Track Reconstruction on CEPC

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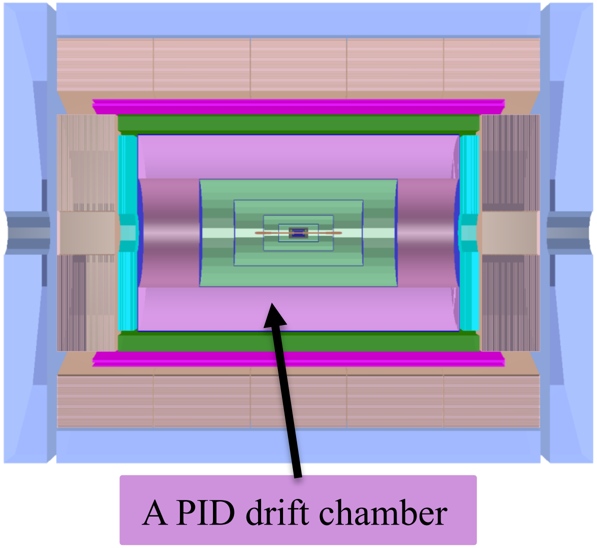
Seminar on Computational Software and Technology for Particle Physics Experiments

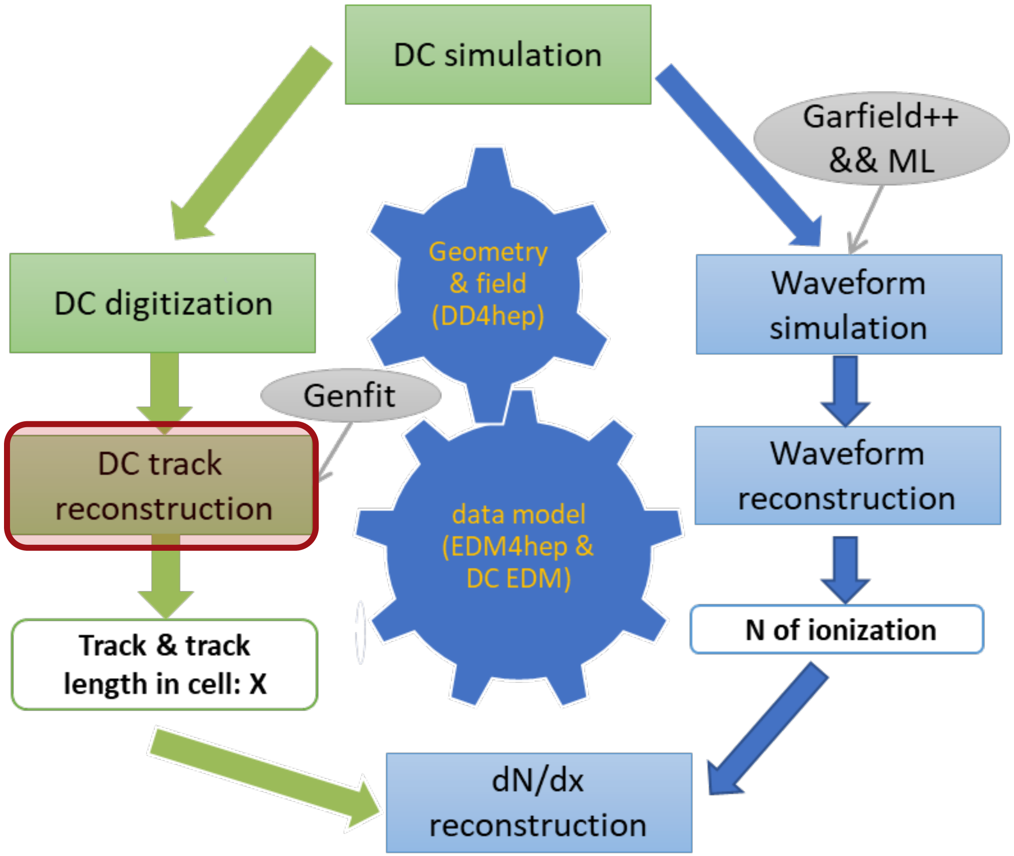
Drift Chamber of CEPC

- 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



DC software

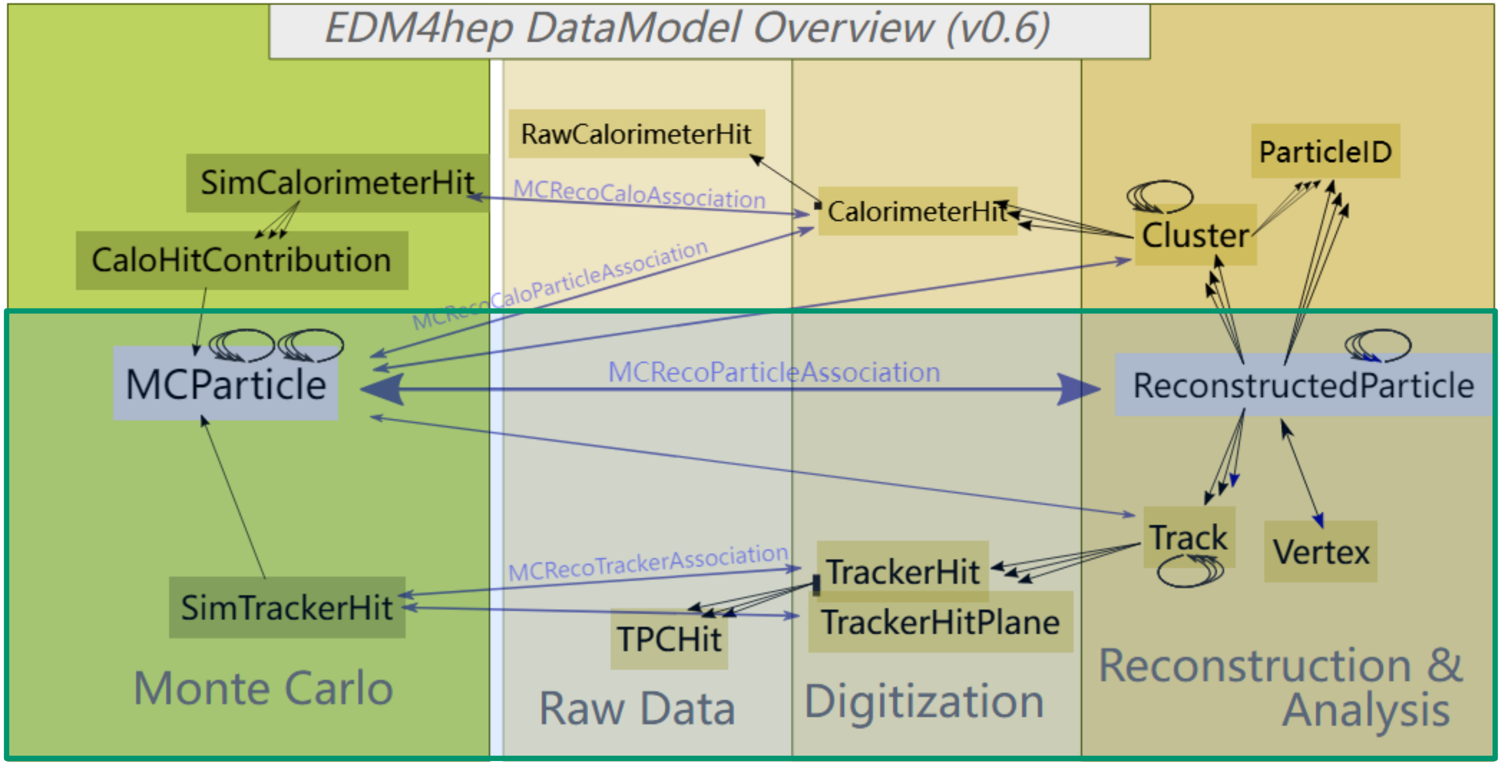
- The drift chamber software has been developed from scratch
- CEPCSW
  - Gaudi based framework
  - External libraries and tools
  - Geometry and field map
  - Data model
- Drift chamber
  - DC simulation: **done**
  - DC digitization: **done**
  - Track finding: **done**
  - Track fitting with measurement: **done**
  - Multi track reconstruction: **done**
  - Waveform simulation: **in progress**
  - Waveform reconstruction: **in progress**
  - dN/dx reconstruction: **in progress**



