Fast Simulation Studies with the EPIC Detector

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

Outline

- EPIC Geometry
  - EPIC Barrel Configuration (used in fast simulation)
- Tracking Performances
  - Spatial Resolution and Multiple Scattering
  - Performances with Dead Layers
- Summary and Future Plan

EPIC Configuration used in Fast Simulation

Barrel Track Model (Cylindrical layers) Based on Kalman filter

```
Detector EPIC: "Detector"
  Name             r [cm]          X0      phi & z res [um] layerEff
0. vertex          0.00          0.0000     -    -         -
1. bpipe           3.18          0.0036     -    -         -
2. VTX1            3.60          0.0005     3     3      0.95
3. VTX2            4.80          0.0005     3     3      0.95
4. VTX3            12.00         0.0005     3     3      0.95
5. BARRSUPPORT     13.50         0.0004     -    -         -
6. BARR1           27.00         0.0025     3     3      0.95
7. BARR2           42.00         0.0055     3     3      0.95
8. MM1    55.00           0.0050    150   150     0.95
9. TOF    64.60           0.0100     30   3000    0.95
```

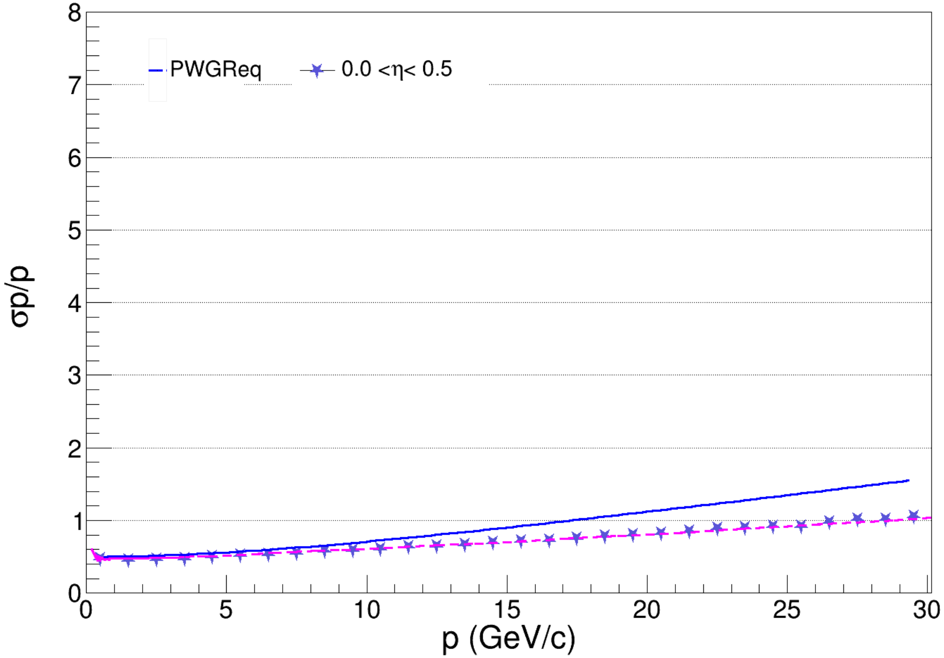
https://wiki.bnl.gov/EPIC/index.php?title=Tracking#Tasks_list

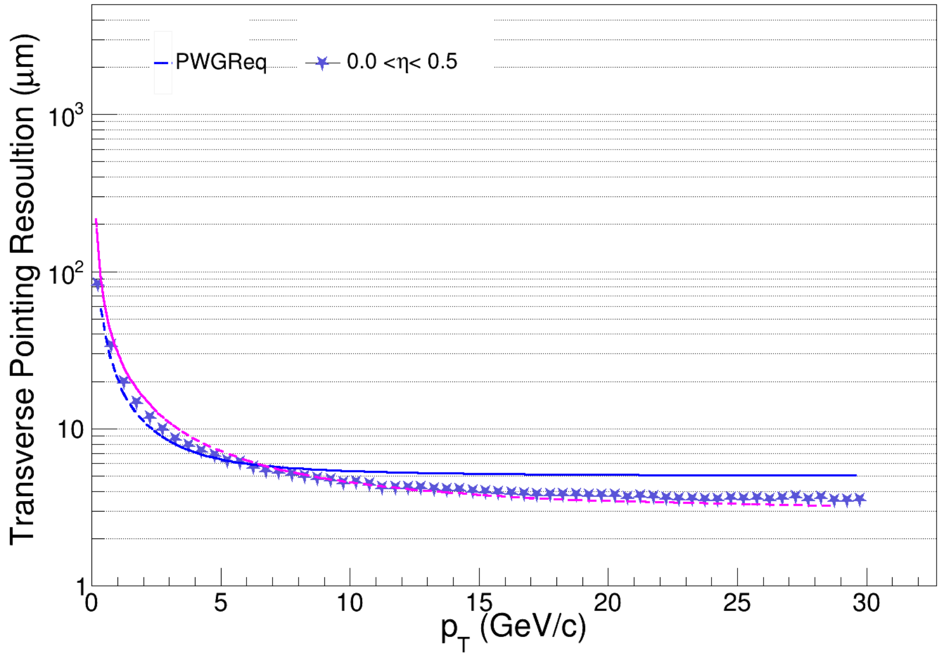
EIC Recons Comparison with Fast Simulation

Blue Marker (DD4HEP), Magenta Fast Simulation, Blue dotted line PWG requirement

epic_brycecanyon.xml with calorimeters and far forward detectors removed

```
shyam@shyam:~/eic/epic$ git tag -l
22.10.0
22.10_rc1
22.11.0
shyam@shyam:~/eic/epic$ git checkout 22.10.0
shyam@shyam:~/eic/epic$ git pull origin main
```





field_map="fieldmaps/MARCO_v.6.4.1.1.3_1.7T_Magnetic_Field_Map_2022_11_14_rad_coords_cm_T.txt"
url="https://github.com/eic/epic-data/raw/64b7ca6306b138b7f000e696c82bd8f72db1da56 MARCO_v.6.4.1.1.3_1.7T_**Magnetic_Field_Map_2022_11_14**_rad_coords_cm_T.txt"

