Material Budget requirements (kickoff meeting)

Yulia Furletova

Outline

We need as less as possible material at all directions !

End of the talk.

Multiple scattering

-Multiple scattering change the trajectory of charged particle (that's why we hate it!)

-The smaller the momentum of the particle, the higher the effect of multiple scattering

-Depends on distance and density of a material

$$\boxed{\sigma_\phi \approx \frac{14\ \mathrm{MeV}/c}{p}\sqrt{\frac{L}{X_0}}}$$

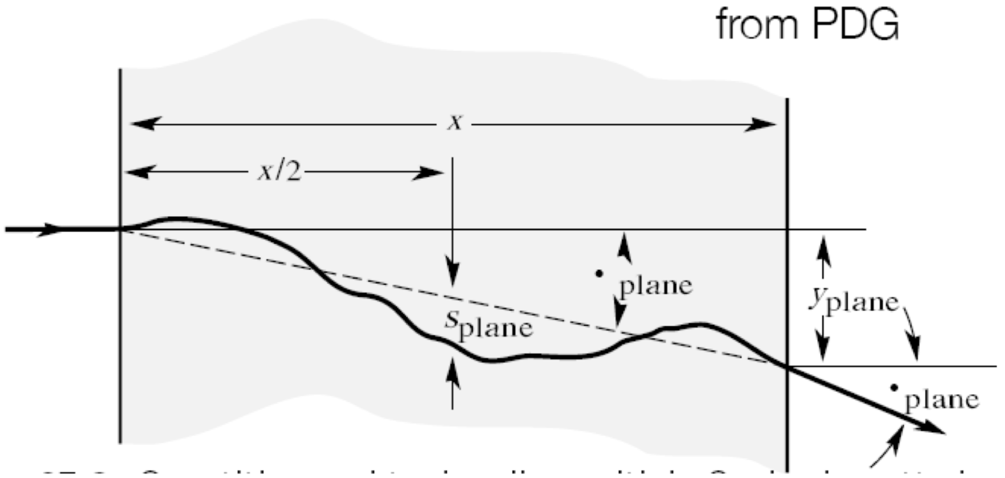
$$\frac{\sigma_p}{p} = \frac{\sigma_R}{R} = \frac{\sigma_\phi}{\phi}$$

as $R = \frac{L}{\phi}$

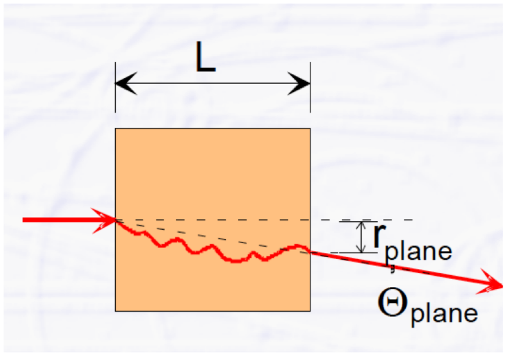
$$\frac{\sigma_p}{p} = \frac{\sigma_\phi}{\phi} = \frac{14\ \mathrm{MeV}/c}{p}\sqrt{\frac{L}{X_0}} \cdot \frac{R}{L} = \frac{14\ \mathrm{MeV}/c}{p}\sqrt{\frac{1}{LX_0}} \cdot \frac{p}{eB} \sim \frac{1}{\sqrt{LX_0}B}$$

Momentum independent!

from PDG



At small momenta this limits resolution of momentum measurement ...



Momentum resolution

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

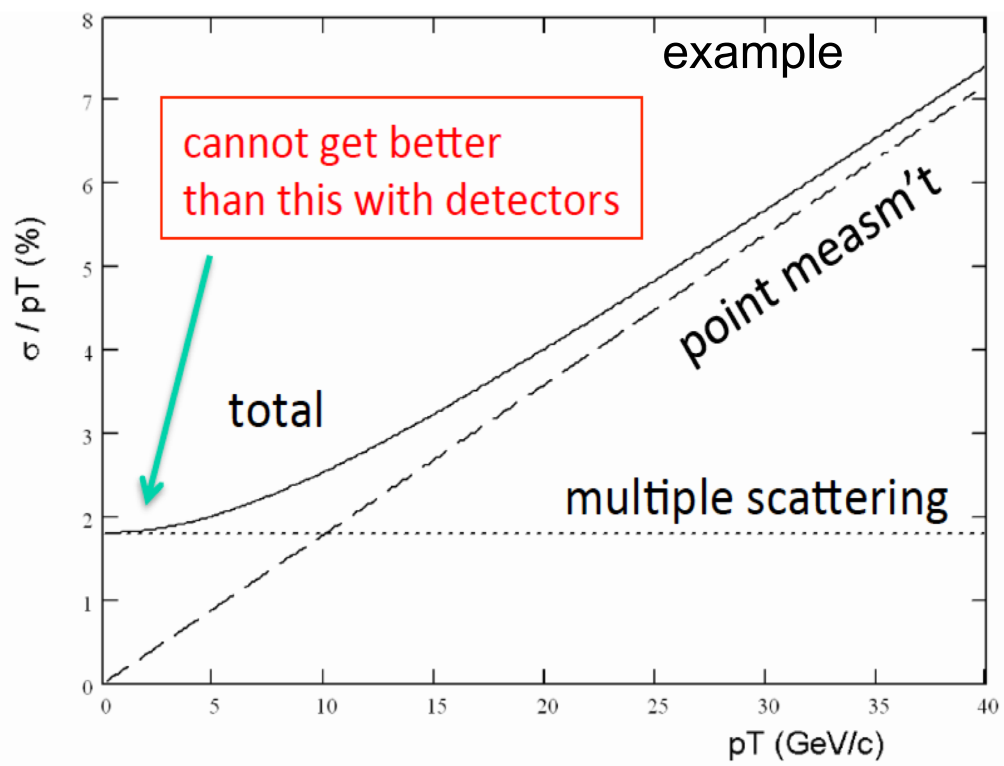
Position resolution (N>10) :

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

Multiple scattering:

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

$$p_T\,[\text{GeV}] = 0.3\cdot B\,[\text{T}]\cdot R\,[\text{m}]$$



Conclusion:
-Optimize material effects (multiple scattering)
optimize amount of material along particle track (sensitive area (Si), support structure, cables..)

Multiple scattering angle

$$\theta_{rms} = \frac{13.6\mathrm{MeV}}{\beta c p}\sqrt{\frac{x}{X_0}}z[1 + 0.038\ln(x/X_0)],$$

1 % of X0 results in a scattering angle of rms = 0.25° for an electron with with a momentum of 1 GeV/c;
for a 300 MeV/c pion the scattering angle is 1°

According to another study, 50 MeV/c pions have a
standard deviation of scattering angles from their original trajectory by more than
2 degrees when passing a single layer of the Belle II Silicon Vertex Detector (SVD).
Whereas, for 1 GeV pions, this value is only 0.04 degrees i.e. 50 times smaller

Waleed Ahmed thesis "Material Budget Studies for the Belle II Detector"

Why it is important to keep low material budget for EIC detector and requirements:

- Compared to HEP, EIC is a low energy machine => with much lower momenta for charged particles
- Minimize multiple scattering for low-momenta charged particles in central detector
- Minimize unwanted photon conversion in front of calorimeter
- EIC HANDBOOK:

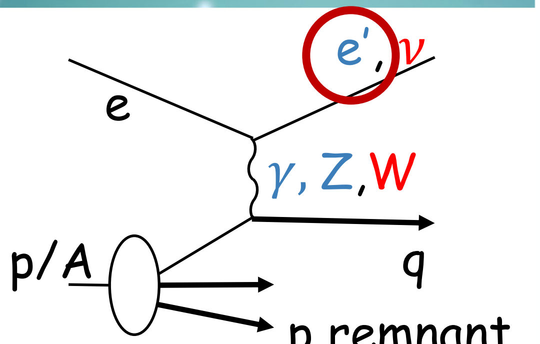
3.2 Detector Goals

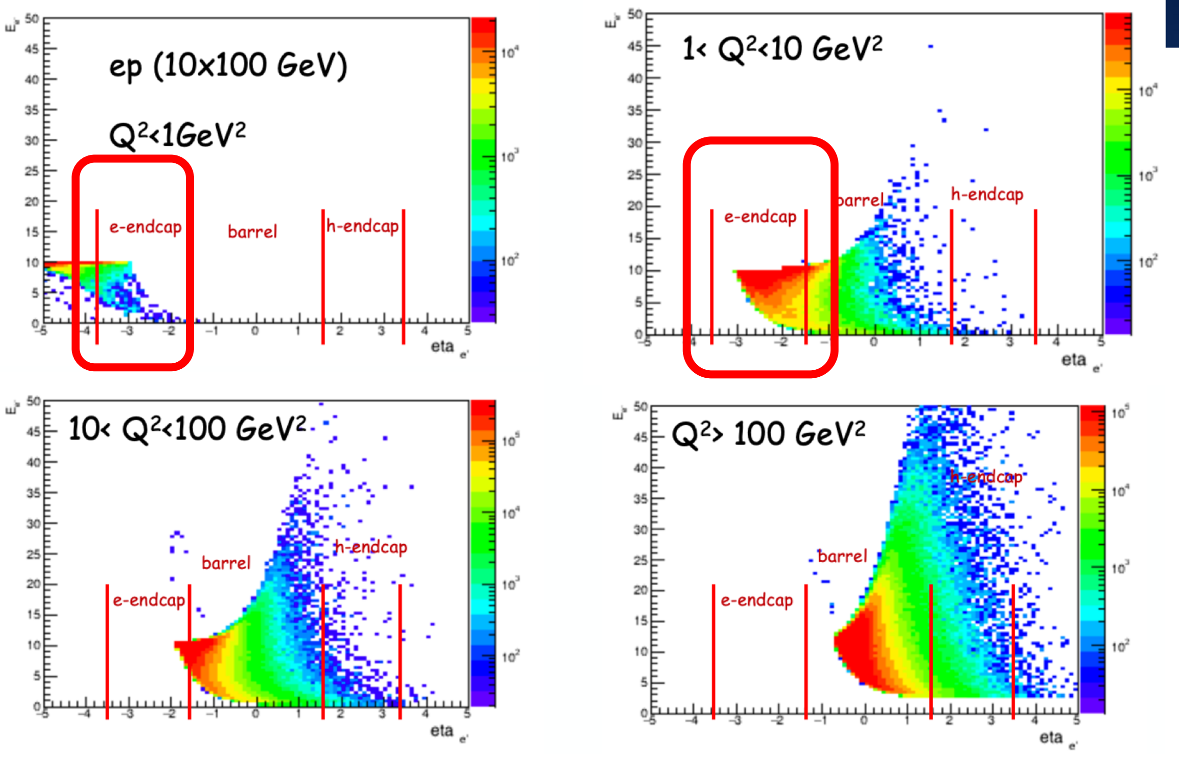
In the previous section we listed the requirements that can be derived from the key physics measurements at an EIC in terms of rapidity coverage, momentum reach, and electron, photon, and hadron identification. What evolves is a detector with the following key features:

