Identifying Variables for Reconstruction of Neutrino Energies

LeRayah Neely-Brown

Supervisors: Joseph Zennamo and Fernanda Psihas

August 13 2021

1 Introduction + Motivation

Neutrinos are the most abundant massive particle in universe [2]. They come from everywhere and trillions are able to pass through the human body every second. Neutrinos come in different variations known as flavors. The three known flavors are muon, electron, and tau. A neutrino phenomenon that researchers around the world study is neutrino oscillation. Neutrino oscillations are defined as neutrinos changing from one flavor to another over time. A prime example of a neutrino oscillation from various studies is a muon neutrino changing into an electron neutrino. Within the Neutrino Division at Fermilab, the Short Baseline Neutrino (SBN) Program is ran in collaboration with numerous scientists and institutions across the globe [4]. The main goal of the SBN Program is to measure how neutrinos change into different flavors throughout the universe. Specifically at Fermilab, researchers observe and analyze how neutrinos produced at the lab oscillate/change into different flavors between detectors. The detectors used within the SBN Program at Fermilab are the Short-Baseline Near Detector (SBND), MicroBooNE, and the Short-Baseline Far Detector (ICARUS). While MicroBooNE is running and collecting data, SBND and ICARUS are not. However, Monte Carlo simulations for SBND and ICARUS provide effective insight on neutrino oscillations and behavior. The key to understanding neutrino oscillations is having precise energy measurements. Precise energy measurements are needed because to effectively detect neutrino oscillations, energies from SBND and ICARUS must be reconstructed precisely. Currently, there is no standard method to reconstruct neutrino energy on either SBND or ICARUS. Consequently, this project's objective is to identify and select variables that will aid in precise energy reconstruction is allows for improved searches for and better understanding of neutrino oscillations.

2 Methods

Before identifying, selecting, and analyzing different variables for precise neutrino energy reconstruction, the Common Analysis Framework (CAF) is an important tool that was needed for the Monte Carlo simulations from both SBND and ICARUS. The CAF provide analysis of Monte Carlo files with high level information and heavy data (i.e. with the use of raw digits/data) and stores needed information in easily accessible small analysis trees [3]. Additionally, the CAF's ability to simultaneously process and analyze the data of the files is important for efficient file runs. Using the CAF (and CAF files) is essential for this project because the Monte Carlo simulation files for SBND and ICARUS were used with the CAF to compute and plot the true energies of both detectors. Plotting the true energies of the neutrinos from both detectors is crucial when understanding neutrino oscillations because the oscillations depend on the neutrinos' true energy [1]. When the neutrino true energies for both detectors are plotted, the next steps are to identify variables that will contribute to precise reconstruction of energies for detecting neutrino oscillations. The variables selected for this project were the neutrino showers and neutrino calorimetric tracks. It was important to see how the energies of these individual variables appeared for each detector to see if they resembled the true energy distributions, which is essential for precisely reconstructing energies. The next step was to combine the sum of both shower and calorimetric track energies within both detectors to analyze and decide if merging the energies of these variables may be even closer to the true neutrino energy values and also lead more precise reconstructed energies.

After deciding to work with the sum of neutrino shower and neutrino calorimetric track energies, 2D plots were created to plot the sum of the selected variables against the true energies. The 2D plots will help determine if there is a strong correlation present between the selected variables and the true neutrino energies. Determining if a strong correlation exists means that the variables selected will serve as precise reconstructed energies and precisely detect neutrino oscillations.

3 Results

I. The true neutrino energy plots for SBND and ICARUS displayed the energies with all track length sizes (in orange) and energies with track length sizes greater than 50cm (in black). The energies were plotted with two different track length cuts because muon neutrinos typically have long track lengths, so it was important to see which neutrinos modeled muon neutrino behavior.

