Crystal ECAL design for CEPC

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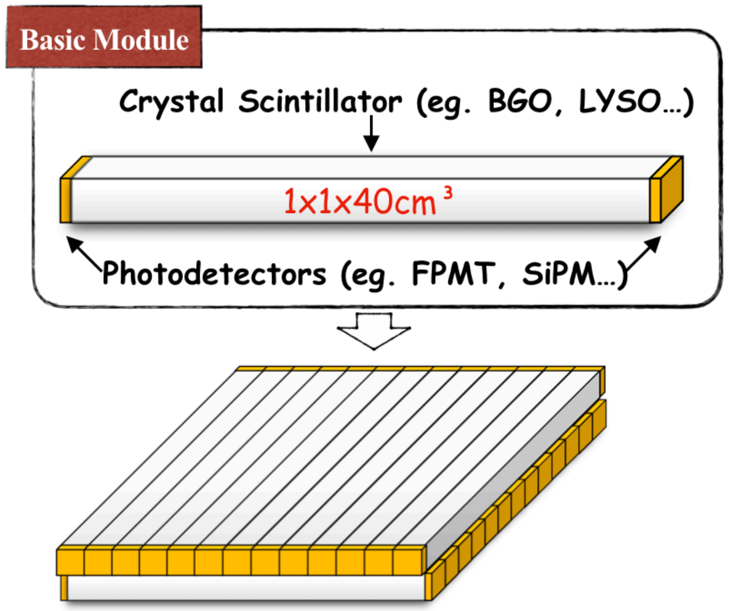
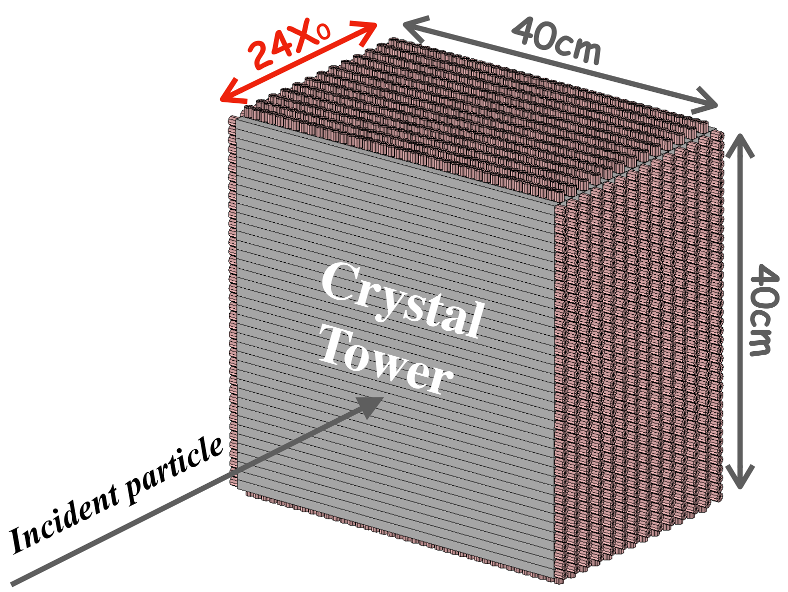
Crystal ECAL Workshop, July 22, 2020

Outline

- **Overview of the homogeneous crystal ECAL design**
- **Physics requirement study**
- **Simple digitization, reconstruction, and pattern study using event display**
  - *Study of di-photon event*
- **Summary**

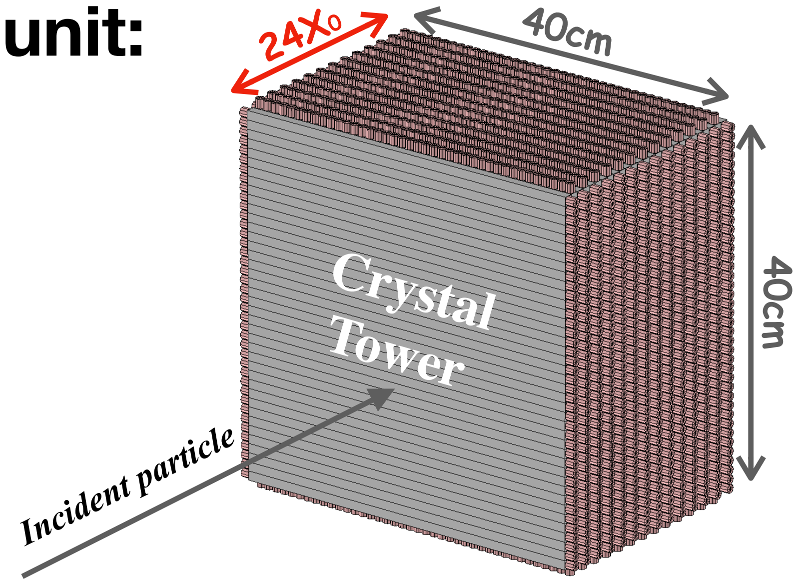




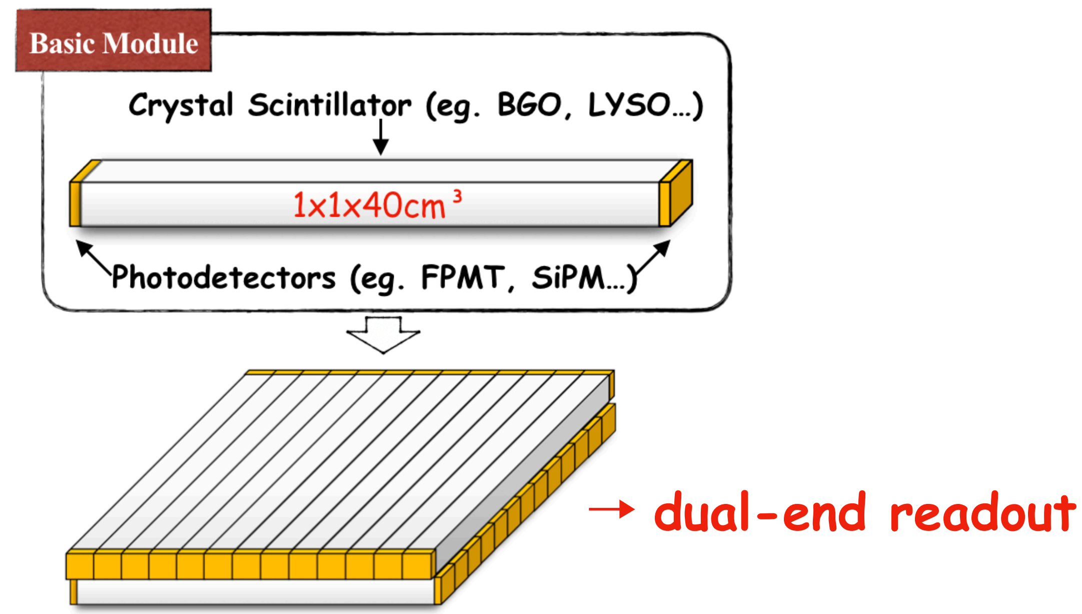
Overview

Ideas on homogeneous crystal ECAL design

Basic unit:



Geometry Structure:



Advantages:

- *Longitudinal granularity guaranteed*
- *Timing measurement for hit positions to get transverse granularity*
  - *ghost ambiguity largely removed*
- *De facto 3D calorimeter by 2D detector components*
  - *#channels, ~15 times less*
  - *Easy for cables*

Key issues:

- *Remaining ambiguity: multiple hits in one crystal bar*
- *Separation of nearby showers*
- *Impact on the Jet Energy Resolution (JER)*

Physics requirement study

Multi-jet events at generator level:

☞ *Calculate the impact point of visible final states on the inner surface of ECAL*

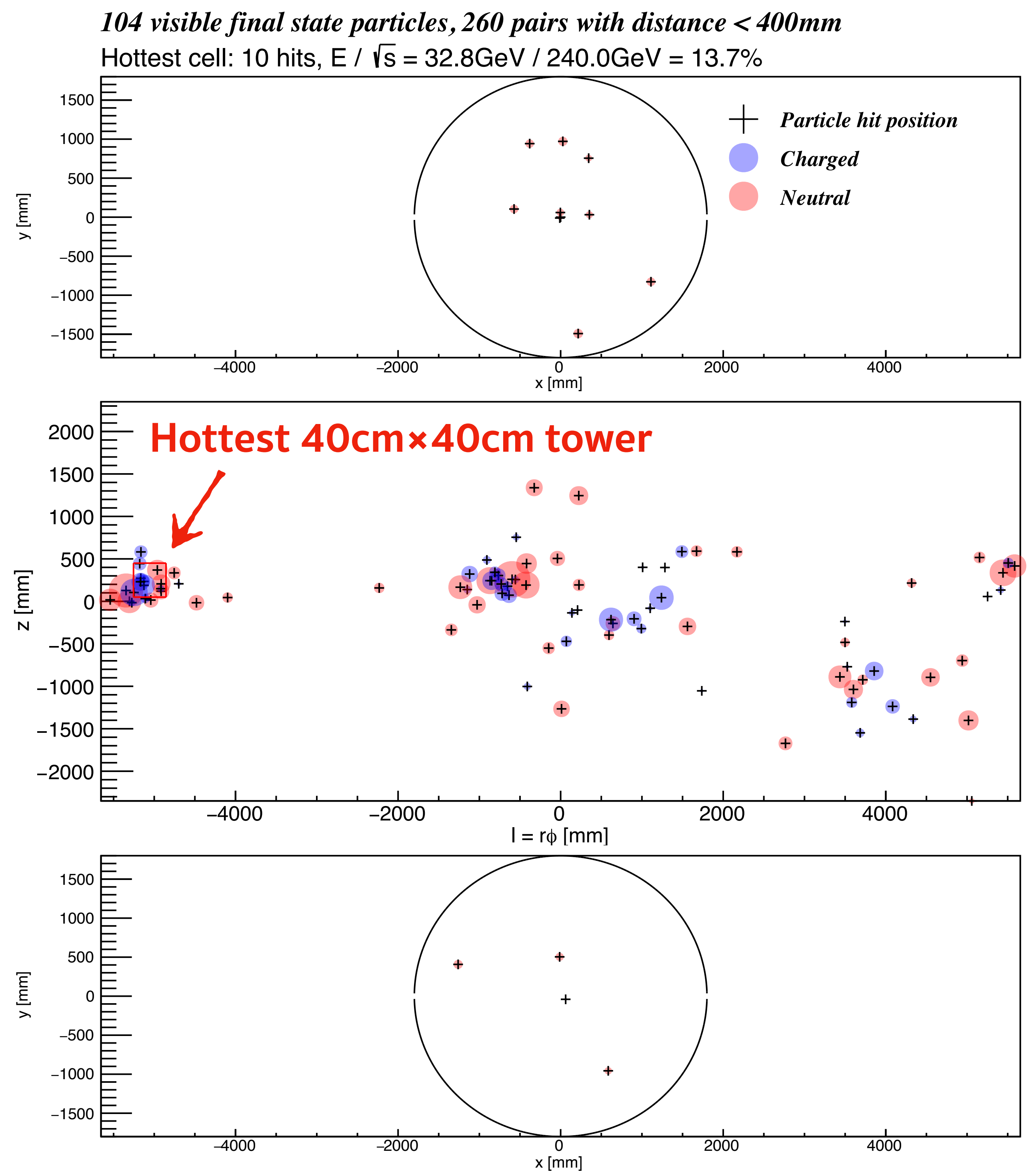
☞ *240GeV, ZH (Z→qq, H→gg) (4-jet event) as an example*

Parameters in calculation:

- *A simple cylinder ECAL*
- *Inner Radius, R=1800mm*
- *Barrel Length, L=4700mm*
- *Magnetic Field, B=3T*

Analysis level:

- *Hottest tower (with maximum energy)*
  - *multiplicity and energy ratio to √s*
- *Average proportion of towers with multi-particle*

