Neutrino energy reconstruction in the DUNE far detector

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Introduction

Attempt to improve neutrino energy reconstruction 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).

Results are shown for reconstruction with both PMTrack and Pandora; the same generated events are used for both versions of reconstruction.

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

Updates

Use new method to calibrate reconstructed momentum by range (contained tracks) and MCS momentum (exiting tracks), and to correct hadronic energy.

Further investigation of tails in plots of resolution of momentum by range.

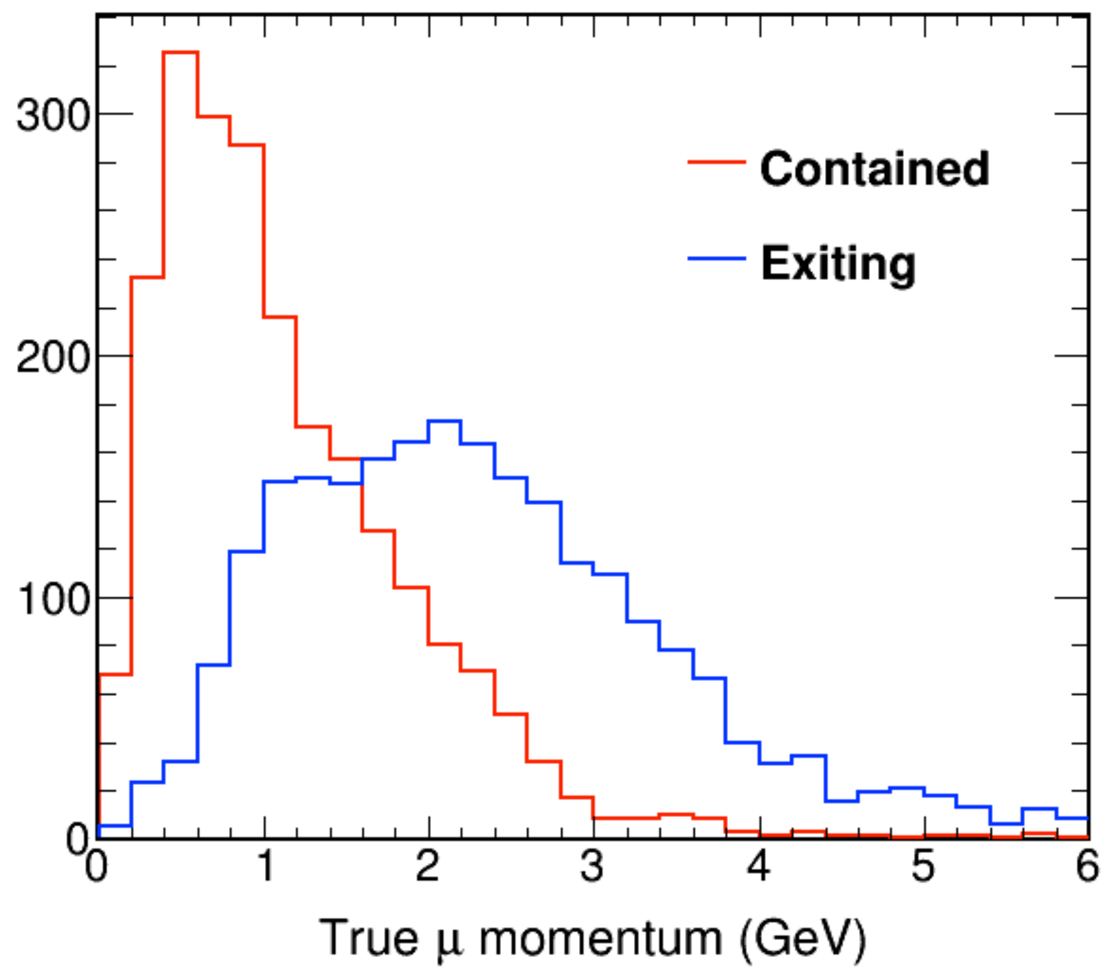
Show neutrino energy resolution separately for contained and exiting tracks, and in 3 bins of true energy.

In order to accommodate this binning, increase number of ν_μ events from 5000 to 16000.

True momentum

True momentum for contained and exiting muons from all true CC events

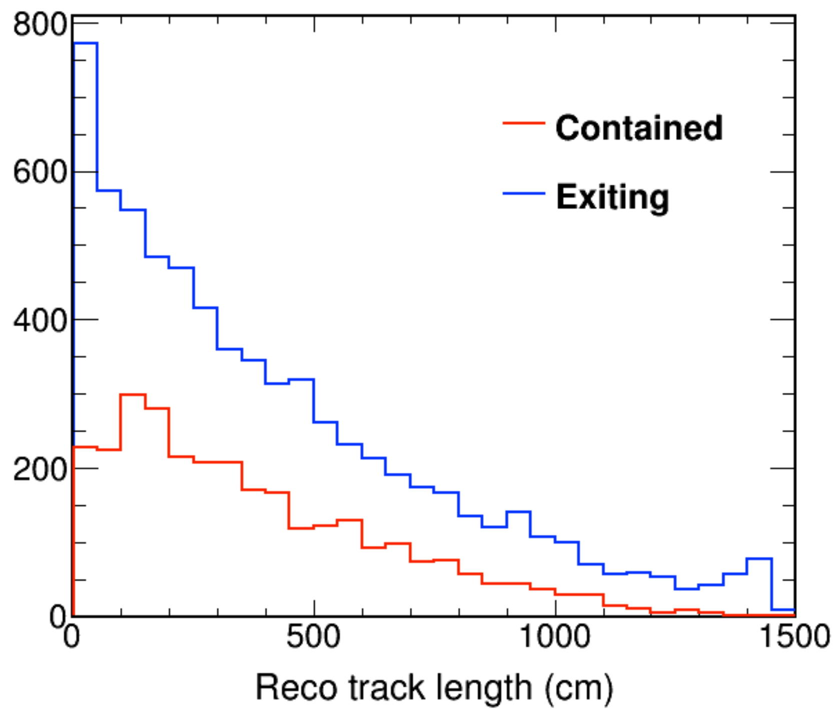
Define reduced volume that is 20 cm narrower than 1x2x6 volume in all 3 dimensions (this is not the same as the fiducial volume). Track is contained if it has no reco hit outside this reduced volume; otherwise it is exiting.

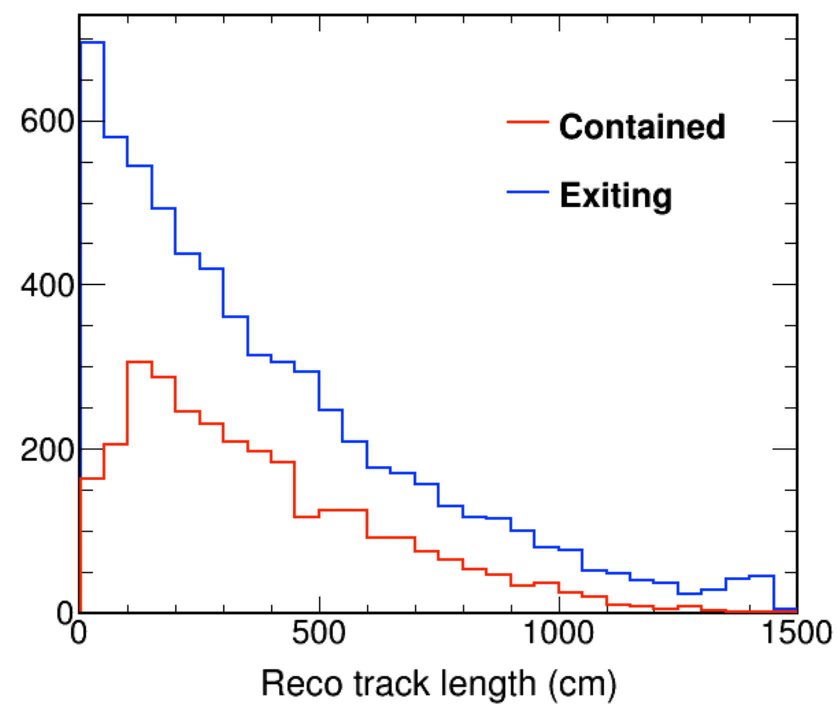


Reconstructed track length

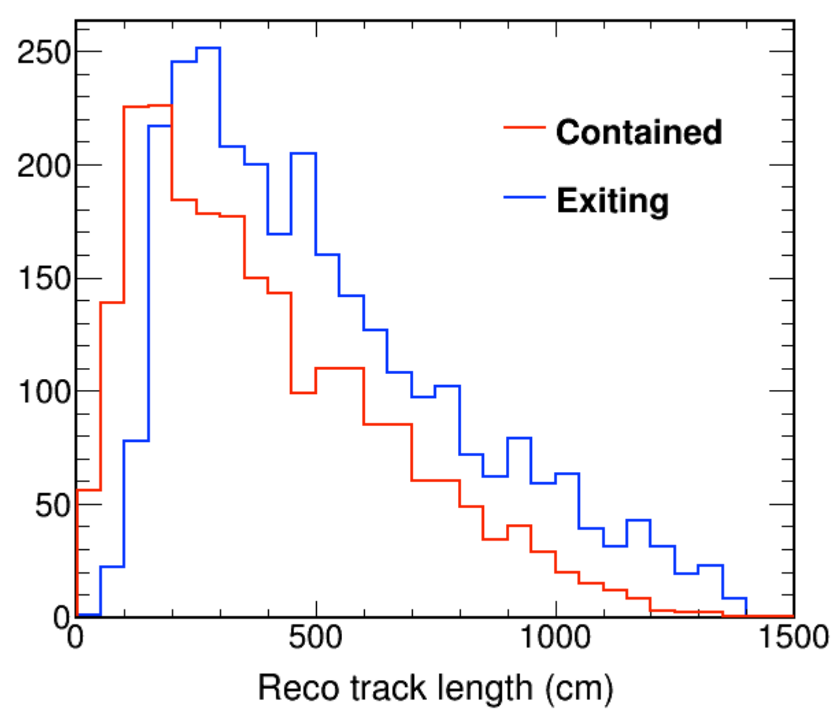
PMTrack

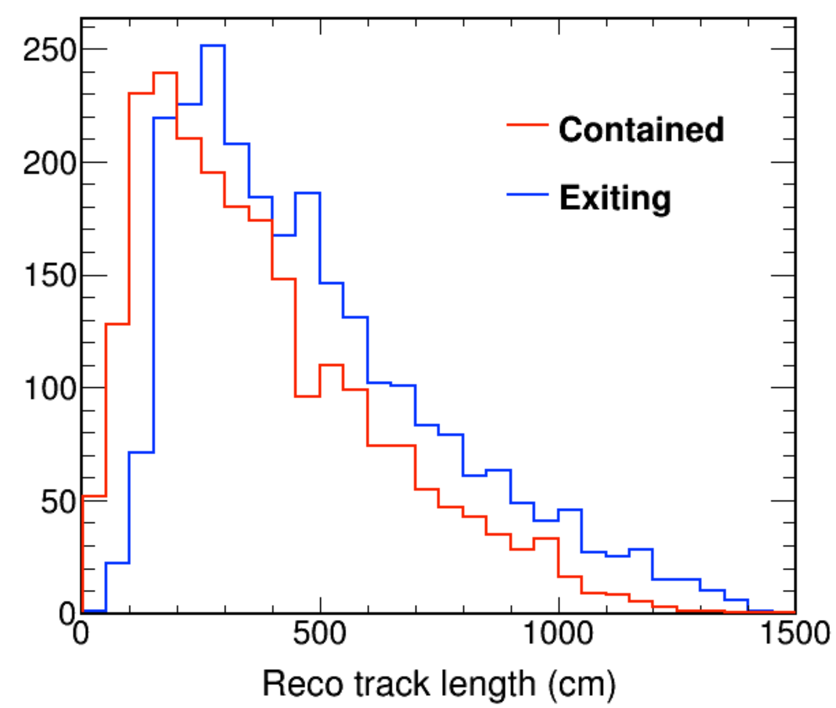
Pandora





All true CC events





True CC events with vertex in 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.

