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

Status of the CEPC Drift Chamber Software

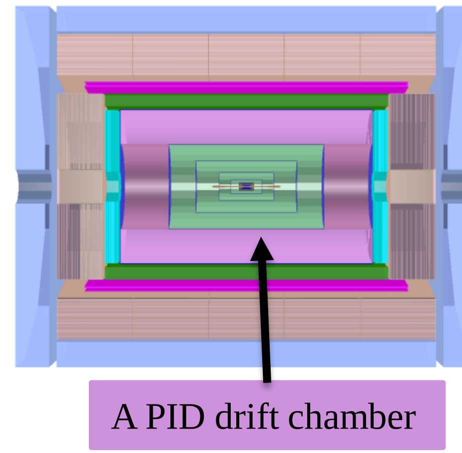
Yao ZHANG(IHEP)

on behalf of the CEPC DC software working group

The CEPC workshop (2022.10.28)

Drift Chamber(DC) Software

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



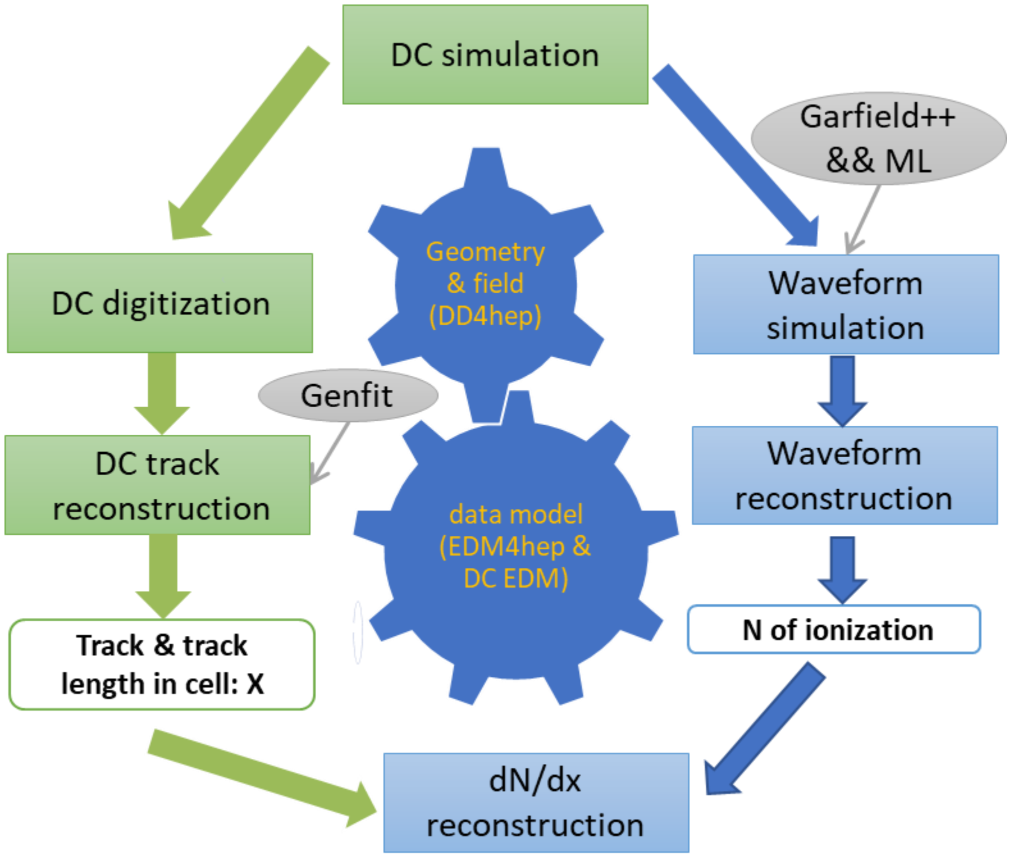
- Motivation of DC software project
  - Development of simulation and reconstruction for DC
  - Support the detector design, optimization and performance study
  - Support physics sensitivity study
- Requirements for DC software
  - Modular design and friendly interfaces
  - Easily integrated with common 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	$\Delta(1/p_T) = 2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$

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

DC software

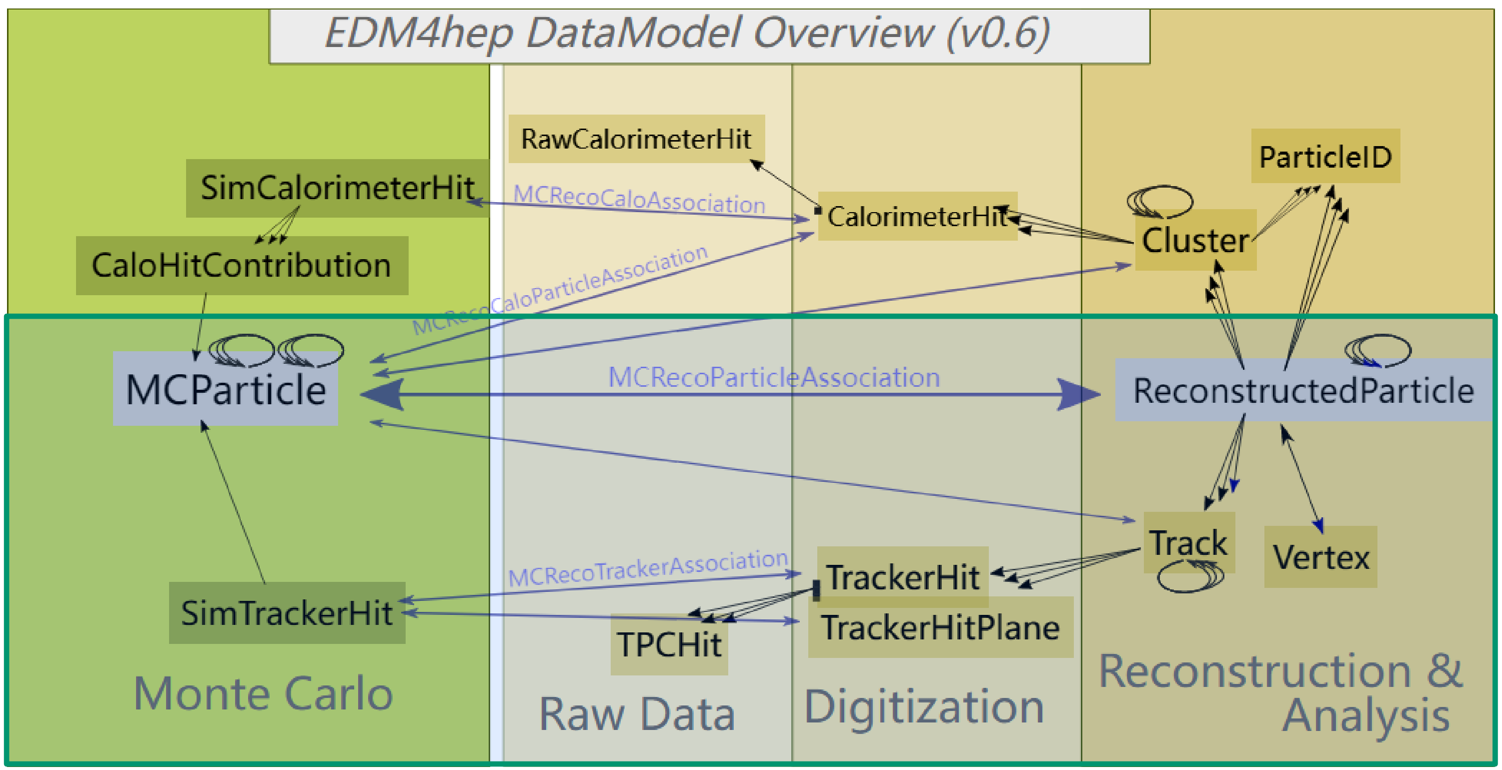
- The drift chamber software has been developed from scratch
- CEPCSW
  - Gaudi based framework
  - External libraries and tools
- Geometry and field map
  - DD4hep
  - Non-uniform magnetic field: **done**
- Data model
  - EDM4hep and FWCore
  - dN/dx event model: **done**
- Drift chamber
  - DC simulation: **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**



Drift chamber simulation and reconstruction flow

Event data model

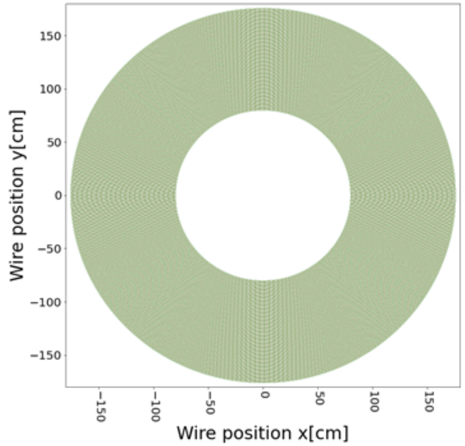
- DC implement the data model following the EDM4hep
- The extension of the current EDM4hep to accommodate the needs from dN/dx studies

