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DRAFT

Letter of Intent

LAr5 - A Liquid Argon Neutrino Detector for Long Baseline Neutrino Physics

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Abstract

This *Letter of Intent* presents the case for developing a *Proposal* to construct a liquid argon neutrino detector with a total mass of approximately 5 kilotons. The detector can be be located in the existing and currently operating NuMI beam. The design of this detector will incorporate techniques which have been discussed for the construction of much larger scale detectors. We contend that a project of this scale is necessary to determine an optimum configuration for the detector masses required to achieve significant sensitivity to measuring CP violation in the neutrino sector. Additionally, we have investigated the physics sensitivity that could be achieved by such a detector and find it to be comparable and complementary to the NOνA experiment. Physics results from both NOνA and LAr5 will yield the best return on the investment that has been made in the NuMI facility.

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1 Introduction

In the past two decades accelerator based neutrino experiments have evolved from using the neutrino as a tool to probe nucleon structure and measure cross sections, to measuring the properties of the neutrino itself - most notably the properties of mass and mixing. The elusive nature of the neutrino makes the experiments difficult. Also, there are no theoretical models to predict the values of the parameters we seek to measure, making our program necessarily data driven.

Following the exciting discovery of neutrino oscillations in atmospheric neutrinos, and the subsequent confirmation by the K2K [1] and MINOS [2] experiments, there is a consensus that the next steps in studying neutrino mass and mixing are to :

1. Determine the rate of $\nu_\mu \rightarrow \nu_e$ oscillations at the "atmospheric" oscillation length, characterized by the mixing angle, θ_{13}
2. Determine the ordering of the three neutrino mass states, known as the "mass hierarchy"
3. Determine whether there is CP violation in the neutrino sector

The scientific case for experiments which can measure these fundamental parameters of the neutrino sector has been documented in numerous studies by proponents as well as review committees. The recent reports by the US Long Baseline Study Group [3] and the DOE/NSF sponsored NuSAG committee [4, 5] are excellent examples.

Experiments addressing item 1 are under construction and should be producing results within the next five years. Item 2 presents more of a challenge, and timely results critically depend on what nature has given us for the value of θ_{13}. Even if θ_{13} is relatively large, item 3 is an experimental challenge which will require a new generation of experiments. Determining an optimum strategy requires careful evaluation of many issues. Regardless of the specific experimental configuration, these experiments will require both detectors and proton sources of unprecedented capability. Fermilab's Project X[6] offers a solution to the proton intensity challenge. The high beam power offered by Project X makes it possible to propose experiments that require more than 10^{22} total protons. These experiments can then measure their running time in years, rather than decades.

While the existing NuMI Facility offers us the capability to begin addressing these important neutrino measurements, it is necessary to extend the experiment baseline for full exploration and definitive measurement of the neutrino mass and mixing parameters. The Homestake mine, which is the location of the proposed DUSEL [7] at a distance of 1300 km from Fermilab, is the natural place to construct a new detector. The longer distance amplifies the need for very massive detectors.

To date, the Super-K water cherenkov detector is the largest single unit neutrino detector to have been constructed, having a total mass of 50 kilotons. Water cherenkov detectors have proven to be an economical way to achieve a large mass detectors and therefore this technology is a serious candidate for future experiments[8].

An alternative technology is liquid argon TPCs which have the potential to be more efficient in identifying ν_e charged current events than the water, and hence the same physics sensitivity could be achieved with significantly less mass. Several studies have concluded that a liquid argon detectors are more efficient than water by factors ranging from 3 to 5. The problem is that to date the largest liquid argon detector to be constructed is the two module, 600 ton ICARUS detector at the Gran Sasso Laboratory[9] - and it has not yet begun operating. Planning future physics projects with unproven technology is not a wise strategy. Determining the best technology to use for the future is. We believe that a multi-kiloton liquid argon detector project will provide vital information towards determining the strategy for configuring detectors to achieve a total mass in the hundred kiloton range.

