Status of CEPC Software

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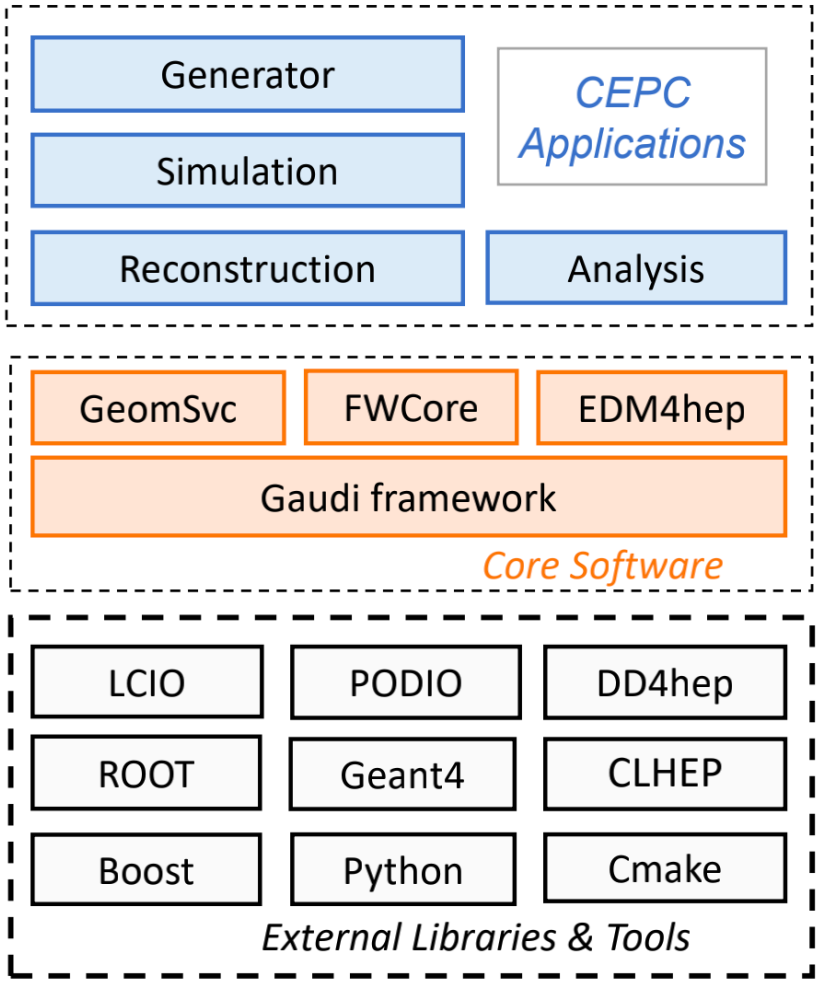
CEPC Day
Feb. 28, 2024

CEPCSW

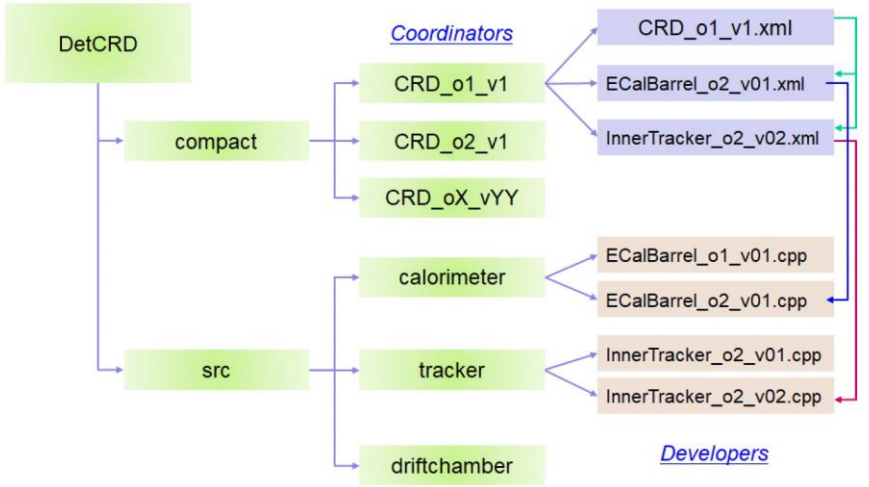
- CEPC software development first started with iLCSoft
  - Reused most software modules: Marlin, LCIO, MokkaC, Gear
  - Developed its own software components for simulation and reconstruction
- CEPC software (CEPCSW) prototype was proposed at the Oxford workshop in April 2019
- Consensus among CEPC, CLIC, FCC, ILC and other future experiments was reached at the Bologna workshop
  - Develop a Common Turnkey Software Stack (Key4hep) for future collider experiments
- CEPCSW software structure
  - Core software
  - Applications: simulation, reconstruction and analysis

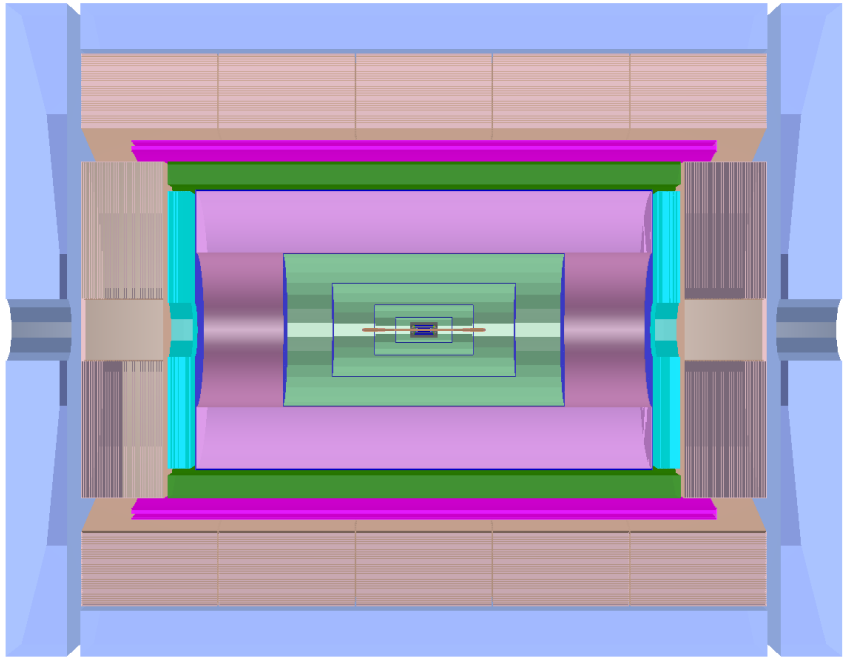
https://github.com/cepc/CEPCSW



Detector Description

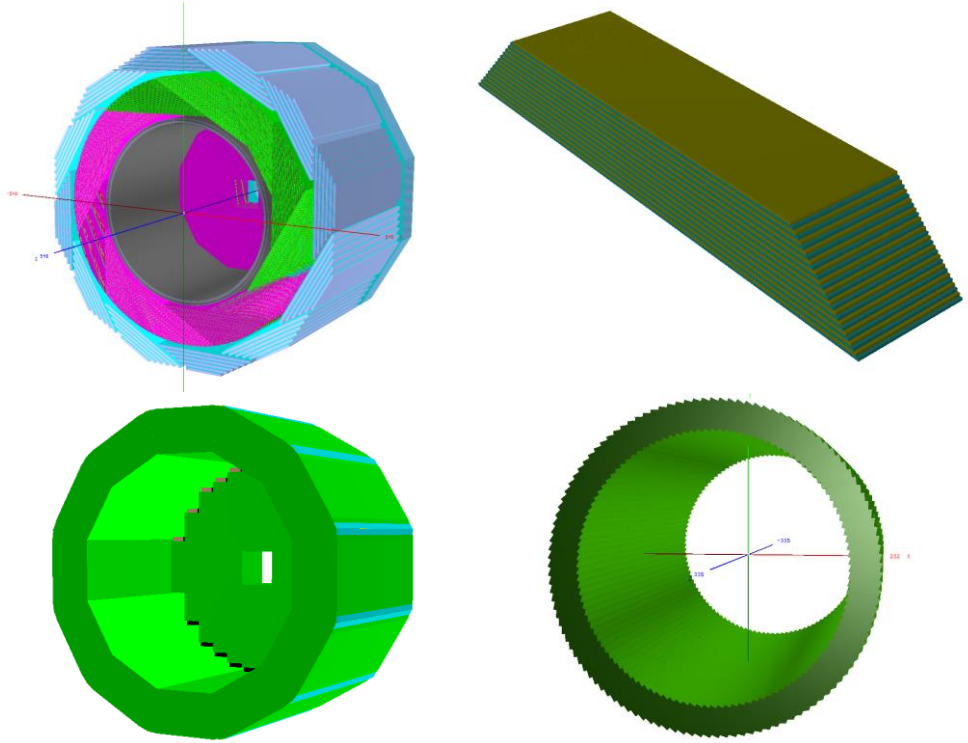
- DD4hep is adopted to provide a full detector description with a single source of information
- CEPC v4 as baseline: TPC & solenoid outside HCal
- CEPC reference detector
  - ➢ 4th conceptual detector
    - ✓ with silicon tracker as main tracker and DC as PID
    - ✓ Coil inside Hcal
  - ➢ Branches
    - ✓ CRD_o1_v01: silicon pixel detector (SPD) as SET/SOT
    - ✓ CRD_o1_v02: silicon strip detector (SSD) as SET/SOT
    - ✓ CRD_o1_v03: MOST2 vertex vs CRD_o1_v01
    - ✓ CRD_o1_v04: 10mm beam pipe vs CRD_o1_v01