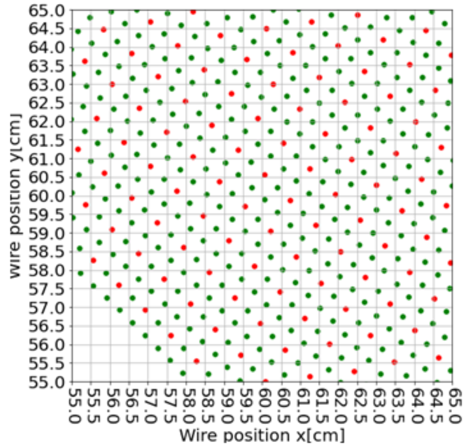


Drift Chamber Parameters in CEPCSW

- 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)

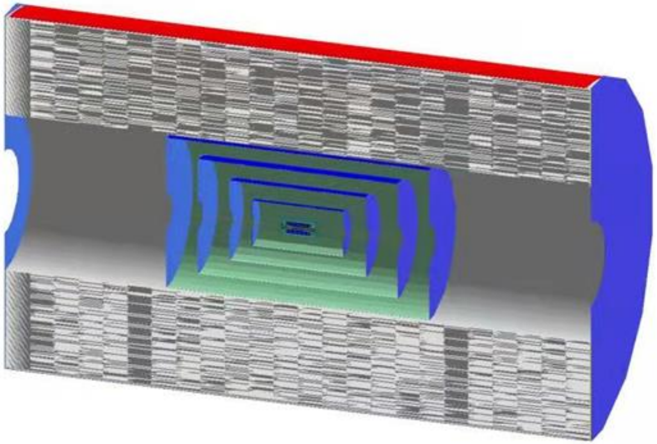




Cell structure

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



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"/>
```

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

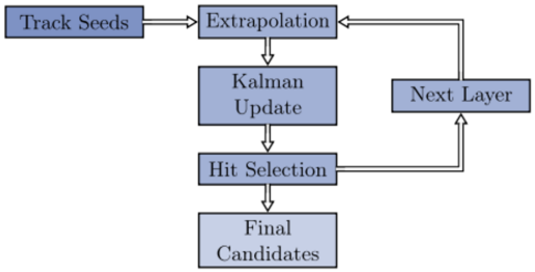
Tracker reconstruction

- Track finding
  - based on MC truth
  - Combinatorial Kalman Filter (CKF)
- Track fitting with tracker measurements
  - Silicon measurement + Drift chamber measurement
  - All following results are Silicon + Drift chamber

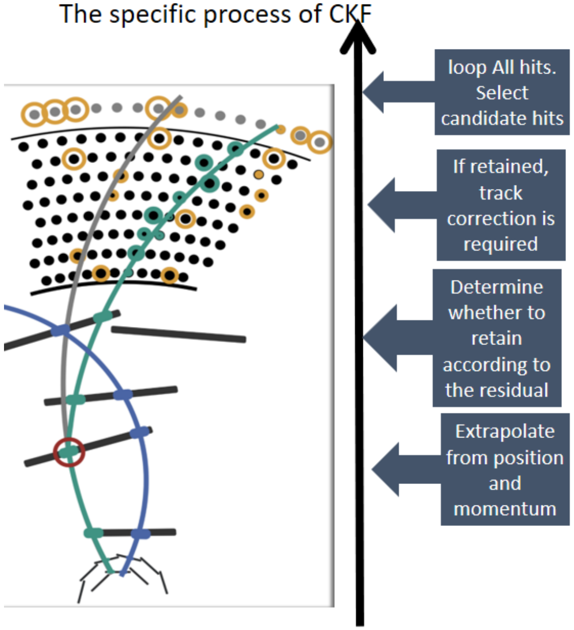
Track Finding by CKF

- Combinatorial Kalman Filter (CKF)
  - A tracking concept that combines track finding and track fitting in a search-tree-based algorithm
  - Used by many high energy physics experiments
- Track finding using CKF in Drift chamber
  - Take reconstructed silicon track as seed
  - Picking DC hits alone track road by quality of Kalman fitting
- Current progress:
  - Reusing CKF method from Belle II

Basic procedure behind the CKF

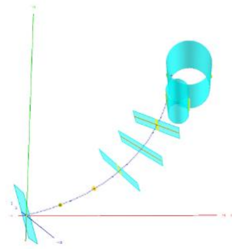


The specific process of CKF



Track Fitting--- RecGenfitAlg

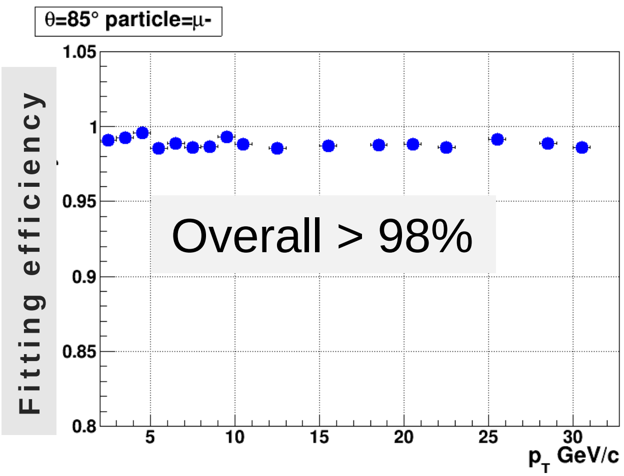
- Based on Genfit (https://github.com/GenFit/GenFit/)
  - An experiment-independent **generic track fitting** framework
