# Preliminary Optimization for the Forth CEPC Tracker

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## Outline

1. Introduction

2. Optimization for the Forth CEPC Tracker

    2.1 Beam Pipe

    2.2 Vertex detector

    2.3 Silicon Internal Tracker

    2.4 Drift Chamber

    2.5 Silicon External Tracker

3. Summary

# 1. Introduction—CEPC Physics requirements

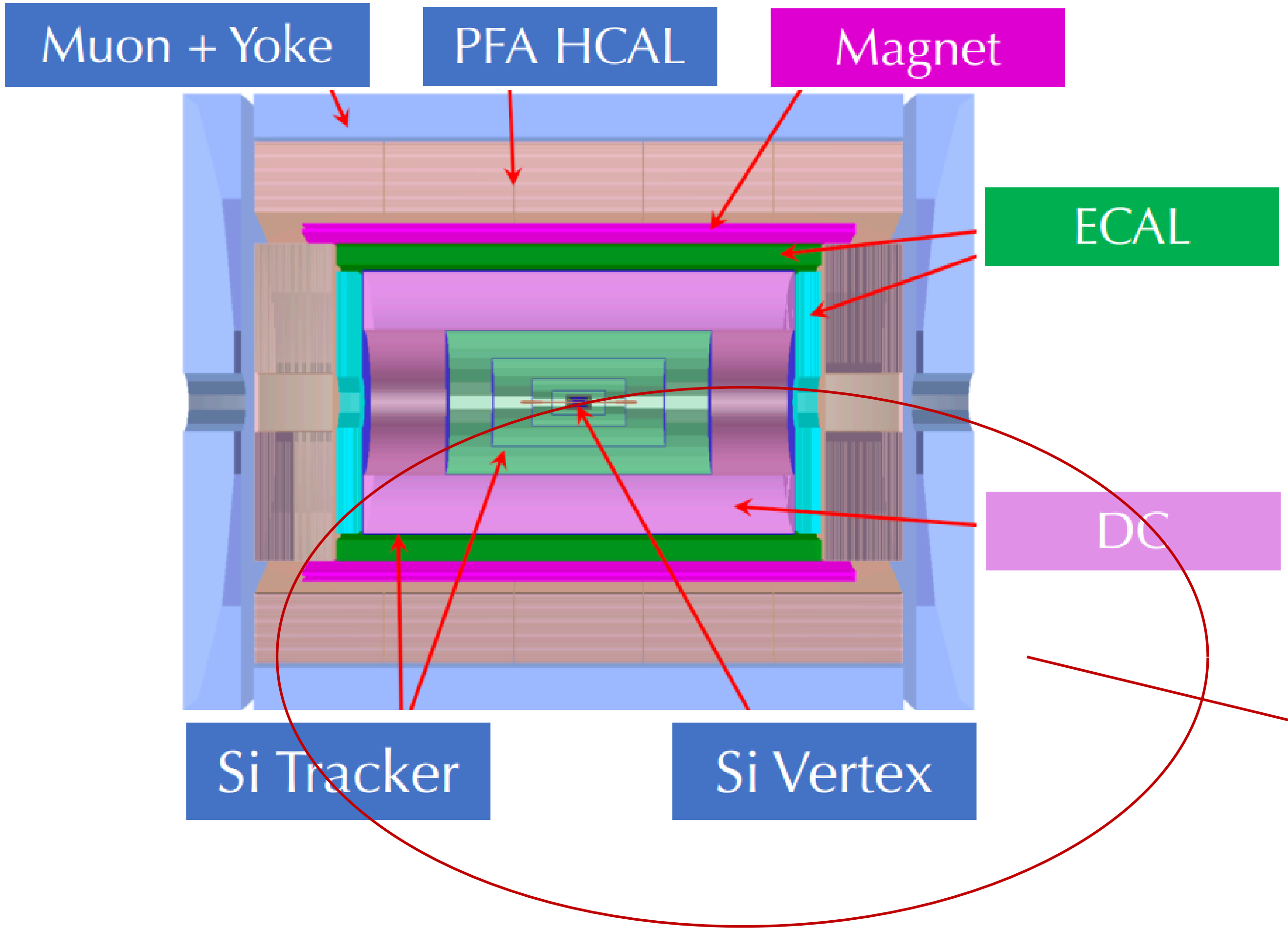
- Higgs physics

| Physics process | Measurands | Detector subsystem | Performance requirement |
|---|---|---|---|
| $ZH, Z \to e^+e^-, \mu^+\mu^-$ <br> $H \to \mu^+\mu^-$ | $m_H, \sigma(ZH)$ <br> $\mathrm{BR}(H \to \mu^+\mu^-)$ | 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 <br> HCAL | $\sigma_E^{\mathrm{jet}}/E = 3 \sim 4\%$ 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 $2\sigma$ 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 $\pi_0/\gamma$ reconstruction
- Solenoid magnet between HCAL and ECAL

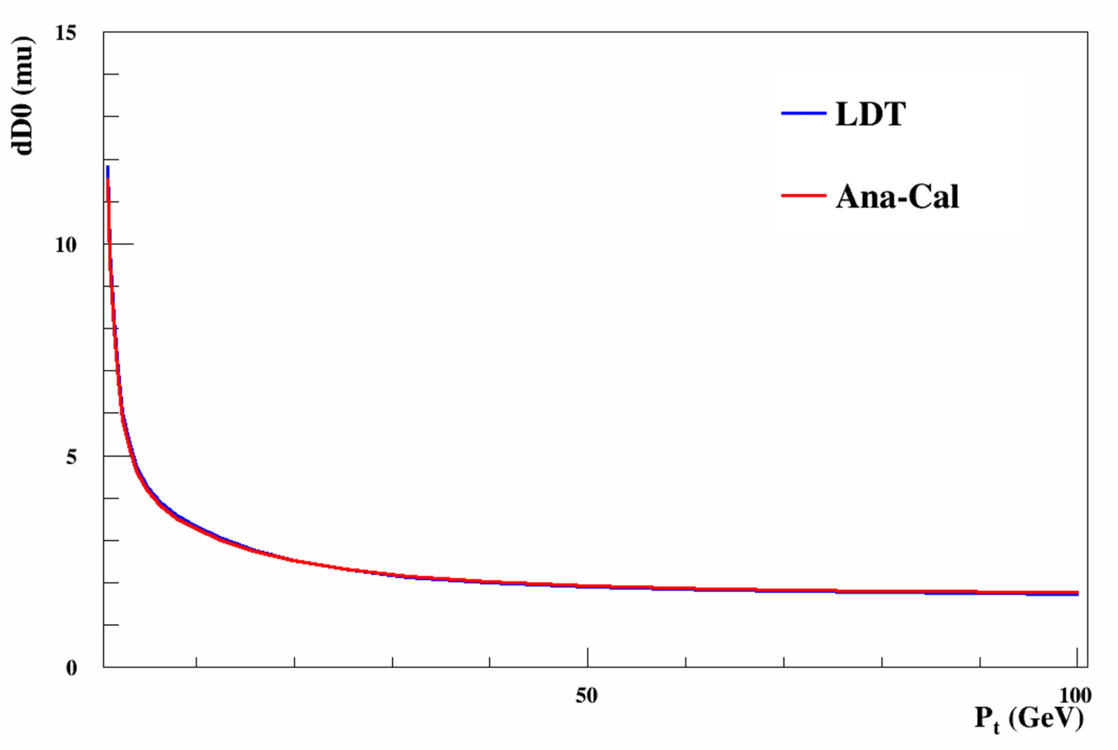
Motivation :

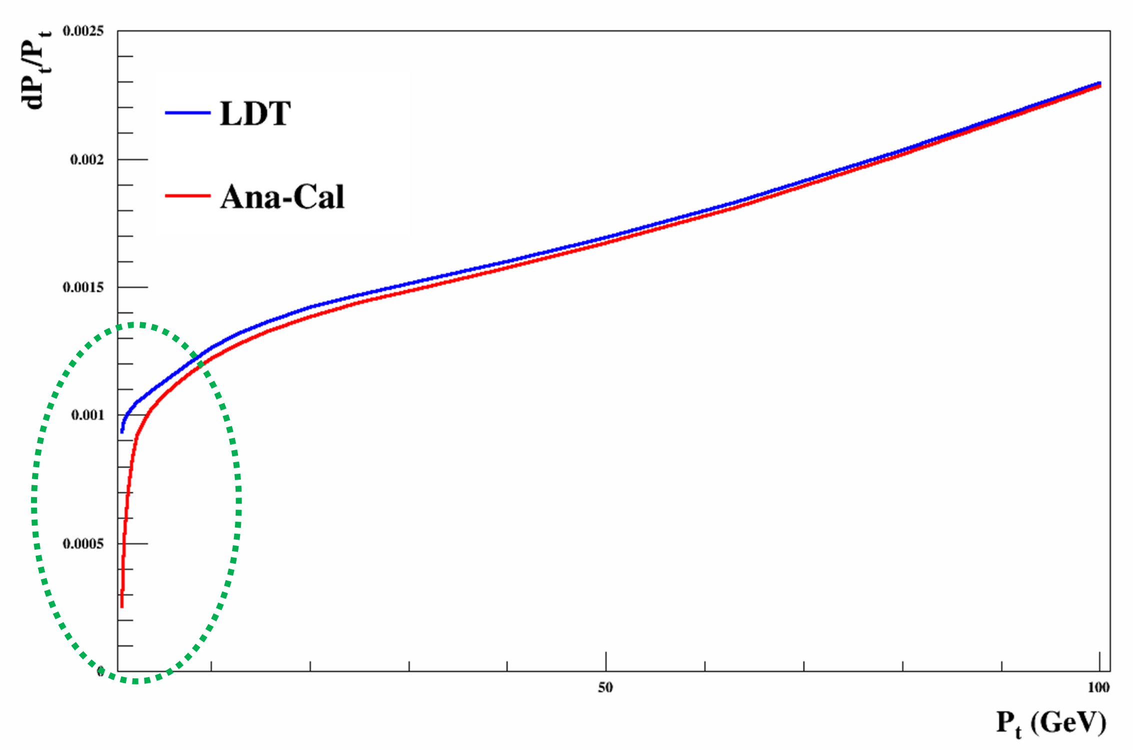
To change the layout and measure the resolution of $d_0$ & $P_t$ as good as possible

