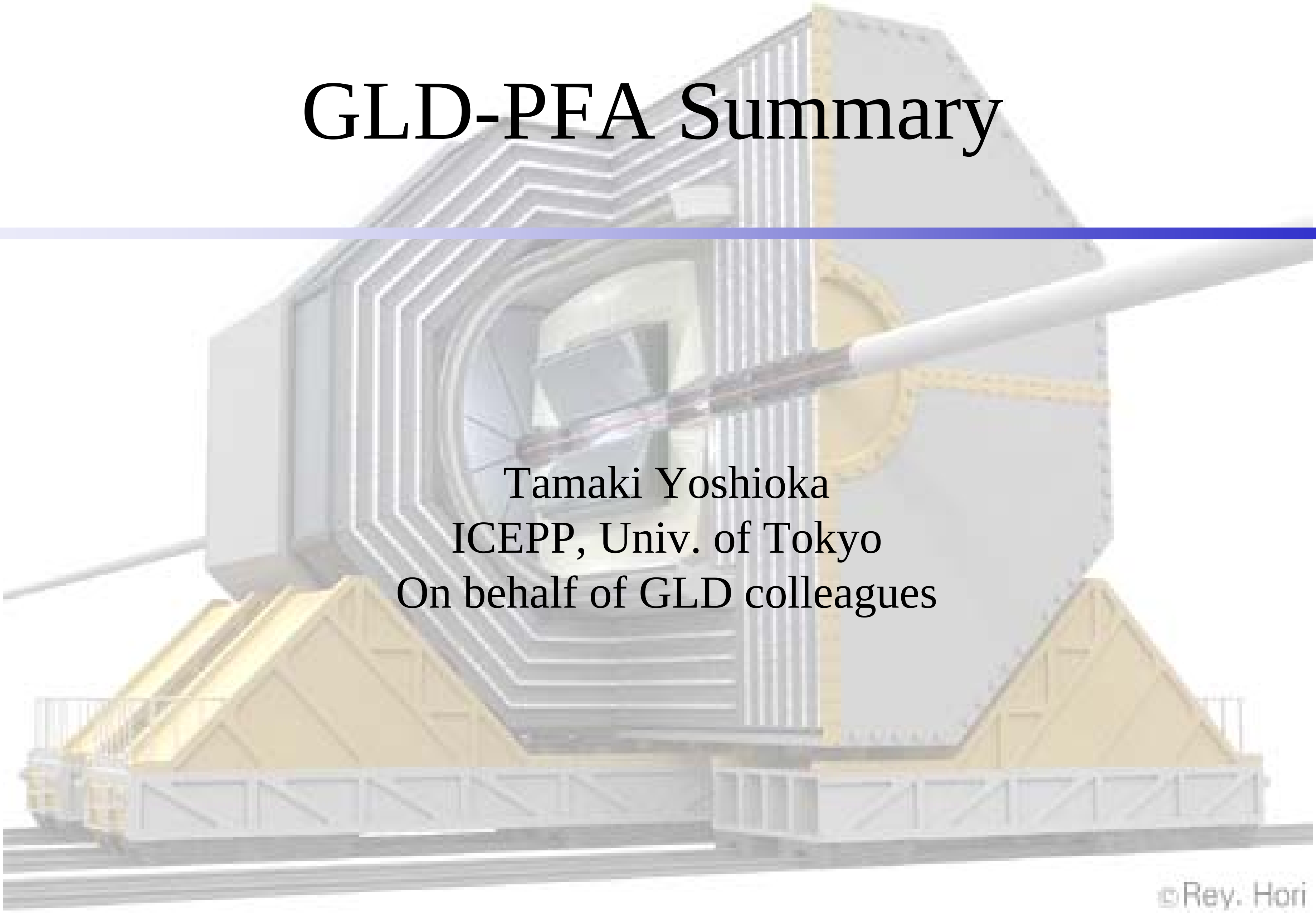


GLD-PFA Summary

Tamaki Yoshioka
ICEPP, Univ. of Tokyo
On behalf of GLD colleagues

PFA Related Talks@Snowmass

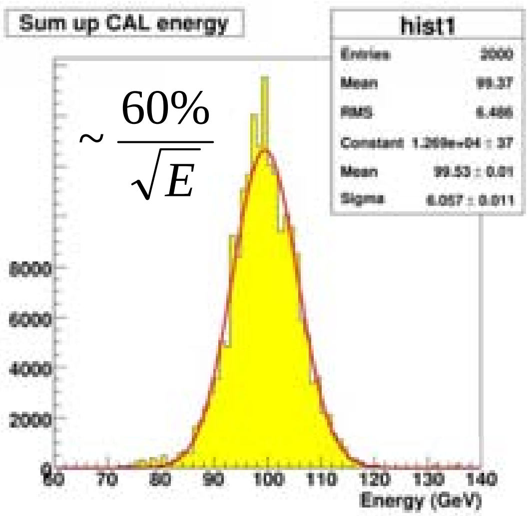
- Particle Flow Algorithm for GLD
  T.Yoshioka
  PFA plenary session on 8/22/2005
  GLD, LDC, SiD joint session on 8/24/2005

- Gamma Finding Procedure for GLD Detector
  T.Fujikawa
  PFA parallel session on 8/22/2005
  GLD, LDC, SiD joint session on 8/24/2005

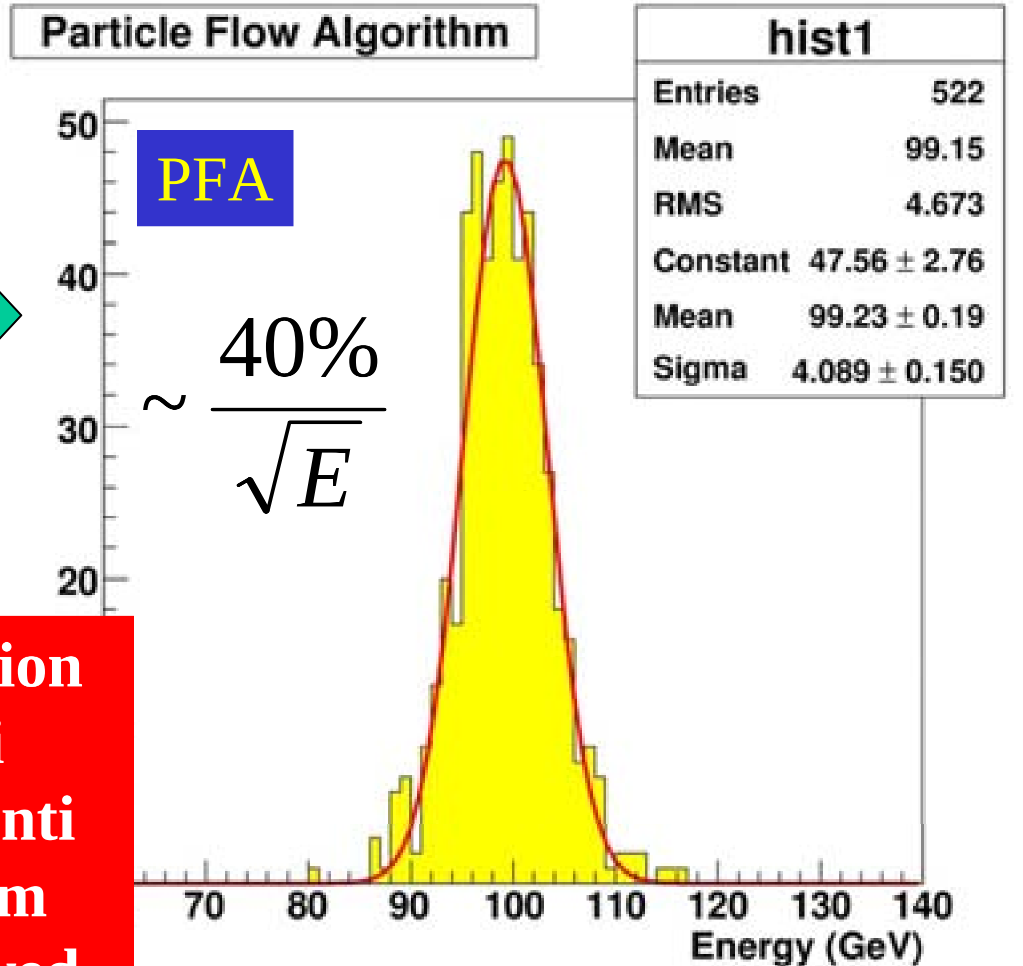
- Calibration Factor
  J.Chang, PFA parallel session on 8/22/2005

Current Status

CAL Energy Sum



$\sim \frac{60\%}{\sqrt{E}}$



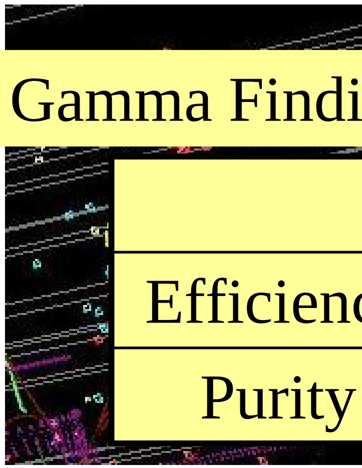
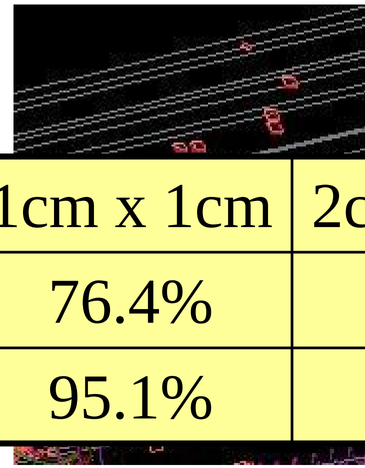
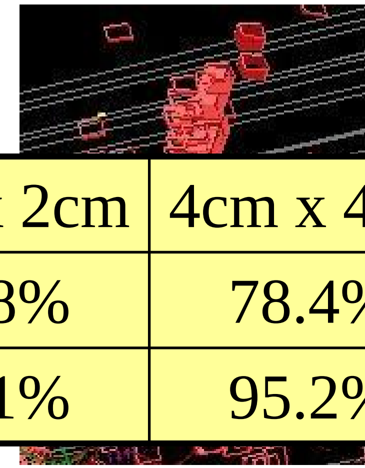
PFA

$\sim \frac{40\%}{\sqrt{E}}$

With reasonable segmentation
ECAL 4cm x 4cm Pb/Scinti
HCAL 12cm x 12cm Pb/Scinti
And simple/robust algorithm
→ ~40% resolution is achieved.

Granularity Study

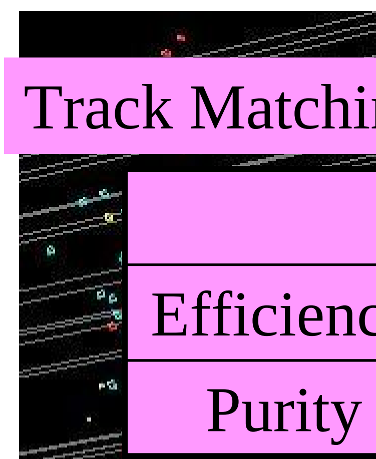
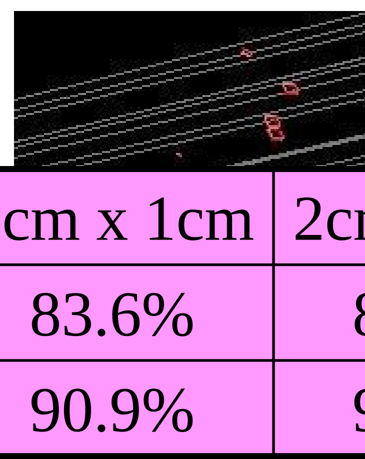
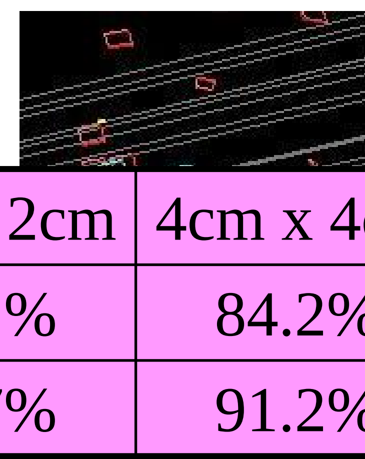
1cm x 1cm | 2cm x 2cm | 4cm x 4cm

before

Gamma Finding

	1cm x 1cm	2cm x 2cm	4cm x 4cm
Efficiency	76.4%	78.8%	78.4%
Purity	95.1%	95.1%	95.2%

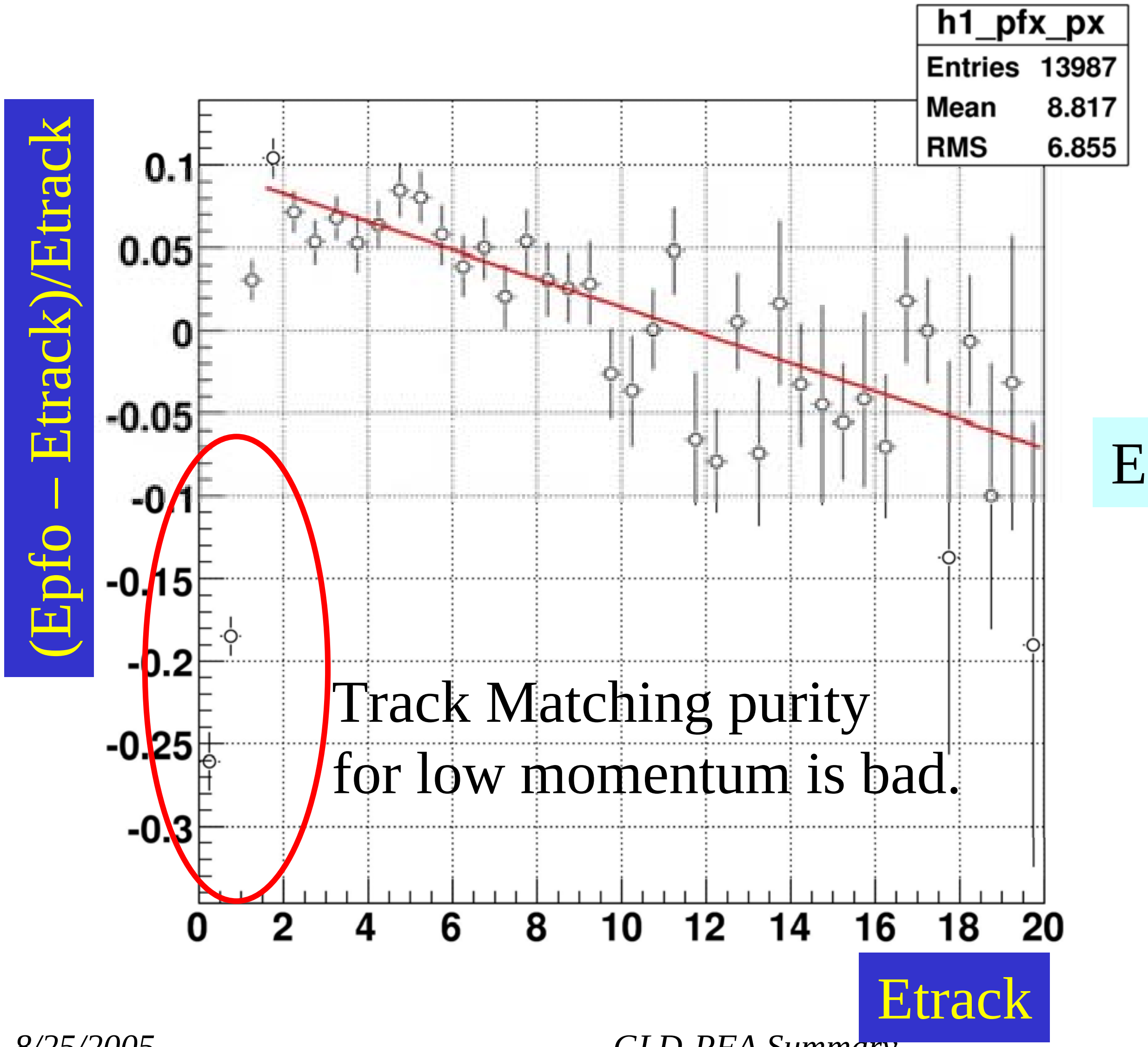




after

Track Matching

	1cm x 1cm	2cm x 2cm	4cm x 4cm
Efficiency	83.6%	84.1%	84.2%
Purity	90.9%	91.7%	91.2%

Track Matching Performance



ECAL : 4cm x 4cm

Plans

- Worse resolution for CAL sum energy.
  → Need to obtain energy dependent calibration factor.

- Granularity study.
  → Might be used another algorithm (pattern recognition etc.) for finer segmentation.
  → Try different tile size at higher energy.

- Bad track matching purity for low momentum track.

- Material study.
- MIP finder.
- Neutral hadron finder.
- …

Summary

Gamma Finding Procedure for GLD Detector
T.Fujikawa
PFA parallel session on 8/22/2005
GLD, LDC, SiD joint session on 8/24/2005

- **We got ~78% efficiency and ~95% purity using the nearest track distance requirement + longitudinal shower profile search.**

- **Current gamma finding method has low purity at low energy region.**

- **Need modification for our current small clustering method and/or tube size for gamma-clustering.**

Next step

Gamma Finding Procedure for GLD Detector
T.Fujikawa
PFA parallel session on 8/22/2005
GLD, LDC, SiD joint session on 8/24/2005

- **Study energy/angle dependent clustering method (change tube size depend on energy etc.) and re-consider small clustering method.**
- **Reject low momentum hadrons. (which related to low momentum track matching)**
- **Study other cell size configuration and other physics event case.**
- **Try to use H-matrix (SiD group proposal)**

Summary

- **Standalone**

  Calibration Factors are based on the best energy resolution basis for hadrons.

  E_tot = a*(E_ecal+ b*E_hcal);

  best energy resolution point

  b=0.7 (2 GeV)

  b=0.75 (3 GeV)

  b=0.8 (4 – 10 GeV)

  b=0.9 (20 – 200 GeV)

  a=(45.88 ± 0.11)*E_beam + (0.01± 0.00)

  <a=50.9 for e–>

  Deviation from linearlity: <3%

pi- **Data** $\sigma/E=(46.3 \pm 0.4)\%/\sqrt{E}+(0.1 \pm 0.1)\%$

MC $\sigma/E=(45.2 \pm 1.0)\%/\sqrt{E}+(3.7 \pm 0.2)\%$

Summary

- Jupiter

  Calibration Factors are based on the best energy resolution basis for hadrons.

  E_tot = a*(E_ecal+ b*E_hcal);

  best energy resolution point

  b=0.7 (2 GeV)

  b=0.9 (3 – 30 GeV)

  a=(20.08 ± 0.13)*E_beam + (0.07± 0.01)

  <a=25.6 for e–>

Deviation from linearlity: <6%

pi-	$\sigma/E=(38.9 \pm 1.5)\%/\sqrt{E}+(3.7\pm 0.4)\%$
KL	$\sigma/E=(38.9 \pm 1.5)\%/\sqrt{E}+(3.5\pm 0.4)\%$
Neutron	$\sigma/E=(49.2 \pm 1.6)\%/\sqrt{E}+(1.2\pm 0.5)\%$

Plan in Snowmass

- Calibrate the low energy gamma (0.1 GeV, 0.2 GeV, ... 10 GeV) in Jupiter → **Done!**
- Calibrate the charged hadrons in the low transverse momentum region (energy dependent and position dependent calibration factors)

Plans after Snowmass

- Current Geant4 version is geant4.7.0.p1 but some bugs are fixed in the geant4.7.1.
  → We need to compare the difference between them and update in Jupiter.
- SiD group said, it is no problem to use LCHadronPhysics as their Hadronic Shower Model. We better try it in the geant4.7.1 again.

Summary

- Obtain energy dependent calibration factor (first priority).

- Improve gamma finding method.
  - → Modify small clustering.
  - → Remove low momentum hadrons.
  - → Try H-Matrix method.

- Improve track matching method.
  - MIP finder.
  - Improve track matching purity for low momentum(< 1GeV). track.

- …

Backup

GLD-PFA Procedure

<u>- Procedure of the GLD-PFA</u>

1. Small Clustering and Gamma Finding
   - Collect fired cells with its neighbors.
   - Separate gamma to hadrons.
2. Cluster-Track Matching
   - Separate charged particles to neutral particles.
3. Assuming the remaining hits be neutral hadrons.

Flow to make PFObject

Gamma Finding

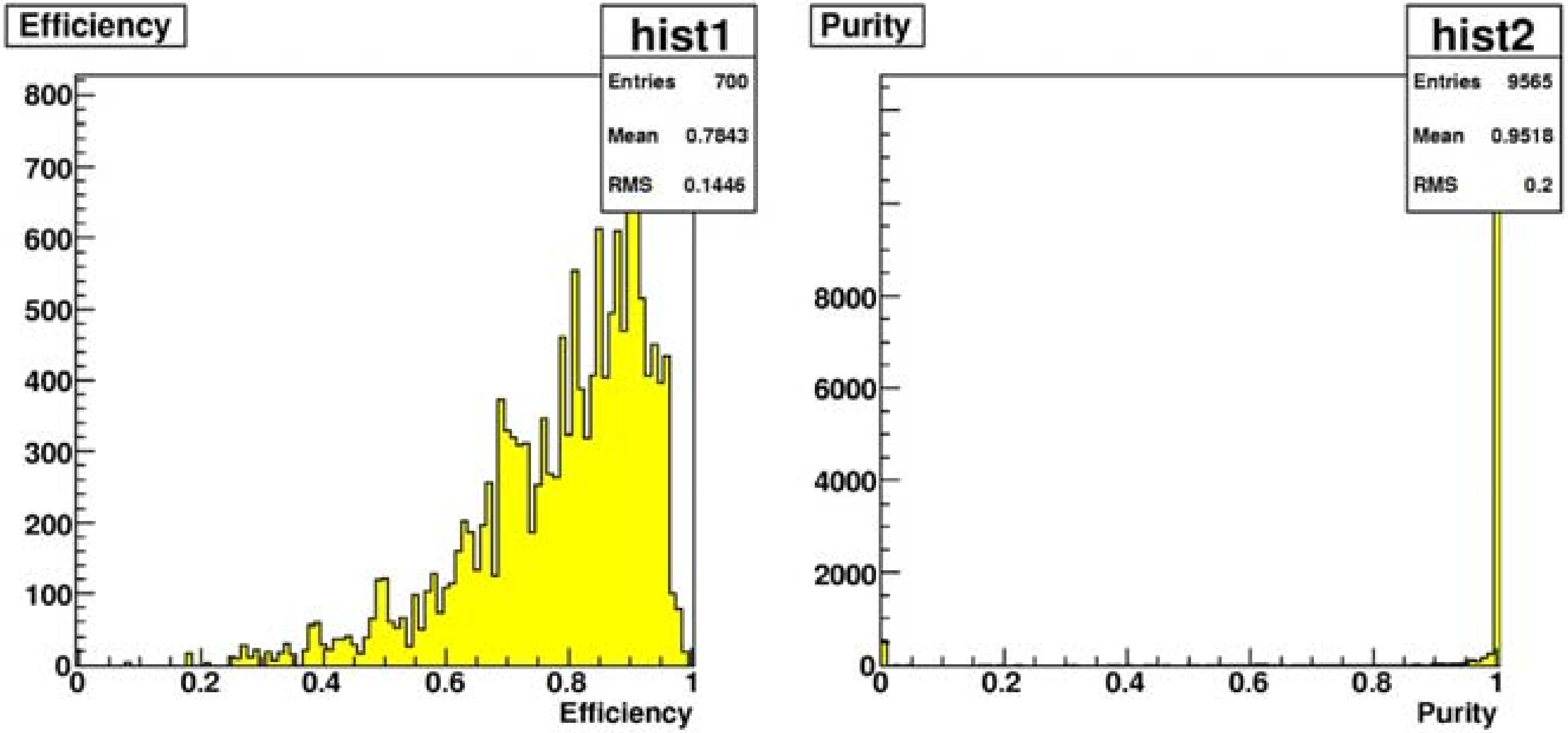
- Procedure of Gamma Finding

1. Find “large” small cluster within ECAL region (called mother “small cluster”.
2. Apply “distance from the nearest track” cut for the mother small cluster.
3. Apply “Gamma-Fitter” cut for mother small cluster.

* Details of the Gamma Finding method will be explained by T. Fujikawa at today’s afternoon session.

Energy Weighted Efficiency/Purity

- Efficiency/Purity of Track Matching is checked by cheating method.

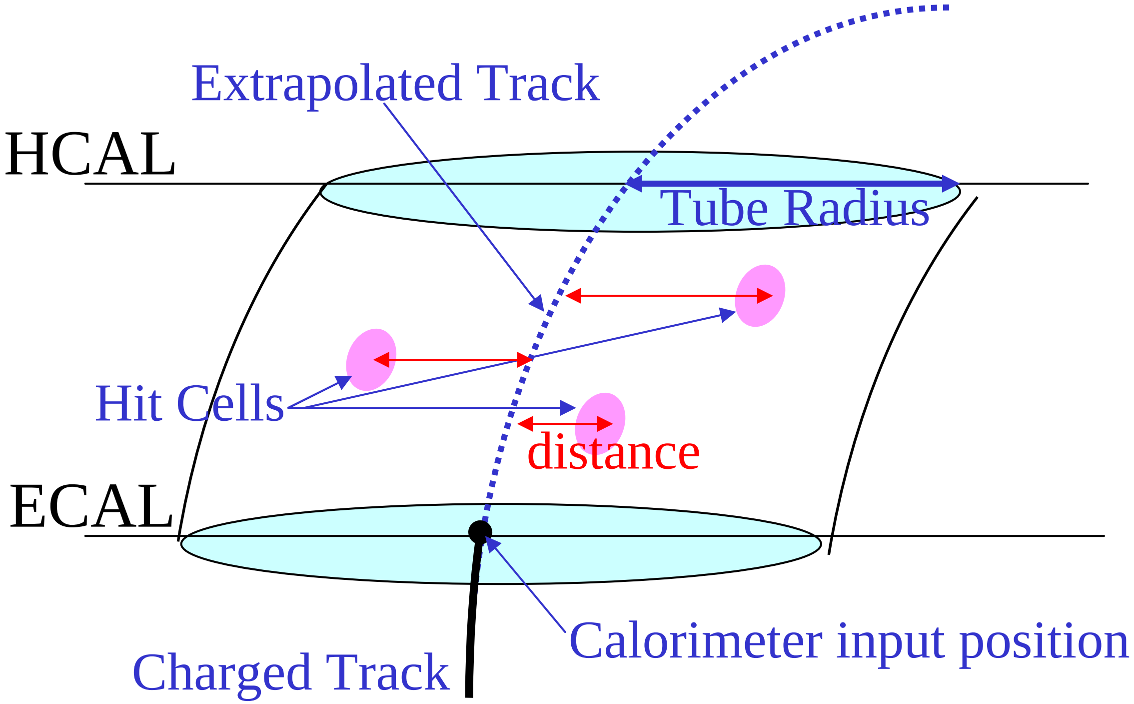


Efficiency : 78.4%

Purity : 95.2%

Track Matching Procedure

- ***Basic Concept*** :
  Extrapolate the charged track and calculate a distance between a calorimeter hit cell and the extrapolated track. Connect the cell that in a certain tube radius (clustering).

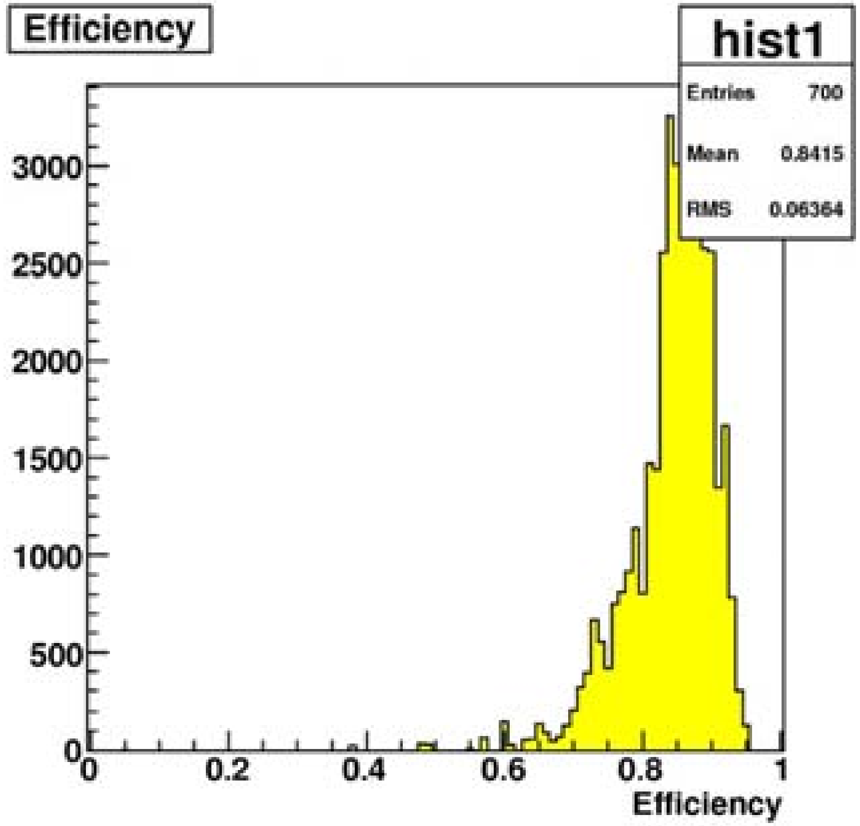


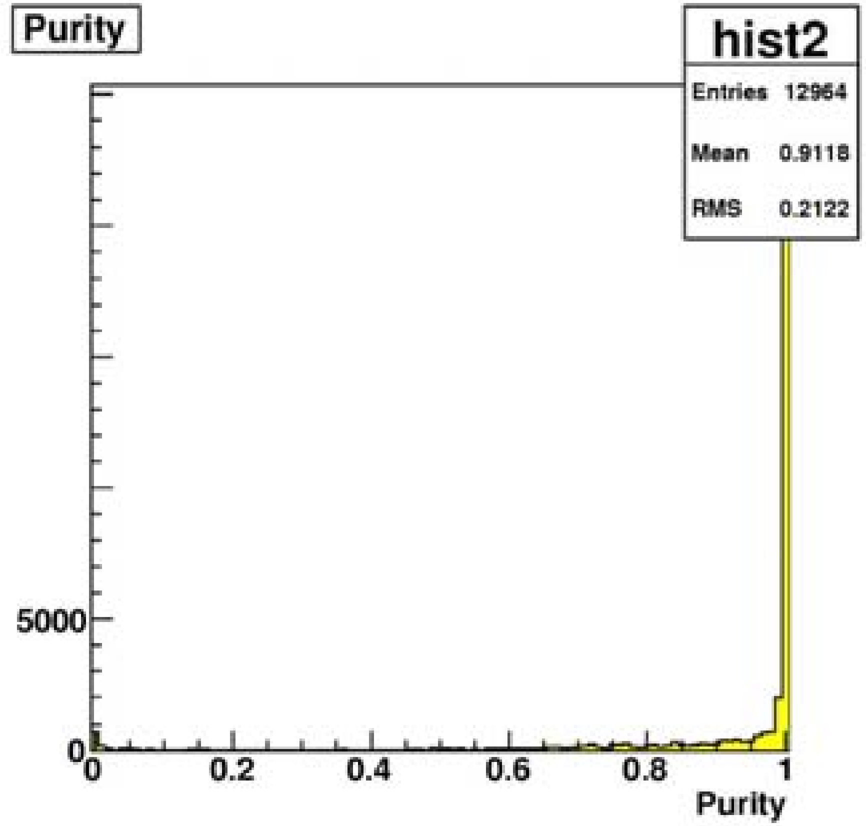
- Calculate the distance for any track/calorimeter cell combination.

