CEPC Software

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for

CEPC software group

IHEP-Dongguan, 2020-08-29

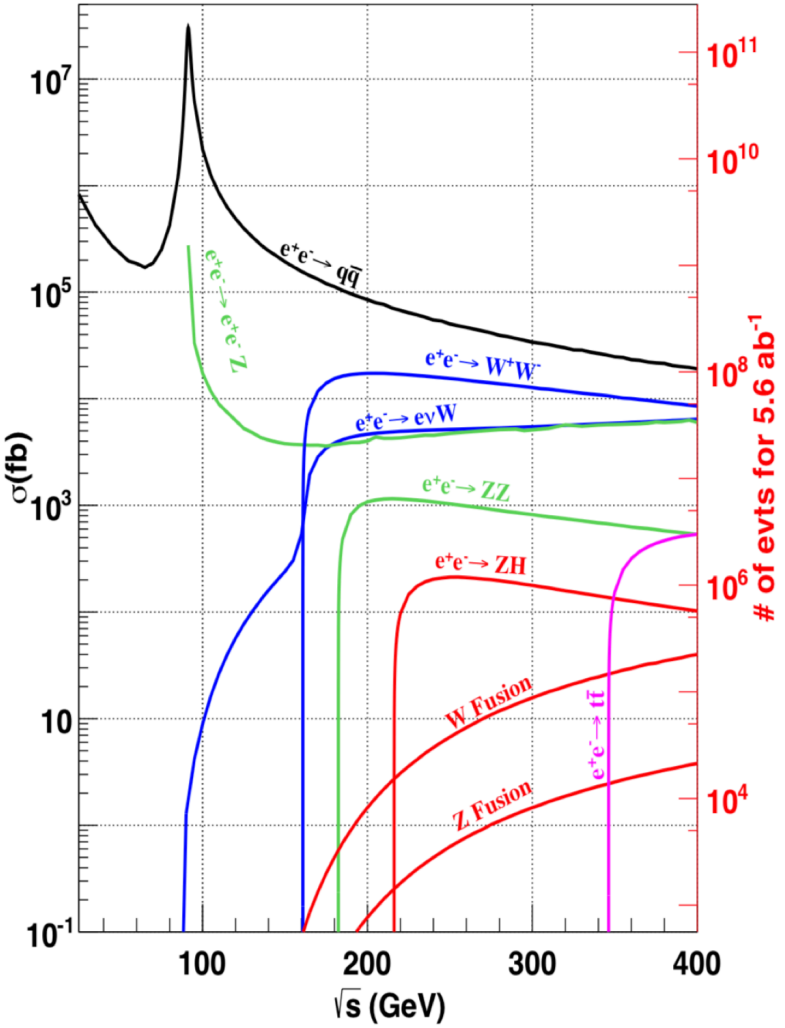
Outline

- Introduction
- From CEPCSOFT to CEPCSW
- Summary

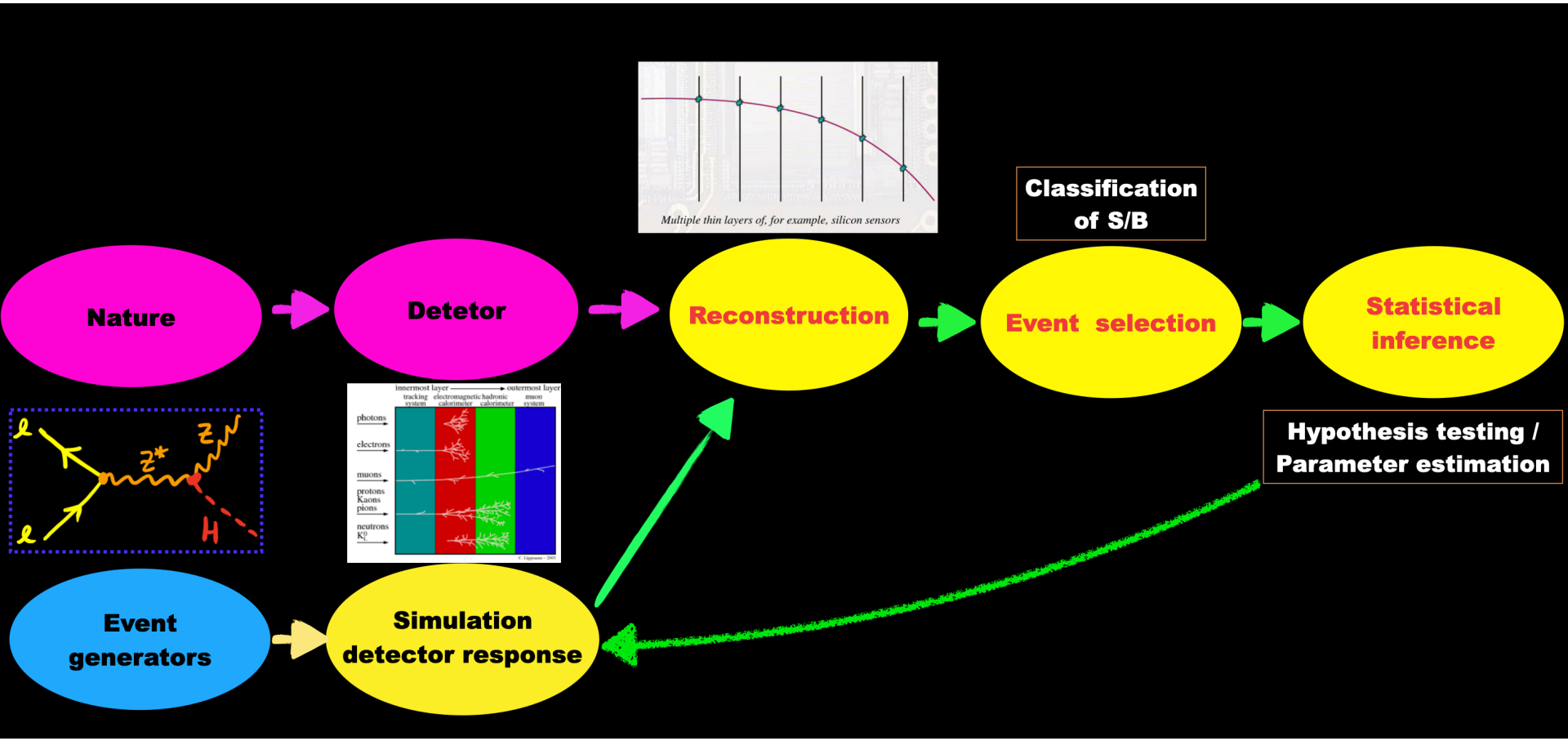
Physics at CEPC

- ✓ CEPC dedicated Higgs precision and probing BSM with Higgs as a portal, as well as precision electroweak test, QCD study, and flavor physics – the natural expansion and tradition of BES

- ✓ CEPC is going to deliver more than 1 M Higgs events, 10^8 WW pairs, and almost 10^{12} Z bosons

