Neutrino energy reconstruction in the DUNE far detector

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Updates

1. Compare MicroBooNE (ref 1) and ICARUS classical (ref 2) methods of estimating muon momentum using multi-Coulomb scattering (MCS).

2. Look at effect of track length on ICARUS MCS method.

3. Look at effect of reconstructed vertex position on reconstructed hadronic energy for ν_μ CC events with exiting tracks.

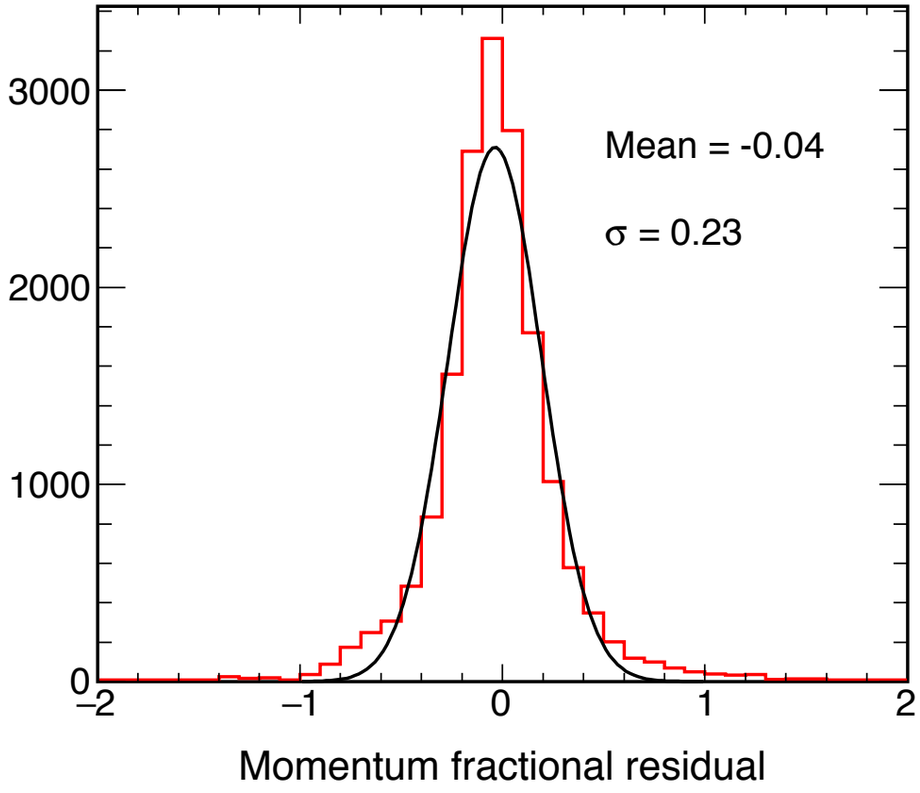
References:

1. https://arxiv.org/abs/1703.06187
2. https://arxiv.org/pdf/hep-ex/0606006v1.pdf

