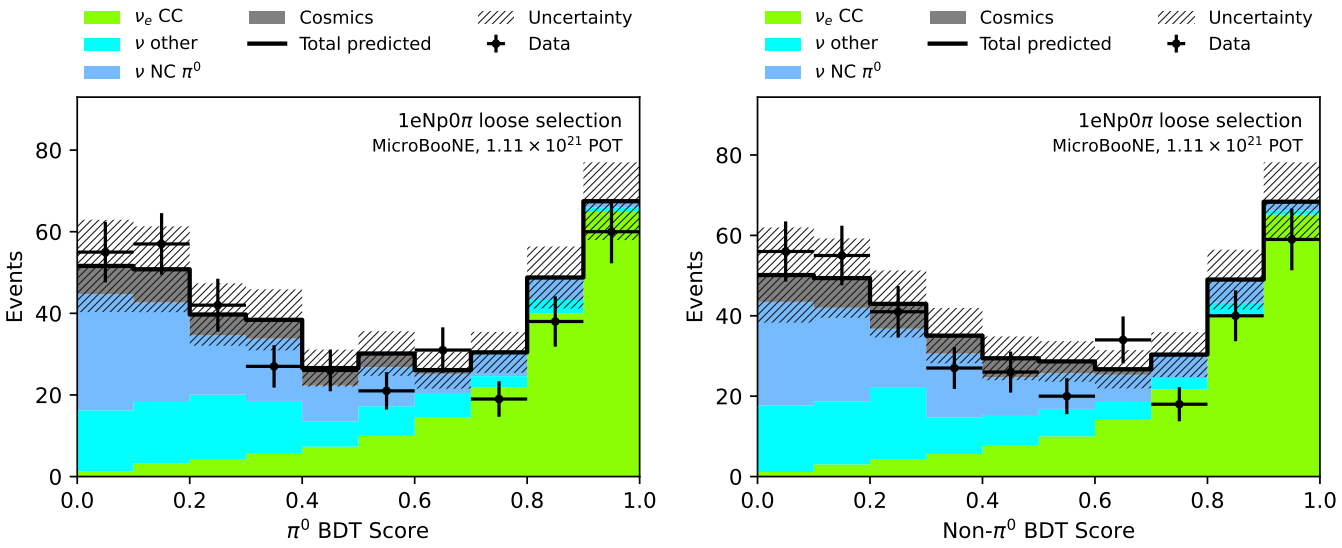
# Auxiliary Materials for Manuscript Entitled "Search for an Anomalous Production of Charged-Current $\nu_e$ Interactions Without Visible Pions Across Multiple Kinematic Observables"

The MicroBooNE Collaboration*

(Dated: December 20, 2024)

This document contains figures that supplement the analysis presented in arXiv:2412.14407.

## I. BDT SCORES




(a) (b)

FIG. 1. Response of the $1eNp0\pi$ selection BDT designed to reject events with $\pi^0$s. Background events are predicted to peak at low BDT scores and electron neutrinos at high BDT scores. Events with BDT score at (a) $\pi^0$ score $> 0.67$ and (b) non-$\pi^0$ score $> 0.70$ are retained as part of the final selection.

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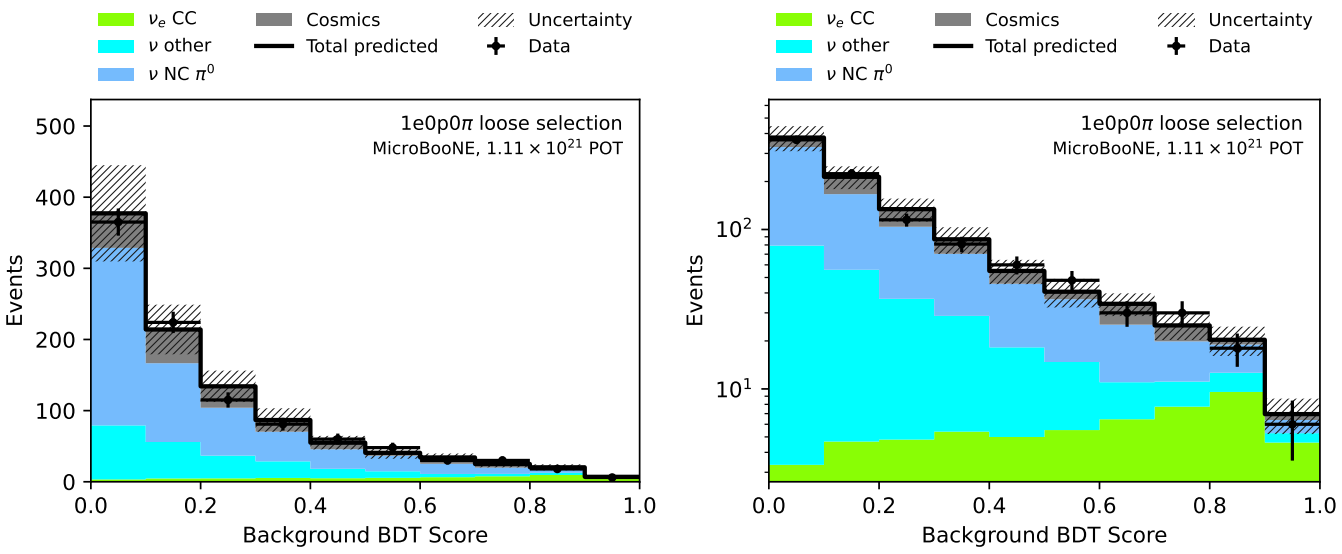



FIG. 2. $1e0p0\pi$ selection BDT response. Background events are predicted to peak at low BDT scores and electron neutrino events at high BDT scores. In the final selection, events with BDT scores above 0.72 are retained. (b) shows the logarithmic scale version of (a).

