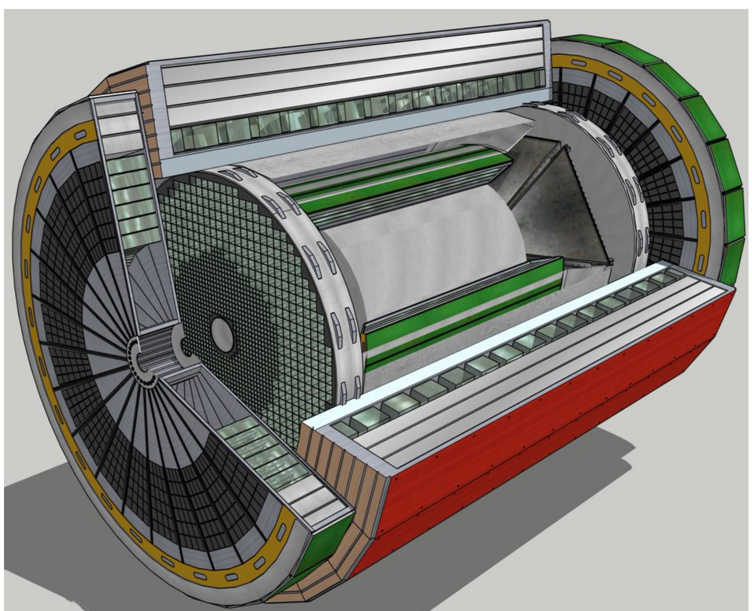
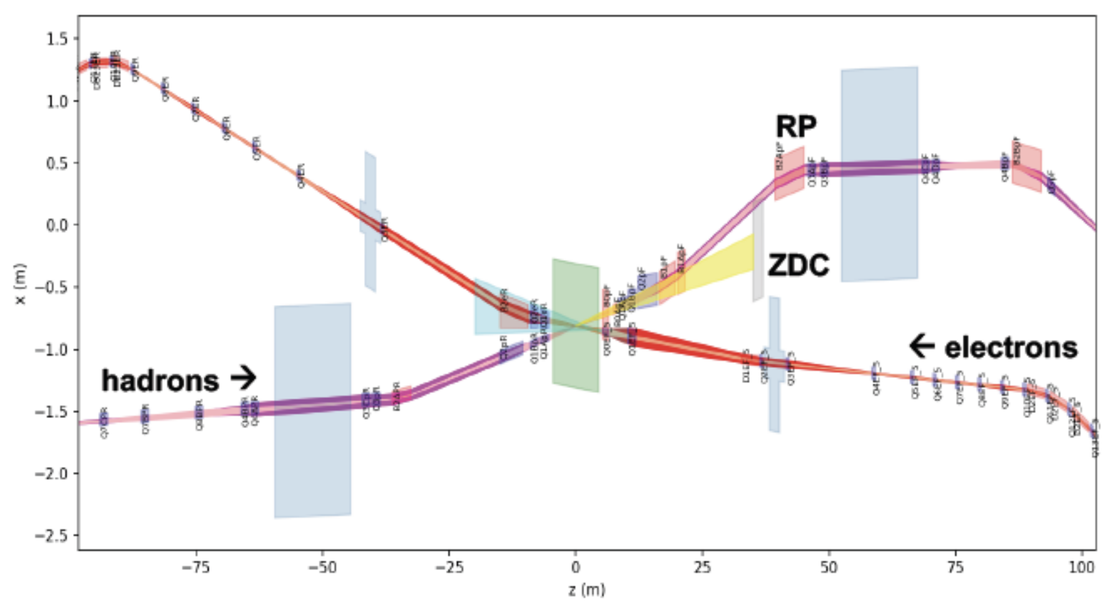
Detector(s) for the Electron Ion Collider

UK EIC Workshop
27 May 2020

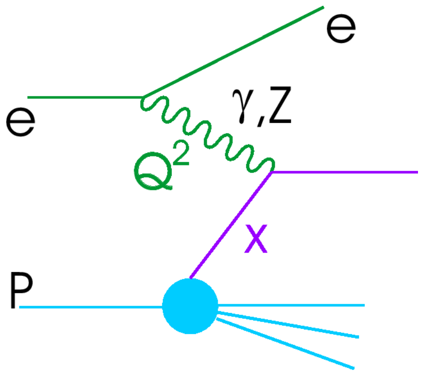
Paul Newman (University of Birmingham)

[Compiled with input from recent talks by many people]

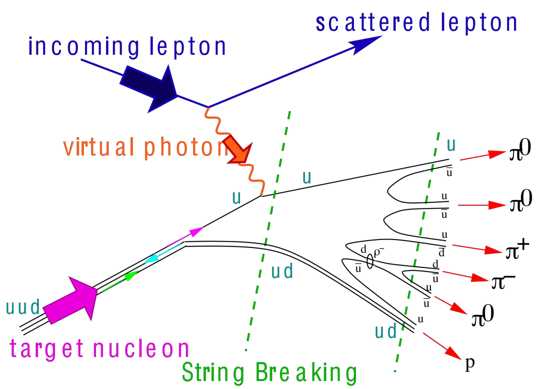




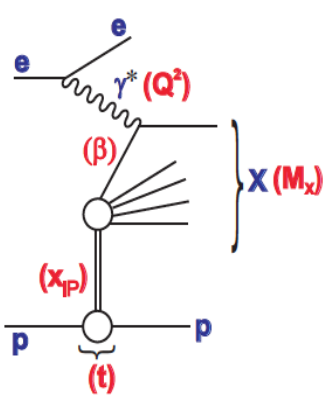
Physics Drivers

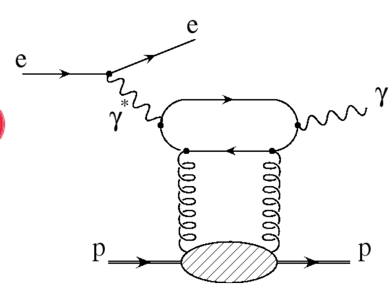


Inclusive Processes: measure (x,Q^2) over wide range
→ ID and precision measurement of scattered electron (down to small E_e and θ_e)
→ Hermetic and precise coverage of hadronic final state for hadron-based kinematic reconstruction



Semi-inclusive processes, heavy flavours, jets:
→ Precision tracking, particle ID, vertexing and jet reconstruction over a wide range of rapidities





Exclusive and diffractive processes:
→ Scattered protons with large fractions of beam momentum in ep
→ Rapidity gap identification
→ Spectator tagging in eD
→ Neutrons and other ion fragments in eA

Corresponding Outline Detector Concepts

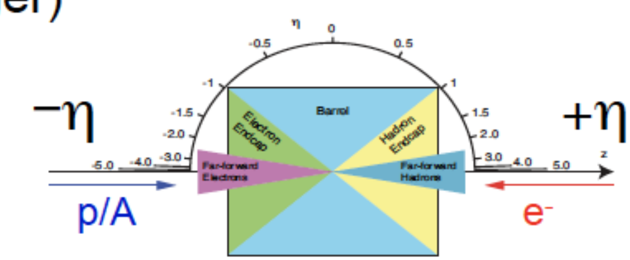
An EIC General Purpose Detector looks superficially a bit like GPDs at other colliders (HERA, LHC, Tevatron, RHIC), except:

- More emphasis on hadronic particle ID
- More emphasis on beamline instrumentation
- Maybe less emphasis on penetrating muons

- Vertex + central + forward/backward tracker layout
- Central detector: hermetic coverage in tracking/calorimetry/PID for $|\eta|<4$

- Advanced far forward instrumentation (Roman Pots, ZDC, etc)
- Far backward instrumentation (Low Q^2 tagger)

