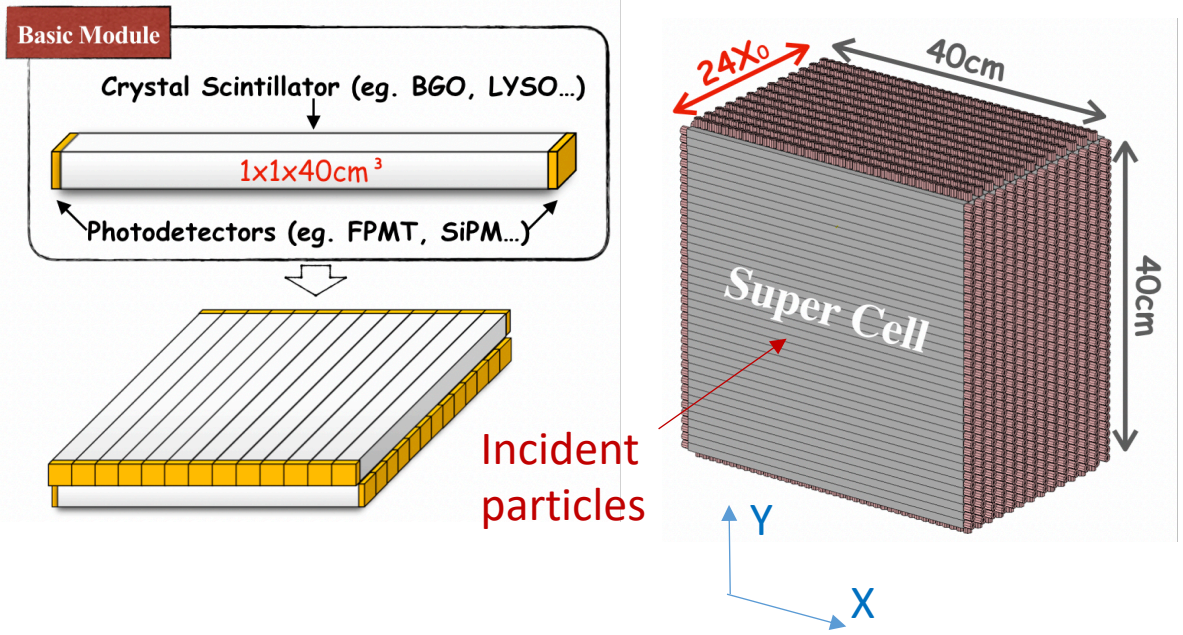
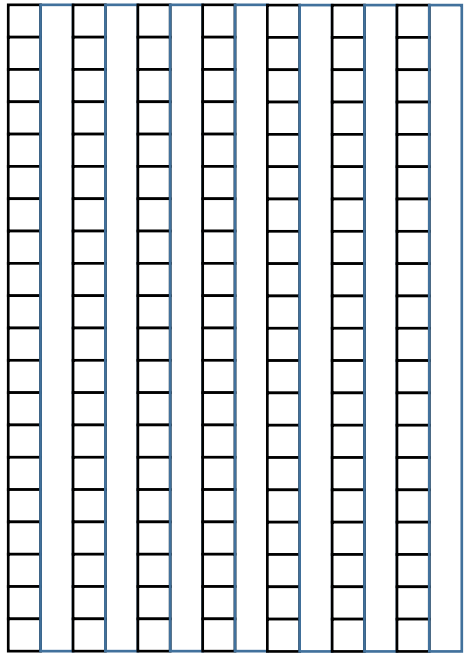
Crystal ECAL with long bars: brief status report

Yong Liu

Dec. 22, 2020

Overview: crystal calorimeter with long bars



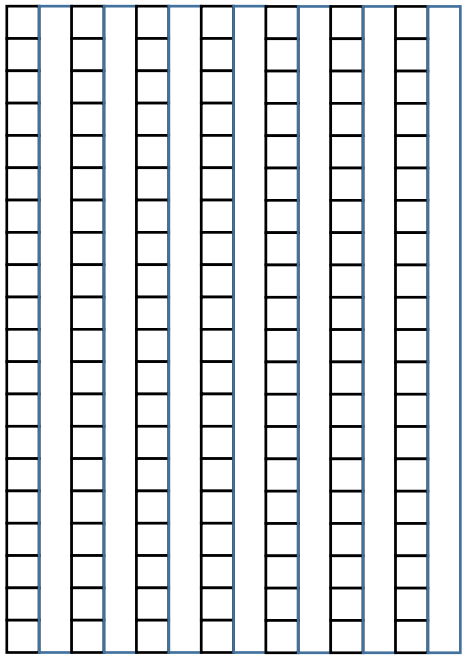


Side View
(one quarter)

- Long bars: 1×40cm, double-sided readout
  - Super cell: 40×40cm cube
- Crossed arrangement in adjacent layers
- Significant reduction of #channels
- Timing at two sides: positioning along bar

- Rec. positions from hits
  - Fine granularity: 10mm
  - Even layers: Y
  - Odd layers: X
- Rec. positions from timing
  - Constraints from timing resolution
  - Even layers: X
  - Odd layers: Y
  - Complementary to hit positions

General status

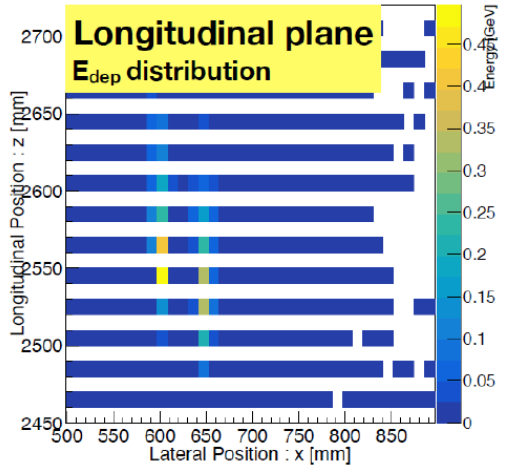


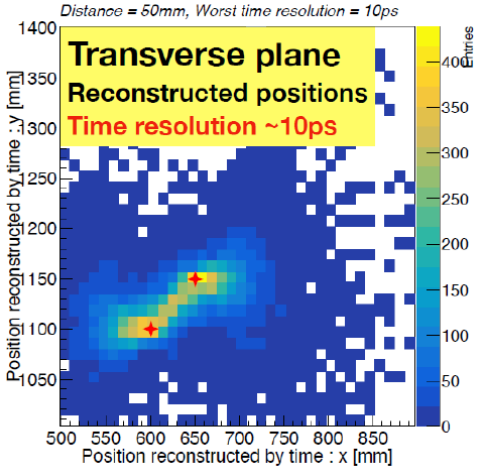
Side View
(one quarter)

- Strategy for separation and reconstruction of (2) nearby showers
- Reconstructed positions: in progress
  - Compare long bars with MC-truth (hereby 1cm^3 cubes)
  - To understand differences due to geometry
  - Focus on EM showers
- EM shower profiles: done
  - Inputs for energy sharing of near-by EM showers
  - Results from Yuexin and Baohua
- Implementation of geometry and digitisation in CEPCSW: Fangyi Guo
- Hadron showers in crystal ECAL: in progress
  - Inputs for jet performance studies
  - Need to well understand the energy calibration (linearity)
  - A separate short talk from Baohua, latest results on the hadron performance of combined ECAL+HCAL (with two ECAL options)

Shower separation and energy reconstruction

1. BarID and LayerID -> crossed bars -> X,Y in 2 adjacent layers
2. Timing info at two ends -> positions (resolve ambiguity)
   - Rough separation of two particles for the Step 3
3. Shower longitudinal profile
   - Rough estimate of incident particle energy; shower maximum
4. Shower axis finding and connection
   - Seeds per layer
   - Connect seeds in layers around the shower maximum
5. Shower lateral profile
   - Use fitting/histogram info (as template) to determine weights of energy splitting: currently focus on EM showers
6. Clustering of bars with weights for energy reconstruction





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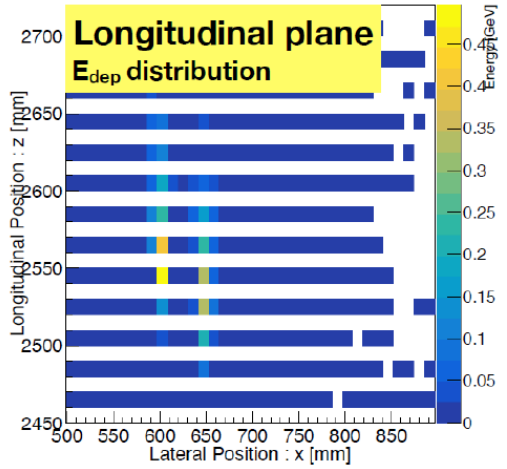

