Challenges of Electron Ion Collider
(focus on detector challenges)

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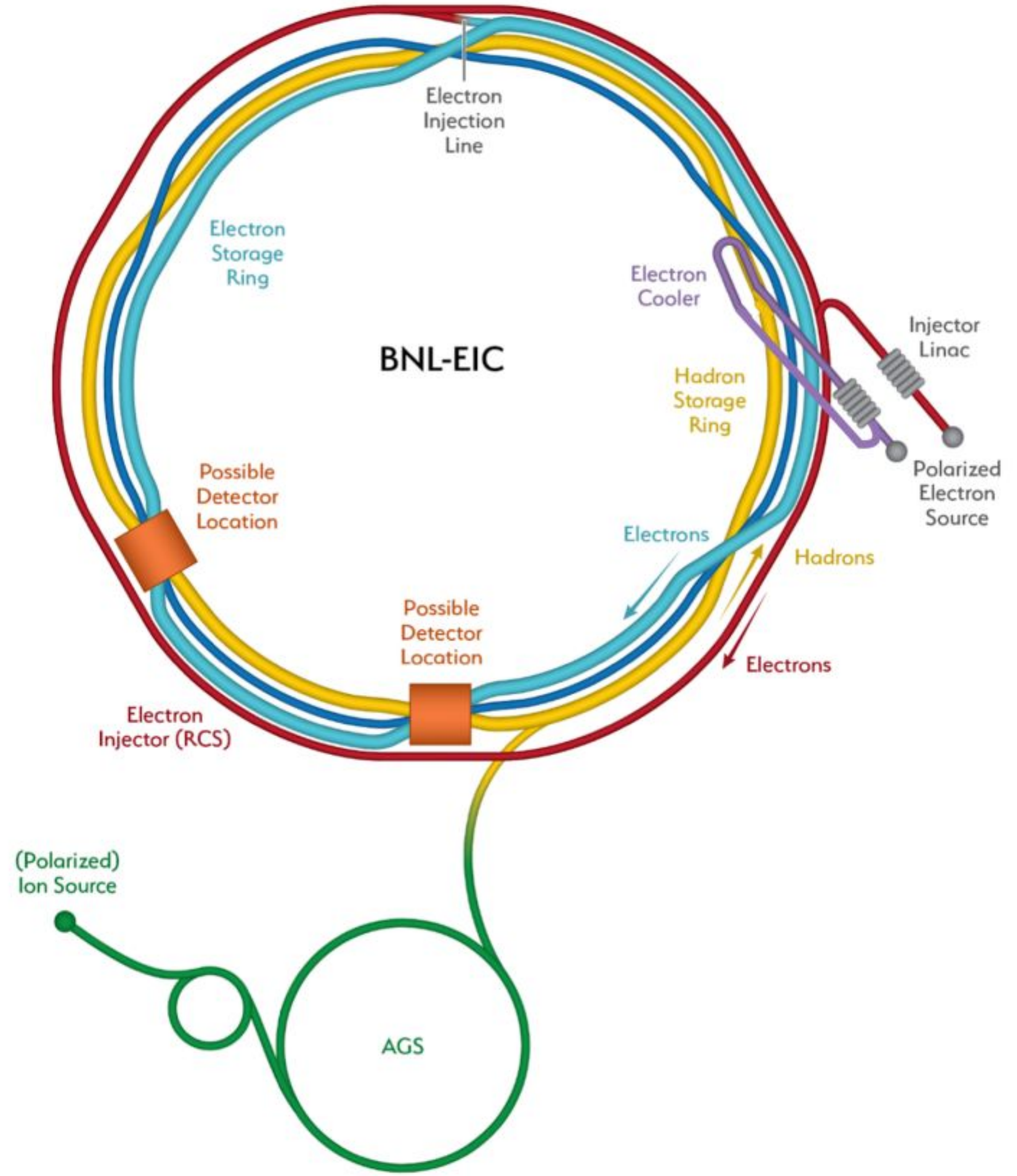
What is EIC?

- Electron Ion Collider (EIC) is a facility being built at BNL to be operational ~2030
- Design requirements:
    - Capable of colliding polarized electrons, light ions and unpolarized heavy ions
    - Center of mass energy range from ~20 to 140 GeV
    - High luminosity for ep collisions ($\sim10^{34}$ cm^{-2} s^{-1})
    - Single interaction region and integrated detector are officially in plan (with capability of adding one more)

EIC design

- Use the existing RHIC ring as Hadron Storage Ring
- Add an electron source and LINAC
- Construct a new Electron Storage Ring
- Add crab cavities near the Interaction Point (IP) to ensure high luminosity



