Neutrino energy reconstruction in the DUNE far detector

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Updates

ν_μ CC events: comparison of calibrations and corrections of track momentum and hadronic energy with and without intercepts.

Started work on neutrino energy reconstruction for ν_e CC events. Found it works reasonably well if using emshower showers and pandora, but not very well with emshower and pmtrack.

ν_μ CC events

Introduction

Reconstruct neutrino energy for ν_μ CC events by estimating momentum of track using range for contained tracks or multiple Coulomb scattering (MCS) for exiting tracks. Then add energy from hits not in track computed from sum of charges of those hits.

Results are from 16000 ν_μ events generated using GENIE in the 10 kt 1x2x6 geometry and reconstructed using standard reconstruction. In each true CC event, use reco track with largest number of hits (also tried longest track and results are very similar).

Define a fiducial volume as $|x|<=310$, $|y|<=550$, $50<=z<=1250$ cm, and include only events with true vertices within this fiducial volume.

Calibrate reco track momentum

Use 5 bins in true momentum: 0.5-1, 1-1.5, 1.5-2, 2-2.5, 2.5-3 GeV

Contained tracks

Plot all the values of reco track length for true muon momentum 0.5-1 GeV in a 1D histogram. Fit a Gaussian to the histogram and obtain the mean and σ of the fit. Repeat with separate 1D histograms for each of the other 4 true momentum bins.

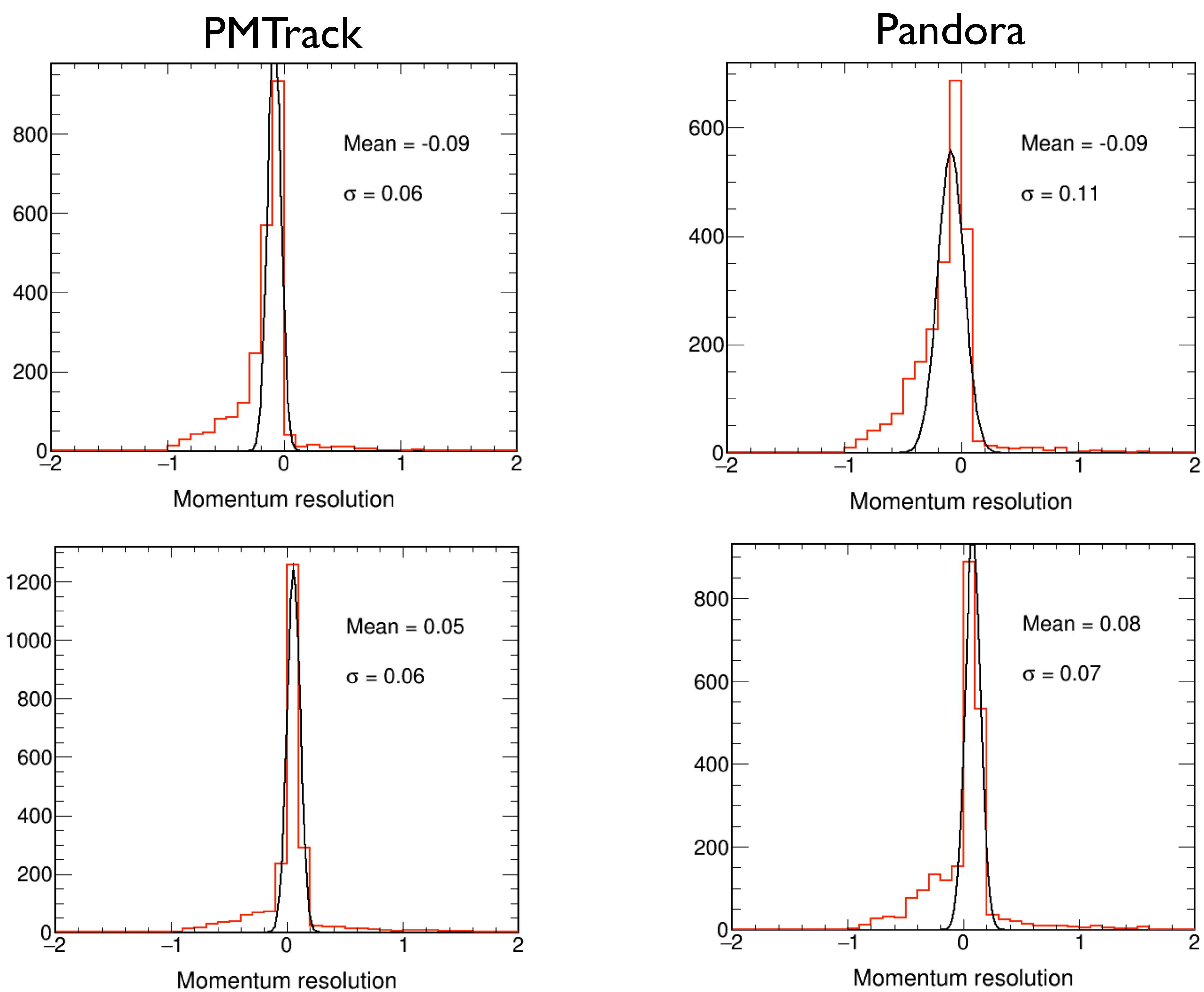
Plot a graph with x values being the centres of the 5 true momentum bins and y values the means of the 5 Gaussian fits. Fit a straight line to this graph.

Exiting tracks

Do the same except use MCS momentum instead of reco track length.