Exiting tracks

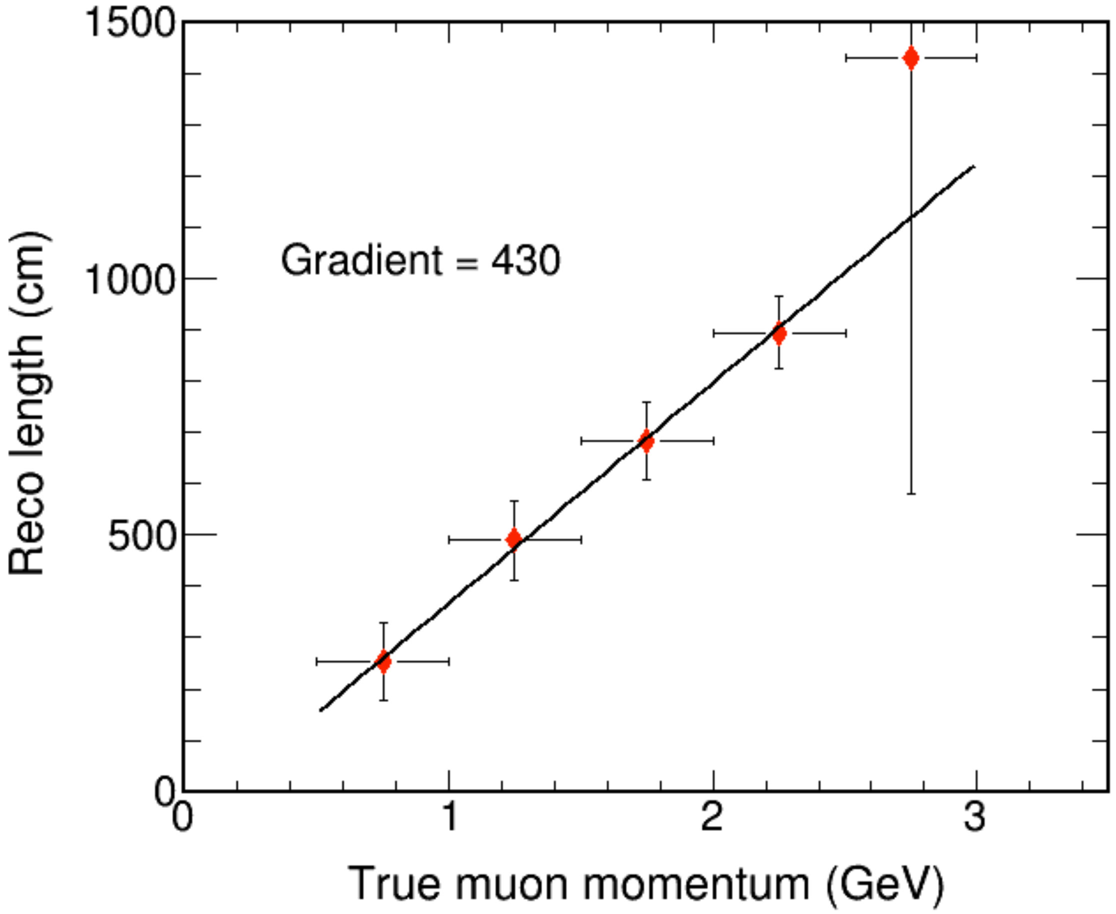
Do the same except use MCS momentum instead of reco track length.

Reco momentum by range

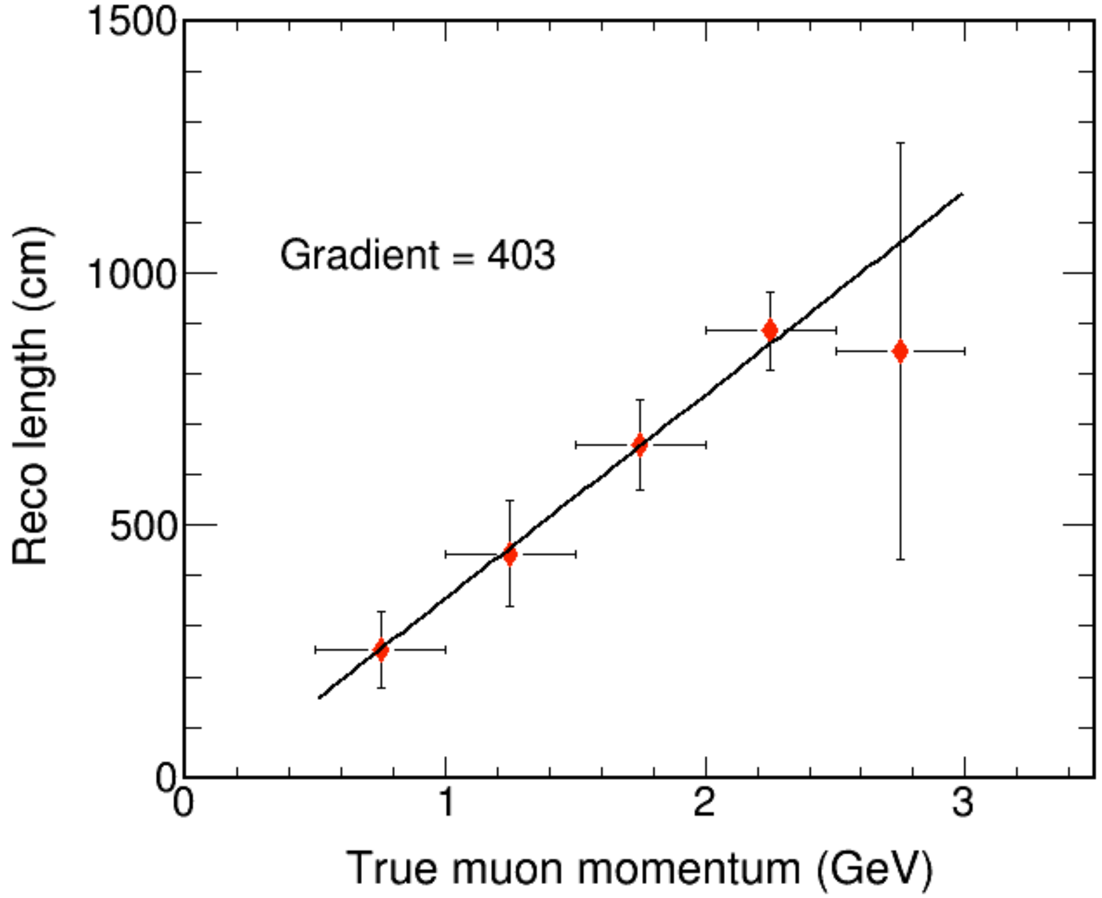
Plot a graph with x values being the centres of the 5 true momentum bins, y values the means of the 5 Gaussian fits, y error bars the σ of the 5 Gaussian fits. Fit a straight line to this graph.

True CC events with contained track

PMTrack



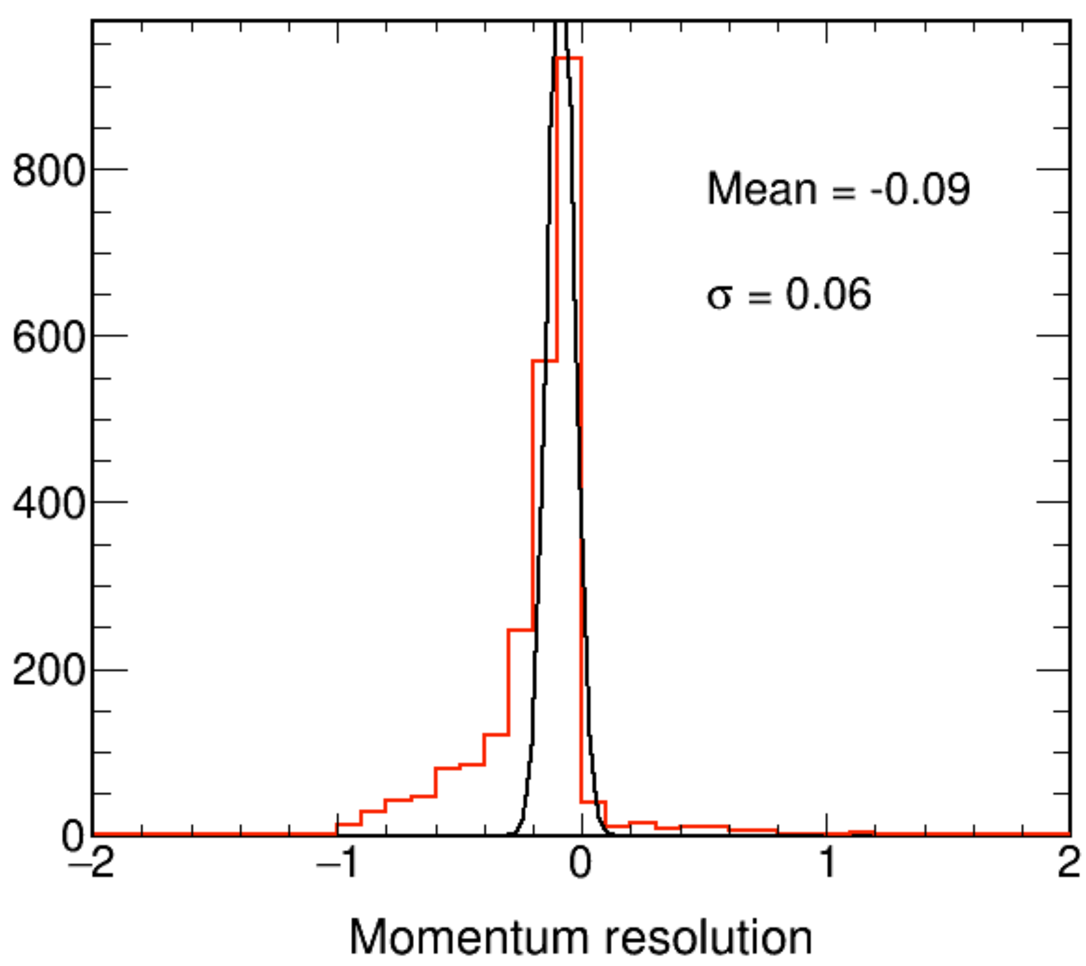
Pandora



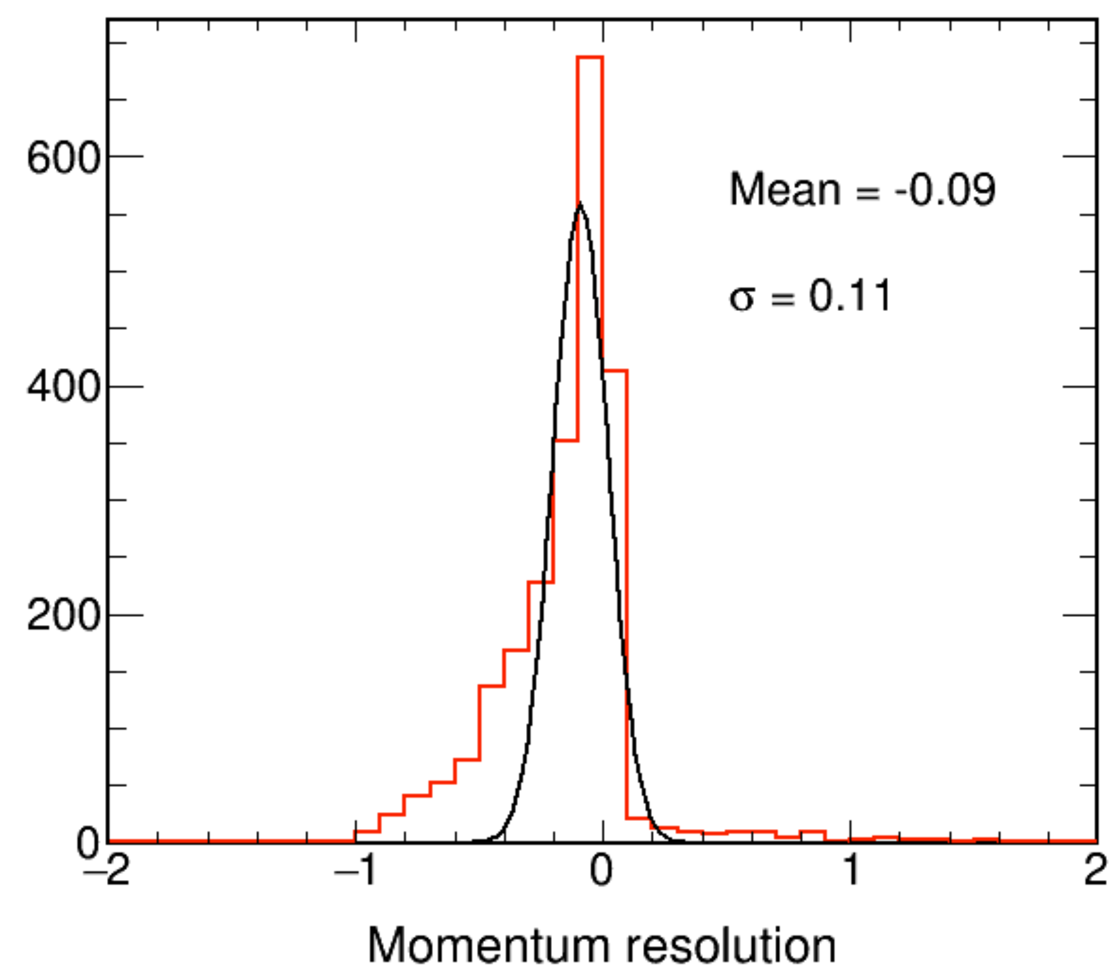
Reco momentum by range

Momentum resolution for track momentum by range
True CC events with contained track
Note: same events used for calibration and to make these resolution plots

PMTrack



Pandora



Reco momentum by range

What is reason for tails on low sides of plots of momentum by range resolution ?

1. Checked for broken tracks including tracks crossing the detector gap at x=0. Did this by looking for a second track in event with direction within 0.1 rad and start < 60 cm from end of first track.

