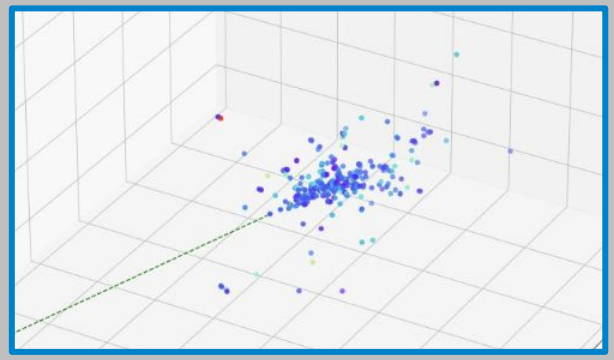
EIC Calorimetry WG Meeting

Argonne NATIONAL LABORATORY

Calorimetry Reconstruction and Benchmarks



ANL EIC Calorimetry Team
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09/15/2021

Content

- General overview of the event reconstruction for calorimeters
  - Digitization
  - Reconstruction
  - Clustering
  - Calibration
- Example of a simple benchmarks
  - Clustering information check
  - Energy resolution

Event Reconstruction for Calorimeters

Current in juggler analysis framework, the clustering is done by

1. digitization -> simulation hits to readout signals
2. readout reconstruction -> readout signals to energy/timing/position/etc (calibration)
3. proto-clustering -> group hits following certain algorithms
4. cluster reconstruction -> reconstruct position/energy/etc from group of hits

Two clustering algorithms are available now

1. Island clustering for 2D hits
2. Topo clustering for 3D hits

Digitization

Simulate the electronics response

Currently in the benchmark:

- ADC channels with dynamic range
- Pedestal (mean + sigma)
- Timing Jitter

ADC_value = hit_energy / dynamic_range * ADC_capacity + pedestal_mean + pedestal_sigma*RandGaus

ADC_value clamped at [0, ADC_capacity]

Reconstruction

Convert ADC channels back to energy, with a threshold

energy = (ADC_value - pedestal_mean) / ADC_capacity * dynamic_range

Threshold cut:

Ignore hits if **ADC_value - pedestal_mean < threshold * pedestal_sigma**

Usually > 3.0 sigma threshold is used in the option file

Digi/Reco in the Clustering Benchmark

https://eicweb.phy.anl.gov/EIC/benchmarks/reconstruction_benchmarks/-/tree/master/benchmarks/clustering

Calorimeter	Readout Unit in Simulation	Dynamic Range	ADC Capacity	Pedestal Mean	Pedestal Sigma	Thres.
ECal Electron Endcap	Module	5 GeV	32768	400	3	4.0
ECal Hadron Endcap	Fiber	50 MeV	32768	400	10	5.0
ECal Barrel (Imaging)	Pixel (0.5 mm)	3 MeV	8192	400	20 (6 keV)	3.0
ECal Barrel (scfi)	Fiber	50 MeV	32768	400	10	5.0
HCal Electron Endcap	Pixel (100 mm)	50 MeV	32768	400	10	5.0
HCal Hadron Endcap	Pixel (100 mm)	50 MeV	32768	400	10	5.0
HCal Barrel	Pixel (100 mm)	50 MeV	32768	400	10	5.0

Ideal Digi/Reco

A large number for ADC capacity, for example: 2**32 - 1

A small number for pedestal sigma, for example: 0.0

In this case, no smearing from electronics response is added into reconstruction

More Realistic Digitization Planned

Add light yield and attenuation for ecals

- Simulation information about path length and energy deposit is available
- Convert it to light yield with Birks constant

Utilize timing information

- Barrel Ecal scfi layers could have eta resolution with timing difference between both ends (to simplify/improve cluster matching; in addition to excellent eta-phi resolution from imaging layers)

Noise generator

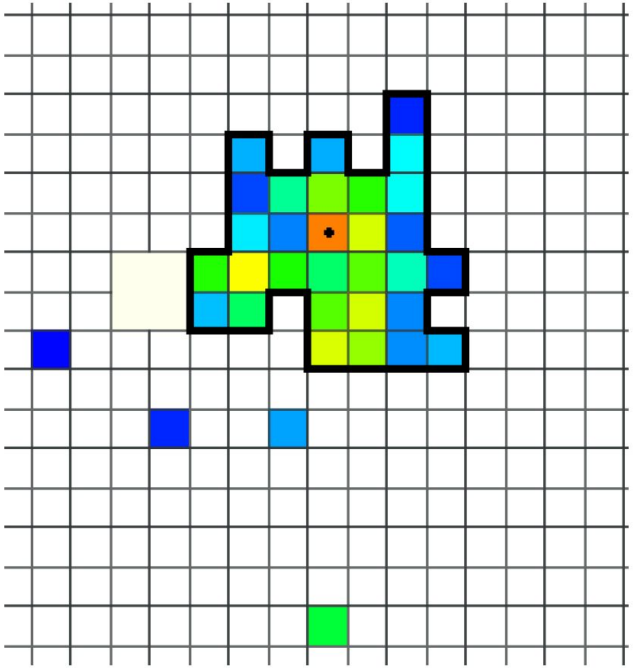
- Add noise for the readout units which do not have hit

Island Clustering

Group all neighbouring hits

- Parameterized conditions for finding neighbors
- Distance in local-XY, local-XZ, local-YZ,
- local-XY scaled by cell dimensions,
- global eta-phi, global R-phi

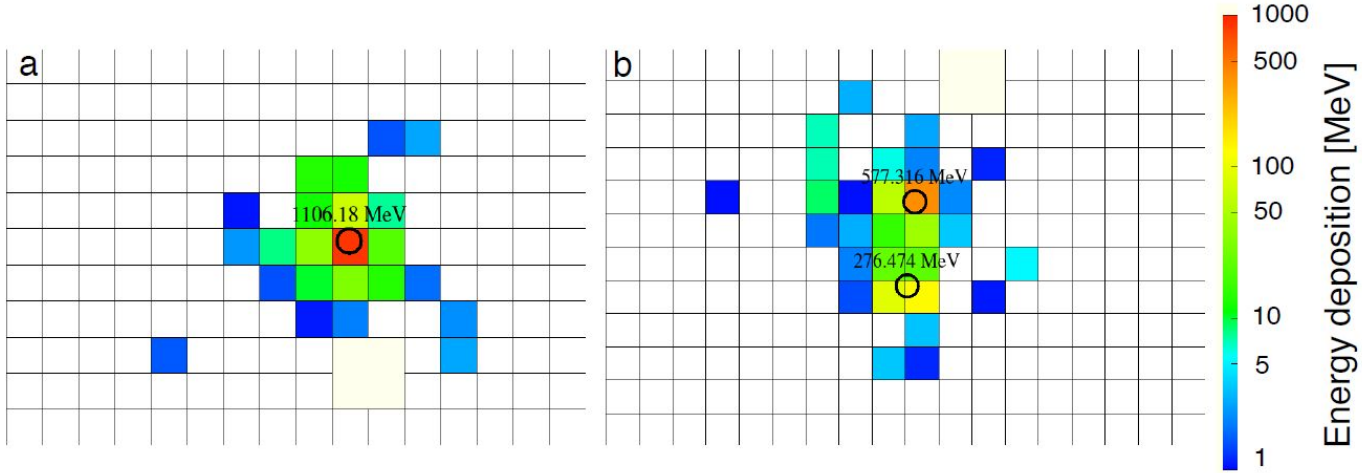
Parameterised minimal energy to be qualified as cluster center, and minimal energy to participate clustering



