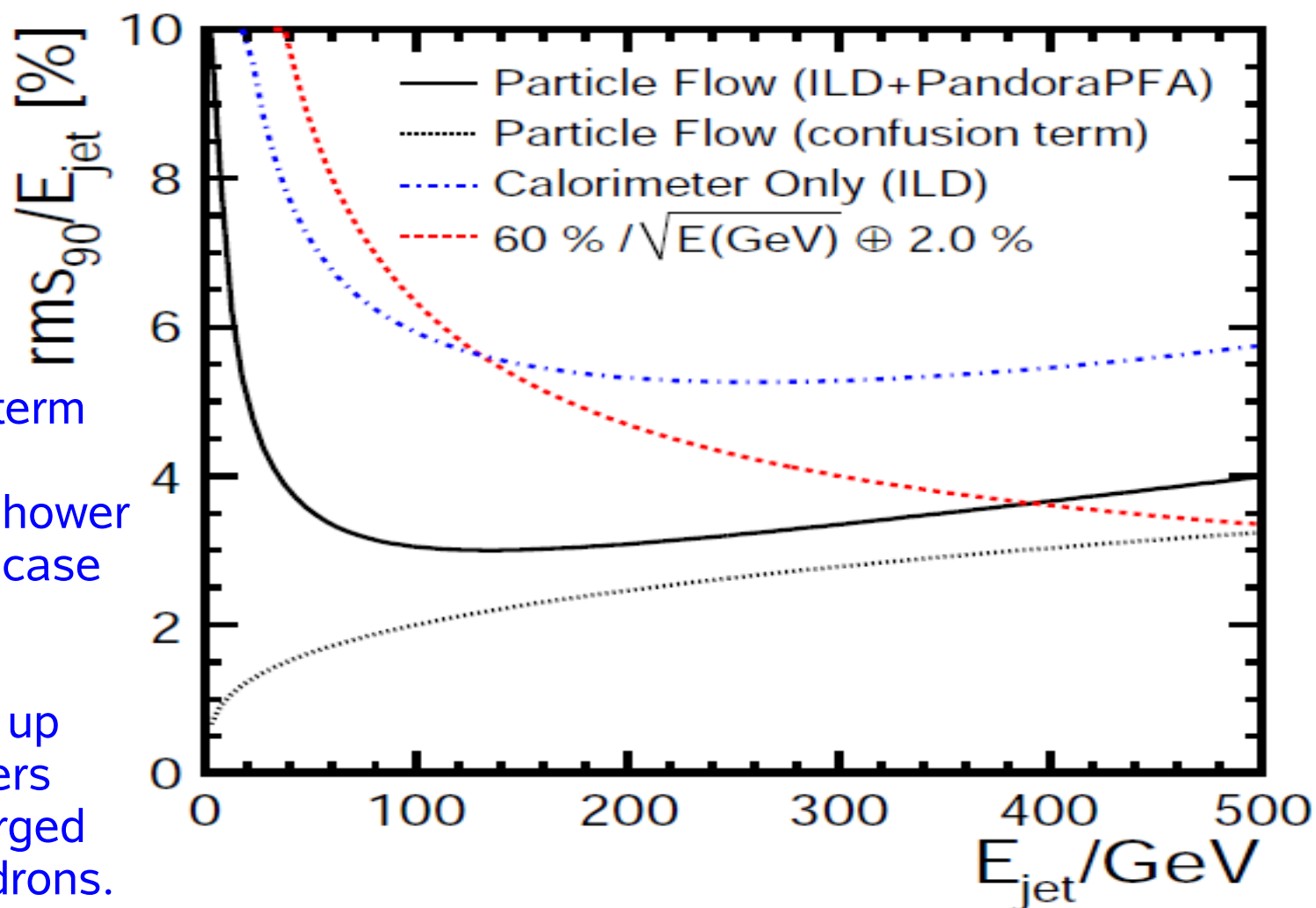# PandoraPFA Tests using Overlaid Charge Pion Test Beam Data

Particle Flow Analysis (PFA) : only the neutral particle energy is derived in a calorimeter whereas the charged particle energy is reconstructed in a tracker.

The confusion term occurs
as a result of shower overlapping, in case when the reconstructing program mixes up hits from showers created by charged and neutral hadrons.

Legend in figure:
- Particle Flow (ILD+PandoraPFA)
- Particle Flow (confusion term)
- Calorimeter Only (ILD)
- $60\ \%\ /\sqrt{E(GeV)} \oplus 2.0\ \%$

y-axis: $rms_{90}/E_{jet}\ [\%]$

x-axis: E_{jet}/GeV

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The PFA was implemented in the PandoraPFA program written by Prof. Thomson as a part of the software for the future International Linear Collider (ILC)
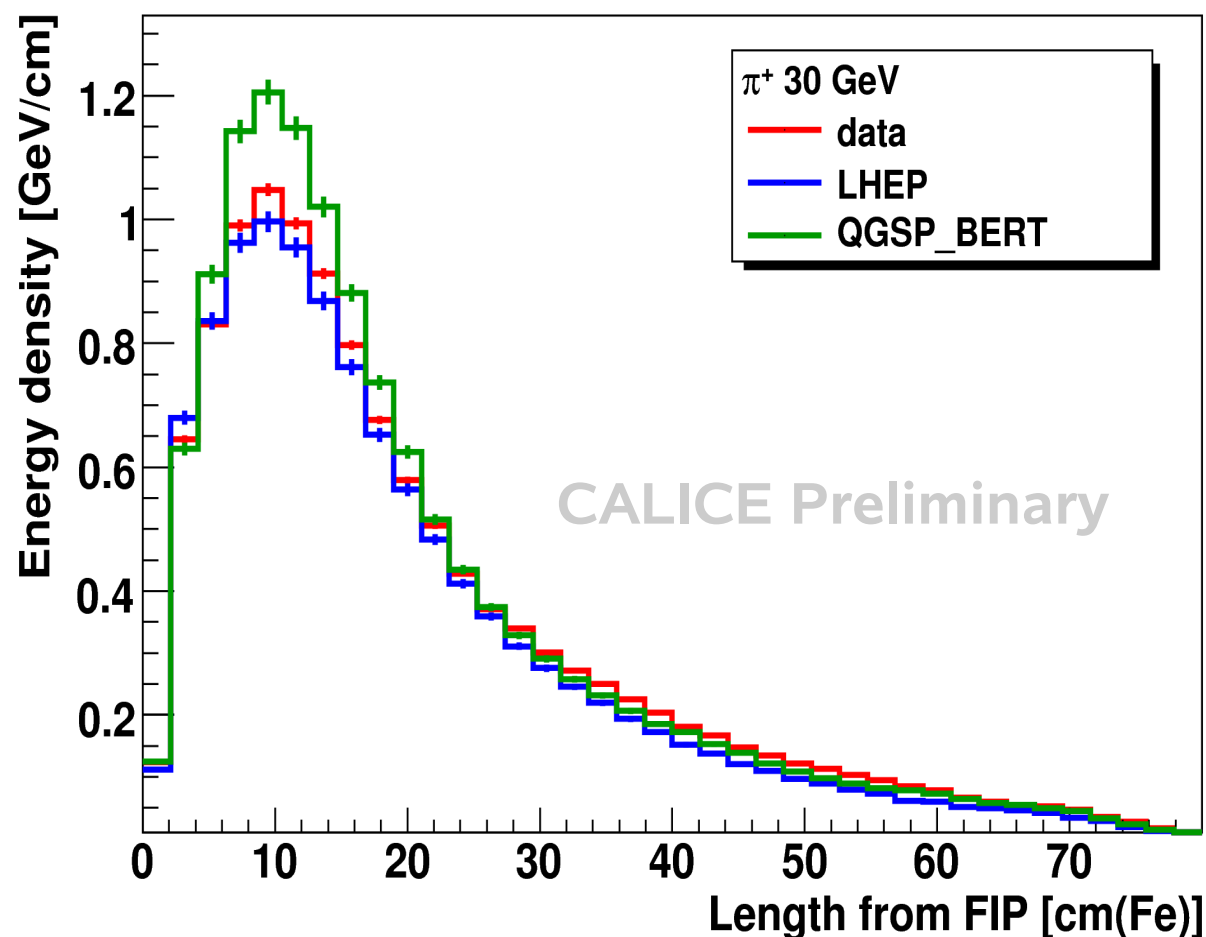

◆ the impact of overlapping showers on energy resolution is known only for MC simulated jets

◆ different MC physics lists give noticeably different predictions for hadron shower shapes

◆ the real detector performance can be not as good as that of the idealized MC model

