Tracking Studies using Fast Simulation and DD4HEP

Shyam Kumar, Annalisa Mastroserio, Domenico Elia, Giacomo Volpe
University and INFN Bari, Italy

Mini-TPC Parameters

1. Configuration with and without TPC (Provided configuration)

2. Magnetic field used is 1.4 tesla.

3. Inner cage and Outer cage material budget.

Ref: // https://pdg.lbl.gov/2005/AtomicNuclearProperties/substances/kapton.html

// Case of P10 gas: (Total 1% as suggested)

Float_t radLInnerCage = 0.005; // 0.5%

Float_t radLOuterCage = 0.005; // 0.5%

Float_t radLPerRow = 0.1/(13289.4);

// P10 = 13289.4; Ne = 3.450E+04

// Case of Ne gas Kepton (1 mm) thickness

Float_t radLInnerCage = 0.0035001750; // Kapton radiation length = 28.57 cm

Float_t radLOuterCage = 0.0035001750; // Kapton radiation length = 28.57 cm

Float_t radLPerRow = 0.1/(3.450e+04); // P10 = 13289.4; Ne = 3.450E+04

4. Other specifications:

Float_t tpcRadialPitch = 0.1 ; // cm

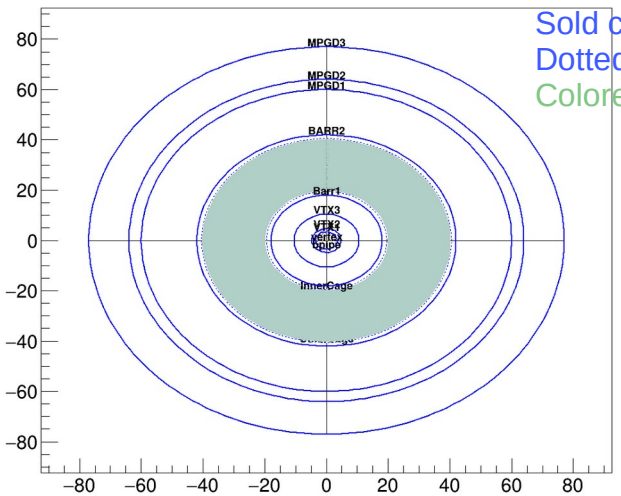
Float_t tpcRows = 200 ; **// 200 points in TPC**

Float_t rowOneRadius = 20.1; // cm

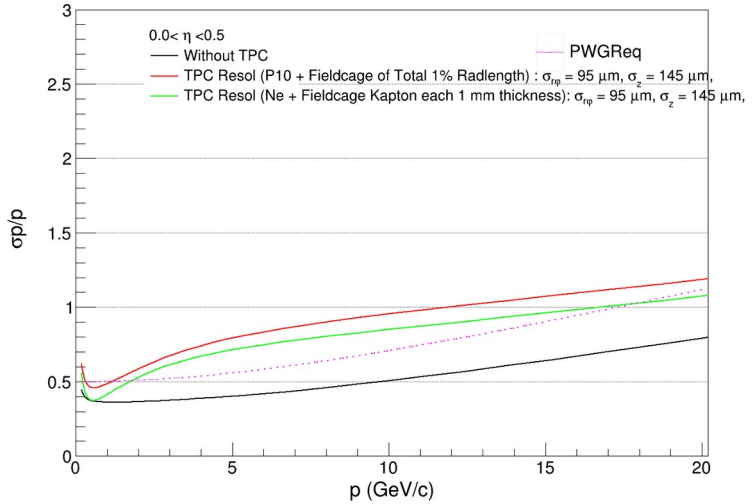
TPC Performance

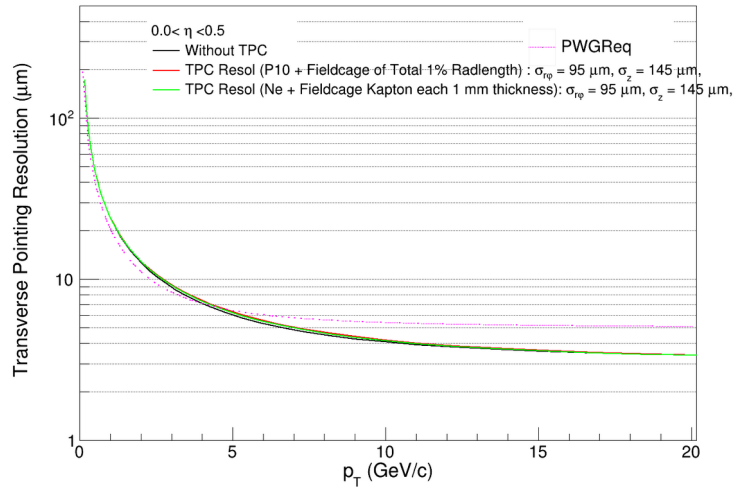
Configuration with Mini-TPC (radius: 20-40 cm)

Name	r [cm]	X0	phi & z res [um]		layerEff
0. vertex	0.00	0.0000	-	-	-
1. bpipe	3.10	0.0022	-	-	-
2. VTX1	3.60	0.0005	3	3	1.00
3. VTX2	4.80	0.0005	3	3	1.00
4. VTX3	10.50	0.0005	3	3	1.00
5. Barr1	18.00	0.0005	3	3	1.00
6. InnerCage	19.50	0.0035	-	-	-
7. tpc_0	20.10	0.0000	95	145	1.00
207. OuterCage	40.50	0.0035	-	-	-
208. BARR2	42.00	0.0055	3	3	1.00
209. MPGD1	60.00	0.0026	55	55	1.00
210. MPGD2	64.00	0.0026	55	55	1.00
211. MPGD3	77.00	0.0026	55	55	1.00



Sold curve: Active layers
Dotted curve: Passive layers
Colored region: Active TPC





Mini-TPC can provide large number of points but degrades momentum resolution as expected

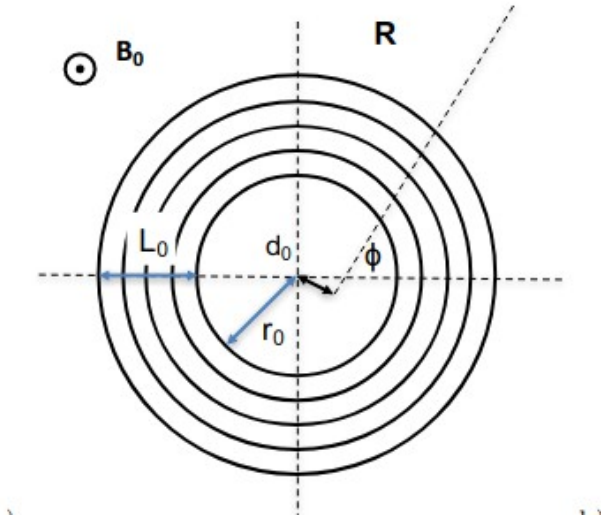
Momentum Resolution

Zbynek Drasal, Werner Riegler

arXiv:1805.12014

Tracking Performances: Momentum and DCA resolutions

Momentum Resolution:affects width of invariant mass peak



p_T resolution:

$$\frac{\Delta p_T}{p_T}\Big|_{res.} = \frac{\sigma_{r\phi}\, p_T}{0.3\, B_0 L_0^2}\sqrt{\frac{720N^3}{(N-1)(N+1)(N+2)(N+3)}} \quad \text{Linear term}$$

$$\approx \frac{12\,\sigma_{r\phi}\, p_T}{0.3\, B_0 L_0^2}\sqrt{\frac{5}{N+5}}$$

$$\frac{\Delta p_T}{p_T}\Big|_{m.s.} = \frac{N}{\sqrt{(N+1)(N-1)}}\,\frac{0.0136\,\mathrm{GeV/c}}{0.3\beta\, B_0 L_0}\sqrt{\frac{d_{tot}}{X_0\,\sin\theta}}\left(1+0.038\ln\frac{d}{X_0\,\sin\theta}\right)$$