- Low material budget in the tracker volume
- 1.4 – 4.0 T central solenoid field



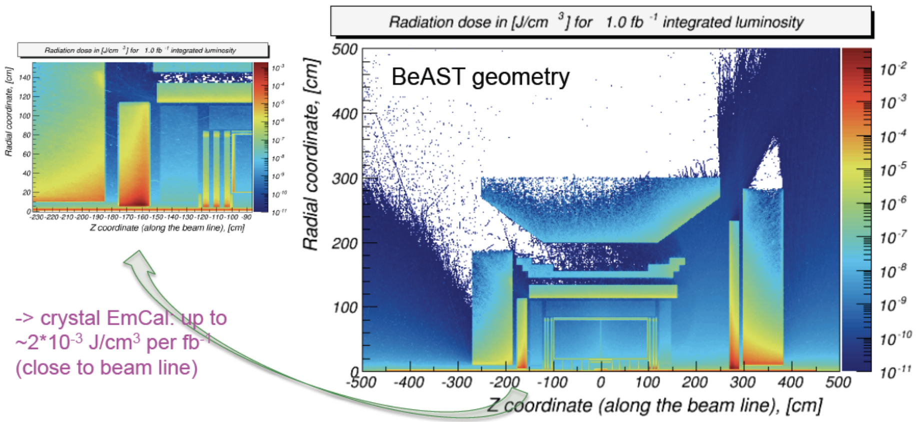
$-4<\eta<4 \sim [2^0 .. 178^0]$

[Furletova, Kiselev, MIT Yellow Report kick-off meeting 12/19]

Limitations / Drivers from Machine

Radiation dose from primary interactions

The (primary) quantity: E_{sum} = "a sum of dE/dx"/"cell volume" for N events



1 rad = 0.01 Gy & [Gy] = [J/kg] & PWO density ~8g/cm^3 -> ~250 rad/year

(at "nominal" luminosity ~10^{33} cm^{-2} s^{-1})

-> looks OK?

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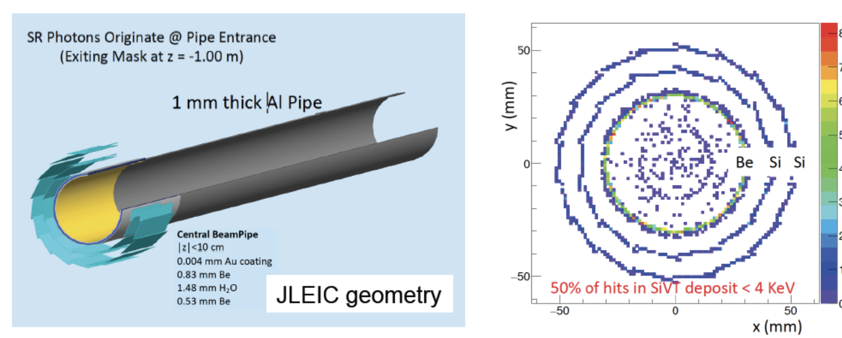
Radiation environment is far far less extreme than LHC GPDs

→ Not driving technologies

Synchrotron radiation

- Crossing angle (no strong electron bending at the IP) does not solve the synchrotron radiation problem completely ...
- ... because of the bending in Final Focusing Quads (FFQs)
- Need either to increase the beam pipe diameter at the IP or install masks or both

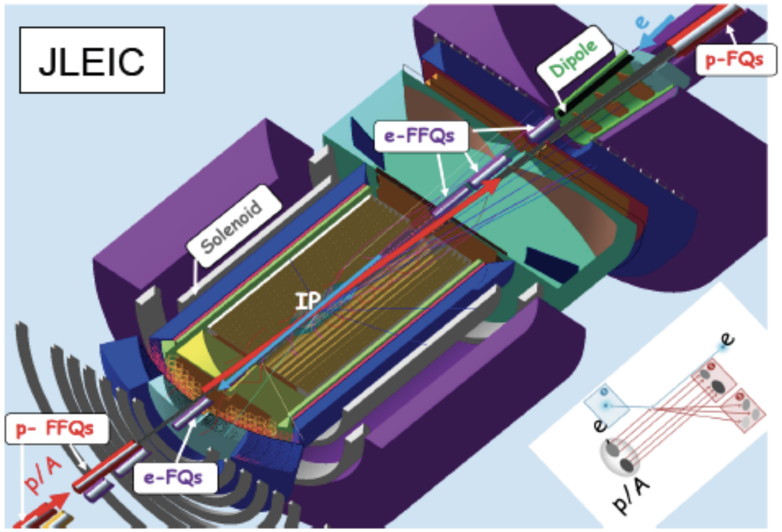
Synchrotron fan induced in FFQs hitting JLEIC SVT tracker after passing 24mm diameter mask at Z=-1m

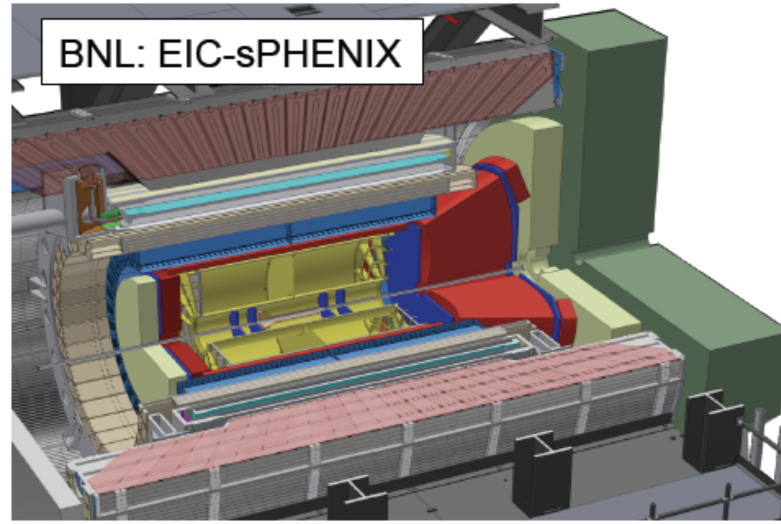


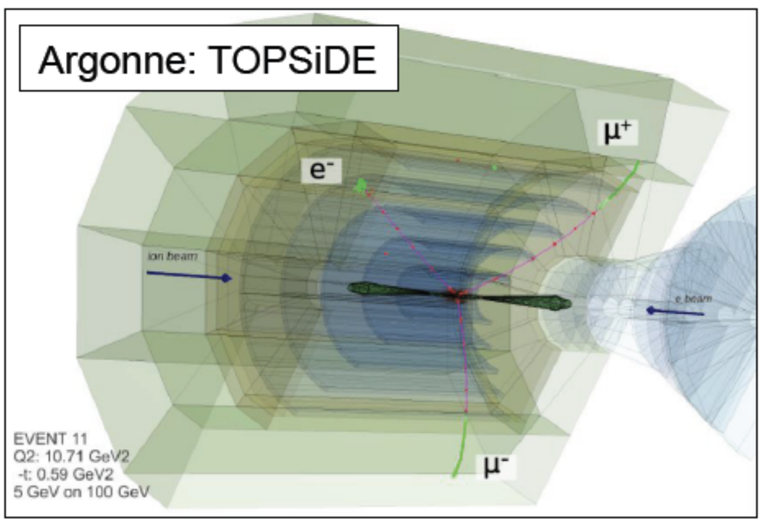
-> tedious optimization work is ongoing for both JLAB and BNL EIC designs

