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TPB thickness and Quantum Efficiency measurements for the new ICARUS T600 light detection system in the SBN program.

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TPB thickness and Quantum Efficiency measurements for the new ICARUS T600 light detection system in the SBN program.

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Abstract.
Tetra-Phenyl-Butadiene (TPB) has been widely used in the last years in LAr experiments due to its property to convert VUV into visible light. To this purpose, a study of its property has been performed in order to obtain the best TPB coating on the PMT sensitive window for the new ICARUS T600 light detection system in the Short-Baseline Neutrino program at FNAL.

1. Introduction

The Short-Baseline Neutrino (SBN) physics program, emerging from a European - US collaboration, includes three Liquid Argon Time Projection Chamber (LAr-TPC) detectors located along the Booster Neutrino Beam (BNB) at Fermilab.
The SBN program goal is to perform sensitive searches for ν_e appearance and ν_μ disappearance in the BNB in order to understand experimental anomalies in neutrino physics and to perform the most sensitive search for sterile neutrinos at the eV mass-scale.

2. The ICARUS T600 Time Projection Chamber

ICARUS T600 will act as the SBN far detector. It successfully operated at Gran Sasso National Laboratories (LNGS) on the CERN Neutrino to Gran Sasso(CNGS) muon neutrino beam from 2010 to 2012 and it was the first large scale LAr TPC to be exposed to a neutrino beam and the largest existing LAr TPC for neutrino physics.
It consists of a large cryostat split into two identical modules and filled with 760-tons of ultra-pure liquid argon. Each module houses two TPCs separated by a common cathode, with a drift length of 1.5 m. Ionization electrons, abundantly produced by charged particles along their path (6000 electrons/mm for minimum ionizing particles at $E_D = 500\ V/cm$), are drifted under uniform electric field towards the TPC anode made of three parallel wire planes. A total of about 53000 wires are deployed, with 3 mm pitch, oriented on each plane at a different angles $(0°, +60°, -60°)$ with respect to the horizontal direction.
By appropriate voltage biasing, the first two wire planes (Induction-1 and Induction-2) provide signals in a non-destructive way, whereas the ionization charge is collected and measured on the last plane (Collection).

2.1. Geometrical reconstruction of an ionizing event in ICARUS T600

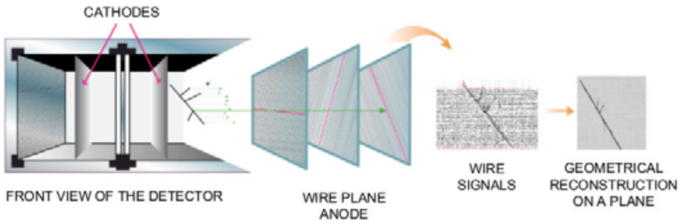

Figure 1: A charged particle ionization path in LAr and its geometrical reconstruction.

Charge signals on the TPC wire planes, from ionization electrons, allow three bi-dimensional pictures of the ionizing event in the plane normal to the drift direction to be obtained. The relative time of each ionization signal, combined with the electron drift velocity information ($v_D \sim 1.6\ mm/\mu s$), provides the position of the track along the drift coordinate. A three-dimensional image of the events can then be reconstructed by combining the wire coordinates on each plane and the measured drift time, with a resolution of about 1 mm^3 (Figure 1). The precise determination of the coordinate along the drift time direction, is derived from the absolute time of the ionizing event by the detection of the scintillation light ($\sim$ 5000 VUV photons/mm at $E_D = 500\ V/cm$ with $\lambda \approx 128\ nm$) produced by LAr. The emission is due to the radiative decay of excited molecules Ar_2^* and it is characterized by two different decay constants ($\sim 6\ ns$ and $\sim 1.5\ \mu s$). To detect the scintillation light, arrays of Photo Multiplier Tubes (PMT) are installed behind the wire planes.

3. The TPB as wavelength shifter

The most efficient way to detect the LAr scintillation is to shift the light to longer wavelengths where the PMT photocatode is sensitive. Tetra-Phenyl-Butadiene (TPB) is the most popular wavelength shifter used in LAr experiments due to its extremely high efficiency to convert VUV into visible photons. To this purpose, a layer of TPB was coated on the PMT sensitive glass window by a thermal evaporator located at CERN. It consists in a vacuum chamber housing two copper crucibles (Knudsen cells) which are connected to an external heating system. The crucibles, filled with the TPB, are heated up to $220°C$. At this temperature, TPB starts to evaporate through a little split in the crucible lid and forms a thin film on the photomultiplier surface. In order to obtain the best thickness uniformity, the photomultiplier is fixed looking downwards with respect to the vertical direction by a dedicate rotating support fastened below the cap of the vacuum chamber.

