Comparison between photon detection efficiency and TPB coating stability of PMTs immersed in liquid argon


ABSTRACT

Detection of liquid argon (LAr) is a very interesting detector option for neutrino experiments. The high density of LAr allows it to give directly to react with neutrinos. The interactions leading to a large absorption of argon in the atmosphere, makes it also a cost-effective medium allowing the construction of a detector of several hundred tons, as LArIC, and even several thousand tons detectors are foreseen for the next generation of experiments, as the Deep Underground Neutrino Experiment (DUNE). Besides, being suitable as a target, LAr can serve at the same time in the detection module for the charged particles outgoing from the interaction vertex. In the location of the LAr, electrons and photons are produced. The electrons are drifted afterwards in an external electric field towards the readout plane where they are collected, drift distances of several meters were achieved corresponding to drift times of few ms, while the separation of the events alone allows the reconstruction of the interaction in the plane perpendicular to the electric field. For the reconstruction of the interaction point along the drift the precise knowledge of t_d is mandatory.

The interaction time, t_d, can be determined by detecting the photons produced together with the electrons in the ionization process. These photons provide a prompt signal on the nanosecond scale. To detect them the integration of an efficient photon detection system (PDS) into the LAr detector is necessary. One difficulty here is related to the fact that the emitted photons have a wavelength in the UV range (160 nm). The classical approach for the PDS is, therefore, the usage of photomultipliers (PMT) coated with tetraphenyl butadiene (TPB) which shifts the UV photons to about 430 nm, a wavelength at which the PMTs are directly sensitive. While the basic concept is well established and was used in several experiments as LArIC, ADEL and Dark Side for example, some aspects of the coating are not well understood. A comprehensive understanding of the PMT behavior, the efficiency of TPB coated and polished PMTs, was followed by a standard procedure, were measured with a set-up at INFN Padova. Also, the immersion of the PMTs with different coating tried to testing showed a significant difference in fast and slow light propagation for the polished PMTs.

LIQUID ARGON TIME PROJECTION CHAMBER (LArTPC)

The liquid argon technology has been chosen for the DUNE underground experiment for the LArTPC for detectors for the study of neutrino oscillations.

- WA105 is a large demonstrator of the dual-phase liquid argon TPC.
- Excellent tracking and calorimetric capabilities (superior to currently operating neutrino detectors).
- Cost effective solution.
- Provides excellent imaging capabilities.
- Built inside a crystal tank.

The design of the WA105 detector (as shown in Fig. 1):

- The crystal has a 1 m thick which limit the heat transfer to make a maximum of 5 W/m2.
- Inner volume has dimensions of 3.8x4.1x3 m (WA105) containing about 700 ton of LAr.
- The sensitive volume has dimensions of 3.4x3.8x2.8 m and contains about 640 ton of active mass.
- The large depths of the detector lead to upscatters of up to 2 G at the cathode which consists of wires to achieve a high transparency for the photons of the primary scintillation light.
- A set of 36 PMTs (Hamamatsu R5912-02mod) are installed about 1 m below the cathode.

Since the PMTs are not directly sensitive to the 160 nm of the primary scintillation light, the surface of the PMTs was coated with (TPB). TPB shifts the light from 12 nm to about 430 nm, a wavelength at which the PMTs highly sensitive.

The basic principle of a LAr TPC is the following (Fig. 2):

- A charged particle traversing the LAr ionizes the argon atoms creating a large amount of electron-ion pairs on its way through the gas.
- Applying an external electric field, the drift, the electrons and ions are separated and drifted to the anode and cathode respectively.
- Electrons produced in the liquid argon are extracted to the anode.
- A readout based on Large Electron Multipliers (LEM) provides amplification before the charge collection inside an anode plane alone with a collection of 20%.
- A silicon detector for t_d ± 10 ns to be detected by an array of PMTs.
- The PMTs (Hamamatsu R5912-02mod) used have:
  - Polished cone surface.
  - Relatively large-detection area (diameter of 8 inches).
  - 14 layers focused dynode stage.
  - Narrow spread in transit time.
  - Excellent charge resolution.
  - Gain ~ 1 x 10^{9}. The PMTs were characterized in terms of quantum efficiency at 120 to 250 nm with a maximum resolution of 20%.

COATING SETUP

An evaporation system (Fig. 3) suitable for large and convex surfaces (instead of a flat one) was designed for the coating of the convex surfaces of the PMTs used for the 36 PMTs inside the CARICO L160 TDC TPC.

- A motorized rotating feedthrough on the top of a vacuum chamber, on which the PMT is mounted at an angle of 40° with respect to the outer.
- A Knudsen cell is mounted below the PMT.

Evaporation is carried out following a protocol that guarantees a high optical yield and uniformity. The procedure takes only 3 h for each PMT.

- When the pressure inside the vacuum chamber is at the order of 1 x 10^{-6} mbar.
- The stainless steel target is rotated at 20 rpm/h.
- The temperature regulator is set to 220°C.
- When the temperature reaches 220°C, the shutter over the cell is opened, letting the material to reach the PMT by evaporation.
- The monitor displays the deposition thickness value both per unit of time.

EVAPORATION UNIFORMITY OVER THE PHOTOCATHODE SURFACE

The most important parameters of the evaporation process have been evaluated by evaporating TPB over a PMT mockup, covered in part with small square foil used as sample points. Figure 4 shows the mock-up. The uniformity of the evaporation over the entire convex photocathode is measured by weighing each sample before and after the process, with a high precision scale. The TPB density as a function of different distances from the PMT window center and the TPB density at different rotation angles at fixed radial distances from the center (0–20 mm) (Fig. 5).

TEST OF THE COATING RESISTANT

The coating done to the PMTs was covered for 10 min of resistant inside a small dewar (Fig. 6):

- Fast rinsing (PMT covered with LAr in less than 30s).
- LAr soaked and LAr drops reached the surface.
- Small holes observable only for polished PMTs due to thermal shock when drops landed (Fig. 6).

CONCLUSION

For the next generation of neutrino oscillation experiment detectors with about 100 ton active mass will be needed. The WA105 detector is a necessary intermediate step for those detectors to prove their technical feasibility and to understand better the effect on the overall photon detection efficiency on the TPB coating stability. The optical characterization of the detector after the coating process was carried out by means of a VUV measurement system developed at the INFN Padova (Fig. 15).

The study was done for two types of PMT’s surface: polished and sandblasted (Fig. 10).

A comparison between the current delivered from the two devices, measured alternatively with a Keithley 2400 sourcemeter and corrected with the photodetection efficiency (e_\text{ph}) by Hamamatsu, provides the relative Q_{\text{TPB}} of the device under test. Available wavelength ranges from 120 to 250 nm with a measurement resolution of 1 nm. The mounting of the device on a rotation stage allows to vary the measurements of the Q_{\text{TPB}} in various positions of the photocathode.

A sample of PMTs, were characterized in terms of quantum efficiency at λ = 120 nm and the distribution of the relative Q_{\text{TPB}} is shown (Fig. 11). The obtained values are distributed in the 10%-20% range, with an average value of 14±0.02 and 13.2±0.01 for polished and sandblasted PMTs respectively. Fluctuations are mainly due to different sensitivity of the bolted photocathodes on different devices.

BIBLIOGRAPHY


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