- Tube radius for ECAL and HCAL can be changed separately.

Energy Weighted Efficiency/Purity

- Efficiency/Purity of Track Matching is checked by cheating method.



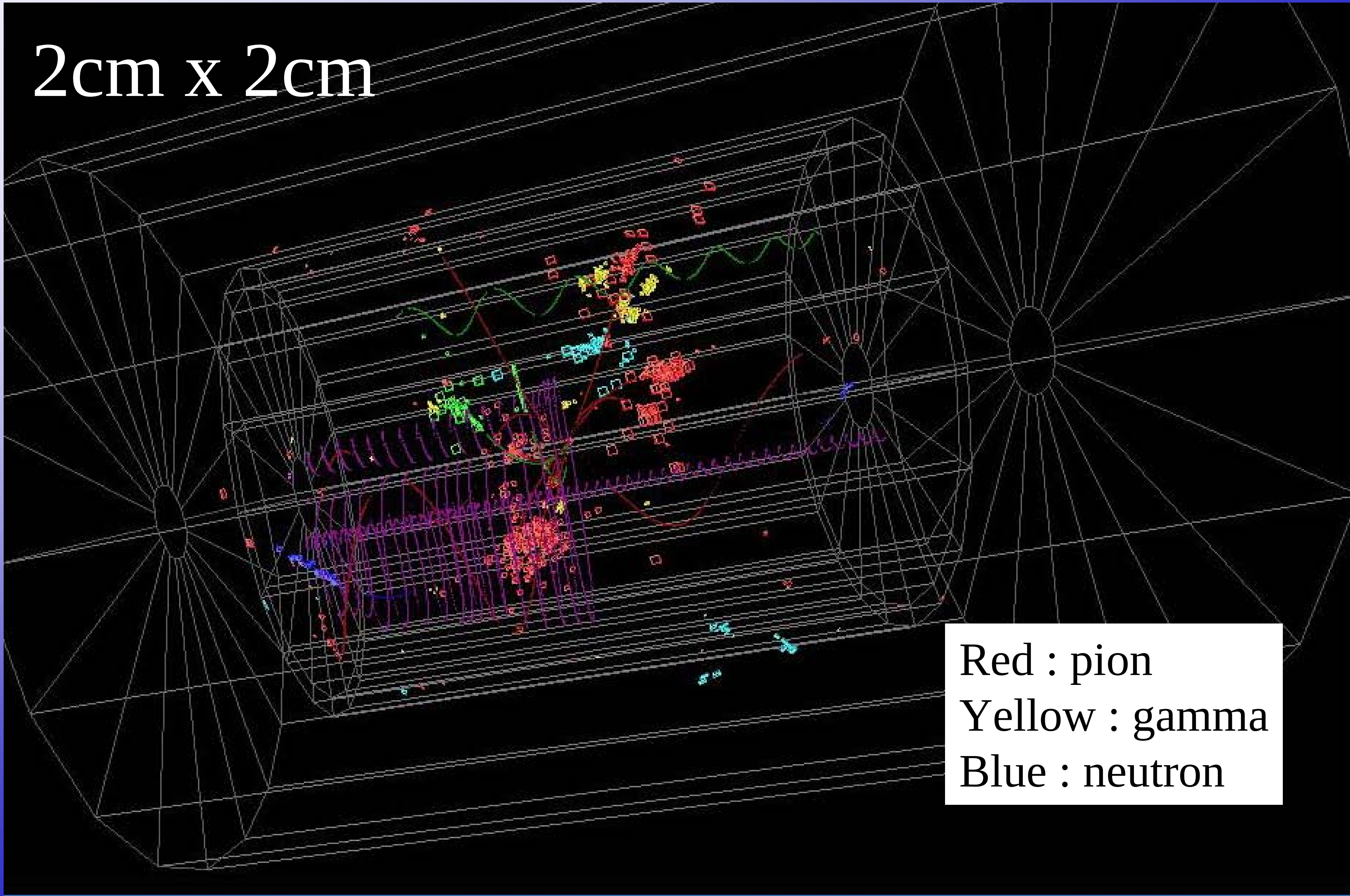


Efficiency : 84.2%

Purity : 91.2%

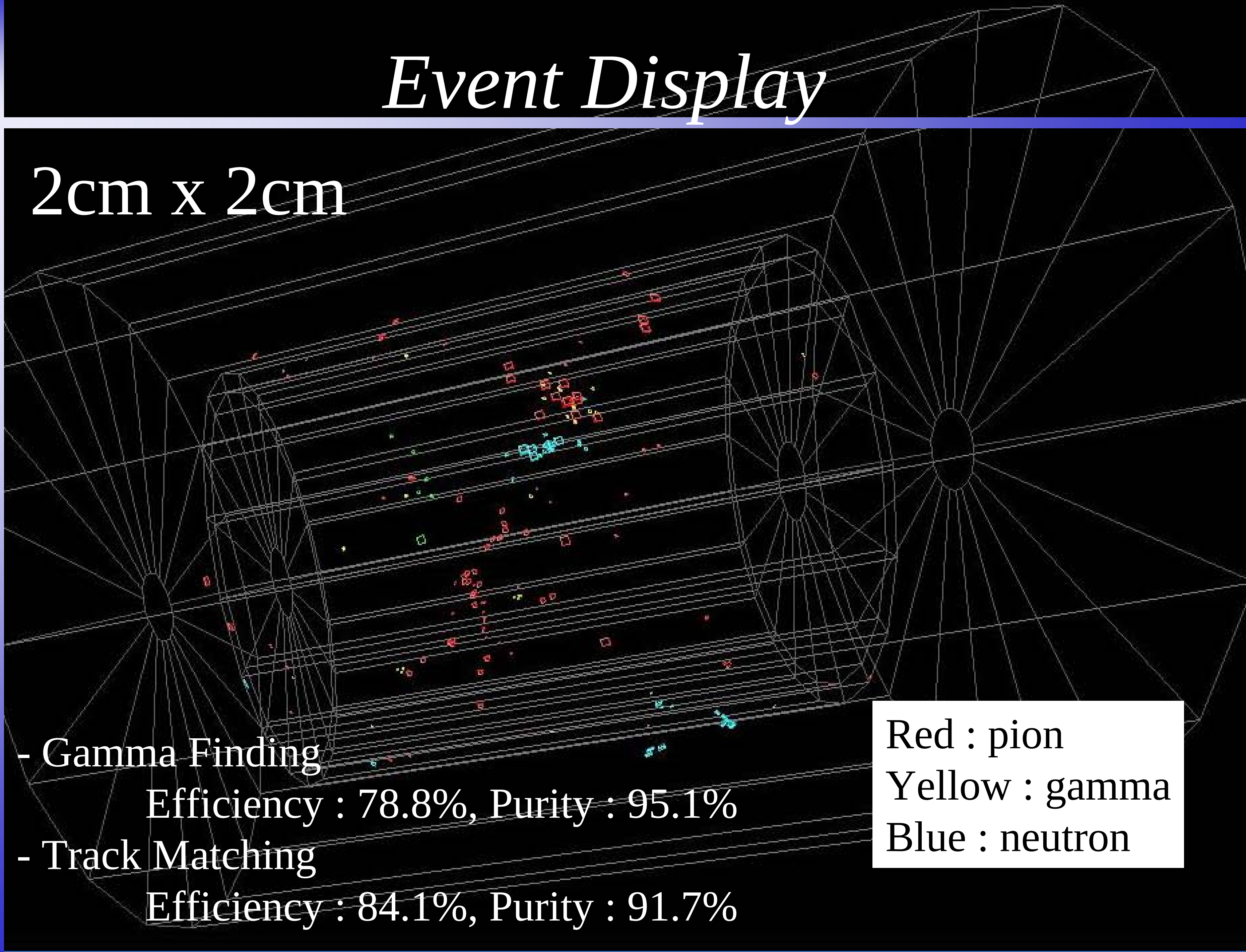
Event Display

2cm x 2cm



Event Display

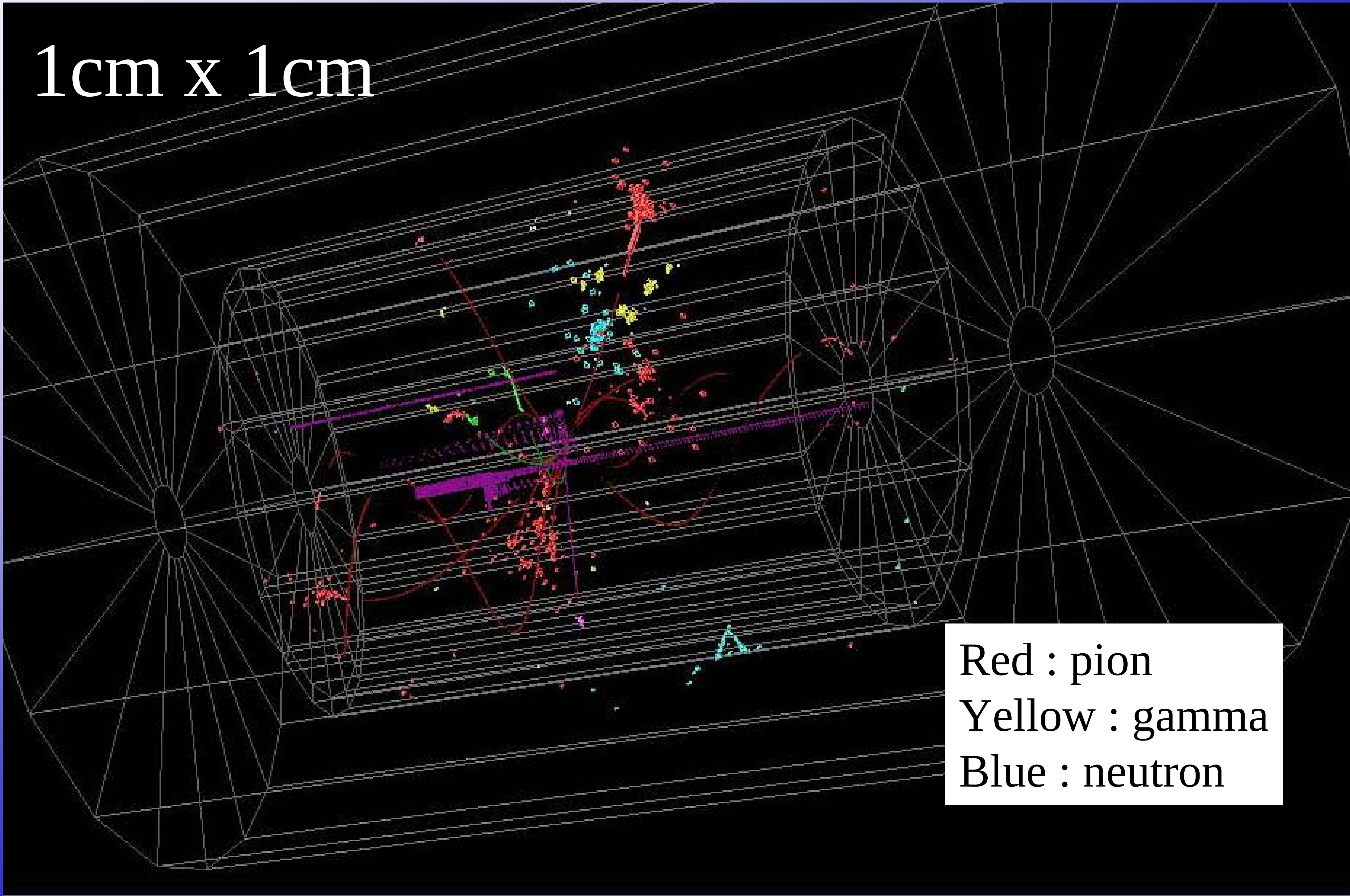
2cm x 2cm



- Gamma Finding
  Efficiency : 78.8%, Purity : 95.1%
- Track Matching
  Efficiency : 84.1%, Purity : 91.7%

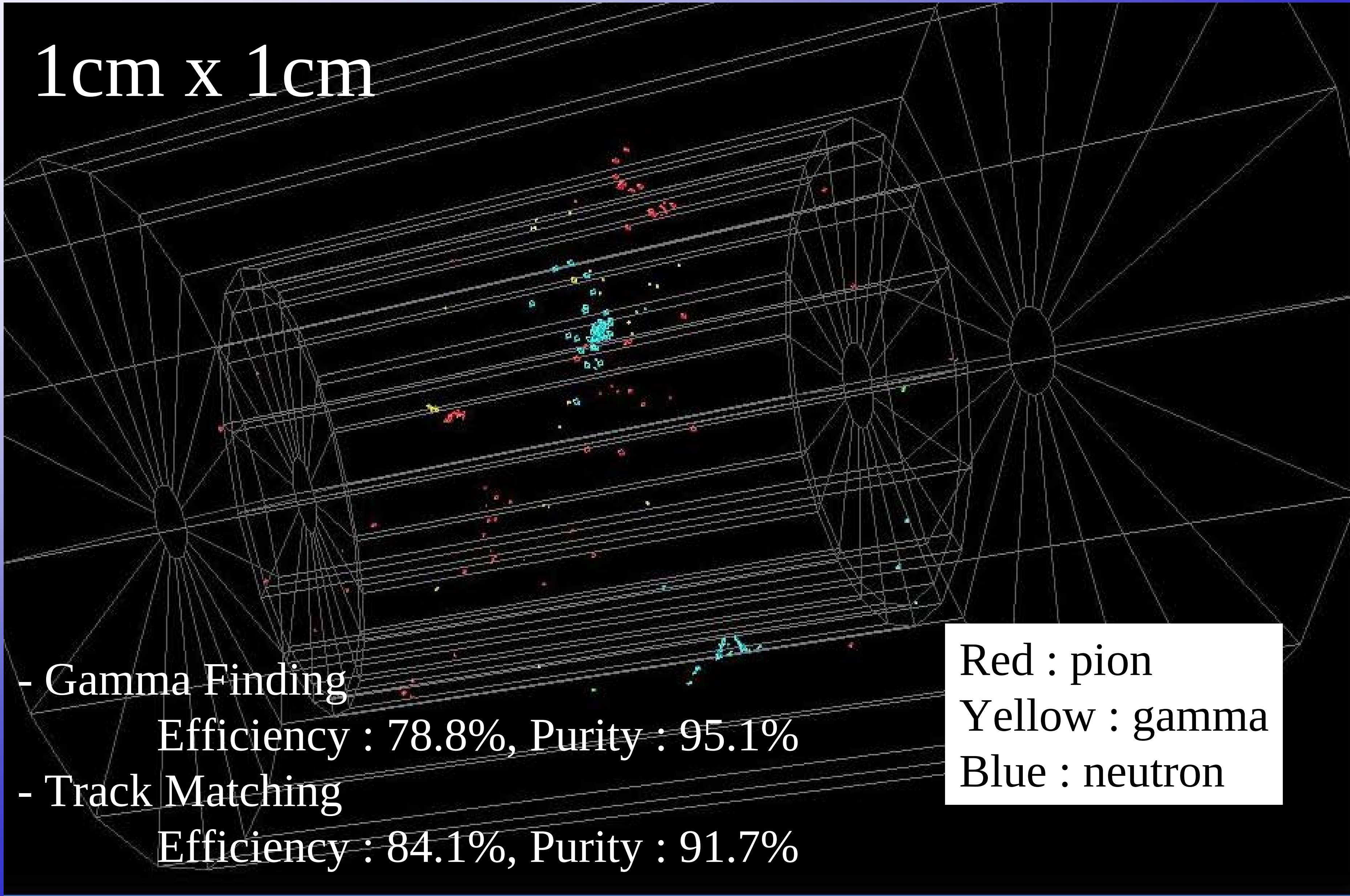
Red : pion
Yellow : gamma
Blue : neutron

Event Display



Event Display

1cm x 1cm

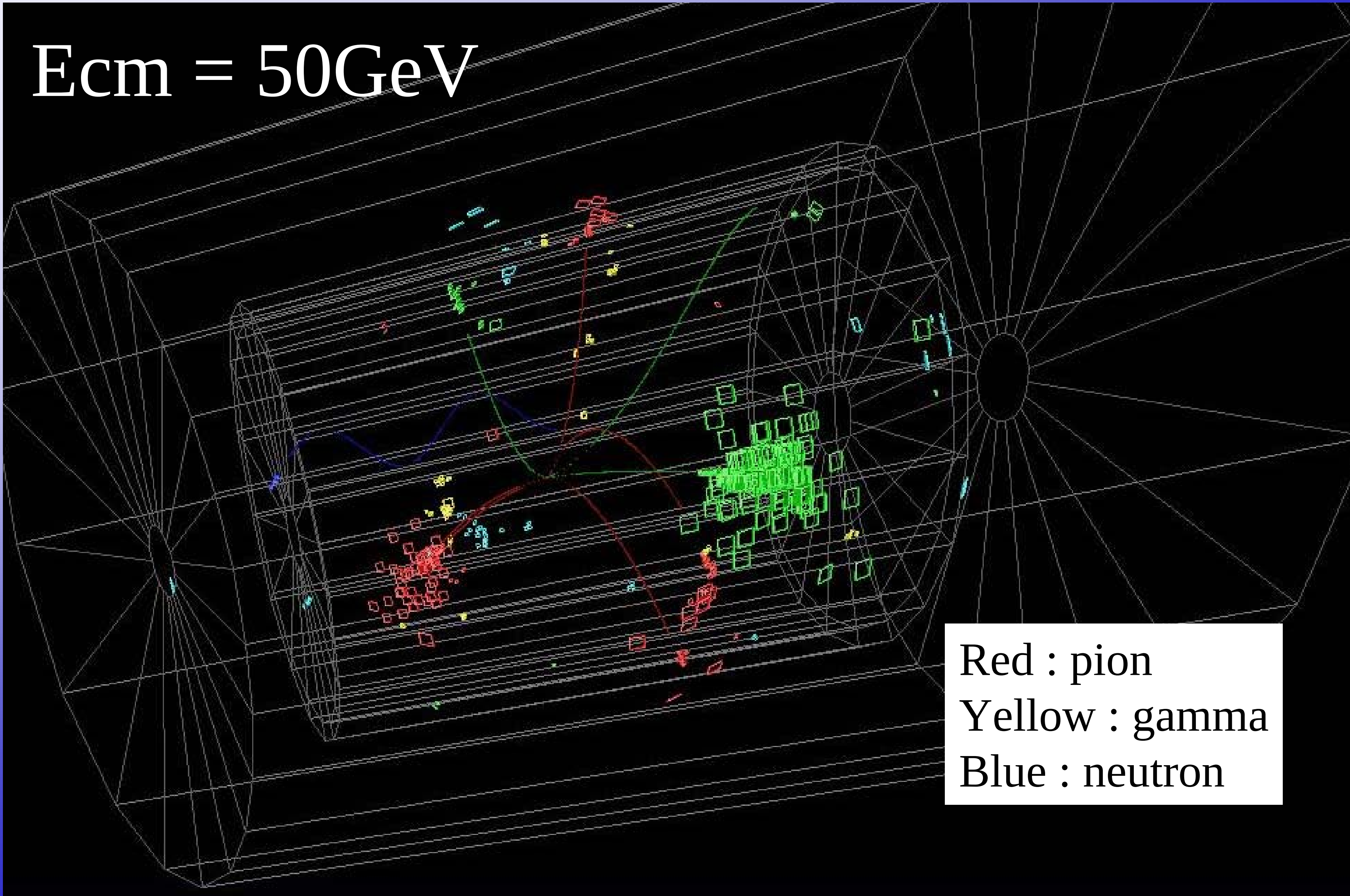


Red : pion
Yellow : gamma
Blue : neutron

- Gamma Finding
  Efficiency : 78.8%, Purity : 95.1%
- Track Matching
  Efficiency : 84.1%, Purity : 91.7%

Event Display

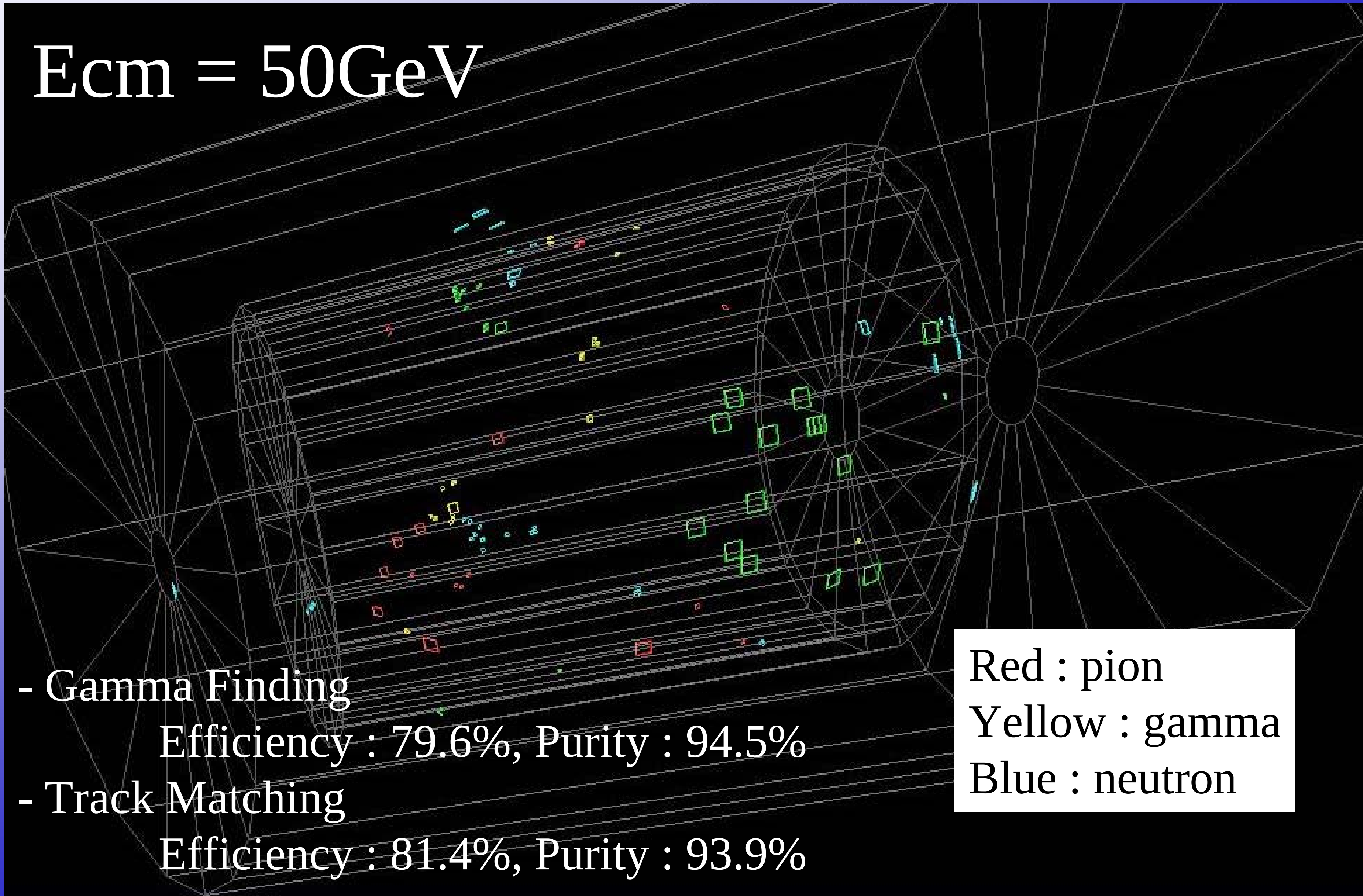
Ecm = 50GeV



Red : pion
Yellow : gamma
Blue : neutron

Event Display

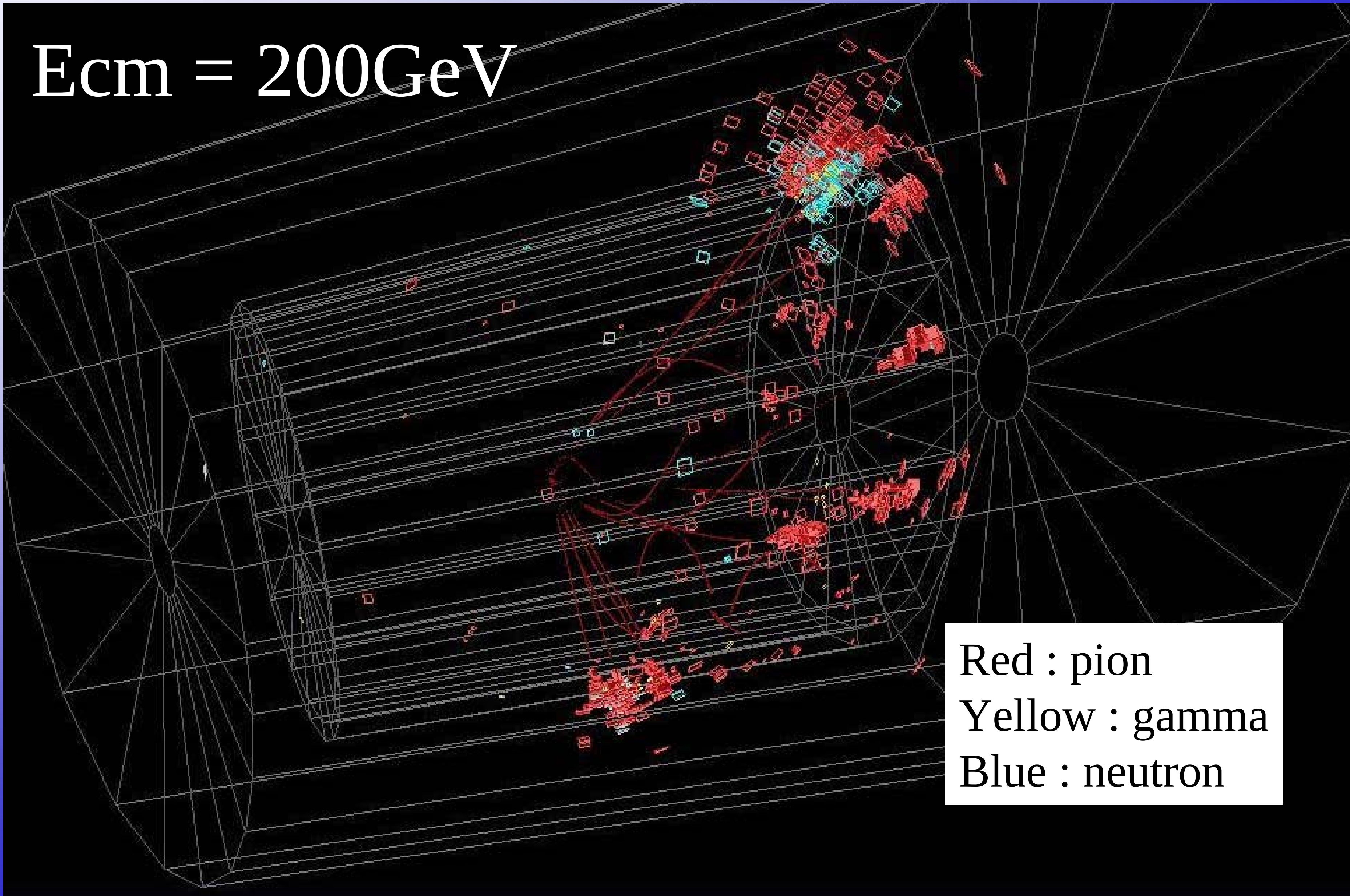
Ecm = 50GeV



- Gamma Finding
  Efficiency : 79.6%, Purity : 94.5%
- Track Matching
  Efficiency : 81.4%, Purity : 93.9%