Island Clustering Splitting

Cluster splitting is available for Island Clustering

- Split based on Local maxima that are qualified as cluster center
- Hits energy split based on local maxima's energies and distances



Topo Clustering

Similar to Island clustering but works for hits from several layers, currently used for imaging layers

Hits at the same layer, local-XY

Hits from different layers, layer id difference and global eta-phi

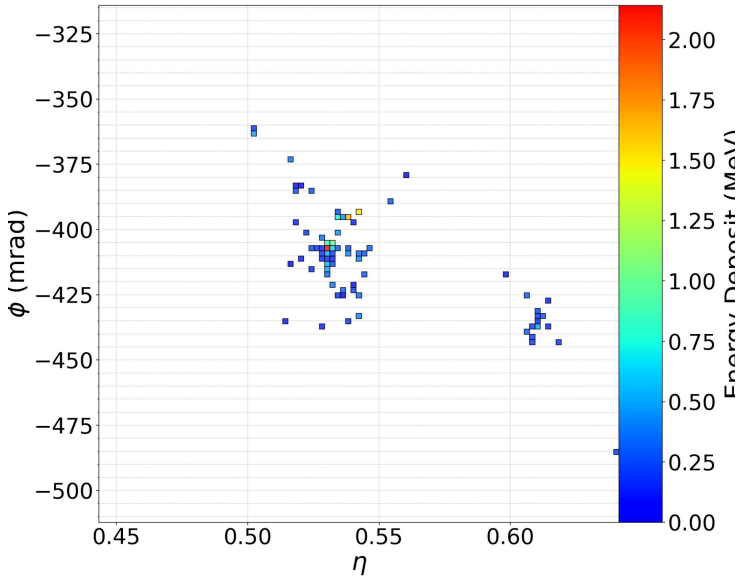
Hits from different sectors, global distance