## II. SHOWER ENERGY DEPOSITION

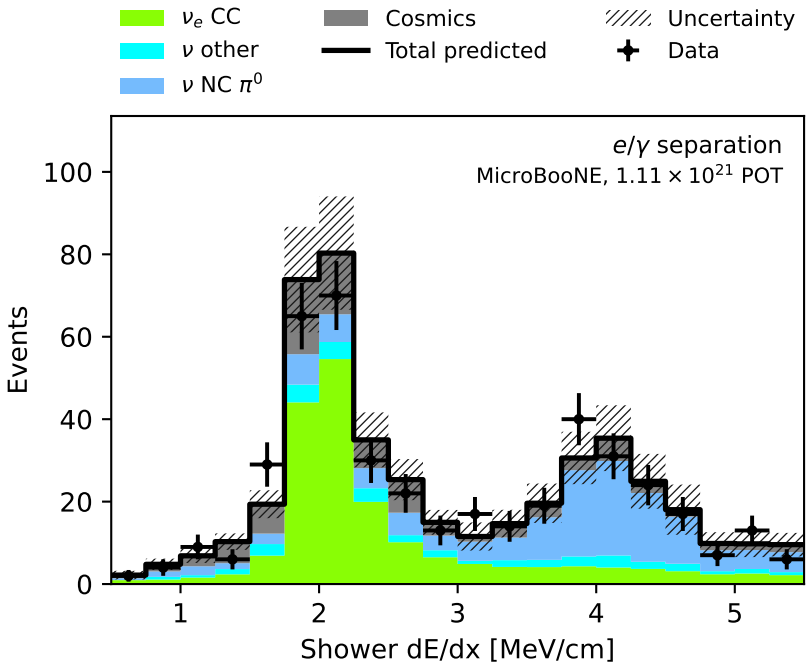



FIG. 3. Energy deposited per unit length ($\mathrm{d}E/\mathrm{d}x$) for electronphoton separation. The figure shows $\mathrm{d}E/\mathrm{d}x$ measured in the $[0, 4]$ cm range from the shower start point for a combination of events with and without protons. Data from the signal region ($E_\nu < 0.65$ GeV) are excluded from this validation plot.

