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Track Reconstruction and Performance on CEPC Drift Chamber

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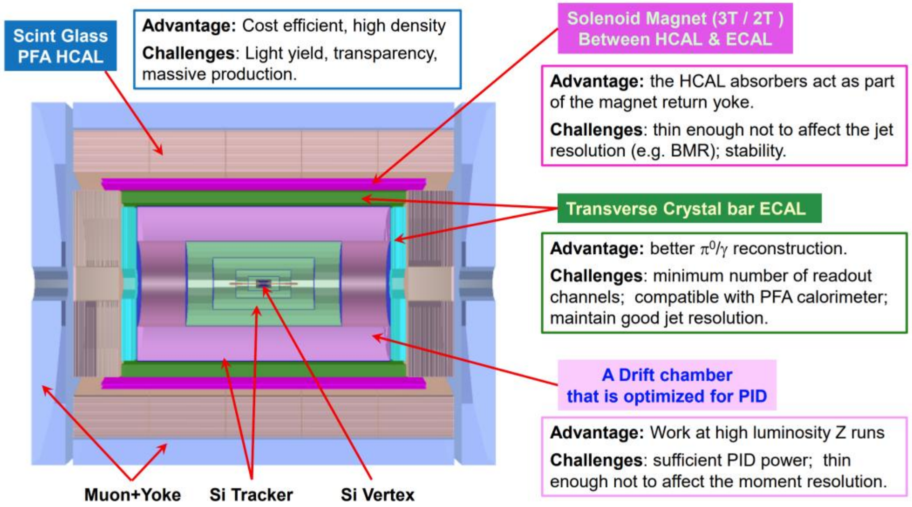
Detector Design

- The CEPC is a 100 km circular electron-positron collider aiming to
  - precisely measure the property of the Higgs boson
  - study electroweak physics at Z-boson peak
- Detailed performance requirements can be found in the CEPC CDR and tracking part includes
  - High track efficiency (~100%) and momentum resolution (~0.1%)

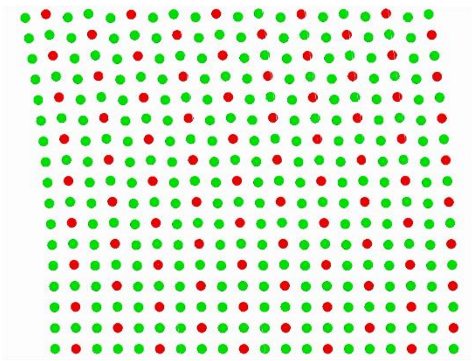


- The 4th conceptual detector was proposed on the basis of the CEPC CDR
  - is characterized by a combination of silicon detectors and drift chamber (DC) designed to provide both tracking and PID for charged particles
- Software development of the DC simulation and track reconstruction is critically important
  - Both detector design and physics potential studies need strong support from simulation and reconstruction

Drift Chamber

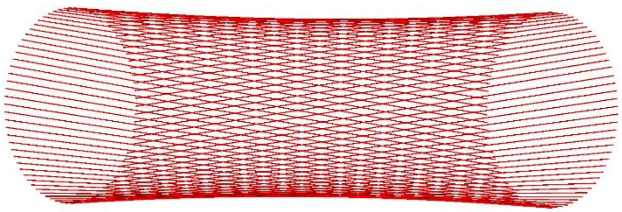
- The drift chamber covers
  - radial range from 800 mm to 1,800 mm
  - Z range from -2,980 mm to 2,980 mm
- Small cell design is chosen to obtain enough number of track hits at the outer radius
  - purely made of stereo wires
  - any two neighboring layers are offset by half a cell for solving the ambiguity
  - the wires on any two neighbouring layers tilt in opposite directions
  - organized into 55 co-axial layers
- The working gas is
  - a mixture of helium and C_4H_{10} with a mixing ratio of 90:10
  - to minimize multiple scattering
- Both inner and outer cylinders are made of carbon fibre

Geometry Parameters	Value
Half length	2980 mm
Inner and outer radius	800 mm ~ 1800 mm
The number of layers	55
Cell size	18 mm × 18 mm
Gas	90%He+10%C_4H_{10}
Single wire resolution	110 μm
Sense to field wire ratio	1:8
Total number of sense wire	25,357
Stereo angle	0.028 rad~0.062 rad
Sense wire	Gold plated Tungsten ϕ = 20 μm
Field wire	Silver plated Aluminum ϕ = 40 μm
Wall	Carbon fiber 0.2 mm(inner) and 2.8 mm(outer)



$r - \phi$ projection of a proportion of the first 10 layers of wires

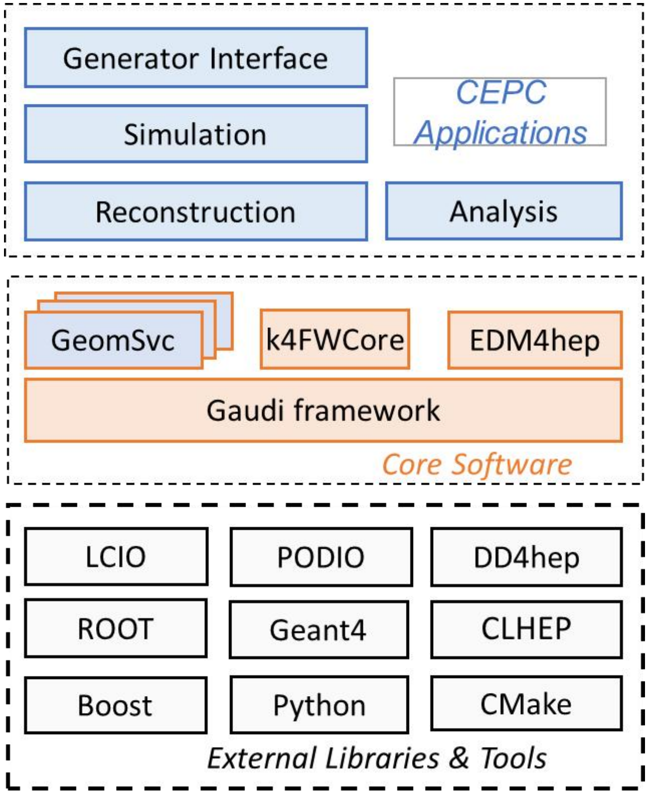
Sense wires of each layer forms a rotating hyperboloid surface



