# Study of the combined performance of the Digital Hadronic Calorimeter and Si-W Electromagnetic Calorimeter for the CALICE R&D Collaboration

Melissa Almanza Soto
M.Sc., McGill University

Advisor: Prof. François Corriveau

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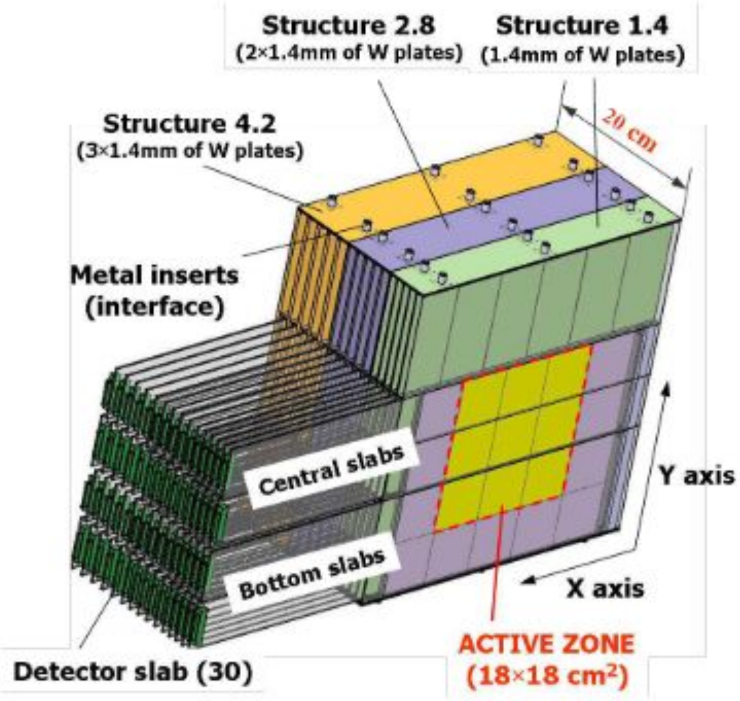
# Introduction

The CALICE collaboration is made of R&D groups working to develop new detectors, originally for high energy e-e+ experiments at the International Linear Collider (ILC), now expanded to generic projects.

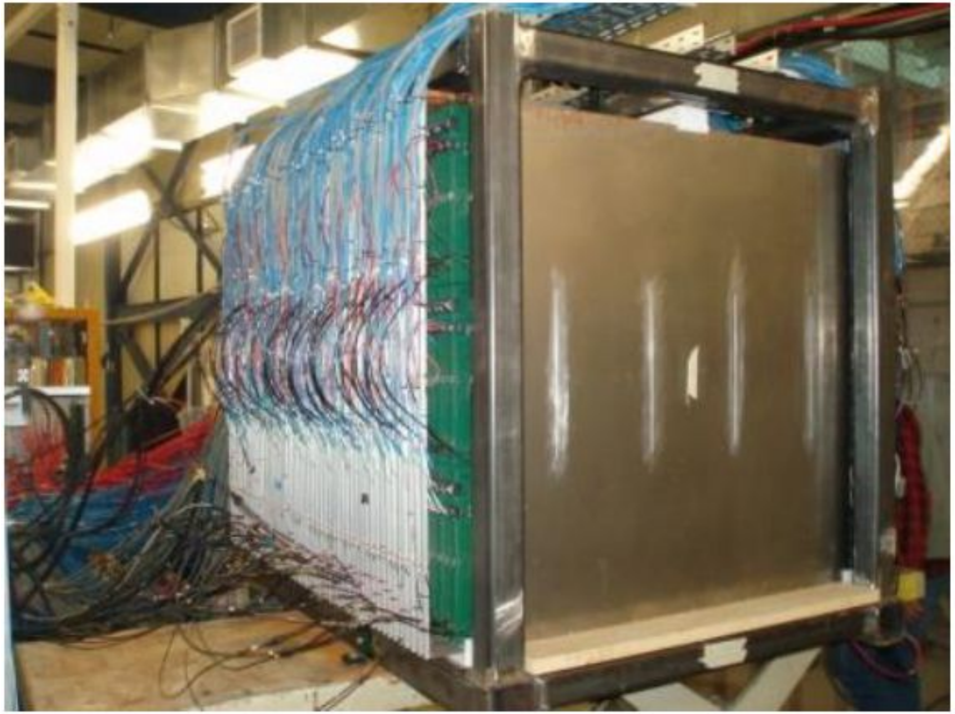
The detectors developed by CALICE use event reconstruction techniques based on Particle Flow Algorithm (PFA). For this reason the electromagnetic and hadronic calorimeters are designed to be highly granular, down to 1 x 1 $cm^2$ cells

# Silicon-Tungsten Electromagnetic CALorimeter (Si-W ECAL)




- Sampling calorimeter
- Silicon active material
- Tungsten absorber layers
- 30 layers
- 24 $X_0$ and 1 $\lambda_I$
- Cell size of 1 x 1 $cm^2$
- 18 x 18 cells per layer
- 9720 Channels
- Signal: Cell energy and (x,y,z) of hit.

# Digital Hadronic CALorimeter (DHCAL)



- Sampling Calorimeter
- Resistive Plate Chambers (RPCs).
- Steel absorber
- 51 layers
- 65 $X_0$ and 7 $\lambda_I$
- Cell size of 1 x 1 $cm^2$
- 96 x 96 cells per layer
- 470,016 channels
- Digital signal: Time and (x, y, z) of each hit