Resolution of track momentum by range

True CC events with contained track



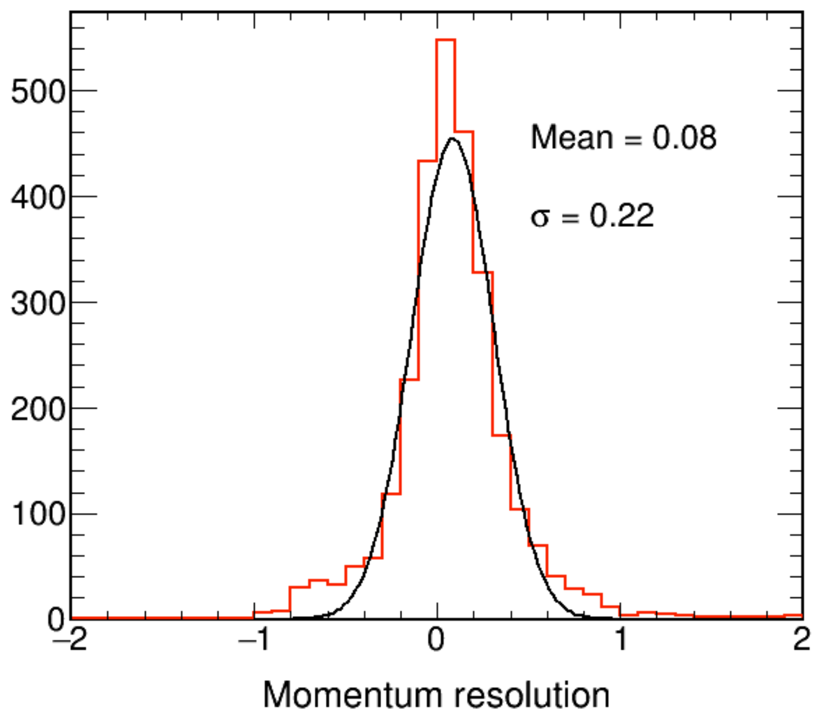
Reco momentum = reco length / gradient

Reco momentum = (reco length - intercept) / gradient

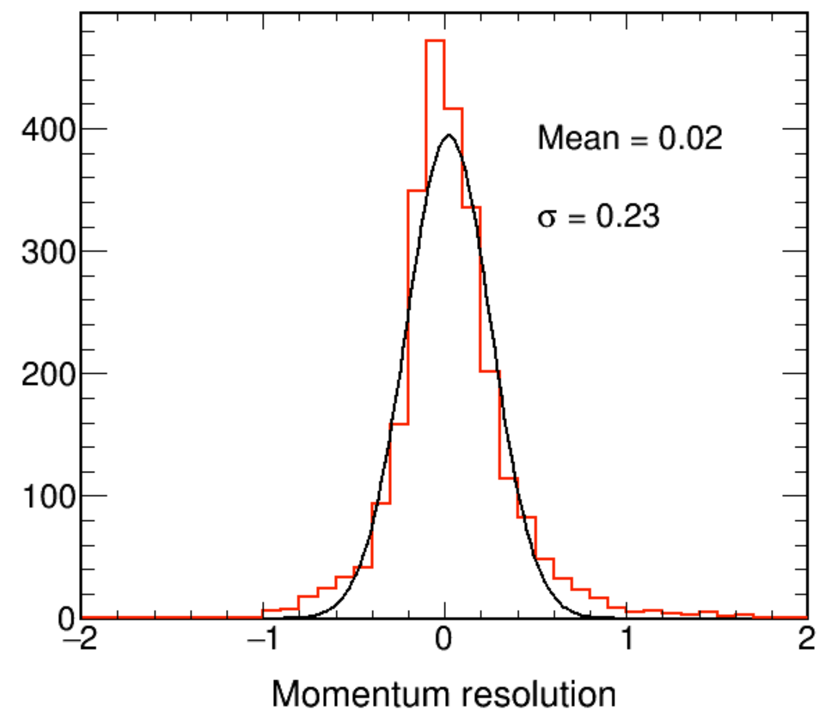
MCS momentum resolution

True CC events with exiting track

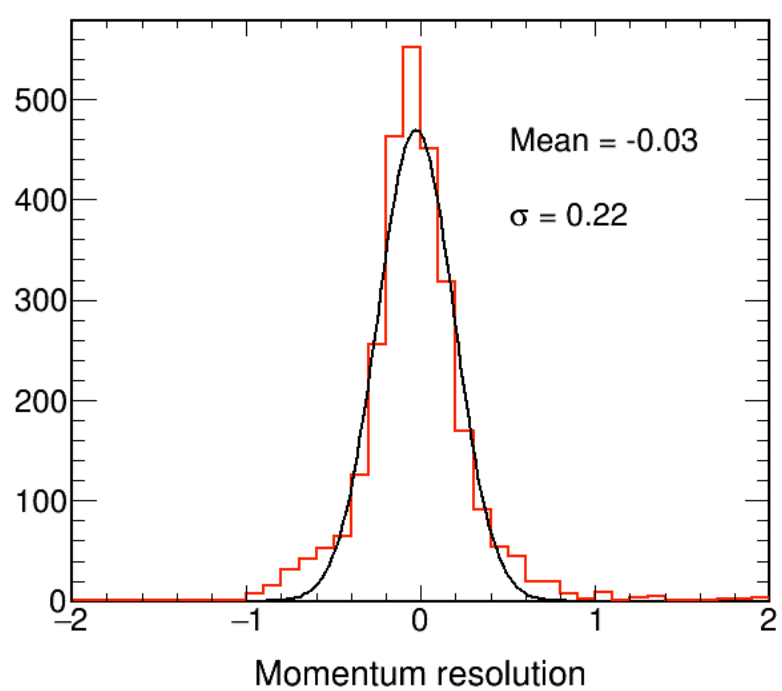
PMTrack

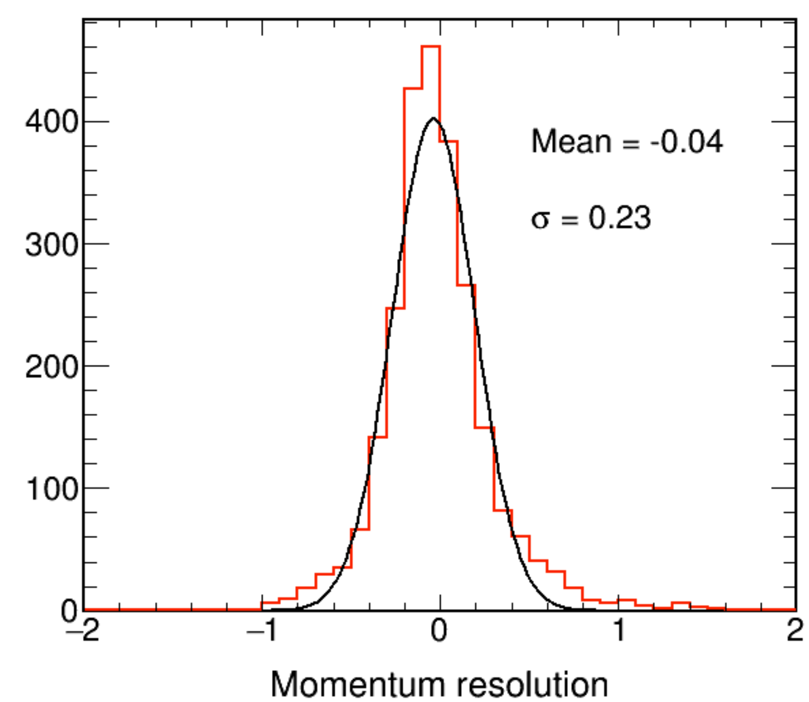


Pandora



Reco momentum = MCS / gradient





Reco momentum = (MCS - intercept) / gradient

Hadronic energy

Estimate reco hadronic energy from hits not in track. Apply lifetime correction and an average recombination correction of 1.0/0.63 to charges of those hits. In practice calculate this as corrected ADC (all hits) - corrected ADC (hits in track).

Then convert to energy: energy (GeV) = corrected ADC * 23.6e-9 / 4.966e-3

This calculation always gives a reco hadronic energy that is too low compared with true hadronic energy. One reason for this is missing energy from neutral particles.

Make a correction using the same method as for contained and exiting tracks.

