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Study of the Performance of a Hadron Calorimeter

Y. Elmahroug[*1], B. Tellili1[1], C. Souga[2]
[1]*Unité de Recherche de Physique Nucléaire et des Hautes Energies, Faculté des Sciences de Tunis,2092 Tunis, Tunisie.*
[1]youssef_phy@hotmail.fr
[2]*Université de Carthage, École Polytechnique de Tunisie, B.P. 743 - 2078 La Marsa, Tunisie.*

ABSTRACT

In this study, the linearity and the energy resolution of a hadron calorimeter based on Glass Resistive Plate Chambers (GRPCs) as an active element and lead as an absorber are examined for two operation modes, analog and digital, by using Geant4 simulation toolkit. This investigation is in order to develop a hadron calorimeter for the future linear collider ILC.

Keywords— Calorimetry, resistive plate chambers, international linear collider (ILC), GEANT4.

I. INTRODUCTION

To complement and possibly beyond the limits imposed by the Standard Model, CERN has built the new proton-proton accelerator LHC. For the same purposes, physicists are already working on next generation accelerators. Thus the project named ILC or International Linear Collider was born. Many interesting physics processes will be provided by the electron-positron collisions at the center-of-mass energies between 500 GeV and 1 TeV in ILC such as W, Z and H heavy bosons processes. These processes will be characterized by multi-jet. A very good energy resolution (30%/√E) is required to the reconstruction of heavy bosons in hadronic final states [1], [2]. Accordingly, the study of a calorimeter performance is an essential step. In this context, several kinds of hadron calorimeters are under construction and testing [3]-[4]. Among the best hadron calorimeters, there are those which use Glass Resistive Plate Chambers (GRPCs) as active elements.

In this paper, a study based on Geant4 is conducted to investigate the performance of a hadron calorimeter using lead as an absorber material and GRPCs as active elements for the future linear collider ILC. This paper aims to the study and simulate the parameters which characterize the functioning of a hadron calorimeter as the energy resolution, the linearity and the reconstructed energy. Also, to make a comparative study between digital and analog methods.

II. MATERIALS AND METHODS

To simulate the operation of a hadron calorimeter, a Monte Carlo simulation program was developed based on the GEANT4 version 9.2.4 [5]. The information collected from this program are handled by another programs based on software Root. The calorimeter used in this study is composed of alternating passive layers and active layers. The dimensions of calorimeters are 100x100x 104.16 cm3 and they are such way that 95% of hadronic shower cascades energy is deposited in the calorimeter [6], [7]. The whole of calorimeter consists of forty layers (absorber + sensitive material). Each active layer is segmented into 1cmx1cm readout cells (pads) and a total of 400000 channels in 40 layers. The absorber is a layer of lead and the sensitive material is GRPCs. To study the performance of calorimeter, we generated negative pions with incident energies varying between 5 and 100 GeV, in the orthogonal direction to the face of the calorimeter were chosen. 10000 events were generated for each level of energy of 5 GeV. The high number of events was necessary to reduce the statistical errors. The objective of this simulation is to reconstruct the energy of the incident pion based solely on the information collected at the active part of calorimeter.

III. RESULTS

The first step for analysing the data simulated by Geant4, is to measure the total deposited energy by a primary pion in the active medium for the analog mode and for the digital mode, instead of using the deposited energy, we counted the total number of hits in the active medium. Indeed, the analog mode is based on the following principle, each cell activated by the passage of a secondary particle sends analog signals to the acquisition chain proportional to the energy deposited in the cell. As against, in the digital mode, a secondary particle passing through the active part is detected by a triggering signal. If the energy measured by an GRPCs is above the threshold, the cell is enabled and a binary signal is sent to the read chain. In this case, an event is characterized by a number of affected cells (hits). A threshold was set at 0.1MIP for both modes, to eliminate electronic noise.The second step for data simulation is plotting and fitting the distributions of the measured energy and number of hits. From the fit parameters, we determined the linearity and the resolution. The distribution of the deposited energy and the distribution of the hits number for primary pion with an energy of 100 GeV are shown respectively in Fig. 1 Fig. 2. We found that the deposited energy by primary pions follows a Landau distribution with right-hand tail due to the Landau fluctuation, but in the digital mode this fluctuation disappears, and the distribution follows a Gaussian distribution.

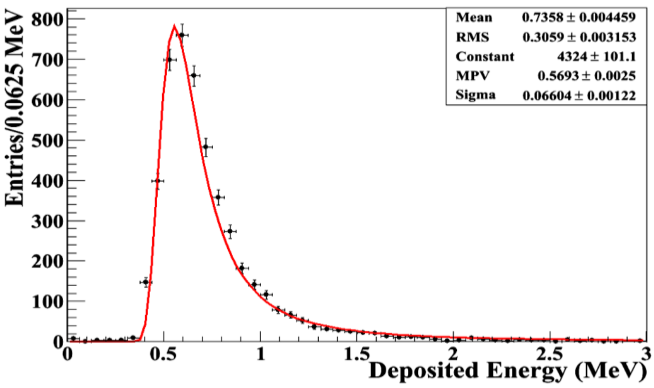

Fig. 1 Distributions of deposited energy for 50GeV pions.

