CEPCSW tutorial: calorimeter and PFA

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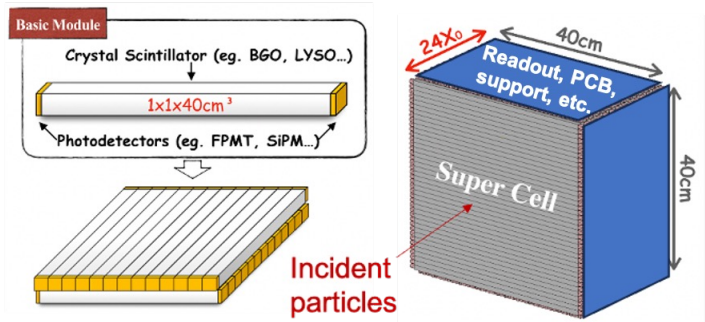
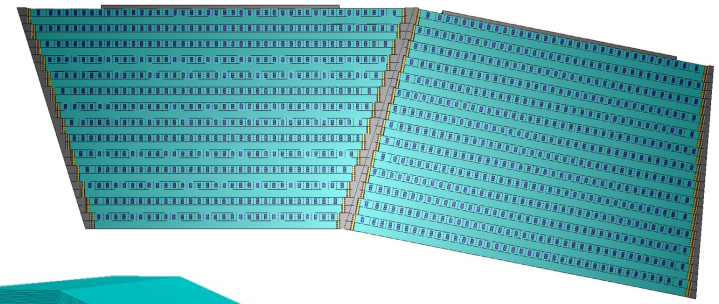
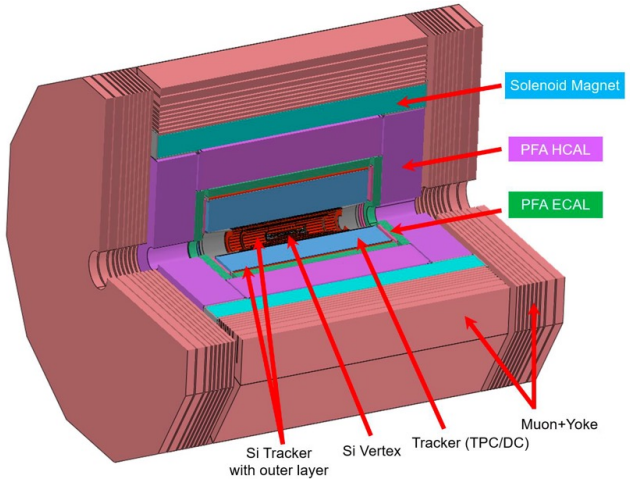
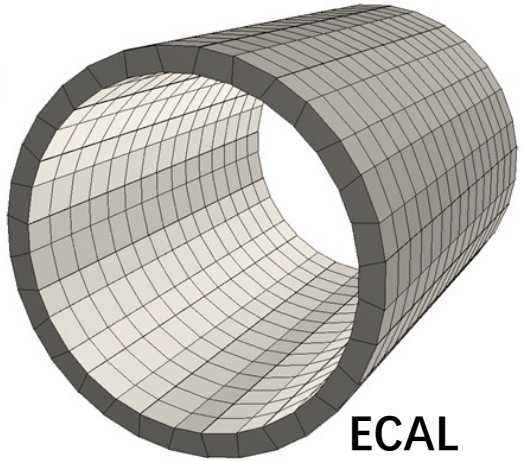
Introduction

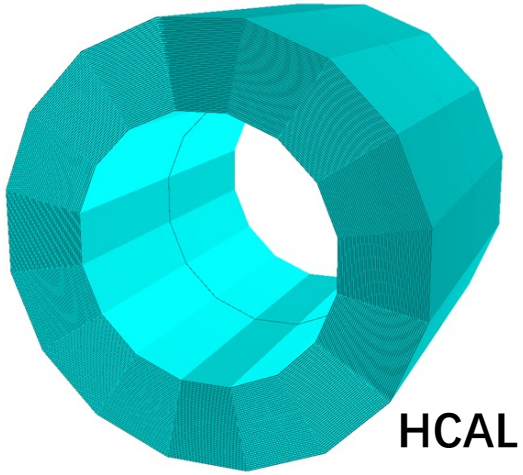
- **PFA calorimeter in CEPC Reference TDR design**
  - Physics target: boson mass resolution $3\sim4\%$.
  - A Homogeneous crystal ECAL
    - Optimal intrinsic EM resolution $\sigma_E/E\sim3\%/\sqrt{E}$.
    - Minimal longitudinal dead material: orthogonal arranged bars.
    - Compatible with PFA.
  - Scintillating glass HCAL
    - High density + enough light yield = better hadronic resolution: $30\sim40\%/\sqrt{E}$
    - Lower cost than crystal.
    - High granularity tiles for PFA.





