Crystal ECAL optimization of detector for CEPC

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- Simulation and reconstruction of the BGO crystal Matrix with 60x60
  - Geometry construction using Geant4 v10.5.0
  - Cluster reconstruction of each layer

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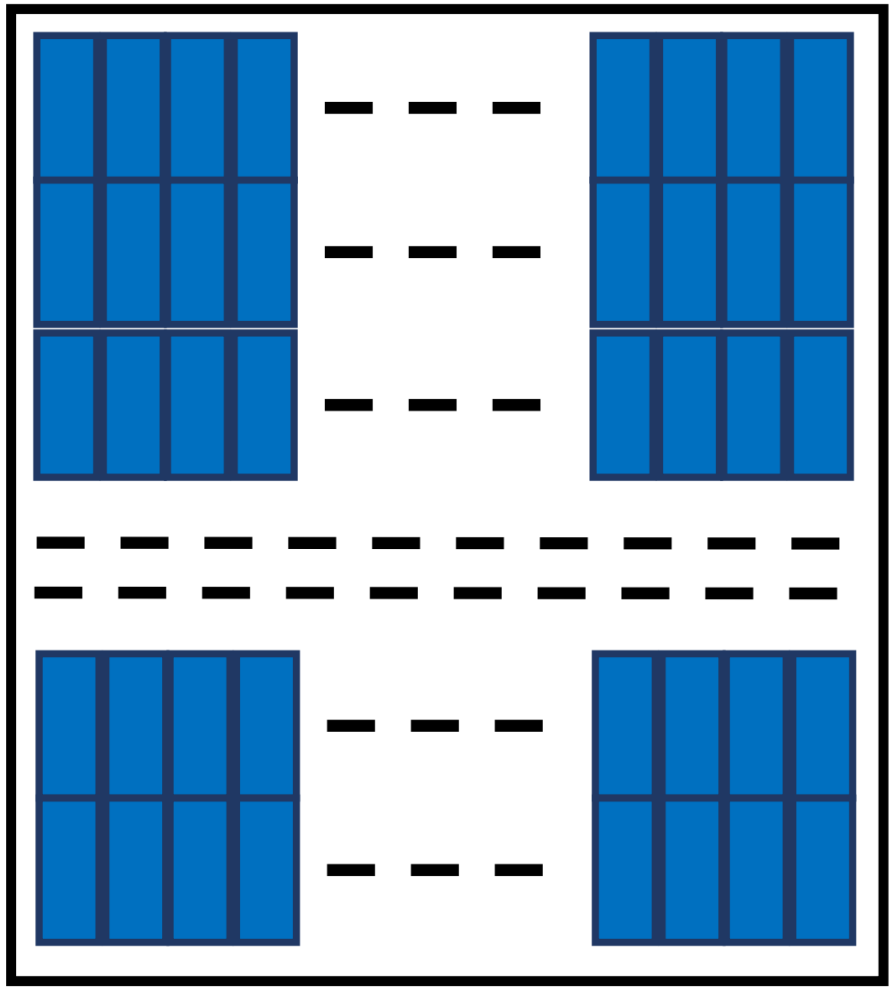
  - The correction of the longitudinal energy leakage for high energy γ
  - Separation performance of the two γ's from π^0 decay

Motivation

- Optimize the crystal granularity to realize the following performance
  - Separation performance (especially 2 γ from high energy π^0 decay)
  - Separate γ and K_L by time and profile of the cluster
  - Whether the energy leakage can be reconstructed by the profile of the cluster
- How to arrange the crystals
  - cellsize?
  - how many layers?
  - depth of each layer?
- Geometry of ECAL at CEPC
  - Crystal cell size, the wrapper
  - Estimate the volume of all Crystals
  - Estimate the number of electronic channels
  - Finally, the ECAL cost is estimated

Geometry construction using GEANT4 v10.5.0

A simplified crystal calorimeter module for CEPC: segmented crystal ECAL



- Construct the Matrix module by GEANT4 v10.5.0
  - Construct a 3D BGO array with 60 ×60 ×60 cells
  - Readout cell size:10mm×10mm×10mm
  - The front face of the array is 1835mm from zero (origin of coordinates).
  - Without any photodetector materials and wrappers
- Geant4 simulate the energy deposited in crystal cell
- Cell Size 10mm is ~ 0.31224° solid angle at θ=90° in Barrel

- For barrel with 1835mm inner radius, the phi direction will arrange ~1150 cells
- CalBarrelHalfZ: 2245mm, will arrange ~4490cells at Z direction
- BGO crystal material properties:
  - Crystal radiation length:~1.12cm;
  - Moliere radius R_M: 2.23cm;

Generate the MC single γ and π^0 samples

- Generate the MC single particles samples in the following:
  - γ samples: 98GeV, 100GeV, 102GeV
  - π^0 samples: 30GeV
  - Momentum Direction： It goes from the origin to the center of the crystal, which is number 30

Complete the cluster reconstruction of each layer

- Reconstruction of each layer
  - Clustering
  - Finding the seed
  - Finding shower based on the simple method of the cluster splitting
- Reconstruction codes have been completed in root analysis(without any frame).

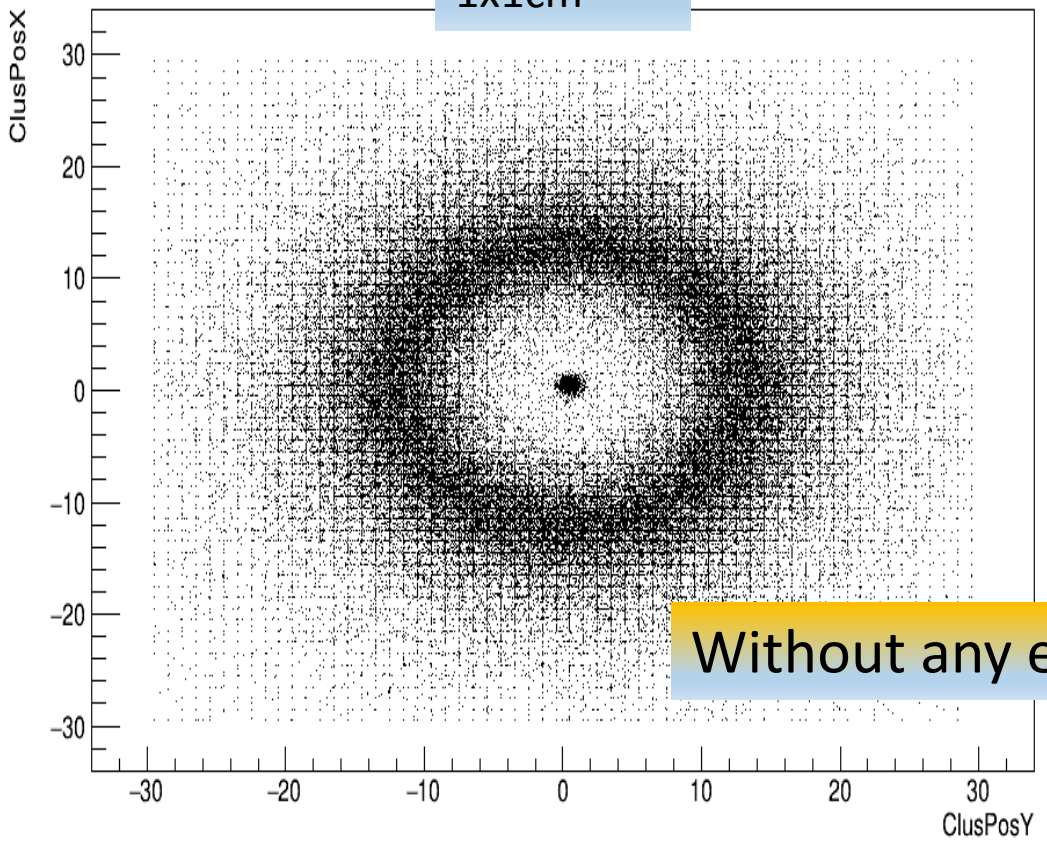
The performance studies in the following

- Performance studies
  - ➢The correction of the longitudinal energy leakage for high energy γ
  - ➢Separation performance of the two γ's from π^0 decay
- The study based on the following ECAL detector.
  - ➢Merge 3 layers into one, i.e., each layer/3cm depth
  - ➢Reconstruction cluster in each layer
  - ➢Consider the detector with the different length
    - ✓With 30cm length (a total of 10 layers)
    - ✓With 27cm length (a total of 9 layers)
    - ✓With 24cm length (a total of 8 layers)

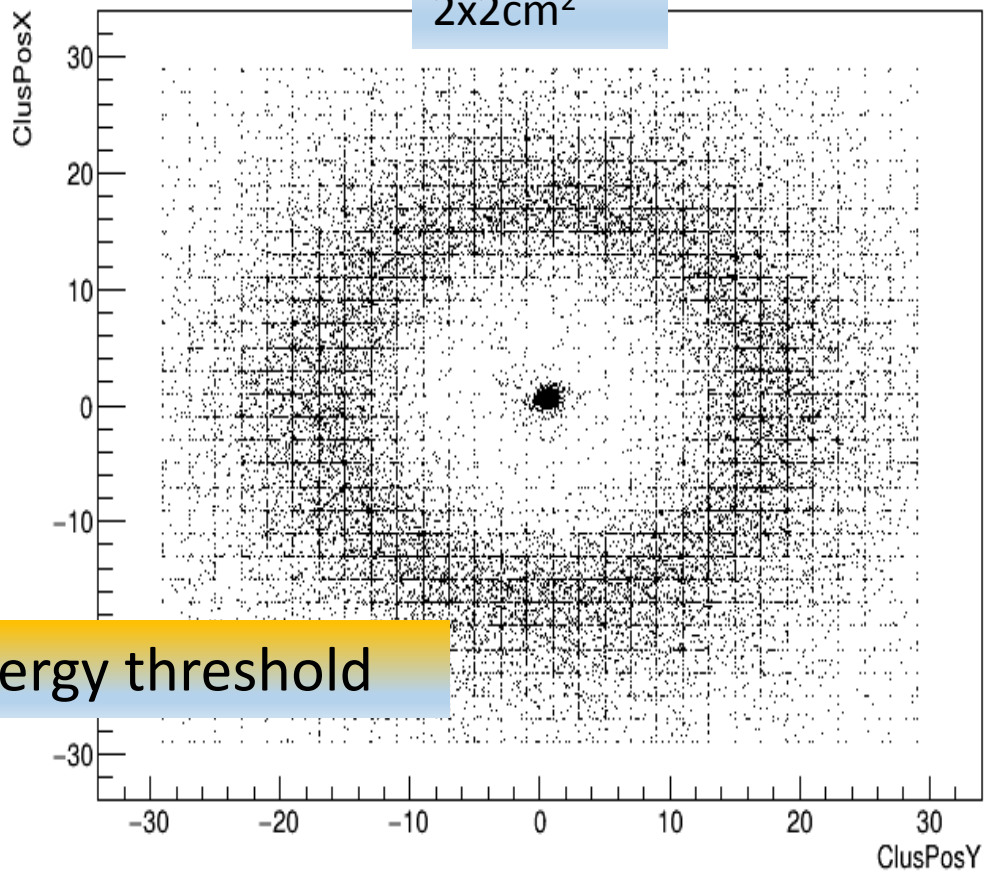
Distribution of Cluster position of 100GeV γ in each layer

There are many clusters reconstructed if any energy threshold aren't used.