2 The Concept

The main components of a liquid argon neutrino detector are a cryogenic vessel to hold the totally active liquid argon target material and a time projection chamber (TPC). Particles created by neutrino interactions in the liquid argon will ionize and in the presence of an electric field will drift over long distances if the argon is pure enough. The electric field is created between cathode and anode planes of the TPC. Millimeter scale position resolution is achievable in such a detector. Pulse height readout from dE/dx enables energy measurement as well. The excellent tracking and vertex resolution leads to high efficiency in particle identification. The ability to distinguish electrons from gammas and π^0's is the main advantage to this detector technology.

Because of the size of the detector volume, evacuation of the cryostat prior to filling it with argon is structurally challenging. Not evacuating prior to filling leads to different major technical challenge - purification of the argon. In designing the detector the technical challenges and risks will need to be evaluated carefully. Whether or not the cryostat is evacuated, we envision a modularized TPC and front end electronics located in the liquid. All aspects of this detector require engineering and R&D.

In recent months, a concept for how to bridge the gap between test stands and the ultimate massive detector has emerged. This concept is to progress through a staged evolution of liquid argon detectors for use in neutrino experiments. Detectors ranging in mass from the ton to kiloton scale can be deployed in existing Fermilab neutrino beams. At each stage, key issues in detector development will be addressed, and the experience gained will be directly applicable to the design of the next phase.

In particular, the Fermilab test, T-962, a.k.a. ArgoNeuT [10], is a 250 liter (0.35 ton) detector that will be installed in the NuMI beam, just upstream of the MINOS Near Detector, in early 2008. The expected event rate is $\sim$200 events per day, so in less than one year of exposure time a significant data set of 1 - 6 GeV neutrino interactions will be available for reconstruction studies.

MicroBooNE (Fermilab P-974 [11]) proposes a 170 ton (total mass) detector located next to MiniBooNE in the Booster Neutrino Beam will also see off-axis NuMI neutrinos. The detector uses electronics immersed in the cryogenic volume, an important step in the on-going R&D program. The MicroBooNE cryostat is designed such that it can be evacuated before filling, or filled from air and purified, as desirable for the larger detectors. In many areas, the value engineering that will take place on the MicroBooNE design will be directly applicable to refining the design and cost estimate for a number systems on the larger detector. The MicroBooNE detector may serve as a near detector for LAr5.

The imminent operation of the ArgoNeuT detector and the advanced design of MicroBooNE will strongly influence the conceptual design of LAr5 for our *Proposal*.

2.1 The Location

We have explored several options for the location of a 5 kiloton mass detector.

We have considered the site of the Soudan Underground Laboratory in northern Minnesota, at a baseline of 735 km where the MINOS Far detector is located. With continued running of the NuMI beam, we contend that this is an ideal location for a liquid argon detector following the completion of the MINOS experiment[2]. There are two primary reasons for this choice of location

1. The MINOS cavern at the Soudan Laboratory exists.

2. The deep underground location insures that the cosmic ray background will not be an issue, and in fact, we are exploring whether a detector of even this small this size may be able to make a contribution in the search for proton decay.

The cavern has dimensions of 13 x 10 x 80 m^3. See Figure 1. A liquid argon detector of dimensions 8 x 8 x 60 m^3 will have a mass of 5.3 kilotons. We propose to construct several modules, each greater than 1 kiloton. The diameter or width/height of a module can be $\sim$8 m. The length will be determined by safety considerations and handling the large volume of cryogenics underground. Lengths of 15-20 meters are feasible. A preliminary concept for argon containment and venting has been developed. We anticipate construction of a dedicated vent shaft at the south end of the cavern.

Alternatively, it has been suggested that a large liquid argon detector can be operated on the surface with little or no overburden needed to reduce cosmic ray induced backgrounds, we have considered siting this detector at Ash River, along side NOνA .

We have identified four potential configurations for siting at Ash River :

1. The detector would be located on the surface, adjacent to the NOνA detector. There would be no overburden over the detector. It may be possible to utilize some of the building infrastructure for support systems and control rooms. Alternatively, modular building units could be constructed to house the systems and control rooms.

2. The detector would be located on the site owned by the University of Minnesota, but not necessarily adjacent to NOνA . The surface site

[2]Removal of the MINOS detector following the completion of the experiment is a condition of the lease agreement between the University of Minnesota and the Minnesota Department of Natural Resources (DNR). However, the two parties are currently in negotiations to extend the lease of the cavern for 10 years, and continued use of the space for experiments is favorable to both parties

Figure 1: A photo of the MINOS cavern in the Soudan Underground Laboratory.

would be excavated such that the circumference of the tank was surrounded by rock. An overburden could be constructed. Modular buildings would be required.

