Status of the CEPC Drift Chamber Software

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1. IHEP

2. Shandong University

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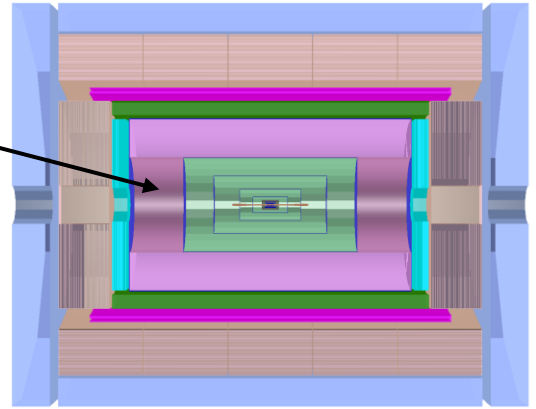
Outline

- Motivation
- Simulation
- Track fitting
- Tracking performance
- Summary

Drift Chamber(DC) Software

- Drift chamber is the key detector in the 4th conceptual detector design to provide PID
  - Good PID ability (2σ π/K separation at P < ~ 20 GeV/c)
  - Precise momentum measurement (eff. ~100%, σp<=0.1%)



- Motivation of DC software project
  - Development of simulation and reconstruction for DC
  - Support the detector design, optimization and performance study
  - Support physics sensitivity study

- Requirements for DC software
  - Modular design and friendly interfaces
  - Easily integrated with common tools (ACTS, Genfit etc.)
  - Reuse existing algorithms from other experiments
  - Application of advanced technic (ML) to simulation and reconstruction

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

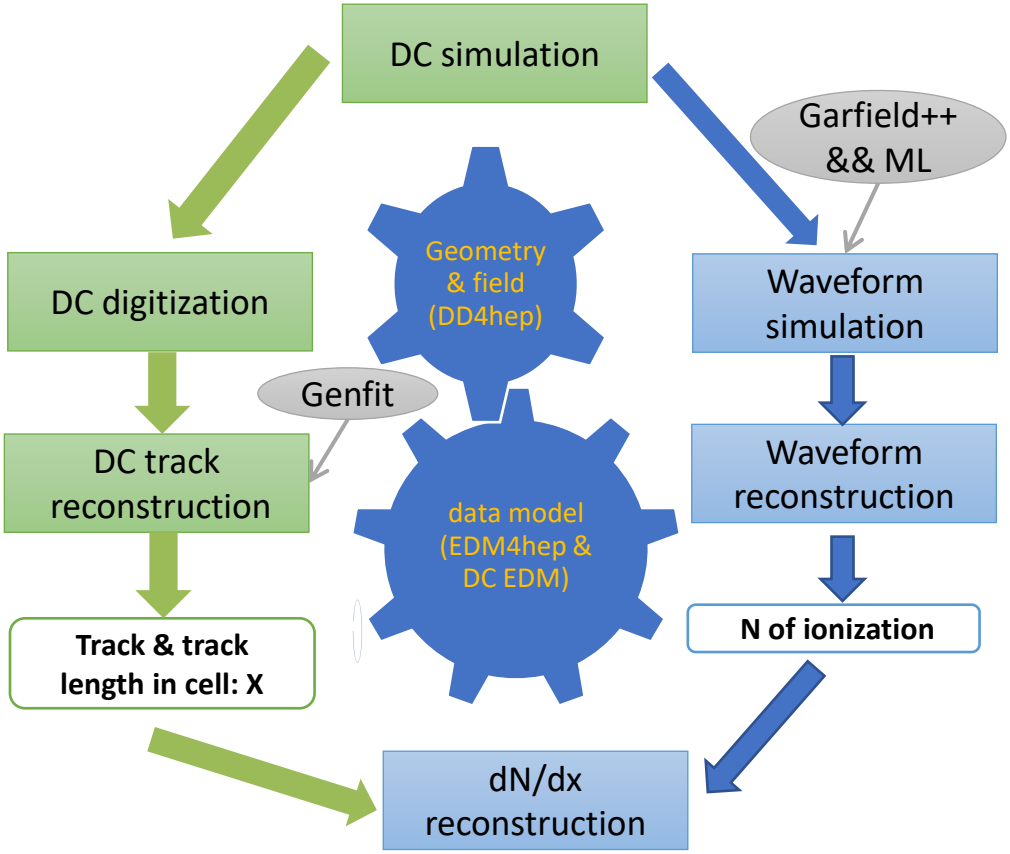
Requirements of The CEPC tracker

- Manpower
  - IHEP: Yao Zhang, Tao Lin, Wenxing Fang, Chengdong Fu, Ye Yuan, Weidong Li
  - SDU: Mengyao Liu, Xueyao Zhang, Xingtao Huang

DC software

The drift chamber software has been developed from scratch

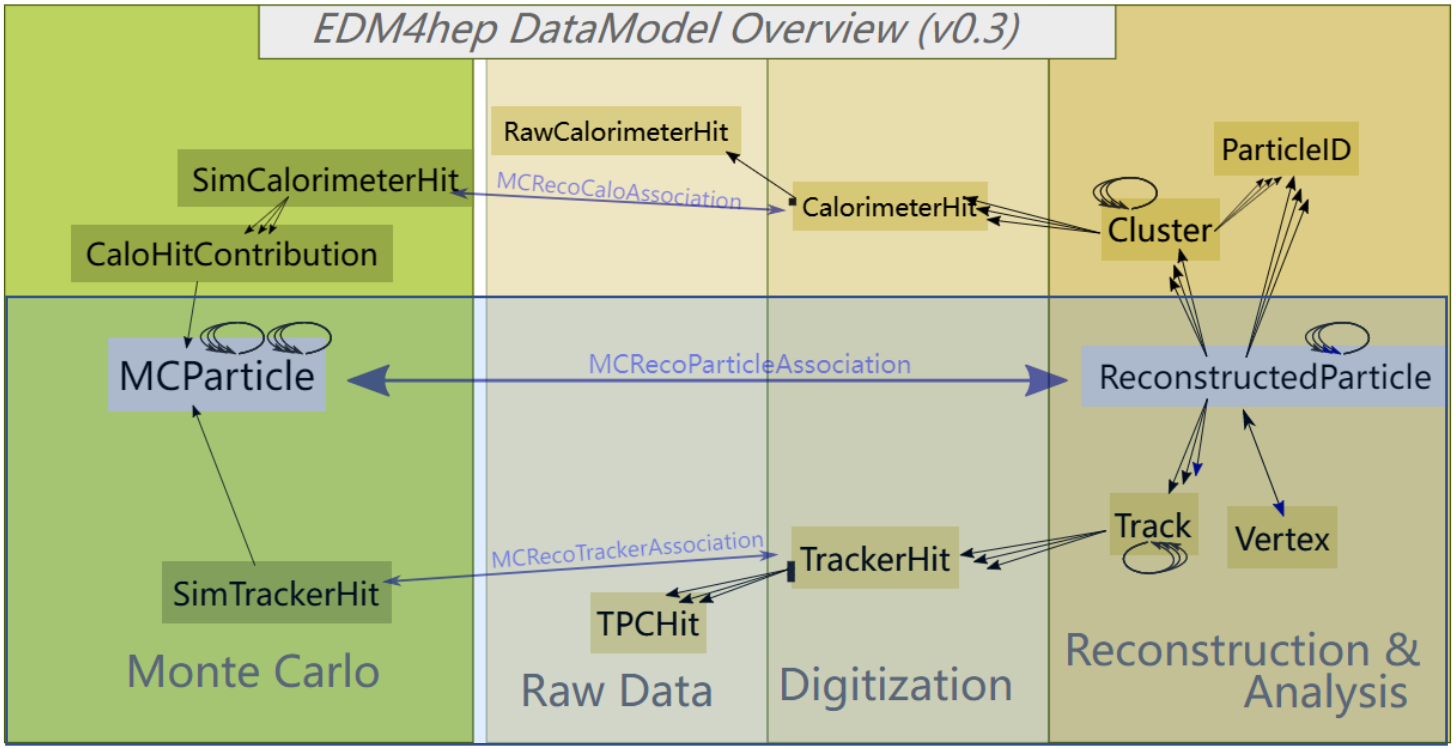
- CEPCSW
  - Gaudi based framework
  - External libraries and tools
- Geometry and field map
  - DD4hep
  - Non-uniform magnetic field: **done**
- Data model
  - EDM4hep and FWCore
  - dN/dx event model: done
- Drift chamber
  - DC simulation: **done**
  - DC digitization: **done**
  - Waveform simulation: in progress
  - Waveform reconstruction: in progress
  - Track fitting with measurement: **done**
  - dN/dx reconstruction: in progress
  - Multi track reconstruction: **done**
  - Performance check: **done**



