Optimization of the tracking system

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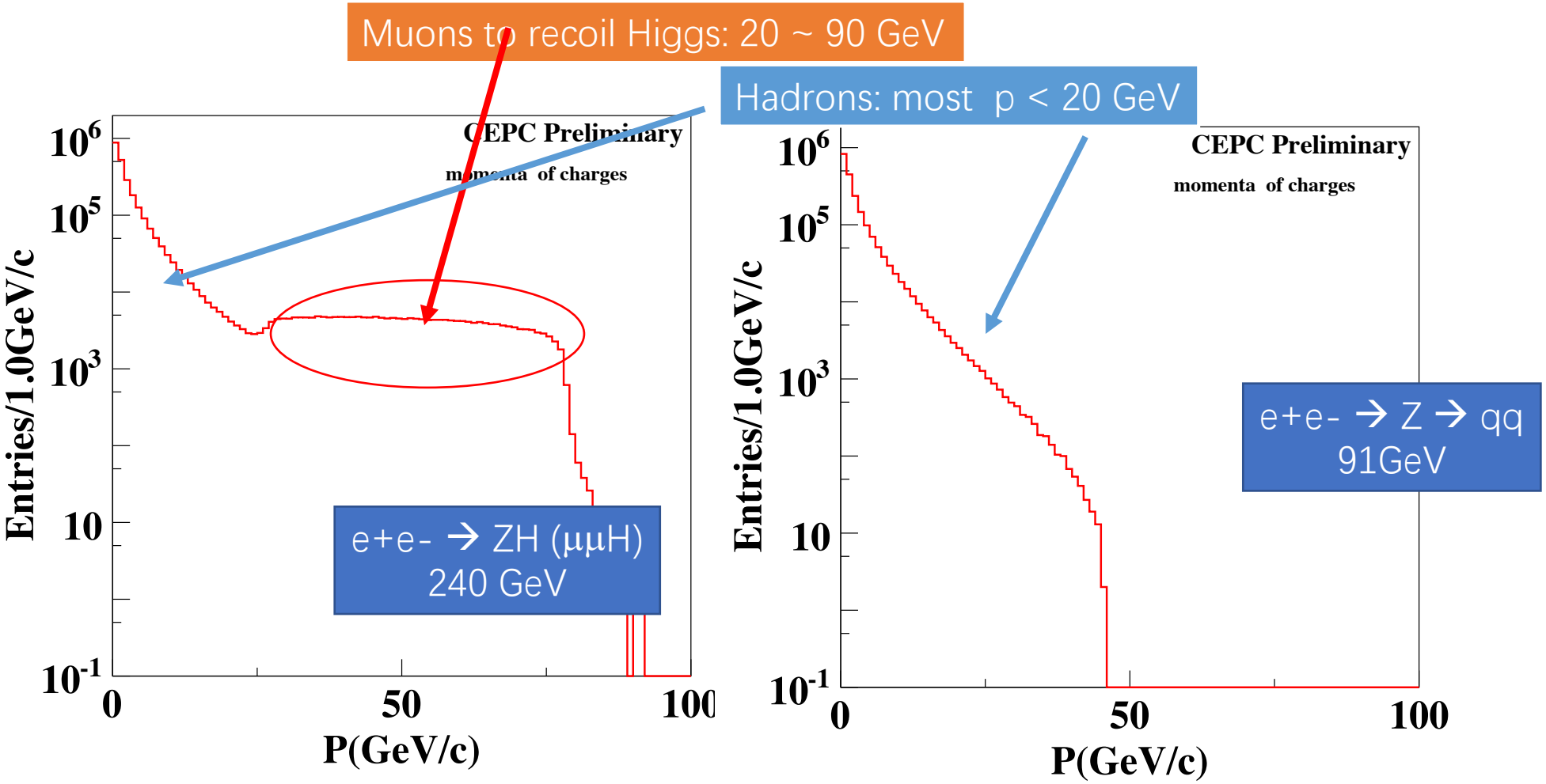
Outline

- **Introduction**
- **Optimizations**
  - **Vertex detector**
  - **Silicon Internal Tracker**
  - **PID Drift Chamber**
  - **Silicon External Tracker**
- **Some preliminary results of Delphes**
- **Summary and Plan**

CEPC Physics requirements: momenta and impact parameter

Momenta of tracks @ 240 & 91 GeV



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	$\sigma_{r\phi} =$ $5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta}(\mu\mathrm{m})$

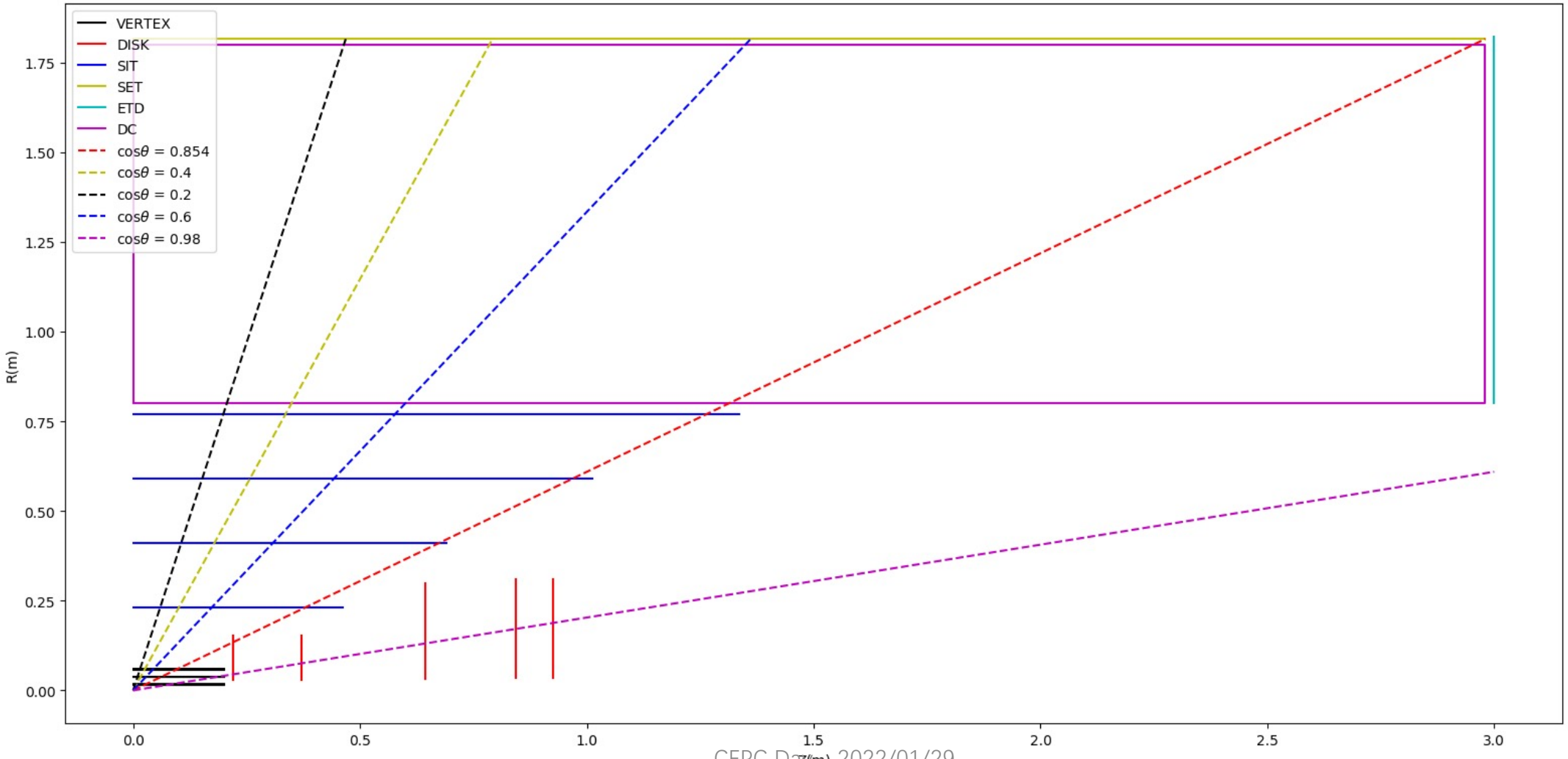
Optimization goal:

Change the layout to achieve the optimal resolutions of d_0 & P_t (d_0, z_0, ϕ, θ, P_t)