Cell size
1x1cm^2

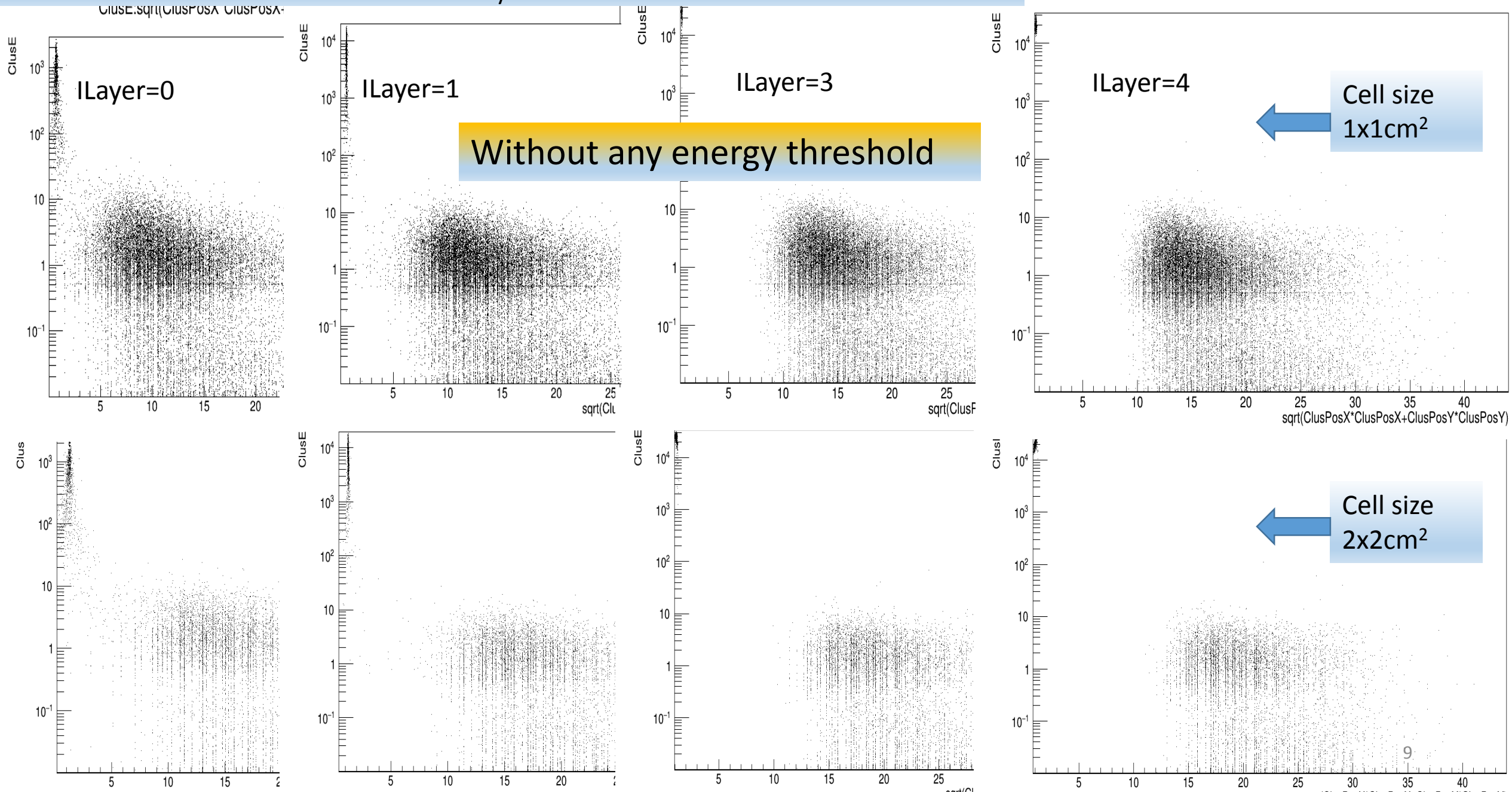


Cell size
2x2cm^2

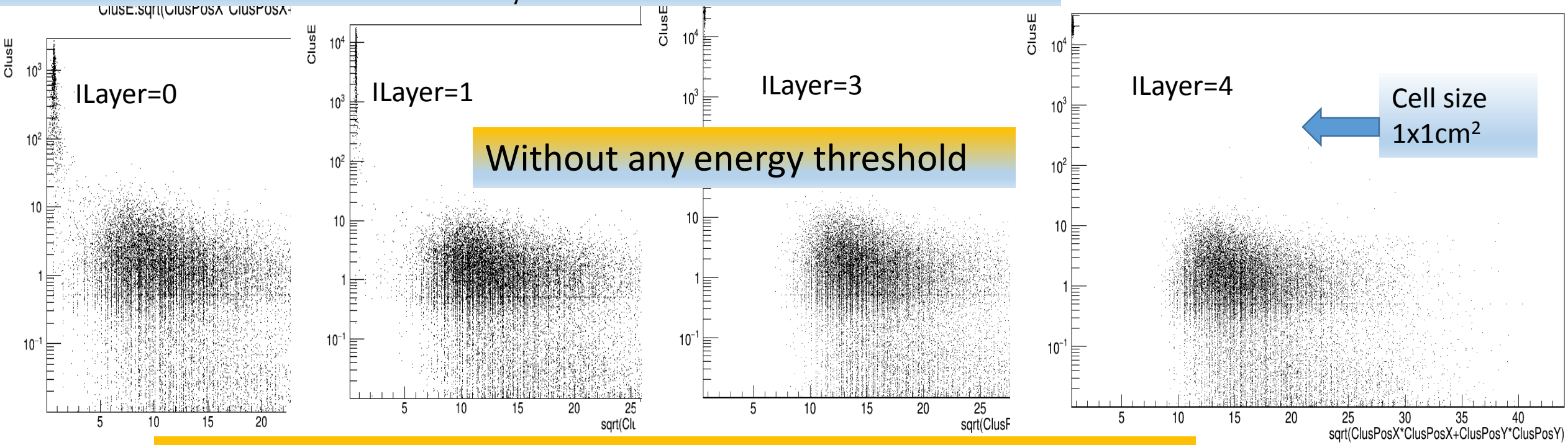


Without any energy threshold

Cluster energy(MeV) Versus R_{xy}(cm) of each layer for 100GeV γ



Cluster energy(MeV) Versus R_{xy}(cm) of each layer for 100GeV γ

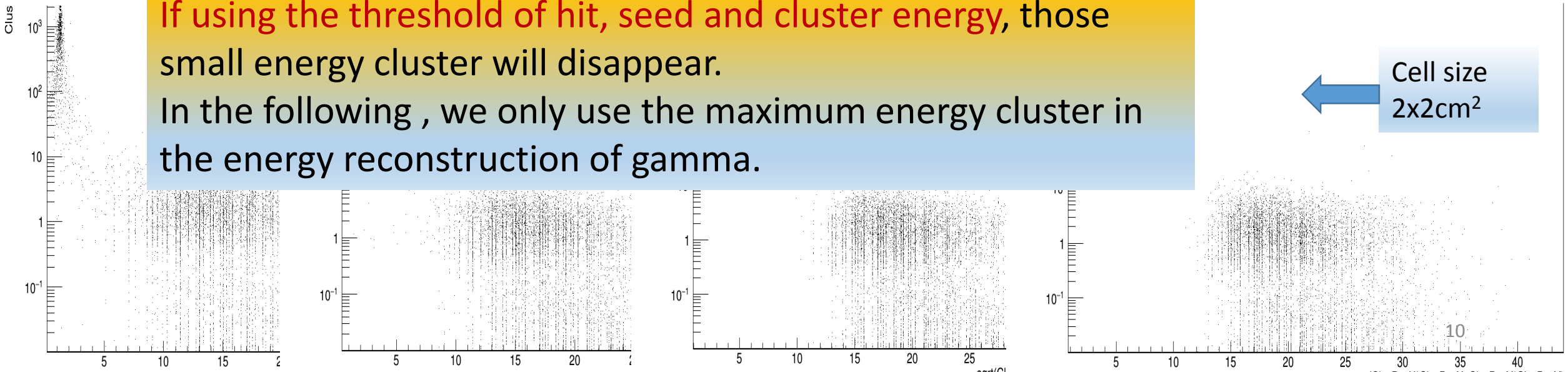


Without any energy threshold

Cell size 1x1cm²

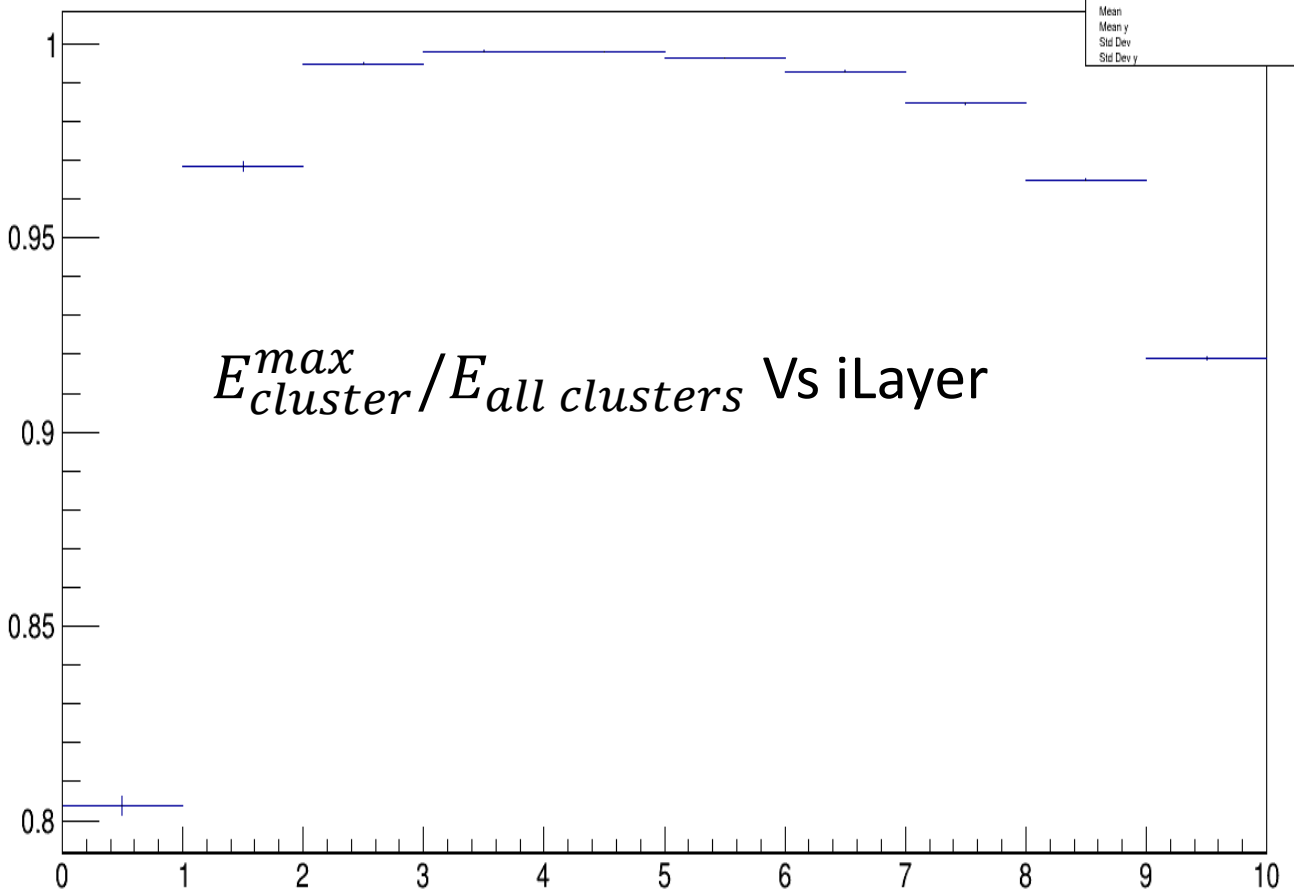
If using the threshold of hit, seed and cluster energy, those small energy cluster will disappear.

In the following , we only use the maximum energy cluster in the energy reconstruction of gamma.

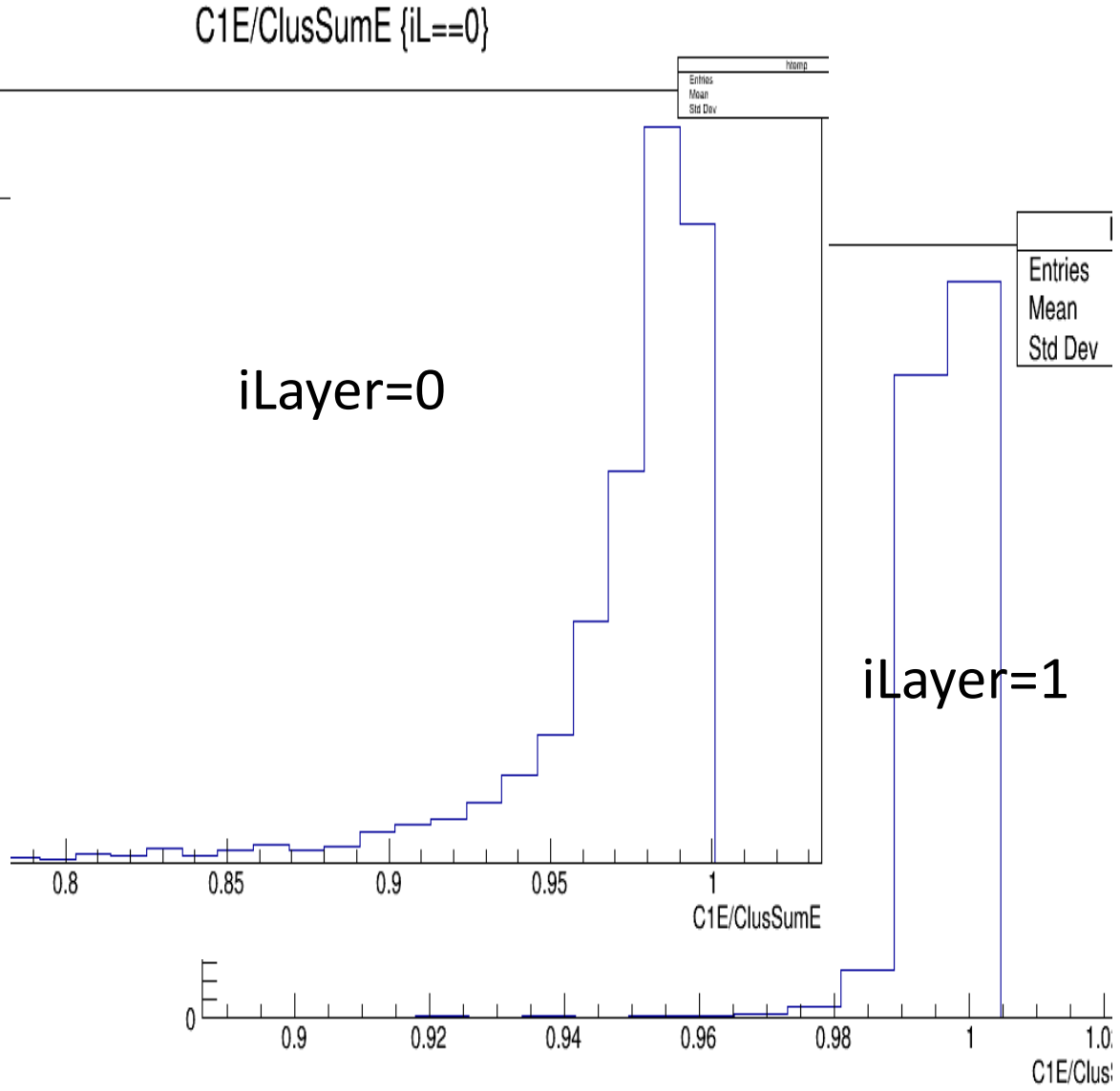


Cell size 2x2cm²

$E^{max}_{cluster}/E_{all\ clusters}$ in each layer(3cm)



$E^{max}_{cluster}/E_{all\ clusters}$ Vs iLayer

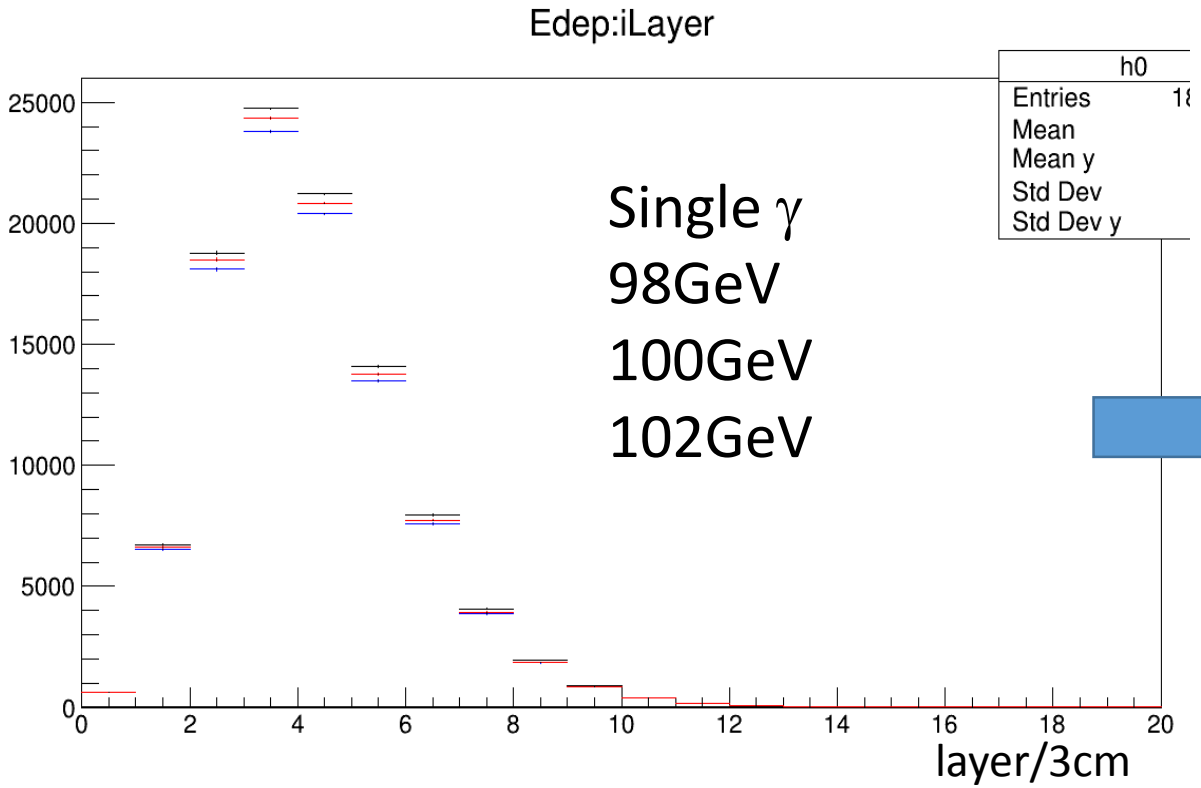


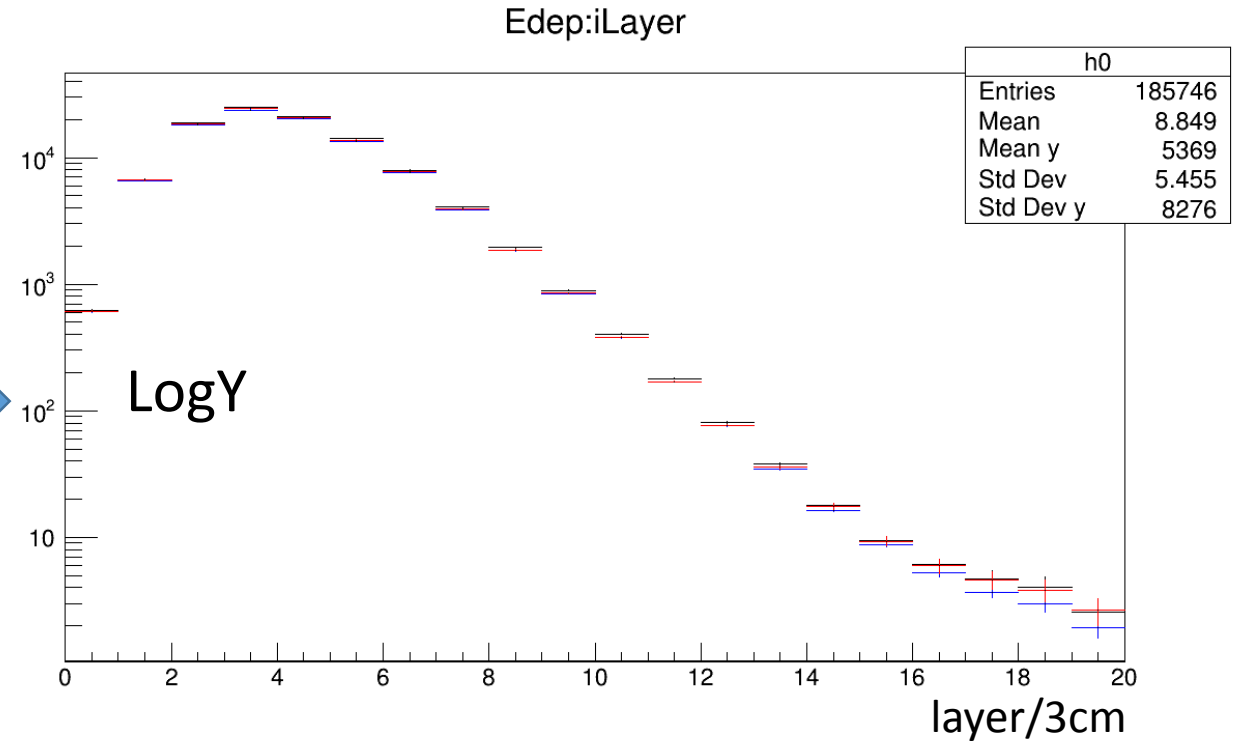
Study of the correction of the Longitudinal shower energy leakage