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Three calorimeter prototypes have been developed and tested in 2007 - 2009:
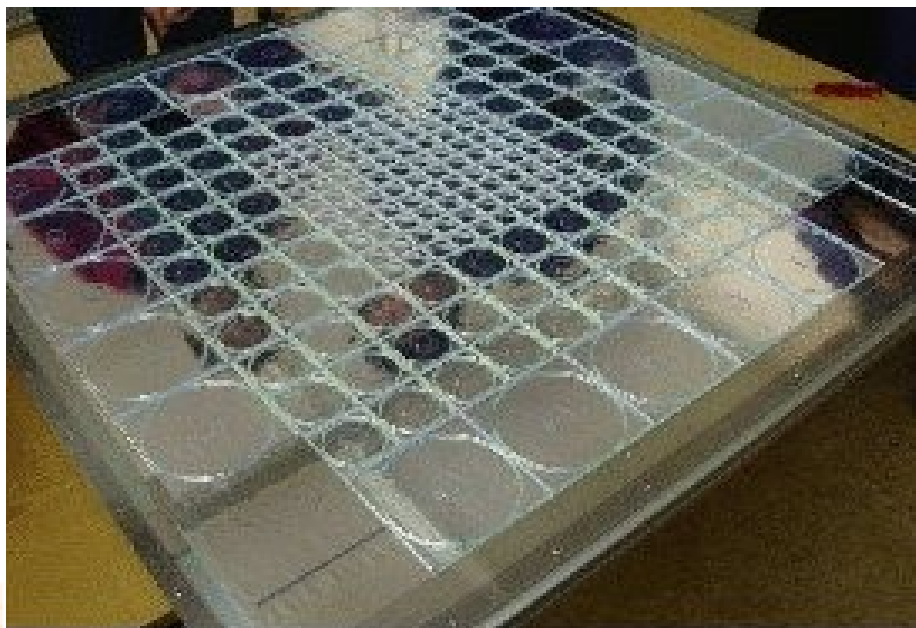
1. Si-W electromagnetic calorimeter (ECAL)

2. Hadronic calorimeter (HCAL) with SiPM readout

3. Tail catcher and muon tracker (TCMT**)**

- ◆ Total effective thickness about 10 nuclear interaction lengths
- ◆ Unprecedented granularity, close to that in ILD
- ◆ About 20,000 cells in the entire prototype
- ◆ 3 years at CERN and FNAL test beams

3

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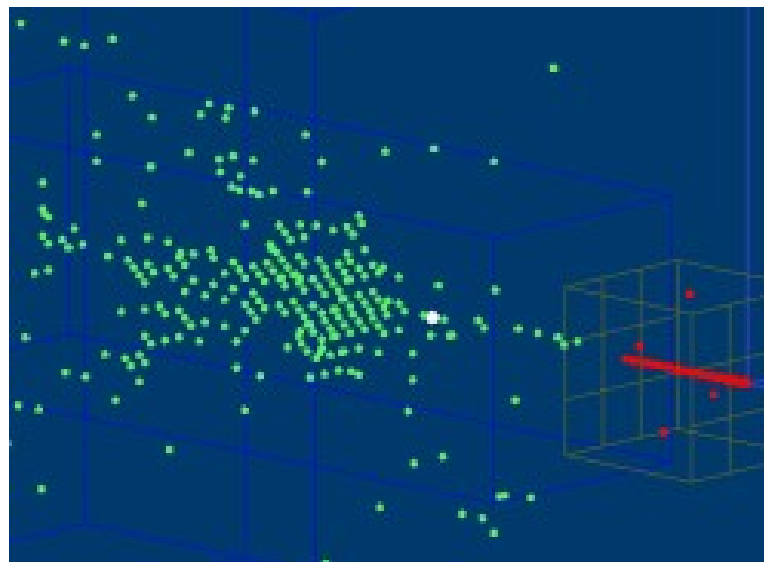
Pion events from several runs (from 10 GeV to 50 GeV) have been selected

◆ To separate positive pions from protons and negative pions from electrons: Cherenkov

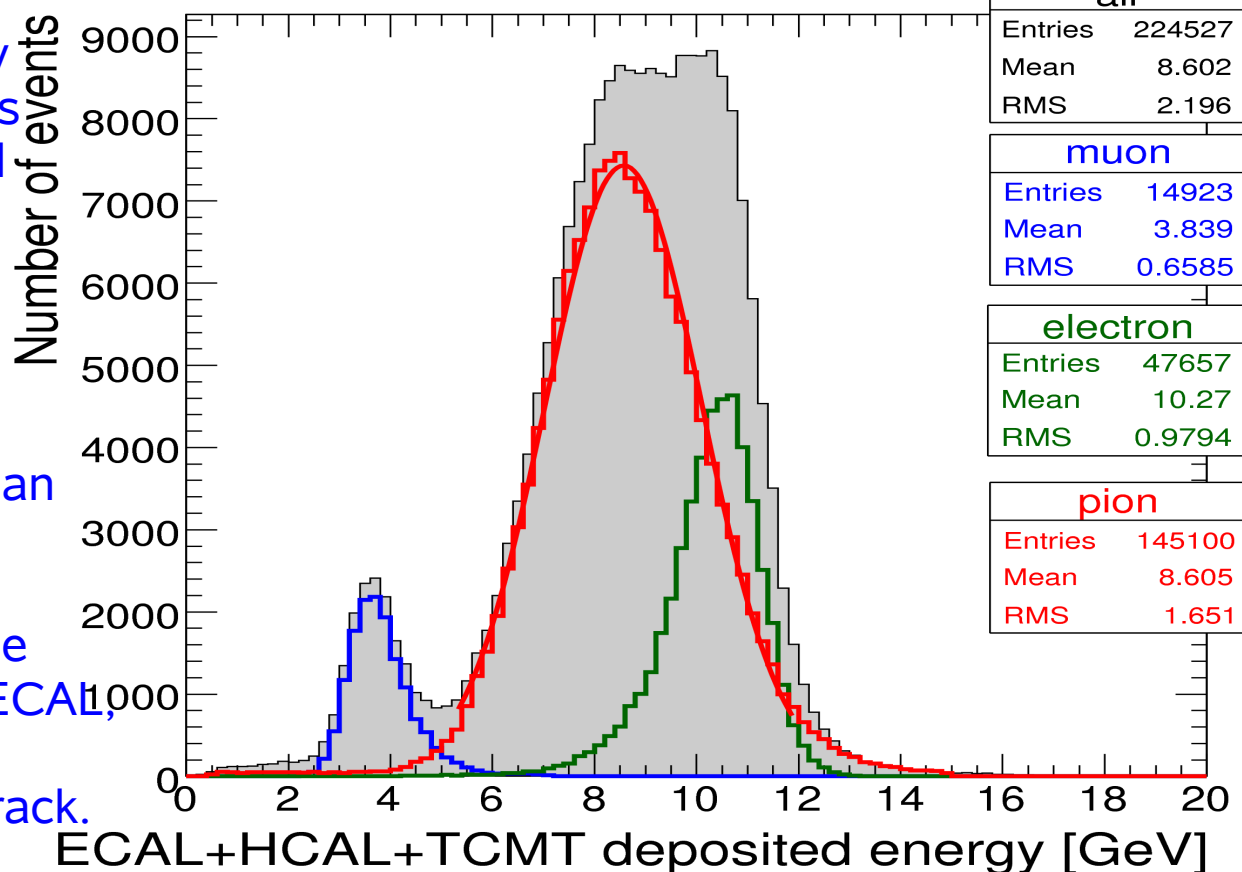◆ Muon events : correlation for energy deposited in different subdetectors of the CALICE detector prototype

◆ Events with too low energy deposition and with no hits in ECAL are also excluded

◆ Multiparticle events were rejected according the following criteria:
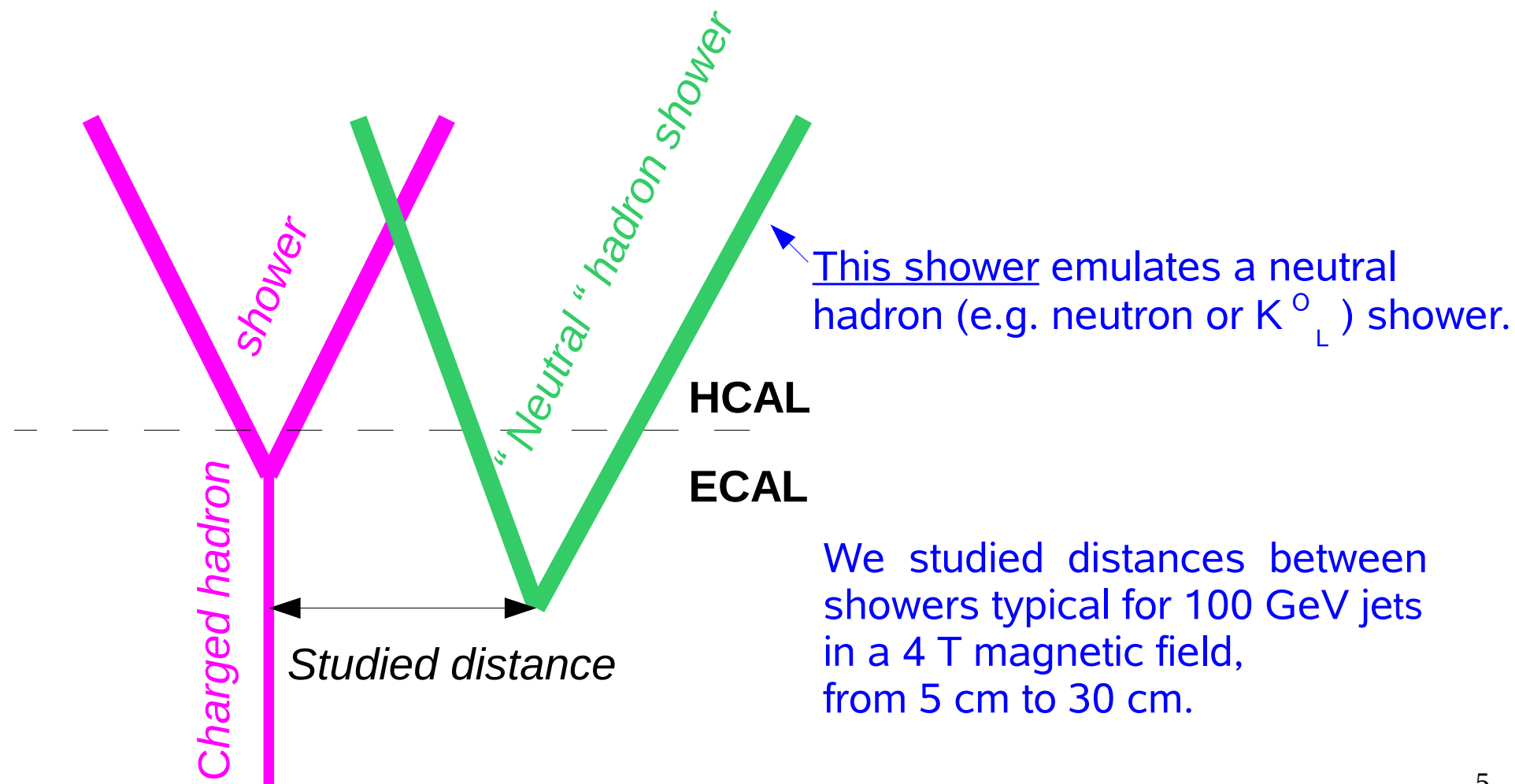
(i) deposited energy larger than 1.5 of beam energy,

