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The Yale Lar TPC

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Abstract. In this paper we give a concise description of a liquid argon time projection chamber (LAr TPC) developed at Yale, and present results from its first calibration run with cosmic rays.

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INTRODUCTION

Liquid argon time projection chambers (LAr TPC) are nearly optimal detectors for neutrino experiments looking for ν_e appearance on a ν_μ beam in the energy range 0.5 – 5 GeV. The LAr TPC technology has been proposed for the measurement of θ_{13}, CP violation in the neutrino sector and determination of the mass hierarchy (e.g. [1, 2, 3]), and to study the MiniBooNE low energy anomaly [4, 5]. The technique is equally promising for proton decay searches [6]. A LAr TPC for neutrino physics was first proposed in 1977 by Carlo Rubbia and a vigorous R&D program was then established, which produced decisive steps in defining the technology and its applicability to particle physics (e.g. [7, 8, 9, 10]). Very remarkably, images taken in a LAr TPC are comparable in quality with pictures from bubble chambers. As for bubble chambers, events can be analyzed reconstructing 3-momentum and particle type for each track in the event image, down to low energy (few MeV for electrons, few tens of MeV for protons); the calorimetric performance ranges from good to excellent, depending on event energy and topology. Equally important, the LAr TPC technology is suitable for very massive (several 10 ktons) detectors, as required in most contemporary neutrino physics. A very active R&D program is on going in the U.S.; as part of this larger effort, a LAr TPC has been developed at Yale starting in 2005. The detector has been commissioned in early 2007, and cosmic ray tracks have been imaged. Preliminary results are presented here.

DESCRIPTION OF THE DETECTOR

1. *Cryogenics:* the LAr TPC is housed in a cylindrical stainless steel vessel of total volume 500 l. The inside walls are electropolished. The vessel is evacuated to few 10^{-6} mbar (at LAr temperature, 87 K) prior to filling with ultra pure LAr. The vessel is cooled to LAr temperature by an open bath filled with commercial, non-purified LAr. It takes about five hours to cool down the system and fill it until the TPC is fully covered (about 250 l of ultra-pure LAr). The total LAr consumption is $\sim$ 1,000 l for a 24 hr long experiment. The top flange of the TPC vessel (Fig. 1-$left$) houses several ports: feedthroughs for the TPC high-voltage, signal cables, test

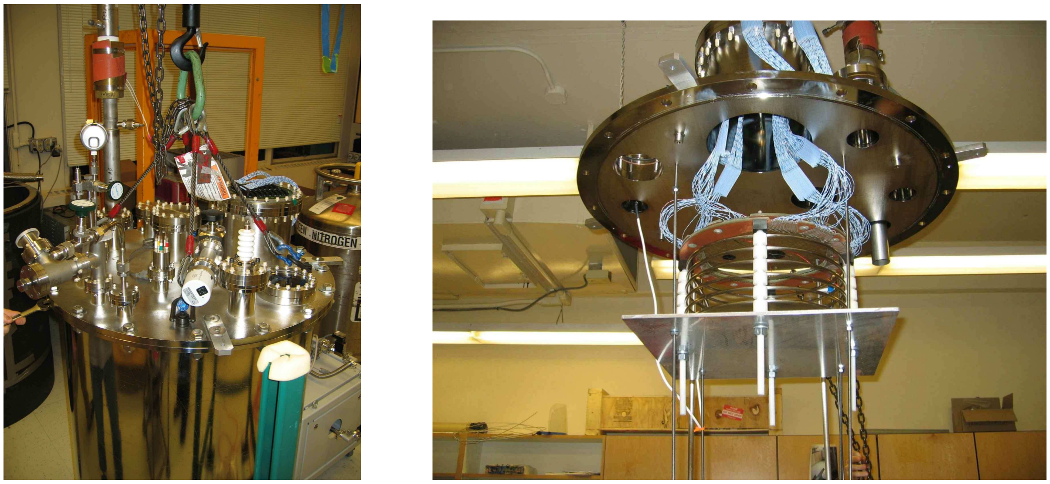

FIGURE 1. *Left:* the top flange, described in the text; *Right:* the TPC, fully cabled, hanging from the top flange.

