



Multi-PMT optical module for undersea neutrino telescopes

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Abstract: For the design of an optical module for deep-sea kilometer sized neutrino telescopes it is important to optimize performance versus cost. In the framework of the KM3NeT design study we have designed an optical module consisting of a single glass pressure vessel and containing up to about 40 small photomultiplier tubes including their readout electronics. The advantage is a much larger photocathode area in a single vessel than is possible with large photomultipliers. Added advantages are obtained for triggering.

Introduction

In the past several years a number of underwater and under-ice neutrino telescopes have become operational. These are relatively small telescopes and at present the move is toward telescopes with an instrumented volume of at least a cubic kilometer, which increases the sensitivity of the telescopes by more than an order of magnitude. The first such detector, Ice Cube, is now being constructed in the Antarctic icecap. In Europe the design has started for a large underwater detector to be deployed on the bottom of the Mediterranean Sea. It is in the framework of this design study that we have investigated the use of a novel optical module consisting of a single glass pressure sphere containing many small photomultiplier tubes. This contrasts with the conventional approach of fitting the largest possible photomultiplier in a pressure sphere.

The original idea for producing such a sphere was put forward by the late Esso Flyckt at the first VLVvT workshop held in Amsterdam in 2003[1]. This Multi-PMT configuration has several advantages. First of all the total photocathode area that can be fitted in a standard 17" glass pressure vessel is significantly larger than with large photomultipliers. As an example 40 3" photomultipli-

ers can be fitted into such a sphere giving a total photocathode area of about 1740 cm², whereas a single 10" tube gives only around 500 cm². Even the largest currently catalogued tube, a 13", has an area of 850 cm². The 3" tubes are also insensitive to magnetic fields of the size of the Earth's and therefore require no shielding as large tubes do.

The second advantage comes in the rejection of background. In the Mediterranean Sea the background is produced from Cherenkov radiation produced by electrons from the decay of ⁴⁰K, which is present in the seawater. This produces a background of mostly single photons at a rate of about 100 Hz per square centimeter of photocathode. At times light produced by living organisms can double this rate. Also this background consists of single photons. The Cherenkov light signal from a traversing muon produces light from a single direction with a significant probability of having more than one photon arriving simultaneously. Separation of single from multiple photon hits is therefore the method of choice for reducing the background. Photomultiplier tubes typically have pulse height resolutions of 30% for single photon hits. This means that about 1% of all single hits will be reconstructed as two photon hits. So a large, 10", photomultiplier will produce a

“trigger” rate of 500 Hz from background and efficiency for genuine two photon signals of 50%, when cutting at a measured pulse height of two photoelectrons. In the case of small photomultipliers two photons can unambiguously be recognized if the two photons hit two separate tubes. In the 40 tube configuration we can select two adjacent tubes as the signal comes from a single direction, whereas the background comes from all directions. This yields a background rate of about 120 Hz. This reduction of the background by a factor four is accompanied by an increase in sensitive area of a factor of three. This gives an overall gain in signal to noise of more than an order of magnitude. Simulations have shown that these optical modules perform somewhat better than configurations with large PMTs when the total photocathode area per detector line is kept constant [2]. Small phototubes also provide better transit time spread features and somewhat better quantum efficiency.

Besides the background from potassium and bioluminescence there is the background caused by muons created in atmospheric interactions. These muons come predominantly from above and need to be correctly reconstructed, as any poor reconstruction inevitably results in background for the signal from neutrinos. The fact that the Multi-PMT solution has a uniform acceptance independent of the direction of the detected light means that the reconstruction quality will also be independent of the track angle and will contribute to an increase of signal to noise. This effect has yet to be quantified in simulations.

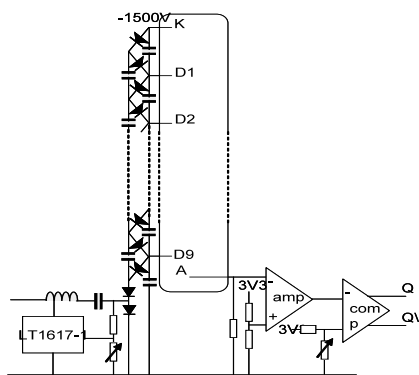


Figure 1: A schematic diagram of the Cockcroft-Walton high voltage power supply

Implementation

The advantages of the Multi-PMT approach seem to be overwhelming; however these could all be nullified if the cost of the system becomes too high. It turns out that the cost of photomultiplier tubes scales approximately as the area of the photocathode for tubes larger than 2". This means that this is no problem. The major concern is of course the generation of the high voltage for the tube and the cost of the readout electronics.

The readout method is the subject of a separate paper to this conference. For the high voltage supply we have developed, at Nikhef, a low cost active base. This base follows the Cockcroft-Walton method. The circuit diagram is shown in figure 1.

