

Development of Large Effective Area and Direction Sensitive Photodetectors

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Abstract

In this note is described the status of the development of large effective area and direction sensitive photodetectors in Genova. We are developing a light guide system for multianodic devices or for PMTs array based on Winston's cone concept; we are also constructing a hybrid PMT with four-folded direction sensitive reading.

I. INTRODUCTION

In a large neutrino telescope the sensitive unit is the optical module, i.e. a glass sphere containing a photodetector and part or all the readout electronics. Up to now, every actual or proposed experiment (with the exception of Lake Bajkal, which will be extensively described later) is supposed to use as a photodetector a simple commercial PMT, 10 to 15" of diameter. We suggest the use of direction sensitive devices, in order to increase the efficiency of the detector decreasing the number of optical modules (OMs), in particular for tracks characterized by low hit multiplicity.

We are developing 2 different systems of light collection, one to be used with 4 commercial 5" PMTs, the other to be used or with an array of small PMTs or with a multianodic device, PMT or HPD, for example. In the meantime we are constructing a prototype of hybrid PMT based on reconversion of primary photoelectrons in a scintillator or in a proportional counter.

II. LIGHT GUIDES FOR 5" PMTs

The first and simplest possibility we are investigating is the implementation of a system of 4 commercial 5" PMTs, coupled to the pressure resistant sphere with Plexiglas light guides.

We basically want to construct a specific Winston's cone to collect light to the PMTs, occupying the largest possible fraction of the volume of the sphere (fig. 1): for this reason the PMTs are not symmetric w.r.t. the sphere axis. This feature makes the light guide harder to be designed, so we started constructing a plaster model of a single sector, and we are now producing a CAD model for factory production.

To ensure the reflection of the light we will use 3M™ Radiant Mirror [1] material, a multilayer reflective film which gives more than 95% (typically 97÷98%) reflectivity in the

whole visible range. The reflective behaviour of this material is due to total reflection of light at the various interfaces between the different layers: this means that there is no metallic deposition that can cause electrical discharges involving the photocathode of the PMT.



Figure 1: 5" PMTs cluster



Figure 2: Plaster model of light guide

III. LIGHT COLLECTORS FOR MULTIANODIC PHOTODETECTORS

As we saw in the previous section, a proper light collection system can convert the information on the direction of incoming light into an information on the position of the hit

on the photocathode. Such a collector can be very effective if used in combination with a multianodic photodetector: in fact, actually available multianodic photodevices are usually characterized by a small and almost flat photocathode, features which make them not suitable as active elements in an OM of a neutrino telescope.

The very good segmentation and imaging capability of, for example, a HPD [2] make this device extremely interesting to reconstruct the position of the track w.r.t. the OM, provided that a proper system can direct the light coming from different directions to different regions of the photocathode. We are developing a “wasps’ nest” light collector which is expressly designed to achieve this goal: the idea is basically an implementation of an array of Winston’s cones which couples the inner surface of the pressure resistant sphere with the front window of the photodetector (see fig. 3).



Figure 3: A 10” HPD coupled to a light collector

This collector slightly increases the light collection efficiency for directions near to the perpendicular to the axis (mainly due to the presence of the mirror at the bottom of the system, which is not oriented along a diameter of the same sphere as all the others mirrors), whereas there is a very good correspondence between incoming light direction and illuminated photocathode region. This can be argued looking at fig. 4, but it was also demonstrated with a simple simulation based on ray tracing used LITRANI (LIght TRansmission in ANIsotropic media) code [3].

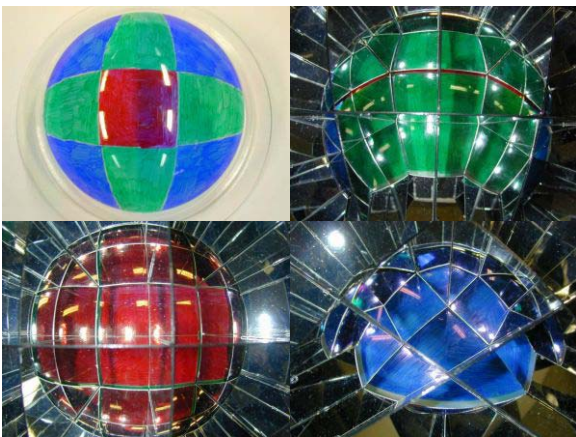


Figure 4: Different views of a coloured dome through the light collector

This system can be also used with an array of small commercial PMTs, but the geometrical coverage is of course better if one can have a single multianodic device in its focus.

At the moment of this writing, we have in our institute a prototype realized with aluminized PETG, which has a reflectivity in the visible region greater than 92% and that can be coupled to a 10” PMT. We are constructing a second prototype in which the reflective material is not metallic (to avoid eventual discharges of the photodetector), but is the 3M™ material which was already described in the previous section.

