Software for the CEPC Drift Chamber

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On behalf of drift chamber working group

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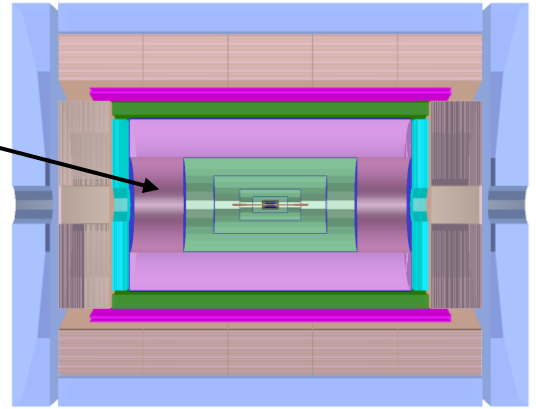
Outline

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

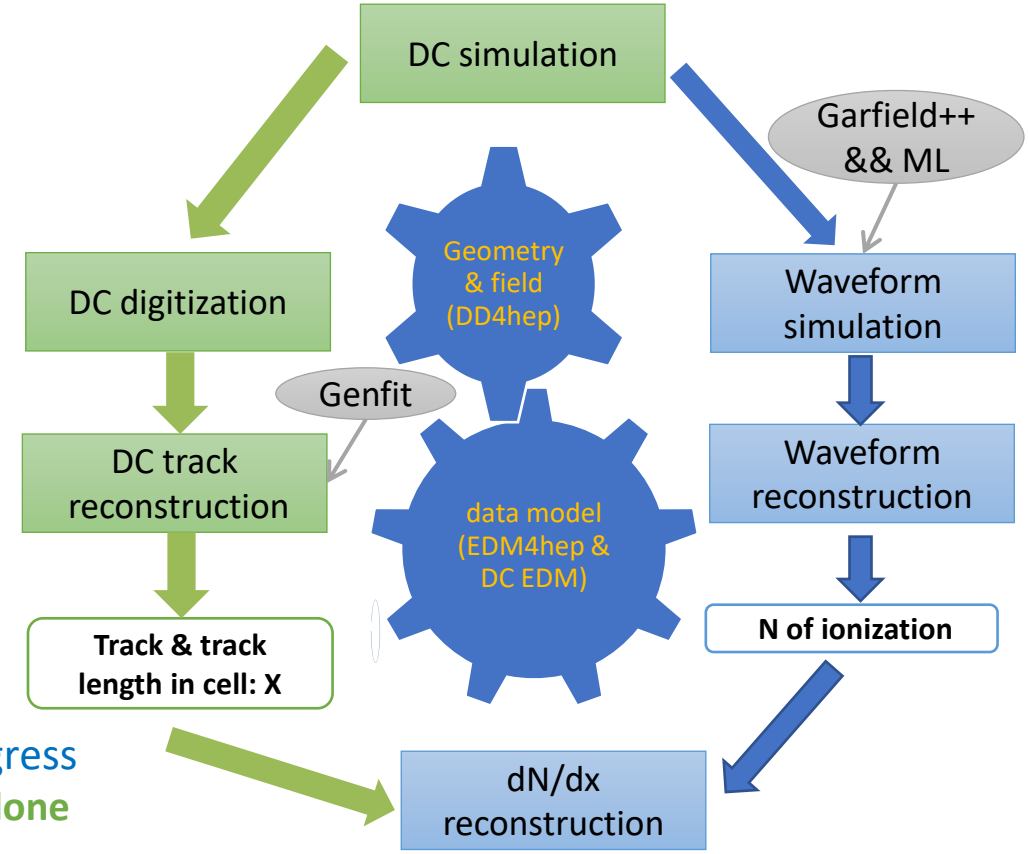
Requirements of The CEPC tracker

- 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