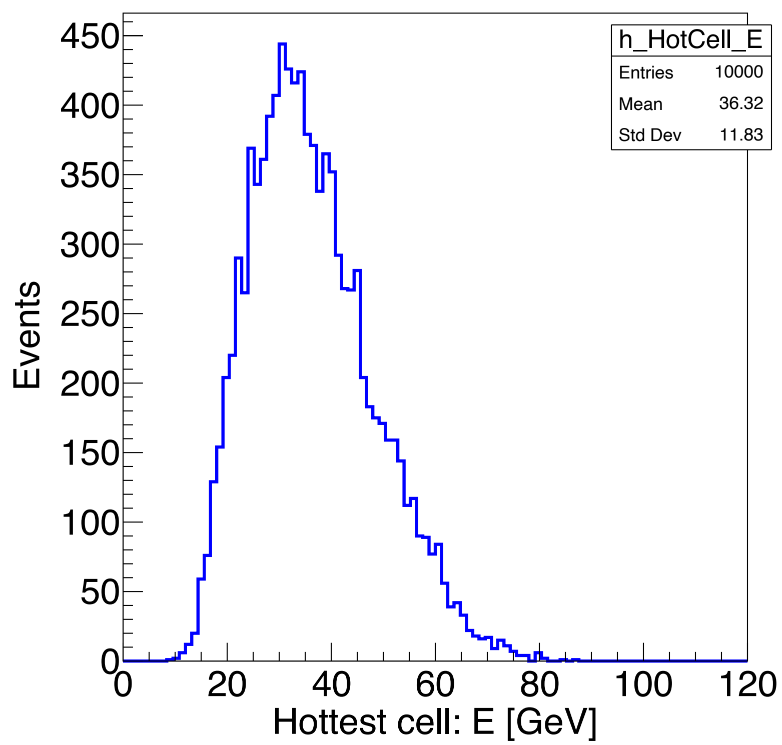


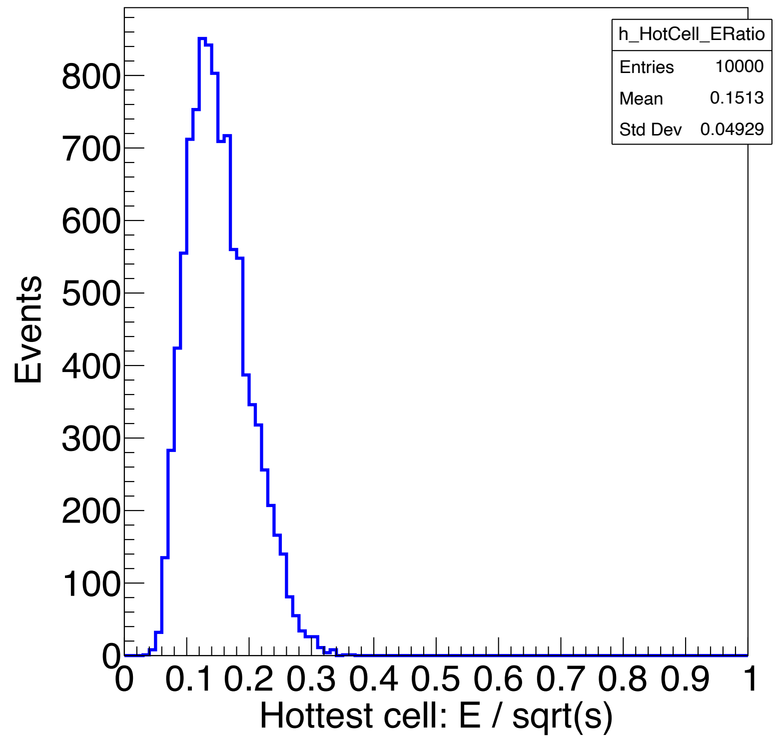
Unfolded cylindrical ECAL

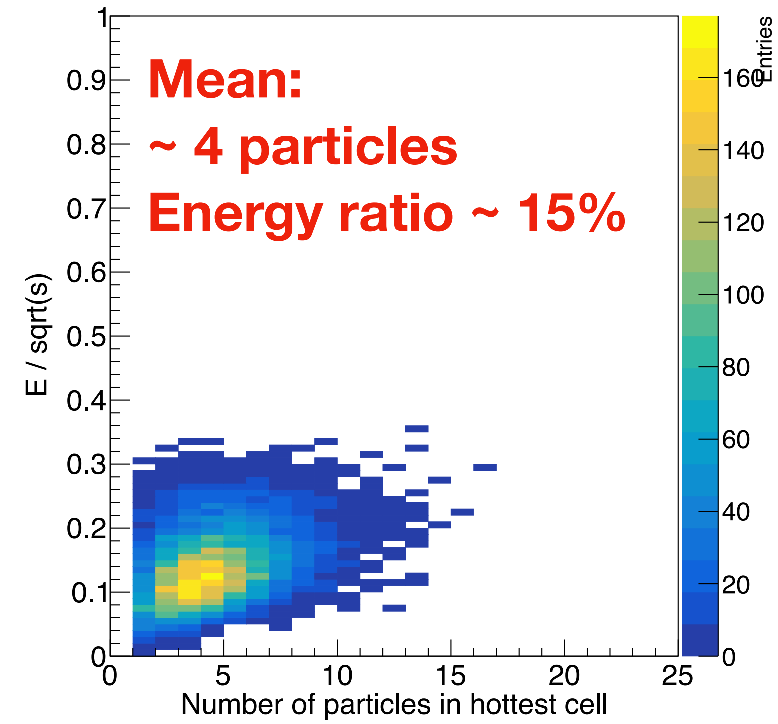
Z→qq
H→gg
240GeV

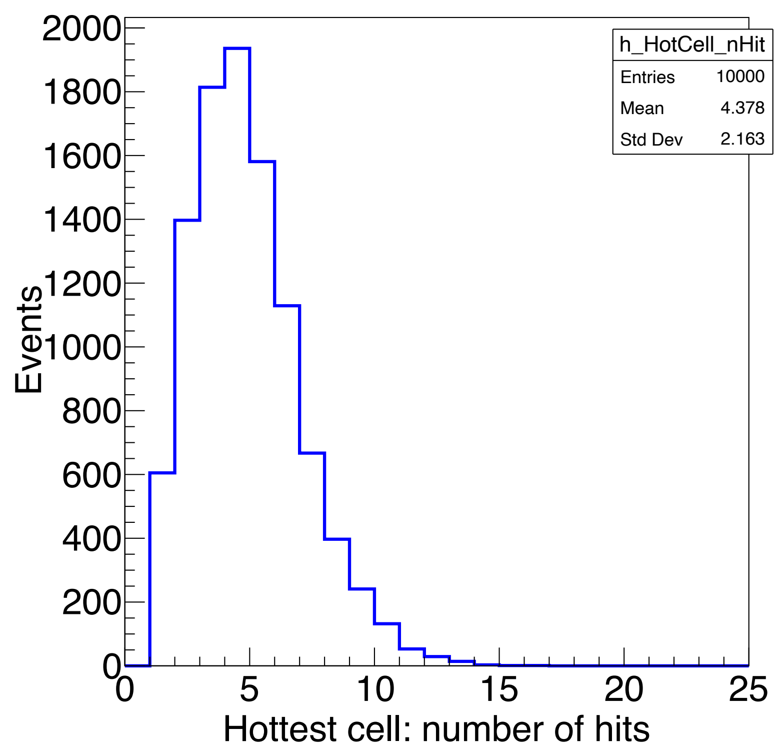
Physics requirement study

Hottest 40cm×40cm tower



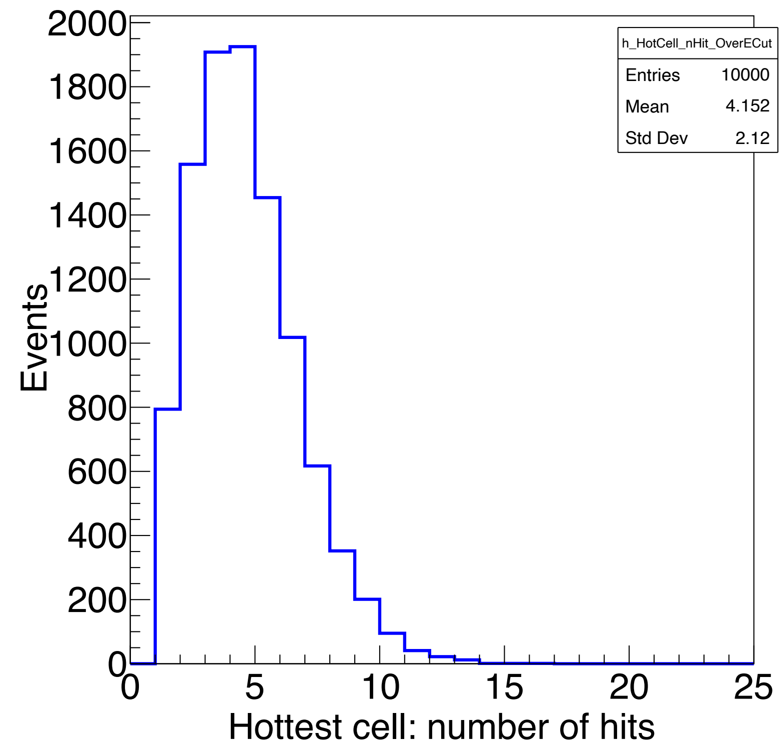






After E threshold

particle E > 0.2GeV

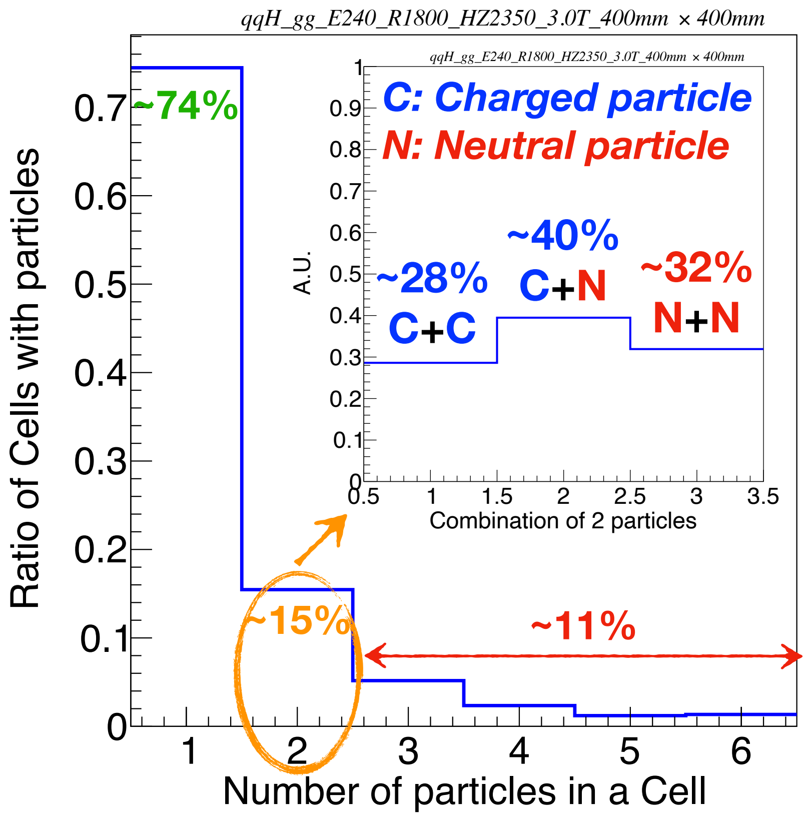


$Z \to qq$
$H \to gg$
240GeV

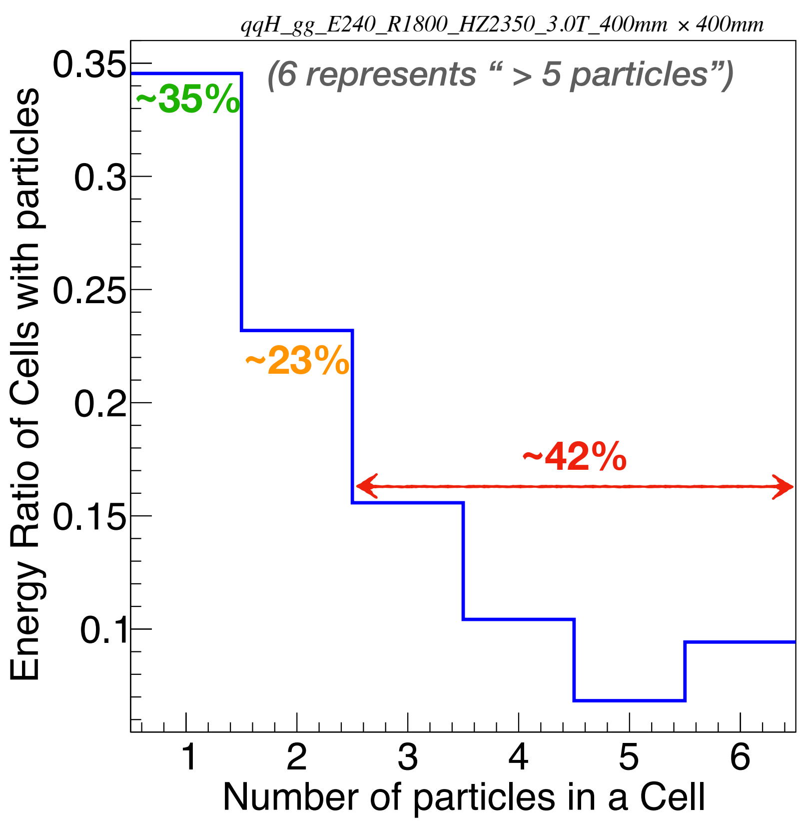
Physics requirement study

