Yellow Report Reference Detector

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EIC@IP6

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Electron-Ion Collider

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U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- ❑ Introduction
- ❑ EIC reference detector components & alternative options
  - ✓ Tracking
  - ✓ EM and hadronic calorimetry
  - ✓ Particle ID
- ❑ Far-forward and far-backward regions
- ❑ Electronics/DAQ
- ❑ Summary

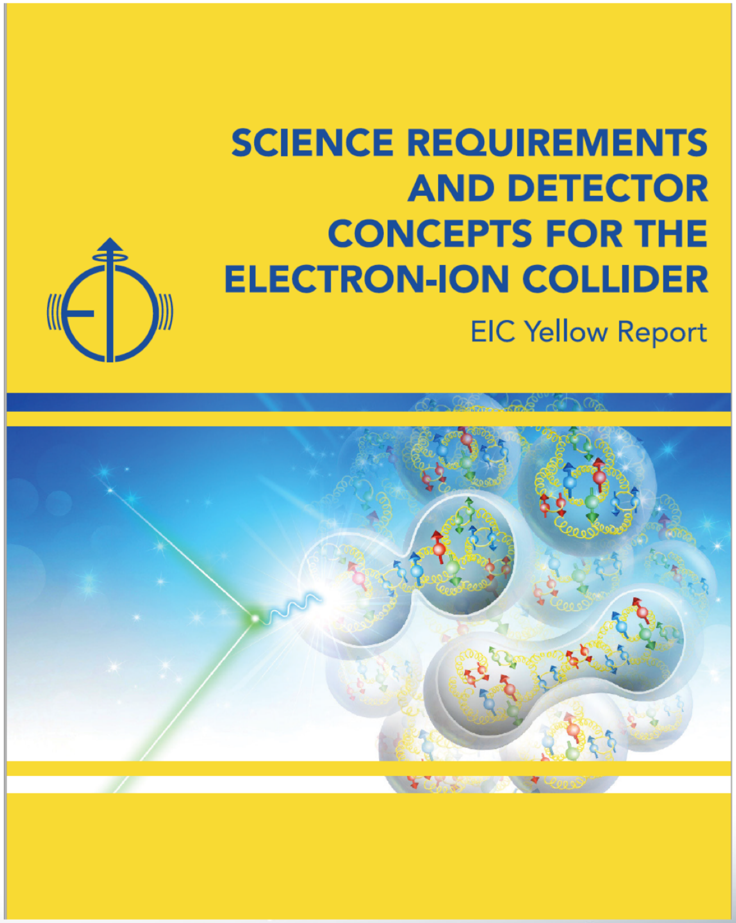
From Yellow report to EIC@IP6

arXiv:2103.05419

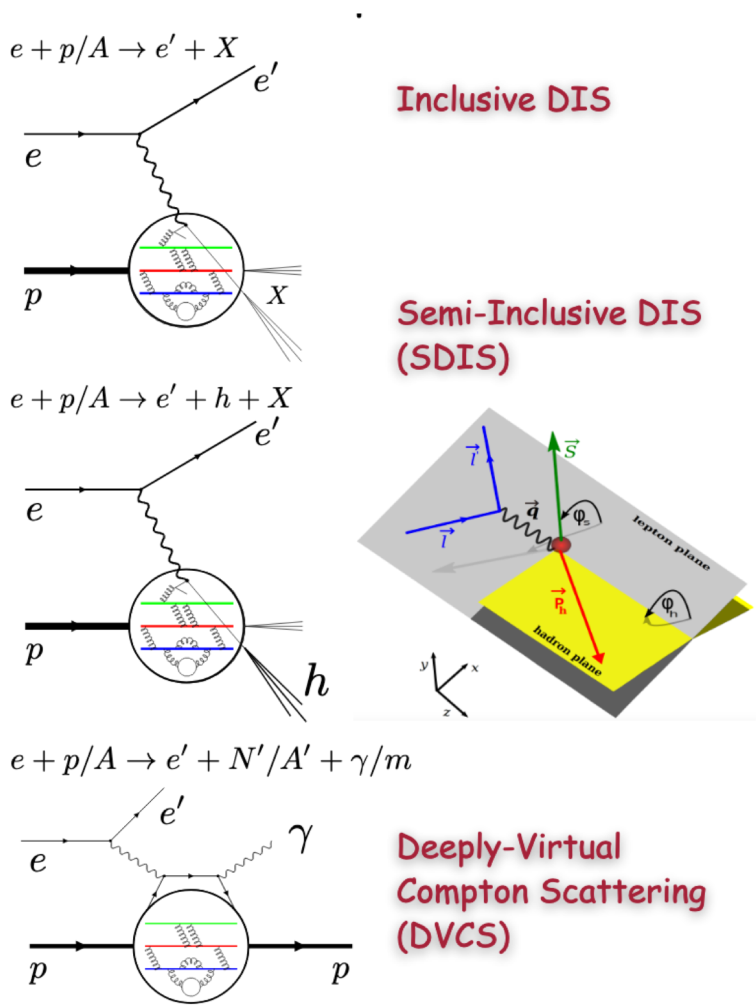
The EIC Yellow Report is a year long EICUG driven activity (from Dec 2019 MIT kickoff meeting - until Dec 2020), which summarizes science requirements for the detectors and possible implementations of the detector technologies at EIC.

~800-page document
412 authors, 151 institutions

This proposal (EIC@IP6) emerged from the Yellow Report discussions. It is based on the Reference detector (next slides) and a new 3T magnet



Physics at EIC



- ❑ Inclusive: unpolarized $f_i(x,Q^2)$ and helicity $\Delta f_i(x,Q^2)$ distributions through unpolarized and polarized structure function measurements (F_2, F_L, g_1)
  - ❑ Define kinematics (x, Q^2) through electron (e-ID is critical) / hadron final state or a combination of both
- ❑ SIDIS: flavor tagging through hadron identification studying FF / TMD's (transverse momentum, k_T dependence)
  - ❑ Azimuthal asymmetry measurement – full azimuthal acceptance
  - ❑ Heavy flavor (charm / bottom): excellent vertex reconstruction
- ❑ Exclusive: tagging of final state proton using Roman Pots studying GPD's (impact parameter, b_T dependence) using DVCS and VM production
- ❑ eA: impact parameter determination / neutron tagging using Zero-Degree Calorimeter (ZDC)

Physics requirements

η	Nomenclature			Tracking				Electrons and Photons			π/K/p PID		HCAL		Muons
				Min p_T	Resolution	Allowed X/X_0	Si-Vertex	Min E	Resolution σ_E/E	PID	p-Range (GeV/c)	Separation	Min E	Resolution σ_E/E	
-6.9 — -5.8			low-Q^2 tagger		$\delta\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV^2										
...	↓ p/A	Auxiliary Detectors													
-4.5 — -4.0			Instrumentation to separate charged particles from γ												
-4.0 — -3.5														~50%/√E+6%	
-3.5 — -3.0									2%/√E+(1-3)%						
-3.0 — -2.5					σ_p/p ~ 0.1%×p+2.0%		σ_{xy}~30µm/p_T+40µm								
-2.5 — -2.0			Backwards Detectors											~45%/√E+6%	
-2.0 — -1.5					σ_p/p ~ 0.05%×p+1.0%		σ_{xy}~30µm/p_T+20µm				≤ 7 GeV/c				
-1.5 — -1.0									7%/√E+(1-3)%	π suppression up to 1:10^4					
-1.0 — -0.5															
-0.5 — 0.0															
0.0 — 0.5		Central Detector	Barrel	100 MeV π 135 MeV K	σ_p/p ~ 0.05%×p+0.5%	~5% or less	σ_{xyz} ~ 20 µm, $d_0(z)$ ~ $d_0(r\varphi)$ ~ 20/p_T GeV µm + 5 µm	50 MeV			≤ 10 GeV/c	≥ 3σ	~500 MeV	~85%/√E+7%	Useful for bkg, improve resolution
0.5 — 1.0											≤ 15 GeV/c				
1.0 — 1.5									(10-12)%/√E+(1-3)%		≤ 30 GeV/c				
1.5 — 2.0					σ_p/p ~ 0.05%×p+1.0%		σ_{xy}~30µm/p_T+20µm								
2.0 — 2.5			Forward Detectors							3σ e/π	≤ 50 GeV/c			~35%/√E	
2.5 — 3.0							σ_{xy}~30µm/p_T+40µm				≤ 30 GeV/c				
3.0 — 3.5					σ_p/p ~ 0.1%×p+2.0%		σ_{xy}~30µm/p_T+60µm				≤ 45 GeV/c				
3.5 — 4.0			Instrumentation to separate charged particles from γ												
4.0 — 4.5															
...	↑e	Auxiliary Detectors													
> 6.2			Proton Spectrometer		$\sigma_{intrinsic}(\|t\|)/\|t\| < 1\%$; Acceptance: 0.2< p_T <1.2 GeV/c										

Figure 8.126: Summary of the Physics Working Group detector requirements

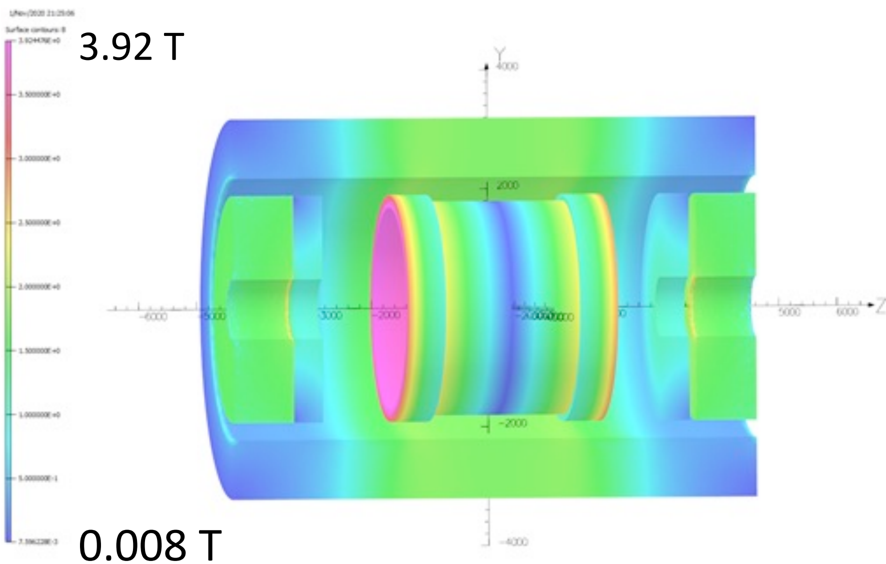
EIC Detector requirements

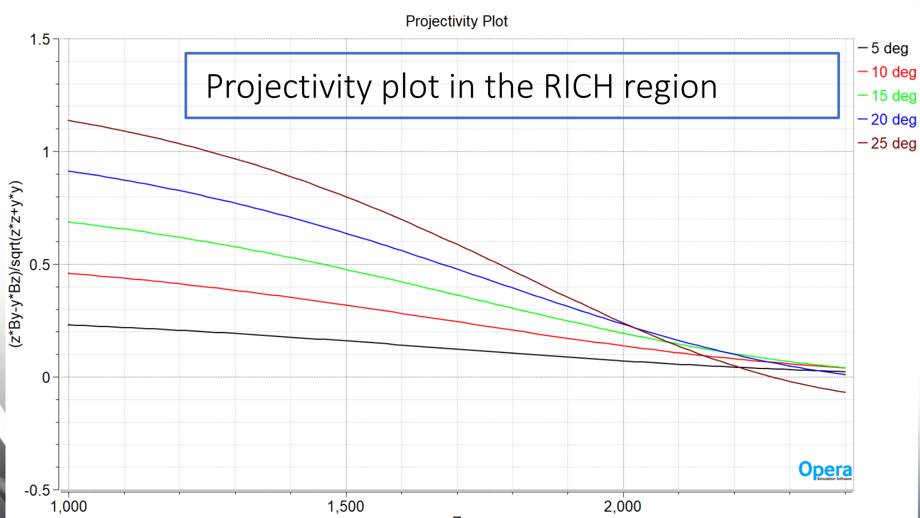
General purpose collider detector

- ❑ Large rapidity ($-4 < \eta < 4$) coverage; and far beyond in the far-forward detector region
- ❑ High precision low mass tracking
  - o small (μ-vertex) and large radius (gaseous-based) tracking
- ❑ Electromagnetic and Hadronic Calorimetry
  - o equal coverage of tracking and EM-calorimetry
- ❑ High performance PID to separate π, K, p on track level
  - o also need good e/π separation
- ❑ Large acceptance for diffraction, tagging, neutrons from nuclear breakup: critical for physics program
  - o Several ancillary detectors integrated in the beam line: low-Q^2 tagger, Roman Pots, Zero-Degree Calorimeter, Off-momentum spectrometer
- ❑ Control of systematics
  - o luminosity monitor, electron & hadron polarimetry

Integration into the Interaction Region is critical

New 3T Magnet





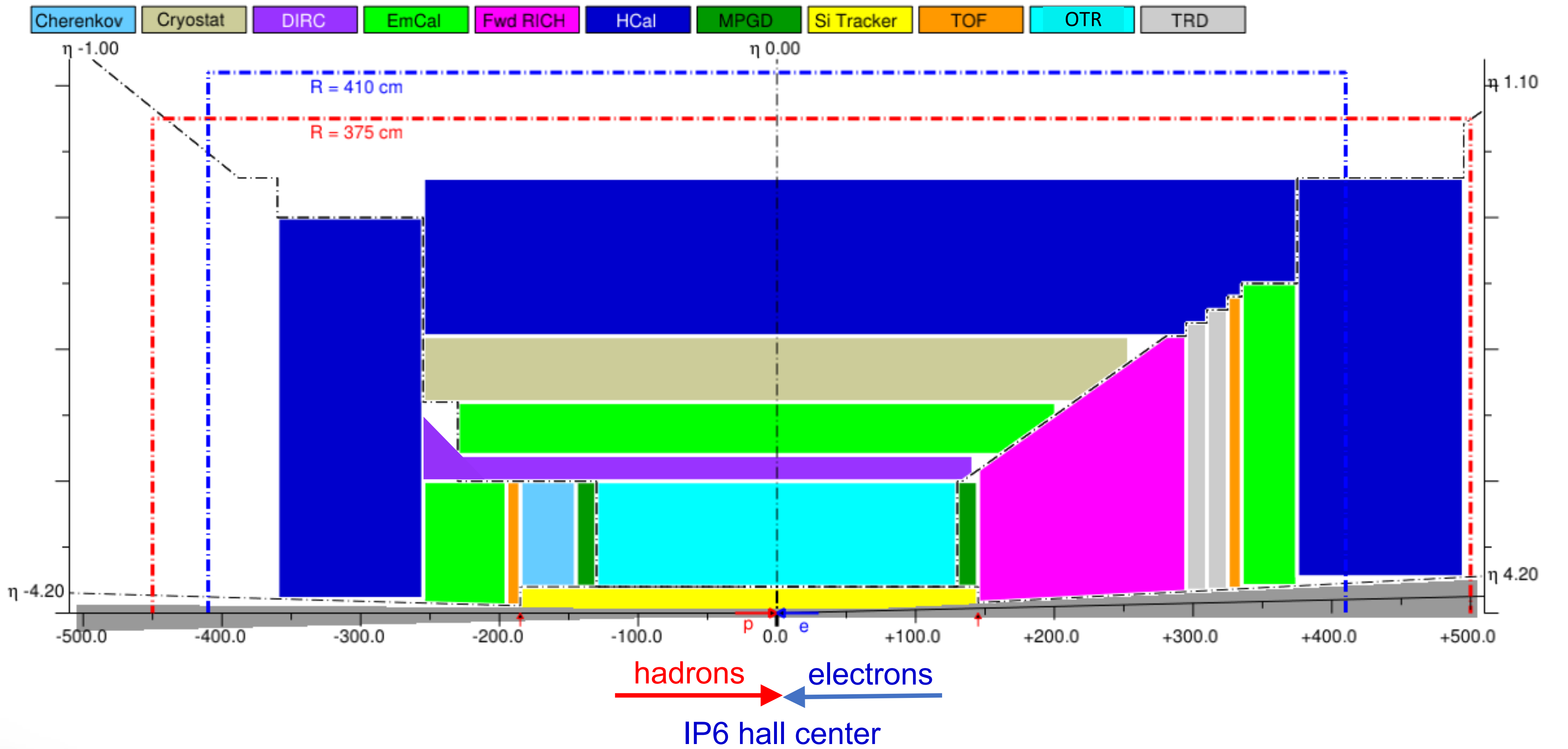
- Specification document is being finalized
  - Account for geometric constraints
  - Observe the projectivity requirement in the forward gaseous RICH volume
  - Optimize for tracking at large |η|

- A preliminary electric design will be available on a time scale of weeks
- Interface to GEANT is technically available (field map import)

Parameter	New Magnet	BABAR/sPHENIX Magnet
Maximum Central Field (T)	3	1.5
Coil length (mm)	3600	3512
Warm bore diameter (m)	3.2	2.8
Uniformity in tracking region ($z = 0$, $r < 80$ cm) (%)	3	3
Conductor	NbTi in Cu Matrix	Al stabilized NbTi
Operating Temperature (K)	4.5	4.5

Table 11.1: Summary of some of the main requirements of the EIC detector solenoid magnet.

