Status of the CEPC Drift Chamber Software

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CEPC Physics and Detector Plenary Meeting

1. IHEP

2. Shandong University

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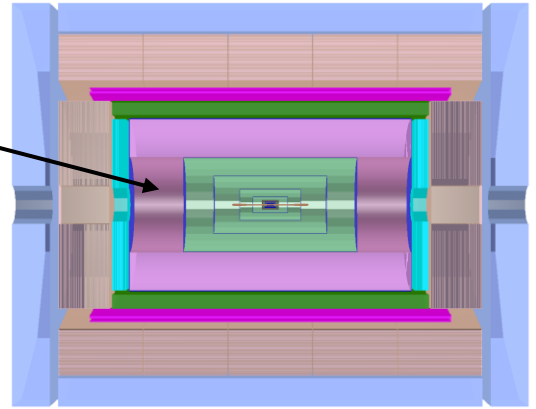
Outline

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

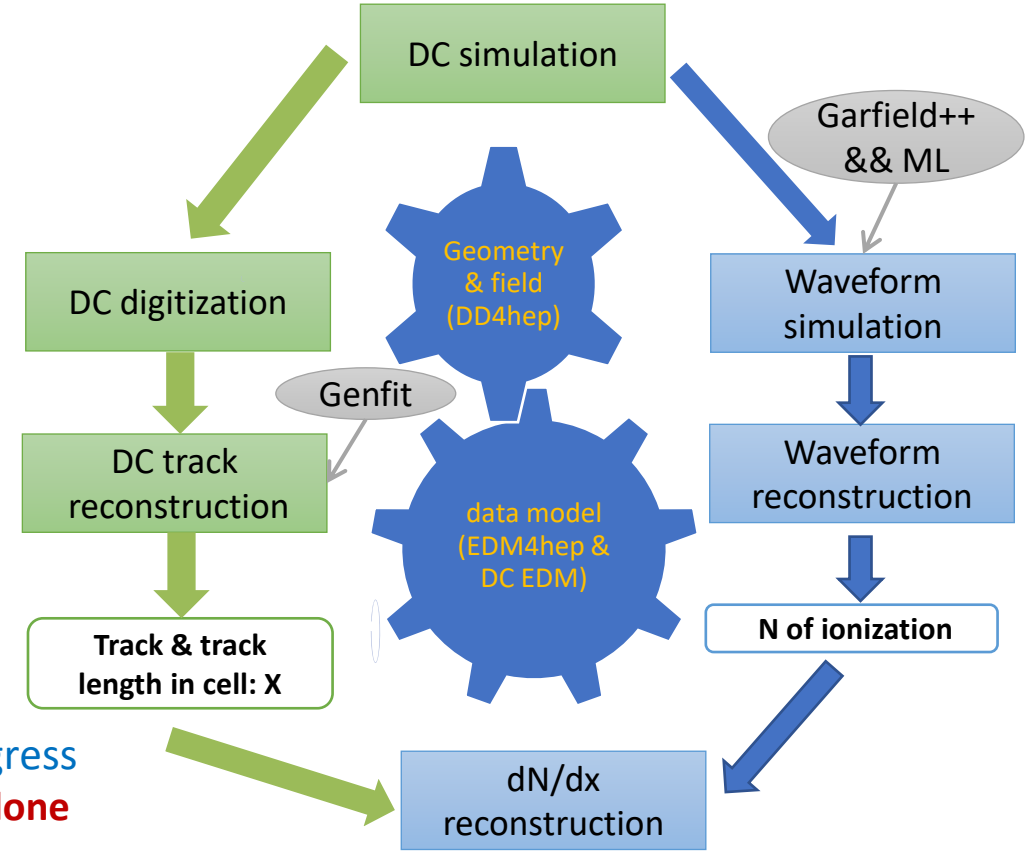
Requirements of The CEPC tracker

- 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

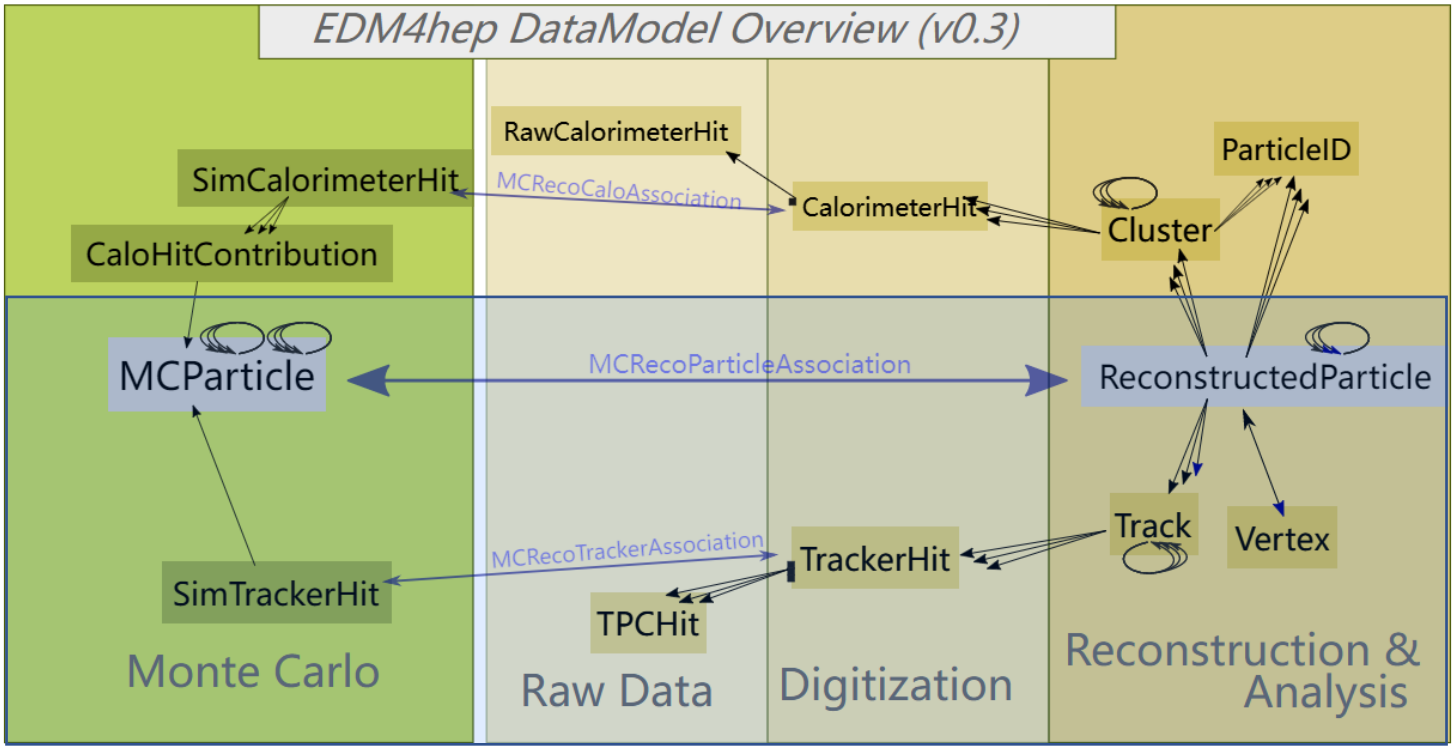
- CEPCSW
  - Gaudi based framework
  - External libraries and tools
- Geometry and field map
  - DD4hep
  - Non-uniform magnetic field: **done**
- Data model
  - EDM4hep and FWCore
  - dN/dx event model: **done**
- Drift chamber
  - DC simulation: **done**
  - DC digitization: **done**
  - Waveform simulation: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



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 is done



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"
  Author : "Wenxing Fang, IHEP"
  Members:
    - unsigned long long cellID      //ID of the sensor that created this hit
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    - int   type                     //type.
    - 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.