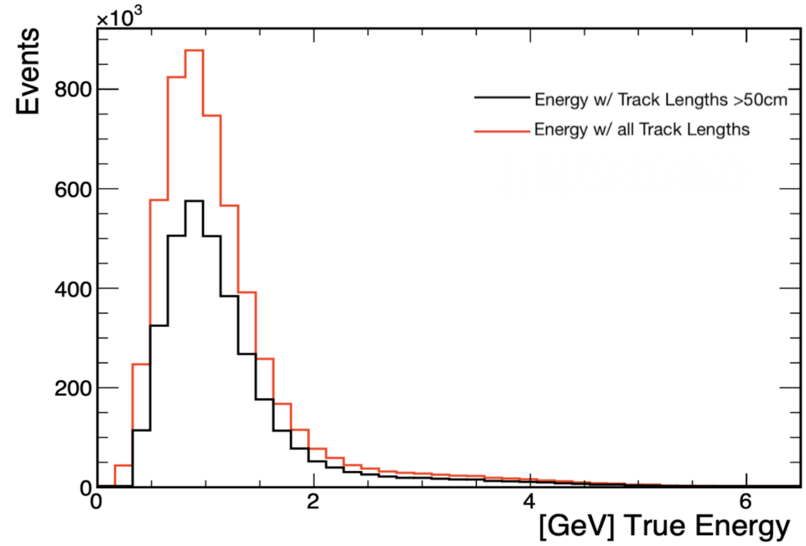

Figure 1: SBND True Energy Plot

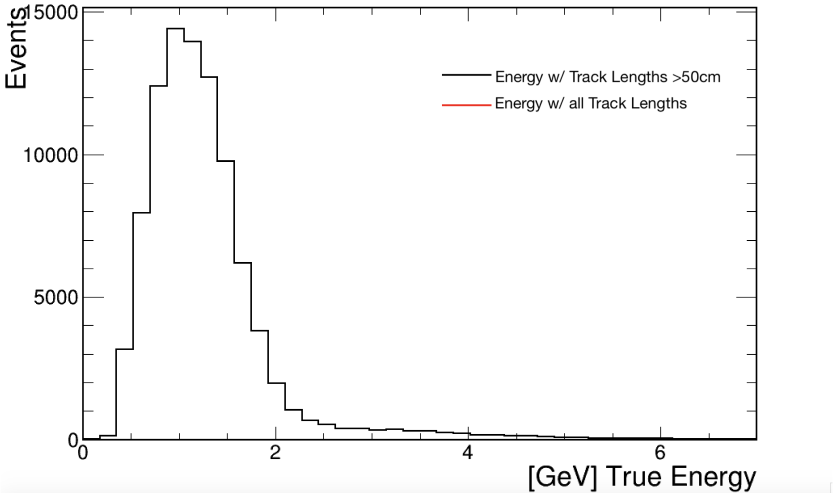

Figure 2: ICARUS True Energy Plot

II. The shower energy plots for SBND and ICARUS showed how much energy is emitted from neutrinos after neutrino interactions occur.

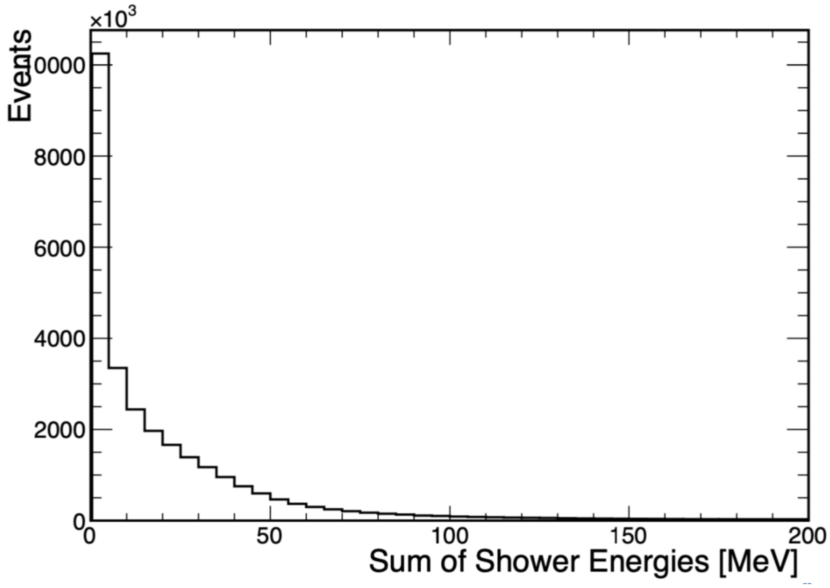

Figure 3: SBND Shower Energy Plot

The shower energies for SBND were low in value and began to plateau near zero energy value.