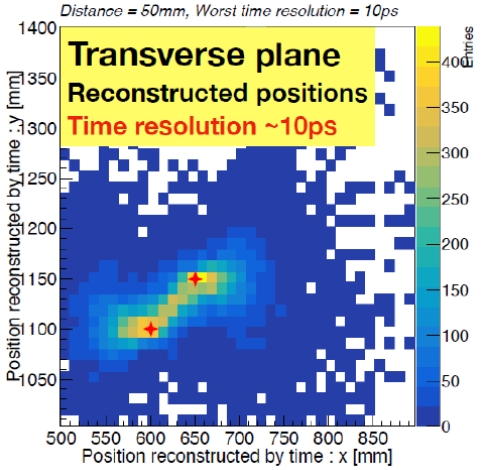

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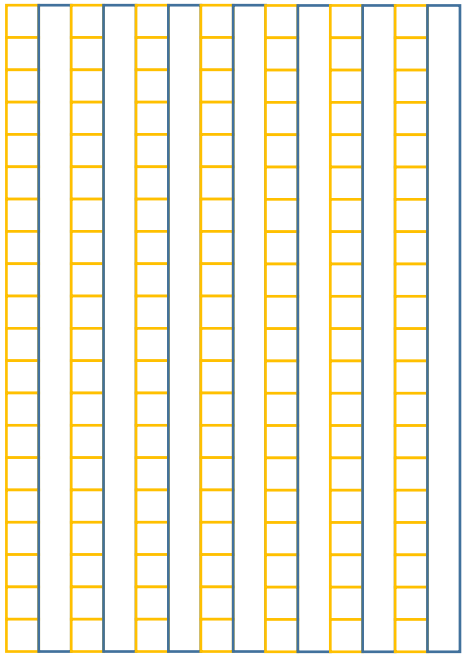
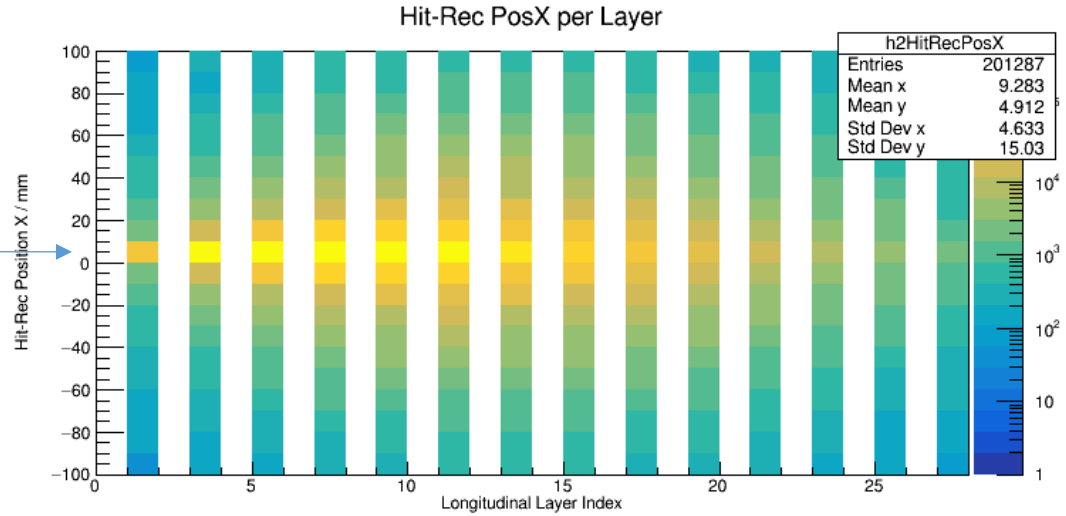
Reconstructed positions from hits

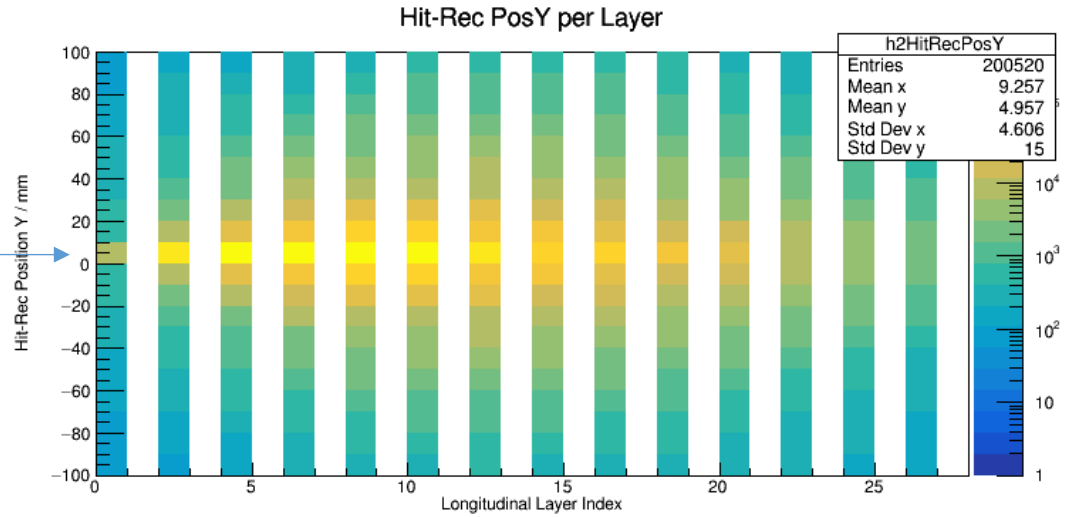
Gamma
(10 GeV)



Side View:
Fine granularity:
hit positions

Incident gamma: 5mm offset along x and y
(to avoid gaps)





Energy-weighted
positions in X and Y

Shower separation and energy reconstruction

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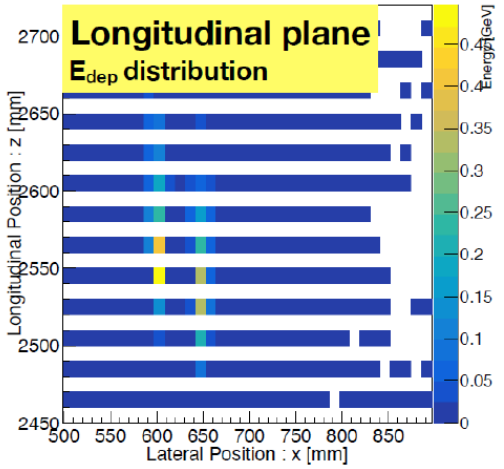

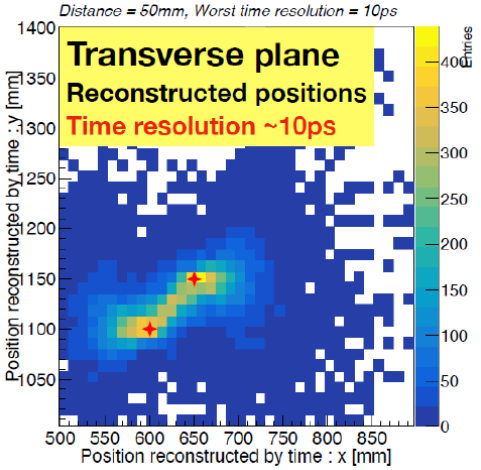

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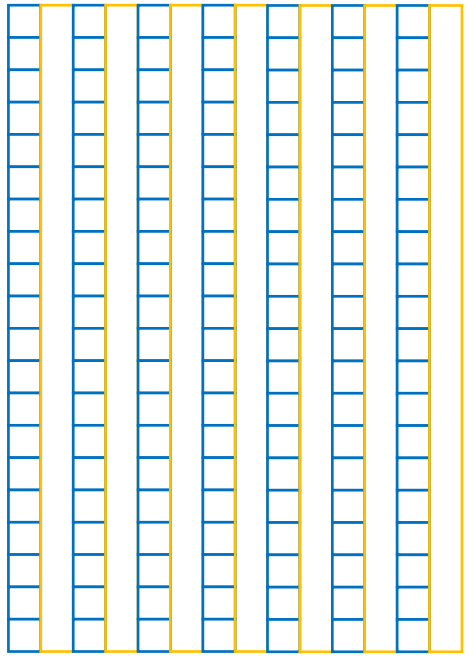
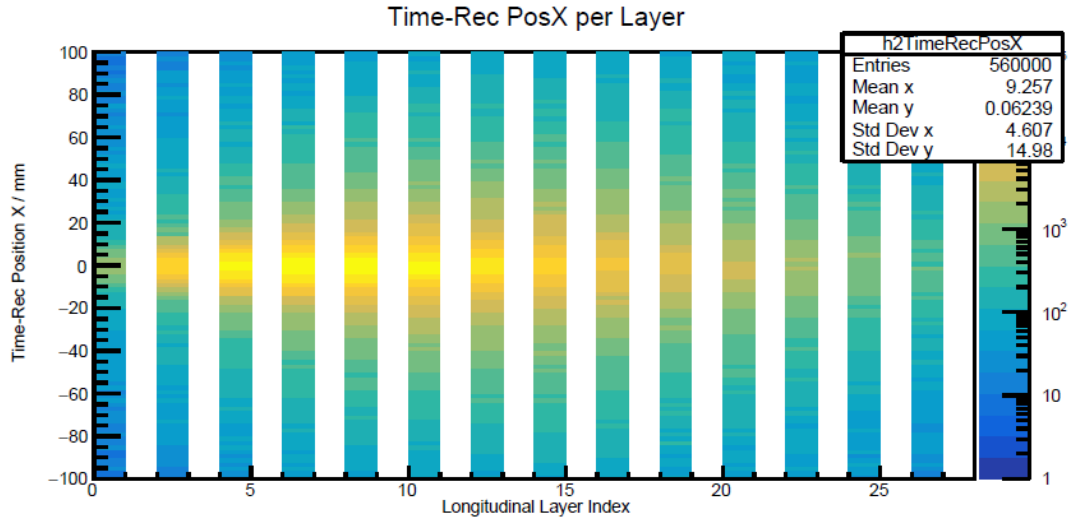
Reconstructed positions from timing

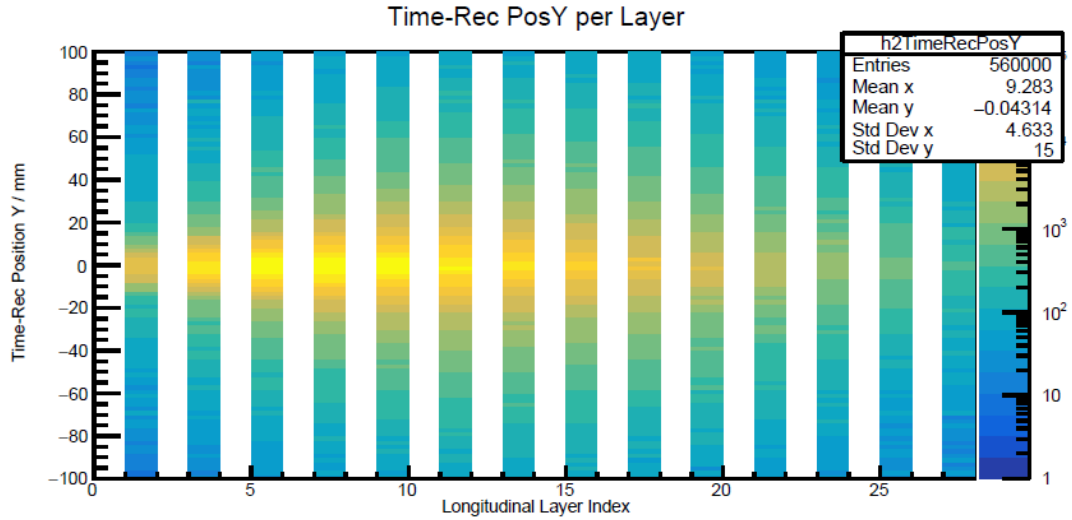
Gamma
(10 GeV)