The correction of the Longitudinal shower energy leakage

- Generate 98GeV,100GeV,102GeV γ
- Study the correction of the Longitudinal shower energy leakage according to the longitudinal shower profile

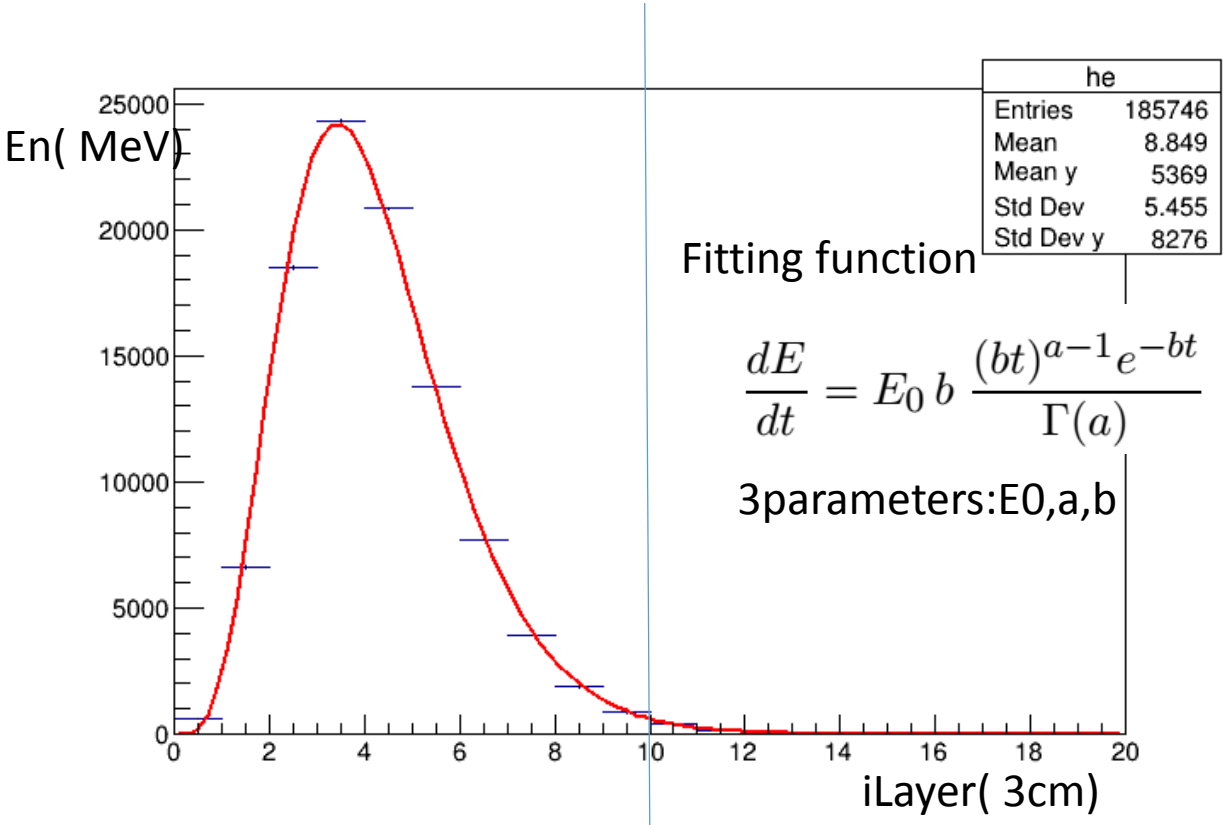
Energy deposited versus iLayer with each layer(3cm)





The longitudinal shower profile

The method of the correction of longitudinal leakage



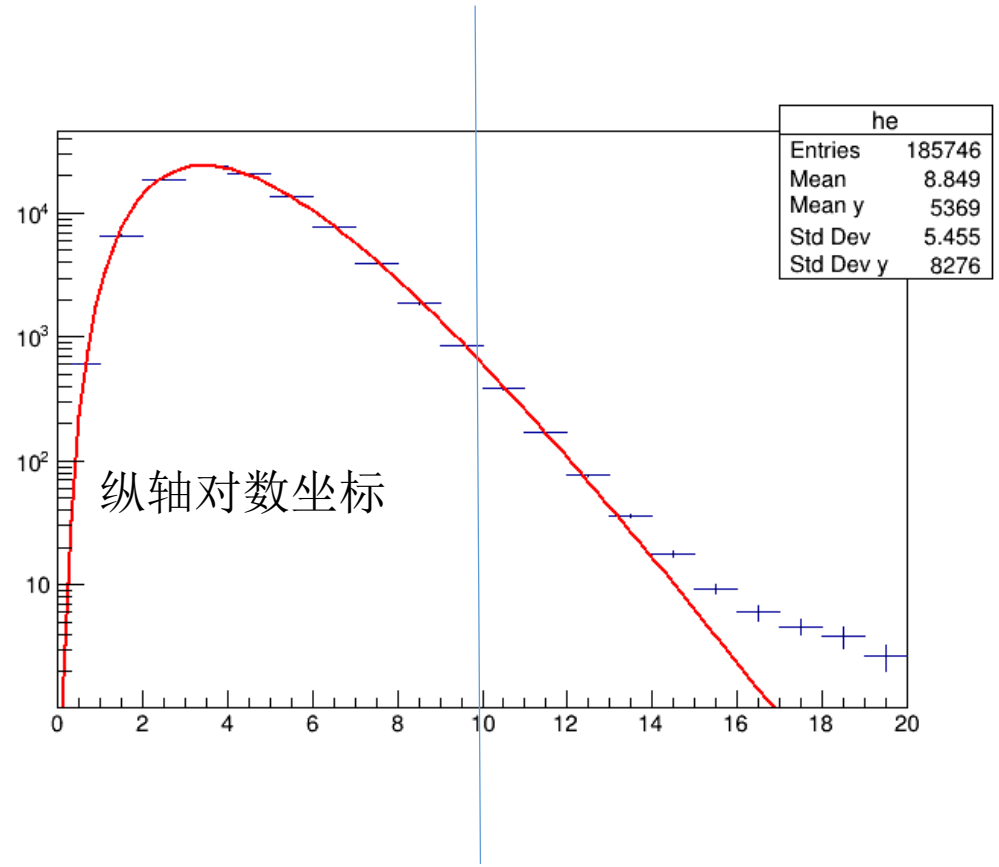
Fitting function

$$\frac{dE}{dt} = E_0\, b\, \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)}$$

3parameters:E0,a,b

Esum30

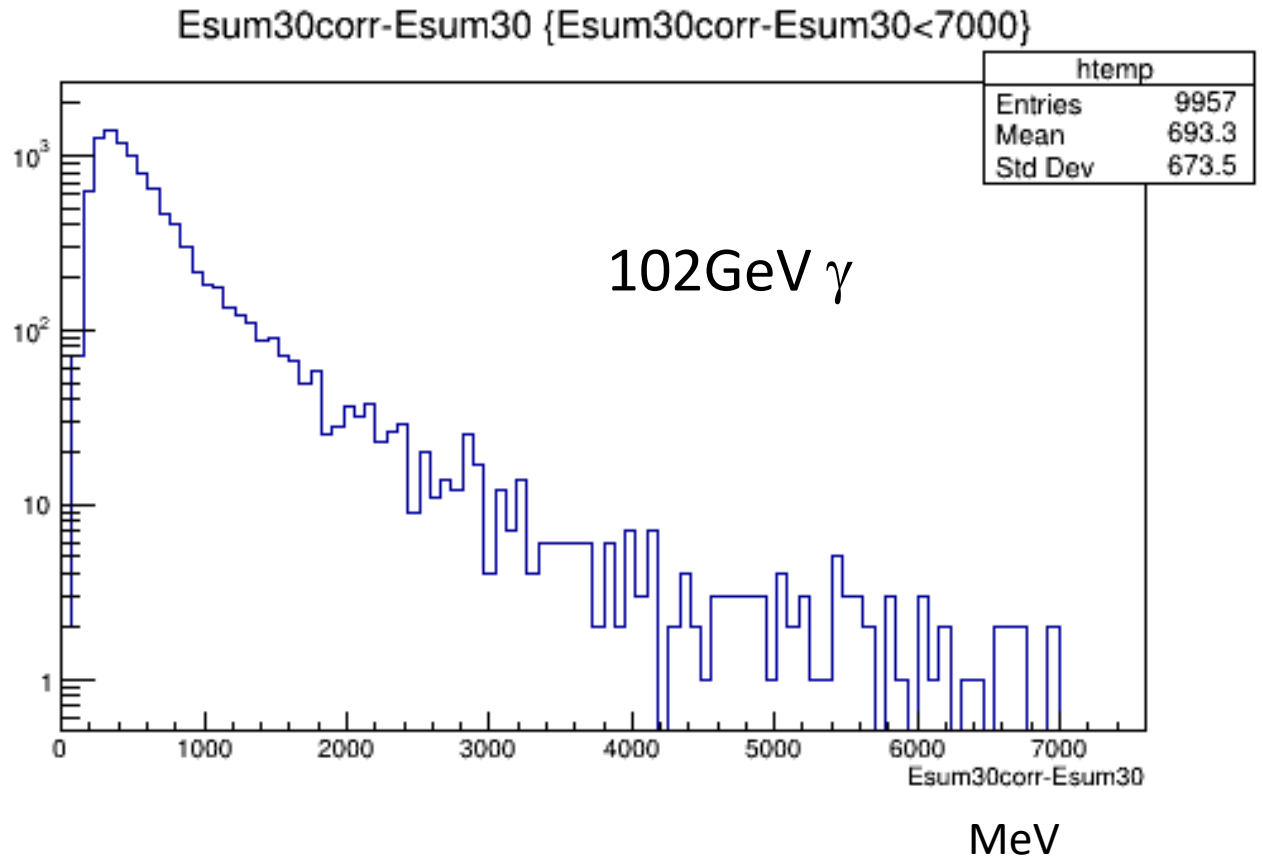
Ecorr=the integeration of fit function in the region[10,17]



The fit function need to be improved

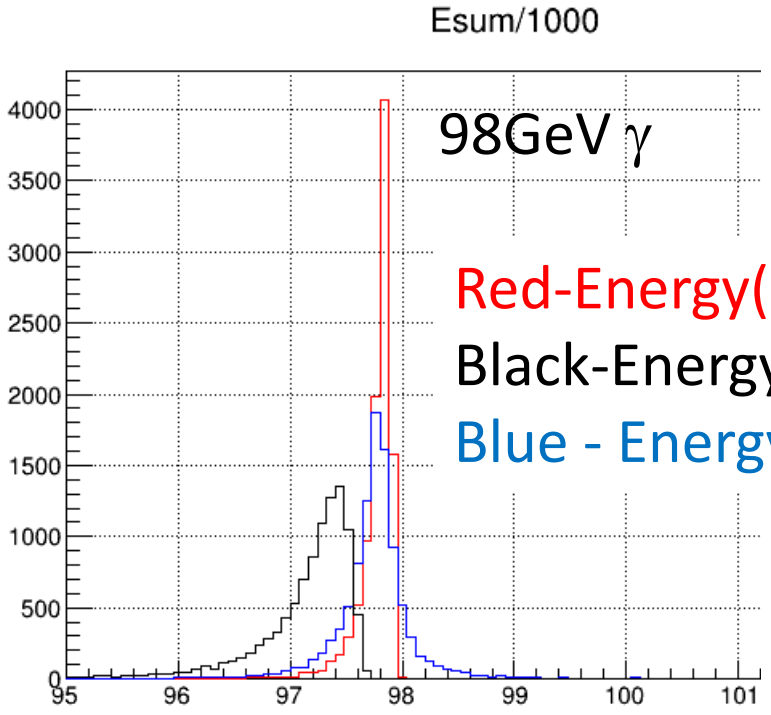
利用前10层或9层测量的能量沉积随簇射深度的变化。并拟合，给出拟合函数。然后根据函数计算超过探测器深度后30cm内的函数积分，即函数在[30cm-60cm] or [27cm-60cm]的积分，作为后端纵向能量泄漏的修正量。

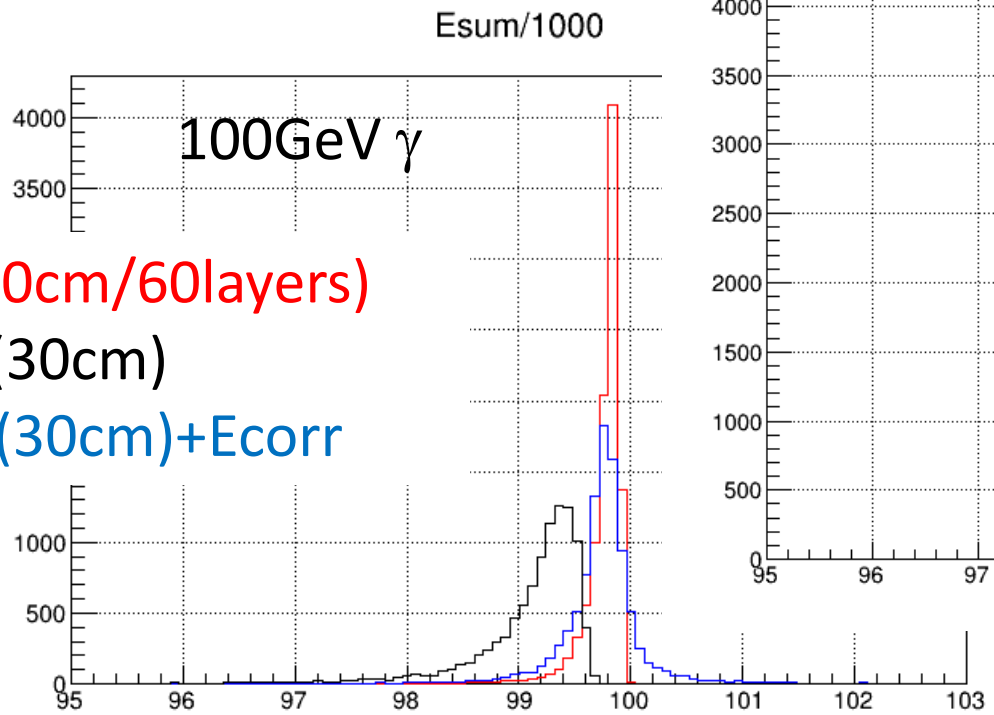
Correction of the longitudinal energy leakage

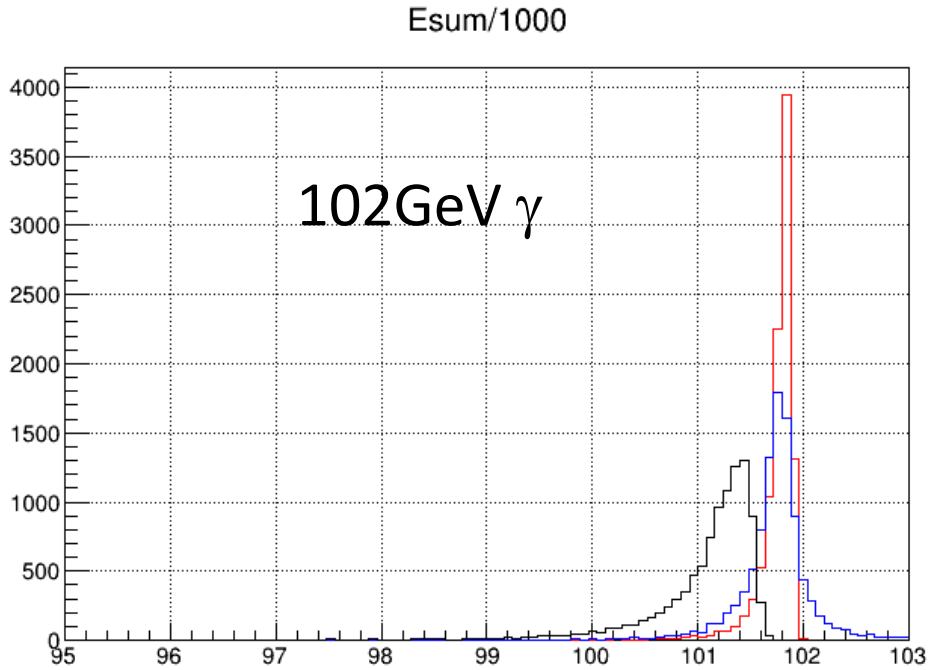


Using the all energy deposited in each layer, i.e., without cluster reconstruction

Energy distribution of 98GeV.100GeV 102GeV γ







Red-Energy(60cm/60layers)

