Update on the distinction of particle type in the very forward calorimeters

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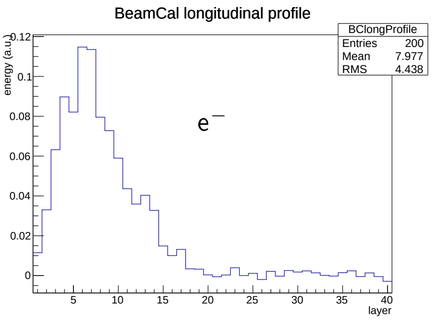
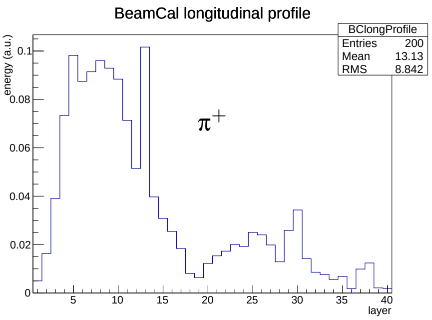
Context

Information available in the FCAL region

- No tracking nor hadronic calorimetry
- Fine details of showers buried in the noise
- Longitudinal and transverse profiles available for the analysis, subject to fluctuations and "competing" with background
- Frequent pileup with Bhabha particles in BeamCal
  - Useful region above ca. 30 mrad





Longitudinal profiles of 300GeV showers at 30 mrad after background subtraction

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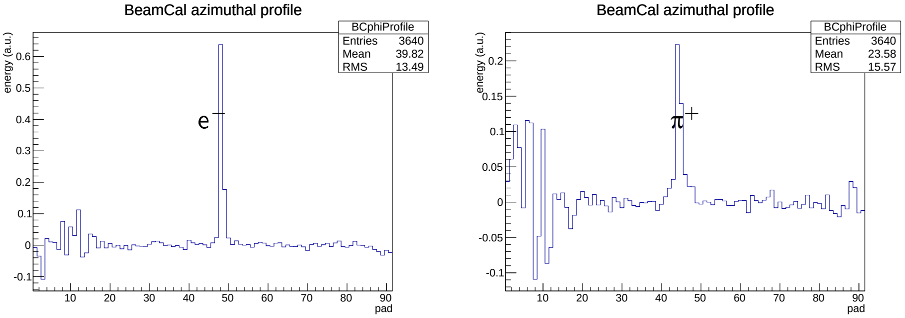
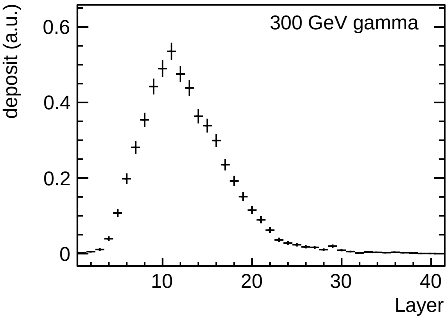


Transverse profile of a 300GeV shower at 30 mrad after background subtraction: left e^-, right π^+

Longitudinal EM shower profiles

EM showers

- Fully contained in the forward calorimeters
- Can be parametrized via the Gamma distribution:
  $\frac{dE}{dx}(x + x_{start}) = kx^{a-1}e^{-bx}$ (Longo and Sestili, NIM 128, 1975)
  - a and b depend on energy
  - Fluctuations of the profile, notably the shower start x_{start}



300 GeV photon shower profile in BeamCal (without background).
Extracted from Mokka data using André's BeamCal Clusterer library

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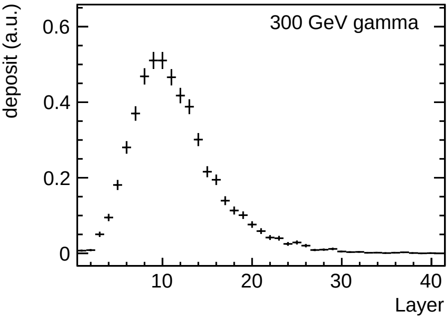

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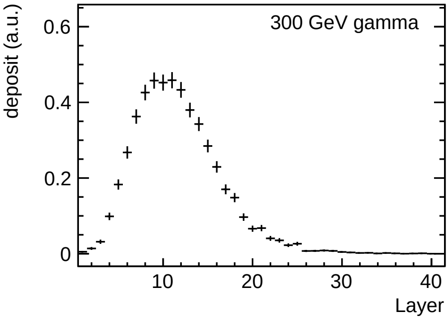

