Excerpt from
Mission Need Statement for a
Long Baseline Neutrino Experiment (LBNE)

Office of High Energy Physics
Office of Science

A. Statement of Mission Need

The mission of the High Energy Physics (HEP) program is to support exploration of the physical universe through the discovery and study of the elementary constituents of matter and energy and the nature of space and time. These areas of research are an integral component for the advancement of all science and technology and an expression of society's timeless intellectual quest to understand the universe. The Standard Model of particle physics represents an unprecedentedly successful description of the elementary particles and their interactions; however, we know this model is incomplete and our present understanding indicates the existence of a more fundamental underlying theory. Elucidating this deeper theory requires a broad research program at the complementary and interrelated Energy, Intensity, and Cosmic Frontiers of particle physics.

At the Intensity Frontier, intense particle beams are utilized to investigate the properties of neutrinos and rare processes, both probes of new physics. Results from the last decade conclusively demonstrate that the three known neutrinos have nonzero mass, mix with one another, and oscillate between generations-properties which represent tantalizing hints of physics beyond the Standard Model. Cosmology indicates that the neutrino mass is less than one-millionth that of the electron, yet oscillation studies from experiments find tiny, but nonzero, mass differences between neutrino generations and large values for two of the three mixing angles. Currently, the individual masses are unknown and only an upper limit exists for the third angle.

The recent progress in neutrino physics has laid the basis for new discovery opportunities. As a fundamental physical constant, measurement of the unknown third mixing angle is of great interest and will influence the direction and evolution of an international neutrino program. Determining the relative masses and mass ordering of the three known neutrinos will give guidance and constraints to theories beyond the Standard Model. The study and observation of the different behavior of neutrinos and antineutrinos traversing matter will offer insight into the dominance of matter over antimatter in our universe and, therefore, the very structure of our universe. The only other source of the matter-antimatter asymmetry, in the quark sector, is too small to account for the observed matter dominance. A popular hypothesis asserts that the asymmetry arises from neutrino interactions and is the subject of intense research.

The Office of High Energy Physics proposes construction of an experiment comprised of a large detector illuminated by a distant, intense neutrino source and a much smaller detector located close to the source. The far detector must be at a long distance from the neutrino source to increase sensitivity to neutrino oscillations and have sufficient sensitivity (through increased size and technological innovation or both) to improve neutrino detection. A new intense neutrino source, pointing towards the detector, is also needed along with a nearby detector to measure the initial composition of the neutrino beam. The increased research capabilities afforded by a long baseline (distance between the detector and the neutrino source) neutrino experiment will enable a world-class program in neutrino physics that can measure fundamental physical parameters, explore physics beyond the Standard Model, and better elucidate the nature of matter and antimatter.

B. Analysis in Support of Mission Need

The U.S. today enjoys a leadership role in exploration of the neutrino properties. The currently operating Main Injector Neutrino Oscillation Search (MINOS) experiment is designed to observe neutrino oscillations using two detectors, one located at Fermi National Accelerator Laboratory (Fermilab) and the other located 730 km away in northern Minnesota in the Soudan Mine. The neutrino source or beam, called Neutrinos at the Main Injector (NuMD), originates at Fermilab.

The neutrino beam is produced by directing a proton beam onto a target where it interacts and produces large numbers of pions. The pions are focused by a magnet into a decay pipe, wherein their decays produce neutrinos. There is a direct relationship between the power of the proton source and the intensity of the neutrino beam. The proton beam and decay pipe must point towards the neutrino detectors. For detectors that are hundreds of kilometers away, the decay pipe actually points down, at an angle, into the Earth.

The fourteen kiloton NuMI Off-axis Neutrino Appearance (NOvA) experiment, under construction approximately 800 km from Fermilab, will succeed MINOS and has been optimized to directly detect oscillations of the electron neutrinos in the NuMI beam. NOvA will provide initial information on the unknown mixing angle and matter-antimatter asymmetries.

Current results and the future promise of new knowledge and discovery indicate that a larger, longer baseline neutrino detector illuminated by a high intensity neutrino beam will be an important and unmatched facility for the US physics program. All three mixing angles could be measured to unprecedented precision and thus guide theorists with improved experimental results. Because the neutrino beam passes through the Earth, the long baseline would enhance matter effects, which, in turn, would improve sensitivity to both the mass ordering and origins of the matter-antimatter asymmetry. Such a facility would require a detector with sensitivity surpassing that of NOvA and be located 1000-1500 km from the neutrino beam source.

A large, long baseline detector and neutrino beam facility can serve a broad, multipurpose program and probe the universe on both the microscopic and astronomical scales. The large detector, if located underground, and thus shielded from cosmic backgrounds, could also be sensitive to proton decay, predicted by grand unified theories which are natural extensions of the Standard Model. As a probe of grand unified theories, proton decay offers access to the highest energy scales in particle physics. Furthermore, an underground detector could serve as an observatory for neutrinos generated by supernovae since the beginning of time and for neutrinos generated more recently by supernovae in our galactic neighborhood, yielding new information on the collapse mechanisms of stars.

