Status of reconstruction in SPD ECal

Andrei Maltsev, JINR (Dubna)

SPD Collaboration Meeting

23-26 October 2023

Requirements on ECAL design from physics analyses

Prompt photons (stage 2):

- interested in p_T > 3-4 GeV, high background from π^0, η, etc.
- Requirement: energy resolution at high (> 5 GeV) energies, π/γ separation

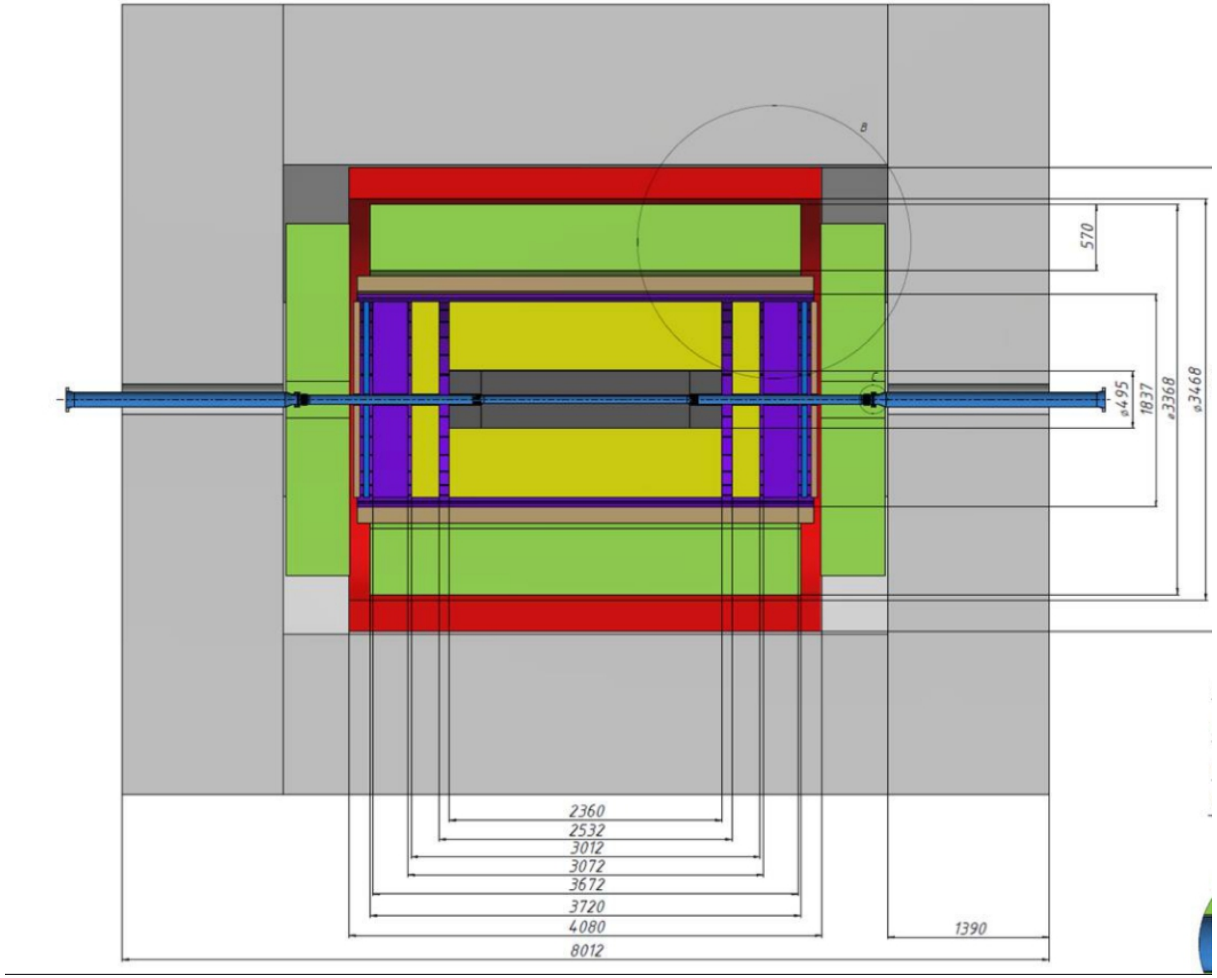
Charmonia (χ_{c1}, χ_{c2}) (stage 2):

