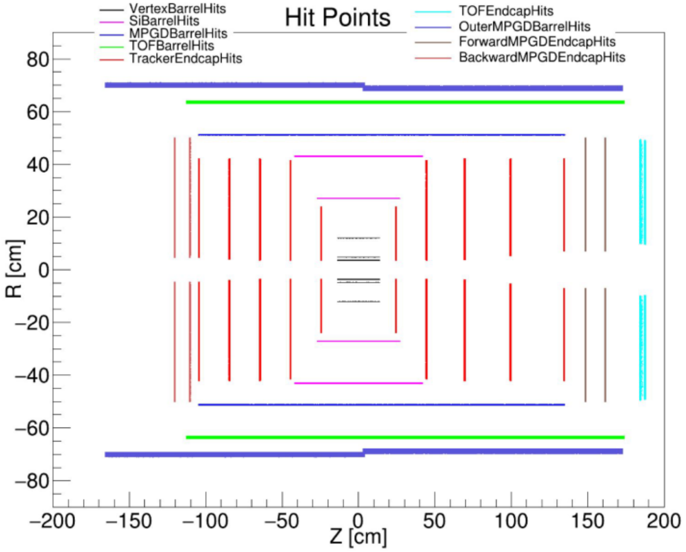
65 nm MAPS technology (ALICE ITS3)
O(20x20 μm^2) pixel size
Total active area of 8.5 m^2

Tracking performance



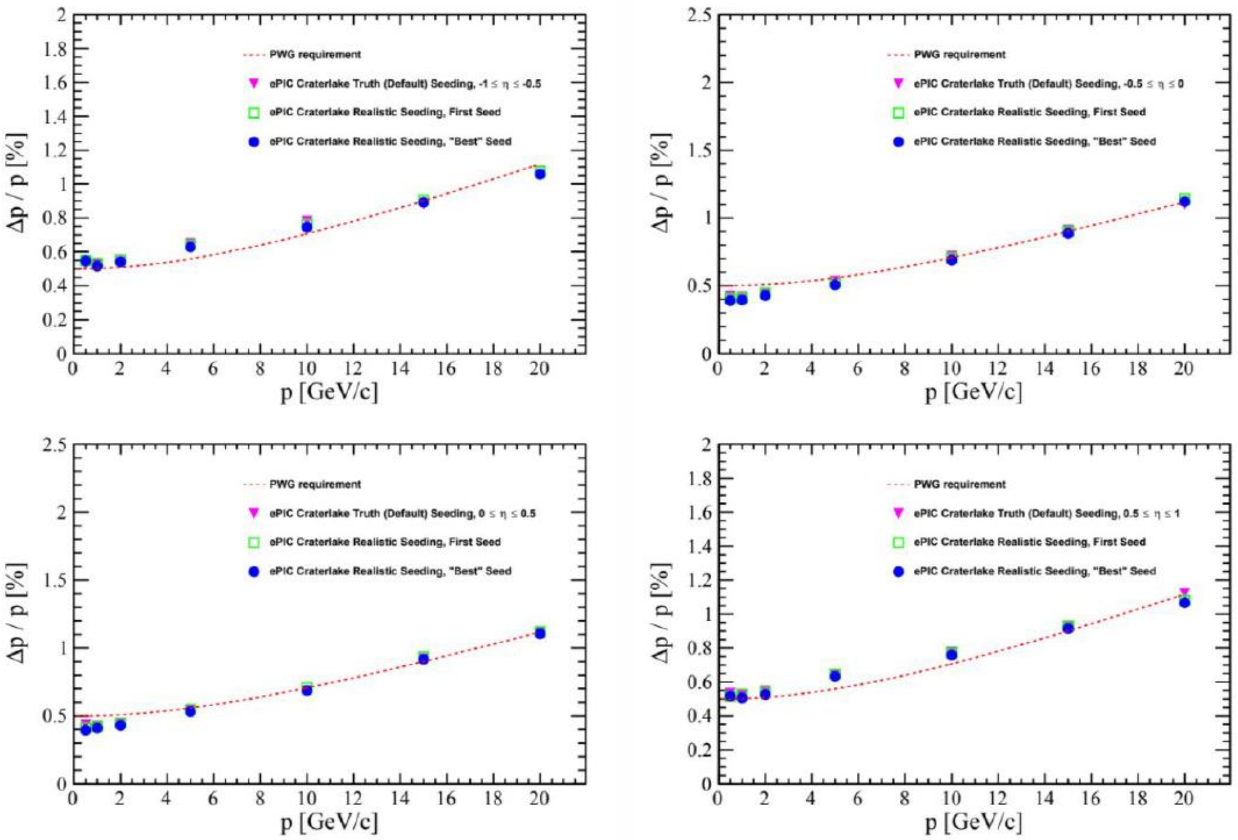
SVT MPGDs ToF (fiducial volume)





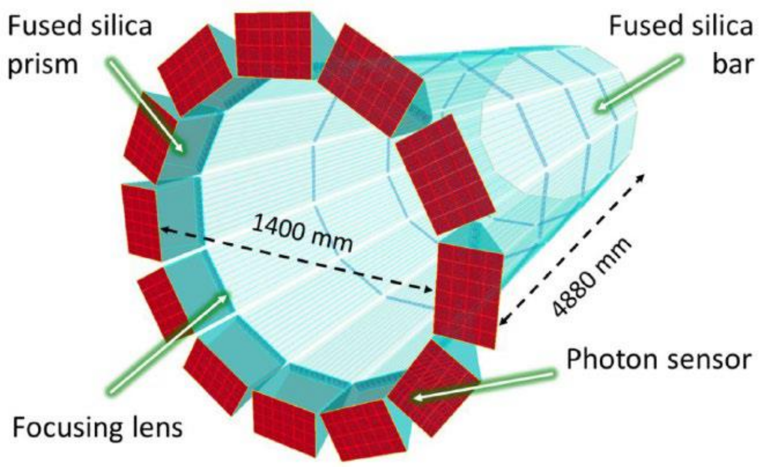
arXiv:1910.03128

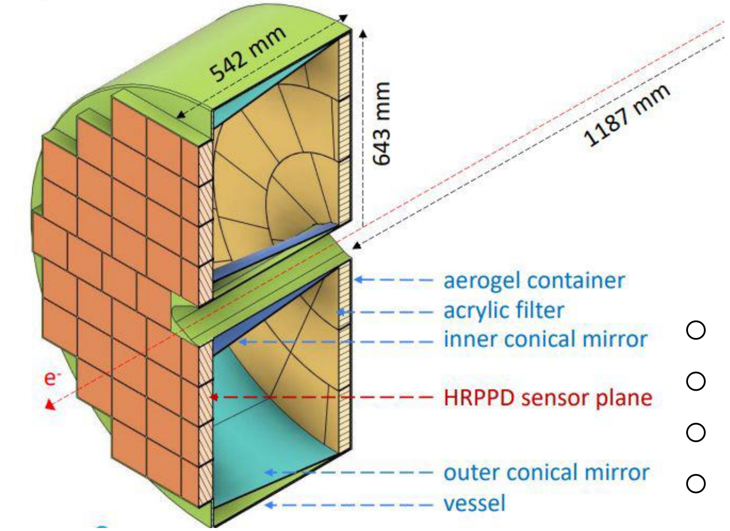
A Common Tracking Software

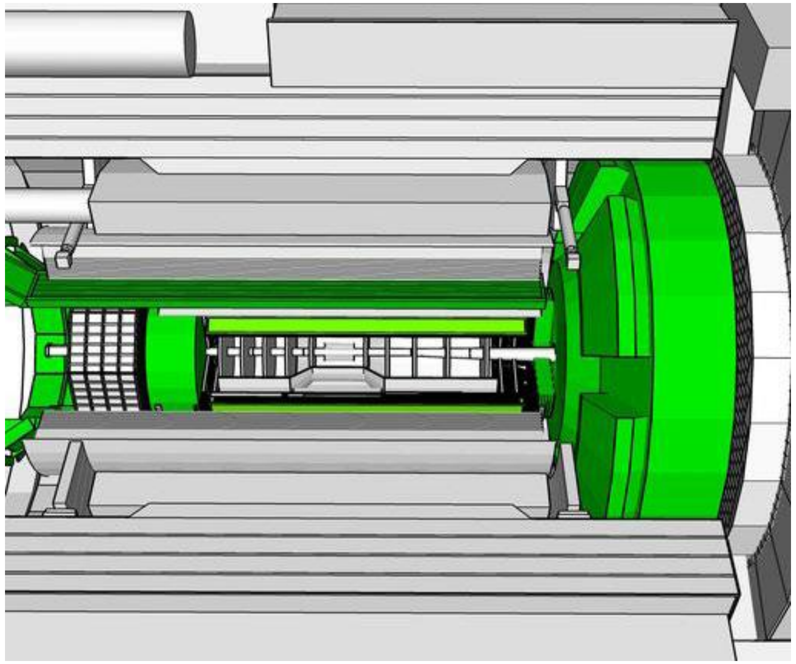


ePIC detector design – PID

High-Performance DIRC
- Quartz bar radiator (reuse BaBAR bars)
- Sensors: MCP-PMTs
- π/K separation up to 6 GeV/c