CEPCSW Software Structure

- CEPCSW software structure
  - Applications: simulation, reconstruction and analysis
  - Core software
  - External libraries

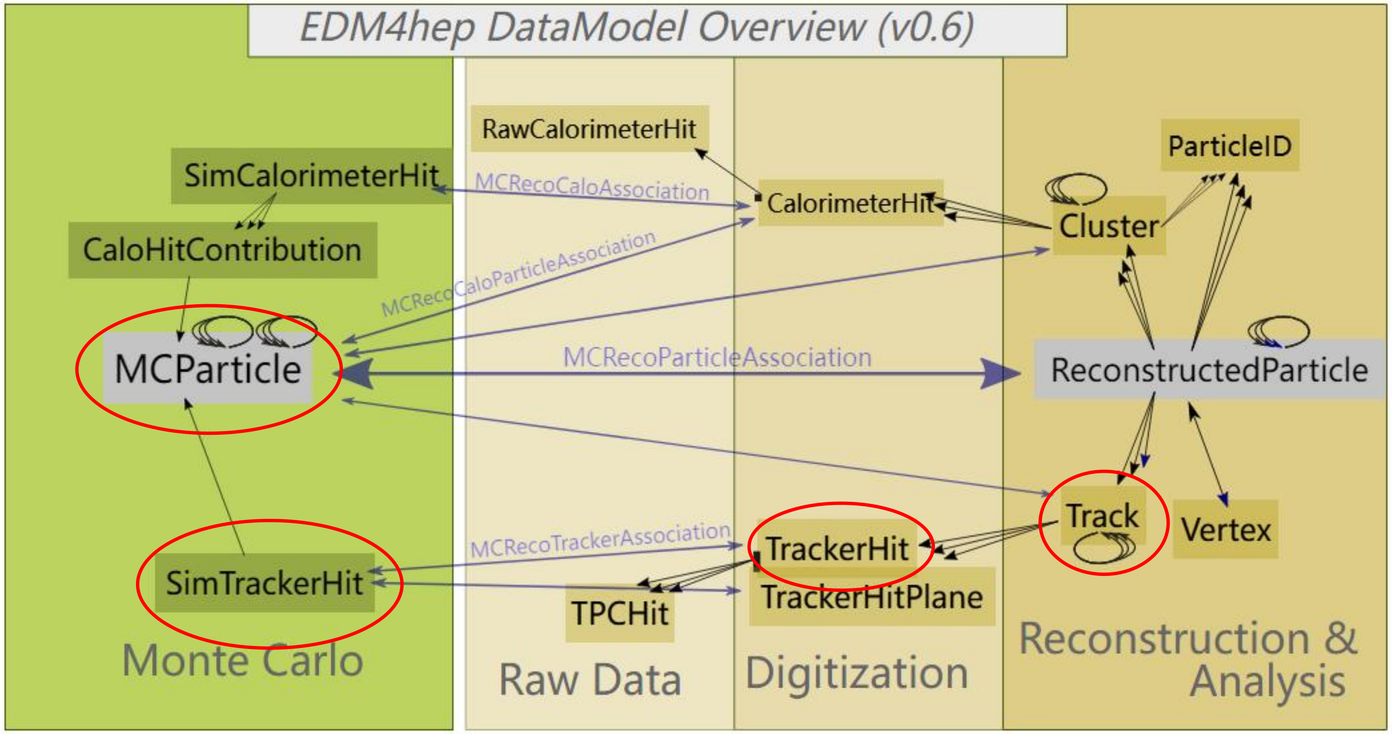
https://code.ihep.ac.cn/cepc/CEPCSW



- Core software
  - Gaudi/Gaudi Hive: defines interfaces to all software components and controls their execution
  - EDM4hep: generic event data model
  - k4FWCore: manages the event data
  - DD4hep: geometry description
  - CEPC-specific components : GeomSvc, detector simulation, beam background mixing, fast simulation, machine learning interface, etc.

Event Data Model (1)

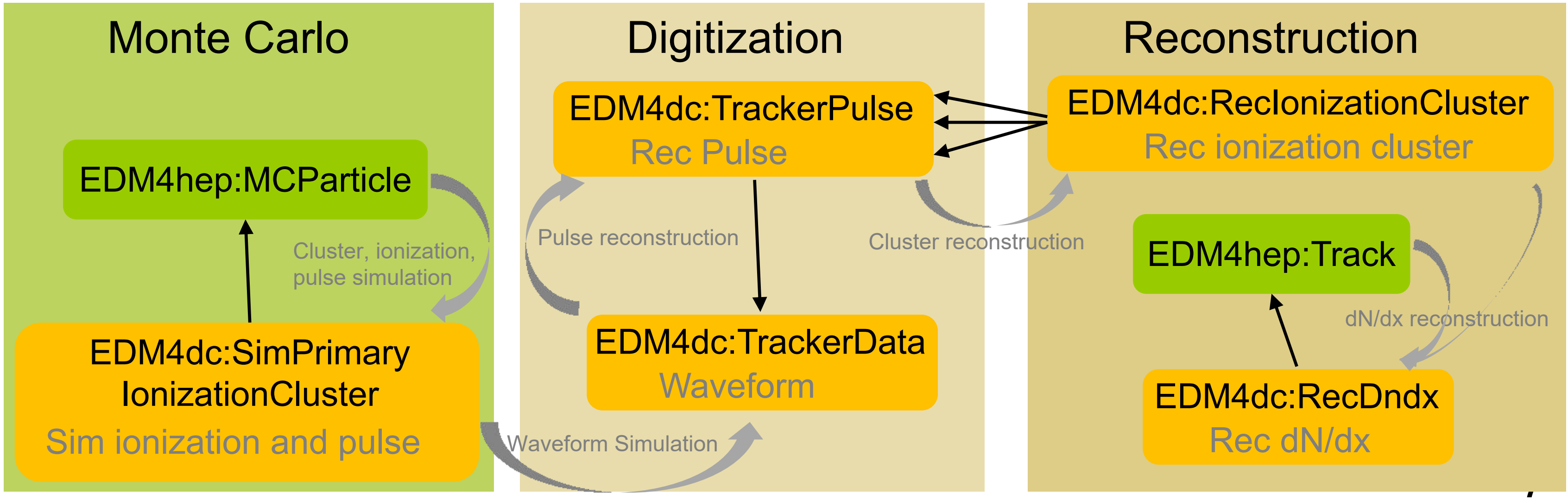
- EDM4hep is the common event data model (EDM) being developed for the future experiments like CEPC, CLIC, FCC, ILC, etc.