Found such second tracks in a few events for both PMTrack and Pandora. Tried excluding these events from the resolution plots, but this made only a very small change to low tails.

2. Also looked for broken tracks where part of the track is outside the detector: increased band at edge of detector that defines contained tracks from 20 to 50 cm. Again this made little difference to the tails.

Reco momentum by range

3. Reco track with largest number of hits might not always be from muon.

Used BackTracker to find GEANT track that contributes most to the energy deposition of the reco track. Found that most reco tracks are matched to muons, but a small number is matched to other particles such as protons or charge pions.

Tried excluding tracks not matched to muons from resolution plots, but again this made only a small difference to the tails.

4. Muon energy might be split between more than one reco track. Tried excluding events with more than one reco track matched to muon from resolution plots. This reduced the number of entries in the histograms, but did not significantly reduce the tails compared with the spike.

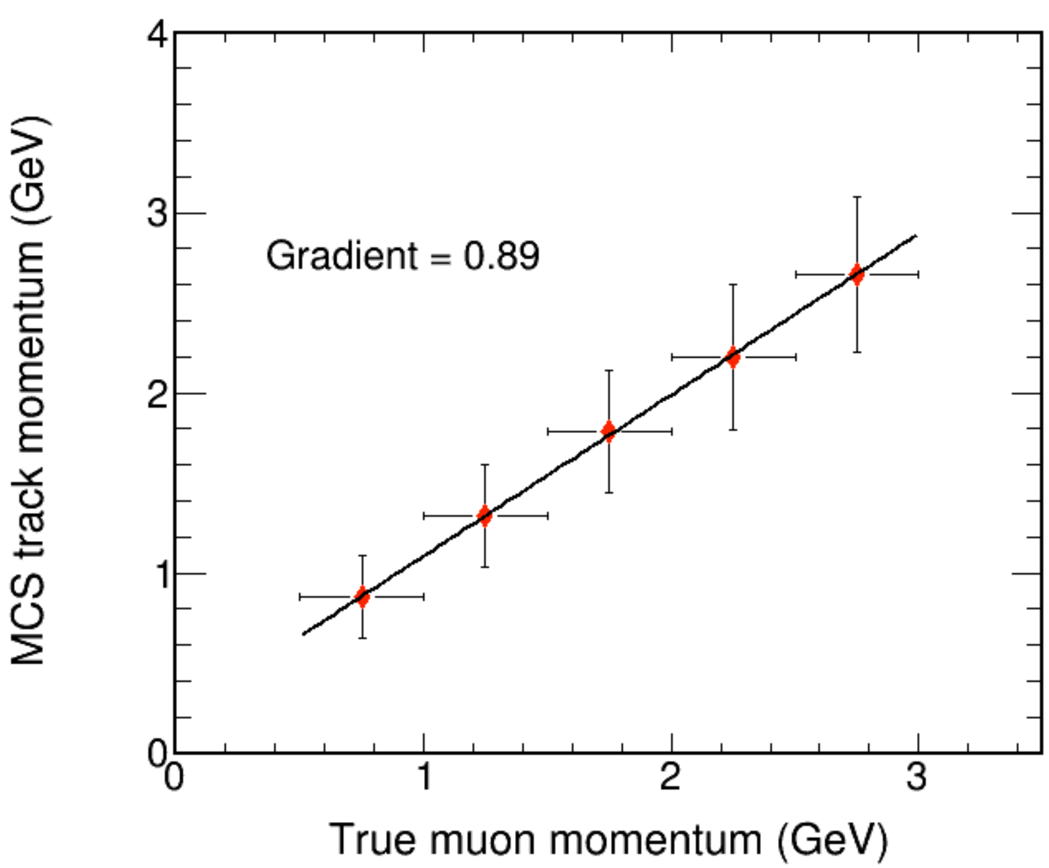
This is not yet resolved, work is still ongoing.......

Calibrate MCS momentum

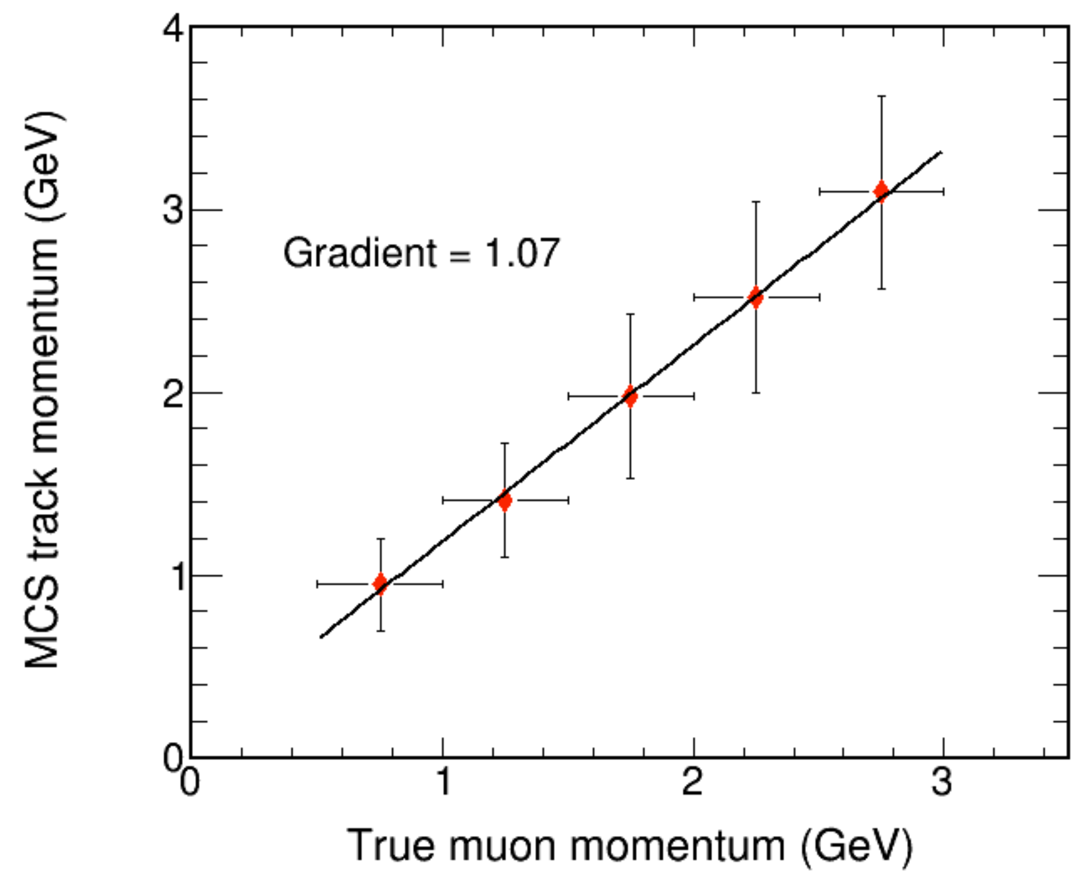
Plot a graph with x values being the centres of the 5 true momentum bins, y values the means of the 5 Gaussian fits, y error bars the σ of the 5 Gaussian fits. Fit a straight line to this graph.

True CC events with exiting track

PMTrack



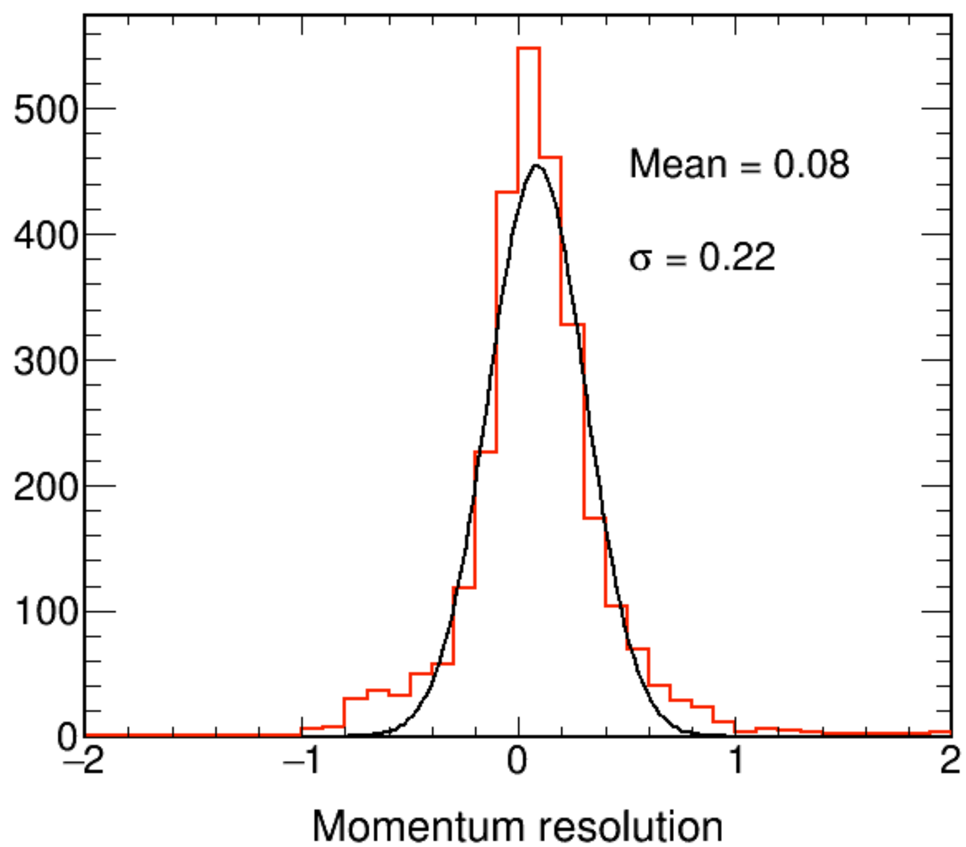
Pandora



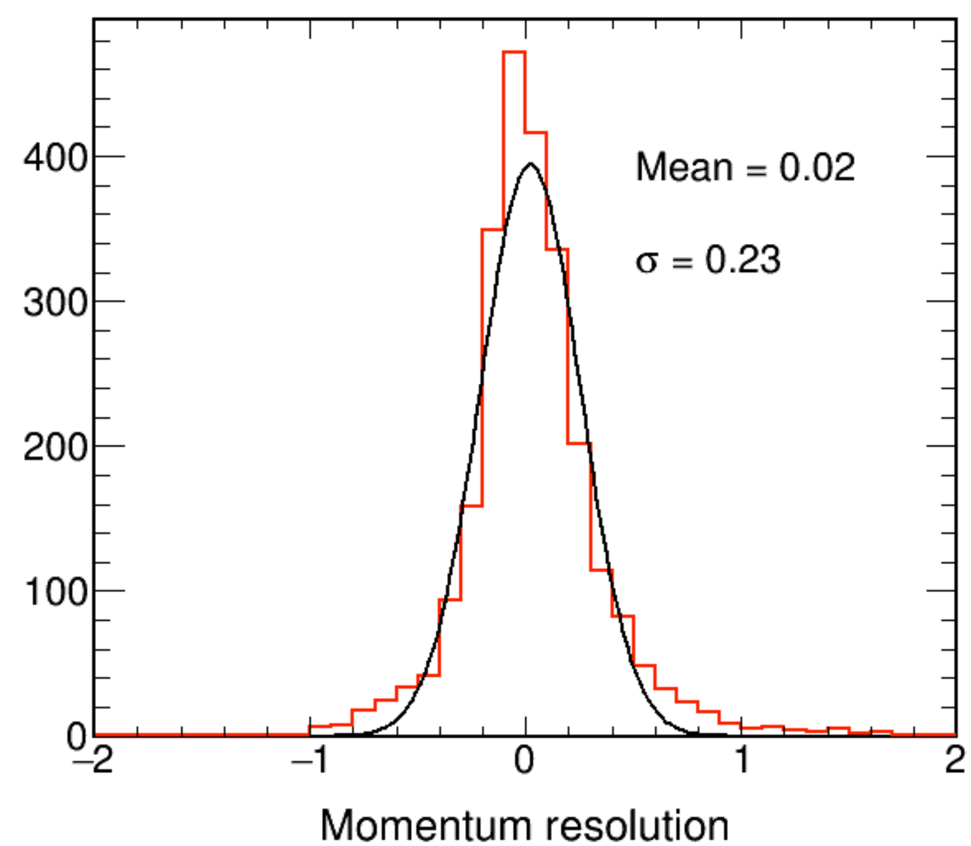
MCS momentum resolution

Momentum resolution for calibrated MCS track momentum
True CC events with exiting track
Note: same events used for calibration and to make these resolution plots