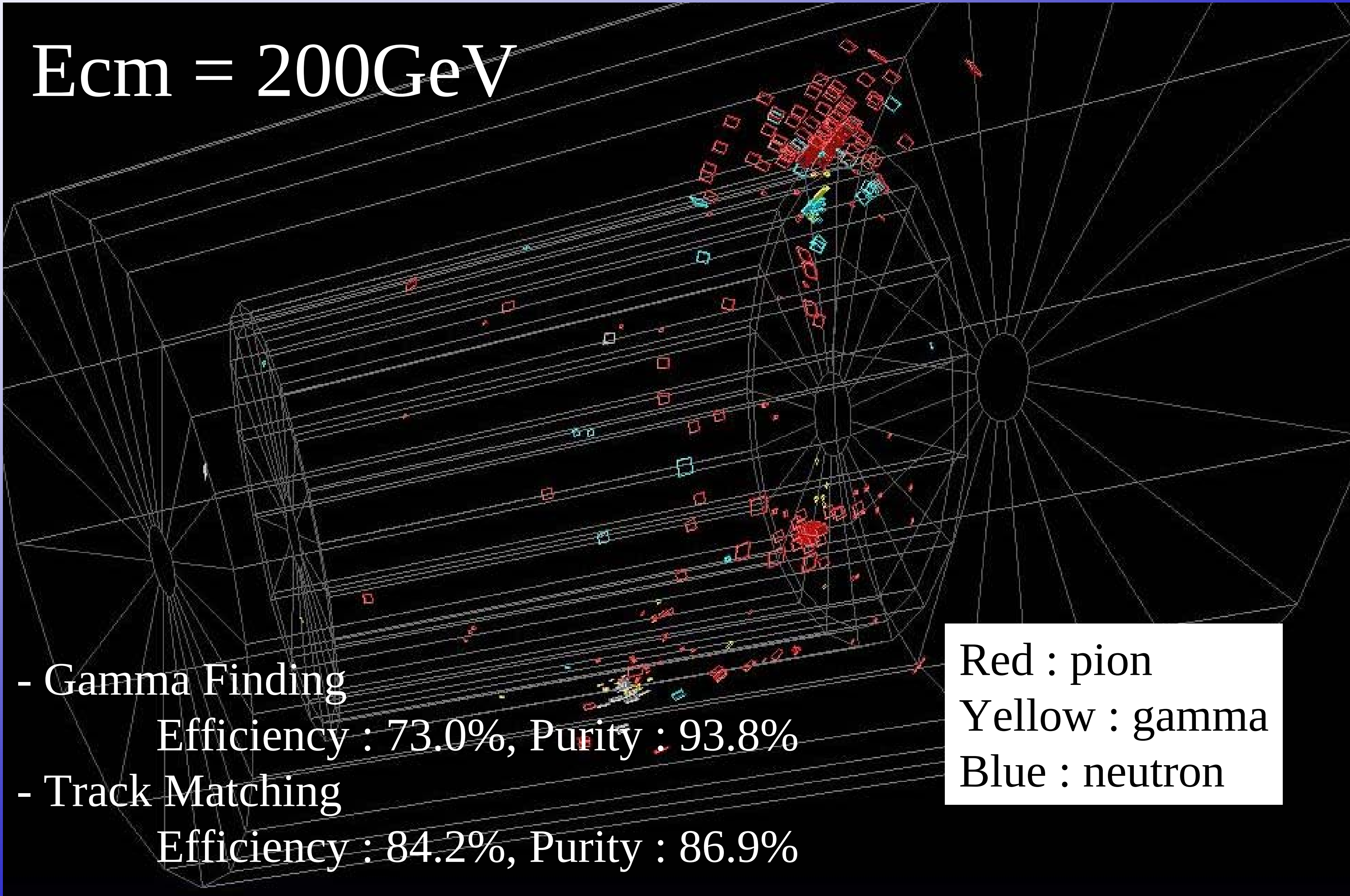
Event Display

Ecm = 200GeV



Event Display

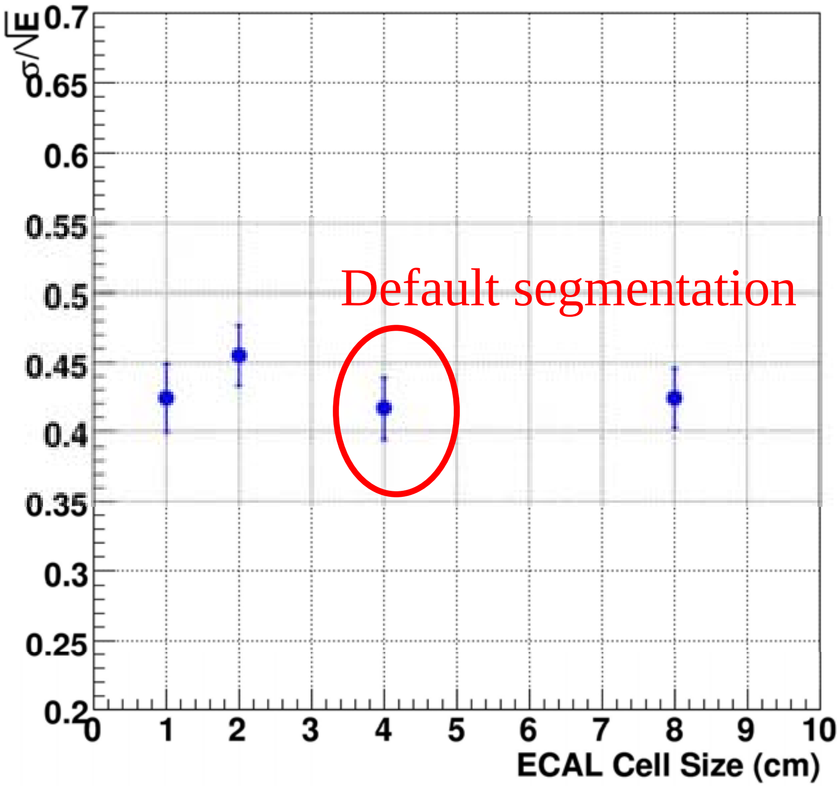
Ecm = 200GeV



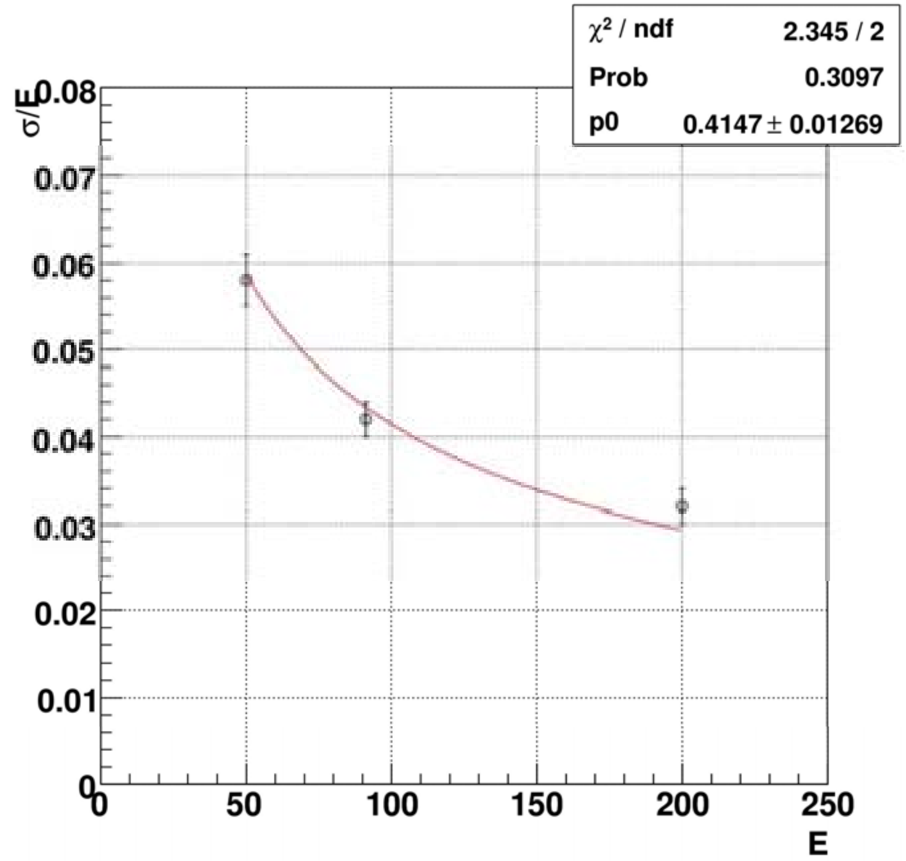
- Gamma Finding
  Efficiency : 73.0%, Purity : 93.8%
- Track Matching
  Efficiency : 84.2%, Purity : 86.9%

Red : pion
Yellow : gamma
Blue : neutron

Results

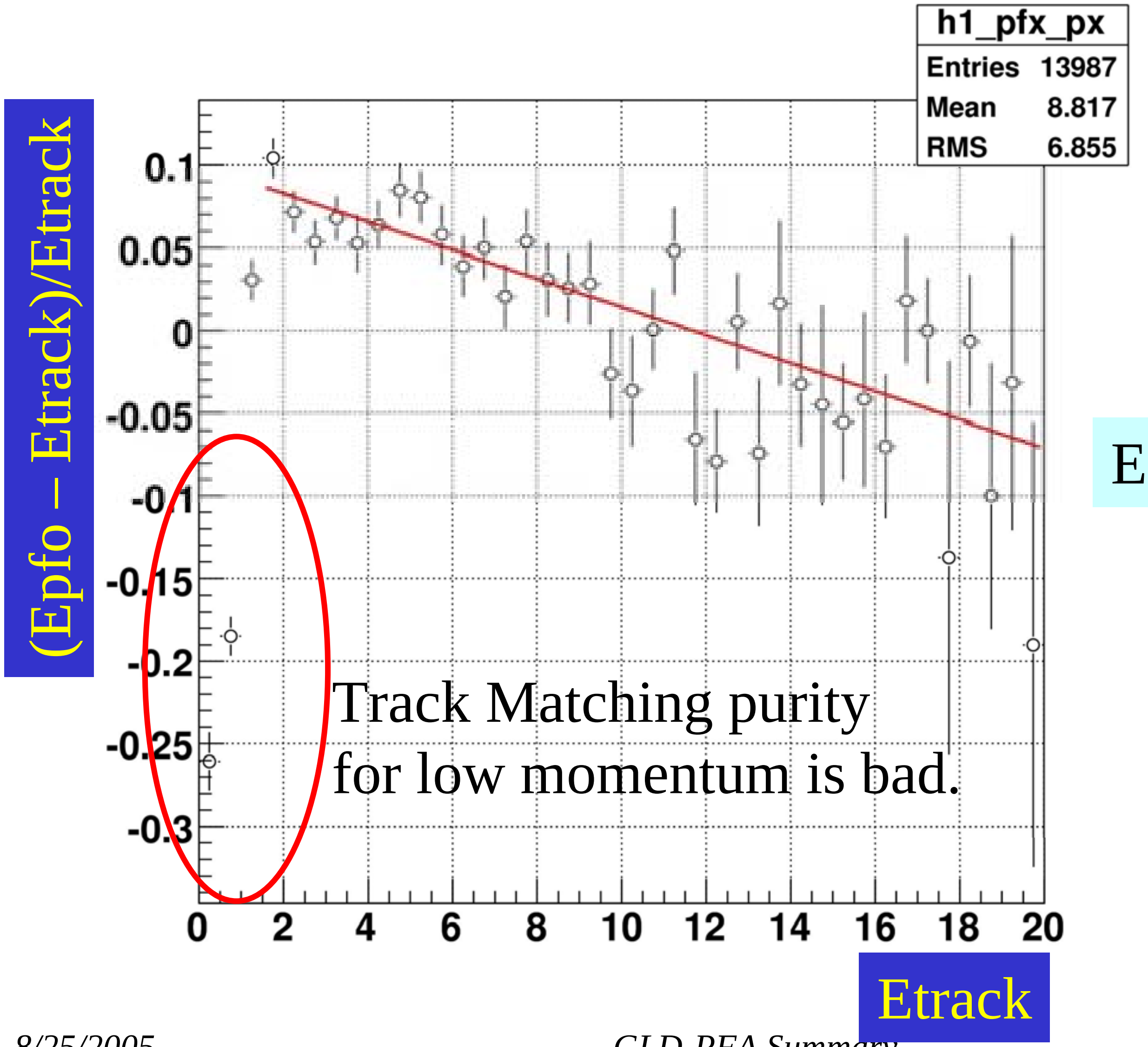


Granularity



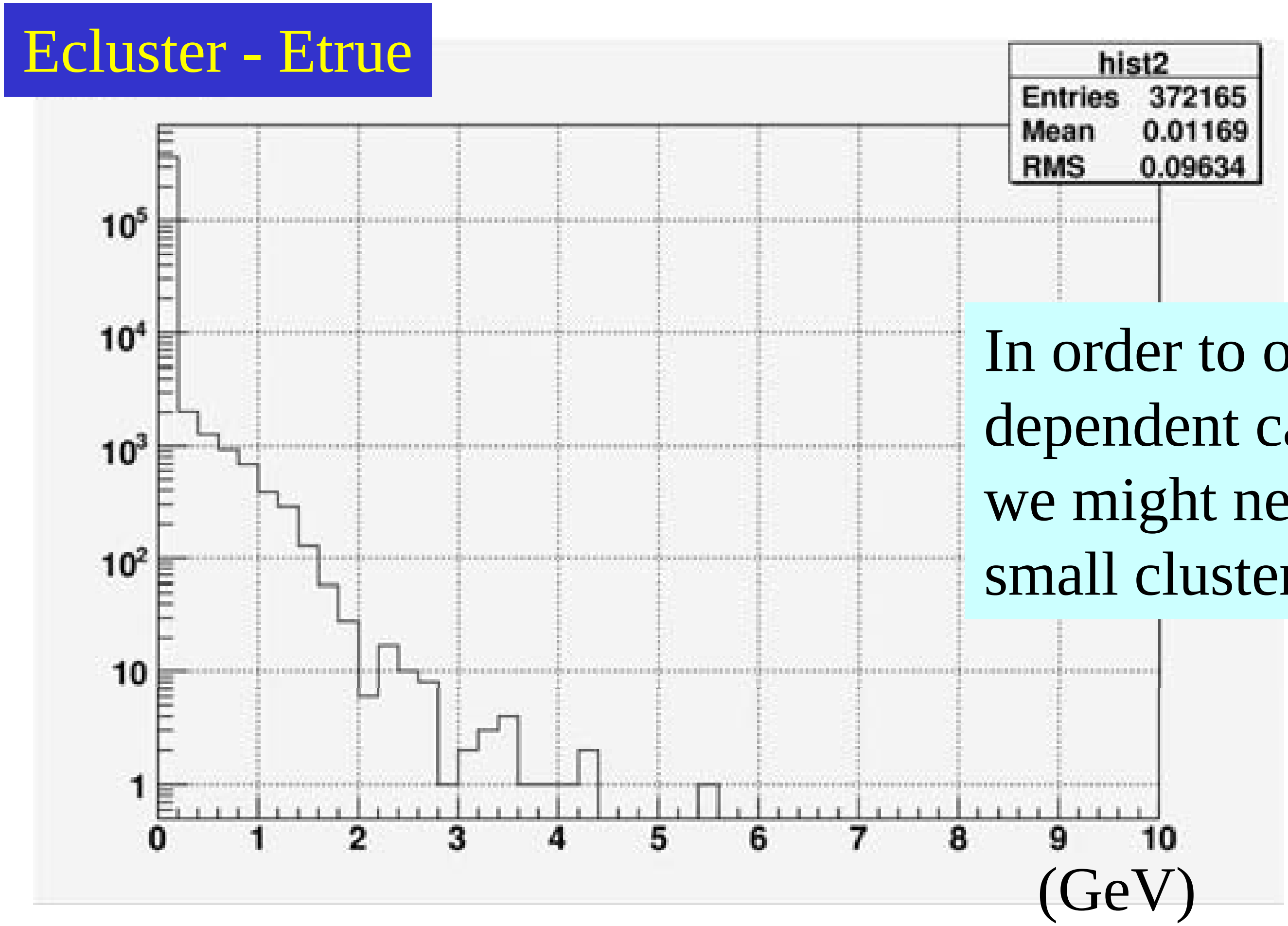
Energy Dependence

Track Matching Performance



ECAL : 4cm x 4cm

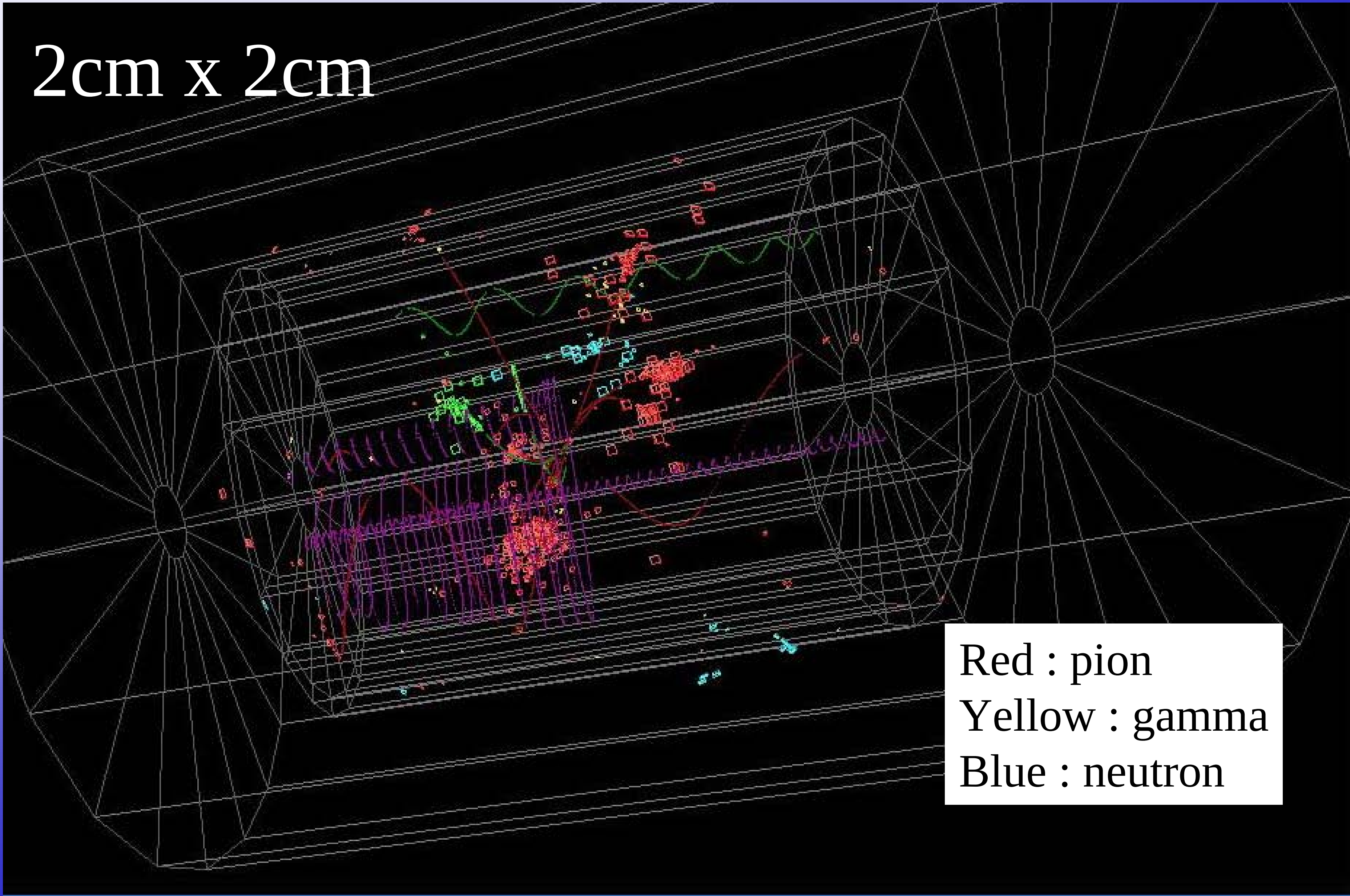
Small Clustering



In order to obtain energy dependent calibration factor, we might need to improve our small clustering.

Event Display

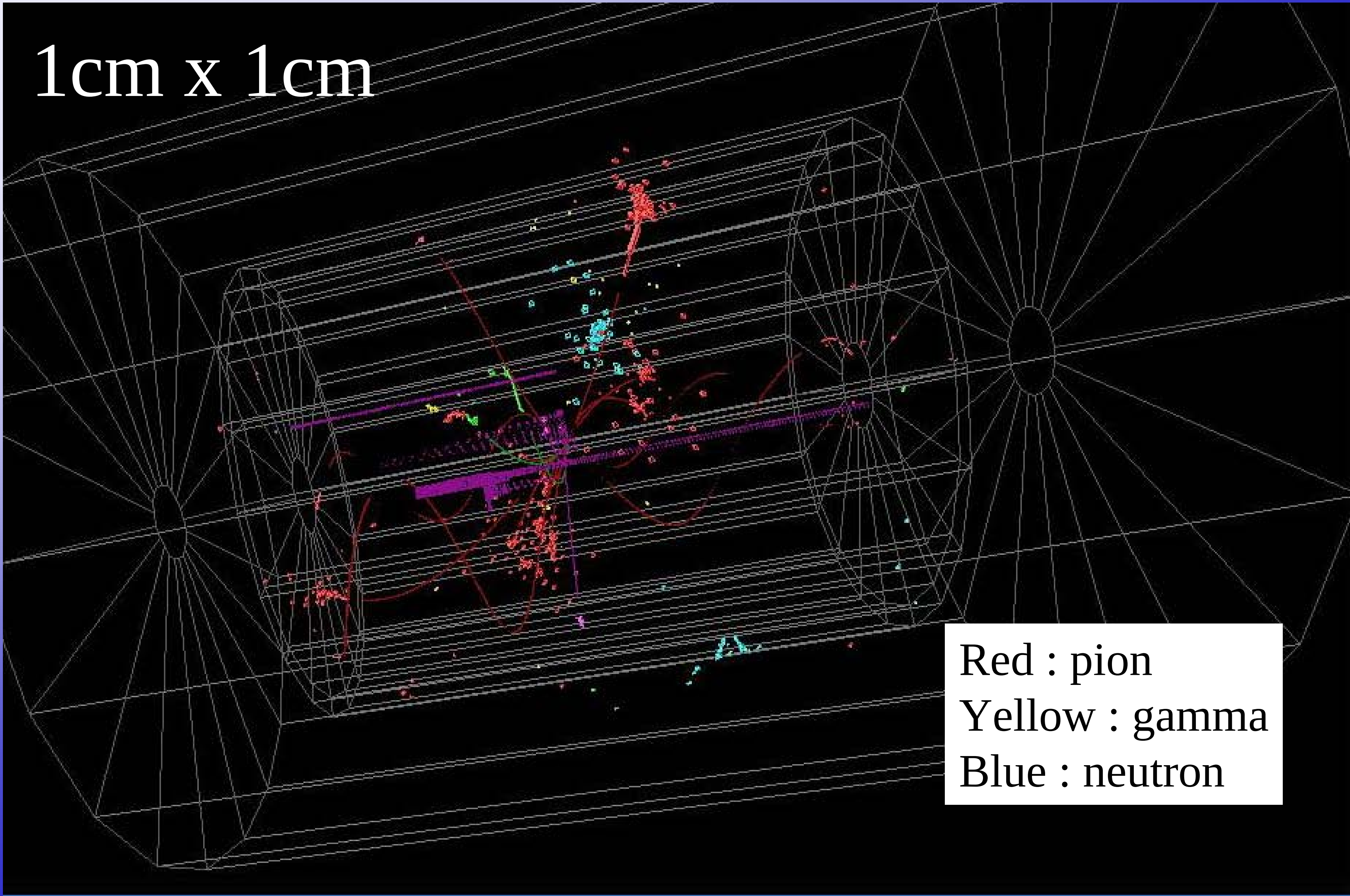
2cm x 2cm



Red : pion
Yellow : gamma
Blue : neutron

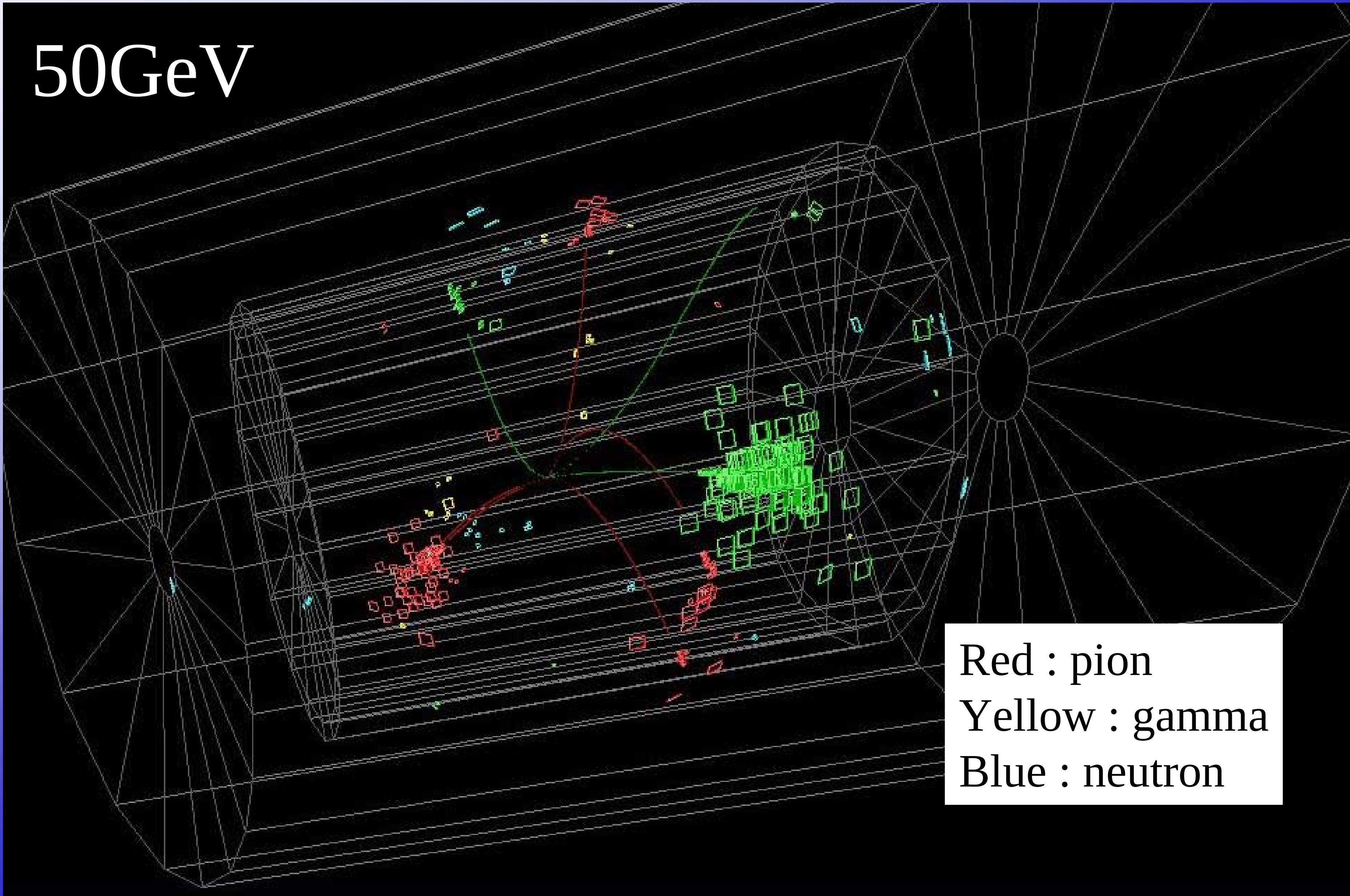
Event Display

1cm x 1cm

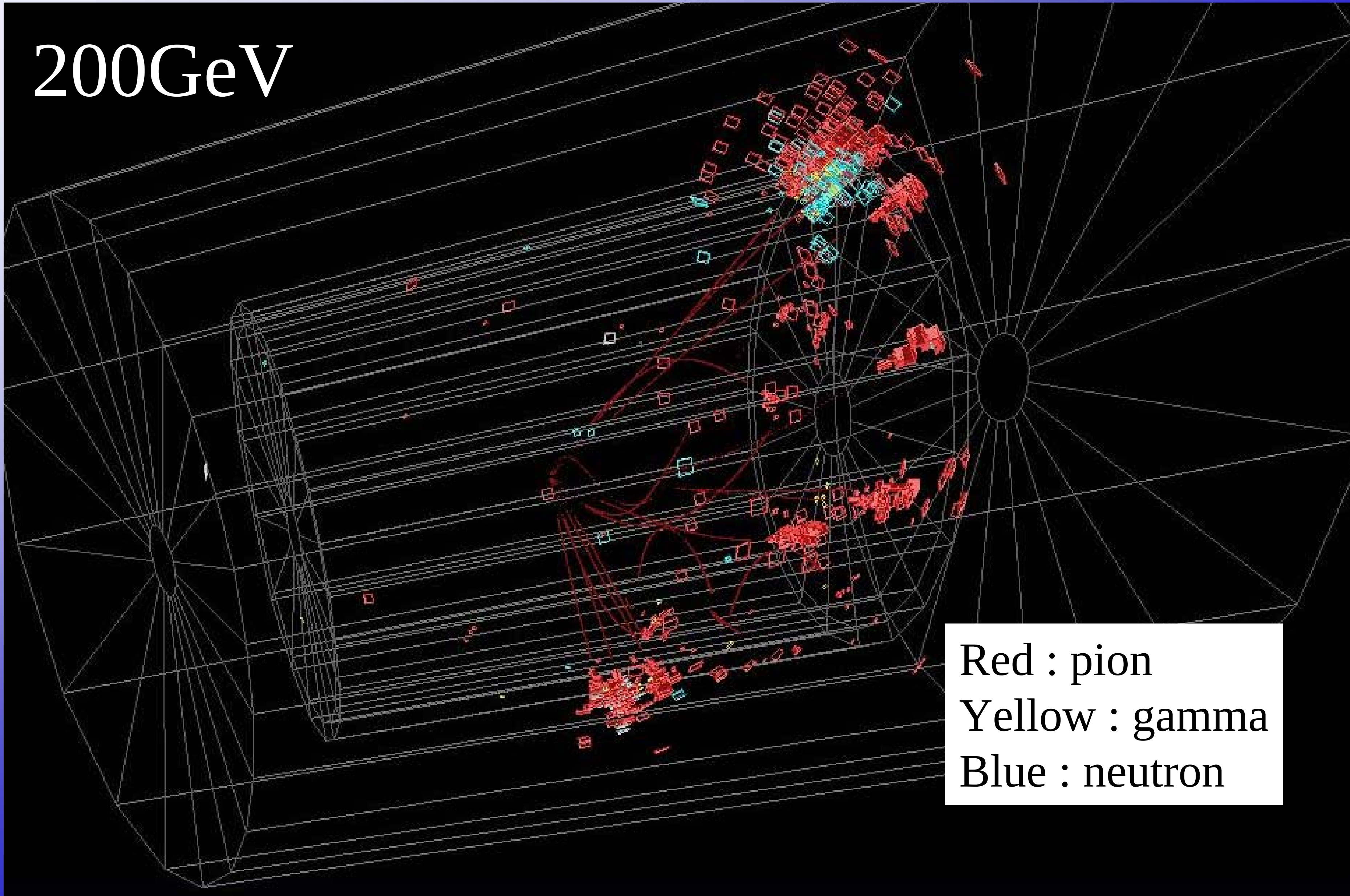


Red : pion
Yellow : gamma
Blue : neutron

Event Display



Event Display



Introduction

- Most of the important physics processes studied in the linear collider experiments have **multi-jets** in the final state.