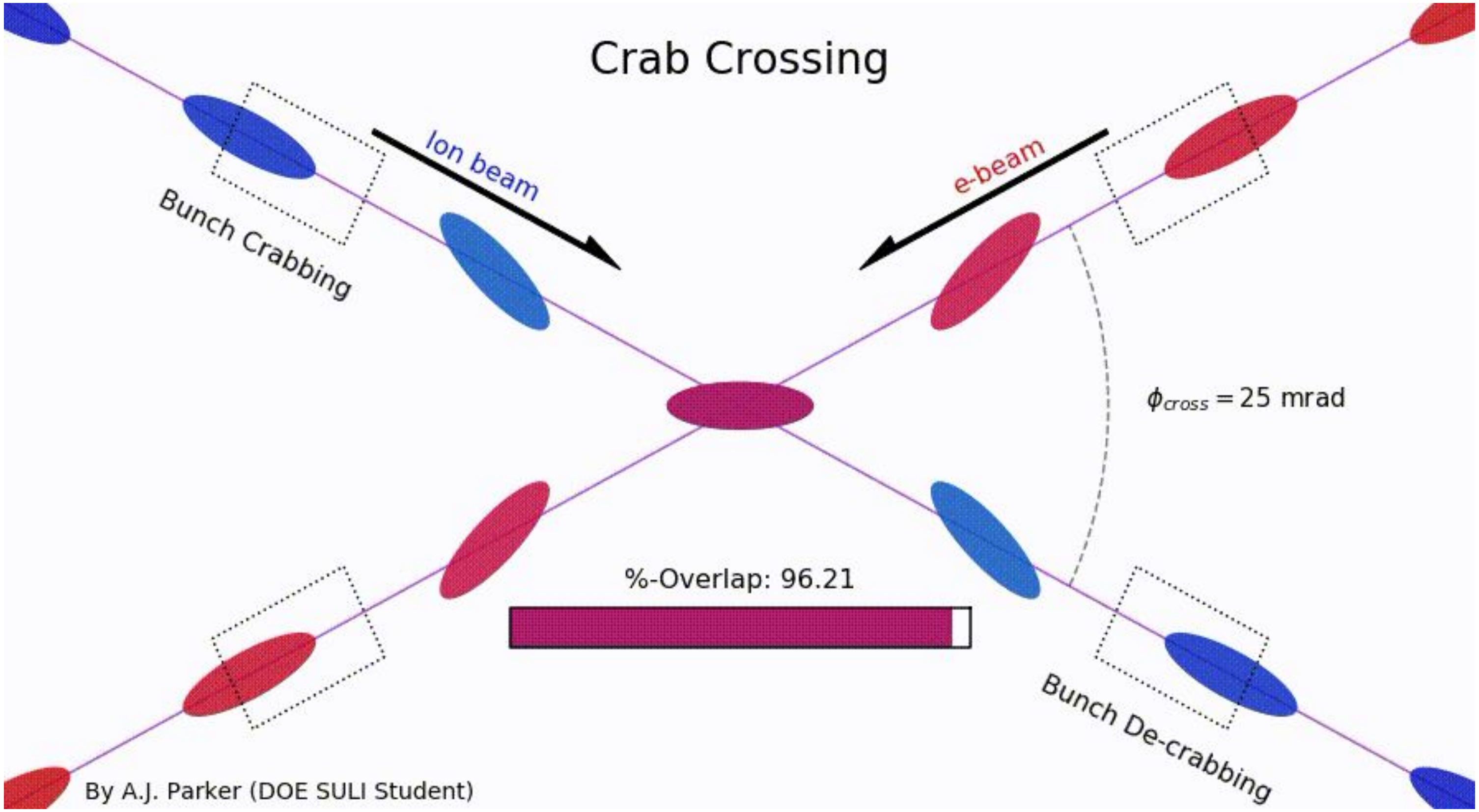
Note on crossing angle

- At majority of collider experiments that I am familiar with, the beams collide head on at the IP
  - True for ATLAS, CMS collisions etc

- At EIC, the beam crossing angle is 25mrad
  - This will reduce the luminosity
  - Beams cross at 25mrad angle
  - Use crab cavities to recover a head on collision!