Drift chamber simulation and reconstruction flow

Event data model

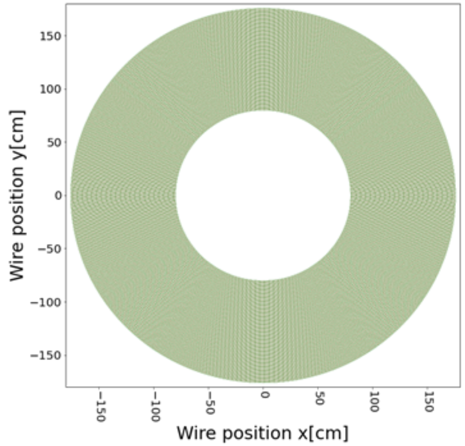
- DC implement the data model following the EDM4hep
- The extension of the current EDM4hep to accommodate the needs from dN/dx studies

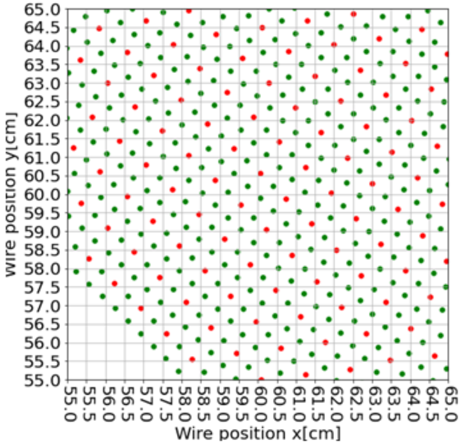


Drift Chamber Parameters in CEPCSW

- 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)

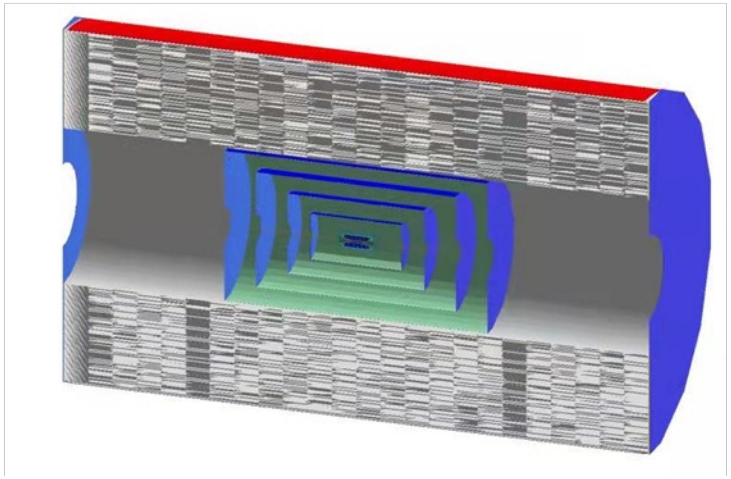




Cell structure

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

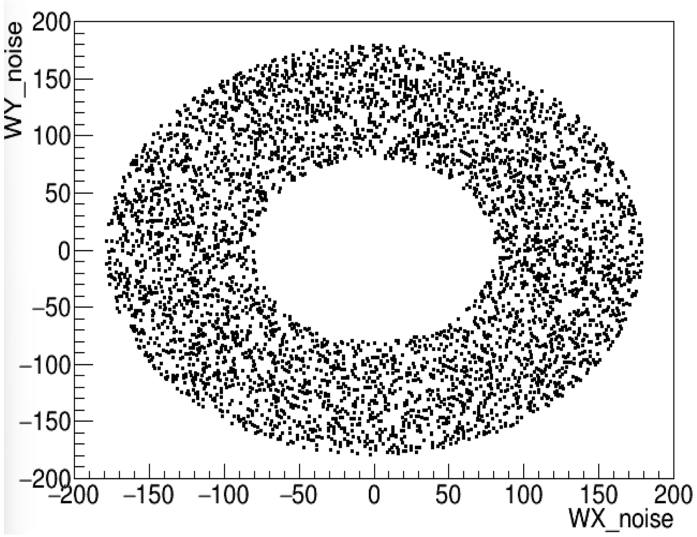
- Following the common scheme for detector description
  - XML based compact files for drift chamber detector description
  - CRD: Detector/DetCRD/compact/CRD_oX_vYY/CRD_o1_vYY.xml
  - Geometry parameters can be flexibly configured

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

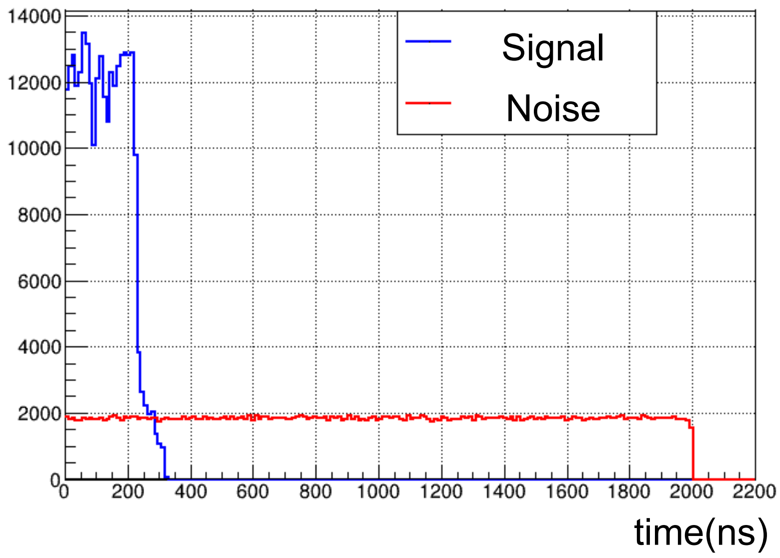
- Cell partitioning with segmentation
  - Consistent between simulation, reconstruction, and analysis
- Simple digitization
  - Constant drift velocity: V_{drift}=40μm/ns & fixed spatial resolution: σ=110μm