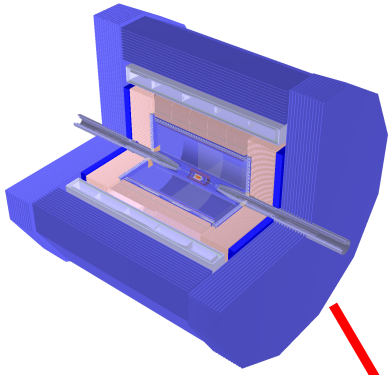


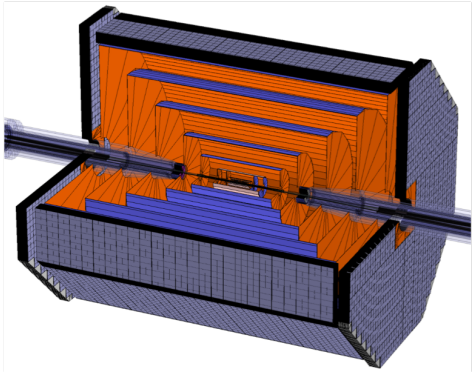
Experiment procedure

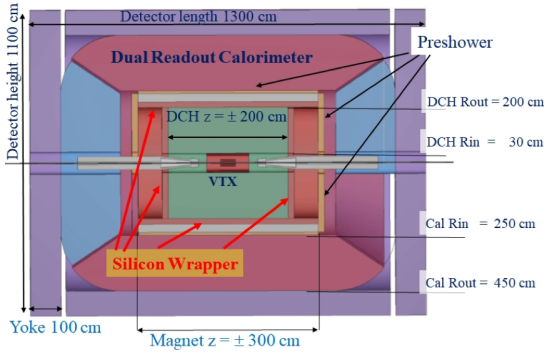


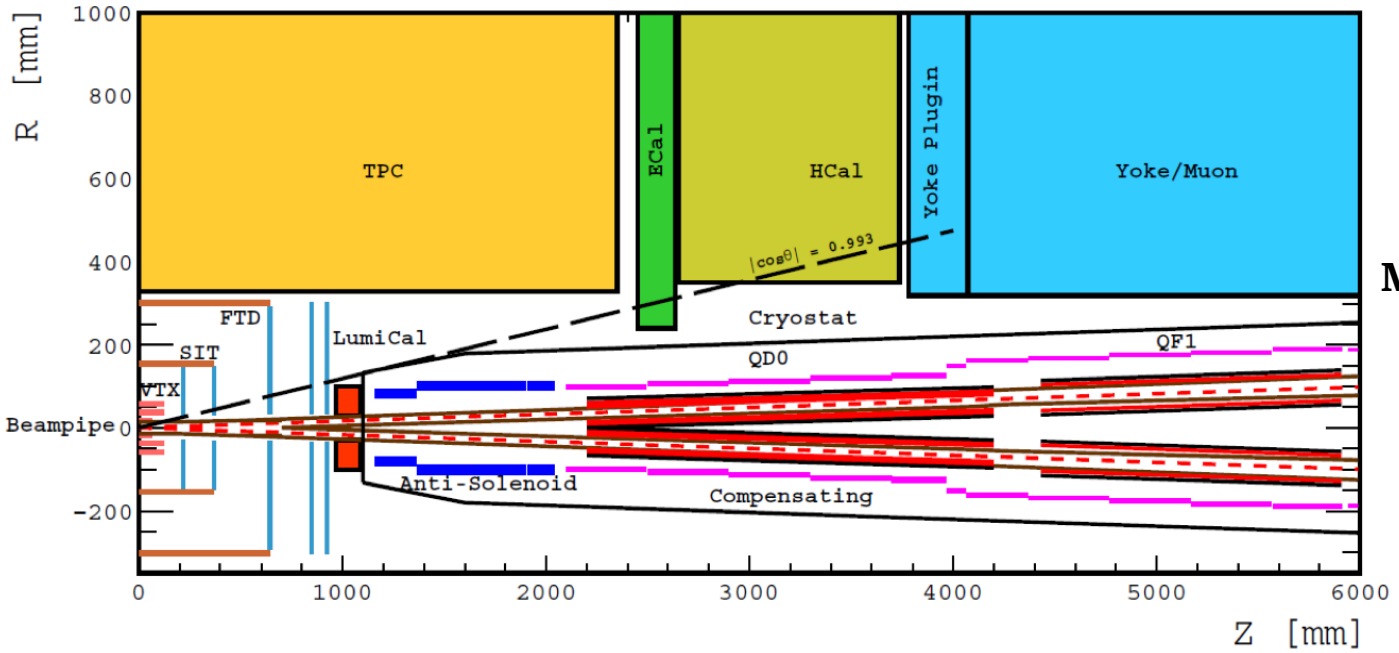
Green loop is the main activity at R&D stage
Yellow ellipses related with software

CEPC: Detector Concepts



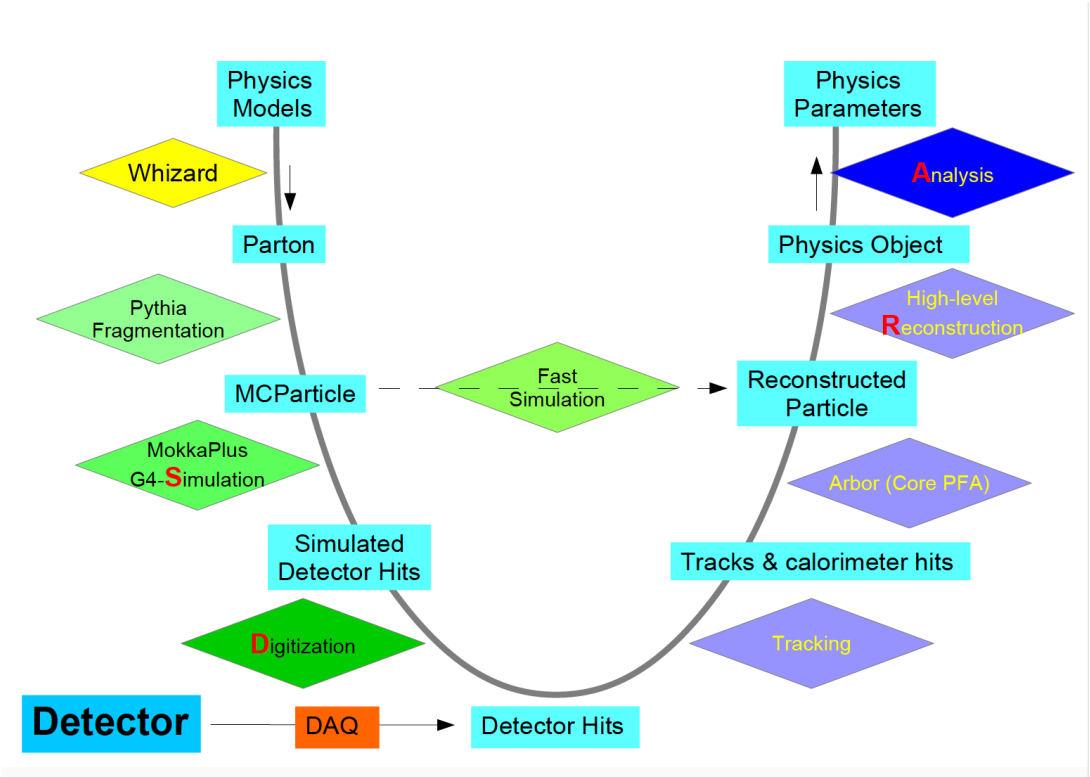






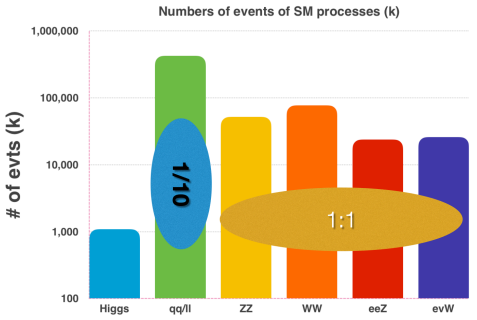
MDI of baseline

CEPC baseline software — http://cepcsoft.ihep.ac.cn/



Generators (Whizard & Pythia)
Data format & management (LCIO & Marlin)
Simulation (MokkaC)
Digitizations
Tracking
PFA (Arbor)
Single Particle Physics Objects Finder (LICH)
Composed object finder (Coral)
Tau finder
Jet Clustering (FastJet)
Jet Flavor Tagging (LCFIPLus)
Event Display (Druid)
General Analysis Framework (FSClasser)
Fast Simulation (Delphes + FSClasser)

