Status of calorimeter software

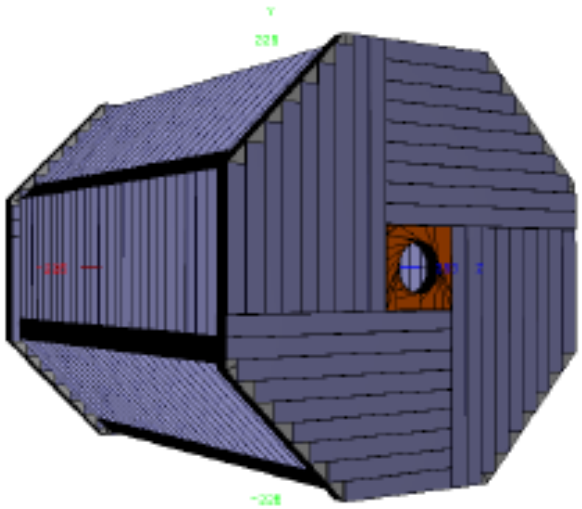
Wu Linghui

For the Calorimeter software group

Dec 2, 2020

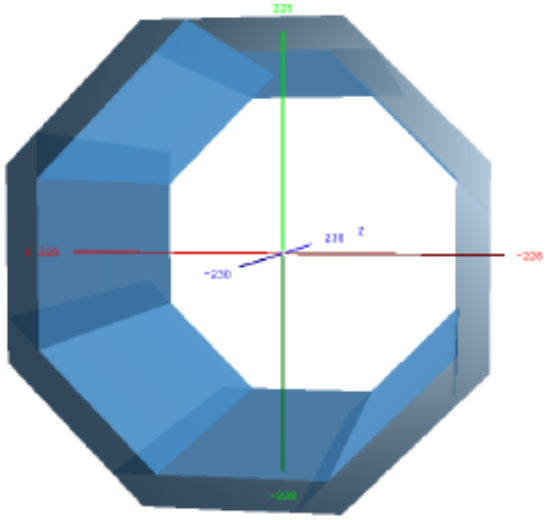
ECAL software in CEPCSW

- CEPC_v4
  - SiW-ECAL is available in the CEPCSW



- CRD ECAL
  - Long BGO crystal bar design

✓ Geometry
✓ Digitization
➢ Reconstruction

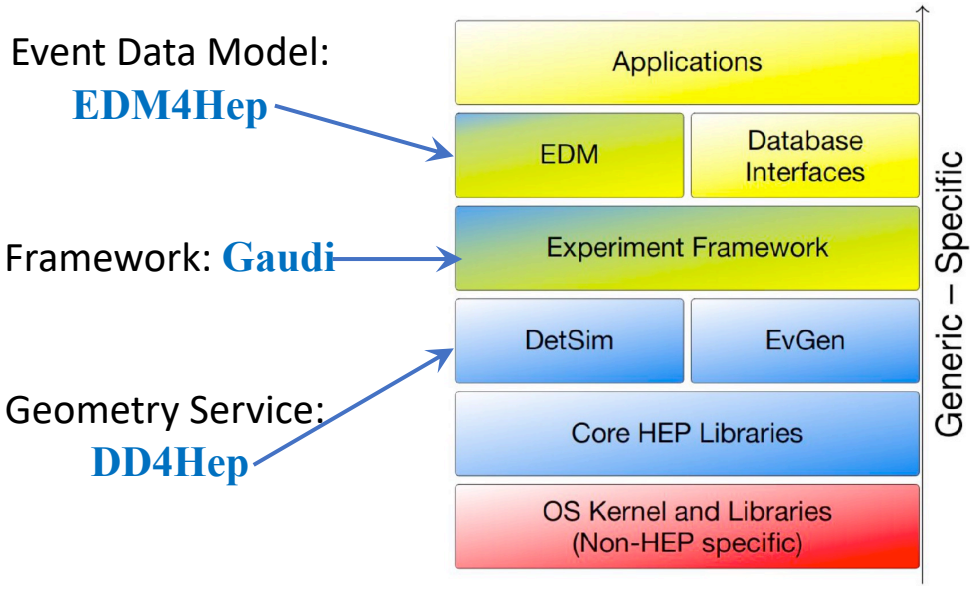


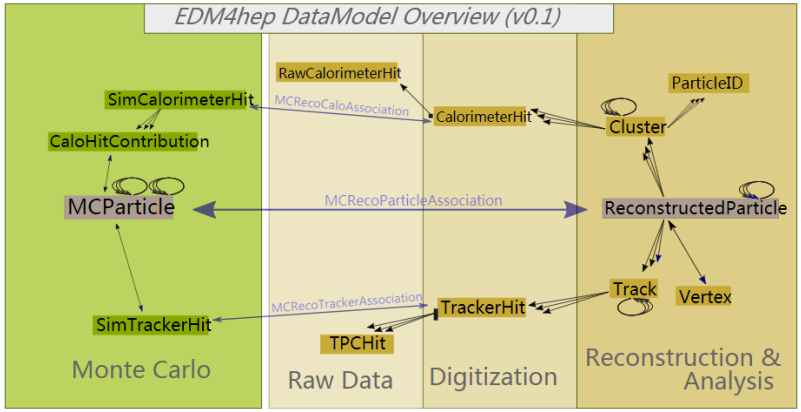
ECAL software of CEPC_v4

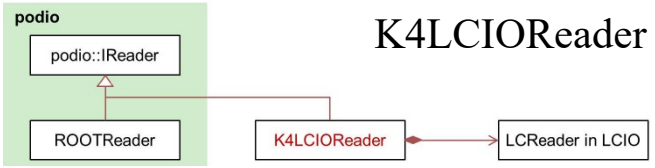
- Detector description & detector responses
- Migration of digitization
- ECAL fast simulation: Frozen shower
- PFA algorithm
  - ✓Pandora
  - Arbor

