



DHCAL Response to Positrons and Pions

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**Technology and Instrumentation in Particle Physics
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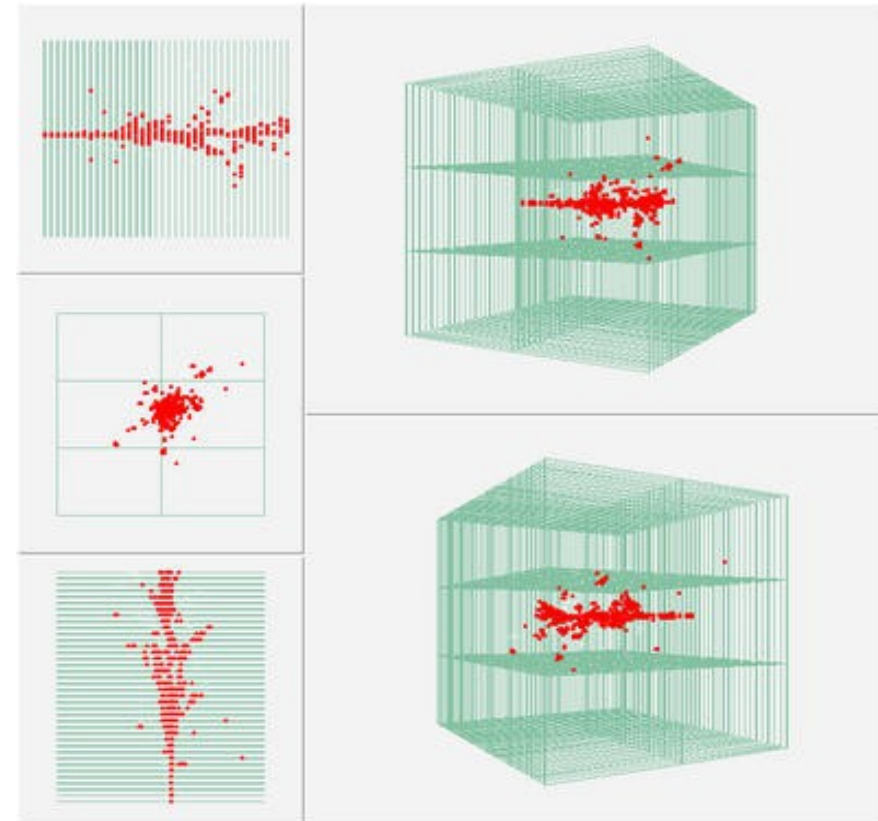
Prelude

- **The large Digital Hadron Calorimeter (DHCAL) prototype was built:**
 - The active medium is Resistive Plate Chambers (RPCs).
 - Sampling calorimeter with 52 layers (38 layers DHCAL, 14 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 $\sim 480\text{K}$ in $\sim 2\text{ m}^3$.
 - Readout is digital: A pad registers a “1” (hit) if the signal it measures exceeds a predefined threshold, “0” otherwise.
- **The DHCAL was tested (is being tested):**
 - At FNAL in October 2010, January 2011, April 2011 (with SiW ECAL) and May 2011 - (currently in the beamline).
 - With a broad-band muon beam, pion and positron beams of various momenta between 2-60 GeV/c and the primary proton beam at 120 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.

A 16 GeV/c pion event



Analysis Strategy - I

Event selection

Cluster hits in each layer using closest-neighbor clustering (1 common side)

- 1) Exactly 1 cluster in layer 1 (\leftarrow rejects multi-particle events)
- 2) Not more than 4 hits in layer 1 (\leftarrow rejects upstream interactions)
- 3) At least 3 layers with hits (\leftarrow rejects spurious triggers, cosmic rays)
- 4) No hits within 2 cm to layer edges (\leftarrow improves lateral containment of showers)

Identify muon tracks

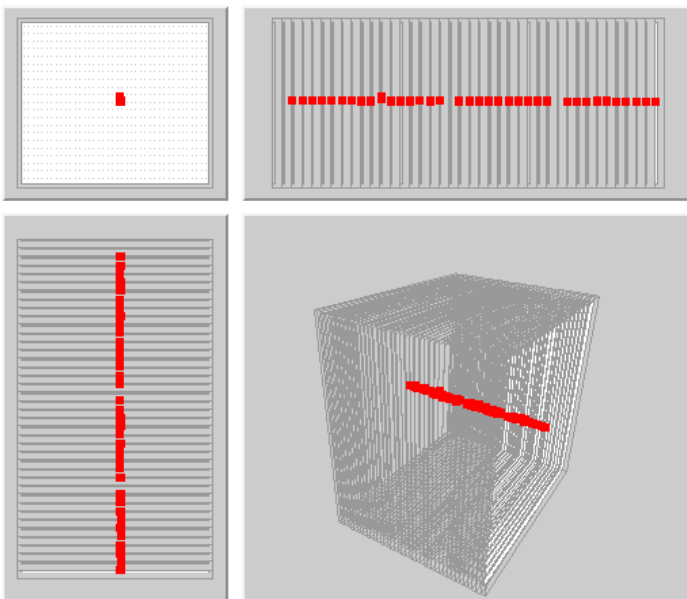
- 1) Count layers with at least 1 hit = N_{active}
- 2) Draw line from cluster in layer 1 with last cluster in stack
- 3) Count clusters in intermediate layers and within 2 cm of line = N_{match}
- 4) Identify layers with additional hits within a cylinder with $1.5 \text{ cm} < R < 25 \text{ cm}$ around line

If $N_{\text{match}} = N_{\text{active}}$ \rightarrow **Identify as muon**

If $N_{\text{match}} > 0.8 N_{\text{active}}$ and no 2 consecutive layers with additional hits \rightarrow **Identify as muon**

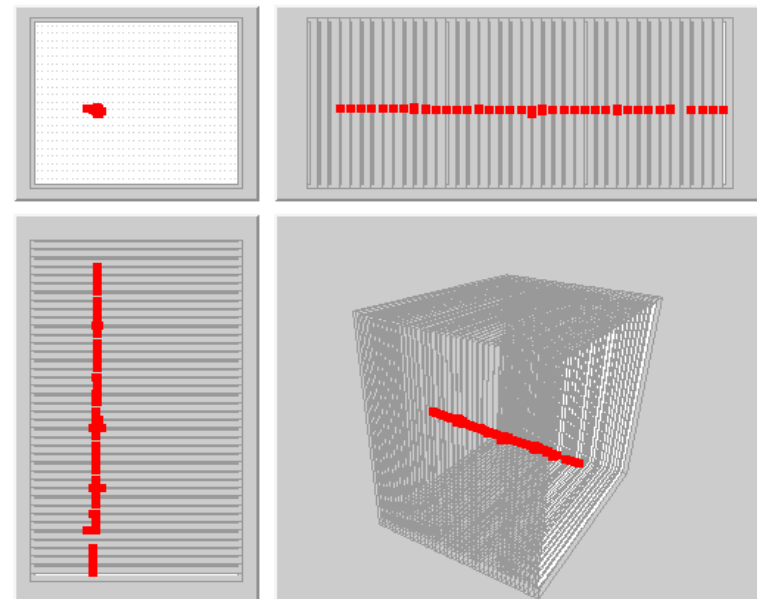
Run 600049:0 Event 576

Time: 4416445
Hits: 74 Energy: xxx mips



Run 600008:0 Event 834

Time: 5893227
Hits: 65 Energy: xxx mips



Analysis Strategy - II

Test muon ID

Muon Run

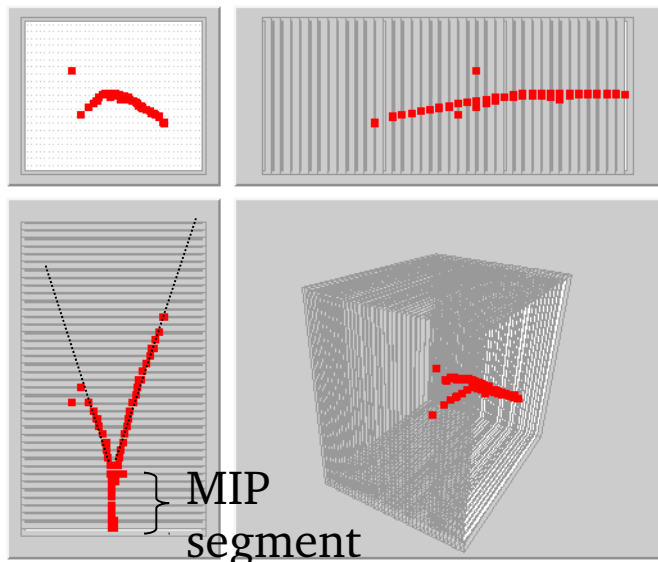
Efficiency $\sim 97\%$

Remaining 3% not included in pion/positron sample, due to longitudinal containment cut

4 GeV/c pion event

Run 600089:0 Event 200

Time: 7907000
Hits: 72 Energy: xxx mips



Pion ID

(Easy at high momenta, tough < 8 GeV/c)