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

*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

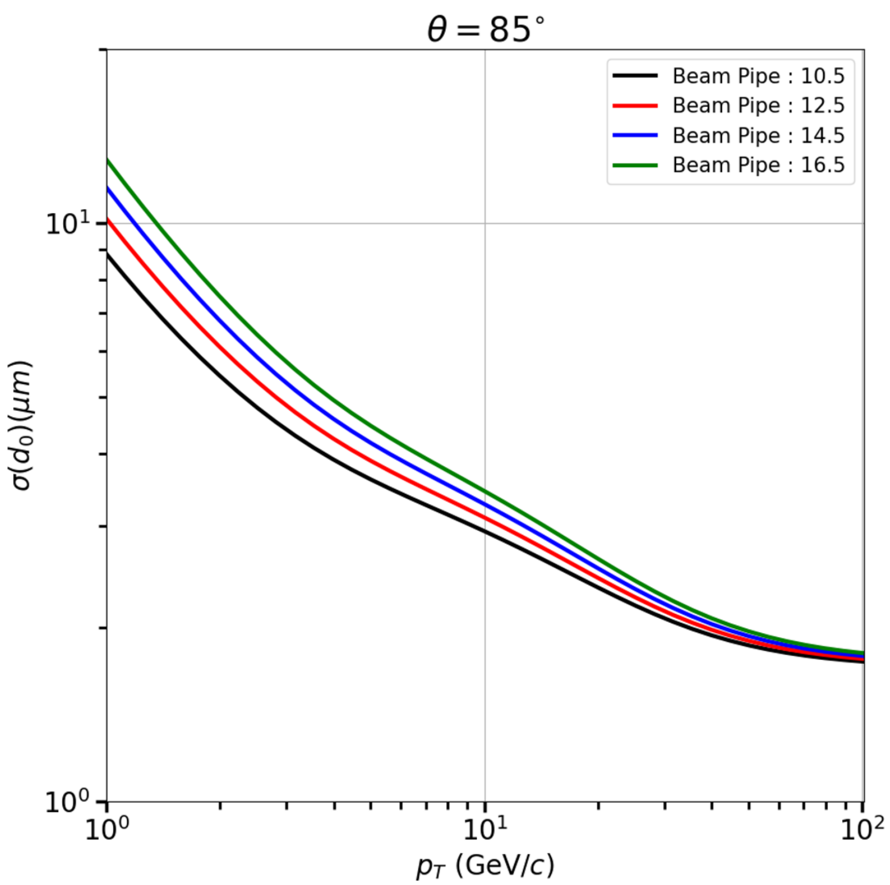
*LDT Ref : HEPHY-PUB-863/08. Version 2.0 - 5 June 2008*

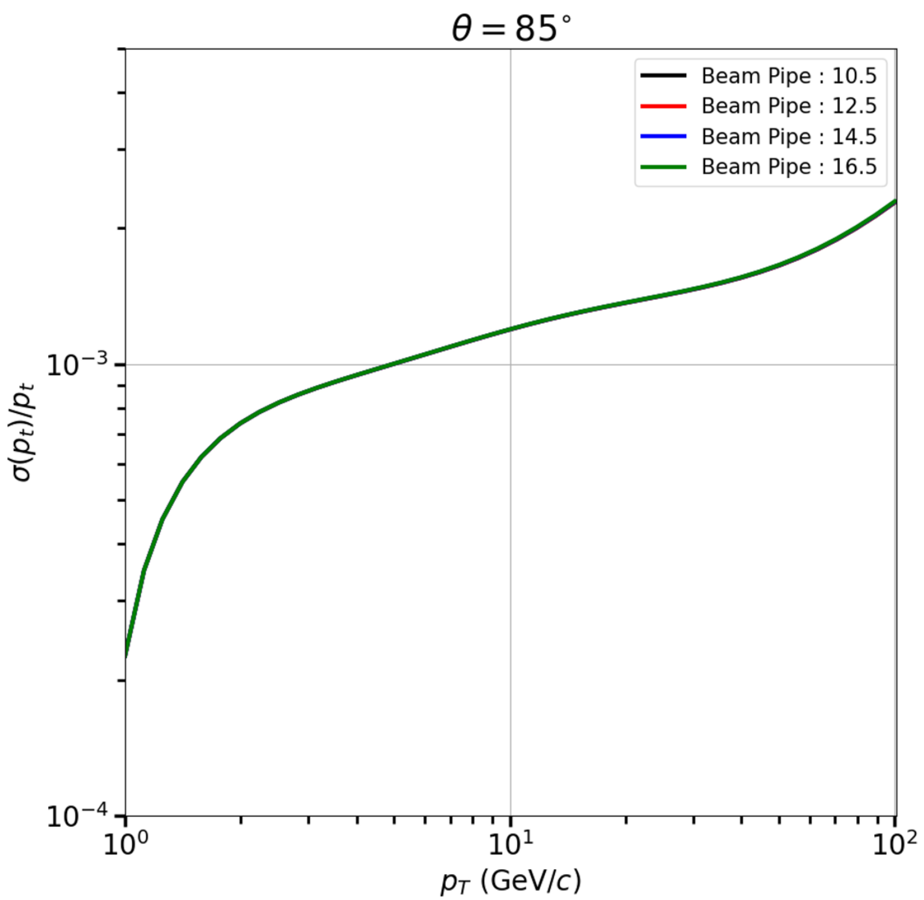
*Ref : Nuclear Inst. and Methods in Physics Research, A 910 (2018) 127–132*

# 2. Initial tracker parameters

| Layers | Radius(mm) | $\sigma_{R\phi}$(mu) | $\sigma_Z$(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 |

