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Development of CEPC Drift Chamber Software

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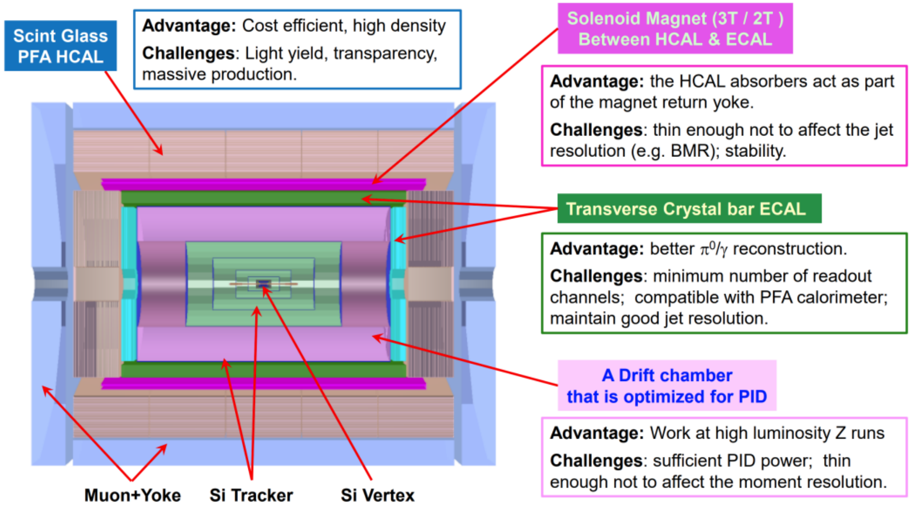
Detector Design

- The CEPC is a 100 km circular electron-positron collider aiming to
  - precisely measure the property of the Higgs boson
  - study electroweak physics at 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%)

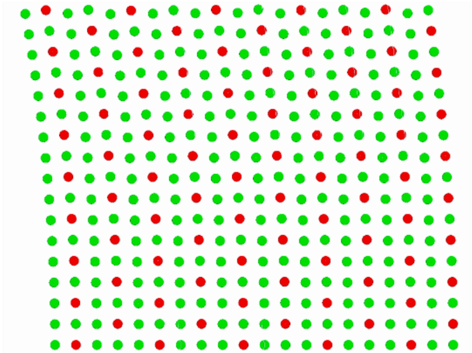


- The 4th conceptual detector was proposed on the basis of the CEPC CDR
  - is characterized by a combination of silicon detectors and drift chamber (DC) designed to provide both tracking and PID for charged particles
- Software development of the DC simulation and track reconstruction is critically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

Drift Chamber

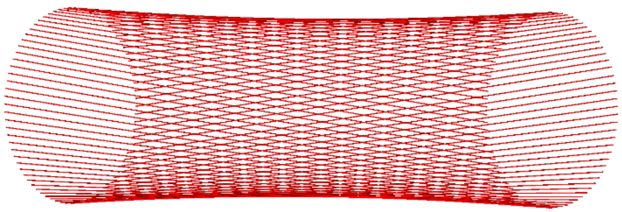
- The drift chamber covers
  - radial range from 800 mm to 1,800 mm
  - Z range from -2,980 mm to 2,980 mm
- A small cell design is chosen to obtain enough number of track hits at the outer radius
  - purely made of stereo wires
  - the sense wire is made of gold-plated tungsten with a diameter of 20 μm
  - the field wire is made of silver-plated aluminium with a diameter of 40 μm
  - 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
- 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)



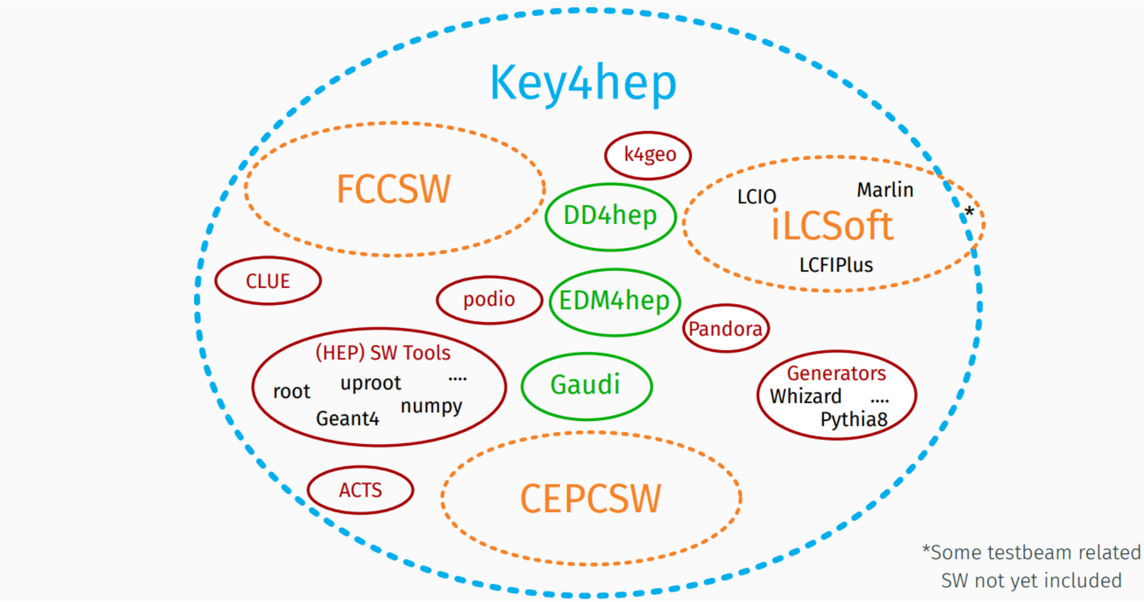
$r-\phi$ projection of a proportion of the first 10 layers of wires