Multiplicity in a 40cm×40cm tower

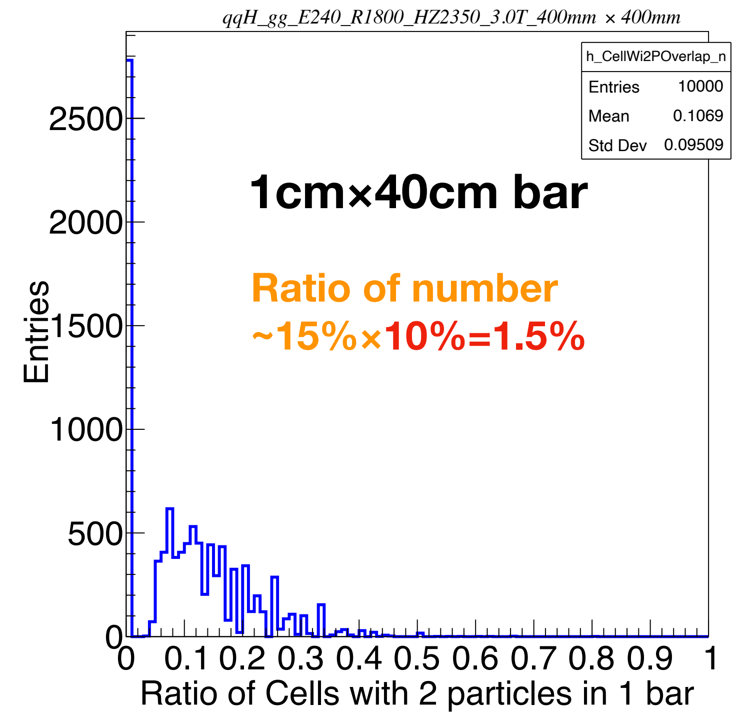
Number

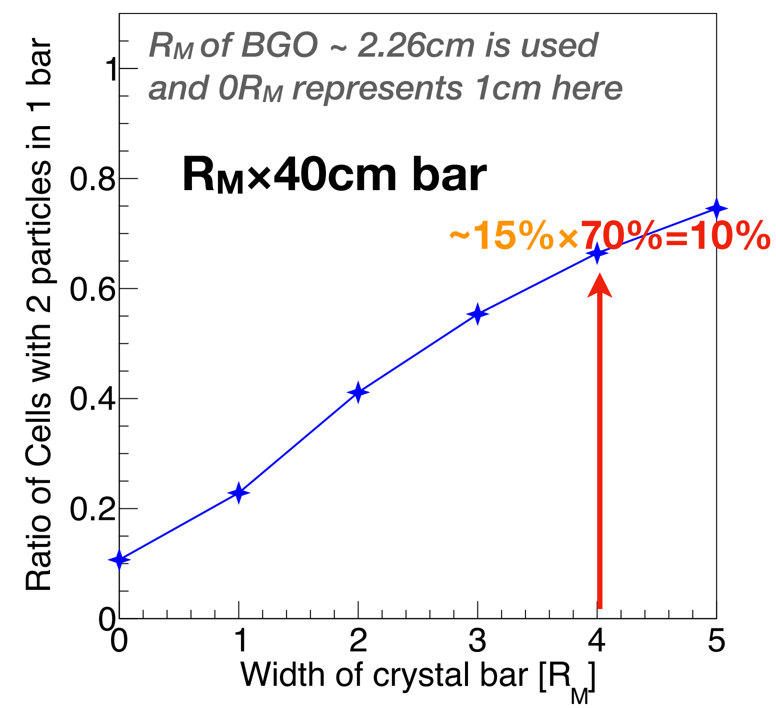


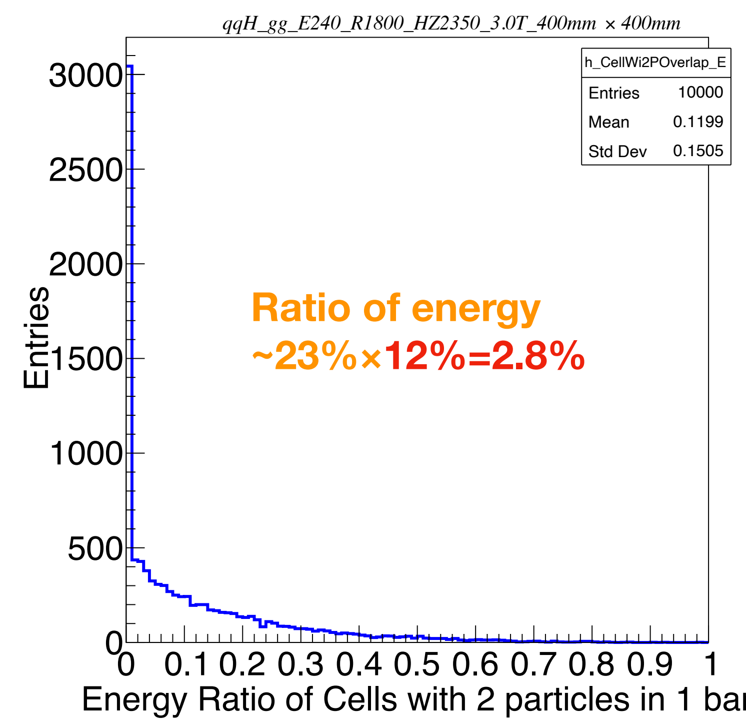
Energy

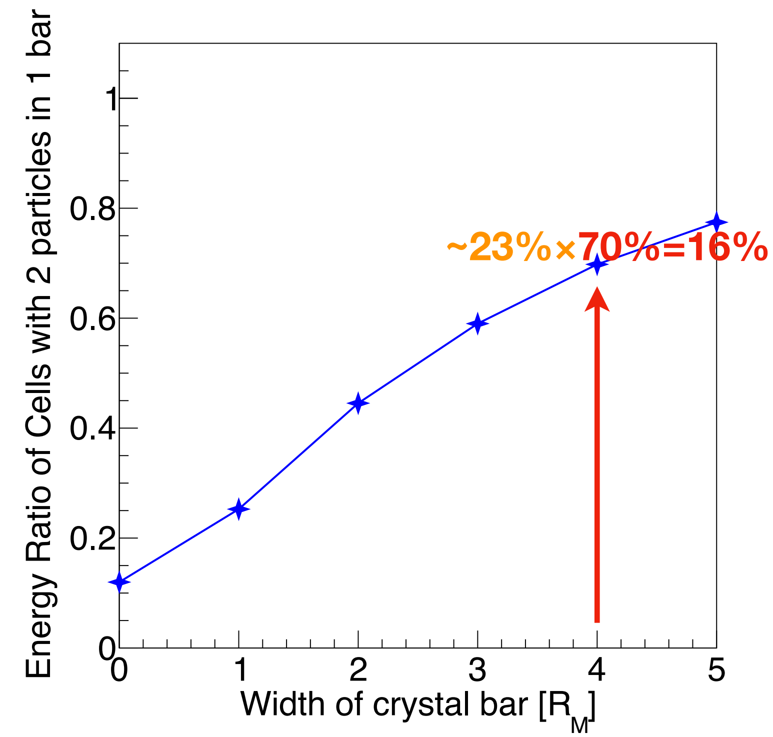


Towers with 2 particles in 1 bar







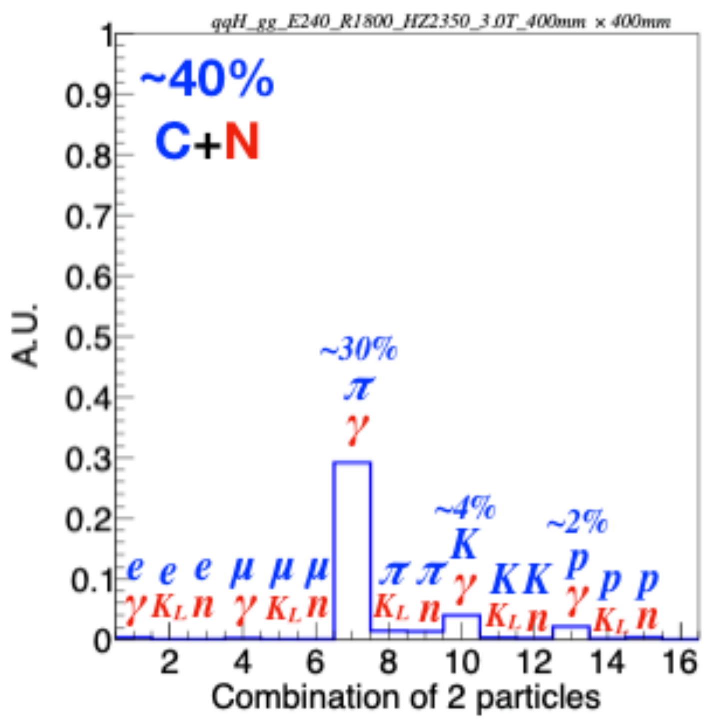


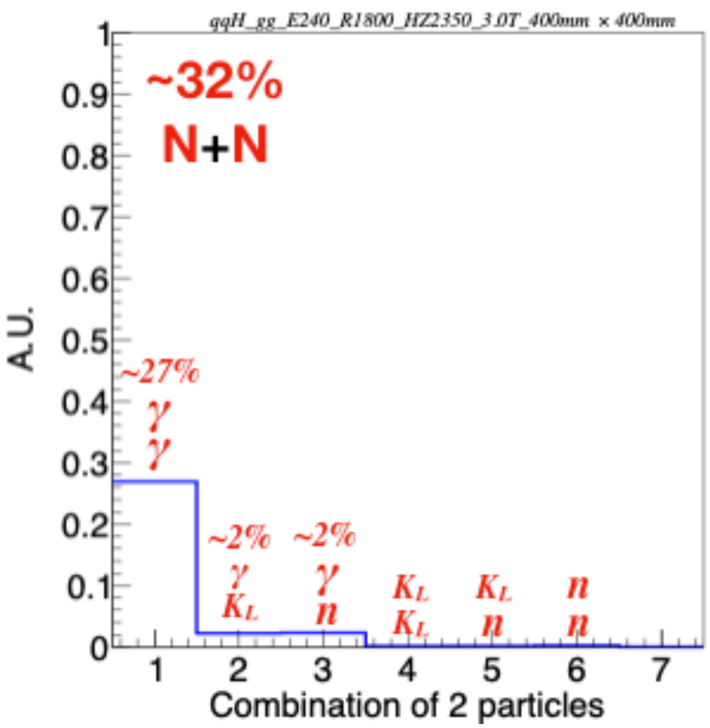
Z→qq
H→gg
240GeV

Physics requirement study

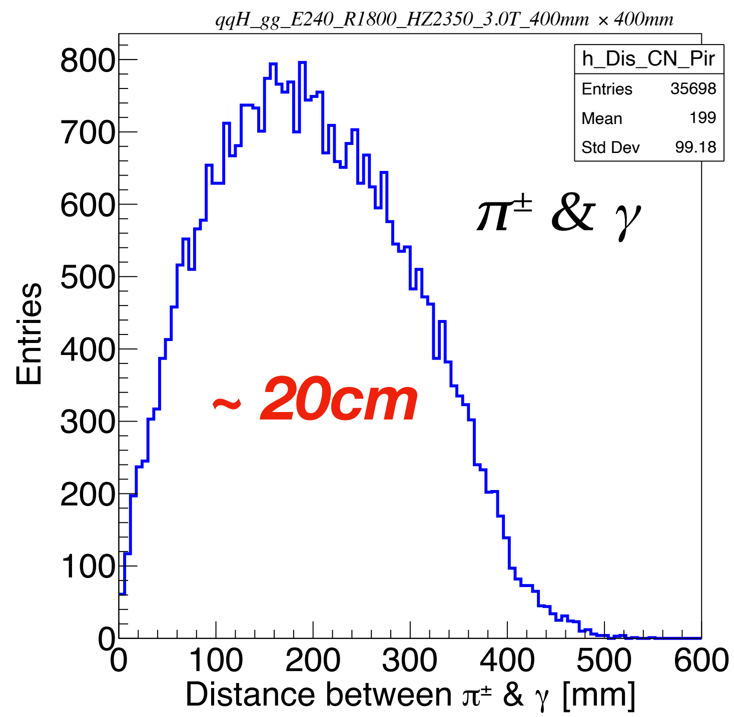
Tower with 2 particles: distance & energy distribution

