

Charged pion reconstruction in a High Granularity Calorimeter environment

P. Tereziu^{1,2}

Supervisors : M. Mannelli², P. Silva²

¹University of Tirana, Faculty of Natural Sciences, Tirana, Albania

²CERN - CMG

Abstract

The goal of the project is to contribute to the study of the performance of the High Granularity Calorimeter (HGCAL) designed to operate in Phase II of the CMS detector at the High Luminosity LHC (HL-LHC). The main properties of the interactions of charged pions with the calorimeter are studied.

Introduction

In the High Luminosity LHC (HL-LHC) , projected for 2023, it is expected that the center-of-mass energy will increase to 14 TeV and that a total integrated luminosity of 3000 fb⁻¹ is achieved. There are however some challenges which detectors need to overcome in order to profit from the physics opportunities at the HL-LHC. An average pileup of 140 is expected with a bunch separation of 25ns. In practice this means that both the energy flow and the occupancy of the detectors will increase drastically in this harsh environment. Therefore Endcap detectors must be upgraded otherwise they won't be able to sustain the radiation damage and we won't be able to distinguish a hard collision from the superposition of pileup events. Recently it has been proposed to replace the endcap calorimeter of CMS with a High-Granularity Calorimeter. Reconstruction algorithms need to be adapted and in that context i have studied how charged pions are expected to interact with the calorimeter.

Strategy followed in the project

We have studied the structure of energy deposited in the calorimeter and it helped us to find how many hits we have reconstructed how energetic they are how collimated showers are. I used the official software of CMS with version 6_2_0_SLHC15 and then I generated 1000 event with particle code 211 (π^-) and code -11 (e^+), with fixed energies (10, 20, 50 and 100 GeV) and fixed pseudorapidity ($\eta=2$). I have used these simulations to compare the differences between pions and positrons.

Characterization of the shower properties in HGCAL

A study of the properties of the signal generated by charged pions is performed using simulated events. Different variables are explored and compared to the ones obtained for positrons.

Place of interaction

Charged pions are charged hadrons which are expected to interact mostly in the hadronic calorimeter. In the electromagnetic calorimeter they are expected to leave low energy ionization deposits. However, due to the material overburden in front of HGCAL we observe that roughly 40% of the charged pions have very early interactions. This has been traced using secondary particles produced in Geant4 (Figure 1). The average particle multiplicity as well as the nature of the particle is energy dependent (Figure 2). Most secondary particles are expected to be hadrons or neutrons.

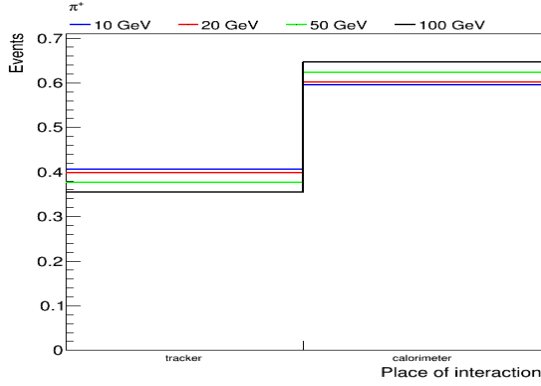


Figure 1 - Location of the interaction of charged pions in the CMS detector. Tracker denotes the Si tracker or the neutron absorber. Calorimeter, the HGCal. The different colours represent the pion energy.

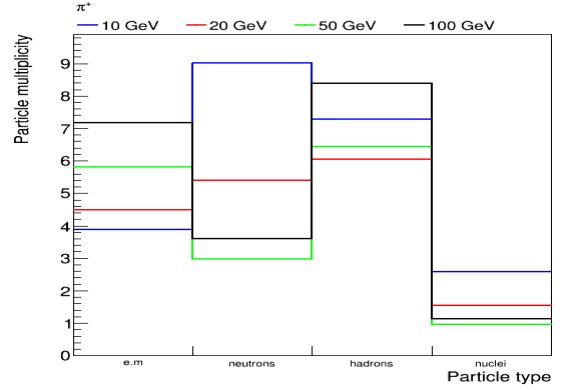


Figure 2 - Average secondary particle multiplicity for charged pion interactions happening in HGCal. The different colours represent the pion energy.

