Preliminary Optimization for the Forth CEPC Tracker

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2022.3.11

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3. Summary

1. Introduction—CEPC Physics requirements

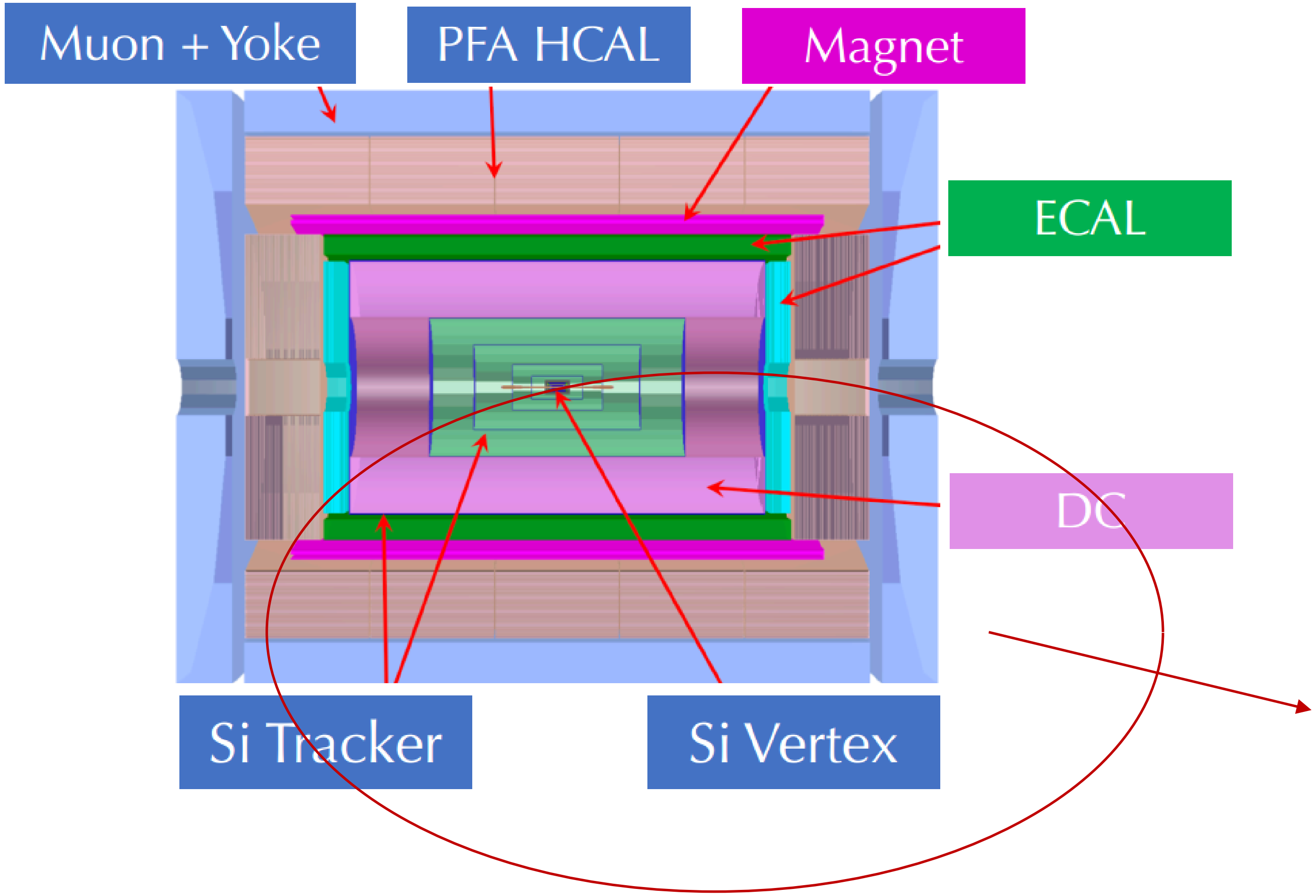
- Higgs physics

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) = 2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} = 5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E =$ 3 ~ 4% at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E = \frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

- Flavor physics: excellent PID, better than 2σ K/π separation up to ~20 GeV
- EW measurements: High precision luminosity measurement, $\delta L/L \sim 10^{-4}$

Ref : https://indico.ihep.ac.cn/event/13888/session/8/contribution/56/material/slides/0.pdf

1. Introduction—CEPC Detector



The Forth CEPC detector concept :

- Silicon Vertex & Silicon Tracker for impact parameters and momentum measurement
- Drift Chamber for PID
- Transverse crystal bar ECAL for π_0/γ reconstruction
- Solenoid magnet between HCAL and ECAL

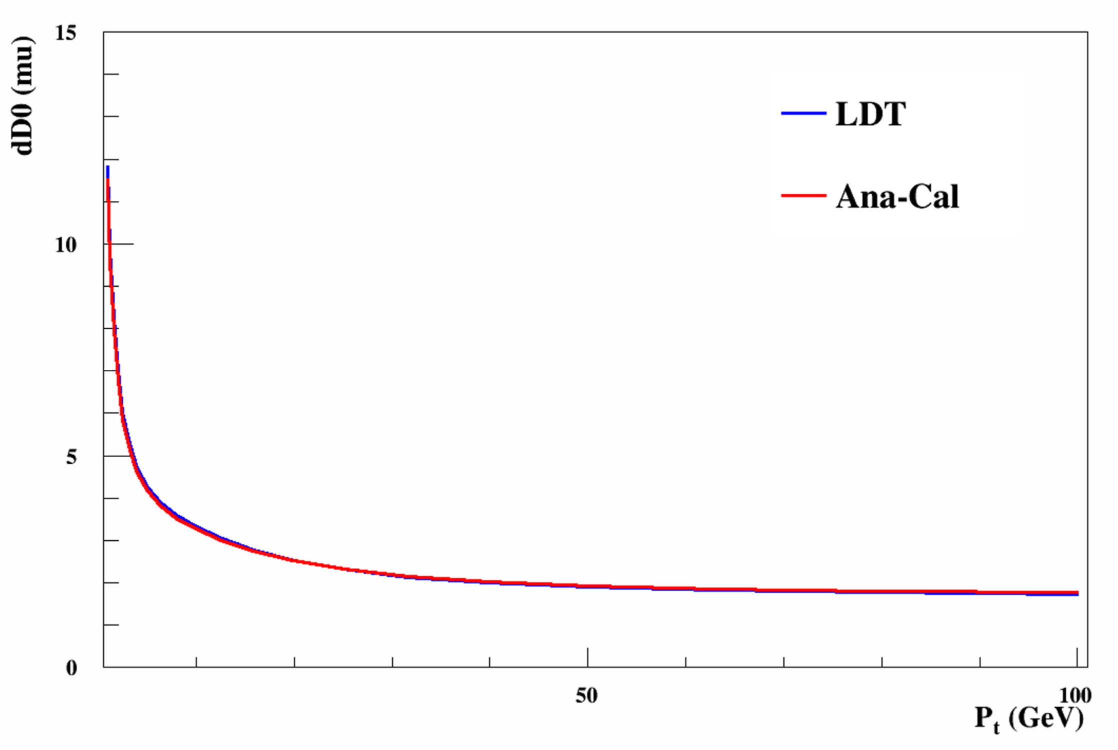
Motivation :

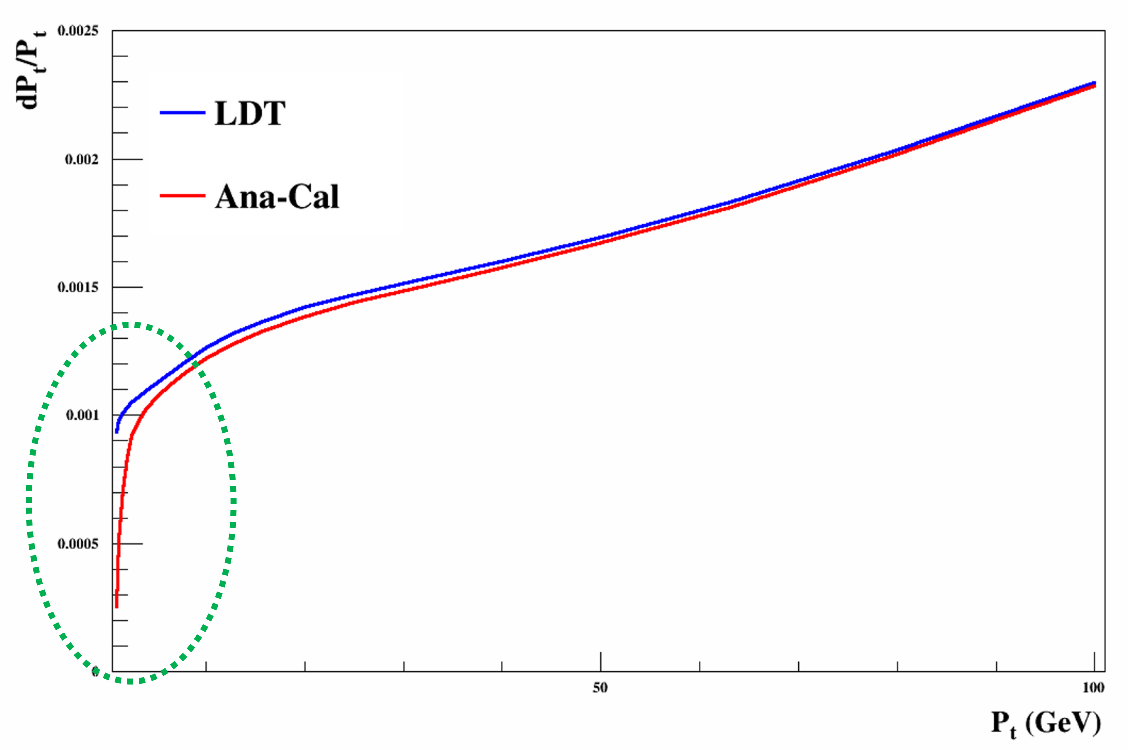
To change the layout and measure the resolution of d_0 & P_t as good as possible

$(d_0, z_0, \phi, \theta, P_t)$

Ref : https://indico.ihep.ac.cn/event/13888/session/8/contribution/56/material/slides/0.pdf

