Tracking for EIC

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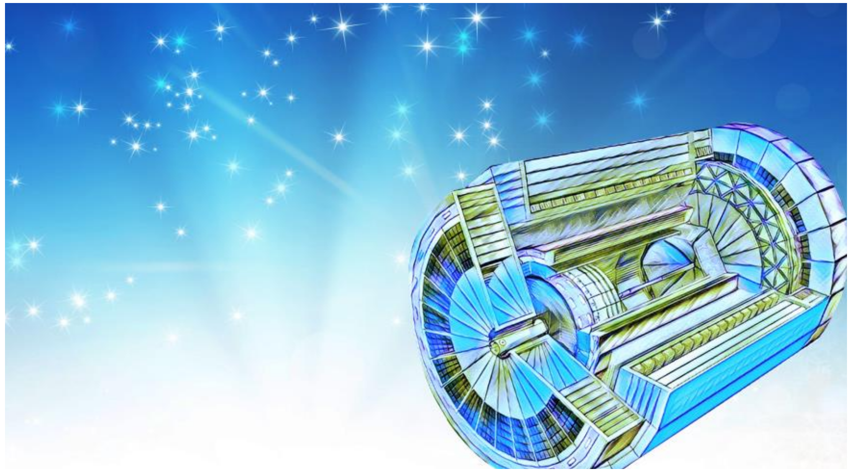
U.S. DEPARTMENT OF ENERGY JSA Jefferson Lab EIC² EIC Center at Jefferson Lab

Outline

- Physics requirements
- Material budget
- Tracking detectors:
  - Vertex
  - Central tracker
  - Endcaps
  - Tracking for PID
  - Fast-timing tracker
- Summary

BNL-NNNNN-YYYY-AA
JLAB-PHY-YY-NNNN
February, 2021

EIC YELLOW REPORT
Volume III: Detector



Tracking

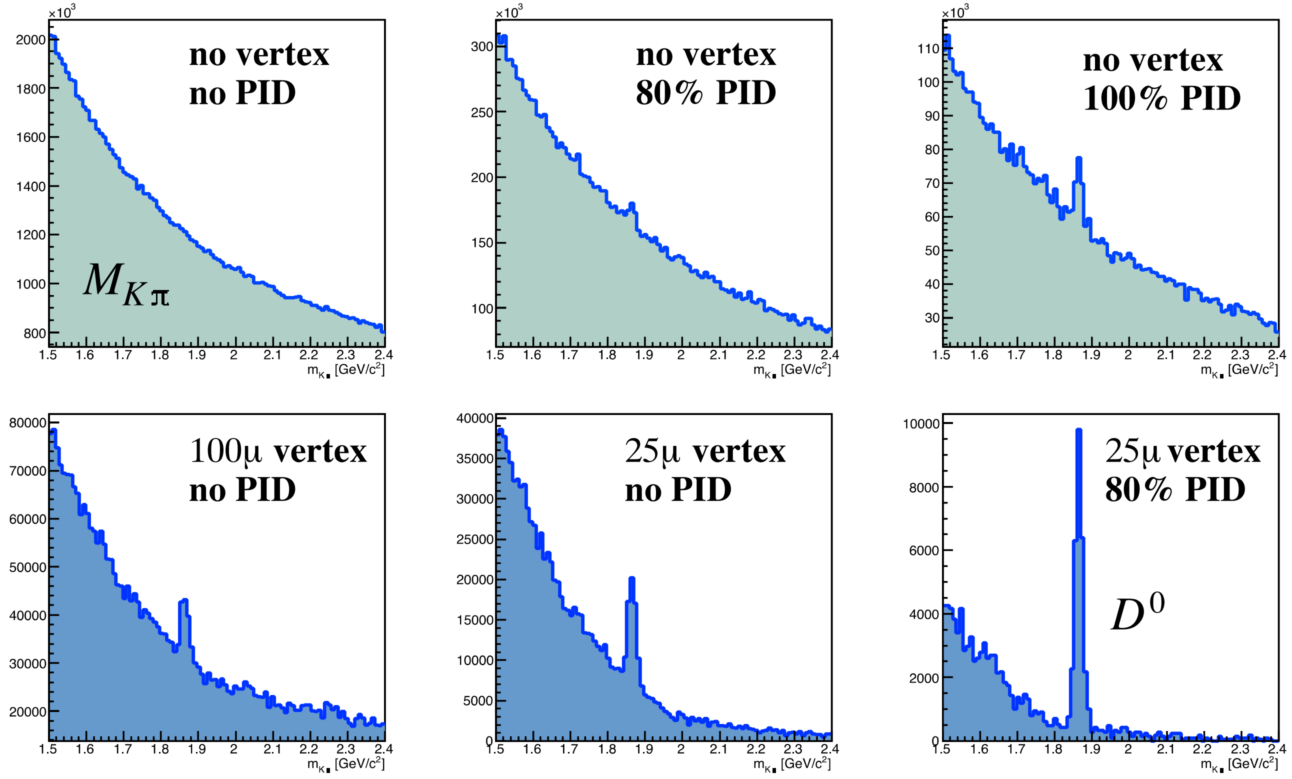
$$Q^2_{\text{EM}} = 2E_e E_{e'} (1 + \cos\theta_{e'}),$$
$$y_{\text{EM}} = 1 - \frac{E_{e'}}{2E_e}(1 - \cos\theta_{e'}),$$
$$x = \frac{Q^2}{4E_e E_{\text{ion}}}\frac{1}{y}$$

- For DIS kinematic reconstruction (via precision measurements of scattering electron angle, or hadrons).

- Momentum measurements (for example, for inv-mass resolution)
- Vertex determination
- For precision jets measurements (particle-flow)
- Improve PID

- For far-forward detection/tagging

$D^0 \rightarrow K\pi$



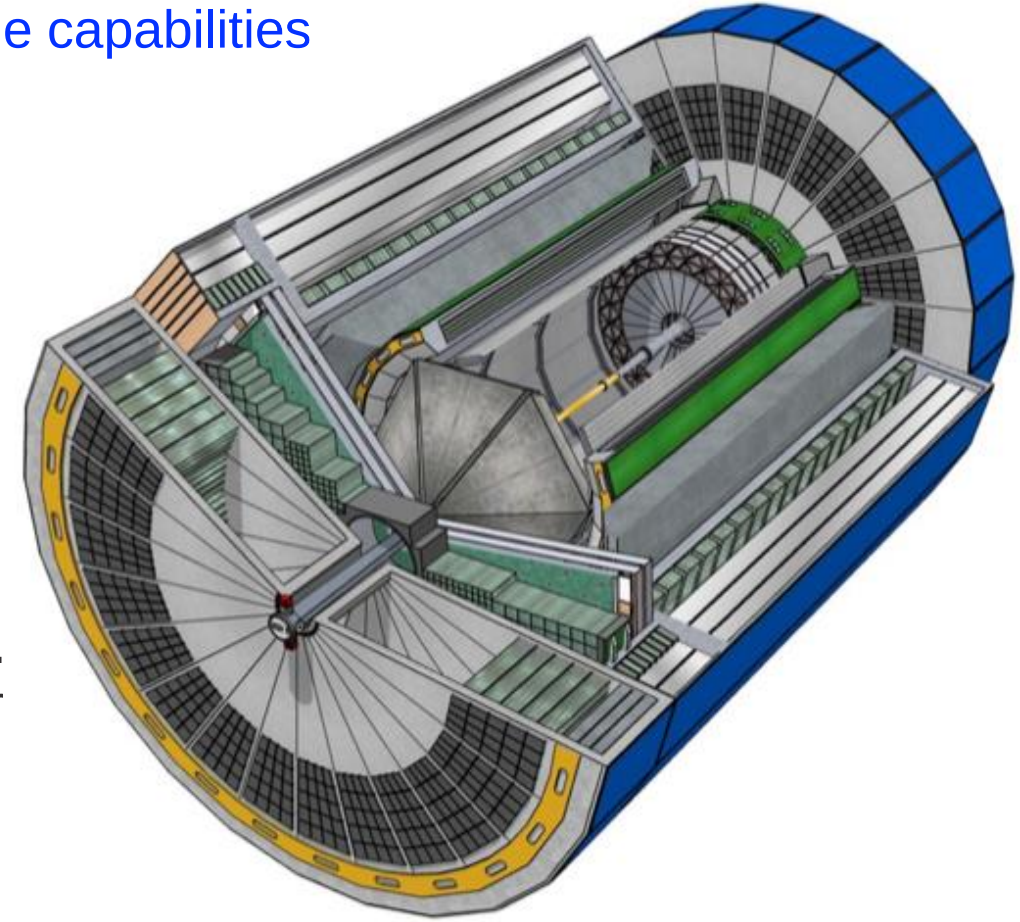
Tracking Requirements from PWGs

Tracking requirements from PWGs						
			Momentum res.	Material budget	Minimum pT	Transverse pointing res.
η						
-3.5 to -3.0	Central Detector	Backward Detector	σp/p ~ 0.1%×p ⊕ 0.5%	~5% X0 or less	100-150 MeV/c	
-3.0 to -2.5					100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 40 µm
-2.5 to -2.0			σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
-2.0 to -1.5					100-150 MeV/c	
-1.5 to -1.0					100-150 MeV/c	
-1.0 to -0.5		Barrel	σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 20/pT µm ⊕ 5 µm
-0.5 to 0						
0 to 0.5						
0.5 to 1.0						
1.0 to 1.5		Forward Detector	σp/p ~ 0.05%×p ⊕ 1%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
1.5 to 2.0					100-150 MeV/c	
2.0 to 2.5					100-150 MeV/c	
2.5 to 3.0			σp/p ~ 0.1%×p ⊕ 2%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 40 µm
3.0 to 3.5					100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 60 µm

Figure 11.1: Requirements for the tracking system from the physics groups.