Drift chamber simulation and reconstruction flow

Event data model

- DC implement the data model following the EDM4hep
- The extension of the current EDM4hep to accommodate the needs from dN/dx studies



EDM development for the drift chamber

- Currently, edm4hep does not include a data model for drift chamber

- The development of EDM for drift chamber is done
  - Using YAML file and podio to produce the EDM
  - Can work together with edm4hep data successfully
    - https://github.com/ihep-sft-group/CEPCSWEDM_test

```
#---------- SimPrimaryIonizationCluster
cepcsw::SimPrimaryIonizationCluster:
  Description: "Simulated Primary Ionization"
  Author : "Wenxing Fang, IHEP"
  Members:
    - unsigned long long cellID      //ID of the sensor that created this hit
    - int size                       //number of electrons created by this primary ionization.
    - float time                     //proper time of the hit in the lab frame in [ns].
    - int   type                     //type.
    - edm4hep::Vector3d position     //the hit position in [mm].
  OneToOneRelations:
    - edm4hep::MCParticle MCParticle //MCParticle that caused the hit.


#---------- SimIonization
cepcsw::SimIonization:
  Description: "Simulated Ionization"
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  Members:
    - unsigned long long cellID      //ID of the sensor that created this hit
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    - edm4hep::Vector3d position     //the hit position in [mm].
  OneToOneRelations:
    - edm4hep::MCParticle MCParticle //MCParticle that caused the Ionization.
    - cepcsw::SimPrimaryIonizationCluster PrimaryIonization //PrimaryIonization that caused the Ionization.
```
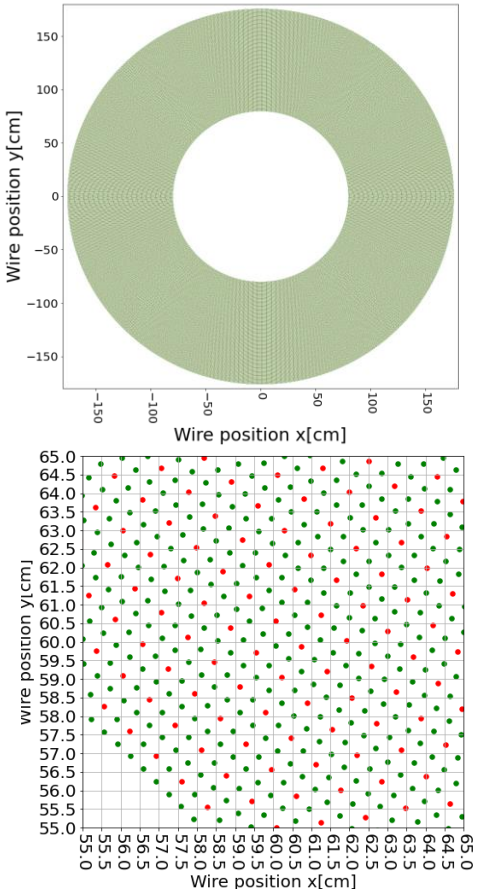

Drift Chamber Parameters in CEPCSW

- The baseline configuration of DC in CEPCSW

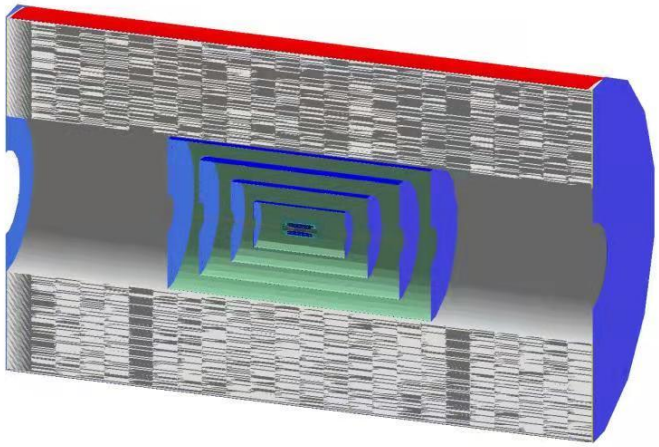
Half length	2980 *mm*
Inner and outer radius	800mm to 1800 *mm*
# of Layers	100/55
Cell size	~10mmx10mm/18mmx18mm
Gas	He:iC_4H_{10}=90:10
Single cell resolution	0.11 *mm*
Sense to field wire ratio	1:3
Total # of sense wire	81631/24931
Stereo angle	1.64~3.64 *deg*
Sense wire	Gold plated Tungsten ϕ=0.02*mm*
Field wire	Silver plated Aluminum ϕ=0.04*mm*
Walls	Carbon fiber 0.2 *mm*(inner) and 2.8 *mm(*outer)



Cell structure

Silicon detectors Parameters in CEPCSW

Silicon tracker	*Number of layer*	*Radius(mm)*	σ_U (μm)	σ_V(μm)
VXD	3 double layers	16-58	2.8/6/4/4/4/4	2.8/6/4/4/4/4
SIT	4 layers	230-770	7.2	86
SOT(SET)	1 layer	1815	7.2	86

