From ArgoNeuT to MicroBooNE

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Abstract. The final unknowns in the neutrino oscillation mixing matrix, including the search for CP Violation in the neutrino sector, offer extraordinary physics opportunities, which make a compelling case for developing the best possible detectors. Liquid Argon Time Projection Chambers (LArTPCs) combine fine-grained tracking with total absorption calorimetry to achieve sensitivities well beyond conventional neutrino detectors. The ArgoNeuT and MicroBooNE projects serve as steps in a development path towards massive kiloton scale LArTPCs for long baseline electron neutrino appearance physics. These experiments combine development goals with exploration of low energy neutrino interaction physics. Progress on ArgoNeuT and MicroBooNE en route to massive LArTPCs for the LBNE program are presented here.

1. Introduction

The recent exciting new results in neutrino physics have both answered many puzzling questions and created many more. Most notably, the first conclusive evidence that neutrinos oscillate and have mass occurred only about 10 years ago. The consequences of this seminal discovery include the possibility that neutrinos and their anti-particles could behave differently suggesting CP Violation in the neutrino sector. As well, neutrinos may have other unexpected properties or unexpected partner particles. Results from the MiniBooNE [2] experiment have ruled out the possibility of two-neutrino oscillations at high $\Delta m^2$. However, they also contain a puzzling new excess below the oscillation region, $<475$ MeV. A 129 event excess ($\sim 3 \sigma$) in this region suggests possible new physics [3, 4, 5, 6, 7, 8, 9, 10, 11]. No matter what the explanation, this surprising low energy excess must be understood.

These surprises offer extraordinary physics opportunities, best addressed with precision detection techniques. Liquid argon Time Projection Chambers (LArTPCs) [1] combine fine-grained tracking with total absorption calorimetry to achieve sensitivities well beyond conventional neutrino detectors. For long baseline neutrino physics, the combination of electron efficiency and neutral current pion (NC$\pi^0$) background rejection make the detectors $\sim 6$ times more sensitive than Water Cerenkov detectors.

Recent progress on the growing US LArTPC R&D effort has been built on the pioneering efforts of the ICARUS collaboration’s LArTPC program. The US program combines test stand measurements with data taking in LArTPCs of increasing sizes towards a final goal of 20 kton modules for the LAr20 detector within LBNE [13]. An overview of the test stands and experiments underway in the US is shown in Figure 1. TPCs scaled in size from test stands to LBNE are shown in Figure 2. Both ArgoNeuT and MicroBooNE are key steps in this path towards massive LArTPCs for CP violation searches.
2. ArgoNeuT

The ArgoNeuT project [14] is a test beam experiment which has run under MOU agreement with Fermilab through February 2010. The cryostat holds ~500 liters of LAr total, and ~175 liters within the 0.5m x 0.5m x 1m TPC. The LArTPC sat just upstream of the MINOS near detector and was exposed to the on-axis NuMI neutrino beam, using the MINOS near detector as a muon catcher. ArgoNeuT was commissioned above ground in 2008 and moved below ground in May of 2009. ArgoNeuT filled and collected neutrino interactions during a first month of commissioning with the NuMI neutrino beam in May of 2009. Commissioning continued throughout the 2009 summer shutdown after which ArgoNeuT collected on the order of ~10k neutrino and anti-
neutrino interactions in its 5 month run exposed to the NuMI anti-neutrino beam. ArgoNeuT was removed in late February of 2010 and will undergo upgrades before a proposed ArgoNeuT phase 2 run.

The ArgoNeuT test has allowed for a first ever large sample of low energy neutrino interactions in an LArTPC collected over a relatively long and stable run. Over the 5 month run, excluding a 2 week down time due to an off-the-shelf cryocooler failure, the test operated at approximately 99% uptime. The detector ran in a "shiftless" mode with emergency monitoring via a pager.

The ArgoNeuT data is being analyzed towards measurements of neutrino cross sections on argon. The 10k neutrino events collected have spurred analysis of and the development of a full MC simulation and automated reconstruction package both for ArgoNeuT and for LArTPC experiments beyond. This analysis framework package, dubbed LArSoft, is described in Section 4.

3. MicroBooNE
MicroBooNE is the next step beyond ArgoNeuT in the US based plan, in developing a fully instrumented LArTPC for neutrino physics. It is a 150 ton LArTPC experiment to be designed, constructed, and installed by 2013, with beam delivery of 6.5E20 protons on target (pot) over 2-3 years of data taking beyond this in the Booster Neutrino Beam at Fermilab.

MicroBooNE has a combination of physics goals and development goals. The physics goals encompass measurements of low energy neutrino interaction phenomena on Argon. The development goals align the MicroBooNE design with the path to larger detectors so that as much as possible can be learned about design and engineering of very large LArTPCs.

MicroBooNE received Stage 1 approval from the Fermilab director in 2008 and has recently been approved for CD-1 by the Department of Energy towards data taking to begin in 2013.

3.1. MicroBooNE physics
MicroBooNE’s physics goals include addressing the low energy excess observed by the MiniBooNE experiment and performing a unique set of low energy neutrino cross section measurements. For the MiniBooNE low energy excess, the $e/\gamma$ separation capability of LArTPCs, unavailable in all previous low energy accelerator neutrino experiments, nearly eliminates muon neutrino induced backgrounds and increases electron efficiency resulting in a $3 - 5\sigma$ significant signal in a detector – the MicroBooNE detector – almost an order of magnitude smaller than MiniBooNE. The Figures below show the expected signal over background in MicroBooNE given the two different interpretations of the low energy excess from the MiniBooNE experiment, electrons or photons.