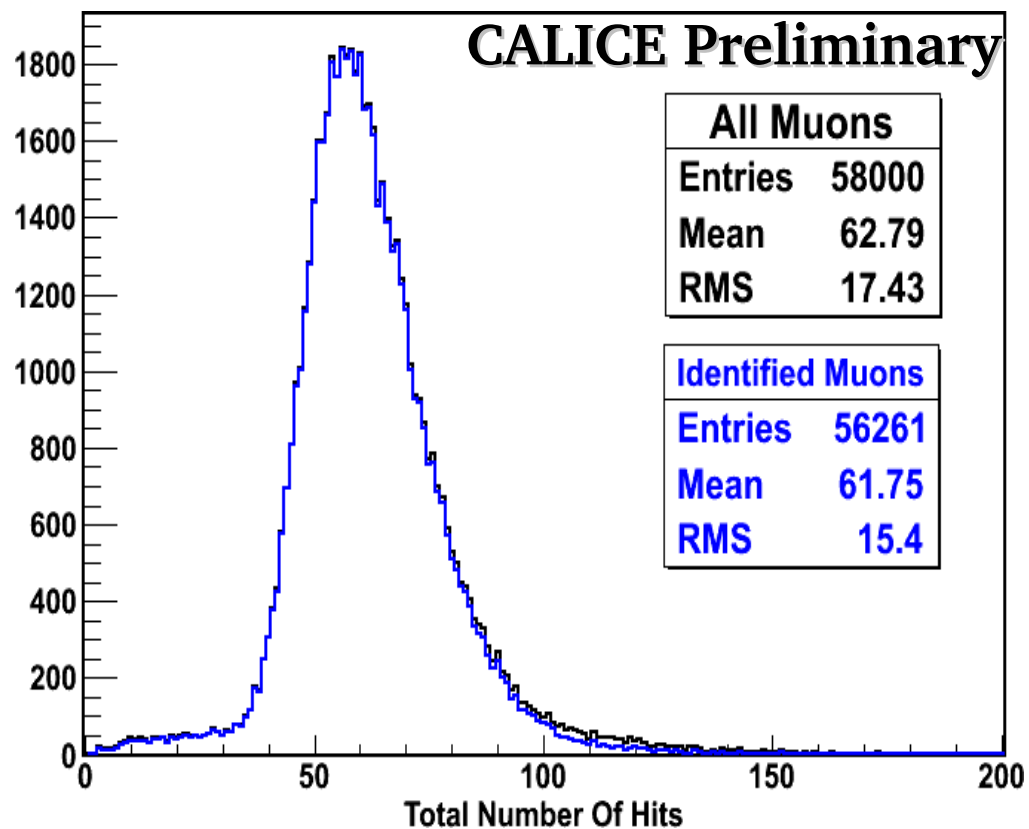
Identify MIP segment starting from layer 1 following the muon id

Identify the clusters in the forward layers and

draw line to last MIP cluster (not compatible with the beam direction)

If at least 4 intermediate clusters \rightarrow **pion**

If 2 track segments found with at least 3 layers and angle $> 20^\circ \rightarrow$ **pion**

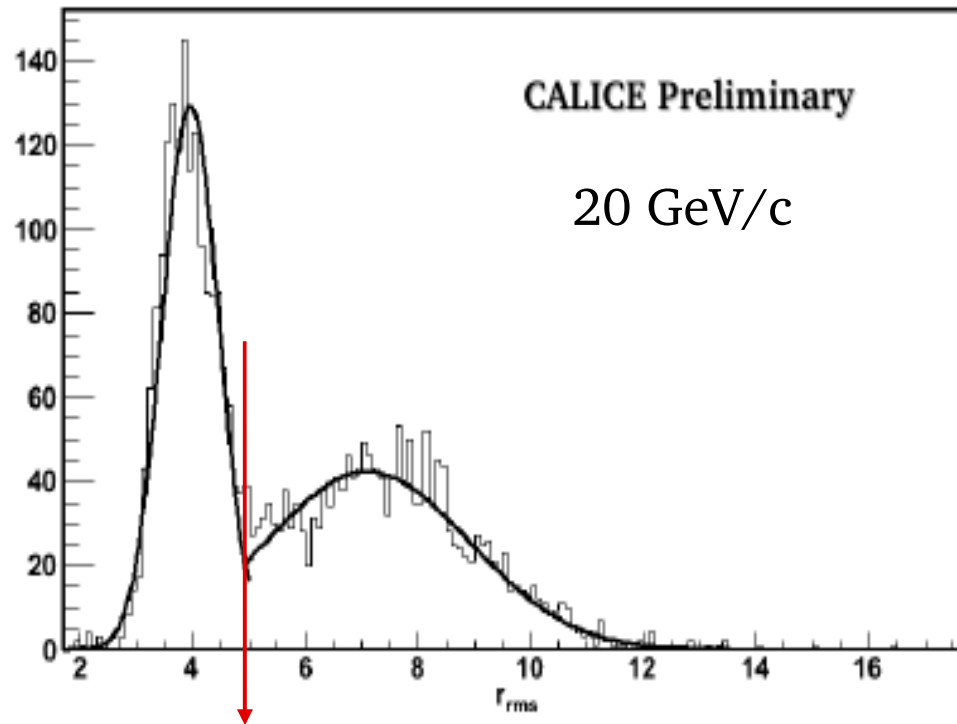


Analysis Strategy - III

Pion And Positron ID:

- For the events not already classified, $r_{rms} = \sqrt{\frac{\sum r_i^2}{N_{Hits}}}$ 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.



If $r_{rms} > 5$ cm \rightarrow **Identify as pion** (this adds 4% of pions)

If $r_{rms} < 5$ cm \rightarrow **Identify as positron** (this is the only positron selection)

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° angle in between. $r_{\text{rms}} > 5$ cm.

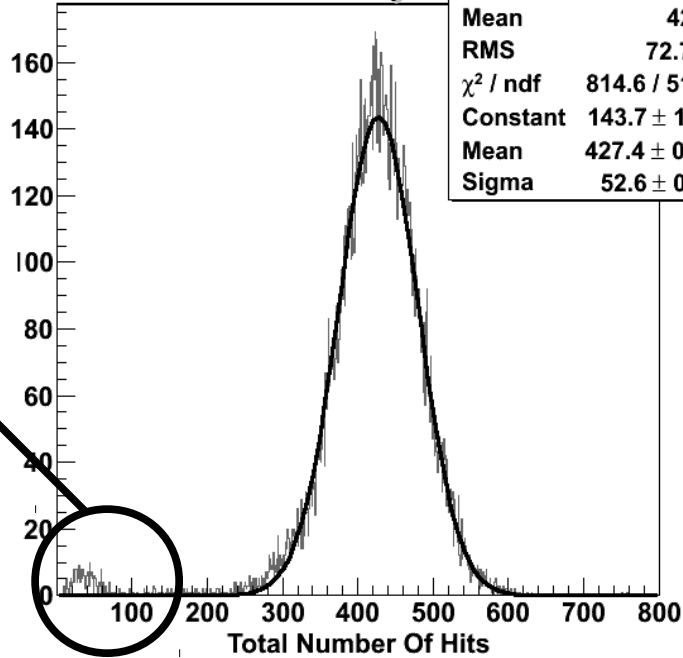
Positrons: $r_{\text{rms}} < 5$ cm.

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

CALICE Preliminary

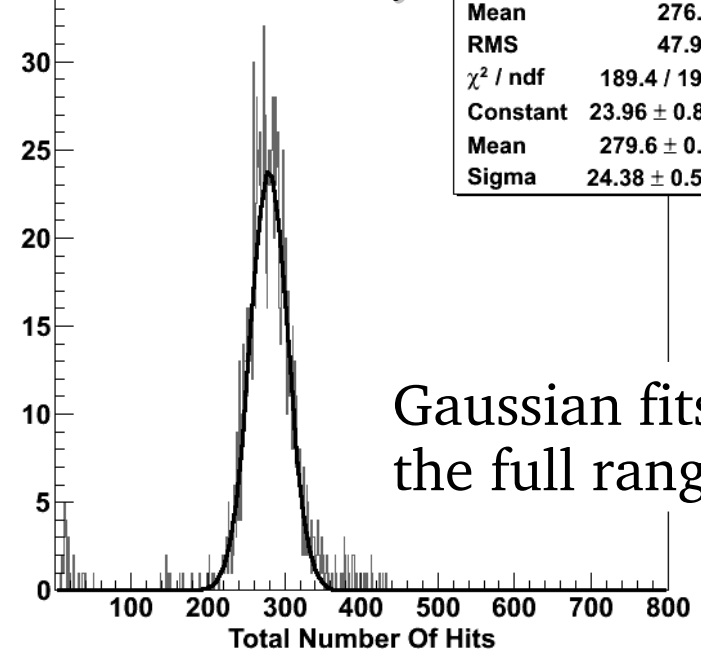
π^+ 32GeV	
Entries	19747
Mean	420
RMS	72.77
χ^2 / ndf	814.6 / 519
Constant	143.7 ± 1.3
Mean	427.4 ± 0.4
Sigma	52.6 ± 0.3



Unidentified μ 's,
punch through

CALICE Preliminary

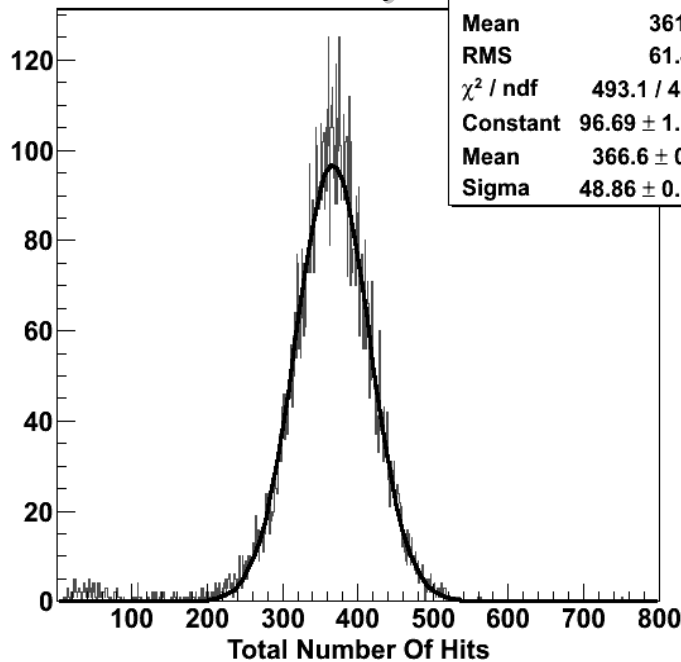
e^+ 32GeV	
Entries	1648
Mean	276.3
RMS	47.95
χ^2 / ndf	189.4 / 197
Constant	23.96 ± 0.81
Mean	279.6 ± 0.7
Sigma	24.38 ± 0.54