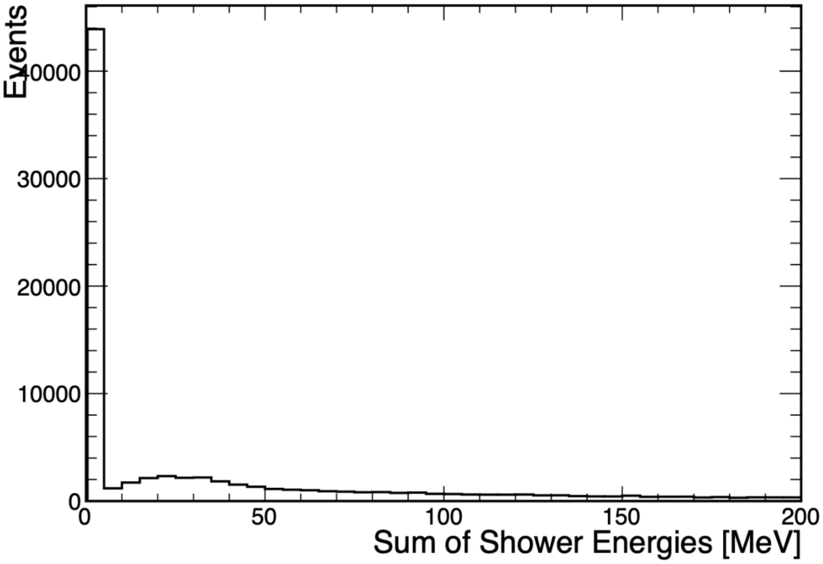

Figure 4: ICARUS Shower Energy Plot

The shower energies for ICARUS were close to zero throughout the plot.

III. The sum of calorimetric track energies measures how much kinetic energy the neutrinos deposit.

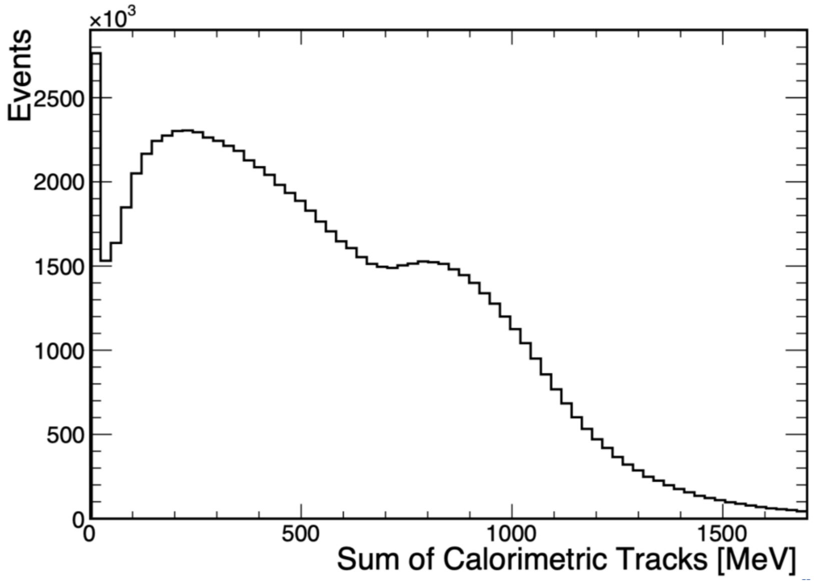

Figure 5: Figure 4: SBND Calorimetric Track Energy Plot

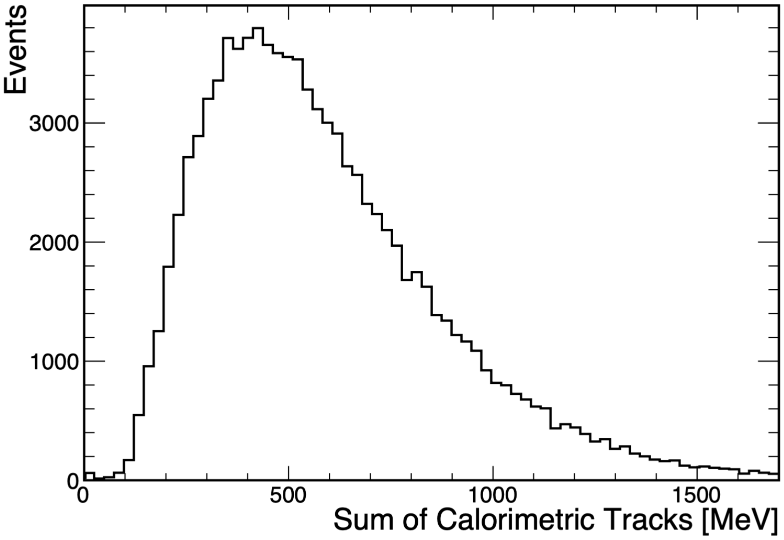

Figure 6: ICARUS Calorimetric Track Energy Plot

The plot for the ICARUS detector resembles the true energy distribution. The ICARUS plot also favors a normalized distribution.