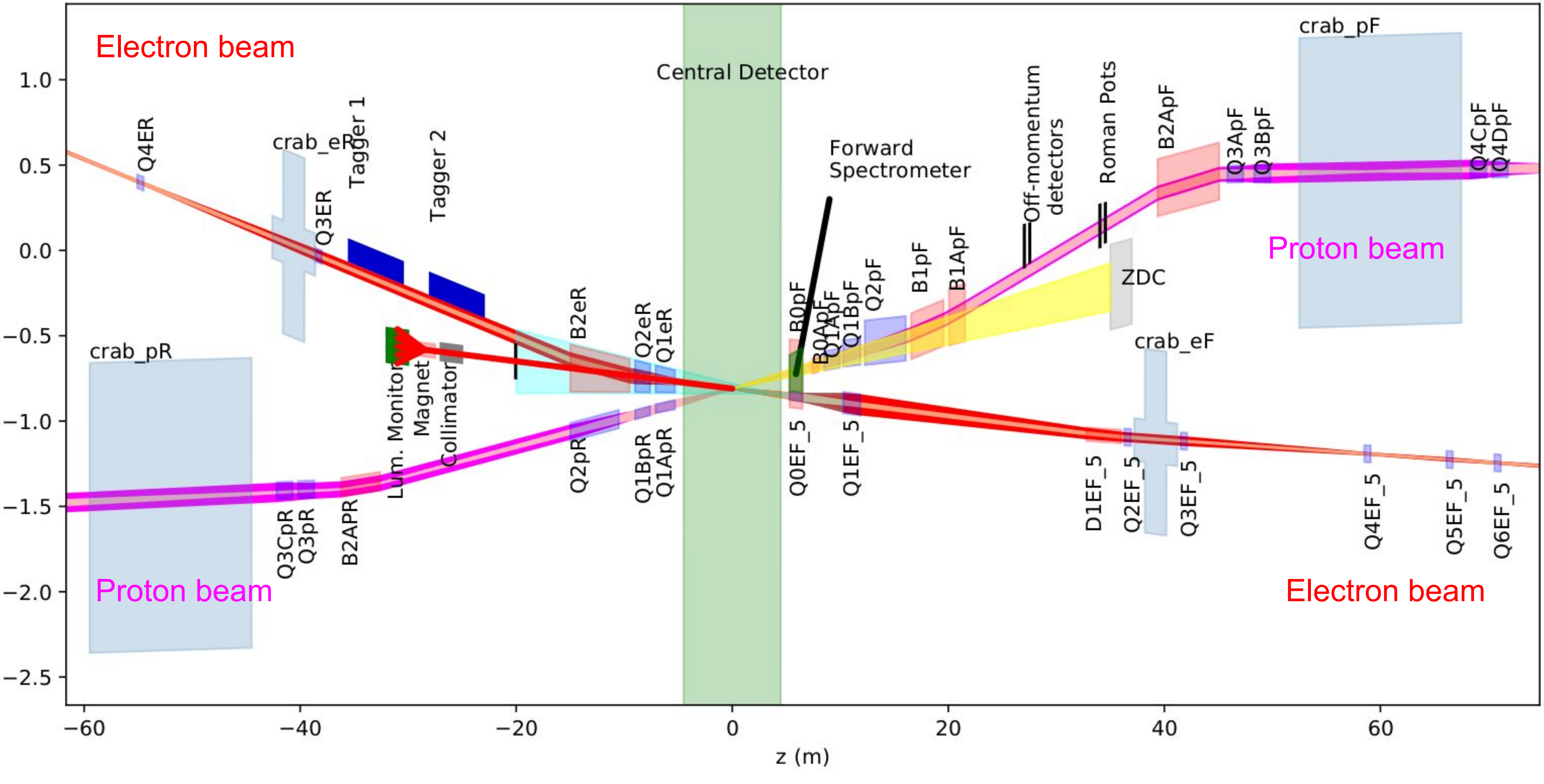
Crab cavities

- Rotating the bunches before collision recovers the head-on collision and mitigates the luminosity loss
- Crab cavities are transversely deflecting RF resonators which perform crabbing or bunch rotation



EIC IP

- Interaction Point top down view

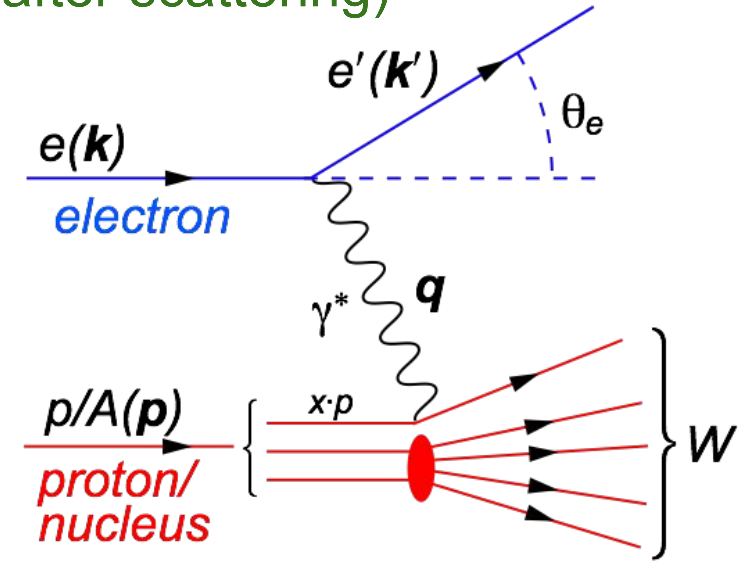


Physics of interest

- All things QCD!
  - How does the mass of the nucleon arise?
  - How does the spin of the nucleon arise?
  - What are the emergent properties of dense systems of gluons?
  - How are the sea quarks and gluons and their spins, distributed in space and momentum inside the nucleon?
  - ….

Detector wishlist at EIC

- The electron and ion beams at EIC are asymmetric
  - One configuration has 18 GeV electron beam colliding with 275 GeV proton beam to give 140 GeV COM energy
  - Boosted kinematics suggesting high activity at large eta
  - For most events, the scattered electron gives very important kinematic information. Important to be able to reconstruct it
  - Need a detector with large eta coverage!
  - Note that we want special forward taggers for hadrons and leptons in the forward region (after scattering)