- need to separate χ_{c1}, χ_{c2} from decay into $J/\psi\ \gamma$
- Requirement: energy resolution at low (< 1 GeV) energies

Online polarizability measurement:

- measure azimuthal asymmetry of π^0 production
- Requirement: energy and position resolution, π/γ separation

ECAL setup



- Sampling: 200 layers × (0.5 mm lead + 1.5 scintillator)
  - ~ 5-6% energy resolution @ 1 GeV
  - ~ 1-2% energy resolution @ 8 GeV
- Cell size:
  - barrel: 34 mm (φ) × 48 mm (Z)
  - endcaps: 40 mm × 40 mm
- Barrel inner radius: 111.4 cm
  - minimal distance between γ's from π0 decay with energy of 8 GeV is about 4 cm
- Distance from primary vertex to endcaps: 204 cm

Current reconstruction workflow

1) per-cell energy calibration: energy deposition in scintillator layers → energy deposition in the entire cell

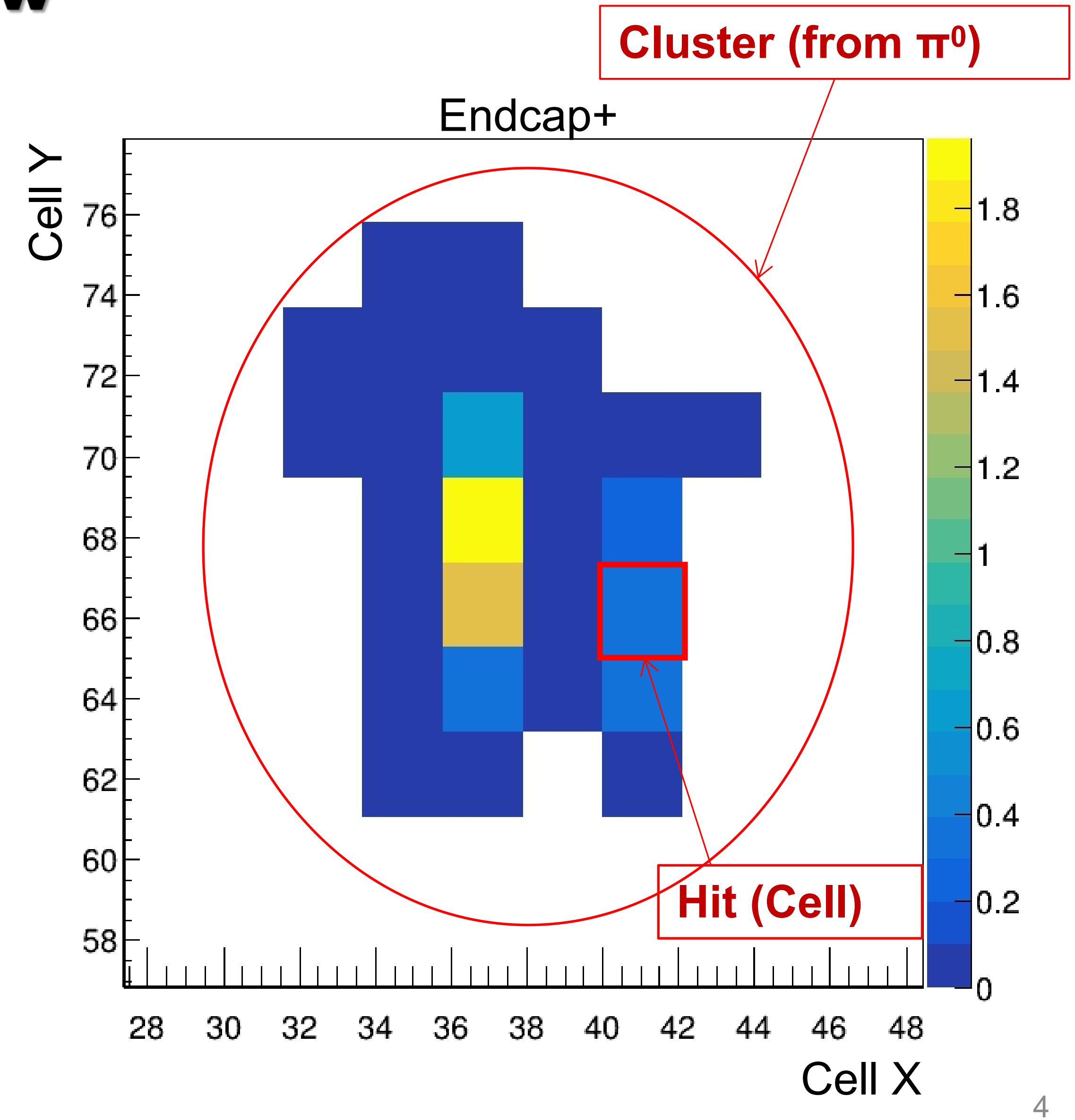
2) clustering: identifying groups of neighboring cells