```
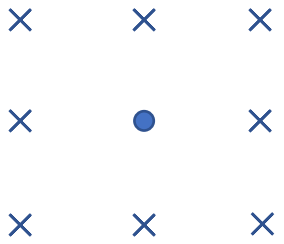

Drift Chamber Parameters in CEPCSW

- The base line configuration of DC in CEPCSW

Half length	2980 *mm*
Inner and outer radius	800 to 1800 *mm*
# of Layers	100/55
Cell size	~10x10mm/18x18mm
Gas	He:C_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

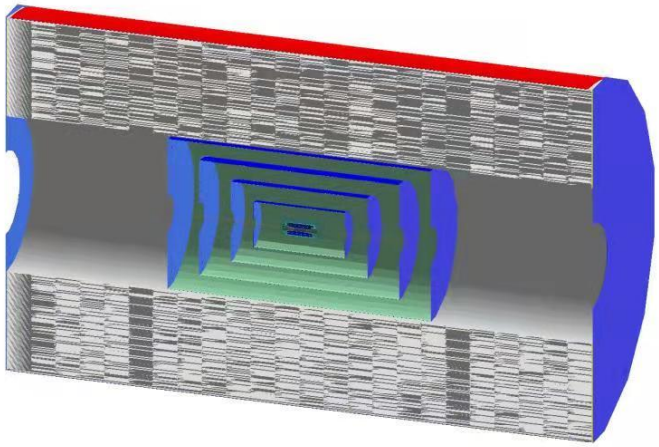


field wire: x, sense wire: o

sense wire : # field wire=1:3

Silicon detectors Parameters in CEPCSW

Silicon detecor	*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	7.2	8.6
SOT(SET)	1 layer	1815	7.2	8.6

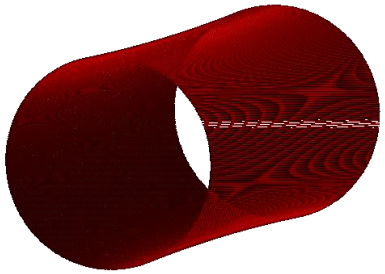


CRD tracker o1 v01

DC Simulation

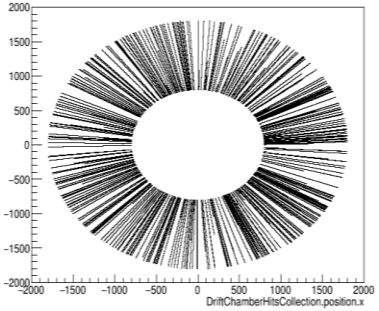
- Following the common scheme for detector description
  - XML based compact files for drift chamber detector description
    - CRD: Detector/DetCRD/compact/CRD_oX_vYY/CRD_o1_vYY.xml
  - Layer number and stereo angle etc. are configurable

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



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



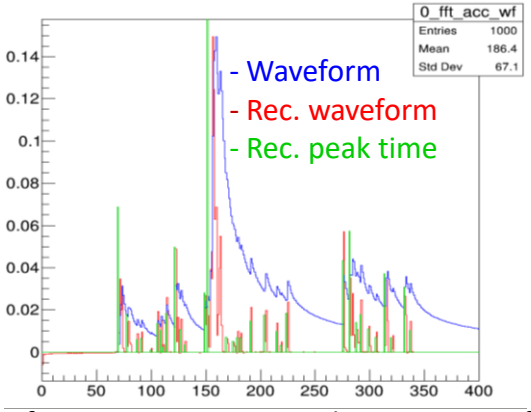
Hitmap of MC hits in DC

Software Development for the Drift Chamber, Yao Z.