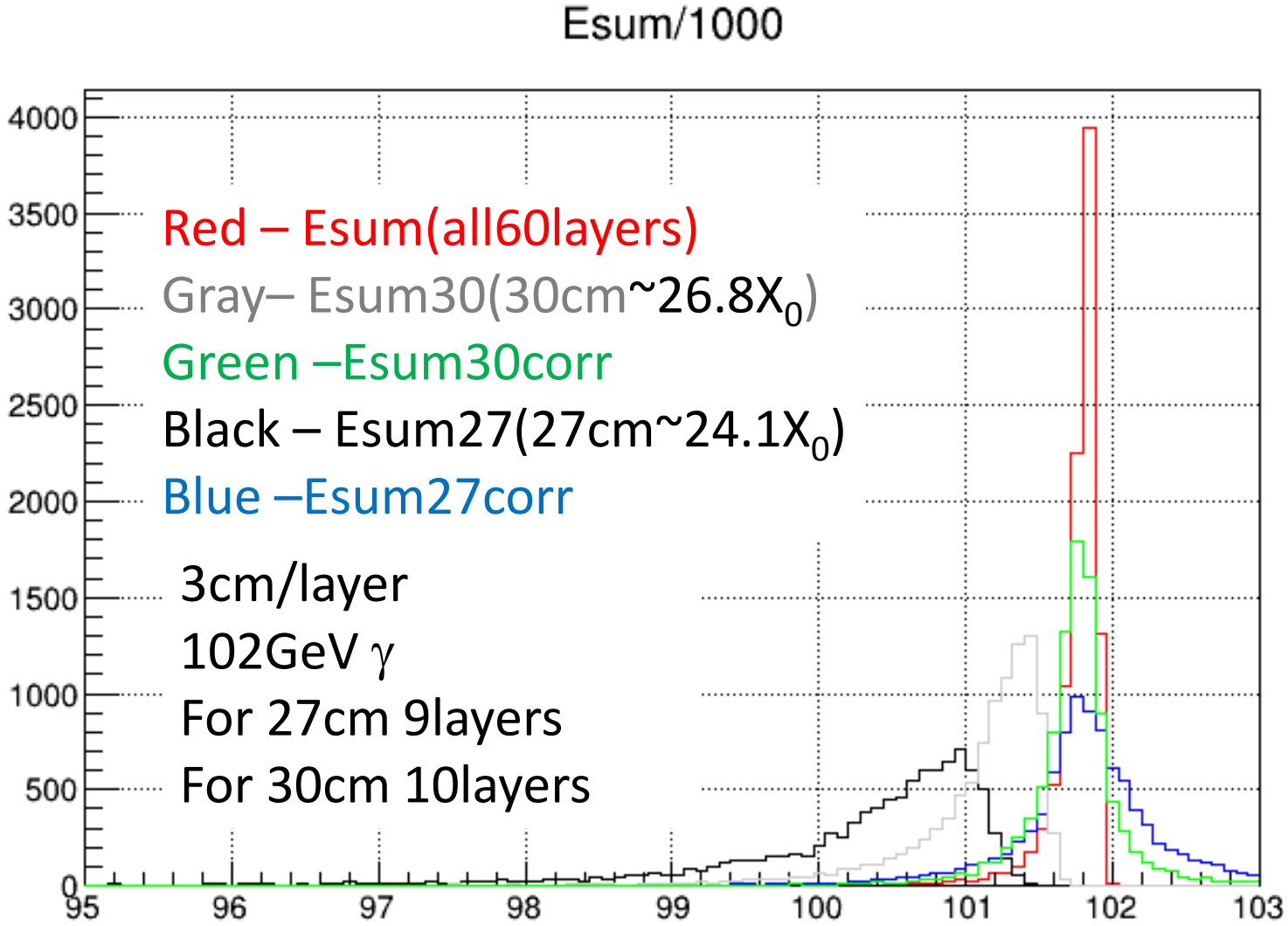
Black-Energy(30cm)

Blue - Energy(30cm)+Ecorr

The energy resolutions are improved
after the correction of the energy leakage at the end of BGO crystal.

Using the all energy deposited in each layer, i.e., without cluster reconstruction

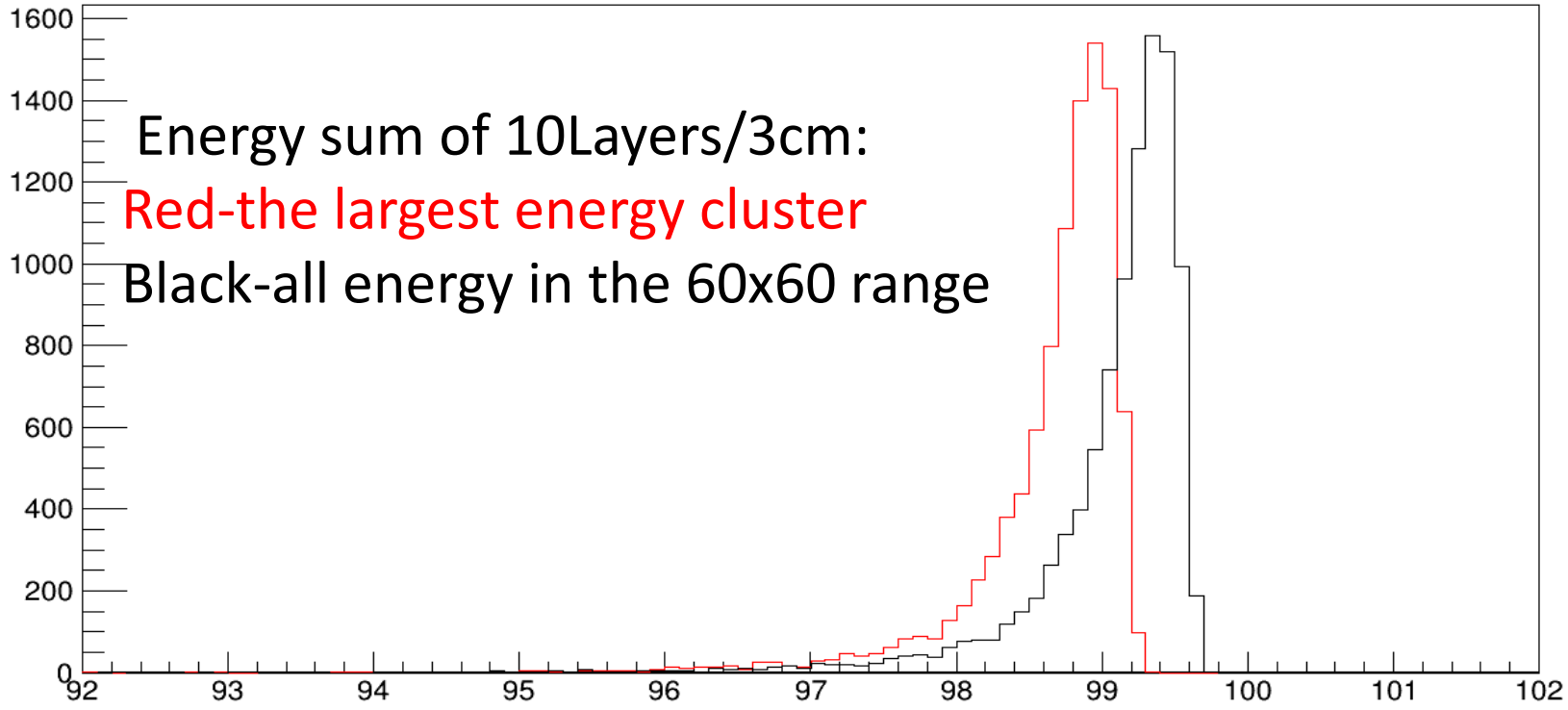
Two cases: the crystal ECAL vertical depth is 30cm~26.8X_0 or 27cm~24.1X_0



In the following,

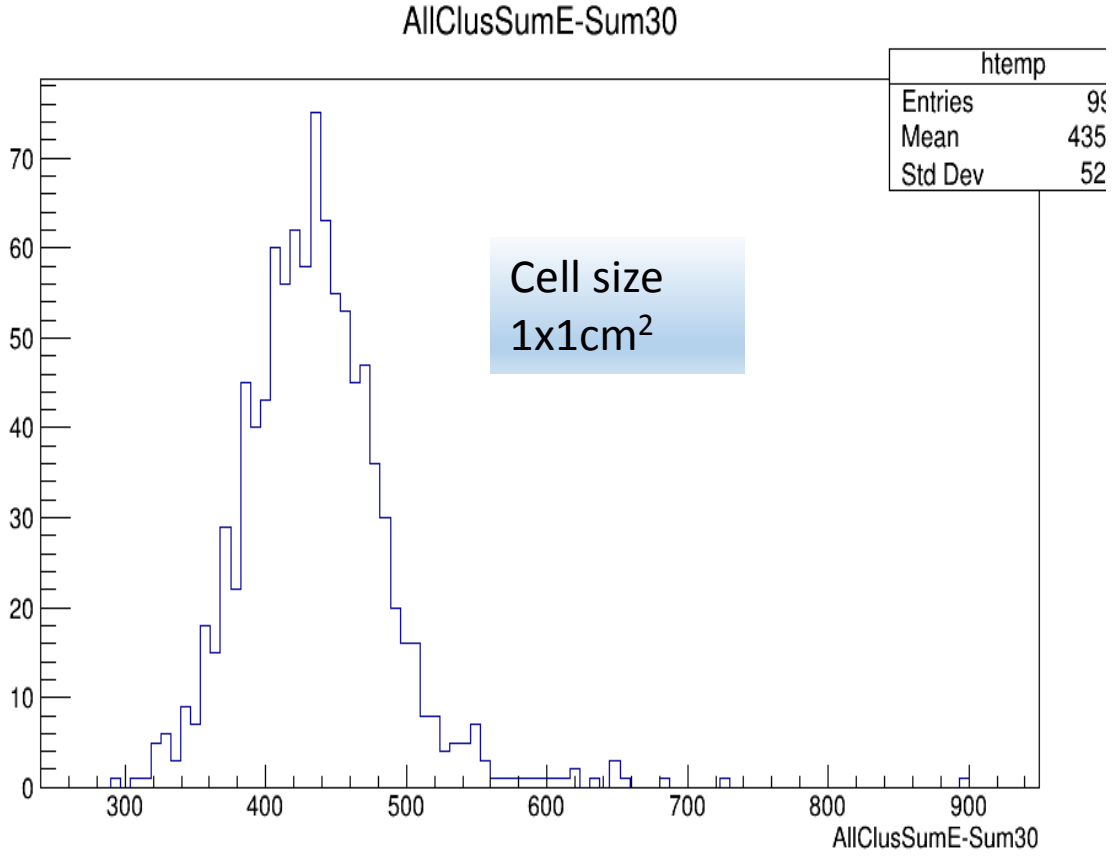
To study the correction of the longitudinal energy leakage

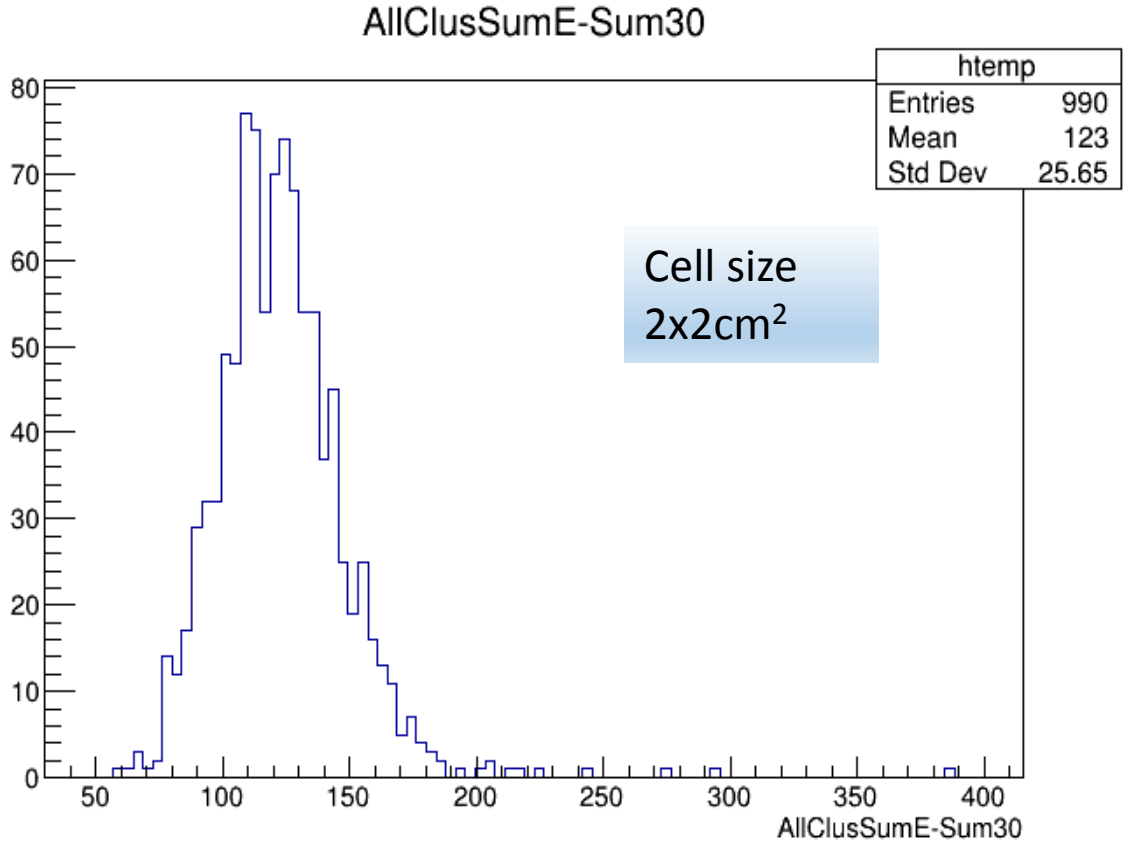
by using the largest energy cluster after the reconstruction



