LB report – Detector Simulation Section

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Liquid Argon TPC detectors, with fine grained tracking and total absorption calorimetry capabilites, suggest great promise for sensitivity to long baseline oscillation physics. Hand scanning studies indicate efficiency for charged current quasi-elastic electron neutrino interactions (ν_e CCQE) greater than 80% and background rejection of neutral current π^0 events by a factor of 70 [1]. Studies from European groups are consistent with these results [2].

As part of this study, tools have been developed to simulate and reconstruct events in the E_ν = 0.5-5 GeV energy region. Studies using these new tools confirm the efficiencies and background rejection from the hand scanning work. Sensitivity calculations folding in these efficiencies, background rejection factors, and resolutions indicate LArTPCs are $\sim$3 times more sensitive than an equal mass of Water Cerenkov detector **??**.

It is primarily the imaging capability that enables LArTPCs to distinguish different event classes from each other. Specifically, while conventional detectors can typically identify only the outgoing lepton in CCQE interactions, LArTPCs can tag both the outgoing lepton and the recoil proton. Furthermore, a LArTPC can easily and unambiguously identify the interaction point of energetic gamma-rays, for example from π^0 decay, if the separation from the primary vertex is larger than 2cm [3].

As part of this study, a GEANT3 simulation of a Liquid Argon TPC was studied and developed to best quantify how much better these detectors are [4]. The Monte Carlo takes hbook files from the NUANCE event generator as input and simultes events in a 7x10x10 m^3 box which is roughly equivalent to 1 kton, suitable for these studies. Events are digitized using standard GEANT libraries, and Monte Carlo truth studies performed on this output. Given the imaging capability of a LArTPC, this is an acceptable approximation of an actual event. The criteria to tag a ν_e CCQE interaction are first to see an electron shower as distinct from a muon track. This is assumed to be 100% efficient. The second criteria is to see a recoil proton coming from the same vertex as the electron. The well established low energy threshold for this is a proton with kinetic energy > 40 MeV [5]. Imposing this requirement, the efficiency for ν_eCCQE events is >90%. As these are first pass truth studies, we default in this study to the more conservative 80% efficiency determination from the hand scanning study. Neutral current π^0 backgrounds, with subsequent $\pi^0 \rightarrow \gamma\gamma$, arise from both $\nu_\mu n \rightarrow \nu_\mu n \pi^0$ and $\nu_\mu p \rightarrow \nu_\mu p \pi^0$ interactions. The first,$\nu_\mu n \rightarrow \nu_\mu n \pi^0$, is rejected because of the lack of any recoil proton. The second,$\nu_\mu p \rightarrow \nu_\mu p \pi^0$, is tagged by observation of a 2cm or larger gap between the vertex of the recoil proton and at least one of the gammas from the decaying π^0 which converts into an e^+e^- shower. Combining these requirements, only 0.5% of the NC π^0 backgrounds are not rejected. Further rejection factors are expected by looking at the energy depostited in the first few centimeters of tracks initiating electron showers versus gamma showers. The overlapping e^+e^- from the gamma shower deposits twice the energy at the beginning of the track as the single electron.

These studies have been performed using a Wide Band Beam flux generated with 40 GeV protons on target used in this study. While a full study to understand reconstruction for the other wide band beam option and the NuMI option, these results, to first order, are relevant across a broad range of energies. In particular, for NC π^0 rejection, the separation between the primary vertex and the closest gamma conversion point is roughly independent of the incoming neutrino energy [3], making these results relevant for the other flux configurations considered in this study. However, high multiplicity events in the DIS region may be very challenging to reconstruct. The effects of DIS interactions for the different flux configurations must be studied.

Advances in automated reconstruction were also pursued as part of this study. Digitized CCQE events were fit using C++ code developed within the ROOT framework. The hough transform based fit algorithm is designed to reconstruct linear tracks through a parametrization by angle. It efficiently identifies both primary and secondary vertices and reconstructs tracks to within 2 degrees RMS [3, 6]. This fitter suffices for events with linear tracks and low multiplicity, so, interactions from quasi-elastic up through the resonance region. As well, a study of the capability to reconstruct electromagnetic showers is in the early stages.

In the future, this simulation and reconstruction package can be used to study energy resolution for different classes of events. For this study, energy resolution is determined from previous work. For CCQE events, a 5% energy resolution is assumed. This is valid down to $\sim$1 GeV, below which few events contribute to the oscillation signals. For non-CCQE events, a 20% neutrino energy resolution is assumed. This is likely too conservative in the resonance region where low multiplicity events can still be well imaged by LArTPCs, but likely not conservative enough for DIS events turning on in the 2-3 GeV region. Understanding these resolutions as a function of energy is part of the ongoing program of simulation and reconstruction studies.

The excellent efficiency and background rejection capabilities of LArTPC detectors translates into a factor of ∼3 improved sensitivity over Water Cerenkov detectors for long baseline physics. Detailed sensitivity studies are described in Section **??**.

References

[1] C. Bromberg *et al.*, “A Large Liquid Argon Time Projection Chamber for Long-Baseline, Off-Axis Neutrino Oscillation Physics with the NuMI Beam”. Submitted to the DOE NuSAG committee. Fermilab-FN-0776-e, 2005. http://www-lartpc.fnal.gov

[2] GLACIER reference

[3] A. Curioni, “Monte Carlo Study of an LArTPC for Neutrino Experiments”. Writeup for the FNAL/BNL Long Baseline Study.

[4] S. Linden, “Simulations”, Workshop on Neutrino Physics with Liquid Argon TPC Detectors, http://www-lartpc.fnal.gov/NewWebsite/atwork/workandconf/2006workshop/program.htm

[5] ICARUS-Milano collaboration, physics/0609205, submitted to Physical Review D.

[6] C. Anderson, “Reconstruction Algorithms”, Workshop on Neutrino Physics with Liquid Argon TPC Detectors, http://www-lartpc.fnal.gov/NewWebsite/atwork/workandconf/2006workshop/program.htm