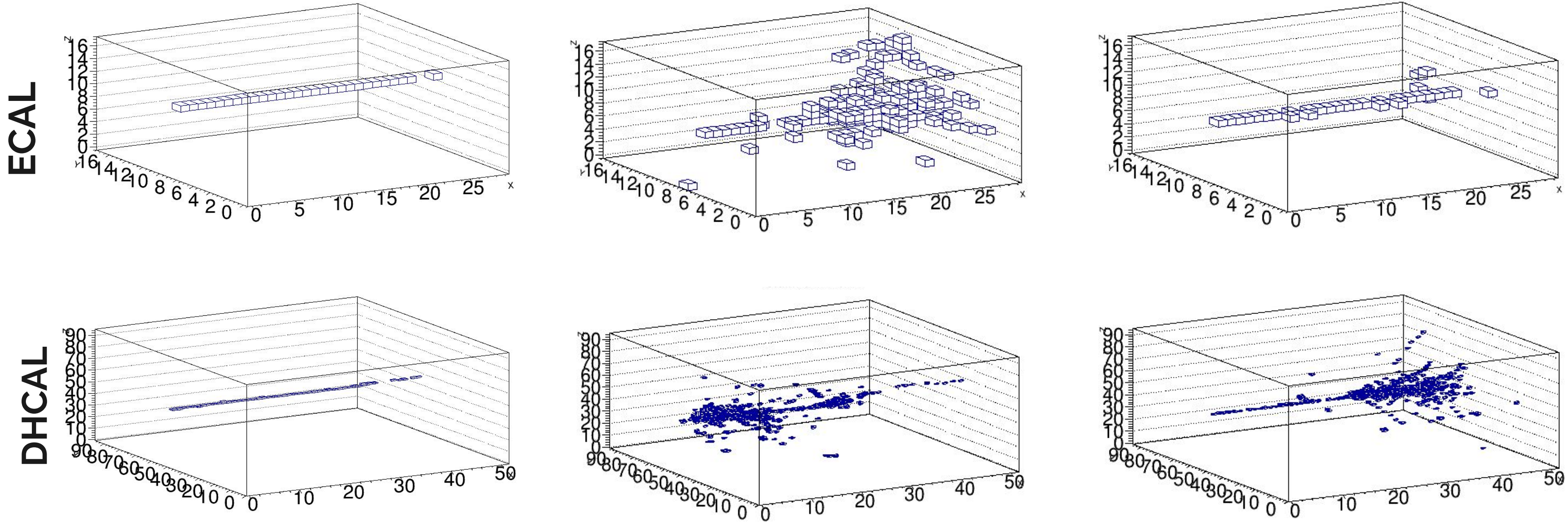
# Data taking period

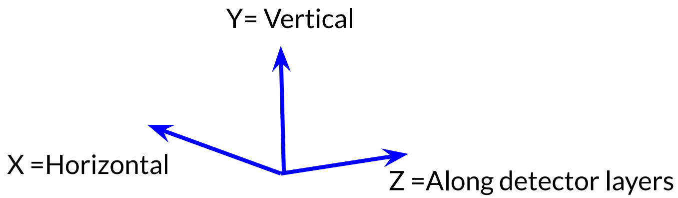
In April of 2011 the experimental setup of ECAL + DHCAL was exposed to a wide range of energies, from 4 GeV to 120 GeV at Fermilab test beam facilities.

In this testing period ECAL was set in front of DHCAL along the beam direction.

## Muon | Positron | Pion

ECAL / DHCAL



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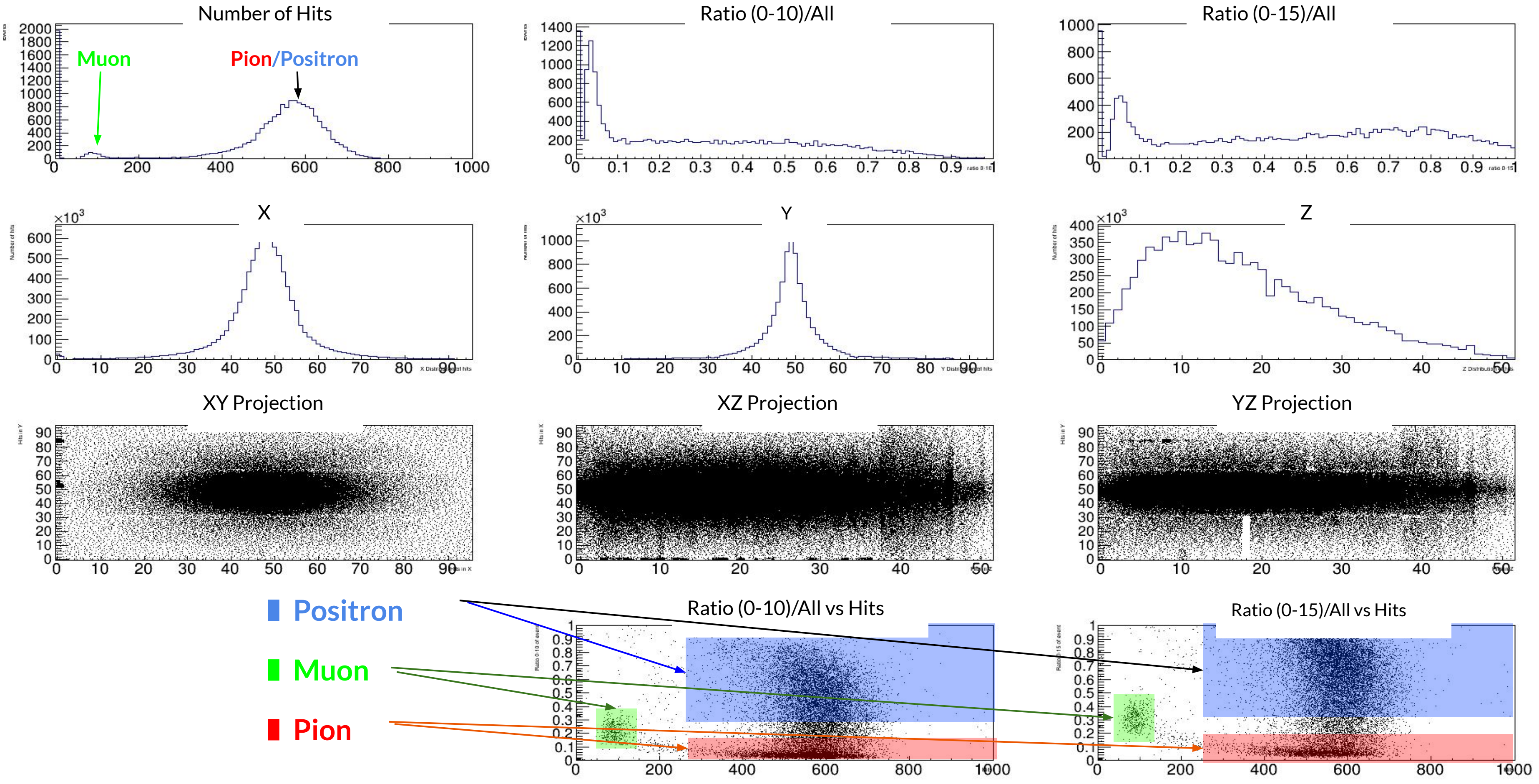
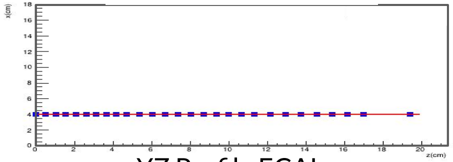
# Standard plots and particle ID