  - Open sourced, active development and large user community
  - Official track fitting for BelleII, also used by PANDA, COMET, GEM-TPC etc.
  - Become the developer of Genfit
- Main 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

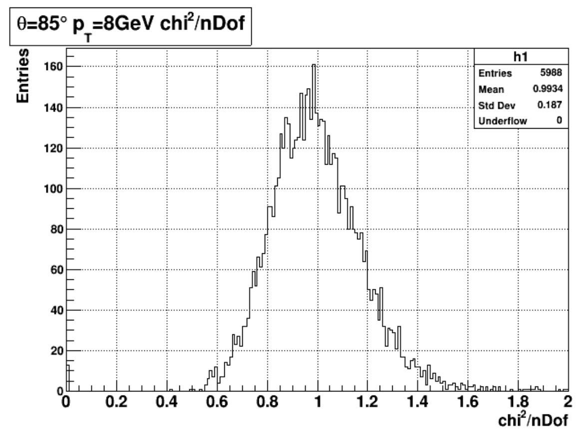


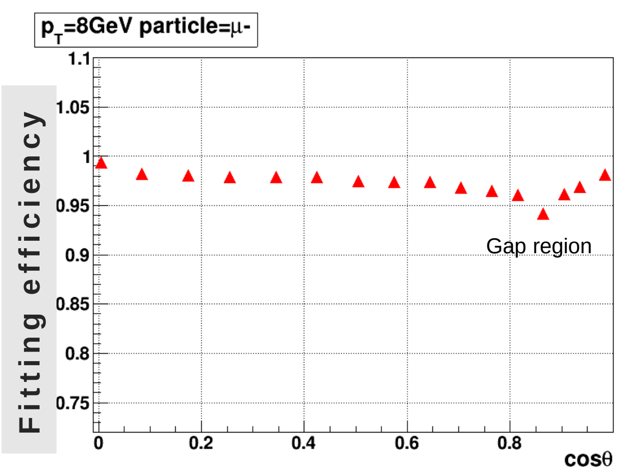
(a) Measurements with covariance (yellow), planar detectors and drift isochrones (cyan), respectively, and reference track (blue).

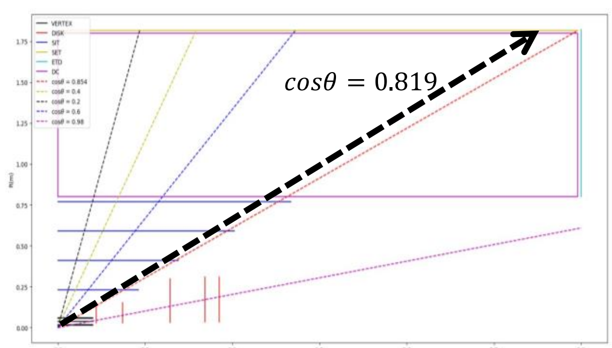
Track fitting efficiency

- Fitting efficiency $= \dfrac{\text{The number of successful combination fitting}}{\text{The number of rec track from slicion}}$

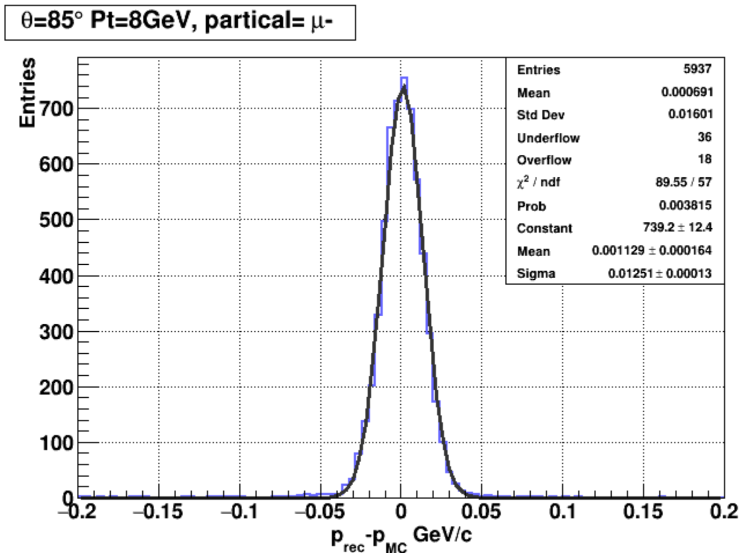


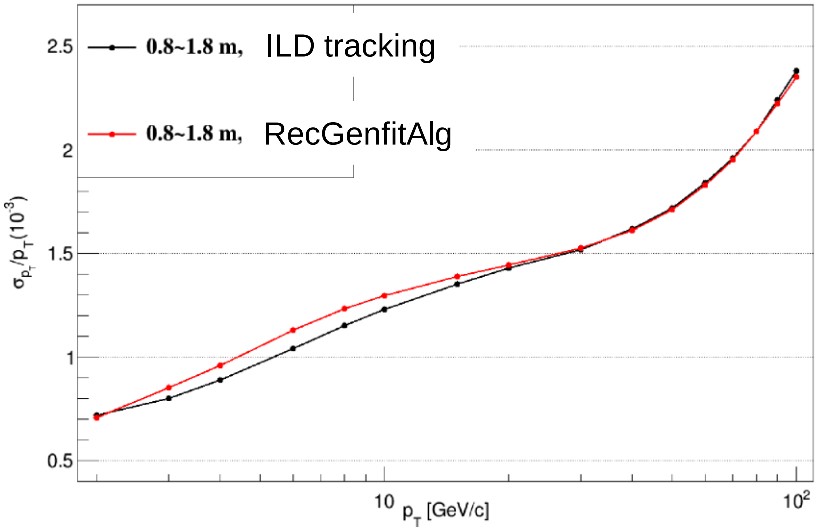




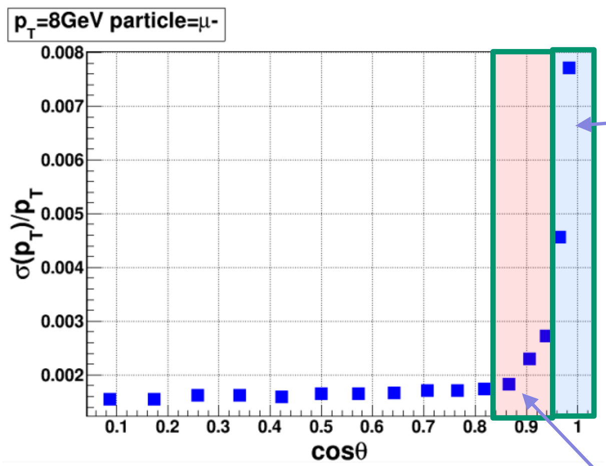


Momentum resolution





p_T resolution vs p_T



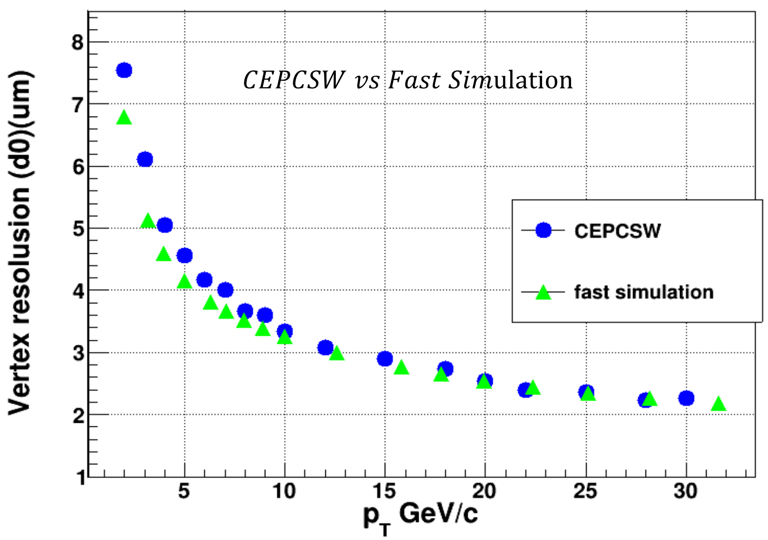
Only silicon is used

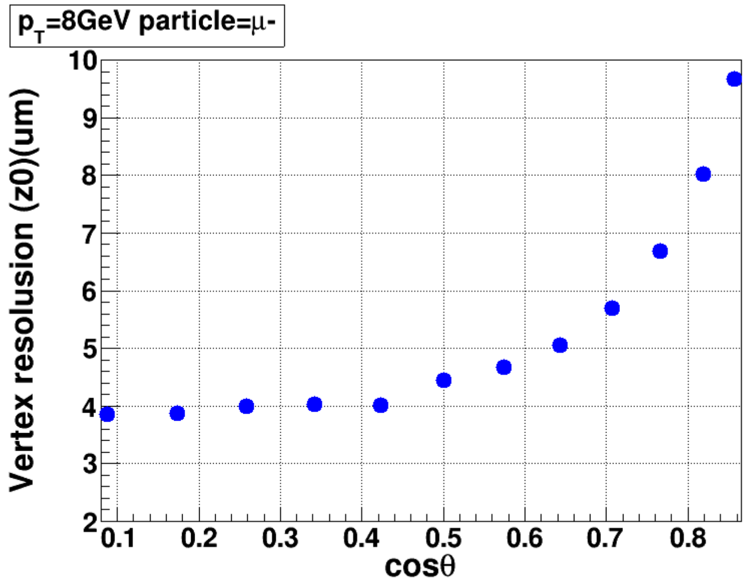
Endcap region

The momentum resolution is reasonable

Impact parameter

- Impact parameter d_0&Z_0 distribution

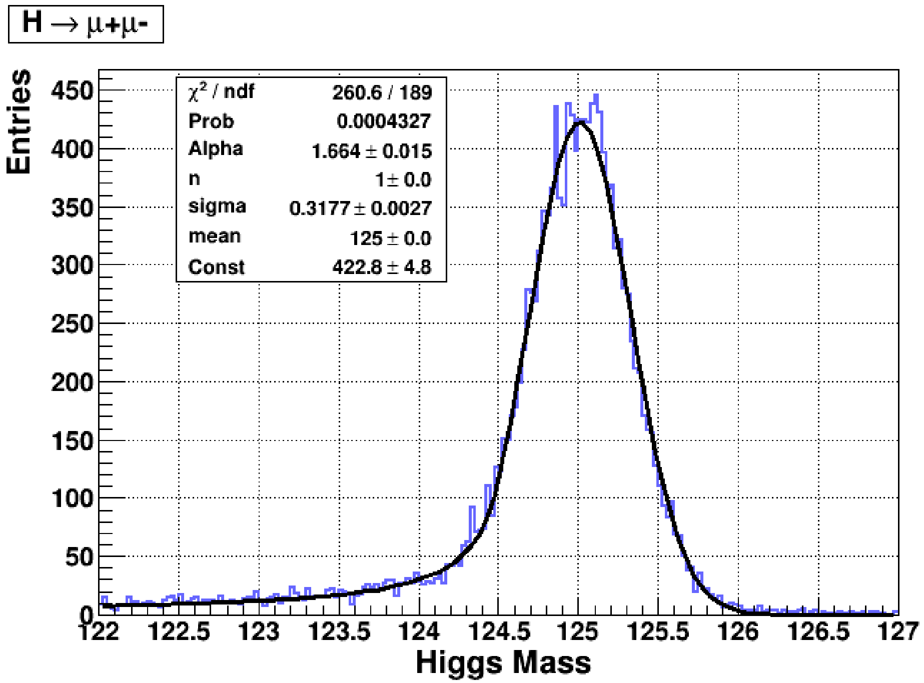




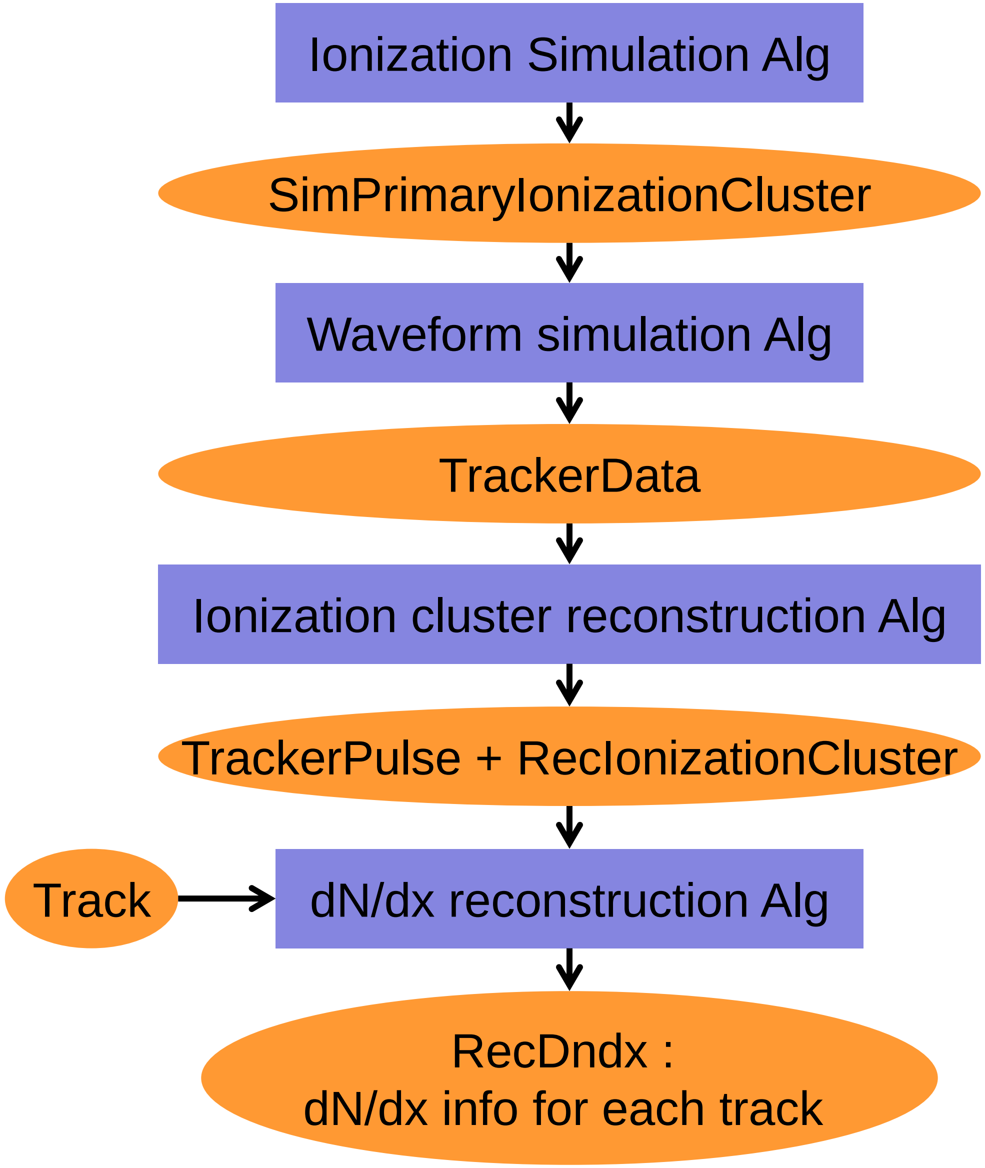
- Consistent with the fast simulation

Multi-track fitting

- Multi-track fitting is realized
- Check with Higgs reconstruction from $\mathrm{H}\rightarrow \mu^{+}\mu^{-}$:

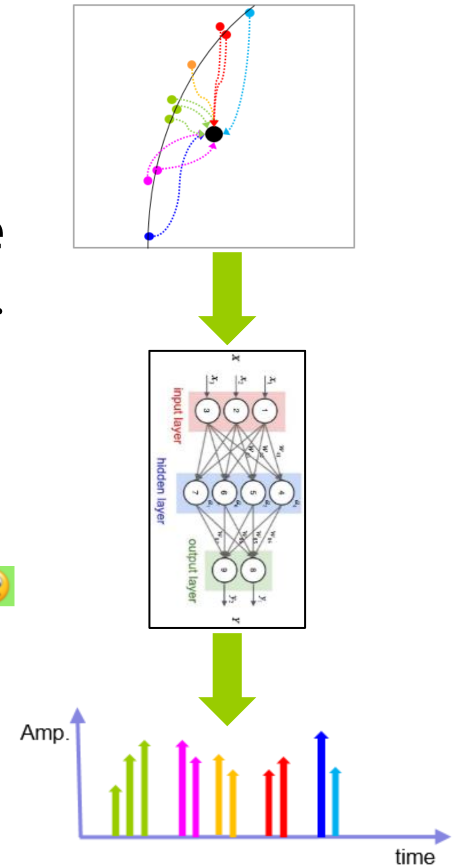


dN/dx study chain in CEPCSW



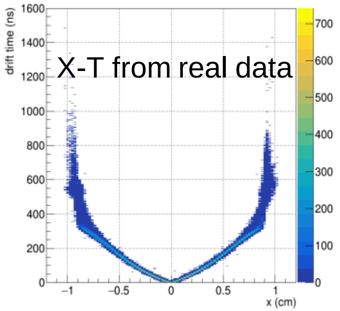
Ionization simulation