## III. SIDEBANDS

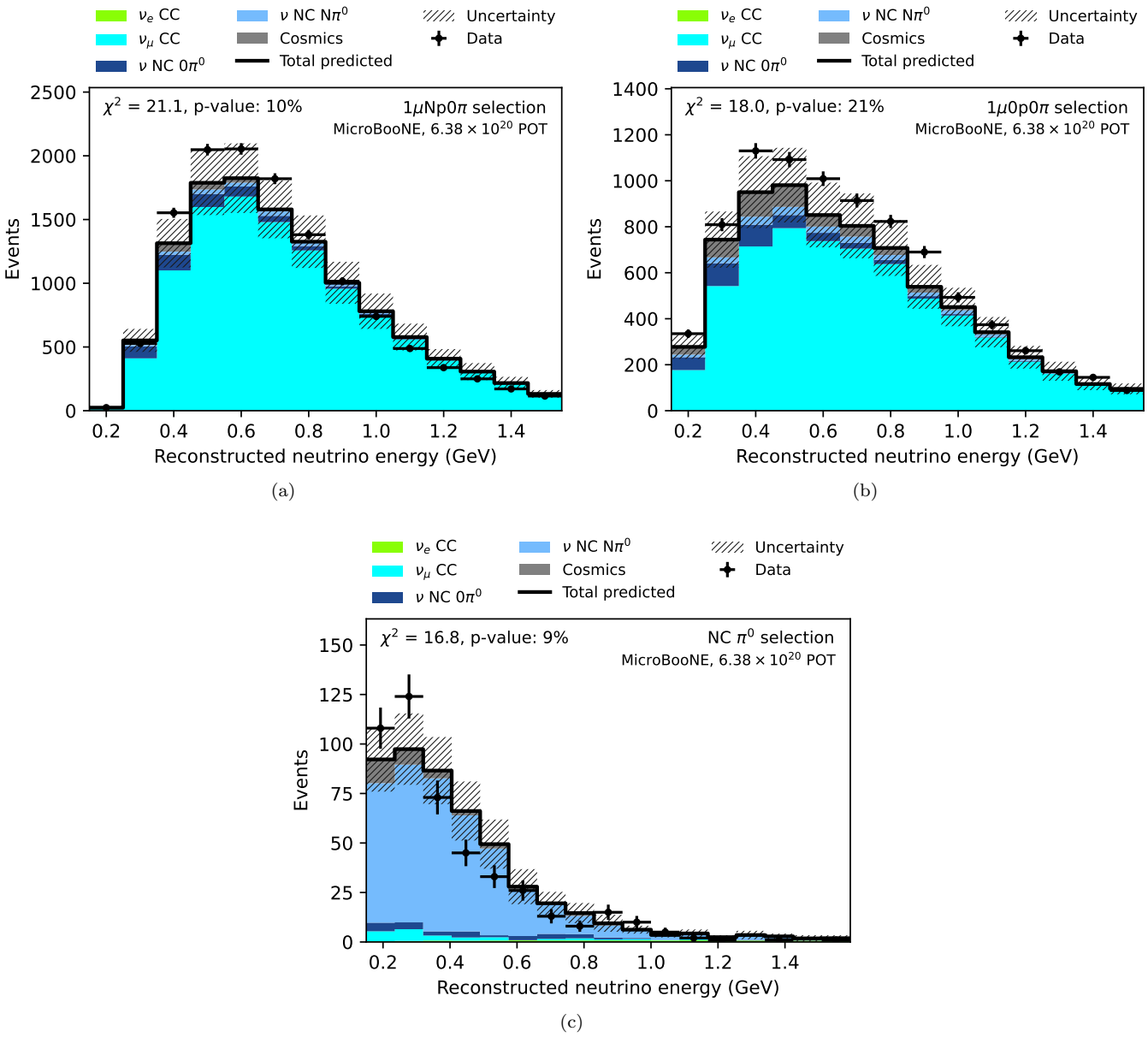
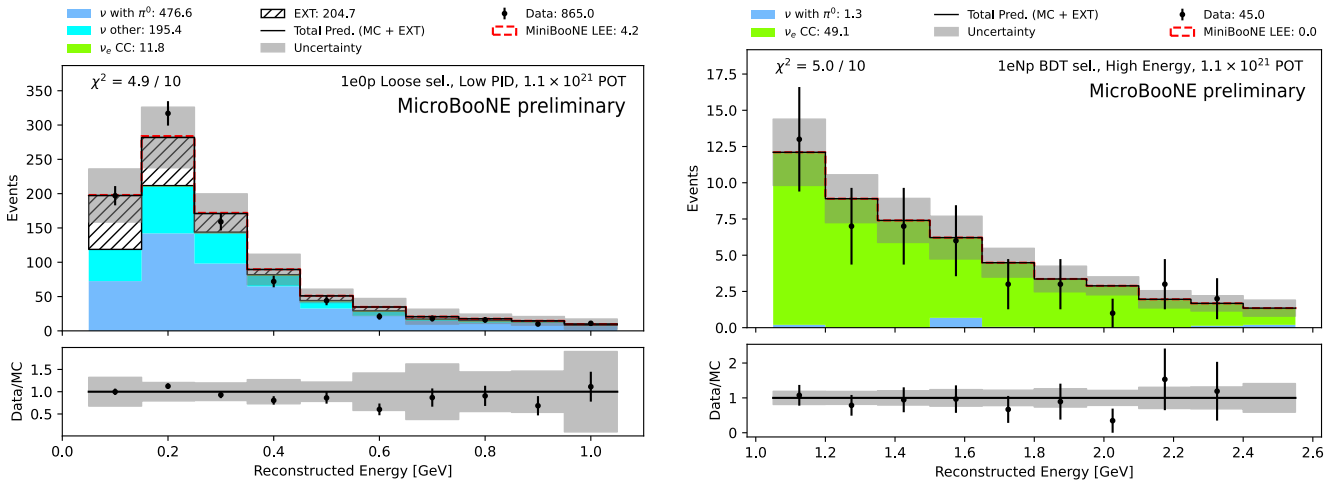


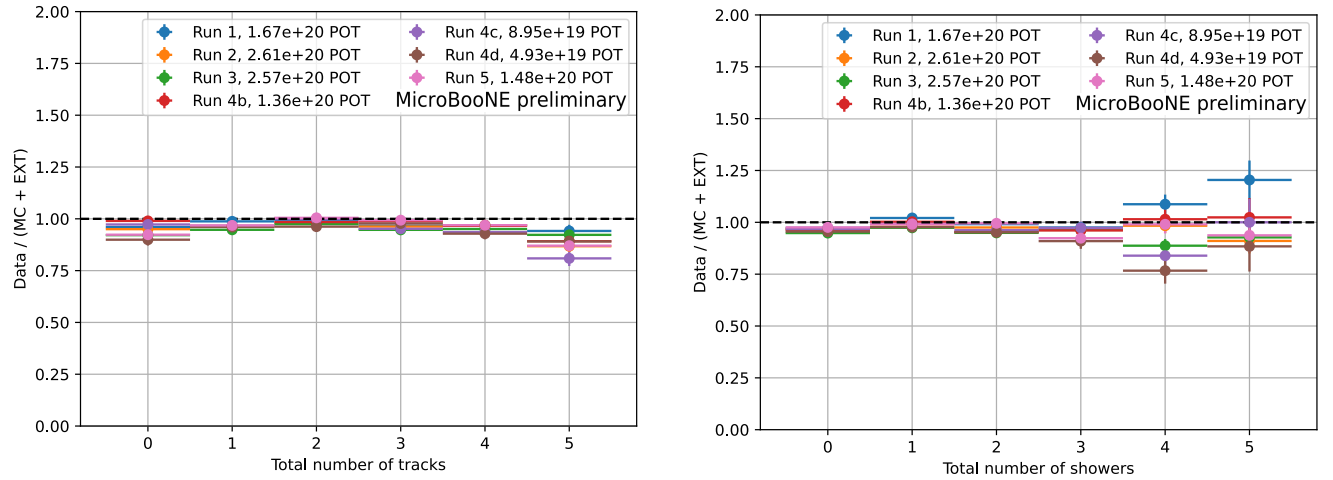

FIG. 4. Distributions of control sample events used in this analysis. The prediction is broken down into charged-current (CC) $\nu_e$ and $\nu_\mu$ interactions, NC interactions not producing neutral pions, NC interactions that produce neutral pions, neutrino interactions outside of the fiducial volume, and cosmic rays mistaken for neutrino interactions. Only bins up to 1 GeV from the NC $\pi^0$ selection are used in the constraint procedure due to low statistics above this energy.