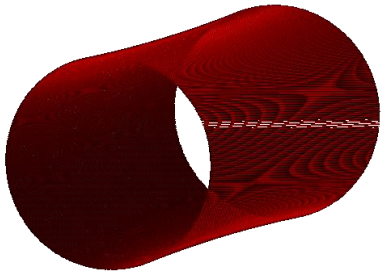


CRD tracker o1 v01

DC Simulation

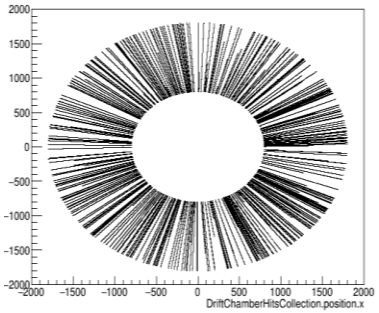
- Following the common scheme for detector description
  - XML based compact files for drift chamber detector description
    - CRD: Detector/DetCRD/compact/CRD_oX_vYY/CRD_o1_vYY.xml
  - Geometry parameters can be flexibly configured

```
<constant name="DC_layer_number" value="55"/>
<constant name="DC_cell_width" value="18*mm"/>
<constant name="Alpha" value="12*deg"/>
```



One stereo layer of drift chamber

- Cell partitioning with segmentation
  - Consistent between simulation and reconstruction
- Simple digitization
  - Constant drift velocity: V_{drift}=40μm/ns & fixed spatial resolution: σ=110mm



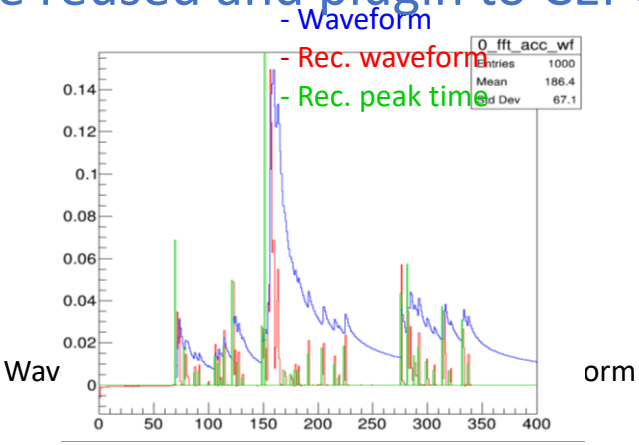
Hitmap of MC hits in DC

Software Development for the Drift Chamber, Yao Z.

dN/dx Simulation and Reconstruction Flow

- Implementation of the DC waveform simulation and analysis ensures the dN/dx study by physics channels
  - Integrate Geant4 and Garfield++ for precise simulation
  - Fast signal response simulation
  - A waveform reconstruction with Fourier transform
  - See Wenxing's talk(Simulation of Detector Response in the Drift Chamber) for detail

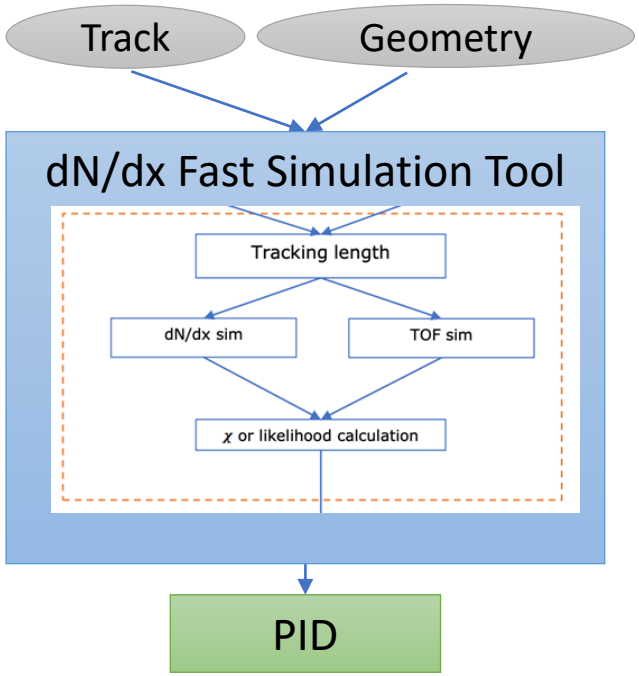
- dN/dx tools can be reused and plugin to CEPCSW



Wav orm

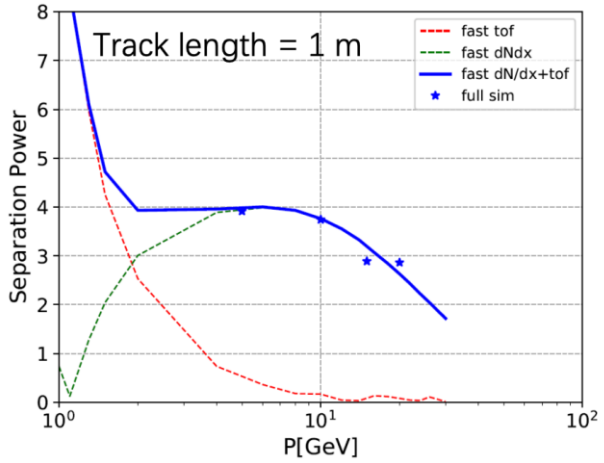
dN/dx Fast Simulation in CEPCSW

- Fast simulation allows quick PID analysis for physics study in CEPCSW
  - A dN/dx model with sampling method simulation tool
- Other dN/dx sim or rec models can be easily plugged in



From Shuiting X. Guang Z. Linghui W.

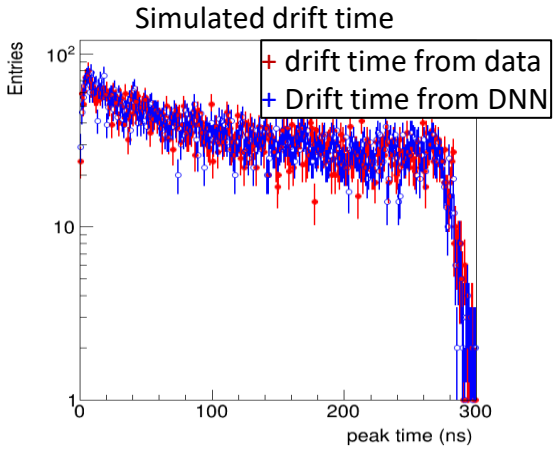
Separation power analysis in CEPCSW with fast simulation tool