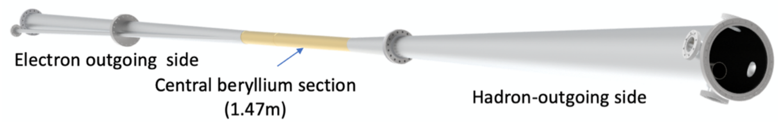
EIC reference detector



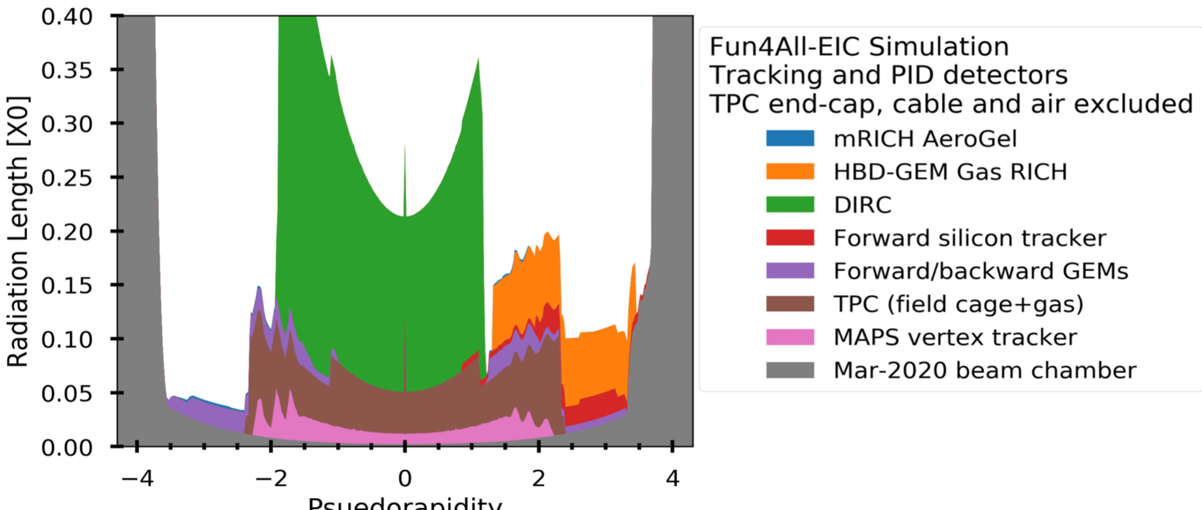
- -4.5 /+5.0 m machine-element-free region for central detector
- 25 mrad crossing angle (current IP6 design)
- Individual detector component space allocations provided by the Yellow Report Working Groups

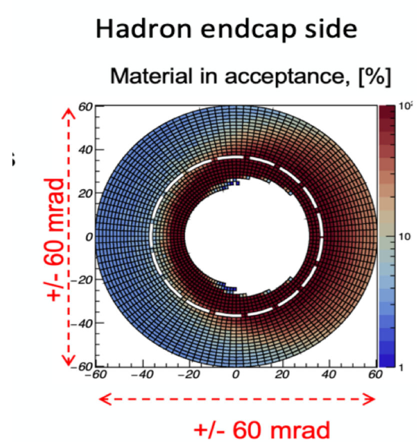
Tracking/Material Budget

- ❑ Vertex + central + forward / backward tracker layout (moderate momentum resolution, vertex resolution ~20 μm)
- ❑ Up to 3 T central solenoid field (maximize B*dl integral at high |η|)
- ❑ Low material budget
  - ❑ Minimize bremsstrahlung and conversions for primary particles
  - ❑ Improve tracking performance at large |η| by minimizing multiple Coulomb scattering
  - ❑ Minimize the dead material in front of the high-resolution e/m calorimeters

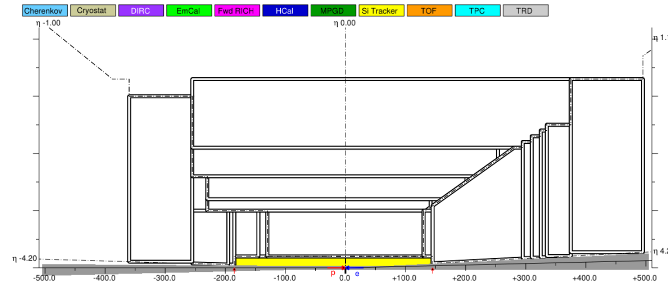


- ❑ Central area of beampipe (around IP):
  ~1.5m of beryllium to minimize multiple scattering for low P_T particles
- ❑ Low-mass exit window for far-forward particles
- ❑ Few % radiation length material thickness for the required angular range (low angle)

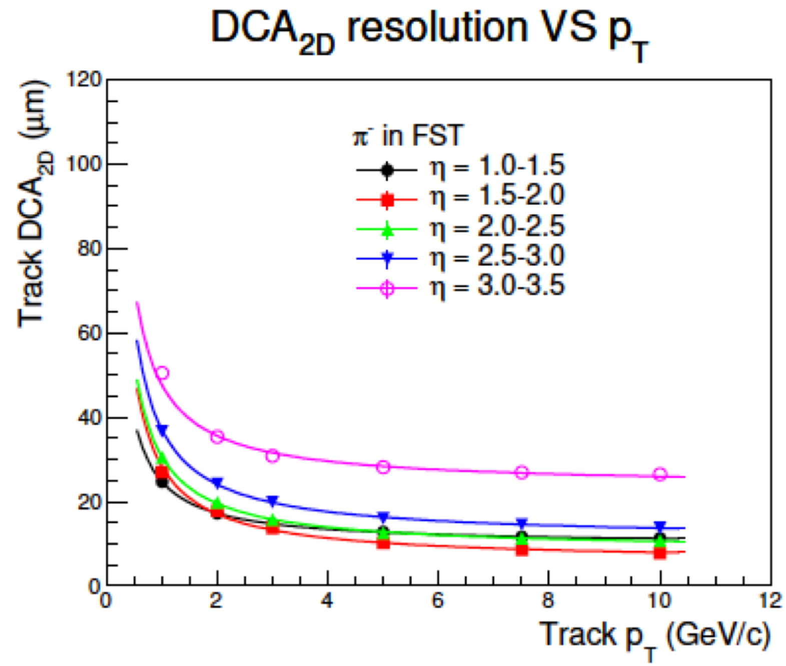


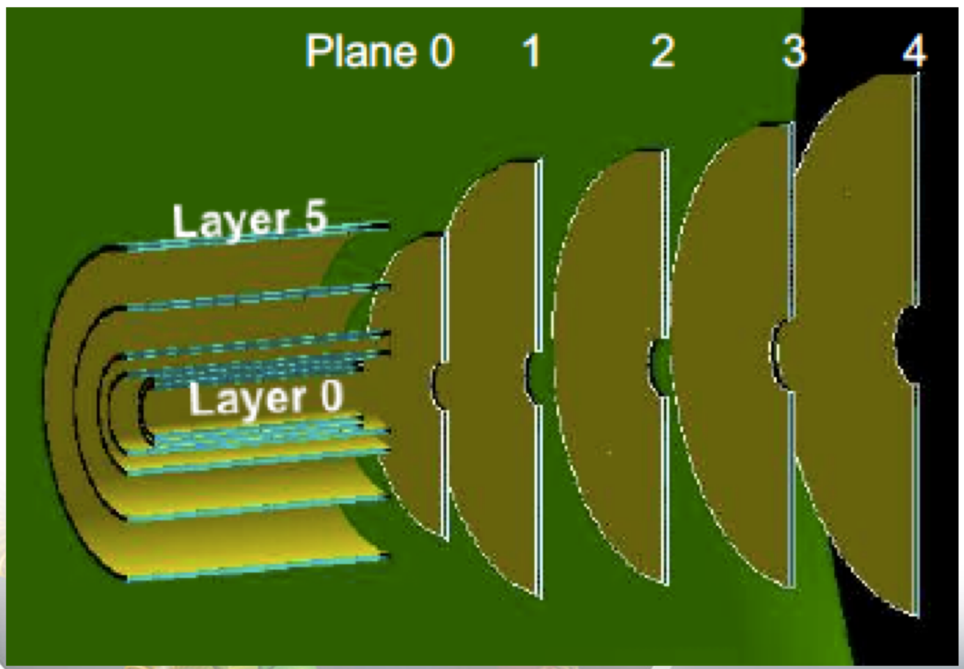


MAPS μVertex

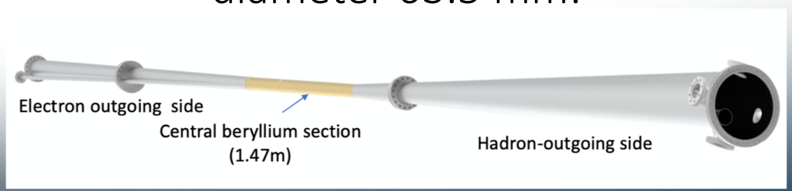


- For primary and secondary vertex reconstruction
- Low material budget:
  - ~0.3% X/X_0 per layer (possibly 0.05% a la ITS3 for ALICE)
- High spatial resolution:
  - 20 μm (or smaller) pixels
- Barrel+ Disks for endcaps



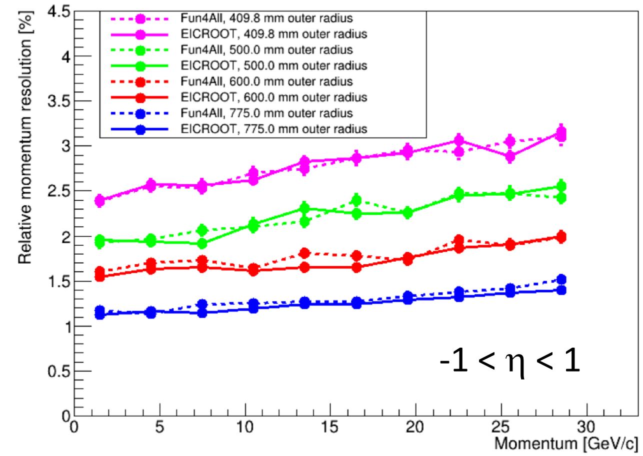


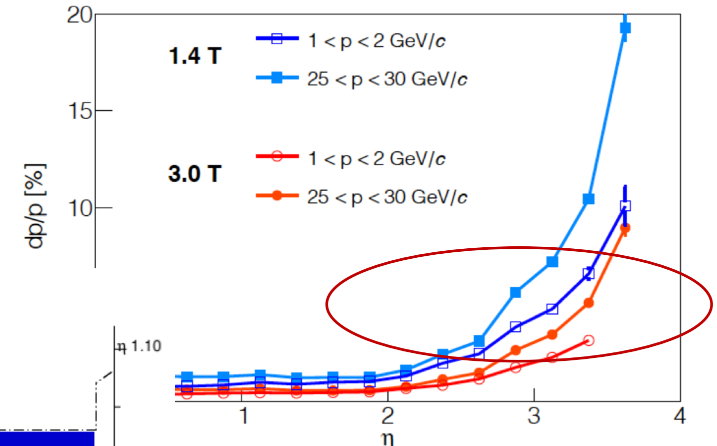
Central beampipe with the outer diameter 63.5 mm:



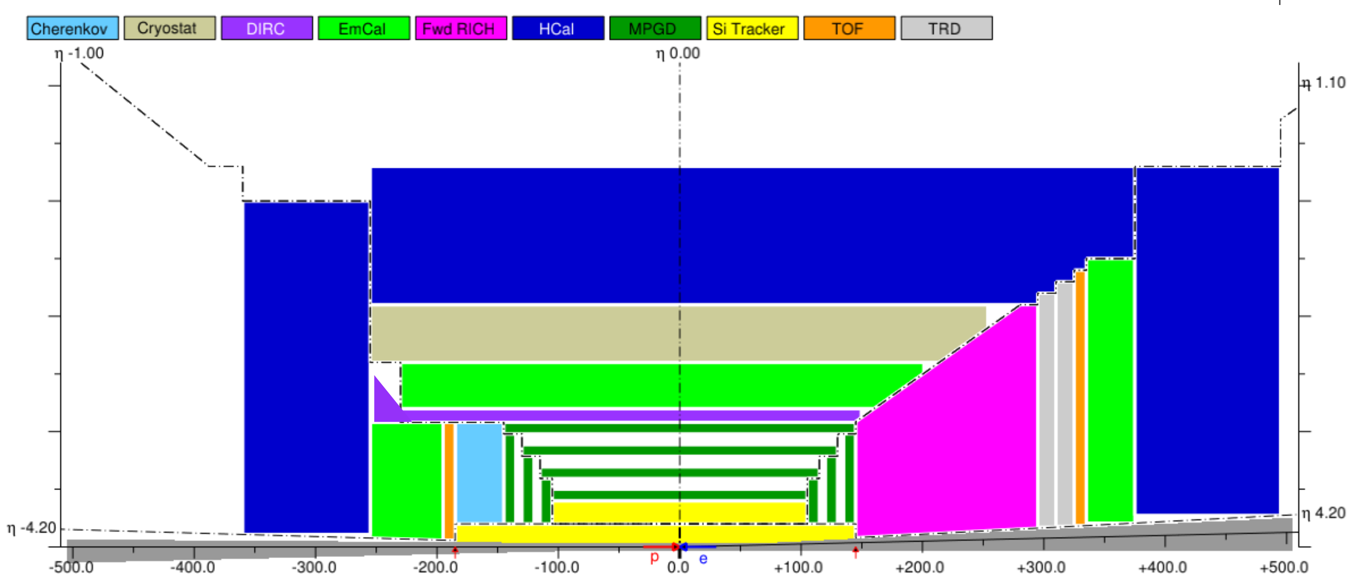
Central tracker

- For momentum reconstruction
- low material budget tracker (gaseous)
- Sufficient spatial resolution
- dE/dx for low-momentum PID (?)
- Tracking layer after DIRC

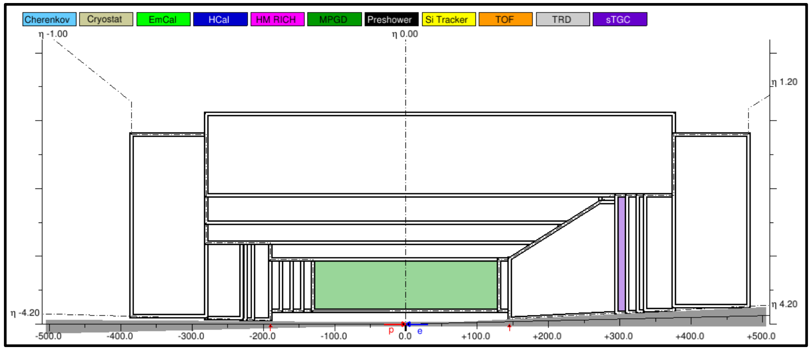




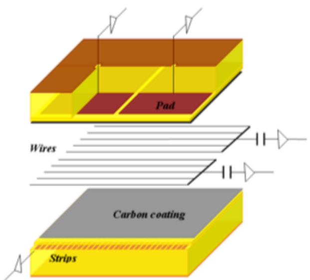
Hybrid version of MPGD + Si tracker
(discussions between eRD6, eRD22 & eRD25)

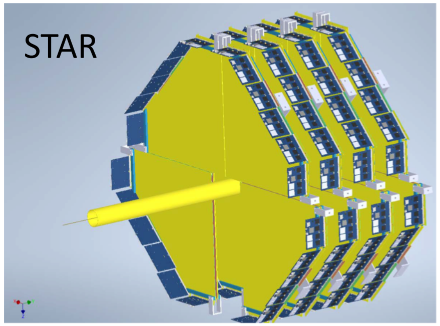


Alternative tracking options



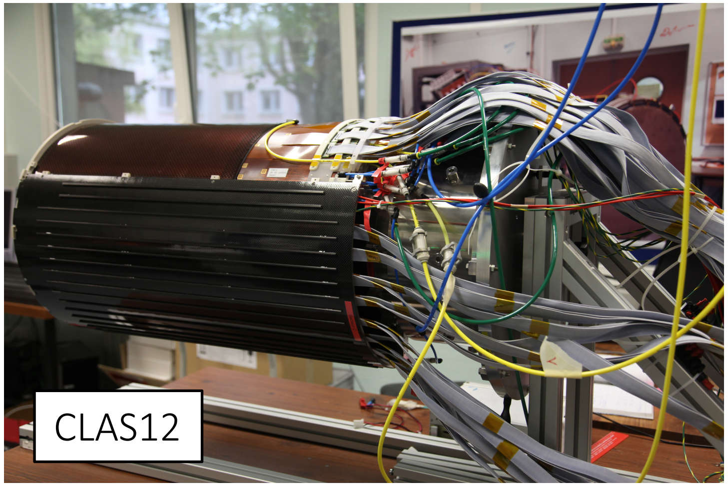
- *sTGC (ATLAS, STAR)*





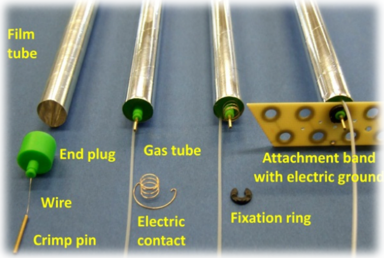
- ~100 μm or better spatial resolution
- cost efficient

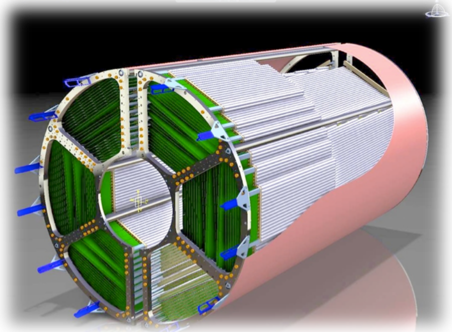
- *Cylindrical MM (or μRwell)*



- 6-8 concentric layers up to R ~ 80 cm
- <100 μm resolution (potentially in 2D)