Side View:
Positions from timing differences at two ends

Incident gamma: 5mm offset along x and y (to avoid gaps)



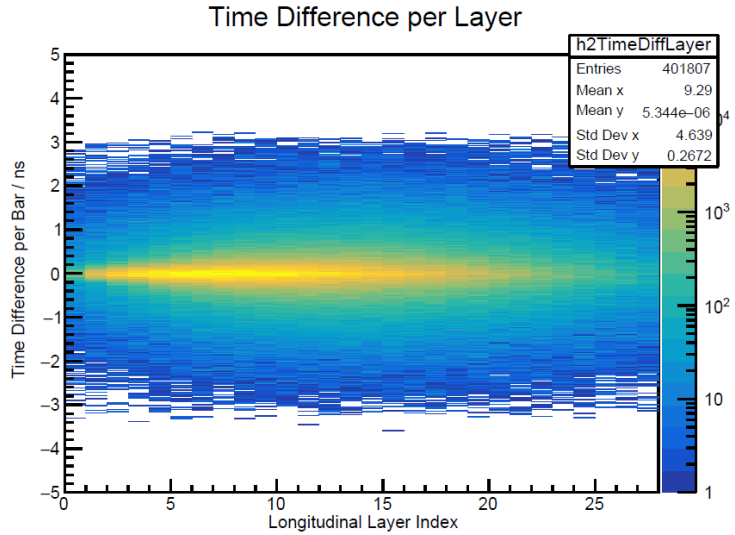


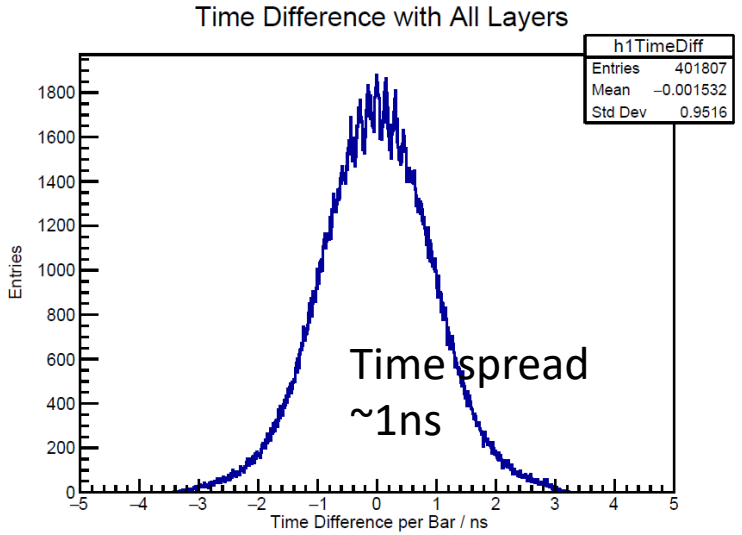
PosX,Y = $\frac{(t1-t2)}{2v}$;
t1, t2 are the timing at two ends; v is the effective velocity

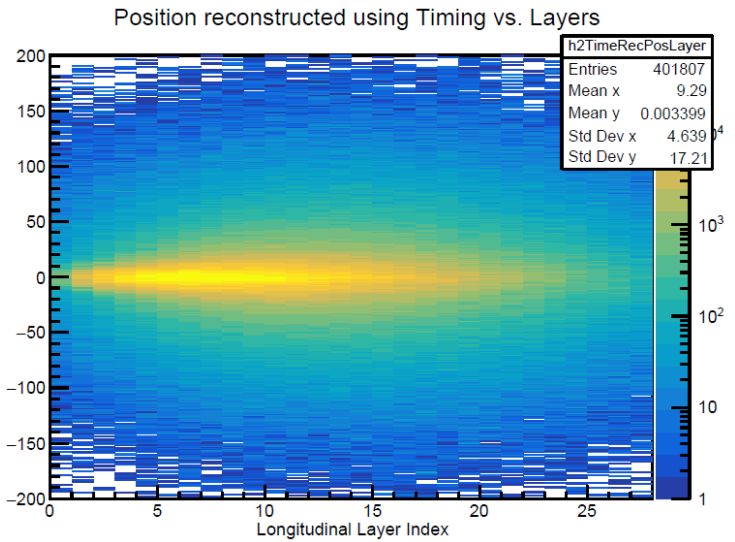
Energy-weighted positions in X and Y

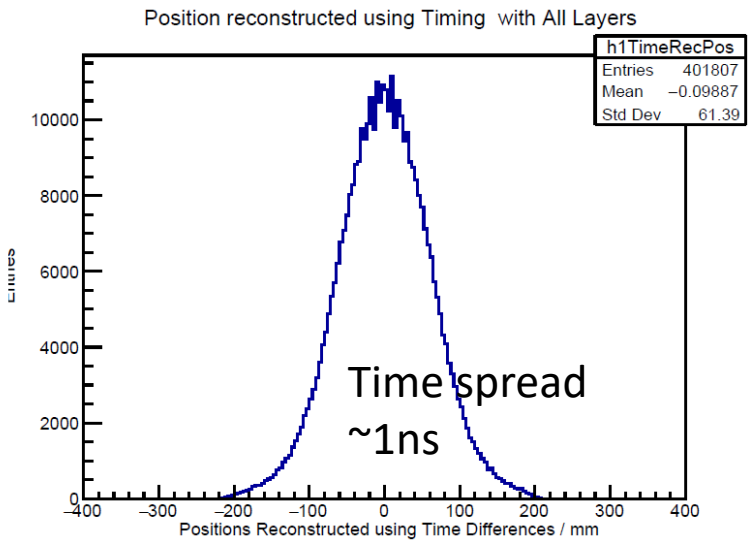
Reconstructed positions from timing

10 GeV gamma





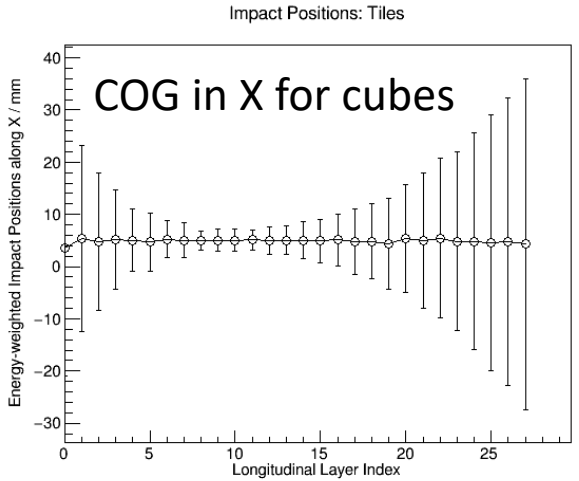


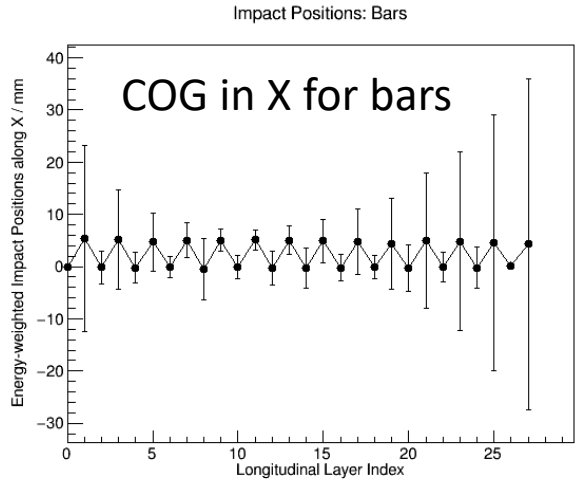


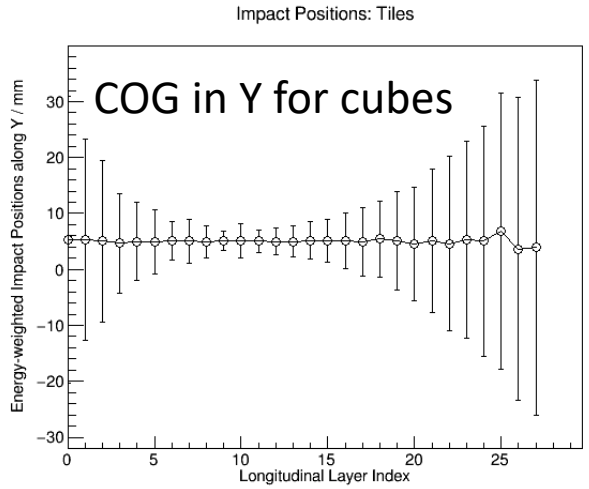
- Timing spread per bar: ~1ns
- Uncertainty of rec. positions from timing: ~60mm
- With energy weights, narrow down positioning precision ~10mm

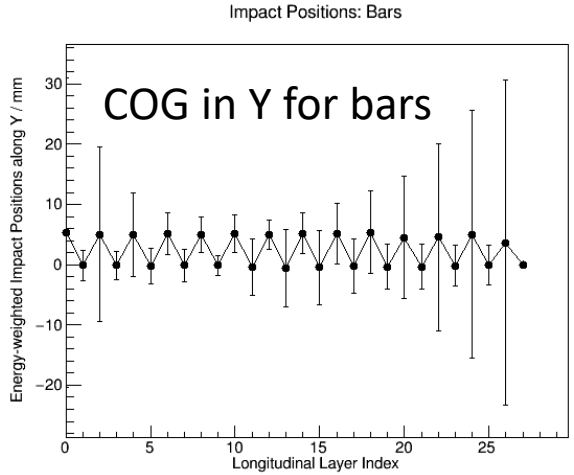
Comparison: long bars vs. cubes

- Figure of merit: Center Of Gravity (COG) per layer of single EM showers









In the bar geometry, within every two adjacent layers, COG-X is determined by hits, COG-Y is by timing, for an odd layer; vice versa for an even layer.