(a) (b)

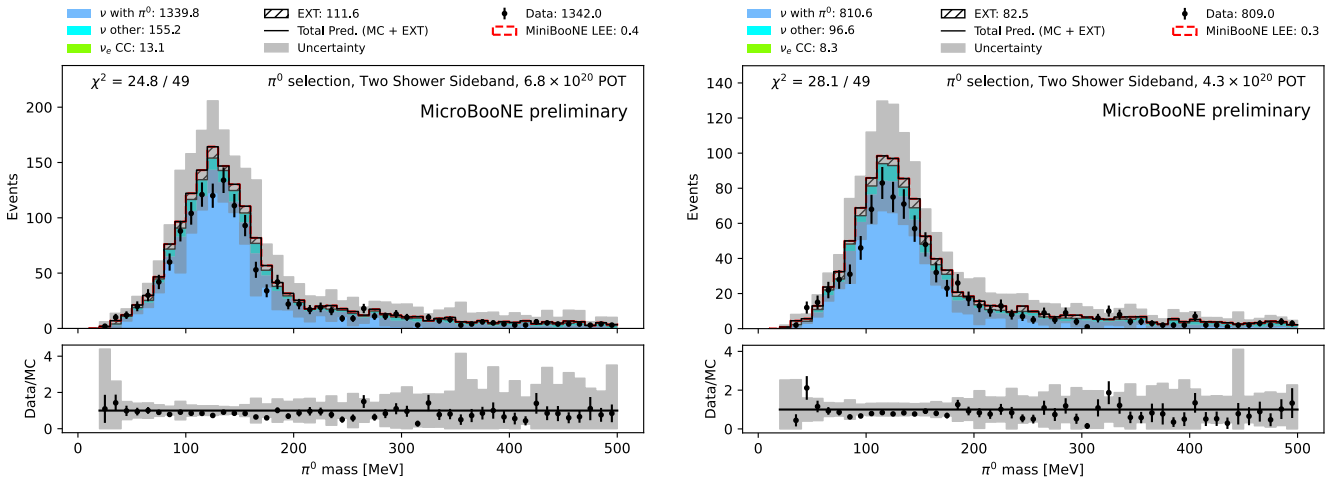
FIG. 5. Data validation sidebands, showing the reconstructed neutrino energy of events passing the $1e0p0\pi$ pre-selection but failing the final BDT selection, as well as events passing the full $1eNp0\pi$ selection with a high reconstructed neutrino energy. These distributions are not used in the constraint procedure.

## IV. DATA VALIDATION



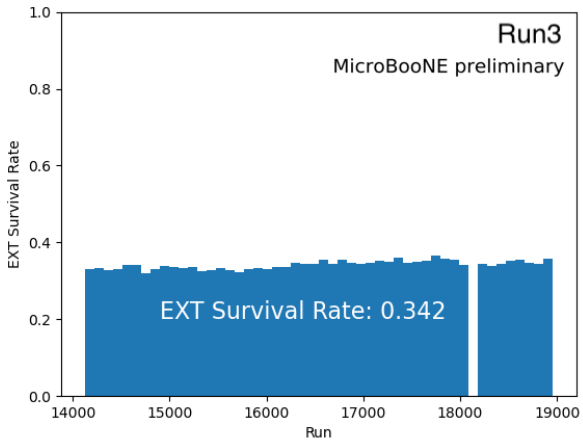

(a) (b)

FIG. 6. Ratio between the observed data events and the prediction for the different run periods used in the analysis, binned in number of tracks and number of showers in the event. Variations across run periods are consistent with statistical fluctuations.

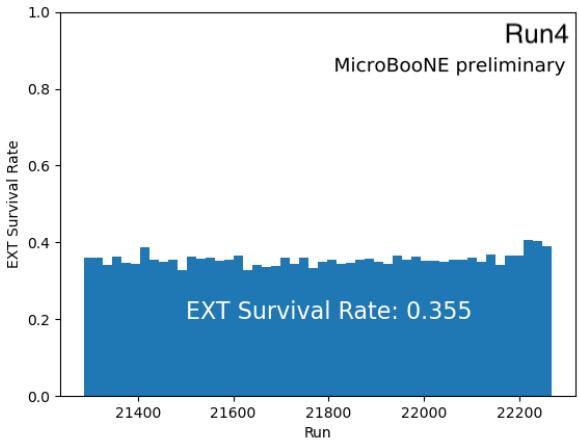



(a) (b)

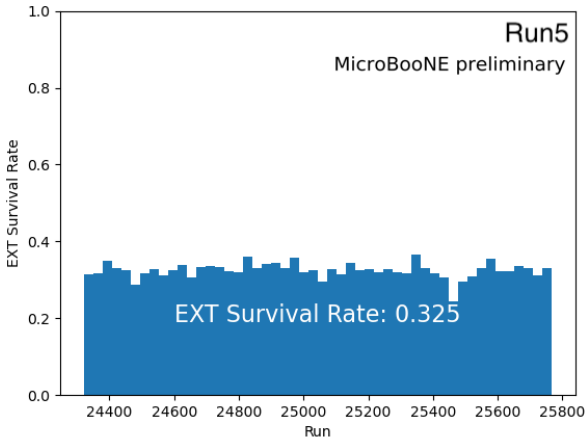
FIG. 7. Neutral pion mass peak, obtained from the invariant mass of the two largest energy showers in the event. The result is shown separately for the first three run periods and the last two run periods.




