Software for the CEPC Drift Chamber

Yao Zhang

On behalf of drift chamber working group

22 December 2021

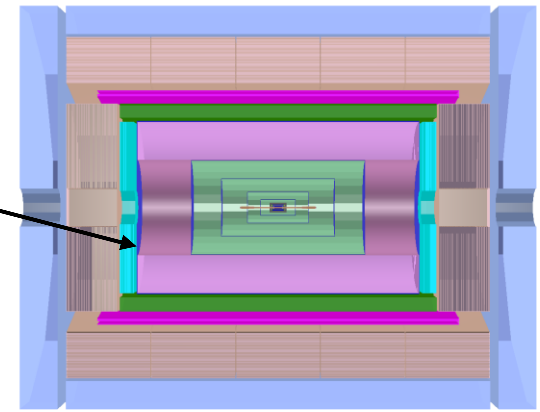
CEPC PhysDet meeting

Outline

- Motivation
- Drift chamber simulation
- dN/dx simulation and reconstruction
- Tracking algorithms
- Summary

Drift Chamber(DC)

- 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%, σ_p<=0.1%)



- Motivation of DC software
  - A demonstration for the development of CEPC software
  - Provide detector layout optimization with full simulation
  - Detailed dN/dx study through physics channels

- Requirements for DC software
  - Configurable simulation
  - Fast iteration for dN/dx study
  - Adaptive tracking

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	m_H, $\sigma(ZH)$ BR$(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$

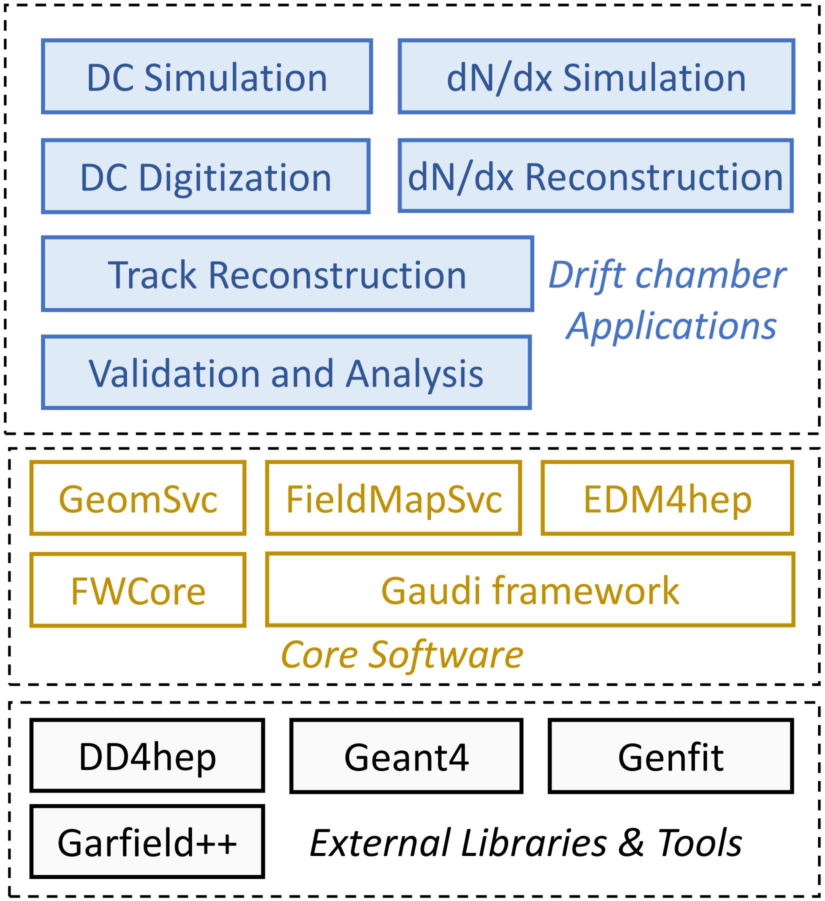
Requirements of The CEPC tracker

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

DC software status in CEPCSW

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**
  - dN/dx simulation: in progress
  - dN/dx reconstruction: in progress
  - Track fitting with measurement: **done**

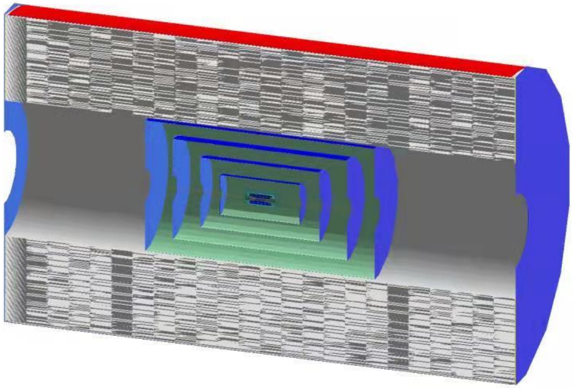


https://github.com/cepc/CEPCSW

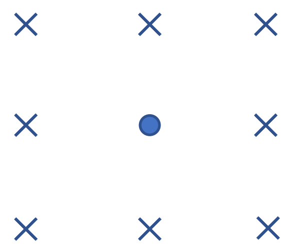
Drift Chamber parameters in CEPCSW

- The base line configuration of DC in CEPCSW

Length	2225 *mm*
Inner and outer radius	800 to 1800 *mm*
# of Layers	100
Cell size	10 *mm* x 10 *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*