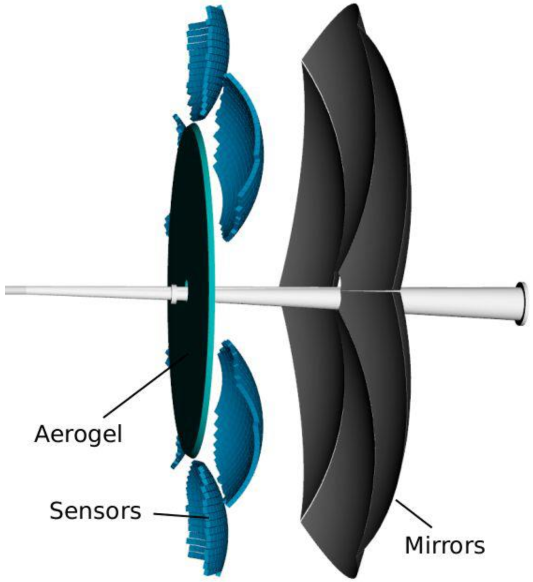




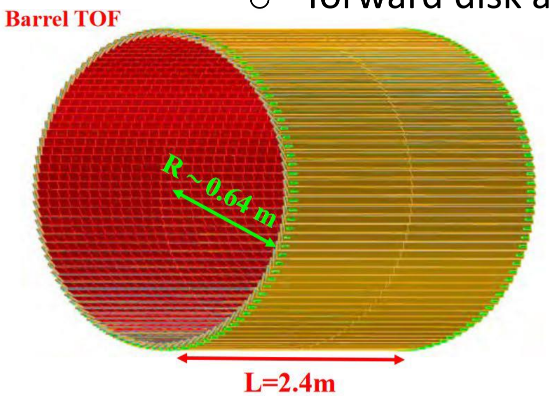


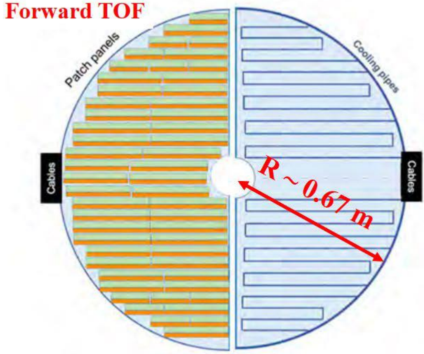
Proximity Focused (pfRICH)
- Long Proximity gap (~40 cm)
- Sensors: HRPPDs (also provides timing)
- π/K separation up to 10 GeV/c
- e/π separation up to 2.5 GeV/c

Dual-Radiator RICH (dRICH)
- C_2F_6 Gas Volume and Aerogel
- Sensors: SiPMs tiled on spheres
- π/K separation up to 50 GeV/c



AC-LGAD TOF
- t = ~30 psec / s = 30 µm
- Accurate space point for tracking
- forward disk and central barrel





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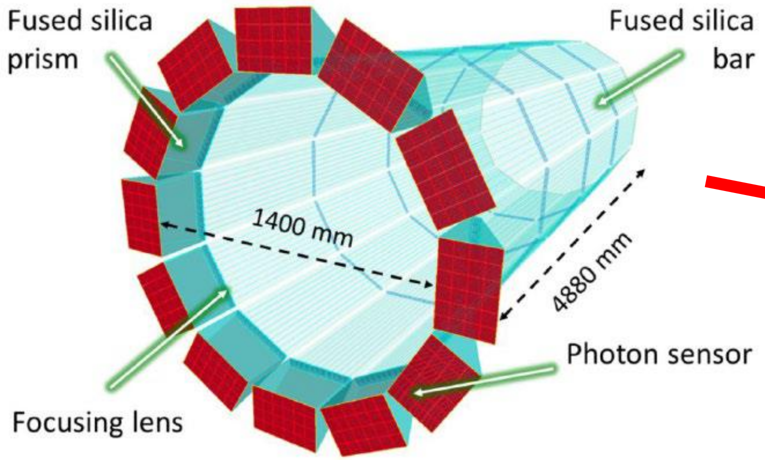