1. Introduction—Software comparison





- LDT by MatLab

Simulation and reconstructed with Kalman Filter with linear approximation

O(10 minutes)

as result check

- Fast Software by Python

Analytic calculation based on least square method

O(1 minutes), more flexible

as main optimization tools

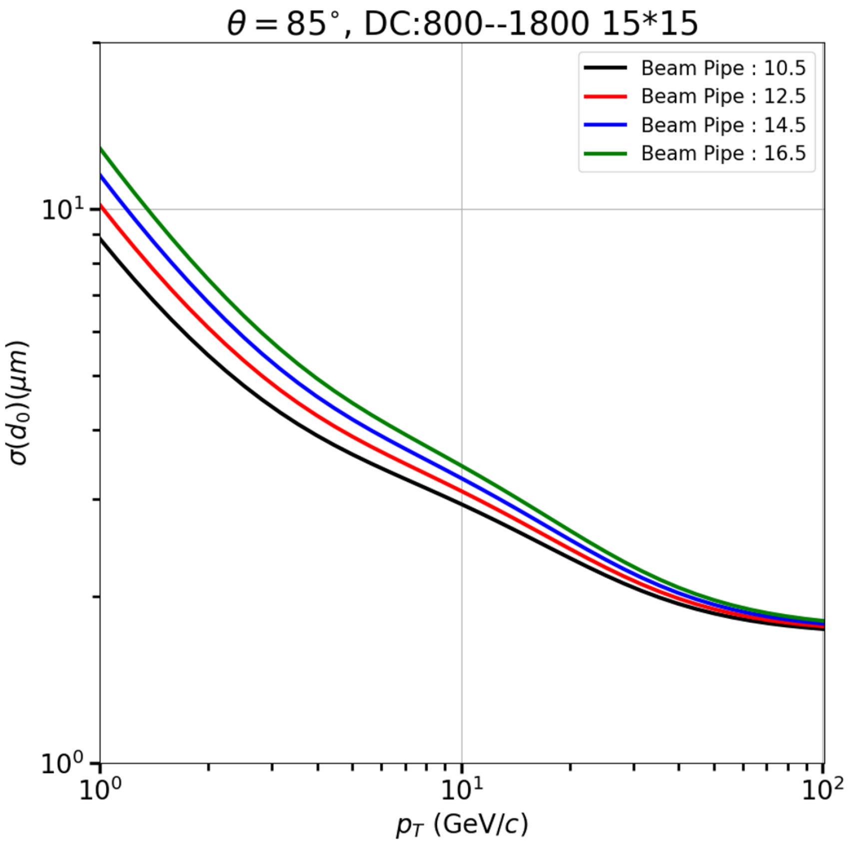
LDT Ref : HEPHY-PUB-863/08. Version 2.0 - 5 June 2008

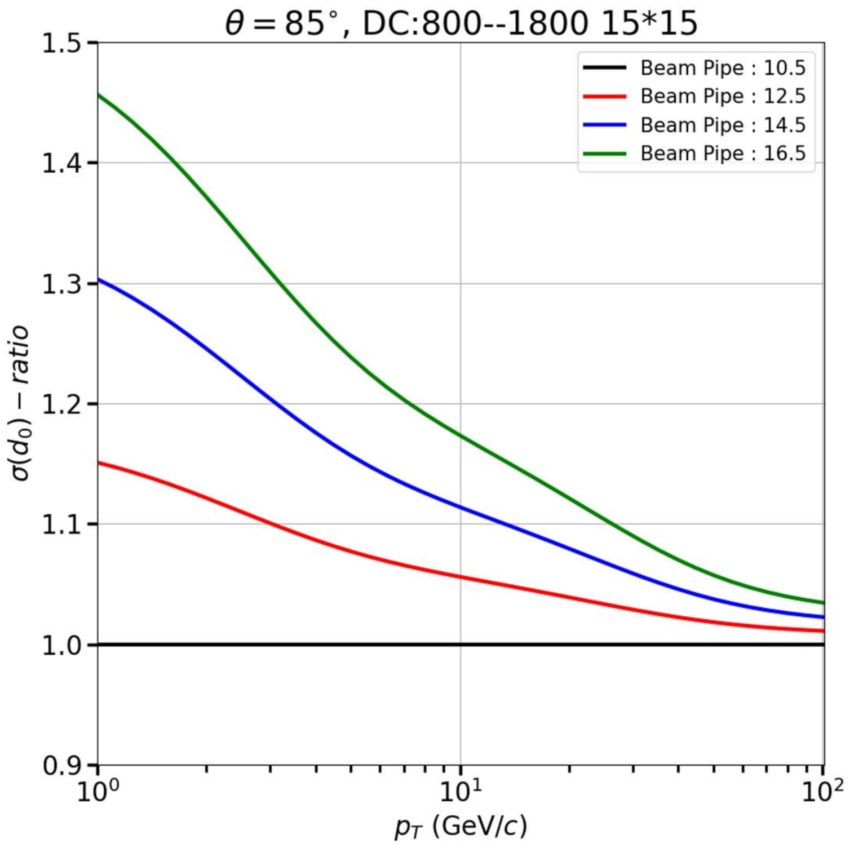
Ref : Nuclear Inst. and Methods in Physics Research, A 910 (2018) 127–132

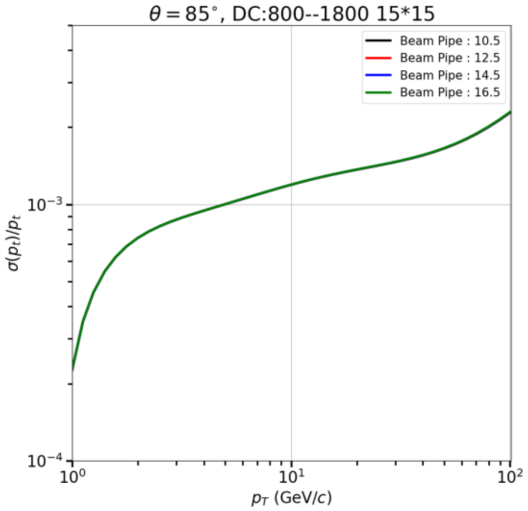
2. Initial tracker parameters

Layers	Radius(mm)	$\sigma_{R\phi}$(mu)	σ_Z(mu)	Thickness(1%/X_0)
Beam Pipe	14.5	-	-	0.15
VTX	Six layers	2.8/6/4/4/4/4	2.8/6/4/4/4/4	0.10
Support of VTX layers	-	-	-	0.10
VTX-shell	One layer	-	-	0.15
SITs	Three layers	7.2/7.2/7.2	86.6/86.6/86.6	0.65
DC inner shell	One layer	-	-	0.104
DC wires (15x15mm) and gas	800 – 1800	100	2828	0.0081+0.00413
DC outer shell	1803.0	-	-	1.346
SET	1811.0	7.2	86.6	0.65