CEPCSW

- CEPC software originally started from the iLCSoft (many thanks)
- Study of CRD (CEPC Reference Detector) is being performed in CEPCSW



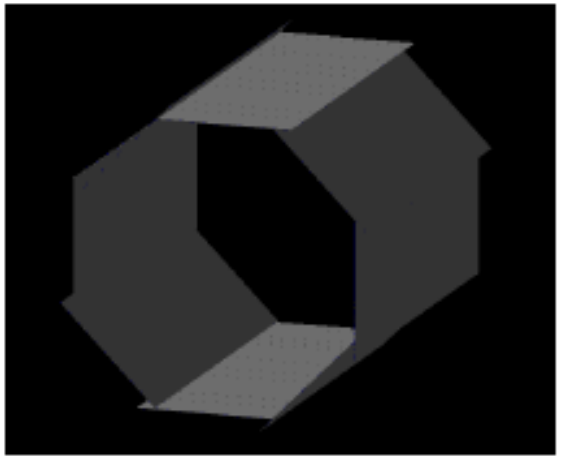




K4LCIOReader

Detector Description & Detector Responses

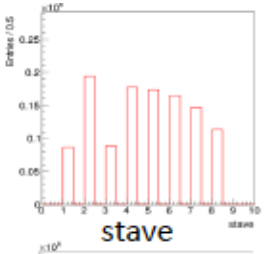
Fu Chengdong, Fang Wenxing, Lin Tao

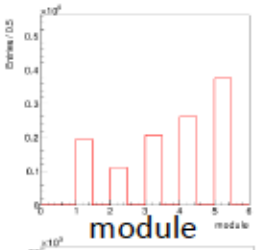


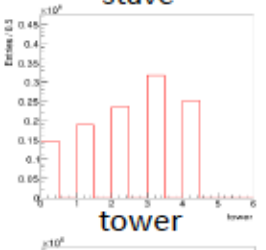
One layer (Si+W+Si) is shown
- 8 staves
- 5 modules per stave
- 5 towers per modules

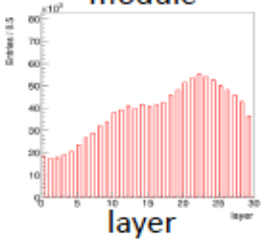
Note: other wafers in this layer are not displayed.

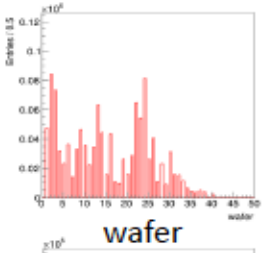
One sensitive layer in a tower

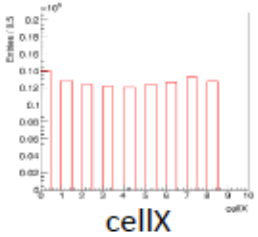


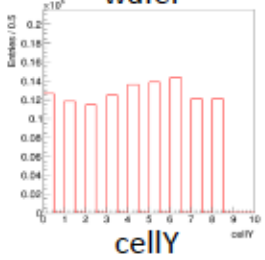












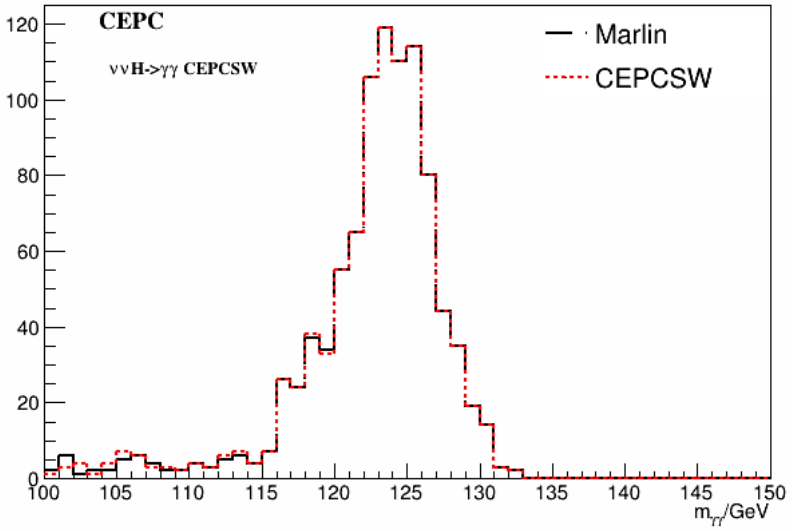
The ID is based on VolumeID (detector) and CellID (segmentation) in DD4hep

Migration of digitization

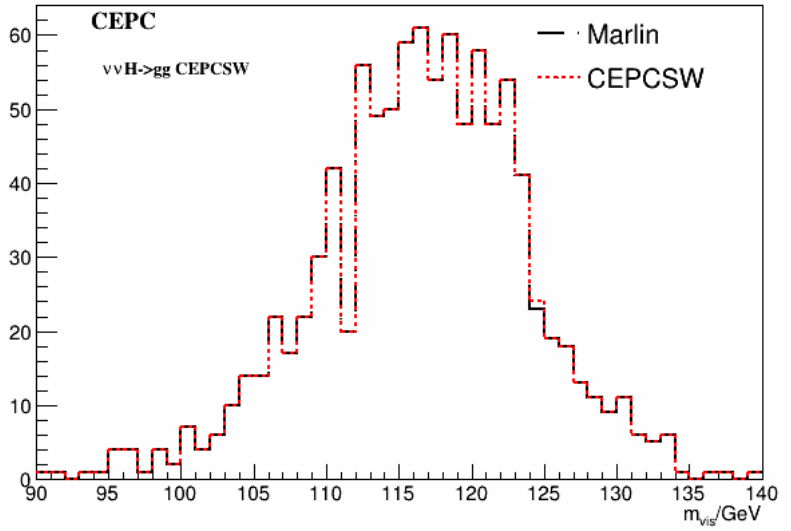
Wu Linghui, Fang Wenxing, Guo Fangyi

- Calorimeter digitization (G2CDArbor) has been migrated from Marlin to CEPCSW
- Validation shows the results in CEPCSW are consistent with that in Marlin