→ *Precise Jet reconstruction is essential.*

- Since the momentum resolution of the charged particle is much better than the energy resolution of the calorimeter, we use

Trackers for charged particles

Calorimeters for neutral particles

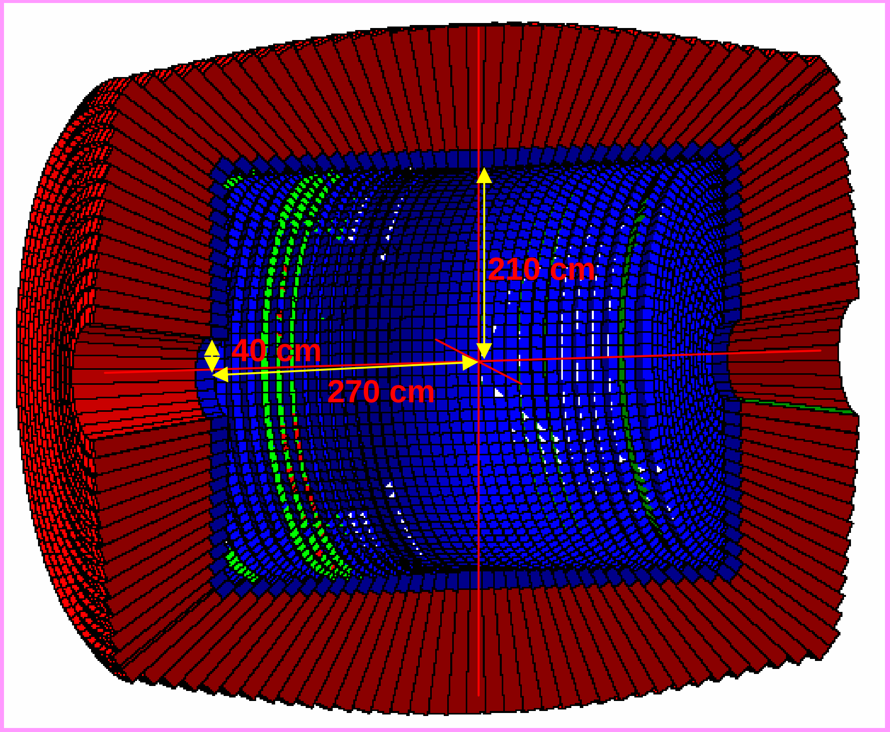
for Jet reconstruction.

→ *Particle Flow Algorithm (PFA)*

- In this talk, we present a performance of the PFA using a full simulator of GLD named **Jupiter**.

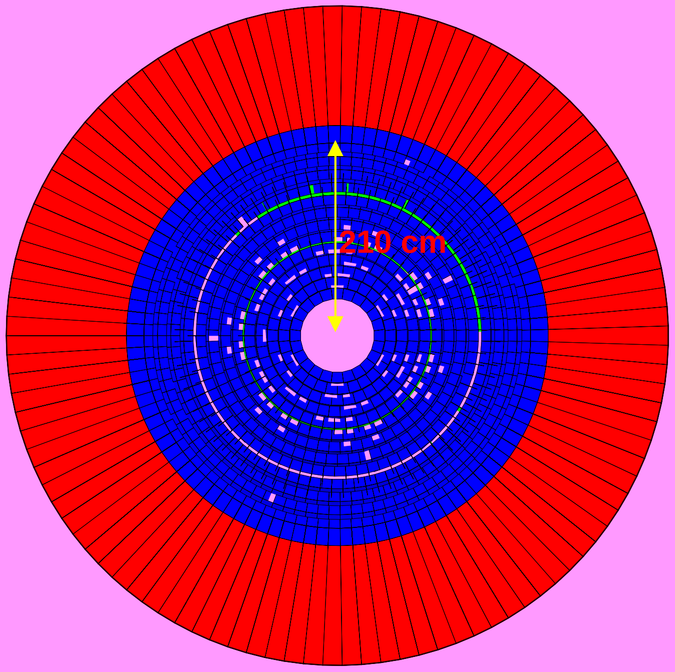
Calorimeter Geometry in Jupiter

- Side view



Barrel Tower Front : 210cm
Endcap Inner R : 40cm
Endcap Tower Front Z : 270cm

- End view

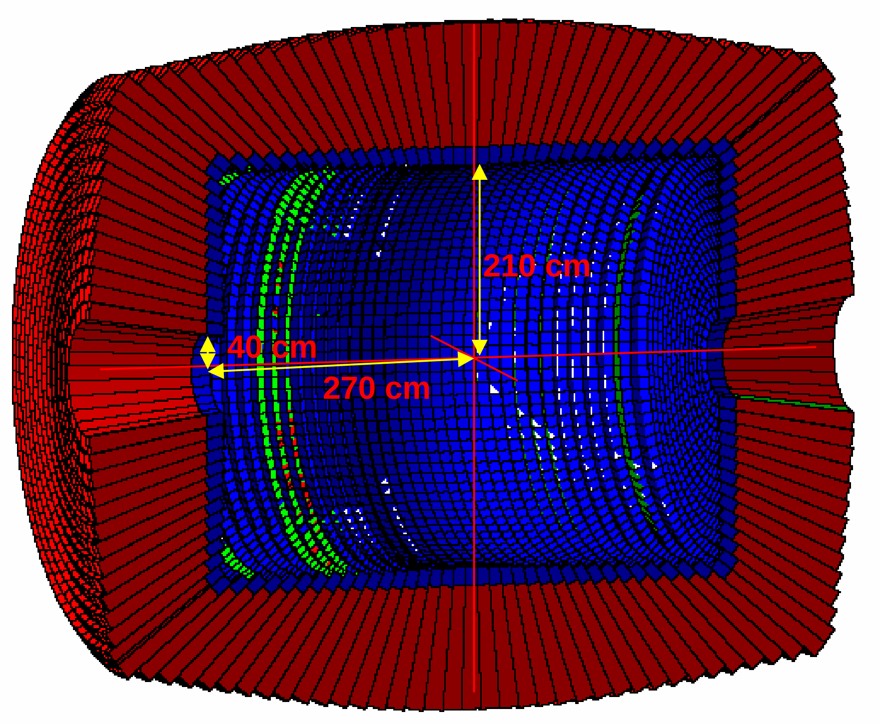


- Consists of tower structure.

Thanks to Y.Yamaguchi (Tsukuba)

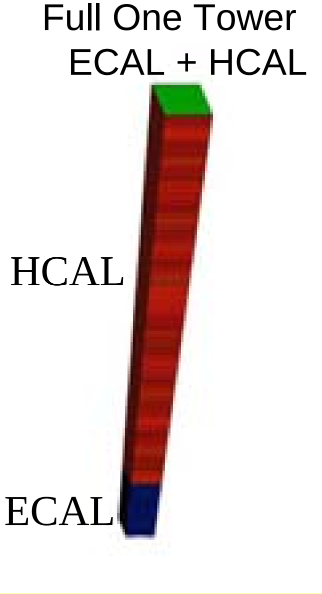
Calorimeter Geometry in Jupiter

- Side view



Barrel Tower Front : 210cm
Endcap Inner R : 40cm
Endcap Tower Front Z : 270cm

- Tower

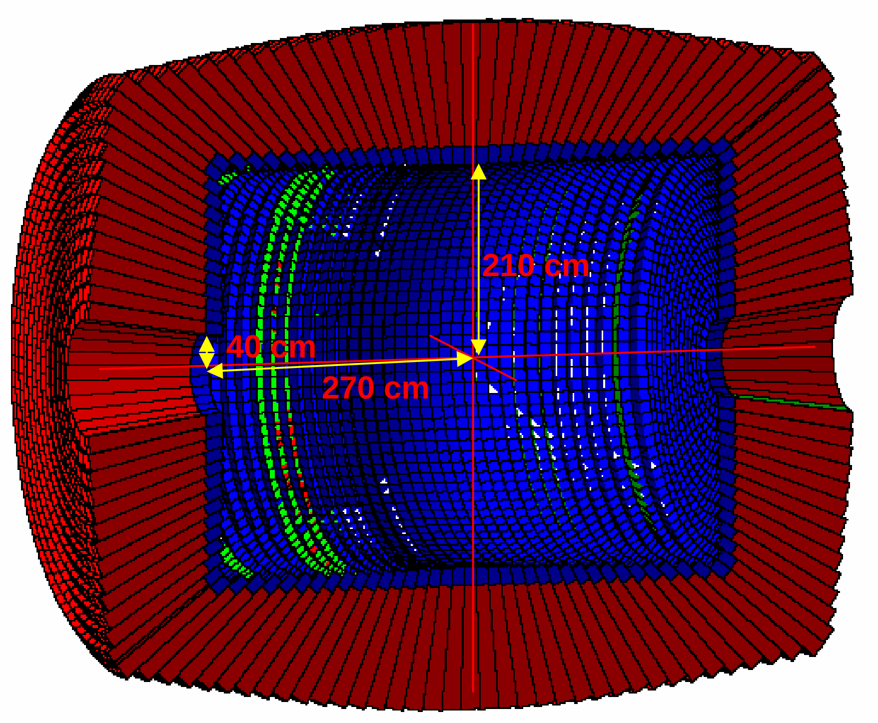


- # of Layers
  ECAL : 38
  HCAL : 130

Thanks to Y.Yamaguchi (Tsukuba)

Calorimeter Geometry in Jupiter

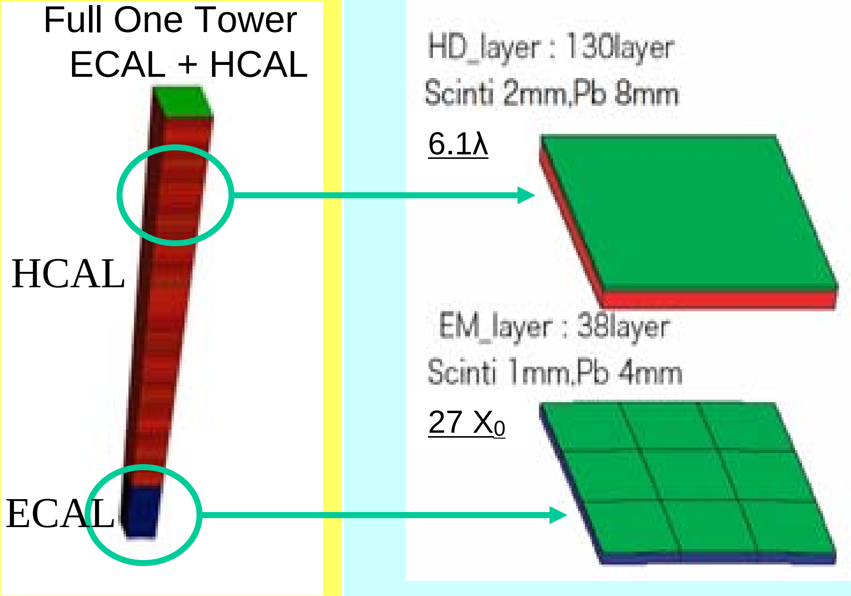
- Side view



Barrel Tower Front : 210cm
Endcap Inner R : 40cm
Endcap Tower Front Z : 270cm

- Tower

- Cell



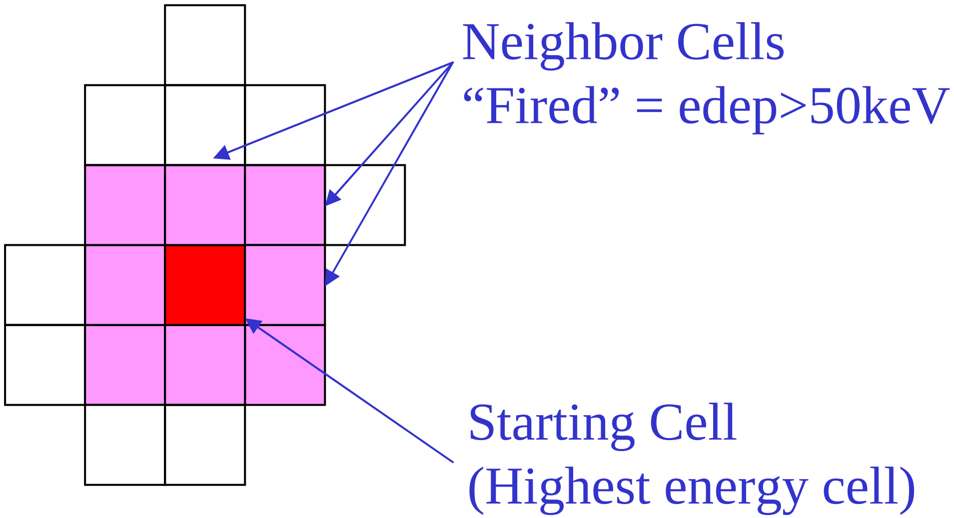
- # of Layers
  ECAL : 38
  HCAL : 130

- Cell Size
  EM : 4cm x 4cm
  HD : 12cm x 12cm

Cell size and material can be changed easily.

Small Clustering

(1) Find the “starting cell” among those “fired cell” in ECAL and HCAL which contains the highest energy deposition.
(2) From the “starting cell”, find its “fired” neighbor cells to form a small cluster.

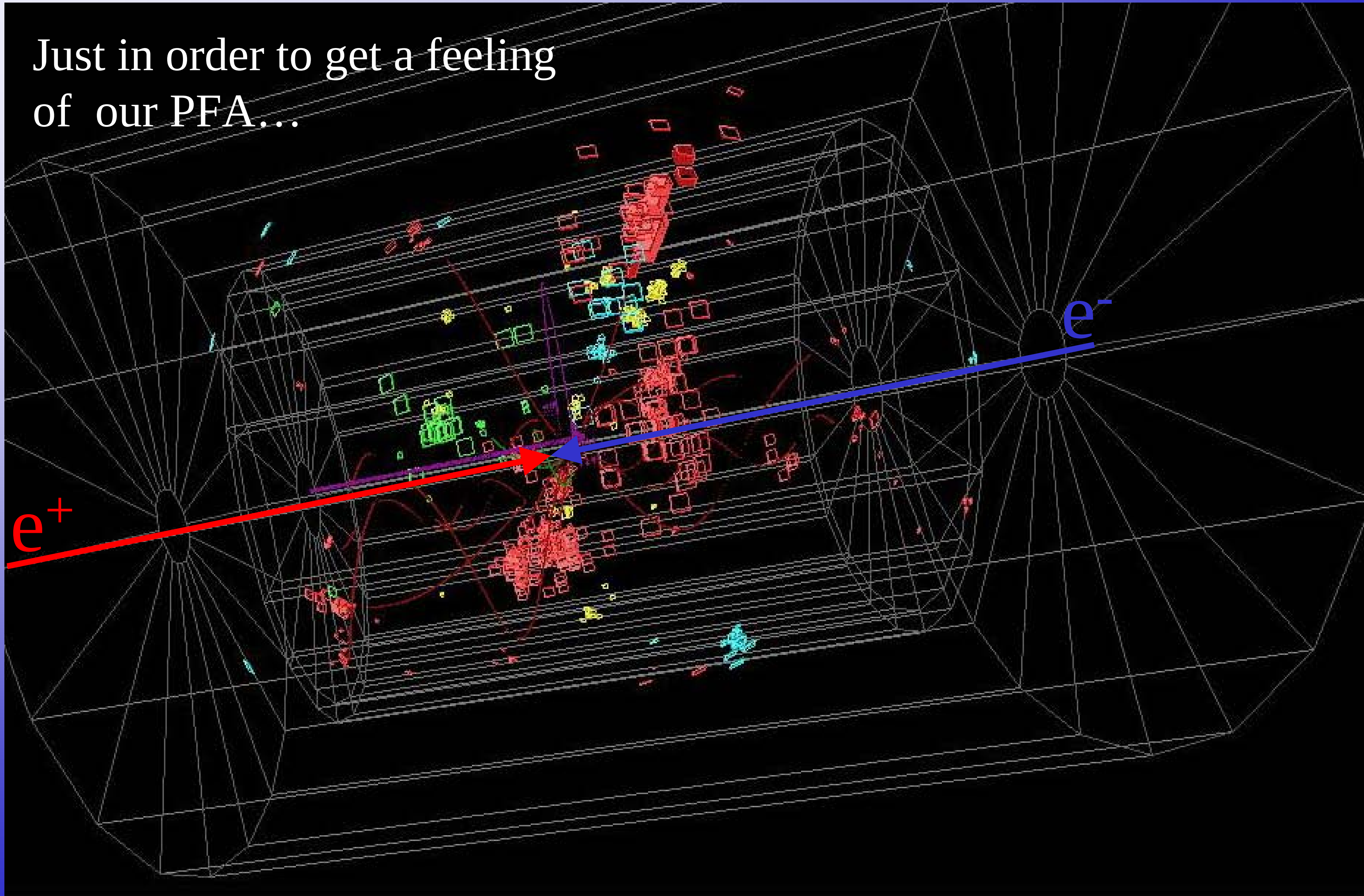


- The small clustering is performed in 3-dimensions.

- If the cluster energy exceeds 50MeV(before calibration), the clustering is stopped.