Sense wires of each layer forms a rotating hyperboloid surface



History of CEPC Software

- The development of CEPC software first started with the iLCSoft
- New CEPC software (CEPCSW) prototype was proposed at the Oxford workshop in April 2019



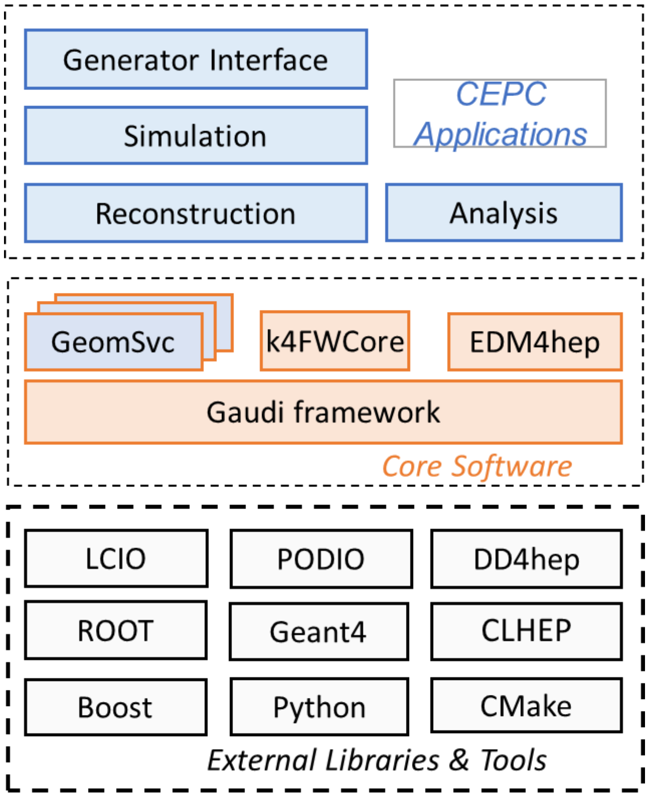
- The consensus among CEPC, CLIC, FCC, ILC and other future experiments was reached at the Bologna workshop in June, 2019
  - Develop a Common Turnkey Software Stack (Key4hep) for future collider experiments
  - Maximize the sharing of software components among different experiments
- Non-goal: develop and maintain project specific software and workflows

(T.Madlener | Key4hep & EDM4hep, CEPC workshop, Edinburgh)