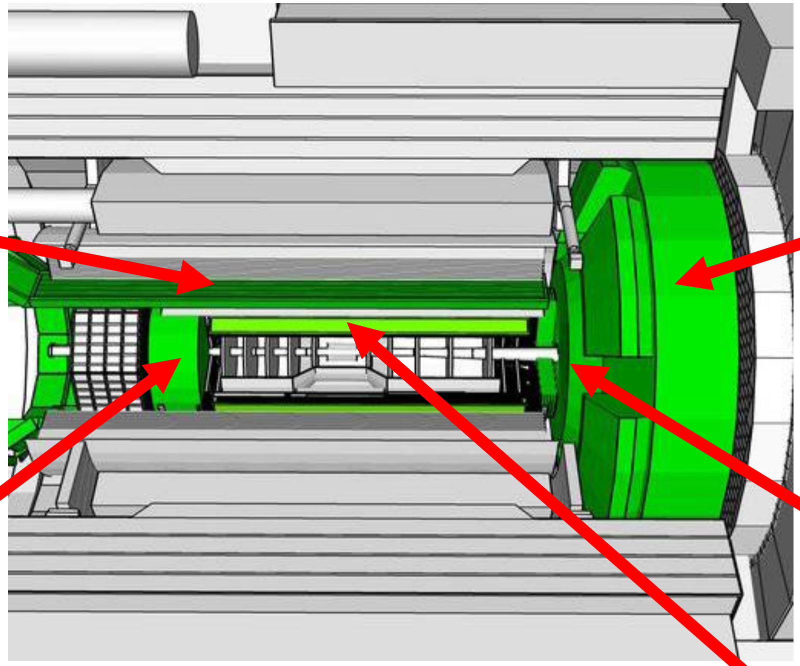

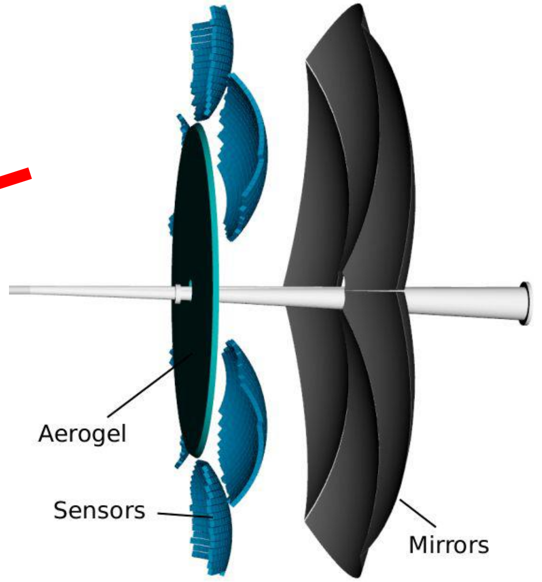

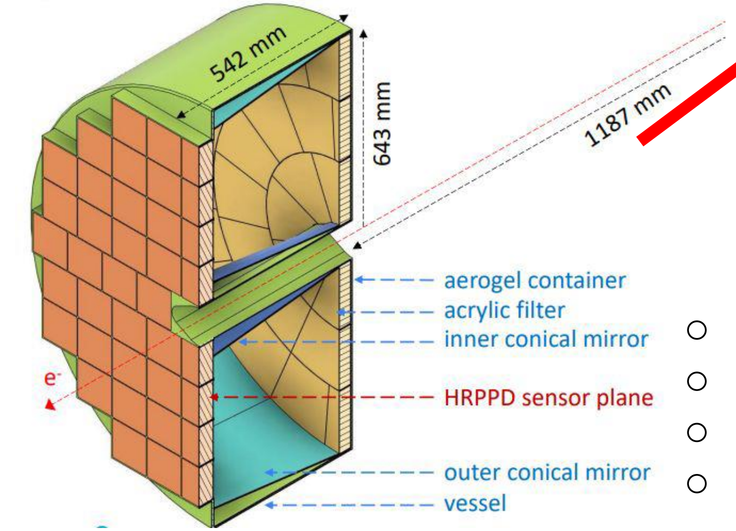

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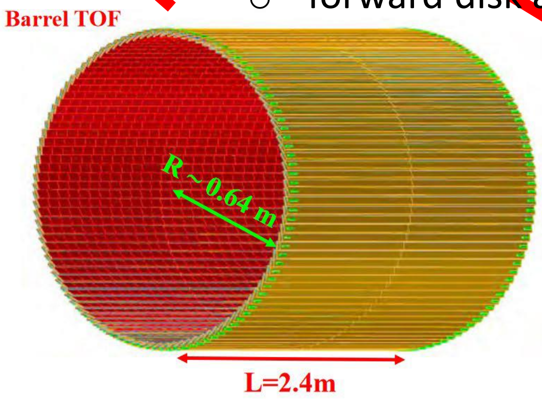
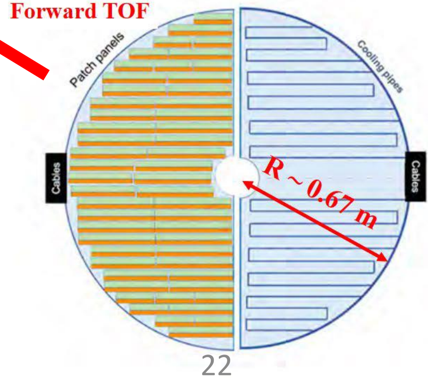
- forward disk and central barrel

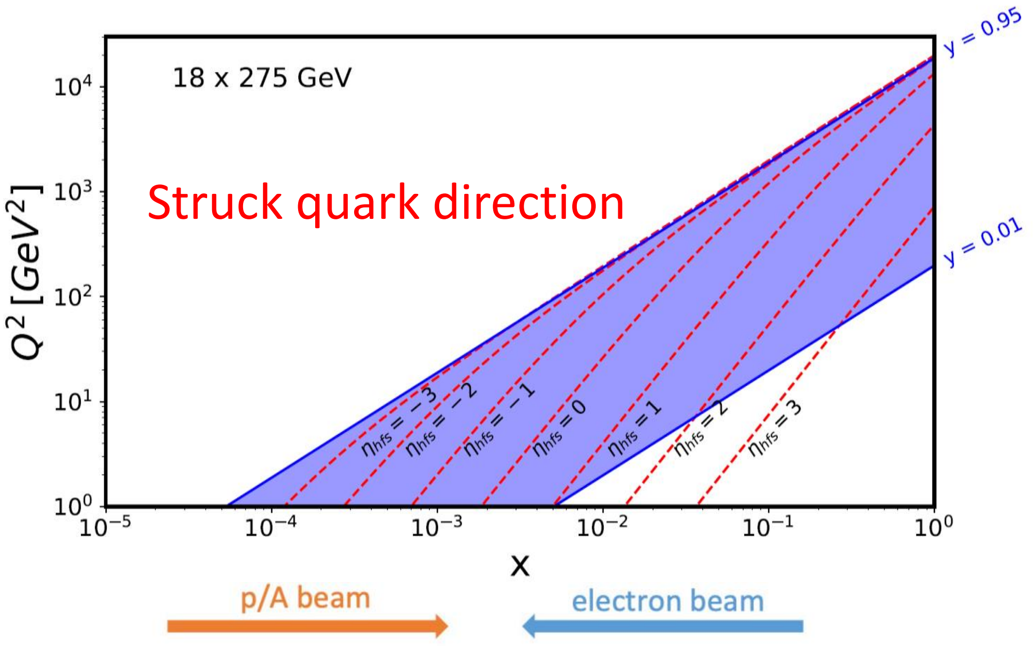




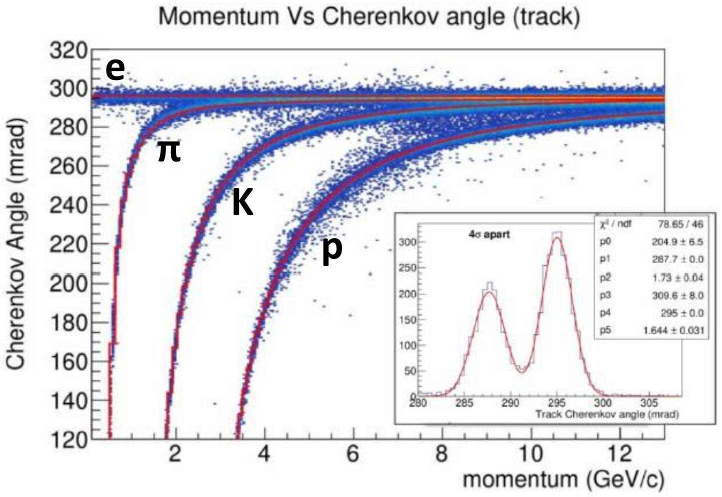
PID detectors – purpose and performance

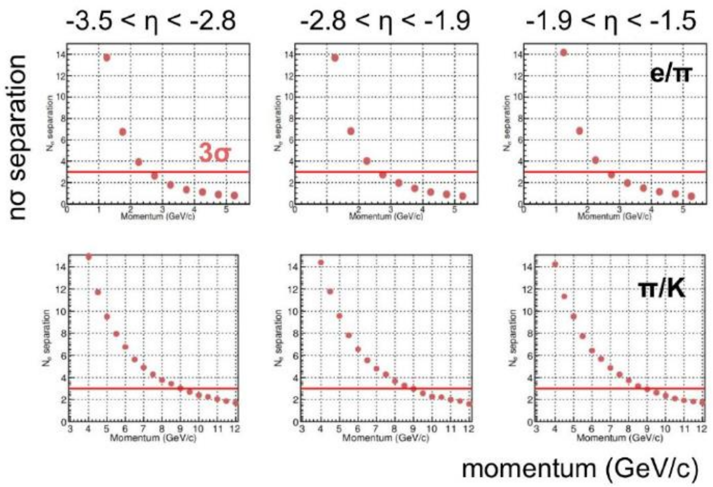
Role of the PID detectors

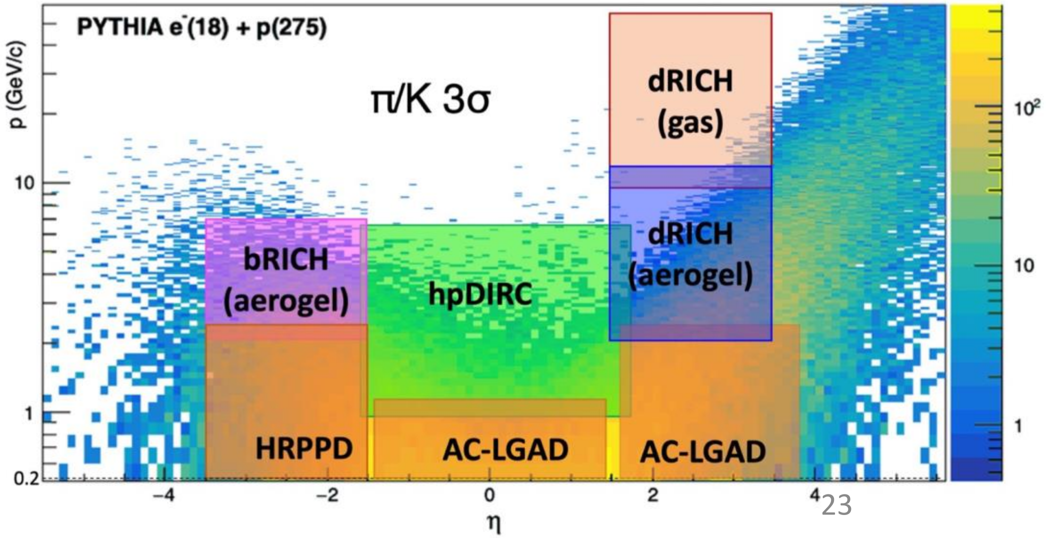
1. Electron ID. Complement the electromagnetic calorimetry to achieve electron-pion separation at low momenta (high y). This is needed for the whole physics program.
2. Hadron ID. Identification of charged pions, kaons, and protons especially for SIDIS and heavy flavor physics.