dN/dx Simulation and Reconstruction Flow

- Implement the DC waveform simulation and analysis Ensure the dN/dx study by physics channels
  - Integrate Geant4 and Garfield++ for precisely simulation
  - Fast signal response simulation
  - A waveform reconstruction with Fourier transform

Simulation of Detector Response in the Drift Chamber, Wenxing Fang, CEPC workshop 2021

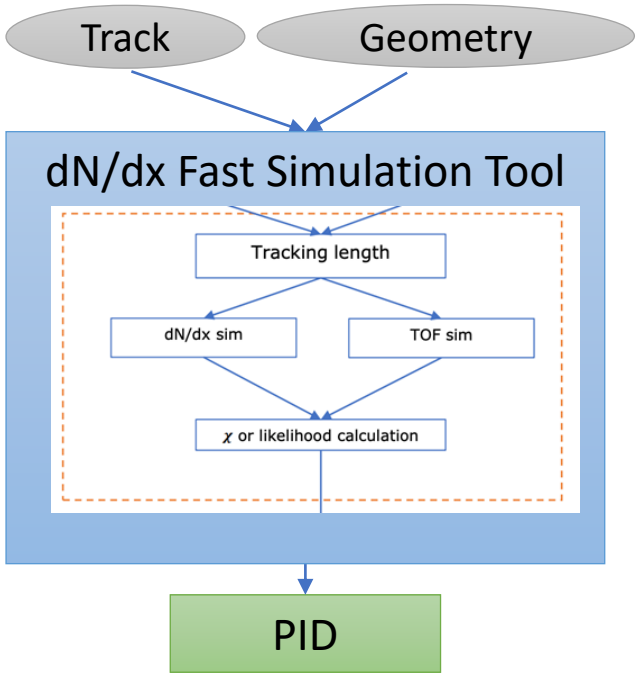


Waveform reconstruction with Fourier transform

- Progress
  - dN/dx tools can be reused and plugin to CEPCSW
  - The event model development for dN/dx

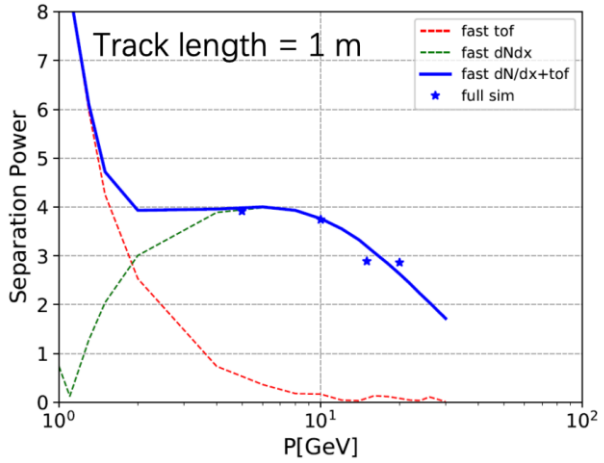
dN/dx Fast Simulation in CEPCSW

- Fast simulation allows quick PID in CEPCSW for physics analysis
  - A dN/dx model with sampling method simulation tool
- Other dN/dx sim. or rec. model is easy to be plugin



From Shuiting X. Guang Z. Linghui W.

