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A FIRST LOOK AT DUMAND3

by

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Since one should always take into account the possibility that an experiment may be successful, it seems appropriate to give some thought to what the next stage of DUMAND after the 9–string DUMAND2 ought to be. In order to do this we start by looking at the largest array one can imagine building at present, and see what happens as you decrease the size from that.

DUMAND2 has nine strings and 216 optical modules. The largest array we have ever considered in the distant past (DUMAND G, 1978 – see Ref. 1) occupied somewhat over a cubic kilometer, had 1261 strings and 22,698 optical sensors. It seemed useful to see what a cubic kilometer array would now look like, given the information amassed since then about module sensitivities, water transparency, etc.

After some preliminary searches, we have concentrated on two possible approaches to a cubic km array that appear to be both feasible and reasonable. They are described as Array VLARRAY3B and SQ3A. They are illustrated in Figs. 1 and 2. VLARRAY3B is a hollow square: two relatively dense outer octagons and a small number of inner strings to fill the central hole – at least partially – to gain better detection efficiency for vertically incident particles. (It must be admitted that this succeeds only indifferently.)

SQ3A, on the other hand, is a sparser array, uniformly filling the same volume. In both cases the number of strings is near 100, only about ten times DUMAND2. The number of modules per string was originally taken as 96, to keep the 10m spacing found optimal for DUMAND 2.

The relative detection efficiency of these arrays is shown in Figs. 3 and 4. (These numbers should not be taken as absolute efficiencies; the software for detection is not yet optimized, and we expect a higher efficiency for track detection to be attained.) Fig. 5 is a histogram of the angular accuracy of SQ3A. (VLARRAY3B is as good for long tracks).The accuracy obtained by so long a detection path is remarkable; the S.D. is about 0.25 degree. The improvement in accuracy of location of a point source over DUMAND2 would be a factor of about 4 in angle, and 16 in the area in which the source is located. It is worth noting that thus far no gamma–ray detection apparatus has obtained such accuracy.

However, it must be remembered that the muon direction is not the same as the incident neutrino direction; the difference is a function of the collision variables, but a measure of the difference is given by the handy formula

$$d\Phi \quad = 25\text{mr}/E^{.5},$$

where E is the neutrino energy in TeV. Thus, for the error in neutrino direction to be as small as the experimental error in muon direction (4mr) the neutrino energy must be at least 36 TeV. The high directional accuracy is thus most valuable at high energies.

It thus appears that the step from DUMAND2 to a cubic km array, with an area of a million square meters – about 50 times greater than DUMAND2 – may not require anything like that increase in equipment or cost. The reason for this is of course the fact that so large an array can be much sparser and still obtain excellent results in angular accuracy and track definition. The strings in SQ3A are 100m apart – greater than the length of a football field. Thus installation and servicing become much easier and less critical.

OPTIMIZING THE MODULE SPACING.

However, while the number of strings goes up from 9 to 109, the number of optical modules goes from 216 to 11,009, a factor closer to 50 than to 10. The number of modules per string goes from 24 to 101, if we keep the module separation at 10m.

Now, 10m was the optimum module separation for DUMAND2. There is no a priori reason why that should be the optimum separation for a much larger array, with more redundancy in signals. Accordingly, we have investigated the effect of varying module spacing in SQ3A. If we keep the array volume constant, increasing the module spacing decreases the number of modules rapidly, with possible savings in the tens of millions of dollars.

The results are most interesting. As the spacing increases, the detection efficiency drops slowly. But we may choose instead to optimize what I have called the "cost effectiveness," which is the detection efficiency per dollar of module cost, or the detection efficiency per module. Both these quantities are plotted in Fig. 6 (actually, detection efficiency per 10,000 modules). The absolute efficiency decreases, slowly at first, as the module spacuing is increased above 10m. But the number of modules, for a fixed detector volume, also drops rapidly, so that the "cost effectiveness" peaks between spacings of 13 and 14 m.

Table 1 show the characteristics of the array as we change the module spacing, keeping the volume constant at a cubic km. Since the estimated module cost is about $10K, a saving of 1000 modules corresponds to a cost saving of $10M.

Finally, we reexamine the properties of the array we have just cost–optimized, to see what we have sacrificed. We take the module separatiion to be 13m (for luck), christen the new array SQ3M, and examine the detection efficiency. The results are shown in Fig. 7.

CONCLUDING REMARKS

The increased string length implies new problems to be solved. All the questions concerning string cable design, data handling, etc., will need to be re–examined. Pending that re–examination, we content ourselves with noting that the deployment problems will not be anything like 50 times as severe; that we will have to reconsider the design of the entire system, but that at first sight it looks as though there is nothing that is obviously impractical.

REFERENCES.

