Mission Need Statement
for
Large Liquid Argon Detector
for Neutrino Physics

Non-Major Systems Acquisition

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Office of High Energy Physics
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SYSTEM POTENTIAL: Non-Major System

A. Statement of Mission Need

The mission of the High Energy Physics (HEP) program is to explore and discover the laws of nature as they apply to the basic constituents of matter and the forces between them. The core of the mission centers on investigations of elementary particles and their interactions. The least well understood of the known elementary particles are the neutrinos.

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….*

B. Analysis to Support Mission Need

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]

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

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]

Alternative 1 – Do nothing

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 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.

If the alternative of "Do Nothing" is chosen (*i.e*. do nothing more), we will not be in a position to develop the detectors that the review panels have recommended as a possible option for large neutrino experiments and a capability gap will develop between the United States and Europe. Should we ever find that we need this technology in the future, we will be far behind in developing it.

Alternative 2 – Build a 100 ton scale Liquid Argon Neutrino Detector

This alternative 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

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

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.

Alternative 3 – Collaborate with other liquid argon TPC development efforts.

The other liquid argon TPC development in the world is ICARUS at the Gran Sasso underground lab in Italy. Much of the basic research into liquid argon technology was first done by the ICARUS collaboration. It is planned to use ICARUS to detect neutrinos beamed from CERN. ICARUS was supposed to be filled with liquid argon by the end of 2008 and be seeing cosmic rays at that time. However, it developed a vacuum leak and now may not be able to operate even in 2009.

The technology used for the 600 ton ICARUS appears to be inappropriate for large scale liquid argon TPC. The features of ICARUS's that cannot be simply scaled to tens of kiloton sizes include its exterior vacuum insulation, its internal multi-module configuration, its large liquid nitrogen consumption (~1000 cc/hr of liquid), and its external (warm) electronics.

C. Importance of Mission Need and Impact If Not Approved

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.

This field is also presently being pursued in Europe and Japan. If this mission is not approved, it will permanently cede leadership in the liquid argon technology and hence high precision CP violation neutrino experiments overseas.

D. Constraints and Assumptions

1. Operational Limitations

There are no foreseen operational limitations in regard to effectiveness, capacity, technology, or organization. If Option 2 were selected and it was desirable to position the detector to investigate the MiniBooNE anomaly, an extension to the MiniBooNE detector hall would have to be built. Care would have to be taken during construction not to damage the MiniBooNE experiment.

2. Geographic, Organizational, and Environmental Limitations

Since the Booster Neutrino Beam exists and is near ground level, it is an ideal beam to demonstrate the effectiveness of a liquid argon detector for Option 2. This site will minimize any organizational and environmental concerns, since the MiniBooNE detector building already houses an existing neutrino experiment.

3. Standardization and Standards Requirements

This project must conform to the applicable design and operational standards of the Fermi National Accelerator Laboratory (FNAL) facility and conform to the project management guidance offered by the DOE O 413.3, Project Management for the Acquisition of Capital Assets.

4. Environment, Safety and Health

All work at the FNAL site will be conducted under its DOE-approved Integrated Safety Management system. FNAL will comply with the requirements of the National Environmental Policy Act (NEPA).

5. <u>Safeguards and Security</u>

None of the work performed at the proposed detector will be classified, and no safeguard and security issues are foreseen during the design, construction, or operation phases. Access to the site will be controlled primarily to ensure worker and public safety and for property protection. Appropriate safeguard and security requirements will be implemented.

6. <u>Project Interfaces and Interaction Requirements</u>

The conditions and interfaces are fairly straightforward. The project would build a detector to operate at Fermilab in the Booster Neutrino beamline (Option 2). The majority of the funding would be supplied from the DOE HEP program. Additional funds may be available from NSF and foreign collaborators.

7. <u>Affordability Limits on Investment</u>

The preliminary Total Project Cost (TPC) range for option 2 is $17-$19 million in then-year dollars.

8. <u>Goals for Limitations on Recurring or Operating Costs</u>

Except for the cost of liquid argon, the cost of operating the chosen detector is expected to be quite modest (i.e., approximately $200k per year). Most routine maintenance and all calibration will be done by the scientific collaboration. A small number of Fermilab staff may be called upon as needed for problems that require special expertise. There will be the cost of consumables like power to operate the detector, spare parts, etc. Presently, liquid argon costs about $1M per kiloton. The initial fill and topping-off of the detector would be operating costs. Care will be taken to retain the argon even through power outages and other events.

9. <u>Legal and Regulatory Constraints or Requirements</u>

The project will be in full compliance with all applicable federal, state, and local requirements. There are no known legal or regulatory issues that could impact the project.

10. <u>Stakeholder Considerations</u>

There are no significant stakeholder issues anticipated. The primary stakeholders in this project are those in the U.S. particle physics community who are pursuing neutrino physics.

11. Limitations Associated with Program Structure, Competition and Contracting, Streamlining, and Use of Development Prototypes or Demonstrations

Adequate technical resources are available at DOE laboratories, collaborating universities, and industry to plan and execute this project on a competitive basis.

E. Resource Requirements and Schedule

The funding profile shown in Table 1 has been estimated for planning purposes only. Neither the profile nor the schedule has been approved at this time. The TPC range may be expected to change when the conceptual design is completed. Changes to the proposed schedule will impact the cost profile. The project would be funded as a Major Item of Equipment.

The preliminary schedule of Critical Decision milestone dates is shown in Table 2.

Table 1: Estimated Funding in Then-year $M

	Option 2 (MicroBooNE)
FY 2010 (OPC)	**1.0**
FY 2011 (MIE)	**8.0**
FY 2012 (MIE)	**6.0**
FY 2013 (MIE)	**4.0**
Total	**19.0**

Table 2: Preliminary Schedule of Critical Decision Milestone Dates

	Option 2 (MicroBooNE)
CD-0 Approve Mission Need	4^{th} quarter FY 2009
CD-1 Approve Alternative Selection & Cost Range	1st quarter FY 2010
CD-2 Approve Performance Baseline	3^{rd} quarter FY 2010
CD-3 Approve Start of Construction	1^{st} quarter FY 2011
CD-4 Approve Start of Operations	4^{th} quarter FY 2013

Critical Decision 0, Approve Mission Need for the Large Liquid Argon Detector for Neutrino Physics (MicroBooNE) Project

Recommendations:

The undersigned "Do Recommend" (Yes) or "Do Not Recommend" (No) approval of CD-0, for the Large Liquid Argon Detector for Neutrino Physics (MicroBooNE) project as noted below.

ESAAB Secretariat, Office of Project Assessment	9/28/09 Date	Yes ✓ No____
Representative, Non-Proponent SC Program Office	Date	Yes____ No____
Representative, Office of Budget	9/28/09 Date	Yes ✓ No____
Representative, Environmental, Safety and Health Division	9/28/09 Date	Yes ✓ No____
Representative, Security Management Division	Date	Yes____ No____
JOHN YATES SC-31.2 Representative, Facilities and Infrastructure Division	9-28-09 Date	Yes ✓ No____
Representative, Grants and Contracts Division	Date	Yes____ No____

Approval:

Based on the information presented above and at this review, Critical Decision-0, Approve Mission Need, is approved and authorization is provided to proceed to initial construction.

Dennis Kovar, Acquisition Executive
Office of High Energy Physics
Office of Science

9/28/09
Date