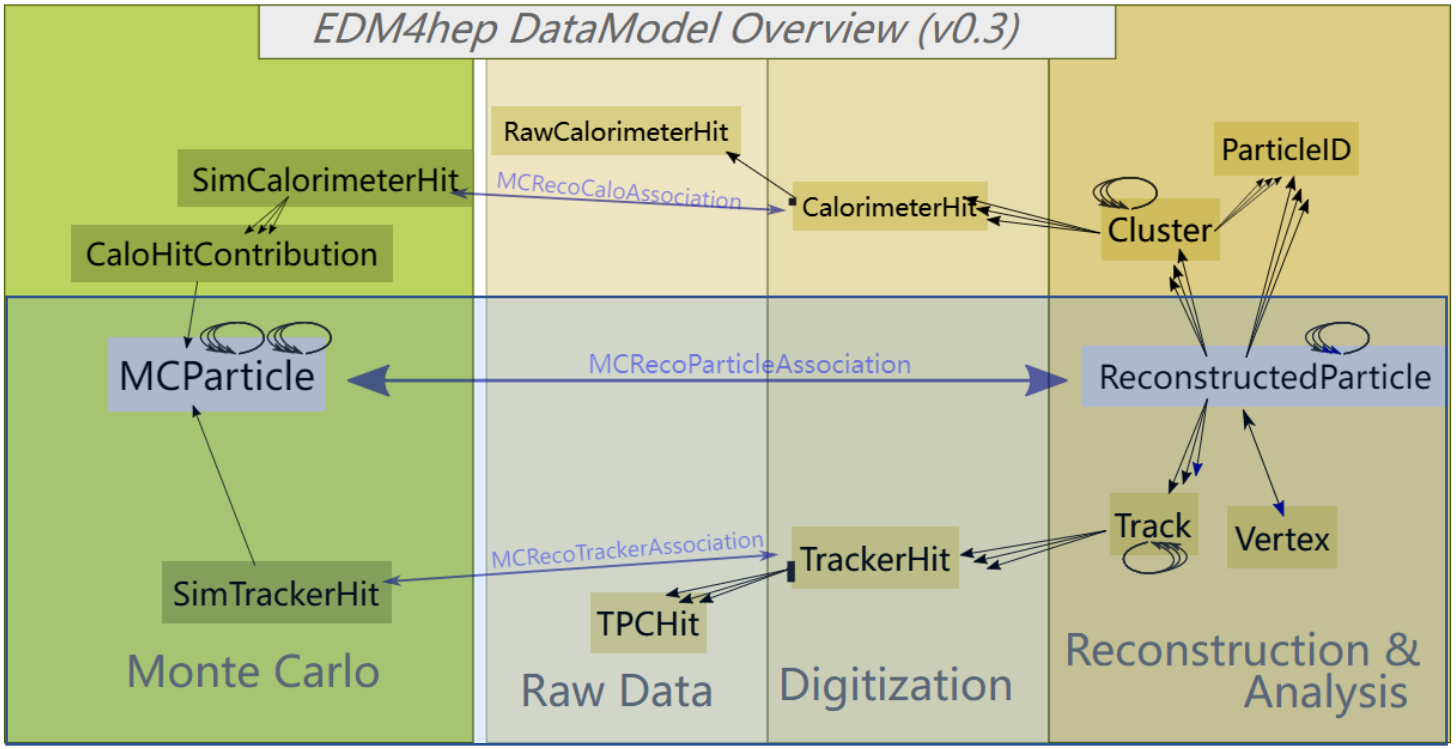
- CEPCSW
  - Gaudi based framework
  - External libraries and tools
- Geometry and field map
  - DD4hep
  - Non-uniform magnetic field: **done**
- Data model
  - EDM4hep and FWCore
  - dN/dx event model: in progress
- Drift chamber
  - DC simulation: **done**
  - DC digitization: **done**
  - Waveform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