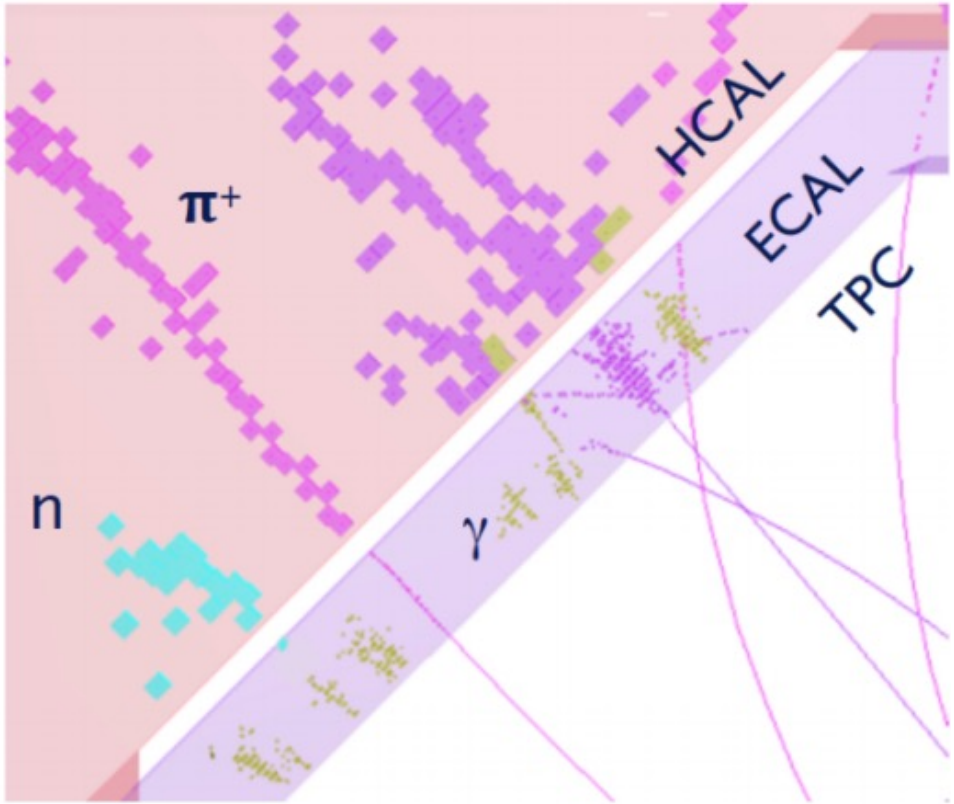






Introduction

- **Particle flow approach: measure objects with most proper sub-detector.**
  - Tracker (charged particles) + ECAL (photons) + HCAL (neutral hadrons)
  - High granularity calorimeter + pattern recognition algorithms (PandoraPFA, ArborPFA).



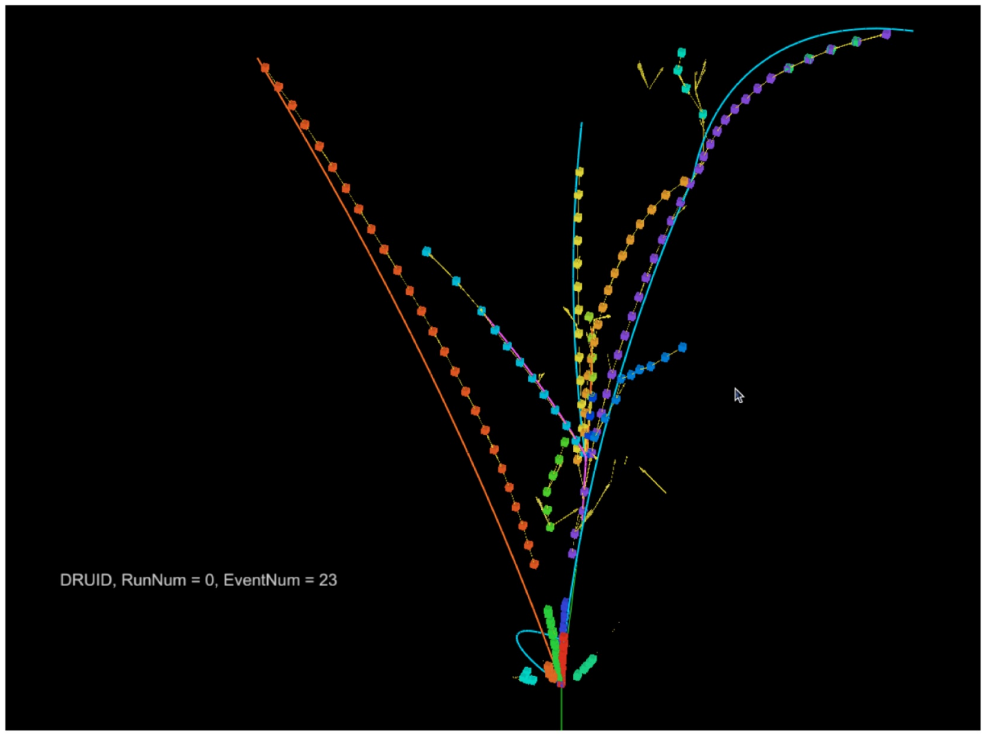
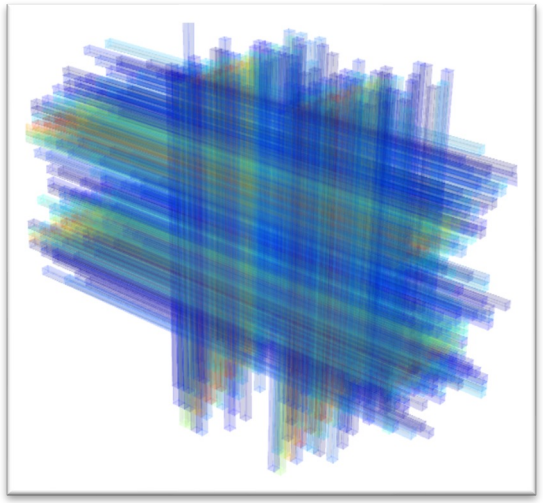