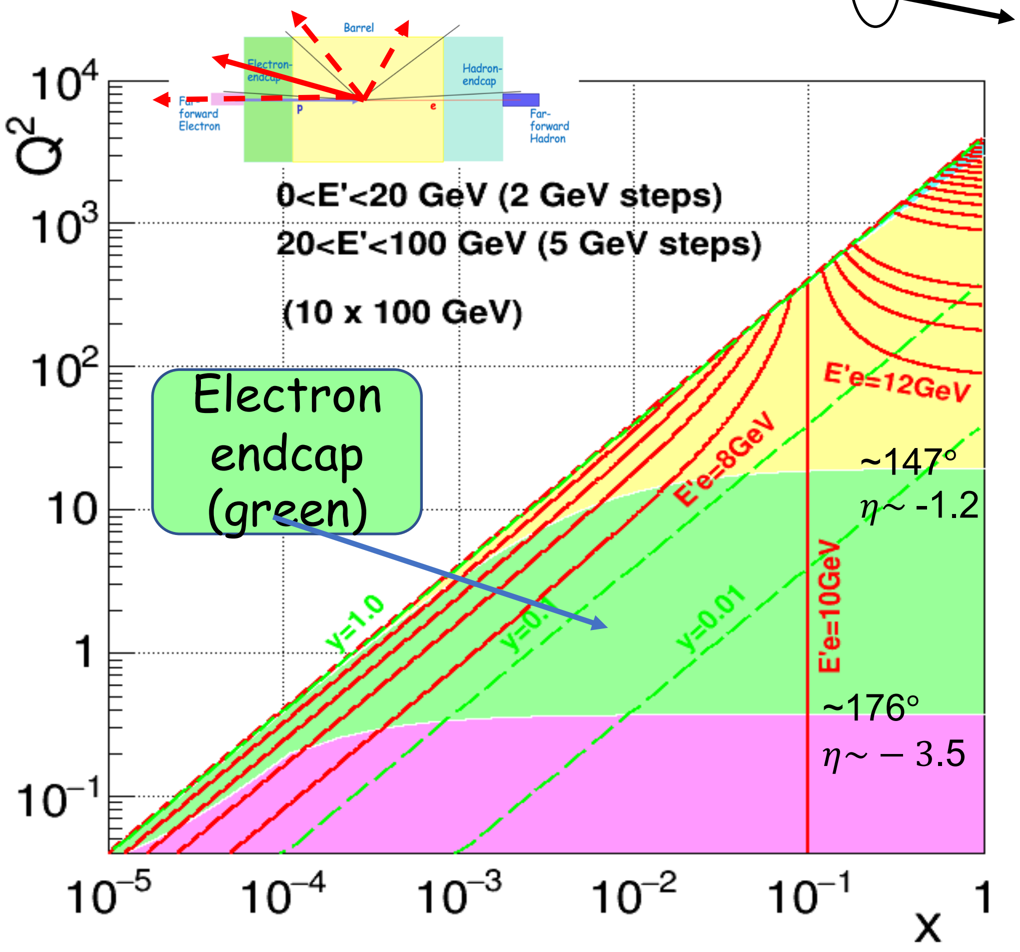
- Hermetic coverage, close to 4π acceptance (pseudo-rapidity range up to ±4)
- Low material budget on the level of 3-5% of X/X_0 for the central tracker region
- Tracking momentum resolution in few % range
- Reliable electron ID
- Good π/K/p separation in forward direction up to ~50 GeV/c
- High spatial resolution of primary vertex on the level of <20 microns

Electron-endcap

Electron Endcap







- Electrons mostly scatters to electron-endcap (green),
- Their energy/momentum are low (below initial e-beam energy)

- Precision measurements of the electron scattered angle => defines precision measurements of Q^2

$$Q^2_{\mathrm{EM}} = 2E_eE_{e'}\,(1+\cos\theta_{e'}),$$

$$y_{\mathrm{EM}} = 1 - \frac{E_{e'}}{2E_e}(1-\cos\theta_{e'}),$$

$$x = \frac{Q^2}{4E_eE_{\mathrm{ion}}}\,\frac{1}{y}$$

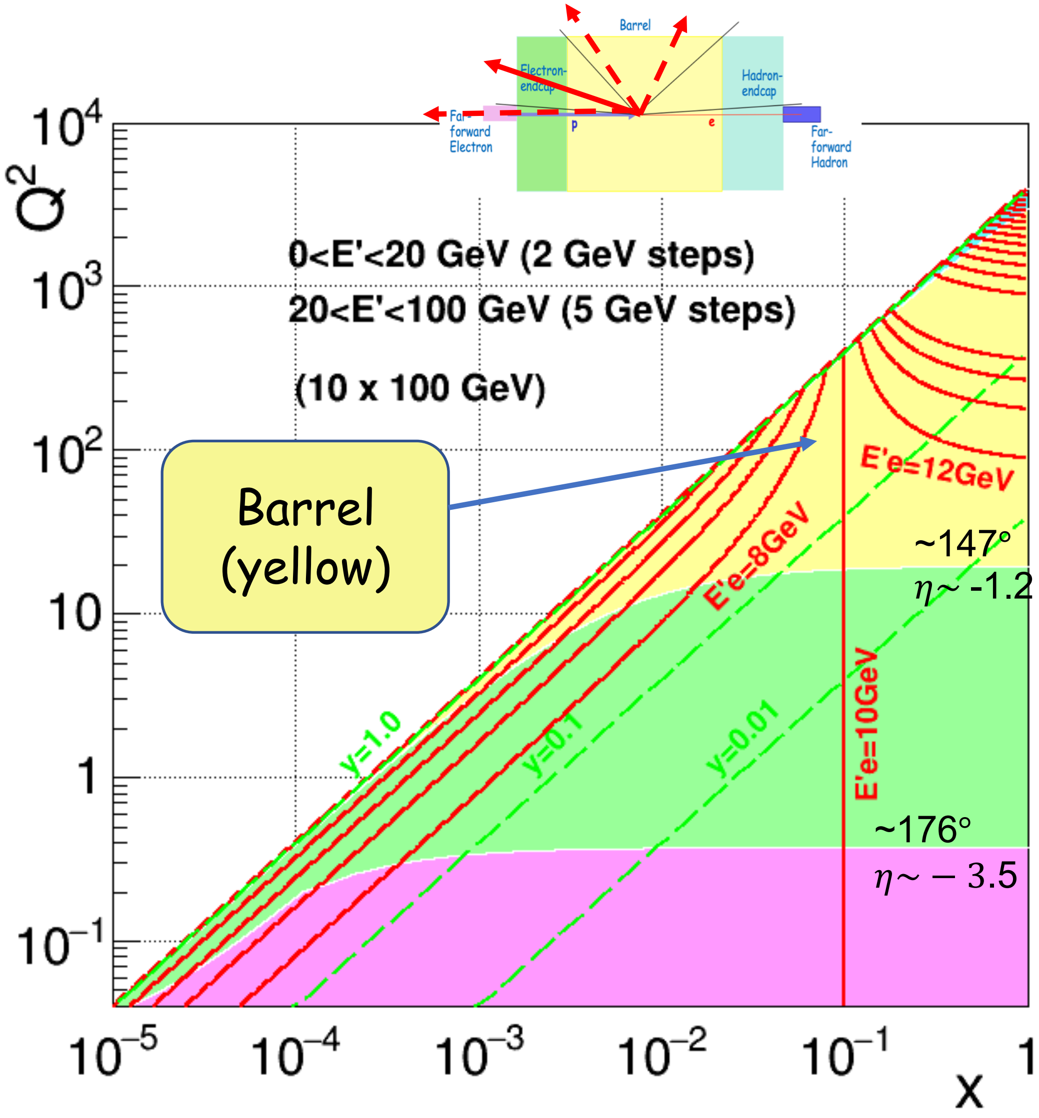
Scattered angle => Q^2

Electron Endcap

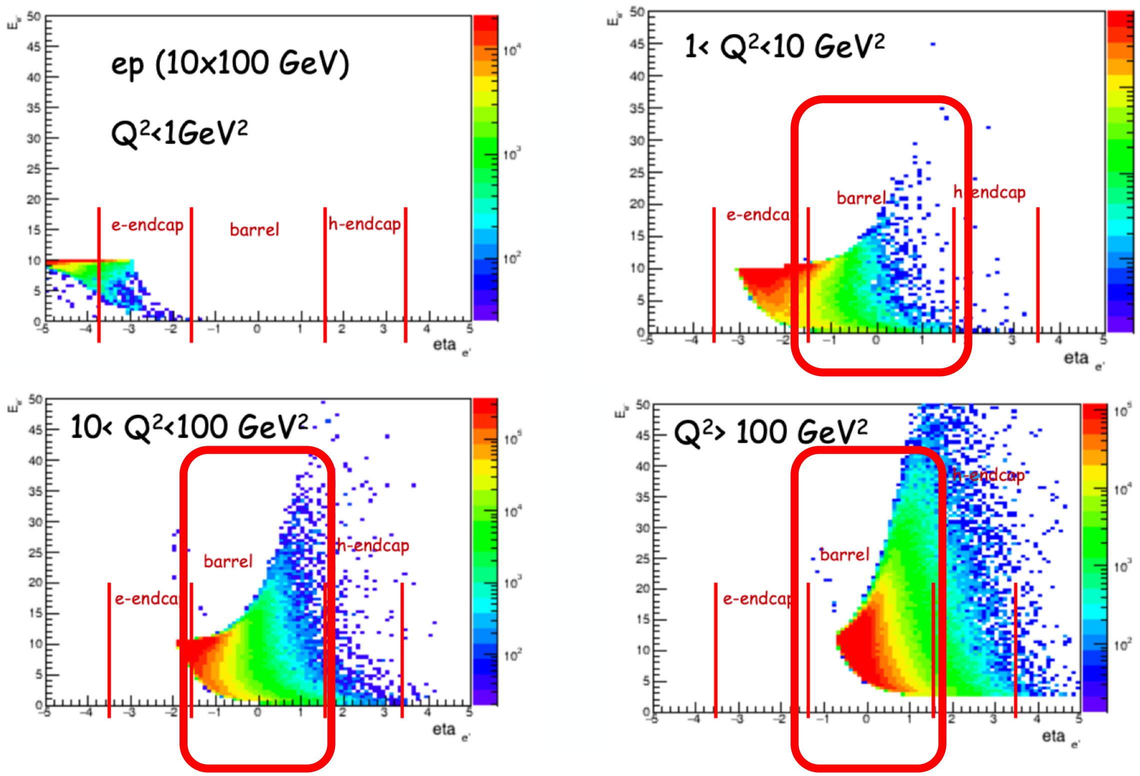
- Need to measure precisely angle (θ, φ) of the scattered electron (at vertex!)
- Directly related to the precision of the kinematic variables (theta_e) , especially for low electron beam energy operation (for example, 5GeV)
- Minimize multiple scattering for the precision measurements of the scattered electron (momentum and angle)

Barrel

Barrel



- Scattered electrons: from very low to very high (above initial beam energy) - depending on Q^2

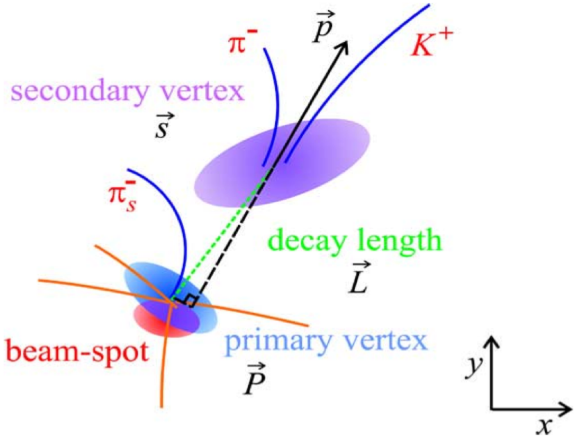


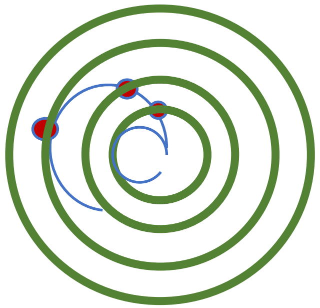
minimize multiple scattering for the precision measurements of the scattered electron / kinematics