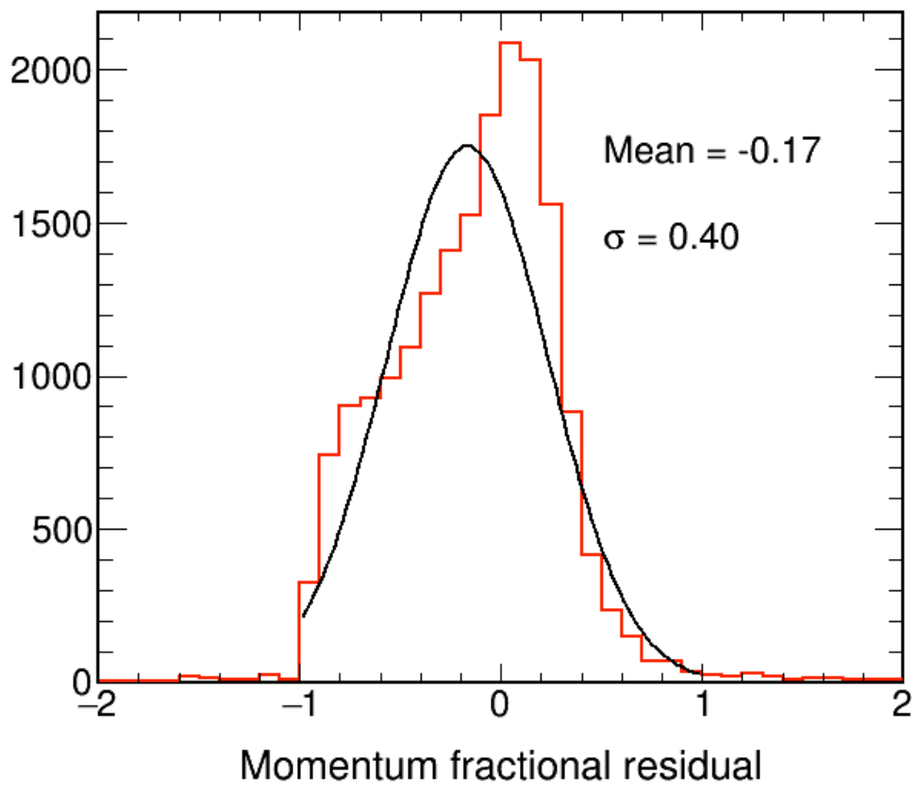
Track momentum residuals

True ν_μ CC events with exiting track

ICARUS



MicroBooNE

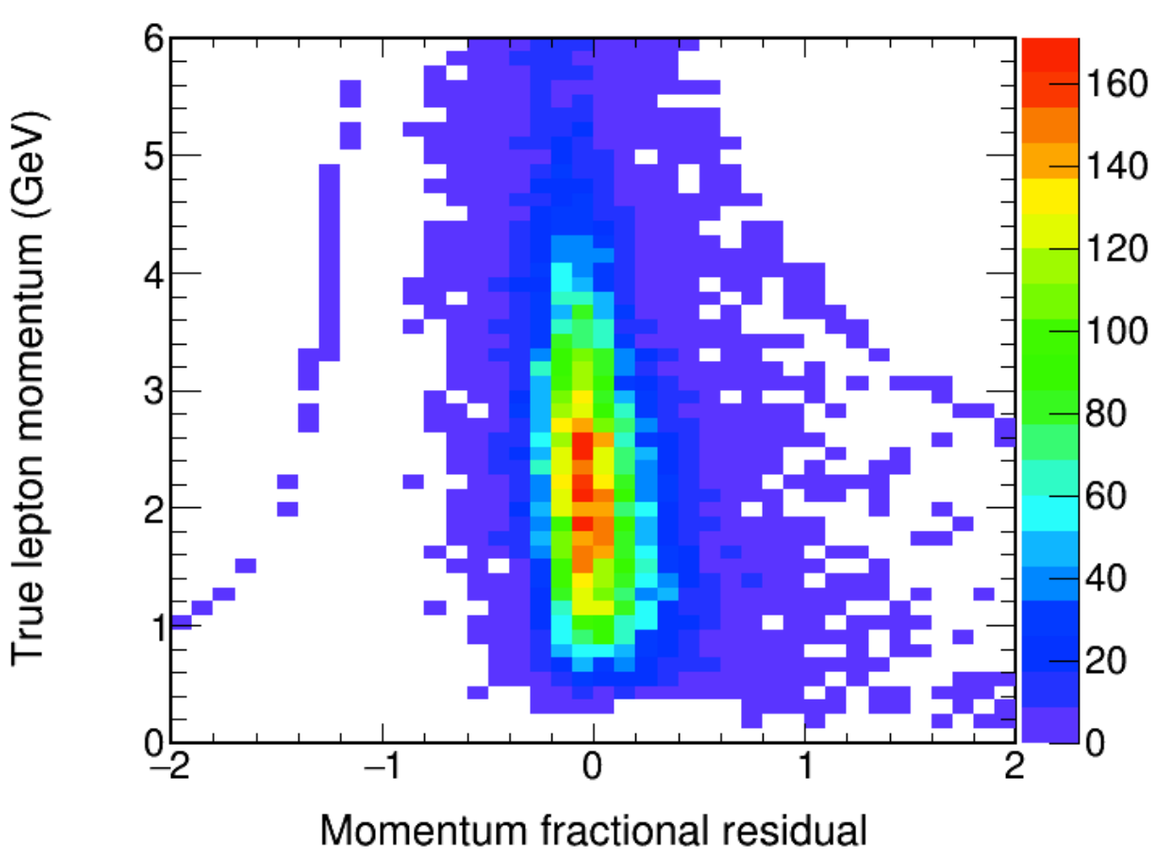


Track momentum residuals

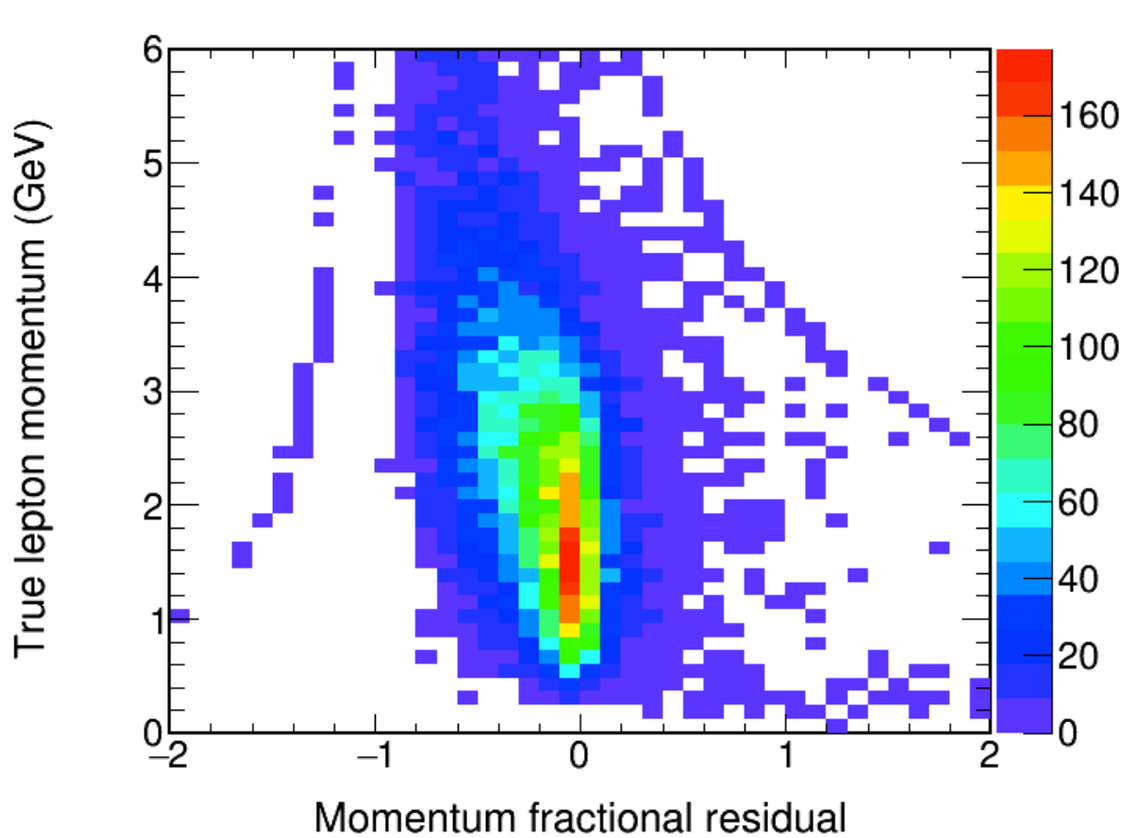
Track momentum residuals as function of true momentum using uncorrected MCS momentum

True ν_μ CC events with exiting track

ICARUS



MicroBooNE



Comparison of methods

Divide track into segments and fit straight line to each segment. Measure angles between fits to successive segments and calculate RMS of these angles.

