CEPC: Full detector simulation

Gang Li for the CEPC software group

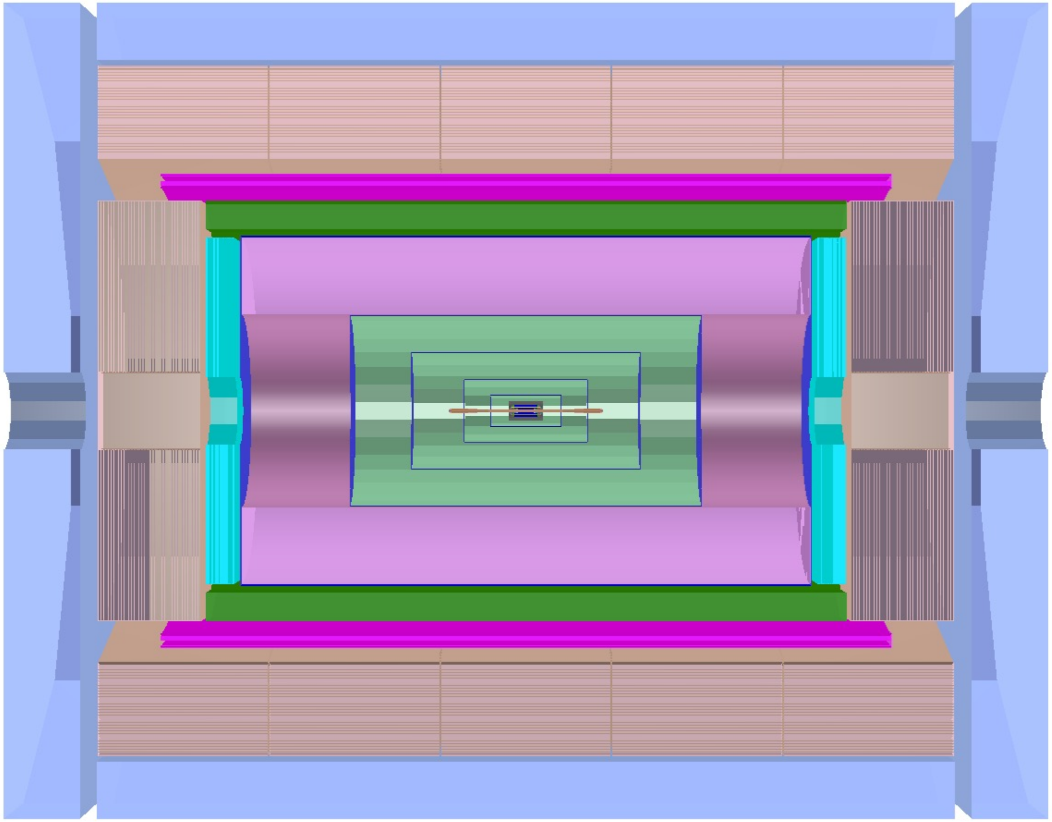
Institute of High Energy Physics, Chinese Academy of Sciences

Beijing, China

ECFA Higgs Factories: First Topical Meeting on Simulation
Feb 01-02, 2022

Outline

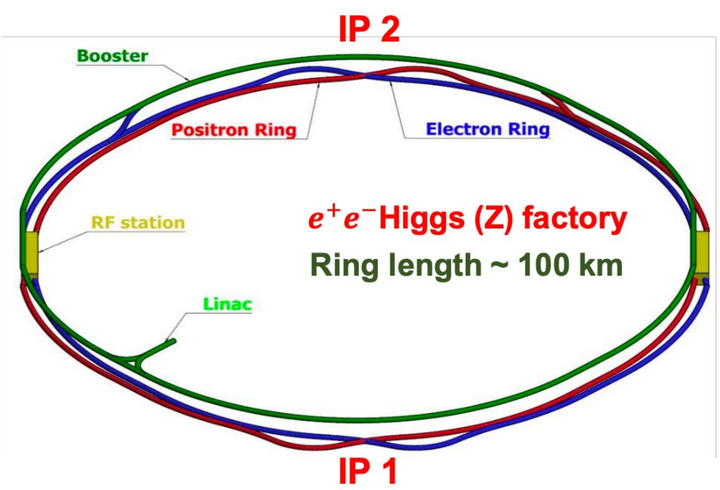
- Introduction
- CEPC detectors
  - Detectors in CDR
  - The 4th conceptual detector
- Full simulation
- Summary



Physics motivation of CEPC

- The CEPC aims to start operation in 2030' , as a Higgs(Z) factory in China, the plan
  - Above ZH threshold(240 GeV) for 7 years
  - Around and at the Z pole for 2 years
  - Around and above WW threshold for 1 year
- Possible pp collide (SppC) of 50 -100 TeV in the future

Operation mode		ZH	Z	W^+W^-
$\sqrt{s}$ [GeV]		~240	~91.2	158-172
Run time [years]		7	2	1
CDR	L / IP [10^{34} cm^{-2}s^{-1}]	3	32	10
	$\int L\,dt$ [ab^{-1}, 2 IPs]	5.6	16	2.6
	Event yields [2 IPs]	1×10^6	7×10^{11}	2×10^7
Latest	L / IP [10^{34} cm^{-2}s^{-1}]	5	105.5	18.7



The large samples from 2 IPs: **10^6** Higgs, **10^{12}** Z, **10^8** W bosons, provide an unique opportunity for

- High precision Higgs, EW measurements,
- Study of flavor physics (b, c, tau) and QCD,
- Probe physics beyond the standard model.

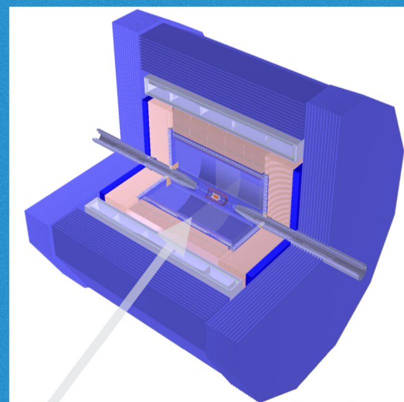
...

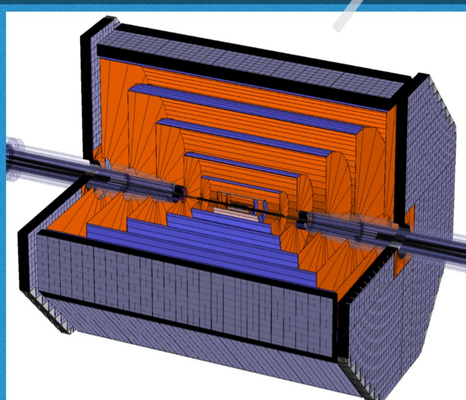
Detector concepts at CDR stage

CEPC plans for 2 IPs

Particle Flow Approach

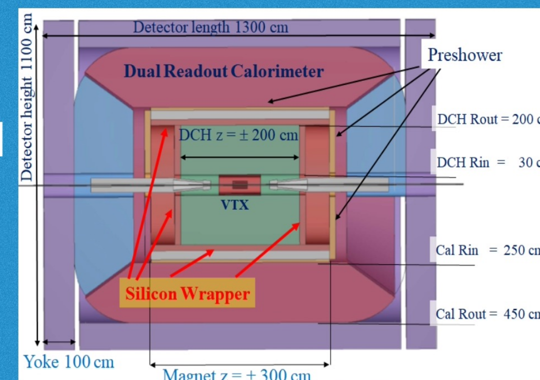
Baseline detector ILD-like (3 Tesla)





Full silicon tracker concept

Low magnetic field concept (2 Tesla)

