A Large Liquid Argon TPC for Off-axis NuMI Neutrino Physics

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Abstract. The ICARUS collaboration has shown the power of the liquid argon time projection chamber (LArTPC) technique to image events with bubble-chamber-like quality. I will describe a proposed long-baseline ν_e appearance experiment utilizing a large ($\geq$ 15 kton[1]) LArTPC placed off-axis of Fermilab's NuMI ν_μ beam. The total LArTPC program as it presently stands, which includes a number of smaller R&D projects designed to examine the key design issues, will be outlined.

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Extracting most of the remaining unknown parameters in the neutrino sector – namely θ_{13}, the neutrino mass hierarchy, and the CP violation phase δ – will require reactor experiments and neutrino beam experiments at differing baselines that are able to measure the $\nu_\mu \rightarrow \nu_e$ oscillation probability. There is a ν_μ beamline being constructed at JPARC for the T2K experiment[1] in Japan with a baseline of 295 km. In the United States there is the already existing NuMI facility[2] at Fermilab which provides a ν_μ beam for the MINOS experiment located 732 km away in a mine in upstate Minnesota.

The beam energy and baseline of MINOS are not optimal for a ν_e appearance experiment. The only way to make a narrow-band ν_μ beam is to utilize the "off-axis" technique[3]. The best off-axis NuMI beam peaks at around 2 GeV. For this neutrino energy and the present measured neutrino Δm^2 values, a baseline of around 1000 km is required in order for a detector to be situated at the first oscillation maximum.

The inherent ν_e content of the beam is the ultimate background. Another possible background to the ν_e signal (i.e., electron appearance from charged-current ν_e interactions) is π^0's produced in neutral-current events. Reducing this puts a premium on detectors that can differentiate electrons from photons. As we will see, the liquid argon time projection chamber (LArTPC)[4] is the ideal detector for separating the ν_e charged-current events from neutral-current events in which a π^0 is produced. The image of a simulated neutral current event with a 1 GeV π^0 ($\nu_\mu + n \rightarrow \nu_\mu + \pi^+ + \pi^- + \pi^0 + n$) in a LArTPC detector, as simulated by a GEANT 3-based Monte Carlo, is shown in Fig. 1. The lower photon shower is clearly identifiable in liquid argon based on the displacement from the vertex and the high pulse height at the shower start. The efficiency for detecting ν_e's in a LArTPC is $\sim$80–90% with a negligible neutral-current π^0 event

[1] The term "Ton" means metric ton, i.e., 1000 kg, throughout this paper.

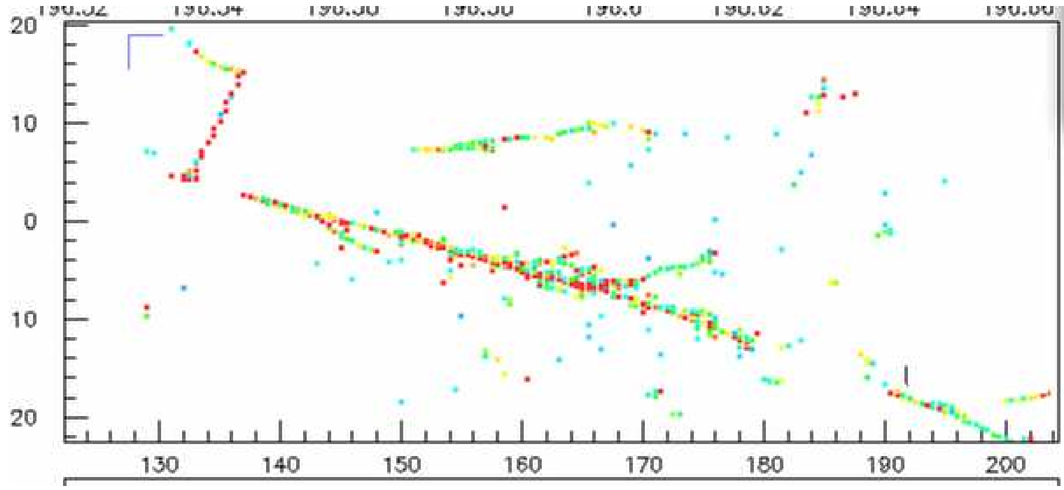

FIGURE 1. A simulated neutral current event with a 1 GeV π^0 ($\nu_\mu + n \rightarrow \nu_\mu + \pi^+ + \pi^- + \pi^0 + n$). Sampling rate is every 3.5% of a radiation length in all three views.

background.

The baseline detector design is optimized for the ν_e appearance experiment although the detector also has capabilities for observing neutrinos from supernovae and sensitivity to some proton decay channels. In the baseline 15 kton detector, the liquid argon is stored in a large, cylindrical, industrial Liquified Natural Gas (LNG) tank. The tank is 29.1 m in diameter and 25.6 m high. The design employs 8 distinct drift regions with 3 metres between cathode planes and signal wires. The drift field is 500 V/cm giving a drift velocity of 1.5 m/ms and a maximum drift time of 2 ms. Following ICARUS, each signal "plane" contains three wire planes – a vertical collection plane and two induction planes strung at $\pm 30^\circ$ to the vertical. The wire pitch is 5 mm. The estimated cost of the 15 kton detector is 57.45 Million dollars not including EDIA or contingency. See [6] for details of the baseline detector design and costing.