It is noticed that ~5mm difference exists between COG determined by timing and hits -> timing less accurate

$$COG_x = \sum_j w_j x_j,\ COG_y = \sum_j w_j y_j$$

$$w_j = E_j / \sum_j E_j$$

E_j as the energy deposition in the j-th long bar per layer

Shower separation and energy reconstruction

1. BarID and LayerID -> crossed bars -> X,Y in 2 adjacent layers
2. Timing info at two ends -> positions (resolve ambiguity)
   - Rough separation of two particles for the Step 3
3. <u>Shower longitudinal profile</u>
   - Rough estimate of incident particle energy; shower maximum
4. Shower axis finding and connection
   - Seeds per layer
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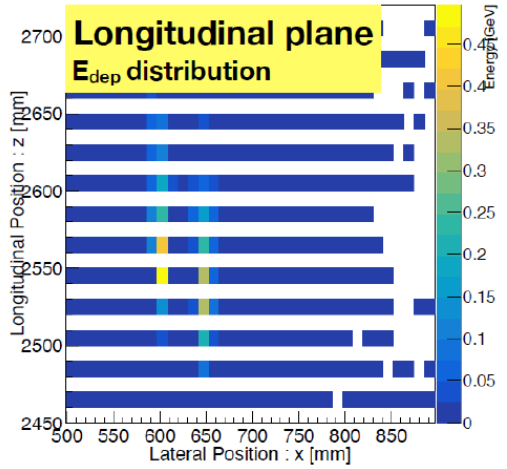

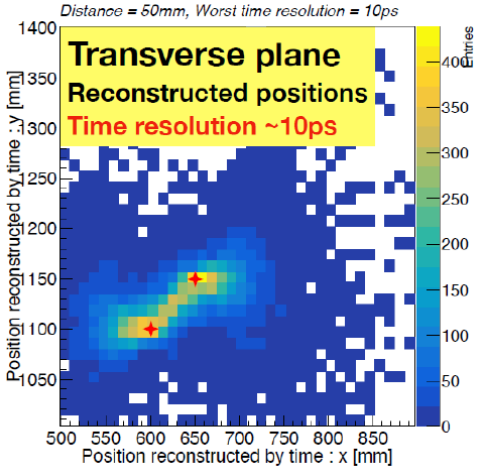

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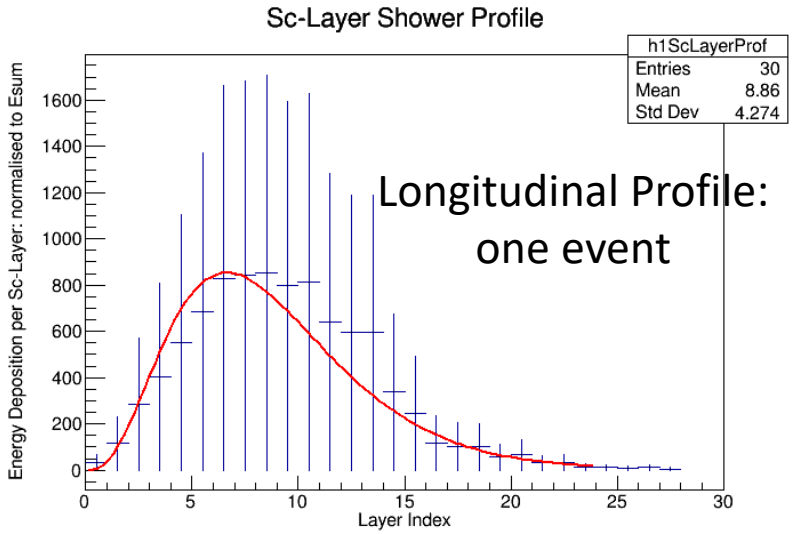
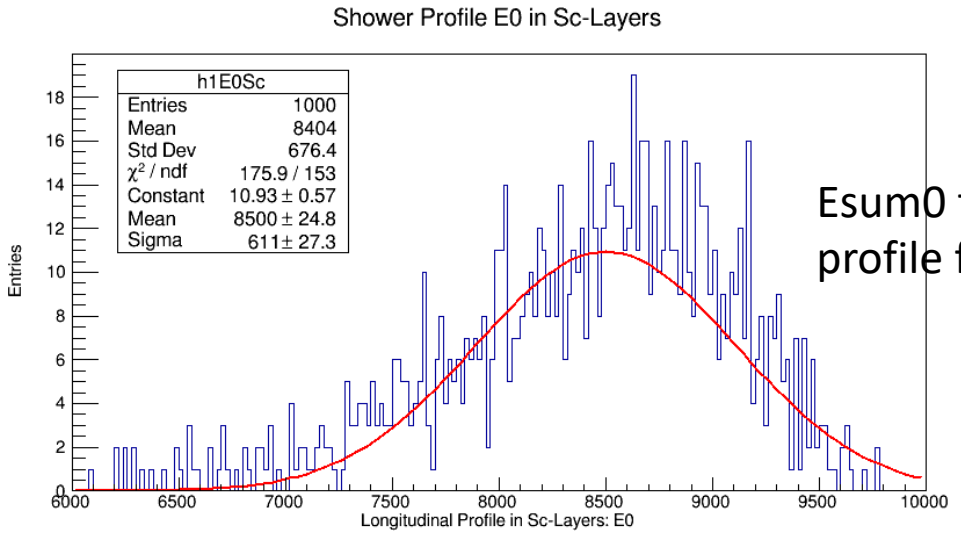
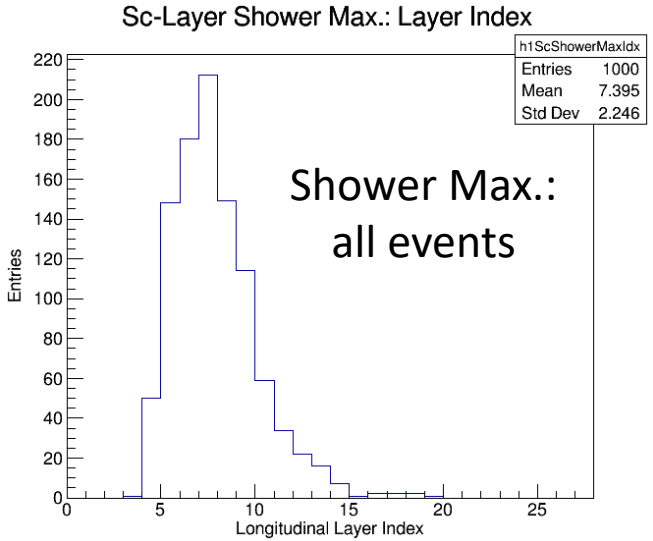
Shower longitudinal profiles: fluctuations

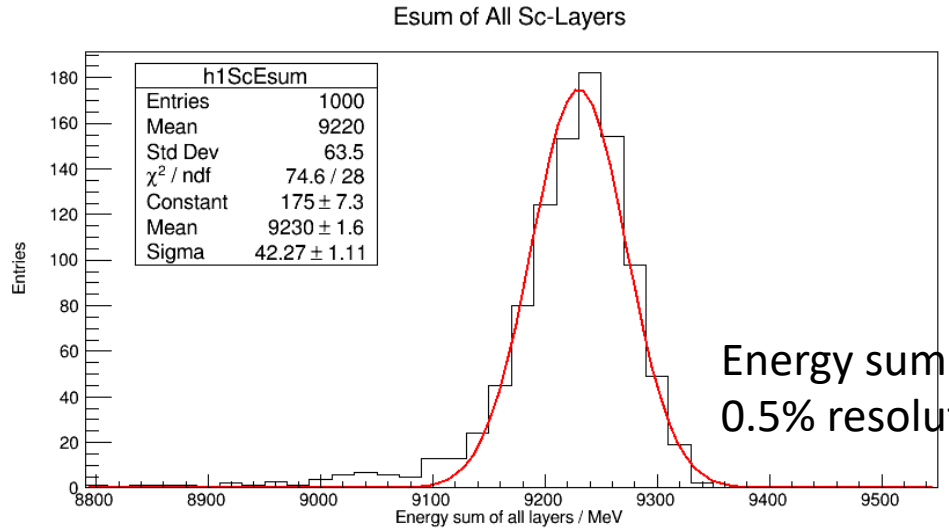




10 GeV gamma

Esum0 from longitudinal profile fit, ~7% resolution





Energy sum of all layers 0.5% resolution

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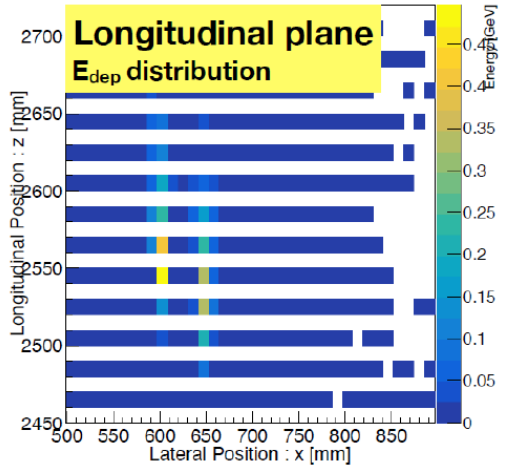