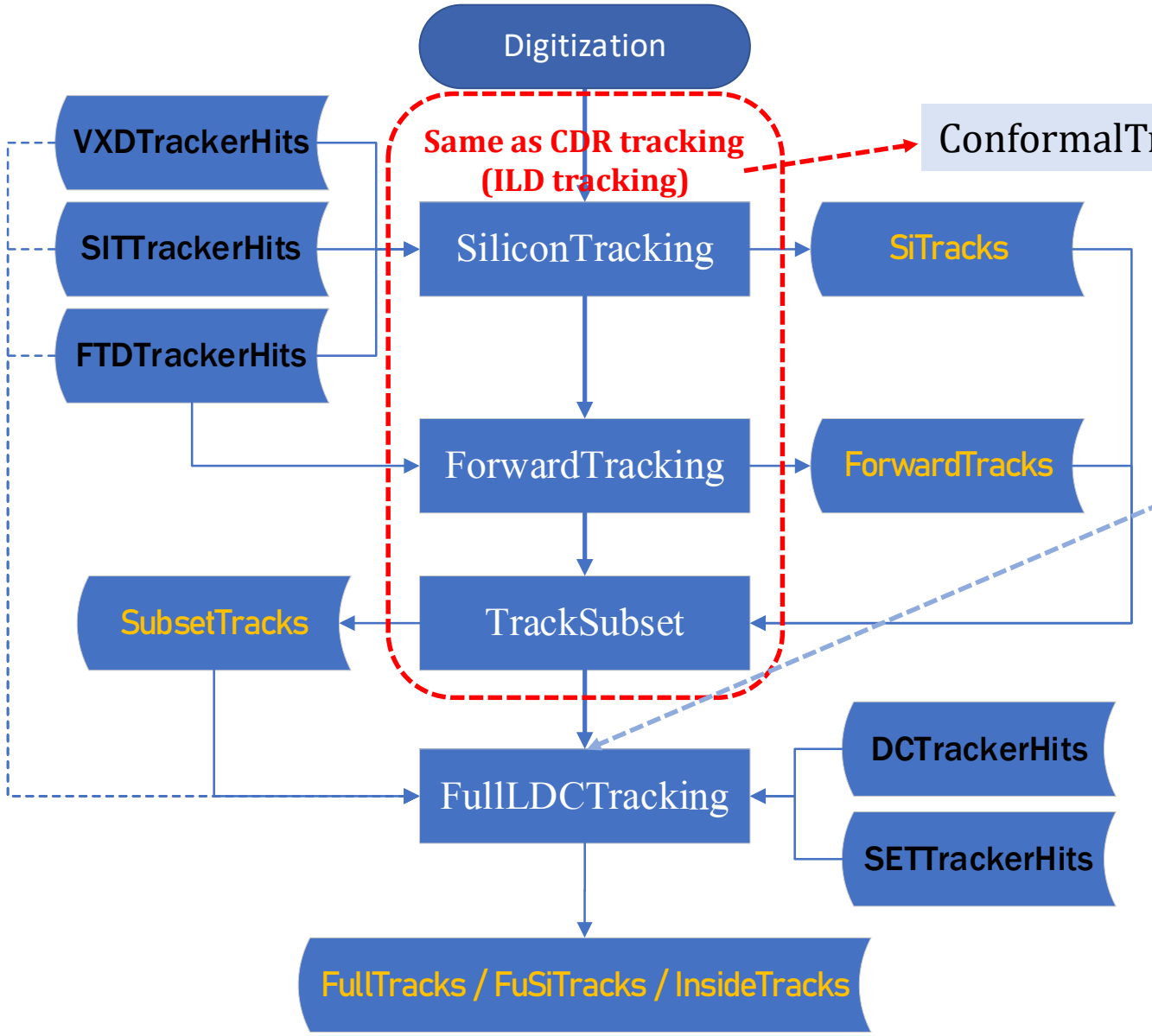
Detector Description

- MDI: Beampipe
- LumiCal: todo
- Vertex
  - VXD04 (ILD-like)
  - SiTrackerStaggeredLadder (MOST2)
- Silicon tracker
  - SIT_SimplePixel, SIT_SimplePlanar
  - SET_SimplePixel, SET_SimplePlanar
  - FTD_SimpleStaggered, SiTrackerSkewRing (support skew angle)
  - TODO: dead region
- DC
  - DriftChamber
- TPC
  - TPC10: to update according TDR

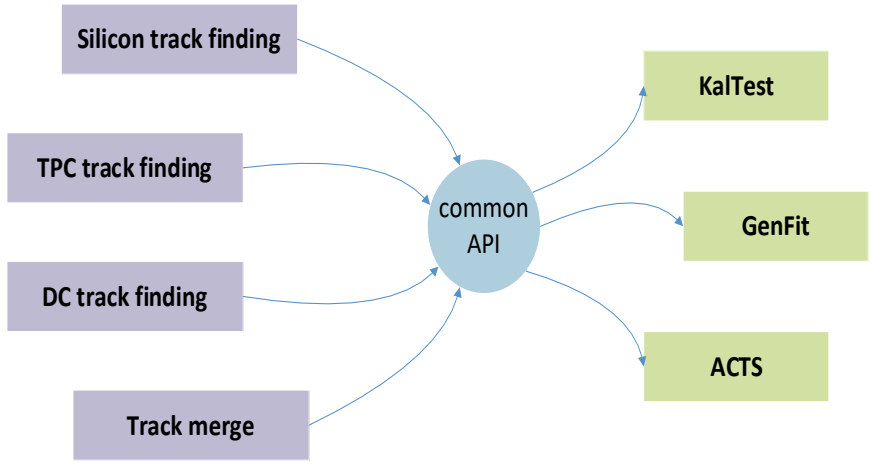


- Ecal, Hcal & Muon
  - SEcal05 (si-W)
  - CRDEcal (4D crystal bar)
  - RotatedCrystalCalorimeter (stereo crystal)
  - SHcalRpc01 (octahedron), SHcalRpc02 (optional side)
  - SHcalSc04
  - Yoke05
  - RotatedPolyhedraBarrelCalorimeter

