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Advances in DUMAND Array Design.

by

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Since the 1980 DUMAND International Symposium, Monte Carlo studies on DUMAND arrays have been concentrated mainly on arrays designed for muon detection. This is the easiest task for a deep ocean array, and we believe we now understand the principles on which such an array should be based.

Muon detection allows the study of both atmospherically-produced muons and of muon neutrinos, both atmospheric and extraterrestrial. The latter also profit from the fact that the effective size of the detector is much enhanced because neutrino interactions outside the array can produce muons that traverse the array (1). This is valuable for astrophysical applications, particularly in searching for extra-terrestrial point sources of neutrinos.

Since last summer several important facts have emerged from our studies.

1. For muon detection, there is no advantage whatever in dense (narrow spaced) arrays. The energy threshold is not appreciably lowered, the detection efficiency is not appreciably increased, the angular resolution is appreciably worse, the effective volume is much reduced, and the cost is no less, for the same number of sensors (2,3).

2. For widely-spaced arrays, the angular resolution improves with increasing array size; but it reaches a value beyond which there is little point in going, with arrays of moderate size - not over ten layers. That limit is imposed by the kinematics of neutrino scattering; the angular resolution need not much exceed the angle between the incident neutrino and the recoil muon. (4)

3. To obtain adequate detection efficiency for muons, an array of six, or perhaps even 5 layers, is sufficient.

4. Contrary to what we thought earlier, it is not necessary to have high-sensitivity sensors to detect muons in wide-spaced arrays (3). If we use asymmetric arrays, in which the strings are widely spaced (wide x- and y-spacing) but more closely spaced sensors in the z-direction - along the strings - entirely satisfactory performance can be achieved with low-sensitivity sensors. A 13" hemispherical PMT, of the type now entering production at EMI, has adequate sensitivity, provided one is willing to accept a reduced efficiency for detecting near vertical muons. For muons of zenith angle θ, the efficiency for $\cos\theta > .95$ is about 60%. Elsewhere it is 90% or more. Fig. 1 shows the performance of the MICRO array, which is an array of 6 x 6 strings 50m apart on a square ground plan, with sensors 25m apart along the 500m-long strings.

5. Hexagonal arrays do not appear as advantageous over rectangular arrays as we thought earlier. They do exhibit increased sensitivity to vertical muons, as would be expected from the geometry, but the overall efficiency in other directions is poorer. Fig. 2 shows the comparison between hexagonal and rectangular arrays.

6. Studies of the effect of anisotropic sensors indicate that the degree of anisotropy exhibited by a photomultiplier with a hemispherical photocathode will be perfectly acceptable, and has no effect other than a lowering of the average sensitivity of the sensor. See Fig. 1.

7. Random errors in the location of array strings, of gaussian distribution with σ up to 5-7m, have no effect on array performance, provided the true string locations are known.

If muon detection were the only criterion for the array, we would now propose for an initial DUMAND installation a square array of either 5x5 or 6x6 strings, 50 meters apart, and 500m long. The deployment of such strings has been studied (See Ref. (5)), and can be done at considerably less cost than previously estimated (6).

For the future: work is under way, both at Hawaii and elsewhere, on the study of DUMAND arrays for other purposes than muon detection:

1. Study of multiple muon bundles from high-energy atmospheric events.
2. Studies on the feasibility of recognizing electron-neutrino interactions, and possibly tau-neutrino interactions. This includes the further study of DUMAND as a detector for neutrino oscillations.
3. Studies of muon neutrino interactions within the array.

The initial DUMAND array, which we hope to determine by the end of this year, will have to embody features that derive from the relative weights accorded to the various purposes.

The remarkable progress made in decreasing the cost of DUMAND arrays is illustrated in Fig. 3, which shows the estimated cost of successive DUMAND arrays, starting from the earliest example for which a cost estimate exists, the 1978 Standard Array, and proceeding through several stages to the presently favored MICRO-DUMAND. While the names indicate progressively smaller arrays, the decrease in effectiveness is nowhere near as rapid as the decrease in cost.

REFERENCES.

