# Deep Underwater Measurements of Cosmic Muons Intensity by the String Detector of Five Photomultipliers

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**Abstract**

Here we present the results of an experiment performed deep underwater -depths 3700-3900 m-, in order to measure the muon flux. The detector consisted of a string of five "HAMAMATSU R-2018" PMT's, lowered from the "Ac. Mstislav Keldysh" research vessel. The measurement was performed off the S.W coast of Peloponese, Greece. During the measurements the ship was drifting. The cosmic ray muons were detected by their Cerenkov radiation in seawater. The effective area of the string-type detector, for vertical muons, was 240 +/- 60 $m^2$. The muon flux at the above mentioned depths was measured to be (0.98+/- 0.4)x $10^{-8}$ muons/$m^2$ sr sec. This result is in good argeement with previous measurements.



## 1) Apparatus

The deep underwater detector for measuring the cosmic muons intensity consists of five photodetectors (PMT), a deep underwater box for the string controller (CS), autonomous power supply (PS), and the block of pressure and orientation gauges (PG).

As photodetectors, the R-2018 HAMAMATSU photomultipliers with a hemispherical photocathode were used. The photocathode diameter is 382 mm. The spectral sensitivity range is 350-650 nm. The quantum efficiency is nearly 0.25 at 420 nm. To protect the PMT's from the water pressure, they were placed in glass spheres, transparent for the blue-green part of the spectrum and supporting pressures up to 670 atm. (BENTHOS, USA).

The electronics crate, in which the signals from the PMT's are treated with digital-analog technics, is placed in the deep underwater controller box. Also in this box are placed the electronics that register the information from the pressure and string orientation gauges, the power supply on/off switches, the timer module, the 8-bit processor and the floppy disk recording device.

The power supply box consists of batteries of 430 Ah total capacity. With 1.5 A consumption at 24 V, the autonomous supply provides 120 hours of continous operation.

The general view of the string is shown in Fig. 1. There are five photodetectors in it, the distance between them being 8 meters.

The preliminary event selection is done as follows: The PMT's anode pulses are amplified, converted to 150 ns ECL pulses and then put in coincidence with each other within a gate of 110 nsec. Everytime there is a five fold coincidence, the Time to Digital Conversion of the anode signals starts and it is stopped by the trailing edge of the latest 150 ns ECL pulse. In this way there is enough delay for the muon to pass through the detector. The "event" trigger goes from the coincidence scheme to the I8085-type processor. Then the processor inhibits the TDC's and starts the program to readout the various gauges. There are counters of background pulses from the PMT's, the pressure gauge and the timer. There is also the possibility to attach in the data record the information from the string orientation, the temperature, the current velocity, salinity and seawater transparency gauges. The duration of the interogation cycle is 128 ms. At the end of the interrogation, a master clear is issued and the whole system is ready to receive new events. The information is stored on a floppy disk.

The event record contains five words of TDC data, five words of the

PMT rate, the depth, the time of registration, the temperature, water transparency and current velocity.

To determine the muon trajectory from the measured time intervals, there was created a lookup table of time interval values for all possible trajectories. The step of this "lattice" is determined by the statistical dispersion of the electron transit time of the PMT's in use (10 ns).

## 2) Experiment

The measurement of the cosmic muon intensity was carried out from the board of "Ac. Mstislav Keldysh" research vessel (RAN). The experiment took place in the Mediterranean Sea, in the region with coordinates 36 30'N and 21 30'E, about 20 miles from the Southwest coast of Greece. The PMT's were looking upwards and during the measurements the ship was drifting. The information volume of 19,008 kBytes from the muon flux at depths of 3600-3900 m was stored on diskettes.

## 3) Results

The parameters characterizing the effective dimensions of deep underwater detectors are: Differential effective area of registration, $S_e f(\theta)$ and differential effective acceptance, $S_e f(\theta)\ \Omega(\theta)$

To calculate the differential effective area of the device by a Monte-Carlo method, the isotropic uniform flux of particles was simulated. Over a sphere of radius R, the points from which the particle trajectories pass, are random, their directions are distributed uniformly in given solid angle. For each trajectory, the probability of reconstructing it is calculated. In this way the number of recorded particles is determined. The ratio of the recorded particles to the total generated particles, multiplied by the area of the sphere of radius R, gives the effective area of the detector.

In our experiment the calculation was made assuming that PMT's are oriented to look upwards. The quantum efficiency and the amplification coefficient of the PMT's were measured at the laboratory. Taking into account the seawater transparency is also important. Preliminary hydrooptical measurements in the region of the experiment showed that the light attenuation coefficient is nearly 0.05 $m^{-1}$ in the wavelength range of 370-510 nm, and that of the absorption is nearly 0.025 $m^{-1}$. The results of calculation of the string's differential effective area and acceptance are shown in Fig. 2.