A good agreement of data points with the fast simulation

Spatial Resolution and Multiple Scattering

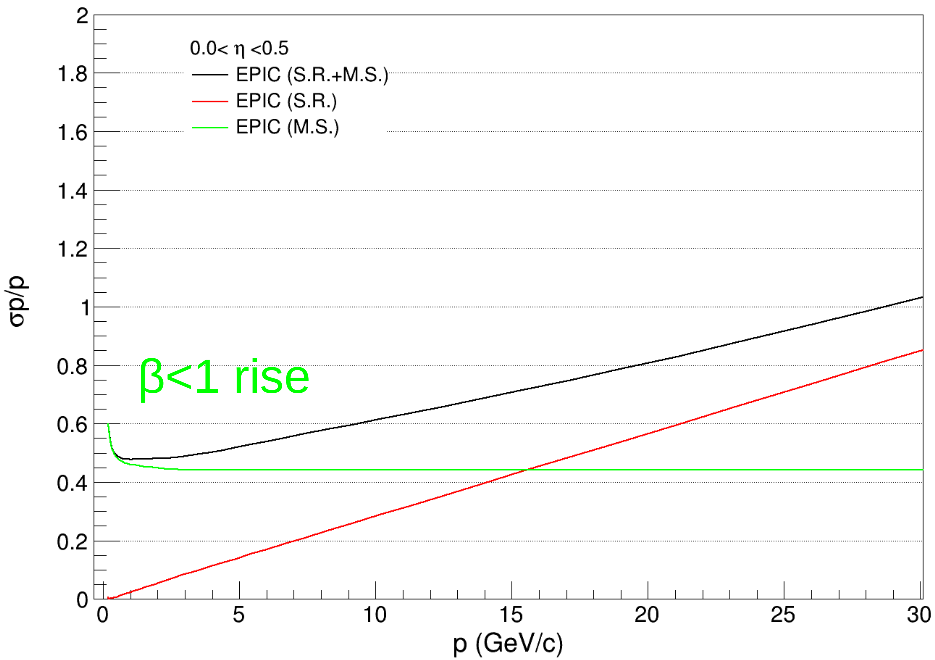
$$\frac{\sigma_{p_T}}{p_T} = \sqrt{\left(\frac{\sigma_{pT_{SR}}}{p_T}\right)^2 + \left(\frac{\sigma_{pT_{MS}}}{p_T}\right)^2}$$

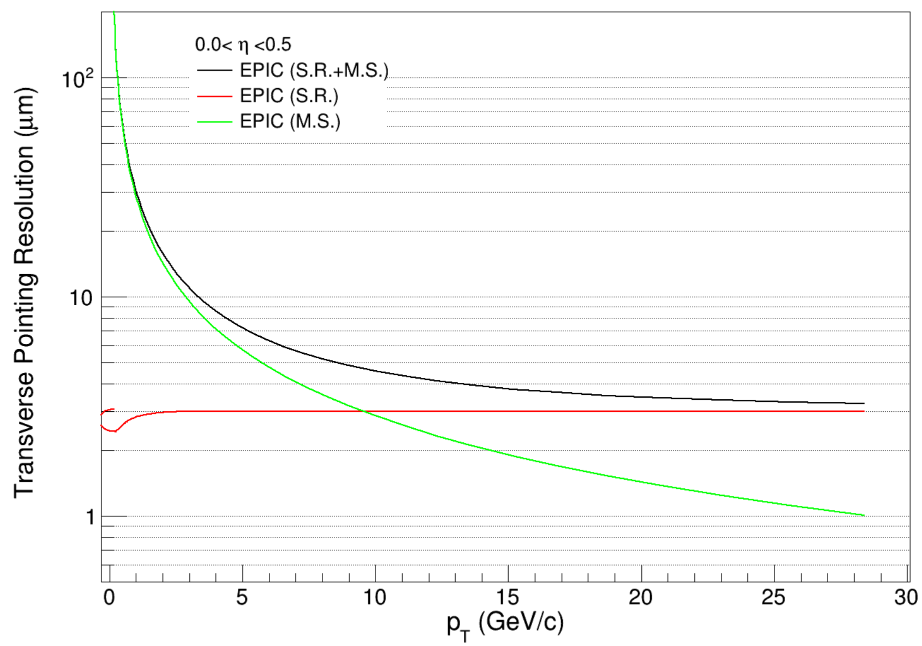
$$\sigma_{d_0} = \sqrt{\sigma_{d0_{SR}}^{\;2} + \sigma_{d0_{MS}}^{\;2}}$$

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

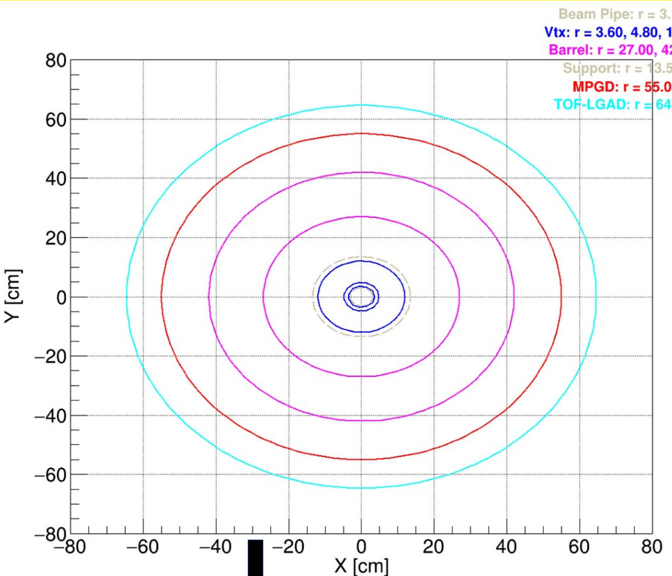
$$\sigma_{pT_{SR}} \propto \sigma_{r\phi}\, p \qquad \sigma_{pT_{MS}} \propto \frac{1}{\beta p}\, p \;=\; \text{const}/\beta$$

