Fermi National Accelerator Laboratory

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Model for Hadronic Calorimeter Profile

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1. HF Profile

The "Hanging File" = HF test apparatus is a rich source of information on the longitudinal development of e and pion cascades for a variety of incident energies and for a variety of calorimeter absorber configurations [1]. The question of hadronic cascades and their longitudinal development is most gracefully addressed in homogeneous absorber configurations. For this reason, this note considers the data for 250 GeV pions incident on a stack of 3/4" Pb absorbers interspersed with 2.5 mm scintillator plates each read out separately. The Pb stack was chosen since the highest Z has the largest ratio of radiation length to interaction length. This large ratio serves to distinguish between the electromagnetic energy deposit and the hadronic energy transport within the cascade.

The profile shown in Fig. 1a arises from averaging the longitudinal energy distribution over many hadronic interactions. There appears to be a sharp rise followed by an exponential decrease in shower energy with depth. However, this profile averages over the fluctuation associated with the interaction point. This point was subtracted, and the profile with respect to the interaction point (and not the front of the calorimeter) is shown in Fig. 1b. This energy profile, in depth, displays some more interesting structure. There is a sharp initial structure, followed by an exponential falloff similar to that seen in Fig. 1a. The initial peak falls off very rapidly, with a depth characteristic of electromagnetic (EM) showers in the Pb stack. The profile on a linear scale appears in Fig. 2. Note that the first cluster is substantial, being responsible for perhaps 1/3 of the total hadronic energy deposit.

2. The Model for Individual Cascades

The structure of individual events was discussed in a previous note [2]. It was asserted that single events could be thought of, at these high energies, as due entirely to EM clusters produced in several sequential "generations". At any depth, the "generation" was 1/3 EM energy which dropped out of the cascade process, while 2/3 of the energy, on average, was transported by charged pions to the next generation interaction point.

The observations of Ref. 2 lead one to make a very simple model. The interaction points of successive generations are chosen out of an exponential distribution with mean free path = the tabulated [3] interaction length. The fact that cascades are then energy dependent in depth simply comes from the fact that more generations are available to higher energy primary hadrons.

$$z\!:\quad e^{-z/\lambda o} \tag{1}$$

At each interaction point, the EM energy fraction is chosen to have a mean of 1/3 of the energy transported to that point. The EM energy is chosen out of a Gaussian with rms characterized by the production of 3 neutral pions. The slow (logarithmic) variation of mean multiplicity with incident energy is ignored.

$$\begin{aligned} Eo\!:\quad & f_o = 1/3 \\ & \langle n_o \rangle = 3, \quad df_o = f_o(0.57) \end{aligned} \tag{2}$$

The sequence is, then, to pick an interaction point using Eq. 1. The EM energy is chosen as a fraction of the incident energy as in Eq. 2. The EM energy is then deposited in the Pb stack with a shape defined by using the shape measured from incident e data. For the 3/4" Pb, the EM cluster spans 7 layers, or ~ 25 Xo. The non EM energy is then transported to the next interaction point, and the process is iterated until the energy is exhausted.

Typical Monte Carlo events are shown in Fig. 3. Note that the number of distinguishable clusters varies considerably. Note also the very large fluctuations in the development of the hadronic cascades. The general appearance of the longitudinal energy dependence is very similar to that seen in the data shown in Ref. 2 by construction.

3. Model for the Profile

The simple model was then used to generate many cascades. They were summed over, and the results are shown in Fig. 4. Note that the initial sharp structure due to the first EM energy cluster, as seen in Fig. 1b, is reproduced. In fact, the general shape and normalization are in very good agreement with the data.

Further studies would include the energy dependence of the profiles and the structure of individual events in the data. The results of this initial study appear to be quite promising, in that the main features of the data can be well understood with a simple physical picture. Obviously, this simple minded approach is no substitute, in serious work, to a full fledged Monte Carlo program.