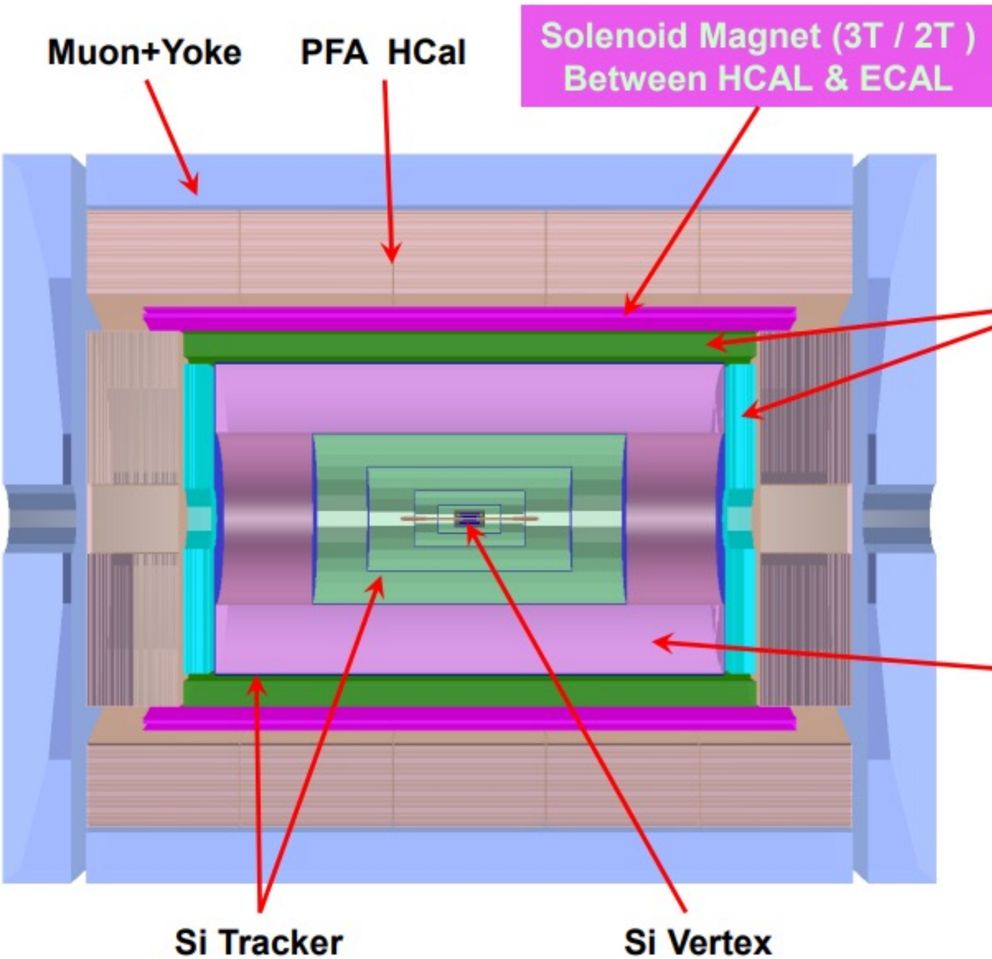


IDEA Concept
also proposed for FCC-ee

PFA: 1 ILD-like, 2 full silicon tracker designs; IDEA with dual readout

Propose a new detector concept, though the above can fulfil the requirements

The 4th Conceptual Detector Design



Advantage: the HCAL absorbers act as part of the magnet return yoke.

Challenges: thin enough not to affect the jet resolution (e.g. BMR); stability.

Transverse Crystal bar ECAL

Advantage: better π^0/γ reconstruction.

Challenges: minimum number of readout channels; compatible with PFA calorimeter; maintain good jet resolution.

Drift chamber that is optimized for PID

Advantage: Work at high luminosity Z runs

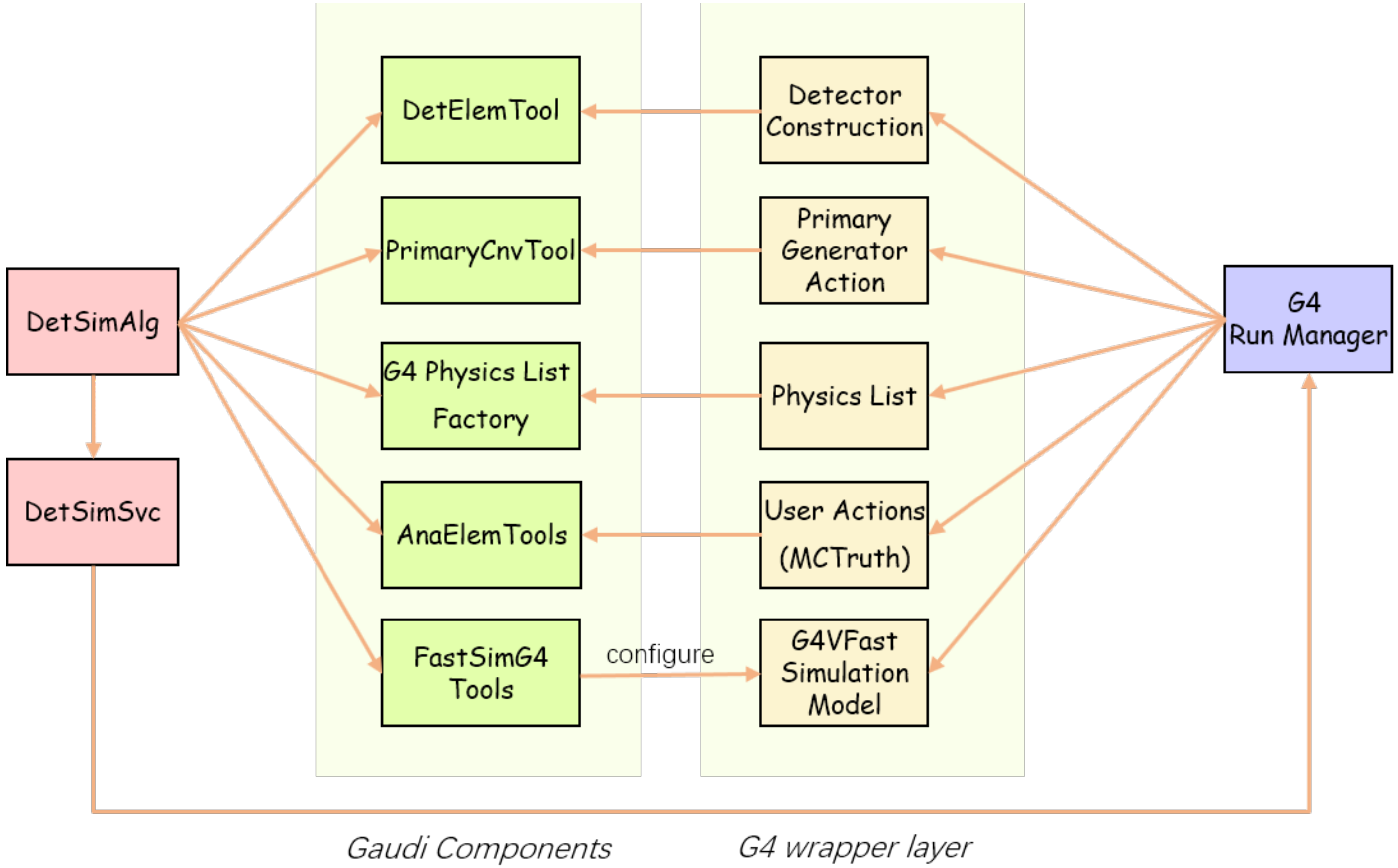
Challenges: sufficient PID power; thin enough not to affect the moment resolution.

Full simulation

Supports both the detector R&D and physics performance study

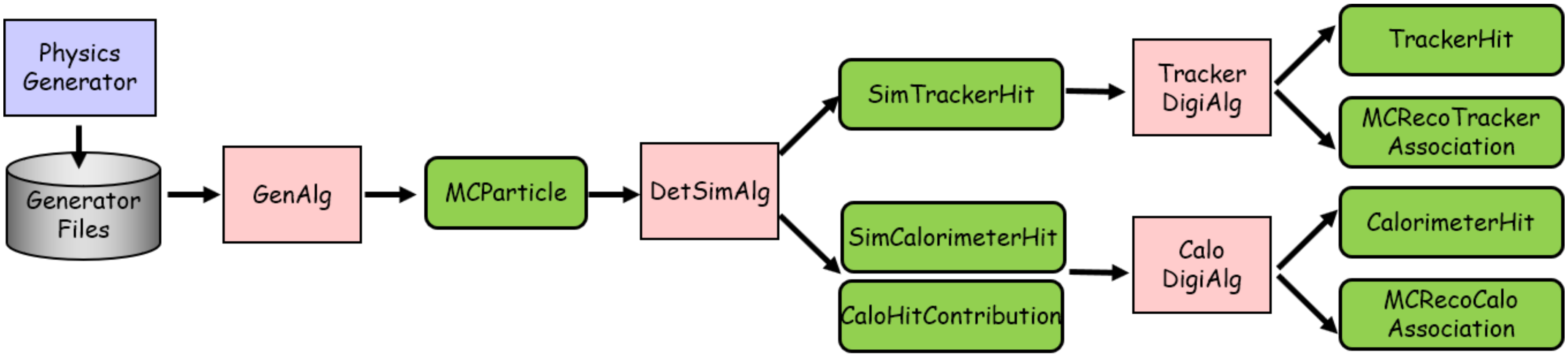
Simulation framework (1)