CEPCSW Software Structure

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

https://github.com/cepc/CEPCSW



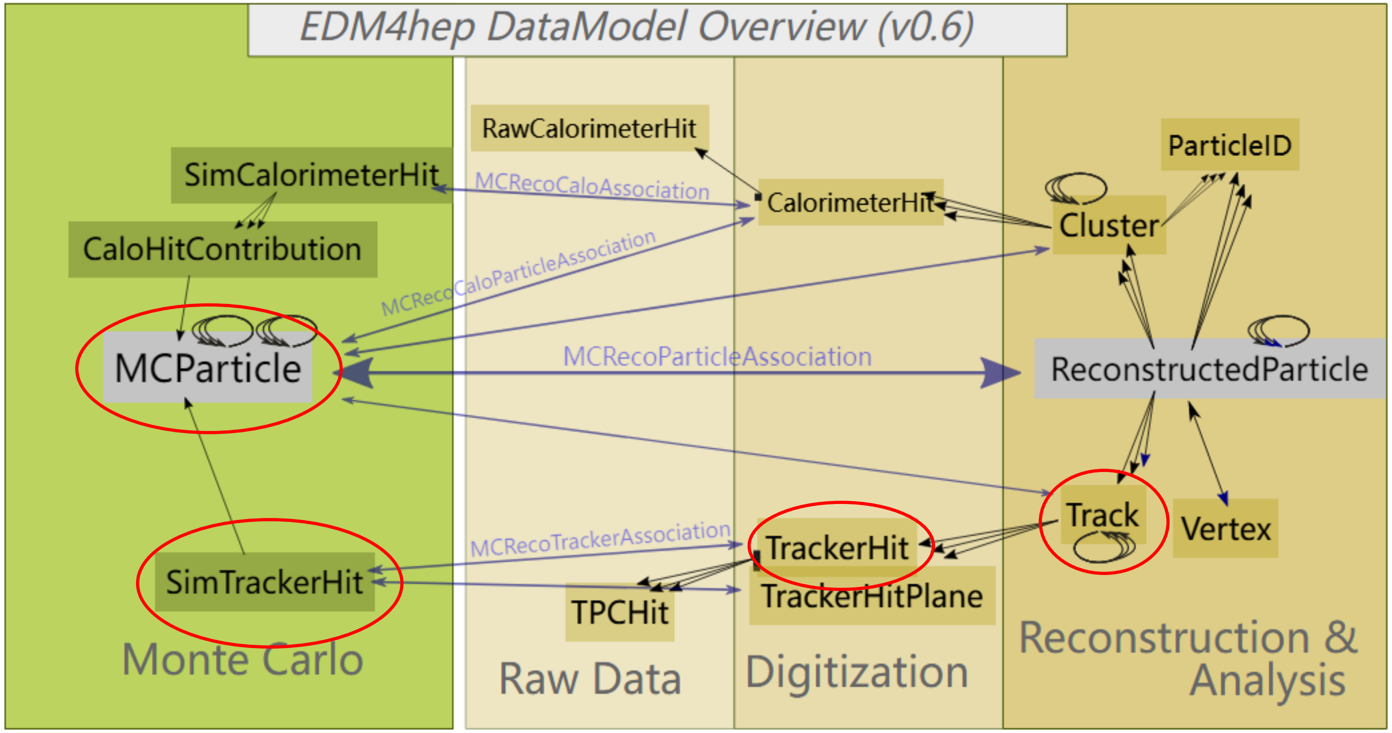
Packages in CEPCSW

- Detector concepts
  - CDR (baseline design)
  - The 4th concept
- MC Generators
  - Multiple formats supported: HepMC, HepEvt, StdHep, LCIO
  - GuineaPig++ for MDI
  - Particle Gun
- Simulation
  - G4 simulation framework
  - Fast simulation algoritrhms e.g.ML-based dE/dx simulation
  - Digitization algorithms for silicon, CALO, drift chamber
- Reconstruction
  - Marlin based tracking algorithms for silicon detector
  - Tracking algorithm for drift chamber
  - Pandora-based PFA
  - Arbor-based PFA
- Analysis tools
  - RDataFrame-based analysis framework
- Examples and docs
  - Usage of EDM4hep, Identifier, etc.

More than 50 packages in total

Event Data Model (1)

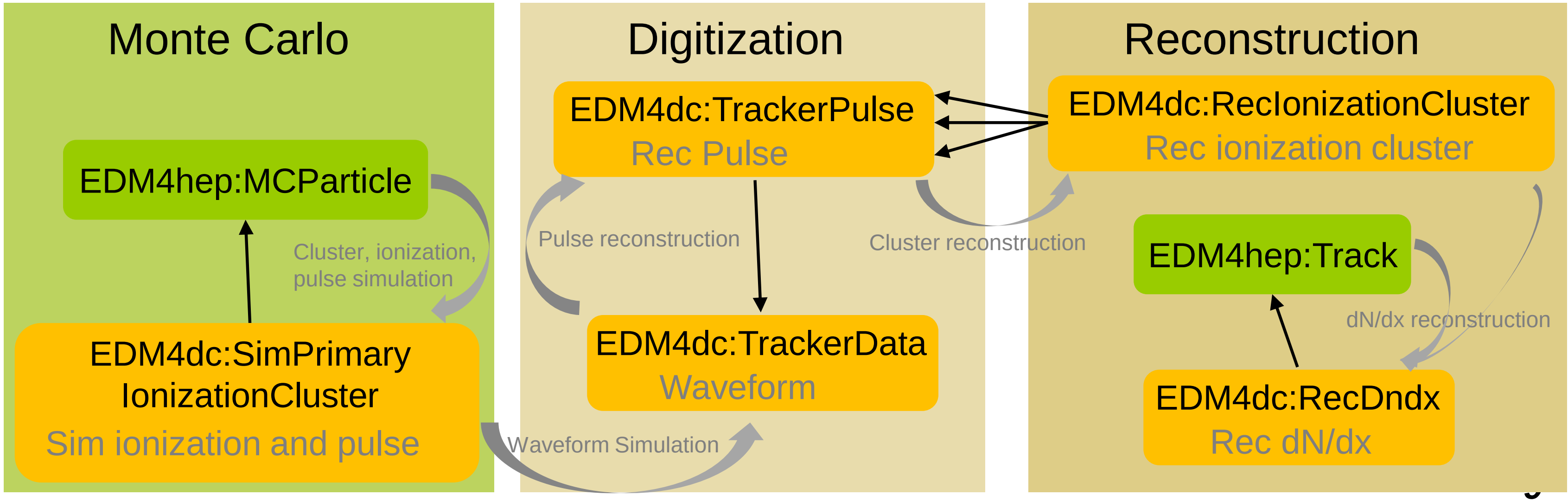
- EDM4hep is the common event data model (EDM) being developed for the future experiments like CEPC, CLIC, FCC, ILC, etc.



- 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.

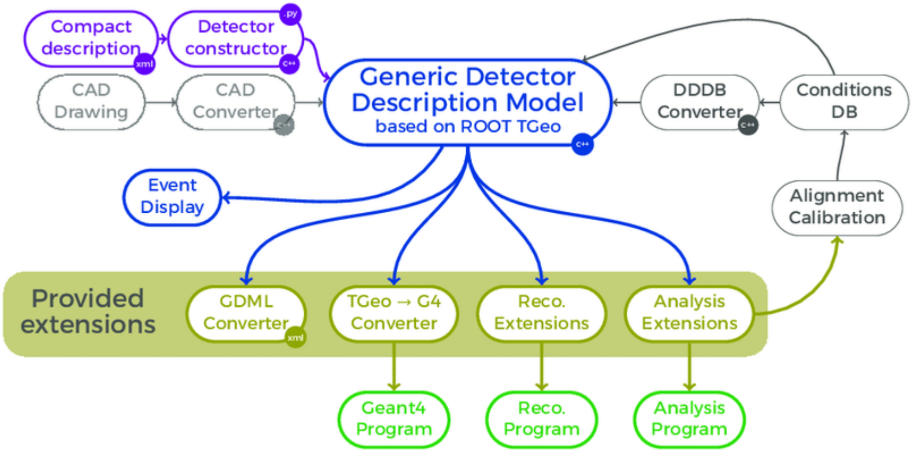
Event Data Model (2)

