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Simulation of H1 Calorimeter Test Data with GHEISHA and FLUKA

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Abstract

Beam test results obtained for the liquid argon calorimeter of H1 are compared to simulation with GHEISHA and FLUKA based on GEANT3.14. The calorimeter is highly segmented and consists of a lead/liquid argon and a steel/liquid argon section of in total 6 interaction lengths. Results are shown for electrons, muons and pions in the energy range 10 to 80 GeV. The quality of hadronic shower simulation is demonstrated in detailed distributions like total energy, longitudinal and transverse profiles, energy fluctuations, clustering and energy weighting.

1 Introduction

The H1 collaboration has reported on various tests performed at CERN with prototypes of the H1 liquid argon calorimeter [1], [2], [3]. In this report I present some comparisons of test data and simulation of a calorimeter stack with exactly the same structure as the H1 detector.

Reliable simulation will be important for the analysis of HERA events especially for the improvement of calibration including the determination of various corrections due to cracks and dead materials in front of the calorimeters.

In the following sections I describe very shortly the calorimeter structure (see section 2), the used simulation codes (section 3), and the definition of energy scales (section 4) for data and Monte-Carlo. This includes comparisons for electrons and muons. In section 5 quite detailed comparisons of data and simulations are presented for pions giving some information on the predictive power of the hadronic shower simulation based on GHEISHA and FLUKA in the frame of GEANT.

2 The Calorimeter Structure

The stack corresponds to a quarter of the inner forward liquid argon calorimeter "IF" of the H1 detector [4].

The front section for e and γ detection ("EC" there after) has a depth of 29 X_0 (1.3 λ) with lead absorber plates and liquid argon gaps of 2.4 mm. Copper claded read out boards are glued on either side of every second lead plate. The pads defining the transverse segmentation are shown in fig.1. The longitudinal structure is given by ganging to towers of 2.5, 5.7, 7.6 and 13 X_0. The corresponding layers of equal depth are labeled K = 0 to 3.

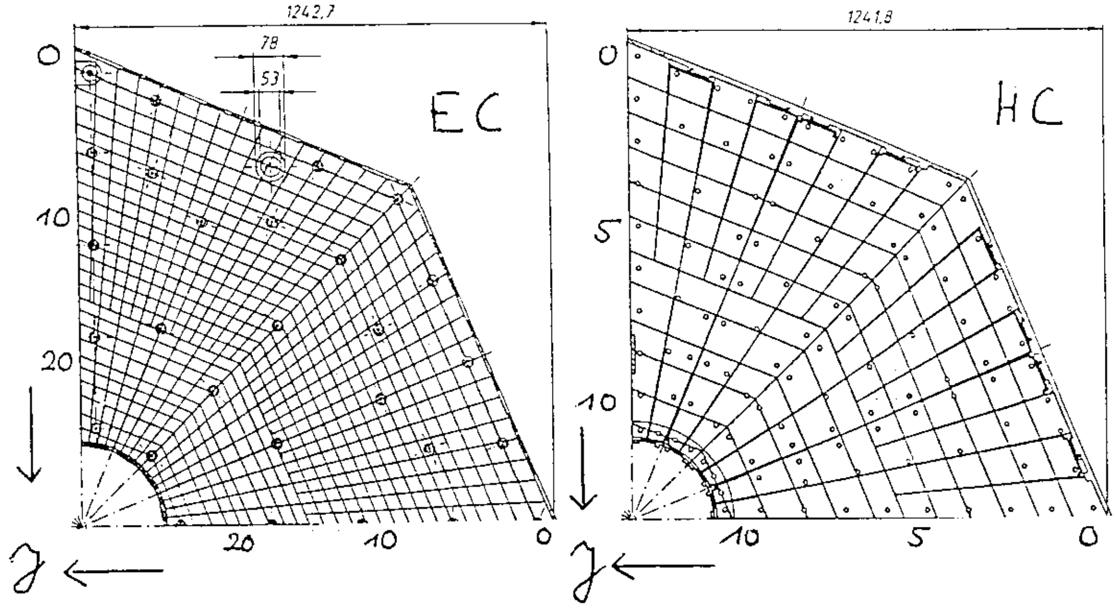

Figure 1: *Transverse structure of the stacks.*

The hadronic calorimeter ("HC") has a depth of 4.6 interaction lengths (λ) (EC + HC : 5.9 λ) with steel absorber plates of 16 mm thickness. A readout structure (2 x 1.5 mm steel, G10), providing two gaps of liquid argon of 2.4 mm, is inserted between every 2 absorber plates. For the transverse structure see fig.1. The longitudinal structure is given by ganging to towers of 0.7, 0.7, 0.9, 0.9 and up to 1.4 λ. The corresponding layers of equal depth are labeled K = 0 to 4. Further details in [4].

3 The Simulation Codes

All simulation is based on a detailed description of the setup in the framework of GEANT 3.14/16. This includes the standard interface to GHEISHA [5] which was slightly modified to improve conservation of kinetic energy in hadronic reactions. As an alternative shower code we used "H1FLUKA". This code is a combination of GHEISHA and FLUKA. All cross sections are taken from GHEISHA, but the production of the hadronic final state particles is taken from FLUKA86 with some modifications. These are mainly to produce final state n and p from evaporation energy and to extend the intranuclear cascade model used by NUCRIN [6] at energies below 5 GeV to higher energies [7]. This code is under further development within H1.

We run GEANT3.14 in AUTO mode, i.e. automatic calculation of tracking parameters. The essential cut off parameters are 200 KeV for γ s and 1 MeV for electrons and hadrons. No correction for saturation of charge collection in liquid argon for heavy particles was applied.

We observed that the standard single precision calculation was not sufficient in all parts of GEANT tracking..

Typical timing is 1 sec/GeV for electrons and 0.5 sec/GeV for pions on IBM 3090.

4 The Electromagnetic Energy Scales

In this report experimental data and Monte Carlo (M.C.) are compared on the basis of an "electromagnetic scale". This scale relates the measured charge (or visible energy in M.C.) to the energy deposited in a given tower by electron showers. Shooting electrons of 30 GeV into the lead stack (EC), we obtain for data (energy-charge relation) $c_{exp}^{EC} = 3.54$ GeV/pC and for M.C. (energy-visible energy relation) $c_{MC}^{EC} = 13.0$ (the corresponding mip sampling fraction is 8.8^{-1}). This scale is defined to be independent of materials in front of the stack. The corresponding corrections to c_{exp}^{EC} were obtained by comparison of measured showers at 30 GeV with simulation where experimental conditions and analysis cuts etc. are taken into account (see fig.2).

