Mission Need Statement
for
an Electron Neutrino Appearance (EνA) Detector

Non-Major Systems Acquisition

July 7, 2005

Originator: **Robin Staffin**
301-903-3624
Associate Director of the Office of Science
for High Energy Physics

CONCURRENCES:

Randy Johnson
Program Manager
Office of High Energy Physics

11/3/05
date

Aesook Byon-Wagner
Acting Director, Facilities Division
Office of High Energy Physics

11/4/05
date

Daniel R. Lehman
Director
Office of Project Assessment

11/4/05
date

Robin Staffin
Associate Director
Office of High Energy Physics
(Acquisition Executive)

11/7/05
date

APPROVED:

Raymond L. Orbach
Director
Office of Science

11/09/05
date

Mission Need Statement
for an
Electron Neutrino Appearance (EνA) Detector

Office of High Energy Physics
Office of Science

SYSTEM POTENTIAL: Non-Major System

A. Statement of Mission Need

The mission of the High Energy Physics (HEP) program is to explore and to discover the laws of nature as they apply to the basic constituents of matter and the forces between them. The HEP Program has a goal to understand the unification of fundamental particles and forces and the mysterious forms of unseen energy and matter that dominate the universe; search for possible new dimensions of space; and investigate the nature of time itself. The least well understood of the known fundamental particles are the neutrinos.

Recent developments are beginning to unravel the mystery of the neutrinos. Perhaps the most significant development 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 (oscillations). Neutrino oscillations can only occur if neutrinos have masses, since the rate of oscillation depends on the difference between the neutrino masses. This is indirect but compelling evidence that at least two of the neutrinos have masses. What makes this particulary striking is that the masses of the neutrinos appear to involve a different physical mechanism than the Higgs mechanism believed to be responsible for the masses of the other known particles, the quarks and charged leptons. The only way the Higgs mechanism can be responsible for neutrino mass is if there is a new fundamental symmetry of nature. In either case the fact that neutrinos have masses has revealed new facets of nature that we do not yet understand.

The experimental study of neutrino oscillations also can offer the possibility of observing a difference in the behavior of matter and antimatter, or CP violation, In the early universe equal quantities of matter and antimatter were created, but the present universe is filled with matter and not antimatter. A slight difference in the behavior of matter and antimatter has been observed in some decays of particles containing heavy quarks, but these effects are too small to explain the observed dominance of matter in the universe. There are interesting models for explaining the observed matter-antimatter asymmetry that involve new sources of CP violation in the neutrino interactions. Thus it is important to look for CP violation in the neutrinos as well as continuing studies of CP violation with quarks.

So far, three types of neutrinos have been observed; electron neutrino, ν_e, muon neutrino, ν_μ, and the tau neutrino, ν_τ; and different detection techniques are required to observe the different types of neutrinos. Therefore completely distinct experiments will be required to measure different types of neutrino oscillations.

For example, the disappearance of ν_μ has been observed by seeing fewer muon neutrinos at a distance hundreds of kilometers from the source than would be expected if neutrinos do not oscillate. It is assumed that most of muon neutrinos from the original neutrino source (neutrino beam) oscillated to ν_τ, since the detectors were sensitive enough to detect ν_e for such a rate of oscillation but not ν_τ. The oscillation of ν_μ into ν_e over those distances may occur, but the rate of such oscillation is smaller than is detectable in current experiments.

Measurement of the oscillation rate from ν_μ to ν_e together with the current disappearance measurement of ν_μ to ν_τ can provide the first logical step towards answering two important questions stated above - the unknown physical source of the mass of the neutrino and the source of the matter-antimatter asymmetry (CP violation). Therefore, an experiment that is highly optimized to detect ν_e together with high intensity neutrino source will be needed. In addition, such an experiment with a neutrino beam that travels a long enough distance will provide necessary information to determine the neutrino mass spectrum by measuring the "mass hierarchy".

Although we now are confident that neutrinos have masses, we only know that there are differences in masses, of which two neutrinos are close in their masses and the other is either significantly heavier or lighter. However, we do not know which neutrino is heavier or lighter than the other two. Fully understanding neutrino masses will require that at least the mass of one neutrino be directly measured and that we determine whether the pair of similar mass neutrinos is heavier or lighter than the other neutrino (the "mass hierarchy"). It should be noted that the direct measurement of one of the masses will require a different technique such as using the neutrino-less double beta decay of certain nuclear isotopes.