- A detector simulation framework developed in CEPCSW.
  - A interface layer developed for Geant4 and Gaudi.
  - The geometries from DD4hep to Geant4 done by DDG4.
  - Could be a hybrid of fast and full simulation



Simulation framework (2)

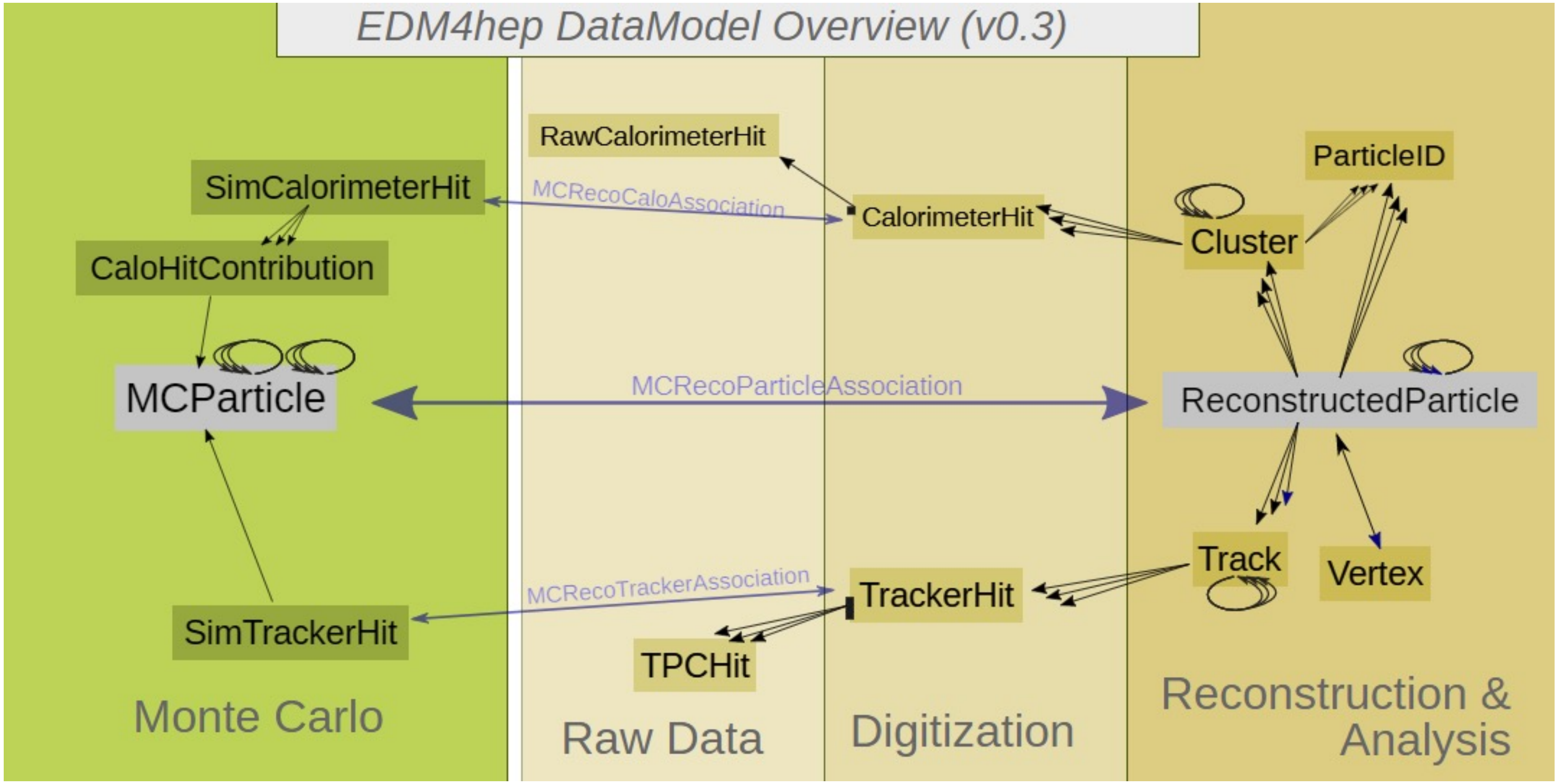
- The simulation chain is complete.



- The MC truth available for performance studies
  - Physics generators create kinematic information of primary MC particles.
  - Detector simulation creates the relationship between MC hits and MC particles.
  - Digitization creates the association between Digi and MC hits.

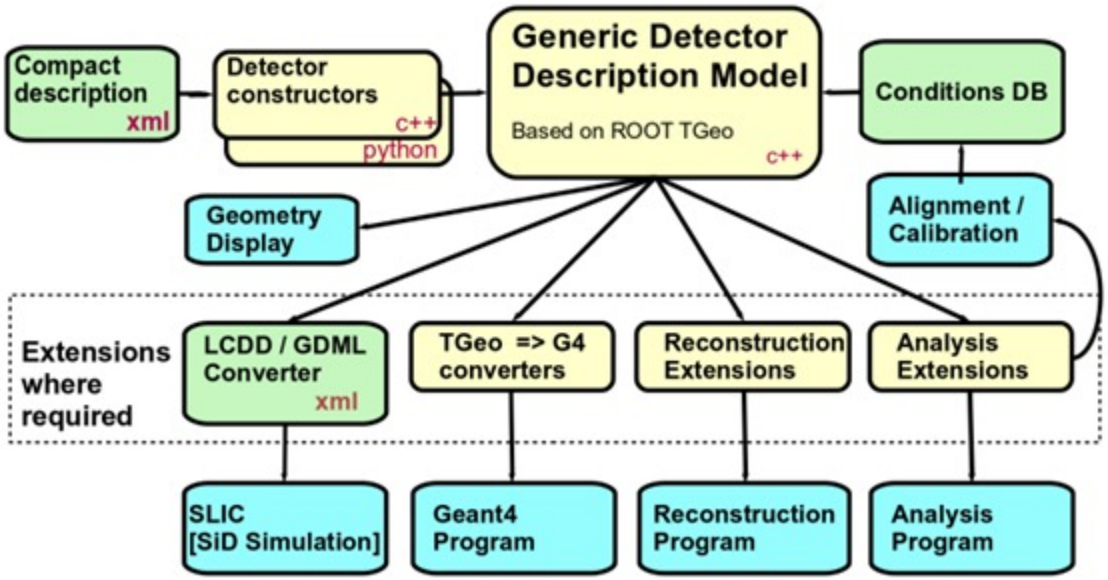
Simulation framework (3) EDM4HEP

- Adopted EDM4hep as the official EDM
- Generated from YAML files via PODIO toolkit
- Full support the detector R&D and physics studies



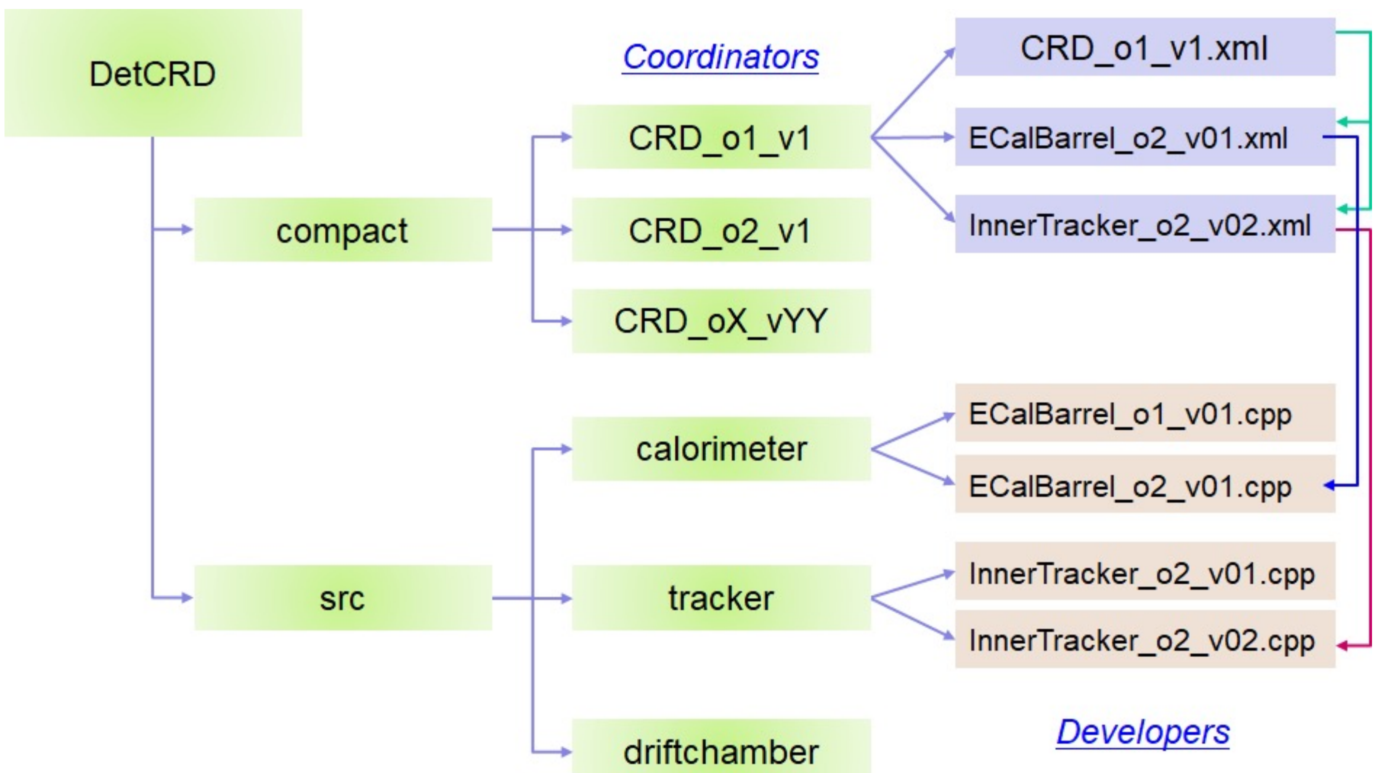
Simulation framework (4)
DD4hep for Detector Description