Detector General Requirements

EIC physics measurements require a detector with unique capabilities



- **Large rapidity ($-4 < \eta < 4$) coverage;** and far beyond in especially far-forward detector regions
- **High precision low mass tracking**
  - small (μ-vertex) and large radius tracking
- Electromagnetic and Hadronic Calorimetry
  - **equal coverage of tracking and EM-calorimetry**
- High performance PID to separate π, K, p on track level
  - also need good e/π separation for scattered electron
  - **precise momentum measurements are very important for PID.**
- Large acceptance for diffraction, tagging, neutrons from nuclear breakup: critical for physics program
  - Many ancillary detector integrated in the beam line: low-Q^2 tagger, Roman Pots, Zero-Degree Calorimeter, ….
- High control of systematics
  - luminosity monitor, electron & hadron Polarimetry

Integration into Interaction Region is critical

Solenoid

- maximize B*dl integral at high |η|
- Detection of low-P_T particles

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.

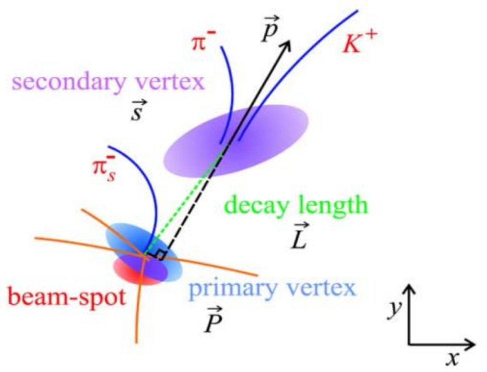
Low momentum particles

Problem of too high magnetic field:

$$D^{*+} \rightarrow D^0\pi_s^+ \rightarrow (K^-\pi^+)\pi_s^+$$

2R > R_{out} (VTX)

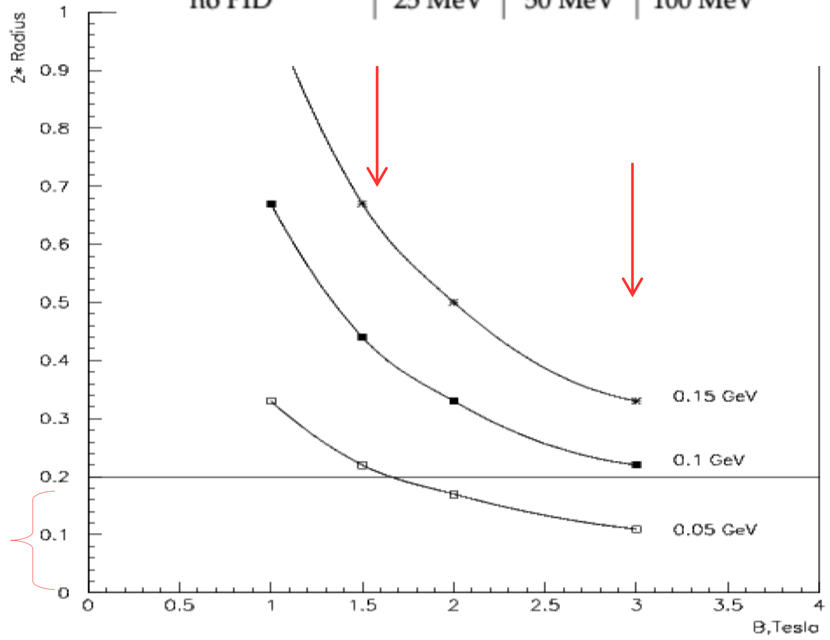
$$R(m) = \frac{P_T(GeV)}{0.3 \cdot B(T)}$$

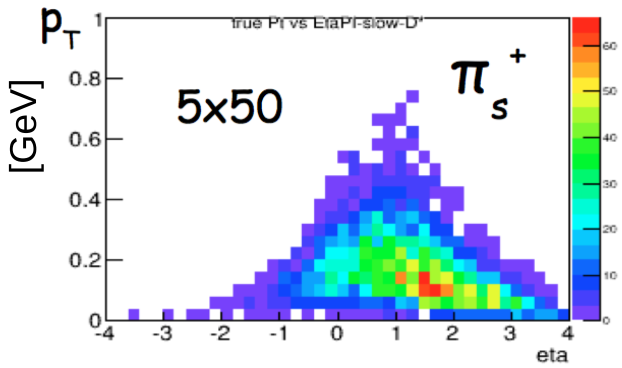


- Min PT measured, min PT reached PID or CAL
- Layered structure of vertex detectors
- For track reconstruction slow particles have to pass at least 3 layers of tracking detector

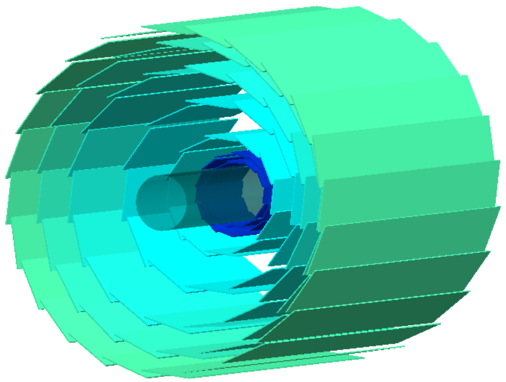
lowest p_T	0.5 Tesla	1 Tesla	3 Tesla
with PID @1m	75 MeV	225 MeV	450 MeV
no PID	25 MeV	50 MeV	100 MeV