References

1. A. Beretvas, et al., "Beam Tests of Composite Calorimeter Configurations from Reconfigurable-Stack Calorimeter", *Nuc. Inst. Meth.*, A329, (1993) 50.
2. D. Green, "EM Clusters in Hadron Showers Using The "Hanging File" Data", Fermilab-FN-612 (1993).
3. Review of Particle Properties, Phys. Rev. D 45 (1992).

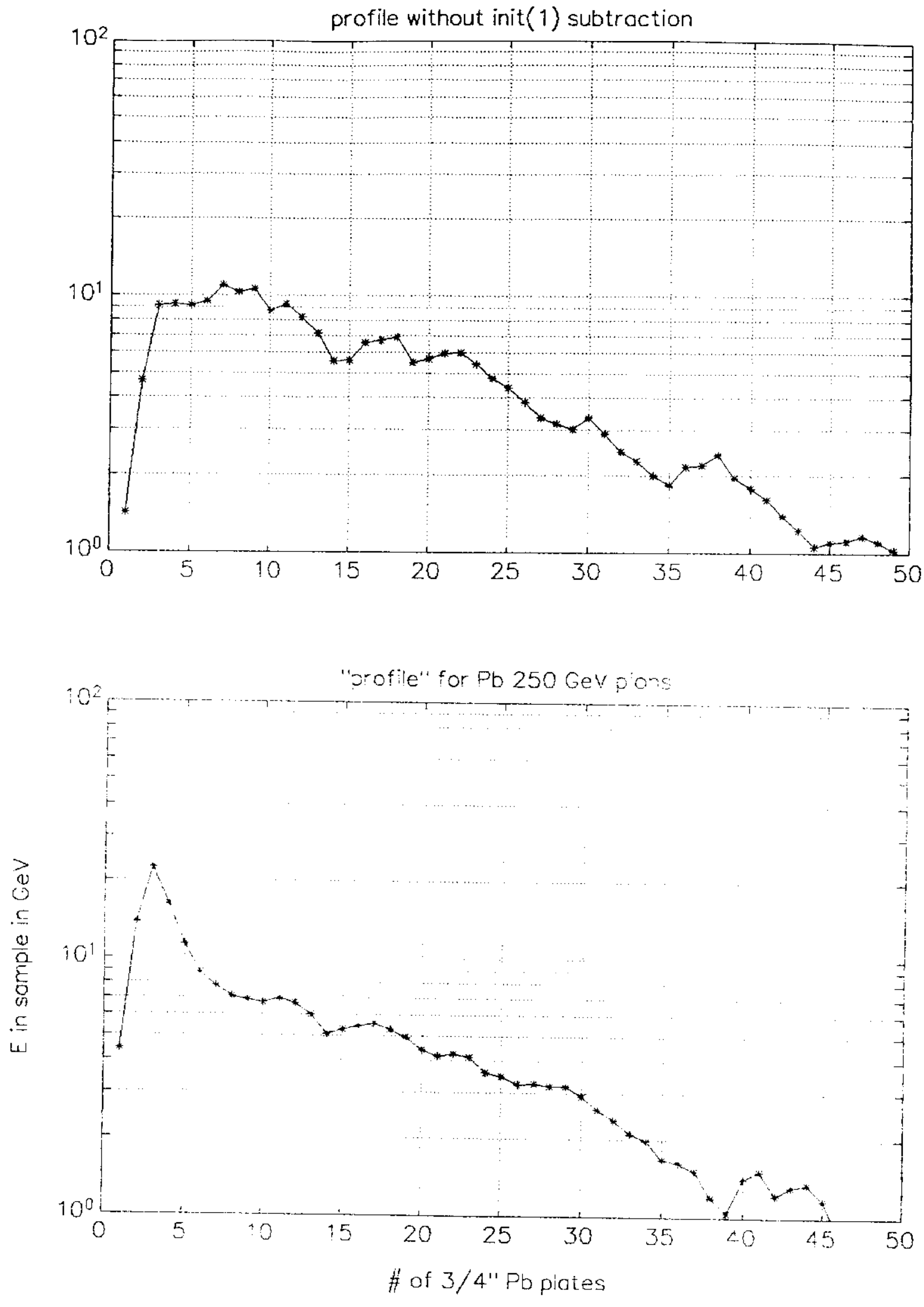

Figure 1. Profiles of 250 GeV hadrons in a homogeneous calorimeter consisting of 3/4" Pb plates.

a. Energy deposit in GeV as a function of layer number integrated over all interaction points.

b. Energy deposit in GeV as a functon of sample number with the distance to the first interaction point subtracted.

