CEPC Tracking System Optimization

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Xin Shi

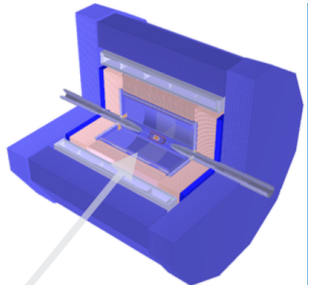
On behalf of the CEPC Tracker Team

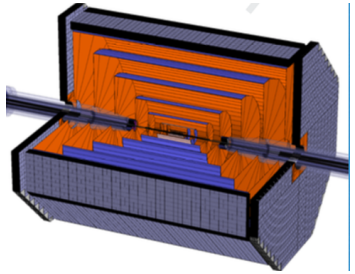
Outline

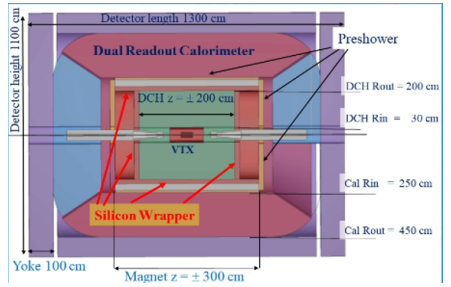
- Introduction
- Drift chamber optimization for PID
- Tracking optimization
- Summary and Plan

Introduction

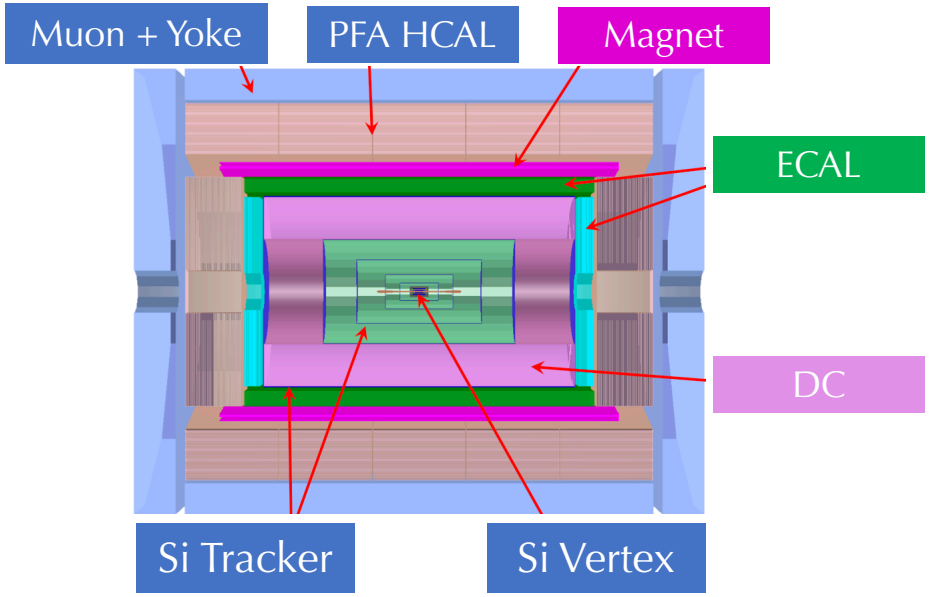
- Three existing detector concept for CDR
  - Silicon + TPC
  - Full Silicon Tracker
  - IDEA Concept







- The 4th detector concept
  - Silicon Vertex + Siliconn Tracker for momentum measurement
  - Drift chamber optimized for PID
  - Transverse crystal bar ECAL optimized for π^0/γ reconstruction
  - Solenoid magnet between HCAL and ECAL



Physics Requirements for CEPC detector

- 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	$\sigma_E^{\mathrm{jet}}/E =$ $3 \sim 4\%$ 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 2σ K/π separation up to ~20 GeV
- EW measurements: High precision luminosity measurement, $\delta L/L \sim 10^{-4}$

Tracking system requirement of CEPC detector

- Vertex :

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

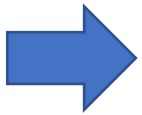
- Silicon Tracker :

$$\Delta(1/p_T) = 2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV})\,\sin^{3/2}\theta}$$

- Drift chamber : 2σ K/π separation up to 20 GeV

Tracker Optimization Roadmap

Performances	Tracker layout
• Momentum resolution • Impact parameter resolution • dE/dx or dN/dx resolution	• Layout of Si trackers • Size and number of cells of the gaseous detector (taking into account X/X0, B, gas …)

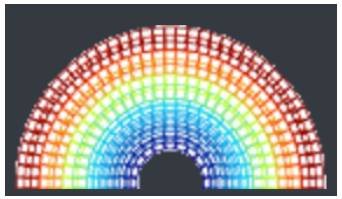


- Short term plan
  - determine the preliminary layout of the tracker with fast simulation
- Long term plan
  - optimize the design with full simulation and benchmark physics channels

Software for tracker optimization

- LiC Detector Toy (LDT)
  A fast single-track simulation and reconstruction tool, aiming at the optimization of tracking detector design
- Acts Common Tracking Software (ACTS)
  An experiment-independent toolkit for charged particle track reconstruction in high energy physics experiments

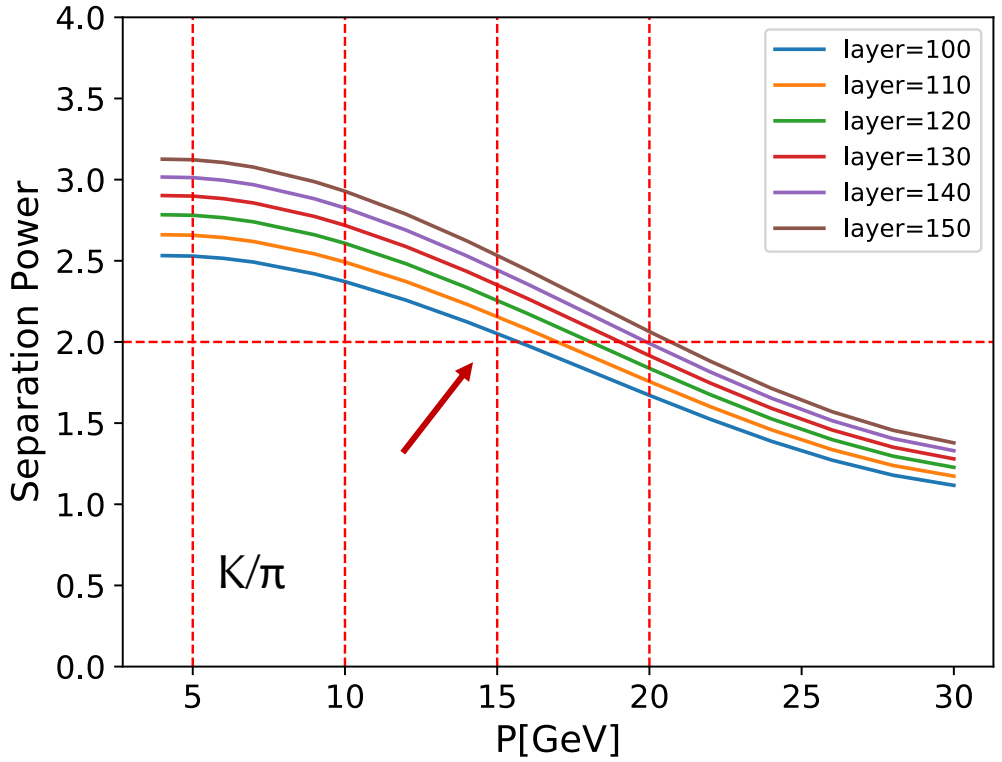
- tkLayout
  A modeling and performance analysis tool developed at CMS for the study of a new silicon tracker