- *Straw tracker (PANDA)*

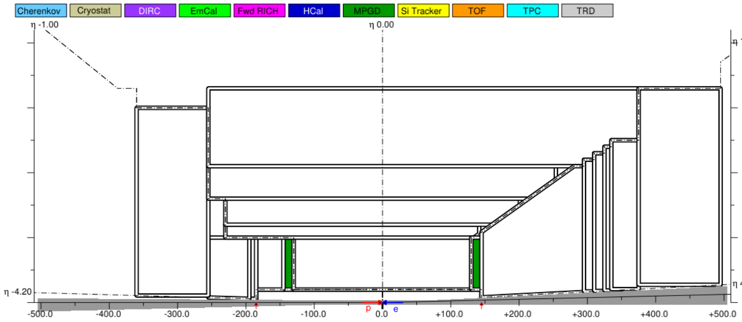


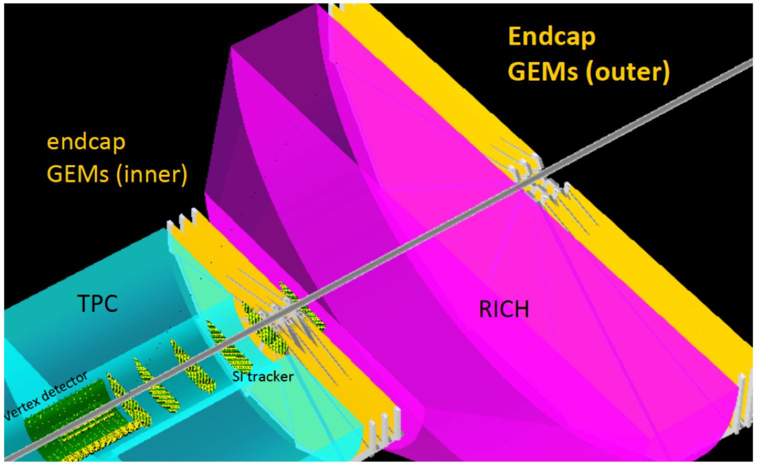


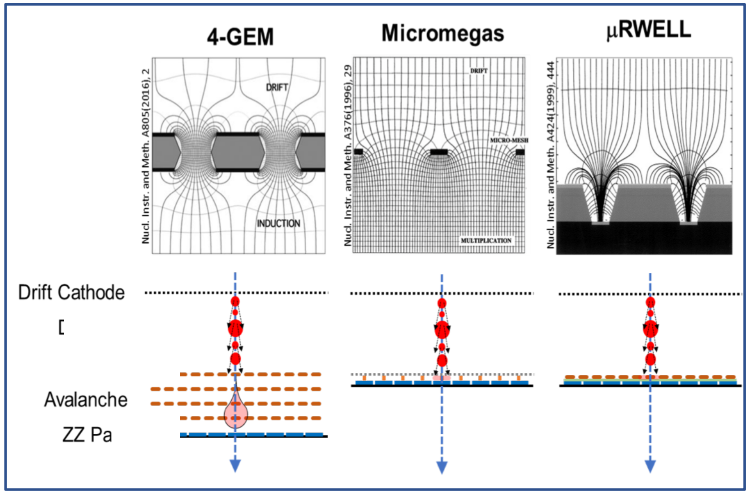
- as light-weight as the other EIC options
- can provide dE/dx (over pressure by design)

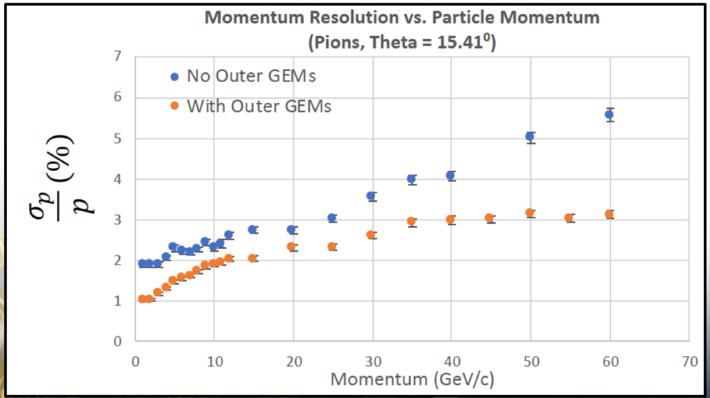
Endcaps: MPGDs

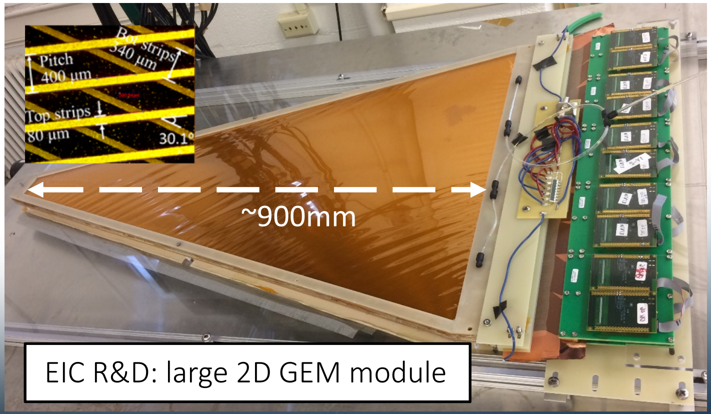
- To improve momentum resolution at large rapidities.
- Spatial resolution well below 100 μm
- Large-area detectors possible
- Cost efficient compared to silicon











EIC R&D: large 2D GEM module

Electro-Magnetic Calorimeter

- Applications
  - Scattered electron kinematics measurement at large |η| in the e-endcap
  - Photon detection and energy measurement
  - e/h separation (via E/p & cluster topology)
  - π^0/γ separation -> may also consider a highly segmented preshower

- Anticipated stochastic term in energy resolution & available space

η	[-4 .. -2]	[-2 .. -1]	[-1 .. 1]	[1 .. 4]
σ_E/E	~2%/√E	~7%/√E	~10-12%/√E	~10-12%/√E
space	~50 cm	~50 cm	~30 cm	~40 cm

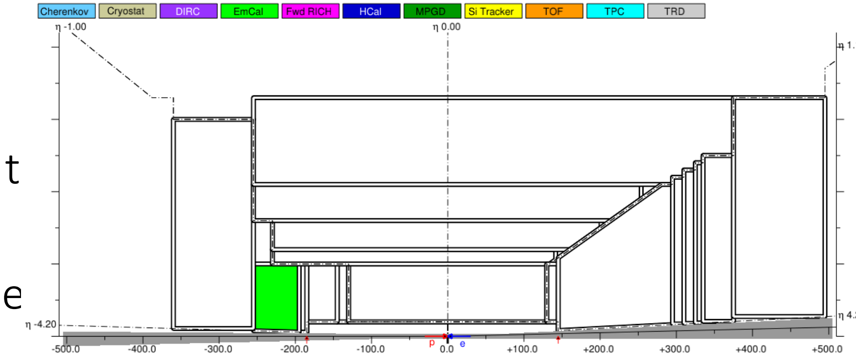
- Other considerations
  - Fast timing
  - Compactness (small X_0 and R_M)
  - Tower granularity
  - Readout immune to the magnetic field

#	Type	samp-ling, mm	f_{samp}	X_0 mm	R_M mm	λ_I mm	cell mm^2	$\frac{X}{X_0}$	ΔZ cm	σ_E/E, % α	β
1	W/ScFi**	∅0.47 ScFi W powd.	2%	7.0	19	200	25^2	20	30	2.5	13
2	$PbWO_4$***	-	-	8.9	19.6	203	20^2	22.5	35	1.0	2.5
3	Shashlyk***	0.75 W/Cu[a] 1.5 Sc	16%	12.4	26	250	25^2	20	40	1.6	8.3
4	W/ScFi** with PMT	0.59^2 ScFi W powd.|	12%	13	28	280	25^2	20	43	1.7	7.1
5	Shashlyk***	0.8 Pb 1.55 Sc	20%	16.4	35	520	40^2	20	48	1.5	6
6	TF1 Pb glass***	-	-	28	37	380	40^2	20	71	1.0	5-6
7	Sc. glass*[b]	-	-	26	35	400	40^2	20	67	1.0	3-4

EIC Yellow Report

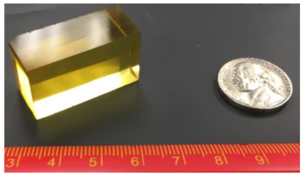
Crystals

- High resolution EmCal in the electron-endcap for t scattering electron measurements
- PWO where space is tight, and the highest possible energy resolution is required
- Scintillating glass (*EIC R&D*) otherwise
  - More cost efficient, easier manufacturing
  - Potentially better optical properties



Example: SC1 glass

2018: 1cm x 1cm x 1cm

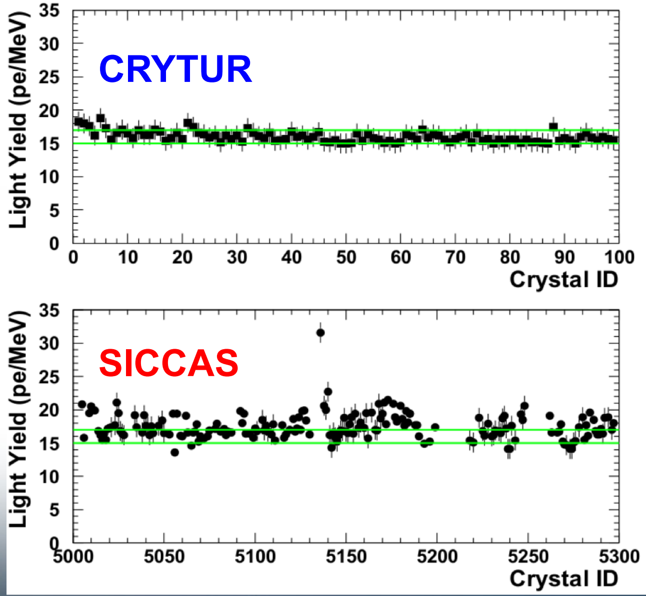


2019: 2cm x 2cm x 4cm

Feb 2020: 2cm x 2cm x 20cm (7 X0)

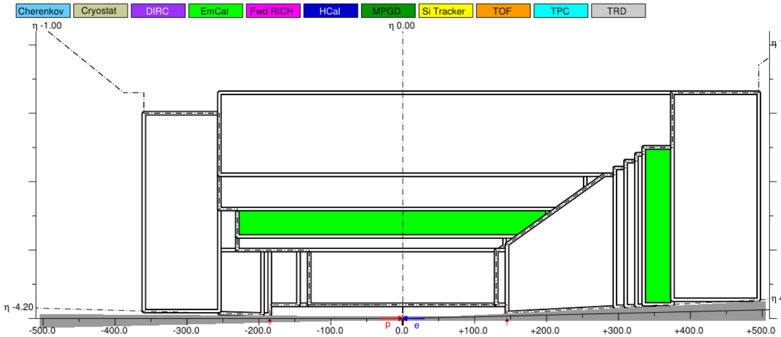
Dec 2020: 2cm x 2cm x 40cm (10-20 X0)

PWO: vendor characterization

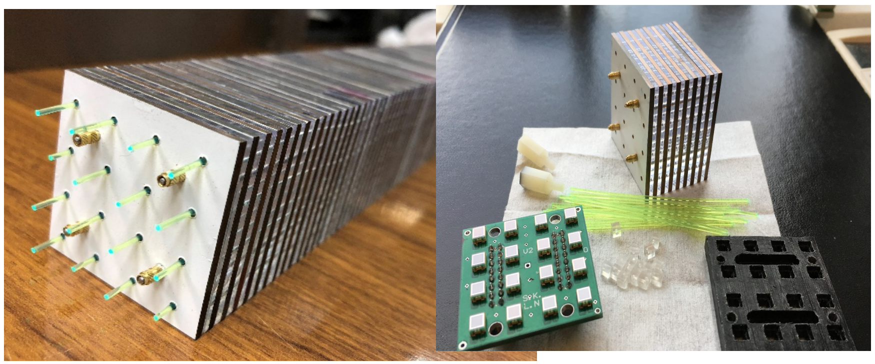


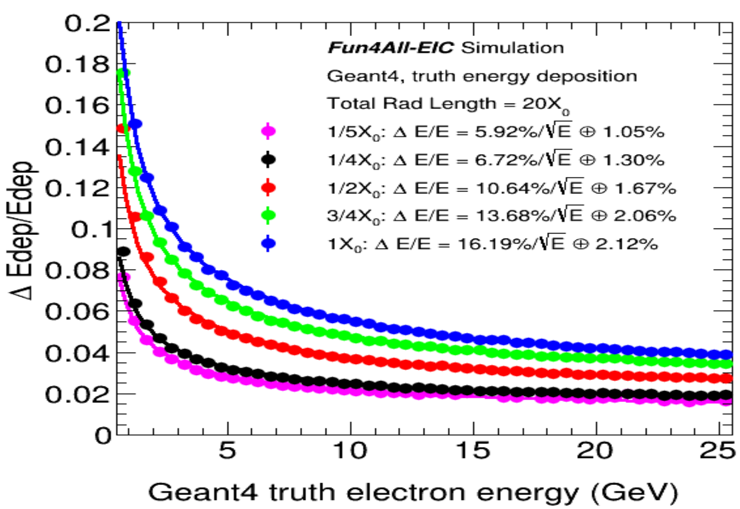
Sampling EmCal

- Well established technology
  - HERA-B, ALICE, PHENIX, PANDA, …
- Medium energy resolution ~7..13%/√E
- Compact (X_0 ~7mm or less), cost efficient

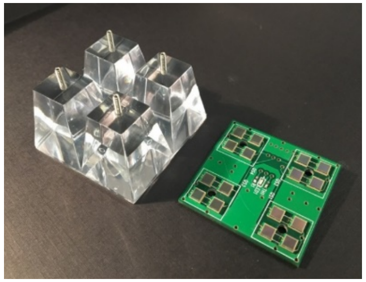


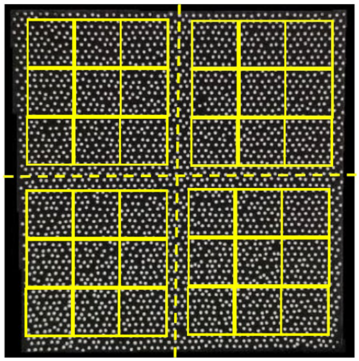
W/Cu/ScTile shashlyk





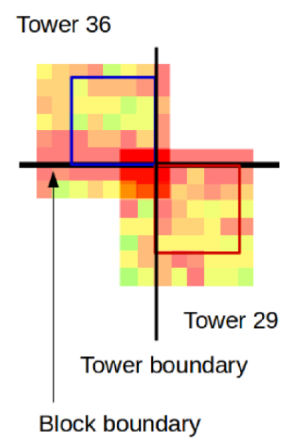
W/SciFi spacal

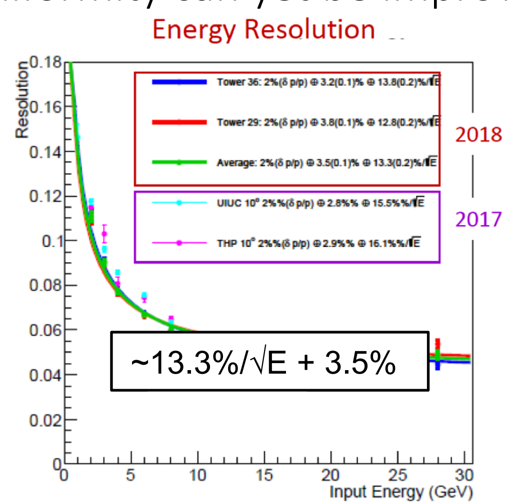




Scintillating Fibers embedded in a W/epoxy mix

Light collection uniformity can yet be improved





Hadronic Calorimeter

- Main purpose: jet energy measurement
  - Particle Flow Algorithm usage anticipated (where HCal role is identification and energy measurements of the neutral hadrons, namely neutrons and K_L)

- In general, the “conventional” hadronic calorimetry is considered per default

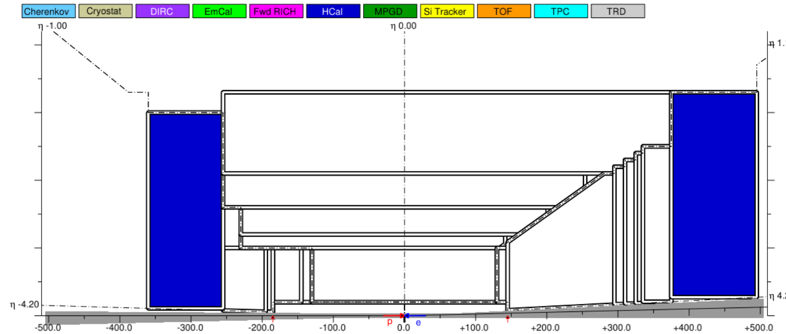
- Anticipated stochastic term in energy resolution & depth

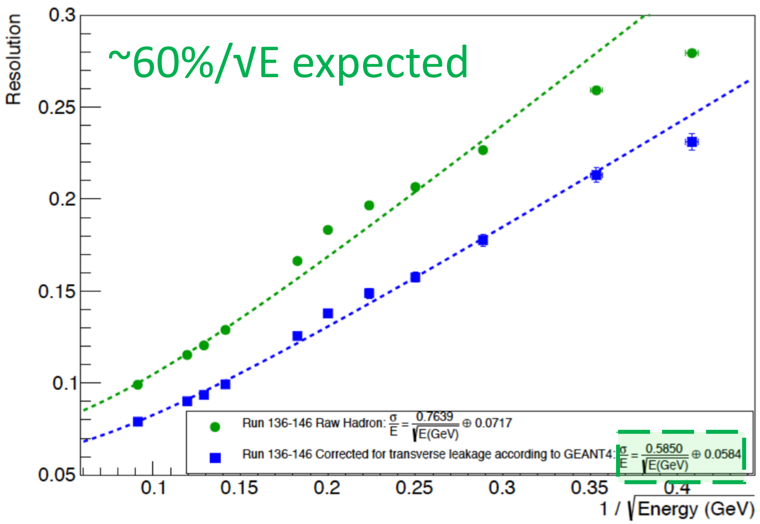
η	[-4 .. -1]	[-1 .. 1]	[1 .. 4]
σ_E/E	~50%/√E + 10%	~100%/√E + 10%	~50%/√E + 10%
depth	~5 λ_I	~5 λ_I	~6-7 λ_I

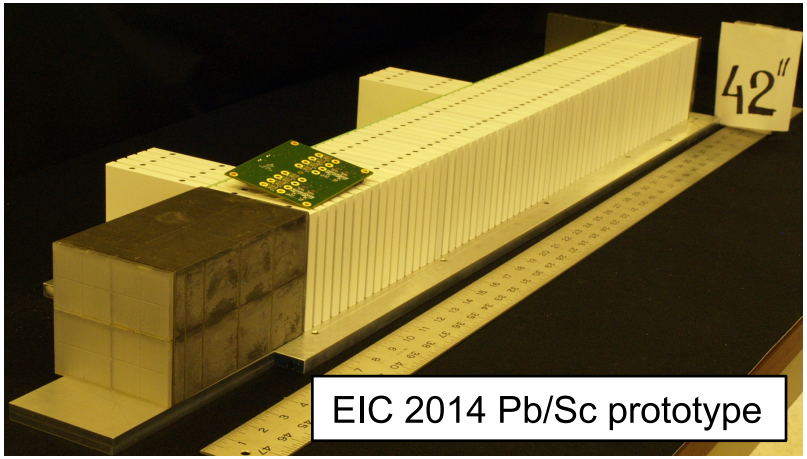
- Other considerations
  - Space!
  - Interplay with EmCal in a “binary” EmCal+HCal configuration
  - Tower granularity (~10 x 10 cm^2 suffices)
  - Readout immune to the magnetic field