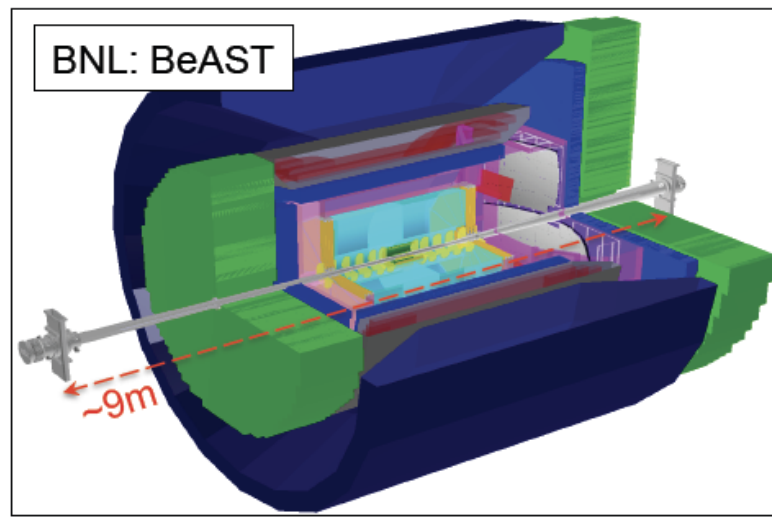
Synchrotron fan has strong impact on interaction region design and hence also on beamline instrumentation

EIC Detector Concepts have a Long History









Ongoing `Yellow Report' process has task of synthesising these ideas into initial design(s) to build collaborations around

Yellow Report Detector Groups

Conveners

- Ken Barish (UC Riverside)
- Tanja Horn (CUA)
- Peter Jones (Birmingham)
- Silvia Dalla Torre (Trieste)
- Markus Diefenthaler, ex-officio (JLab)

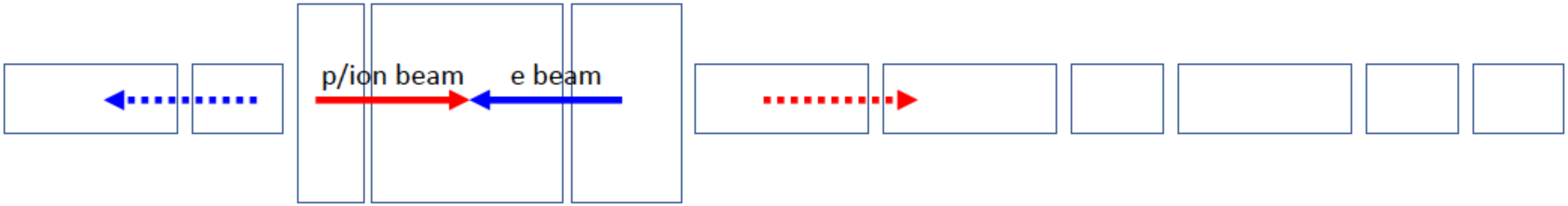
Fast paced development …
- Subgroups meet every 1-2 weeks
- 4 Plenary workshop sessions in 2020

Subgroups

The Working Group is divided in the following subgroups. To join a group and its mailing list, contact the conveners.

- **Tracking (+vertexing),** Conveners: Kondo Gnanvo (UVA), Leo Greiner (LBNL), Annalisa Mastroserio (INFN), Domenico Elia (INFN)
- **Particle ID**, Conveners: Tom Hemmick (SBU), Patrizia Rossi (JLab)
- **Calorimetry (EM and Hadronic),** Conveners: Vladimir Berdnikov (CUA), Eugene Chudakov (JLab)
- **Far-Forward Detectors**, Conveners: Alexander Jentsch (BNL), Michael Murray (Kansas)
- **DAQ/Electronics**, Conveners: Andrea Celentano (INFN), Damien Neyret (CEA Saclay)
- **Polarimetry/Ancillary Detectors**
  - Conveners: Elke Aschenauer, Dave Gaskell
  - Mailing list: eicug-polarimetry@eicug.org
  - Indico
- **Central Detector/Integration & Magnet,** Conveners: Willliam Brooks, Alexander Kiselev (BNL)
- **Forward Detector/IR Integration,** Convener: Yulia Furletova (JLab)
- **Infrastructure and Installation,** Convener: TBA
- **Detector Complementarity,** Conveners: Elke Aschenauer (BNL), Paul Newman (Birmingham)

What is in place already? - Cartoon / Model



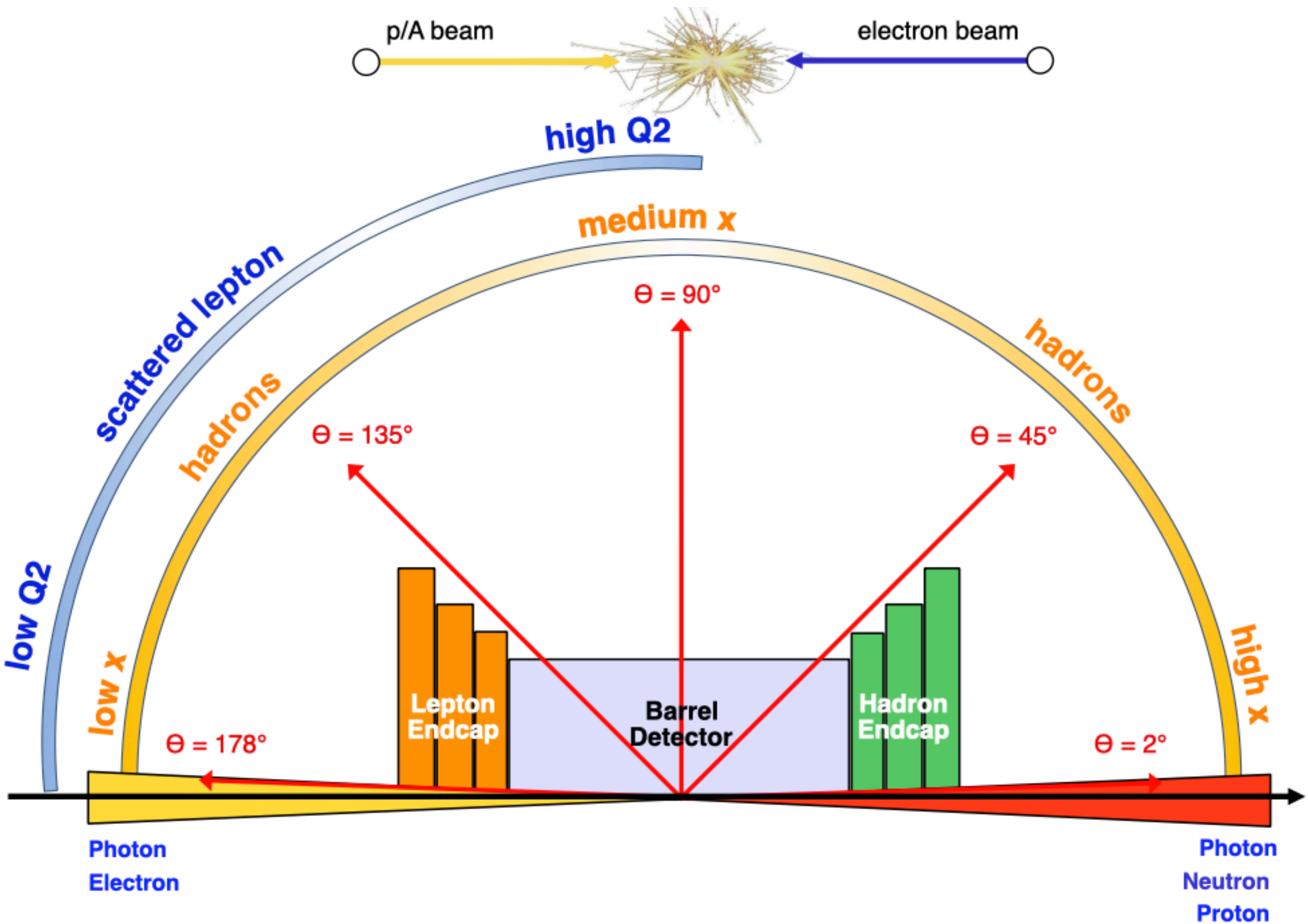
far-backward e detection	e final-focus quads	"Central detector", includes e endcap, central, and p/ion endcap detectors	Ion final-focus quads	far-forward h detection	forward dipole	far-forward h detection	forward dipole	far-forward h detection
Low-Q^2 spectroscopy		Inclusive Structure Functions, TMDs, heavy flavors and jets, electrons for GPDs		Baryon decay π/K structure evaporated n		GPDs/DVCS, tagging, diffraction		lowest-t, diffraction
GEMs Diamond detectors?		Vertex and Tracking detectors, particle identification detectors, calorimetry detectors, muon detectors, etc.		GEMs ZDCs e/γ calorim.		GEMs Roman pots e/γ calorim.		Roman pots GEMs?