3) reconstruction: get particle position and energy from cluster using empirical expressions

4) π/γ ID: based on cluster shape analysis

Caveats:

- empirical calibrations in the reconstruction step sensitive to ECAL setup, maintenance is time-consuming
- no reconstruction of individual photons in case of π0 ID (yet)
- only full simulation of ECAL showers



Current workflow

1) per-cell energy calibration: energy deposition in scintillator layers → energy deposition in the entire cell

2) clustering: identifying groups of neighboring cells

3) reconstruction: get particle position and energy from cluster

4) π/γ ID: based on cluster shape analysis → only for π^0 background rejection so far

A possible approach

1) per-cell energy calibration: energy deposition in scintillator layers → energy deposition in the entire cell

2) clustering: identifying groups of neighboring cells

3) π/γ ID: based on cluster shape analysis

- π^0 → 4) reconstruct 2 photons
- γ → 4) reconstruct 1 photon

Another possible approach

1) per-cell energy calibration: energy deposition in scintillator layers → energy deposition in the entire cell

2) clustering: identifying groups of neighboring cells

3) reconstruction: get particle position and energy from cluster

4) π/γ ID: based on cluster shape analysis

→

1) per-cell energy calibration: energy deposition in scintillator layers → energy deposition in the entire cell

2) clustering+reconstruction+PID

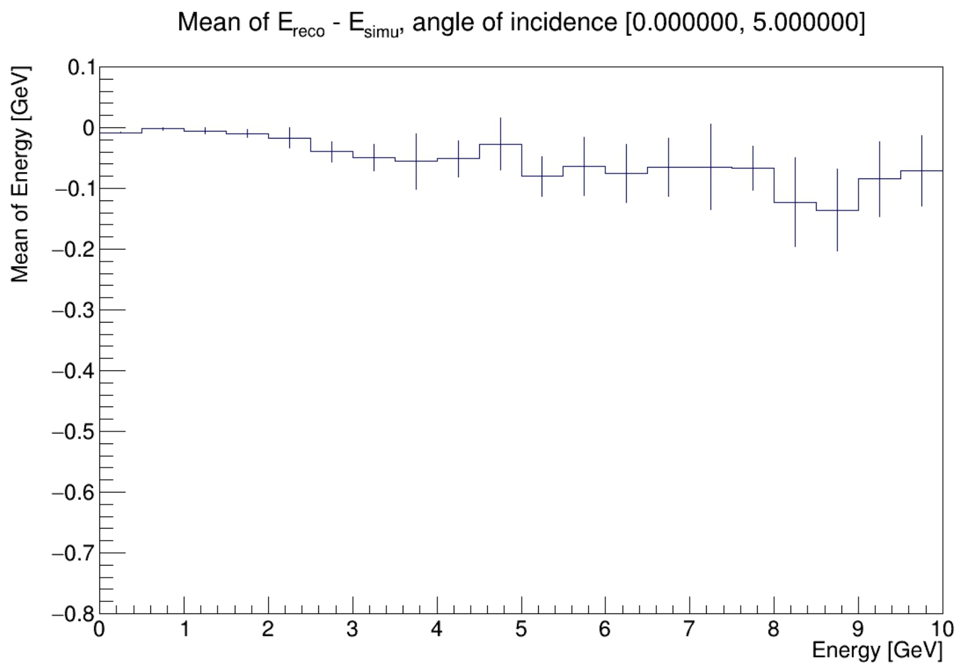
with a convolutional neural network approach

