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THE BOTTOM-MOORED STRING

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ABSTRACT

It is proposed that the DUMAND Short Prototype String be deployed on the ocean bottom, connected to shore by an 8-fiber electro-optic cable. This instrument will be capable of setting limits which would rule out certain classes of candidates for the dark matter of the galaxy in the mass range 10^{14} to 10^{24} GeV/c^2, comparable to underground experiments. It would have an effective area for muons from cosmic rays and neutrinos of 200 m^2, larger than all but two of the current underground experiments.

Introduction

In 1985 is was proposed that the next stage of DUMAND be three strings of seven optical modules each, deployed on the bottom and connected to shore by an E-O cable.[1] This ***"TRIAD"*** had an effective area of 3000 m^2 and an angular resolution of 5-10^o. The basic concept was to build upon what we have learned from the SPS and take a small incremental step, but one which would have capabilities to do good physics. However, if we make as our goal the detection of very high energy muon neutrinos from binary systems such as Cygnus X-3, the TRIAD is not quite good enough to make such detection likely. The current best calculations[2] indicate that a detector of at least 10^4 m^2 is need to give a good chance of such a detection. This is probably impractical **underground**, and studies indicate that an **undersea** detector would require at least of the order of 100 PMT's to acheive this goal.[3] An array of this magnitude would constitute a rather large increment for the DUMAND project to undertake immediately after the SPS.

The SPS now exists as a working instrument into which much blood, sweat and tears have been poured. It would appear sensible to pursue further experiments with this instrument which is, after all, an excellent piece of engineering and has by now undergone extensive testing. However it does not seem that further ship-suspended experiments beyond the original plan to count muons are worthwhile, from either a physics or engineering standpoint. Not only is the physics of marginal interest, but this would not move us in the direction of a sea-bottom instrument. A more logical step would be to deploy the SPS on the bottom, with a cable connection to shore. Of course, this can only be justified if it is shown that useful physics can be done. In the following section we make such a proposal and argue that the physics is indeed worthwhile.

The Bottom-Moored Short Prototype String

It is proposed that the next stage of DUMAND be a deployment of the SPS on the ocean bottom at the DUMAND site off the Big Island, attached to shore by an 8-fiber electro-optic cable (see Fig. 1). The purposes of the experiment would be:

☞ Search for certain classes of heavy dark matter with flux limits which are comparable to what can be obtained underground.

☞ Look for muons from extraterrestrial sources, either as the products of neutrinos or other more exotic objects.

☞ Measure muons from atmospheric neutrinos.

☞ Measure comic ray muons.

☞ Measure environmental parameters at the DUMAND site, including some of biological or oceanographic interest.

☞ Test the deep ocean engineering concepts needed for larger arrays.

Search for Dark Matter

This proposal is based on the report ***"Dark Matters Under Land and Sea"*** .[4] The results of the calculations detailed in that report are just summarized here. References to other work may also be found in Ref. 4.

There are reasons to speculate that the dark matter which comprises 90-99% of the universe could be composed of non-nucleonic particles with masses much greater than atoms. For example, particles are expected to exist at the various unification or compactification scales, 10^{14} - 10^{19} GeV/c^2 or 10^{-10} to 10^{-5} g. If they form a cloud throughout the galaxy, they would be moving at about 250 km/s relative to the earth. The flux of these particles can be estimated from their expected density if they constitute the major mass of the galaxy.

Even if neutral, certain classes of candidates for dark matter (quark nuggets, monopoles) can heat matter by collisions, losing energies of many GeV per cm and emitting visible light. Those with a mass greater than 10^{14} GeV/c^2 would penetrate 4000 m.w.e. of rock or water, reaching an array on the ocean bottom. In a transparent medium such as water, they could then be detected ~100 m away by phototubes of the type developed for DUMAND. For example, the effective area of the SPS for a 10^{19} GeV/c^2 (Planck mas) dark particle is ~7×10^4 m^2.(4)

The SPS operating for a year on the ocean floor could set a flux limit comparable to the largest planned underground experiment, MACRO. It could help rule out a large class of candidates as the major component of dark matter in the galaxy.