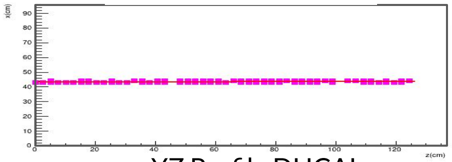


# Alignment with muons methodology

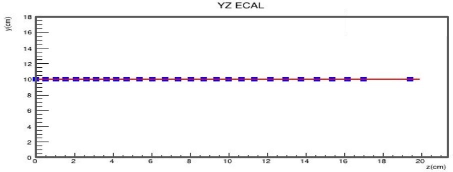
XZ Profile ECAL



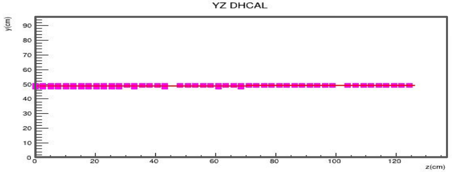

XZ Profile DHCAL




YZ Profile ECAL




YZ Profile DHCAL

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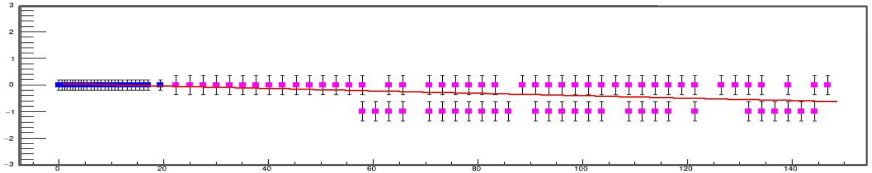
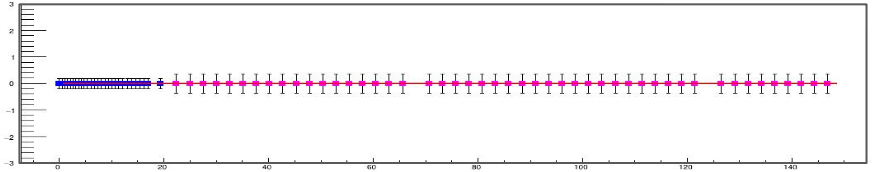
XZ Profile ECAL + DHCAL Global fit



YZ Profile ECAL + DHCAL Global fit



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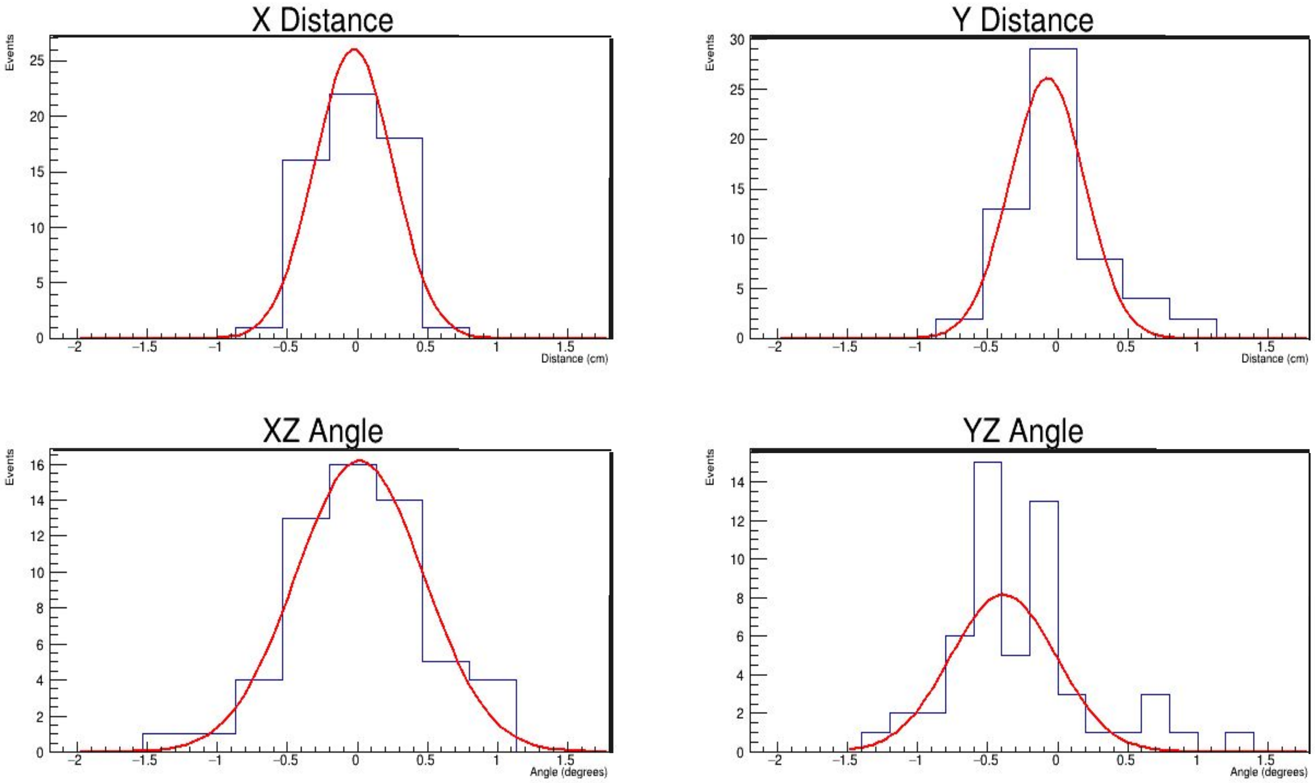
1. Selection of good muon tracks
   - Discard hits outside of ±2 cells from first hit in ECAL
   - Discard layer with >4 hits
2. Fit of the track in XZ and YZ profiles for each ECAL and DHCAL
3. Use fit information to move DHCAL
4. Fit the resulting full track