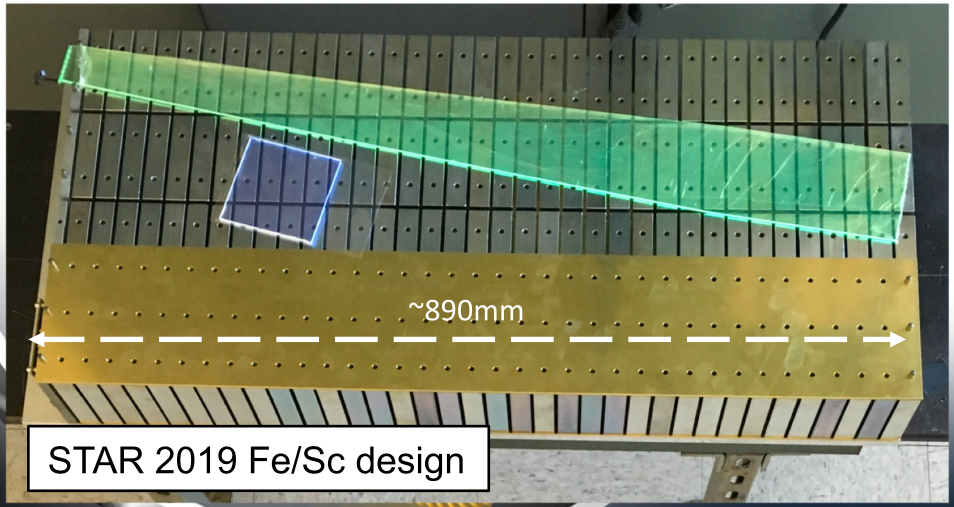
Fe/Sc sandwich

- HCAL in endcap
- Compact LEGO-style design
  - Can be used with a mixed Fe/Pb absorber

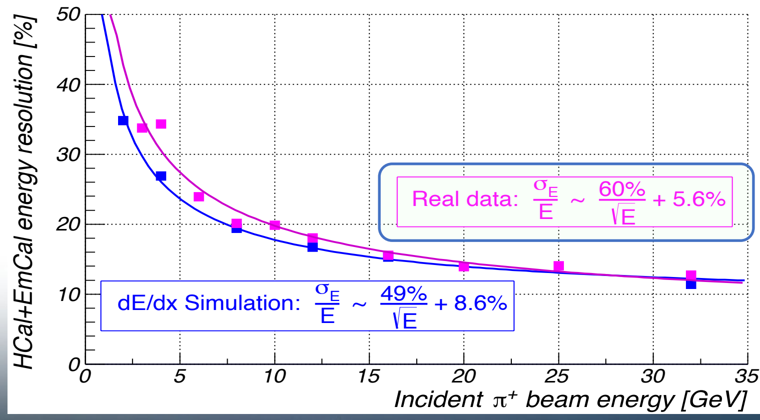





EIC 2014 Pb/Sc prototype

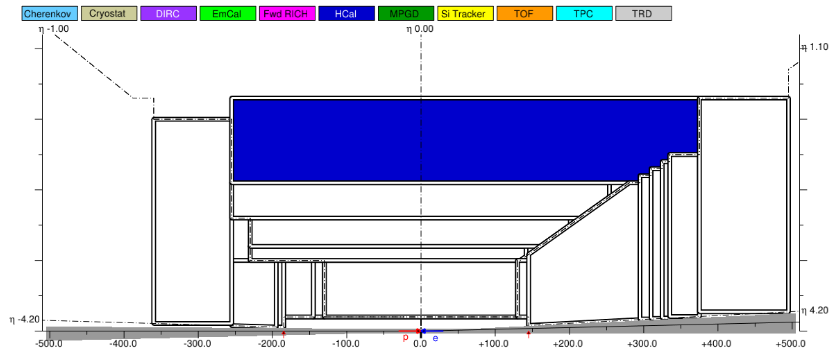


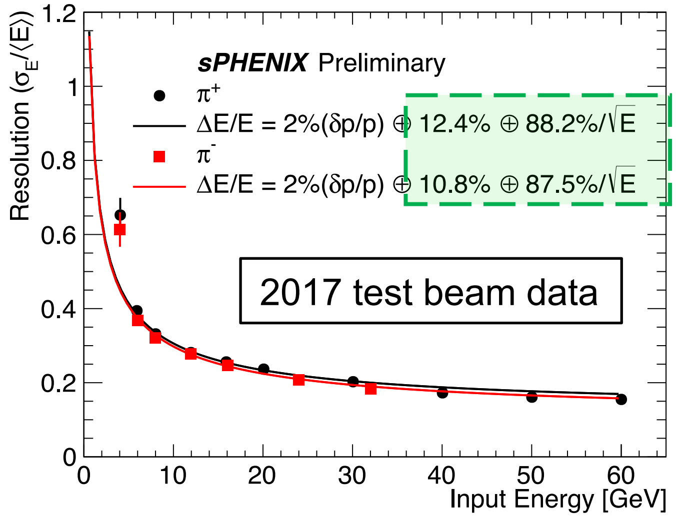
STAR 2019 Fe/Sc design



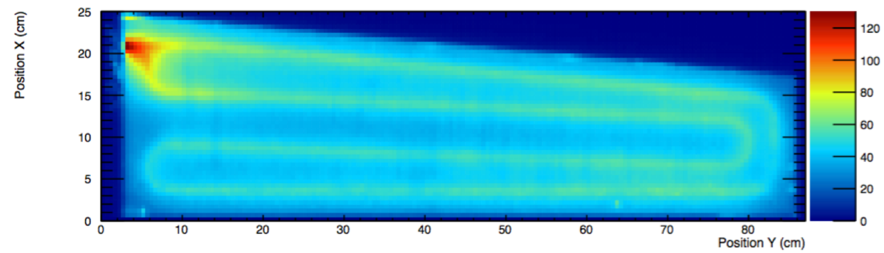
Fe/Sc (barrel)

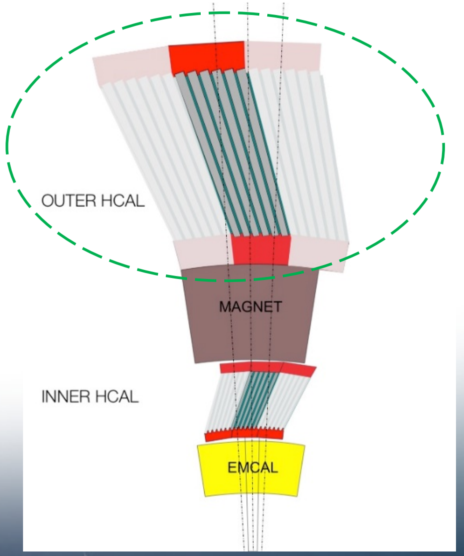
- Similar as used in sPHENIX
  - Solid 32-sector steel frame, but only ~3.5 λ_I
  - Moderate energy resolution





Scintillator plate with embedded WLS fiber





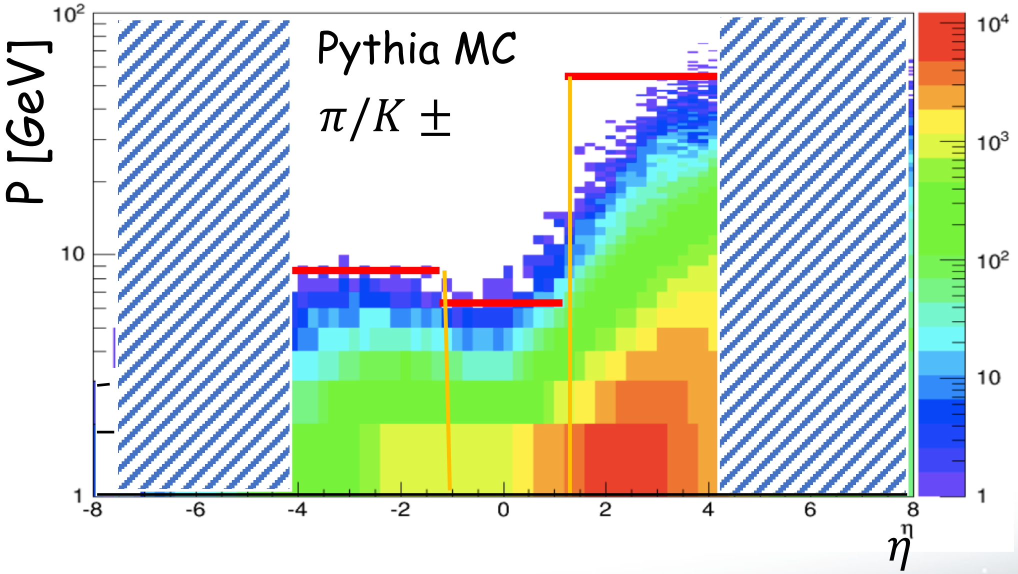
Particle ID

- In general, need to separate:
  - Electrons from photons -> 4π coverage in tracking
  - Electrons from charged hadrons -> mostly provided by calorimetry
  - Charged pions, kaons and protons from each other -> Cherenkov detectors

Physics requirements:

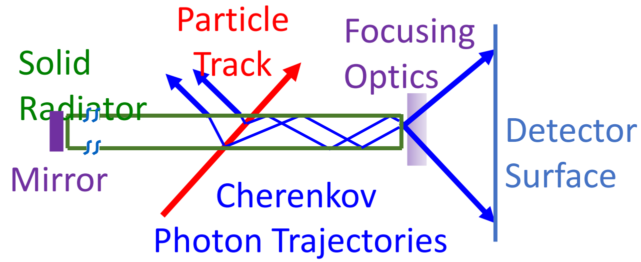
Rapidity	π/K/p and π0/γ	e/h	Min pT (E)
-3.5 – -1.0	7 GeV/c	18 GeV/c	100 MeV/c
-1.0 – 1.0	8-10 GeV/c	8 GeV/c	100 MeV/c
1.0 – 3.5	50 GeV/c	20 GeV/c	100 MeV/c

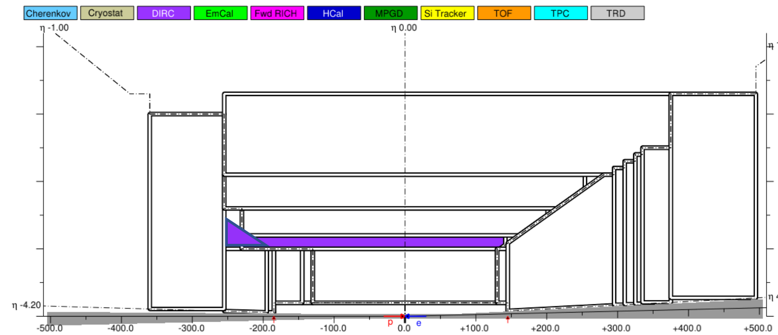
Illustration of PID detectors achievements:



Cherenkov detectors, complemented by other technologies at lower momenta

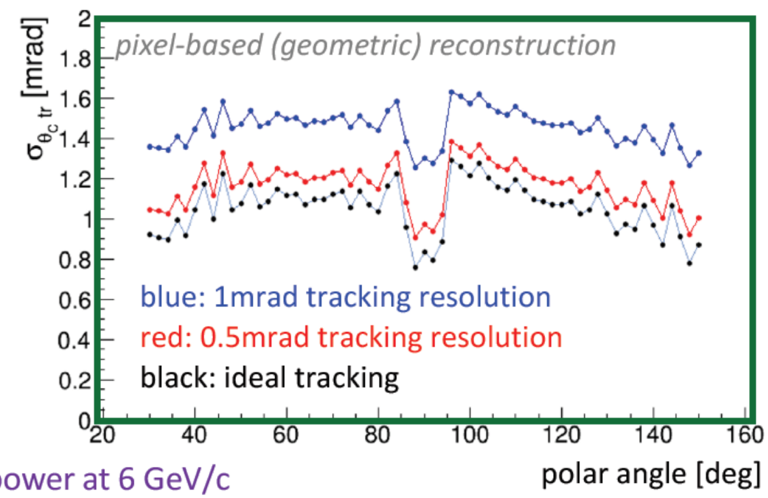
DIRC

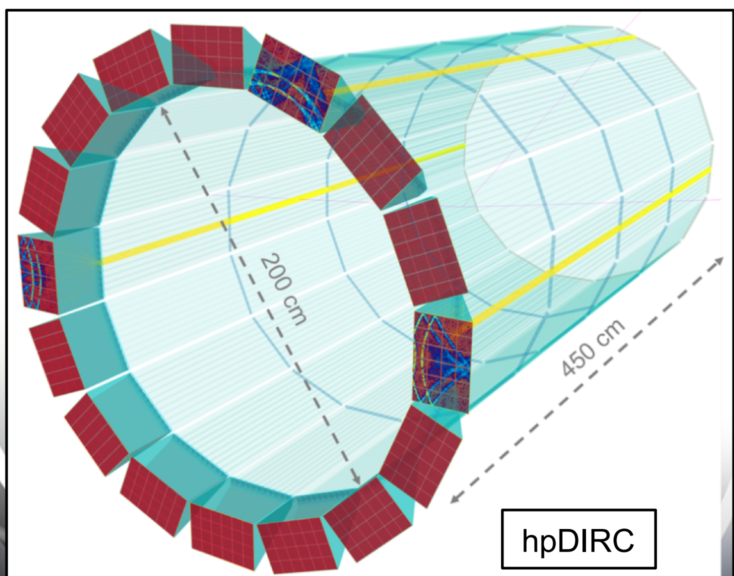




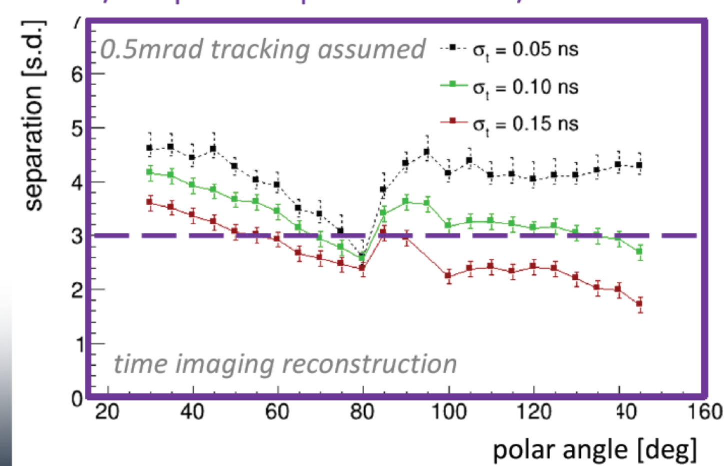
- Radially compact (~ 8-10 cm)
- high-performance DIRC with better optics and <100 ps timing (π/K up to ~6 GeV/c)
- Re-use BaBar quartz bars ?
- Integration into a 4π detector can be challenging

Cherenkov angle resolution angle per particle





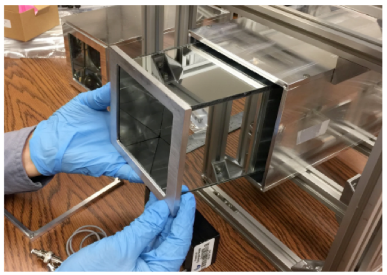
π/K separation power at 6 GeV/c



Modular-RICH(mRICH)

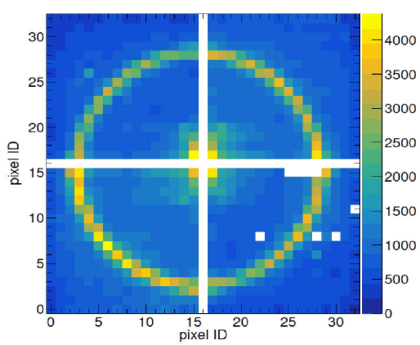
- *For hadron PID in the electron end-cap*
- *Compact* version of a conventional aerogel-based proximity focusing RICH

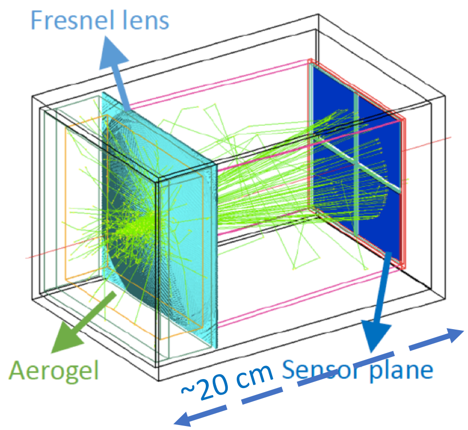
New features: a) separation of optical and electronic components; b) longer focal length (6”); c) 3mm x 3mm photosensors.