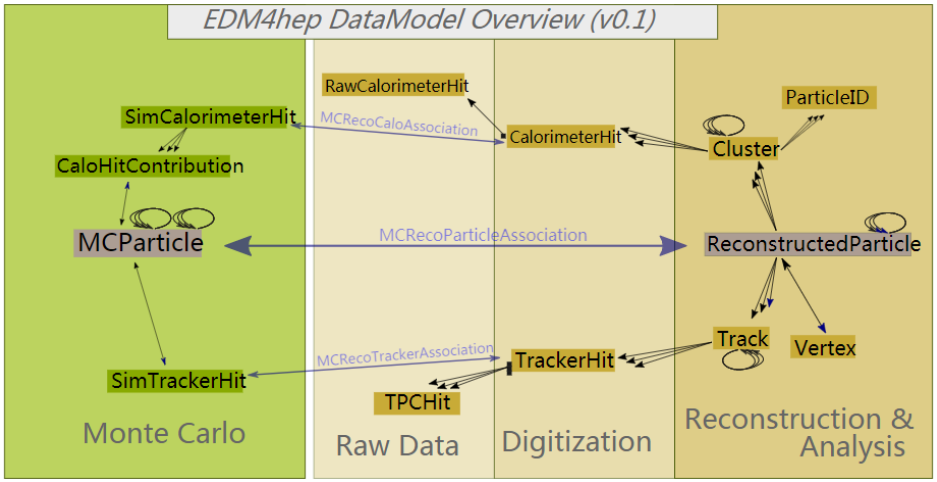
- Using for performance study and physics simulation
- A complete set of full simulated samples at 240 GeV and
- Others at alternative energy points

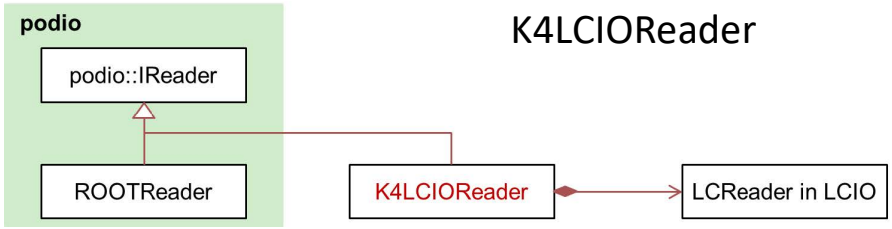


New CEPC software—CEPCSW

CEPC Software Prototype

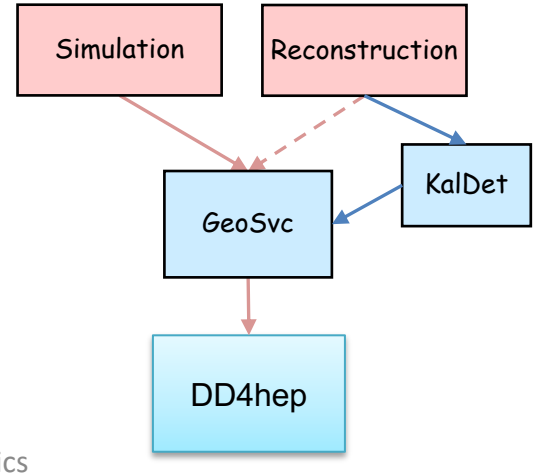
- EDM4Hep: official and common event data model in Kep4Hep
  - V0.1 has been released and performed in CEPCSW
  - Close to plcio





- Unified geometry service
  - Interfaced to DD4Hep
  - Used by simulation and reconstruction
  - To keep compatible during migration,

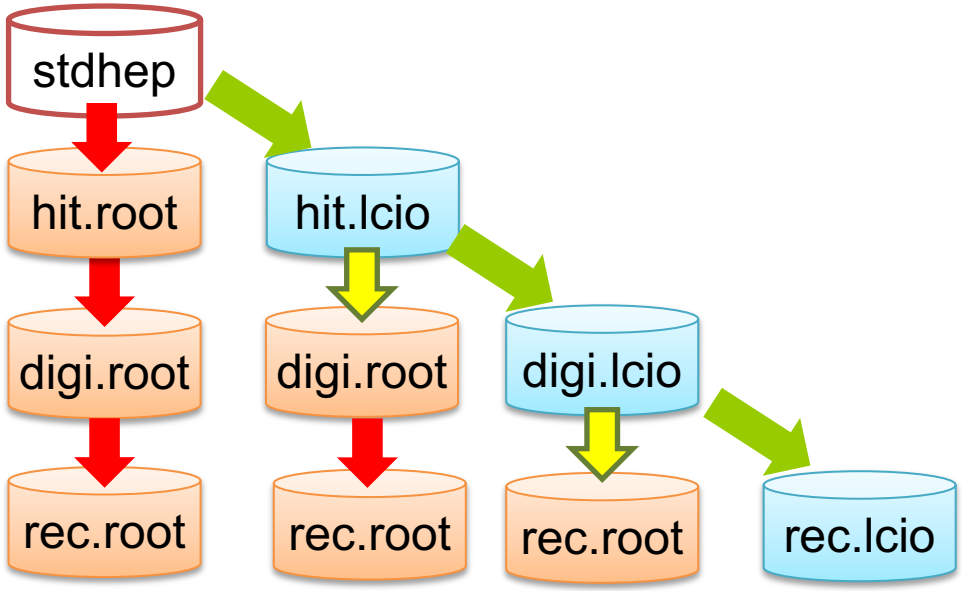
  KalDet is kept but the underlying geometry information is from GeoSvc



