DIR-16-91
(Revised February 18, 1992)

# MIS-IDENTIFIED EVENTS IN DUMAND II

V.J. Stenger
Hawaii DUMAND Center
February 18, 1992

**Preface to the Revision**

This is a revised and updated version of DIR-16-91, previously entitled "Fake Events in DUMAND II." The main new result is an updated estimate of the cosmic ray background, including previously ignored multiple muons. A few other corrections and changes have been made, and the title changed (at the urging of Ken Young) to more accurately reflect the fact that several of the backgrounds talked about here are not really "fake events" but signals in another context.

**Abstract**

*The rate of events that will masquerade as extraterrestrial point source neutrinos is estimated for four major known backgrounds. For each of 8,000 $1^o$ pixels in range $-1 < \cos\theta_Z < .2$, where $\theta_Z$ is the zenith angle, the number of mis-identified events per year is found to be: $0.40 \pm 0.08$ for random background ($K^{40}$ and uncorrelated bioluminescence at 60 KHz singles rate), $0.63 \pm 0.36$ for downward single cosmic ray muons, $0.15 \pm 0.07$ for downward multiple cosmic ray muons, and $0.35 \pm 0.01$ for muons from atmospheric neutrinos. The sum is $1.53 \pm 0.38$ per year, close to the design goal of about one event per year and sufficiently low to permit signal detection at about 10 events per year.*

**Introduction**

This report gives my current estimate of the background of mis-identified neutrino point sources events in the DUMAND II Octagon array. The precise results of any such calculation depend greatly on the assumptions made for simulating, triggering, filtering, and fitting. The calculation must be constantly updated as better information on the array becomes available and better algorithms for data analysis are developed.

The search for extraterrestrial signals in DUMAND is made more effective by being signal-limited rather than background-limited when searching for point sources. This makes it in principle possible to detect a signal of just a few events, nominally ten, per year. The design goal has been to achieve a background of less than one event per year in each pixel that is searched for a point source.

Obviously, the smaller the pixel size, the lower the background. Pixel size will depend on our angular resolution. The current fitting algorithm in DUMC gives a distribution in pointing error that peaks between $0.5^{\circ}$ and $1^{\circ}$, depending on the hardness of the spectrum, but has a long tail that makes the average error not too meaningful. The median error is perhaps more descriptive and is typically $1.5^{\circ}$ in the presence of noise, depending on assumptions and parameters, such as PMT time resolution, but is also sensitive to the tail of the distribution and the PMT time jitter.

For the present study, I assume that the goal of a $1^{\circ}$ pixel is ultimately achievable. The results presented here will scale as the pixel area. If we assume a circular pixel of $1^{\circ}$ radius, the pixel area will be $\delta\Omega = 0.95$ msr. Then the $\Omega = 2.4\pi$ sr of the celestial sphere at zenith angles greater than $80^{\circ}$ can be divided up into about 8,000 pixel elements. In what follows, I will use this figure.

**Run Conditions**

For this study, the following conditions were used: The array contained half Hamamatsu and half Philips tubes. Although the differences between the two are not yet fully implemented in the simulation, this is not felt to be critical to the conclusions. A Gaussian time jitter with $\sigma_t = 2.5$ ns was used for both tubes, with a 1 ns rounding error from digitization added in quadrature. The internal optical module (OM) threshold was set at 1/3 pe. For more details on the optical module simulation, see Ref. 1, though this is a bit out-of-date.

A random singles rate of 60 KHz was used for each PMT – our best guess from SPS data. A hardware trigger T3.OR.TE was applied. These triggers are described in Ref. 2. A 15 ns "difference of time differences" was used for T3, and the threshold total array charge for the TE trigger was set at 30 p.e. Note that a satisfactory algorithm for simulating the measured PMT charge obtained onshore does not yet exist because we still do not have any data to base it on, so TE is not adequately simulated. I find that TE does not let in a significant number of point-source events not already admitted by T3 and could be discarded if necessary in the software analysis of point source candidates.