Reconstruction: Tracking



In each tracking algorithm,
Kalman filter is called once



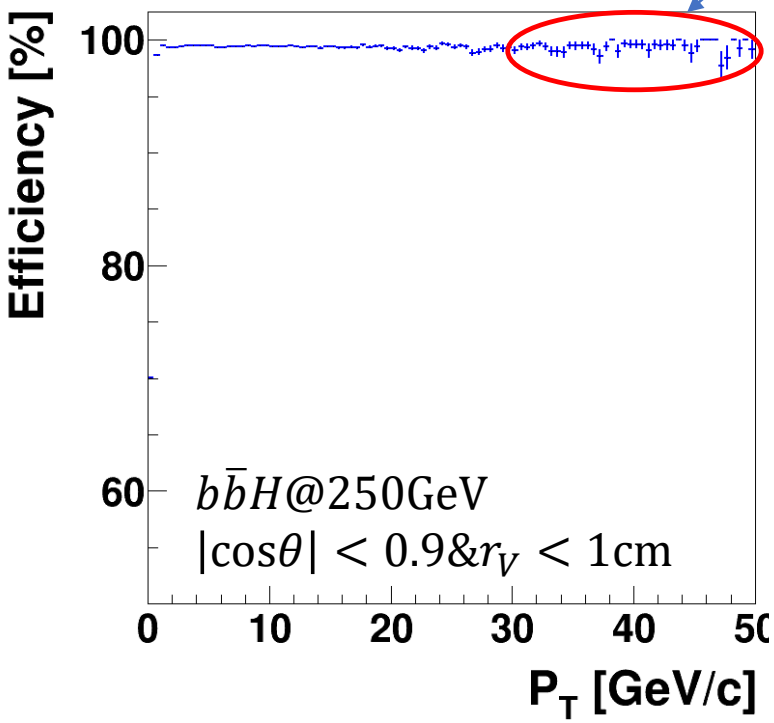
Matrix manager for finding and fitting

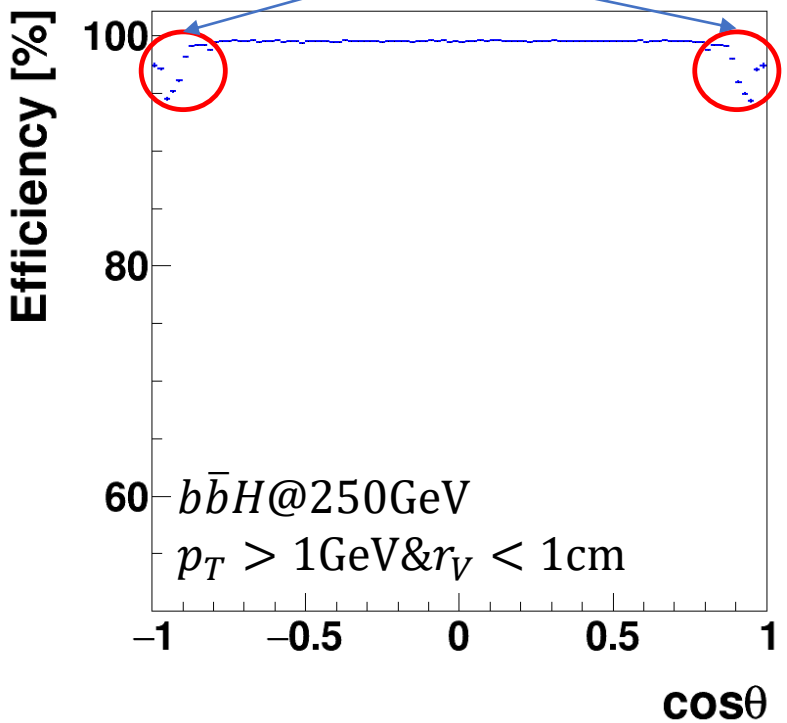
Tracking Efficiency

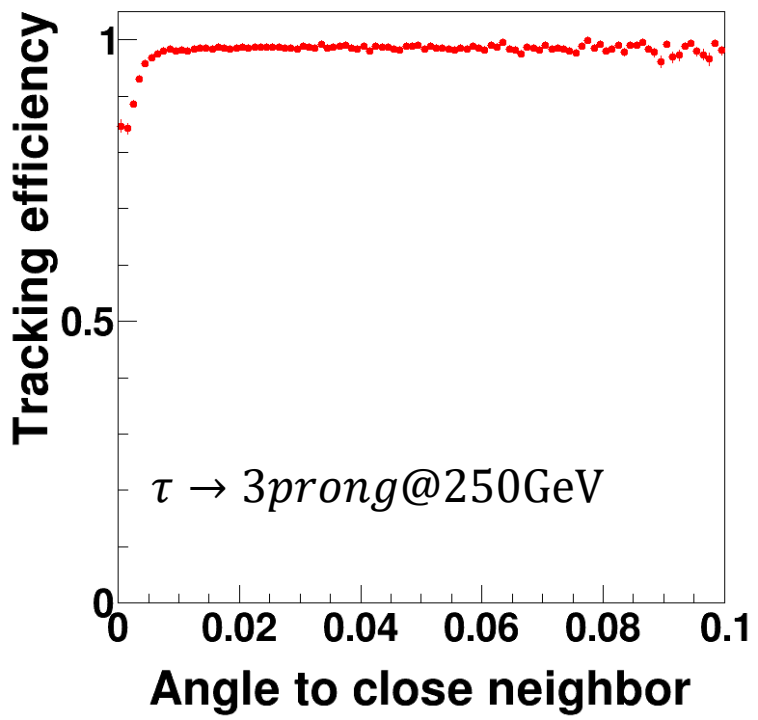
- Observed particles (N): has ≥6 linked tracker hits
  - Has linked track (Nf)
  - ε=Nf/N
- Understandable