Gaussian fits for
the full range

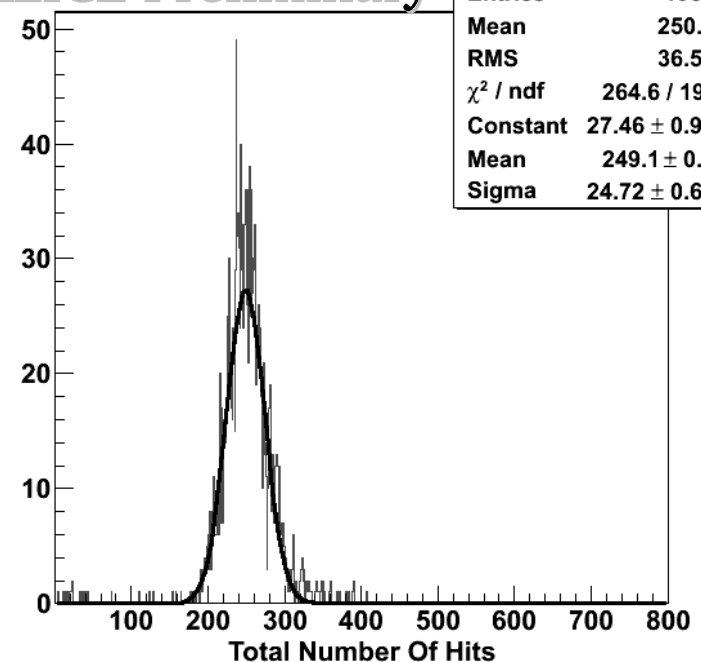
CALICE Preliminary

π^+ 25GeV	
Entries	12320
Mean	361.9
RMS	61.43
χ^2 / ndf	493.1 / 437
Constant	96.69 ± 1.13
Mean	366.6 ± 0.5
Sigma	48.86 ± 0.36



CALICE Preliminary

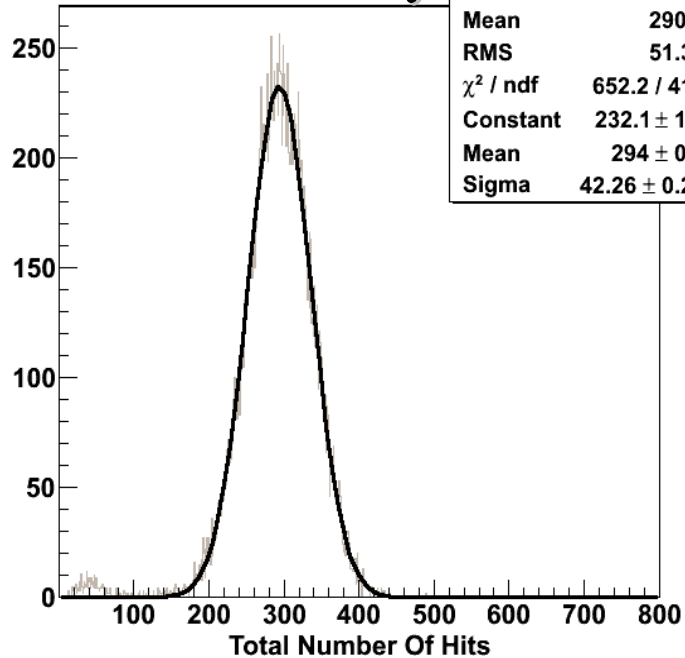
e^+ 25GeV	
Entries	1956
Mean	250.5
RMS	36.52
χ^2 / ndf	264.6 / 191
Constant	27.46 ± 0.92
Mean	249.1 ± 0.6
Sigma	24.72 ± 0.60



Particle ID Results in Oct '10 Data

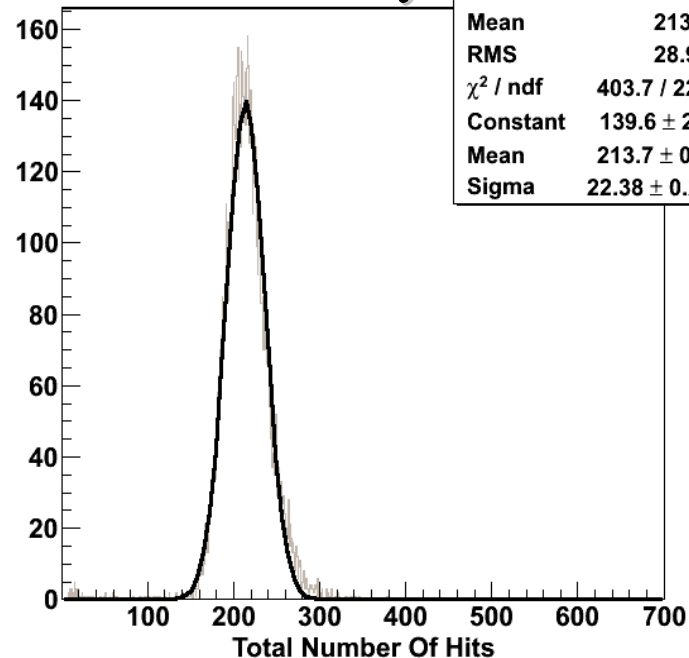
CALICE Preliminary

π^+ 20GeV	
Entries	25218
Mean	290.7
RMS	51.38
χ^2 / ndf	652.2 / 410
Constant	232.1 ± 1.8
Mean	294 ± 0.3
Sigma	42.26 ± 0.20



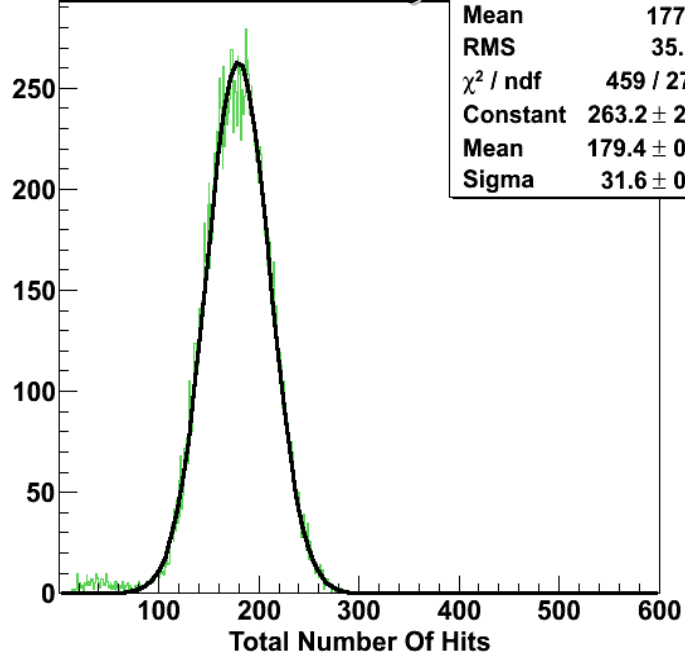
CALICE Preliminary

e^+ 20GeV	
Entries	8232
Mean	213.7
RMS	28.95
χ^2 / ndf	403.7 / 226
Constant	139.6 ± 2.1
Mean	213.7 ± 0.3
Sigma	22.38 ± 0.21



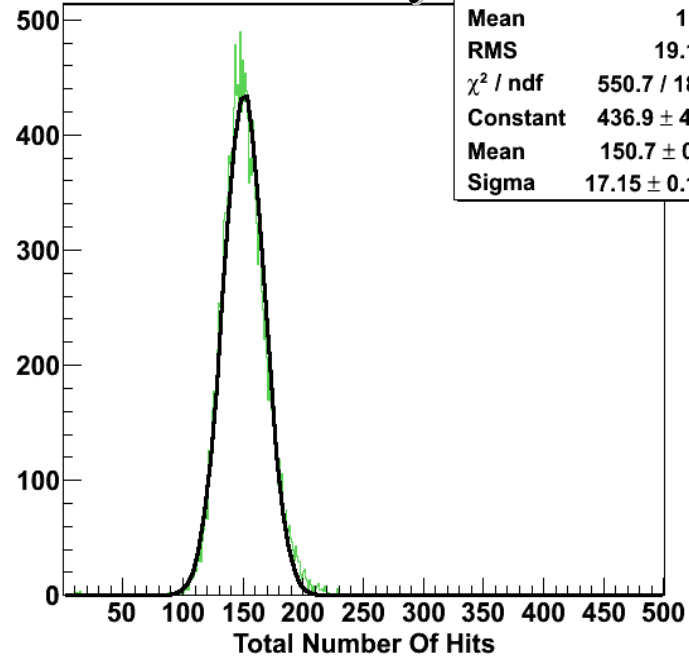
CALICE Preliminary

π^+ 12GeV	
Entries	21301
Mean	177.7
RMS	35.11
χ^2 / ndf	459 / 279
Constant	263.2 ± 2.2
Mean	179.4 ± 0.2
Sigma	31.6 ± 0.2