3.1. Definition of evaporation parameters

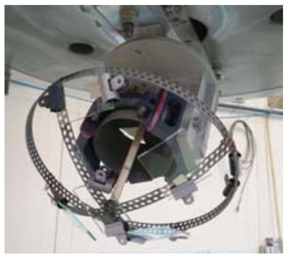

Figure 2: Picture of the PMT mock-up.

Before starting the production, a series of tests was done in order to fix some parameters like the coating thickness (and then the TPB quantity per evaporation) and the deposition rate, namely the coating thickness per unit of time, and therefore the temperature time rise. Tests were performed with a hollow photomultiplier mock-up (see in Figure 2) on which mylar samples were fixed in different positions. Each sample has been weighted before and after the process to determine the coating density. In this way, a study of the evaporation uniformity was performed as a function of the position on the PMT sensitive window. Quantum Efficiency measurements were then performed by a VUV monochromator by comparing the cathodic current of the PMT, with the reference coated sample in front, with the current value of a calibrated photodiode. Quantum efficiency was derived by the equation:

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$$QE_{DUT}(\lambda) = QE_{NIST}(\lambda) \times \frac{I_{DUT}(\lambda) - I_{DUTdark}}{I_{NIST}(\lambda) - I_{NISTdark}} \quad (1)$$

where QE_{DUT} and QE_{NIST} are respectively the sample and the calibrated photodiode (tabulated value) quantum efficiency, I_{DUT} and I_{NIST} are respectively the cathodic photomultiplier and photodiode current values and I_{dark} are the dark currents. Further uniformity measurements were performed directly on some of the coated PMTs that were later installed on the T600 detector.

3.2. Coating thickness and evaporation rate

To define the optimal *coating thickness*, a series of evaporations with different quantities of TPB were performed. The resulting curve is shown in Figure 3. Basing on this, an average coating density of 0.21 mg/cm^2 was chosen in order to stay in the flat portion of the curve and to limit quantum efficiency fluctuations. For this reason, the quantity of TPB was fixed to 0.815 g per evaporation. Then, different heating procedures have been used in order to define the best *deposition rate* for the established quantity of TPB. The obtained curves (Figure 3) show best quantum efficiency values for high evaporation rate (about 6.5 $-$ 7 $\text{Å}/s$). The thickness uniformity on a PMT sensitive window is also show (Figure 4).

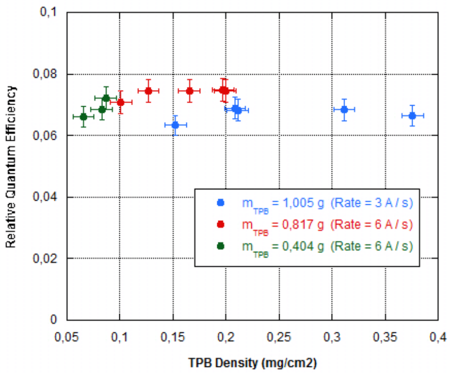

Figure 3: Relative Quantum Efficiency as a function of samples coating density for different process rates.

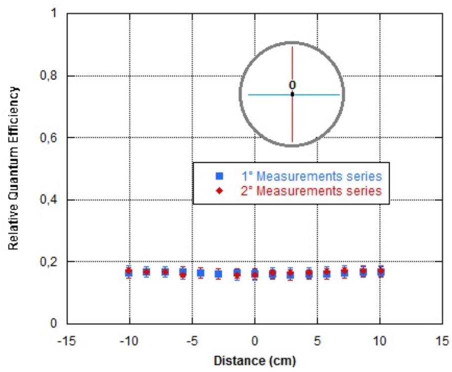

Figure 4: PMT thickness uniformity on their sensitive window.

4. Conclusions

During the series production, 365 PMTs were coated for the T600 detector (360 needed). For every production run, a mylar sample was fixed in a dedicated support in order to check the coating density as was done in the preliminary phase. The resulting distribution of the coating densities related to PMTs of the series production is shown in Figure 5, which demonstrates the good reliability of the adopted technique.

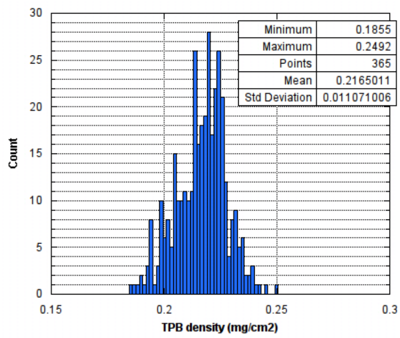

Figure 5: Resulting distribution of the coating densities.

References

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