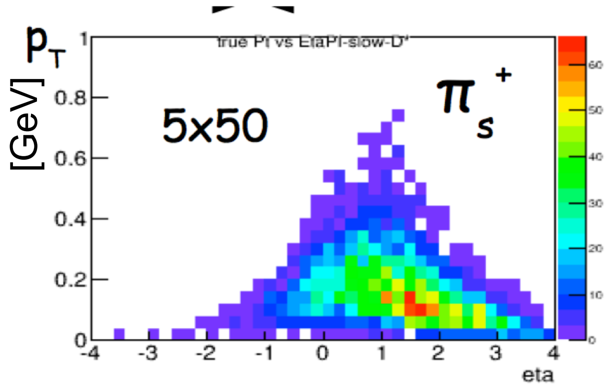
Scattered angle -> Q^2

Barrel

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





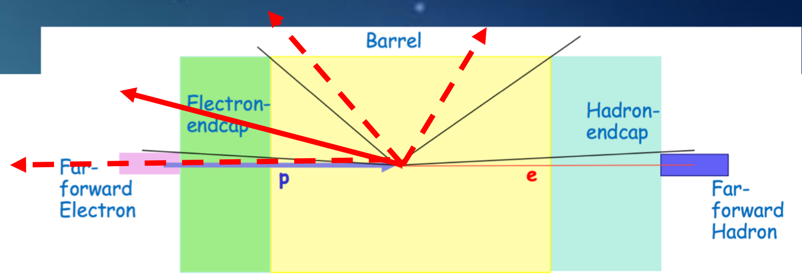


- Beampipe: Beryllium!
- First few layers of Vertex detector with minimum material (including sensitive area, support structure, cooling, cabling, readout, etc.
  => "Vertex detector are going towards 0.1-0.2% X_0 per layer"
  (EIC detector HANBOOK)
- "To protect sensitive detector from beam-induced background beampipe needs proper cooling and isolation, which increases both the material budget and the effective beam pipe radius"(EIC detector HANBOOK)

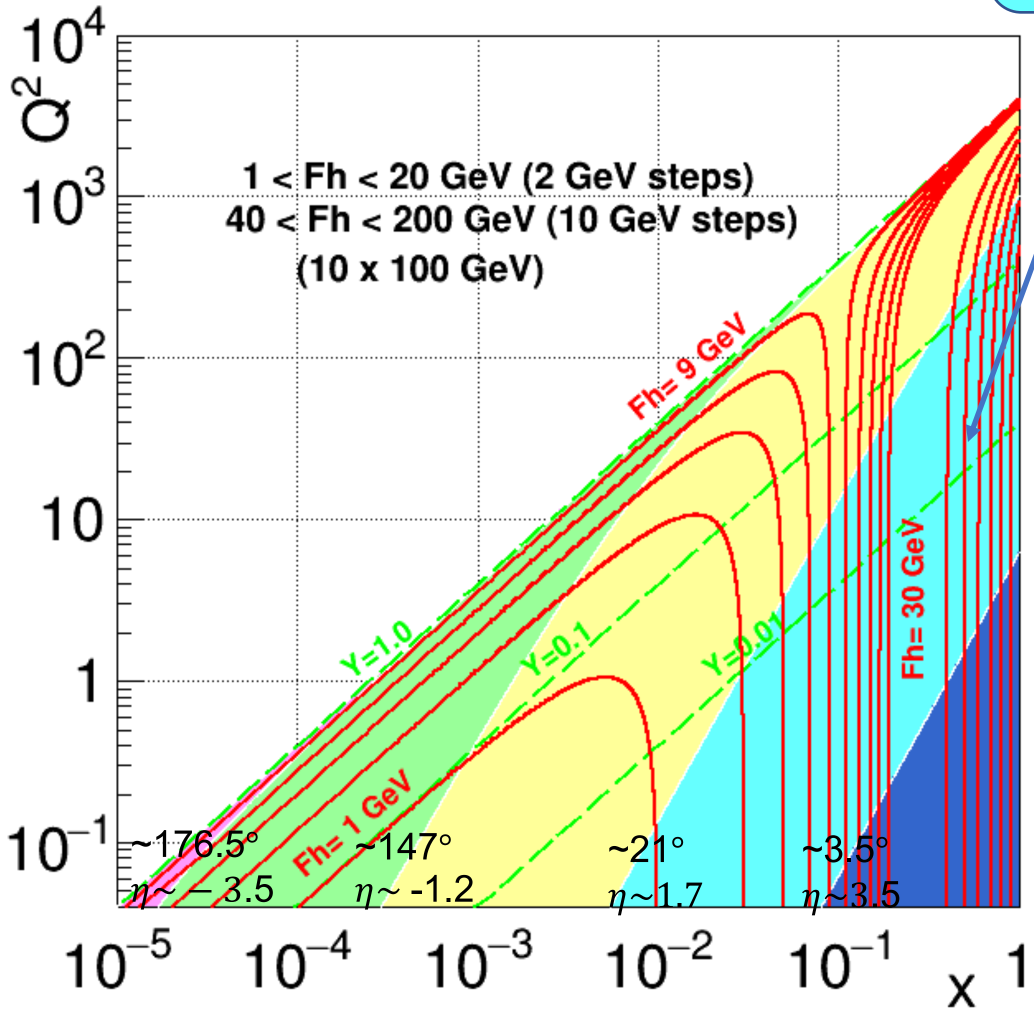
Need minimum material in the barrel, to minimize multiple scattering for low-pt particles
(invariant mass resolution)

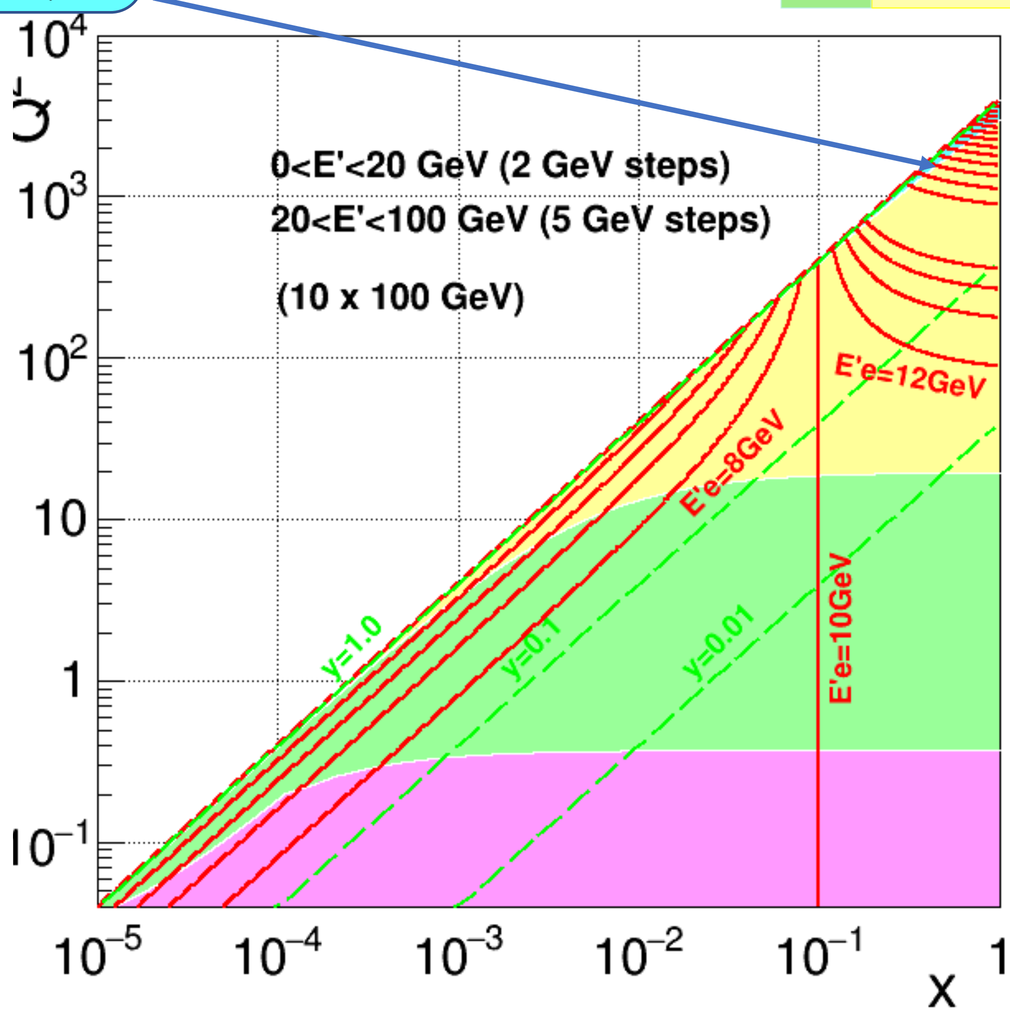
Hadron endcap

Hadron-endcap



Hadron endcap (blue)





Scattered electron's energy/momentum is very high…
hadrons/jets energies are high … but !

Hadron-endcap

But…. Due to the kinematic boost, most of the decay particles also goes into the hadron-endcap (decay products of J/PSI, Charm, etc…)

Their energy/momentum are not so high …. and a multiple scattering will effect an invariant mass resolution

Since we relay only on solenoid filed, and measure Pt, which is small … a multiple scattering will play a role for reconstruction of the total momenta.

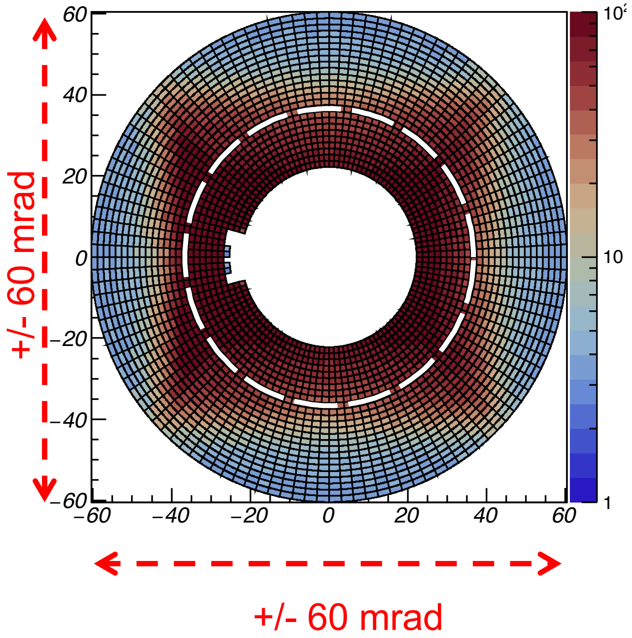
Preliminary estimates

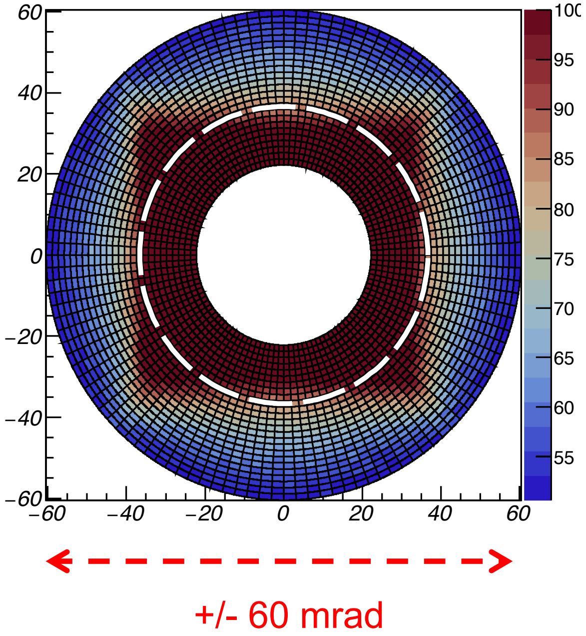
Beampipe, electron acceptance

A. Kiselev

Material in acceptance, [%]