CALICE Preliminary

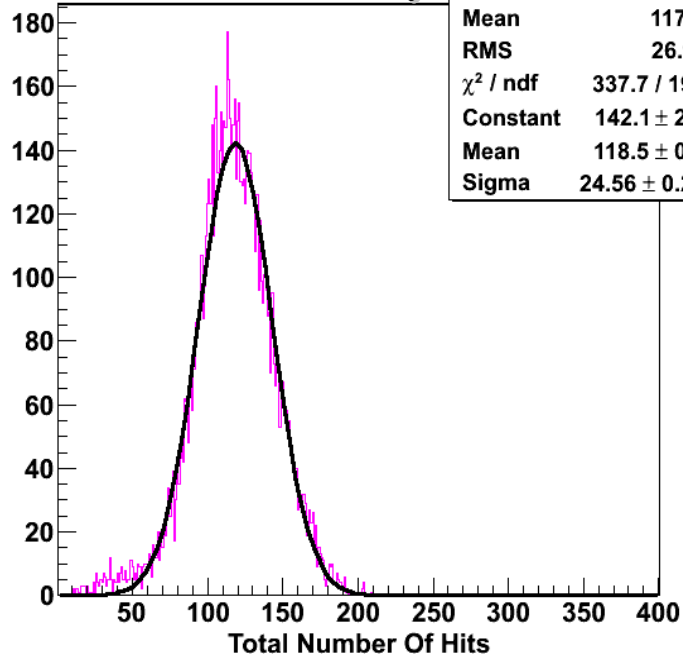
e^+ 12GeV	
Entries	19320
Mean	151
RMS	19.12
χ^2 / ndf	550.7 / 186
Constant	436.9 ± 4.0
Mean	150.7 ± 0.1
Sigma	17.15 ± 0.10



Particle ID Results in Oct '10 Data

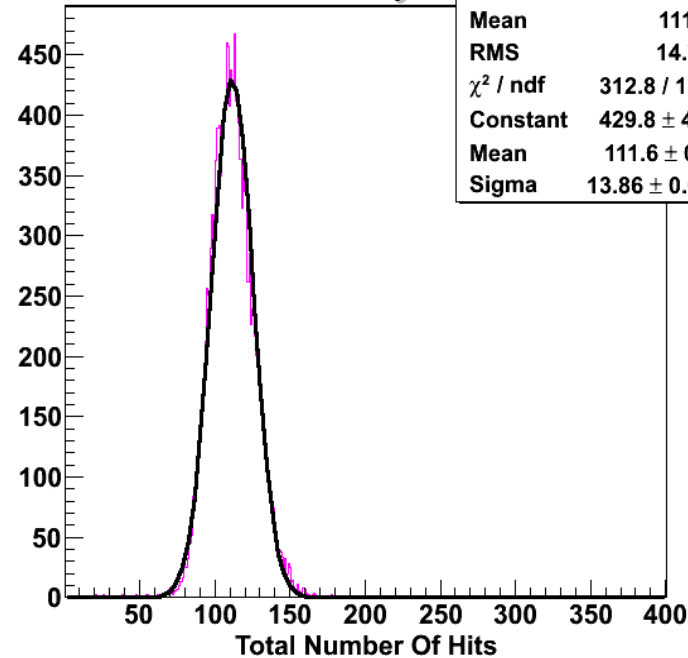
CALICE Preliminary

π^+ 8GeV	
Entries	9081
Mean	117.2
RMS	26.91
χ^2 / ndf	337.7 / 190
Constant	142.1 ± 2.0
Mean	118.5 ± 0.3
Sigma	24.56 ± 0.22



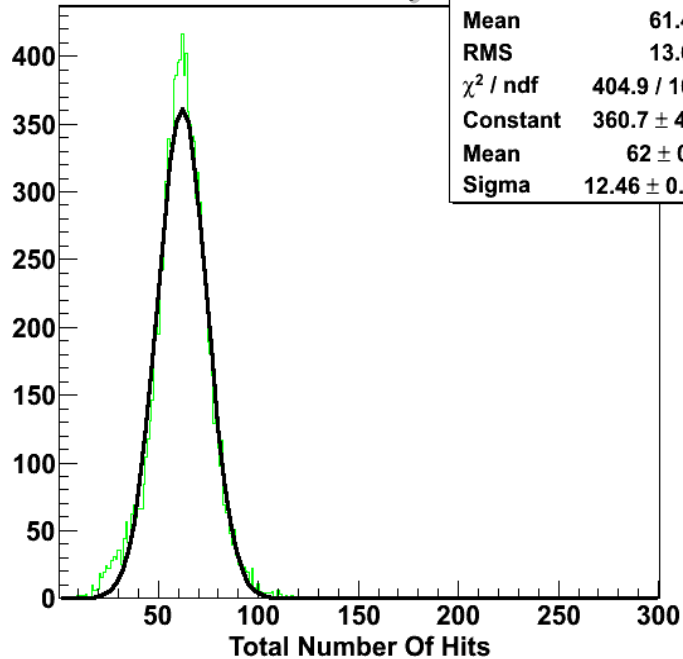
CALICE Preliminary

e^+ 8GeV	
Entries	15246
Mean	111.6
RMS	14.76
χ^2 / ndf	312.8 / 136
Constant	429.8 ± 4.4
Mean	111.6 ± 0.1
Sigma	13.86 ± 0.08



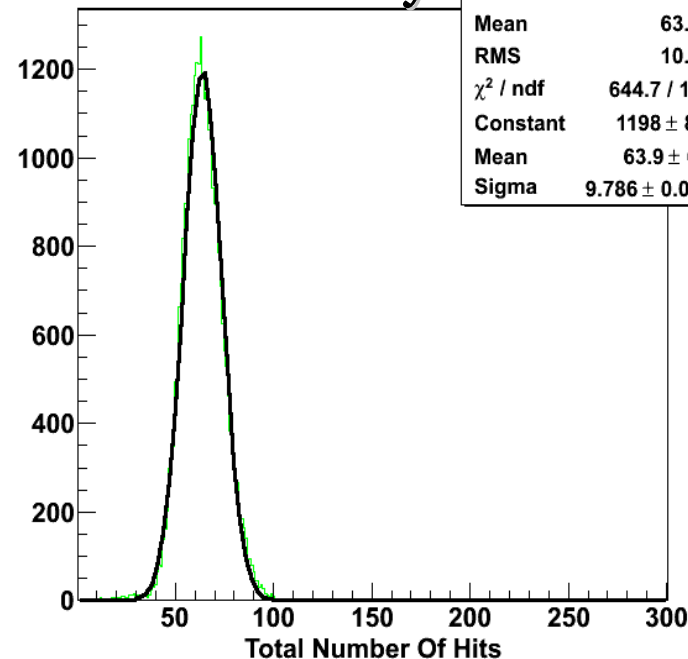
CALICE Preliminary

π^+ 4GeV	
Entries	11668
Mean	61.49
RMS	13.63
χ^2 / ndf	404.9 / 103
Constant	360.7 ± 4.7
Mean	62 ± 0.1
Sigma	12.46 ± 0.11



CALICE Preliminary

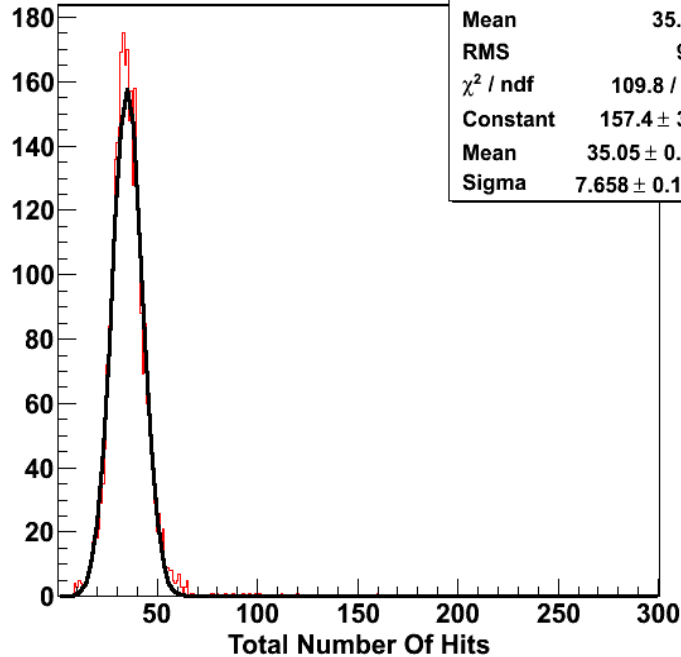
e^+ 4GeV	
Entries	30042
Mean	63.83
RMS	10.53
χ^2 / ndf	644.7 / 100
Constant	1198 ± 8.9
Mean	63.9 ± 0.1
Sigma	9.786 ± 0.044



