DUMAND-8-93

Fermilab Library
0 1160 0029948 1

ISU-αHEP-93-1

DUMAND-8-93

Estimate of Downgoing Atmospheric Muon Background Events in DUMAND II

A. Okada[a] and K. Mauritz O'Brien[b]
for the DUMAND Collaboration*

[a] Institute for Cosmic Ray Research, University of Tokyo
3-2-1 Midori-cho Tanashi-shi, Tokyo 188, Japan
[b] Department of Physics & Astronomy, Iowa State University
Ames IA 50011 USA

FERMILAB
JUN 14 1993
LIBRARY

ABSTRACT

The 9-string DUMAND II array at a 4.8 km water depth is expected to trigger at about 1 Hz on downgoing muons, yielding about 30 million such events per year. Out of a sample of 6.18×10^6 simulated muons, about 10^{-4} of these downgoing events were misreconstructed such that they became a background to an upgoing $\nu_\mu \rightarrow \mu$ event sample at the level of ≈ 2 events/pixel/year, where one pixel is the experimental solid angular resolution of $\pi(.017)^2$ steradians. Optimization of this background rejection with respect to putative signals requires further development. At present, 1.8π steradians of the full 4π steradian point source search solid angle has background less than 1/pixel/year.

1. INTRODUCTION

The downgoing muon events are primarily energetic muons from the decays of pions and kaons produced in hadronic interactions in the upper atmosphere. Those muons with energy exceeding about 1 TeV can reach the DUMAND array at 4.8 km depth, and Čerenkov light at 42° from these tracks can be intercepted by the hemispherical photocathodes of the optical modules which are directed downwards to be maximally efficient for upgoing events. The angular distribution of the incident muons is sharply peaked at zero zenith angle as displayed in Figure 1. In the presence of background light, misreconstructed muons may fake upgoing physics events from $\nu_\mu \rightarrow \mu$. The physics goal of DUMAND II for a neutrino point source search (Bosetti, *et al.*) is a background of less than 1 event per pixel per year in the 2.4π steradian solid angle below $\cos\theta_{\rm zenith}=0.20$.

2. SIMULATION AND TRIGGERING

The simulation includes the effects of muon bremsstrahlung, fluctuations in the Čerenkov photon yield, fluctuations in the transit time in the optical module, K^{40} decays, dark current, bioluminescence and the scattering and energy loss of muons in the water. The muon is generated with a uniform distribution on a circle of radius 170 m centered on the DUMAND II array and perpendicular to the sampled muon direction. The starting point of the muon in the simulation is 50 m above the top of the array, and the minimum sampled energy is 10 GeV. The trigger requires signals on three adjacent strings and signals on 12 optical modules within 1 μsec. Within a string, two adjacent optical modules with times t_1 and t_2 must satisfy $|t_1 - t_2| < 50ns$, and two modules separated by one inactive module must satisfy $|t_1 - t_3| < 90ns$. The timing signals from three adjacent optical modules, t_1, t_2 and t_3, must satisfy

$$-7ns < (t_1 - t_2) - (t_2 - t_3) < 60ns.$$

Under these conditions, about 1 in 5 of the 6.18 million generated muons within 170 m of the array center satisfies the trigger condition, yielding 1.30 million muons for subsequent reconstruction in this simulation.

3. RECONSTRUCTION

The reconstruction algorithm (Okada) requires ten or more optical modules to participate in the track fit and three or more strings. During the fit, if the time residual of an optical module is greater than 12 ns, that optical module is discarded from subsequent fits, and up to five such exclusions are allowed. After the final fit, if the nearest optical module is farther away than 50 m, the fit is rejected. (The mean optical attentuation length is about 40 m at 450 nm.) The search procedure uses a grid search first, followed by a chi-squared minimization. The hypothesis tested is a straight line of variable length near the DUMAND volume, with fitted parameters being the track coordinates and space angles. Finally, the hypothesis is accepted if the chi-squared per degree-of-freedom is less than 6. Generally, the algorithm obtains good fits, as is evident from the chi-squared distribution in Figure 2. Typically, 20 optical modules among 3-4 strings are used in a successful fit.