Background simulation

- Realized simulation of random background
  - Uniform layer by layer
- Noise level control with job option

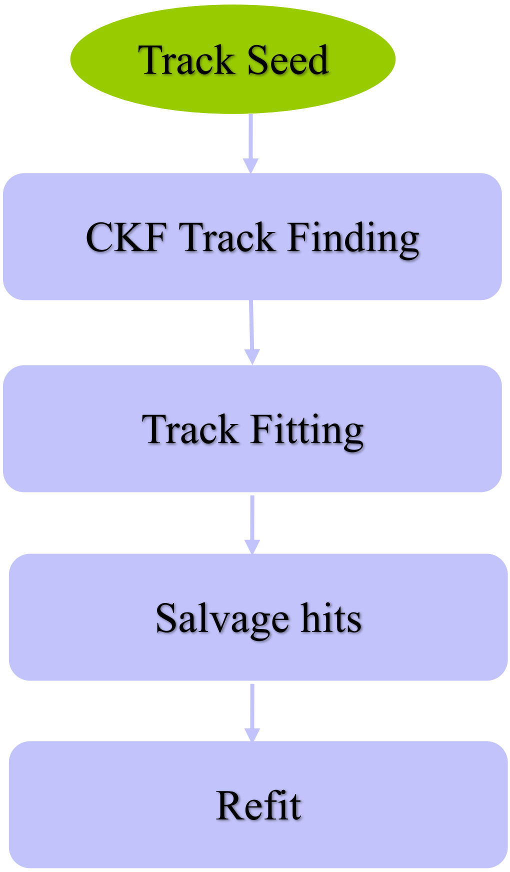


event display with noise level of 20%



Track reconstruction

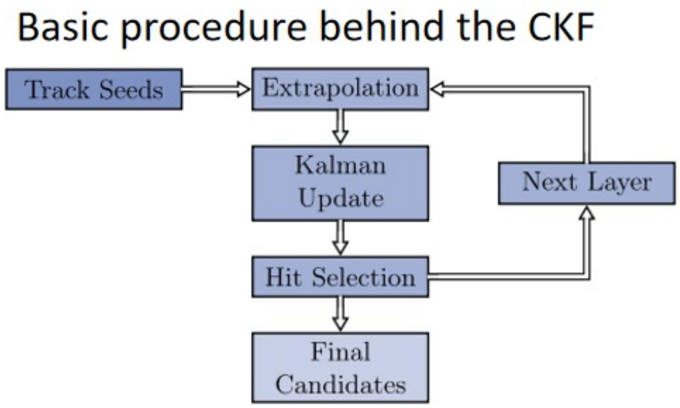
- **Track finding**
  - Track seed: MCParticle or SiTrack
  - Combinatorial Kalman Filter (CKF)
- **Track fitting**
  - Drift Chamber
  - Silicon + Drift chamber
  - Salvage hits

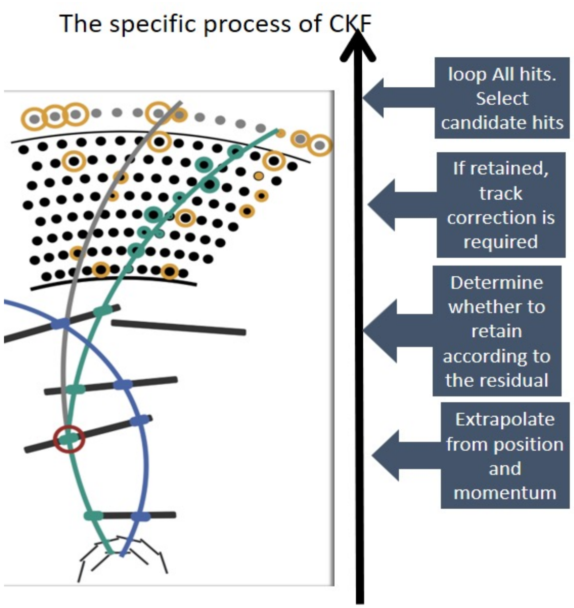


Track Reconstruction flow

Track Finding by CKF

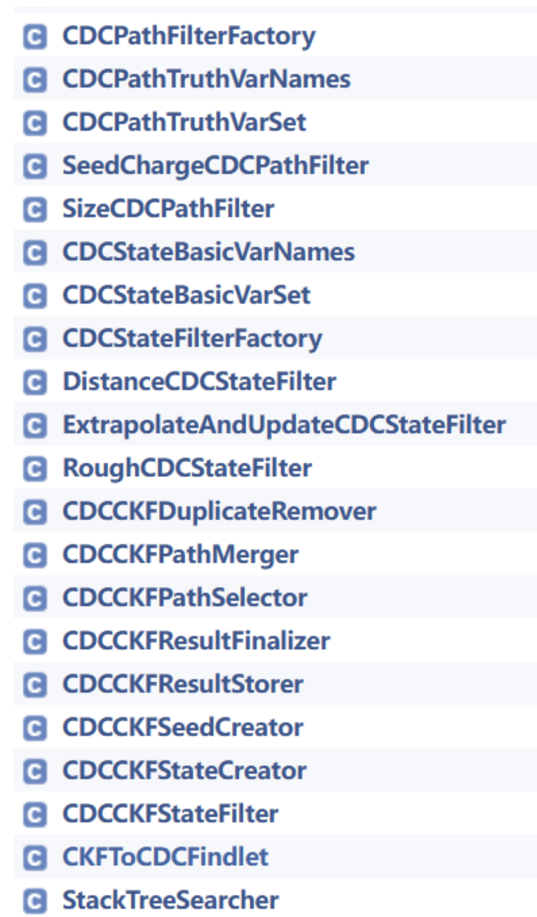
- Combinatorial Kalman Filter (CKF)
  - Combines track finding and track fitting in a search-tree-based algorithm
  - Used by many high energy physics experiments
- Track finding using CKF
  - Take reconstructed silicon track as seed
  - Pick DC hits alone track road by quality of Kalman fitting





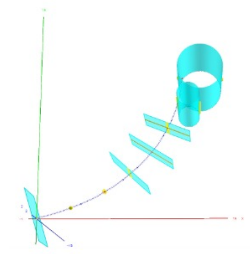
Track Finding by CKF

- Based on the track finding algorithm of Belle II
  - CKFToCDCFindlet(main algorithm)
  - CDCCKFSeedCreator
  - CDCCKFStateFilter
  - …
- Integration with CEPCSW
  - Field: GenfitField
  - Geometry:DD4hep
  - Data io:EDM4hep