Energy deposited around the largest energy cluster for 100GeV γ

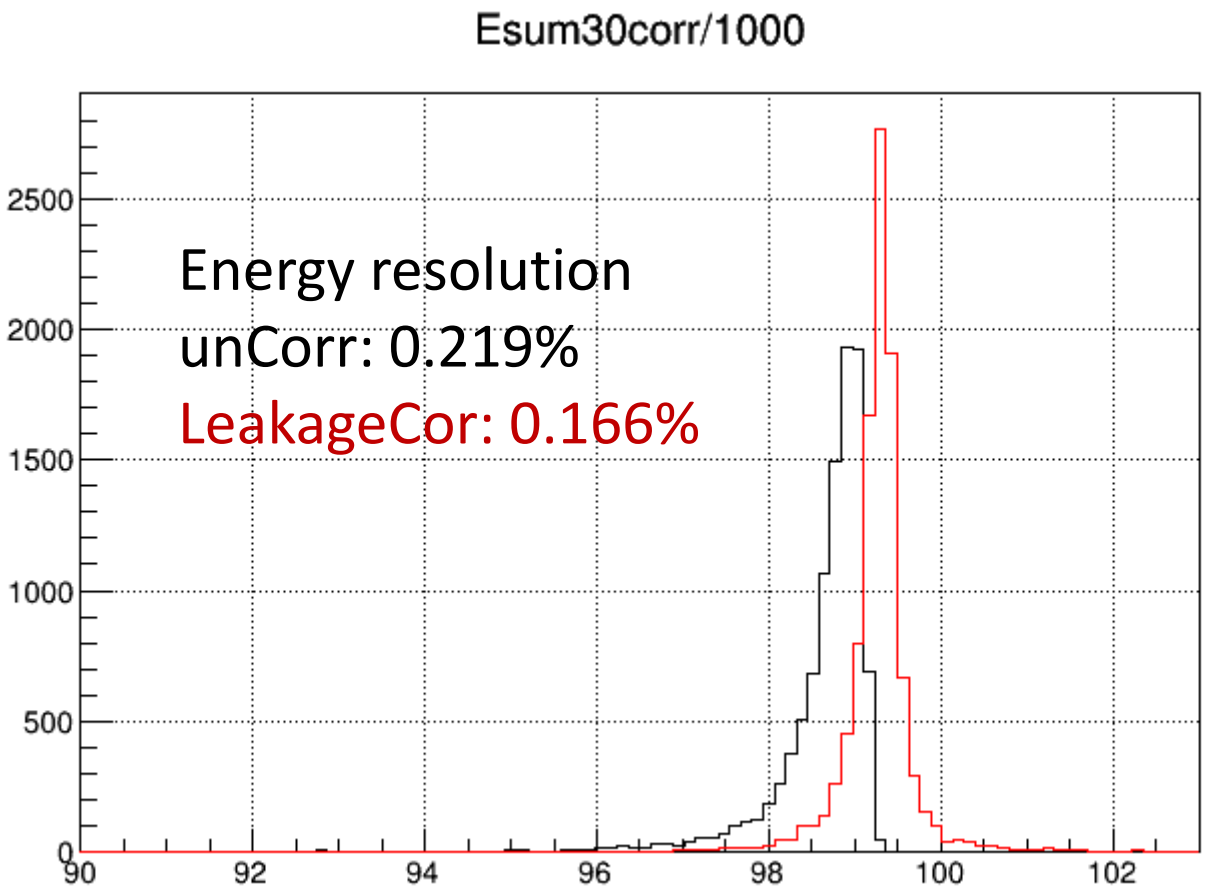
Sum of 10Layers/3cm

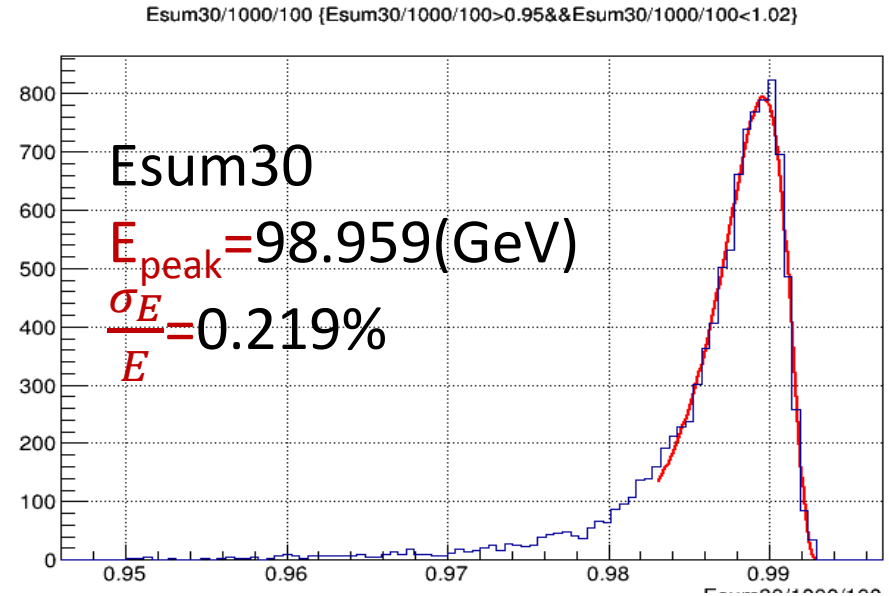


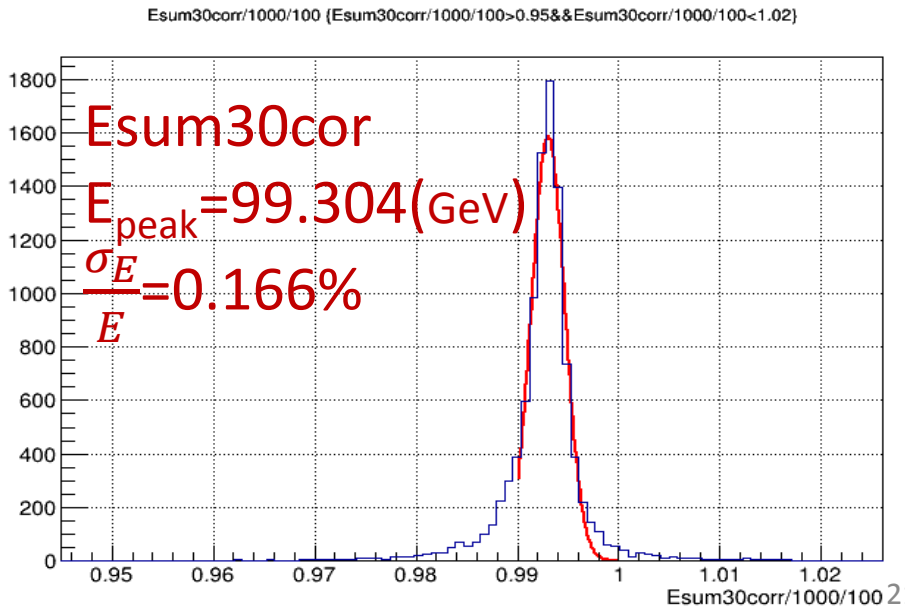


Energy measurement of 100GeVγ with 30cm depth crystal

30cm(~26.8X_0) length BGO
10 layers/3cm
Cell size 1x1cm^2

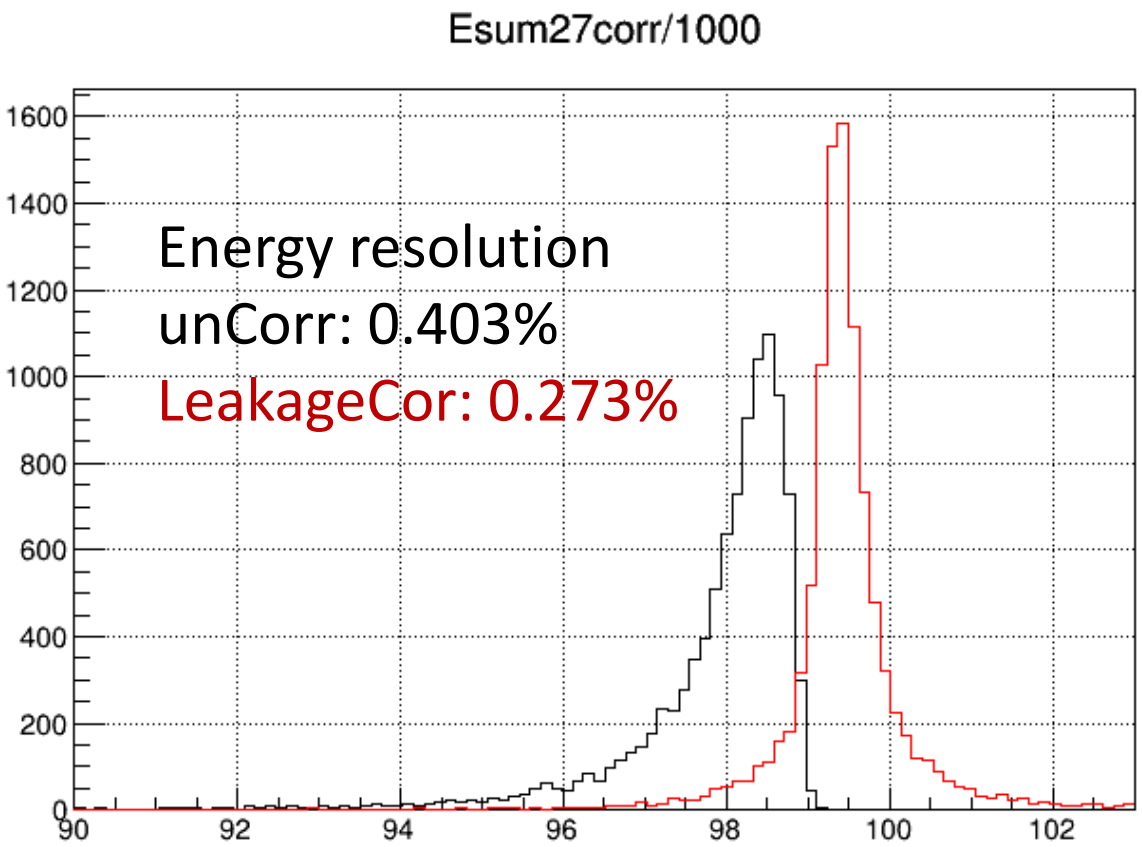


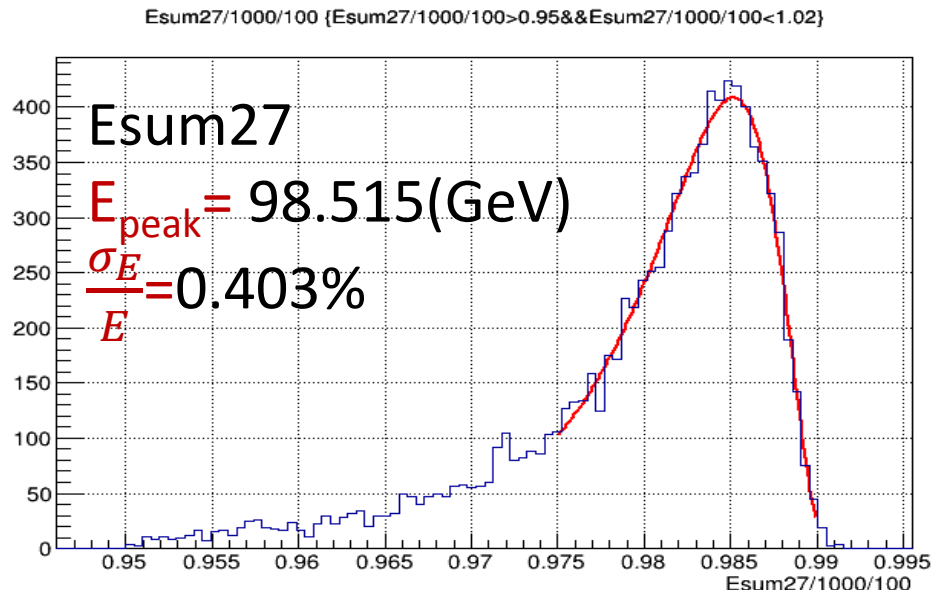


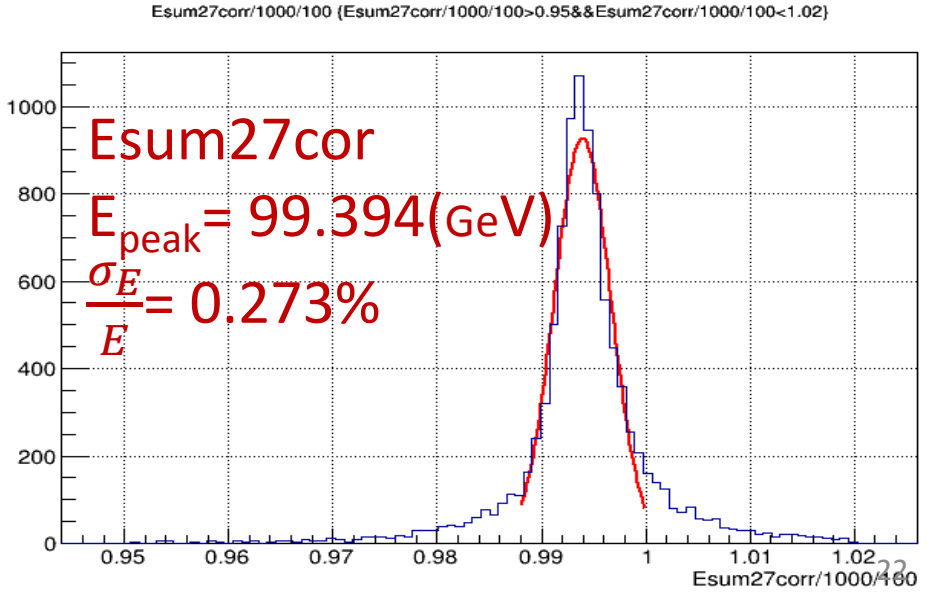


Energy measurement of 100GeVγ with 27cm depth crystal

27cm(~24.1X_0) length BGO
9 layers/3cm
Cell size 1x1cm^2

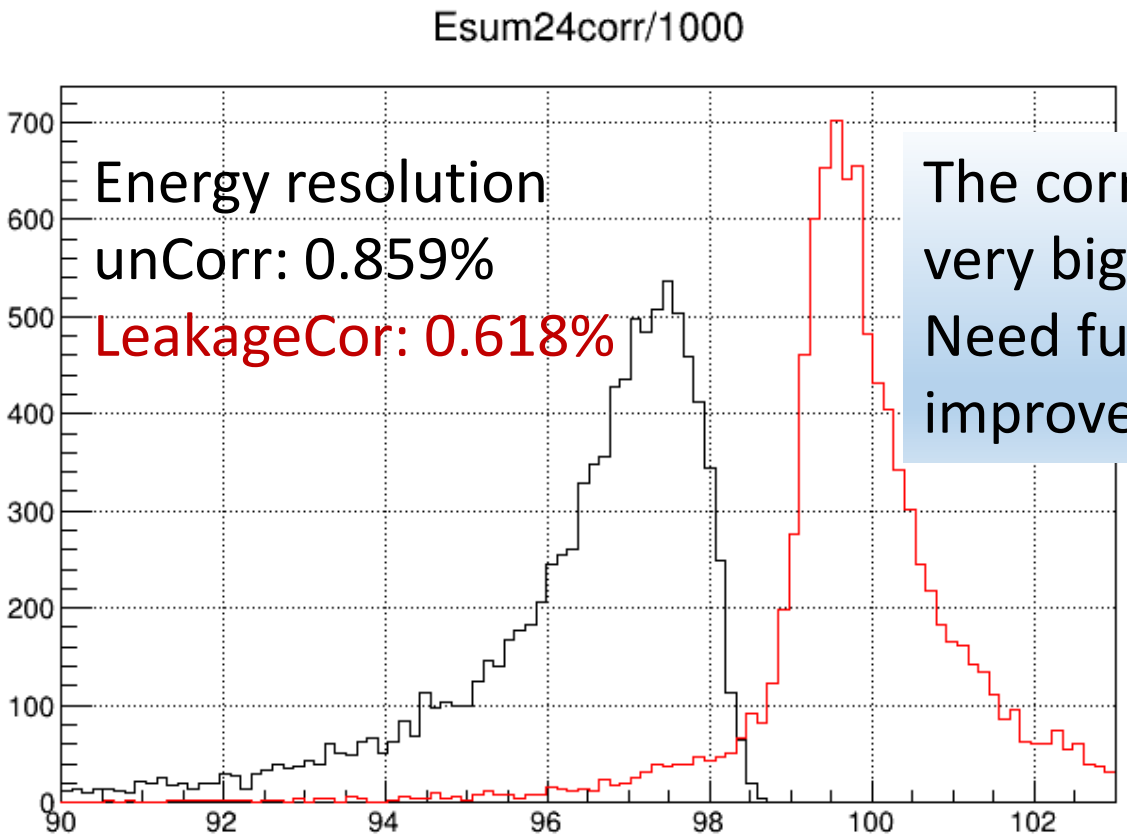




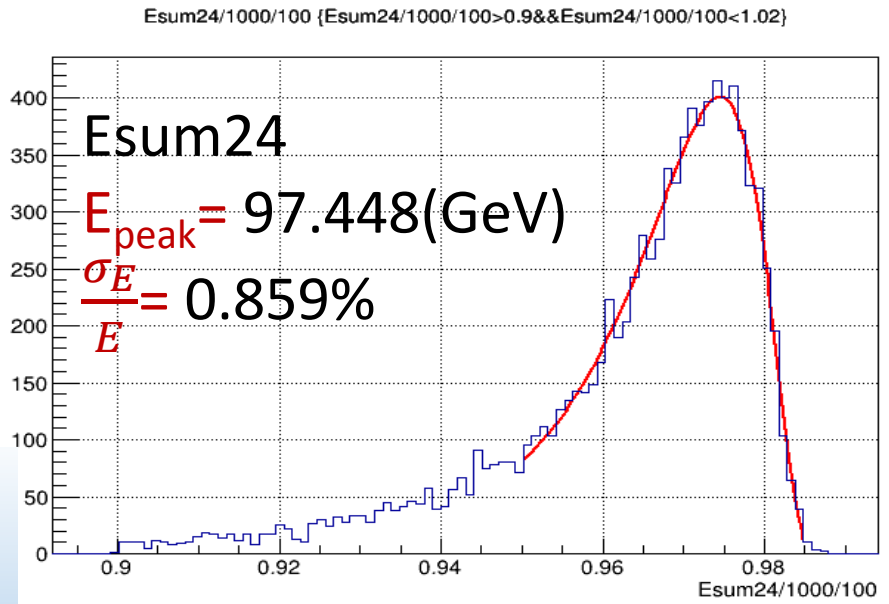


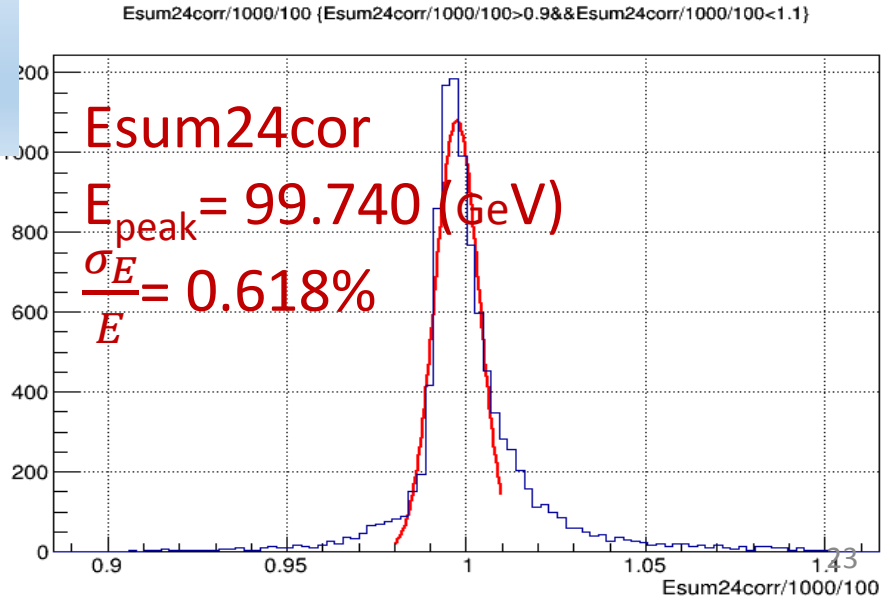
Energy measurement of 100GeVγ with 24cm depth crystal

