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MONTE CARLO SIMULATION OF THE ALEPH HADRON PROTOTYPE CALORIMETER

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ABSTRACT

In this paper the capability of GHEISHA as hadron shower generator is investigated and discussed by comparing the test run data from the ALEPH hadron calorimeter prototype with the Monte Carlo simulation developped in the GEANT3 framework. The results on muon, electron and pion simulation are reported. The longitudinal development of hadron showers is well reproduced and saturation effects are also explained. The resolution of the calorimeter for incident pions as computed by Monte Carlo method is slightly larger than what observed.

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INTRODUCTION

A large scale simulation of the performance of the detectors employed in LEP experiments is a basic tool for the analysis of physics results. In particular a careful simulation of hadron showers is required to achieve realistic measurements of the total energy of the events and for muon identification. In the present work a description of a complete shower Monte Carlo simulation for the ALEPH hadron calorimeter is presented and results are compared to the test run data obtained by exposing a prototype module to a CERN secondary beam [1].

The geometry of the prototype calorimeter has been fully described using the GEANT3 framework[2]. GEANT3 is a CERN application program designed to help the description of complex detectors and to enable tracking of several particles per event through the apparatus. The evolution of hadron showers is described by the GHEISHA program [3] which includes all the relevant hadronic processes. Electromagnetic interactions of electrons and photons are dealt with by the EGS code [4].

In the following when referring to EGS and GHEISHA we mean the code as implemented in GEANT3 system which is only a part of the original one.

DESCRIPTION OF THE APPARATUS

The prototype module consists of 22 iron slabs 5 cm thick plus a last one 10 cm thick interleaved with layers of plastic streamer tubes [1]. Figure 1a shows the layout of the streamer tube plane as implemented in GEANT3. The program describes also the readout system which consists of 4 mm wide aluminum strips parallel to the wires and square copper pads. The digital readout of the strips gives the geometrical pattern of the event projected on a plane orthogonal to the tubes. The analog readout of the sum of the signals from the pads is linearly related to the energy deposited in the towers.

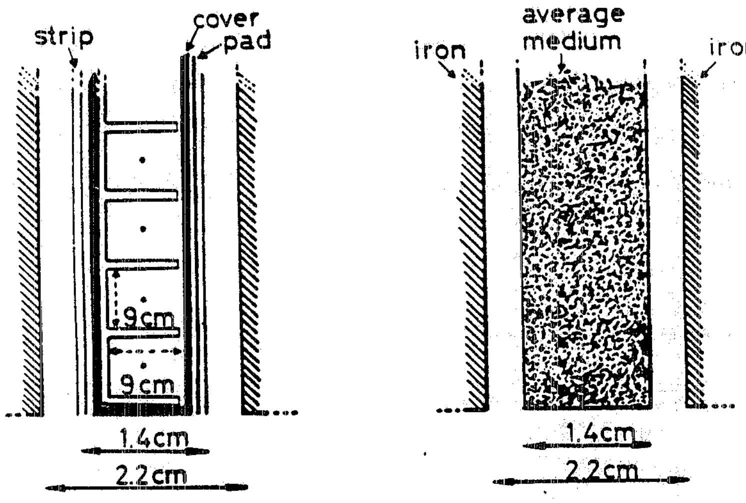

FIG. 1 - Layout of the streamer tube plane as implemented in GEANT3: a) detailed description; b) average description.

Description of the muon chamber layers is also implemented. The first layer is placed just behind the last absorber of the calorimeter, and the second one at a distance of 50 cm. Each layer of chambers includes two planes of streamer tubes staggered by 0.5 cm, read out in the two transverse coordinates by means of strips.

In order to speed up the Monte Carlo calculations a simplified description of the streamer tube plane has been also implemented, where an equivalent average medium is considered (Fig. 1b). In this last approach the geometrical inefficiencies of the apparatus due to the streamer tube walls are also correctly taken into account.