(ii) shower start in HCAL while having more than 50 hits in ECAL,

(iii) several parallel primary track.

all	
Entries	224527
Mean	8.602
RMS	2.196

muon	
Entries	14923
Mean	3.839
RMS	0.6585

electron	
Entries	47657
Mean	10.27
RMS	0.9794

pion	
Entries	145100
Mean	8.605
RMS	1.651

Number of events

ECAL+HCAL+TCMT deposited energy [GeV]

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To test PandoraPFA, we overlaid two pion showers taken from test beam data

We deleted all hits before the shower start of one of these showers and moved it at a studied transverse distance from the other shower.
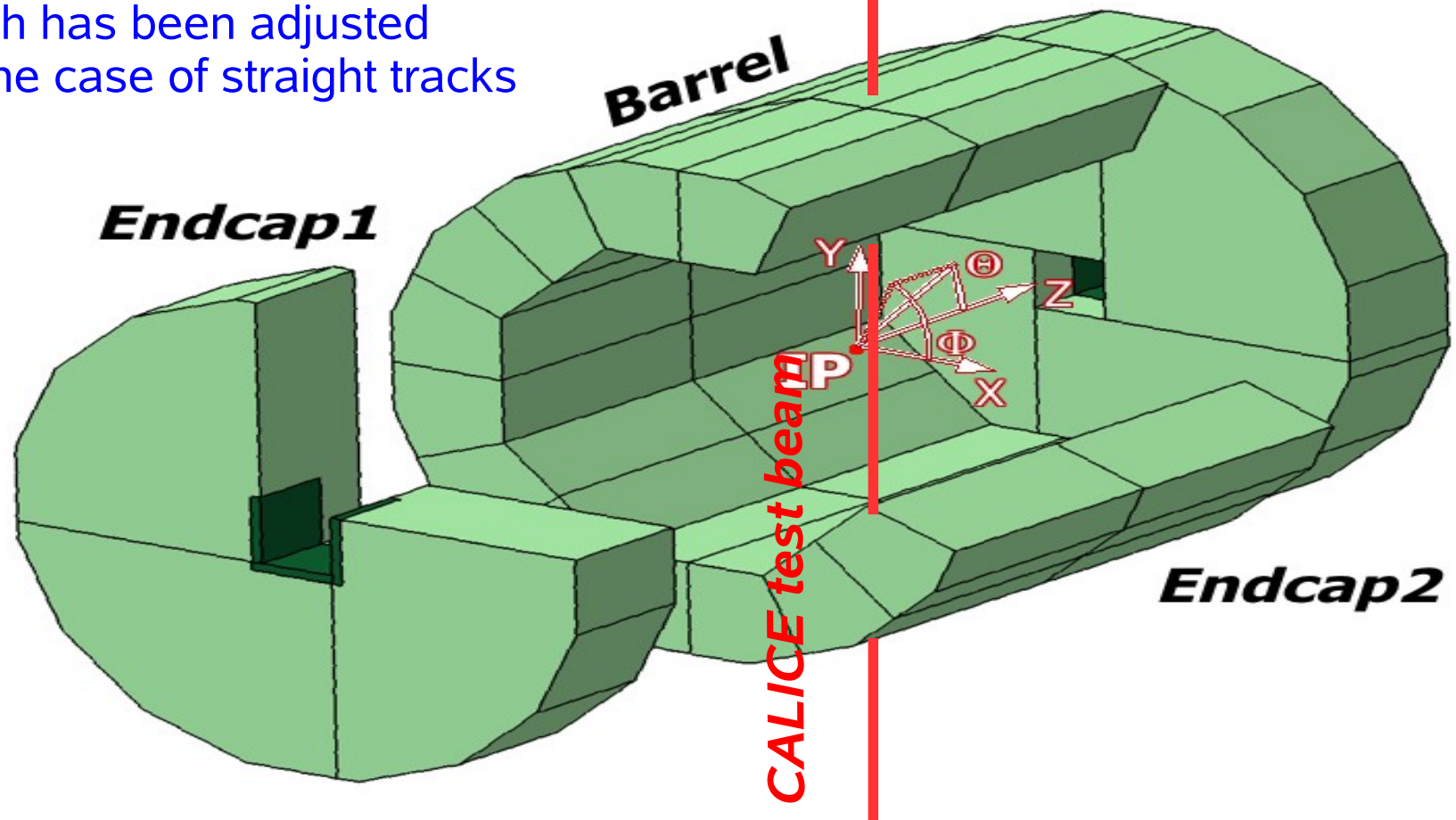
This shower emulates a neutral hadron (e.g. neutron or K^O_L) shower.

HCAL

ECAL

We studied distances between showers typical for 100 GeV jets in a 4 T magnetic field, from 5 cm to 30 cm.

Studied distance

Charged hadron

shower

"Neutral " hadron shower

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We mapped hits of both showers to the top octant of the detector similar to ILD, but with thicknesses of layers and absorbers equal those in the CALICE calorimeter prototype

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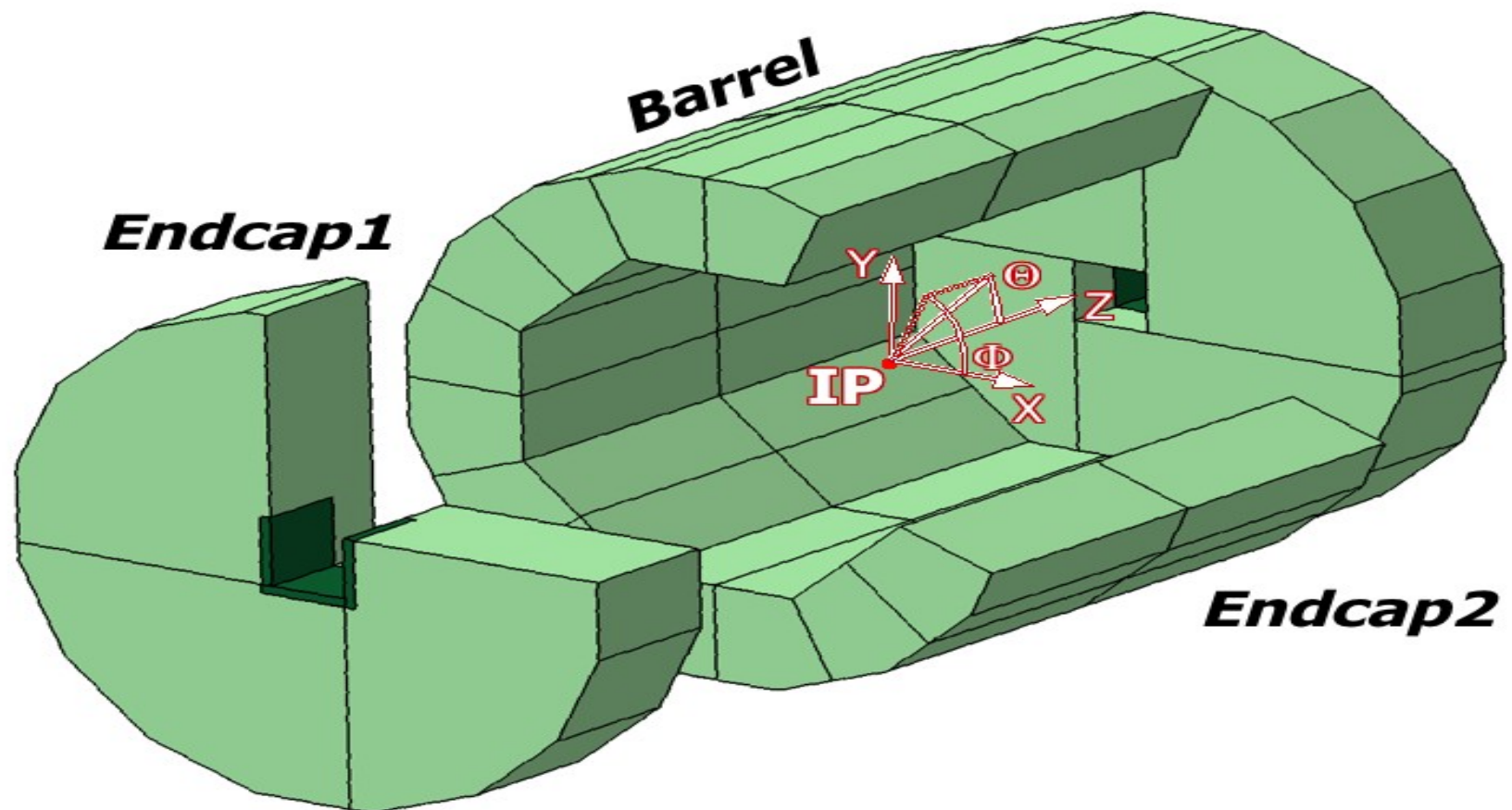
We mapped hits of both showers to the top octant of the detector similar to ILD, but with thicknesses of layers and absorbers equal those in the CALICE calorimeter prototype