First Si disk at this distance, [cm]

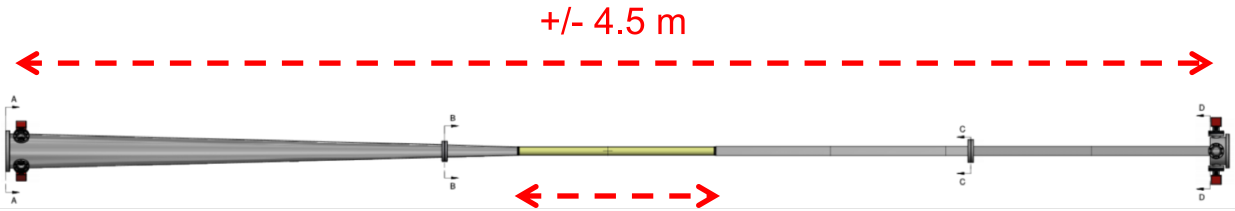




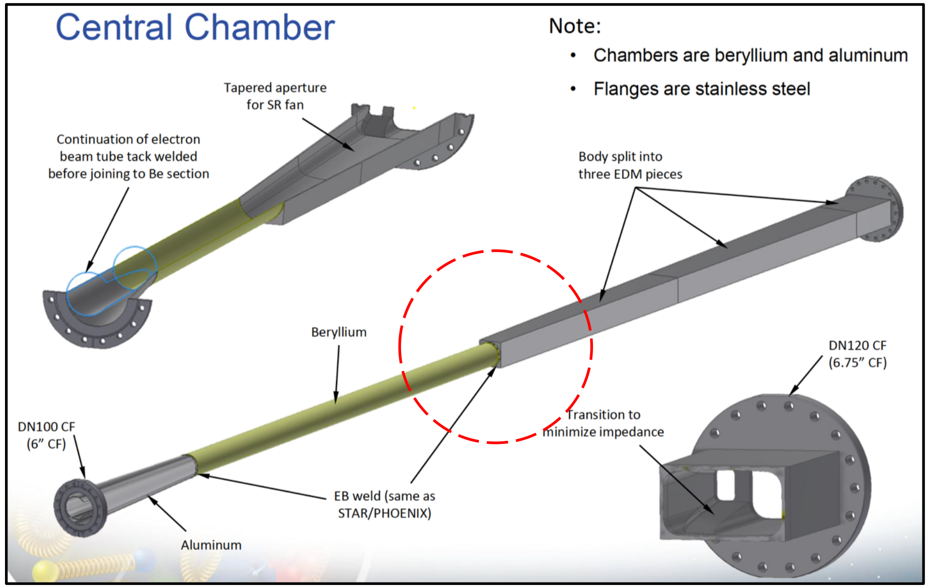
Central area (around IP) ok
Beryllium beampipe
Diameter 62.0 mm inner, 63.5 mm outer
Later: water cooling

Cones & rectangles: Al (needs improvement)

Plots: -4.5 < η < -3.5 band; white circle: η = -4.0

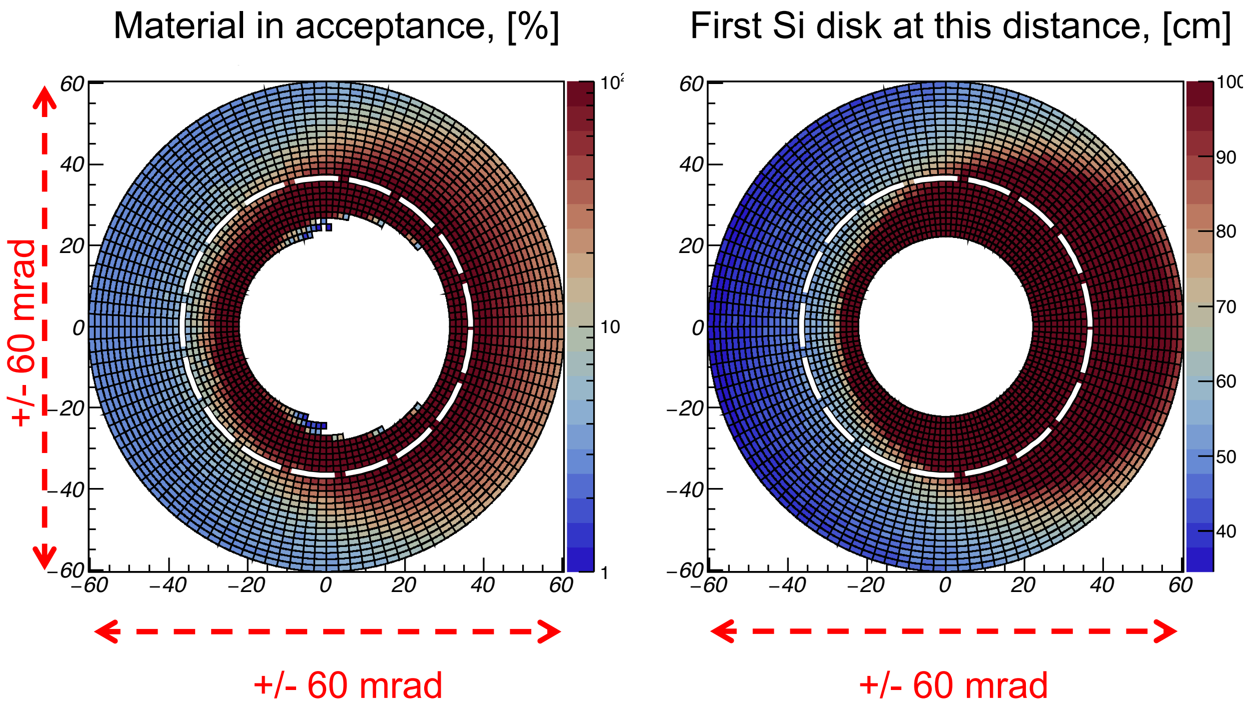


Side view



Beampipe, hadron acceptance

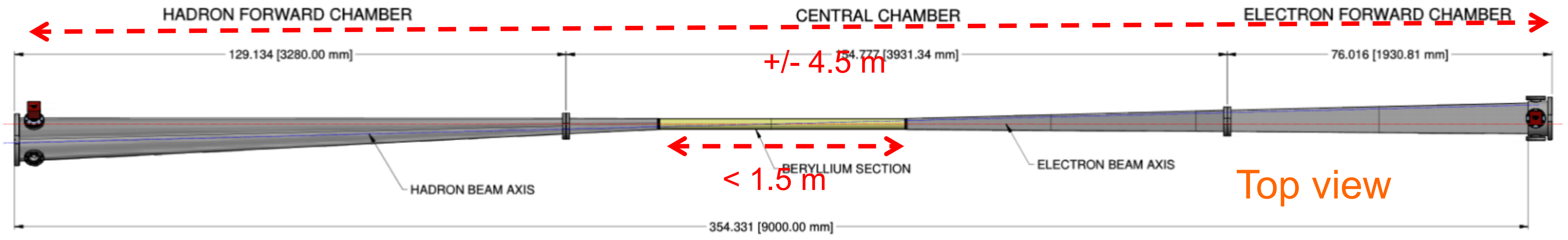
A. Kiselev



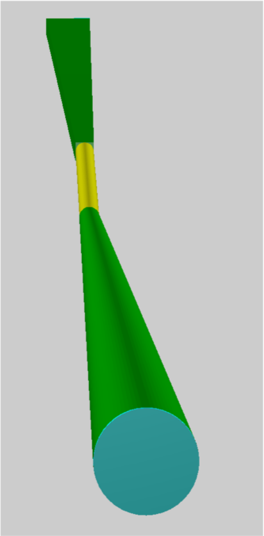
Central area (around IP) ok
Beryllium beampipe
Diameter 62.0 mm inner, 63.5 mm outer
Later: water cooling

H-pipe cone: Al (needs improvement)

Plots: 3.5 < η < 4.5 band; white circle: η = 4.0



ROOT TGeo model used for the scans



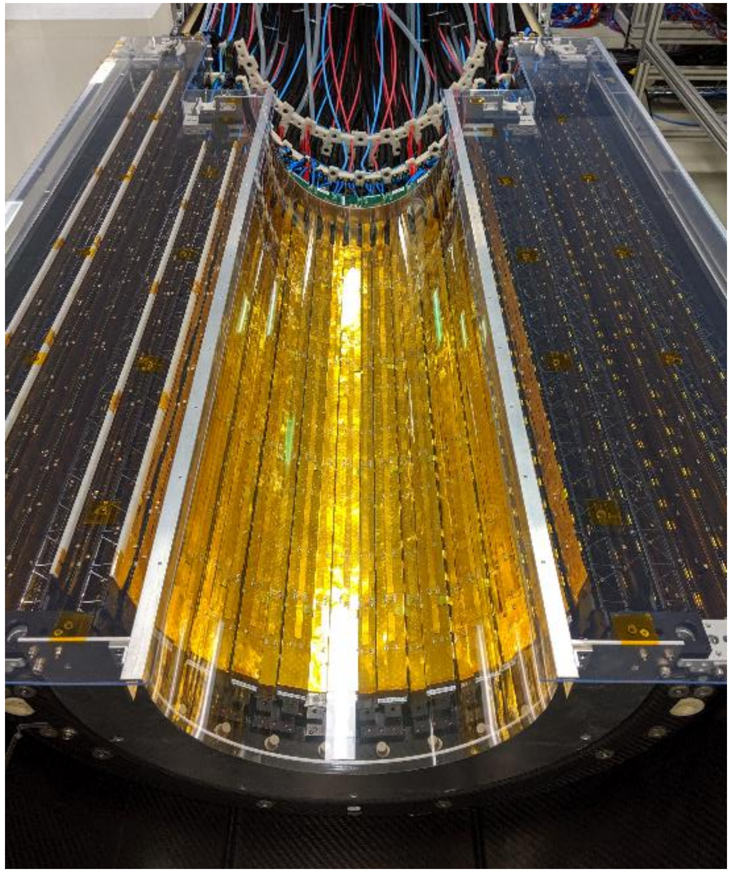
What to expect for radiation lengths for EIC structures - Current SOTA

Leo Greiner
(see next talk)

ITS2 Vertexing: ALICE ITS layers 0-2
0.3% per layer

- 50 um thick silicon
- Water cooled
- Aluminum conductor data/power flex-PCBs

ITS2 Barrel: ALICE ITS layers 3-6
~1.1% per layer



What to expect for radiation lengths for EIC structures - Discs

Leo Greiner
(see next talk)

Using existing ALPIDE based ITS inner barrel staves as reference

Discs up to ~60 cm diameter can be composed of existing ITS inner layer designs and can be expected to have approximately the same radiation length including overlap.