Fluctuations in the measurements of Čerenkov light, the presence of a 50 kHz single photoelectron trigger rate per optical module from K^{40} in the water, dark current in the photomultiplier tubes, and muon tracks which are not well contained within the central volume of the array all contribute to potential misreconstructions of downgoing muons. For the vast majority of the tracks, the reconstructed angular resolution is excellent at about 0.8^o as shown in Figure 3, and ordinary measurement fluctuations yield a high-side tail on this distribution.

The reconstructed muon zenith angular distribution is shown in Figure 4 for 1.81×10^5 reconstructed events. A total of 3772 events in this distribution are below a cosine of 0.2 (about a zenith of 78^0) corresponding to a misreconstruction rate of 10^{-4} per incident muon. These events are a potential background to an upgoing $\nu_\mu \rightarrow \mu$ physics event sample. A subsequent attempt at fitting a subsample of these events, essentially using a finer grid search, more careful background hit rejection and a tighter selection on the quality of the fit at $\chi^2/\mathrm{dof}<2.6$ reduces this rate by an additional factor of 6. It is evident from Figure 4 that this background is negligible for large zenith angles, and that the sensitivity of a point source search will be zenith-angle dependent.

There are about 8000 pixels in the solid angle 2.4π steradians below $\cos\theta_{\mathrm{zenith}}=0.20$, and at a 10^{-4} misreconstruction rate we expect about 18,000 events in this solid angle, which exceeds our goal of less than 1/pixel/year. However, the results of this calculation indicate that 1.8π of the 4π steradian solid angle for point sources searches has a misreconstructed muon background of less than 1/pixel/year. An independent calculation (Stenger) has found a misreconstruction rate of 0.63 ± 0.36 /pixel/year for misreconstructed downward muons in this same solid angle, in addition to 0.40 ± 0.08 /pixel/year from random noise, 0.15 ± 0.07 /pixel/year from multiple cosmic ray muons, and 0.13 ± 0.01 /pixel/year from atmospheric ν_μ's.

Further work at optimization of background rejection relative to signal efficiency for several putative models is required. In addition to further selection criteria, the final reduction in point source background is expected from a visual scan of all events beyond a zenith of 78^0.

ACKNOWLEDGEMENTS

We gratefully acknowledge the support of the US Department of Energy, the Japanese Ministry of Science, the Japan Society for the Promotion of Science, the Swiss, US and Japanese National Science Foundations, the State and University of Hawaii, and the Iowa State University Project Vincent computing environment.

REFERENCES

* A description of DUMAND II and a full author list are in a companion paper submitted to this conference, "Update on Status of DUMAND", C.M. Alexander, et al.

Bosetti, P.C., *et al.*, "Proposal for a Deep Ocean Neutrino Astrophysics Facility - DUMAND II," HDC-2-89, U. Hawaii, Manoa.

Okada, A., "Sensitivity of DUMAND II to AGN Neutrinos," in *Proc. Workshop on High Energy Neutrino Astrophysics*, University of Hawaii, Manoa, Honolulu, Hawaii, March 23-26, 1992, eds. V. Stenger, J.Learned, S.Pakvasa, and X.Tata.

Stenger, V.J., "Fake Events in DUMAND II", DIR-91-16, Oct. 1991; and, subsequent private communications.