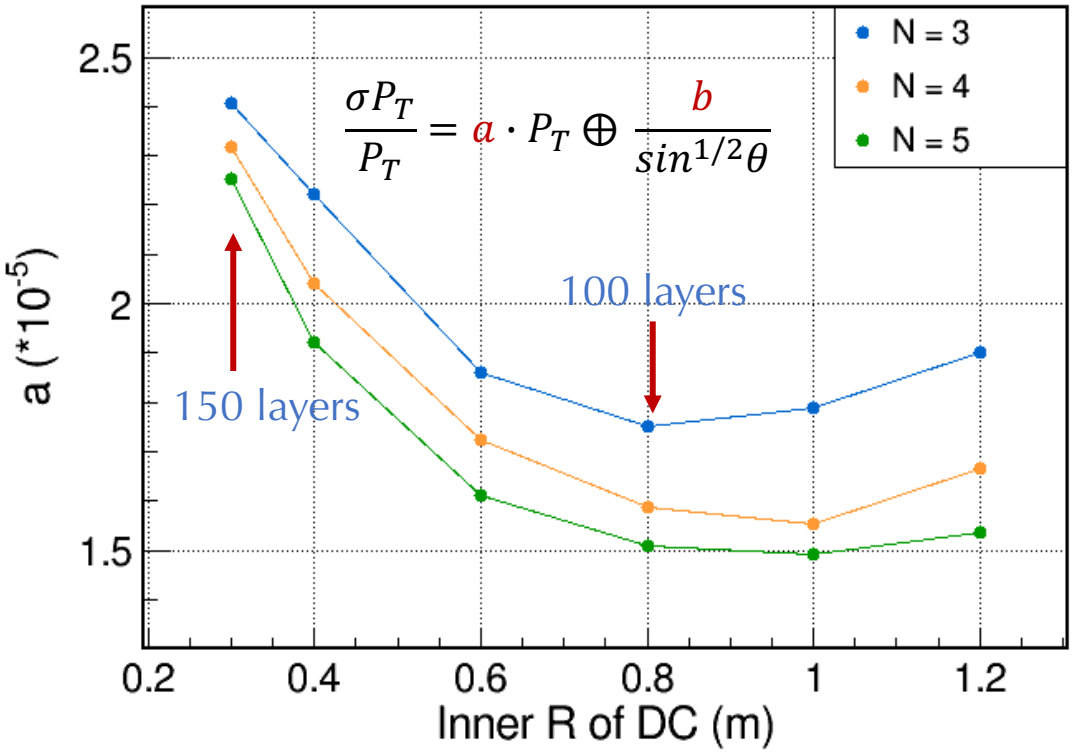


- Fast Tracker Simulation (FastTrkSim)
  A fast simulation for tracking detector optimization, developed by Linghui Wu
- Validation with different fast simulation tools

Size of Drift Chamber

- Investigating momentum resolution using FastTrkSim
  - Outer R of DC is fixed to be 1.8m, one layer of silicon (SET) outside of DC
  - N layers of SITs between vertex detector and DC with equal spacing (N=3,4,5)



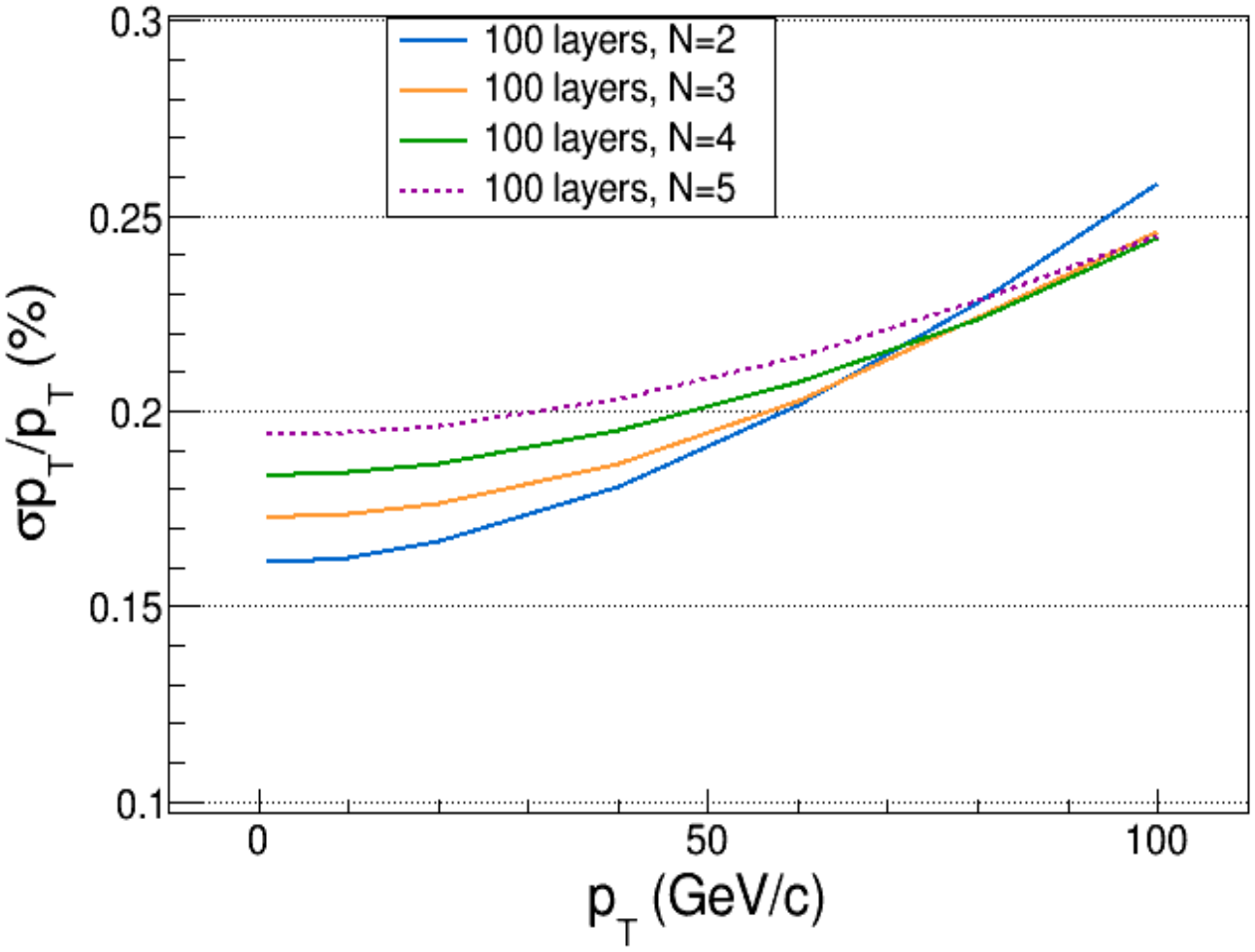


- **100 layers** of DC (from **0.8m** to **1.8m**) to balance momentum resolution and PID