The muon flux intensity at a depth H is connected with the measured rate of muons with:



$$F=\int I(\theta)\ S_e f(\theta)\ d\Omega$$

F is the measured rate of muons recorded at H m.w.eq. depth.
$\Omega$ is the solid angle in which the muon flux is detected
$S_e f(\theta)=f(\theta)\ S_e f(0)$ is the differential effective
area of the device, $S_e f(0)$ is the effective area for vertical tracks.
The dependence of the muon flux intensity from the zenith angle is:
$I(\theta,H)=I(0,H)\cos^m(\theta)$,
where the index "m" depends from the depth at which the measurements were carried out. Since with the device, we can measure the zenith angle of the muon trajectories, it should be possible to be able to determine the index "m" from our measurements. Unfortunately, because of the string length of 32 m and the use of "five out of five" selection trigger, there is a strong dependence of the effective area from the zenith angle (Fig. 2). Due to this fact the accuracy in the determination of index "m" is poor.

Preliminary treatment of the data showed that the event counting rate, by the string detector was 0.009086 Hz. Total number of events recorded was 297, out of which 129 were initiated by muons (satisfied our criteria) and 128 were background events. The intensity of the water luminencence was measured by the five pmt's to be 597 +/-150 photons/$cm^2$sec.

The event distribution versus the zenith angle is shown in Fig. 3. Making the correction for the differential acceptance, the angular distribution of cosmic ray muons intensity at the depth H is obtained in Fig. 4.

## 4) Conclusion

During an experiment with a deep underwater muon string of five pmt's, there were registered events from cosmic ray muons. The dependence of the muon flux from the zenith angle was obtained. Measured at depths of 3700 to 3900 m, the vertical intensity of cosmic muons is (0.98 +/- 0.4) $E^{-8}$ 1/$m^2$ sr s. The data obtained are in good agreement with previous measurements and calculations.