No splitting implemented currently

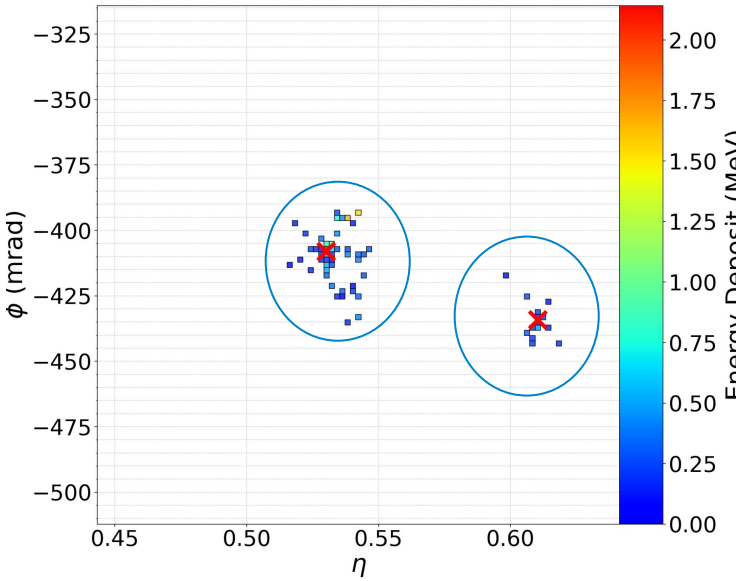
Mostly MIP signals in imaging pixels

Example for Barrel Calorimeter - 3D Clustering

All Hits



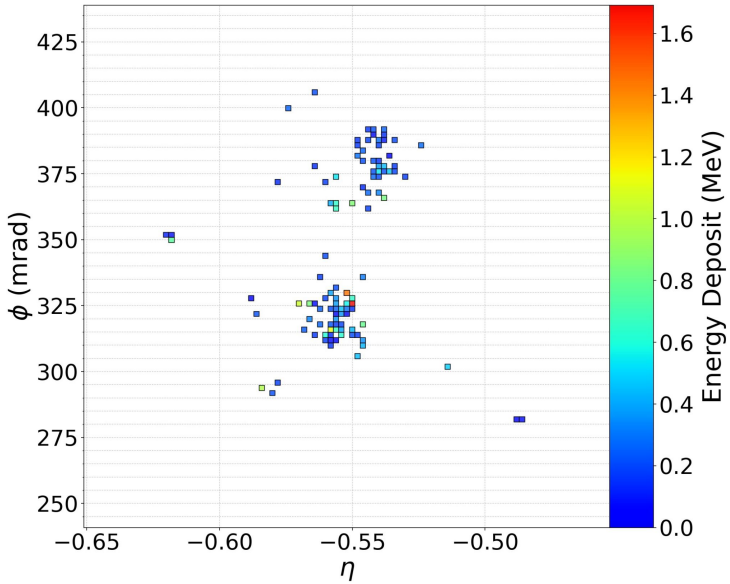
Clusters and True gamma positions



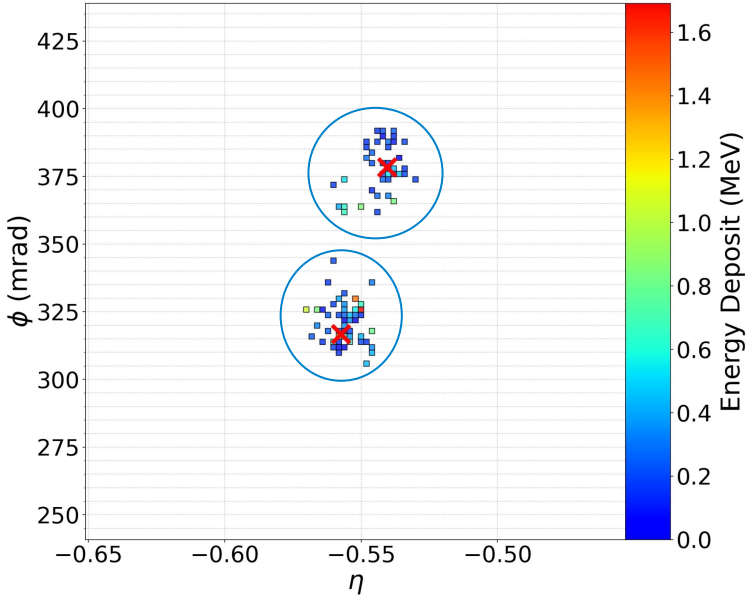
Plots from Jihee Kim

Example for Barrel Calorimeter - 3D Clustering

All Hits



Clusters and True gamma positions

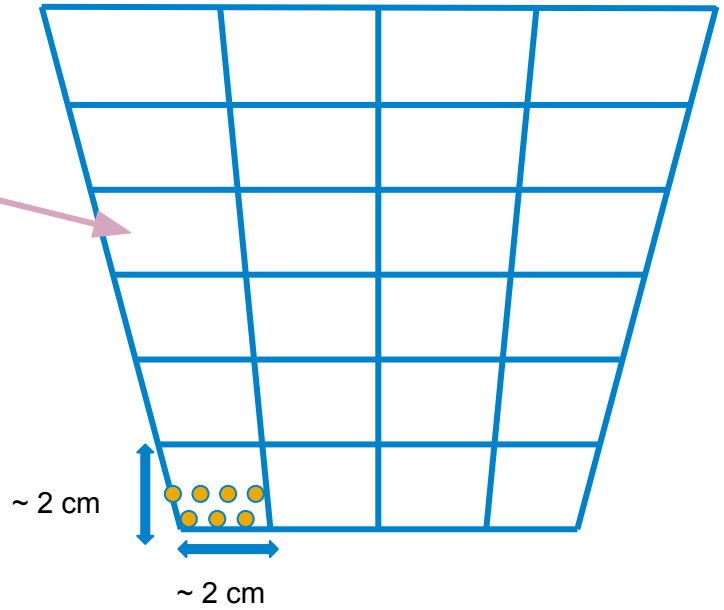


Plots from Jihee Kim

SiFi Calorimeter

Current Readout Implementation in dd4hep

- Readout unit in simulation is 1 fiber
- Fibers are divided into grid as shown in the picture (trapezoidal shape with height ~2cm)
- Clusters reconstructed using Island Clustering with input on the level of grid elements (not fibers)
- **In GlueX** every element of the grid connected to a lightguide
- Lightguides: from 21×21 mm^2 to 27×25 mm^2
- SiPM sensor area: 13×13 mm^2
- 4×4 array of 3×3 mm^2 tiles. Each composed of 3600 50×50 μm^2 pixels

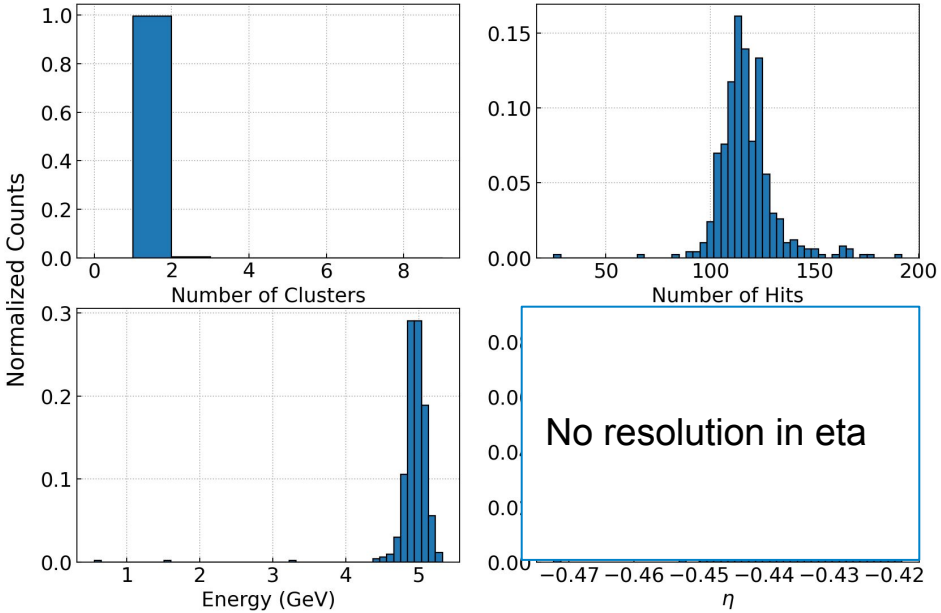


SiFi and Img Calorimeter Calibration

- Sampling fraction corrected energy from Geant4 simulation
- This constant is taken from 5 GeV electrons
- Correction separately for Imaging layers and ScFi layers
- Additional correction to be applied on the reconstruction level (how large correction is needed?)
- Calibration as a function on energy, eta, particle type...

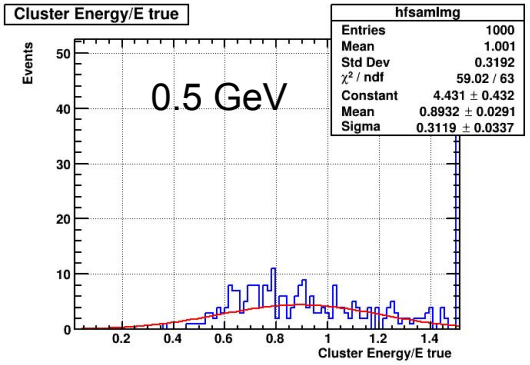
2D Island Clustering for ScFi layers

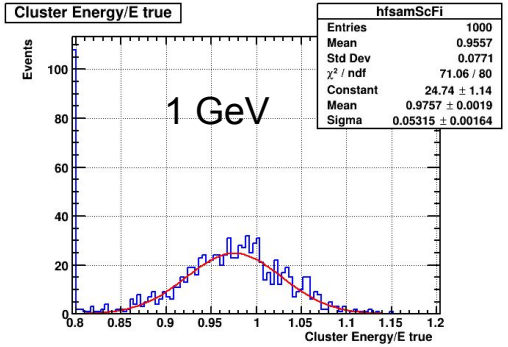
- 5 GeV electrons, generated flat in theta **98.9-90.1** deg.
- Calibration correction based on Geant4 sampling fraction for 5 GeV electrons ~ 10.4%.

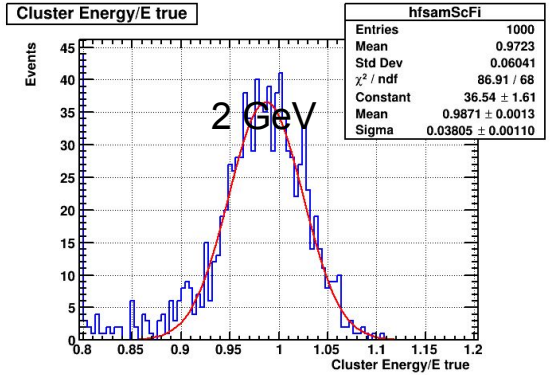


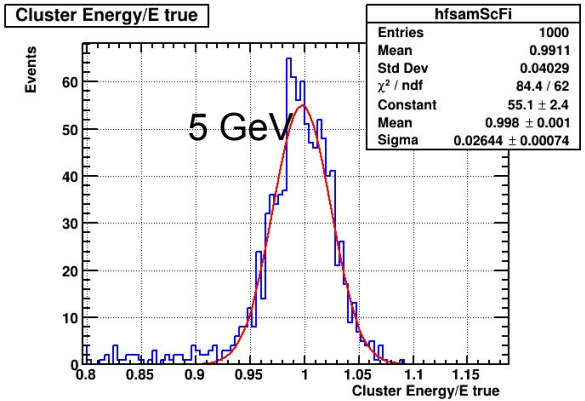
Energy resolution scan for ScFi layers

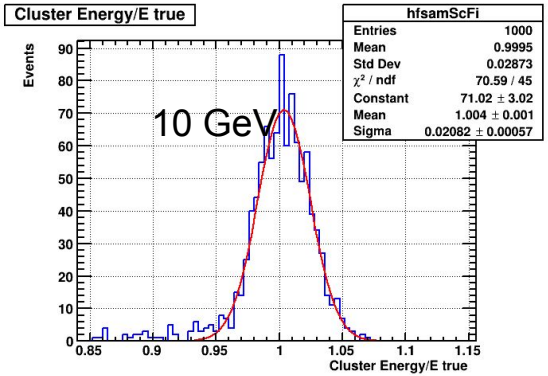
photons, theta = (89.9,90.1) deg, after reconstruction