- Originally developed for ILC and CLIC but with all of HEP in mind.
- A complete detector description with a single source of information
  - Geometry, materials, visualization, readout, alignment, calibration, reconstruction etc.
- Covering the full life cycle of an experiment
  - Detector concepts, optimization, construction and operation



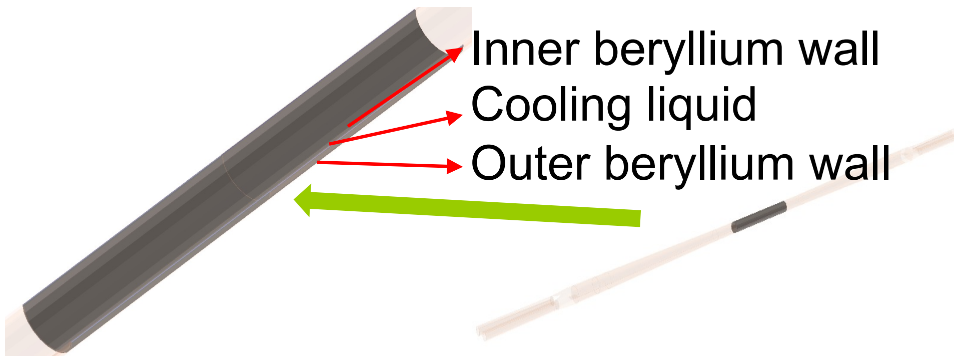
Simulation framework (5)
Detector Geometry Management

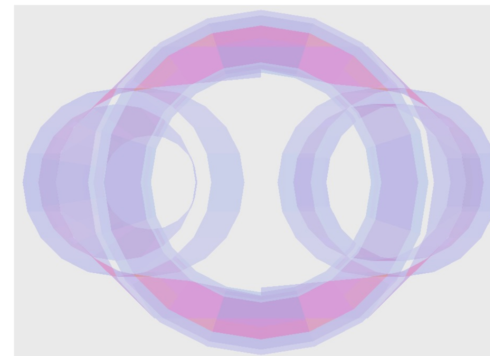
- The detector geometry convention
  - Sub-detectors: described by the XML compact files and the C++ constructors.
  - Full-detector options: only configured by the compact files.
- All the detector options will be managed by database and git repository.



Geometry implementation

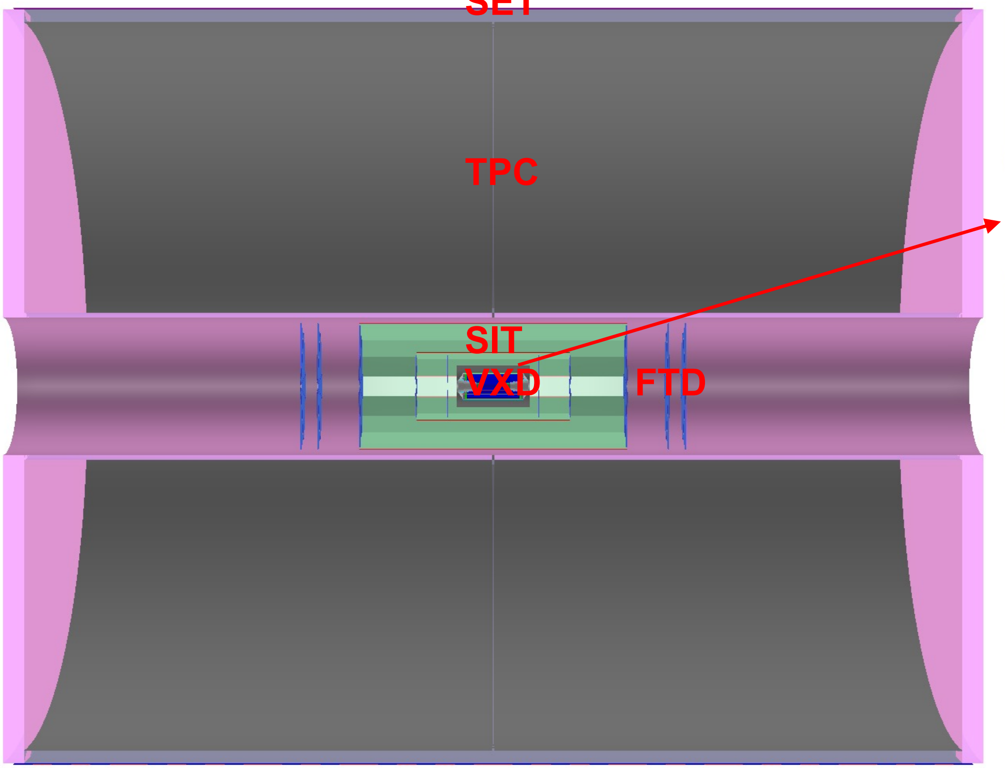
- Beampipe

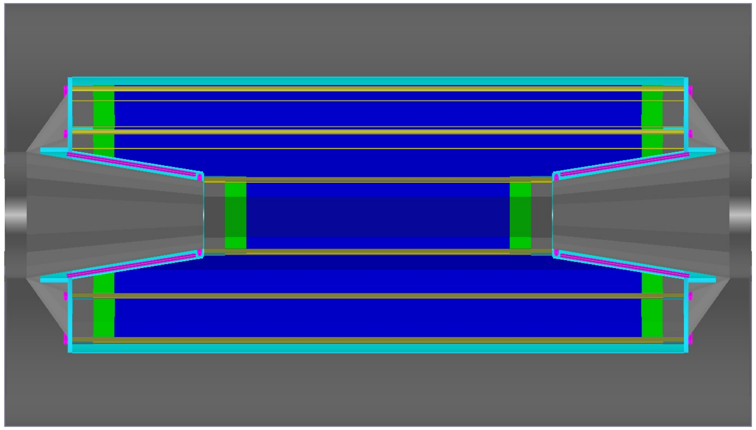




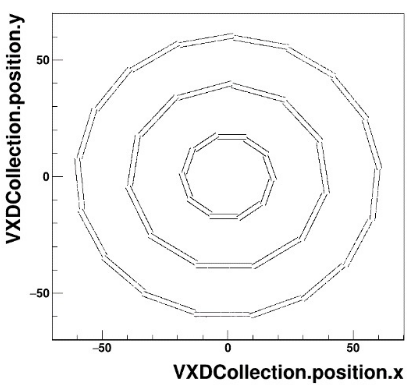
- Silicon tracker
  - Barrel (CDR like): VXD04, SIT_Simple_Pixel, SET_Simple_Planar
  - Endcap: SiTrackerSkewRing similar with FTD of ILD, but support skew
- Drift chamber (DC): Cell partitioning with segmentation
- High granularity crystal calorimetry: crystal bar
- Hcal: CDR like or AHcal
- Magnet: DD4hep_Solenoid_o1_v01
- Yoke and muon detector: rotated polyhedral calorimeter and PolyhedraEndcapCalorimeter2

