PandoraPFA Tests using Overlaid Charged Pion Test Beam Data

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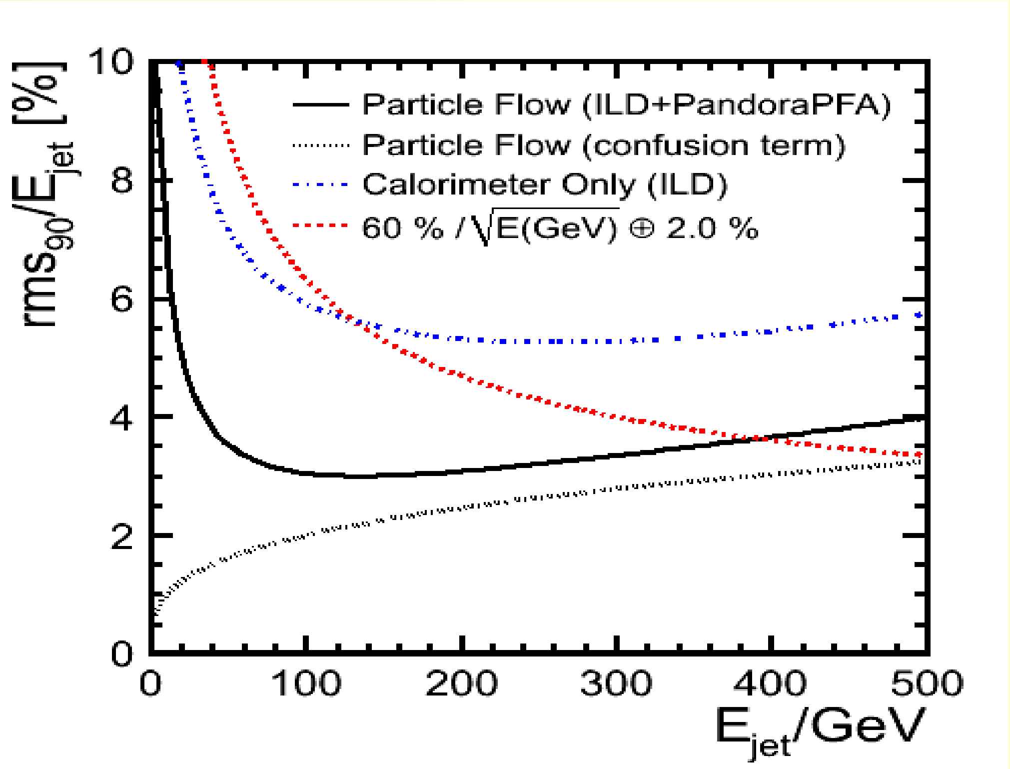
Introduction

- The Particle Flow Analysis (PFA) is a reconstruction algorithm which implies only the neutral particle energy have to be obtained from a calorimeter while the charged particle energy is reconstructed in a tracker, where the resolution is much better than in the calorimeter
- The PFA was implemented in the PandoraPFA program (M. Thomson) as a part of the software for the future International Linear Collider (ILC)
- PandoraPFA was tested using Monte Carlo simulated jets and was widely used for the detector optimization for the ILC
- The capability of the reconstruction program to recover the neutral hadron energy in the vicinity of a charged hadron is of crucial importance because the recovery mistake would degrade the energy resolution



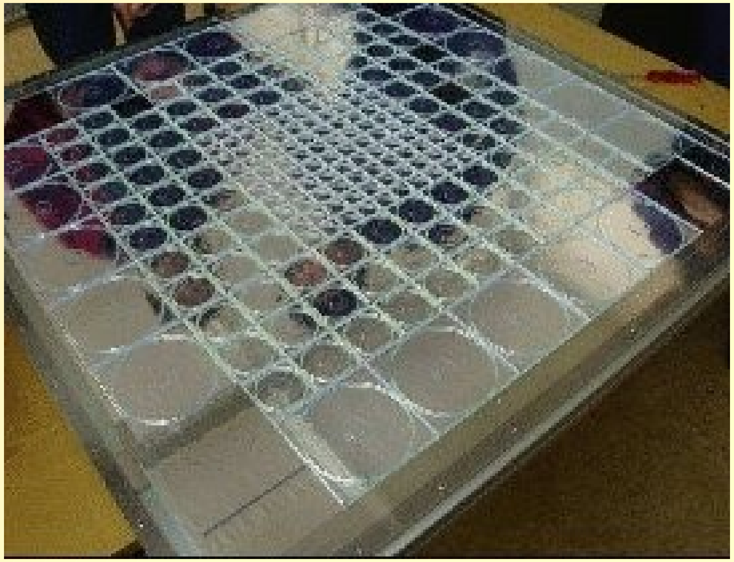
The CALICE (CAlorimeter for LInear Collider Experiment) Collaboration is R&D group of more than 300 physicists and engineers developing high performance detectors for the ILC

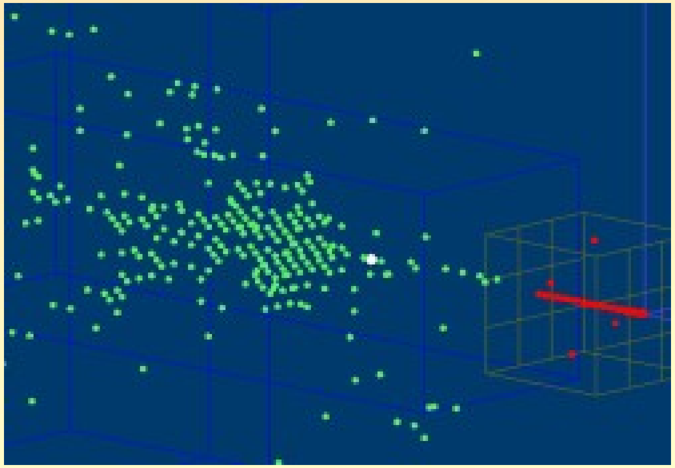
- The collaboration has developed prototypes of the three main calorimetric subsystems of a future calorimeter with the total effective thickness about 10 nuclear interaction lengths:

Si-W electromagnetic calorimeter (ECAL)

Hadronic calorimeter (HCAL) with SiPM readout

Tail catcher and muon tracker (TSMT)





- The granularity of the HCAL in the zone close to the beam line coincides with which was chosen for a full-size detector

- The calorimeter prototype has been studied at CERN and FNAL test beams for 3 years

The CALICE test beam data were used to test the PandoraPFA program

Motivation

- The confusion occurs as a result of shower overlapping, in case when the reconstructing program mixes up hits from showers created either by charged and neutral hadrons or by a neutral hadron and a photon