The physics program enabled by a large, long baseline, detector and neutrino beam facility is fully consistent with the Secretarial Strategic Priority of Science, Discovery, and Innovation. The program would demonstrably "Advance fundamental knowledge in high energy physics and nuclear physics that will result in a deeper understanding of matter, energy, space and time." A diverse program in neutrino physics would also help ensure that the U.S. maintains leadership at a scientific forefront of particle physics.

The May 2008 report of the Particle Physics Project Prioritization Panel (P5, a subpanel of the High Energy Physics Advisory Panel or REPAP) strongly recommended continued exploration of the Intensity Frontier and, particularly, of neutrino properties. To quote, "The panel recommends a world-class neutrino program as a core component of the US program, with a long-term vision of a large detector in the proposed DUSEL and a high- intensity neutrino source at Fermilab." The proposed Deep Underground Science and Engineering Laboratory (DUSEL) is under development by the National Science Foundation (NSF).

The large, long baseline detector and neutrino beam project and program are well coordinated with the current and planned activities of the U.S. particle physics program. The NSF proposed DUSEL site at Homestake Mine in Lead, South Dakota, represents a good possible location of the detector since it offers depth for shielding and distance for neutrino oscillations. As part of the NuMVMINOS project, Fermilab has already developed the expertise for construction of neutrino beams. The 700 kW upgrade of the Fermilab proton source, a component of the current NOvA project, offers a platform from which to launch a new neutrino beam for a long baseline detector.

Capability Gap

There is a capability gap in the U.S. High Energy Physics program and world-wide particle physics program for neutrino physics. Further progress in the investigation of neutrino mass ordering and matter-antimatter asymmetry requires a combination of larger detectors and more powerful beams capable of observing an order of magnitude more neutrino interactions where the beam and detector(s) must be separated by 1000-1500 km. No existing or planned facility in the U.S. or internationally fills this capability gap.

C. Importance of Mission Need and Impact If Not Approved

The members of the P5 HEPAP subcommittee examined the scientific opportunities and options for mounting a world-class program over the next decade and identified a US program at the Intensity Frontier as a unique, compelling scientific opportunity that would deliver outstanding discoveries and advancements while also providing the foundations for a potential return of the Energy Frontier to a US facility. These new capabilities could be realized in a cost-effective manner by building on existing infrastructure at Fermilab and US expertise in detector technology and through a partnership between DOE and NSF. This long baseline neutrino experiment project is the first and a critical step towards realizing this long term strategic plan for the US HEP program.

Neutrino oscillations experiments with baselines less than 1000 kilometers are running or being developed in the United States, Japan, and Europe. However, only the United States has the ability to extend the baseline to greater than 1000 kilometers. Neither, the Japanese or the Europeans have been able to identify a suitable site with a long baseline due to the fact that they would need to extend into other countries and therefore would need to find partners in those countries willing to host the detector. Despite discussions at the level of the interested scientists, no international partnerships have developed. For example, a long baseline experiment utilizing the neutrino beam in Japan would need to have a detector in China or Korea. Neither country has expressed interest in such a program

Lack of approval would deny US researchers the opportunity to maintain and enhance a world-leading program in neutrino physics. Lack of approval would undermine DOE REP's strategic plan to mount a balanced and vital US program in particle physics in the next decade. Without the research capabilities implemented in this project, crucial information fully characterizing the neutrino sector, such as the value of the third mixing angle and the degree of CP violation, would not be obtained; our ability to understand the matter-antimatter asymmetry in the universe would be compromised.

D. Constraints and Assumptions

1. <u>Operational Limitations</u>

There are currently no operational limitations concerning the effectiveness, technology, or organization of the project. Water Cherenkov detectors, one possible technology choice for the long baseline neutrino experiment detector, have been operated successfully underground at a number of sites. Alternatively, liquid argon detectors offer interesting advantages over water Cherenkov detectors, but research and development is necessary to prove their cost and effectiveness. Neutrino beams for remote use have recently been constructed and operated at both Fermilab and in Europe.

2. <u>Geographic, Organizational, and Environmental Limitations</u>

There are two main geographic limitations: distance and depth. As discussed in the *"Report of the US long baseline neutrino experiment study"*, commissioned by the directors of Fermilab and Brookhaven National Laboratory (BNL), separating the detector and neutrino source by 1000-1500 km or more ensures improved sensitivity for oscillation measurements.

Since detection capabilities for proton decay observation are similar to those for neutrino oscillation measurements a large detector could be used to search for both. A detector designed to perform both measurements would significantly expand the scientific reach of the detector. Searches for proton decay require shielding from cosmic rays. The detector could also be utilized for neutrino astronomy which requires on the order of 3,000 meters of water equivalent (mwe) of overburden, approximately equal to 1,000 meters of rock. (One mwe is the overburden that provides the same shielding as one meter of water.) Since the beamline, and possibly the large detector, may be located underground, appropriate measures will be required to provide access and ensure safety.