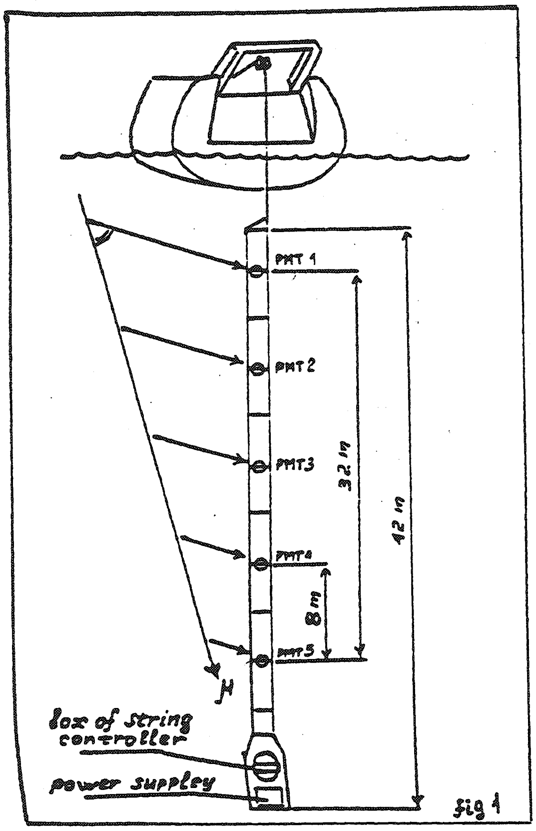


fig 1

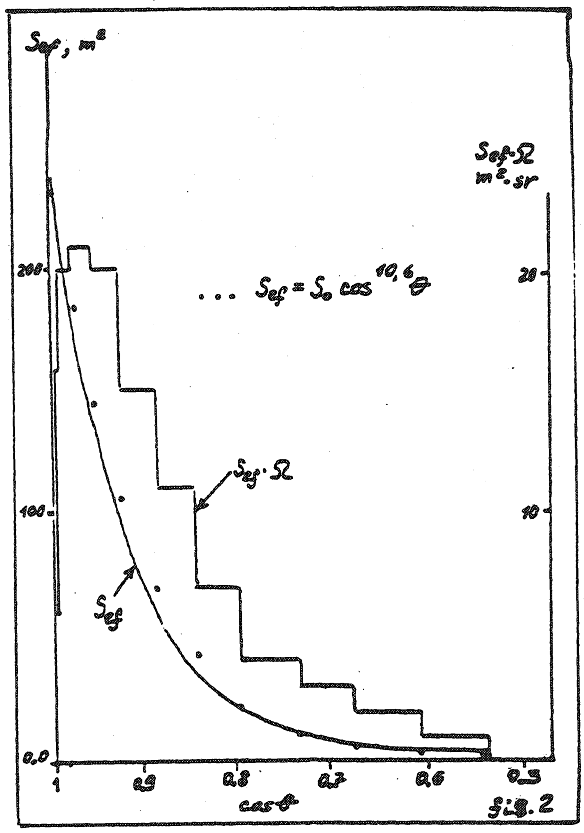


fig. 2

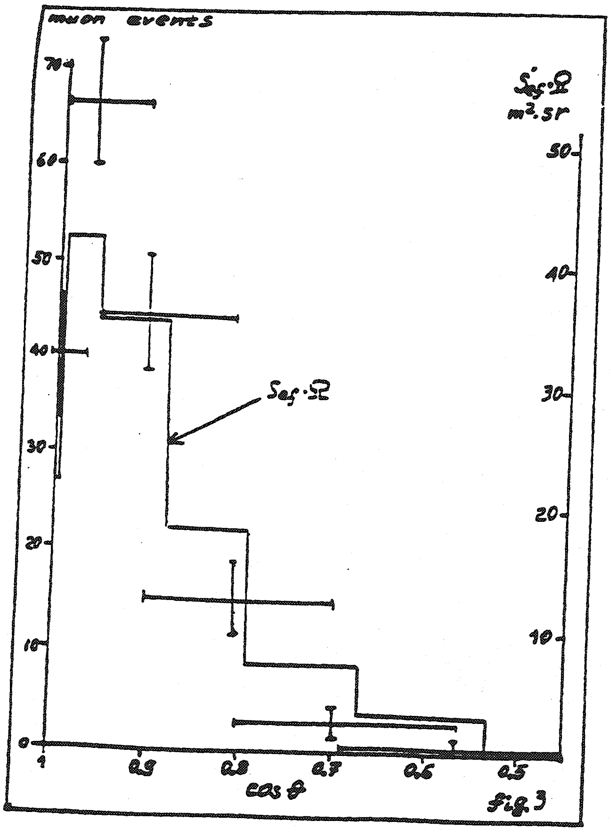


fig. 3

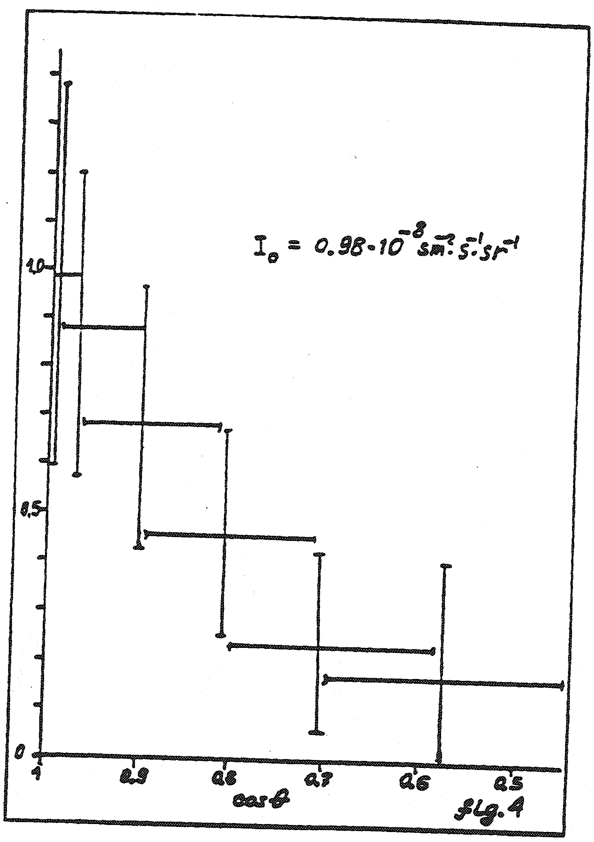
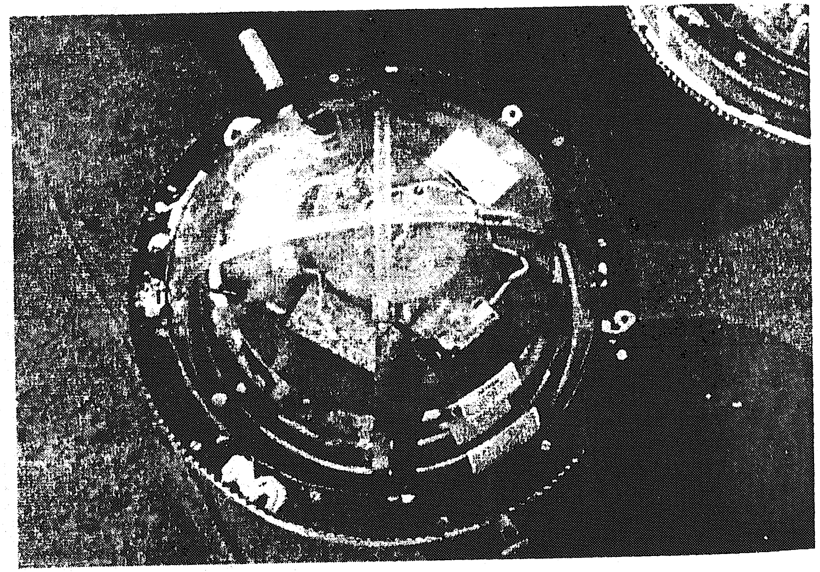


fig. 4



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Edited by L.K.Resvanis