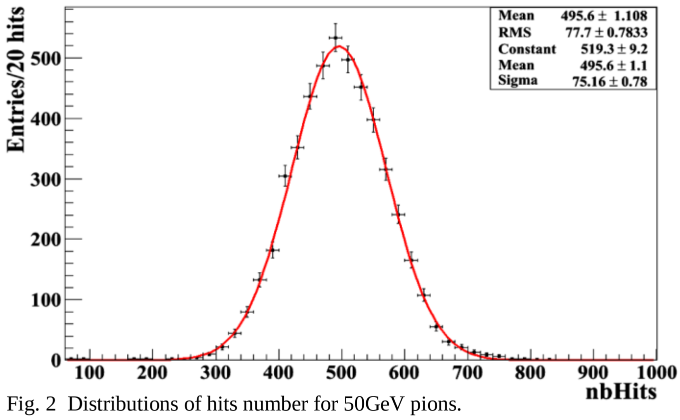

Fig. 2 Distributions of hits number for 50GeV pions.

The determining of the proportionality factor between signal and the primary pions energy is divided into two main stages. In the first step, we took the average value of deposited energy and the hits number from the Gaussian and Landau distributions. The second step consists in plotting these values and then a linear interpolation is performed by a polynomial function of first degree.

The linearity between the calorimeter response and the primary pions energy for digital and analog modes are shown respectively in Fig. 3 and Fig. 4. We see that the deposited energy and the hits number are proportional to the incident energy.

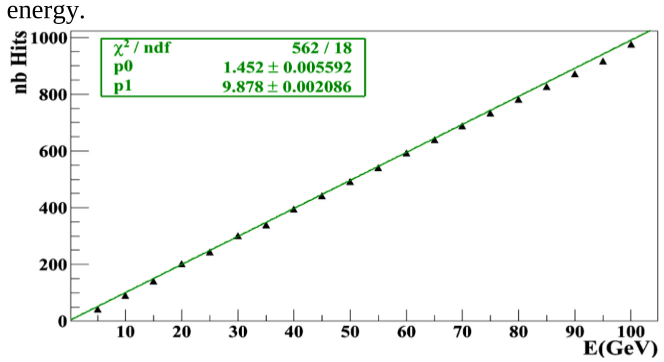

Fig. 3 Linearity between the hits number and the incident energy for digital readout.

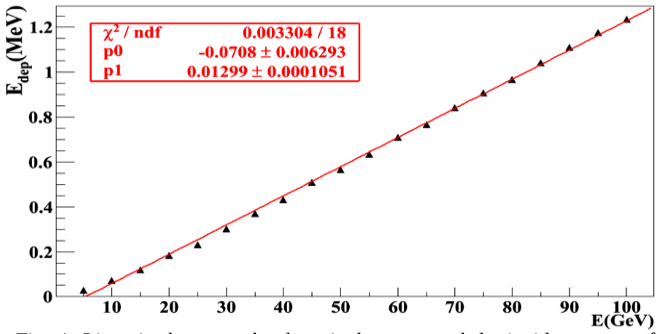

Fig. 4 Linearity between the deposited energy and the incident energy for analog readout.

The resolution is defined as the ratio between the width at half height and the mean value. We determined it, then we plotted as a function of the primary pion energy. The same method used to estimate linearity was used to determine the energy resolution. The fit parameters of the deposited energy distribution or hits number were used. The obtained values are plotted as a function of primary pions energy. The fitting was done by the following resolution function:

$$\frac{\sigma}{E} = \frac{S}{\sqrt{E}} + \frac{N}{E} + C \qquad (1)$$

With S the term of stochastic, C is a constant and N the electronic noise term is not taken into account because there is no electronic noise in Monte Carlo simulations. The energy resolution for digital and analog modes is presented in Fig. 5.

At low energies, the energy resolution in the digital mode is better than in the analog mode, this can be explained by the fact that in an analog calorimeter, the deposited energy by a pion in GRPCs presents a large tail due to Landau fluctuations.These fluctuations increase the energy resolution for the analog readout compared to the digital case, because these effects are suppressed in the digital mode. However, for high energies, we observe the degradation of the resolution in digital mode which is caused by saturation effects of hits number. Indeed, at high incident energy, the shower particle density will be very high, and this increases the probability that a cell will be crossed by several secondary particles, but these particles will be counted as one hit.

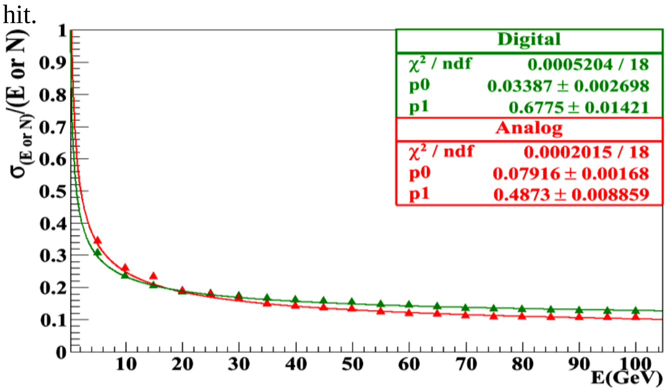

Fig. 5 Comparison between the energy resolution of the digital readout and that of the analog (p0=C and P1=S).

IV. Conclusions

The simulation study of the hadron calorimeter characteristics which uses lead as an absorber and resistive plate chambers as an active medium, shows that at low energies, the energy resolution is better for the digital mode than for the analog mode, and the opposite for high energies. However, the calorimeter linearity response is better for the analog mode than for the digital mode. The analog resolution is dominated only by Landau fluctuations, but in the digital mode the resolution and linearity are degraded by the saturation effect which can be suppressed by applying two or three thresholds.

V. References

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