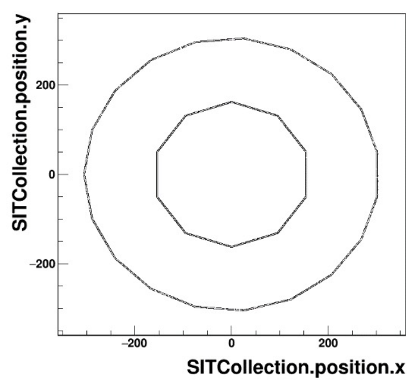
CDR Tracker with TPC

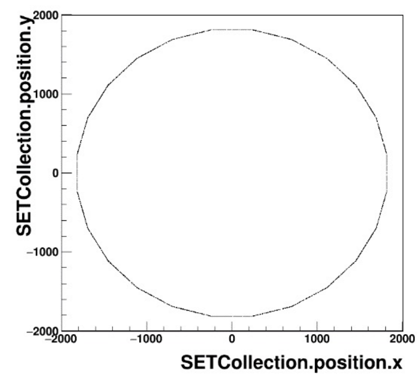


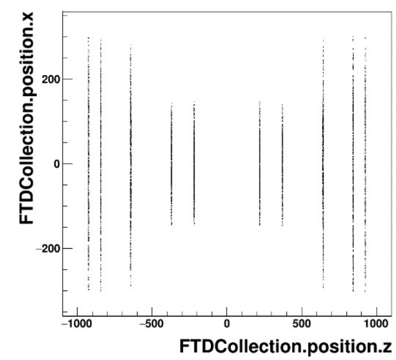


Driver:
VXD04
SIT_Simple_Planar
TPC10
SET_Simple_Planar
FTD_cepc



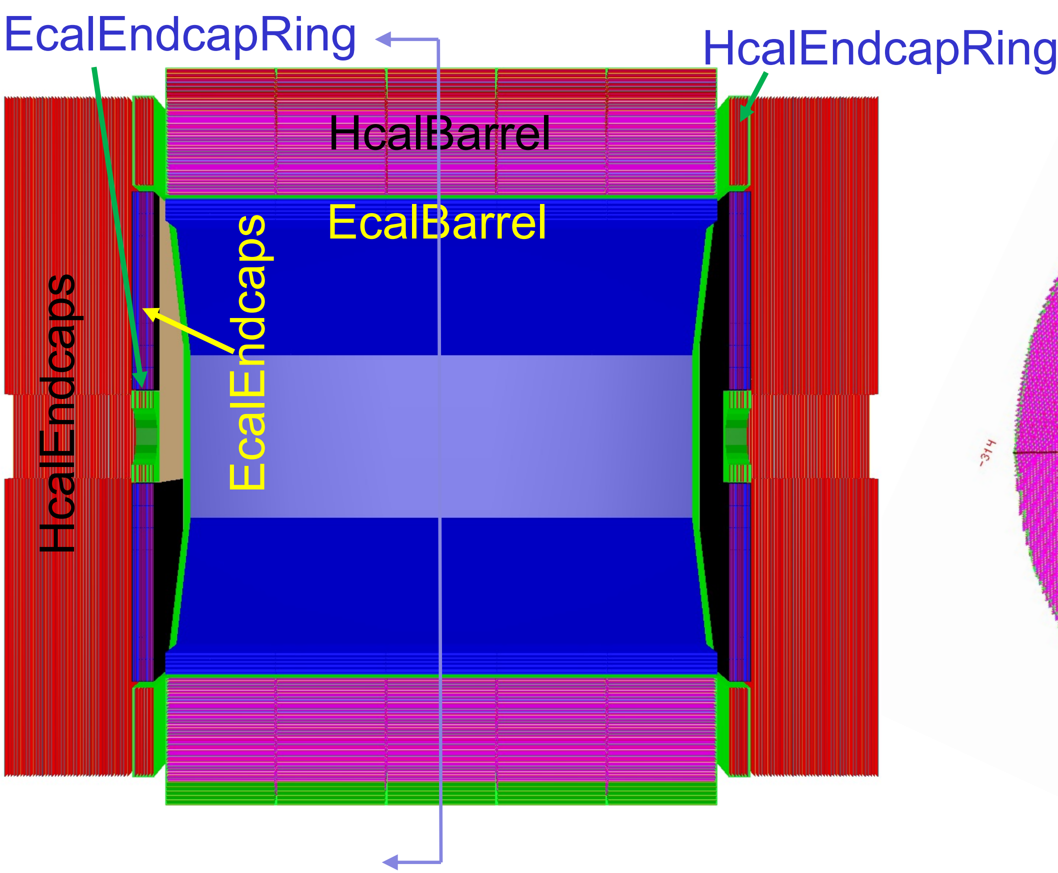


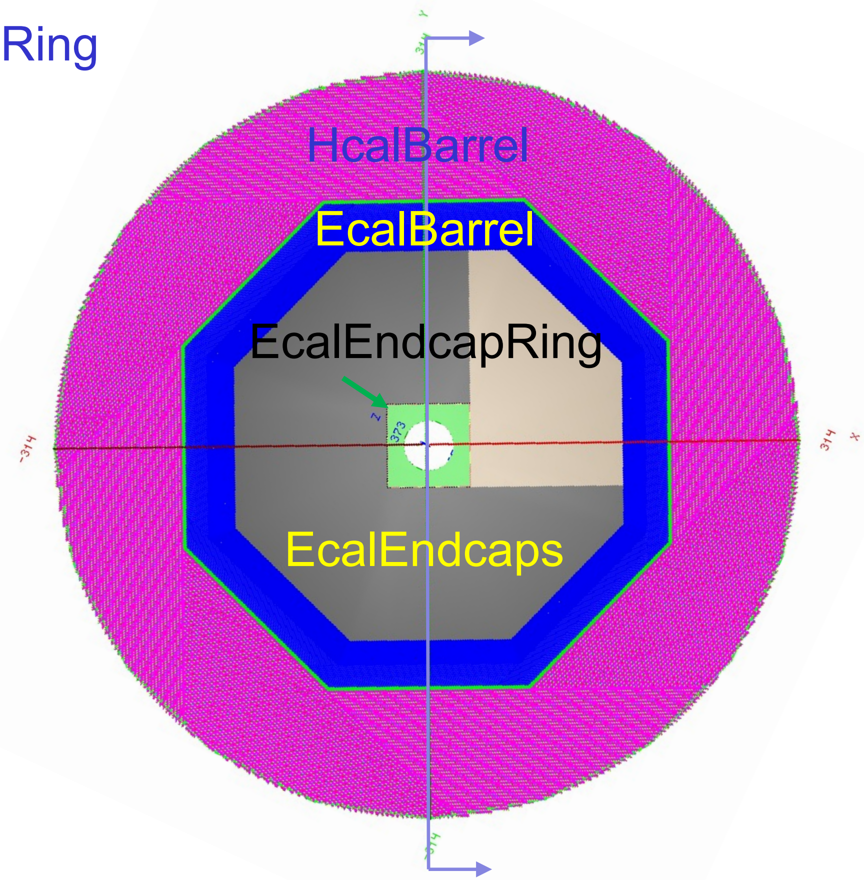




Calorimeters

- Si-W Ecal: SEcal05
- RPC-based Hcal (Semi-Digital Hadron Calorimeter): SHcalRpc01patch
- Yoke with scintillator Muon Detector: Yoke05patch
- Extensibility: radius, length, layer/module number, layer structure, symmetry