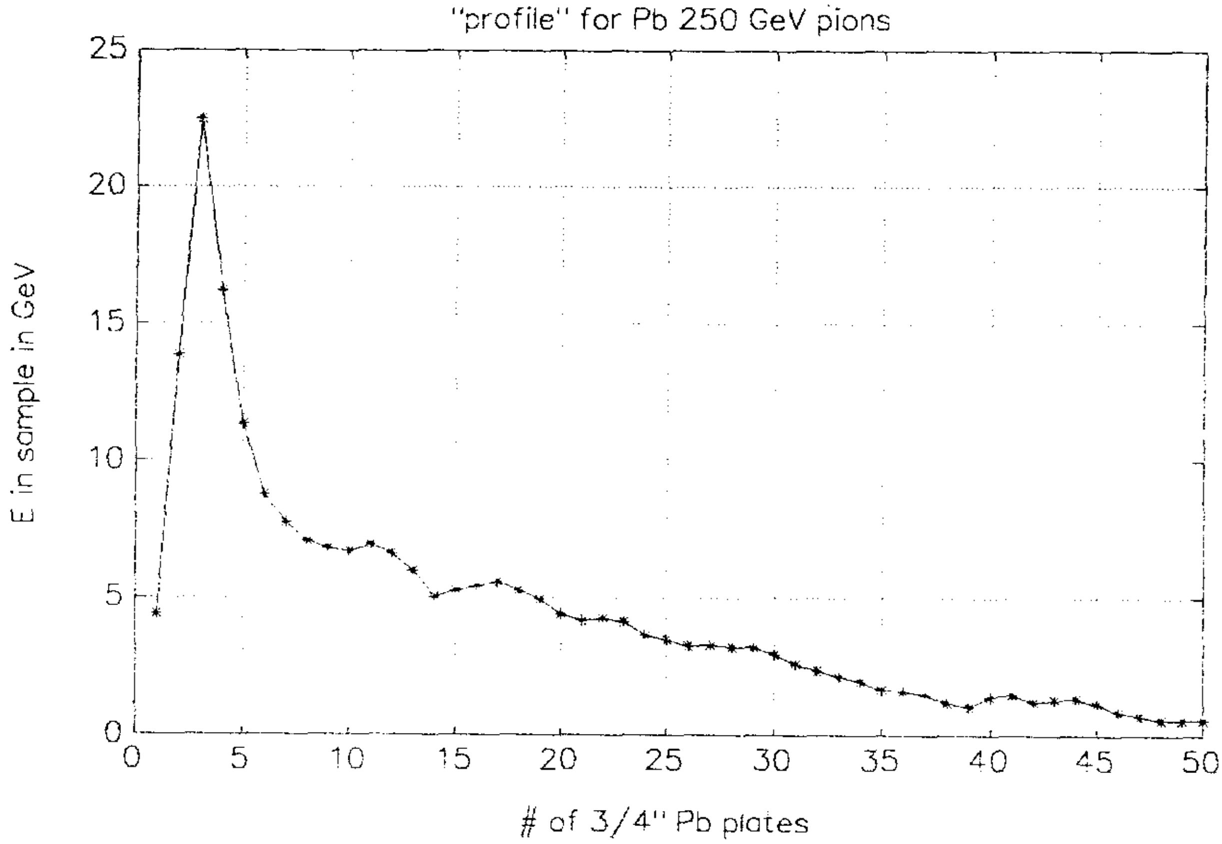

Figure 2. Profile in GeV of 250 GeV hadrons in the 3/4" Pb HF stack with the first interaction point subtracted - linear energy scale.

