A Clustering Algorithm for LumiCal

Halina Abramowicz, Ronen Ingbir,
Sergey Kananov, Aharon Levy, Iftach Sadeh

Tel Aviv University
DESY

FCAL Collaboration
High precision design

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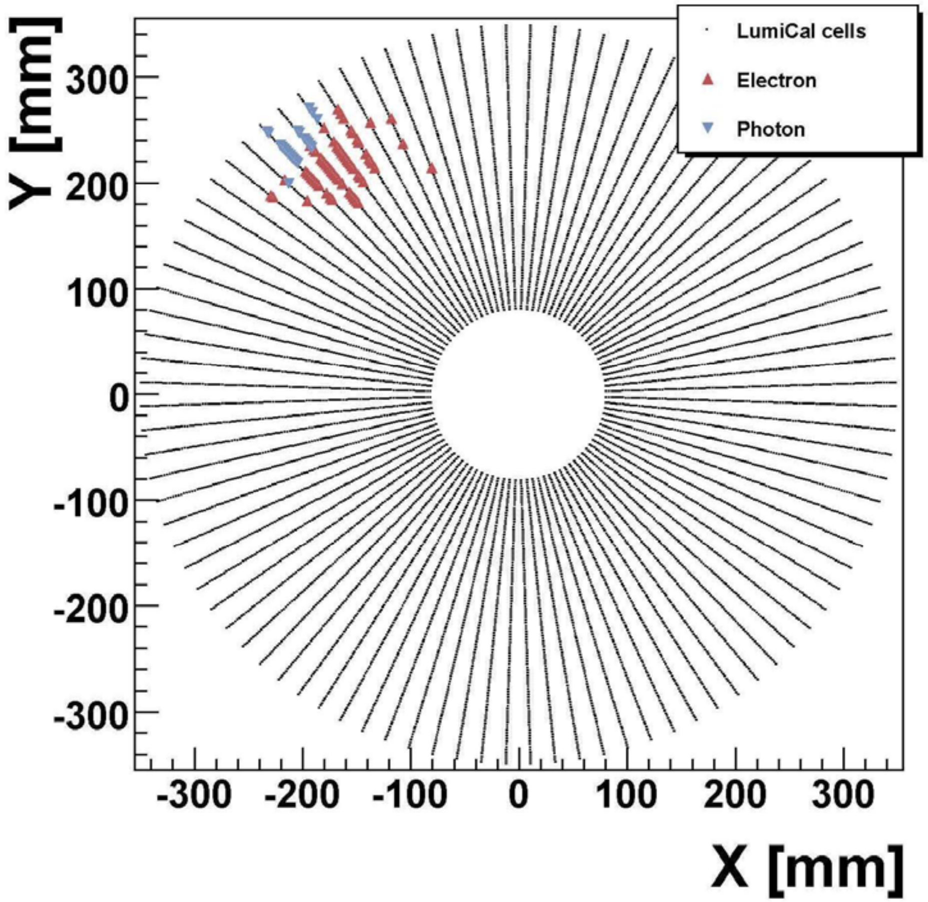
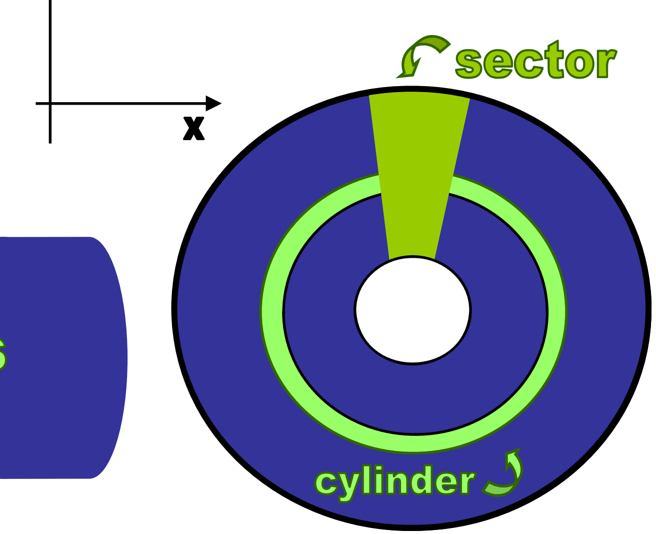
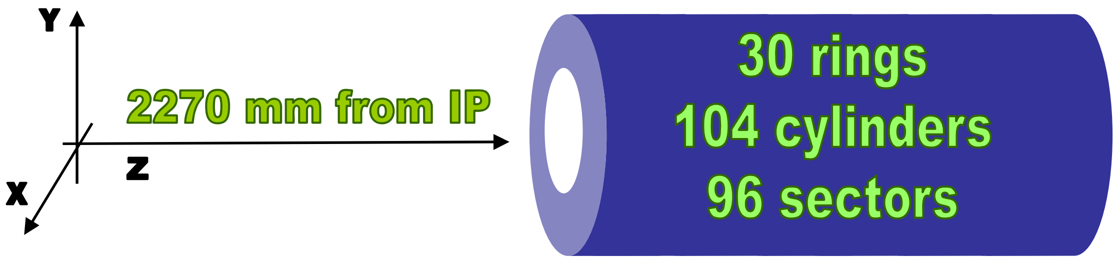
Detector design



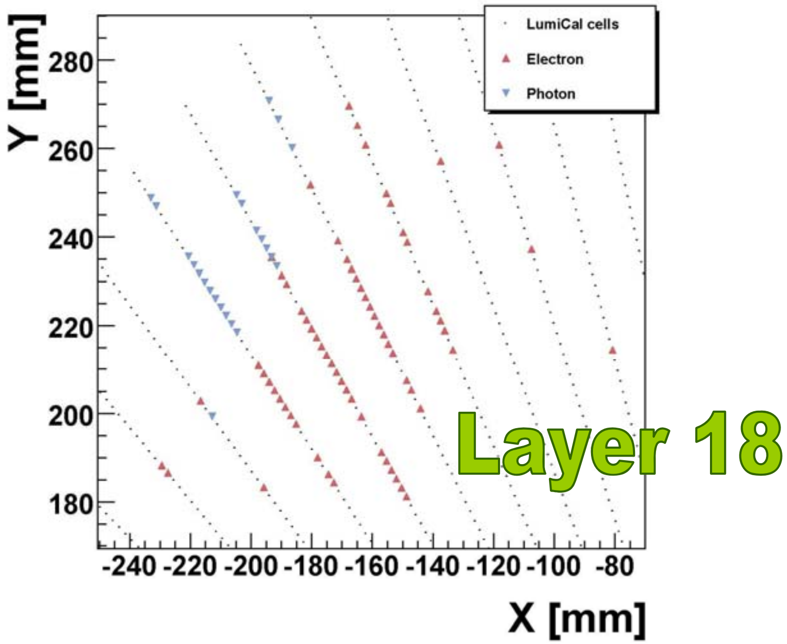
- Layer Gap - 0.1 mm
- Silicon Thickness - 0.3 mm
- Support Thickness - 0.6 mm
- Tungsten Thickness - 3.5 mm

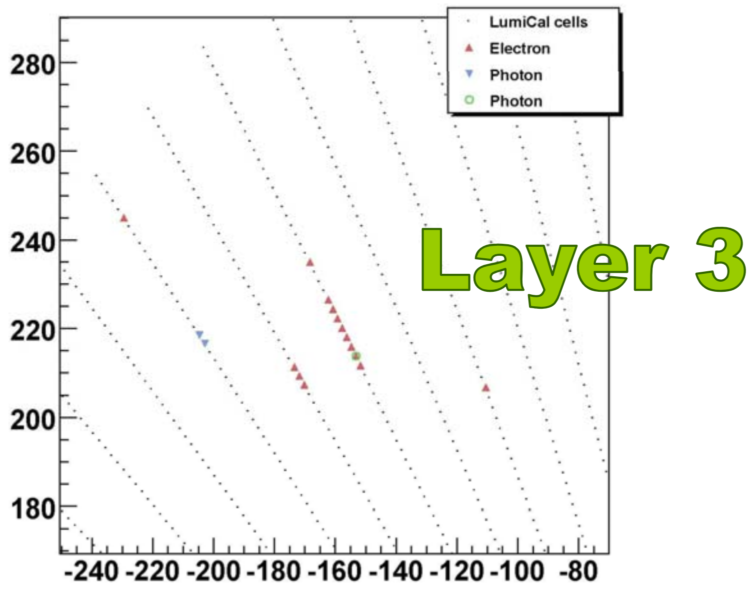
- Inner Radius - 80 mm
- Outer Radius - 350 mm
- Phi Cell Size - 131 mrad
- Theta Cell Size - 1.15 mrad
- Crossing Angle - 0 mrad