24cm(~21.4X_0) length BGO
8 layers/3cm
Cell size 1x1cm^2



The correction is very big.
Need further improvement





Energy peak and resolution of 100GeVγ after the cluster reconstruction

Preliminary results in the following

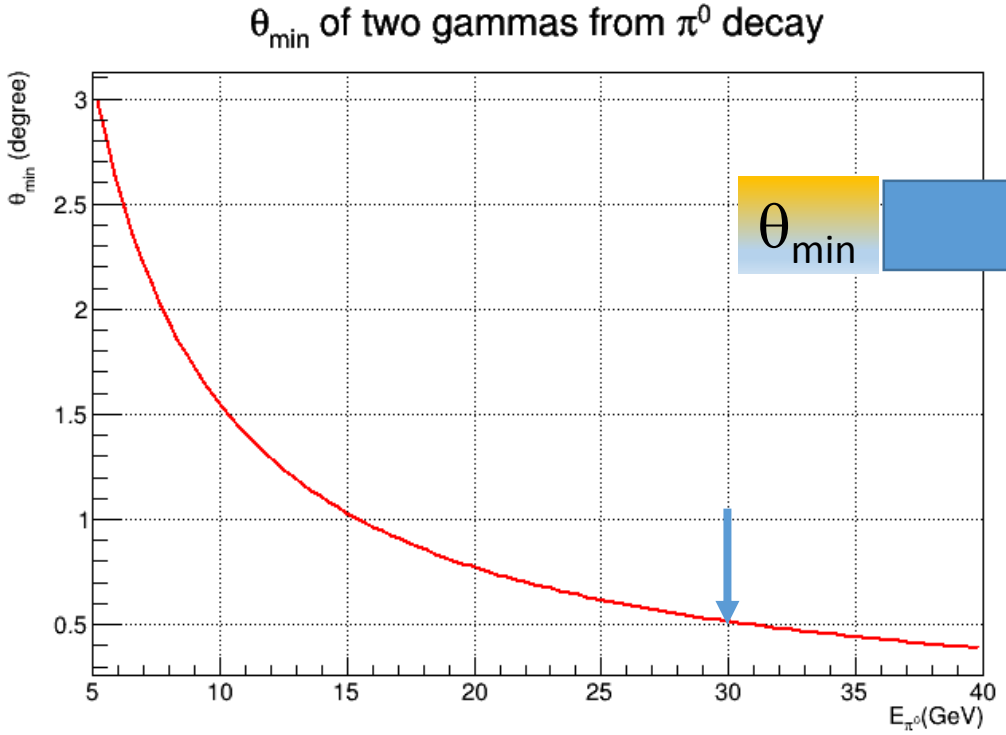
- Energy peak and energy resolution

• Cell size	1x1cm^2		2x2cm^2	
• Hit en-threshold	0.01MeV		1MeV	
• Esum30:	98.959	0.219%	99.030	0.219%
• Esum30cor:	99.304	0.166%	99.354	0.176%
• Esum27:	98.515	0.403%	98.559	0.410%
• Esum27cor:	99.394	0.273%	99.444	0.276%
• Esum24:	97.448	0.859%	97.495	0.860%
• Esum24cor:	99.740	0.618%	99.773	0.645%

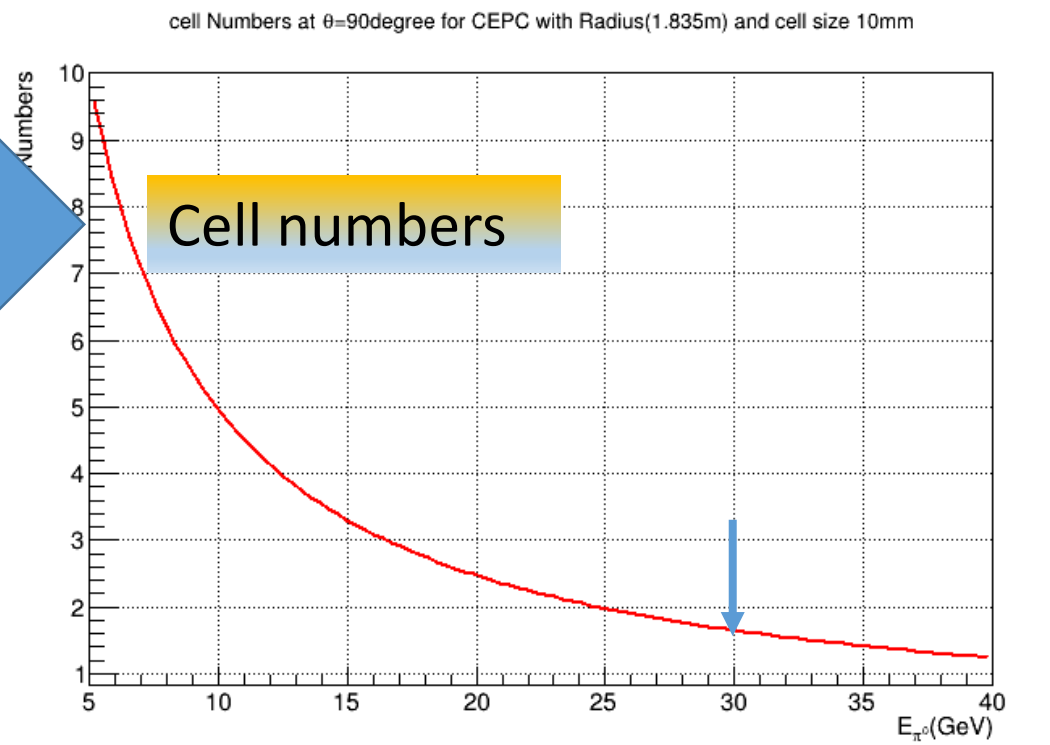
Study of the separation performance of two γ from 30GeV π^0 decay

Separation performance of 2γ from the π^0 decay in qualitative analysis

- Convert the θ_{min} into the cell numbers at θ=90° for CEPC with Radius(1.835m) and the cell size 10mm.
- One crystal has the maximum angle~0.31224° at θ=90° in barrel.



θ_{min}

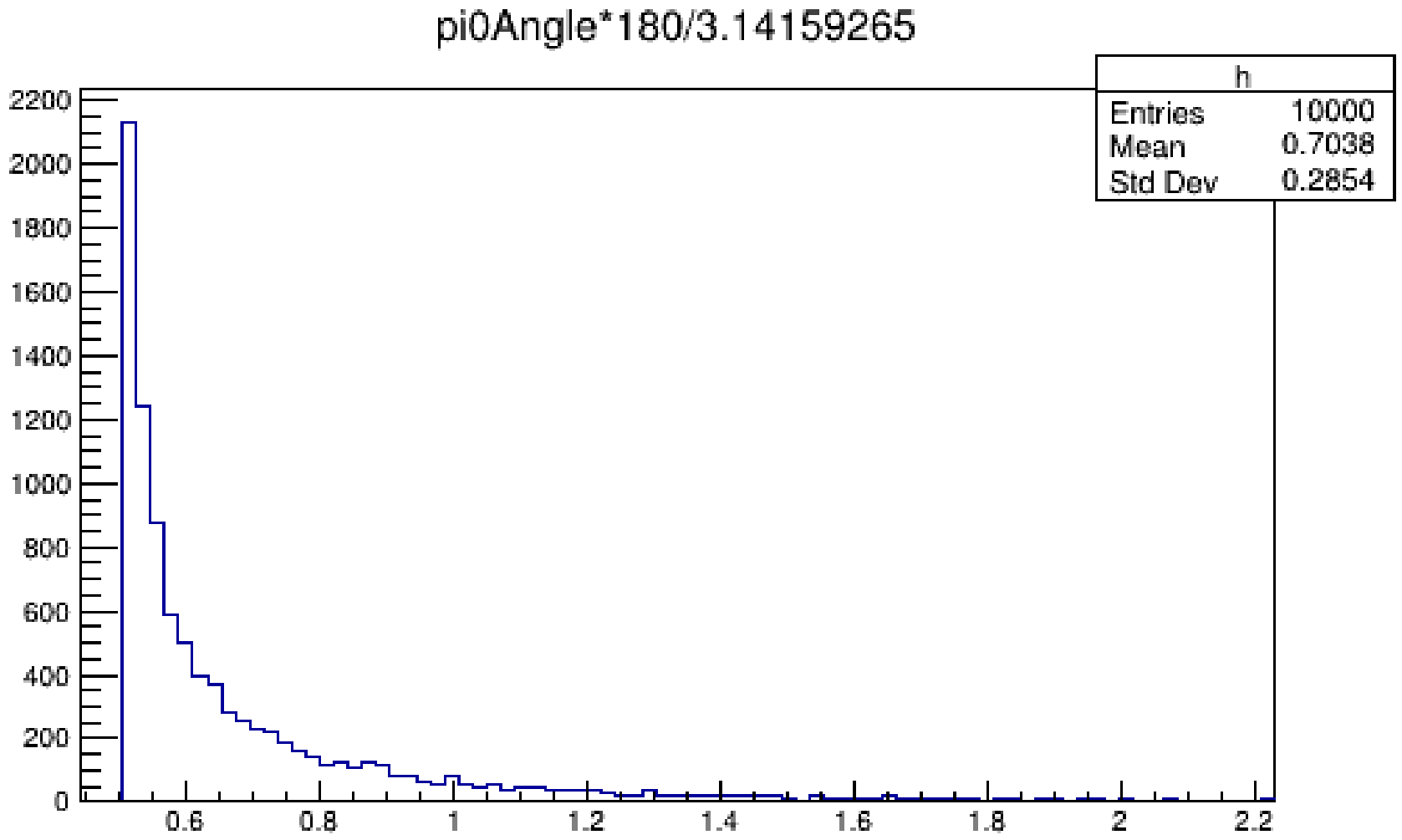


Cell numbers

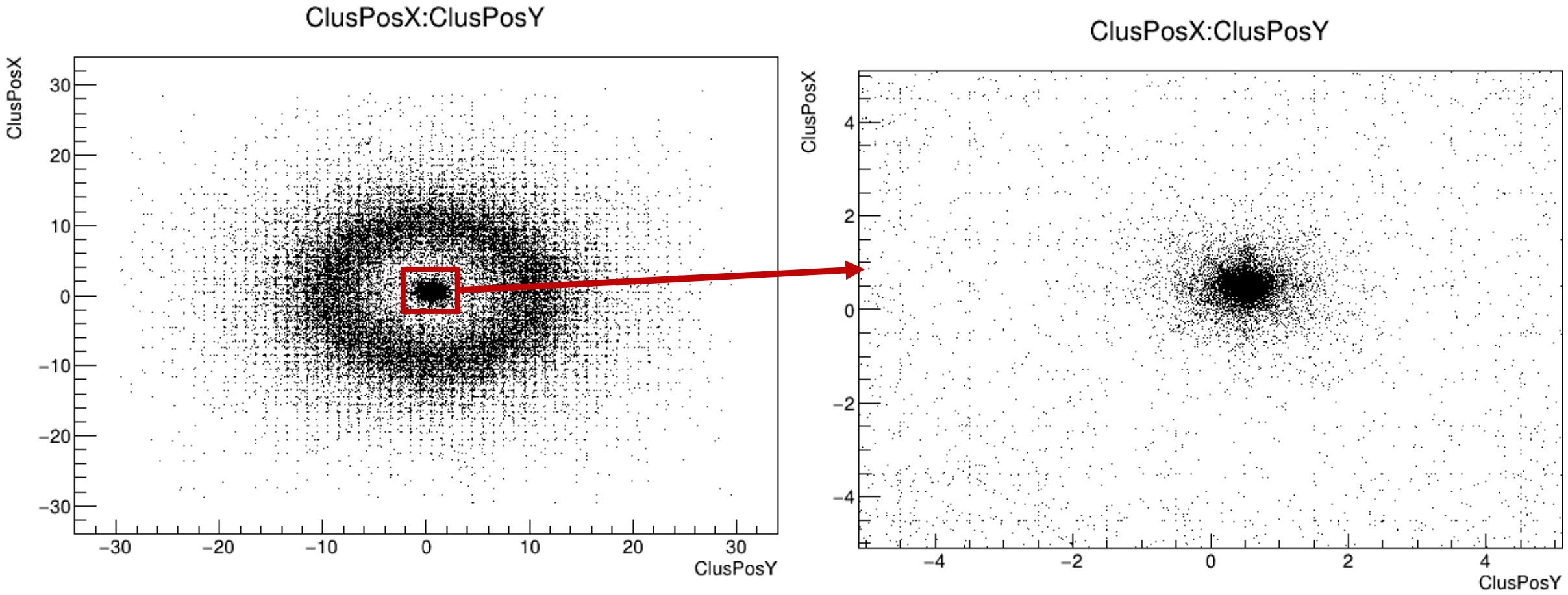
θ_{min} versus π^0 momentum

Cell numbers versus π^0 momentum

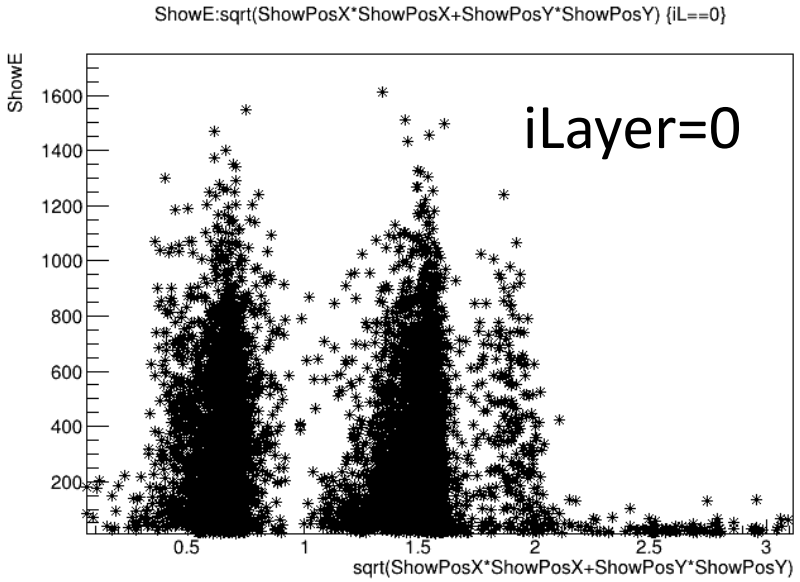
Angle of 2 gammas from 30GeV Pi0 decay

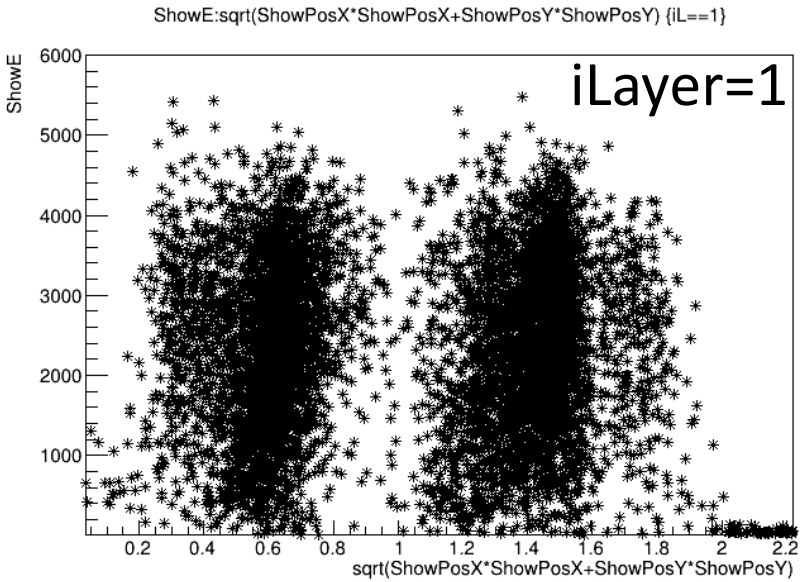


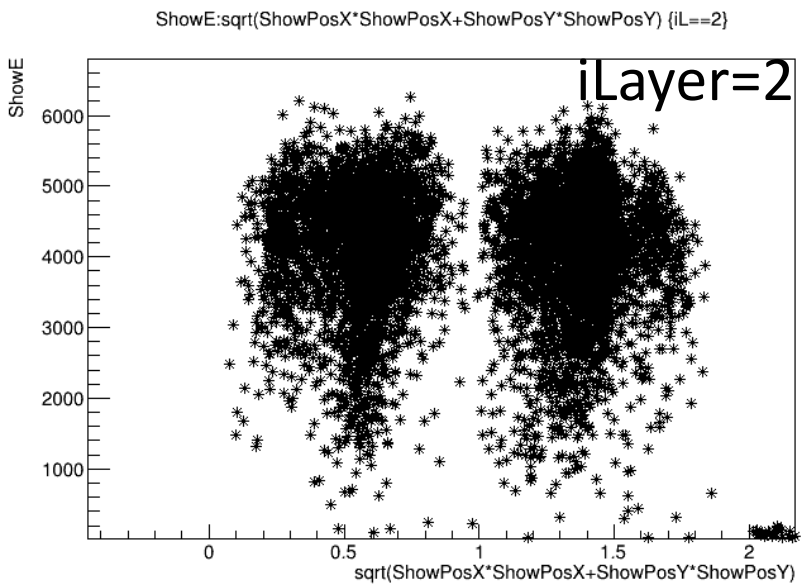
Select the events with the angle of 2γ in the 0.513°-0.515° range