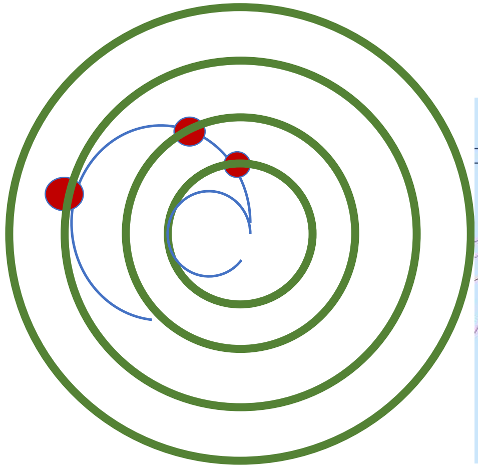
VTX

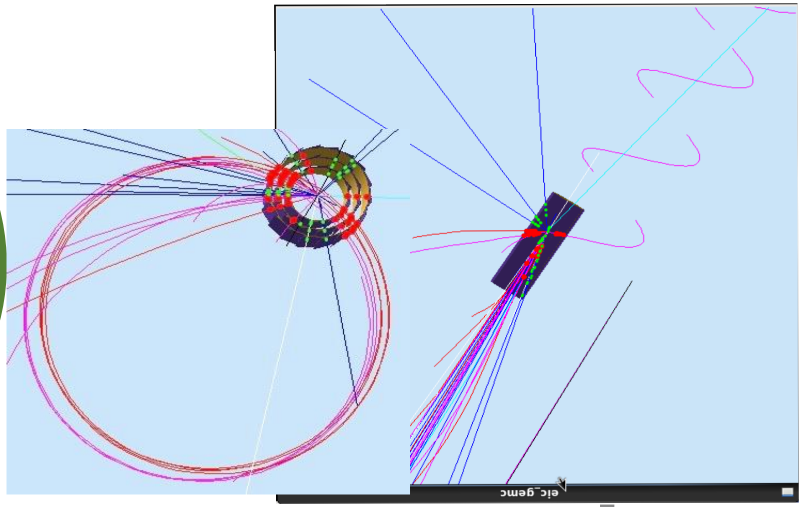




Barrel part of vertex detector

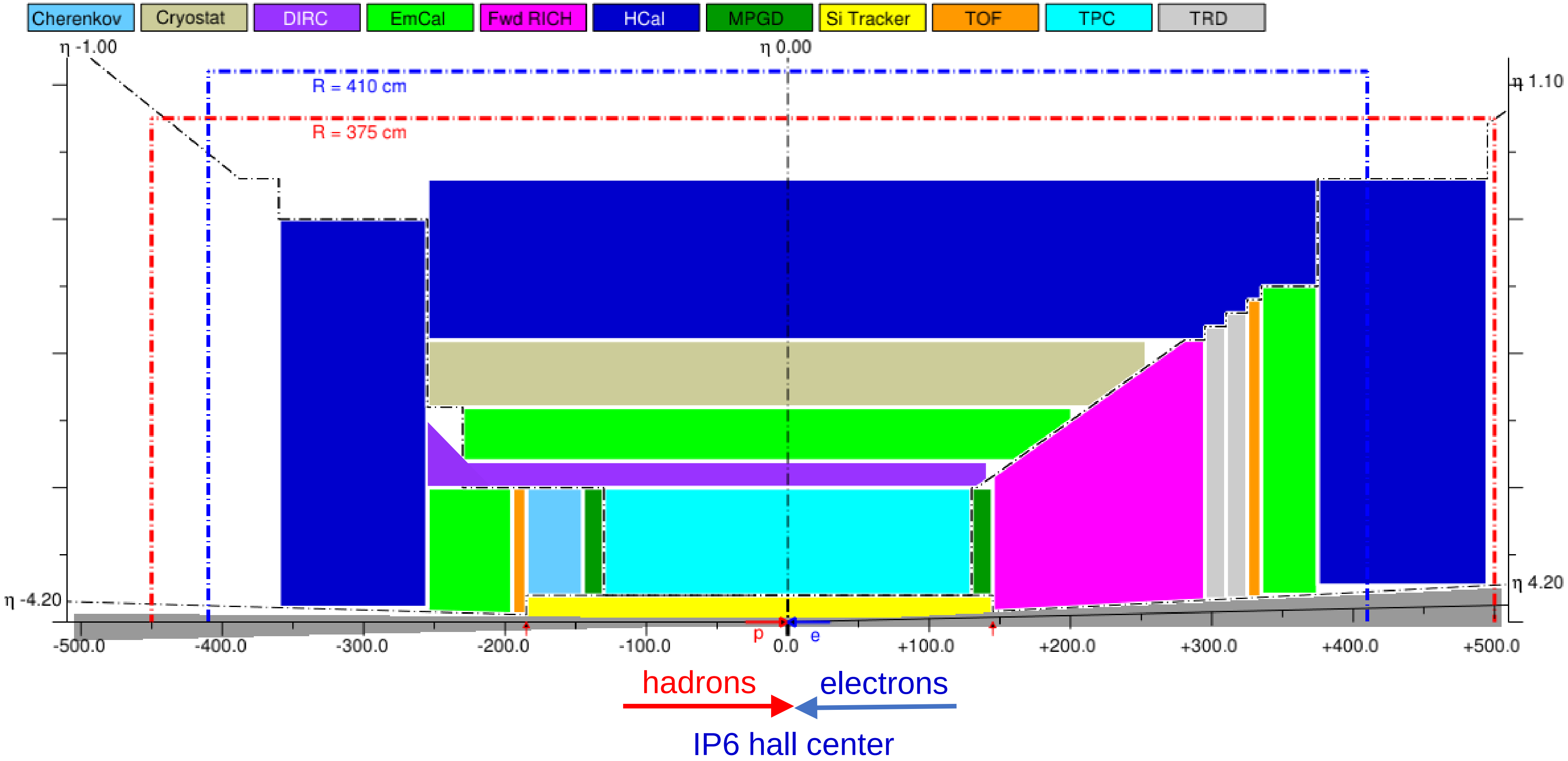






Beampipe: 3.2cm
Inner layer of outer tracker: 20 cm

EIC reference detector

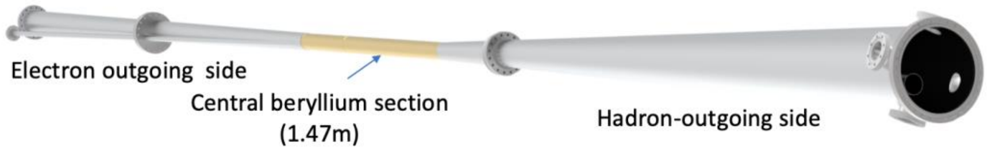


- ✓ -4.5 /+5 m machine element free region for central detector
- ✓ 25mrad crossing angle
- ✓ Individual detector component space allocations provided by the Yellow Report Working Groups

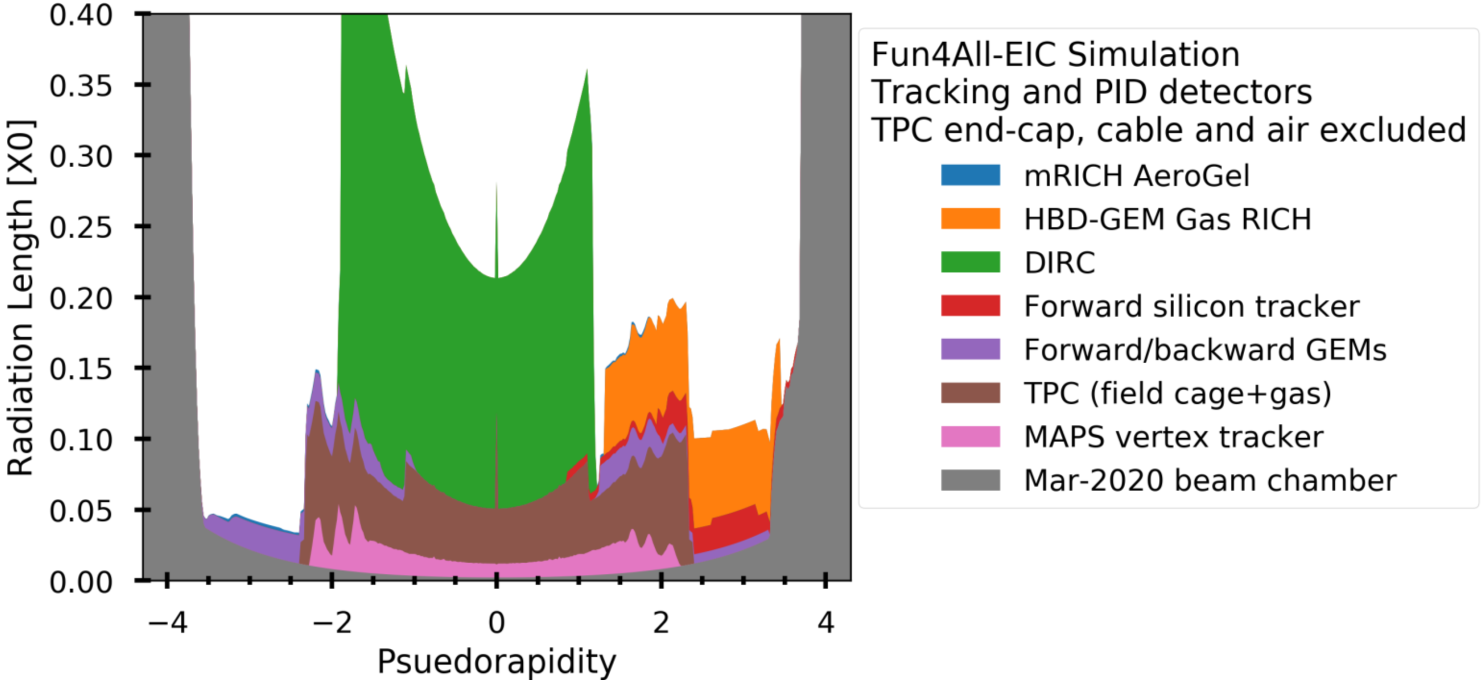
*) This figure is modified to be in phase with the YR efforts and will be updated in the CDR

Tracking/Material Budget

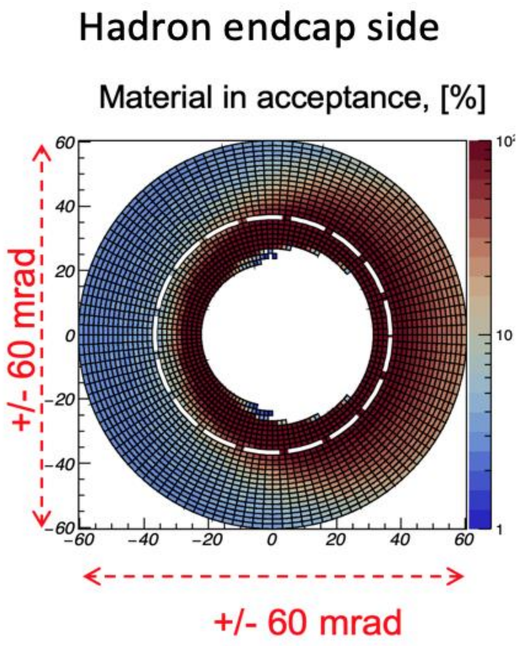
- Low material budget
  - Minimize bremsstrahlung and conversions for primary particles
  - Improve tracking performance by minimizing multiple Coulomb scattering
  - Minimize the dead material in front of the high resolution e/m calorimeters



- ❑ Central area of beampipe (around IP):
  ~1.5m of beryllium to minimize multiple scattering for low Pt particles
- ❑ Low-mass exit window for far-forward particles

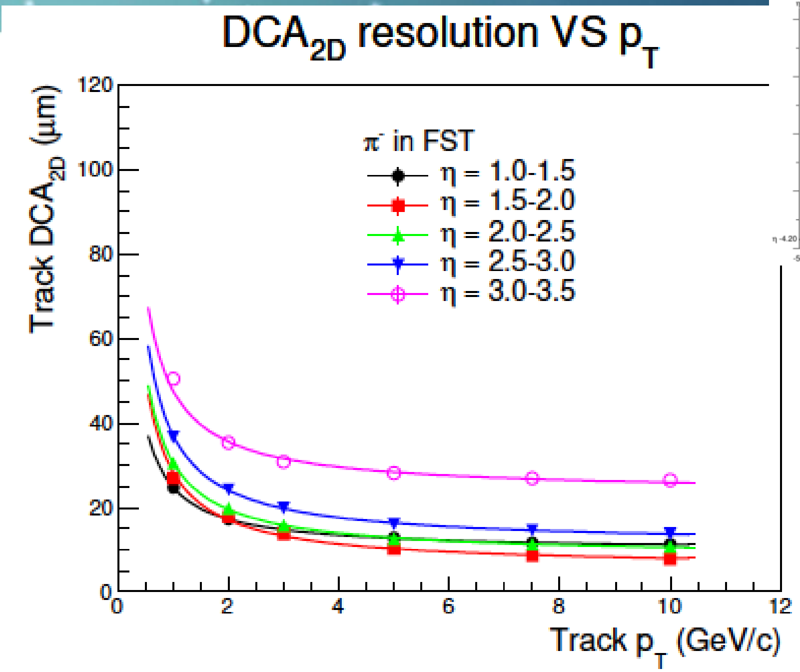


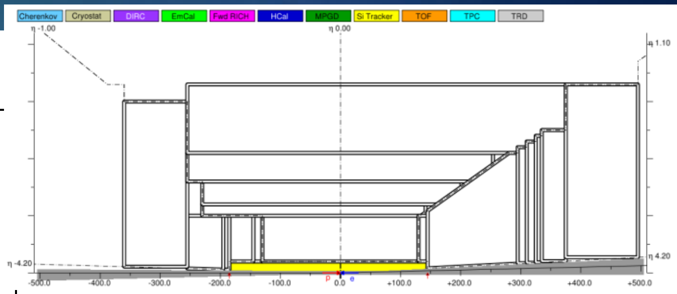
- ❑ Few % radiation length material thickness for the required angular range (low angle)