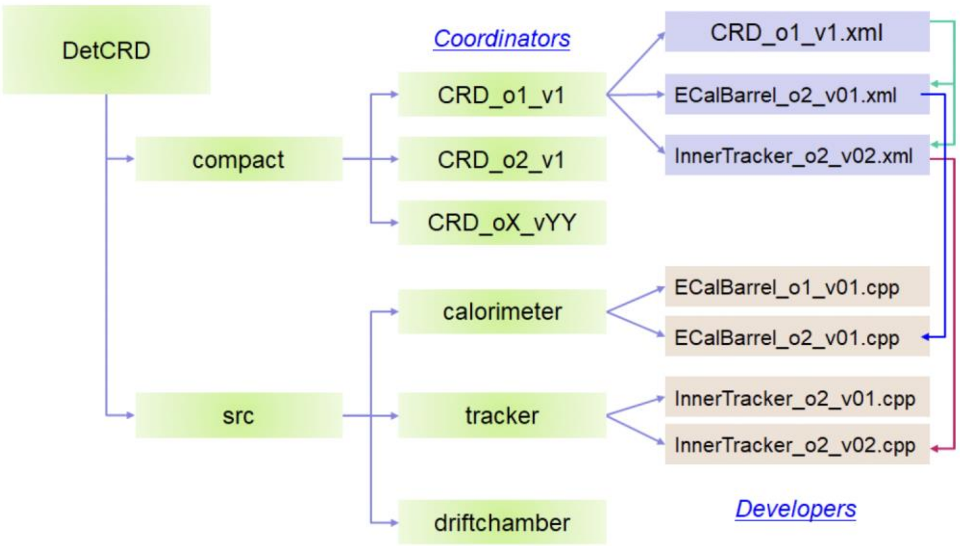
- As the development progressed, the previous versions of EDM appeared not able to fit all the requirements brought by newly added detector like the CEPC's drift chamber.
- Due to the strong flexibility of EDM4hep, TPCHit was extended to accommodate the new needs:
  - Discussions inside EDM4hep group 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

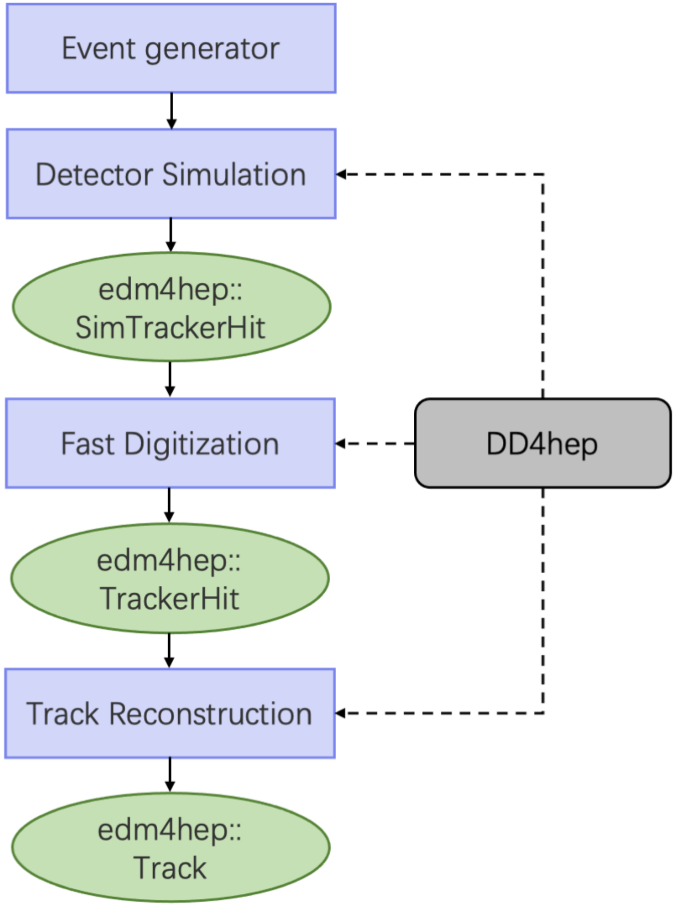
- DD4hep was adopted to provide a full detector description, which was generated from a single source (XML files)
- The control of geometry version can be easily achieved just by versioning the changes to the set of XML files
- Different detector design options are managed in the Git repository and a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