IV. HYBRID PHOTOMULTIPLIERS

The most challenging project we are pursuing is a prototype of a hybrid photomultiplier based on the Lake Bajkal Quasar370 and the Philips SMART. This two objects have the same main features, i.e. a large, almost hemispherical photocathode from which the photoelectrons are accelerated to an inorganic scintillator by a high voltage (20 kV or so). The light produced in the scintillator is then read by a commercial small-diameter PMT. A schematic of the Quasar370 is in fig. 5.

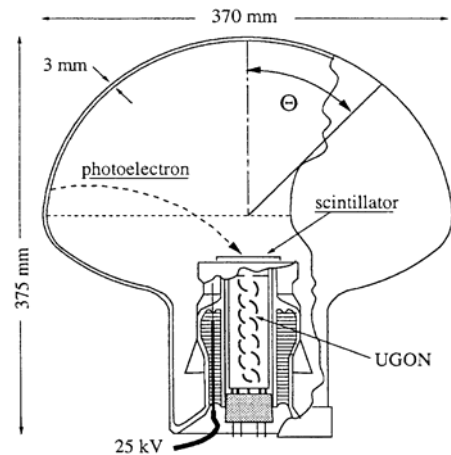


Figure 5: Schematic of a Quasar370

This kind of photodetector has two main positive features: better energy resolution and transit time spread (TTS) than an equivalent diameter PMT. The improvement of energy resolution is due to the high gain of the first step (the reconversion of the primary photoelectron in the scintillator): a typical spectrum of a Quasar370 tube is reported in fig.6. The decrease of TTS is possible if the trajectories of primary photoelectrons are optimized: in fact, TTS in large-diameter PMTs is mainly due to the difference in path-length of photoelectrons between the photocathode and the first dynode.

The aim of an optimisation of TTS was one of the guidelines of our development: for our 13” project, thanks to a careful design of the back half of the tube, the simulations said that TTS can be reduced (in the path between photocathode and scintillator) to approx. 1ns. This TTS has to

be combined with the TTS of the PMT used to collect the light from the scintillator (which is less than 1ns for PMTs smaller than 2" of diameter) to obtain a total TTS smaller than 1.5ns, to be compared with the values for commercial PMTs of that diameter, i.e. 3÷5ns.

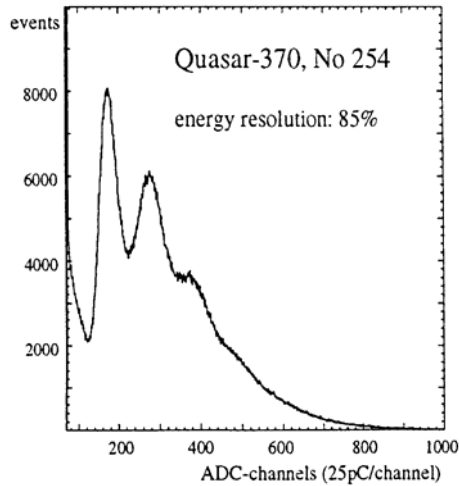


Figure 6: Spectrum of a Quasar370: it has to be noted the good separation on the single-photoelectron peak from background

The other guidelines of our project were a simple design, which is expressed in a perfectly hemispherical front half and a segmentation of the active area which is expressed by an optimisation of primary photoelectrons trajectories, to preserve a rough imaging in the focus of the accelerating potential. According to the simulations, at 25kV a pointlike source on the photocathode becomes a 5mm diameter spot on the scintillator (figs. 7 and 8).

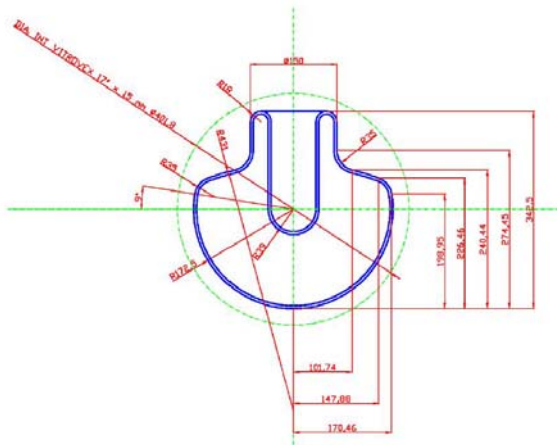


Figure 7: Improved design for our prototype

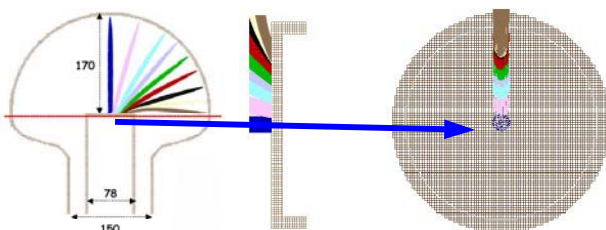


Figure 8: Imaging capability of our prototype at 25kV

To detect the photoelectrons, three ways were taken into account: silicon based detectors (such as in HPDs, this way was stopped trying to achieve a collaboration with expert people), “proportional chambers” and a scintillator, like in the original projects.