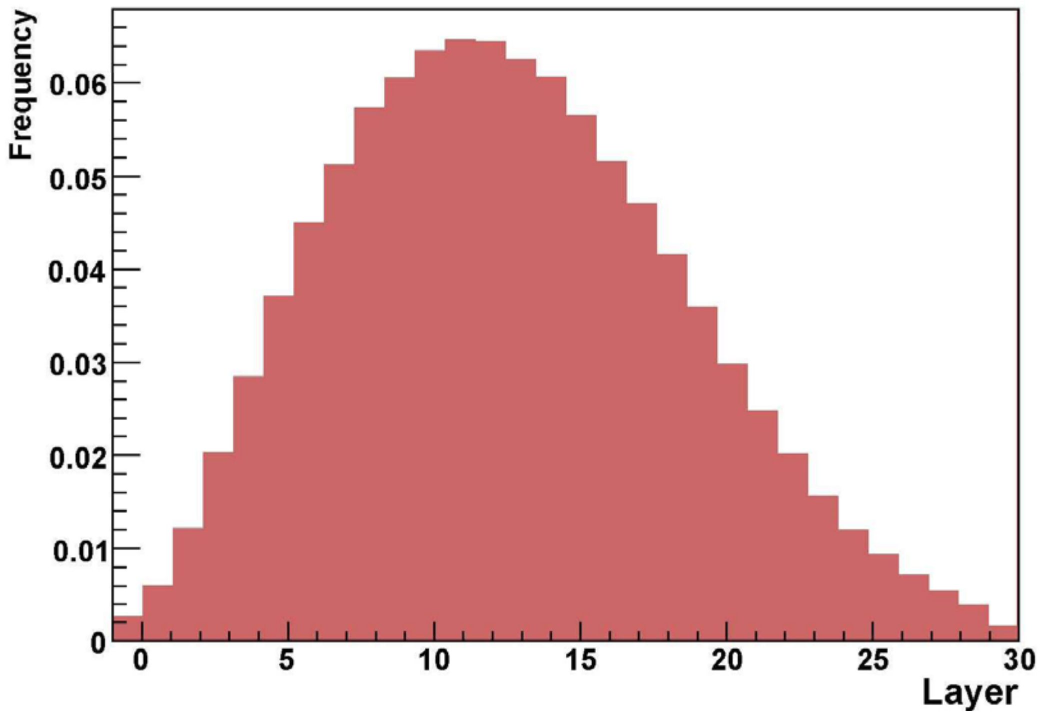


Properties of an EM shower in LumiCal





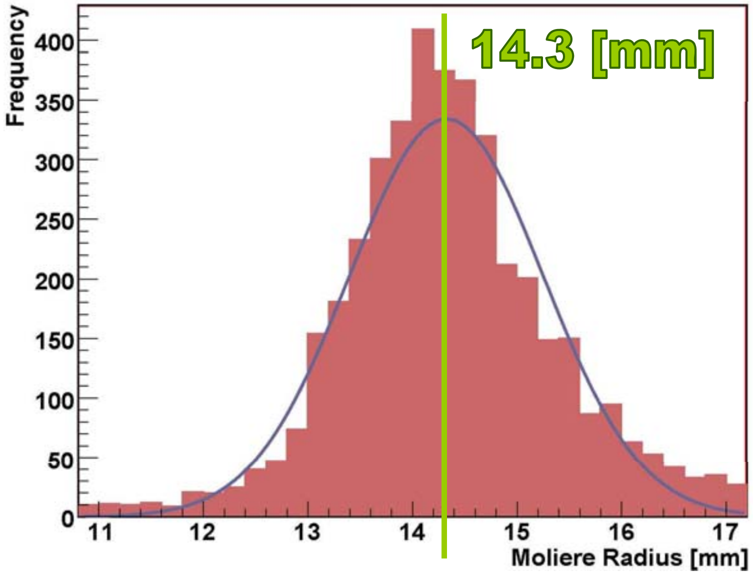
(normalized) Number of hits per layer



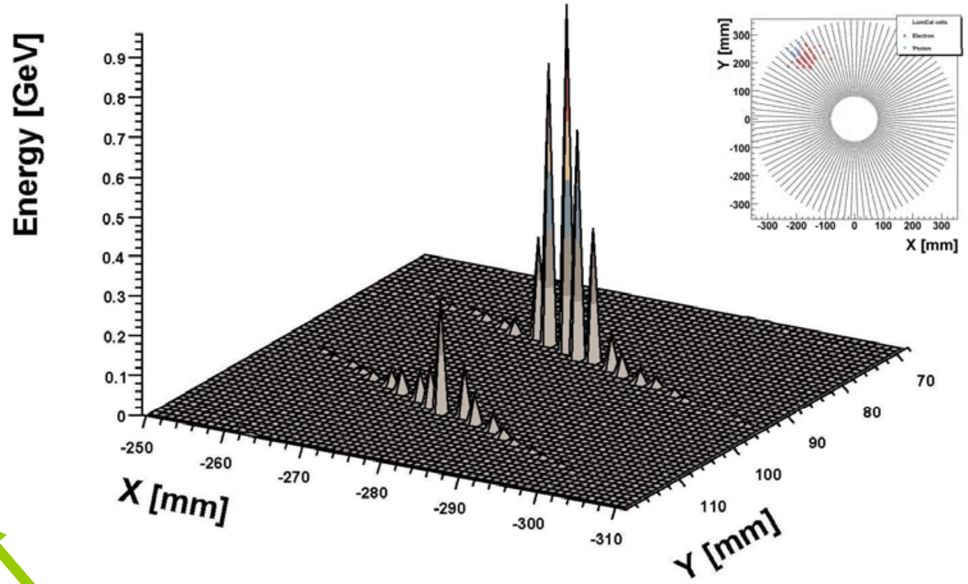
- Shower-peak layers are those layers which contain a significant fraction of the total hits $(\geq 4\%)$.

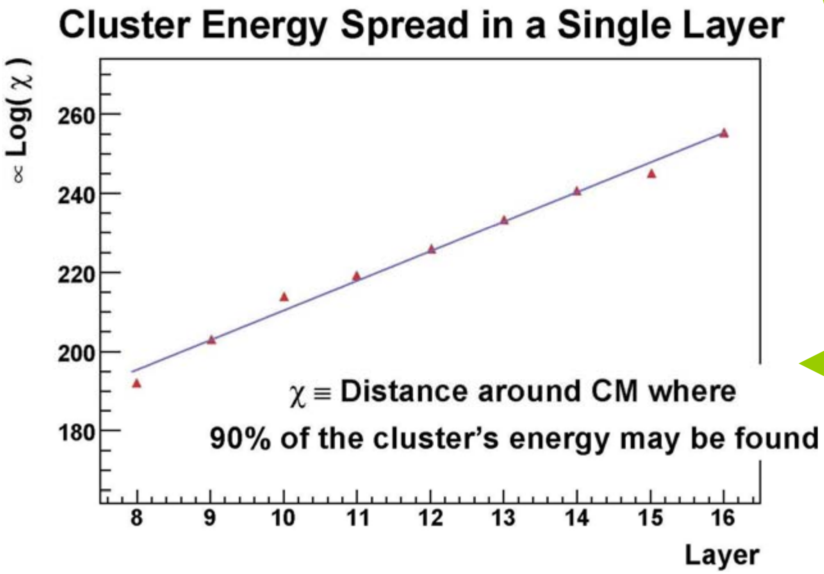
Properties of an EM shower in LumiCal

Moliere Radius



Integration over all layers
(after some energy cut)