These estimates were made with a Monte Carlo calculation, using a practical trigger which provides effective discrimination against K^{40} and bioluminescence backgrounds. A dark particle moving at a speed βc = 250 km/s will appear as a pulse typically a few hundred μs long, depending on distance from the array and dark particle mass. The interval between arrival times of the pulses at the PMT's at either end of the 30 m long string will be $122\cos\theta/\beta$ μs, where θ is the angle the particle's track makes with the string. In order to distinguish the signal from bioluminescence, the signature for the dark particle would be long pulses in several phototubes separated in arrival times by at least a few tens of μs. The current results are based on the requirement that at least three PMT's have hits with a peak phototube current of one photoelectron/μs, ten times K^{40} background, and that at least two PMT's have their peak signals separated by >10 μs.

Other Physics

A bottom-moored SPS will have an effective area for muons of about 200 m^2, when operated with a coincidence trigger which adequately supresses background light.[5] This would give an event rate of one muon per minute for downward cosmic rays, perhaps half that if we point the PMT's down, to maximize the sensitivity to upward tracks. This should make possible a determination of the cosmic ray muon flux under 4500 m.w.e of homogeneus overburden. The event rate for muons from **atmospheric neutrinos** would be about 400 per year over 3π solid angle. These could be used for studies of neutrino oscillations, among other things.

The 200 m^2 effective area for muons is larger than all existing underground detectors except Baksan and IMB. Other experiments being built, such as MACRO at Gran Sasso, will have greater area; but the SPS would still be a rather cost-effective instrument capable of continuing searchs for muons from extraterrestrial neutrinos or more exotic objects as well as study cosmic ray muons and neutrinos, possibly before these larger experiments come online.

Measurement of Environmental Parameters

The SPS is already well-instrumented for the measurement of environmental parameters on the ocean bottom. It contains hydrophones which will be able to monitor the acoustic background, and possibly search for ultra high energy events. The Caltech Environmental Module, with its Neal-Brown package, will continuously monitor ocean currents as well as keep tabs on the instruments orientation and acceleration. Signals from the calibration module will be used to measure the water clarity and obtain a time-profile of bio-fouling. The long time scale variations of the light-level of the PMT's will provide information on bioluminescence. Other instruments, such as seismometers, can be added to the existing package without major difficulty. There will more more than adequate bandwidth for any number of environmental instruments.

Engineering Tests

The long-term deployment of the SPS on the bottom will make it possible to more stringently test the engineering concepts which would be applied in any larger array. These include the fiber optic system, connectors and penetrators, corrosion, biofouling, mooring, electro-optic cable attenuation, and so on. The list is endless.

Configuration of Instrument

The proposal being made does not envisage many changes to the existing SPS. As seen above, a wider PMT spacing would improve the ability to measure the speed and direction of a slow moving particle, but this might not prove practical. One change to the SPS configuration which will be practical, since it represents a simplification, is to assign each PMT to a separate fiber in the shore cable, where now they must be multiplexed onto a single one. Since an 8-fiber cable is contemplated, this would still leave one channel for the Environmental Module and associated instruments, which could probably also be shared with a communication channel from shore. The current String Bottom Controller, which does the multiplexing was the most difficult development of the experiment and responsible for considerable delay. While this appears now to be working, the advantages of a dedicated fiber for each PMT are many: simplicity, reliability, greater signal bandwidth, to name a few. The complicated electronics tasks can then be done on shore.

Deployment

Finally, it should be mentioned that even the TRIAD would have required a major deployment design effort. Although this has not yet been given much thought, it would seem that the bottom-moored SPS can be deployed with rather straight-forward extensions of the existing system used in the ship-suspended test.

Conclusion

It is proposed that the existing DUMAND SPS be deployed on the ocean bottom, connected to shore with an 8-fiber electro-optic cable. This instrument is a logical next step for DUMAND, paving the way for eventual larger arrays, but also having scientific capabilities in its own right which should justify the incremental expenditure ($300,000 estimated for cable and deployment) required. The Bottom-Moored SPS would have an effective area for muons from cosmic rays and neutrinos of 200 m^2, larger than all current underground instruments except IMB and Baksan. This area would give an event rate of cosmic ray muons with energies above 3 TeV at the surface of about 1 muon per minute; the rate of muons from atmospheric neutrinos would be about 400 per year. Most importantly, it would be capable of setting flux limits which would rule out certain classes of candidates for the dark matter of the galaxy in the mass range 10^{-11} to 1 g.

REFERENCES

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The Bottom-Moored SPS