3. The detector would be constructed under rock cover by making use of the elevation at the site and minimizing the amount of excavation.

4. The detector would be constructed in a cavern at a depth of 25 - 50 m with access shafts. This would surround the detector with rock providing significant shielding from cosmic ray associated backgrounds. This is the most expensive option.

Determining which of these options is optimal would depend on the cost of the site preparation and the amount of overburden required to control cosmic ray backgrounds in the detector.

Finally, we have been asked to consider the possibility of siting a 5 kiloton detector at the Homestake mine assuming that a new neutrino beam from Fermilab existed. It appears feasible that the detector could be constructed in a new cavern at the 300 foot drive-in level. Construction of the detector at the 4850' level would encounter similar issues as siting at Soudan.

While there are differences in these configurations in terms of location, beams, and physics reach, there are many similarities in terms of detector design, underground siting, and the necessary R&D program. At this time we are focusing on development of the Soudan Cavern as our first choice location. External factors affecting funding and schedules may cause us to revisit this decision at a later time.

2.2 The Configuration

Both a cylindrical and rectangular volume oriented along the beam direction are well suited to containment of the neutrino interactions coming from the neutrino beam. For both economical and technical reasons there are pros and cons to both configurations. We note that the ICARUS detector and the proposed ModuLAr [12] are rectangular volumes. Discussions with our mechanical engineers favor a cylinder for structural reasons. The simplicity of a rectangular TPC leads to a debate about the optimum combination of vessel and TPC configurations. This is one of the main design tasks we will develop for a proposal.

The important parameters to determine for the TPC are :

1. the drift distance
2. the wire pitch on the sense planes
3. the wire orientation of the sense planes

As a starting point we have chosen a cylindrical cryostat and a rectangular TPC with the the parameters listed in Table 1. The basic concept is an enlarged, and doubled version of the MicroBooNE TPC and is only meant to give the reader a feel for the level of complexity in the project. A realistic design will be developed based on detailed simulations and experience gained in the on-going program.

2.3 The Neutrino Beam

The on-axis location of LAr5 would be complimentary to that of the NOνA detector which is to be located 12 km off-axis at Ash River, Minnesota, at

drift distance	4 meters
wire pitch	3 - 5 mm
number of sense planes	3
sense plane spacing	3 - 5 mm
sense wire orientation	0, $\pm$30-60^0
number of readout channels	25-50 K

Table 1: TPC parameters for LAr5 based on the MicroBooNE TPC design

a baseline of 810 km. The off-axis NOνA location exploits the characteristic narrow band beam that is created due to the kinematics of the π decays. A narrow band beam peaked near the oscillation maximum reduces the number of background events from neutral current interactions and allows an energy cut to reduce background from higher energy beam ν_e 's which is important for the NOνA technology. The on-axis location sees a broad band beam and has a higher event rate, including background, than off-axis. We contend that a high resolution detector like liquid argon is capable of exploiting the higher event rate because of the ability to eliminate backgrounds.

We note here that the NuMI Facility was designed with the capability of producing neutrino beams over a broad range of energies. This flexibility comes from the ability to adjust the location of the focusing horns with respect to the hadron production target. In Figure 2 we show an example of signal and background for the on- and off-axis locations for both the medium and low energy beams. The plots show the ν_e signal for $\sin^2 2\theta_{13}=0$ and the intrinsic ν_e beam background. A detector efficiency of 80% is assumed.

Consideration of this detector at the DUSEL site was done assuming a new wide band beam designed to have a broad neutrino energy spectrum between 2 and 6 GeV.