This high voltage supply is incorporated onto a PCB which fits within the diameter of the rear of the Photonis XP53X2 photomultiplier¹ used for the test (see fig. 2). The high voltage supply also incorporates an amplifier and comparator so that the final signal output is an LVDS square wave-over-threshold pulse. Fig.3 shows the output of the circuit in response to a single photoelectron signal. The cost of these units comes in at less than €25 per board. The power consumption of each of these HV units is below 100 mW for a total consumption inside the sphere of about 4 W.

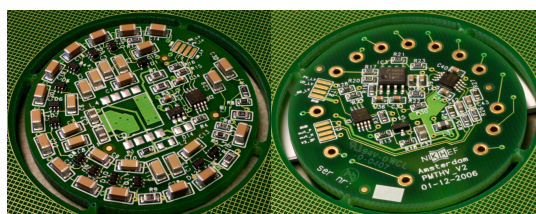


Figure 2: The Cockcroft-Walton HV supply. Amplifier and comparator are on the right and high voltage generator is on the left.

Measurements and calculations of the heat transfer from inside the sphere to the seawater outside show that a temperature of below 30° C can be maintained if less than 7 W is dissipated inside

¹ The Photonis company kindly donated 35 of these tubes for our tests.

the sphere. The present design thus leaves a tight but not unreasonable 3 W for the remaining read-out electronics.

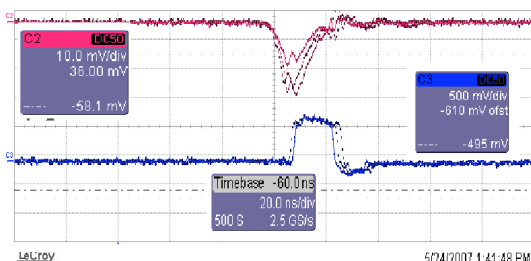


Figure 3: Oscilloscope trace of several single photo-electron signals (upper trace, 10mV/div) and the time over threshold output (lower trace, 500mV/div). Time base is 20ns/div.

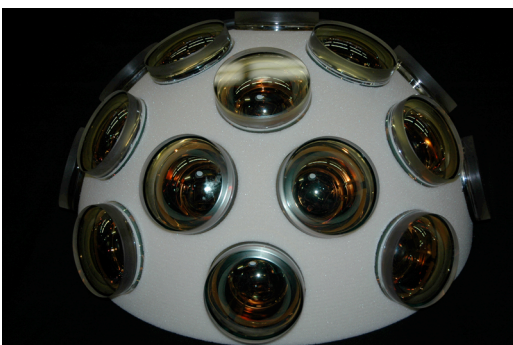


Figure 4: A total of 20 photomultiplier tubes arranged in a hemispherical Styrofoam shell.



Figure 5: The high voltage end of the photomultiplier tubes fitted in the Styrofoam shell. Most of the attached cables are for testing purposes only.

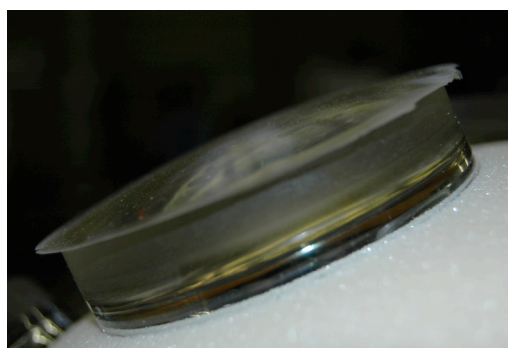


Figure 6: The silicon rubber “contact lens” shaped to the inner diameter of the glass sphere and connected to the face of the photomultiplier tube.

The suspension of the phototubes themselves inside the sphere was solved by machining expanded Styrofoam to a spherical shape and then milling holes for the photomultiplier tubes. In the production phase of such an optical module of course this technique will be replaced by expansion molding. Fig. 4 shows the arrangement for one half of the sphere containing 20 photomultiplier tubes, while fig. 5 shows the inside of this setup with the high voltage boards in place. The tubes have axial freedom of motion of around 5 mm to allow for the deformation of the sphere under the pressure of around 400 bars. At this pressure the diameter of the sphere reduces by around 4 mm. The optical contact with the glass is assured through the use of silicon rubber “contact lenses” glued to the face of the photomulti-

plier, as shown in figure 6. The particular compound being used is GE RTV615, which has transparency properties similar to the Wacker 'Siligel' as used by Antares. The maximum thickness of the "contact lens" is 4 mm. Shaping the front face of the tube to match the inner surface of the sphere or faceting the inner surface of the sphere are being investigated.

Conclusions

The use of many small photomultiplier tubes inside a glass pressure vessel has many advantages over a single large tube.

- Signal to noise reduction of more than one order of magnitude.
- Larger photocathode area in each pressure vessel.
- Uniform acceptance.
- No magnetic shielding needed
- Typically somewhat better quantum efficiency

Tests are proceeding to verify the full design.

References

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- [2] S.Kuch, Ph.D.Thesis, University of Erlangen, 2007.