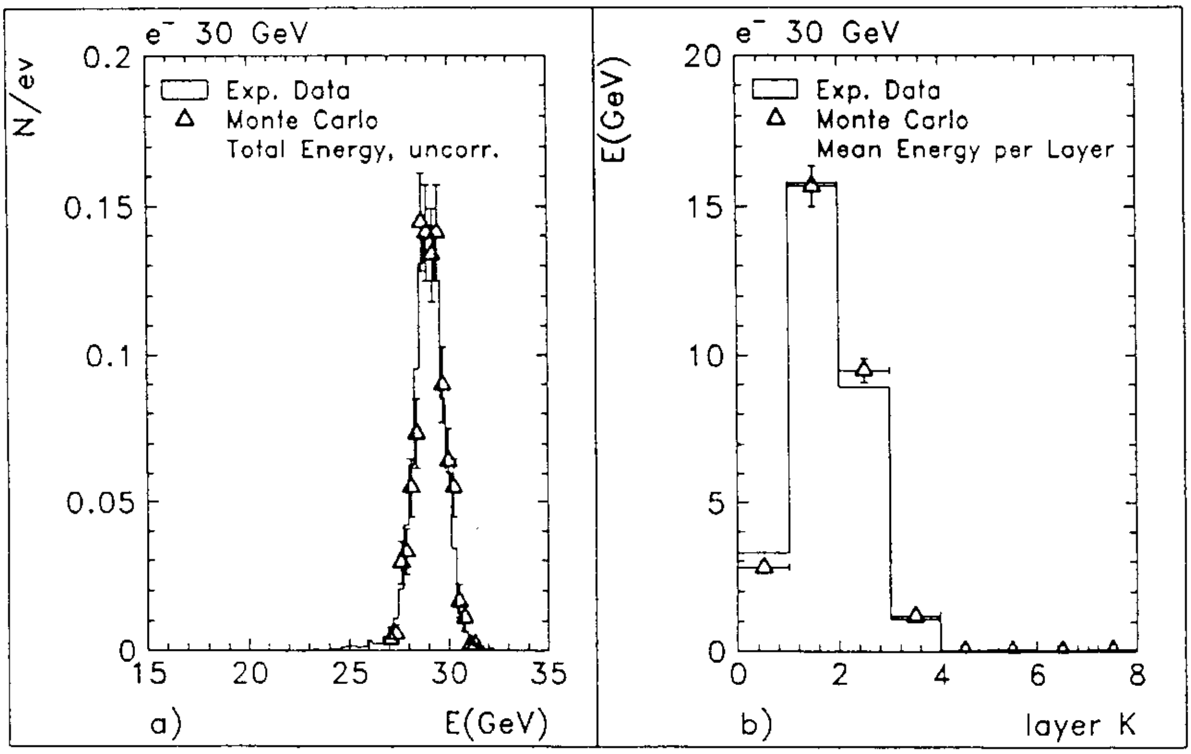

Figure 2: *e^- 30 GeV. a) total energy b) mean energy per layer.*

The experimental calibration takes into account a charge collection efficiency of 93% as deduced from the high voltage plateau curve.

Simulation of electrons gives for the hadronic stack $c_{MC}^{HC} = 26.8$ (the corresponding mip sampling fraction is 24.2^{-1}). Here the experimental calibration constant is scaled from EC by Monte Carlo. For further details see [8].

The same relative normalization of data and M.C. could have been obtained using muons within a few per cent. Fig 3 shows the mean charge per layer K throughout the stack. [1] In other words, the relative normalization of data and M.C. obtained with electron showers is valid also for muons.

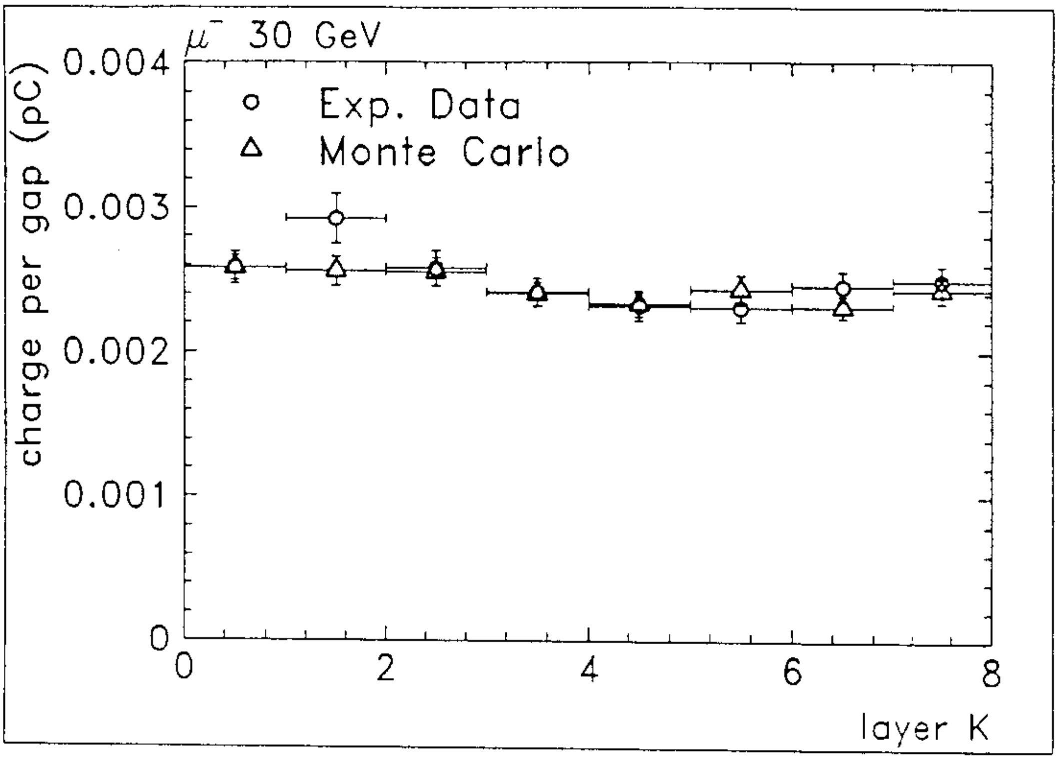

Figure 3: *μ^- 30 GeV, Mean charge per layer.*

5 Results for Pions

The following points are relevant for the reconstruction of experimental and simulated events:

- Energies are based on the electromagnetic scale (section 4). As both stacks are non compensating, pions are reconstructed on this scale with reduced energies (e.g. if $E_\pi = 30$ GeV, $E_{rec}^{e.m.scale} = 22$ GeV).