Number of layers for Si tracker

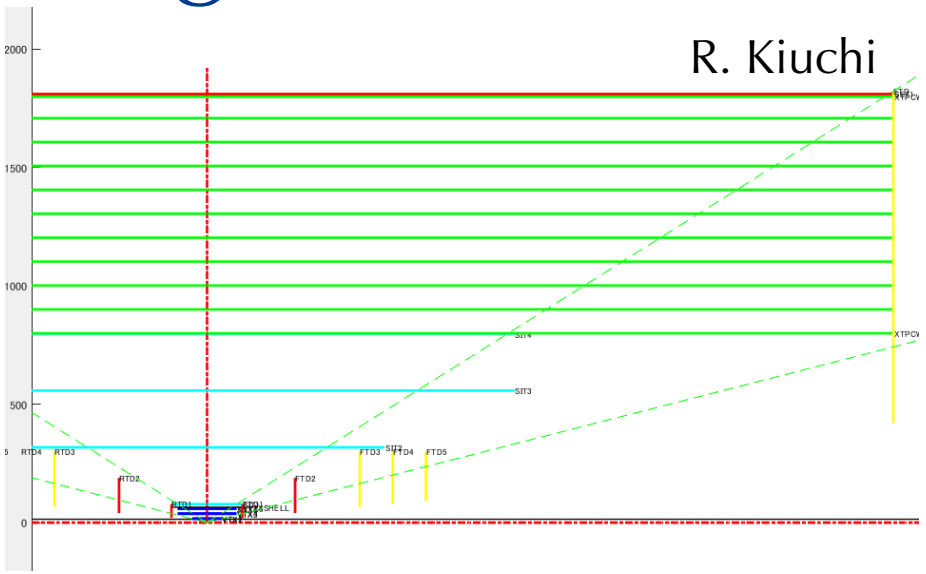
- 3 or 4 layers of silicon tracker between VXD and DC

- Start with 4 layers as baseline with more space points for low momentum tracking