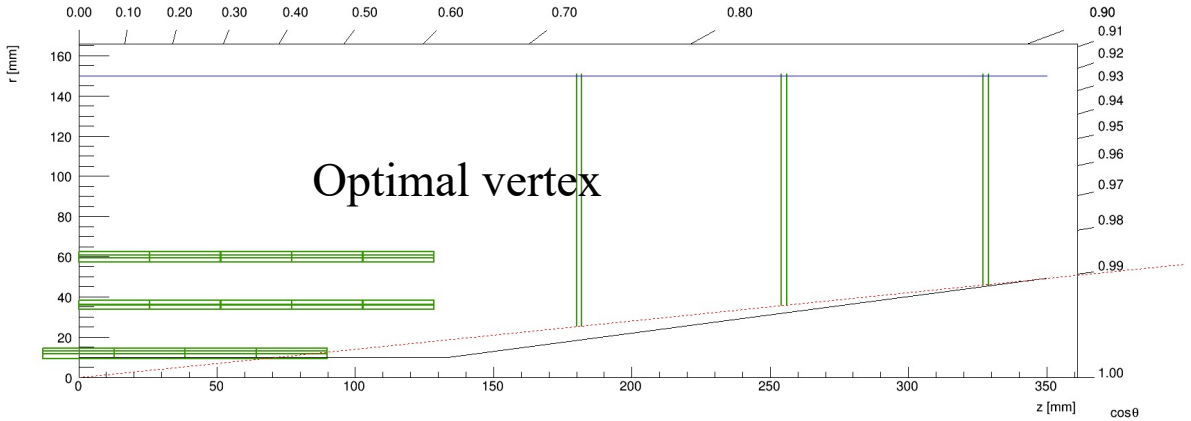
Tracker parameters

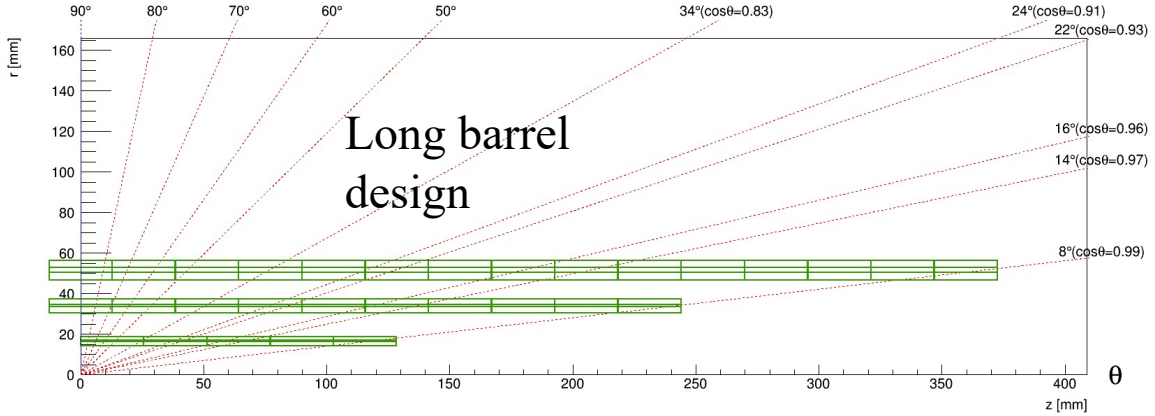
	Radius(mm)	$\sigma_{R\phi}(\mu m)$	$\sigma_Z(\mu m)$	Thickness(X_0 %)
Beam Pipe	14.5	-	-	0.15
VTX	3 double layers	2.8/6/4/4/4/4	2.8/6/4/4/4/4	0.10+0.10+0.10
VTX-shell	1 layer	-	-	0.15
SITs (HV-CMOS 25x300 μm^2)	3 layers	7.2/7.2/7.2	86.6/86.6/86.6	0.65
DC inner wall	1 layer	-	-	0.104
DC cell (66 x15x15mm)	---	100	2828	0.0081+0.00413
DC outer wall	1803.0	-	-	1.346
SET (HV-CMOS 25x300 μm^2)	1811.0	7.2	86.6	0.65

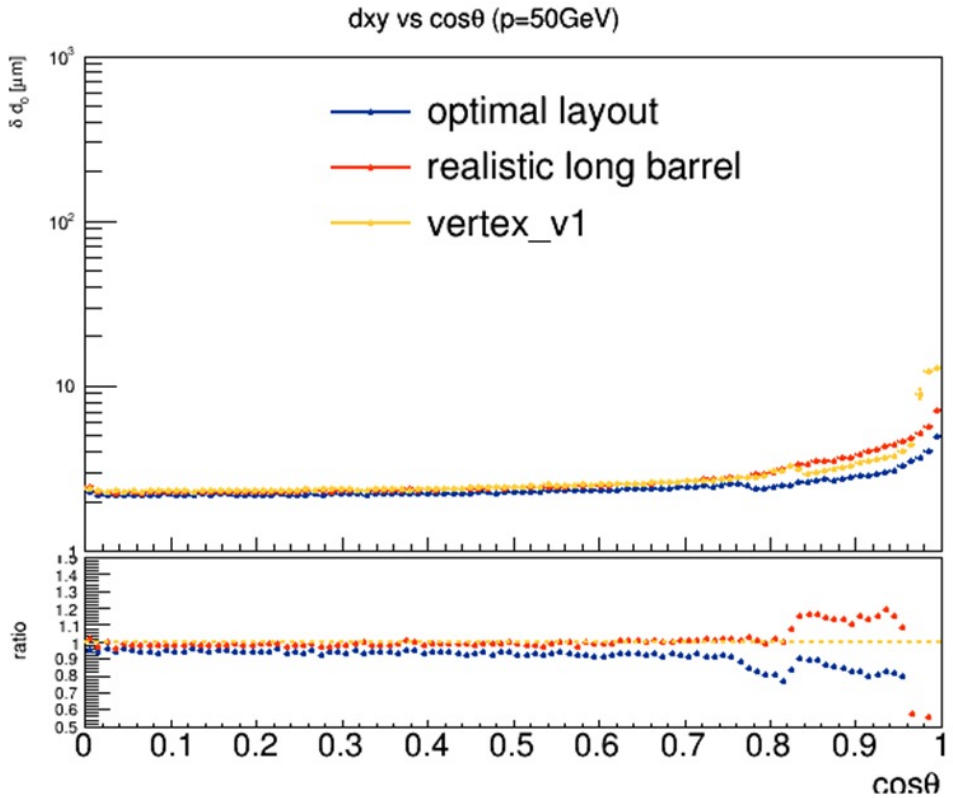
Geometry in CEPCSW



VTX study



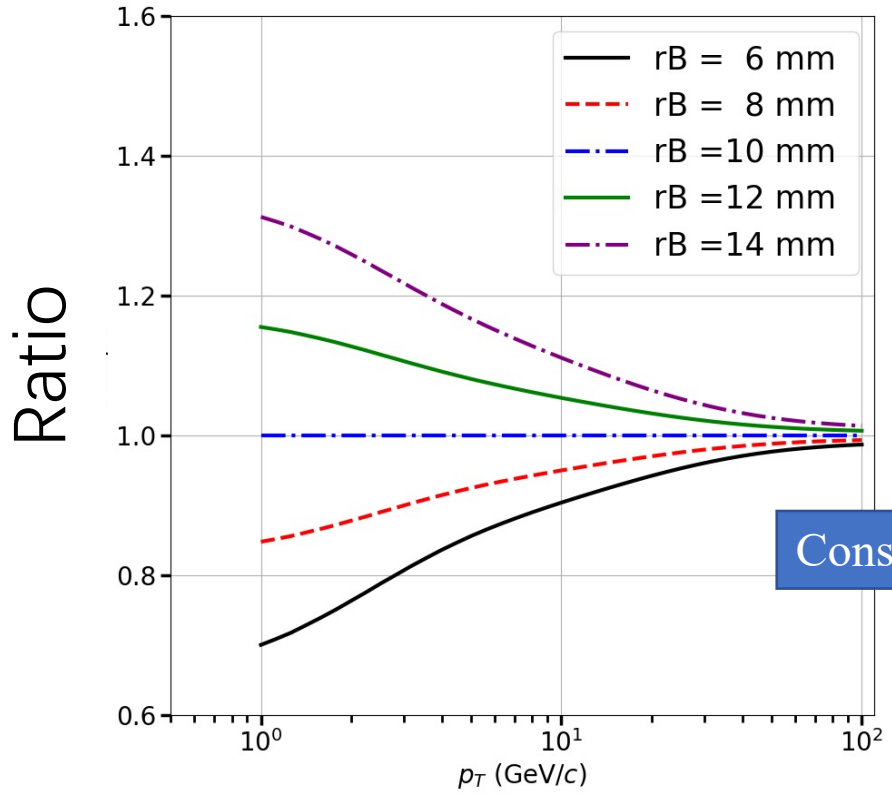




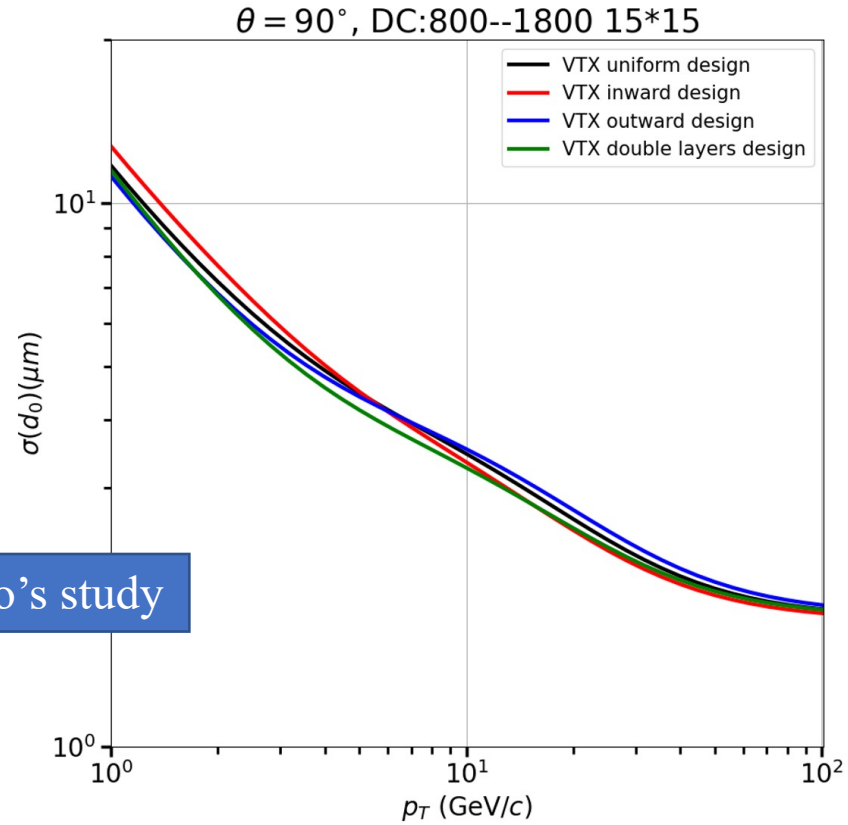
The d0 resolution of optimal vertex layout is much better than long barrel and realistic implementation of CDR vertex), especially in the front region (>20%).