2.1 Beam Pipe – Radius changed

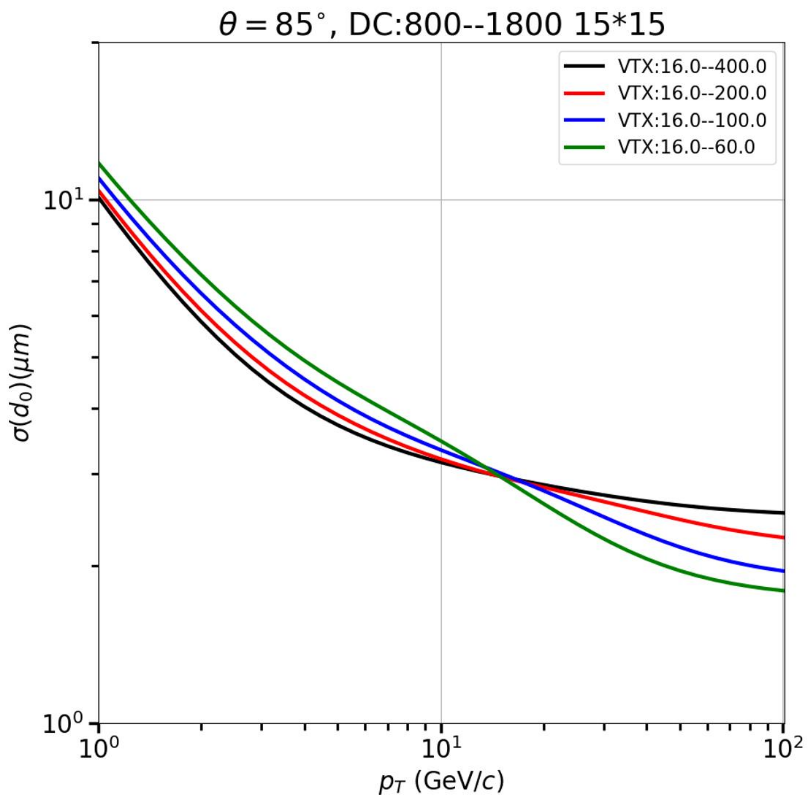


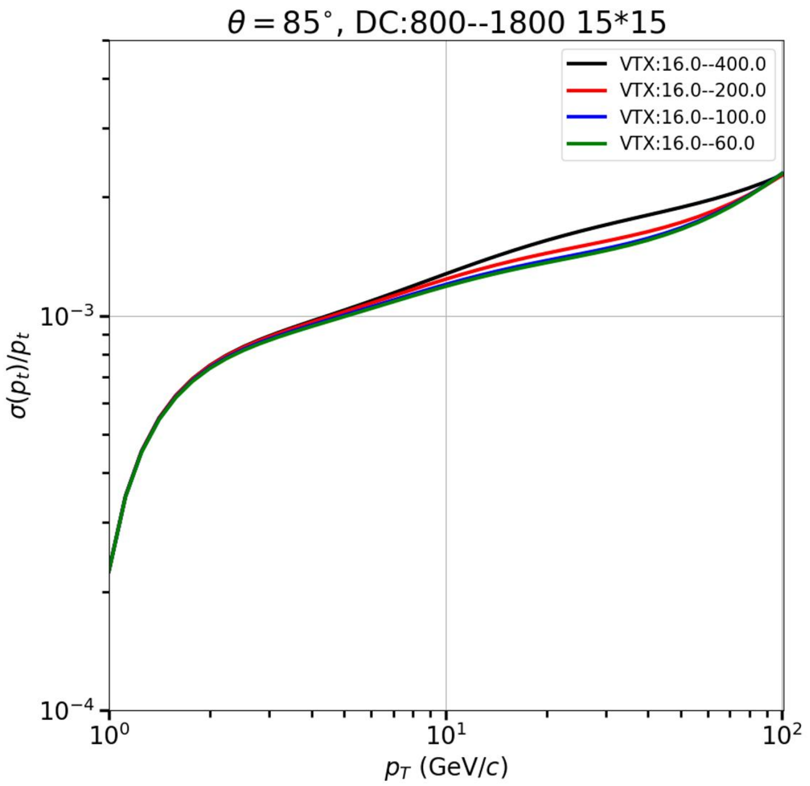




- Inward Beam Pipe, better $\sigma(d_0)$

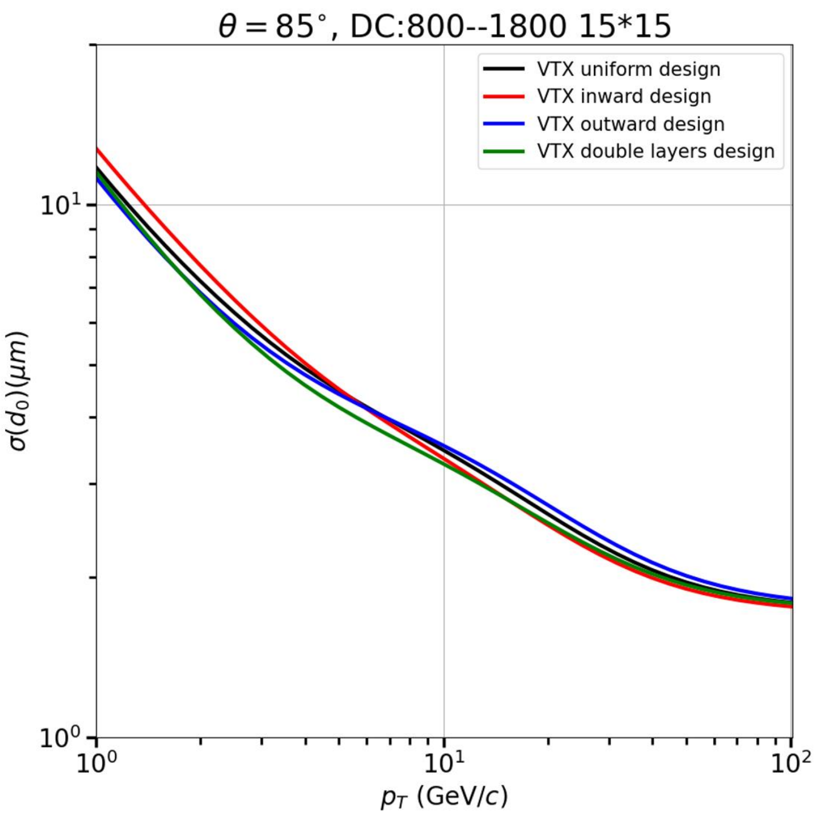
2.2 VTX – Inner radius fixed, changing Rout

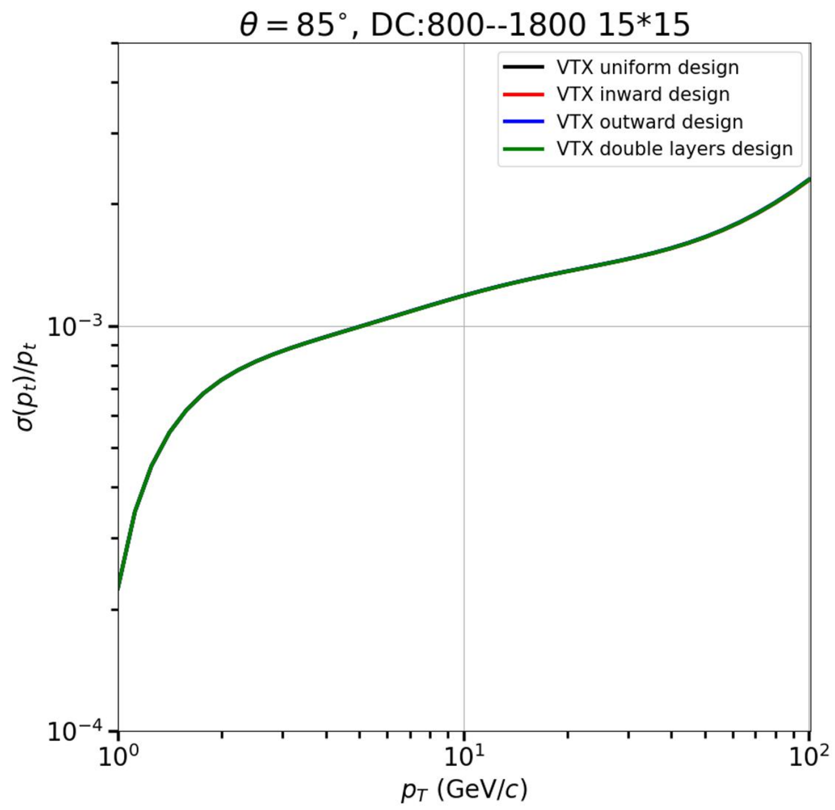




- Smaller Rout, a little worse $\sigma(d_0)$ at low Pt, but much better at high Pt
- Smaller Rout, better $\sigma(P_t)/P_t$
- Smaller Rout, less silicon cost
- 16.0 – 60.0 mm is recommended

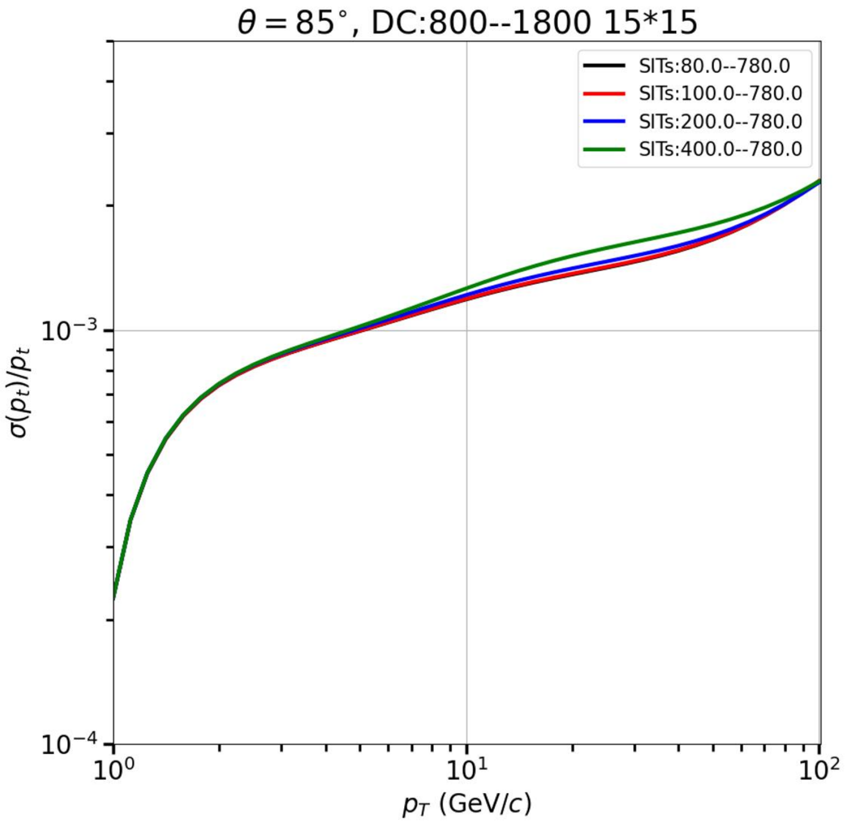
2.2 VTX – Changing layout with Rin – Rout = 16 – 60 mm

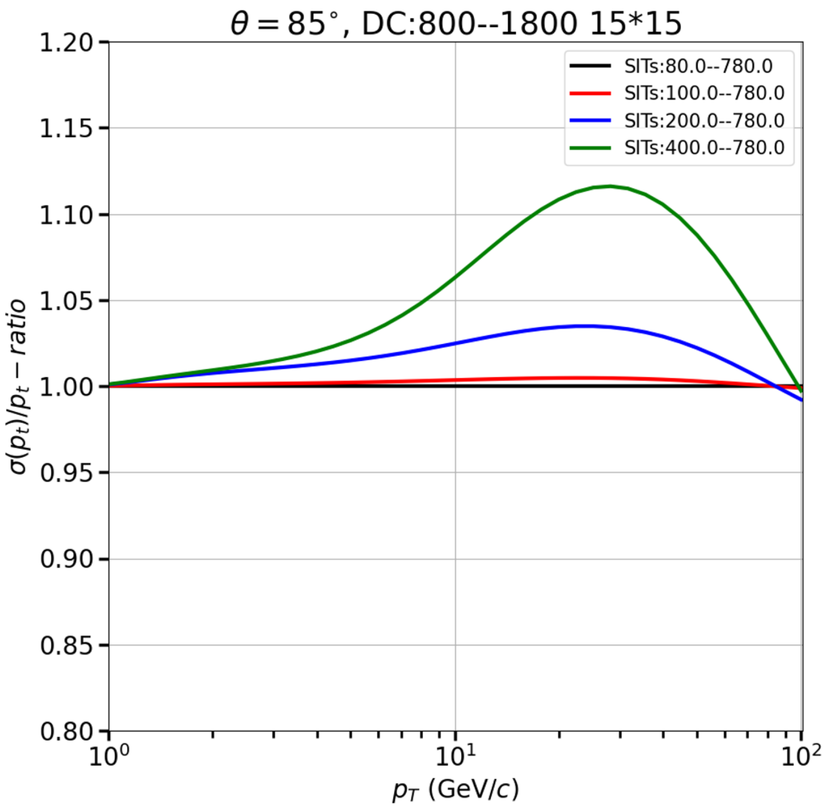


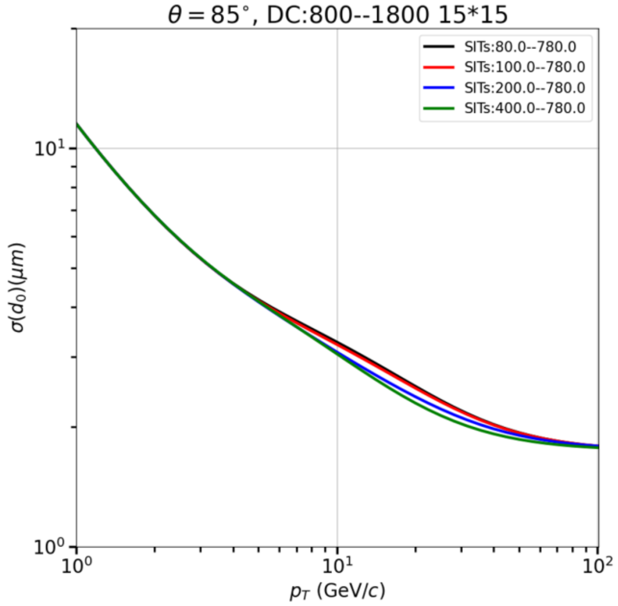


- Double layers design, less material of supports
- Double layers design, better $\sigma(d_0)$
- Little influence on $\sigma(P_t)/P_t$
- Double layers and equally spacing are favored