After triggering, the simulated events are passed through a series of data-reduction stages that are described in detail in Ref. 4:

(1) **Filtering.** OM hits that are outside a Cherenkov light cone centered at the trigger hit are discarded.

(2) **Pre-Fit.** A non-iterative space-time preliminary fit is performed. Its results are used to define the starting parameters of the $\chi^2$ fit.

(3) **$\chi^2$ Fit.** An iterative search is made for the best fit to the event. Both single muon track and vertex cascade hypotheses are tested, but this report will be limited to the background to the muon track hypothesis. The $\chi^2$ search was performed with five parameters: three giving the position of the muon at t = 0 and two giving the muon's direction.

OM hits having large $\chi^2$ pulls are discarded in each of the above fits, and the fit may be re-done several times on a given event. Discarded hits are ignored in the succeeding analysis steps. By this elaborate but straight-forward mechanism, an original average of 13 background hits in each valid event is reduced to 0.5 in the final fit.[4]

After each of these stages of analysis is performed, an optional set of simulated software cuts are applied to the events. These can be different at each stage, but for simplicity have been taken to be the same for the purposes of this study. Actually, no cuts need be performed until the end of the final stage of track fitting, but computer time is saved by throwing out events as soon as possible in the data reduction stream.

The following cuts were applied for this report:

C1: The number of OMs was required to be at least 10;

C2: The number of strings with OM hits was required to be at least 3;

C3: Various combinations of adjacent cluster coincidences on at least three strings string were applied, with the following combination leading to an acceptable false event rate: (3-3-2), (4-2-2), (5-3-1). Here the notation is the same as used in the DUMAND proposal[3]; see also Ref. 5. An event is passed if it meets any one of the three cluster combinations shown: two 3-folds and a 2-fold, two 2-folds and a 4-fold, or a 5-fold, 3-fold and 1-fold. (Note, however, that C3 is less restrictive than the combinations proposed in References 3 and 5).

**Mis-identified Events from Random Noise**

Let me first estimate the mis-identified event background that results from random OM noise due to $K^{40}$ or uncorrelated bioluminescence.

Although the false trigger rates can be estimated without a Monte Carlo, I have made several runs of 30,000 events, requiring about a day's CPU time each, to check the trigger rates. First I generated all the OM hit times randomly within 1137 ns and than ran them through T3.OR.TE. The result was 110 triggers, which translates to a 3.7 KHz trigger rate.

All but two of these these triggers resulted from TE, implying a 110 Hz T3 rate. J. Learned independently estimates 50 Hz for T3, which is consistent, and "about 1,000 Hz" for TE at a 25 pe threshold, which is probably consistent.[2] (Recall, onshore PMT charge is not properly simulated.) While TE lets in far more background, it may efficiently trigger on other classes of events, such as high energy bursts outside the array, and should be maintained as long as the data harvesting system can handle it.

In principle, one can generate a large number of random events and see how many are reconstructed as a muon track. However, an inordinate amount of computer time is required to determine the random mis-identified event rate by simply running events all the way through to track fitting. A few numbers illustrate why. Since it takes 1 $\mu$s for a particle moving at the speed of light to traverse the array, and we intend to set our PMT thresholds as low as possible, we can assume we will transmit events at 1 MHz, or $3\times10^{13}$ events per year. To determine if our mis-identified neutrino point source background is less than 1 per year to 95% confidence level, we need to run our simulation until we get 3 events that look like neutrinos. If we assume all 8,000 pixels are equivalent, we can randomly sample these. So we need to run about a billion events. DUMC runs at about a thousand events per VAX 3600 CPU hour, so I would need a million hours, or about 100 years, of VAX time.

Instead, I have generated background hit times so as to pass *a'priori* cut C3. Events passing C3 are likely to also pass T3, though this is not assumed and all triggers and cuts are applied to each event generated.

