Research and Development for Massive Liquid Argon TPCs (LArTPC) for Long-Baseline Neutrino Physics

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The recent DOE CD-0 Mission Need Statement for an Electron Neutrino Appearance Experiment (EνA) states the requirements for a long-baseline ν_e appearance oscillation experiment as:

> "An experiment that is highly optimized to detect ν_e together with a high intensity neutrino source will be needed."

Liquid Argon Time Projection Chambers (LArTPC) [1] are optimal for this physics. Their fine-grained tracking capability, like that of bubble chambers of the past, combined with total-absorption calorimetry and scalability, make them natural candidates for large-scale, precision neutrino detectors. The success of the ICARUS T600 ($\sim$ 600 ton) program shows that these detectors are technically feasible on a "small" scale [2]. Building these detectors on a scale suitable for long-baseline, low-energy neutrino experiments requires additional R&D.

Construction of a $\sim$ 100-ton prototype TPC to operate on the surface NuMI beam or Booster Neutrino Beam (BNB) at Fermilab is a crucial step in the program *en route* to realization of a massive LAr detector. This prototype will provide the first large data set of low-energy ν_e and ν_μ interactions in a liquid argon detector, and will be a test bed for electronics, data acquisition, and reconstruction and analysis techniques. As well, it is of a size appropriate for University groups to design, construct and ship to Fermilab for data taking. A suitable level of funding required for this project in FY2006 is $300k, with $920k in FY2007 and $650k in FY2008 to complete the project in a timely manner.

This document describes the motivation for using massive LArTPCs for neutrino physics, and outlines the R&D efforts on a $\sim$ 100-ton detector on which the University groups will focus. Further details of the overall program can be found in ref. [3].

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1 An R&D Program for a Massive LArTPC Detector

The use of liquid argon as a medium in an imaging detector is now a proven technique. This idea has been developed from the original proposals and modest test setups of some 20 years ago [1, 4] to the large multi-ton devices of the ICARUS collaboration [2]. These detectors are optimal for the EνA experiment as the efficiency for detecting ν_e's in a LArTPC is ∼80-90% [3]. This is a substantial improvement from a ∼25% ν_e efficiency in conventional water Čerenkov or liquid scintillator detectors. In addition, the largest background, from neutral-current π^0 interactions, is reduced from the size of the intrinsic ν_e background in conventional experiments to a negligible level in LArTPCs.

The sensitivity of these detectors, described in [3] and [5], motivates an R&D program *en route* to realization of massive detectors. This R&D program is sketched in Figure 1 and consists of three main components, addressed by a collaboration of University groups and the Fermilab group.

1. A number of technical test set-ups directed to answering specific questions pertaining to a massive LArTPC (Fermilab focus).
2. The construction of a $\sim$ 30-ton fiducial mass ($\sim$ 100-ton total argon mass) detector in which interactions can be fully reconstructed. This detector will be placed in the halo of the NuMI and/or Booster Neutrino beams, where it can collect $\sim 10^3$ ν_e (and $\sim 10^4$ ν_μ) interactions in the energy range 0.5-2 GeV (University focus).
3. The construction and partial outfitting of a commercial tank of $\sim$ 1-kton capacity using the same techniques as proposed for the 15-kton detector. This will serve as the test-bed to understand the issues of industrial construction (entire Collaboration).

2 The $\sim$ 100-Ton Prototype

This document emphasizes the $\sim$ 100-ton LArTPC prototype as a large but manageable project for the University groups and as a crucial step towards realization of a massive LArTPC detector for neutrino physics.

Long-baseline neutrino oscillation studies will measure neutrino interactions at energies below 5 GeV where quasi-elastic, single-pion, and deep-inelastic processes contribute. It is crucial that the rates of these processes for both ν_e and ν_μ be established in a short-baseline environment[1] as a prerequisite to the long-baseline oscillation studies.

For this purpose, a $\sim$ 30-ton fiducial mass LArTPC will be located on the surface at Fermilab in a position to observe neutrinos in the the large-angle halo of the NuMI and/or Booster Neutrino beamlines. A sample of ν_e and ν_μ interactions on the order of 1,000 and 10,000 events, respectively, can be collected in 1-2 years of operation [3]. These events, together with the cosmic ray events that will also be collected, will form a very valuable sample on which the electronics, data acquisition, and analysis software for a LArTPC can be optimized. This enterprise will also allow a physics collaboration to coalesce (including

[1] A short-baseline LArTPC is the best detector to followup on a positive result from MiniBooNE.