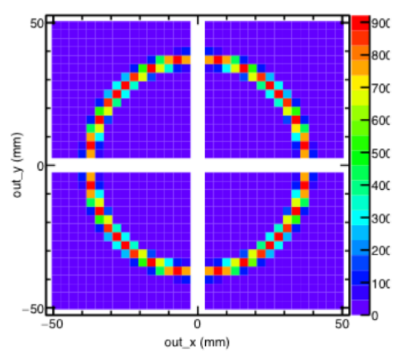
2nd mRICH prototype was tested at Fermilab Test Beam Facility in June/July 2018

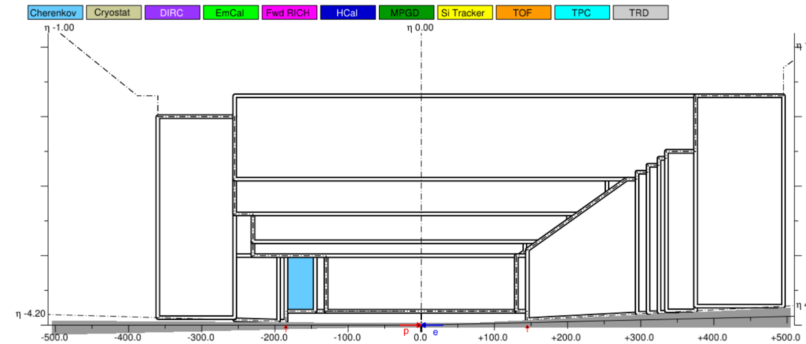
Beam Test at Fermilab

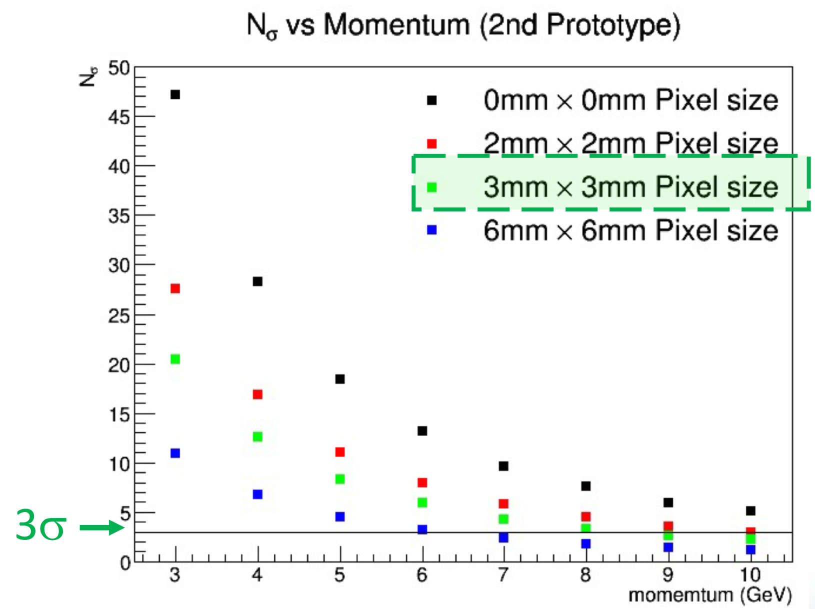




GEANT4 Simulation





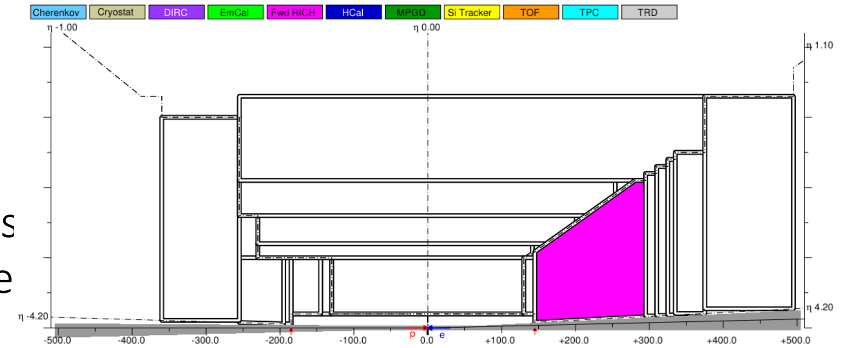


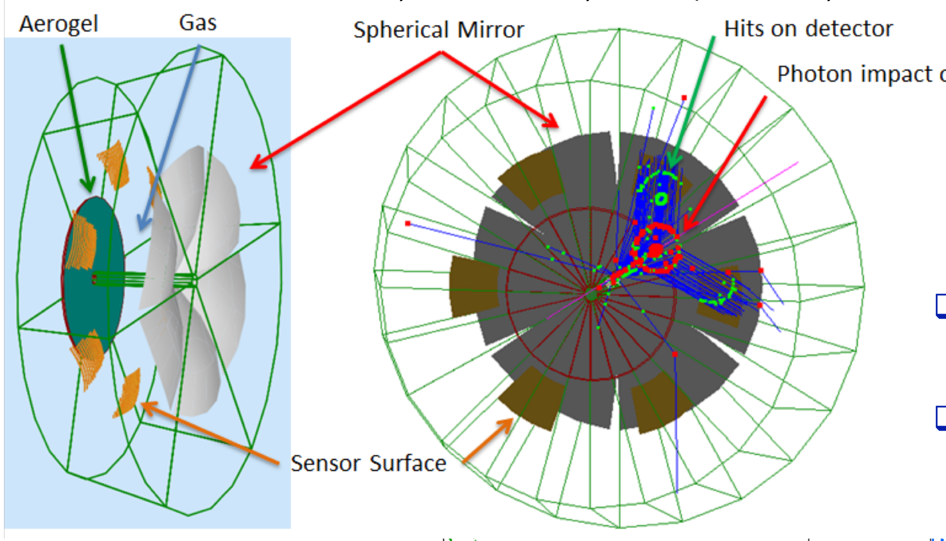
Expect π/K 3σ separation up to 8-10 GeV/c

- Was also tested with SiPM readout
- LAPPD readout – summer 2021

Dual radiator RICH

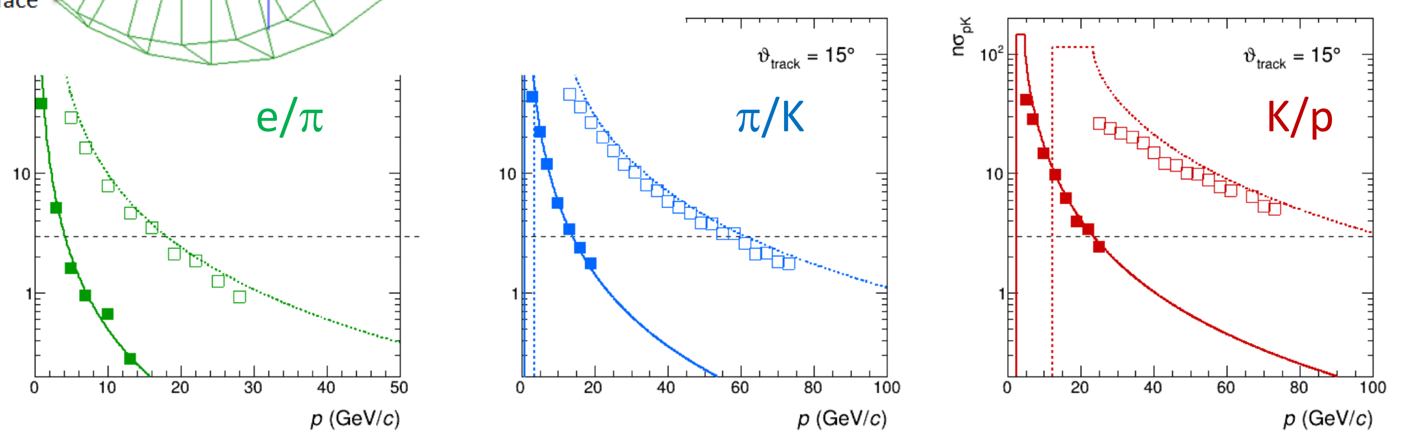
- Hadron PID in the forward/hadron end-cap
- Use a combination of aerogel and C_mF_n with indices of refraction matching EIC momentum range in the forward endcap
- Similar to LHC-b, HERMES, JLAB/Hall-B, …





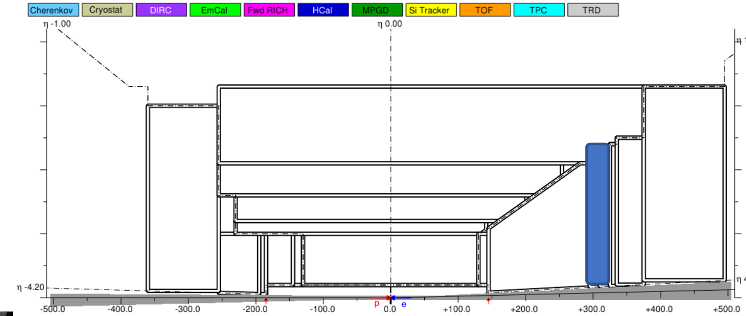
Radiators: Aerogel (n_{AERO}~1.02) + Gas (n_{C2F6} ~ 1.0008)
Detector: 0.5 m^2/sector , 3x3 mm^2 pixel
Single-photon detection in ~1T magnetic field
Outside acceptance, reduced constraints

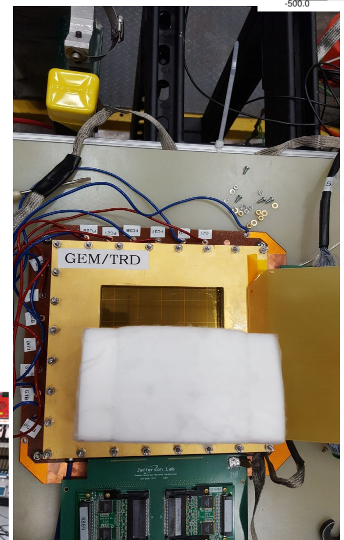
- Continuous >3σ π/K separation up to 60 GeV/c and K/p separation to higher momenta
- >3σ e/π separation up to ~15 GeV/c

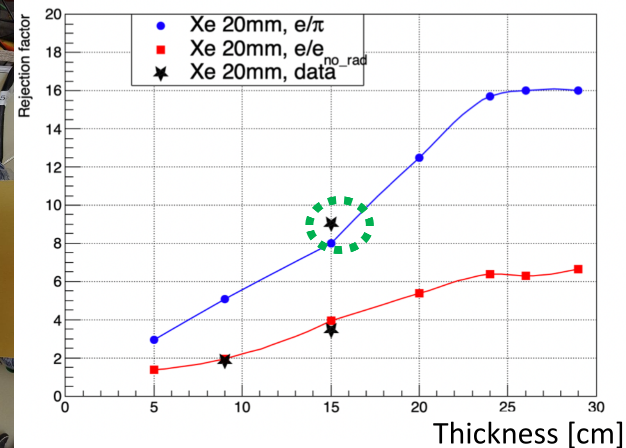


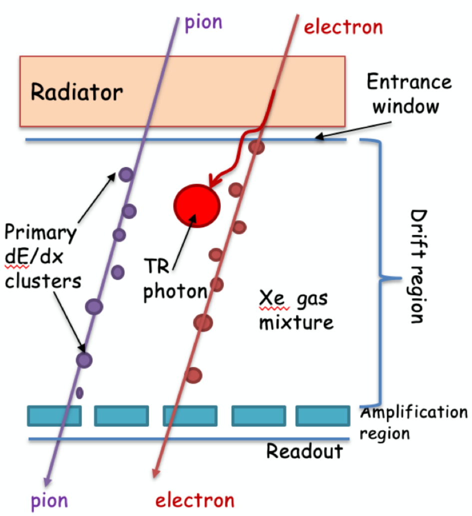
Additional e$^-$ ID

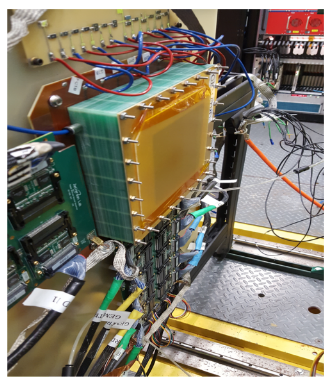
- To improve e-identification for leptonic/semi-leptonic decays.
- In addition to Calorimeters and Cherenkov detectors in the hadron-endcap considering TRD.
- GEM -TRD/Tracker :
  - e/π rejection factor ~10 for momenta between 2-100 GeV/c from a single ~15cm thick module.

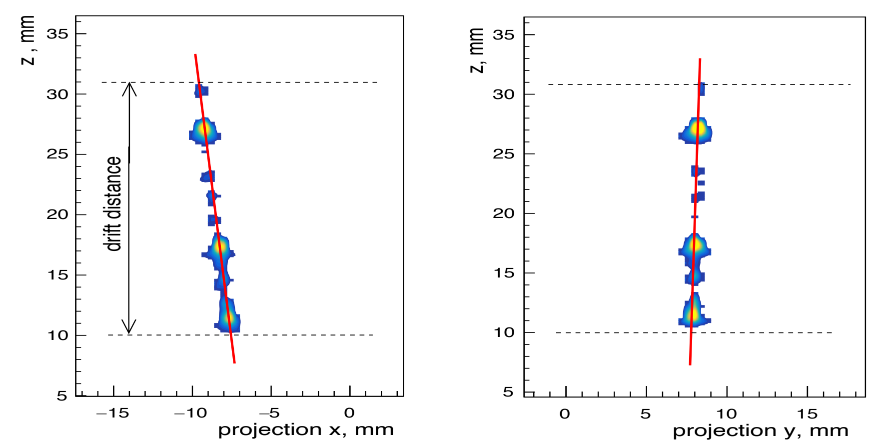








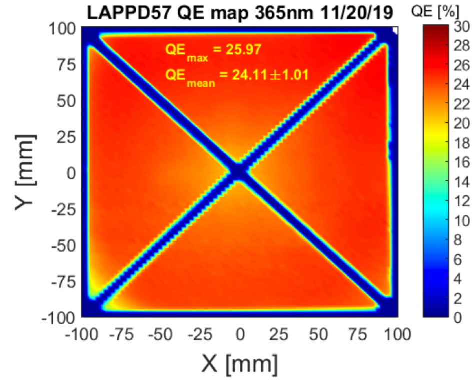




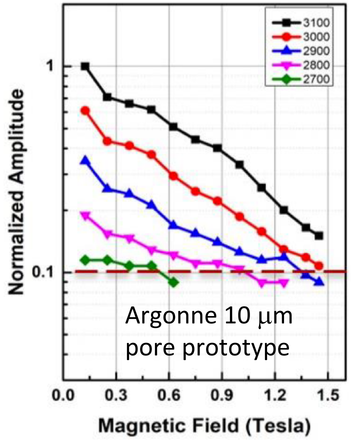
- Very precise Tracking segment behind dRICH:

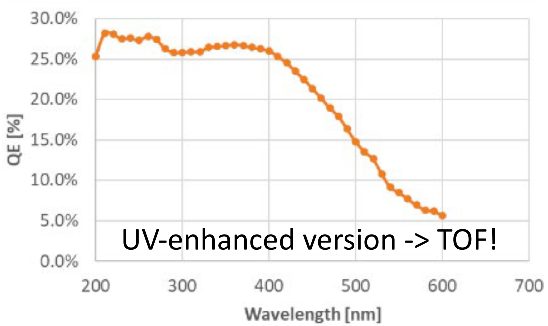
High resolution timing technologies

- MCP-PMT / LAPPD



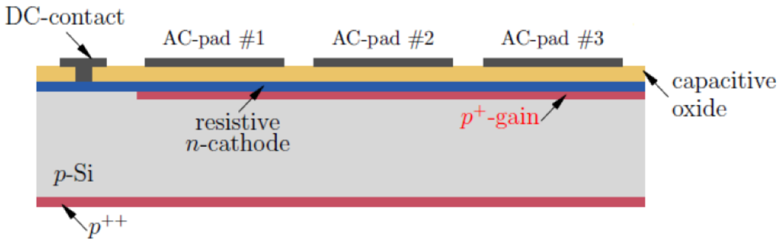
- QE routinely >20%
- >90% gain uniformity
- Single photon TTS <50 ps
- Performance in high B field is still of a concern

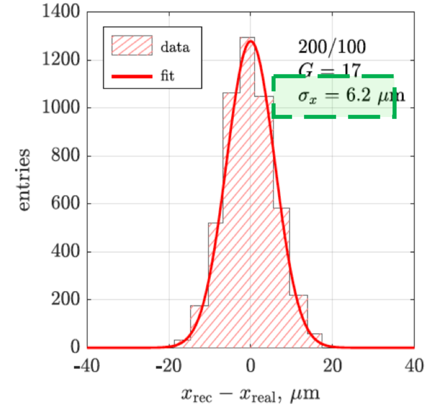


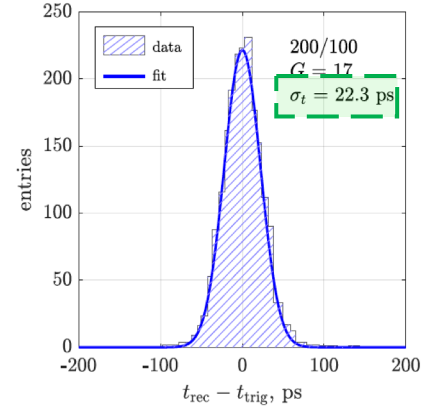


Expecting affordable detectors with <10ps timing on the EIC CD-2 time scale

- (AC)-LGAD

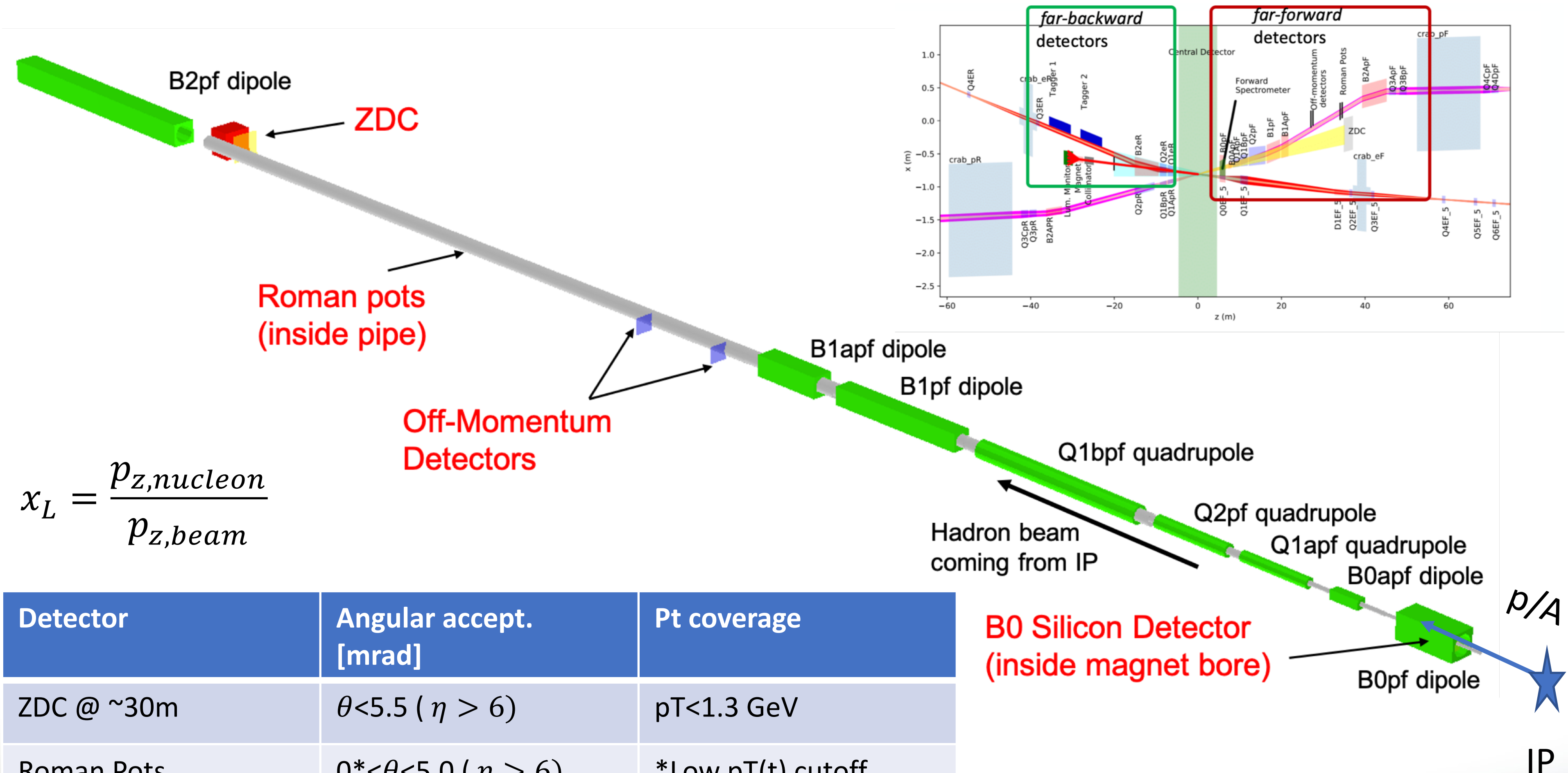






- Detectors can provide <20ps / layer
- AC-coupled variety gives 100% fill factor and potentially a high spatial resolution (dozens of microns) with >1mm large pixels