Validation of ECAL



Validation of HCAL

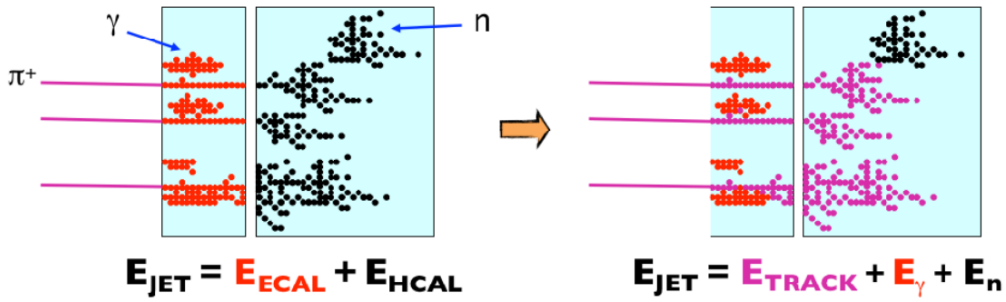


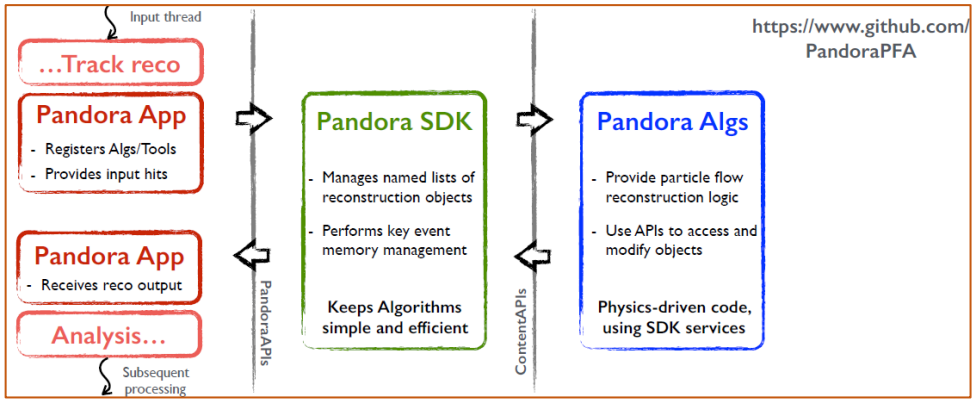
LCIO data as input

Pandora

Fang Wenxing

- Pandora is a general pattern recognition algorithm developed to study PFA calorimeter.
- Applications of Key4Hep
- Available in CEPCSW





- Pandora App: a Gaudi algorithm in CEPCSW. It provides input objects and receive reconstructed objects.
- Pandora SDK: managing pandora objects.
- Pandora Algs: reconstructing objects.

Arbor

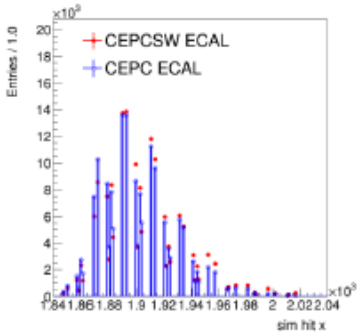
Yu Dan, Ruan Manqi

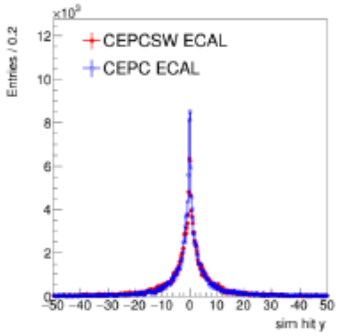
- A dedicated particle flow reconstruction toolkit
- Composed of a clustering module and a matching module
- Migration to CEPCSW is ongoing

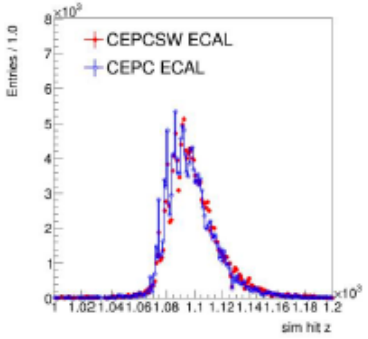
CEPC_v4 validation

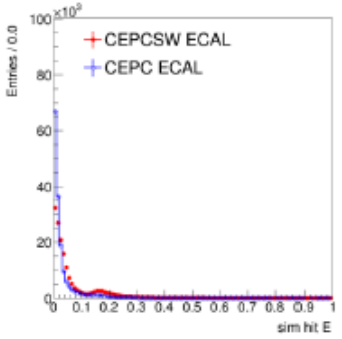
Fang Wenxing, Fu Chengdong, Lin Tao

Check with γ (some difference may be related with G4 configuration)

