Improved Supernova Pointing for DUNE

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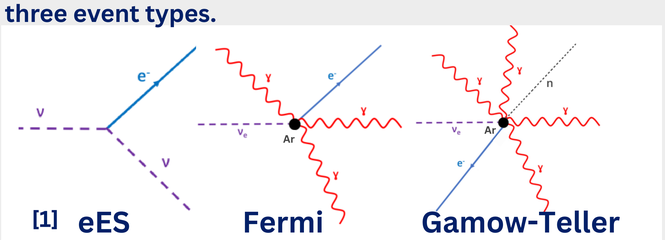
Motivations

The Deep Underground Neutrino Experiment (DUNE) is highly sensitive to the electron neutrino burst from a galactic core-collapse supernova. This neutrino burst can be used to point back to the supernova. The primary directional information comes from elastic scattering off electrons; however, the dominant interaction is the charged-current absorption of electron neutrinos by argon.

The cross section for this interaction has two distinct nuclear transitions: Fermi and Gamow-Teller, each with different angular distributions for the outgoing electron. Distinguishing these transitions may improve supernova pointing precision by complementing elastic-scattering events. We present a two-stage model for classifying eES, Fermi, and Gamow-Teller events, and demonstrate the pointing power of DUNE with these three event types.



[1] eES Fermi Gamow-Teller

Channel	Expected event count
$\nu + e^- \to \nu + e^-$ (all flavors)	**325.8 (9.0%)**
$\nu_e + {}^{40}\mathrm{Ar} \to e^- + {}^{40}\mathrm{K}^*$	**3300.0 (91.0%)**
$\nu_e + {}^{40}\mathrm{Ar} \to e^- + {}^{40}\mathrm{K}^*$ (Fermi)	904.9 (25.0%)
$\nu_e + {}^{40}\mathrm{Ar} \to e^- + {}^{40}\mathrm{K}^*$ (Gamow-Teller)	2395.1 (66.0%)

Expected number of interactions for supernova neutrinos at 10 kiloparsec obtained from the GKVM model for a detector fiducial mass of 40 kton. The numbers in bold are from the previous pointing paper with MARLEY 1.2.0. [2]

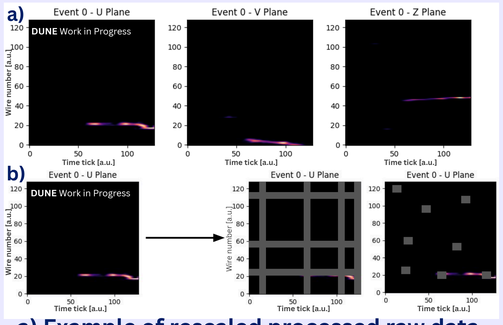
References

[1] Roeth, A. J. (2020). Supernova pointing resolution of DUNE [Conference presentation]. 40th International Conference on High Energy Physics (ICHEP 2020).
[2] DUNE Collaboration. (2025). Supernova pointing capabilities of DUNE. Physical Review D, 111(9), 092006.
[3] Gardiner, S. (2021). Simulating low-energy neutrino interactions with MARLEY. Computer Physics Communications, 269, 108123.
[4] DUNE Collaboration. (2025). Neutrino interaction vertex reconstruction in DUNE with Pandora deep learning. The European Physical Journal C, 85(6), 697.

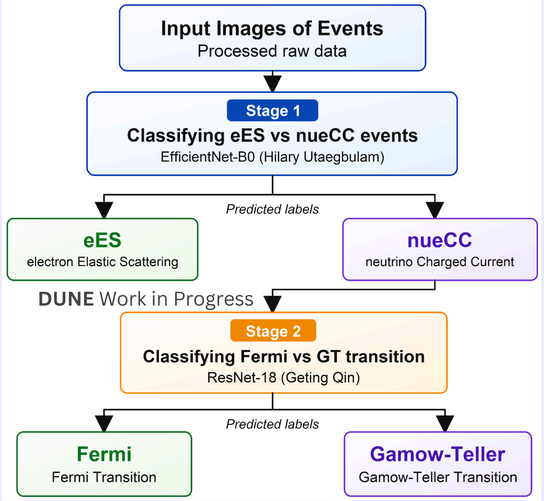
Methods

Two-Stage Classification Pipeline

Training on MARLEY 1.2.0 [3] simulated events with detector responses and electronic noise in the DUNE Far Detector with horizontal drift. 10k events for each type, with flat neutrino energy and fixed direction.
Augmentations include random flipping, translation, row/column masking, and min-max normalization.

