Instrumentation of A New Direction Sensitive Segmented Optical Module.

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Abstract

An efficiency increase in the intermediate energy region for an underwater neutrino telescope could be an important development to gain better sensitivity in the study of the physical processes concerning the deep universe and to have a useful tool for better detector calibration with atmospheric neutrinos. A new, direction sensitive, segmented optical module is under development in Genova. According to preliminary simulations, this kind of device can - together with a dedicated track reconstruction strategy - improve by a significant factor the telescope sensitivity at low and intermediate energies. This optical module will feature a newly-developed 10” Hamamatsu 4-anode PMT coupled to dedicated electronics to be integrated in the NEMO readout chain. The first directional OMs will be installed at the NEMO test site during the preliminary phase of the experiment.

Key words: Neutrino Detector, Cosmic Rays, Photon Detector
PACS: 95.55.Vj, 13.15.+g, 29.30.-h, 42.79.Pw

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1. Advantages of Directional Optical Modules

Deep sea neutrino telescopes were designed - since the late 1970s - with a common structure: an array of vertical structures featuring a series of layers of light sensitive elements, usually called Optical Modules (OM). After the pioneering work of the Dumand Collaboration [3], new techniques were developed both for sea water and for polar ice detectors [4], [5], [6], [7].

All the developed optical modules have a very similar structure. A pressure resistant glass sphere hosts a large hemispherical photomultiplier, optically coupled to the sphere using a layer of optical gel or glue. The power supply and front-end electronics are usually included in the sphere and directly connected to the PMT. This setup is well proven, and allows for good track reconstruction if the number of hits is sufficiently high - i.e. 10 or more - before filtering and noise suppression. This means that the track length must be sufficiently long, due to the limited density of sensitive elements which can be installed in this kind of detector. A steep reduction in efficiency at enegies below 1 TeV is expected in a cubic kilometer scale detector, even when instrumented with $\sim 10^4$ OMs.

The hit multiplicity is partially recovered by grouping several OMs in each layer: this is realized,

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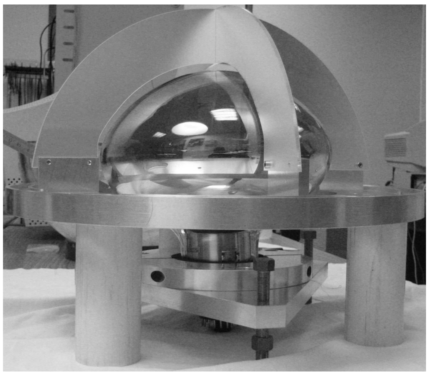

Fig. 1. Placement of the mirrors before the installation of the multianode PMT in the pressure resistant glass sphere.

for example in ANTARES, with 3 OMs looking in different directions and placed at small distances from one another [8]. Nevertheless, the number of OMs is limited by cost considerations, and for low energy tracks the poor definition of the track position w.r.t. the OM itself is a limitation on the reconstruction capability for the detector as a whole.

We decided to ask industry to develop a 4-anode 10" PMT with at least the same photocathode area as a traditional PMT of equivalent diameter. This solution has a better granularity, but is compatible with the present readout chain with only minor improvements.

Such a kind of PMT can be coupled to a custom light guide - divided in 4 sectors with mirrors - which can relate the incoming light direction to the photocathode quadrant which is hit. Thus, the angular acceptance (granularity) of each quadrant is finer than that of a single anode PMT, allowing the position of the track w.r.t. the OM to be much better measured. This can improve the track reconstruction. The arrangement of the PMT and the mirrors, before installation in the glass sphere, is shown in Fig. 1.

Several simulations were made, or are underway, to determine the improvement achieveable using these directional OMs, as shown in Fig. 2. The effective area of a cubic kilometer detector, with NEMO geometry, increases up to more than a factor of two at low energies ($\sim 100\,\mathrm{GeV}$) and reaches the "standard value" at energies of the order of $100\,\mathrm{TeV}$. In fact, at high energies the track emits light which can be collected by several towers, so no further improvement is possible, since the effective area of the detector is almost equivalent to the geometrical area of the whole detector. On the other hand, at low energies the effective area is the sum of effective areas of several small detectors (corresponding to the single vertical structures which make the whole telescope), so the potential increase is much larger.

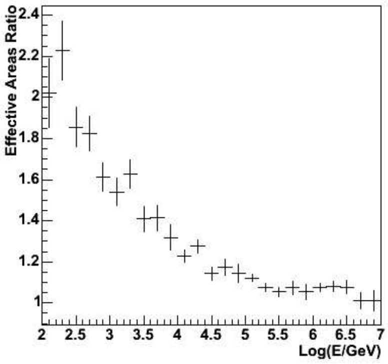

Fig. 2. Ratio of the effective areas calculated for a cubic kilometer detector with and without directional OMs: a gain of a factor 2 is predicted at low energy.

2. Directional OM Realization

The realization of a directional OM requires the development of completely novel technologies, including:
- a 4-anode PMT,
- the light guides,
- power supply and voltage divider,
- frontend electronics.