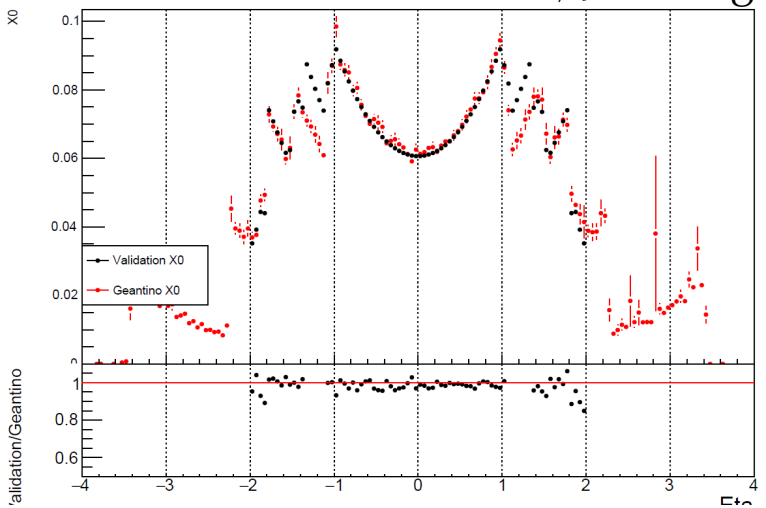


Configuration for simulation study

R. Kiuchi

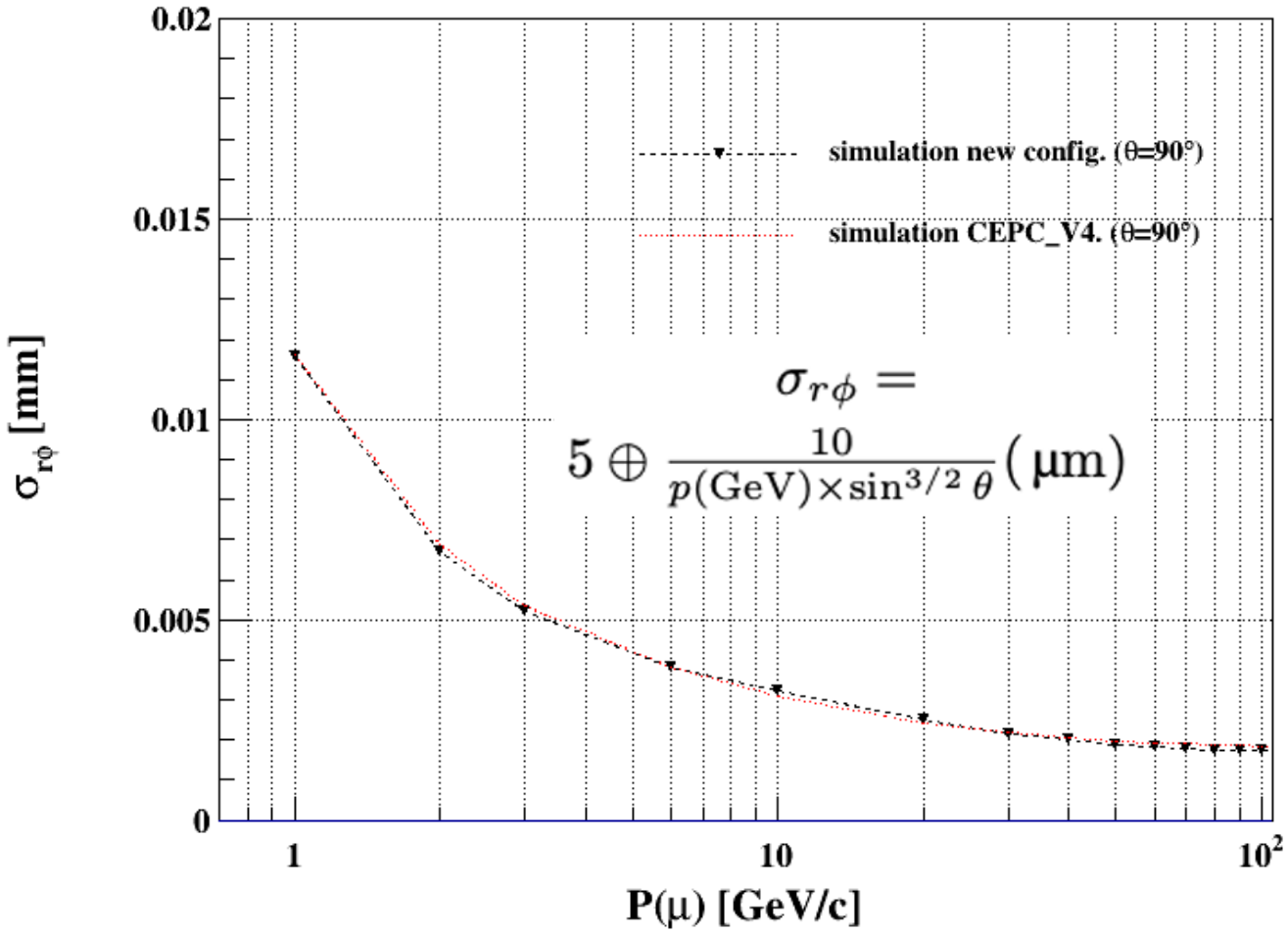


Y. Chen, J. Zhang



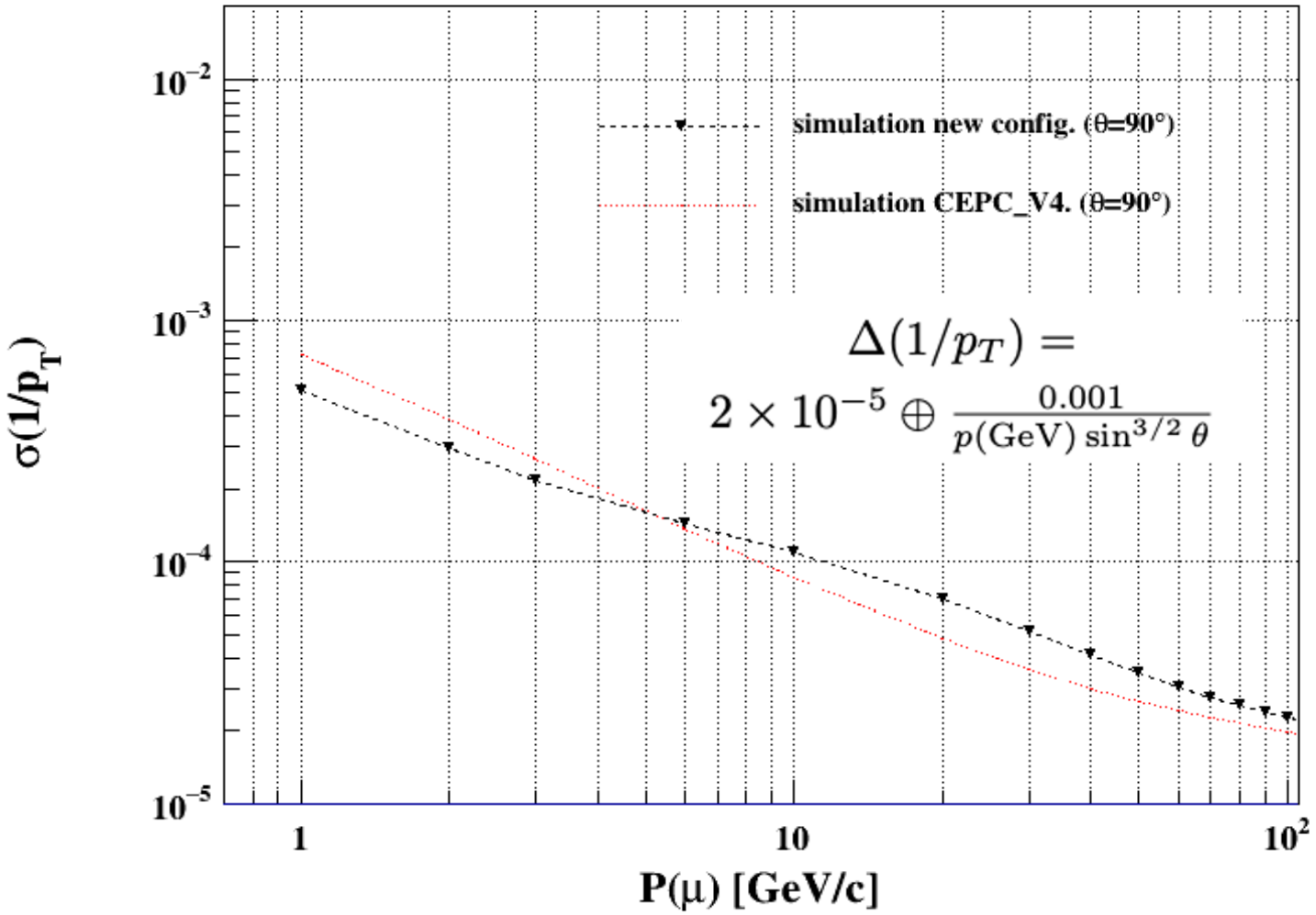
Sub detector	N layers	Resolustion (μm)		Material budget (%X_0)
		r-ϕ	z	
VXD	6	2.8 / 6 / 4 / 4 / 4 / 4	2.8 / 6 / 4 / 4 / 4 / 4	0.15 per layer
SIT	4	7.2	86.6	0.65 per layer
DC (cell 1x1cm^2)	100	100	2000	1.2
SET	1	7.2	86.6	0.65
Total	111	--	--	5.35

Impact parameter resolution



- As expected, no change for impact parameter resolution, fulfilled the requirement