- Smaller radius of beam pipe
- More disks
- Longer innermost layer

Zeng Hao did extensive studies in the context of MOSTII project



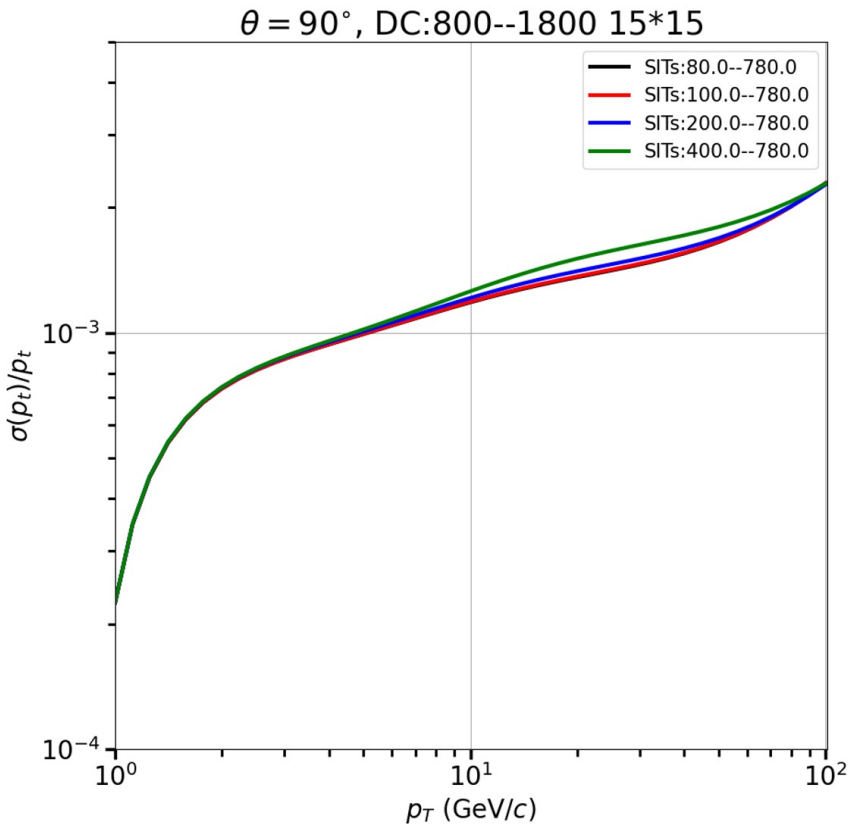
Consist with Zeng Hao's study

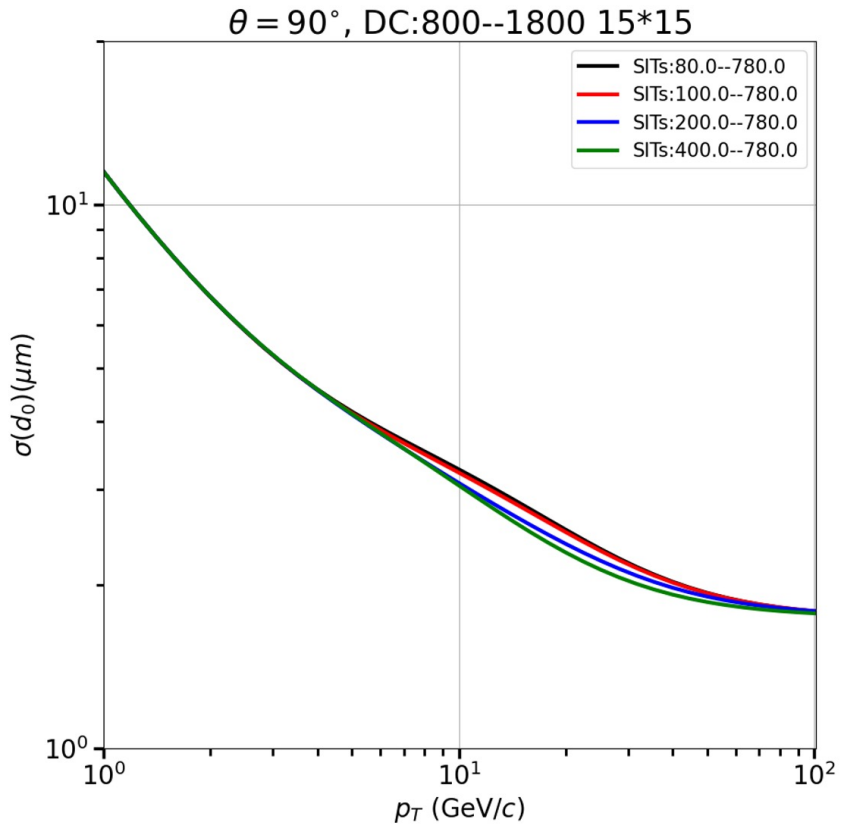


Smaller Rin improve d0 significantly

Double layers equally spacing favored

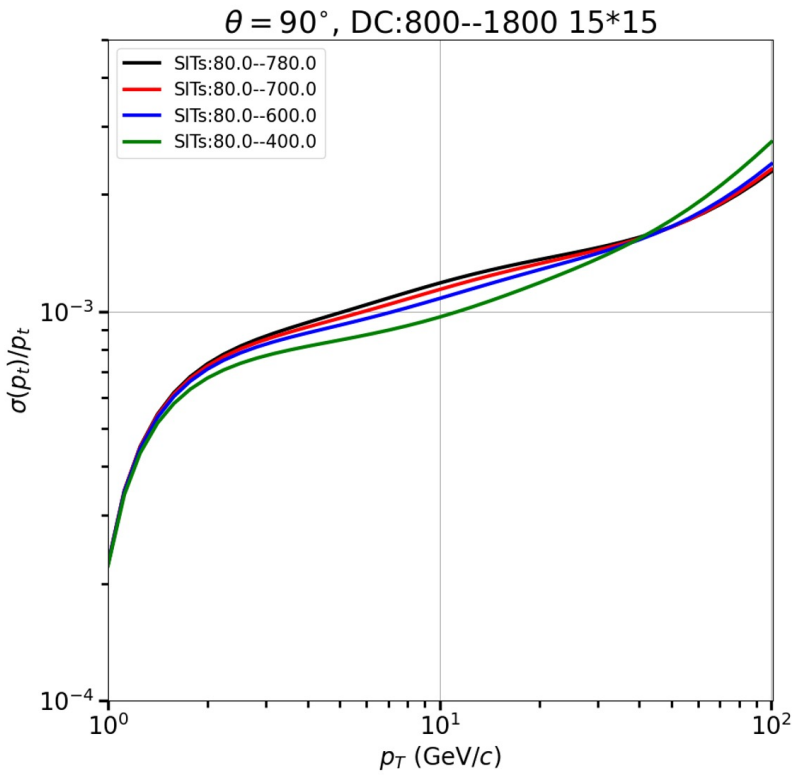
SITs – inner radius

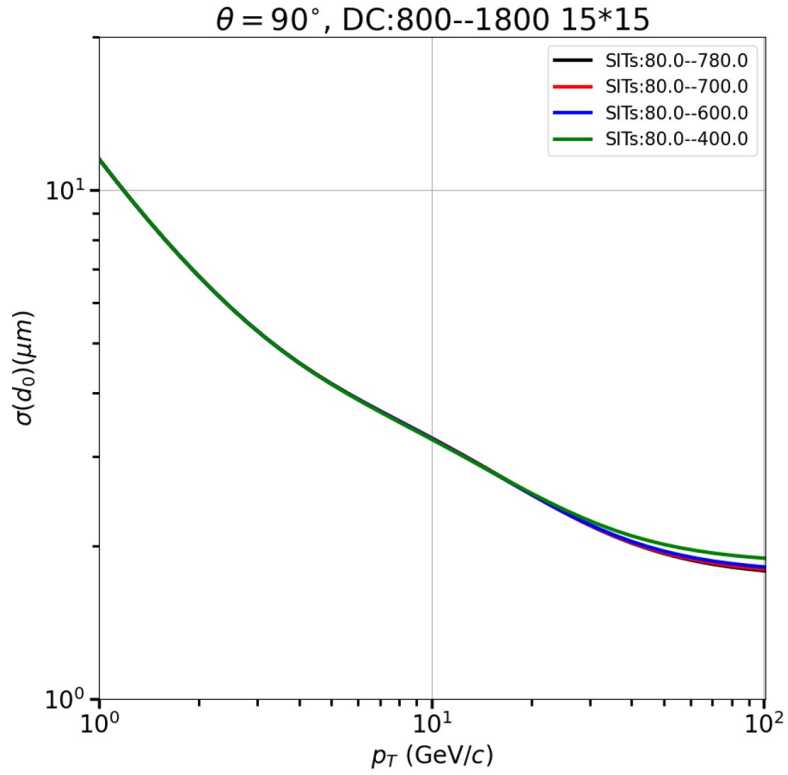




- Smaller Rin, better $\frac{\sigma(P_t)}{P_t}$ and a little bit worse $\sigma(d_0)$
- 80.0 mm is recommended