Track Fitting

- 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



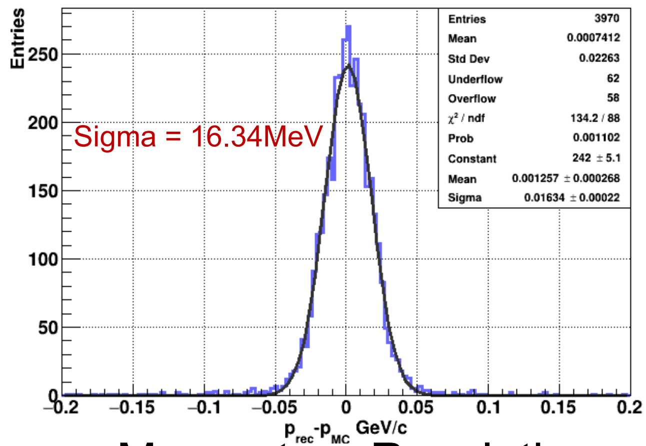
(a) Measurements with covariance (yellow), planar detectors and drift isochrones (cyan), respectively, and reference track (blue).

Track Fitting

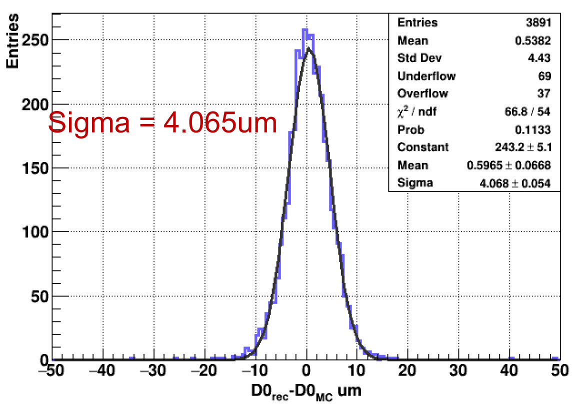
- New implemented of a track fitting with Genfit in CEPCSW
  - Get BField from DD4hep
  - Material and geometry from DD4hep
  - Event data model with EDM4hep
  - A wrapper to the Genfit track and fitters
- RecGenfitAlg
  - Kalman track fitting combine the silicon detector and drift chamber
  - Space point measurement
  - Pixel, strip and wire measurements

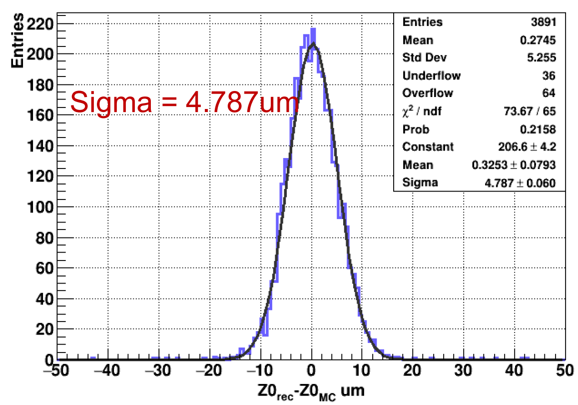
Performance of Track Reconstruction

- Sample:
  - single particle($\mu^-, \theta = 50°$)
  - $p_T = 10GeV$
  - Without noise