Particle ID Results in Oct '10 Data

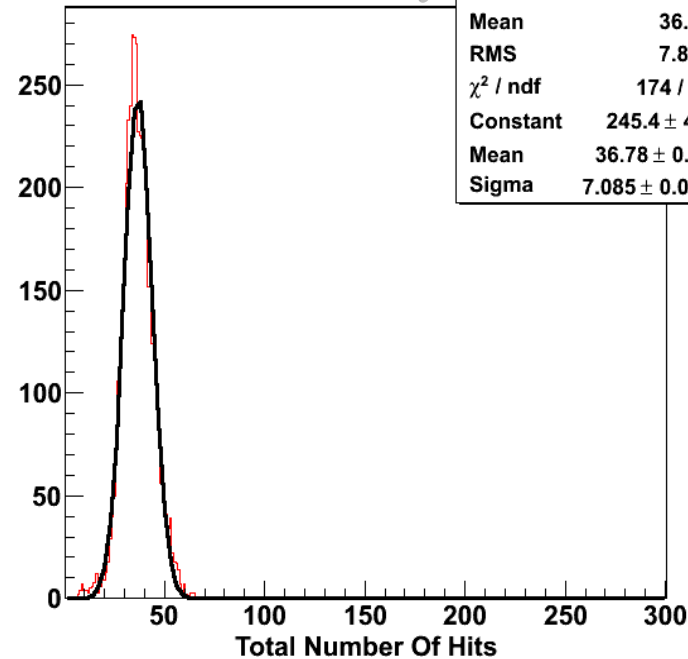
CALICE Preliminary

π^+ 2GeV	
Entries	3130
Mean	35.52
RMS	9.2
χ^2 / ndf	109.8 / 67
Constant	157.4 ± 3.8
Mean	35.05 ± 0.14
Sigma	7.658 ± 0.124



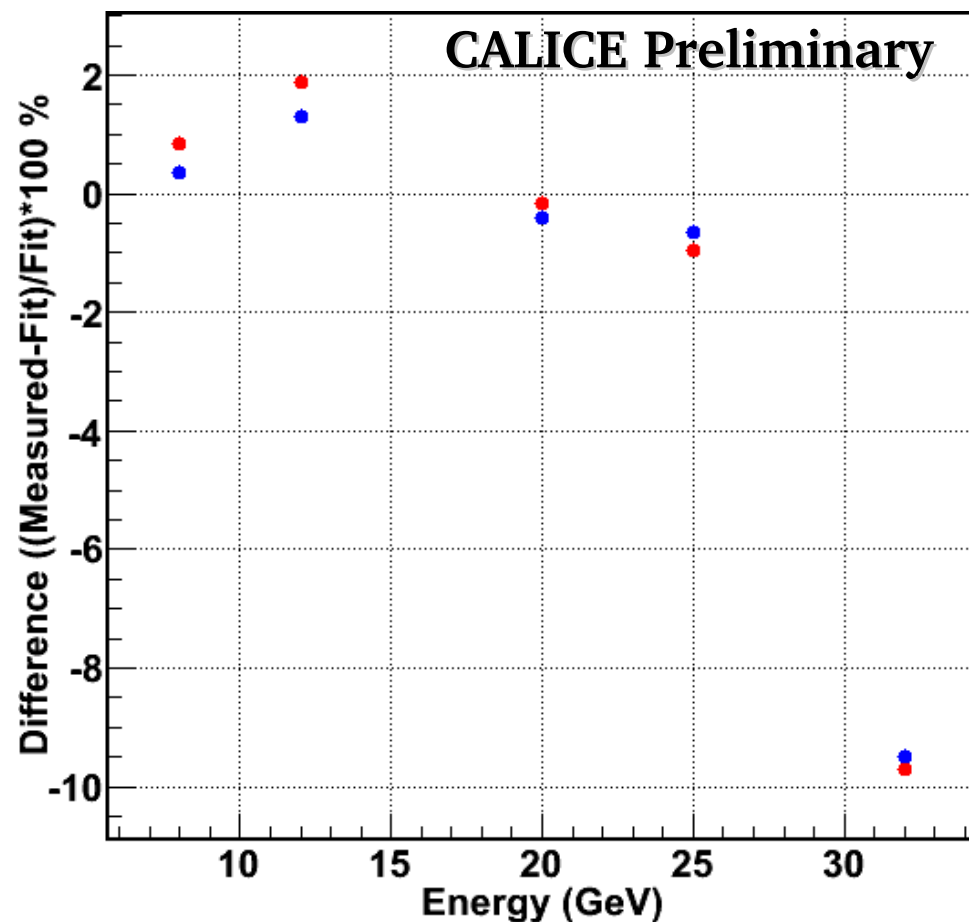
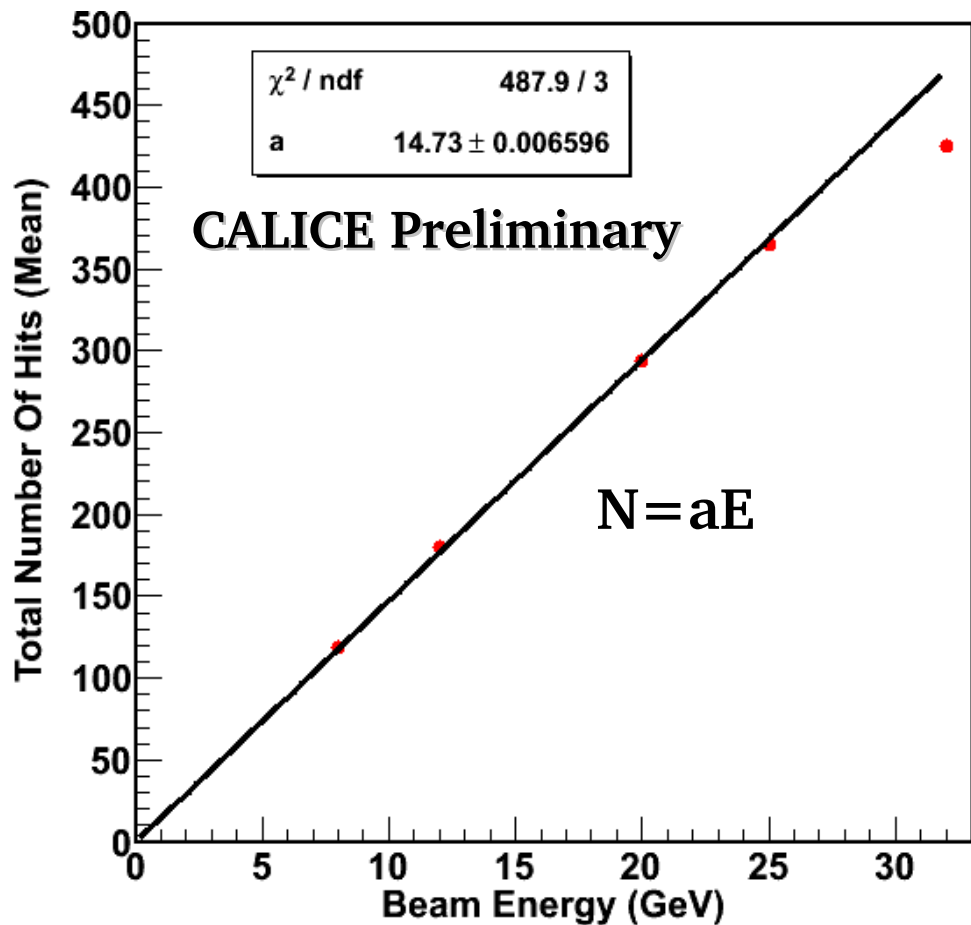
CALICE Preliminary

e^+ 2GeV	
Entries	4532
Mean	36.76
RMS	7.813
χ^2 / ndf	174 / 59
Constant	245.4 ± 4.9
Mean	36.78 ± 0.12
Sigma	7.085 ± 0.094



For $< 8 \text{ GeV}/c$, 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.

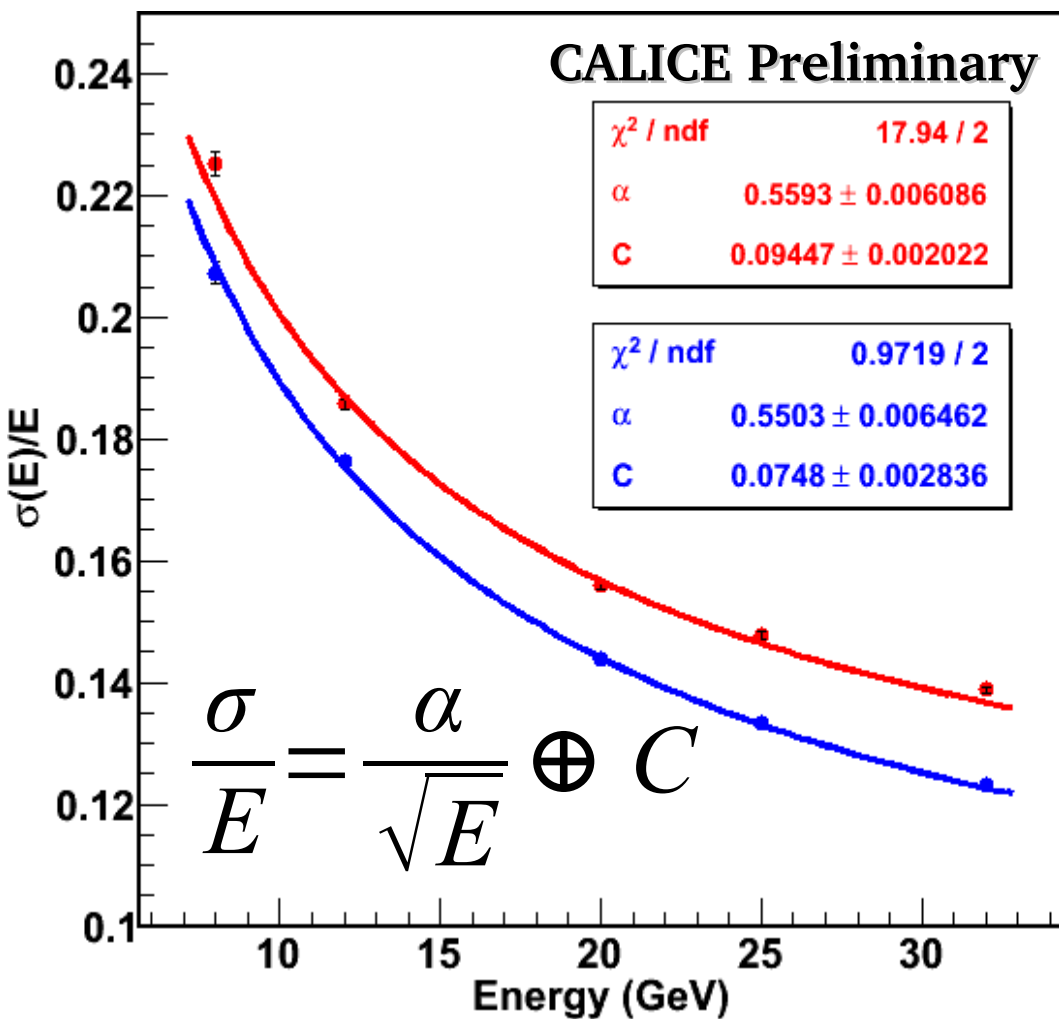
DHCAL Response To Hadrons (Oct '10 Data – Pion ID)