3 Preliminary Sensitivity Calculations

We have explored the physics sensitivity of the LAr5 detector to $\sin^2 2\theta_{13}$ and the mass hierarchy, for the various locations that we have considered. In the NuMI beam the sensitivities were calculated for both the low and medium energy configurations and we find the best sensitivities in the low energy configuration. Calculations including the LAr5 sensitivity with the NOνA detector have also been done. However, how well we can ultimately do by

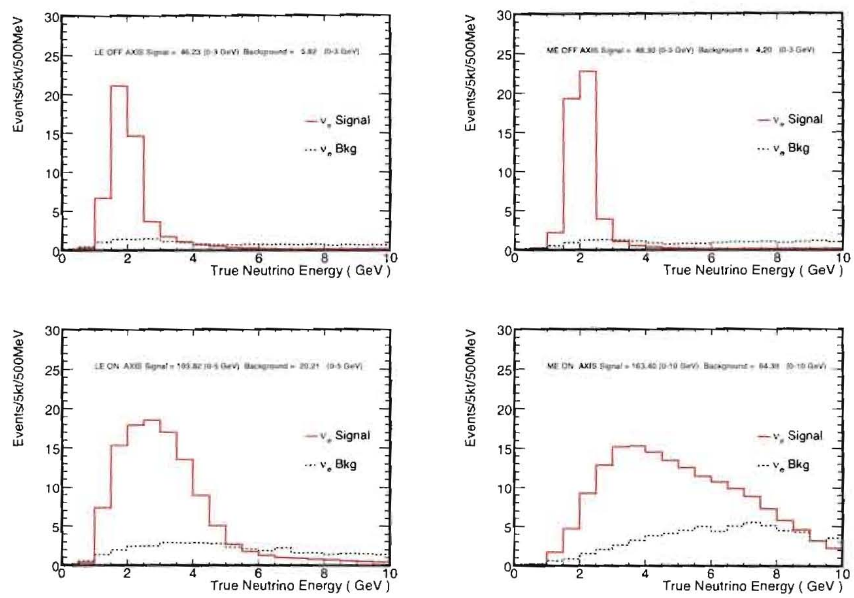

Figure 2: ν_e signal ($\sin^2 2\theta_{13} = 0.1$) and ν_e intrinsic background spectra for the NuMI low and medium energy configurations (ν mode).

combining data from the two detectors will depend on when LAr5 would become operational, and optimization of the run plan. The realization of neutrinos from a Project X intensity upgrade would result in a superior program. Sensitivities at the Homestake distance are comparable to the NuMI distance for measurement of the angle and better for the mass hierarchy due to the increased matter effect.

Since these analyses are preliminary we have decided to not include them in this document, but are prepared to discuss them in a presentation. A complete analysis will be included in the Proposal.

4 Schedule

We believe that the concept presented in this *Letter of Intent* should be developed into a project that will directly address the question of a *technology decision* for very massive detectors of the "Phase II" program and at the same time increase the physics reach of the "Phase I" program. We plan to develop a *Proposal* which focuses on the project justification, technical feasibility and determination of a cost range and risk factors. We plan to develop this proposal throughout 2008. If approved, we can then begin working on a Conceptual Design Report. If our design results in a technically feasible project that fits within reasonable budgetary resources, our goal would be to achieve a CD-1 decision at the end of 2009.

The years 2010 and 2011 will be focused on development of the *Technical Design Report* and the associated requirements for the CD-2. We would hope to get to a CD-3 by the end of 2012. A three year construction project could lead to an operational detector around 2015.

5 Summary and Conclusions

We believe that the case for building a liquid argon neutrino detector in the mass range of 5 kilotons is very strong. This size should be adequate to determine the cost and scalability of the liquid argon detector technology. At the same time we would be able to increase the physics return on the investment made in the NuMI and NOνA Projects. This detector project, along with the Project X intensity upgrade, would offer a vibrant neutrino physics program throughout the next decade.

The purpose of this *Letter of Intent* is to request support for the development of a full *Proposal* to demonstrate that this detector can be constructed for a reasonable cost and on a reasonable time scale. We have the physicist manpower to do this, but we require engineering support to determine the costs for the cavern modifications, cryogenic and purification systems, and mechanical structures including the cryostat and TPC. Engineering for the electronics is already underway for several smaller efforts and work towards this proposal would become a natural extension of those.

The success of a project on this scale will enable us to determine a strategy and plan for a physics program that can achieve significant sensitivity for discovering CP violation in the neutrino sector. It is a long term vision that can ultimately be achieved beginning with well-defined smaller steps.

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[6] The report of the Fermilab Steering Group can be found at http://www.fnal.gov/pub/directorate/steering/fermi_quantum.shtml

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