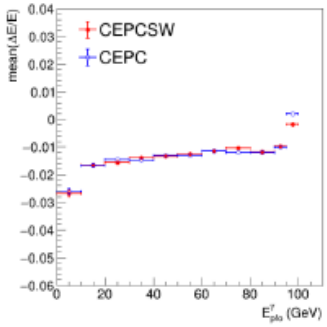


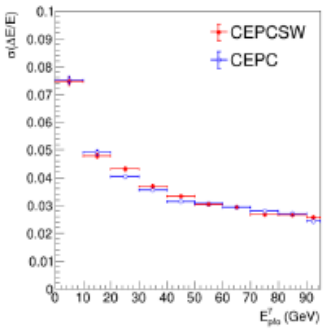


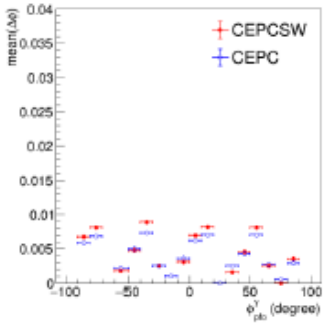


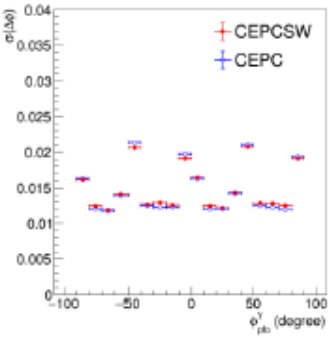


Physics performance check





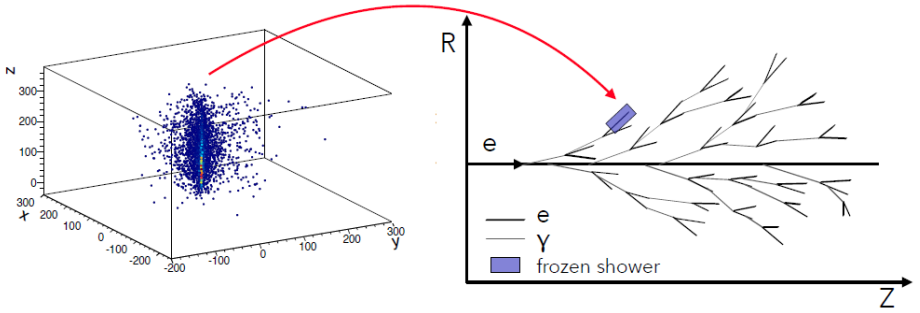


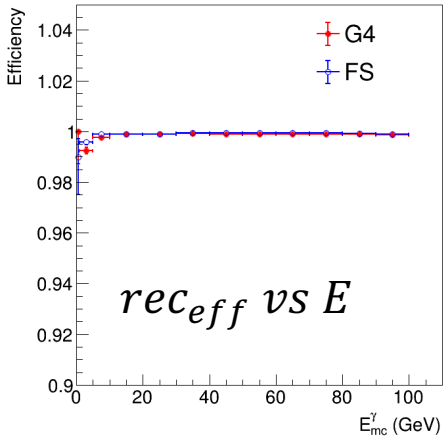


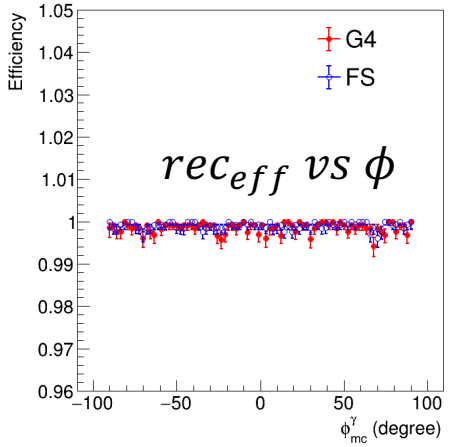
ECAL fast simulation: Frozen shower

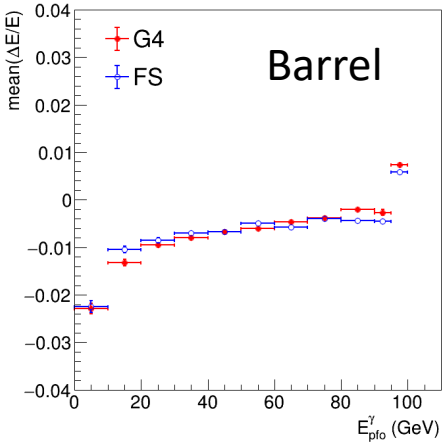
Fang Wenxing

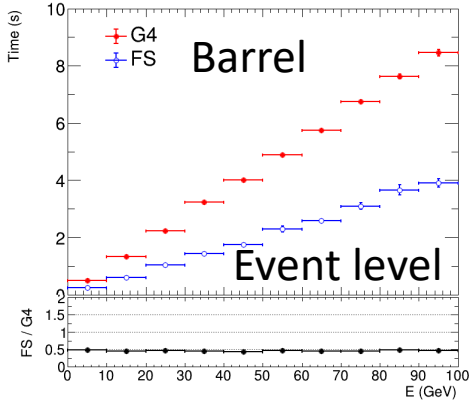
- Full simulation of calorimeter is time consuming
- Study FS to speed up simulation
  - Good agreement between G4 and FS
  - Around one time speed up can be obtained
  - Performance check with γ











Currently the FS work is under LCIO CEPC software framework

CRD ECAL

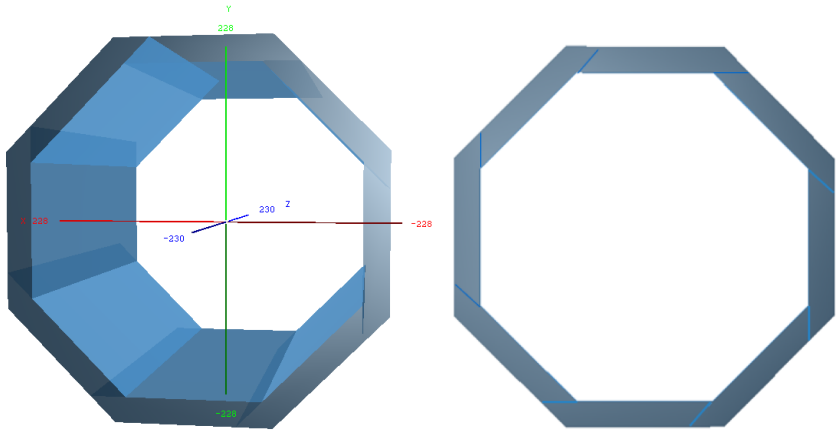
- Geometry construction
- Simulation and Digitization
- Reconstruction