physics examples

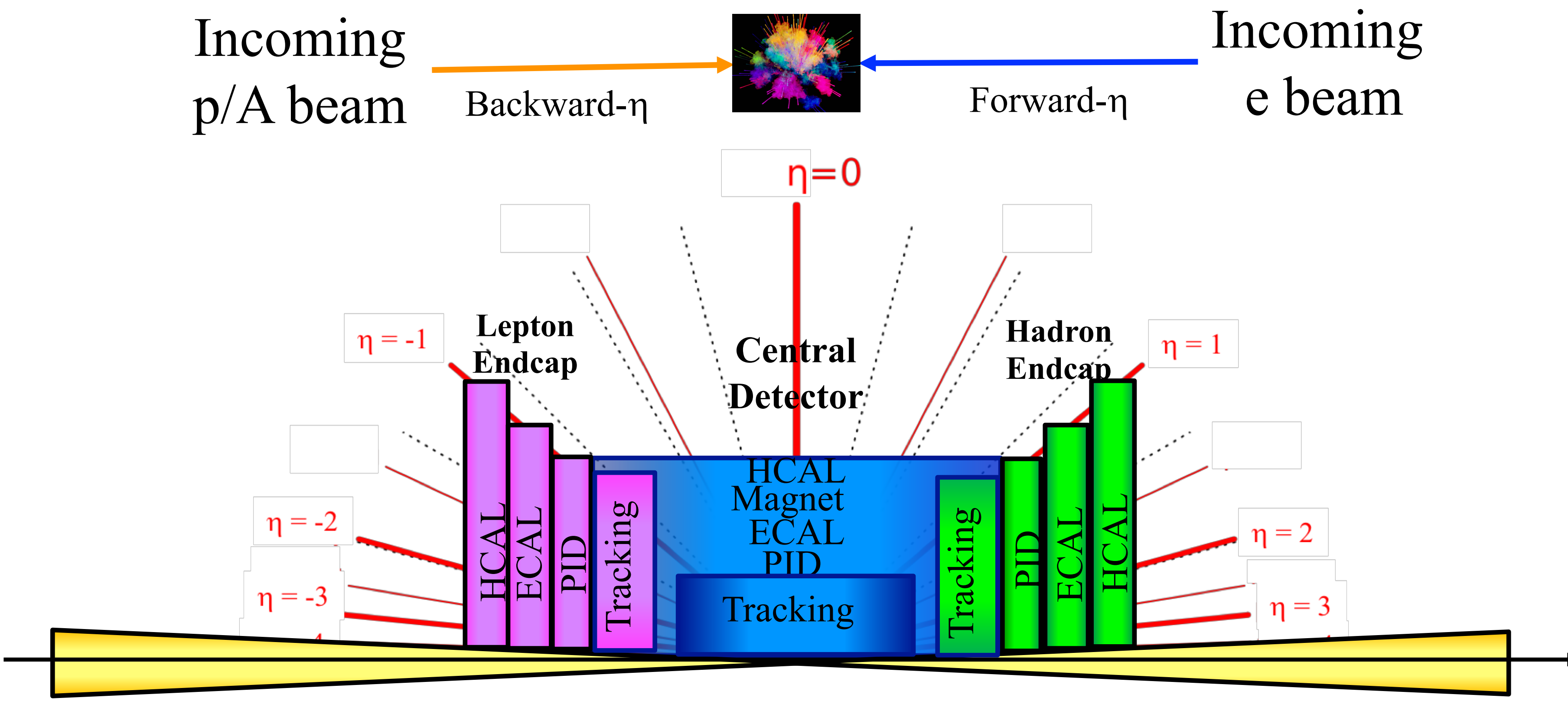
detector examples

[Horn, Pavia Yellow Report meeting 05/20]

What is in place already? - Schematically



A bit more detail (recent baseline design)