Drift chamber simulation and reconstruction flow

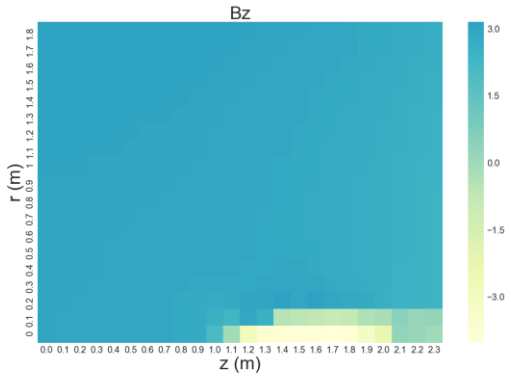
Event data model

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

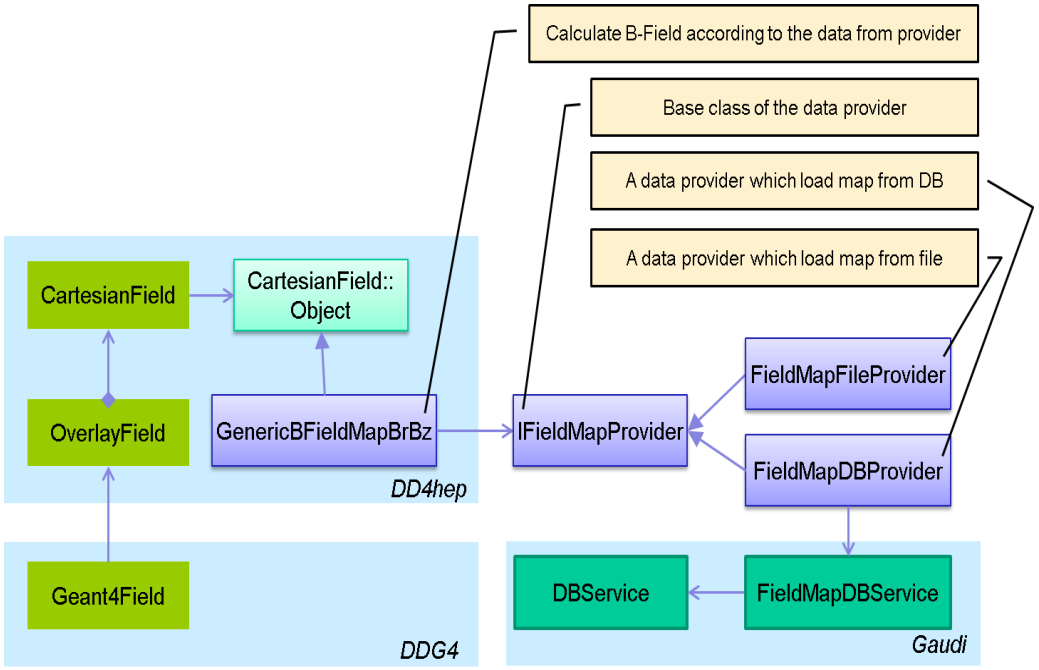


Non-uniform B-Field

- 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



Filed map

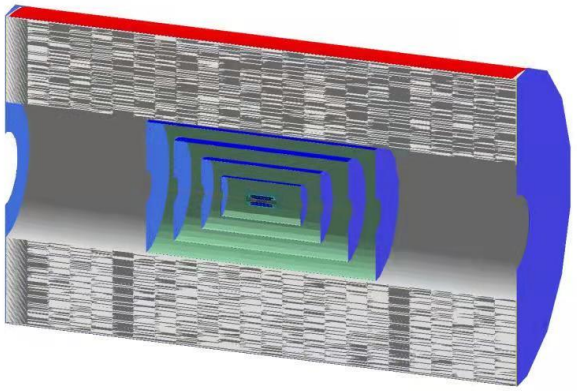


B-field service in CEPCSW

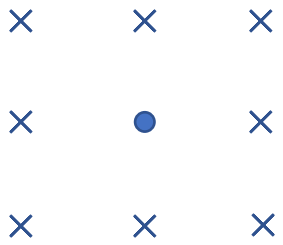
Drift Chamber Parameters in CEPCSW

- The base line configuration of DC in CEPCSW

Half length	2980 *mm*
Inner and outer radius	800 to 1800 *mm*
# of Layers	100
Cell size	~9.6 *mm x 9.6 mm*
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
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)