CRD tracker o1 v01



field wire: x, sense wire: o

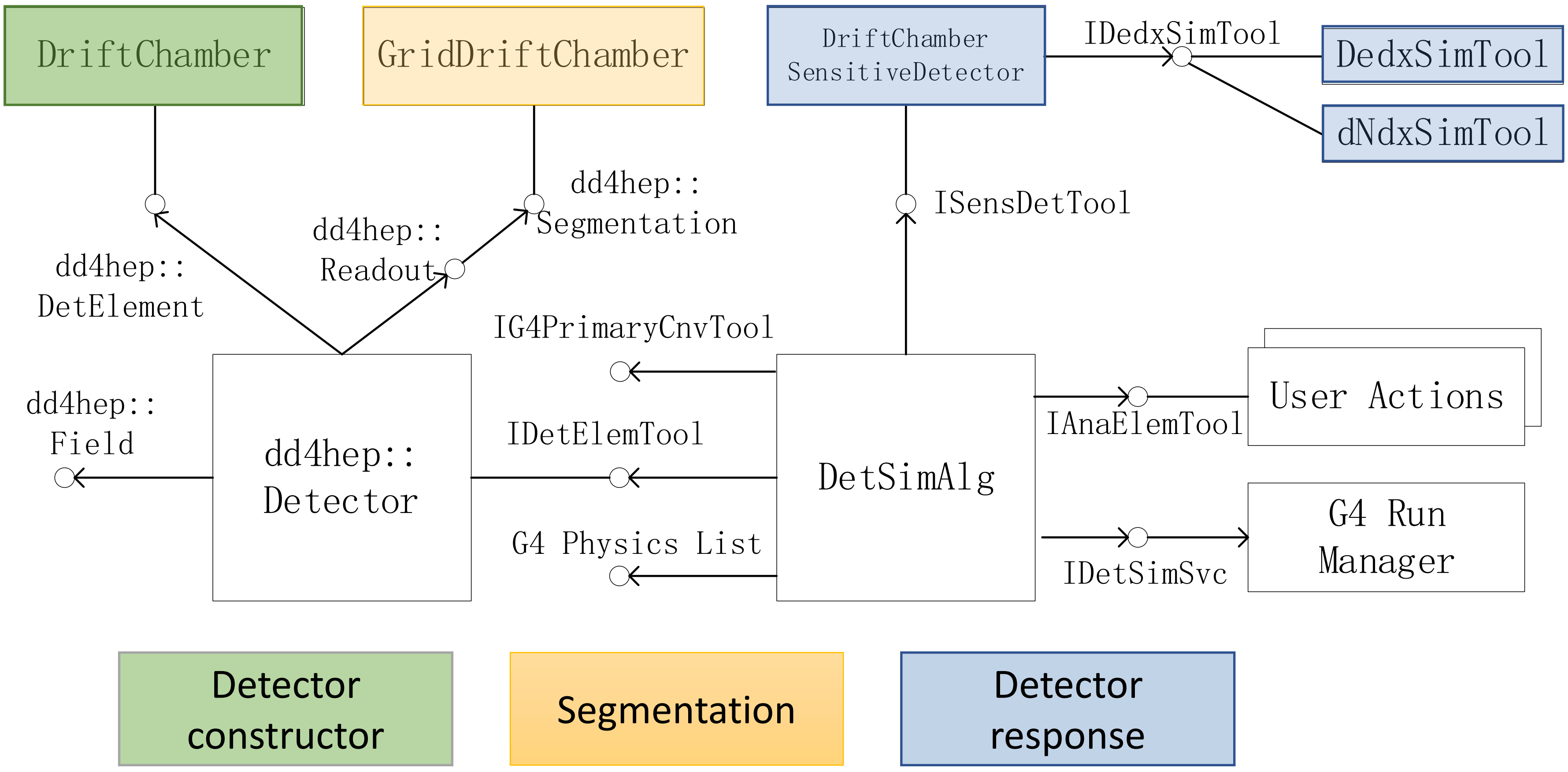
Cell structure

DC simulation

- Flow of DC simulation

DC simulation in the simulation framework

- A new implementation of drift chamber in the CEPCSW



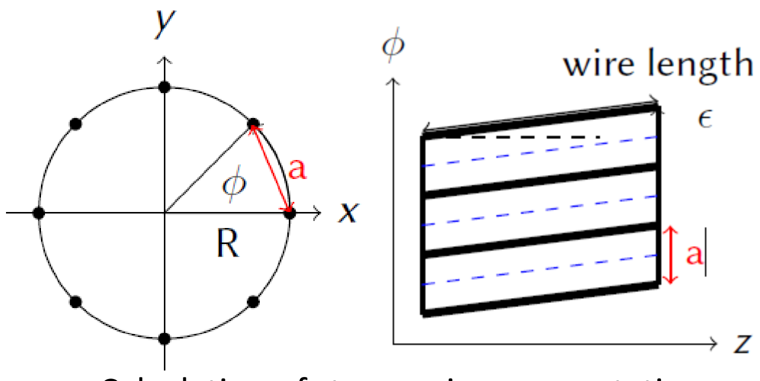
Geometry description and simulation

- 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_oX_vYY.xml
- Layer, number and stereo angle of DC are configurable
- Solved overlap between detector elements

- Hit simulation in Geant4
  - Stepping in the gas with a configurable G4Step length

Cell partitioning with segmentation

- Large number of cells (>80k)
- Segmentation make a fast way to find the location of the closest wire hit
  - Associates a unique cellID to the wires
- Consistent between simulation and reconstruction
  - The segmentation information is created while building geometry
  - Access same segmentation at the digitization and tracking stage