ICARUS

$$\theta_0^{rms} = \frac{13.6\ MeV}{\beta c\, p}\, z \sqrt{\frac{l}{X_0}} \left[1 + 0.038 \cdot ln\left(\frac{l}{X_0}\right)\right]$$

$$(\theta_{meas}^{rms})^2 = (\theta_0^{rms})^2 + (\theta_{noise}^{rms})^2$$

Angular resolution = const x $l^{-3/2}$

10 segment lengths 5-25 cm (track < 2.5 m)
13 segment lengths 5-35 cm (track > 2.5 m)

MicroBooNE

$$\sigma_o^{\mathrm{HL}} = \frac{S_2}{p\beta c} z \sqrt{\frac{\ell}{X_0}} \left[1 + \epsilon \times \ln\left(\frac{\ell}{X_0}\right)\right]$$

$$\sigma_o = \sqrt{(\sigma_o^{\mathrm{HL}})^2 + (\sigma_o^{\mathrm{res}})^2}$$

Angular resolution = 3 mrad (MicroBooNE)
= ? (DUNE)

Segment length = X_0 = 14 cm (fixed)

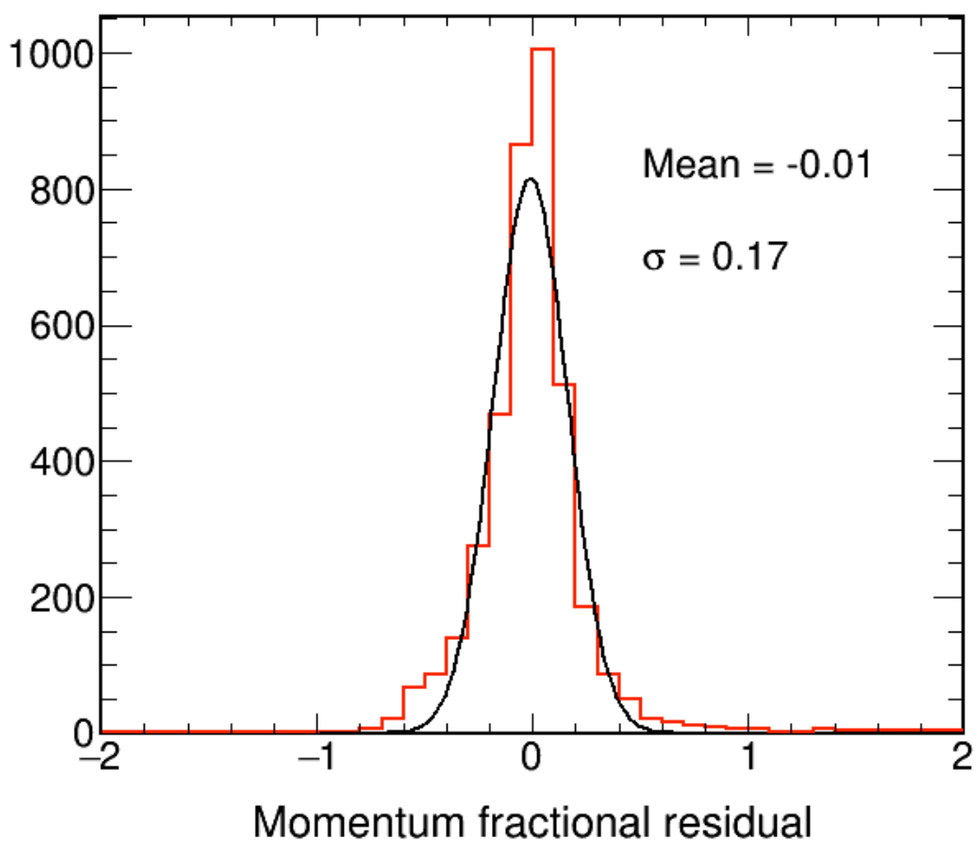
As momentum increases, RMS scattering angle decreases. This means RMS angle becomes more comparable with angular resolution of detector, and measurement of RMS angle deteriorates. Only way to avoid this deterioration of measurement of RMS angle is to increase segment length l.