IV. The sum of shower and calorimetric track energies showcases the neutrino energies when both energy variables are combined.

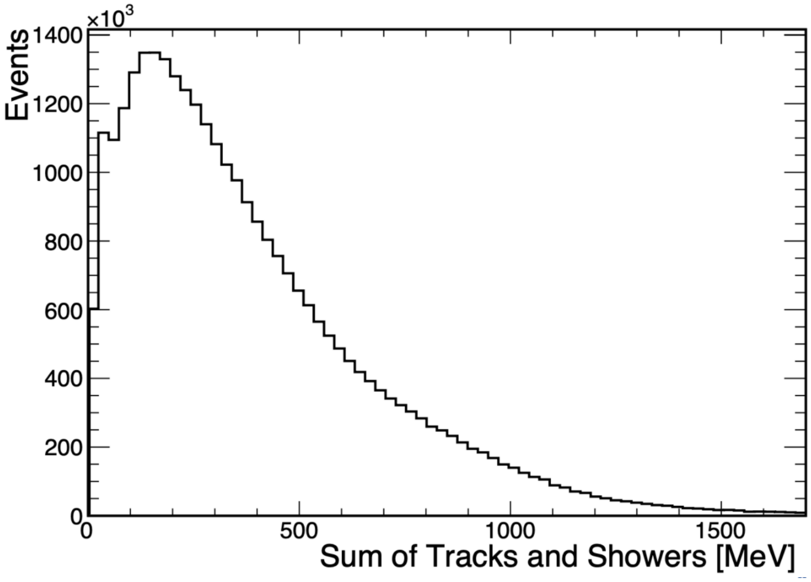

Figure 7: SBND Sum of Shower and Calorimetric Track Energies Plot

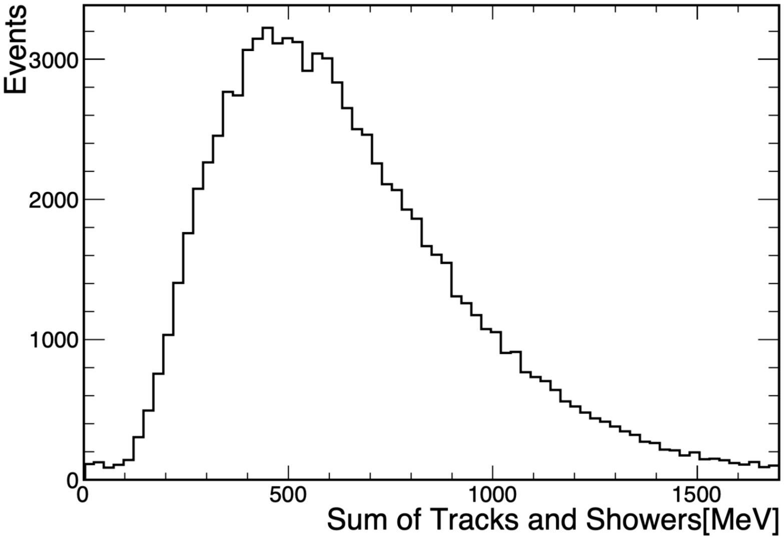

Figure 8: ICARUS Sum of Shower and Calorimetric Track Energies Plot

The plot of the sum of both variables also favor a normalized distribution. Once again, the ICARUS sum of showers and calorimetric tracks plot closely follows the same trend as the ICARUS true energy plots.

V. The 2D plots for SBND and ICARUS represent the sum of shower and calorimetric track energies plotted against the true energy values.