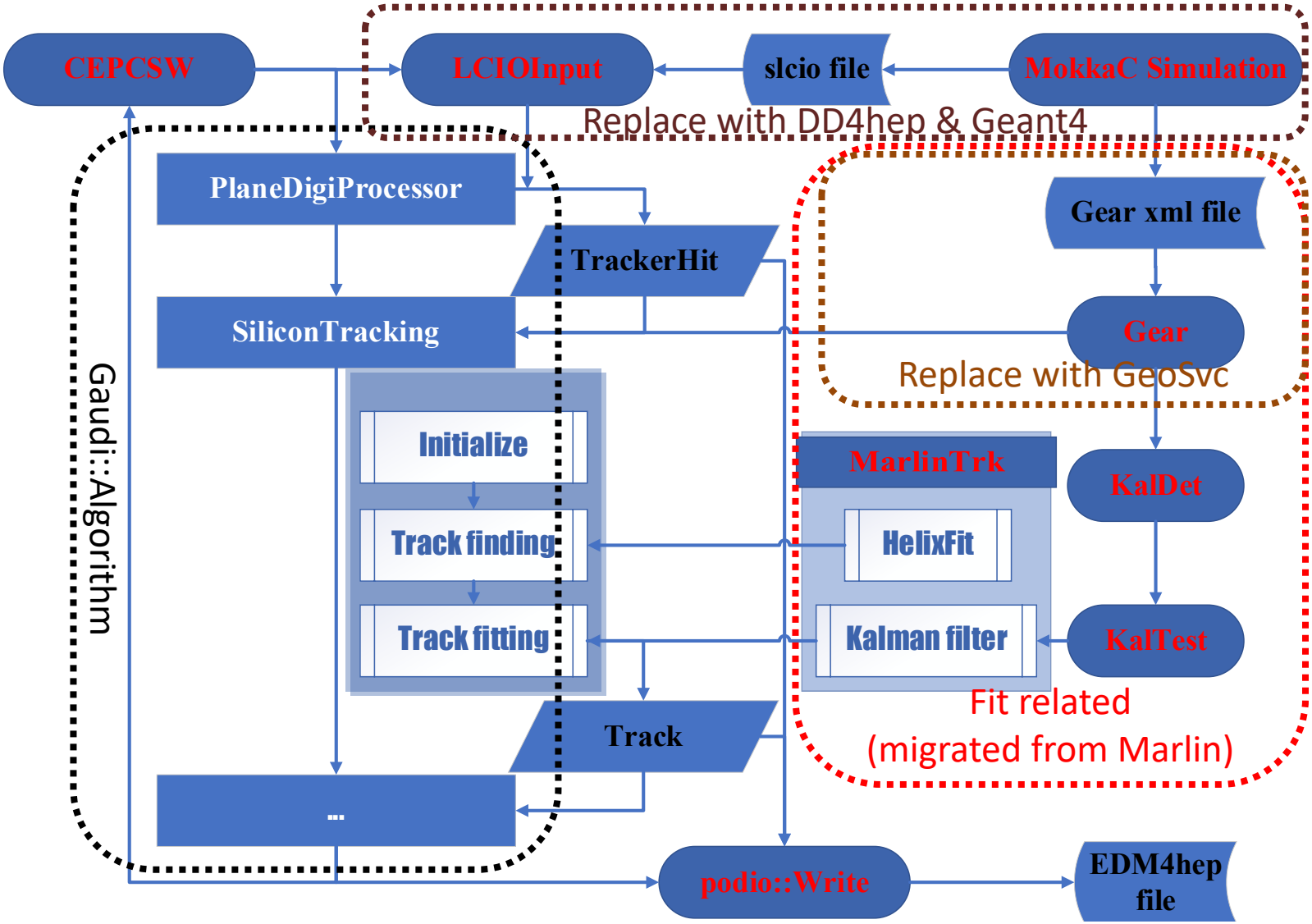
Roadmap for porting Sim/Digi/Rec

- To porting Sim/Digi/Rec in parallel, two major development branches
  - One is based on the LCIO reader and only update the I/O and EDM parts in the algorithms. The output is EDM4Hep.
  - The other based on the DD4hep. All the I/O and EDM is EDM4hep.

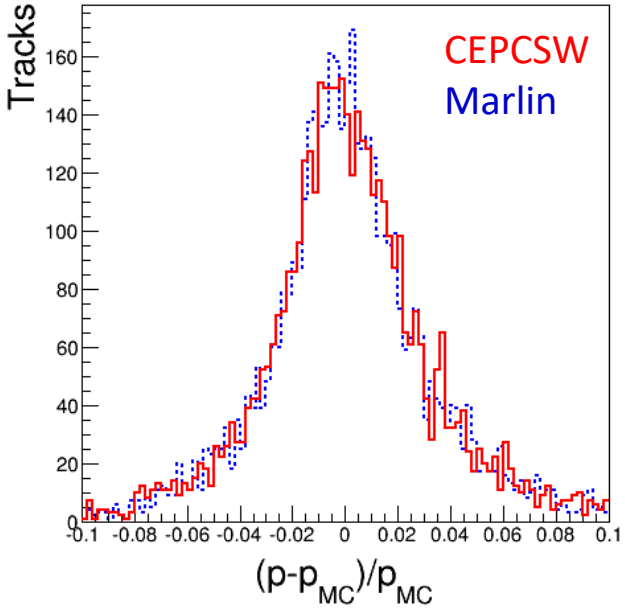
- **The Green arrows:**
  - LCIO+Mokka+Marlin
- **The Yellow arrows:**
  - Input: LCIO
  - Output: EDM4hep
- **The Red arrows:**
  - EDM4hep+DD4hep