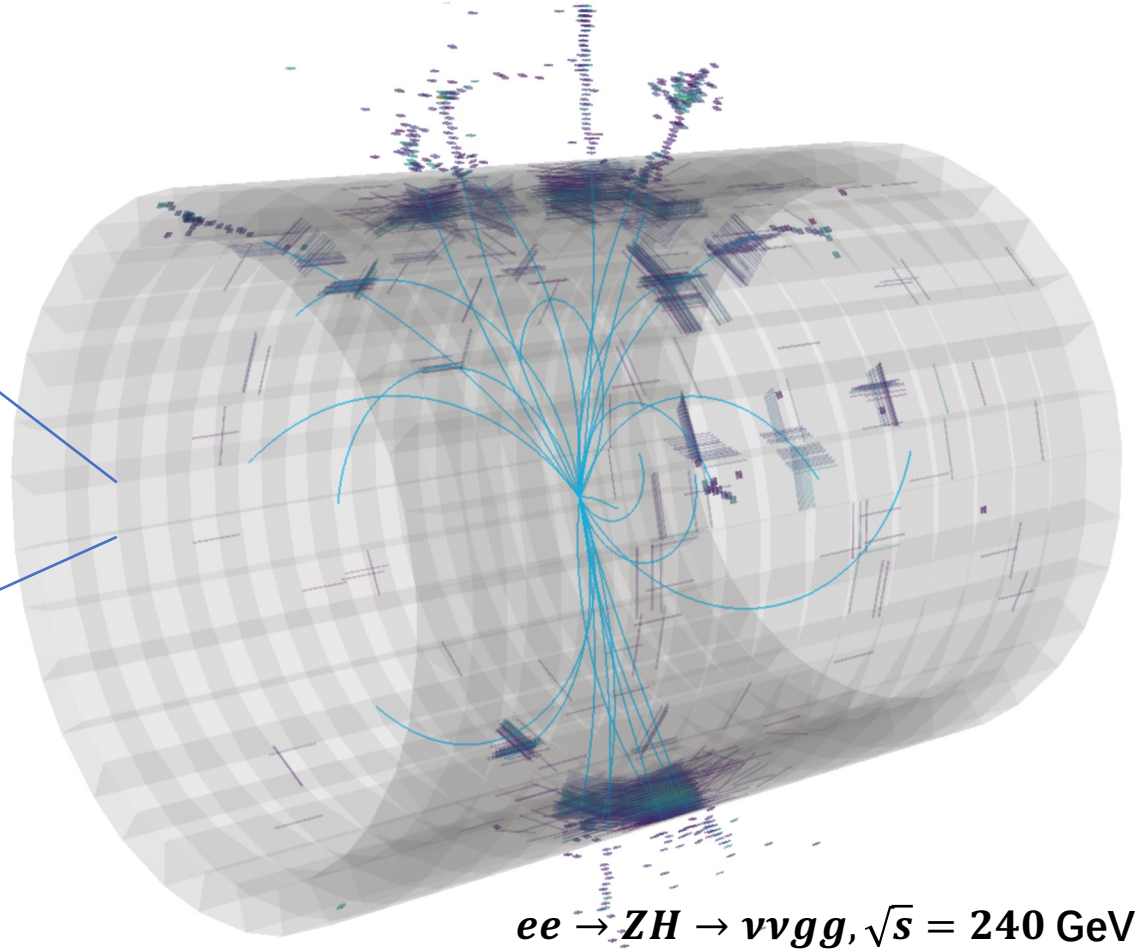
Figure 3: A 20 GeV K_L^0 shower reconstructed by Arbor Algorithm