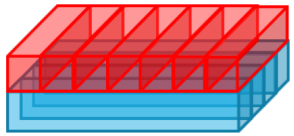
Geometry construction

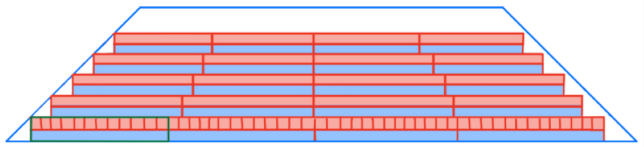
Guo Fangyi, Fu Chengdong

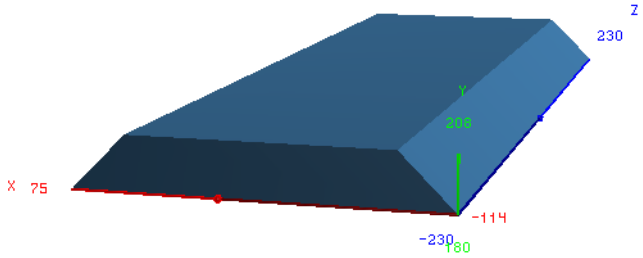
A full BGO crystal barrel ECAL

- Crystal bar:
  - BGO: $X_0 = 1.12cm$, $R_M = 2.23cm$
  - Size: $1cm \times 1cm \times \sim 40cm$
  - Dual-end readout
- Basic Unit — Super Cell
  - 2 layers of vertically intersected crystal bars
  - Size: $\sim 40\text{cm} \times \sim 40\text{cm} \times 2cm^2$
- Detector
  - $R = 1.8m$, $L = 4.6m$, $H = 28cm$
  - 8 same trapezoidal staves
- Ideal detector without electronics, supporting, etc.
- DD4Hep is used for geometry construction.





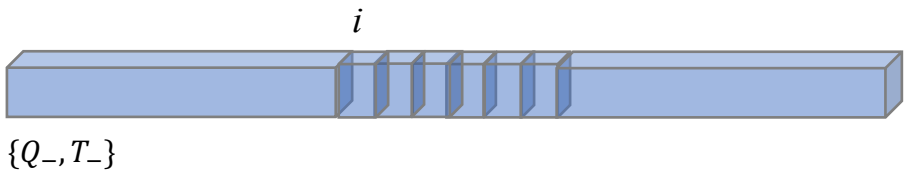




Simulation and digitization

Guo Fangyi, Wu Linghui, Sun Shengsen

- Simulation is implemented with Geant4
- Digitization for one bar
  - Double-end T & Q readout



For i-th G4Step: $Q_{\pm}^{i} = E_0 \cdot e^{-\frac{\frac{L}{2} \pm z_i}{L_{Att}}}, \quad T_{\pm}^{i} = Gaus(z_{\pm}^{i}/v,\ \sigma_T)$

For each end of the bar: $Q_{\pm} = \sum_{step} Q_{\pm}^{i}, \quad T_{\pm} = \min(T_{\pm}^{i})$

Simplified case: $L_{Att} = \infty$, so $Q_{\pm} = E_{tot}$

Hit reconstruction

Guo Fangyi, Wu Linghui, Sun Shengsen

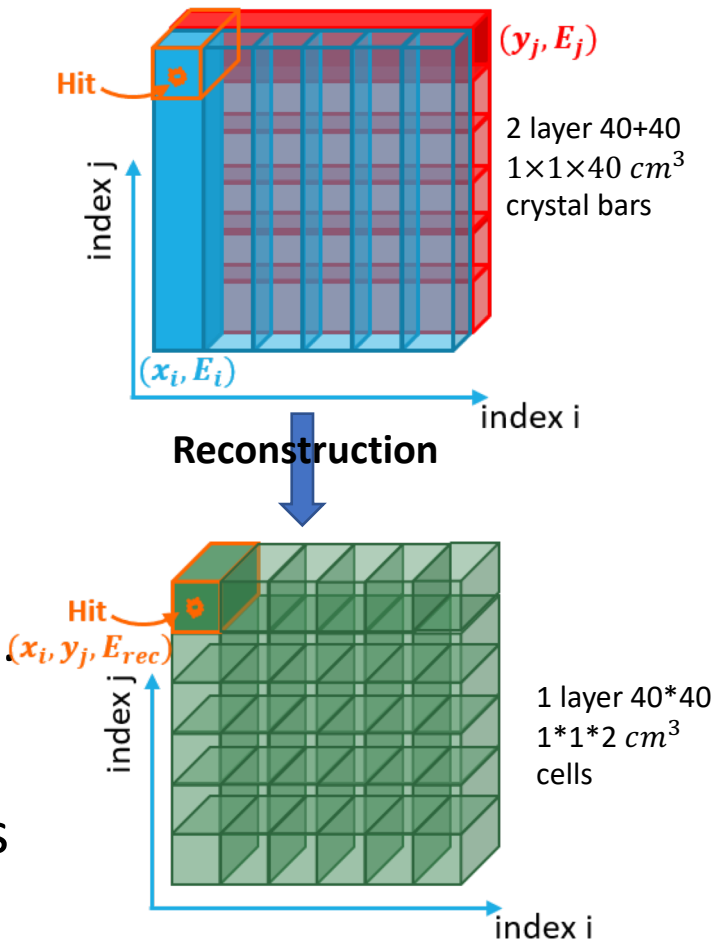
- Hit reconstruction: cross locating of bars.
  - Position: $(x_i, y_j, \frac{(z_i+z_j)}{2})$
  - Energy: use energy distribution in cross bars as fraction:

$$E_{rec} = E_i \times f_i + E_j \times f_j,$$
$$f_i = \frac{E_j}{\Sigma E_j}, \quad f_j = \frac{E_i}{\Sigma E_i}$$

  - Position from time:

$$x_T = x_{bar} + \frac{T1-T2}{2} v, \sigma_x = \frac{\sigma_T}{\sqrt{2}} v.$$

If$(|x_T - x_{rec}| > N\sigma_x)$ remove this hit.