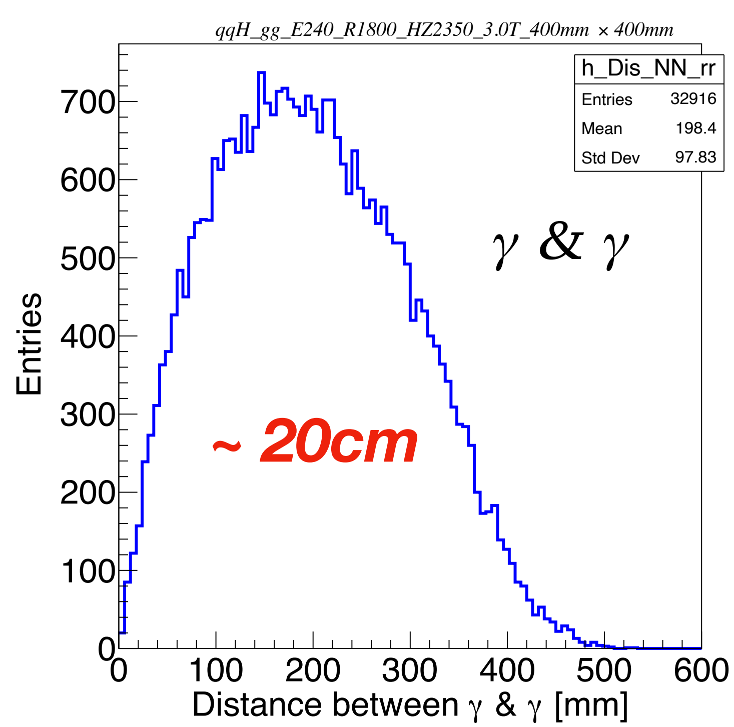
Combination



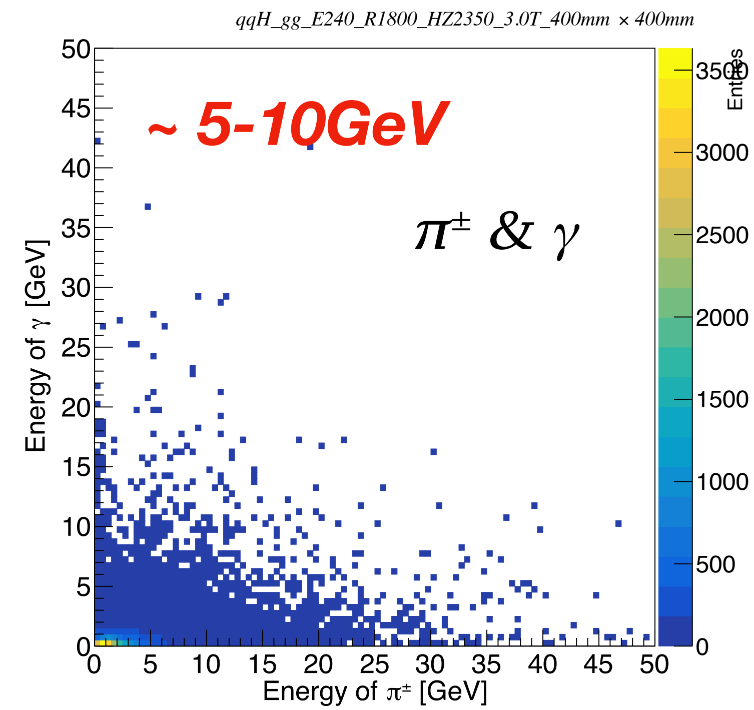


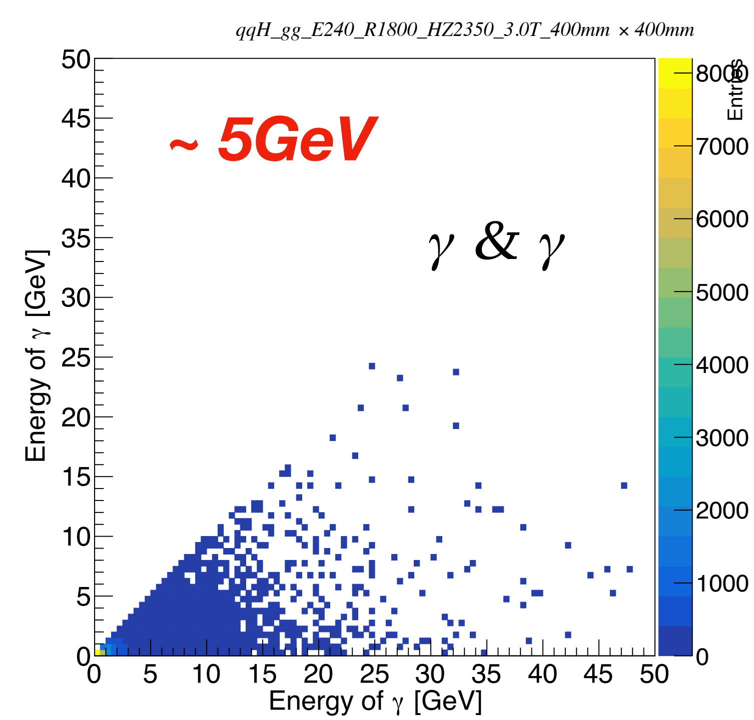
Distance





Energy

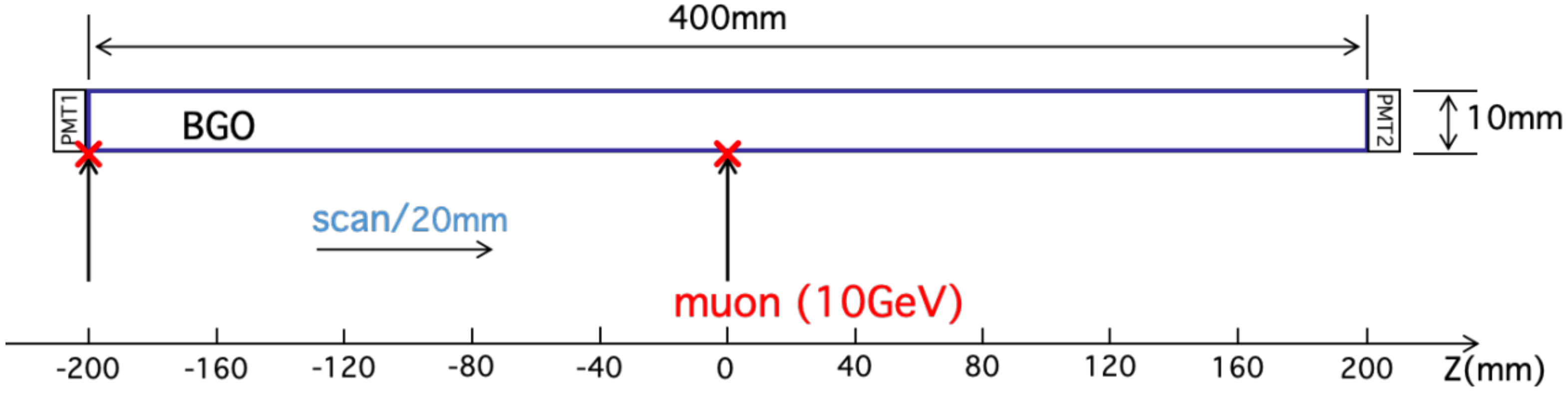


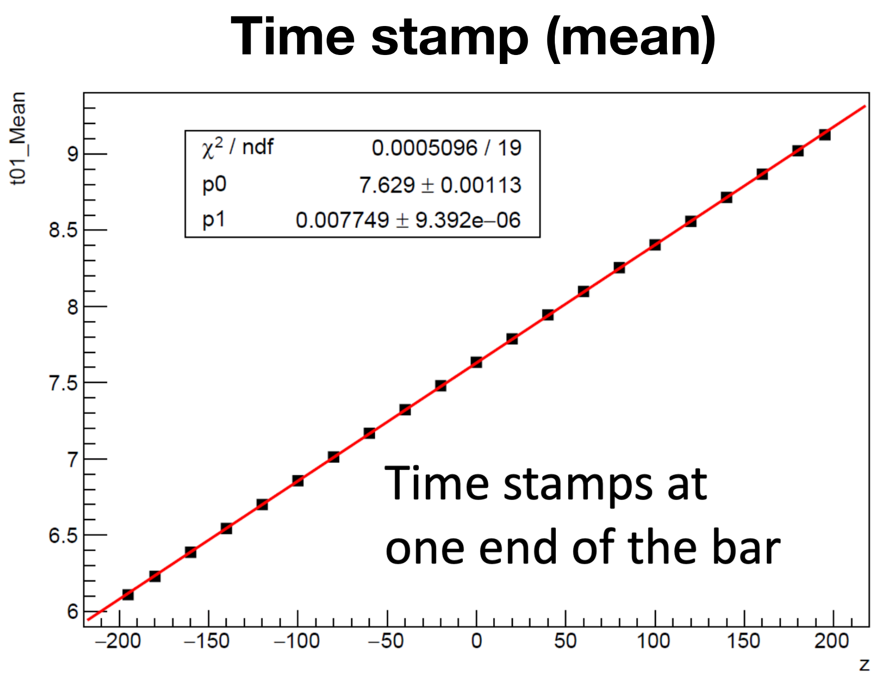


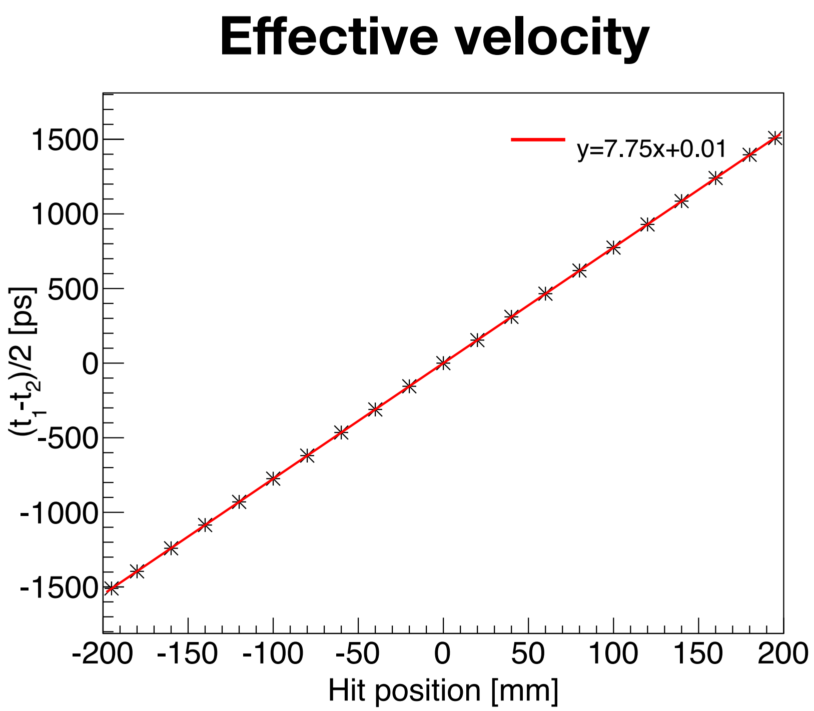
Simple digitization of crystal bars

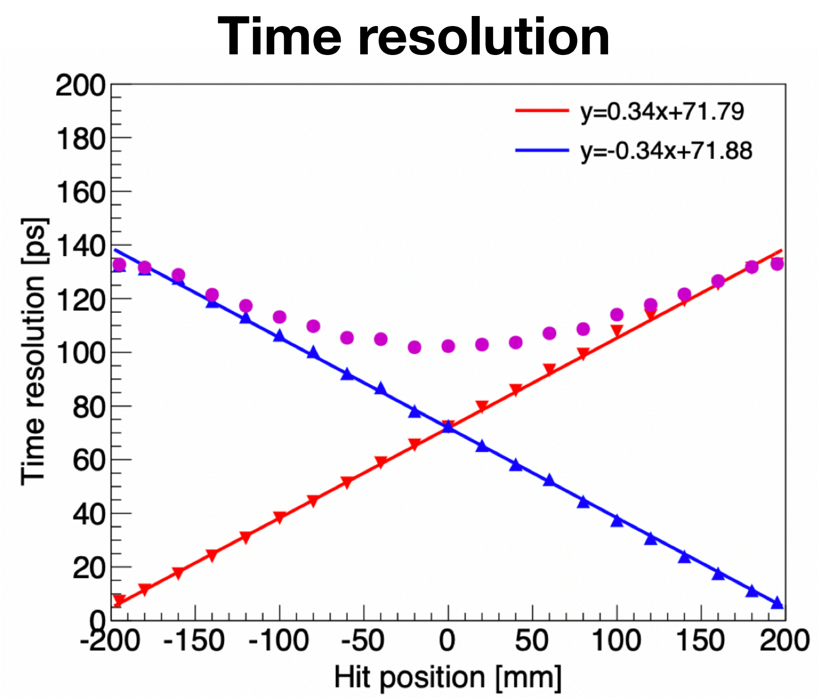
Currently focus on the digitization of time:

- *2 time stamps at each end of a crystal bar*
- *Based on the stand-alone Geant4 full simulation of a single crystal bar with complete optical processes including scintillation, light propagation, and attenuation.*

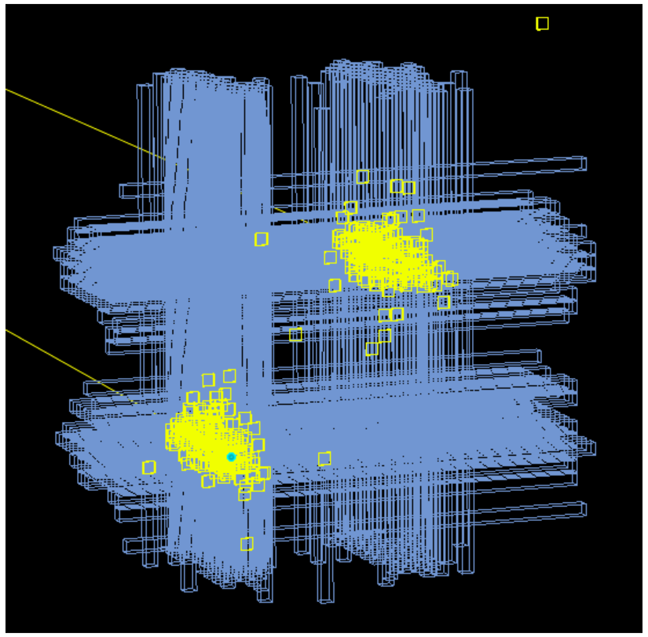








Reconstruction: pattern study using Event Display

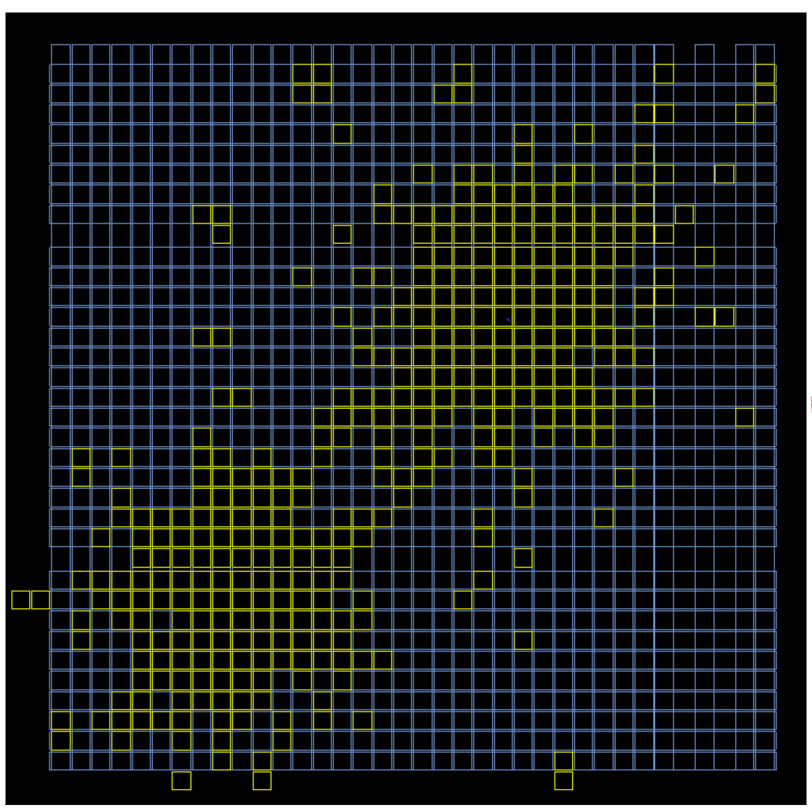


2 parallel 5GeV γ

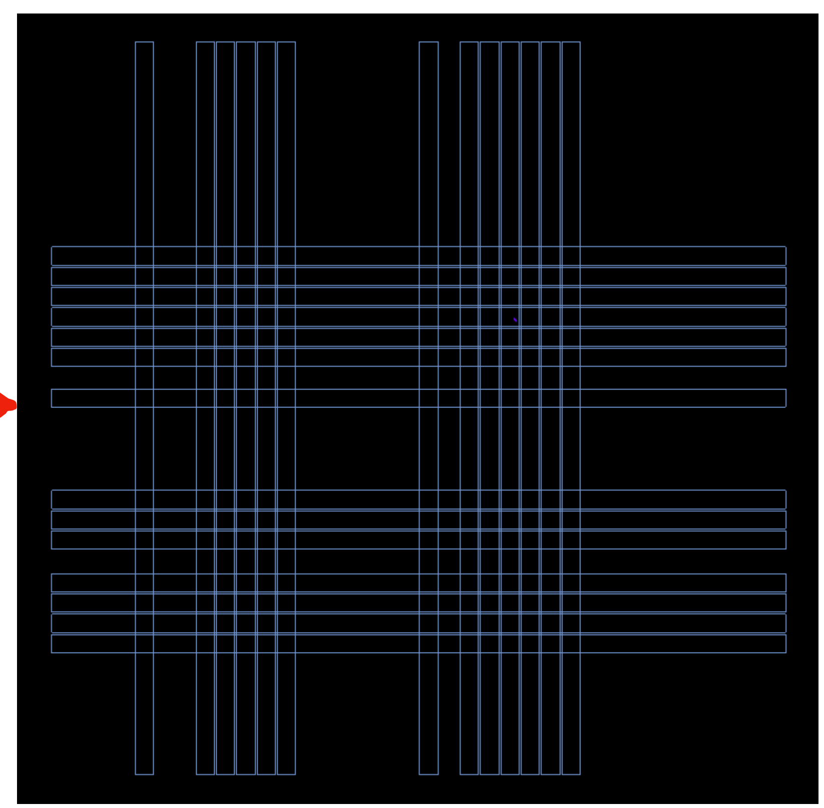
distance ~20cm along the diagonal

→ can be separated.

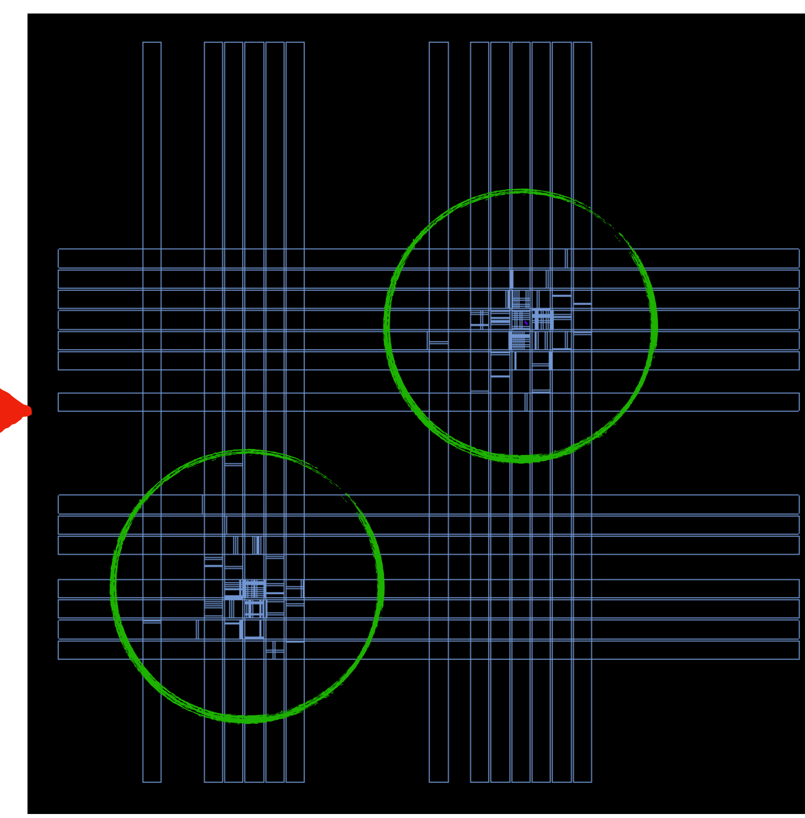
Simulated Hits (yellow cells)



Digitized Long Bar Hits (E_{dep} > 1 MIP)