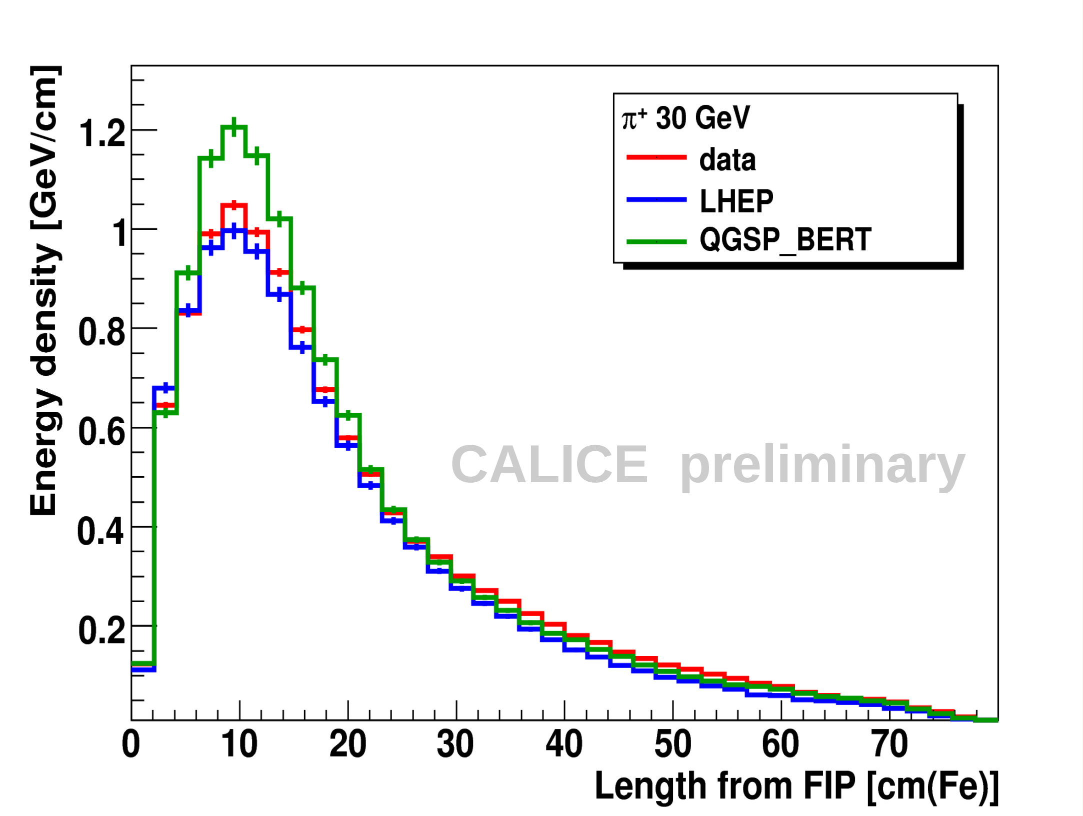
- In case of the confusion between a neutral hadron and a photon, one can use energy profiles of electromagnetic showers, which are well predicted by Monte Carlo

- In case of the two hadron showers overlap, the energy profiles are almost useless and only topological and energy criteria can help to disentangle showers

- The impact of the overlapping of showers on energy resolution is known for MC simulated jets

- Different MC physics lists give noticeably different predictions for hadron shower shapes

- The real detector can have not as good performance as its idealized MC model



Pion events from several runs (from 10 GeV to 50 GeV) have been selected

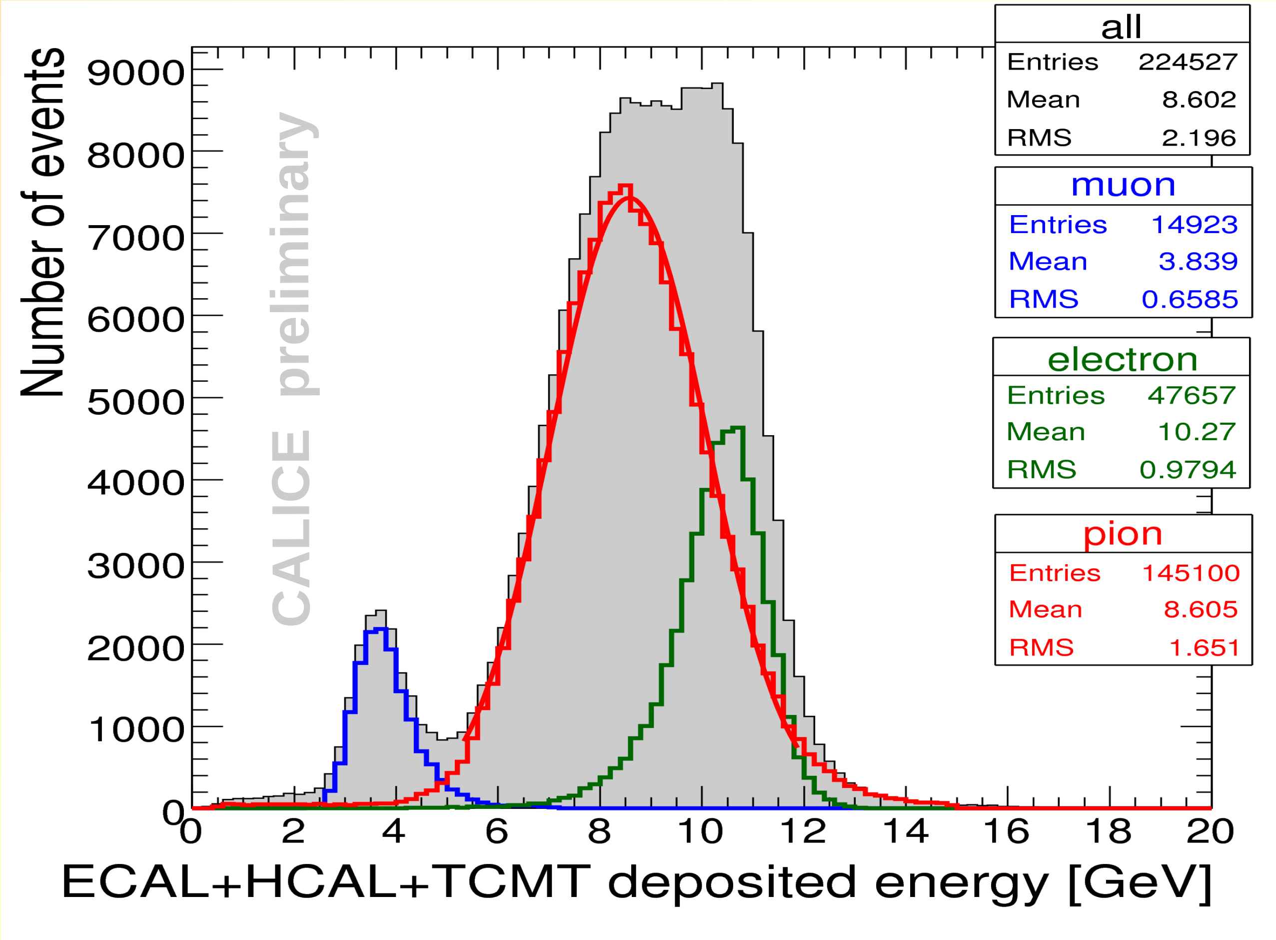
- The Cherenkov trigger information was used to separate positive pions from protons and negative pions from electrons

- Muon events were separated using the correlation for energy deposited in different subdetectors of the CALICE detector prototype

- Events with too low energy deposition and with no hits in ECAL are also excluded from the analysis

