



# ECL Software

## *Status Update*

**B. Oberhof\***  
for the SW group  
\*LNF-INFN

Belle2 Italian Meeting  
21-22 May 2015,  
LNF-INFN, Frascati, Italy

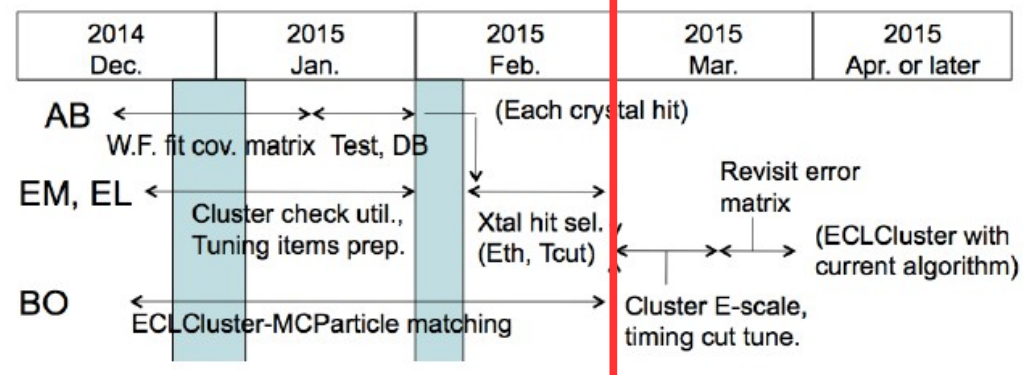


# Outline



- Much work done in last months on various parts of simulation & reco
- New Digitizer with updated covariance matrix (A. Bobrov, G. De Nardo)
- New ECLCluster-MCParticle matching module (B. Oberhof)
- Code validation & performance analysis, tools development (E. De Lucia, E. Manoni, B. Oberhof) *See Elisa's talk for details!*
- Little late on schedule but most of the hard work is done

## Short term plan from Miyabayashi-san



K. Miyabayashi  
B2GM, Nov. 14

Working ECLCluster to MCParticle truth matching (with beam background mixed in)	Benjamin Oberhof
ECLCluster reconstruction without the bias in energy when beam background is mixed in	Alex Bobrov
Proper treatment of ECLClusters timing and selection to reduce the array size when beam background is mixed in	Elisa Manoni or Erika de Lucia

# Waveform fit

A. Bobrov & G. De Nardo

- Time and energy reconstruction in an ECL channel:

$$\chi^2(A, p, t_0) = \sum_{ij} (y_i - Af(t_i - t_0) - p) S_{ij}^{-1} (y_j - Af(t_j - t_0) - p)$$

Where  $S_{ij} = \overline{(y_i - \bar{y}_i)(y_j - \bar{y}_j)}$  is covariance matrix

$$Af(t_i - t_0 - \delta t) = Af(t_i - t_0) + A\delta t f'(t_i - t_0) = Af(t_i - t_0) + Bf'(t_i - t_c)$$

Minimisation  $\chi^2(A, B, p) \rightarrow$  linear equations

$$\sum_{ij} f_i S_{ij}^{-1} (y_j - Af_j - Bf'_j - p) = 0$$

$$\sum_{ij} f'_i S_{ij}^{-1} (y_j - Af_j - Bf'_j - p) = 0$$

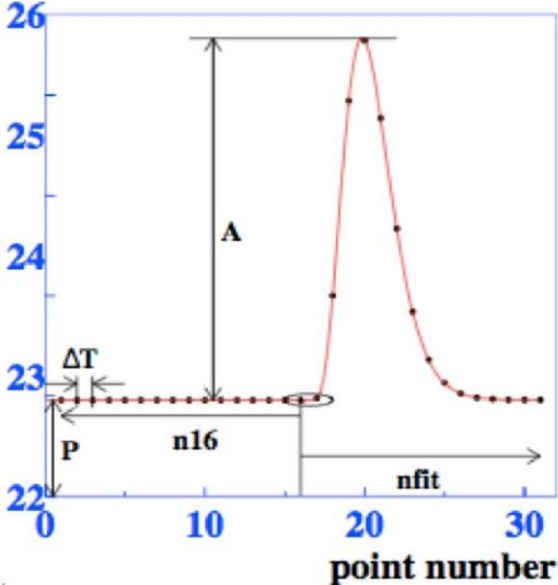
$$\sum_{ij} S_{ij}^{-1} (y_j - Af_j - Bf'_j - p) = 0$$

$$A = \sum_k fg31_k (S^{-1}) y_k$$

$$B = \sum_k fg32_k (S^{-1}) y_k$$

$$p = \sum_k fg33_k (S^{-1}) y_k$$

$fg31, fg32$  and  $fg33$  directly depend from elements  $S^{-1}$  and signal shape  $f, f'$





# ECLDigitizer module

A. Bobrov & G. De Nardo

- waveform fit performed in basf2 module ECLDigitizer
- energy deposit from GEANT from Datastore (ECLHit)
- Until now: pre-calculated fixed numbers hardcoded in module common for all crystals
  - waveform shape
  - few parameters needed by fit algorithm
  - covariance matrix
- no bkg accounted for in covariance matrix
- Alex Bobrov determined individual covariance matrix for all crystals
- Includes electronic noise and bkg effects
- For calibration we need to store 16000 parameters for each crystal  
→ total amounts to about 400Mb
- Size can be reduced by sharing same objects for groups of similar crystals (based on bkg and noise conditions)
- S. De Jong & C. Hearty have found that 300 objects are enough (100 BWD, 100 Barrel, 100 FWD) → 30 Mb



# New ECLDigitizer

A. Bobrov & G. De Nardo

- In future covariance matrix will vary in run-dependent manner
- The plan is to read fit functions + algorithm parameters + covariance matrix from condition database
- Condition database is not going to be available in short term
- Intermediate solution is to store data in a single root file (G. De Nardo)
  - output file of Alex's calibration procedure
  - root file read by ECLDigitizer
  - data format (data object) as similar as possible to what is going to be in the condition database

Covariance matrix:	136 floats
Function shape:	10 floats
Algorithm pars:	10 integers

- Single object size is  $156 \times 4$  bytes = 624 bytes
- Max total size = 1 data structure x crystal = 5.45 MB

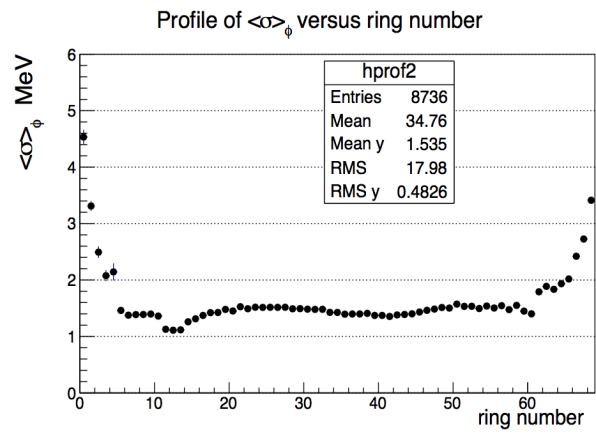
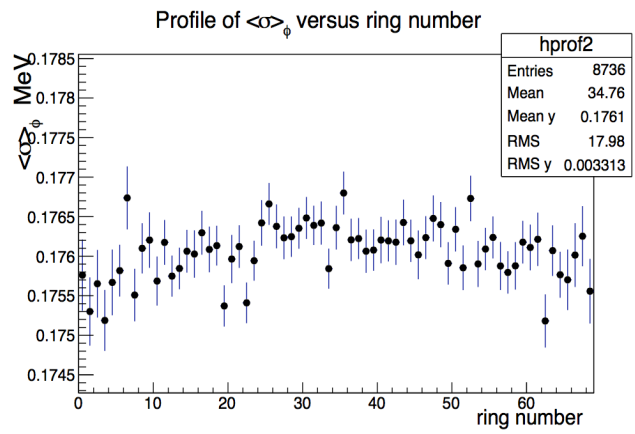
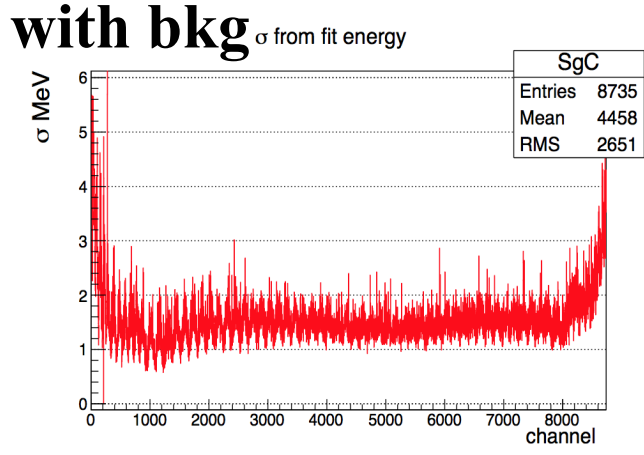
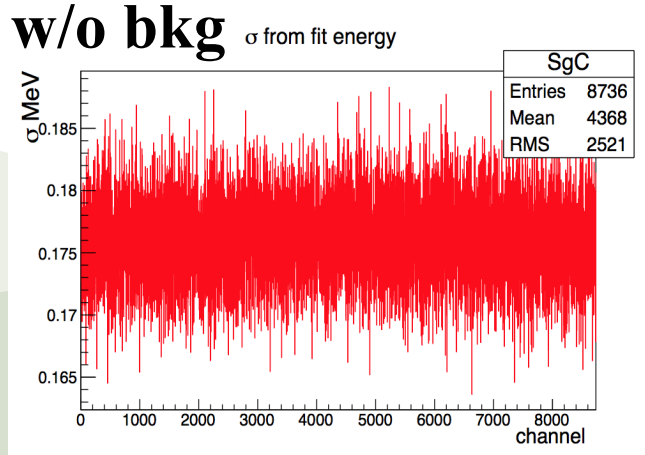


# Digitizer calibration



A. Bobrov & G. De Nardo

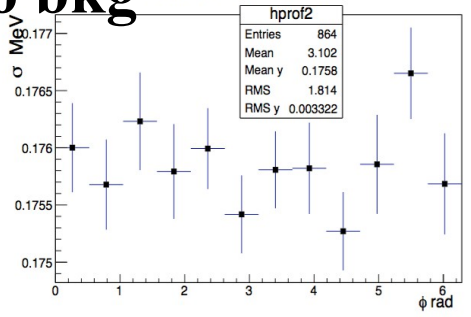
- Adding a 100 MeV ECLHit to each crystal



*See Elisa's talk for details!*

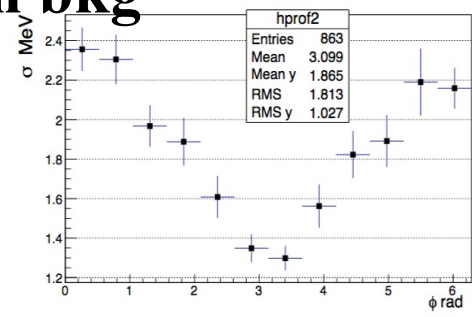
w/o bkg

Profile of  $\sigma$  versus  $\phi$  forward

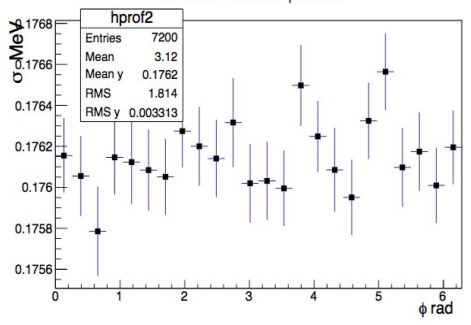


with bkg

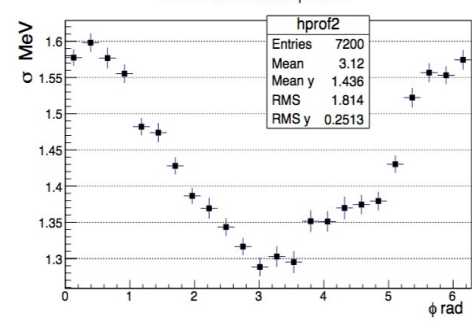
Profile of  $\sigma$  versus  $\phi$  forward



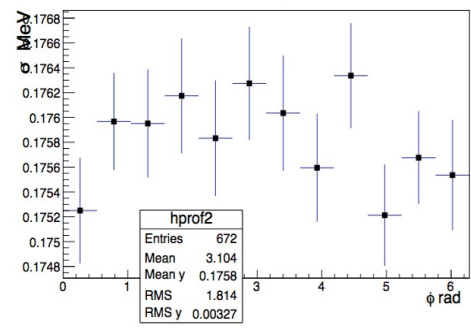
Profile of  $\sigma$  versus  $\phi$  barrel



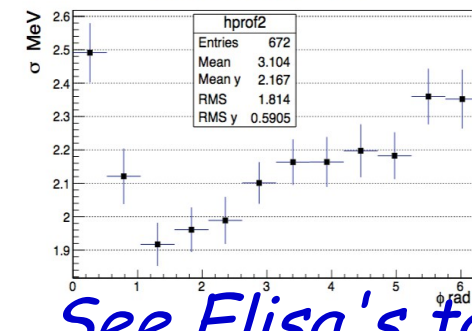
Profile of  $\sigma$  versus  $\phi$  barrel



Profile of  $\sigma$  versus  $\phi$  backward



Profile of  $\sigma$  versus  $\phi$  backward



See Elisa's talk for details!





