DHCAL Response to Positrons and Pions

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Prelude

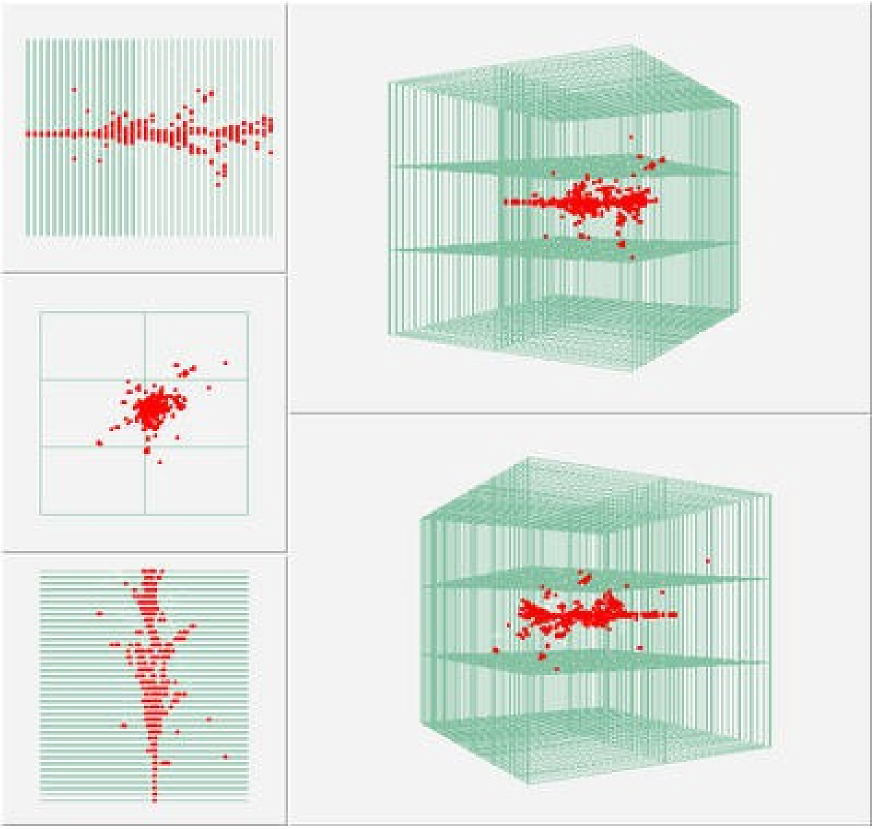
- **The large Digital Hadron Calorimeter (DHCAL) prototype was built:**
    - The active medium is Resistive Plate Chambers (RPCs).
    - Sampling calorimeter with 51 layers (38 layers DHCAL, 13 layers tail catcher - TCMT).
    - Each layer has 96 x 96 readout channels (pads) of size 1 cm x 1 cm.
    - Total number of readout channels is >470K.
    - Readout is digital: A pad registers a “1” (hit) if the signal it measures exceeds a predefined threshold, “0” otherwise.
- **The DHCAL was tested:**
    - At FNAL in October 2010 and January 2011.
    - With a broad-band muon beam, and pion and positron beams of various momenta between 2-60 GeV/c.

Scope

- Promptly investigate the calorimetric properties of the DHCAL with preliminary methods. Calorimeter response not yet calibrated, assuming uniform layer to layer response.

- Initiate the development of DHCAL-specific algorithms in calorimetry.

- Validation of the DHCAL concept.



Analysis Strategy - I

1. Event selection:

- Muon (Pion) events were triggered by the coincidence of two 1 m x 1 m (20 cm x 20 cm) scintillators.

- Look at layers 1-38 in October 2010 runs.

- Only one cluster in Layer 1 with at most four hits (Hits are clustered using a nearest neighbor approach. If two hits share a common edge, they are assigned to the same cluster). This selection rejects multiple particles in DHCAL.

- At least 3 active layers (layers with at least one hit). This selection rejects wrong triggers e.g. cosmic rays through trigger counters.

- No hits in the outer two pads in any layer (transverse containment).

2. Muon ID:

- Pick the cluster in Layer 1 and another cluster starting from the last layer and running towards Layer 1, and form a line joining these clusters.

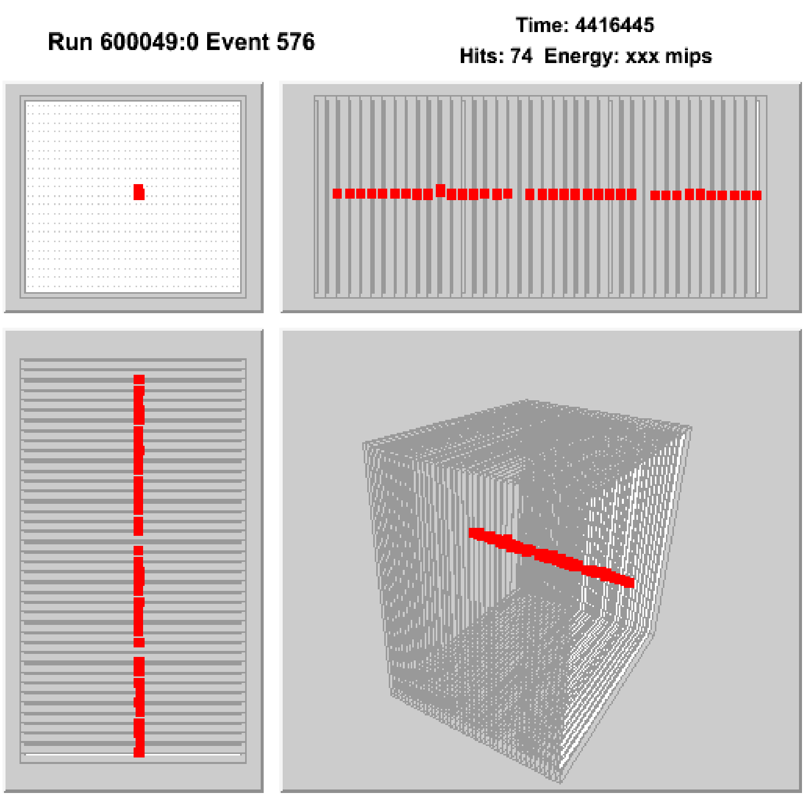
- Look at the layers in between the picked layers. Find the number of layers with clusters at a distance less than 2 cm from the line. There should be no hits in this layer from 1.5 cm to 25 cm from the predicted point (isolation criteria).

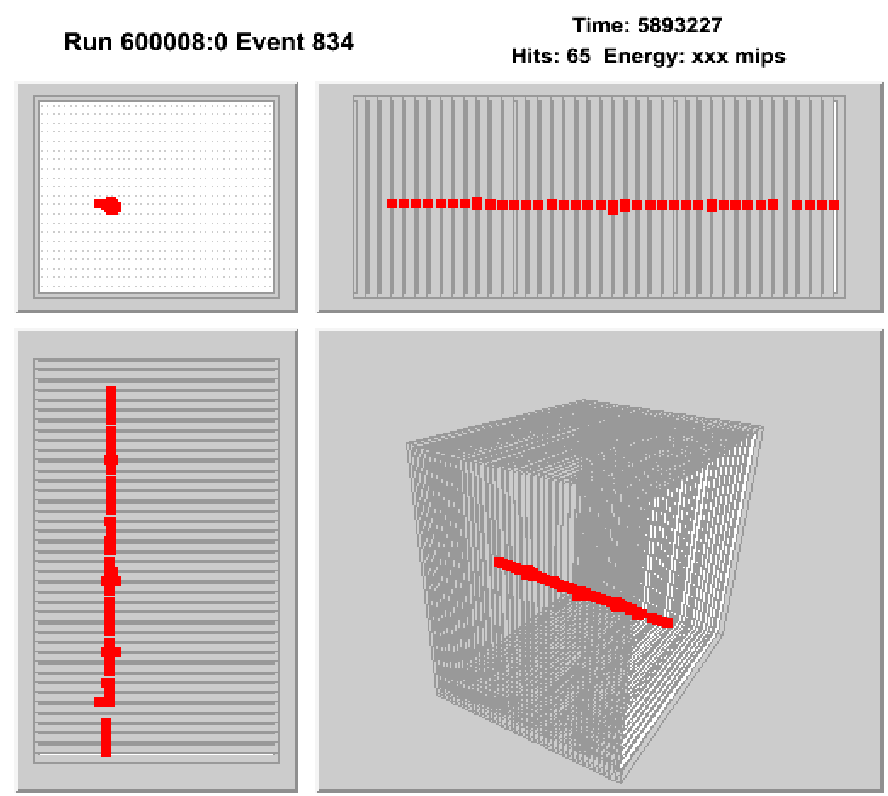
Analysis Strategy - II

2. Muon ID:

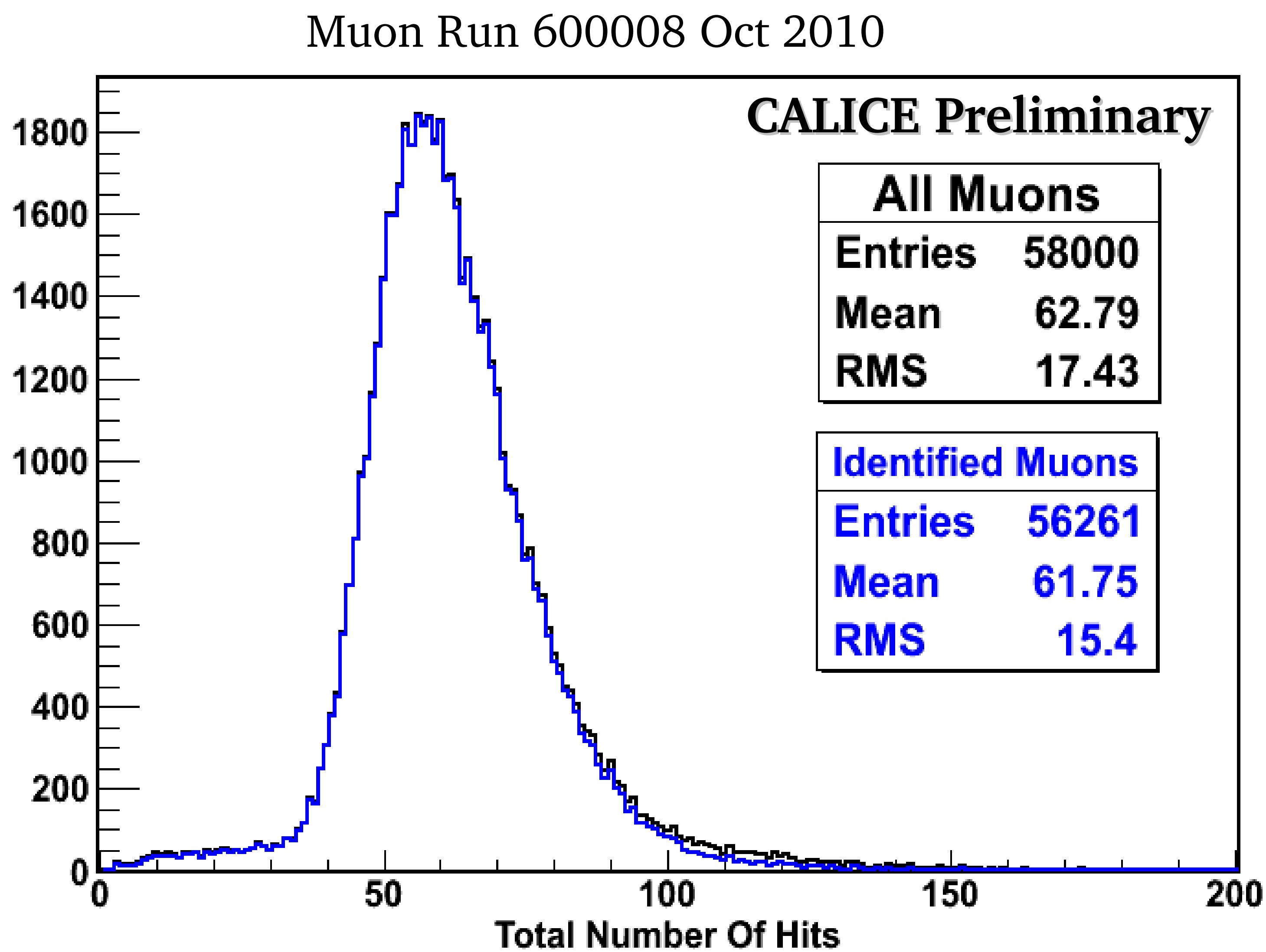
- If N_LayersInLine=N_LayersActive, identify as a muon.