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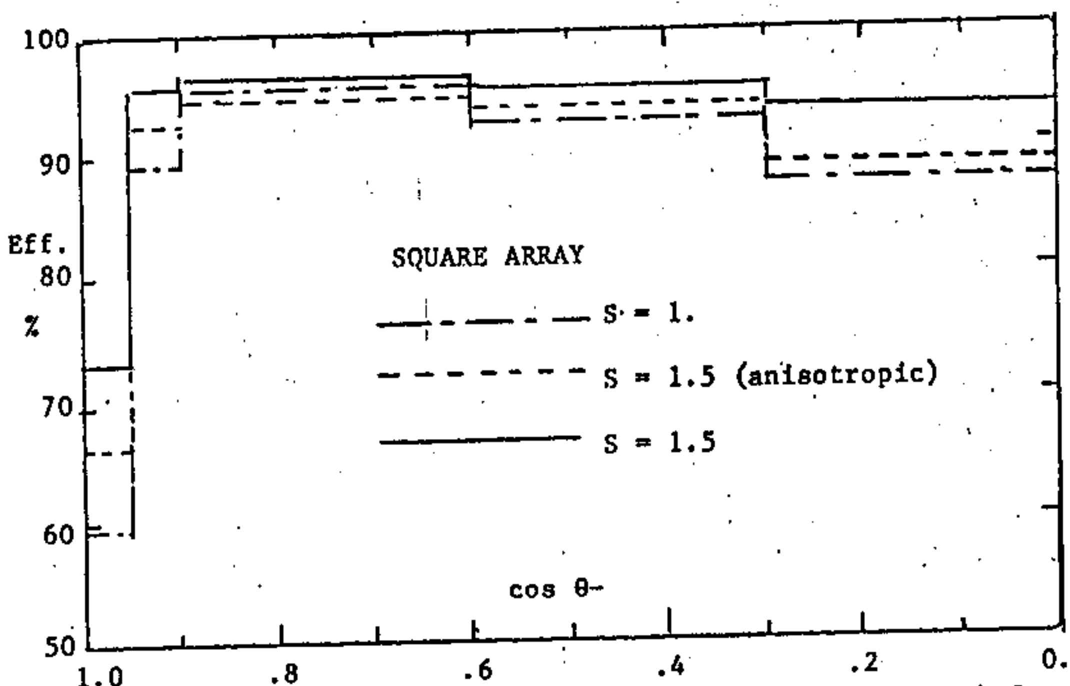

Fig. 1. Efficiency vs cosθ for 36-string array (250x250x500m) for minimum-ionizing muons; three different sensor sensitivities shown.