# Muon alignment results

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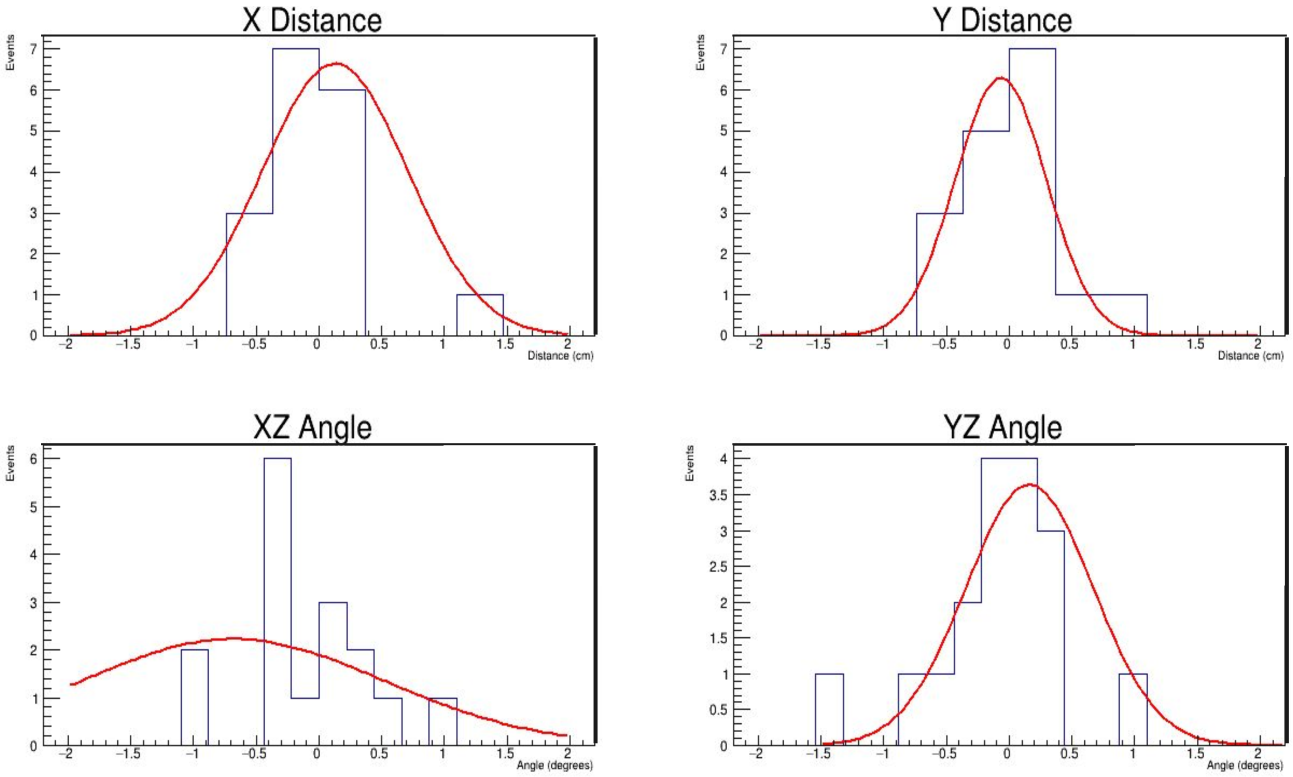
- The results of the fits for the moved DHCAL tracks are consistent with 0.
- Alignment precision is between 0.2 and 0.4 cm for the distances (cell size is 1 $cm^2$).
- Precision for the angles is 0.2 and 0.7 degrees.
- It is possible to align the detectors using the muon tracks.

# Alignment correction in pions

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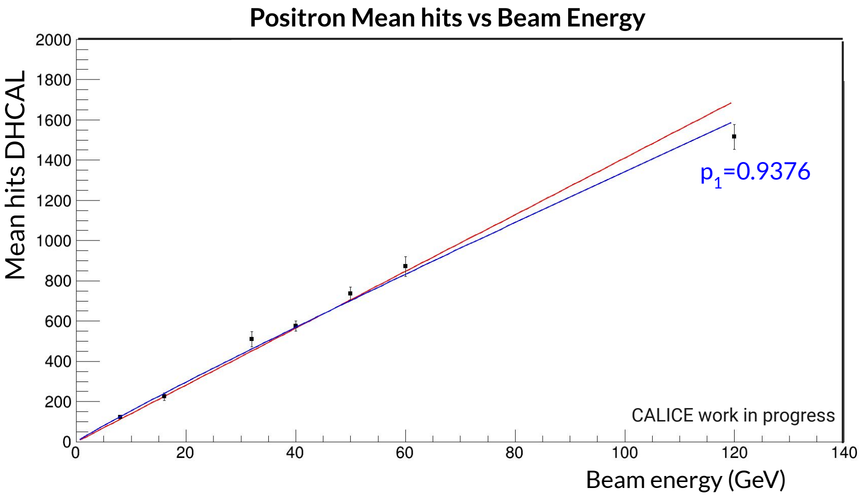
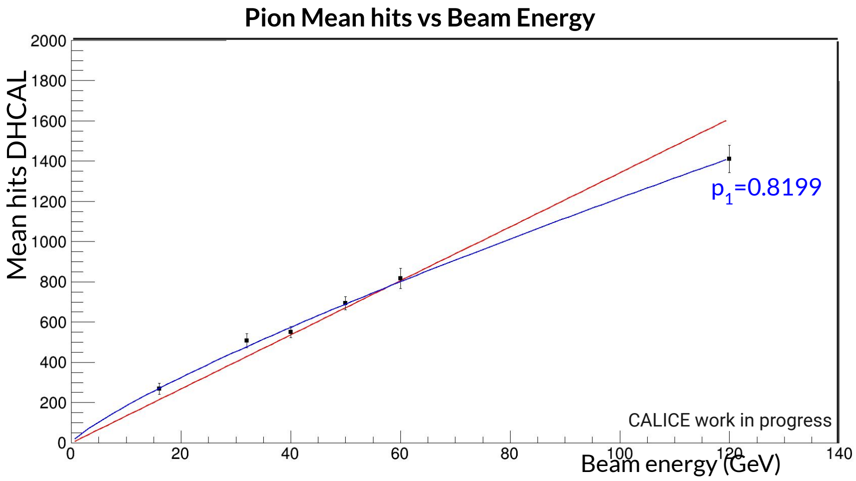
A correction on the alignment of the initial Minimum Ionizing Particle (MIP) tracks from the pions was made using the muon alignment results.

- ❖ For the analysed runs the alignment precision is:
  - ➢ 0.2-0.6 cm for the distances
  - ➢ 0.2-0.9 degrees for angles

It is also possible to use the initial MIP tracks from pions to perform the alignment measurements.

