Year Two: Toward Expansion of the Standard Model Using Multi-Hadron Final States and Muon Neutrino Reconstruction

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Neutrino oscillation measurements aim to find fundamental physics beyond the Standard Model, but precision is limited by our inability to distinguish genuine signals from interfering nuclear reactions that produce similar signatures. A previously observed deficit in muon-neutrino events at Fermilab is compatible with a theoretical new particle, but could also arise from poorly understood interactions inside argon nuclei. Current methods treat this ambiguity as a roughly ±30% systematic uncertainty. This two-year study developed an end-to-end analysis framework to address this challenge. Year 1 established machine learning-based event reconstruction and selection in the ICARUS detector, achieving kinematic distributions across 6,282 events. Year 2 added a novel hypergraph-based classification system that maps neutrino interactions through resonance production to final topologies, explicitly modeling Final State Interactions where 40-60% of produced pions are absorbed before escaping the nucleus, counteracting effects that scramble oscillation signatures. By constructing energy-dependent response matrices with smooth interpolation across 0.3-3.0 GeV, this project achieved 94% prediction accuracy, an 82% improvement over standard methods. By investigating hadronic decay patterns, we uncovered a significant revision in previous theoretical sterile neutrino scenarios that would require impossible particle production patterns. This methodology is directly applicable to scientists throughout the field of particle physics and the $3 billion DUNE experiment, providing a systematic path to distinguish true signal from detector systematics in the search for new subatomic particles.

Awards Won:

Second Award of $2,400