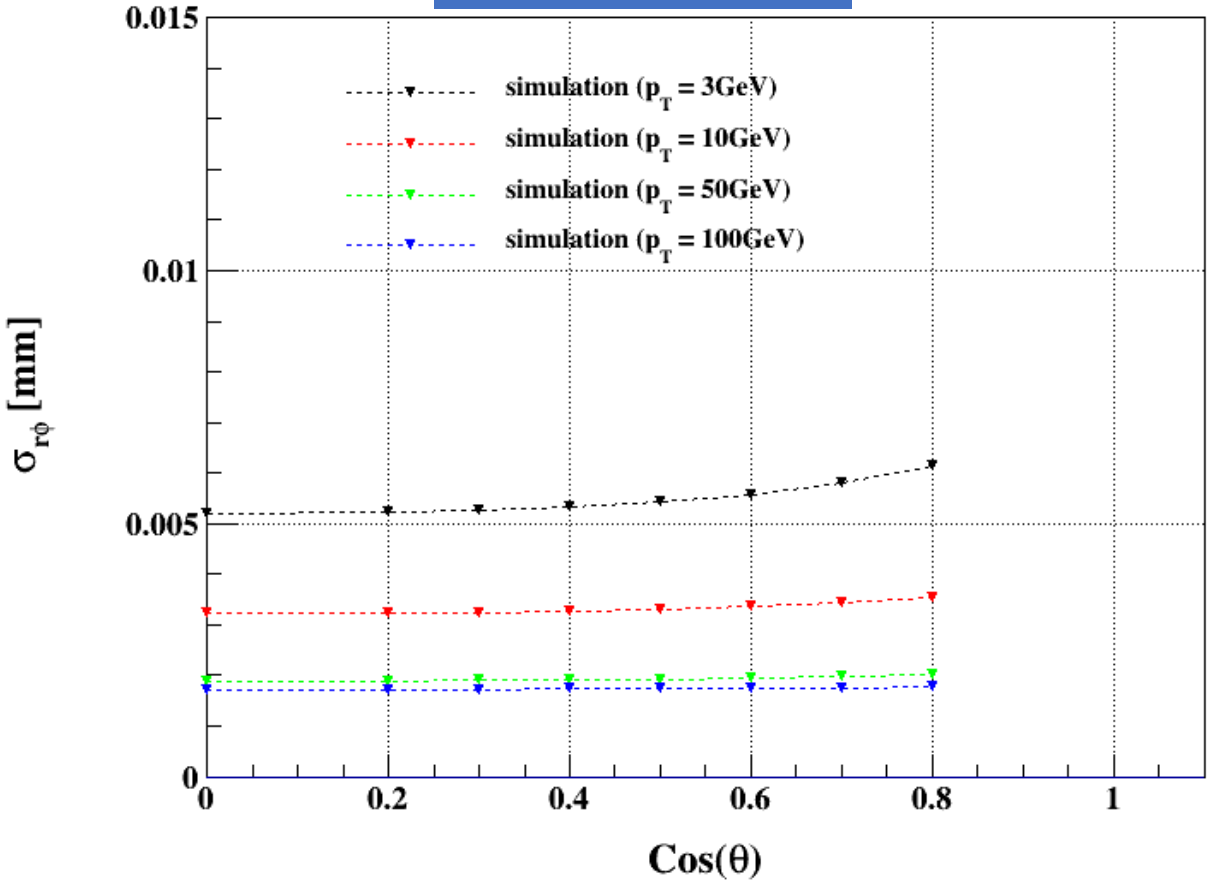
Momentum resolution



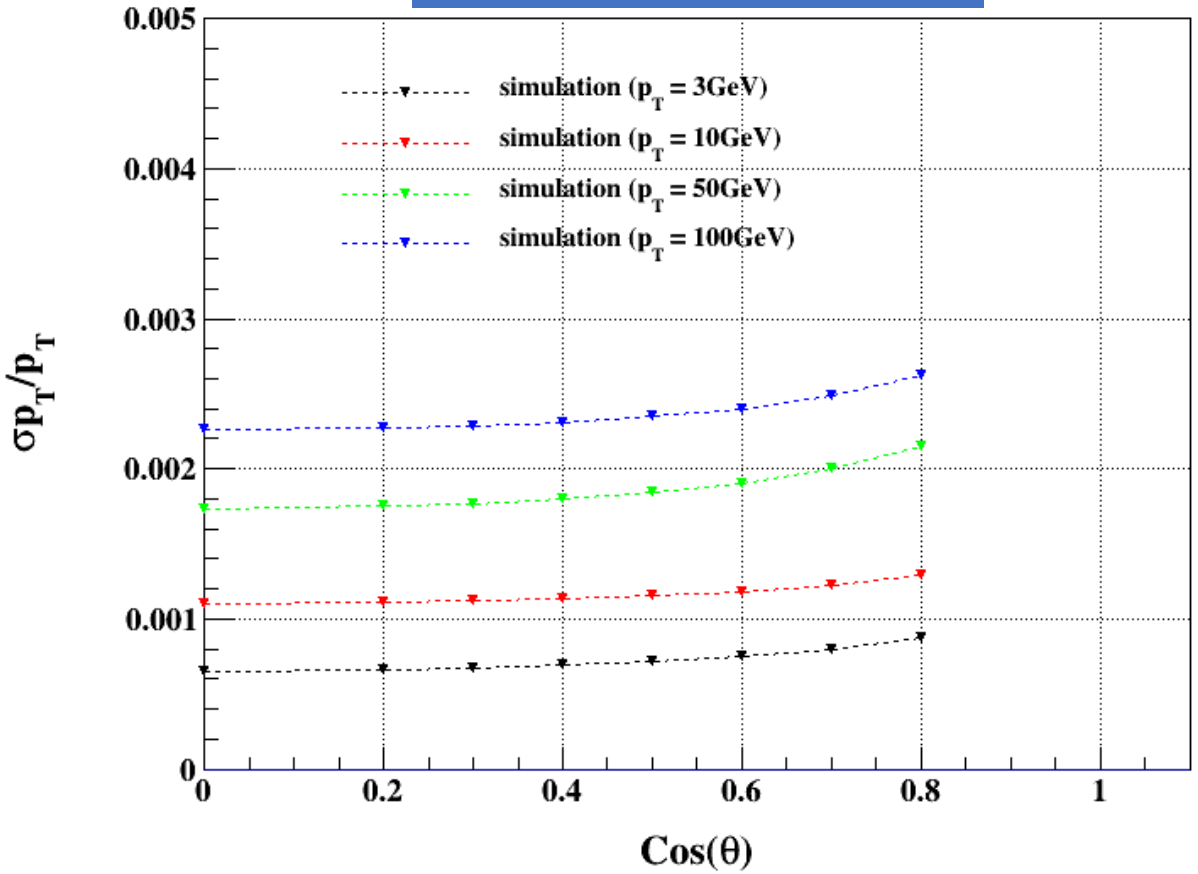
- Better resolution at low momentum

Cos(θ) dependence

IP resolution



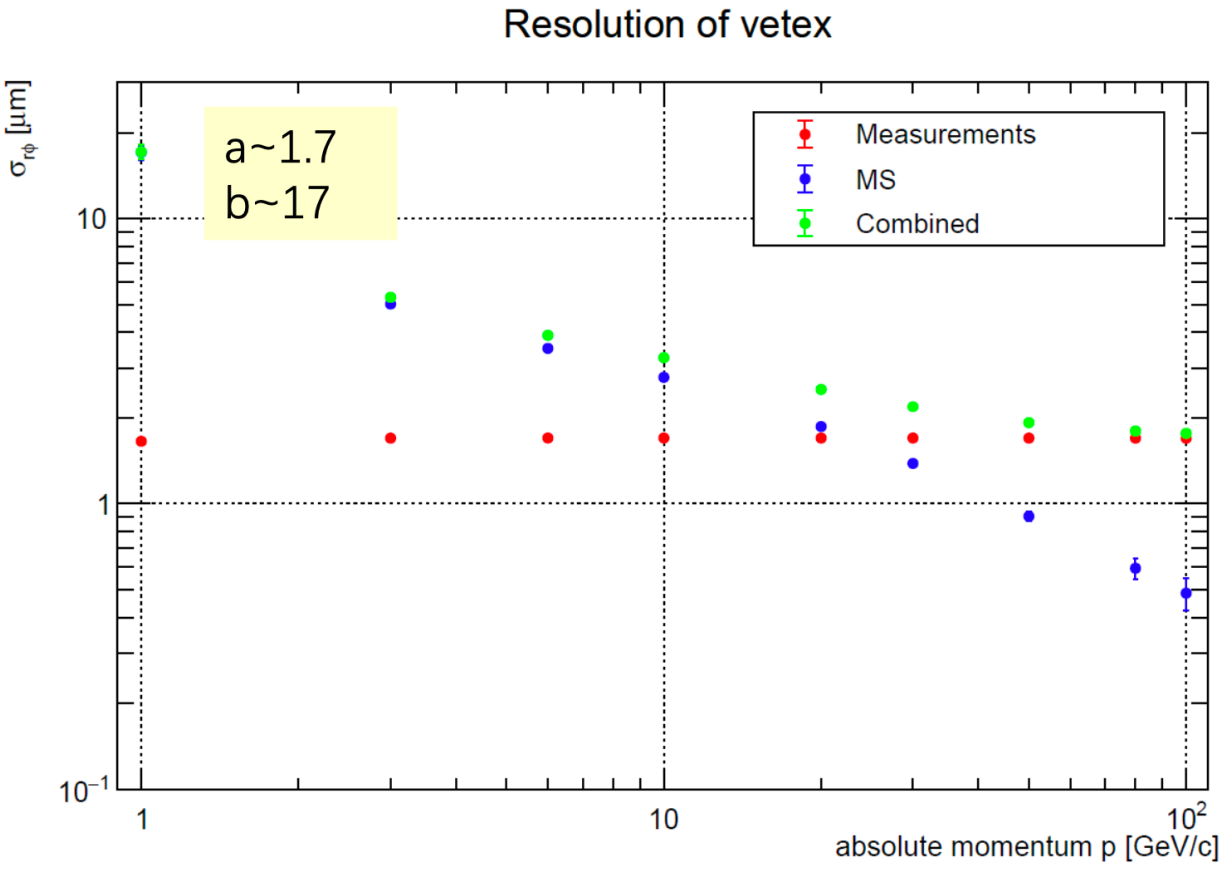
Momentum resolution

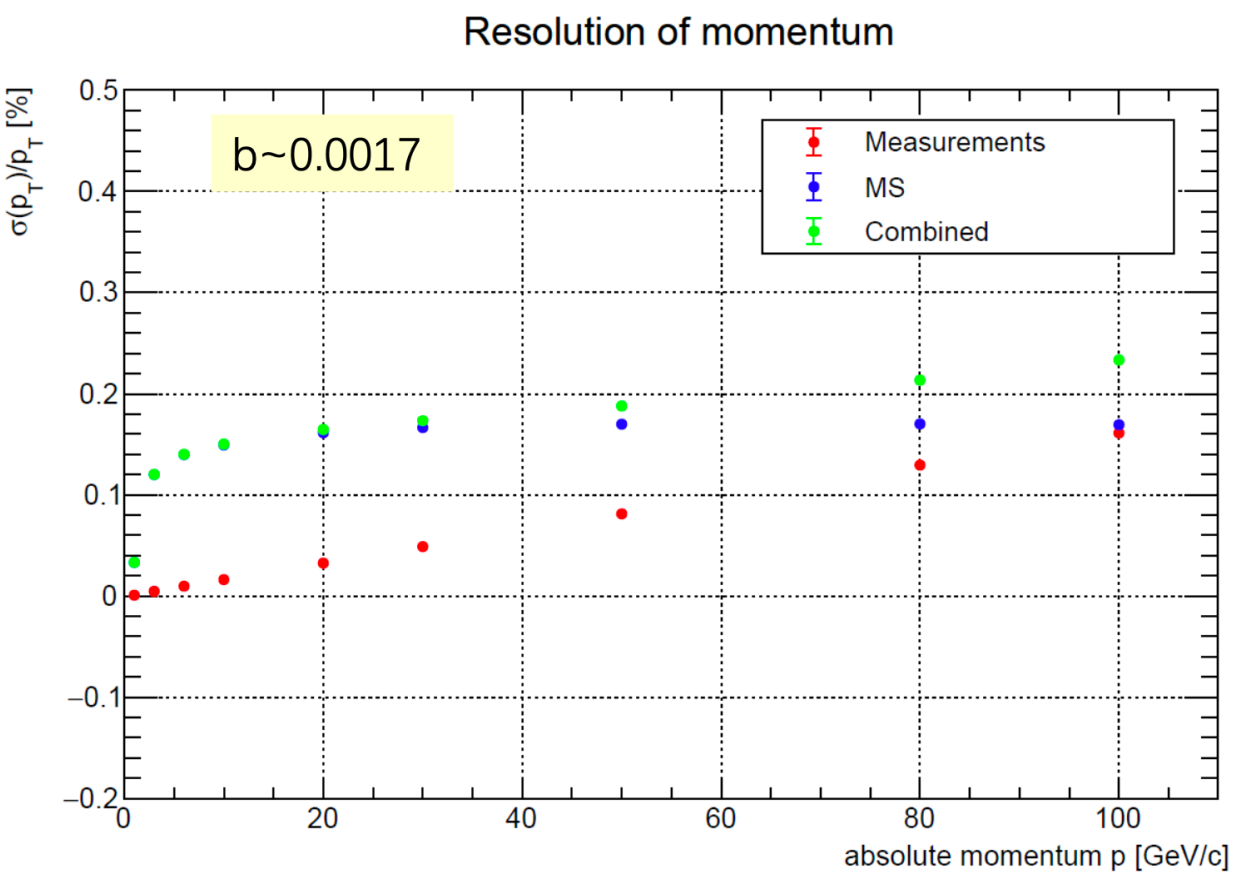


- Slight degradation of in the forward region due to material budget increase

Y. Chen, J. Zhang

Cross check with ACTS





- Roughly consistent results with LDT

Summary and Plan

- The tracking system of the 4th CEPC detector concept has been evaluated
