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Status of the ArgoNeuT and MicroBooNE Experiments

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Abstract. Liquid Argon (LAr) time projection chambers are a promising technology for future large-scale neutrino detectors. Their spatial resolution and ability to measure dE/dX make them well suited for identifying and measuring the properties of neutrino interactions and rejecting background processes. The development of this technology in the United States is taking a staged approach, with current efforts combining research and development and Physics goals in varying amounts. The ArgoNeut experiment, a primarily R&D effort, consists of a cryostat containing 0.24 t of LAr. It is currently in the NuMI beam at Fermilab and will take neutrino data this spring. It will provide a test-bed for development of analysis techniques for LAr detectors. The MicroBooNE cryostat will contain 170 t of LAr and will be located in the Booster neutrino beam at Fermilab. MicroBooNE will develop and test processes for building a large LAr detector, as well as make relevant neutrino cross section measurements for future long baseline neutrino experiments and study the MiniBooNE low energy excess.

Keywords: Neutrino, Liquid Argon, Time Projection Chamber
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INTRODUTION

There is compelling evidence for the disappearance of ν_μ and ν_e as they propagate from their production point [1, 2, 3, 4, 5, 6]. This disappearance has been best described as oscillations between the active neutrino flavors; as neutrinos of one flavor propagate, they are able to change into neutrinos of another flavor. The oscillation is allowed because neutrinos have mass, and the flavor states are linear combination of the neutrino mass states. The flavor states and mass states are related by a unitary 3×3 matrix known as the PMNS matrix [7]. Thus, the mixing between the neutrino flavors is determined by three mixing angles, the difference between the squared mass values of the mass states, and one CP violating phase.

The atmospheric neutrino experiments such as Super-Kamiokande were the first to report significant deficits of atmospheric ν_μ propagating over baselines longer than several hundred kilometers [1, 2]. Since then the K2K and MINOS experiments have observed the disappearance of ν_μ produced in neutrino beams from man-made accelerators over baselines of 250 km and 750 km respectively [5, 6]. These experiments have made precision measurements of the atmospheric mass squared splitting, $|\Delta m^2_{32}|$, and the associated mixing angle, θ_{23}. The observation of the disappearance of ν_e from the Sun and the disappearance of $\overline{\nu}_e$ from man-made reactors has allowed experiments such as SNO and KamLAND to make precision measurements the solar mass squared splitting, Δm^2_{21}, and the associated mixing angle, θ_{12}. Based on these measurements, it is known that the mixing angles θ_{23} and θ_{12} are both near their maximal allowed values, and that

$|\Delta_{32}| \gg \Delta_{21}$. The CHOOZ reactor neutrino experiment has placed limits on the size of the final mixing angle, θ_{13}, however no direct measurement has been made [8]. The CHOOZ limit indicates that this mixing angle is much smaller than the other mixing angles. The remaining parameters describing neutrino oscillations among the active flavors are then θ_{13}, the CP violating phase, δ, and the mass hierarchy, that is whether the third mass eigenstate is the heaviest or lightest eigenstate.

The next generation of neutrino oscillation experiments will attempt to determine these final parameters. To do so, the experiments will need to be much more efficient in their detection of ν_e interactions and their rejection of background processes, such as neutral-current interactions resulting in $\pi^0 \rightarrow \gamma\gamma$. Additionally, the new experiments will have to be much more massive than current experiments in order to search for the subdominant oscillation mode, $\nu_\mu \rightarrow \nu_e$, as that mode holds the information about both θ_{13} and δ. One detector technology that promises to both provide efficient signal identification as well as being a cost effective design for large detectors is liquid argon time projection chambers.

LIQUID ARGON TIME PROJECTION CHAMBERS

Liquid argon (LAr) time projection chambers (TPCs) function in an analogous manner to gas TPCs. An electric field is established between a cathode on one side of the TPC and readout wires positioned on the opposite side. There are at least two planes of readout wires in the TPC, with each plane at an angle to the next, in order to provide three-dimensional position determination. A minimum ionizing particle traversing the LAr will liberate 55,000 electrons from the argon for every centimeter it travels; the electrons drift toward the readout planes under the influence of the electric field. The measurement of the position in the third dimension is determined by the time it takes for the signal ionization electrons to drift to the readout planes. The typical field strength in an LAr TPC is 500 V/cm, which corresponds to a drift velocity of 1.55 mm/μs.

This technology is attractive for building large scale detectors as the channel count, which is a main cost driver, goes as a fraction of the surface area of the detector, rather than the entire surface area as in a Cherenkov detector, or as the volume in a segmented scintillator detector. The primary challenge in building a LAr TPC is keeping the argon free from electronegative impurities that would cause the ionization electrons to recombine before reaching the readout wires.