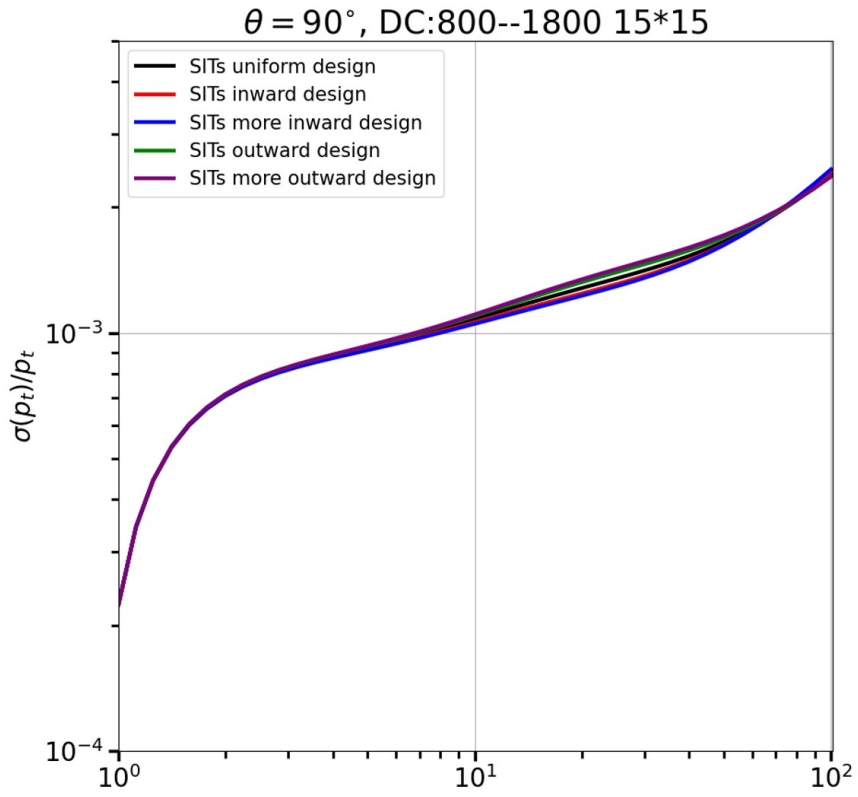
SITs – Outer radius (volume)

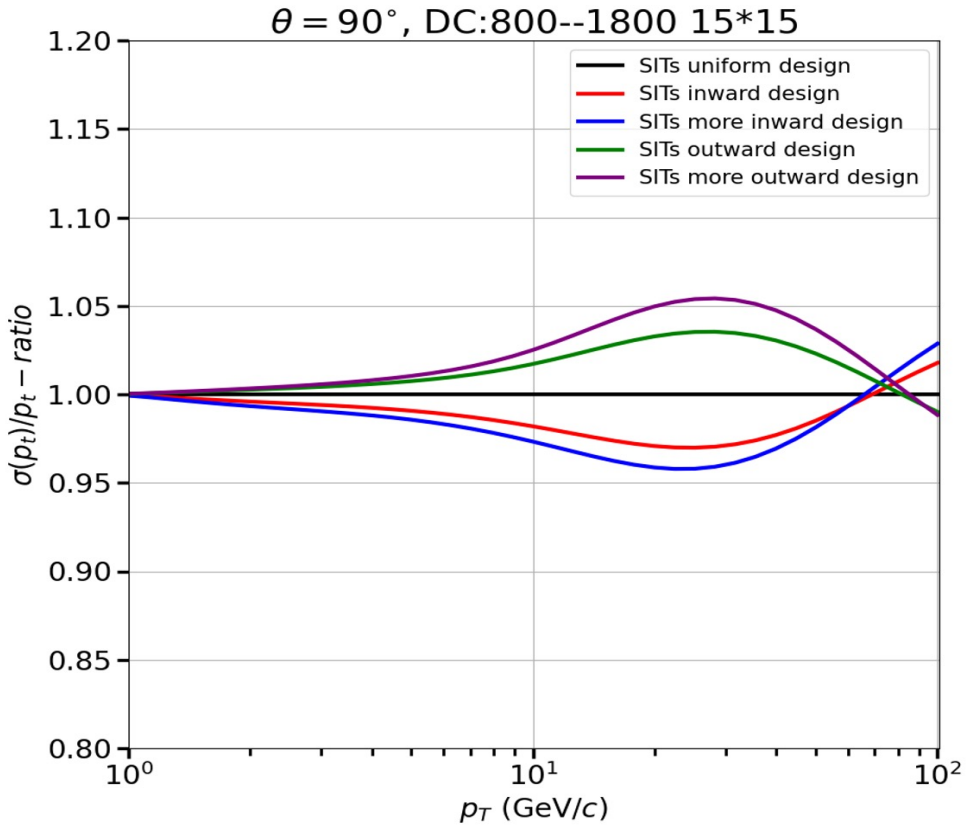




- Smaller Rout, better $\sigma(P_t)/P_t$ at intermediate Pt, while a little worse at high Pt
- Smaller Rout, slightly effect on $\sigma(\mathrm{d_0})$
- 600.0 mm is recommended, which makes more room for DC

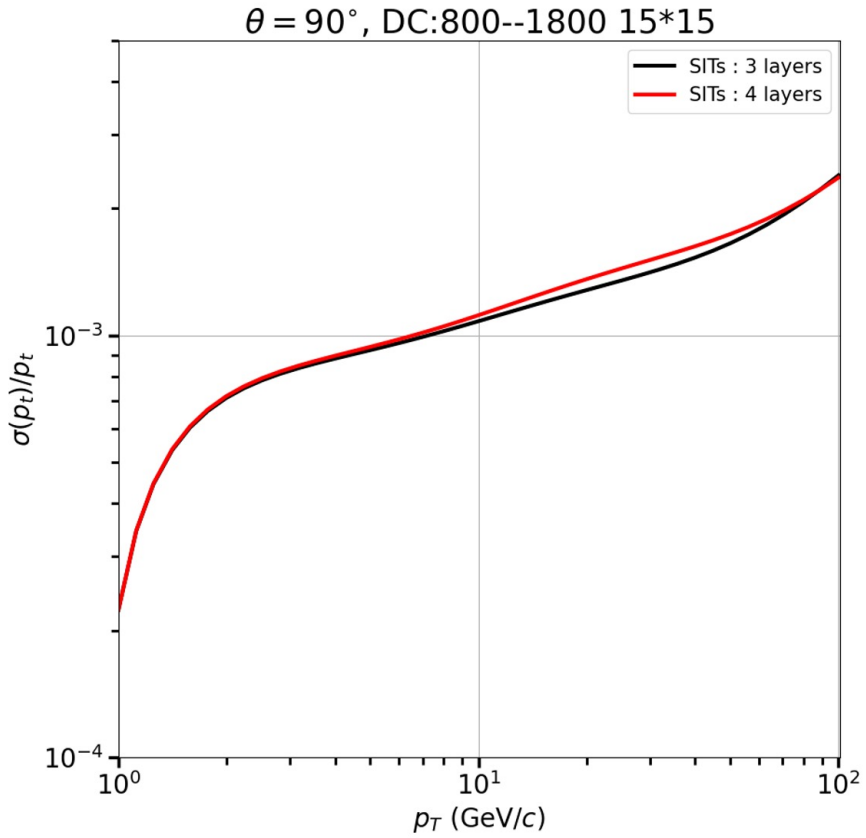
SITs – layout (position of the middle layer)