The use of the average medium description produces the same results as the detailed description for what concerns the global properties of the showers studied in this paper. The obvious advantage is a reduction of the CPU time per event by a factor of 2. The following description refers therefore to this version of the Monte Carlo simulation.

DESCRIPTION OF THE ALGORITHMS FOR ANALOG AND DIGITAL READOUT

The streamer operation mode of the hadron calorimeter is modelled by assuming that each track of the shower entering a tube releases a number of streamers depending on its projection along the wire direction. Furthermore each streamer development produces a charge in a well localized region which remains insensitive to others streamers in the same event.

In order to simulate the number of streamers produced per event the following operations are made:

i) for each track of the shower its projection (wire segment) along the wire is computed;

ii) all the wire segments obtained in a single tube are then simultaneously analyzed considering only once the overlap regions;

iii) an average number of streamers $< N_s >$ is associated to wire segments of length L according to the parametrization

$$< N_s > = 1 \quad \text{if } L < \partial$$
$$< N_s > = 1 + (L-\partial)/\partial \quad \text{if } L > \partial$$

where ∂ represents the dead region due to a particle crossing the wire perpendicularly. A fit to muon data gives for ∂ the value 0.34 cm. The result on $< N_s >$ versus the impinging angle in the calorimeter are compared to experimental muon results in Fig. 2.

The charge of each streamer is given according to the probability distribution shown in Fig. 3. This distribution, which accounts for charge fluctuations has been obtained experimentally by considering muons impinging in the calorimeter perpendicularly and producing therefore one streamer per plane.

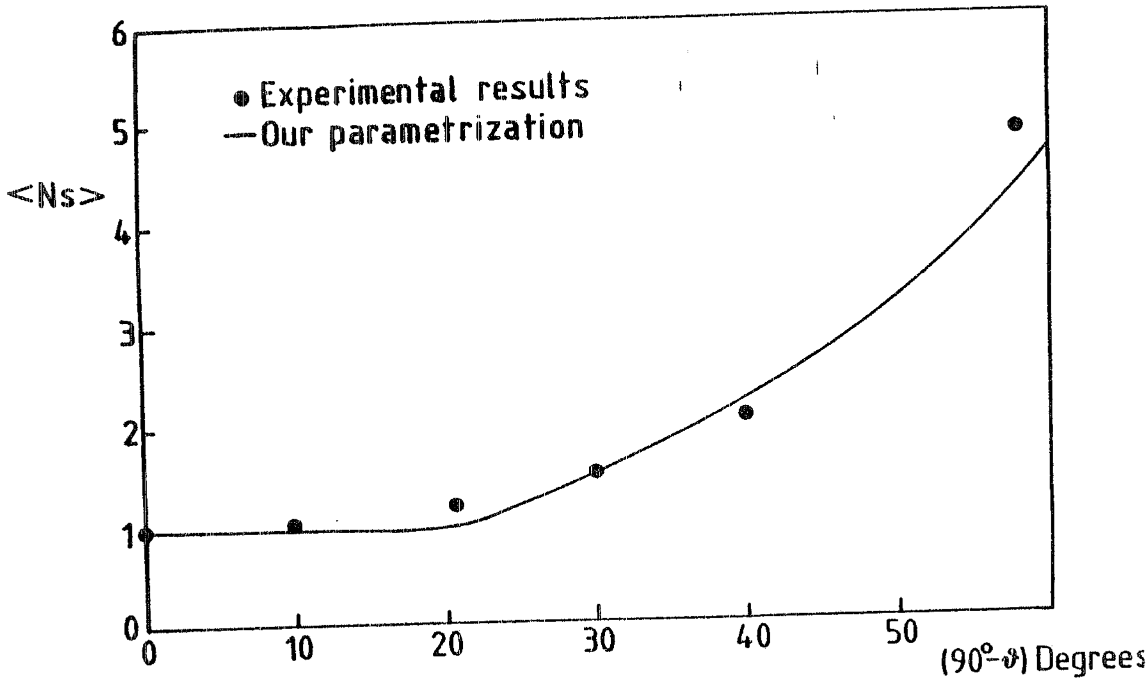

FIG. 2 - Average number of streamers vs the impinging muon angle.