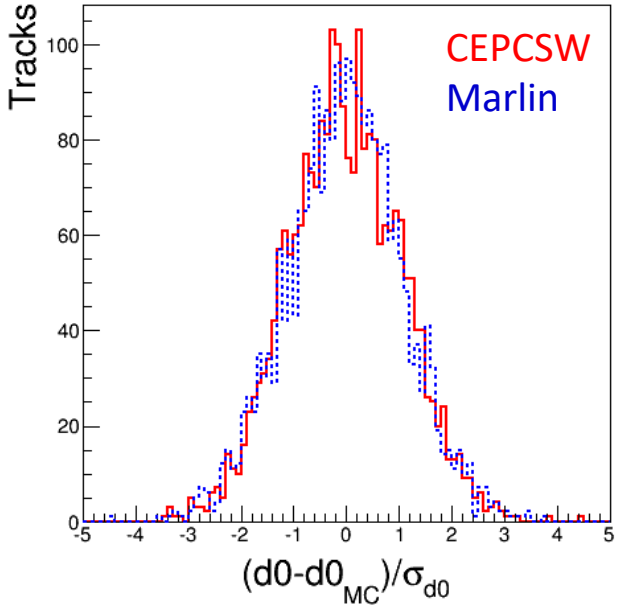


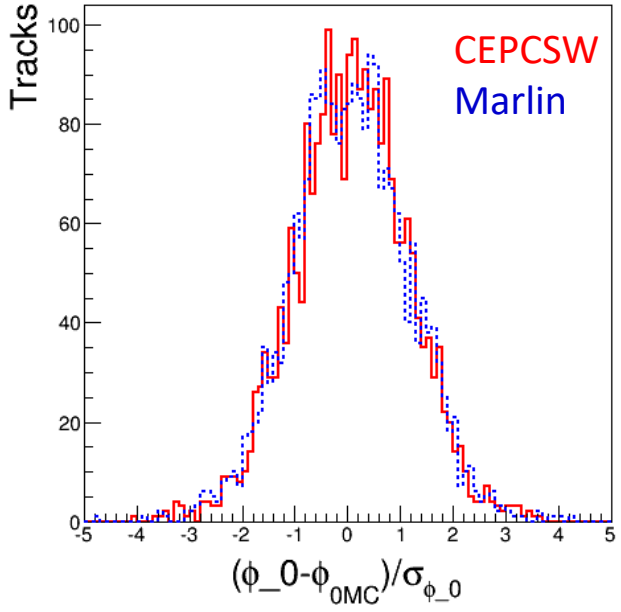
CEPCSW Silicon Tracking Flow

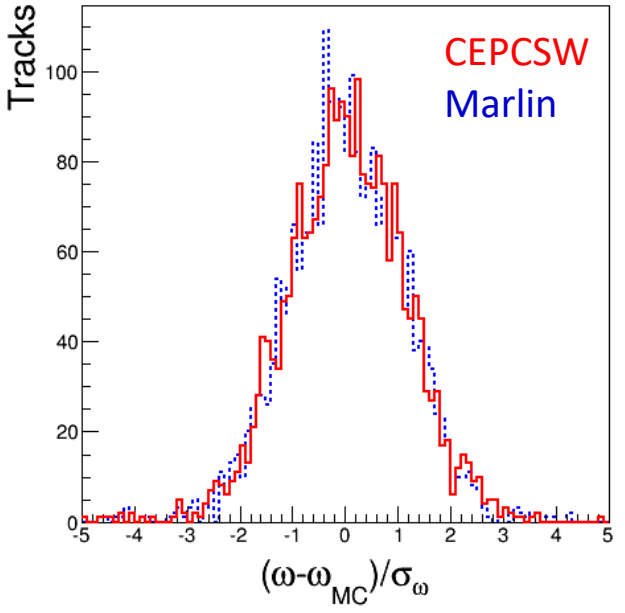


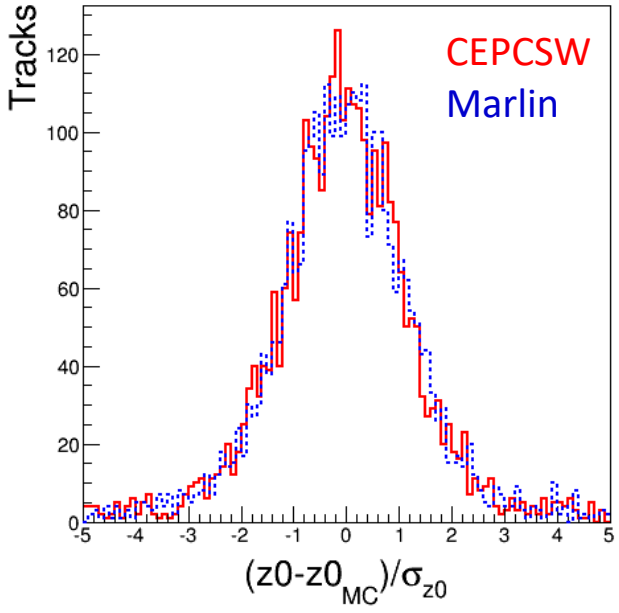
Two ways: CEPCSW+LCIO&Gear, fully CEPCSW

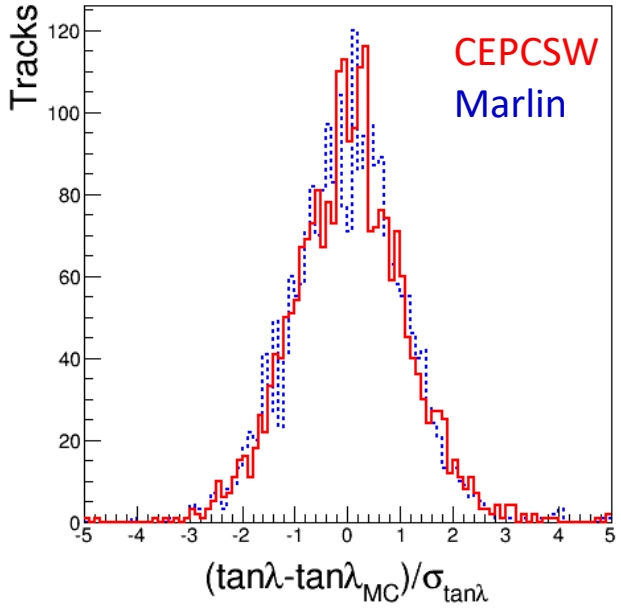

Tracks
CEPCSW
Marlin
$(p-p_{MC})/p_{MC}$


Tracks
CEPCSW
Marlin
$(d0-d0_{MC})/\sigma_{d0}$


Tracks
CEPCSW
Marlin
$(\phi\_0-\phi_{0MC})/\sigma_{\phi\_0}$


Tracks
CEPCSW
Marlin
$(\omega-\omega_{MC})/\sigma_{\omega}$


Tracks
CEPCSW
Marlin
$(z0-z0_{MC})/\sigma_{z0}$

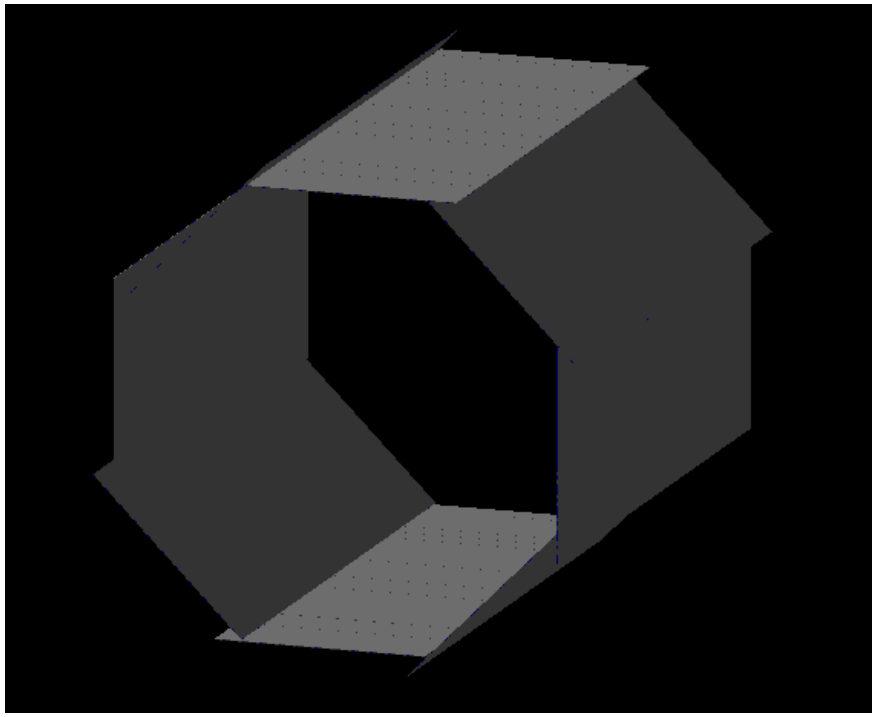

Tracks
CEPCSW
Marlin
$(\tan\lambda-\tan\lambda_{MC})/\sigma_{\tan\lambda}$

Porting ECAL simulation into CEPCSW

- Status: SiW-ECAL is available in the CEPCSW
- The detector description is available for both simulation and reconstruction.
  - DD4hep version is from Chengdong.
  - Detector parameters (XML based compact file): Detector/DetCEPCv4/compact
  - Detector constructors (C++ based): Detector/DetCEPCv4/src/calorimeter/
    - SEcal05_Barrel, SEcal05_Endcaps, SEcal05_ECRing
- Detector response simulation for ECAL is done.
  - Package Simulation/DetSimSD is created for geant4 simulation.
    - CalorimeterSensDetTool: integrated with Gaudi
    - CaloSensitiveDetector: integrated with Geant4
    - DDG4SensitiveDetector: integrated with DDG4 to get VolumeID/CellID
- EDM4hep based calo hit objects and McTruth info are saved.
  - SimCalorimeterHitCollection (cellID, energy, position…)
  - CaloHitContributionCollection (Particles'PDG, energy, time, position…)