- Drift chamber with 100 layers (0.8m ~ 1.8m) can reach up to 2σ K/π separation at 15 GeV as a starting point
- With 4 layers of SIT reached better resolution in low momentum

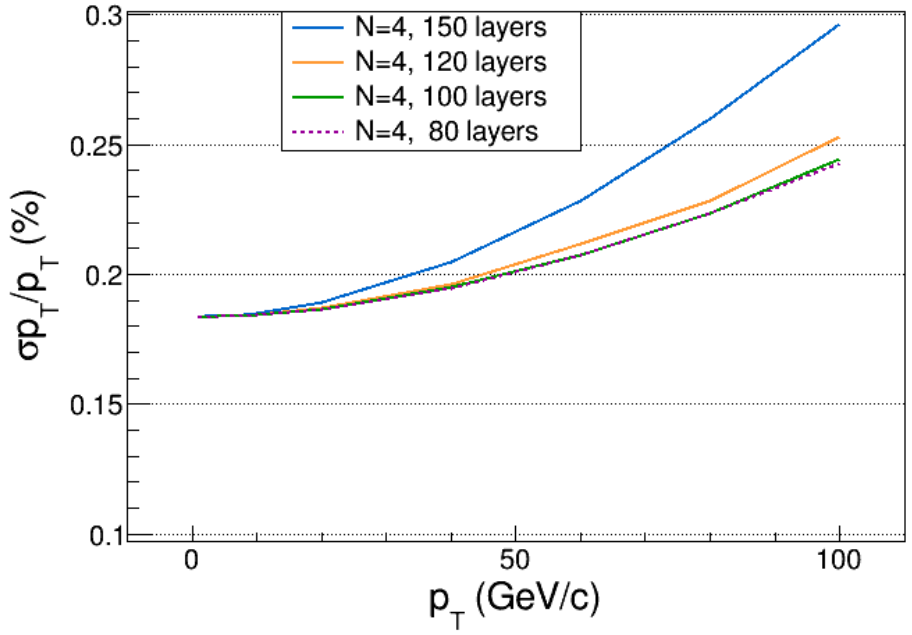
Plan

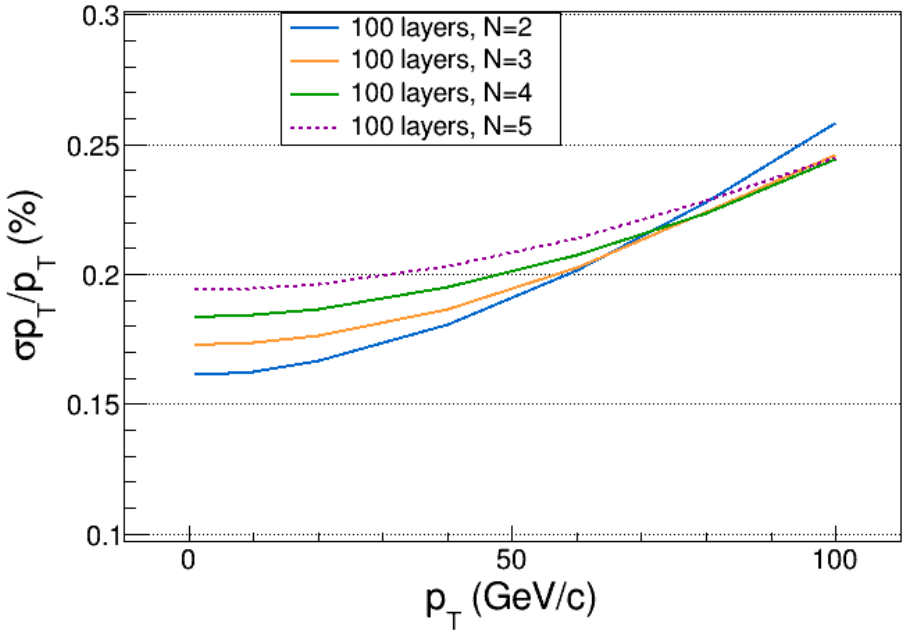
- Drift Chamber with further validation and optimization with full simulation
- Improve the tracking system with material, si-tracker resolution, layout
- Systematic study with EndCap region
- Consider smaller tracker volume