statistical with less tracks

CDR VXD + 5layer endcap: not enough hits in forward region



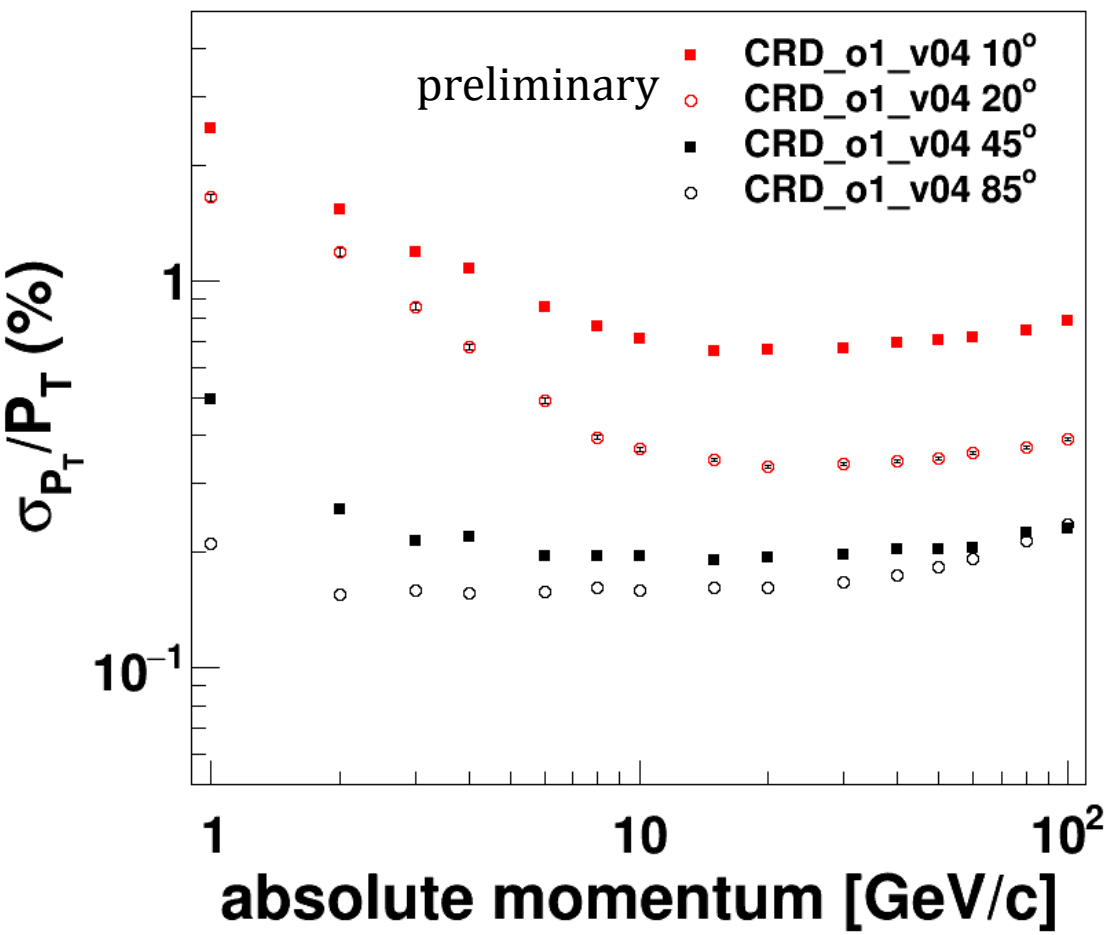


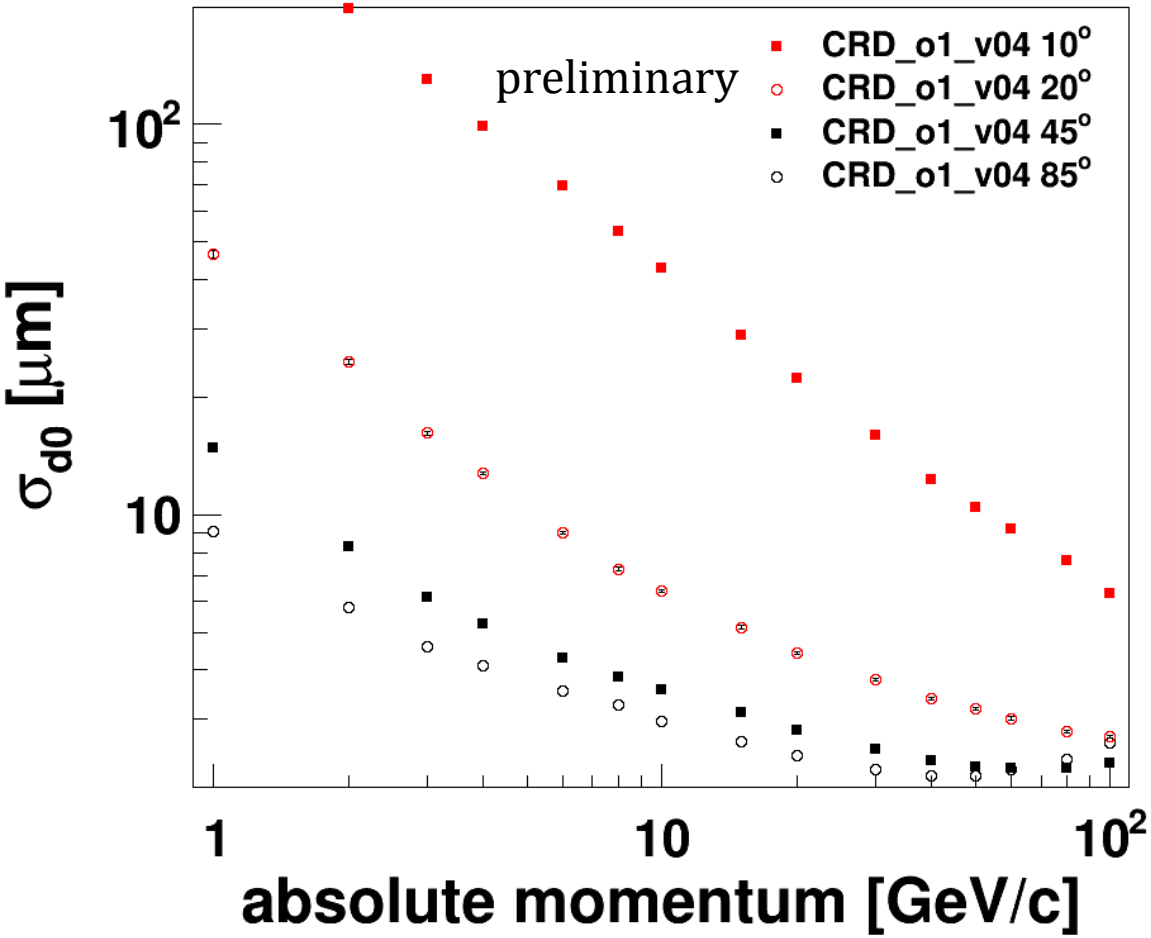


ILD tracking @ CRD_o1_v04 preliminary

Track Resolution

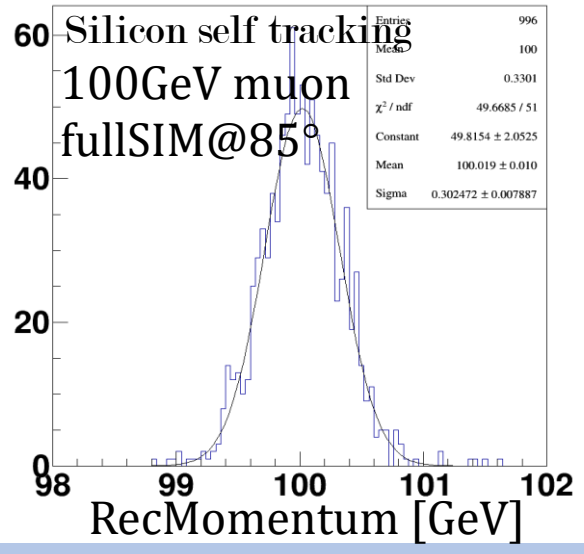
- σ_{IP}=(15μm, 36nm, 2.8mm)

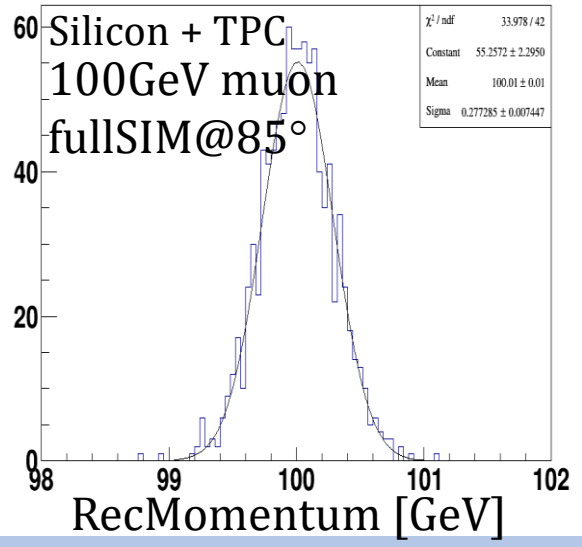


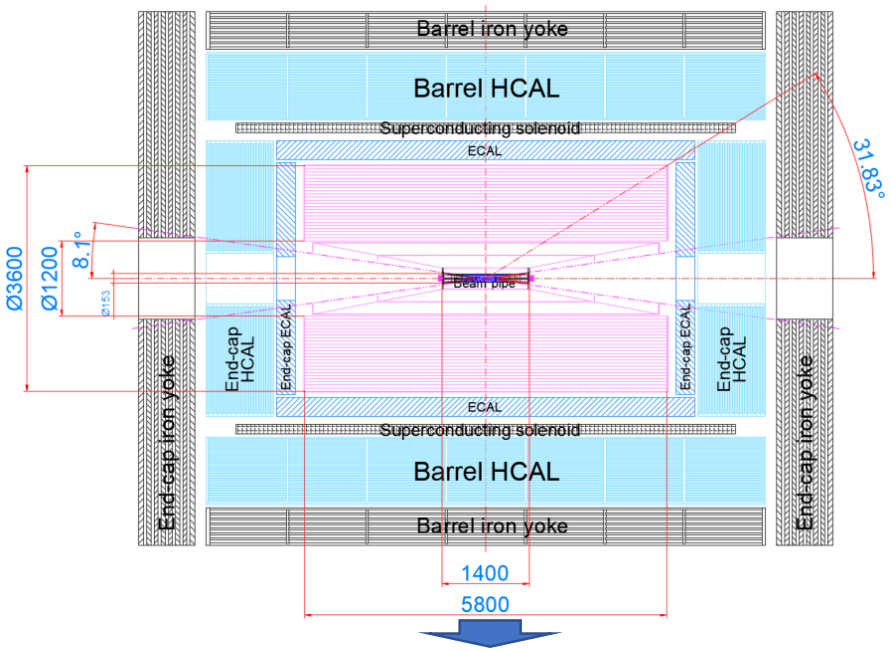


Tracking (from 4th to ref-TDR)