Introduction

- **New PFA for CEPC reference detector: CyberPFA for crystal bar ECAL.**

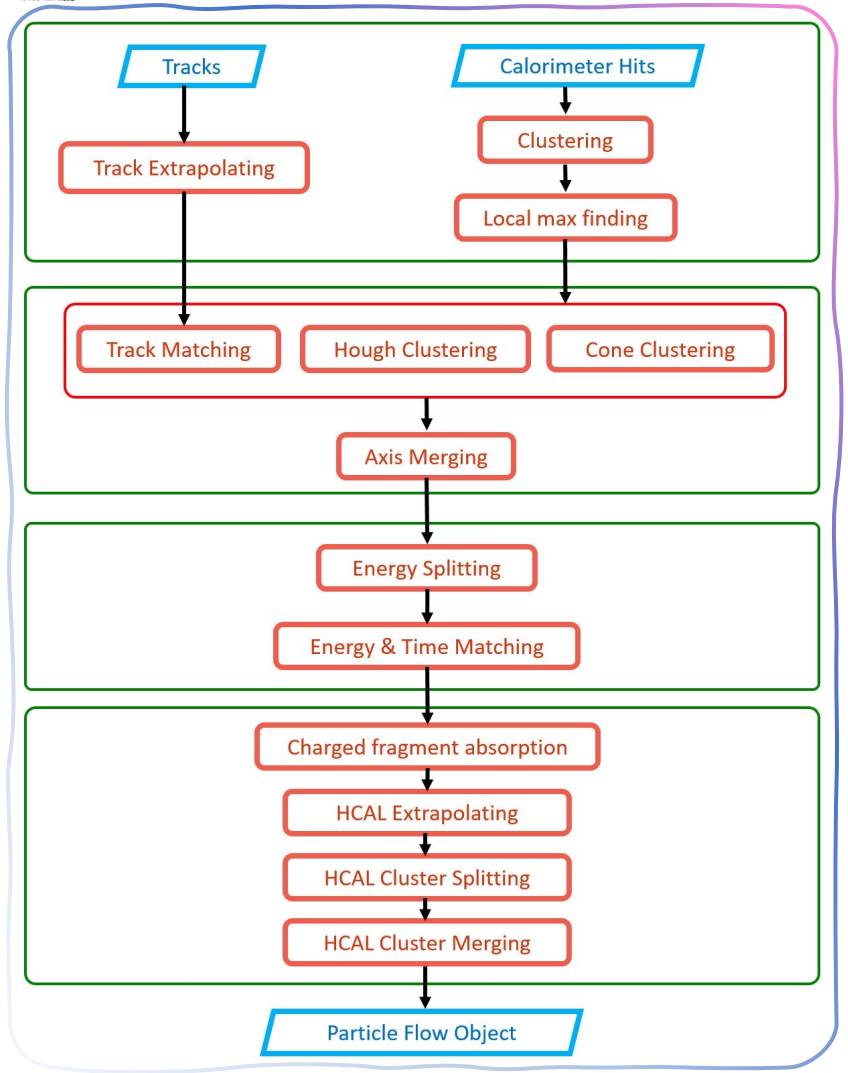


2 photons, distance = 15 cm



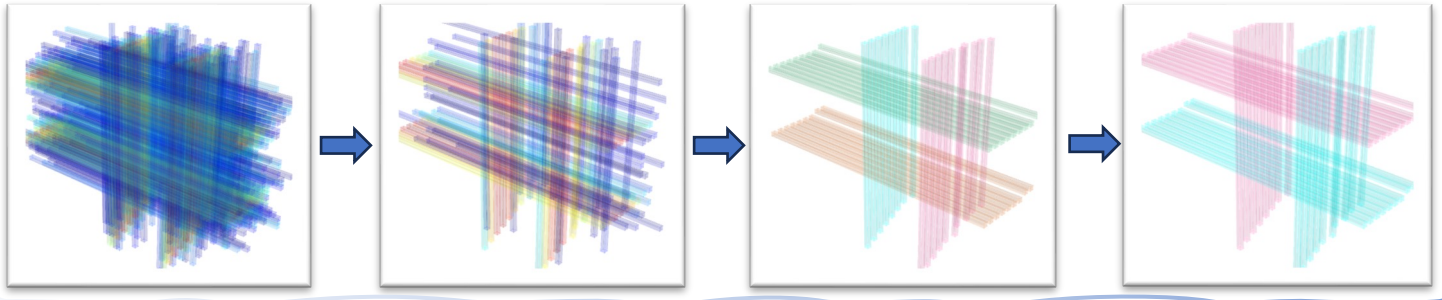
$ee \rightarrow ZH \rightarrow \nu\nu gg, \sqrt{s} = 240$ GeV

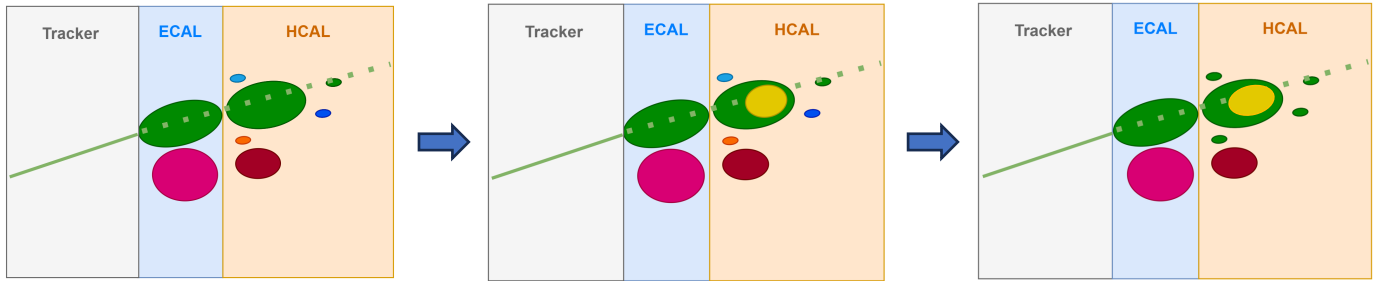
CyberPFA for crystal bar ECAL reconstruction



Step 1: preparation
Step 2: shower recognition
Step 3: energy splitting & ambiguity removal
Step 4: clustering and reclustering

Event display: 2 photons, $E_\gamma = 5$ GeV, distance = 15×15 cm.





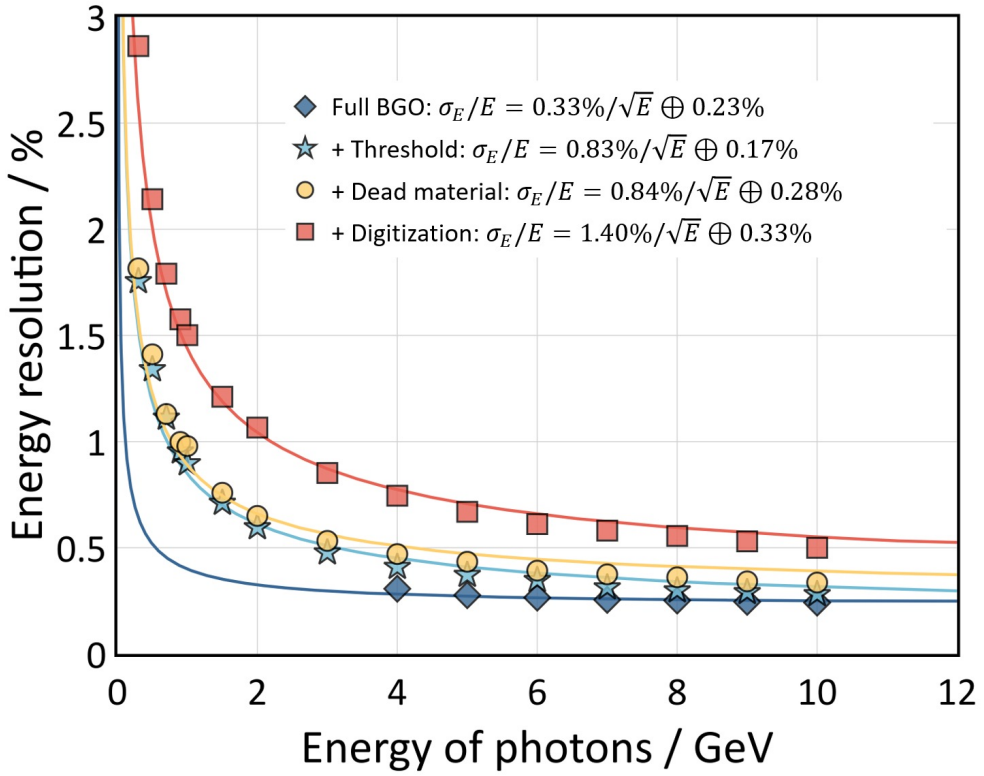
Extrapolate track to connect ECAL and HCAL clusters