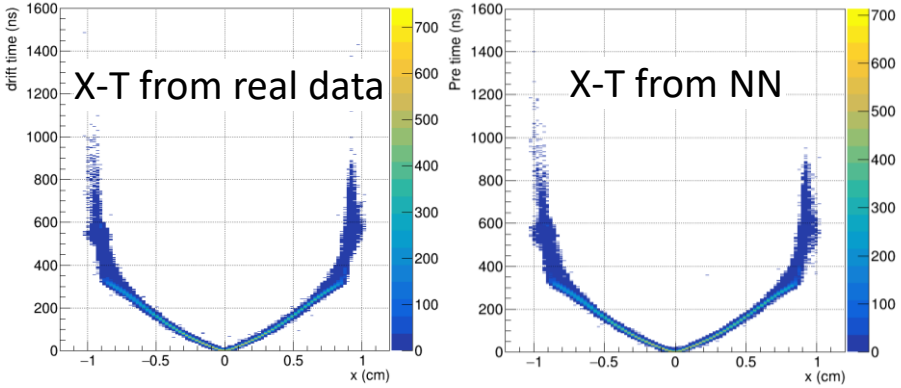


Update of the PID drift chamber study, Guang Zhao

Drift time fast simulation based on real data

- Drift time fast simulation with Neural Network(NN)
  - Model: Deep Neural Networks
  - Dataset: BESIII radiative Bhabha
  - Motivation: validate the fast simulate method with NN

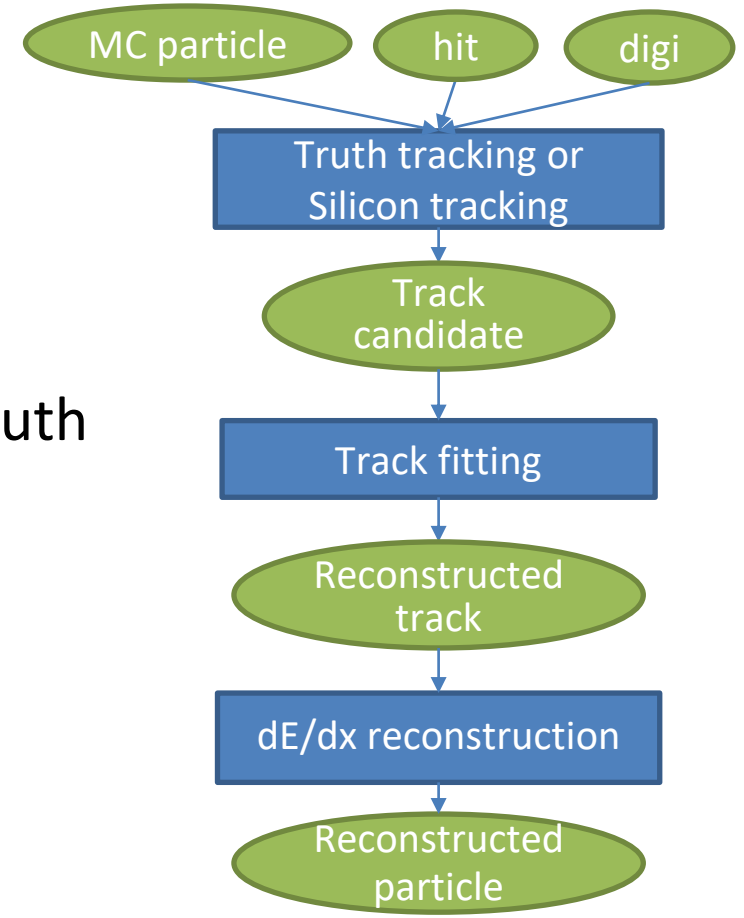




- The preliminary study shows good consistency between data and NN
- The simulation of cluster time with same method is expected

CEPC v4 tracker reconstruction

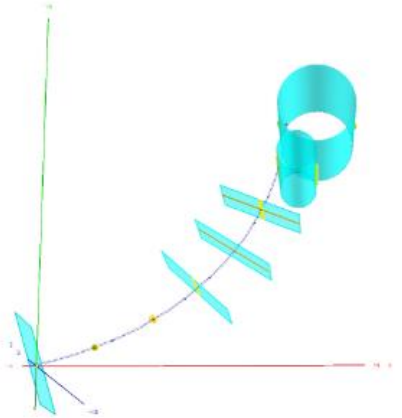
- CEPC v4 tracking flow is implemented
- Track fitting with tracker measurements
  - Silicon measurement + Drift chamber measurement
- Multi-track track finding based on MC truth
- Performance check has been done
  - Preliminary result is reasonable
  - Consistent with fast simulation



Data flow of DC reconstruction

Track Fitting--- RecGenfitAlg

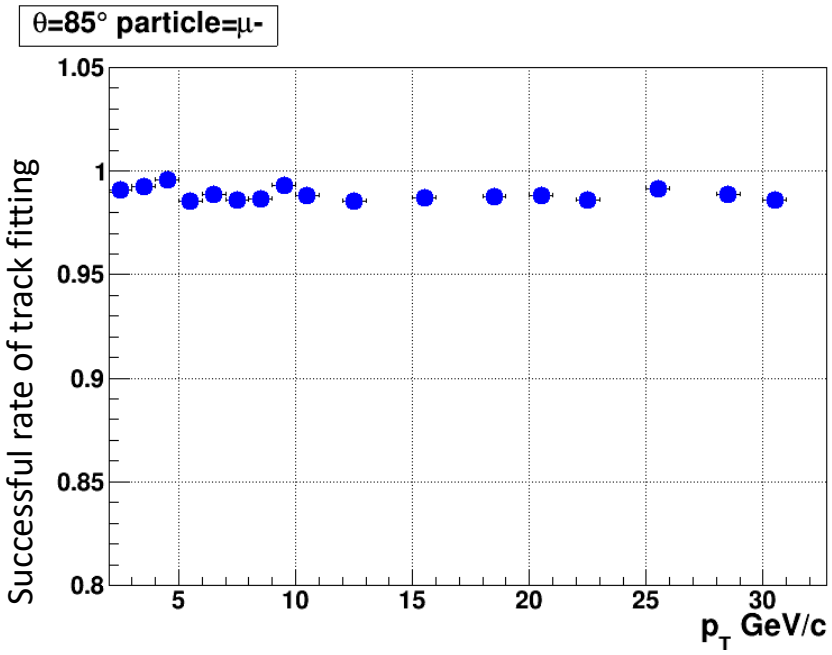
- Based on Genfit (https://github.com/GenFit/GenFit/)
  - An experiment-independent generic track fitting framework
  - Open sourced, active development and large user community
  - Official track fitting for BelleII, also used by PANDA, COMET, GEM-TPC etc.
  - Become the developer of Genfit
- Main features of Genfit
  - Support various detector types:
    - Pixel or strip
    - TPC
    - Drift chamber or tube
    - and combinations of above
  - Detector geometry and field map can be easily integrated
    - GDML and ROOT format
  - Various fitting algorithms available : Kalman filter, DAF, GBL etc.
  - Extrapolation tools