Hit dispersion

Figure 3 shows different views of a typical charged pion shower in HGCal. Charged pion showers are expected to be wider with respect to positrons and to have a larger dispersion in the transverse plane.

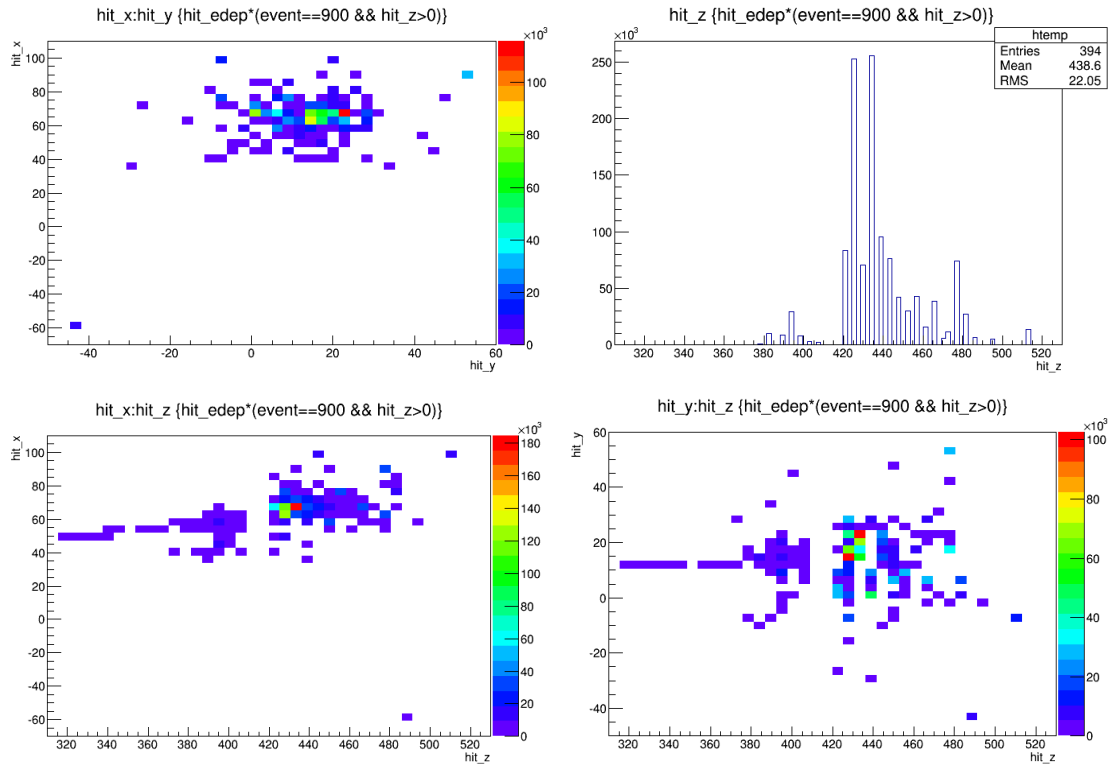


Figure 3 - Different views of a charged pion shower initiated in HGCal. Top left, bottom left and bottom right correspond to the xy, xz and yz views. The colour code represents the energy recorded in GeV. The top right plot shows the total energy recorded (in GeV) as function of the longitudinal depth in the calorimeter. Coordinates are measured in mm.

Longitudinal energy profile

Figures 4 and 5 show the longitudinal energy profile, i.e. the average energy deposited as function of the layer in HGCal, by positrons and charged pions correspondingly. The energy has been normalized to that of a minimum ionizing particle (MIP). As can be seen, most positrons deposit all their energy up to layer 30 which corresponds to the end of the electromagnetic calorimeter (ECAL) while charged pions have a significant amount of energy deposited in the last layers of ECAL and in the hadronic calorimeter layers (HCAL). We notice that due to the non negligible amount of early interactions there average energy deposited in ECAL by charged pions is large and corresponds, in average, to $\frac{1}{4}$ of that deposited by a positron.