A joint study on the future of neutrino physics was published in November 2004 by four divisions of the American Physical Society: Division of Nuclear Physics, Division of Particles and Fields, Division of Astrophysics, Division of Physics of Beams. They recommended *"a comprehensive U.S. program to complete our understanding of neutrino mixing, to determine the character of the neutrino mass spectrum and to search for CP violation among neutrinos."* The report describes one required component of the program as, *"A timely accelerator experiment with comparable* $\sin^2 2\theta_{13}$ *sensitivity and sensitivity to the mass hierarchy through matter effects."*

HEP is proposing an experiment based on a detector capable of addressing ν_μ to ν_e oscillations and the "mass hierarchy". This experiment and detector will support 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 structure of nuclear matter in its most extreme conditions...* and *7. Provide the Nation's science community access to world-class research facilities....*

B. Analysis to Support Mission Need

Two of the questions discussed above: the observation of ν_μ to ν_e oscillations and the determination of the mass hierarchy can be answered by a single experiment. Such an experiment would use a beam of muon neutrinos produced at an accelerator and detected in two locations: one close to the accelerator to demonstrate that the beam at this point is nearly pure muon neutrinos and a second detector several hundred kilometers from the first detector. The observation of ν_μ to ν_e oscillations requires a large detector that is optimized to detect the interactions of electron neutrinos.

Various project scopes will be evaluated, including the risk of doing nothing, and presented to the Acquisition Executive at Critical Decision (CD) 1:

Option 1: Fabrication of new detectors (a large far detector and a small near detector) with better sensitivity for electron neutrinos using existing neutrino beam facility. The Neutrinos at the Main Injector (NuMI) facility at Fermilab produces the world highest intensity neutrino beam and is being used for the MINOS experiment which has the far detector located in Soudan Mine in northern Minnesota. The MINOS experiment is measuring the neutrino oscillations by observing the disappearance of (lack of) ν_μ in the far detector. However, MINOS is not sensitive to detecting electron neutrinos. The intensity of the existing NuMI facility is sufficiently high enough that there will be no need for modification of the NuMI facility.

Option 2: Participate in a future experiment in Japan. A neutrino beam comparable to NuMI is under construction at the Japan Proton Accelerator Research Complex in Tokai, Japan. The neutrino beam will be aimed at an existing far detector in Kamioka, Japan, but one or two small detectors will need to be built near the neutrino source. The distance between neutrino source and far detector will be only 1/3 of that in Option 1 and the size and sensitivity of the far detector will be limited to existing capability.

Option 3: Do nothing. Some progress in this area may be made in Japan but the long distances needed for the mass hierarchy measurements and the expandability toward future program (higher beam intensity needed to study CP violation and origin of neutrino mass) will only be available for the option in the U.S site.

C. Importance of Mission Need and Impact If Not Approved

The DOE strategic goal to advance scientific understanding includes a strategy to study the lack of symmetry in the universe in order to reveal its key secrets. 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's high energy physics program. It was the main motivation for the construction of the B Factory, an electron-positron collider at Stanford Linear Accelerator Center (SLAC), where CP violation in the B meson sector was discovered in 1999 and will continue to be studied for several more years.

The successful measurements of CP violation at the B Factory have clearly shown that CP violation of B mesons alone is not sufficient to explain the matter-antimatter asymmetry of the universe. The neutrino sector is the most promising area for new discoveries in CP violation, and the Electron Neutrino Appearance Detector is the next logical step in that program.

Failure to approve this mission need statement will leave the United States without a world class facility in accelerator neutrino physics, which would be contrary to the DOE strategic goal, *providing world-class scientific research capacity and advancing scientific knowledge*. In addition, while the proposed Japanese experiment may yield some interesting results, the very long range neutrino beams needed to complete the program are only possible in the United States.

D. Constraints and Assumptions

1. Operational Limitations

There are no foreseen operational limitations in regard to effectiveness, capacity, technology, or organization. The criteria for the reliable operation of this type of experiment are well established from years of experience in operating the MINOS detector or the detector located in Kamioka. All detector technologies being considered are well understood by experimenters in high energy physics at both the universities and the national labs. The major differences for Option 1 from the existing MINOS and Kamioka detectors are that the new detector will be significantly larger, however it will be located on the surface rather than in a mine. No mine safety training will be required for workers. Access to the site will not be limited by the availability of hoist operators. Flammable and other dangerous materials can be handled more easily above ground than is a mine.