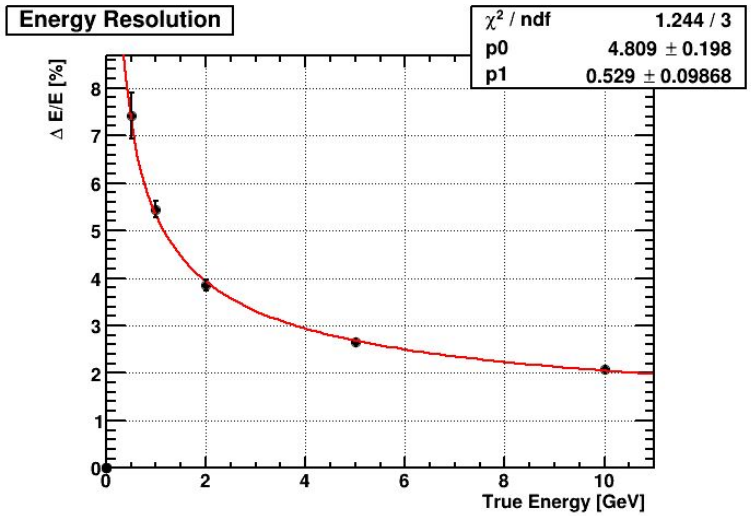




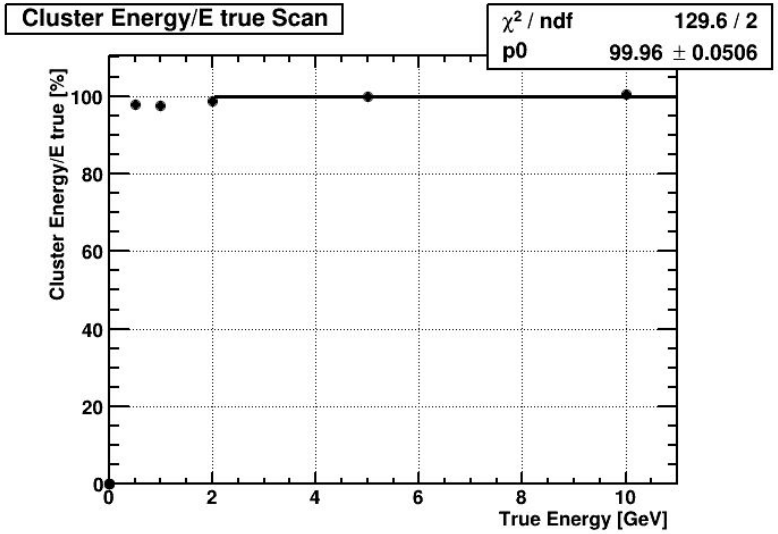

```
scfi_barrel_daq = dict(
        dynamicRangeADC=50.*MeV,
        capacityADC=32768,
        pedestalMean=400,
        pedestalSigma=20)
```

Energy resolution scan for ScFi layers

photons, theta = (89.9,90.1) deg, after reconstruction



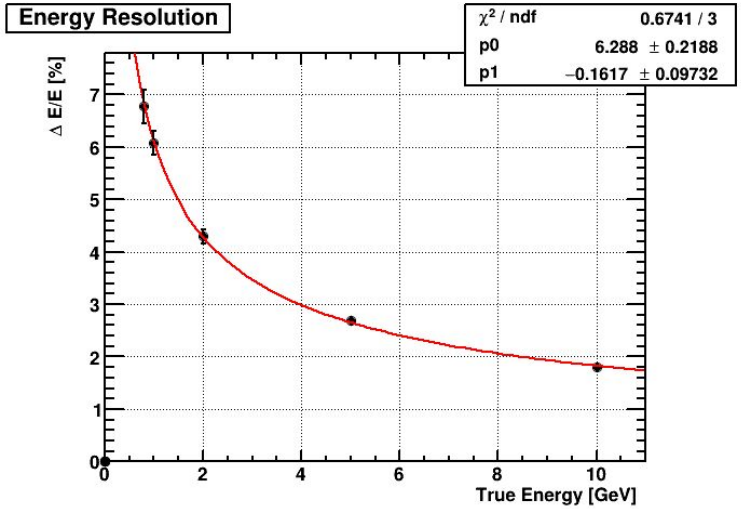
Energy resolution



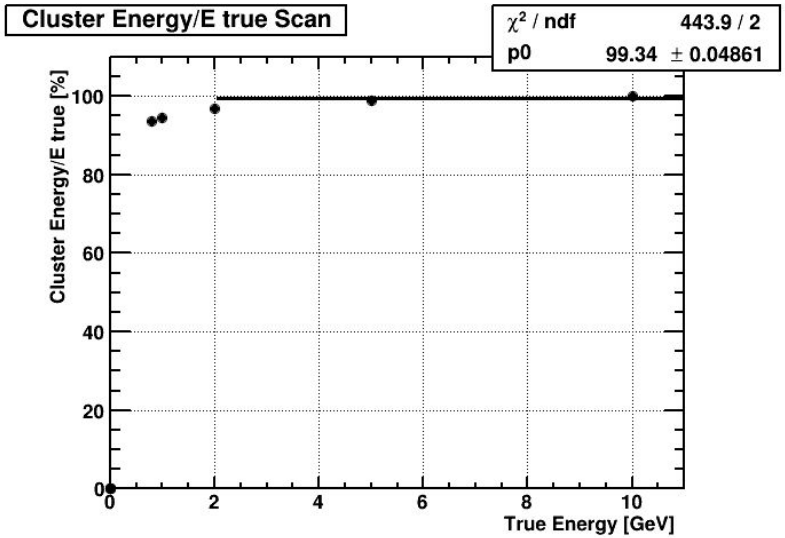
Peak position scan

Energy resolution scan for ScFi layers

electrons, theta = (89.9,90.1) deg, after reconstruction



Energy resolution

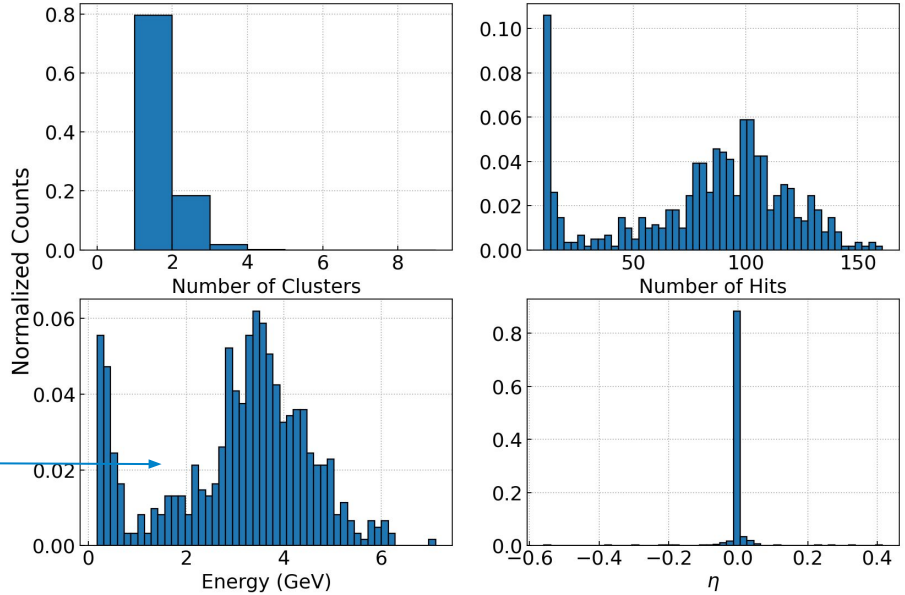


Peak position scan

3D Clustering for imaging layers

- 5 GeV electrons, generated flat in theta **98.9-90.1** deg.
- Calibration correction based on Geant4 sampling fraction for 5 GeV electrons ~ 0.6%.

