Excerpts from the Mission Need Statement for a Large Liquid Argon Detector for Neutrino Physics (MicroBooNE)

Office of High Energy Physics
Office of Science

Perhaps the most significant development in particle physics in the last several years is the discovery that the three known types of neutrinos mix with one another. The results of a number of experiments together provide convincing evidence for neutrino oscillations, a quantum mechanical phenomenon in which neutrinos of one type turn into neutrinos of another type.

A variety of experiments are currently being conducted in the U.S. including the Mini-Booster Neutrino Experiment (MiniBooNE) and the Main Injector Neutrino Oscillation Search (MINOS) to study neutrino oscillations. Both of these experiments use neutrinos with energies from about 0.5 GeV to 3 GeV, since neutrinos with these energies provide the largest oscillation effects. MINOS has published improved parameters for muon-type neutrino beam oscillations and MiniBooNE has shown that the Liquid Scintillator Neutrino Detector (LSND result (an earlier experiment performed at Los Alamos National Laboratory that showed an excess of electron-type neutrinos in a muon-type neutrino beam) cannot be interpreted as a two-neutrino oscillation. However, experiments like these also often find titillating new effects (such as the MiniBooNE low-energy excess) that illustrate how little we know about neutrino interactions and that beg to be verified and explored.

Recent theories have suggested neutrinos may explain why the universe is made up primarily of matter instead of antimatter. If the mixing between all of the neutrinos is big enough and a parameter known as the CP-violating phase is not too small, then the antimatter could decay away much more quickly than the matter. Two experiments are presently under construction that might give us a initial measurement of this CP violating phase: the NOvA experiment that will use a Fermilab beam directed to a detector in northern Minnesota and, in Japan, a similar experiment (T2K) will take neutrinos produced at the new accelerator complex at Tokai and direct them toward the Super-K detector in the Kamioka mine.

It is anticipated that to measure the CP violation parameter accurately it will take an extremely powerful beam directed over a very long distance toward a massive detector of 100 to 1000 kilotons. There are two possible technologies for this large detector: a water Cherenkov counter (a much larger version of the Super-K detector) or a large liquid argon detector. The advantage of the former is that it is a proven technology whose cost can be accurately estimated. Its disadvantage is that it has known backgrounds that will limit the accuracy of the measurement. The advantage of the liquid argon technology is that it holds the potential to greatly reduce the backgrounds in the measurement and thus greatly improve the measurement accuracy. The disadvantage is that the U.S. has little to no experience in building large-scale liquid argon time projection chambers. Europe has built the ICARUS experiment that is in the Gran Sasso Underground Laboratory in the Italian Alps.

The purpose of the program started by this mission need statement is to develop that experience by building a smaller, precursor version of the large detector and using it to do important neutrino physics research (*e.g*. measuring neutrino-argon cross sections and exploring the MiniBooNE low-energy excess).

This project supports the Department of Energy's Science Strategic Goal within the Department's Strategic Plan dated September 30, 2003: *To protect our National and economic security by providing world-class scientific research capacity and advancing scientific knowledge*. Specifically, it will support the two Science strategies: *1. Advance the fields of high-energy and nuclear physics, including the understanding of … the lack of symmetry in the universe, the basic constituents of matter…* and *7. Provide the Nation's science community access to world-class research facilities….*
The joint study on neutrinos by the American Physical Society in 2004 discussed the importance learning how to build large detectors:

> *The development of new technologies will be essential for further advances in neutrino physics. .... Similarly challenging are the ideas for massive new detectors that will yield the largest and most precise samples of neutrino data ever recorded.*[1]

On July 13, 2007, Neutrino Scientific Assessment Group (NuSAG) submitted its report to the High Energy Physics Advisory Panel (HEPAP). One of its recommendations was the following:

> *A phased R&D program with milestones and using a technology suitable for a 50-100 kton detector is recommended for the liquid argon detector option. Upon completion of the existing R&D project to achieve purity sufficient for long drift times, to design low noise electronics, and to qualify materials, construction of a test module that could be exposed to a neutrino beam is recommended.*[2]

A small demonstration project is presently underway at Fermilab. Argoneut is a ¼ ton liquid argon drift chamber that is presently in the NUMI beam at Fermilab. It will take data during the present Fermilab running cycle. This project will demonstrate that

---

[1] *The Neutrino Matrix,* http:// www.aps.org/policy/reports/multidivisional/neutrino/upload/main.pdf

[2] http://www.sc.doe.gov/np/nsac/docs/report_7_13_07.pdf

neutrino interactions can be detected in a liquid Argon drift chamber and will give the collaborators their first chance to demonstrate that they can reconstruct events from the drift chamber data. It is not a detector that is easily or economically scalable to a multi-ton or kiloton size nor is it a detector that is capable of making accurate neutrino measurements (it is just not big enough). As such, it is only a technical demonstration project.

Building a 100 ton scale Liquid Argon neutrino detector is the next logical step in the development of the liquid argon technology. It will explore facets of making a scalable detector (a detector that can be gas purged rather than vacuum purged and a detector without vacuum insulation, both features of a kiloton detector). It will be big enough to make physics measurements (the proponents proposed to put the detector in the Booster Neutrino Beamline at Fermilab and explore the low energy anomaly of MiniBooNE) yet small enough to mitigate a lot of the cost and operational risks of a kiloton scale detector. Should the U.S. choose to build a large neutrino detector illuminated by neutrinos from a Fermilab beamline, this detector could be the near detector for that system.

This proposal for this detector (known as MicroBooNE) was presented to the Fermilab PAC in June 2008. Their response to that proposal was:

> *The MicroBooNE experiment is a combination of strategic detector R&D with a physics component. The detector R&D focuses the LAr detector development in North America and is one of the intermediate steps required for a possible much larger LAr detector for the longbaseline oscillation program and for a proton decay experiment. Many, but not all, of the issues required for construction and operation of a much larger LAr detector can be addressed with the MicroBooNE detector. The physics program involves the measurement of low-energy neutrino interactions utilizing the unique capabilities of a LAr TPC (including addressing the possible low-energy excess observed by MiniBooNE). The MicroBooNE collaboration brings together strong components of the LAr community from universities and national laboratories. The Committee recommends that P-974 MicroBooNE be granted Stage I approval, and further recommends that the collaboration and Fermilab work together to finalize the size of the experiment so as to optimize the balance between the physics and longer-term LAr detector R&D goals.*

The MicoBooNE proposal was approved by the Fermilab Director in July, 2008.

The liquid argon detector program is part of a larger program to understand neutrino oscillations and to study charge-parity (CP) symmetry violation in neutrino interactions. The Department of Energy (DOE) strategic goal to advance scientific understanding includes a strategy to study the lack of symmetry in the universe. The study of CP violation falls under this strategy. Since the discovery of CP violation in 1964, it has been an important component of the DOE HEP program with the Stanford Linear

Accelerator Center (SLAC) B-Factory being the most recent large-scale facility to address it.