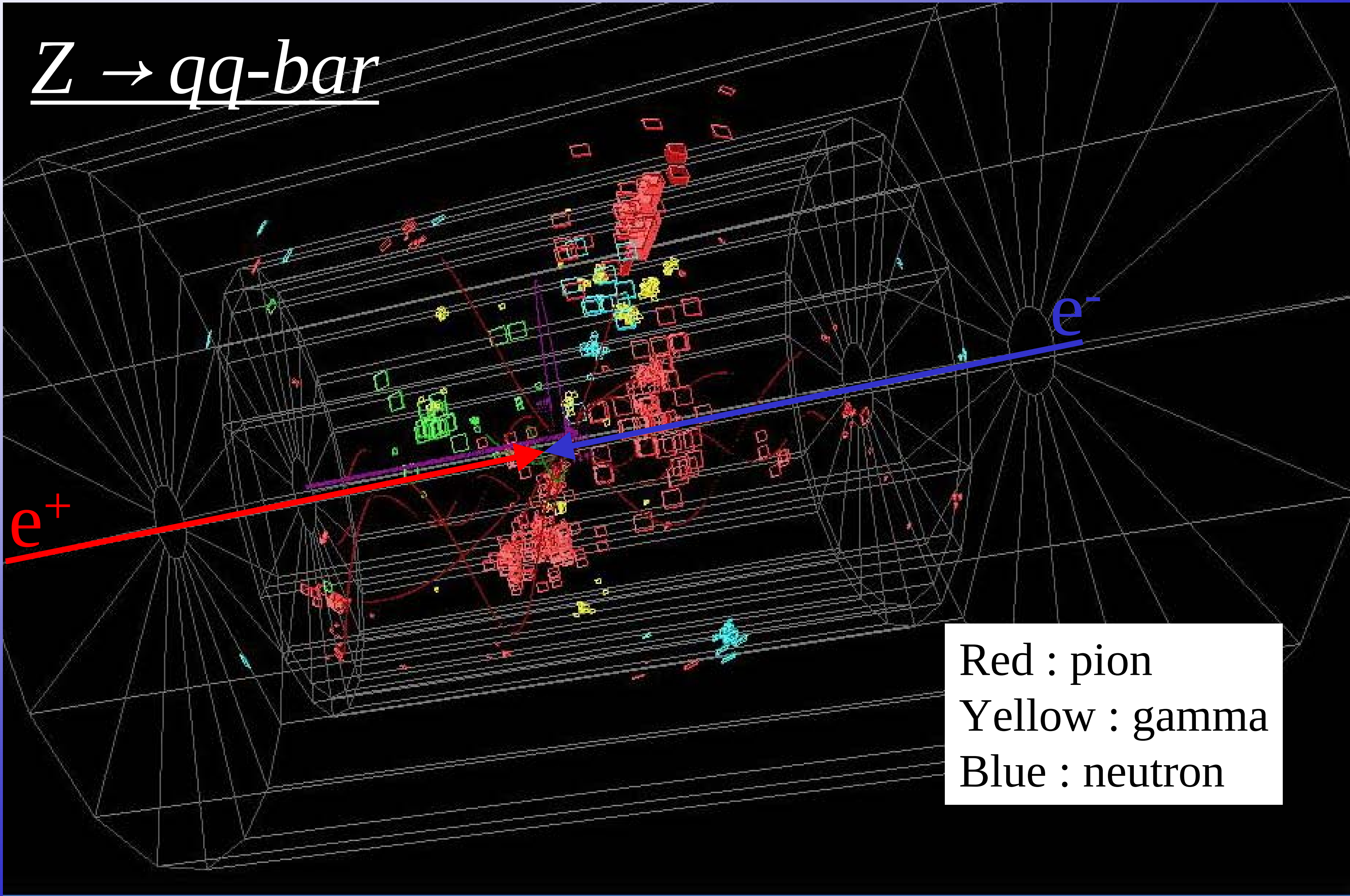
Event Display

Just in order to get a feeling
of our PFA…



Event Display

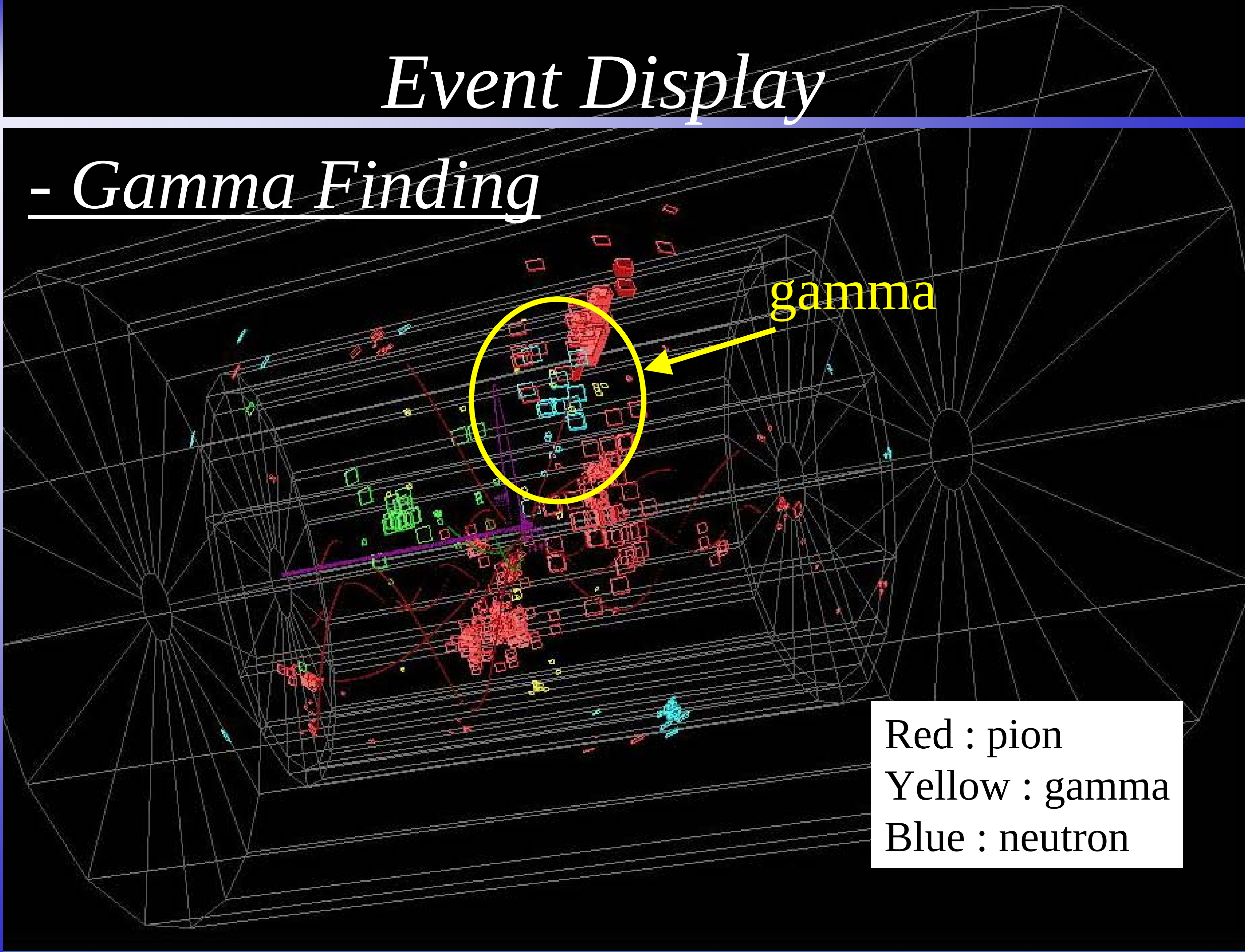
Z → qq-bar



Red : pion
Yellow : gamma
Blue : neutron

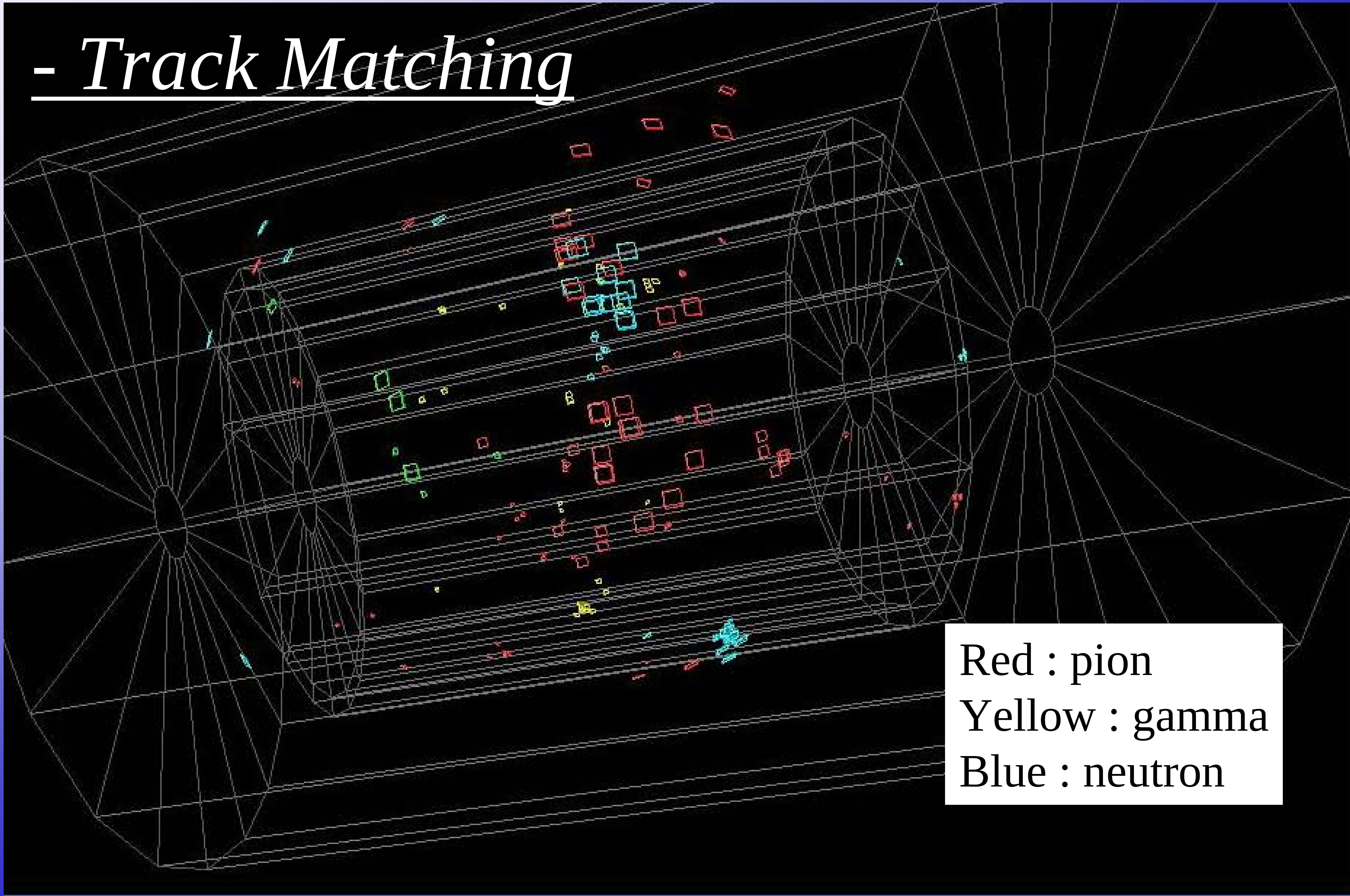
Event Display

- *Gamma Finding*



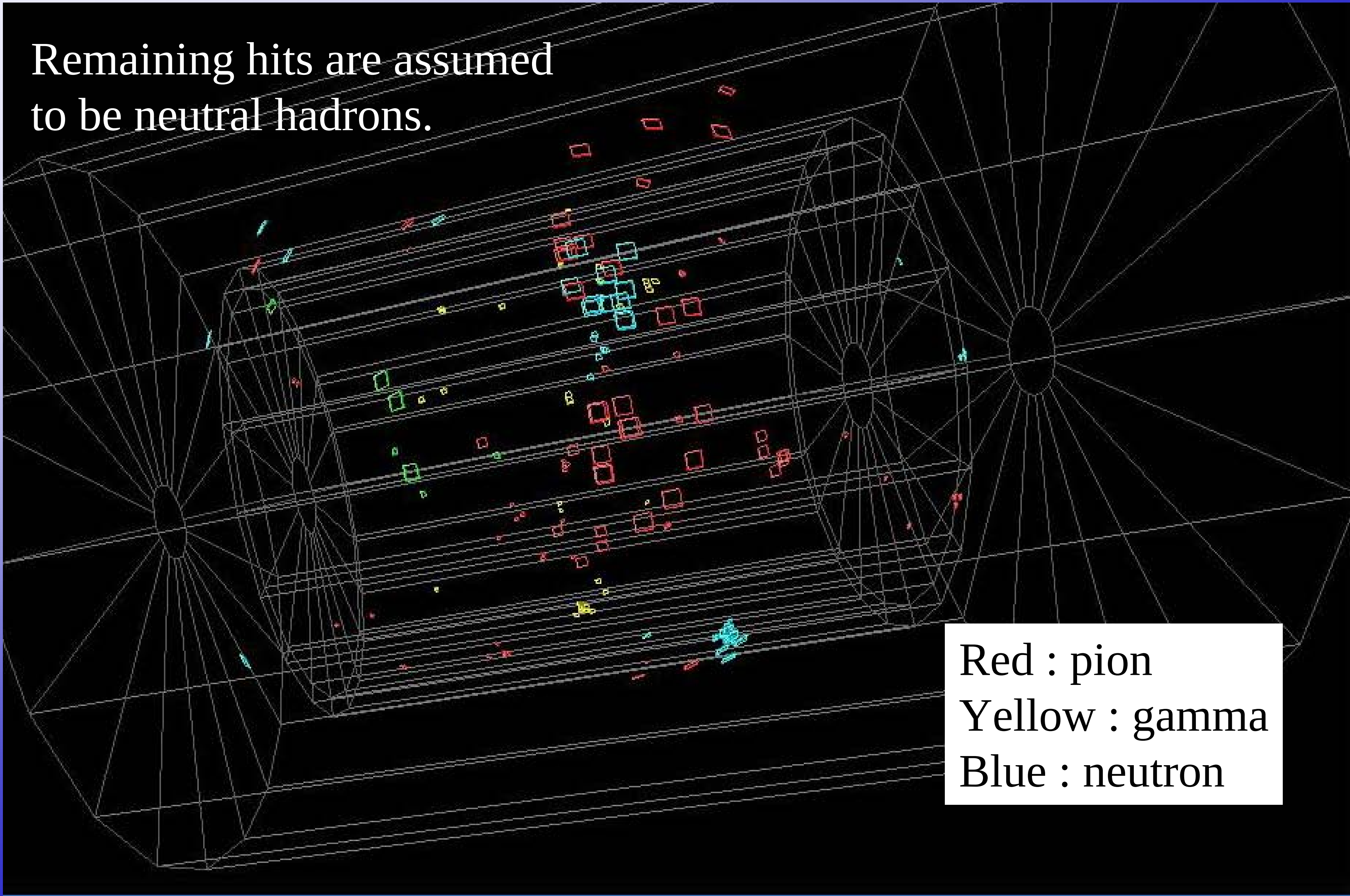
Event Display

- Track Matching



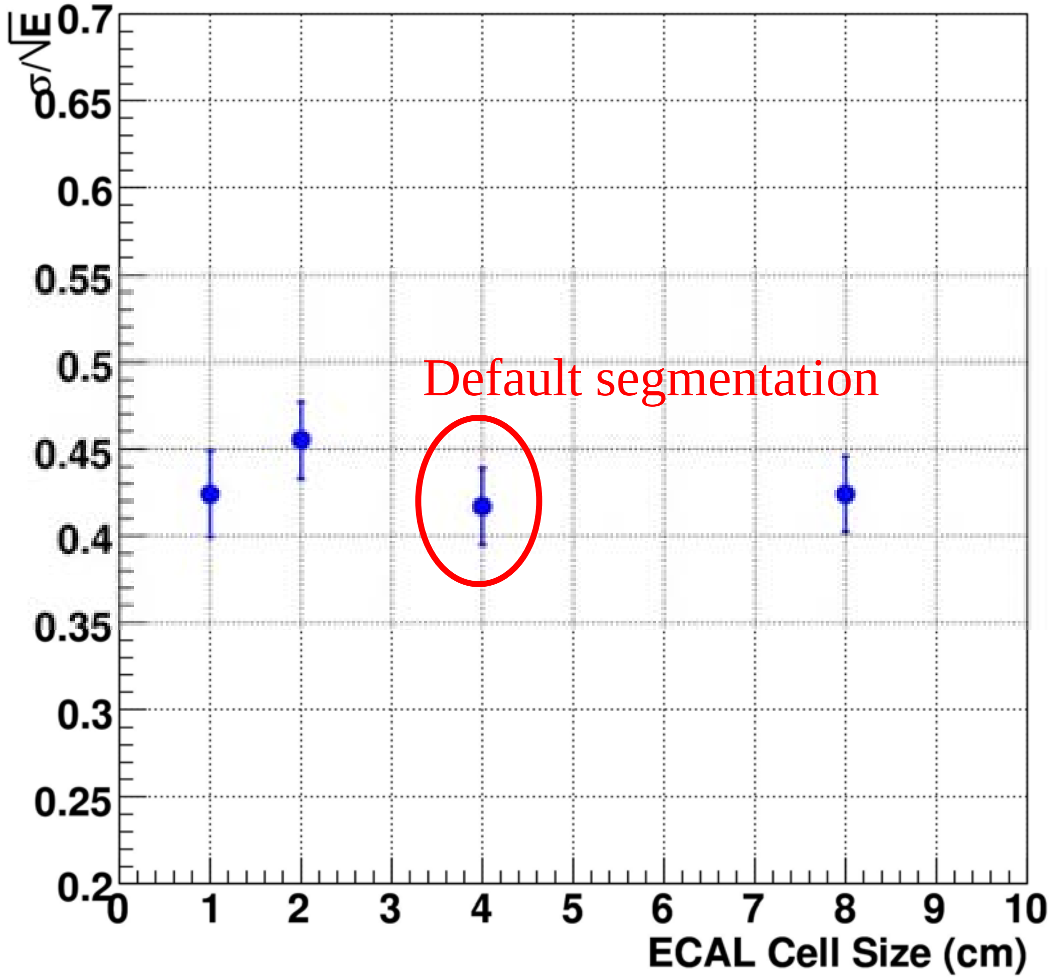
Event Display

Remaining hits are assumed to be neutral hadrons.



Red : pion
Yellow : gamma
Blue : neutron

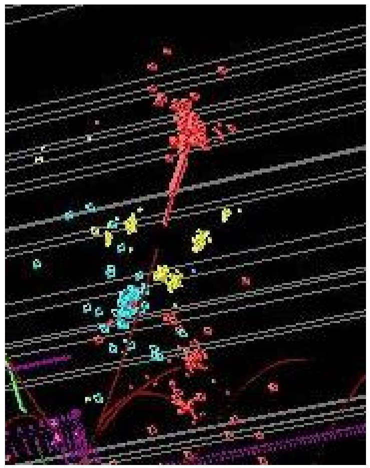
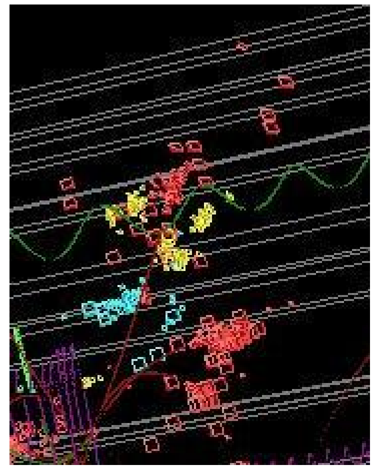
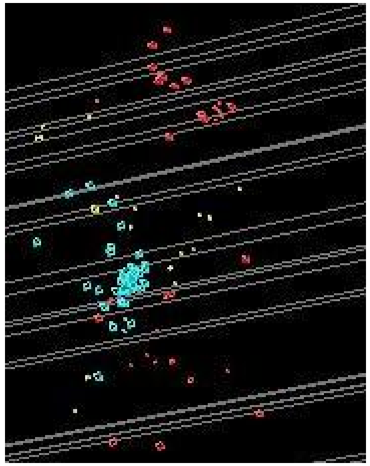
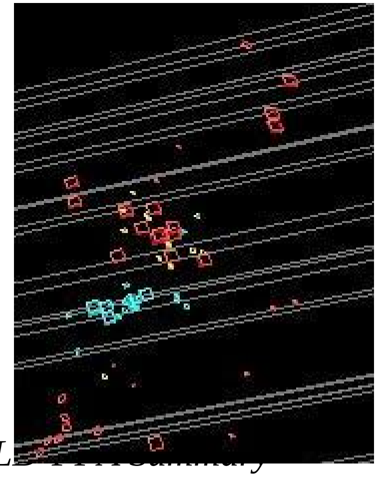
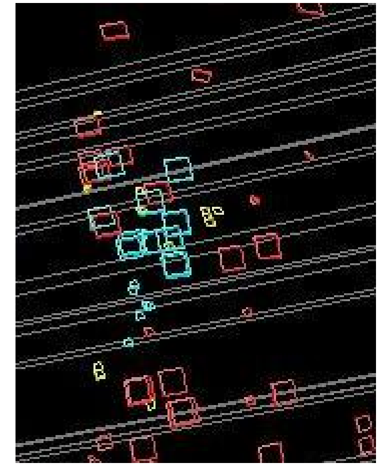
Granularity Study



- Different granularity is tested.

- So far, no gain with finer segmentation. (under study)

Granularity Study

	1cm x 1cm	2cm x 2cm	4cm x 4cm
before			
after			

Summary

- Simple scheme of PFA with full simulator of GLD has achieved jet energy resolution of ~40%/sqrt(E).
    - Gamma Finding
        Efficiency : 78.4%, Purity : 95.2%
    - Track Matching
        Efficiency : 84.2%, Purity : 91.2%

  for 4cm x 4cm ECAL segmentation.

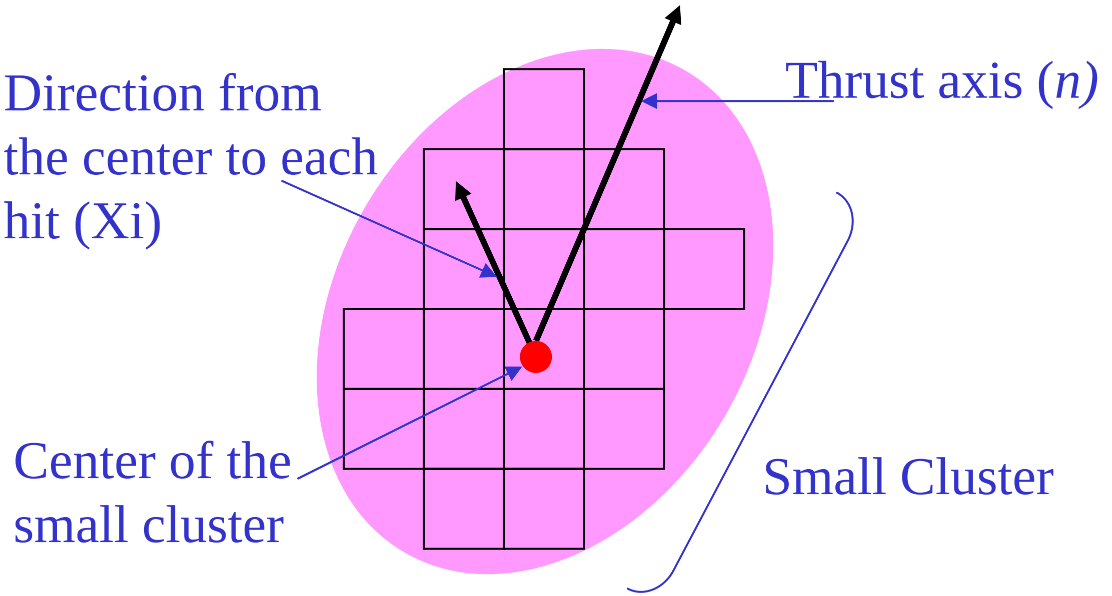
- Study on different granularity is now on-going. So far, no gain with finer segmentation.

Variables for Small Cluster

- ***Energy-weighted Thrust & Broadening***

$$T \equiv \frac{\sum_i |\vec{X}_i \cdot \vec{n}| E_i}{\sum_i |\vec{X}_i|}$$

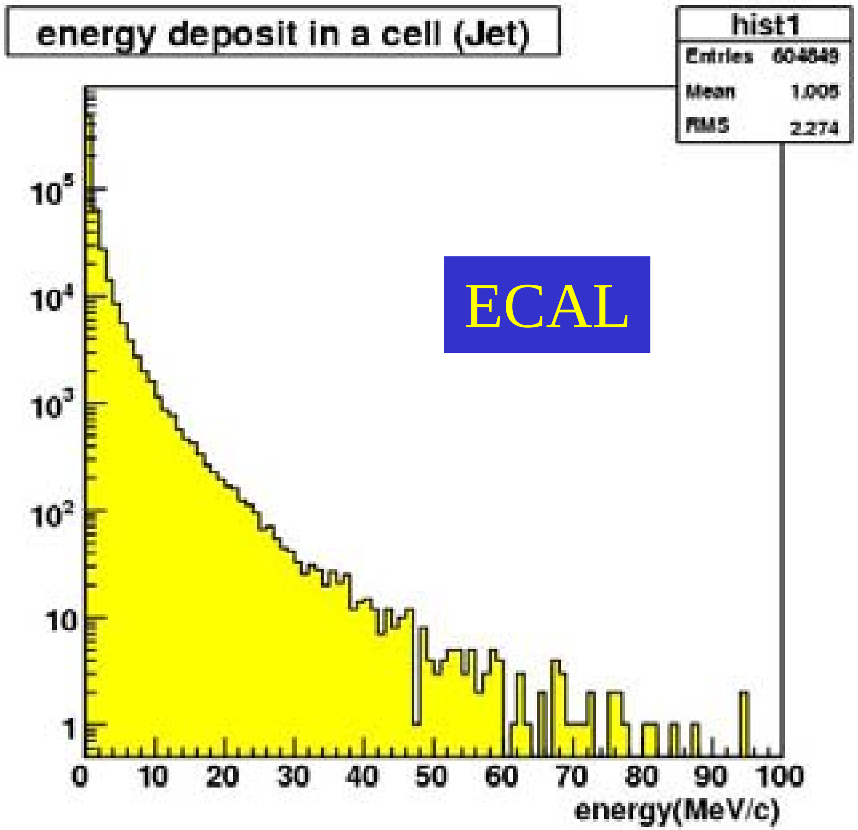
$$B \equiv \frac{\sum_i |\vec{X}_i \times \vec{n}| E_i}{\sum_i |\vec{X}_i|}$$

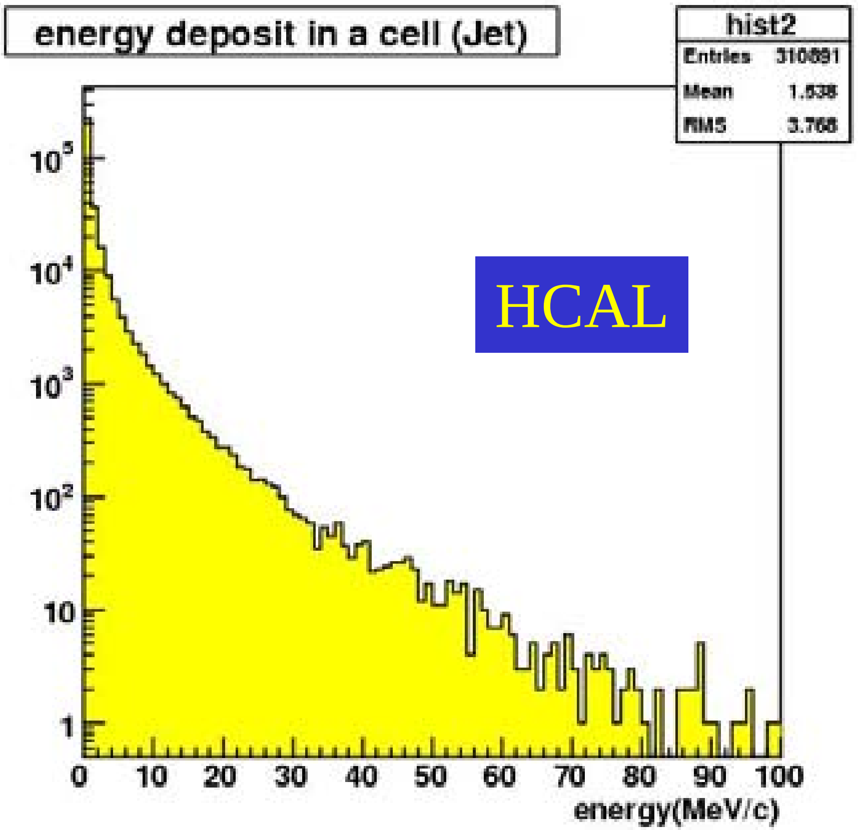


- Thrust axis n is defined as to maximize the T.

Energy Deposit in a Cell

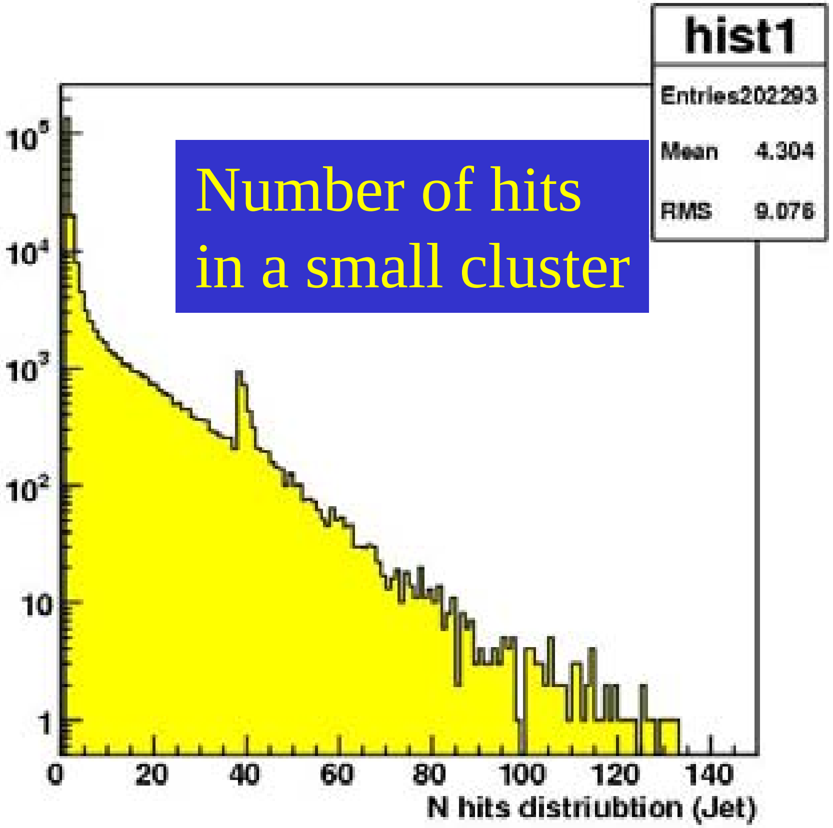
- Z → qq-bar(q = u,d,s)@91.187GeV.

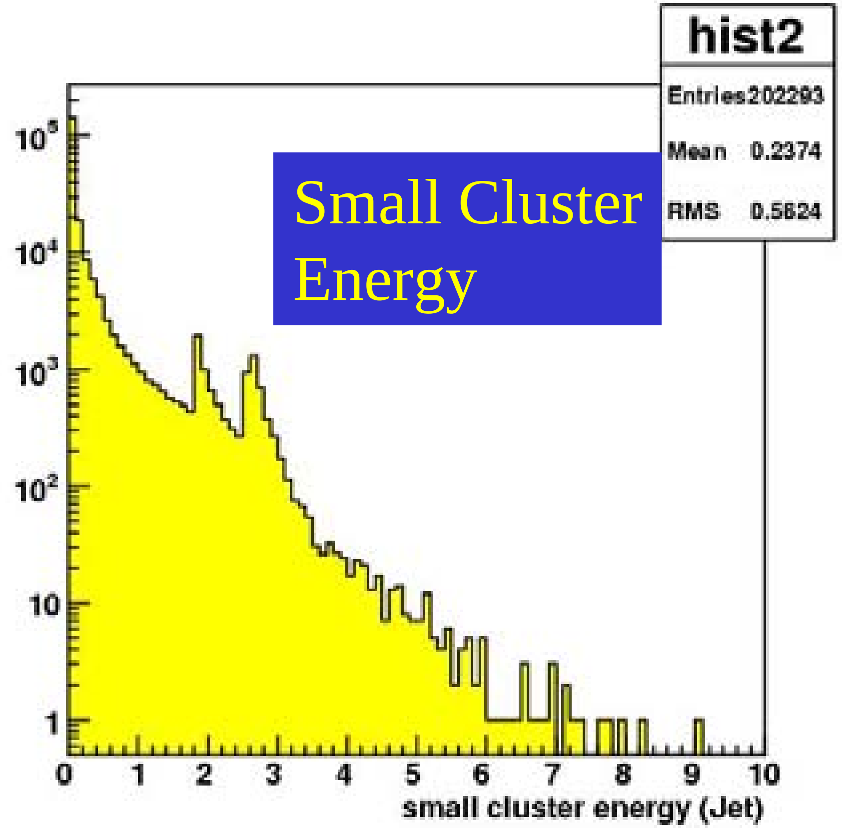




Small Cluster Distributions

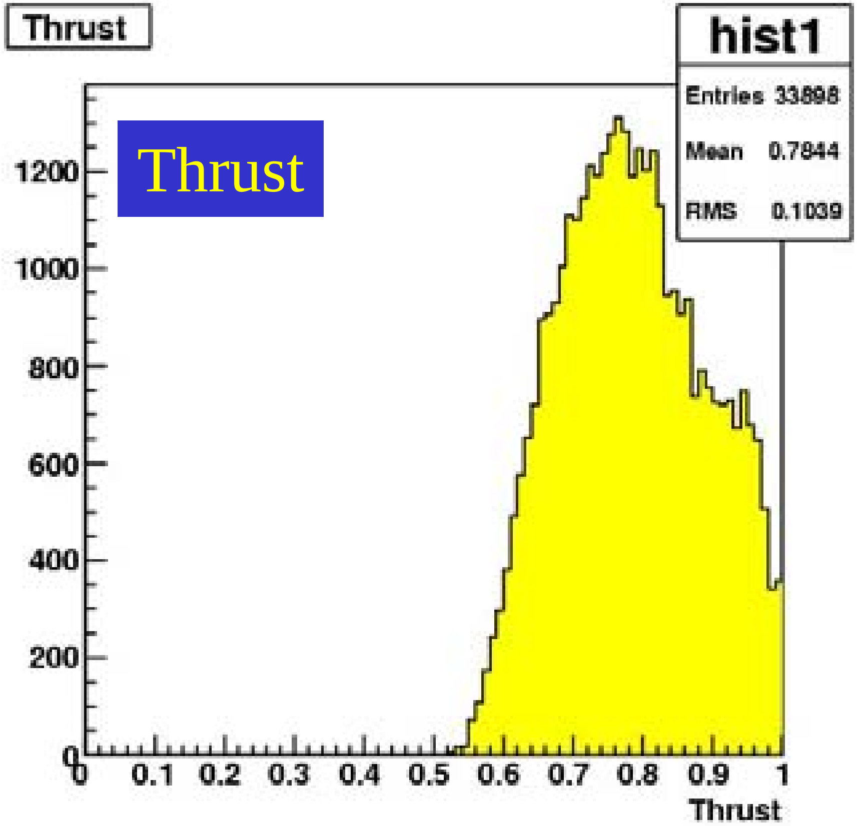
- Z → qq-bar(q = u,d,s)@91.187GeV.

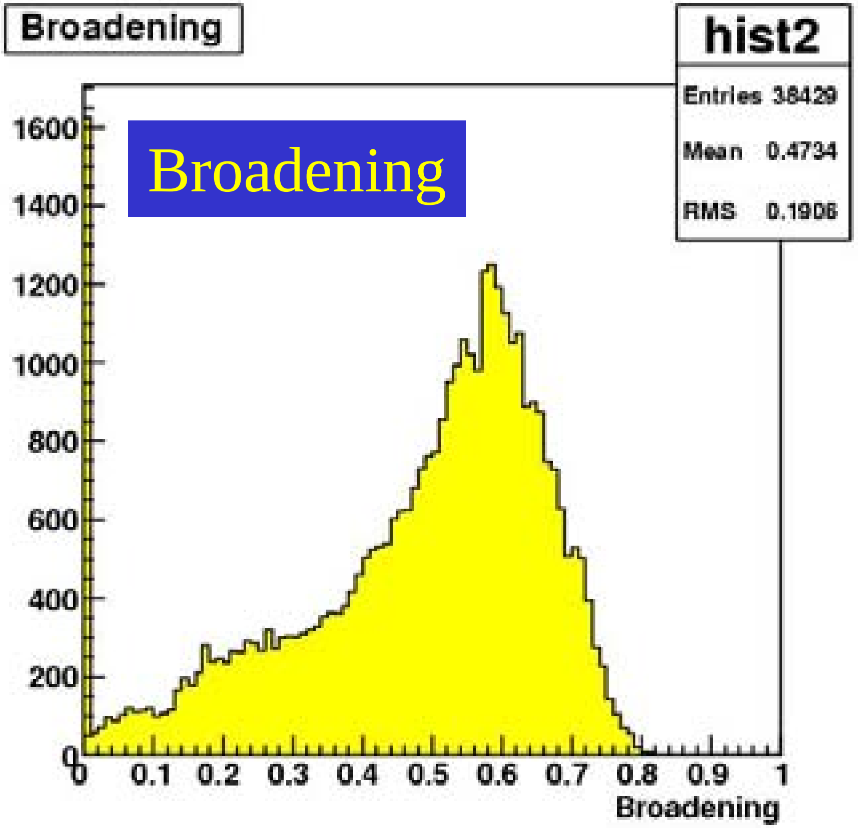




Thrust and Broadening

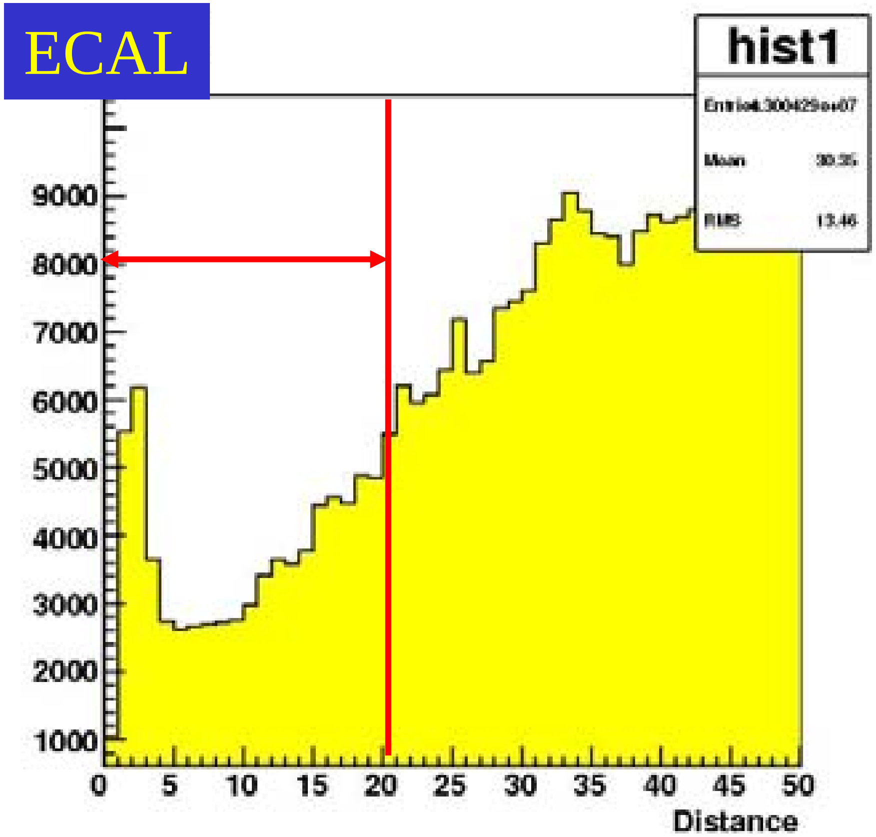
- Z → qq-bar(q = u,d,s)@91.187GeV.