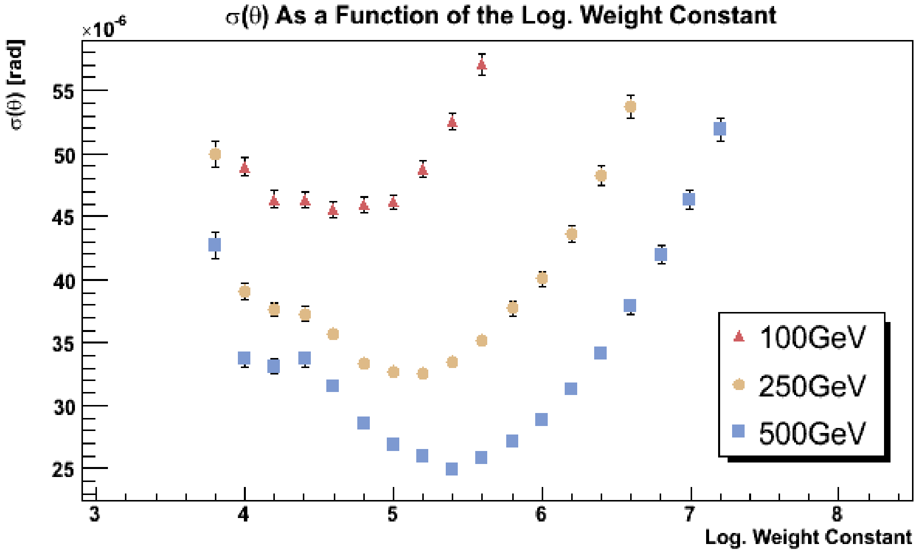


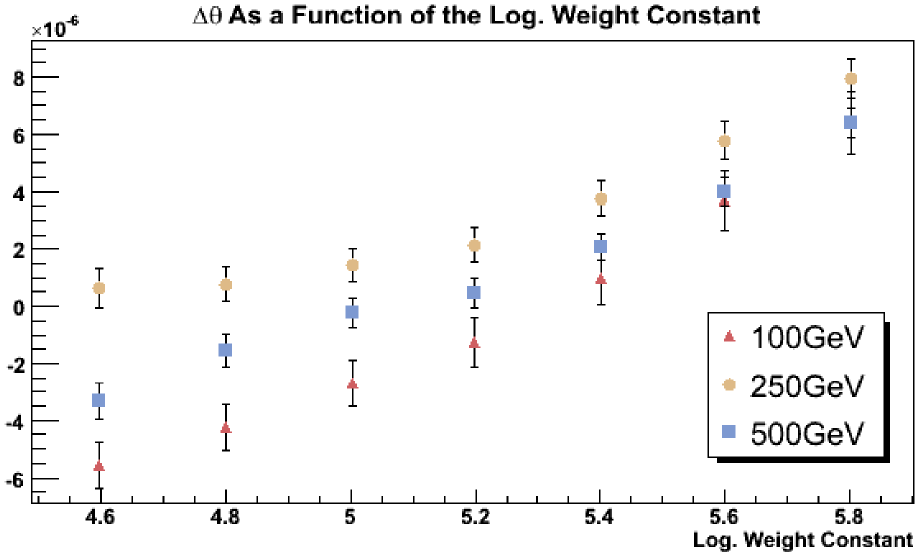
- The Molière radius is a global detector constant.
- Energy spread increases for deeper layers.

Properties of an EM shower in LumiCal

- The 2D center of mass (CM) of each cluster is computed using **logarithmic weighting** → Only hits of high energy contribute.

An example by way of θ reconstruction





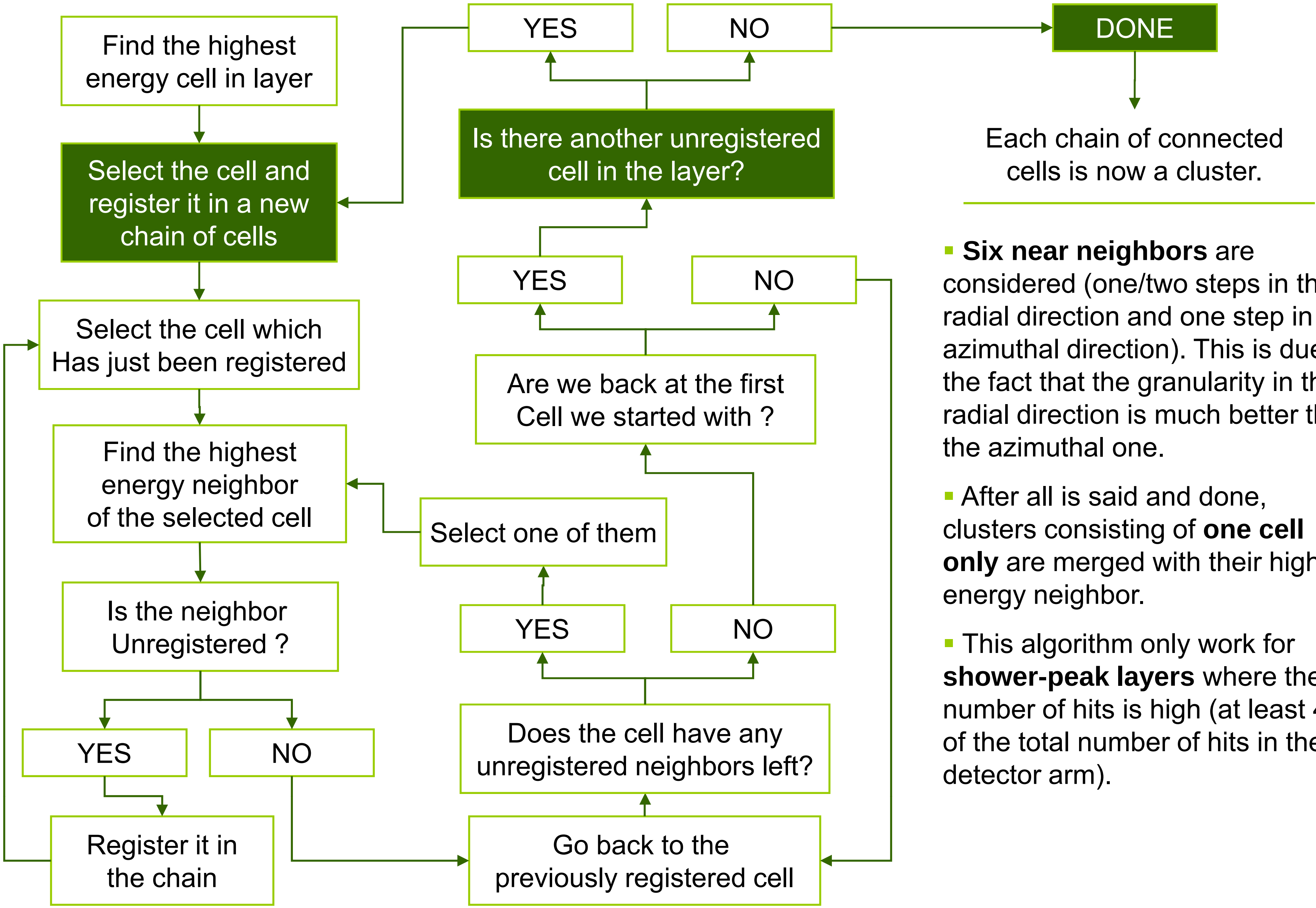
$$\theta_{rec} = \frac{\sum \theta_{Hit} \times W_{Hit}}{\sum W_{Hit}} \; , \quad W_{Hit} \equiv MAX\left\{ Const + Log\left(\frac{E_{Hit}}{E_{Total}}\right), 0 \right\}$$

Outline of the algorithm

1. Perform initial 2D clustering in shower-peak layers.
2. Extrapolate “virtual cluster” CMs in non shower-peak layers, and build real clusters accordingly.
3. Build (global) 3D “super clusters” from all 2D layer clusters.
4. Check cluster properties, and (try to) re-cluster if needed.

- Events were generated with **BHWIDE** (1.04) and simulated by **Mokka**(v06-03-p01) using **Geant4**(v4.8.1.p02). The super-driver LumiCalX of the LDC(00-03Rp) model was used to build LumiCal in Mokka.
- The clustering algorithm was written as a **Marlin** processor, using Marlin(v00-09-08).

Nearest neighbor 2D clustering

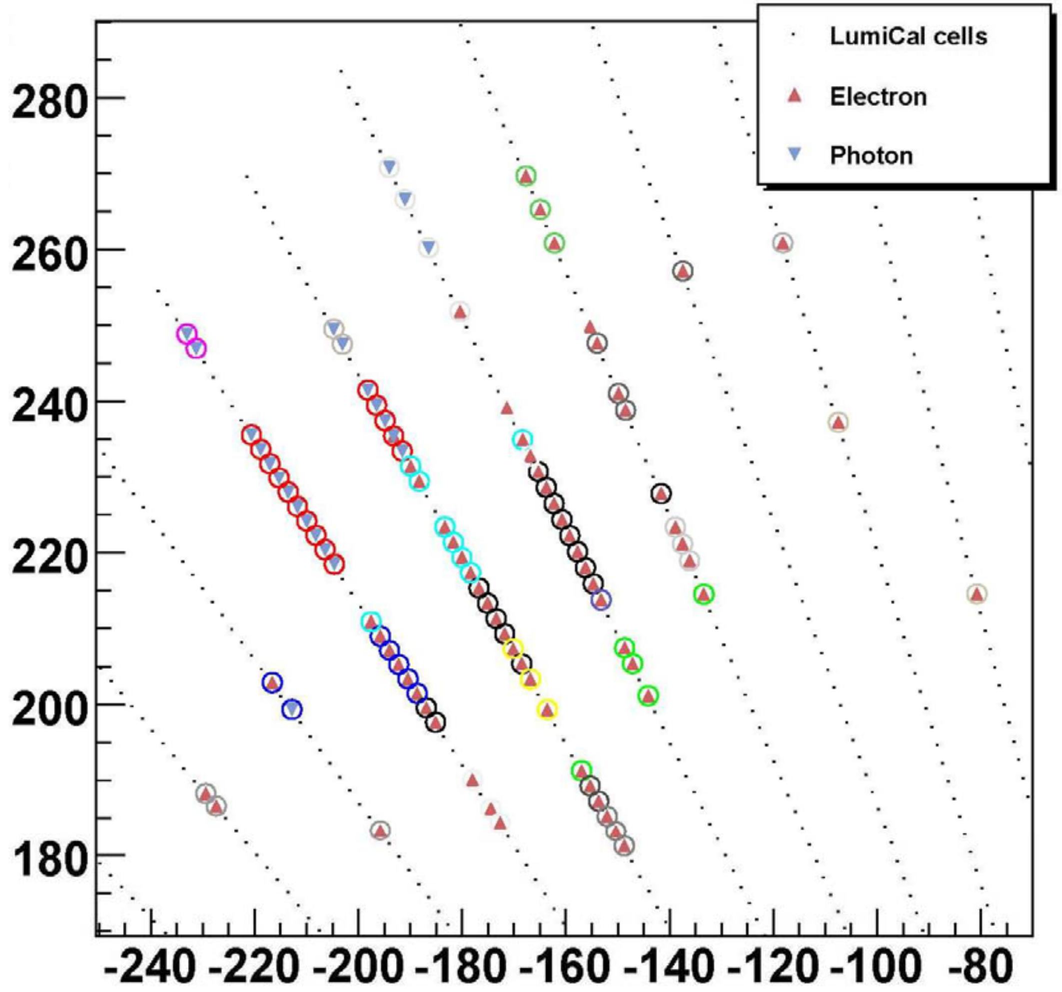


- **Six near neighbors** are considered (one/two steps in the radial direction and one step in the azimuthal direction). This is due to the fact that the granularity in the radial direction is much better than the azimuthal one.
- After all is said and done, clusters consisting of **one cell only** are merged with their highest energy neighbor.
- This algorithm only work for **shower-peak layers** where the number of hits is high (at least 4% of the total number of hits in the detector arm).