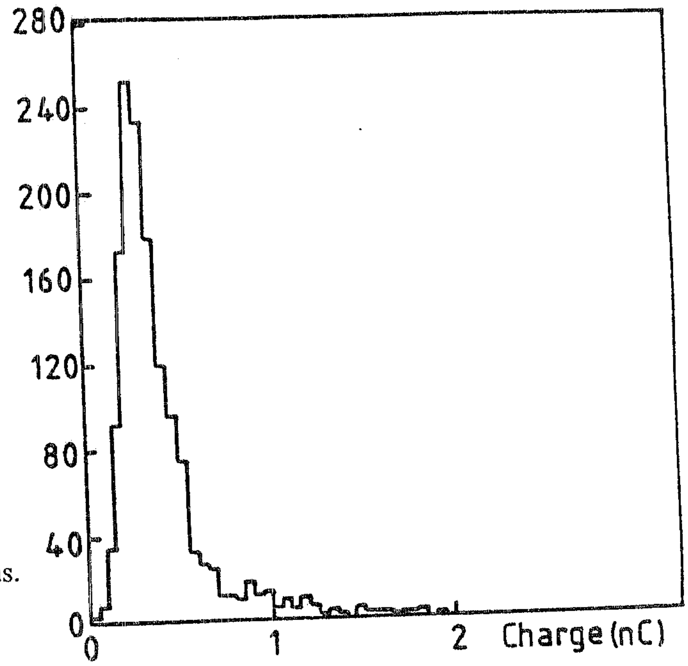

FIG. 3 - Single streamer charge fluctuations.

The charge produced in a streamer process induces signals on a cluster of strips around the fired tube. The probability of having a cluster of $N_t = N_i + 1$ strips induced by N_s streamers in a tube has been approximated with a Poisson like distribution

$$P(N_i) = e^{-a}\, a^{N_i} / N_i\,!$$

where $a=k N_s$. The parameter k represents the probability that a single streamer fire more than one strip, and may be easily evaluated by experimental results on muons. It is found k=0.5.

Results for muons entering the calorimeter at different angles are given in Table I.

TABLE I - Average number of strips fired (N_t), charge (nC) and resolution (σ_E/E) for muons hitting the calorimeter at different angles according to GHEISHA calculation and test run data in paranthesis. Data at 90° are used as input for calibration

Θ	90°	60°	50°
$\langle N_t \rangle$	36 (36)	39 (41)	45 (46)
Charge (nC)	.32 (.32)	.46 (.47)	.65 (.66)
σ_E/E (%)	23.0 (23.0)	17.5 (17.0)	13.5 (13.0)

For electrons, the Monte Carlo response depends heavily on the cut-off momenta below which particles are no longer propagated. The best results are obtained by stopping photons below 1 MeV and electrons and positrons below 1.5 MeV. The average charge deposited by electrons versus their energy is shown in Fig. 4. Experimental values are also given for comparison.

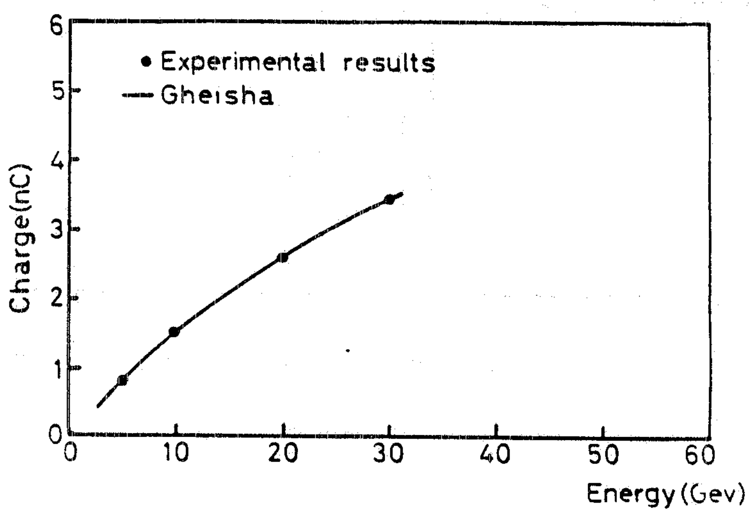

FIG. 4 - Average analog response for electrons vs energy.

