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Nuclear Physics B (Proc. Suppl.) 215 (2011) 255–257
NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS
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Optical Readout Technology for Large Volume Liquid Argon Detectors

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A recent experimental investigation successfully demonstrated the proof of principle stage of a new technique for operating Liquid Argon Time-Projection Chambers. We present an overview of this technique, and plans for follow-up experimental work.

1. Introduction

Liquid argon technology is now rather mature, driven primarily by the ICARUS program [1] which has proven the principle of operation of a Liquid Argon Time-Projection Chamber (LArTPC) for up to 600 ton mass. A detector capable of delivering the neutrino physics program of the future [2] will however need to be on a grander scale still with a fiducial mass of perhaps up to 100 kton.

Scaling up to a detector of this size will present considerable difficulties, particularly in the readout phase. We discuss an alternative to wire plane readout and double-phase argon which may prove more suitable for a large scale LAr TPC.

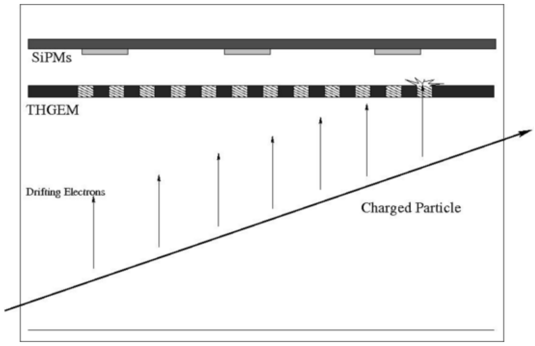

Figure 1. Liquid Argon Time Projection Chamber (TPC) with Thick Gas Electron Multiplier (THGEM) and optical readout using Silicon Photomultipliers (SiPM).

2. Optical Readout Tracking Concept

The principle of an optical readout of a LAr TPC is illustrated in Figure 1. The readout plane consists of a Thick Gas Electron Multiplier (THGEM) and a sparse array of Silicon Photomultipliers (SiPM).

The THGEM as shown in Figure 2 has an electric field applied across the dielectric, hence there is a strong dipole electric field in the THGEM holes. As ionisation electrons are accelerated towards the readout plane, they gain enough energy to excite argon atoms in the THGEM holes, the light from which is readout using the SiPMs.

The behaviour of the THGEM has been observed [3] to be significantly different in liquid and gas argon; no ionisation electrons are observed in the LAr THGEM, whereas ionisation electrons are expected and observed in THGEM holes in GAr [4].

As illustrated in Figure 1, the electroluminescence from the THGEM plane is read out using a sparse array of SiPMs. There are therefore fewer readout channels than THGEM holes, but res-

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0920-5632/$ – see front matter
doi:10.1016/j.nuclphysbps.2011.04.023

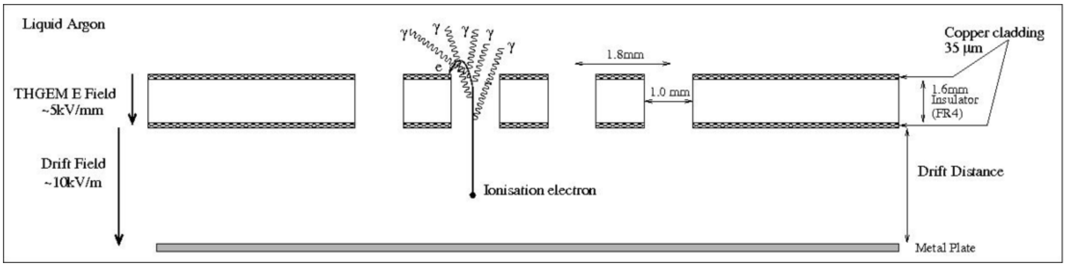

Figure 2. Schematic diagram of a THGEM in liquid argon.

olution remains at the THGEM hole separation size, since it is possible to reconstruct position using the relative amounts of light detected at each SiPM.

Silicon Photomultipliers from SensL have been shown [5] to work well at $-196°C$, with a high gain of the order of 10^6.

The system described above has a modest number of readout channels, and uses cheap materials, such as argon, and copper coated printed circuit board (for THGEMs), and is therefore a cost effective detector to build on large scales, such as those needed for the next generation of neutrino detectors.

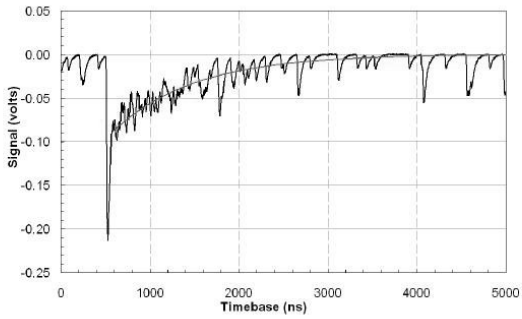

Figure 3. Secondary scintillation light pulse produced by Fe55 source in LAr system.