(a)




(b)




(c)

FIG. 8. Rate of events passing a selection requiring no CRT hits in time with the PMT trigger for events collected without beam, shown as a function of the run number for the last three data taking periods.

## V. CHI2 DISTRIBUTIONS

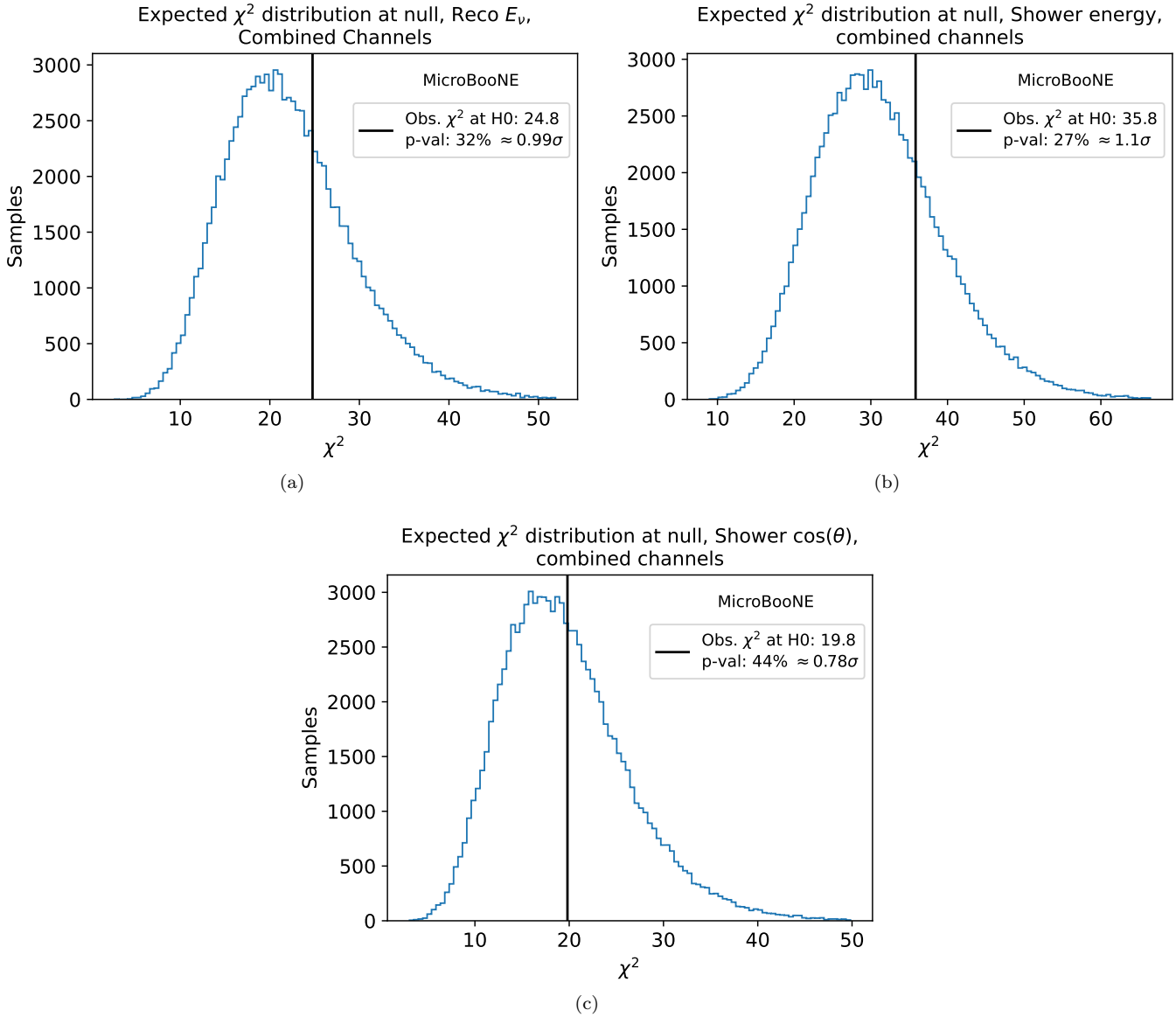
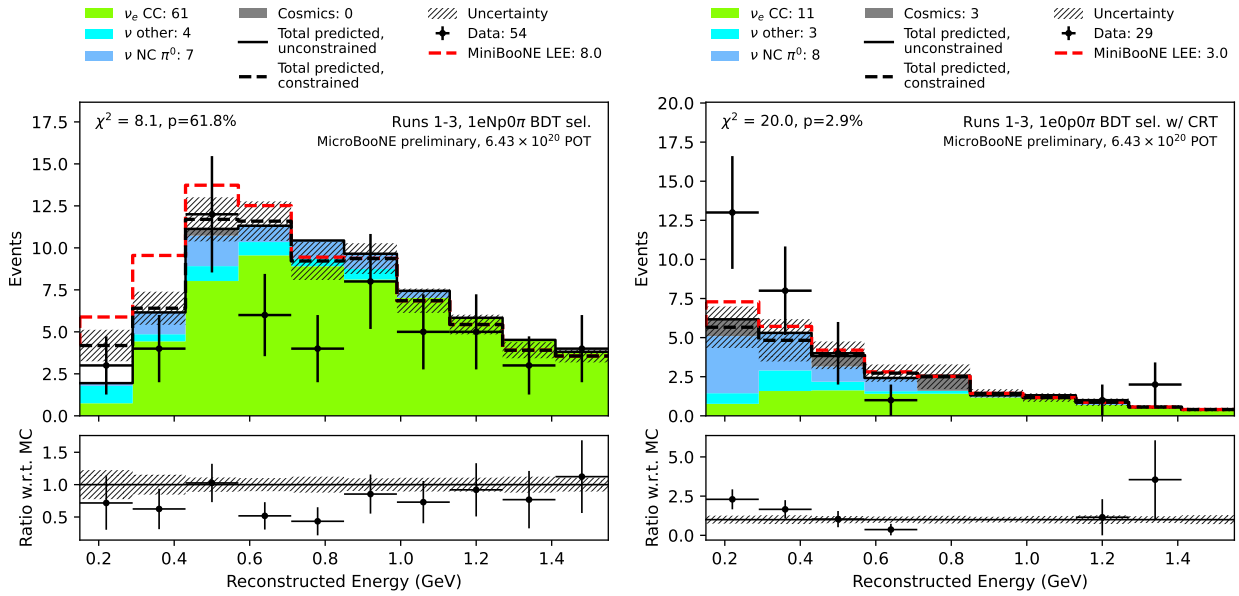