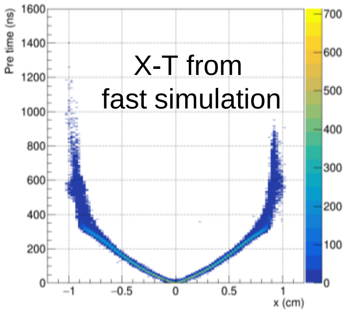
- The ionization simulation is done by combining Geant4 and TrackerHeed
  - TrackerHeed (from Garfield++) used for ionization process simulation
  - Geant4 for particle propagation (decay) in the detector, interaction with detector material, …
- Pulse simulation for each ionized electron
  - The Garfield++ simulation takes a long time
  - NN is used for fast simulation, simulating the time and amplitude of each pulse, more details in this talk



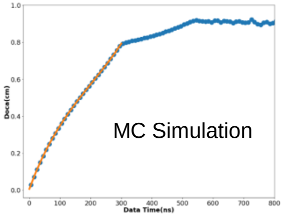
Check the fast simulation method using real data

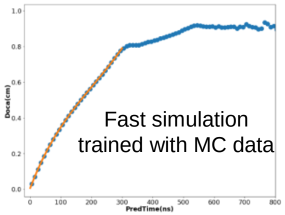
- Try to validate the fast simulate method by learning the X-T relation from real data using neural network
- Dataset: BESIII radiative Bhabha
- The preliminary study shows the X-T distribution of data and fast simulation is consistent

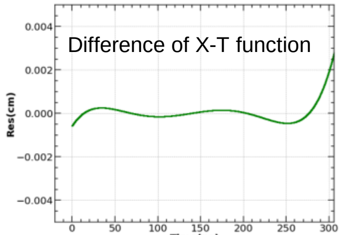




- The application of fast simulation on the BESIII MC data shows the X-T relationship can be reproduced

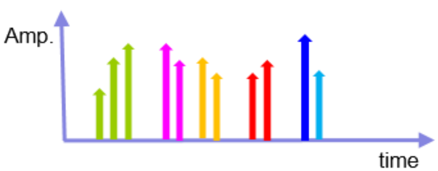


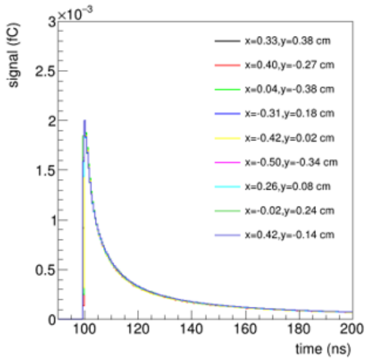


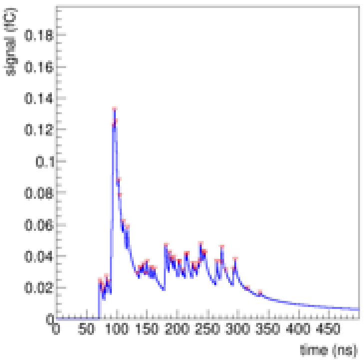


Waveform simulation

- From Garfield++ simulation, it was found that the normalized pulse shapes are quite similar, the differences between pulses are the time and amplitude
- Using the simulated pulse time and amplitude together with the pulse shape template, the waveform can be easily simulated