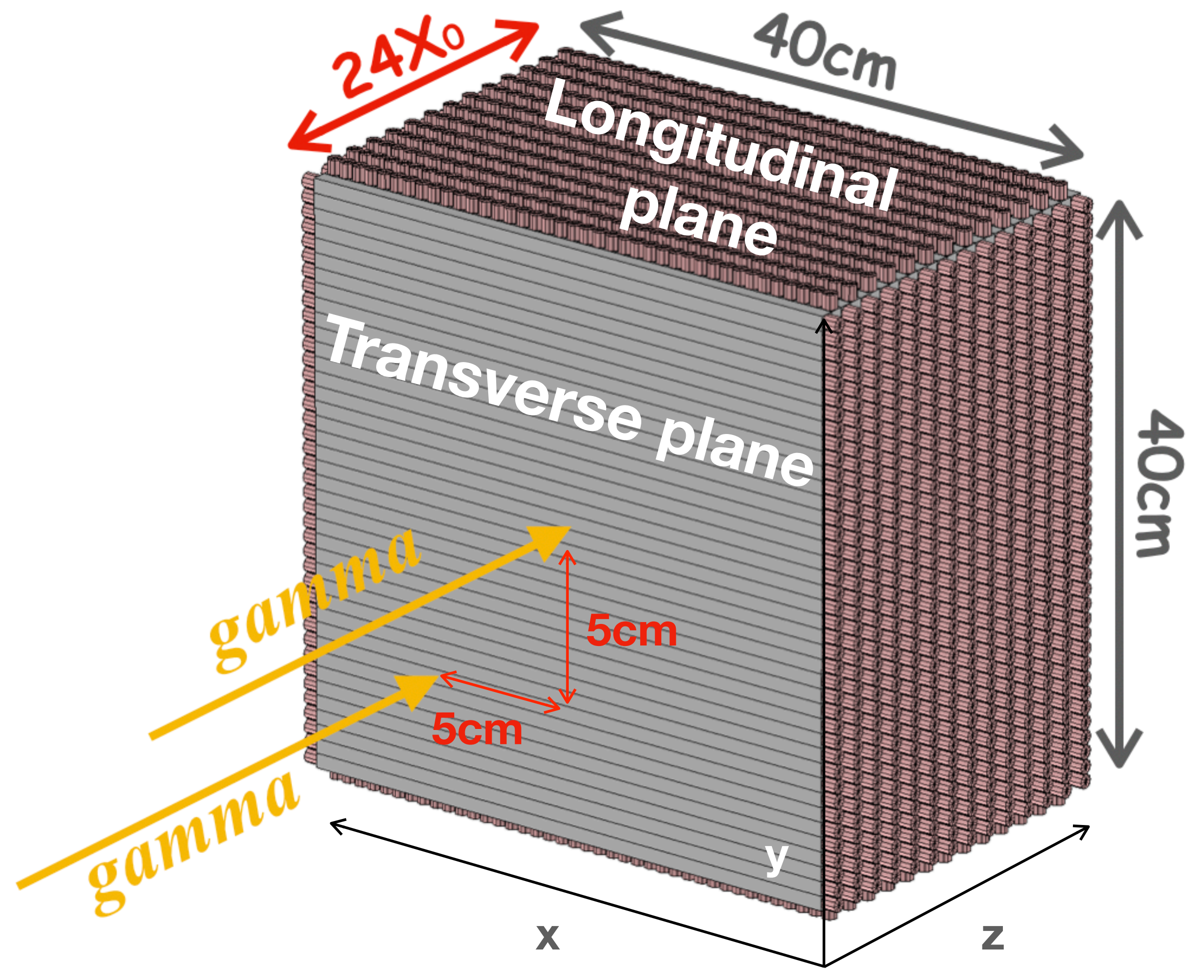


Reconstructed positions using time difference of 2 ends

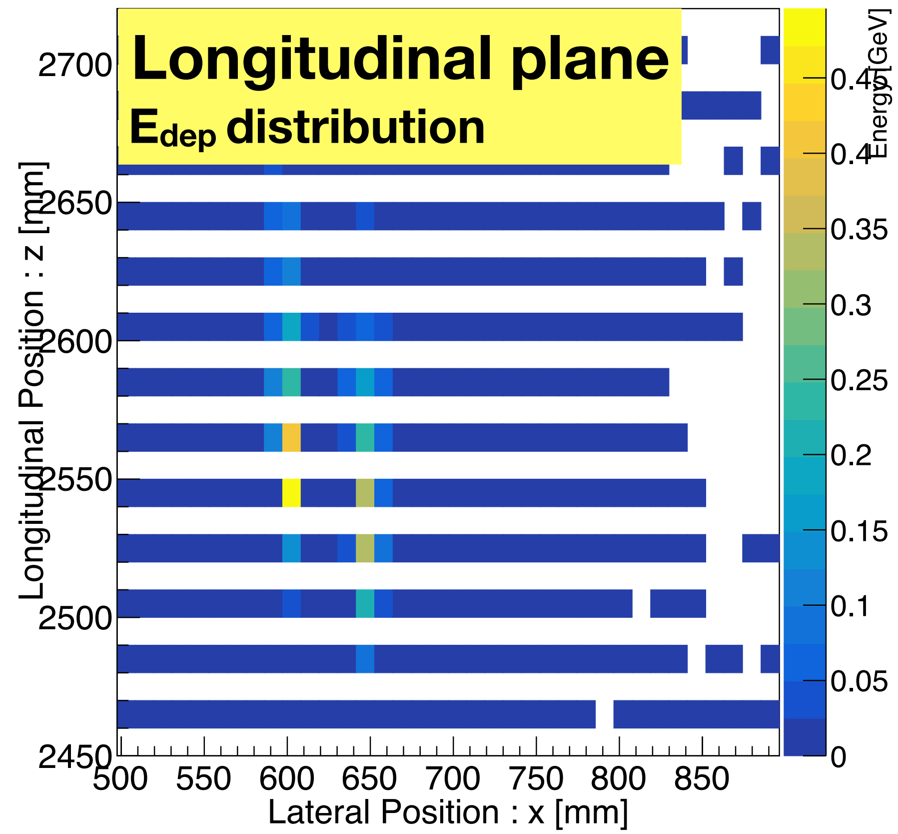


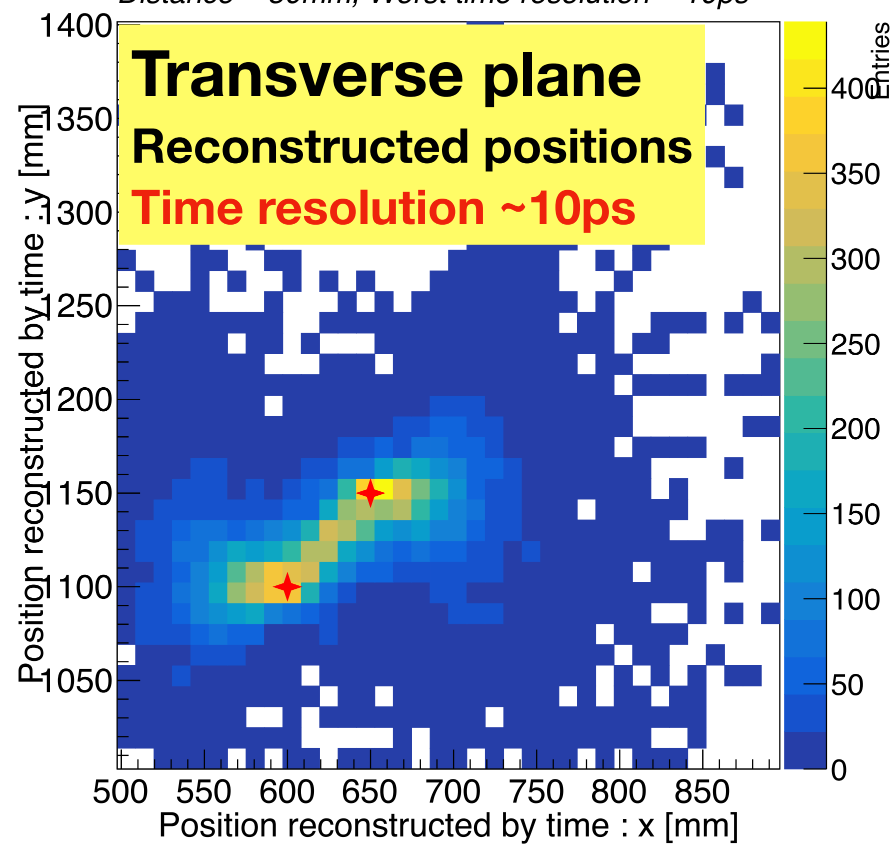
MIP energy = 8.77MeV for 1cm thick BGO

Preliminary Study of di-photon separation



5cm ~ 2R_M for BGO (R_M=2.26cm)

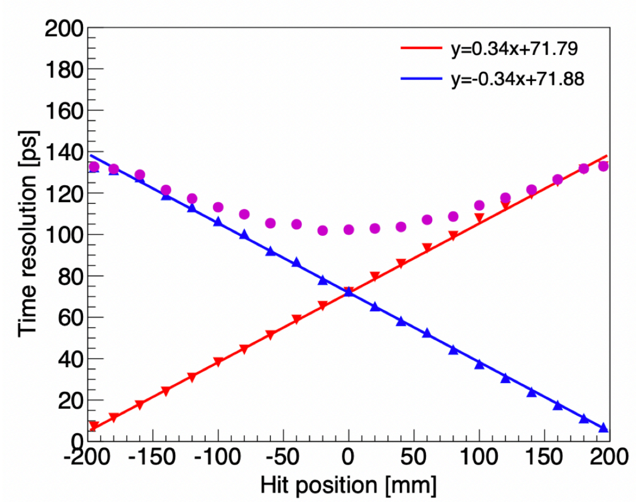




Preliminary Study of di-photon separation

Vary the time resolution artificially:

- *Maintain the dependence on hit position, change the slope to get worst time resolution of single end from 10ps to 500ps.*



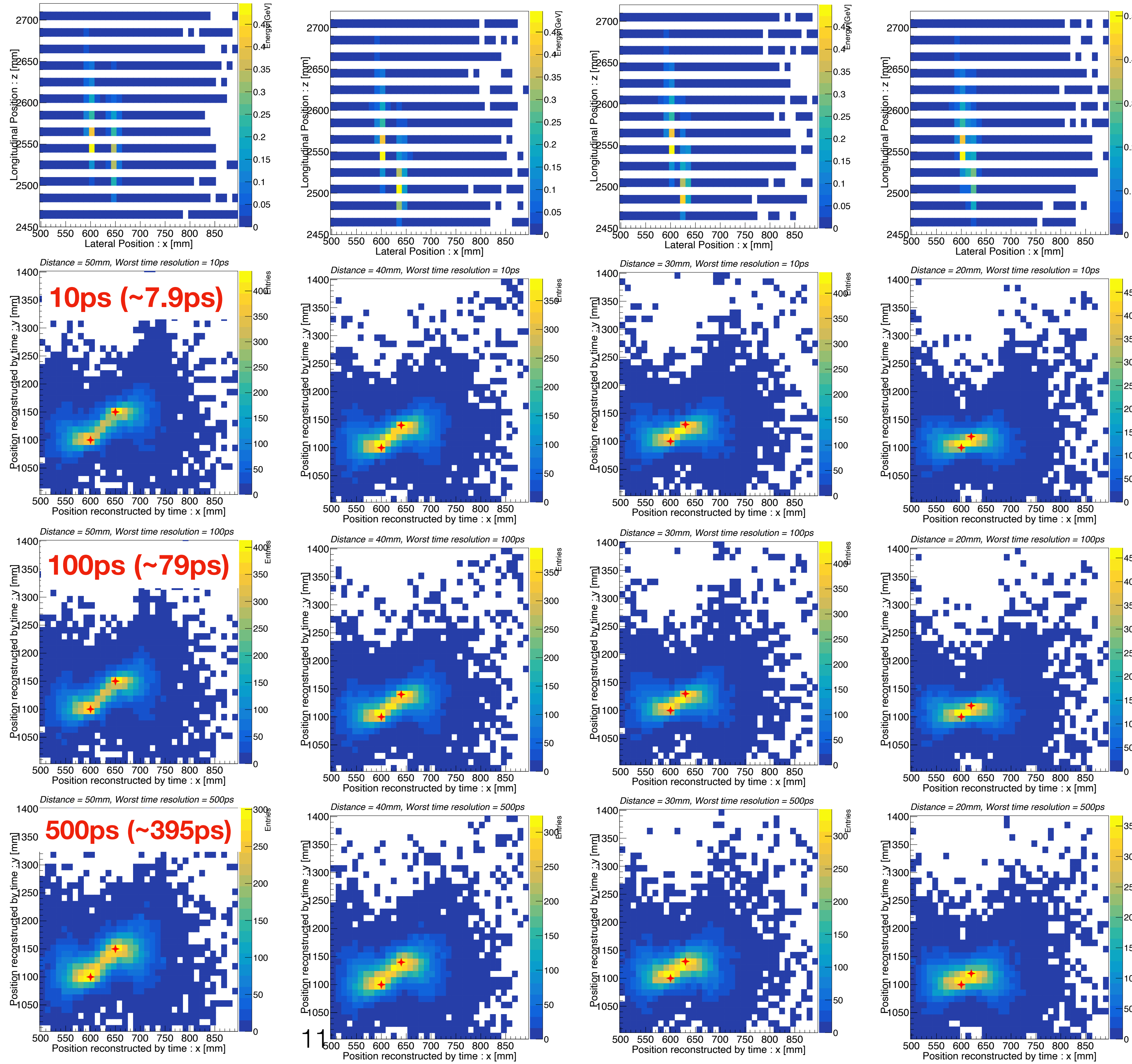
Critical separation distance (with the help of energy info.):

~ 3cm (~4cm along the diagonal), mainly limited by R_M.

Separation power is not so sensitive to time resolution.

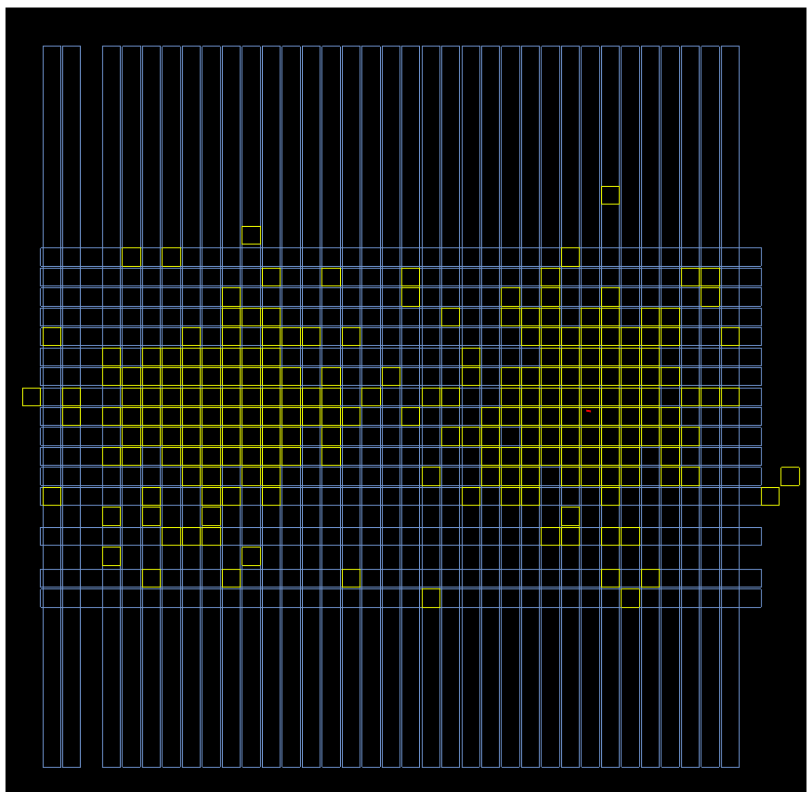
(Only preliminary results of current simple digitization, need to check and understand further…)

5cm 4cm 3cm 2cm

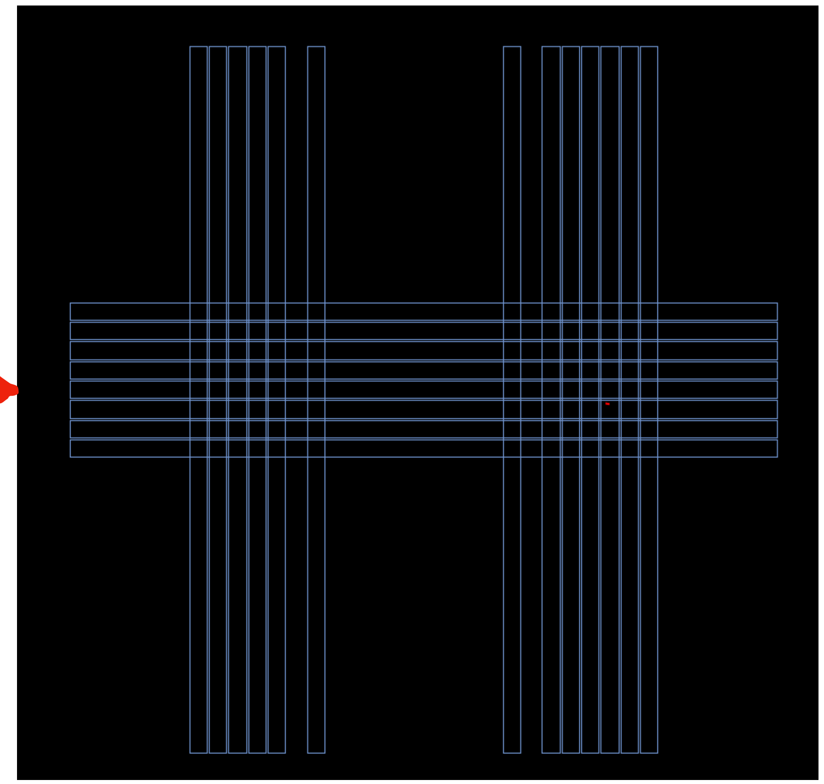


Reconstruction: pattern study using Event Display

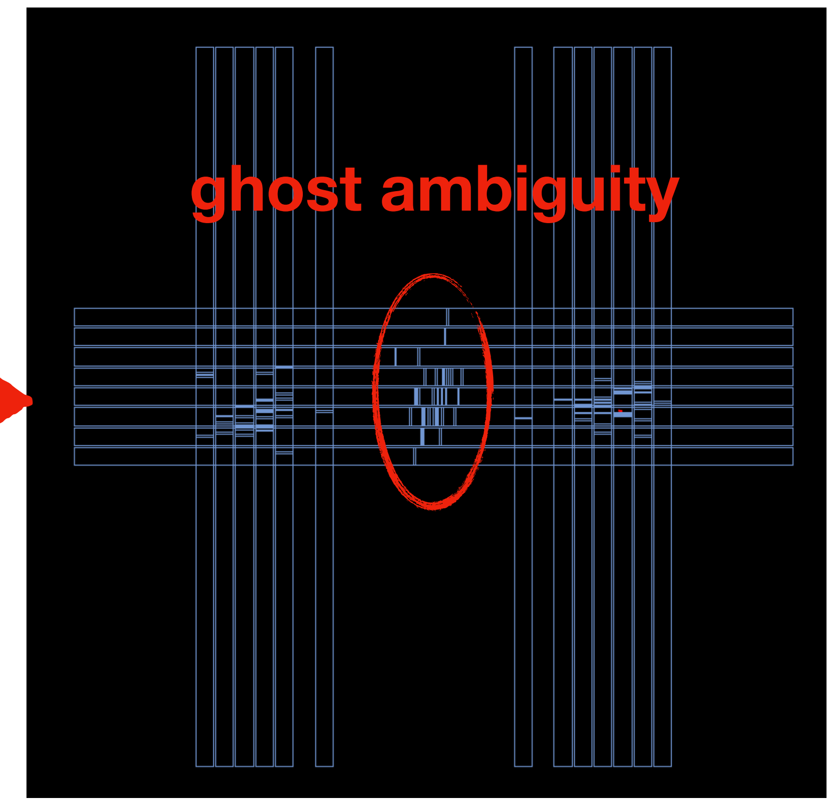
Simulated Hits (yellow cells)