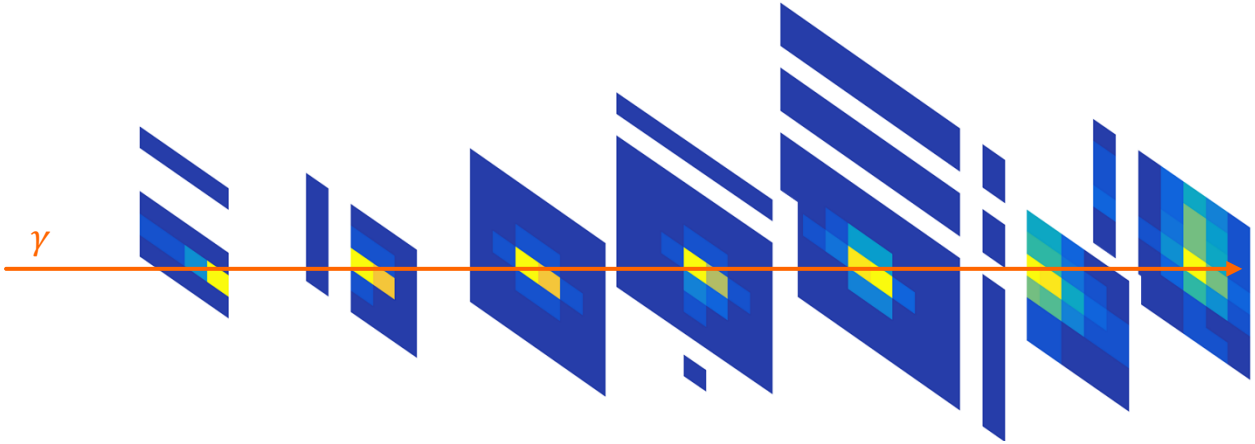


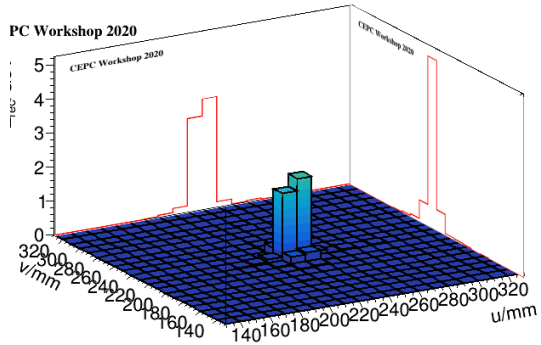
- Truth-level Simulated hit: merge G4steps in each 1*1*1 cm^3 cube as a truth hit.

Hit reconstruction

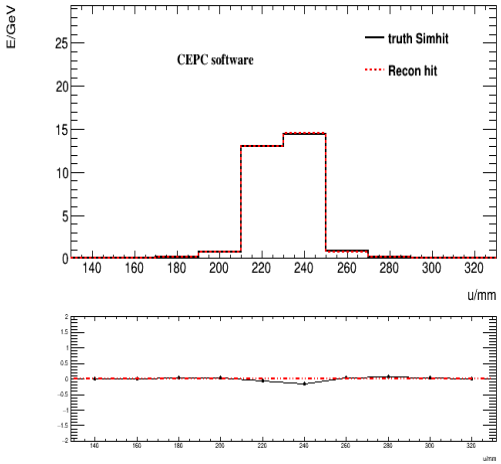
Guo Fangyi, Wu Linghui, Sun Shengsen

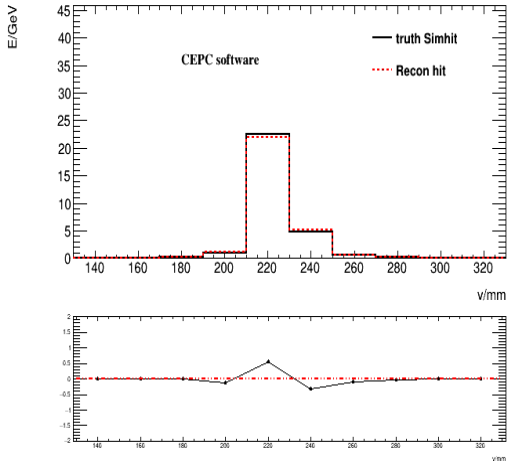
- Performance of a 30GeV single photon.
  - $L_{Att} = \infty, \mathrm{N} = \infty$
  - Energy threshold for each crystal bar: 3MeV.
  - Vertical shoot at the central of one super cell in first super-layer.