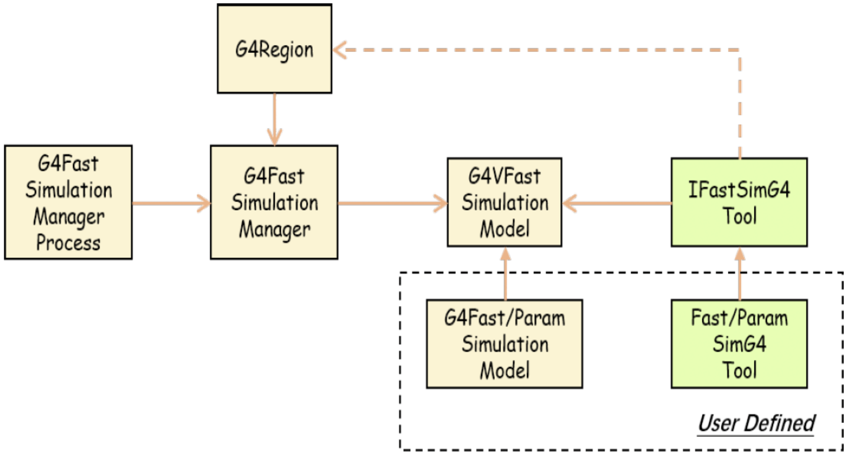
Data Processing Flow

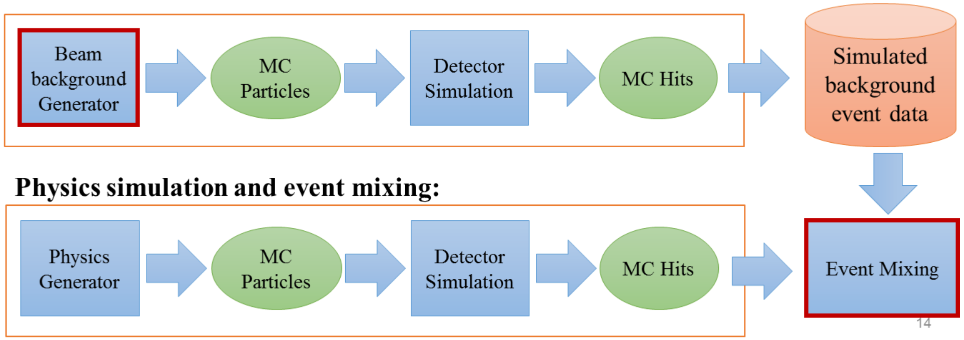
- Event generation
  - produces a list of particles each of which is generated from a single interaction with a vertex located at the geometric origin
- Detector simulation
  - generated events are passed into the simulation where each particle is propagated through the detector using Geant4.
- Digitization
  - 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)

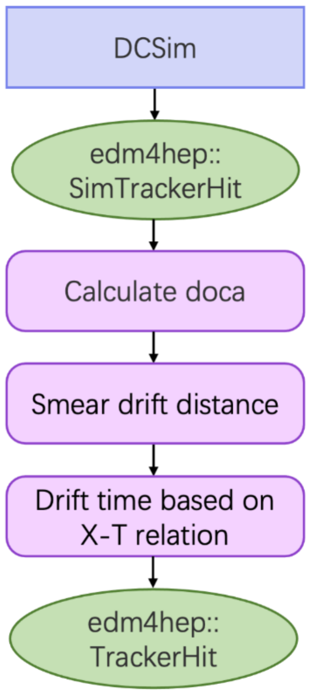
- The simulation framework was developed and the simulation chain is complete for sub-detectors such as:
  - silicon detectors, time projection chamber, drift chamber and calorimeters
- The region-based fast simulation interface was also developed to integrate different of fast simulation modules into the detector simulation
- An event mixing tool was also provided to mix different types of backgrounds with physics signals at hit level.

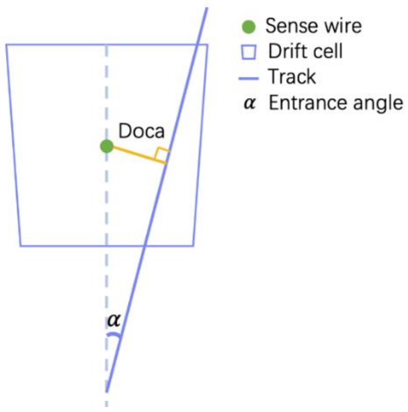




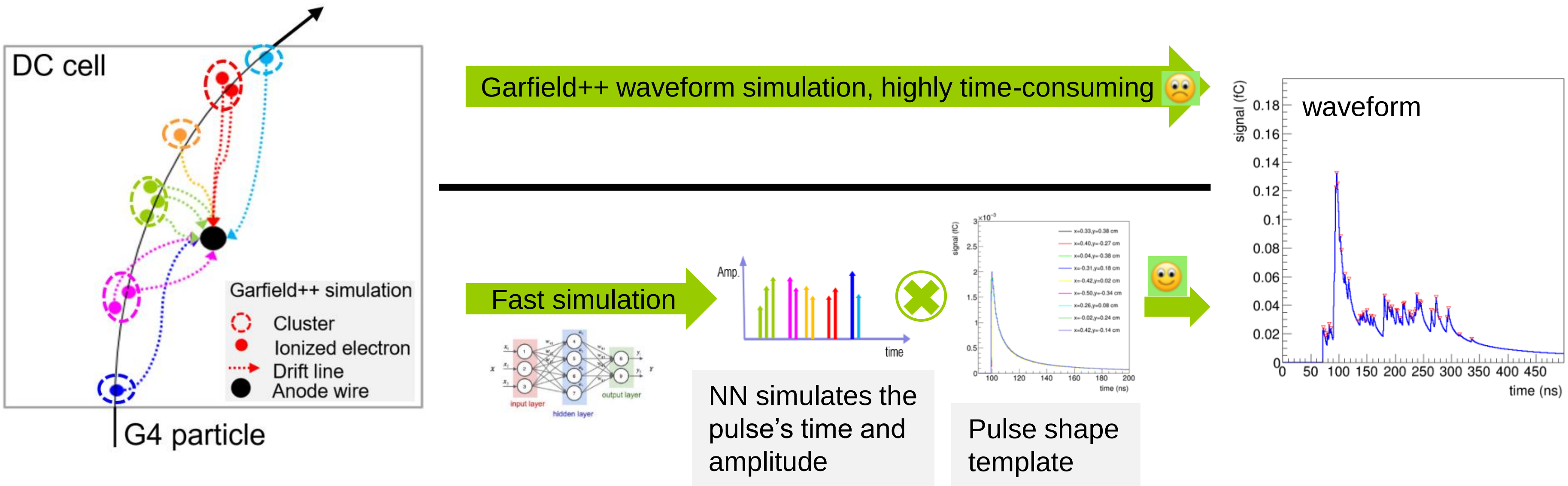
DC Simulation (2)

- 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 and converted to drift time based on X-T relation



