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MONTE CARLO STUDIES OF DUMAND ARRAY PERFORMANCE

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The results of Monte Carlo simulations of the DUMAND optical array are summarized.

The DUMAND optical array has been the subject of extensive study by Monte Carlo simulation techniques[1-5]. As these studies have evolved to greater and greater levels of sophistication our confidence that an array can be built at reasonable cost which will do important physics and astronomy has steadily improved to the point where there are few remaining doubts. Our studies of muon detection and reconstruction are essentially complete. We are sure that we can detect muons with greater than 90% probability at energies above a few hundred GeV and, at least for large arrays, reconstruct these with an angular precision of a few mr and an energy resolution of 40-50%. The exact properties will, of course, depend on the details of the final array design. The remaining work on muons concerns the capability to distinguish multiple muons and the response of the array to closely packed muon bundles.

We have not reached a comparable understanding of hadron or electromagnetic cascade detection and reconstruction and work on this is proceeding. Preliminary results[1,2,4] show that, even for arrays with widely spaced sensors in which light from the cascade reaches only one or two modules, the energy resolution should also be about 40-50%. No direction reconstruction is possible in this case, but if at least a portion of the array contains sensors 15-20 m apart we have a preliminary indication that an angular resolution of about 100 mr should be possible for e-m cascades in that segment.

Our studies show that the critical parameters of any array are:

1. The sensitivity of each sensor module. This we define as S, the mean number of photoelectrons which are produced at the PMT photocathode for an incident Cerenkov light intensity of 100 photons m^{-2}. Typical values are 1.5 for a direct-view 13" PMT and 6 for a large light-collecting sensor such as Sea Urchin[6]. The obvious general principle that "the more sensitive the better" is tempered by considerations of the cost of deployment[7,8] and other disadvantages associated with the necessarily greater size of a light-collecting sensor module (see below). Also, there is an interesting limit of $S \cong 10$ beyond which there is little improvement in array performance[4] (see Fig. 1). These considerations have led us to currently prefer the direct view PMT sensor with $S = 1.5$[8].

2. The horizontal and vertical detector spacings. Early studies took $\Delta_V = \Delta_H$ (cubic array) but it is now clear that any array is likely to be deployed as a set of vertical strings and closer spacings vertically make sense economically. We have been pleasantly surprised that such "asymmetric arrays" are highly efficient except for muons in a

small vertical solid angle[8,9]. Typical values now favored are $\Delta_H = 50$ m and $\Delta_V = 20$ m. For a given sensitivity, the sensor spacing also governs the energy threshold. We have found that once above this threshold, which is as low as 100 GeV for most configuations considered, there is only slight improvement in array performance with increasing energy[5].

3. The resolving time. This depends on the size of the detector module and will be worse for large light collectors than for the bare PMT detector. If this is kept to a few ns then by using timing information the angular resolution of muons is significantly improved over a purely spacial reconstruction, from typically 10-15 mr down to 2-3 mr[3,5]. At this point the error in neutrino direction may be determined mainly by the angle between the neutrino and muon in the interaction. It is estimated that 63% of the interactions at a neutrino energy E_ν TeV will have an angle less than $25/\sqrt{E_\nu}$ mr[10].

4. The overall size of the array. This, of course, affects the event rate but is also important in giving sufficient lever arm and time delay for muon reconstruction. In fact, the importance of the latter can be seen in the result that when two array configurations of the same ratio of sensor spacing to length are compared, the one with the larger spacing gives better angular resolution.

There are a number of other parameters which affect the performance of the array and are considered in the Monte Carlo simulations but found to be less critical than those listed above. The threshold setting, i.e., the number of photoelectrons which define a detector "hit", has generally been set at 2 or 3. This affects mainly rejection of K^{40} backgound noise and not the overall detection efficiency and reconstruction accuracy.

We have also taken into account the anisotropy of response of PMT's and found the effects of second order importance[8].

Other experimental conditions such as detector module deadtime, which affects multiple track reconstruction, are also being simulated.

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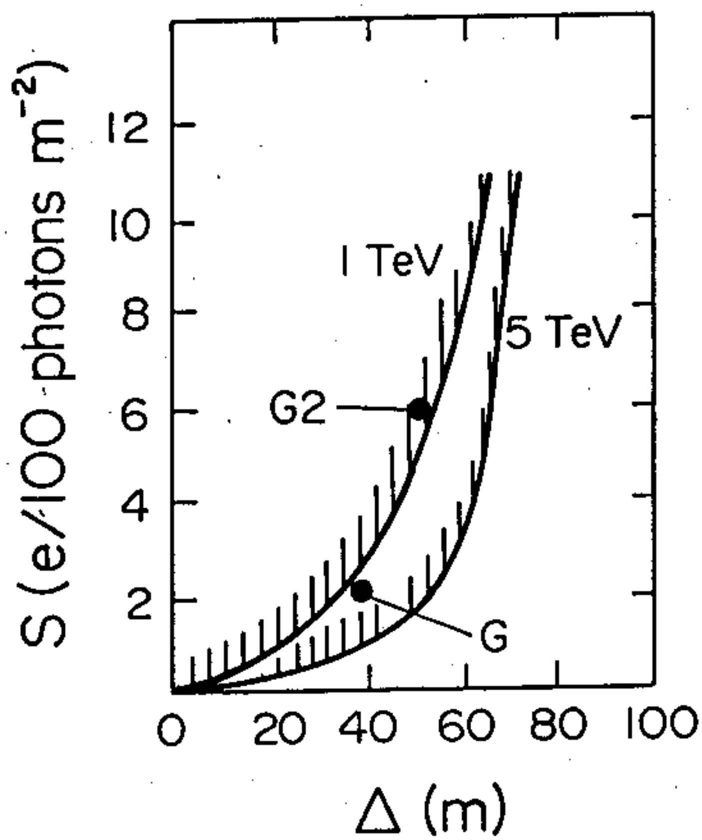

Fig. 1. Contours of 90% detection efficiency for 1 TeV and 5 TeV muons as a function of the detector module sensitivity S and spacing Δ for cubic arrays. The points marked G and G2 correspond to early array designs.