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

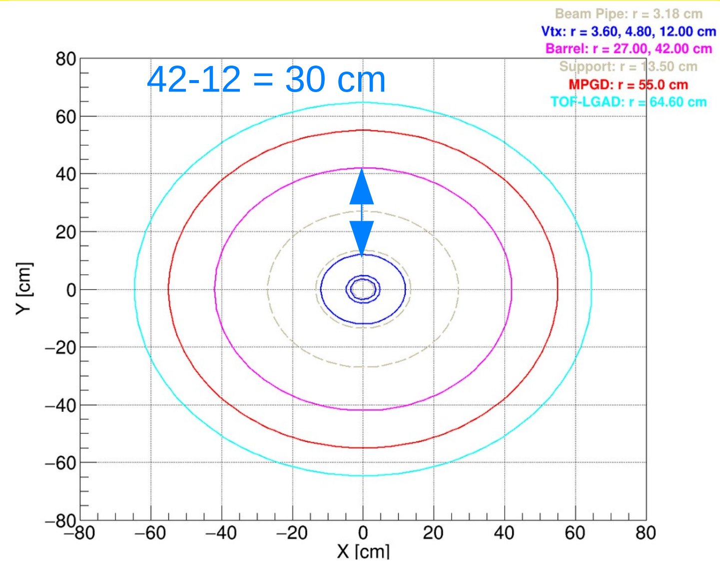




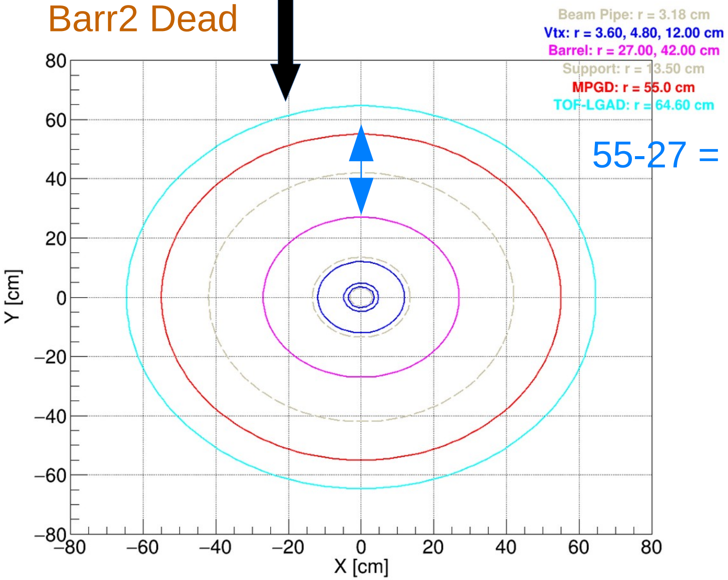
Performances with Dead Layers



Barr1 Dead

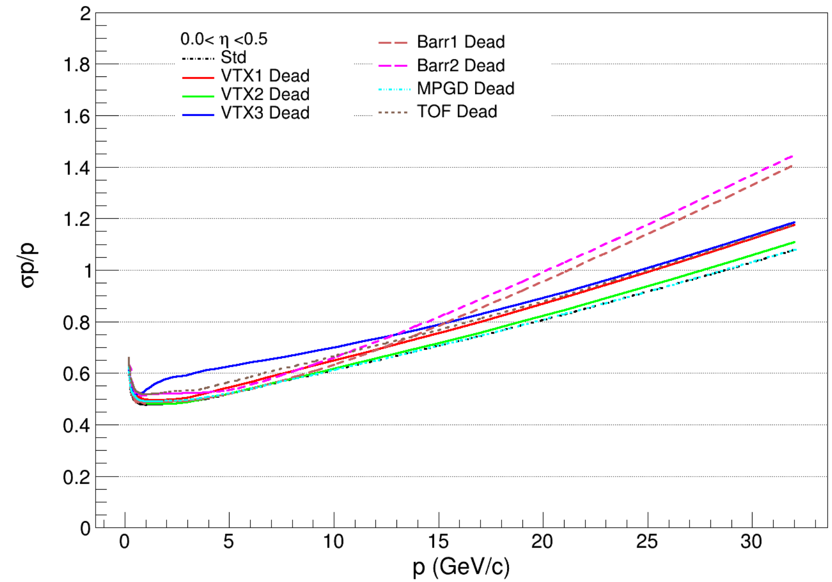


Barr2 Dead

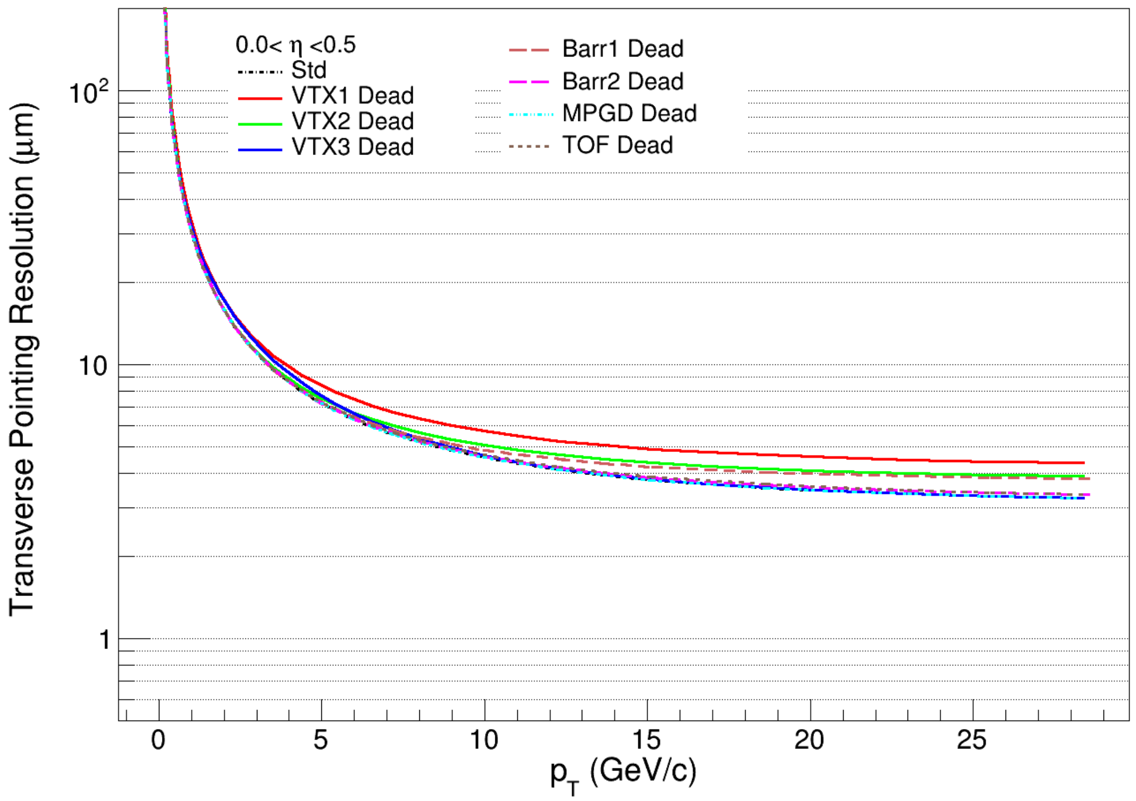