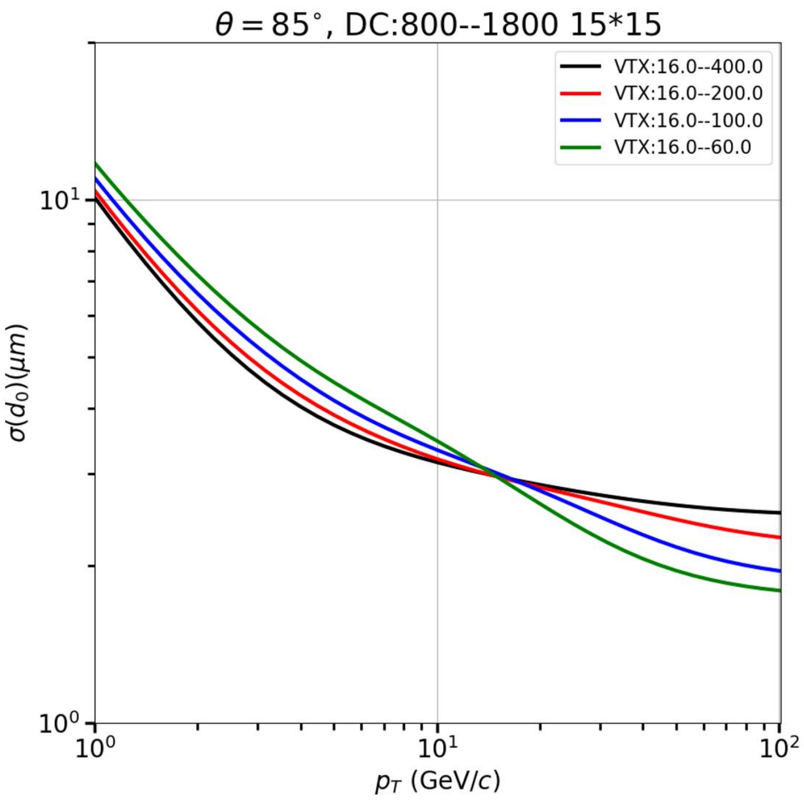
# 2.1 Beam Pipe – Radius changed

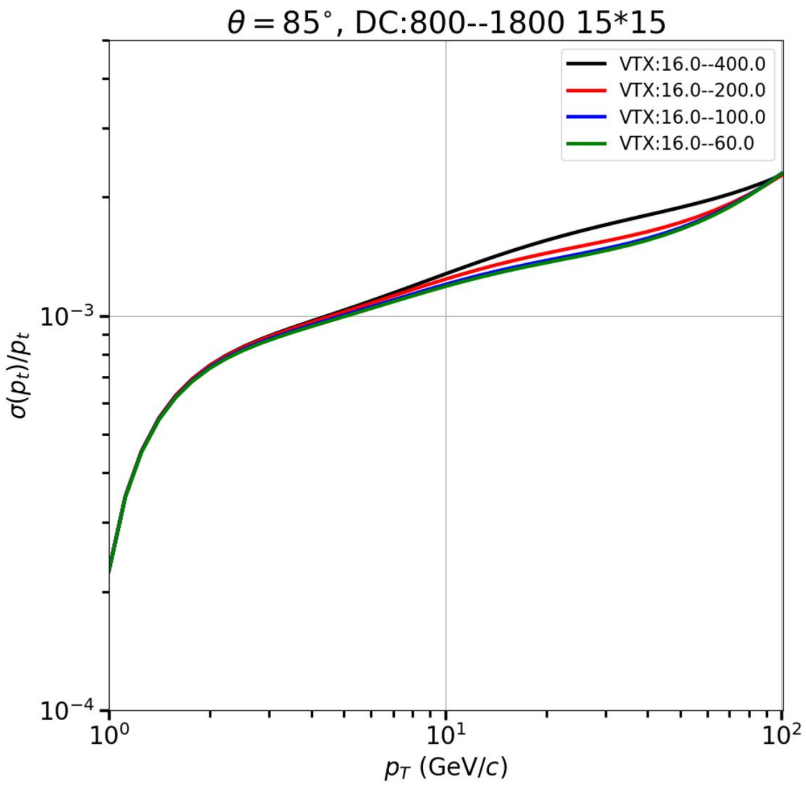



- Inward Beam Pipe, better $\sigma(d_0)$

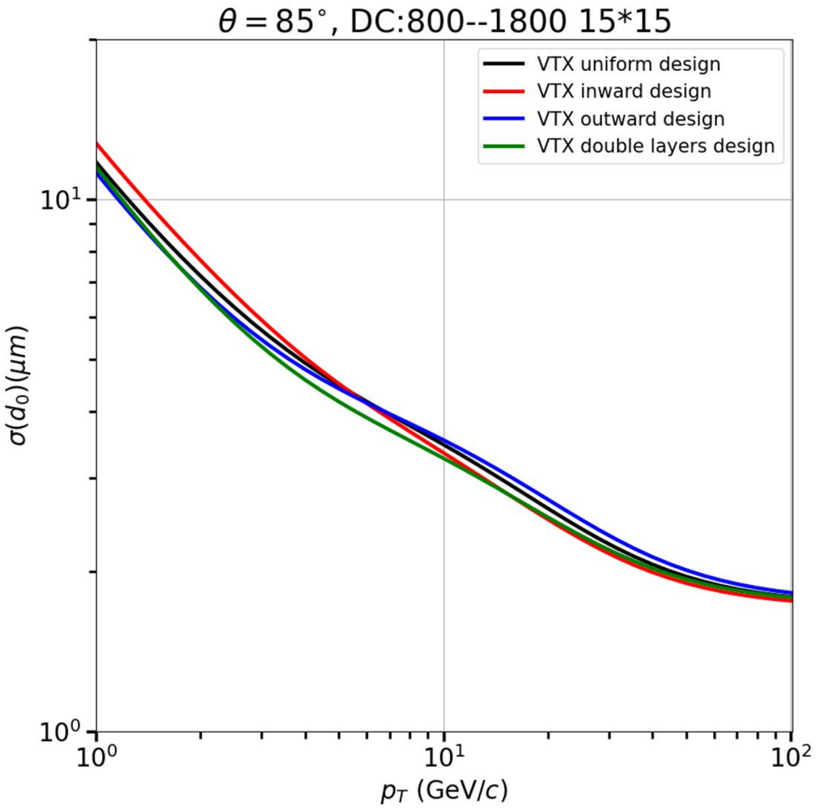
# 2.2 VTX – Inner radius fixed, changing Rout

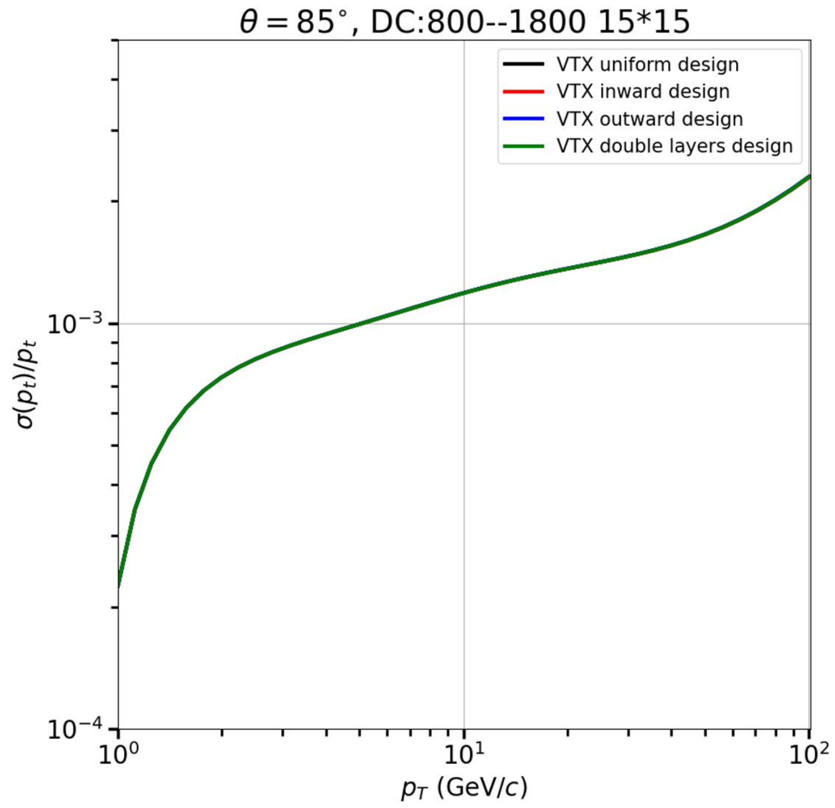



- Smaller Rout, a little worse $\sigma(d_0)$ at low Pt, but much better at high Pt
- Smaller Rout, better $\sigma(P_t)/P_t$
- Smaller Rout, less silicon cost
- 16.0 – 60.0 mm is recommended

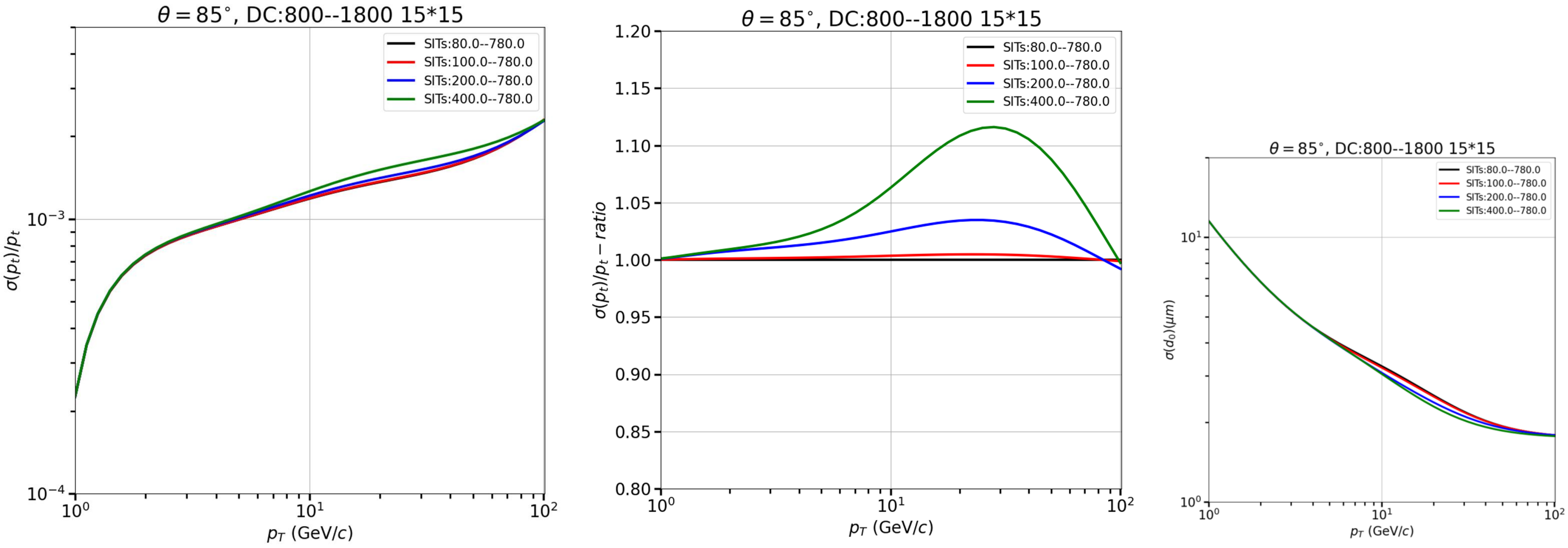
# 2.2 VTX – Changing layout with Rin – Rout = 16 – 60 mm