2.1. *The 4-anode Photomultiplier*

The 4-anode PMT was realized by Hamamatsu, modifying a R7081 PMT. Two samples were delivered. The angular acceptance was measured by the manufacturer and - when compared to a R7081 model - shows a more uniform behaviour as a function of the incidence angle - mainly due to the larger surface of the first dynode - with a steep decrease in performance only seen at polar angles

	Requirement	R7081	Prototype
nominal voltage	$< 2000\,\mathrm{V}$	1340 V	1550 V
gain	$5 \cdot 10^7$	$5 \cdot 10^7$	$5 \cdot 10^7$
peak to valley ratio	> 2	2.8	~ 3
dark noise (thr. 0.3 pe)	$< 10000\,\mathrm{Hz}$	910 Hz	$\sim 1200\,\mathrm{Hz}$
transit time spread	$< 4\,\mathrm{ns}$	3 ns	$\sim 4\,\mathrm{ns}$

Table 1
Performance of the 4 anode prototype compared to a 10-inch Hamamatsu R7081-20.

exceeding 80 degrees. A series of measurements was performed at the NEMO group test facility at INFN Sezione di Catania. We studied the single photoelectron peak, the transit time spread, the gain and the cross-talk of the prototype to have a complete characterization and to allow a comparison with previous models. A summary of these measurements is shown in Table 1.

2.2. *High Voltage Generation*

In a deep sea neutrino telescope, high voltage is generated directly inside the pressure resistant sphere. For commonly used PMTs, such as the Hamamatsu R7081-20, commercial high voltage generators exist, produced for example by ISEG Spezialelektronik GmbH. A dedicated power supply was developed and built by the INFN Sezione di Genova for the 4-anode PMT, and is shown in Fig. 3.

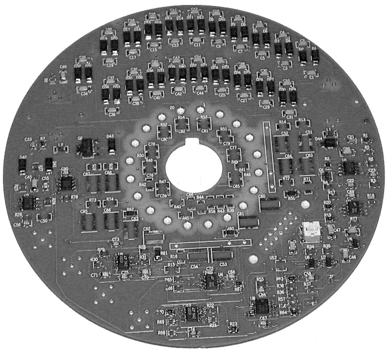

Fig. 3. The newly developed power supply and voltage divider for the 4-anode PMT.

2.3. *Cross-Talk Handling*

The main issue with such a large multi-anode PMT is cross-talk between the channels: this is due both to electric coupling between dynode cascades and to wrongly collected photoelectrons. The cross-talk was initially measured in INFN Sezione di Catania [9], showing a significant amount of fake hits due to electric coupling between the dynode cascades. This is evident when looking at the signals, as shown in Fig. 4.

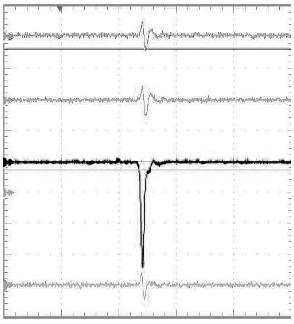

Fig. 4. The real and induced signals on the four anodes when only one quadrant is lighted (black line): while real hits have a significant area, fake hits have oscillatory behavior and negligible area.

A dedicated active filter was designed and realized at INFN Sezione di Genova . With this filter, the oscillatory signals were attenuated and the only remaining cross-talk was related to internally reflected photons and wrongly focused photoelectrons. The frequency of fake signals is roughly equal to the number of photoelectrons of the main signal, making possible a good discrimination of the lighted quadrant.

All these measurements were realized on the naked PMT, without glass sphere, optical guide or mu-metal screen.

2.4. *The Light Guide*

To optically couple the multi-anode PMT and the pressure resistant sphere a custom light guide is needed: directional behavior is achieved with a sufficiently thick guide (8 cm or more, i.e. the thickness is comparable with the transverse dimensions of the quadrants) and a mirror system that guar-

Fig. 5. The complete Directional Optical Module ready to be tested. The mu-metal cage and the mirror system are visible.

antees a good separation between the quadrants. The guide acts as a Winston cone: the total effective area of the OM is almost unchanged, but a good correlation between incident light direction and hit position is achieved [10].

Both a plexiglass and an optical gel guide were realized. The first has better optical performance, while the second features far better mechanical characteristics due to the greater elasticity and the smaller number of different materials involved. The optical gel guide was chosen for our prototype.

The light guide is completed by a mirror system that concentrates the light on the different quadrants of the cathode. The mirror system was realized with custom-shaped plexiglass plates and high reflectivity foils. Several foils were characterized - based on both aluminized plastics and on multilayer sandwiches of many transparent foils of different refractive indices - before choosing the best solution [11]. The best performance was achieved with 3M Vikuiti ESR Film [12], a non-metallic adhesive multilayer foil. This foil was used in our prototype.

A photograph of the OM is shown in Fig. 5.

2.5. *Assembly and Testing*

The first Directional Optical Module was completely assembled, featuring the multi-anode PMT realized by Hamamatsu and the electronics developed in Genova.

Attenuation measurements were made to compare the response of the OM with the response of the "naked" PMT. The preliminary results confirm our simulation, and show a decrease of 5% in the light reaching the photo-cathode.

Following on from this preliminary characterization, a more complete characterization of the OM as a whole is underway in our water vessel, detecting Čerenkov light produced by cosmic muons.

3. Perspectives and Acknowledgments

A prototype for a directional OM for deep sea neutrino telescopes was realized at INFN Sezione di Genova. The characterization of this OM is underway, in preparation for the installation of two directional OMs at the NEMO Capo Passero site.

Reconstruction code optimization is underway, and preliminary results are very encouraging. An increase of the overall detector sensitivity of a factor of two is predicted by MonteCarlo simulations at low energies.

I'm grateful to Katia Fratini, Mauro Taiuti and Marco Brunoldi for their valuable help.

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