pfRICH simulated performance



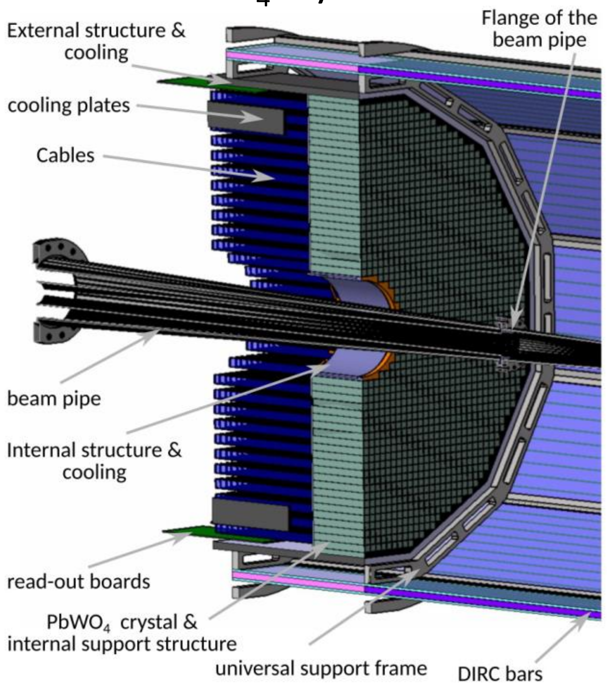


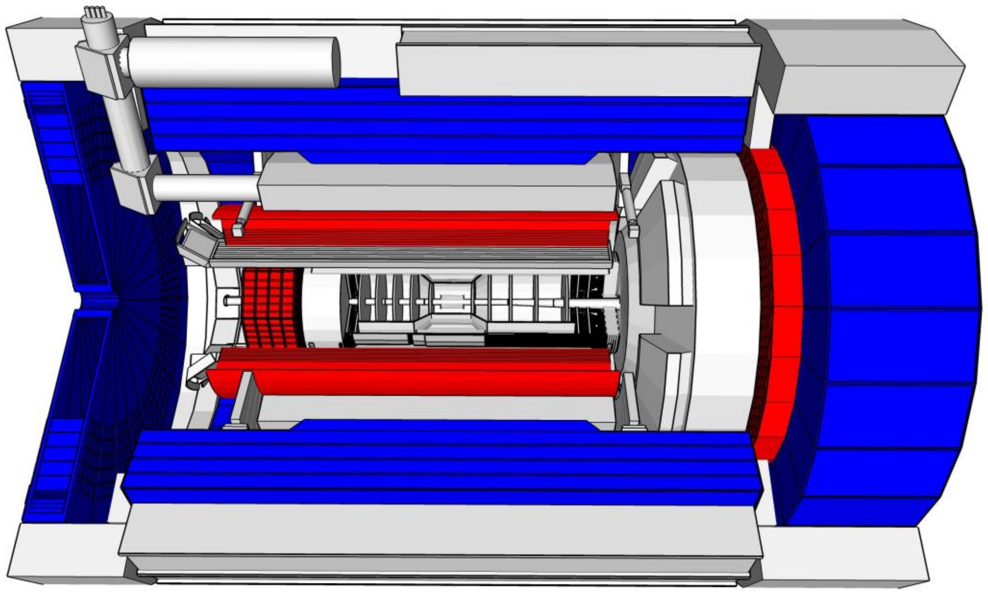


ePIC detector design – electromagnetic calorimetry

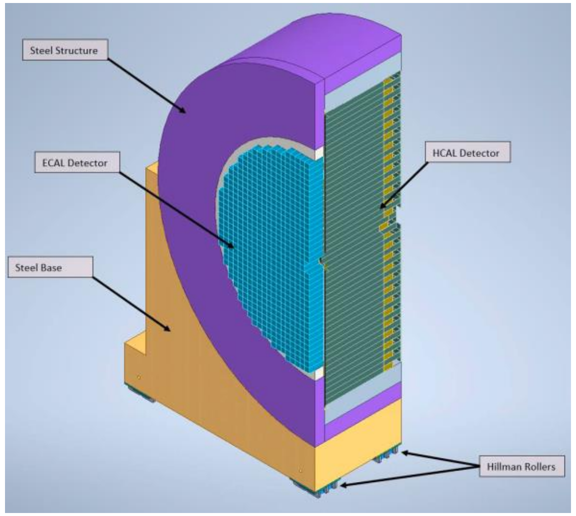
Electron Endcap EMCal

$PbWO_4$ crystals



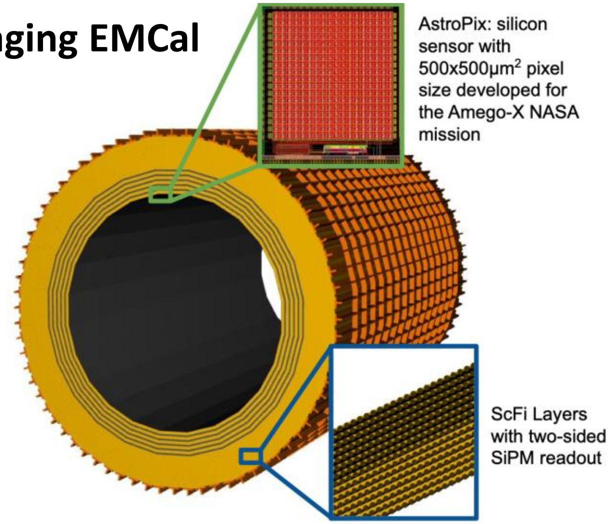


Hadron Endcap EMCal



High granularity W-powder/SciFi EMCal

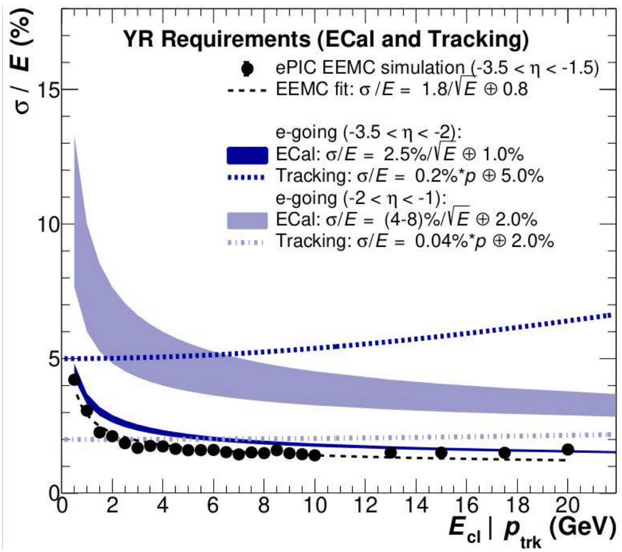
Barrel Imaging EMCal

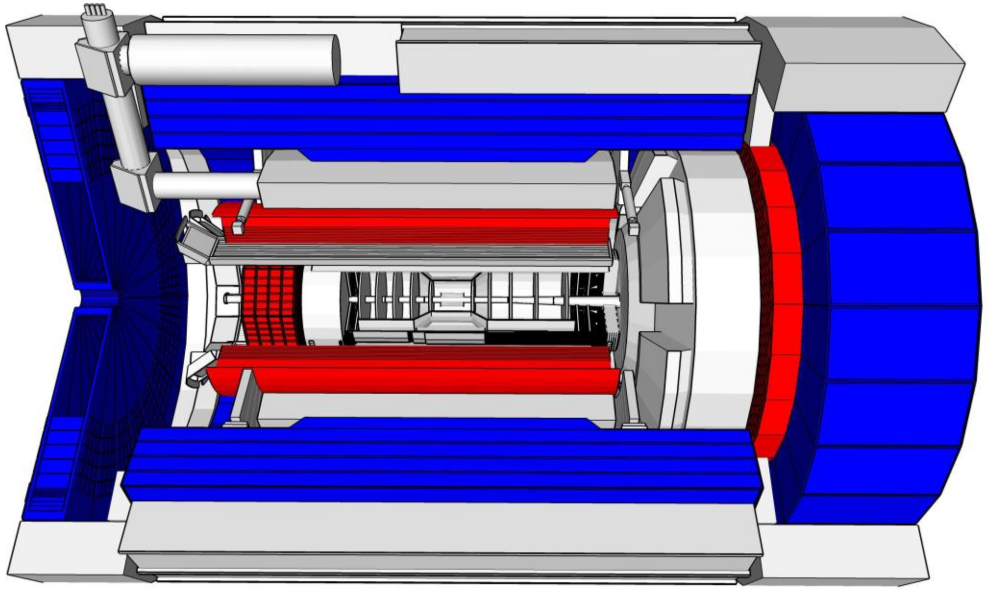


All calorimeters read with SiPMs

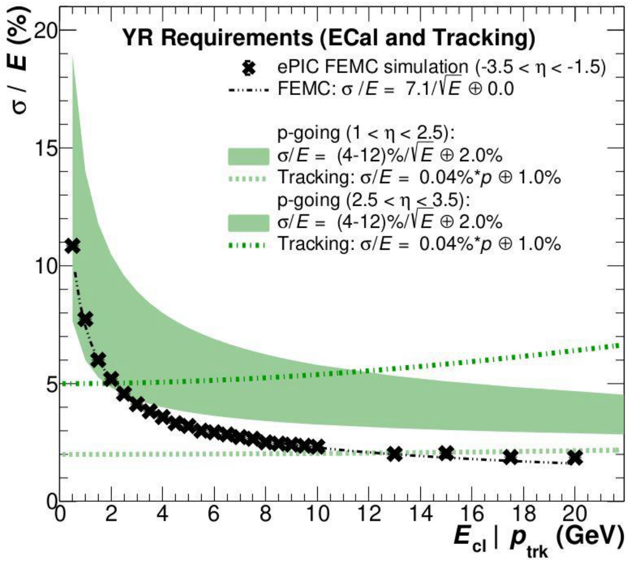
ePIC detector design – electromagnetic calorimetry