The agreement shown for muons and electrons confirms the reliability of the choosen algorithms. Even the saturation effect which is typical of the streamer operation mode is well reproduced. Digital patterns for muons and electrons obtained with this simulation are shown in Fig. 5a and Fig. 5b respectively.

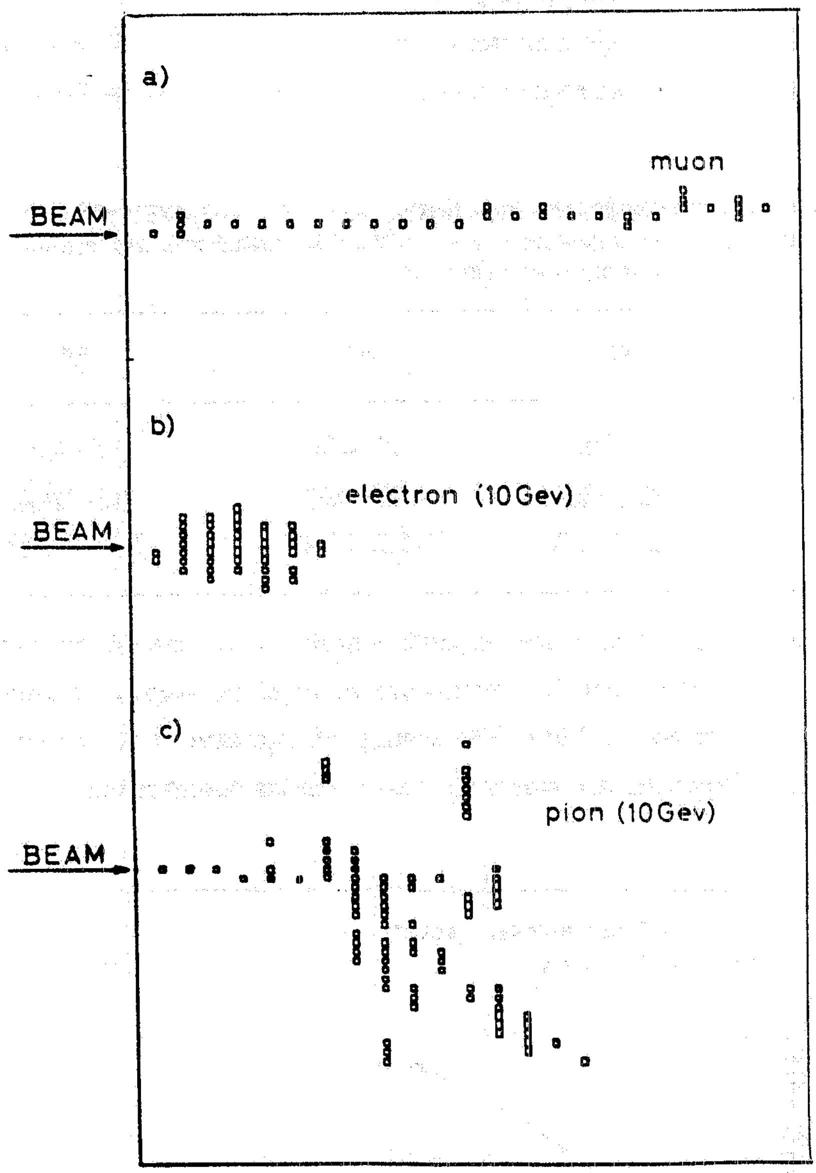

FIG. 5 - Monte Carlo digital pattern for muons(a),electrons(b) and pions (c).