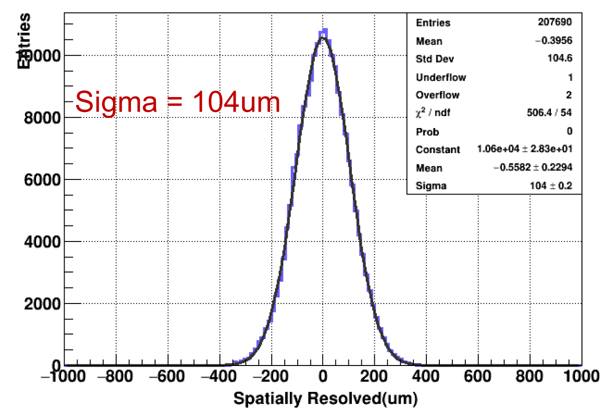


Momentum Resolution





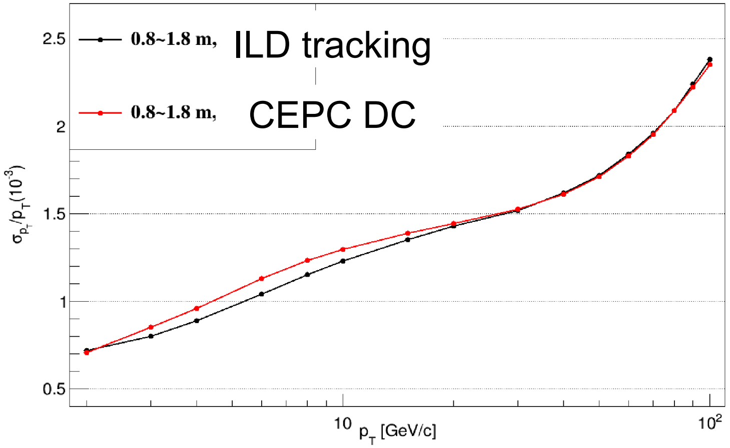
Vertex Resolution



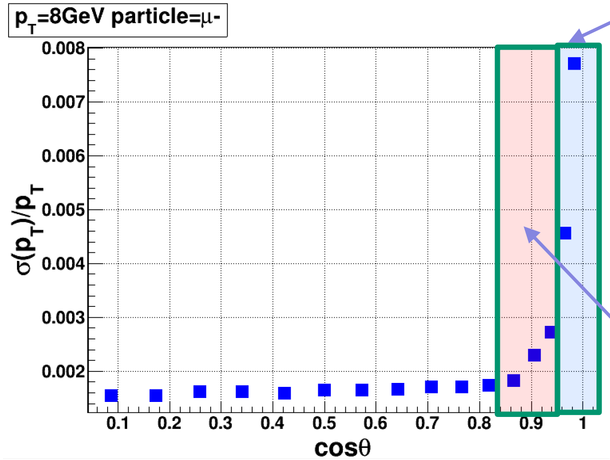
Spatial Resolution

Performance of Track Reconstruction

- Momentum Resolution v.s. $p_T, cos\theta$
- Vertex Resolution v.s. p_T

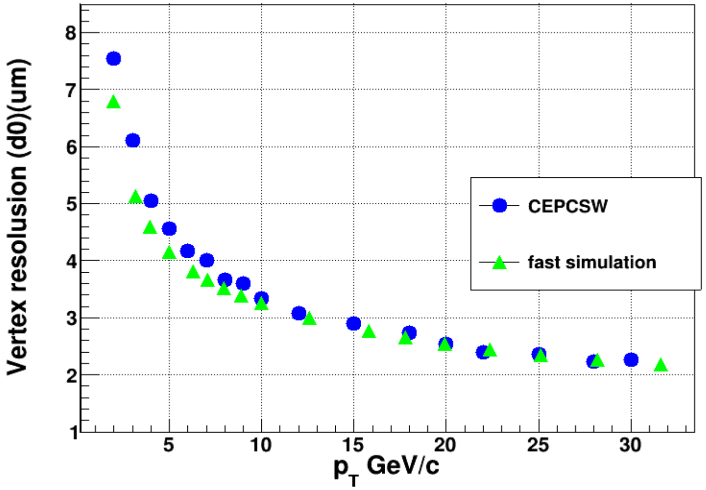


Only silicon is used



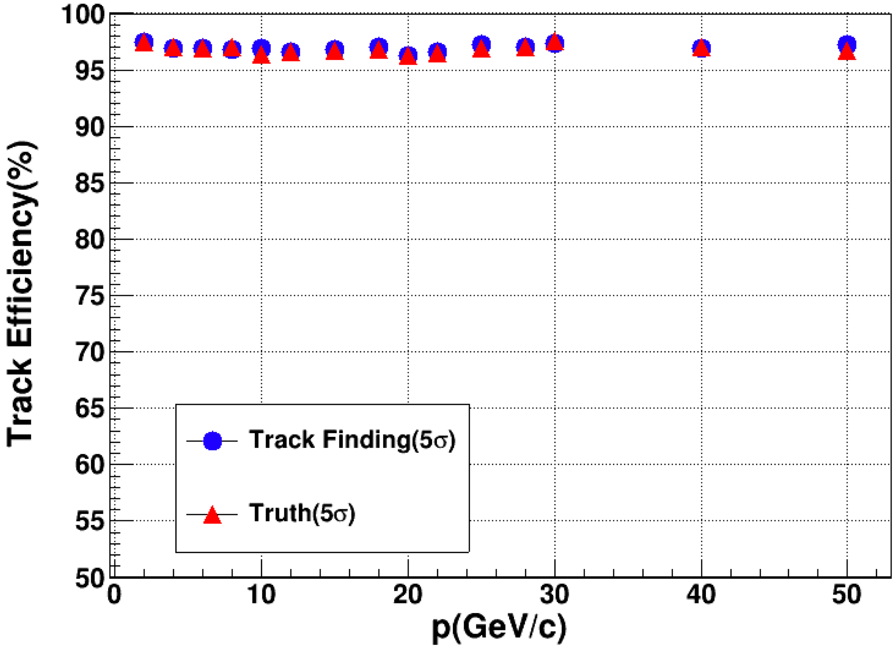
Endcap region

The momentum resolution is reasonable



Performance of Track Reconstruction

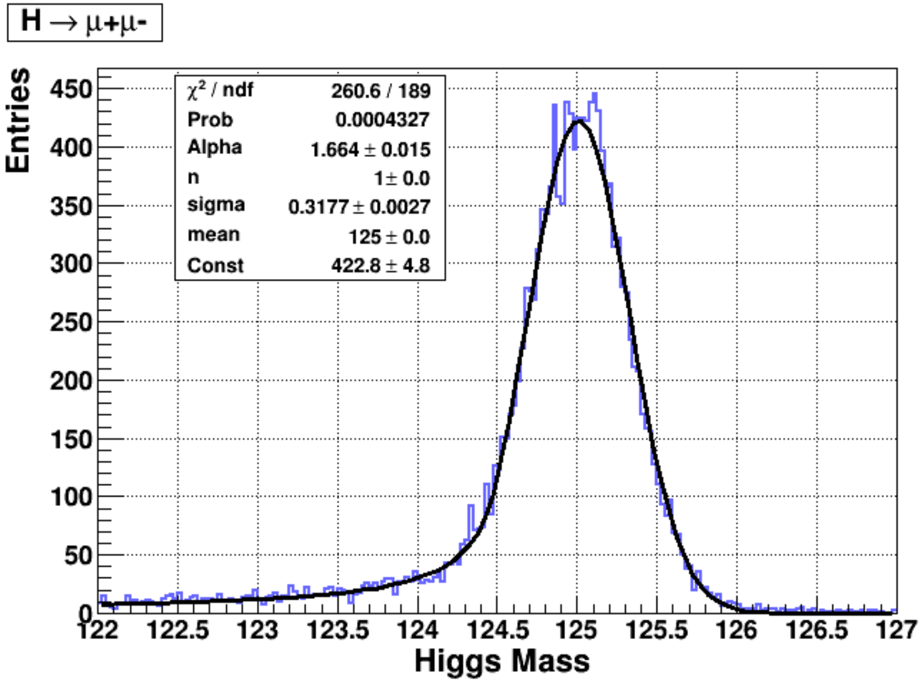
- Sample:
  - single particle($\mu^-, \theta = 50°$)
  - Without noise
- Track Efficiency
  - $(\mathrm{pT_{Rec}} - \mathrm{pT_{MC}}) < 5\sigma_{\mathrm{pT}}$
  - $(\mathrm{D0_{Rec}} - \mathrm{D0_{MC}}) < 5\sigma_{\mathrm{D0}}$
  - $(\mathrm{Z0_{Rec}} - \mathrm{Z0_{MC}}) < 5\sigma_{\mathrm{Z0}}$



➢ The track efficiency is consistent with result using truth

Physical event reconstruction

- Check with Higgs reconstruction from $H \rightarrow \mu^{+}\mu^{-}$
- Can be used for physical event reconstruction