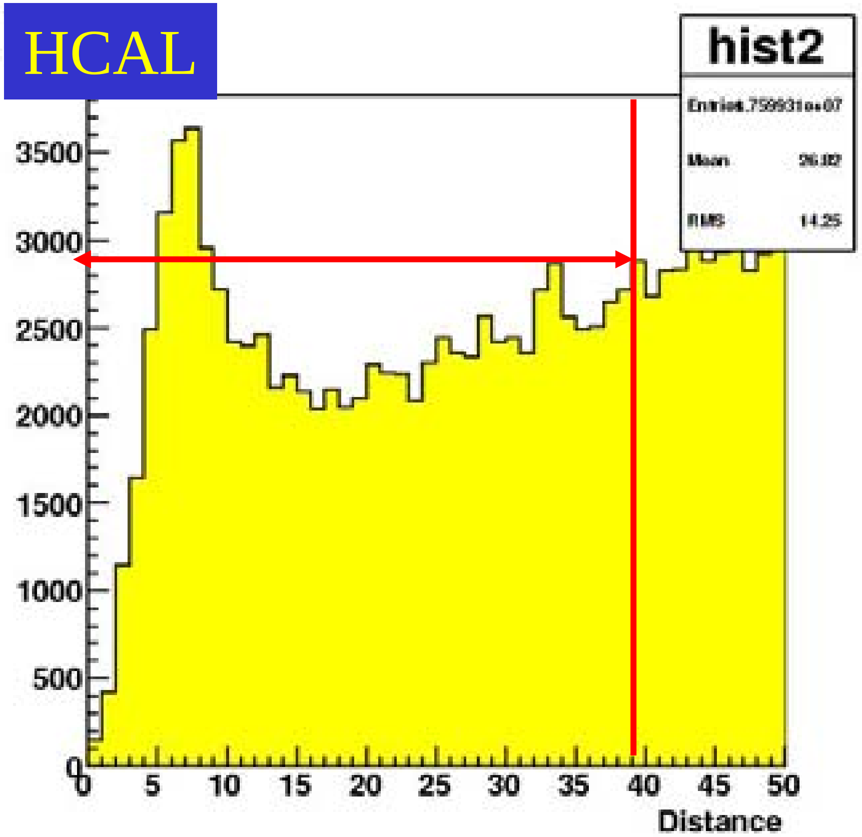




Distance Distribution

- Z → qq-bar(q = u,d,s)@91.187GeV.





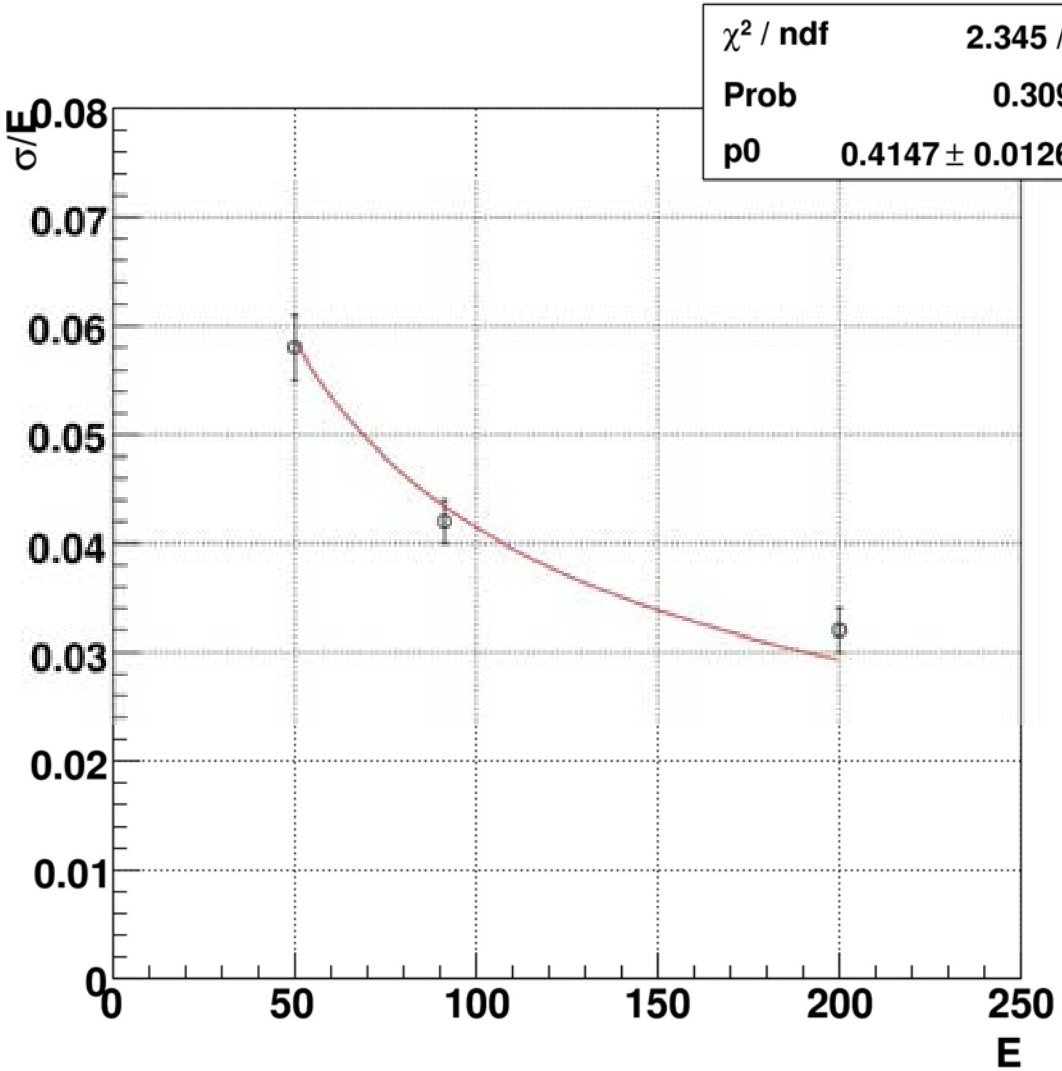
Track Matching Procedure

- More detail of the procedure…

(1) Sum up calorimeter cell energies within a tube for a track (Ecluster).
(2) If Ecluster > Etrack x (0.4 x nsigma + 1), stop the clustering for the track. If not, perform (1) for each track. (We assume the calorimeter resolution of 40%.)
(3) Widen the tube radius (only a Rstep) and perform (1) and (2) again.
(4) Perform (1)-(3) until the tube radius reach the max radius (Rmax).

Parameters (nsigma, Rstep and Rmax) should be optimized.

Energy Dependence



- Different initial energy is checked with the initial state radiation be turned off.

Gamma Finding procedure for GLD Detector

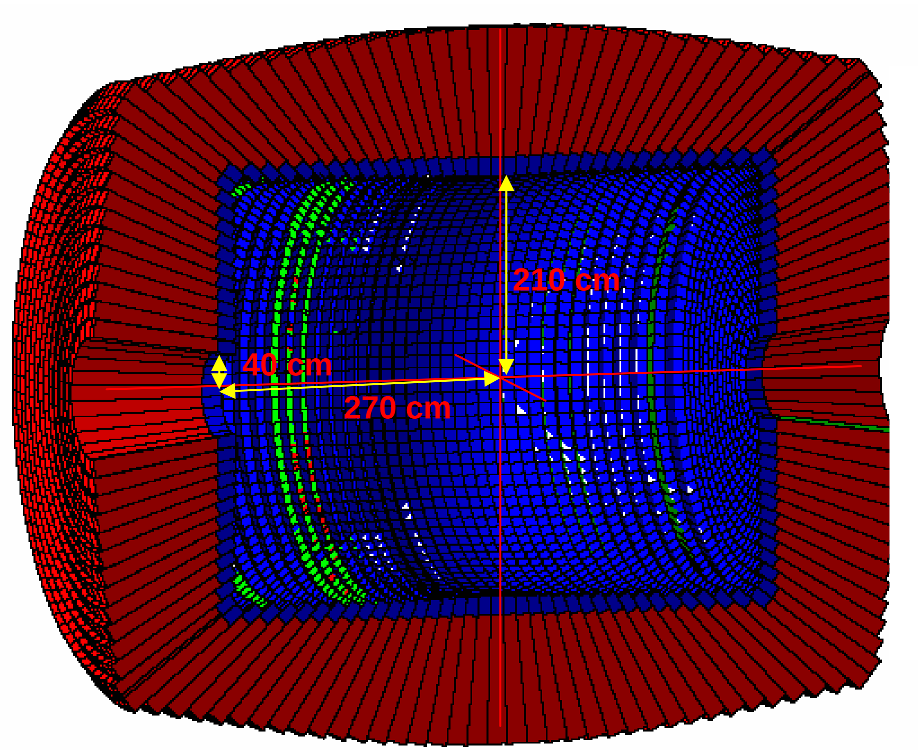
T.Fujikawa(Tohoku Univ.), M-C. Chang(Tohoku Univ.), K.Fujii(KEK), A.Miyamoto(KEK), S.Yamashita(ICEPP), T.Yoshioka(ICEPP)….

Motivation

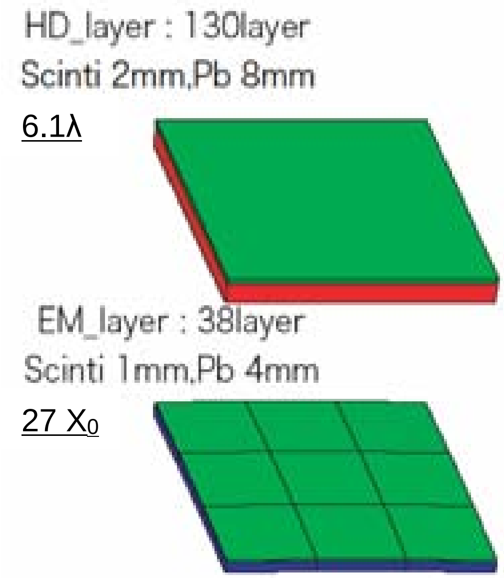
To get high energy resolution in multi-jet event, we use the tracker information for charged particles and calorimeter hits information for neutral particles. (tracker resolution is much better than calorimeter's.)

Particle Flow Algorithm (PFA) is studied to achieve an event reconstruction. We studied part of PFA, "gamma finding method" for GLD detector, using full simulator (Jupiter).

Detector configuration



Full One Tower
EM + HD



Y.Yamaguchi (Tsukuba Univ.)

In current Jupiter, calorimeter has tile type geometry. The default tile size is 4cmx4cm/12cmx12cm for ECAL/HCAL. We used this configuration mainly.

Flow of the gamma finding

As a first step of the clustering, we collect hit cells with its neighbors (at most with ~50MeV energy deposit). We call it “small cluster”. Our gamma finding method is performed based on the small clusters.

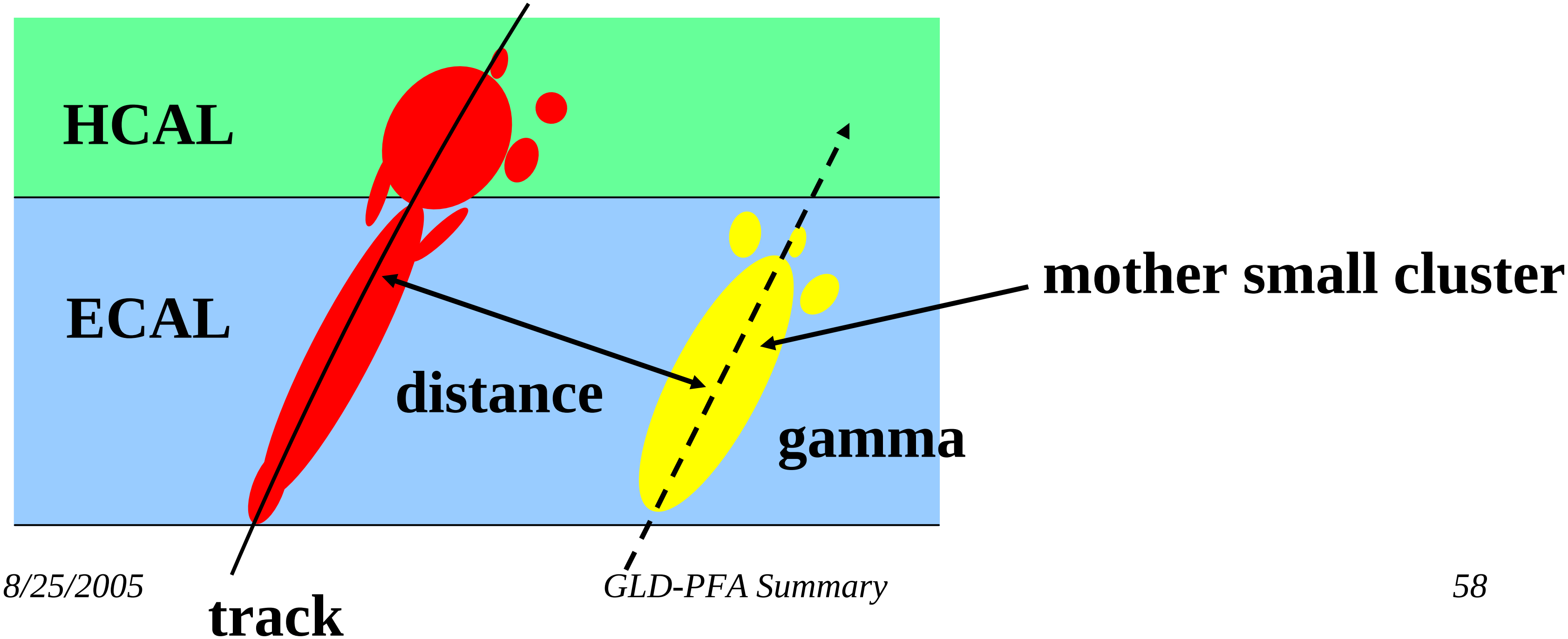
The flow of Gamma Finding

1. **Find “large” small cluster within ECAL region (we call it “mother small cluster”).**
2. **Reject mother small clusters which are close to the track.**
3. **Collect small clusters within a tube.**
4. **Select gamma-like clusters using longitudinal shower profile.**

Gamma finding method

1. The distance from the nearest track

Calculate the distance between mother small cluster and its nearest track. The distance is used to separate gamma from charged particles.



Gamma finding method

2. Longitudinal shower profile

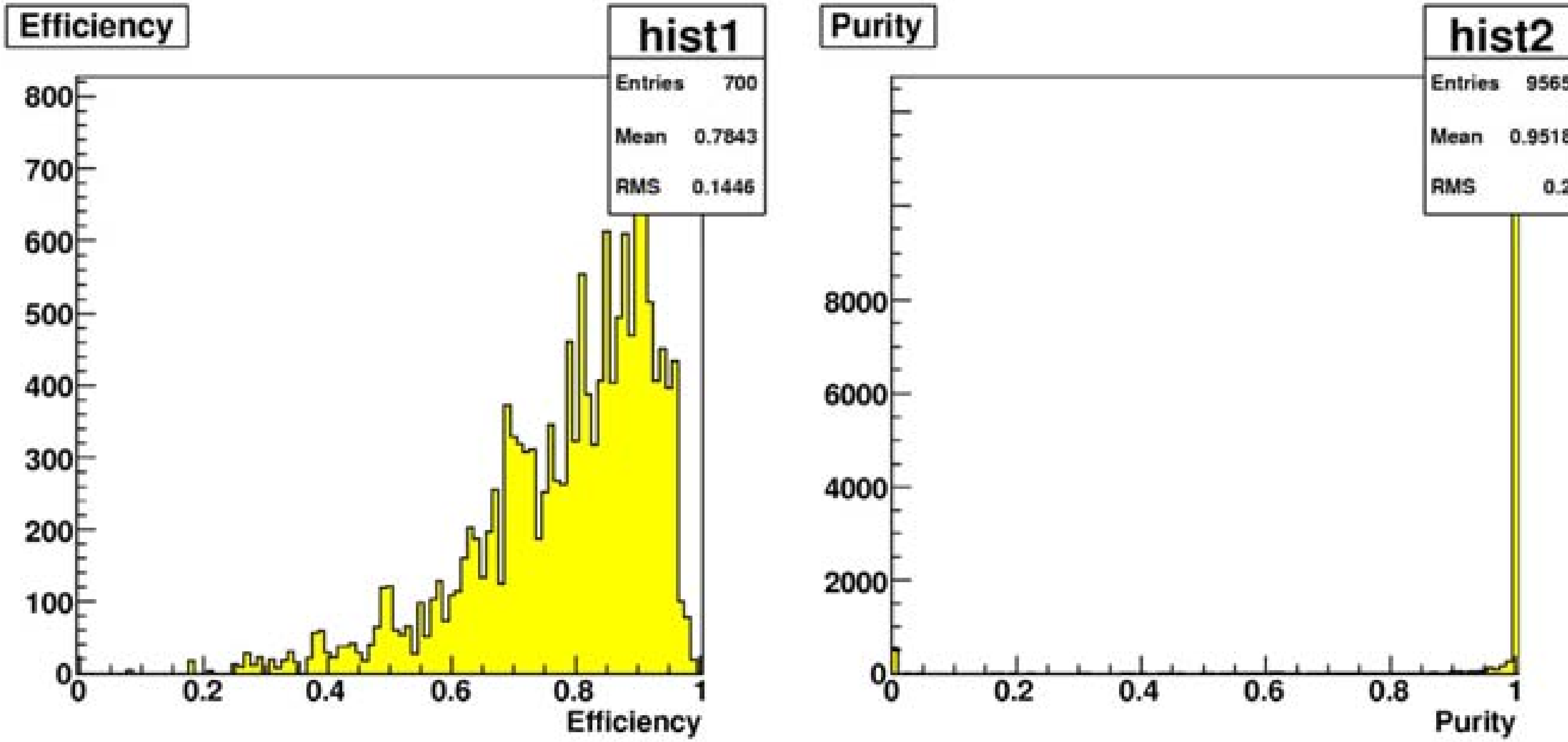
Make a small tube (R = 5cm) along mother small cluster's thrust axis in the ECAL region. (thrust axis is calculated using energy weighted fired cell position)

Check longitudinal shower profile within a tube.

1. **Calculate mean shower depth from ECAL inner surface**
2. **Fit the shower profile by gamma distribution function.**
3. **Fit the shower profile by linear function. (reject MIP)**
4. **Calculate the layer ID which has maximum total energy deposit.**

(please check slide in PFA session (22th

Result of efficiency and purity

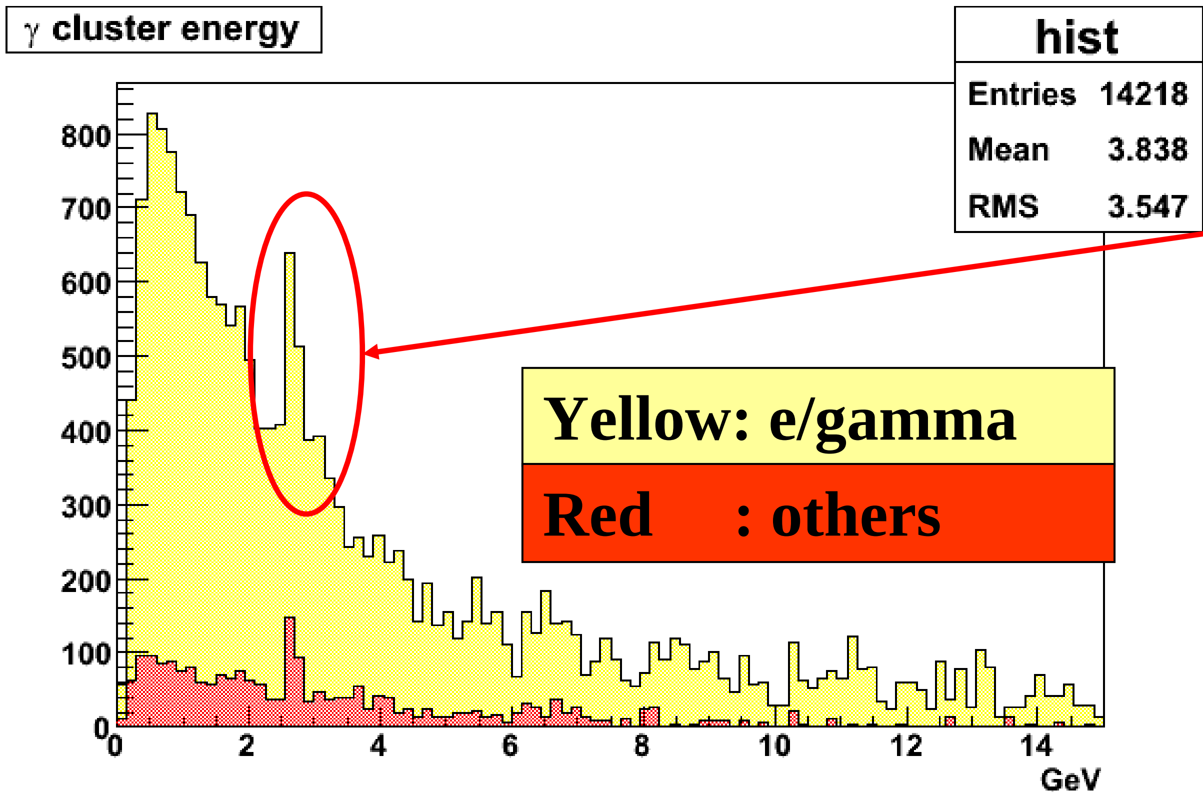


(Z->qqbar @ Ecm = 91.2 GeV)

e,gamma:Efficiency = 78.4%, purity = 95.2% (e-weighted)

Problem and Idea

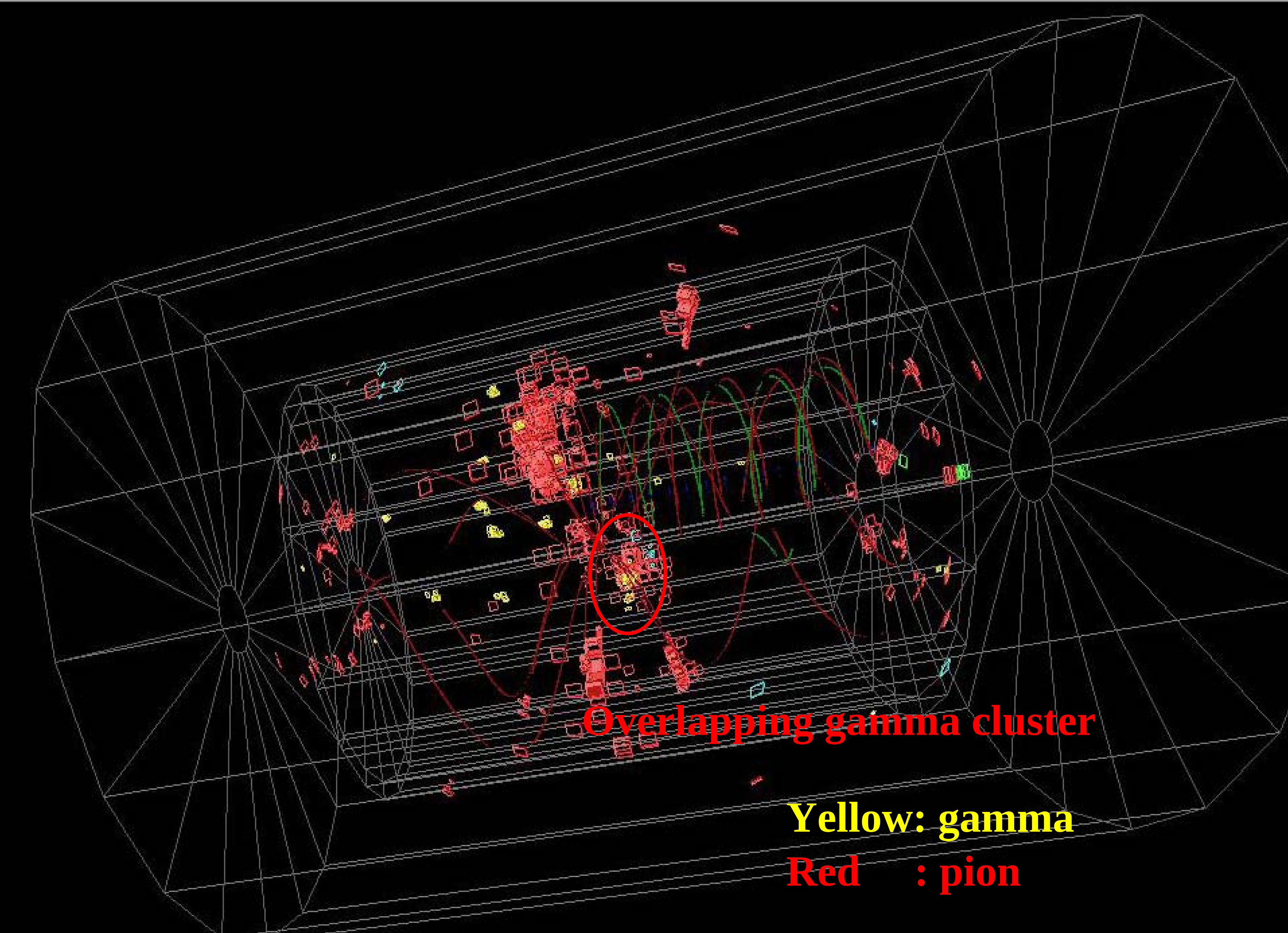
Cluster energy and purity

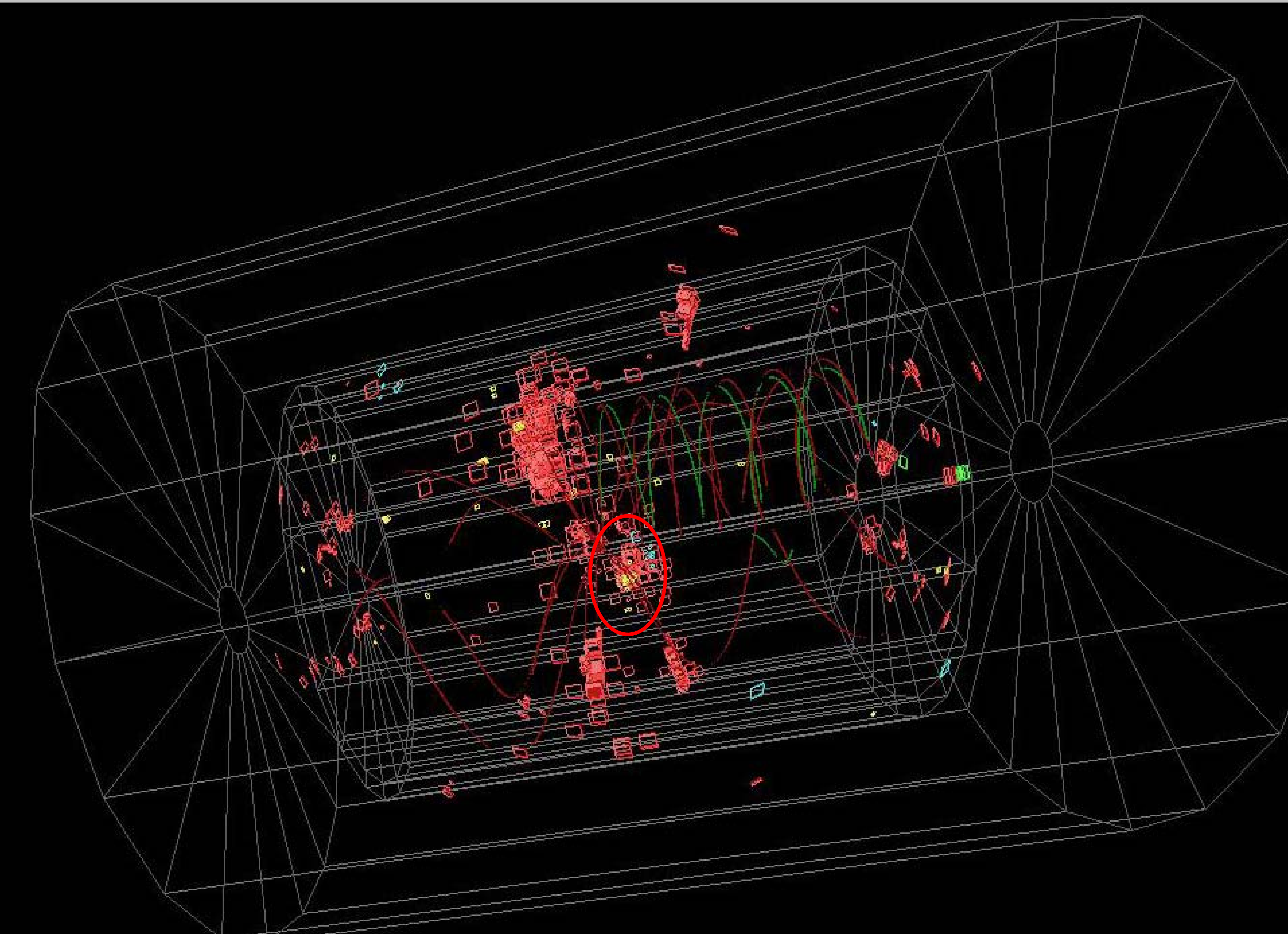


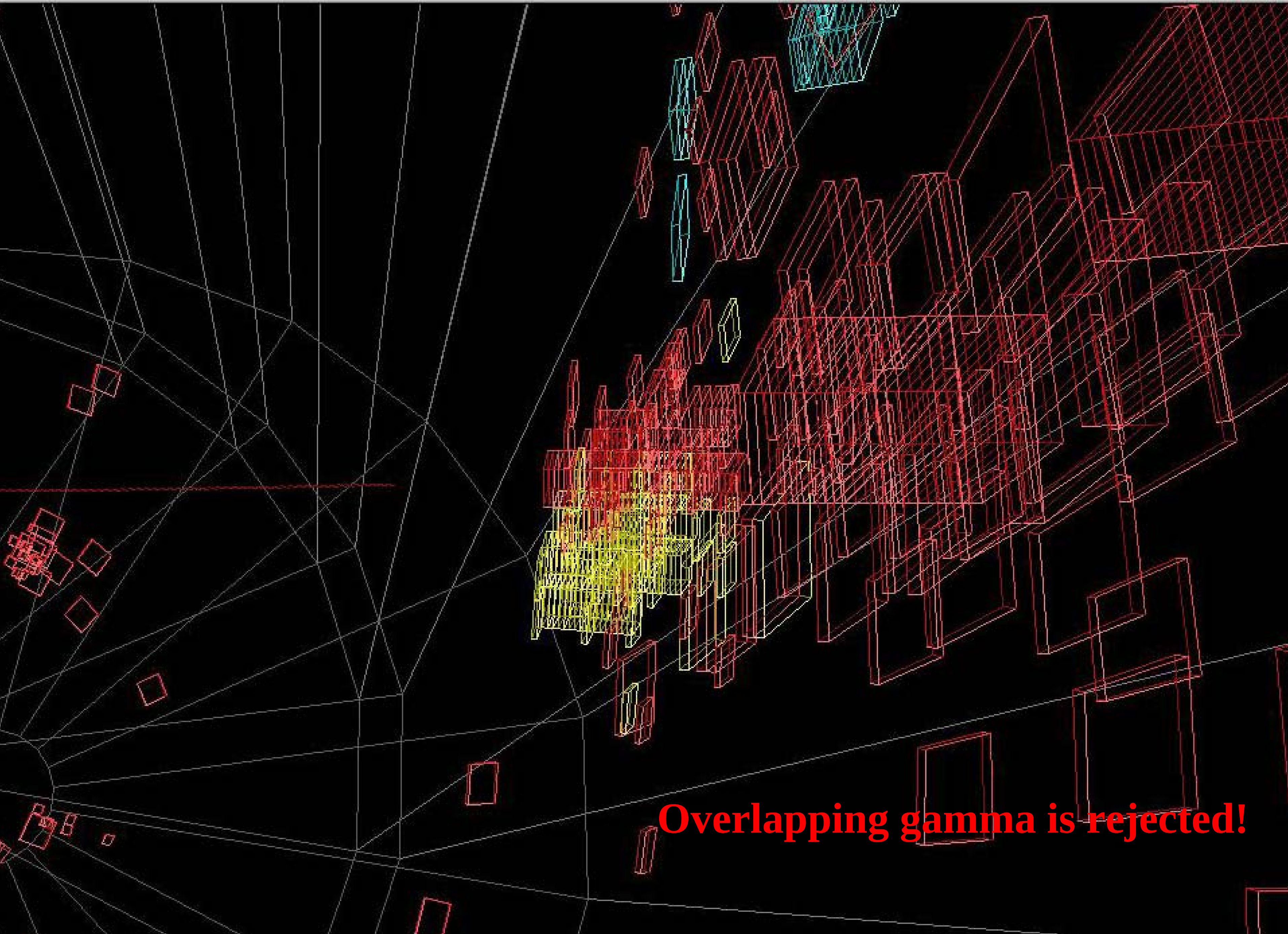
This peak consists to Small cluster's energy upper limit!