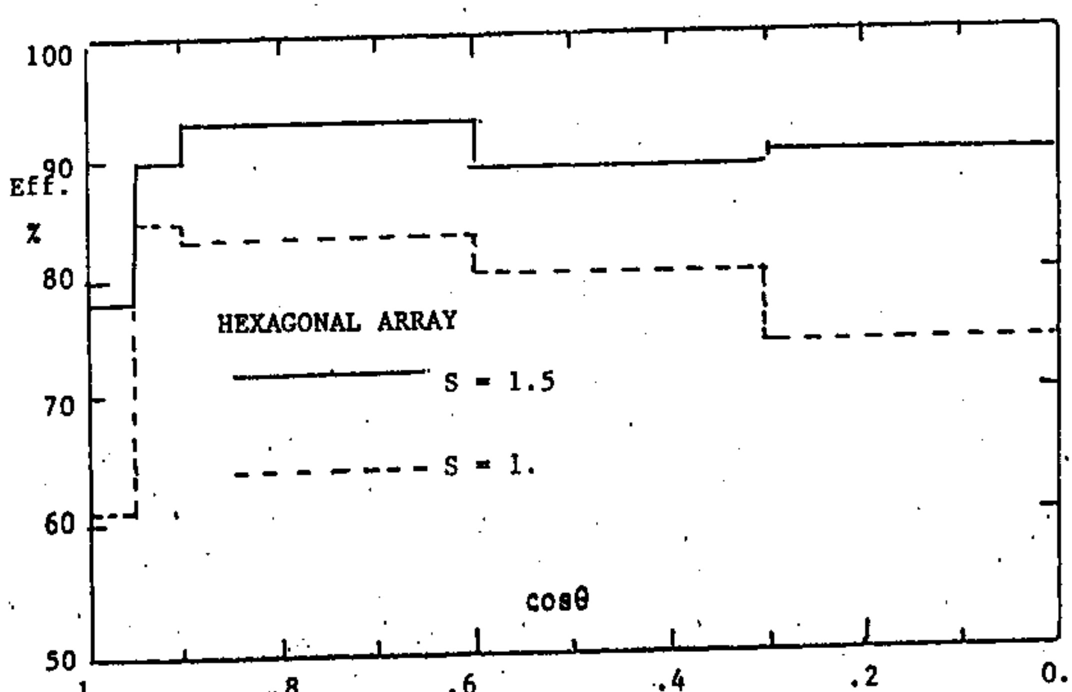

Fig. 2. Efficiency vs. cosθ for 39-string hexagonal array, of same spacing as square array above. Note decrease in efficiency.

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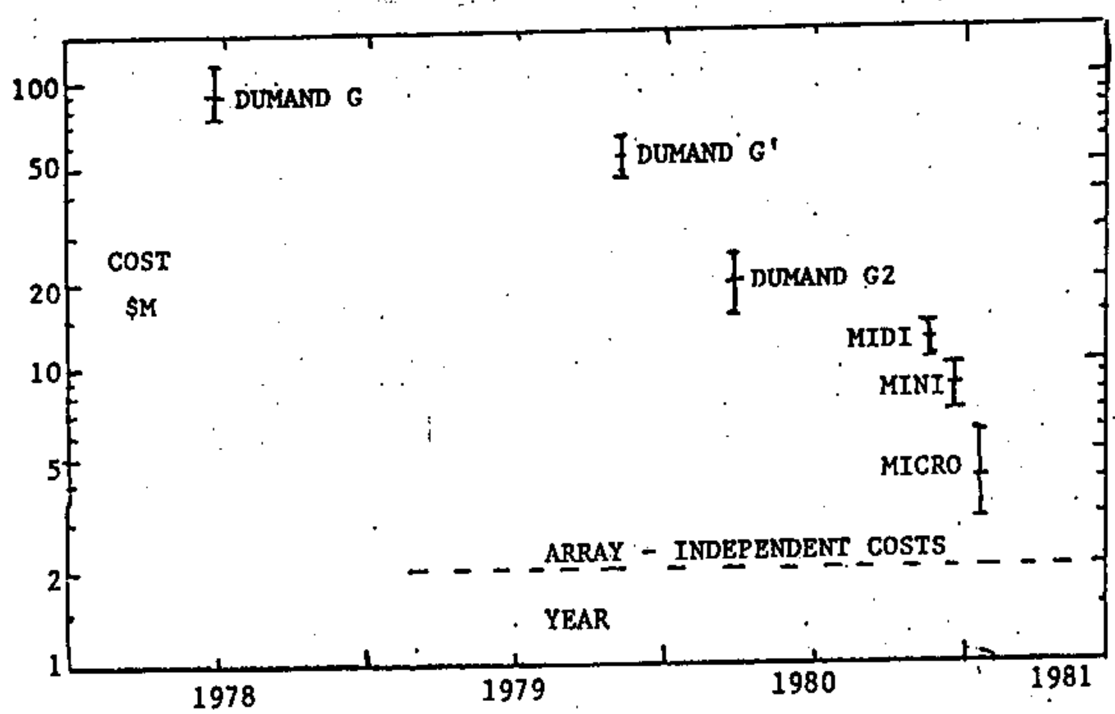

Fig. 3. This plot demonstrates the successful pursuit of the goal of decreasing the cost of the DUMAND array. Each cost drop is the result of identifiable improvements. E.g. the drop by a factor of 2 from DUMAND G to DUMAND G' is primarily due to the introduction of Sea Urchin. The last three arrays represent current thinking on three possible types of array. MIDI and MINI are relatively large, and MICRO is a small array with remarkably good particle-detection properties that will allow useful initial experiments at low cost.