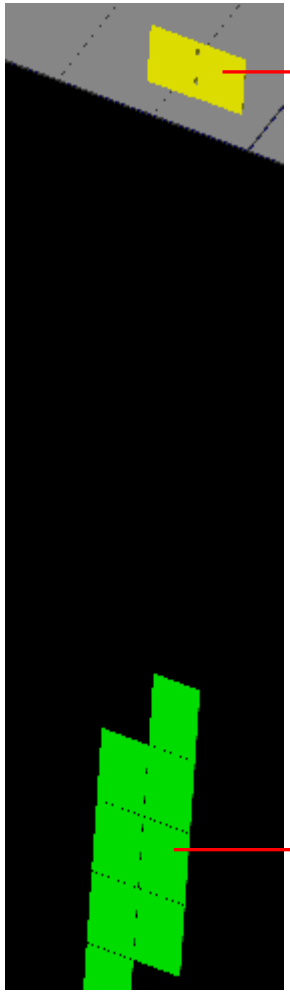
The detector could be visualized in G4

- One layer (Si+W+Si) is shown



Logical volume: EcalBarrel_alveolus_layer0

- 8 staves
- 5 modules per stave
- 5 towers per modules

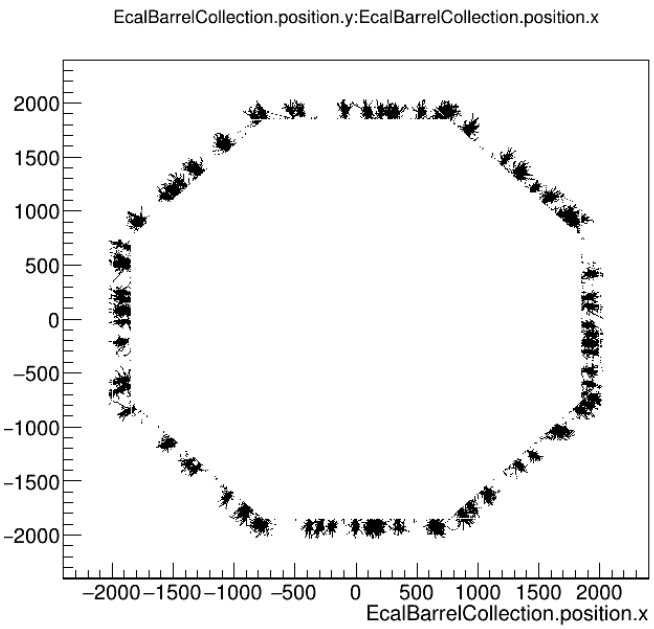


Note: other wafers in this layer are not displayed.

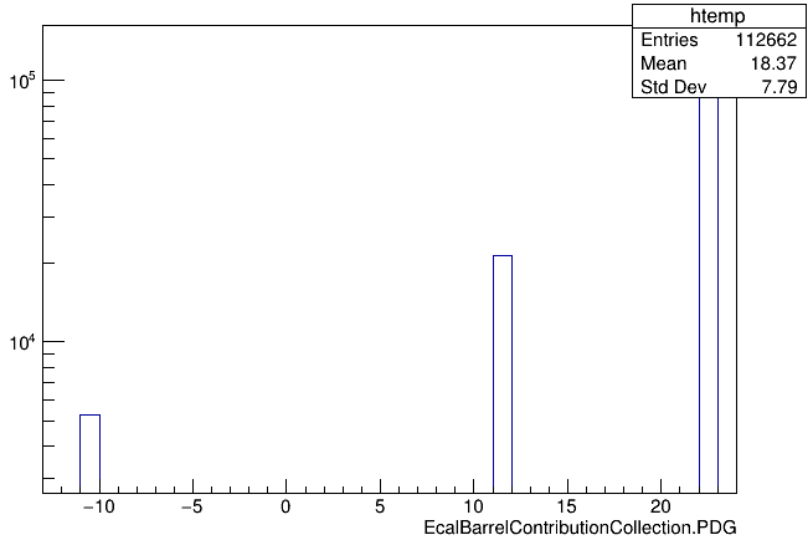
One sensitive layer in a tower

The detector responses (barrel)

- All the information are stored in ROOT for further validation.
  - 6 collections are saved
    - EcalBarrelCollection, EcalBarrelContributionCollection
    - EcalEndcapsCollection, EcalEndcapsContributionCollection
    - EcalEndcapRingCollection, EcalEndcapRingContributionCollection



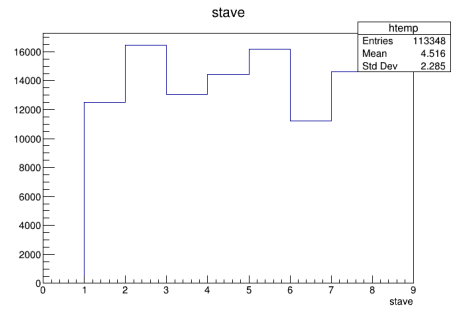
Hit position (x:y)



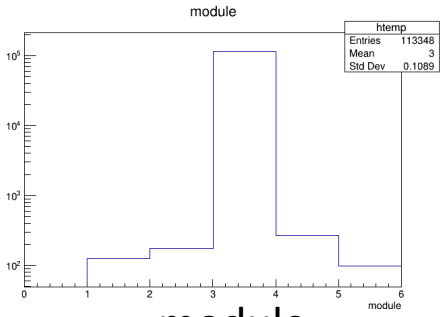
MC particle contribution (PDG: e+, e-, gamma)

Gamma, 1GeV, theta=90deg, phi=[0,360deg], 100 events , No B-field

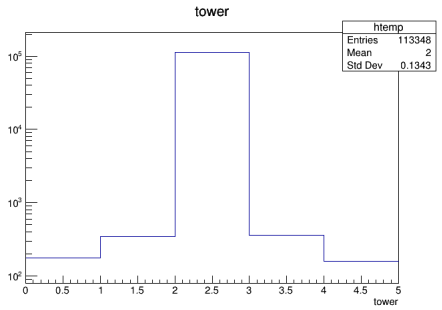
ID distribution (barrel)