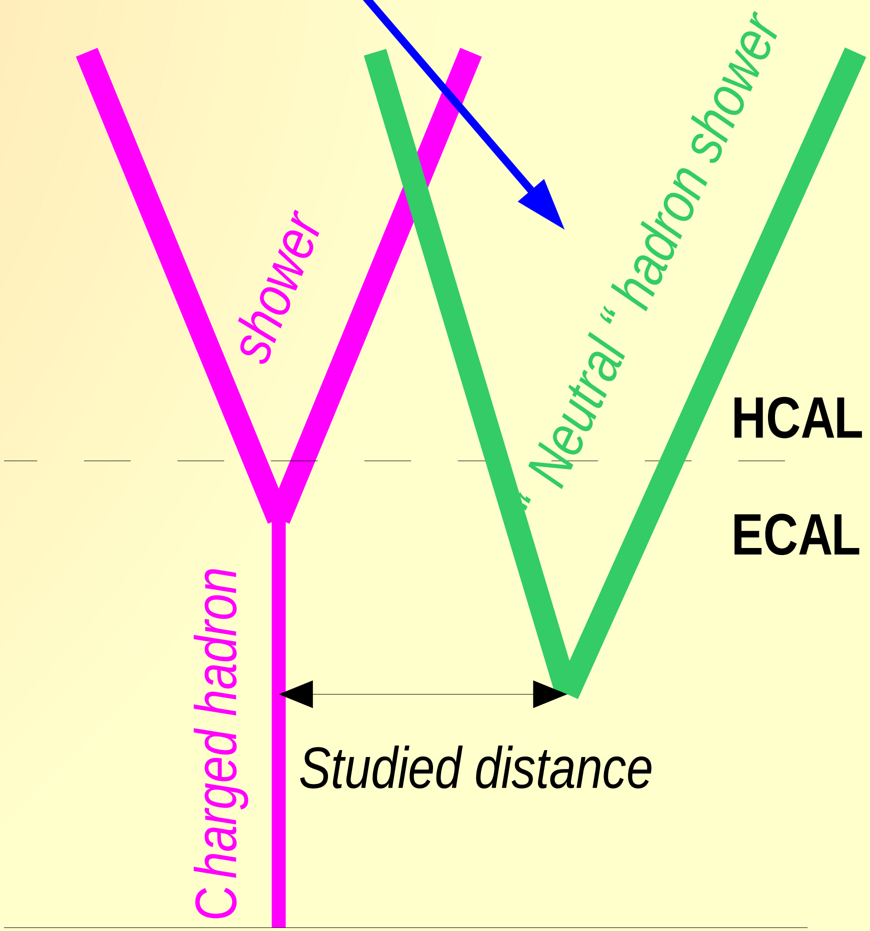
- Multiparticle events were rejected according the following criteria:

(i) deposited energy higher than 1.5 of beam energy,
(ii) shower start in HCAL while having more than 50 hits in ECAL,
(iii) several parallel primary track.



For one of the two events we move all hits at a studied transverse distance from their original position, keeping only hits placed behind the shower start. This event emulates a neutral hadron (e.g. neutron or K^0_L) shower

- To test PandoraPFA, we overlaid two events from different runs
- We used showers with 95% energy containment in ECAL and HCAL
- Beam smearing was corrected: every event was moved to zero XY position before mixing
- We mapped hits of both events to the top octant of the Large Detector Concept (LDC) geometry
- The structure of the CALICE prototype and the LDC are reasonably similar, the existing difference does not simplify the task for the program to disentangle sowers
- We studied distances between showers from 5 cm to 30 cm, typical for a 100 GeV jet

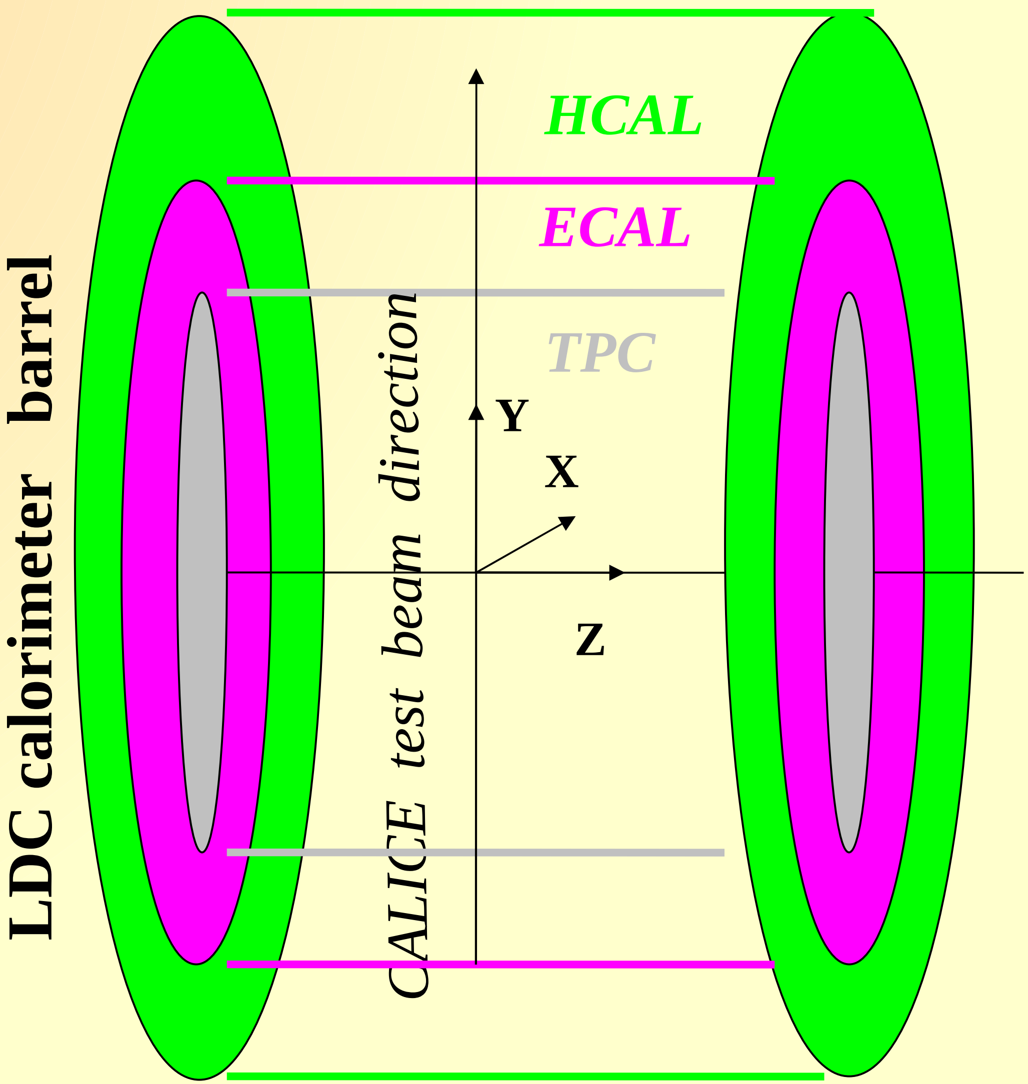


File with the two overlapping showers was passed to the PandoraPFA processor which has been adjusted to the straight track of the CALICE test beam. The shower energy *recovered* by the program was compared with the energy *measured* by the CALICE calorimeter prototype