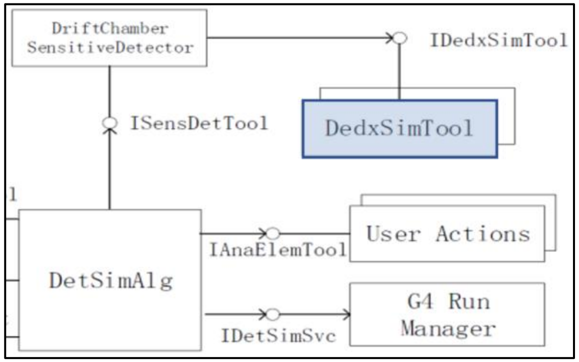
Calculation of stereo wire segmentation

Simple digitization

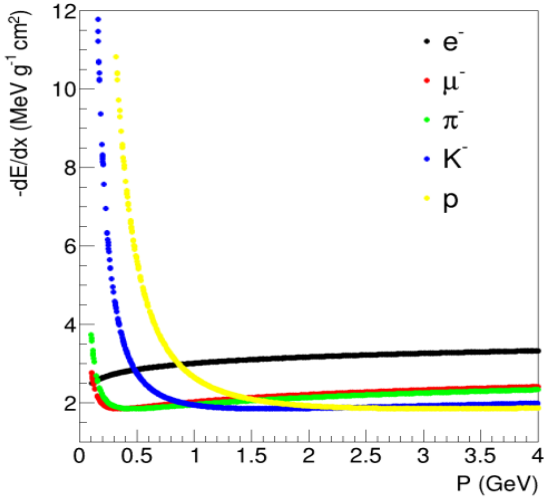
- Use segmentation to get cellID
- Sum the charge deposition of each cell
- Compute the distance of the closest approach in each cell
  - Constant drift velocity: V_{drift}=40μm/ns
  - Fixed spatial resolution: $\sigma_{r\phi}$=110μm (σ_z=1mm for space point)
- Make association between truth hits and digis

dE/dx simulation

- The configurable fast sampling tool
  - Hit/track level sampling from empirical formula
  - Other sampling method is easy to be plugged in

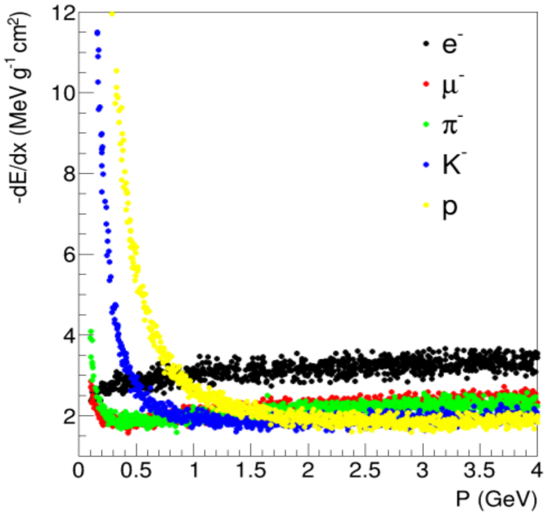


dE/dx from Bethe-Bloch equation



5% smeared

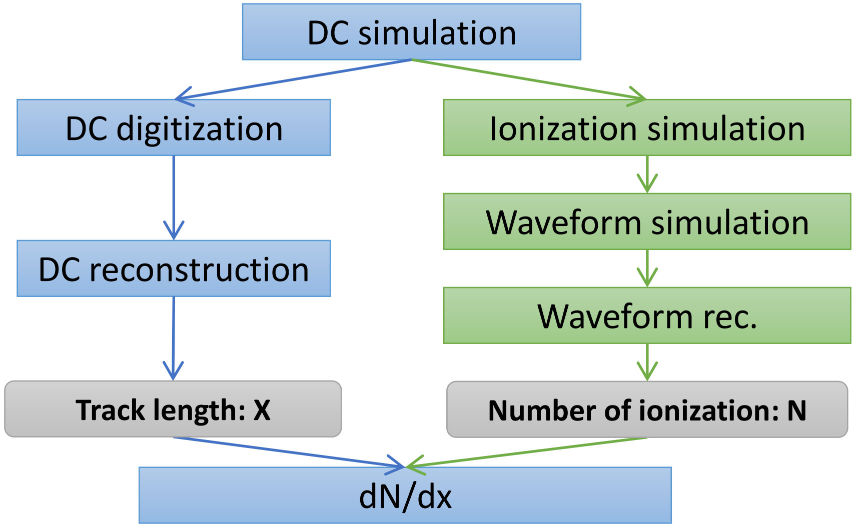
dE/dx after fast sampling



dN/dx simulation and reconstruction

- A track level dN/dx sim. with Garfield++ in CEPCSW is ready

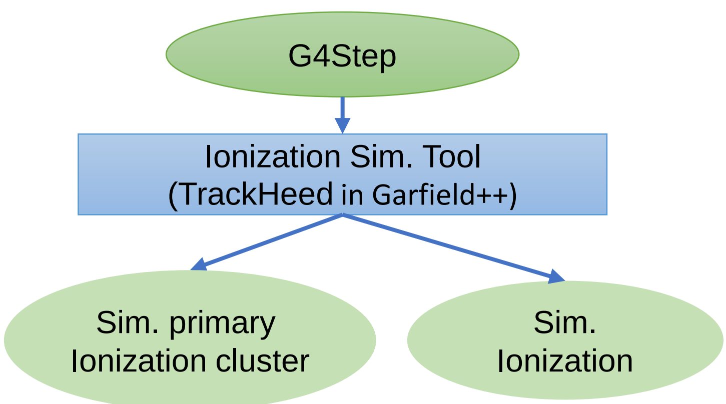
- Development of a novel hit level dN/dx sim. and rec. is on going