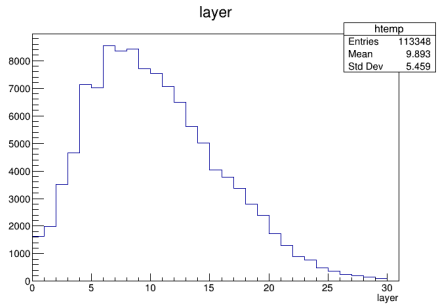
stave



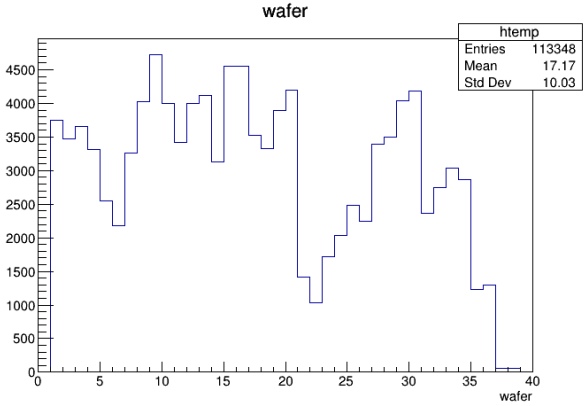
module



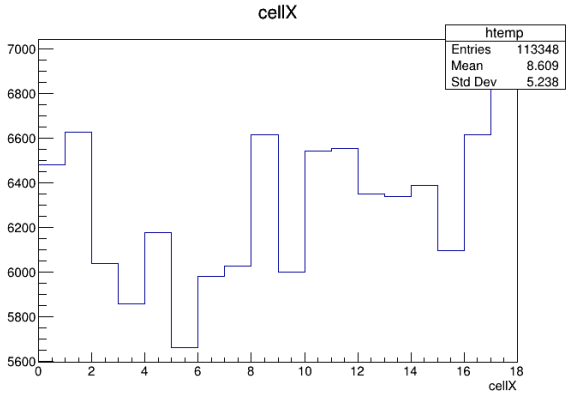
tower



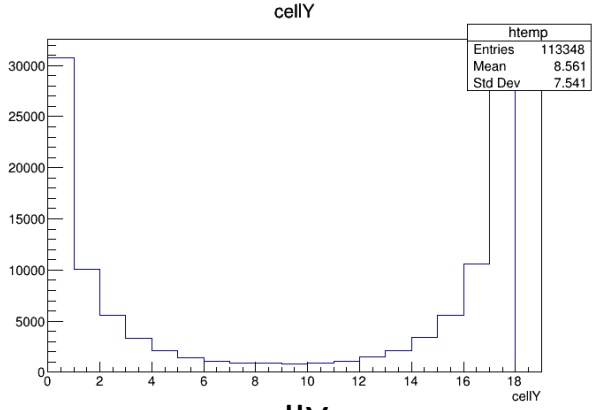
layer



wafer



cellX



cellY

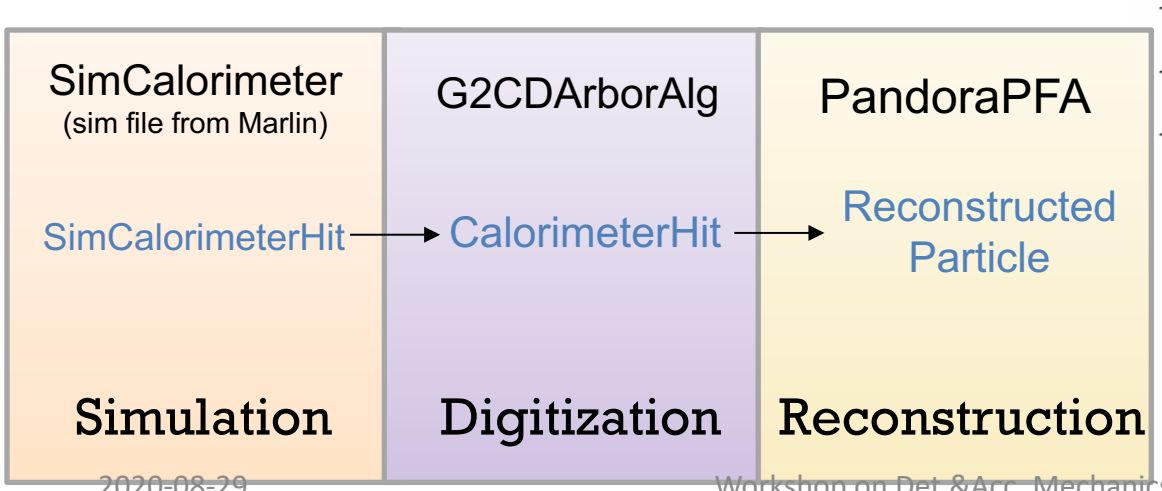
The ID is based on VolumeID (detector) and CellID (segmentation) in DD4hep.

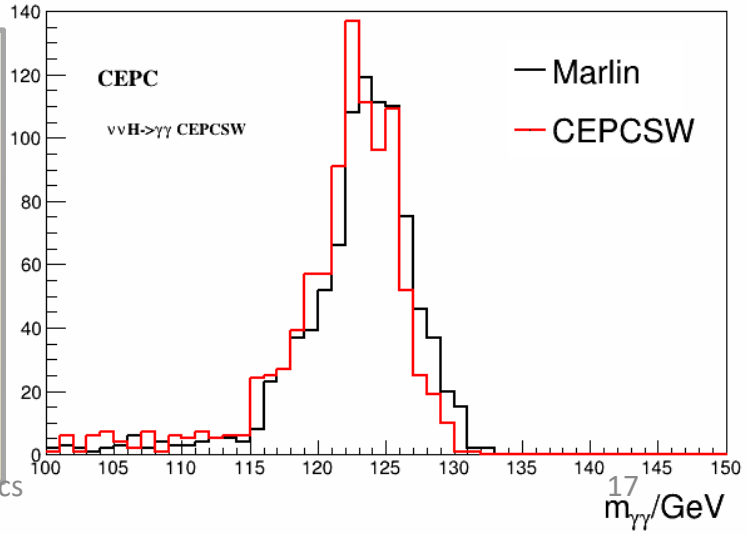
Problem: the ID definitions are not same for CEPCSW and Mokka.

Need further studies. See issue: https://github.com/cepc/CEPCSW/issues/5

Migration of calorimeter digitization

- Calorimeter digitization algorithm (G2CDArbor) was migrated from Marlin to CEPCSW
  - Use EDM4Hep event data model
  - Comparison of reconstructed results between Marlin and CEPCSW
    - **ECAL**: slight difference might be caused by different configuration parameters and version of PandoraPFA. Further check is in progress
    - **HCAL**: to be validated



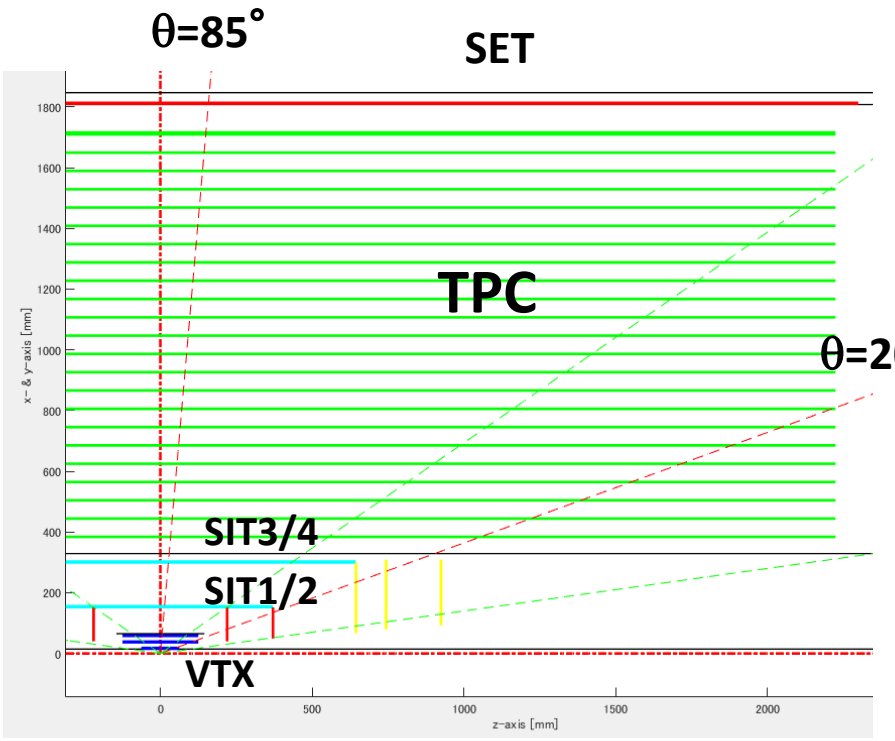


Motivation for Silicon + Drift Chamber Tracker

- Explore a different tracker option for CEPC, our own design
- Capable for both tracking and PID (flavor, JES, jet flavor tagging ,...)
- Combine the Silicon technology (strip, CMOS) and Drift chamber technology (IDEA, dE/dx, cluster counting, ...)
- Provide concrete platform to integrate smaller crystal ECAL
- Open path for better particle ID with future timing layer (LGAD) between SDT and crystal ECAL

