First results on the distinction of particle type in the very forward calorimeters

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Context

Context for particle distinction in the FCAL region

Luminosity measurement

- Final-state Bhabha particles ($e^{\pm}$, γ)
- Energy cut (mostly final particles close to the beam energy)
- Angular acceptance of the LumiCal - ca. 2° to 4-5°
- Systematic error from hadronic background in the permille order (ILC)

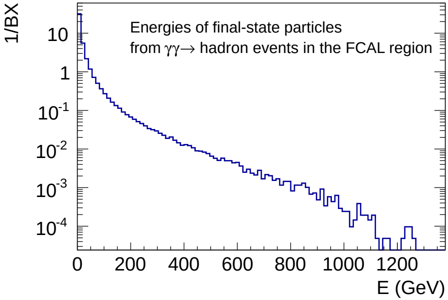
Particle tagging in physics analyses

- Tag high-energy electrons (usually) to reject background processes
- Relevant to a variety of analyses with missing-energy signature: Higgs decays, DM or stau searches
- ...

Hadrons at very low angles

Inventory of final-state hadrons from $\gamma\gamma \to$ *hadrons* at 3 TeV CLIC (Generator data T. Barklow et al., LCD-Note-2011-020)

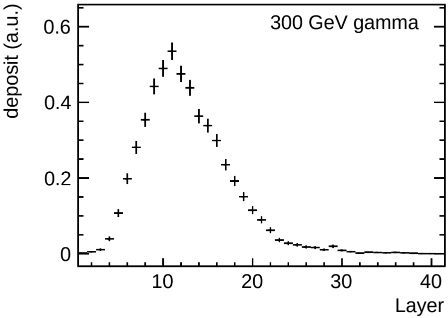
Particle	Particles/(20 BX) in the FCAL region, above 200 GeV
All (including γ)	12
$\pi^{\pm}$	8
$K_L + K^{\pm}$	1.6
$p + n$	1.0



Method to distinguish particle types

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).
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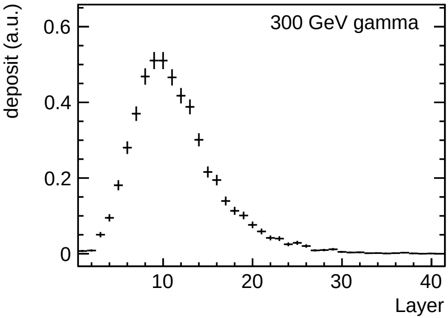

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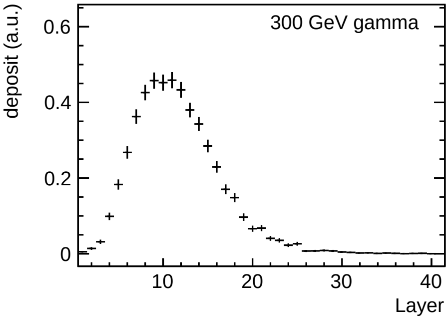

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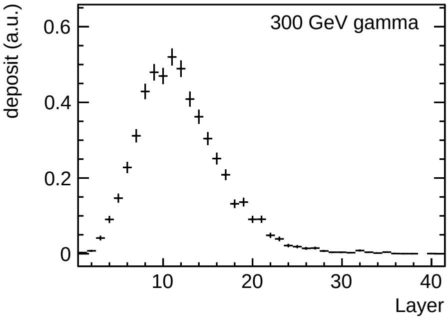

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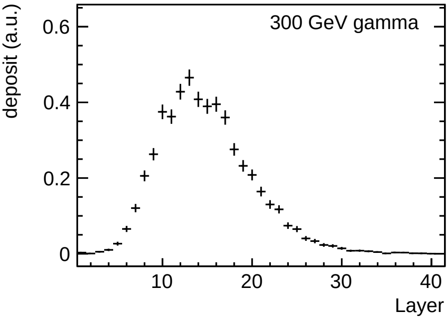