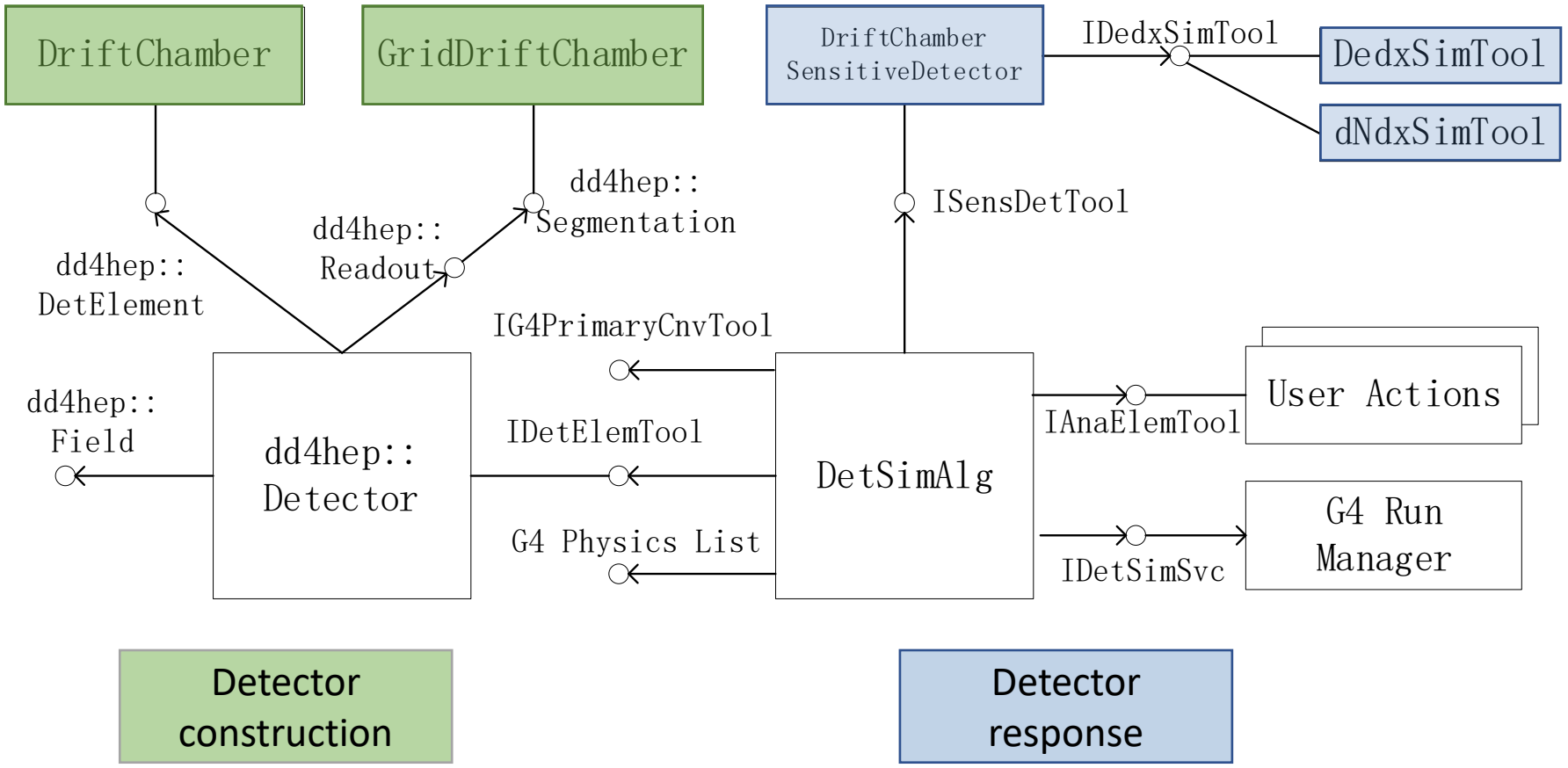
CRD tracker o1 v01



field wire: x, sense wire: o
Cell structure

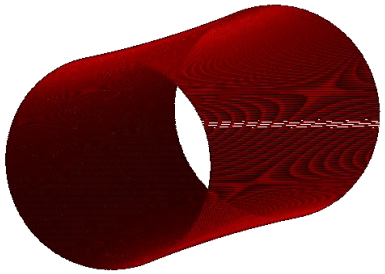
DC Simulation in the Simulation Framework

