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 late 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 ~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 day) periods. Deep underground detectors have explored the muon flux at fixed depths and with areas of no more than ~ 100 m^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 ambiguity 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[4] 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 character-
istics. 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 with little increase in effort.

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 four detectors were a necessary minimum (if we were to set coinci-
dence thresholds at the photoelectron level). Five detectors offers 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 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 instru-
ment 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
5/81). 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 megaband
(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), slow logic for the
recognition of bioluminescent
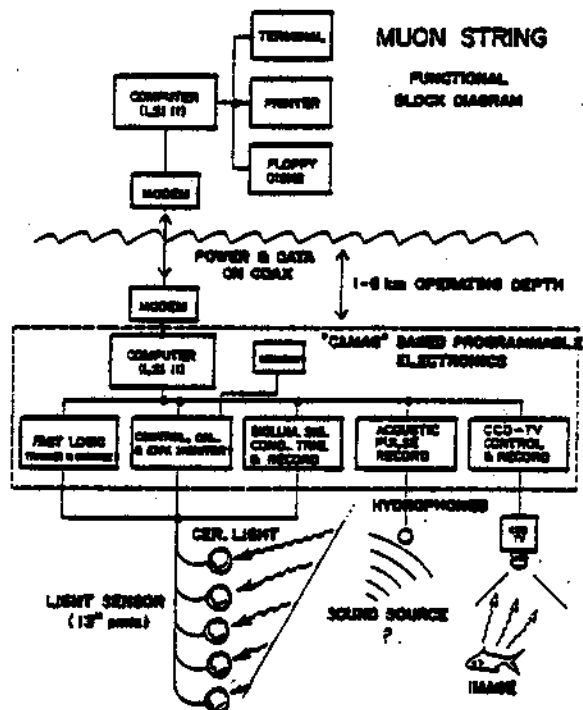
light pulses. The fast logic, divided into high level and low level discrimination, offers triggering and counting in a highly flexible manner. Monte Carlo studies have shown that certain ratios of coincidence rates can be used independently to monitor the ocean transmissity and detector sensitivity. 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 (unexpected but unexplored) 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 ±14° 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 5/81 and software writing is well underway. We anticipate being ready for test deployment later this year. The most significant problem as of now is the availability of an appropriate deployment platform. We have located and been assured the use of an oceanographic barge (the ORB) which can be deep-ocean 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.

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-AC03-76ER00511, and others), the Office of Naval Research and the State of Hawaii.

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