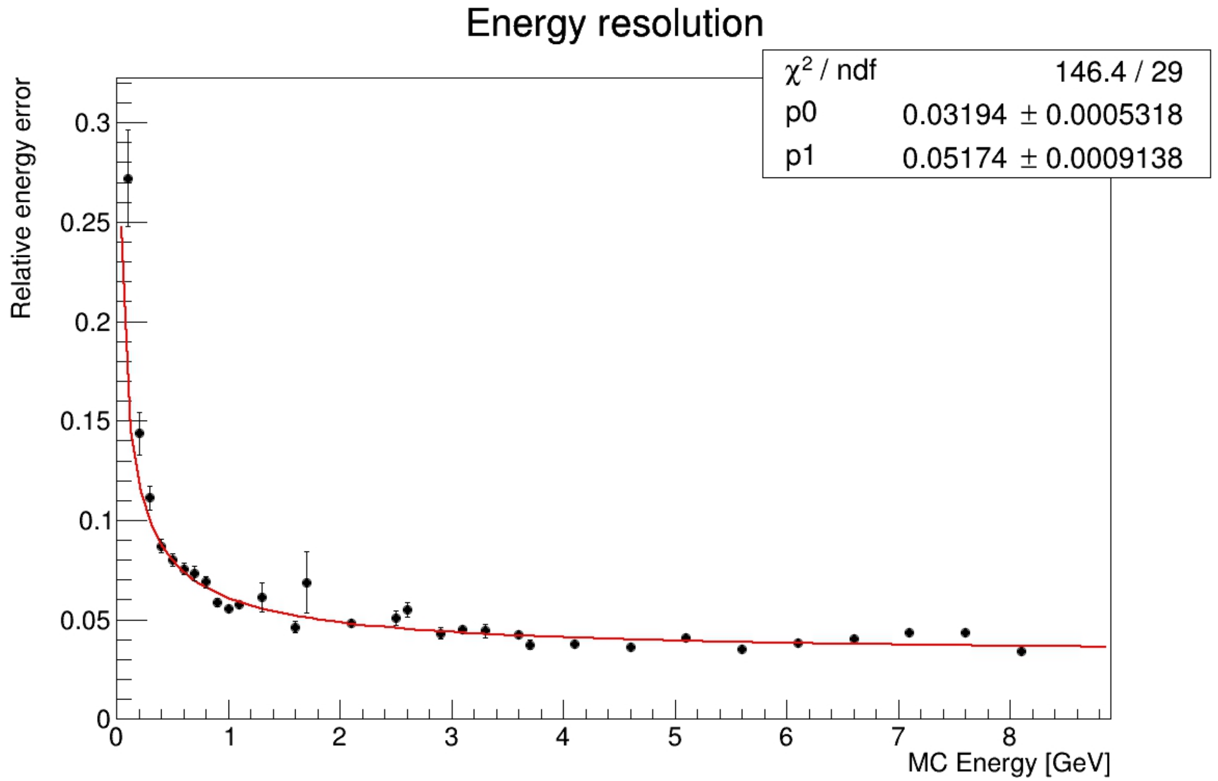
Still in research stage

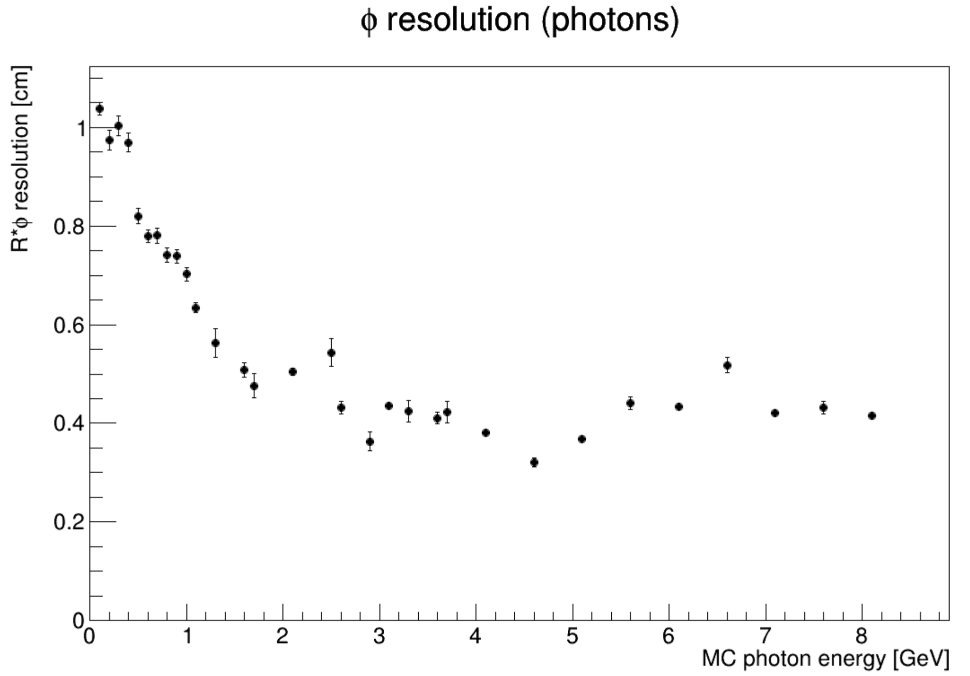
Status of photon reconstruction

- using weighted average with empirical corrections depending on energy/angle

- repository of performance tests for ECAL: $SPDROOT/macro/performance-tests/ecal-reconstruction