Electron Endcap EMCal

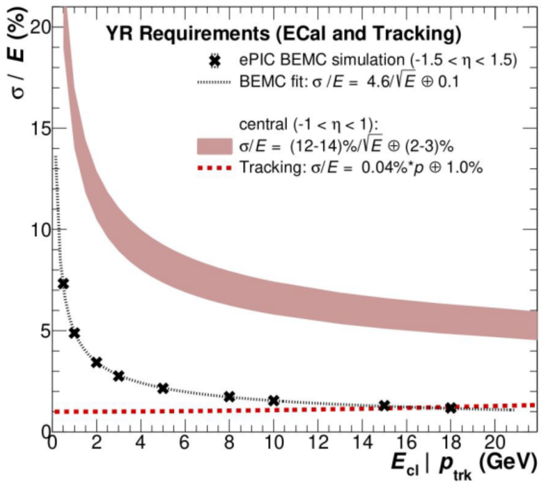


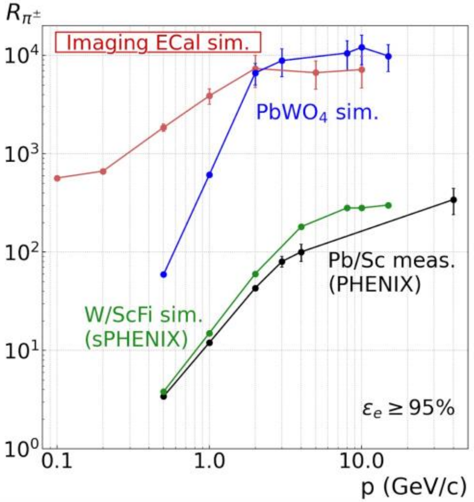


Hadron Endcap EMCal



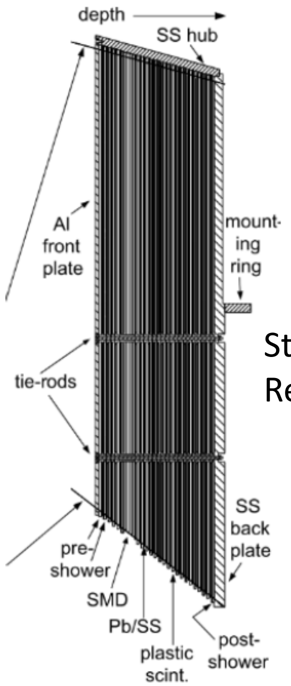
Barrel Imaging EMCal



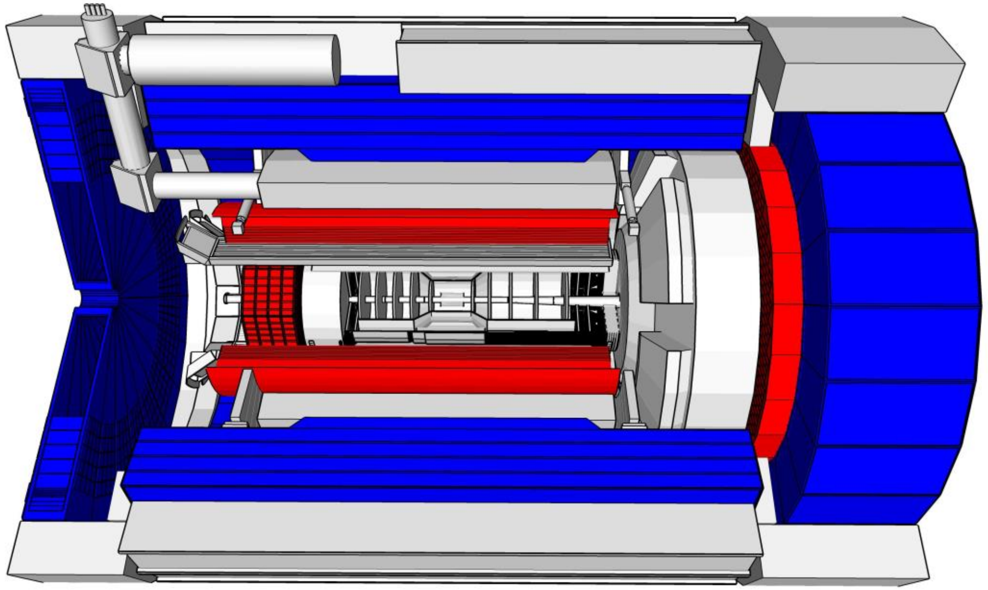


ePIC detector design – hadronic calorimetry

Electron Endcap HCal



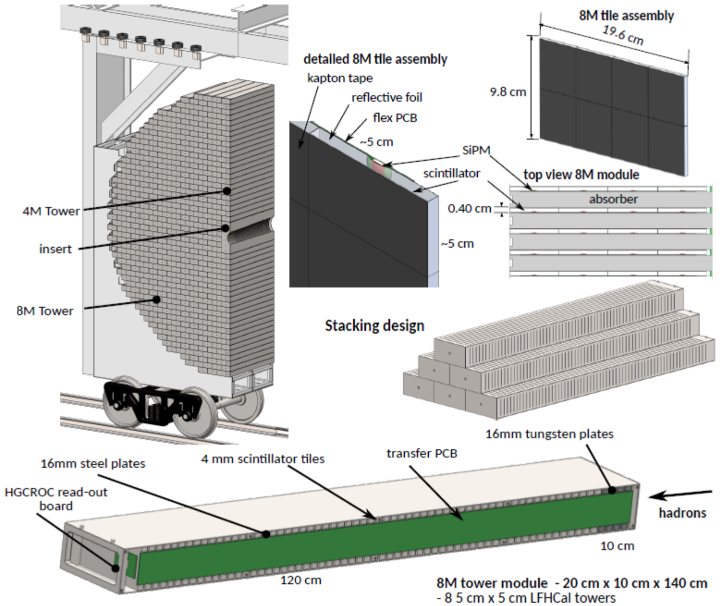
Steel/Scint. Sandwich (10 layers)
Reuse of STAR Scint. tiles



Hadron Endcap HCal

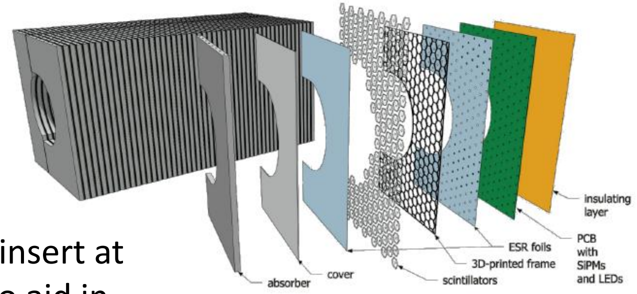
Longitudinally separated HCAL
Steel/Scint. & W/Scint. sandwich