COMPARISON BETWEEN DATA AND SIMULATION

A special run has been taken with the prototype at a beam energy of 10 Gev by summing the collected charge plane by plane in order to measure the longitudinal shower profile. The data for 90^0 pions are shown in Fig.6 together with the result of the simulation.

A typical digital pattern for a 10 GeV pion is reported in Fig. 5c.

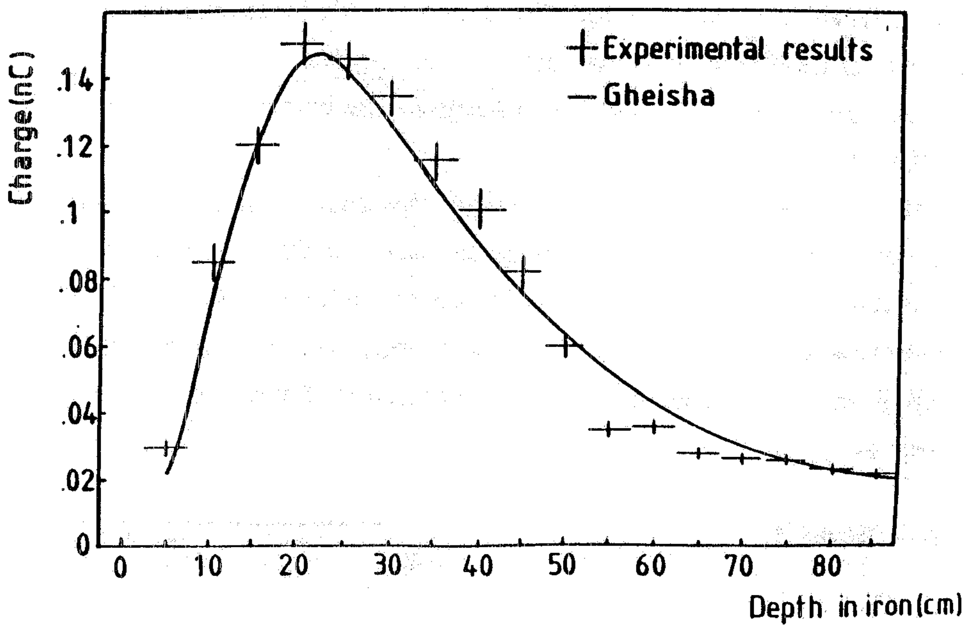

FIG. 6 - Analog longitudinal shower profile for 10 GeV pions.

In order to study the tail of the longitudinal profile, the rate of punch–through particles has been investigated at different beam energies as a function of the iron depth. Such a rate is defined, at a given depth, by the fraction of particles firing at least one tube in the corresponding plane. This rate is shown versus iron depth in Fig. 7 at various energies.