[1] A cut at 2.5 σ of the random noise distribution is applied.

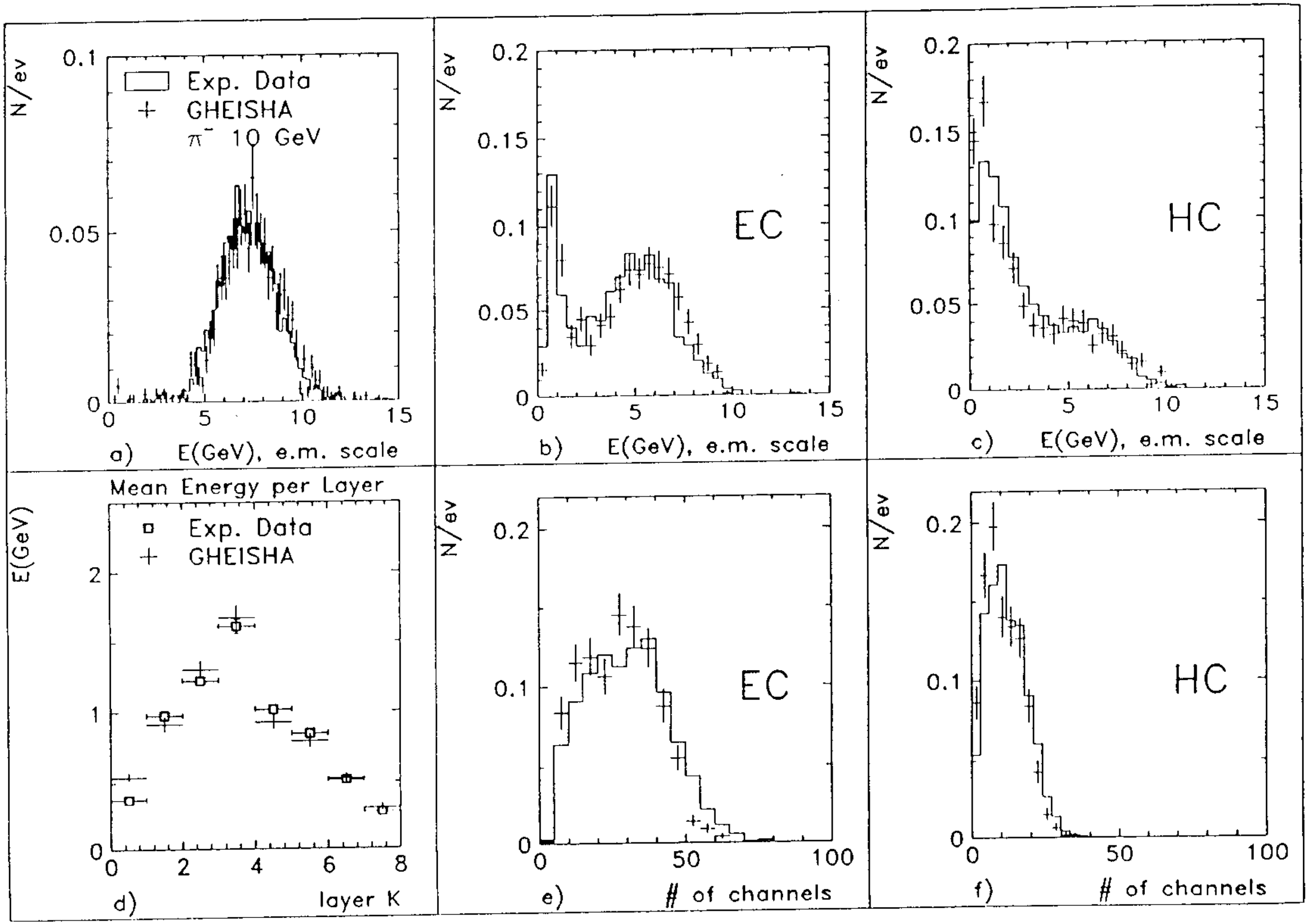

Figure 4: π^- *10 GeV. Comparison of data and GHEISHA*