PMTrack



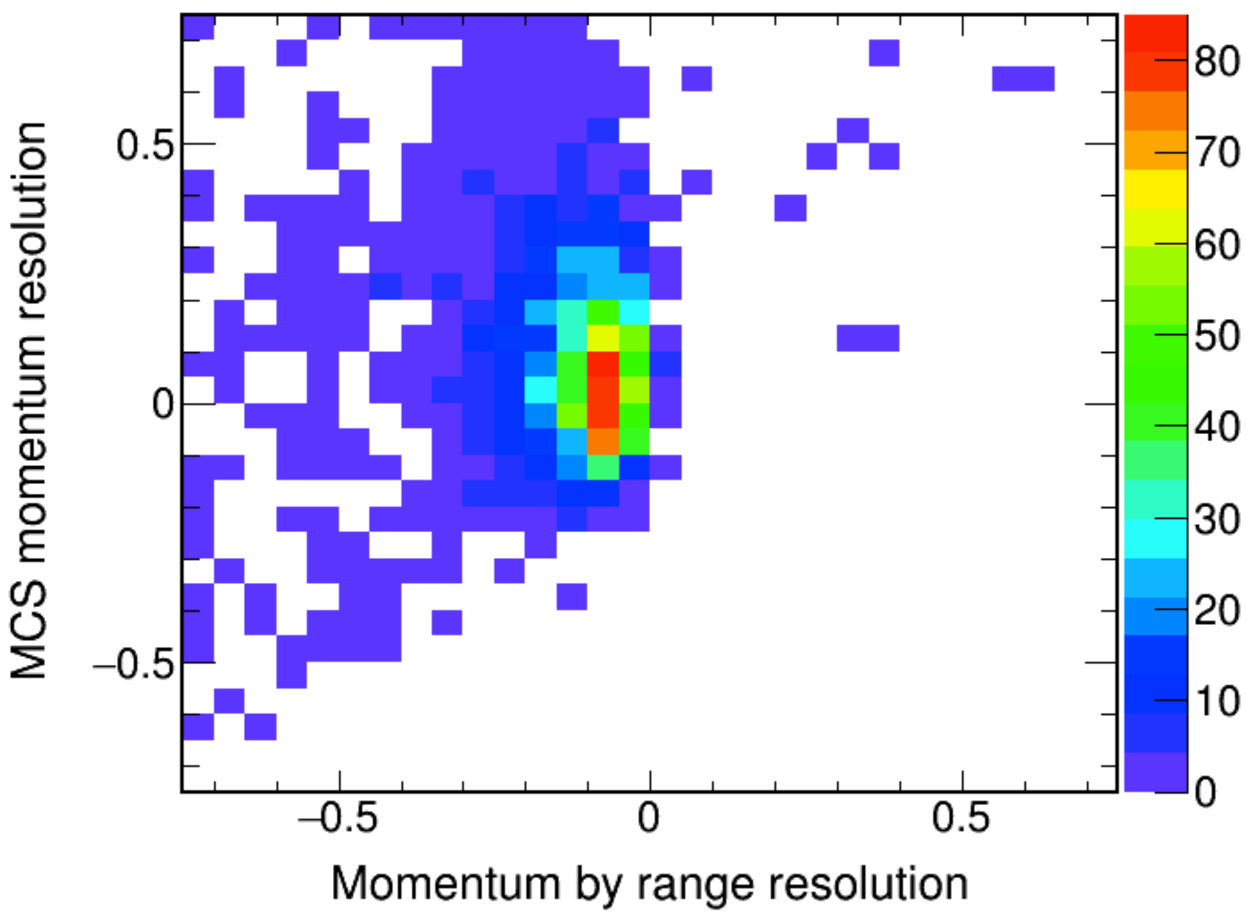
Pandora



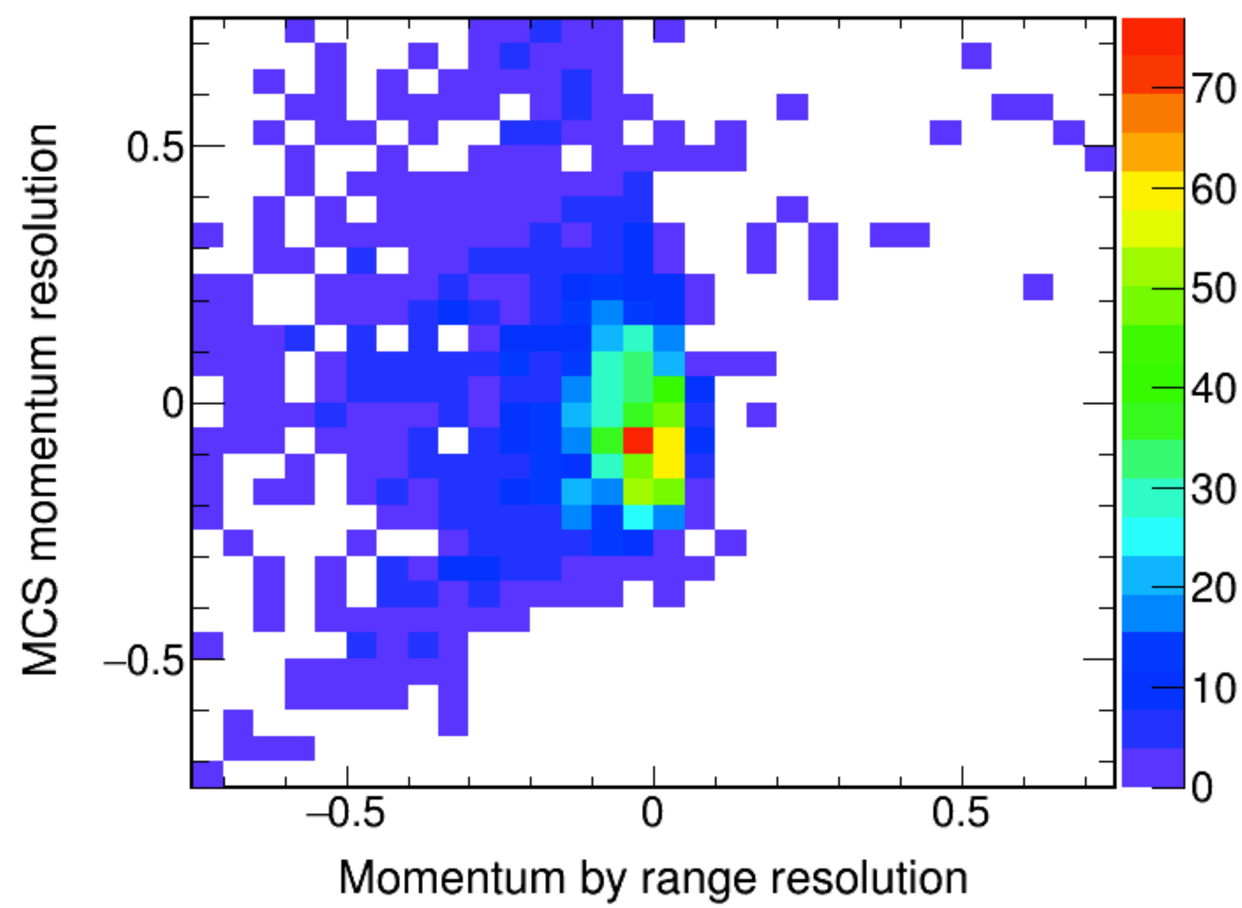
Range vs MCS momentum resolution

True CC events with contained track

PMTrack



Pandora



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. Need to correct for this, one way of doing it is the Myatt method*.

Project hadronic momentum vector into plane containing incoming neutrino and outgoing muon. Scale this vector so that it balances the muon momentum perpendicular to the neutrino beam direction (if scale factor is negative it is a "failure"). Neutrino momentum is then calculated as vector sum of muon and hadron momenta.

* Ref: http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/09/369/9369312.pdf (pages 24-25)

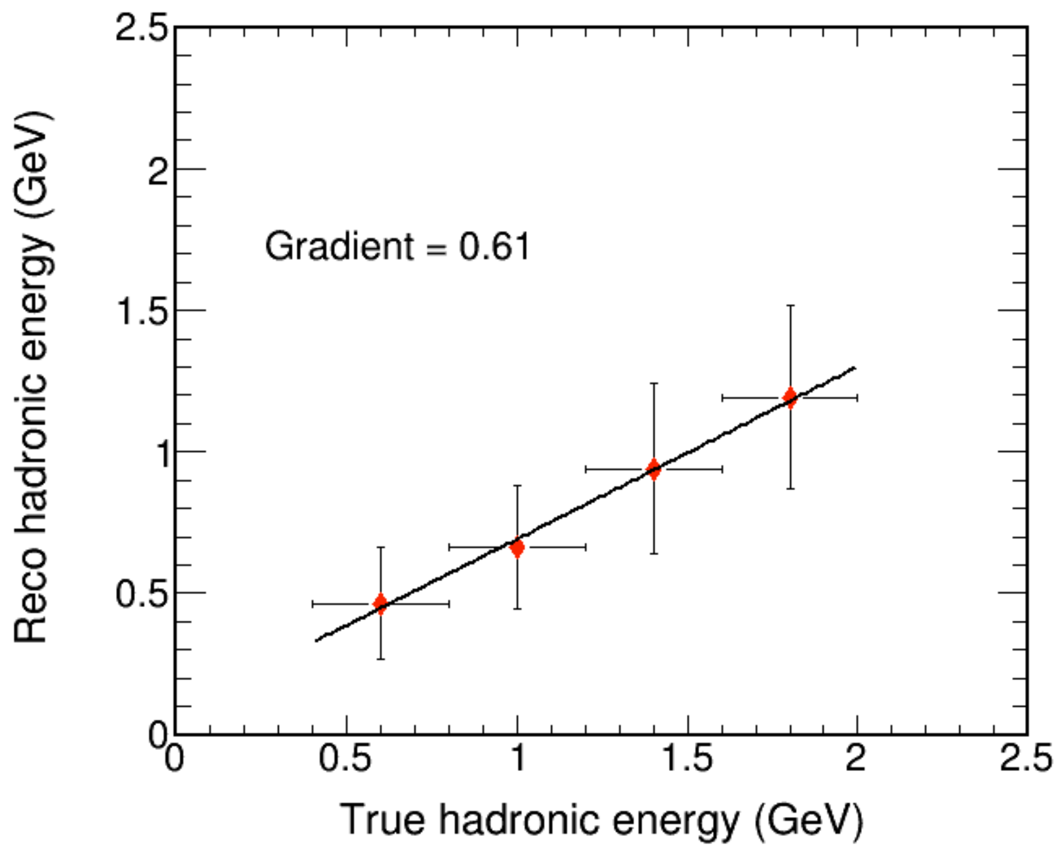
Hadronic energy

Our reconstruction is not yet good enough to use Myatt method. Instead make a correction using the same method as for contained and exiting tracks. Calculate true hadronic energy as true ν_μ energy - true μ momentum.

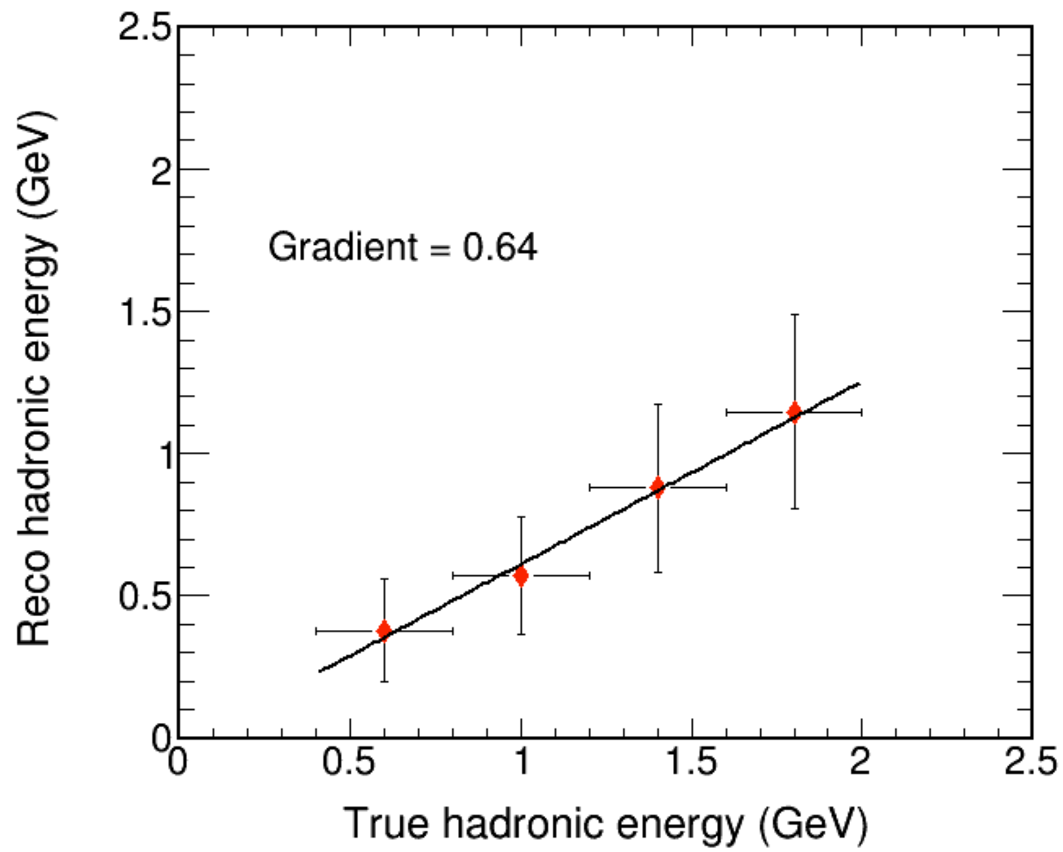
Then use 4 bins in true hadronic energy: 0.4-0.8, 0.8-1.2, 1.2-1.6, 1.6-2.0 GeV.