- EDM4hep describes event objects created at different data processing stages and also reflects the relationship between them.
- For the drift chamber, MCParticle, SimTrackerHit, TrackHit, Track have been used since the begin of the software project.

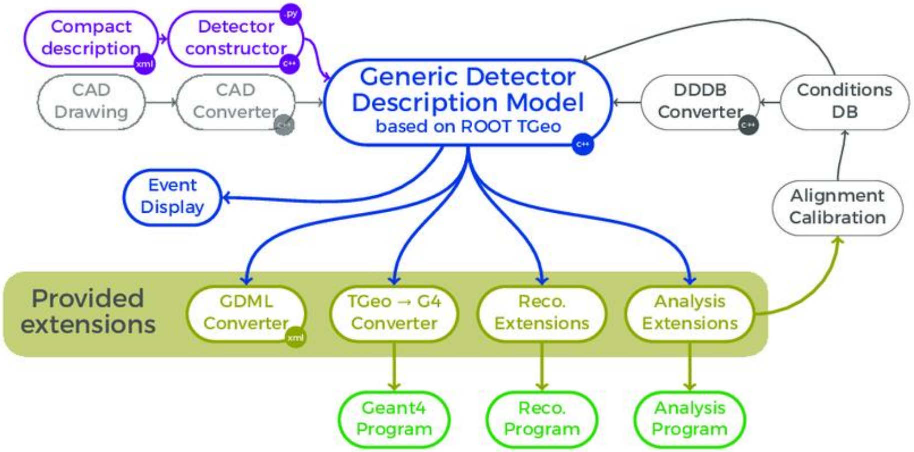
Event Data Model (2)

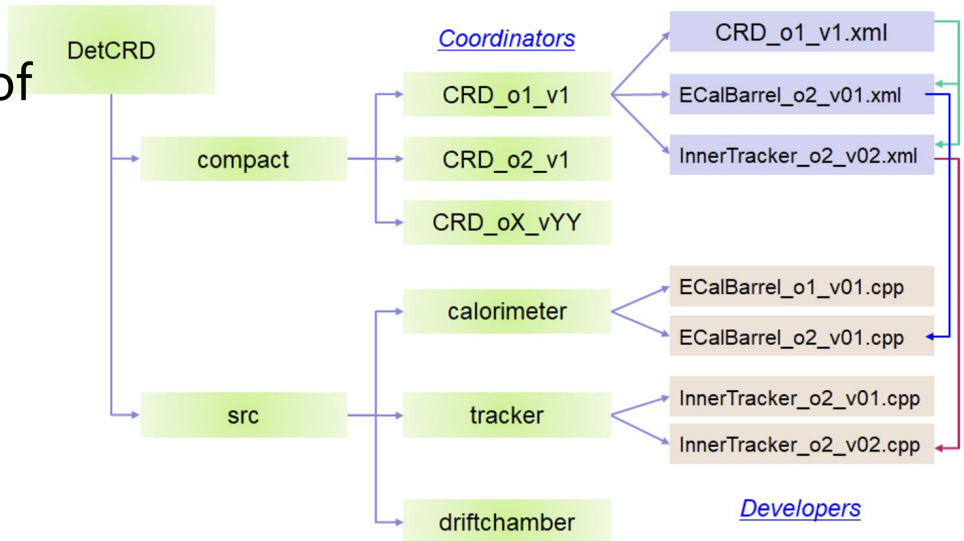
- As the development progressed, the previous versions of EDM appeared not able to fit all the requirements brought by newly added detector like the CEPC’ s drift chamber.
- Due to the strong flexibility of EDM4hep, TPCHit was extended to accommodate the new needs:
  - Discussions inside EDM4hep group and also with the IDEA-CEPC drift chamber working group
  - By using the upstream mechanism of PODIO, a common EDM was implemented for both TPC and drift chamber



Detector Description

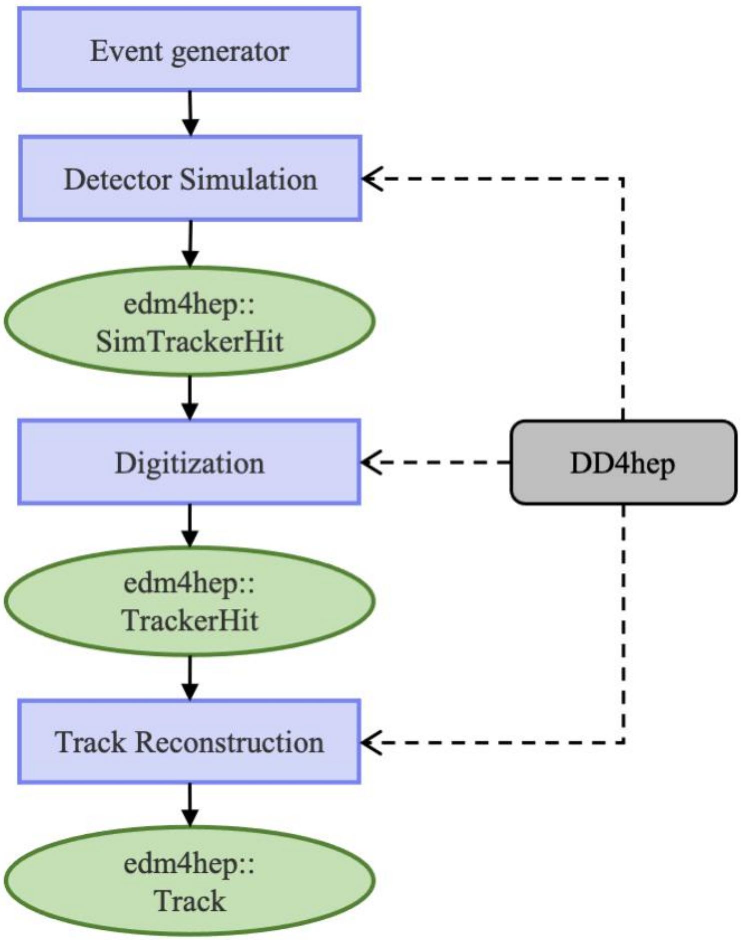
- DD4hep was adopted to provide a full detector description, which was generated from a single source (XML files)
  - Detector/DetCRD/compact/CRD_common_v01/DC_Simple_v01_05.xml
- The control of geometry version can be easily achieved just by versioning the changes to the set of XML files
- Different detector design options are managed in the Git repository and a simulation job can be easily configured in runtime
- The non-uniform magnetic field was also implemented in CEPCSW