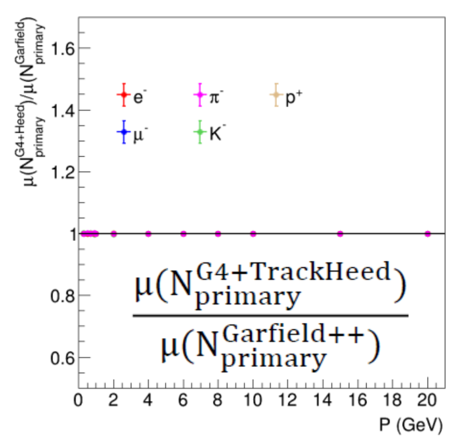
dN/dx simulation and reconstruction flow in CEPCSW

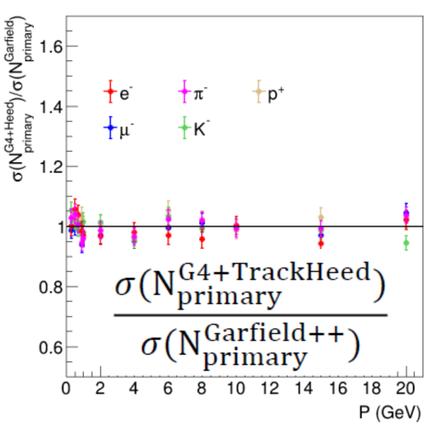
Ionization simulation

- Integrate Geant4 and Garfield++
  - For each G4Step, using Garfield++ to simulate the ionization process
  - The kinetic energy will be updated according to the energy loss in the ionization
  - The information about primary and total ionizations will be saved in EDM
  - Non-uniform magnetic field can be handled easily
- Garfield++ standalone and integrated simulation are consistent



Integrate Garfield++ and Geant4

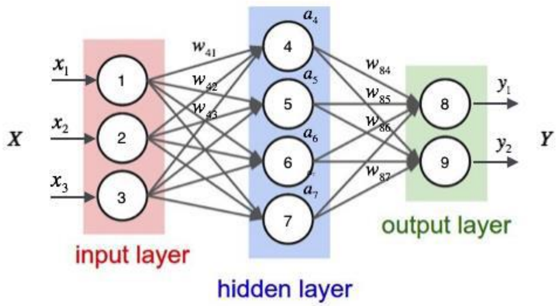




Compare between Garfield++ standalone and integrated simulation

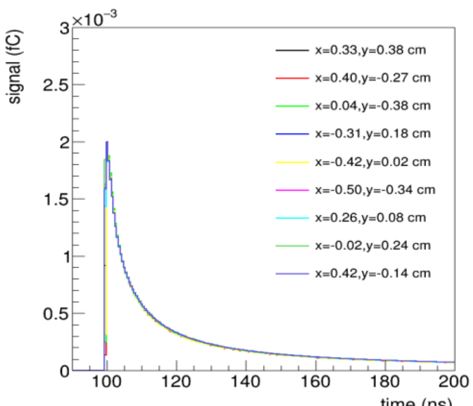
Fast waveform simulation

- It is extremely time consuming by using Garfield++ to simulate the waveform
- The simulation result from Garfield++ shows that:
  - The waveform shape of each ionized electron is similar
  - Main difference is the begin time and amplitude
  - Combine induced current of single electron to waveform
- Using machine learning technic
  - Train sample is from Garfield++ simulation
  - Use Deep Neutral Network (DNN) model
  - Generate begin time and amplitude of each ionized electron

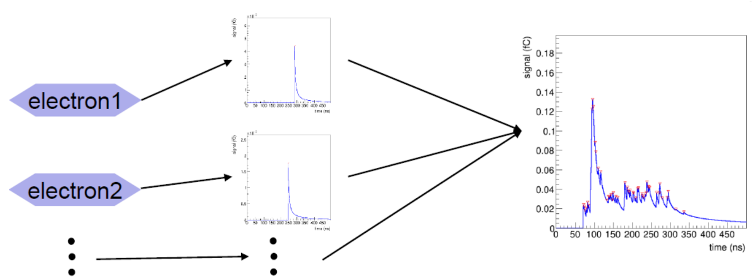


deep neutral network (DNN) structure

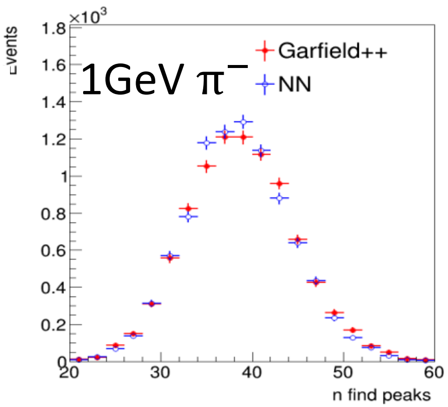
- Good agreement between DNN and Garfield++ with ~200 times speed up