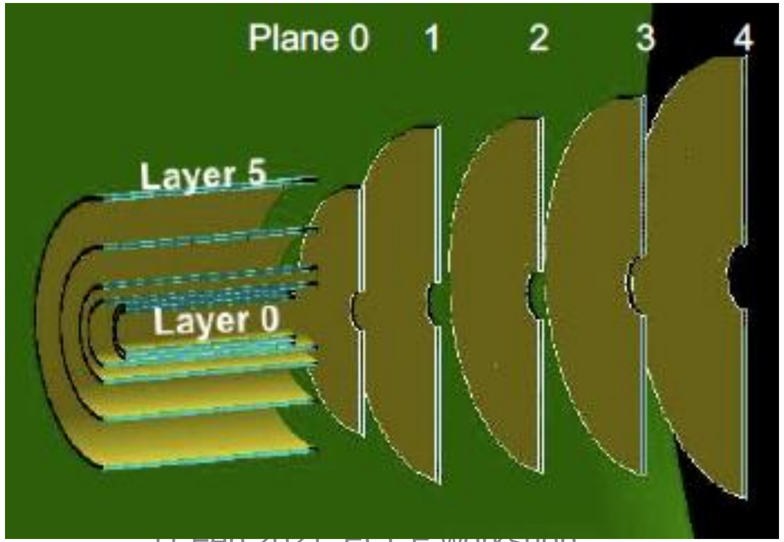


Vertex

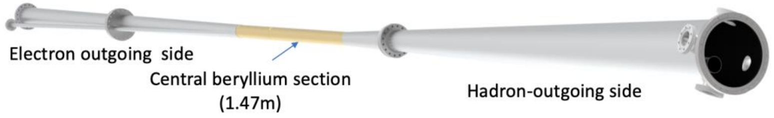
- For primary and secondary vertex reconstruction
- Low material budget:
  - ~0.3% (possibly 0.05% a la ITS3 for ALICE) X/X_0 per layer
- High spatial resolution:
  - 20 μm (or smaller) pixels
- Barrel+ Disks for endcaps

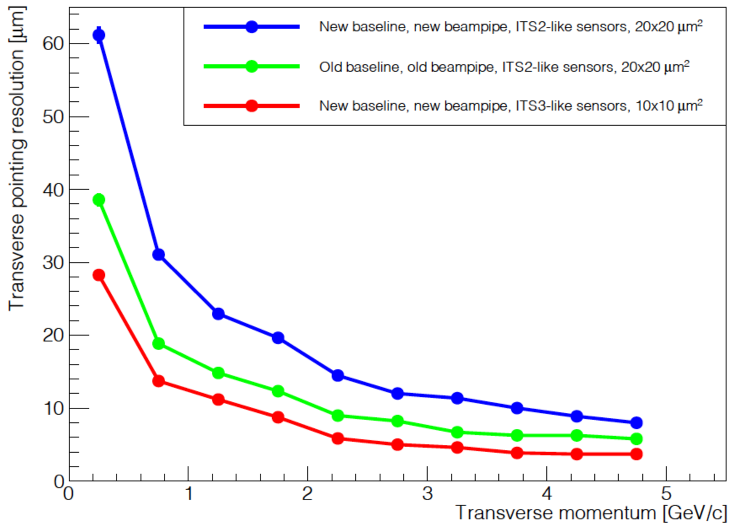






Central beampipe with the outer diameter 63.5 mm:





Si technology

(MAPS, DEPFET(Belle-II) , LGAD, Si-strip or hybrid pixel detectors)

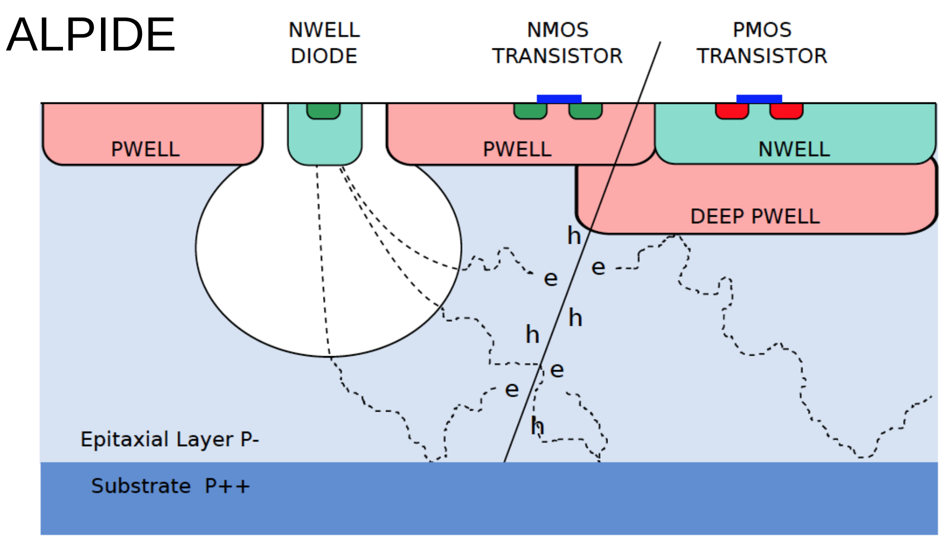
MAPS:

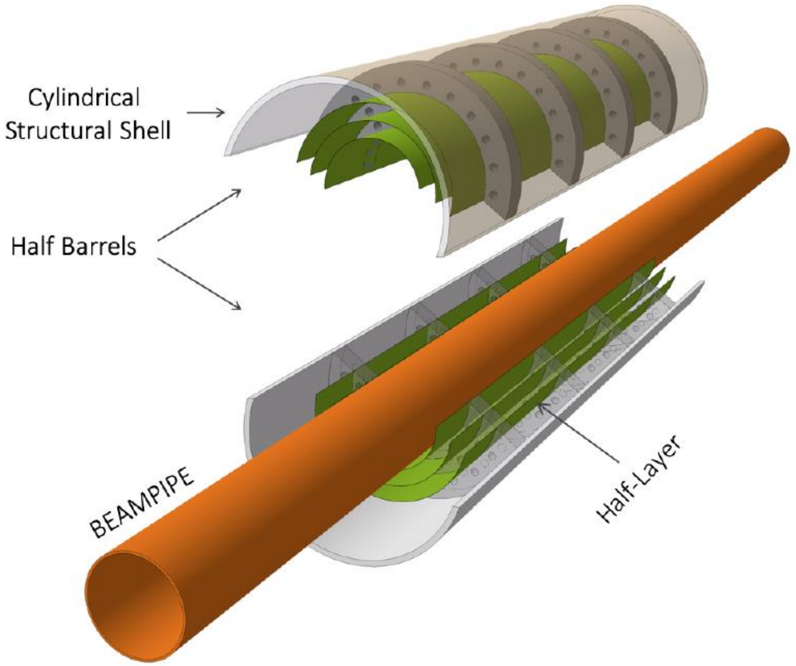
STAR experiment:
Traditional MAPS **MIMOSA** => charge collection by **diffusion** (slow)

ALICE Inner Tracker (ITS2):
ALPIDE is fabricated in a commercial 180 nm CMOS imaging process provided by Tower Jazz.
partially depleted substrate and thus collect part of the charge by **drift**.

Depleted MAPS (**DMAPS**) are fabricated in High Voltage or High Resistivity commercial 150/180nm CMOS imaging technology

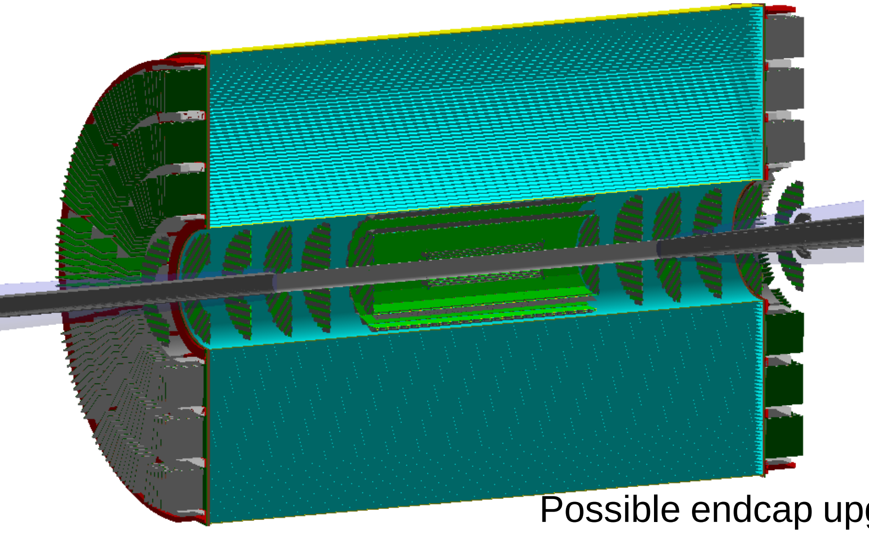
65 nm MAPS sensor for **ITS3** detector concept (under development) : 10um pixel pitch, lower material budget.