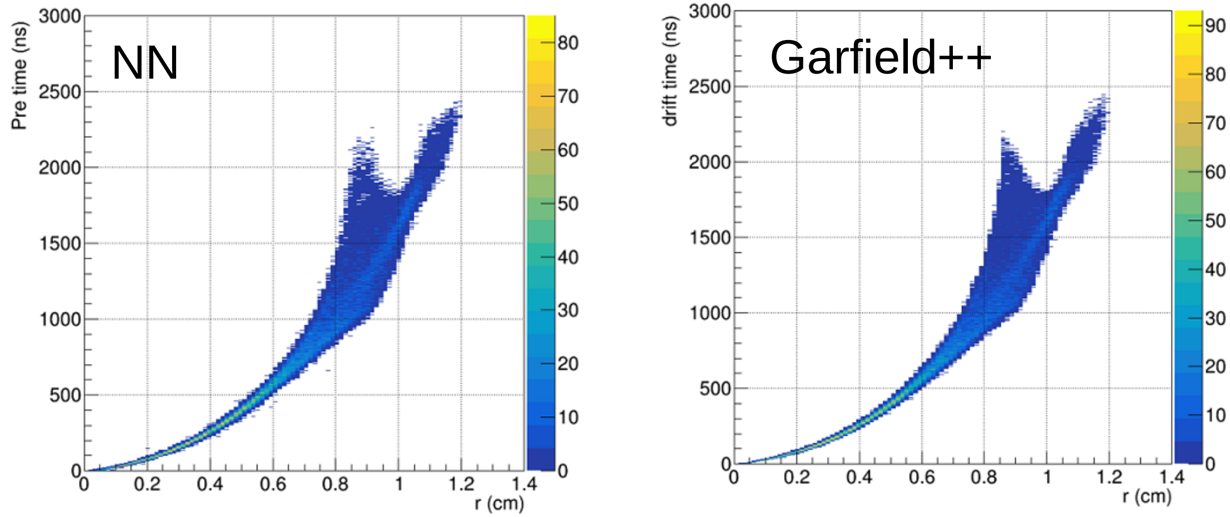


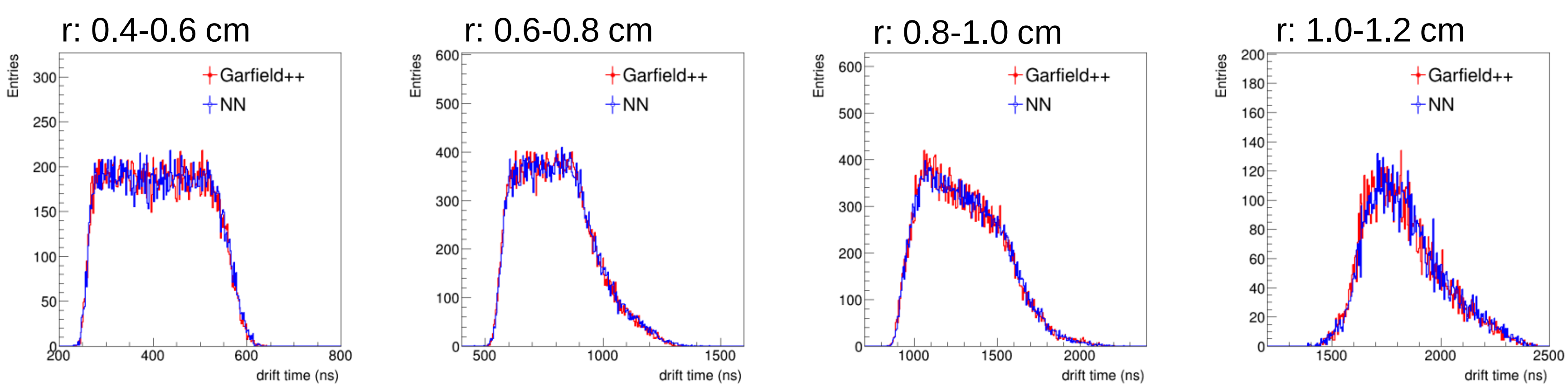
DC Simulation (3)



- TrackHeedSimTool (Gaudi tool) was implemented by combining Geant4 and Garfield++ to simulate the complete response of the gaseous detector
  - Input: G4Step information (particle type, initial position, momenta, and step length)
  - Using TrackHeed(from Garfield++) to create the ionization electron-ion pairs (for both primary and secondary ionizations), the deposited energy will be used to update the energy of the G4Particle
  - Using NN to simulate the time and amplitude of each pulse for each ionized electron (for fast waveform simulation)

DC Simulation (4)