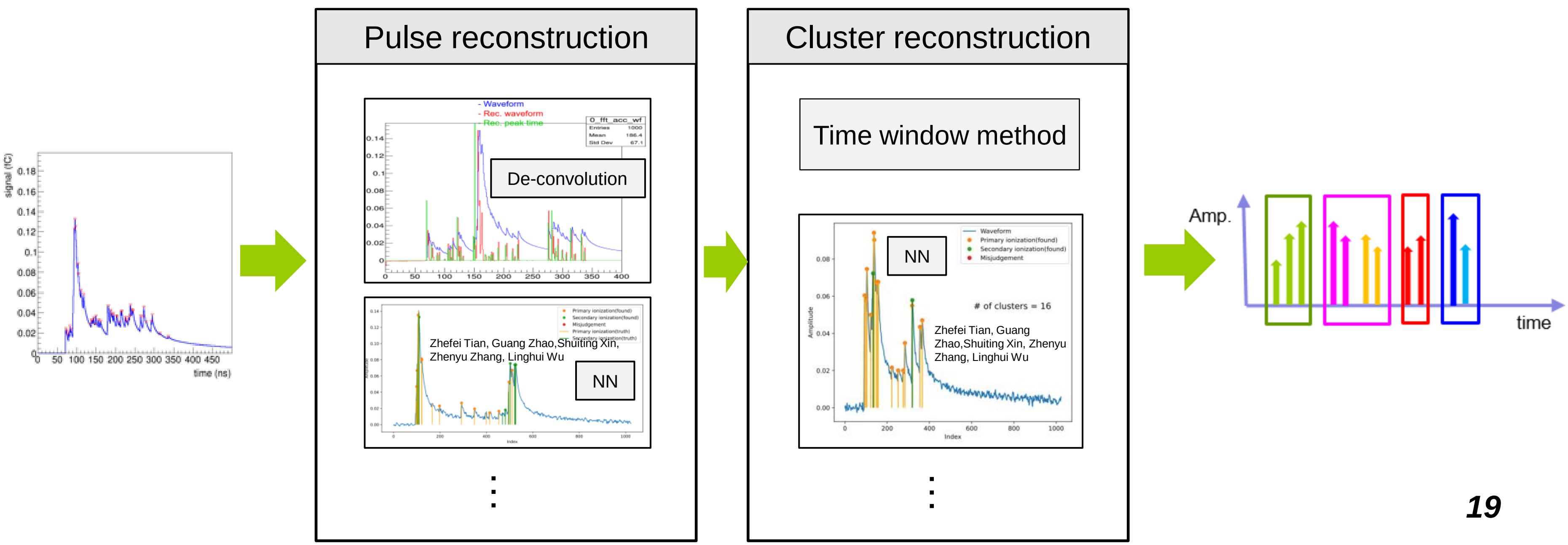


- To be more realistic, effects from the electronic noise and electronic response can be introduced to the waveform

Ionization cluster reconstruction

- Using simulated waveform as input.
  - Firstly, it reconstructs pulses (peak finding, derivative, deconvolution, NN, …)
  - Then it clustering the reconstructed pulses into several ionization clusters (time window, NN, …)

- Outputs: reconstructed pulses and ionization clusters



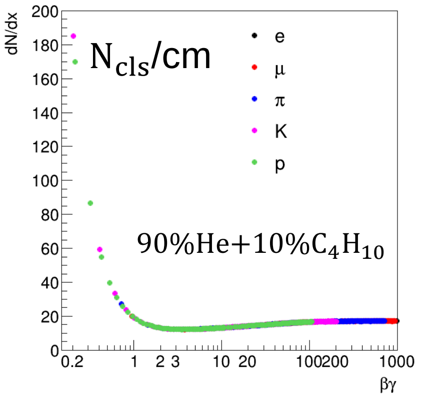
dN/dx reconstruction

- Inputs: the reconstructed track and reconstructed ionization cluster
- From the reconstructed track, one can get the track length in each drift chamber cell (dX). And the reconstructed ionization cluster gives the number of clusters in each cell (dN)
- The dN/dx for each cell can be calculated. The truncated mean method could be used to calculate dN/dx for each track
- Output: RecDndx including the dN/dx, particle type, and chi for different particle hypotheses, …

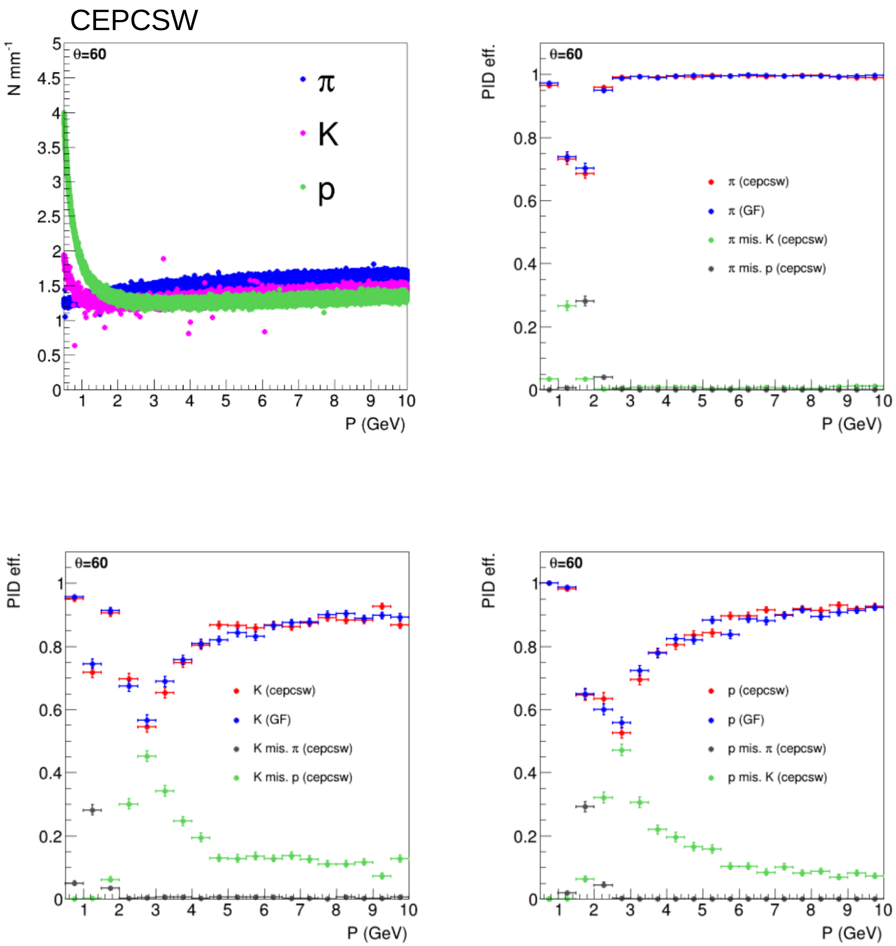
```
#-------------  RecDndx
edm4dc::RecDndx:
  Description : "dN/dx info of Track."
  Author : "Wenxing Fang, IHEP"
  Members :
    - float dNdx
    - float dNdxError
    - int16_t particleType
    - int16_t type
    - std::array<edm4dc::Hypothesis, 5> hypotheses
  VectorMembers:
    - edm4dc::HitLevelData hitData
  OneToOneRelations:
    - edm4hep::Track track
```