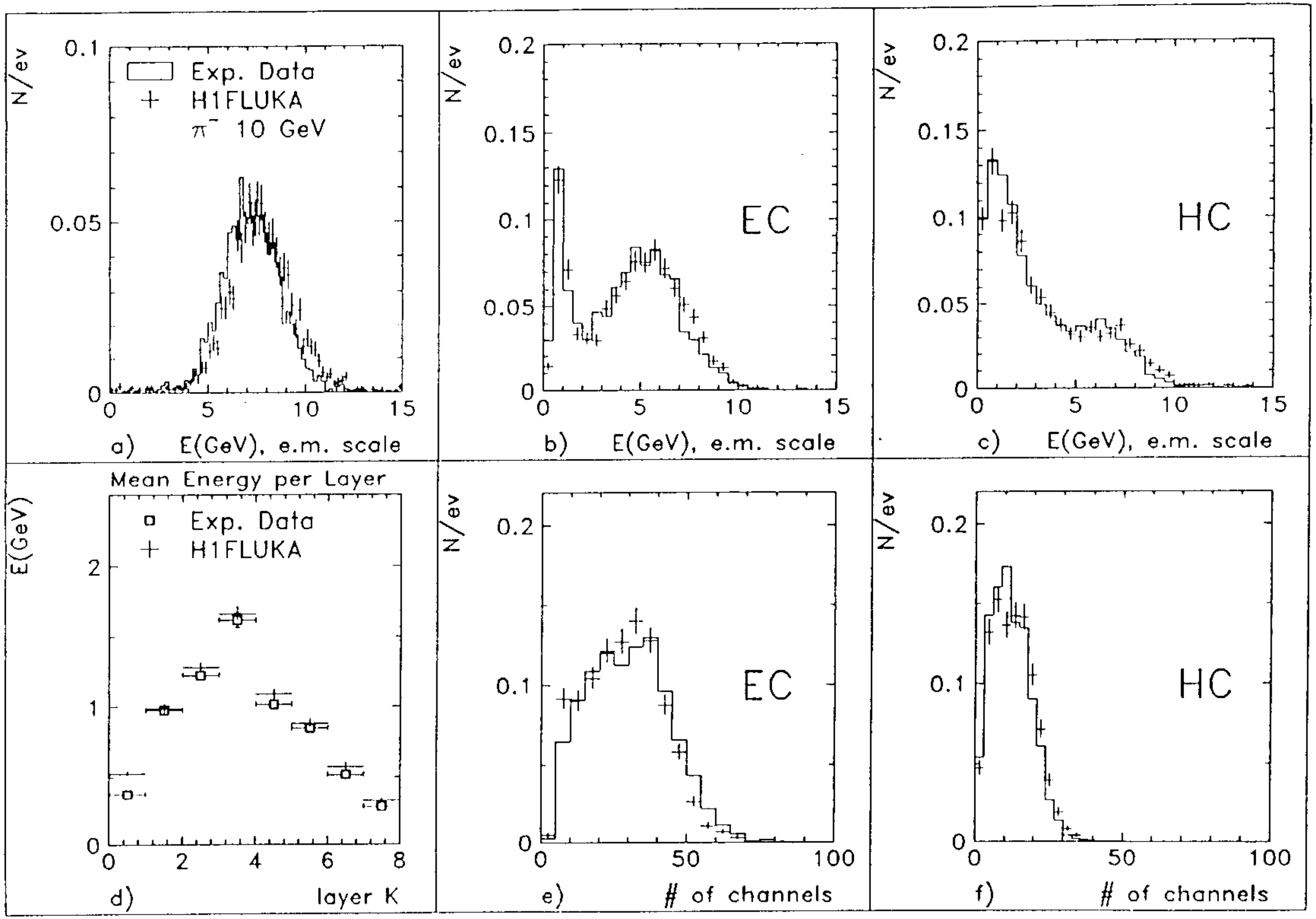

Figure 5: π^- *10 GeV. Comparison of data and H1FLUKA*

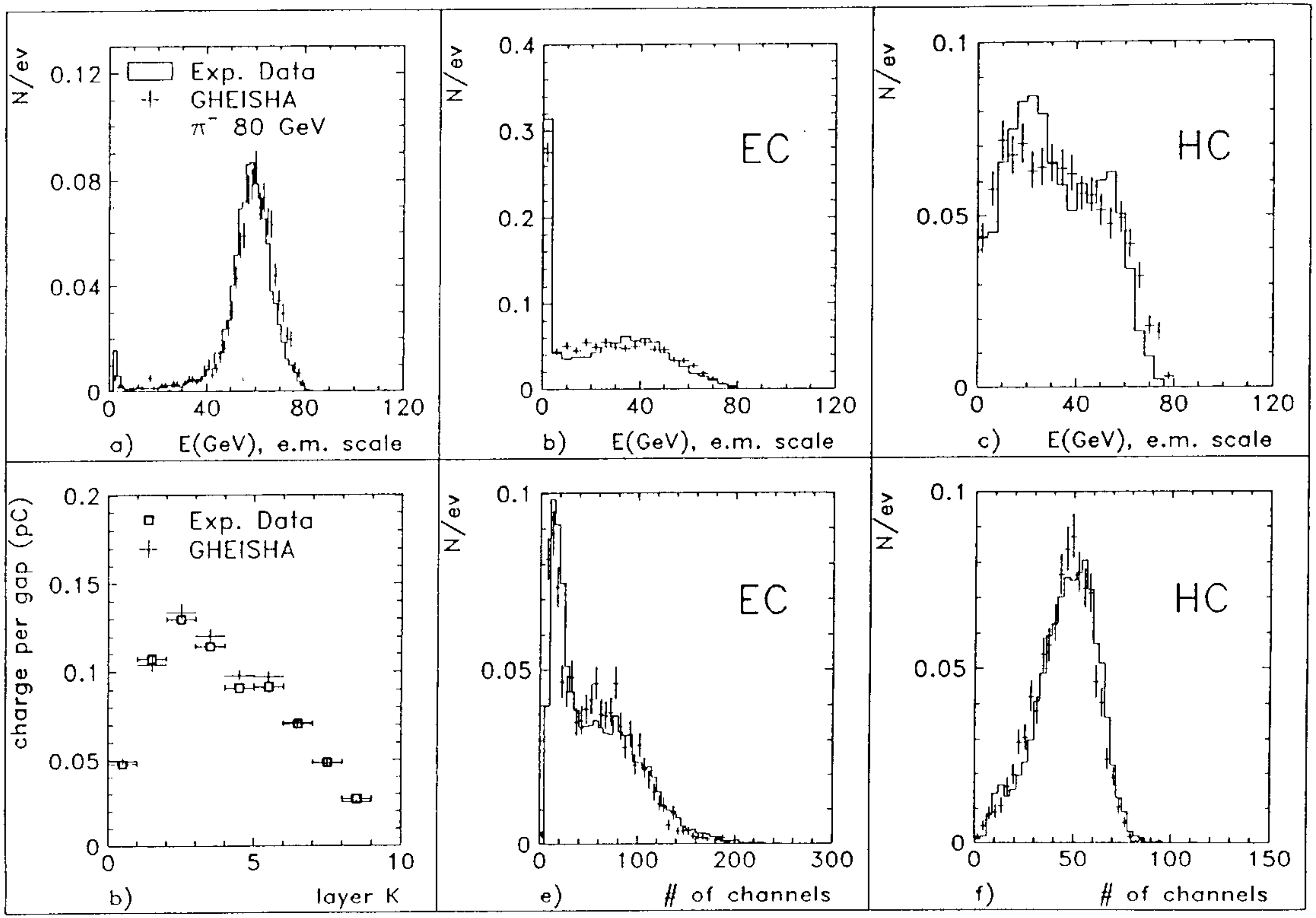

Figure 6: π^- *80 