MicroBooNE method at low true momentum

MicroBooNE method works well at low true muon momentum

True ν_μ CC events with exiting track

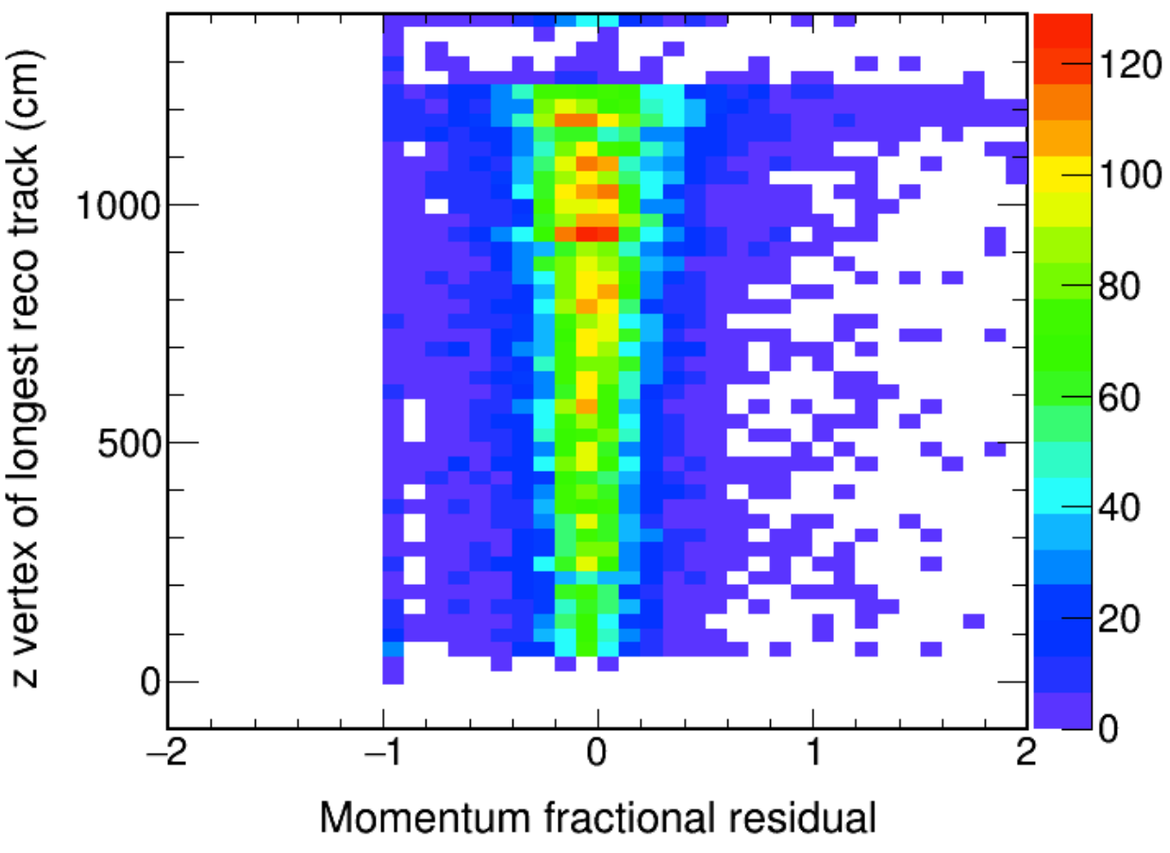
Include only tracks with true muon momentum < 1.5 GeV in correction and residuals