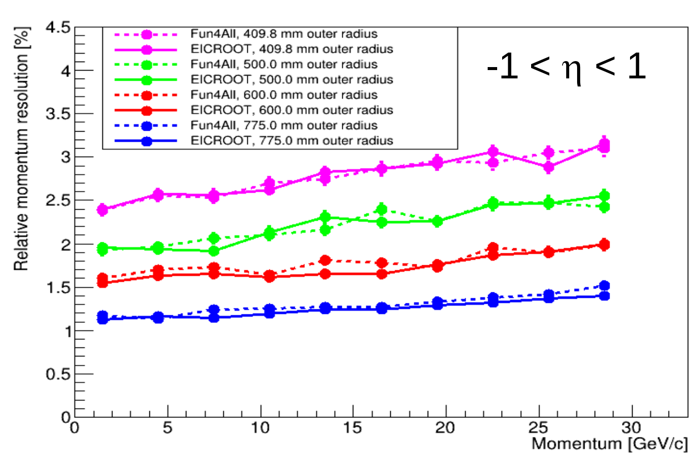


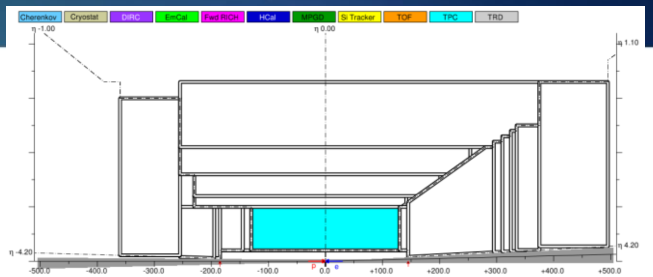


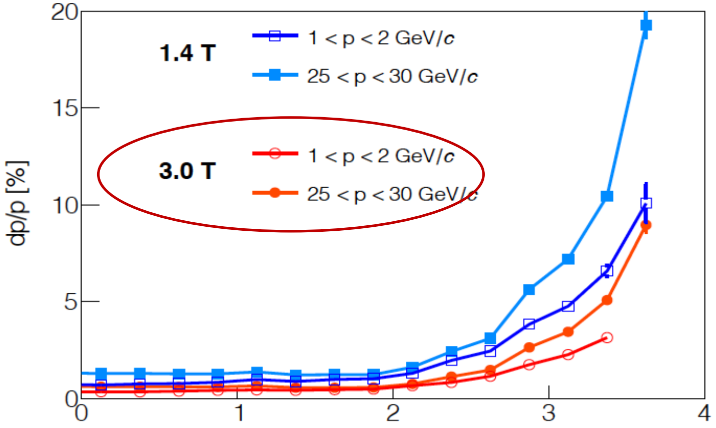
Central tracker

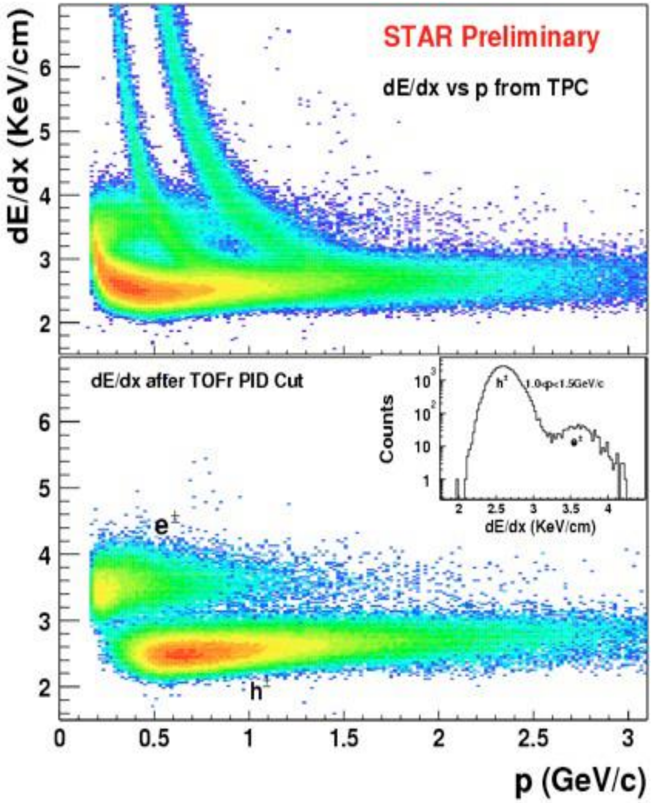
- For momentum reconstruction
- Sufficient spatial resolution
- dE/dx for low-momentum PID
- TPC: low material budget tracker (similar to STAR, sPHENIX, ALICE…)