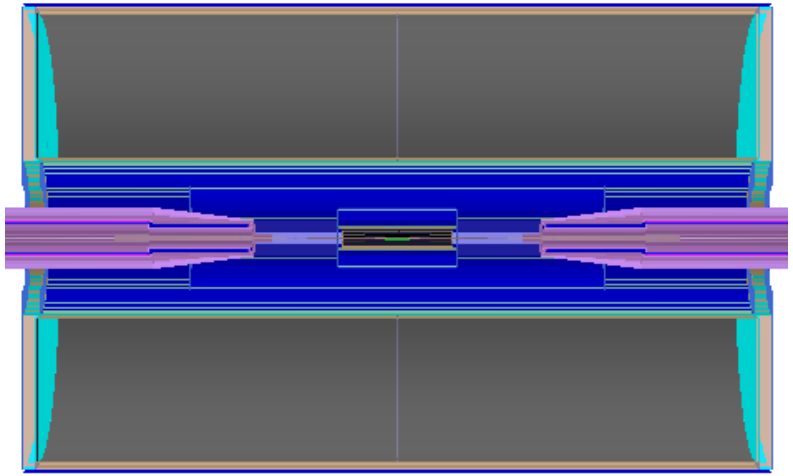
- First step: work chain validation
  - Geometry: √
  - Digitization: √
  - Reconstruction: √
- Next step:
  - Geometry update
  - Digitization:
    - ➢ Study of affect on performance
  - Reconstruction:
    - ➢ Performance with background and noise





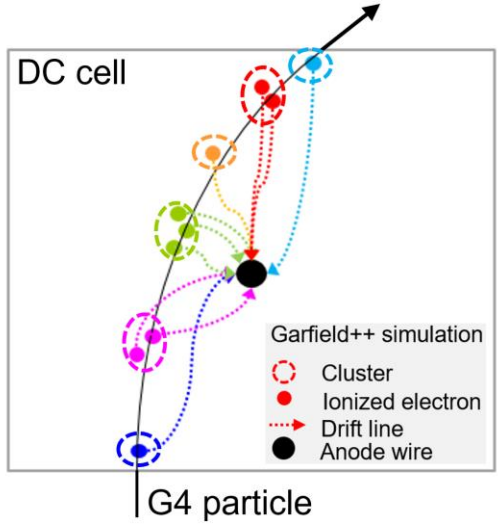


MDI+Tracker (Silicon+TPC)



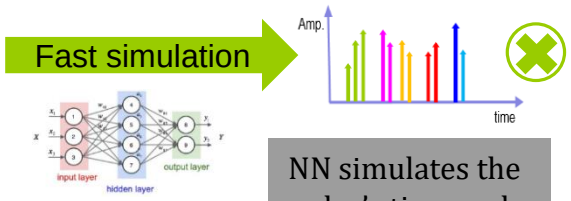
VXD material budget (MOST2 Cu→Al), less than MOST2 but >CDR

Drift Chamber Simulation

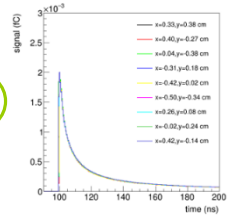


Garfield++ waveform simulation, highly time-consuming

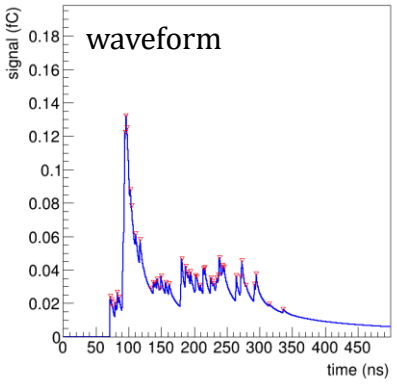
Fast simulation

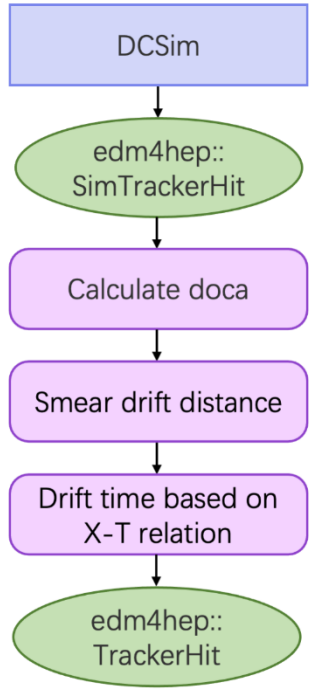


NN simulates the pulse's time and amplitude



Pulse shape template

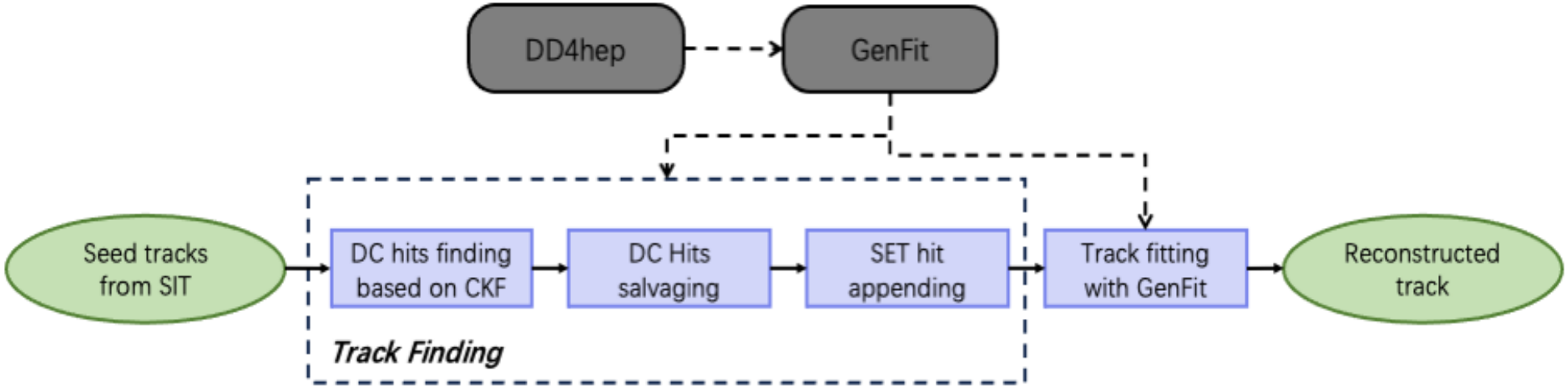




- Simplified digitization method was implemented to support the development of tracking algorithm
- Doca is smearing with a width equivalent to the wire resolution (110um) and converted to drift time based on X-T relation
- TrackHeedSimTool was implemented by combining Geant4 and Garfield++ to simulate the complete response of the gaseous detector

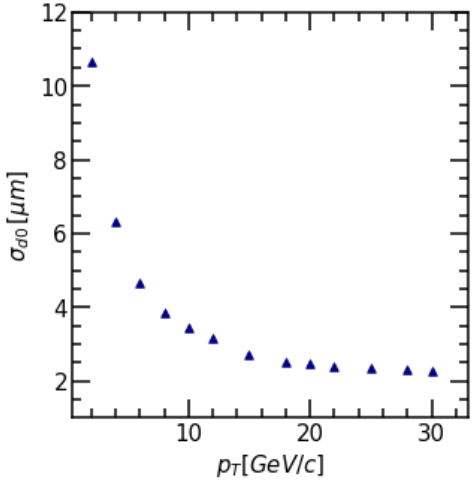
Drift Chamber Reconstruction

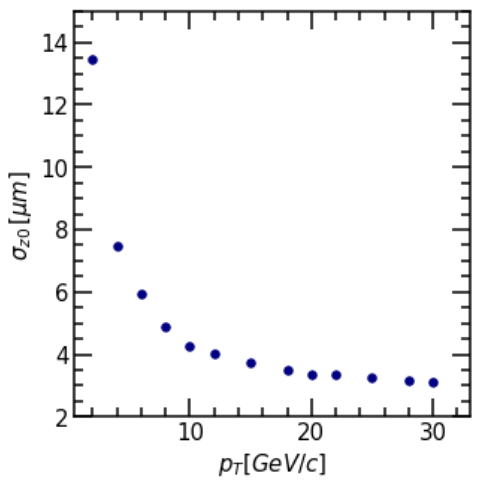
- Tracking with combinatorial Kalman Filter (CKF) method, combing track recognition and track fitting
- Track segments in silicon detector is used as seed tracks, are extrapolated to the DC, and DC hits belonging to the track are collected.
- Track fitting with the tool of Genfit