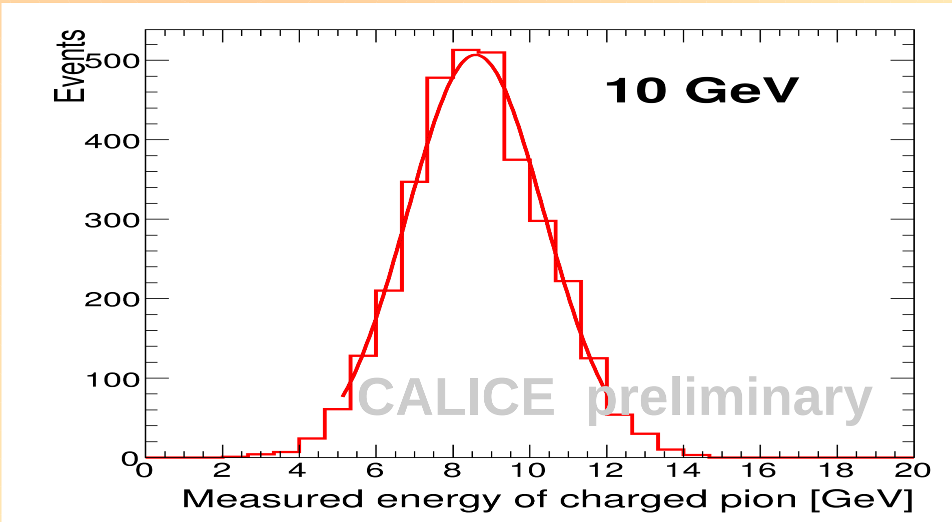
- Instead of helix fit for the Time Projection Chamber (TPC) hits, we give to PandoraPFA a straight track at zero XZ position with normal incidence and definite energy

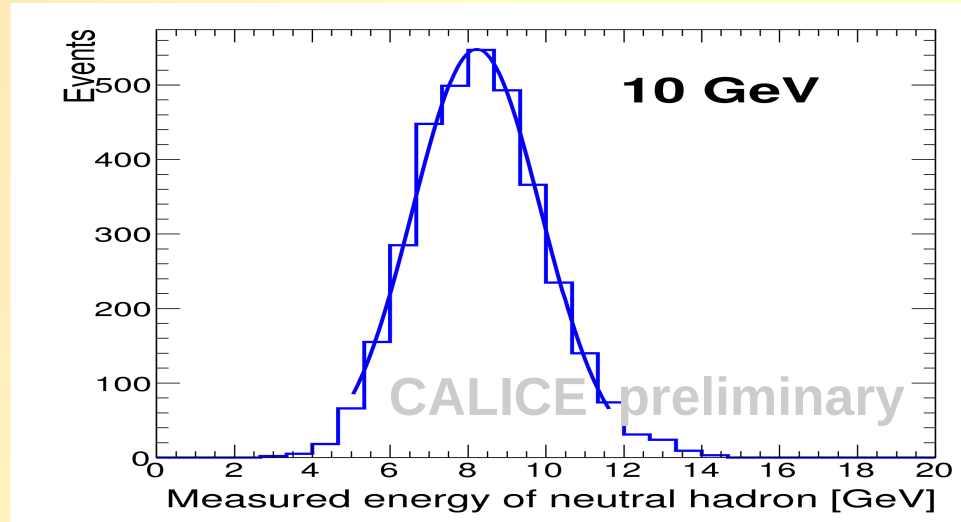
- We include a hit to the neutral hadron shower if PandoraPFA has not include this hit into the charged hadron shower

- We do not use those sections of PandoraPFA which are irrelevant to the CALICE configuration, e.g. kink track cluster association, primary photon recovering and multi-track cluster association splitting

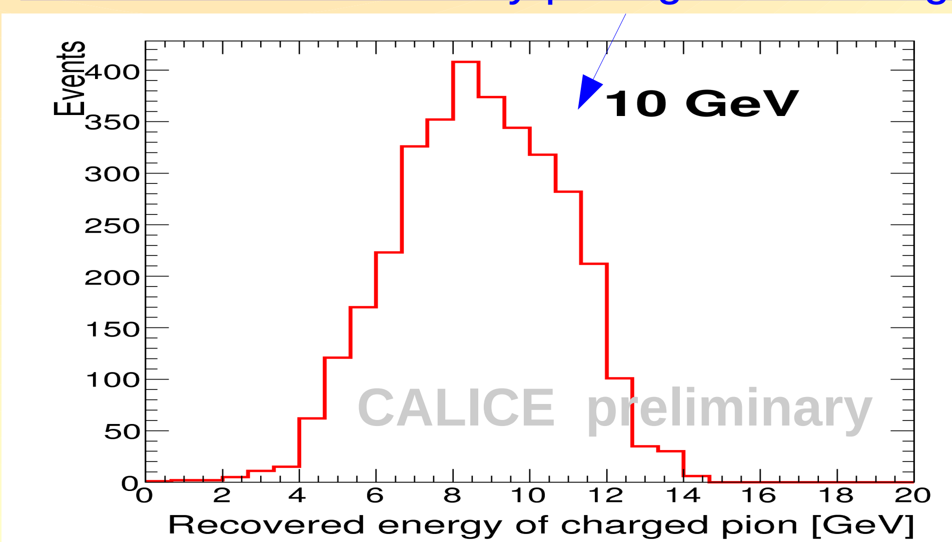


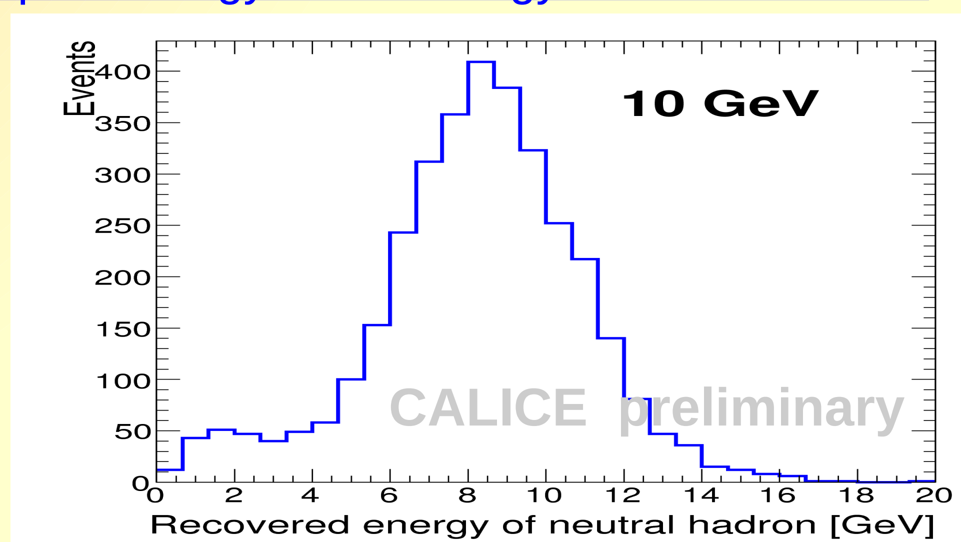
The energy distribution of the 10 GeV charged (left) and neutral (right) hadron, *measured* in the CALICE prototype (top) and *recovered* by PandoraPFA (bottom) for the 15 cm distance between corresponding showers