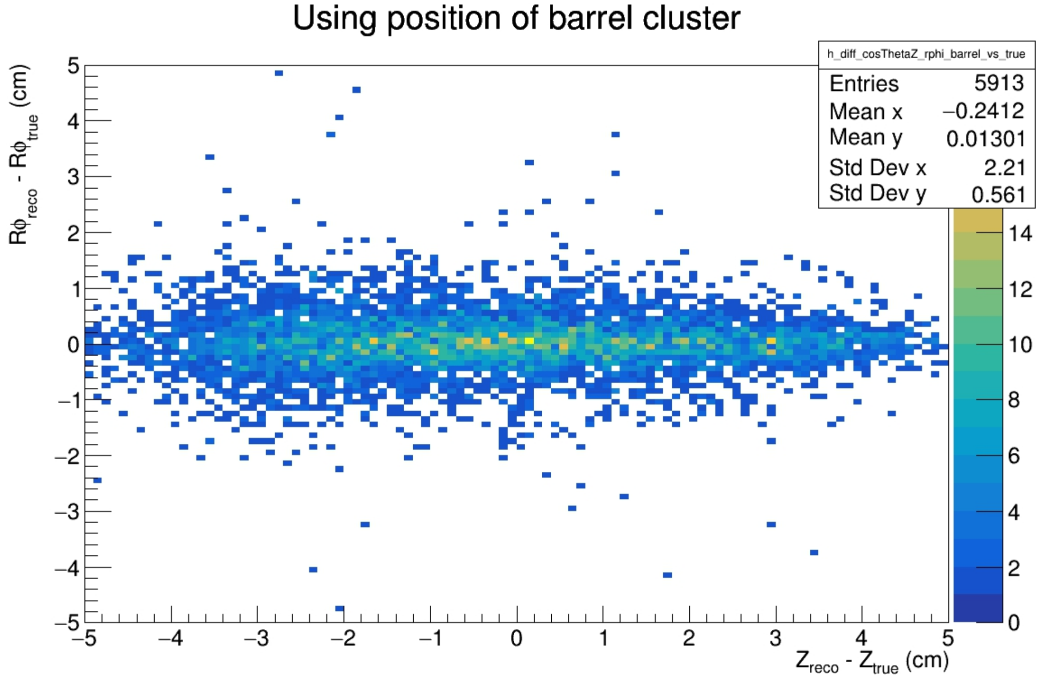
Prospects for cluster reconstruction

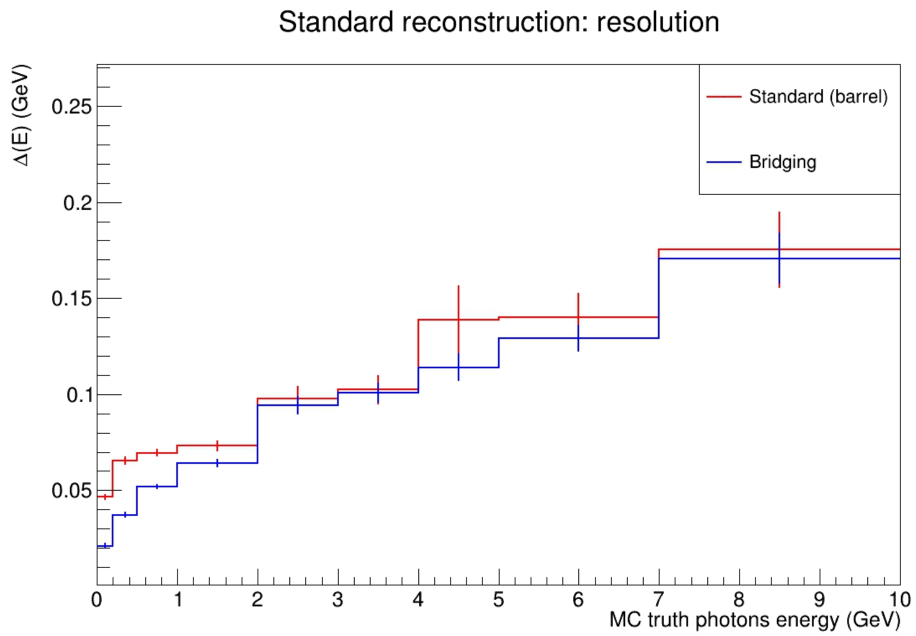
Future steps of the improvement of the reconstruction include:

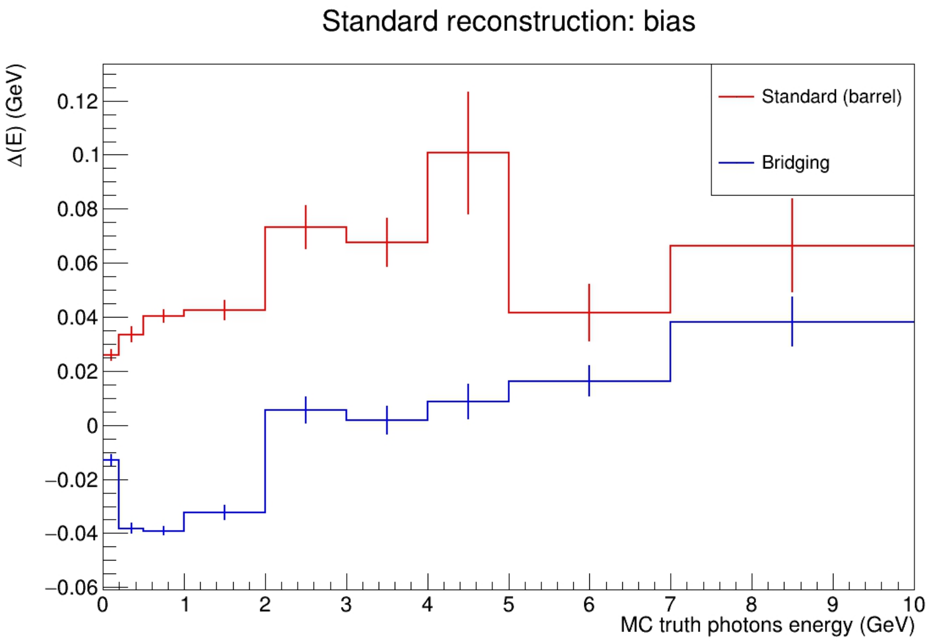
- reconstruction of single-shower clusters using machine learning methods and comparison with the simple algorithm;
- reconstruction in case of two-shower cluster (e.g. from π^0): individual photons, or π^0 as a whole, while avoiding bias due to the training sample (π^0/η etc.);
- the most general case: any number of showers in a cluster, reconstruction of the calorimeter as a whole (or with its regions of interest), possibly even using information from tracking detectors or RS.