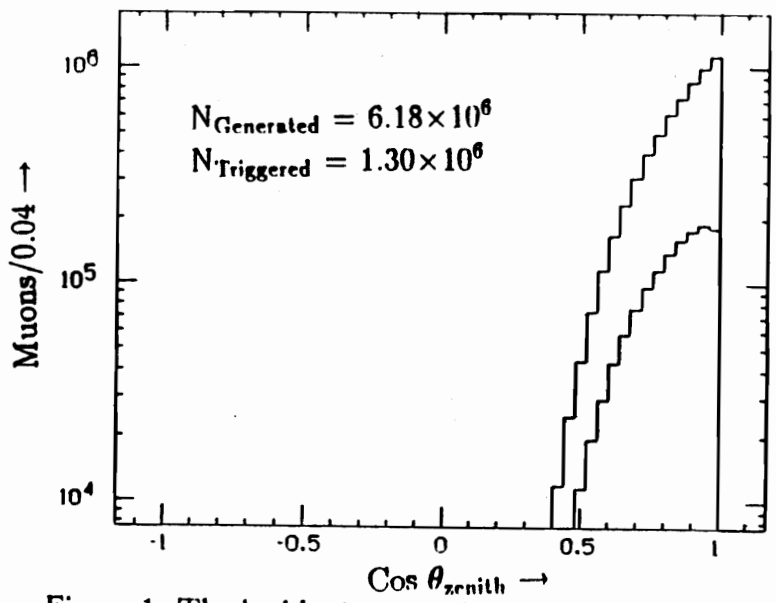

Figure 1. The incident atmospheric downgoing muon angular distribution for all muons reaching DUMAND depth at 4.8 km (upper curve) and muons which satisfy the DUMAND trigger (lower curve).

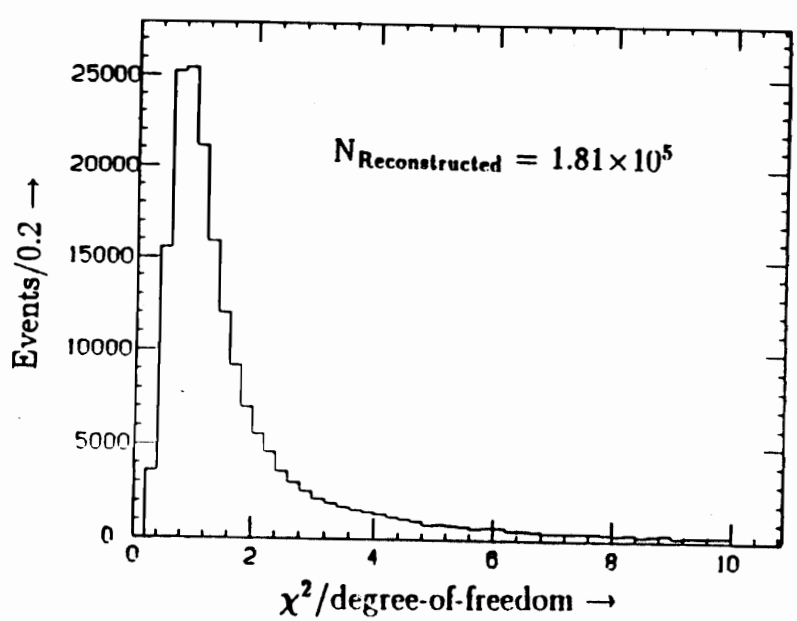

Figure 2. Chi-squared distribution for all fits to triggered muons. The figure contains 181,000 events.