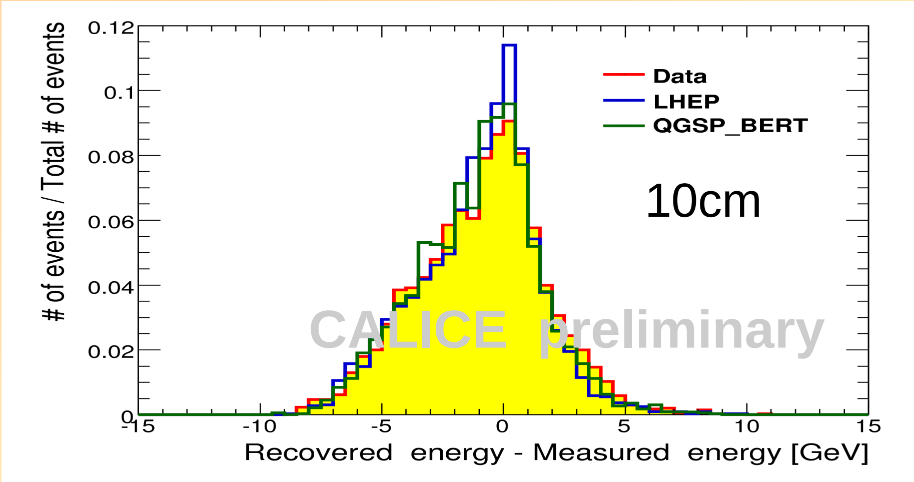


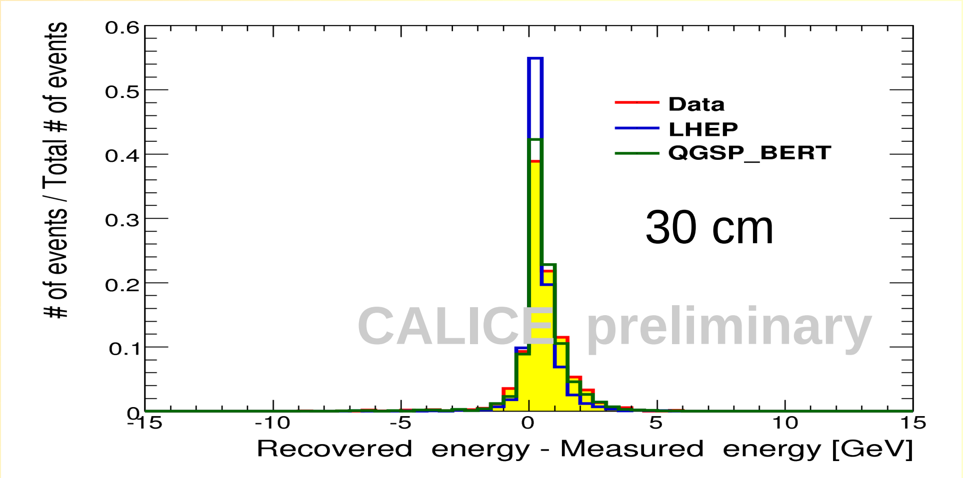
The shoulder caused by pulling of the charged pion energy to the energy known from TPC



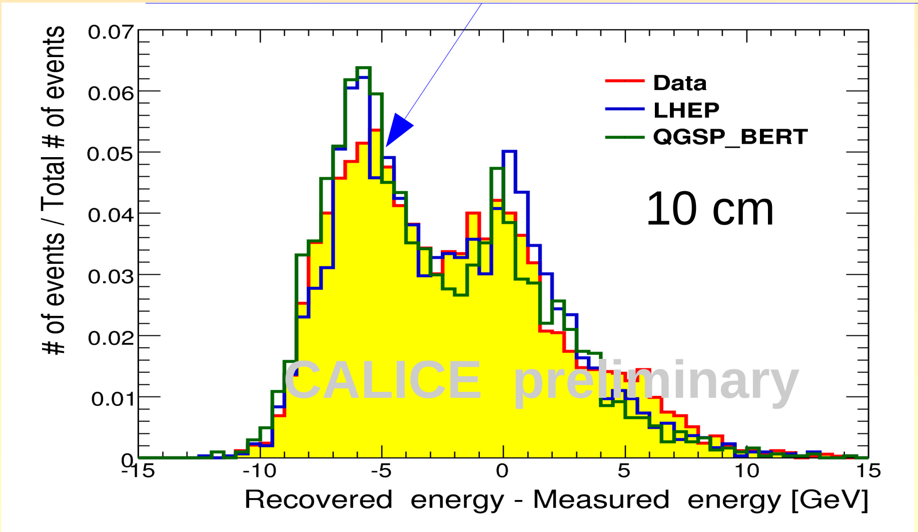


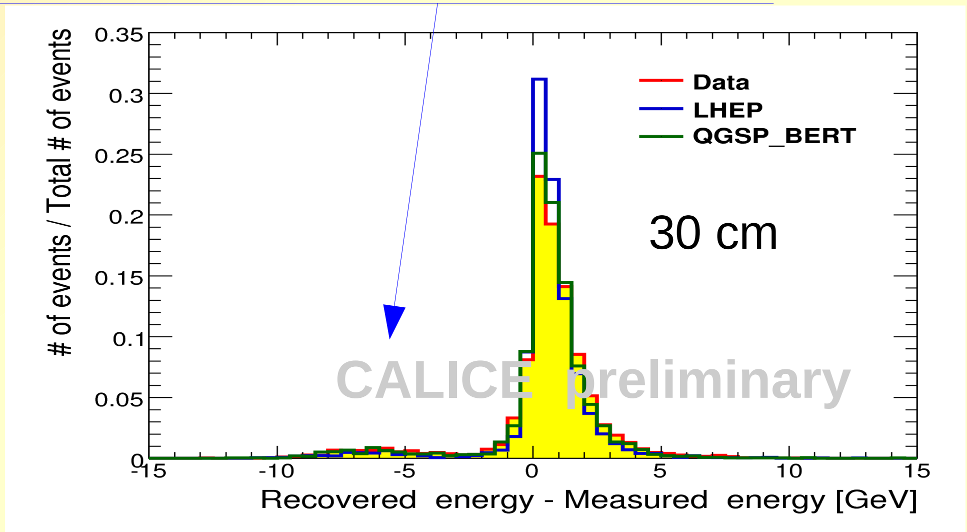
The difference between the *recovered* energy and the energy *measured* by the calorimeter prototype for the 10 GeV neutral hadron placed at different distances from the 10 GeV (top) and 30 GeV (bottom) charged pion