- A new implementation of drift chamber in the CEPCSW

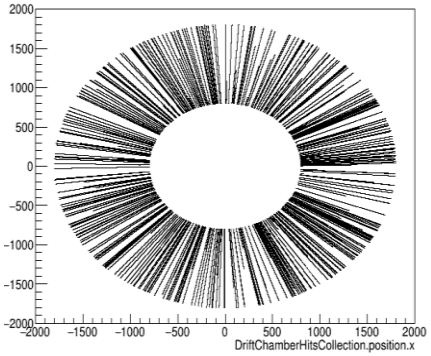


DC Simulation

- Following the common scheme for detector description
  - DC constructor (axial and stereo layers available)
    - Detector/DetDriftChamber/src/driftchamber/DriftChamber.cpp
    - Detector/DetSegmentation/src/GridDriftChamber.cpp
  - XML based compact files for drift chamber detector description
    - DC : Detector/DetDriftChamber/compact/det.xml
    - CRD: Detector/DetCRD/compact/CRD_oX_vYY/CRD_o1_vYY.xml
  - Layer number and stereo angle etc. are configurable
- Cell partitioning with segmentation
  - No cell volume in Geant4 to speed up simulation
  - Flexible way to virtual mapping between cell and position
  - Consistent between simulation and reconstruction
- Simple digitization
  - Constant drift velocity: V_{drift}=40μm/ns & fixed spatial resolution: σ=110mm
  - Make association between truth hit and digit



Stereo layer of drift chamber

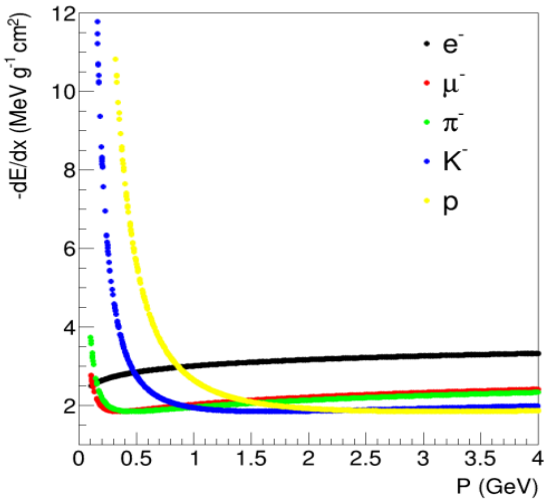


Hitmap of MC hits in DC

dE/dx Simulation

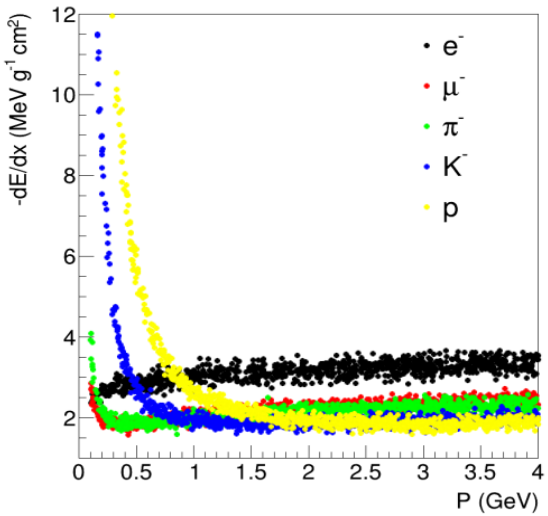
- The configurable fast sampling tool
  - Hit/track level sampling from empirical formula
  - Other sampling method is easy to be plugged in
- A track level dN/dx simulation in CEPCSW is ready