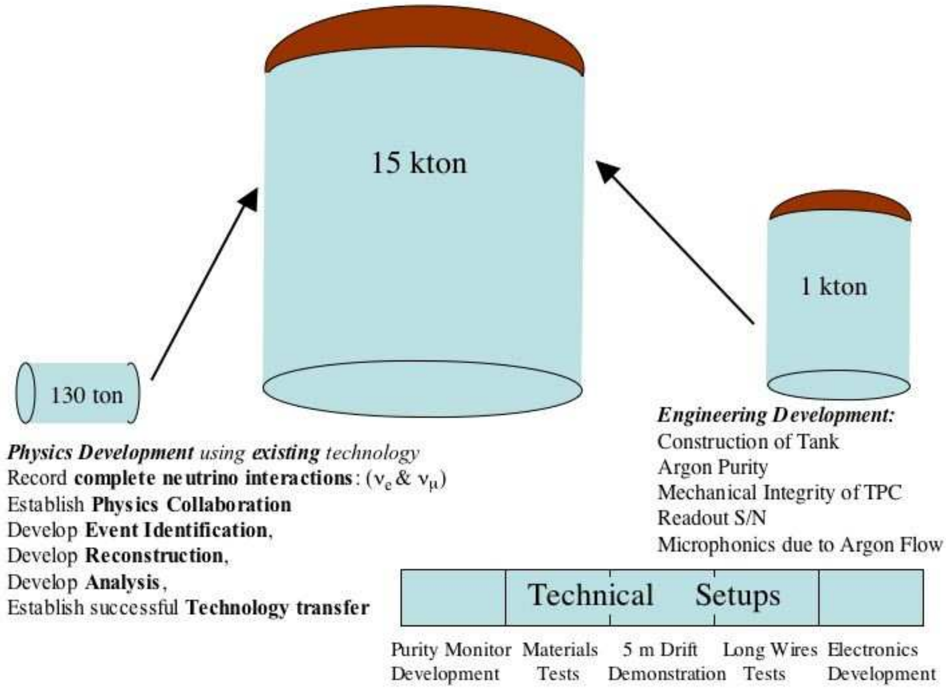

Figure 1: Scheme of the LArTPC R&D program of which the $\sim$ 100-ton protoytpe is a key part.

possible collaboration with ICARUS groups), students to be trained, and the North American groups to develop and demonstrate our own hands-on mastery of this technology.

A fiducial mass of $\sim$ 30 tons translates to a total mass of $\sim$ 100 tons. A detector geometry that accommodates $\sim$ 30 tons fiducial mass can have a cylindrical volume of 7 m length and 2.1 m diameter, with outer dimensions of approximately 10 m $\times$ 3.0 m in diameter. The signal collection electrodes will consist of a set of wire planes that contain the axis of the cylinder, with field cage on the outer surface of the cylinder, as shown in Figure 2.

While this detector is sizable, it is still small enough that it can be constructed by the University groups and transported via wide-load truck to Fermilab upon completion. Table 1 sketches a breakdown of the (unloded) cost for this project over the next 3 years, with a focus on costs in FY2006.[2] With design and prototype work in FY2006, cryostat and TPC construction in FY2007, and installation in FY2008, data taking will begin in late 2008.

The R&D work is spread between the University groups with Princeton and Yale focusing on electronics, argon purification and fabrication of the electrode structure, UCLA focusing on the HV system, and with the Tufts group focusing on software and computing. Design work for the cryostat, leading to a commercial procurement, will involve all of the University groups.

[2]In addition to support from DOE, the University groups are also seeking additional funding from other sources.

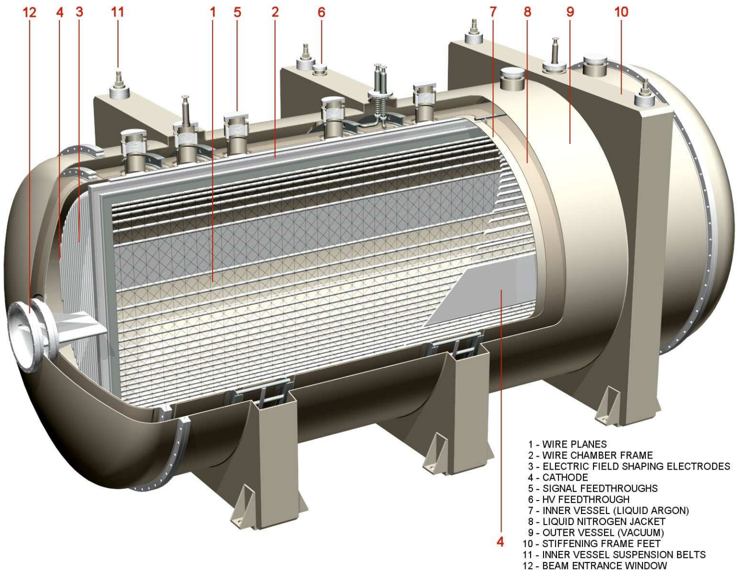

Figure 2: Schematic of cryostat and inner TPC of the $\sim$ 100-ton prototype [6].

3 Conclusions

The recent DOE CD-0 mission statement calls for a detector optimized for long-baseline, ν_e-appearance, oscillation physics. Liquid Argon TPCs are the best detectors for this physics and are technically feasible on a reasonable timescale. *En route* to their realization, several issues must be addressed by R&D to guide design and construction of a massive detector. An aggressive but achievable schedule indicates that after three years of R&D, including the $\sim$ 100-ton detector discussed here, the approval process for a massive LArTPC EνA detector can begin in 2010.

References

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Liquid Argon TPC R&D Cost Estimate
(In thousands of US $ (FY06))

100-ton neutrino detector prototype (30-ton fiducial)			
FY2006			
Cryostat and TPC Design	100		
Electronics Development			
Engineering	50		
Test stand	20		
200 Ch. Prototype	20		
Purification System Eng.	30		
Purity Tests	30		
Software and Computers	20		
HV Design and Prototype	20		
Calibration Techniques	10		
Sub-total		300	
FY2007			
Cryostat	750		
Wire chamber, Field Cage	150		
Software and Computers	20		
Sub-total		920	
FY2008			
Electronics (4000 wires)	250		
Liquid Argon Inventory	200		
Feedthrough (HV/Signal)	100		
Cryogenic Equipment	80		
Software and Computers	20		
Sub-total		650	
Total for 100 t prototype (30-t fiducial)			**1870**
Technical Set-ups			*600*
1000 ton tank			*4000*

Table 1: Breakdown of preliminary costing for LArTPC R&D program *with activity outside the present University initiative shown in italics*. Only M&S costs related to the detector hardware R&D are shown. Operational costs are not shown.