- If N_LayersInLine>0.8*N_LayersActive, identify as a muon required that no two consecutive layers violate the isolation criteria (this is to include muon tracks with higher multiplicities in a few layers due to delta ray production, while avoiding interactions).





Muon ID



- Muon ID efficiency ~ 97%.
- ~ 95% of unidentified muons are eliminated in pion and positron analysis with the requirement of no hits in Layers 37-38 (last two layers).

Analysis Strategy - III

2. Pion ID:

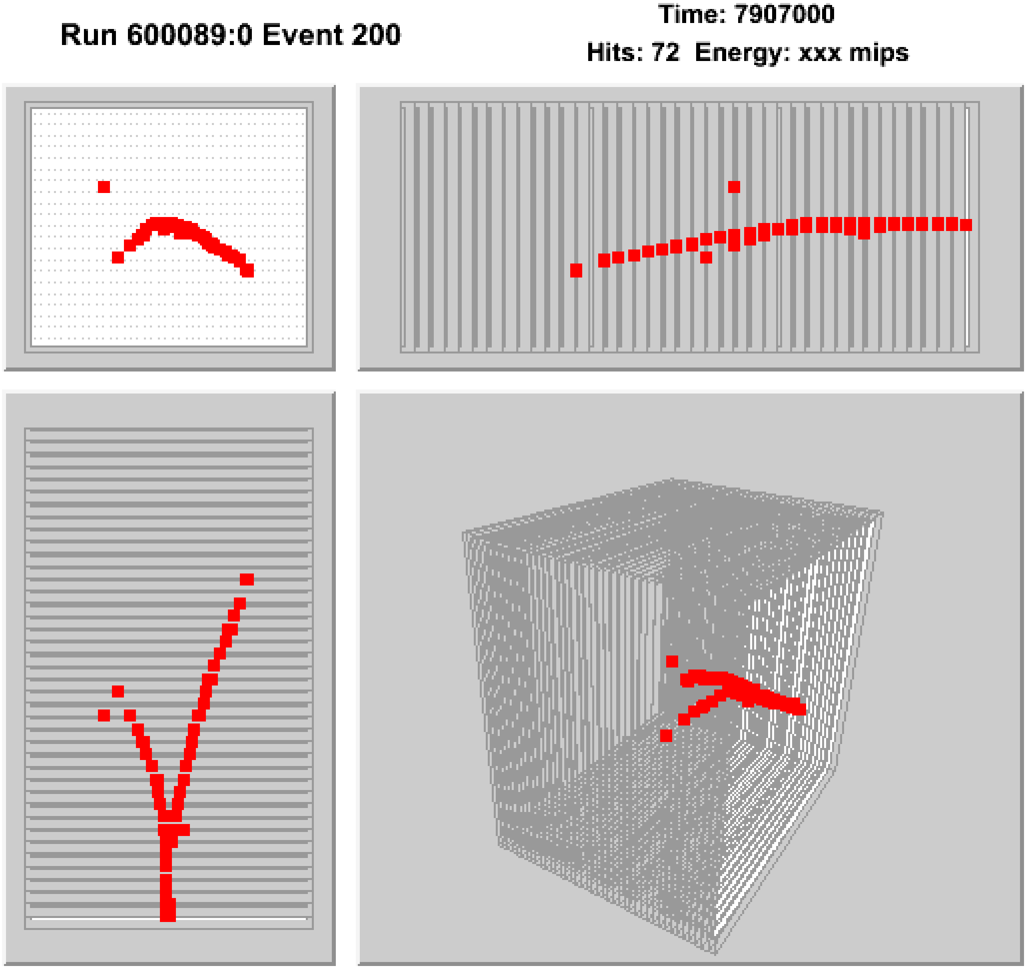
- Identify the MIP segment with an algorithm similar to Muon ID, but this time going from Layer 1 to last layer. The MIP segment ends at the "last MIP layer".

- Pick the cluster in the last MIP layer and another cluster (not aligned with the MIP segment) starting from the last layer and running towards the last MIP layer.

- Look for aligned clusters in intermediary layers (track segments).

- Identify as pion if:

  - At least one track segment with length>3 layers is found.
  - Two track segments with length=3 layers and angle>20º in between is found.



4 GeV pion

Analysis Strategy - IV

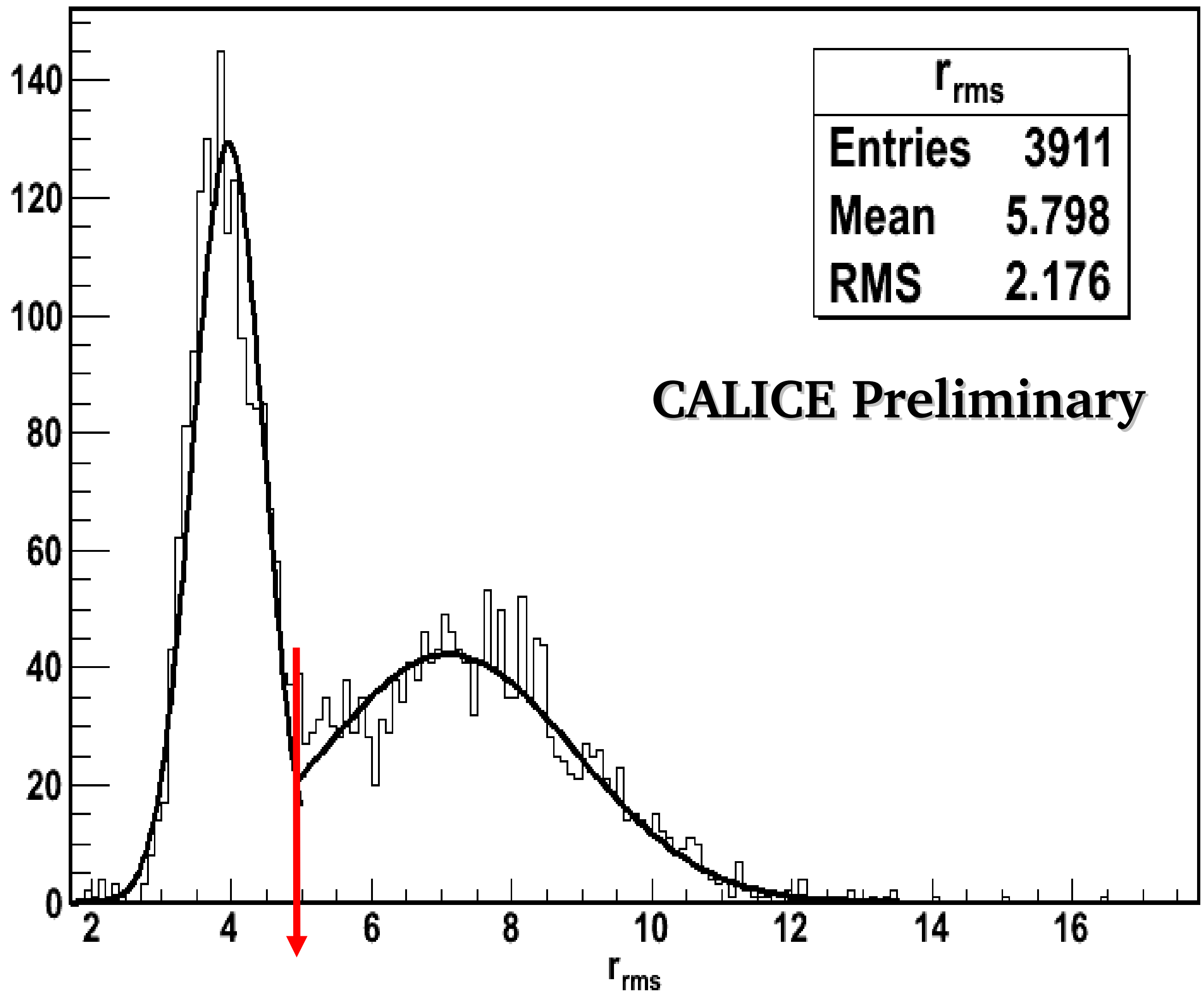
2. Pion And Positron ID:

- For the remaining events,

$$r_{rms} = \sqrt{\frac{\sum r_i^2}{N_{Hits}}}$$

variable is defined, where r_i is the distance of each hit to the x-y center of all the hits in the corresponding layer and N_{Hits} is the total number of hits.

Pion And Positron ID



r_{rms} for 20 GeV runs. A cut at 5 is applied to distinguish pions ($r_{rms}>5$) and positrons ($r_{rms}<5$). The fraction of pion (positron) events identified by this selection is ∼4% (100%) of all identified pions (positrons).

Topological Particle ID - Summary

Muons: All active layers have aligned clusters with no more than two consecutive layers with non-isolated clusters.