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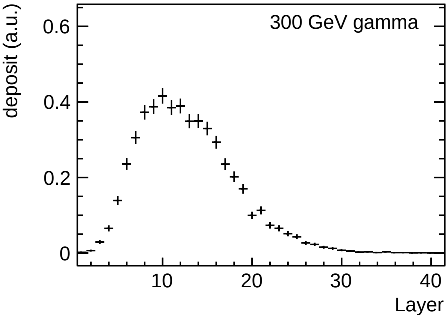

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Hadronic showers

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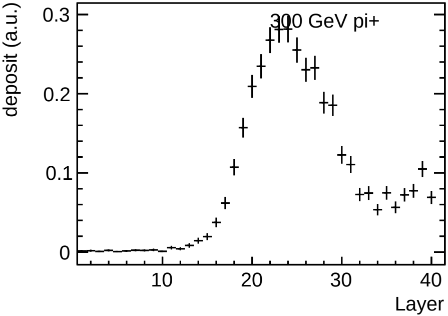
- Very random profiles, often with multiple clusters



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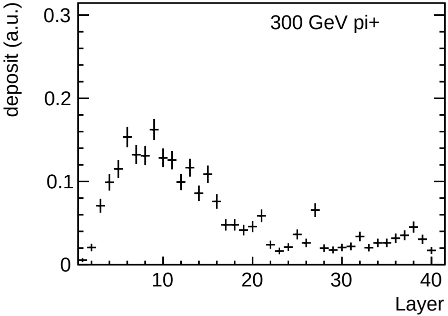

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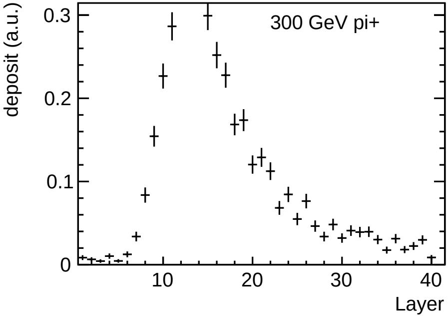

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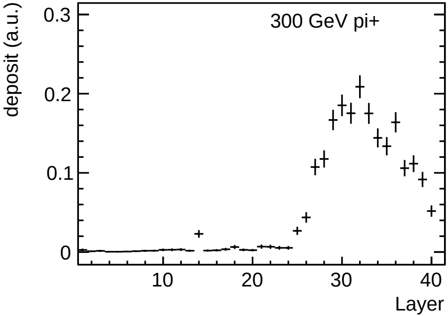

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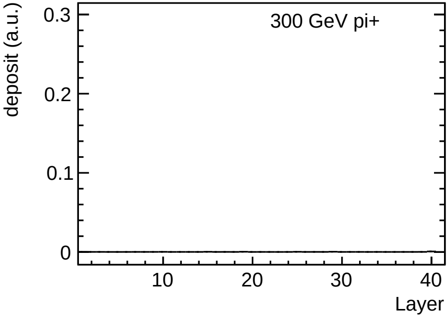

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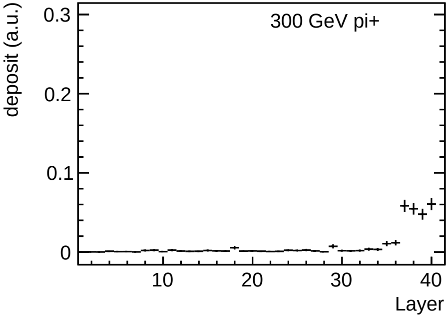

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Strategy

- Start with EM vs. hadronic showers
- Compare typical longitudinal profiles
- Find a pattern (a "typical shower") for a given shower type, and perform type distinction by the maximum correlation coefficient,