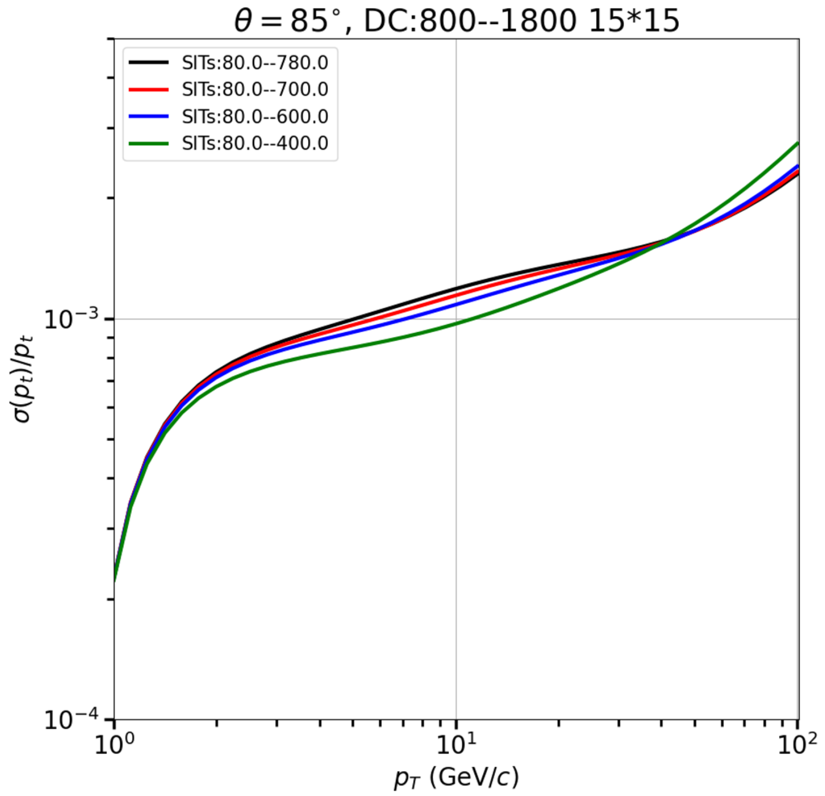

- Double layers design,  less material of supports
- Double layers design, better $\sigma(d_0)$
- Little influence on $\sigma(P_t)/P_t$
- Double layers and equally spacing are favored

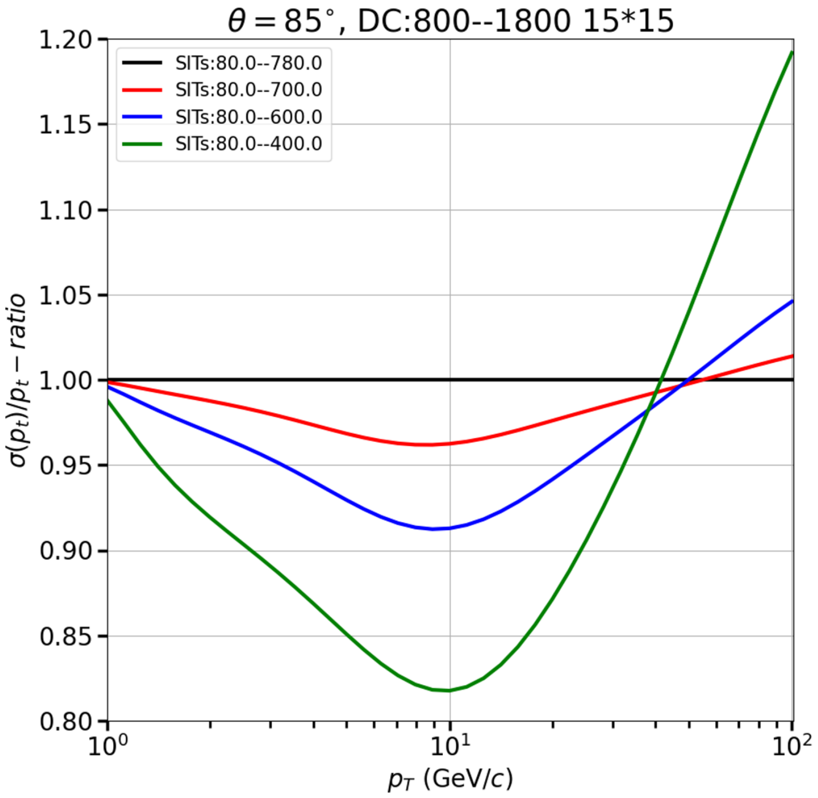
# 2.3 SIT – Outer radius fixed, changing Rin

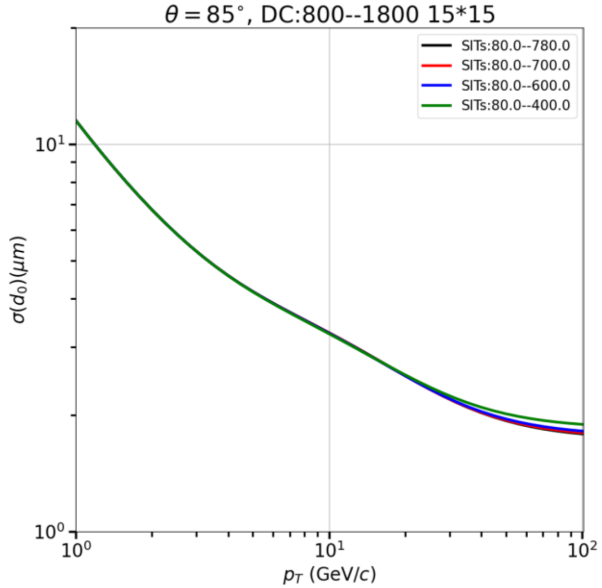



- Smaller Rin, better $\sigma(P_t)/P_t$ except very high Pt
- Smaller Rin, a little bit worse $\sigma(d_0)$
- Smaller Rin, less cost
- 80.0 mm is recommended