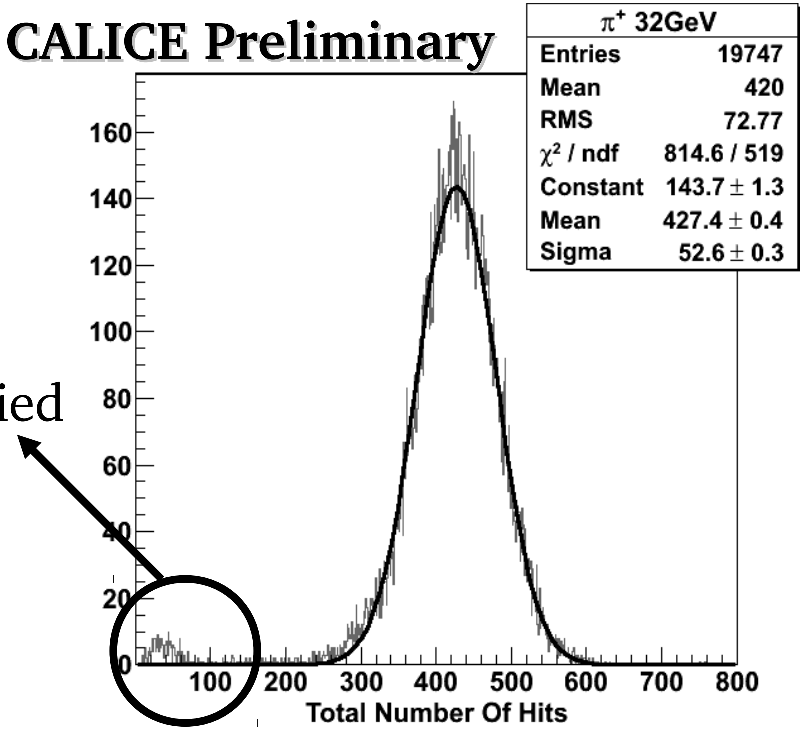
Pions: At least one track segment in the interaction region that spans at least four layers and is not compatible with the beam direction. If such a track segment is not found, at least one pair of track segments that span three layers with at least 20^{o} angle in between. $r_{rms} > 5$.

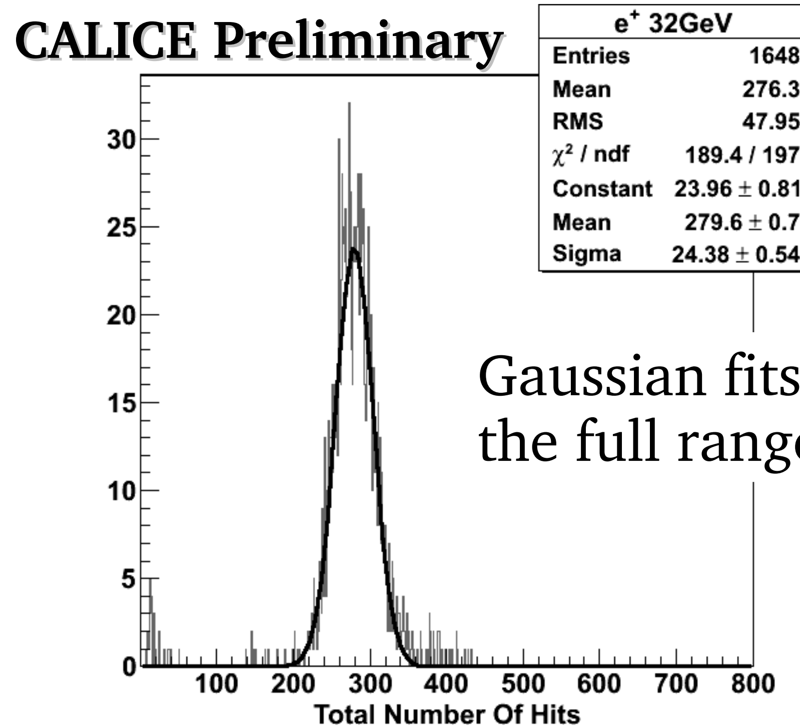
Positrons: $r_{rms} < 5$.

This is a preliminary particle ID method to provide a first look at the data. More refined methods are being developed.