In addition, rare events such as coherent pion production, kaon production for proton decay studies, and $\nu_e$ CCQE interactions can be studied using MicroBooNE’s high efficiency detector. Some of these interaction channels have never before been measured at these energies. All of these measurements are described in more detail in the MicroBooNE proposal, proposal addendum, and the Conceptual Design Report [15].

3.2. MicroBooNE development
The MicroBooNE detector is an 89 ton active volume LArTPC enclosed in a cylindrical cryostat ~4m in diameter and ~ 12 m long. The inner TPC is 2.6m x 2.6m in cross section and 10.4m long in the beam direction. Ionization electrons from charged particles are drifted via a 500V/cm electric field, at 1.6 mm/µs to wire chamber planes on the beam right side of the detector, where they are readout. A PMT array behind the TPCs wire chamber planes records prompt scintillation light used for background rejection, and to determine $T_0$ for non-beam events. The conceptual design of the PMT and TPC array are shown in Figure 5.
In addition to MicroBooNE’s physics goals, the experiment has development goals which include achieving purity in a fully instrumented non-evacuable vessel, development of cold low-noise electronics, and development of design and construction techniques to be employed in larger detectors. These development goals are summarized in other proceedings from this workshop.

In addition to these hardware development goals, MicroBooNE will provide a large sample of fully contained neutrino interactions which motivates development of a fully automated simulation and reconstruction package. The package under development called LArSoft, or Liquid Argon Software, is designed to be adaptable for other LArTPC experiments. Presently, it is actively being used by ArgoNeuT, MicroBooNE, and the LBNE efforts. Progress on LArSoft is described in the section below.
Figure 5. Conceptual design of time projection chamber in MicroBooNE cryostat

Figure 6. 3D reconstruction of a large sample of through going muons in the ArgoNeuT detector

4. LArSoft
The LArSoft simulation and reconstruction package is under active development by experiments including ArgoNeuT, MicroBooNE, and LBNE. Data and Monte Carlo events are reconstructed in 2D and 3D images. Figure 6 shows a large sample of through going muons in ArgoNeuT reconstructed in 3D. The reconstruction chain includes hit finding, line finding, vertex finding, density clustering, 3D image reconstruction, and calorimetry. Figure 7 shows the hough transform based line finding and huff vertex finding applied to a candidate neutrino interaction from the ArgoNeuT data set. Figure 8 shows the density based (DBSCAN [16]) clustering algorithm applied to a candidate neutral current pion event from ArgoNeuT. Rapid development progress is underway with a full reconstruction chain for data and Monte Carlo anticipated soon.
5. Conclusions
A development program is underway in the US towards construction of very massive LArTPC detectors for the LBNE experiment. ArgoNeuT and MicroBooNE are key experiments in this development path. Both have physics and development goals being pursued which have been described here.
References

[1] C. Rubbia, “The Liquid-argon time projection chamber: a new concept for Neutrino Detector”, CERN-EP/77-08 (1977).

[2] A. A. Aguilar-Arevalo et al. [The MiniBooNE Collaboration], “A Search for Electron Neutrino Appearance at the Delta m**2 1 eV**2 Scale,” Phys. Rev. Lett. 98, 231801 (2007) [arXiv:0704.1500 [hep-ex]].

[3] M. Maltoni and T. Schwetz, “Sterile neutrino oscillations after first MiniBooNE results,” arXiv:0705.0107 [hep-ph].

[4] S. Goswami and W. Rodejohann, “MiniBooNE Results and Neutrino Schemes with 2 sterile Neutrinos: Possible Mass Orderings and Observables related to Neutrino Masses,” arXiv:0706.1462 [hep-ph].

[5] H. Pas, S. Pakvasa and T. J. Weiler, “Sterile - active neutrino oscillations and shortcuts in the extra dimension,” Phys. Rev. D 72, 095017 (2005) [arXiv:hep-ph/0504096].

[6] C. Giunti and M. Laveder, “νe Disappearance in MiniBooNE,” arXiv:0707.4593 [hep-ph].

[7] T. Katori, A. Kostelecky and R. Taylor, “Global three-parameter model for neutrino oscillations using Lorentz violation,” Phys. Rev. D 74, 105009 (2006) [arXiv:hep-ph/0606154].

[8] A. de Gouvea and Y. Grossman, “A three-flavor, Lorentz-violating solution to the LSND anomaly,” Phys. Rev. D 74, 093008 (2006) [arXiv:hep-ph/0602237].

[9] X. Q. Li, Y. Liu and Z. T. Wei, “Neutrino decay as a possible interpretation to the MiniBooNE observation with unparticle scenario,” arXiv:0707.2285 [hep-ph].

[10] A. E. Nelson and J. Walsh, “Short Baseline Neutrino Oscillations and a New Light Gauge Boson,” arXiv:0711.1363 [hep-ph].

[11] J. A. Harvey, C. T. Hill and R. J. Hill, “Anomaly mediated neutrino-photon interactions at finite baryon density,” arXiv:0708.1281 [hep-ph].

[12] See, for example, talk by Mark Dierckxsens, BNL’s uDiG workshop, 2008.

[13] www-lbne.fnal.gov

[14] The Argon Neutrino Test, Fermilab Test Beam Experiment, T962. http://t962.fnal.gov

[15] Website for the MicroBooNE Experiment: www-microboone.fnal.gov

[16] M. Ester, H.-P. Kriegel, J. Sander, X. Xu, "A density-based algorithm for discovering clusters in large spatial databases with noise”, Proceedings of Second International Conference on Knowledge Discovery and Data Mining, 1996.