Backup

Optimization of inner DC size

- Reducing size of DC could improve momentum resolution significantly. 100 layers might be proper taking into account both tracking and PID
- For DC with 100 layers, 3 or 4 layers of CMOS pixel tracker between vertex detector and DC should be good. 4 layers of pixel tracker might be better because of :
  - Better momentum resolution for high momentum tracks
  - More space points for low momentum tracking

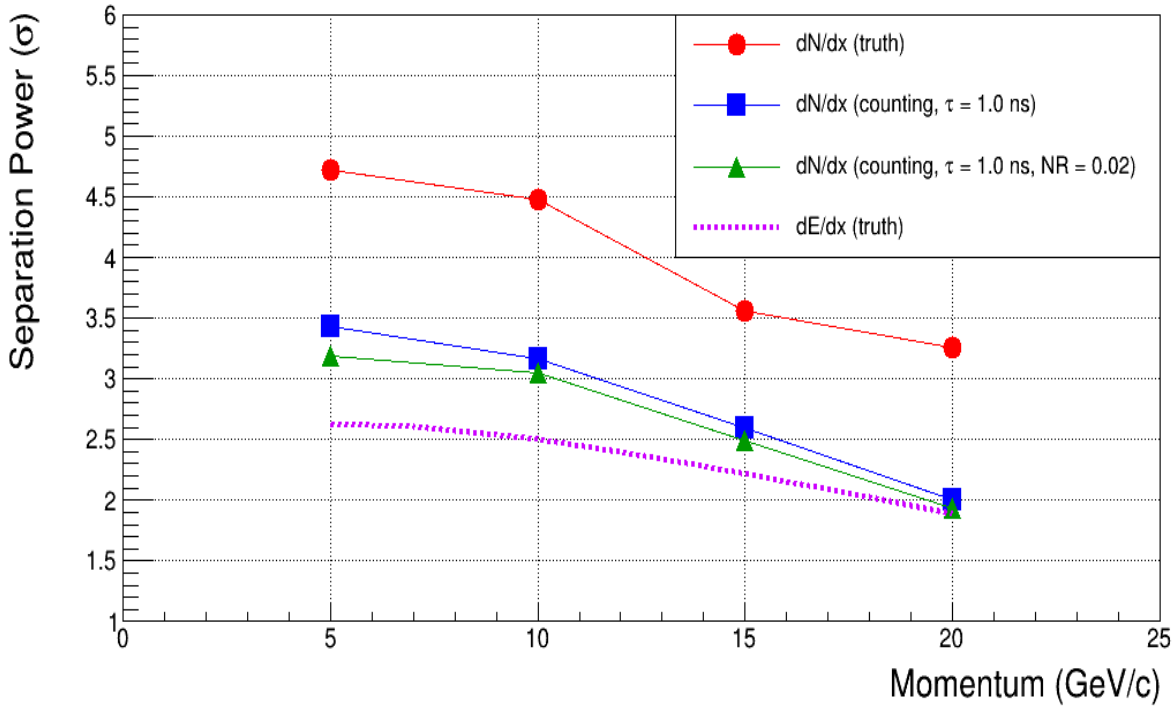


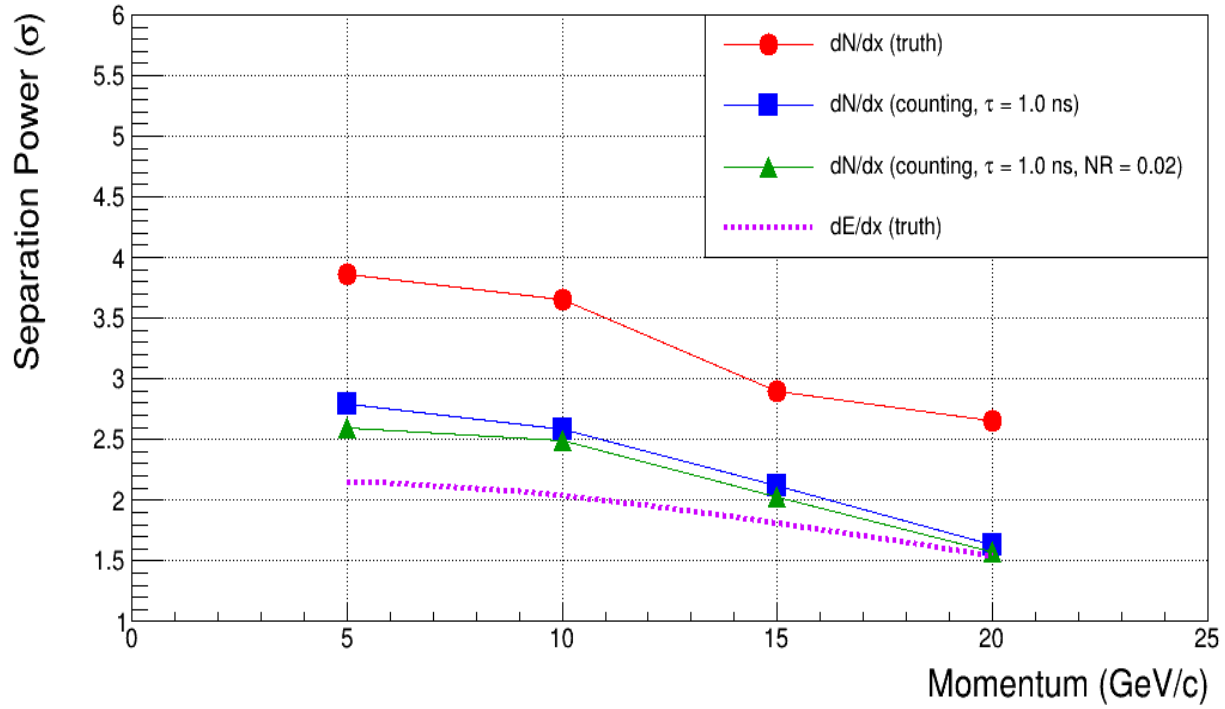


Constrains from PID

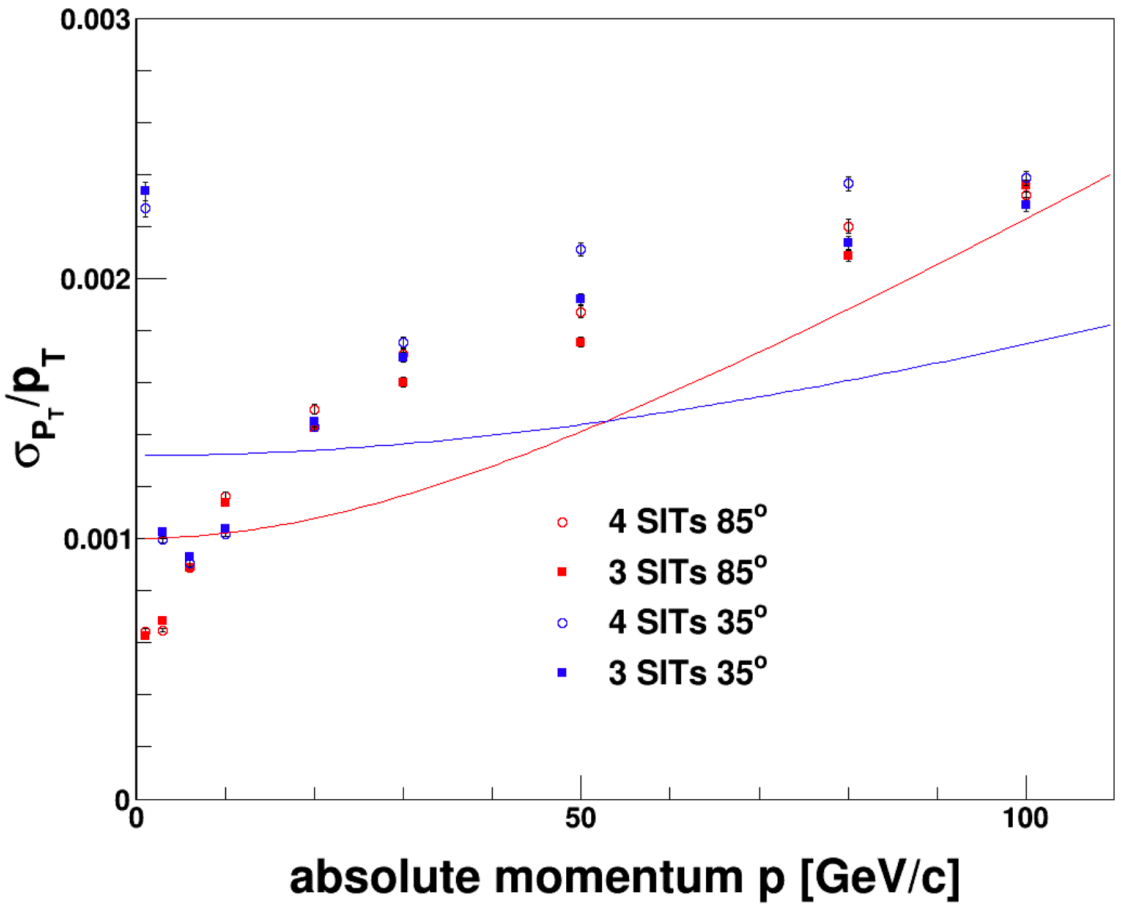
More detail see Guang Zhao's Talk

- A full simulation including signal induction, response of pre-amplifier and white noise is performed





Cross check with full simulation using tkLayout



- Consistent results with LDT and ACTS

Options

- SIT/SET
  - Material
    - 0.17mm Si + 1.0mm C = 0.65% X0
    - 0.15mm Si + 0.5mm C = 0.39% X0
  - Layer
    - 3 SIT + 1 SET
    - 4 SIT + 1 SET
- SET
  - Pixel: σ_{rphi} = 7.2μm, σ_z = 86μm
  - Strip: σ_{rphi} = 7.2μm double → σ_{rphi} = 5.1 μm, material × 2
- Air from VXD shell to DC: 0.18% X0
- DC
  - shell
    - inner: 0.2mm CarbonFiber = 0.07% X0
    - outer: 2.8mm CarbonFiber = 0.49% X0
  - radius
    - 805-1805: GasHe_90Isob_10 = 0.07% X0
    - 1005-1805: GasHe_90Isob_10 = 0.06% X0

Baseline CRD Config file Vertex + SIT

```
Vertex Detector (VTX)

Number of layers             :   8
Description (optional)       :   |-Beamt.-|----------------------------Vertex detector----------------------------------|
Names of the layers (opt.)   :   XBT,      VTX1,        VTX2,      VTX3,       VTX4,       VTX6,      XVTX6,      XVTXSHELL
Radii [mm]                   :   14.5,     16.0,         18,        37.0,       39,         58,        60,         65
Upper limit in z [mm]        :   4225,     62.5,         62.5,      125,        125,        125,       125,        145
Lower limit in z [mm]        :  -4225,    -62.5,        -62.5,     -125,       -125,       -125,      -125,       -145
Efficiency RPhi              :   0,        1.00,         1.00,      1.00,       1.00,       1.00,      1.00,       0
Efficiency 2nd coord. (eg. z):  -1
Stereo angle alpha [Rad]     :   pi/2
Thickness [rad. lengths]     :   0.0015,   0.0015,       0.0015,    0.0015,     0.0015,     0.0015,    0.0015,     0.0015
error distribution           :    0
0 normal-sigma(RPhi) [1e-6m] :    2.8, 6, 4, 4, 4, 4