# 2.3 SIT – Inner radius fixed, changing Rout

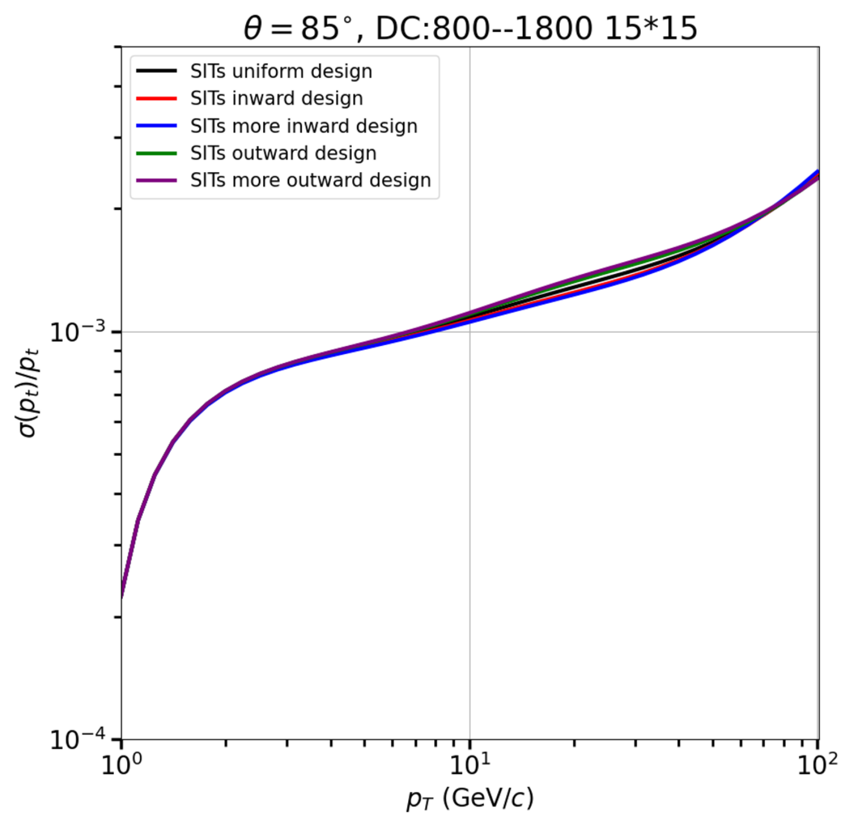


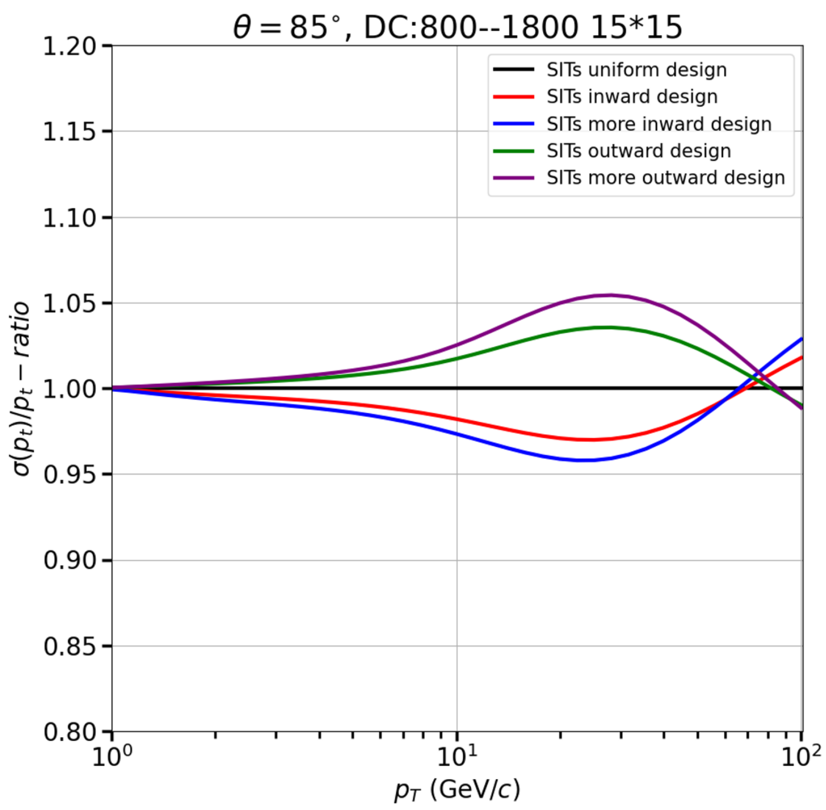



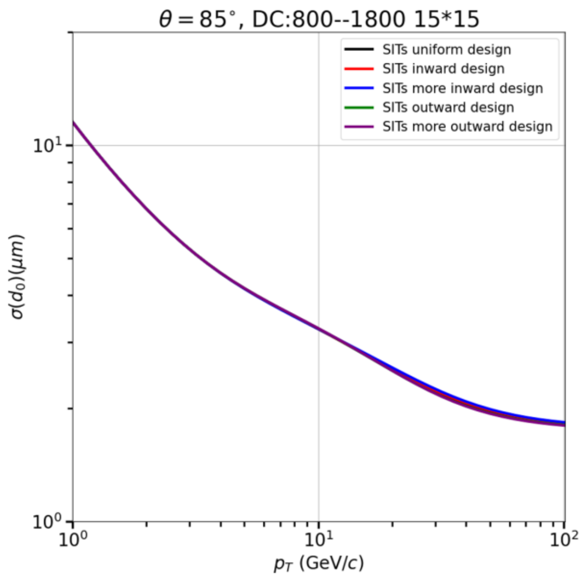




- Smaller Rout, better $\sigma(P_t)/P_t$ at intermediate Pt
- Smaller Rout, slightly worse $\sigma(d_0)$
- Smaller Rout, less cost
- 80.0 – 600.0 mm is recommended

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

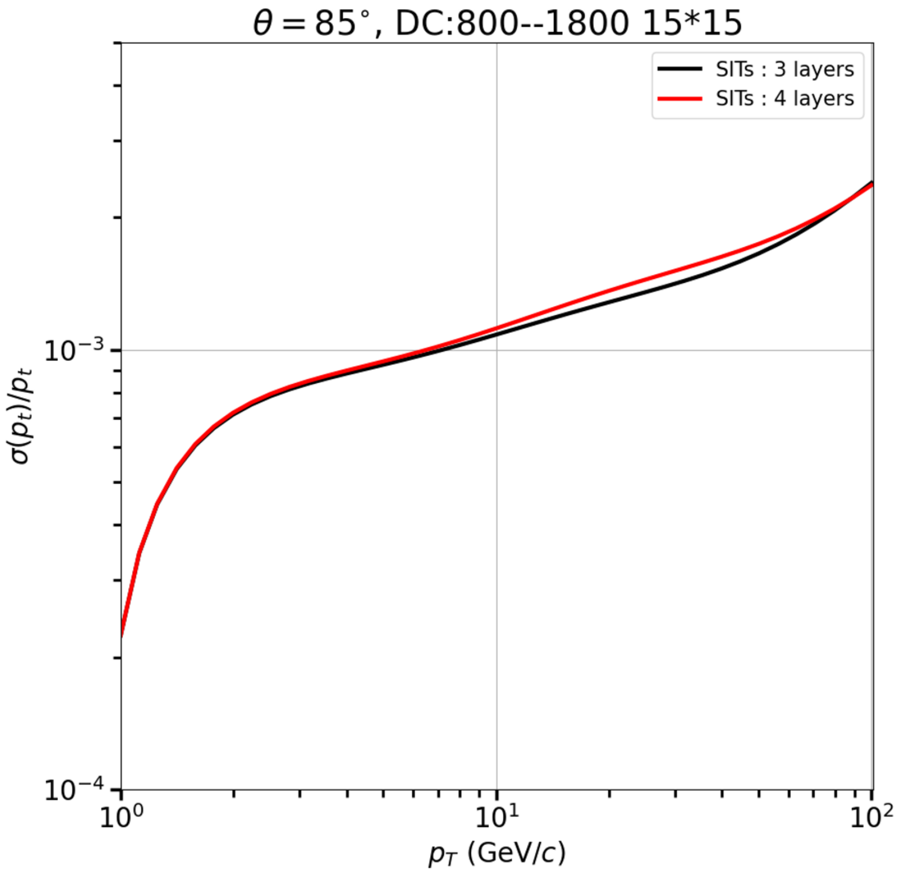


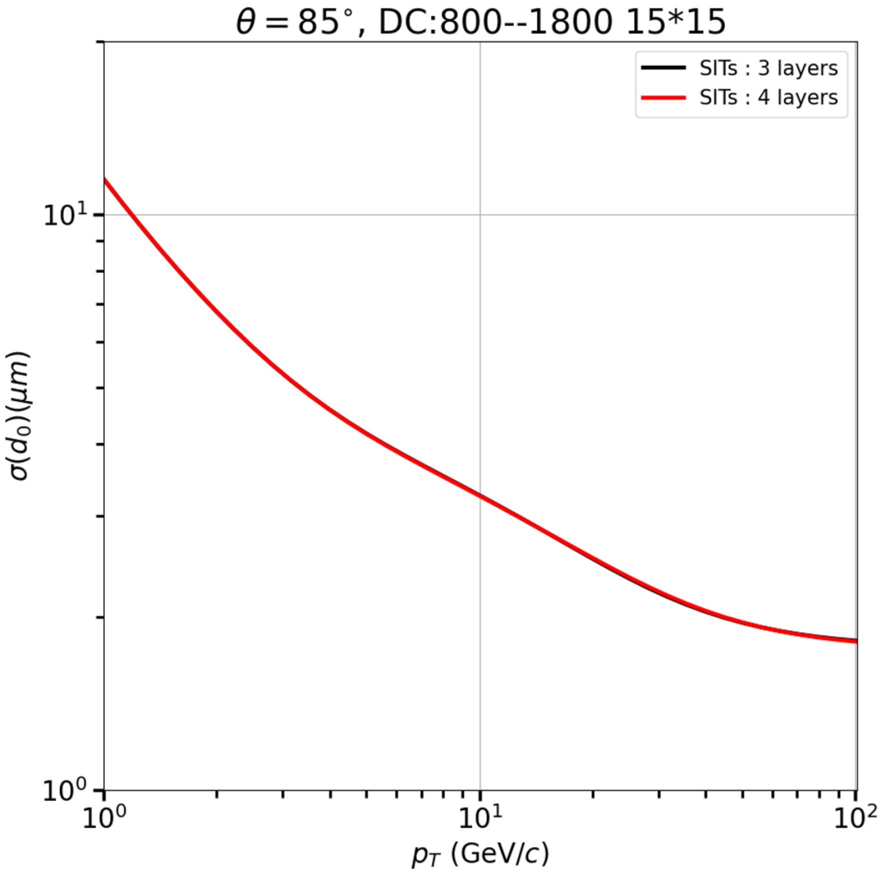




- Inward layout, better $\sigma(P_t)/P_t$ except > 50 GeV
- Little influence on $\sigma(d_0)$
- Inward design is favored