- low Q^2 scattered leptons
- Bethe-Heitler photons for luminosity

Luminosity Detector

Low Q^2-Tagger

Hadron and Lepton Polarimetry

- Intact protons in ep
- Neutrons and nuclear fragments in eA

Zero Degree Calo

Forward Tracking

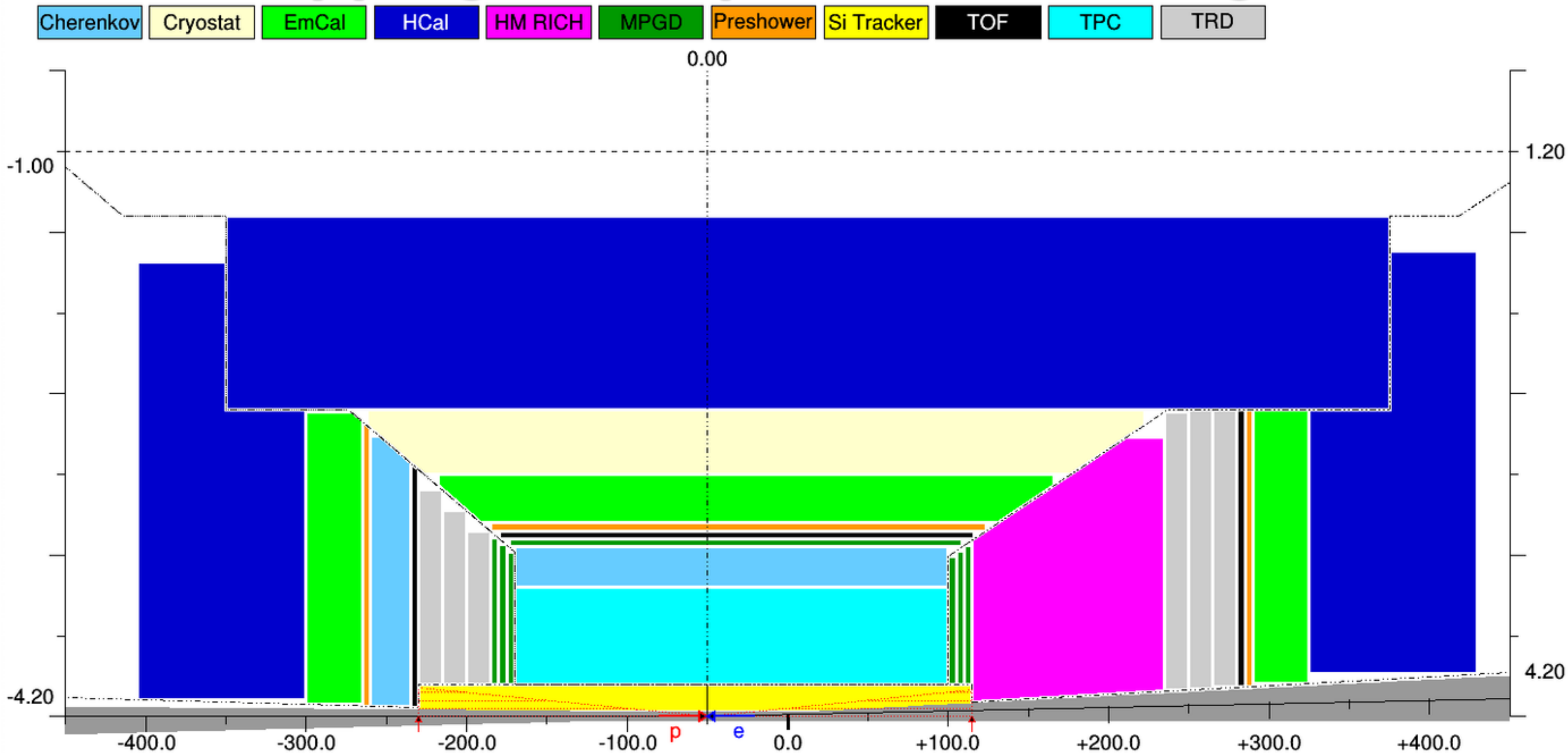
Interactive Detector Matrix

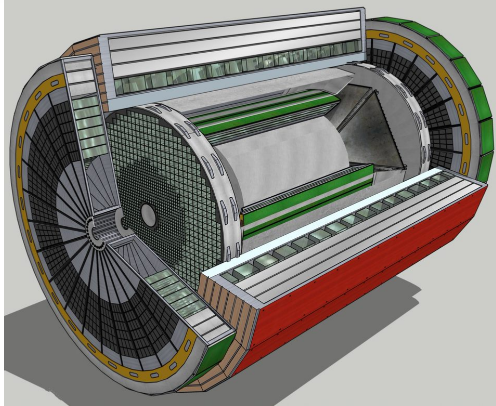
η	Nomenclature			Tracking			Electrons		π/K/p		HCAL	Muons
				Resolution	Allowed X/X_0	Si-Vertex	Resolution σ_E/E	PID	p-Range (GeV/c)	Separation	Resolution σ_E/E	
-6.9 to -5.8	↓ p/A	Auxiliary Detectors	low-Q2 tagger	$\sigma_\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV^2								
...												
-4.5 to -4.0			Instrumentation to separate charged particles from photons									
-4.0 to -3.5							$2\%/\sqrt{E}$					
-3.5 to -3.0	Central Detector		Backward Detector	$\sigma_p/p \sim 0.1\% \oplus 0.5\%$	~5% or less X	TBD		π suppression up to 1:10^4	≤ 7 GeV/c	≥ 3 σ	~50%/$\sqrt{E}$	
-3.0 to -2.5												
-2.5 to -2.0				σ_p/p $0.1\% \oplus 0.5\%$			$2\%/\sqrt{E}$					
-2.0 to -1.5				σ_p/p $0.05\% \oplus 0.5\%$			$7\%/\sqrt{E}$					
-1.5 to -1.0							$7\%/\sqrt{E}$					
-1.0 to -0.5			Barrel	σ_p/p $\sim 0.05\% \times p + 0.5\%$		$\sigma_{xyz} \sim 20$ µm, $d_0(z) \sim d_0(r\Phi) \sim 20/p_T$ GeV µm + 5 µm	(10-12)%/$\sqrt{E}$		≤ 5 GeV/c			TBD
-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 $\sim 0.05\% \times p + 1.0\%$		TBD			≤ 8 GeV/c		~50%/$\sqrt{E}$	
1.5 to 2.0												
2.0 to 2.5									≤ 20 GeV/c			
2.5 to 3.0				$\sigma_p/p \sim$ $0.1\% \times p + 2.0\%$								
3.0 to 3.5									≤ 45 GeV/c			
3.5 to 4.0	↑ e	Auxiliary Detectors	Instrumentation to separate charged particles from photons									
4.0 to 4.5												
...			Neutron Detection									
> 6.2			Proton Spectrometer	$\sigma_{intrinsic}(\|t\|)/\|t\| < 1\%$; Acceptance: $0.2 < p_T < 1.2$ GeV/c								

- Summarises EIC detector outline and requirements
- Plan to link to corresponding studies

https://physdiv.jlab.org/DetectorMatrix/

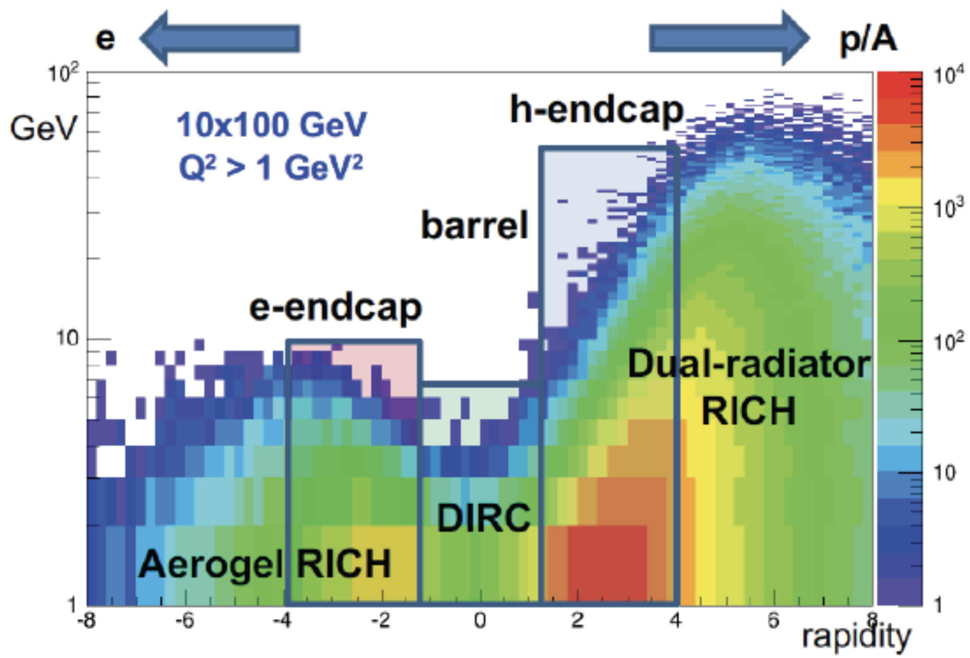
Mapping onto Specific Tecnologies

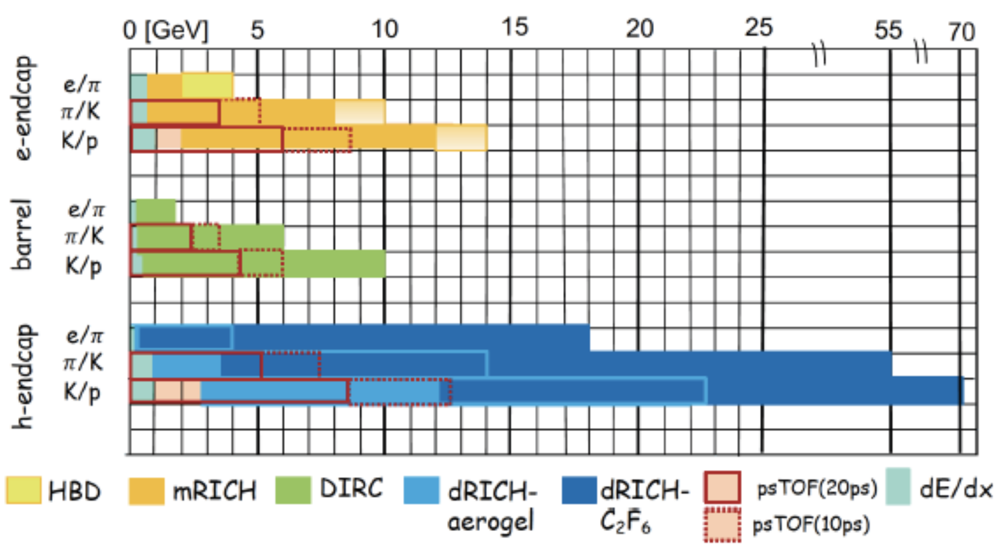




- Recent `Toy Model` baseline design, for implementation in GEANT etc
- Early days; by no means set in stone
- There should be more than one detector!