The ICARUS experiment [9] is an example of a functioning LAr TPC. It has taken cosmic ray data with one of the two modules comprising the full detector. The resulting events have incredible resolution in the drift direction, with the resolution being on the order of 0.5 cm. Such high resolution is what enables LAr TPCs to distinguish between charged-current ν_e interactions versus neutral-current π^0 interactions.

While there is a large experience with this detector technology in Europe, the United States program is in its early stages. The technology has been strongly endorsed by P5 [10], and several institutions have joined the effort to develop the United States LAr program with experiments based at Fermilab. The program is following a phased approach where TPCs of increasing size will be built in order to understand the technology and the unique challenges it represents. In addition to small test stands built at both Fer-

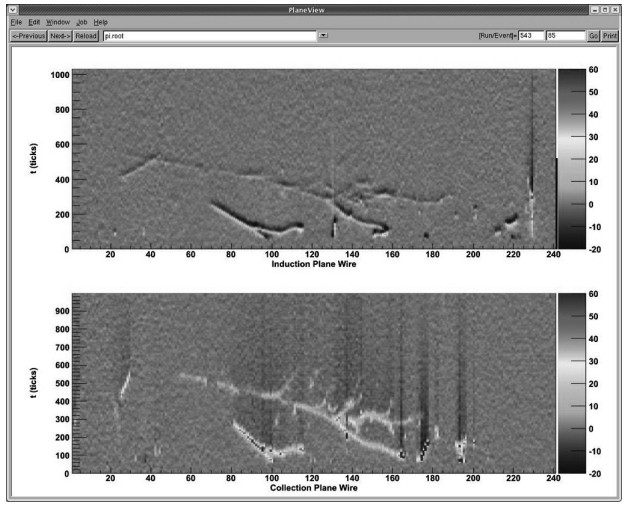

FIGURE 1. A neutrino interaction in the ArgoNeuT TPC. The top panel shows the signal from the first readout plane, the bottom is the last readout plane. The $y-$axis shows the distance from the readout plane and the $x-$axis is the wire number. The grey scale indicates the signal size. This is possibly a neutral-current π^0 interaction with $\pi^0 \to \gamma\gamma$.

milab and Yale, larger experiments are at various stages of planning and execution. The ultimate goal of the program is to build a detector with a mass on the scale of 50 kt to be placed in a neutrino beam at a distance of $\sim$ 1300 km from the neutrino production target.

ARGONEUT

The largest LAr TPC currently operating in the United States is the Argon Neutrino Teststand, or ArgoNeuT. The cryostat contains a total of 0.24 t of LAr and the TPC has a maximum drift distance of 50 cm. It is placed in the NuMI [6] beam directly in front of the MINOS near detector [11]. The experiment is funded by the DOE and NSF and the collaboration comprises six institutions from both the United States and Italy. The goals of the experiment are to gain experience in building and running a LAr TPC, including understanding how to operate such a TPC safely underground, developing simulation and analysis techniques, and measuring the neutrino charged-current quasi-elastic cross section.

The TPC has three wire planes, each consisting of 240 sense wires, however only signal from the last two planes is used for event reconstruction. The sense wires are 0.15 mm diameter berilium and copper wires with a pitch of 4 mm between wires. The spacing between the planes is also 4 mm. The wires are oriented at an angle of 60° from each other.

ArgoNeuT was placed in the MINOS hall in December 2008. It was filled with LAr on May 8, 2009. The first neutrino interactions seen in a LAr TPC in the United States were recorded a few weeks later. Figure 1 shows a neutrino interaction inside the TPC; this interaction is possibly $\pi^0 \to \gamma\gamma$.

MICROBOONE

MicroBooNE is the next step in the United States LAr program. The cryostat will contain 170 t of LAr and the TPC will have a 2.5 m drift distance. The goals of MicroBooNE are to combine hardware R&D with a relevant physics program that includes measurement of neutrino cross sections and studying the MiniBooNE low energy excess [12]. The experiment has received stage 1 approval from Fermilab and is currently in the process of becoming a DOE project. The TPC will have a fiducial volume of 70 t and use 10,000 readout wires distributed among 3 readout planes. The wire and plane pitch will each be 3 mm. One of the main hardware goals of MicroBooNE is to understand the operation of electronics within the cryostat while keeping the purity of the LAr high as well as how to bring the signals from the electronics out of the cryostat and to the data acquisition computers.

MicroBooNE will be located in the Booster neutrino beam at Fermilab [13], although it will also observe neutrinos from the off-axis component of the NuMI beam. It is expected to run for two to three years with an anticipated start date in 2012.

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