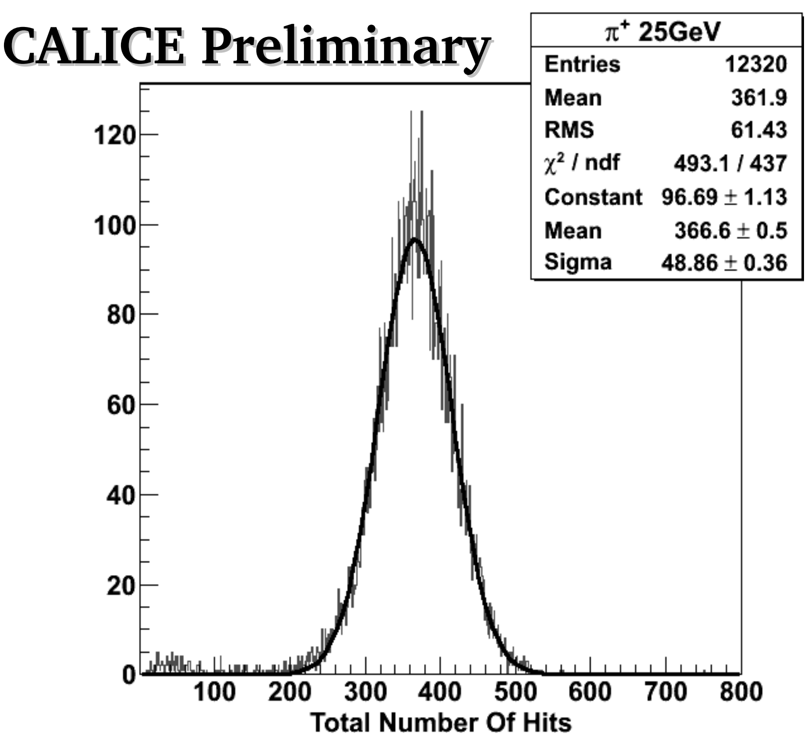
Particle ID Results in Oct '10 Data

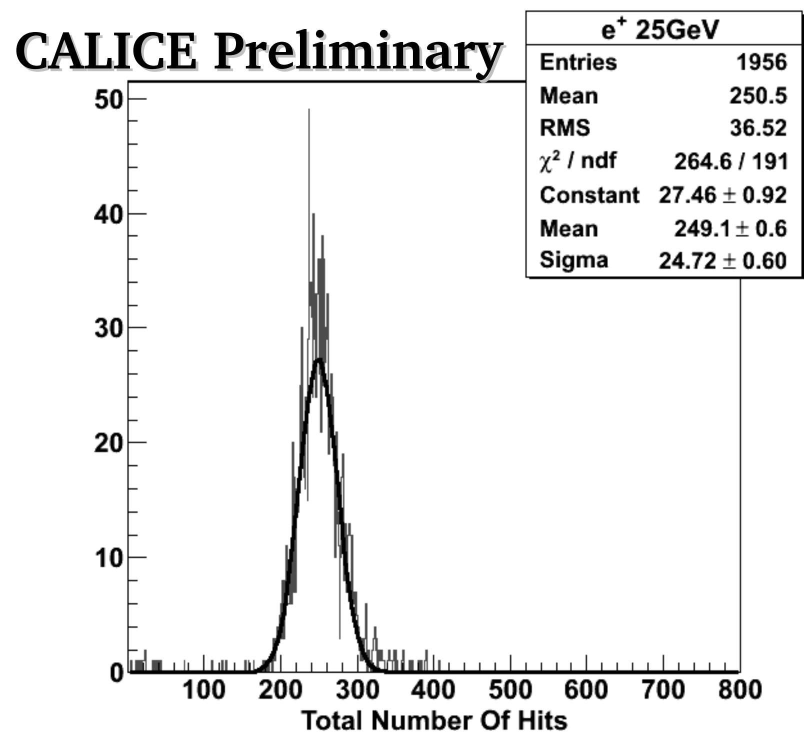
Unidentified μ's



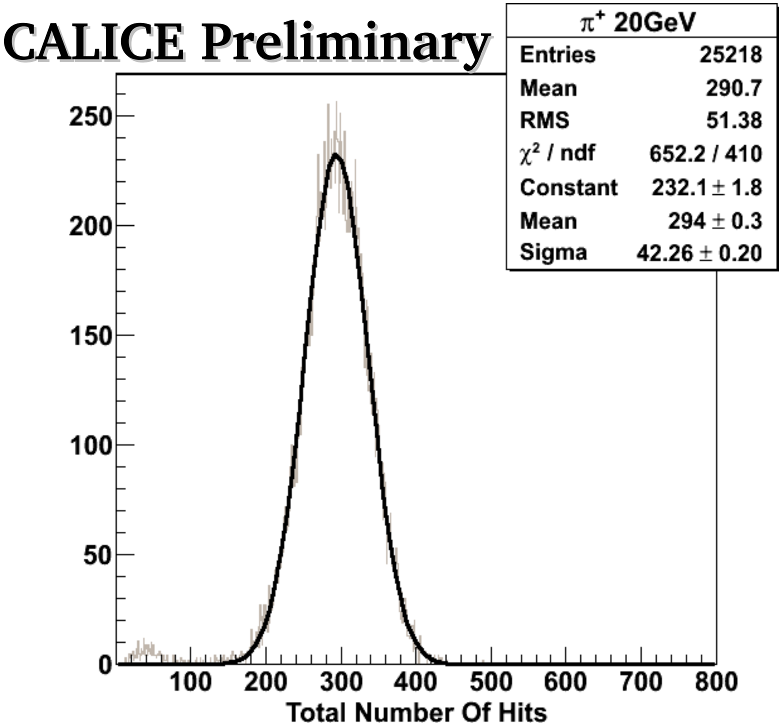


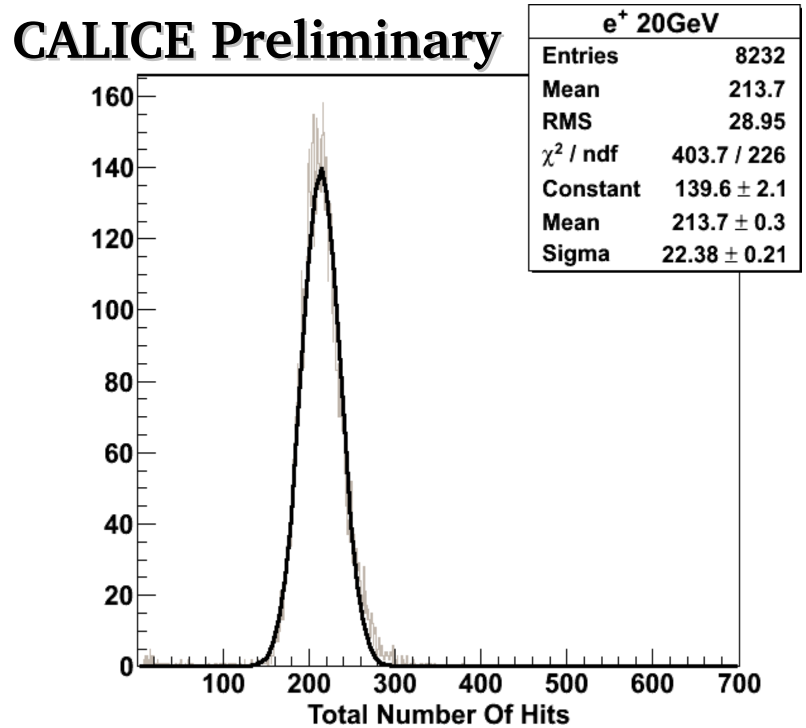
Gaussian fits for the full range

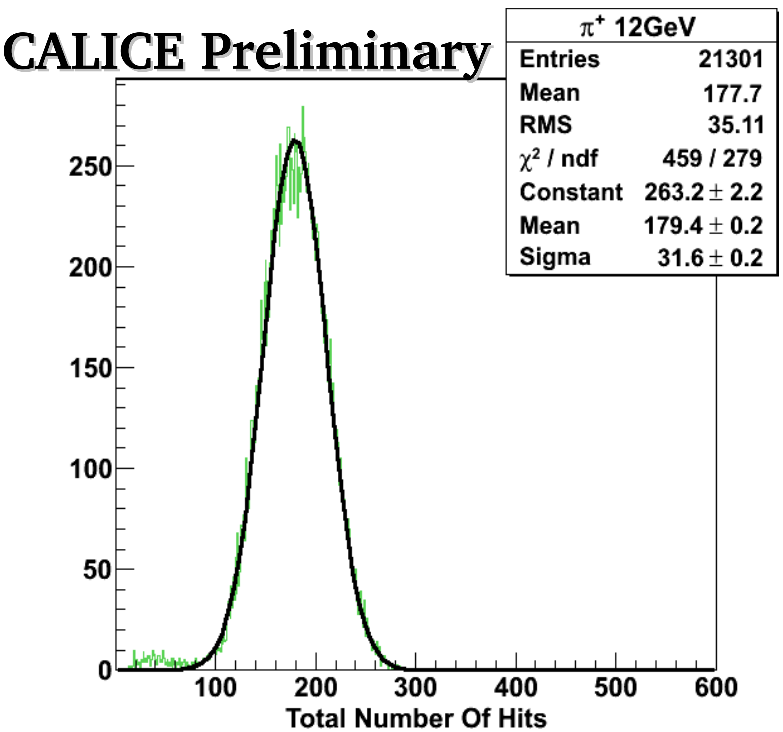


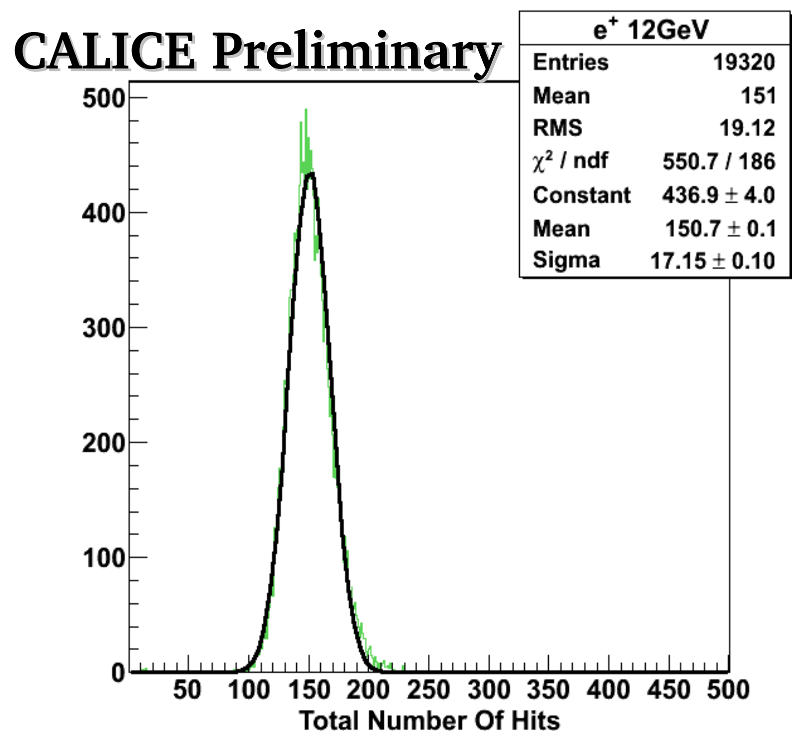


Particle ID Results in Oct '10 Data









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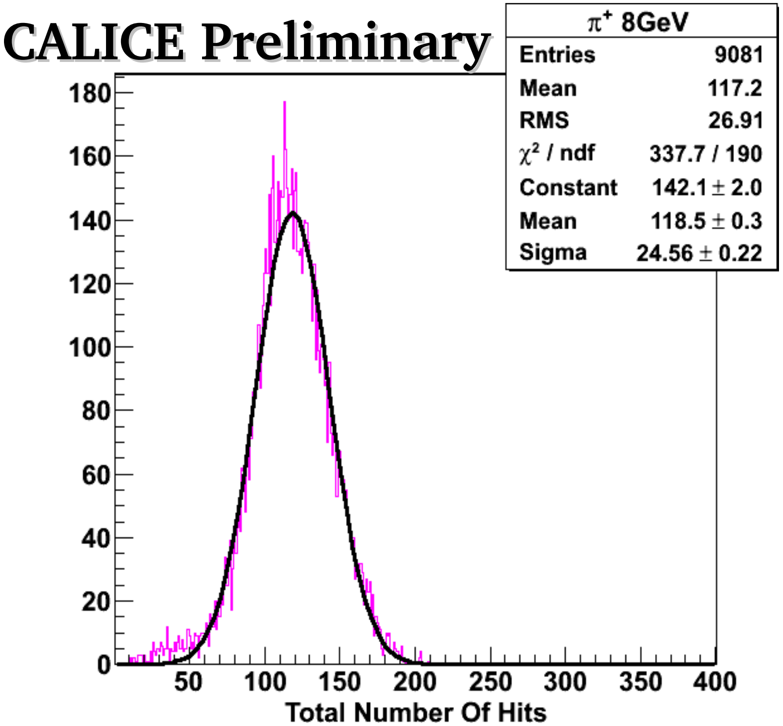
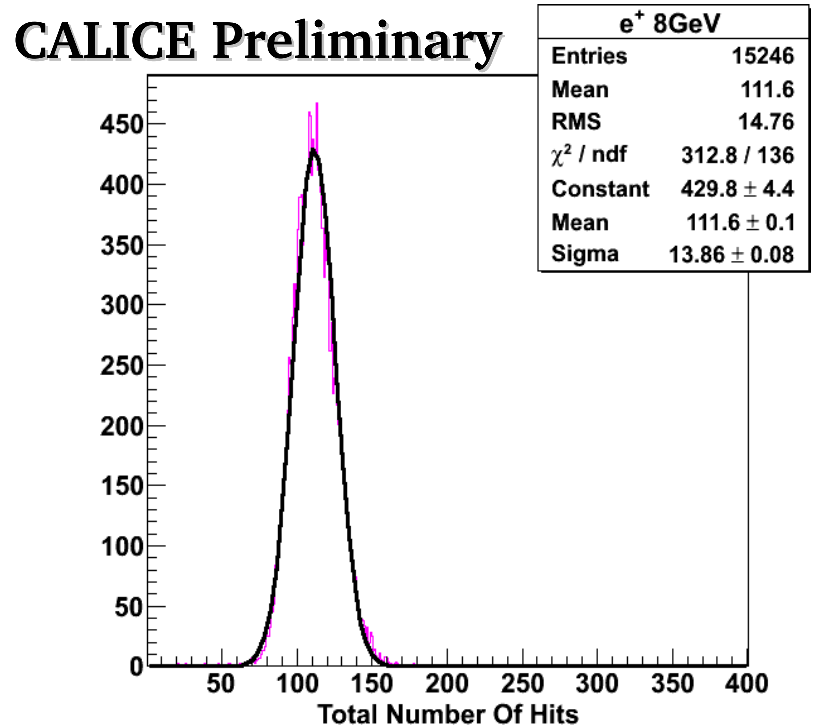
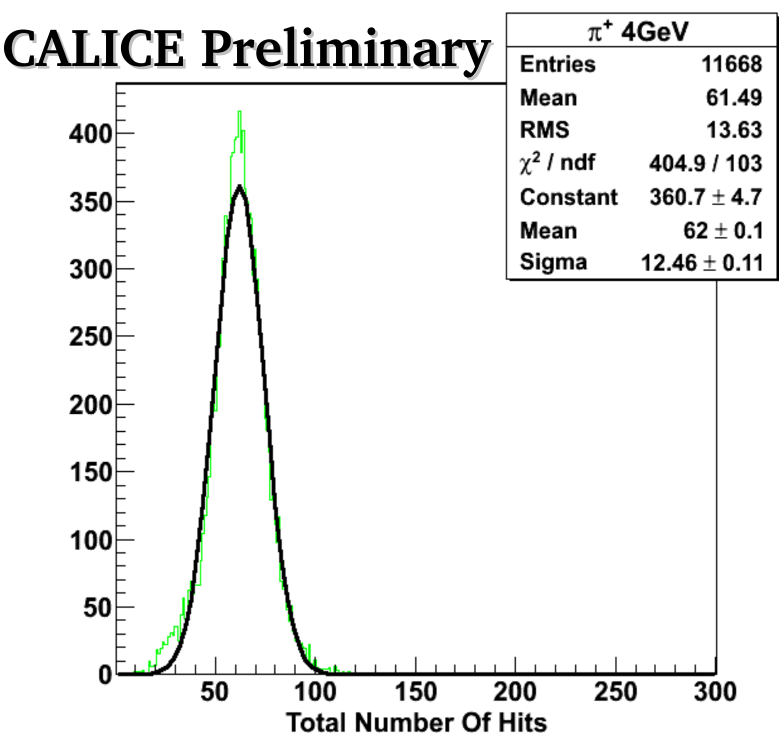
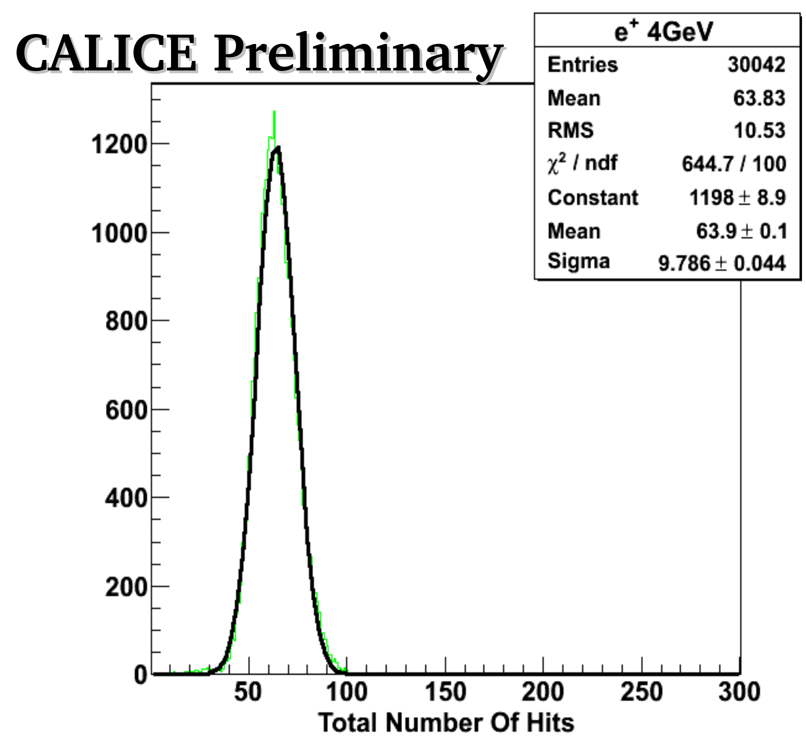
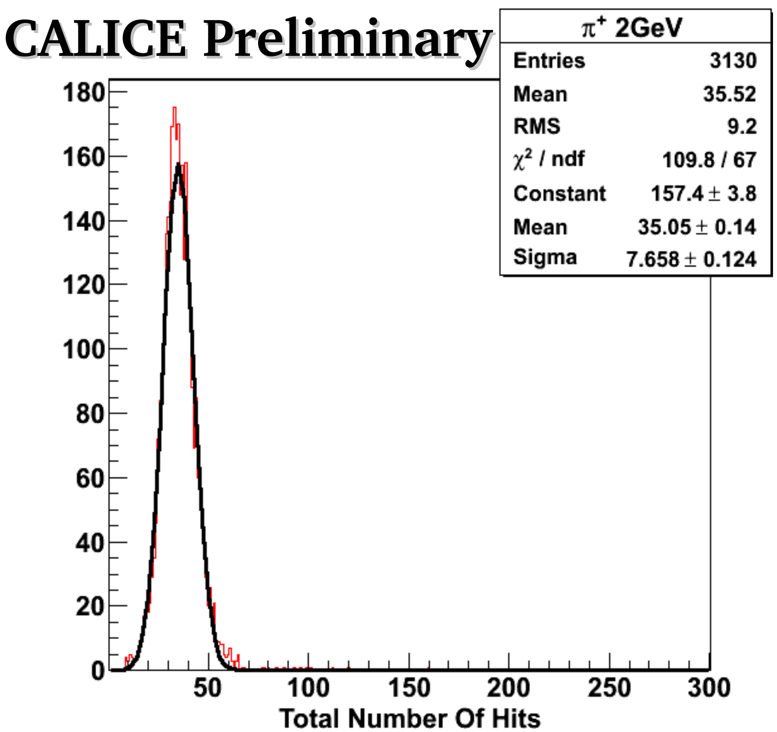