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

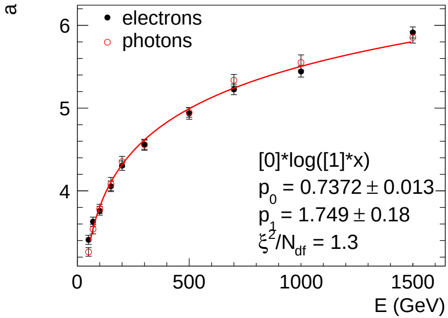
h_i = "data" (histogram)
$f_i(x^*_{start}) = f(x_i - x^*_{start})$ = "pattern" (function)

The "typical" EM shower

- Need the **average** profile shape **relative to the shower start**, x_{start}
- Direct averaging of profiles would result in smearing in the longitudinal direction
- Solution: central moments of the Gamma distribution
  - a and b can be expressed in terms of $\bar{\mu}_2$ and $\bar{\mu}_3$:
    $a = 4\frac{\bar{\mu}_2^3}{\bar{\mu}_3^2}, \qquad b = 2\frac{\bar{\mu}_2}{\bar{\mu}_3}$
  - Central moments can be averaged over the data sample
    $\bar{\mu}_n(f_x) = \mu_n(\bar{f}_x)$
  - Fluctuation of x_{start} removed by definition
  - Energy dependence of a and b can be calibrated from data (simulation or test-beam data)

Energy dependence of a and b

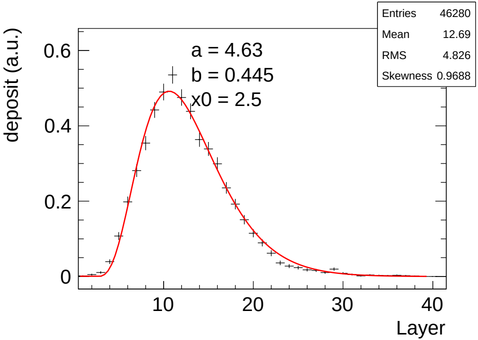
- a and b both depend on energy as, for example, $a = p_{0,a} log(p_{1,a} E)$
- a and b determined for electrons and photons at several incident energies in the range 50 – 1500 GeV, fitted the dependence
- Consistent values of a and b for $e^{\pm}$ and γ
  $\rightarrow$ $e^{\pm}$ and γ have **the same**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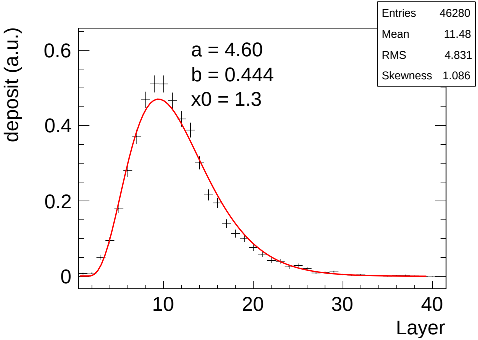

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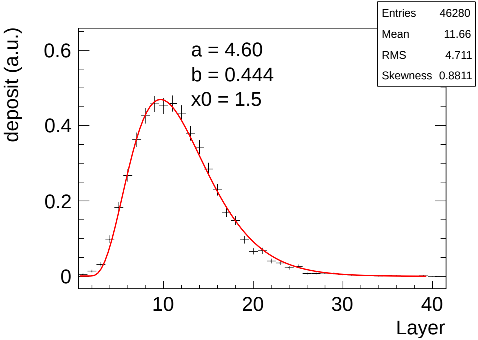

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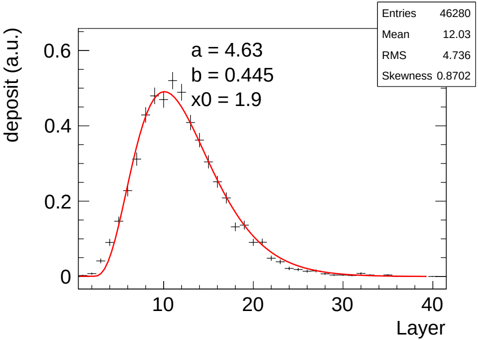