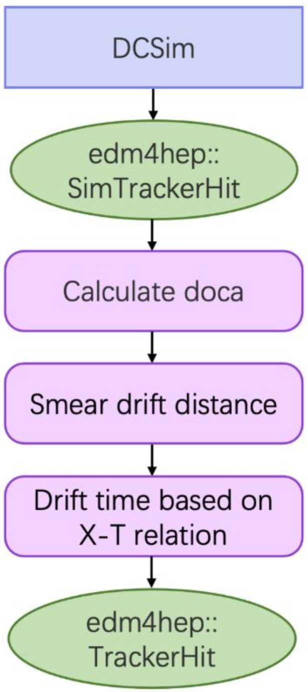
Data Processing Flow

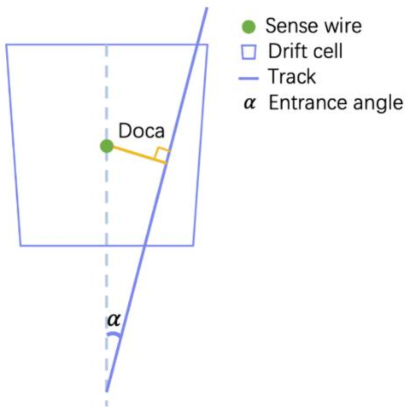
- **Event generation**
  - produces a list of particles each of which is generated from a single interaction with a vertex located at the geometric origin
- **Detector simulation**
  - generated events are passed into the simulation where each particle is propagated through the detector using Geant4.
- **Digitization**
  - the response of the elementary detector modules is modelled
  - Besides Monte Carlo (MC) hits from signal event, the digitization also takes hits from background events as its input
- **Reconstruction**
  - reads in charge or/and time information and generates tracks and showers for tracking detector and calorimeter, respectively



DC Simulation (1)

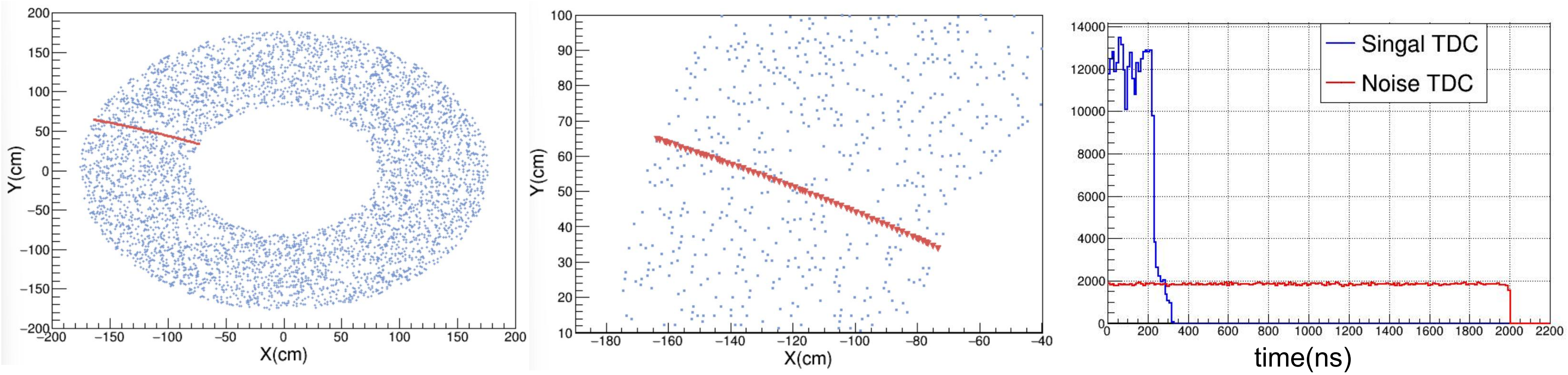
- In CEPCSW, the Geant4 run manager is wrapped by a Gaudi service
  - enabling the Gaudi to control the event loop of the simulation
  - initializing geometry, physics lists and user actions
  - providing standard user interfaces for interacting with Geant4
- Owing to the simulation service, what needs to be implemented for the drift chamber is
  - only its detector geometry and detector response
- Simplified digitization method was implemented to support the development of tracking algorithm
  - When the particle enters a drift cell, the distance between every Geant4 step and the sense wire of the cell is recorded
  - The smallest distance is regarded as Doca, the closest approach of the particle trajectory to the sense wire
  - The Doca is smeared using a Gaussian function with a width equivalent to the wire resolution (110μm)and converted to drift time based on X-T relation
  - Wire efficiency: 100% , Constant drift velocity: V_{drift}=40μm/ns





Mixing Background

- To simulate the real detector condition
- Noise level:
  - uniform, random
  - can be configured flexibly
- Signal & Noise time
  - noise time window: 0~2000ns



The position of the noise hit (blue) and signal hit (red) on the XY plane with a noise level of 20%