# Linearity of DHCAL-Only Hits comparison for positrons and pions June 2011

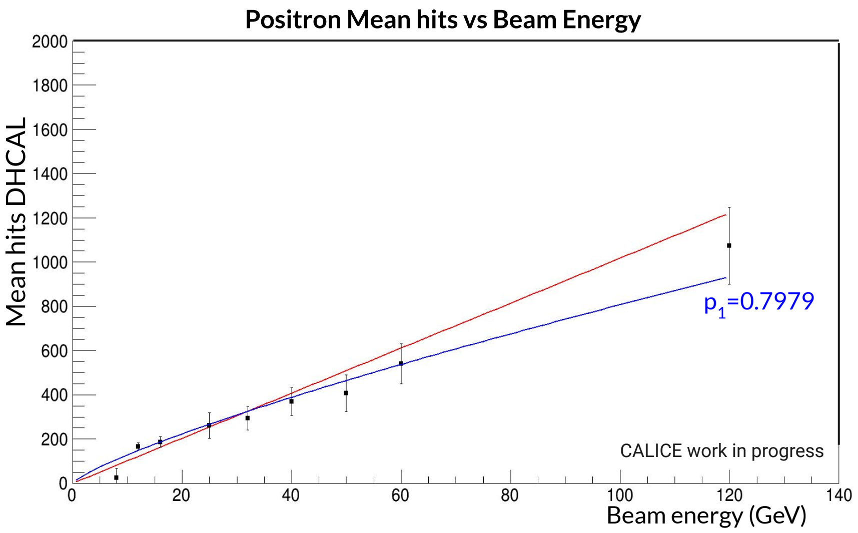


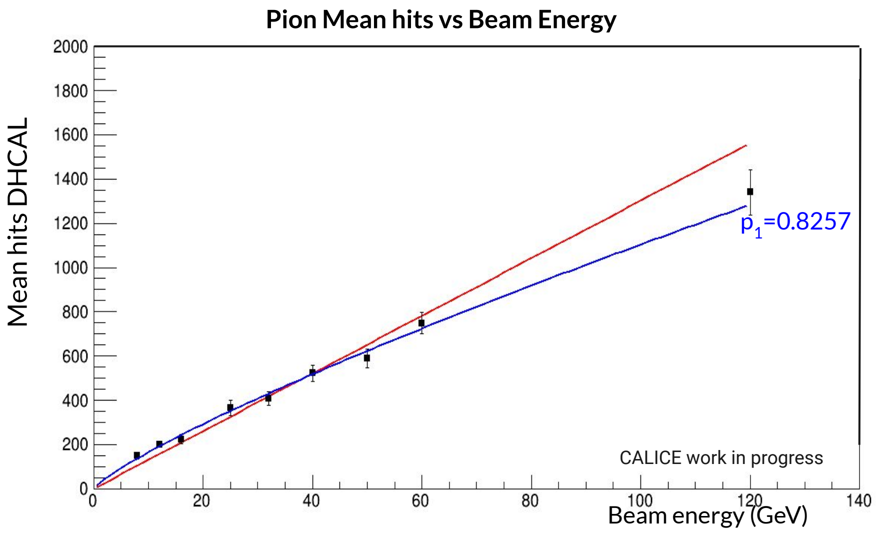




Example of DHCAL Mean hits vs Energy.

- There are saturation effects.
- Red line is a linear fit $N_{Hits}=p_0E_{Beam}$
- Blue line is an exponential fit $N_{Hits}= p_0E_{Beam}{}^{p_1}$ to measure for the saturation.

# Energy response ECAL + DHCAL experimental setup



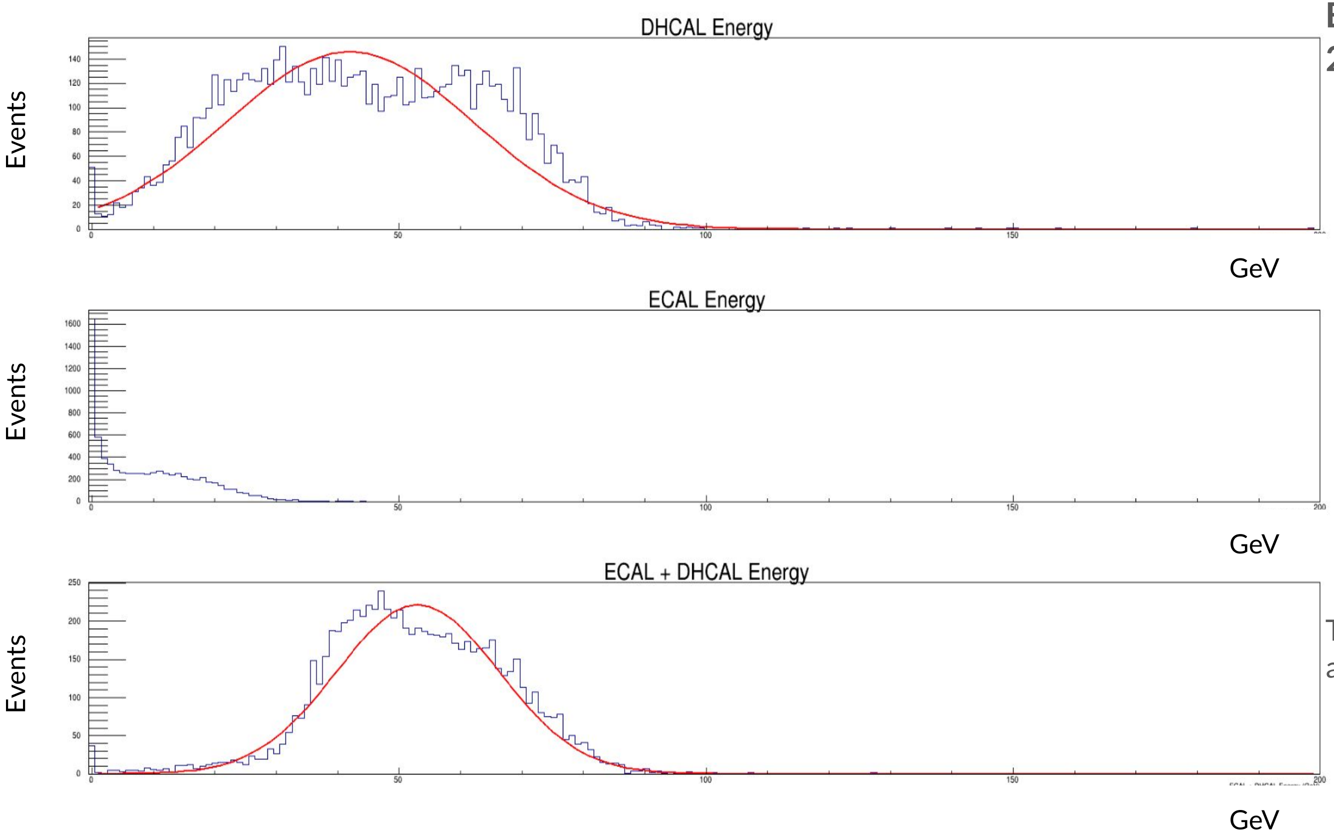

Example of DHCAL Mean hits vs Energy.

- Red line is a linear fit $N_{Hits}=p0E_{Beam}$
- Blue line is a linear fit $N_{Hits}=p0E_{Beam} + p1$

- Positron plot:
  - The mean number of hits for all energies is lower compared to the previously showed testing period, this is because part of the electromagnetic shower is deposited in ECAL for this period.

- Pion plot:
  - Pions with their shower contained within DHCAL were selected to measure the energy deposition relation to the number of hits using the saturation fit.

# Energy calibration ECAL + DHCAL positrons

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### Example: Positrons 60GeV April 2011

- ➢ The distribution of energy in DHCAL using the saturation fit is plotted in the top histogram.
  - ○ **μ**=42 GeV, **σ**=20.1 GeV
- ➢ Center plot shows the energy distribution in ECAL
- ➢ Distribution of ECAL Energy + DHCAL Energy($N_{Hits}$) on the bottom histogram.
  - ○ **μ**=53 GeV, **σ**=13.2 GeV

