On the Detection of UHE Cascade Showers with DUMAND II

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Abstract

The detection efficiency and the energy and angle resolutions of UHE single cascade showers in the DUMAND II octagon array are examined via reconstruction of simulated cascade events, followed by a rough estimation of the effective detection volume, which is $\sim 10^8\ m^3$ for the cascade of 5000 TeV. Only for this purpose, however, a wider span of the detector array would obtain a better performance.

1 Introduction

If the ultra high energy (UHE) neutrino flux from the active galactic nuclei (AGN) is almost the same as theoretically expected [Stanev, T.], DUMAND II will be large enough to detect order of 100 events/year of both muons and cascade showers produced by such diffuse AGN neutrinos [Learned, J.G.]. In case of the muon detection, Monte Carlo studies have shown that the dominant atmospheric neutrino background can be suppressed by a rough muon energy cut [Okada, A.]. Since the energy deposit of a muon nearby the detector array is rather small when compared with that of an UHE cascade, the distance of well detected muons is at most several tens meters out from the array. In case of the UHE cascade detection, for example that from the 6.4 PeV Glashow resonance by ν_e, the sensitive volume can be as large as a sphere with radius of several hundred meters. But, if such a cascade far from the array can not be properly reconstructed and then the energy resolution is too poor, the really useful sensitive volume must be reduced.

This is a preliminary trial of UHE cascade reconstruction applied to simulated events.by Monte Carlo.

2 DUMAND II and simulation of cascade events

DUMAND II is composed of 9 vertical "strings" of 24 optical modules (OMs) each, tethered from the bottom of the ocean. The strings are located at the vertices of a 40 m equilateral octagon, and the ninth string is at the center of the octagon. The vertical spacing of the OMs is 10 m. The 15" photomultiplier (PMT) in the OM looks downward.

The obtained data at each OM are detection time of photoelectrons (explicitly the first one when there is a small time spread in a packet of photons) and an equivalent quantity of the total charge of the photoelectrons.

The present simulation of cascade events is a simplified one. When a cascade is produced, all Cherenkov photons are assumed to be emitted from a point with a certain angular distribution which is prepared beforehand as the extrapolation of average behaviour of low energy electromagnetic cascades. Photons are absorbed gradually on the way to the OM. Poisson statistics are taken into account about the number of photons hitting each OM. Further, the total charge of the photoelectrons is smeared by the detection efficiency (which also depends on the incident angle of photons) and by the finite charge resolution of PMT.

The time structure in the photon packet is actually somewhat complicated, but now we only assume a standard deviation of 6 ns as the detection time of a photoelectron at the OM. The deviation includes the detector error itself ($\sim$ 3 ns).

There is background light in the ocean due to K^{40} decay and bioluminescence. Here a random noise of 100 KHz is assumed at the PMT output.

3 The method of cascade reconstruction

Here the reconstruction means estimating the spatial position, direction and the energy of the cascade, that is, determining those parameters so as to minimize the following function F :

$$F = w_1 \cdot \sum_{i(OM)} \frac{\left(T_i(x,y,z) + \tau - t_i\right)^2}{\sigma_t^2} + w_2 \cdot \sum_{i(OM)} \frac{\left(E \cdot Q_i(x,y,z,\theta,\phi) - q_i\right)^2}{\sigma_q^2}$$

Here,

x, y, z : Spatial position of the cascade center,

θ, ϕ : Zenith and azimuth angle of the cascade axis,

$T_i(x,y,z)$, $Q_i(x,y,z,\theta,\phi)$: Expected time (in units of ns) and pulse charge (in units of photoelectrons) for the i-th OM, when the cascade energy is 1 TeV. Following the above simplified assumption, those are expressed explicitly with R_i, the distance between the cascade position and the i-th OM ;

$$T_i = (n/c) \cdot R_i$$
$$Q_i = \eta\, A_{OM}\, I_\gamma(\Theta_{cas})\, \frac{exp(-R_i/R_{abs})}{R_i^2}$$

where η, A_{OM} and $I_\gamma(\Theta_{cas})$ are the OM detection efficiency depending on the PMT polar angle, the area of OM, and the photon density per solid angle, respectively,

t_i, q_i : Data of time and pulse charge at the i-th OM,

σ_t, σ_q : Standard deviations of time and pulse charge, here assumed ;

$$\sigma_t = 6 \text{ ns}$$
$$\sigma_q = \sqrt{0.1\, q_i^2 + q_i + 1}$$

τ : Start time of emitted photons from the cascade, which is a dependent parameter ;

$$\tau = -\sum (T_i - t_i)/\sigma_t^2$$

E : Energy of the cascade in units of TeV, also a dependent parameter ;

$$E = \frac{\sum(Q_i q_i/\sigma_q^2)}{\sum(Q_i^2/\sigma_q^2)}$$

w_1, w_2 : Constants to adjust relative weight of each term.

If we assume a constant σ_t, the first term of F is a function of only x, y and z, i.e. independent of the cascade direction, as easily seen from the explicit expression of T_i. So, the cascade direction and also energy can be determined only by the second term.

How to set the weights w_1 and w_2 seems to be a kind of technical problem. Here, three (or the first two) steps of procedure were tried ; first $w_1 = 1$ and $w_2 = 0$, secondly $w_1 = 0$ and $w_2 = 1$ and finally $w_1 = w_2$.