Summary

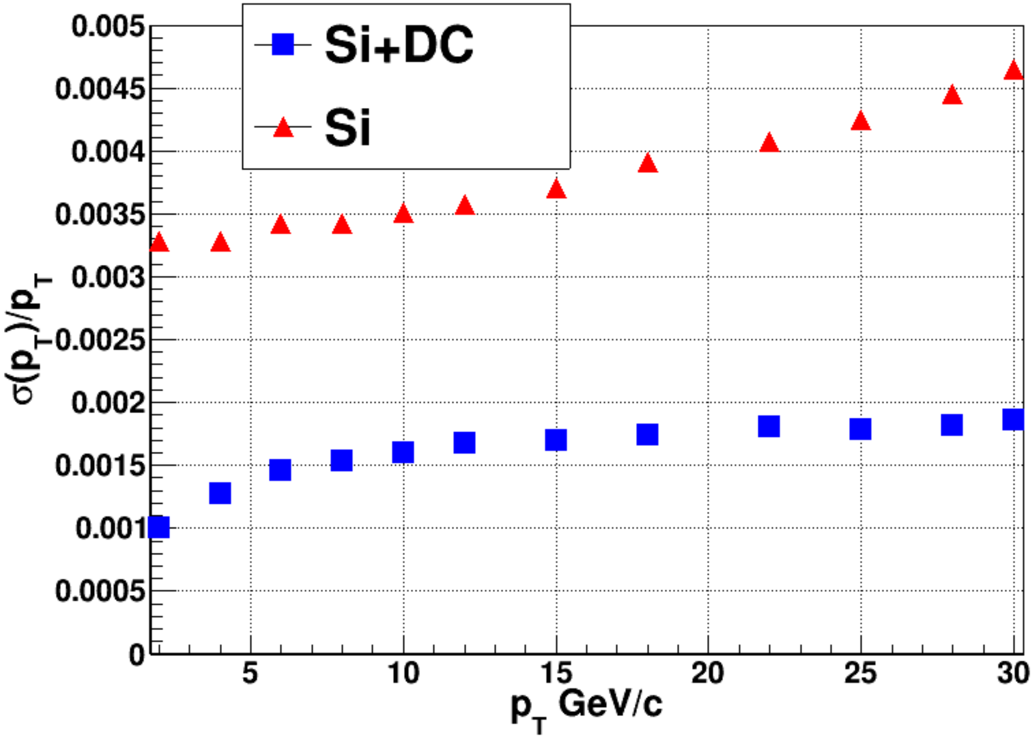
- Developed drift chamber software from scratch.
- Completed the whole process from detector simulation, digitization, tracking to physical event reconstruction.
- Can be used for detector optimization and physical analysis.

Thank you for your attention!

Back up

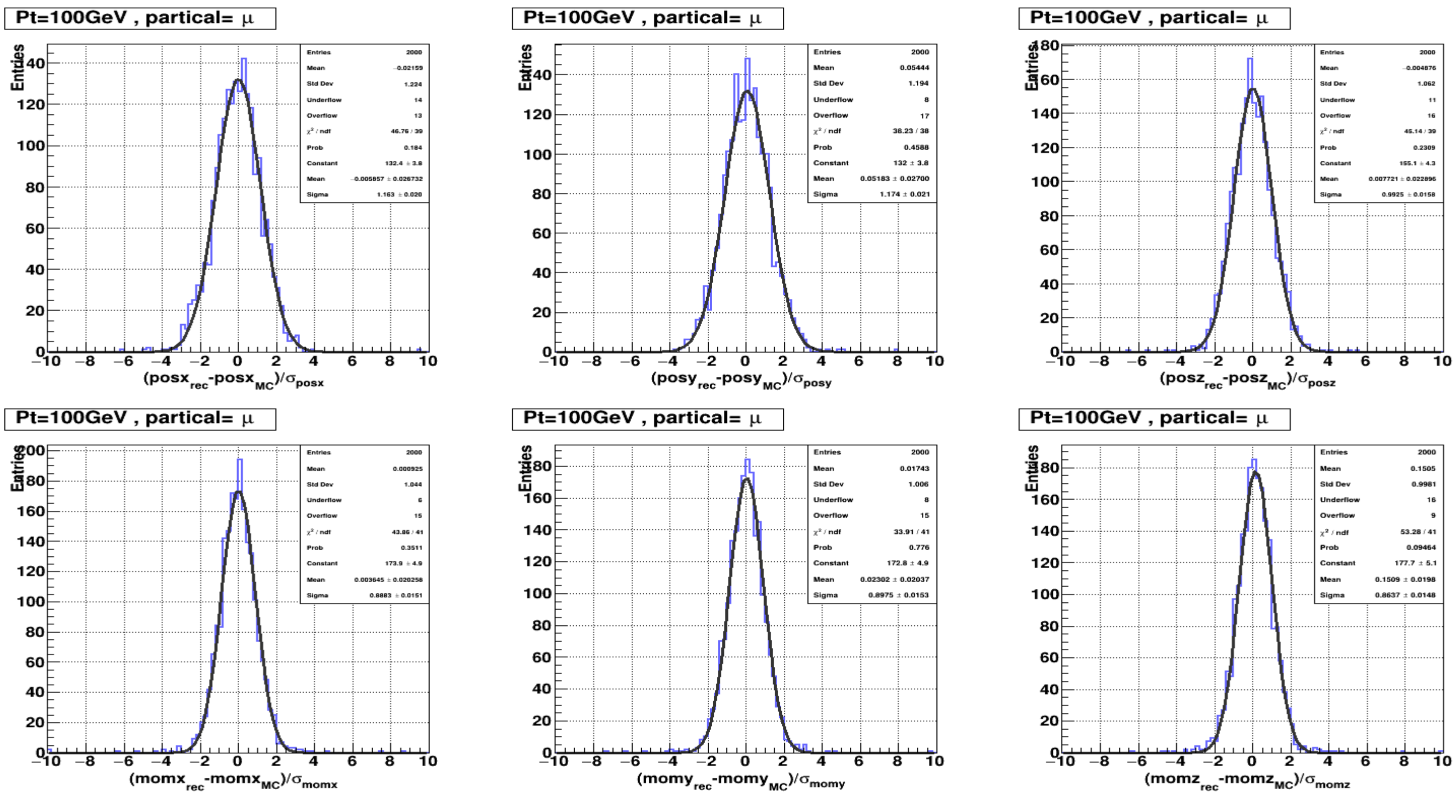
Silicon+DC vs Silicons

- Got better momentum measurement with the drift chamber



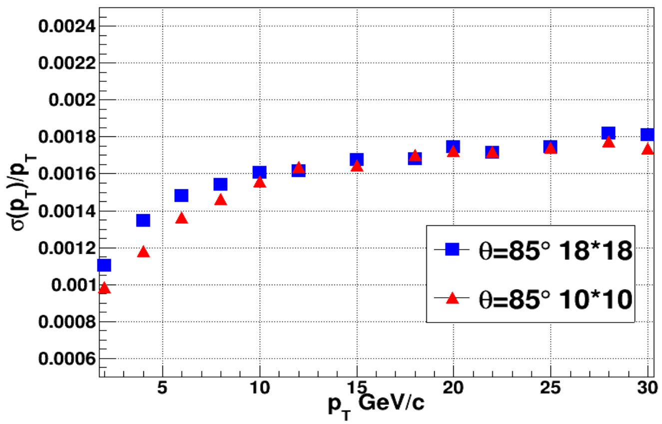
Single track performance validation

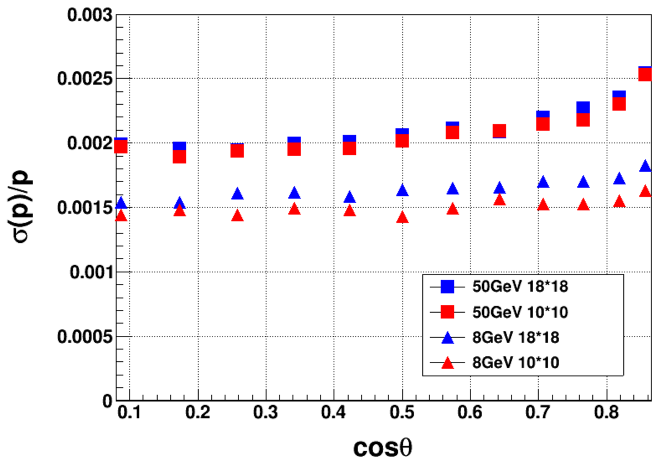
- Track parameters pull distribution is reasonable