Far forward (hadron going) region



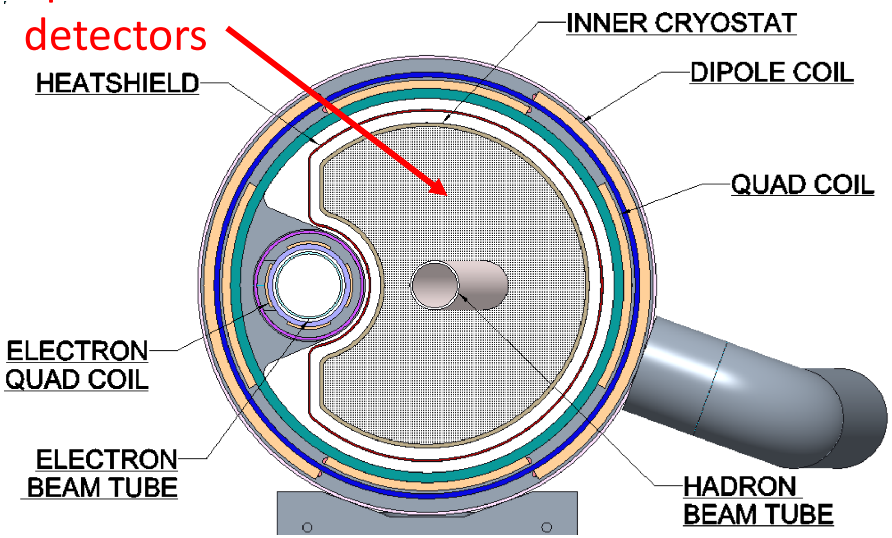
$$x_L = \frac{p_{z,nucleon}}{p_{z,beam}}$$

Detector	Angular accept. [mrad]	Pt coverage
ZDC @ ~30m	θ<5.5 ($\eta > 6$)	pT<1.3 GeV
Roman Pots	0*<θ<5.0 ($\eta > 6$)	*Low pT(t) cutoff (beam optics)
Off-Momentum Detectors	0.0< $\theta < 5.0$ ($\eta > 6$)	Low-rigidity particles from nuclear breakups
B0 forward spectrometer	$5.5 < \theta < 20.0$ (4.6< $\eta < 5.9$)	High pT(t)

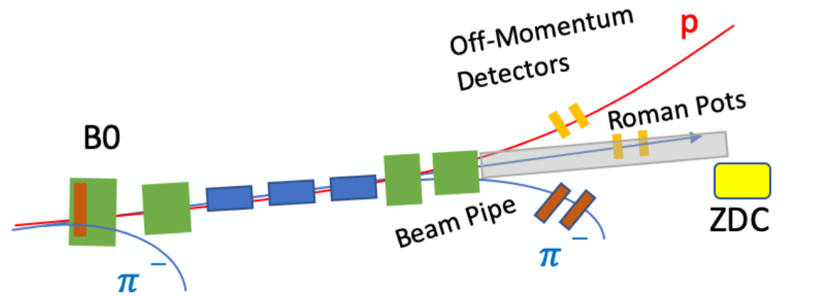
Far-forward detectors

B0-spectrometer (5.5 < $\boldsymbol{\theta}$ < 20.0 mrad)

- ❑ Warm space for detector package insert located inside a vacuum vessel to isolate from insulating vacuum.
- ❑ Higher granularity detectors needed in this area (**MAPS**) with layers of fast-timing detectors (**LGADs**)
- ❑ Shape and coverage of B0 tracker needs to be further evaluated

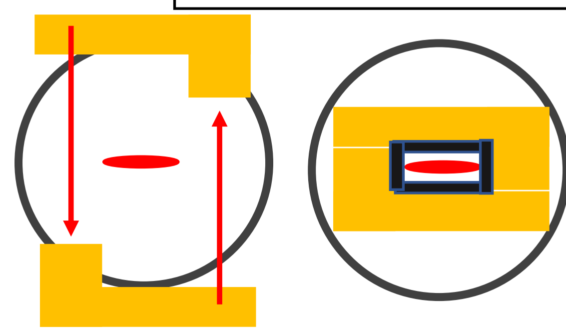


Roman-Pots and Off-momentum detectors 0.0* (10σ cut) < $\boldsymbol{\theta}$ < 5.0 mrad



- ❑ Low Pt particles P_T < 1.3 GeV
- ❑ RPs: movable, integrated into the vacuum system
- ❑ Fast Timing and moderate granularity
- ❑ (500x500 μm^2)
- ❑ AC-LGADs

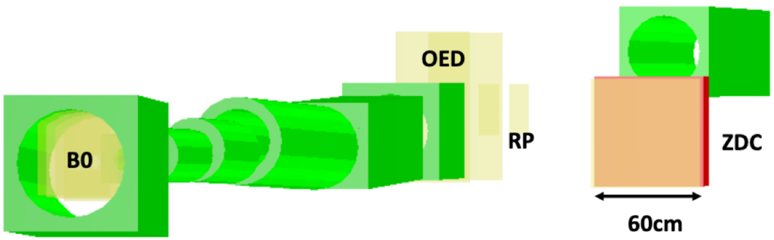
$$\sigma(z) = \sqrt{\varepsilon \cdot \beta(z)}$$

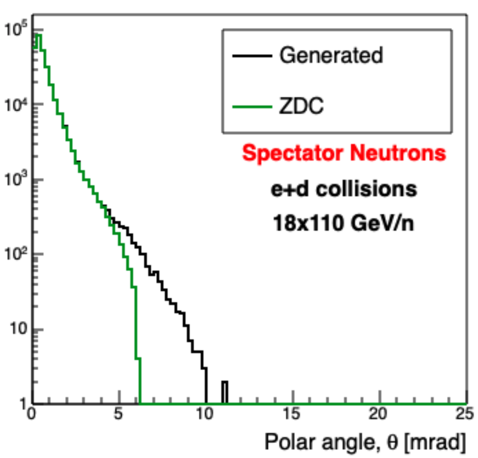


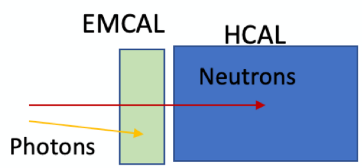
Far-forward/backward detectors

Zero Degree Calorimeter

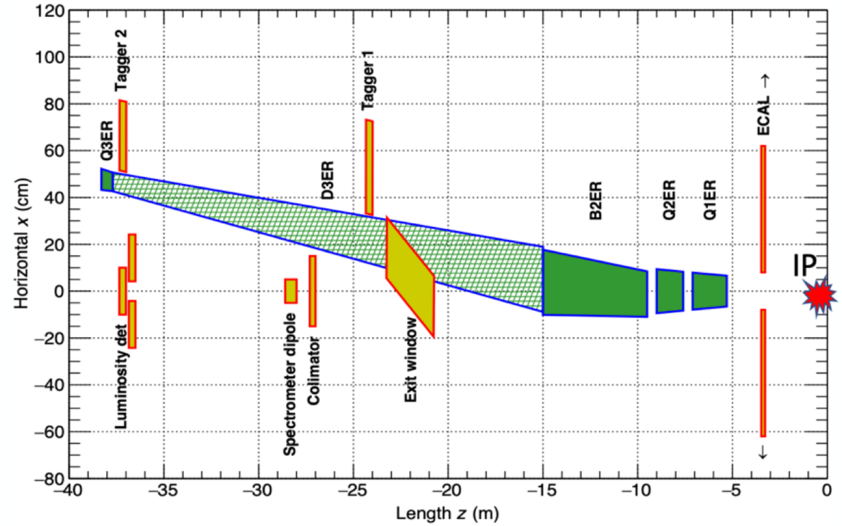
- For detection of neutrons and photons (0<θ<5.5 mrad)
- (Limited by bore of magnet where the neutron cone has to exit)
- **Pb/Sci Calorimeter** (FoCAL…)





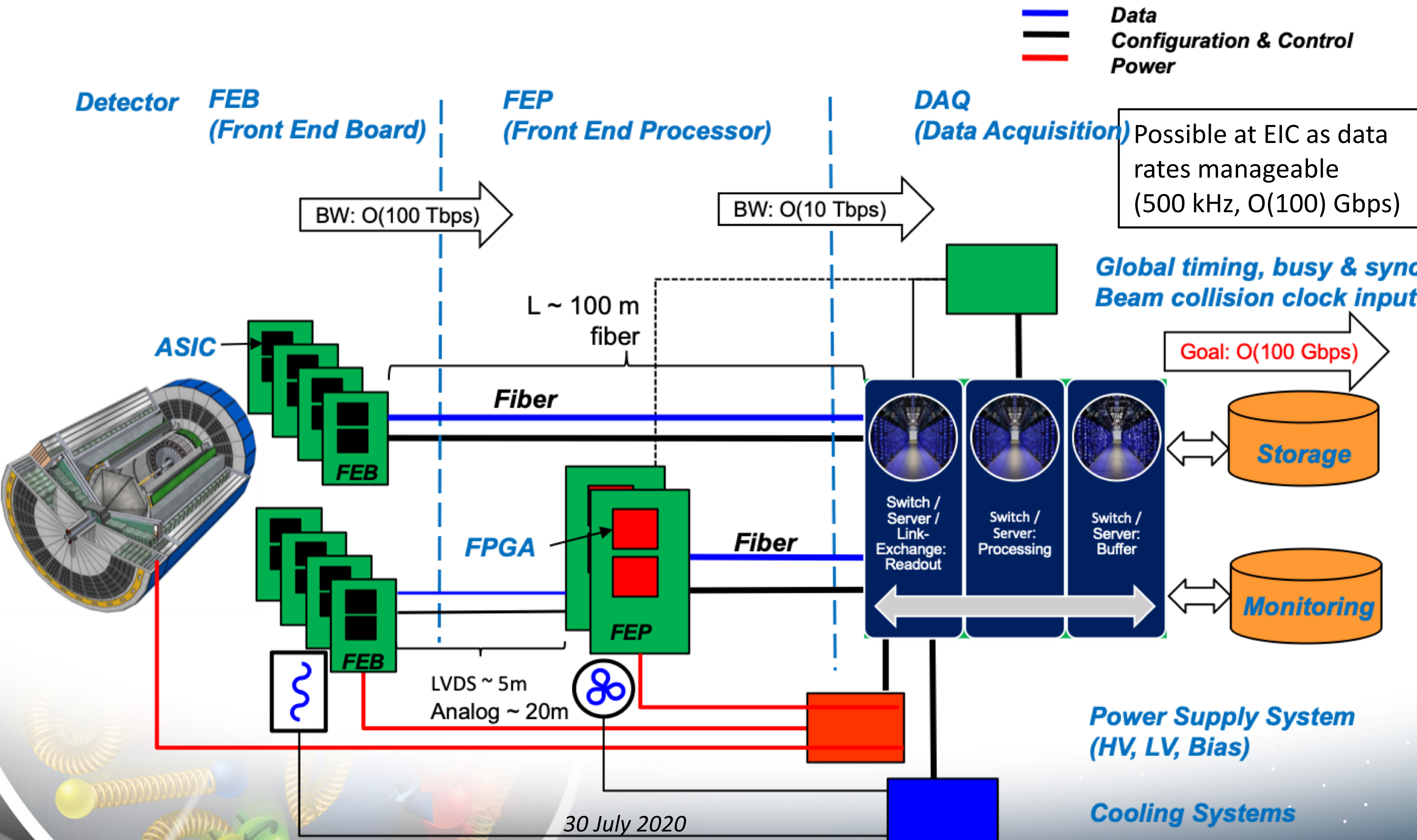


Far-backward (electron-going) region



- This area is designed to provide coverage for the low-Q^2 events (photoproduction).
- **Si-strip detectors** (or Timepix or diamond) detectors for precise position/angle
- **W/ScFi**, etc for energy measurements
- Similar technology for luminosity detector

Reference Detector – Streaming Readout Architecture

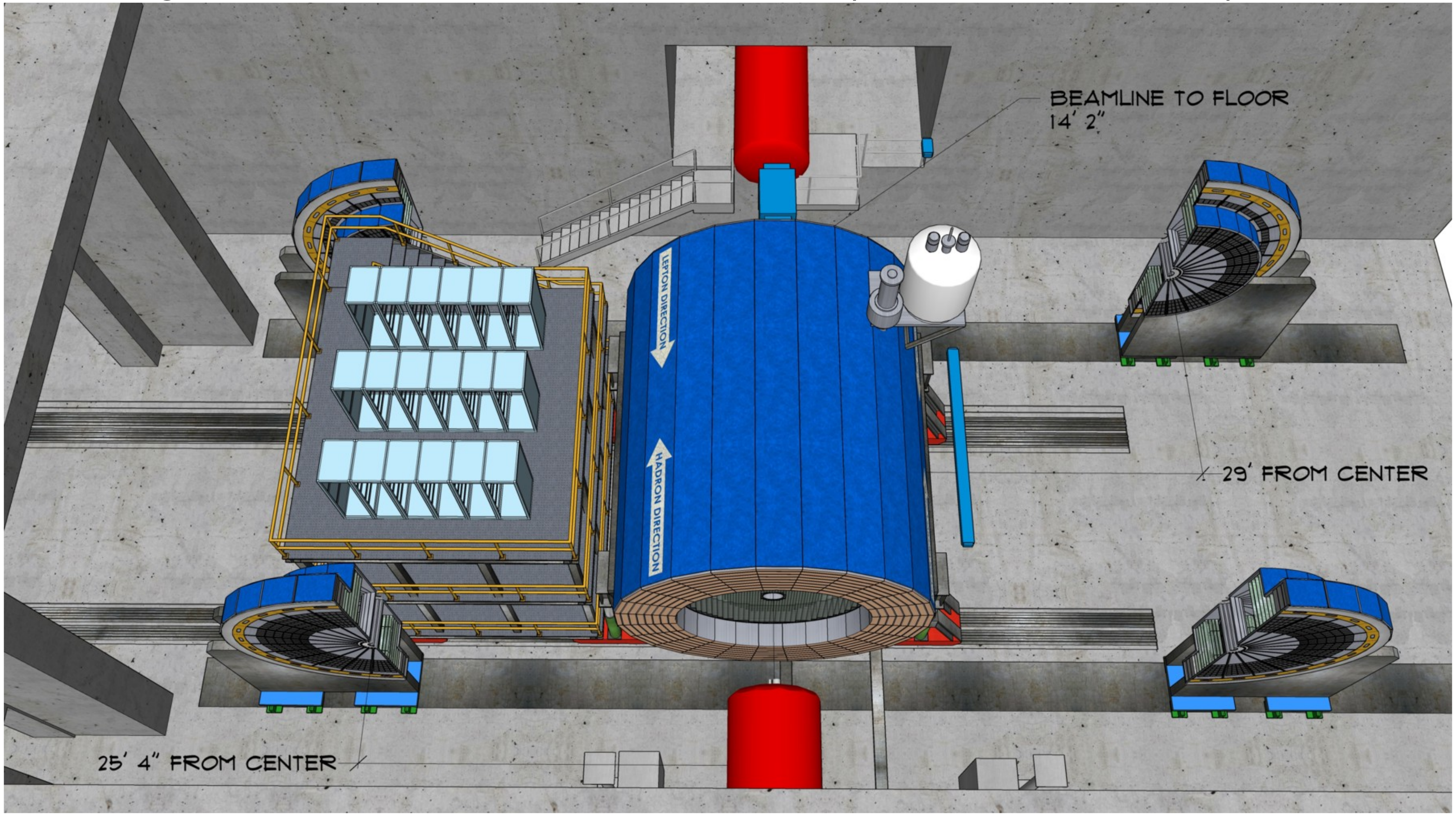


Possible at EIC as data rates manageable (500 kHz, O(100) Gbps)