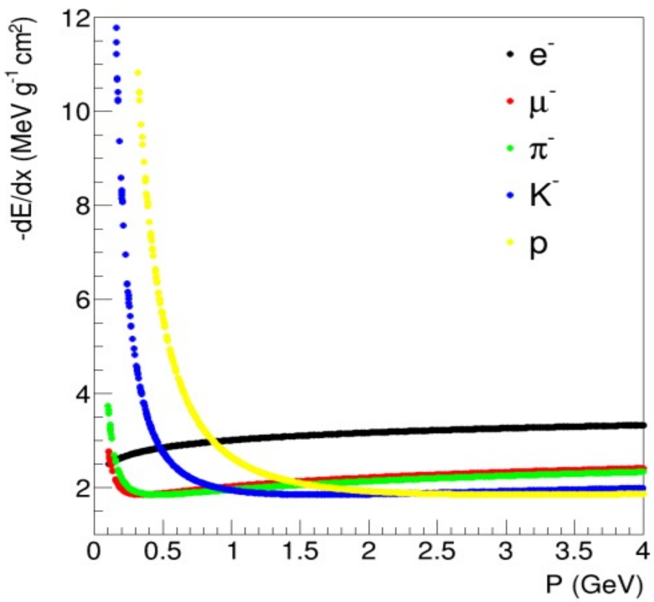




dE/dx Simulation

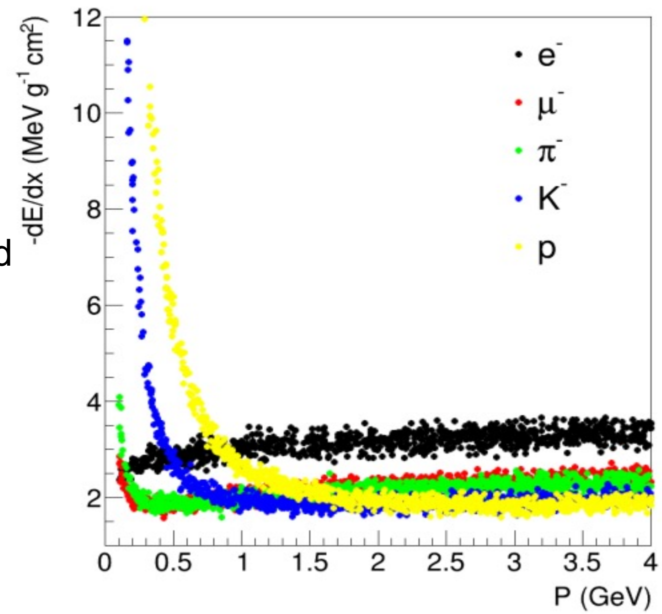
- A configurable fast sampling tool
  - Hit/track level sampling from empirical formula
  - Other sampling method is easy to be plugged in
- A track level dE/dx simulation in CEPCSW is ready

dE/dx from Bethe-Bloch equation



5% smeared

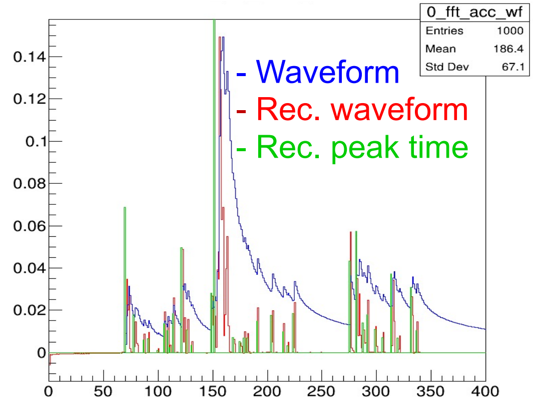
dE/dx after fast sampling



dN/dx Simulation and Reconstruction

- Integrate Garfield++ in the simulation
  - To handle energy loss and ionization process more precisely
- A waveform generation based on neural network developed
  - Based on Garfield++ but ~ 200 times faster than Garfield++
- A preliminary waveform reconstruction with Fourier transform
  - Other algorithms can also be plugin easily
- The event model for dN/dx study is under development
  - Depends on the PID algorithm

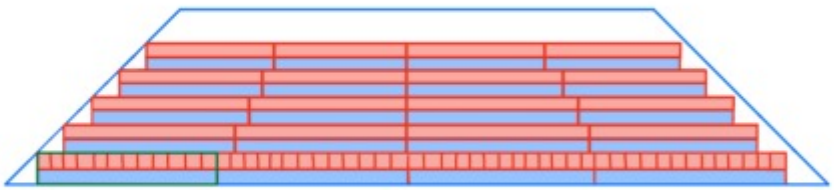
The results of stand-alone simulation for the protype study will be integrated into CEPCSW

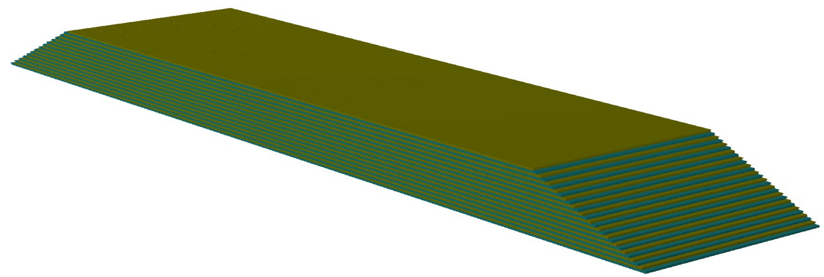


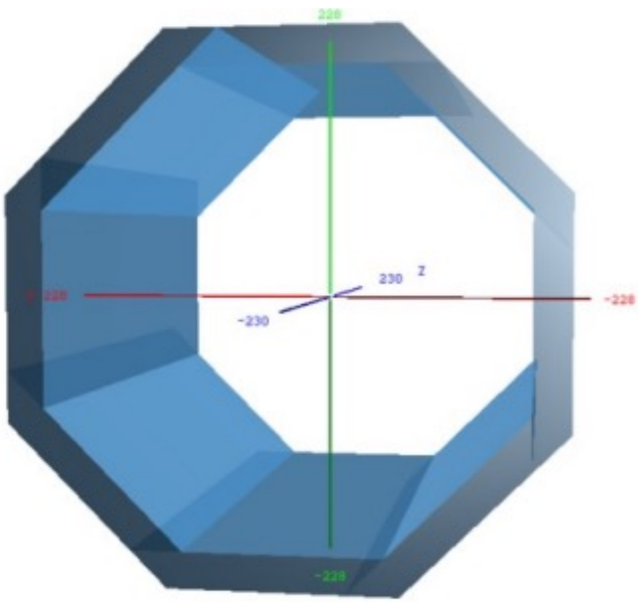
Waveform reconstruction with Fourier transform

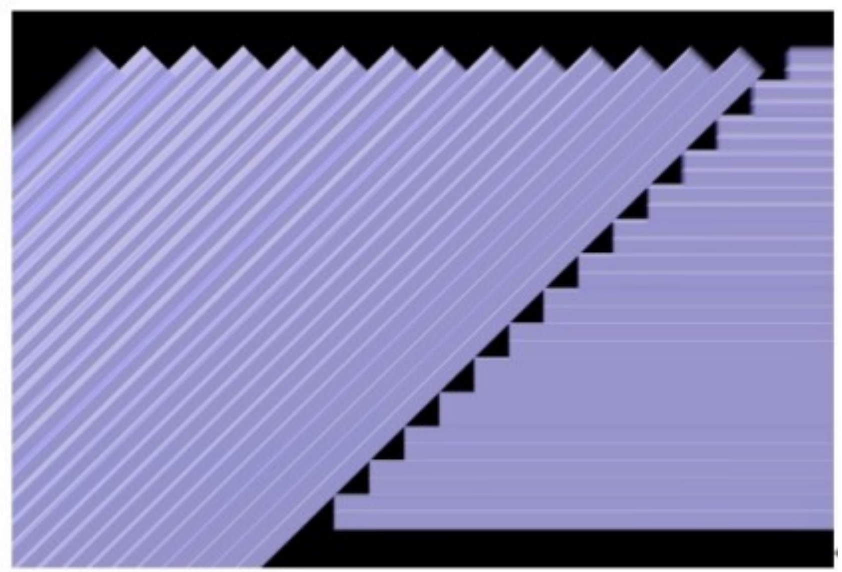
High Granularity Crystal Calorimetry

- 8 staves in R-phi (Barrel)
  - Reconstruction is being developed based on the simulation
  - A 12 staves geometry scheme to be supported optional
- Endcap will be ready soon



