CALPRO, an unconventional calorimetry approach

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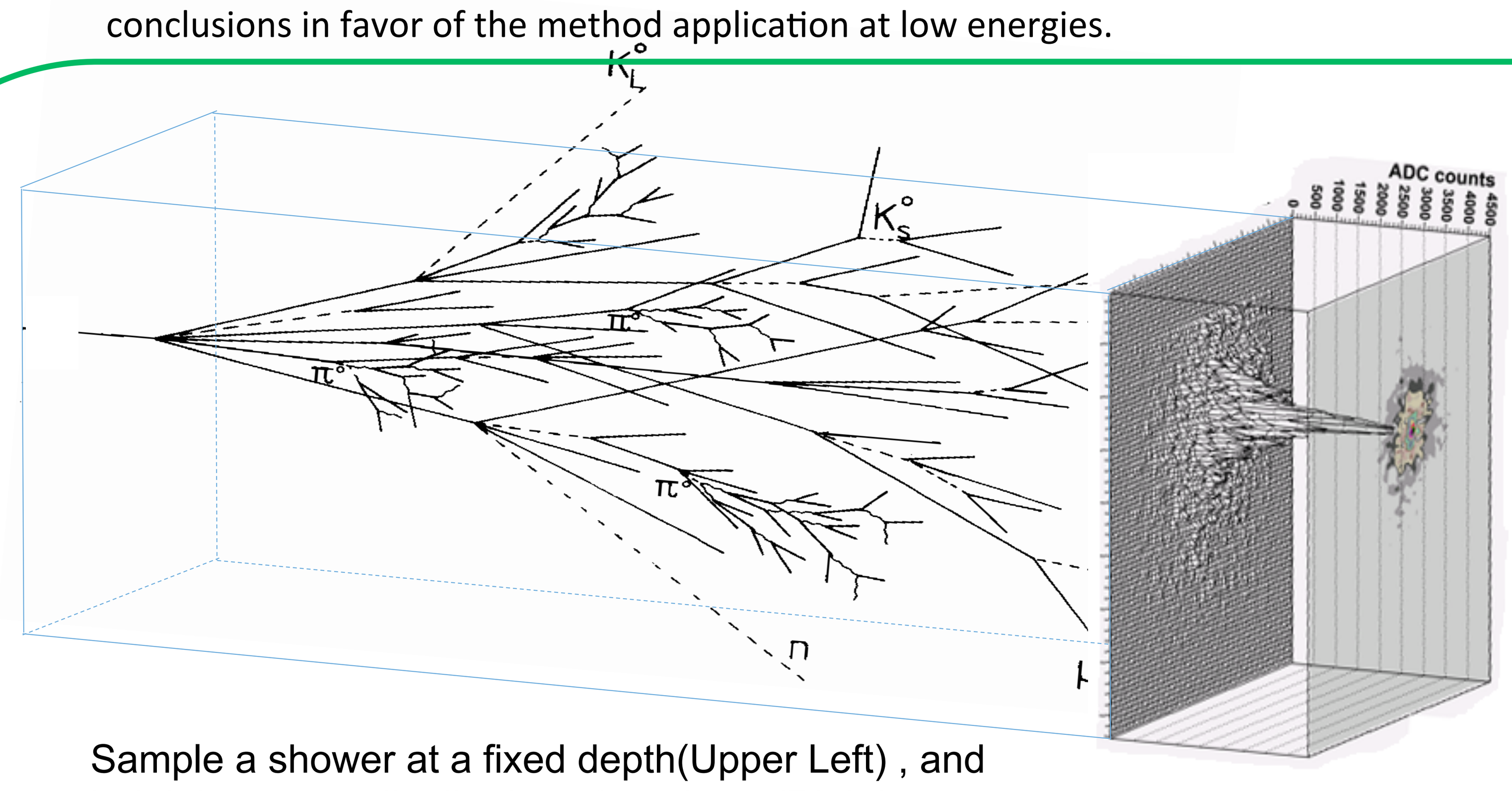
We propose a calorimetry approach unconventional and innovative. The method is based on the measurement of the lateral distribution of charged particles around the shower axis, it has been used for the first time in the energy determination of Extensive Air Showers at very high energy (> 100 TeV) with single layer detector [1], providing an energy determination with resolution of about 10% for energies above 100 TeV. It has some peculiar characteristics which can be summarized in the following three points: 1) measurement of the shower energy by means of a single sampling; 2) calorimetry which renounces the classic concept of containment of the shower; 3) possibility to separate primary masses. In order to validate and extend this technique at lower energies, specific simulation have been performed through GEANT4 in the energy range 100 GeV - 10 TeV for different particles. A simple geometry has been simulated, namely an Iron block with square section (1x1 m2) orthogonal to the beam and depth varying from 5 cm to 1 m. After analysis of the simulated shower events, we got to positive conclusions in favor of the method application at low energies.