Nearest neighbor 2D clustering

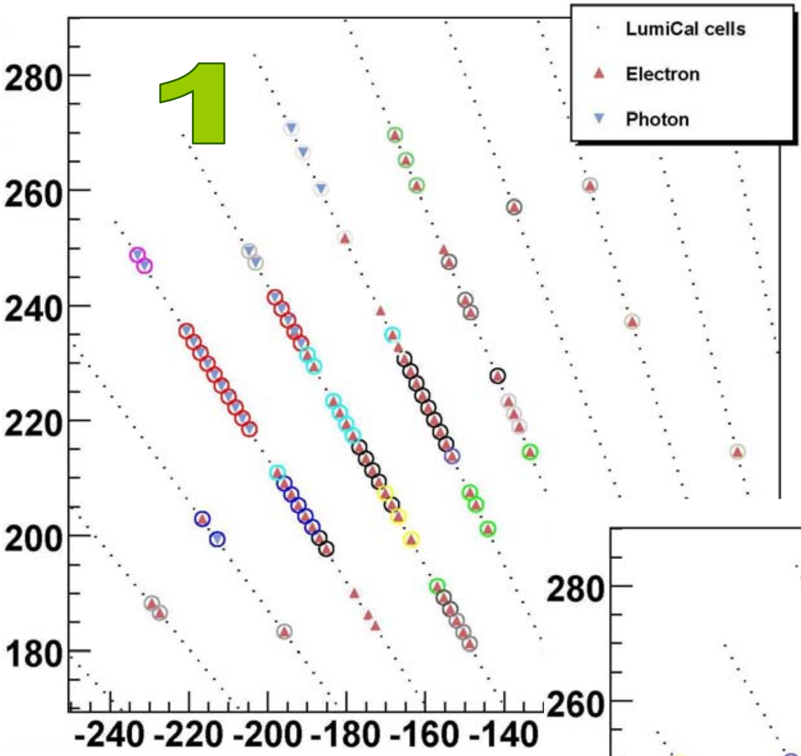
1. Each cell connects to its highest energy neighbor.
2. Small local clusters are created from the groups of connected cells.

- Initial clustering does not use low energy hits (hit must be $\geq 1\%$ of the total energy in the detector arm).
- This only work for the shower-peak layers where there are many hits.
- **Free Parameters:**
  - Who are a cell's near neighbors?
  - What's the minimal number of hits that makeup a shower-peak layer?
  - Which cells are considered as near neighbors?



(Each circle-color represents a different cluster)

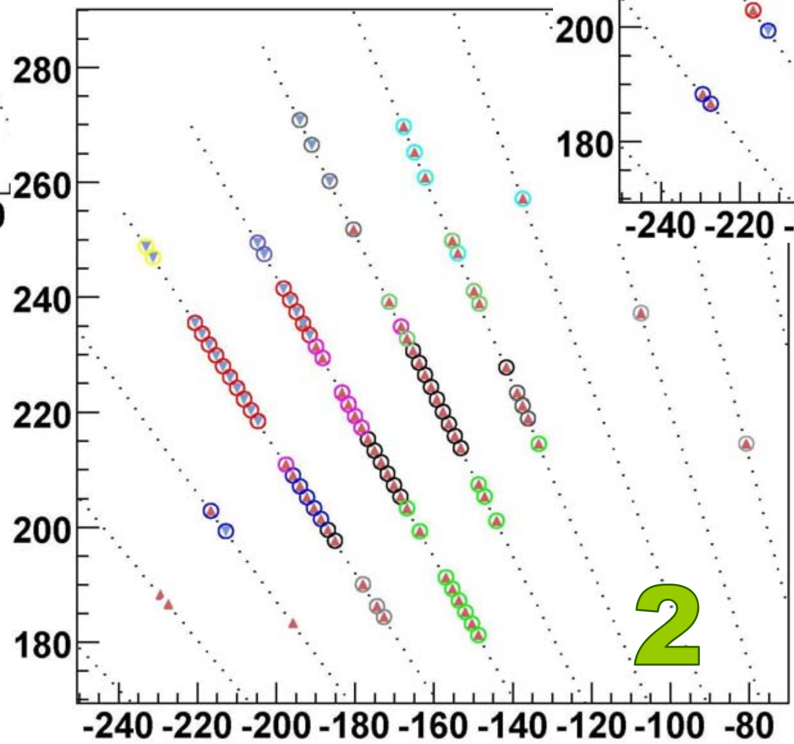
2D Cluster merging (in small steps)

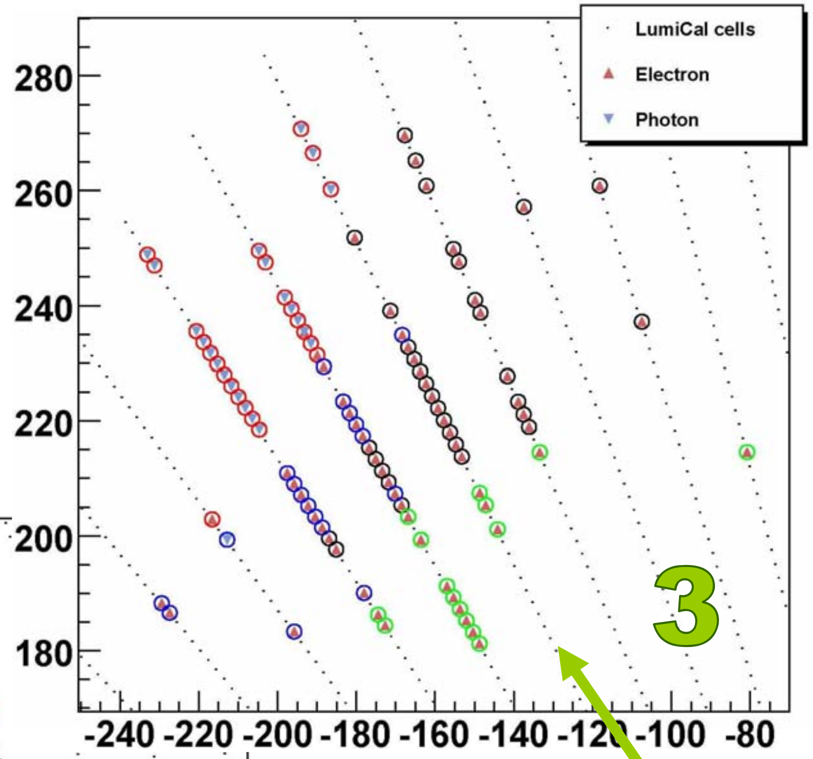


- Clusters must be merged carefully to maintain separation of the different particles.

$$W_{Merge} \propto \frac{(\text{Energy})^{\alpha}}{(\text{Distance})^{\beta}}$$

(For some positive α,β)





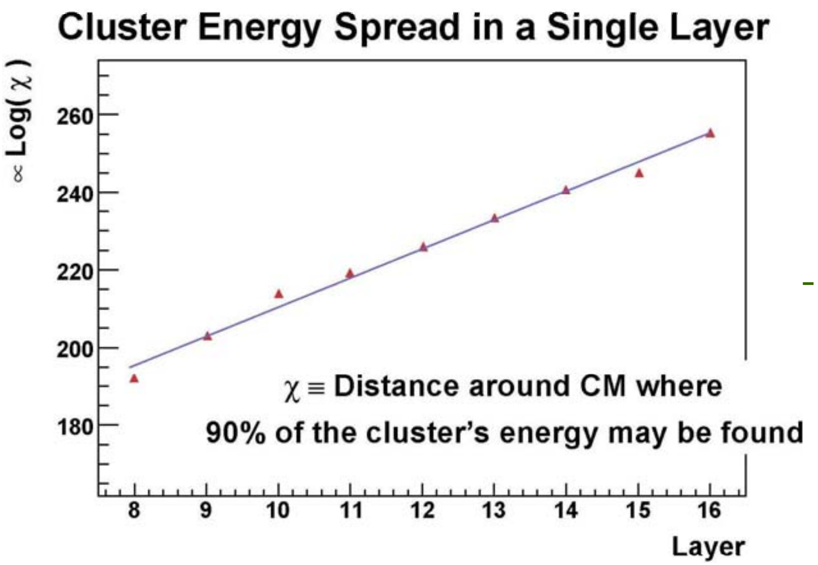
- Still too many clusters remain:
  - **4** clusters (red, blue, black, green).
  - **2** particles.