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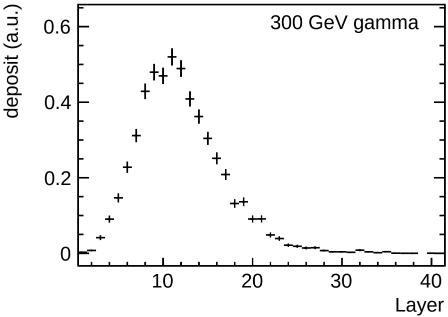

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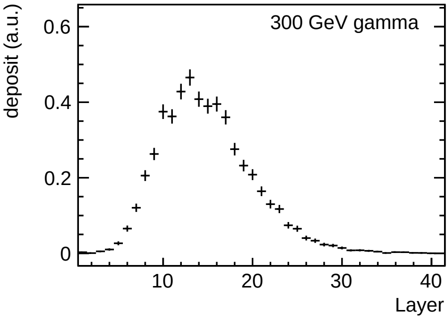

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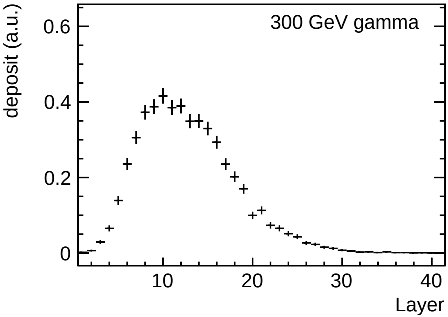

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Hadronic showers

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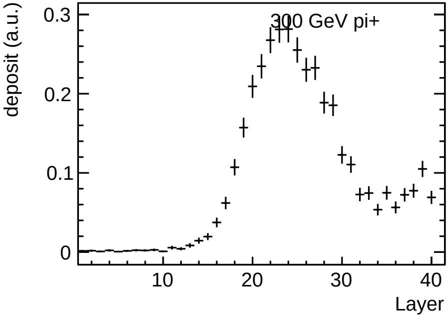
- Very random profiles, often with multiple clusters



300 GeV π^+ shower profile in BeamCal (without background)
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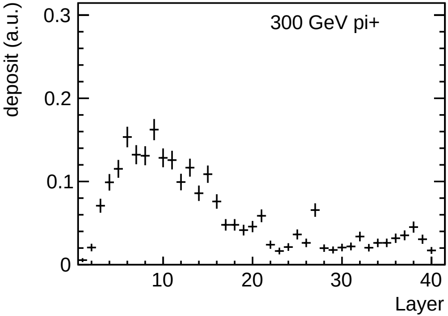

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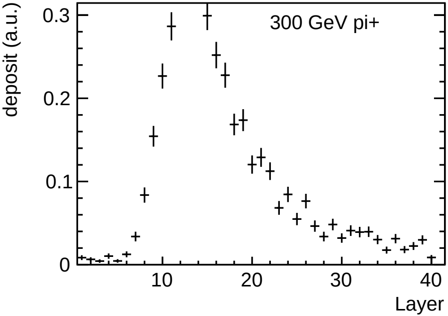

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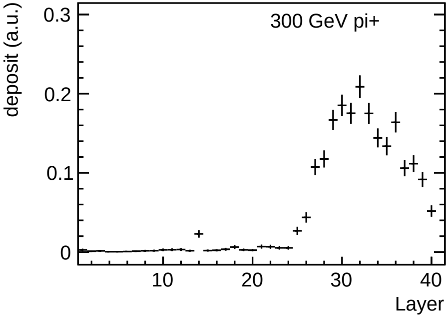

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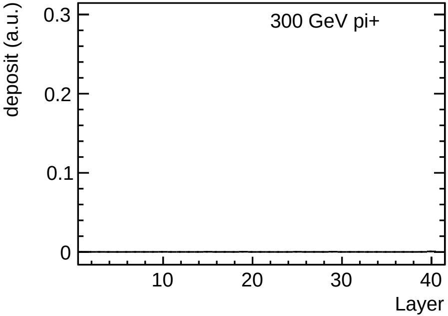

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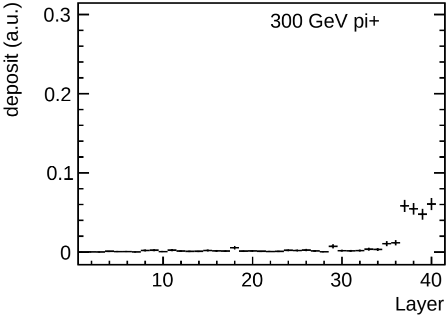

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Distinction by the longitudinal profile (only)

Basic strategy

- In case of EM showers, one can define a typical shower profile with one free parameter – x_{start}
- Perform type distinction by the maximum correlation coefficient with the typical profile,

$$\rho_{max}(h, f) = \frac{\sum_{i=1}^{N_h} h_i f_i(x^*_{start})}{\sqrt{\sum_{i=1}^{N_h} h_i^2}\sqrt{\sum_{i=1}^{N_h} f_i^2}} \tag{1}$$