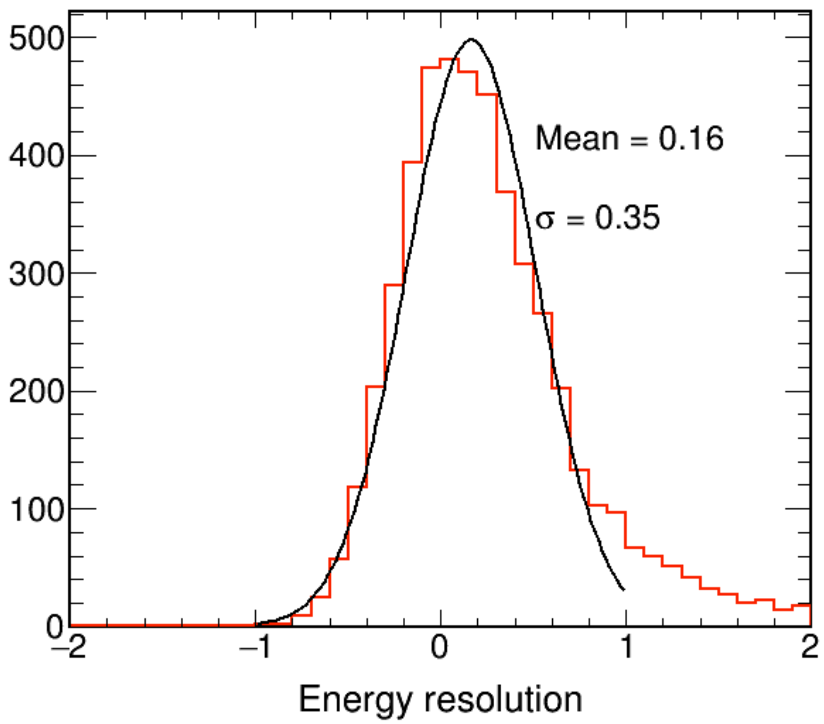
Hadronic energy resolution

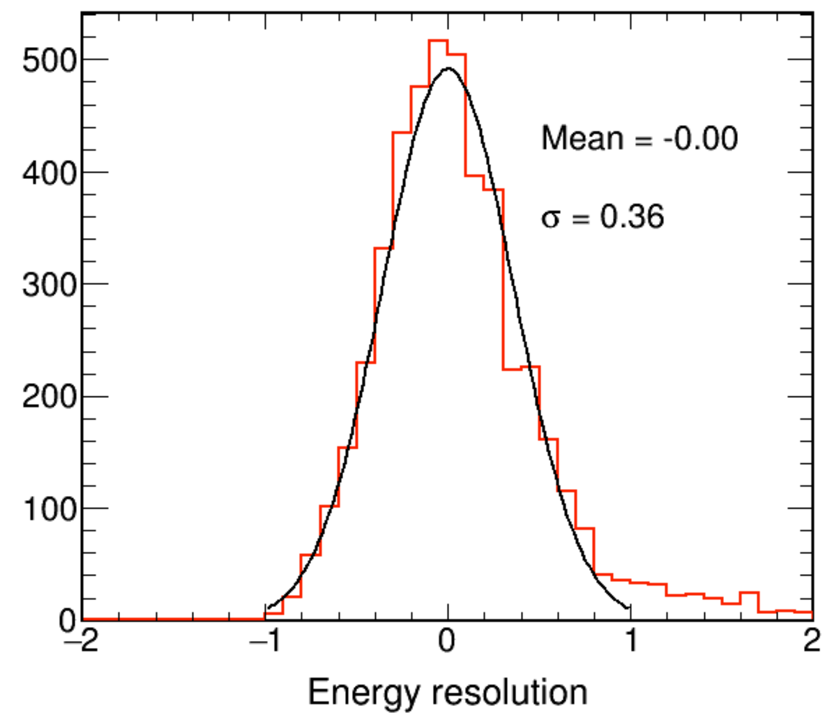
True CC events

PMTrack

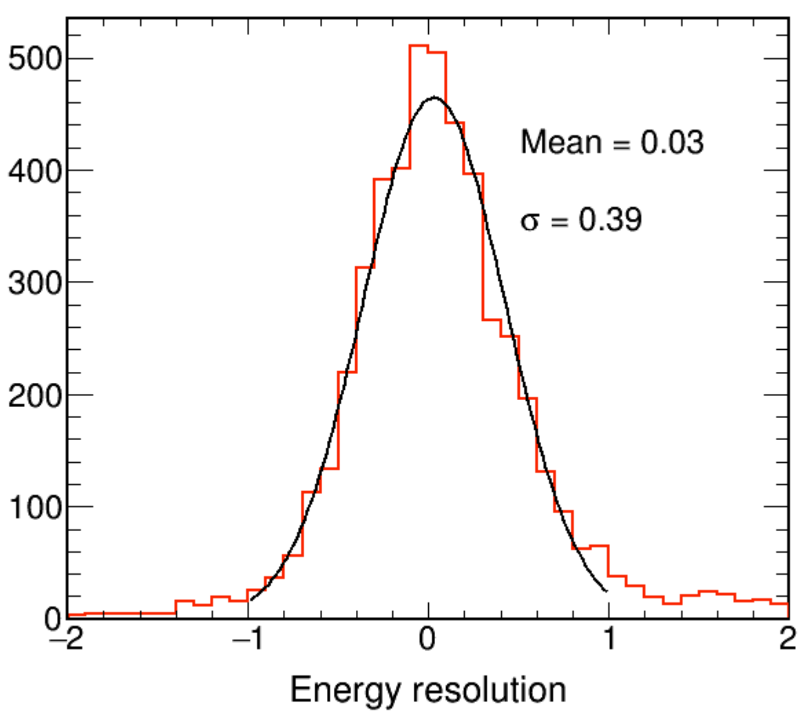
Pandora

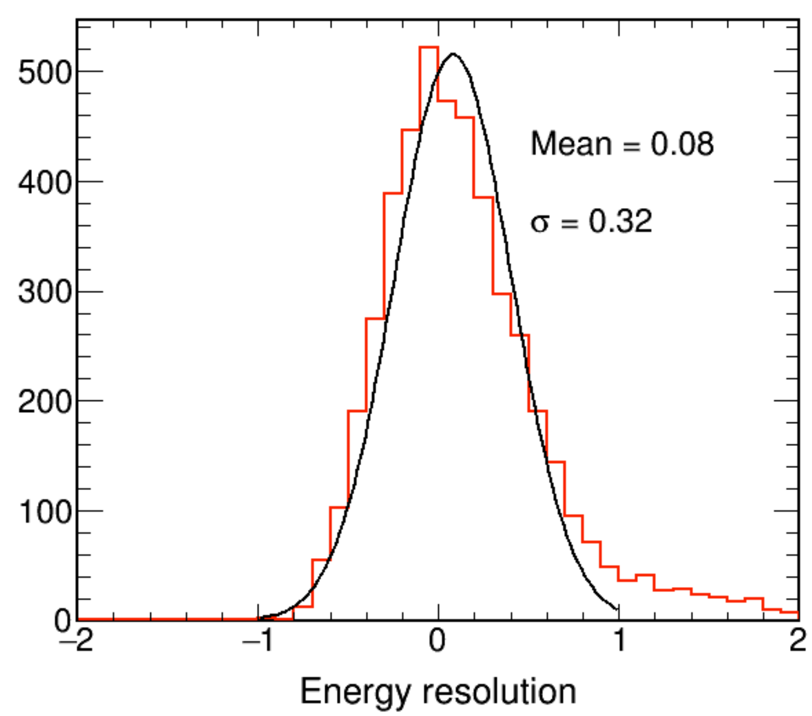
Use gradient only





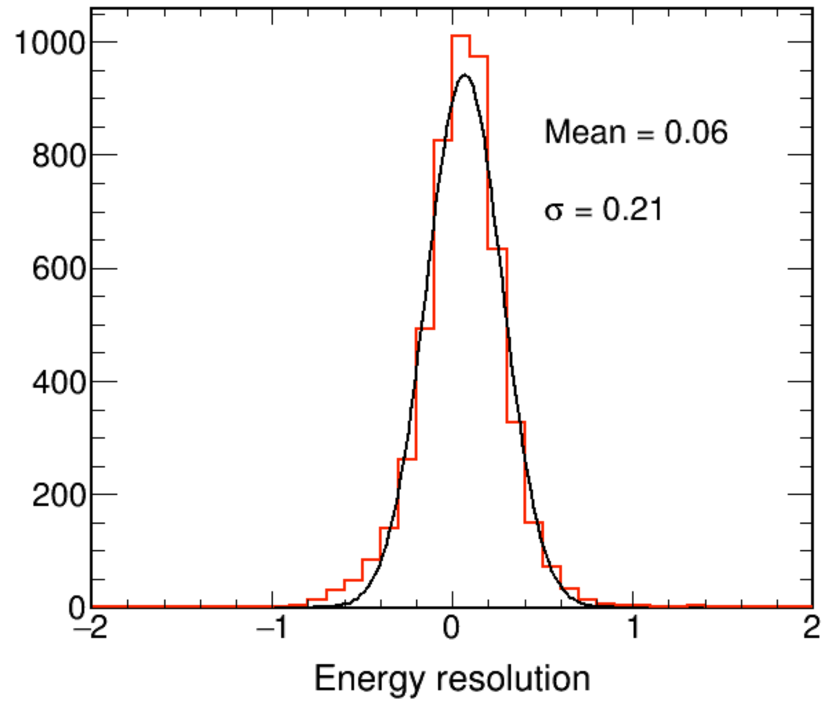
Use gradient and intercept

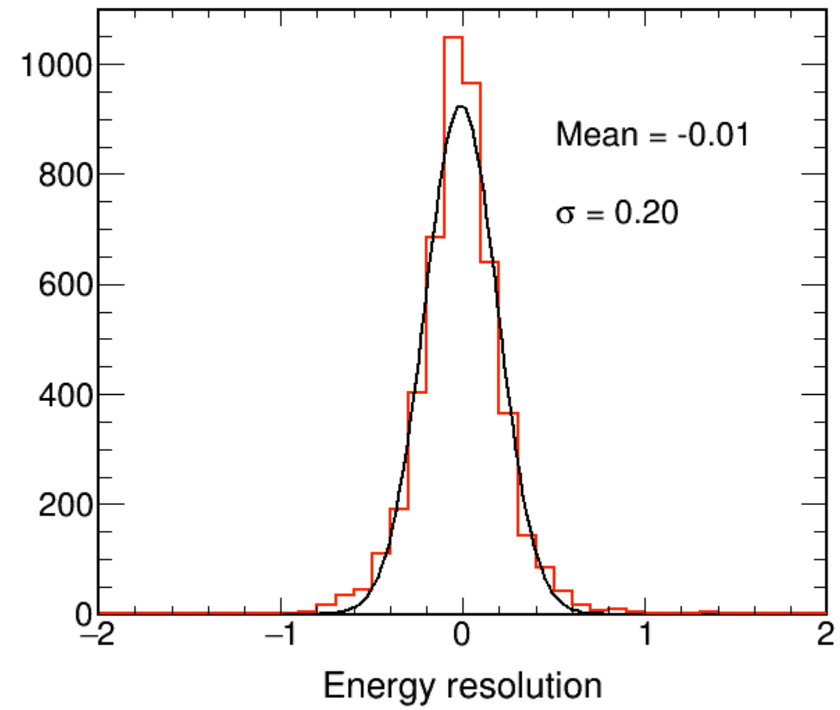




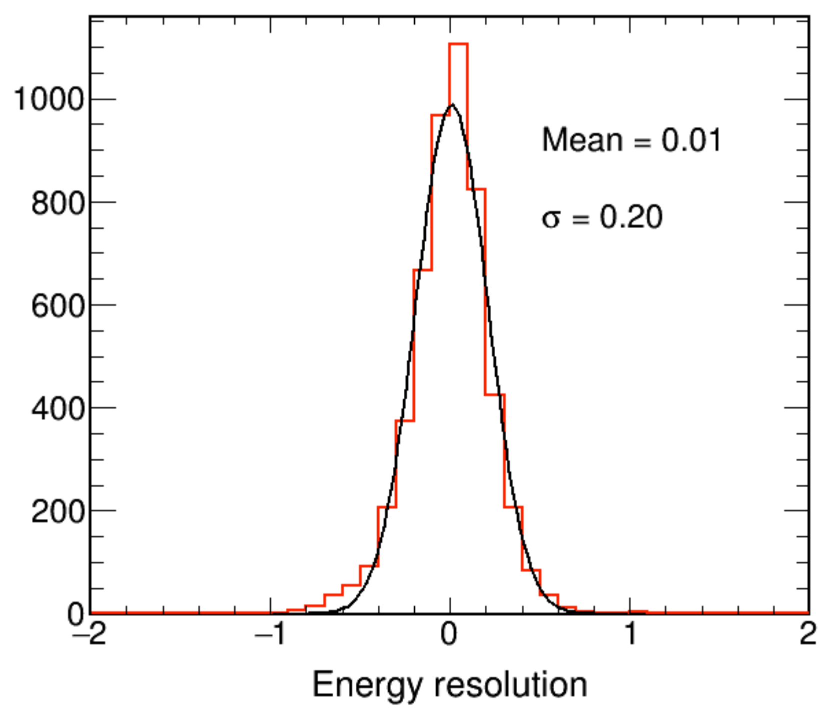
ν_μ energy resolution

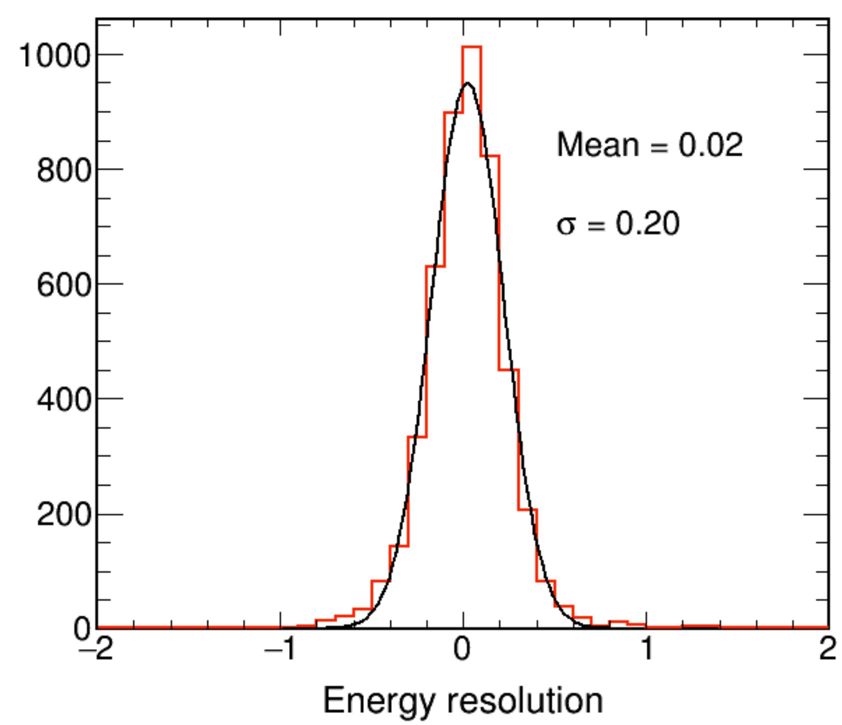
PMTrack	Pandora	True CC events





Use gradients only





Use gradients and intercepts

ν_e CC events

Introduction