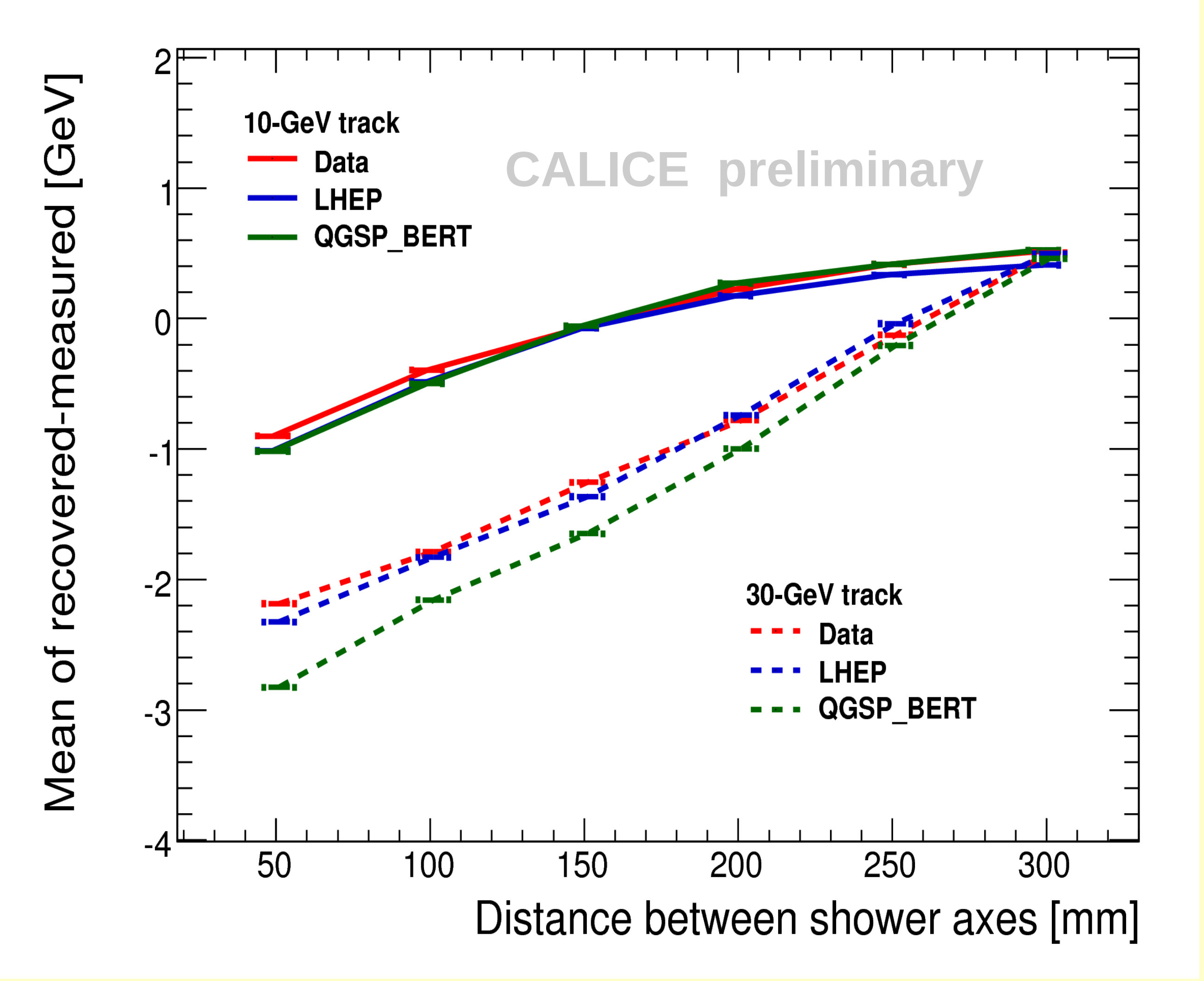
This spike is a result of the attachment of the neutral shower to the charged one





The mean difference between the *recovered* energy and the *measured* energy for the 10 GeV neutral hadron versus the distance from the 10 GeV charged pion (continuous line) and the 30 Gev charged pion (dashed line)

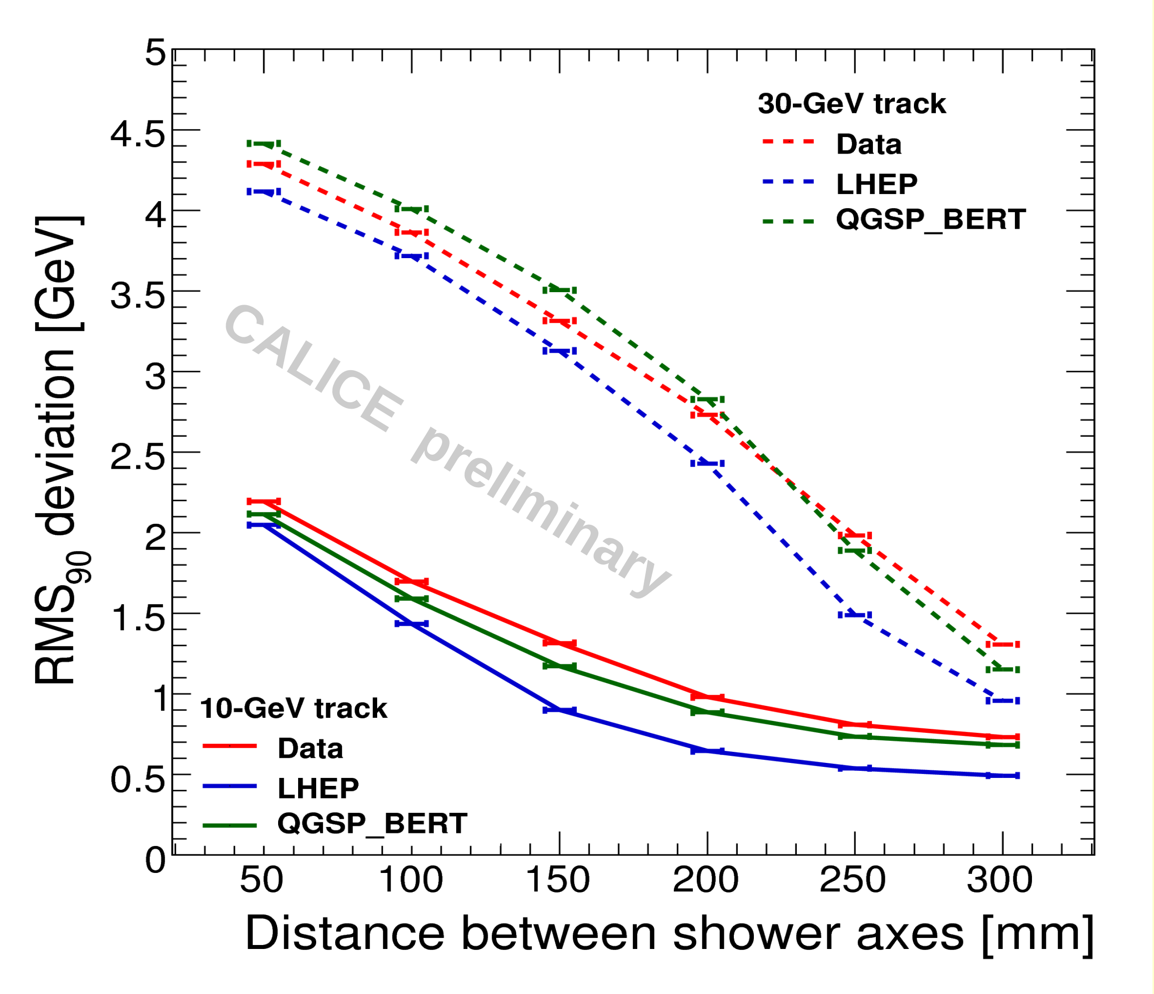
At large distances where the confusion vanishes , the mean recovered energy of the neutral hadron becomes larger than its mean measured energy because we include in the neutral hadron energy the energy of isolated hits and small clusters which in fact belong to the charged hadron shower but could not be associated with it because of remoteness