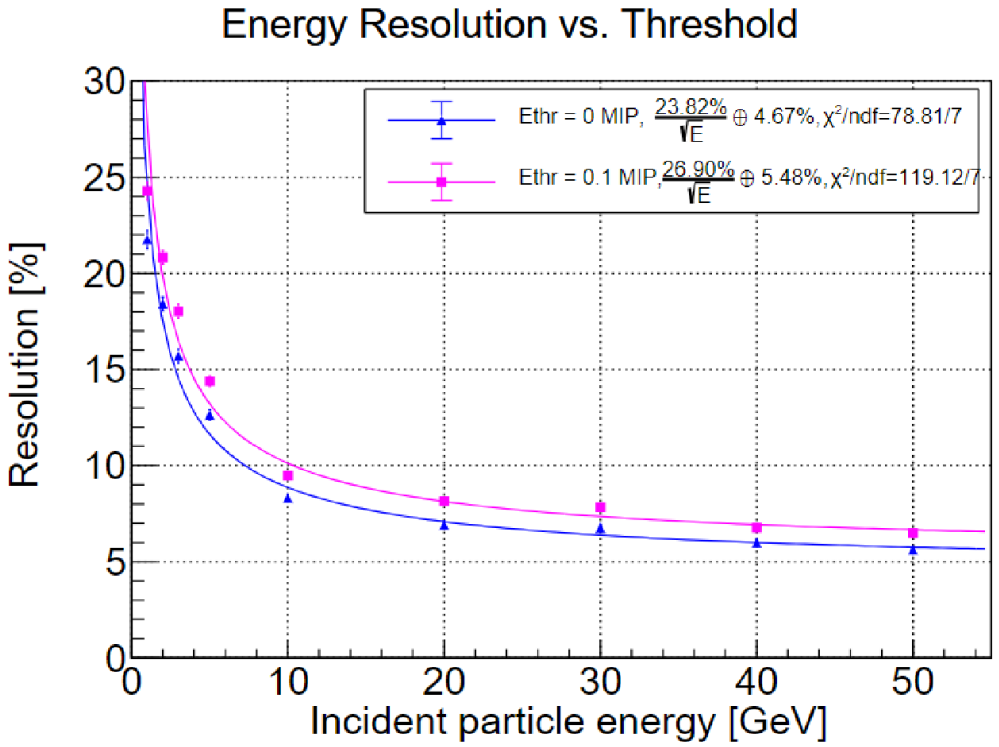
Split a neutral cluster if $E_{cluster} > P_{track}$

Check and merge fragments into core cluster.

Performance

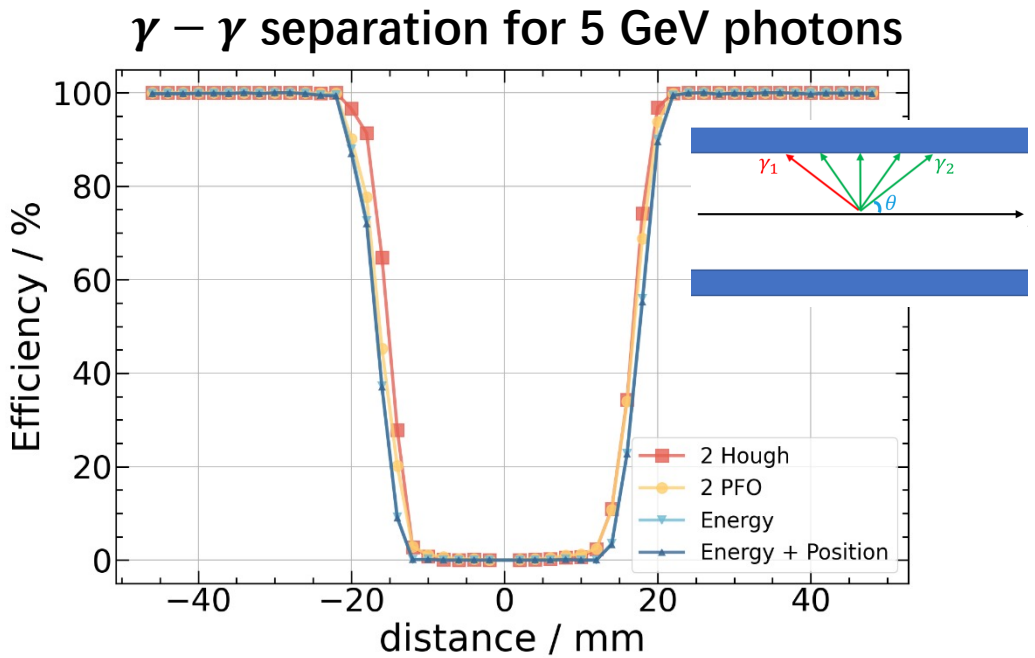
- **Single particle energy resolution**
  - ECAL: $\sigma_E/E \sim \frac{1.40\%}{\sqrt{E}} \oplus 0.33\%$
  - HCAL: $\sigma_E/E \sim \frac{26.9\%}{\sqrt{E}} \oplus 5.48\%$ (still developing)