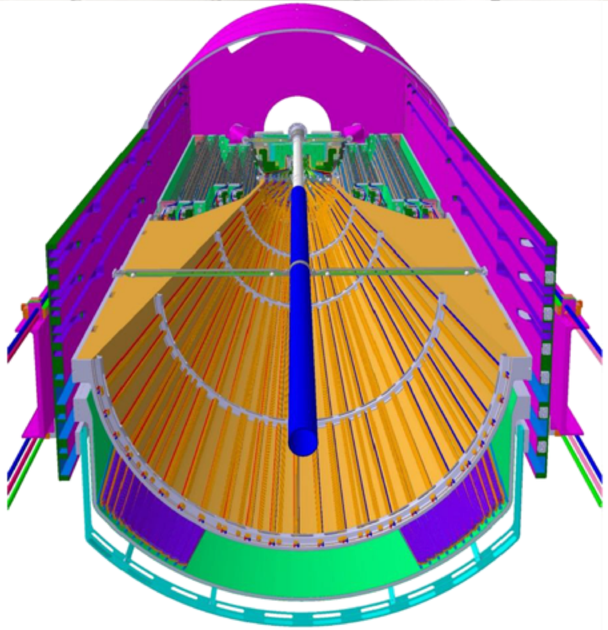
Discs larger than 60 cm diameter

- In this case one may expect that the voltage drops will start to become more significant over the length of the stave and will need correspondingly larger thickness of the Aluminum power distribution layer.
- Assume that we need to increase conductor thickness by 30% for every 10 cm increase in length. (we can also assume that the mass required to keep stave stable increases at the same rate)
- Services come from both sides of the disc and are still consistent with requirements/cm^2

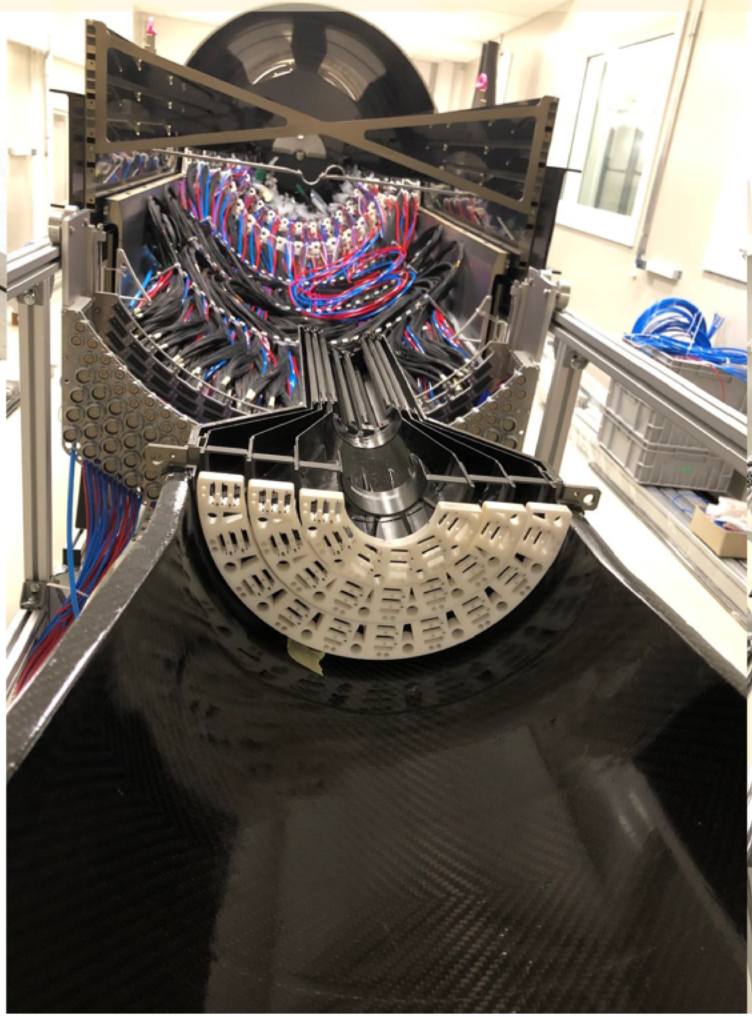
Discs at 80 cm diameter => 0.4% radiation length
Discs at 100 cm diameter => 0.5% radiation length
etc.

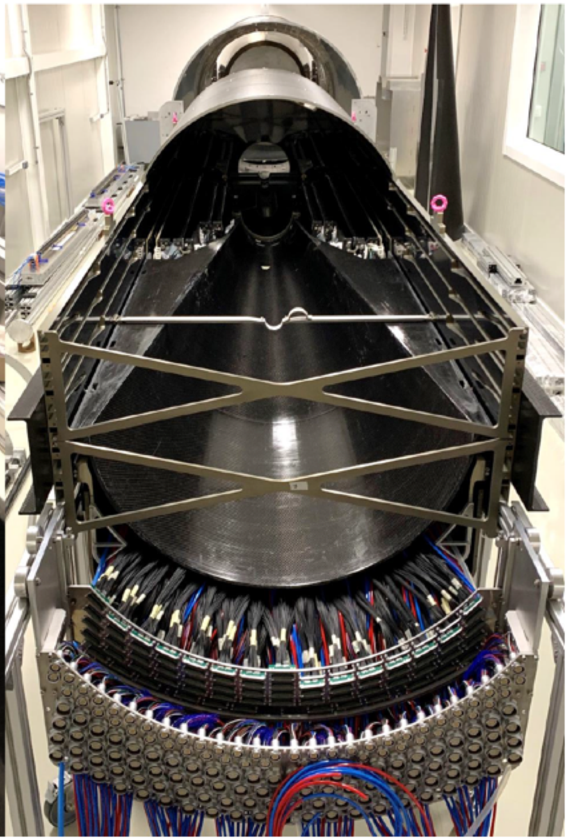
Leo Greiner
(see next talk)

ITS IB Half-Barrel Bottom H-barrel final dummy stave-rod **dry insertion in the Cage**



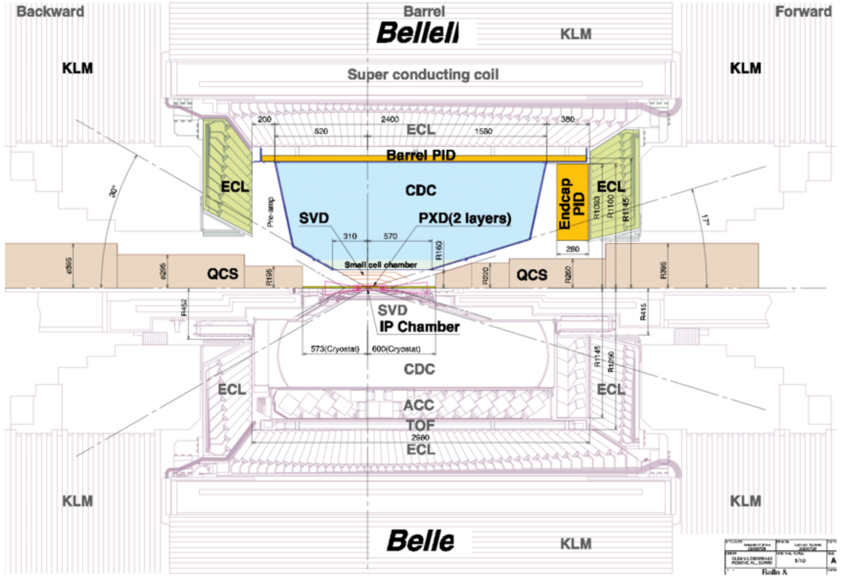
Corrado Gargiulo



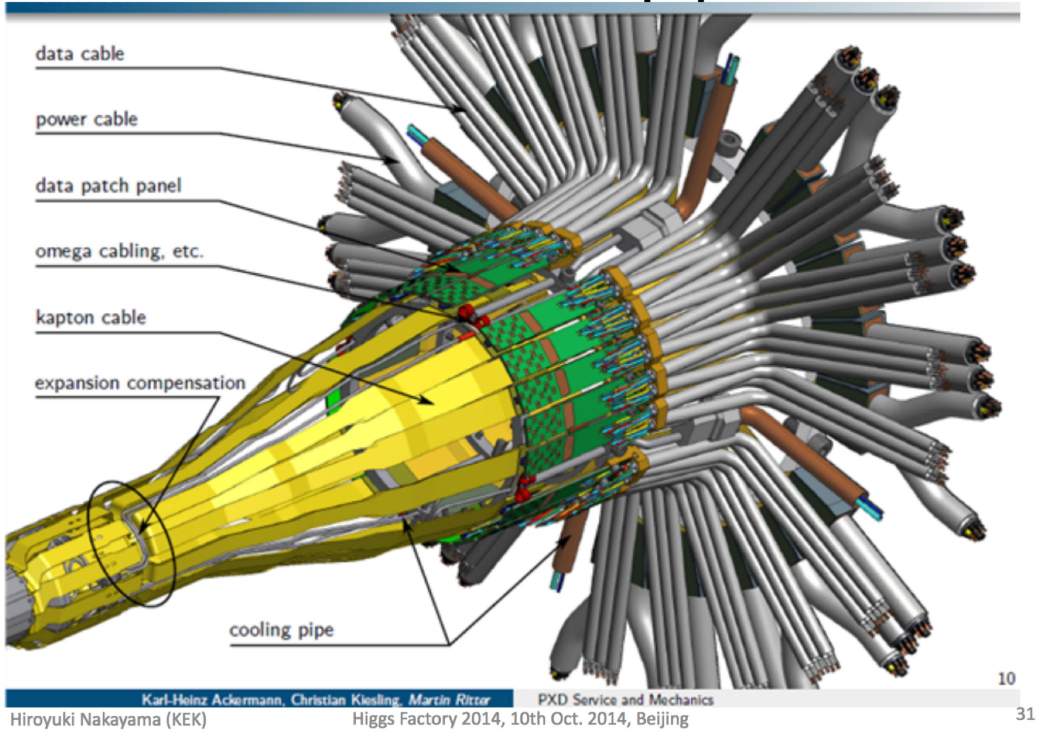


Belle-II PXD

Cables, pipes, support structures for vertex detector
Relatively symmetric accelerator energy design, mosty measure at central rapidity.



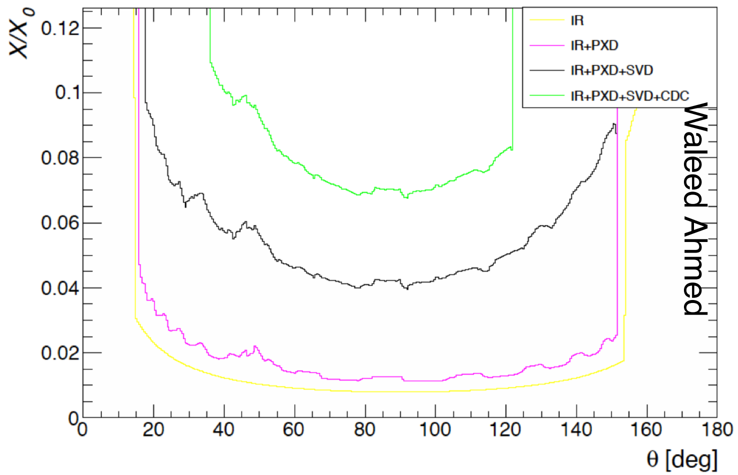
PXD cables & pipes



2 layers PXD ~ 0.2 % X_0!!!

	Material in this study $[X/X_0]$	Material in previous study$[X/X_0]$ [9]
IR	0.01	0.008
IR+PXD	0.0125	0.01
IR+PXD+SVD	0.045	0.045
IR+PXD+SVD+CDC	0.07	0.07

Table 6.1 – Comparison of inner detector material between this study and the previous one in [9].