# MC Matching: reminder

B. Oberhof

- Various different flaws in ECL MC-Matching in old code (build-2015-01-03) which have now been disentagled:
- Analysis package (NtupleMaker) related:
  - Bkg index not properly set → all clusters associated to MCParticles (and other complications) (fixed by A. Zupanc after last B2GM)
- ECL package related
  - Daughters of decaying particles not treated properly in ECLMCMatching module → clusters associated to decaying particle (fixed before last B2GM)
- No proper treatment of multiple-association implemented in ECLMCMatching module (still open task at last B2GM):
  - Impossible to separate bkg and physics contribution (crucial for analysis)
  - Impossible to distinguish properly overlapping MCParticles (less frequent in practice but important for code consistency)

**Fixed!**





# MCMatching Updates

**B. Oberhof**

- 2 new modules in ECL package right now:
  - ECLMCMatch:  
implements a temporary fix requested by analysis people at last B2GM. Module handles multiple association but gives no weights. Relation between MCParticle and eclCluster is set only if energy contribution in terms of hits is  $>$  than a fixed amount (50%, empirically tuned). Has been tested and appreciated by analysis people.
  - ECLMCMatching (new version):  
Tentative final version. Handles properly multiple association, weights (energies) are calculated based on SimHits for every MCParticle and stored in the relation array. Distinction between signal and bkg is based on bkgTag. Positive feedback from analysis people.

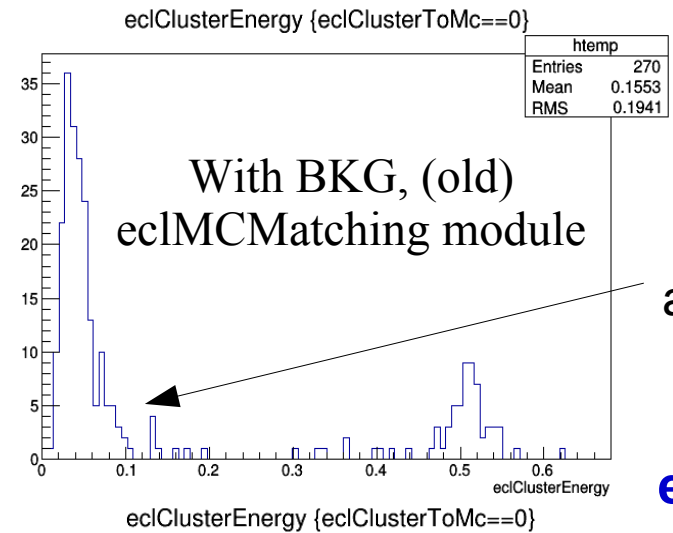
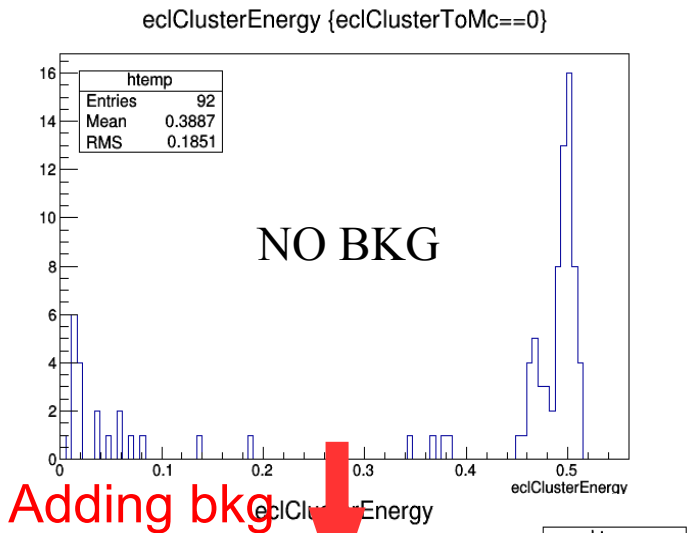


# ECLMCMatch module



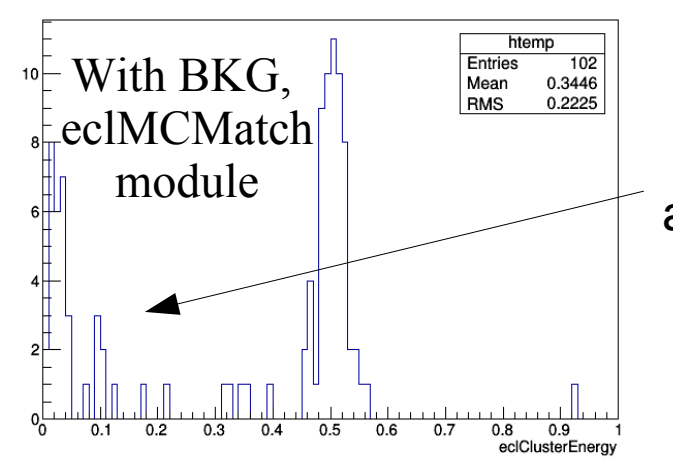
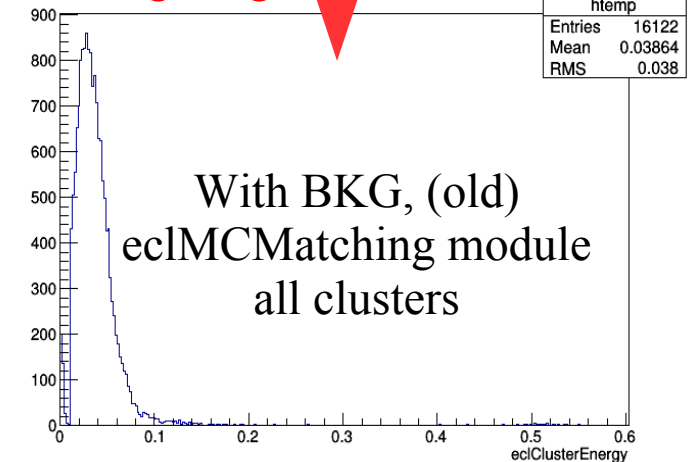
B. Oberhof

- Single 500 MeV photon, full solid angle, 100 evts (old Digi)



Low E clusters associated to MC particle

**old eclMcMatching**



Low E clusters associated to MC particle

**eclMcMatch**

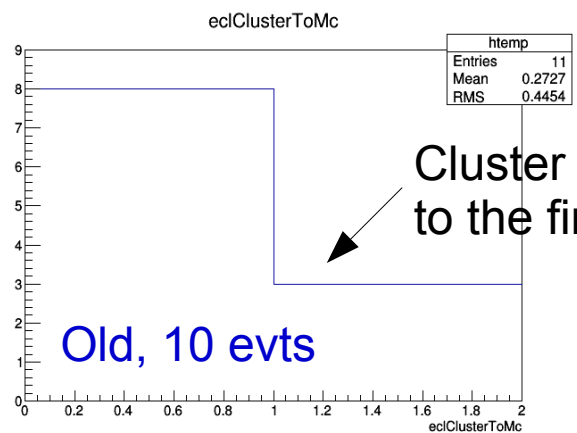
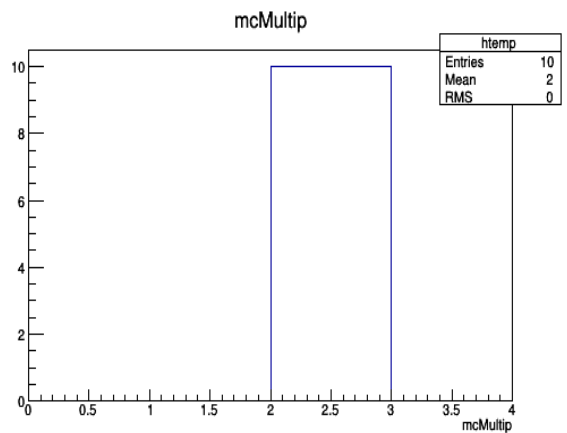


# new ECLMCMatching



B. Oberhof

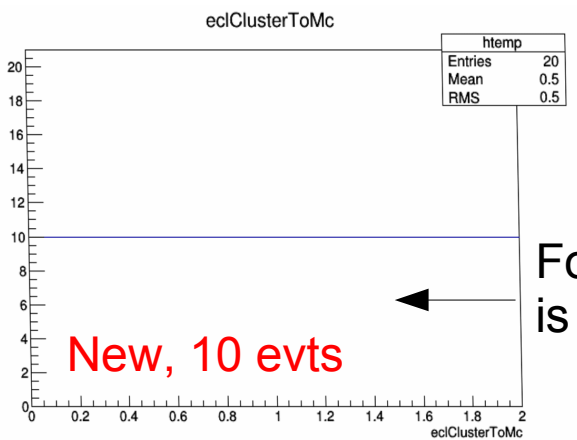
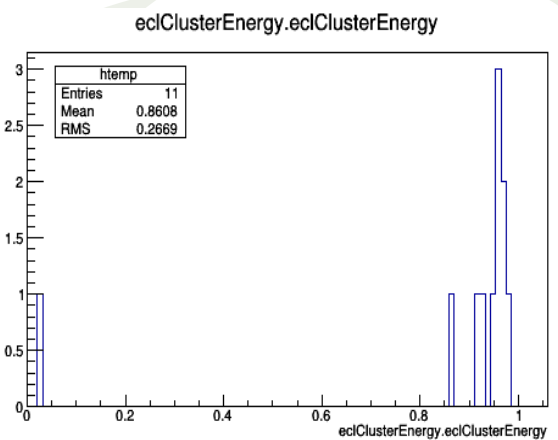
- Results for 2 "collinear" 500 MeV photons ( $80 < \theta < 80.1$ ,  $160 < \phi < 160.1$ ), 10 events, no bkg



Cluster is randomly associated to the first or second MCParticle

Old, 10 evts

old eclMcMatching

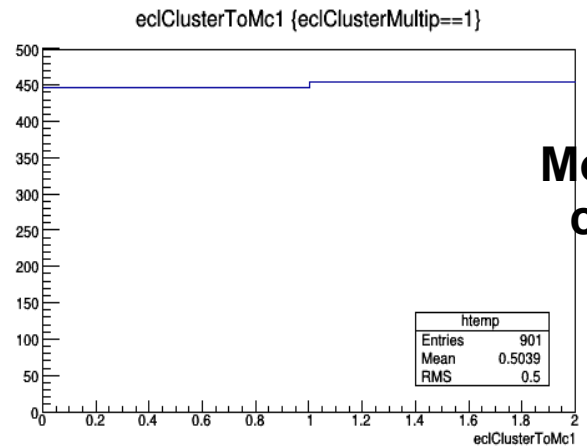


For each MCParticle there is a relation to the Cluster

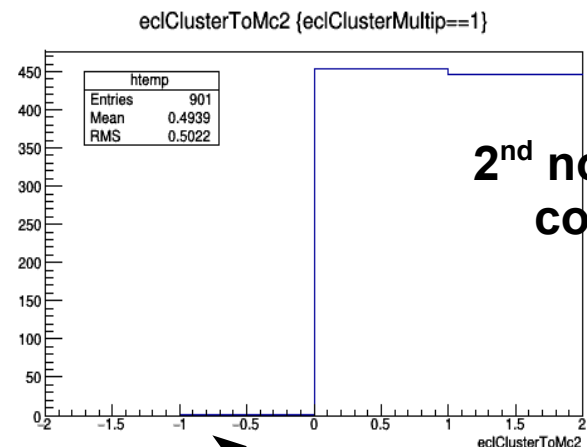
New, 10 evts

new eclMcMatching

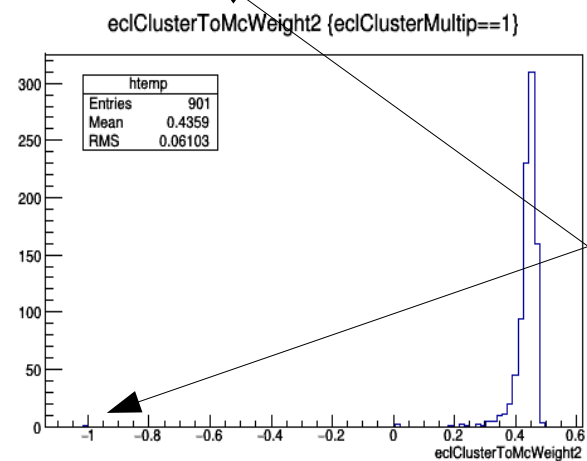
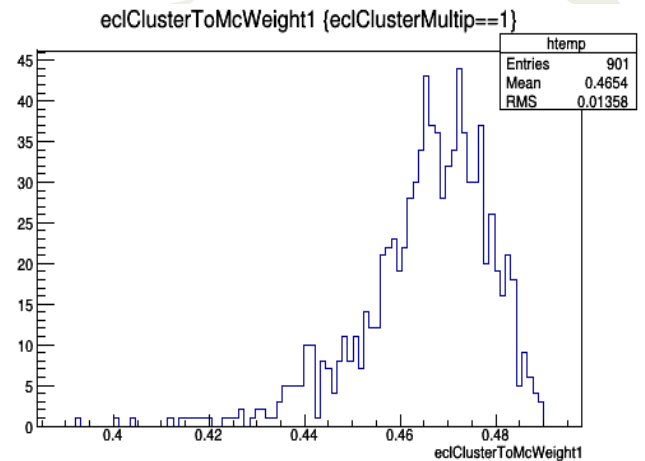
- Results for 2 “collinear” 500 MeV photons ( $80 < \theta < 80.1$ ,  $160 < \phi < 160.1$ ), 1000 events, no bkg