# 2.3 SIT – Add one more layer



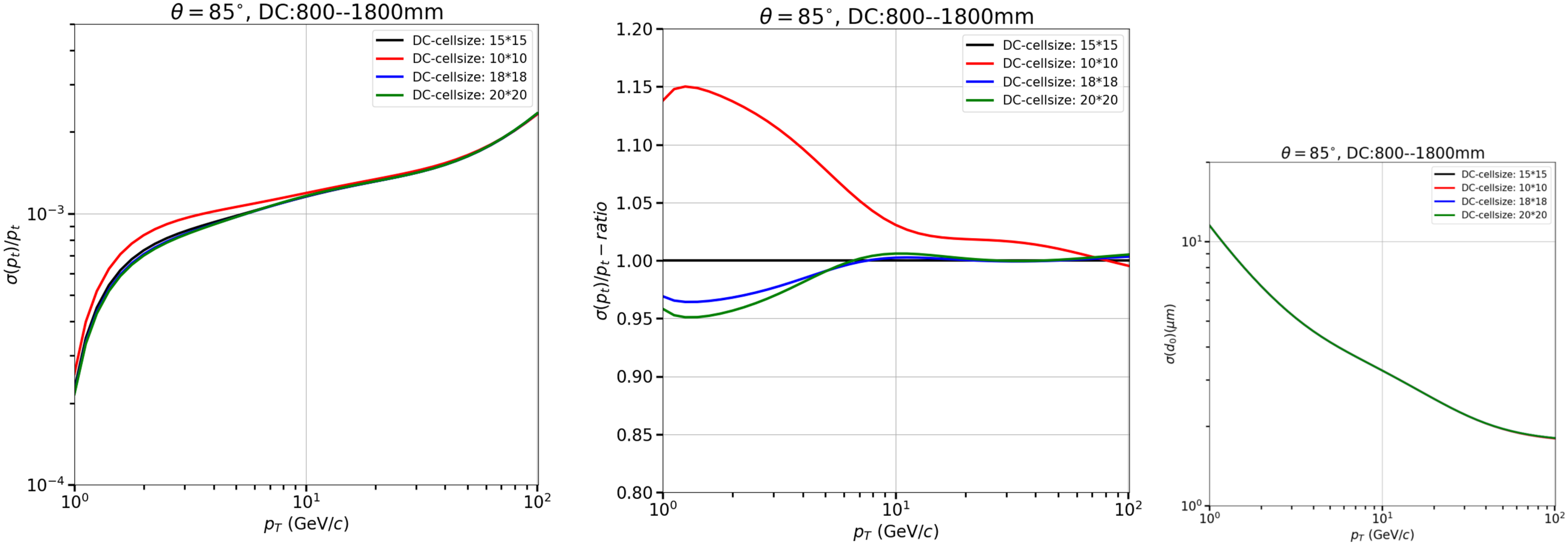




- More material & more multiple-scattering
- No improvement to $\sigma(P_t)/P_t$ & $\sigma(d_0)$
- No need add one more layer

# 2.4 DC – Volume

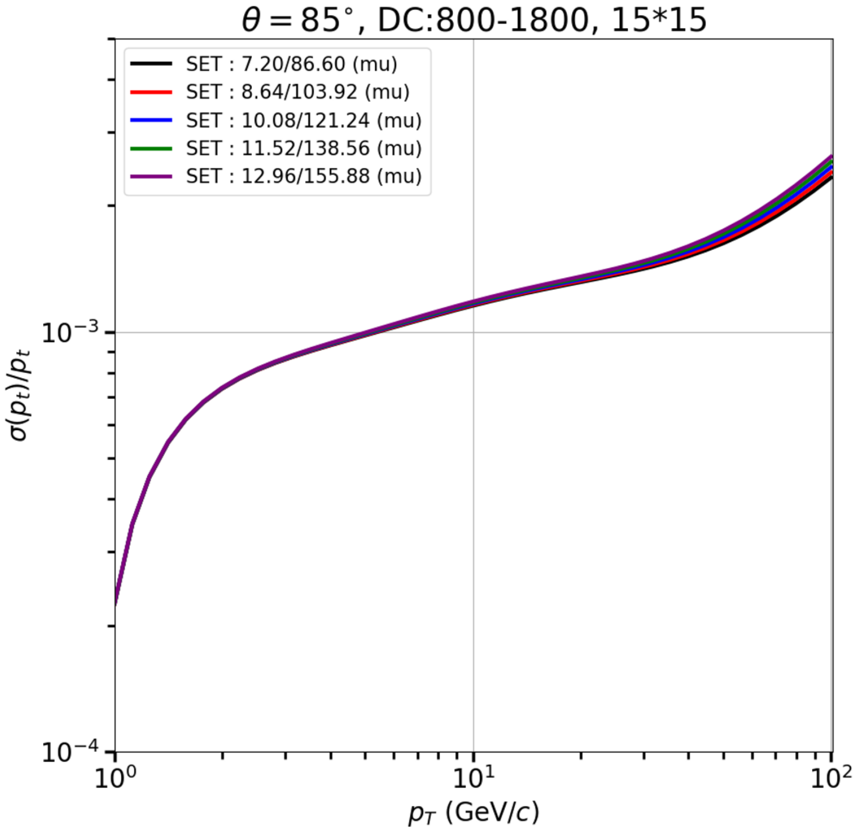
- Mainly determined by PID
- $\delta R$ >= 1.0 m
- Keep 800 – 1800 mm by now
- To be updated following with PID study

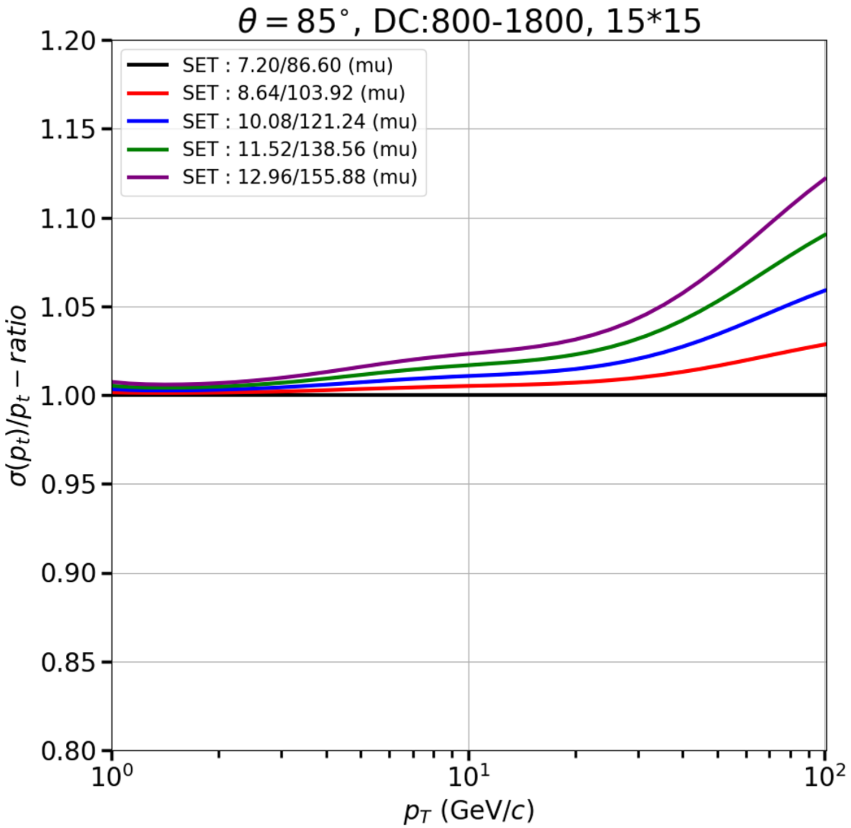
# 2.4 DC – Cell-size

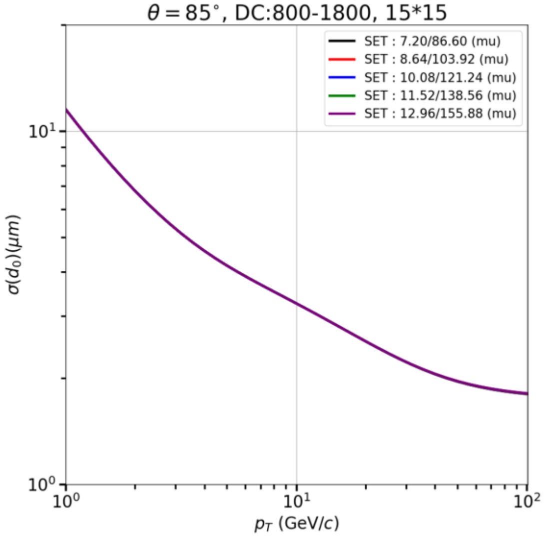



- Larger cell-size, less material & less multiple-scattering → better $\sigma(P_t)/P_t$ at low Pt
- Larger cell-size, easier engineering
- Hardly affects $\sigma(d_0)$
- Larger cell-size favored