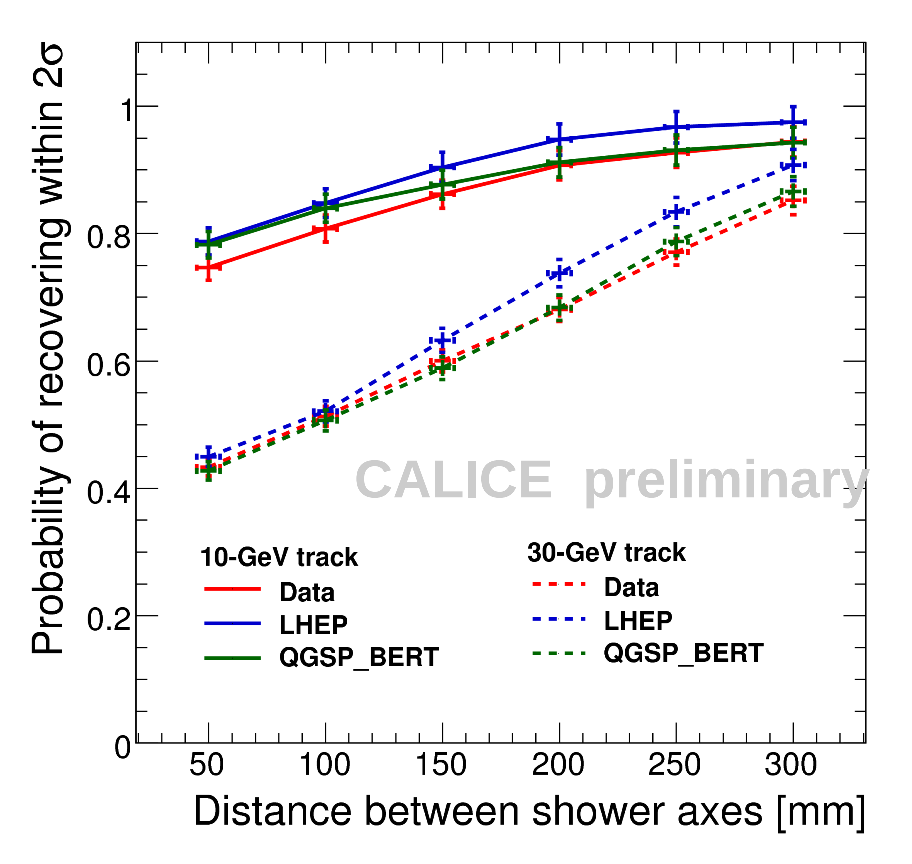
The RMS$_{90}$ deviation of the *recovered* energy of the neutral 10 GeV hadron from its *measured* energy versus the distance from the charged 10 GeV (continuous line) and the 30 GeV (dashed line) pions for beam data and for both LHEP (blue) and QGSP_BERT (green) physics lists

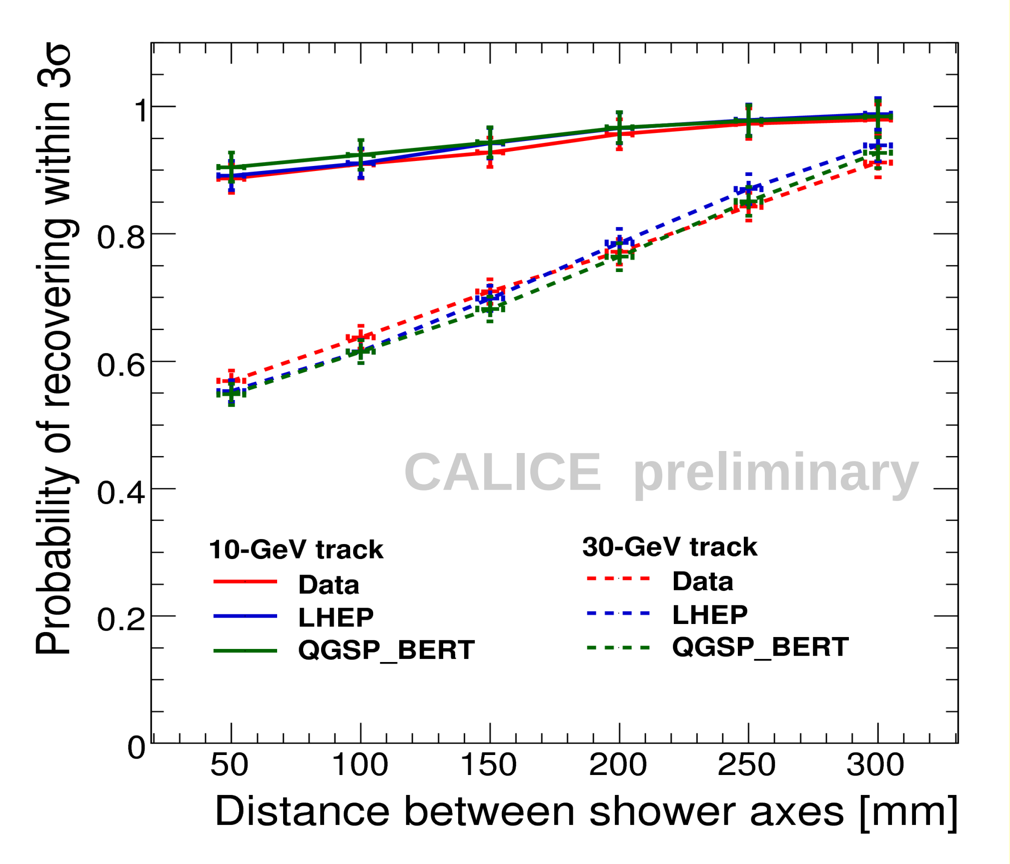
- The deviation is particularly large for the 30 GeV charged pion. However an energetic fragment has low probability to exist in a 100 GeV jet

- The confusion naturally depends on the transverse size (radius) of showers. The LHEP based simulation, which gives smaller shower radii, predicts smaller confusion for the distances larger than 10 cm for 10 GeV charged pion and 20 cm for the 30 GeV charged pion