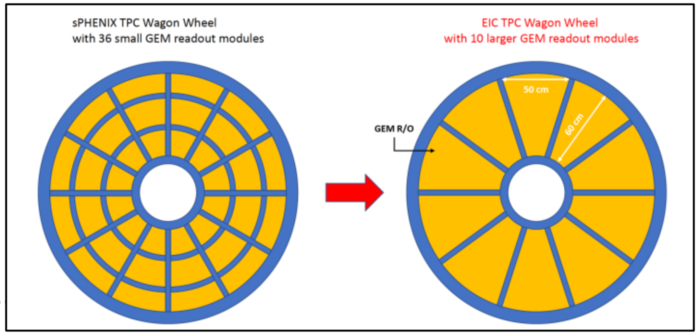


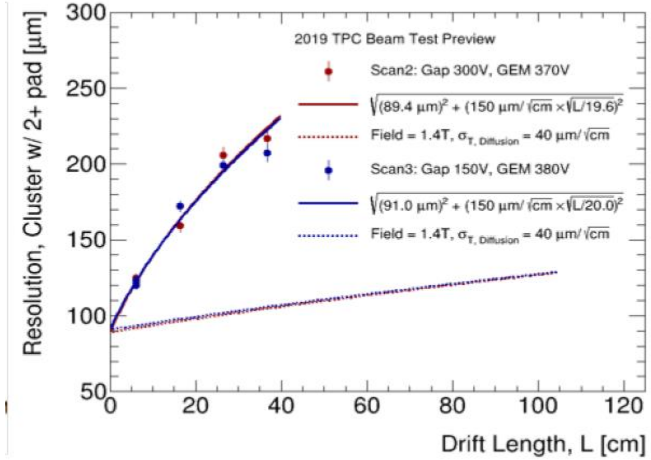




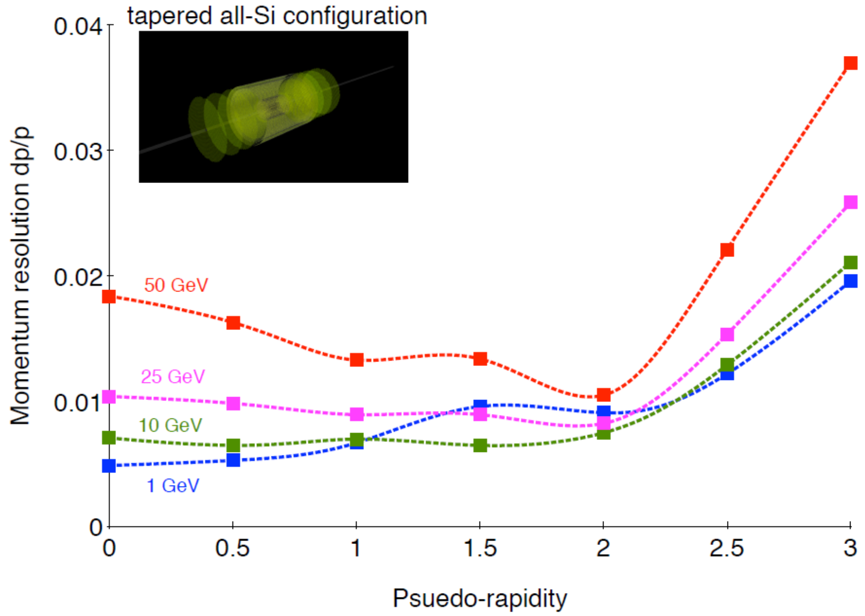


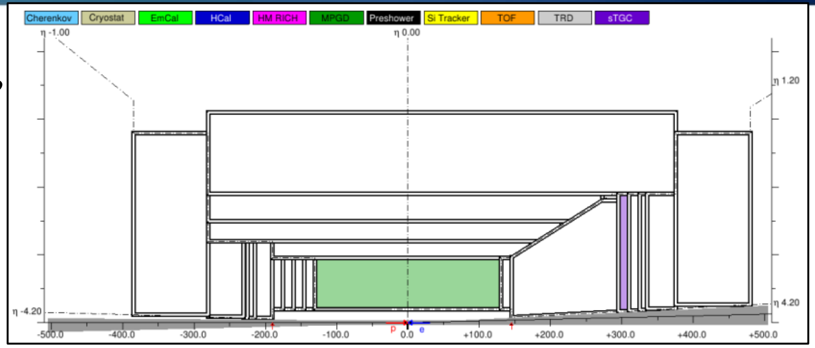
Possible endcap upgrade for EIC

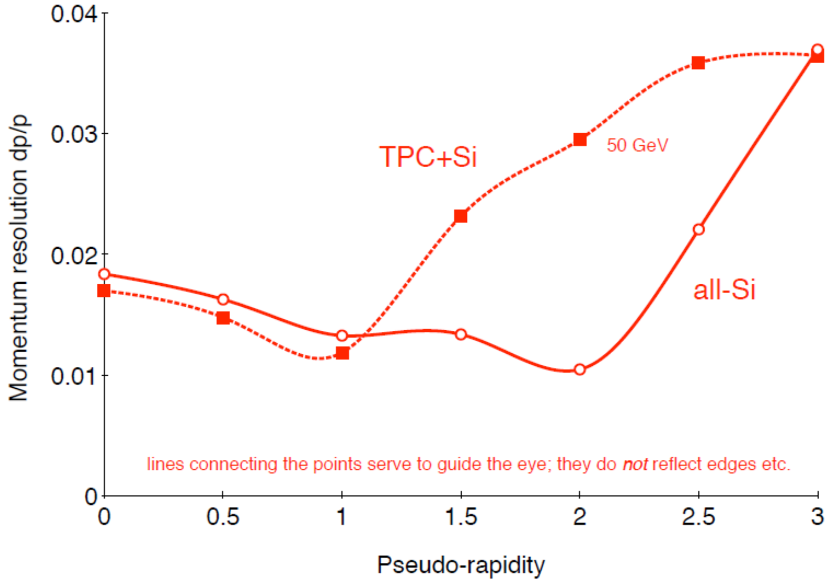


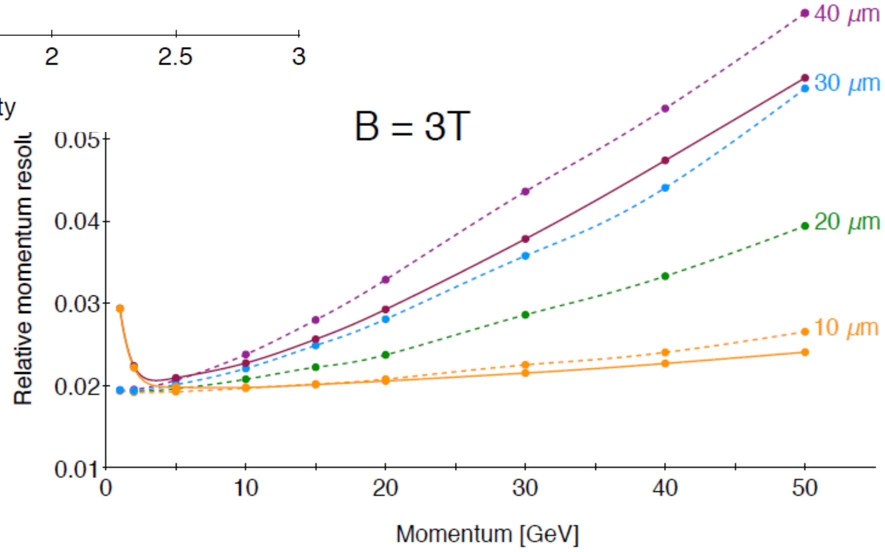


Si-tracker resolution versus pixel size and all-Si solutions versus all-Si+TPC

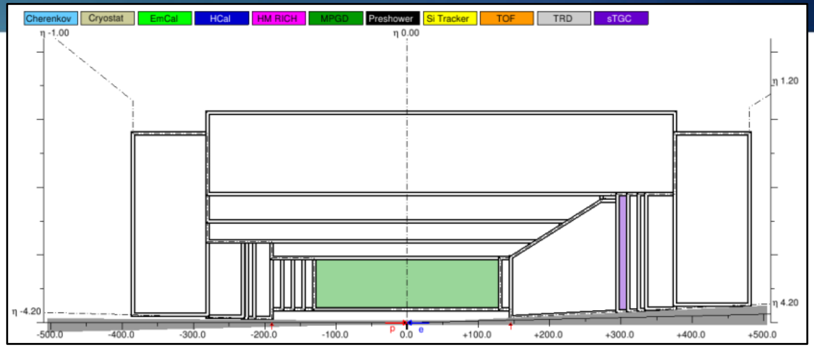






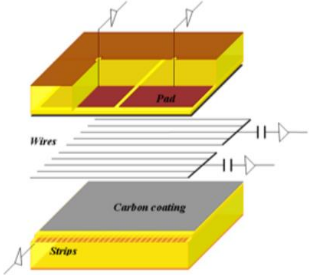


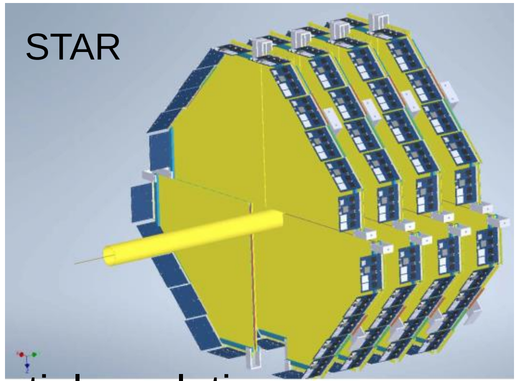
Alternative options



Small-strip Thin Gap Chambers (sTGCs)

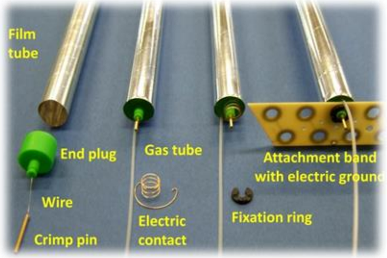
- *ATLAS, STAR*

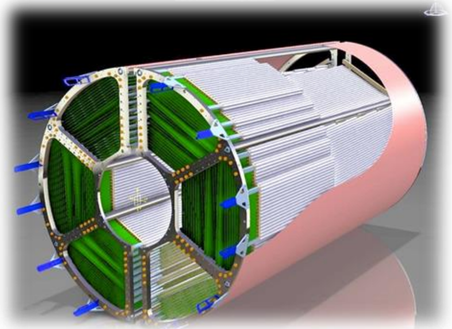




- 0.5%X0/layer
- ~100 μm or better spatial resolution
- cost efficient

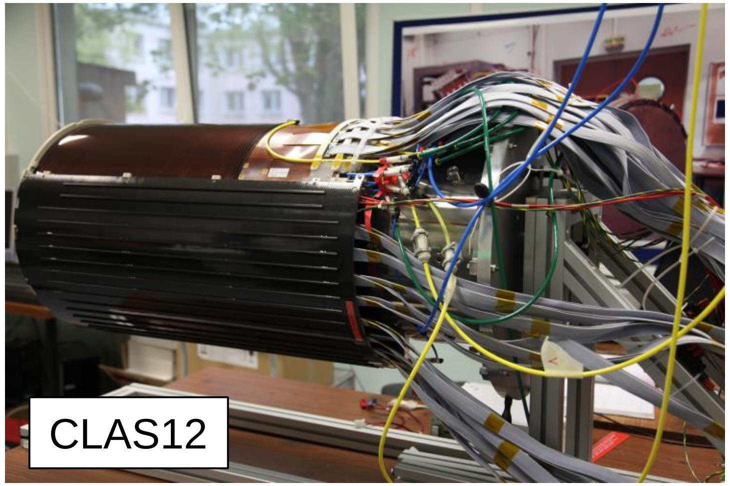
- *Straw tracker (PANDA)*





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

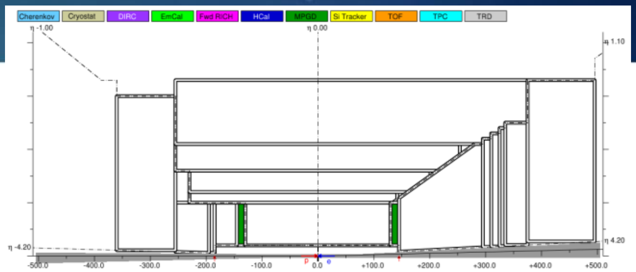
- *Cylindrical MM (or μRwell)*



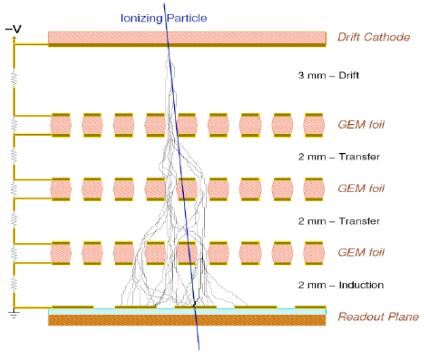
- 6-8 concentric layers up to R ~ 80 cm
- ~0.5% X_0/X per layer
- <100 μm resolution (potentially in 2D)

Endcaps: MPGDs

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

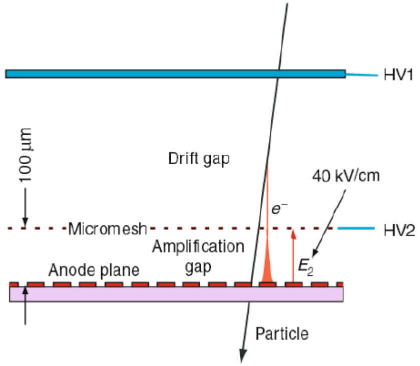


GEM: Gas Electron Multipliers



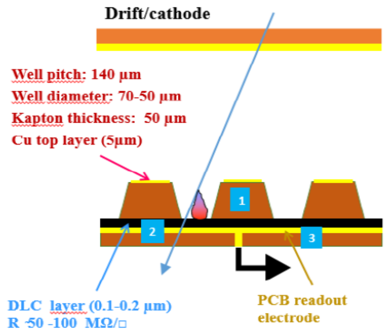
F. Sauli, Nucl. Instr. and Meth. A386 (1997) 531

Micromegas: Micro Mesh Gaseous Structure

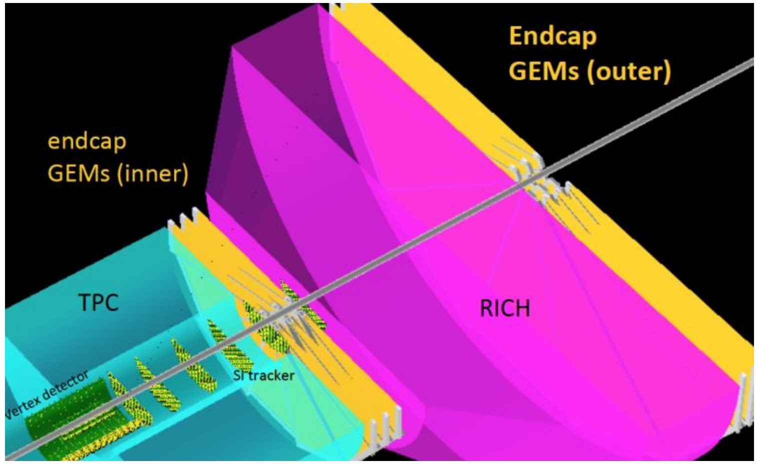


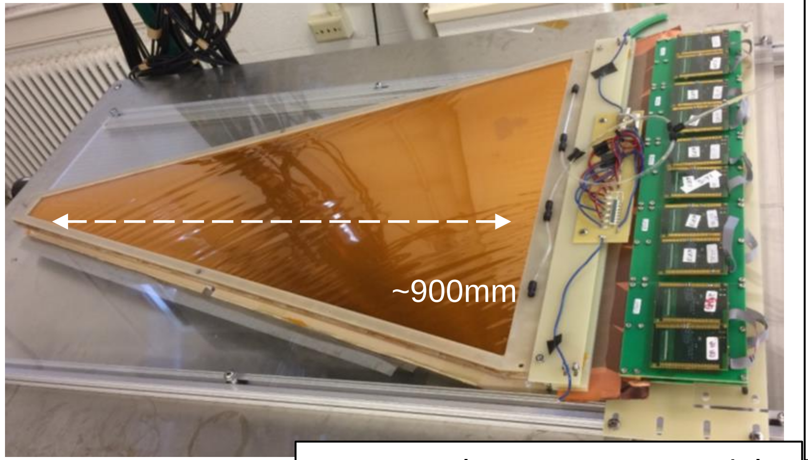
Giomataris, Nucl. Instr. and Meth. A419 (1998) 239