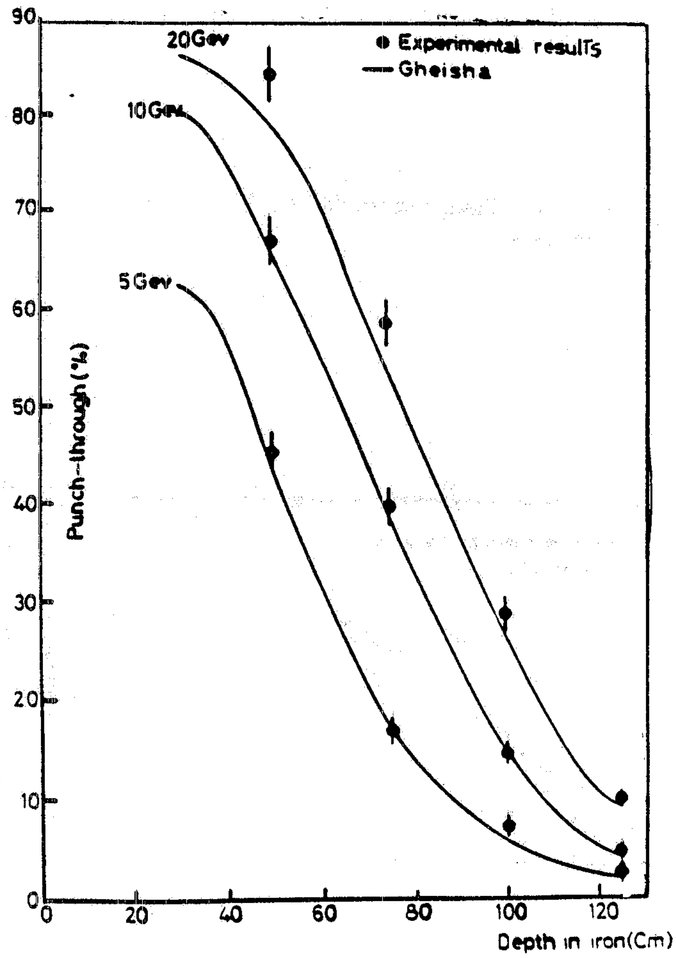

FIG. 7- Percentage of punch-through particles vs iron depth at various energies.

All previous results allow to conclude that the Monte Carlo simulation reproduces quite well the longitudinal shower development in the prototype calorimeter.

The energy response and the resolution have also been investigated for pions in the energy range from 5 to 50 Gev.

Fig. 8 shows the Monte Carlo distribution of the total charge for 20 GeV pions. Calibration curve and energy resolution for incident pions are shown in Fig. 9a and 9b respectively. The linear trend of the total charge versus the energy is well reproduced even if all Monte Carlo points lay below the experimental points and the saturation effect at energies greater than 40 Gev is slightly overestimated. Discrepancies are also visible in the energy dependence of the resolution which can be parametrized as

$$\sigma_E/E = 84\ \%/\sqrt{E}$$

in the Monte Carlo calculation,while the corresponding experimental result is

$$\sigma_E/E = 78\ \%/\sqrt{E}$$

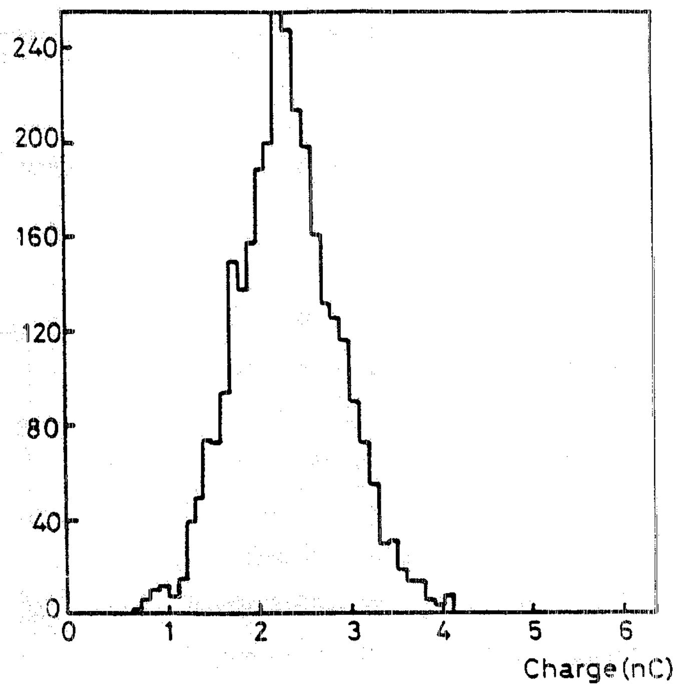

FIG. 8 - Total charge distribution for 20 GeV pions.