We can't contain enough small clusters within R=5cm tube.

Purity is worth at low energy region. It means low energy (charged) hadrons are regarded as gamma.


Overlapping gamma cluster
Yellow: gamma
Red : pion




Overlapping gamma is rejected!

Problem

1. **We can’t collect gamma origin small clusters by R=5cm tube (with 4cm tile size configuration)**
2. **How to reduce low momentum hadrons contamination?**
3. **How to separate overlapping clusters?**

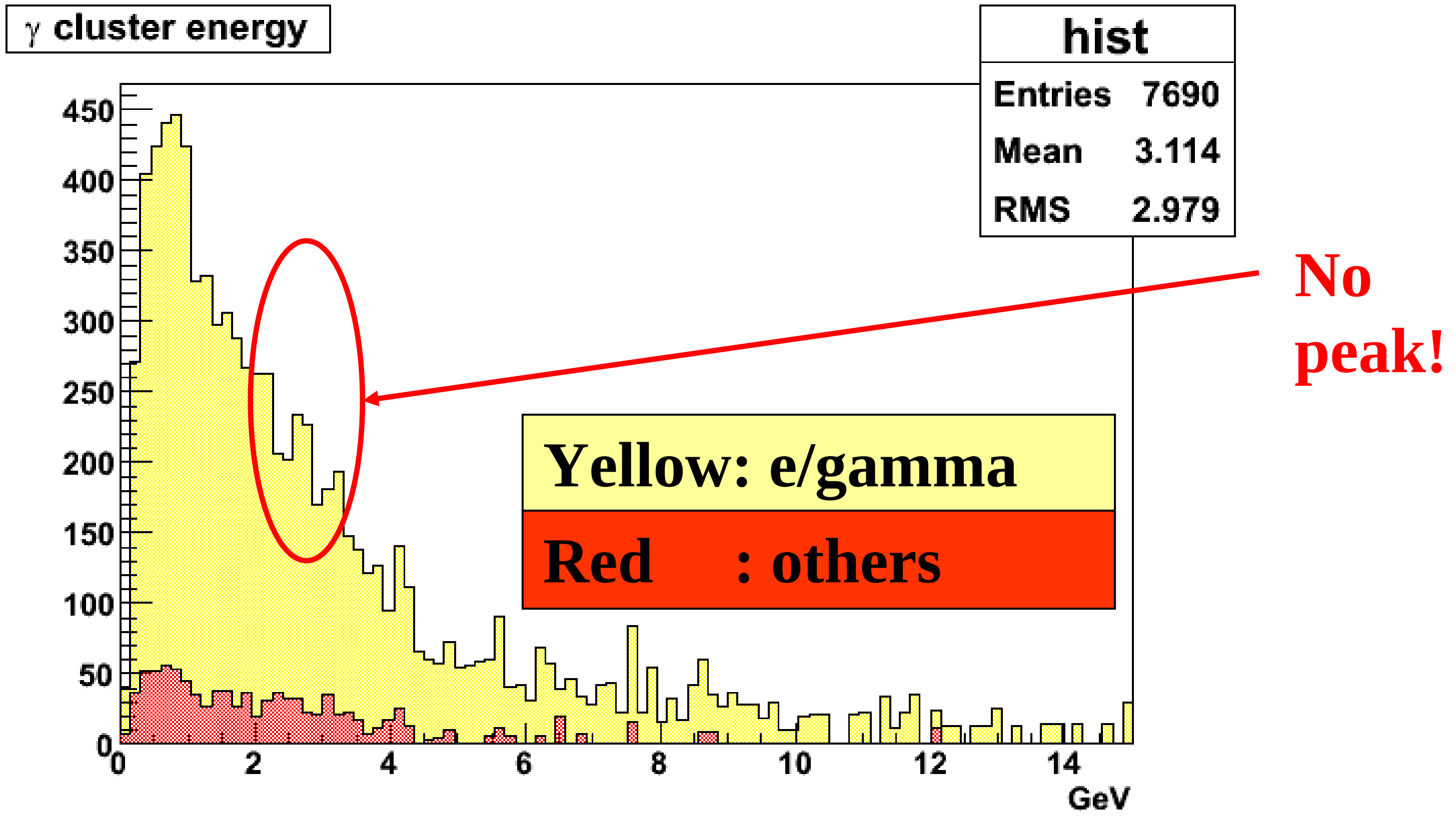
How to collect small clusters?

To collect enough small clusters…

1. **Make tube radius larger → purity become worth**
2. **Make tile size smaller (R_M ~ 2cm.→5cm is enough large)**
3. **Modify small clustering method**
4. **Do not use small clustering method → ??**

etc…

1cm x 1cm tile size case



We can collect small clusters by simple tube method.

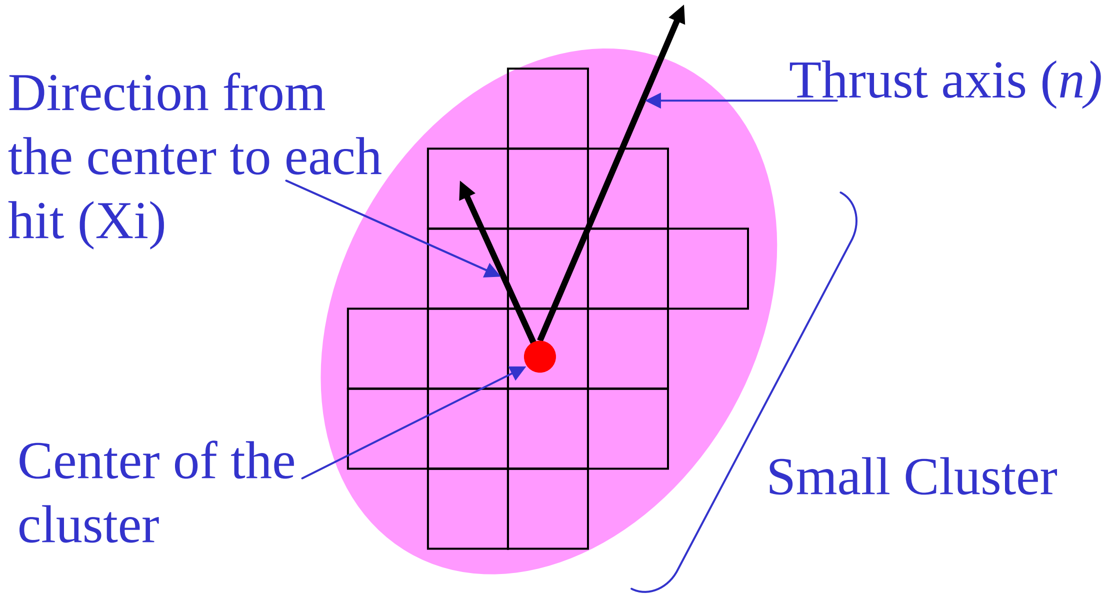
How to reject low momentum hadrons?

We have useful variables…

- *Energy-weighted Thrust & Broadening*

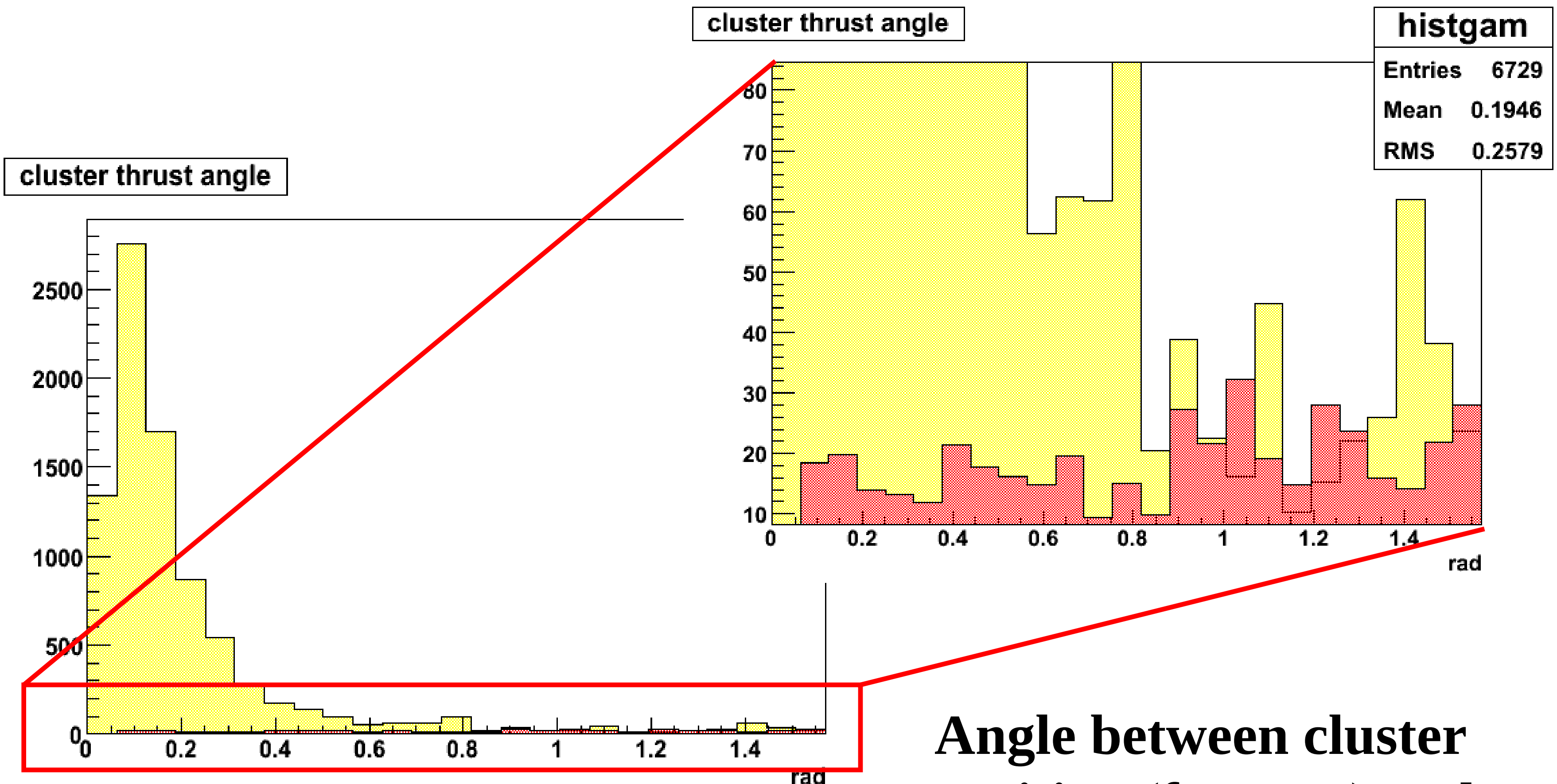
$$T \equiv \frac{\sum_i |\vec{X}_i \cdot \vec{n}| E_i}{E_{total} \sum_i |\vec{X}_i|}$$

$$B \equiv \frac{\sum_i |\vec{X}_i \times \vec{n}| E_i}{E_{total} \sum_i |\vec{X}_i|}$$



- Thrust axis n is defined as to maximize the T.

Cluster direction



Angle between cluster position (from IP) and thrust axis.

with 1cm x 1cm tile size configuration

How to separate overlapping clusters?

We need to modify small clustering algorithm…

Current small clustering algorithm:

1. Find the most energetic hit cell

2. Collect its fired neighbors from the closest one (spherical)

(upper limit for total energy deposition ~50MeV)

Idea (Not studied yet)

1. Collect neighbor cells using tube?? (set tube radius larger and larger)

2. Set high energy threshold → small clustering → Set energy threshold lower → small clustering → …. (use energy density)

3. Do not set energy upper limit??

Summary

· **We got ~78% efficiency and ~95% purity using the nearest track distance requirement + longitudinal shower profile search.**

· **Current gamma finding method has low purity at low energy region.**

· **Need modification for our current small clustering method and/or tube size for gamma-clustering.**

Next step

- **Study energy/angle dependent clustering method (change tube size depend on energy etc.) and re-consider small clustering method.**
- **Reject low momentum hadrons. (which related to low momentum track matching)**
- **Study other cell size configuration and other physics event case.**
- **Try to use H-matrix (SiD group proposal)**

Backup Slides

Clustering flow for GLD detector

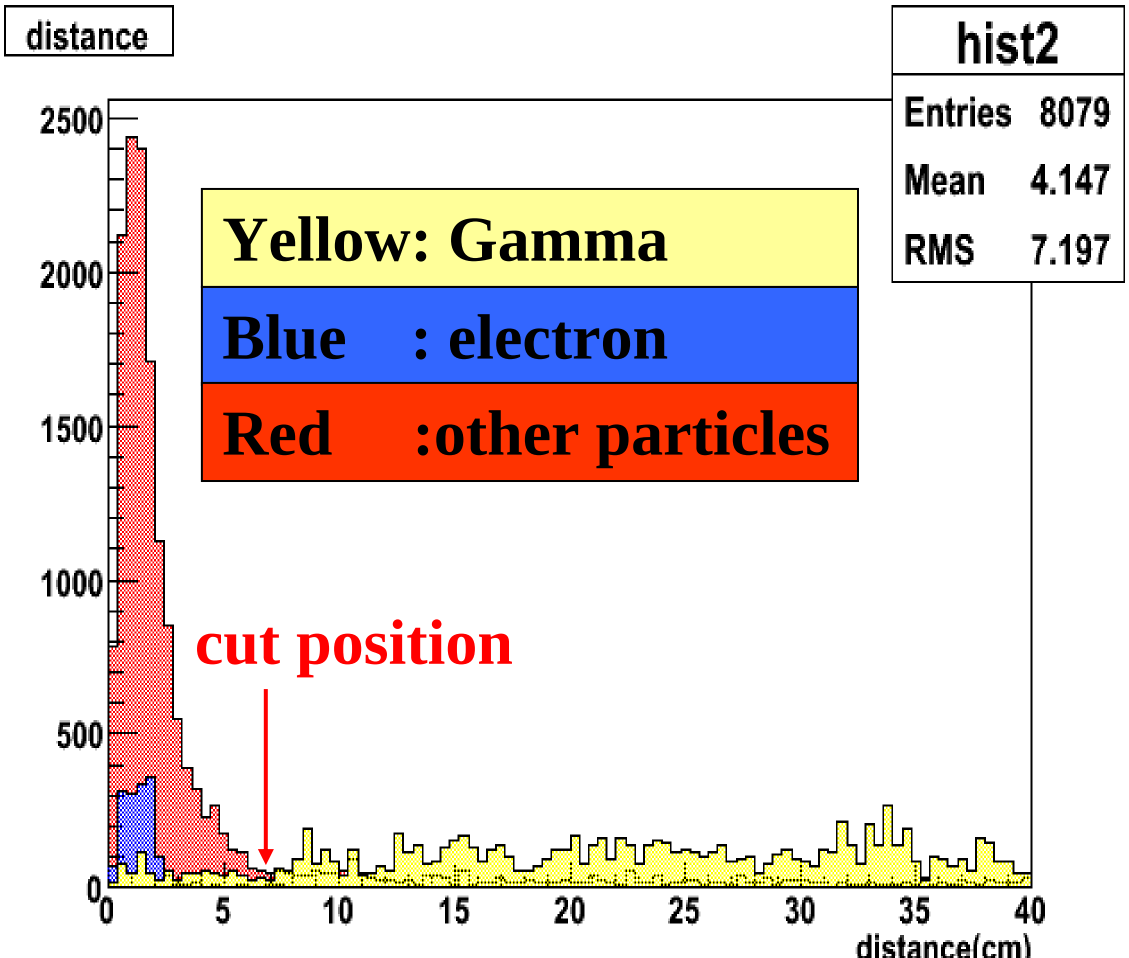
- Procedure of the GLD-PFA

1. Small Clustering and Gamma Finding - Collect fired cells with its neighbors. - Separate gamma from hadrons.
2. Cluster-Track Matching - Separate charged particles from neutral particles.
3. Assuming the remaining hits are neutral hadrons.

Flow to make PFO

Note. Muon is rejected by cheated method at first

Distance from the nearest track



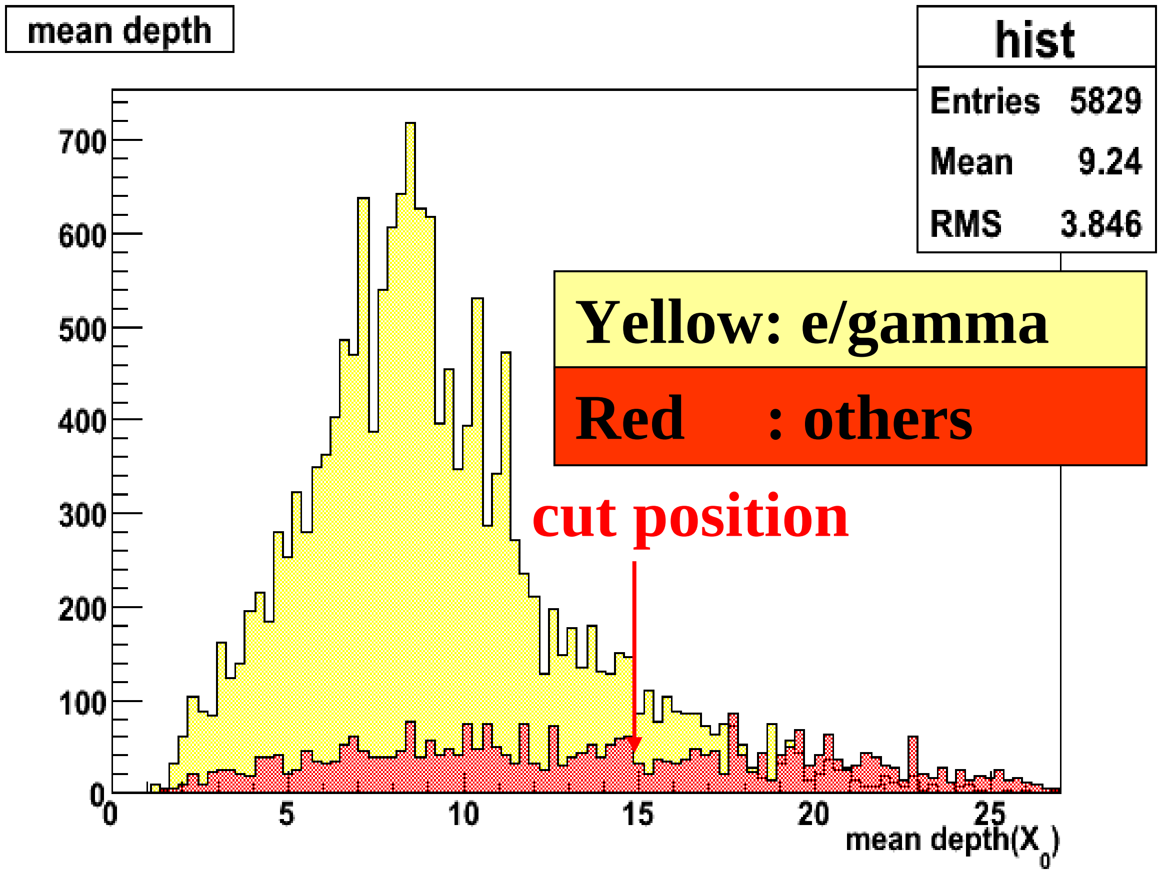
This plot shows distributions of the distance from the nearest track for all “mother” small clusters within ECAL region. (energy-weighted)

We set a cut at 7cm.

(Z->qqbar @ Ecm = 91.2 GeV)

Longitudinal shower profile

1. Mean shower depth (energy-weighted)



This plot shows a calculated mean shower depth from first layer (in unit of X0).

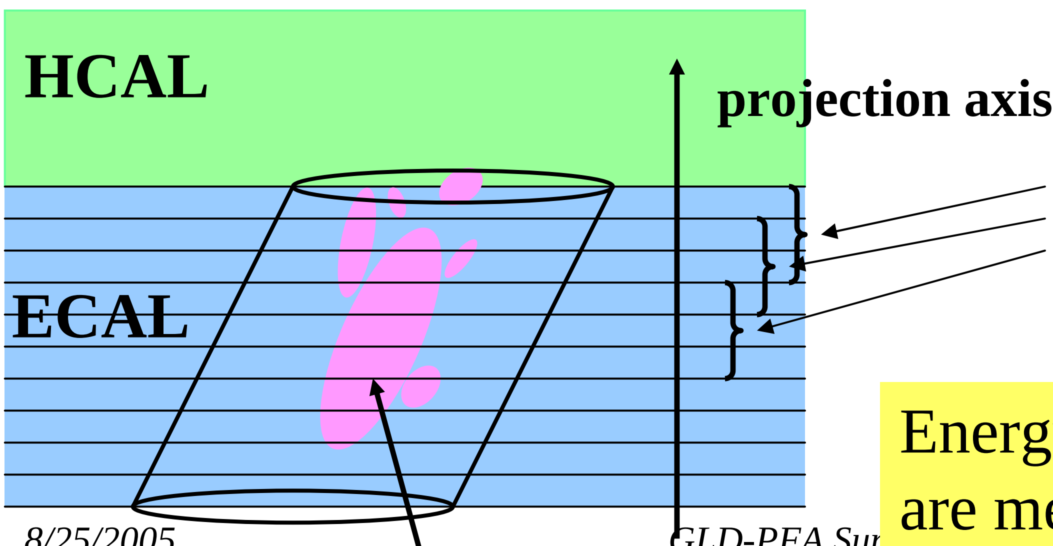
We set a cut position at **X0 = 15**.

(Z->qqbar @ Ecm = 91.2 GeV)

Longitudinal shower profile

2. Fit by gamma-distribution

Fit the longitudinal shower profile of the energy deposition within a tube as an electromagnetic cascade (gamma-distribution function).



take an average energy deposit for each 3-layers

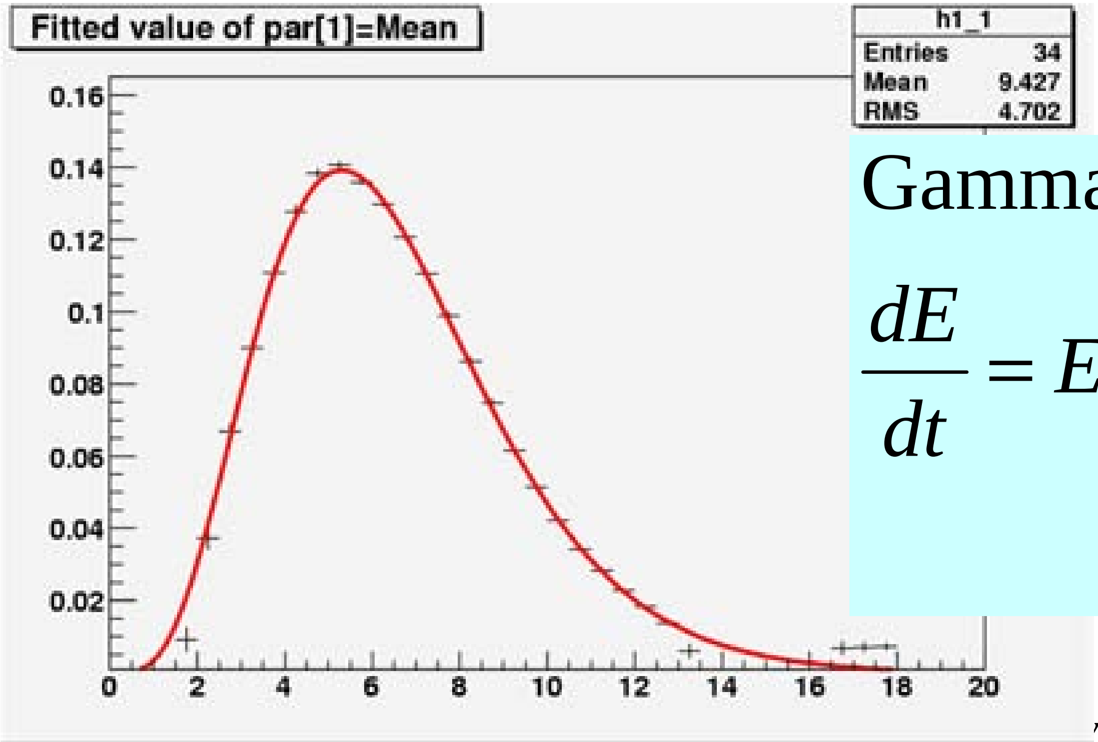
mother small cluster

Energy deposit in three layers are merged to reduce fluctuation.