Normalized single electron waveforms



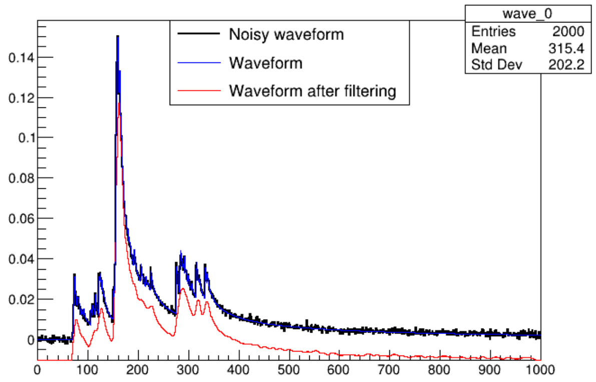
Fast waveform simulation in CEPCSW



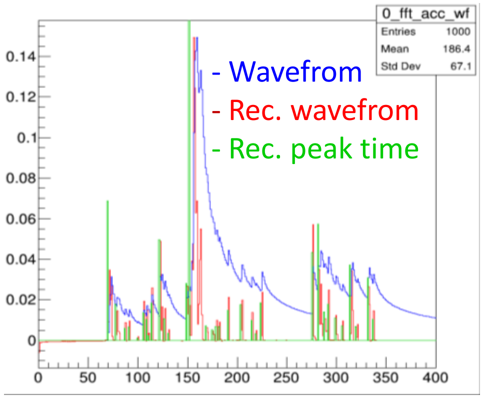
Number of find peaks with Garfield ++ and DNN method

Waveform reconstruction

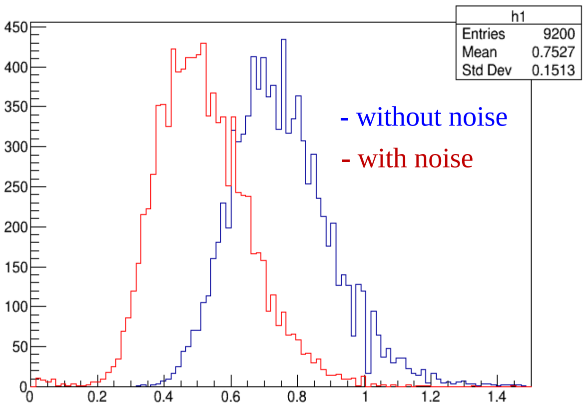
- Original waveform from Garfield++
- Add a Gaussian noise
- Filter out high frequency noise through a Fourier filter
- Obtain the waveform after de-convolution based on the average waveform
- Peak finding algorithm to get peak time



Wavefrom analysis with Fourier filter



Waveform reconstruction

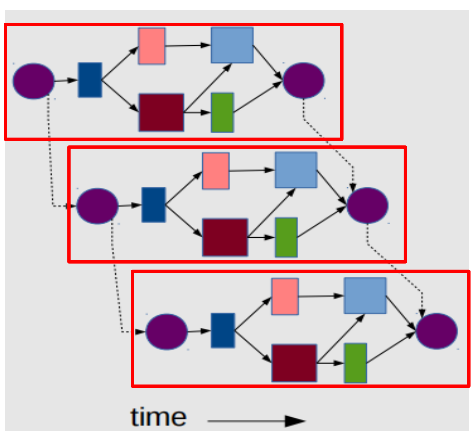


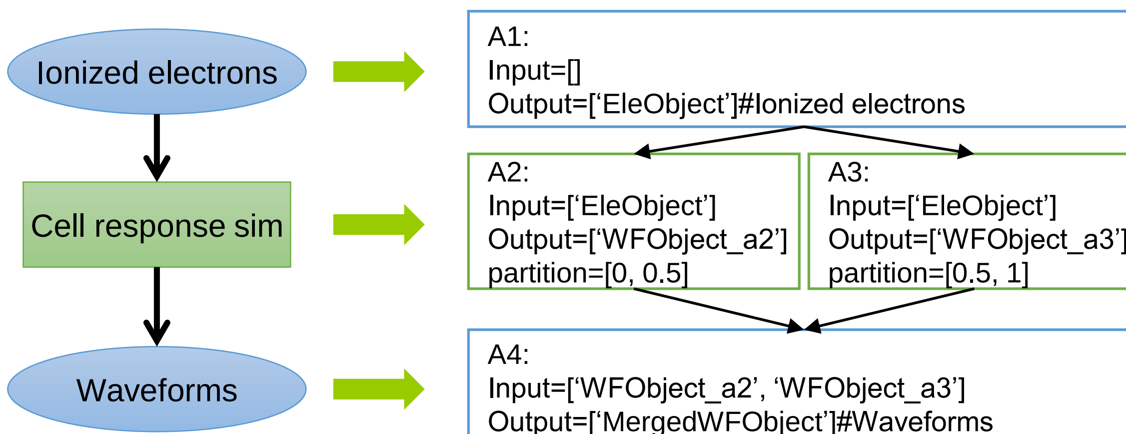
Peak finding efficiency

$\varepsilon = N_{peak}/N_{total\ ionization}$

Parallel waveform simulation

- Gaudi Hive: multi-threaded, concurrent extension to Gaudi
- Data Flow driven mechanism
  - Algorithms declare their data dependencies
  - Scheduler automatically executes Algorithms as data becomes available
- Multiple algorithms and events can be executed simultaneously
- Using Gaudi Hive for waveform simulation of drift chamber
- Works well for standalone simulation
- Next plan is to combine with Geant4 simulation