Files with two overlapped shower were passed to the PandoraPFA program which has been adjusted for the case of straight tracks

Barrel

Endcap1

Endcap2

CALICE test beam

P

Y

Z

X

Θ

Φ

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# The energy distribution for the 10 GeV charged (top) and neutral (bottom) hadron, _measured_ in the CALICE prototype
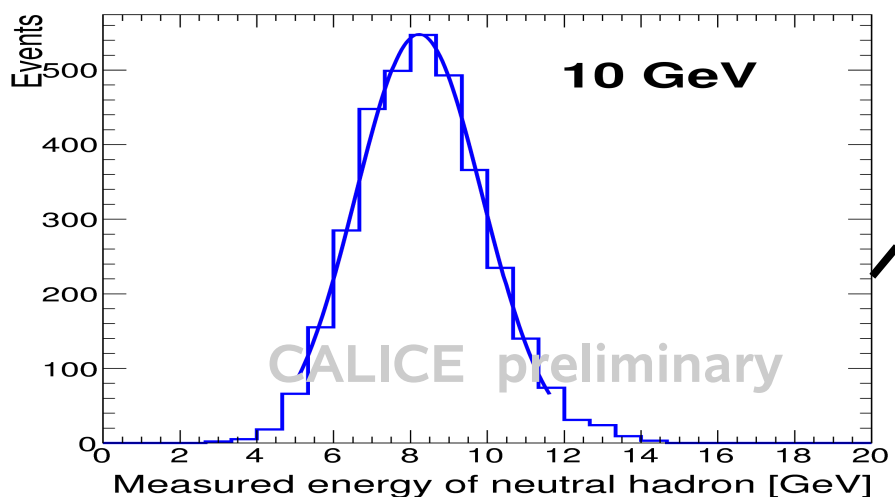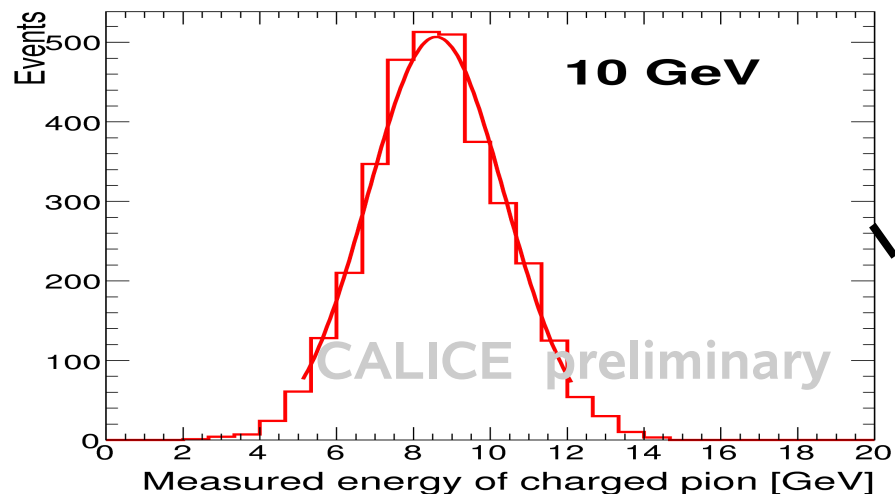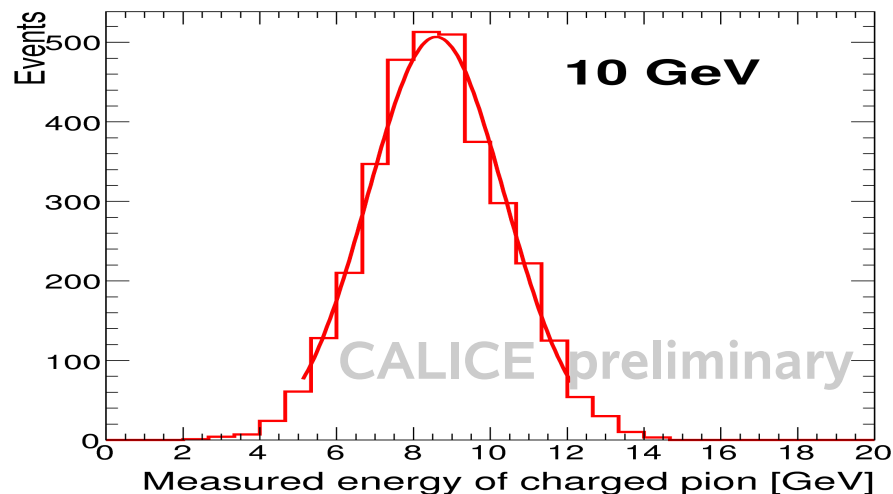