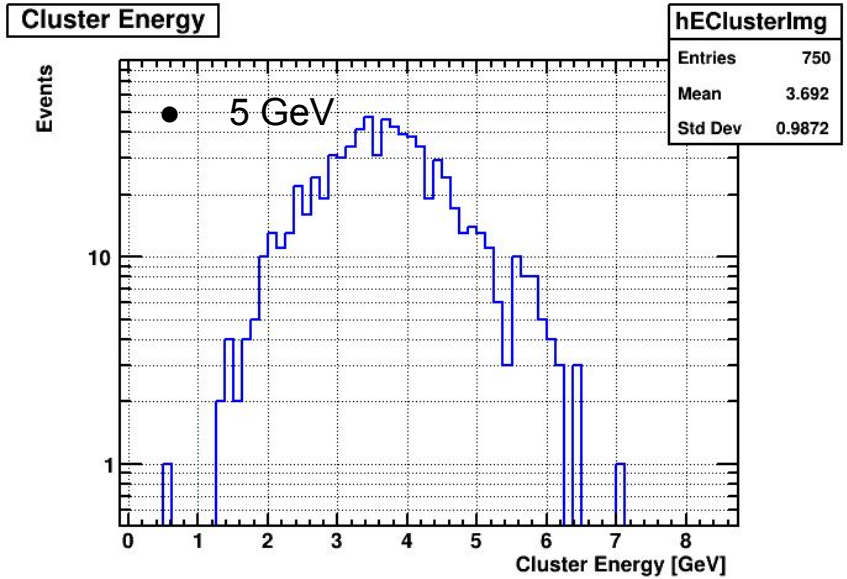
Energy of each cluster

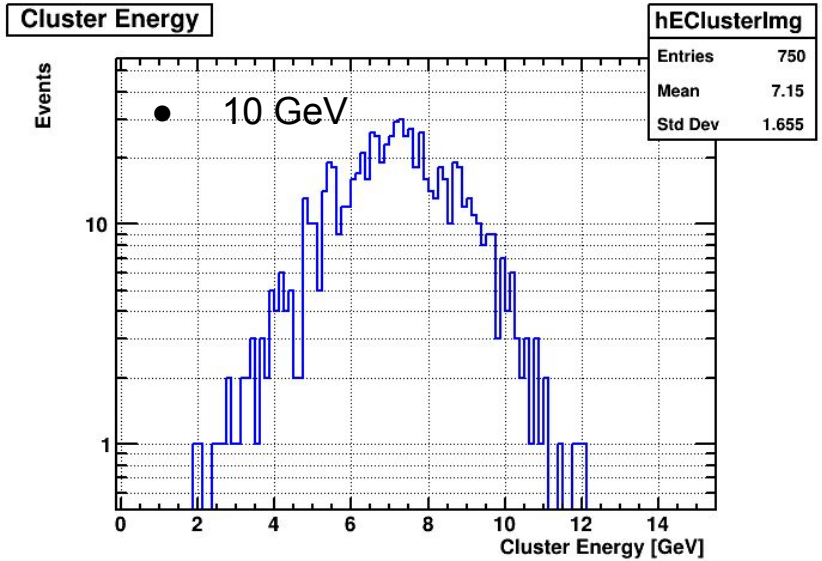


Cluster requirement
nb of hits > 15 hits
energy > 0.5 MeV

3D Clustering for imaging layers

- 5 GeV electrons, generated flat in theta **98.9-90.1** deg.
- Calibration correction based on Geant4 sampling fraction for electrons ~ 0.6%.

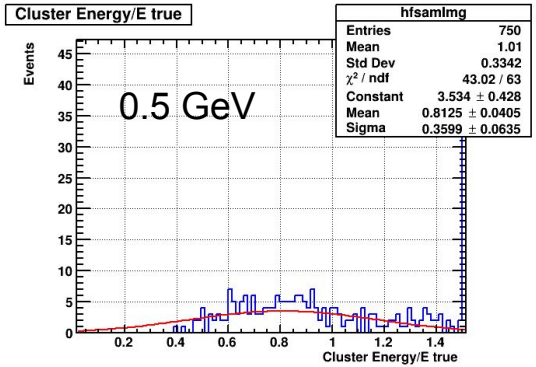


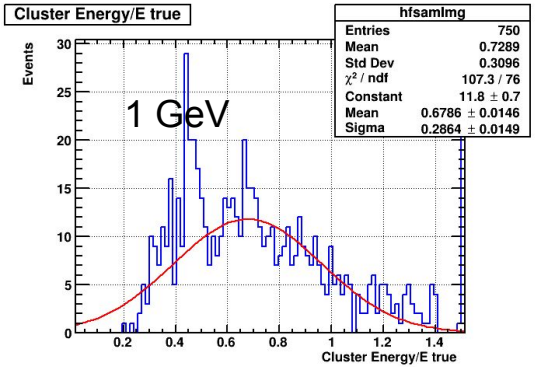


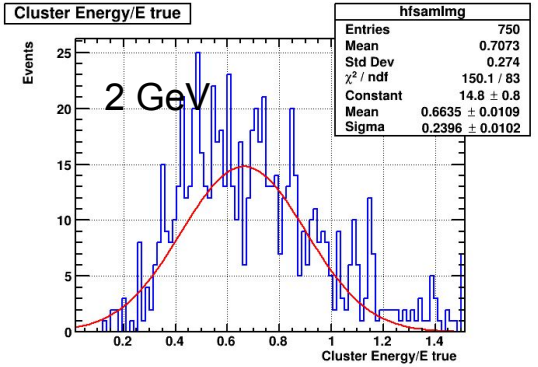
Sum of cluster energy in event

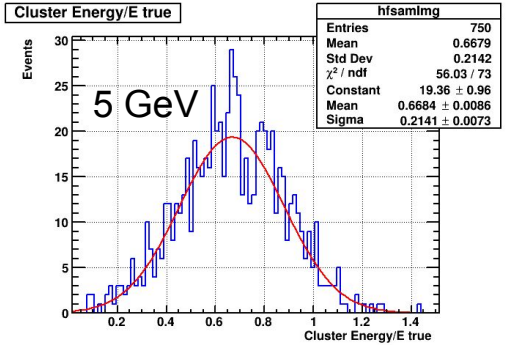
Energy resolution scan for lmg layers

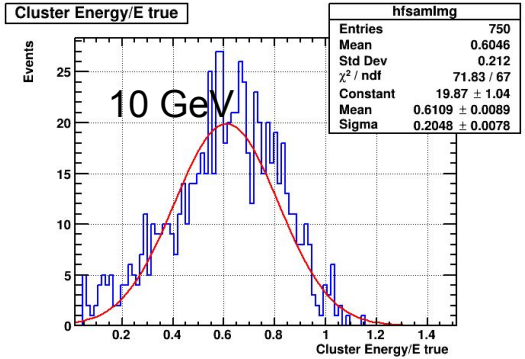
photons, theta = (89.9,90.1) deg, after reconstruction