2. Geographic, Organizational, and Environmental Limitations

The site would need to be located far distance away from the neutrino source with year round road access, adequate power and internet connectivity. For optimal scientific results, it is estimated that the preferred distance between the detector and the neutrino source should be about 750~850 km. Option 1 will require approximately 20-40 acres of usable land.

3. Standardization and Standards Requirements

This project will conform to the applicable design and operational standards, and conform to the project management guidance offered by the DOE O 413.3, *Project Management for the Acquisition of Capital Assets,* and DOE M 413.3 *Project Management for the Acquisition Of Capital Assets*

4. Environment, Safety and Health

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

5. Safeguards and Security

None of the work performed 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. Project Interfaces and Interaction Requirements

For Option 1, the proposed experiment would use a different neutrino beam energy than the currently operating MINOS experiment. Under the current operation plan for the NuMI beam line, the MINOS experiment will complete data-taking in 2010. There may be a short period when either the new experiment or MINOS cannot use its preferred beam energy. This should not last for more than a year is most likely to not occur at all. For Option 2, roles and responsibilities of international partners would have to be established through communication and appropriate agreements and the host country (Japan) would have to make arrangements for the site. An Integrated Project Team for the proposed project will soon be identified.

7. Affordability Limits on Investment

The preliminary Total Project Cost (TPC) range is $135-150 million in then-year dollars for Option 1 and $15-17 million in then-year dollars for Option 2. Contributions from NSF or international collaborators are possible, but the current planning assumption is that all costs will be borne by the High Energy Physics (HEP) program of DOE.

8. Goals for Limitations on Recurring or Operating Costs

The experience with MINOS is the best guide to the cost of operating the detector under Option 1. MINOS will be in routine running by FY 2006 and $7-$10 million is planned for the operation of the far and near detectors and the NuMI beamline. The operating costs of the new detector will be similar. Under Option 2 the bulk of the operations cost will be paid by the Japanese collaborators, however a proportional contribution to the operation of the detector only has been traditional in high energy physics. The experience with experiments in Japan has been to contribute several hundred thousand dollars per year to the operating costs.

9. Legal and Regulatory Constraints or Requirements

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. Stakeholder Considerations

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. Applicable Conditions and Interfaces

The selection of the site will have a significant impact on the applicable conditions and interfaces. Some of the candidate sites for Option 1 are on state land and other sites are on private land. Any site will require arrangements to be made with the owners.

F. Resource Requirements and Schedule

The following profile has been estimated for planning purposes only. The funding profiles are shown for the two options discussed above. The profiles support the upper level of the cost ranges given. It is assumed that the either option will be funded as a Major Item of Equipment.

Estimated Funding
(Then Year M$)

	Option 1	**Option 2**
Cost Range	**135-150**	**15-17**
FY 2007	10.3	5.0
FY 2008	18.9	5.0
FY 2009	51.2	5.0
FY 2010	43.5	2.0
FY 2011	26.1	-
Totals	**150.0**	**17.0**

The following table shows the preliminary milestone schedule for Critical Decisions. It is an achievable schedule.

Preliminary Critical Decision Dates

	Option 1	Option 2
CD-0 Approve Mission Need	4th quarter FY 2005	4th quarter FY 2005
CD-1 Approve Alternative Selection and Cost Range	3rd quarter FY 2006	3rd quarter FY 2006
CD-2 Approve Performance Baseline	1st quarter FY 2007	1st quarter FY 2007
CD-3 Approve Start of Construction	3rd quarter FY 2007	3rd quarter FY 2007
CD-4 Approve Start of Operations	4th quarter FY 2011	4th quarter FY 2010

G. Development Plan

The selection of individual experiments that best fulfill the goals of the neutrino program will be done based on the recommendation of the Neutrino Scientific Assessment Group, a joint subpanel of the High Energy Physics Advisory Panel (HEPAP) and the Nuclear Science Advisory Committee (NSAC). This will be used as input to the CD-1, Approve Alternative Selection and Cost Range. The prioritization of neutrino experiments relative to other efforts in the HEP program will be done by Particle Physics Project Prioritization Panel (P5), a HEPAP subpanel. Since accurate cost information will needed by P5, a P5 recommendation will occur at or after CD-2, Approve Performance Baseline.