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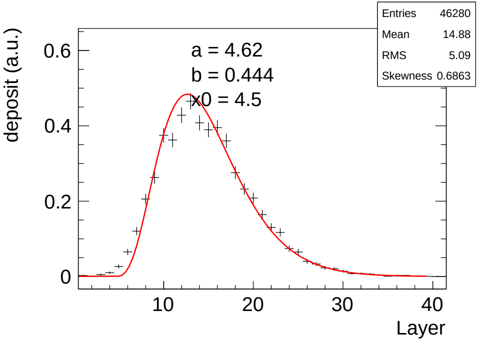

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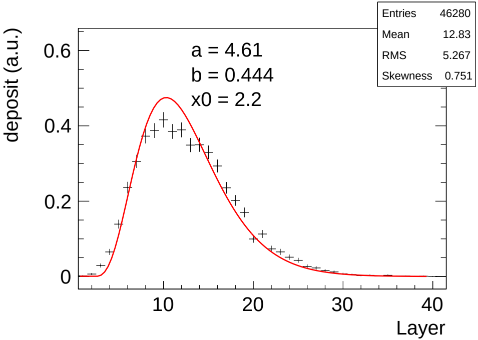

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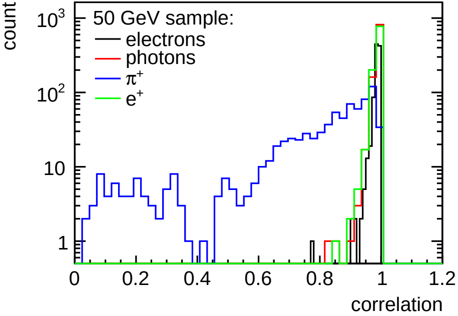
Results

Distinction of shower type

- 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



Note: A fraction of charged pions do not induce shower in the BeamCal (15% at 50 GeV, down to 5% at 1500GeV)

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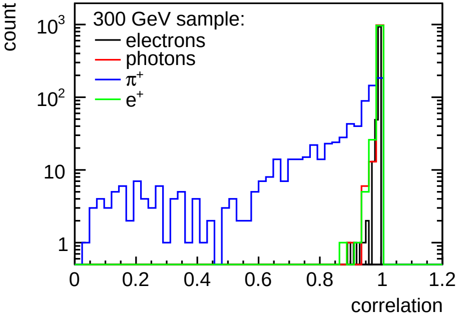

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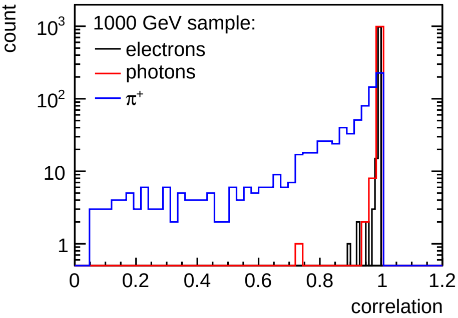

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Summary and Outlook

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- Forward calorimeters offer good distinction of hadronic vs. the EM showers (as we supposed)
- Correlation coefficient between the EM shower pattern and the detected shower is a good variable for this purpose
  - Fast procedure
  - Small number of parameters to calibrate (5, including the energy calibration)
  - All EM showers show similar distributions of correlation, and very different to the hadronic showers
  - Position of the cut does not depend on energy

Outlook

- Test kaons, neutrons and protons
- Add the presented discrimination procedure to André's implementation of clustering in BeamCal
  - Information available on the total deposited energy and the pads that belong to the analysed shower
  - Background subtraction already in there
  - The measured longitudinal profile can be built from pads that belong to the analysed shower – important in presence of background
- Test in realistic conditions
  - Beam-induced backgrounds
  - Final-State Radiation – merged showers from multiple EM particles
- Apply to selected physics analyses and luminosity measurement