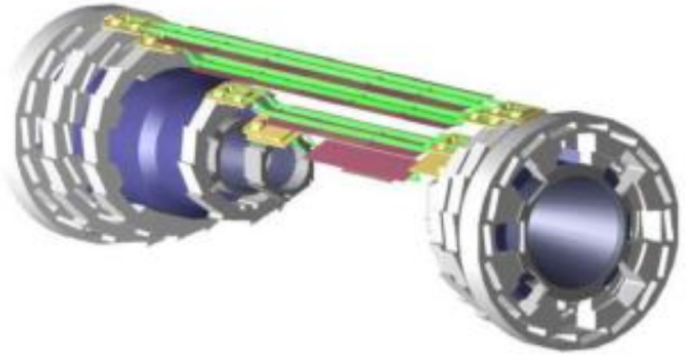


Figure 6.2 – Global view of inner detectors release-08. This plot represents the same information as the previous one but for the new release.

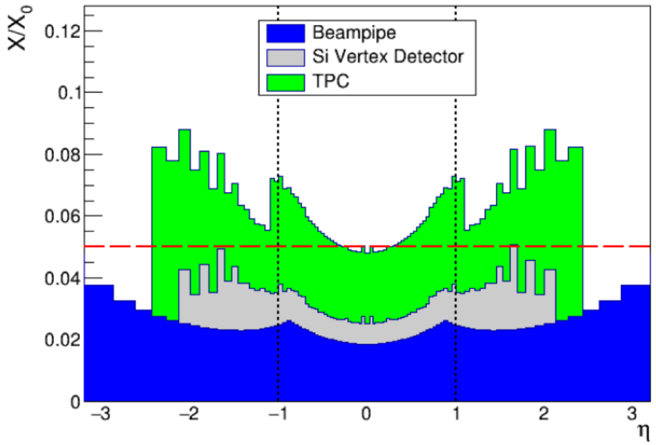
Tracking

Qinhua Huang for CEA Saclay'sEIC group

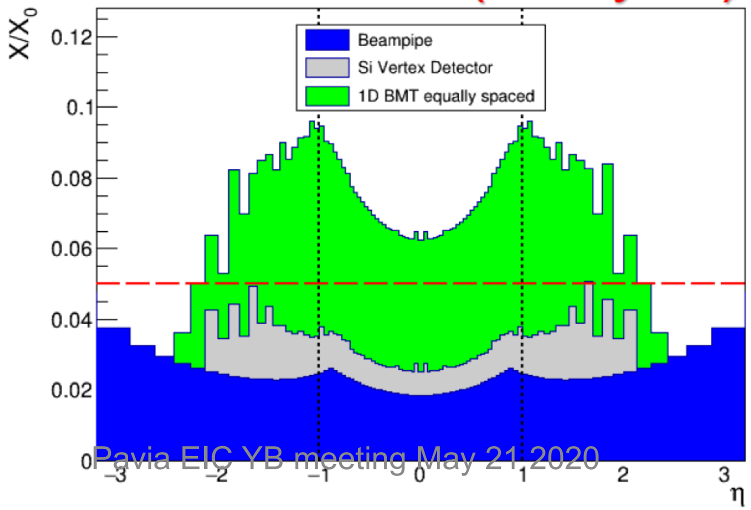
Material budget

- Material scan for TPC, 1D and 2D readout MPGD trackers
- N.B. Handbook requires a X/X0<5% for central tracker
- 2D readout can achieve this goal

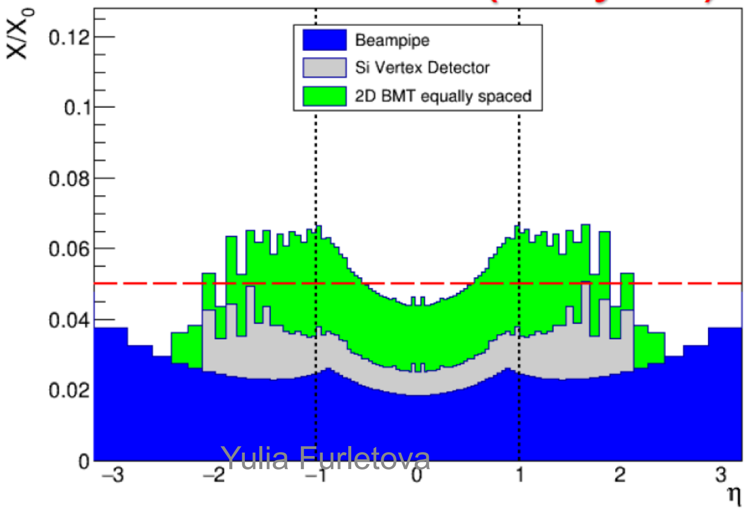
TPC



MPGD 1D RO (12 layers)



MPGD 2D RO (6 layers)