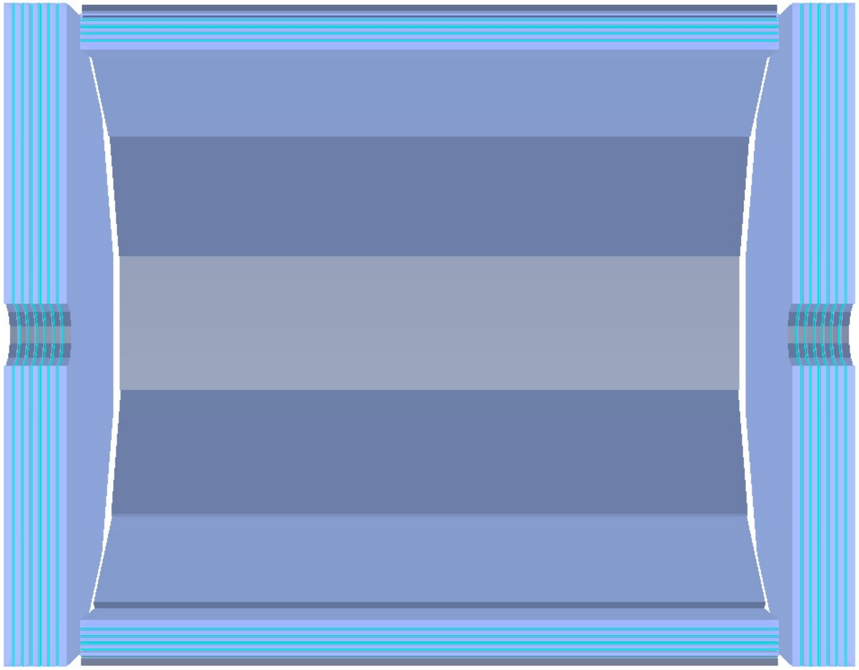


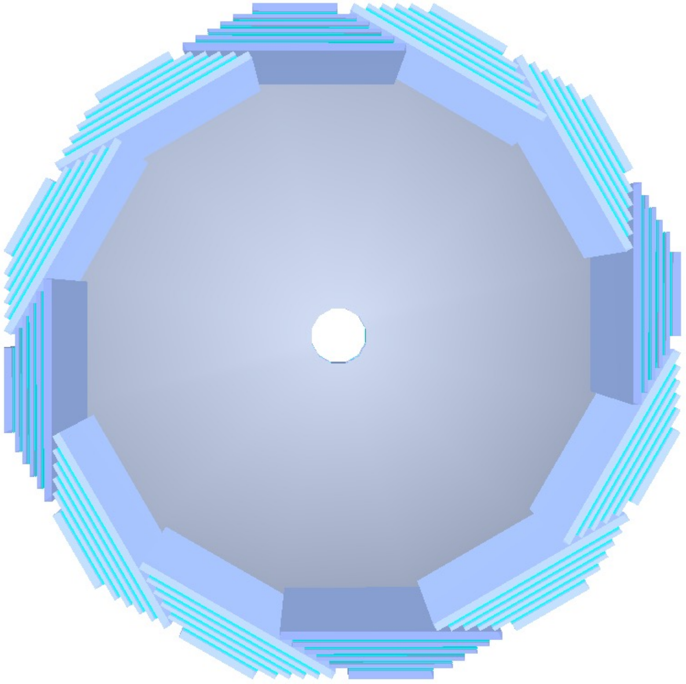




Yoke and Muon Detector

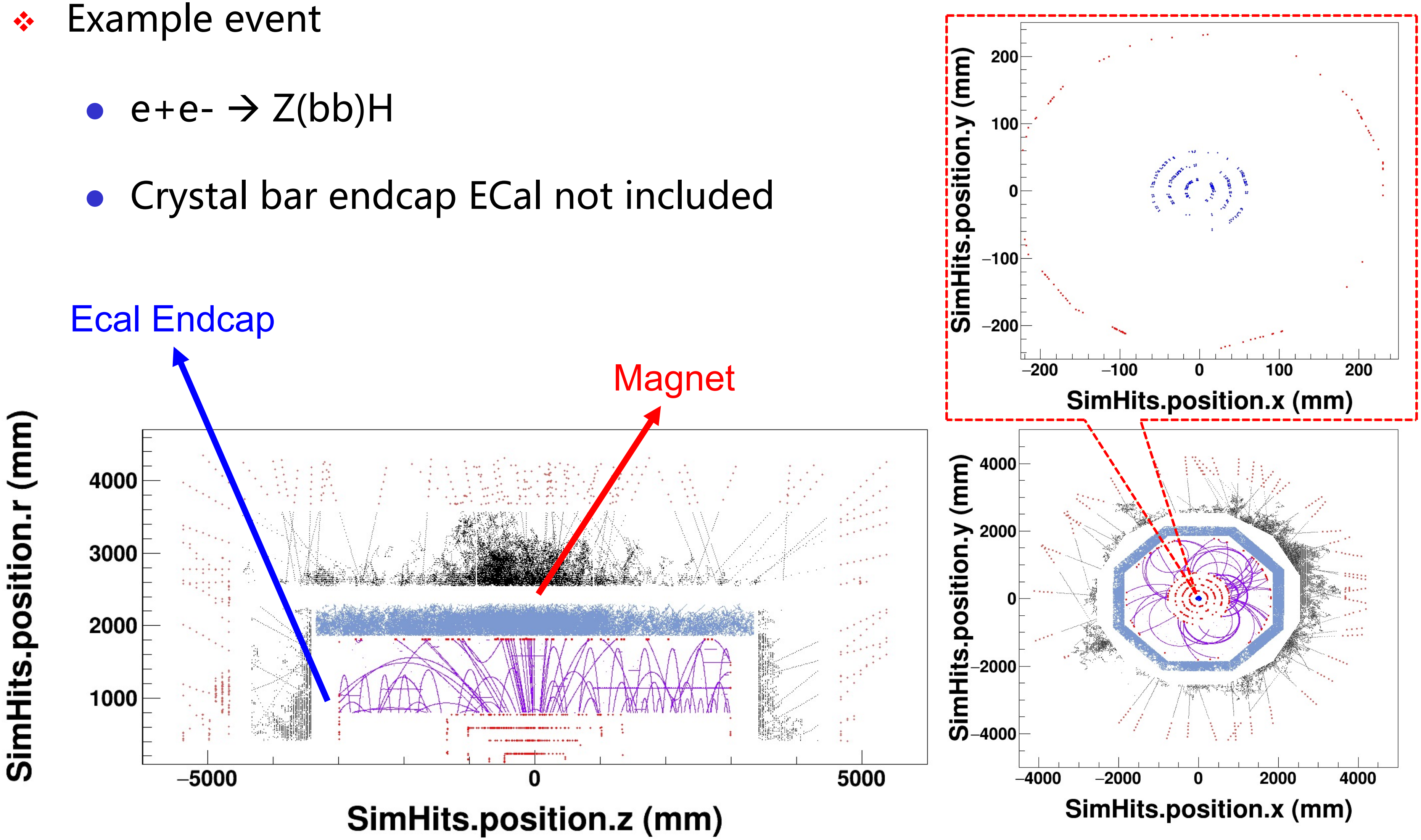
- Configurable # of staves (baseline: 12)
- Configurable components
  - Iron-Air-module-Air-Iron
  - Module
    - Scintillator as sensitive





Simulated Hits

- Example event
  - e+e- → Z(bb)H
  - Crystal bar endcap ECal not included



Summary

- CEPC Simulation study going well in the CEPCSW
- Could support various detector concepts R&D
- The new conceptual detector under study:
  - PID tracker
  - Crystal bar ECal & Scintillator glass HCal
  - Thin magnet
- Dedicated reconstruction algorithms under development
- Could meet the requirement of physics study in the near future
- Everyone welcome to have a try …

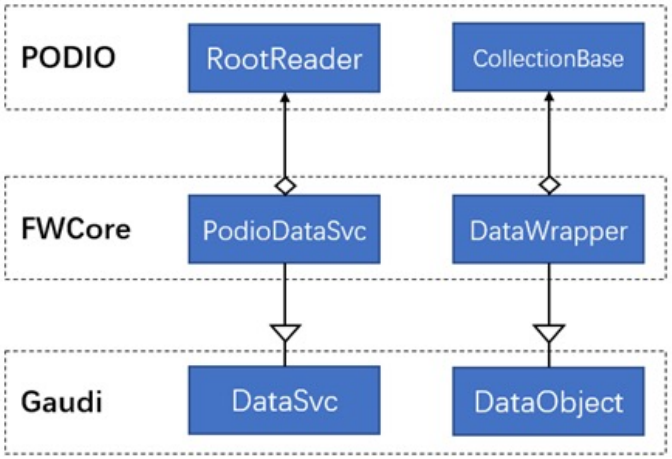
from https://github.com/cepc/CEPCSW

```
$ git clone git@github.com:cepc/CEPCSW.git
$ cd CEPCSW
$ git checkout master # branch name
$ source setup.sh
$ ./build.sh
$ ./run.sh Examples/options/helloalg.py
```