Rapidity of scattered electron

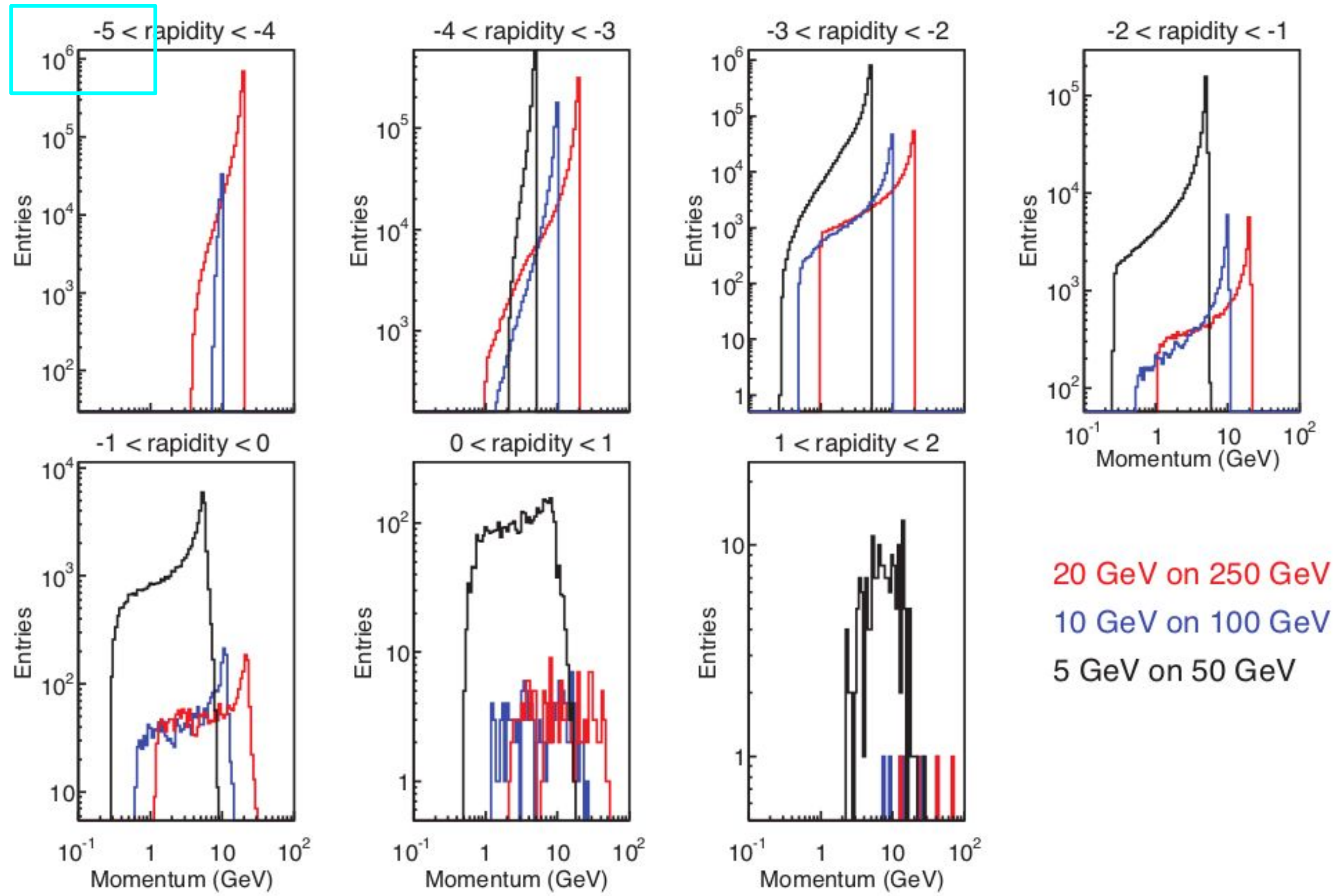


Figure 6.3: The momentum distribution for the scattered lepton for different center-of-mass energies and different rapidity bins in the laboratory frame. The following cuts have been applied: $Q^2 > 0.1$ GeV^2, $0.01 < y < 0.95$ and $-5 <$ rapidity < 5

Rapidity of photon from Compton scattering

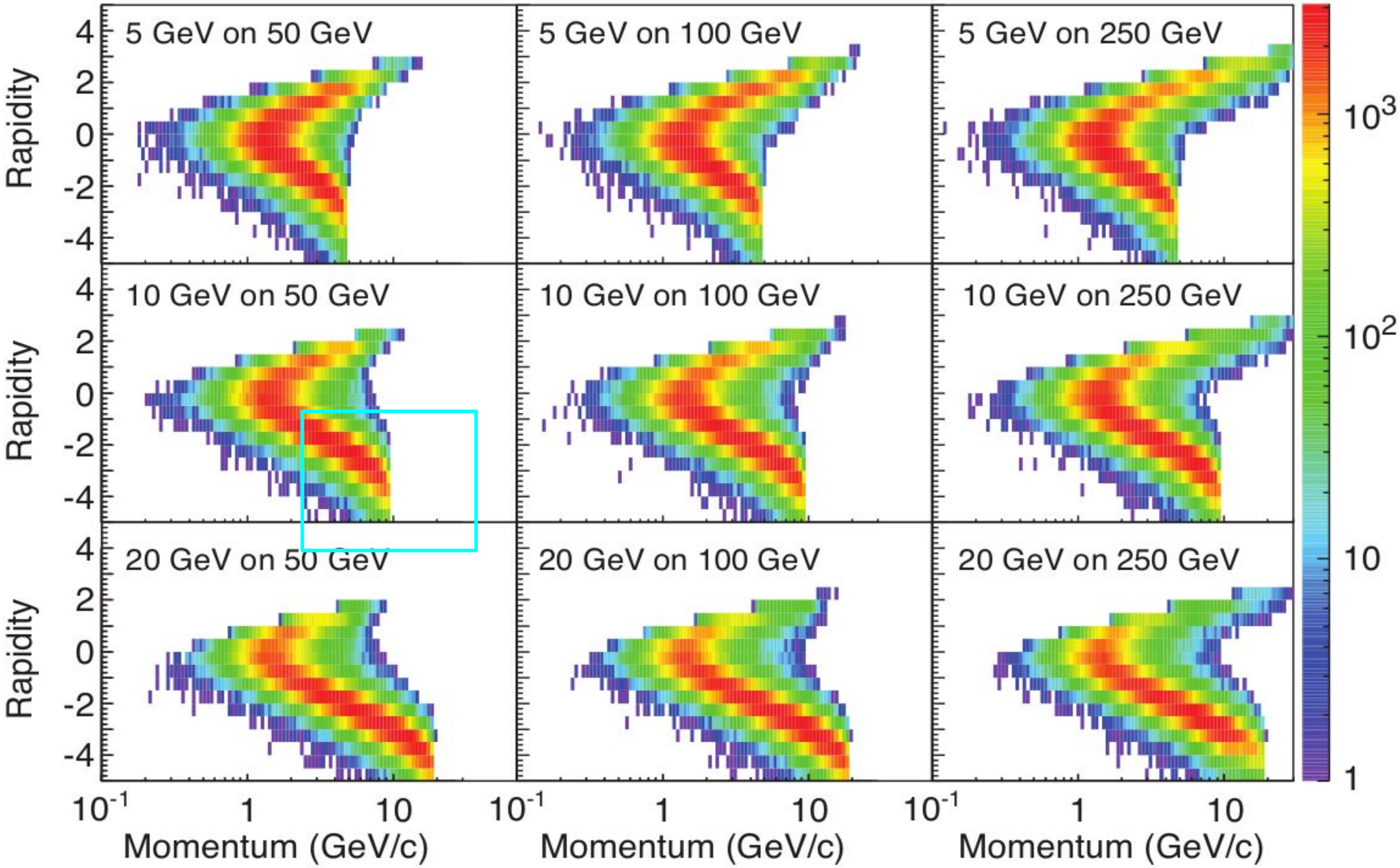


Figure 6.4: The energy vs. rapidity in the laboratory frame for photons from DVCS for different center-of-mass energies (top) and the correlation between the scattering angle of the DVCS photon and the scattered lepton for three different center-of-mass energies. The following cuts have been applied: $Q^2 > 1.0$ GeV^2, $0.01 < y < 0.95$, $E_\gamma > 1$ GeV and $-5 <$ rapidity < 5.