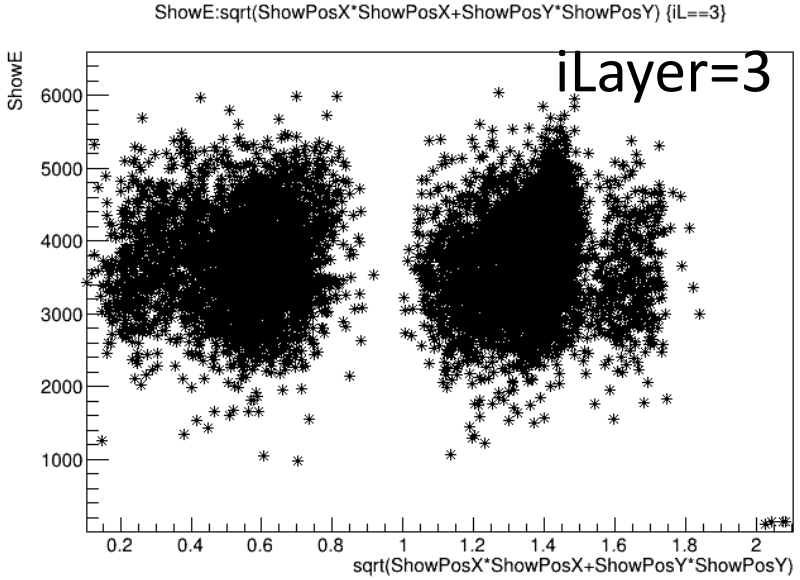


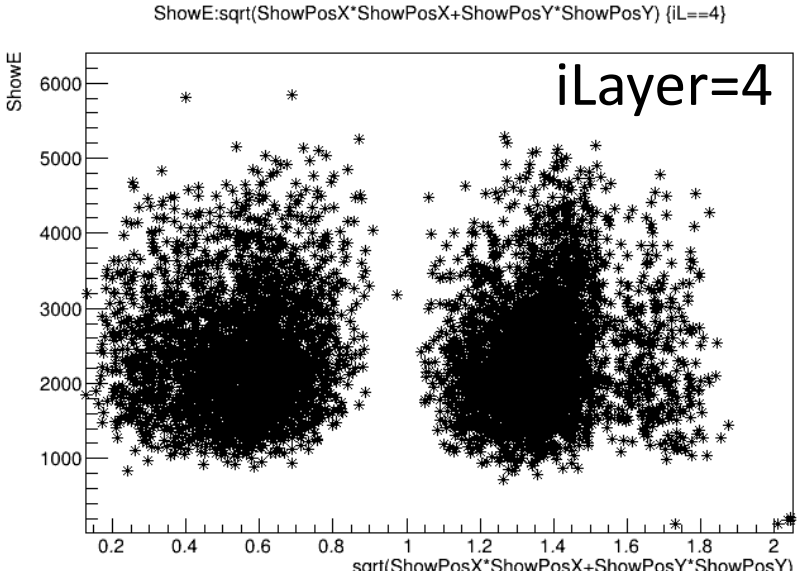
ShowE3x3 versus ShowRxy of the shower from the largest energy cluster splitting



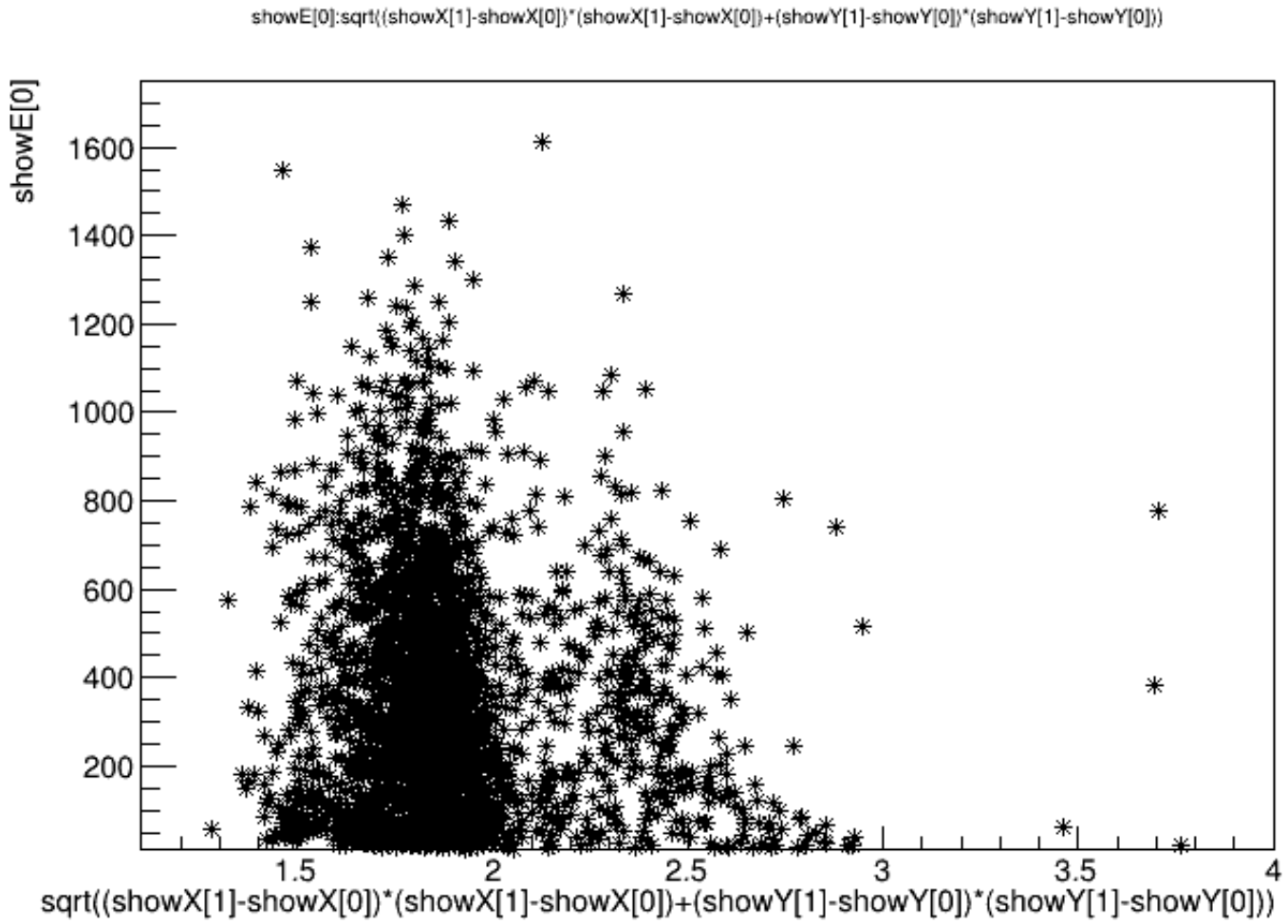








There are 2 showers in Rxy<2.5 range. Shower energy versus Mod(Pos0-Pos1)

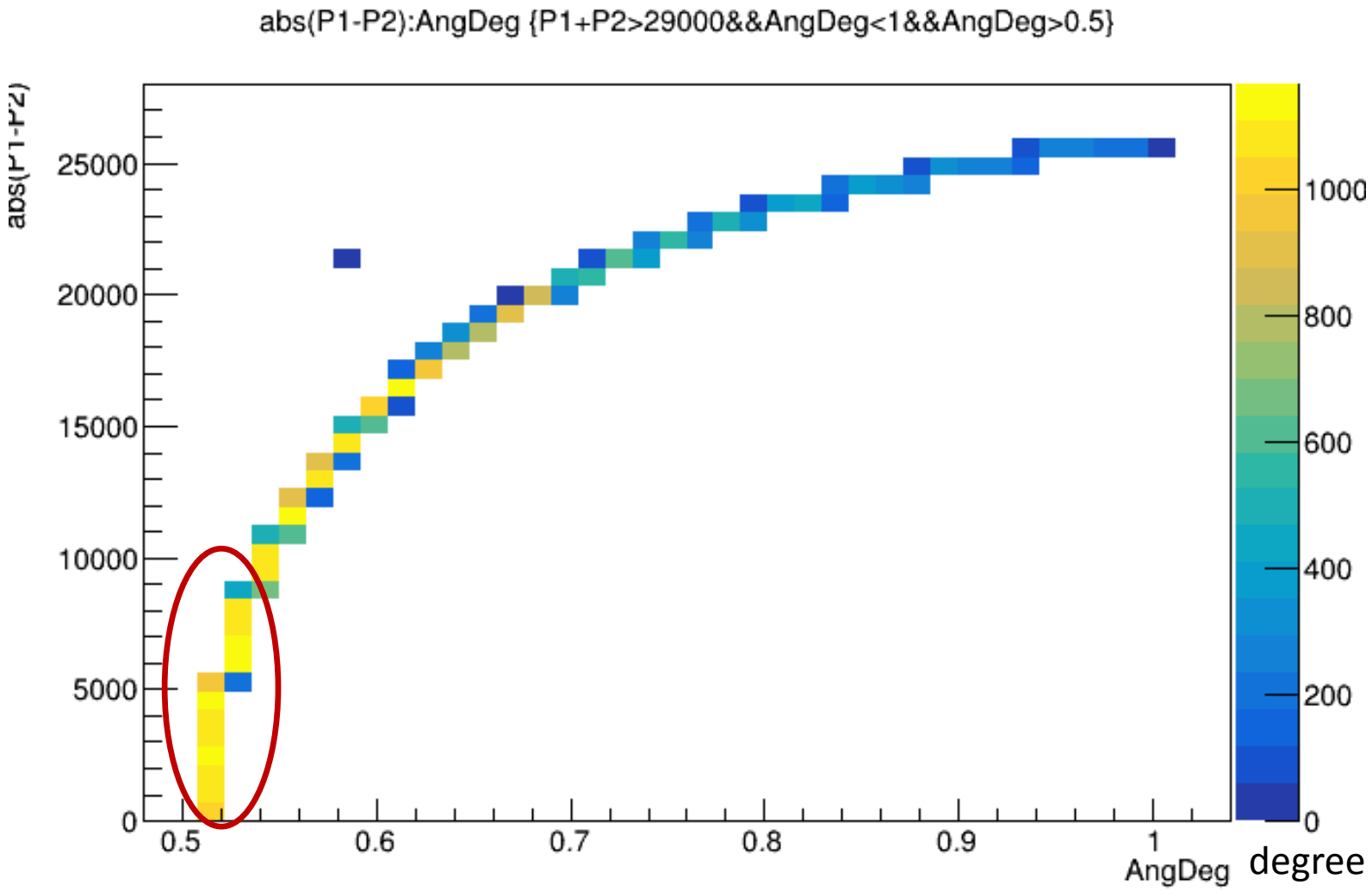


The distance between two showers is >1cm.
So we can see the two isolate gamma.