2.3 SIT – Outer radius fixed, changing Rin

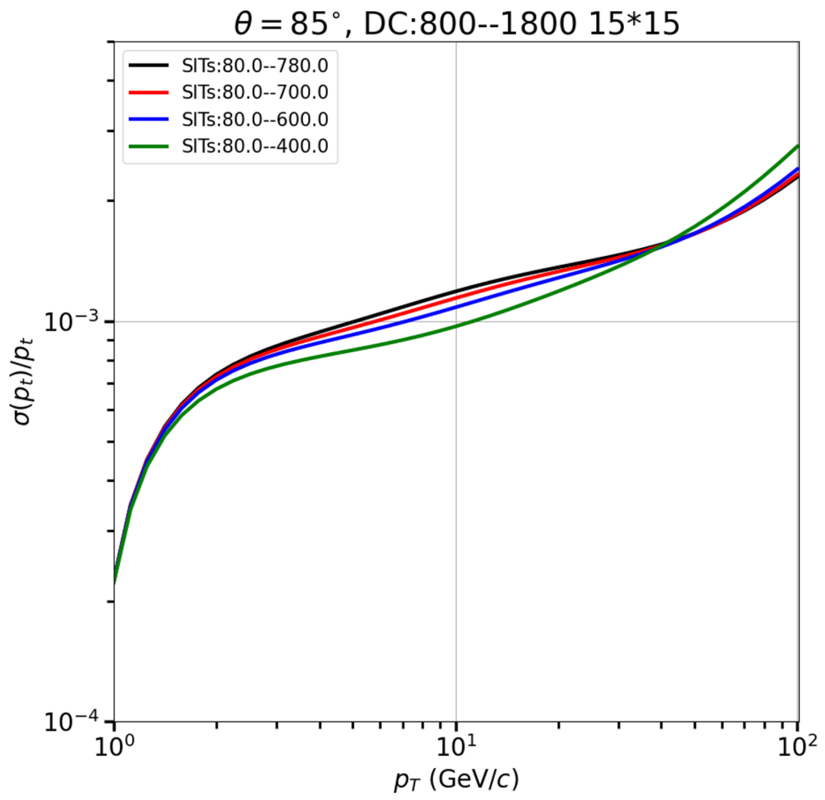


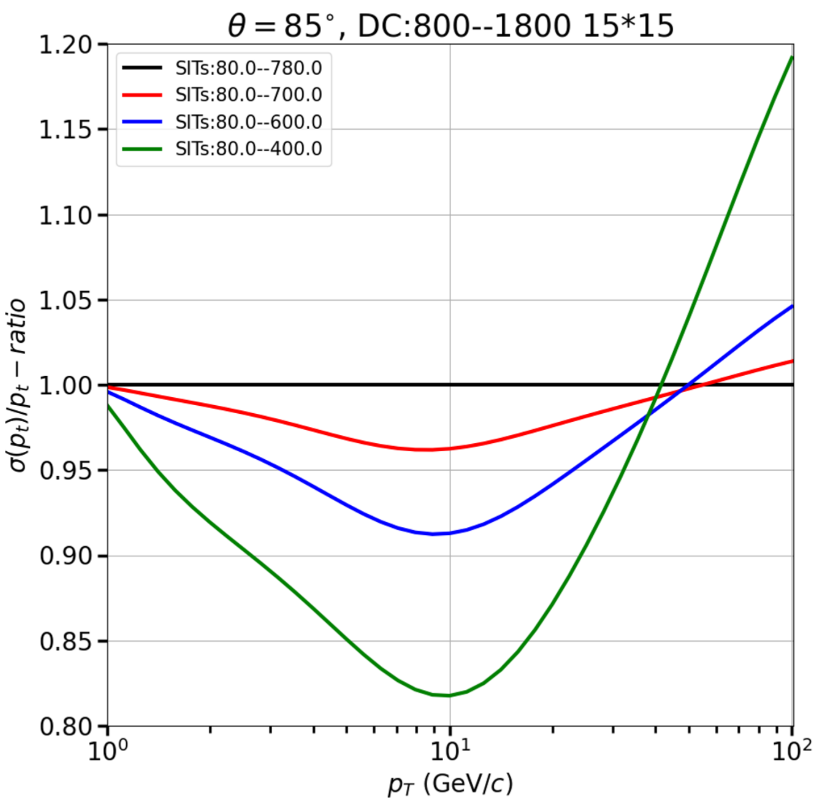


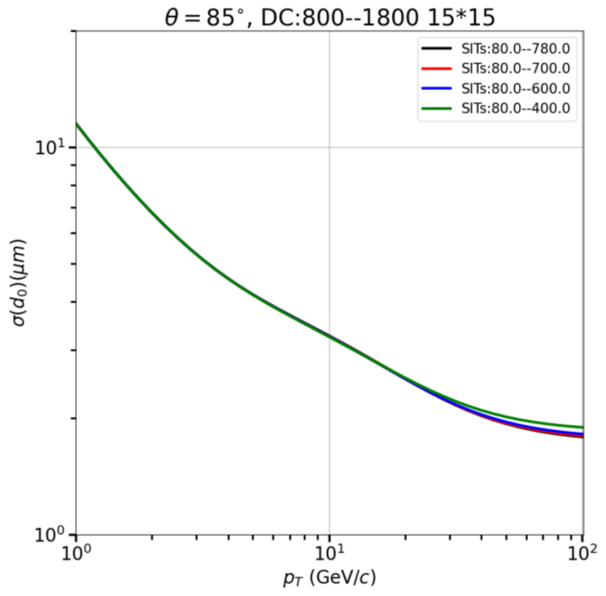


- Smaller Rin, better $\sigma(P_t)/P_t$ except very high Pt
- Smaller Rin, a little bit worse $\sigma(d_0)$
- Smaller Rin, less cost
- 80.0 mm is recommended