dE/dx from Bethe-Bloch equation



5% smeared

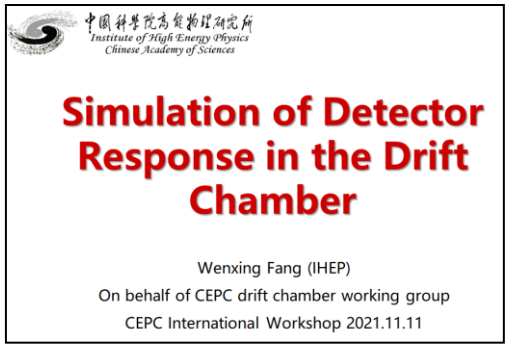
dE/dx after fast sampling

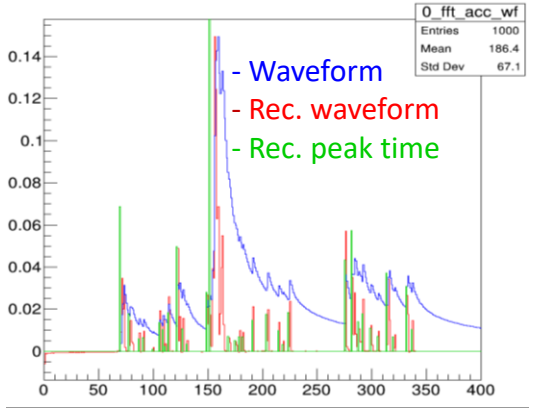


dN/dx Simulation and Reconstruction

See W.X. Fang's talk for detail

- Implement the DC waveform simulation and analysis
- Integrate Geant4 and Garfield++ for precisely simulation
  - To handle a more precise energy loss and ionization process
- Fast signal response simulation
  - A neural network waveform generation is developed
  - Gives ~ 200 times speed up according to Garfield++
- A waveform reconstruction with Fourier transform
  - Other reconstruction algorithm can be easily plugin
- The event model for dN/dx study is under development
  - dN/dx tools can be reused and plugin to CEPCSW
- Ensure the dN/dx study by physics channels



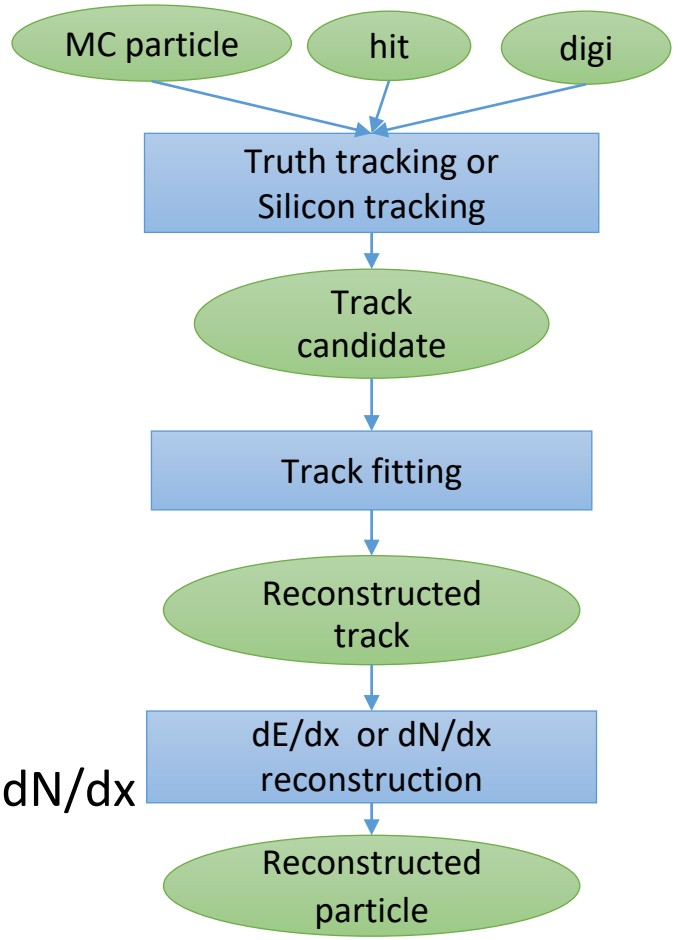


Waveform reconstruction with Fourier transform

DC Reconstruction

Realized the flow of DC track reconstruction in CEPCSW

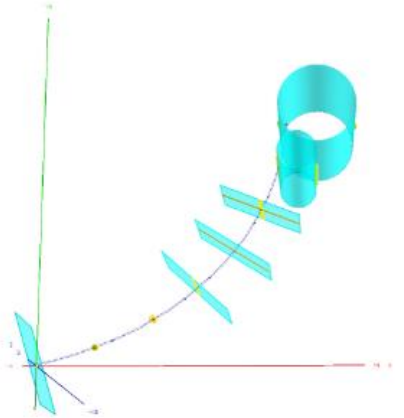
- Track finding
  1. A fake track finding from MC truth
  2. Silicon tracking migrated
- Track fitting
  1. New developed track fitting -- RecGenfitAlg
  2. A full silicon+DC tracking -- KalTest
- dE/dx and dN/dx reconstruction
  - Dummy algorithm to provide track level dE/dx or dN/dx