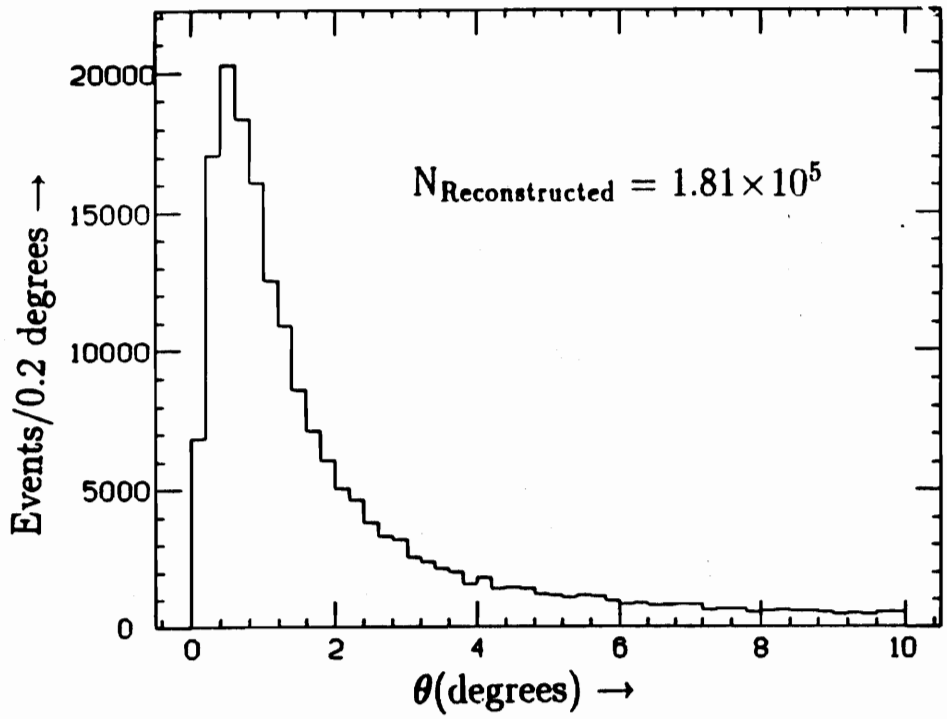

Figure 3. Angular resolution of fitted muons. The most probable value is 0.8^0. There are 1.81×10^5 events in this plot.

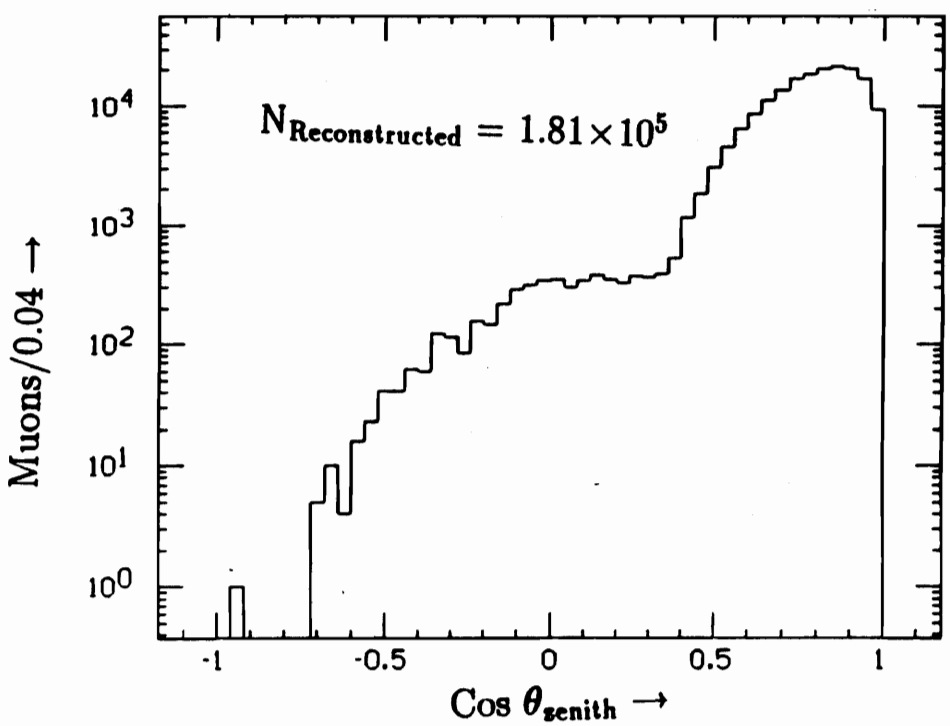

Figure 4. The reconstucted and fitted zenith angular distribution. The population of events below cosine 0.20 is 3772 events out of 1.30×10^6 triggered events.