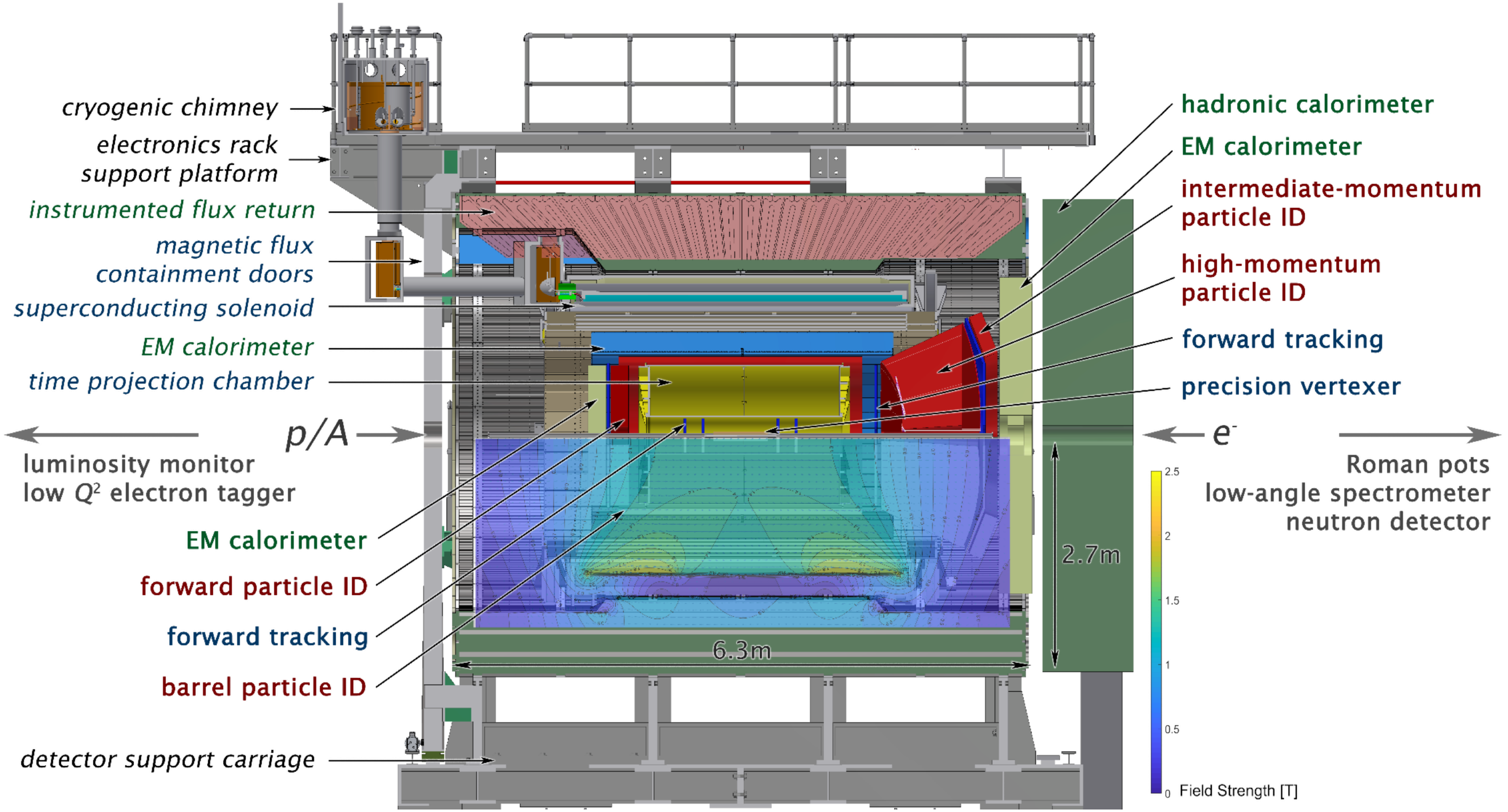


3

One detector model used in this study

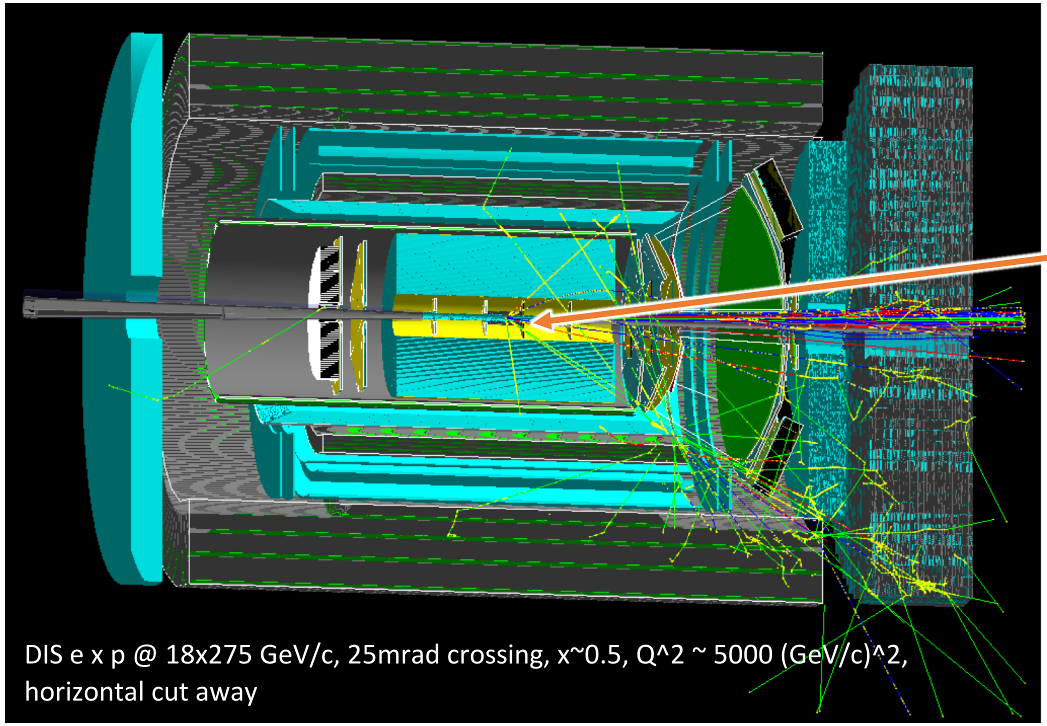
Jin Huang

2014 concept: arXiv:1402.1209 [nucl-ex], 2018 update: sPH-cQCD-2018-001



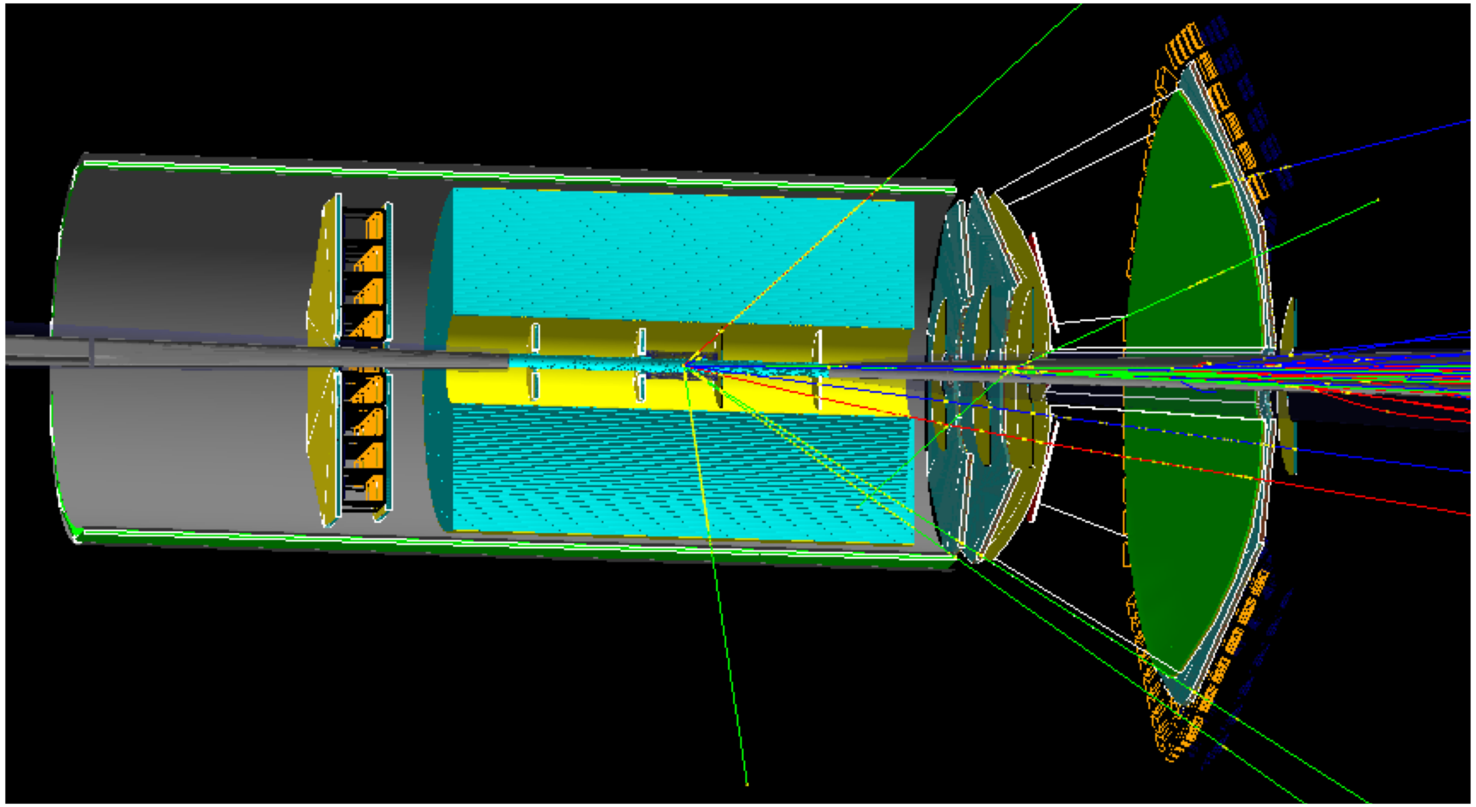
The detector model in simulation

- Geant4-Material scan in simulation in Fun4All
- https://github.com/eic/Singularity



Only tracker + PID are scanned

Reproduce: https://github.com/blackcathj/macros/tree/display-EIC-BeamPipe-materialscan/macros/g4simulations

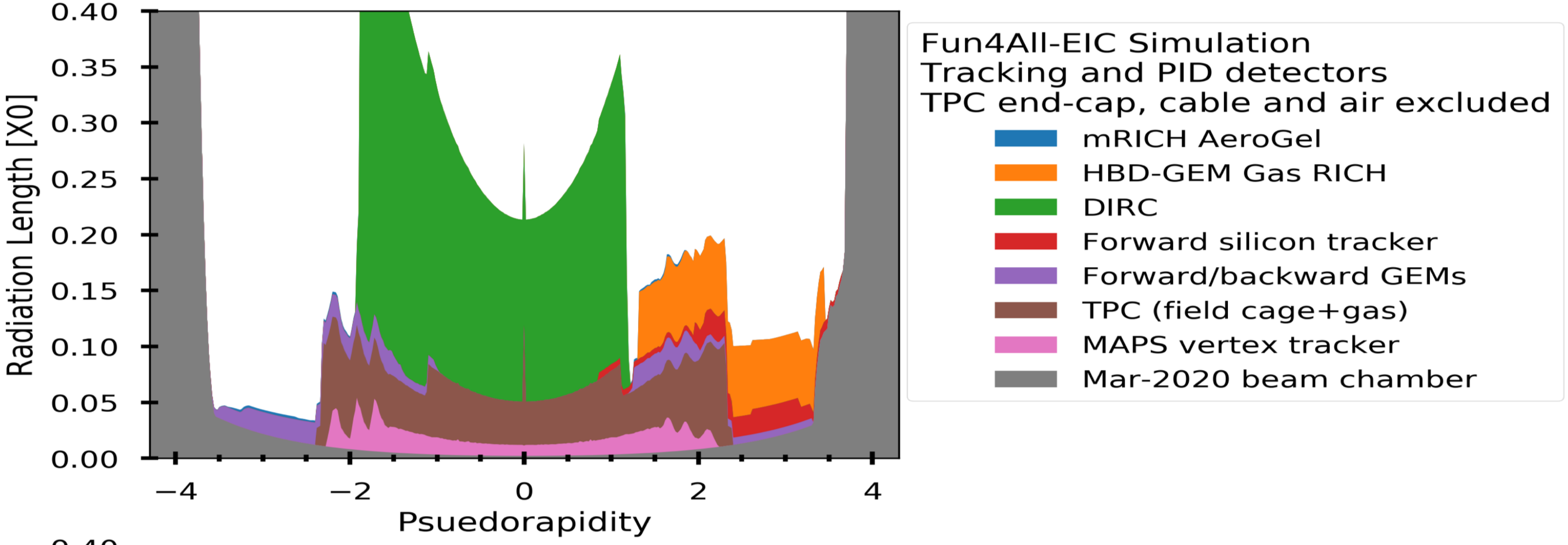


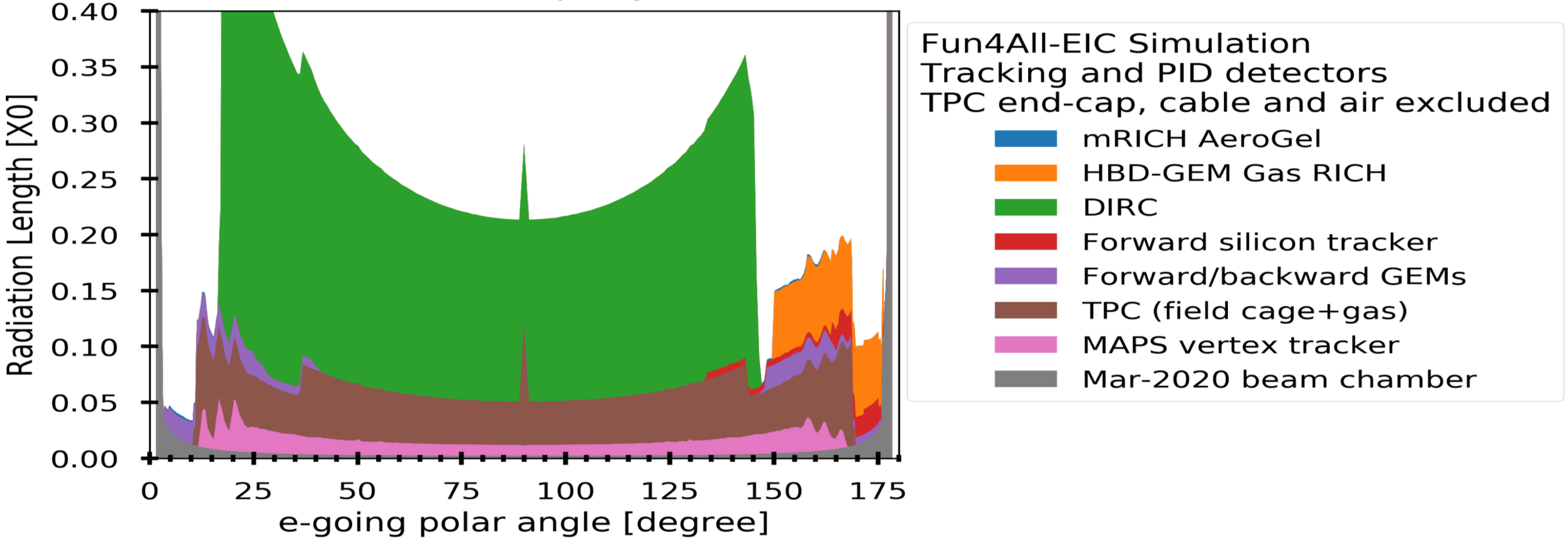
- TPC end-cap not include (15% X0 Al?). Hope can be thinned with carbon fiber
- mRICH support not included
- All off-active area cabling not included. To be implemented from Leo
- Air disabled (0.3% X0 per meter)

Yulia Furletova

Results

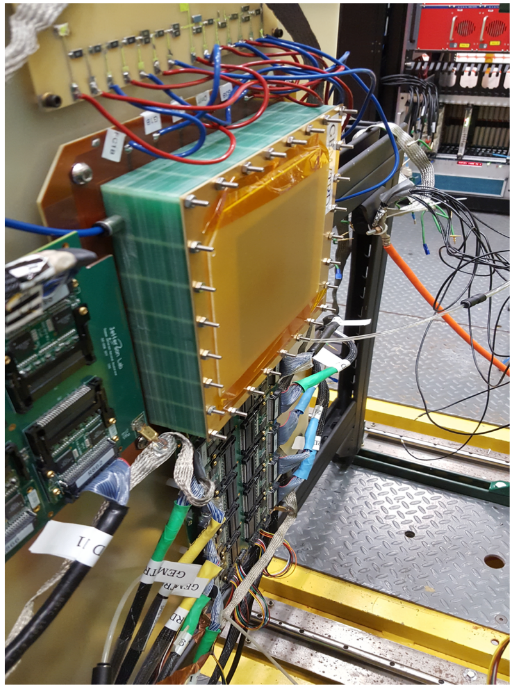
Reproduce: https://github.com/blackcathj/macros/tree/display-EIC-BeamPipe-materialscan/macros/g4simulations

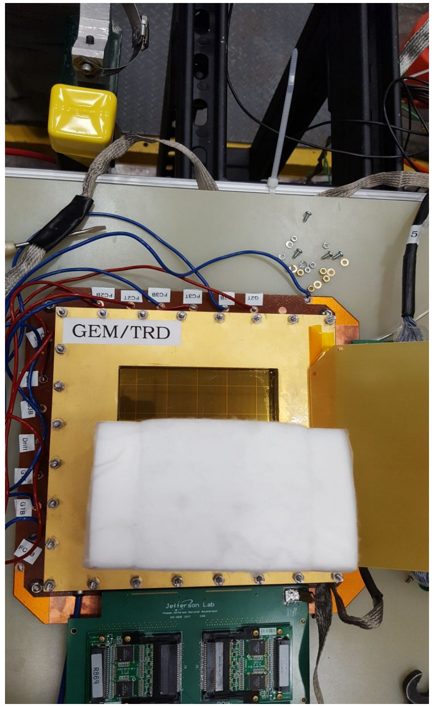




GEMTRD (e/π separation)