55-27 = 28 cm

VTX3 dead: 27-4.8 = 22.2 cm



Performances with Dead Layers

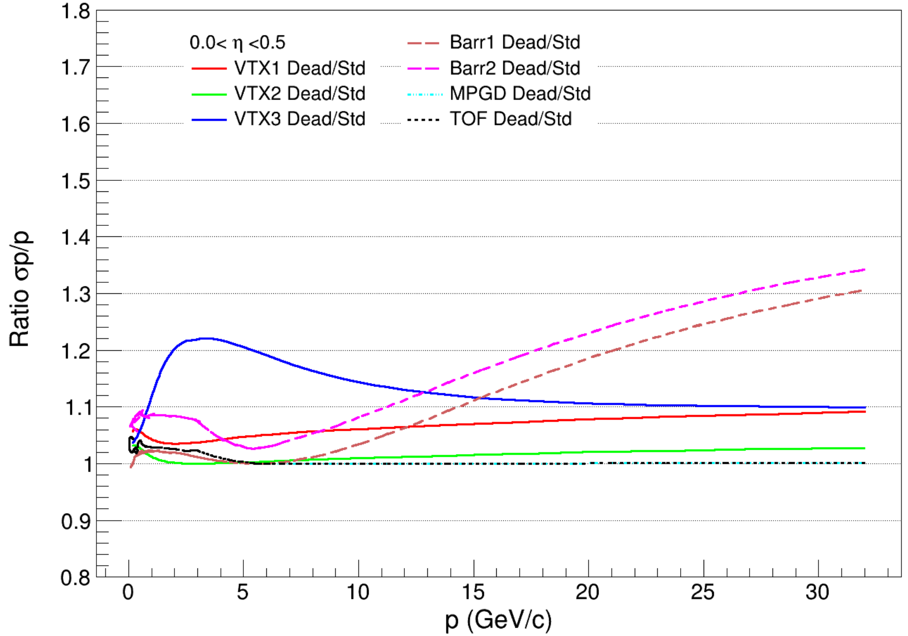


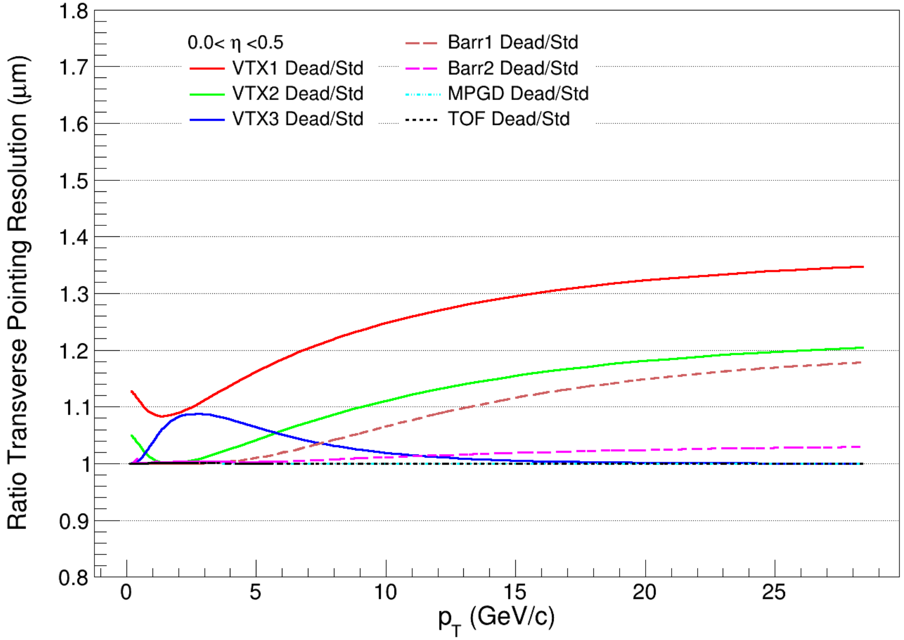
r_0/L_0 is very important for DCA_{xy}

Standard $r_0/L_0 = 3.6/(64.6-3.6) = 0.059$

VTX1 Dead = $4.8/(64.6-4.8) = 0.080$