The same analysis was repeated for 50 GeV and 120 GeV

# Conclusions

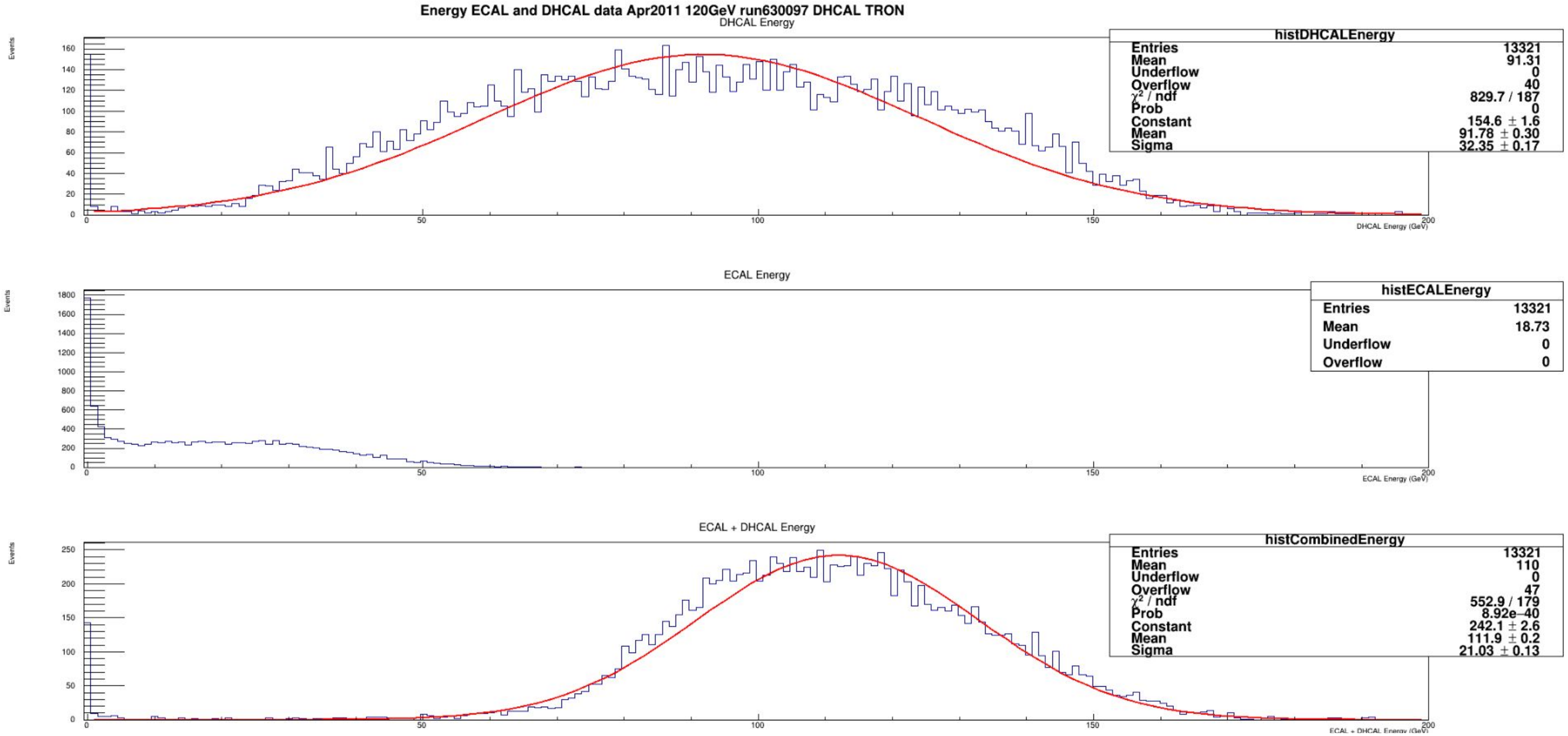
- The data itself can be used to align ECAL to DHCAL.
- Linearity and saturation effects are being studied.
- Resolution response will be investigated next.

- High granularity detectors are powerful instruments for future experiments.

# References

1. Repond, J., Yu, J., Hawkes, M., Mikami, Y., Miller, O., Watson, K., Wilson, A., Mavromanolakis, G., Thomson, A., Ward, R., Yan, W., Badaud, F., Boumediene, D., Crloganu, C., Cornat, R., Gay, P., Ph Gris, Manen, S., Morisseau, F., … Yang, J. (2008). Design and electronics commissioning of the physics prototype of a si-w electromagnetic calorimeter for the international linear collider. Journal of Instrumentation, 3(8). https://doi.org/10.1088/1748-0221/3/08/P08001
2. Adams, C., Bambaugh, A., Bilki, B., Butler, J., Corriveau, F., & Cundiff, T. (n.d.). Design , Construction and Commissioning of the Digital Hadron Calorimeter - DHCAL. 1–22.

# Extra

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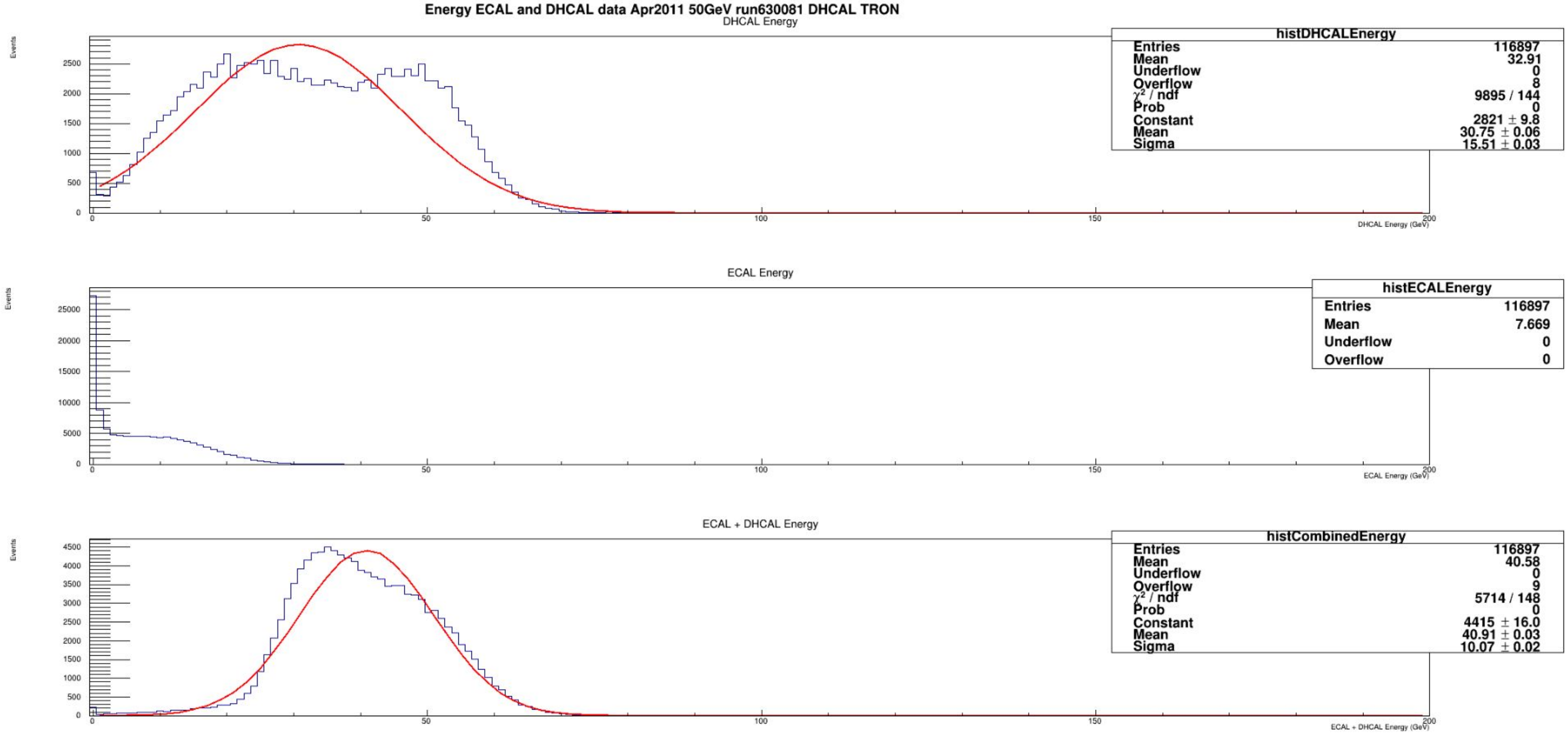