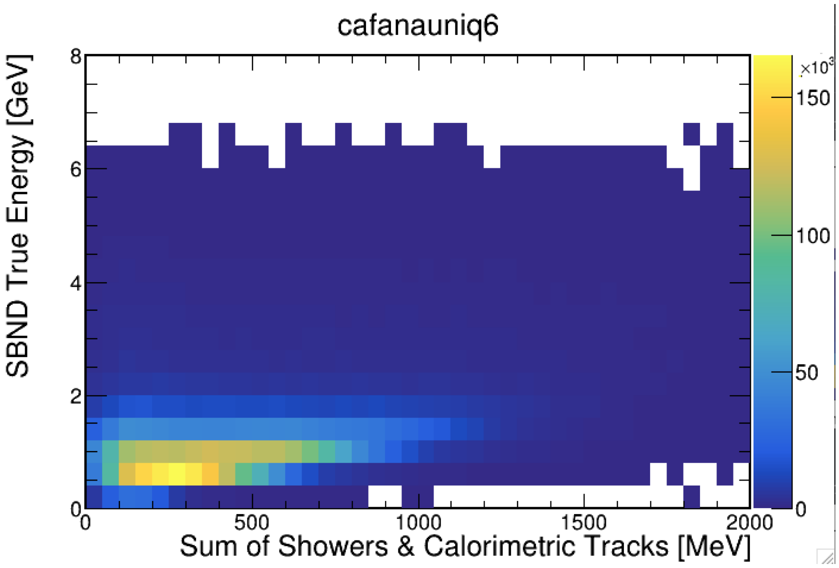

Figure 9: SBND Sum of Shower and Calorimetric Track Energies vs True Energies Plot

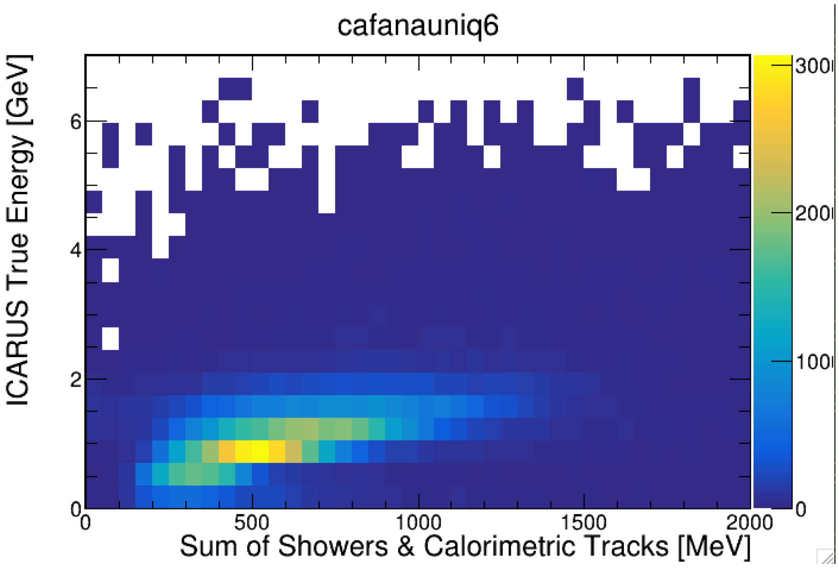

Figure 10: ICARUS Sum of Shower and Calorimetric Track Energies vs True Energies Plot

Both plots follow a linear trend, but the true energies are more present than the sum of shower and calorimetric track energies for both of plots for each detector.

4 Conclusion

A 1:1 correlation within a 2D plot comparison is ideal for precise reconstruction of energies. Unfortunately, the correlation for both detectors is a bit below that. This means an undercut of energies is present within the sum of shower and calorimetric track energies in comparison to the true value energies. However, there is *still* a correlation seen between the selected variables and the true energies within both detectors. It is also seen that a a higher correlation is present within the ICARUS detector. With this information, it is imperative that more Monte-Carlo events/files are ran for both detectors to accumulate more statistics to show that there may be a stronger correlation present. Furthermore, refining the binning of the 2D plots will help uncover how close the correlation is between the true energies and the sum of shower and calorimetric track energies. Following these modifications, it is imperative to begin smearing the reconstructed energies to observe how precise and effective the energies are in relation to the true energies when detecting neutrino oscillations. Overall, the sum of shower and calorimetric track energies variable is a substantial variable to begin with when attempting to precisely reconstruct the energies within SBND and ICARUS.

5 Acknowledgements

I would like to extend my thanks to my supervisors Joseph Zennamo and Fernanda Psihas for their guidance, insight, and support throughout this productive summer.

Also, a huge thank you to Fermilab, the SIST/GEM Committee, and the National GEM Consortium for allowing me to participate in this research this summer.

References

[1] Nick Grant. "Meeting of APS Division of Particles and Fields". In: pp. 1–3.

[2] *Neutrinos*. May 2020. URL: `https://www.fnal.gov/pub/science/particle-physics/experiments/neutrinos.html`.

[3] $SBN_{w}orkshop_{2}021_{t}utorial_{A}pril06$. Apr. 2021. URL: `https://www.dropbox.com/s/nq3r8demweml4n5/SBN_workshop_2021_tutorial_April06.mp4?dl=0`.

[4] *Short-baseline neutrino program.* June 2018. URL: `https://sbn.fnal.gov/`.