Endcap-barrel bridging

- using sum of endcap+barrel energies and the position of the barrel cluster gives satisfactory results
- criteria for bridging clusters: $0.805 < \cos(\theta_{barrel}) < 0.85$; $\Delta(\cos(\theta)) < 0.03$; $|\Delta\varphi| < 0.04$







Status of pi/gamma separation

- Neural network predicting particle type based on shape variables
- Can be extended to 3/6 outputs for reconstruction of energy/position (work in progress)

Input parameters

- X/Y for endcaps or Z/ϕ for barrel, inputs shown in red

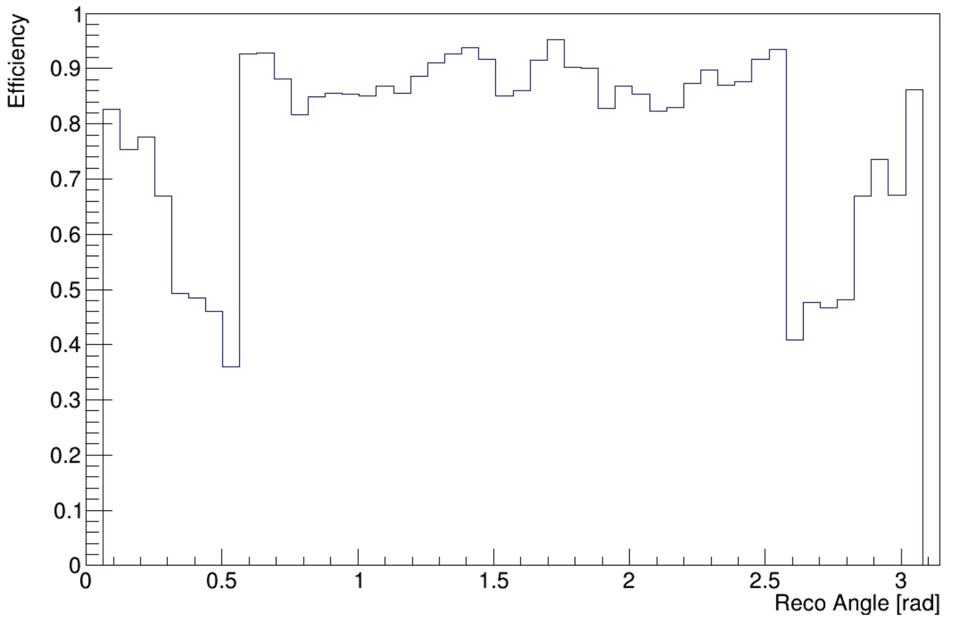
Energy distribution

- S_1, M_2 – cells with first and second largest energies
- S_9, S_{25} – sum of energies in 3×3, 5×5 regions around cell with highest energy
- S_6 – maximum energy in 3×2 region containing both first and second largest energy cells
- $\frac{S_1}{S_9}, \frac{S_9-S_1}{S_{25}-S_1}, \frac{M_2+S_1}{S_4}, \frac{S_6}{S_9}, \frac{M_2+S_1}{S_9}, \frac{S_4}{S_{25}}$