30 July 2020

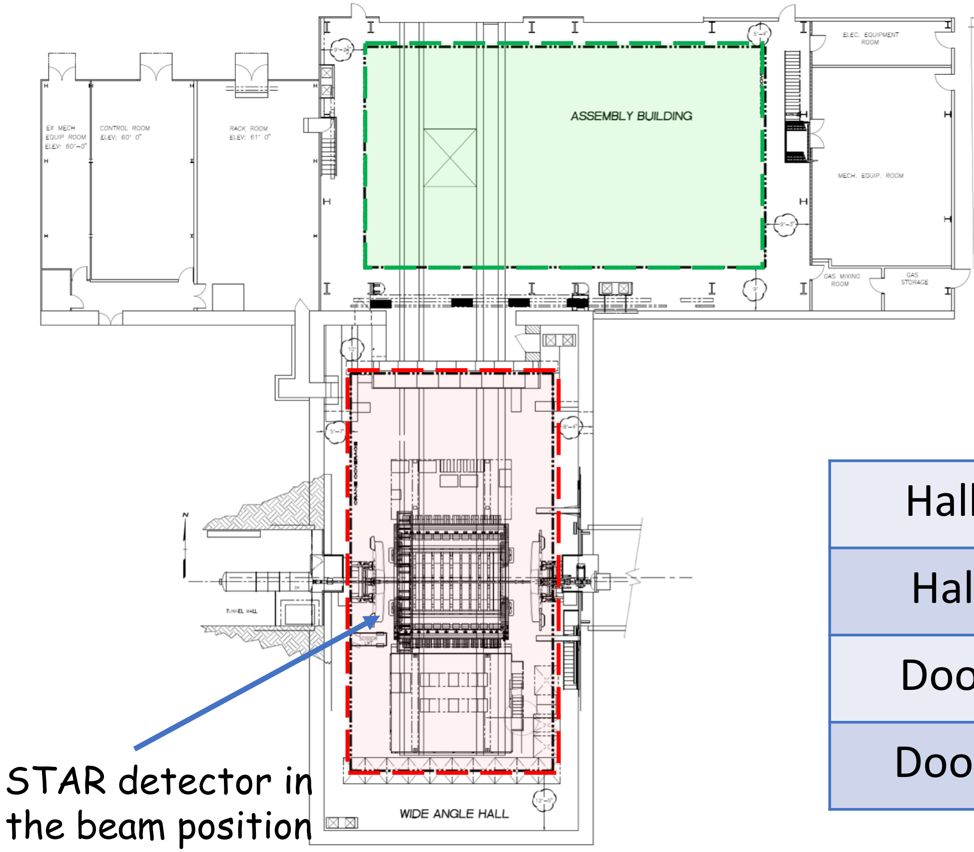
Central detector maintenance

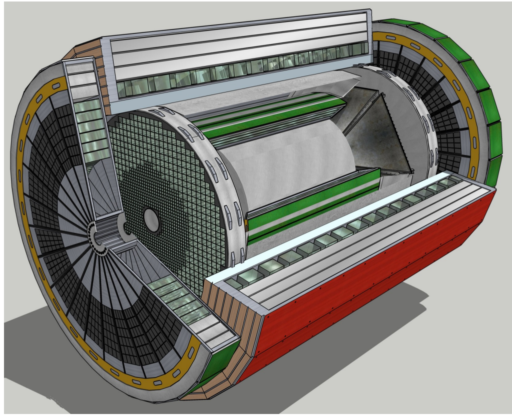
- Short access (hours)– no major disassembly actions
- Longer access mode for maintenance (endcaps rolled out)



- **Scheduled maintenance** (months) – detector moved to the assembly hall
  - The only option to access the central tracker and the forward / vertex / backward silicon trackers

Central detector installation in IP6





Hall length	~3200 cm
Hall width	~1615 cm
Door width	823 cm
Door height	823 cm

- Limited space along the beam line (the final focusing quads are placed as close to the IP as possible in order to maximize the luminosity)
- Barrel part of the main detector is designed to fit through the door
- Use large assembly hall for the long detector maintenance

Summary & Outlook

- EIC reference detector
  - It is based on the EICUG community effort, and presented as such in the CDR
  - The Yellow Report physics studies show that it meets the requirements
  - A new 3 T magnet matching this configuration is being designed as we speak

  - The detector includes a variety of different technologies for tracking, calorimetry, particle identification and ancillary detectors along the beam line
  - The technology choice is largely determined by the EIC Detector R&D Program

- A concrete configuration will be defined shortly in the detector proposal drafting process, based on the groups joining the effort, within the available cost range

- The detailed Geant4 simulations will be conducted for this coherent detector setup

- The simulation environment(s) for the purposes of preparing a detector proposal must be agreed upon quickly, with the understanding that we need reliable working tools *now*, and more detailed / realistic studies than the ones in the YR are required

Backup

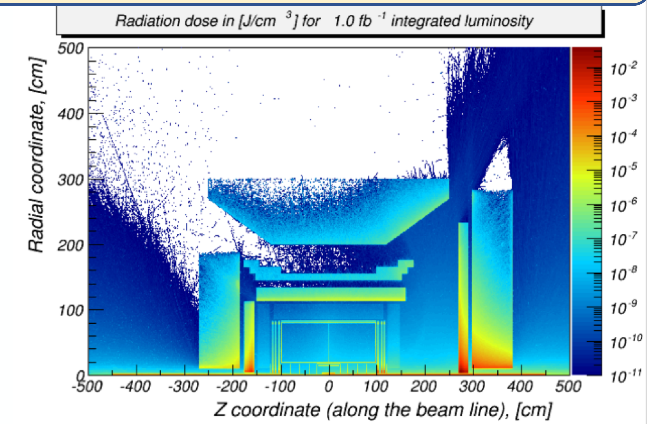
Background/radiation

- The HERA and KEK experience show that having backgrounds under control is crucial for the EIC detector performance

- There are several background/radiation sources :
  - primary collisions
  - beam-gas induced
  - synchrotron radiation

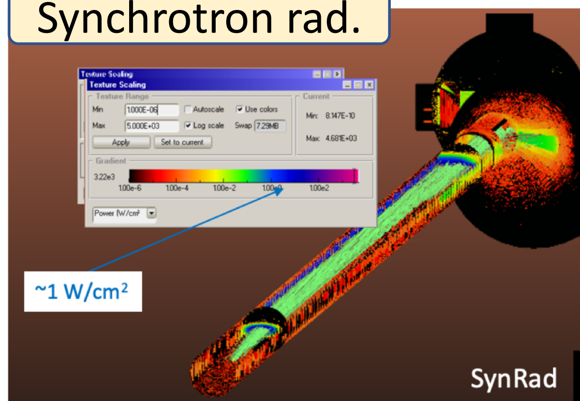
- The design of absorbers and masks must be modeled thoroughly

Primary collisions/ionizing radiation



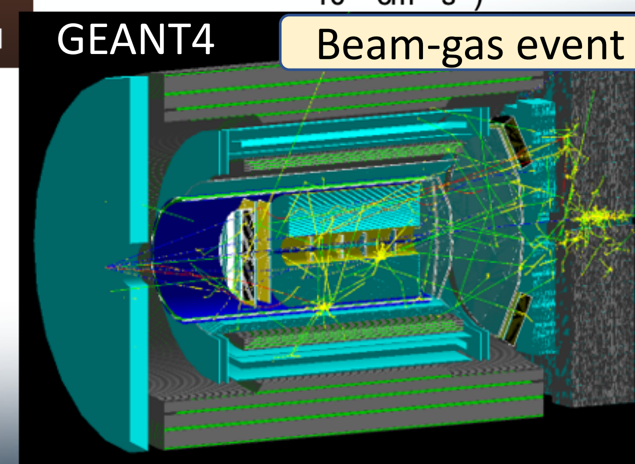
-> backward EmCal: ~250 rad/year (at a "nominal" luminosity ~10^{33} cm^{-2} s^{-1})

Synchrotron rad.

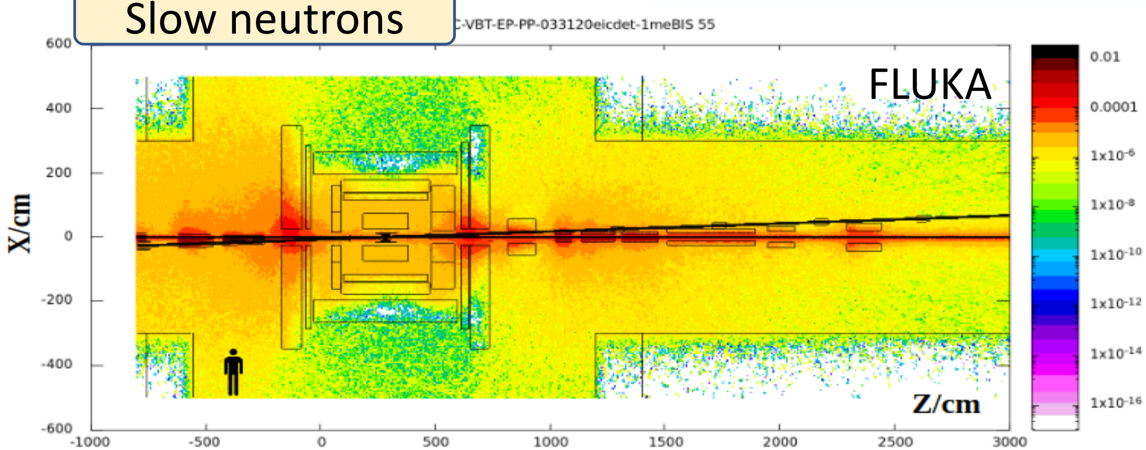


GEANT4

Beam-gas event



Slow neutrons

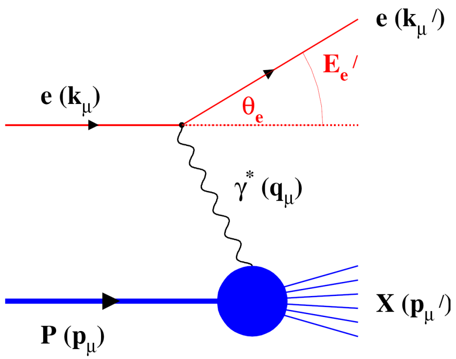


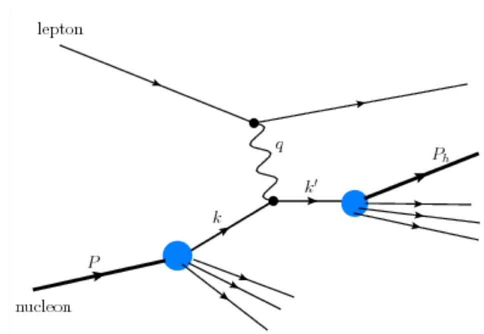
EIC physics measurements

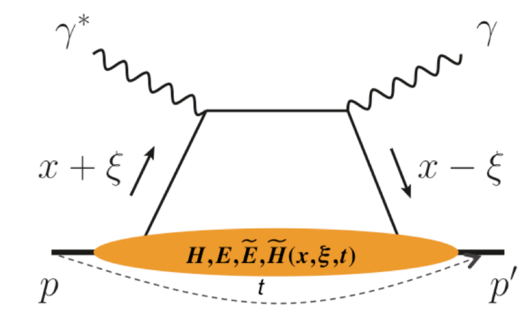
Parton Distributions in nucleons and nuclei

Spin and Flavor structure of nucleons and nuclei | **Tomography Transverse Momentum Dist.**

QCD at Extreme Parton Densities - Saturation | **Tomography Spatial Imaging**







inclusive DIS (ep/eA)

- measure scattered lepton
  - → large kinematic coverage (where reach to lowest x,Q^2 also impacts IR design)
  - → event kinematics reconstruction (tracking, e/m calorimetry)
  - → high quality electron ID in the whole acceptance

semi-inclusive DIS (ep/eA)

- measure scattered lepton and hadrons in coincidence
  - → hadron identification over entire acceptance
  - → tracking
  - → hadronic calorimetry (jets)
  - → vertexing (charm)

exclusive processes (ep/eA)

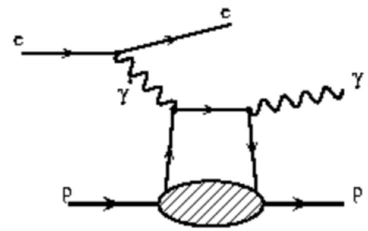
- measure all particles in event
  - rapidity gap: hermeticity
  - far forward instrumentation (recoil protons, exclusivity)

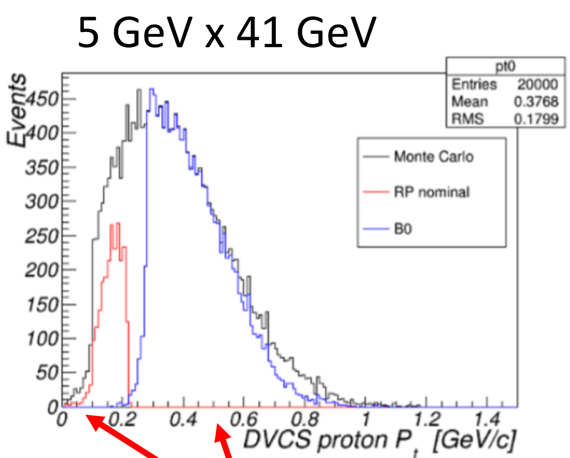
IR-related physics requirements

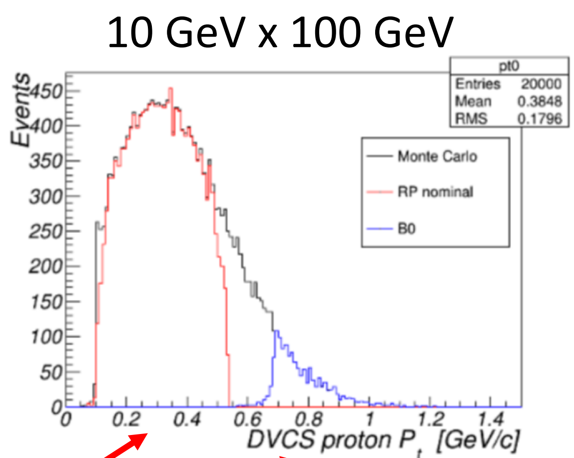
Table 2.2: Summary of the requirements from the physics program on the overall IR design.

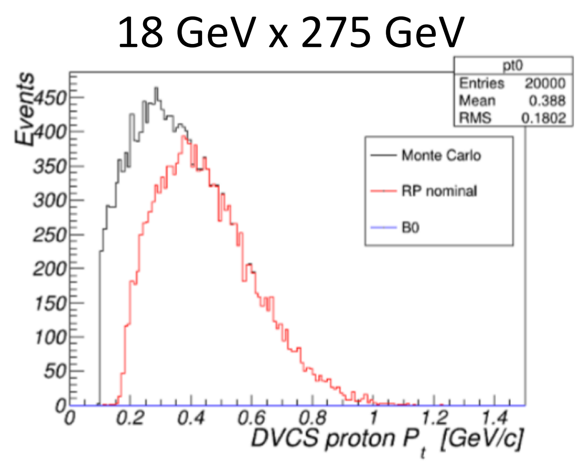
	Hadron	Lepton
Machine element free region	$\pm 4.5\,$m main detector beam elements $< 1.5^\circ$ in main detector volume	
Beam Pipe	Low mass material, i.e. Beryllium	
Integration of detectors	Local Polarimeter	
Zero Degree Calorimeter	60cm x60cm x 2m $@s = 30\,$m	
scattered proton/neutron acc. all energies for e+p	Proton: $0.18\,\text{GeV/c} < p_T < 1.3\,\text{GeV/c}$ $0.5 < x_L < 1 (x_L = E'_p / E_{Beam})$ Neutron: $p_T < 1.3\,\text{GeV/c}$	
scattered proton/neutron acc. all energies for e+A	Proton and Neutron: $\theta < 6\,$mrad (for $\sqrt{s} = 50\,$GeV) $\theta < 4\,$mrad (for $\sqrt{s} = 100\,$GeV)	
Luminosity	Relative Luminosity: $R = L^{++/--} / L^{+-/-+} < 10^{-4}$	
		γ acceptance: $\pm 1\,$mrad $\rightarrow \delta L/L < 1\%$
Low Q^2-Tagger		Acceptance: $Q^2 < 0.1\,$GeV

Forward Proton Acceptance





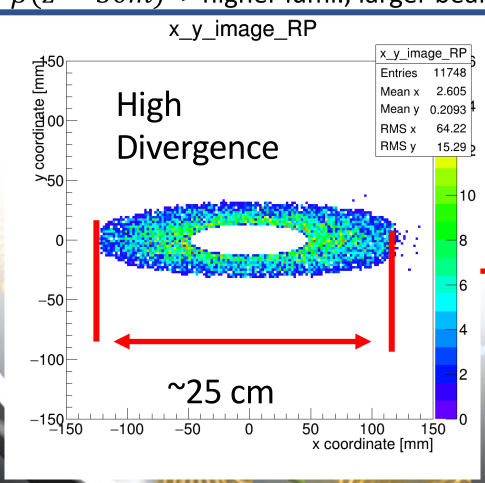


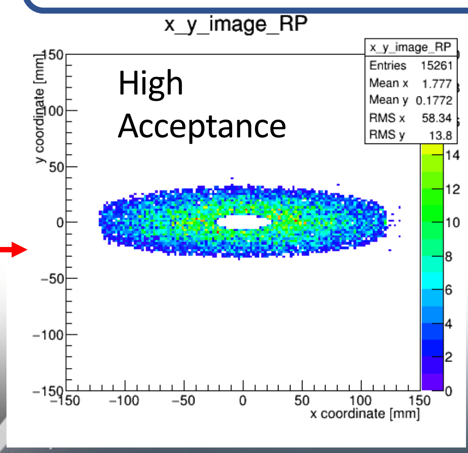


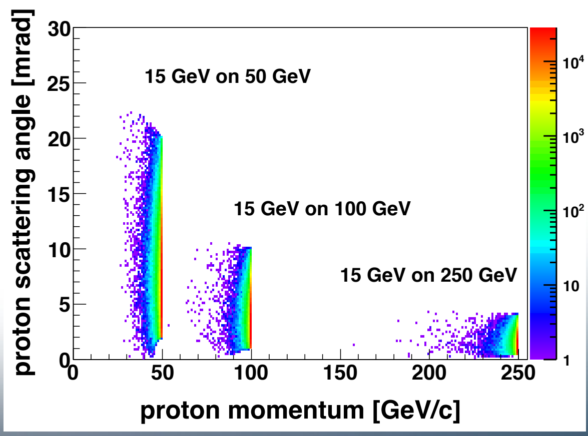
Need both detector systems together here!