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- COM energies range from 20-140 GeV!
  - We need a detector to reconstruct many particles like electrons, photons, hadrons (distinguishing pions, kaons, protons etc) and muons at wide range of energies and large acceptance

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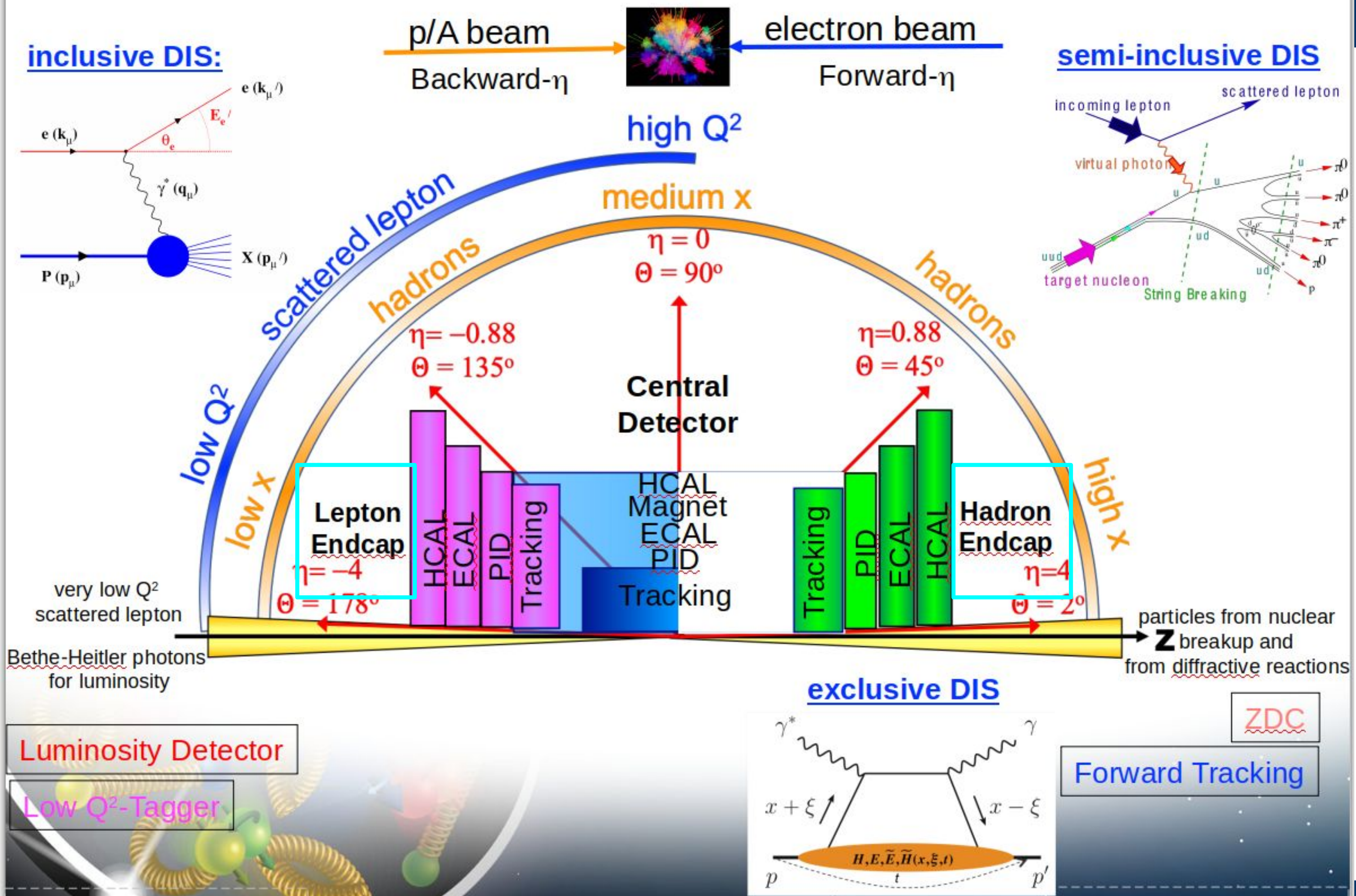
- Other necessary features:
  - Radiation hard detectors (less than LHC)
  - efficient readout rate (no pileup as collision rate is every 500kHz=2000ns)
  - costs around $250M

How would your detector look like based on these requirements?

Take a minute to think about it.