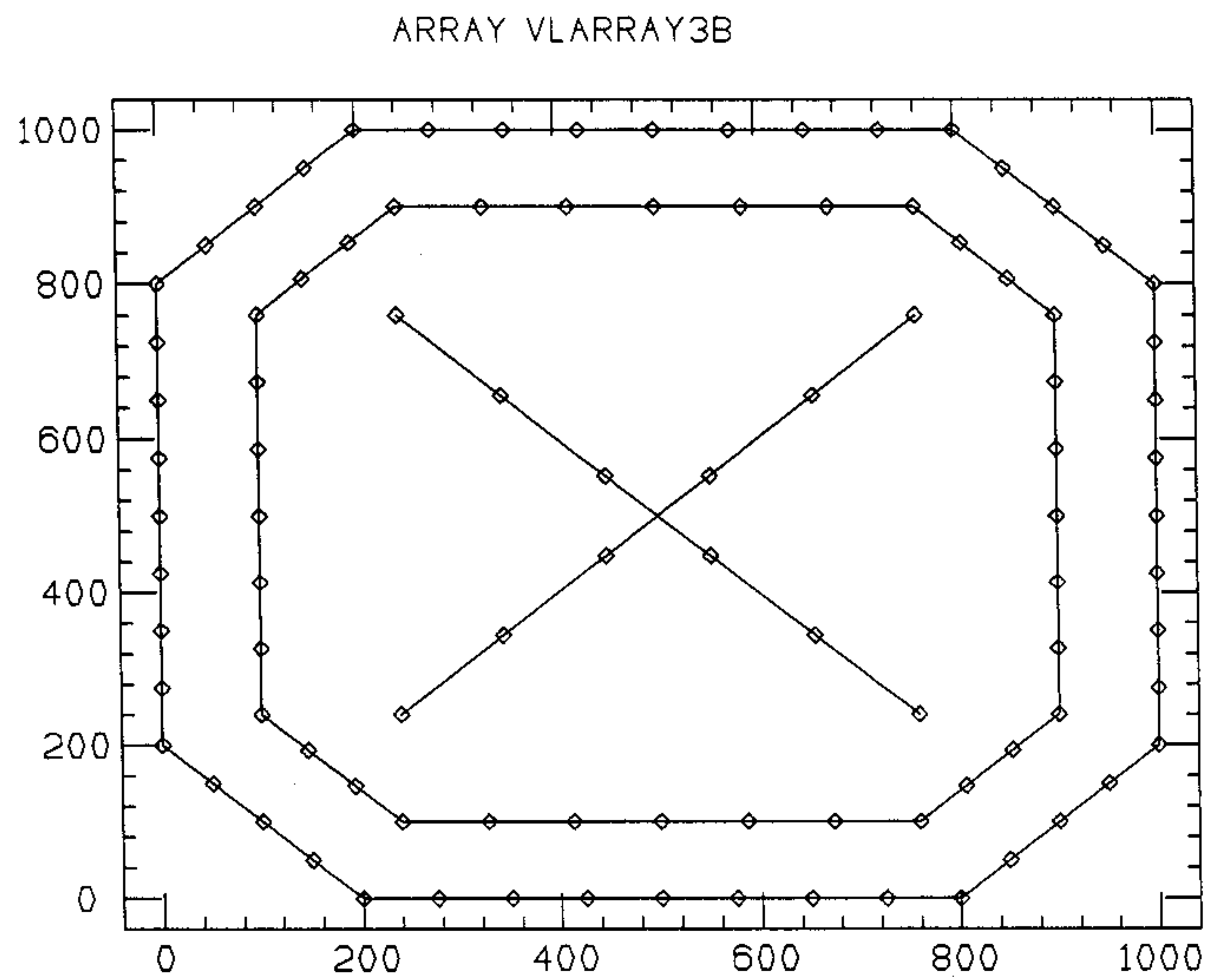
1. A. Roberts and G. Wilkins, Proc. 1978 DUMAND Summer Workshop, Vol. 3, p. 9 (1978). DUMAND, Scripps Inst. of Oceanography, LaJolla, CA.