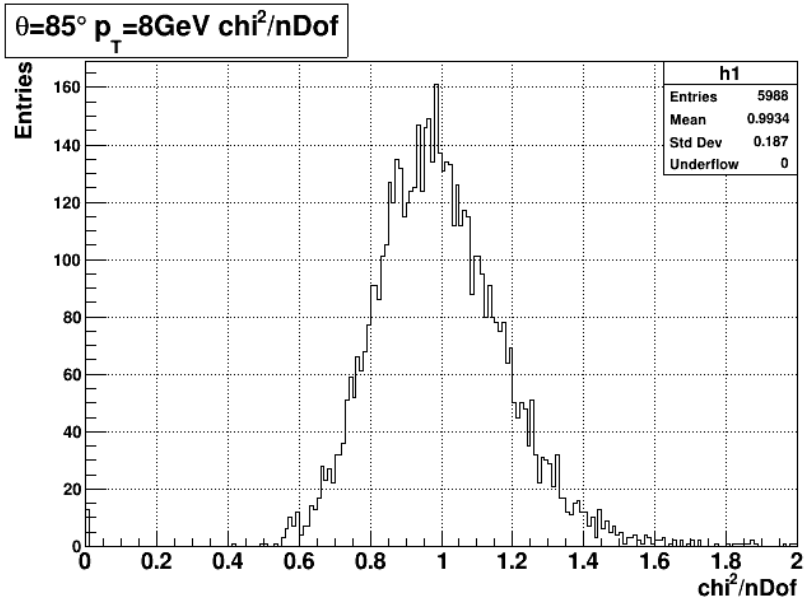


(a) Measurements with covariance (yellow), planar detectors and drift isochrones (cyan), respectively, and reference track (blue).

Fitting quality

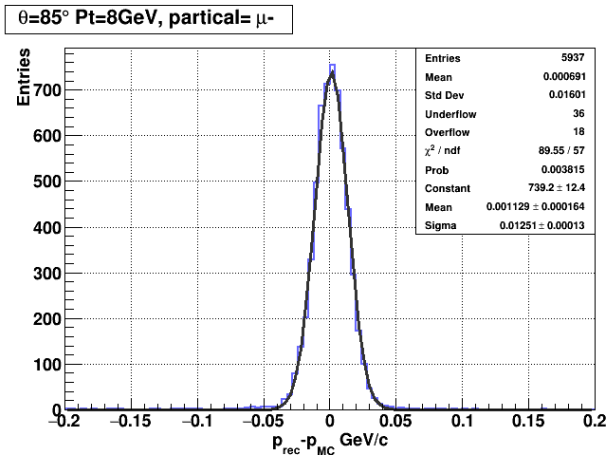
- $\varepsilon = \frac{The\ number\ of\ \text{track fitted}\ successful}{The\ number\ of\ \text{total track}}$