2D Clustering in non shower-peak layers

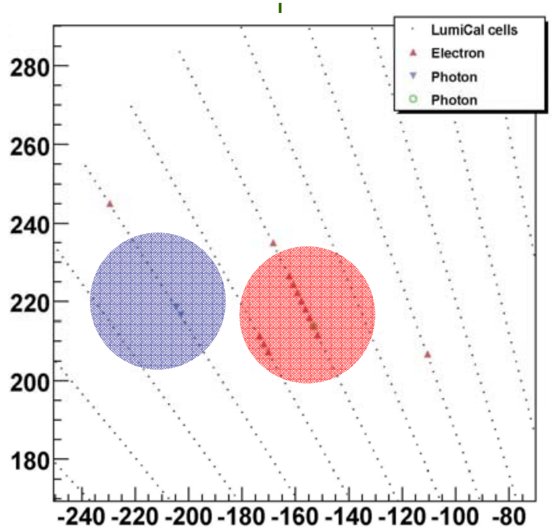
Add small energy hits to existing clusters

Set the number of global clusters (majority rule)

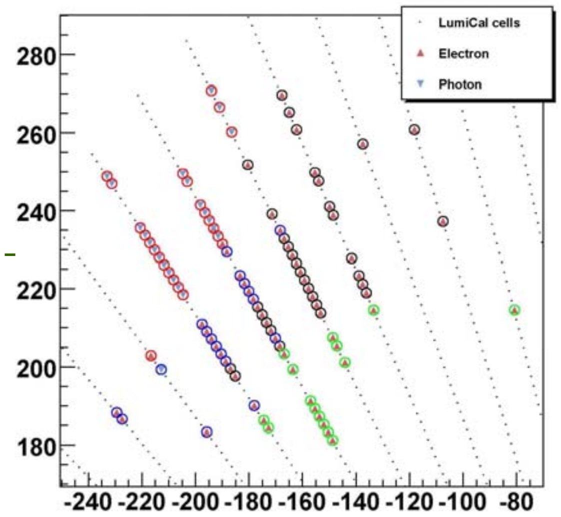
Fit straight lines through cluster CMs and extrapolate virtual-cluster CMs in non shower-peak layers



Create clusters in non shower-peak layers by adding hits inside χ around the virtual-cluster CMs



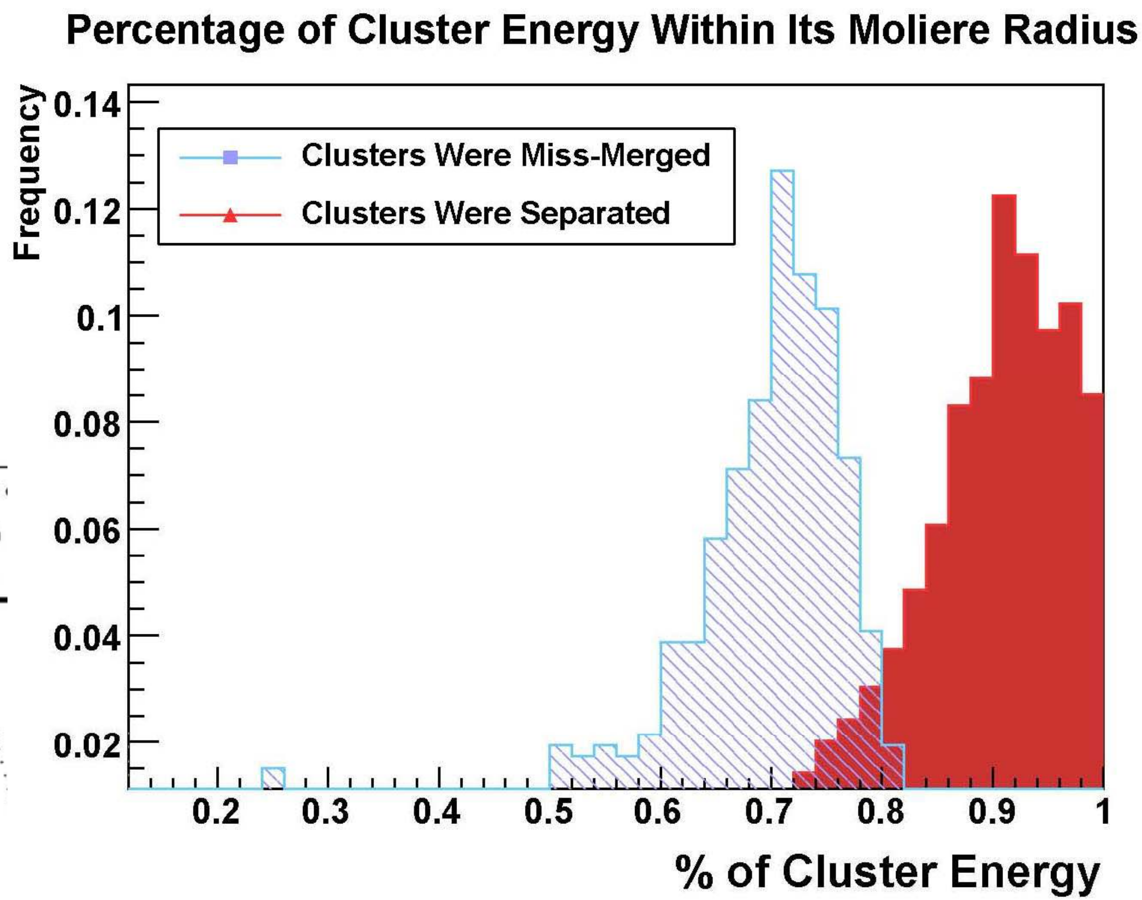
Fix shower-peak Layers which have the wrong number of clusters

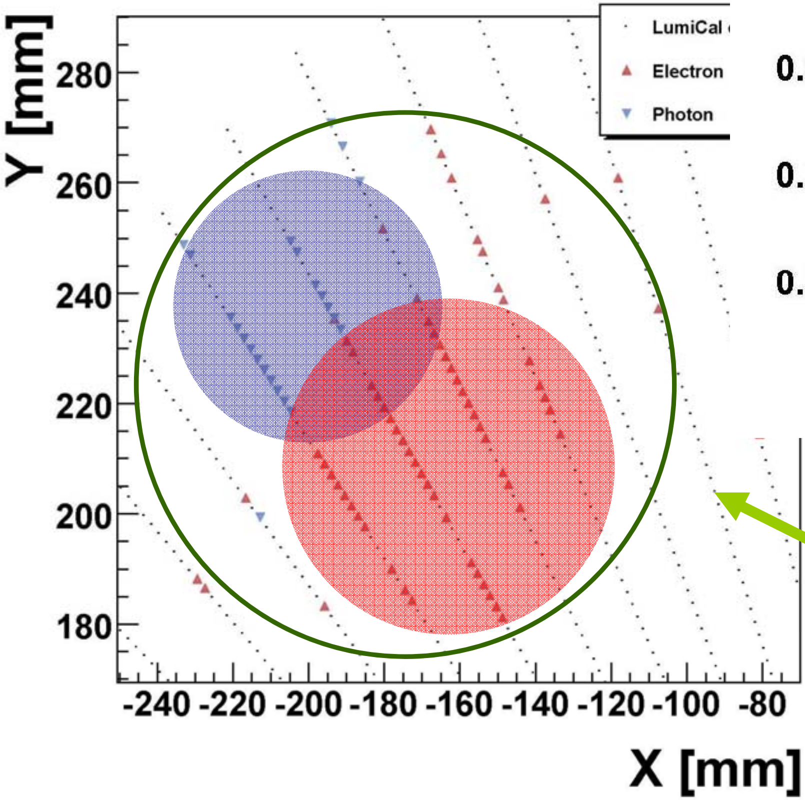


Merge 2D layer clusters into global 3D super-clusters

Molière Radius corrections

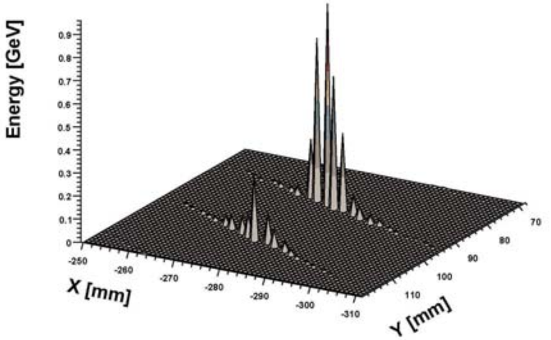
- Inside a cluster's Molière radius should be found ~90% of the cluster's total energy.

