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THE MUON STRING
- AN UNDERSEA COSMIC RAY EXPERIMENT -

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ABSTRACT

A cosmic ray muon depth-angle-intensity measurement is planned for initial deployment at depths from 1-4.5 km in the ocean near Hawaii during the winter of 1981-82.

I. INTRODUCTION AND MOTIVATION.

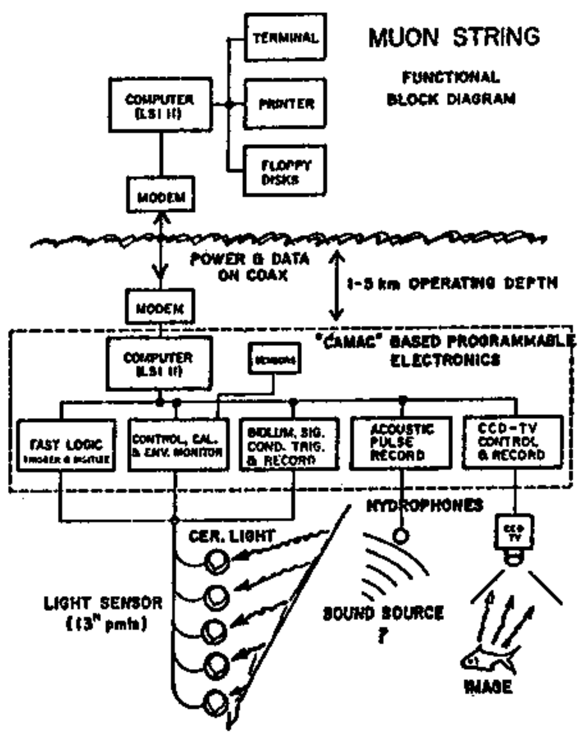
During the first year of operation of the Hawaii DUMAND Center a number of proposals were considered for a first in-ocean elementary particle detection experiment. In mid-1980 it was realized that a substantial muon counting experiment could be carried out utilizing the new generation of large phototubes. In particular, the EMI 13" hemispherical PMT fits nicely into the standard 17" Benthos oceanographic housing providing a transparent and sturdy pressure-tolerant package. A string of five of these tubes in coincidence (the "Muon String") should, according to our Monte Carlo studies, be able to "see" single muons in the clear deep-ocean water near Hawaii at ranges greater than 10m and with an effective cross section for minimum ionizing muons of $\sim 700m^2$. Previously, Japanese[1] and Russian[2] groups have lowered detectors of $3m^2$ and $1m^2$ into the ocean to depths of 1.4 km and 3.5 km for short (few days) periods.[5] Deep underground detectors have explored the muon flux at fixed depths and with areas of no more than $\sim 100m^2$.[3] A new generation of proton decay detectors will soon be in operation that will extend the muon sensing total area to a value about equal to that predicted for the muon string. As is well known, a major source of uncertainty in underground muon depth-intensity studies arises from the lack of precision of knowledge of the total overburden and its composition. Under-ocean studies offer the prospect of much better precision of depth recording (0.1%), and of being able to vary the depth with the same instrument.

Additionally, we will be able to carry out several other studies with little increase in effort. We will observe a few neutrino induced muons, we can carry out a search for previously suggested "anomalous cascades"[4] and conduct various studies of the ocean background light. The latter will arise from radioactivity induced Cerenkov radiation, mostly associated with K^{40} decays, but also (possibly) from bioluminescence. Very little is known about the latter in the deep ocean in terms of frequency of occurrence, spatial extent, nature of sources and temporal characteristics. The muon string will be the most sensitive light detector ever deployed in the ocean and will have thereby new capabilities to study bioluminescence. As will be discussed in the following, fortuitously available channels of electronics will make possible some additional acoustic and optical imaging studies.

II. DESIGN

As a first in-ocean counting experiment, it was important to use a minimal number of elements. Noise rates make random coincidences at the threefold level too frequent in comparison to predicted muon rates, so that a minimum of four detectors are required (if we are to set coincidence thresholds at the one photoelectron level). Five detectors offer some gain in sensitivity and added reliability. The amount of effort to deploy these five detectors is sufficiently large that the addition (at little cost in electronics) of many more channels (to the same number as a full DUMAND string of about 20 detectors) will be relatively simple. Another requirement for the first ocean exposure is for easy retrievability, and thus we've designed a ship-based instrument with the capability to bring the instrument back to laboratory conditions in a few hours. Another design goal was for a system with flexible reprogrammability and on-line operator monitoring and control.

DUMAND signal processing studies have shown that fiber optic data transmission will be very important in future array designs. We would have preferred to begin operations with such a cable but, though the signal handling technology exists, an integrated cable with adequate power transmission and mechanical strength is perhaps one year away (as of 9/81). We have obtained a 5.5 km long standard oceanographic armored (50Ω) coaxial cable. We can multiplex signals and power on this single line but the bandwidth is restricted to a few megahertz by frequency dependent losses.