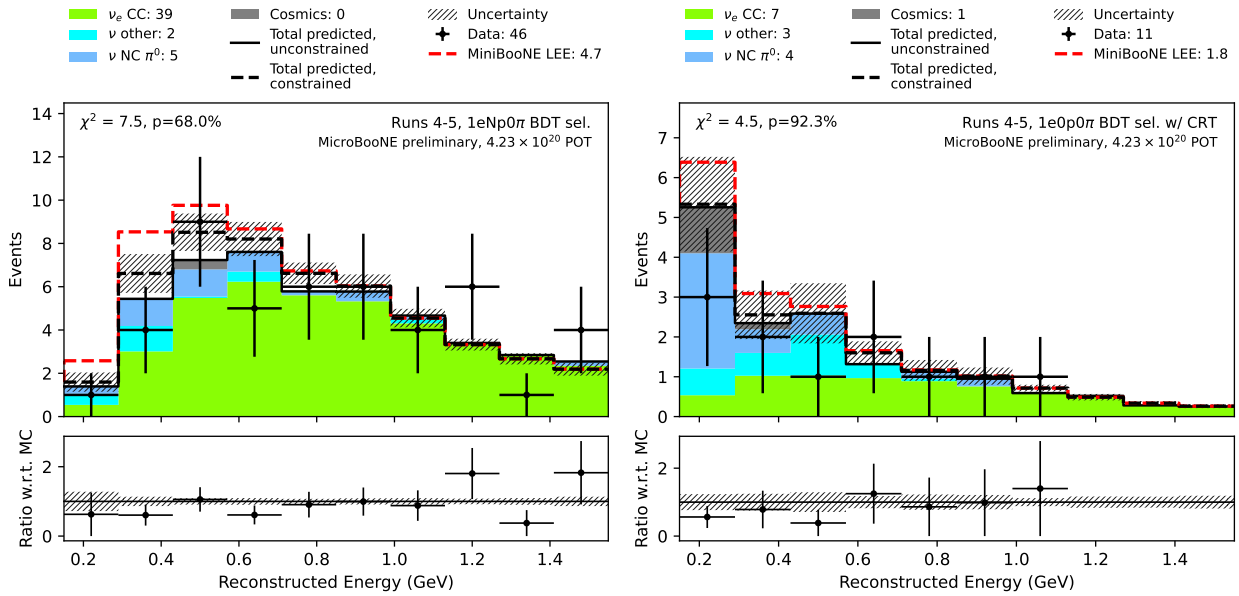

FIG. 9. Expected $\chi^2$ distributions for the null hypothesis test, as well as the observed value in data, shown for the results in terms of reconstructed neutrino energy, electron energy, and electron angle.