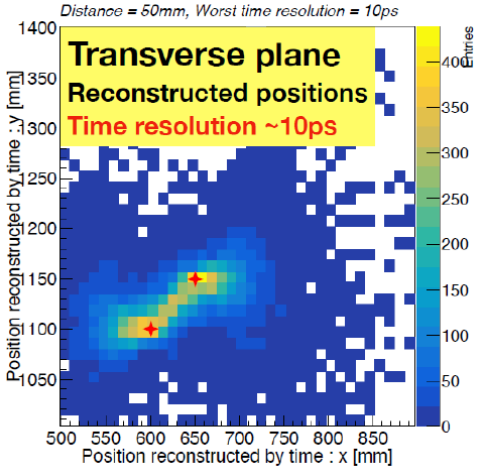

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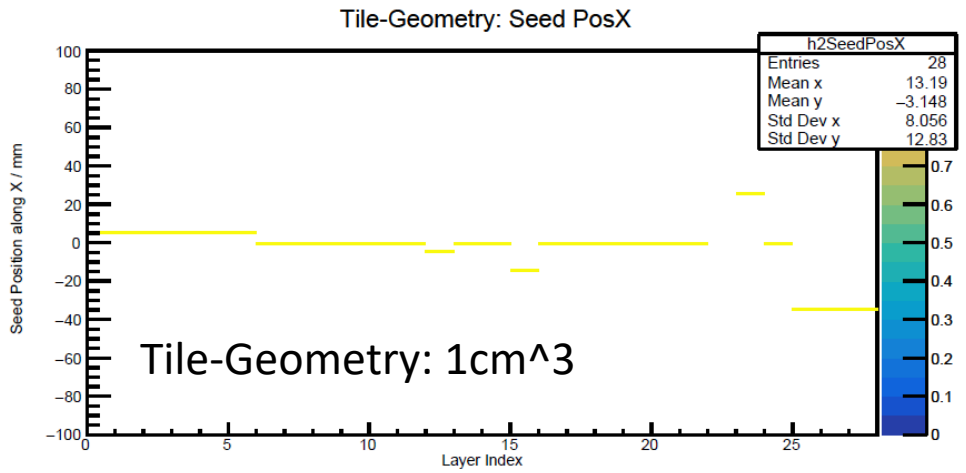
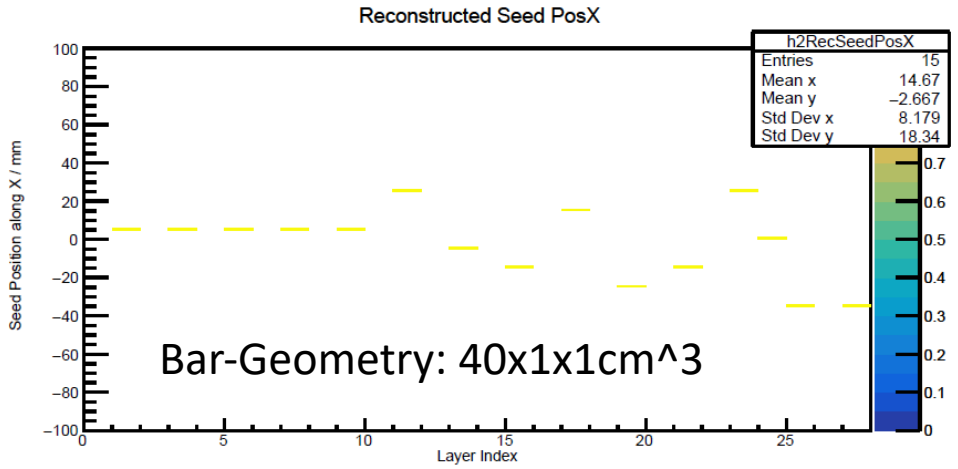
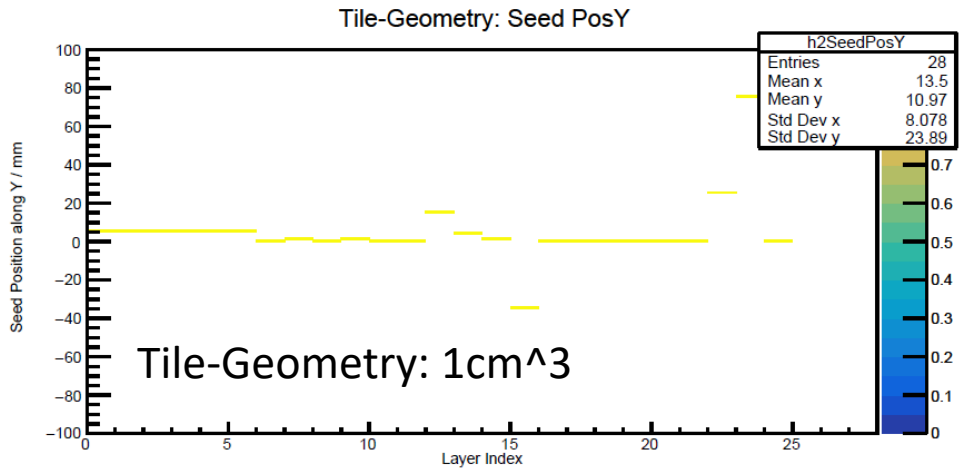
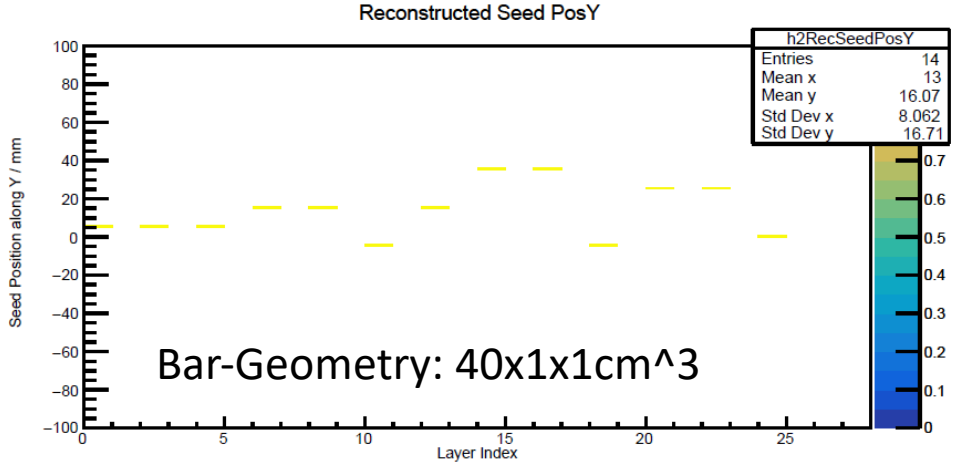
Show axis: seed per layer

- The tile/bar with maximum energy deposition (per layer)





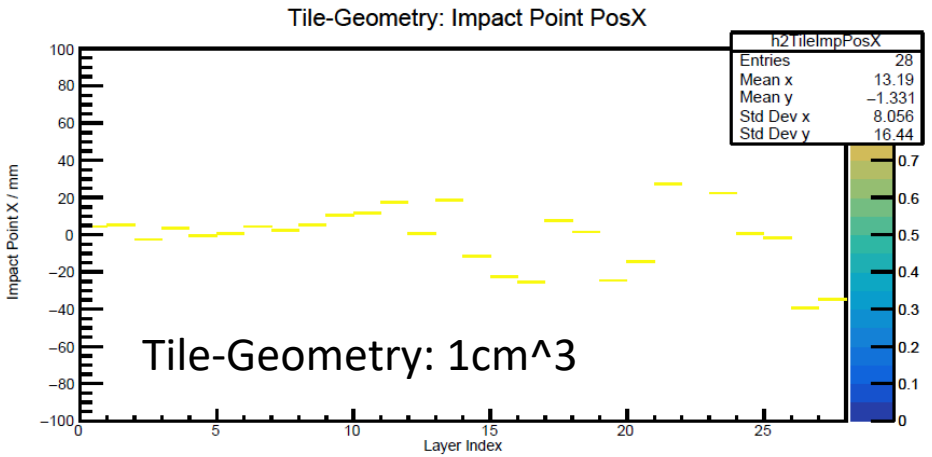


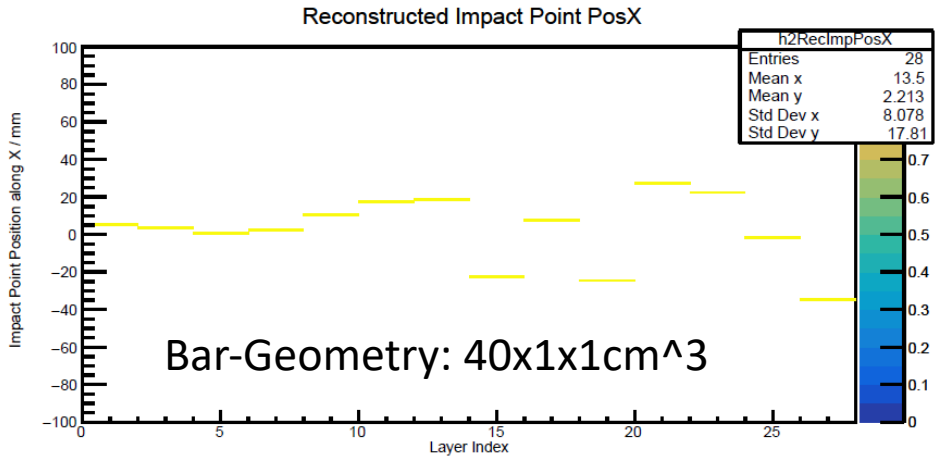


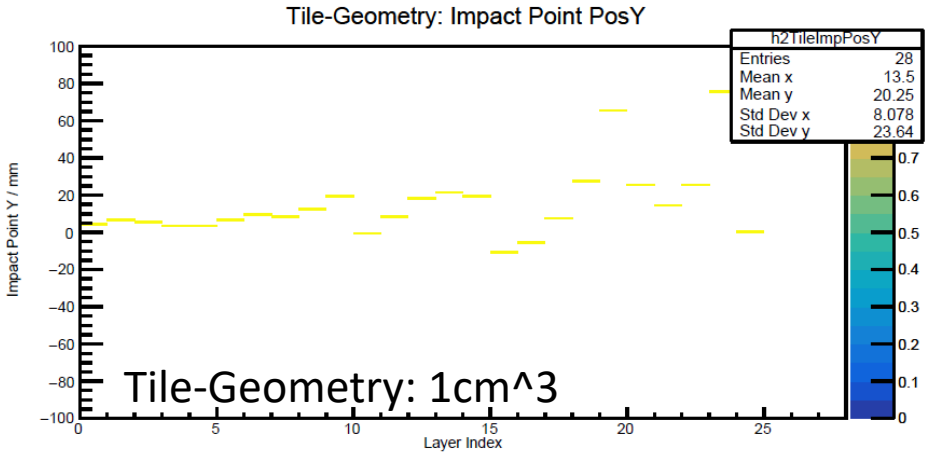
Event-2

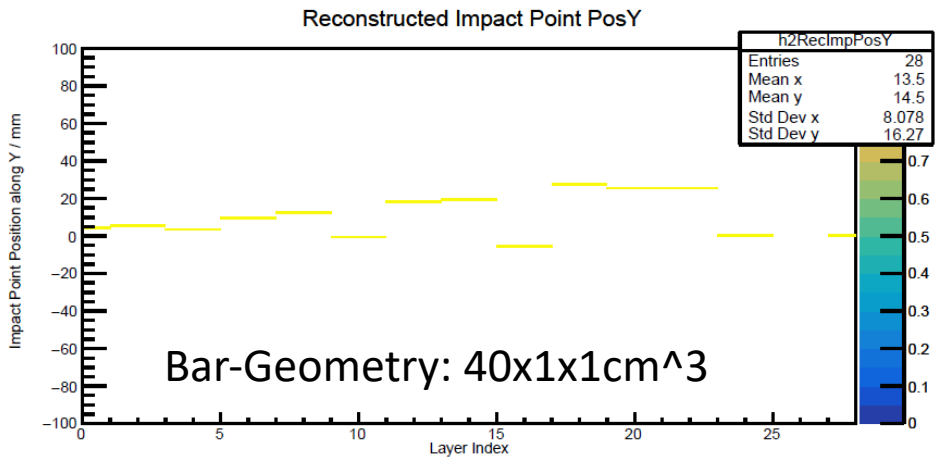
Show axis: Center Of Gravity (COG) per layer