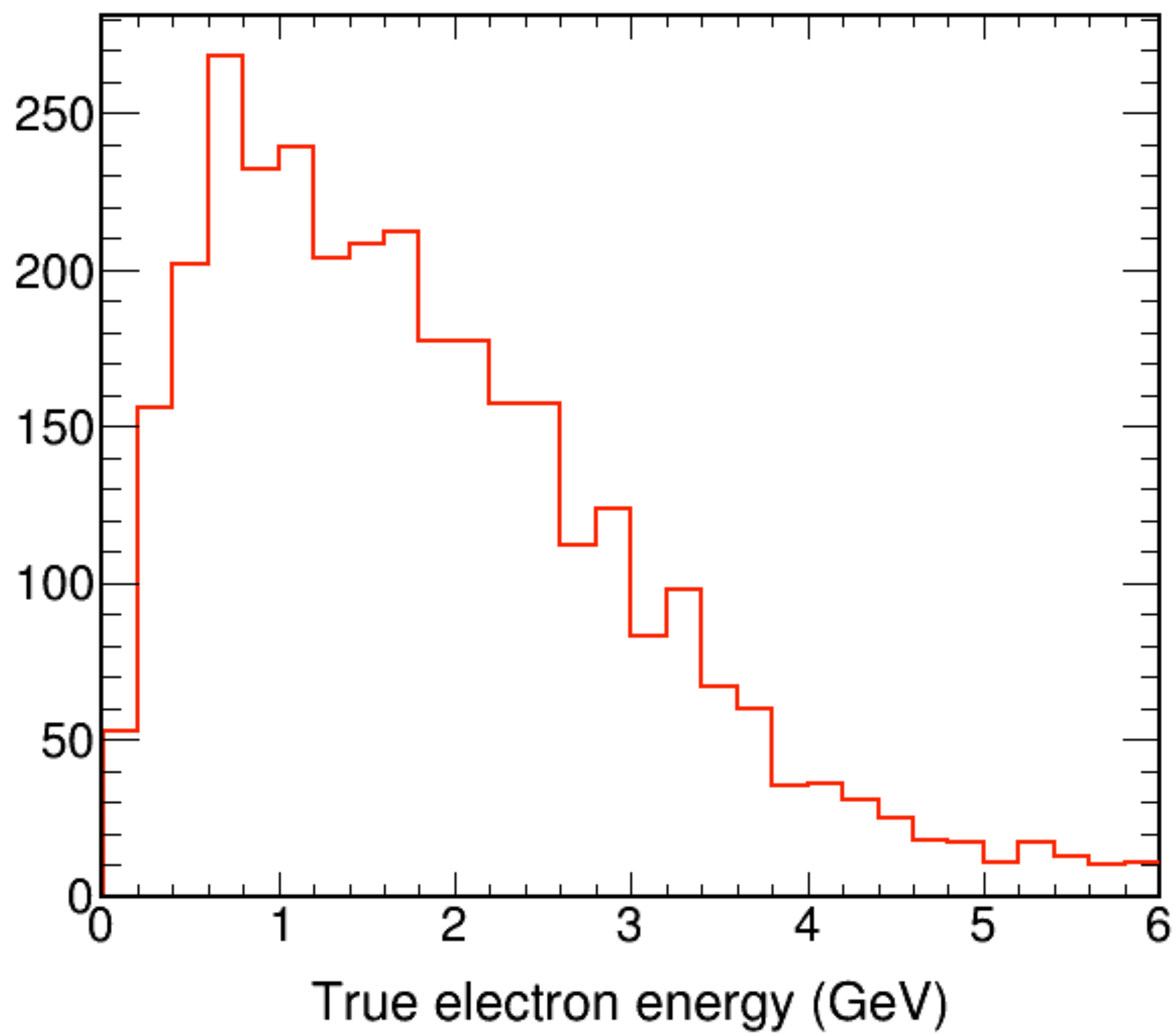
Results are from 10000 ν_e events generated using GENIE in the 10 kt 1x2x6 geometry and reconstructed using standard reconstruction. In each true CC event, use reco shower with highest total hit charge. Apply lifetime and average recombination corrections, convert total hit charge to energy and make correction using true electron energy.

Then add hadronic energy from hits not in shower computed from sum of charges of those hits. Convert sum of charges to energy and make correction using true hadronic energy.

Same fiducial volume is used as for ν_μ CC events.