Both DOE and NSF propose to be involved in all aspects of the project. A letter from DOE Undersecretary for Science Dr. Steve Koonin and NSF Director Dr. Arden Bement has been sent to OMB indicating the support of the two agencies in a joint endeavor at DUSEL. A Joint Oversight Group (JOG) has been established chaired by the DOE Associate Director of Science for High Energy Physics, DOE Associate Director for Nuclear Physics and the NSF Director of Physics to coordinate the planning for a physics research program at DUSEL. Provisions will also be required for the participation of university and foreign partners. If an underground site is selected, there may be environmental aspects associated with possible excavation.

7. Affordability Limits on Investment

The scientific community has accepted and supports the P5 recommendation because of the scientific importance, the potential impacts of the science, and the affordability within the context of the 2-agency plan. It is in this context that the LBNE project is expected to proceed (i.e., in the expectation that funding from both agencies will be used to implement and support the operations of the long baseline neutrino experiment and extraction of the science). At this time it is not clear what portions of the LBNE project will be supported by DOE and NSF. Therefore in order to proceed in a manner that will inform DOE management, OMB and Congress of the range of DOE's cost for LBNE project, an estimated cost is provided for a LBNE project that assumes no contributions from NSF. The LBNE is composed of a neutrino beamline and a large neutrino detector located a long distance from the neutrino beam. Depending on the technology used this detector may need to be located underground to reduce the background interference from cosmic rays to a manageable level. Therefore the cost estimate is built up from the cost estimates for four parts: 1. the neutrino beamline, 2. the neutrino detectors, 3. the large underground cavern needed to house the large detector and 4. the infrastructure needed to support the construction and operation of the large detector underground.

Neutrino Beamline: The neutrino beamline will resemble the Neutrinos at the Main

Injector beamline completed at Fermi National Accelerator Laboratory in 2005. The civil construction took place from 2000 to 2005. The actual cost of that work, excluding project management, was used as the basis of the cost estimate of the LBNE beamline.

Neutrino Detectors: The cost of the LBNE detector is determined largely by size. The NOvA detector currently under construction will have a volume of 14-15 kilotons. To supersede past results and those anticipated from NOvA, a next-generation detector must be roughly an order of magnitude larger, which is about 100 kilotons of fiducial volume. The more conventional of the proposed technologies is a water Cerenkov detector.

Caverns for the Large Detectors: The cavern cost estimate is based on an extrapolation from the experience on the MINOS detector.

Infrastructure for Underground Detector Operations: The estimate for the infrastructure needed to construct and operate the large detectors was derived from the DUSEL conceptual design report developed for the NSF.

E. Applicable Conditions and Interfaces

An appropriate US laboratory will be selected for managing and coordinating the DOE project. Other US laboratories will work with the lead laboratory to establish individual deliverables for the project. Significant contributions from university groups, other agencies, and foreign institutions are also anticipated, and the lead laboratory will establish management structures to facilitate participation and communication.

The HEPAP P5 report recommends that DOE collaborate with NSF to establish an experimental neutrino program. Any DOE contributions to such a collaboration would be subject to established procedures.

F. Resource Requirements and Schedule

The following profile has been estimated only for planning purposes. Neither the profile nor the schedule has been approved. The estimated cost of the project can be expected to change when the size and site of the detector and the power of the beam are fully determined. Changes in any proposed scope and schedule will impact the cost profile. The table below shows the preliminary schedule for Critical Decisions for the experiment.

Preliminary Critical Decisions

CD-0 Approve Mission Need	1st quarter FY 2010
CD-1 Approve Alternative and Cost Range	1st quarter FY 2011
CD-2 Approve Performance Baseline	3rd quarter FY 2012
CD-3 Approve Start of Construction	1st quarter FY 2014
CD-4 Approve Start of Operations	2nd quarter FY 2020

G. Development Plan

Project management will require a number of strategic choices. Because Fermilab has extensive experience with project management and construction of neutrino beams and because BNL has a long history with construction and operation of neutrino detectors, the two laboratories could have roles in project management, detector design, and beam development.

Two major uncertainties, one scientific and one technical, will be addressed by the development plan. The magnitude of the third mixing angle will establish the size of the detector and the intensity of the beam. This information should become available by 2012 from experiments currently in fabrication and under construction determining a natural timeframe for a project baseline. For equivalent sensitivity a detector based on liquid argon could be significantly smaller than a water Cherenkov detector and, in principle, offer considerable cost savings. A research and development project will be required to prove the performance and determine the cost of a liquid argon detector. The research and development may be completed in time for a project baseline; if not, liquid argon might be appropriate for future experiments with improved sensitivity.

As pointed out in section B, the Particle Physics Project Prioritization Panel saw the NSF DUSEL initiative to be a good match to the needs of a long baseline neutrino experiment. OHEP has been in discussions with the NSF Physics Division on cooperating during the development of these two initiatives, but will not commit to the DUSEL location for the long baseline neutrino experiment until the DOE alternatives analysis is completed.

Following an affirmative decision to pursue a long baseline detector and neutrino beam, the development plan may be required to address interagency aspects of the initiative. Any required coordination between the agencies will be undertaken by the DOE program managers.