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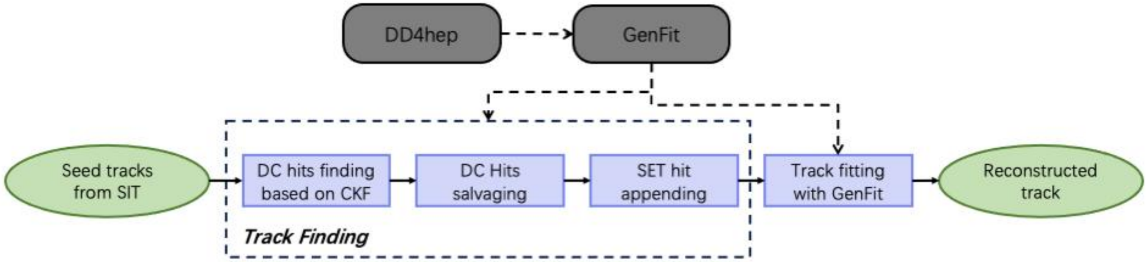
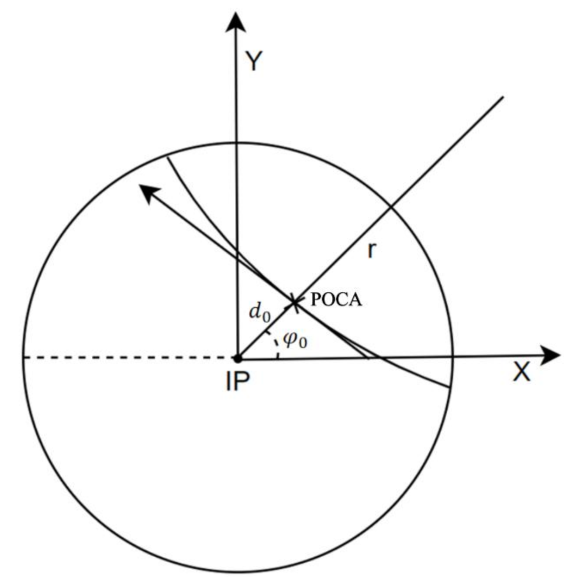
Track Reconstruction(1)

- Tracking with Combinatorial Kalman Filter (CKF) method
  - Combining track recognition and track fitting
- Implementation of track finding with CKF was based on the code of Belle II experiment
  - Conversion of event data between different representations:
    - CKF and EDM4hep (track finding)
    - GenFit and EDM4hep (track fitting)
  - Track segments reconstructed in the silicon detector, called seed tracks, are extrapolated to the DC and all the DC hits belonging to the track are collected
- Track fitting with the tool of Genfit
  - An experiment-independent framework for track reconstruction
  - Contains a Kalman Filter, a Deterministic Annealing Filter, and a General Broken Lines fitter
  - Developed in the PANDA and has also been used by the Belle II, Fopi, and GEM-TPC experiments.



Track Reconstruction (2)

- Track parameterization
  - $P \equiv (d_0, \varphi_0, \omega, z_0, tan\lambda)^T$
  - $p_T > 0.8GeV$, eliminating the possibility of multiple circular tracks
  - Helix parameters at the first hit, to accurately describe the track of charged particles

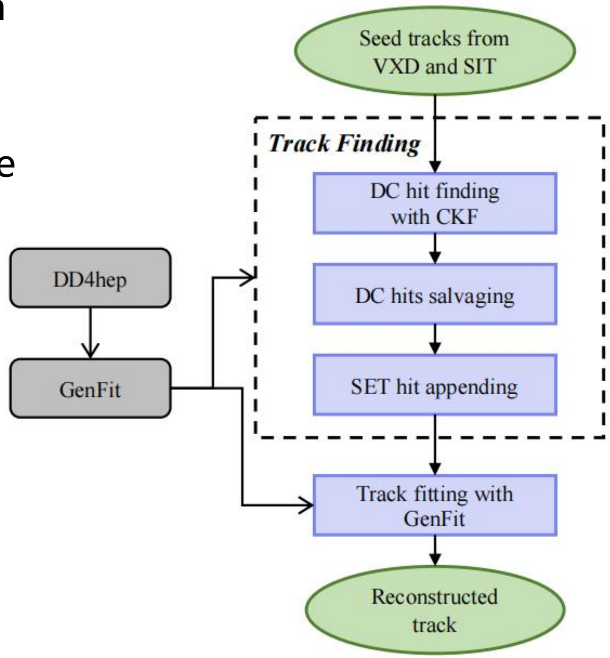


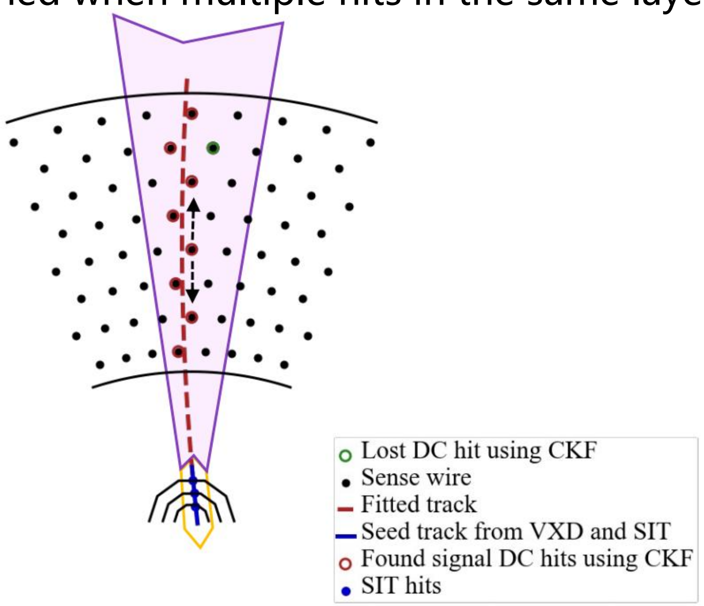
- Access to detector geometry and magnetic field:
  - CEPCMagneticFieldProvider:
    - Inheriting AbsBField of GenFit
    - Providing the magnetic field map at specific positions by integrating with DD4hep
  - CEPCMaterialProvider:
    - Inheriting AbsMaterialInterface of GenFit
    - Obtaining the geometry parameters and material based on GeomSvc

Track Finding

❖ Hits finding

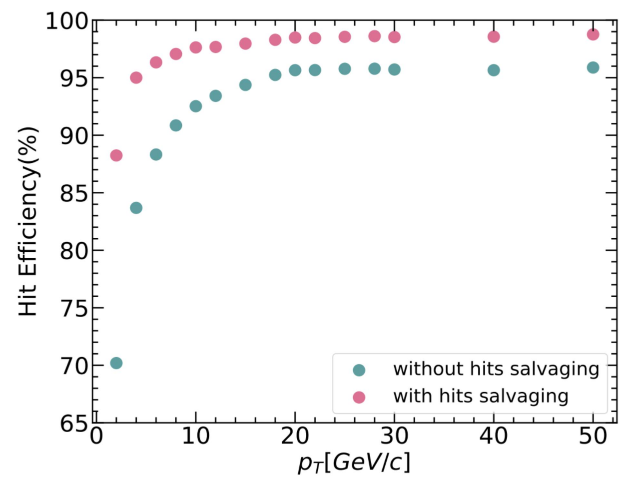
- Based on CKF
- Extrapolation starts from a seed track, consisting of a least 3 space points, found in the silicon detector (VXD+SIT)
- Iteratively searching for hits and collecting hits in the outer neighbouring layer
- Extrapolated track length, the number of hits, chi2, etc
- Limitation: due to tight conditions, only one hit remined when multiple hits in the same layer