True CC events

PMTrack



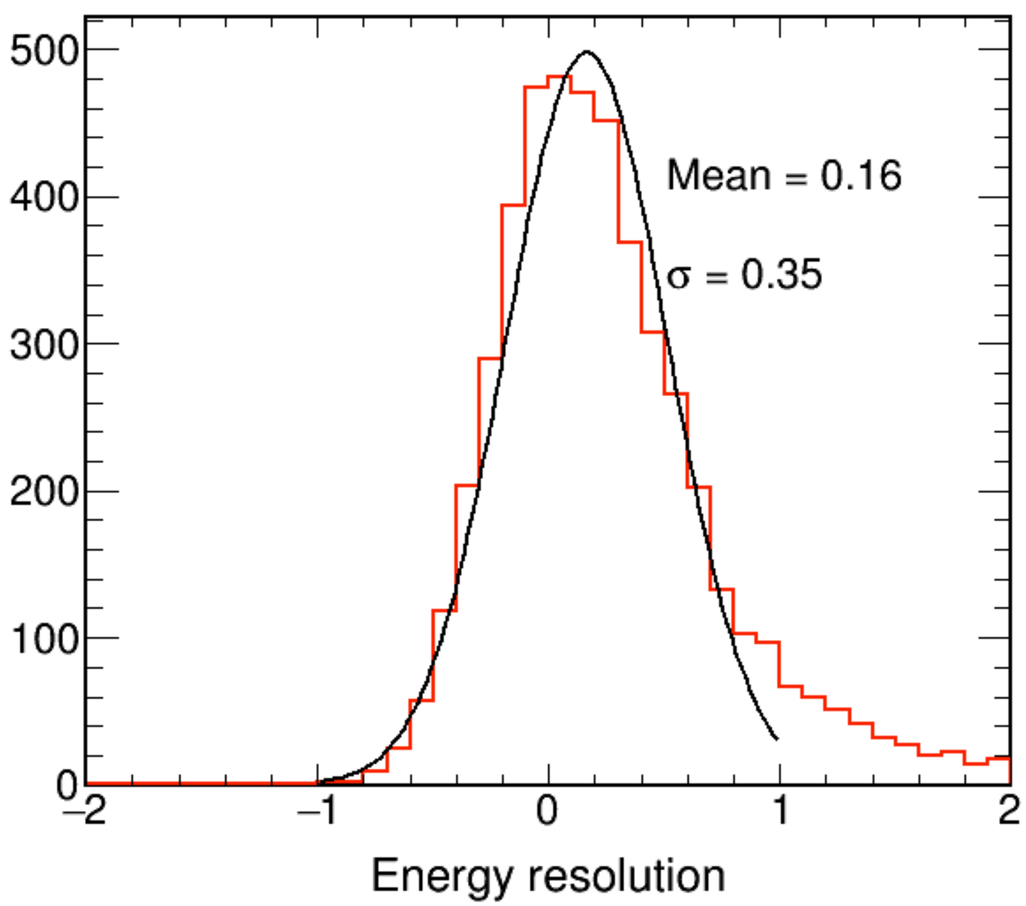
Pandora



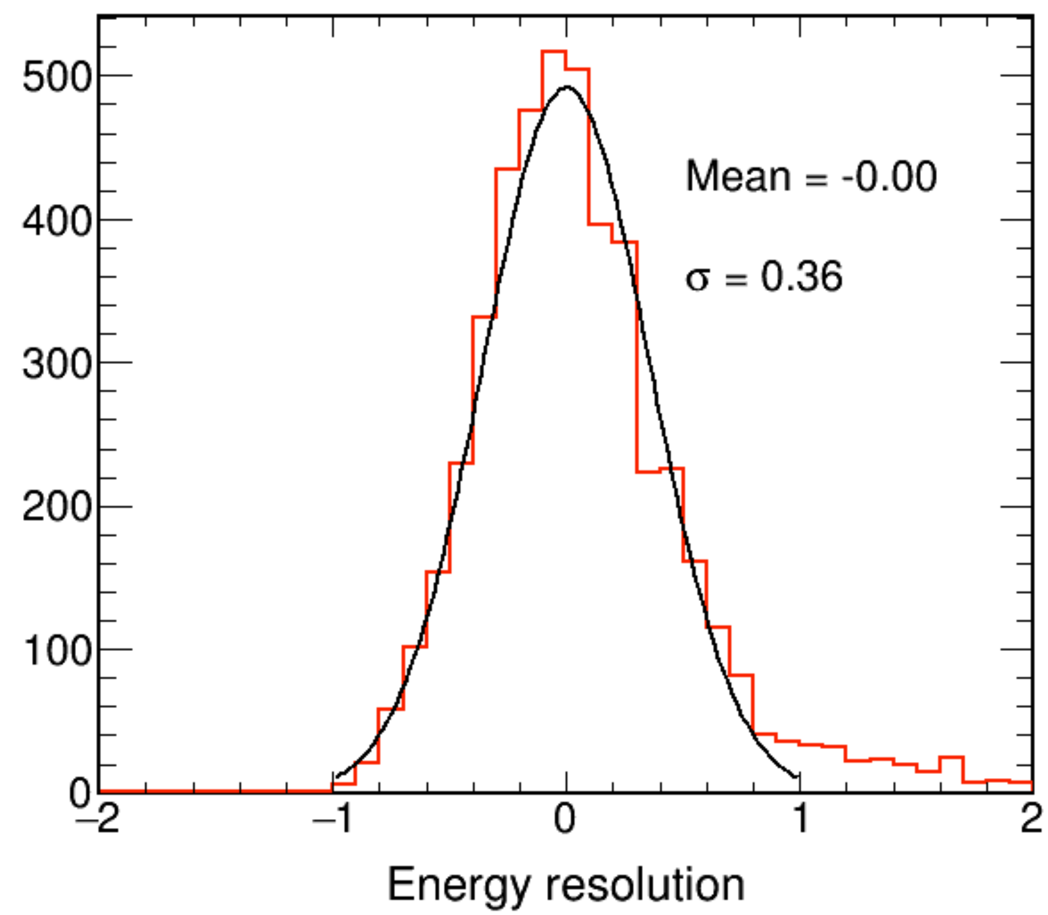
Hadronic energy resolution

True CC events
Note: same events used for calibration and to make these resolution plots

PMTrack



Pandora

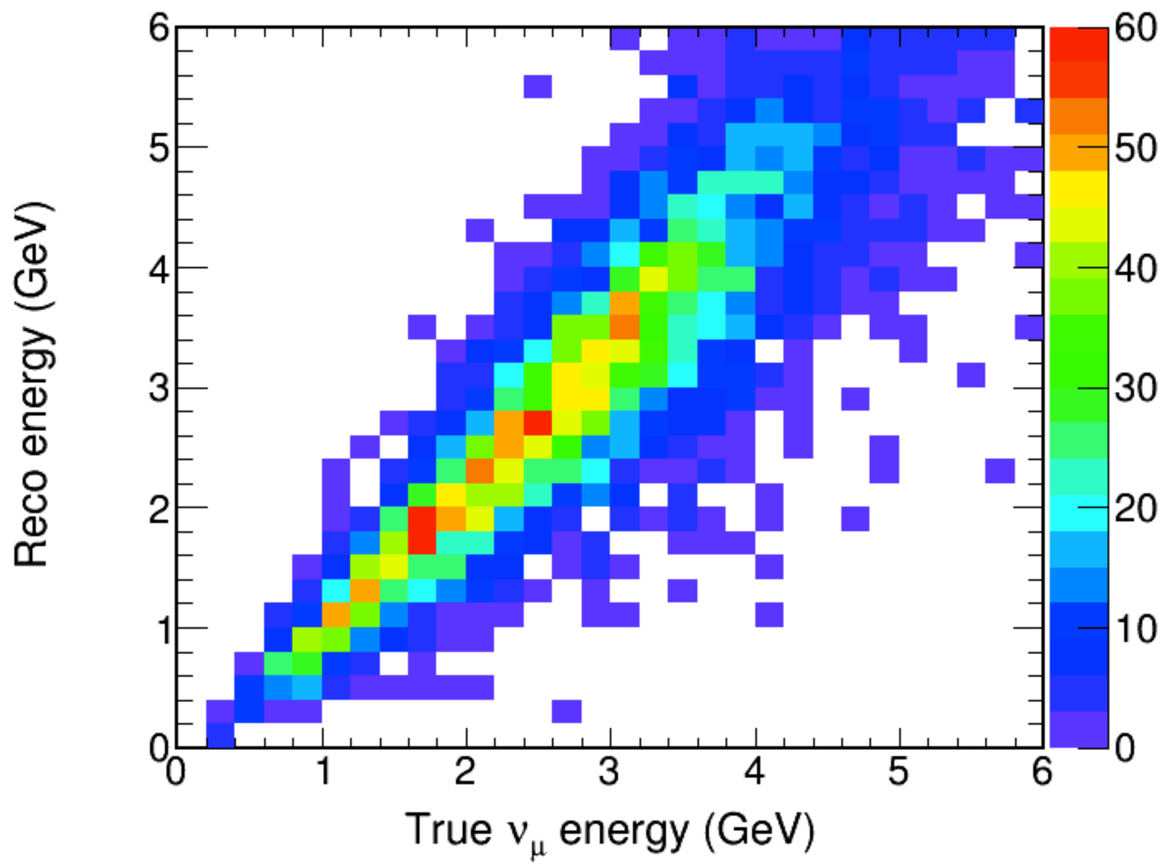


Reco vs true ν_μ energy

Estimate reco ν_μ energy by adding corrected reco hadronic energy to track momentum from range (contained tracks) or calibrated MCS momentum (exiting tracks).