TABLE 1

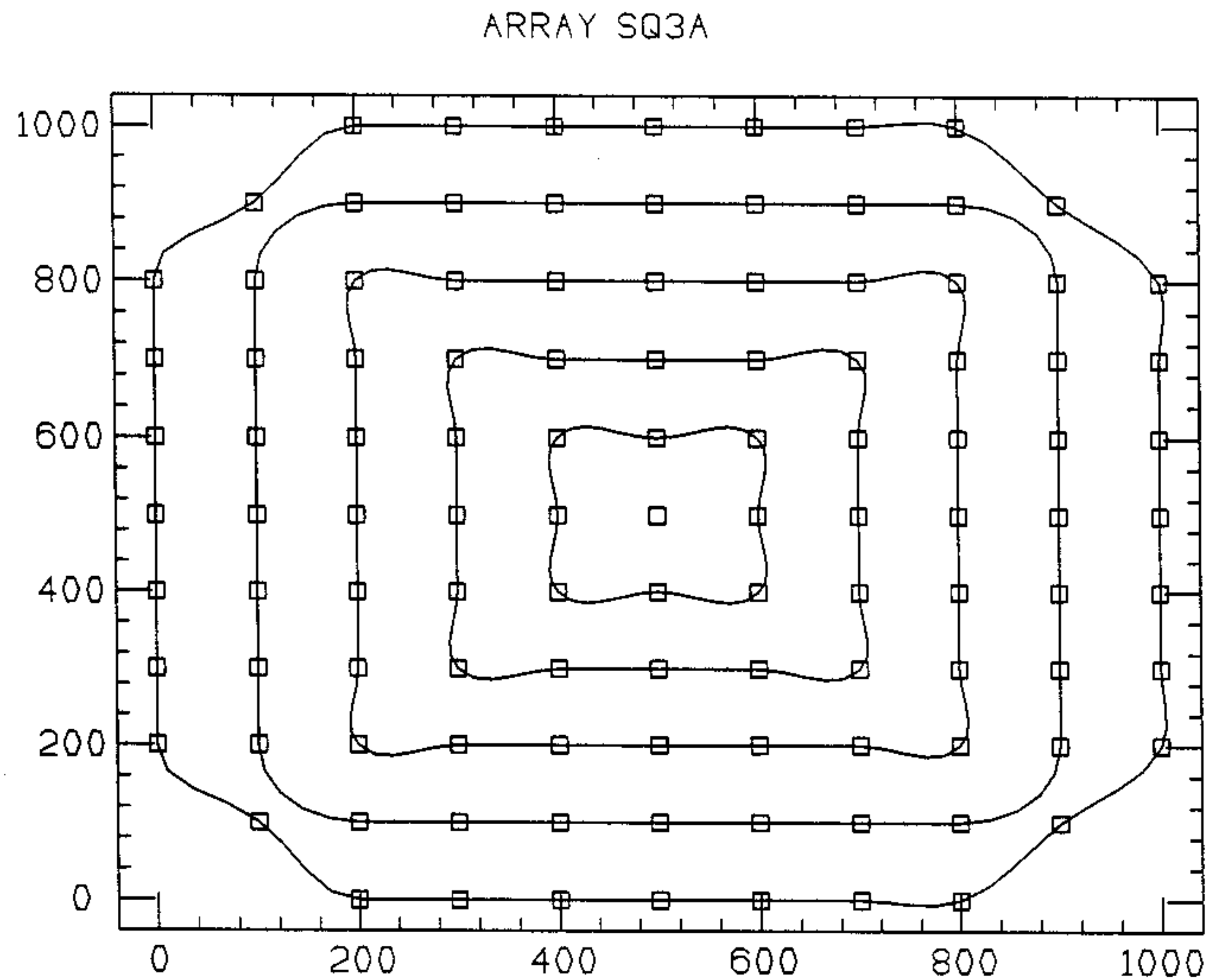
Comparison of String Module Spacings

(The array is assumed to be 109 strings with 100m spacing)