Momentum resolution check

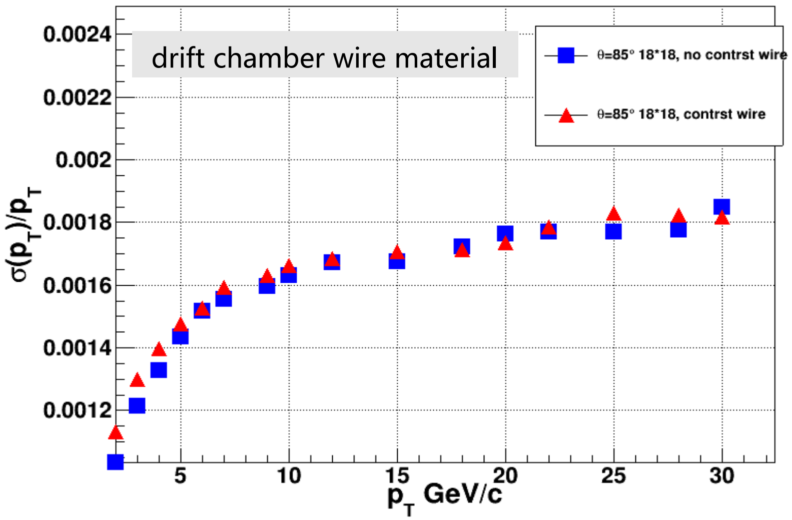
- Two cell size setups are studied
  - 10mmx10mm and 18mmx18mm

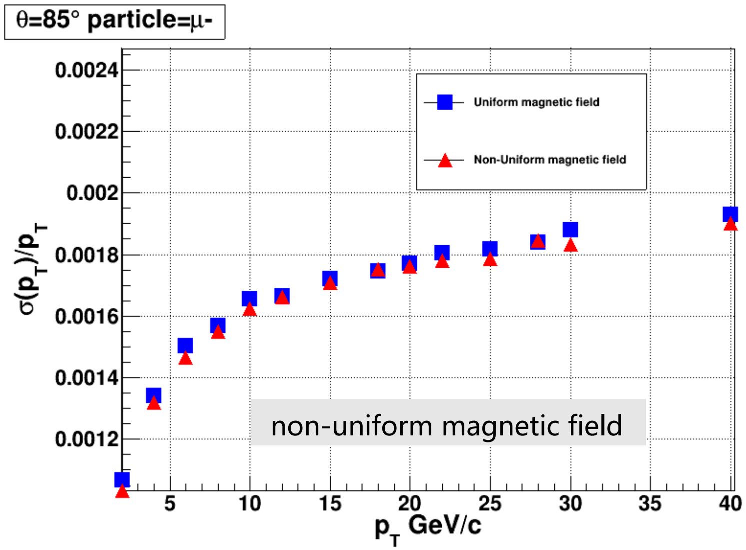




- Almost no effect on high momentum region

Momentum resolution check

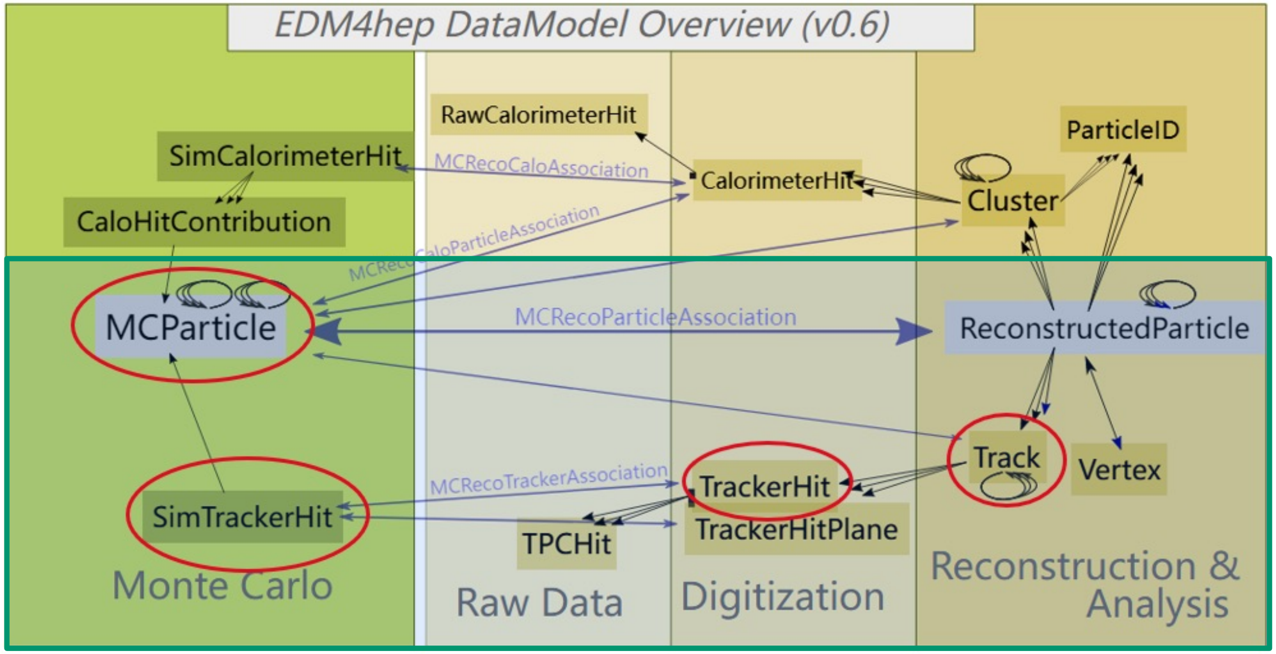




- drift chamber wire material : Small effect on low momentum region(pT<5GeV)
- Almost no effect after using non-uniform magnetic field