SiPM-on-tile readout



Barrel HCal

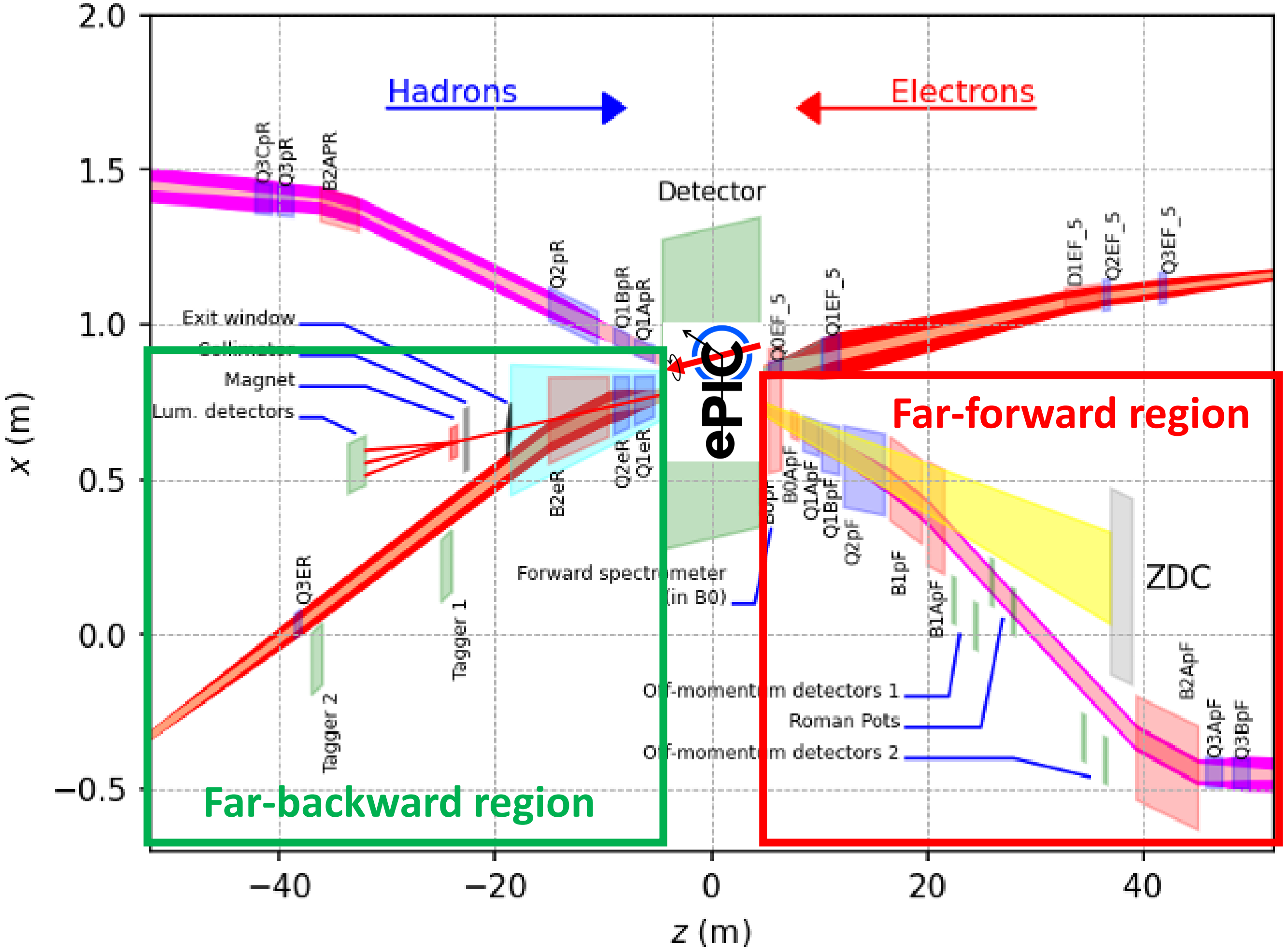
sPHENIX barrel calorimeter with new SiPMs



High-granularity insert at most forward η to aid in reconstruction of HFS

All calorimeters read with SiPMs

EIC Interaction Region (IR)