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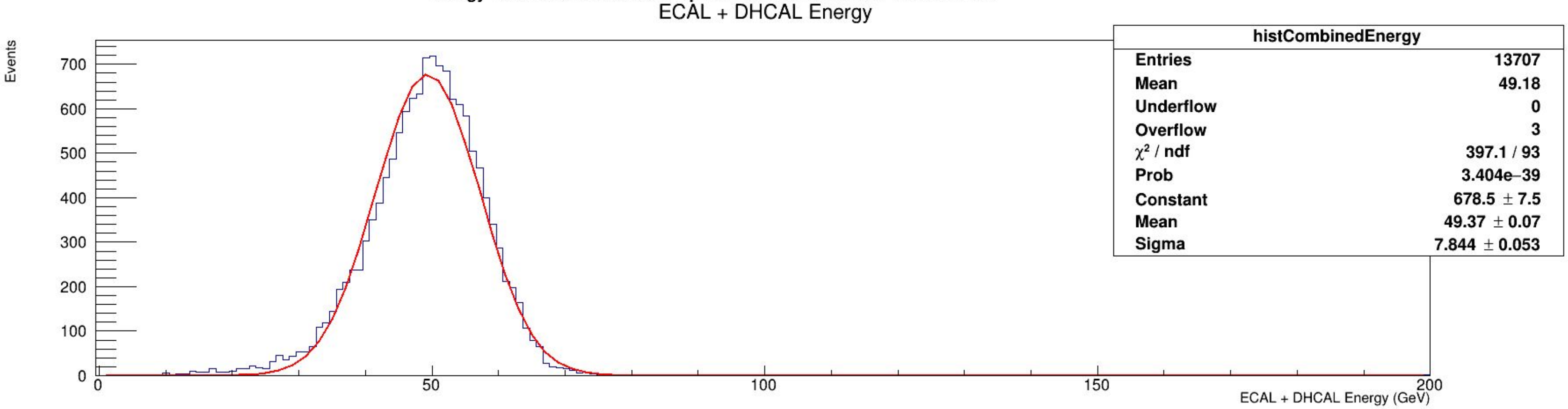
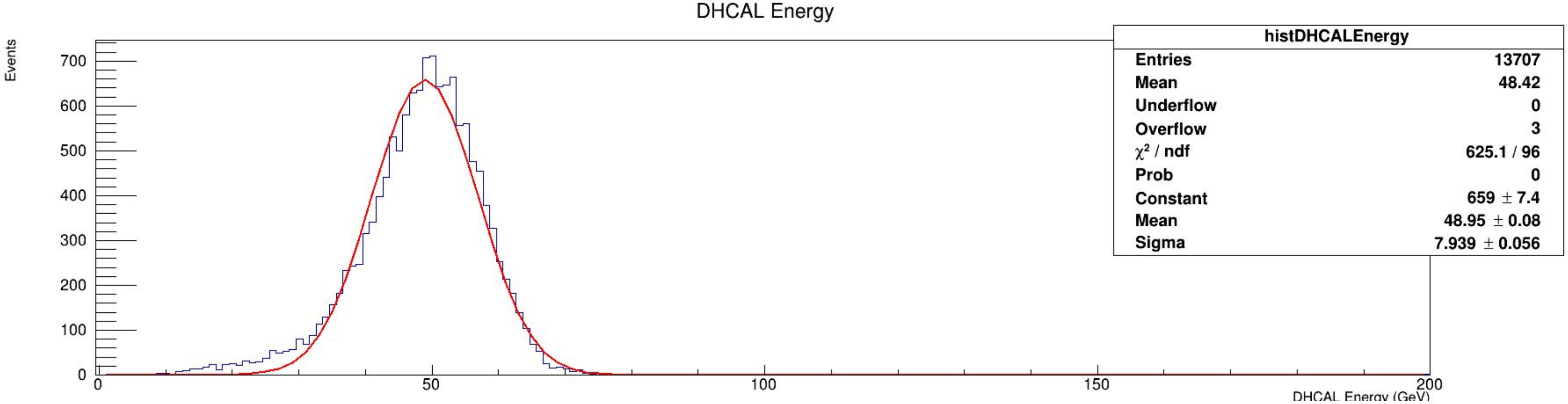
**Energy ECAL and DHCAL data Apr2011 50GeV run630081 DHCAL PION**