Constant term (at β<1 increase)

Based on Gluckstern Approach (equal distance between planes and equal spatial resolutions)

https://indico.bnl.gov/event/16352/contributions/65463/attachments/42152/70572/EIC_Detector1_Tracking_Shyam.pdf

SR (Spatial Resolution): Uncertainity associated with finite size of pixels

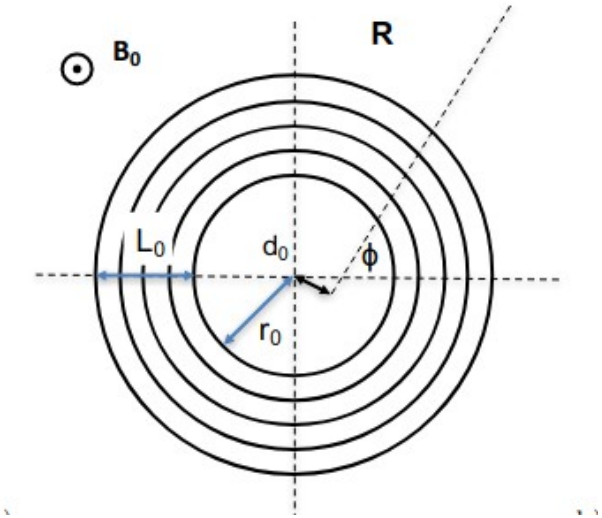
MS (Multiple Scattering): Uncertainity associated with thickness of Material

$$\frac{\sigma_{pT}}{p_T} = \sqrt{\left(\frac{\sigma_{pT_{SR}}}{p_T}\right)^2 + \left(\frac{\sigma_{pT_{MS}}}{p_T}\right)^2}$$

DCA_{xy} Resolution

Zbynek Drasal, Werner Riegler

arXiv:1805.12014



DCA Resolution: Reconstruction of secondaries

DCA_{xy} resolution:

$$\Delta d_0|_{res.} \approx \frac{3\sigma_{r\phi}}{\sqrt{N+5}}\sqrt{1+\frac{8r_0}{L_0}+\frac{28r_0^2}{L_0^2}+\frac{40r_0^3}{L_0^3}+\frac{20r_0^4}{L_0^4}}$$

$$\Delta d_0|_{m.s.} \approx \frac{0.0136\,\mathrm{GeV/c}}{\beta p_T} r_0\sqrt{\frac{d}{X_0\sin\theta}}\sqrt{1+\frac{1}{2}\left(\frac{r_0}{L_0}\right)+\frac{N}{4}\left(\frac{r_0}{L_0}\right)^2}$$

$$\sigma_{d_0}=\sqrt{\sigma^2_{d0_{SR}}+\sigma^2_{d0_{MS}}}$$

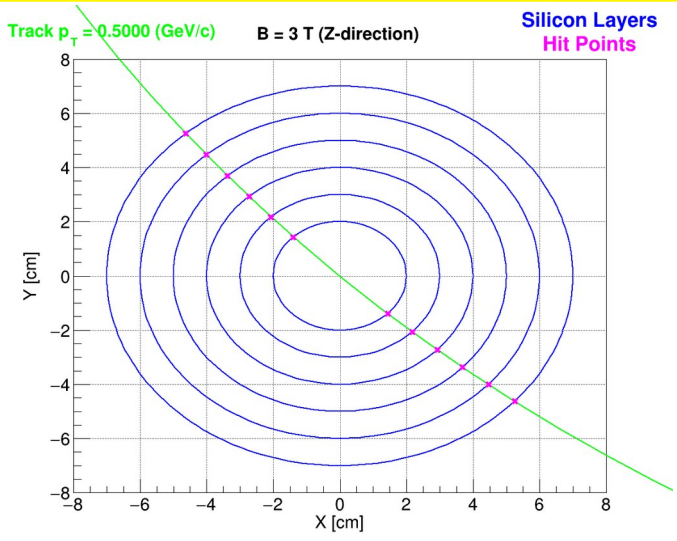
(r_0/L_0) is very important for DCA_{xy} resolutions

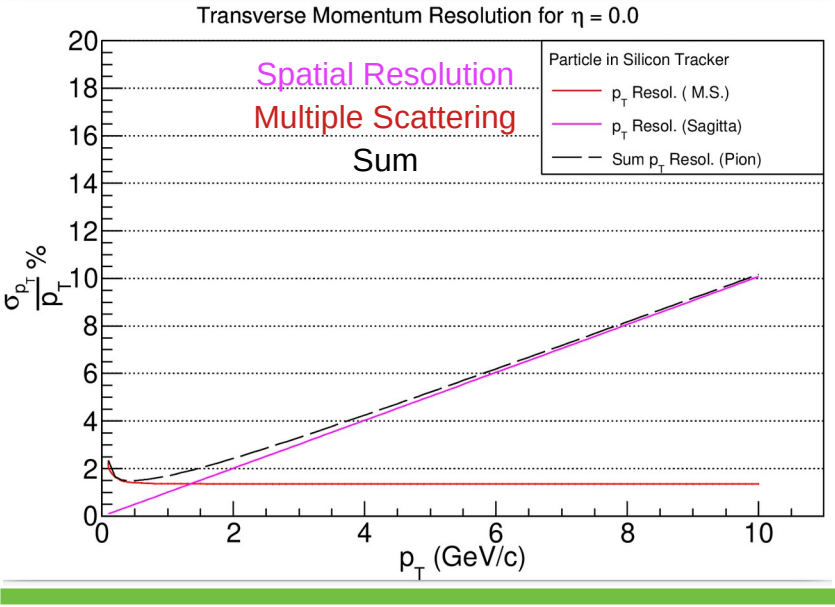
Simple Example

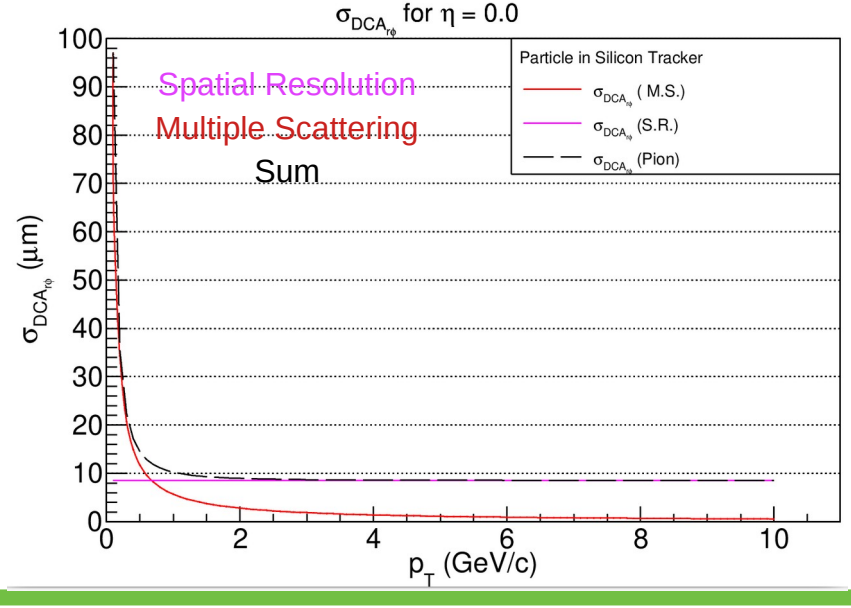
Consider an example of silicon layers of 50 μm thickness

r_0 = 2 cm L_0 = 7-2 = 5 cm;