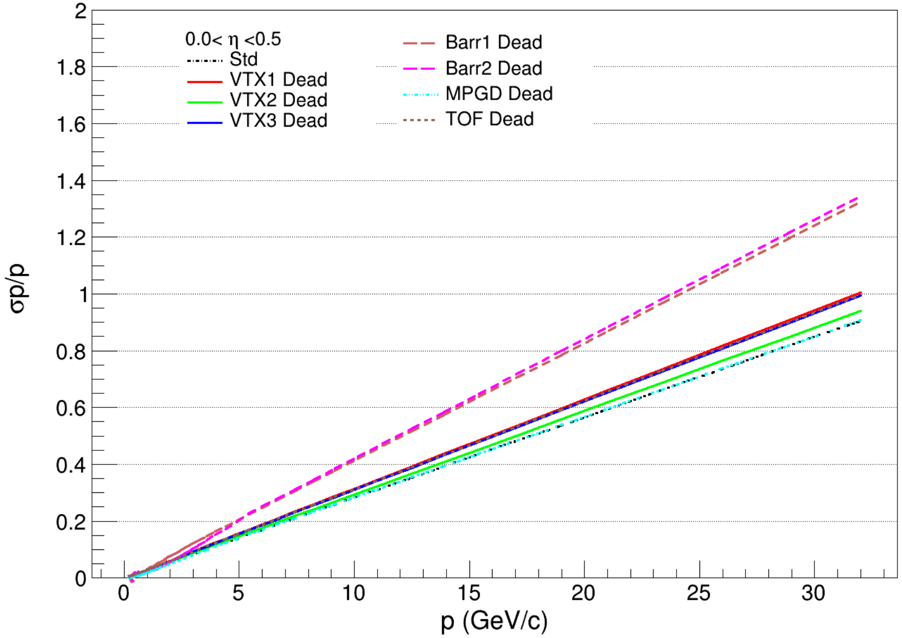
Performances with Dead Layers

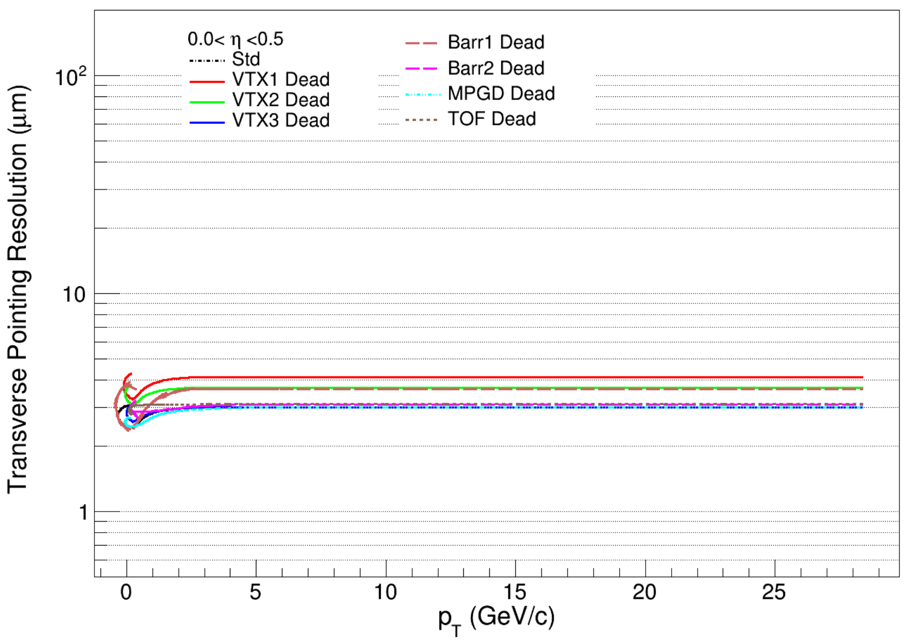




VTX3 detector resolution is an important constraint for track extrapolations

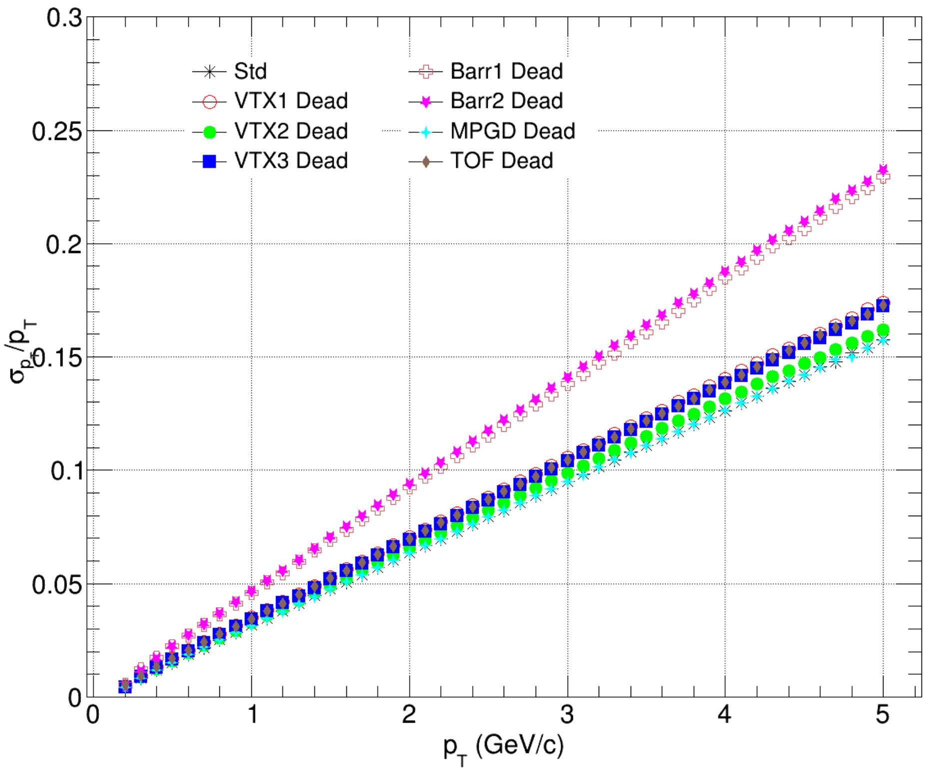
Performances with Dead Layers (Spatial Resolution Term)