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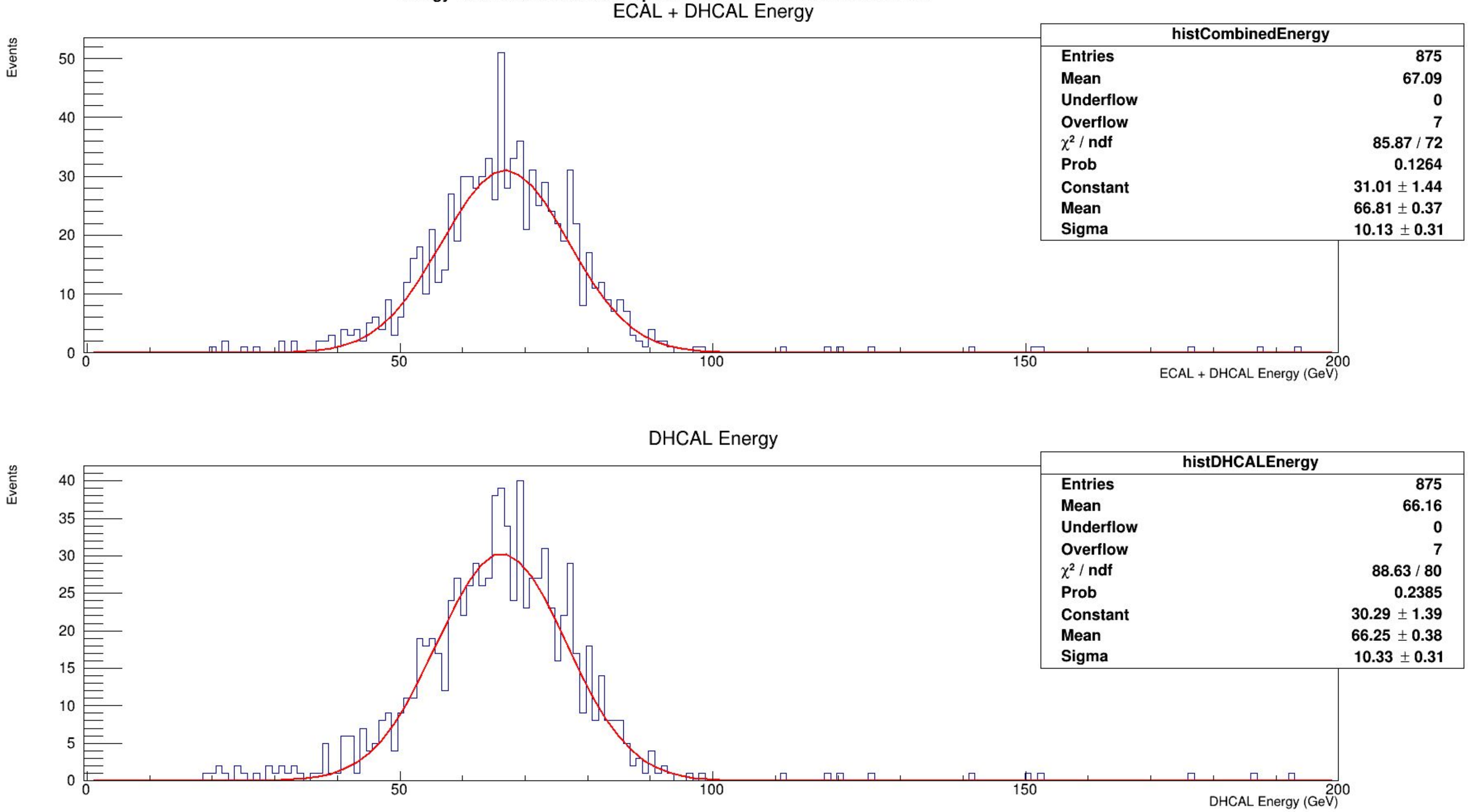
**Energy ECAL and DHCAL data Apr2011 60GeV run630092 DHCAL PION**

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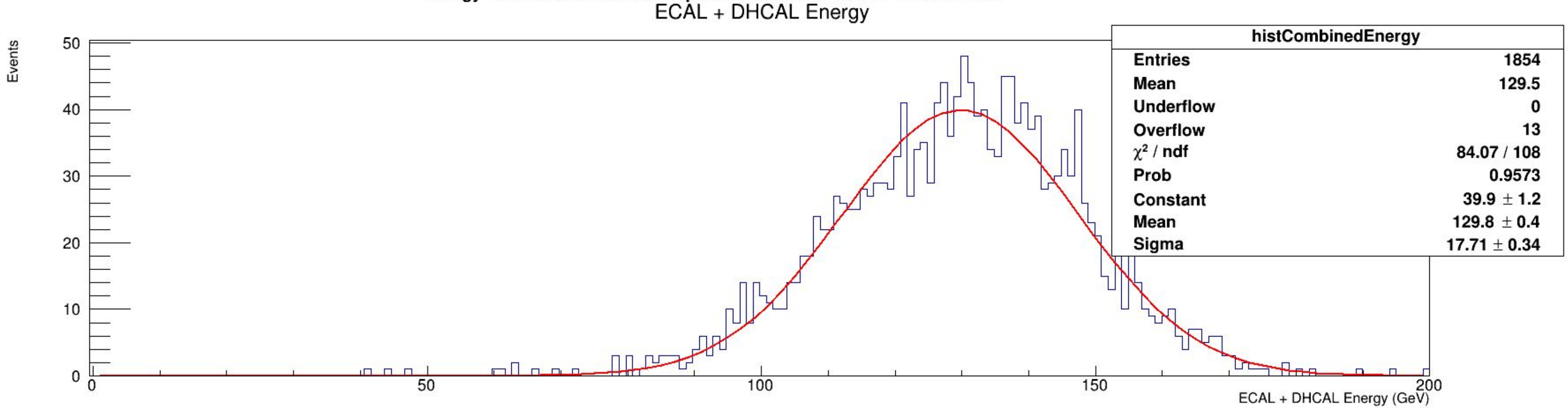
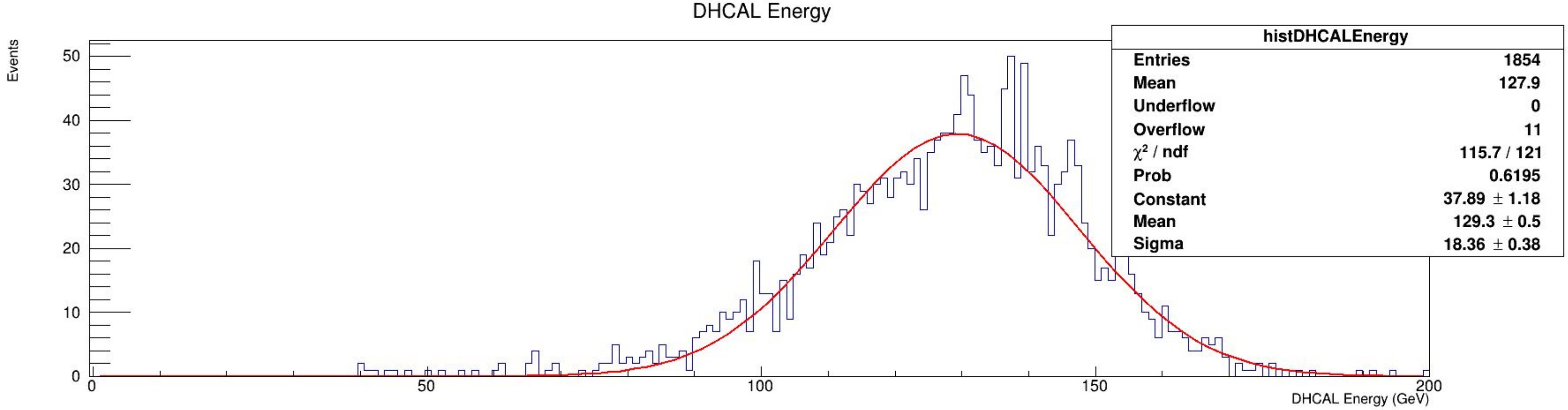
Energy ECAL and DHCAL data Apr2011 120GeV run630097 DHCAL PION

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