Procedure



Sample a shower at a fixed depth(Upper Left) , and build the lateral distribution of particles (Right).

Calculate **the truncated size Pxx,** which is the number of particles within a **xx** distance from the axis, and the **lateral age s' parameter** by fitting the lateral distribution of particles with a Nishimura-Kamata-Greisen (NKG) like function:

$$f(r,s') = K \cdot \left(\frac{r}{r_M}\right)^{s'-2}\left(1-\frac{r}{r_M}\right)^{s'-4.5}$$

Calculate Y(s',Pxx), as

$$Y(s', Pxx) = s' + 0.8\,Log(Pxx)$$

Y has a linear relation with the logaritm of the energy shower

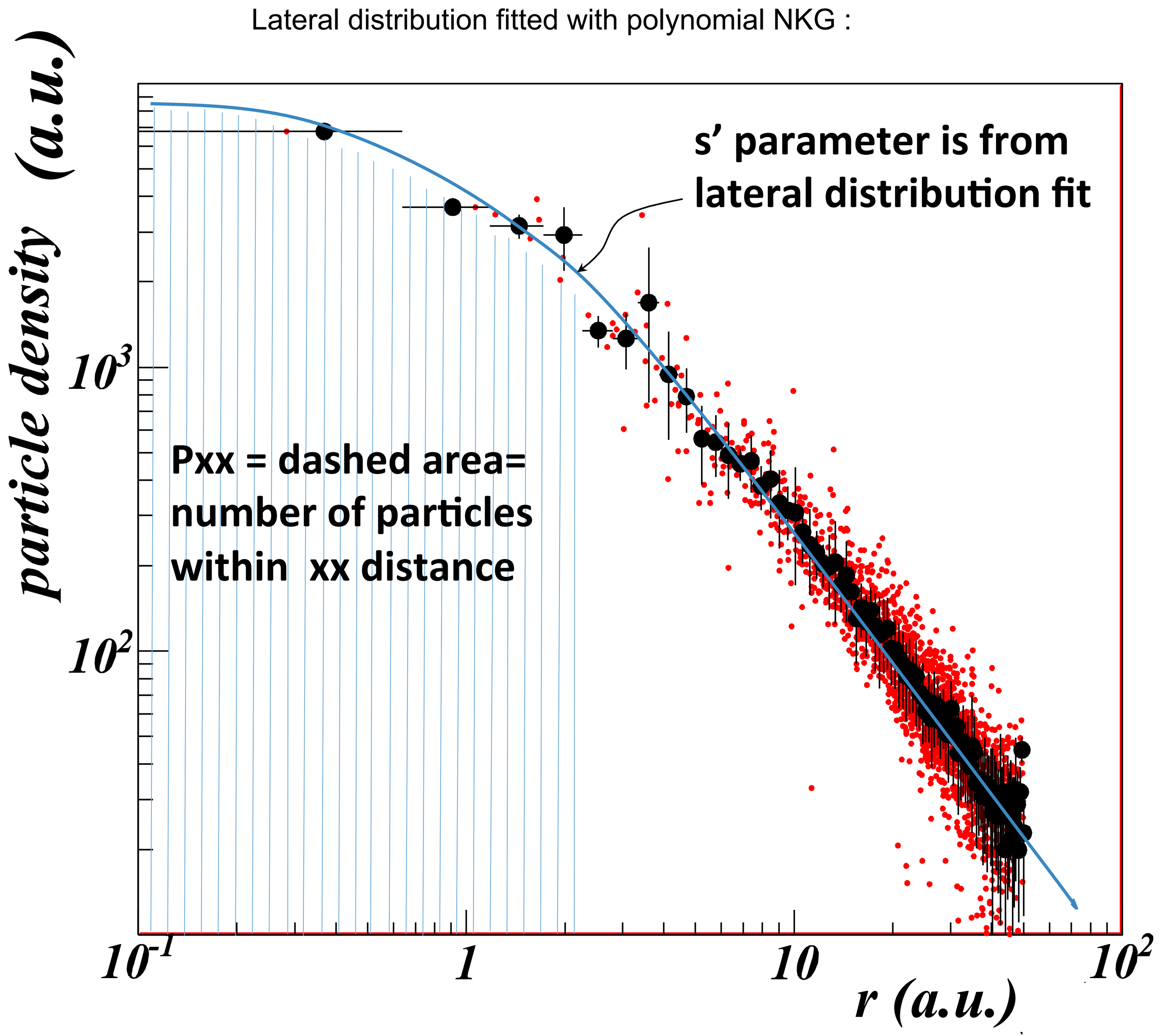
$$Y(s', Pxx) = A + B\,Log(E),$$

Therefore the shower energy can be calculated by

$$Log(E_{rec}) = (Y(s', Pxx) - A)/B$$

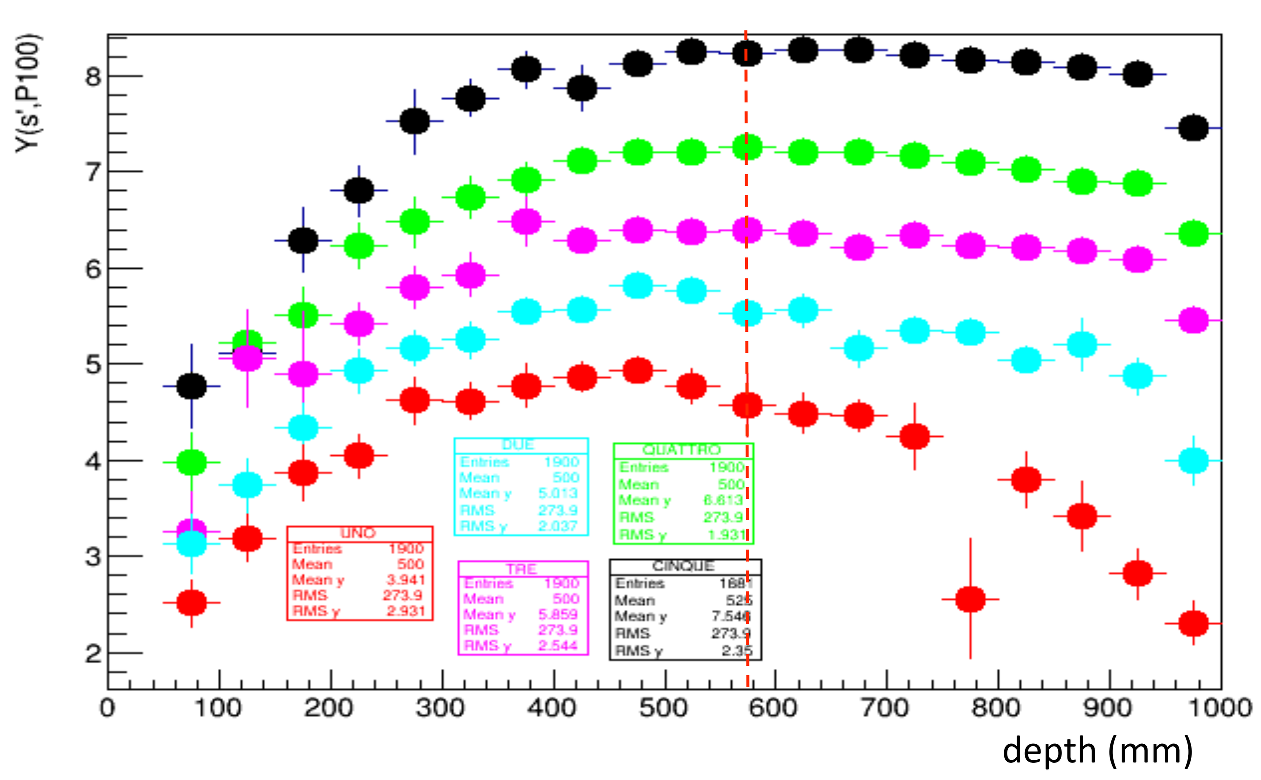
A and B are from MC simulations.