         sigma(z)    [1e-6m] :    2.8, 6, 4, 4, 4, 4
Silicon Inner Tracker (SIT)

Number of layers             :   6
Description (optional)       :   |----------------Inner tracker-----------|TPC inner wall|
Names of the layers (opt.)   :   SIT1,          SIT2,        SIT3,        SIT4,        XTPCW1,       XTPCW2
Radii [mm]                   :   78.0,          318.0,       558.0,       798.0,       799,          1801
Upper limit in z [mm]        :   150.0,         750.0,       1300,        1300,        2900,         2900
Lower limit in z [mm]        :  -150.0,        -750.0,      -1300,       -1300,       -2900,        -2900
Efficiency RPhi              :   1.00,          1.00,        1.00,        1.00,        0,            0
Efficiency 2nd coord. (eg. z):  -1,
Stereo angle alpha [Rad]     :   pi/2,
Thickness [rad. lengths]     :   0.0065,        0.0065,      0.0065,      0.0065,      0.002,        0.01
error distribution           :   0
0 normal-sigma(RPhi) [1e-6m] :   7.2
         sigma(z)    [1e-6m] :   86.6
```

Baseline CRD Config file DC+ SET

```
Time Projection Chamber (TPC)
sigma^2=sigma0^2+sigma1^2*sin(beta)^2+Cdiff^2*6mm/h*sin(theta)*Ldrift[m]
Number of layers              :   100
Radii [mm]                    :   800,1800
Upper limit in z [mm]         :   2900
Lower limit in z [mm]         :   -2900
Efficiency RPhi               :   1
Efficiency z                  :   1
Thickness [rad. lengths]      :   0.00003356
sigma0(RPhi) [1e-6m]          :   100
sigma1(RPhi) [1e-6m]          :   0
Cdiff(RPhi)  [1e-6m/sqrt(m)]  :   0
sigma0(z)    [1e-6m]          :   2828
sigma1(z)    [1e-6m]          :   0
Cdiff(z)     [1e-6m/sqrt(m)]  :   0
```

```
Magnetic field and beam spot

Solenoid magnetic field [T]  :    3.0
Range in x [mm]              :   -0.0    0.0
Range in y [mm]              :   -0.0    0.0
Range in z [mm]              :   -0.0    0.0
```

```
Silicon External Tracker (SET)

Number of layers              :   1
Description (optional)        :   |--------------External Tracker--
Names of the layers (opt.)    :   SET1,
Radii [mm]                    :   1811,
Upper limit in z [mm]         :   2900,
Lower limit in z [mm]         :  -2900,
Efficiency RPhi               :   1.00,
Efficiency 2nd coord. (eg. z):  -1,
Stereo angle alpha [Rad]      :   pi/2,
Thickness [rad. lengths]      :   0.0065,
error distribution            :   0
0 normal-sigma(RPhi) [1e-6m] :   7.2,
         sigma(z)    [1e-6m] :   86.6,
```