Reco energy against true ν_μ energy
True CC events

PMTrack



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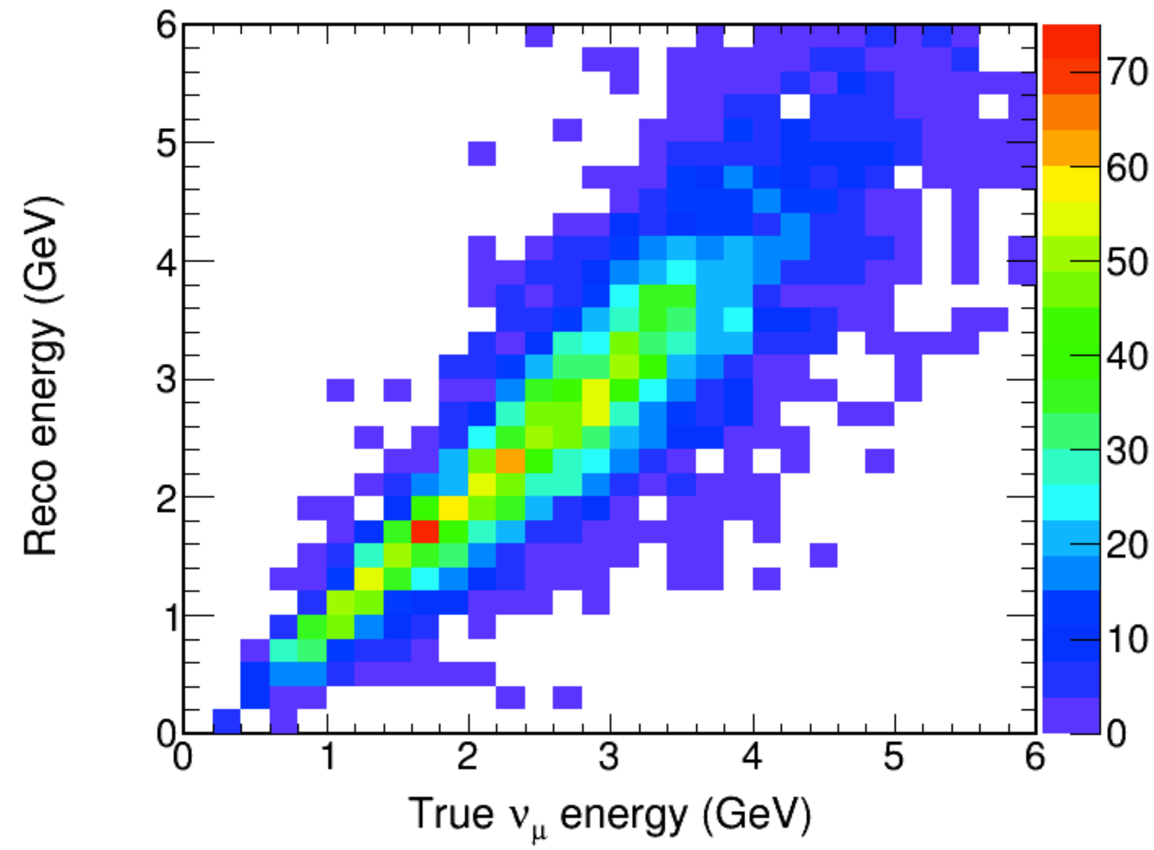
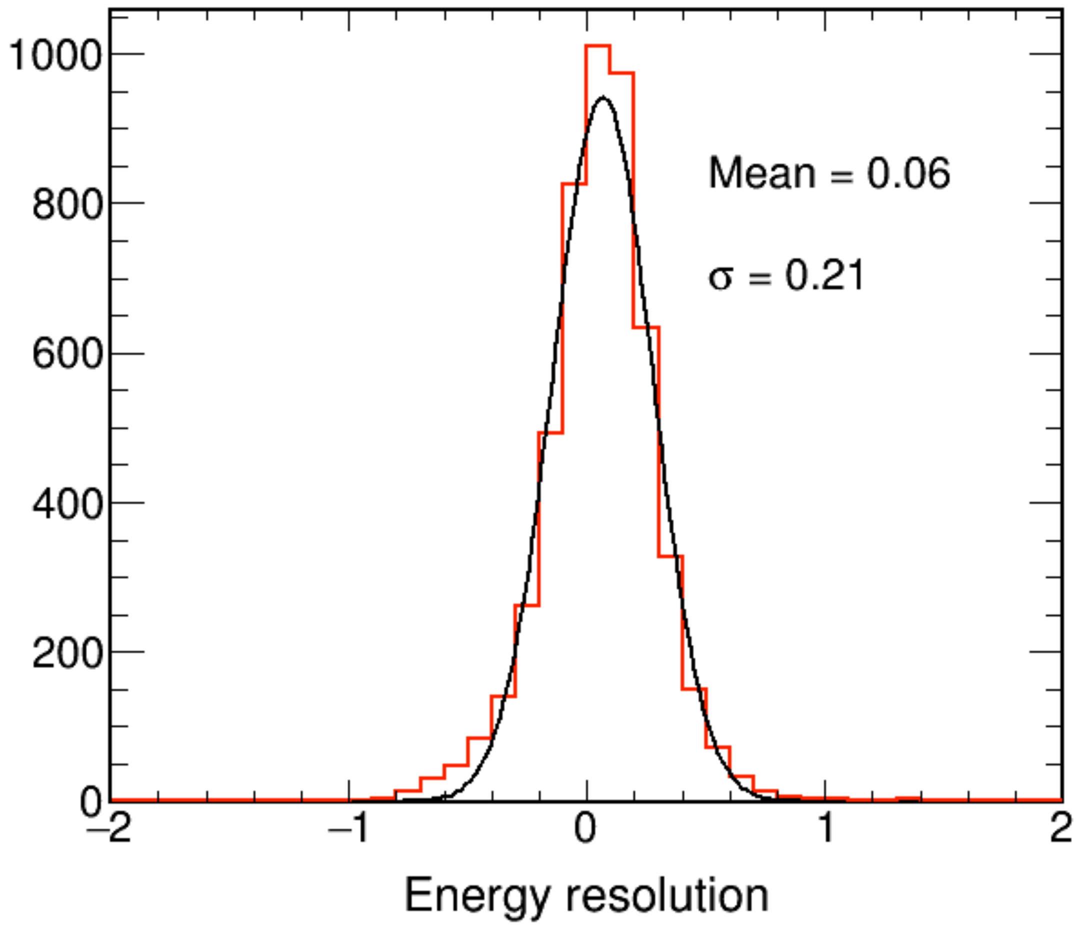


ν_μ energy resolution

True CC events

PMTrack



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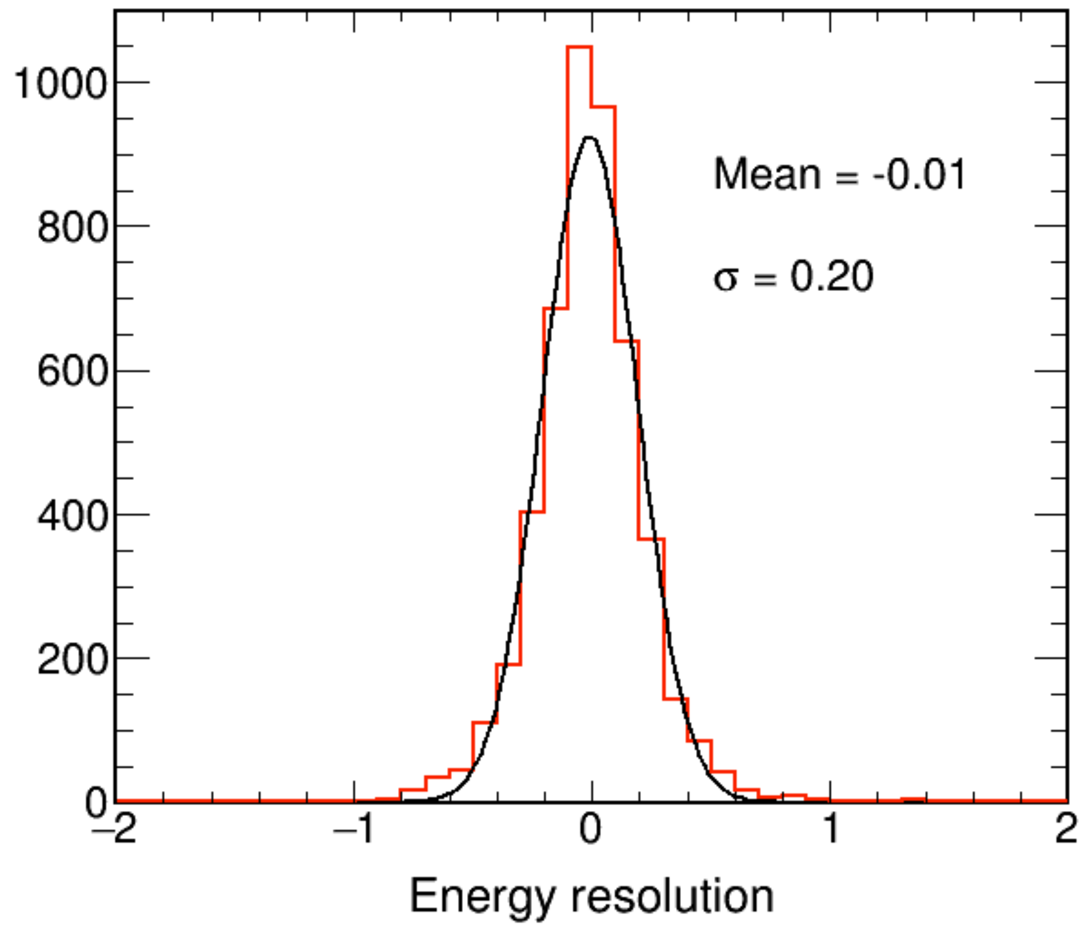


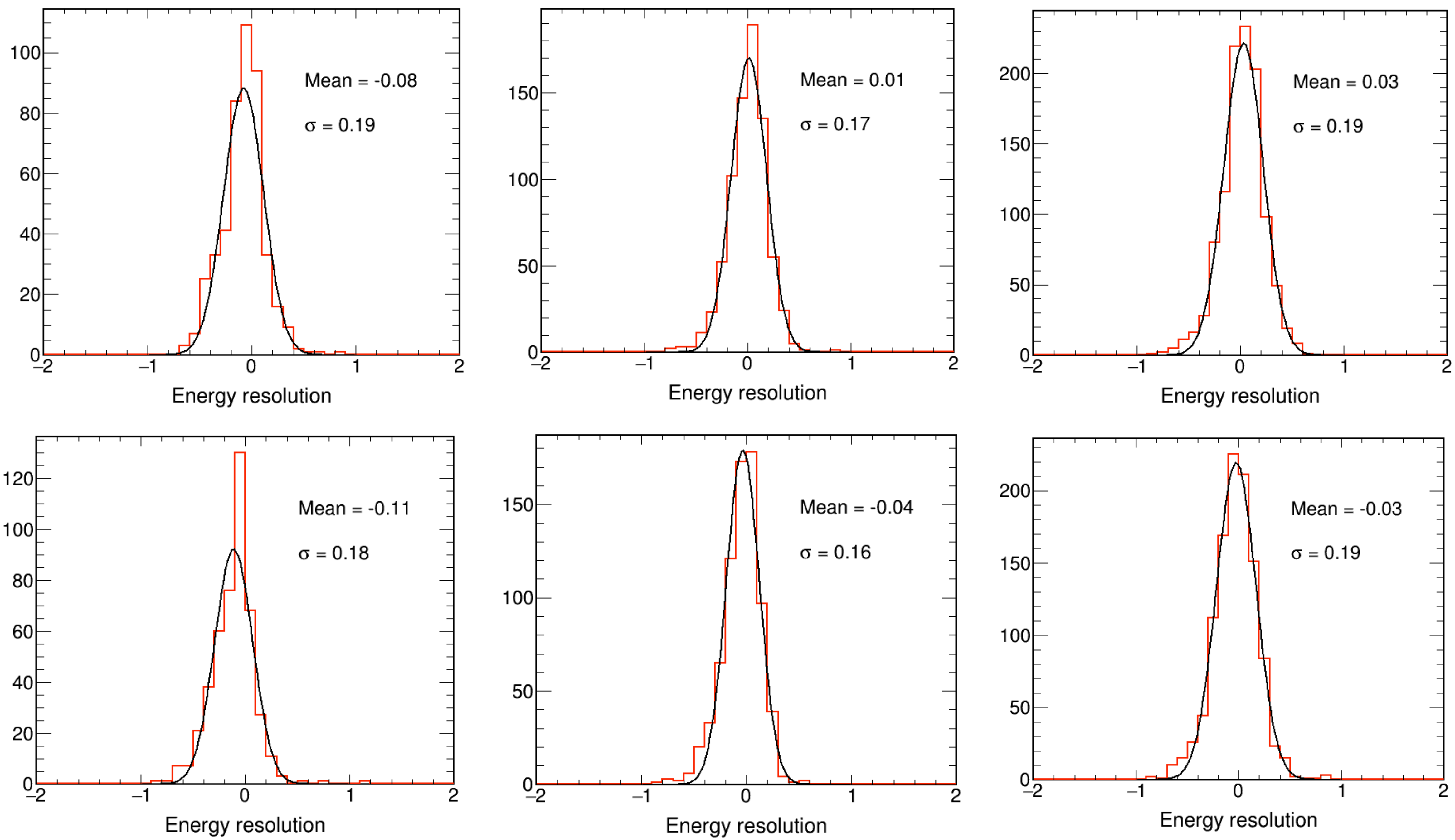
ν_μ energy resolution (contained tracks)

True CC events

	True ν_μ energy < 1.5 GeV	1.5 <= true ν_μ energy <= 2.5 GeV	True ν_μ energy > 2.5 GeV

PMTrack

Pandora



ν_μ energy resolution (exiting tracks)