Disentangling
by PandoraPFA

Overlay

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The energy distribution for the 10 GeV charged (top) and neutral (bottom) hadron, _measured_ in the CALICE prototype (left) and _recovered_ by PandoraPFA (right) for the 15 cm distance between corresponding showers
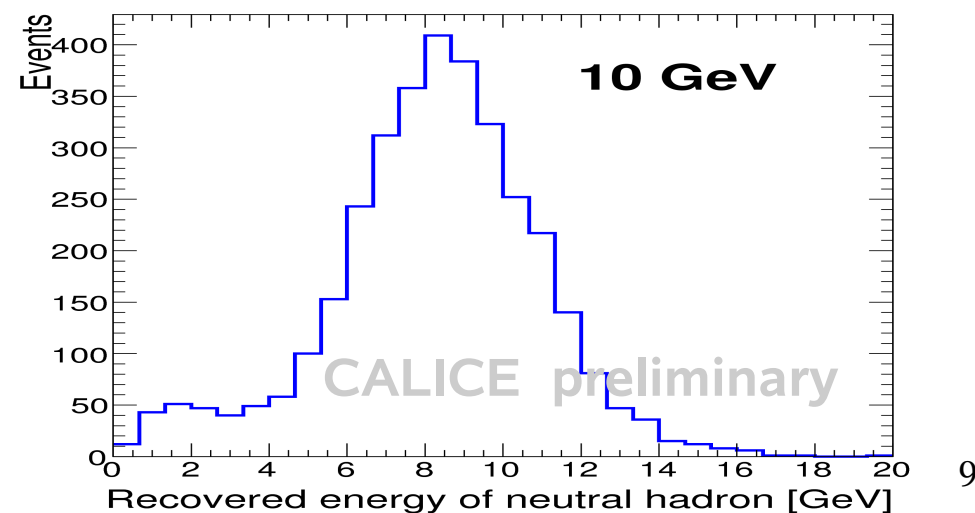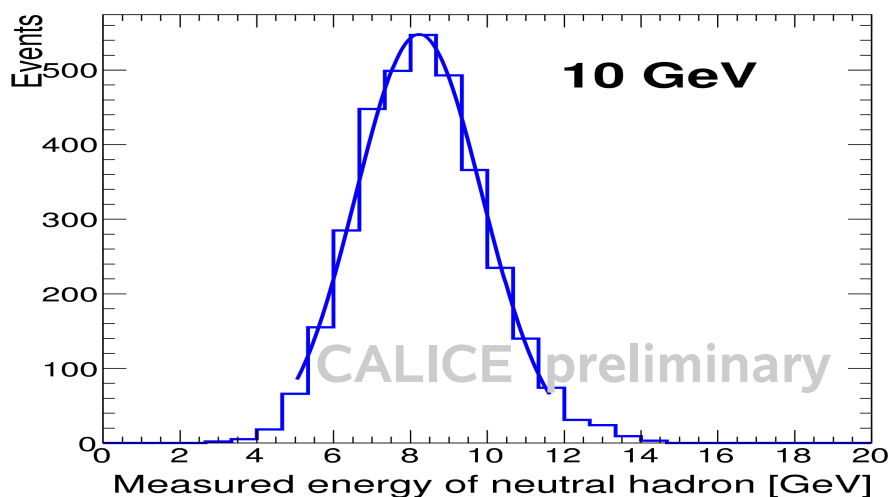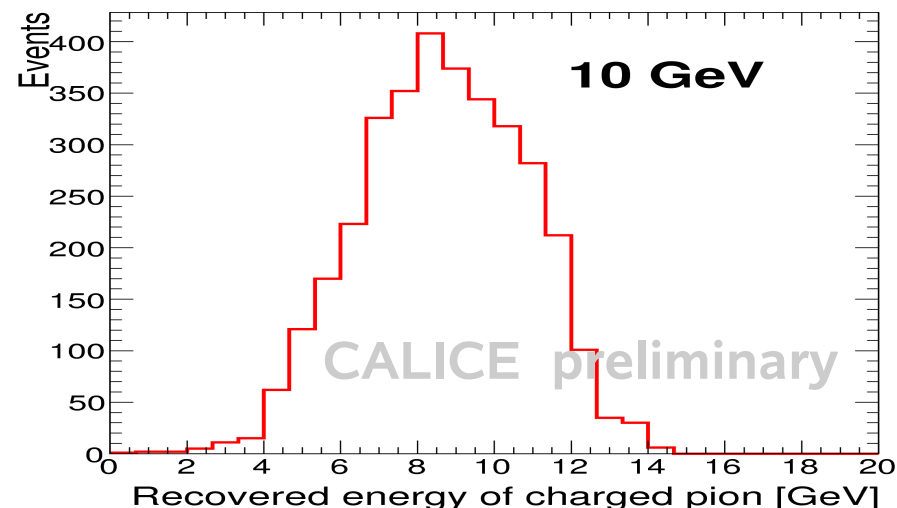
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The difference between the _recovered_ energy and the _measured_ energy of the 10 GeV neutral hadron placed at different distances from the 10 GeV (top) and 30 GeV (bottom) charged pion
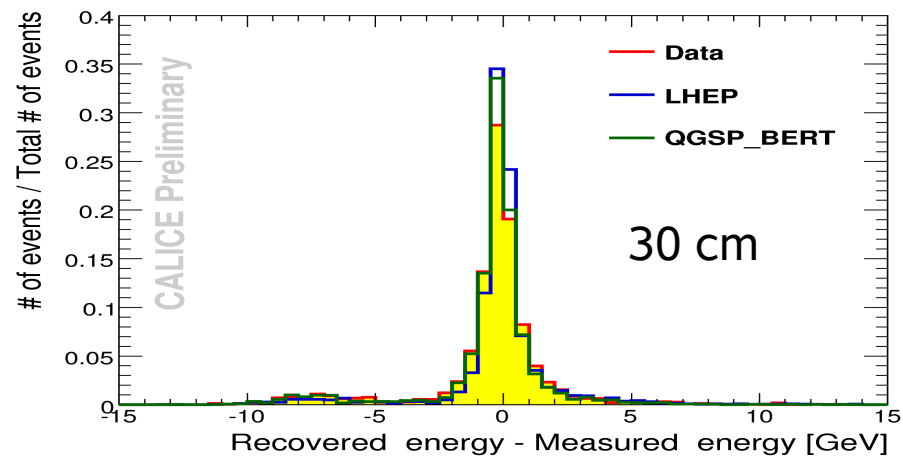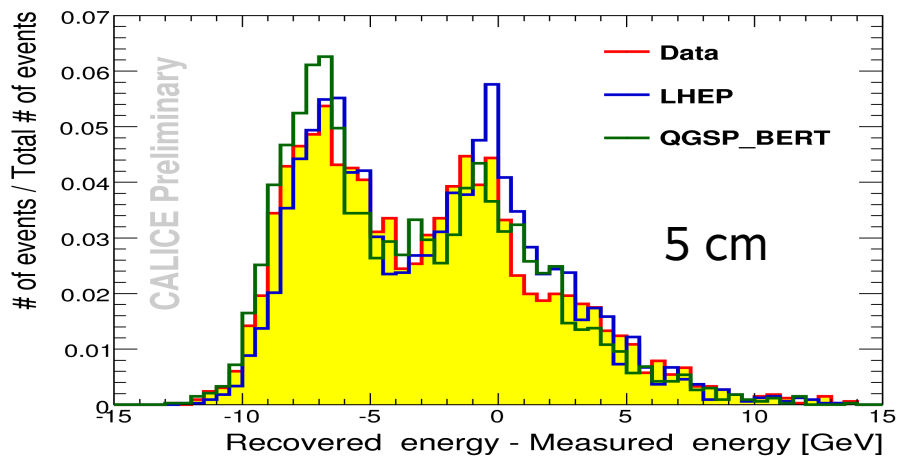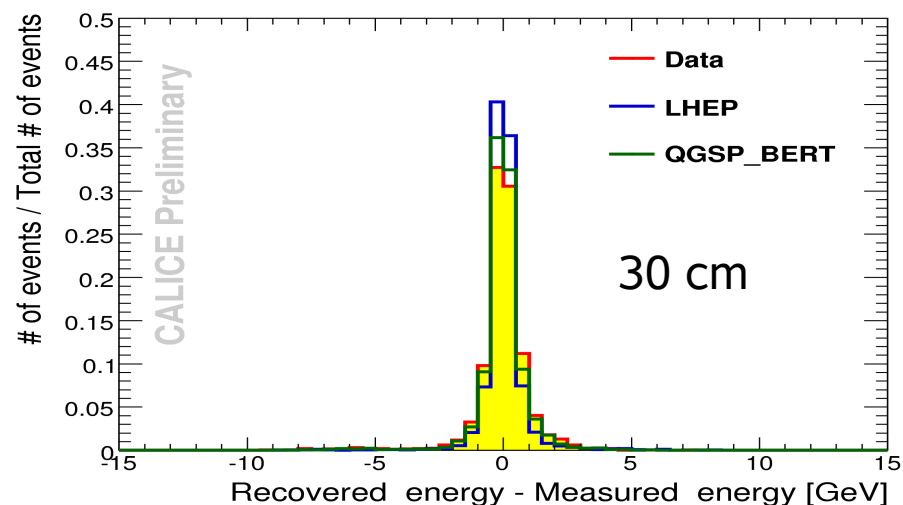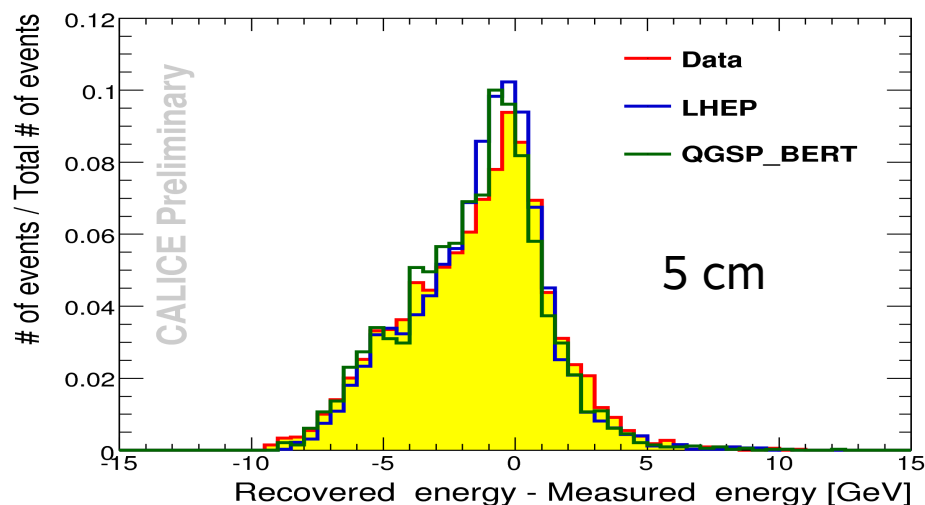
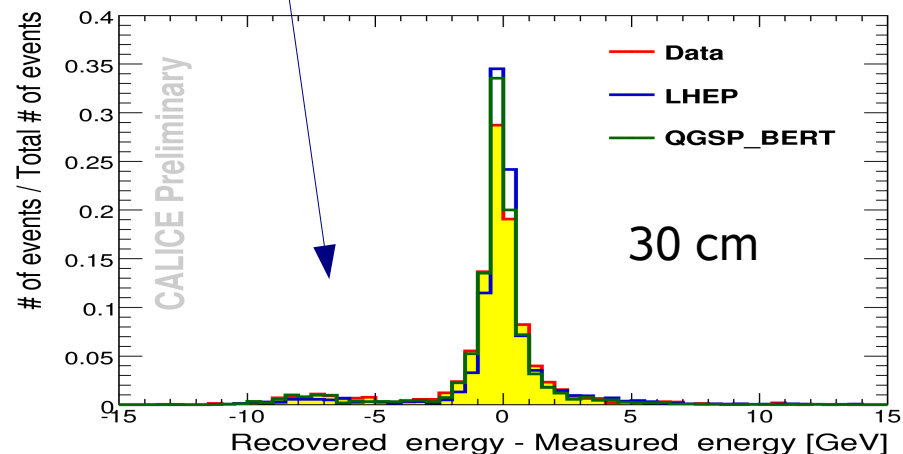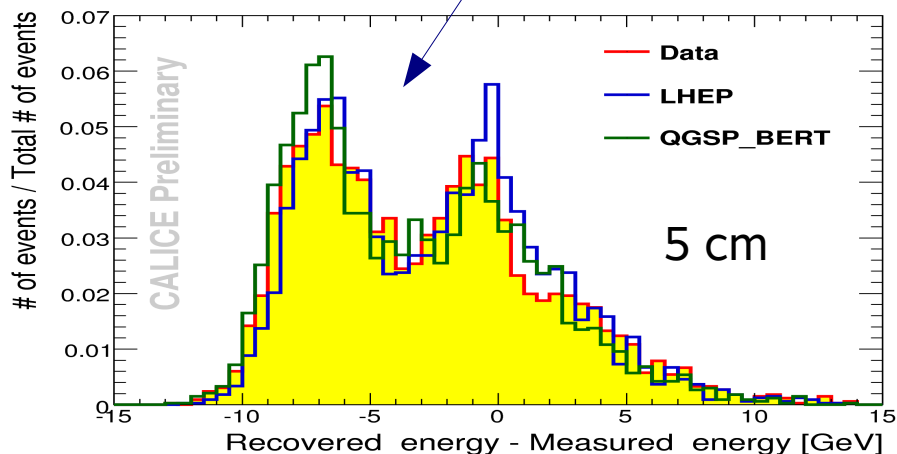**The difference between the *recovered* energy and the *measured* energy of the 10 GeV neutral hadron placed at different distances from the 10 GeV (top) and 30 GeV (bottom) charged pion**
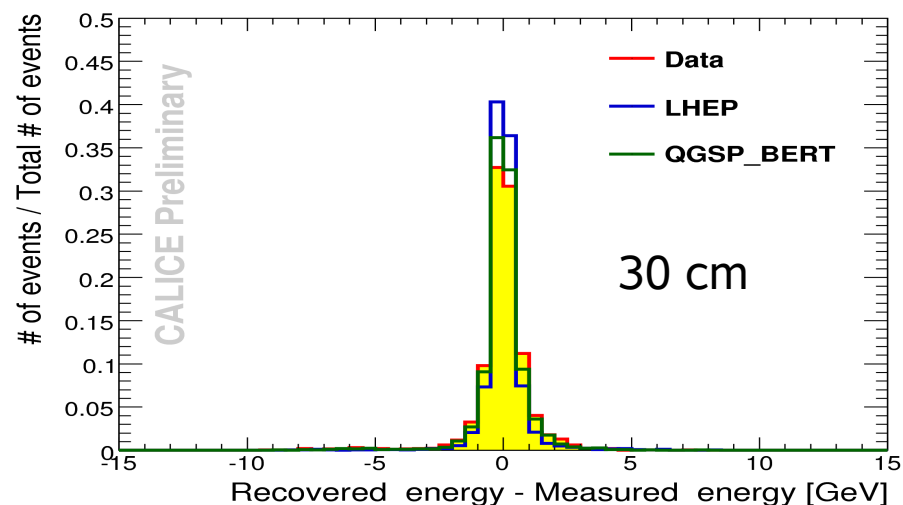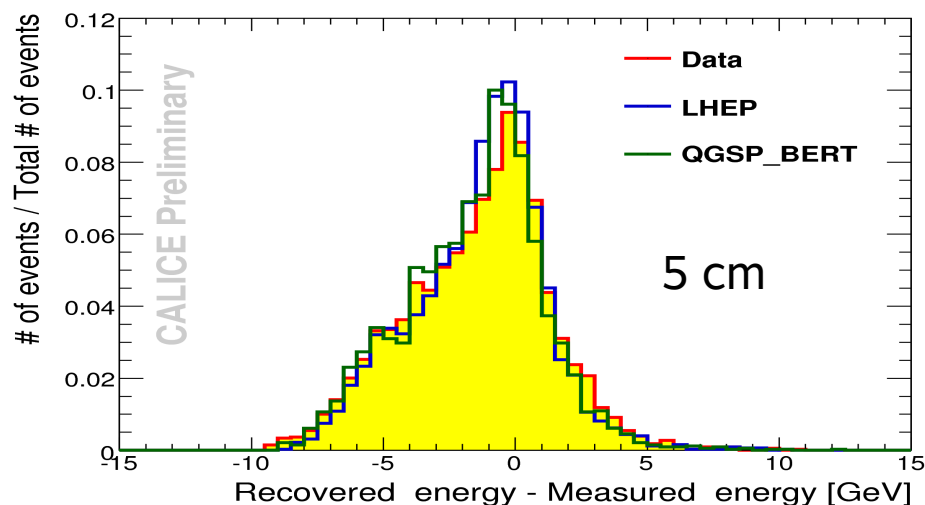
This spike is a result of the attachment of the neutral shower to the charged one