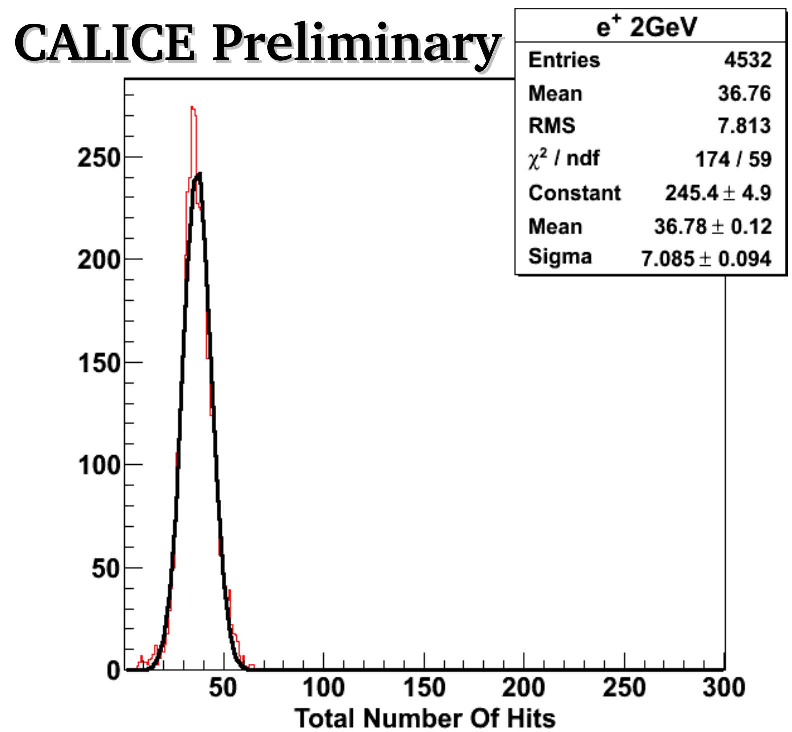






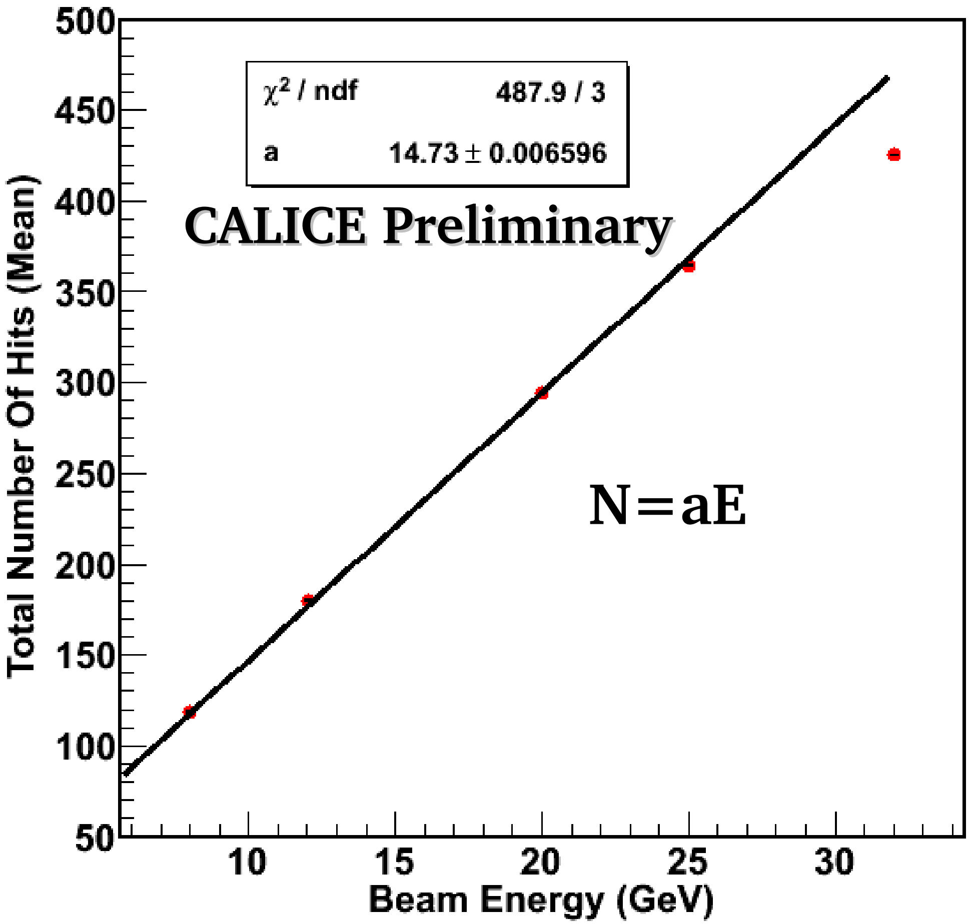
Particle ID Results in Oct '10 Data

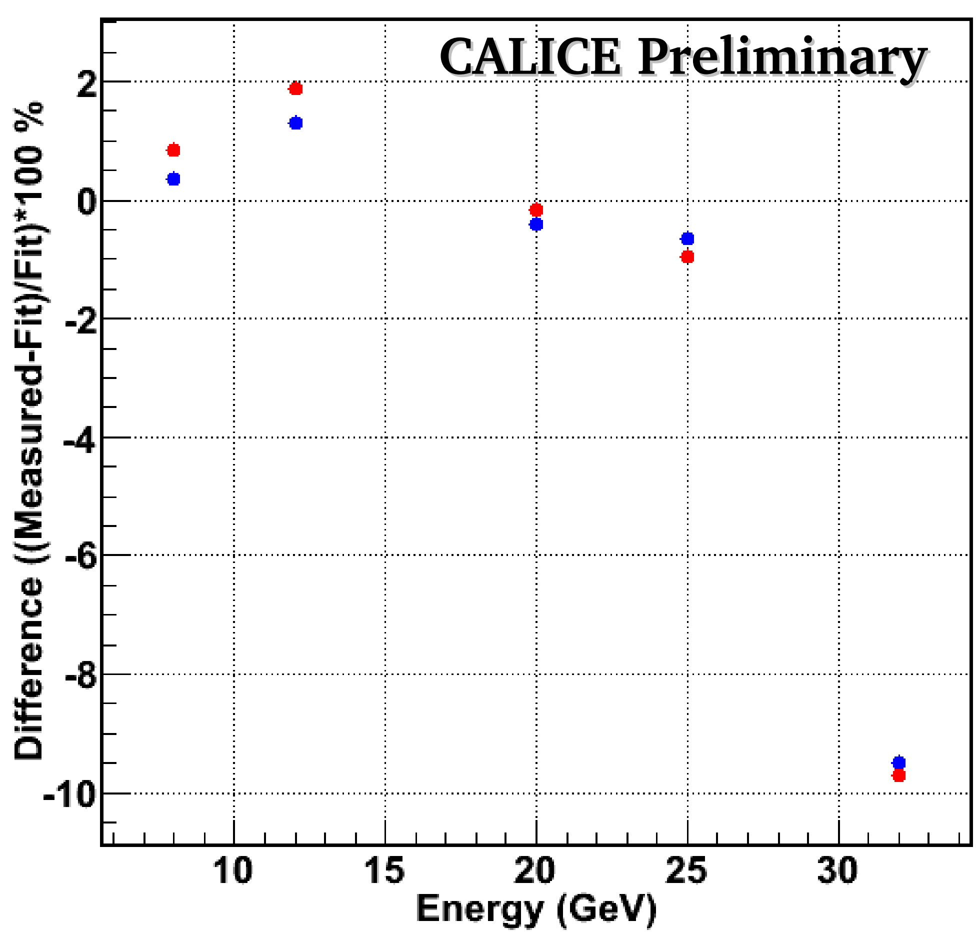




For < 8 GeV/c, the calorimeter is close to compensating. At these momenta, the pion selection is overwhelmed with positrons. We are not able to provide an unbiased sample of pions.

