Development of Liquid Argon Time Projection Chambers for the Intensity Frontier

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Executive summary: The liquid argon time projection chamber (LArTPC) is widely regarded as a critical detector technology for the next generation of neutrino physics and particle astrophysics experiments. This technology has been selected for the far detector of the LBNE experiment, based largely on the promise of highly efficient high-resolution reconstruction of neutrino events. Although I have no hands-on experience with LArTPC technology, I have followed its development worldwide and appreciate its great potential. The Intensity Frontier Fellowship allowed me to take my sabbatical year resident at Fermilab in order to gain some expertise and make connections with the world-leading community centered there.

Activities related to LBNE.

Prior to my IF Fellowship, I was already an established member of LBNE. My activities related to LBNE were facilitated in many ways by being resident at Fermilab. LBNE has been in a nearly constant state of self-evaluation and case-building. While at Fermilab, I participated in Physics Working Group activities established the case for underground running as well as for an aggressive choice in detector mass, well in excess of the 10-kton benchmark. My interest was to enable particle astrophysics and nucleon decay as major physics topics. I was convener of the Nucleon Decay Physics Working group and hosted nearly monthly working group meetings. A significant deliverable for the year 2013 was the LBNE Science Opportunities Document[1], to which I contributed various numbers, figures and wording (sometimes with only a little arm twisting by the editors).

The year 2013 also coincided with the Snowmass Summer Study, where I had organization responsibilities in the Intensity Frontier Working Group. Some of the major tasks included: co-organizing a parallel session at the Argonne Intensity Frontier Meeting, co-organizing a parallel session at the main Snowmass meeting in Minneapolis, and writing the (40-page) Baryon Number Violation sub-group report[2]. In all of these activities, I was greatly assisted by my fantastic partner, Prof. Kaladi Babu from Oklahoma State. I was also greatly assisted by having my center-of-activity be at Fermilab and in the midwest in

[1] http://arxiv.org/abs/1307.7335
[2] http://arxiv.org/abs/1311.5285
[3] "Proton Decay", Jan 2013 Fermilab Summer Seminar
[4] "Natural Neutrinos", Allure of Ultrasensitive Experiments Academic Lectures

general, as well as being relieved of teaching duties by my sabbatical, URA, and Intensity Fellowship support.

Unexpected, but in retrospect predictable, benefits of my residency at Fermilab were greatly increased connections with the U.S. neutrino community, particularly those interested in LArTPC technology. Since my main research is based in Japan with the Super-Kamiokande detector, and since usually my time is spent at Boston University, it is easy to miss out on the casual interactions that are commonplace at a national laboratory. It was my great pleasure to have daily conversations with the inhabitants of WH12W, particularly Steve Brice, Rob Plunkett, and Sam Zeller. Since MicroBooNE construction was underway, I was able to periodically stick my nose in and get an appreciation for the assembly of that particular LArTPC. I was able to attend the many seminars held at Fermilab, including the Intensity Frontier Seminar series and the Allure of Ultra Sensitive Experiments Academic Lectures. I was also pleased to return the favor and give lectures in each of those series[3,4]. I was able to attend the LIDINE workshop on scintillation in noble liquids—a workshop I may not have attended if the potential barriers of distance and time were not lifted. Residency at Fermilab allowed me to see excellent talks by upcoming young researchers, learn more about the experiments and projects underway, and meet first-hand the people doing the work. I can't emphasize enough how valuable this seems. I feel like I have augmented my understanding of the worldwide neutrino program and greatly expanded my sphere of contacts.

Activities related to LArIAT.

With the Intensity Frontier Fellowship, I began to gain personal experience with LArTPC technology. The best way to gain experience with LArTPCs is to build and operate one with a purpose in mind. Therefore, I joined a group of Fermilab and university scientists[5] planning to operate a modified ARGONEUT detector in a charged particle test beam at the Fermilab Test Beam Facility. The project is dubbed LArIAT, short for Liquid Argon In A Testbeam. This will be one of very few controlled studies of a LArTPC with charged particles. Detailed characterization of the performance of LArTPCs is still in infancy, and I have hopes to extract valuable data on the interaction of pions with argon that should inform simulations of neutrino interactions and proton decay.

Whereas at the time of my proposal, it was thought that LArIAT would be assembled and taking data before the end of my residency, unfortunately all-too-commonplace issues with funding and equipment delivery delayed the start to early 2015. Although this was disappointing, I found the intervening time offered a variety of projects to connect me to the experiment. I addition, I was able to attend meetings live, not by phone, and have made personal connections with my new collaborators. For example, although it took place the subsequent summer (2014), I was able to work with a graduate student from Chicago (Will Foreman)

[3] "Proton Decay", Intensity Frontier Seminar

[4] "Natural Neutrinos", Allure of Ultrasensitive Experiments Academic Lectures

[5] LArIAT is led by my past postdoc, Jen Raaf (FNAL), and a past collaborator from MACRO, Flavio Cavanna (Yale/FNAL). I am pleased to be working with them again.

and a visiting student from Florence (Irene Nutini) in developing an amplifier circuit board for mounting and operating SiPMs to be used in LArIAT.

One of the most personally rewarding activities was to host a B.U. undergraduate, Ryan Linehan, during the summer of my residency (2013) as well as the subsequent summer (2014). Ryan worked with the group that assembled trigger counters for installation in both the Test Beam Facility as well s the LBNE 35-ton prototype. He also worked with simple beamline reconstruction code and has been learning GEANT and the LArSOFT analysis package. Ryan will write a Work for Distinction thesis, due May 2015, hopefully with the first LArIAT data. Ryan plans on attending graduate school thereafter.

My first foray towards a LArIAT hardware contribution was working with Prof. Mitch Soderberg of Syracuse/FNAL on the TPC wire planes. He proposed to replace the wire planes from ARGONEUT due to concerns of stability after several years if non-use. To rebuild them in the same fashion would require machining a large area of copper plated G10, which is a rather messy and inelegant approach. I suggested using standard PCB fabrication (etched copper on FR4). My postdoctoral associate, Dan Gastler, undertook this task and delivered this component for LArIAT. After assembly in Lab 6, Ryan and I did wire-plane electrical testing. In addition, I designed and fabricated a small filter card required for operation of the TPC wire planes.

I also was pleased to give a hand at the Fermilab Test Beam Facility when manpower was needed to run cables or take commissioning shifts with beam (but no detector). In addition, I worked with Brian Rebel, Michelle Stancari, and Alberto Marchionni to specify and order the commercial readout electronics required for the TPC.

Other activities.

I also took the opportunity to work with Fermilab engineer Jin-Yuan Wu on an electronics project related to water Cherenkov technology. As part of this project, we supervised two Illinois Math and Science Academy (IMSA) students, who met with us weekly during 2013 (and I met with them by video upon return to Boston). Subsequently, I renewed my collaboration with Dr. Wu to pursue some ideas for electronic readout of PMTs for water Cherenkov detectors such as Hyper-K. At this time we are building a prototype circuit using Wu's FPGA-based TDC; I arranged U.S.-Japan program funding for this effort. I would say this is another example of the kind of connection that might have only been made thanks to my residency at Fermilab.

Naturally, I also obliged to maintain my other ongoing activities that were not directly related to the topic of my Intensity Frontier Fellowship. I made good use of the video conferencing facilities to hold weekly group meetings with my group at B.U. and lead monthly international working group meetings with Super-K. I was also benefited from useful discussions with and assistance from Reidar Hahn and Cynthia Sazama that facilitated a major activity for 2014— hosting the Neutrino 2014 Conference in Boston.