```
components:
    #---------- Hypothesis for 5 particle types
    edm4dc::Hypothesis:
      Members:
        - float chi2       // chi2
        - float expected   // expected value
        - float sigma      // sigma value

    #---------- hit level data
    edm4dc::HitLevelData:
      Members:
        - uint64_t cellID    // cell id
        - uint32_t N         // number of reconstructed ionization cluster.
        - float  eDep        // energy deposit.
        - float  pathLength  // track path length in [mm].
```



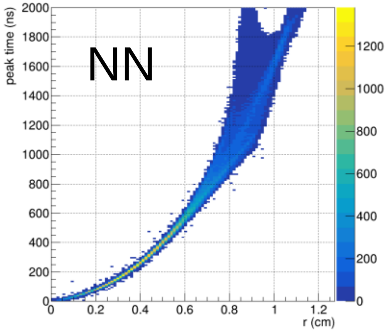
Preliminary dN/dx PID results



- Checked the dN/dx PID performance for gas ($90\%He+10\%C_4H_{10}$) using CEPCSW and Garfield++
- Using MC truth information (number of clusters, tracker length)
- The PID performance obtained in CEPCSW has good agreement with the standalone Garfield++ simulation

More be to studied for dN/dx

- Ionizations from secondary particles, backgrounds
- effect from track reconstruction
  - using a more realistic drift time (X-T) simulation



- Check the performance of different pulse and ionization cluster reconstruction algorithms
- Due to the space charge effect can not be simulated by Garfield++. This effect may be extracted from experimental data and considered in the dN/dx reconstruction stage

Summary

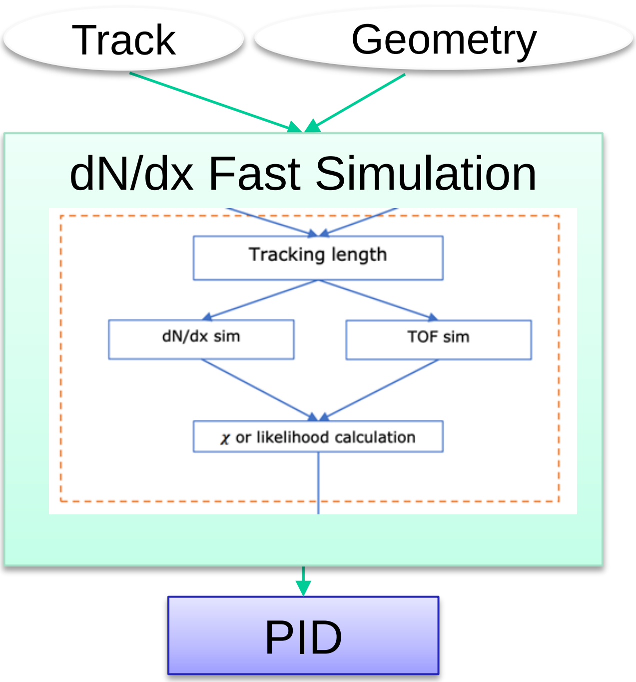
- The DC simulation and track reconstruction in the CEPCSW is presented
- The multi-track fitting has been developed with Si+DC measurements and the performance is reasonable
- The chain of dN/dx study in CEPCSW is presented
- The preliminary results for dN/dx PID performance in CEPCSW are checked, they are in good agreement with the results from the standalone Garfield++ simulation
- Future plan:
  - Continue working on track finding
  - Track reconstruction with background mixing and using more realistic X-T relation