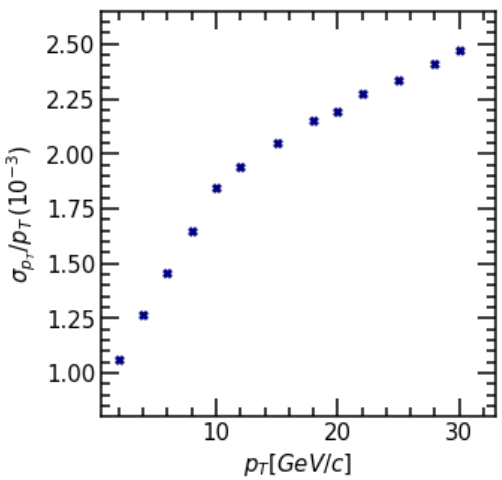


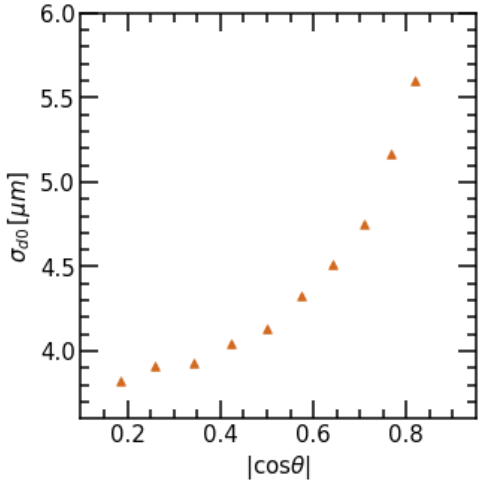
Drift Chamber Reconstruction

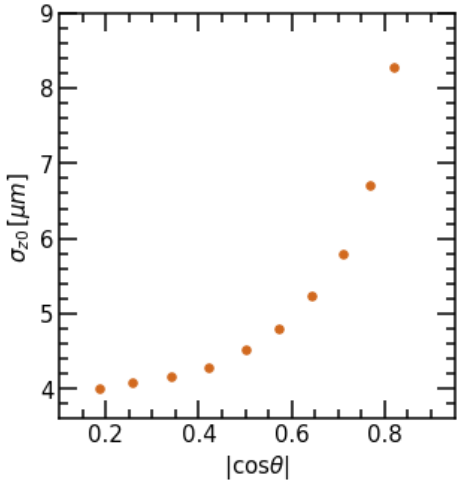
Track parameters resolution

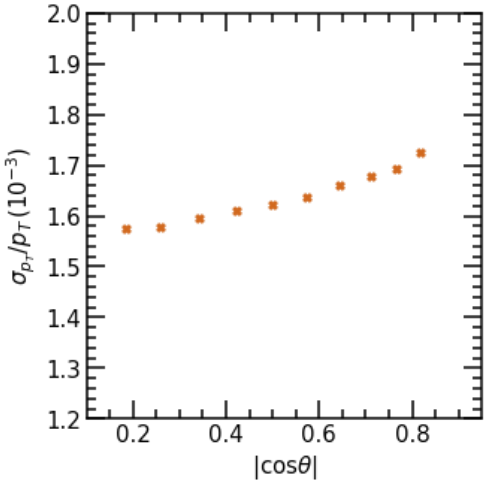


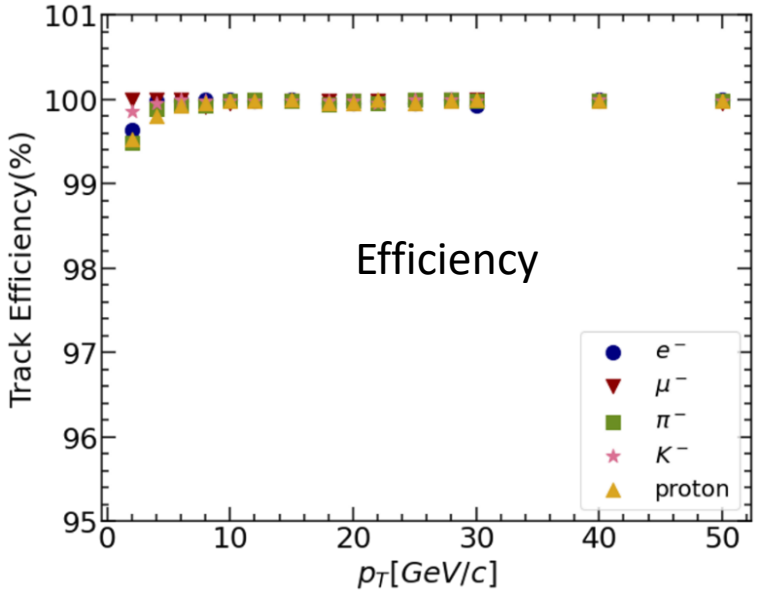


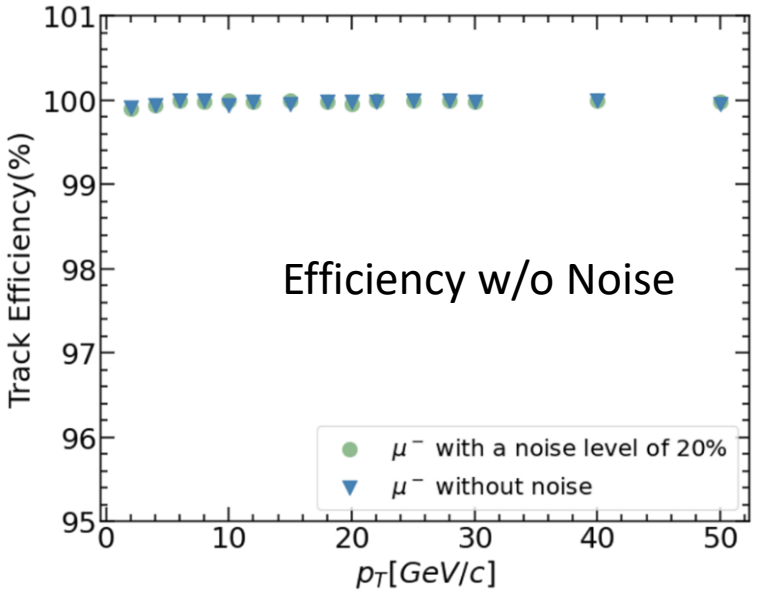






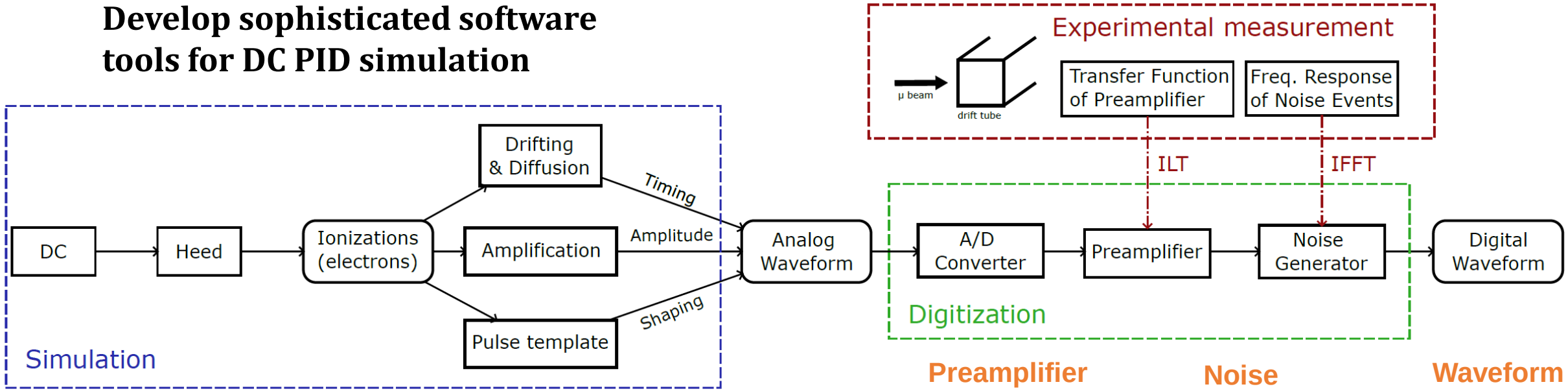




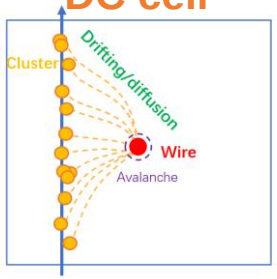


Cluster Counting dN/dx Simulation

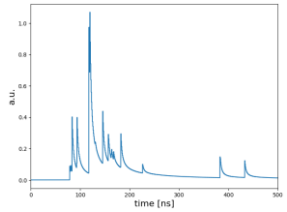
Develop sophisticated software tools for DC PID simulation