- Energy weighted positions along X and Y (in transverse plane)









$$COG_x = \sum_j w_j x_j$$

$$COG_y = \sum_j w_j y_j$$

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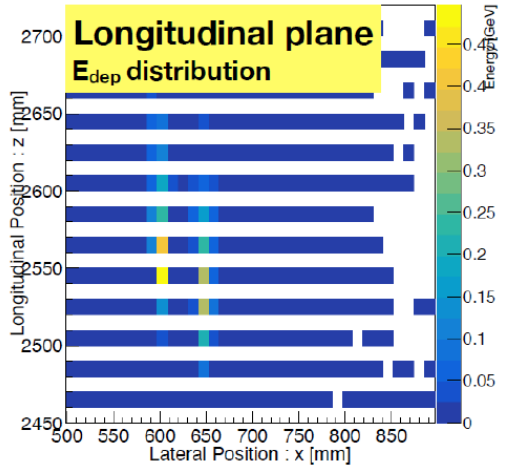

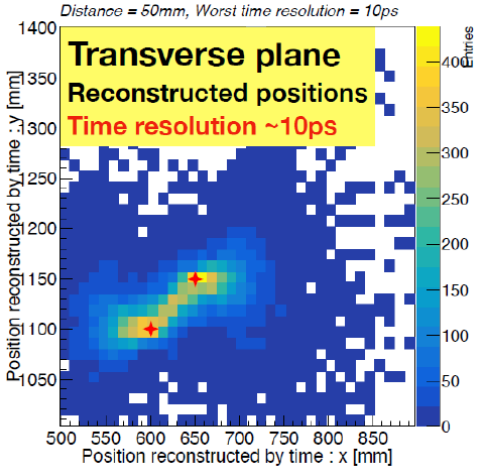

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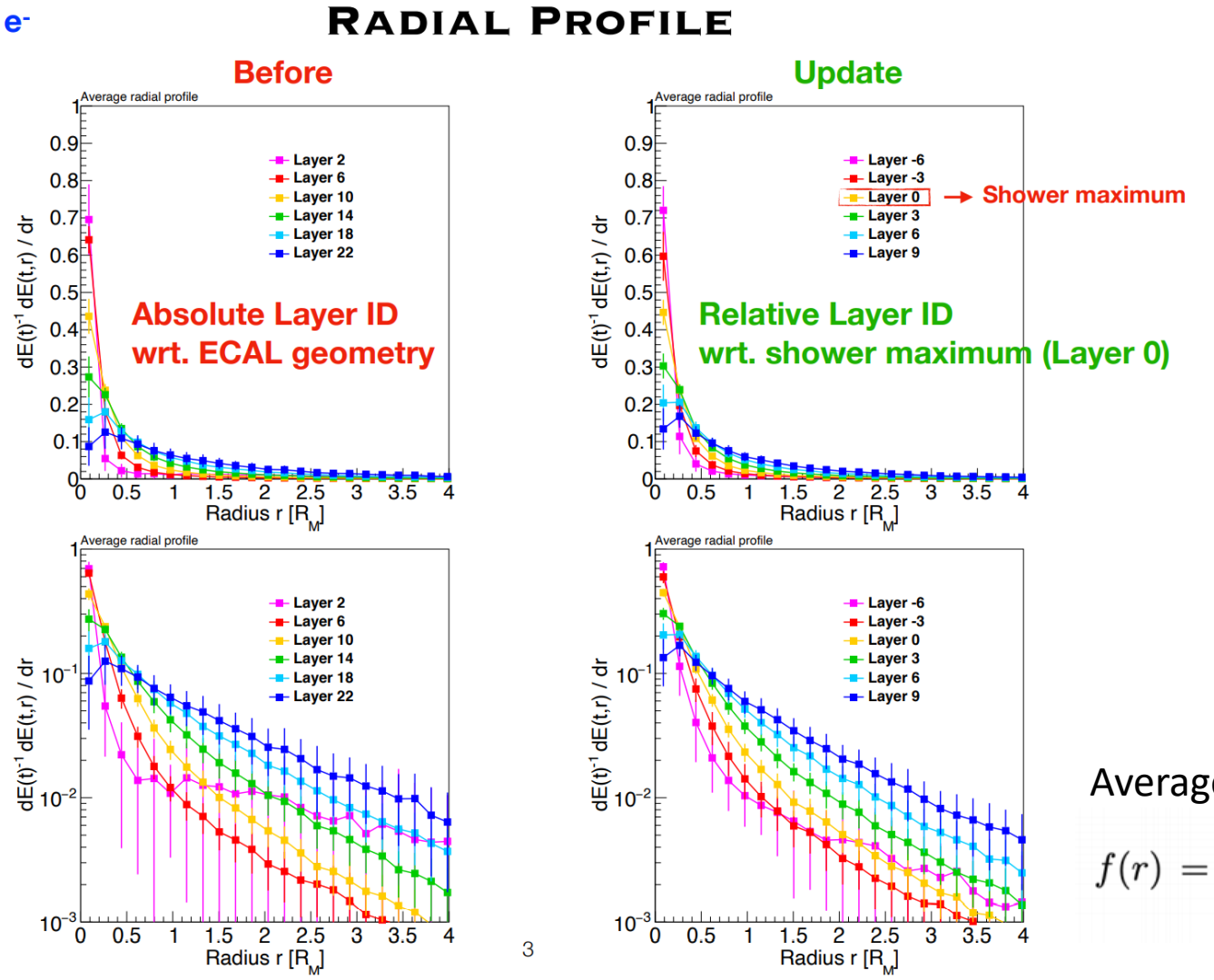
Shower lateral profile: layer-wise

100GeV e-



- EM shower lateral profiles
  - Histograms stored for each longitudinal layer
  - "Normalised" to the shower maximum
  - Need to locate the shower axis beforehand
  - Assign weights for energy splitting in the same bar
- Other trials
  - Tried to use models to fit the curves

Average radial energy profiles

$$f(r) = \frac{1}{dE(t)}\frac{dE(t,r)}{dr} \qquad \begin{aligned} f(r) &= p f_C(r) + (1-p) f_T(r) \\ &= p\frac{2rR_C^2}{(r^2+R_C^2)^2} + (1-p)\frac{2rR_T^2}{(r^2+R_T^2)^2} \end{aligned}$$

Activities in CEPCSW: selected

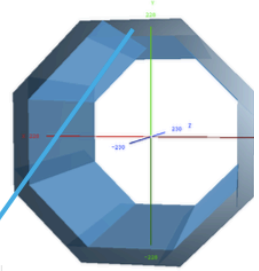
Fangyi Guo

- Implementation of geometry and digitization in CEPCSW: done

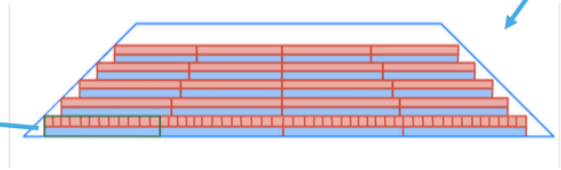
Geometry construction

In each trapezoidal module:

- 28 **layers**, counting 2 layers as a **super-layer**.
- In each super-layer, **layer0** goes horizontal(ϕ-direction), **layer1** goes longitudinal(z-direction).
- Basic unit for reconstruction: ~40cm*~40cm*2cm **block**.
- Each block has ~40(layer0)+~40(layer1) crystal bars.
- 4 blocks in ϕ, 10 blocks in z direction.
- *Left a ~2 cm blank at the edge of module.



40cm*40cm*2cm block



A module in x-y plane, with part of bars.

Simulation and digitalization

Construct the geometry in DD4hep.

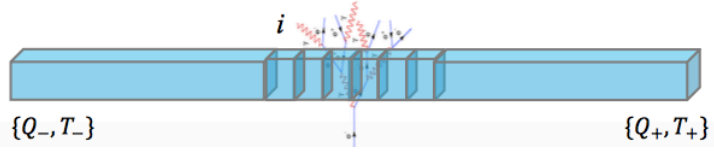
Simulation could be performed with Geant4 in CEPCSW.

Digitalization for one long crystal bar:

- Readout information: 2-side Q and T.
- Contribution from G4step i:

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

  $Q_{\pm} = \sum_{step} Q_{\pm}^{i},\ T_{\pm} = \min(T_{\pm}^{i})$
- Simplified condition: $L_{Att} = \infty$, so $Q_{\pm} = E_{tot}$.



Activities in CEPCSW: selected

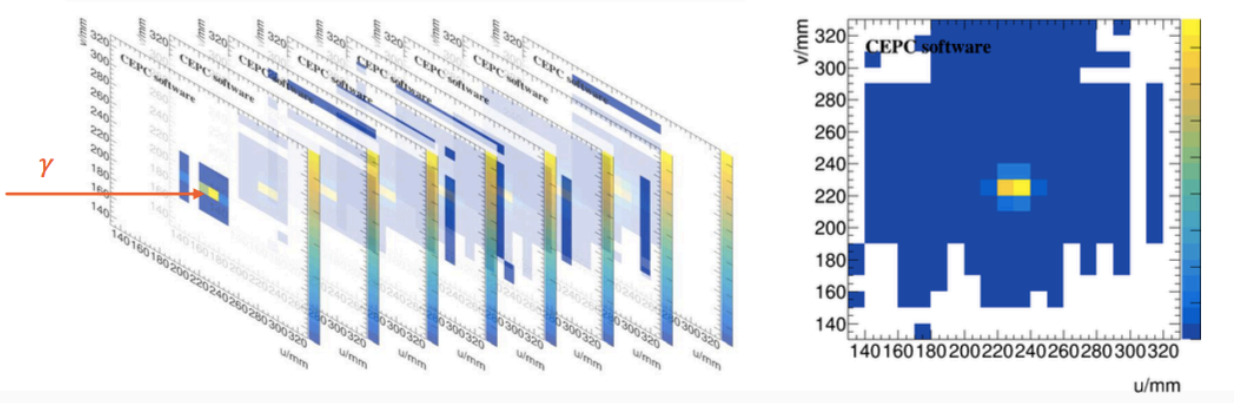
Fangyi Guo

- Hit position reconstruction

Hit reconstruction single photon

Check performance with 30GeV single photon.