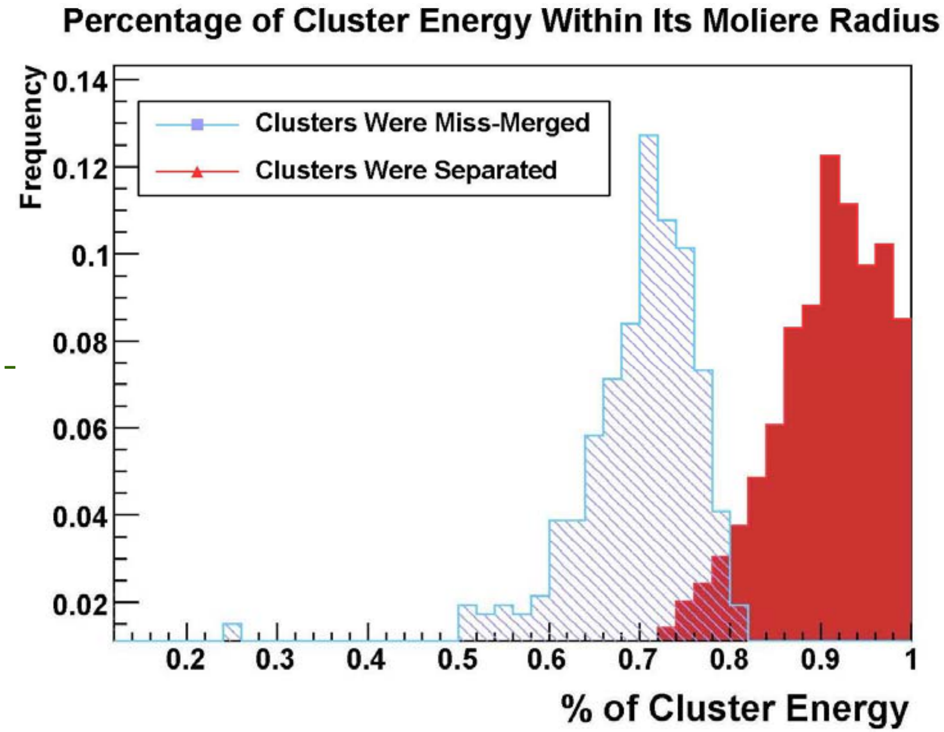




- Two clusters (blue & red full circle) are merged by mistake (green hallow circle).

Molière Radius corrections





If for all clusters together $E_{\text{In Molière}} < 90\%$, or if for any single cluster $E_{\text{In Molière}} < 80\%$,

Build new projection-clusters

Is ($E_{\text{In Molière}} < 80\%$) for each of the projection-clusters?

YES → Raise the minimal cell energy threshold

Are there enough cells remaining?

YES → Build new projection-clusters

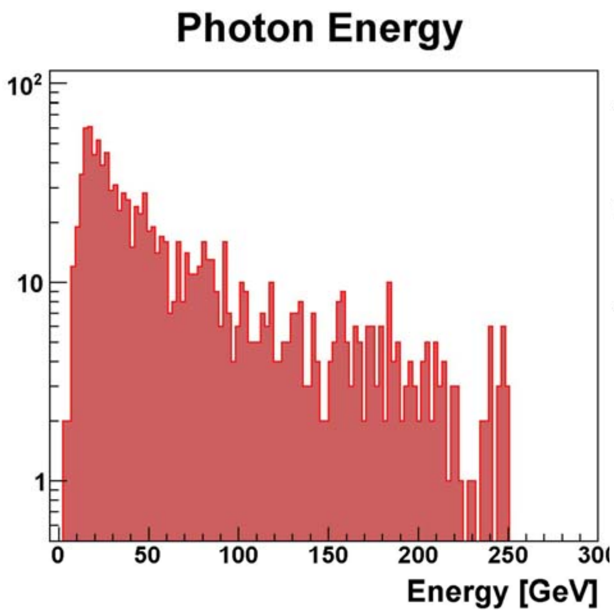
NO → Correction failed

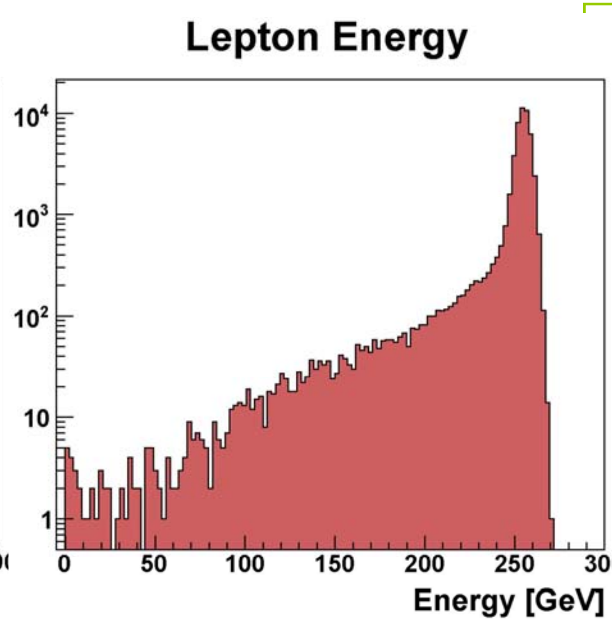
NO → Check if the projection-clusters are an improvement on the original clusters

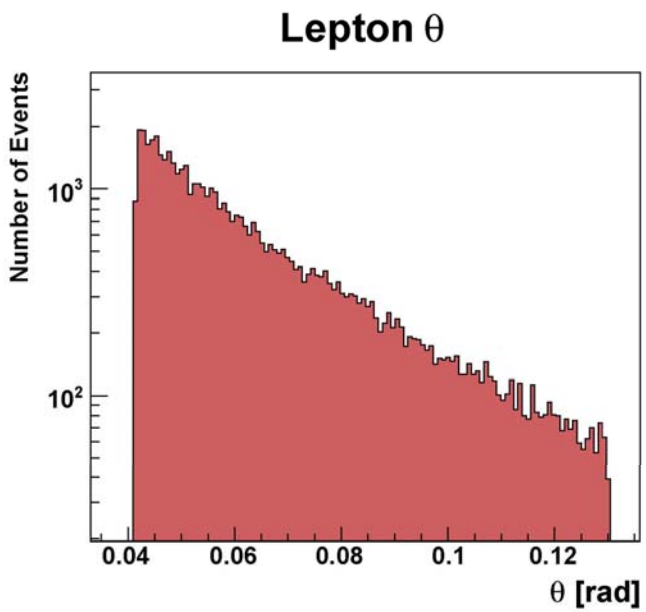
NO → Correction failed

YES → Correction Successful

Physics sample - Bhabha events



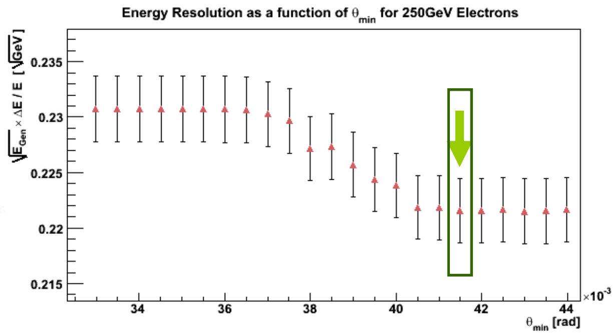




$3 \cdot 10^4$ Bhabha events

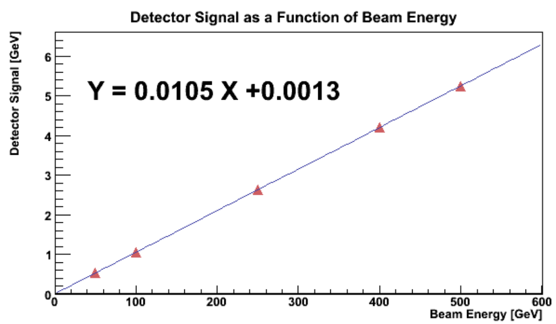
$\left(\sqrt{s} = 500 \text{ [GeV]}\right)$