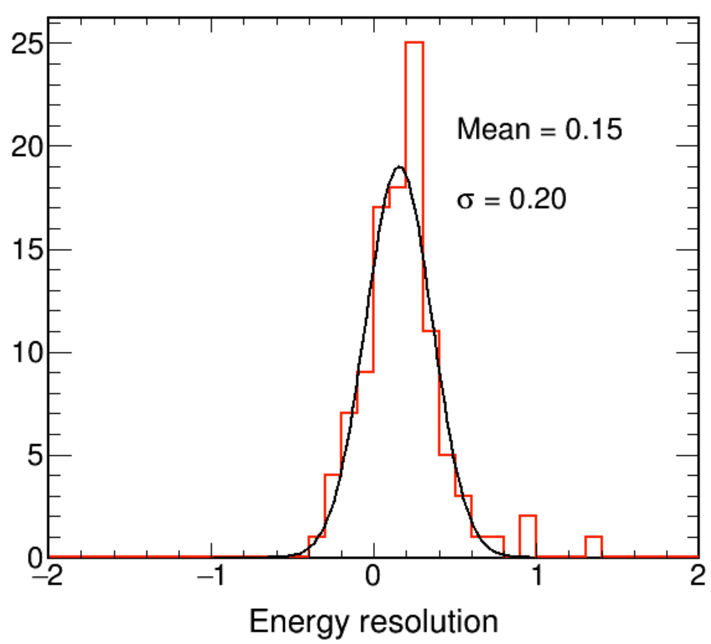
True CC events

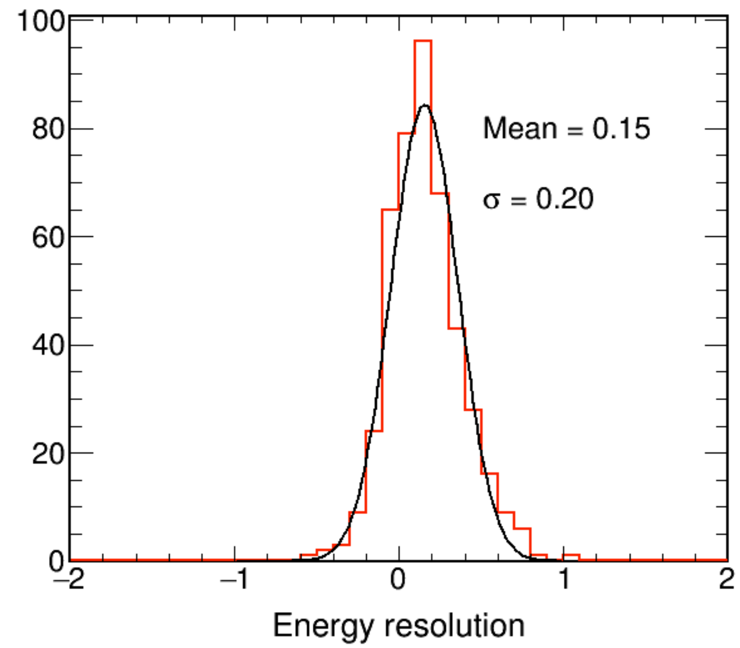
True ν_μ energy < 1.5 GeV

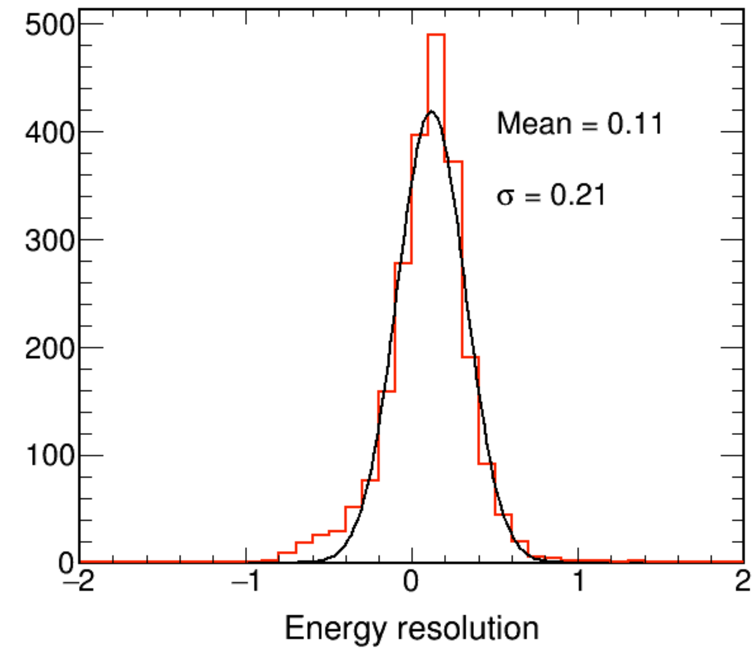
1.5 <= true ν_μ energy <= 2.5 GeV

True ν_μ energy > 2.5 GeV

PMTrack







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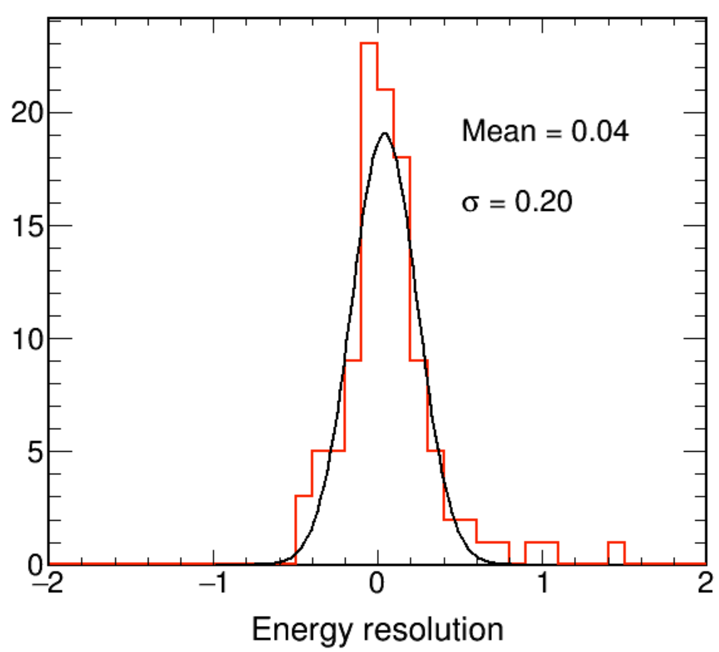
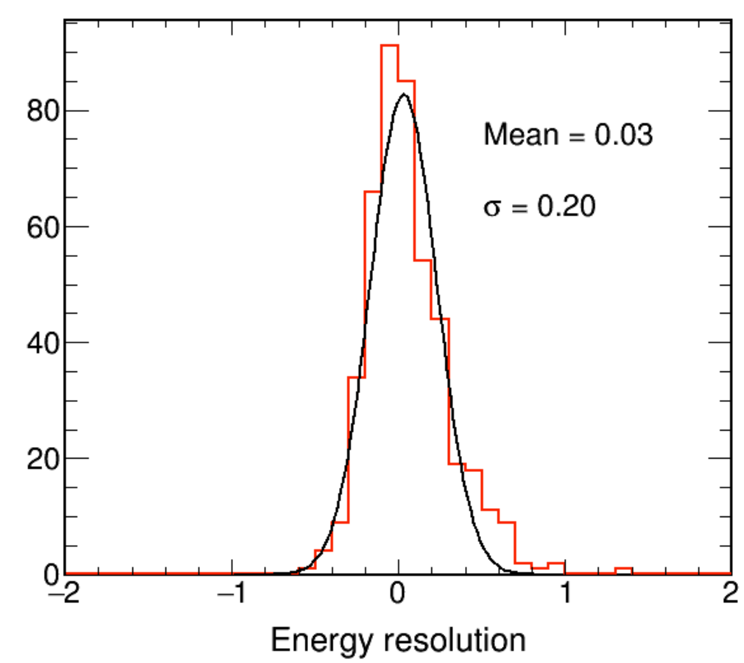
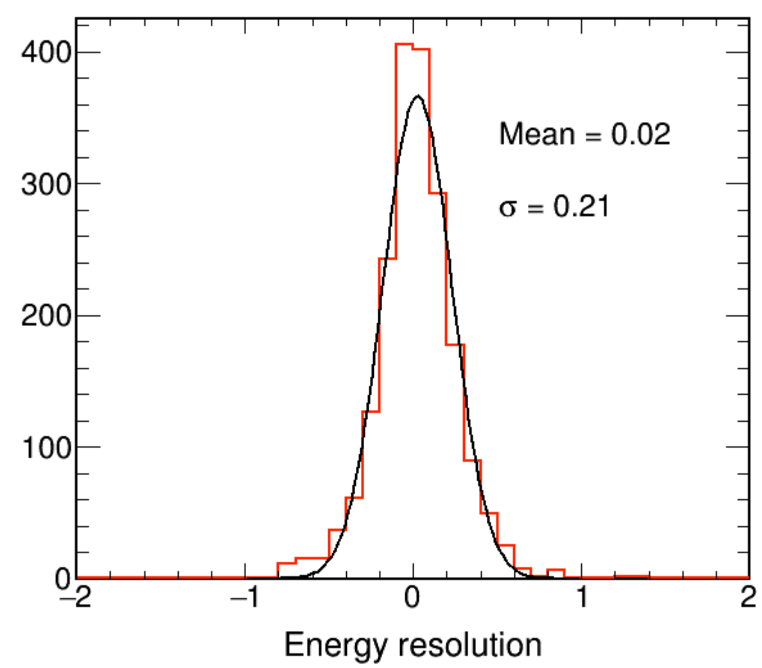






BACKUP SLIDES

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

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

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.

Reco momentum by range

Calibrate reco momentum by range by plotting reconstructed track length against true momentum for true CC events with contained track, and fit with a straight line. If the whole histogram is used, the fit is dragged down by events with poorly reconstructed length.

To overcome this, make the fit in 2 stages:

1. For each bin in true momentum, find bin in reco length that has highest bin content, and calculate gradient using centre of that bin. Take average of gradients for all bins in true momentum as initial estimate of gradient.

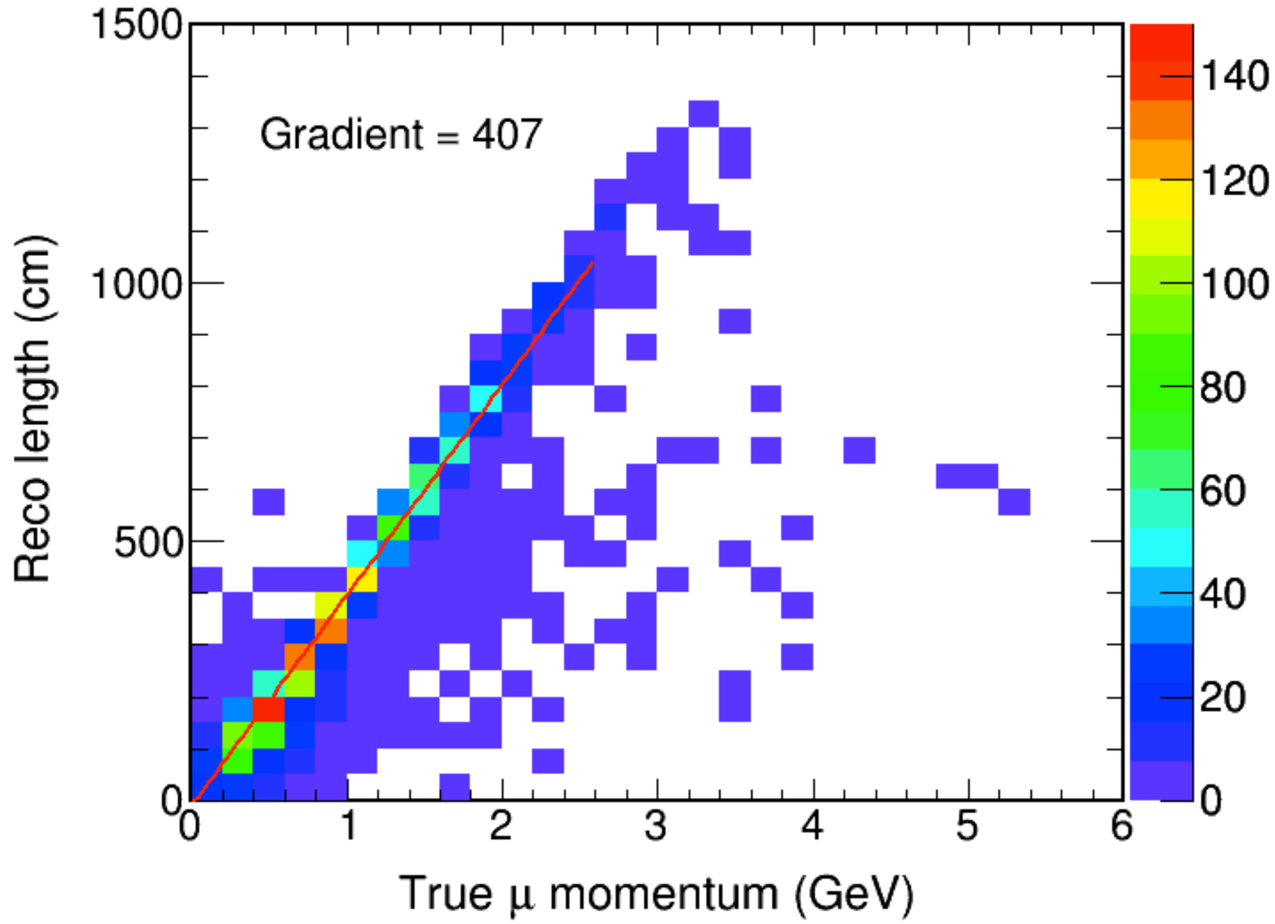
2. Make fit excluding bins whose centres have gradients more than 20% different from initial estimate.