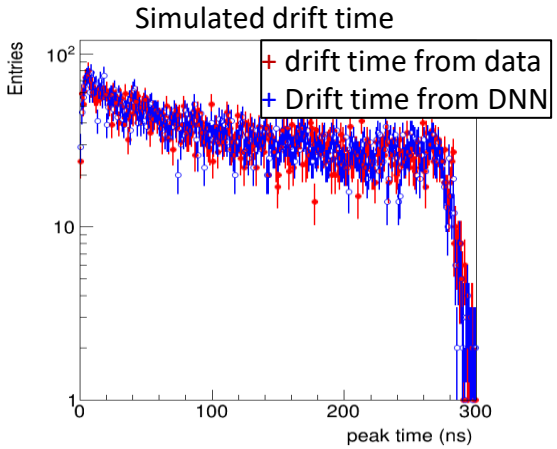
Separation power analysis in CEPCSW with fast simulation tool

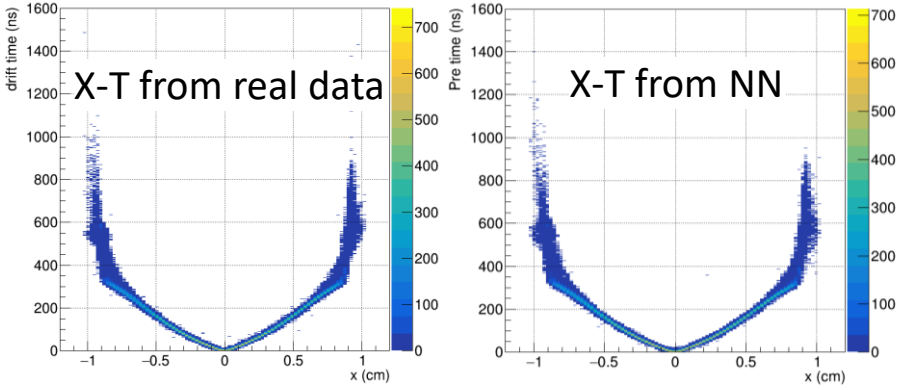


Update of the PID drift chamber study, Guang Zhao

Drift time fast simulation based on real data

- Drift time fast simulation with neural network
  - Model: Deep Neural Networks
  - Dataset: BESIII Radiation bhabha
  - Motivation: validate the fast simulate method with NN



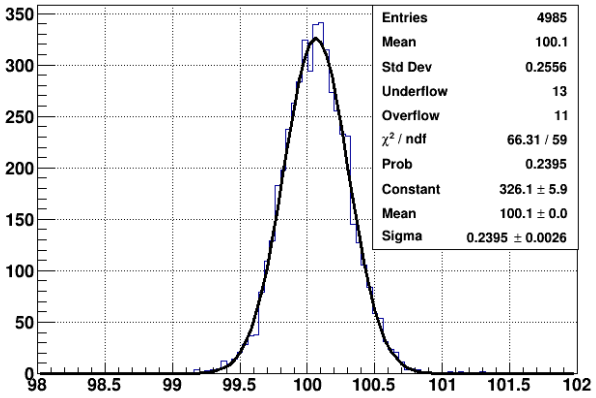


- The drift time simulate with NN is promising
- The preliminary study shows good consistent between data and NN
- The simulation of cluster time with same method is expected

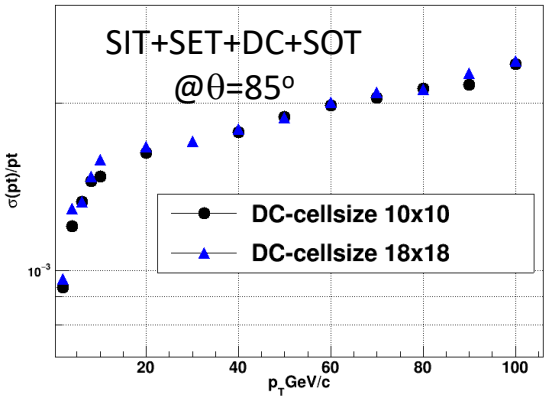
Track Fitting with tracker measurements

- The track fitting development in CEPCSW
  - Use a Genfit as external libraries to do kalman track fitting
  - Intergrate Bfield, material and geometry from DD4hep and EDM4hep