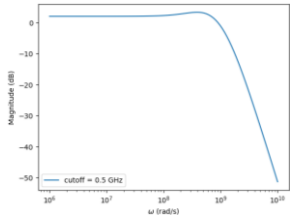
DC cell



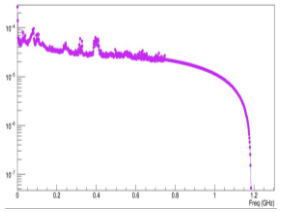
Induced signal



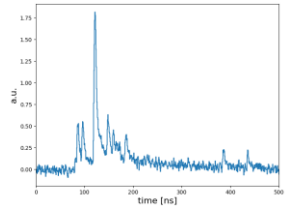
Preamplifier



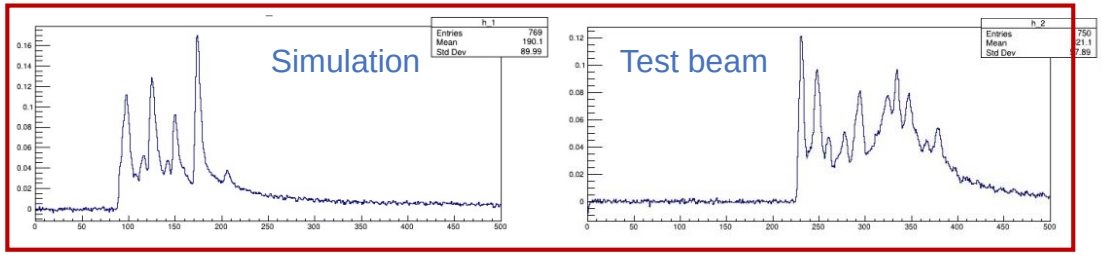
Noise



Waveform

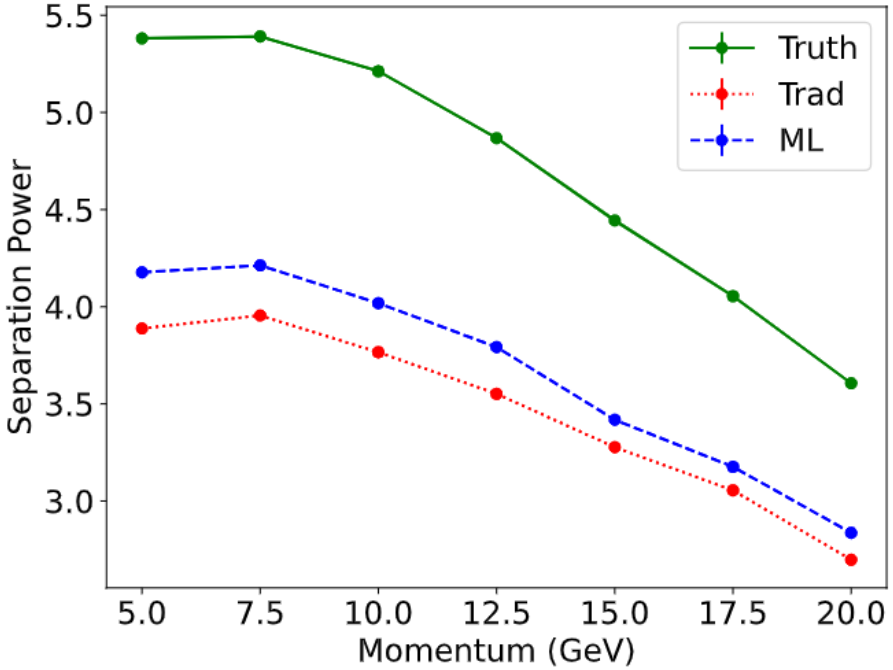


Tuned MC is comparable to data



dN/dx Reconstruction and PID Performance

- Traditional algorithm
  - Derivative-based peak finding
  - Peak merging clusterization
- ML algorithm (supervised, MC)
  - LSTM-based peak finding
  - DGCNN-based clusterization
- ML algorithm (semi-supervised, data)
  - Domain adaptation

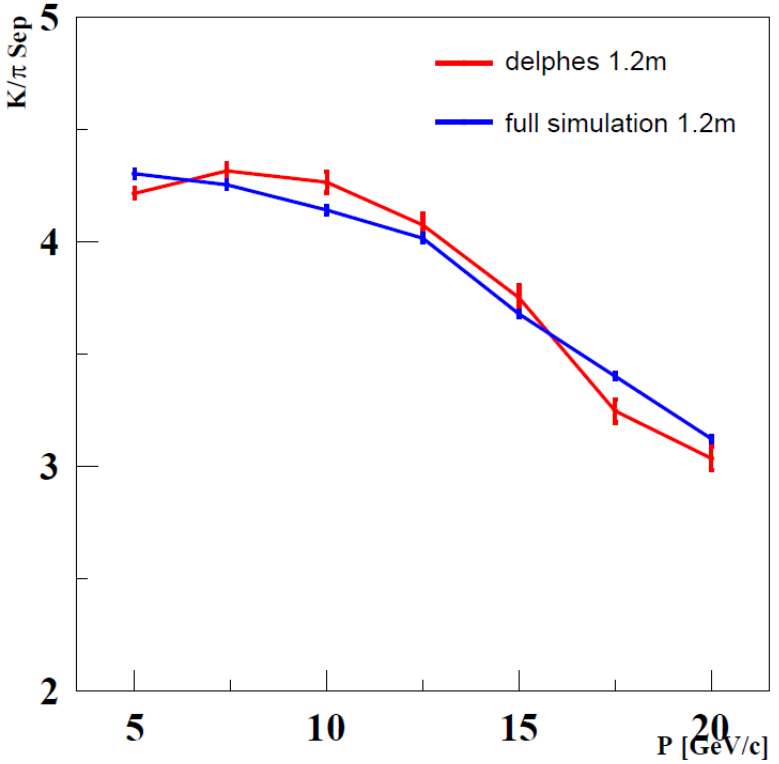


- **For 1m track, close to 3σ K/π separation @ 20 GeV/c**
- **~10% improvement with ML (equivalent to a detector with 20% larger radius)**

Track-level Model for CEPCSW

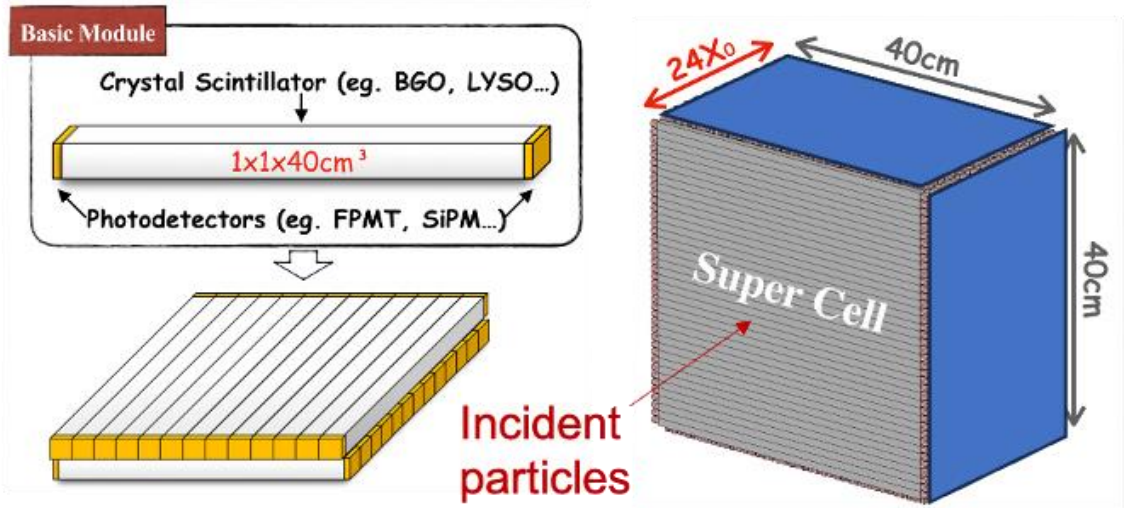
- Taking input from full simulation
- Parameterization interface:
  - Input: βγ and cosθ of a track
  - Output: Track-level dN/dx
- Barrel model is completed. An end-cap model is being developed.