EIC General Purpose Detector: Concept

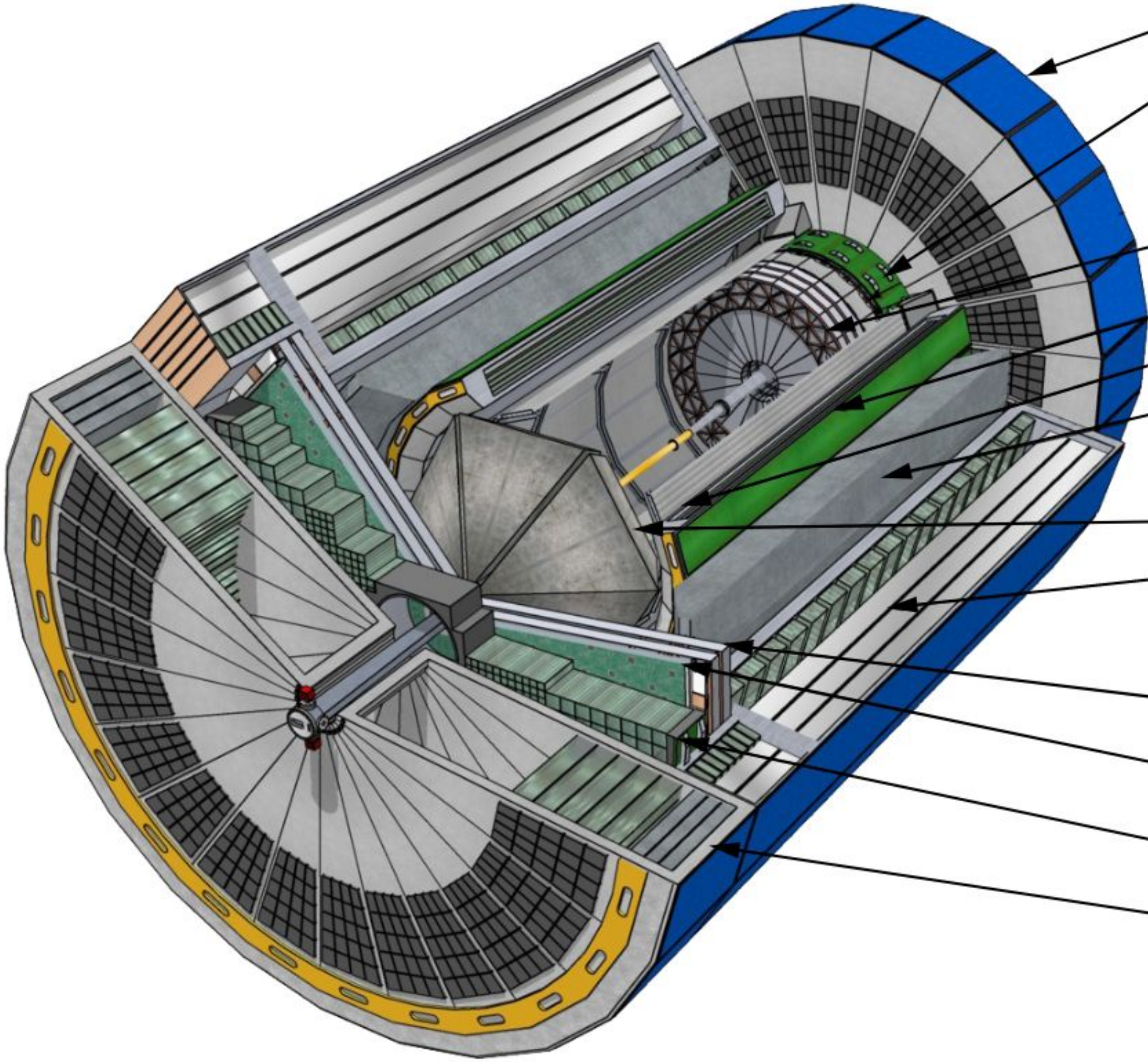


Detector design requirements

η	θ	Nomenclature			Tracking: Resolution	Tracking: Relative Momentum	Tracking: Allowed X/X_0	Tracking: Minimum-pT	Tracking: Transverse Pointing Res.	Tracking: Longitudinal Pointing Res.	Electrons and Photons: Resolution σ_E/E	Electrons and Photons: PID	Electrons and Photons: Min E Photon	π/K/p: p-Range (GeV/c)	π/K/p: Separation	HCAL: Resolution σ_E/E	HCAL: Energy	Muons
< -4.6		↓ p/A	Far Backward Detectors	low-Q2 tagger														
-4.6 to -4.0					Not Accessible													
-4.0 to -3.5						Reduced Performance												
-3.5 to -3.0			Central Detector	Backward Detector		σ_p/p ~0.2%×p⊕5%	~5% or less X	70-150 MeV/c (B=1.5 T)			1%/E ⊕ 2.5%/√E ⊕ 1%	π suppression up to 1:1E-4	20 MeV	≤ 10 GeV/c	≥ 3 σ	50%/√E⊕10%	~500MeV	Muons useful for bkg, improve resolution
-3.0 to -2.5																		
-2.5 to -2.0						σ_p/p~ 0.04%×p⊕2%												
-2.0 to -1.5									dca(xy) ~ 40/pT µm ⊕ 10 µm	dca(z) ~ 100/pT µm ⊕ 20 µm	2%/E ⊕(4-8)%/√E ⊕ 2%	π suppression up to 1:(1E-3 - 1E-2)	50 MeV					
-1.5 to -1.0																		
-1.0 to -0.5				Barrel		σ_p/p ~0.04%×p⊕1%		200 MeV/c	dca(xy) ~ 30/pT µm ⊕ 5 µm	dca(z) ~ 30/pT µm ⊕ 5 µm	2%/E ⊕(12-14)%/√E ⊕ (2-3)%	π suppression up to 1:1E-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 ~0.04%×p⊕2%		70 - 150 MeV/c (B = 1.5 T)	dca(xy) ~ 40/pT µm ⊕ 10 µm	dca(z) ~ 100/pT 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 ~0.2%×p⊕5%												
3.0 to 3.5																		
3.5 to 4.0				Instrumentation to separate charged particles from photons		Reduced Performance												
4.0 to 4.5		↑ e			Not Accessible													
> 4.6			Far Forward Detectors	Proton Spectrometer Zero Degree Neutral Detection														