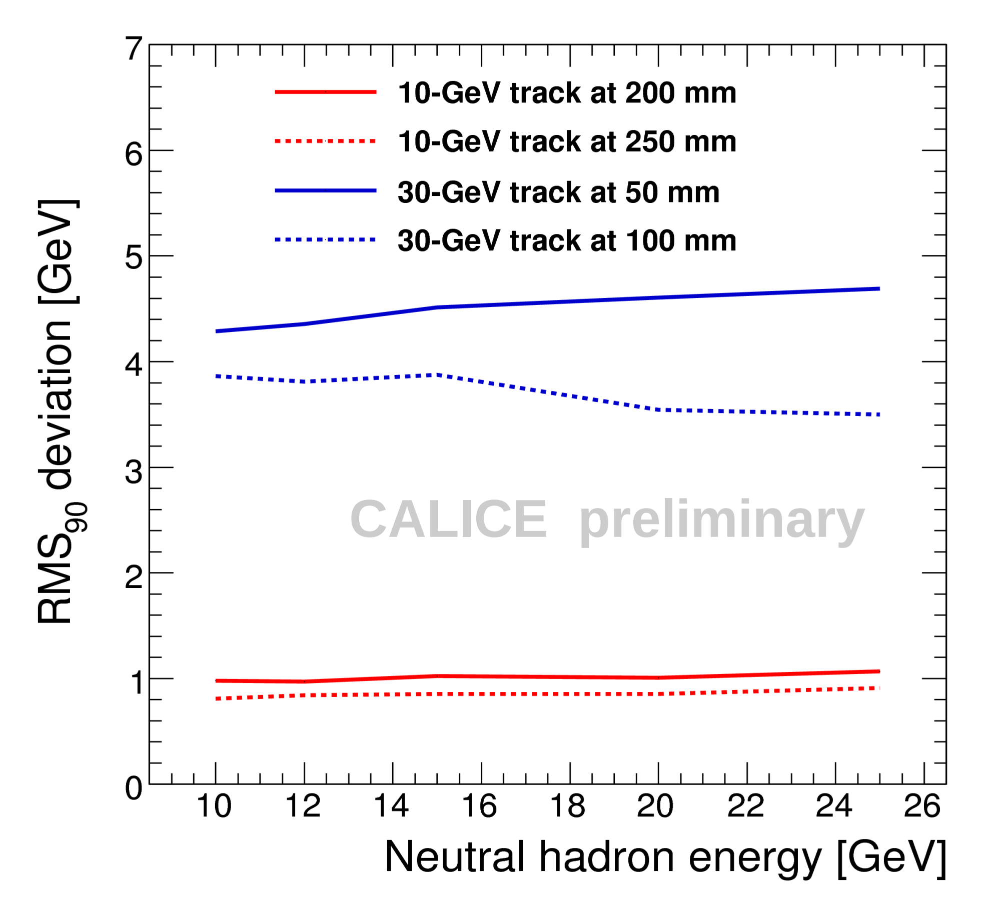


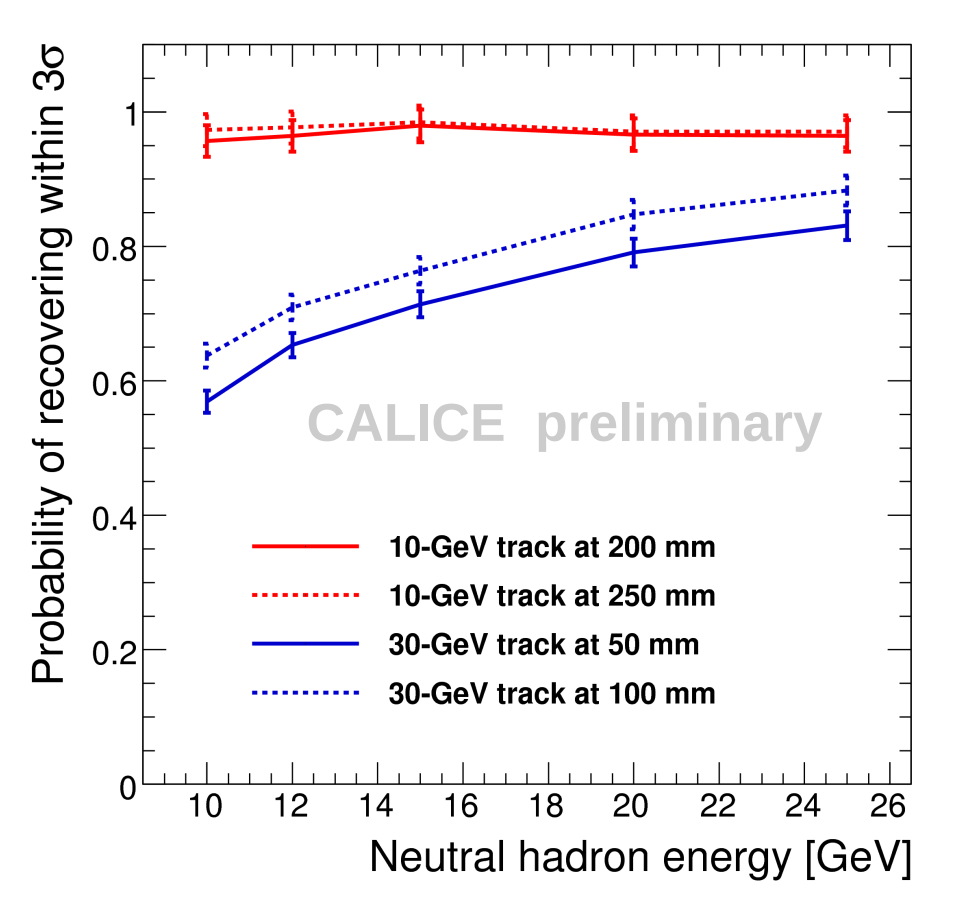
The probability to recover the 10 GeV neutral hadron energy within 2 (left) and 3 (right) standard deviations from its real energy versus the distance from the charged 10 GeV (continuous line) and 30 GeV (dashed line) pion for test beam data (red) and for both LHEP (blue) and QGSP_BERT (green) physics lists





RMS$_{90}$ deviation of the *recovered* energy of a neutral hadron from its *measured* energy (left) and the probability to recover the neutral hadron energy within 3 standard deviation (right) in the vicinity of the 10 GeV (red lines) and 30 GeV charged pion (blue lines) versus the neutral hadron energy for typical distances between neutral and charged hadrons in a 100 GeV jet





Conclusions

- For the first time the PandoraPFA algorithm was tested using real CALICE test beam data. For this purpose, we mapped pairs of CALICE test beam events shifted by the definite transverse distances from each other to the LDC detector geometry

- For the case of one charged and one neutral hadron, we estimated the confusion error of the recovered neutral hadron energy for hadron energies from 10 GeV to 50 GeV, typical for a 100 GeV jet

- We have confronted our result for test beam data with the result of Monte Carlo simulations for LHEP and QGSP_BERT physics lists. The results for the data and MC are in a good agreement. No hidden imperfections in the real data (non perfect calibration, non uniformity of tile response, cross talk between tiles, etc.) which could deteriorate the PFA performance were found. The PandoraPFA performance for the real data is as god as for MC simulation

- Good agreement with MC together with the successful PandoraPFA performance for simulated jets demonstrates that the extrapolation to the complete detector is reliable and allows us to consider the PandoraPFA program as a good reconstruction tool for a full-size experiment

- We point out that LHEP physics list gave worse predictions for test beam data than the QGSP_BERT one