In order to bring the system into operation speedily and flexibly, we decided to utilize a remote CAMAC system placed in a pressure housing adjacent to the photodetectors. Communication will be via (fsk) 1 megabaud (DMA transfer) modems, communicating between LSI 11 computers; one at the surface acting as operator interface and data recorder and the other acting as intelligent crate controller at depth. The CAMAC system, shown schematically in Fig. 1, contains fast logic, fast pulse digitization, and slow wave form digitization (up to 4 MHz), and slow logic for the recognition of bioluminescent light pulses. The fast logic, divided into high level and low level discrimination, offers triggering and counting in a highly flexible manner. Monte Carlo studies have shown that certain ratios of coincidence rates can be used independently to monitor the ocean transmissivity and detector sensitivity. We also will have cross- calibrations from laboratory studies, monitoring of a radioactive source and an LED pulser on each phototube, and monitoring of the omnipresent light from K^{40} decays. Achieving good absolute rate measurements will require great care; we aim for ±10%. Relative (intercomparison of data from various depths) calibration should be much simpler and we believe will be achievable at the 1% level.

The waveform recorder will be utilized as a multichannel pulse recorder permitting snapshots of waveforms to be displayed and/or recorded. We will be able to modify the time scale and trigger conditions remotely. Available additional channels will be instrumented with hydrophones to permit a survey of deep ocean high frequency noise and search for correlations with optical pulses. Also, we plan to add a CCD TV channel (utilizing the same waveform recorder) which will allow imaging of possible bright sources of light. Bioluminescent fishes with bright emitting regions may be detectable in this way. Also there is the exciting, though seemingly unlikely, possibility of recording an image of a particle cascade of the type observed in the Kolar Gold Fields[4] (estimated rate: once per fortnight).

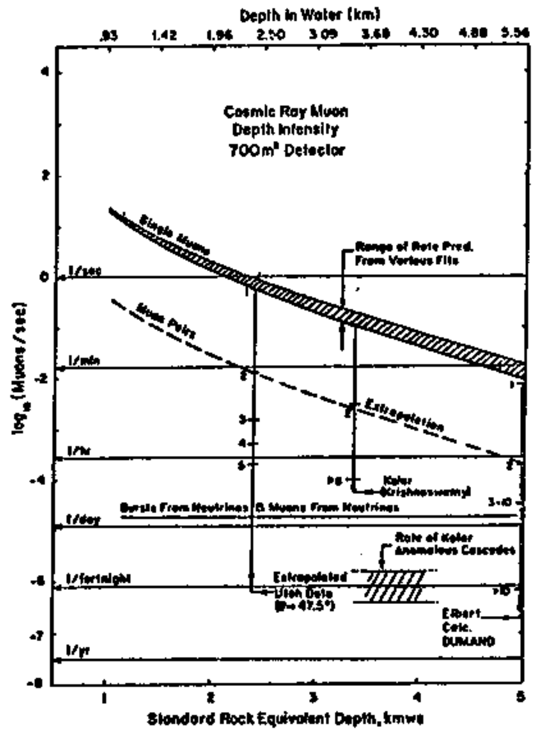
Also necessary in the design of this instrument are photomultiplier controls as well as environmental monitoring. We will have the ability to individually switch, control, and monitor each PMT voltage. The crate controller will continuously check PMT conditions and noise rates, using the background (K^{40}) light as the fundamental stability monitor. Other conditions to be monitored include pressure, temperatures, orientation, various power supply voltages, and air circulation (fans are needed for cooling some of the electronics).

The pressure housing for the electronics consists of three 22" diameter spheres split by a common vertical 4" thick aluminum plate. The center plate has three large holes and contains the mountings for the two CAMAC crates and power supplies. There are also holes in the center plate for connectors from the main cable and the cables to each detector, and there are holes interconnecting the neighboring spherical volumes. The housing design is an outgrowth of one long and successfully used for deep-ocean seismometry.

III. EXPECTED PERFORMANCE AND SCHEDULE

As a cosmic ray muon experiment, we anticipate improving the muon depth intensity curve to a precision of ~1% in the range of 1-4.5 km. The rate as a function of depth is shown in Fig. 2. Muon zenith angles will be determined crudely by timing (and somewhat by pulse height) to a resolution of $\pm 14^{\circ}$ permitting a study of angular distributions along with depth. Making the first observations of neutrino induced muons underwater will be a landmark step towards DUMAND. Observation of unusual interactions and correlations with acoustic pulses, while seemingly unlikely would be very exciting. Background studies of light, sound and biology will be of use to DUMAND and provide new data useful to other fields.

The detector components are nearly all on hand and being assembled as of 9/81 and software writing is well underway. Testing in a pressure tank at Pearl Harbor is scheduled for November 1981. We anticipate being ready for test deployment in December 1981. The most significant problem as of now is the availability of appropriate deployment platforms.



Preliminary tests will be carried out from the University of Hawaii oceanographic vessel, R/V Kana Keoki. A second test may utilize a U.S. Navy oceanographic vessel of the Agor class, in spring 1982. For extended data acquisition we have located an oceanographic barge (the ORB) which can be deep-ocen moored and has personnel facilities, power, motion compensating winch, laboratory space, and a dry center well. We have, however, to arrange the transport of this vessel from San Diego to Hawaii, and the date at which this will occur is uncertain. It is likely that first data taking with the muon string will thus be delayed until early 1982, and a lengthy exposure will not occur before summer 1982.

We must acknowledge the help of many people in the preparation of this experiment particularly at the institutions of the authors and at the Marine Physical Laboratory of Scripps in San Diego. Grants and encouragement have gratefully been received from the Department of Energy (Contract No. DE-AM03-76SF00235 and others), the Office of Naval Research and the State of Hawaii.

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