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 a 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 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-anodic PMT coupled to a dedicated electronic to be integrated in the NEMO readout chain: the first directional OMs will be installed in the NEMO test site during the preliminary phase of the experiment.

Key words: Neutrino Detector, Cosmic Rays, Photon Detector
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1. Advantages of Directional Optical Modules

Deep sea neutrino telescopes were designed since the late 70s, 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 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 quite a 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 large. This is due to the limited density of sensitive elements which can be installed in such kind of detector. A steep reduction of the efficiency under 1 TeV is the observed effect for a cubic kilometer scale detector, instrumented with $\sim 10^4$ OMs.

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

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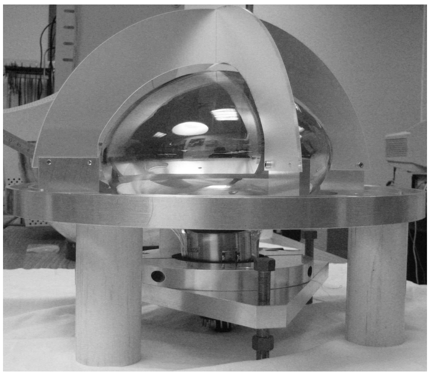

Fig. 1. Placement of the mirrors before the installation of the multianode PMT in the pressure resistant glass sphere.

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

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

Such a kind of PMT can be coupled to a proper 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 of each quadrant is smaller than that of a single anode PMT. Therefore the position of the track w.r.t. the OM is measured much better. This can improve the track reconstruction. The arrangement of the PMT and the mirrors, before the installation in the glass sphere, is shown in Fig. 1.

Several simulations were done and are underway to determine the improvement which can be achieved 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 TeV. In fact, at high energies the track emits light which can be collected by several towers, so no 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 increase is large.

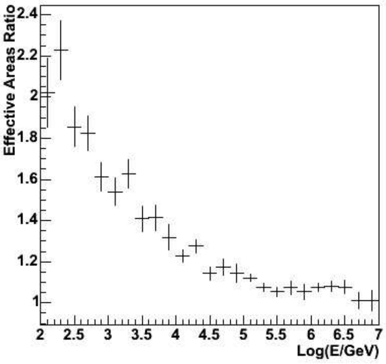

Fig. 2. Ratio of the effective areas calculated for a cubic kilometer detector with and without directional OMs: a gain of a factor 2 is predicted at low energy.

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 compared to a R7081 model, shows a more constant behaviour as a function of the incidence angle, with a steep decrease at angles greater than 80 degrees: this is mainly due to the larger surface of the first dynodes.

	Requirement	R7081	Prototype
nominal voltage	< 2000 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 Hz	910 Hz	~ 1200 Hz
transit time spread	< 4 ns	3 ns	~ 4 ns

Table 1
Performances of the 4 anodic prototype compared to Hamamatsu R7081.

A series of measurement were performed at the testing facility of the NEMO group at the 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 make feasible 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 Hamamatsu R7081-20, commercial high voltage generators and supply exist, produced, for example, by ISEG Spezialelektronik GmbH. A dedicated power supply was developed and built by Genova division for the 4-anode PMT, it is shown in Fig. 3.

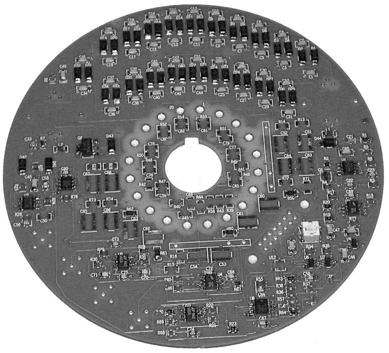

Fig. 3. The newly developed power supply and voltage divider for the 4-anode PMT.

2.3. *Cross-Talk Handling*

The main issue with a so large multi-anode PMT is the cross-talk between 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.

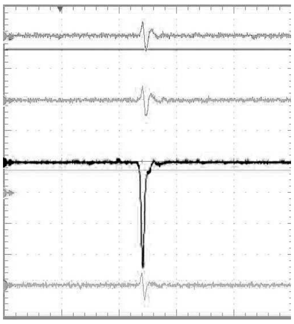

Fig. 4. The real and induced signals on the four anodes when only one quadrant is lighted (black line): while real hits have a significant area, fake hits have oscillatory behavior and negligible area.

A proper active filter was designed and realized in Genova. With this filter, the oscillating signals where attenuated and only the 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 measurement where 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 proper light guide is needed: the 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 guarantees a good separation between the quadrants.

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

The guide which is so realized acts as a Winston cone: the total effective area is almost unchanged, but a good correlation between incident light direction and hit position is achieved [10].

Both a plexiglas and an optical gel guide where realized. The first has better optical performances, while the second features by far better mechanical characteristics. This is due to the greater elasticity and to the minor 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 properly shaped plexiglass plates and high reflectivity foils. Several foils were characterized, both based on aluminized plastics and on multilayer sandwiches of many transparent foils with different refractive indices before choosing the best solution [11]. The performances were achieved with 3M Vikuiti ESR Film [12], a non-metallic adhesive multilayer foil, which was used in our prototype realization.

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

2.5. *Assembling and Testing*

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

We did an attenuation measurement, to compare the response of the OM with the response of the "naked" PMT. The preliminary results confirm the simulation we did, showing a decrease of 5% of the light that reaches the photo-cathode.

After 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 in the INFN Sezione di Genova. The characterization of this OM is underway, in sight of the installation in the Capo Passero site of two directional OMs.

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.

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