2.3 SIT – Inner radius fixed, changing Rout

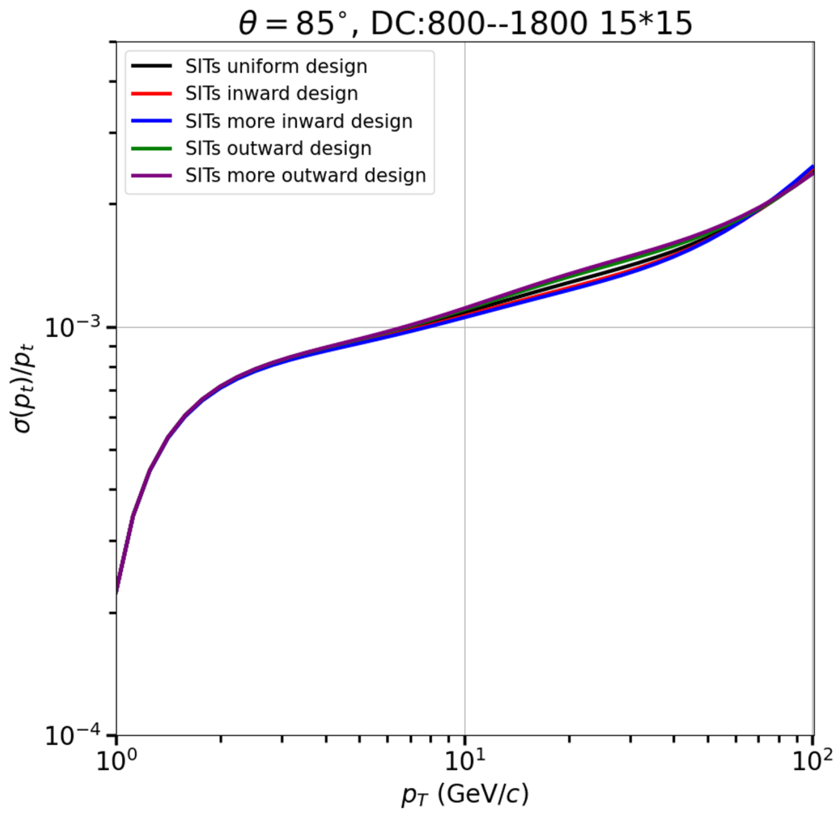


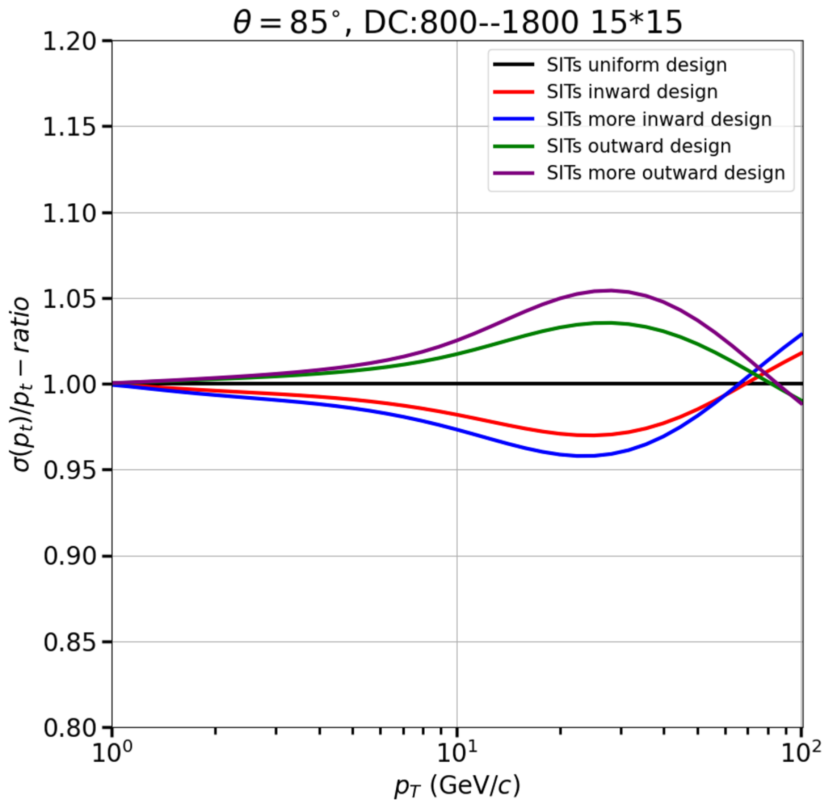


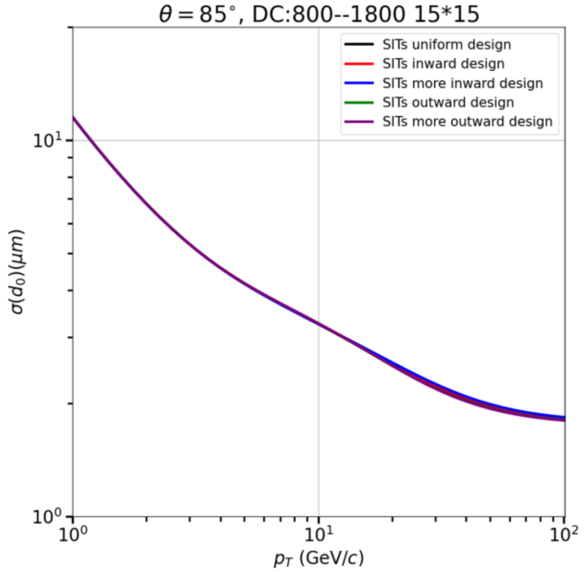


- Smaller Rout, better $\sigma(P_t)/P_t$ at intermediate Pt
- Smaller Rout, slightly worse $\sigma(d_0)$
- Smaller Rout, less cost
- 80.0 – 600.0 mm is recommended

2.3 SIT – Changing layout (position of mid-layer) with Rin – Rout = 80 – 600 mm

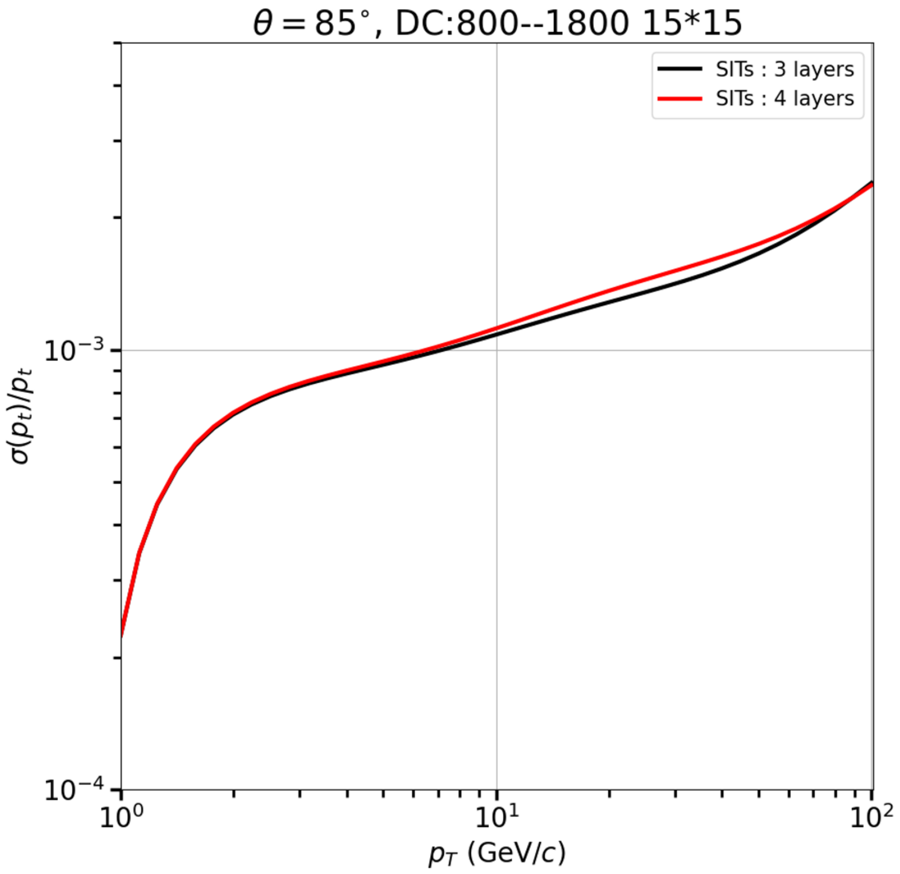


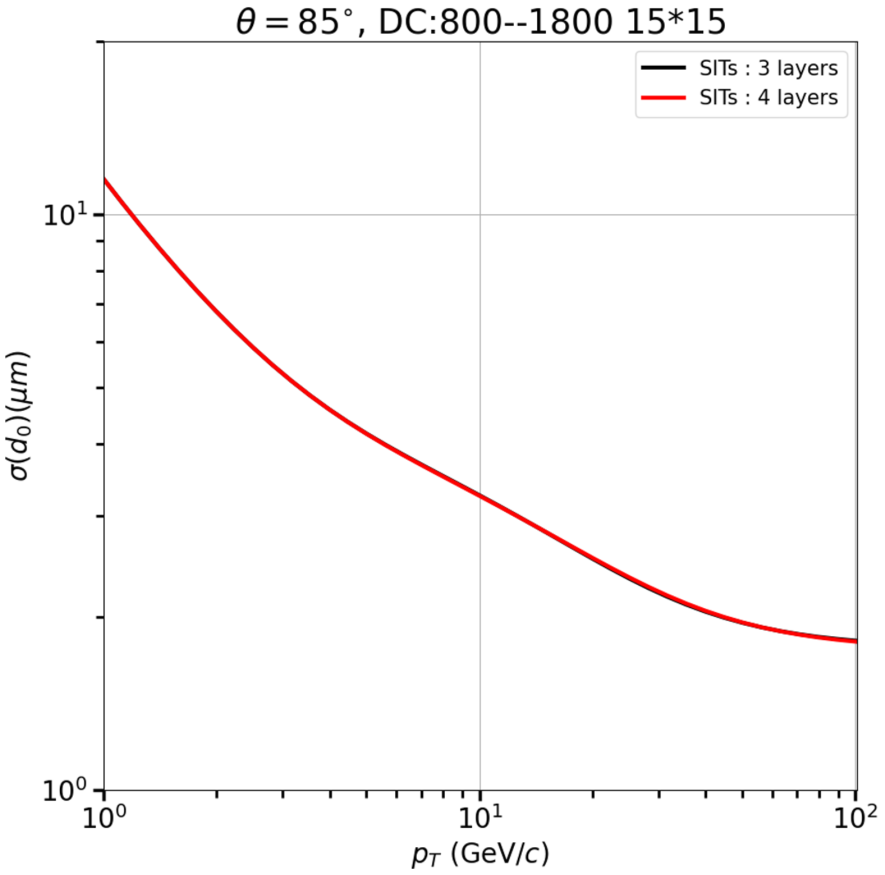




- Inward layout, better $\sigma(P_t)/P_t$ except > 50 GeV
- Little influence on $\sigma(d_0)$
- Inward design is favored