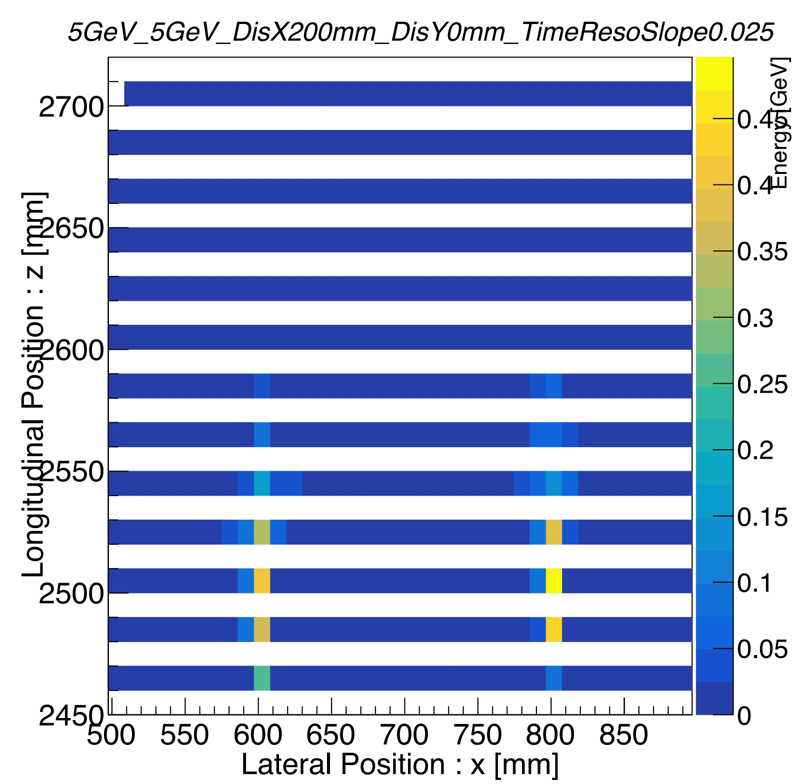


Digitized Long Bar Hits (E_{dep} > 1 MIP)



Reconstructed positions using time difference of 2 ends





2 parallel 5GeV γ, hit the same bar, 20cm away

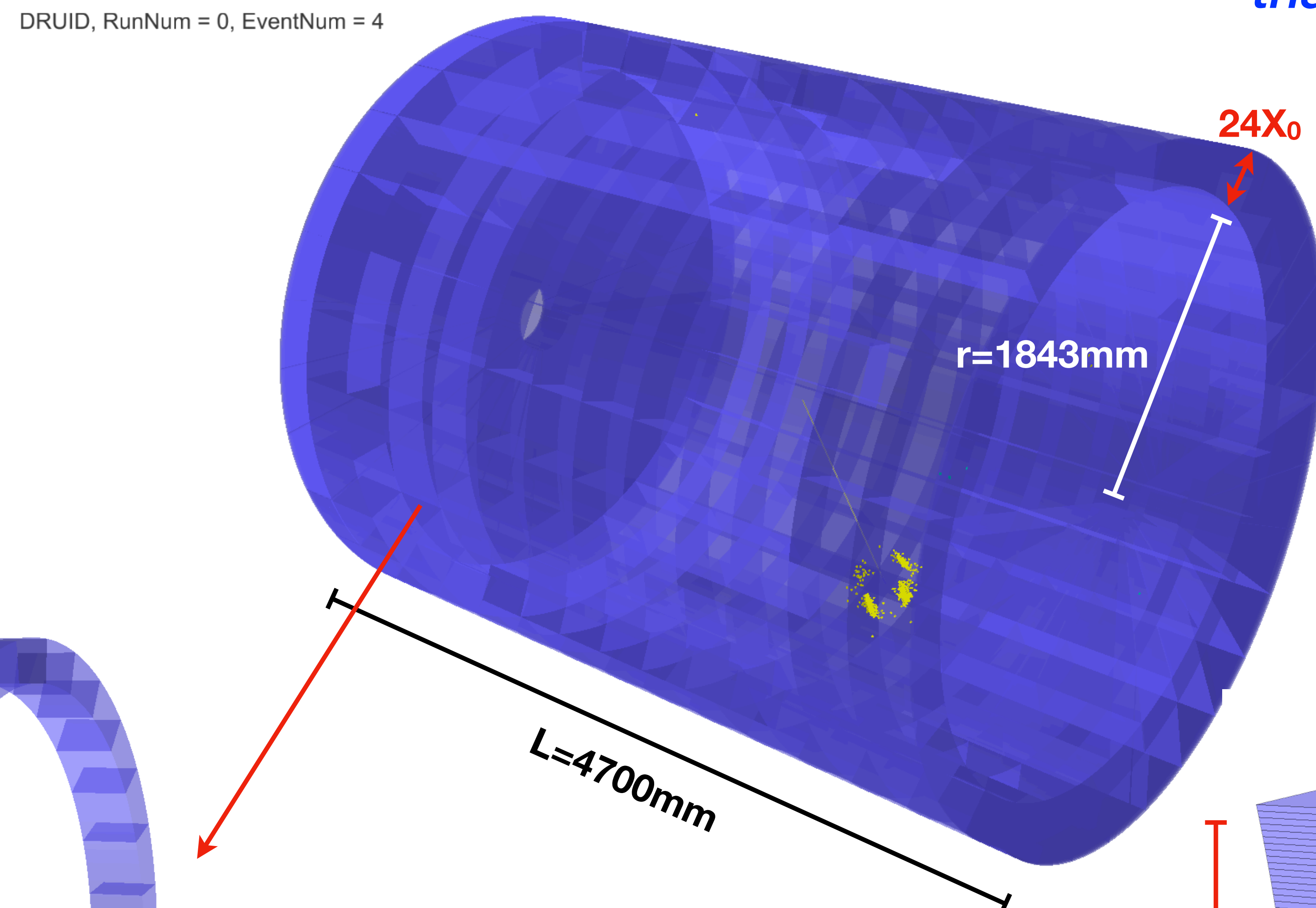
- *If one crystal bar has >1 particles with E_{dep} > 1MIP, position reconstructed will be biased.*
- *Ambiguity can be removed by longitudinal position and energy*

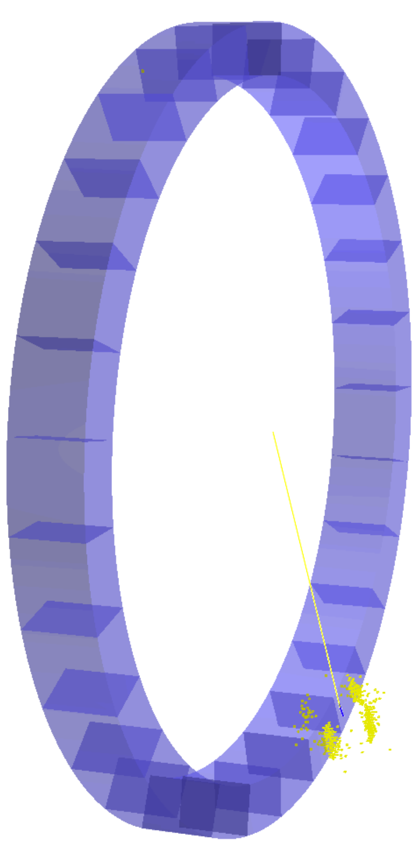
MIP energy = 8.77MeV for 1cm thick BGO

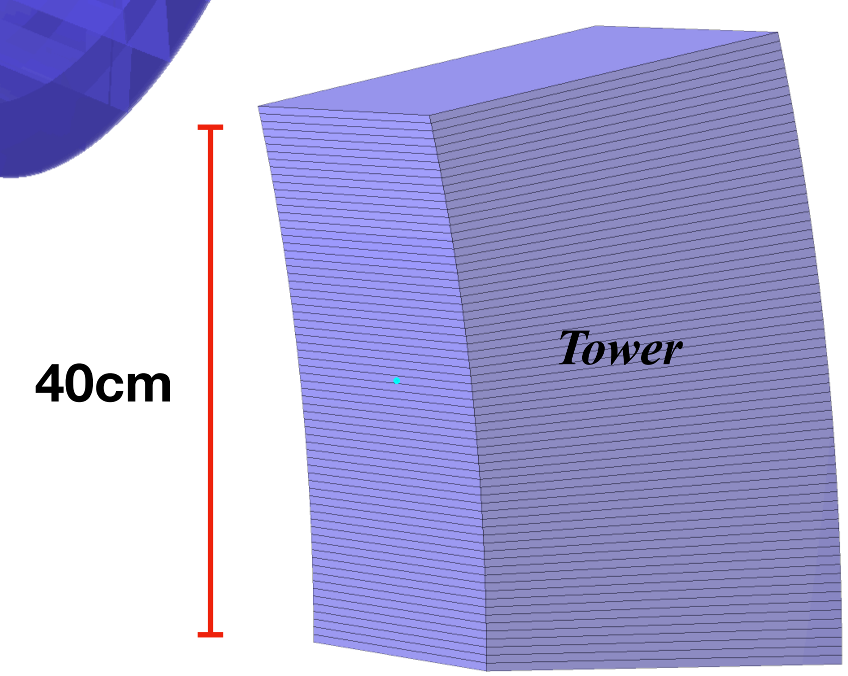
4π geometry with long bars

Has been implemented in full CEPC detector simulation

thanks to Chengdong Fu



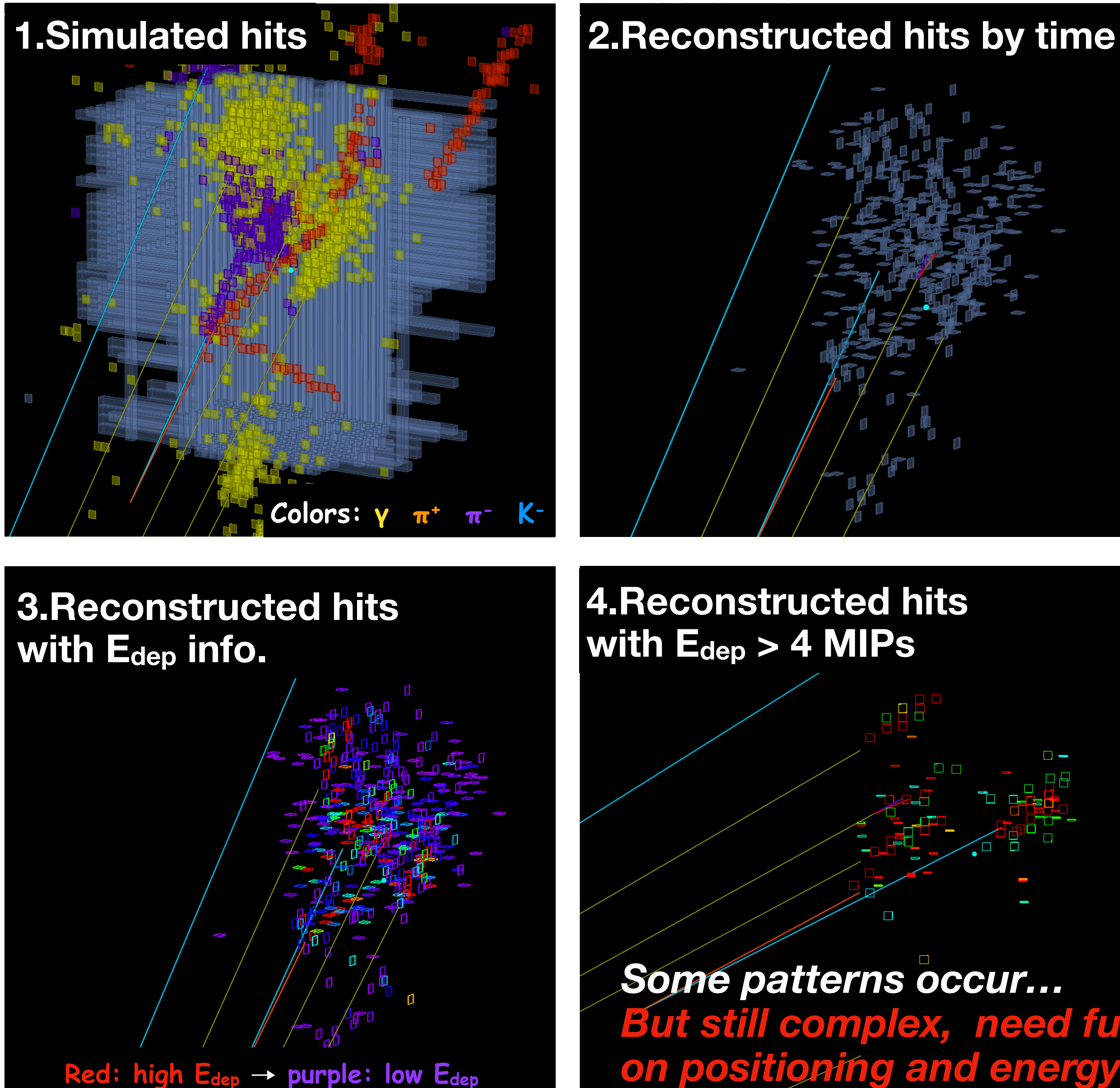




Geometry:
Basic Cell: 1cm×1cm×40cm, long bar
Tower: 40cm×40cm×24X_0 (~ 27cm for BGO)

Pattern study using Event Display

Jet event, with increasing multiplicity and combinations



Some patterns occur…

But still complex, need further study on positioning and energy sharing.