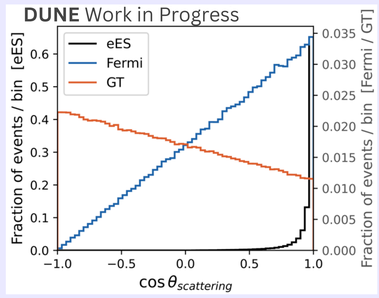


a) Example of rescaled processed raw data.
b) Examples of data augmentation.



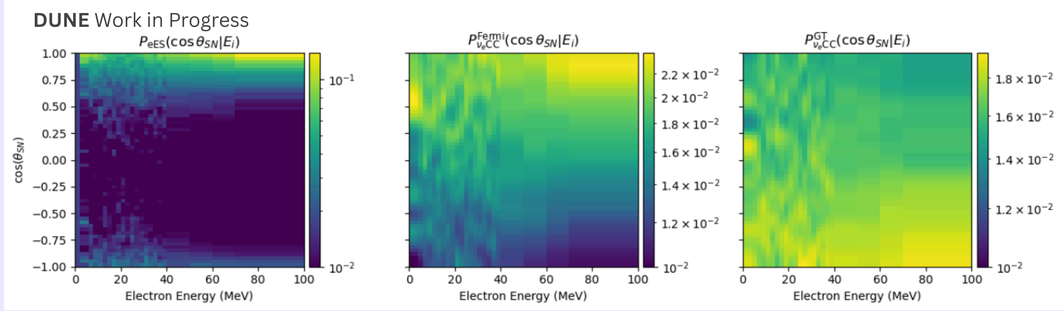
Schematic of the two-stage pipeline. Stage 1: EfficientNet-B0 classifies eES vs. nueCC events. Stage 2: ResNet-18 classifies Fermi vs. Gamow-Teller transitions for nueCC events that pass Stage 1.

Maximum Likelihood Estimation for Burst Pointing



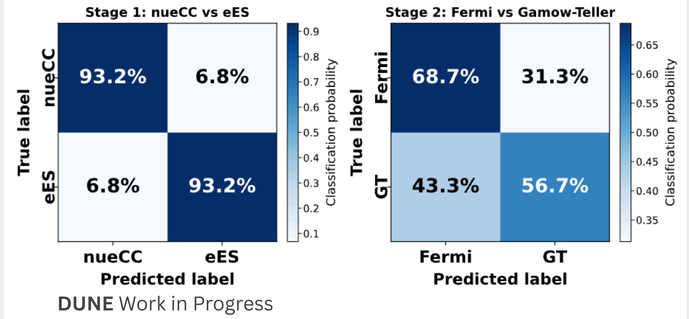
Distribution of the true cosine scattering angle for event types.

- Using track-like events reconstructed by Pandora: 0.14 million eES events and 0.83 million nueCC events, with radiological decay background [4].
- Construct probability density functions for each class with the event energy and the dot product of the reconstructed electron direction and the sampled supernova direction.
- Minimized the negative log-likelihood to find the best fit for the reconstructed supernova direction.

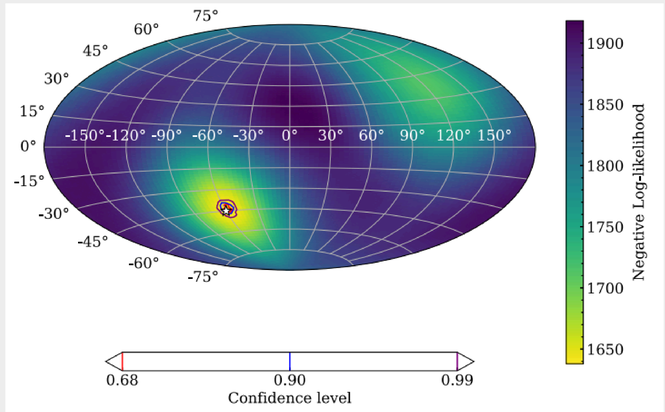


Probability density functions of eES, Fermi, and Gamow-Teller with 2D Gaussian smoothing.

Results



Classification accuracy of the two-stage pipeline.



An example directional map filled with negative log-likelihood values from the previous pointing paper, with Projection Matching as the reconstruction algorithm. [2]

Sample	Perfect cls.	Realistic cls.
10 kt	$\sigma_{68} = 6.55°$	$\sigma_{68} = 8.76°$
40 kt	$\sigma_{68} = 3.29°$	$\sigma_{68} = 4.27°$

Pointing resolution with perfect and realistic classification of eES and nueCC events with the listed detector fiducial mass, results from the previous pointing paper. [2]

Current efforts are underway to incorporate eES, Fermi, and Gamow-Teller for pointing. Stay tuned for upcoming results!

Acknowledgments

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