GeV. Comparison of data and GHEISHA*

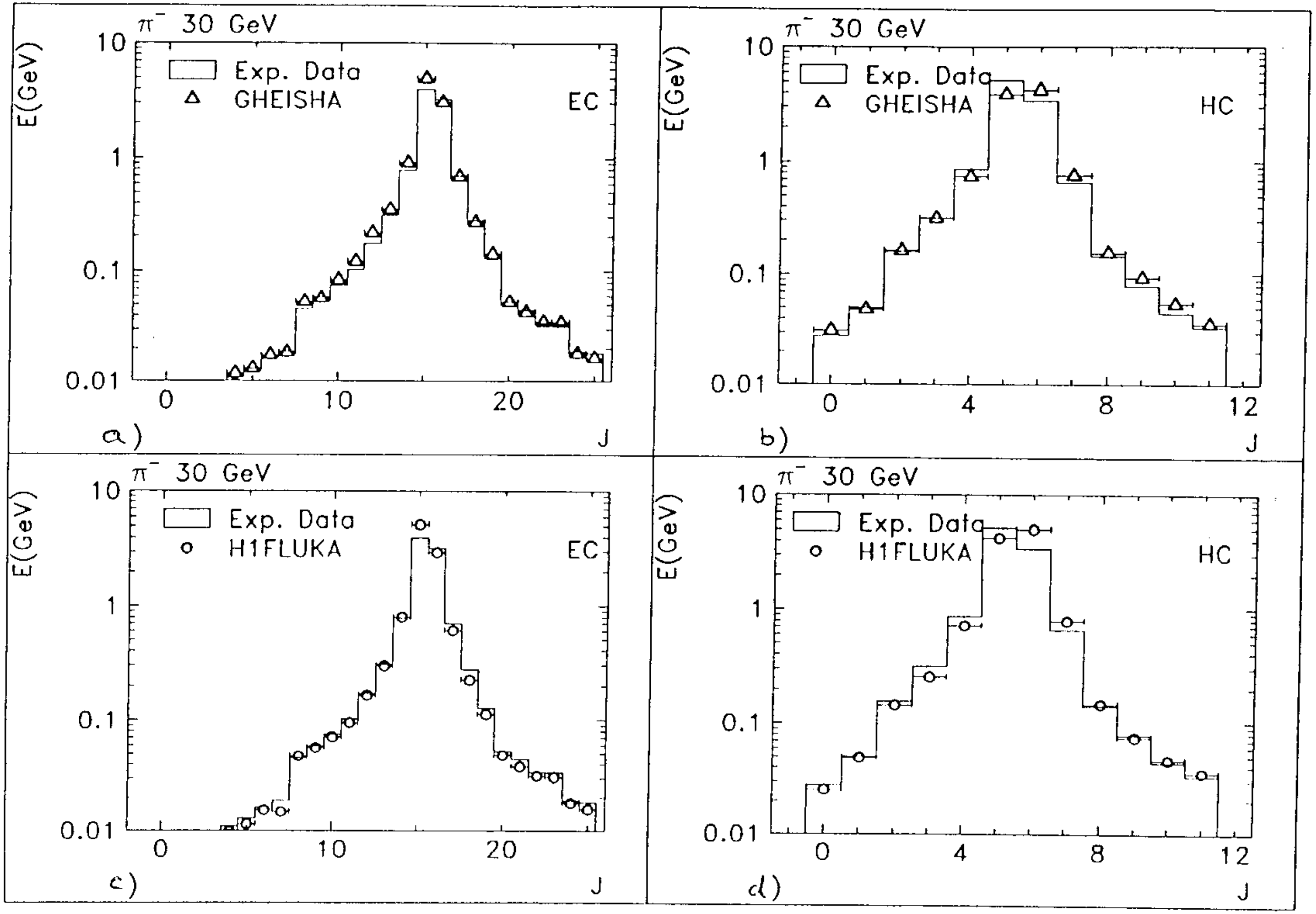

Figure 7: *mean energy versus transverse division J (see fig.1) for the EC- and HC-stack.*