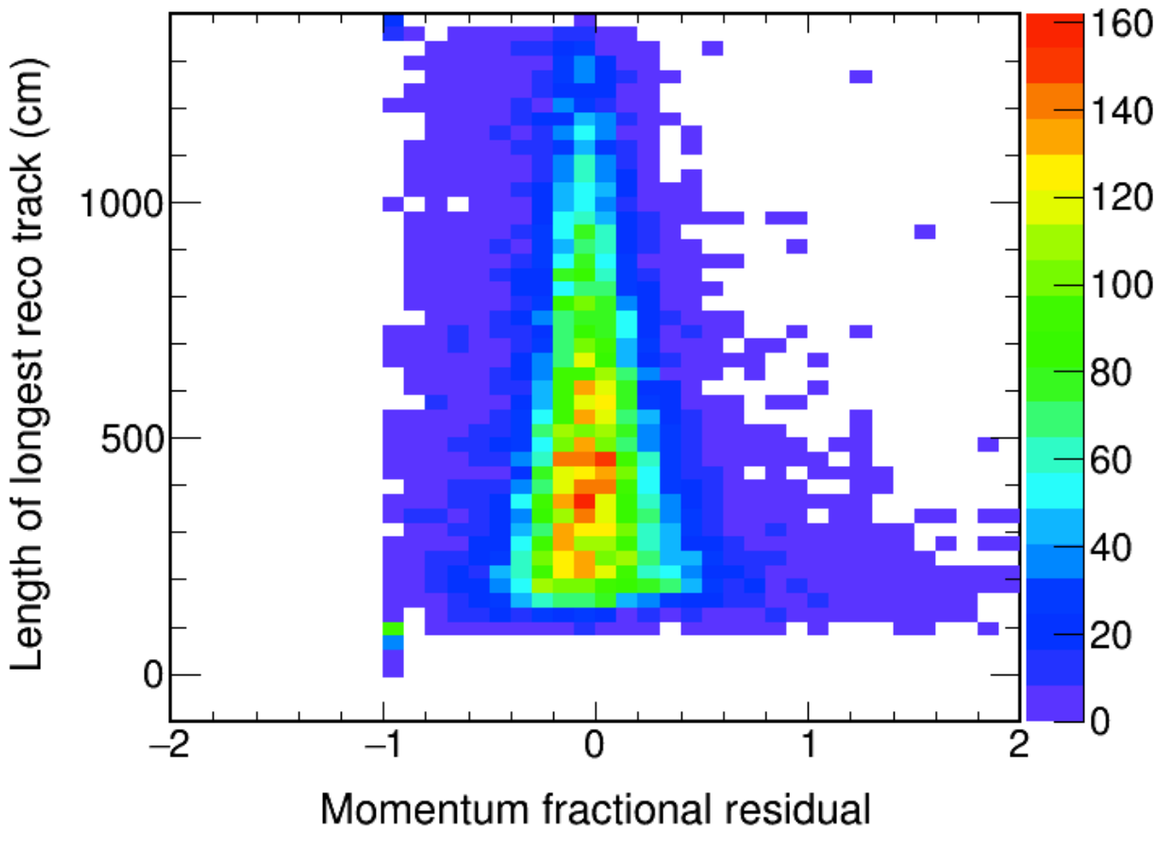


Effect of vertex position and track length

ICARUS track momentum residuals

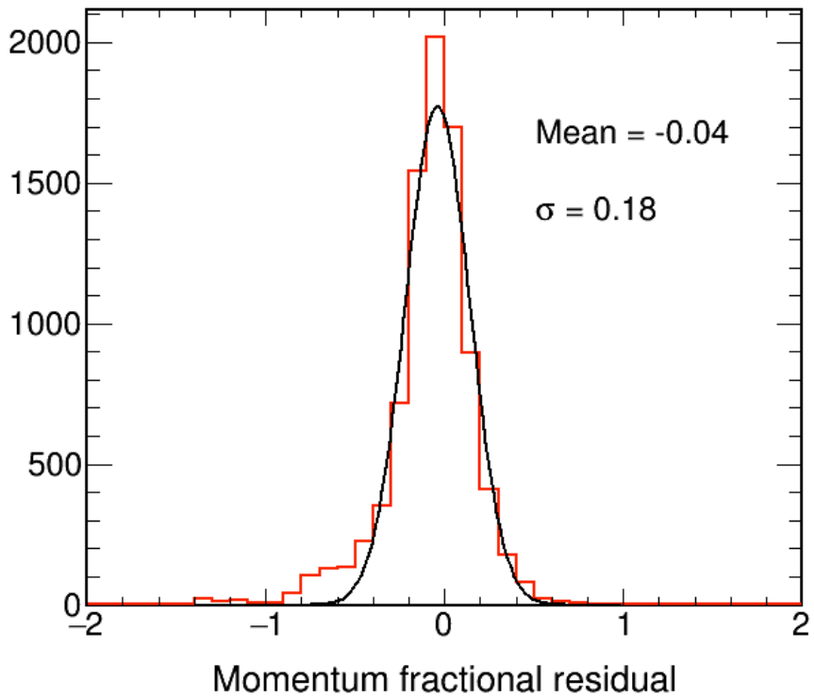
True ν_μ CC events with exiting track





Effect of track length

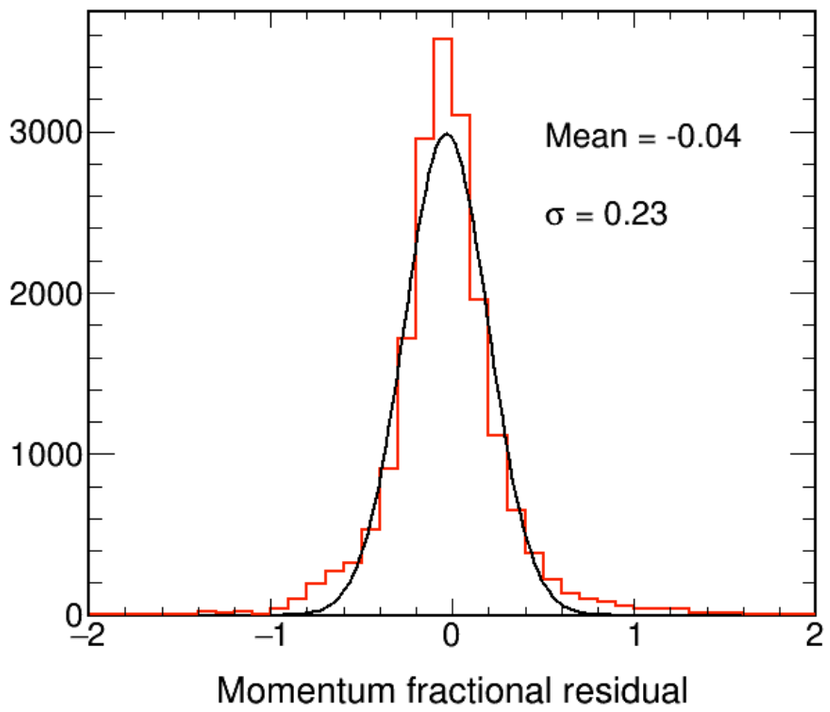
Longest reco track > 500 cm



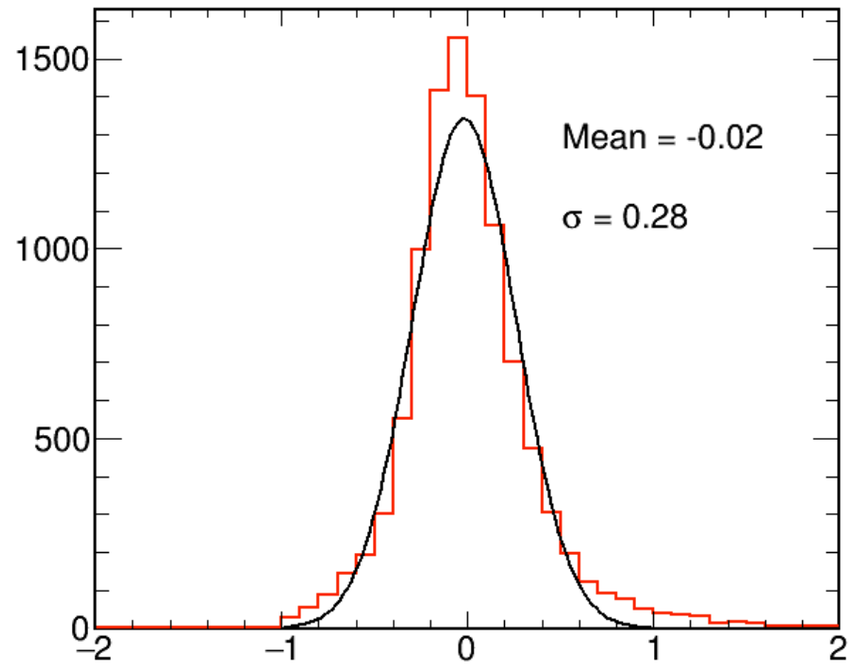
ICARUS track momentum resolution