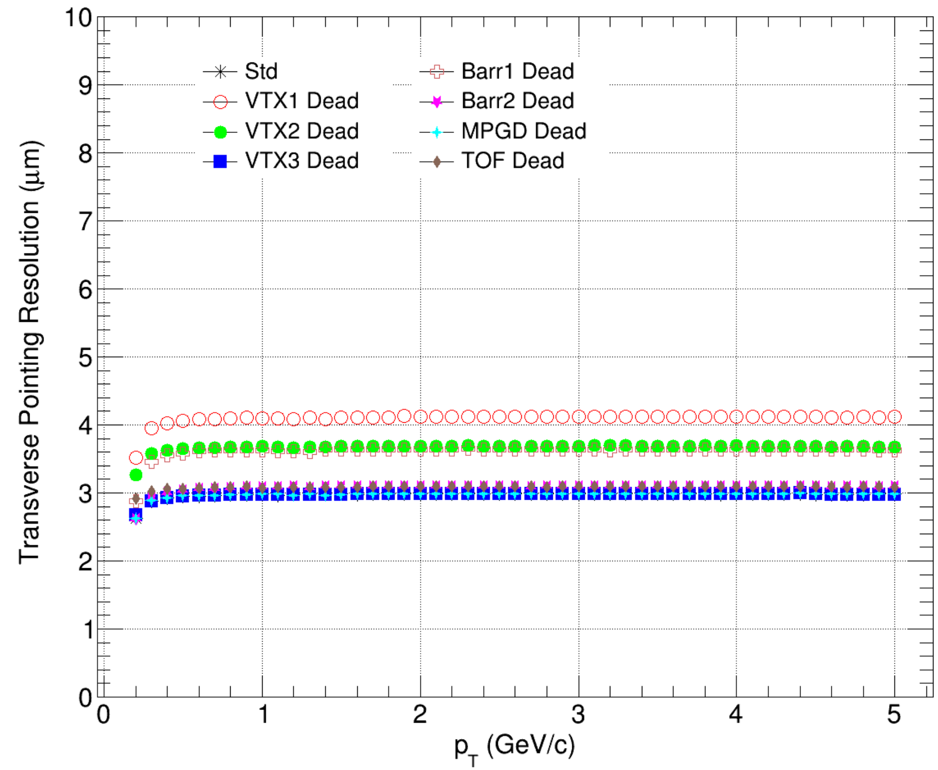




Fast Simulation (Spatial Resolution)

Low Momentum Range



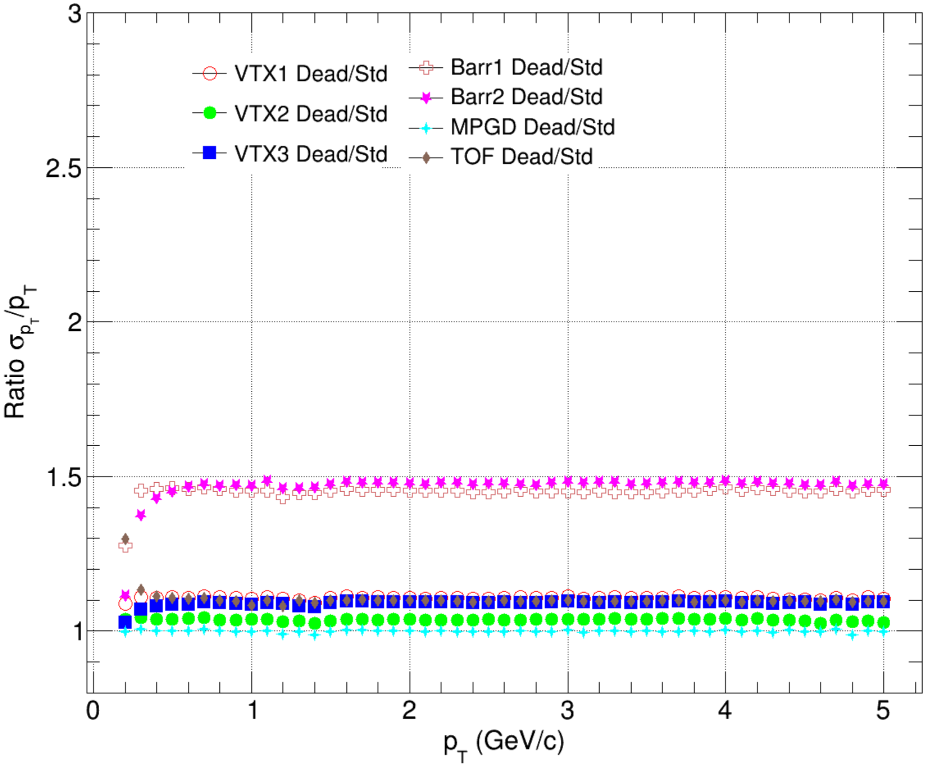


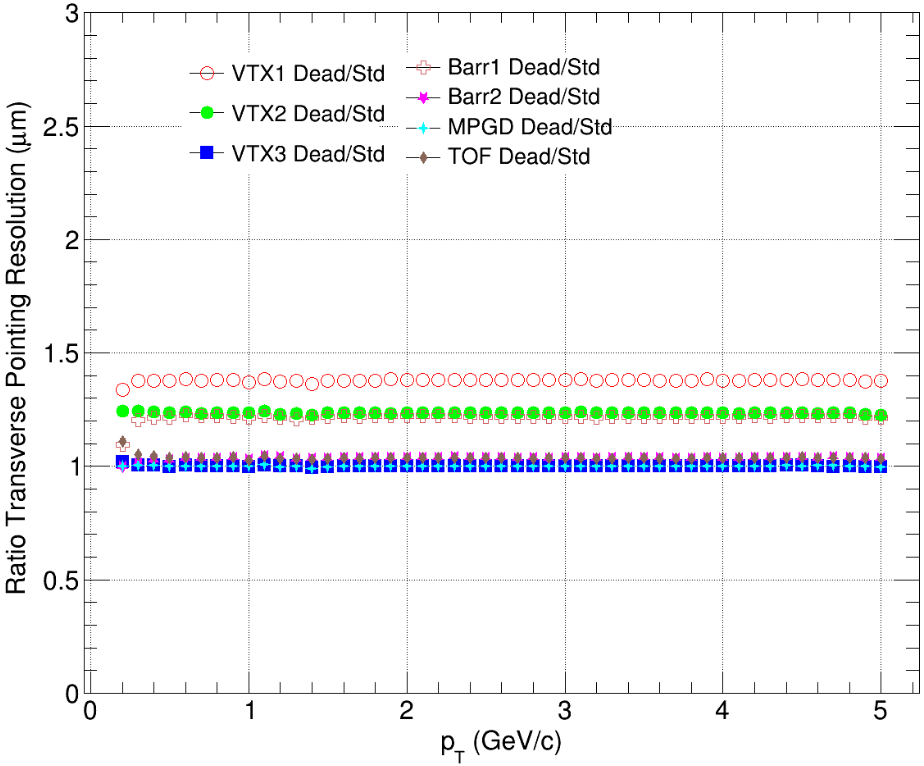
Not a Kalman filter

Fast Simulation developed by S.Kumar, Annalisa, F. Colamaria

Fast Simulation (Ratios Spatial Resolution)