Data flow of DC reconstruction

Track Fitting--- RecGenfitAlg

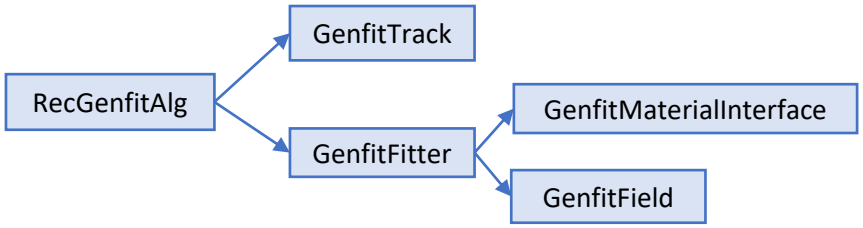
- Based on Genfit (https://github.com/GenFit/GenFit/)
  - An experiment-independent generic track fitting framework
  - Open sourced, active development and large user community
  - Official track fitting for BelleII, also used by PANDA, COMET, GEM-TPC etc.
  - Become the developer of Genfit
- Main features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



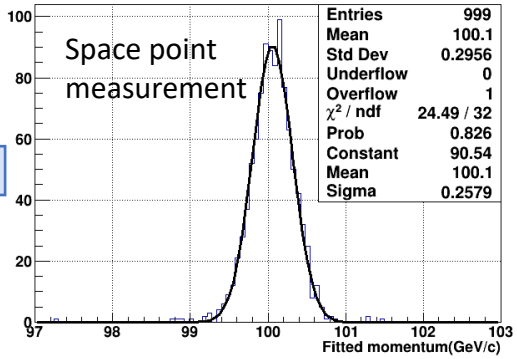
(a) Measurements with covariance (yellow), planar detectors and drift isochrones (cyan), respectively, and reference track (blue).

Track Fitting--- RecGenfitAlg

- New implemented of a track fitting with Genfit in CEPCSW
  - Implemented Genfitfield class to get BField from DD4hep
  - Implemented GenfitMaterlInterface class to get material and geometry from DD4hep
  - A track converter event data model with GenfitTrack with EDM4hep
  - A wrapper class GenfitFitter to the Genfit track fitters
- RecGenfitAlg
  1. Kalman track fitting combine the silicon detector and drift chamber
  2. Space point measurement is implemented
  3. Pixel, strip and wire measurements are realized, validation is on going

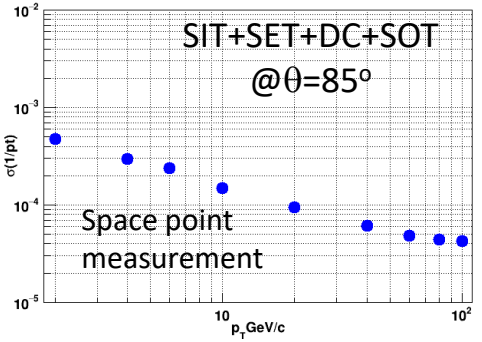


Interface classes to the Genfit in CEPCSW



Momentum distribution

VXD×6: $\sigma_{rphi,z}$=2.8μm,6μm,4μm,4μm,4μm,4μm
SIT ×4: σ_{rphi}=7.2μm, σ_z=86μm
DC ×1: σ_{rphi}=110μm, σ_z=1mm
SOT×1: σ_{rphi}=7.2μm, σ_z=86μm