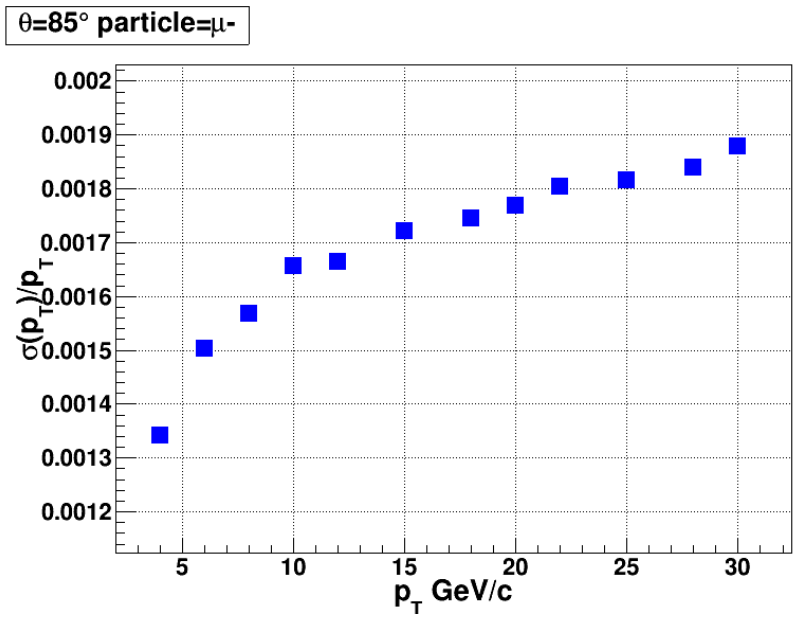


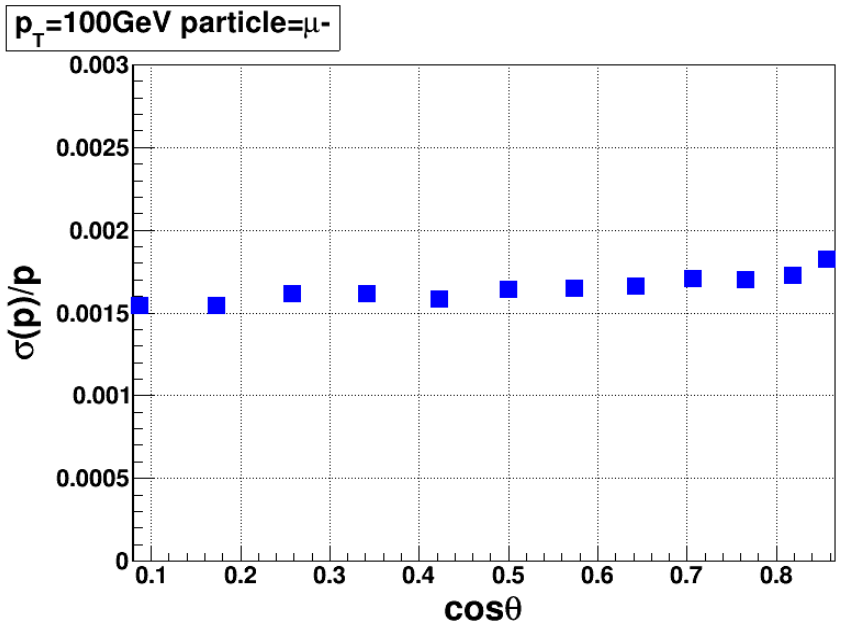


- The successful rate of track fitting is around 99%

Momentum resolution



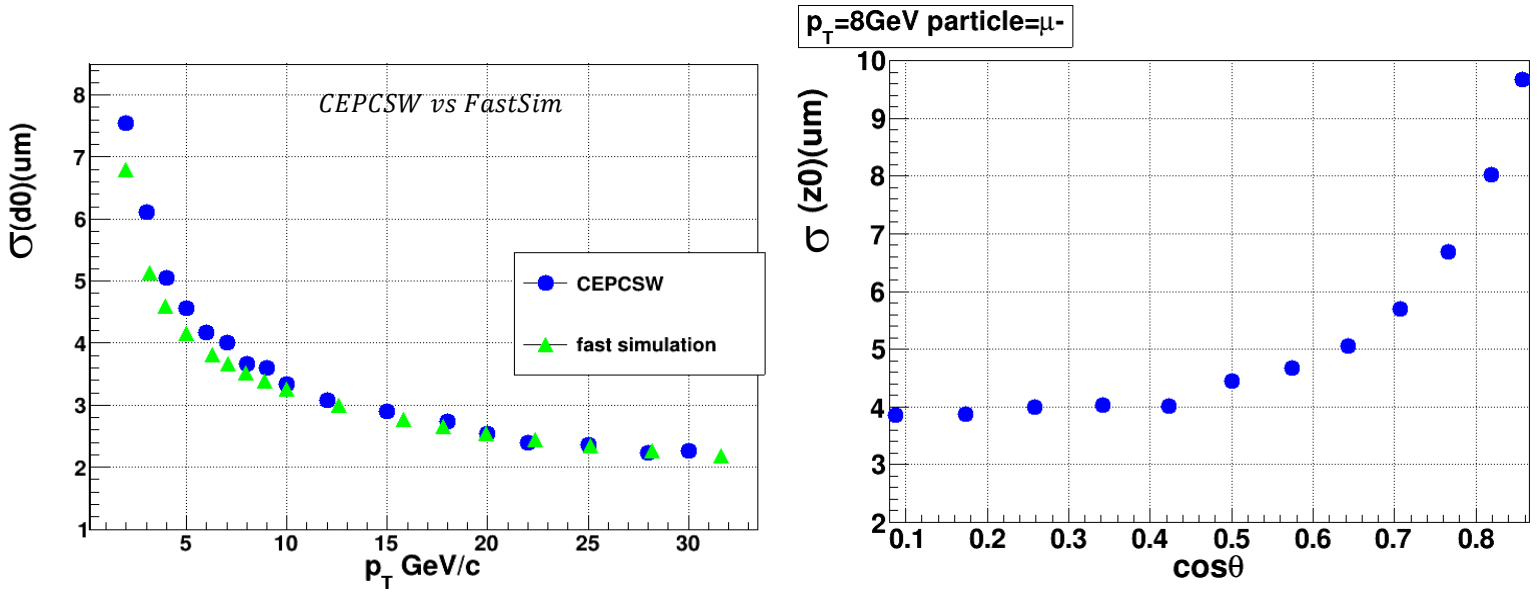




- The momentum resolution is reasonable

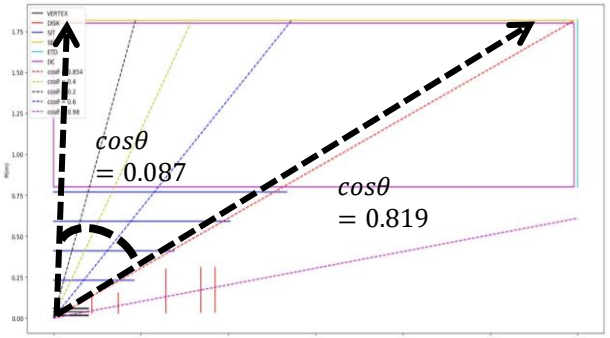
Impact parameter

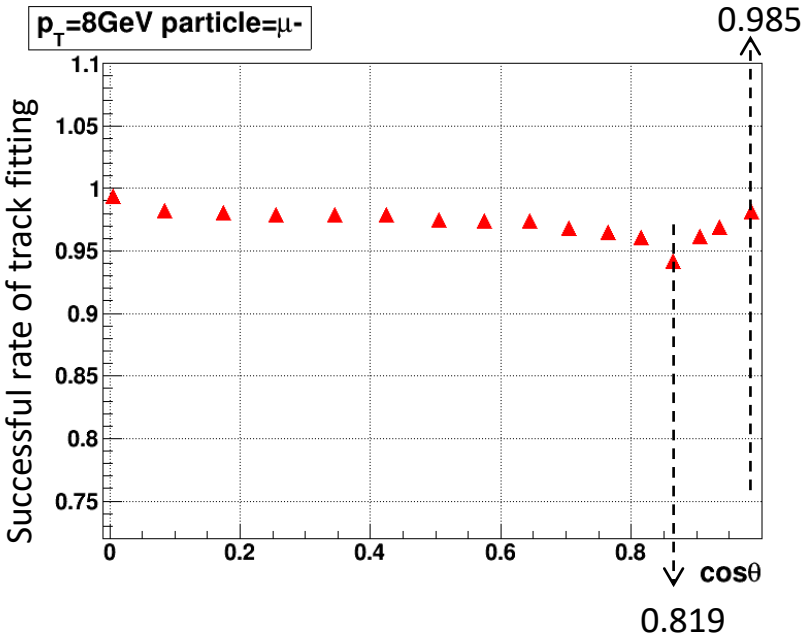
- Impact parameter d_0&Z_0 distribution

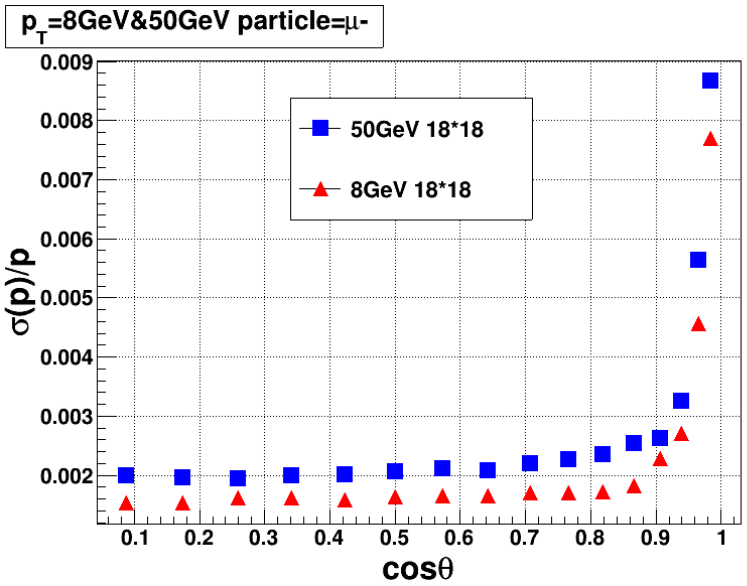


- Consistent with the fast simulation

Fitting quality v.s. dip angle



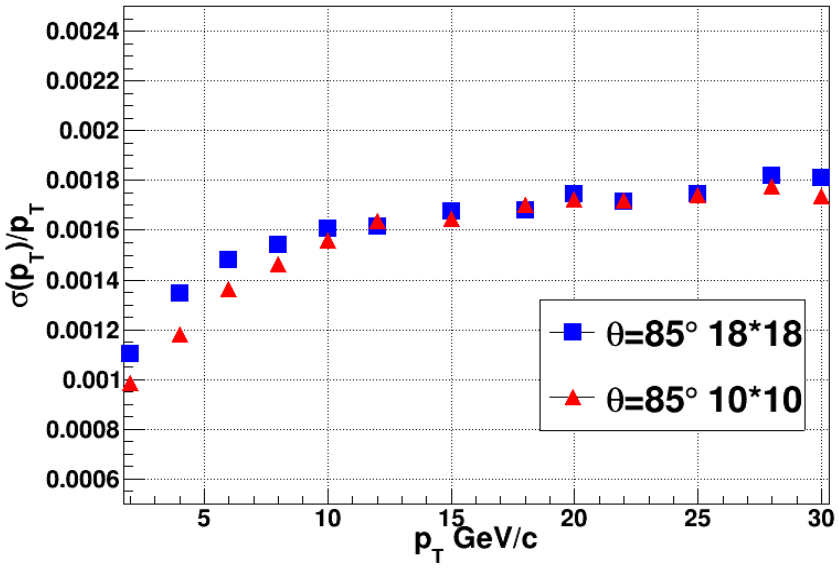