Longitudinal shower profile

2. Fit by gamma-distribution

The result of fitting for a single particle case (gamma at 3GeV)

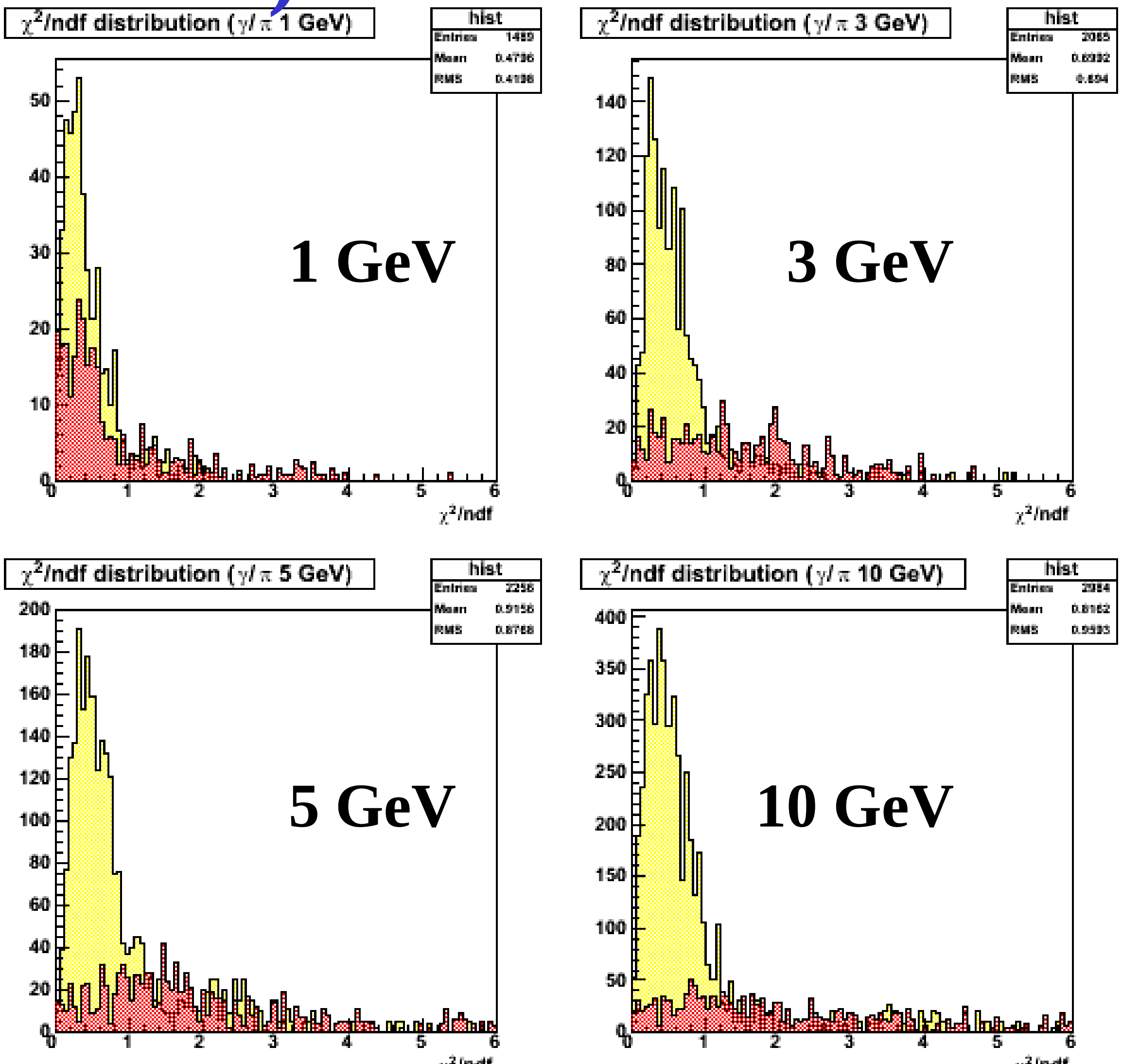


Gamma Distribution Function

$$\frac{dE}{dt} = E0 \cdot b \frac{(bt)^{a-1}\exp(-bt)}{\Gamma(a)}$$

where $t = x / X_0, b \cong 0.5$

Fit by gamma distribution (single particle)

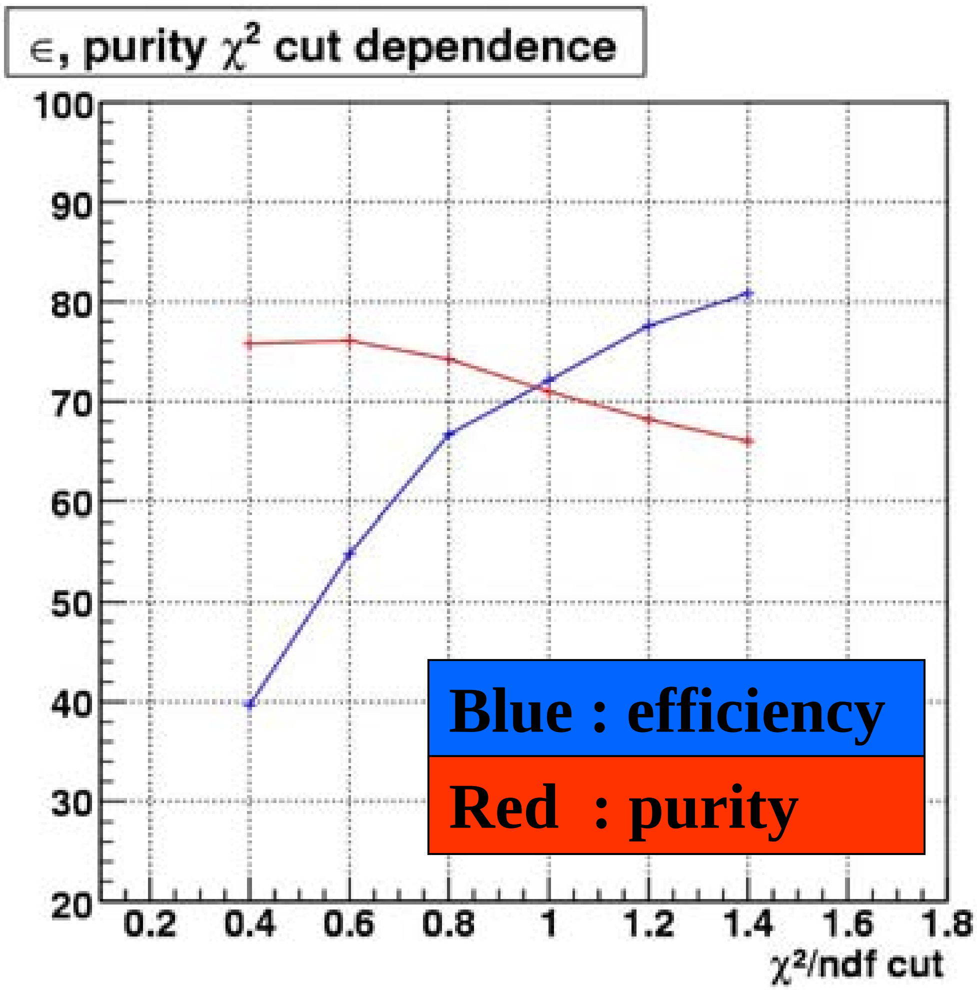


Yellow: gamma

Red : pion

In low momentum case, we can not separate pion from gamma effective.

Fit by gamma distribution

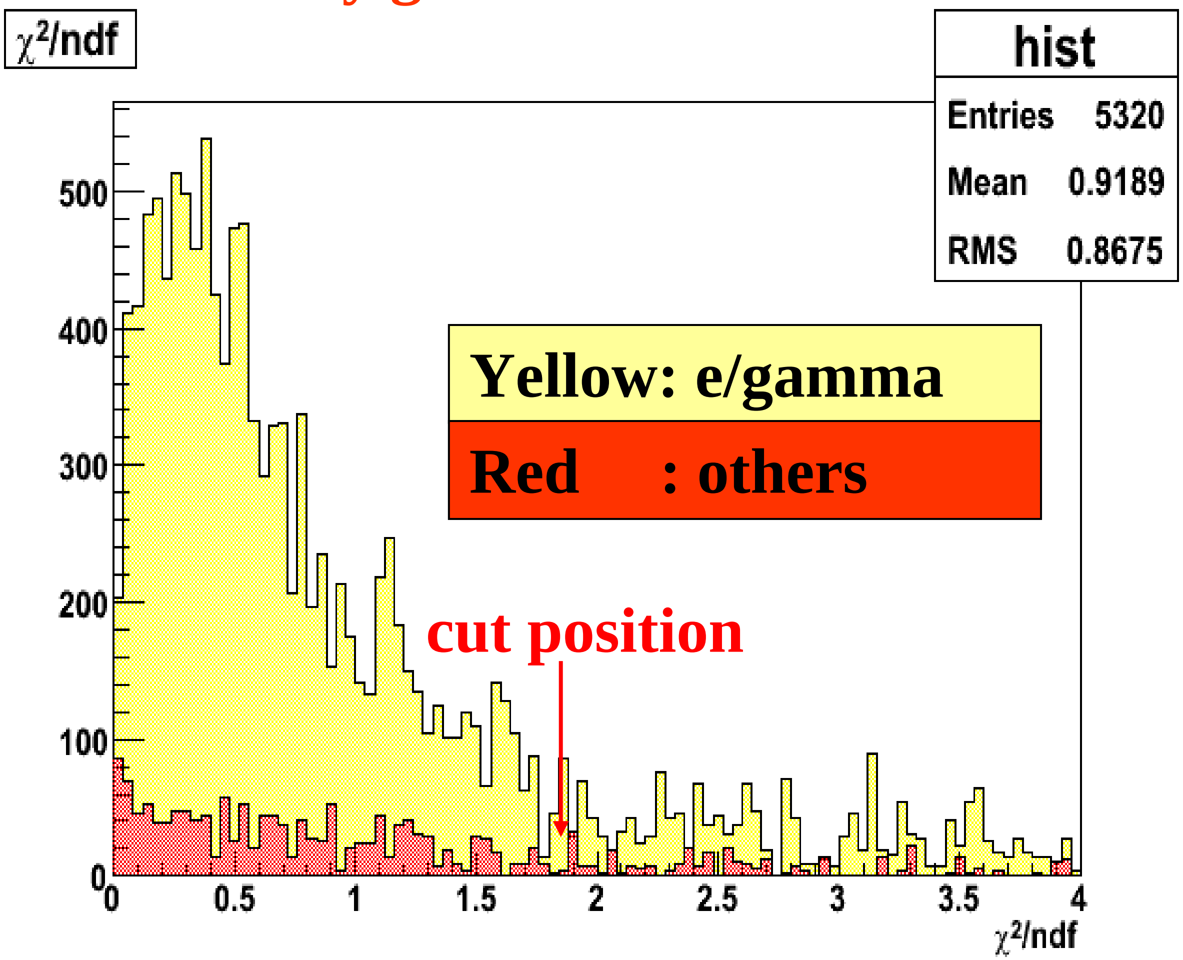


If we set a cut using a result of fit by gamma-distribution, it doesn't have high efficiency for electron/gamma finding. (maximum ~ 90%)

(Z->qqbar @ Ecm = 91.2 GeV)

Longitudinal shower profile

2. Fit by gamma-distribution



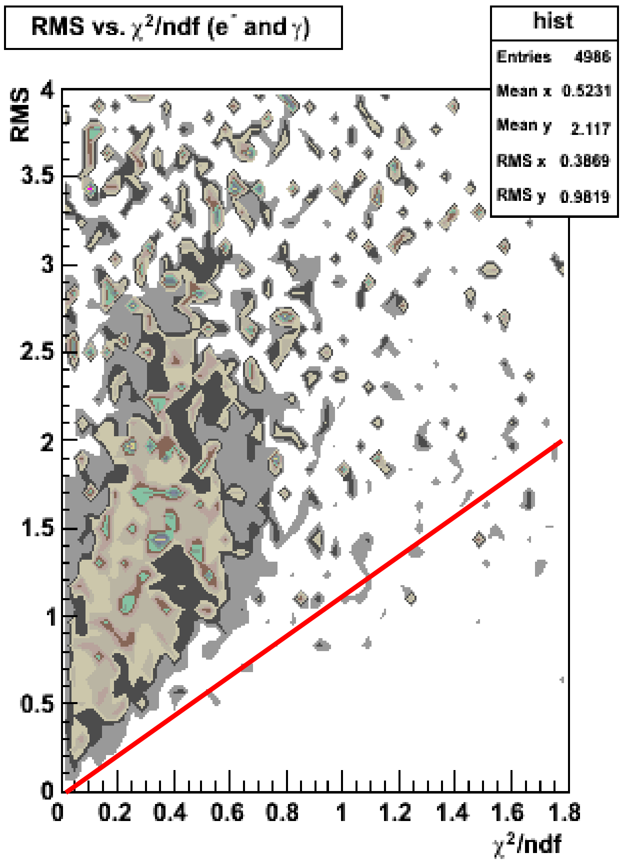
(Z->qqbar @ Ecm = 91.2 GeV)

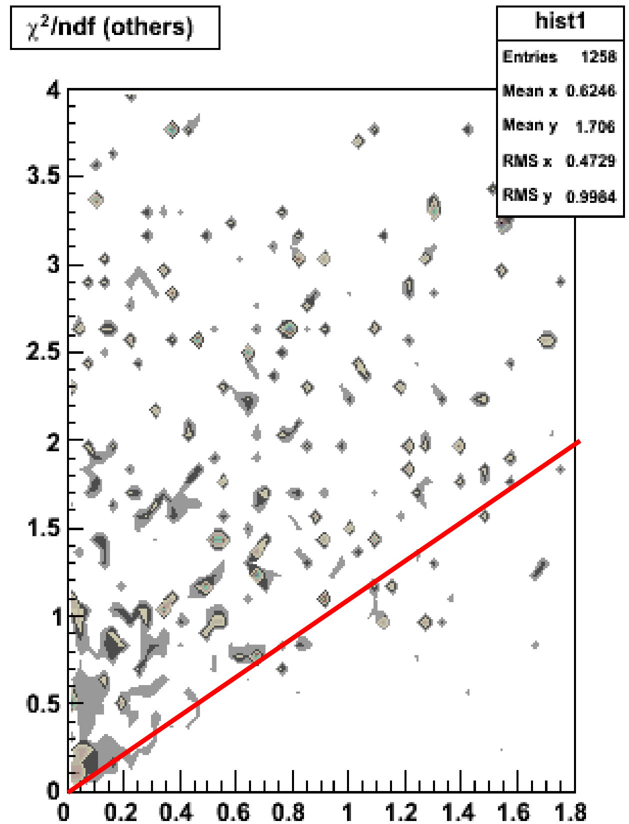
This plot shows a chi2/ndf result of fit. Fit is performed for longitudinal shower profile (energy deposit) by gamma-distribution.

We set a cut for chi2/ndf at 1.8.

Longitudinal shower profile

3. Fit by linear function (to reject MIP)





This plot shows a RMS vs. Chi2/ndf distribution.

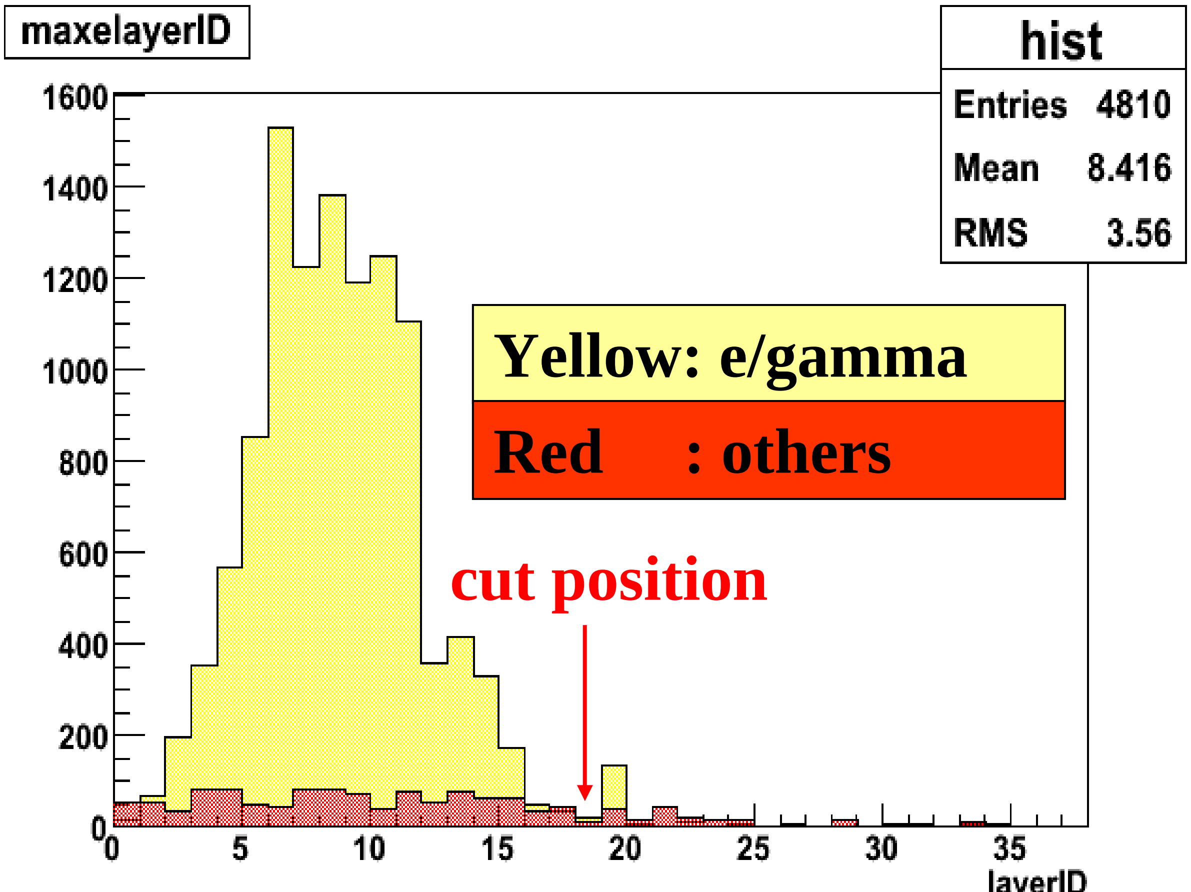
The fit result of RMS is used for the cut.

(RMS > chi2/ndf) **Because of some MIP cluster pass the chi2/ndf cut…**

(Z->qqbar @ Ecm = 91.2 GeV)

Longitudinal shower profile

4. Maximum energy deposition layer

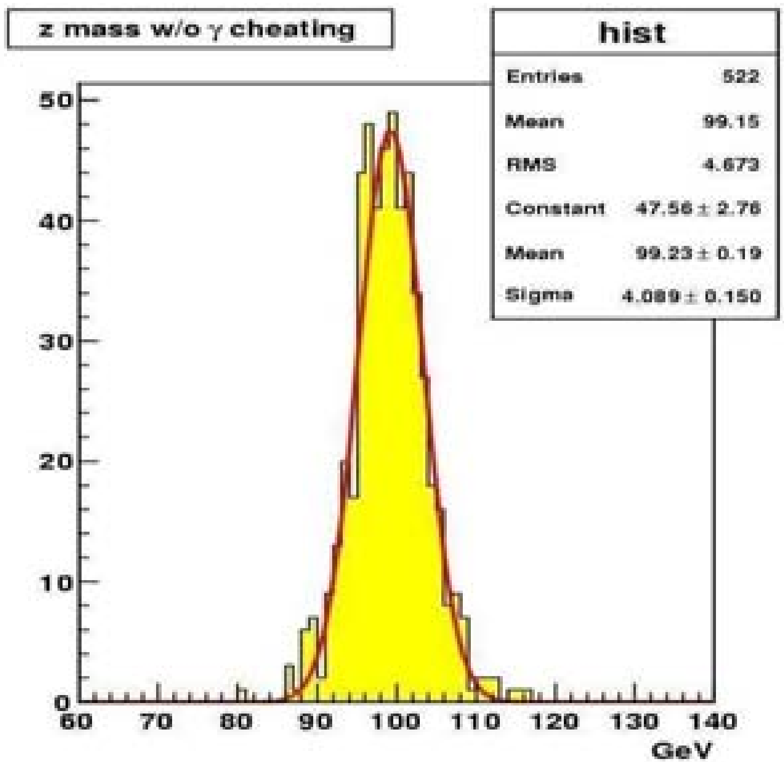


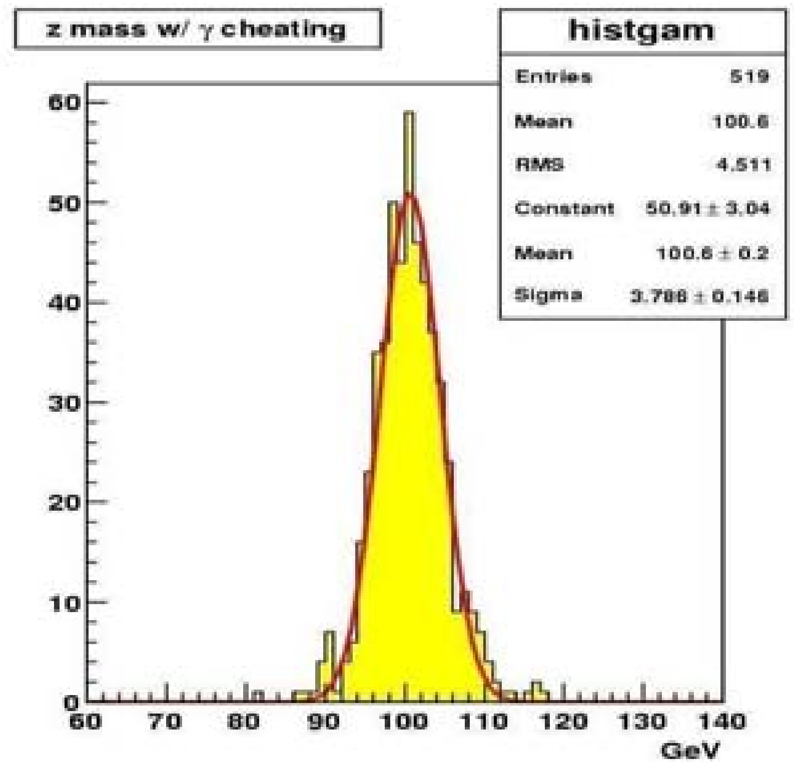
This plot shows a calculated layer ID which has maximum total energy deposit.

We set cut at 19.

(Z->qqbar @ Ecm = 91.2 GeV)

The result of energy sum





Realistic gamma finder

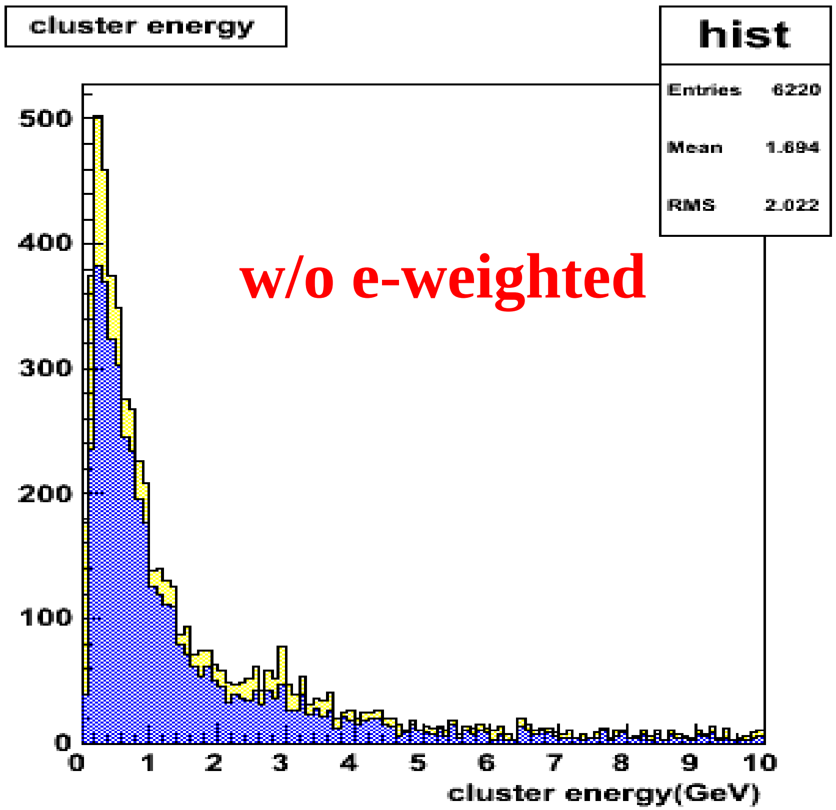
$$\sim 40.9\% / \sqrt{E}$$

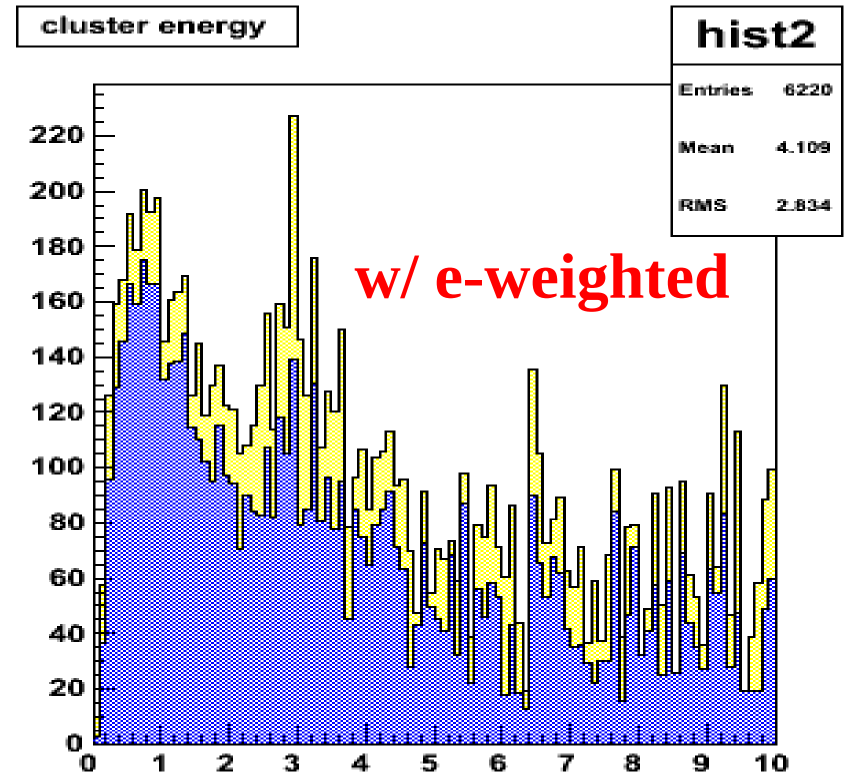
Cheated gamma finder

$$\sim 37.9\% / \sqrt{E}$$

track matching : $\varepsilon \sim 84.2\%$, *purity* $\sim 91.2\%$, missing energy (neutrino etc.) cheated

Cluster energy and efficiency



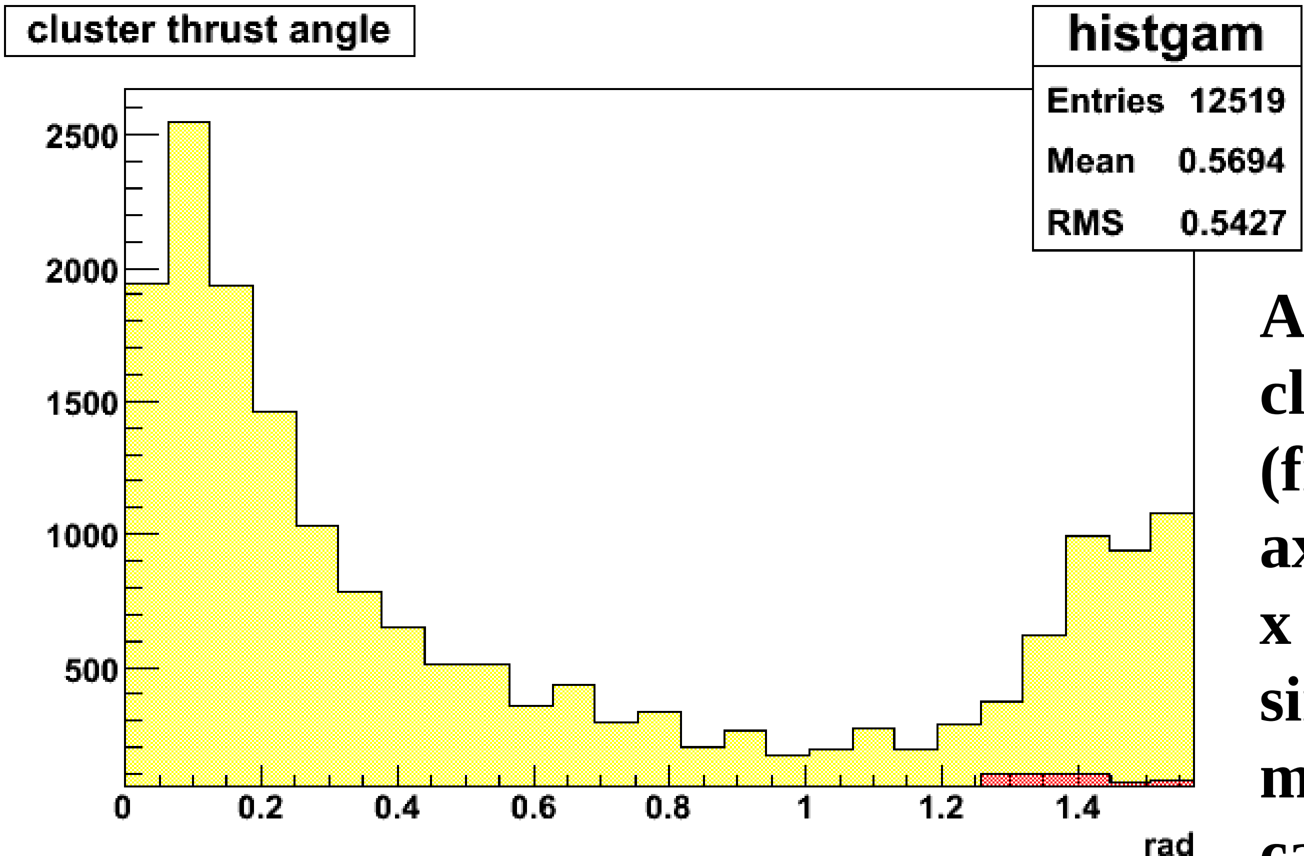


In low energy region, an efficiency of "Number of cluster" is low, but "Energy" efficiency is not so bad.

Yellow:Total

Blue :Regard as gamma

Cluster direction



with **4cm x 4cm tile size** **configuration**

Angle between cluster position (from IP) and thrust axis. (If we use 4cm x 4cm tile and simple calculation method, we cannot calculate thrust correctly)