**Most energetic contribution**



**2<sup>nd</sup> most energetic contribution**

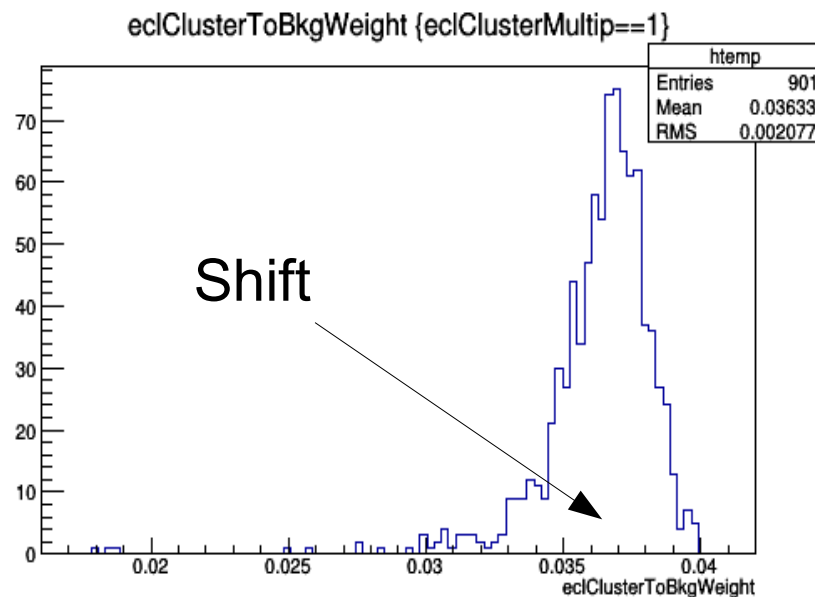
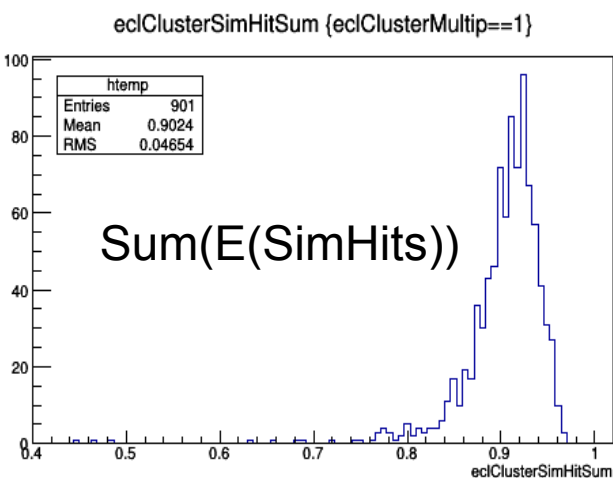
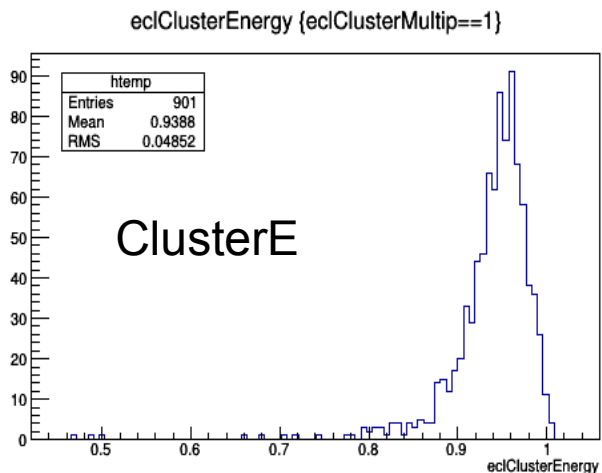


-1 if relation is missing

# Energy: reco vs sim

B. Oberhof

- Results for 2 “collinear” 500 MeV photons ( $80 < \theta < 80.1$ ,  $160 < \phi < 160.1$ ), 1000 events, no bkg



ClusterE-Sum(E(SimHits))



# Matching Issues

B. Oberhof



- As far as tested ECLMCMatching module works properly, BUT:
- Individual bkg contributions cannot be distinguished with current module (no SimHit info available for bkg). Is this something that we want/need?
- Currently the weight is given as energy as sum of SimHit for that McParticle, i.e. weights are not normalized to 1
- Association is not “unitary”, i.e. the sum of contributions from eclSimHits does not equals eclClusterEnergy (minimal violation, few % level) → which normalization should we use?
- Module widely uses RelationArrays → should be replaced
- Technical: being based on the old module the new one first sets relations for eclShowers and then derives them for eclClusters. Should this be avoided or can we live with it (for now)?

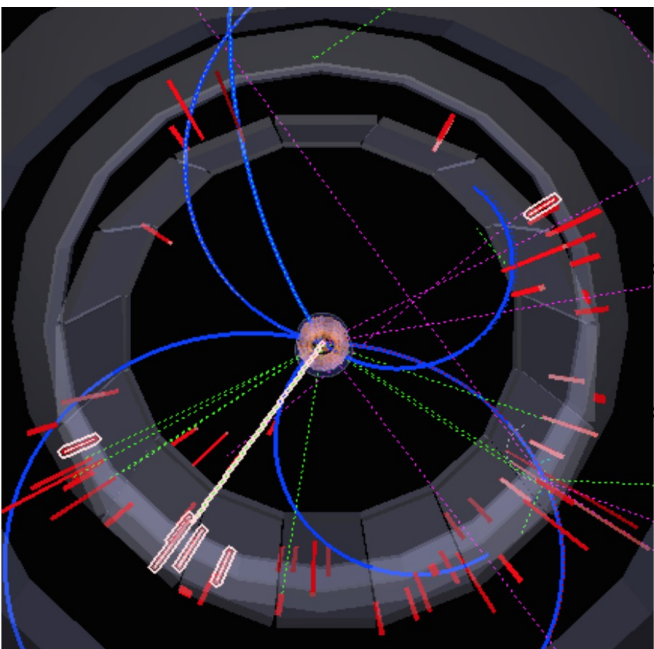
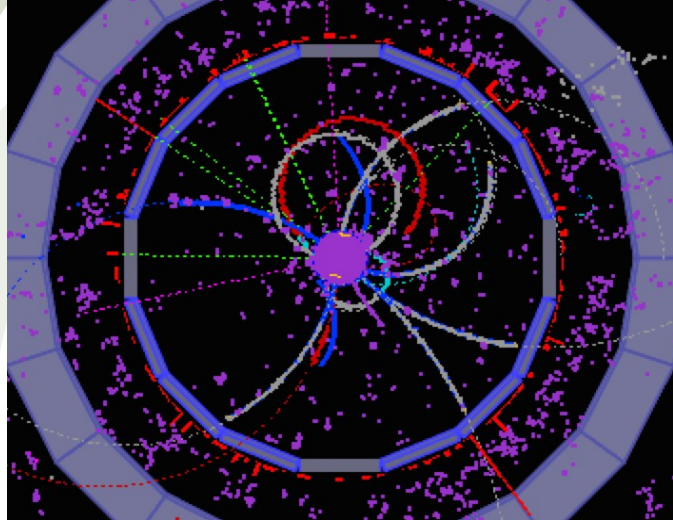


# Other Matching Issues

B. Oberhof

- Many clusters associated to same MCParticle
- As shown by C.Pulvermacher's talk at B2S&C Workshop

```
ClusterID: 99 Energy: 0.154656 MCParticle: 18 Weight: 0.004955
ClusterID: 99 Energy: 0.154656 MCParticle: 50 Weight: 0.118820
ClusterID: 103 Energy: 0.141146 MCParticle: 49 Weight: 0.119273
ClusterID: 108 Energy: 0.228280 MCParticle: 6 Weight: 0.199814
ClusterID: 109 Energy: 0.061838 MCParticle: 24 Weight: 0.007245
ClusterID: 120 Energy: 0.045514 MCParticle: 23 Weight: 0.008001
ClusterID: 122 Energy: 0.047243 MCParticle: 24 Weight: 0.008237
ClusterID: 123 Energy: 0.187011 MCParticle: 24 Weight: 0.007856
ClusterID: 123 Energy: 0.187011 MCParticle: 44 Weight: 0.129715
ClusterID: 123 Energy: 0.187011 MCParticle: 66 Weight: 0.033713
ClusterID: 124 Energy: 0.213817 MCParticle: 24 Weight: 0.177046
ClusterID: 124 Energy: 0.213817 MCParticle: 44 Weight: 0.018088
ClusterID: 125 Energy: 0.043376 MCParticle: 24 Weight: 0.017983
ClusterID: 127 Energy: 0.037415 MCParticle: 24 Weight: 0.006799
ClusterID: 128 Energy: 0.037433 MCParticle: 24 Weight: 0.006360
ClusterID: 130 Energy: 0.039216 MCParticle: 24 Weight: 0.004657
ClusterID: 138 Energy: 0.219670 MCParticle: 54 Weight: 0.004045
ClusterID: 138 Energy: 0.219670 MCParticle: 68 Weight: 0.154552
ClusterID: 138 Energy: 0.219670 MCParticle: 75 Weight: 0.033293
ClusterID: 139 Energy: 0.051356 MCParticle: 54 Weight: 0.000001
ClusterID: 143 Energy: 0.046245 MCParticle: 24 Weight: 0.000347
ClusterID: 147 Energy: 0.046772 MCParticle: 24 Weight: 0.000852
ClusterID: 150 Energy: 0.035795 MCParticle: 24 Weight: 0.000000
ClusterID: 151 Energy: 0.034844 MCParticle: 54 Weight: 0.000337
```



[DataStore / MCParticles / \[34\]](#) [Back](#)

### MCParticles[34] - gamma

[Previous](#) [Next](#)

Charge=0, PDG=22 (gamma)  
pT=0.372147, pZ=0.0292783  
V=(0.01, -0.03, 0.03)  
Mother: MCParticles[21] (pi0)

### Related Objects

- this <- [ECLClusters\[24\]](#) (weight: 0.00353)
- this <- [ECLClusters\[34\]](#) (weight: 0.00753)
- this <- [ECLClusters\[36\]](#) (weight: 0.000268)
- this <- [ECLClusters\[39\]](#) (weight: 0.108)
- this <- [ECLClusters\[40\]](#) (weight: 0.312)
- this <- [ECLClusters\[41\]](#) (weight: 0.00343)

### Object Details

Belle2::MCParticle (A Class to store the Monte Carlo particle information.)

**m\_plist**  
transient pointer to particle list ->28f4

(here: cluster 24 with 3rd-smallest weight)



- Similar problem is seen for charged tracks
- Additional (and detailed) testing is necessary

- Same ECLCluster is linked to one track multiple times?
- A large number of ECLClusters have suspiciously similar energies (about half of all clusters lie between 155 and 160 MeV)?
- Meaning of relation weights documented somewhere?

Needs agreement among ECL and Analysis people,  
will be fixed soon

Tracks[2]

[Previous](#) [Next](#)

Related Objects

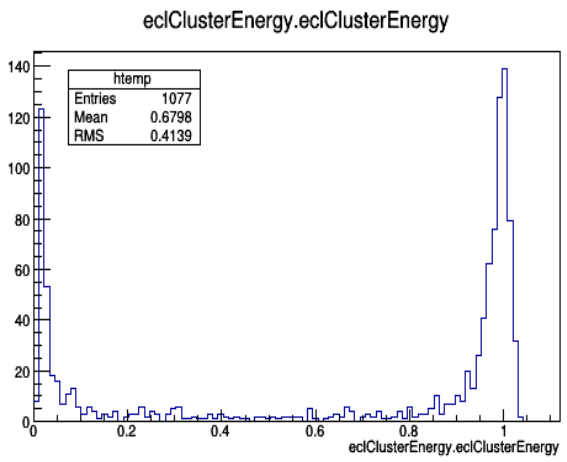
this -> [MCParticles\[10\] - e-](#)  
this -> [PIDLikelihoods\[2\]](#)

this <- [ECLClusters\[1\]](#)  
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this <- [ECLClusters\[2\]](#)  
this <- [ECLClusters\[2\]](#)  
this <- [ECLClusters\[2\]](#)

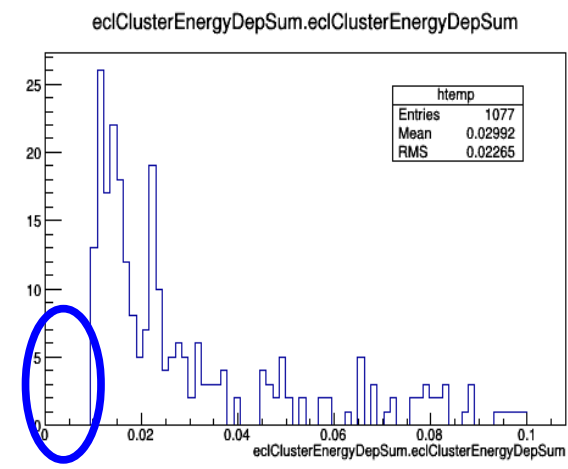
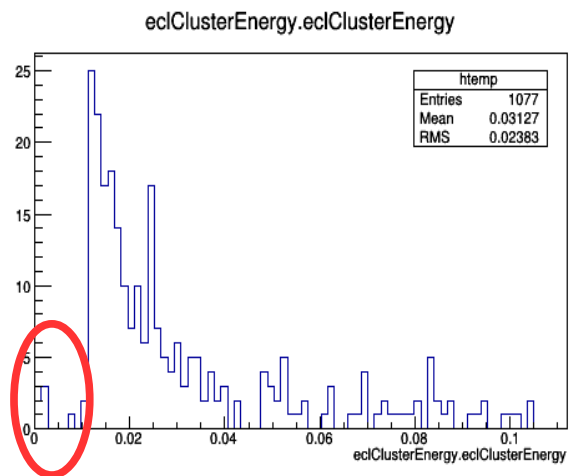
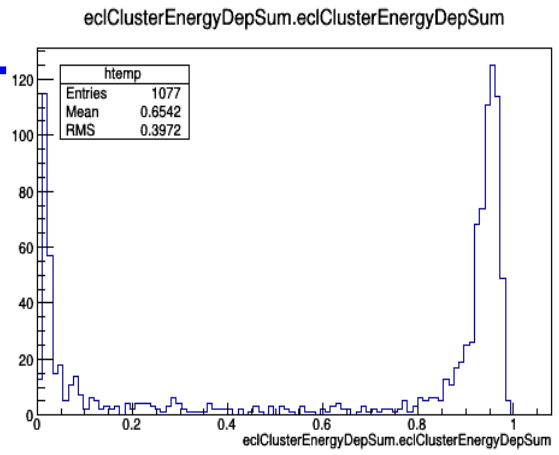
Object Details