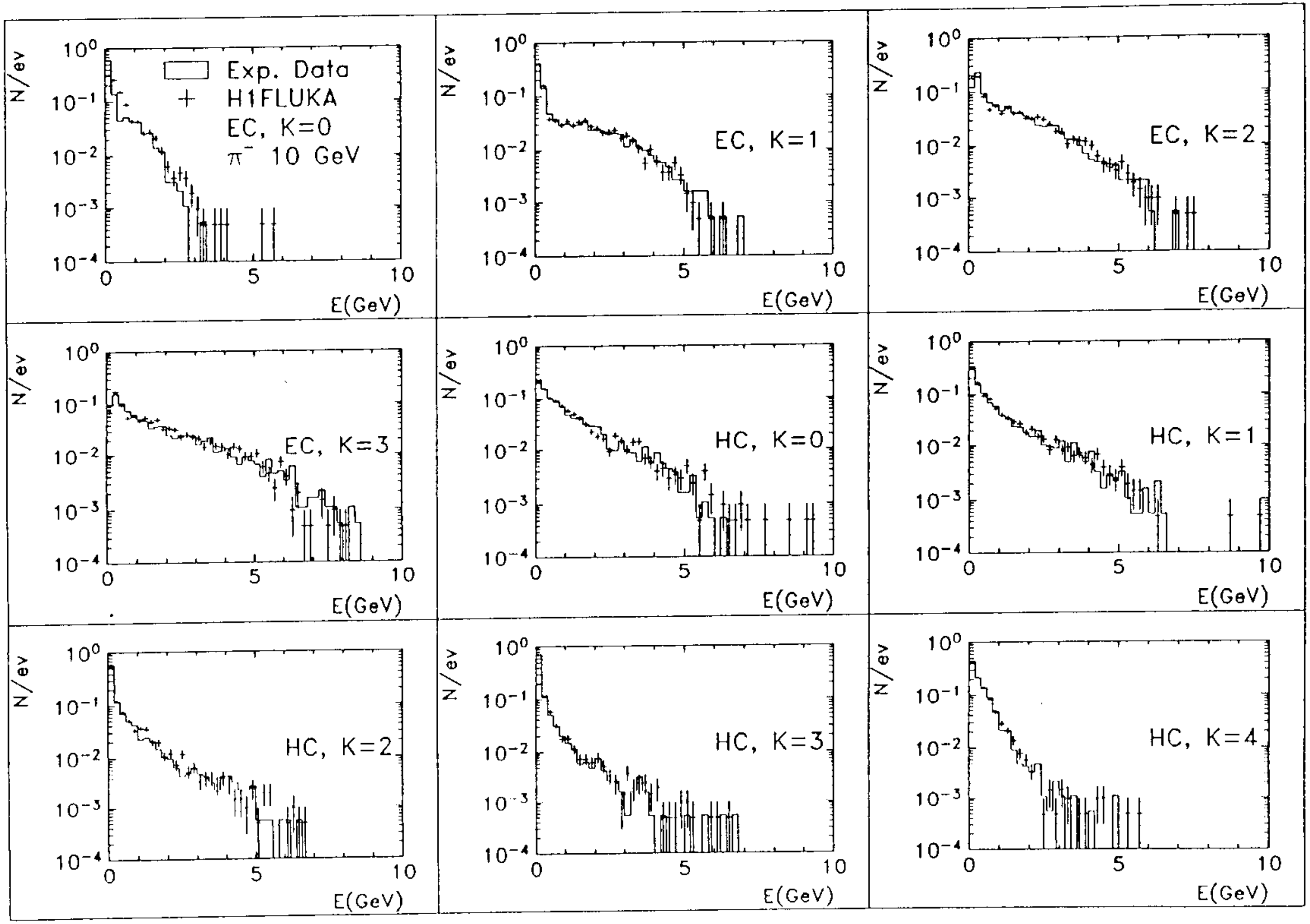

Figure 8: *Energy per layer. π^- 10 GeV. Data (histo.) and H1FLUKA (symbols).*

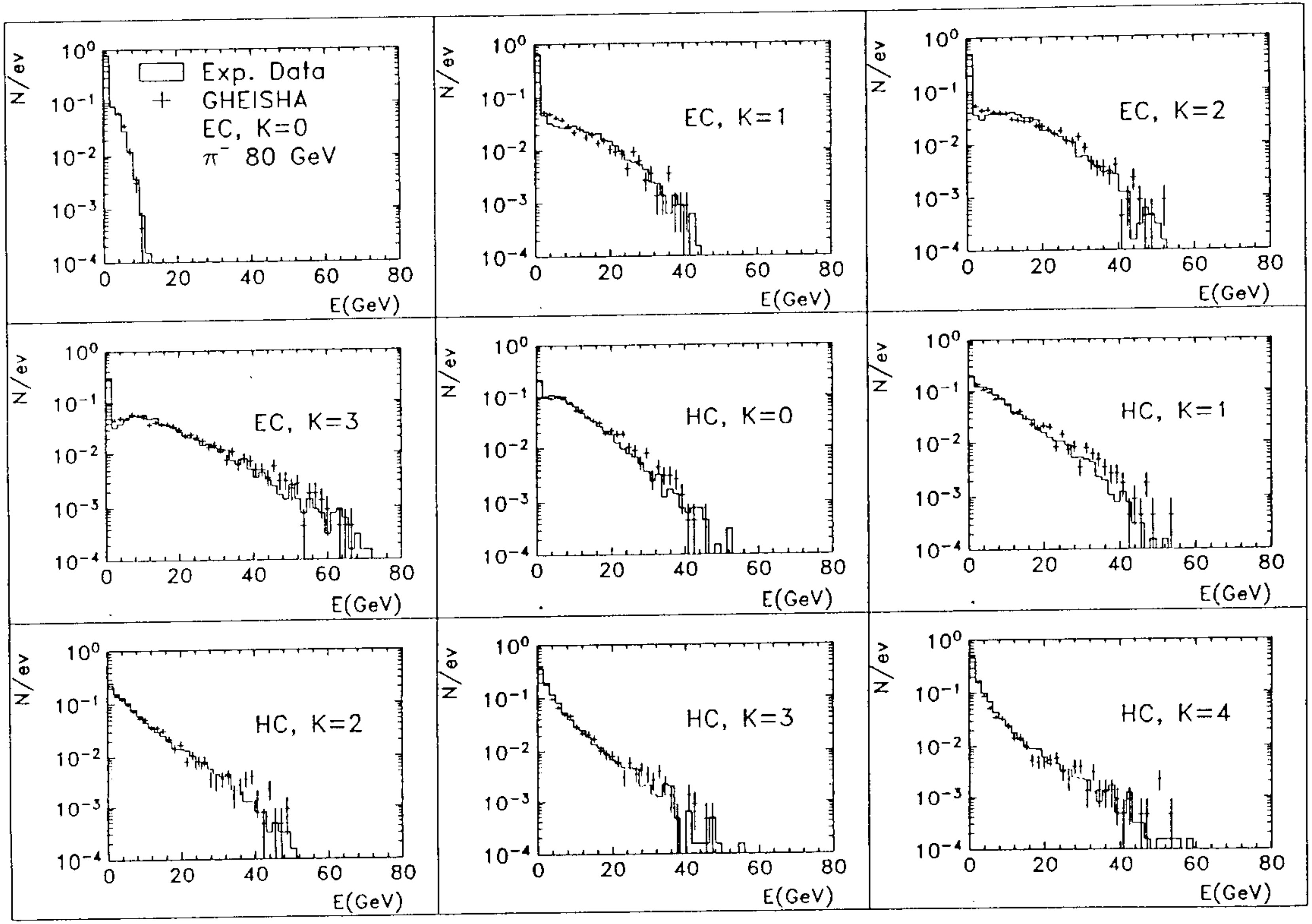

Figure 9: *Energy per layer. π^- 80 GeV. Data (histo.) and GHEISHA (symbols).*

- To reduce the influence of electronic noise, channels are only accepted if they are above 3 σ of the random noise distribution. This corresponds on average to about 0.01 pC. For comparison, the signal of a mip is about 0.03 pC per channel.
- Measured random events are overlayed to the Monte Carlo events. They are then treated with the same cut at 3 σ noise level.
- An instrumented iron tail catcher is not used in this analysis except at 10 GeV where it is used as veto against muons. This rejects also about 5% of pions.

The general patterns of the pion showers are described quite well by both codes, GHEISHA and H1FLUKA (figs. 4, 5, 6). This implies also some measures of the geometrical size of the showers such as the distributions of the number of channels above the cut at 3 σ. This is shown separately for the EC- (e)) and HC-stack (f)). The simulated total energy (a)) is in general too high (1% to 3% for GHEISHA, 6% to 8% for the H1FLUKA in the range 10 to 80 GeV). The preliminary H1FLUKA code produces too large energies in the hadronic stack (fig. 5 c)). Besides this tail the distributions of H1FLUKA look at least as good as those of GHEISHA. Note that no tuning to the present data is involved and no saturation for heavy shower particles is applied to either program (section 3).