A. Silicon based HPMT

As it is shown in [4] a silicon detector, s.a. a APD, can be used to detect primary photoelectrons. The performances of this device are very good in energy resolution but have to be improved in timing, if one decides to use them in a neutrino telescope. In principle, our prototype can be equipped with a system of silicon detectors, with almost no modifications w.r.t. the actual design.

We have contacts with people working on HPD at CERN and with industries involved in this kind of development, but, at this time, we are not directly following this path. For this reason, I won't say more about this possibility.

B. Gas based HPMT

A second possibility we are investigating is the use of a proportional chamber as photoelectron detector. We tested a “leak microstructure” (constructed by Mariano Lombardi, INFN-LNL), which consists of a copper plate at high negative voltage and an array of steel needles at 0V, in isobutane gas. An aluminized Mylar window, at the same potential of the copper plate, guarantees the right shaping of the electric potential. In this way, the electrons that enter the gas volume are attracted to the needles: at short distances to them, the gradient of the electric field is large, so there is a multiplication due to ionisation, contained in a very small volume. A schematic of this detector is shown in fig. 9.

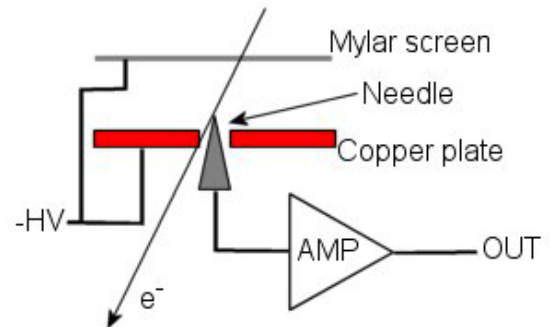


Figure 9: Schematic of a leak microstructure

In our set-up the distance between the copper plate and the Mylar window is 1mm and the needles are placed on a square grid of 1mm step. With HV set to -1500V and a fast, homemade amplifier we get signals of 100mV height, ~1ns rise time and ~40ns fall time. We also got a good time resolution for this device: mainly thanks to the Mylar screen, as a matter of fact, we got a time distribution of hits (measured in coincidence with a thin scintillator coupled to a 1/2" PMT) whose spread was ~10ns FWHM.

The timing of this kind of detector, in principle, can be lowered to values ~4ns, choosing a proper gas mixture of

isobutane and argon: this value is expected to be the physical limit because of the finite drift speed of the electrons in gas.

At present time, this solution is subleading with respect to the “scintillator based” one: in fact, it turned out that the implementation of the proportional counter into a HPMT is a challenging task, mainly because of the thinness of the window separating the gas from the vacuum where the photocathode is evaporated.

C. Scintillator based HPMT

The main project we are developing is a “direct” improvement of the Quasar370 tube, i.e. a HPMT with a raw imaging capability. In our project, the YAP scintillator layer is “observed” by 4 1” PMTs: thanks to the focusing capability shown in fig. 8, we expect a good correspondence between the quadrant of the photocathode from which the photoelectron is emitted and the PMT that fires.



Figure 10: Implementation of the 4 PMTs in the centre of the HPMT

V. STATUS AND PERSPECTIVES

A. Light guides

At the moment of this writing, we have a prototype of the light guide for the 10” PMT and we are constructing another one with improved light collection efficiency at the edge. We plan to implement it in a glass sphere in the next months.

In the meantime, we are constructing a CAD model of the light guides for the 5” PMTs, which should be constructed before the end of 2003.

B. Hybrid photomultipliers

We are getting know-how about photocathode evaporation on a smallest version of the glass bulb of the HPMT; in the meantime we are doing a series of mechanical tests on the largest version.

The vacuum line and control system for evaporation is complete and we expect to perform the first attempt in the first half of November.

C. Simulations and far plans

Everything we are doing has to both by simulations and tests: we expect to perform a simulation of the performance of our devices implemented in a km³ detector in the first half of 2004.

We have also started the development of a facility to test complete OM in water: this will be done in collaboration with Pisa section of INFN and it will be used to test all our prototypes. Some test in collaboration with Saclay lab of IN2P3 is also foreseen to have a comparison with previous results

VI. CONCLUSION

In Genova we are developing a series of solutions to achieve in a single OM more signals, bringing information about the direction of incoming photons.

We believe such kind of devices can ameliorate the performances of the detector without proliferation of the number of OMs and can also give more information for reconstruction of short tracks.

We are following two main projects: a system of light guides for multianodic devices or for arrays of PMTs and a particular type of hybrid PMT.

According to our plans, we expect to have fully functional and characterized prototypes before the second half of 2004.

VII. REFERENCES

- [1] [http://www.3m.com/product/f_index/Film_3M\(TM\)_Radiant_Mirror_\(Z1\)_00.jhtml](http://www.3m.com/product/f_index/Film_3M(TM)_Radiant_Mirror_(Z1)_00.jhtml)
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- [4] M.Giunta, *The HPD Detector*, in these Proceedings – Y. Yoshizawa, *Developments for Large Formats Detectors*, in these Proceeding