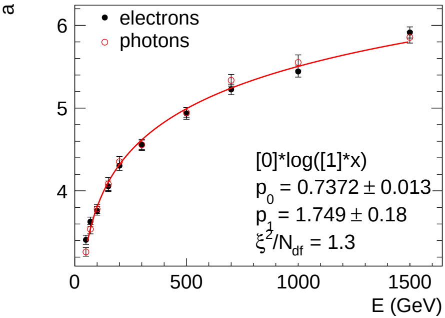
h_i = "data" (histogram)
$f_i(x^*_{start}) = f(x_i - x^*_{start})$ = "pattern" (function describing the typical EM shower)

The typical EM shower

- Looking for the **average** profile shape **relative to** x_{start}
- Solution: average central moments of the Gamma distribution
  - The 2nd and 3rd central moments describe the Gamma distribution uniquely and independently of the longitudinal position of the shower
  - $a = 4\frac{\bar{\mu}_2^3}{\bar{\mu}_3^2}, \qquad b = 2\frac{\bar{\mu}_2}{\bar{\mu}_3}$
  - Energy dependence of a and b can be calibrated from data (simulation or test-beam data)

Energy dependence of a and b

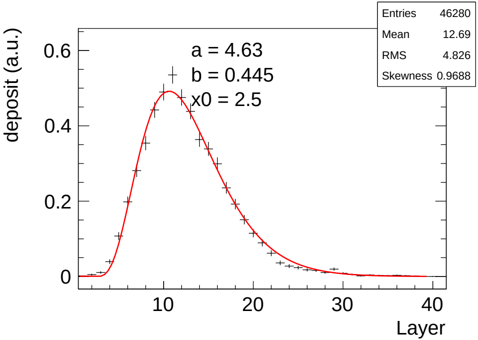
- a and b both depend on energy as, for example, $a = p_{0,a} log(p_{1,a} E)$
- a and b determined for electrons and photons at several incident energies in the range 50 – 1500 GeV, fitted the dependence
- Consistent values of a and b for $e^{\pm}$ and γ
  $\rightarrow$ $e^{\pm}$ and γ have **the same** longitudinal profile
  (up to a small difference in x_{start} distribution)



Dependence of the profile parameter a on the incident energy

Illustration of the matching

- Plot the Gamma distribution over individual profiles:
  - a and b determined from the global calibration, using the "data" energy
  - x_{start} selected for maximum correlation
  - k (the norm) selected to give the same integral



300 GeV photon shower profile in BeamCal (without background), with "matched" Gamma distribution from the global calibration

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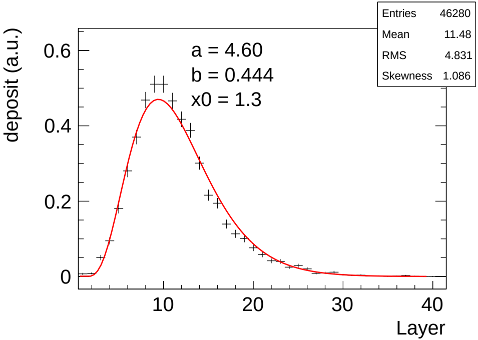

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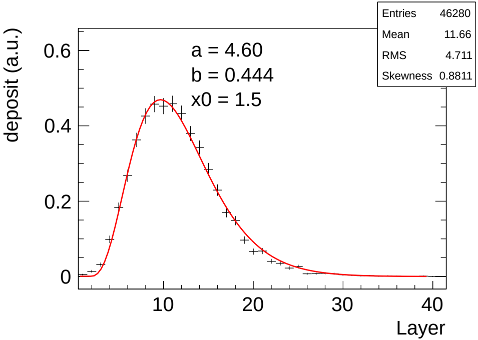

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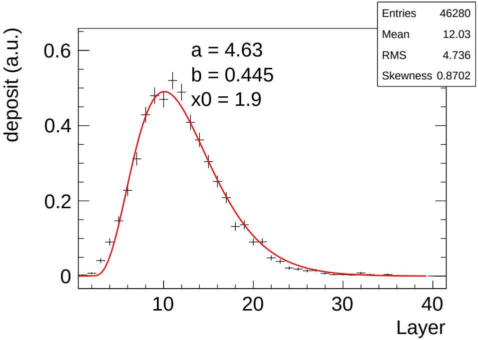