- Tracking from 200 MeV in barrel (3T magnet) and >70 MeV in forward/backward detector (1.5T magnet)
- ECAL to record electron and photon ID shower
- HCAL to measure hadrons
- Particle distinction for pions/Kaons/protons in few GeV range
- Far forward electron tagger to measure the scattered electrons
- Proton spectrometer to measure far forward protons

EIC detector

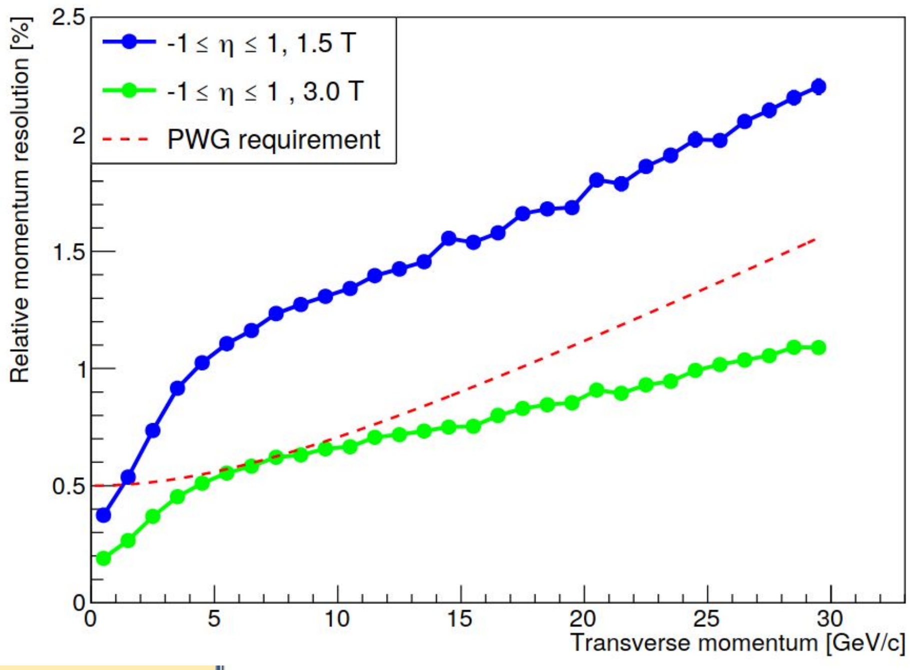


Subdetectors

system	system components	reference detectors
tracking	vertex	MAPS, 20 um pitch
	barrel	TPC
	forward & backward	MAPS, 20 um pitch & sTGCs[c]
	very far forward & far backward	MAPS, 20 um pitch & AC-LGAD[d]
ECal	barrel	W powder/ScFi or Pb/Sc Shashlyk
	forward	W powder/ScFi
	backward, inner	$PbWO_4$
	backward, outer	SciGlass
	very far forward	Si/W
h-PID	barrel	High performance DIRC & dE/dx (TPC)
	forward, high p	double radiator RICH (fluorocarbon gas, aerogel)
	forward, medium p	
	forward, low p	TOF
	backward	modular RICH (aerogel)
e/h separation at low p	barrel	hpDIRC & dE/dx (TPC)
	forward	TOF & areogel
	backward	modular RICH
HCal	barrel	Fe/Sc
	forward	Fe/Sc
	backward	Fe/Sc
	very far forward	quartz fibers/ scintillators

Tracking

- Silicon technology is used for vertex tracking
  - High granularity and low material budget
- TPC is used for barrel tracking (Ezra's talk here)
  - Good momentum resolution, provides additional particle ID information through dE/dx
- Forward and backward detectors are also silicon based MAPS sensors
  - Low dissipation allows operation at room temperature =low material budget



system	system components	reference detectors
tracking	vertex	MAPS, 20 um pitch
	barrel	TPC
	forward & backward	MAPS, 20 um pitch & sTGCs[c]
	very far forward & far backward	MAPS, 20 um pitch & AC-LGAD[d]