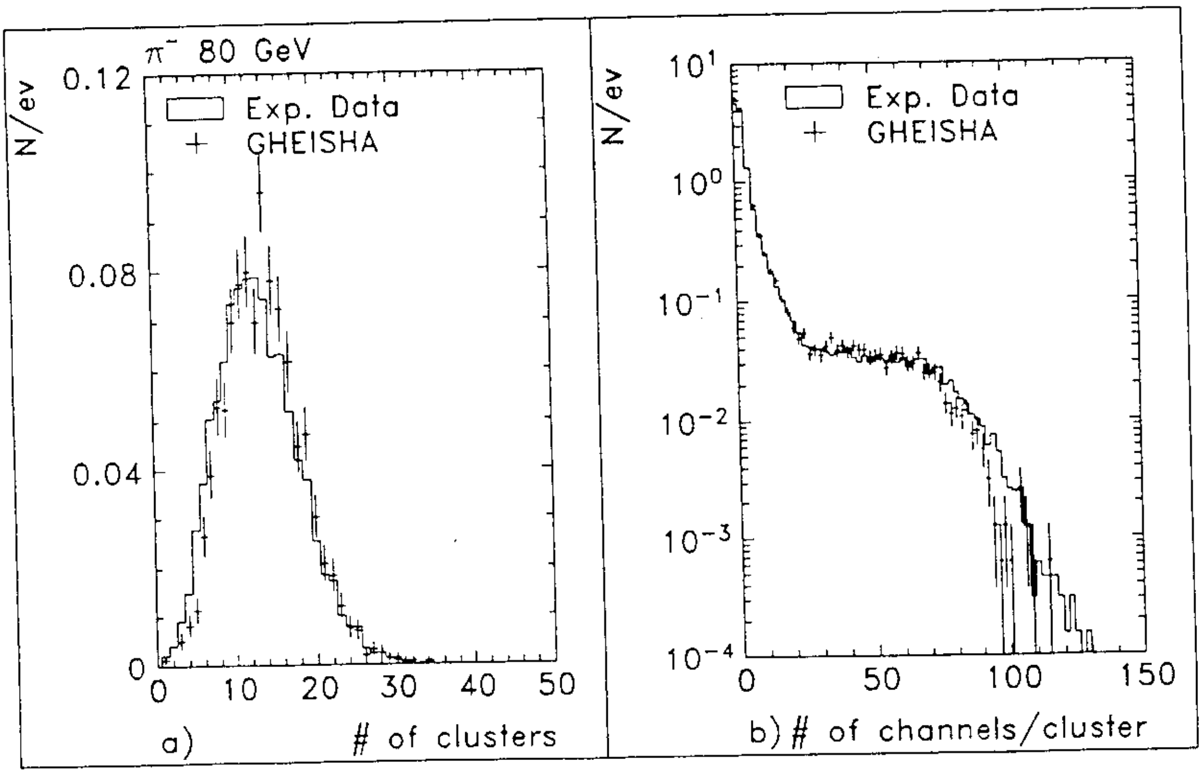

Figure 10: *Clustering for data (histo.) and GHEISHA (symbols). π^- 80 GeV. a) number of clusters, b) number of channels above 3 sigma cut.*

Both, GHEISHA and H1FLUKA describe transverse profiles well. This is shown separately for EC and HC in fig. 7 for pions of 30 GeV. [2]

The energy fluctuations of the individual layers (summing transversely) are well described by both programs over several orders of magnitude (figs. 8, 9).

As a further test of the simulation of general shower properties the standard cluster code of H1 is applied with low energy thresholds. This code merges geometrically connected cells (above 5 MeV) inside one layer into "subclusters". These subclusters in turn are merged into a "cluster" if they roughly line up geometrically with respect to the vertex (beam in present case), with the condition that the energy of one subcluster exceeds 50 MeV.

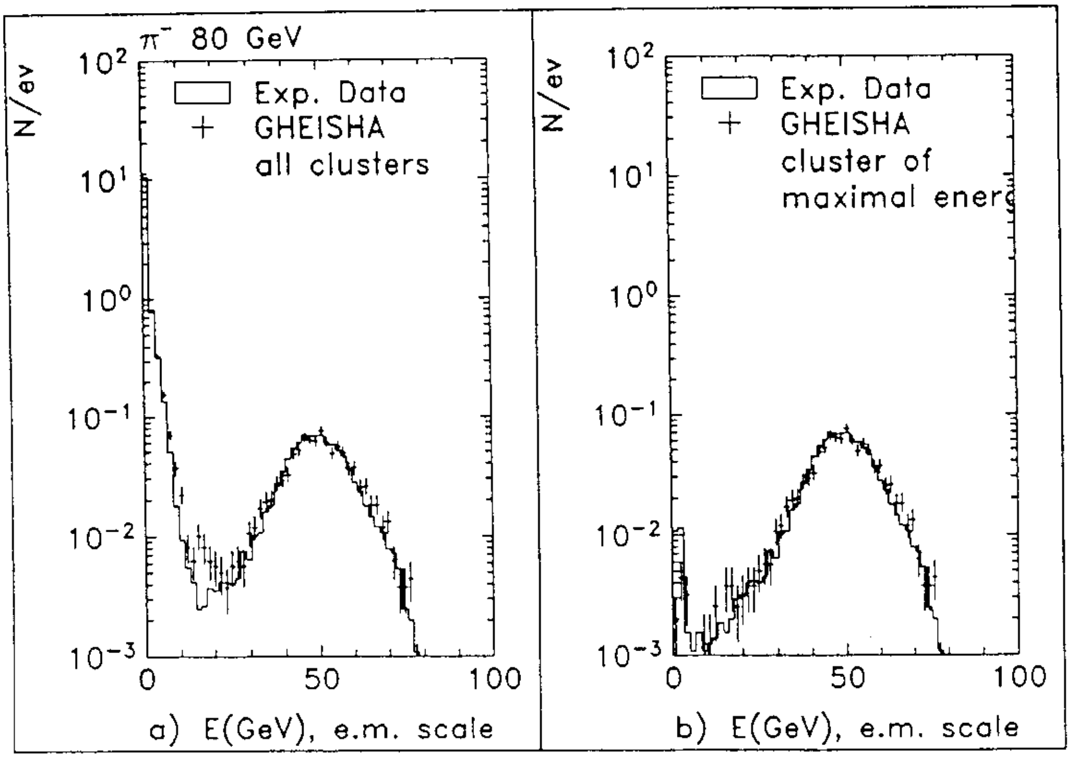

Figure 11: *Energy distribution of clusters for data (histo.) and GHEISHA (symbols). π^- 80 GeV. a) all clusters per event, b) selection of cluster with maximal energy.*

Due to the low thresholds an incident pion of 80 GeV leads to about 15 clusters (fig. 10). Most of them comprise only a small number of cells (fig. 10 b)) and have very little energy (fig. 11). The number and properties of small isolated clusters (which are mostly not due to noise) are predicted remarkably well by GHEISHA.