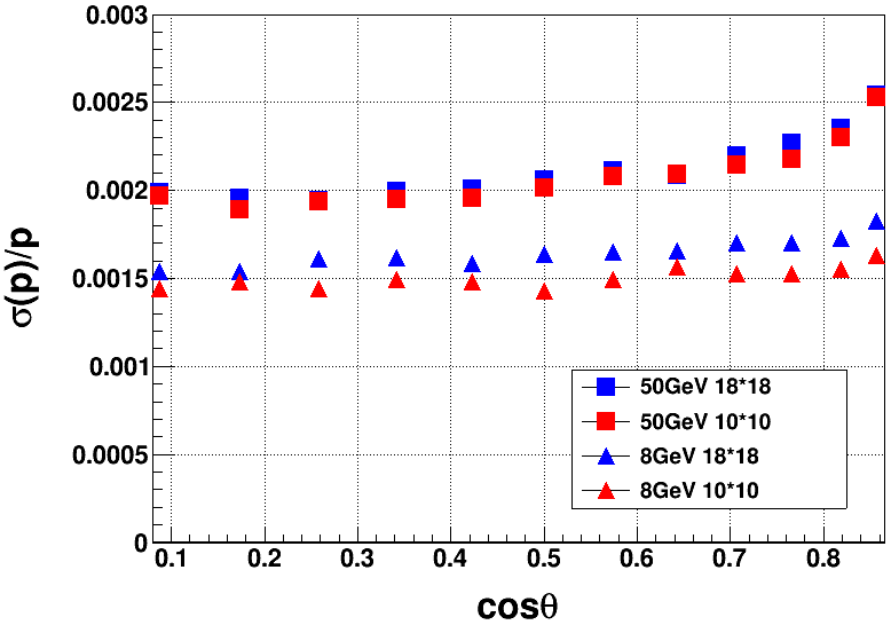


- No big difference between barrel and end-cap region for fitting efficiency
- The momentum resolution become worse at end-cap

Effect of cell size

- Two cell size setups are studied
  - 10mmx10mm and 18mmx18mm

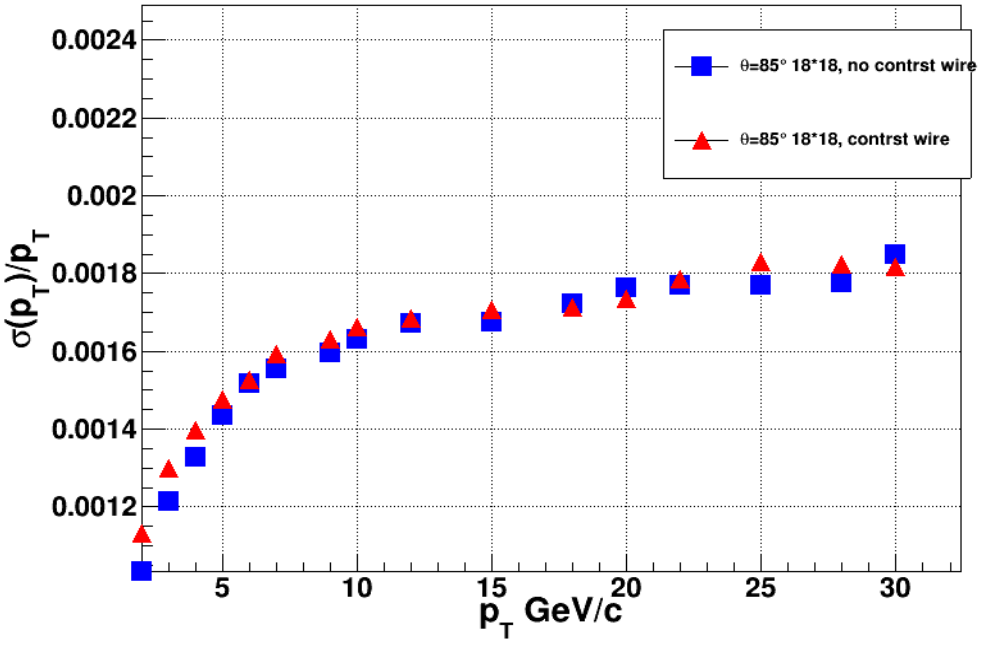




- Almost no effect on high momentum region

Effect of drift chamber wire material

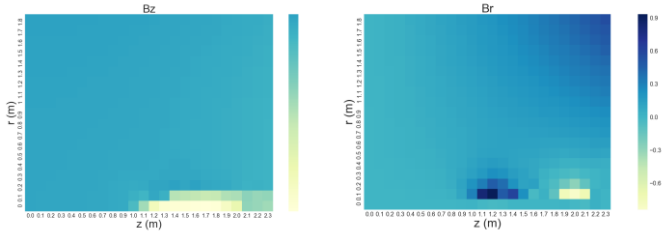
- With and without wire construction in simulation



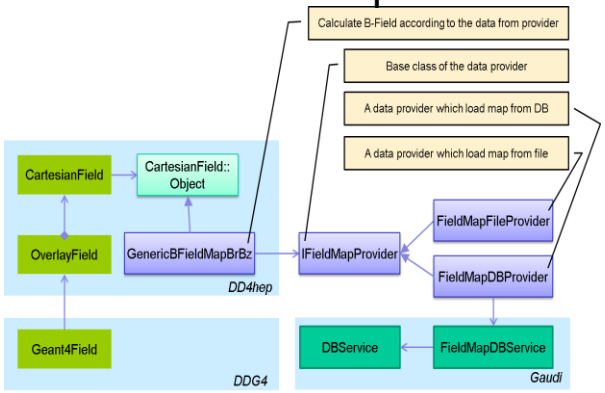
- Small effect on low momentum region(p_T<5GeV)