Single module (X/X0) :
Radiator (10cm) ~ 1.5 % X_0 (for fleece, could go down with mylar foils)
Xenon gas (2.0 cm) ~ 0.1% X_0
Triple GEM with readout at active area ~ 0.7% X_0
(could go down to 0.4%, current eRD6)

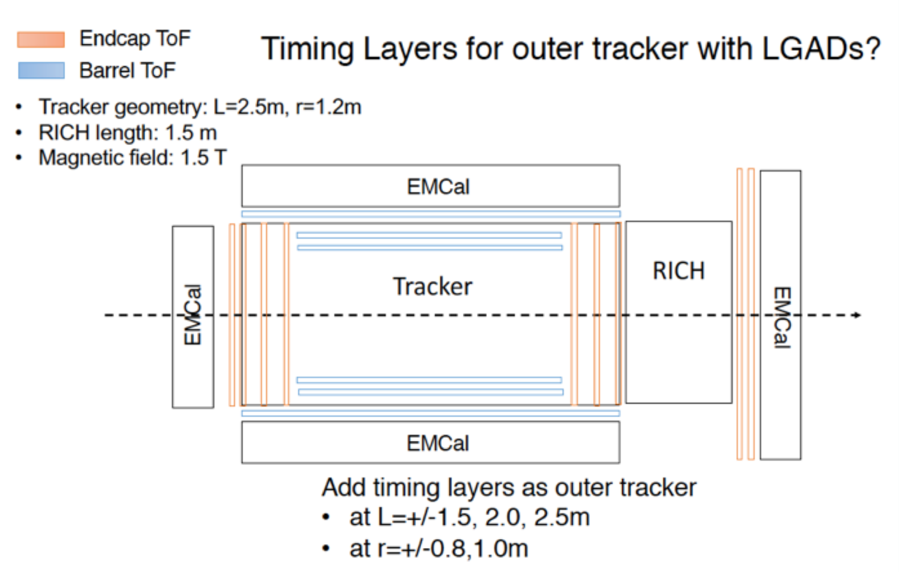




PID

Thomas Hemmick

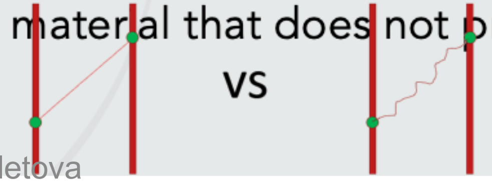
PID detectors (DIRC, mRICH, dRICH) relay on precise momentum and angular resolutions from tracker at the entry and exit point of a PID detector, and require " very low material budget between the interaction point and the calorimeters" (EIC detector HANDBOOK.



- **Several technologies reviewed, no one chosen yet**
- AC-LGADs could provide a very good tracking layer (~100 um) + timing (20 ps)
- External start time provided by forward detectors could be helpful
- Study of Self-timing (Internal) using tracks

TOF needs a measurement of p and L

- As δt→5 ps, requires precision path length L (c*δt~1.5 mm…tracking must exceed this.)
- Multiple scattering might be the biggest worry, need to ensure low material budget and/or enough tracking layers to catch scattering.
- Depends partly upon the material that does not provide position measurement:



Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

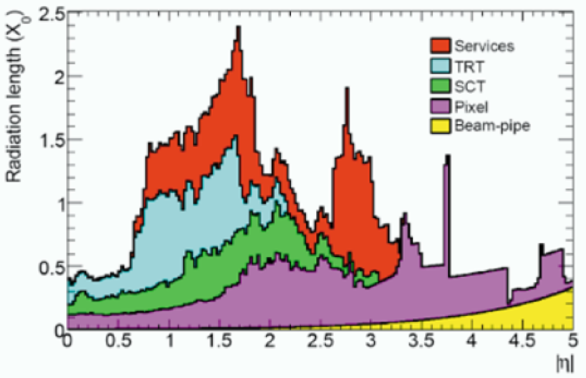
JSA

CMS/ATLAS comparison

Material Budget

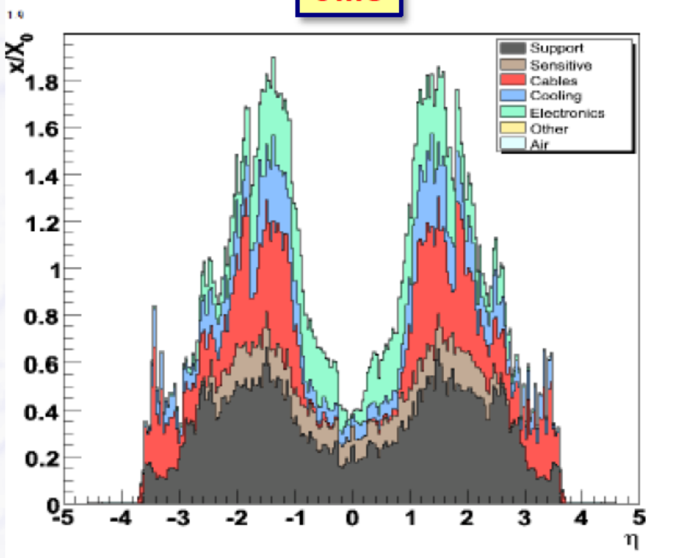
- **Tracking Detectors should be light -weighted and thin**
  - multiple scattering by material degrades resolution at low momenta
  - unwanted photon conversions in front of calorimeters
  - material often very inhomogeneous (in particular Si detectors)
- **Power & cooling adds most of the material**
  - not the Si sensor material

ATLAS



$\|\eta\|$	radiation length	interaction length
< 1	$\sim 0.2\,X_0$	$\sim 0.05\,\lambda$
< 3.3	$\lesssim 0.5\,X_0$	$\lesssim 0.2\,\lambda$

CMS



Detectors – an Introduction *Michael Hauschild - CERN, page 28*

Conclusion/plans/to-do list

- We need to minimize amount of material at all directions!
- Important for low-momenta particles
- Minimize unwanted photon conversion in front of calorimeter

- Need to keep in mind an asymmetric beam energy setting at EIC (example, 5x100 GeV)

- For each detector (subdetector) setup/configuration we need to make a connection how it would affect physics (Q2, inv mass, etc) , and find a way how to minimize amount of material.

- Include support structures
- Include cooling
- Include HV, low voltage cabling ….
- Include readout cabling (or maybe wireless ??) ;-)
- Etc.

next contribution talks :
Matt Posik -> eRD6
Leo Greiner -> Silicon

Backup

eRD6

Matt Posik

Tracking

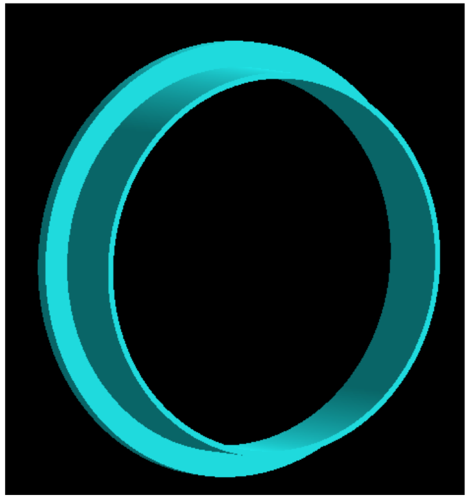
Matt Posik for eRD6

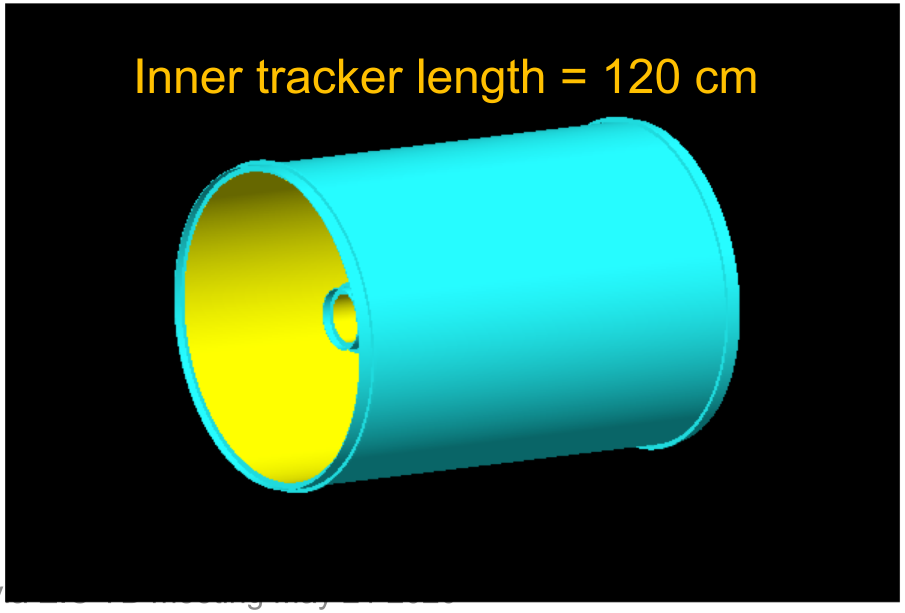
- ❑ Support Ring Structure Geometry
  - o Tube: thickness = 0.5 cm, length = 7.2 cm
  - o Ring (inner): thickness = 1.6 cm, length = 1.2 cm
  - o Ring (outer): thickness = 0.5 cm, length = 1.2 cm

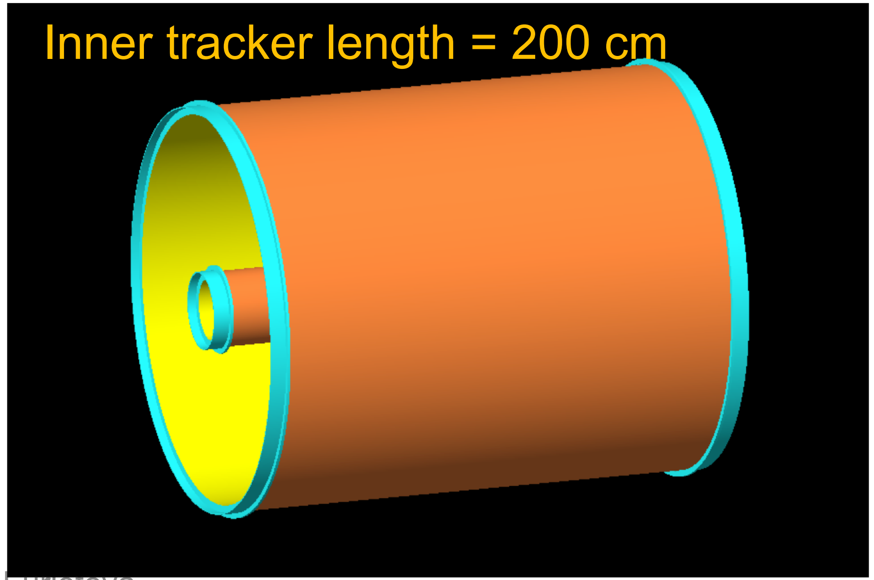
- ❑ Material Scan
  - o 2 micro-Rwell cylinders
    - • Inner det. radius = 12.5 cm (length = 120 cm)
    - • Outer det radius = 80.0 cm (length = 200 cm)

FIT mock prototype (support ring)

Simulation implementation







Tracking

Matt Posik for eRD6

- Next Steps Implement
  - supports every ~ 50 cm
  - Readout card material
  - endcap