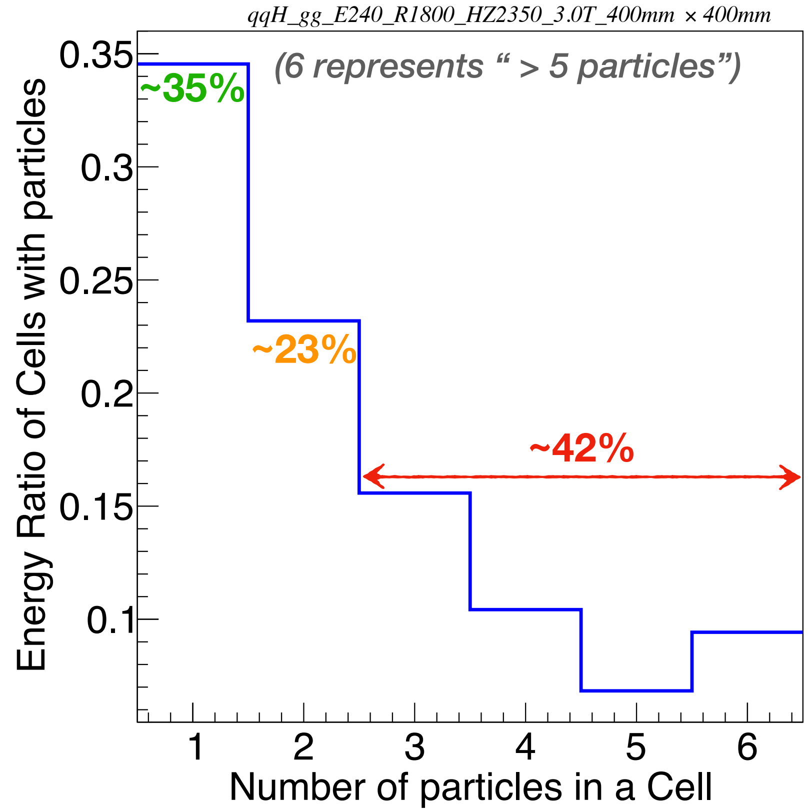
Summary

☞ ***Multi-jet events are studied at generator level***

- *Particle multiplicity, energy and combinations in a 40x40cm^2 tower.*
- *~60% energy of 4-jet event is in towers with only 1-2 particle(s).*

☞ ***Di-photon events are studied at reconstruction level***

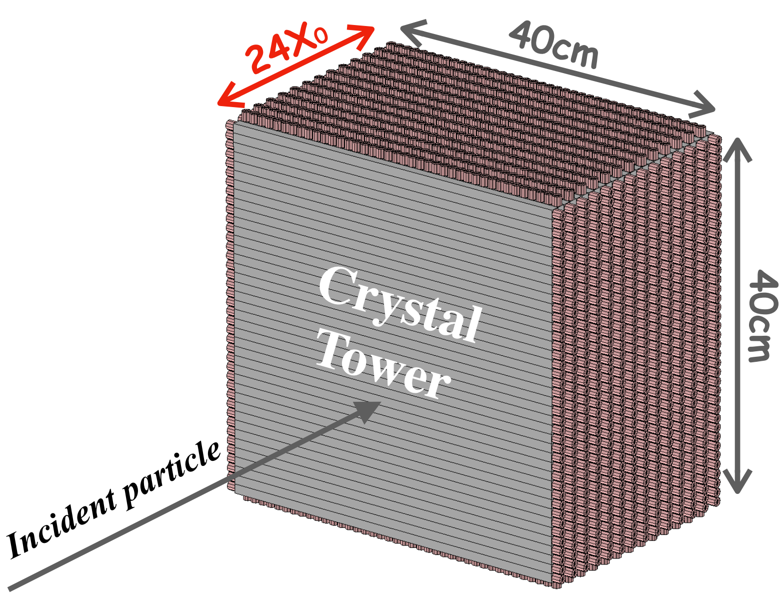
- *Simple digitization of time is developed.*
- *Towers with 1~2 particle(s) have no big problem to reconstruct.*



Future:

☞ *Pattern study of jet events using Event Display.*

☞ *To get ideas on reconstruction of more complex cases with > 2 particles in a tower.*

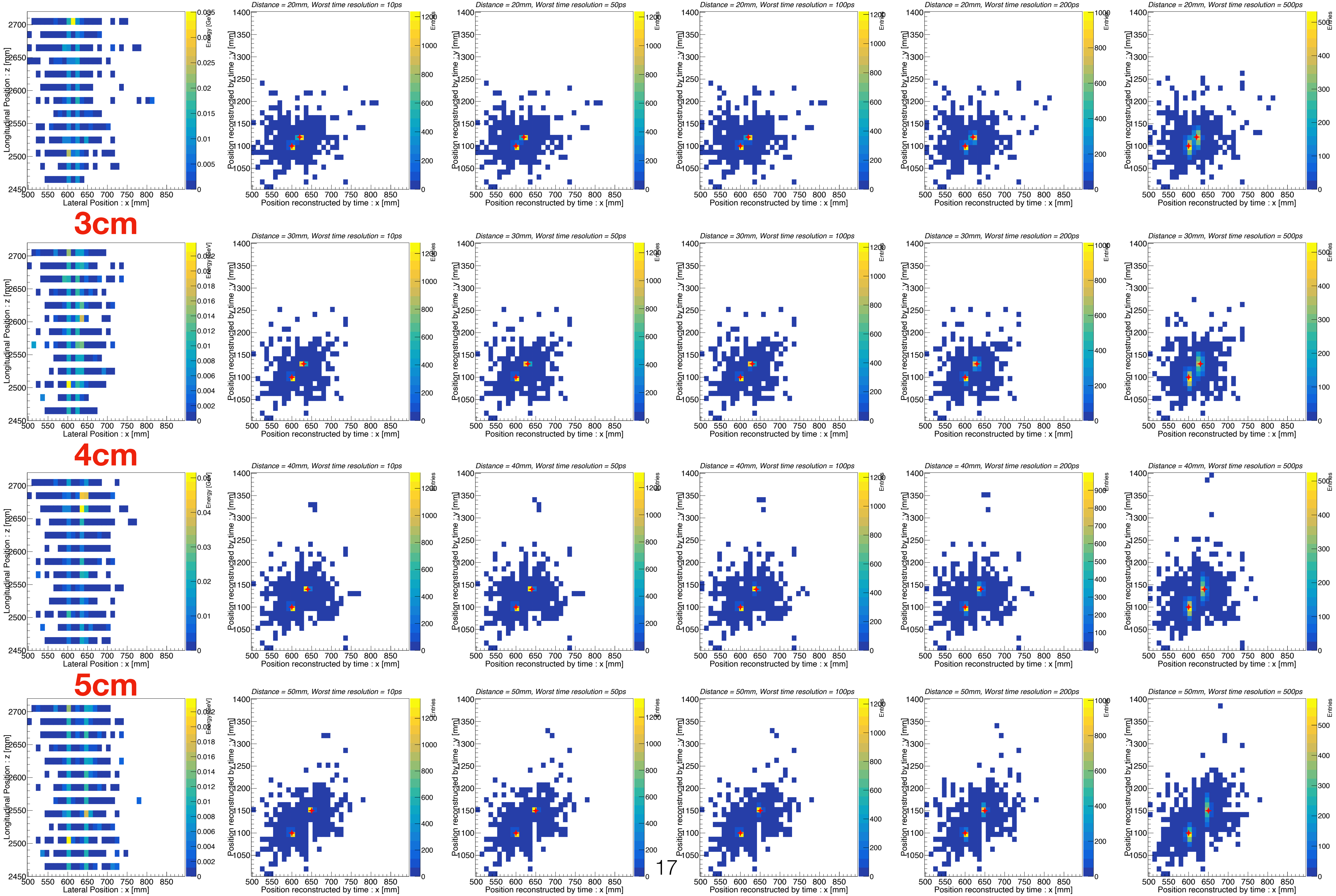


Thanks!

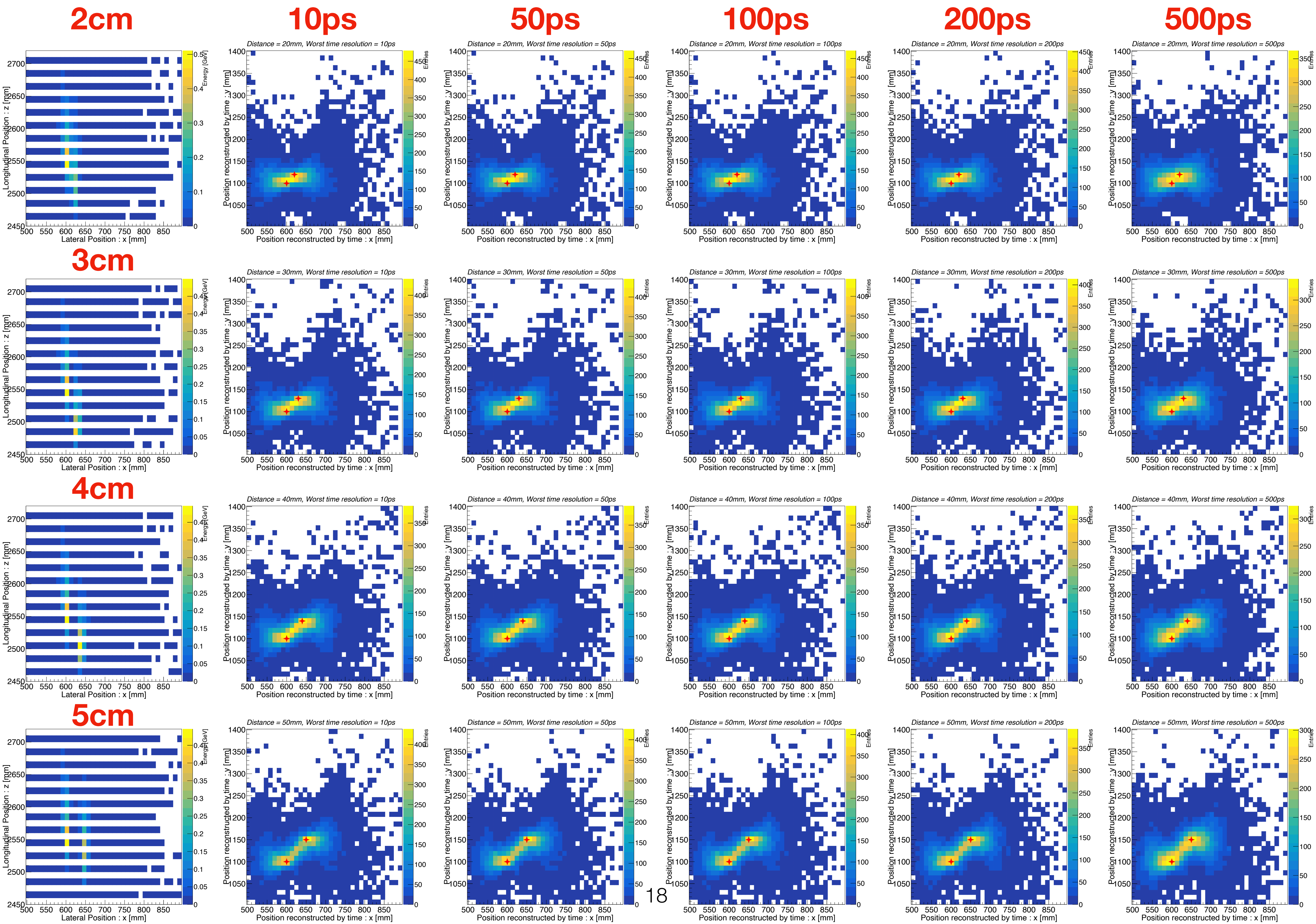
Backup

10GeV di-muon along diagonal

2cm | 10ps | 50ps | 100ps | 200ps | 500ps

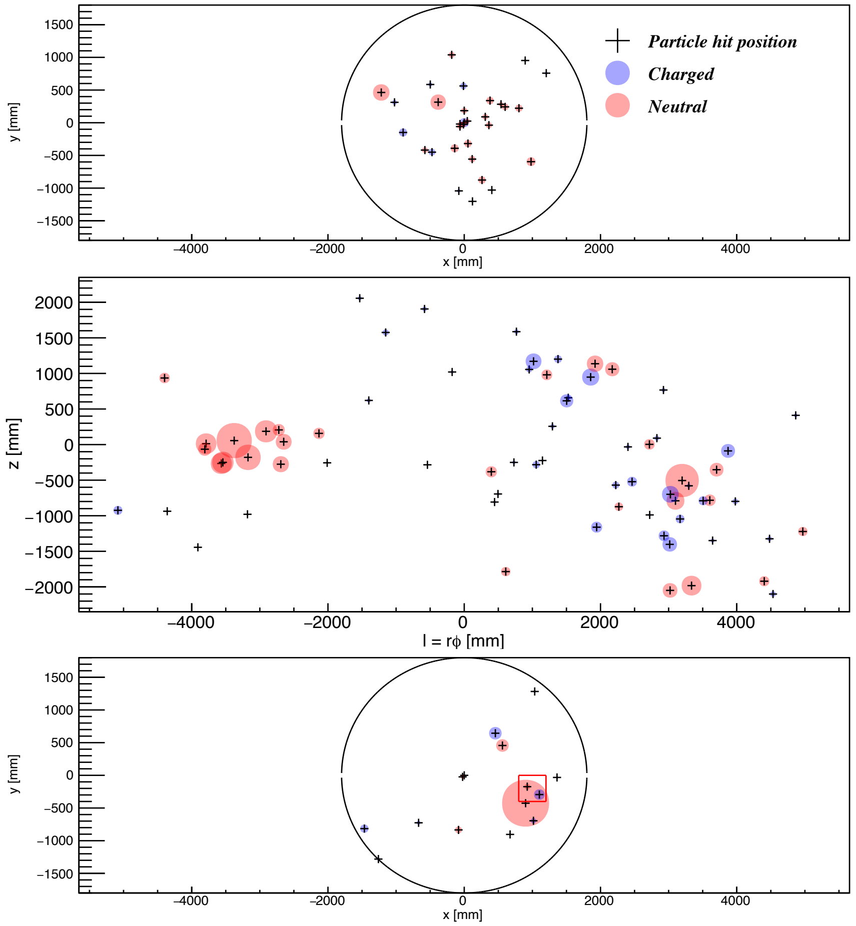


5GeV di-photon along diagonal



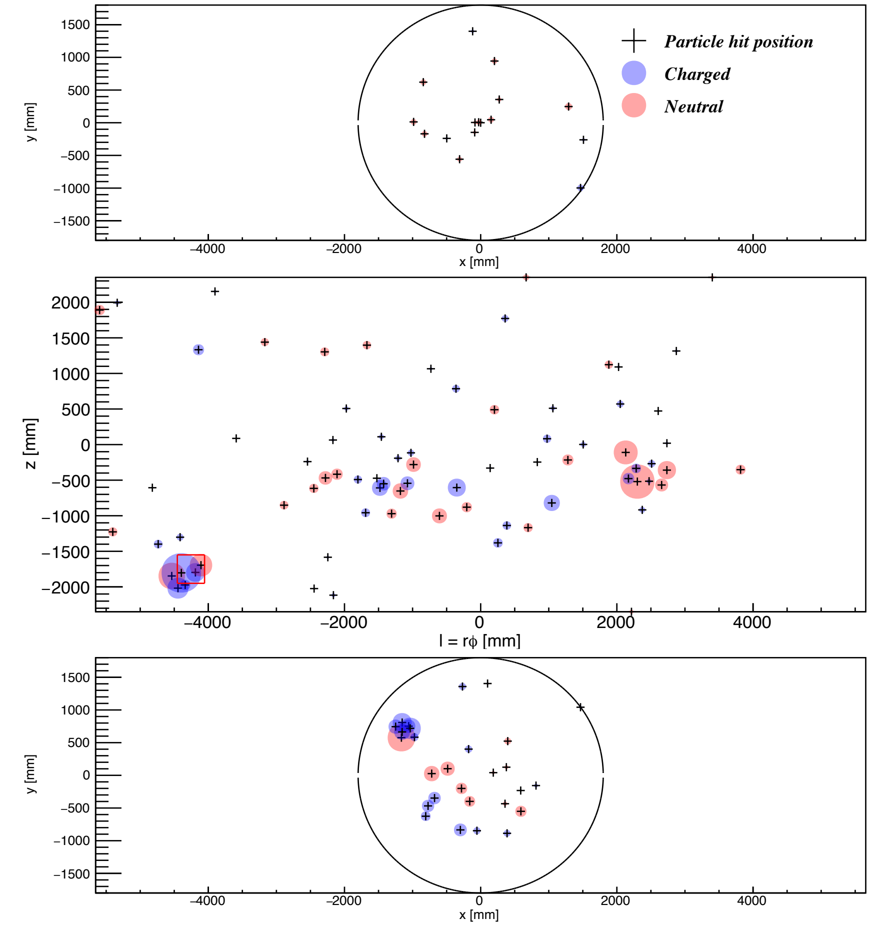
126 visible final state particles, 142 pairs with distance < 400mm