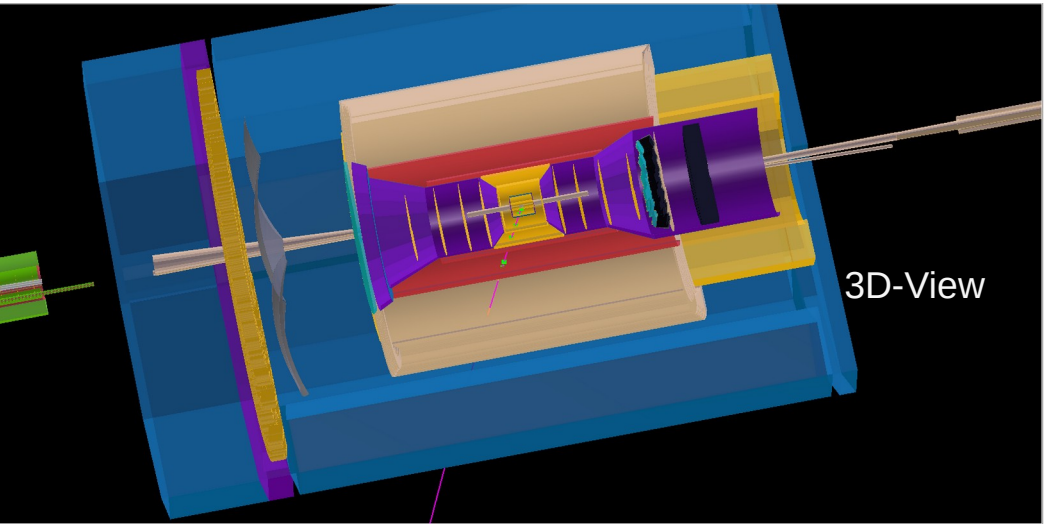
$$\sigma_{r\phi} = 10\,\mu m$$

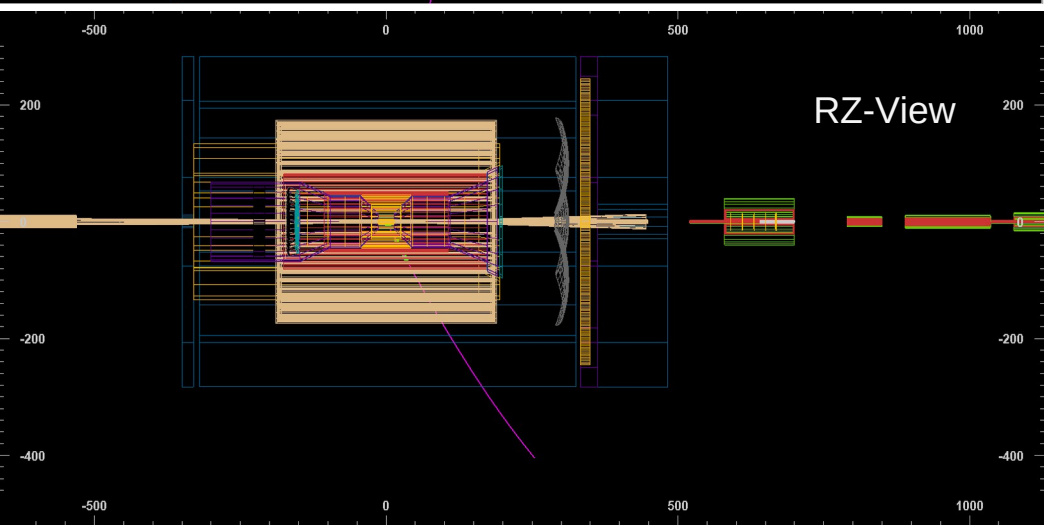






10 K pi+ simulation in DD4HEP

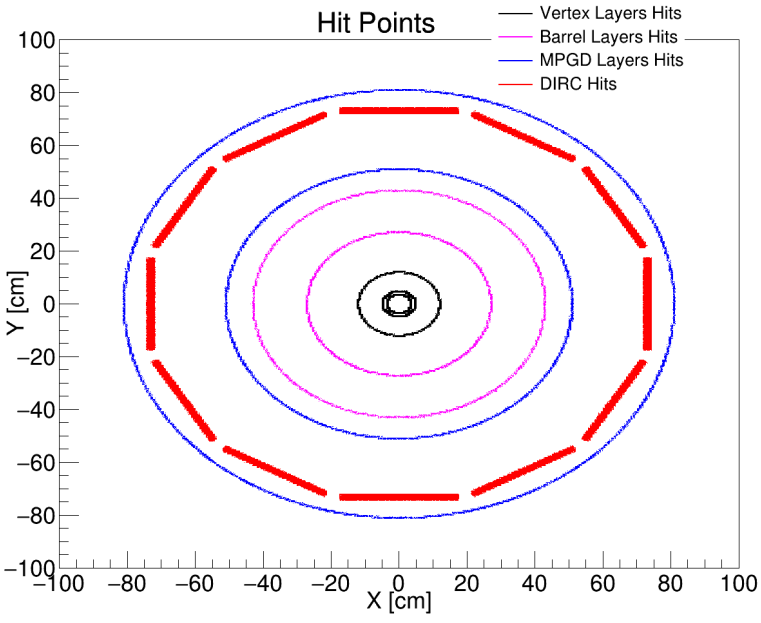


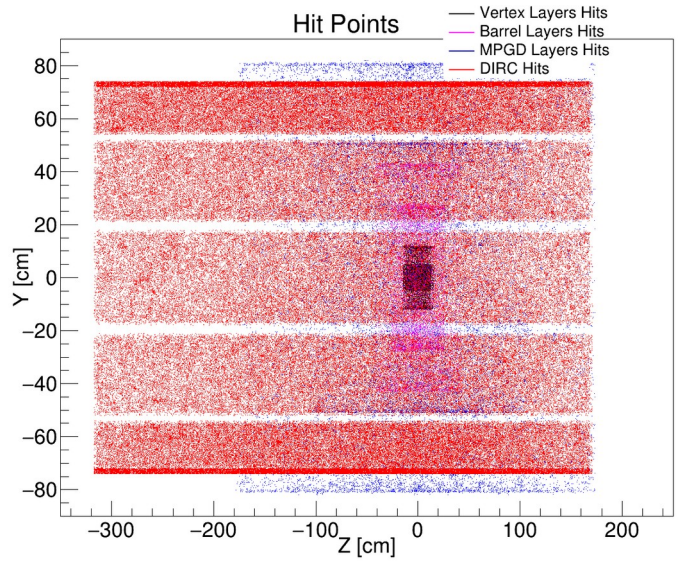


Event display (Track and Hits)