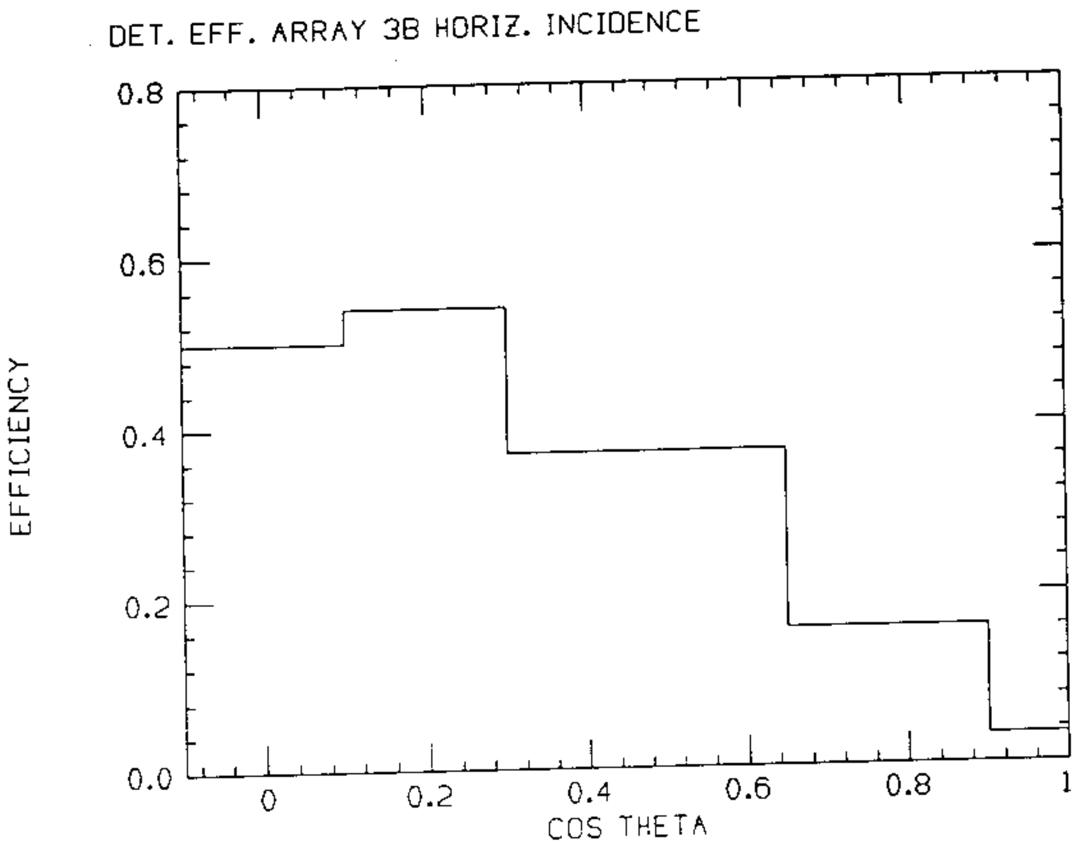
Module Spacing, m	No. of Modules per string	String Height, m.	Tot. No. of Modules
10	101	1000	11,009
12	84	996	9,156
13	77	1001	8,393
14	72	994	7,848
16	63	992	6,867



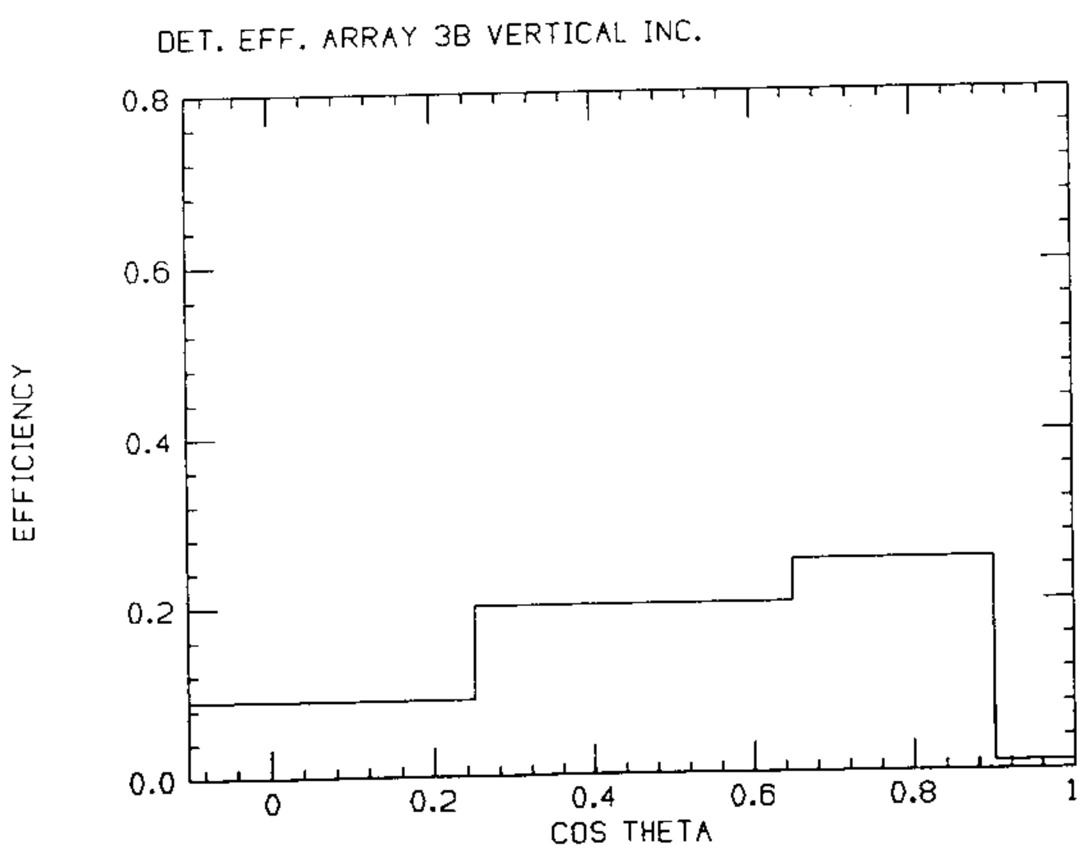
1. Schematic of VLARRAY 3B. There are 85 strings arranged in a double hollow square, with 12 additional inside strings to improve efficiency, especially for vertically incident particles. Outer strings are 75m apart.