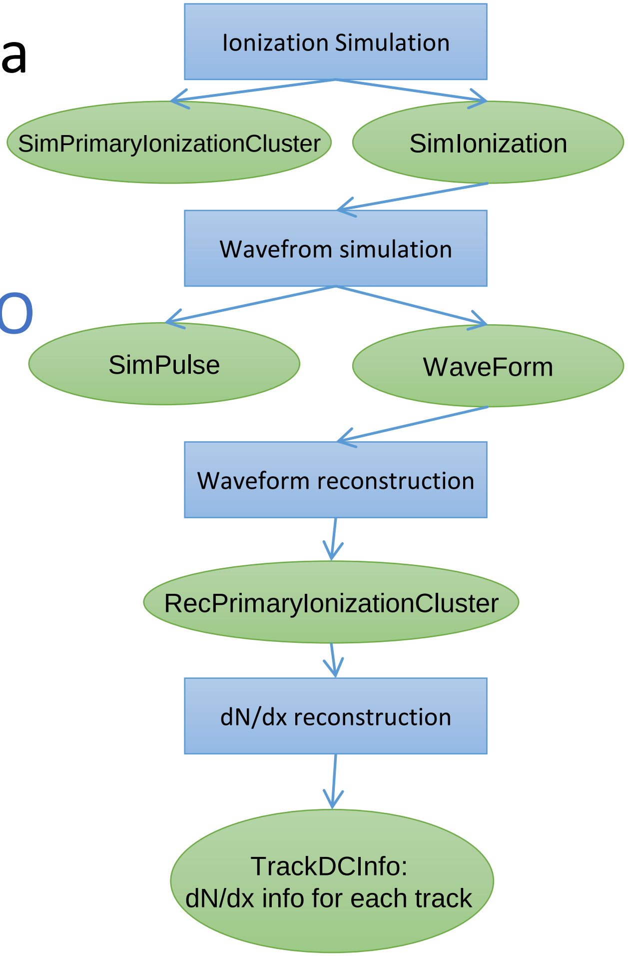




Event data model for dN/dx

- Currently, EDM4HEP does not includes data model for drift chamber

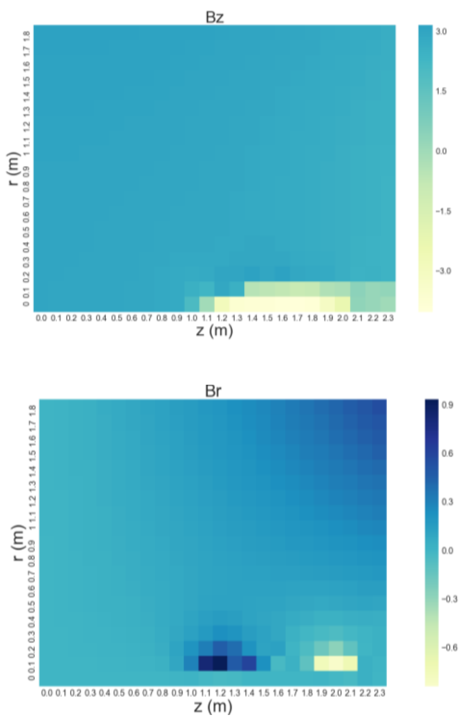
- Developed the EDM for DC based on PODIO
  - SimPrimaryIonizationCluster
  - SimIonization
  - SimPulse
  - WaveForm
  - RecPrimaryIonizationCluster
  - TrackDCInfo (dN/dx info for each track)



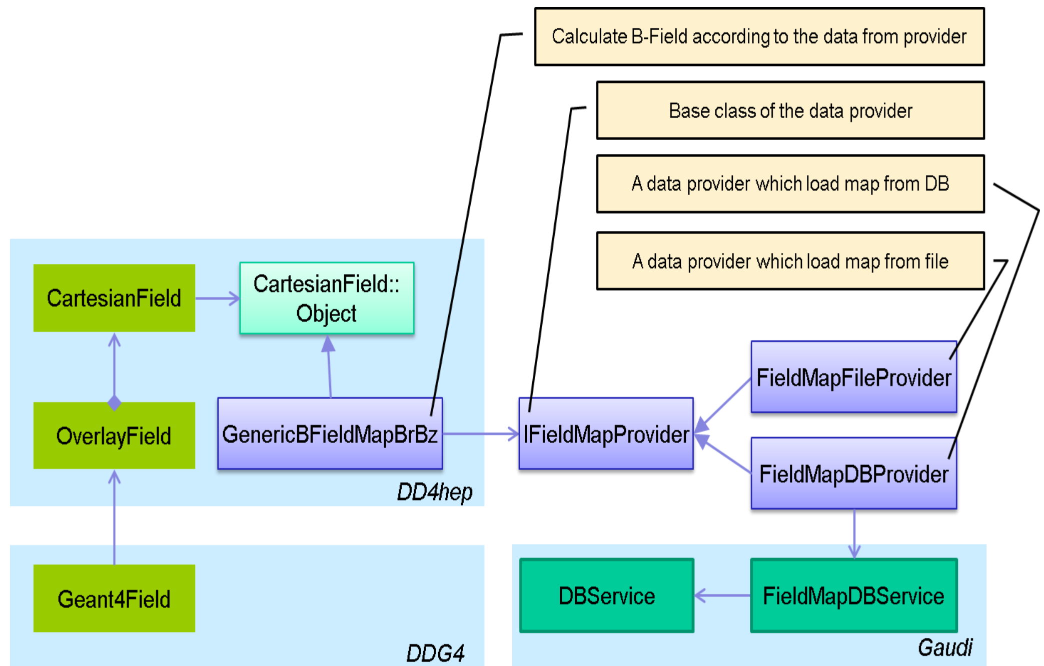
Data flow of dN/dx sim. and rec.