H1 uses energy weighting algorithms to achieve an effective compensation by off line analysis of events, exploiting the fine segmentation of the calorimeter to recognize

[2]The discrepancy in the energy sharing at the centre corresponds to a small mismatch of the position of the beam. Not all channels at the edge of EC are equipped with electronics leading to apparent steps in fig. 7 a) and c).

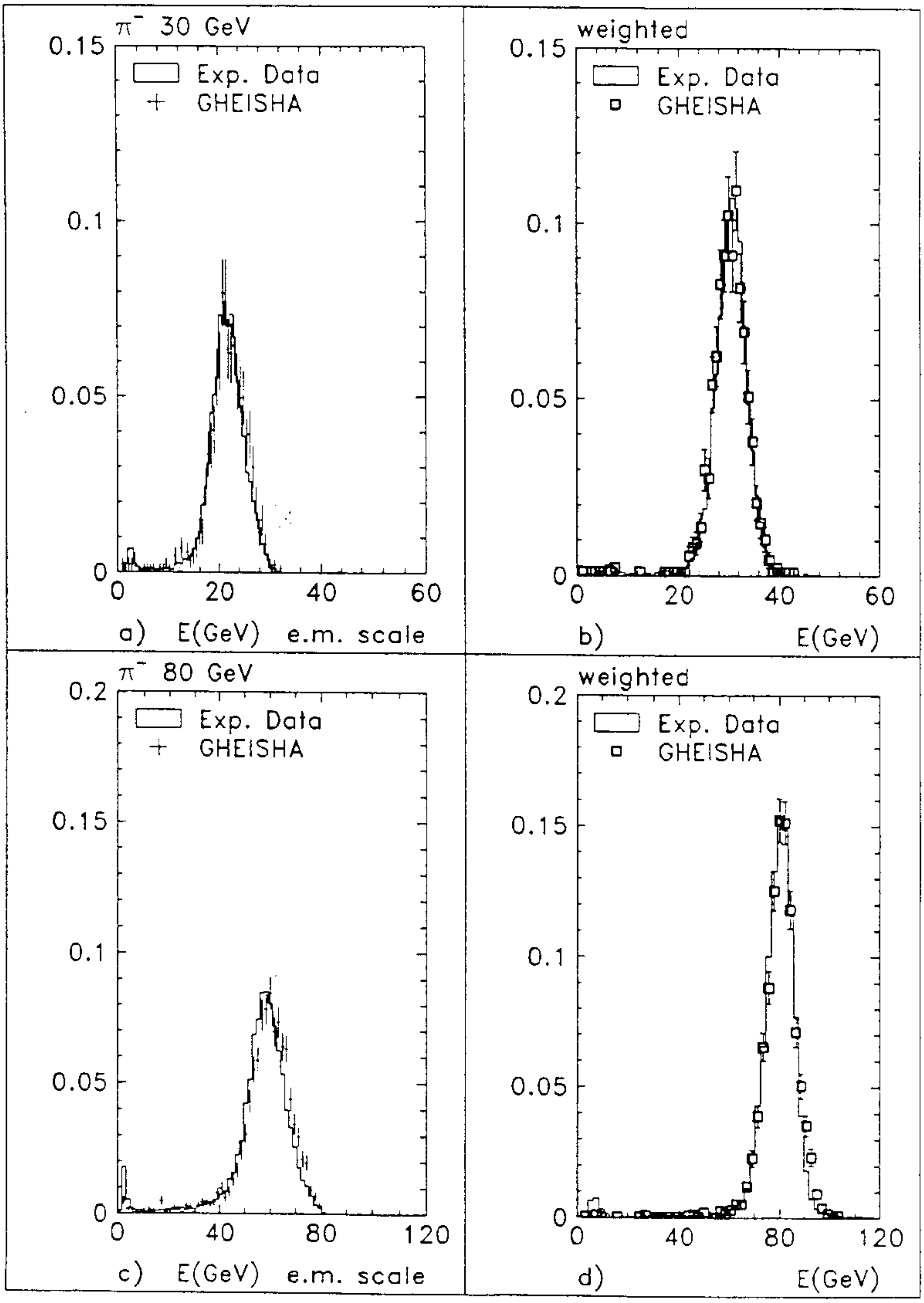

Figure 12: π^- *30 and 80 GeV on e.m. scale (a),c) and weighted (b),d)). Weighting functions are taken from GHEISHA for both, data and simulation.*

electromagnetic components (π^0) in hadronic showers. This was shown to work for test beam data [1], [2] and [3] and for simulated jets [9]. It is helpful for the analysis of HERA events if such algorithms can be derived in good approximation from Monte Carlo. As a simple test, weighting parameters are determined from pion induced showers at 30 and 80 GeV which are simulated by GHEISHA. They are then applied to the experimental and simulated events. Fig. 12 shows that the weighting parameters deduced from Monte Carlo work well also for data.

6 Conclusions

- GHEISHA and H1FLUKA show remarkable agreement with pion data at 10 to 80 GeV in various distributions as energy distribution per layer, transverse profiles, cluster properties.
- The total response observed for pions is too high for GHEISHA (1% to 3%) and preliminary H1FLUKA (6% to 8%). (Neither program was tuned yet to the H1 data.)
- The same relative calibration of Monte Carlo and data can be achieved by electrons or muons.
- Energy weighting parameters can be derived from Monte Carlo and applied to data.

Acknowledgements

The results presented are based on the work of numerous colleagues of the H1 collaboration. Discussions with H. Fesefeldt are gratefully acknowledged.

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