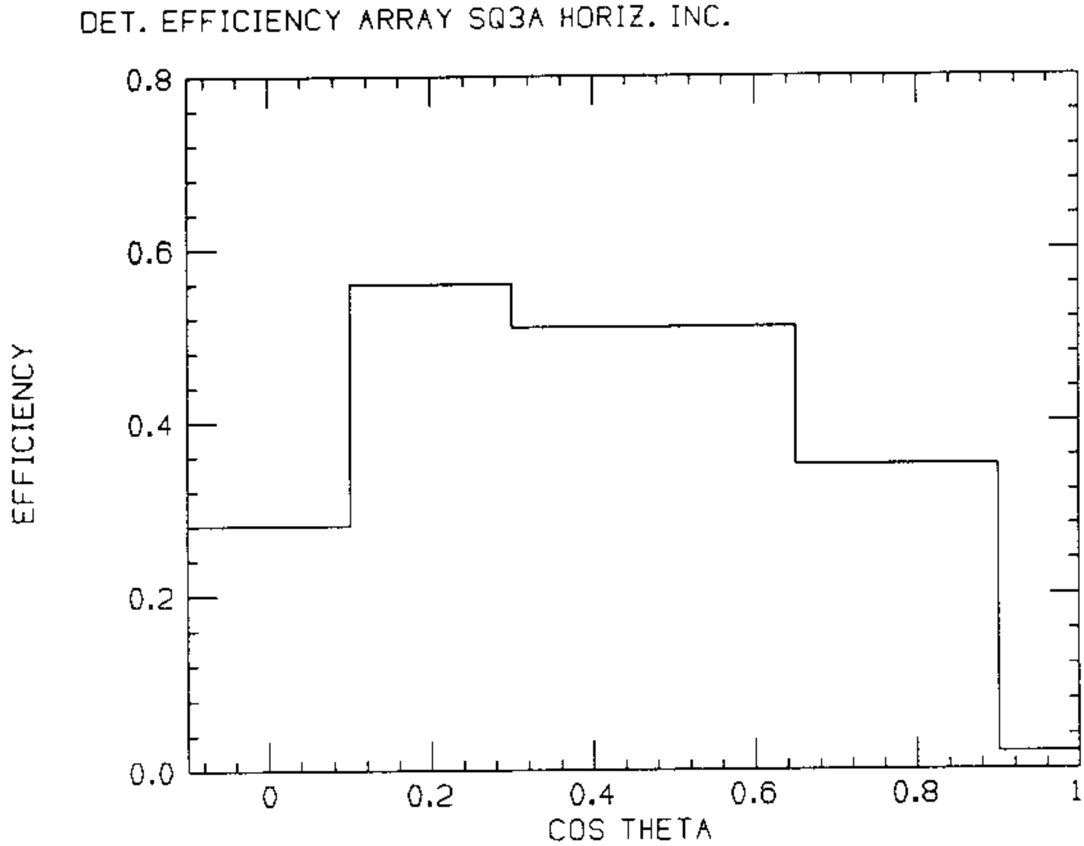
2. Schematic of ARRAY SQ3A. This is a conventional square array with 100m spacing, with a total of 109 strings, 12 more than 3B. In both arrays the corners are clipped to save strings which are unnecessary.In both arrays, the lines joining the strings are for purely visual purposes, to make the diagrams more apparent.