The mean difference between the *recovered* energy and the *measured* energy of the 10 GeV neutral hadron versus the distance from the 10 GeV and 30 GeV charged pion for test beam data and MC

CALICE Preliminary

10-GeV track
— Data
— LHEP
— QGSP_BERT

30-GeV track
- - - Data
- - - LHEP
- - - QGSP_BERT

Mean of recovered-measured [GeV]

Distance between shower axes [mm]

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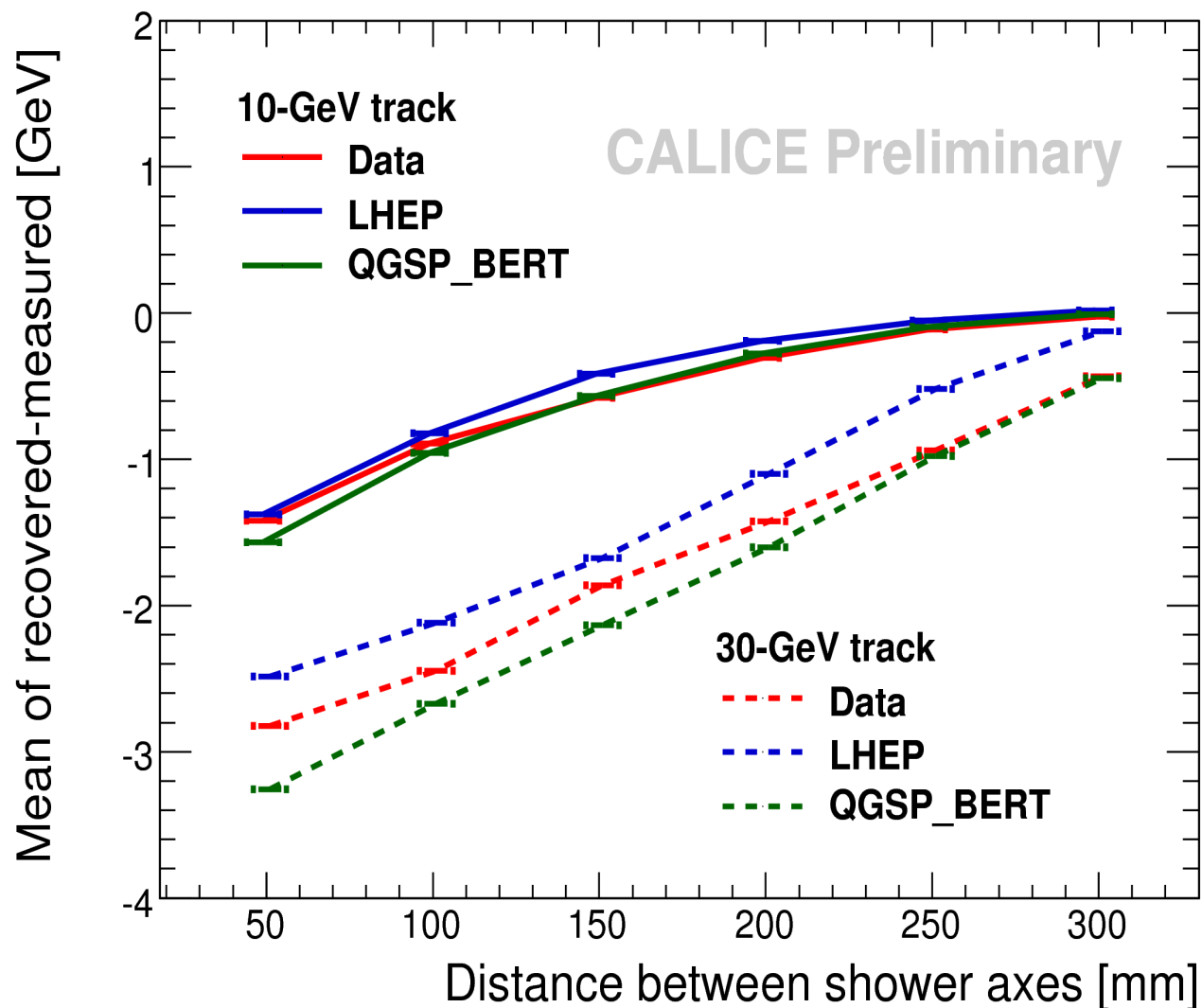*Oleg Markin   ITEP(Moscow) & DESY*