3. Proof of Principle

The proof of principle has recently been established [3]. In this experiment ionisation electrons were generated in the liquid argon via the interaction of a 5.9 keV Fe-55 gamma source. These electrons were drifted under the influence of a 2.5 kV/cm field towards a 1.5 mm thick THGEM, which itself had a field of 6.61 kV/mm.

A SensL SPM1000 device was used for the photon detection, coated with a wavelength shifter, tetraphenyl butadiene (TPB), to enable observation of UV light in the high quantum efficiency region of the device. Figure 3 is an example of a pulse observed by the SiPM in the above conditions.

As the drift field was decreased, the number of events observed decreased (Figure 4), suggesting the light being produced was secondary scintillation in the holes. For further details see [3].

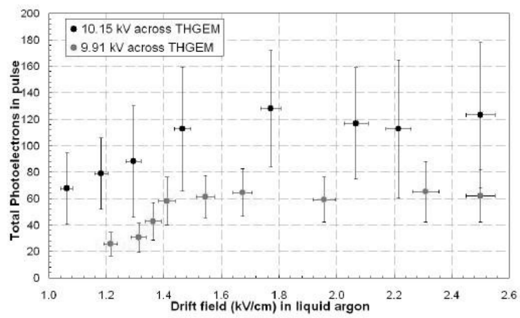

Figure 4. Number of Photoelectrons detected vs. Drift field to THGEM.

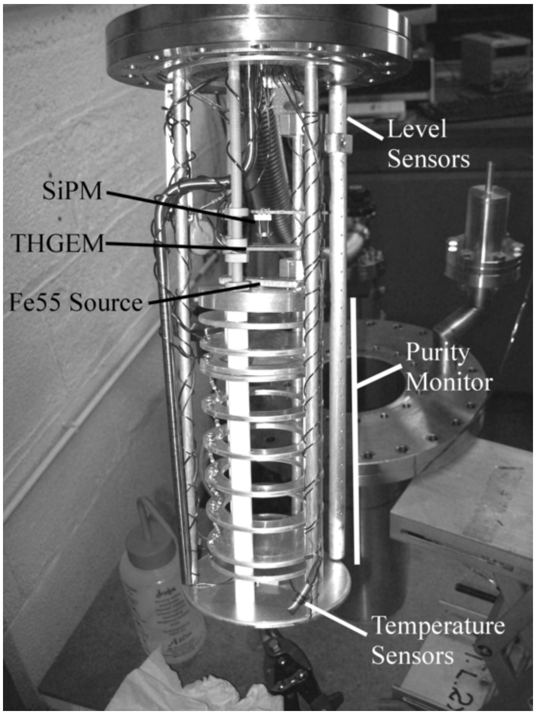

Figure 5. The experimental setup at Warwick.

4. Experiment Plans

Forthcoming experiments aim to confirm the proof of principle, and extend our knowledge of the behaviour of a THGEM in liquid argon.

4.1. Confirming the Proof of Principle

The basic experimental setup (see Figure 5) remains similar to that described in the previous section, using a similar source and drift distance.

The system differs from the previous experiment in that it uses a THGEM with smaller dimensions; 0.8 mm thickness, 0.6 mm holes with 1.2 mm pitch. The SiPM used has a larger active area, 9 mm^2, and will therefore give better statistics.

The SiPM in the previous setup was exposed only to the light in one THGEM hole, whereas the SiPM in the current setup will be exposed to the full 900 mm^2 area of the THGEM.

4.2. Improving THGEM models

Models currently suggest that the majority of the secondary scintillation light emitted is in the UV range, hence the use of wavelength shifter in [3]. Recent work [6] suggests that there will be photons emitted in the near infra-red range. It is for this reason that the current system uses no wavelength shifter.

Subsequently, varying optical filters will be used on the SiPM to further categorise the wavelengths produced.

4.3. Tracking

Since tracking will be the prospective application of this readout technology, we aim to measure cosmic ray muon tracks in the current test stand. Using a small array of SiPMs it will be possible to test the resolution of the tracking, and the cold electronics for the x,y plane.

Measuring the first tracks using a THGEM with optical readout in a LAr TPC is a major step towards demonstrating that the readout technology is fit for purpose.

5. Conclusions

This readout technology has the potential to provide a feasible alternative to the wire readout. Further development of THGEMs with an optical readout could lead to this technology having a role in large volume LArTPCs of the future.

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