True electron energy

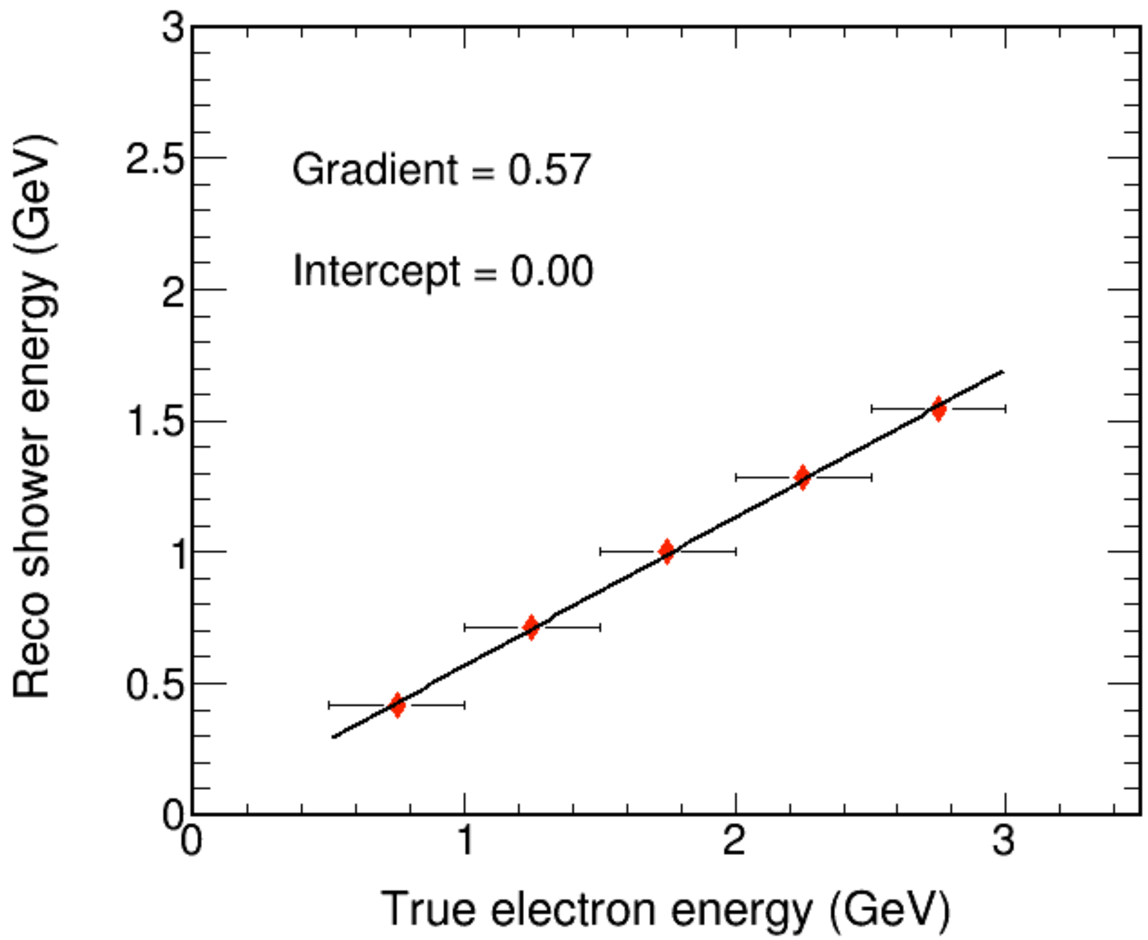
True CC events



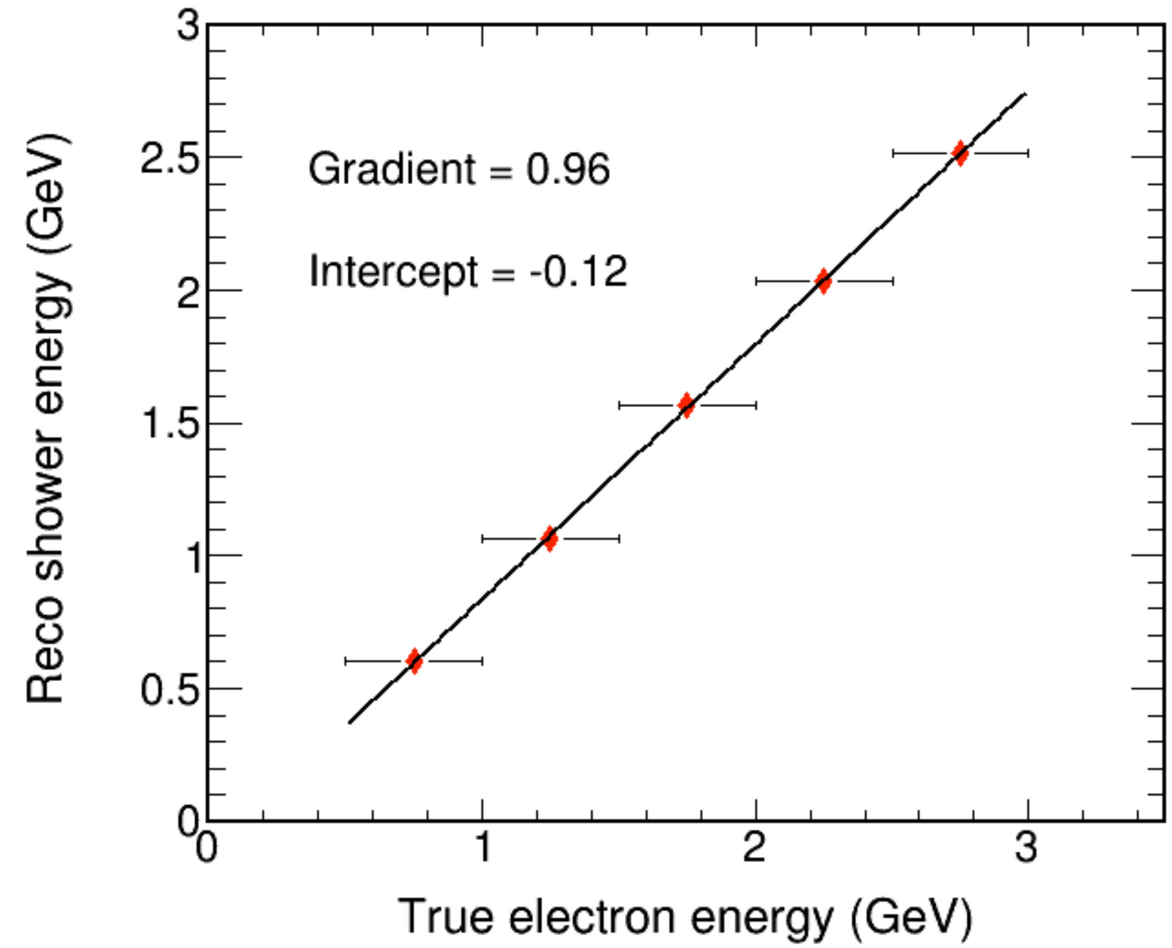
Correction for shower energy

True CC events
emshower showers

Set VertexLabel, TrackLabel and CalModuleName to pmtrack

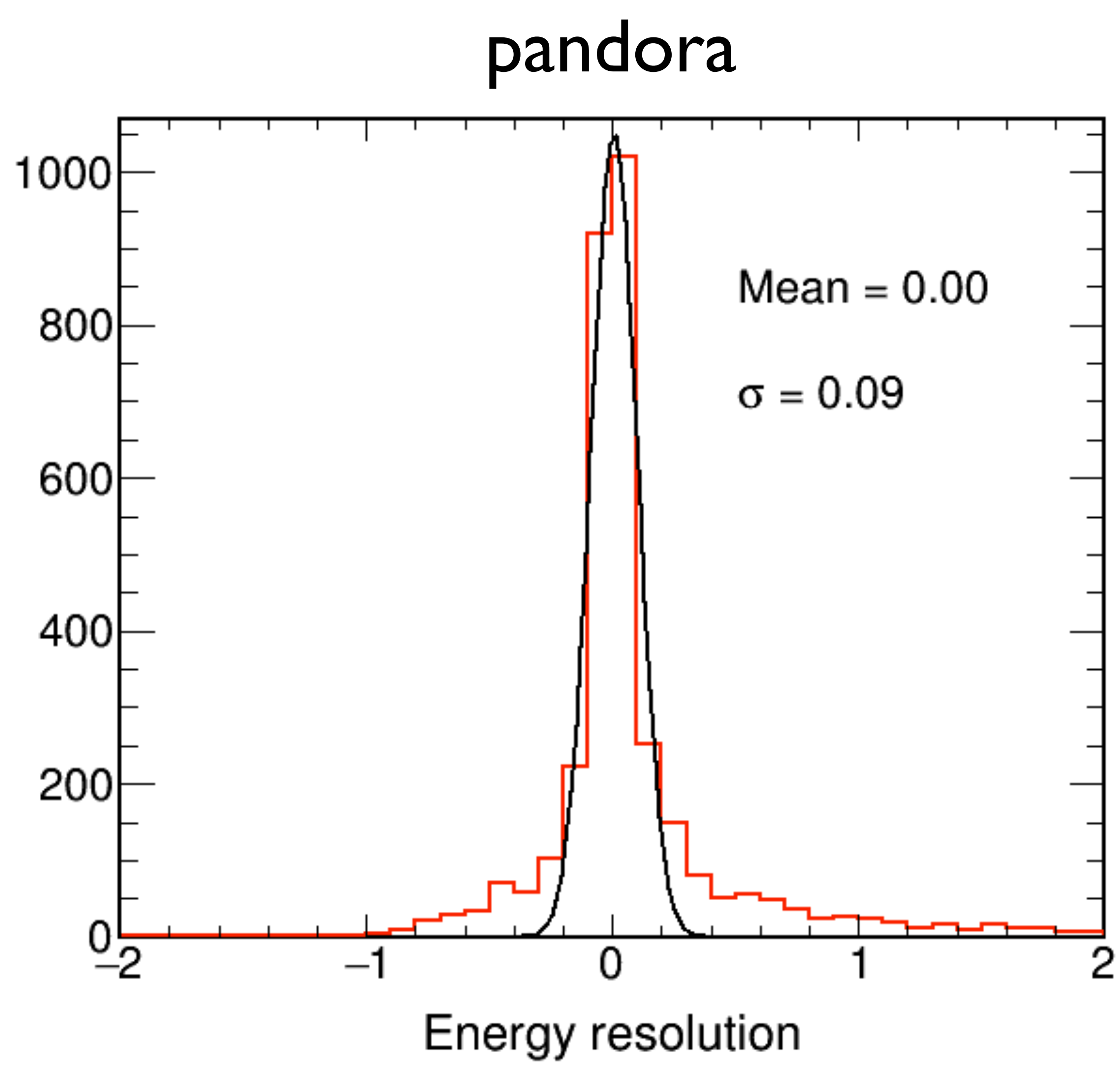


Set VertexLabel, TrackLabel and CalModuleName to pandora



Shower energy resolution

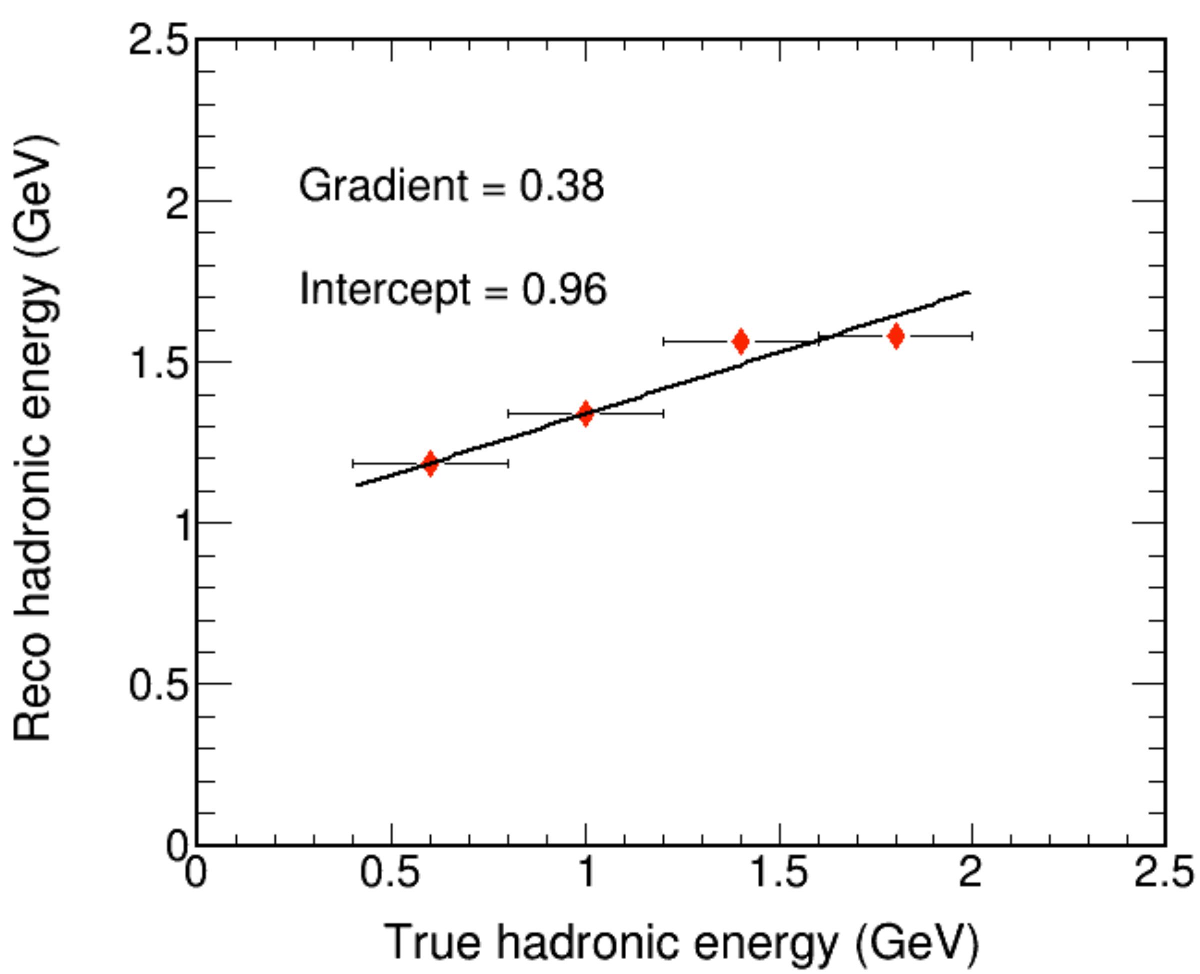
True CC events



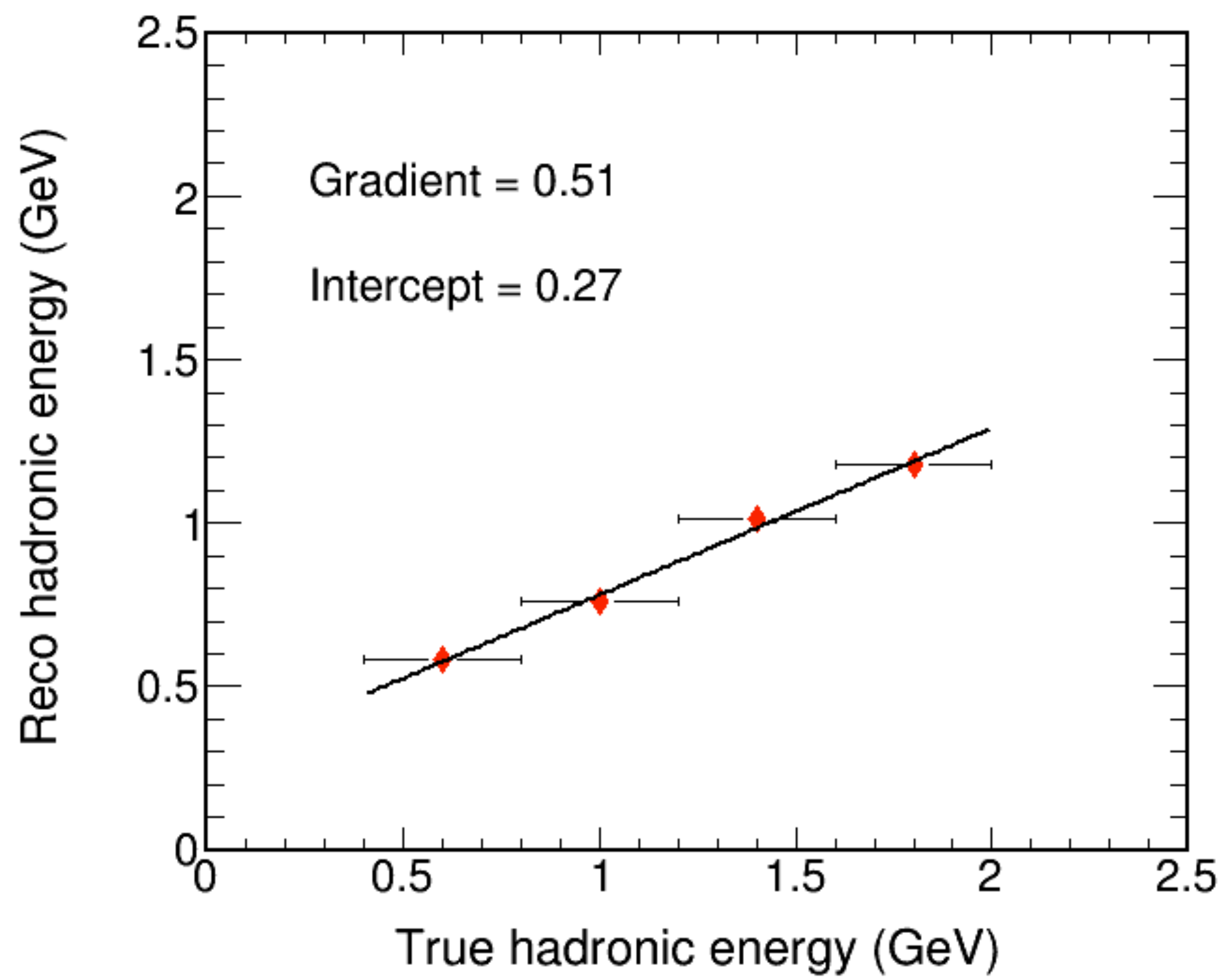
Correction for hadronic energy

True CC events
emshower showers

pmtrack



pandora

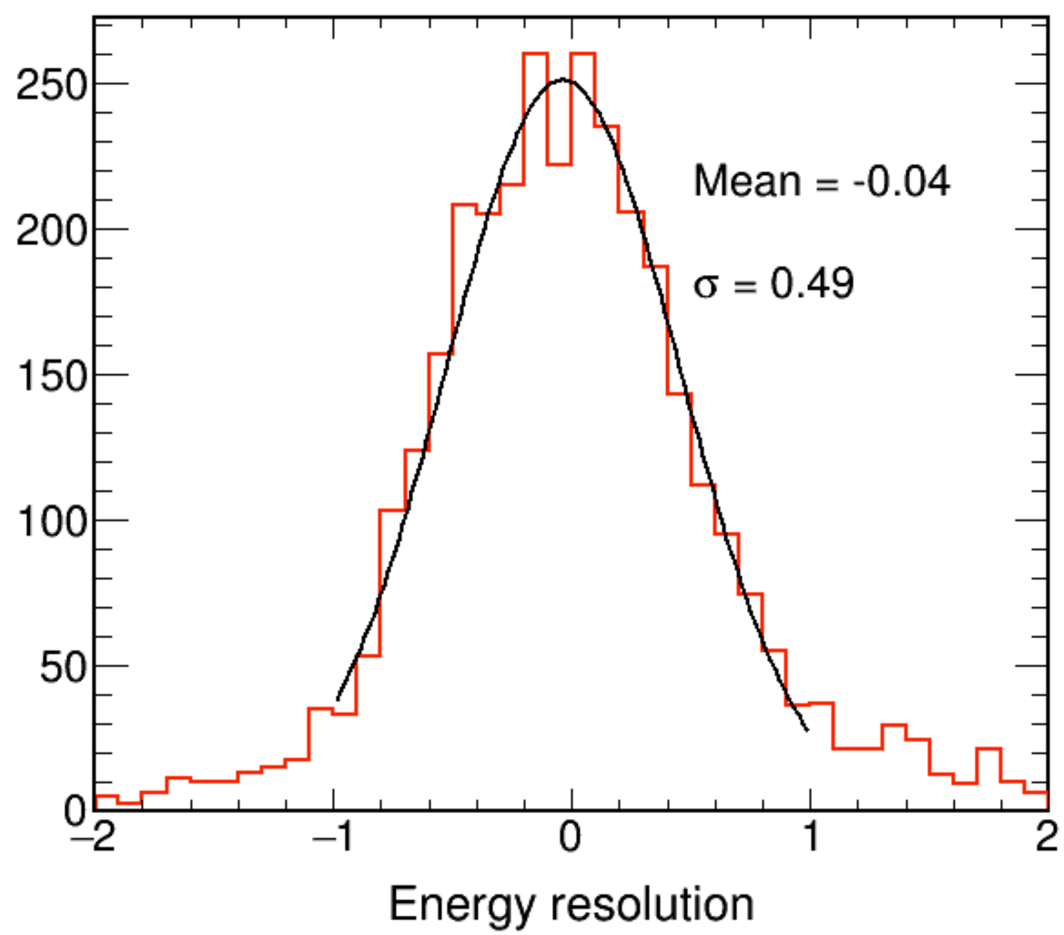


Hadronic energy resolution

True CC events