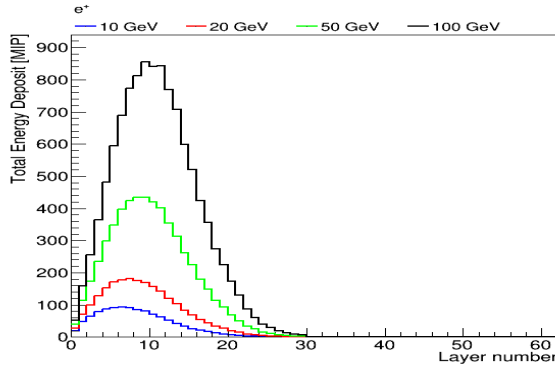


Figure 4 - Longitudinal energy profile for positrons.

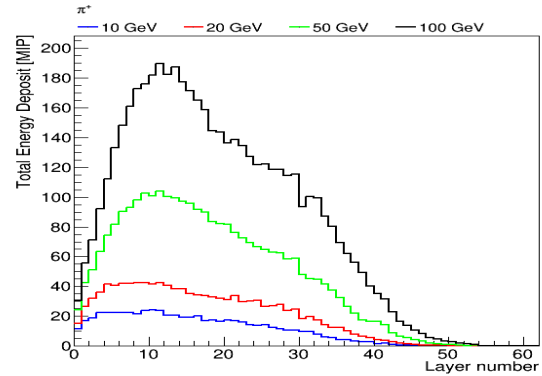


Figure 5 - Longitudinal energy profile for charged pions.

Hit multiplicity

We observe that the hit multiplicity scales with incoming energy for both positrons (Fig. 6) and pions (Fig. 7). We notice however the presence of a two component spectrum for charged pions. The non-gaussian component is due to ionization deposits in ECAL and it's almost independent of the energy.

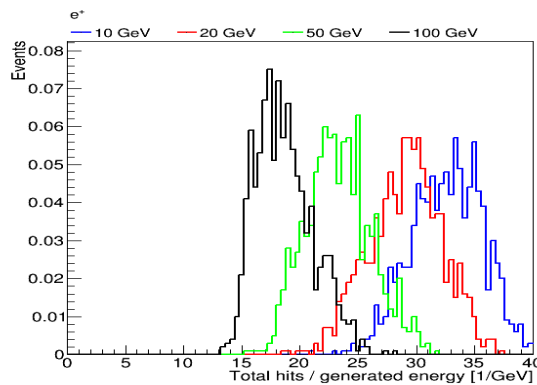


Figure 6 - Normalized hit multiplicity for positrons.

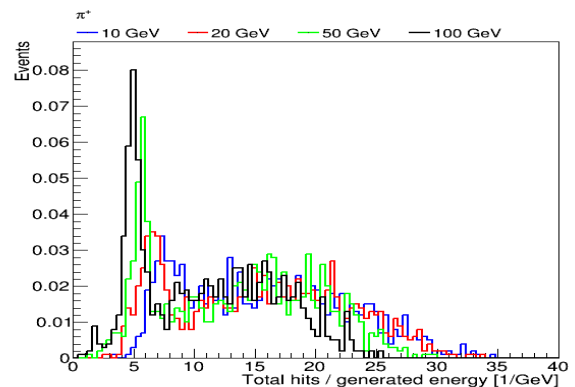


Figure 7 - Normalized hit multiplicity for charged pions.

Conclusions

After having studied generic properties of charged pions in HGCal, such as energy depositions and number of hits and having compared their behavior to that of single positrons, we conclude that :

- $\sim 40\%$ of pions interact before reaching calorimeter, mostly due to the current model of neutron shielding in the simulation;
- the multiplicity and nature of secondary particles is energy dependent;

- charged pions are expected to produce less hits, less energetic, with respect to positrons;

Further studies will require a calibration of the response of ECAL and HCAL for a proper energy estimation. The variables explored can be used in the future to develop a particle identification for HGCal.

References

- CMS collaboration, Projected performance of an upgraded CMS detector at the LHC and HL-LHC, CMS-NOTE-13-002
- CALICE collaboration, Tracking within Hadronic Showers in the SDHCAL prototype using Hough Transform Technique, CAN-047
- CALICE collaboration, "Interactions of Pions in the CALICE Silicon-Tungsten Calorimeter Prototype", CAN-050