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The mean difference between the _recovered_ energy and the _measured_ energy of the 10 GeV neutral hadron versus the distance from the 10 GeV and 30 GeV charged pion for test beam data and MC
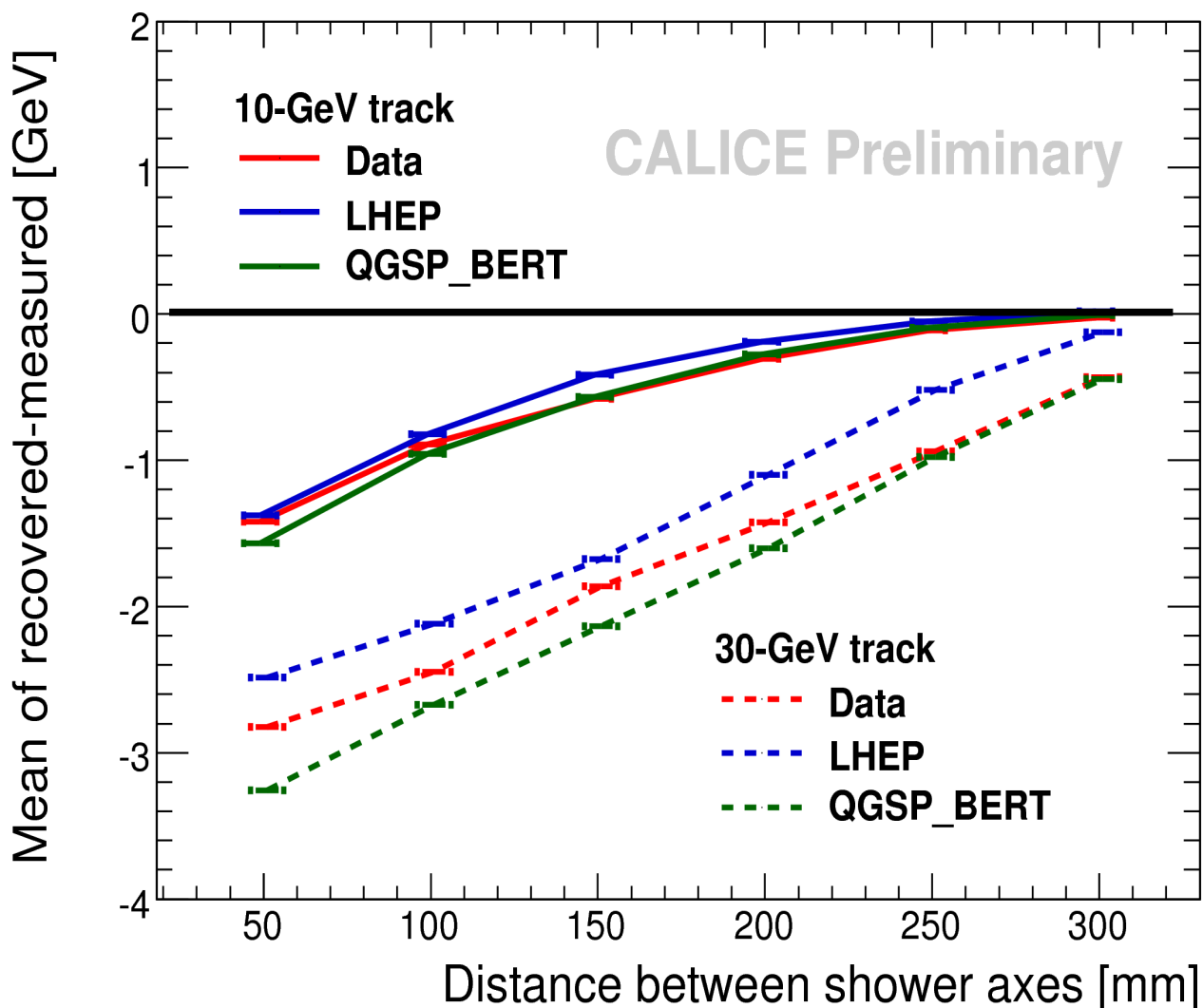

The confusion depends on the transverse size (radius) of showers and their internal structure.

The LHEP based simulation gives more narrow and more compact showers.

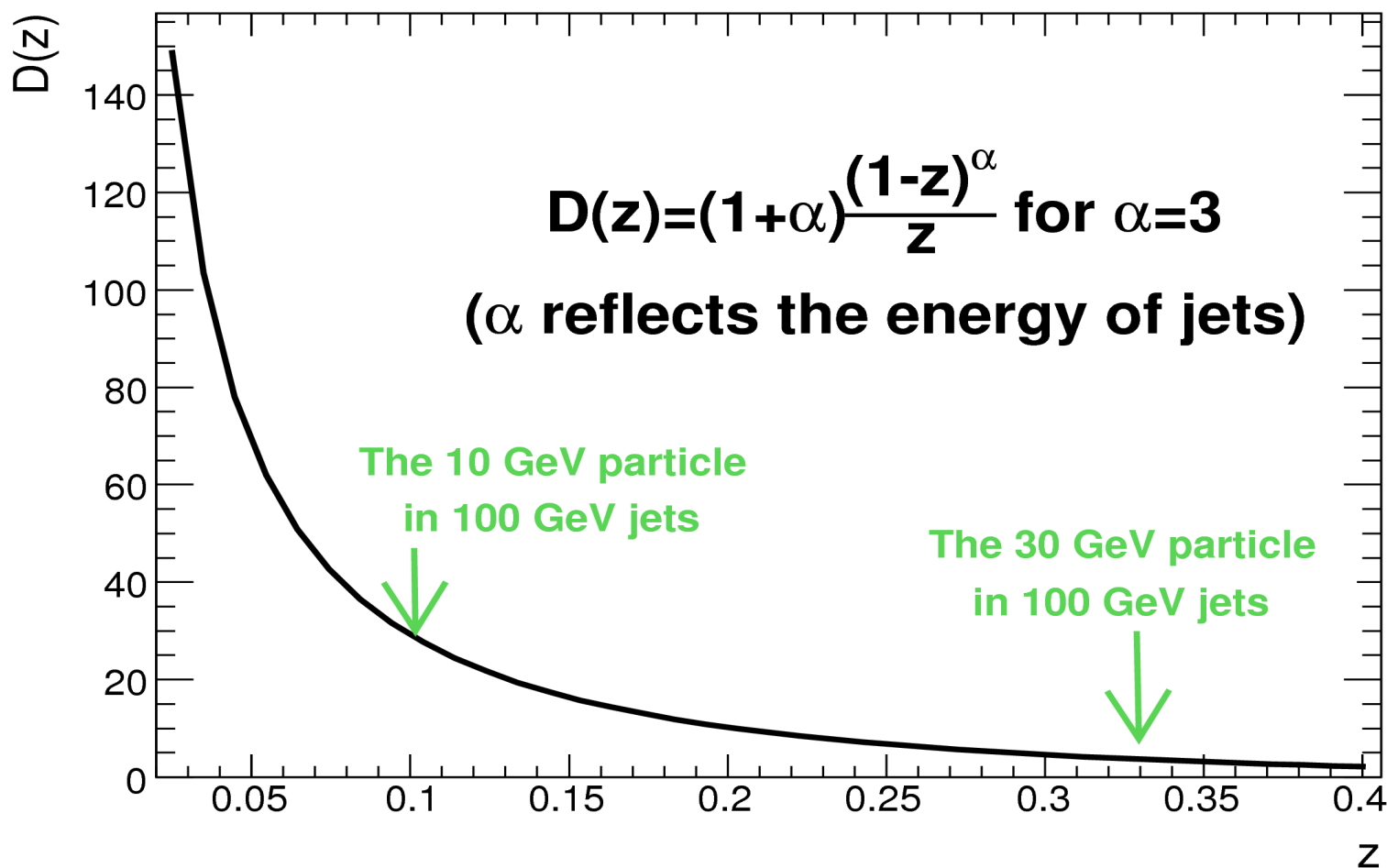Therefore, it predicts the confusion smaller than it is in reality.