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

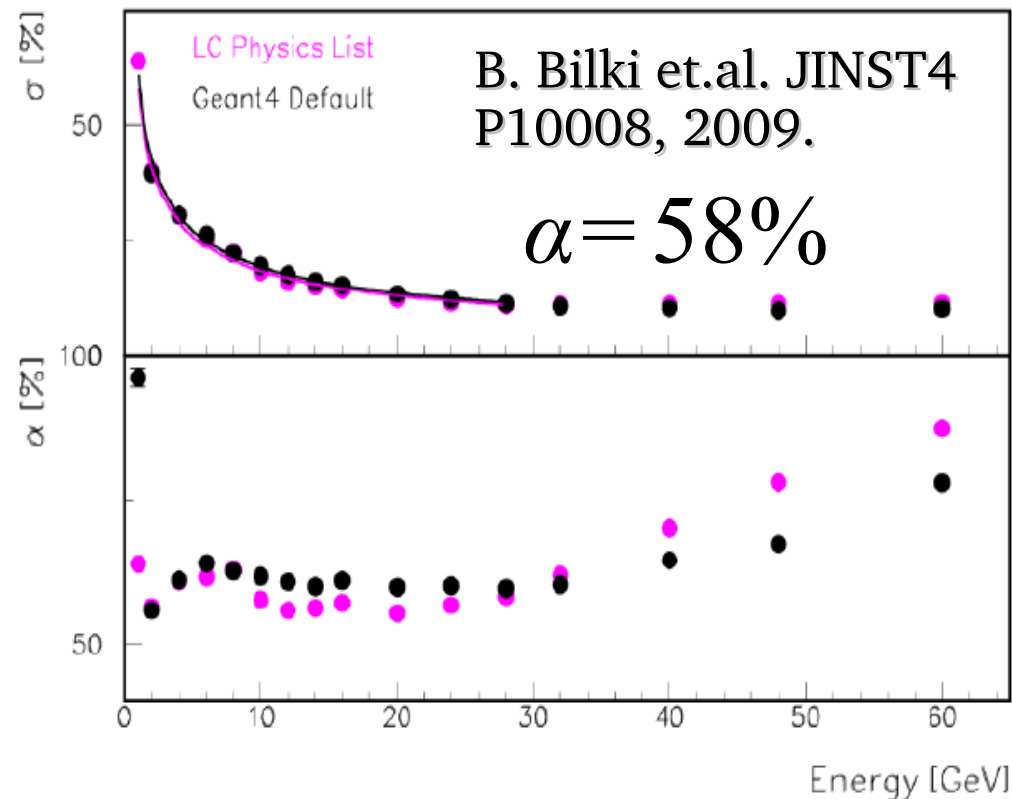
Standard pion selection
+ No hits in last two layers

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



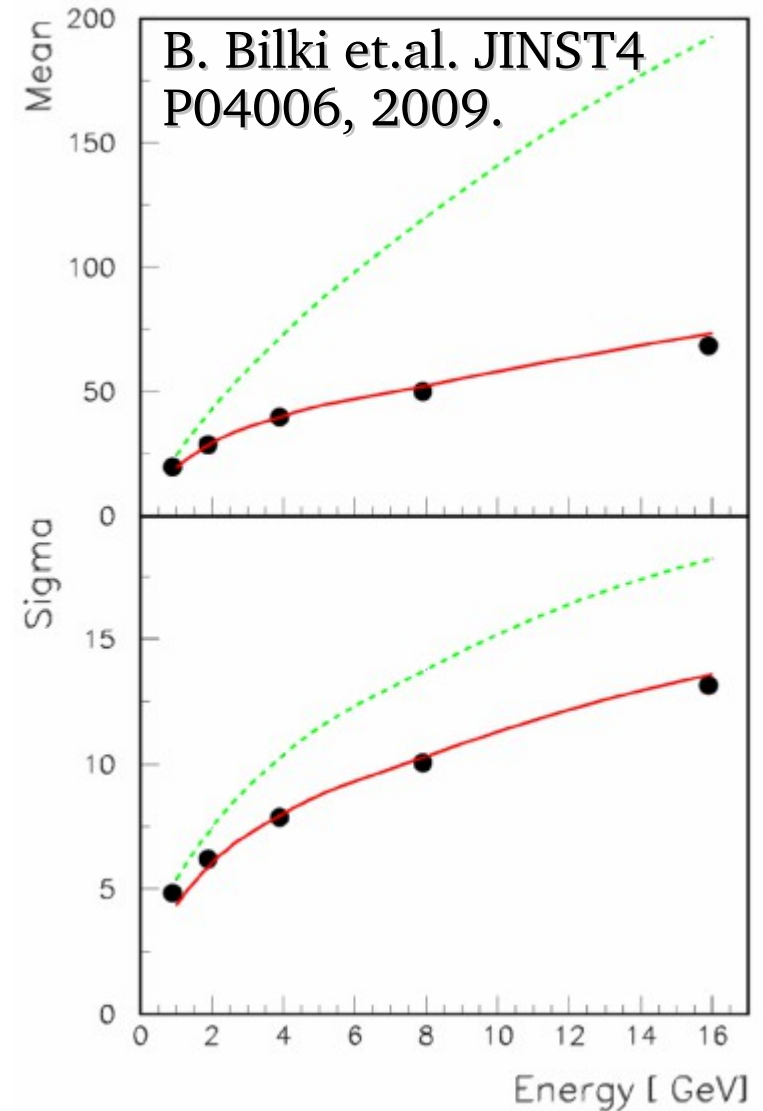
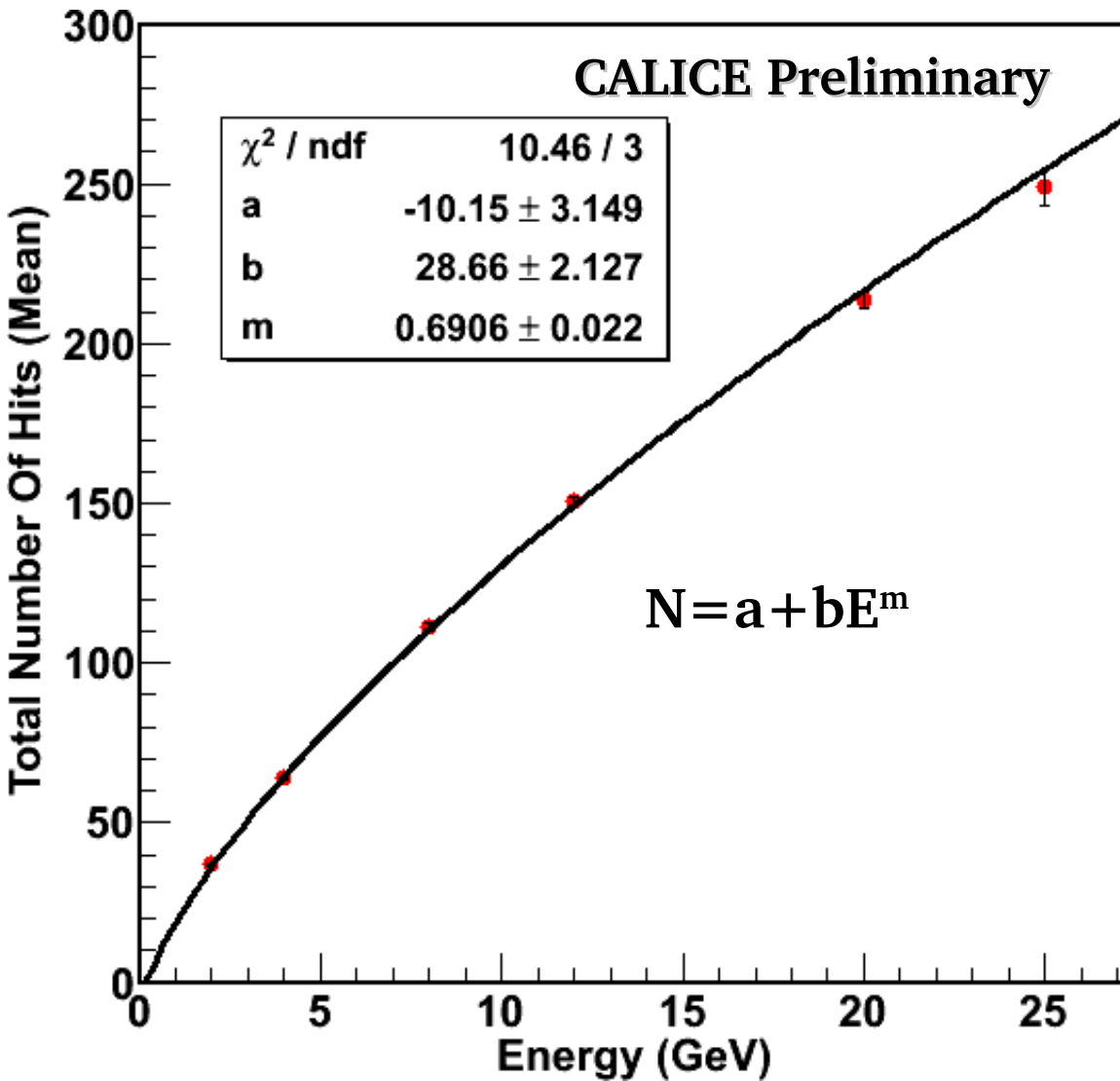
32 GeV data point is not included in the fit.