Tail below -1 is due to subtracting the intercept of the correction. Intercept is > 0; when this is subtracted from low values of reco hadronic energy, this can make the reco hadronic energy < 0.

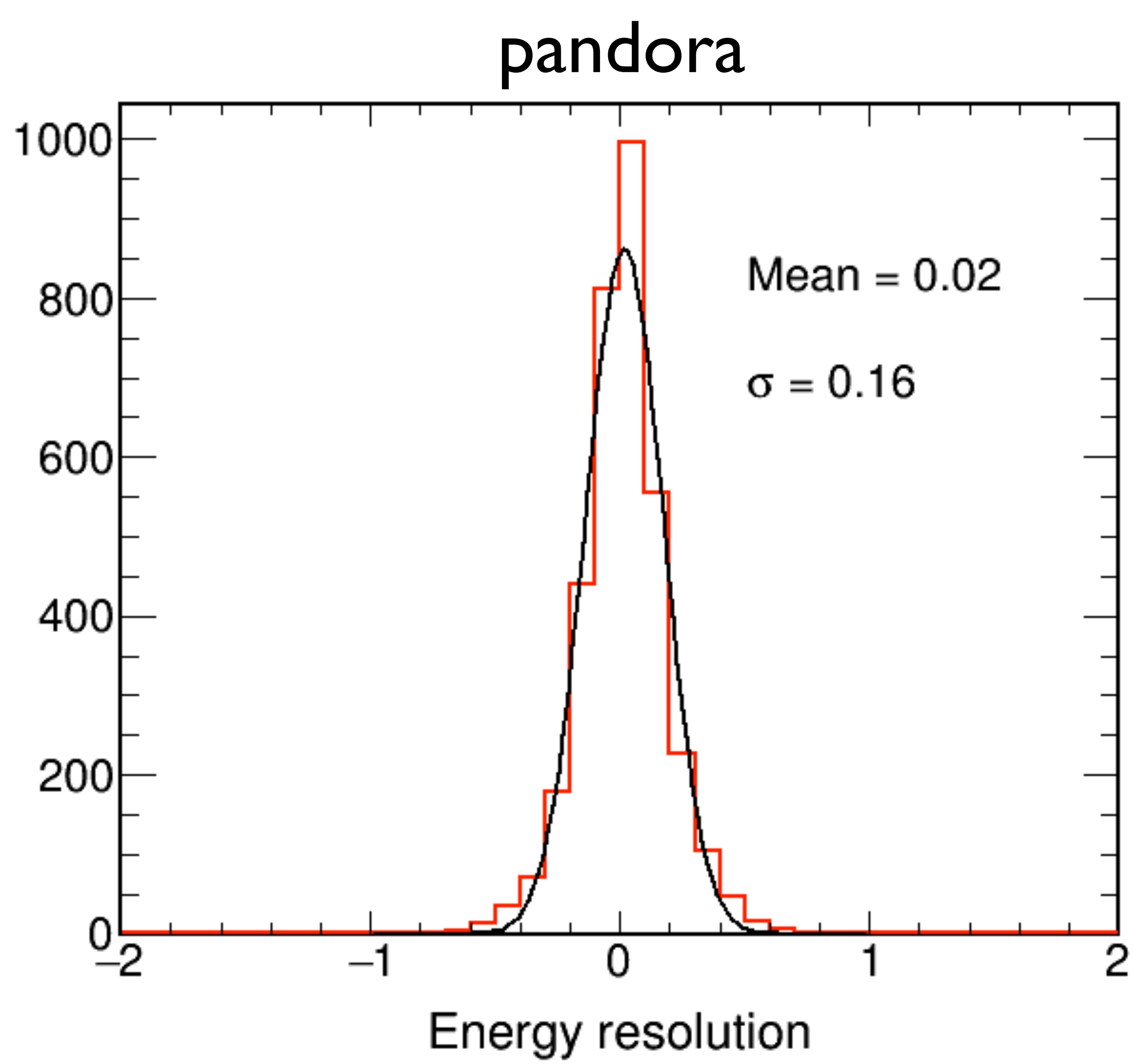
pandora



Neutrino energy resolution

True CC events

If corrected reco hadronic energy < 0, set it to 0



BACKUP SLIDES

Multiple Coulomb scattering

Estimate of track momentum using MCS is made using the TrackMomentumCalculator class in larreco/RecoAlg.

This description is taken from an ICARUS paper at

https://arxiv.org/pdf/hep-ex/0606006v1.pdf

I have read the code in TrackMomentumCalculator and believe that it does this or something similar to this.