- 1 GeV pGun photon, full solid angle, 1000 evt
- Large number of low E clusters → material?
- Clusters with  $E < 10$  MeV → probably problem in clustering algo

**RECO**

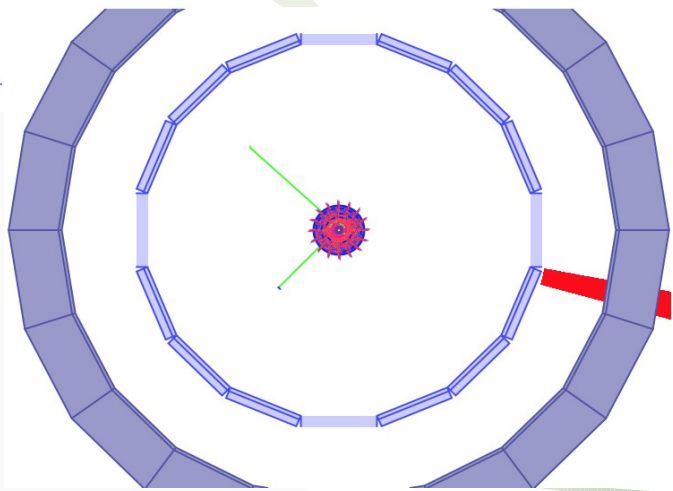
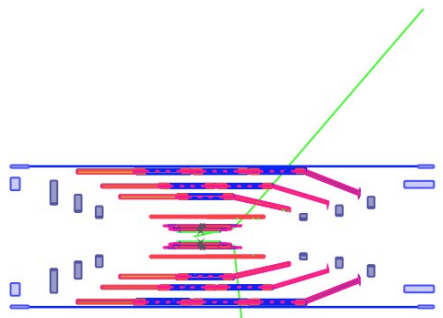


**GEANT**

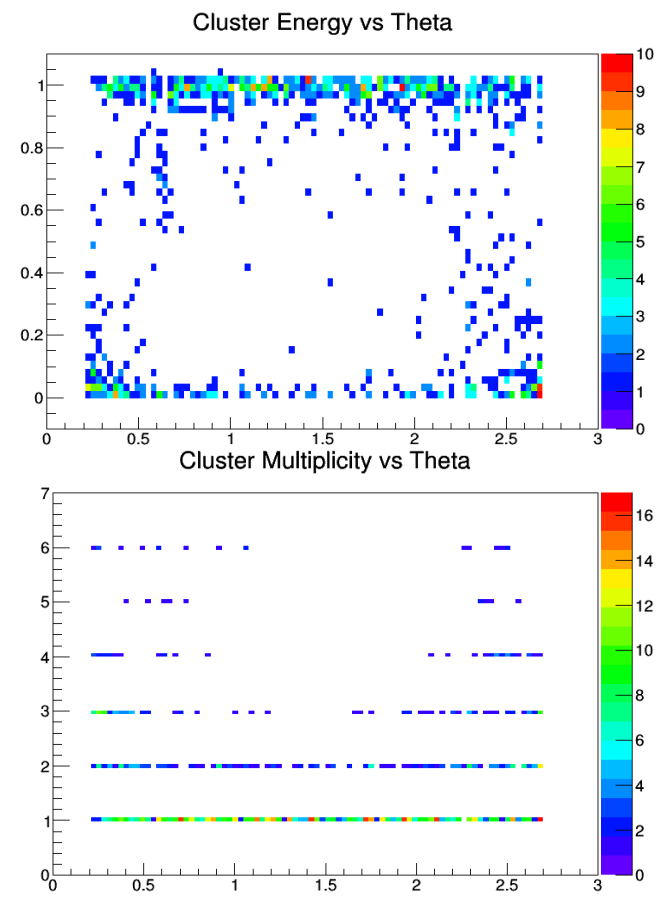


- Big effect in the FWD direction → material budget?

500 MeV photon, theta=12.5 deg.  
(ECL starts at 12.01 deg)



1 GeV photon, full omega



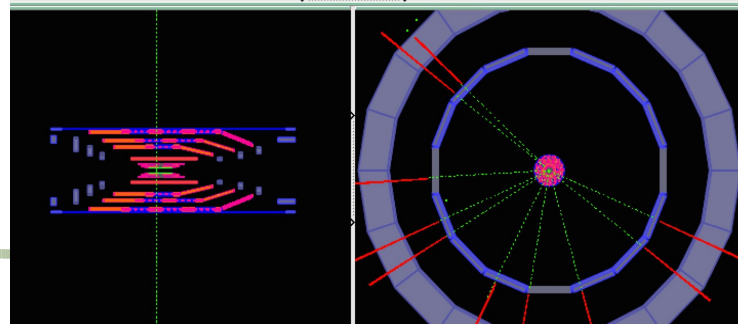
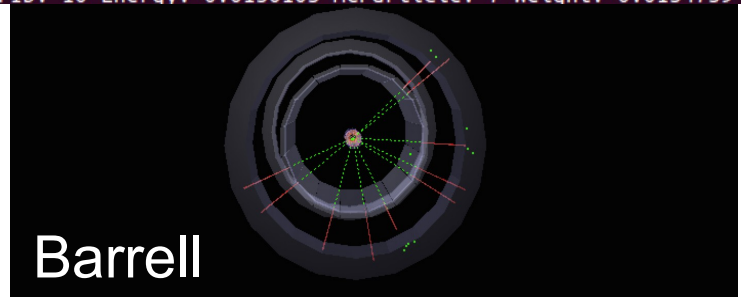
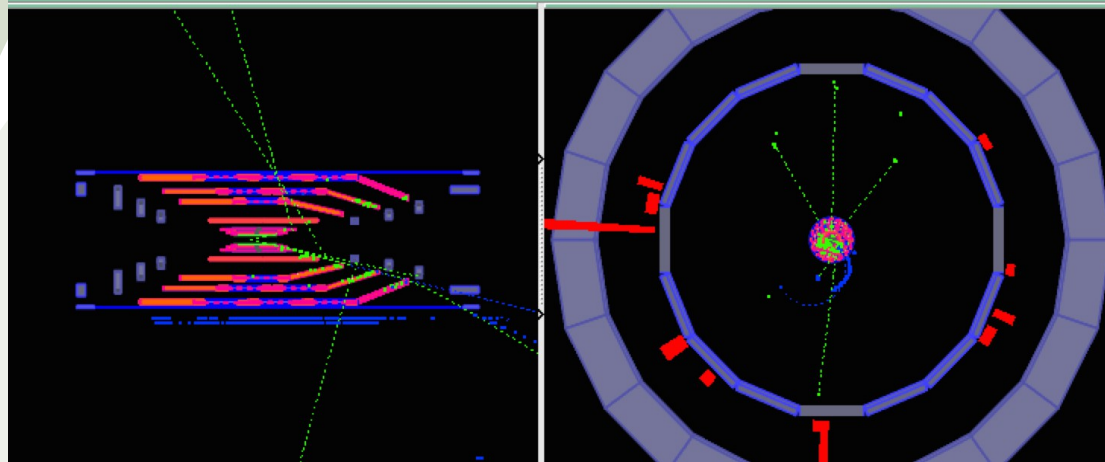
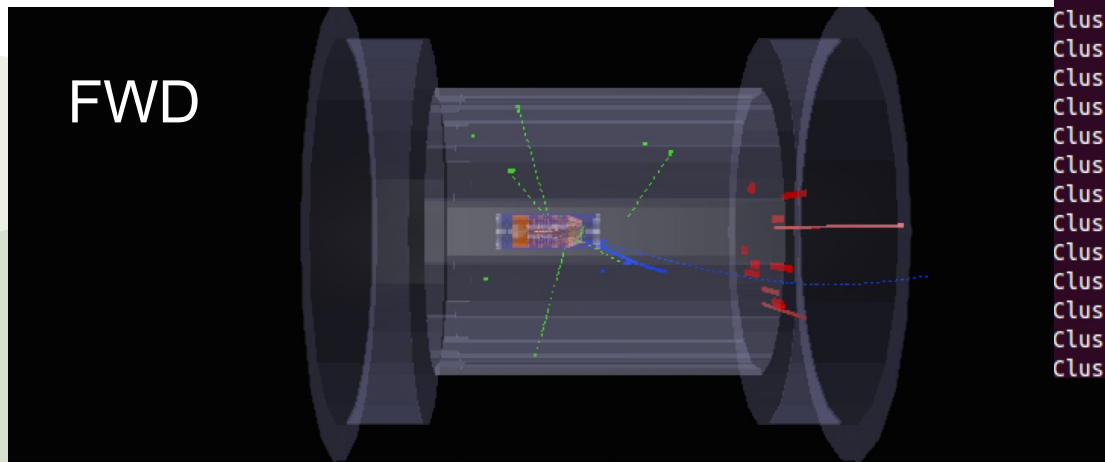
# Clustering FWD

B. Oberhof

- 10 500MeV photons,  $12.5 < \theta < 14$  deg,  $\phi$  free, (corresponds to 2 innermost rings)  $\rightarrow$  1 “survivor”

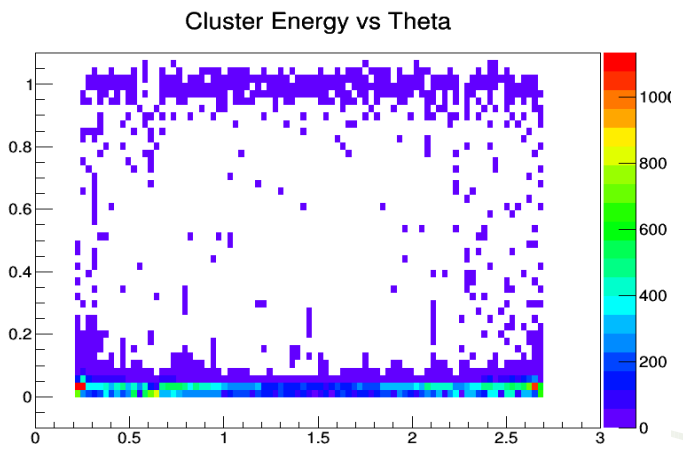
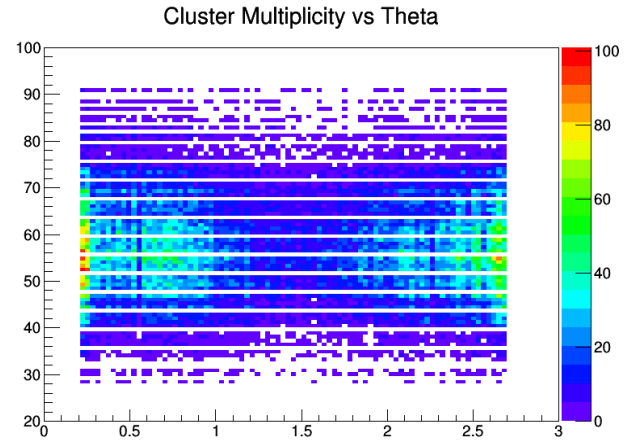
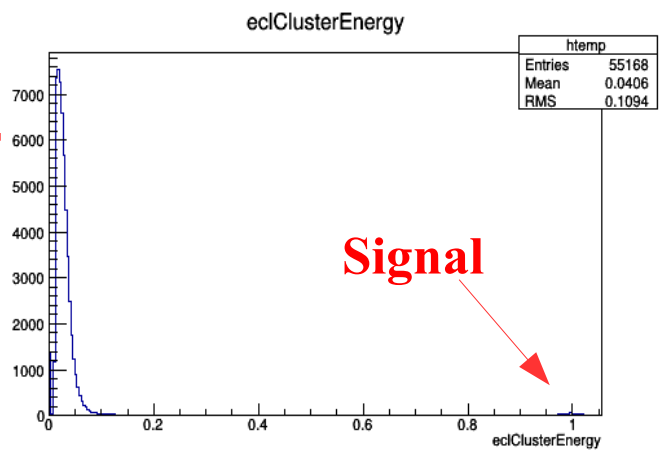
```

ClusterID: 0 Energy: 0.037531 MParticle: 7 Weight: 6.17898e-05
ClusterID: 0 Energy: 0.037531 MParticle: 9 Weight: 0.038868
ClusterID: 1 Energy: 0.0961378 MParticle: 7 Weight: 6.17898e-05
ClusterID: 1 Energy: 0.0961378 MParticle: 9 Weight: 0.0924112
ClusterID: 2 Energy: 0.0208089 MParticle: 3 Weight: 0.0192064
ClusterID: 2 Energy: 0.0208089 MParticle: 4 Weight: 0.0040366
ClusterID: 3 Energy: 0.242226 MParticle: 3 Weight: 0.000510999
ClusterID: 3 Energy: 0.242226 MParticle: 4 Weight: 0.230913
ClusterID: 4 Energy: 0.0431432 MParticle: 10 Weight: 0.0402325
ClusterID: 5 Energy: 0.0191602 MParticle: 2 Weight: 0.0173313
ClusterID: 6 Energy: 0.01453 MParticle: 10 Weight: 0.0129558
ClusterID: 7 Energy: 0.0215995 MParticle: 7 Weight: 0.0201124
ClusterID: 8 Energy: 0.0382603 MParticle: 2 Weight: 0.00141424
ClusterID: 8 Energy: 0.0382603 MParticle: 5 Weight: 0.0338492
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ClusterID: 10 Energy: 0.0150103 MParticle: 7 Weight: 0.0134739
    
```

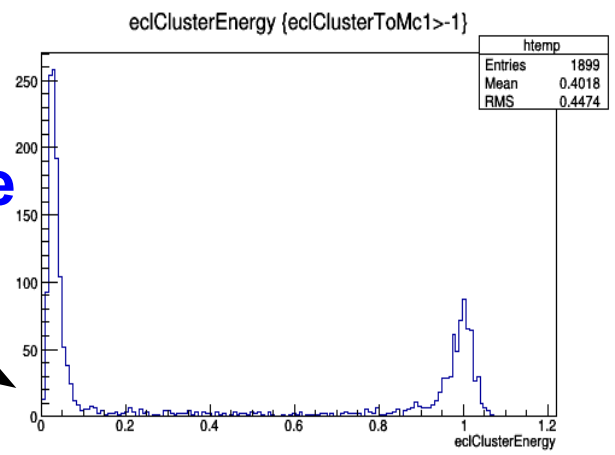
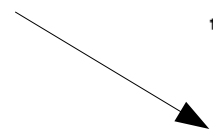


- 1 GeV pGun photon, full solid angle, 1000 evt + bkg
- Large lowE tail not easy to trace back, consistent with pile-up?
- Studies are ongoing..