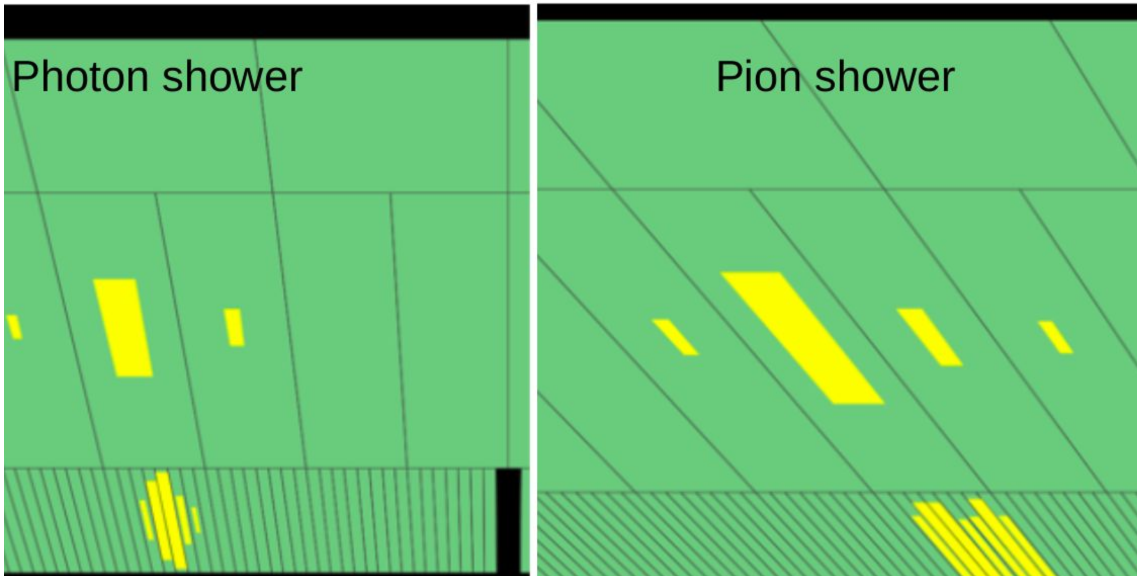
ECAL

- Requirements:
  - Measure scattered electron kinematics
  - Photon and electron energy measurement
  - electron/hadron separation (together with HCAL)
  - pi0/photon separation (can be achieved with highly segmented presampler)
  - Fast timing, compact, highly granular

η	-4 to -2	-2 to -1	-1 to 1	1 to 4
$\sigma_E / E \cdot \sqrt{E / 1\,\text{GeV}}$	2%	7%	10-12%	10-12%

ECal	barrel	W powder/ScFi or Pb/Sc Shashlyk
	forward	W powder/ScFi
	backward, inner	$PbWO_4$
	backward, outer	SciGlass
	very far forward	Si/W

ECAL



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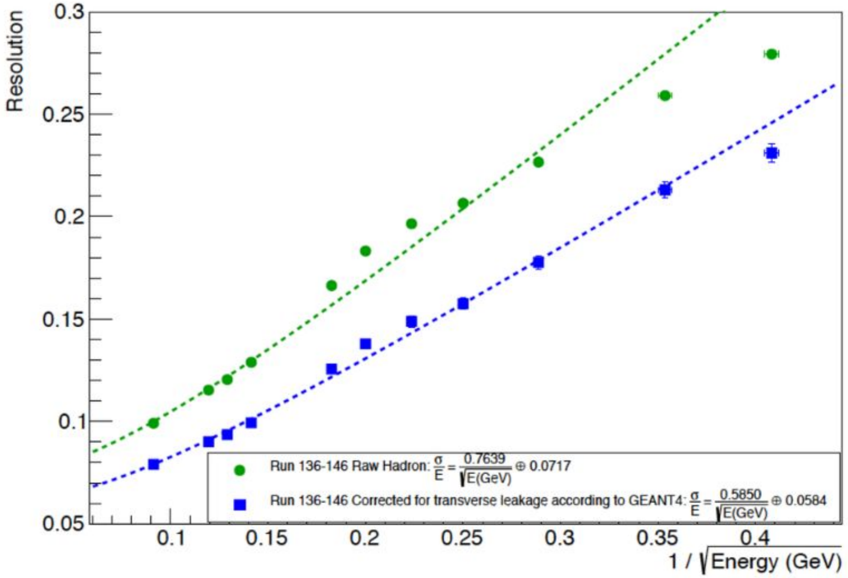
	forward	W powder/ScFi
	backward, inner	$PbWO_4$
	backward, outer	SciGlass
	very far forward	Si/W

HCAL

- Requirements:
  - Measure the energy deposition of hadrons

η	EIC Specifications		Conservative option	
	σ_E/E, %	E_{min}, MeV	σ_E/E, %	E_{min}, MeV
-3.5 to -1.0	$45/\sqrt{E}+7$	500	$50/\sqrt{E}+10$	500
-1.0 to +1.0	$85/\sqrt{E}+7$	500	$100/\sqrt{E}+10$	500
+1.0 to +3.5	$35/\sqrt{E}$	500	$50/\sqrt{E}+10$	500



$$\sigma(E)/E \approx 0.06 \oplus 0.59/\sqrt{E}$$

HCal	barrel	Fe/Sc
	forward	Fe/Sc
	backward	Fe/Sc
	very far forward	quartz fibers/ scintillators

PID

- Very critical to the entire experiment
- Needs to provide good distinction between particles and low contamination
- To distinguish
  - Electrons from photons -> Tracker coverage 4pi
  - Electrons from charged hadrons -> Use ECAL+HCAL for this
  - Charged pions, kaons and protons -> mainly Cherenkov detectors
    - See Ryan's talk here
    - Note that other technologies are used at low energies

h-PID	barrel	High performance DIRC & dE/dx (TPC)
	forward, high p	double radiator RICH (fluorocarbon gas, aerogel)
	forward, medium p	
	forward, low p	TOF
	backward	modular RICH (aerogel)
e/h separation at low p	barrel	hpDIRC & dE/dx (TPC)
	forward	TOF & areogel
	backward	modular RICH

Summary

- The EIC enables us to probe QCD in a completely new fashion
- The preliminary detector design is in place
    - Many subdetector technologies have been considered before choosing the reference detector
    - There are ongoing studies to finalize the number of layers, pixel size and other details
- EIC has a capability of an additional IP and has scope for another detector
    - Scientific community is supporting this idea and some of the alternate detector technologies can be used for this detector

Accelerator Technical Reviews	Spring -- Autumn 2021
Start Preliminary Design	April 2021
Detector Proposals Submitted	December 2021
Selection of Project Detector	March 2022
Start Earned Value Tracking	Summer 2022
Clarify In-kind Deliverables - Agreements	Summer/Fall 2022
Goal for CD-2 Approval	January 2023
Goal for CD-3 Approval	March 2024
Goal for CD-4 Early Project Completion	**July 2031**

E.C. Aschenauer

References

- EIC Yellow Report
- EIC CDR
- Electron Ion Collider: The next QCD frontier
- Special thanks to APS conference EIC session X04 (If you have registered for the conference, you have access to these)