2.3 SIT – Add one more layer



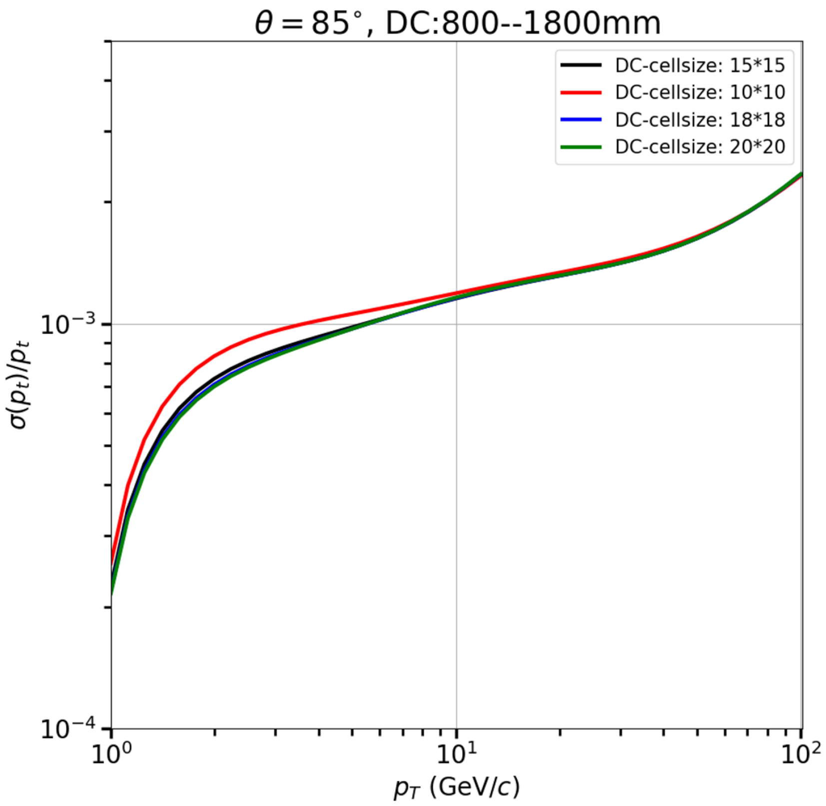


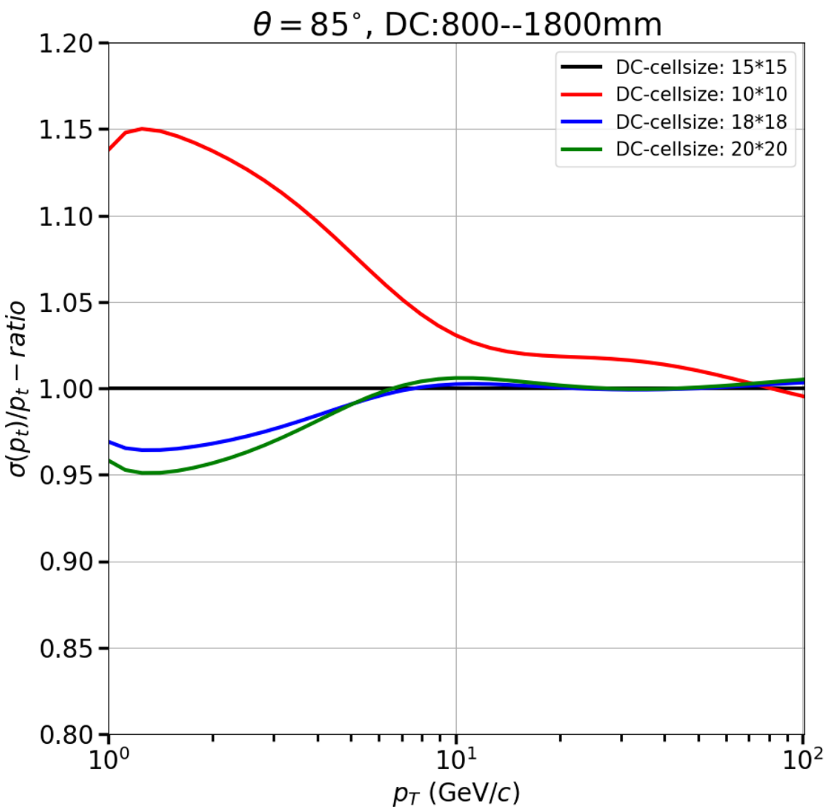
- More material & more multiple-scattering
- No improvement to $\sigma(P_t)/P_t$ & $\sigma(d_0)$
- No need add one more layer

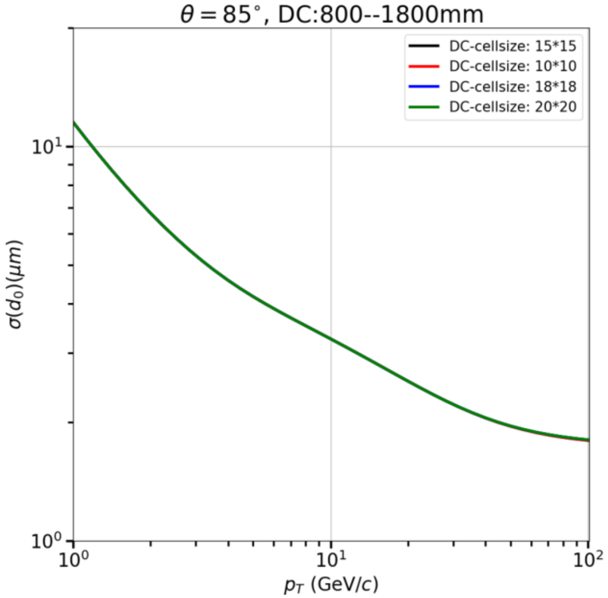
2.4 DC – Volume

- Mainly determined by PID
- δR >= 1.0 m
- Keep 800 – 1800 mm by now
- To be updated following with PID study

2.4 DC – Cell-size

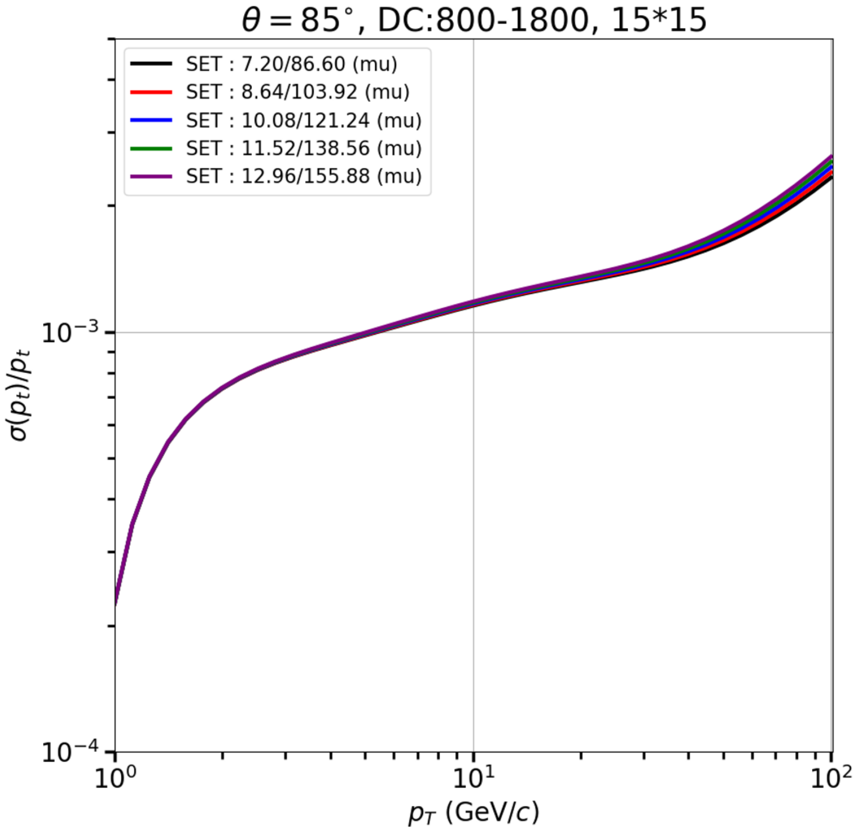


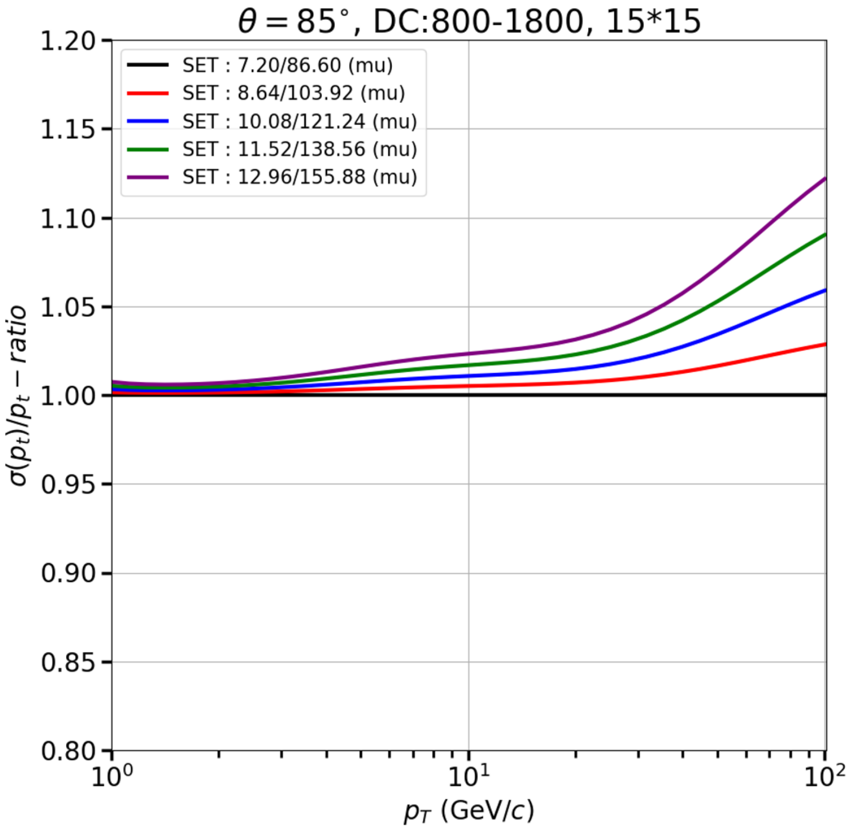


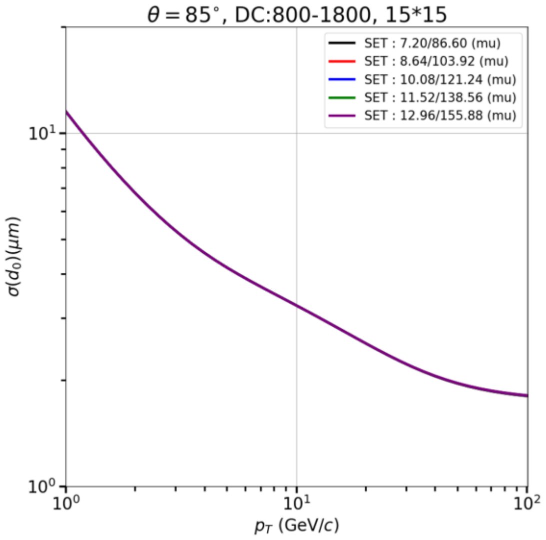


- Larger cell-size, less material & less multiple-scattering → better $\sigma(P_t)/P_t$ at low Pt
- Larger cell-size, easier engineering
- Hardly affects $\sigma(d_0)$
- Larger cell-size favored

2.5 SET – Resolution







- Little effect on $\sigma(P_t)/P_t$ when spatial resolution getting worse
- No influence on $\sigma(d_0)$
- Less cost when loosing the requirement on spatial resolution
- Could take larger pixel size