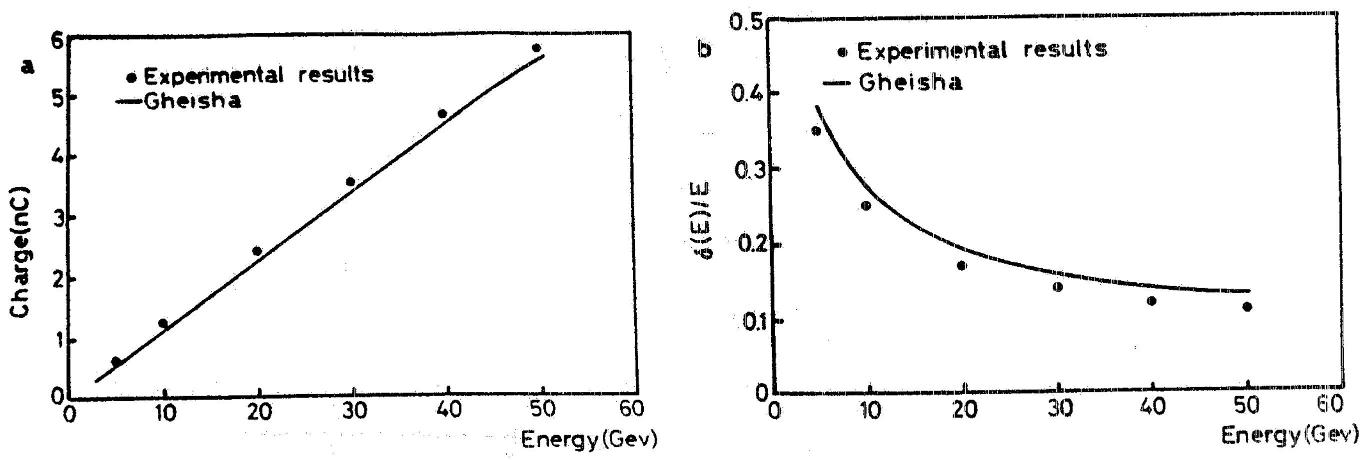

FIG. 9 - Calibration curve (Fig.10a) and energy resolution (Fig.10b) for pions from 5 to 50 GeV.

Other authors have reported results on hadron shower simulation by the GHEISHA code. In particular the behaviour of the CDHS iron calorimeter has been simulated in reference [5]. It was found that the calculated resolution was 20% larger than the experimental one.

The L3 collaboration, on the other hand , finds the GHEISHA Monte Carlo resolution in good agreement with the observed one [6]. The L3 hadron calorimeter prototype was similar to the ALEPH test apparatus as far as the streamer chambers are concerned, but used very thin copper layers (12 mm) as absorber. The influence of the thickness on the resolution has been studied by the L3 Collaboration by sampling every n-th layers. The data show that the square of the energy resolution varies linearly with the sampling thickness; when interpolating these results at an equivalent iron thickness of 5 cm the resolution agrees with the GHEISHA calculation made for ALEPH. This allows to conclude that the present Monte Carlo results are not in contradiction with what previously published.

Finally, the Monte Carlo calculation gives an e/π charge ratio at 5 Gev of 1.48 ± 0.05 to be compared with the experimental one of 1.33 ± 0.04 .

In the simulation muons are used to calibrate the energy response to hadron. For pions,the GHEISHA algorithms produce a number of track segments smaller than in the actual events.This characteristic is probably responsible of the slightly larger energy resolution and, at the same time, of the larger e/π ratio.

As mentioned in the introduction, the GHEISHA code implemented into the GEANT3 system is only a part of the original GHEISHA code. The question may arise whether the slight discrepancy observed between Monte Carlo calculated and experimental resolution may be due to this incompleteness. However calculations performed by the author [7] in the framework of the original GHEISHA code, are very similar to those obtained in the GEANT3 system (see Table II).

TABLE. II - Resolution and e/π charge ratio at differen beam energies obtained using the original GHEISHA code.

E (GeV)	$\sigma_E/\sqrt{E}$ (Gev $^{-1/2}$)	e/π
5	$.76 \pm .02$	1.62 ± 0.05
10	$.87 \pm .02$	1.30 ± 0.03
20	$.84 \pm .02$	1.06 ± 0.02

The digital response of the hadron calorimeter has also been investigated. The program computes the number of strips fired (hits in the following) as function of the energy of the incoming particle. This quantity is expected to show a large saturation effect as the energy increases, since the probability of having more tracks crossing the same tube increases with the shower density, i.e. the shower energy.