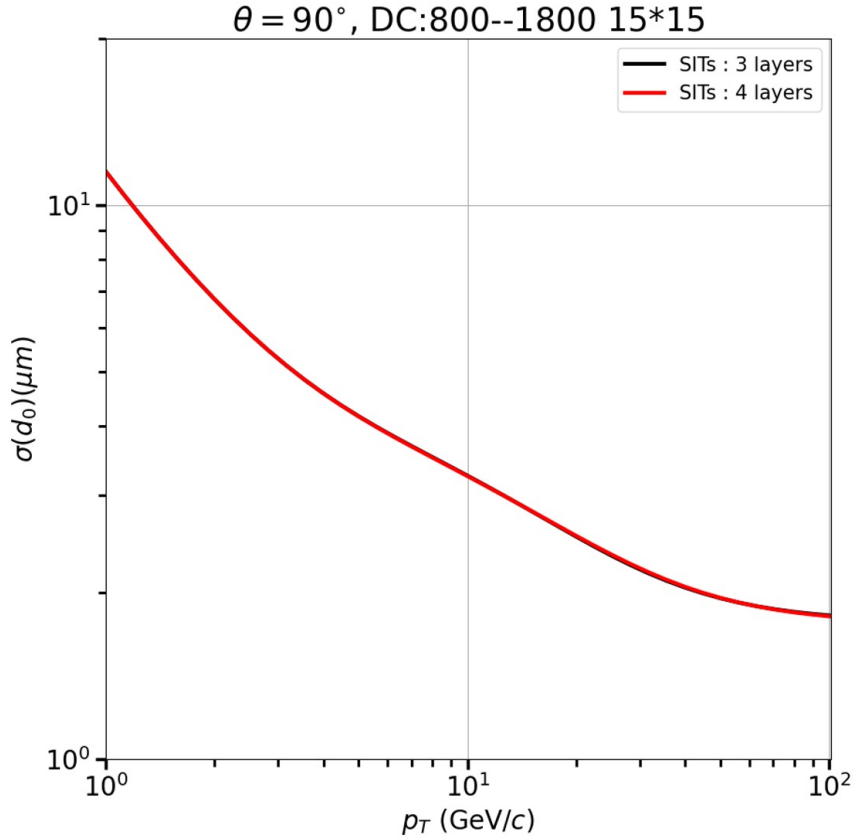




- Inward layout, better $\sigma(P_t)/P_t$ except > 50 GeV
- Inward design is recommended

SITs – one more SIT layer?



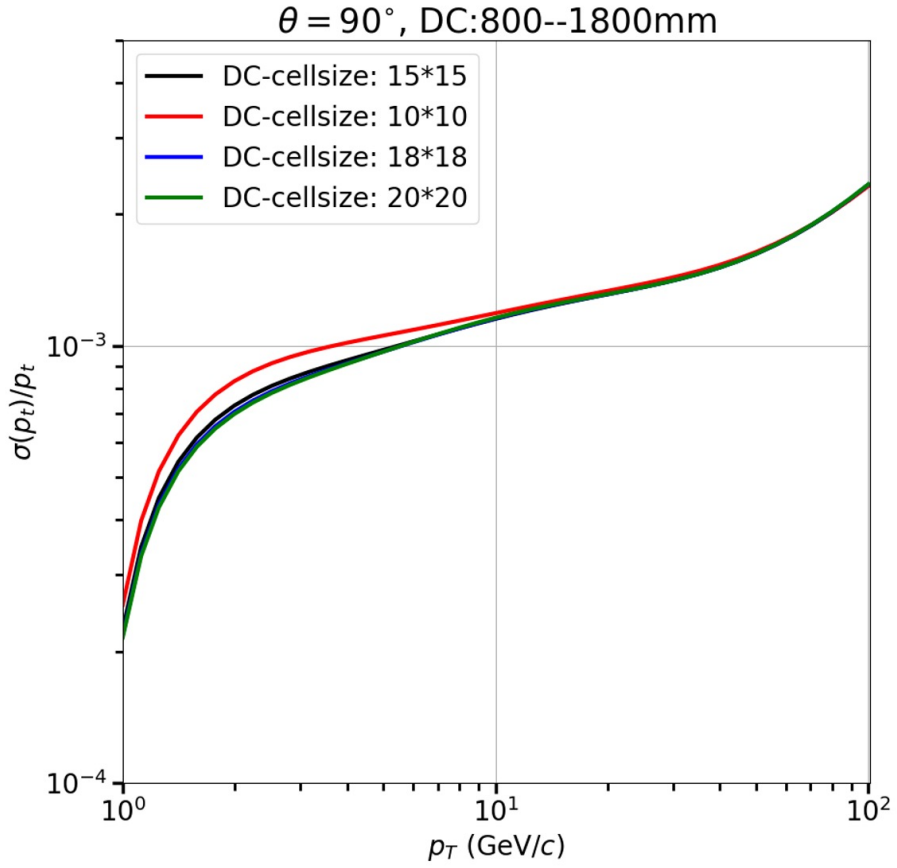


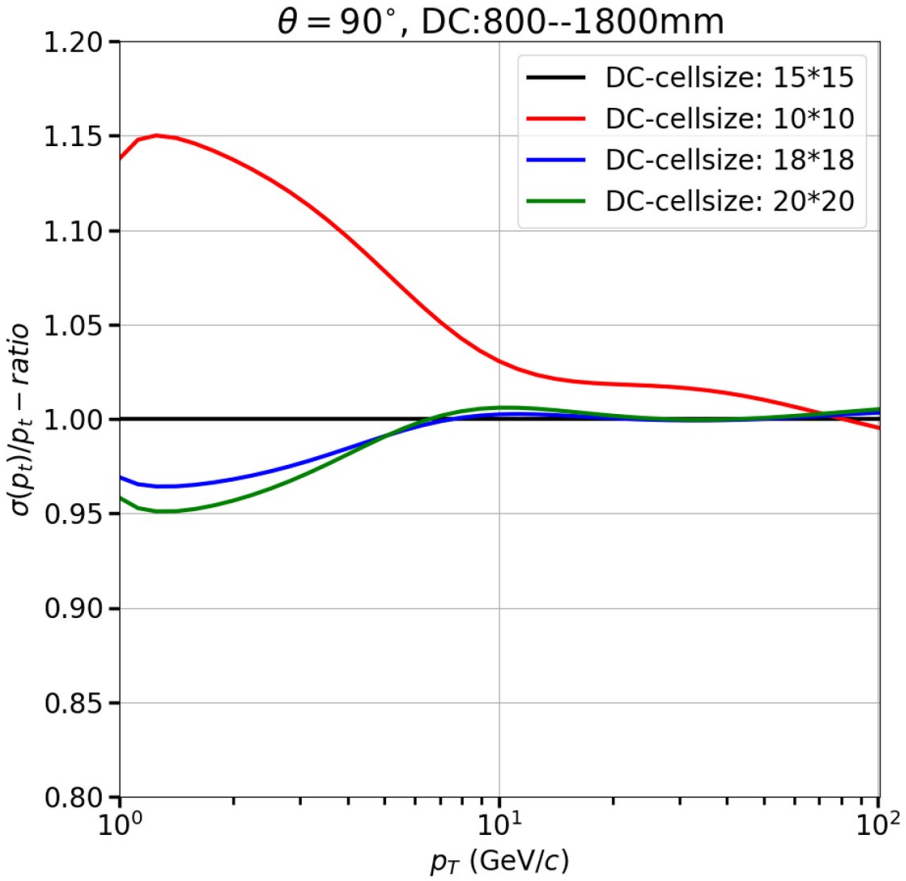
- No improvement to $\sigma(P_t)/P_t$ & $\sigma(\mathrm{d}_0)$
- Introduces more material & multiple-scattering
- 3 layers of SITs recommended