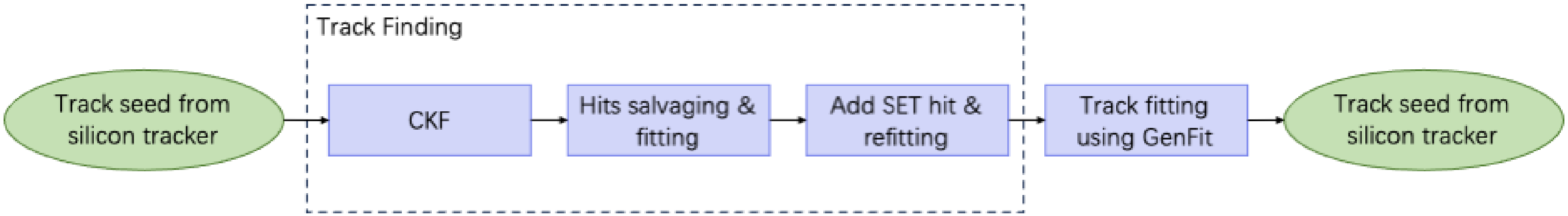




- Good agreement between the NN and Garfield++ simulation

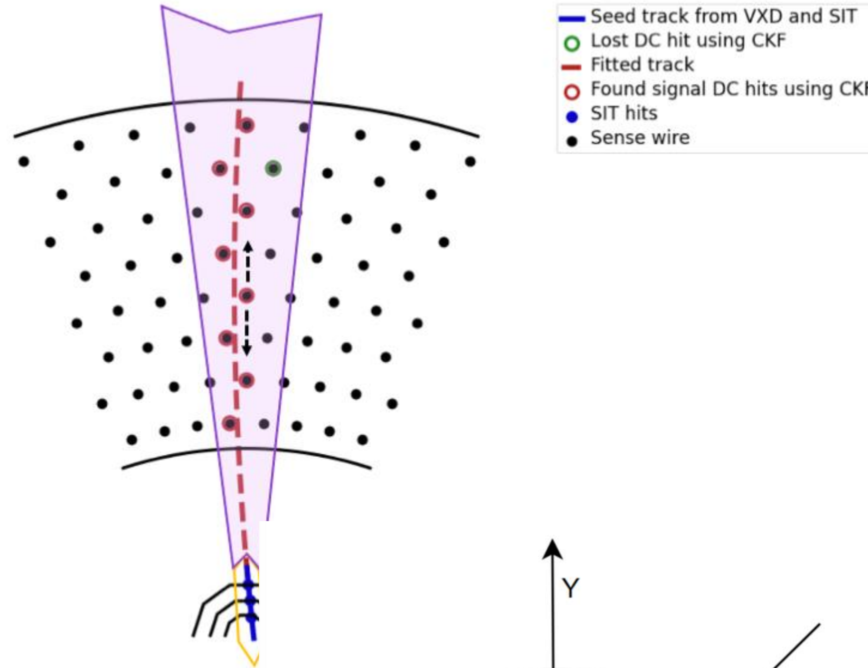
Track Reconstruction (1)

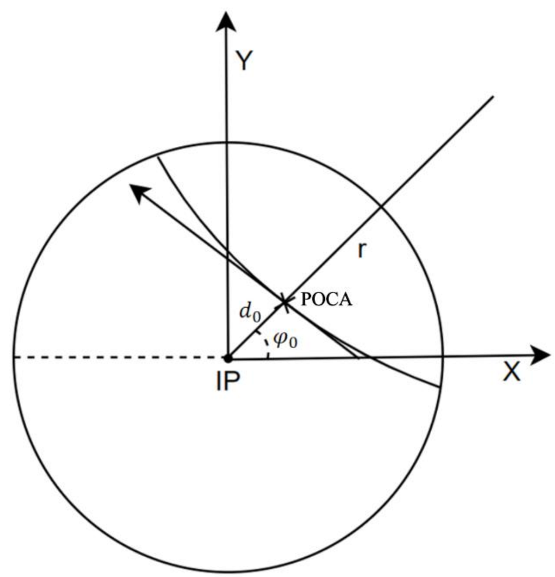
- Tracking with Combinatorial Kalman Filter (CKF) method
  - Combining track recognition and track fitting
- Implementation of track finding with CKF was based on the code of Belle II experiment
  - Track segments reconstructed in the silicon detector, called seeds, are extrapolated to the DC and all the DC hits belonging to the track are collected
- Tack 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)

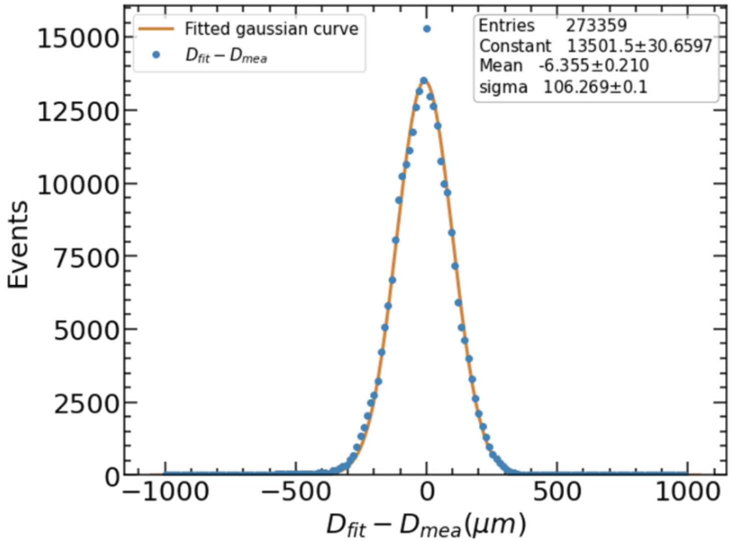
- Integration with CEPCSW
  - Conversion of event data between different representations
  - Access to detector geometry and magnetic field
- Track extrapolation
  - Extrapolation starts from a seed, consisting of a least 3 space points, found in the silicon detector
  - Iteratively searching for hits and collecting hits in the outer neighbouring layer
- Salvaging hits
  - Hits are examined again to determine its association with the current track according to track length and Doca
- Track parameters
  - Helix parameters at the point of closest approach (POCA) to the interaction point (IP)