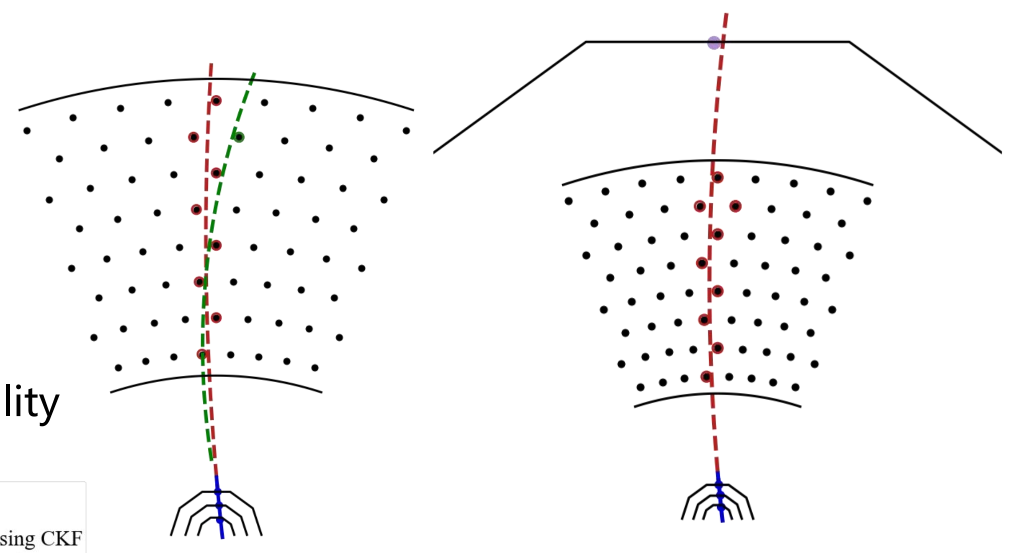


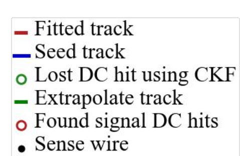
Track Finding

- Hits salvaging
  - Fully self-developed
  - The supplement to the hit finding algorithm
  - Hits are examined again to determine its association with the current track according to track length and doca
  - Improving track quality and hit efficiency(ϵ)
    - $\epsilon = \frac{N_{found\ signal\ hits}}{N_{truth\ signal\ hits}}$



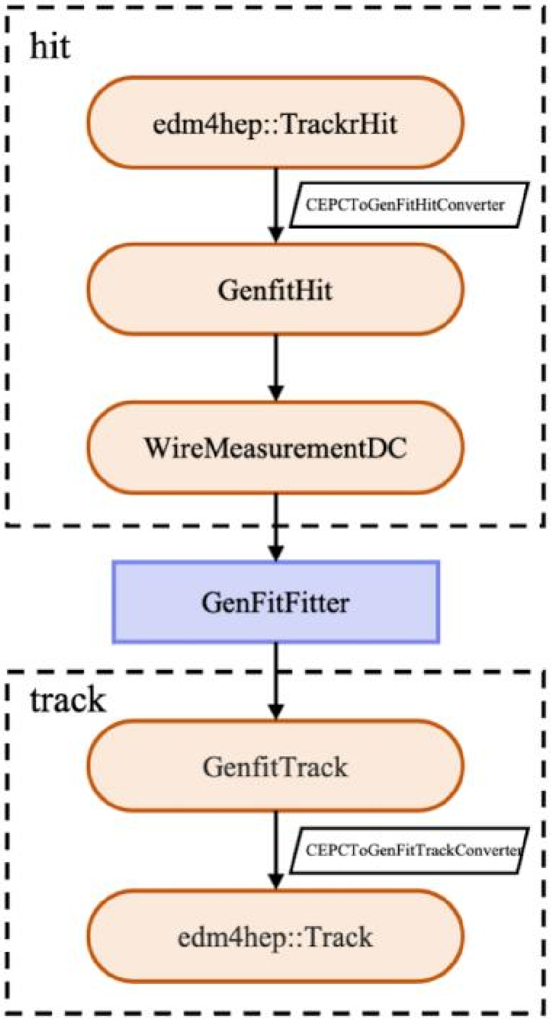
- Hits appending
  - Extrapolating to the SET plane
  - $(Pos_{extra} - Pos_{truth}) < 3\sigma$
  - enhancing the accuracy and reliability





