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

My research has two goals. The first goal is to study the muon antineutrino interactions with the NOvA reversed horn current (RHC) data taken right before the 2016 summer shutdown of the neutrino beam.

A short period of NOvA 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 cross section. In analyzing the ν_μ data, the collaboration found there were significant deficiencies in the Monte Carlo compared with data, and these deficiencies led to large systematic uncertainties in NOvA's first oscillation analyses [2] [3].

Since then, the collaboration has achieved a great improvement in estimating the hadronic energy in the neutrino events, 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, issues still remain. There is still a 2.5% shift in the reconstructed neutrino energy, and there are still data/MC discrepancies particularly in high inelasticity, low muon track length situations. Antineutrino data, with different interaction cross section and inelasticity, could shed lights on these issues.

Besides the impact on the oscillation analyses, investigations also show it is feasible to do a CC inclusive cross section measurement, even perhaps a double differential measurement with this small dataset of the near detector data. Since most modern long baseline neutrino oscillation experiments use $\nu_\mu/\bar{\nu}_\mu$ beam, the inclusive cross section measurement could contribute not only to NOvA, but also to the community. In addition, this measurement could serve as one the 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 the inclusion of MEC effect makes the MC agree with data very well for the forward horn current (FHC) data. However, the current MEC model for $\bar{\nu}_\mu$ cannot compensate the MC deficiency in RHC, especially at the visible hadronic energy close to zero. One of the speculations states the NOvA detectors might see neutrons, and methods for measuring and reconstructing neutrons are under investigation. Our group 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.

My second goal is to manage the data driven trigger (DDT) software. 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 DDT.

So far the DDT codebase is managed in a per package manner, meaning the individual author of the packages takes the responsibility that his or her code builds and takes sensible data. However, past experience shows this way sometimes leads to code redundancy, such as a same reconstruction algorithm being implemented in different packages. Besides, the lack of validation procedures also resulted in nonsensical data. The DDT group has come up with the idea of cleaning up the DDT codebase, making it more modular, and having a person to watch over the consistency between packages and tag releases. Also, the developers are requested to follow a validation procedure before deployment, and a person will be supervising this process. I am taking this role as the code manager. Furthermore, since the current DDT uses multi release build (MRB) as its build system, which leads to inconsistency between the online and the offline DDT builds, the DAQ and the DDT group plan to migrate the build system back to the older SRT. I will also be working on this together with people from DAQ and DDT group.

Office space with a computer for code development and software for data analysis are readily accessible. I am looking at a funding of $___________.

Proposed Timeline

<table>
<tr><th>time</th><th>$\bar{\nu}_\mu$ interaction & cross section</th><th colspan="2">DDT</th></tr>
<tr><td>2 weeks</td><td>event selection & efficiency</td><td rowspan="5">code management</td><td rowspan="3">SRT transition</td></tr>
<tr><td>2 weeks</td><td>neutrino flux, target nucleons</td></tr>
<tr><td>4 weeks</td><td>systematic uncertainties</td></tr>
<tr><td>4 weeks</td><td>background</td><td></td></tr>
<tr><td>12 weeks</td><td>MEC for RHC, energy scale</td><td></td></tr>
</table>

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`.