DHCAL Response To Hadrons (Oct '10 Data – Pion ID)

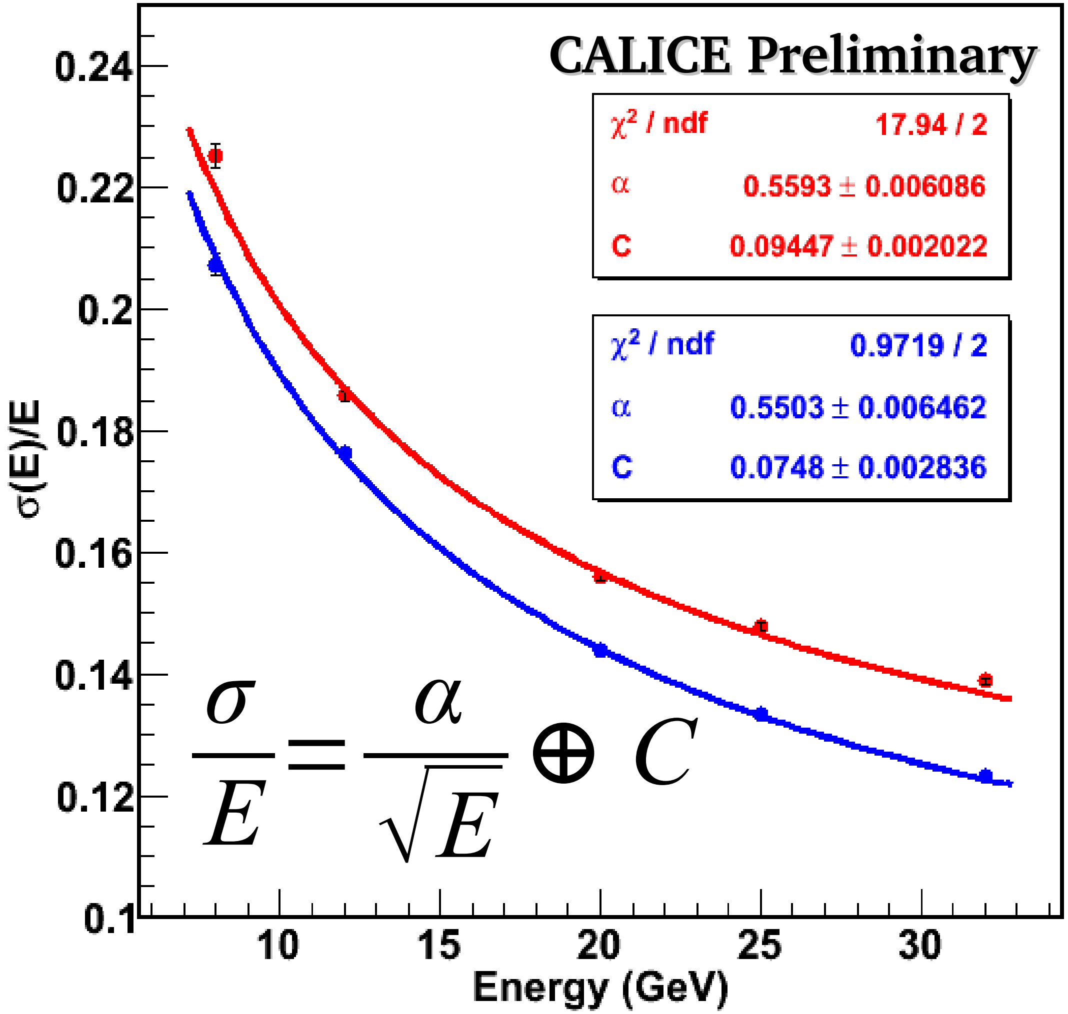


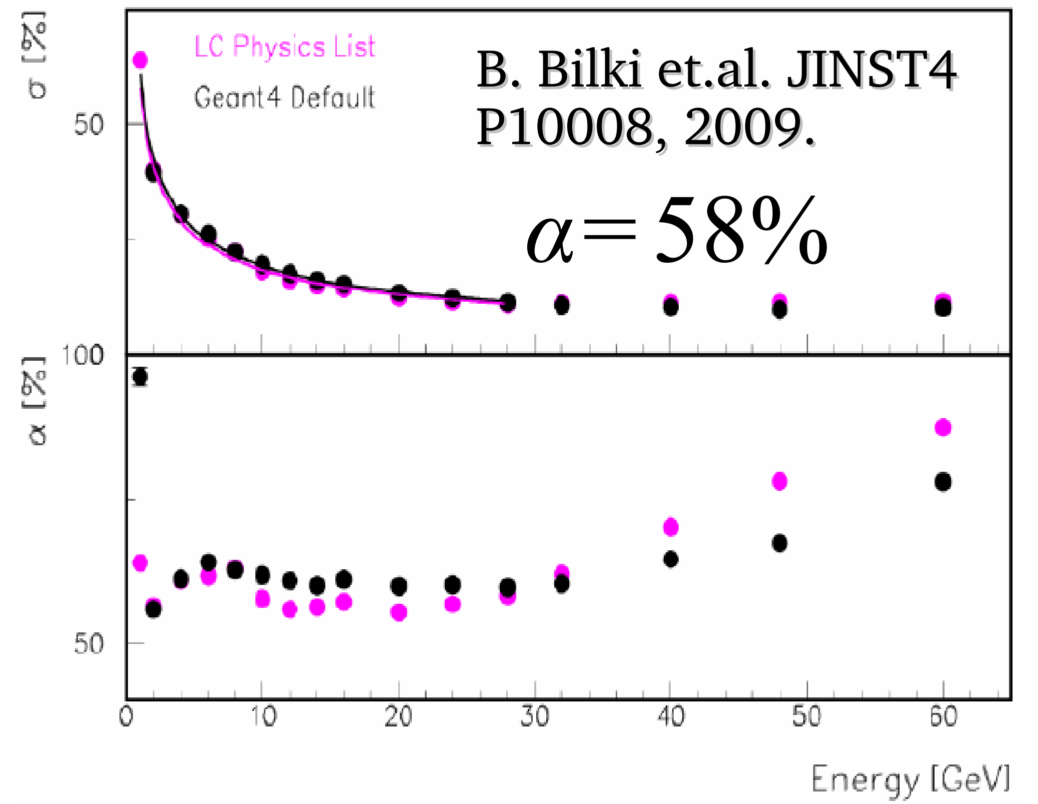


32 GeV data point is not included in the fit (saturation effects become visible).

Standard pion selection
+ No hits in last two layers

DHCAL Response To Hadrons (Oct '10 Data – Pion ID)





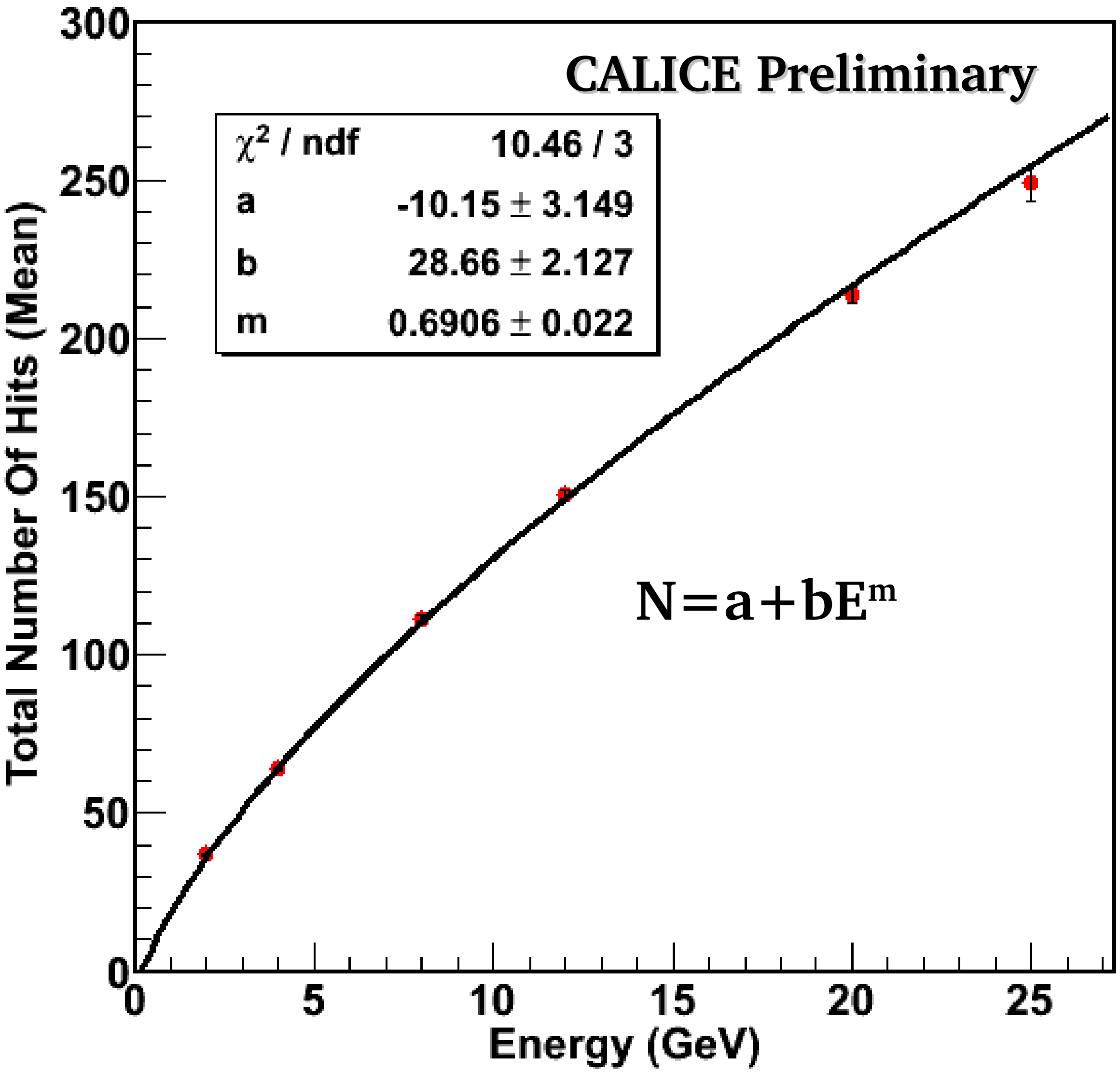
MC predictions for a large-size DHCAL based on the small-size prototype results.