The technologies being considered are liquid scintillator, solid scintillator, liquid argon, water cerenkov, and resistive plate chambers. All are well established in high energy physics. The goal of the research and development will be to determine how far the technologies can be successfully scaled up. Larger detector elements will require fewer channels of readout electronics for the same total volume of detector. The expense of readout electronics is proportional to channel count. Therefore the R&D will be aimed at determining how to minimize cost while achieving the physics goal of the experiment. The cost of the development will depend on the option is selected. It will range from $1 million to $5 million.

DOE F 1325.8
(8-89)
EFG (07-90)

United States Government | Department of Energy

memorandum

DATE: AUG 2 4 2005

REPLY TO ATTN OF: Sal Golub
Acting Director, Office of Program Analysis and Evaluation (ME-20)

SUBJECT: Mission Need Analysis for an Electron Neutrino Appearance (EνA) Detector

TO: Raymond Orbach
Director, Office of Science

REF: Statement of Mission Need for an Electron Neutrino Appearance (EνA) Detector, Non-Major Systems Acquisition

As required by DOE M 413.3-1, Project Management for the Acquisition of Capital Assets Manual, the Office of Program Analysis and Evaluation has completed an independent assessment (see attachment) of the referenced Mission Need Statement (MNS). Our recommendation is that the Director of the Office of Science should approve the Mission Need Statement.

Should you need additional information, please contact me at (202) 586-4043 or your staff may contact Kevin Shaw at (202) 586-5068.

Attachment: Analysis of Mission Need Statement for an Electron Neutrino Appearance (EνA) Detector

cc:
Susan J. Grant, Chief Financial Officer
Patricia Hodson, Director, Office of Budget
Robert L. McMullan, Acting Director, Office of Engineering and Construction Management
Robin Staffin, Associate Director of the Office of Science for High Energy Physics

Analysis of Mission Need Statement for an
Electron Neutrino Appearance (EνA) Detector

Sponsoring Organization: Office of High Energy Physics (HEP) within the Office of Science (SC)

Background

Neutrinos are one of the fundamental particles which make up the universe. They are also one of the least understood. Neutrinos are similar to the more familiar electron, with one crucial difference: neutrinos do not carry electric charge. Because neutrinos are electrically neutral, they are not affected by the electromagnetic forces which act on electrons. Neutrinos are affected only by a "weak" sub-atomic force of much shorter range than electromagnetism, and are therefore able to pass through great distances in matter without being affected by it.

So far, three types of neutrinos have been observed. Each type of neutrino is related to a charged lepton (which gives the corresponding neutrino its name). Hence, the "electron neutrinos" (ν_e) are associated with the electron, and two other neutrinos are associated with other charged leptons: the muon neutrinos (ν_μ) and the tau neutrinos (ν_τ). However, different detection techniques are required to observe the different types of neutrinos.

Perhaps the most significant development in the last several years in the study of neutrinos is the convincing evidence for neutrino oscillations, a quantum mechanical phenomenon in which neutrinos of one type turn into neutrinos of another type (oscillations). For example, the disappearance of ν_μ has been observed by seeing fewer ν_μ at a distance hundreds of kilometers from the source than would be expected if neutrinos do not oscillate. It is assumed that most of the ν_μ from the original neutrino source (neutrino beam) oscillated to ν_τ, since the detectors were sensitive enough to detect ν_e for such a rate of oscillation but not ν_τ. The oscillation of ν_μ into ν_e over those distances may occur, but the rate of such oscillation is smaller than is currently detectable.

Neutrino oscillations can only occur if neutrinos have masses, since the rate of oscillation depends on the difference between the neutrino masses. What makes this particularly striking is that the masses of the neutrinos appear to involve a different physical mechanism than the Higgs mechanism believed to be responsible for the masses of the other known fundamental particles, the quarks and charged leptons. The only way the Higgs mechanism can be responsible for neutrino mass is if there is a new fundamental symmetry of nature. In either case the fact that neutrinos have masses has revealed new facets of nature that we do not yet understand.

Although we now are confident that neutrinos have masses, we only know that there are differences in masses, of which two neutrinos are close in their masses and the other is either significantly heavier or lighter. However, we do not know which neutrino is heavier or lighter than the other two.

Mission Need

Fully understanding neutrino masses will require that at least the mass of one neutrino be directly measured and that we determine whether the pair of similar mass neutrinos is heavier or lighter than the other neutrino (the "mass hierarchy").