Limits on θ that prevent leakage

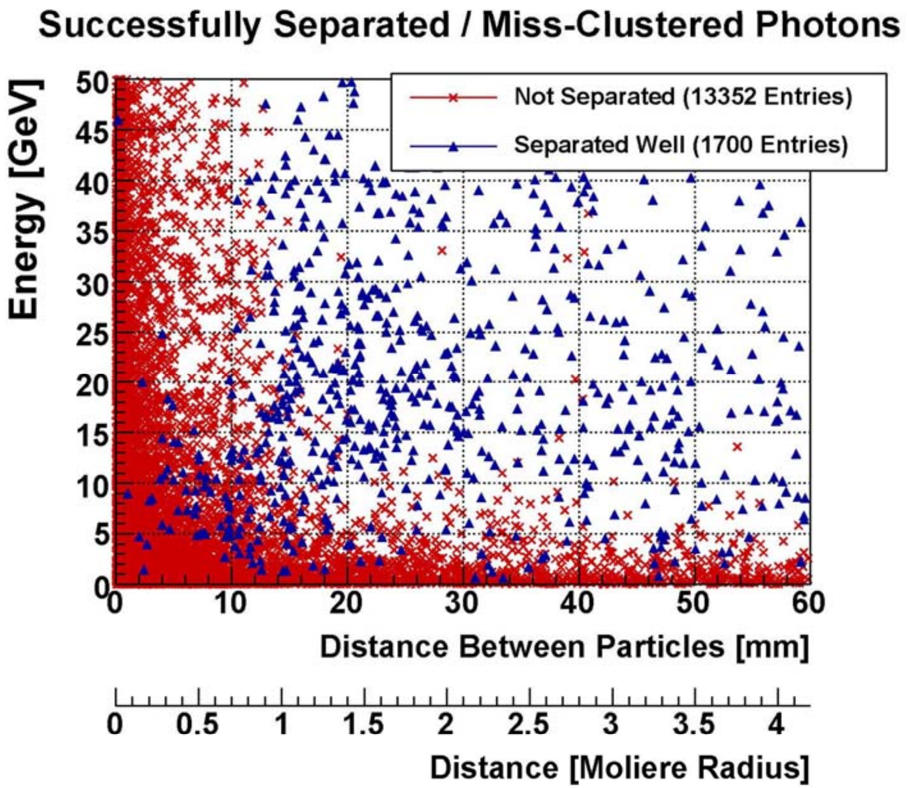


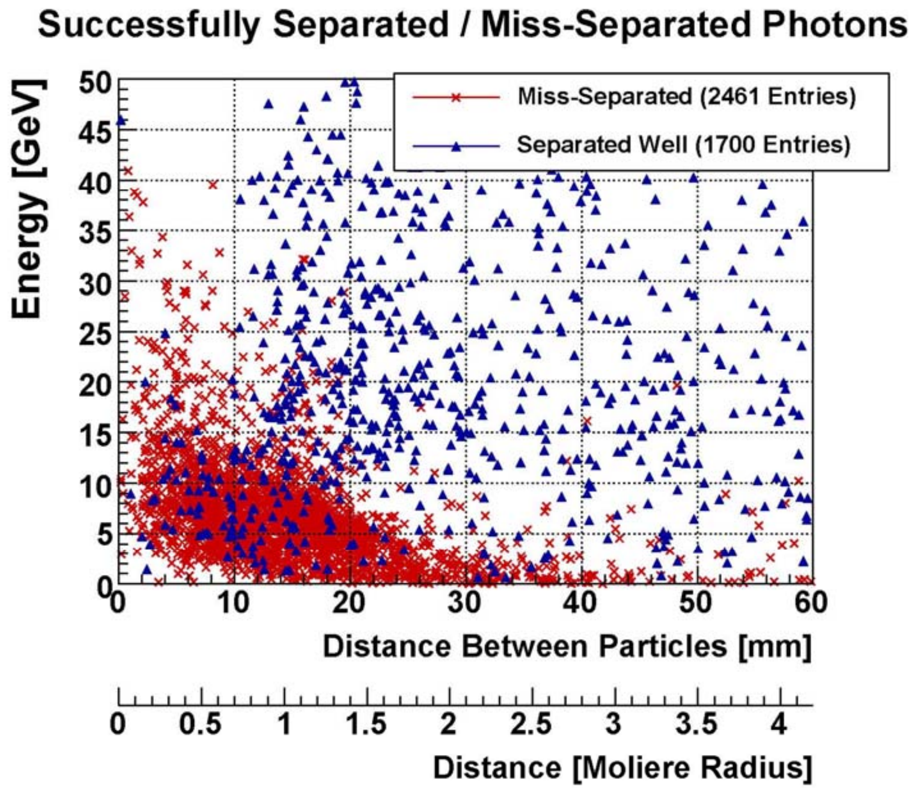
$0.0415 < \theta < 0.131$ [rad]

Calibration of the detector-signal to energy



So… does it all work?





- Choose a cut on energy of **15 [GeV]** and integrate clusters that are closer than **one Molière radius**.

So… does it all work?

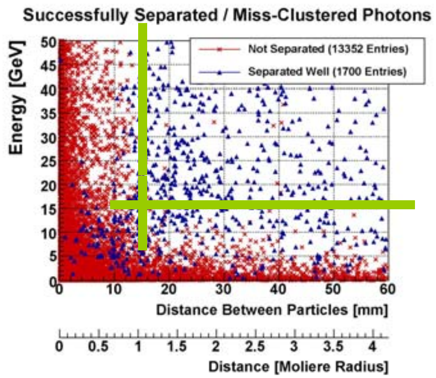
- **Some numbers:**

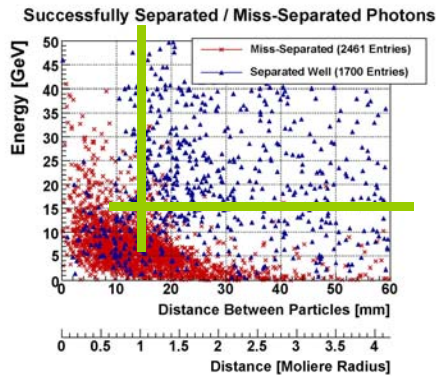
(30,000 Bhabha events)

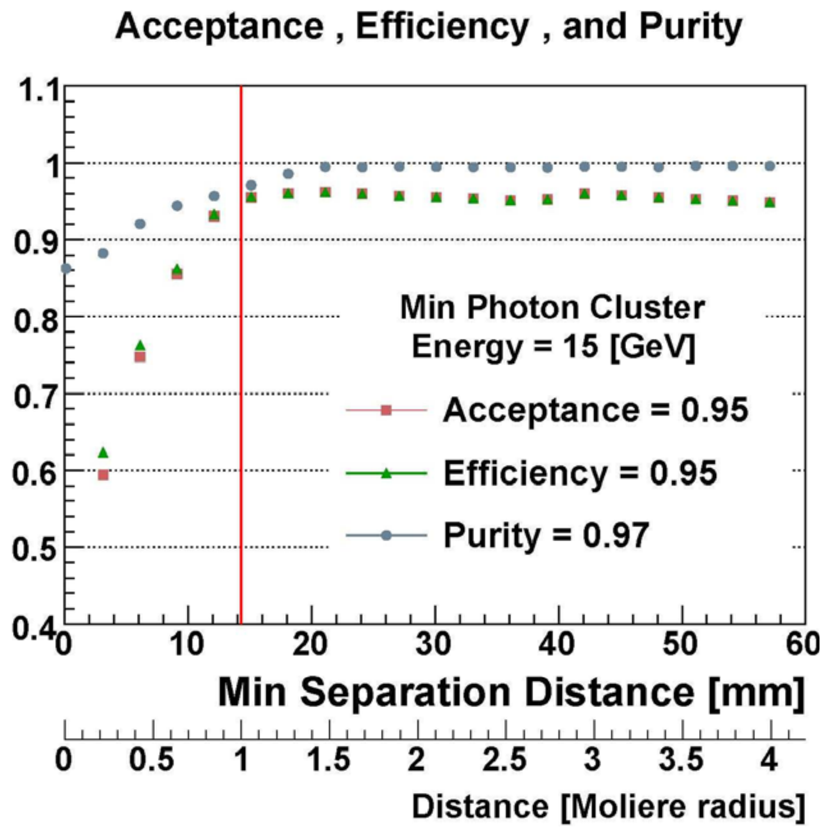
- For a minimal separation distance of **one Molière radius** we have:
  - Separated well - 1118 clusters
  - Not separated - 57 clusters
  - Miss-separated - 40 clusters

- For a minimal separation distance of **two Molière radius** we have:
  - Separated well - 774 clusters
  - Not separated - 35 clusters
  - Miss-separated - 4 clusters

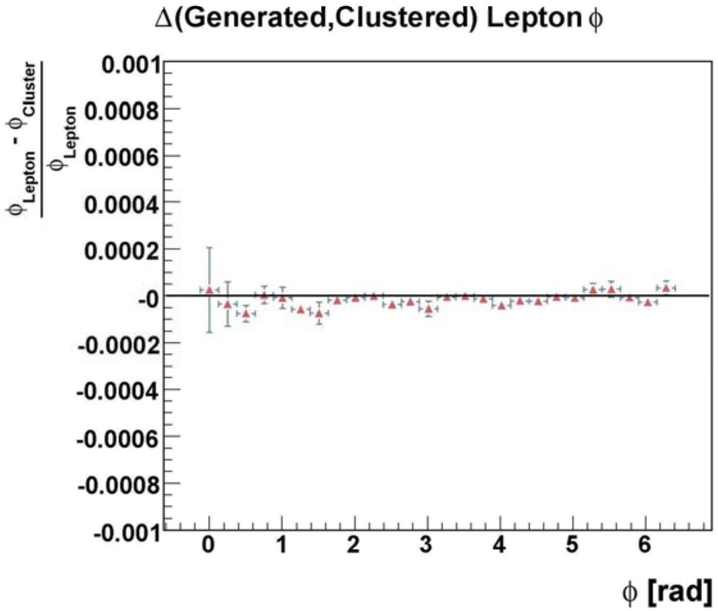
  (The purity goes to ~ 99%)