Drift Chamber – Volume

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

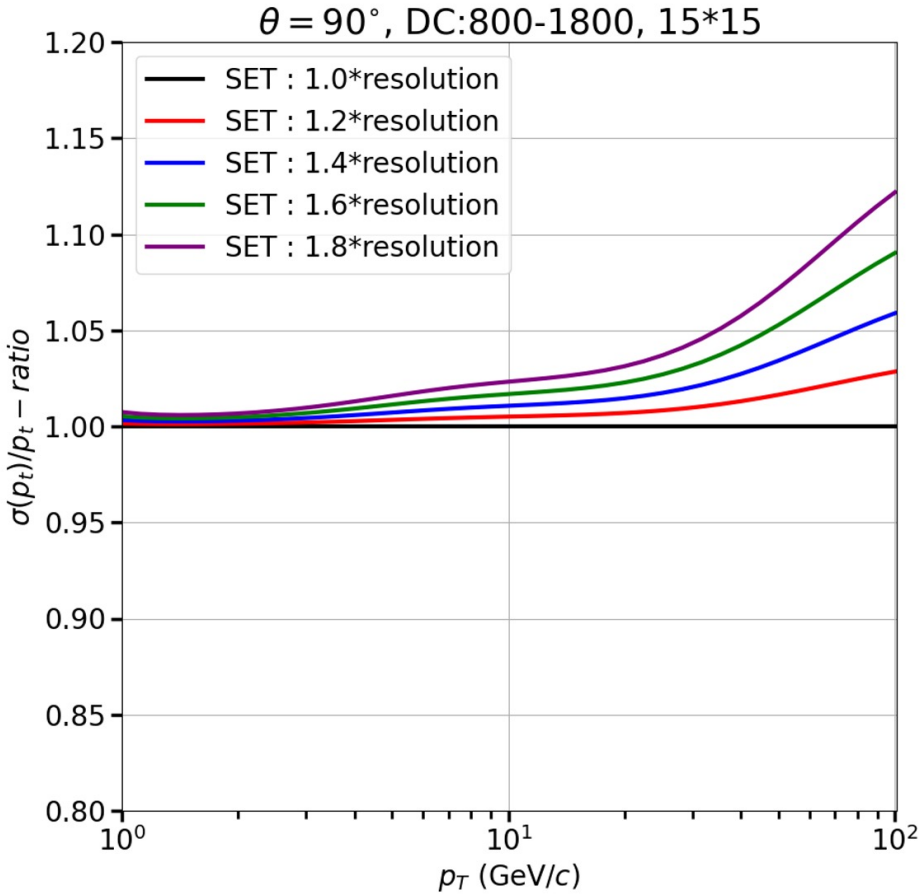
DC – cell-size and # of layers

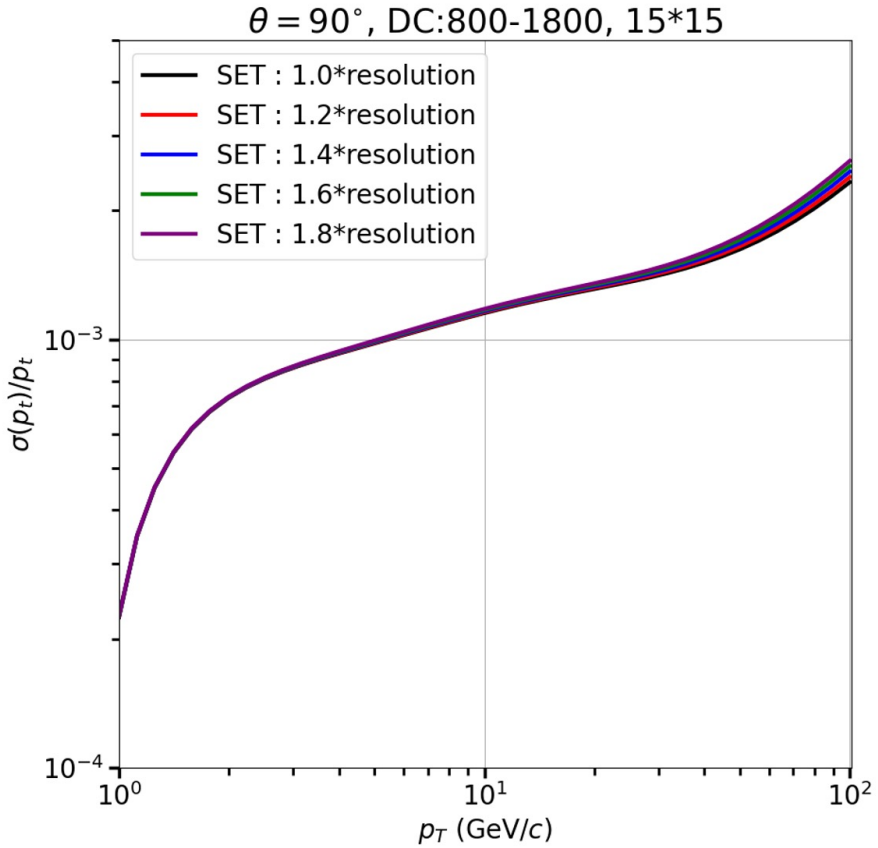




- Larger cell, less material & less multiple-scattering → better $\sigma(P_t)/P_t$ at low Pt
- Larger cell, easier engineering
- So larger cell-size favored

SET – resolution (25x300 μm²)





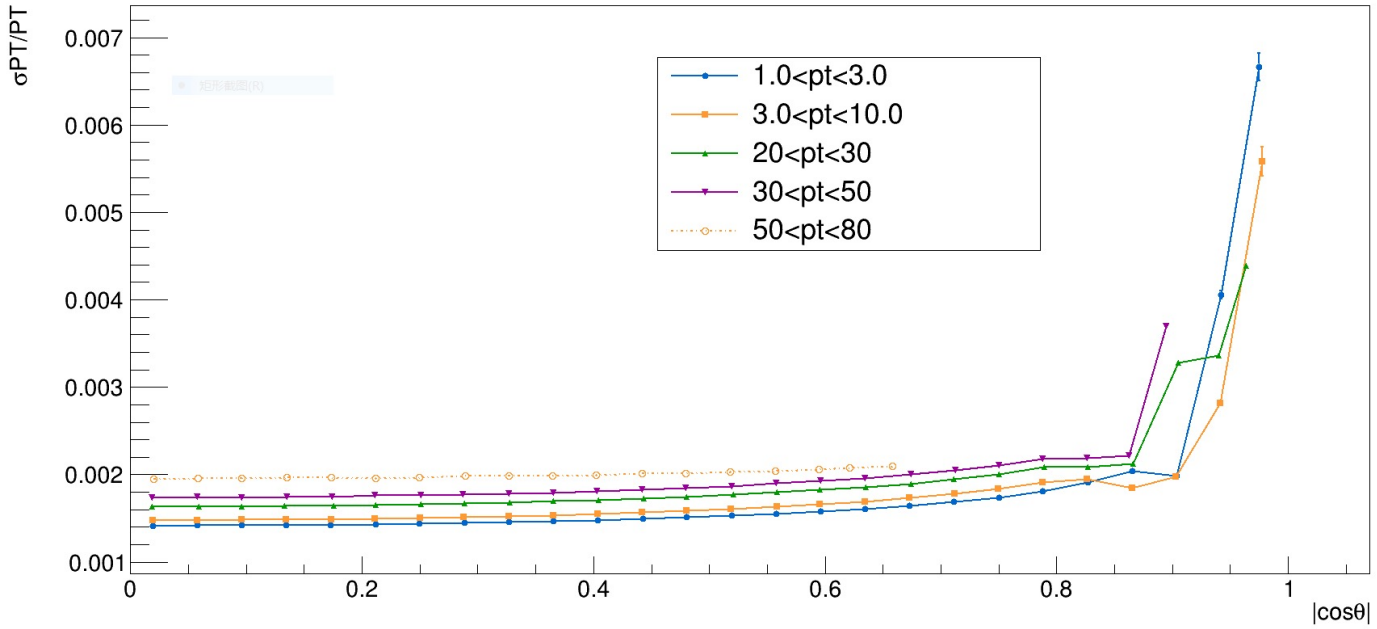
- No much effect on $\sigma(P_t)/P_t$ when spatial resolution getting worse
- No influence on $\sigma(d_0)$
- Could take larger pixel size

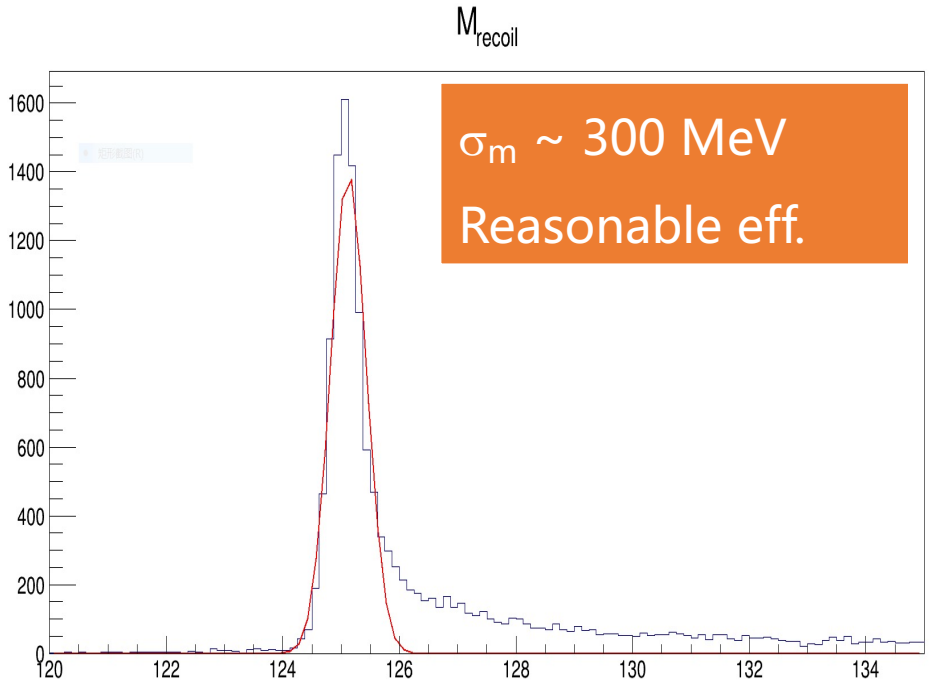
Preliminary results of Delphes

Fast simulation framework

- Track with covariance matrix
- Assuming perfect PFA
- Good PID simulation
- Good interfaces to generators, FastJet, root, etc