Lateral distribution fitted with polynomial NKG :



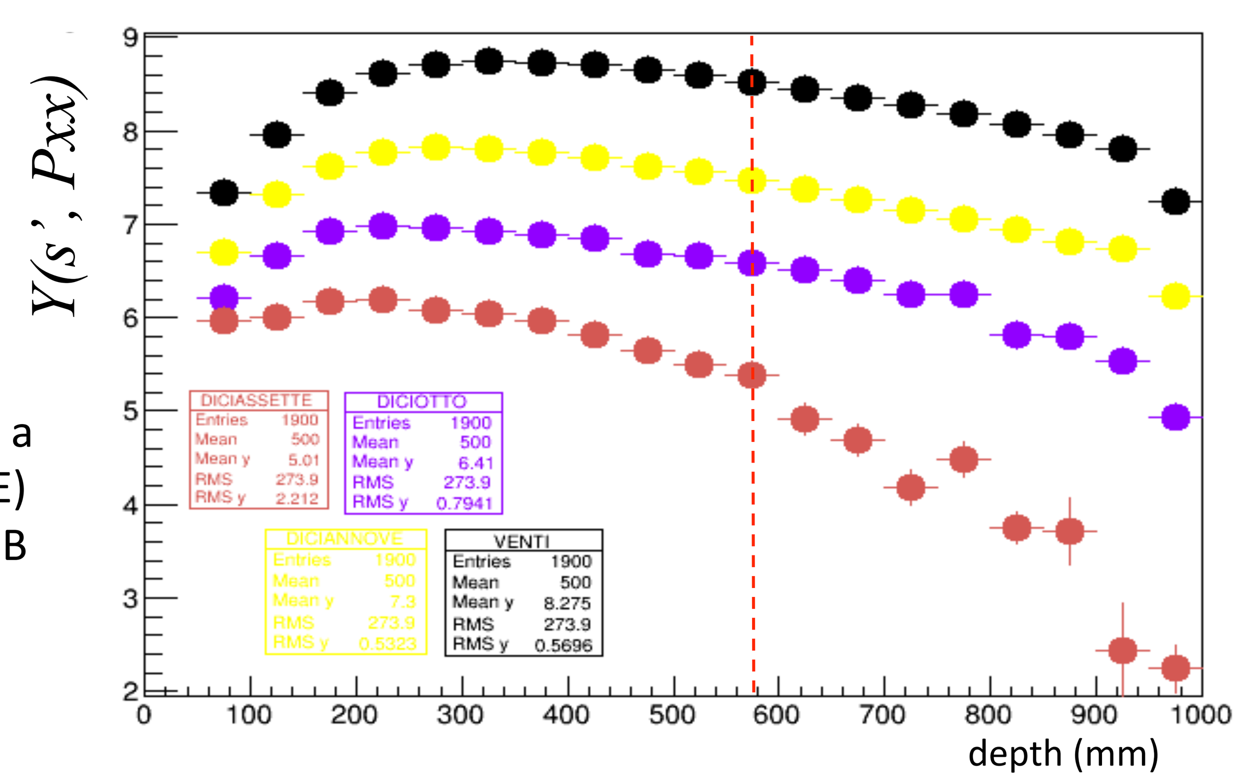
Energy reconstruction/ MC simulations

MC events produced by GEANT4 using the hadron interaction model FTFP_BERT in a sampling calorimeter of dimensions **1mx1mx1m** in which **4.9 mm** of absorber (iron) and **0.1 mm** of sensitive material (liquid argon)are alternated along the arrival direction of the impinging particle. In total, therefore, there are 200 samples. Of these 200 samples, only 20 were used, that is the particles sampled every **50 mm** from the primary entry point. Showers belonging to 6 primaries and 5 energies have been analyzed: specifically protons, pions+, pions-, helium nuclei, carbon nuclei and iron nuclei at the energies of 100 GeV, 300 GeV, 1 TeV, 3 TeV and 10 TeV. A satistics of 100 events has been generated for each particle and each energy. According to MC events best xx was 100 mm.