3. Summary

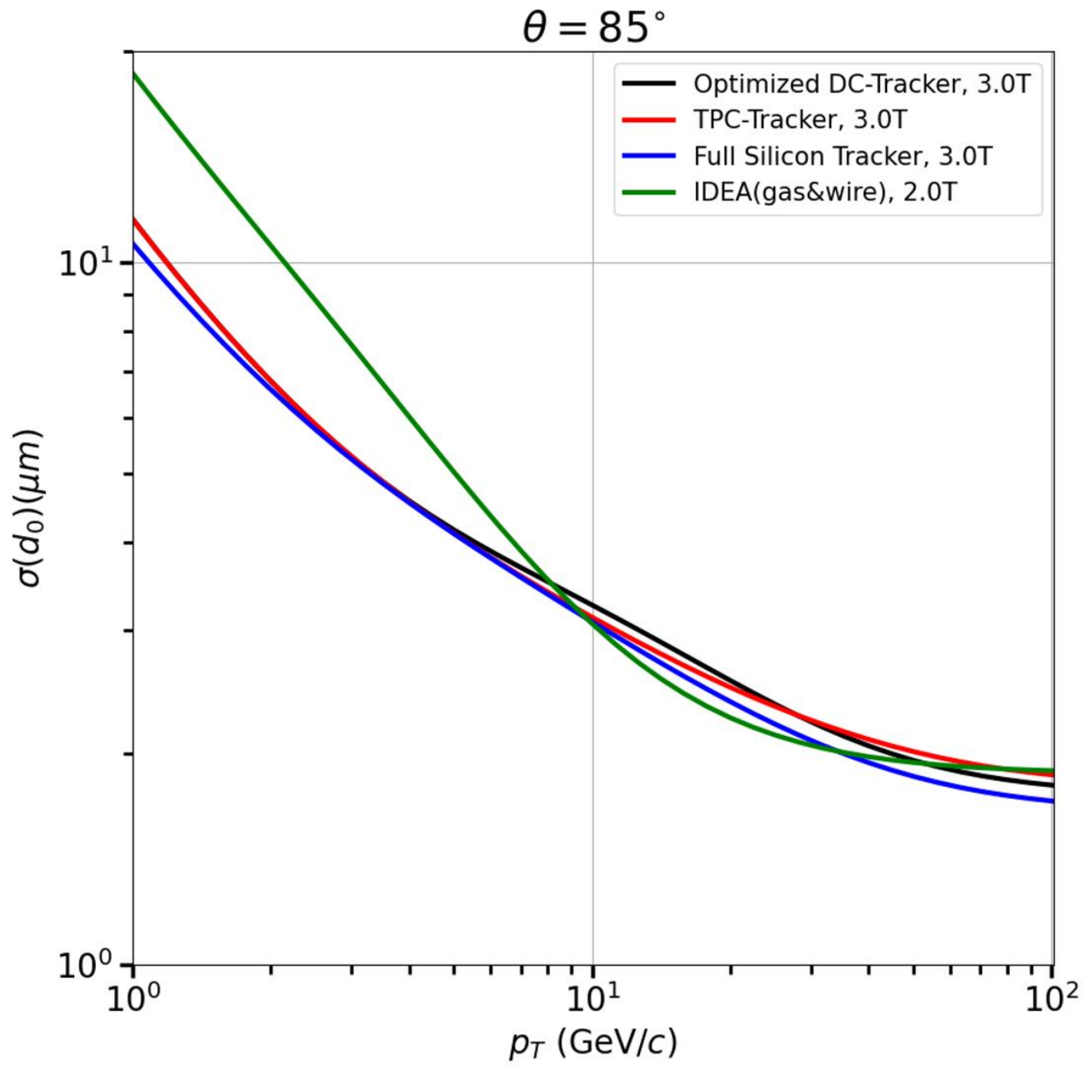
Tracker layout optimization gives some preliminary recommendations :

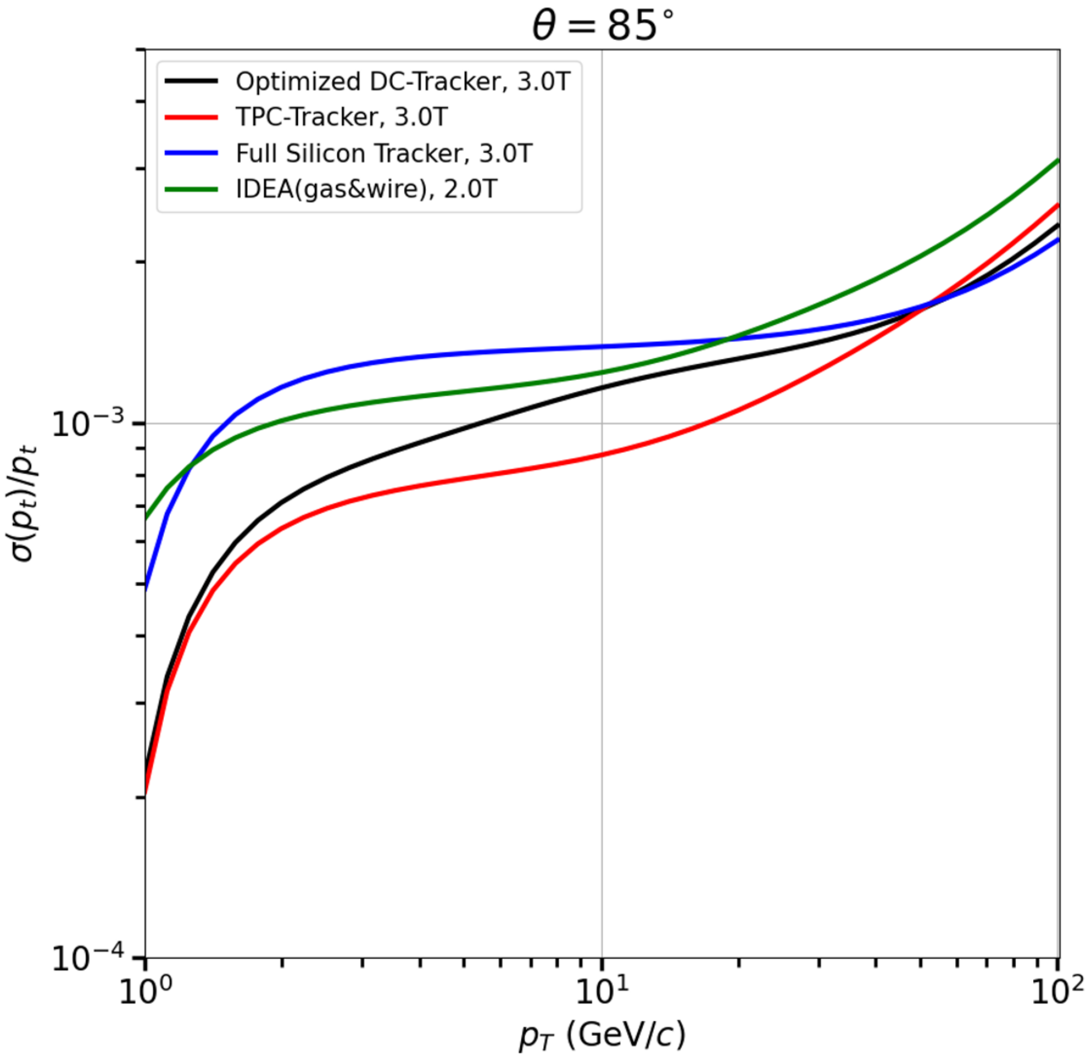
- Beam Pipe
  - Smaller radius of beam pipe gets better $\sigma(d_0)$
- VTX
  - Smaller Rin & Rout of the VTX get better $\sigma(d_0)$ and $\sigma(P_t)/P_t$
  - Double layers design favored
  - Corresponding to previous research
- SIT
  - Favors smaller Rin & Rout, and inward layout
- Drift chamber
  - Volume determined by PID
  - Tracking favors larger cell-size
- SET
  - The requirement on spatial resolution could be loosed

3. Summary – Optimized DC-Tracker

Layers	Radius(mm)	$\sigma_{R\phi}$(mu)	σ_Z(mu)	Thickness($1\%/X_0$)
Beam Pipe	14.5	-	-	0.15
VTX	16/18/37/39/58/60	2.8/6/4/4/4/4	2.8/6/4/4/4/4	0.10
Support for each VTX layer	-	-	-	0.10
VTX-shell	65.0	-	-	0.15
SITs	80/316/790	7.2/7.2/7.2	86.6/86.6/86.6	0.65
DC inner shell	798	-	-	0.104
DC wires (18*18mm) and gas	800 -- 1800	100	2828	0.00972+0.00344
DC outer shell	1803.0	-	-	1.346
SET	1811.0	7.2	86.6	0.65

3. Summary – Comparing different designs





Thanks

Backup

1. Analytic calculation

$$\chi^2 = (\boldsymbol{y} - \boldsymbol{G}\boldsymbol{a})^{\boldsymbol{T}} \boldsymbol{W} (\boldsymbol{y} - \boldsymbol{G}\boldsymbol{a})$$

$$\boldsymbol{W} = \boldsymbol{C}_{\boldsymbol{y}}^{-\mathbf{1}}$$

$$\boldsymbol{C}_{\boldsymbol{a}} = \left(\boldsymbol{G}^{\boldsymbol{T}} \boldsymbol{C}_{\boldsymbol{y}}^{-\mathbf{1}} \boldsymbol{G}\right)^{-\mathbf{1}}$$

$$f(x) = F(a_i, x)$$

$$\boldsymbol{G}_{\boldsymbol{mn}} = \frac{\partial F(a_i, x_n)}{\partial a_m}$$

$$x = d_0 \cos\phi + R[\cos\phi - \cos(\phi + \varphi)]$$

$$y = d_0 \sin\phi + R[\sin\phi - \sin(\phi + \varphi)]$$

$$z = z_0 - R \tan\lambda \cdot \varphi$$

$$xy_{meas} = r \cdot \tan^{-1}\frac{y}{x}$$

$$z_{meas} = z$$

<u>If the xy_{meas} is used parabolic not helix function to fit :</u>

For RES only :

$$\frac{\Delta P_t}{P_t} \propto a P_t$$

$$\Delta d_0 \propto a$$

$$\Delta z_0 \propto a$$

$$\Delta \theta \propto a$$

$$\Delta \phi \propto a$$

For M.S. only :