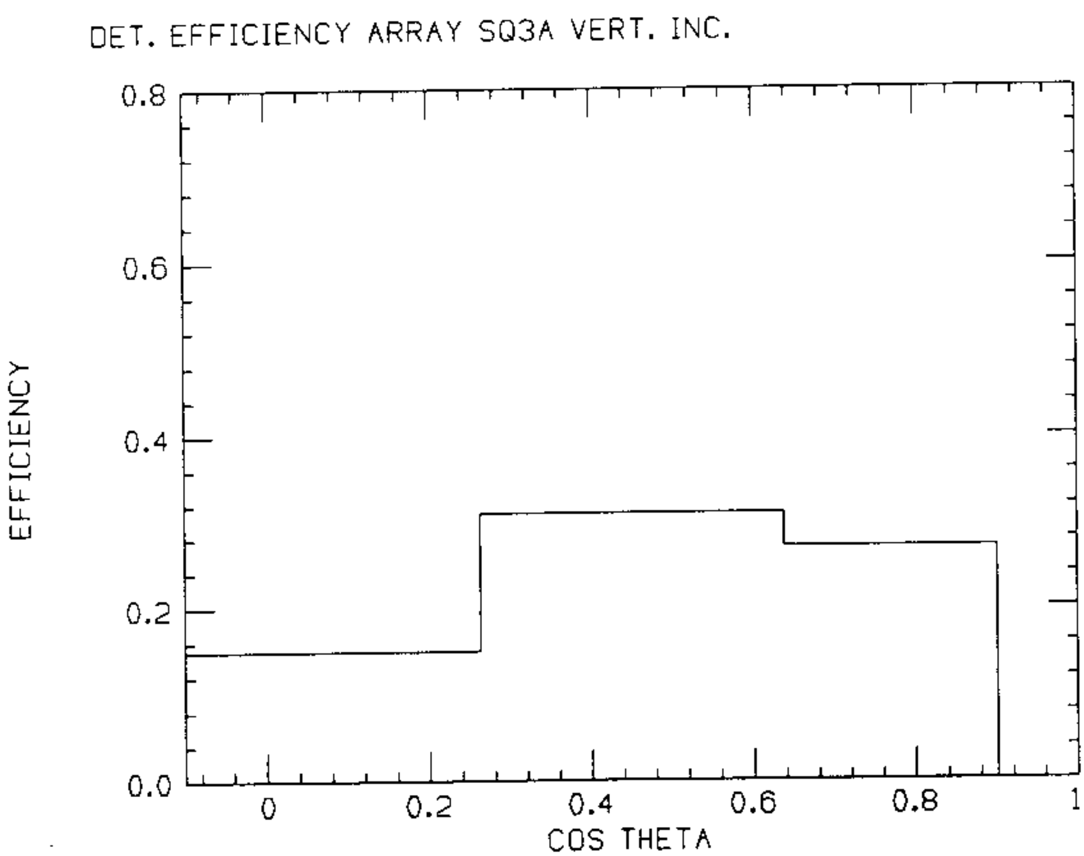
3. Fig. 3a. Detection efficiency of Array 3B for horizontally incident particles as a function of angle.



3b. The same, for vertical incidence. Note decreased efficiency for vertical incidence of hollow square.



4. Fig. 4a. Detection efficienct of Array SQ3A for horizontally incident particles.



4b. The same, for vertical incidence. Note the improved efficiency for a uniform array.

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      46         X
      44         X
      42         X
      4Ø         X
      38        5X
      36        XX
      34        XX
      32        XX
      3Ø        XX
      28        XX
      26        XXX
      24        XXX
      22        XXX
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 * BIN WID = Ø.12ØØE+ØØ       * MEAN VALUE   = Ø.12Ø3E+Ø1     * R . M . S = Ø.2361E+Ø1     * ABNOR CHA= Ø.ØØØØE+ØØ
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Fig. 5. The precision of determining the direction of an incident muon. This distribution is about 0.2 the width predicted for DUMAND 2, because of the much greater path length available. Both 3B and SQ3A exhibit this accuracy. It will allow more precise location of point sources.