The average number of hits versus the pion energy is compared with the experimental results in Fig.10. This simple model is sufficient to describe correctly the effects of the streamer operation mode on the digital read-out.

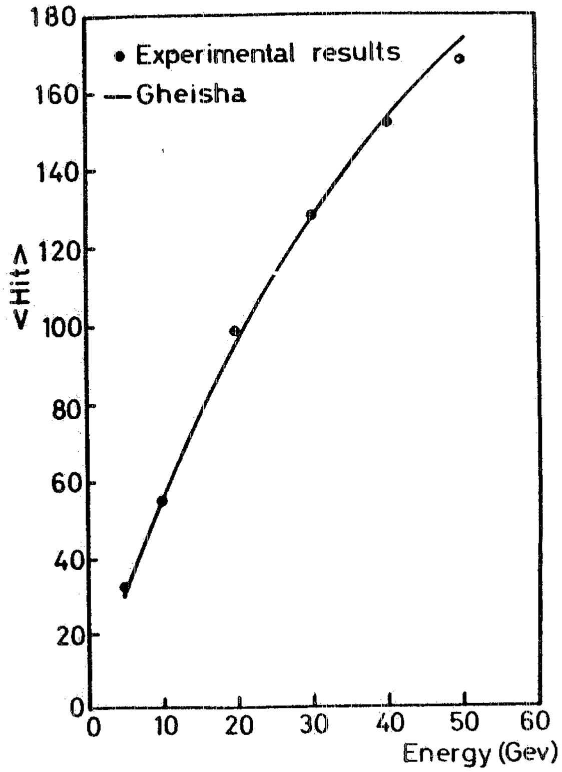

FIG. 10- Average number of hits vs pion energy

As already mentioned ,the strip digital read-out produces a geometrical pattern of the event which allows an immediate visual distinction among electron showers,hadron showers and minimum ionizing particles.

This tracking capability of the hadron calorimeter has already been exploited to discriminate between pions and muons [8]. A set of discriminant variables has been constructed on the basis of the digital pattern,such as first interaction plane,last fired plane,maximum shower width,event centroid along the beam,hit number on planes 1 to 7, 8 to 14 and 15 to 23. The interaction plane is the first of two subsequent planes on which the width of the shower is greater than two fired strips.

The maximum shower width is the maximum distance between the first and the last strip fired in each plane.In this approach an hadron shower is completely described by the values of those variables,which can be computed in the Monte Carlo generated events and compared with the experimental ones,giving information on the degree of similarity of the two samples.

The results, given in Table III and Table IV for muons and pions,show the good capability of the Monte Carlo program in reproducing the qualitative feature of the digital pattern of the events.

TABLE III- Average values of the discriminant variables for 10 Gev muons.

	EXP. DATA	GHEISHA
Interaction plane	21.9 ± 5.3	22.9 ± 3.8
Last plane	$22.6\,^{+0.4}_{-0.8}$	$22.8\,^{+0.2}_{-0.4}$
Max. Shower width	4.2 ± 2.6	4.9 ± 0.3
Centroid	11.4 ± 1.1	11.9 ± 0.7
Hits 1-7	9.9 ± 2.8	10.4 ± 1.8
Hits 8-14	10.2 ± 3.0	10.8 ± 1.9
Hits 15-23	12.1 ± 3.0	13.5 ± 2.2

TABLE IV - Average values of the discriminant variables for 10 Gev pions.

	EXP. DATA	GHEISHA
Interaction plane	4.9 ± 4.4	4.9 ± 4.8
Last plane	13.2 ± 6.6	12.7 ± 4.5
Max. Shower width	25.7 ± 7.4	21.7 ± 7.8
Centroid	6.7 ± 3.0	7.1 ± 2.7
Hits 1-7	35.0 ± 16.6	33.5 ± 9.0
Hits 8-14	18.4 ± 14.8	18.7 ± 10.0
Hits 15-23	5.3 ± 11.0	4.7 ± 5.8

ACKNOWLEDGEMENTS

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