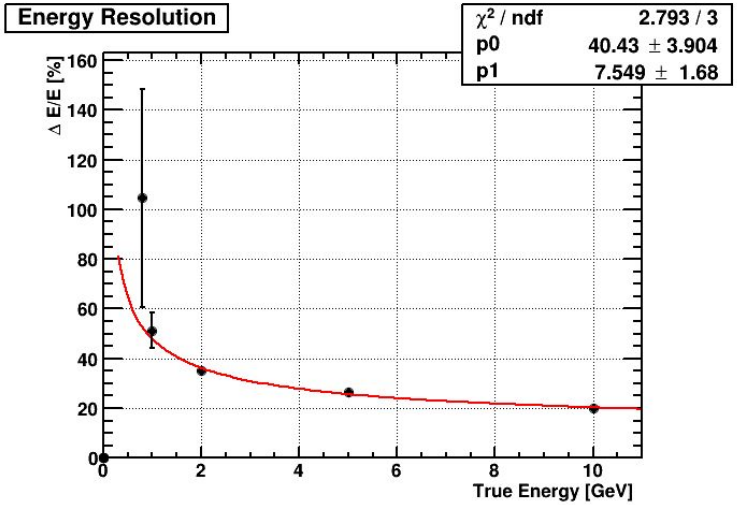




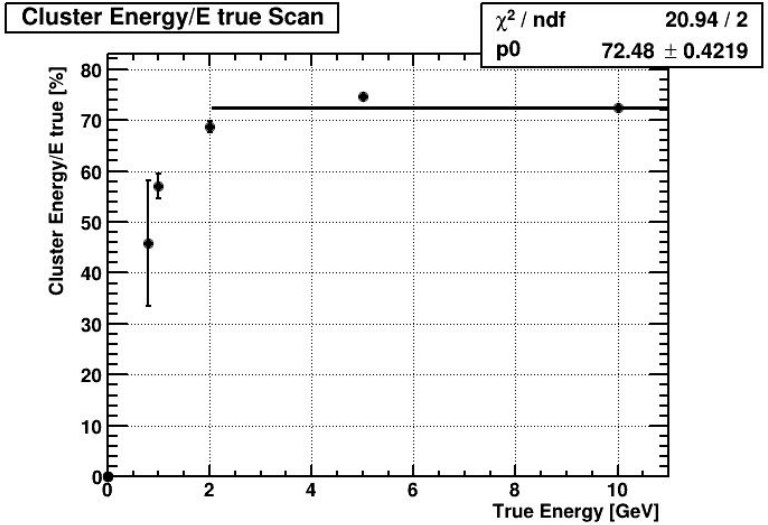

```
imcaldaq = dict(
        dynamicRangeADC=3*MeV,
        capacityADC=8192,
        pedestalMean=400,
        pedestalSigma=50)
# 50/32767*3 MeV ~ 5 keV
```

Energy resolution scan for ScFi layers

photons, theta = (89.9,90.1) deg, after reconstruction



Energy resolution



Peak position scan

Correction of ~ 1/0.7 should be applied

Useful links

Software documentation:

https://ip6soft.readthedocs.io/en/latest/

Software tutorial:

https://eic.phy.anl.gov/tutorials/eic_tutorial/getting-started/quickstart/

ATHENA Slack channel: #software-helpdesk

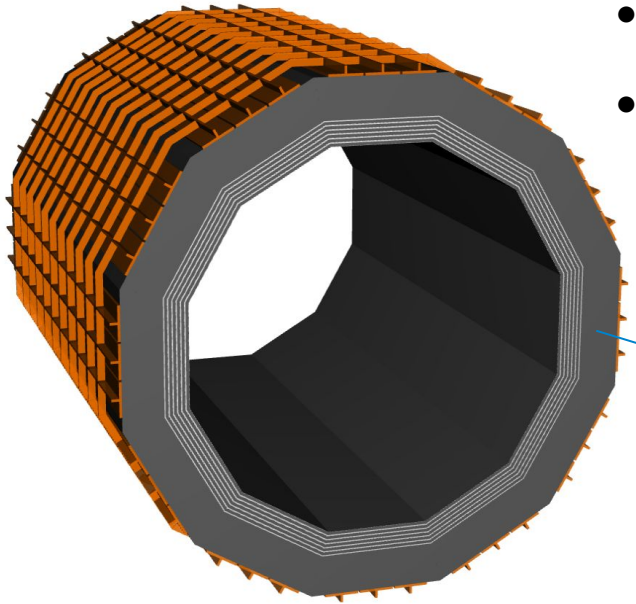
https://eicip6.slack.com/archives/C02267ZDARF

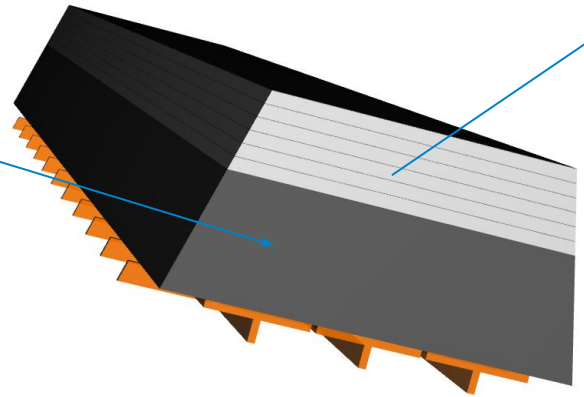
Possible tasks

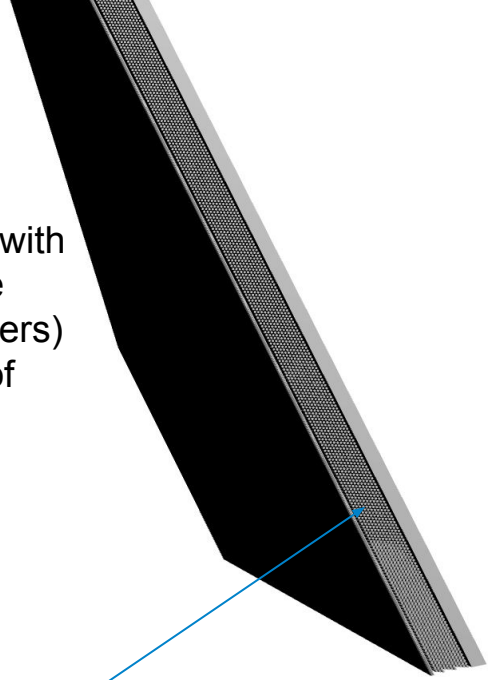
1. Optimization of the clustering parameters for imaging calorimeter layers - Efficiency of clustering as a function of energy and angle for different particle types (electron, gamma, + pions) for different clustering algorithm parameters (min nb of hits, min Energy, distance to neighbor). (observables to study: number of clusters, energy of cluster, phi, eta, threshold energy for particles to reach the barrel).
2. Optimization of the clustering parameters for ScFi calorimeter layers - same as above for ScFi clusters
3. Improving the energy correction for em showers in Barrel - energy calibration: looking at energy response from electrons, photons with different energies with the current energy correction and extracting correction factors as a function of energy (e.g., energy losses in ScFi layers), eta, maybe particle type. These new energy correction parameters are not implemented into the reco algorithms yet, so this would be the input for the implementation.
4. Optimizing parameters for the merging clusters from ScFi and Img clusters - clusters are merged based on their phi position and energy reconstructed from ScFi and Img clusters (observables to study: number of merged clusters for different Delta Energy, Delta Phi as a function of energy, angle, particle type; studying typical differences between reconstructed energy, cluster phi, number of clusters from ScFi and Img layers and applying it to the algorithm). The simplified algorithm is currently implemented, and this studies will be an input to improve it.