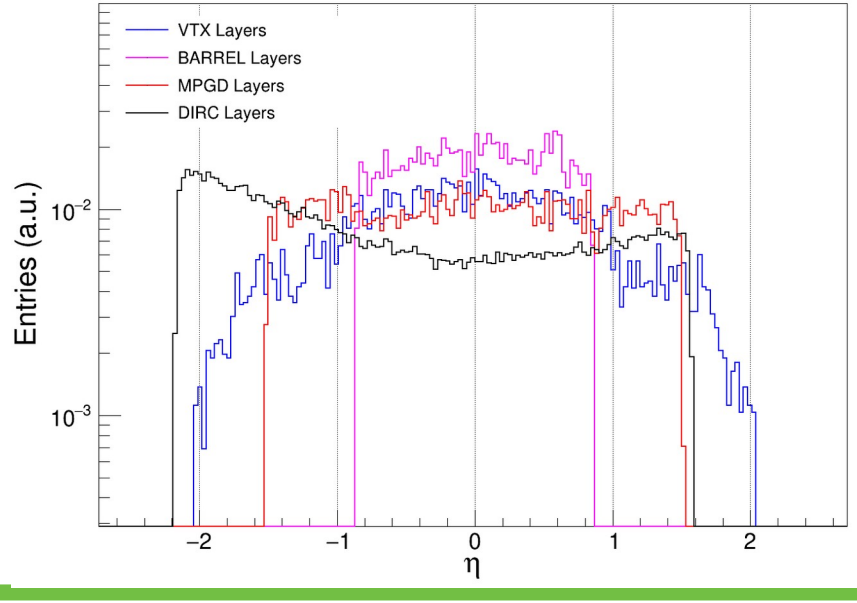
Magenta: Track
Green: Hits

Hit Distribuitions





Hit Points and Eta distribuitions

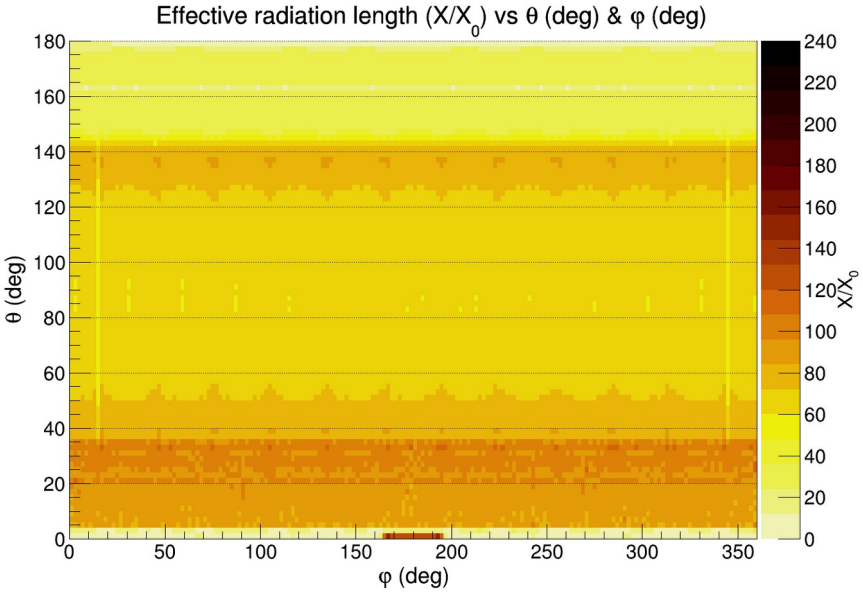


Material Budget

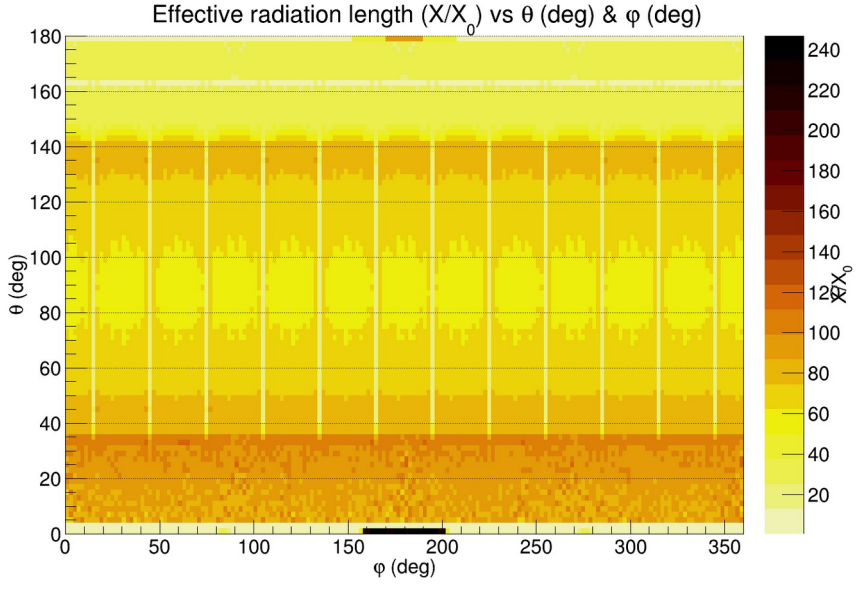
I know three ways to Estimate:

1. Register in and out position in a material (G4Step), we need trackId and Hit Id: Previously estimated in fun4All (Not supported in DD4HEP)
2. Material scan command of Geant4 listed below
3. Using Geometry information

Geantino scan (EPIC)



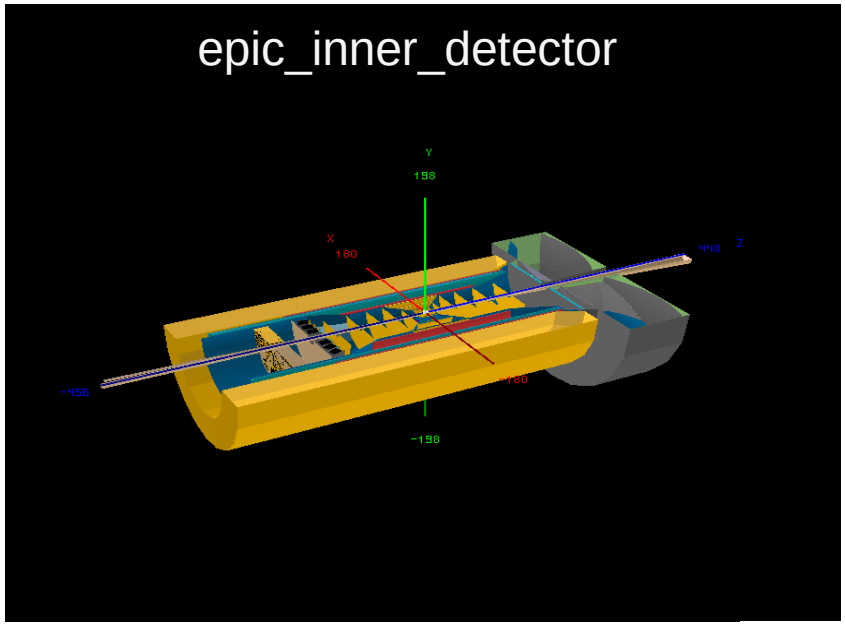
Geometry scan (EPIC)



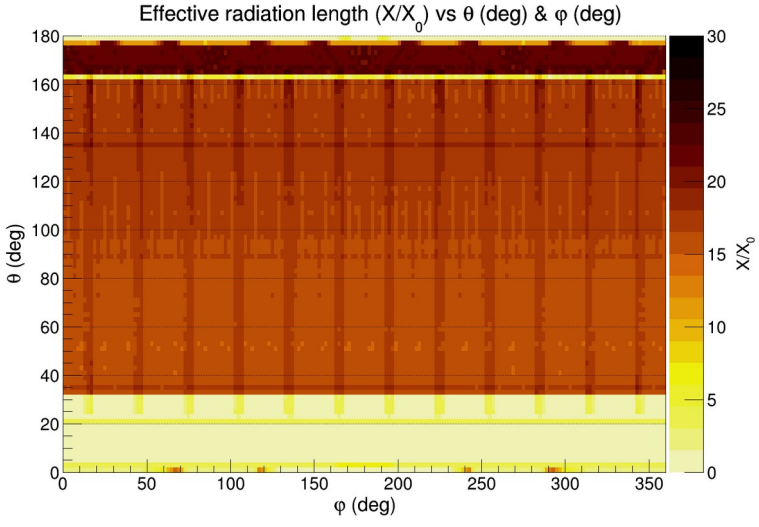
// Commands GEANT4
/control/matScan/phi 360 0 360. deg
/control/matScan/theta 180 0 180. deg
/control/matScan/scan