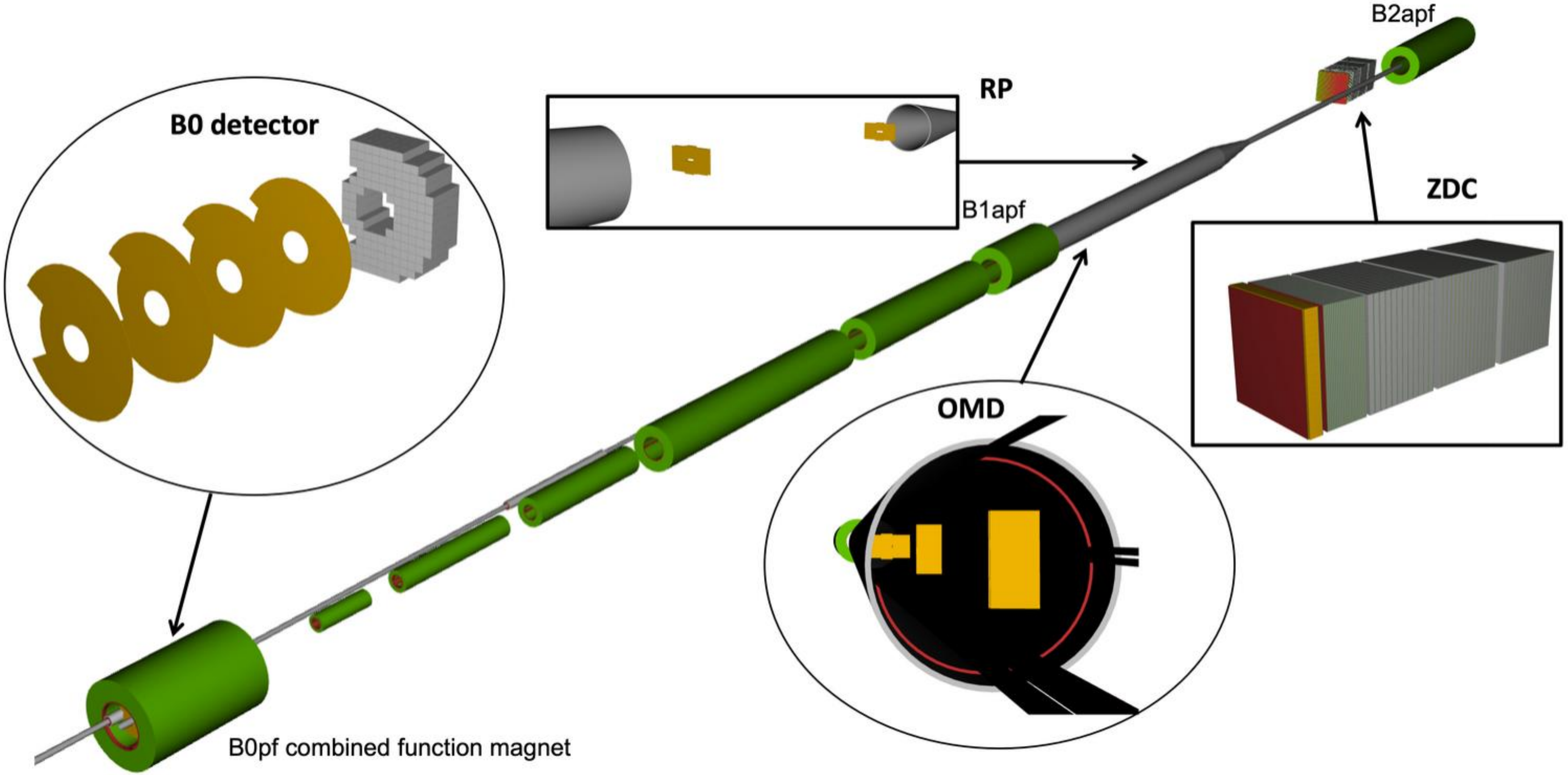


IR design is critical for EIC science

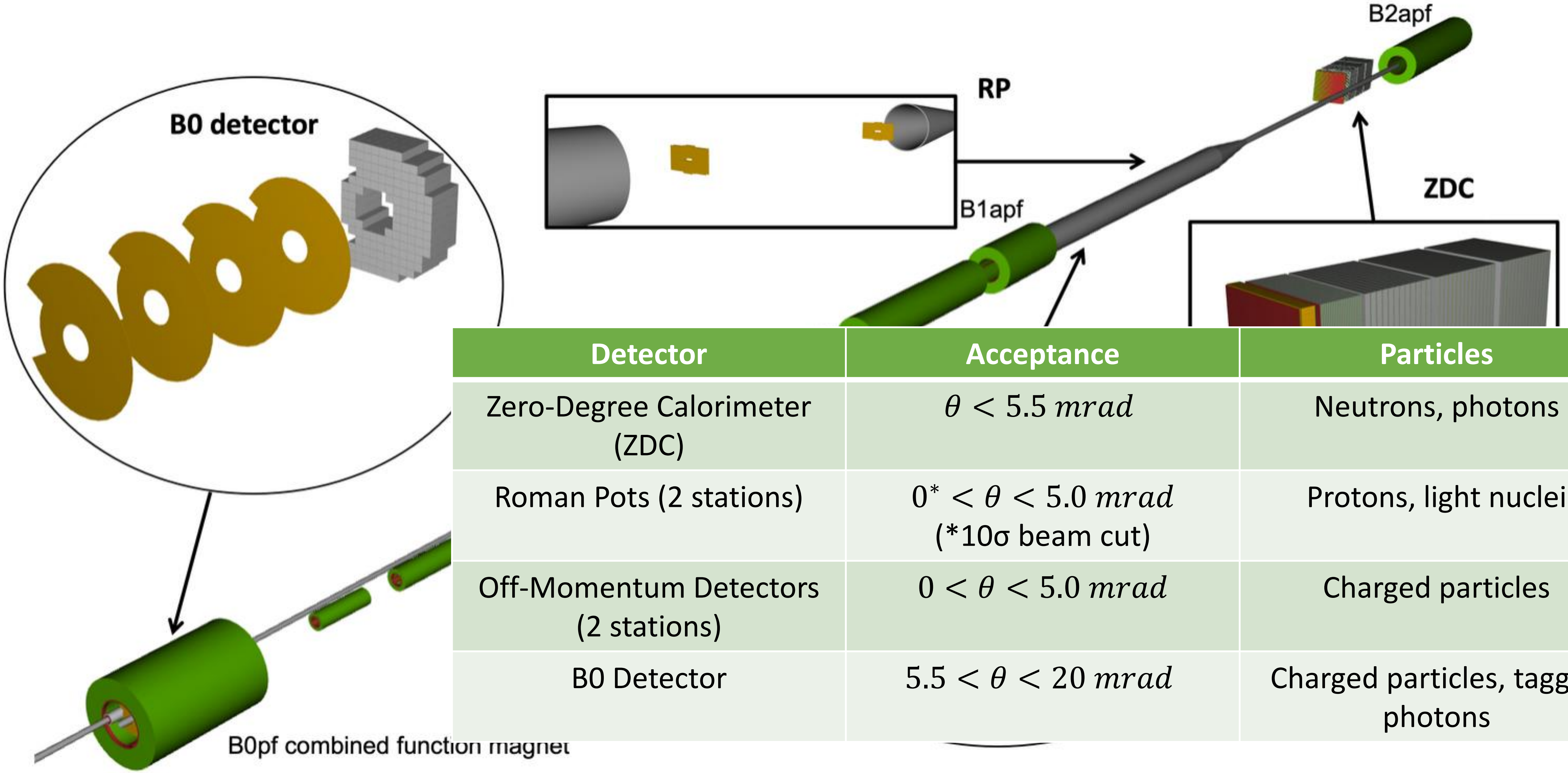
Far-forward region: Many physics channels require the tagging of charged and neutral particles scattered at very small angles to the incoming proton/ion beam. Detectors in this region are the B0, Off-Momentum detectors, Roman Pot detectors, and Zero-Degree calorimeter.

Far-backward region: Measurement of the absolute and relative luminosity, as well as tagging of low-Q^2 electrons. The detectors in this region are the Direct Photon detector, the Pair Spectrometer, and the Low Q^2 taggers.

Far-forward region



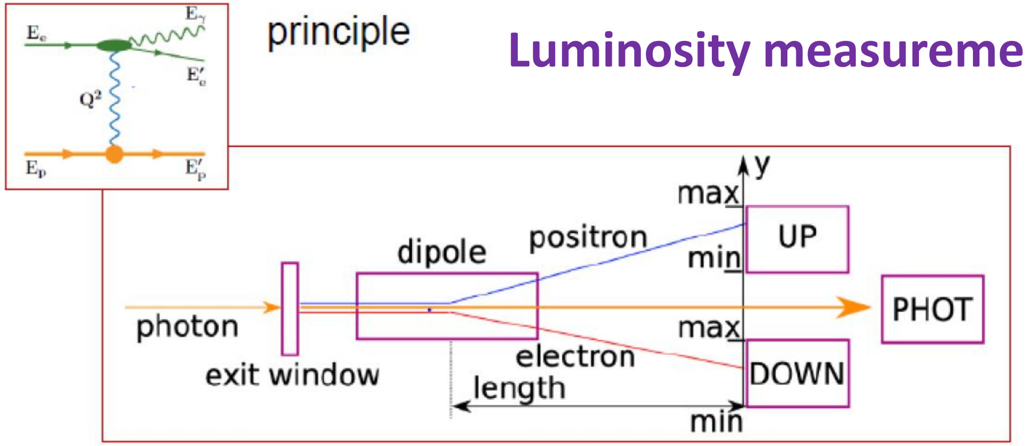
Far-forward region



Detector	Acceptance	Particles
Zero-Degree Calorimeter (ZDC)	$\theta < 5.5\ mrad$	Neutrons, photons
Roman Pots (2 stations)	$0^{*} < \theta < 5.0\ mrad$ (*10σ beam cut)	Protons, light nuclei
Off-Momentum Detectors (2 stations)	$0 < \theta < 5.0\ mrad$	Charged particles
B0 Detector	$5.5 < \theta < 20\ mrad$	Charged particles, tagged photons

Far-backward region

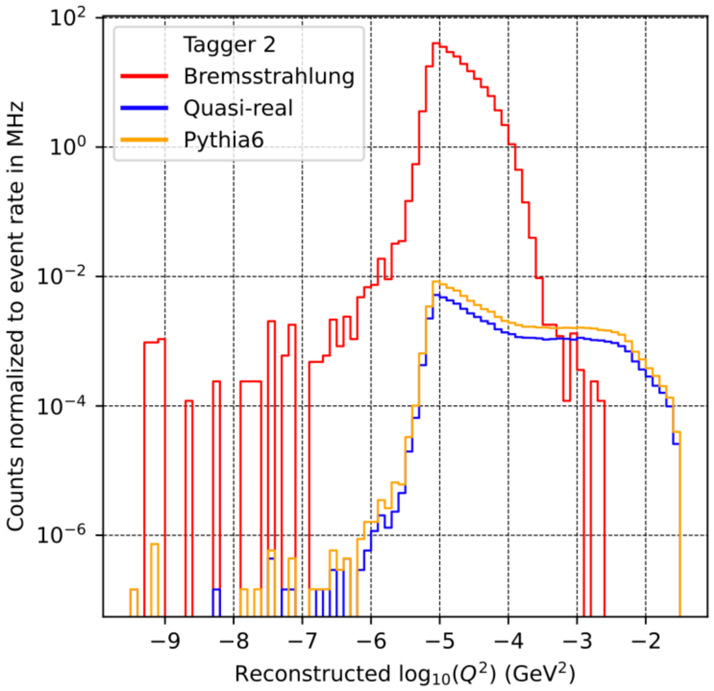
Luminosity measurement

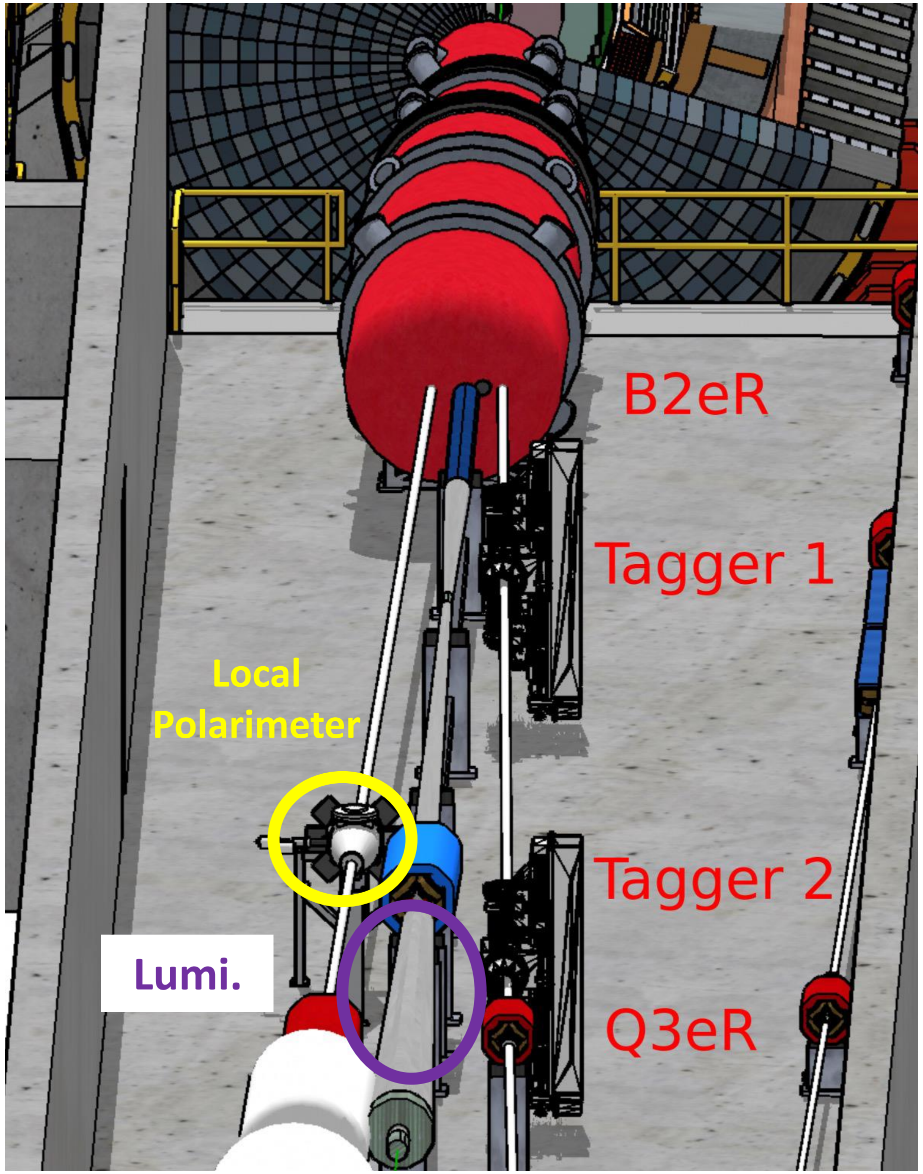


Measure luminosity with an absolute precision better than 1% and a relative precision better than 10^{-4}.

