0.1 () Samples Fit Binning

The () ND280 BANFF fit uses the samples described in **??**. The bin edges are tabulated below.

- FHC CC 1-Track bin edges:
  p [GeV/c]: 0, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 1, 1.25, 1.5, 2, 3, 4, 5.5, 30
  $\cos\theta$: -1, 0.7, 0.8 , 0.88, 0.94, 0.96, 0.975, 0.99, 1
- FHC CC N-Tracks bin edges:
  p [GeV/c]: 0, 0.4, 0.5, 0.6, 0.7, 0.8, 1, 1.2, 1.5, 1.8, 2.2, 2.7, 3.5, 5, 10, 30
  $\cos\theta$: -1, 0.65, 0.77, 0.85, 0.9, 0.94, 0.97, 0.99, 1
- RHC CC 1-Track bin edges:
  p [GeV/c]: 0, 0.4, 0.5, 0.6, 0.7, 0.8, 1, 1.25, 1.5, 2, 3, 30
  $\cos\theta$: -1, 0.82, 0.87, 0.9, 0.93, 0.95, 0.97, 0.99, 1
- RHC CC N-Tracks bin edges:
  p [GeV/c]:0, 0.5, 0.9, 1.25, 1.6, 2, 3, 8, 30
  $\cos\theta$: -1, 0.8, 0.89, 0.95, 0.97, 0.99, 1
- RHC CC 1-Track bin edges:
  p [GeV/c]: 0, 0.4, 0.6, 0.8, 1.1, 2, 10
  $\cos\theta$: -1, 0.78, 0.84, 0.89, 0.92, 0.95, 0.97, 0.98, 0.99, 1
- RHC CC N-Tracks bin edges:
  p [GeV/c]:0, 0.4, 0.6, 0.8, 1, 1.5, 2, 3, 10
  $\cos\theta$: -1, 0.7, 0.8, 0.85, 0.9, 0.94, 0.965, 0.98, 0.99, 1

0.1.1 Fit Binning Determination

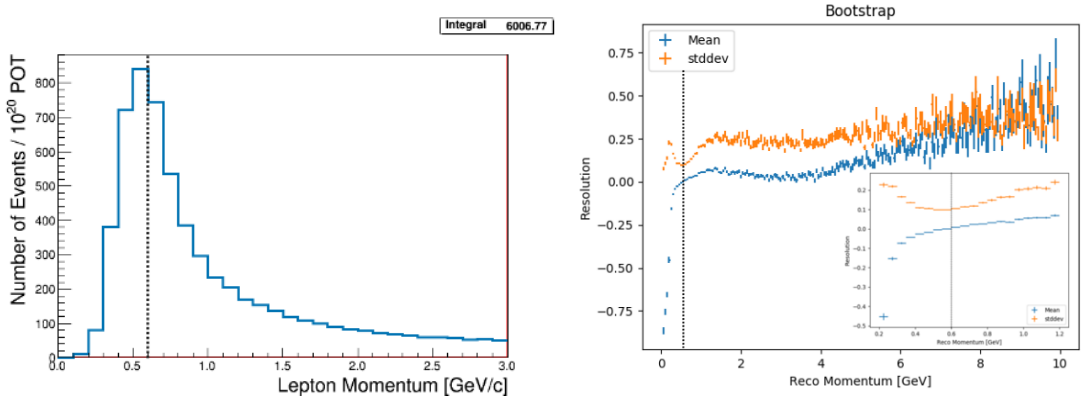
The fit binning is designed to optimized to ensure at least 1 predicted Monte Carlo (MC) event in each bin when scaled to the collected data POT. The fit bins must also account for detector smearing effects. In order to mitigate smearing and event migration, the reconstructed kinematics were examined to their MC truth value using only correctly identified leptons in one-dimensional kinematic slices. Since the MC provides about 10× the data statistics, the statistical uncertainty for each bin should be negligible for high statistics regions. The kinematics are scanned across their full relevant spaces in order to understand the needed width for a fit bin. The first fit bin is always defined from the kinematic maximum.