Low Momentum Range





Not a Kalman filter

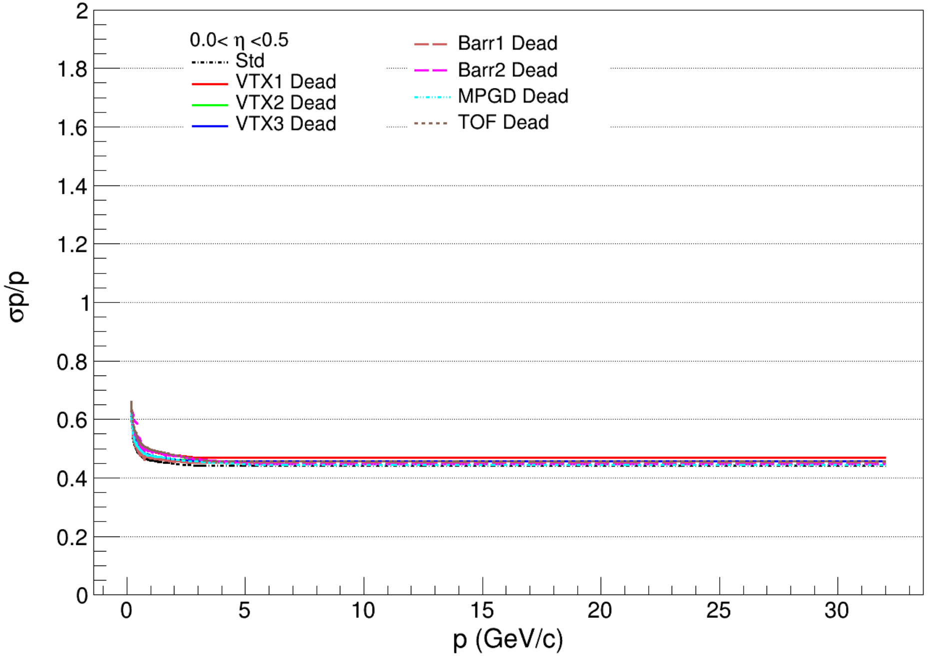
Fast Simulation developed by S.Kumar, Annalisa, F. Colamaria

Performances with Dead Layers (Multiple Scattering Term)

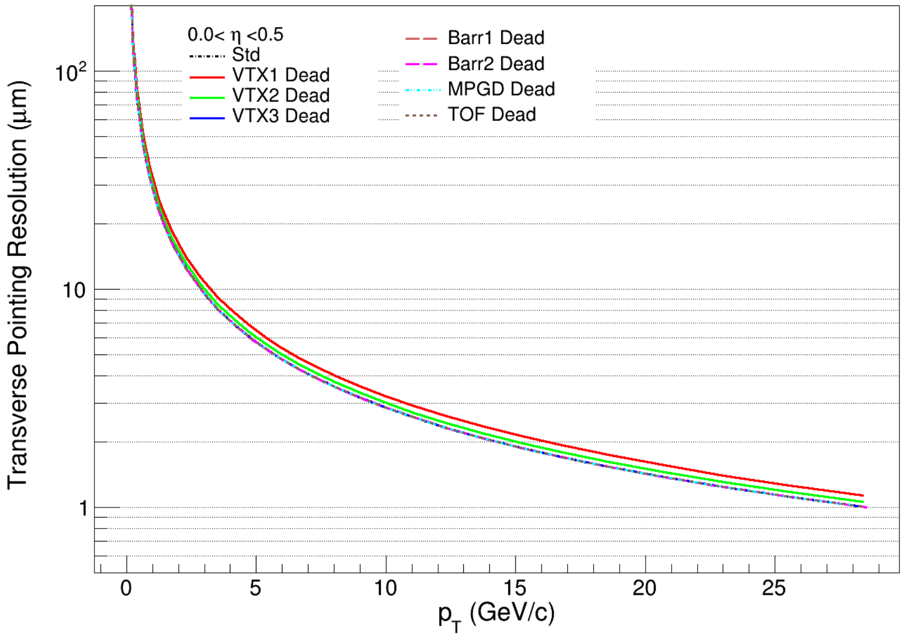
$$\frac{\Delta p_T}{p_T}\Big|_{m.s.} = \frac{N}{\sqrt{(N+1)(N-1)}} \frac{0.0136\,\mathrm{GeV/c}}{0.3\beta\, B_0 L_0} \sqrt{\frac{d_{tot}}{X_0\,\sin\theta}} \left(1 + 0.038\ln\frac{d}{X_0\,\sin\theta}\right)$$

$$\sigma_{d0_{MS}} \approx 0.0136\,(GeV/c) * \sqrt{\frac{d}{X_0 \sin\theta}} \left(\frac{r_0}{\beta\, p_T}\right) \sqrt{1 + 0.5 * \left(\frac{r_0}{L_0}\right) + 0.25 * N * \left(\frac{r_0}{L_0}\right)^2}$$

r_0 and r_0/L_0 is very important for DCAxy (MS)