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

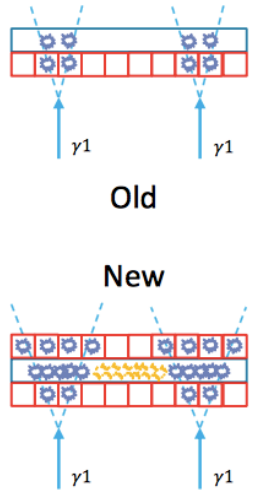


New reconstruction concept

Use a sandwich structure to reconstruct hit

Hit position in transvers bar depends on hits in previous and following longitude bars.

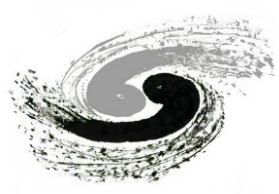
- Pros:
  - DigiHit size 1*1*1 cm^3
  - More flexible for crystals' placement.
  - Further remove ghost hits from wrong combination in one super-cell.
- Cons:
  - New ghost hits in transvers bars due to wrong combination in 2 longitude layers.
- Possible solution: do this reconstruction in Pandora. Use track projection as a seed to remove ghost hits. (position and direction)



Summary and plan

- Figured out a first skeleton for reconstruction of (2) near-by showers
  - Separation and energy splitting
- Necessary information almost ready
  - Seed/COG, timing, shower shapes, etc.

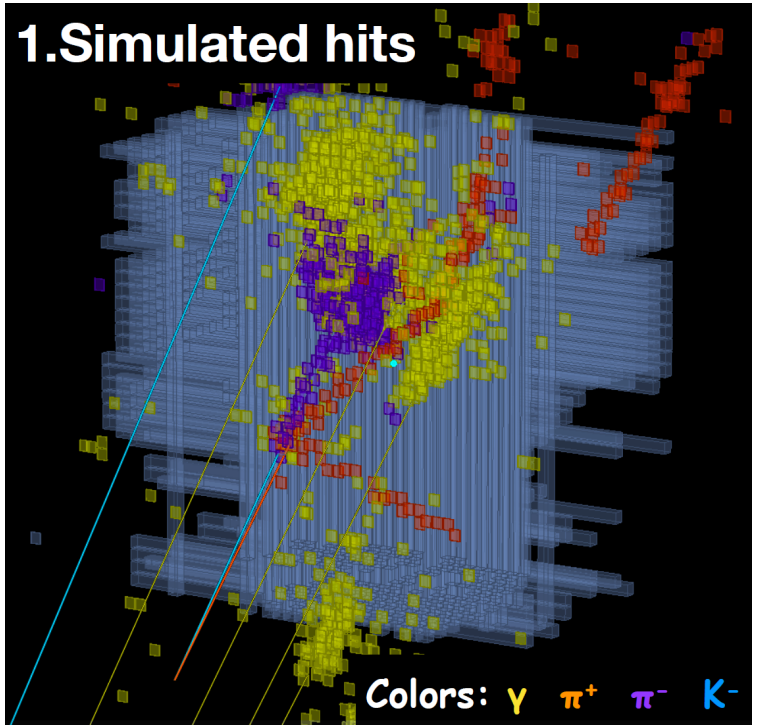
- Plan to implement a first reconstruction algorithm in software

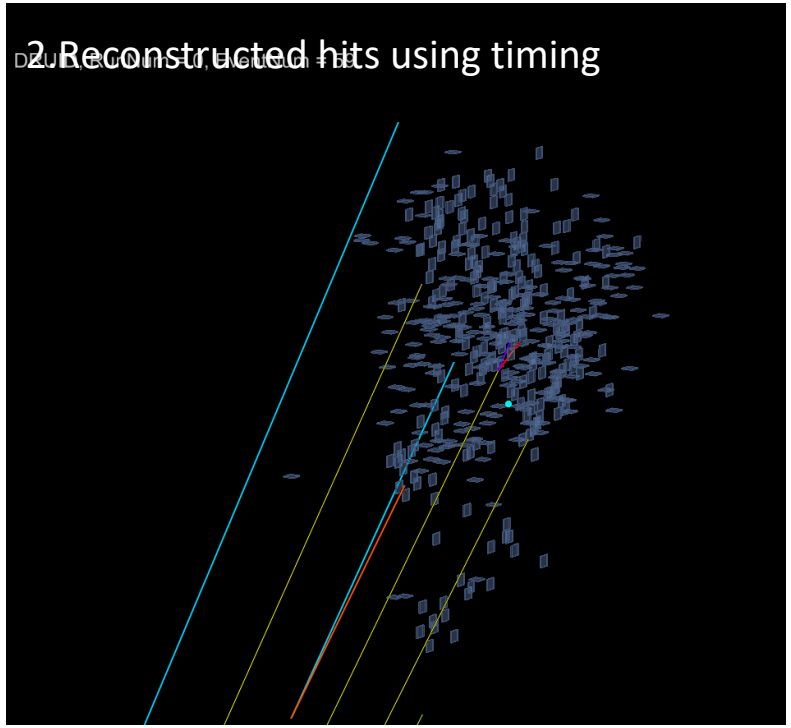


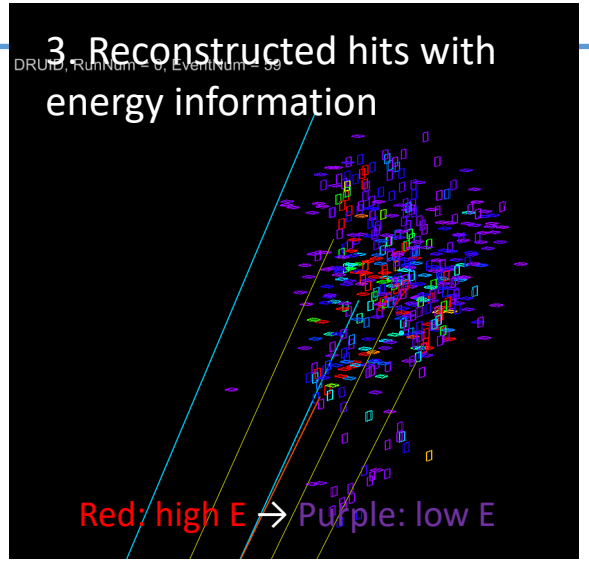
Backup

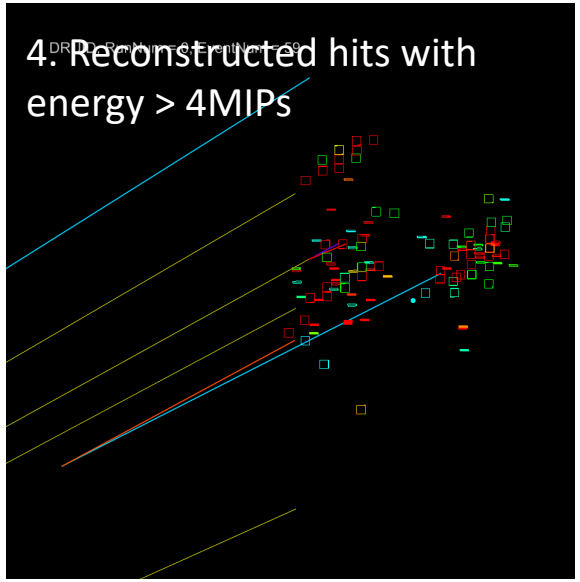
Pattern studies using Event Display

- Patterns for first impression, but still complex
- Need further studies on positioning and energy splitting