A charged particle traversing a medium is deflected through many small angle scatterings.

Divide the track into segments of equal length. Fit a straight line to each track segment.

Multiple Coulomb scattering

For each consecutive pair of segments, the scattering angle is the difference between the segment angles.

Compute the RMS of the scattering angle distribution.

Repeat for different segment lengths, and fit for p and C in

$$\theta^{rms}_{meas} = \sqrt{\left(\frac{13.6\ MeV}{\beta c\, p}\, z \sqrt{\frac{l}{X_0}} \cdot \left[1 + 0.038 \cdot ln\left(\frac{l}{X_0}\right)\right]\right)^2 + \left(C \cdot l^{-3/2}\right)^2}$$

where β is velocity, p momentum and z charge of particle
X_0 is radiation length, l is segment length, C $l^{-3/2}$ is noise

One advantage of this method is that it can be used equally well for stopping and exiting particles.

Module labels

GenieGenModuleLabel:	generator
VertexLabel:	pmtrack
HitLabel:	linecluster
TrackLabel:	pmtrack
ShowerLabel:	emshower
SpacePointLabel:	pmtrack
TrackingLabel:	largeant
CalModuleName:	pmtrackcalo

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TrackLabel:	pandora
ShowerLabel:	emshower
SpacePointLabel:	pandora
TrackingLabel:	largeant
CalModuleName:	pandoracalo