  - More detailed dN/dx performance check

Thank you for your attention!

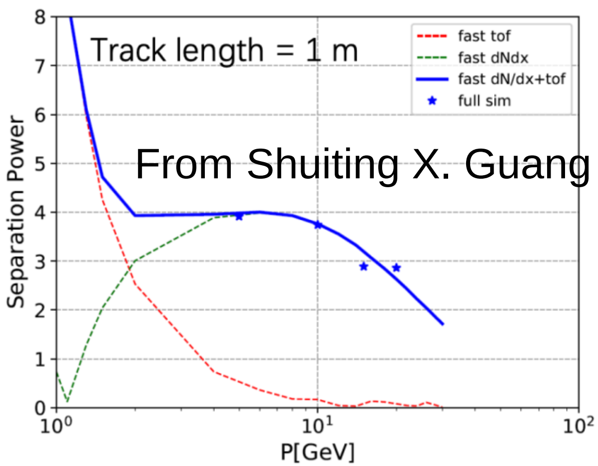
Back up

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



Separation power analysis in CEPCSW with fast simulation tool

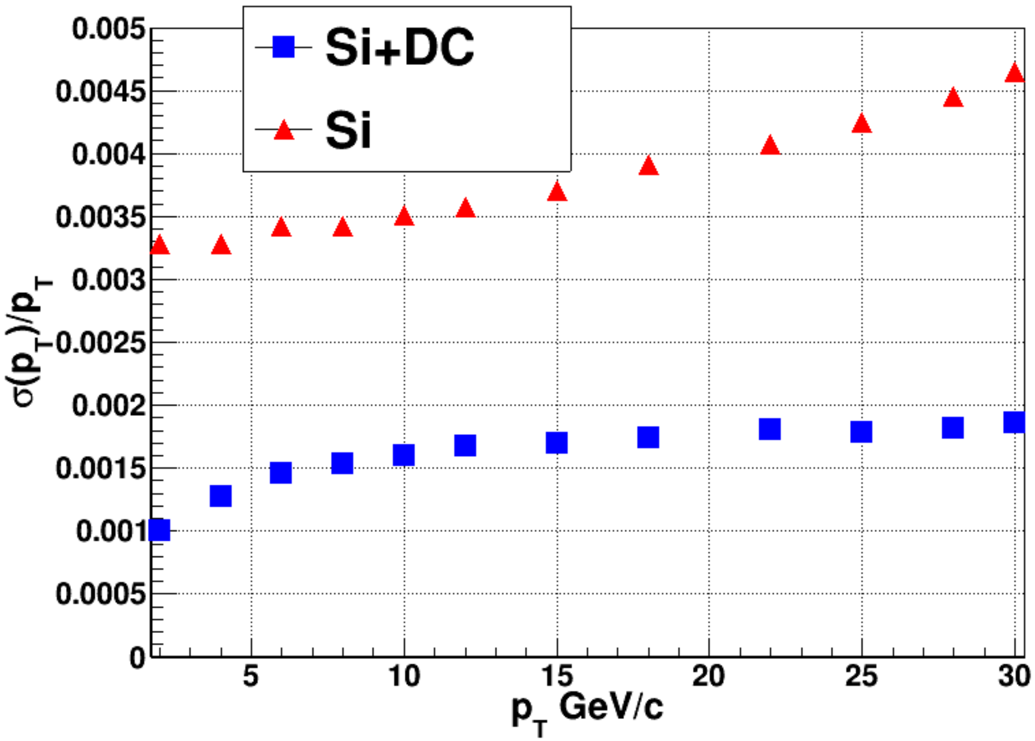


From Shuiting X. Guang Z. Linghui W.

[Update of the PID drift chamber study, Guang Zhao]

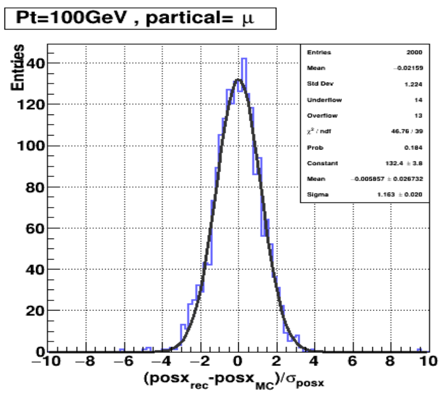
Silicon+DC vs Silicons

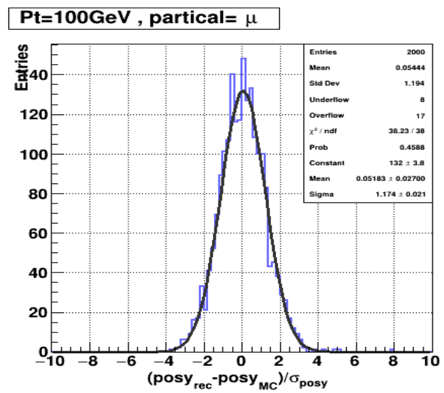
- Got better momentum measurement with the drift chamber

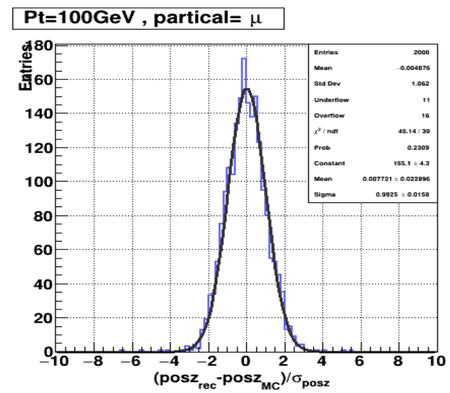


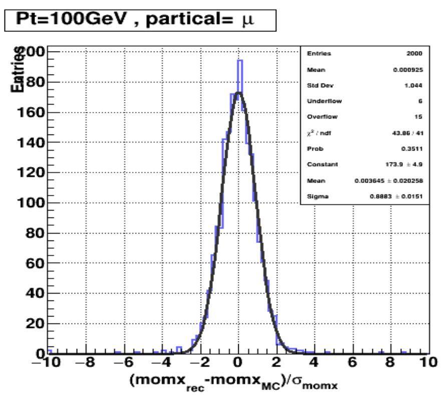
Single track performance validation

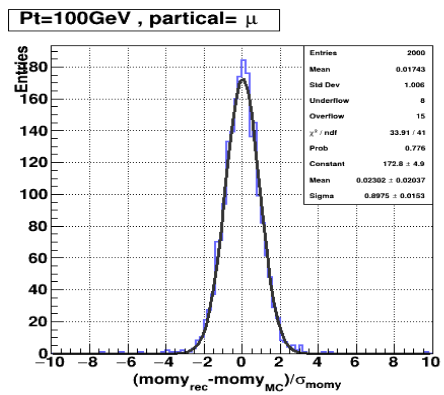
- Track parameters pull distribution is reasonable

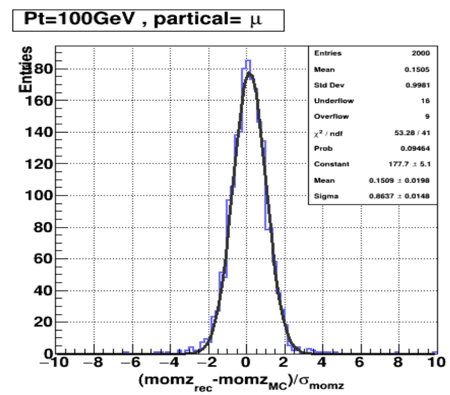






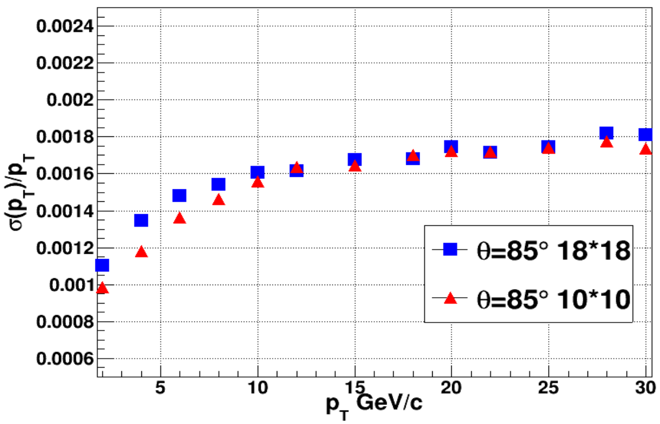


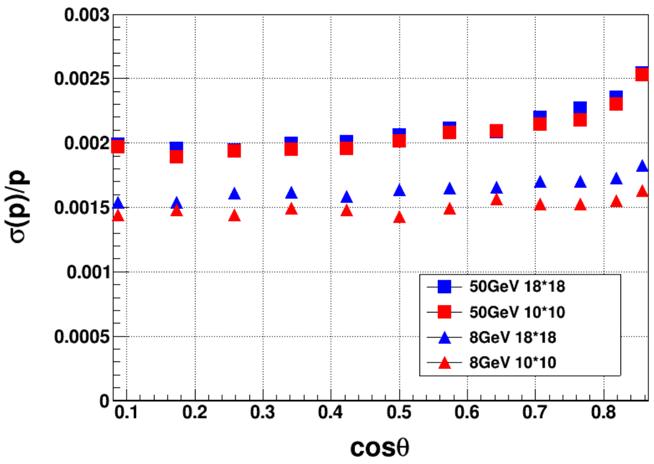




Momentum resolution check

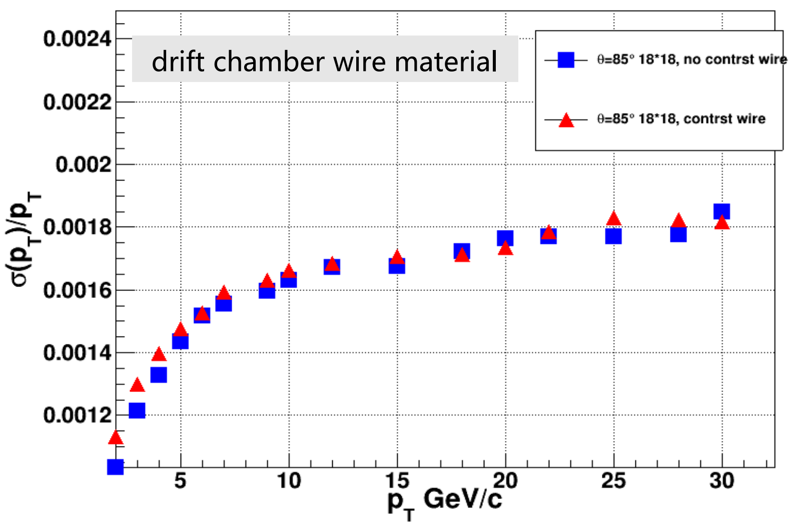
- Two cell size setups are studied
  - 10mmx10mm and 18mmx18mm

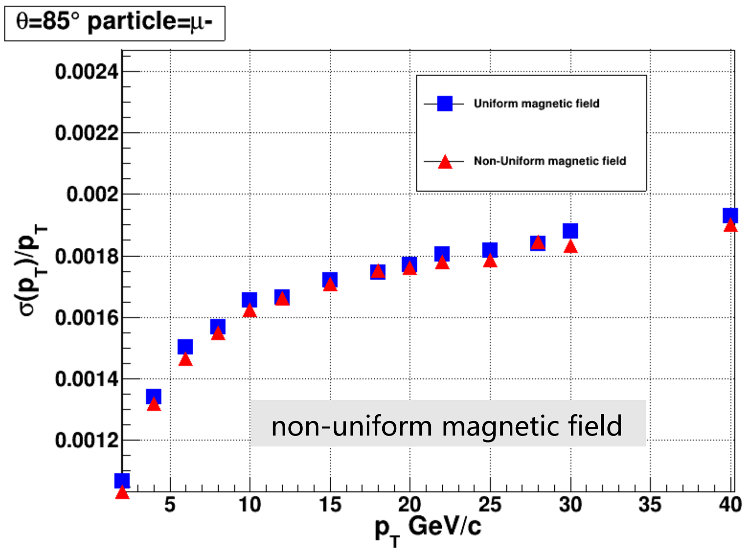




- Almost no effect on high momentum region

Momentum resolution check

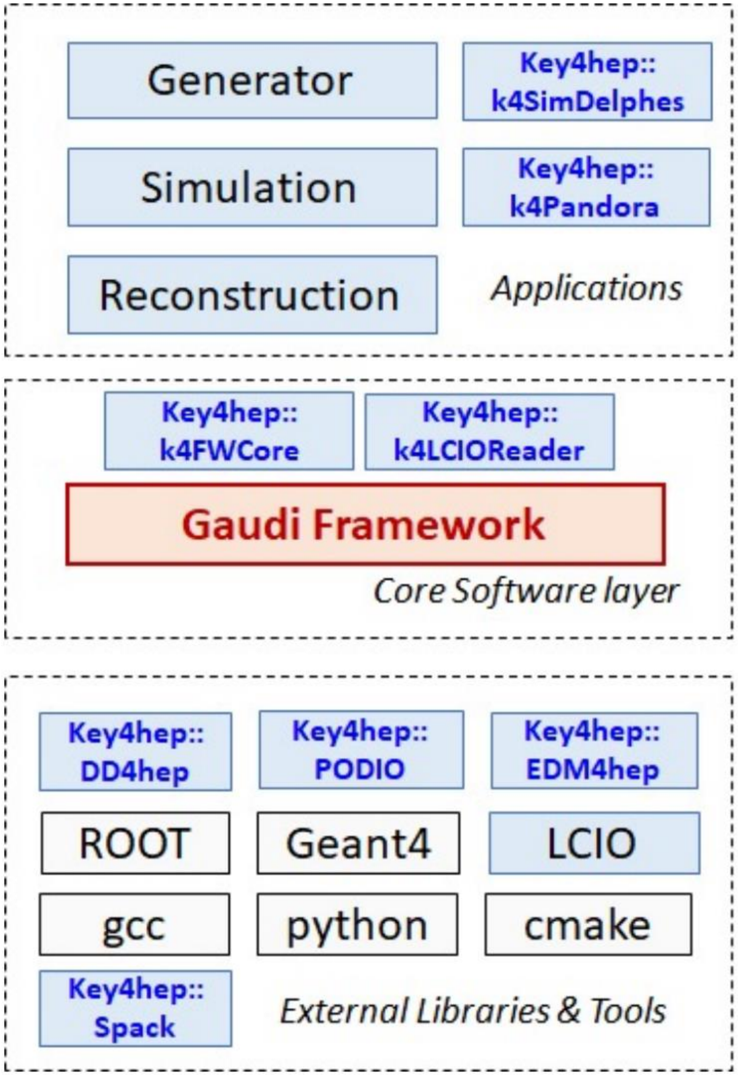




- drift chamber wire material : Small effect on low momentum region(pT<5GeV)
- Almost no effect after using non-uniform magnetic field

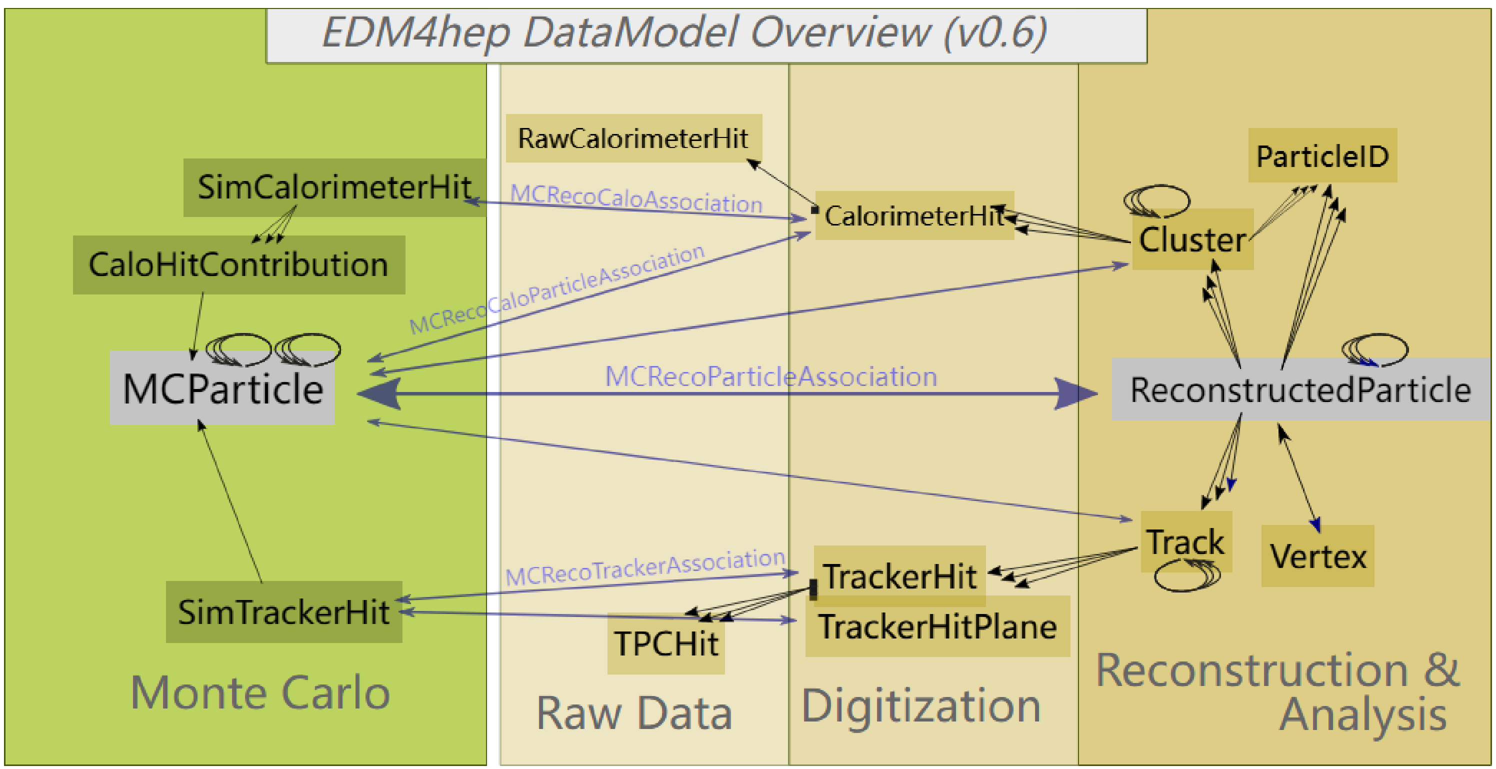
CEPCSW Software

- CEPCSW software structure
  - External libraries:
    - DD4hep: complete detector description (geometry, B field, Material, …). Consistent description (simulation, reconstruction, analysis)
    - EDM4hep: the generic event data model for HEP experiments (see next slide)
    - …
  - Core software:
    - Gaudi framework: defines interfaces to all software components and controls their execution
    - K4FWCore: data service for EDM4hep
  - Applications:
    - CEPC-specific software: generator, Gean4 simulation, reconstruction, and analysis