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The RMS deviation of the _recovered_ energy of the neutral hadron from its energy _measured_ in the calorimeter can be interpreted as a confusion error
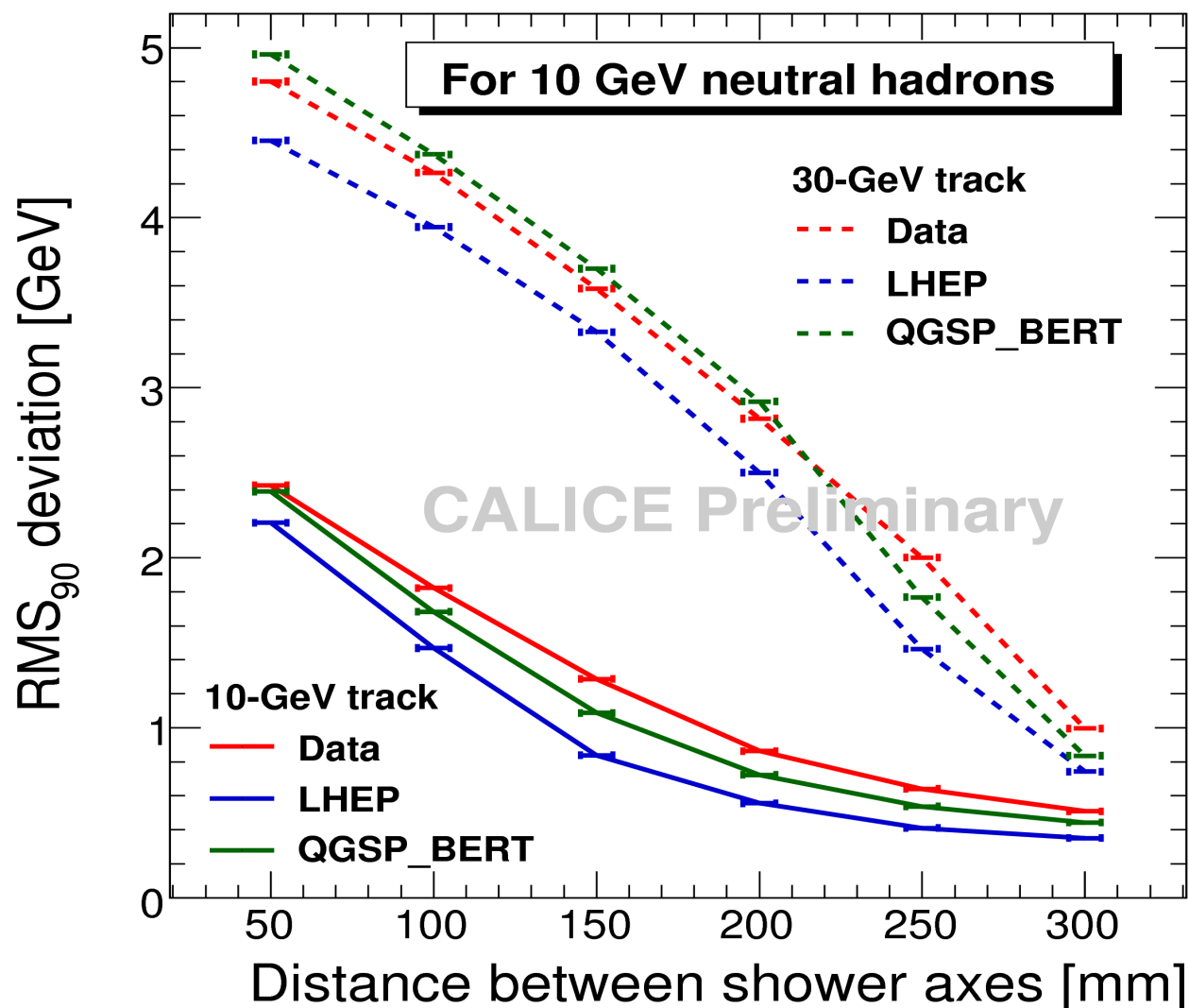
The deviation is particularly large for the 30 GeV charged pion at short distance from the neutral hadron.

This does not give a large contribution to the confusion error for jets since such an energetic particle has low probability to exist in 100 GeV jets.

For 10 GeV neutral hadrons

30-GeV track
- - - Data
- - - LHEP
- - - QGSP_BERT

CALICE Preliminary

10-GeV track
— Data
— LHEP
— QGSP_BERT

RMS_{90} deviation [GeV]

Distance between shower axes [mm]

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In jets the probability to find the charged particle carrying a fraction *z* of the jet energy is approximately given by a normalized Fragmentation Function *D(z)*

$$D(z)=(1+\alpha)\frac{(1-z)^{\alpha}}{z} \text{ for } \alpha=3$$

(α reflects the energy of jets)

The 10 GeV particle in 100 GeV jets

The 30 GeV particle in 100 GeV jets

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The probability to recover the 10 GeV neutral hadron energy within 2 and 3 standard deviations from its real energy versus the distance from the charged 10 GeV and 30 GeV pion for test beam data and MC

CALICE Preliminary

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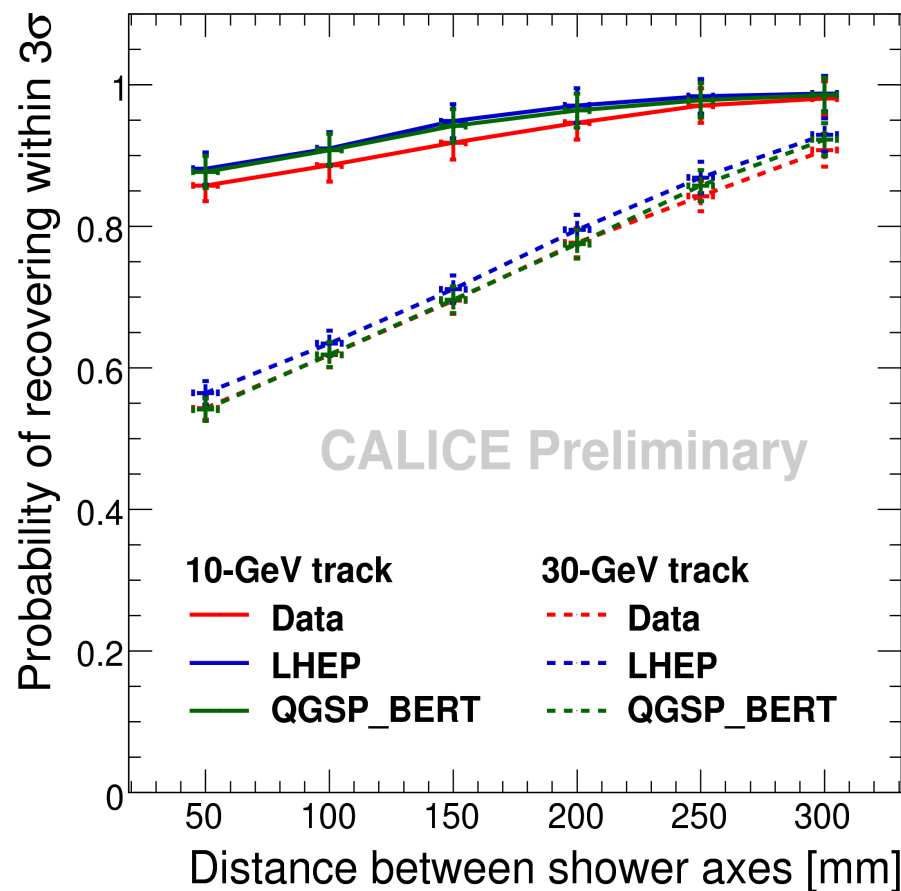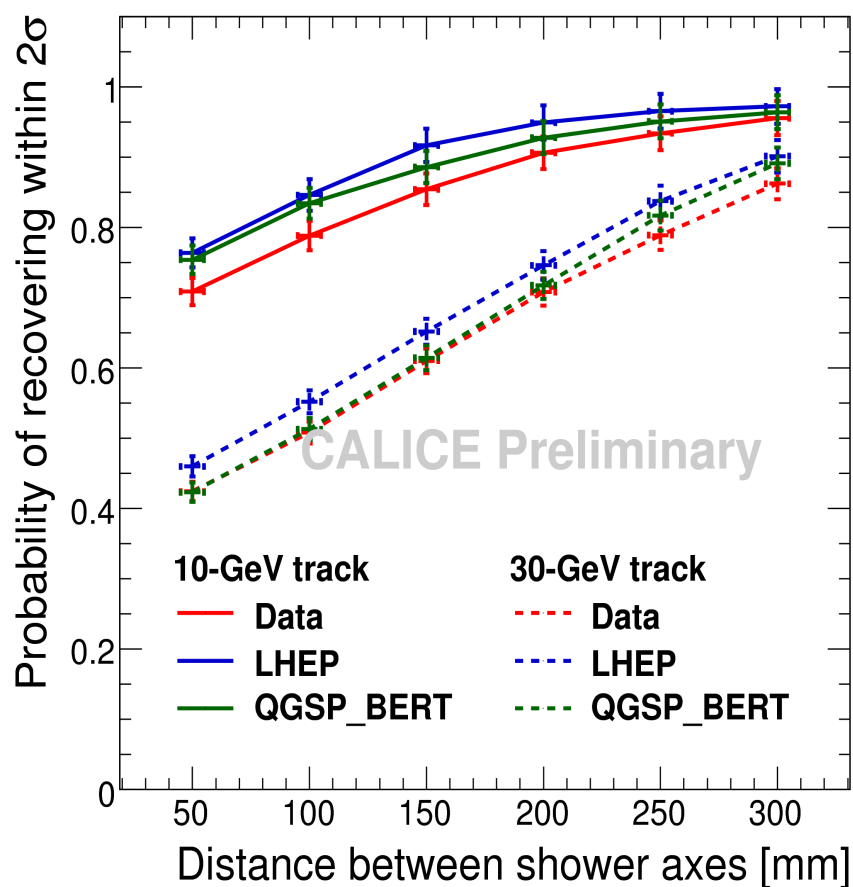
Summary

- For the first time the PandoraPFA algorithm was tested using real CALICE test beam data. We mapped pairs of CALICE test beam events shifted by the definite transverse distances from each other to the ILD 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's energies from 10 GeV to 50 GeV, typical for 100 GeV jets.

- Our results for separation of overlapped test beam showers were confronted with the results of Monte Carlo simulation for two different 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, noisy SiPMs) which could deteriorate the PFA performance were found. The PandoraPFA performance for the real data appears to be as good as for the MC simulation.

- Good agreement with MC together with the successful PandoraPFA performance for simulated jets demonstrates that the extrapolation to the full-size experiment is reliable.

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