Detailed Considerations: Hadron Particle ID

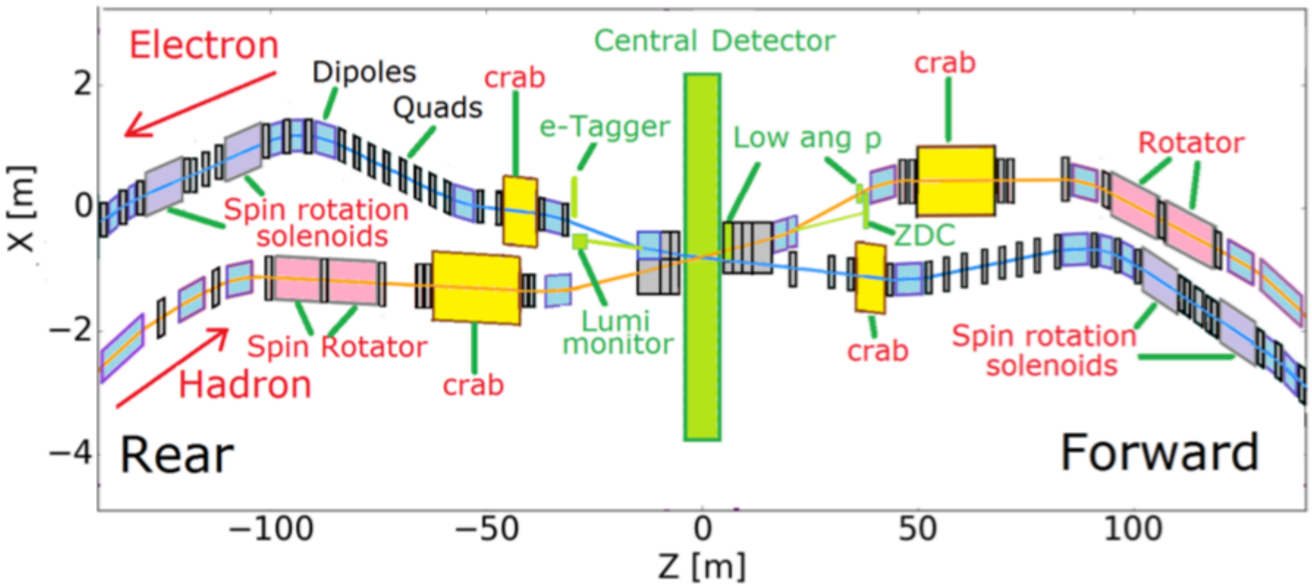




- **h-endcap:** a RICH with two radiators (gas + aerogel) is needed for π/K separation up to ~50 GeV/c
- **e-endcap:** A compact aerogel RICH with π/K separation up to ~10 GeV/c
- **barrel:** A high-performance DIRC provides a compact and cost-effective way to cover the area with π/K separation up to ~6-7 GeV/c
- TOF and/or dE/dx in a TPC can cover lower momenta

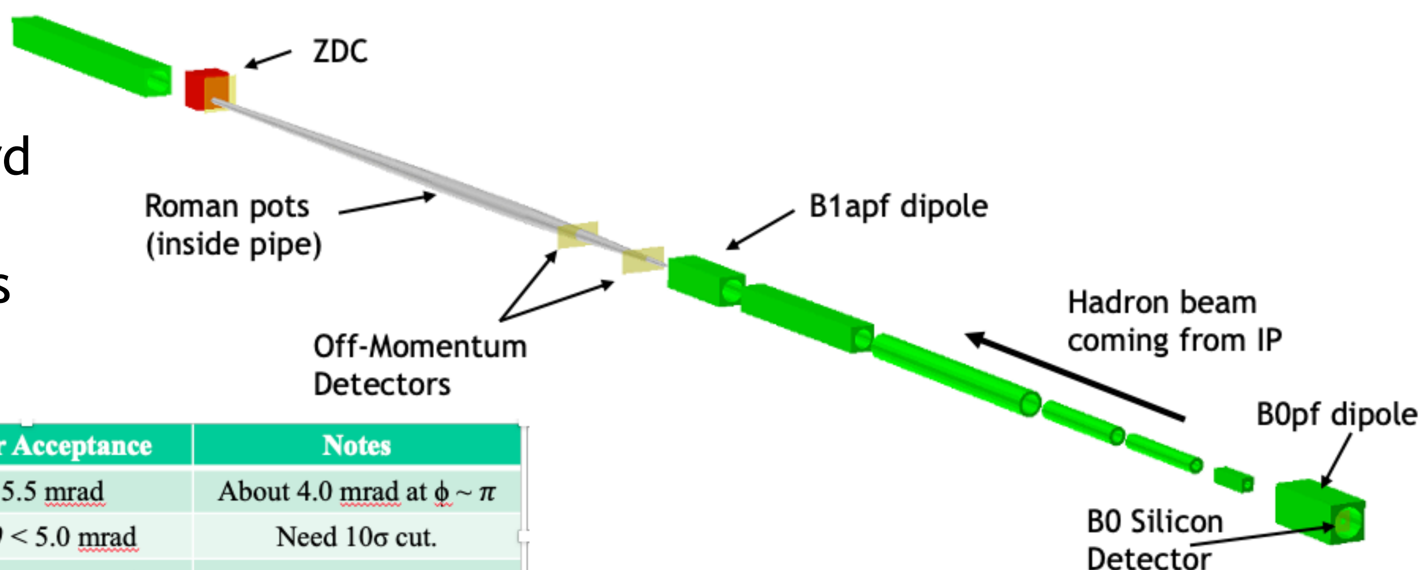
[Example design]

Detailed Considerations: Beamline



Baseline design for 'first' interaction Region

[See Andrei's Talk]



Example far-forward (beamline) design, meeting constraints of machine / IR

Detector	Angular Acceptance	Notes
ZDC	$\theta < 5.5$ mrad	About 4.0 mrad at $\phi \sim \pi$
Roman Pots	$0.0 < \theta < 5.0$ mrad	Need 10σ cut.
Off-Energy Detectors	$0.0 < \theta < 5.0$ mrad	
B0 Sensors	$5.5 < \theta < 20.0$ mrad	

High energy colliders have at least 2 detectors

DOE Statement:

EIC scope includes the machine upgrades to RHIC asset and two interactions regions with one of the interaction regions outfitted with a major detector.
Scientific instrumentation for the second interaction region not included in the scope.