Standard pion selection
+ No hits in last two layers



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

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

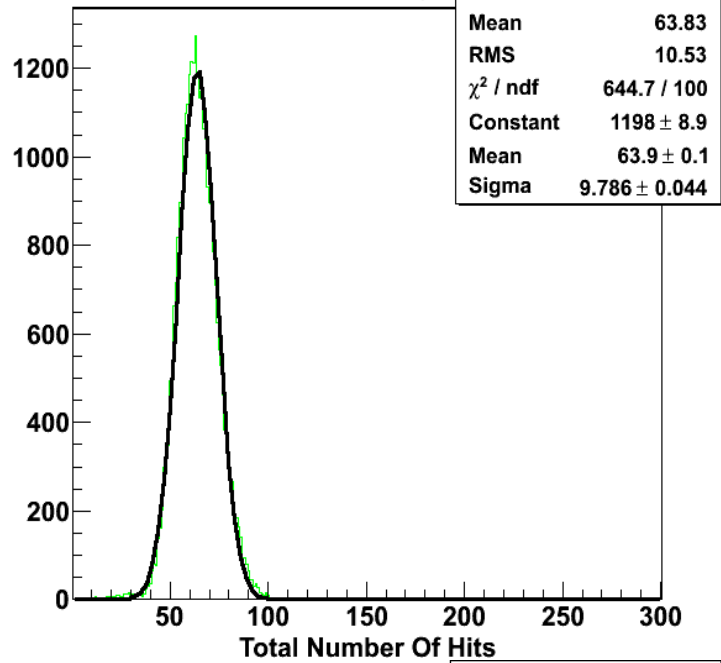


⇒ Reconstruct the positron energies using this fit function on an event by event basis.

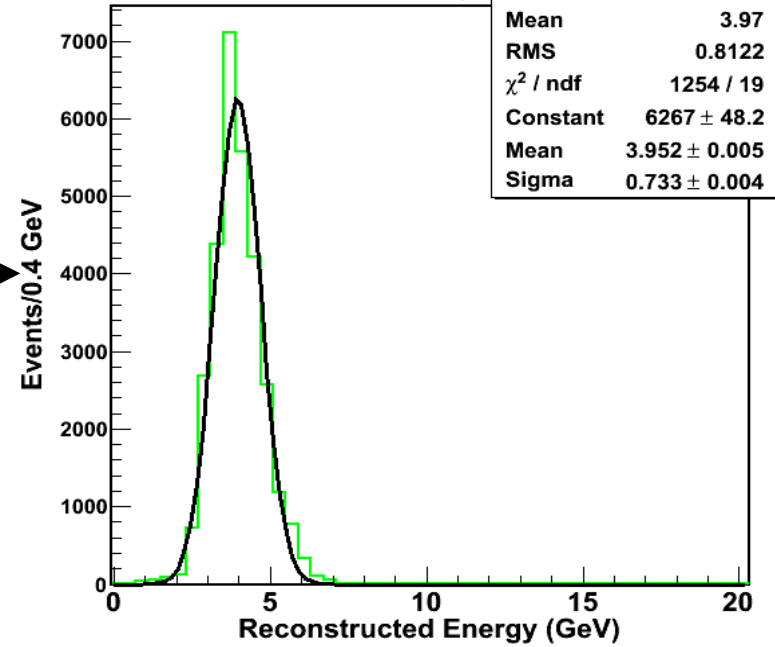
Data (points) and MC (red line) for the small-size prototype and the MC predictions for a large-size DHCAL (green, dashed line).