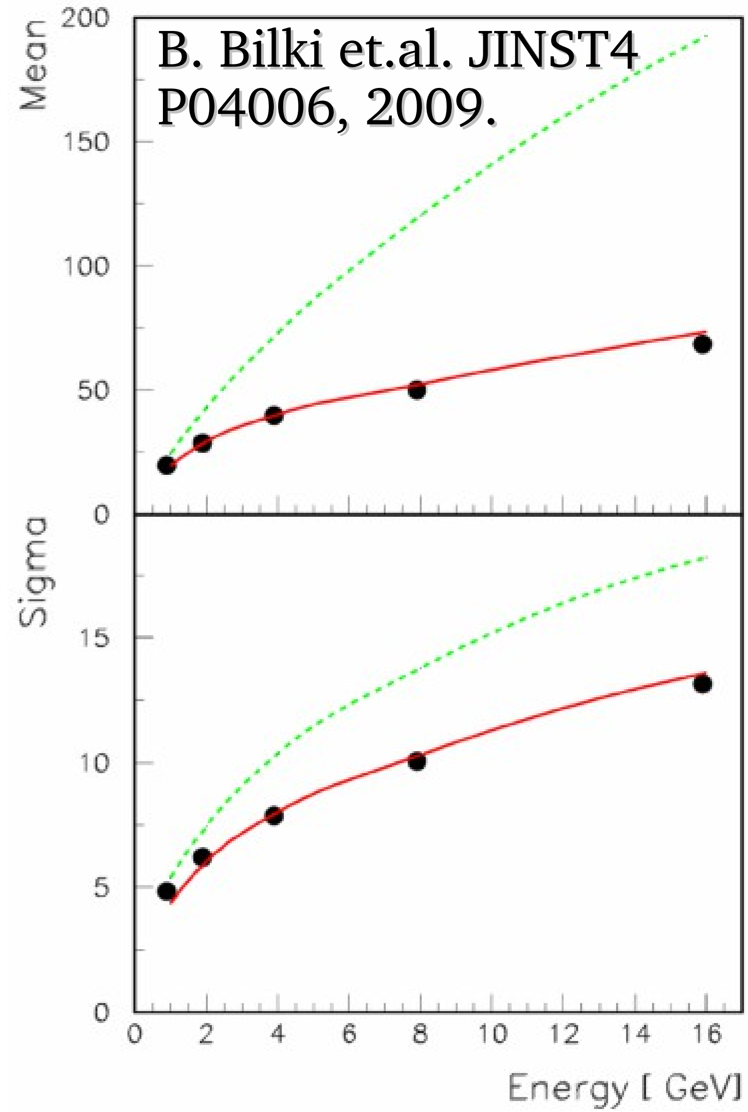
32 GeV data point is not included in the fit.

Standard pion selection

+ No hits in last two layers

DHCAL Response To Positrons (Oct '10 Data – Positron ID)

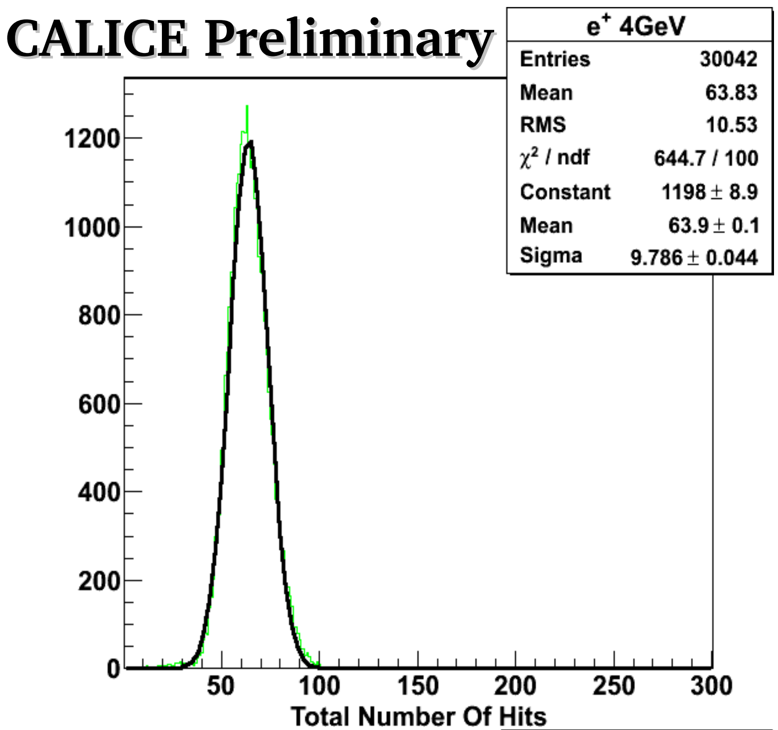


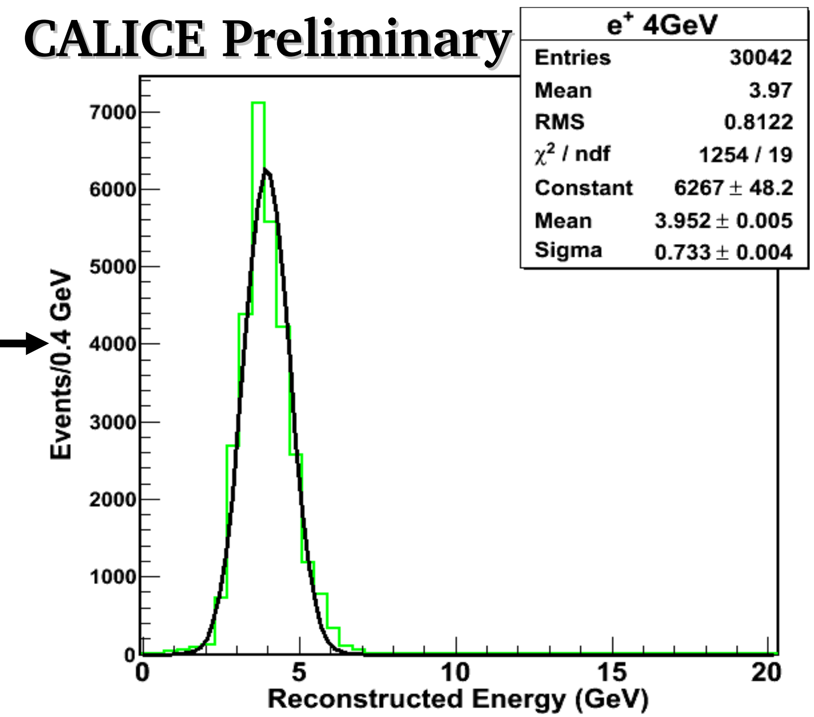


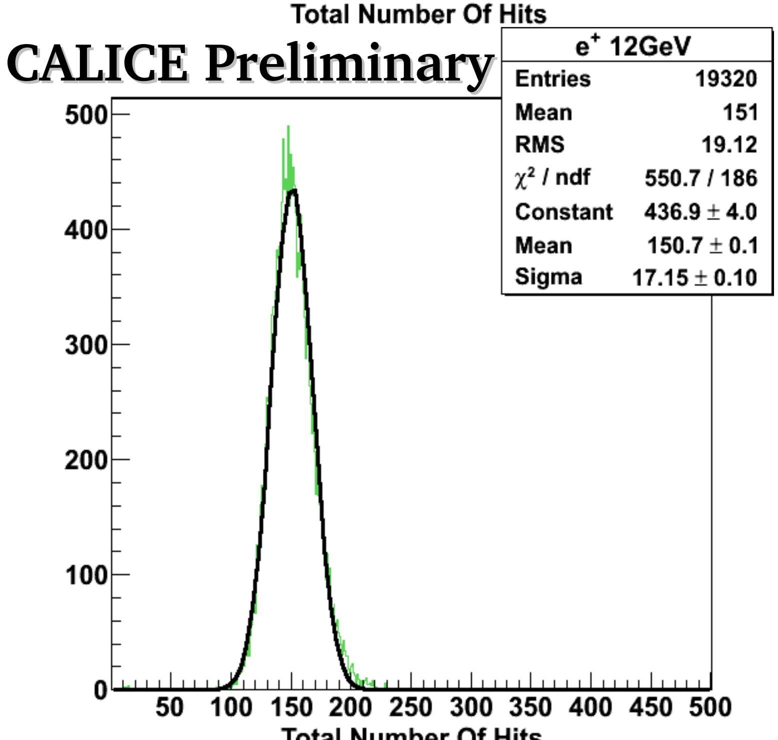
Reconstruct the positron energies using this fit function on an event by event basis.

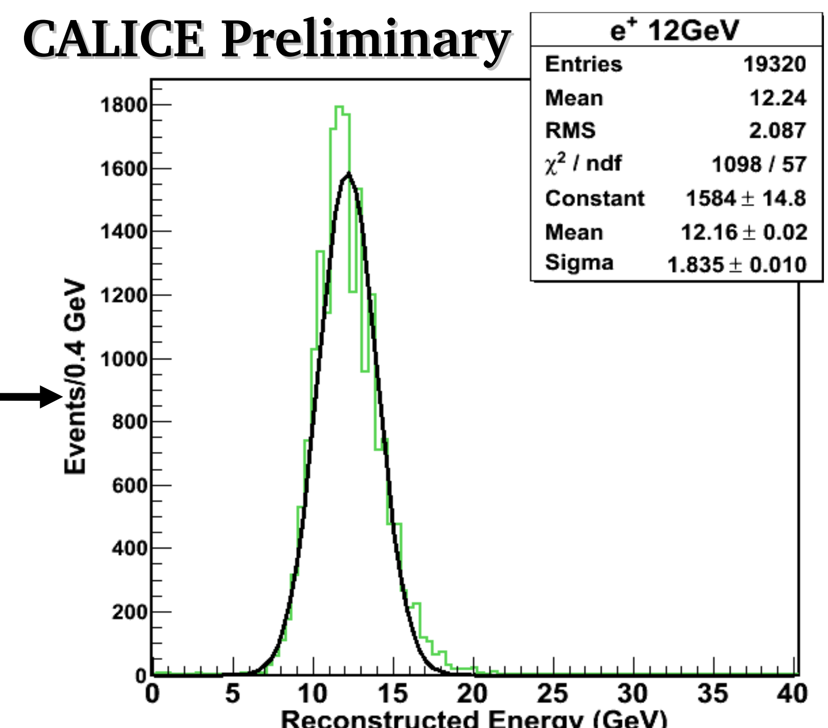
Data (points) and MC (red line) for the small-size prototype and the MC predictions for a large-size DHCAL (green, dashed line).

DHCAL Response To Positrons (Oct '10 Data – Positron ID)