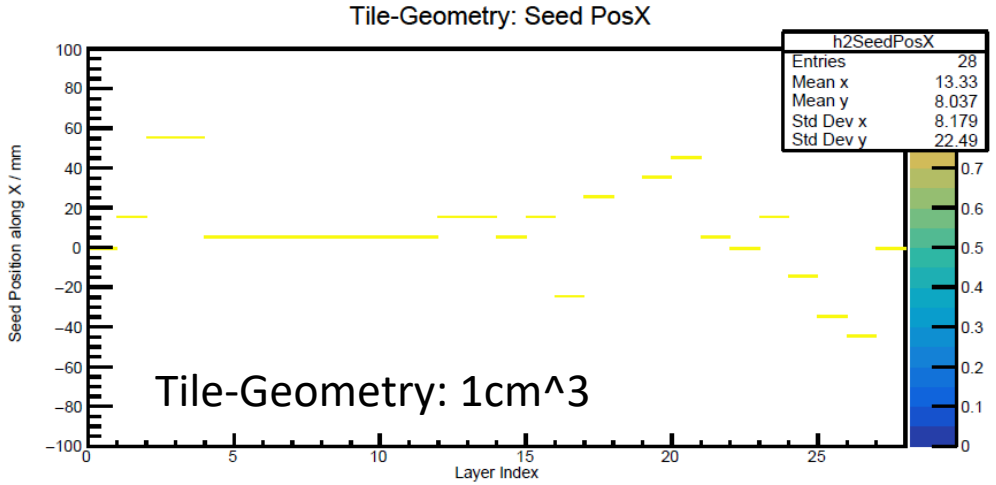


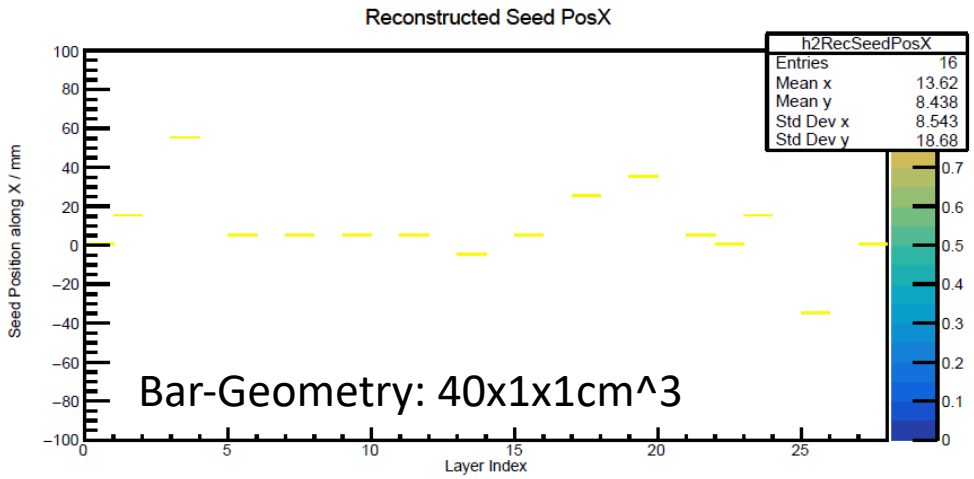


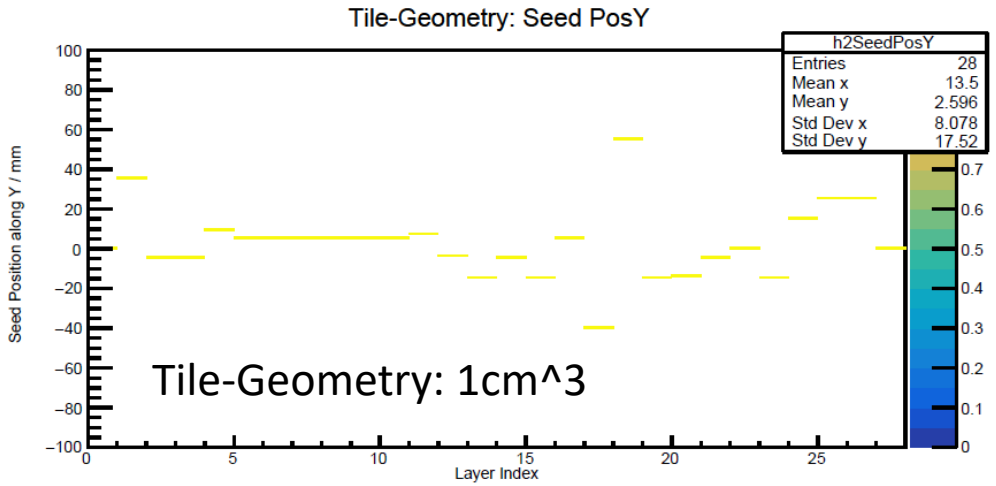


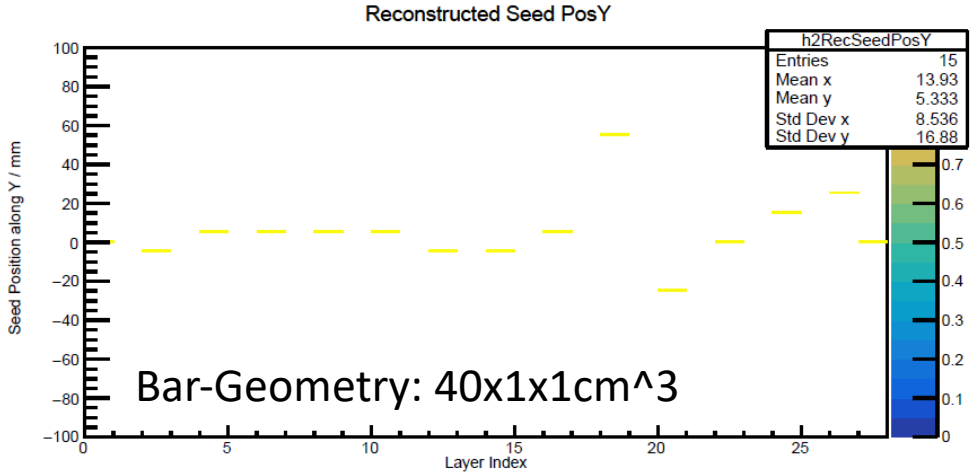
Seed per layer

- The tile/bar with maximum energy deposition (per layer)





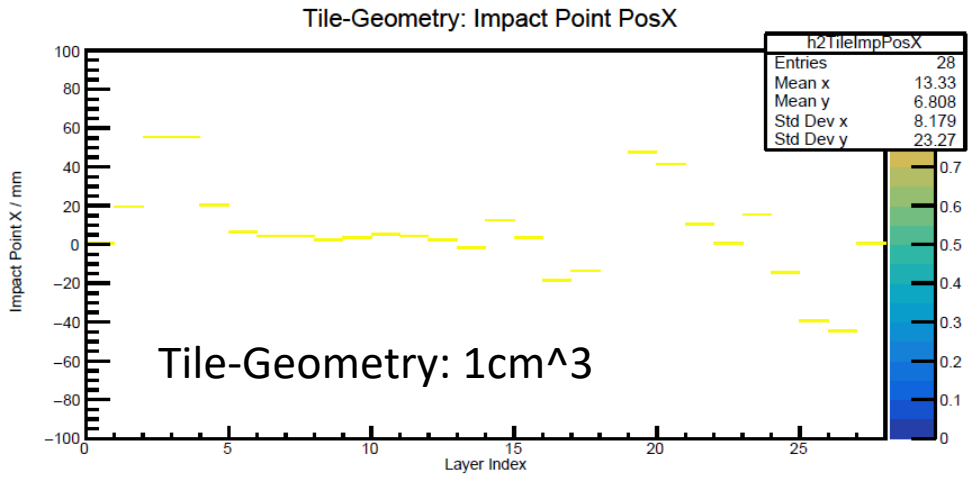


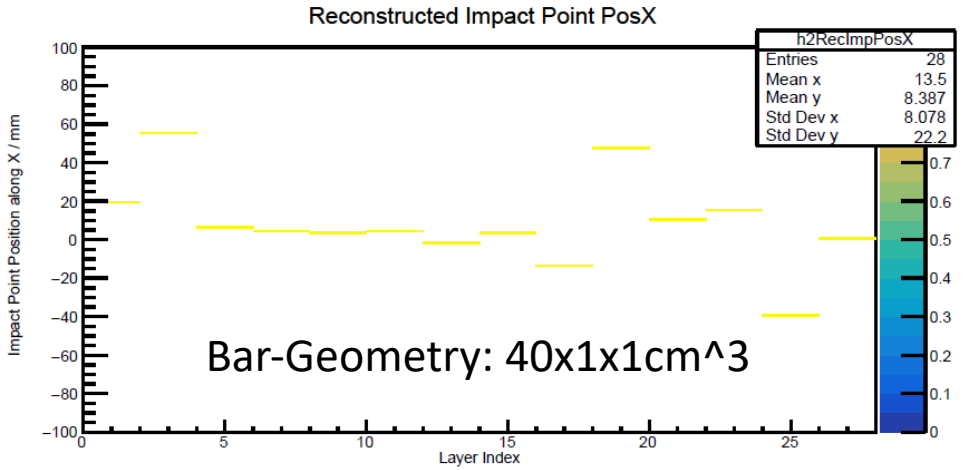


Event-1

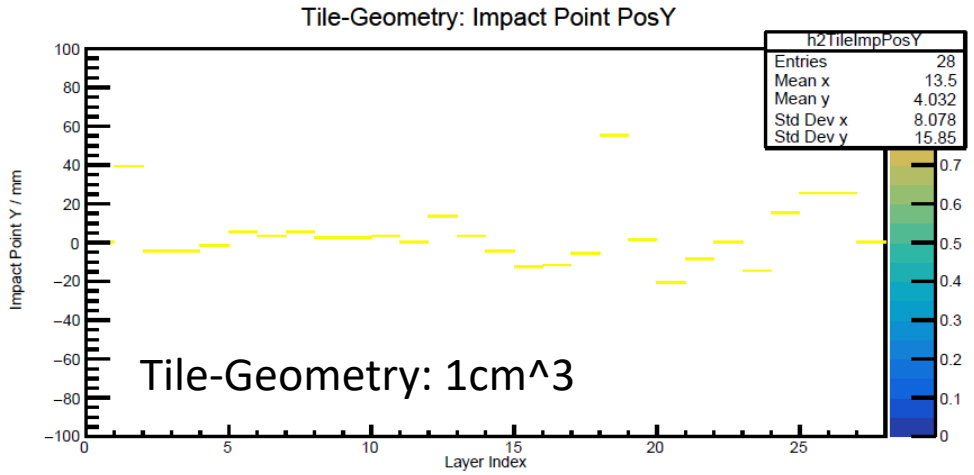
Center of gravity per layer

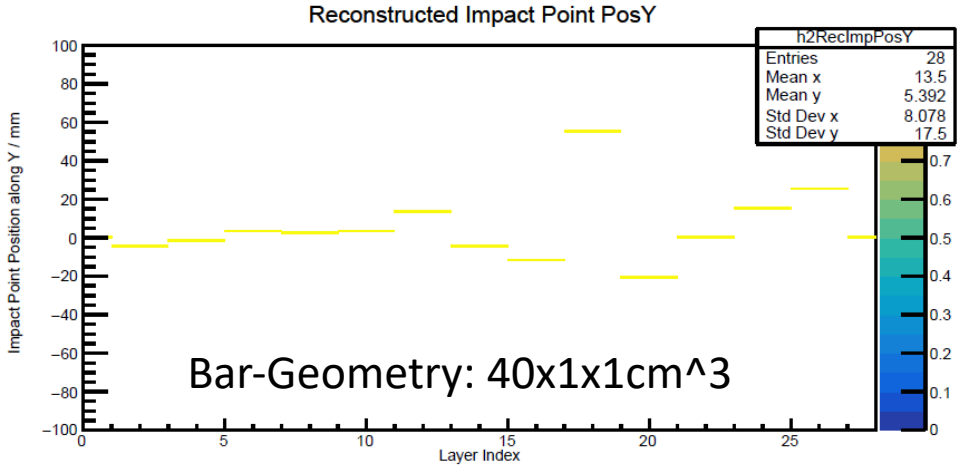
- Energy weighted positions along X and Y (in transverse plane)





$$COG_x = \sum_j w_j x_j$$





$$COG_y = \sum_j w_j y_j$$

Event-1