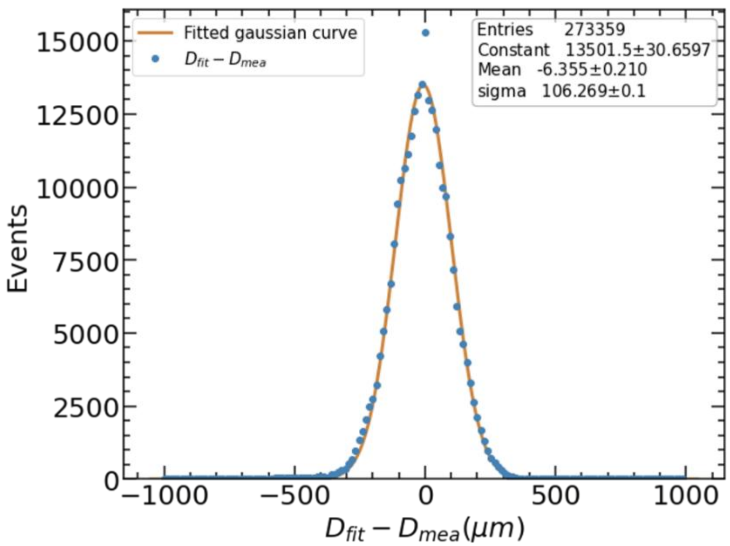
Track Fitting

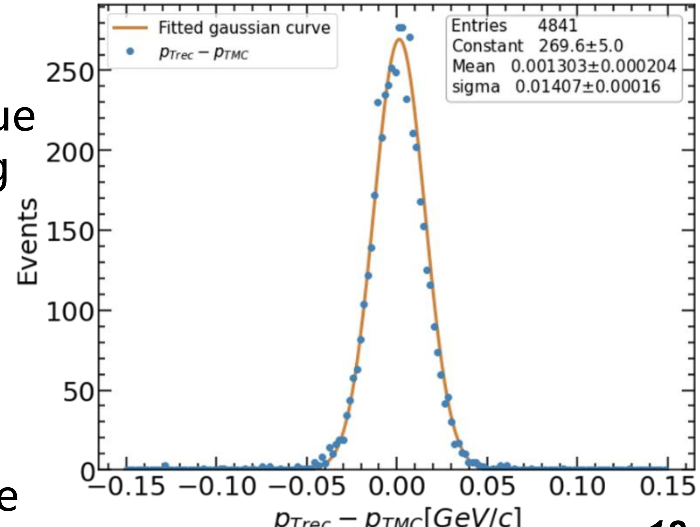
- Based on the GenFit package
- Integration of CEPCSW with GenFit
  - CEPCToGenFitHitConverter:
    - creating a GenfitHit object based on TrackerHit
    - as the input of track fitting
  - WireMeasurementDC:
    - Inheriting from WireMeasurement
  - GenfitFitter:
    - Inheriting from AbsKalmanFitter, is used to call the fitter in the GenFit package
    - Enabling the configuration of the magnetic field, material effects, and fitter type
  - CEPCToGenFitTrackConverter:
    - Storing the results of the track fitting, including fit status(χ^2, NDF, p-value, track length, etc.)
    - Constructing a Track object as the output



Performance(1)

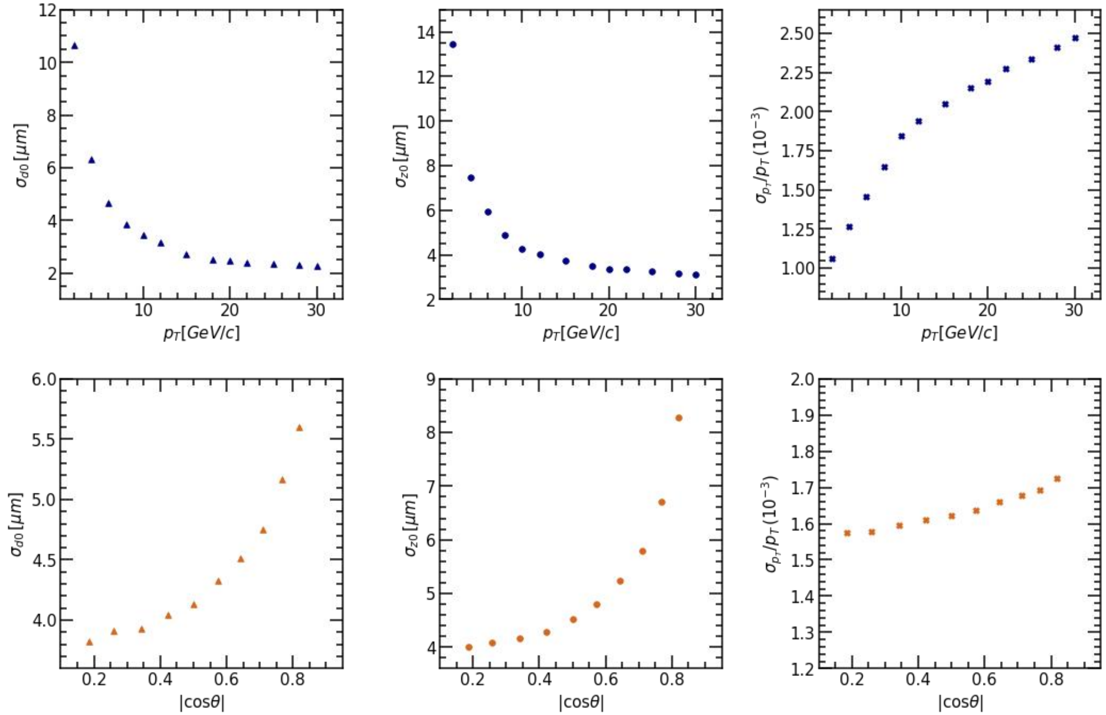
- Single particles:
  - $(e^-, \mu^-, \pi^-, K^-, p)$:
    - $p_T \in [2,\ 50]\ GeV$
    - Polar angle: $|cos\theta| < 0.776$
    - Azimuthal angle: $\phi \in [-\pi\ ,\ \pi\ ]$
- Spatial resolution
  - Single μ^- with 10 GeV
  - Spatial resolution: 106 μm
  - Slightly below the set value of 110 μm, due to the method of fitting tracks containing measurement points
- Momentum resolution
  - Single μ^- with 10 GeV
  - A resolution of 14 MeV which satisfies the requirement in CEPC CDR (per mille level)





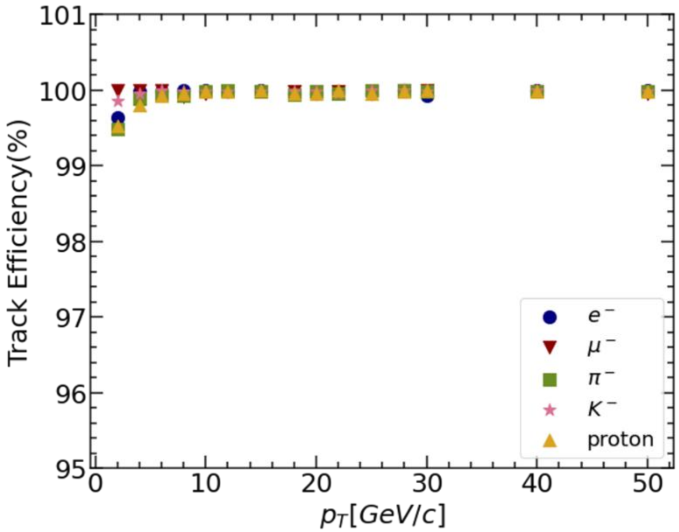
Performance (2)