Non-uniform B-Field

- A generic B-field is developed under the simulation framework
  - CSV-like format data from magnetic group
  - Field map can be load from the file or database



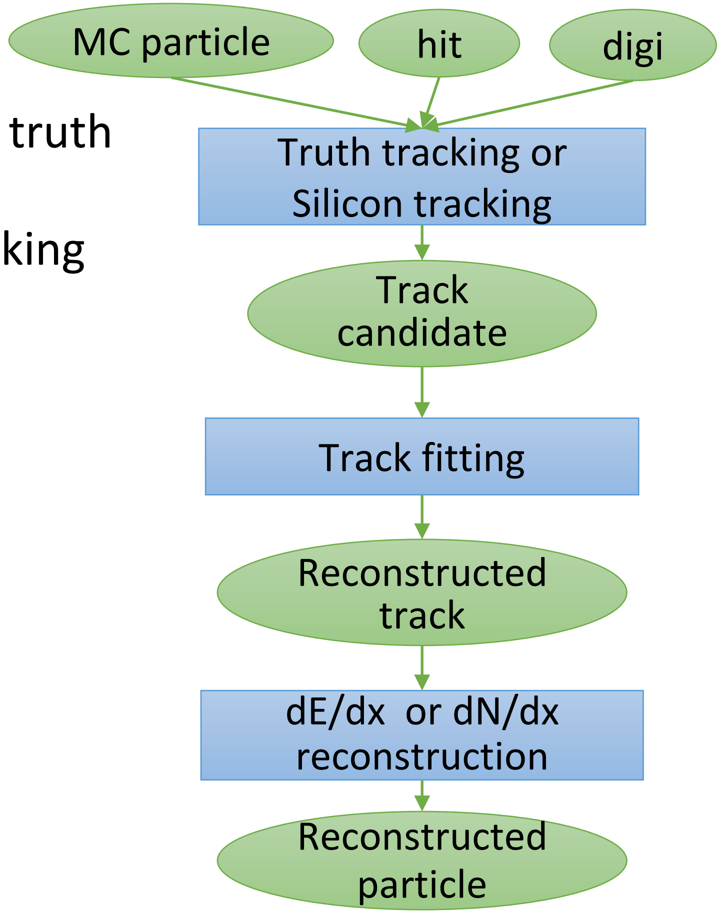
Filed map



B-field service in CEPCSW

DC reconstruction

- Track finding
  1. Truth tracking: A fake track finding from MC truth
  2. Silicon tracking migrated
  3. Traditional and machine learning based tracking development is needed
- Track fitting
  1. New developed track fitting -- RecGenfitAlg
     - A combined track fitting of silicon + DC realized
  2. A full silicon+DC tracking -- KalTest
     - Working for DC space point
- dE/dx and dN/dx reconstruction
  - A dummy reconstruction algorithm
    - Provide track level dE/dx or dN/dx

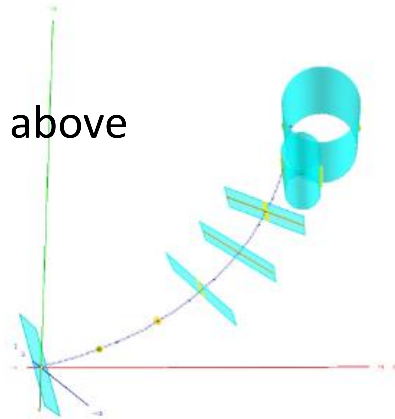


Data flow of DC reconstruction

Track fitting(I)--- 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
  - Genfit is in the official external library in CEPCSW

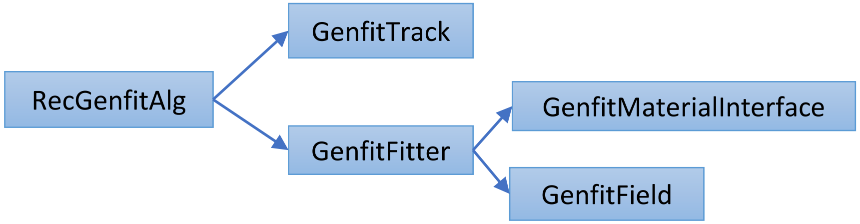
- Main features of Genfit
  - **Support various detector types**:
    - pixel, strip, TPC, drift chamber or tube and combinations of above
  - Detector geometry: ROOT(easy to integrate with DD4hep)
  - Provide several fitting algorithms
    - Kalman filter, DAF, GBL etc.
  - Extrapolation tools



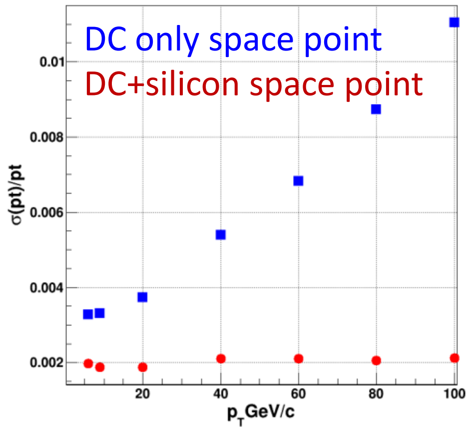
(a) Measurements with covariance (yellow), planar detectors and drift isochrones (cyan), respectively, and reference track (blue).

Track fitting(I)--- RecGenfitAlg

- Implemented a new track fitting algorithm based on Genfit
  - Implemented Genfitfield class to get BField from DD4hep
  - Implemented GenfitMaterlInterface class to get material and geometry from DD4hep
  - A GenfitTrack with the EDM4hep converter to handle track and measurements
  - A wrapper class GenfitFitter to the Genfit track fitters
- Features of RecGenfitAlg
  - Access and store track and hits followed EDM4hep
  - Combination fitting of silicon and drift chamber
  - **Space point measurement** for both silicon and DC with fixed resolution
  - **pixel/strip silicon and wire measurements**



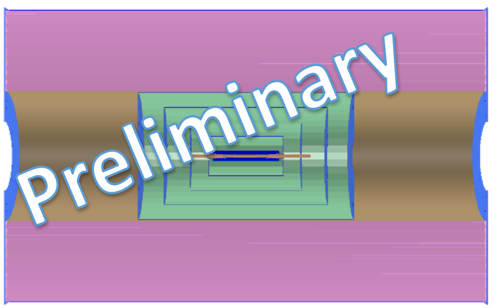
Interface classes to the Genfit in CEPCSW