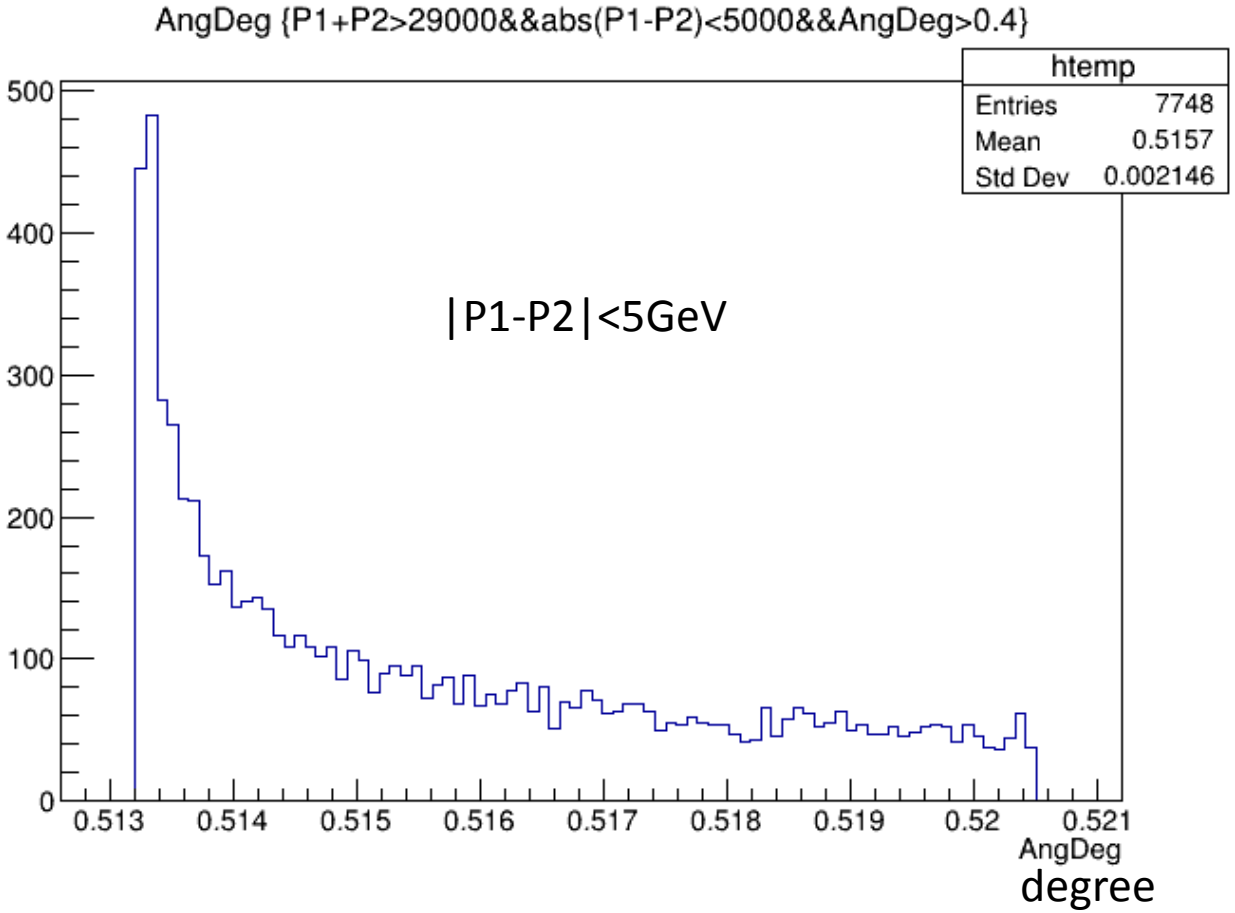
Shower reconstruction for each layer

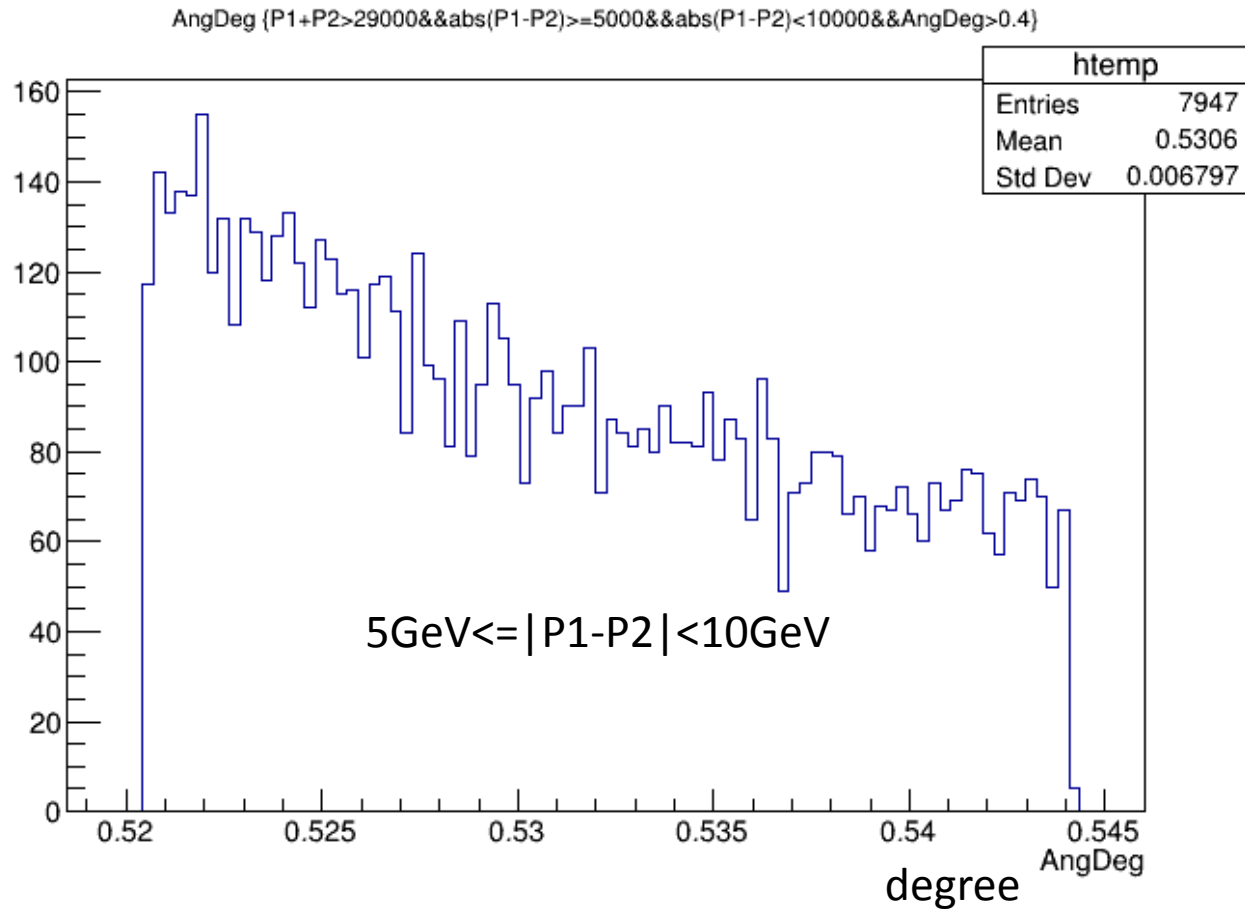
- Study the separation performance of two photon from π^0 decay by using the showers in the first layer (3cm depth)
- if Nshower>1, firstly find the seed with the maximum energy and then find the nearest shower to it, and calculate their distance(in unit of cell number).
- If the minimum distance minDis>=2, the two γ's can be separated.

|P1-P2|(MeV) vs. Angle(degree) of 2 γ's from 30GeV π^0 decay



Angle distribution of two γ with |P1-P2|<5GeV and 5GeV<=|P1-P2|<10GeV





Separation performance of 30GeV π^0

- Select the following pi0 event with:
  - ✓ The energy sum of two γ : P1+P2>29GeV,
  - ✓ |P1-P2|<5GeV, it is directly related with the angle of two γ
  - ✓ minDis is the minimum distance of the maximum energy shower and the other shower

|P1-P2|	Nshower>1	Nshower=1
<5GeV (0.5132-0.5206Degree)	90.4% (88.3% minDis=2)	9.6%
[5,10)GeV (0.5206-0.544Degree)	79.1%(78.6% minDis=2)	20.9%
	distinguishable	indistinguishable

From the following table, we can see that the separation performance of two γ from 30GeV π^0 decay is about 80-90%

Summary

- Construct the matrix module with 60x60x60cm^3 by Geant4
- Complete the cluster/shower reconstruction of each layer
- Give some preliminary study results
  - Study the correction of the longitudinal energy leakage, the energy resolution can be improved by ~20%
  - Study the separation performance of 2γ from 30Gev π^0 decay is about 80-90%
  - This is only a preliminary result, and a tentative research.
  - Need to further study

Something that needs to be studied in detail

- How to set the threshold of the hit, seed and cluster energy?
- How to split a cell energy in the cluster splitting? The cluster splitting in each layer should be different from the crystal ECAL without longitudinal layers.
- The match of cluster/shower each layer
  - ➢give the reconstruction of the energy deposited of a track
  - ➢Reconstruct the 2γ from π^0 decay, and reconstruction π^0
- ……..

Thank you!

backup

- clustPos=0.477604 0.519215
- clustEnergy=98861.6
- seed Energy=54226.8 30 30
- seed Energy=33.1851 28 23
- seed Energy=19.8042 37 26
- seed Energy=17.6524 26 40
- seed Energy=17.1744 32 22
- seed Energy=17.1328 33 39
- seed Energy=16.802 36 24
- seed Energy=14.817 25 24
- seed Energy=12.4722 19 31
- seed Energy=12.4193 38 34
- seed Energy=11.8849 23 38
- seed Energy=11.8118 38 32
- seed Energy=11.7346 22 24
- seed Energy=11.4955 19 20
- seed Energy=11.3723 22 36
- seed Energy=11.0891 30 21
- seed Energy=10.8403 21 21
- clustMapsize=1
- showerMapsize=17

0-30cm depth
$1x1cm^2$

- Hit energy threshold 1MeV
- Seed energy threshold 10MeV
- Cluster energy threshold 25MeV
- For the case of $1x1cm^2$, there are more seeds than the case of $2x2cm^2$.
- It will increase the difficulty of the reconstruction that there are many seeds in a cluster .

- clustPos=0.72671 0.769649
- clustEnergy=99030.5
- seed Energy=65428.2 15 15
- seed Energy=25.7649 13 20
- seed Energy=13.1846 10 10
- seed Energy=10.0269 17 24
- clustMapsize=1
- showerMapsize=4

0-30cm depth
$2x2cm^2$

- clustPos=-0.719511 -0.332572
- clustEnergy=515.369
- seed Energy=23.7056 27 28
- seed Energy=22.3388 30 33
- seed Energy=17.501 25 27
- seed Energy=15.4631 30 29
- seed Energy=10.9566 27 34
- seed Energy=10.7088 27 22
- clustMapsize=1
- showerMapsize=6

30-60cm depth
$1x1cm^2$

clustPos=0.107784 0.0837499
clustEnergy=602.476
seed Energy=39.7544 14 14
seed Energy=15.6516 13 11
seed Energy=13.1234 15 11
clustMapsize=1
showerMapsize=3

30-60cm depth
$2x2cm^2$

Specific contents of MC study

- The mission of ECAL CEPC is the measurements of the energy, location and time of electromagnetic shower.
- Precision γ/e measurements enhance physics discovery potential in HEP experiments.
- Performance of crystal calorimeter in γ/e measurements is well understood:
  - The best possible energy and position resolutions;
  - Good γ/e identification and reconstruction efficiency.

Crystal Size optimization by studying the following contents:

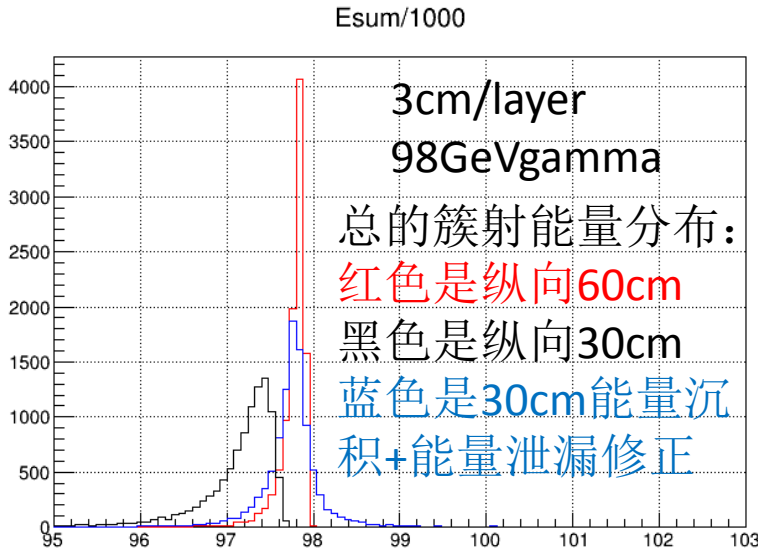
1. The measurement of energy and time
2. γ Energy resolution versus γ energy
3. The ability to identify the showers(Separation performance of two γ from high energy pi0 decay)
4. K_L measurement
5. Energy leakage at the backend of crystal ECAL

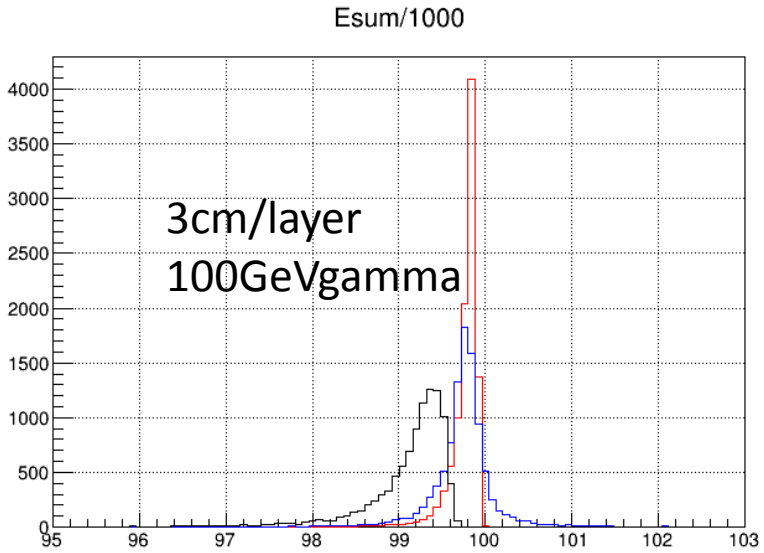
Give some distribution such as

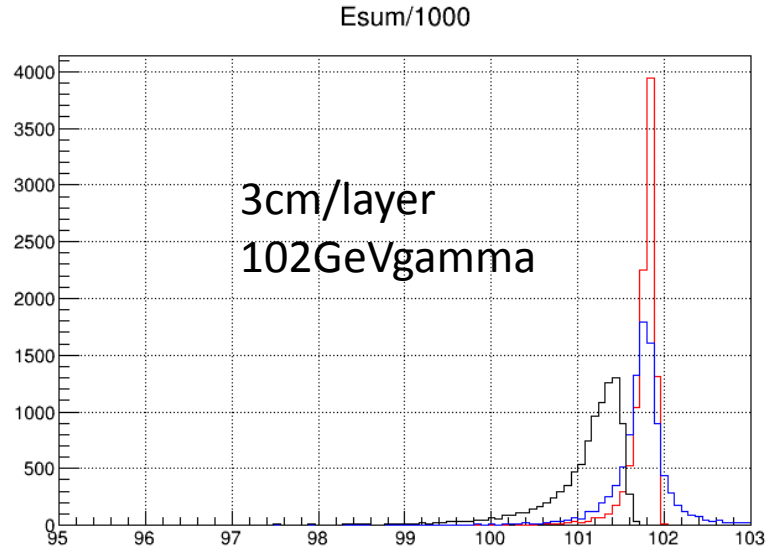
- Energy distribution with the first 30 layers and all 60 layers
- Shower longitudinal profile (EM interaction)
- Shower Transverse profile with second Moment
- The minimum angle of 2γ from pi0 decay varies with pi0energy. And estimate the 2γ separation performance

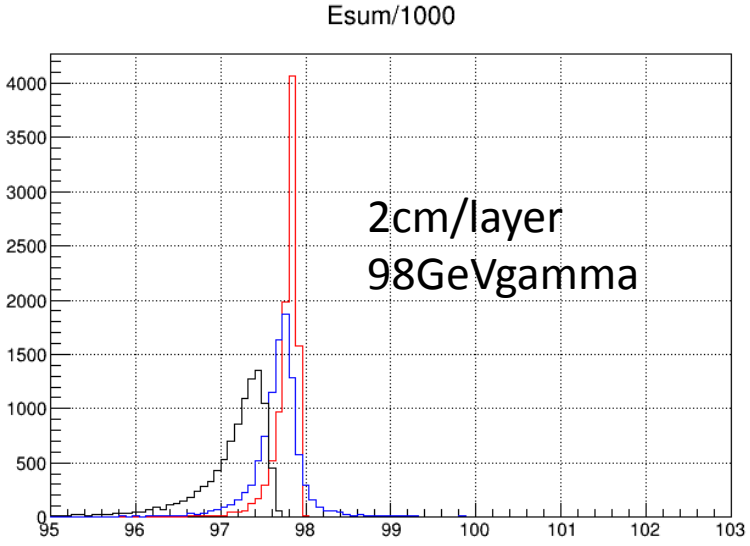
Shower Energy distribution

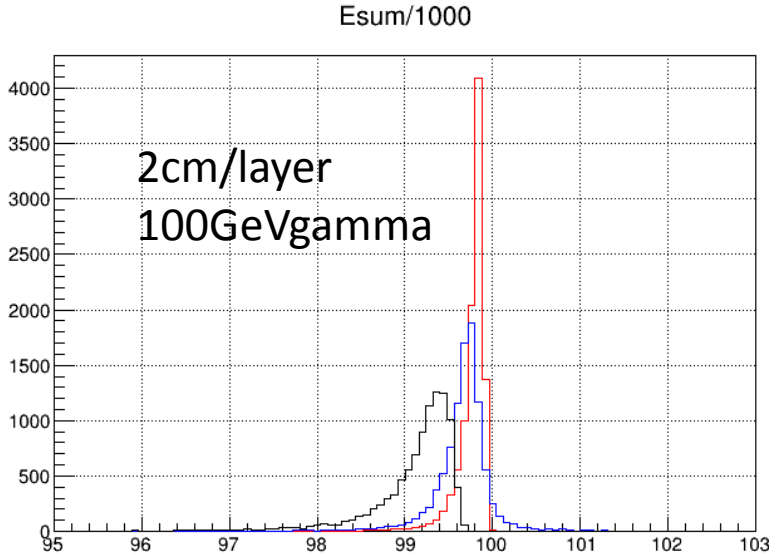
Red-Energy(60cm/60layers) Black-Energy(30cm) Blue - Energy(30cm)+Ecorr

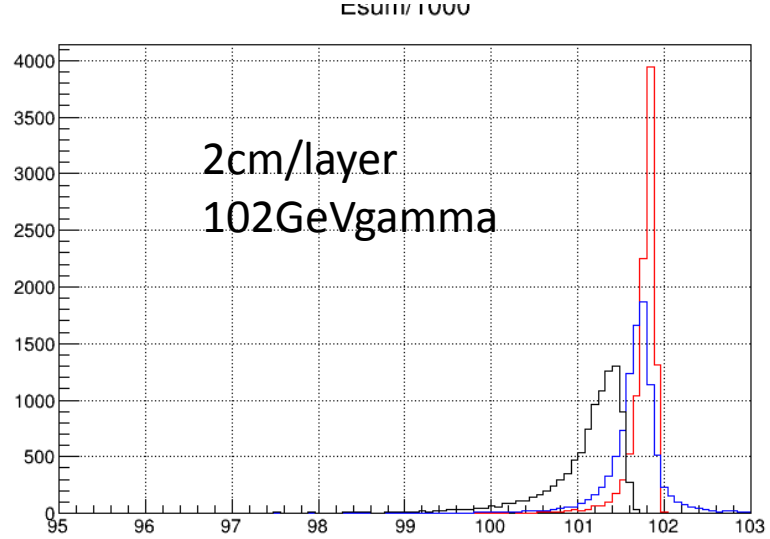












The energy resolutions are improved after the correction of the energy leakage at the end of BGO crystal