True ν_μ CC events with exiting track

All events

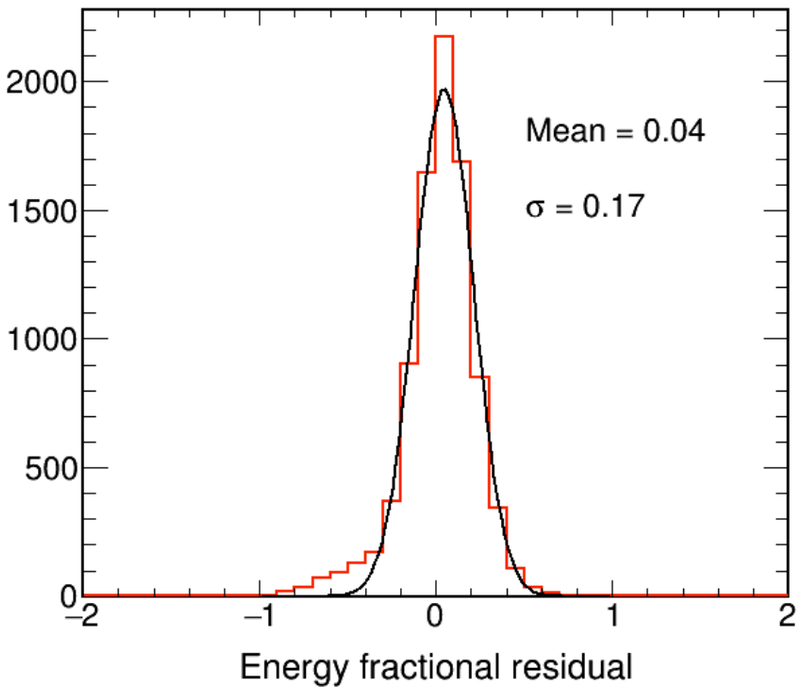


Longest reco track < 500 cm



Effect of track length

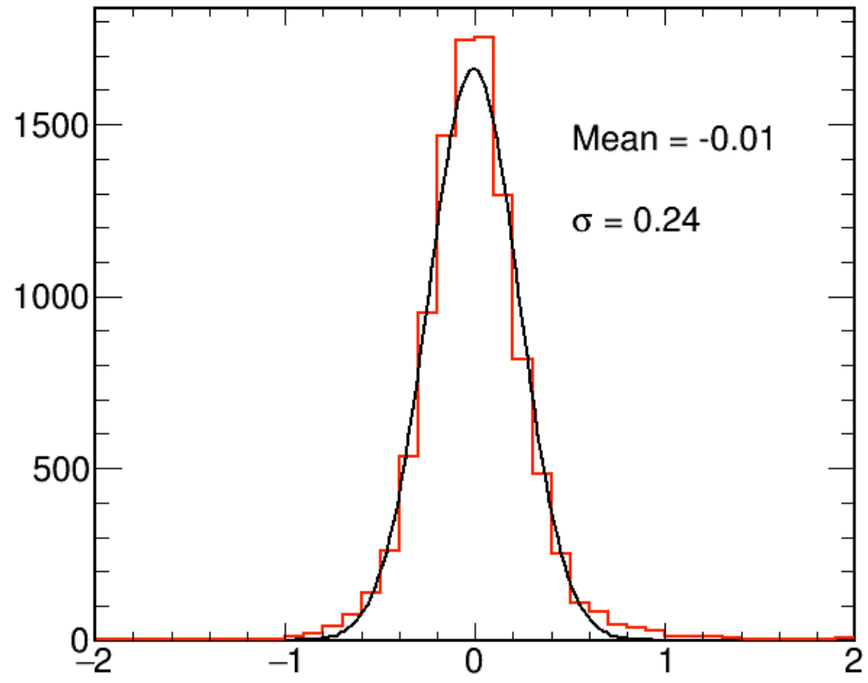
Longest reco track > 500 cm



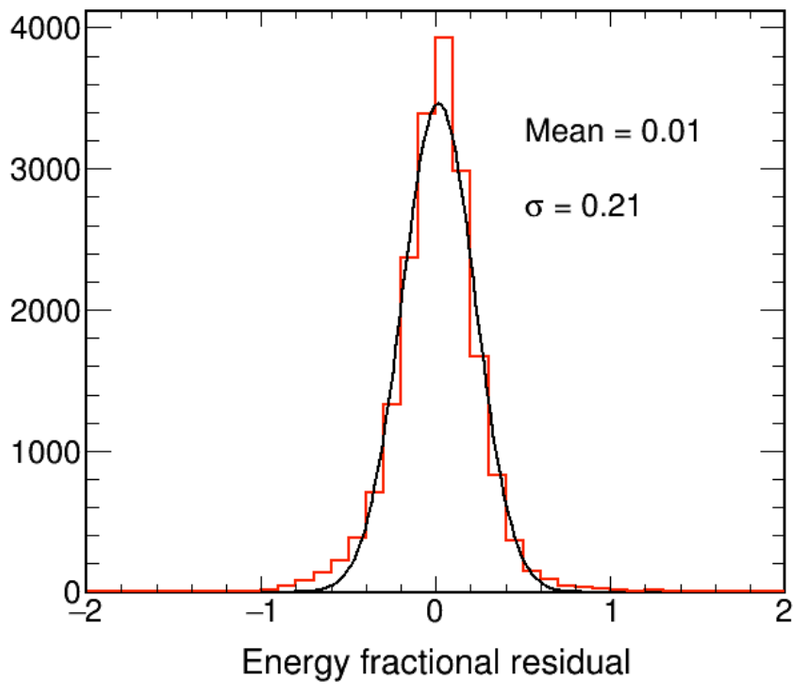
ν_μ energy resolution using ICARUS MCS

True ν_μ CC events with exiting track

Longest reco track < 500 cm

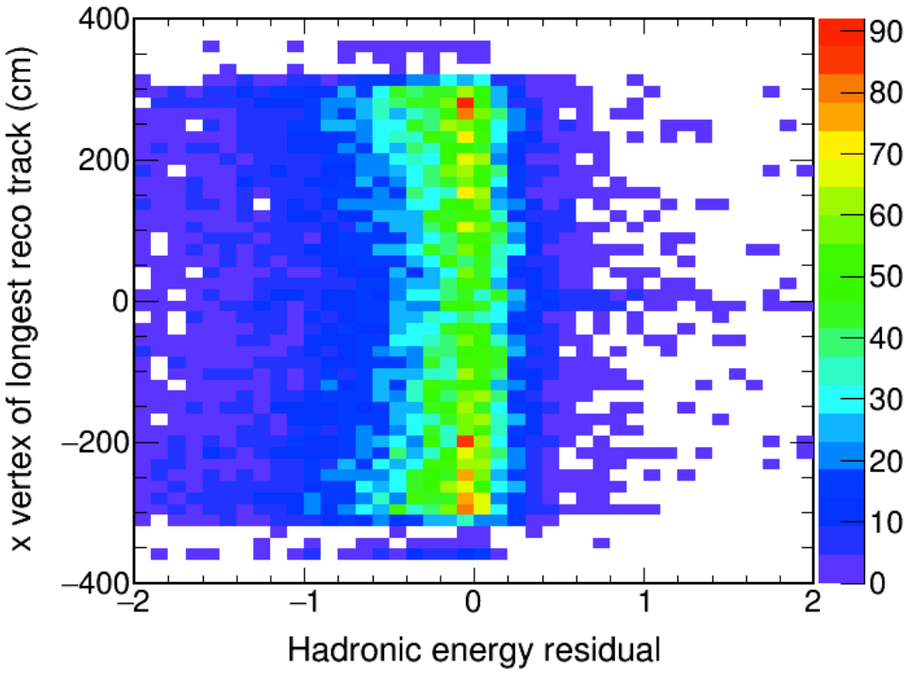