Difference in two methods

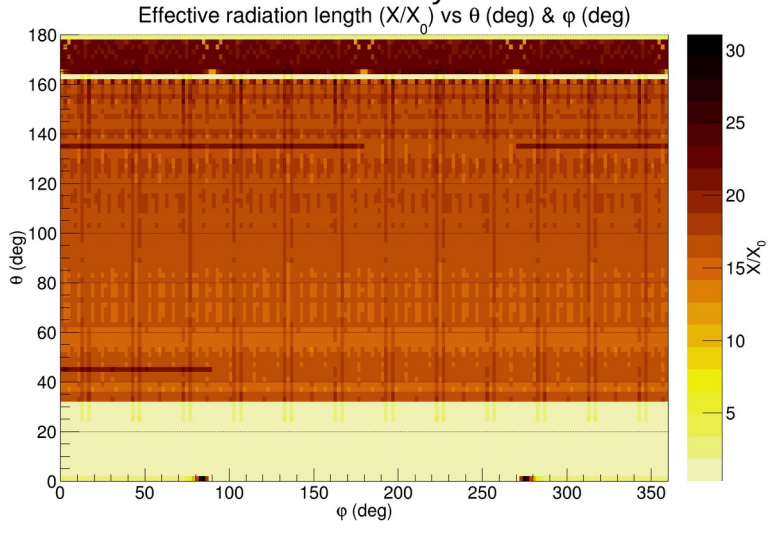
EPIC_Inner Detector



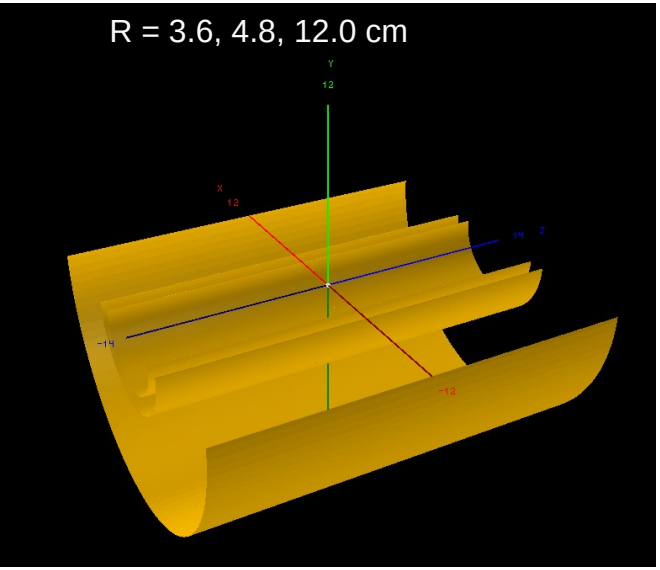
GEANT4

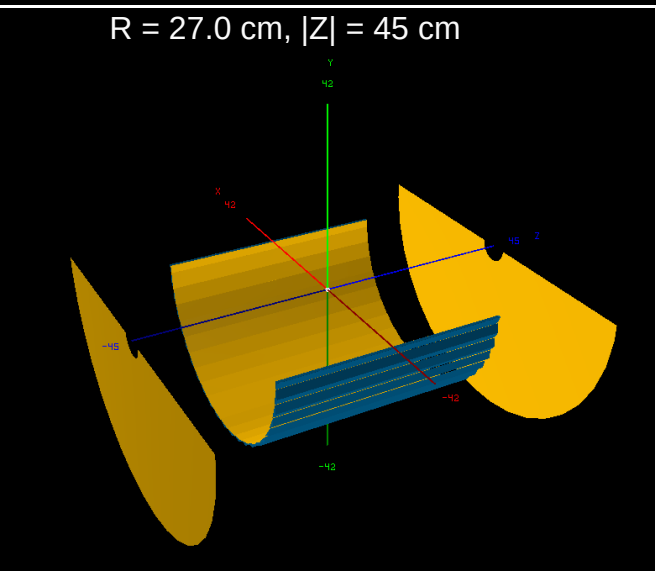


Geometry



Material Budget (Silicon Tracker)





Last layer = 12 cm

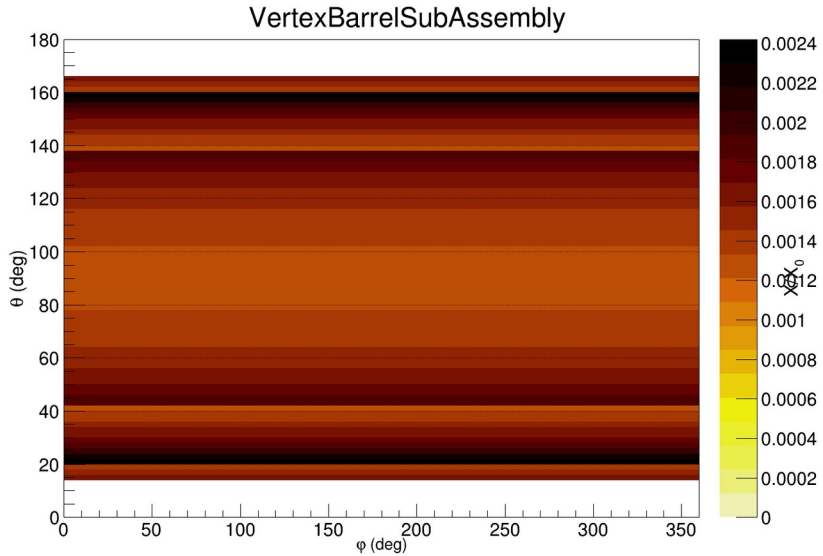
Material budget = 0.0005*3 = 0.0015

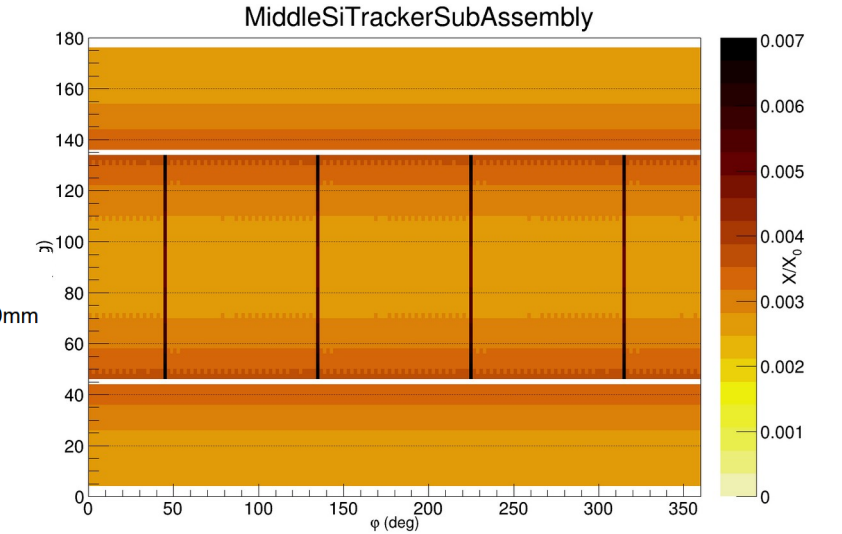
Barrel:

	r [mm]	l [mm]	X/X0 %
Layer 1	36	270	0.05
Layer 2	48	270	0.05
Layer 3	120	270	0.05
Layer 4	270	540	0.25
Layer 5	420	840	0.55