pulse and capacitive level meter, high voltage feedthrough and optical feedthrough for a purity monitor mounted inside the vessel, pumping line, filling line, relief valve, pressure gauges, and a window. All the seals are CF or VCR. The top flange itself is sealed using a Viton O-ring, therefore the system is not designed to be vacuum-tight at LAr temperature in steady state. The adopted filling procedure is to break the vacuum using ultra-pure cold Ar gas while the LAr open bath is about half full. In steady state the system runs at an overpressure of 0.3 atm. The relief valve has been provided by H. Jostlein of FNAL.

2. *Liquid Ar purification:* the necessity to drift free electrons in LAr for O(1 millisecond) or longer sets very stringent requirements on the purity of LAr, at the level of several tens of parts per trillion of O_2-equivalent contamination (cf. few parts per million in commercially available LAr). The filters to purify LAr have been developed and built at FNAL and are described in [11]; a detailed paper is in preparation. The filter itself is made of a copper alumina catalyst [1], packaged in a CF nipple with sinterized steel caps. The filter is regenerated in place at Yale. Commercial grade LAr is purified with a single pass through the filter, without any additional molecular sieve, at a rate of $\sim$60 l/hr. To measure the electron lifetime independently of the TPC operation, a purity monitor (see [10], and provided by the FNAL group) was mounted underneath the TPC. A loss of drifting charge due to attachment to impurities of less than 10% over a drift time of 0.5 ms has been repeatedly measured in the TPC vessel, stable over a period of 24 hours without recirculation.
3. *TPC and Electronics:* the fiducial volume of the LAr TPC (Fig. 1-*right*) is a cylinder of 33 cm diameter and 17 cm tall. The field cage is made of 6 hollow stainless steel rings, separated by Teflon spacers, and connected through a chain of 100 MΩ resistors. There are two parallel readout wire planes, with 50 wires each

[1] Engelhard Copper Alumina catalyst CU-0226S

and a wire pitch of 5 mm. Flat cables are soldered to the wire planes and reach the readout electronics through a signal feedthrough (INFN-Padova / ICARUS), which holds 512 channels. The readout electronics is the same as the ICARUS one and has been provided by the INFN-Padova / ICARUS group [10].

RESULTS

The LAr TPC has been tested on the readily available cosmic rays. During data taking the electric field in the drift region was 100 V/cm, and 250 V/cm between the induction and the collection planes. The signals from the induction plane were rather noisy due to capacitive coupling with the high voltage in the drift region, and are not presented here. The data acquisition was triggered on the sum coincidence of one board (25 channels) of the collection plane. Some events recorded during a cosmic ray run are shown in Fig. 2 and 3. The signal is well visible over noise on each of the hit wires. The drift velocity in LAr at 100 V/cm is 0.5 mm/μs, with a maximum drift time of 340 μs.