Low Q^2 taggers

Clean photoproduction (Quasi-real, Pythia6) signal can be taken over a limited region of $10^{-3} < Q^2 < 10^{-1}$ GeV².



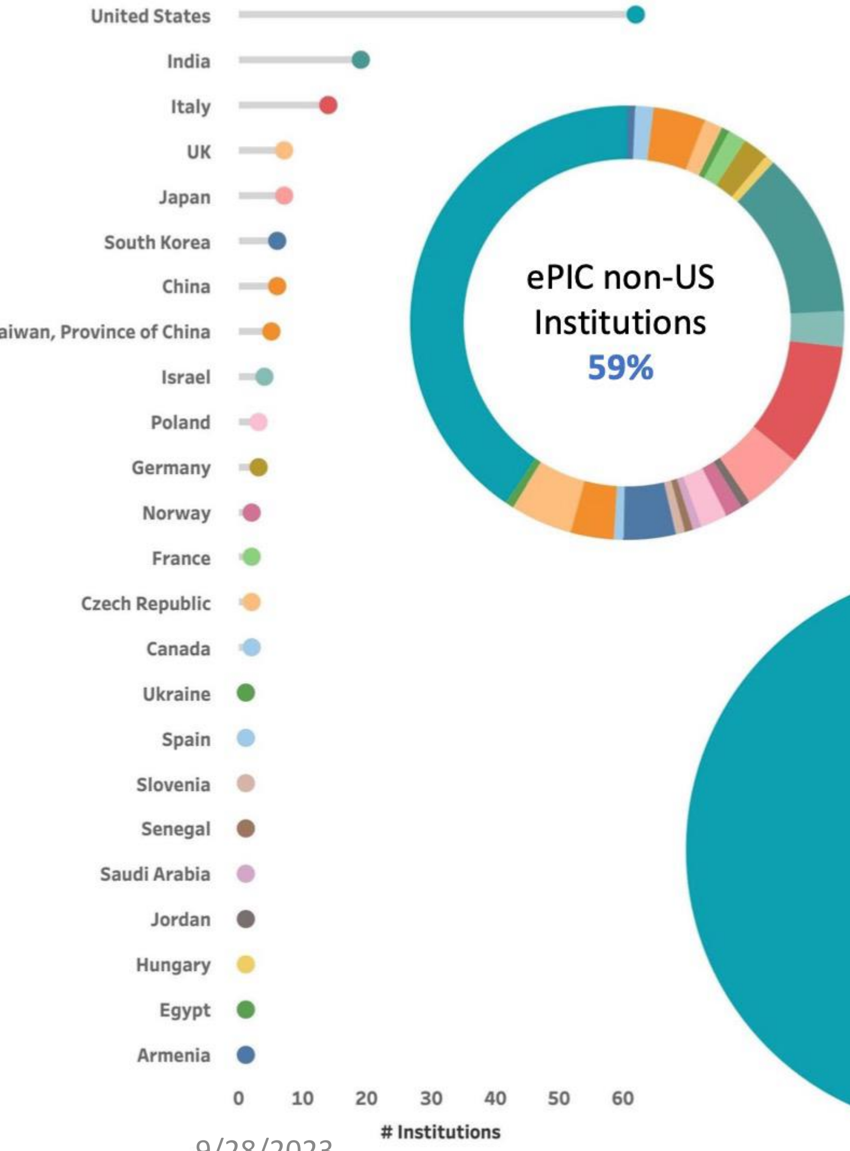


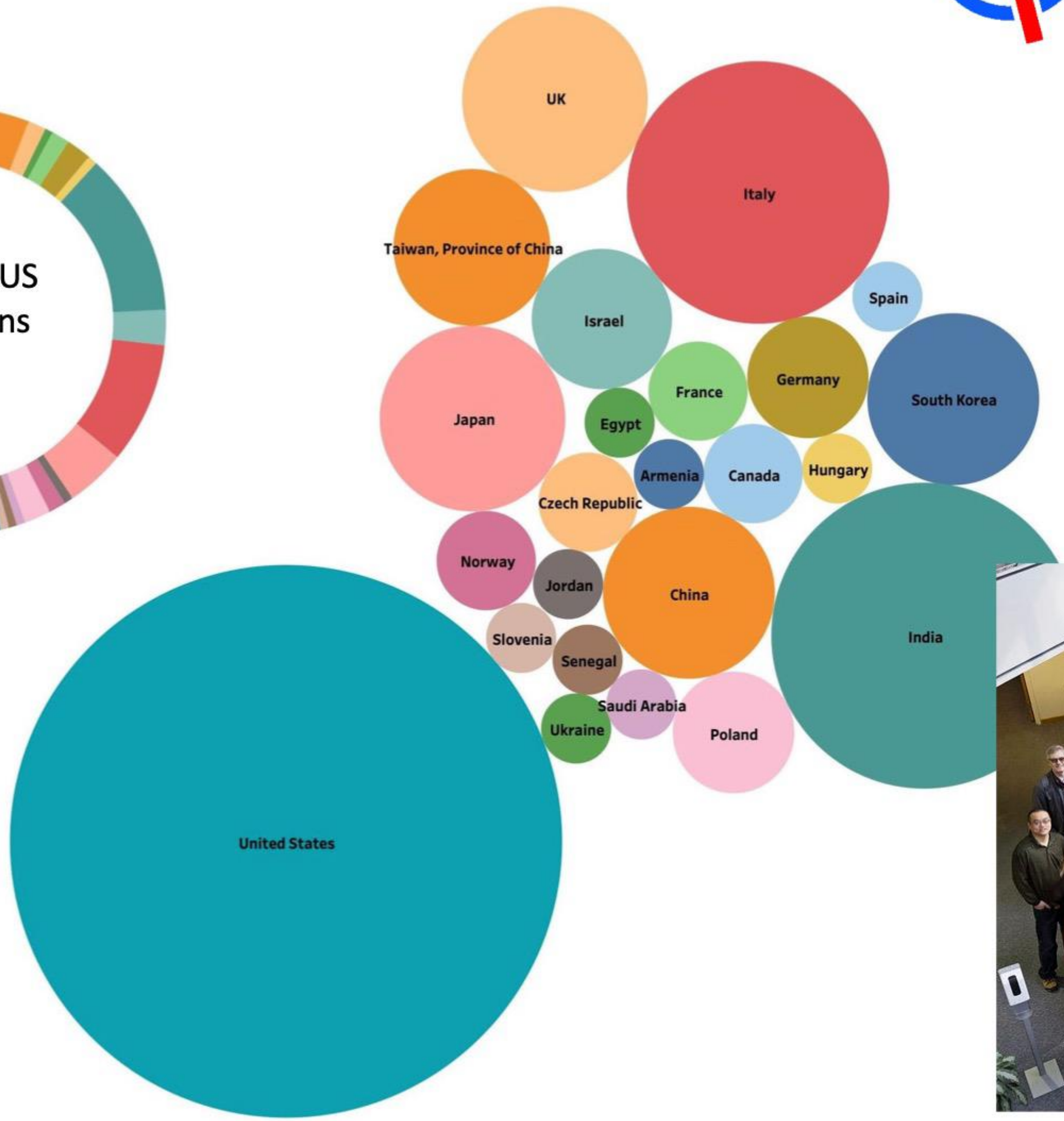
The ePIC Collaboration

171 institutions
24 countries

500+ participants

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





Summary

- The EIC project is on schedule. See tomorrow's talk by C. Montag for details.
- ePIC is a new collaboration formed last year to build the first EIC detector and realize the science potential of the EIC.
- The detector design is mature and uses innovative technologies. A Technical Design Report (TDR) is coming.