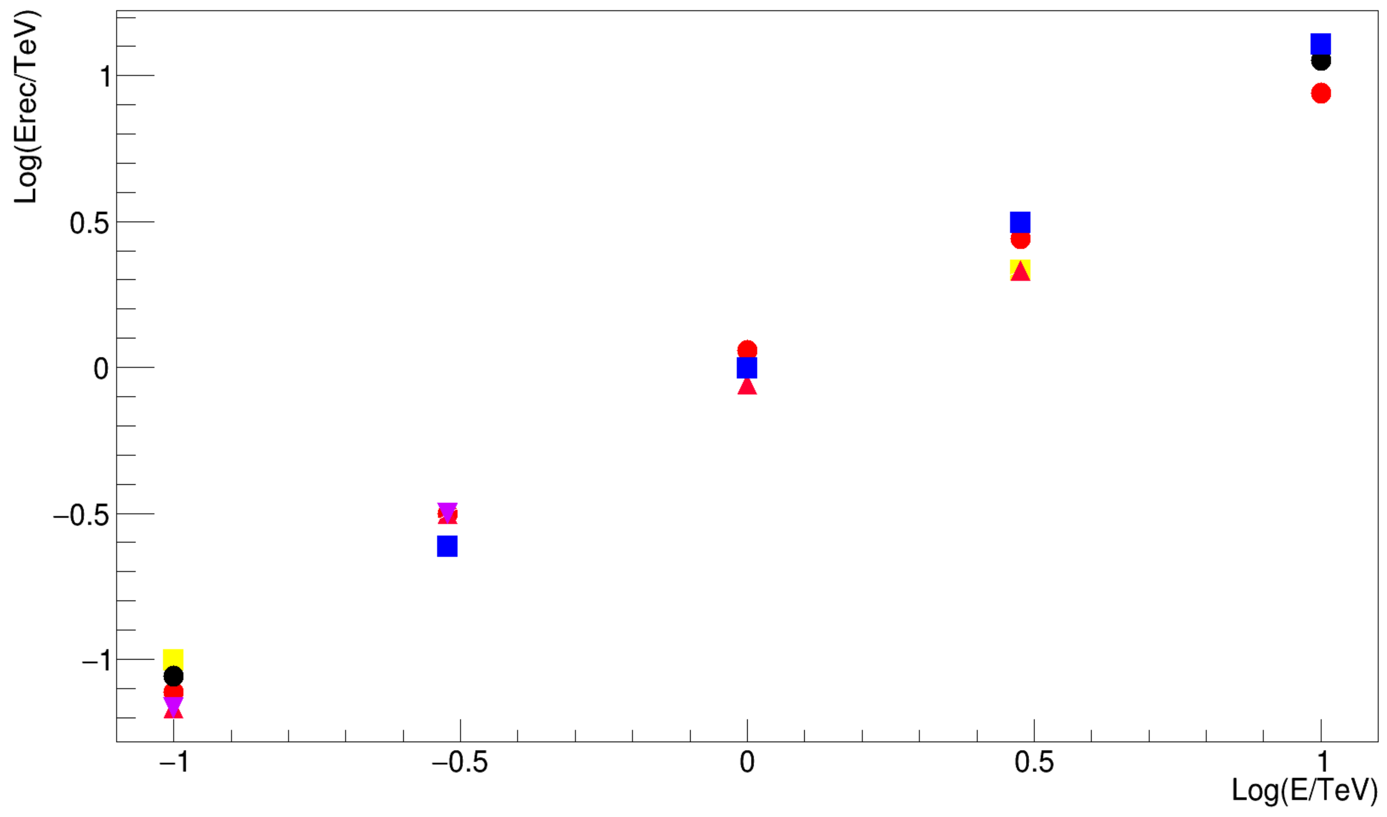
Y as a function of depth - Protons - 100 GeV (red); 300 GeV (celestial); 1 TeV (fuchsia); 3 TeV (green); 10 TeV (black)

Fitting points at a fixed depth (Y, E) allow for A and B determination



Y as a function of depth - Iron - 300 GeV (pink); 1 TeV (purple); 3 TeV (yellow) - 10 TeV (black)

Results



Logarithm of the reconstructed energy vs the logarithm of the true energy - depth is 570 mm - Protons (red circles); Pions + (yellow squares); Pioni- (pink triangles); Elio4 (purple inverted triangles); Carbon12 (black circles); Iron (blue squares)

The percentage error on reconstructed energy, for protons, goes from 60 % at 300 GeV, to 45% at 10 TeV.

[1] M Iacovacci, S. Mastroianni, et al., "A general estimator of the primary cosmic ray energy with the ARGO-YBJ experiment", PoS(ICRC2015)382