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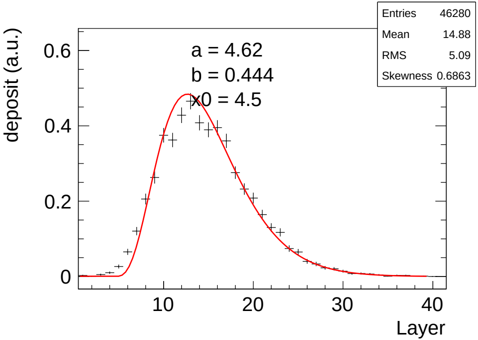

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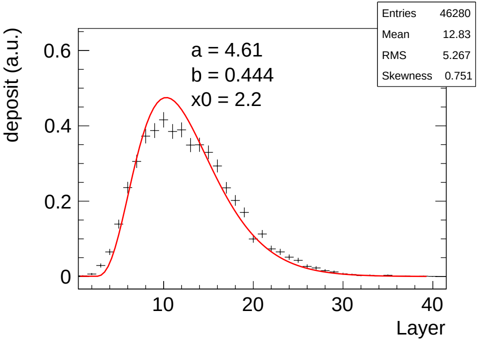

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Modifications of the clustering algorithm

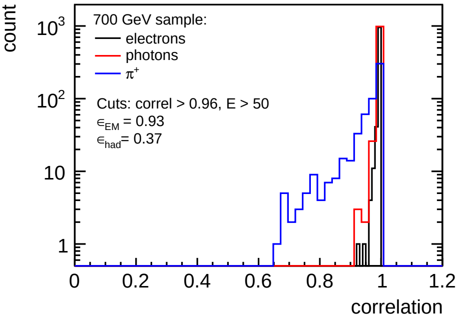
Clustering

- Subtract average background deposition from all pads
- Look for pads with remaining deposition above $N\sigma$ background fluctuation
  - Background is not normally distributed – 1-sided fluctuations above 4σ in more than 2% of all pads
  - Optimal cut at 6σ (1% random fluctuation)
- Look for towers with an **uninterrupted** array of at least $N_{min.size}$ pads above $N\sigma$ cut (Note: this favors EM showers over the hadronic ones)
- Cluster neighboring towers passing the size cut + one neighboring level of individual pads passing the $N\sigma$ cut
- Reject clusters smaller than 2x the tower size cut
- Determine the position of the cluster $\theta_{cluster}, \phi_{cluster}$ from weighted pad centres
- Extract shower profile from all pads within a cylinder with radius ρ, centered at $\theta_{cluster}, \phi_{cluster}$

Results

Distinction by the longitudinal profile

- Plot of the correlation coefficient for EM and hadronic showers
  - Coefficient very close to 1 for all EM showers
  - Wide distribution for charged pions
  - Selection can be made by an energy-independent cut on the correlation coefficient



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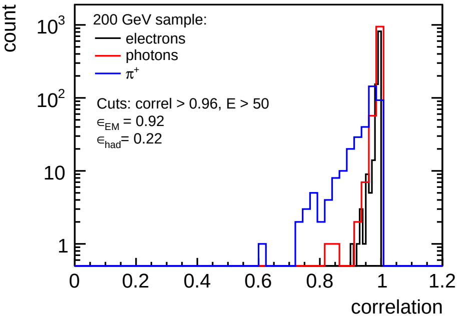

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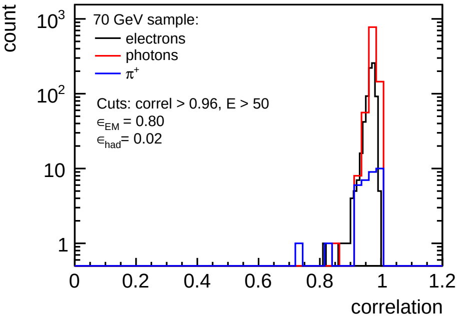

Summary and Future Plans

Summary

- Distinction by the longitudinal shower profile: Correlation coefficient between the "typical" longitudinal EM shower pattern and the detected shower
  - Fast procedure
  - Small number of parameters to calibrate (5, including the energy calibration)
  - All EM showers show similar distributions, and very different to the hadronic showers
  - Robust in high-background conditions
  - 2 to 40% (depending on energy) hadronic showers pass the cut at 20 mrad
- Clustering was adapted to preserve the shower profile in the conditions of high background level
- Particle discrimination implemented in the BeamCal clustering library
  - FCAL/Software/FCalClusterer/branches/particleDiscrimination

Future plans

- Clean up the code
- Try to increase the sensitivity of the clustering algorithm, reduce the fake rate and not favor EM showers
- Optimize energy extraction
- Add transverse characteristics of the profile to the procedure
- Add LumiCal
  - The clustering algorithm should provide the longitudinal profile and energy of the shower
  - Challenge: Intermediate angles between BeamCal and LumiCal
- Test in concrete physics analysis cases