Reco momentum by range

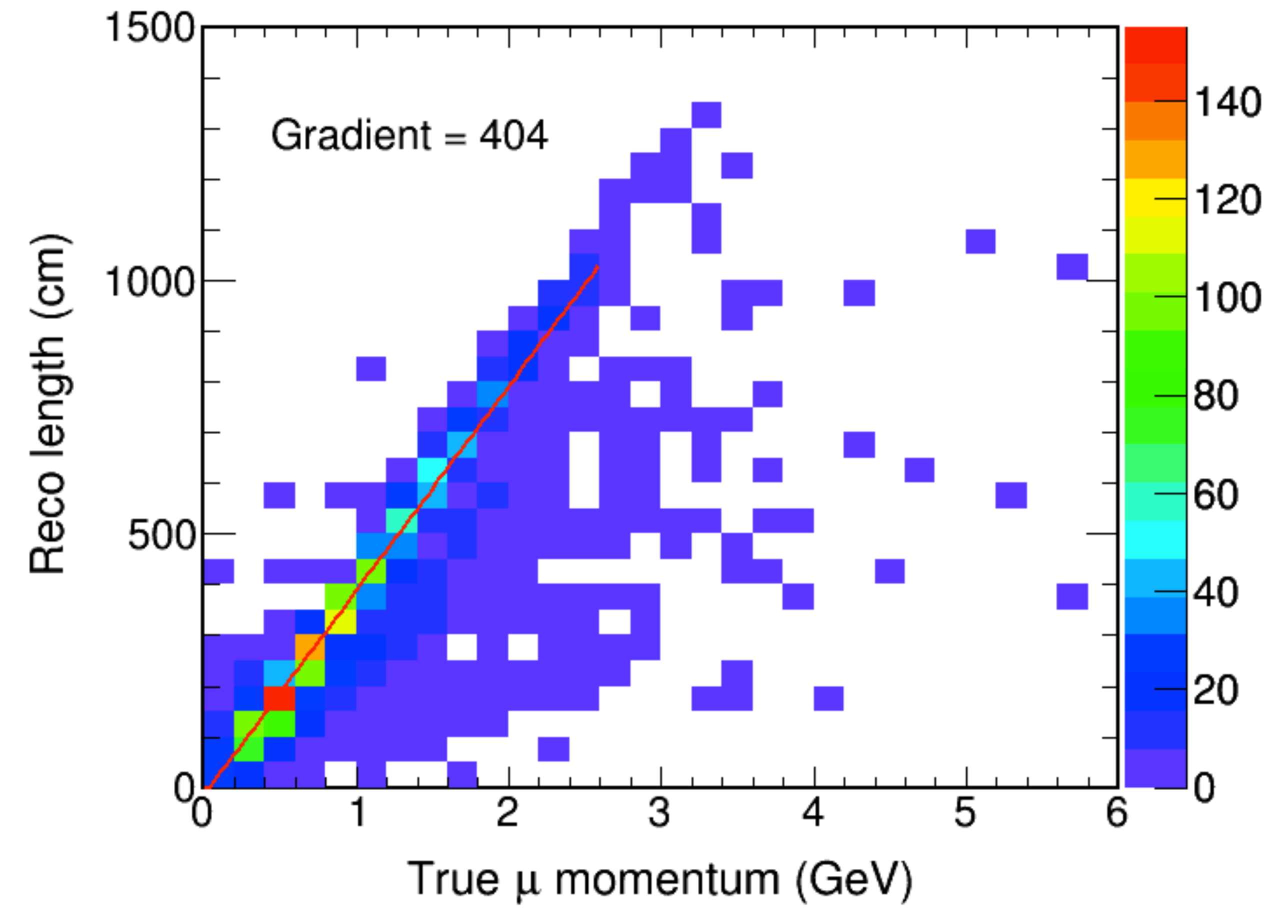
Plot reconstructed track length against true momentum in order to calibrate reco momentum by range.

True CC events with contained track
Make fit in 2 stages

PMTrack



Pandora

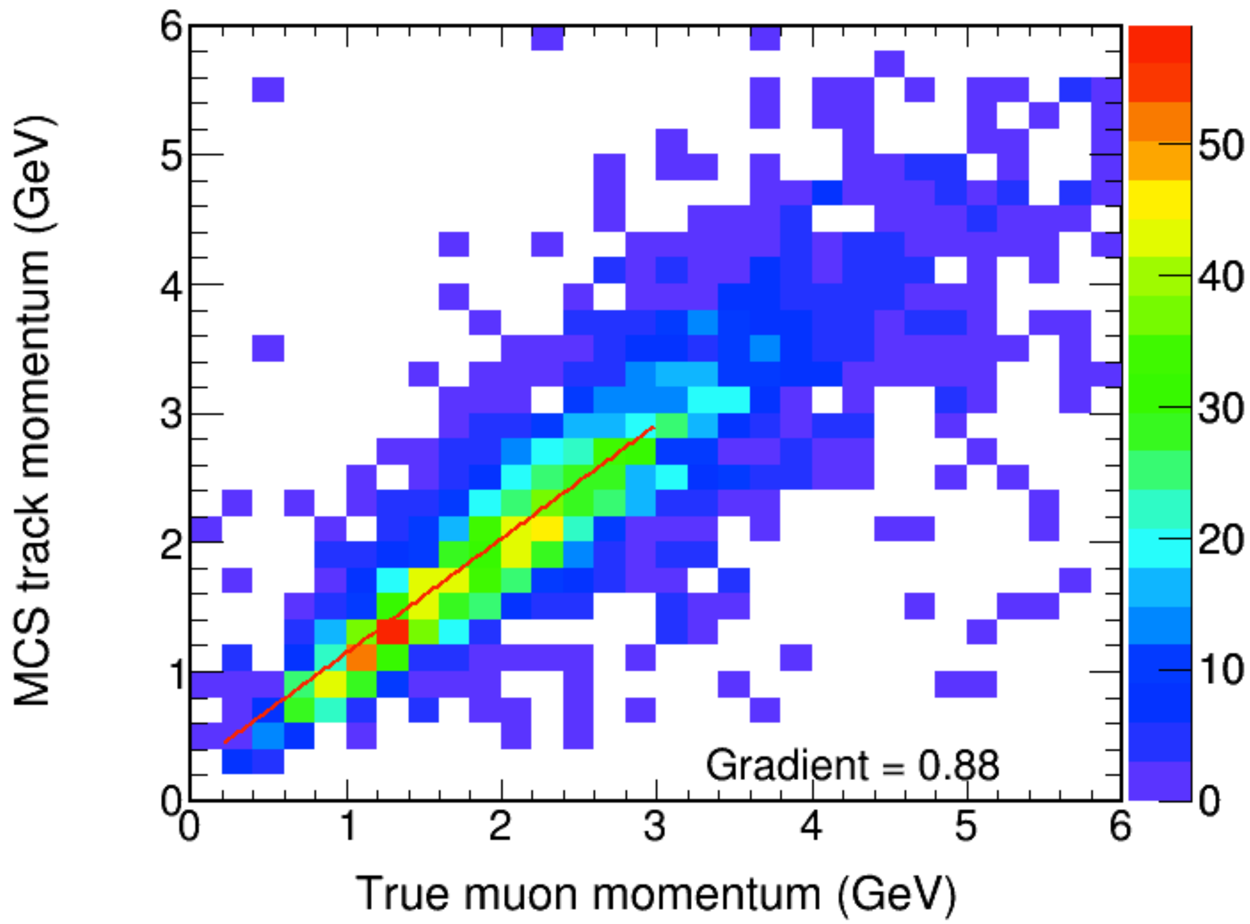


Calibrate MCS momentum

Plot MCS momentum against true momentum in order to calibrate MCS momentum.

True CC events with exiting track

PMTrack



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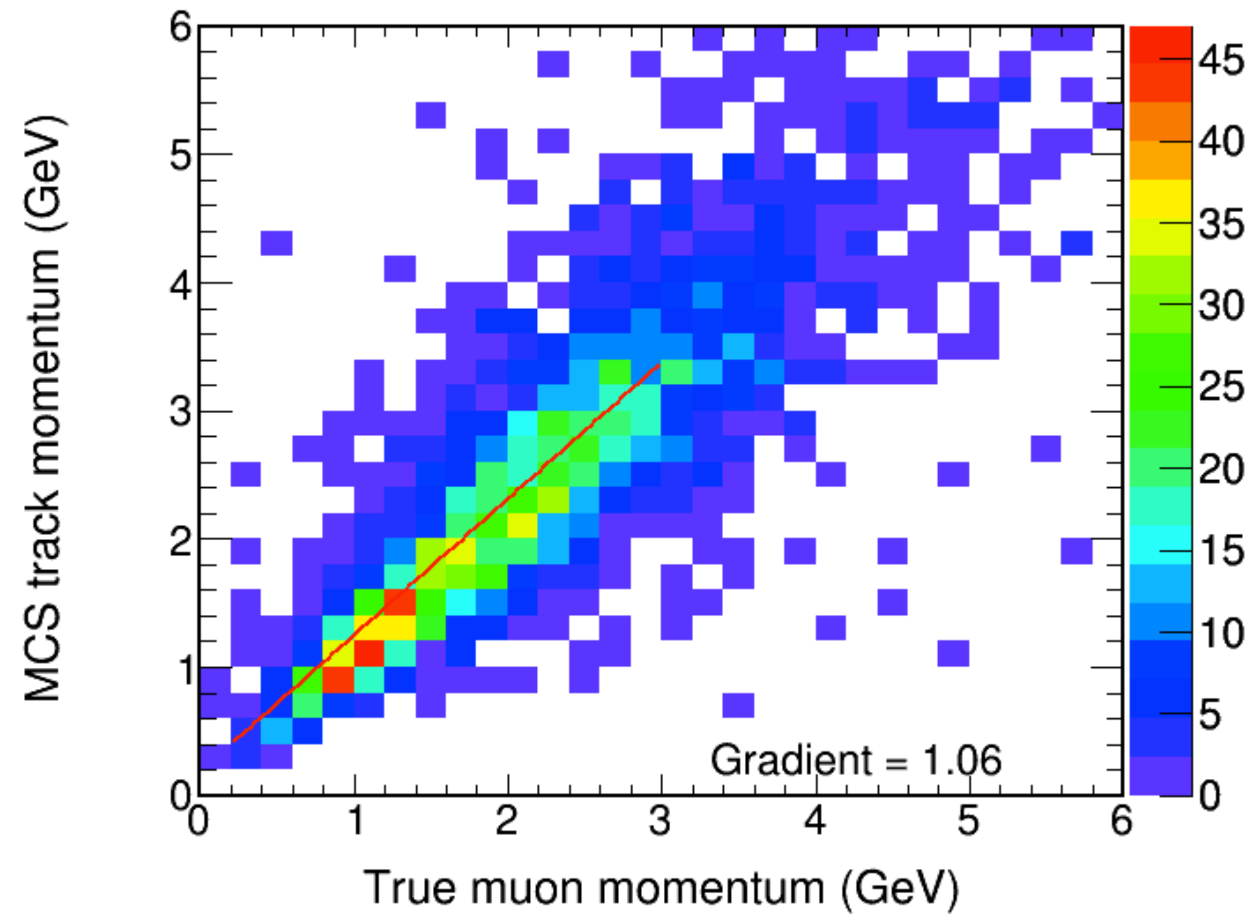


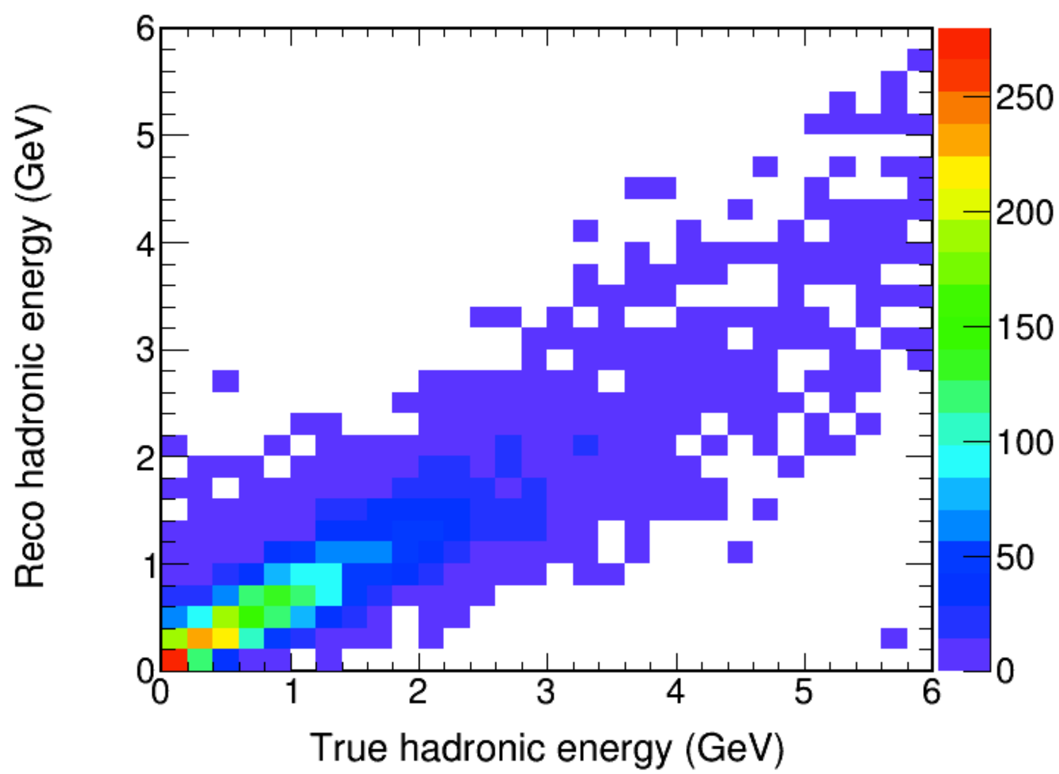
Hadronic energy

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.

True CC events

PMTrack



Pandora