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

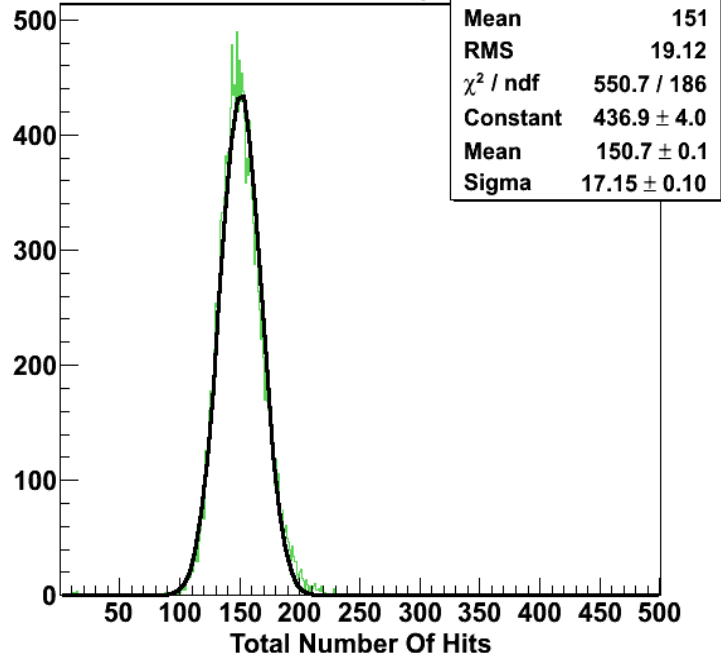
CALICE Preliminary



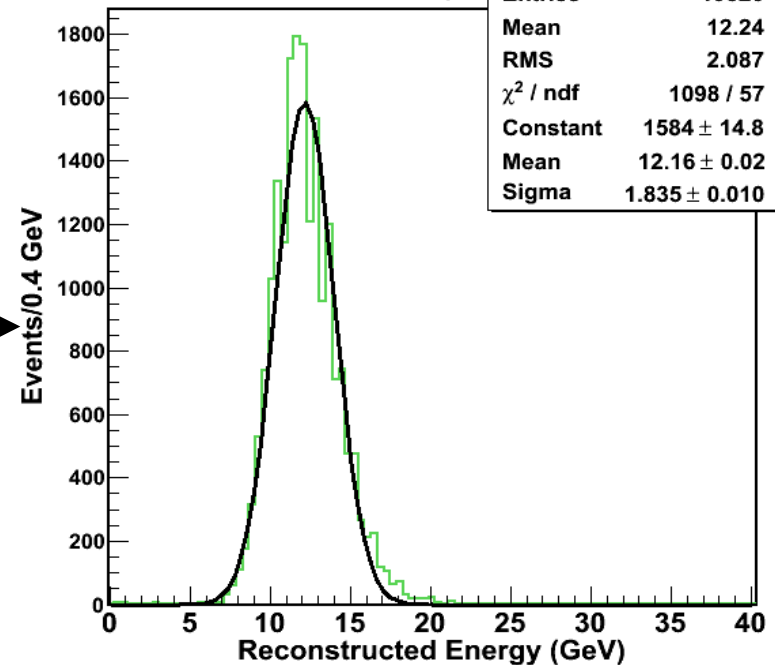
CALICE Preliminary



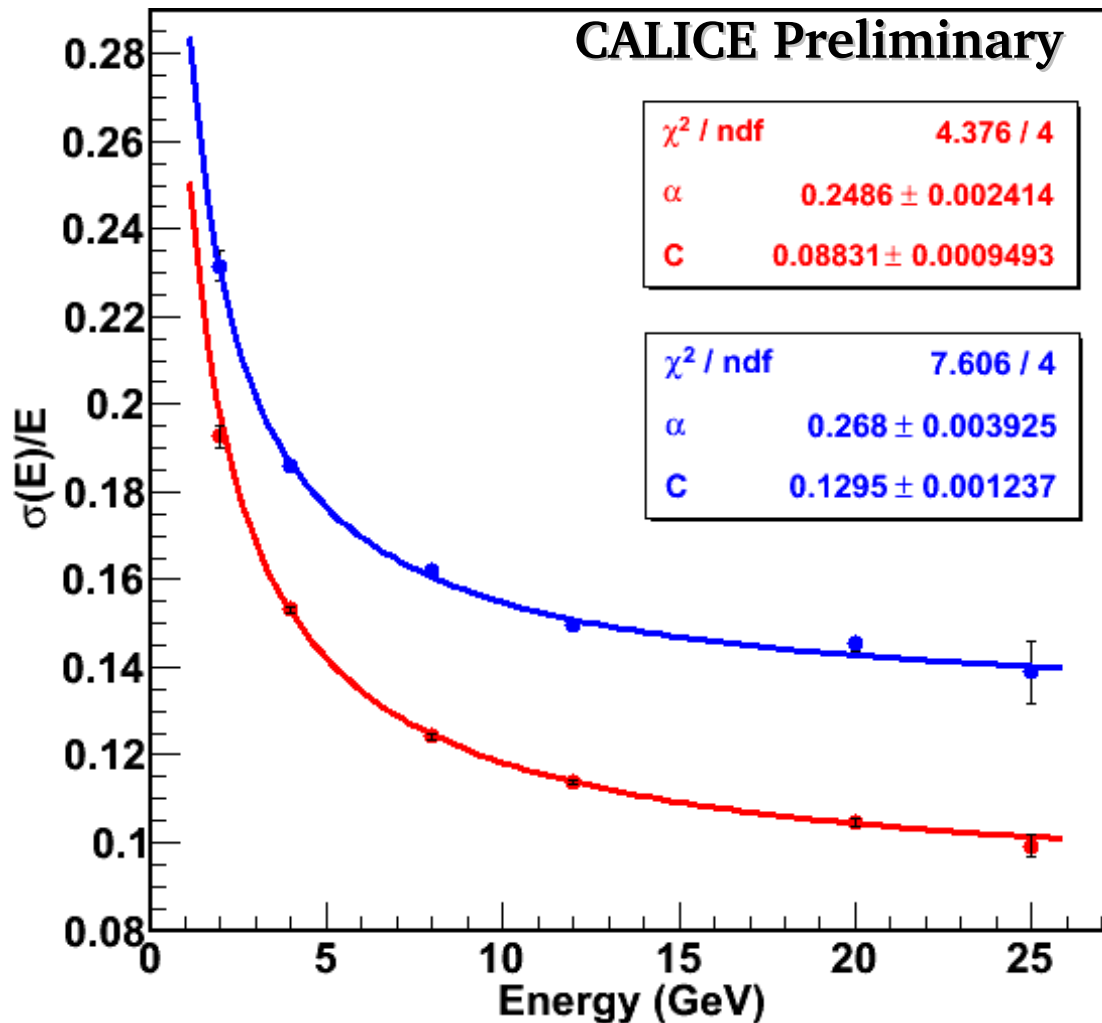
CALICE Preliminary



CALICE Preliminary



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 ongoing successful test beam campaigns, 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.

- 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

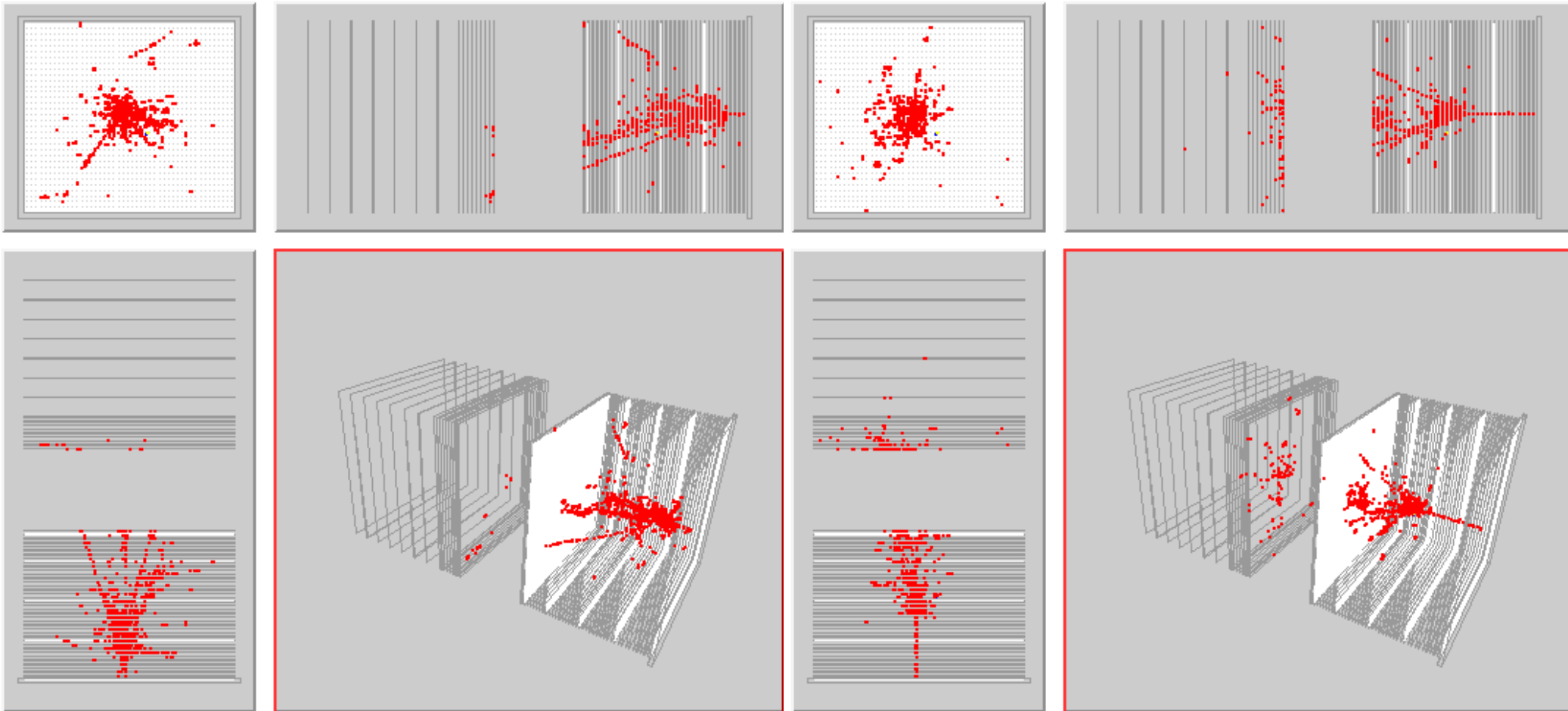
60 GeV/c pions in DHCAL

Run 219:0 Event 20

Time: 7431059
Hits: 890 Energy: xxx mips

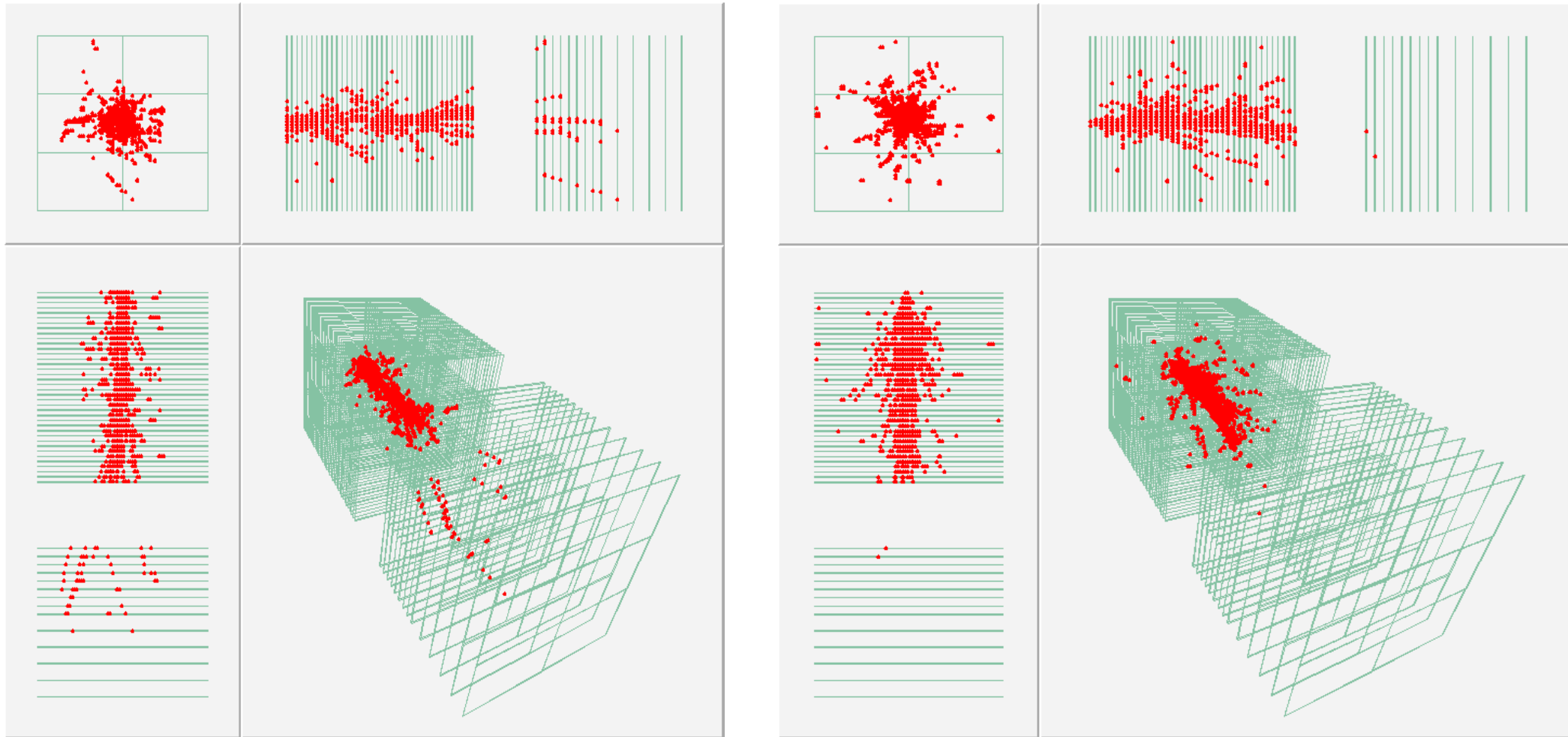
Run 219:0 Event 24

Time: 7740759
Hits: 731 Energy: xxx mips



Epilogue

120 GeV/c protons in DHCAL



Epilogue

Combined System (SiW ECAL+DHCAL) in 3D