- We have a pretty good idea how one basic detector layout might look (technologies and details still being developed)

- Second detector is a blank page → major opportunity to refine and enhance EIC physics program

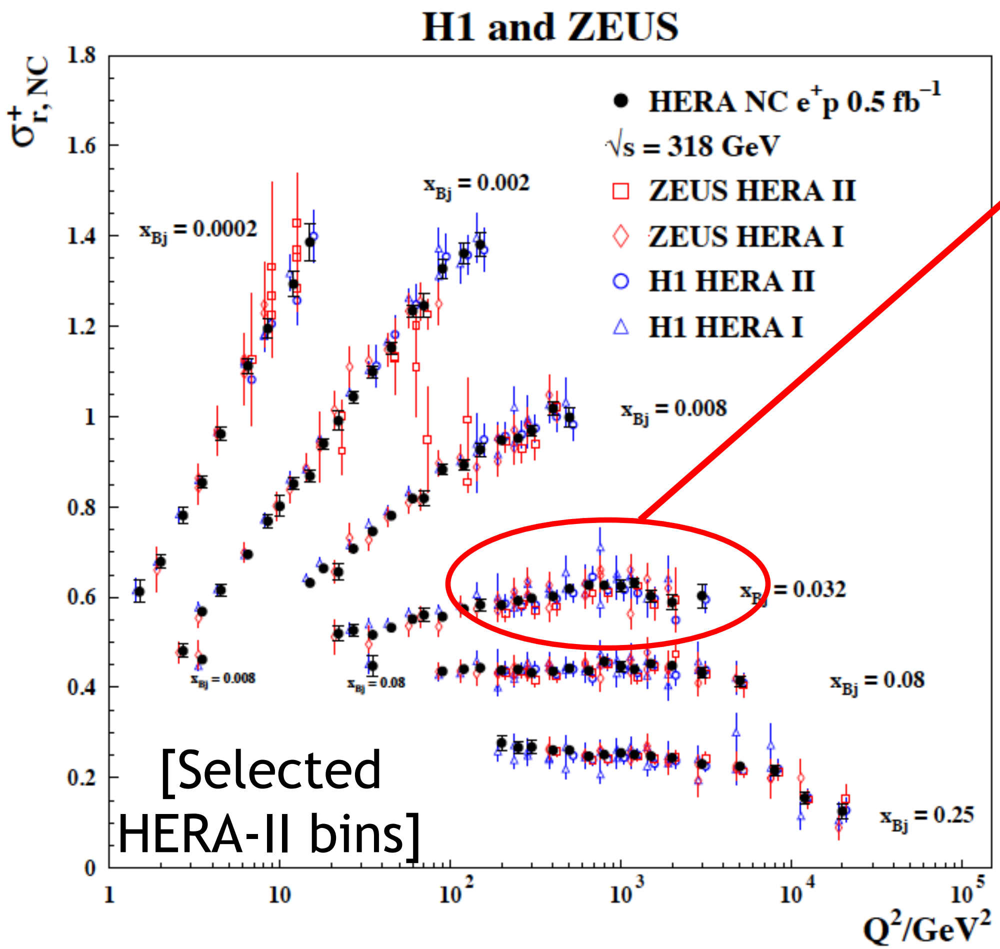
- Clear motivation to have a second GPD-type detector, to cross-check important results, but other considerations …

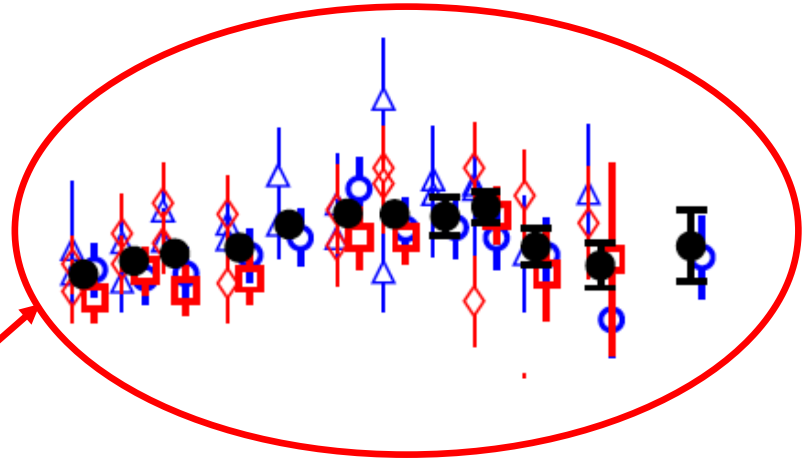
→ can we base design on two complementarity detectors from the outset?

Complementary Detector Motivations

1) Cross-checking important results (obvious!)

2) Cross calibration (eg H1 v ZEUS)

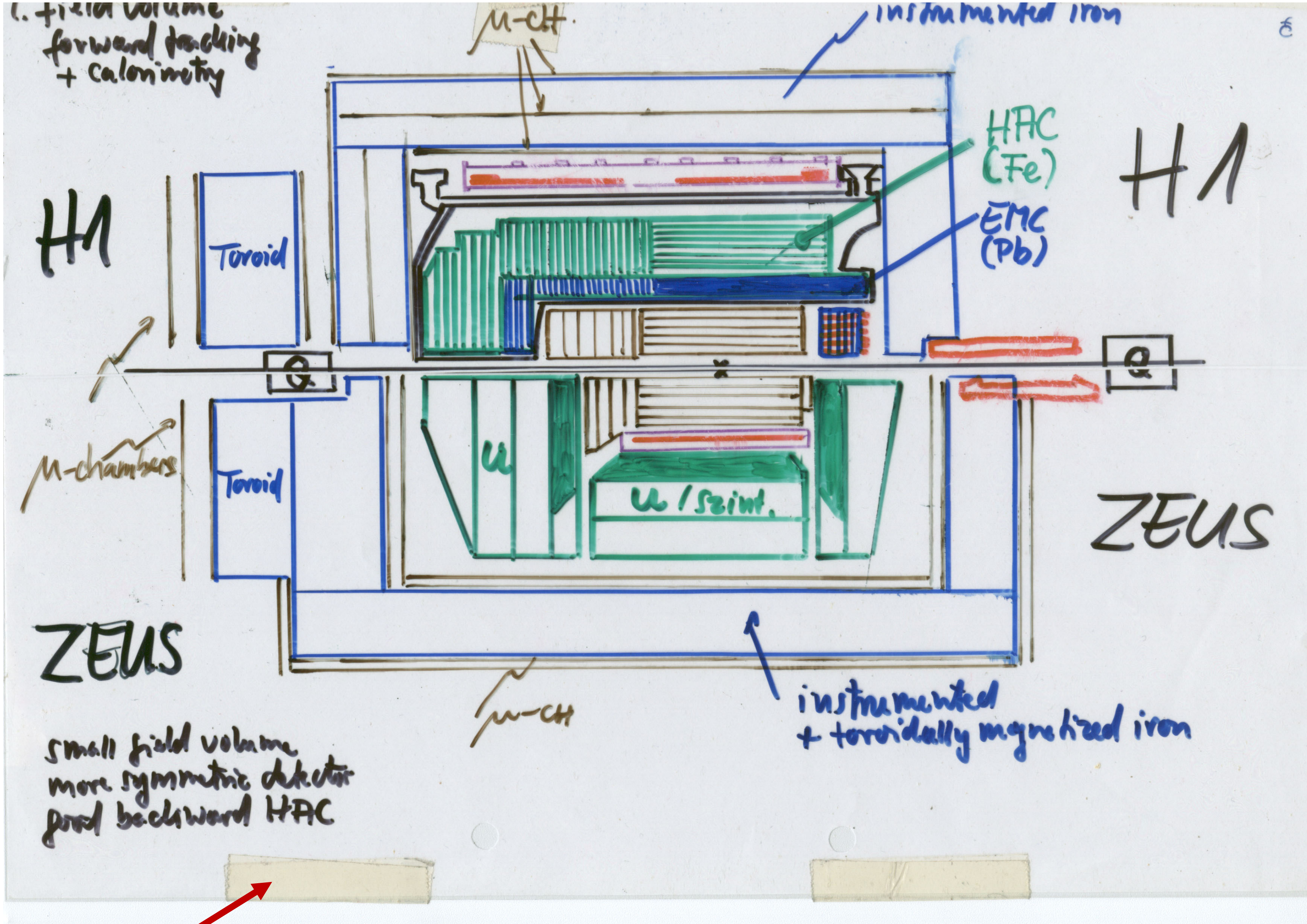




- Combining data gave well beyond the √2 statistical improvement …
- Different dominating H1, ZEUS systematics…
- Effectively use H1 electrons with ZEUS hadrons

… not all optimal solutions have to be in one detector…

Complementary design of H1 and ZEUS?