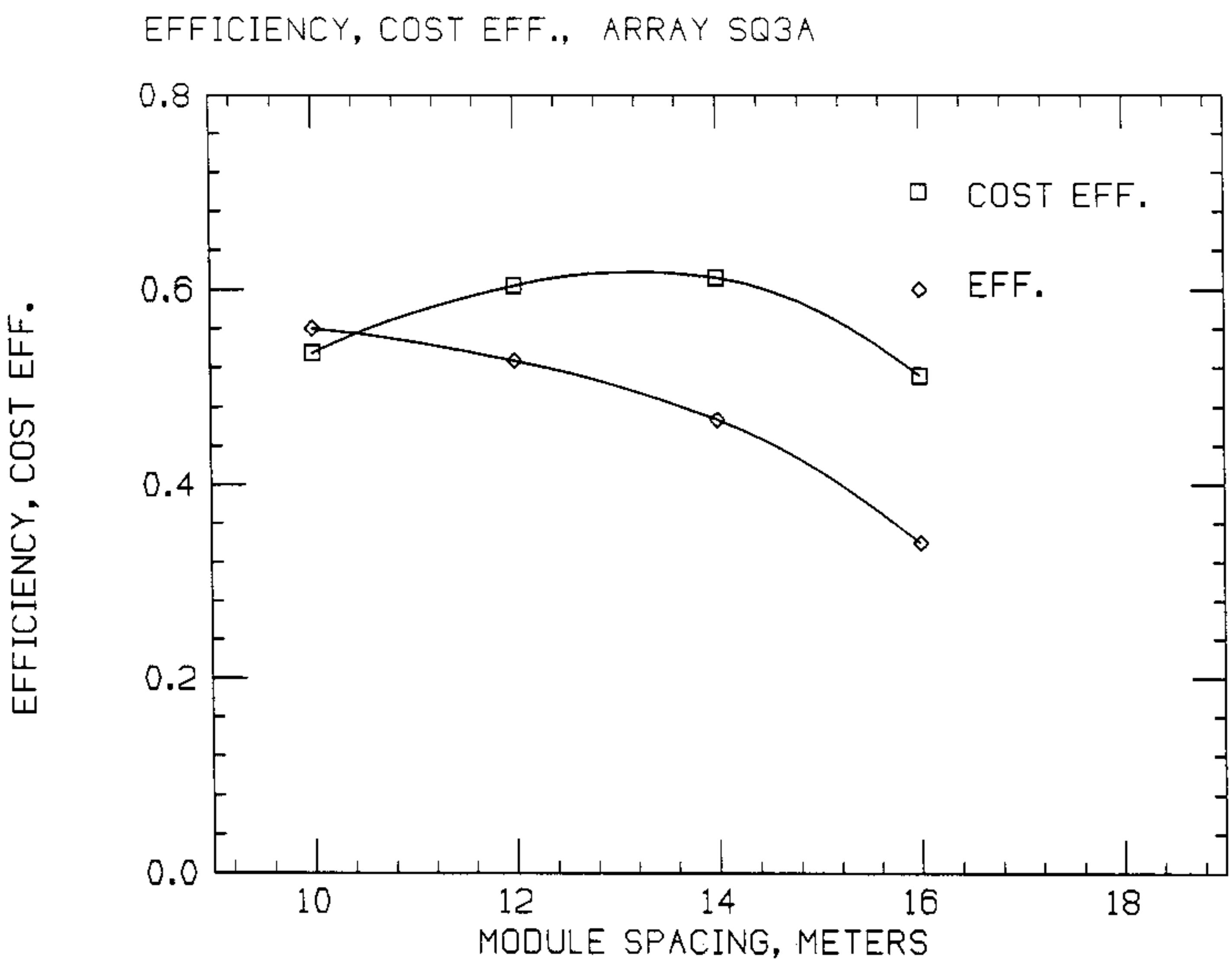


Fig. 6a. Variation of detection efficiency as a function of string module spacing for the array SQ3A. This slow variation permits the trade-off of detection efficiency for array economy. Thus, changing the module spacing from 10 to 12 meters saves 1744 modules, and decreases detection efficiency from 0.56 to 0.526.

6b. "Cost effectiveness", defined as efficiency per 10,000 modules. The larger spacings gain while efficiency drops more slowly than the number of modules. The optimum comes around a spacing of 13 to 14m.

