Research Proposal for the NPC Fellowship

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Title
Study of muon antineutrino charged-current interactions and management of data-driven trigger for NOvA

The proposed research has two goals. The first goal is to study the muon antineutrino interactions with the NOvA near detector data taken with horn current reversed before the 2016 summer shutdown of the neutrino beam.

A short period of NOvA reversed horn current (RHC) data was taken from June 30, 2016 to July 30, 2016. The purpose of this dataset is to give information for NOvA's Monte Carlo tuning and physics modeling [1]. NOvA's neutrino beam energy, which is tuned for long baseline oscillation measurements, sits on an intricate energy range where all the major neutrino-nucleus interaction modes, namely quasielastic, resonant production, and deep inelastic scattering, have a significant contribution to the total interaction cross-section. In analyzing the ν_μ data, the collaboration found that there were significant inconsistencies between simulation and data in hadronic energy estimation, and these inconsistencies led to large systematic uncertainties in NOvA's first oscillation analyses [2] [3].

There have been significant improvements in hadronic energy estimation since NOvA's first analyses, including the incorporation of the meson exchange current (MEC) model into the GENIE neutrino generator, a reduction in the rate of nonresonant single pion production, and a reassignment to the uncertainties for charged-current (CC) quasielastic scattering [4]. However, even with these major improvements, discrepancies remain between data and simulation. There is still a 2.5% shift in the reconstructed neutrino energy, and there are still data/MC discrepancies particularly in high-y, low muon track length situations. Antineutrino data, with different interaction cross section and y distribution, could shed lights on these issues.

In addition to improvements to the oscillation analysis, investigations also show that it is feasible to perform a CC inclusive cross section measurement. Furthermore, statistics were large enough during the RHC that a double differential measurement may be possible. Since most modern long baseline neutrino oscillation experiments use $\nu_\mu/\bar{\nu}_\mu$ beam, the inclusive cross section measurement could not only contribute to NOvA, but such a measurement would be of interest to the neutrino community in general. In addition, this measurement could serve as one of the first measurements in the energy region of NOvA on the global plot [5]. This measurement includes studies on event selection and its efficiency, neutrino flux, number of target nucleons, energy scale, background, unfolding, GENIE physics modeling, and corresponding uncertainties. Some of the items share results with the ν_μ CC inclusive measurement, while others require independent studies.

GENIE physics modeling is particularly interesting among the items. There is evidence of 2p2h effects also in the RHC data [6]. A data/MC comparison shows that the inclusion of MEC effect leads to better data MC agreement for the forward horn current (FHC) data. However, the current MEC model for $\bar{\nu}_\mu$ only partially improves the data/MC agreement - disagreement is greater at low visible hadronic energy. One hypothesis is that the NOvA detectors might see neutrons, and methods for measuring and reconstructing neutrons are under investigation. Our group at Colorado State University plans to take on this problem by looking at the event topology at the very low visible hadronic energy and see if any event topology in data but not in MC can be identified. MEC effects in other variables such as the invariant hadronic mass W and the four-momentum transfer Q will also be pursued.

The second goal of the proposed research is to provide improvements to the data-driven trigger (DDT) - specifically involving code and package management. One of the innovative features of NOvA's data acquisition (DAQ) is that the detectors operate in a trigger-less mode, continuously sending data to the buffer nodes with capacity of at least ~ 20 s worth of data. The system then waits for the information of the beam spill to arrive and makes trigger decisions. Keeping tens of seconds of data in the buffer node farm opens up the capability of searching for interesting events not associated with the beam pulses. This kind of trigger is NOvA's data-driven trigger.

The DDT code base has been managed in a per package manner, meaning that the individual author of the packages takes the responsibility that his or her code builds and takes sensible data. This model of DDT package management has become cumbersome and prevents careful validation from routinely occurring. One of the priorities of the DDT group is to reorganize the DDT software packages to centralize common algorithms like clustering and tracking. Such improvement will make the code easier to manage and make it easier for new group members to quickly become engaged in trigger development. The DDT and DAQ groups also plan to migrate to the SRT build system from the multi release build (MRB) system. Using SRT could avoid inconsistencies between the online and the offline DDT builds. I am taking the role as the manager of the DDT code base and working on the build system migration.

Office space with a computer for code development and software for data analysis are readily accessible. To cover my travel and local expenses, I am requesting a budget of $\underline{12,000}$ for a six-month period.

Proposed Timeline

time	$\bar{\nu}_\mu$ interaction & cross section	data-driven trigger	
2 weeks	event selection & efficiency	code management	SRT transition
2 weeks	neutrino flux, target nucleons		
4 weeks	systematic uncertainties		
4 weeks	background		
12 weeks	MEC for RHC, energy scale		

References

1. Ryan Patterson. A request for a short run in $\bar{\nu}$ mode. `http://nova-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=15361`.
2. P. Adamson et al. (NOvA Collaboration). First measurement of muon-neutrino disappearance in NOvA. *Phys. Rev. D 93, 051104(R)*, 2016.
3. P. Adamson et al. (NOvA Collaboration). First Measurement of Electron Neutrino Appearance in NOvA. *Phys. Rev. Lett. 116, 151806*, 2016.
4. J. Wolcott, H. Gallagher, T. Olson, and T. Mann. GENIE central value tune and uncertainties for Second Analysis. `http://nova-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=15214`.
5. G.P. Zeller. Neutrino Cross Section Measurements. `http://pdg.lbl.gov/2015/reviews/rpp2015-rev-nu-cross-sections.pdf`.
6. S. Bashar, T. Olson, and T. Mann. Evidence for 2p2h in Visible Hadronic Energy of NOvA Antineutrino Charged Current Scattering. `http://nova-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=15991`.