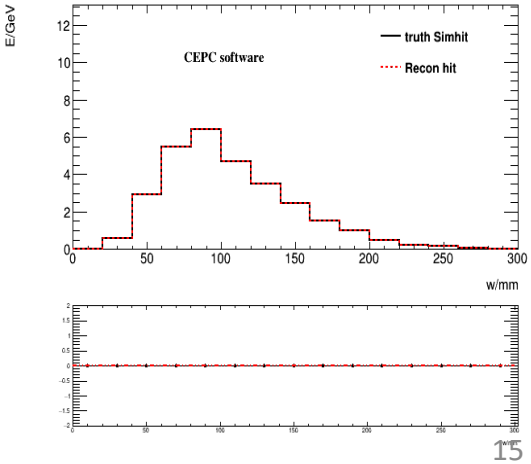




E_{rec} and projection in one super-layer

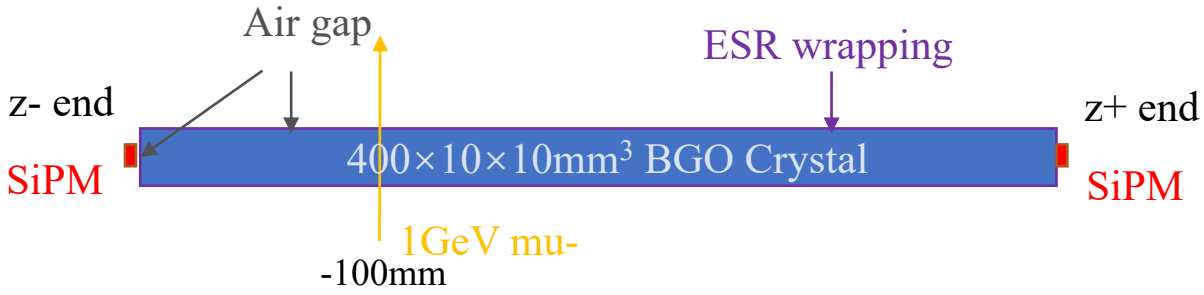


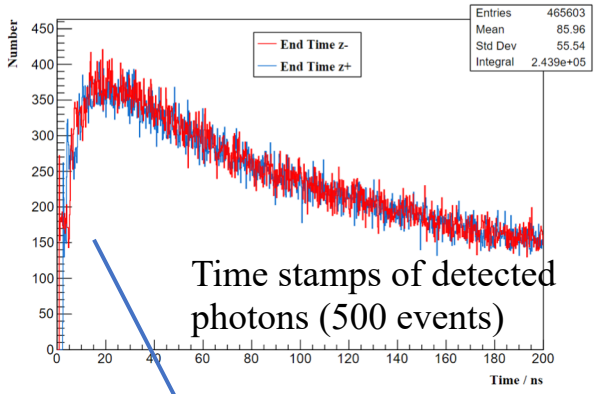


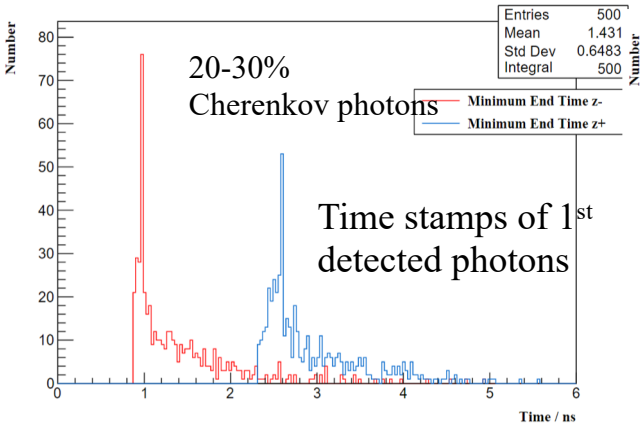


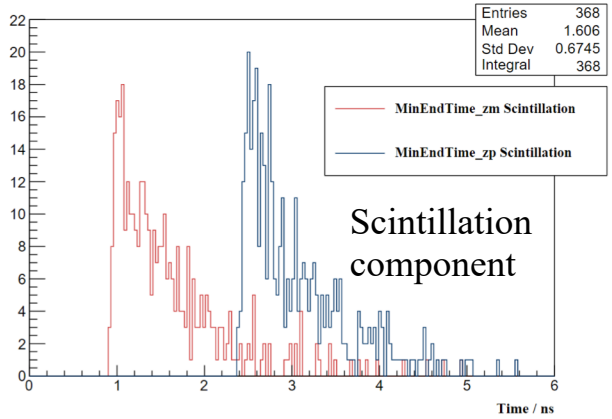
Full simulation of single crystal bar

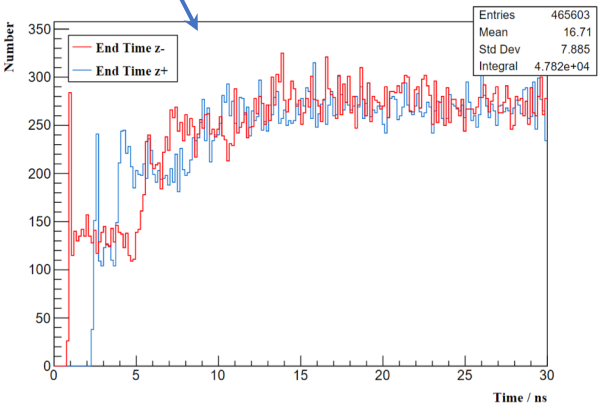
Qi Baohua, Liu Yong

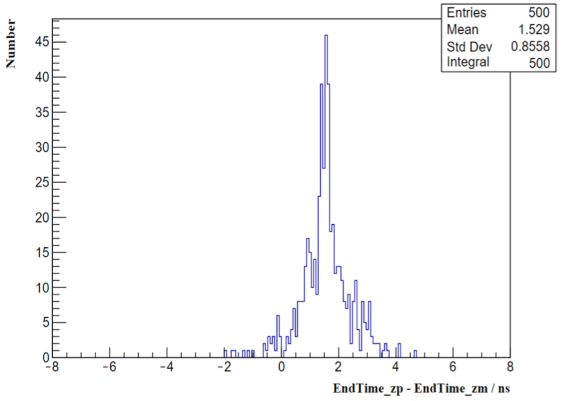


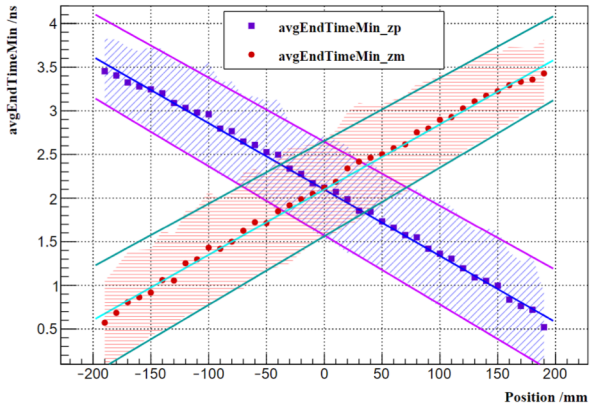








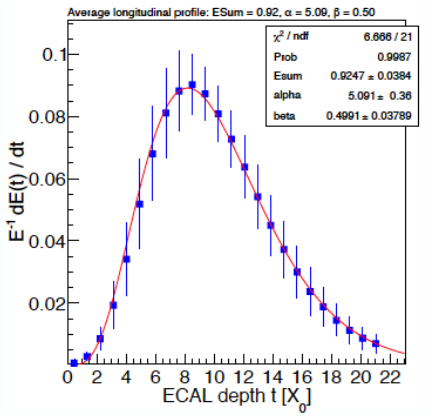


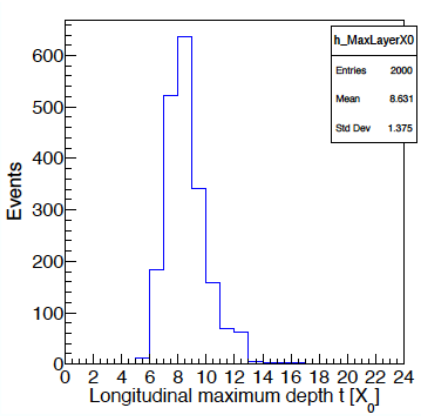


EM shower profile

Wang Yuexin, Liu Yong

Longitudinal profile (100GeV e⁻)





$$
\begin{aligned}
f(r) &= p f_C(r) + (1-p) f_T(r) \\
&= p \frac{2 r R_C^2}{(r^2 + R_C^2)^2} + (1-p) \frac{2 r R_T^2}{(r^2 + R_T^2)^2}
\end{aligned}
$$

The following formulae are used to parameterize the radial energy density distribution for a given energy and material:

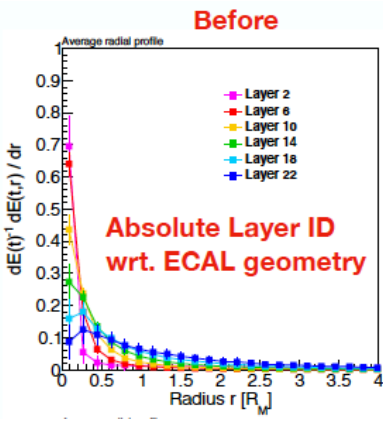
$$\tau = t/T$$

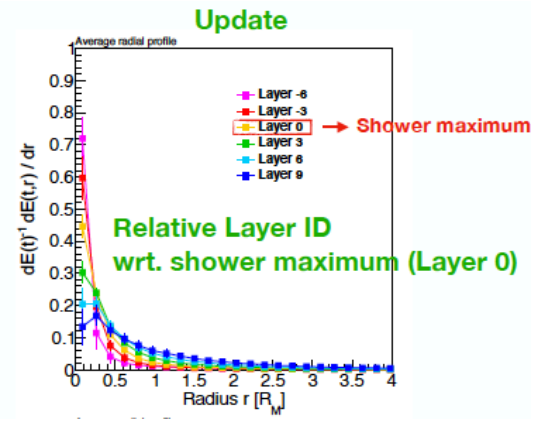
$$R_{C,hom}(\tau) = z_1 + z_2 \tau \quad (24)$$

$$R_{T,hom}(\tau) = k_1 \{\exp(k_3(\tau - k_2)) + \exp(k_4(\tau - k_2))\} \quad (25)$$

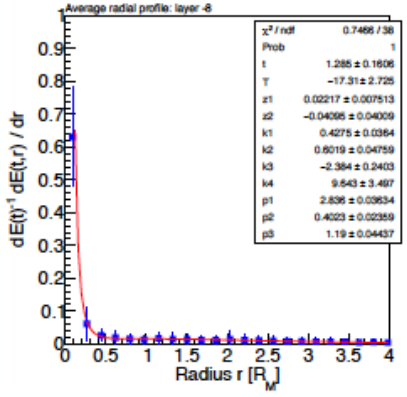
$$p_{hom}(\tau) = p_1 \exp\left\{\frac{p_2 - \tau}{p_3} - \exp\left(\frac{p_2 - \tau}{p_3}\right)\right\} \quad (26)$$

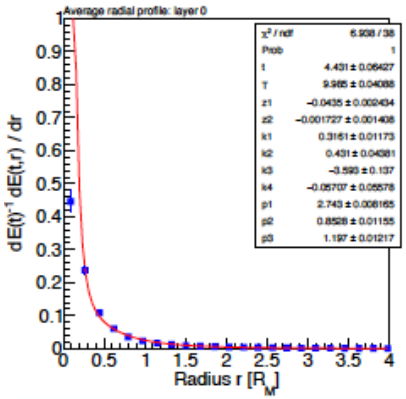
Radial profile (100GeV e⁻)





Fit to the formula





Plan

- Release of 1st version of CEPCSW
  - SiW-ECAL design will be released
  - Software validation is ongoing
- Work of long crystal bar design in CEPCSW
  - Shower reconstruction (energy split, ghost hit recognition)
  - Study of cluster feature with physics events
- Study of crystal and shower
  - Full simulation of single crystal bar
  - Shower profile study