Intensity Frontier Fellowship Report

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I was a Fermilab Intensity Frontier (IF) Fellow from October 2013 to June 2014. During that period I had a continuous presence at Fermilab from October 17, 2013 to March 31, 2014. In the role of MINOS/MINOS+ Physics Analysis Coordinator, which I held from January 2013 to June 2014, my main focus during the Fellowship was on preparing new results from MINOS and the very first results from MINOS+ for presentation at the Neutrino 2014 international conference, held in Boston, MA in June 2014. I was mostly interested in helping to develop a novel search for sterile neutrino oscillations in the MINOS data. This analysis has developed into arguably the most complex long-baseline neutrino oscillation analysis to date, as it requires entertaining the possibility that sterile neutrinos are massive enough that oscillations into sterile neutrinos may occur within the short baseline ($\sim$ 1 km) of the MINOS/MINOS+ ND. In such cases, the ND is no longer a reliable predictor of the neutrino flux and composition for the FD, and cancellation of beam flux and cross-section uncertainties, one of the greatest advantages of two-detector experiments, no longer occurs.

My presence at Fermilab allowed me to mentor the post-docs and graduate students working in the analysis, and in particular work closely with my own post-doc, Dr. Adam Aurisano, who is based at Fermilab, in laying down the framework for fitting the data to 3+1 neutrino mixing models, computing sensitivities to sterile neutrino oscillations, and evaluating the associated systematic uncertainties. I also assisted graduate student Ashley Timmons in developing a Feldman-Cousins correction for the fit results and guided graduate student Navaneeth Poonthottathil in starting a search for sterile neutrinos in the MINOS antineutrino-enhanced sample, which has not yet been attempted in a long-baseline neutrino experiment. This analysis is converging and first results are expected during the present year. Being at Fermilab also enabled me to be in close contact with the MINOS Production, Monte Carlo, and Calibration coordinators, to ensure that the required samples were available to the analysis groups on a timely basis.

I was subsequently chosen by the MINOS/MINOS+ Collaboration to present the new results at Neutrino 2014, with my presence there supported by the IF Fellowship. Both the talk and results were very well received. Such high-profile talks are extremely important for young tenure-track scientists, and the IF Fellowship played an essential role in enabling the success of my talk. Results from the sterile neutrino analysis will be submitted very soon to Phys. Rev. Letters for publication. Further, during Neutrino 2014, I initiated a collaboration between the MINOS and Day Bay experiments seeking to combine each experiment's constraint on neutrino disappearance into sterile neutrinos to rule out the

majority of the region of parameter space where potential evidence for sterile neutrino mixing has been reported by the LSND and MiniBooNE experiments. This effort has had strong contributions from my research group, specifically from Dr. Adam Aurisano, post-doctoral fellow with the University of Cincinnati, and is now quickly converging, after Adam successfully created a MINOS constraint on sterile neutrino disappearance based on the CLs technique. The results will be submitted for publication to Phys. Rev. Letters, and will set a precedent and model for close collaboration between two very different neutrino experiments. This model may serve as a prototype in the future to develop experiment-driven global fits encompassing all major neutrino experiments, to obtain the best possible reach in measuring parameters like the neutrino mass hierarchy or establishing CP violation in the lepton sector.

In parallel, the IF Fellowship allowed me to work very closely with my graduate student Shaokai Yang in starting to lay down the groundwork for sterile neutrino oscillation searches with the NOvA experiment. Between October 2013 and April 2014, Shaokai became proficient in using the NOvA offline code and investigated energy containment of neutral-current events in the NOvA Near and Far detectors. An energy-dependent depletion of neutral-current events between the Near and Far detector would be the strongest smoking gun in NOvA to indicate evidence of sterile neutrino mixing. Shaokai showed results of his studies at multiple phone meetings and also at the NOvA collaboration meeting in summer 2014. He was subsequently asked by the NOvA Nue/NC conveners to also study containment of ν_e charged-current events, and the results of his studies were used to validate the fiducial volume containment cuts to be applied in producing first results from the search for ν_μ to ν_e oscillations in NOvA, which is the primary analysis of the experiment. Shaokai successfully completed his Ph.D. oral candidacy exam in September 2014. Since then, Shaokai, with my and Adam's assistance, has ported the MINOS/MINOS+ code used to compute sterile oscillation probabilities to the NOvA offline framework, has shown the code is working as expected, and is working on producing sensitivities to sterile neutrino mixing in NOvA, to be tentatively shown during the APS meeting in April 2015.

In my role as NOvA Detector Simulations co-coordinator, being at Fermilab allowed me to guide Adam's work in improving simulation of noise in the experiment's Monte Carlo. I coordinated with NOvA's Deputy Project Manager Rick Tesarek, and the Near Detector avalanche photo-diode (APD) installation experts, the installation of a number of APDs at the NDOS test stand, where they were used to take very long pedestal scans. Since these APDs are not connected to cells with liquid scintillator, they provide a data-driven estimate of the non-physics noise caused by APDs and front-end electronics boards. Adam has used results of these runs to tune NOvA's noise simulation and improve data/Monte Carlo agreement. These enhancements have been included in the latest round of Monte Carlo

production.

During my time at Fermilab, I regularly participated in the local weekly MINOS/MINOS+ meetings and also in newly-incepted Fermilab NOvA analysis meetings, providing advice and guidance where possible. I also presented a seminar titled ”Planning for Future Neutrino Experiments” during the Intensity Frontier Seminar Series to provide a big picture perspective to the audience of how the most pressing problems in neutrino physics are to be tackled in the next 10-20 years and go over the major challenges facing the proposed experiments.

The Fermilab’s Intensity Frontier Fellowship allowed me to take a semester of research assignment during which I had no teaching duties. Such semesters are extremely valuable for tenure-track assistant professors at research universities, as they allow one to focus exclusively on research productivity, which is the most relevant criterion in tenure decisions at research institutions.

In summary, I gratefully acknowledge the IF Fellowship support, which benefitted greatly my research group. I believe there were also long-term benefits for MINOS/MINOS+ and NOvA experiments from my increased research focus and presence at Fermilab. The IF Fellowship can make a very significant impact in the career of a young scientist, be it a postdoctoral researcher, a university professor, or a scientist at a national laboratory. Therefore, I hope the program continues and thrives during the upcoming years, as the Intensity Frontier will assume the central role in the US High-Energy Physics program, and Fermilab will reinforce its role as the World’s leading facility in neutrino physics research.