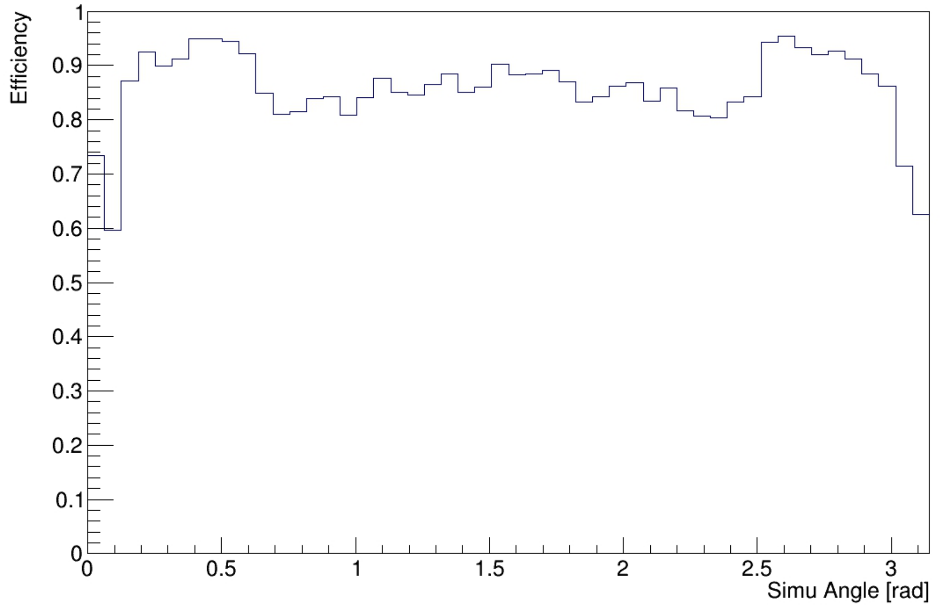
Size/shape

- $|x_{cog}|_{25} = |\frac{\sum_{i=1}^{25} E_i X_i^{rel}}{S_{25}}|$, $|y_{cog}|_{25} = |\frac{\sum_{i=1}^{25} E_i Y_i^{rel}}{S_{25}}|$
- $S_{\alpha\beta} = \frac{\sum_{i=1}^{N} e_i(\alpha_i-\alpha_c)(\beta_i-\beta_c)}{\sum_{i=1}^{N} e_i}$, $\alpha, \beta : X, Y$
- $\rightarrow S_{XX}, S_{YY}, S_{XY}$
- $r2 = \langle r^2 \rangle = S_{XX} + S_{YY} = \frac{\sum_{i=1}^{N} e_i((x_i-x_c)^2+(y_i-y_c)^2)}{\sum_{i=1}^{N} e_i}$
- $\kappa = \sqrt{1 - 4\frac{S_{XX}S_{YY}-S_{XY}^2}{(S_{XX}+S_{YY})^2}} = \sqrt{1 - 4\frac{\det S}{\mathrm{Tr}^2 S}}$
- Angle θ of incidence

Gamma ID efficiency: events with 1 cluster, PID=22



Pi0 ID efficiency: events with 1 or 2 cluster, PID=111 where 1 cluster



Conclusions

- With the exception of barrel-endcap bridging (is being implemented), the simple simulation/reconstruction works:
  - reconstruction of individual photons gives adequate results for all angles in barrel and endcap;
  - π^0/γ separation implemented with ~80-90% efficiency, depending on the angle/energy;
  - bridging algorithm developed, to be implemented;

- biggest future milestone: splitting of a single cluster in case of it being produced by several particles:
  - ideally: a fast CNN-based approach that takes the entire calorimeter, or its regions of interest, as input;
  - next step: reconstruction of individual photons in case of single-shower of two-shower (π^0) clusters;

- other important points:
  - documentation of ECAL classes (MC cluster/MC particle/RC particle etc.)
  - bug fixes (ECAL particle association bug reported by Ruslan Akhunzyanov, warnings about vertex ordering reported by Artem Ivanov, etc.)