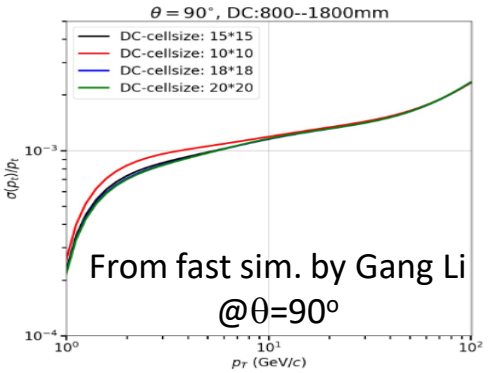
- Track fitting with detector measurements is implemented
  1. Track fitting **combine the silicon detector and drift chambe**r
  2. The preliminary result is consistent with fast simulation



Fitted momentum of 100GeV μ^-



Momentum resolution v.s. p_T



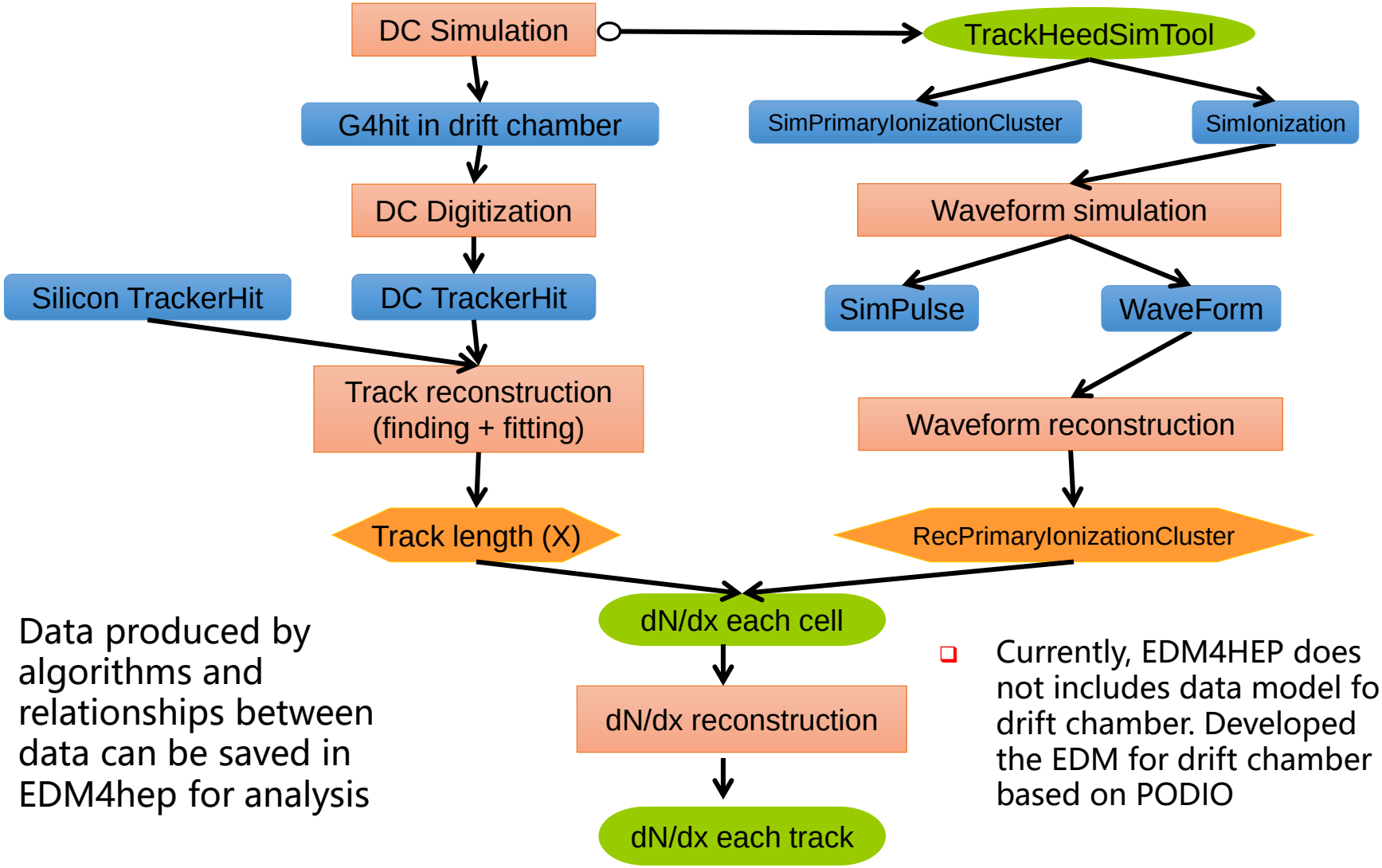
Summary

- The fast dN/dx analysis is available in CEPCSW
- The fast simulation of dN/dx based on real data is under study
- The track fitting with Si+DC combined measurement is realized

- 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!

Schema of dN/dx study in CEPCSW



- Data produced by algorithms and relationships between data can be saved in EDM4hep for analysis

- Currently, EDM4HEP does not includes data model for drift chamber. Developed the EDM for drift chamber based on PODIO