# 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

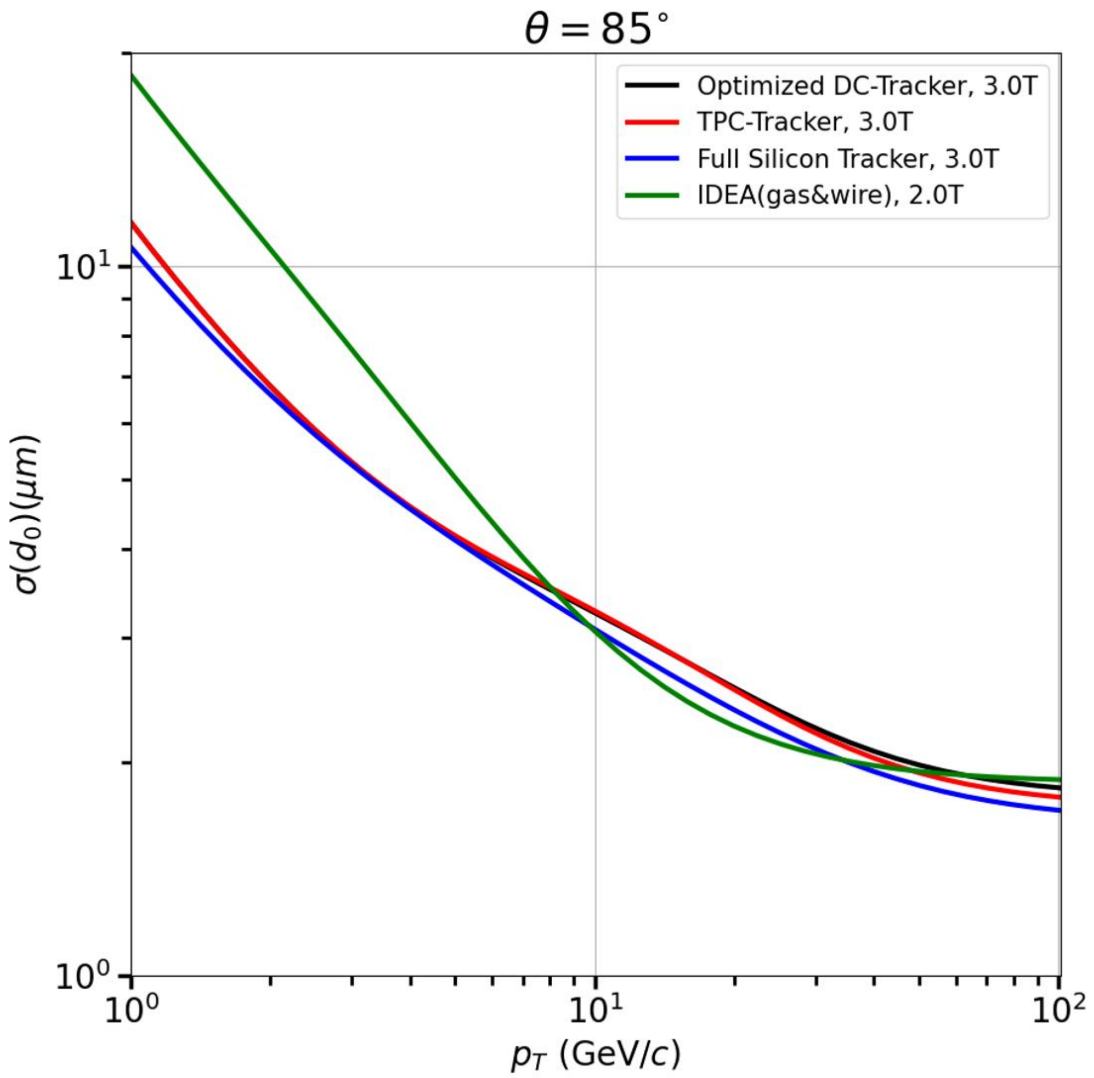
Tracker layout optimization gives some preliminary recommendations :

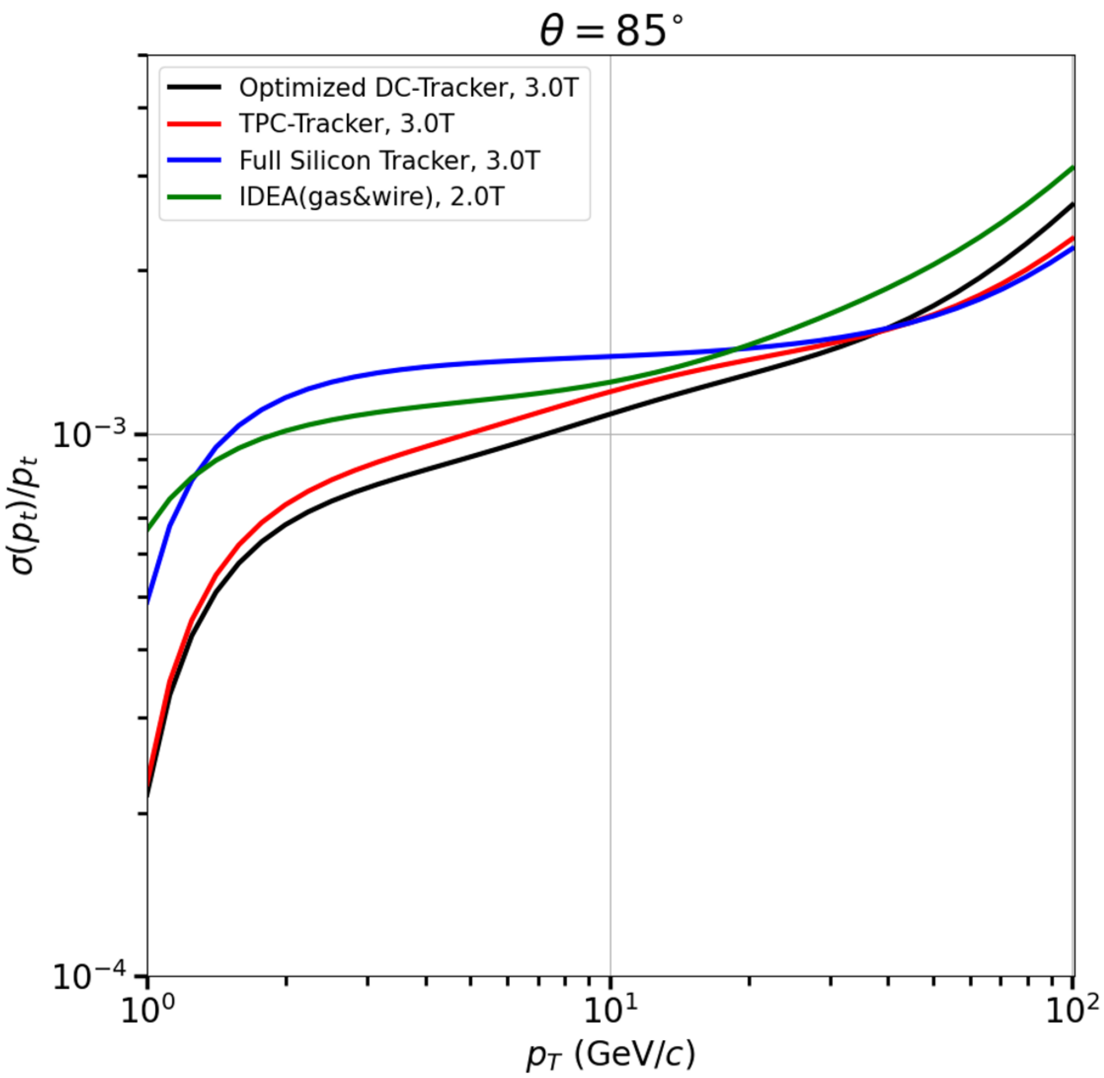
- Beam Pipe
  - Smaller radius of beam pipe gets better $\sigma(d_0)$
- VTX
  - Smaller Rin & Rout of the VTX get better $\sigma(d_0)$ and $\sigma(P_t)/P_t$
  - Double layers design favored
  - Corresponding to previous research
- SIT
  - Favors smaller Rin & Rout, and inward layout
- Drift chamber
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

# 3. Summary – Recommended Tracker

| Layers | Radius(mm) | $\sigma_{R\phi}$(mu) | $\sigma_Z$(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 | 80/253/600 | 7.2/7.2/7.2 | 86.6/86.6/86.6 | 0.65 |
| DC inner shell | 798 | - | - | 0.104 |
| DC wires (20*20mm) and gas | 800 -- 1800 | 100 | 2828 | 0.0108+0.0031 |
| DC outer shell | 1803.0 | - | - | 1.346 |
| SET | 1811.0 | 11.5 | 138.5 | 0.65 |