Good for physics performance study and pheno. study





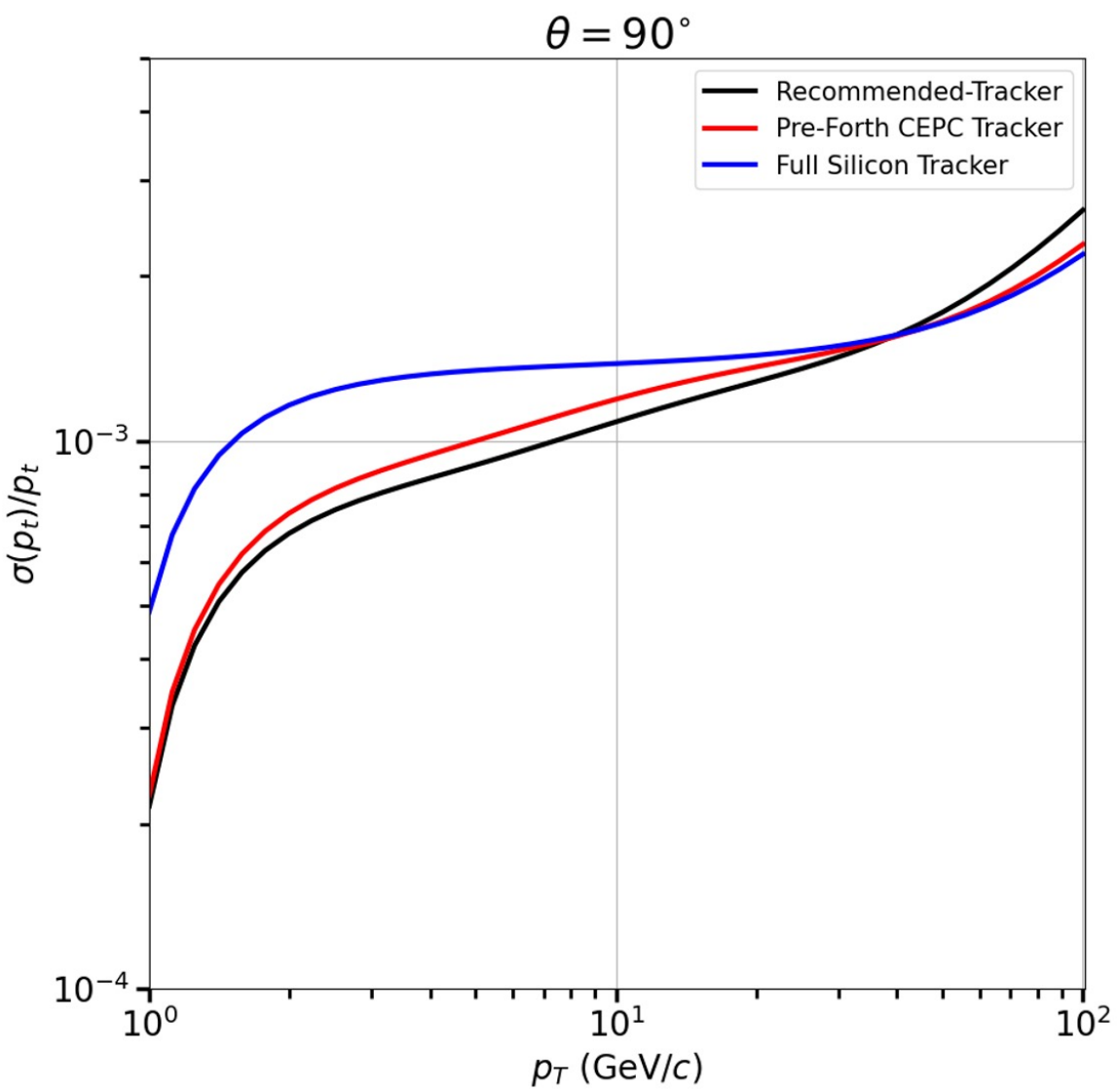
Forward region & PID need more work

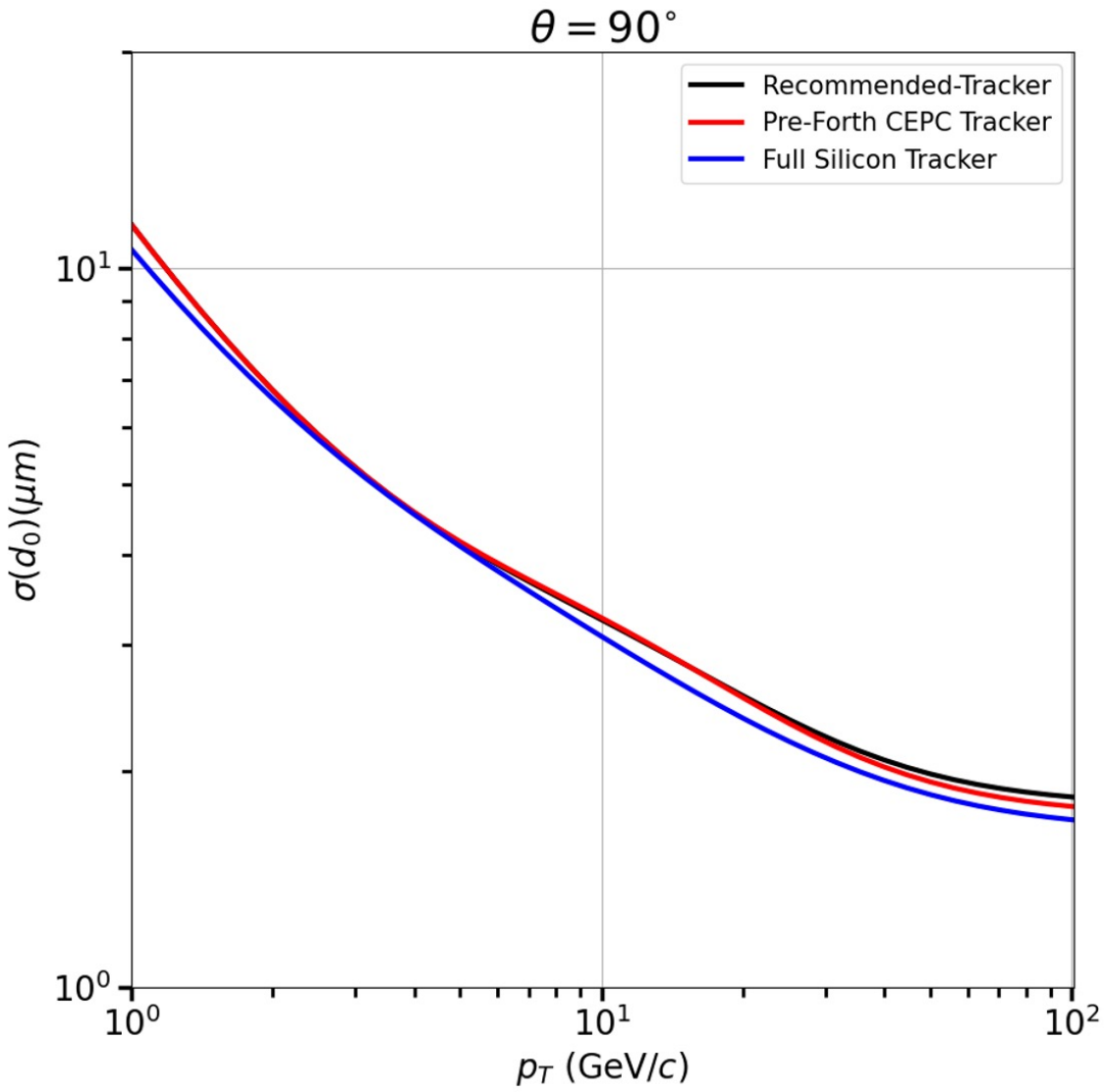
Summary

Some preliminary recommendations

- VTX: confirms the results of Zeng Hao
  - Smaller Rin achieves better $\sigma(d_0)$ and $\sigma(P_t)/P_t$
  - double layer and equally spacing
- SIT
  - Smaller Rin & Rout, and inward layout
- Drift chamber
  - Volume should be determined by PID
  - Tracking favors larger cell: less materials is friendly to low pt tracks
- SET
  - The requirement on spatial resolution could be loosed

Summary – Comparison





Summary – Recommended parameters

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
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 (HV-CMOS 25x300 μm^2)	1811.0	11.5	138.5	0.65