Event Data Model

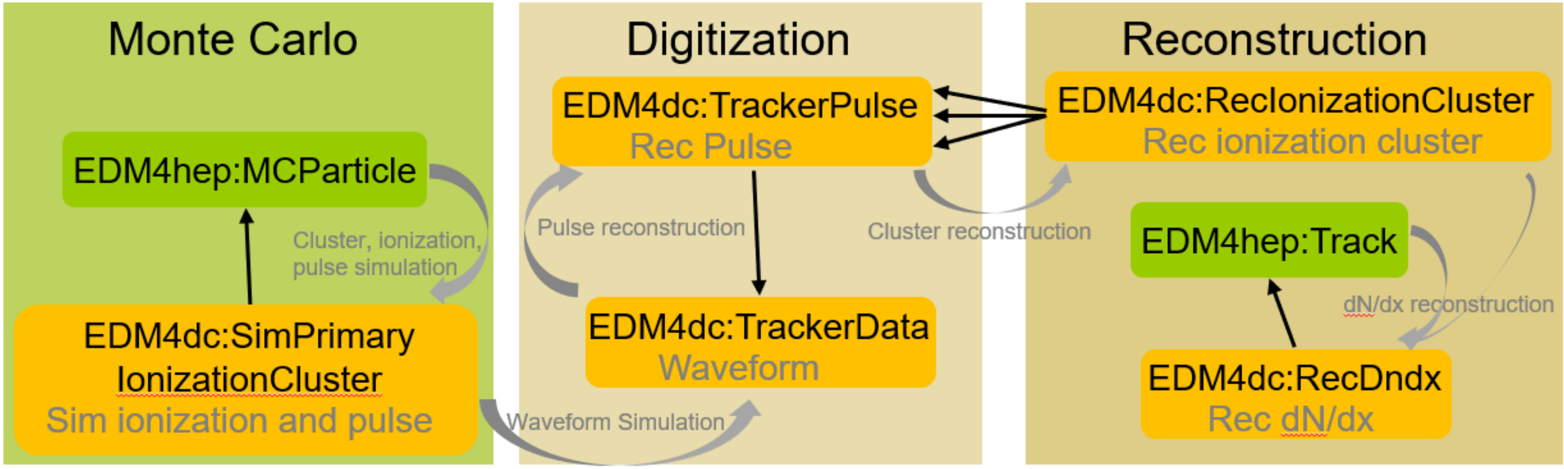
- DC implements the data model following the EDM4hep (commonly used by ILC, FCC, CEPC, CLIC, ...)



- For drift chamber track simulation and reconstruction: MCParticle, SimTrackerHit, TrackHit, Track

EDM4hep Extension

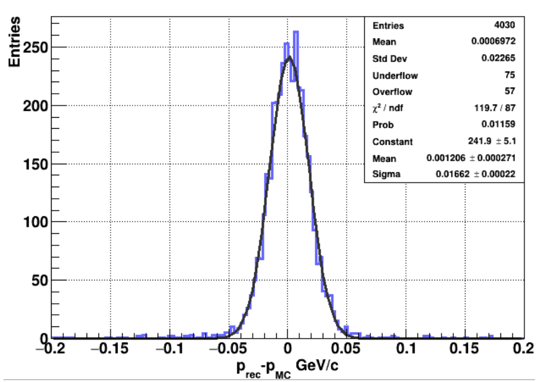
- Extending the EDM4hep:
  - To facilitate dN/dx study: simulation and reconstruction
  - The extended EDMs are general and can be used both for the drift chamber and the TPC
  - Have been merged into EDM4hep

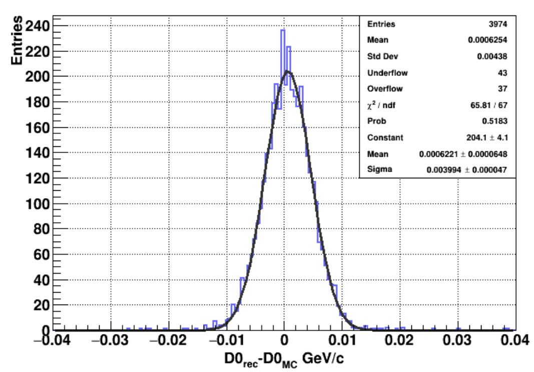


TrackFinding Performance

➢ With Noise

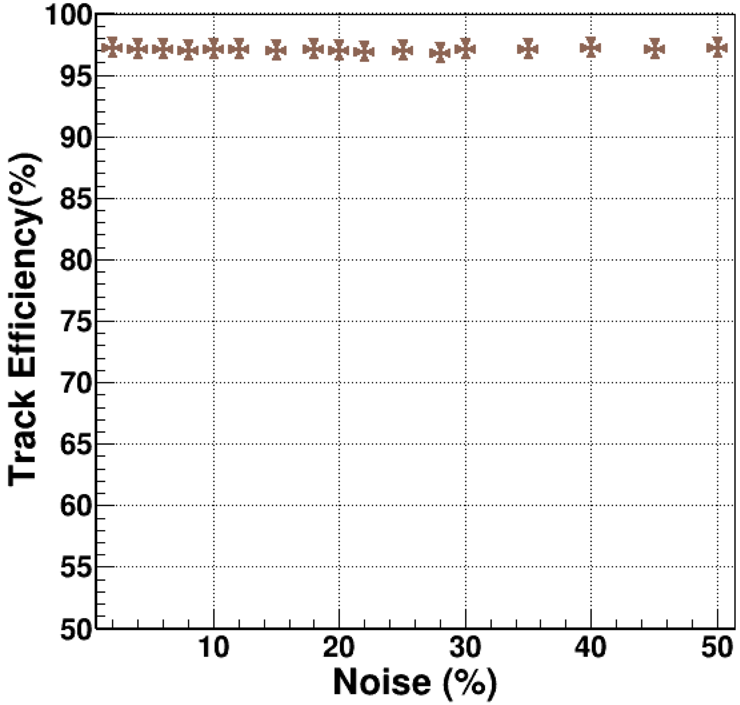
- Sample: singal particle(μ^-, θ=50$^{\circledcirc}$,p_T=10GeV)
- Momentum resolution:16.62MeV
- Vertex resolution: 3.994um
- Fitting track effiency($= \frac{\text{Num}_{\text{rec}}}{\text{Num}_{\text{truth}}}$) v.s. noise level
- The fitting track efficiency remains at 97%





Performance of Track Reconstruction

- Sample:
  - single particle($\mu^-, \theta = 50°, p_T = 10GeV$)
  - *With noise*
- Track Efficiency
  - $(\mathrm{pT_{Rec}} - \mathrm{pT_{MC}}) < 5\sigma_{\mathrm{pT}}$
  - $(\mathrm{D0_{Rec}} - \mathrm{D0_{MC}}) < 5\sigma_{\mathrm{D0}}$
  - $(\mathrm{Z0_{Rec}} - \mathrm{Z0_{MC}}) < 5\sigma_{\mathrm{Z0}}$



➢ Track efficiency is not affected by background

TrackFinding Performance

- Track finding efficiency$(=\frac{N_1}{N_2})$ v.s. p_T
  - N2: number of McParticle
  - N1: $(\frac{N_{FoundSingalHit}}{N_{SingalHit}})$>50%
- hit efficiency $(=\frac{N_{FoundSingalHit}}{N_{SingalHit}})$ v.s. p_T
- Sample: singal particle(μ^-, θ=50$^{\circledcirc}$)
- Without noise
- Track finding efficiency is basically maintained at 100%
- Low-momentum particle track in circles lead to low hit efficiency