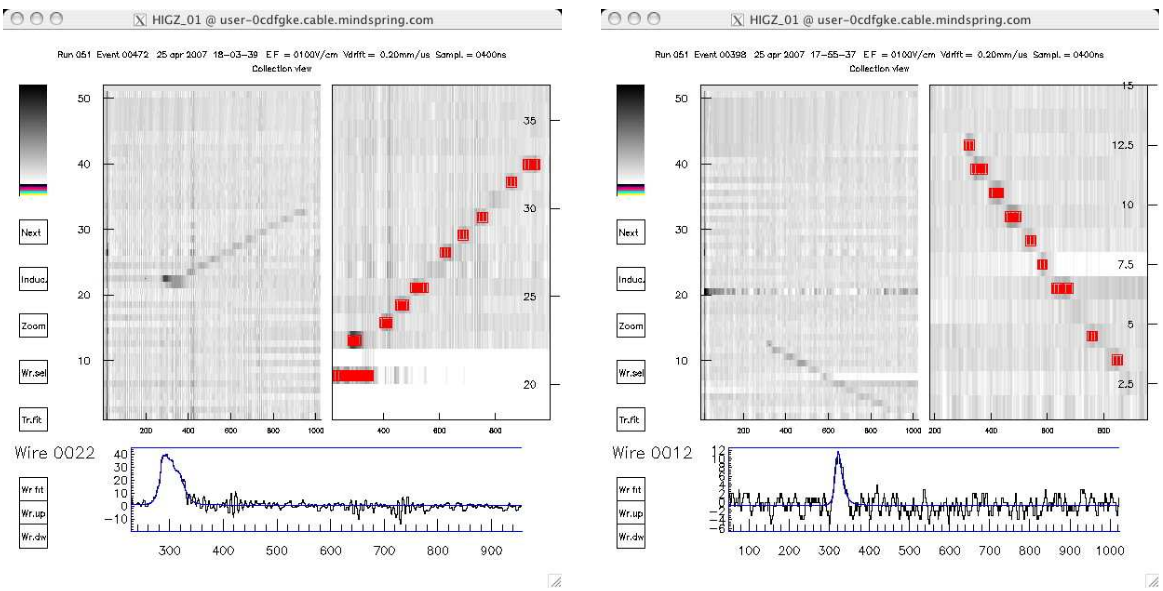

FIGURE 2. Two raw images of muons crossing the TPC, displayed as wire number *vs.* drift time [0.4 μs]. In both cases the zoomed image is also shown; the superimposed *squares* show the *hit position* determined by an automated fit of the waveform. The bottom panels show two waveforms, with the fit superimposed.

CONCLUSIONS

A prototype LAr TPC has been designed, built and tested at Yale over a period of two years. It has been developed as a handy R&D tool for the university setting, with the possibility of repeated runs over a short period of time. The LAr purification is a recent development, applied for the first time to a working imaging instrument, while the readout electronics has been provided by the ICARUS collaboration. The success in

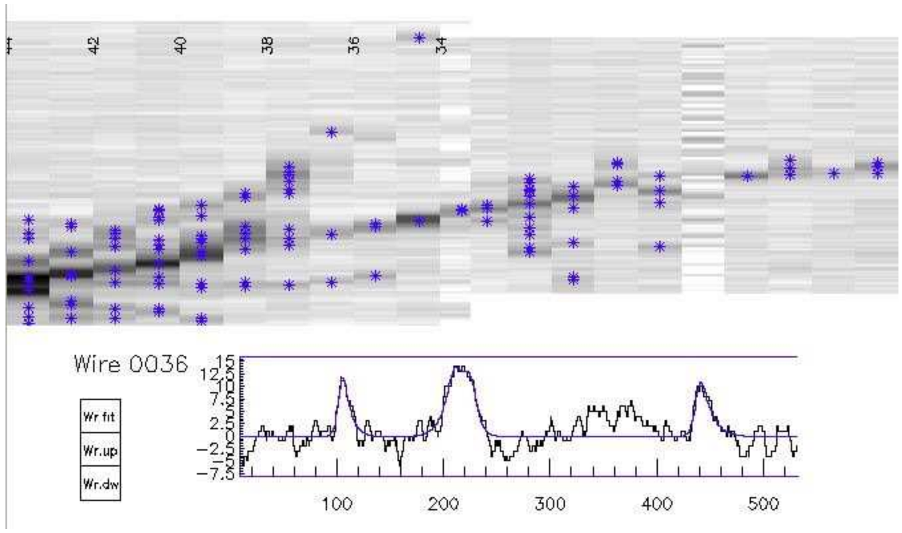

FIGURE 3. Raw image of an e.m. shower, displayed as drift time [0.4 μs] *vs.* wire number.

imaging cosmic rays marks an important milestone in terms of technology transfer for the US LAr TPC effort.

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