Making 1^{st} layer dead L_0 changes



Making 1^{st} layer dead r_0 and L_0 changes

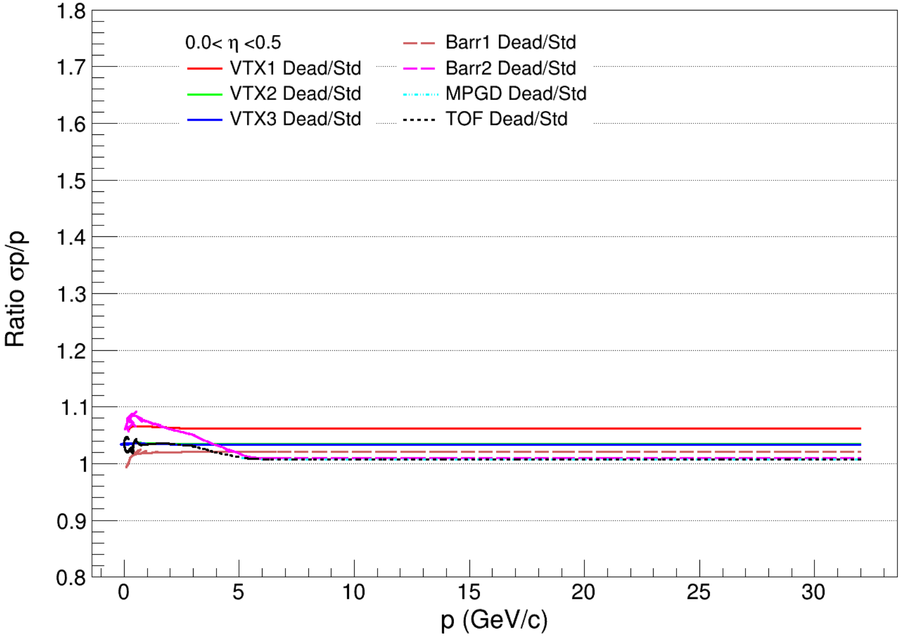
r_0/L_0 (Std) = 3.6/(64.6-3.6) = 0.059

r_0/L_0 (VTX1 Dead) = 4.8/(64.6-4.8) = 0.080

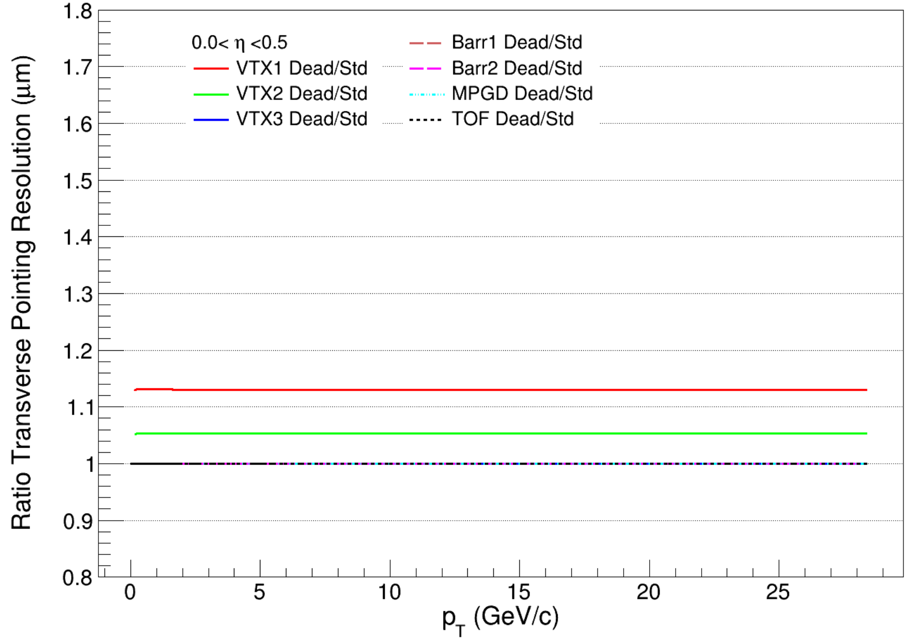
Performances with Dead Layers (Ratios of Multiple Scattering Term)

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

$$\sigma_{d0_{MS}} \approx 0.0136\,(GeV/c) * \sqrt{\frac{d}{X_0 \sin\theta}}\left(\frac{r_0}{\beta p_T}\right)\sqrt{1+0.5*\left(\frac{r_0}{L_0}\right)+0.25*N*\left(\frac{r_0}{L_0}\right)^2}$$



Making 1st layer dead L_0 changes



Making 1st layer dead r_0 and L_0 changes

r_0/L_0 (Std) = 3.6/(64.6-3.6) = 0.059

r_0/L_0 (VTX1 Dead) = 4.8/(64.6-4.8) = 0.080

Summary and Future Plan

- Checked the contribuition of spatial resolution and multiple scattering using FastSimulation
- Checked the dead layer effect on the tracking performances
- Future Plan:
  - Check the performances again once ETOF issue is fixed
  - Also the other studies as number of hits, chi2, etc with realistic seeding

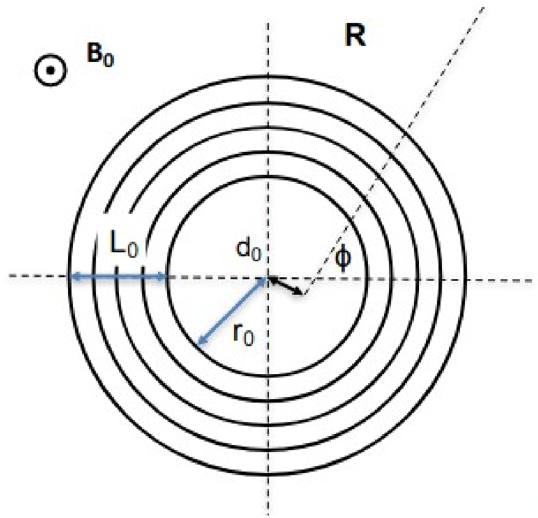
Momentum Resolution

Zbynek Drasal, Werner Riegler

arXiv:1805.12014

Tracking Performances: Momentum and DCA resolutions

Momentum Resolution:affects width of invariant mass peak



p_T resolution:

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

Linear term

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

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

Constant term (at β<1 increase)

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

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

MS (Multiple Scattering): Uncertainty 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

arXiv:1805.12014

r_0 : distance of near hit

L_0: distance between near and farthest hit from the beamline

DCA$_{xy}$ increases at larger η because r_0/L_0 increases

DCA$_{xy}$ resolution:

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

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

(r_0/L_0) is very important for DCA$_{xy}$ resolutions

$$\sigma_{d_0}=\sqrt{\sigma_{d\,0_{SR}}^2+\sigma_{d\,0_{MS}}^2}$$

Barrel

r0 = 3.6; L0 = 64.0-3.6; N = 7;

$\sigma_{r\phi}=10\,\mu m/\sqrt{12}$

Expected DCAxy Resol Barrel (SR): 3.14743 µm

Forward/Backward

Double_t rmin[5] = {3.67617,3.67617,4.07617,5.37617,7.07617};
Double_t rmax[5] = {24.00010,42.500107,43.12010,43.12010,43.12010};
Double_t z[] ={25., 45., 70., 100., 135.};
Double_t L_0 = 43.12010-3.67617;   N = 4; // number of points

$\sigma_{r\phi}=10\,\mu m/\sqrt{12}$

Expected DCAxy Resol Forward (SR): 4.10559 µm

if (L_0 = 20cm then Expected DCAxy = 5.543 µm)

Simple Example

Consider an example of silicon layers of 50 µm thickness

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

$$\sigma_{r\phi} = 10\,\mu m/\sqrt{12}$$