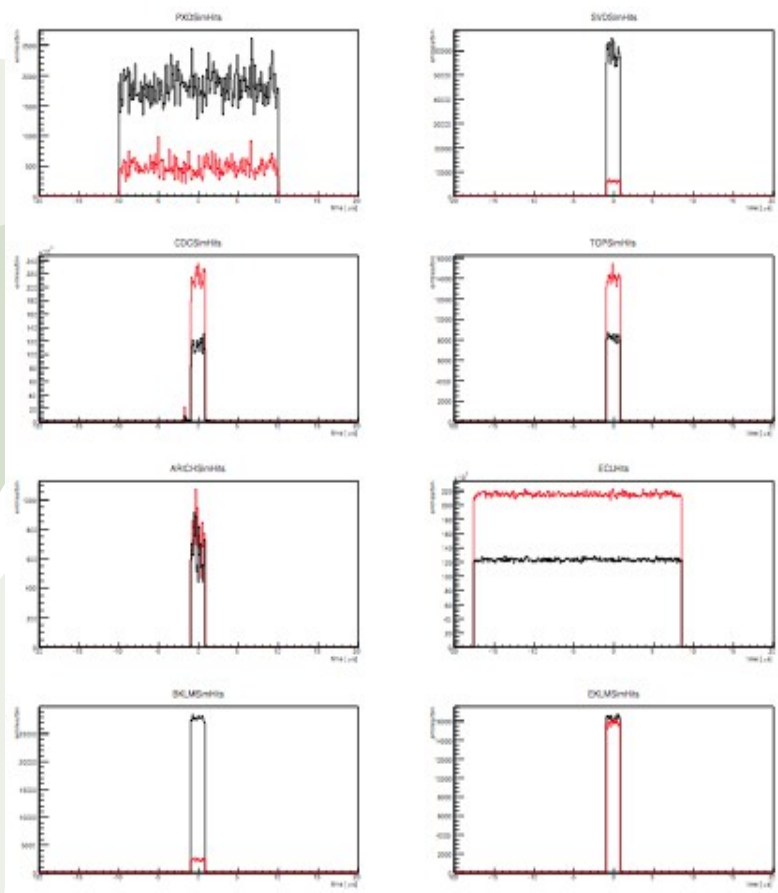
FULL



From  
MCParticle



- No stability of bkg conditions as  $f(t)$
- We need tools to monitor ECL bkg levels both at sim and reco level
- Problem has been addressed to Nakayama-san

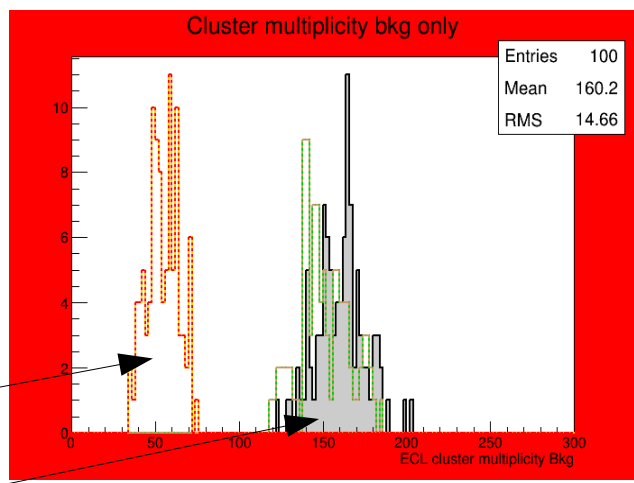


Last week

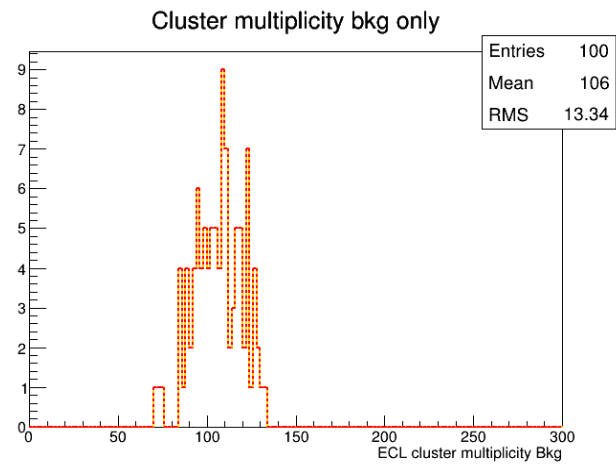
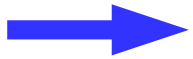


New Digitizer

Old Digitizer



This week





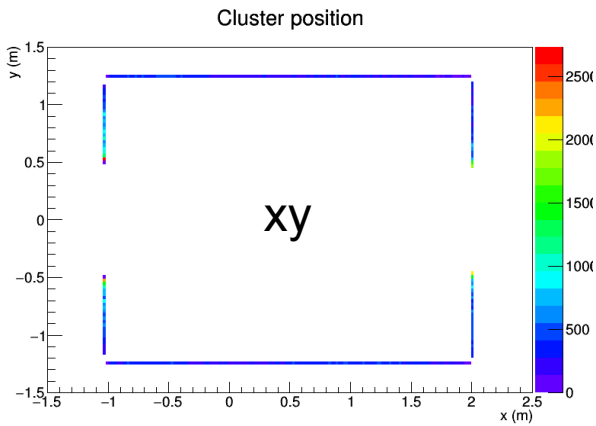
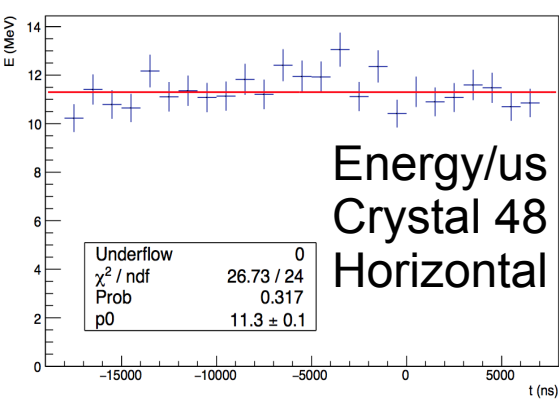
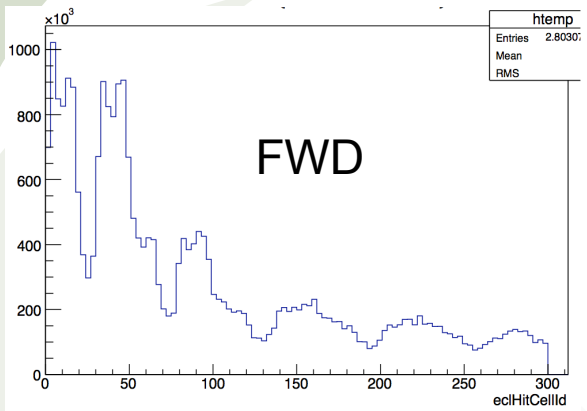
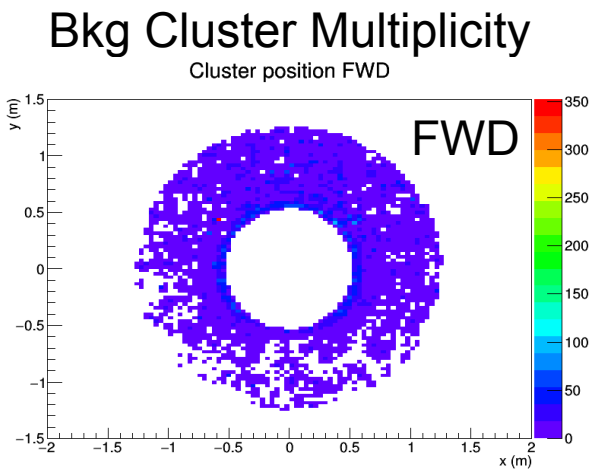
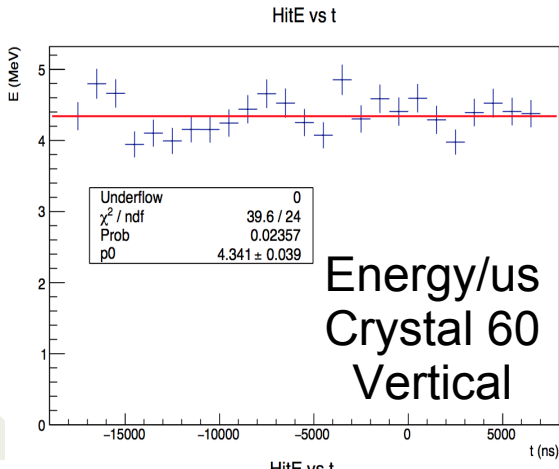
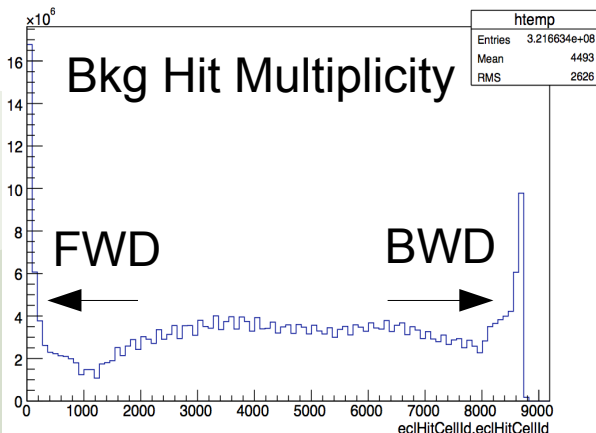


# Other Stuff



B. Oberhof

- Started to study quantitatively pile-up
- Development of validation and analysis tools is ongoing in parallel





- Much progress on the ECL reconstruction SW in last months
- New ECLDigitizer provides improved performance w.r.t. previous versions and better bkg rejection. Interface with conditions DB will be included once DB will be available.
- MC-Matching issues have been fixed with positive feedback from analysts. Weighting scheme has to be discussed in more detail considering analysts.
- All updates will be available in the next SW release
- Clustering algorithm shows some flaws → studies ongoing
- Work has started to define some reference selection criteria when beam background is added → starting point for the development of the new clustering algorithms and to improve ECL performance



# *Backups*



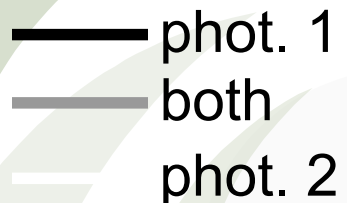
# Old ECLMcMatching Module



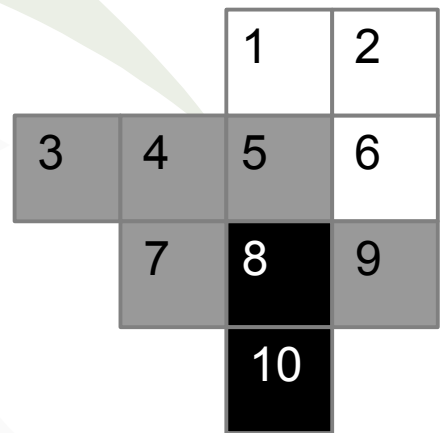
B. Oberhof

- In old eclMCMatching module:
- Association was done 1 (cluster) to 1 (MCParticle)
- The MCParticle giving highest contribution to the cluster in terms of eclDigits was associated with it
- A eclDigit is associated to a particle if the corresponding eclHit is, no matter what is its real contribution in terms of E
- Besides loss of information (true energy contribution, multiple-matching) this may also lead to wrong results

2 photons, 1 cluster



TrueE(1)=200 MeV  
 TrueE(2)=300 MeV  
 ClusterE=480 MeV



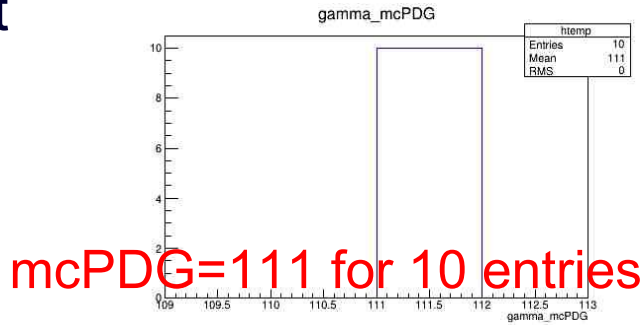
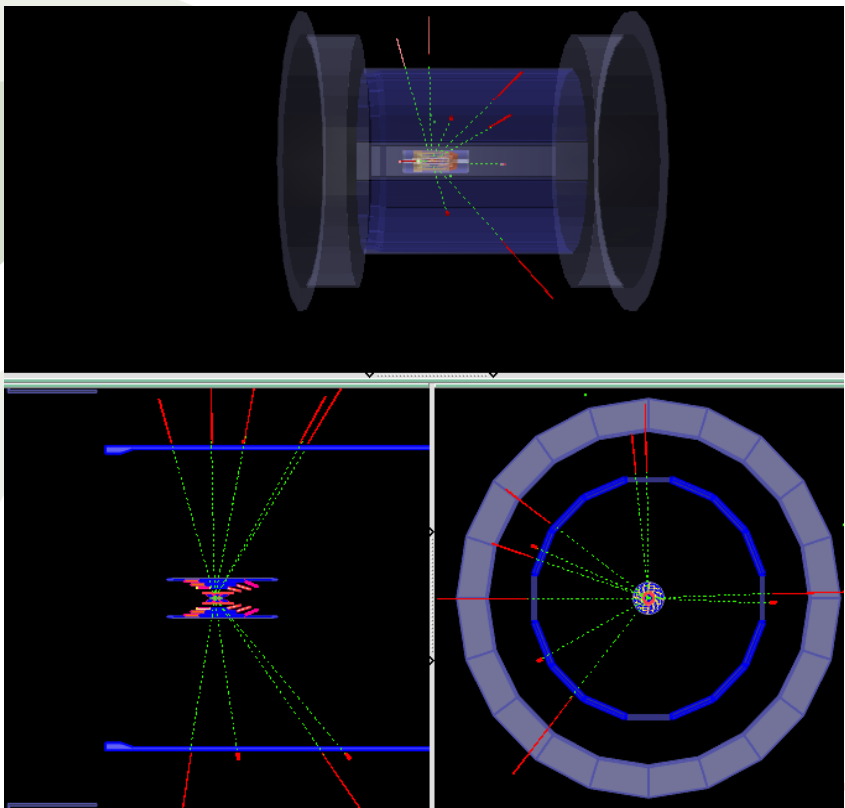
Digit content:

1 - 100	
2 - 120	
3 - 300	Sum(1)=4350
4 - 450	Sum(2)=3420
5 - 1200	
6 - 150	MCParticle 1
7 - 800	is associated
8 - 1000	to 480 MeV
9 - 300	
10 - 300	

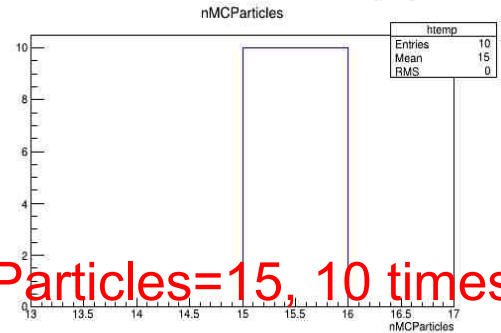
# Old MCMatching bugs

From last B2GM

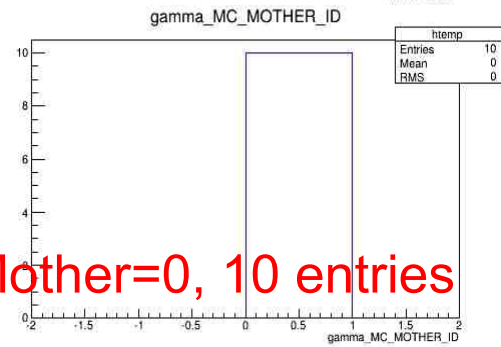
- Many flaws in ECL related MC matching
- e.g. 5 neutral pions, 1 GeV each, 1 evt
- Build-2014-09-01, default Sim&Reco,
- Flat ntuple using NtupleMaker



mcPDG=111 for 10 entries



nMCParticles=15, 10 times



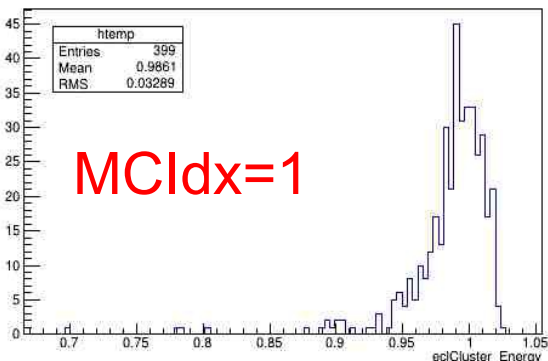
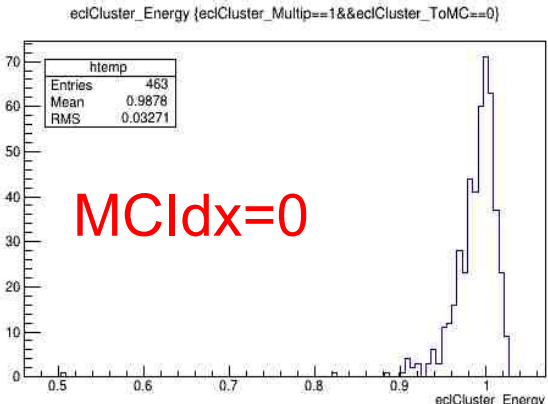
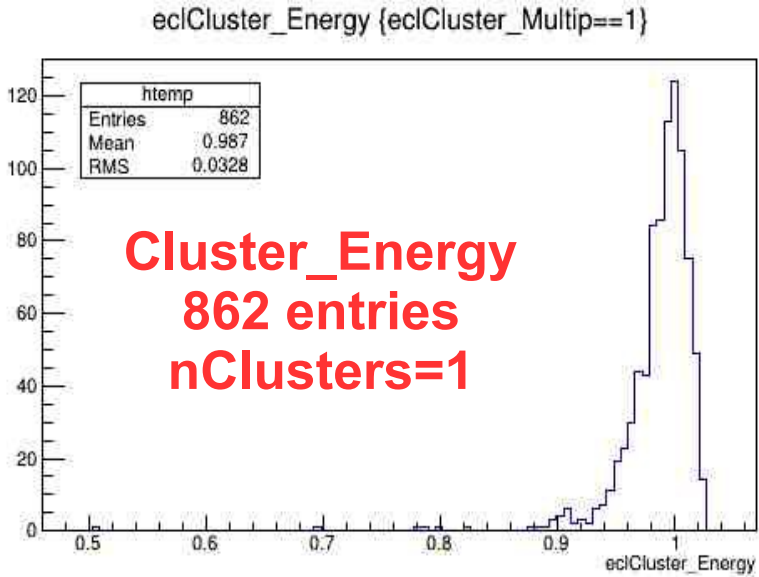
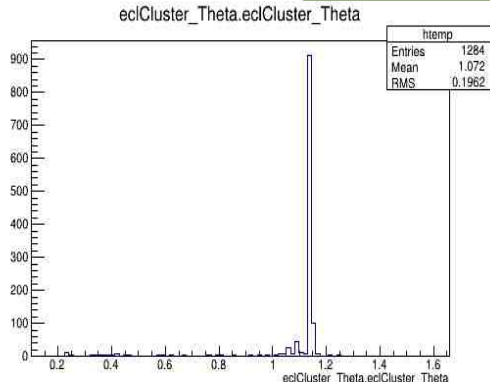
MCMother=0, 10 entries



# Multiple matching

From last B2GM

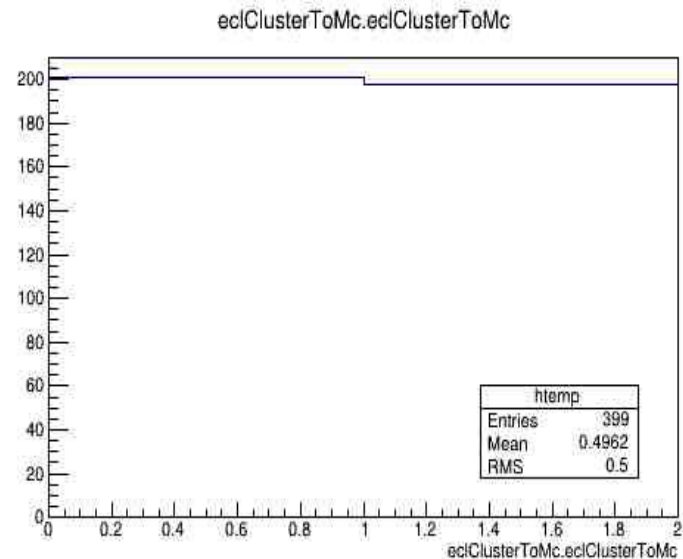
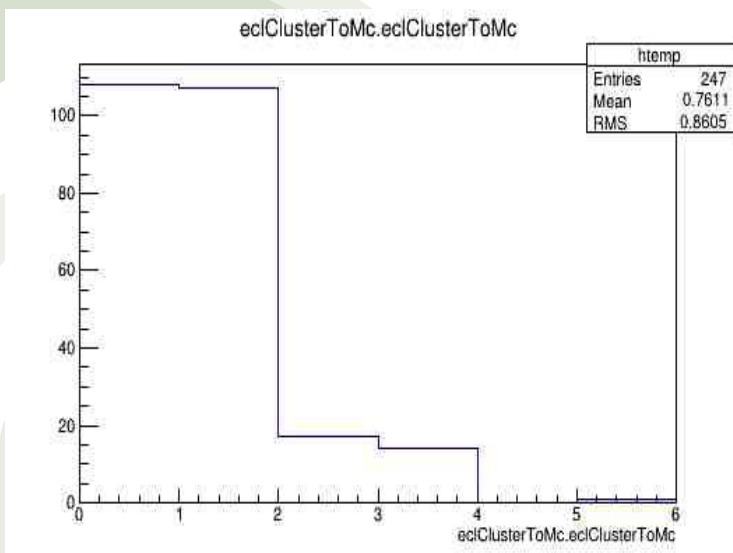
- Two “nearby” photons  $\Delta\theta < 1^\circ$ ,  $\Delta\phi < 1^\circ$
- 500 MeV each, single cluster 1 GeV
- Cluster info is not shared between the MC cand



**MCCandidate\_Idx associated to cluster**

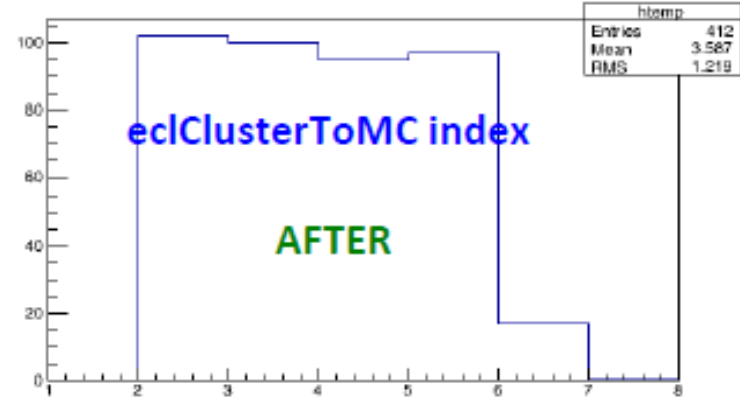
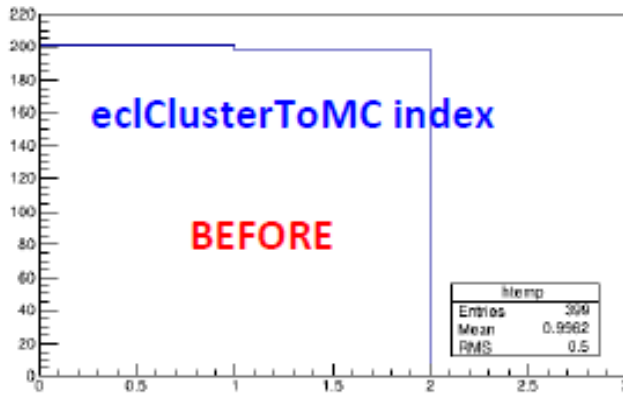
- Distinguish individual energy releases crucial when bkg is added
- We are currently at work on that: weights will be introduced to handle multiple association and bkg

- Previous bugs were related to improper treatment of unstable particles and their decay products, example:
- 1<sup>st</sup> case: 2 photons 1 GeV each, 100 evt → resulting clusters are correctly associated to primary photons
- 2<sup>nd</sup> case: 2  $\pi^0$ , 500 MeV each, 200 evt → all resulting clusters are associated to the primary particles

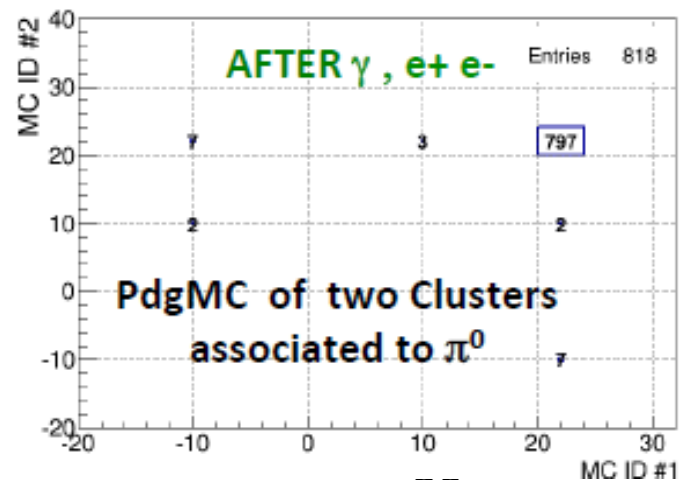
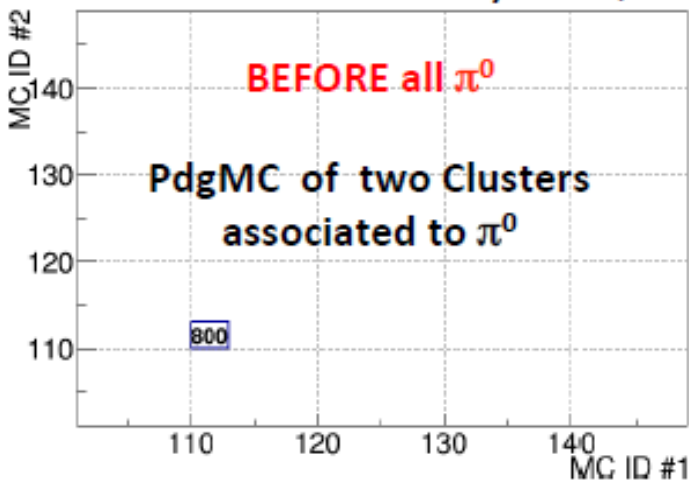