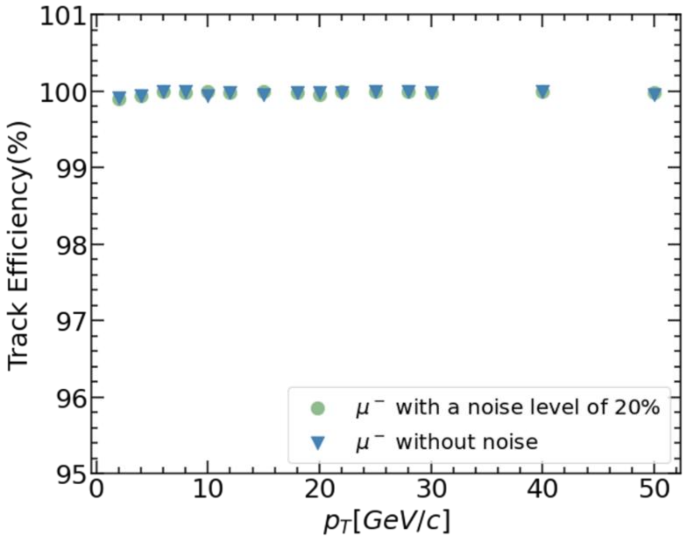
- Track parameters resolution
  - Due to material effects, σ_{d0} & σ_{z0} are worse at low transverse momentum and large $|cos\theta|$.
  - At low momentum regions, multiple scattering dominates.
  - At high momentum regions, the resolution of p_T is determined by the single-point resolution of the track, leading to worse of resolution with increasing p_T .



Performance (3)

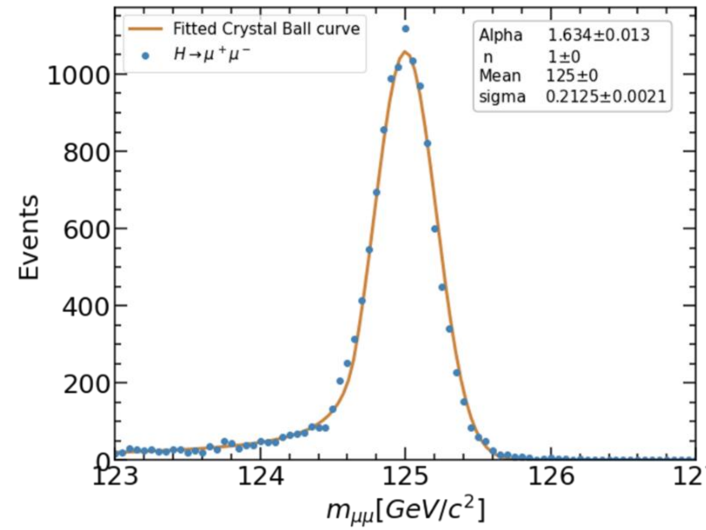
- Tracking efficiency ε_{track}:
  - $\varepsilon_{track} = {N_{rec}}/{N_{seed}}$
    - N_{rec}: the number of good-track, good-track: $\chi^2 < 400$ and the number of DC hits > 6
    - N_{seed}: the number of the satisfactory seed tracks, which are successfully reconstructed with VXD and SIT
  - Tracking efficiency as the function of measured p_T for different types of particles
    - all types particles above 99.5%
  - Tracking efficiency vs p_T for single μ – with/without adding 20% noise
    - remaining consistently above 99.8%
    - good stability and robustness
  - Multi-tracks:
    - Preliminary research is done
    - The MC events have an average of 10 tracks with an average momentum of 2 GeV. The tracking efficiency of 99.6% is obtained.

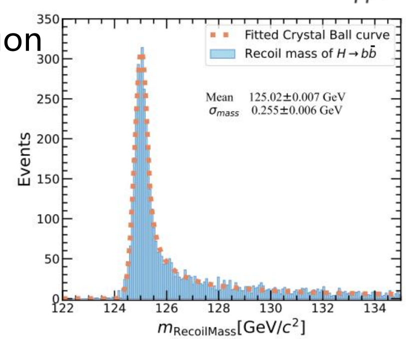


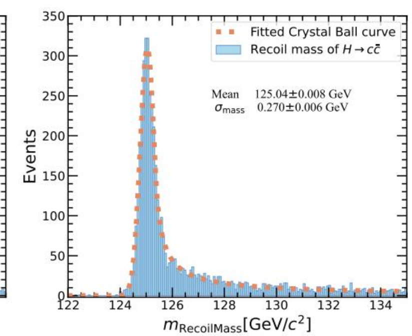


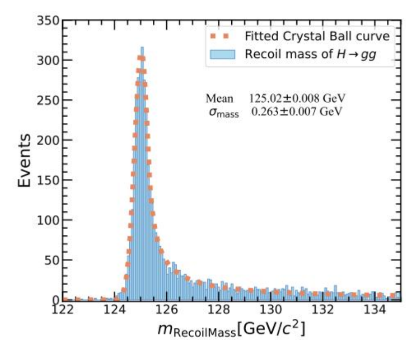
Performance (4)

- Physics Events:
  - $e^+e^- \rightarrow ZH\,,\ H \rightarrow \mu^+\mu^-$
    - two charged tracks in the final state
    - Each muon has a momentum greater than 10 GeV
    - mean =125GeV, $\sigma = 0.21GeV$
  - Check the recoil mass of higgs boson
    - $e^+e^- \rightarrow \mu^+\mu^- H, H \rightarrow b\bar{b}, c\bar{c}, gg$
      - The invariant mass of the reconstructed muon pair is close to the invariant mass of the Z boson
  - Track efficiency:
    - $e^+e^- \rightarrow \mu^+\mu^- H, H \rightarrow gg$
    - Each event has 30 tracks on average
    - ~92.6%









Summary

- As a component of the CEPC’ s 4th conceptual detector, the drift chamber (DC) has been added to the simulation chain
  - Detector geometry and simulation of detector response
- The DC Tracking algorithm was implemented by reusing the code of Belle II and its performance meets expectations
- Implemented track fitting based on the GenFit software package, achieving high track efficiency.
- Further development will be based on
  - More realistic simulation of detector response in drift chamber

Thank You！

谢谢