Disks:

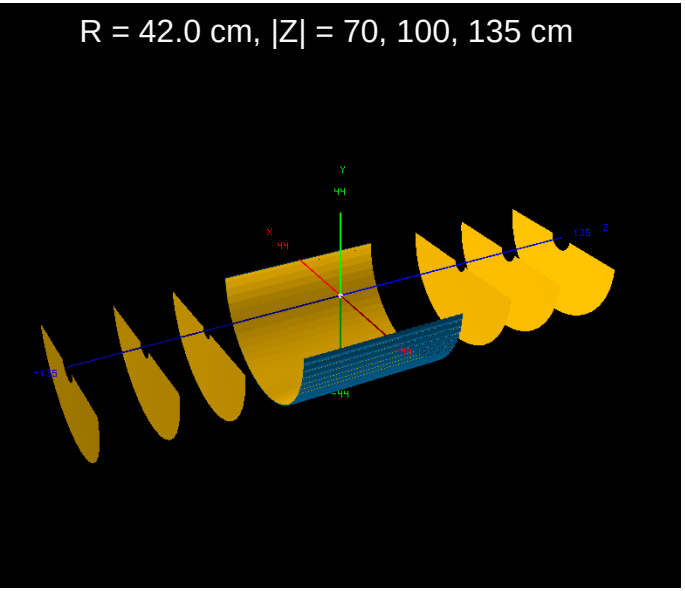
- Suggested |z| = 250, 450, 700, 1000, 1350* mm.
- r_{out} = 430mm** at |z| > 430mm, ~230 mm at |z| = 250mm
- X/X0 ~ 0.24% per disk

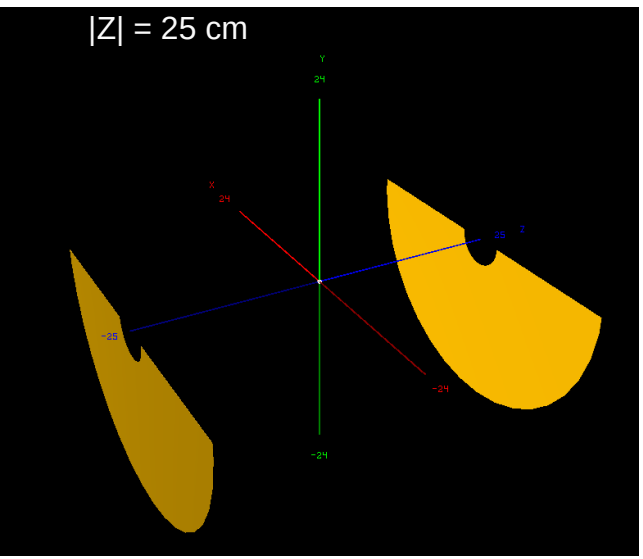




https://indico.bnl.gov/event/16868/contributions/67568/attachments/43002/72304/20220829%20-%20Silicon%20Consortium.pdf

Material Budget (Silicon Tracker)





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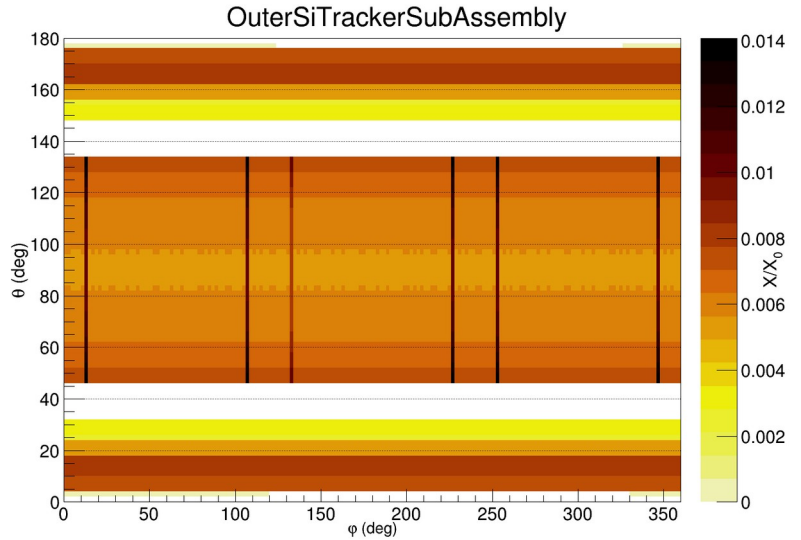
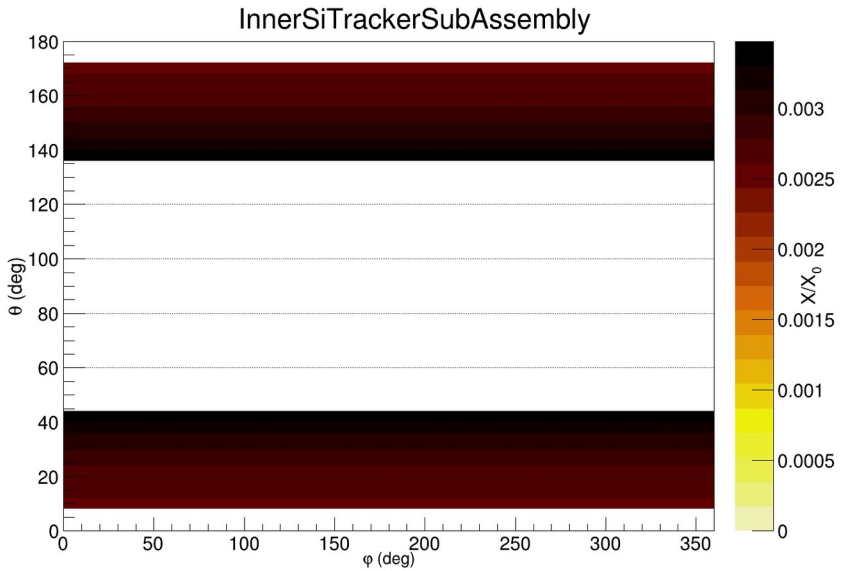
Layer 5	420	840	0.55

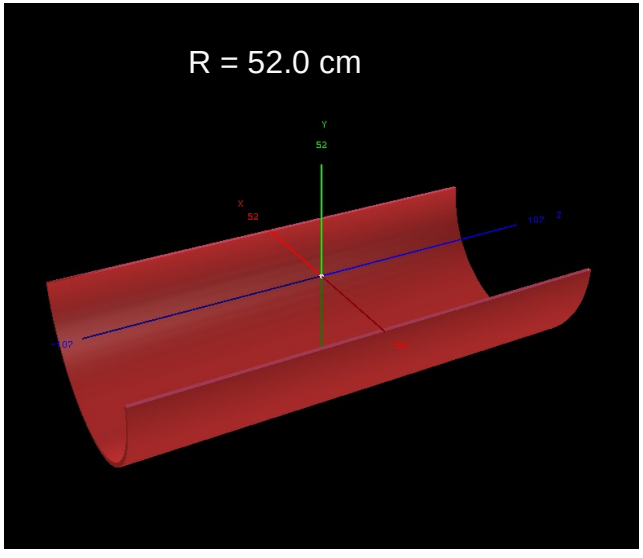
Disks:

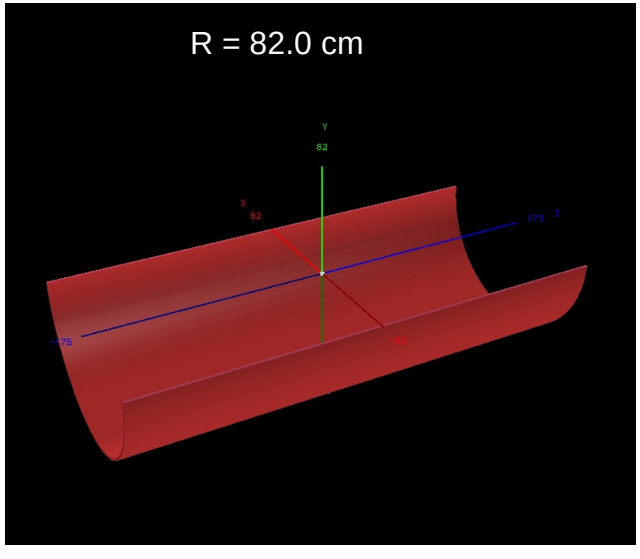
- Suggested |z| = 250, 450, 700, 1000, 1350* mm.
- r_{out} = 430mm** at |z| > 430mm, ~230 mm at |z| = 250mm
- X/X0 ~ 0.24% per disk

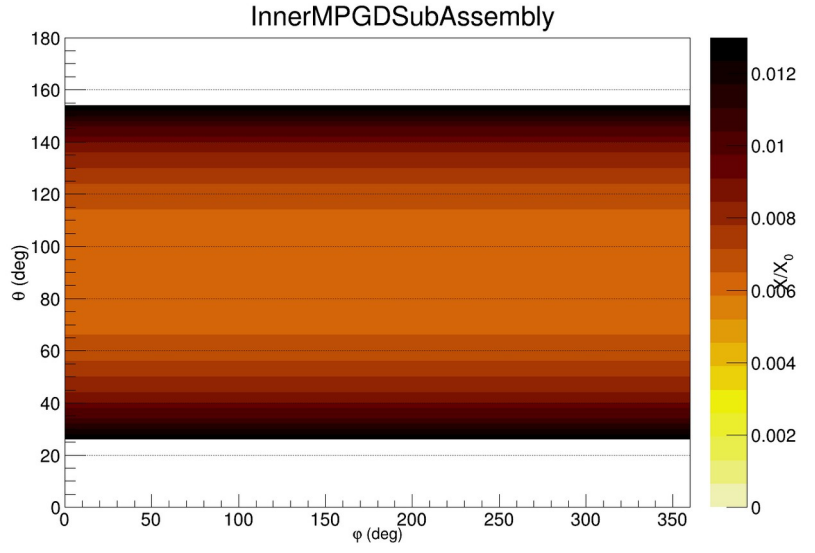


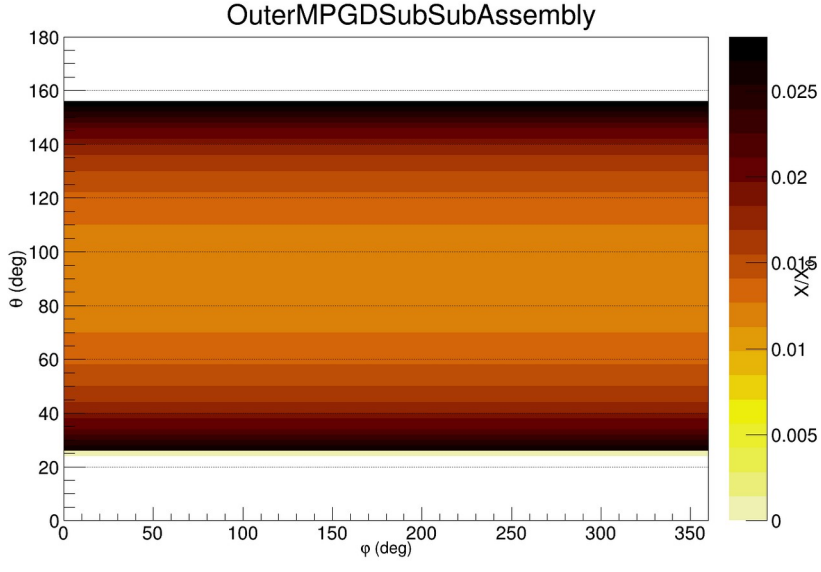


Material Budget (MPGD Layers)