ScFi Calorimeter

- 6-9 imaging layers separated with 13*1.22 mm = 15.86 mm wide layers of ScFi (13 layers of fibers)
- 15*13*1.22 mm = 237.9 mm of ScFi calo in the back
- 1 mm diameter fibers in Pb

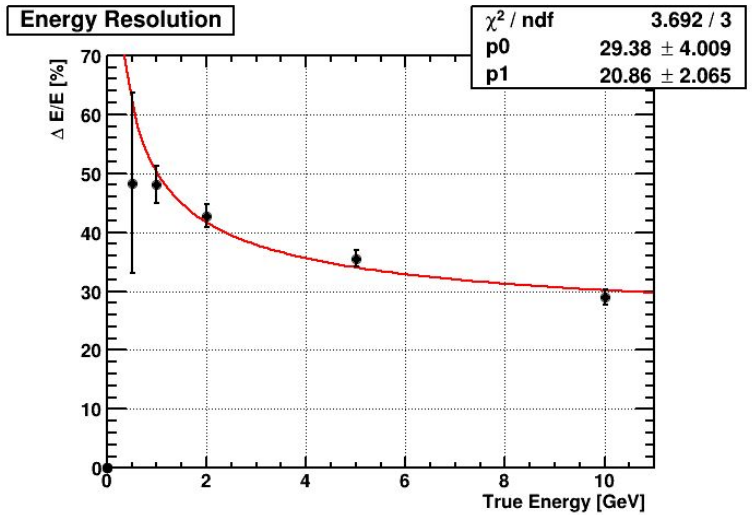




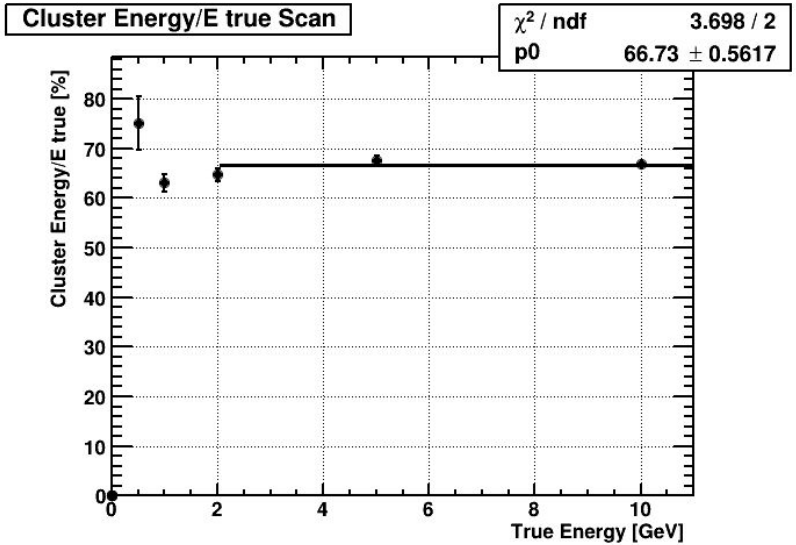


Energy resolution scan for ScFi layers

photons, theta = (89.9,90.1) deg, after reconstruction



Energy resolution

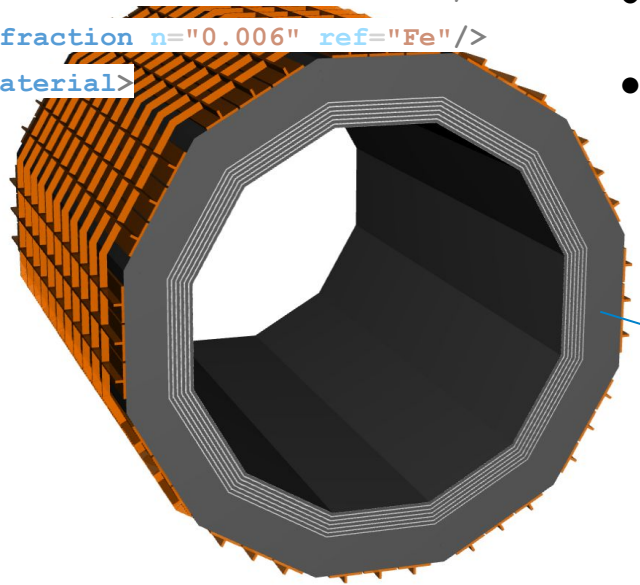


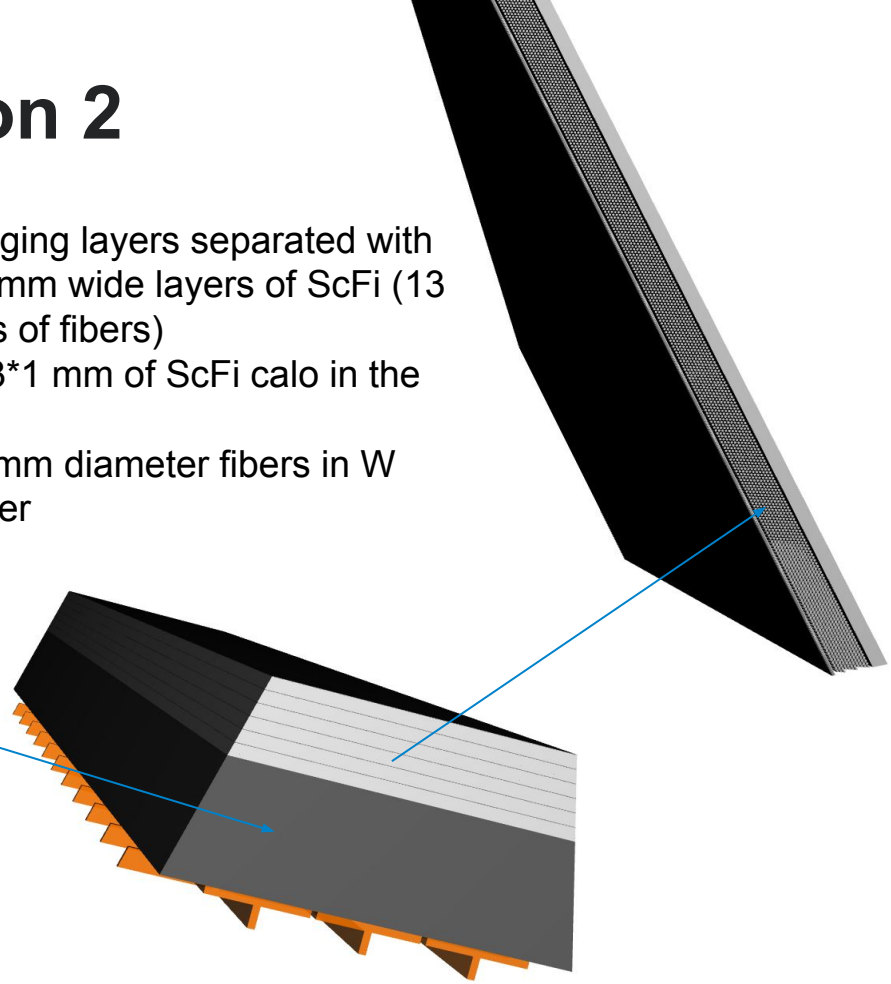
Peak position scan

ScFi Calorimeter - Option 2

```
<material name="TungstenPowder">
  <D value="11.25" unit="g / cm3"/>
  <fraction n="0.954" ref="W"/>
  <fraction n="0.040" ref="Ni"/>
  <fraction n="0.006" ref="Fe"/>
</material>
```