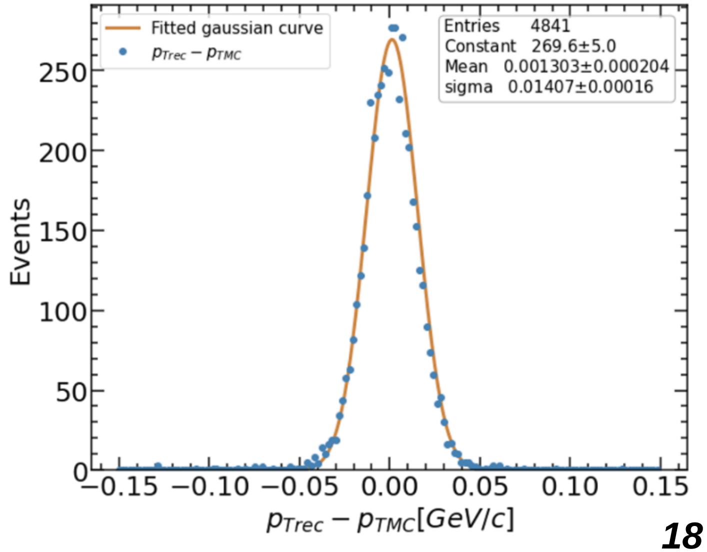




Track Reconstruction (3)

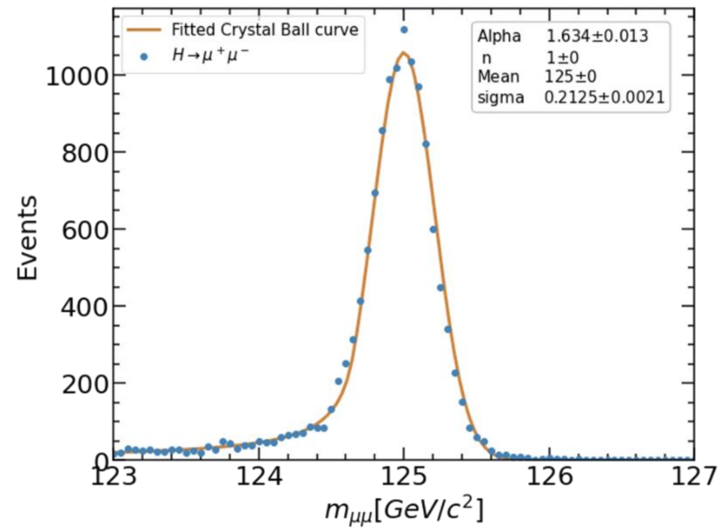
- Event generation
  - Particle gun : 10 GeV μ particles
    Polar angle: $cos\theta < 0.776$
    Azimuthal angle: ϕ $[-\pi, \pi]$
- Spatial resolution
  - Spatial resolution: 106 um
  - Consistent with the value set in the simulation which is 110 um
- Momentum resolution
  - A resolution of 14 MeV which satisfies the requirement in CEPC CDR (per mille level)

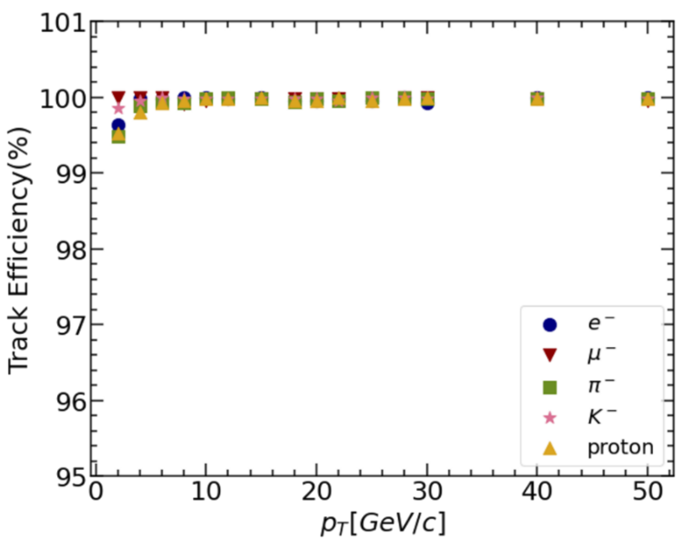


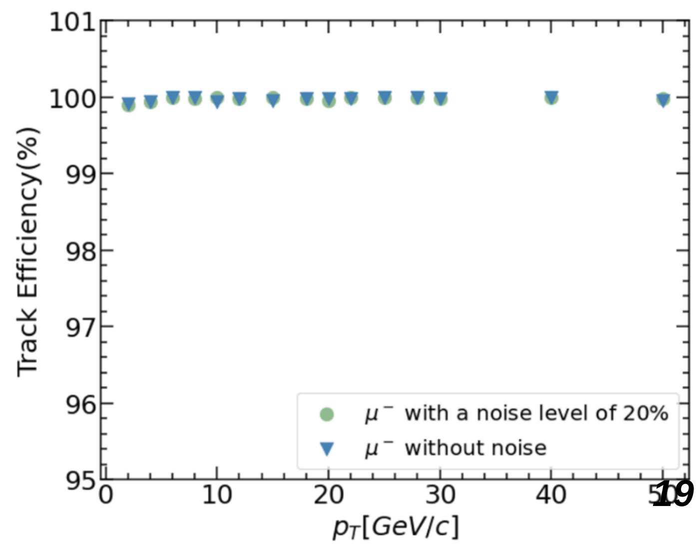


Track Reconstruction (4)

- Events with two muons :
  - $e^+e^- \rightarrow ZH, H \rightarrow \mu^+\mu^+$
- Tracking efficiency
  - Good track: $\chi 2$ < 400 and No of DC hits > 6
  - Tracking efficiency as the function of measured pT for different types of particles
  - Tracking efficiency vs pT for single $\mu-$ with/without adding 20% noise







Summary

- As a component of the CEPC's 4^{th} 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
- Further development will be based on
  - More realistic simulation of detector response in drift chamber

Thank You！

谢谢