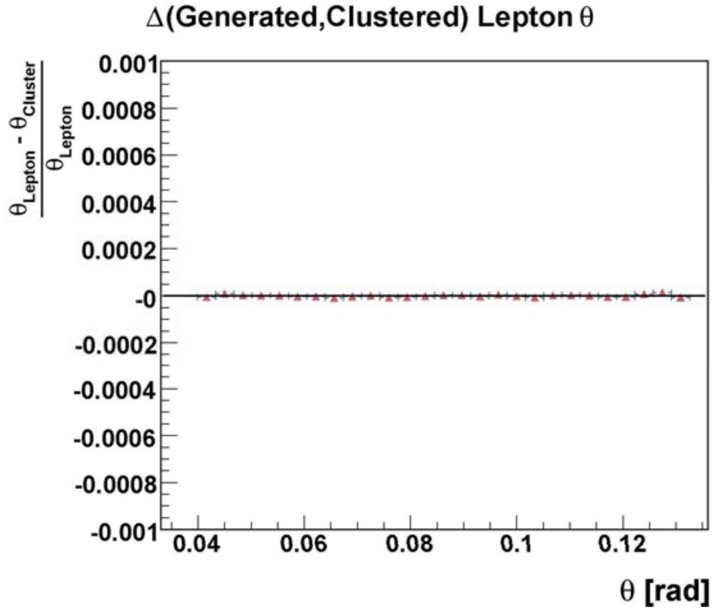


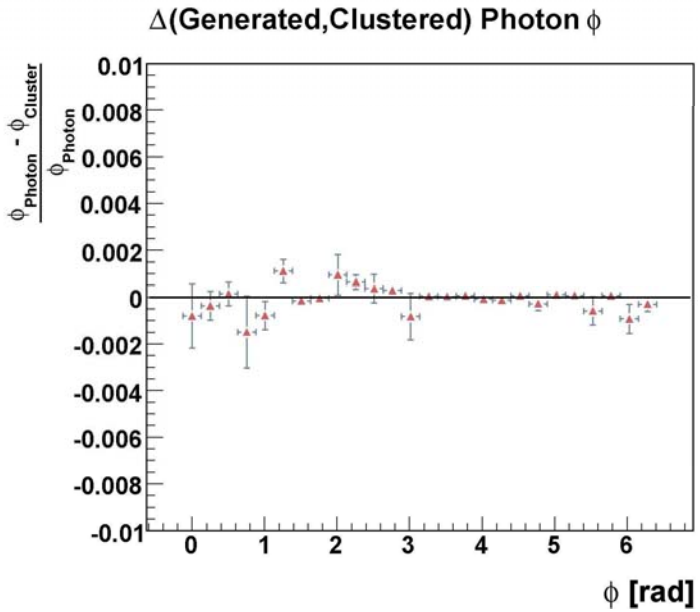


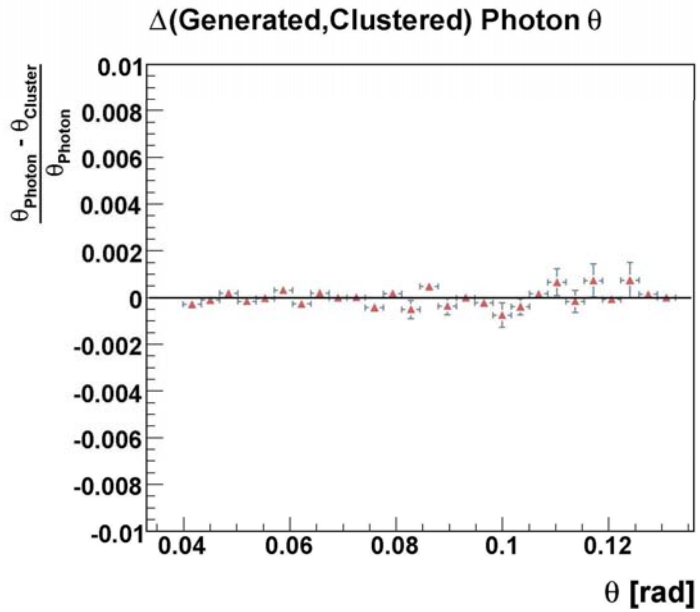


Results - Position reconstruction

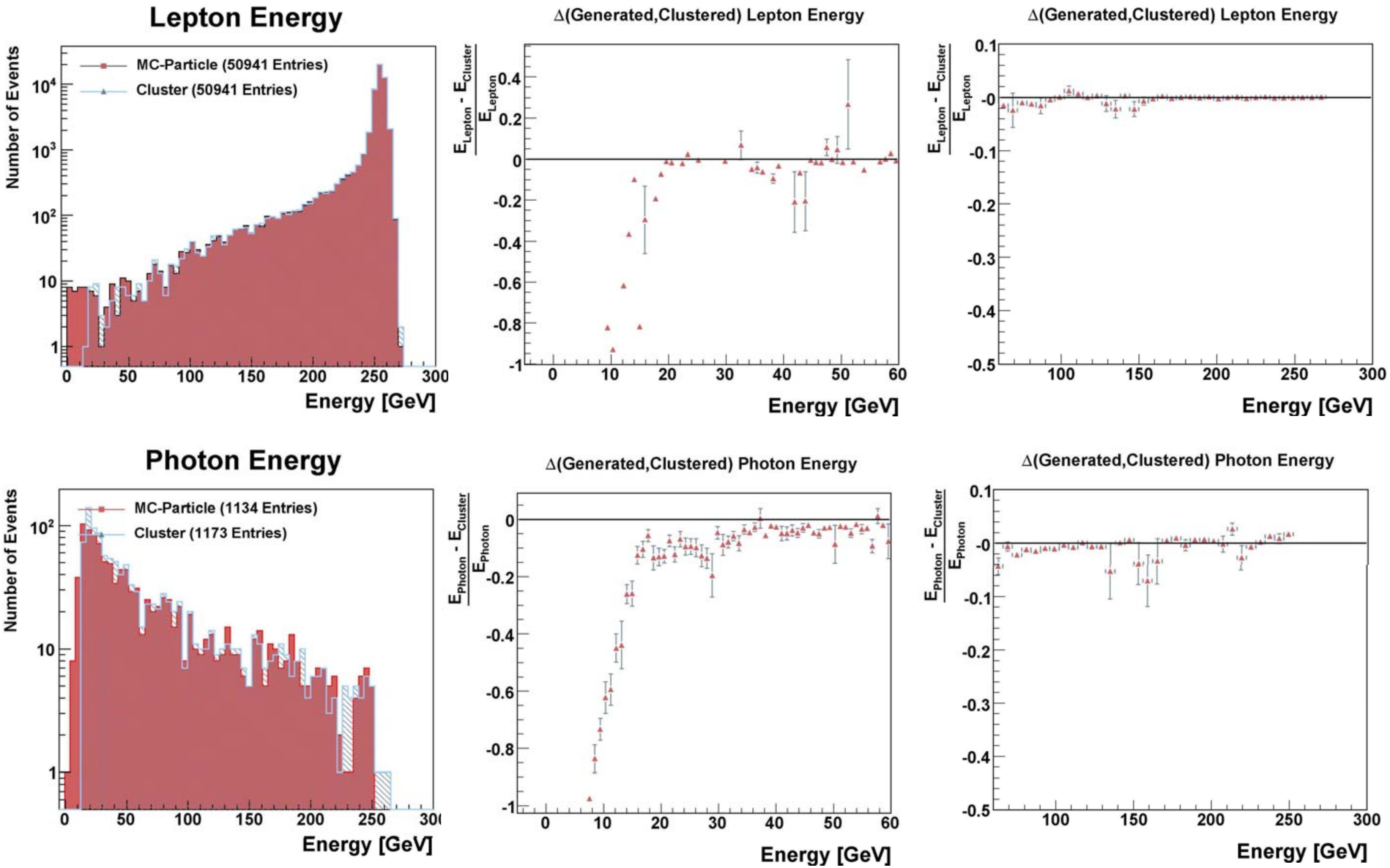








Results - Energy reconstruction



Has yet to be optimized…

Summary

1. A clustering algorithm is being developed for LumiCal.
2. For a Bhabha event sample, with a cluster energy cut of 15 GeV, and cluster separation of at least one Molière radius, position resolution of better than 0.1% is achieved.
3. Under these constraints, the acceptance and efficiency are 95%, while the purity is 97%.
4. Energy resolution still requires further studies.
5. Next steps also include optimization of the free parameters of the algorithm, as well as variations in LumiCal geometry.