μRWELL: Resistive micro-WELL Detector

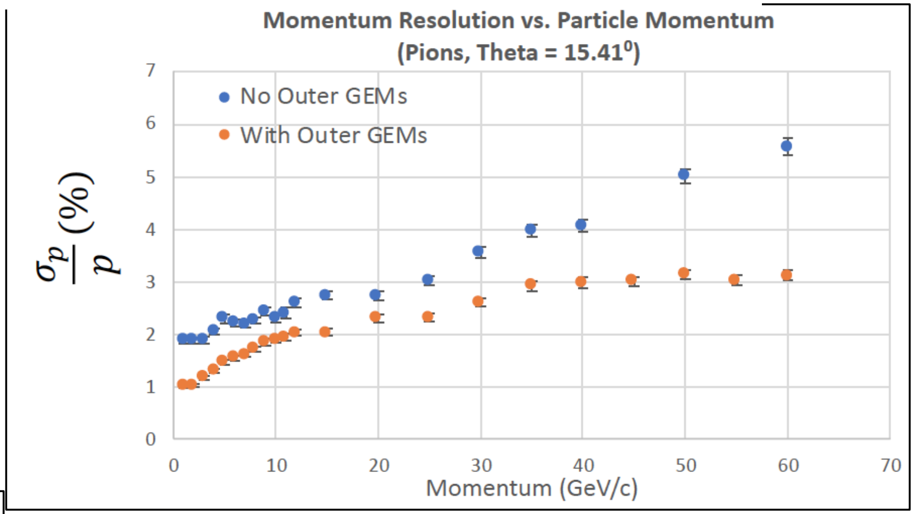


Bencivenni et al., 2015_JINST_10_P02008

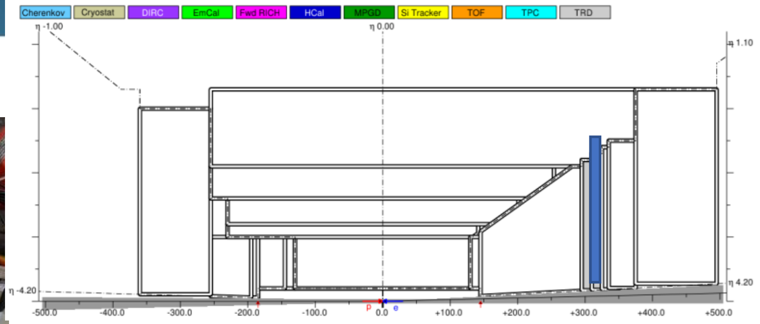




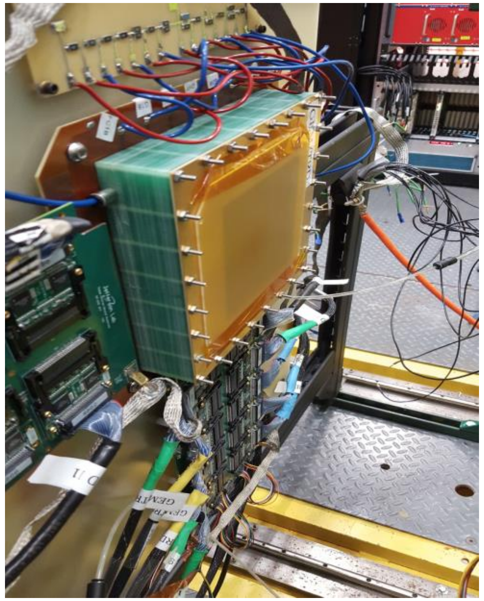
EIC R&D: large 2D GEM module

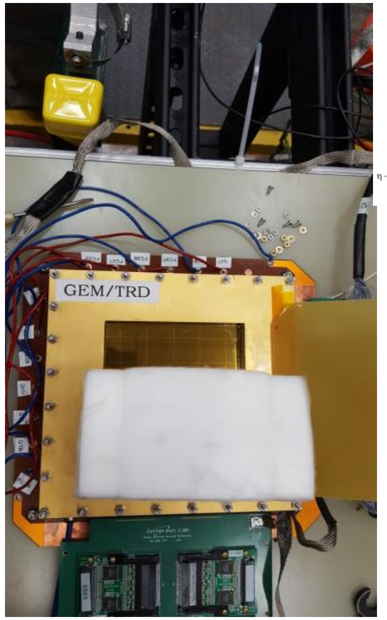


Additional e⁻ ID

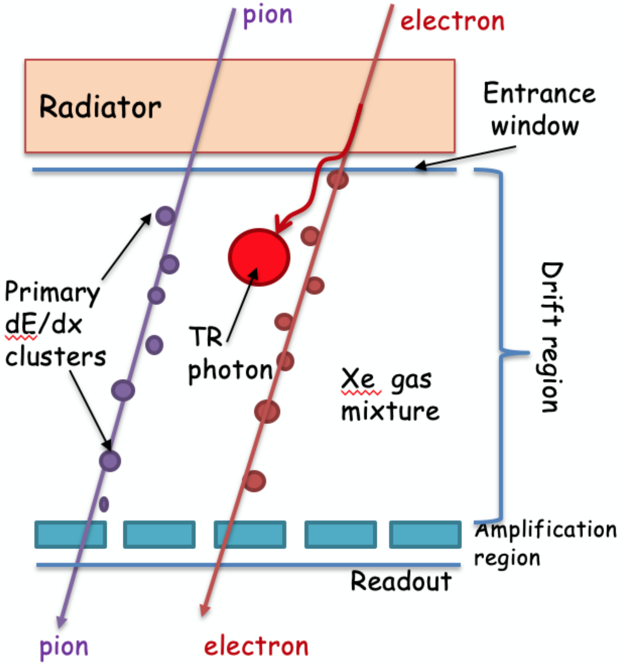


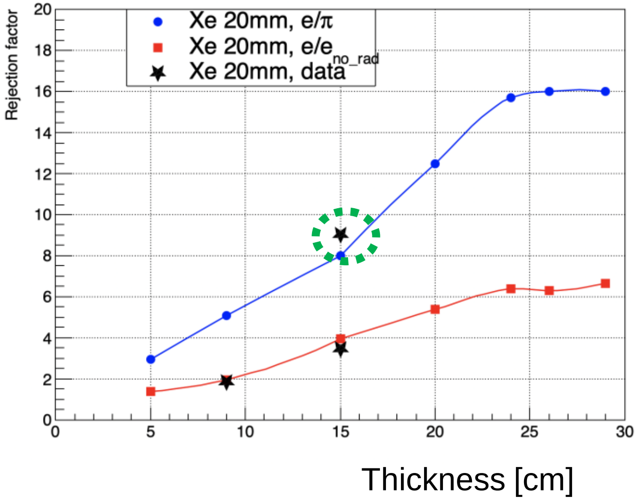
- To improve e-identification for leptonic/semi-leptonic decays.
- In addition to Calorimeters and Cherenkov detectors in the hadron-endcap considering TRD.
- GEM -TRD/Tracker :
  - e/π rejection factor ~10 for momenta between 2-100 GeV/c from a single ~15cm thick module.

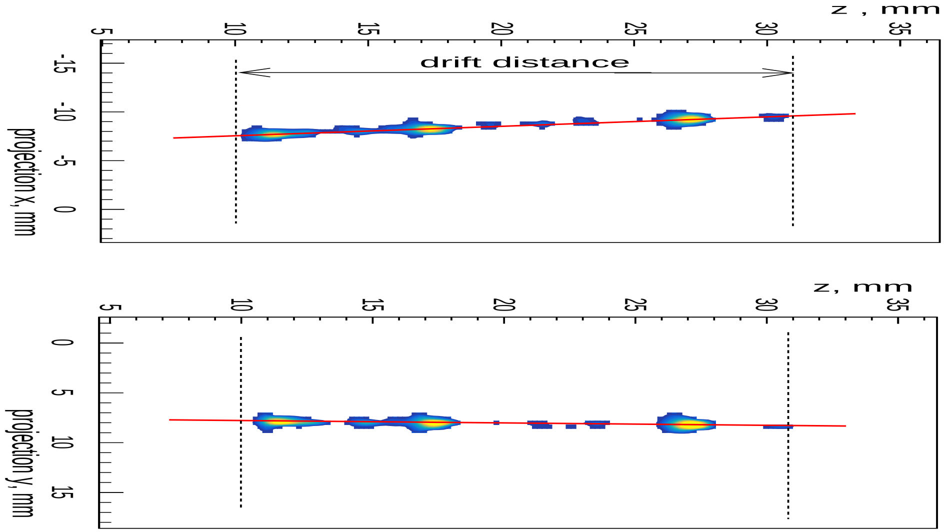




Could provide high precision track segment behind dRICH:

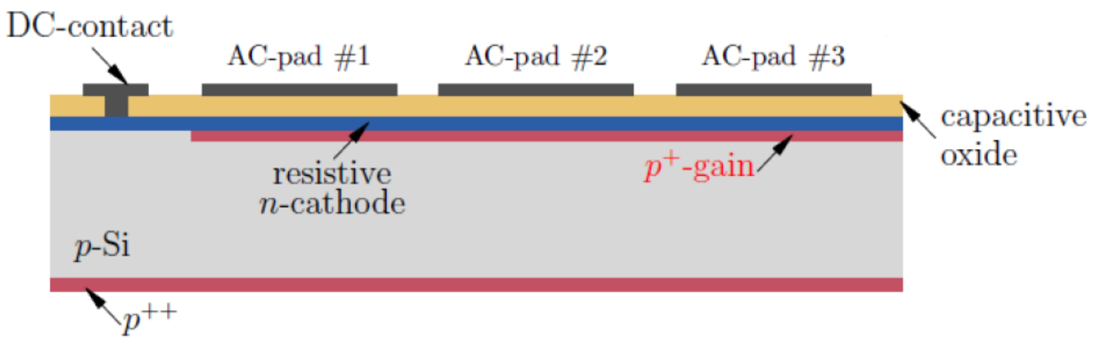


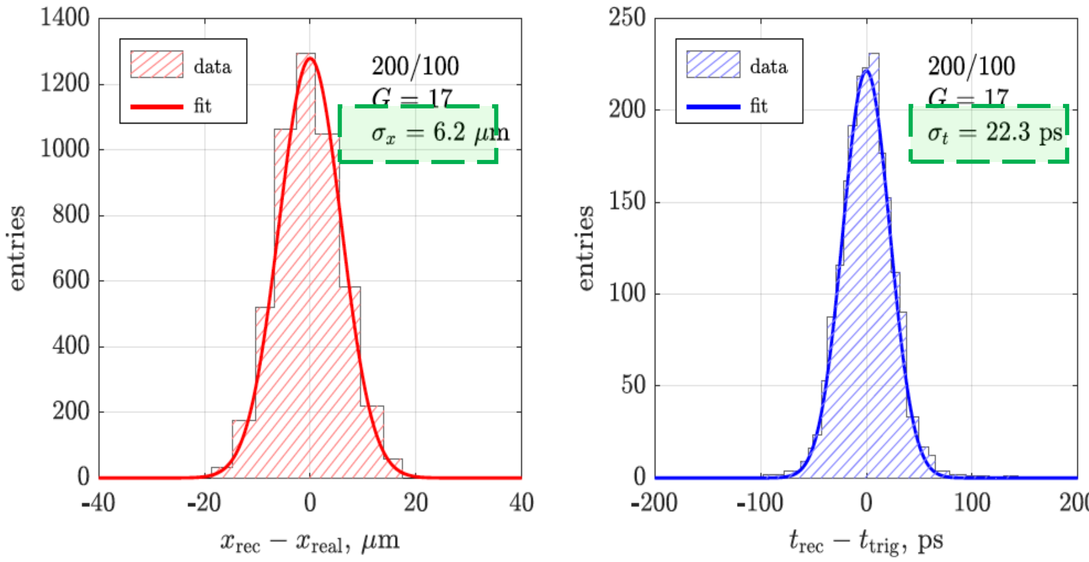




High resolution timing technologies

- *(AC)-LGAD*

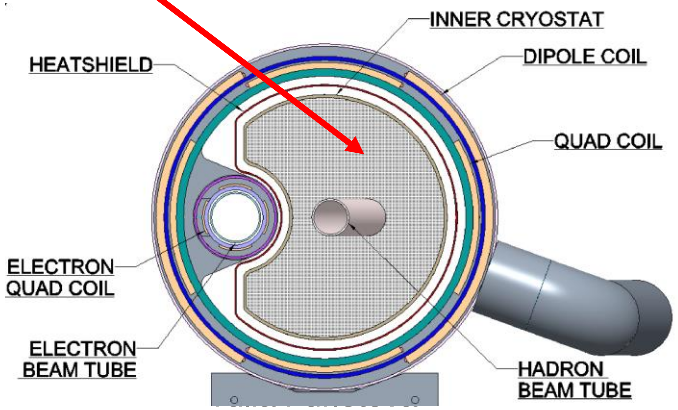


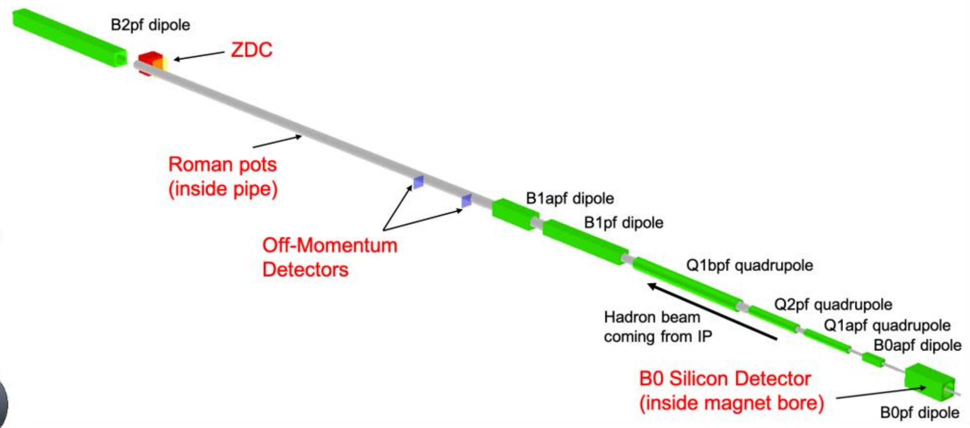


- Detectors can provide <20ps / layer
- moderate granularity (500x500μm^2)
- AC-coupled variety gives 100% fill factor

B0 : Space for detectors

- For far-forward area:
  Roman Pots,
  Off-momentum detectors,
  B0-detectors (in combination with high resolution Si-pixels)





Summary

- Low-mass, high-resolution tracker for momentum measurements and high-granularity, low-mass vertex detector are needed for EIC.
- Geant4 simulation of fully integrated tracking system with support structure, FE-electronics, cables, cooling, etc… is needed to estimate impact of material budget on resolution and tracking performance.
- A mitigation of background (for example, synchrotron radiation) is very important!

Backup

Momentum resolution

$$\frac{\sigma_{p_T}}{p_T} = \sqrt{\left(\frac{\sigma_{p_T}}{p_T}\right)^2_{\text{meas}} + \left(\frac{\sigma_{p_T}}{p_T}\right)^2_{\text{MS}}}$$

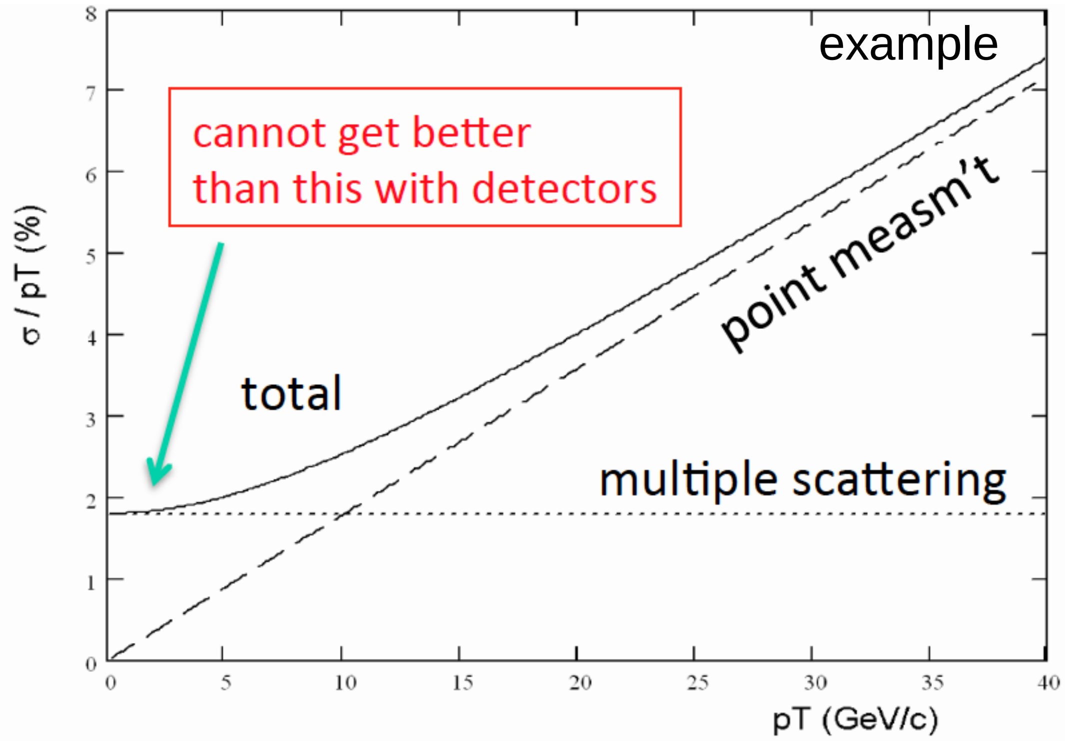
Position resolution (N>10) :

$$\frac{\sigma(p_T)}{p_T}^{\text{meas}} = \frac{\sigma(x)\cdot p_T}{0.3BL^2}\sqrt{\frac{720}{N+4}}$$

Multiple scattering:

$$\frac{\sigma(pT)^{\text{MS}}}{p_T} \approx \frac{1}{\sqrt{LX_0}B}$$

p_T [GeV] = 0.3· B [T] · R [m]



Conclusion:
- Optimize material effects (multiple scattering)
  optimize amount of material along particle track (sensitive area (Si), support structure, cables..)
- The longer L is better ($1/L^2$)
- Place first plane as near as possible to IP
- P_T is linearly better with B-field, but…
- Increase N (but only as $1/\sqrt{N}$)
- Improve hit point resolution (σ_{meas})