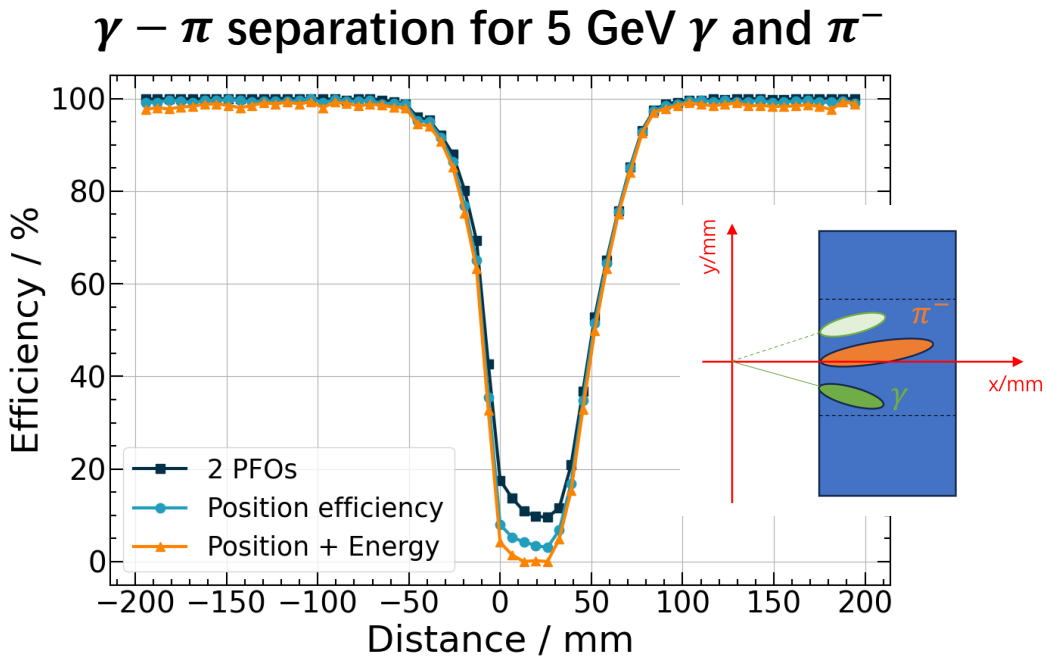




Separation performance

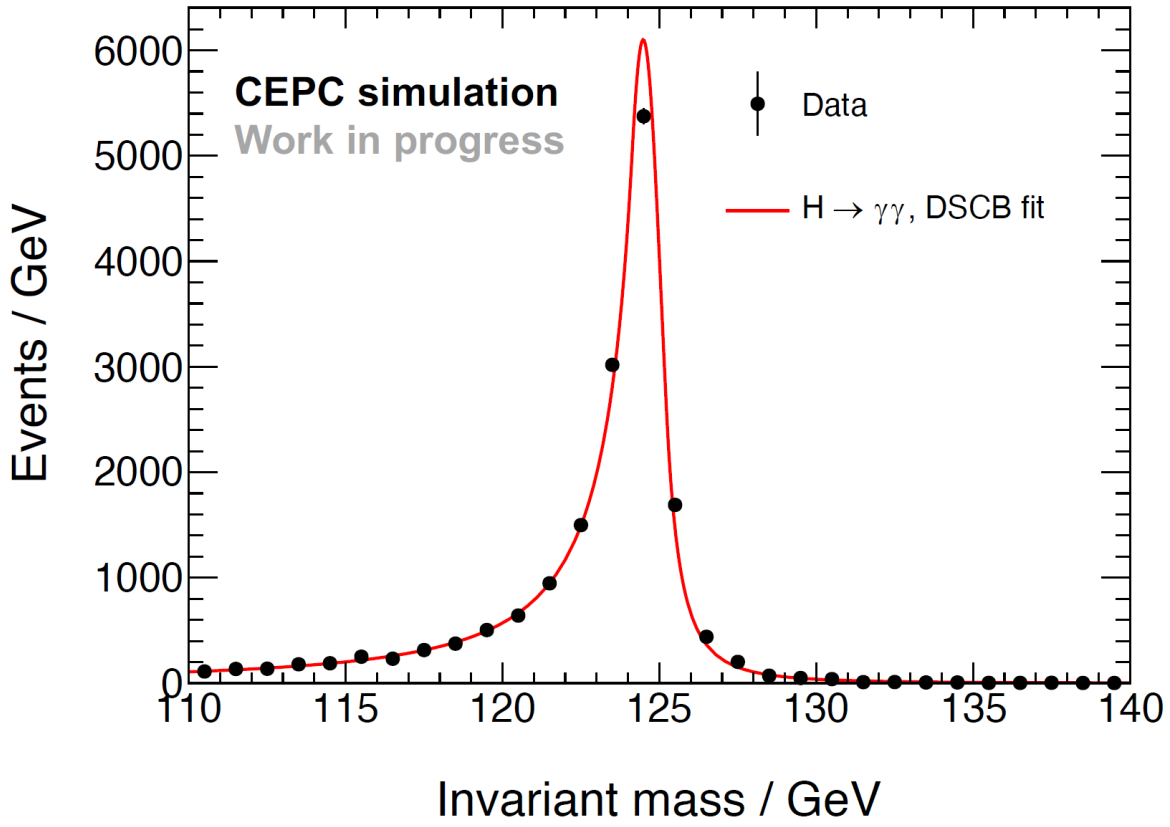
- **Close-by particle separation**
  - Key performance in PFA reconstruction.
  - $\gamma - \gamma$ separation: 2.2 cm @ 100% efficiency.
  - $\gamma - \pi$ separation: 10 cm @ 100% efficiency.





Physics performance: $H \to \gamma\gamma$

- **Physics process: $ee \to ZH \to \nu\nu\gamma\gamma$ in $\sqrt{s} = 240$ GeV**
  - Full simulation and digitization. Energy correction in crack region has been applied.