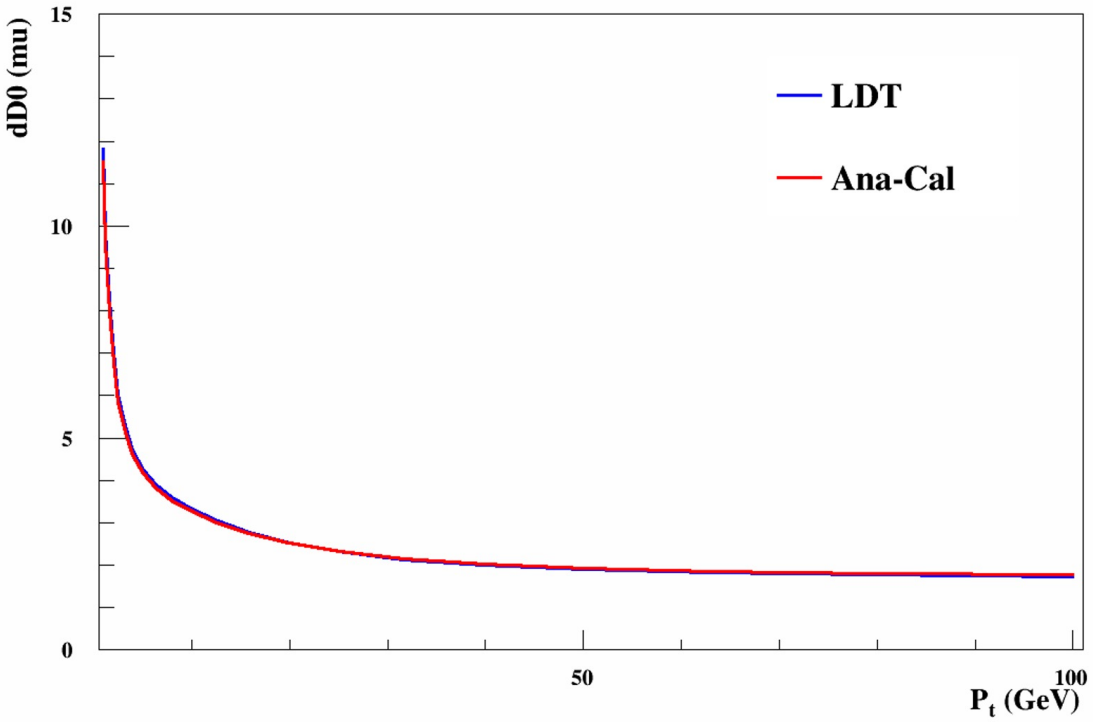
Plan

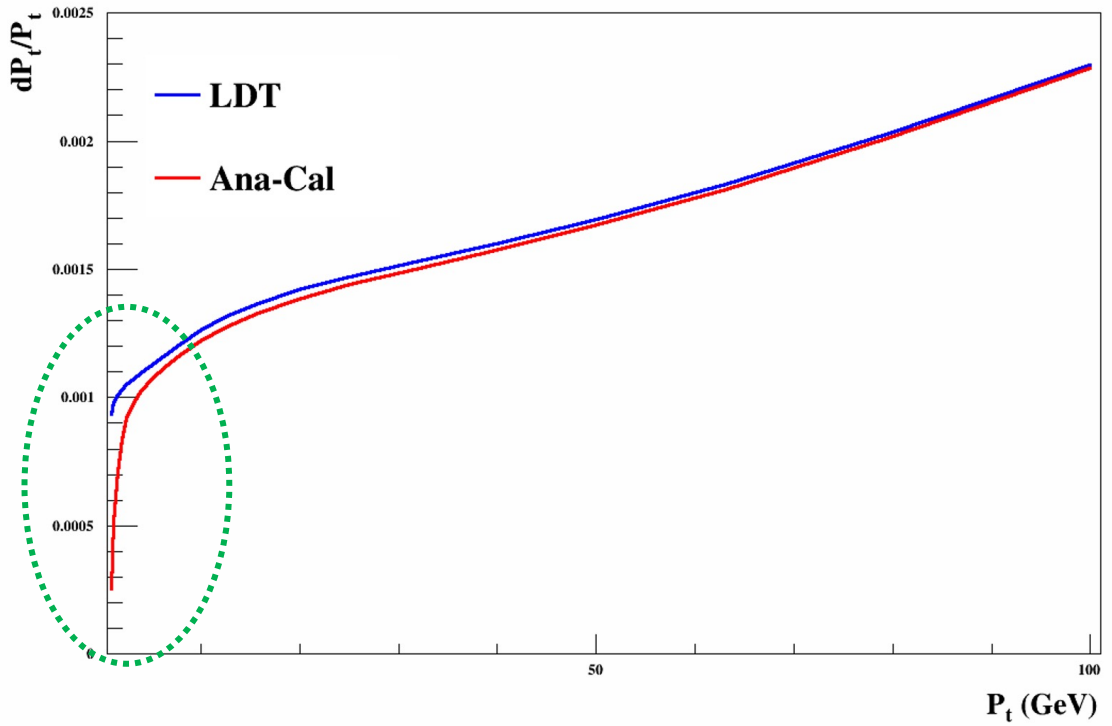
- More studies with full simulation
- Update according to DC study
- Demonstrate the physics significance of this PID tracker
  - Cluster counting & ToF

Thanks

Backup

Introduction—tools and comparison





- LDT by MatLab

Simulation and reconstructed with Kalman Filter with linear approximation

O(10 minutes)

as result check

- Calculation

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

Analytic calculation

Least square: $\chi^2 = (\boldsymbol{y} - \boldsymbol{G}\boldsymbol{a})^{\boldsymbol{T}} \boldsymbol{C}_{\boldsymbol{y}}^{-\mathbf{1}} (\boldsymbol{y} - \boldsymbol{G}\boldsymbol{a})$

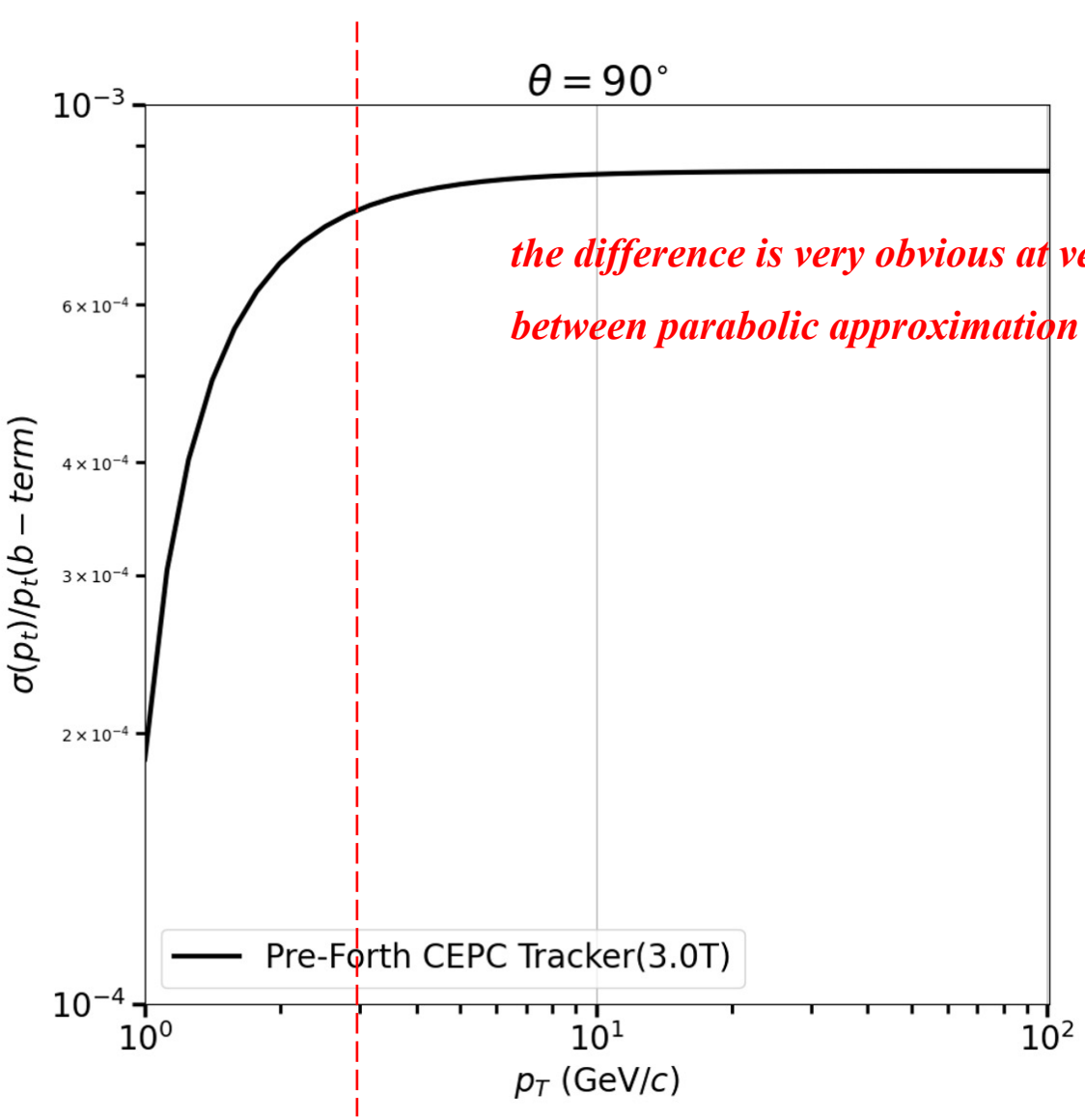
Covariance of 5-parameters : $\boldsymbol{C}_{\boldsymbol{a}} = \left(\boldsymbol{G}^{\boldsymbol{T}} \boldsymbol{C}_{\boldsymbol{y}}^{-\mathbf{1}} \boldsymbol{G}\right)^{-\mathbf{1}}$

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

Helix:

$$x = d_0 \cos\phi + R[\cos\phi - \cos(\phi + \varphi)]$$
$$y = d_0 \sin\phi + R[\sin\phi - \sin(\phi + \varphi)]$$
$$z = z_0 - R \tan\lambda \cdot \varphi$$

1. Analytic calculation



the difference is very obvious at very low momentum range

between parabolic approximation and strict helix fit