All events



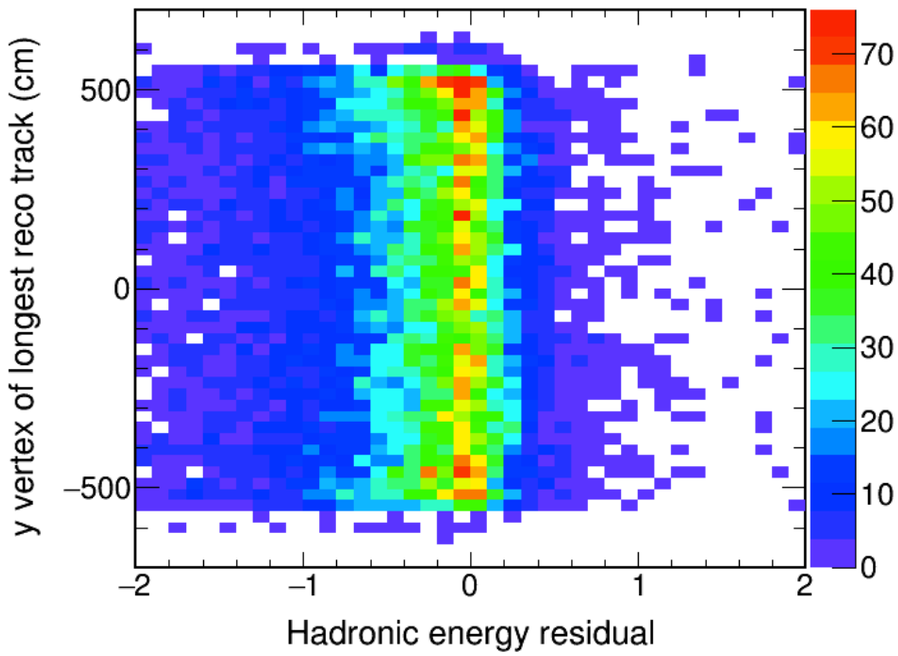
Hadronic energy residuals

x vertex of longest reco track



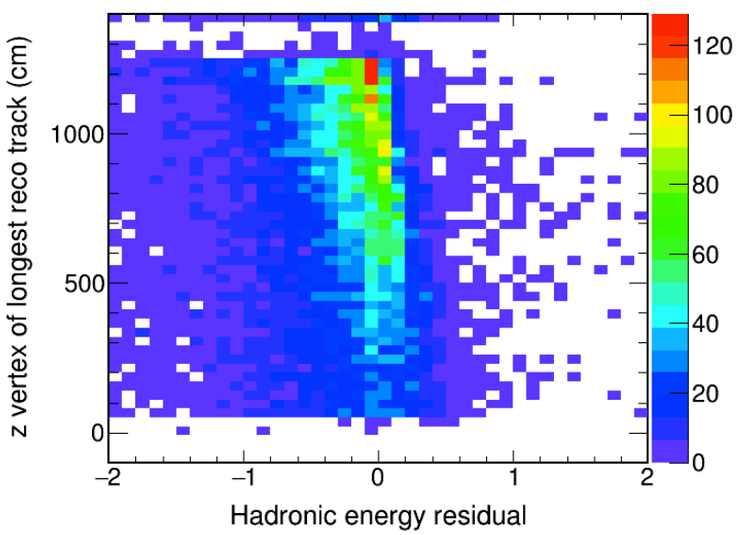
True ν_μ CC events with exiting track

y vertex of longest reco track



Hadronic energy residuals using ICARUS MCS against reco vertex position
Note: these are residuals (reco-true), not fractional residuals.