Double-side CB fit, $\sigma(m_{\gamma\gamma})$ = 0.57 GeV

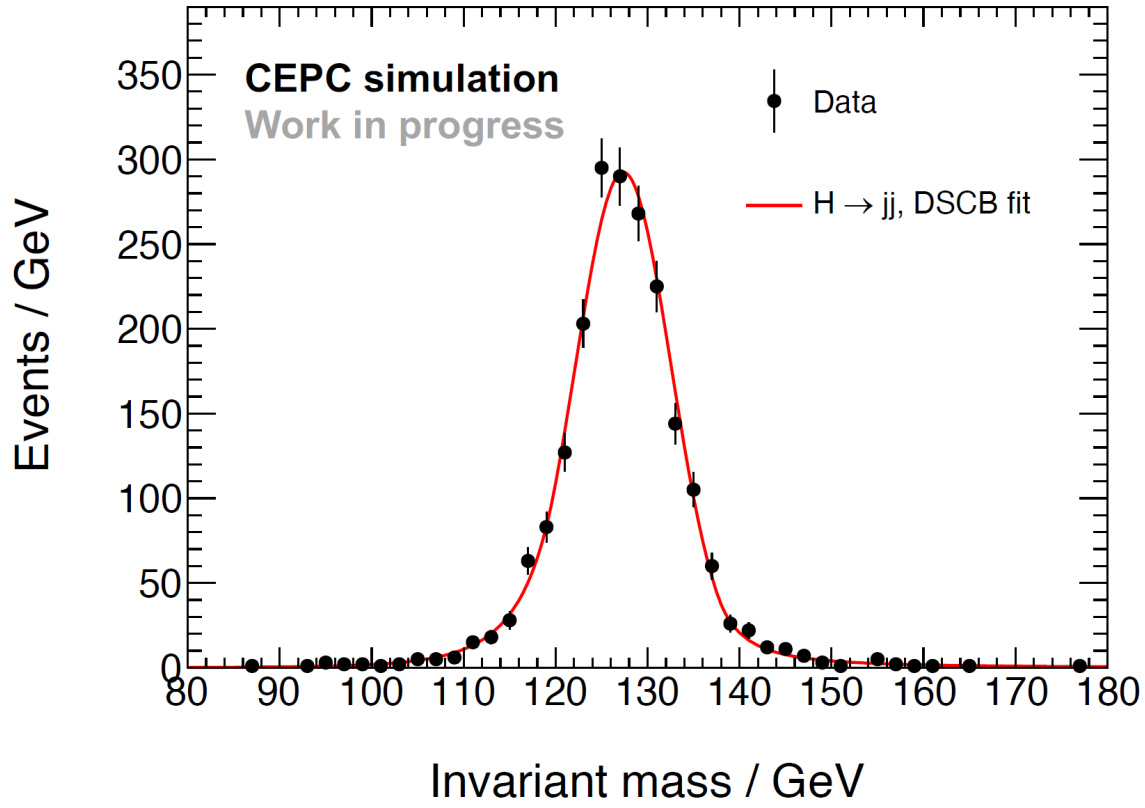
Long tile from:

- longitudinal energy leakage.
- Imperfect correction in crack region.

Can be fixed with better photon energy correction in the future.

Physics performance: $H \to gg$

- **Physics process: $ee \to ZH \to \nu\nu gg$ in $\sqrt{s} = 240$ GeV**
  - Full reconstruction in CEPC detector: Silicon + TPC tracker, crystal ECAL, glass tile HCAL.



$m_{jj} = 127.3$ GeV, $\sigma(m_{jj}) = 5.23$ GeV

Boson mass resolution (BMR) 4.11%.

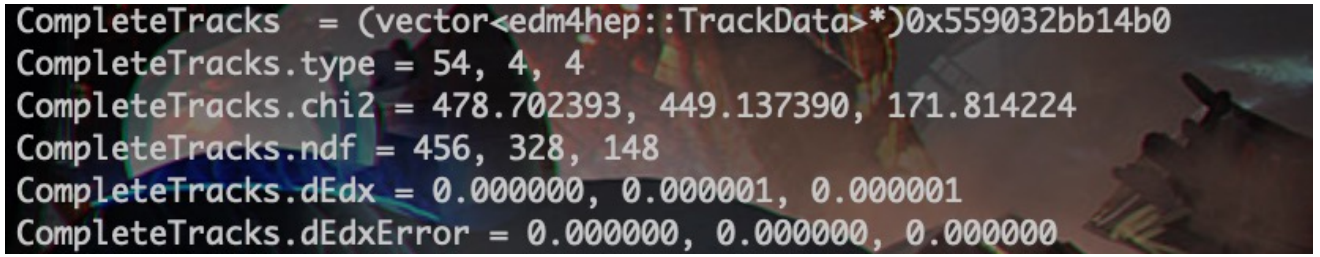
With truth track: BMR 3.73%.

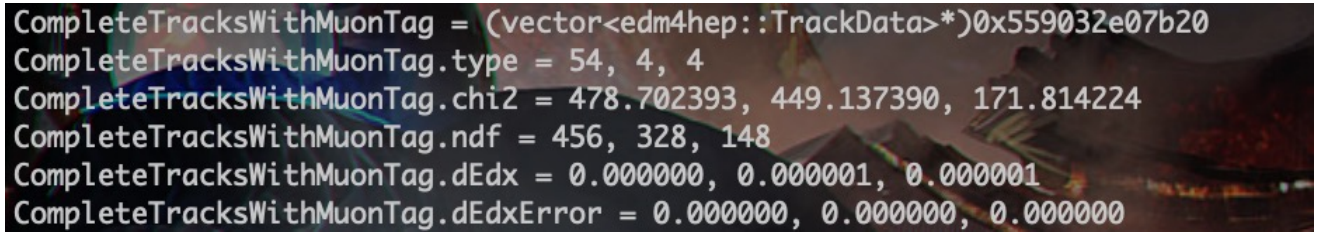
Working flow in CEPCSW

- **Simulation: Reconstruction/PFA/CyberPFA/script/sim.py**
  - L9: random number can be specified.
  - L19: Readin geometry: *TDR_o1_v01/TDR_o1_v01.xml*
    - Long barrel vertex, SIT+TPC+SET, crystal bar ECAL, glass tile HCAL, muon chamber.
  - L35~63: readin generator info
    - Support particle gun, stdhep, slcio, hepmc as readin info.
    - Pile-up study is supported with some specific timing setting.
  - L98~101: output file.
  - L108: max event number. If not specify: EvtMax = -1.