$$\frac{\Delta P_t}{P_t} \propto b$$

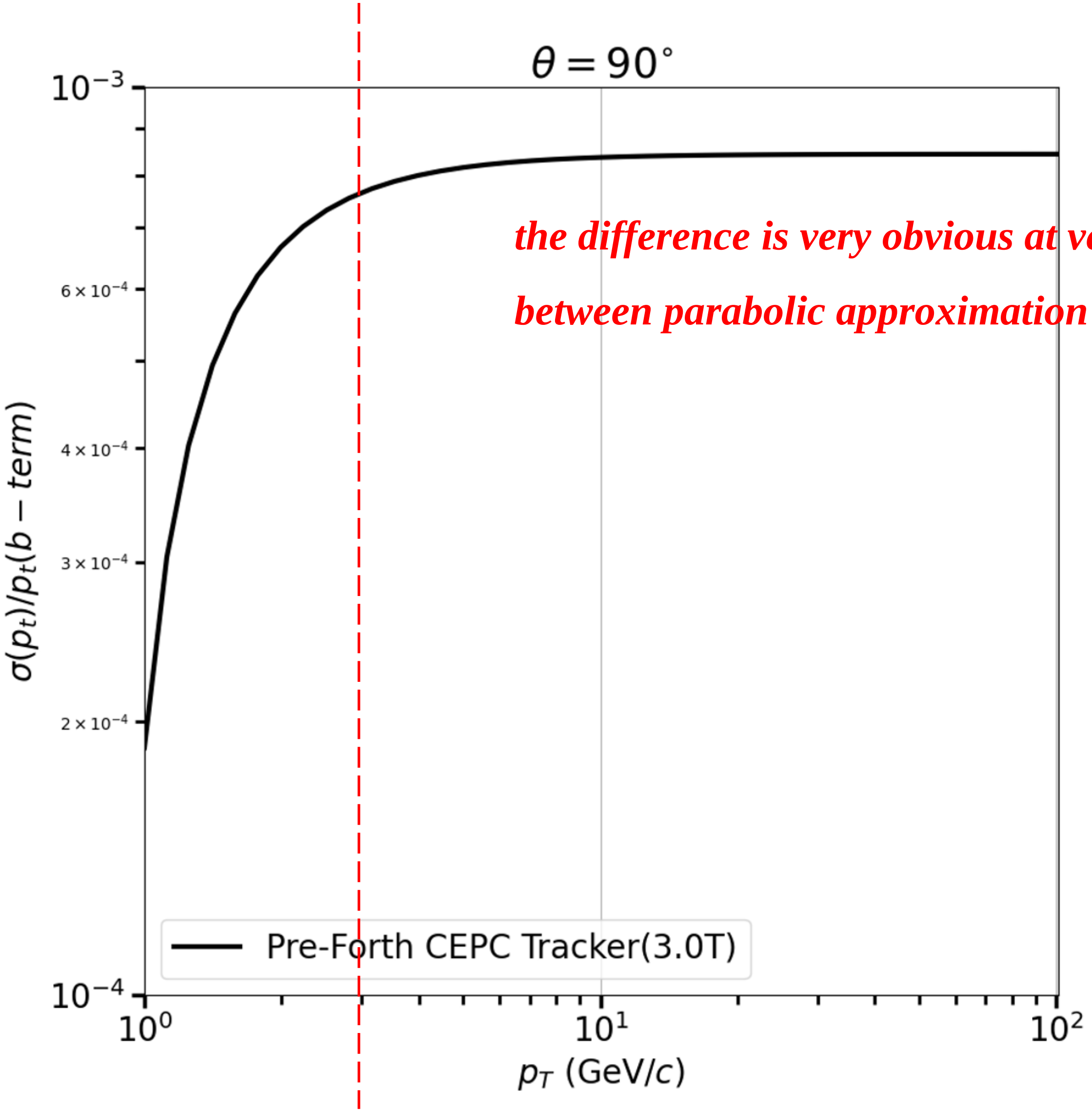
$$\Delta d_0 \propto \frac{b}{P_t}$$

$$\Delta z_0 \propto \frac{b}{P_t}$$

$$\Delta \theta \propto \frac{b}{P_t}$$

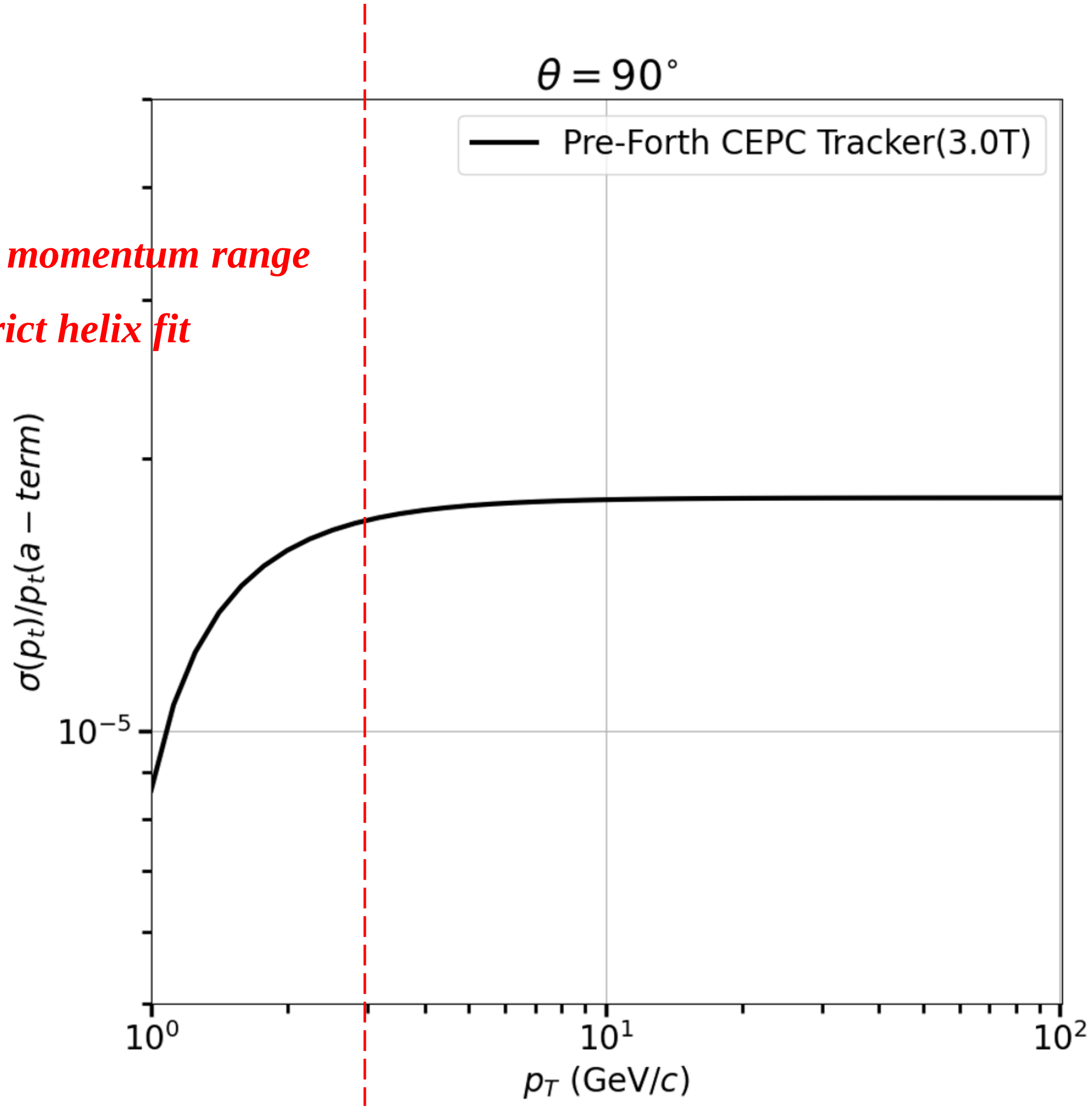
$$\Delta \phi \propto \frac{b}{P_t}$$

1. Analytic calculation



the difference is very obvious at very low momentum range

between parabolic approximation and strict helix fit



2. Geometry – TPC-Tracker

Layers	Radius(mm)	$\sigma_{R\phi}$(mu)	σ_Z(mu)	Thickness($1\%/X_0$)
Beam Pipe	14.5	-	-	0.15
VTX	16/18/37/39/58/60	2.8/6/4/4/4/4	2.8/6/4/4/4/4	0.15
VTX-shell	65.0	-	-	0.15
SIT	153/300	7.0/7.0	7.0/7.0	1.30
TPC inner shell	329	-	-	0.51
TPC (220 space points)	384 -- 1716	100	1000	0. 005194
TPC outer shell	1808	-	-	0.518
SET	1811.0	7.0	7.0	1.30

2. Geometry – IDEA(GAS&WIRE)

Layers	Radius(mm)	$\sigma_{R\phi}$(mu)	σ_Z(mu)	Thickness(1%/X_0)
Beam Pipe	15.0	-	-	0.59
VTX	17/23/31	3.0/3.0/3.0	3.0/3.0/3.0	0.299
SIT	320/340	7.0/7.0	7.0/7.0	0.502
DC inner shell	345	-	-	0.084
DC wires (112 layers) and gas	360 -- 2000	100	2828	0.0079+0.0042
DC outer shell	2020	-	-	1.200
SET	2040/2060	7.0/7.0	90.0/90.0	0.502

2. Geometry – Full Silicon Tracker

Layers	Radius(mm)	$\sigma_{R\phi}$(mu)	σ_Z(mu)	Thickness(1%/X_0)
Beam Pipe	14.0	-	-	0.15
VTX	16/25/37/38/58/59	2.8/4/4/4/4/4	2.8/4/4/4/4/4	0.15
Support for each VTX layer	-	-	-	-
VTX-shell	65.0	-	-	0.15
SIT	153/321/603	7.2/7.2/7.2	86.6/86.6/86.6	0.65
SET	1000/1410/1811	7.2/7.2/7.2	86.6/86.6/86.6	0.65