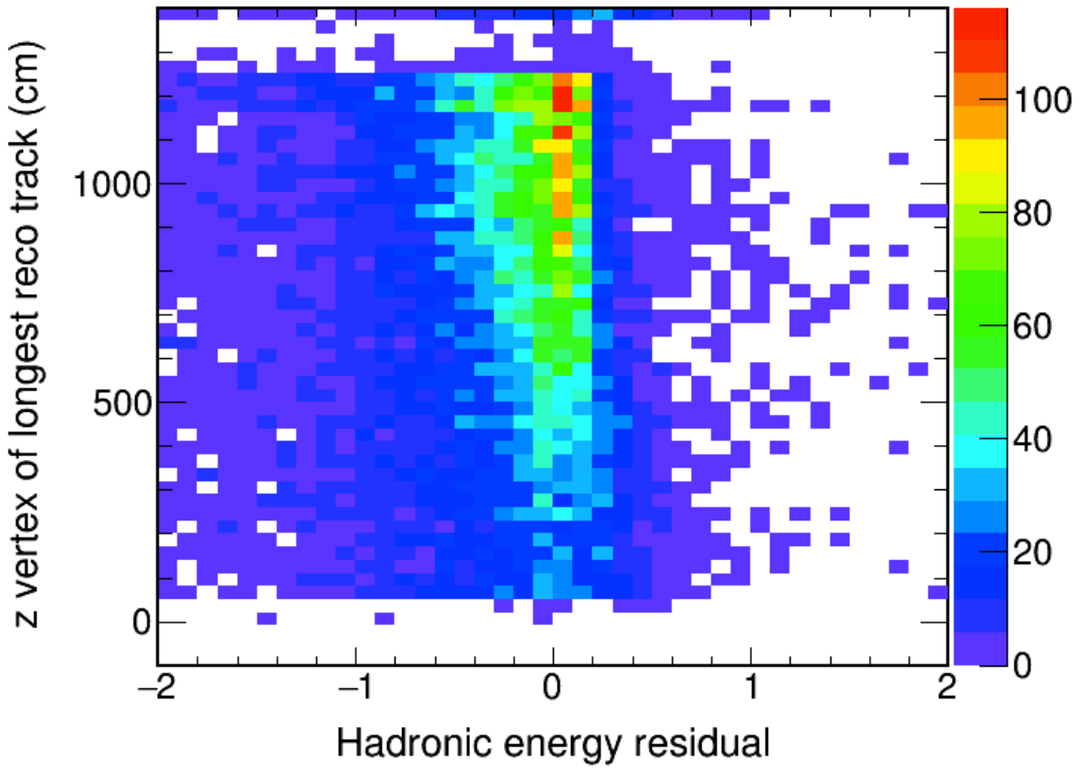
z vertex of longest reco track



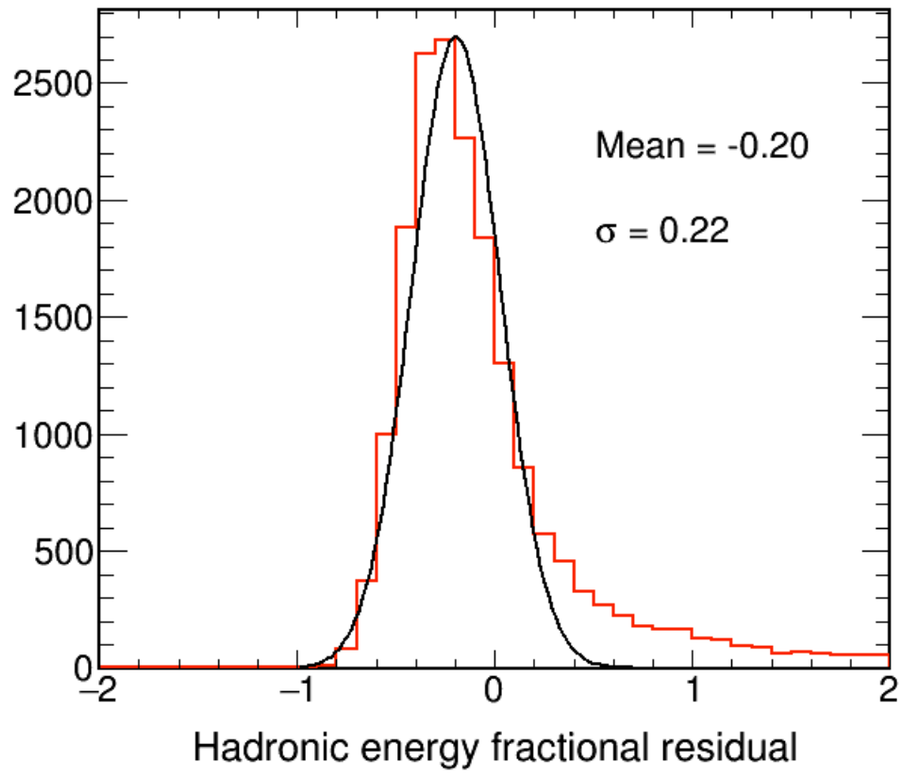
When reco vertex near edge of detector, hadronic shower may not be contained (more vertices are near edge for exiting tracks than for contained tracks).

MicroBooNE method at low true momentum

Try making ad hoc tweak of uncorrected hadronic energy as function of reco z vertex position



Fractional residuals of hadronic energy have narrower width but are biased. Don't use this ad hoc tweak.



Summary

The MicroBooNE method for MCS works well at low true muon momentum, but gives values that are too low at high momentum. For this reason, continue to use the ICARUS classical method for MCS.

The resolution of the ICARUS method improves significantly with increasing length of track within the detector.

The residuals of hadronic energy for ν_μ CC events with exiting tracks suggest that the hadronic showers are not contained when the reco vertex is near the edge of the detector.

In the full-sized far detector, consider using a fiducial volume cut at least 500 cm before end in z. This will help energy resolution for ν_μ CC events with exiting tracks, but it must be weighed against loss of statistics.