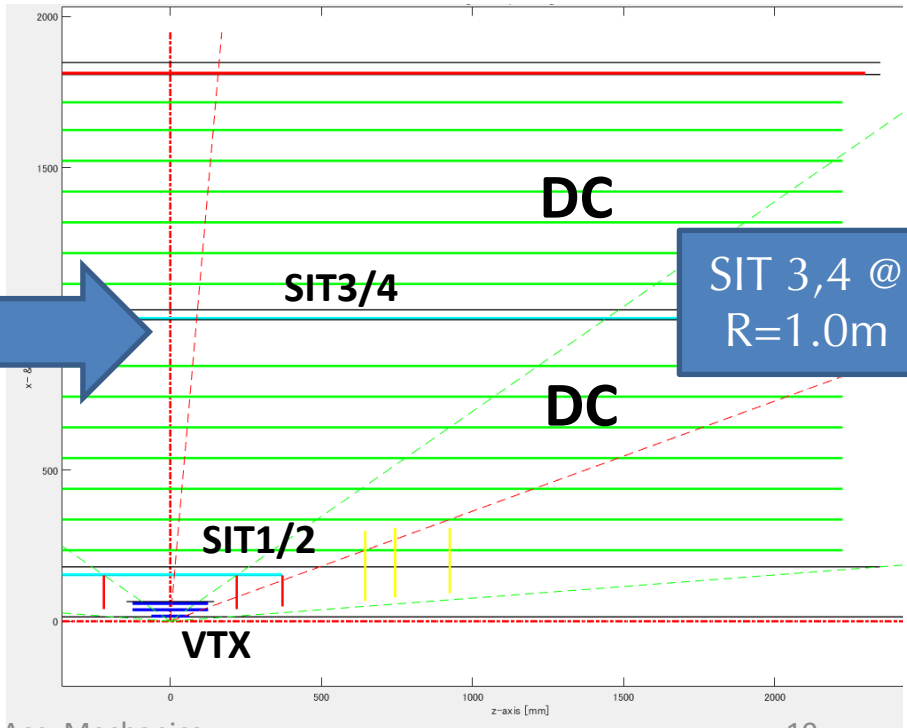
CEPC Silicon + Drift Chamber Tracker

- Based on the baseline Silicon + TPC
- Replace TPC layers with two drift chamber layers
  - SIT 3&4 at R~1.0m / larger cell size of DC than TPC



baseline

θ=20°



Plan for SDT Simulation in CEPCSW

- **The SDT simulation will be developed within the CEPCSW simulation framework for further performance studies.**

✓ **Event Data Model: EDM4hep**

  - **SimTrackerHit and TrackerHit will be extended if variables are missing.**

- **Detector description: develop a preliminary detector**
  - **A preliminary version will be implemented in DD4hep, including geometry, gas, and materials.**
  - **The detector description will be used in both simulation and reconstruction.**
  - **ID convention: for consistency between simulation and reconstruction.**
  - **Magnetic field: for study of impact of non-uniformity of magnetic field.**
- **G4 sensitive detector: simulate realistic detector responses.**
  - **First version: the position and deposit energy of the hit**
  - **Second version: the dE/dx, drift time …**

A comment on detector performance and data-taking

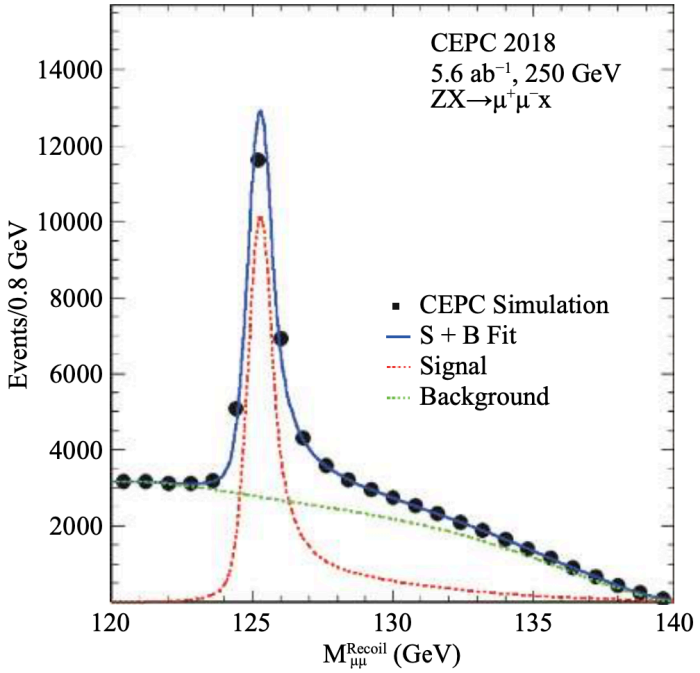
Resolution of instrument

$$\hat{\sigma}_m = \frac{\hat{\sigma}}{\sqrt{n}}$$

Stat. uncertainty

Statistics

6.5 MeV based on 18k signals



Conclusion: if resolution doubles, 4-times of statistics is needed to compensate it.

--- --- 4-times means 4x7 years! Don't lose performances

Summary

- **CEPCSOFT supported preCDR & CDR studies, still supporting detector some R&D.**
- **The CEPC new software under developing with lots of modern software technologies: DD4hep, new tracking software, particle flow algorithms, machine learning, ….**
- **R&D of new detector concepts and the optimization with physics benchmarks is the main tasks of our software, as well as the software itself.**

Backup slides

Bench mark physis processes

Physics process	Measurands	Critical detector	Required performance
$ZH \to l^+l^-X$	m_H, σ_{ZH}	Tracker	$\Delta(1/P_T) = 2 \times 10^{-5} \oplus \frac{10^{-3}}{P(\text{GeV})\sin^{\frac{3}{2}}\theta}$
$H \to \mu^+\mu^-$	$B(H \to \mu^+\mu^-)$		
$H \to b\bar{b}, c\bar{c}, gg$	$B(H \to b\bar{b}, c\bar{c}, gg)$	Vertex	$\sigma_{r\phi} = 5 \oplus \frac{10}{p(\text{GeV})\sin^{\frac{3}{2}}\theta}(\mu\text{m})$
$H \to q\bar{q}, W^+W^-, ZZ$	$B(H \to q\bar{q}, W^+W^-, ZZ)$	ECAL, HCAL	$\sigma_E^{jet} = 3 \sim 4\,\%$ at 100GeV
$H \to \gamma\gamma$	$B(H \to \gamma\gamma)$	ECAL	$\frac{\Delta E}{E} = \frac{0.20}{\sqrt{E(\text{GeV})}} \oplus 0.01$