Working flow in CEPCSW

- **Track finding and fitting: Reconstruction/PFA/CyberPFA/script/tracking.py**
  - L6: readin file from sim.py
  - L18: geometry must be constant with the simulation. Same as following digi and rec process.
  - L58~end: tracker digitization and tracking algorithms.
    - Silicon track => TPC track => combined track [*CompleteTracks*]
    - A truth muon tag is added (L229), in a new track collection [*CompleteTracksWithMuonTag*]
  - L118: some messy info (e.g. tracker hits) can be drop for lower storage space.



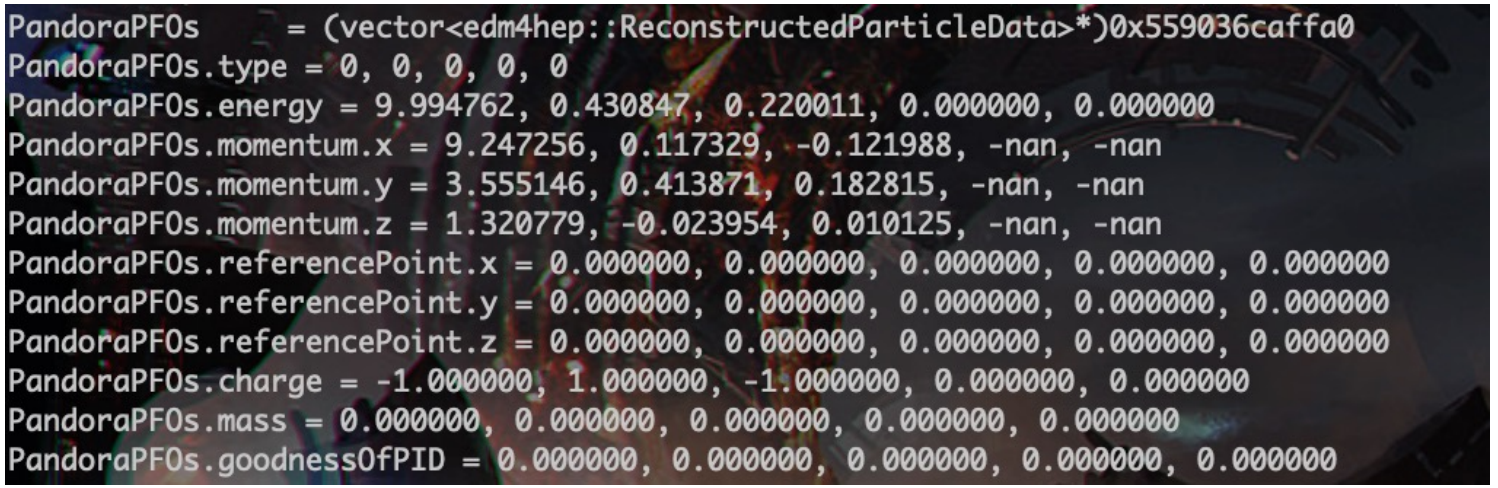


Working flow in CEPCSW

- **Calorimeter digitization: Reconstruction/PFA/CyberPFA/script/digi.py**
  - L6: Readin file from tracking.py
  - L47: readin collections. Only barrel ECAL and HCAL hits are considered.
  - L61~78: ECAL digitization, L81~111: HCAL digitization
    - Only read ECAL barrel hits [L65], readin a collection is not supported yet.
    - Calibration is not fully studied yet (CalibECAL=1 (should be ~1.05), CalibHCAL=1 (should be ~4))
    - A ntuple file for debug is generated (L77~78, L110~111) and can be muted.
    - Output collections:
      - Digitized hits: ECALBarrel, HCALBarrel
      - DigiHit – SimHit connection: ECALBarrelAssoCol, HCALBarrelAssoCol
      - DigiHit – MCParticle connection: ECALBarrelParticleAssoCol, HCALBarrelParticleAssoCol

Working flow in CEPCSW

- **PFA reconstruction: Reconstruction/PFA/CyberPFA/script/rec.py**
  - L23: Readin file from digi.py
  - L60, 61: a debug file. can be muted.
  - Final output: Reconstructed particle: PandoraPFOs
    - A PFO - MCParticle truth link is on preparing.



EDM4hep objects' definition and functions can be found in:
/cvmfs/cepcsw.ihep.ac.cn/prototype/releases/externals/103.0.2/EDM4hep/include/edm4hep/

Working flow in CEPCSW

- **What is missing for physics analysis:**
  - Event vertex reconstruction
  - PFO to jets: jet clustering algorithms (e.g. anti-kt)
  - Low level object ID: $e, \mu, \gamma, K, \pi, p, n$
  - High level object/event ID: jet origin
  - Event processing tool:
    - Select the interesting objects depend on analysis channel.
    - Convert the CEPCSW format output (Podio) to analysis level ntuple.
  - Some optimization:
    - Photon / hadron energy correction with ID;
    - Converted photon reconstruction and correction;
    - …

- **Feedbacks are welcome!**