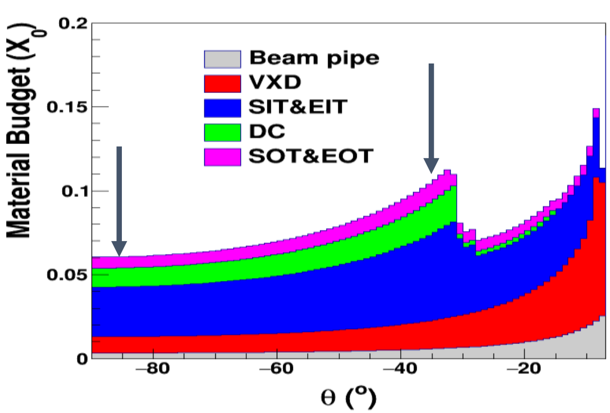


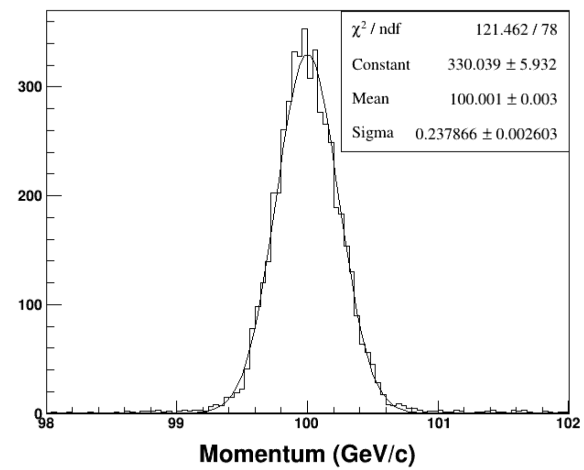
Momentum resolution v.s. p_T

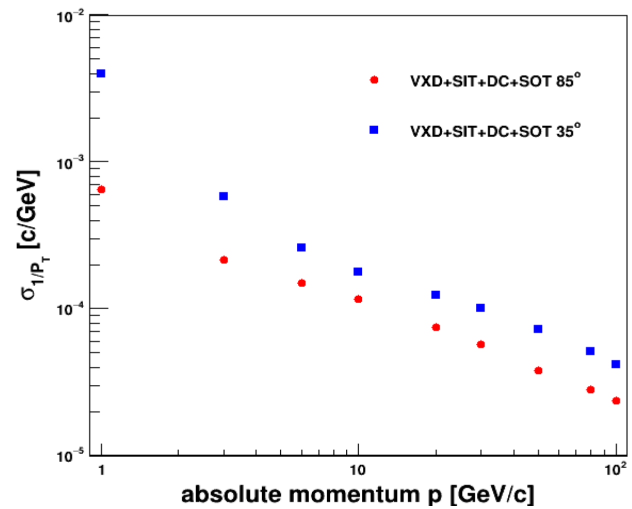
Track fitting(II) --- KalTest

- 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









Paper and talk

- A Conceptual Detector Design for the CEPC (software)

2.3.3 Simulation

For drift chamber, the simulation of charged particle ionization using Garfield++[] is adopted. However, it is extremely time-consuming for simulating avalanche of electrons. To overcome this barrier, a fast simulation method based on machine learning have been developed. Data from the Garfield++ simulation is used to train a fully-connected neural network. And the achieved neural network model is then used to transform the information of an ionized electron to its corresponding hit pulse on the signal wire. After the conversion completes, the waveform is created just by piling up the pulses according to their arrival time.

2.3.4 Reconstruction

2.3.4.2 Drift chamber

The drift chamber reconstruction is consist of a Monte Carlo truth-based track finding followed by a track fitting. The track finding combine good hits of the single particle trajectory from all the sub-detectors and make a candidate track, whereas the track fitting provide the track status estimation by doing a Kalman filtering. The track fitting algorithm is integrated to an experiment-independent track fitting toolkit [GENFIT](https://github.com/GenFit/GenFit). A deterministic annealing filter (DAF) with a reference track is adopted to improve the robustness

- "Precise simulation of drift chamber in the CEPC experiment" accepted by ACAT 2021 as an oral presentation

Regular meeting

- CEPC drift chamber group meeting each Friday
  - Called by Yao Zhang

CEPC漂移室软件会议纪要 (Archive note)

21-10-23

召集人：张瑶
参会人：李卫东，林韬，方文兴，张瑶，袁野，刘梦瑶

- 准备workshop报告
  - DC模拟重建整体
  - dN/dx: 跟Garfield整合，快速模拟，并行，简化数据模型
- 物理分析
- DC斜丝模拟
  - 调整参数解决与硅探测器的overlap
  - 信号丝场丝比例默认 1:3

- Join regular meeting of cluster counting and detector layout

Plan

- dN/dx
  - Waveform simulation and waveform reconstruction
- More realistic sim. and rec.
  - Background mixing and tracking with background
- Tracking
  - Validation of the track fitting
- Detector design
  - Study tracker layout performance with full simulation
  - Study dN/dx performance under CEPCSW

Summary

- The drift chamber software developed from scratch
- The stereo wire version of DC software is released
  - The configurable simulation
  - Fitting algorithms with wire, pixel/strip measurement
- Status
  - The dN/dx simulation and reconstruction in CEPCSW is on going
  - Combine Gaudi-Hive with Geant4 simulation is on going
  - The performance of tracking is under study

Thank you!