EDM4hep

- Common EDM: ILC, FCC, CEPC, CLIC, …
- Efficiently implemented (fast data access, efficient memory usage)
- Support multi-threading
- Potentially heterogeneous computing
- Easy to generate the C++ code from a high-level description of the desired EDM (YAML file) using the podio

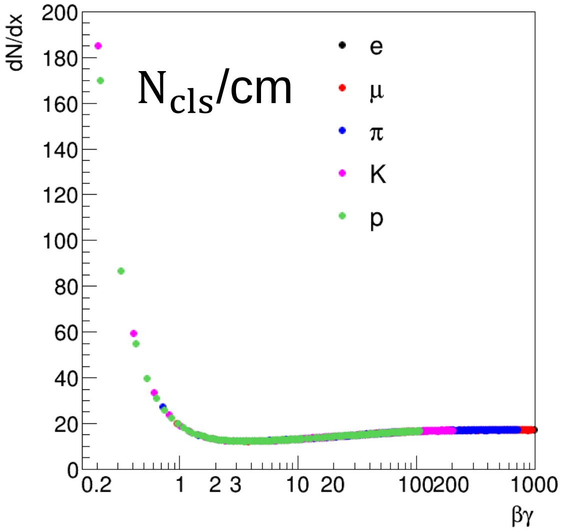


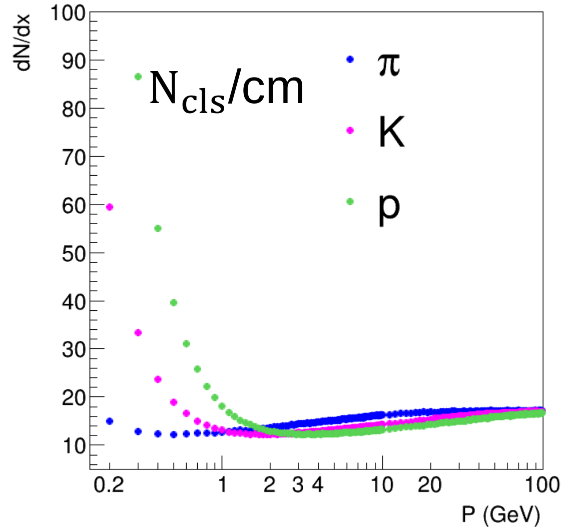
EDM4hep Extension

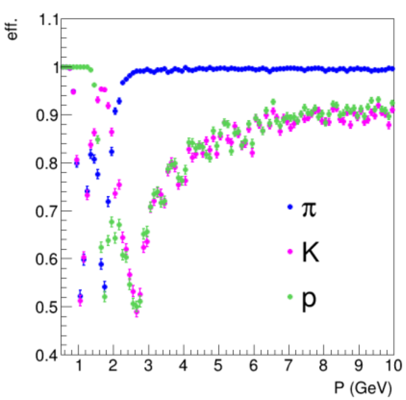
- Currently, the EDM4hep does not include the EDM for dN/dx study, we extended it by using the extension mechanism of podio (very convenient)
- Following EDMs are extended (more details in following slides):
  - SimPrimaryIonizationCluster
  - TrackerData
  - TrackerPulse
  - RecIonizationCluster
  - RecDndx
- The extended EDM is supposed to be used both for the drift chambers and the TPC

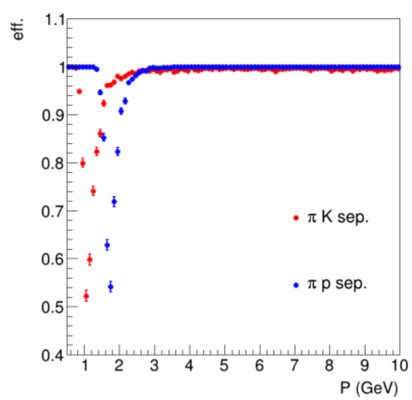
Garfield++ simulation

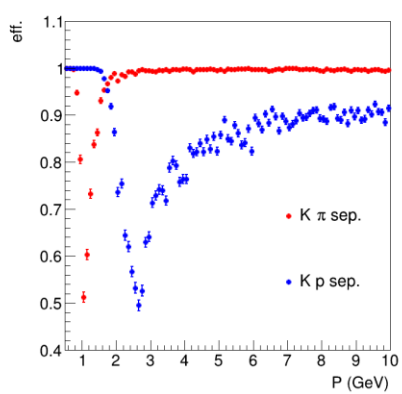
$90\%He+10\%C_4H_{10}$

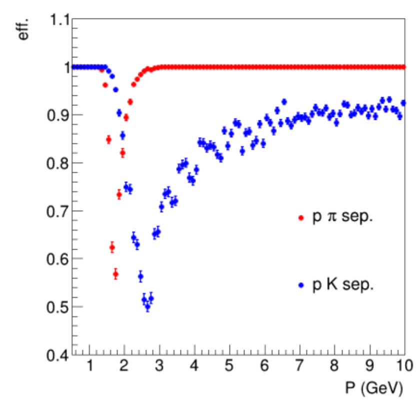








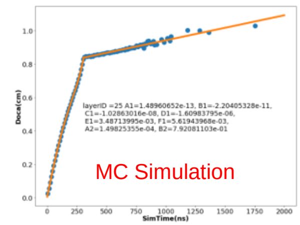


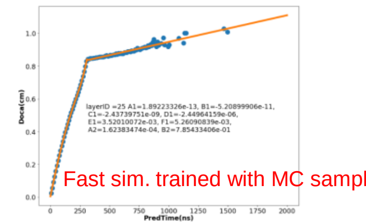


1 meter length

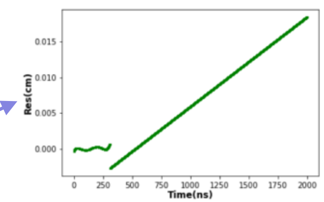
Check the fast simulation method using real data

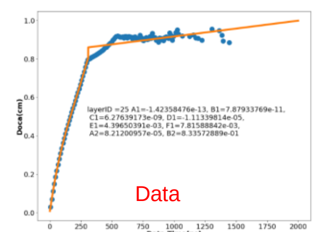
- To evaluate the fast simulation performance:
  - Step1, calibrating the X-T relation from data and the fast simulation
  - Step2, checking the track reconstruction performance by using the calibrated X-T curve

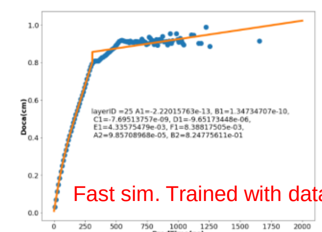




- Step1 ,calibrating the X-T relation
  - First tested with BESIII MC simulation data
    - Fitting the mean of Doca in different time bins using polynomial
    - Very good agreement for time<250ns, small difference for large time region







  - For real data (more complex):
    - For time < 250ns, very good agreement. For large time region, more proper way of doing the calibration is needed