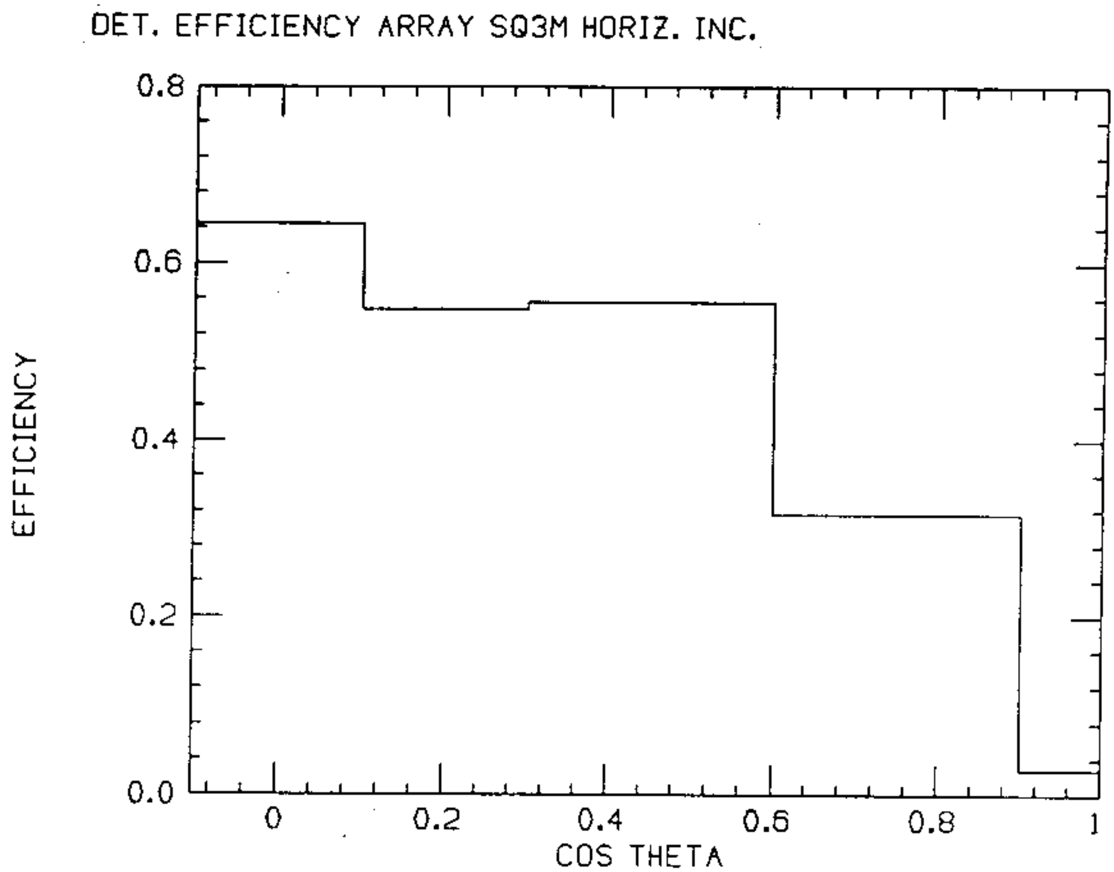
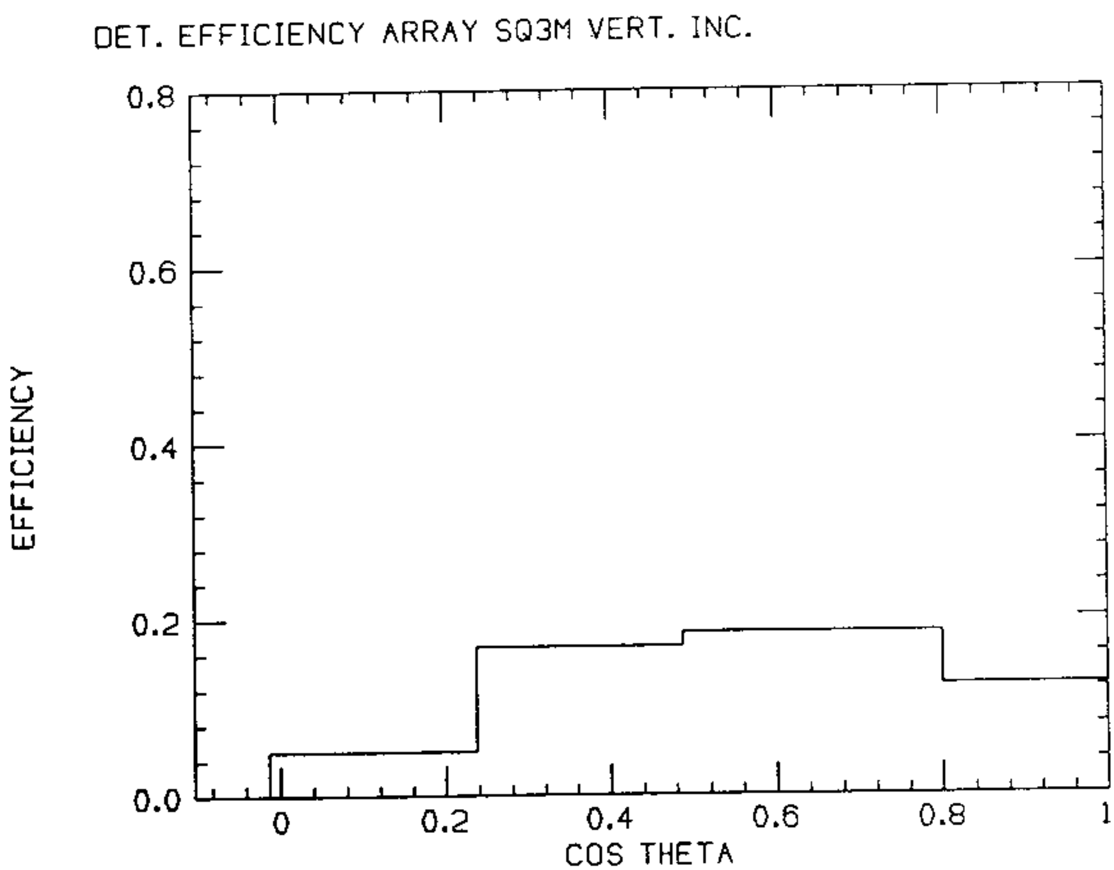


Fig. 7a. Detection efficiency of array SQ3M for horizontally incident particles. Module spacing is 13m.



7b. Detection efficiency for vertically incident particles, 13m. module spacing.