Analysis of Mission Need Statement for an
Electron Neutrino Appearance (EνA) Detector

Policy Impact (goal cascade)

None, the scope of the effort is within the Department's General Goal 5: Provide world-class scientific research capacity needed to: ensure the success of Department missions in national and energy security; advance the frontiers of knowledge in physical sciences and areas of biological, medical, environmental, and computational sciences; or provide world-class research facilities for the Nation's science enterprise.

Analysis of Project

HEP is proposing an experiment based on a detector capable of addressing ν_μ to ν_e oscillations and the "mass hierarchy". Such an experiment would use a ν_μ beam produced at an accelerator and detected in two locations: one close to the accelerator to demonstrate that the beam at this point is nearly pure ν_μ and a second detector several hundred kilometers from the first detector. The observation of ν_μ to ν_e oscillations requires a large detector that is optimized to detect the interactions of ν_e.

Three options were identified in the MNS which will be presented to the Acquisition Executive at Critical Decision (CD) 1:

- Option 1: Fabrication of new detectors (a large far detector and a small near detector) with better sensitivity for ν_e using the existing Neutrinos at the Main Injector (NuMI) facility at Fermilab. NuMI is currently being used for the MINOS experiment which has a far detector located in Soudan Mine in northern Minnesota. The MINOS experiment is measuring the neutrino oscillations by observing the disappearance of (lack of) ν_μ in the far detector. However, MINOS is not sensitive to detecting ν_e.
- Option 2: Participate in a future experiment in Japan. A neutrino beam comparable to NuMI is under construction at the Japan Proton Accelerator Research Complex in Tokai, Japan. The neutrino beam will be aimed at an existing far detector in Kamioka, Japan, but one or two small detectors will need to be built near the neutrino source. The distance between neutrino source and far detector will be only 1/3 of that in Option 1 and the size and sensitivity of the far detector will be limited to existing capability.
- Option 3: Do nothing. Some progress in observing oscillations could be made in Japan but the long distances needed for the mass hierarchy measurements are not available.

Cost and Schedule

A preliminary cost range for Option 1 is \$135-150M, and Option 2 is \$15-17M. Based on the high end of the cost range for Option 1, the following profile has been estimated for planning purposes only. (It is assumed that either option will be funded as a Major Item of Equipment.)

Estimated Funding
(Dollars in millions)

	Option 1
FY 2007	10.3
FY 2008	18.9
FY 2009	51.2
FY 2010	43.5
FY 2011	26.1
Totals	**150.0**

The following table shows the preliminary milestone schedule for Critical Decisions associated with Option 1.

Preliminary Critical Decision Dates

	Option 1
CD-0 Approve Mission Need	4th quarter FY 2005
CD-1 Approve Alternative Selection and Cost Range	3rd quarter FY 2006
CD-2 Approve Performance Baseline	1st quarter FY 2007
CD-3 Approve Start of Construction	3rd quarter FY 2007
CD-4 Approve Start of Operations	4th quarter FY 2011

Issues: Something that questions the basis of the mission need, and warrants not recommending approval of the MNS.

None.

Observations: Something that does not prevent issuing the approval recommendation for the MNS, however could impact the ability to carry out the project.

None.

Recommendation

The Program Secretarial Officer for this activity, the Director of Office of Science, should approve the Mission Need Statement.

Electron Neutrino Appearance (EvA) Detector CD-0 Review

Recommendations

The undersigned "Do Recommend" (Yes) or "Do Not Recommend" (No) approval of CD-0, Approval Mission Need Statement, for an Electron Neutrino Appearance (EvA) Detector.

[signature] 11/22/05 — Yes ✓ No ___
ESAAB Secretariat, Office of Project Assessment / Date

[signature] 11-22-05 — Yes ✓ No ___
Representative, Non-Proponent SC Program Office/ Date

[signature] 11-22-05 — Yes ✓ No ___
Representative, Environmental Safety and Health Division/ Date

[signature] 11/21/05 — Yes ✓ No ___
Representative, Office of Budget and Planning / Date

[signature] 11-21-05 — Yes ✓ No ___
Representative, Security Management Team / Date

Yes ___ No ___
Representative, Grants and Contracts Division / Date

[signature] 11-22-05 — Yes ✓ No ___
Representative, Laboratory Infrastructure Division/ Date

Electron Neutrino Appearance (EvA) Detector CD-0 Review

Approval

Based on the material presented above and this review, Critical Decision 0, Approve Mission Need, is approved.

James F. Decker
Principal Deputy Director
Office of Science

11/22/05
Date