- Previous flaws in MC matching have now been fixed
- Fixes will be included in next integration build

2  $\pi^0$ /event, E=0.5 GeV, 100 events



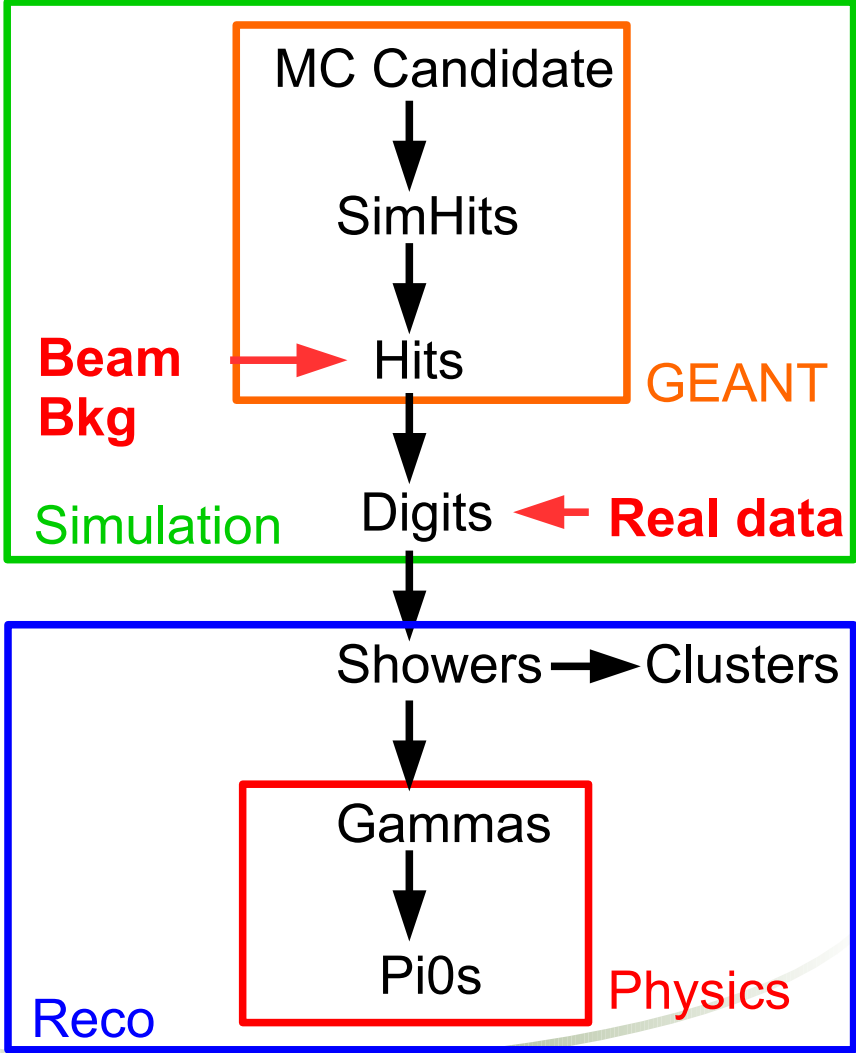
$\pi^0$ /event, E=0.5 GeV, 1000 events





# Weighted matching

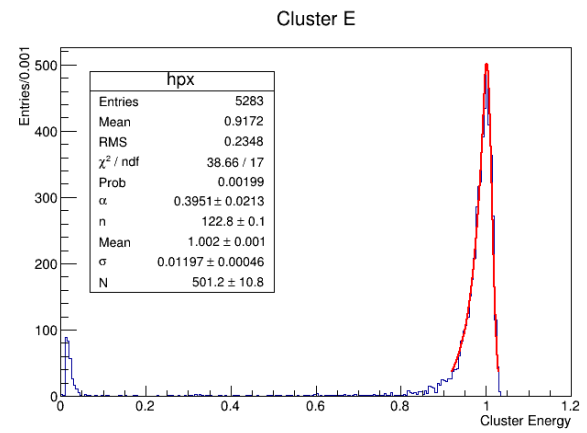
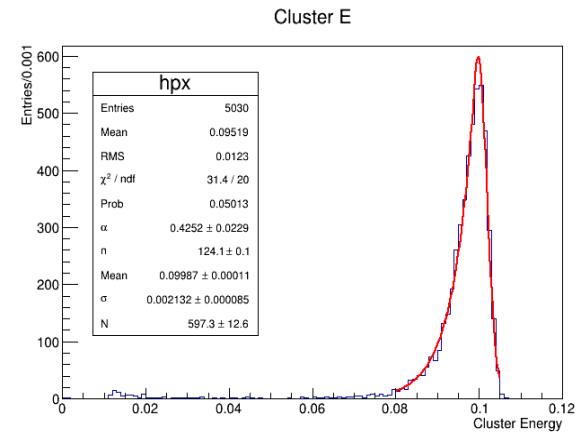
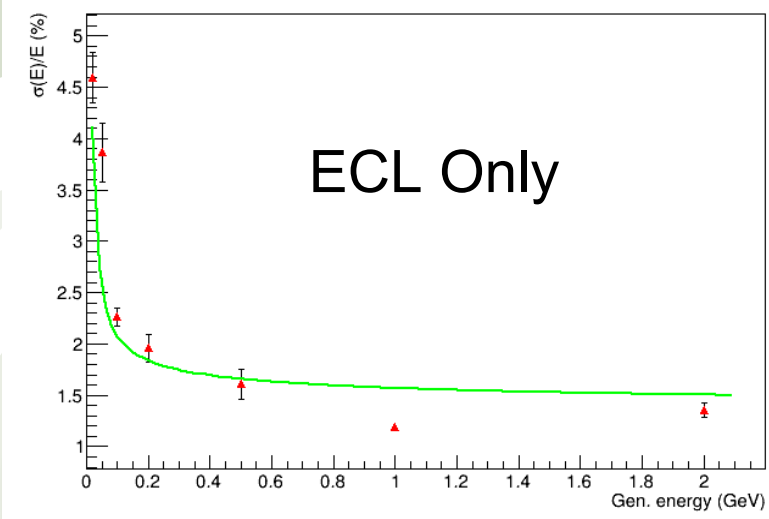
- MCMatching for reconstructed quantities is done in ECLMCMatching module
- In ECLMCMatching information about MCParticles is inherited from EclHits and propagated
- Matching for Hits is done at Simulation stage (SensitiveDetector.cc)
- Idea is to use EnergyDep as weights at SimHits level and then propagate them to the final analysis objects



- Our studies are oriented to::
  - evaluate intrinsic ECL performance
  - study the effect of other subdetectors
  - study suitable bkg rejection criteria

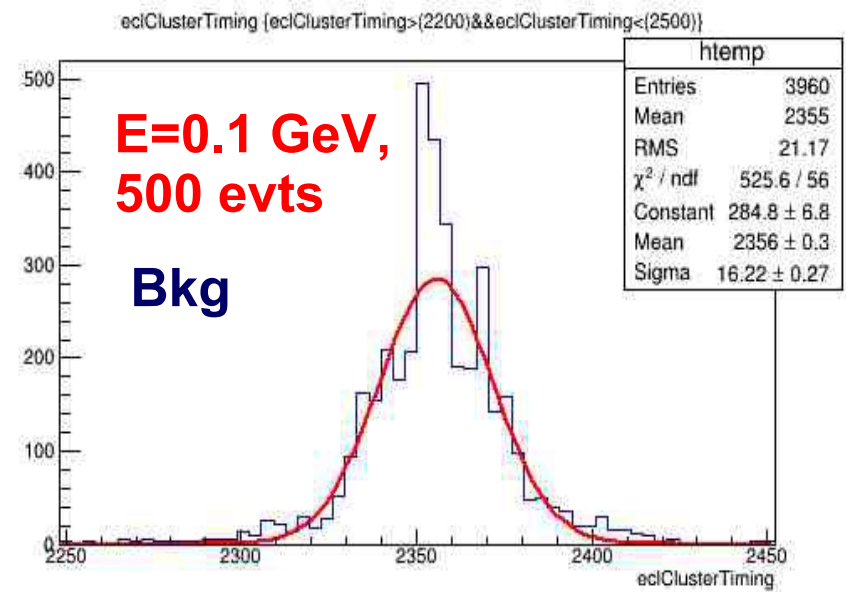
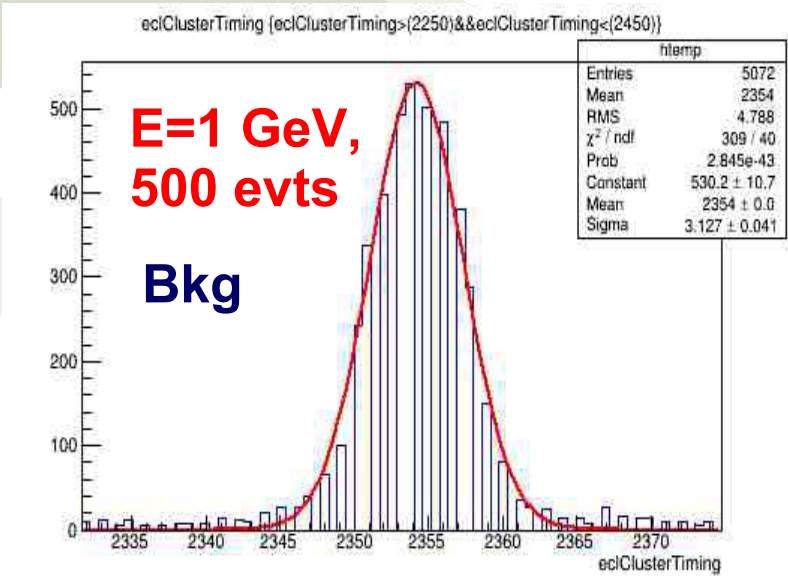
$$\frac{\sigma_E}{E} = \sqrt{\left(\frac{0.066\%}{E}\right)^2 + \left(\frac{0.81\%}{\sqrt{E}}\right)^2 + (1.34\%)^2},$$

Energy resolution



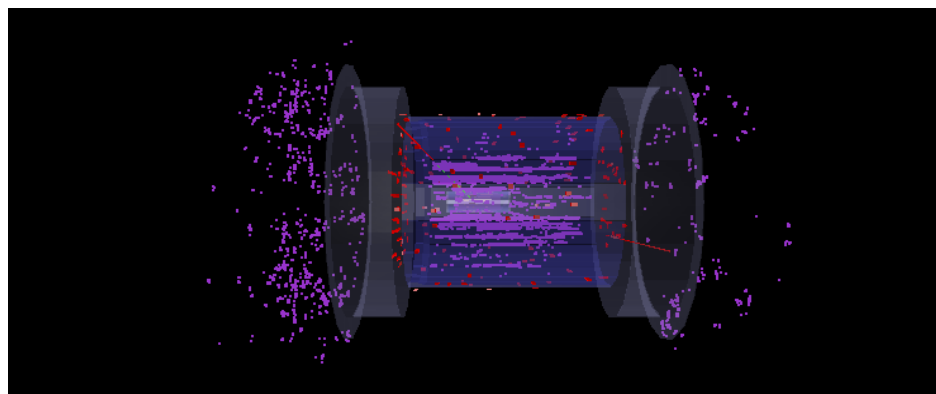
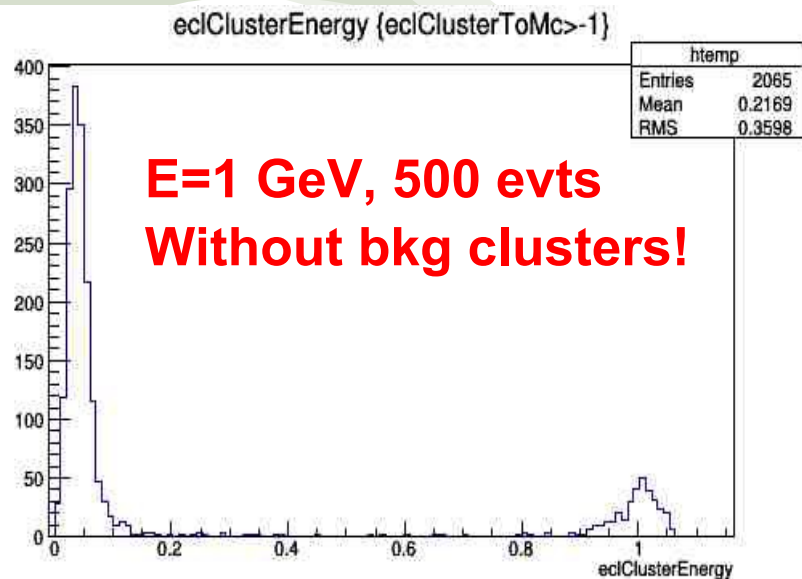
- A new validation script to fit resolution and plot as f(E) in under preparation and will be uploaded soon

- We have started studies to define suitable selection criteria when beam bkg is mixed in
- From timing distributions without bkg we derive resolution
- We used 1GeV for consistency checks and then studied 100MeV case, 500evt each, full solid angle
- Resolution: 1.4 ns at 1 GeV, 6ns at 100 MeV