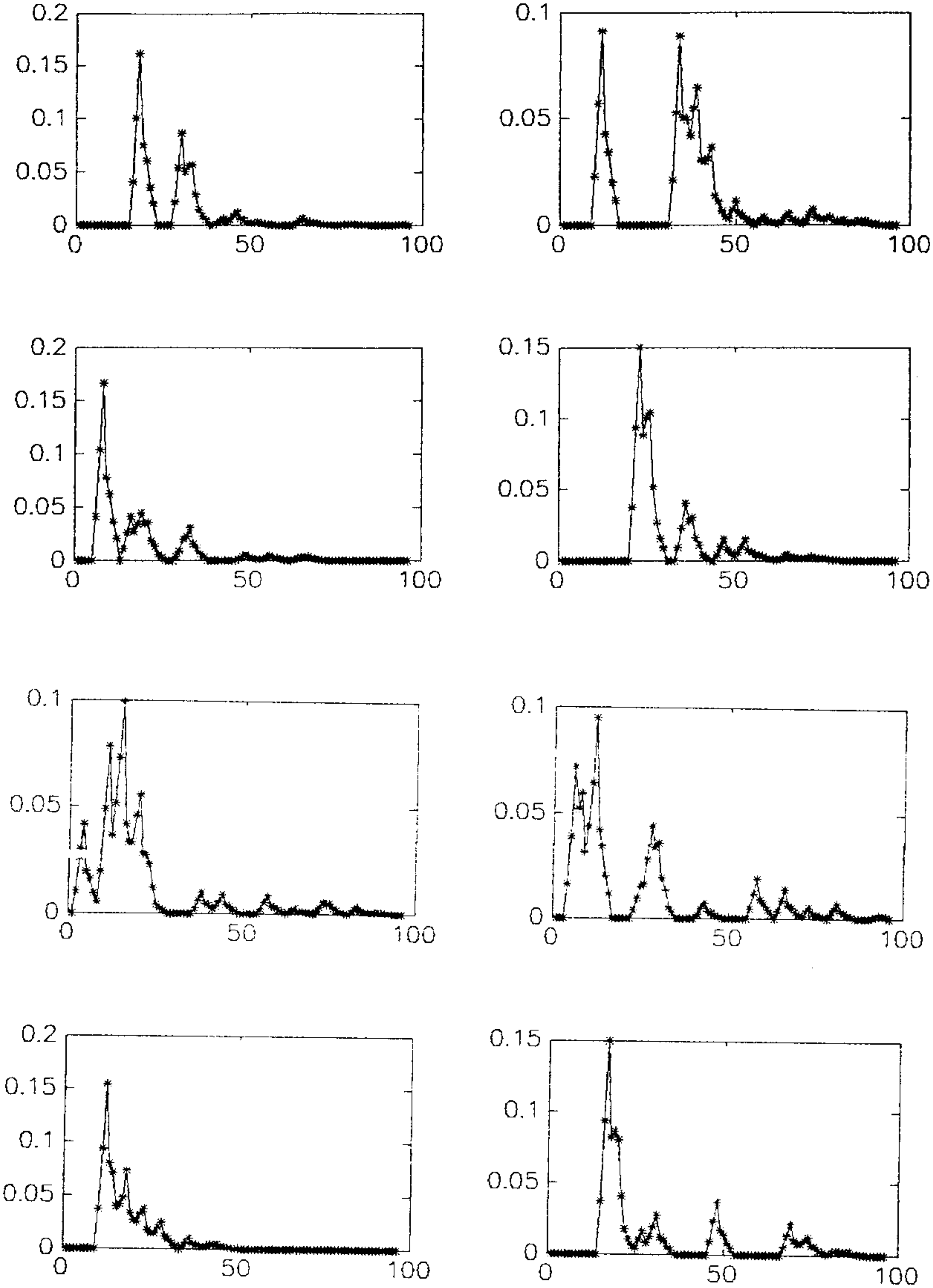

Figure 3. Single event longitudinal energy deposit for 8 sequential events generated using the model described in the text. The plots are fractional energy deposit vs. sample number. The EM clustering is quite distinct.