Extras

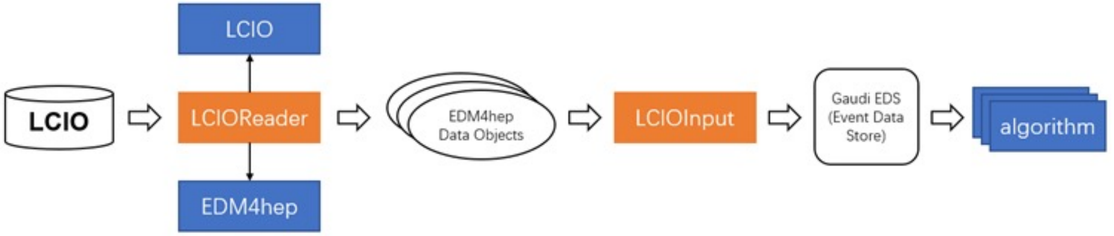
k4FWCore: Data Management in Gaudi

- k4FWCore provides the management of EDM4hep in Gaudi.
  - PodioDataSvc: data I/O (PODIO)
  - DataWrapper: PODIO data collection managed in Gaudi's Event Data Store.



https://github.com/key4hep/k4FWCore

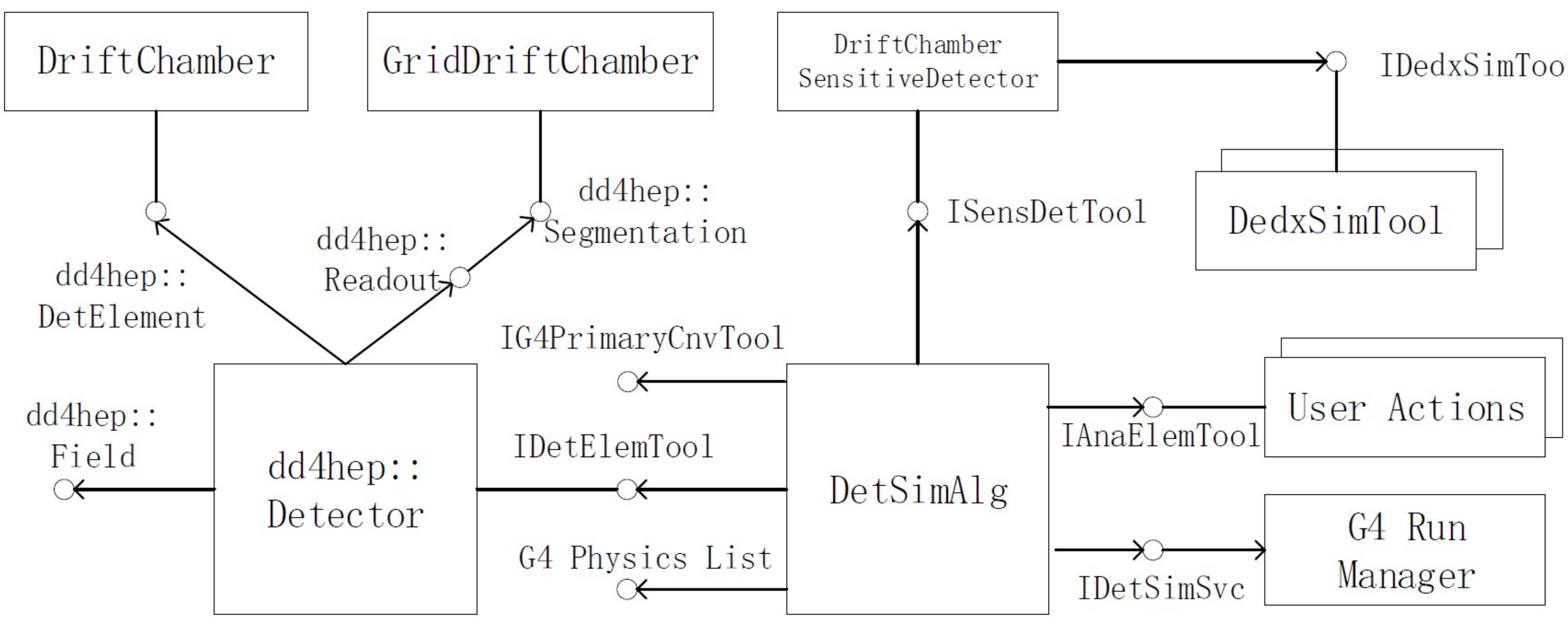
- k4LCIOReader: generate EDM4hep data collections on the fly from LCIO input files in Gaudi.



Developed by Jiaheng Zou (IHEP), https://github.com/key4hep/k4LCIOReader

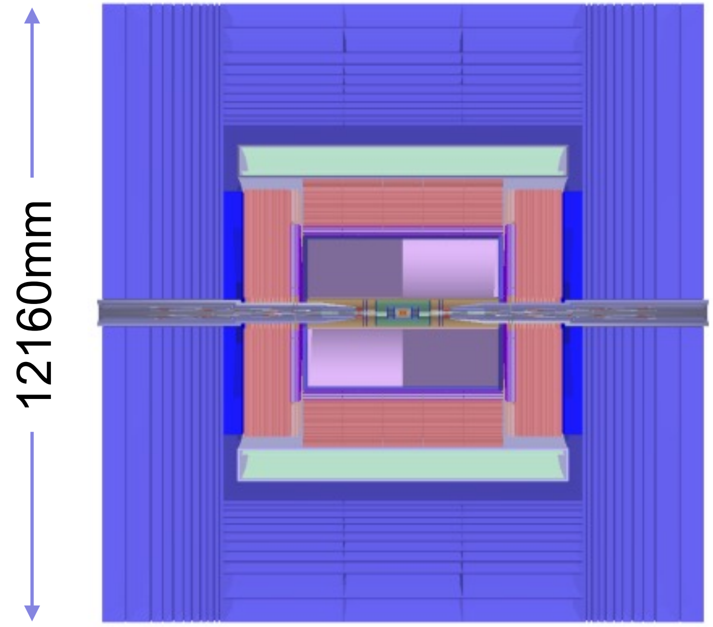
Simulation framework (3)

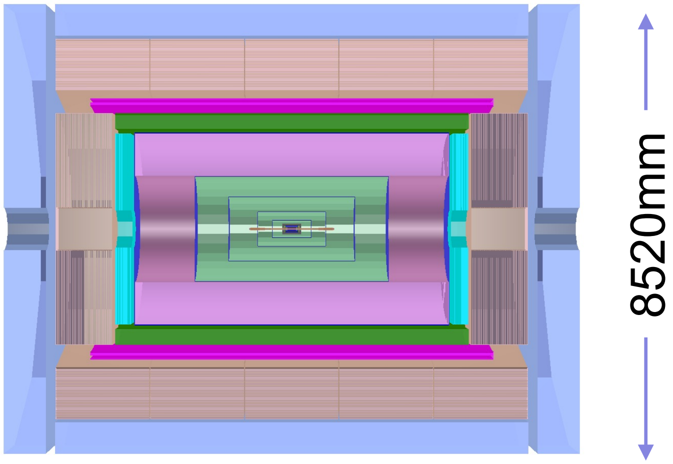
- An example: Drift Chamber
  - The drift chamber software is developed from scratch.
  - The simulation of dN/dx is implemented in Gaudi tools.
  - Non-uniform B-fields is also implemented for the performance study.



Detector Concepts

- CEPC developed several detector concept in past ten years (2012-2022), and two concepts are most important in history: one is the baseline design for conceptual design report (CDR) and another is the fourth conceptual detector design proposed in 2021 spring.
- Besides these two baseline concept in study timeline, many alternative detector concepts are also studied, such as design with full silicon tracker, innovative detector for electron-positron accelerator (IDEA), rotated crystal calorimeter. In these detector concepts, part of sub-detectors are replaced with different types and others are kept same as the baseline.





CDR Baseline Detector Simulation

- ILD-like detector, replaced with new MDI and optimized size, layout
- Simulation software
  - cepcsoft: migrated from ILCSoft (thanks ILC group), separated simulation and reconstruction
    - modified Mokka as description: correction, more support, new sub-detector drivers
    - database and Mokka command as parameter input
    - Geant 4.9.6.p02
  - CEPCSW: developing in Key4hep based on Gaudi, complete simulate-reconstruct-analysis chain or separated
    - DD4hep: migrated from Mokka drivers (lcgeo and new constructors)
    - compact files as parameter input
    - Geant 4.10.06.p02

Progress

- Besides DC and Ecal, other sub-detectors have similar structure with CDR detector concept, in order to continue use some reconstruction for silicon tracker and hadronic calorimeter for study.
- Step by step, the CDR-like sub-detectors are replaced with new detector concept.
- At any step, a full simulation with complete detector is possible for study.
- At first step, only dominant components are considered in simulation, such as support layer and sensitive layer, and implementation of parts of mechanics and electronics are ongoing.
  - New vertex detector
  - Detail magnet