# 3. Summary – Comparing different designs



Thanks

# Backup

# 1. Analytic calculation

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

$$\boldsymbol{W} = \boldsymbol{C_y^{-1}}$$

$$\boldsymbol{C_a} = \left(\boldsymbol{G^T C_y^{-1} G}\right)^{-1}$$

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

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

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

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

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

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

$$z_{meas} = z$$

If the $xy_{meas}$ is used parabolic not helix function to fit :

For RES only :

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

$$\Delta d_0 \propto a$$

$$\Delta z_0 \propto a$$

$$\Delta\theta \propto a$$

$$\Delta\phi \propto a$$

For M.S. only :

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

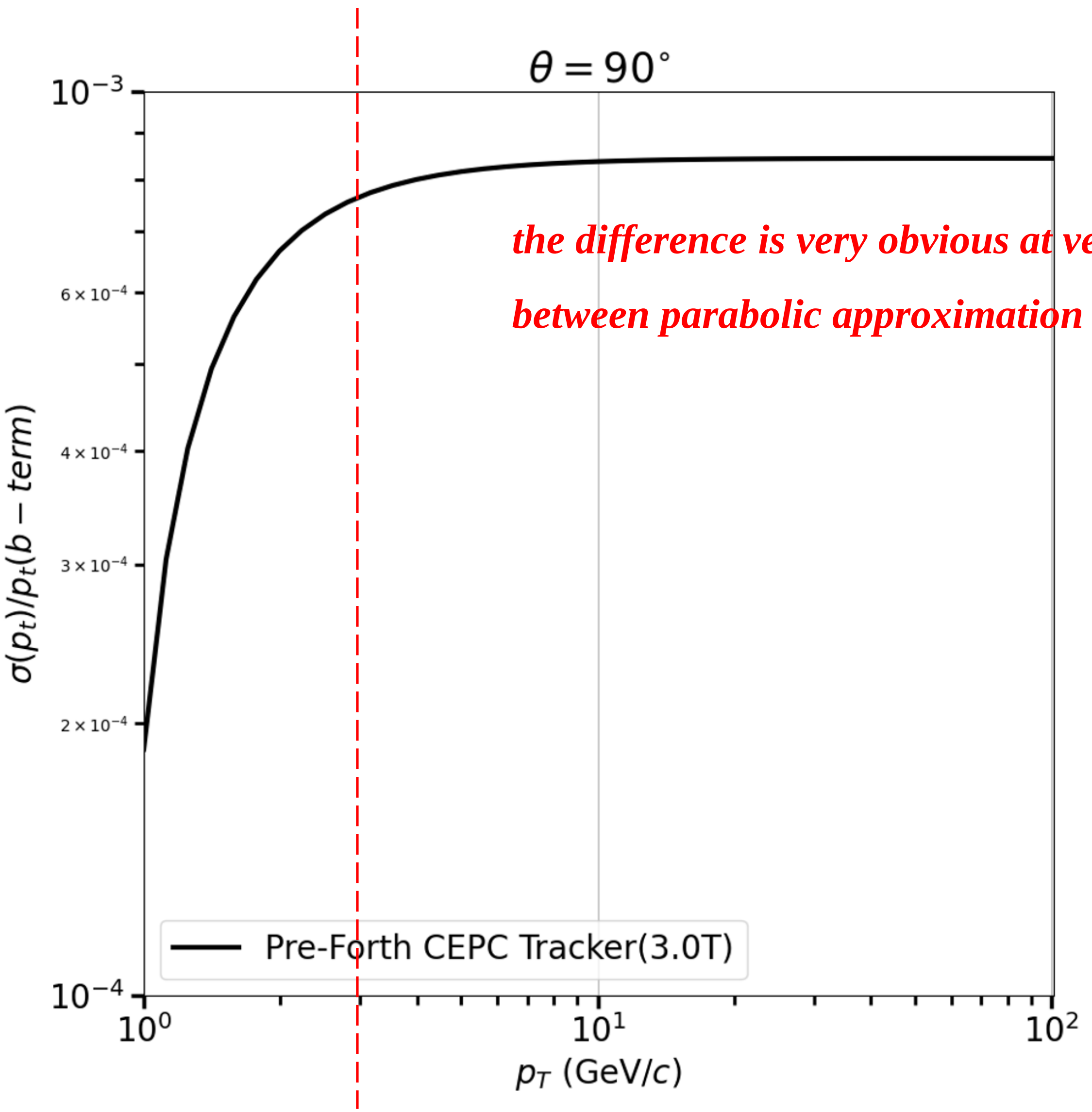
$$\Delta d_0 \propto \frac{b}{P_t}$$

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

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

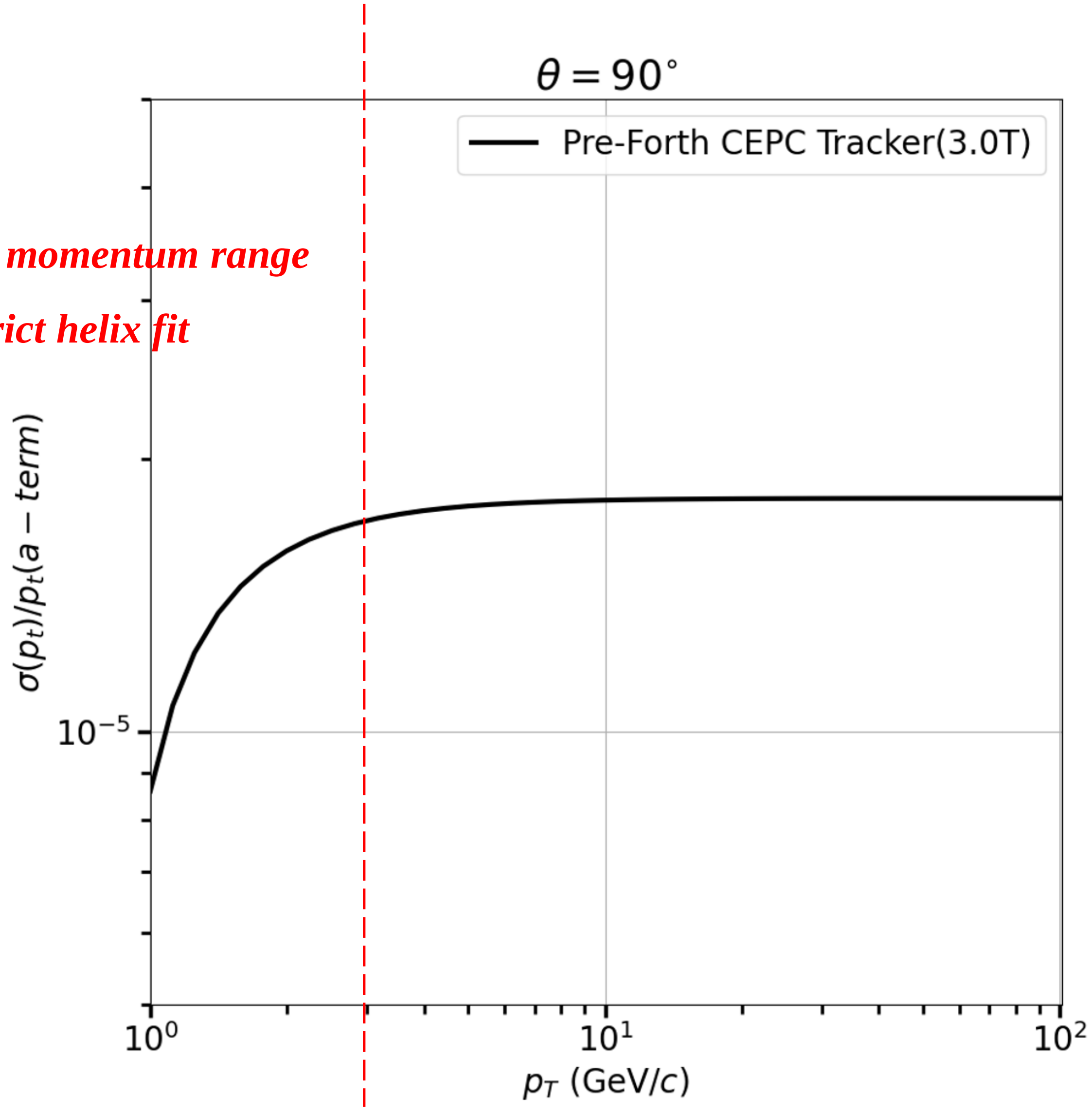
$$\Delta\phi \propto \frac{b}{P_t}$$

# 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) | $\sigma_Z$(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 | 78/437/796 | 7.2/7.2/7.2 | 86.6/86.6/86.6 | 0.65 |
| DC inner shell | 798 | - | - | 0.104 |
| DC wires (15*15mm) 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. Geometry – Full Silicon Tracker

| Layers | Radius(mm) | $\sigma_{R\phi}$(mu) | $\sigma_Z$(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 |
| SITs | 153/321/603 | 7.2/7.2/7.2 | 86.6/86.6/86.6 | 0.65 |
| SETs | 1000/1410/1811 | 7.2/7.2/7.2 | 86.6/86.6/86.6 | 0.65 |