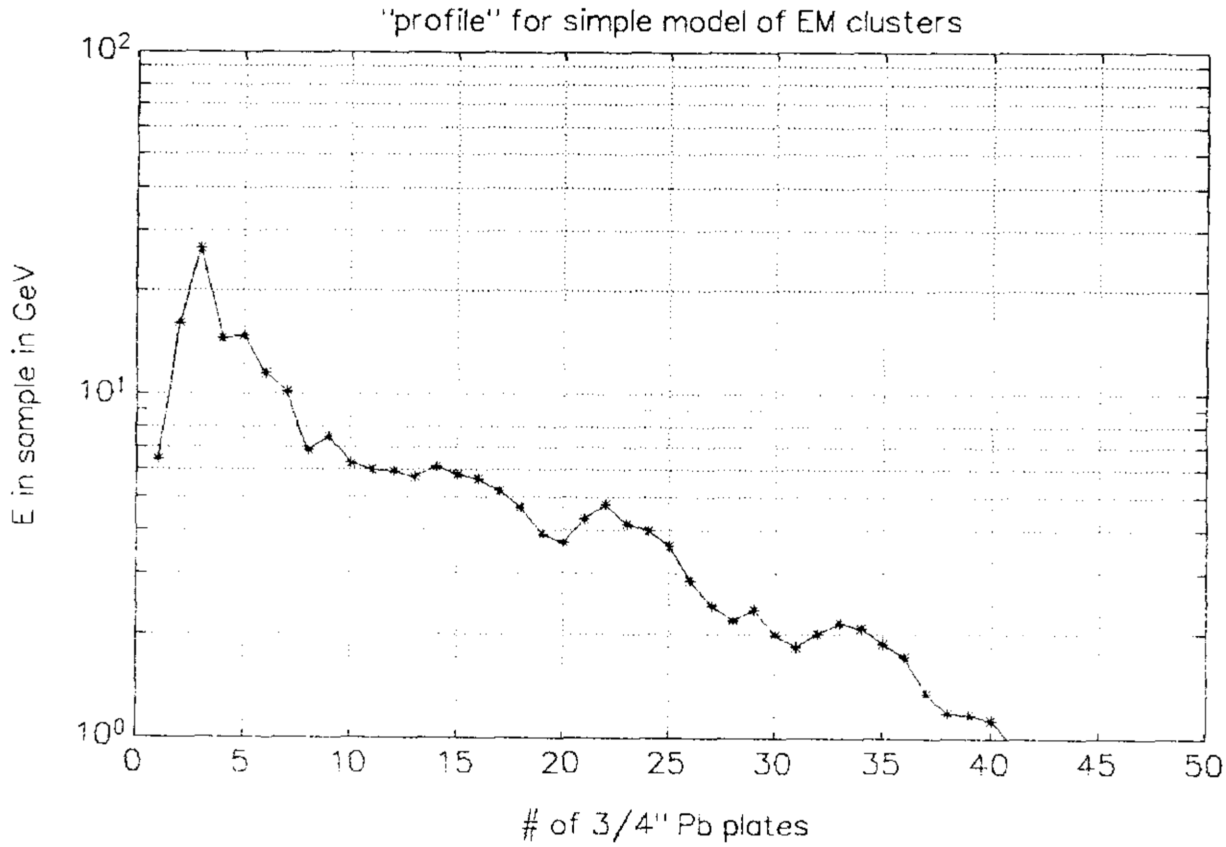

Figure 4. Profile of 250 GeV hadrons as energy in GeV vs. sample number generated using the model described in the text. The experimental profile given in Fig 1b. should serve as the point of comparison.