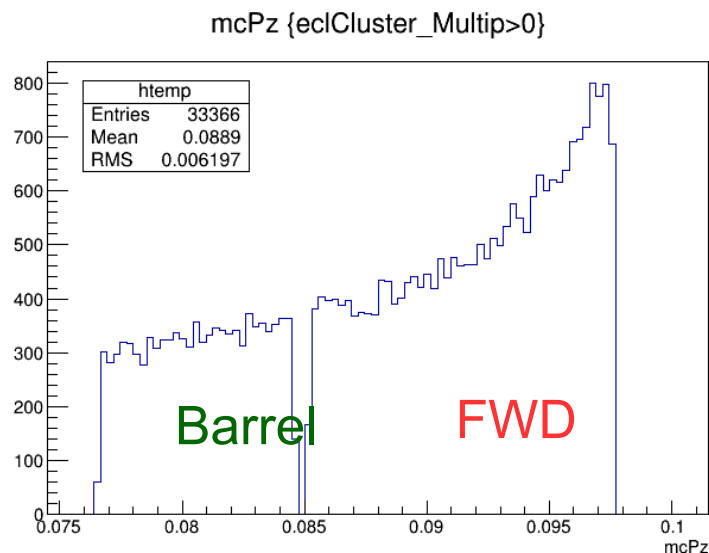
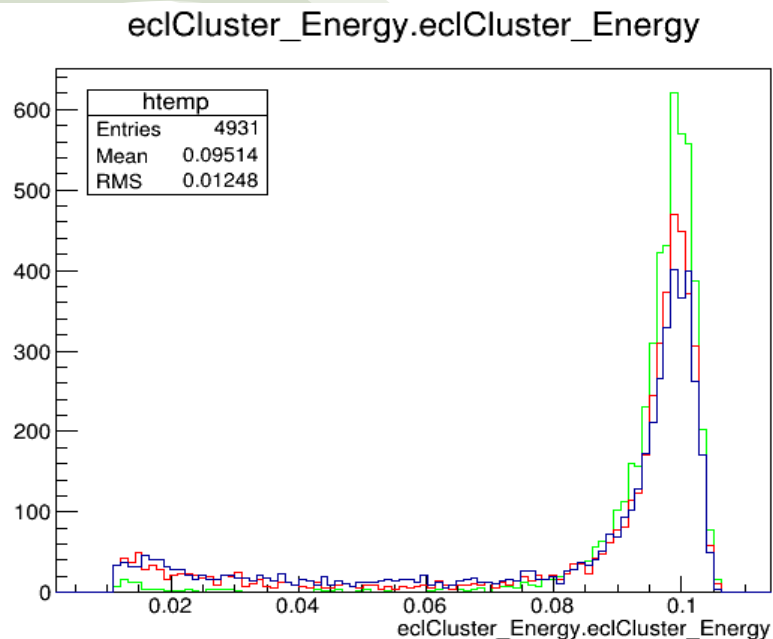


**x scale is in ECL "steps", 1 ecl "step" = 0.37 ns**

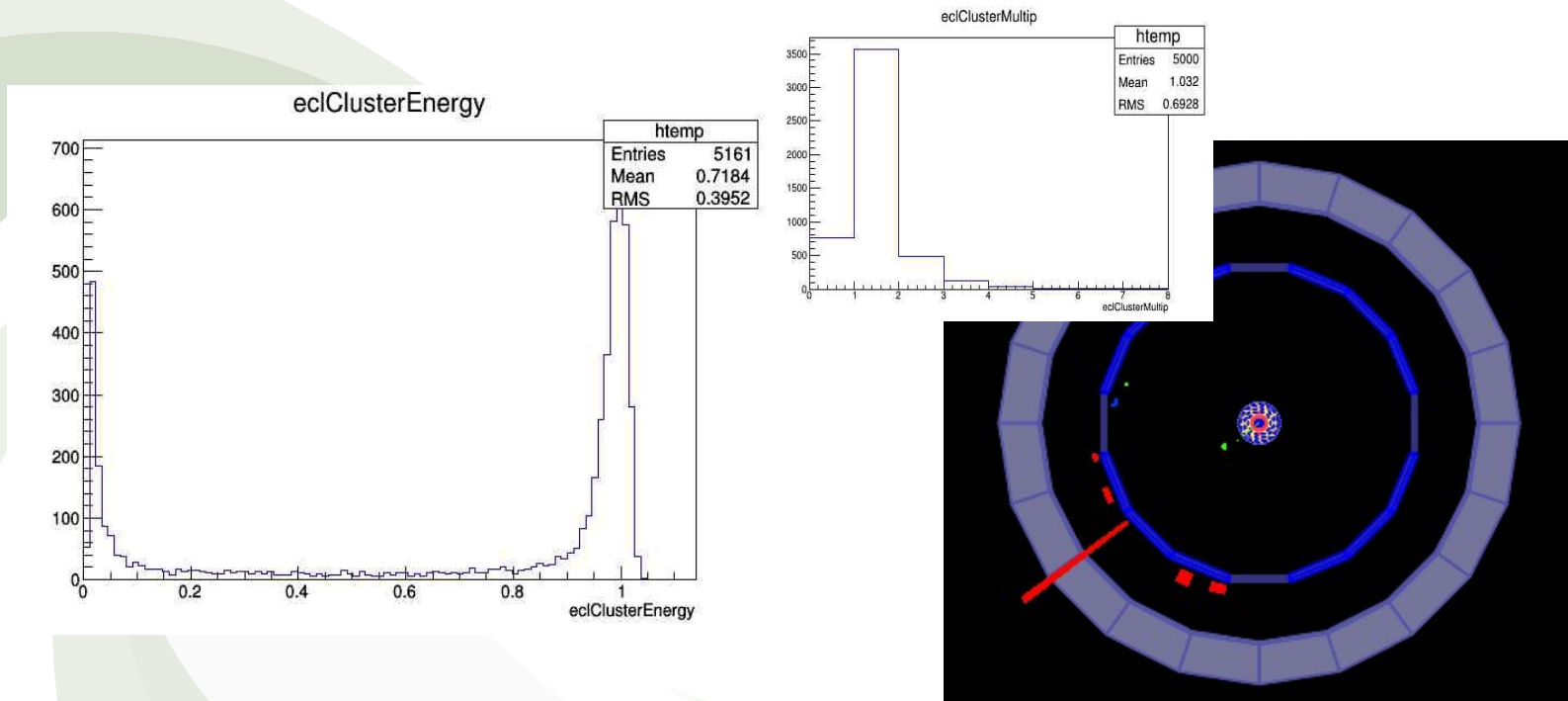
- When beam-bkg is added the number of (non bkg-related) low-energy clusters increases dramatically
- Probably a pile-up effect: bkg energy release “promote” clusters which otherwise would be under threshold
- For this reason in the following we require a “well reconstructed photon”, i.e. the cluster energy to be at least 0.5 times the energy of the generated photon, to be included in efficiency



- Compared 3 different geometries:
  - ECL only (green)
  - Full detector without ARICH (red)
  - Full detector (blue)
- Little effect of subdet material on resolution, rather on efficiency
- The nominal geometry and actual MC acceptance are different (MC acceptance is  $12.4^\circ - 31.35^\circ$ )

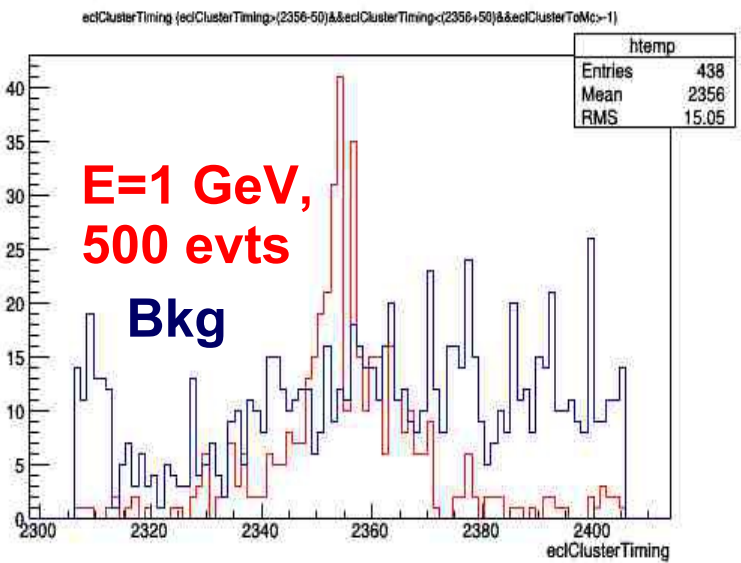


- High energy photons generate large numbers of low energy clusters
- This effect is increased by the introduction of beam-bkg (see later)
- This has to be considered in the definition of the efficiency



# Timing with bkg

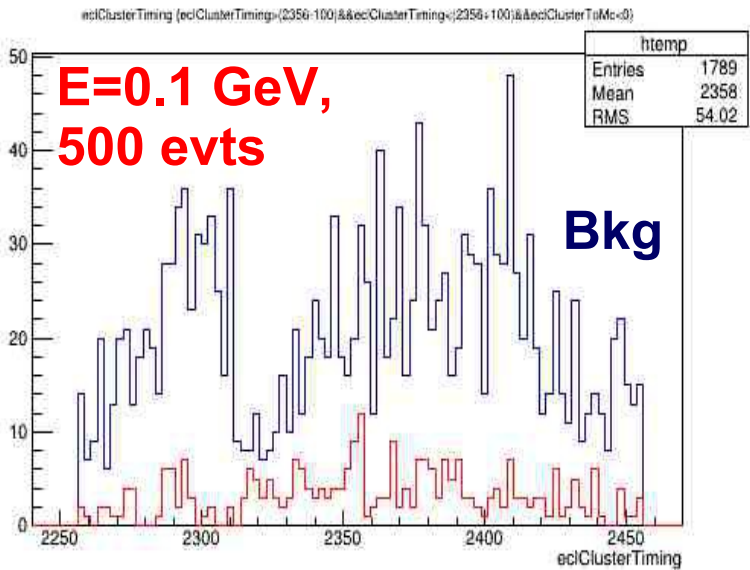
- Cluster timing distribution is broadened by background
- Ongoing work on clustering aims to improve resolution with bkg
- For now, to keep reasonable efficiency we have to enlarge default 3sigma timing interval by x2



1 GeV resolution 3 steps

#non-bkg cl. (#cl.  $E > 0.5E_0$ ) #total clusters

- Any selection: 2065 (381 > 0.5), 81217
- +-10 steps: 280 (260 > 0.5), 486
- +- 20 steps: 365 (330 > 0.5), 782
- +- 50 steps: 438 (368 > 0.5), 1357



0.1 GeV, resolution is 16 steps

- Any selection: 713 (415 > 0.05), 81470
- +-50 steps: 178 (167 > 0.05), 1091
- +- 75 steps: 239 (221 > 0.05), 1702
- +- 100steps: 280 (261 > 0.05), 2069

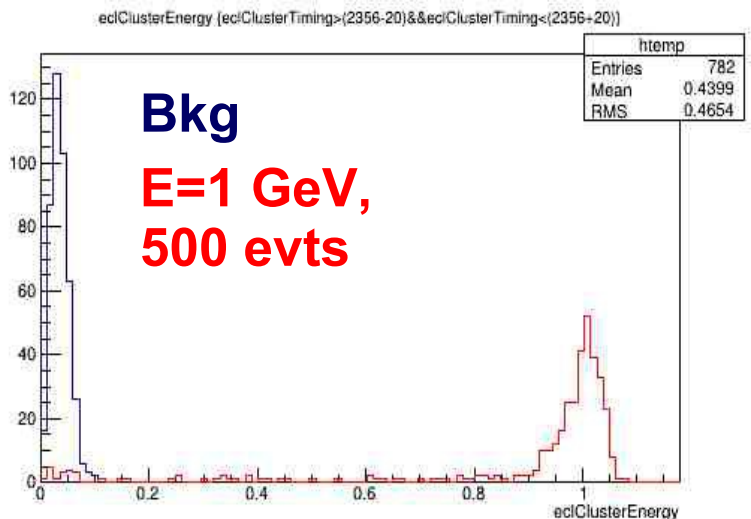


1 ecl "step" = 0.37 ns



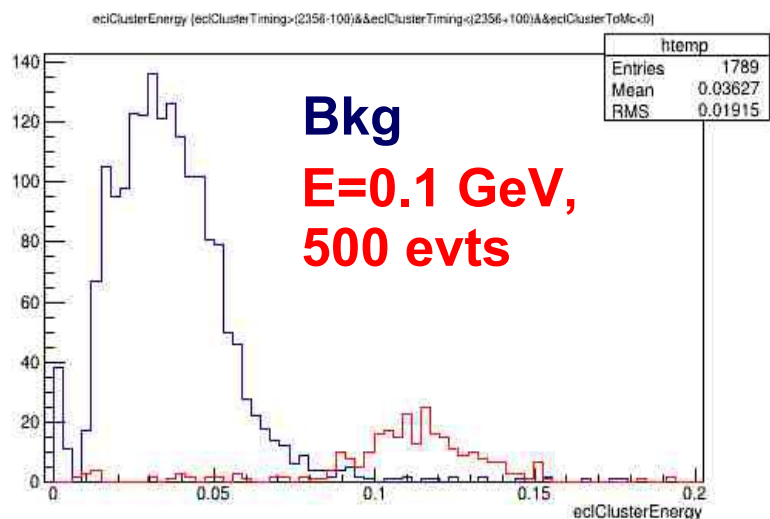
# Energy threshold

- After selecting a reasonable time window set cuts on the minimum cluster energy
- Using  $|t-t_0|=7.4$  ns and  $|t-t_0|=37$  ns
- At moment it seems difficult not possible to select neutrals with  $E < 100$  MeV without additional criteria



- +- 20 steps &&  $E > 0.01$ : S/N=43%
- +- 20 steps &&  $E > 0.02$ : S/N=46%
- +- 20 steps &&  $E > 0.05$ : S/N=77%
- +- 20 steps &&  $E > 0.075$ : S/N=92%
- +- 20 steps &&  $E > 0.1$ : S/N=95%

**Eff. = 87%, S/N = 95%**



- +- 100 steps &&  $E > 0.01$ : S/N=13%
- +- 100 steps &&  $E > 0.02$ : S/N=15%
- +- 100 steps &&  $E > 0.05$ : S/N=44%
- +- 100 steps &&  $E > 0.08$ : S/N=85%
- +- 100 steps &&  $E > 0.09$ : S/N=87%

**Eff. = 58%, S/N = 87%**