## VI. POST-UNBLINDING STUDIES



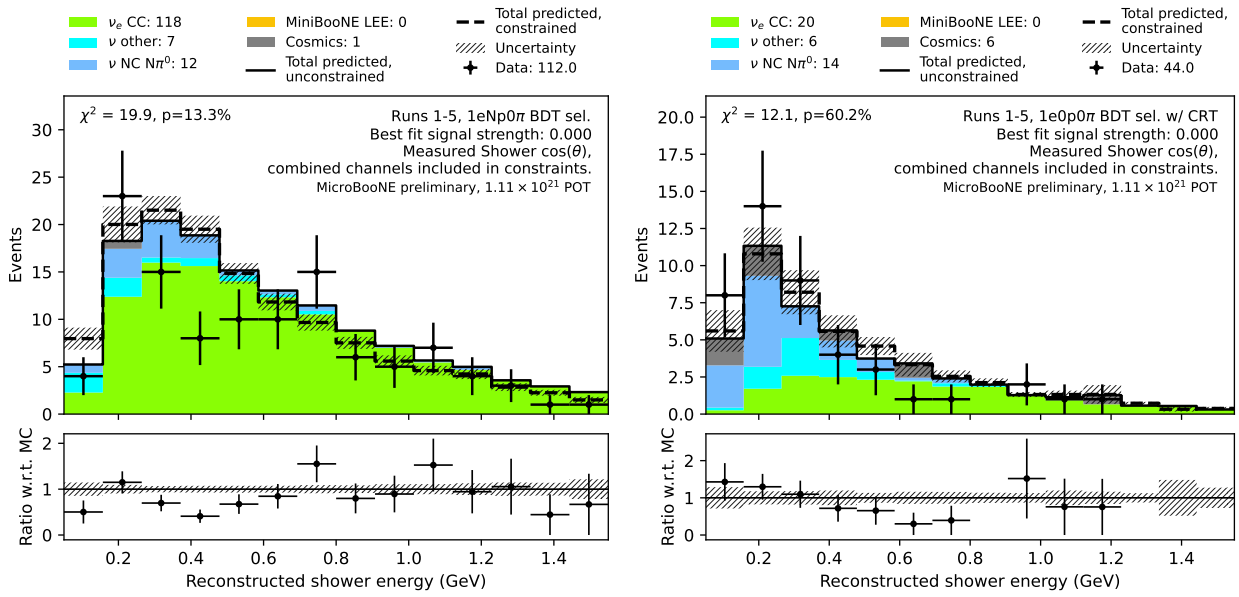

(a) (b)

FIG. 10. Observed data and prediction when using only the first three run periods, for the 1$e$N$p$0$\pi$ and 1$e$0$p$0$\pi$ selections.



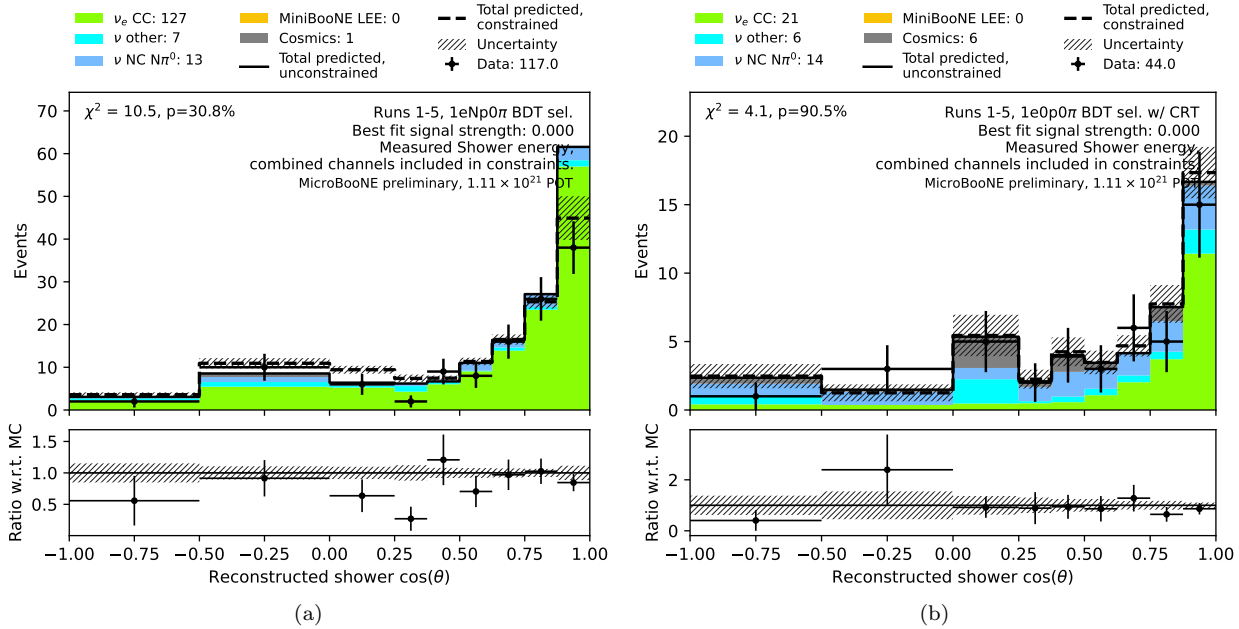

(a) (b)

FIG. 11. Observed data and prediction when using only the last two run periods, for the 1$e$N$p$0$\pi$ and 1$e$0$p$0$\pi$ selections.




(a) (b)

FIG. 12. Results shown as a function of the shower energy when the prediction is constrained with the nominal three sidebands plus the observed data in the shower angle, for the 1$e$N$p$0$\pi$ and 1$e$0$p$0$\pi$ selections.




(a) (b)

FIG. 13. Results shown as a function of the shower angle when the prediction is constrained with the nominal three sidebands plus the observed data in the shower energy, for the 1$e$N$p$0$\pi$ and 1$e$0$p$0$\pi$ selections.