Momentum resolution v.s. p_T

Future Plan

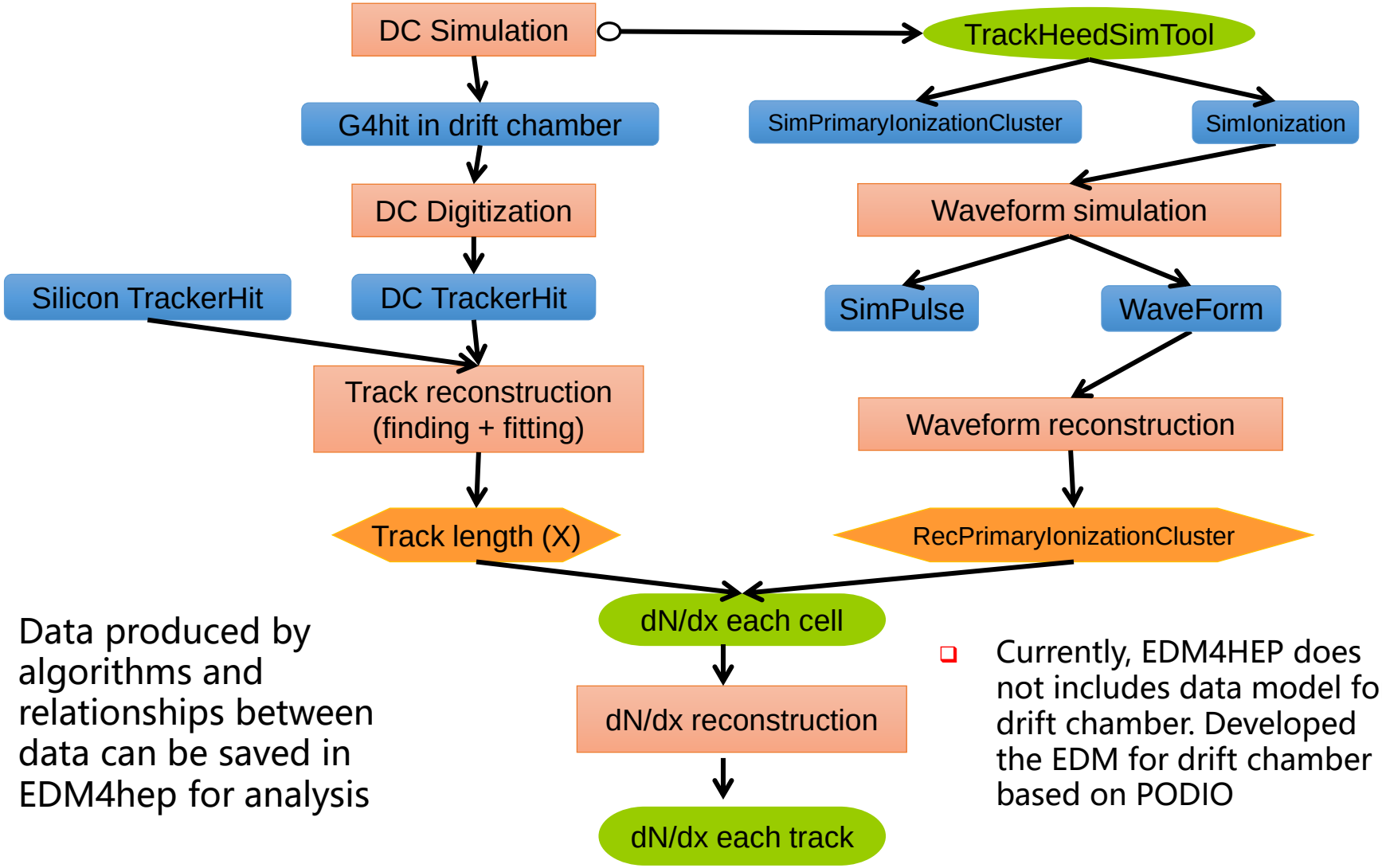
- dN/dx
  - Event data model development
  - Waveform simulation and analysis study
- Background in simulation and reconstruction
- Track finding development
  - Machine learning
  - Track finding from silicon seed or self-tracking
- Release for detector and physics performance study

Summary

- A drift chamber software developed from scratch
- The stereo wire version of DC software is released
  - The configurable simulation
  - Precise dN/dx simulation
  - Fitting with detector measurement
- Future plan
  - The precise dN/dx simulation and analysis study in CEPCSW
  - Validation and performance study of tracking
  - Develop the track finding algorithm

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

Track fitting --- KalTest

- Geometry
  - VXD×6: $\sigma_{rphi,z}$=2.8μm, 6μm, 4μm, 4μm, 4μm, 4μm
  - SIT ×4: σ_{rphi}=7.2μm, σ_z=86μm
  - DC ×1: σ_{rphi}=110μm, σ_z=1mm
  - SOT×1: σ_{rphi}=7.2μm, σ_z=86μm