4 Results and concluding remarks

The zenith angles of generated events are larger than 80° and the distribution follows the expected one from isotropic extraterrestrial neutrino sources. Three fixed energies are examined, $E_0 = 200$ TeV, 1000 TeV and 5000 TeV. Events with 50 or more hit OMs are selected and put into the reconstruction program.

When the obtained distance R between the array center and each cascade location is smaller than 200 m, the energy resolution is fairly good as seen in Fig.1, but not satisfactory when $200 < R < 300$ m (Fig.2). When $R > 300$ m, so far, fits are poor to get any meaningful information.

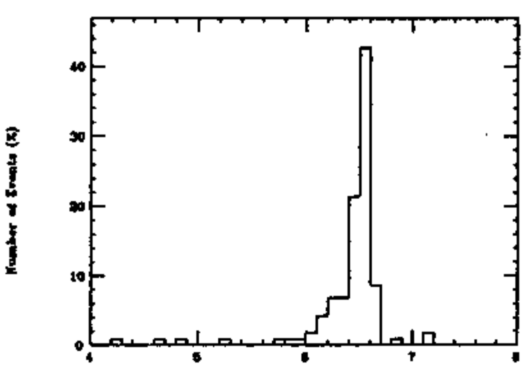

Fig.1 : E_0=5000 TeV, $R < 200$ m
Energy Resolution ~ 55 %

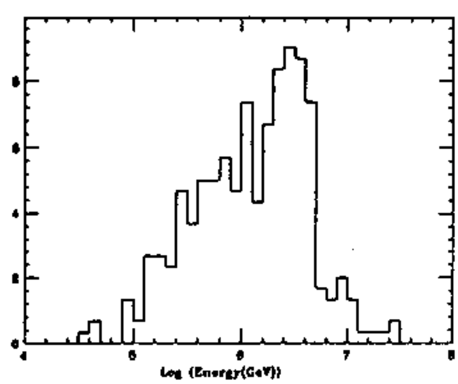

Fig.2 : E_0=5000 TeV, $200 < R < 300$ m
Energy Resolution ~ 140 %

The angular resolution has a similar tendency. When $E_0 = 5000$ TeV, the medians of the angle error are 3.6° and 12.3° for $R < 200$ m and $200 < R < 300$ m, respectively. With a cascade very far from the detector array, the part of Cherenkov cone intercepted by the array can not show any clear curvature. Then, an unhappy estimation error of typically two times the Cherenkov angle (2 × 42°) may occur.

In the table below, the effective volumes after reconstruction are listed for $R < 200$ m and for $R < 300$ m. (Recall that R is the obtained distance by fitting.)

	$E_0 = 200$ TeV	$E_0 = 1000$ TeV	$E_0 = 5000$ TeV
$R < 200$m	$2.8 \times 10^7 m^3$	$3.8 \times 10^7 m^3$	$4.2 \times 10^7 m^3$
$R < 300$m	$3.9 \times 10^7 m^3$	$6.9 \times 10^7 m^3$	$10.8 \times 10^7 m^3$

The results are preliminary. We are preparing for a more realistic simulation, including the effects of optical scattering in water.

Finally, although DUMAND II is already optimized for the detection of muons, if the sides of the octagon array are four times larger (40 $\rightarrow$ 160 m), the energy resolution of cascade becomes much better : Fig.3 at $R < 200$ m, $E_0 = 200$ TeV and Fig.4 at $200 < R < 300$ m, $E_0 = 5000$ TeV, and the median errors of angle are 3.2° and 4.8°, respectively. However, the muon detection would be harder. This suggests a possible evolution towards "DUMAND III" should we see signals with the first few strings.

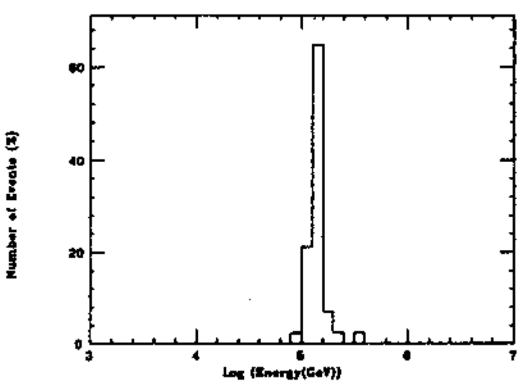

Fig.3 : E_0= 200 TeV, $R < 200$ m
Energy Resolution ~ 30 %

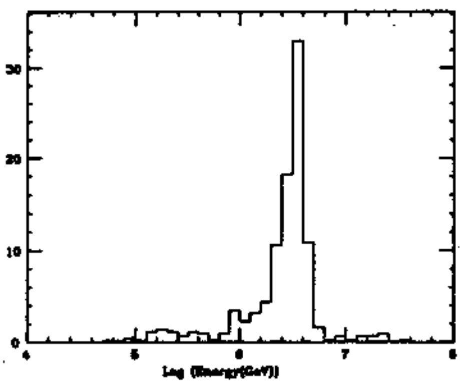

Fig.4 : E_0=5000 TeV, $200 < R < 300$ m
Energy Resolution ~ 65 %

5 Acknowledgements

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