## VII. ANALYSIS IMPROVEMENTS

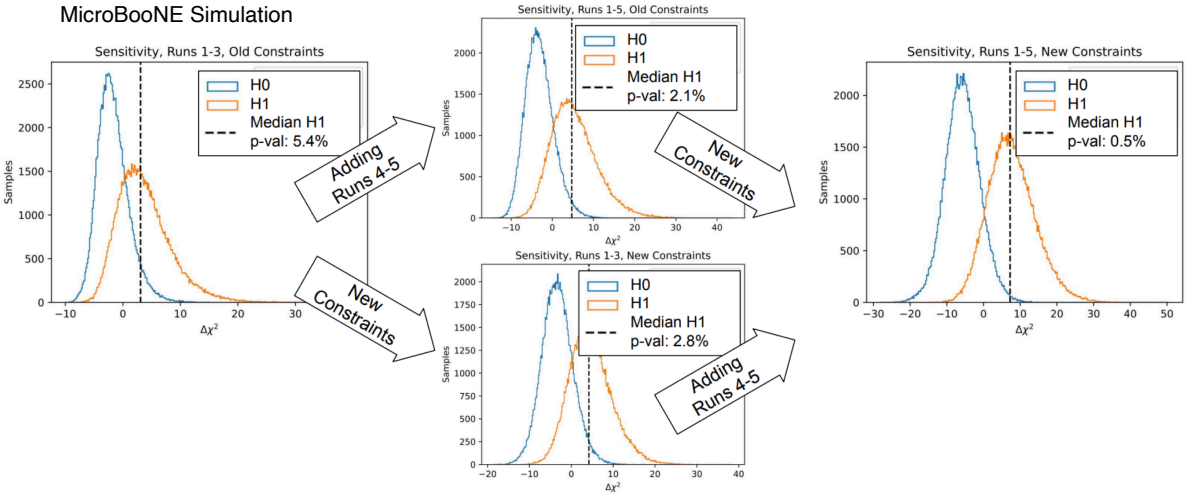
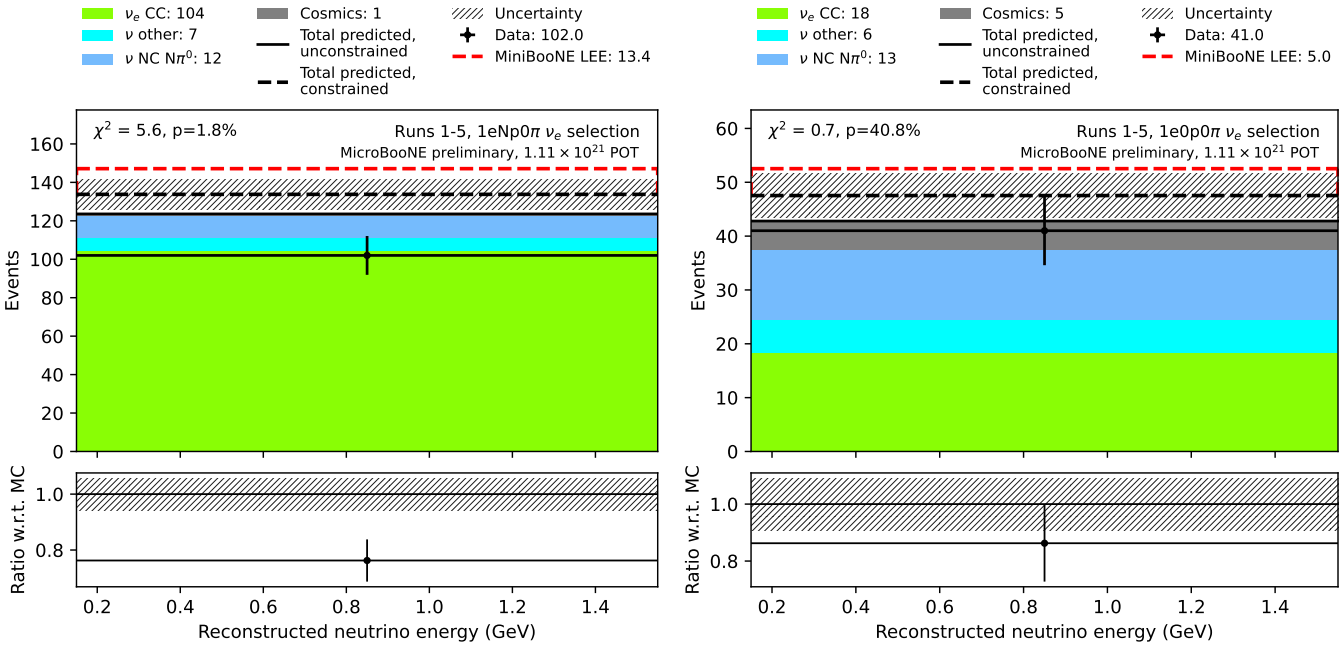



FIG. 14. Summary of the impact of analysis improvements in terms of median p-value for the signal hypothesis (H1), showing the result of including the two additional data taking periods, the result of updating the procedure for constraining systematics, and the combined impact of these two updates.

## VIII. NORMALIZATION TESTS

The following figures show the results of the one-bin normalization test used to determine the significance of the over-prediction observed at medium energies in the analysis. For this purpose, all events with reconstructed neutrino energy between 0.15 GeV and 1.55 GeV were placed into a histogram with a single bin. We then calculated the predicted event count in this histogram, including all systematic uncertainties and the same constraint procedure as outlined in the letter describing this analysis. The LEE model shown in these figures is the model derived from unfolding the CCQE reconstructed neutrino energy, which is referred to as "Signal Model 1" in the letter.




(a) (b)

FIG. 15. One-bin normalization test. Events are binned in a single bin from 0.15 GeV to 1.55 GeV. The MiniBooNE LEE prediction uses Signal Model 1, described in the letter.