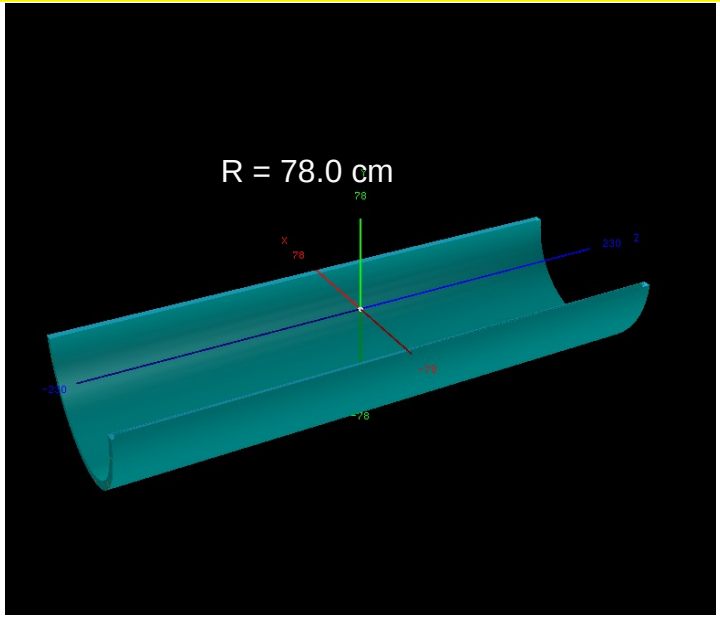


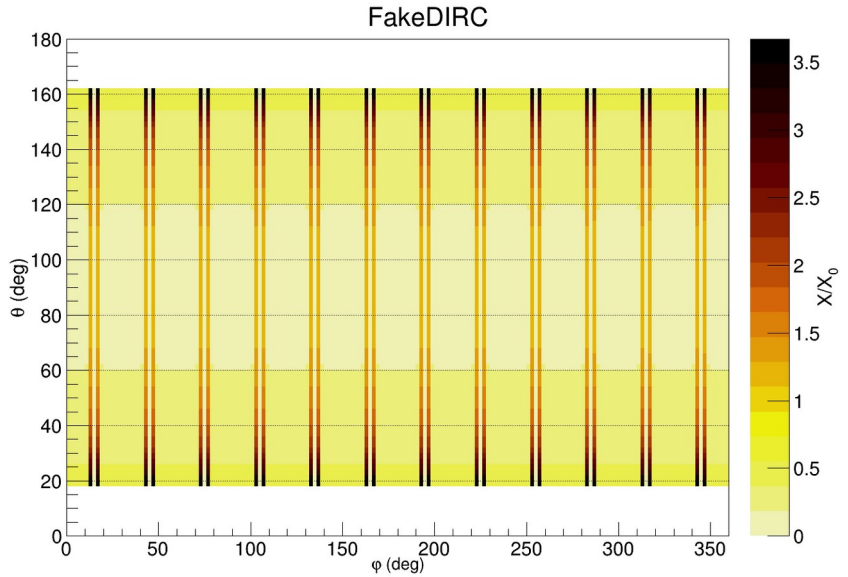


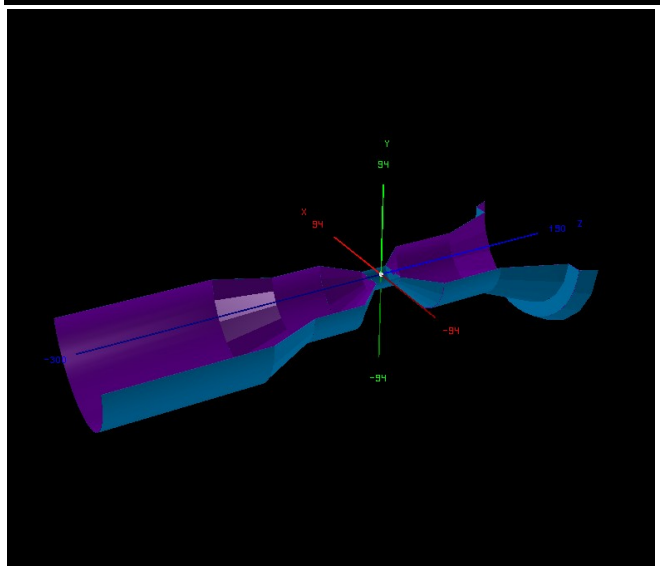


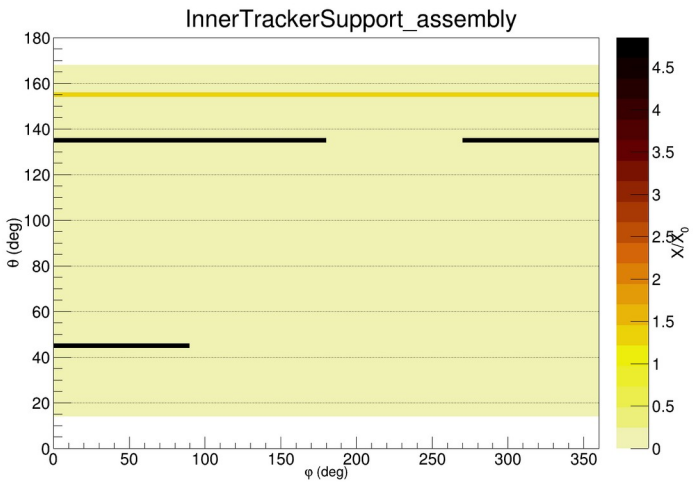


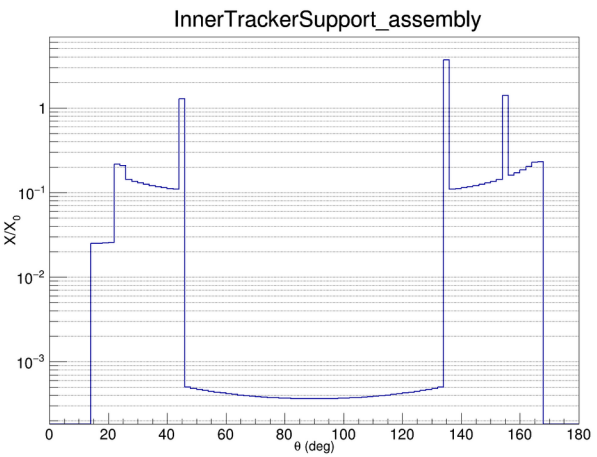
Material Budget (DIRC Layer)



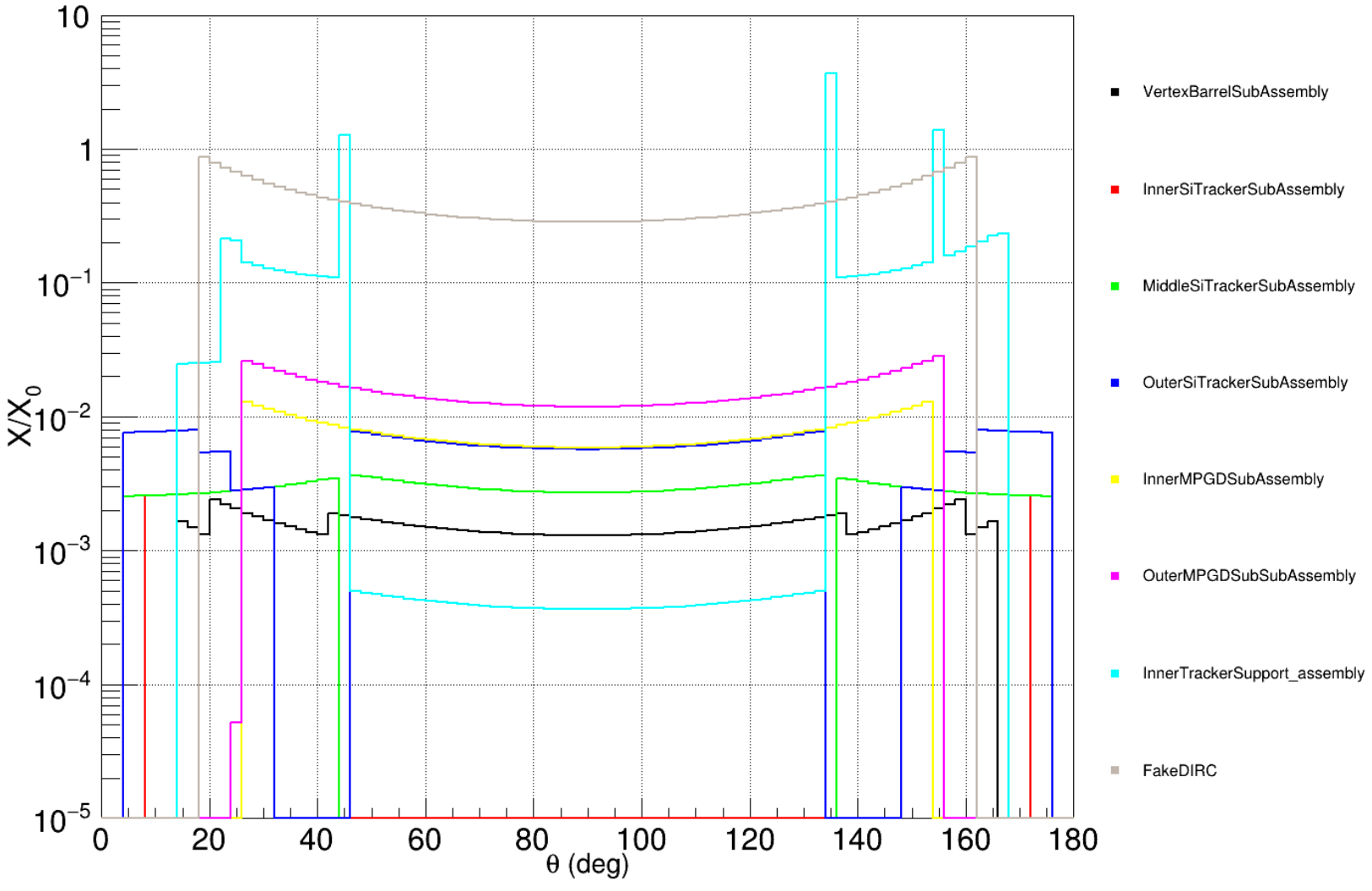








Material Budget



Summary and Future Plan

- Presented the performance of mini-TPC corresponding to the configuration provided.
- Shown Hit map, Eta map, Event display, Material map further studies are going on.
- Waiting for the working version of reconstruction script for further study.
- Need to validate Fast Simulation code with the new configuration presented by Rey (Thanks Rey for latest code in Fun4All).
- I am planning to look at track finding and fitting in which I can contribute if there is a possibility?