For the momentum bins, the momentum resolution is compared to MC truth . The momentum resolution is defined as

$$R(r,t) = \frac{r-t}{t},$$

where r is the reconstructed momentum and t is the true value. The momentum was scanned in finite bin widths with the mean and standard deviation of the resolution R extracted. The mean and standard deviation are used as a proxy for the true bias and true resolution, respectively. In addition, a bootstrapping algorithm was employed to understand the accuracy of the sample estimates. Bootstrapping in this context is sampling over all relevant values of true momentum and randomly replacing the values. For each scanned bin, at least 1000 bootstrapping sampling with replacement was performed. In the case of large variances in the bootstrapping samples, additional 10000 sampling with replacement were performed. The results for analyzing the FHC CC 1-Track selection is shown in Figure 1 on page 2.

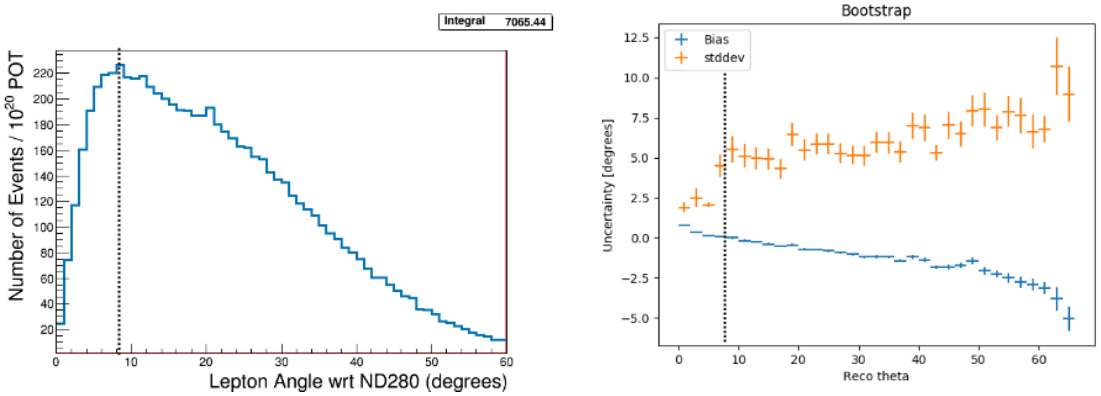
The angle bins are treated in an almost identical manner. While the fit bins and physics parameterized in $\cos\theta$, the angle with respect to the z-axis, the detector smearing is a function of the angle θ. In addition, since the angle can be nearly zero for the most forward-going tracks, the resolution was not used to characterize the angular uncertainties. Instead, the difference between the true and reconstructed angle were analyzed as shown in . The mean and standard deviation were studied. Bootstrapping was again used to quantify the accuracy of the mean and standard deviation.



(a) Momentum event distribution

(b) Momentum resolution

Figure 1: The momentum event distribution and uncertainty for FHC CC 1-Track events is shown above. Only correctly identified muons are shown. (a) The number of events per unit momentum is scaled to 10^{20} POT which is the approximate scale for all the samples in this analysis. A dashed line indicates the maximum of the peak. (b) The resolution of the momentum measurement is shown for a wide region of momenta. In the inset is the resolution zoomed near the momentum distribution maximum. Like in (a), a dashed line shows the momentum maximum.



(a) Angular event distribution

(b) Angular residuals

Figure 2: The angular event distribution and uncertainty for FHC CC 1-Track events is shown above. Only correctly identified muons are shown. (a) The number of angular events is scaled to 10^{20} POT which is the approximate scale for all the samples in this analysis. A dashed line indicates the maximum of the peak. (b) The residual of the angular measurement is shown up to where there are sufficient statistics. Like in (a), a dashed line shows the momentum maximum.