Non-uniform B-Field

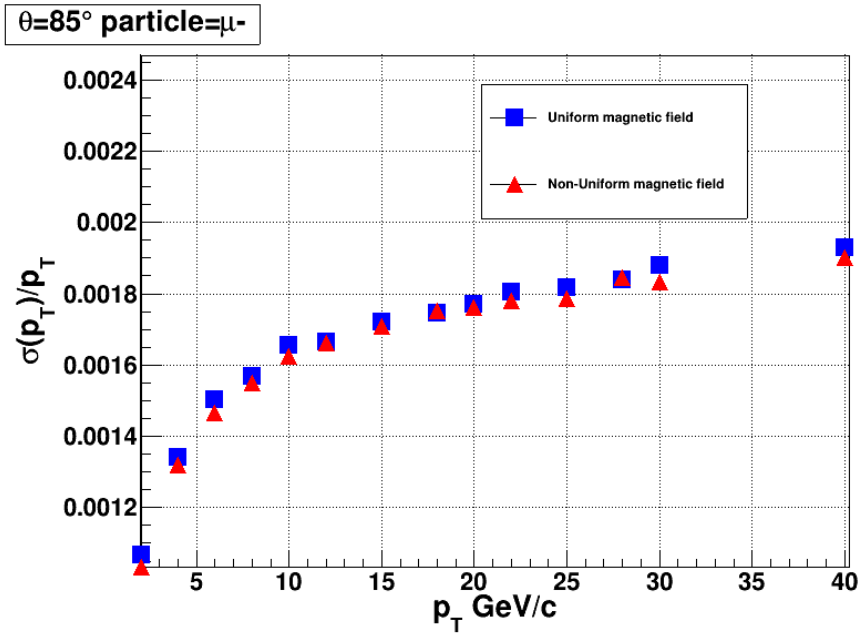
- A generic B-field service is developed and integrated with DD4hep
  - CSV-like format data from magnetic group
  - Bz=3Tesla, in DC region non-uniformity<5% in z direction and <55% in radial
- The correction of non-unifom B-Filed is done in track fitting



Filed map



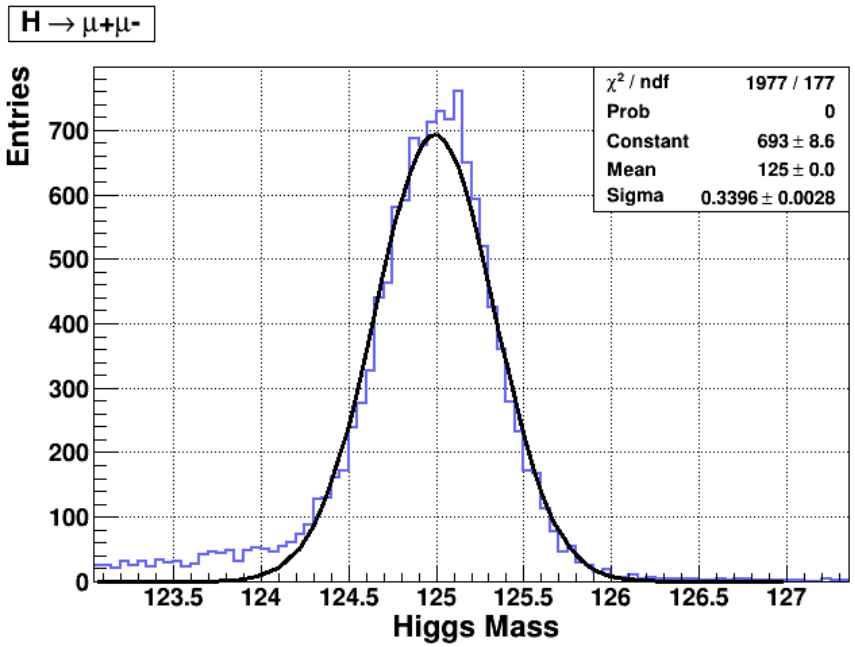
B-field service in CEPCSW



Almost no effect after using non-uniform magnetic field

Event track fitting

- Event level multi-track fitting is realized
- Higgs mass from H–>μ+μ–:

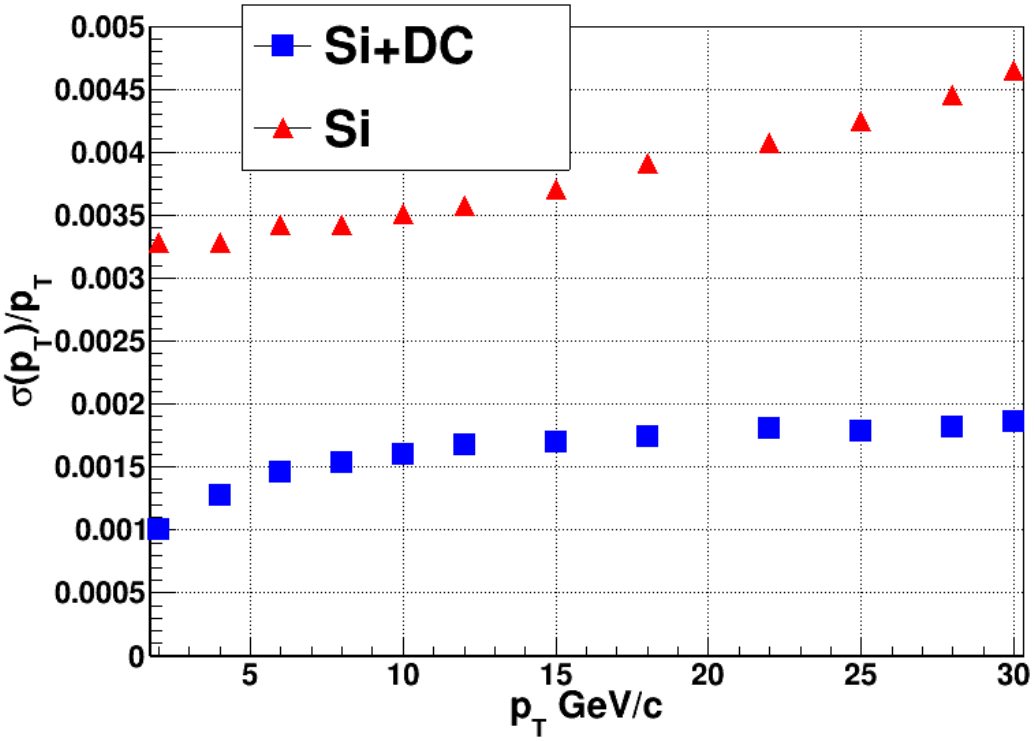


Summary

- The fast dN/dx analysis is available in CEPCSW
- The fast simulation of dN/dx based on real data is under study
- The multi-track fitting has been developed with Si+DC measurements
- The performance check for Silicon+DC is done
- The first release of CEPC tracking software is ready
- Future plan
  - dN/dx
    - Waveform simulation and analysis study
    - Fast simulation according to data with NN
  - Background in simulation and reconstruction
  - Track finding development
    - Machine learning
    - Track finding from silicon seed or self-tracking
  - Release for detector and physics performance study

Thank you!

Silicon+DC vs Silicons



- Got better momentum measurement with the drift chamber

Single track performance validation

- Track parameters pull distribution is reasonable