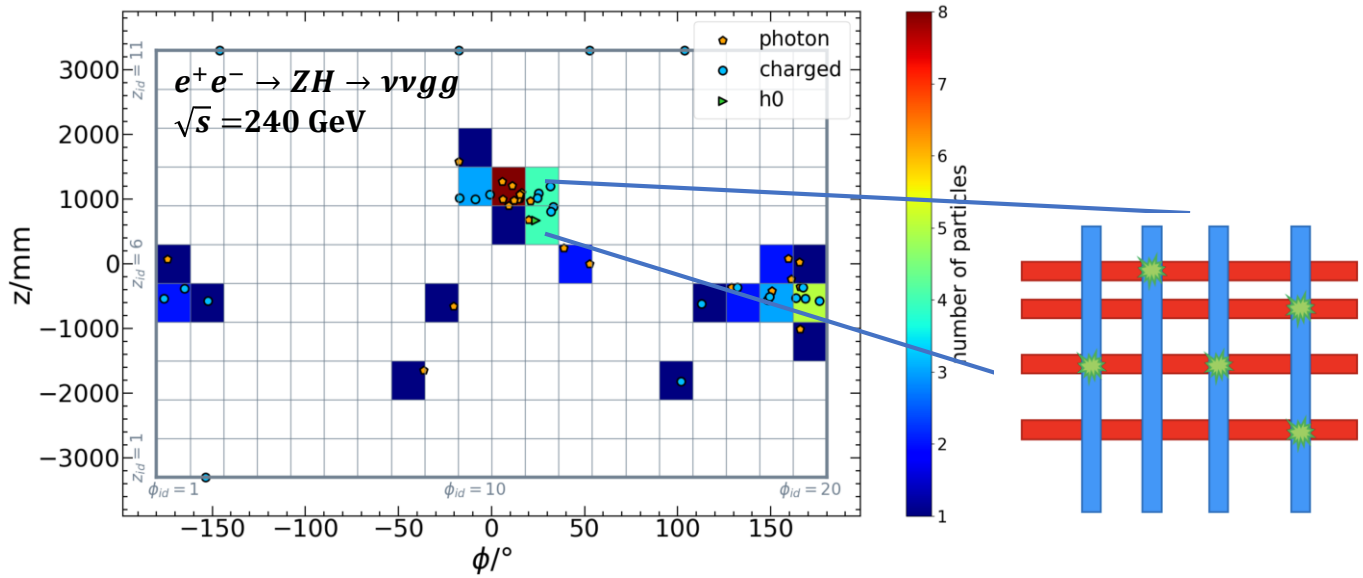
K/π separation power



Track-level model is consistent with full simulation

Simulation and Simplified Digitization of ECAL



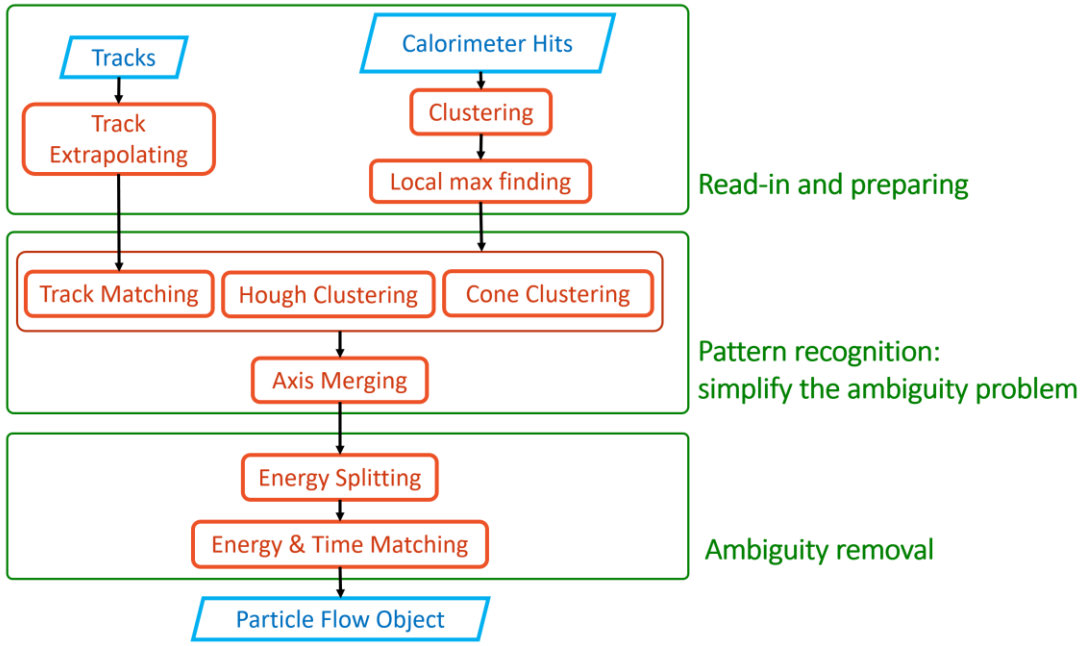


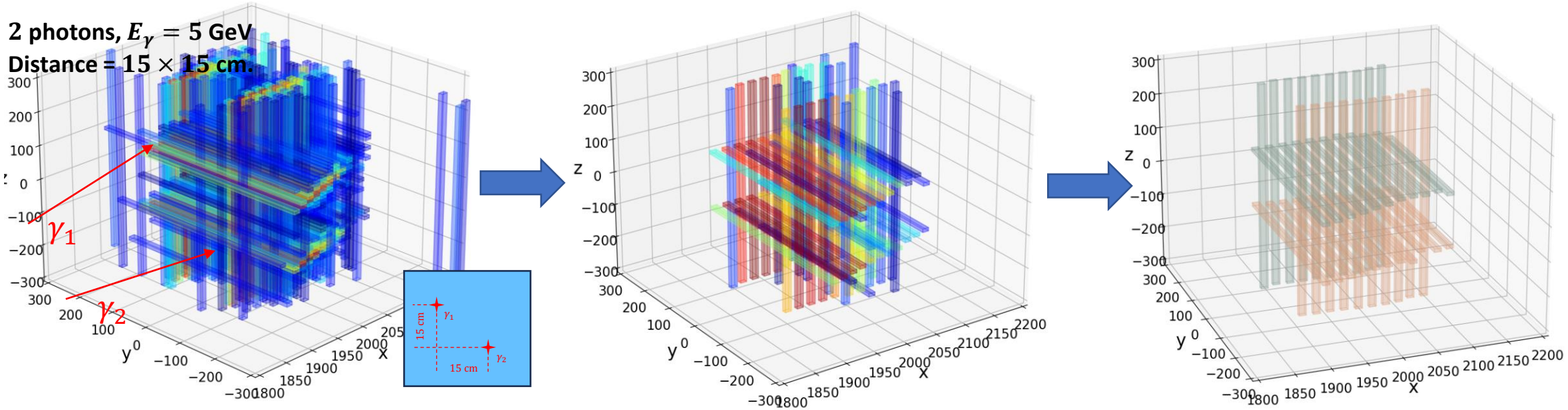
- Global: octagonal ECAL, $R = 1.86$ m, $L = 6.6$ m, $H = 28$ cm
- Crystal Bar: $1 \times 1 \times 40{\sim}60$ cm^3
- Super Cell: 2 layers of perpendicular crossing bars $\sim 40 \times \sim 60 \times 2$ cm^3
- Ideal digitization: no dead area, supporting, mechanics, etc.

Reconstruction of ECAL

Software task:

* Clustering
* Pattern recognition
* Overlap: energy splitting
* Ambiguity problem





Summary and Plan

- Toward TDR: A CEPCSW Version Release
- Geometry:
  - Almost all options are ready
  - Update according the latest design
  - Endcap, ……
- Digitization: some requirements for electronics
- Reconstruction/Performance
  - Vertex + Silicon Tracker + TPC available
  - DC tracking & dN/dx will be ready soon
  - Reconstruction of ECal is under developing
  - Achieved the first stage target of Arbor porting
- Beam background
  - Interfaces and convert need to be tuned
- Automated Validation System

Thank you !