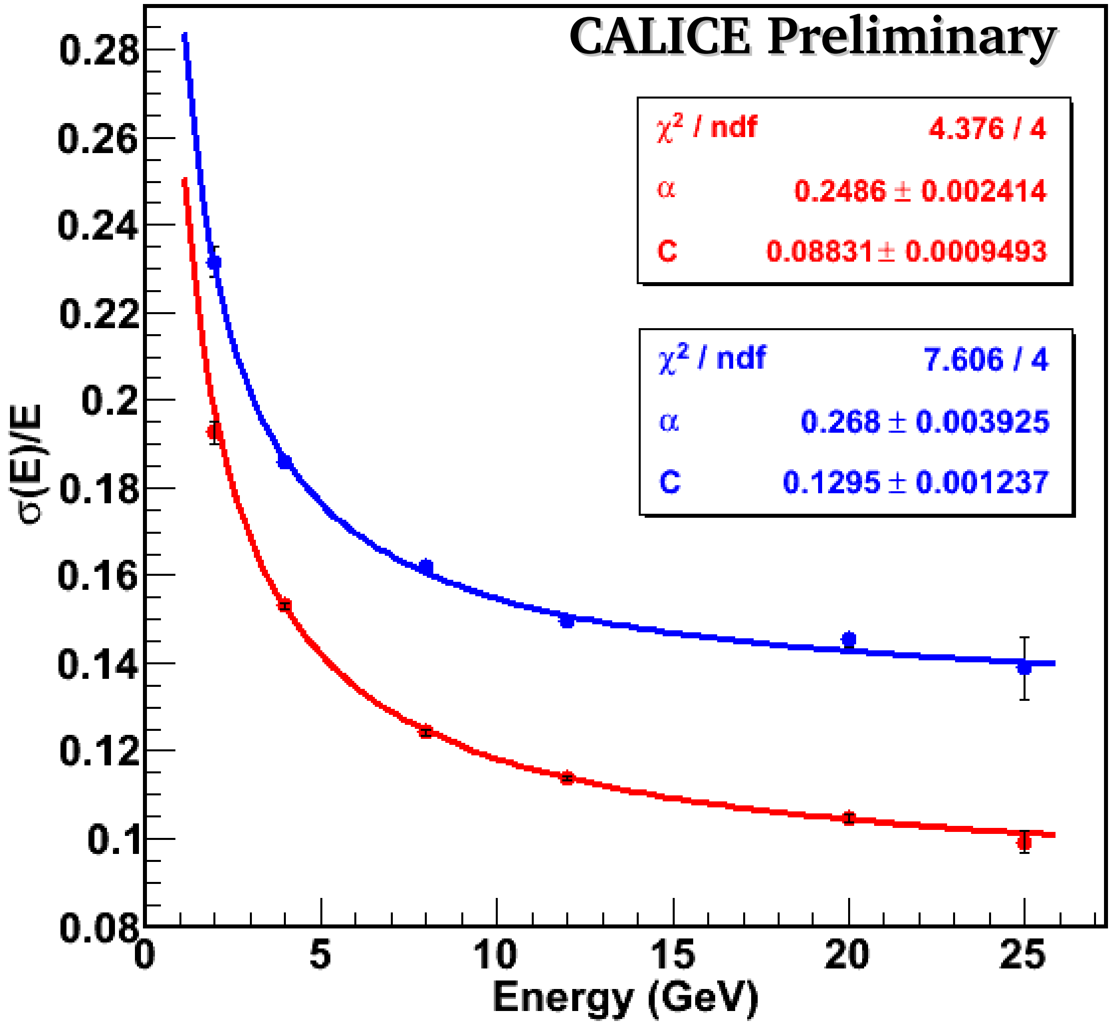








DHCAL Response To Positrons (Oct '10 Data – Positron ID)



$$\frac{\sigma}{E} = \frac{\alpha}{\sqrt{E}} \oplus C$$

Uncorrected for non-linearity

Corrected for non-linearity

Summary

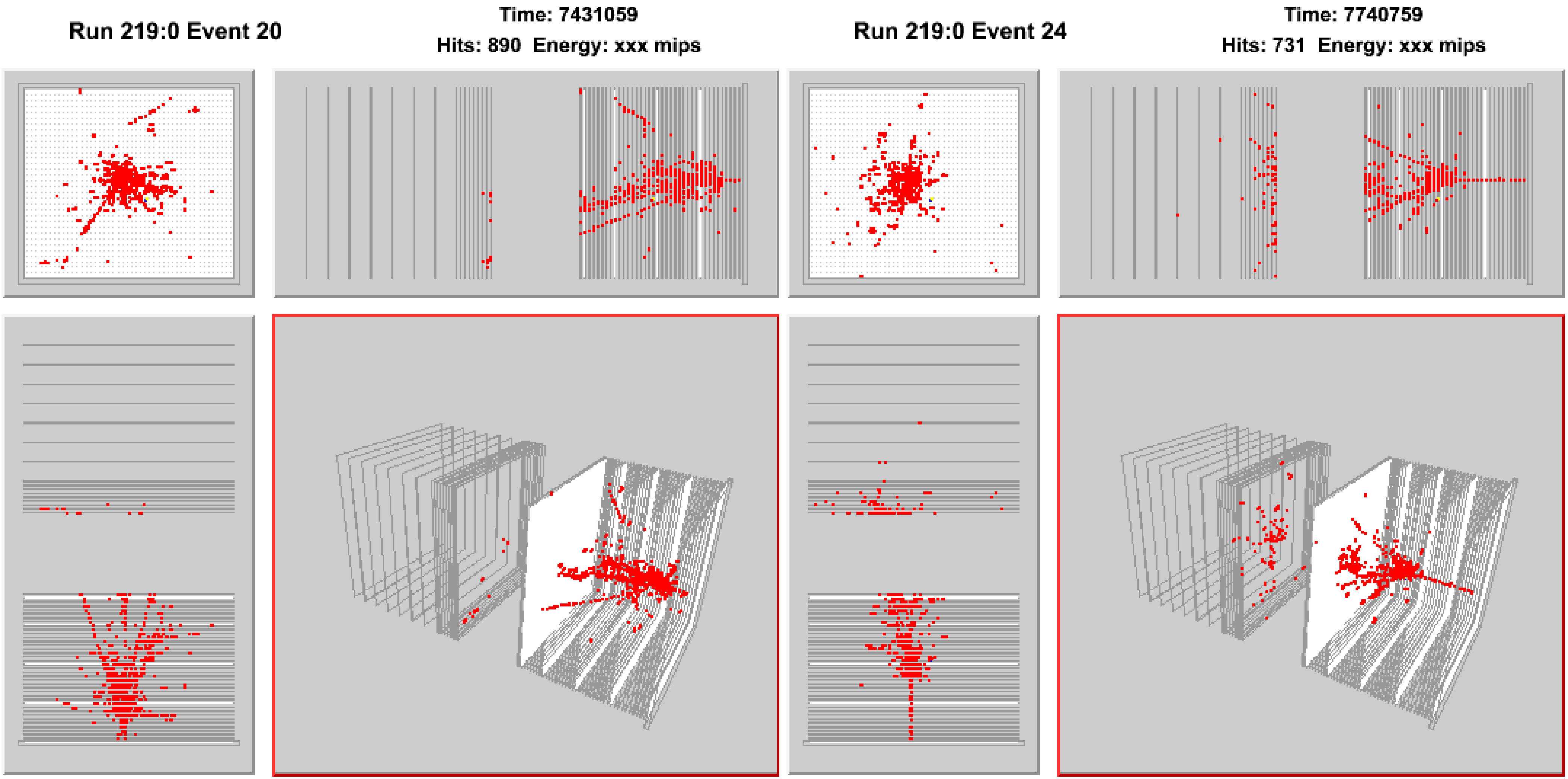
- With the two successful test beam campaigns in October 2010 and January 2011, the digital hadron calorimeter concept is being validated under extensive physics and technical tests. Here, we present a first look analysis on the October 2010 secondary beam data to obtain the digital hadron calorimeter properties. More sophisticated analyses will be forthcoming in the near future.

- The particle identification algorithms defined here provide sufficiently well discrimination at high energies. However, the complications in the event topologies at low energies require further studies to integrate these energies into the calorimetric measurements. These new algorithms are expected to improve the current measurements as well. With the present algorithms, a hadronic energy resolution of $\frac{\sigma}{E}=\frac{55\%}{\sqrt{E}}\oplus 7.5\%$, and an electromagnetic energy resolution between 24% and 14% in the energy range of 2 – 25 GeV are obtained.

- Further methods are being developed to obtain unbiased samples of pure beam particles and to obtain the DHCAL response not only as an energy measuring calorimeter, but also as a unique source of information of detailed hadronic interactions with unprecedented spatial resolution.

Epilogue

60 GeV/c pions in DHCAL



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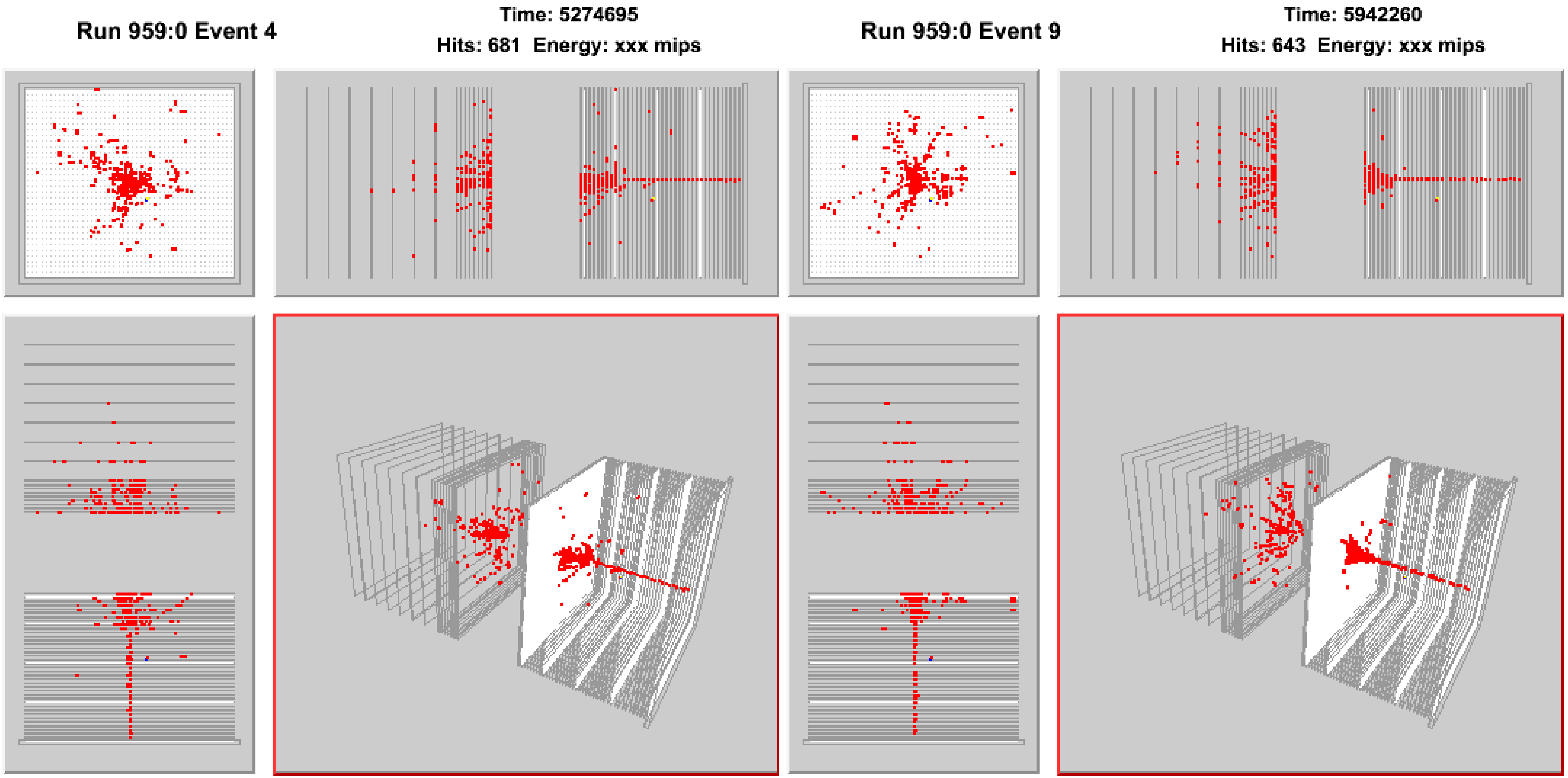

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