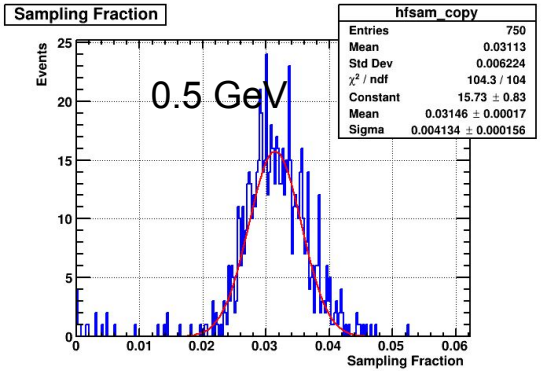
- 6 imaging layers separated with 13*1 mm wide layers of ScFi (13 layers of fibers)
- 15*13*1 mm of ScFi calo in the back
- 0.46 mm diameter fibers in W powder

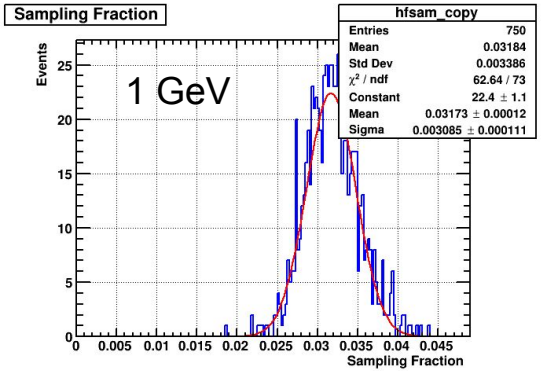


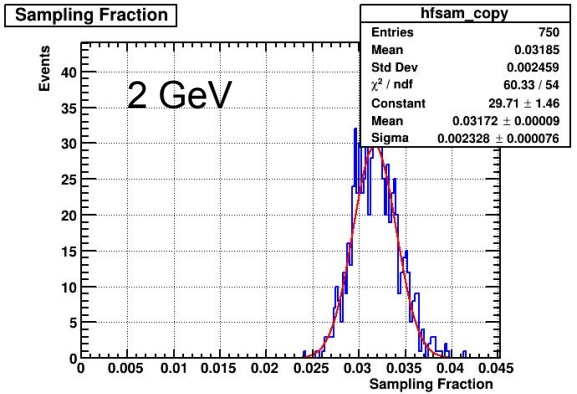


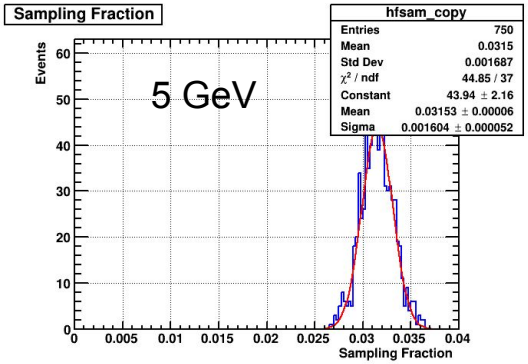
Energy resolution scan for ScFi/W

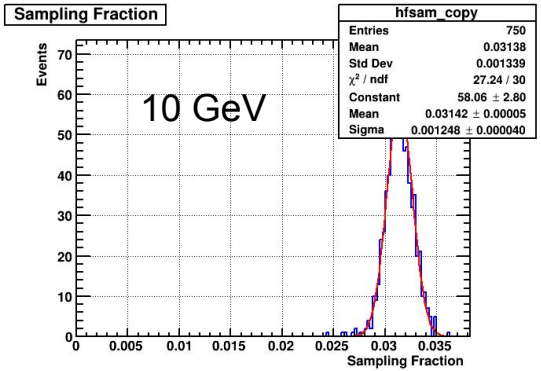
photons at theta=(89.9,90.1) deg, **Geant4 information only**, no reconstruction





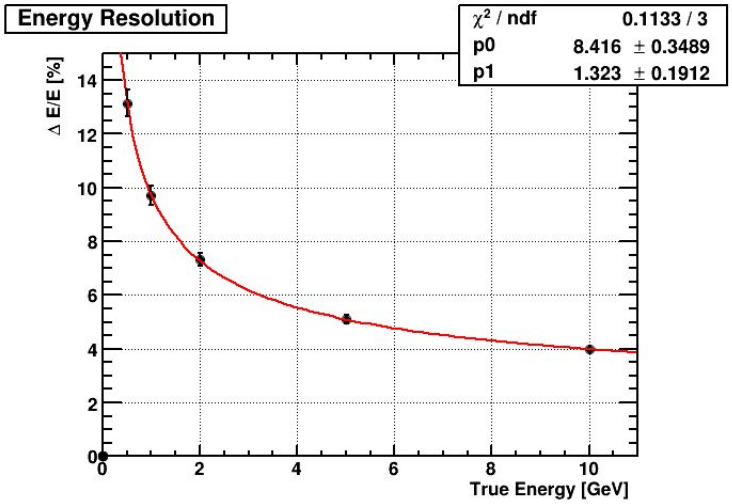




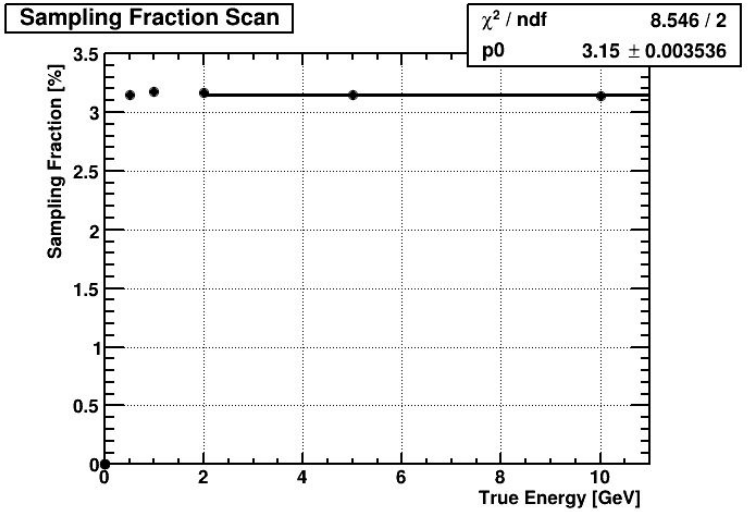


Energy resolution scan for ScFi/W

photons, **Geant4 information only**, no reconstruction



Energy resolution



Peak position scan