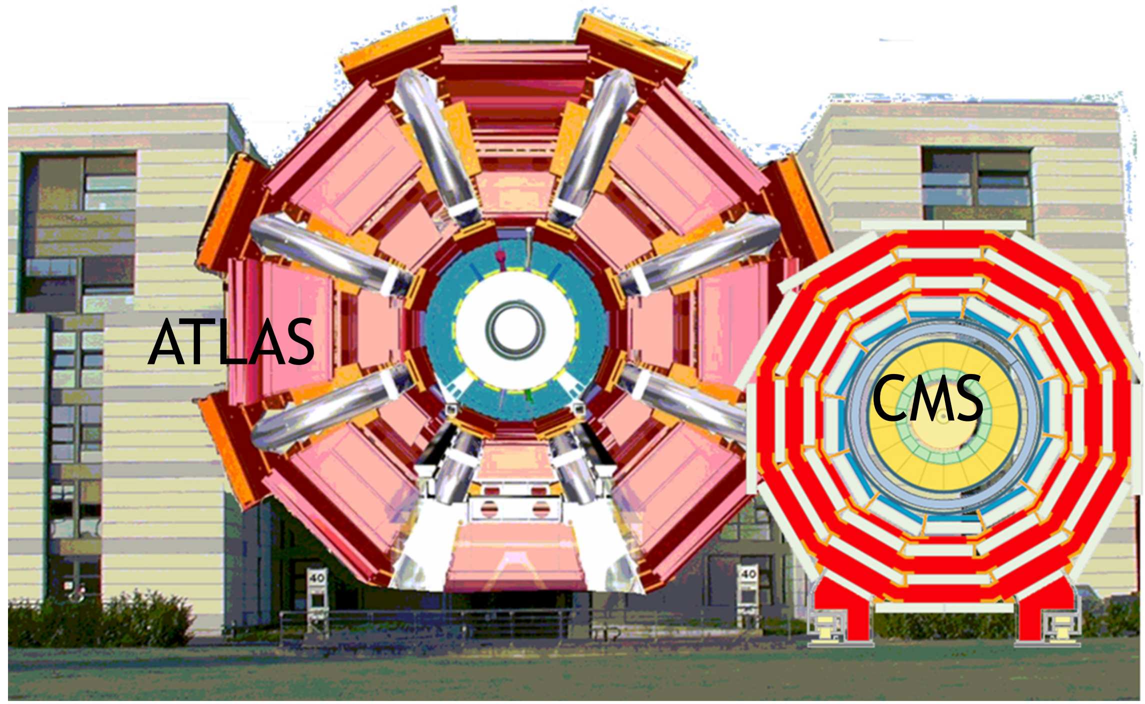
User defined animation

[Franz Eisele, ~ 1986]

Complementary Detector Motivations

3) Redundancy versus unforeseen technology problems …

… by applying different detector technologies and philosophies to similar physics aims



4) Different primary physics focuses …

…optimizing overall sensitivity to EIC physics programme …

→ \`Complementarity\` working group exploring physics needs and technology options

Some Opportunities for Complementarity

- **Solenoid field**

→ High field for precise measurement of high p_T charged particles (scattered electron, leading particles in SiDIS …)
→ Lower field for acceptance of lower p_T charged particles (spectroscopy, some charm decays …)

- **Muon identification**

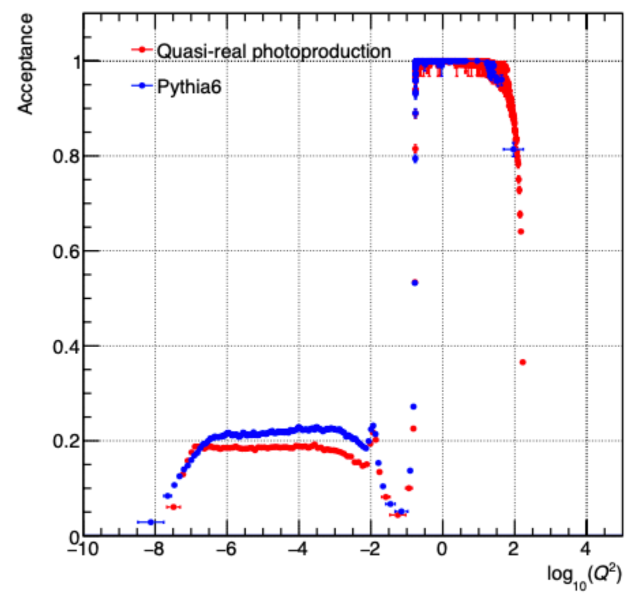
→ Limited need for dedicated outer muon chambers (maybe for J/Ψ or heavy flavour decays?) … Are HCAL patterns enough?
→ One detector could have barrel and/or forward muon chambers if physics motivation becomes clearer

- **Dipole and low Q^2 tagger set-up**

→ Is it possible to place Q^2 gap in different places?
→ Would have implications for IR design?

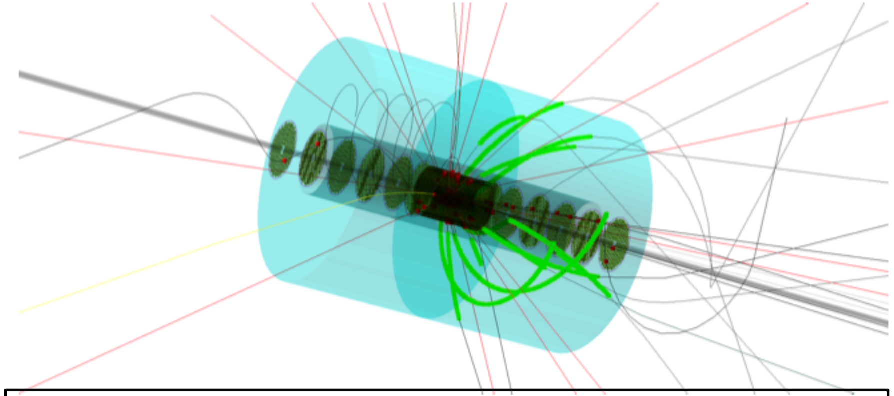
- **Beamline proton and neutron instrumentation**

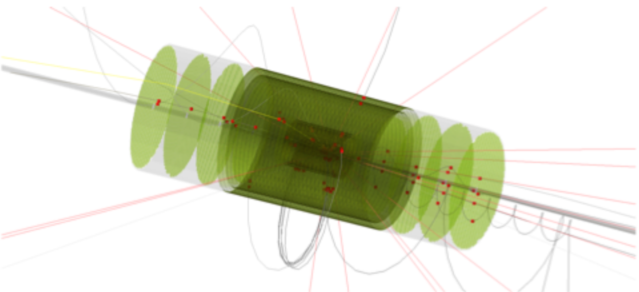
→ Place Roman pots at secondary beam focus to extend acceptance in scattered proton energy?



- **Optimise to Performance at different $\sqrt{s}$**

EIC Complementarity through Detector Technology Choices: e.g. Tracking Region





1) Si + TPC - Based on BeAST

- 80cm outer radius TPC
- MAPS Si inner barrels and disks

2) All Silicon Concept

- 45cm outer radius
- MAPS barrels and disks (15m^2)

[Sichtermann, Pavia Yellow Report meeting 05/20]

- Si version matches / slightly improves momentum, vertexing performance and saves space to implement other (PID?) detectors
- TPC version provides PID from dE/dx & keeps low material budget

Other such examples under consideration.

Summary

- EIC detector designs are developing fast, with many new ideas in context of Yellow Report

- Expression of Interest Call (Rolf's talk) provides framework for next steps

… currently a world of opportunity …