Hottest cell: 1 hits, E / $\sqrt{s}$ = 33.4GeV / 240.0GeV = 13.9%



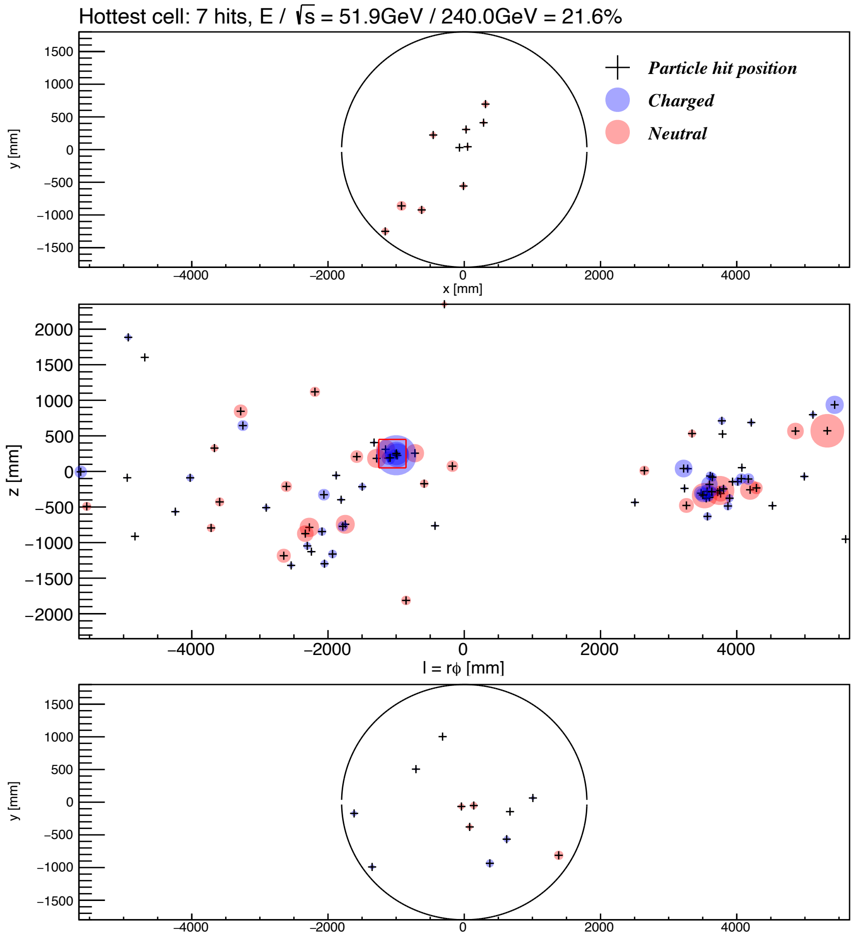
125 visible final state particles, 150 pairs with distance < 400mm

Hottest cell: 3 hits, E / $\sqrt{s}$ = 36.6GeV / 240.0GeV = 15.3%



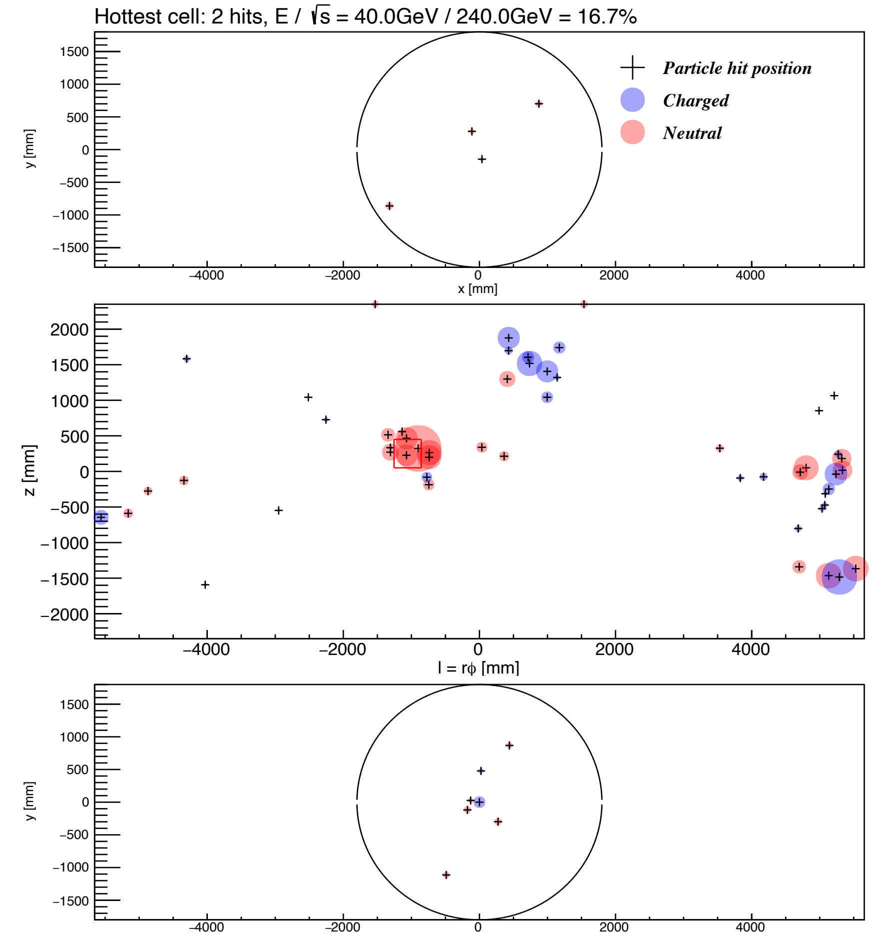
121 visible final state particles, 332 pairs with distance < 400mm

Hottest cell: 7 hits, E / $\sqrt{s}$ = 51.9GeV / 240.0GeV = 21.6%

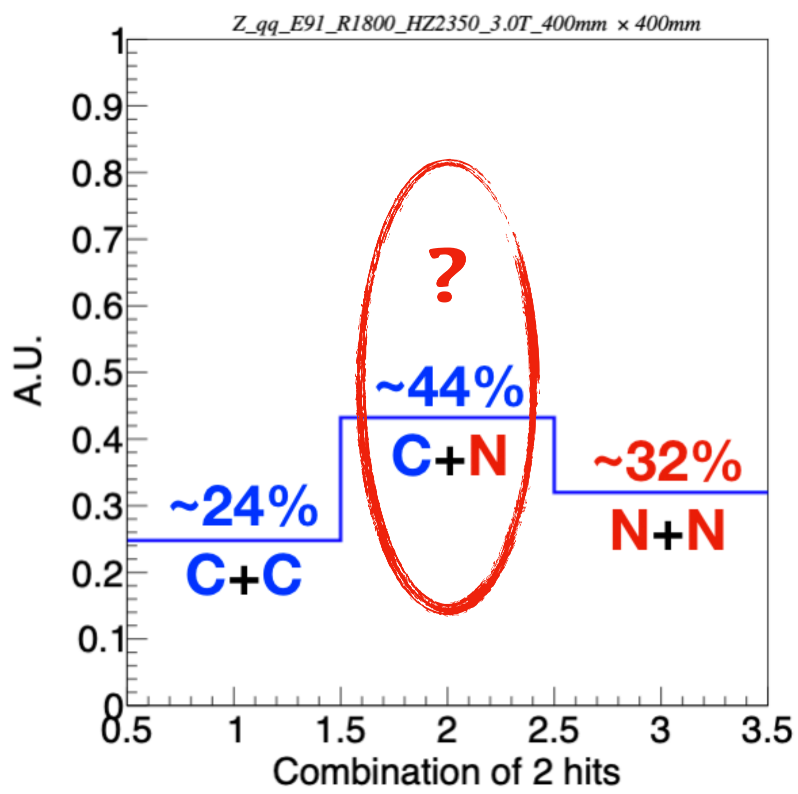


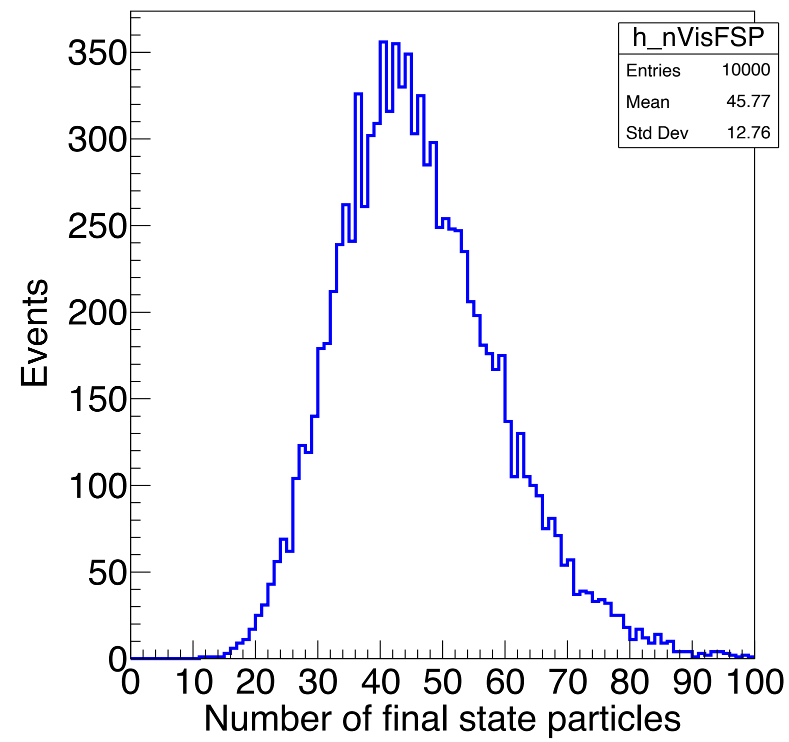
68 visible final state particles, 69 pairs with distance < 400mm

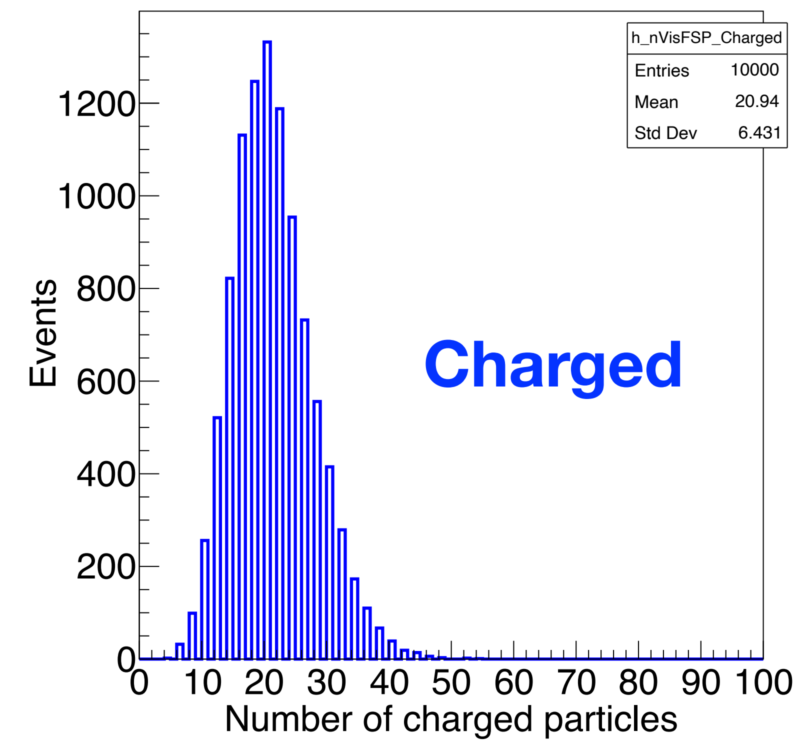
Hottest cell: 2 hits, E / $\sqrt{s}$ = 40.0GeV / 240.0GeV = 16.7%



Why "C+N" is the most?







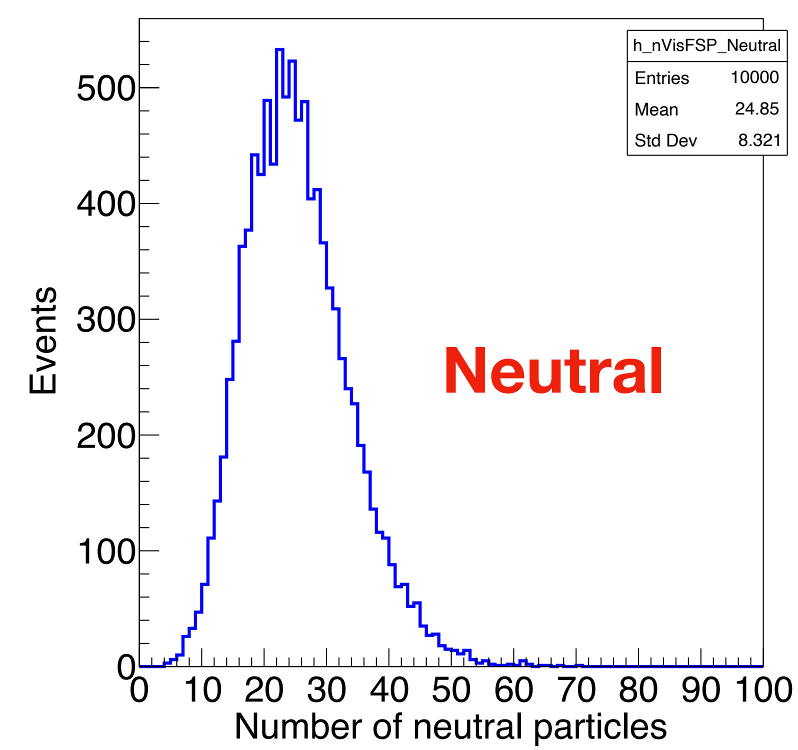
Derivation

$$All\ combinations: C_n^2 = \frac{n!}{2!(n-2)!} = \frac{n(n-1)}{2}$$

$$CC: C_{n_C}^2 = \frac{n_C(n_C-1)}{2} \approx \frac{\frac{n}{2}(\frac{n}{2}-1)}{2} = \boxed{\frac{\frac{n^2}{4}-\frac{n}{2}}{2}} \approx C_{n_N}^2 : NN$$

$$\wedge$$

$$CN = C_n^2 - C_{n_C}^2 - C_{n_N}^2 \approx \boxed{\frac{n^2}{4}}$$



Multiplicity of nearby 2 particles VS B Field

At Different E(Pt) Threshold