High Divergence: smaller β^* at IP, but bigger $\beta(z = 30m)$ -> higher lumi., larger beam at RP

High Acceptance: larger β^* at IP, smaller $\beta(z = 30m)$ -> lower lumi., smaller beam at RP

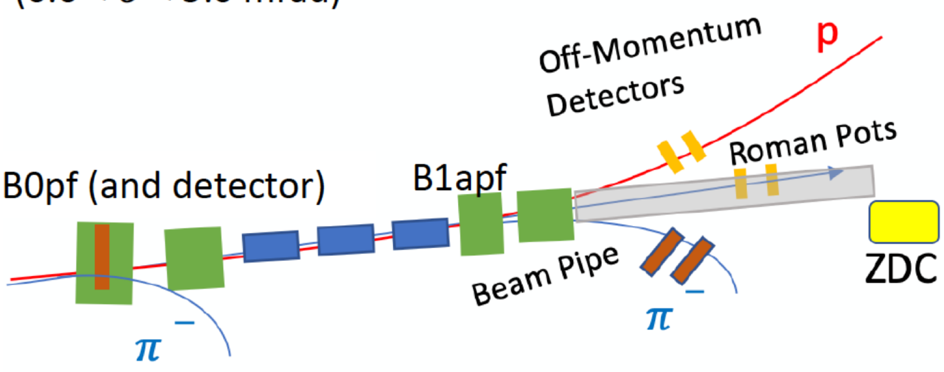


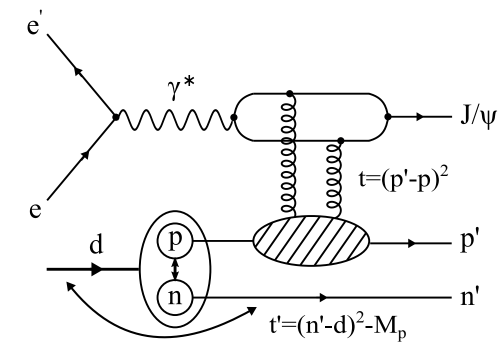




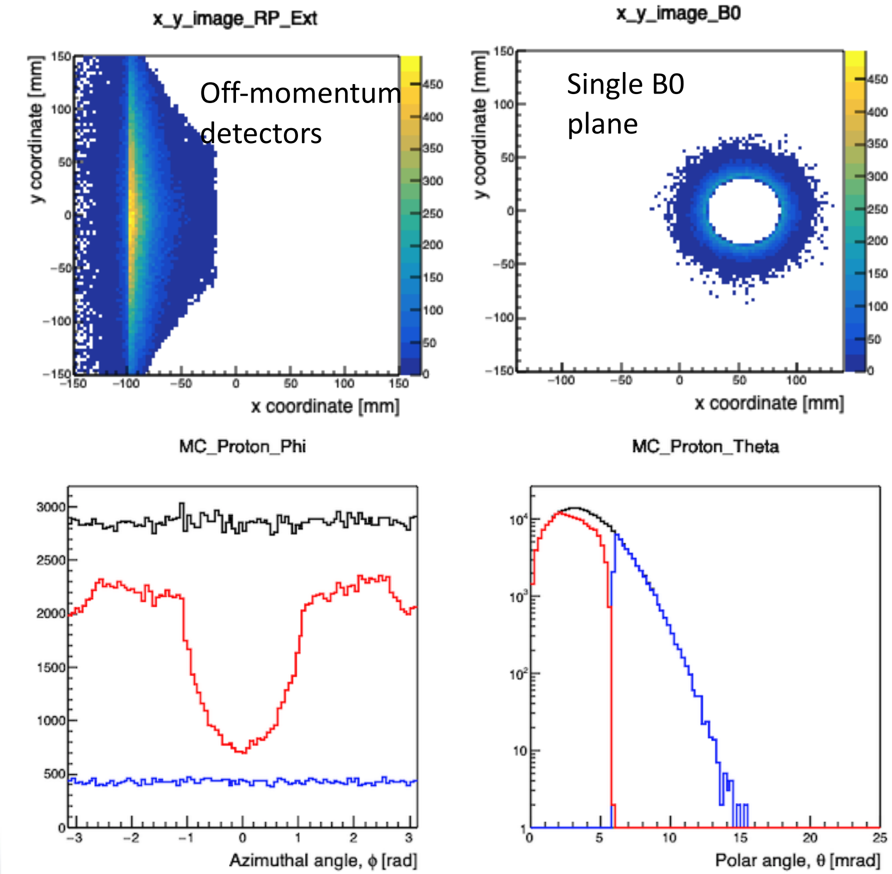
Off-Momentum detectors

(0.0 < θ < 5.0 mrad)





- Protons that come from nuclear breakup have a different magnetic rigidity than their respective nuclear beam (x_L<1)
- This means the protons experience more bending in the dipoles.
- As a result, small angle (θ < 5mrad) protons from these events will not make it to the Roman Pots, and will instead exit the beam pipe after the last dipole.
- Detecting these requires "off-momentum detectors":
- Timing is important: **LGATs**

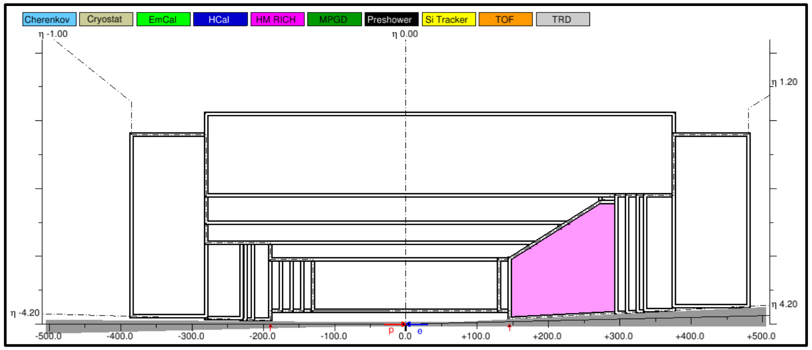


Neutron spectator/leading proton case.

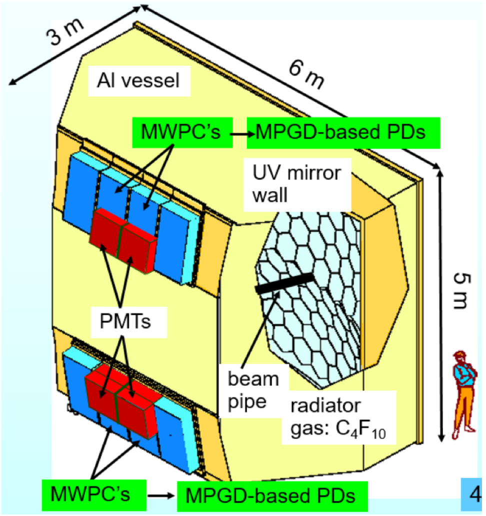
ed (18x110GeV)

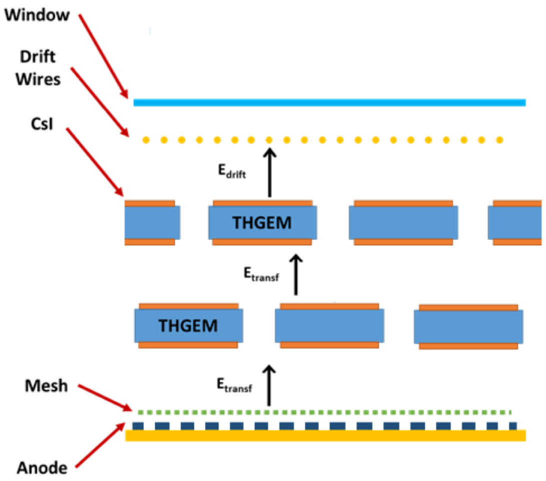
Alternative option

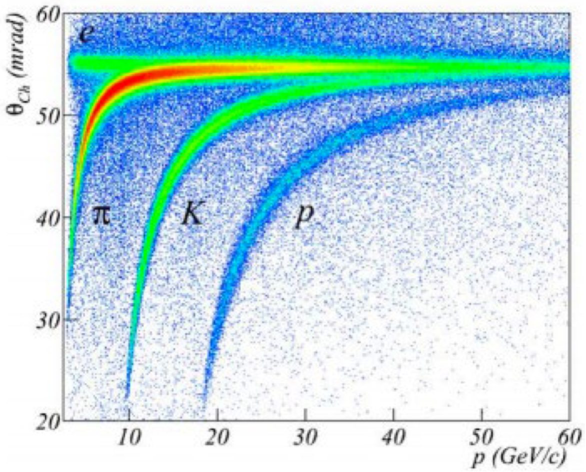
- Use a single-radiator high-momentum RICH
  - Will need to complement it by other PID detectors at lower momenta



- *COMPASS RICH (or a GEM-based window-less version by Stony Brook)*



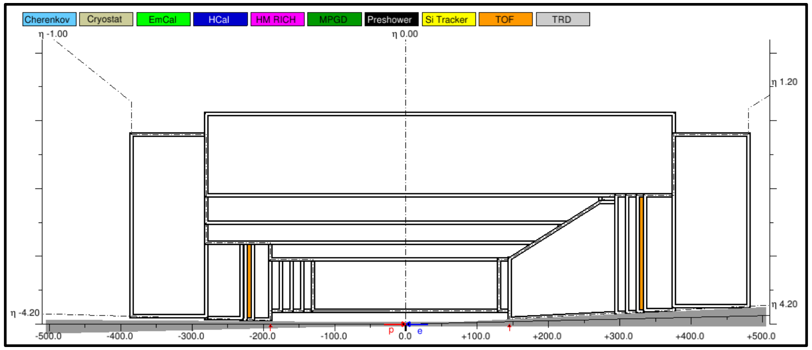


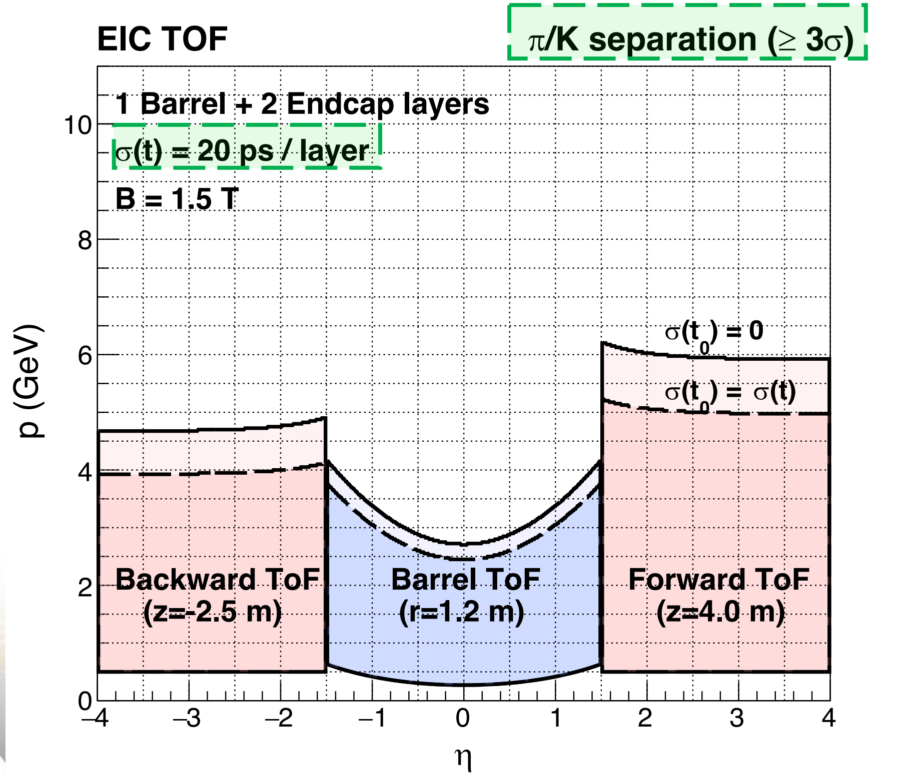


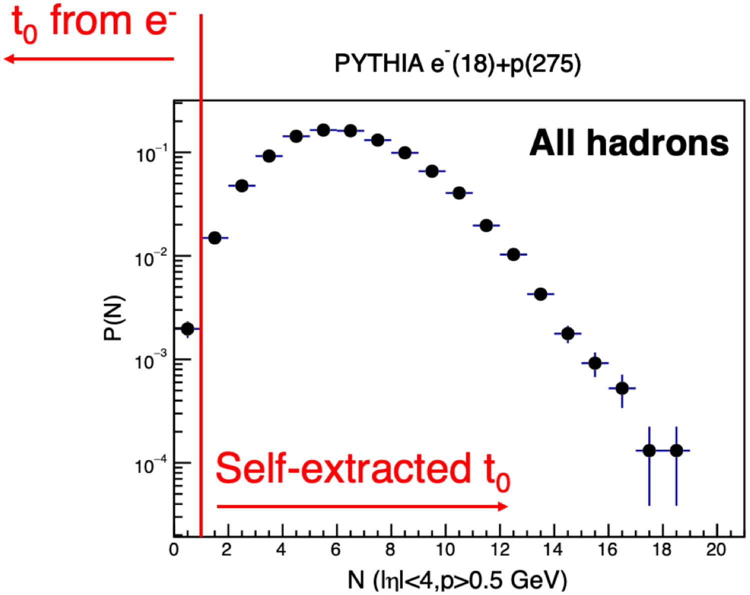
- A single-radiator design with the relatively heavy C_4F_{10} radiator
- After upgrade: UV range, CsI-coated THGEM-based photon detectors
- A detector like this would fit EIC needs provided perhaps a lighter radiator (with the π/K separation up to at least ~50 GeV/c) is used

Time of Flight PID

- May sound hopeless for a compact detector, but in fact it is not
  - Need very high resolution timing detectors
  - Must resolve all the issues with t_0, clock distribution, long term stability, path length, etc.



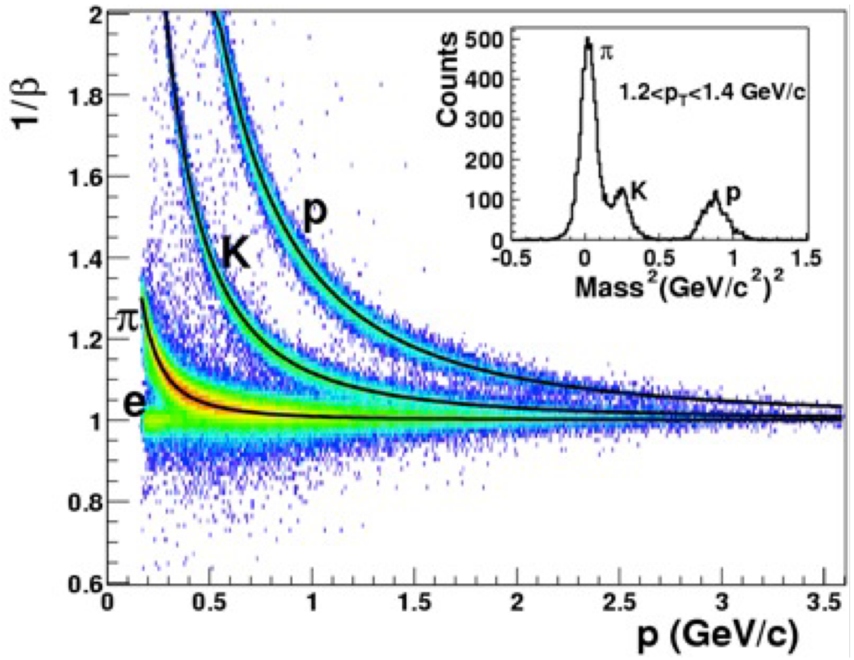




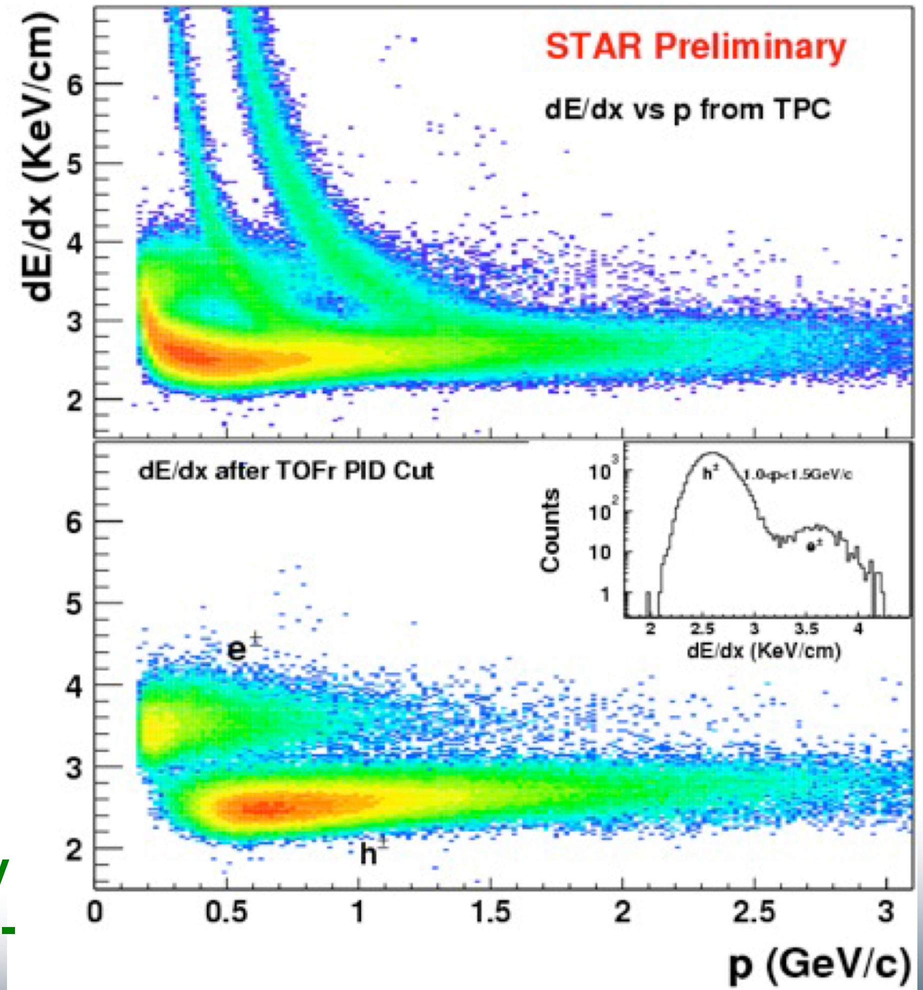
- 4π coverage in high-resolution TOF preferred
- May use identified electrons as t_0 input
- May use combinatorial analysis for high charged track (hadron) multiplicity events

TOF + dE/dx

Time of Flight alone



dE/dx alone



dE/dx with a hard ToF cut

-> Note: combining information from several independent PID detectors can drastically improve the selection quality (in this example provides clear electron-hadron separation up to ~3 GeV/c