The success of the ICARUS T600 ($\sim$600 ton) LArTPC demonstrated the feasibility of the technique on a "small" scale[5]. Building LArTPC detectors of the scale necessary for long-baseline neutrino physics requires additional R&D. A schematic of the R&D programme proposed by scientists from Fermilab and a number of North American universities[6] is shown in the Fig. 2. The programme includes:

1. A number of technical test setups directed to answering specific questions pertaining to a massive LArTPC (e.g., long drift, argon purity, wire tensioning, etc.).
2. The construction of a 30–50 ton fiducial mass ($\sim$100–130 ton total argon mass) detector in which electron neutrino interactions can be fully reconstructed and a range of 2 GeV neutrino interactions studied. This detector will operate where it can obtain a sizeable number of neutrino interactions from the Fermilab NuMI and/or Booster Neutrino beams.
3. The construction and partial outfitting of a commercial tank of 1 kt capacity using the same techniques as proposed for the 15-50 kton tank. This will serve as the test-bed to understand the issues of industrial construction.

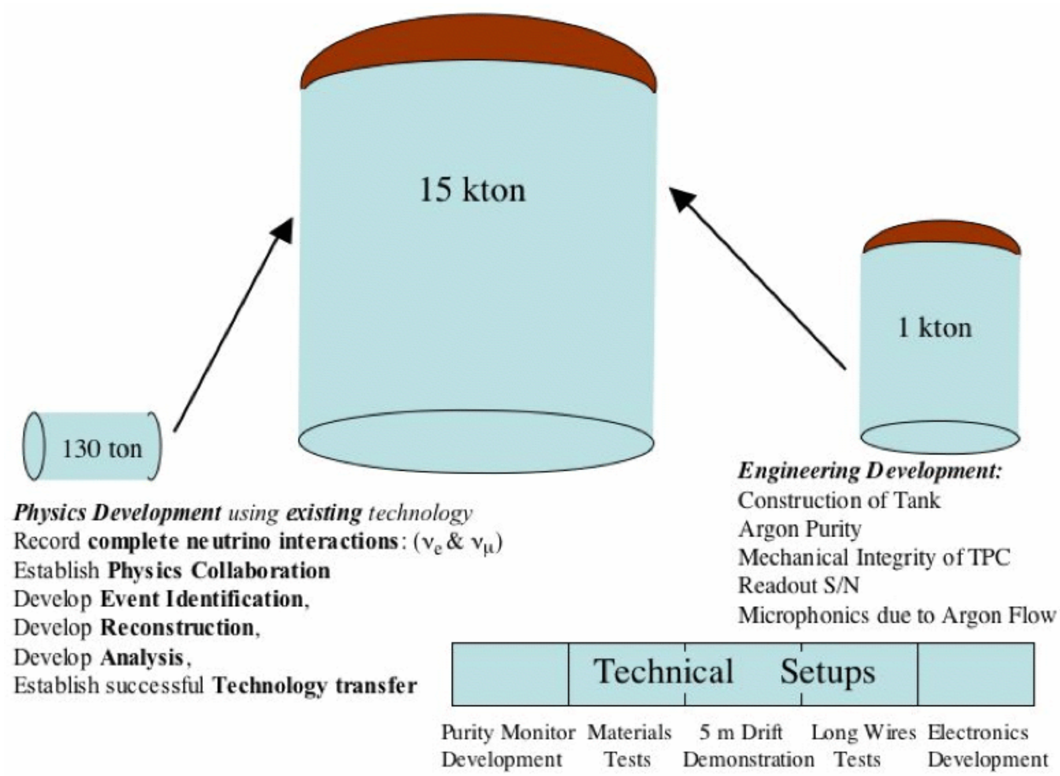

FIGURE 2. Proposed R&D programme towards realization of a large LArTPC.

In conclusion, the liquid argon time projection chamber (LArTPC) is an ideal detector for a long-baseline $\nu_\mu \to \nu_e$ oscillation experiment since it has been shown to be highly efficient ($\sim$80 – 90%) for reconstructing charged-current ν_e events while reducing the background due to neutral-current events containing π^0's to a negligible level. We have proposed an R&D programme[6] to allow for the realization of a large scale (10's of ktons) LArTPC to continue the quest towards measuring the remaining unknown parameters in the neutrino sector.

REFERENCES

1. Y. Itow et al., KEK-REPORT-2001-4 (2001).
2. J. Hylen et al., FERMILAB-TM-2018 (1997).
3. D. Beavis et al., BNL-52459 (1995).
4. C. Rubbia, CERN-EP/77-08 (1977).
5. S. Amerio et al., *Nucl. Inst. & Meth. A* **527**, 329-410 (2004)
6. C. Bromberg et al., FERMILAB-FN-0776-e (2005).