The procedure is summarized as follows: A random multiplet of adjacent OMs on a random string is selected. The multiplet size is randomly chosen from the allowed combinations. Strings are treated independently, with no cross string correlations assumed since the triggers and cuts used make no such assumption. [Note: I have thought of simulating cuts with cross-string coincidences, but decided that since causality is already built into the track fit, this is unlikely to make a significant improvement]. Within each multiplet, a random OM is chosen and assigned a random hit time within the 1137 ns array trigger gate. The first hit is assigned $t = 0$ and designated as the trigger. Random times are then assigned within each multiplet within a smaller time window that depends on the multiplet size.

For the rest of the array, random background is generated by choosing random OMs and random times within the 1137 ns array time window. The total number of OMs hit, including those within the C3 configuration, is selected from a Poisson distribution with a mean of 13, corresponding a singles rate of 60 KHz. This procedure is the same as used for the studies of signals and other backgrounds.

By a separate, non-Monte Carlo calculation I have estimated that the rate of random events which will pass cut C3 is 0.0042 Hz. I have used the Monte Carlo to generate 1,000 events to pass C3 *a'priori*, as described above. Of these, 996 actually pass all triggers and cuts, and 24 or 2.4 %, give a muon track fit. Thus the mis-identified event rate from randoms is $(0.0042)(0.024) = 1.0\times10^{-4}$ Hz, leading to false signal of $B = 0.40 \pm 0.08$ per year per pixel.

**Mis-identified Events from Single Cosmic Ray Muons**

Single muons have been generated with the spectrum and zenith angle distribution expected for cosmic rays at a depth of 4.5 km. The events were given a $\cos^5\theta_Z$ distribution, which is in agreement with DUMAND I results.

A total of 30,000 events were generated and processed through the same triggers, cuts, filters, and fits described above. The effective area was determined to be $A_{eff} = 2830 \pm 90\ m^2$ for for events passing all the way through to track fit. (The PMTs all point down, and cosmic ray muons have low energy, so the effective area for cosmic rays is considerably less than that for upward neutrinos, typically 20,000 $m^2$ at 5 TeV). Of the 1106 fits found, 3 were reconstructed with $\cos\theta_Z < 0.2$, the region we will search for neutrino signals. The number of events per year in a $1^o$ pixel on the sky is then:

$$C = \frac{\delta\Omega}{\Omega} F_\mu A_{eff} \epsilon_c = 0.63 \pm 0.36\ y^{-1} \qquad (2)$$

where $\Omega/\delta\Omega = 8000$, $F_\mu = 2.1 \times 10^{-5}\ m^{-2}s^{-1}$ is the muon flux, and $\epsilon_c = 3/1106 = 0.0027$ is the fraction of single cosmic ray muons which are mis-identified neutrino events.

**Mis-identified Events from Multiple Cosmic Ray Muons (Muon Bundles)**

Multimuons have been generated according to the multiplicity and distance separation distributions measured by Frejus.[6] The multiplicity distribution used was:

$$\frac{dN}{dn} \sim n^{-\nu} \qquad (3)$$

where n is the number of muons and I use $\nu = 5.44$, which neglects the slight n-dependence of $\nu$ in the Frejus parameterization and roughly fits their data. I generate n by the algorithm: $n = 2z^\alpha$, where z is a random number between 0 and 1 and $\alpha = 1/(1-\nu)$. I find that 63% of the multiple muons have n = 2, so this is the main component for background considerations.

The distribution of distances of muon track from the central core of the bundle is given by:

$$\frac{dN}{dr} = \frac{r}{r_o} \exp(-r/r_o) \qquad (4)$$

where $r_o = 1.74$ m for n = 2, 1.62 m for n = 3, and 1.42 m for $n \geq 4$. The zenith angle variation on $r_o$ has been neglected. Note that $r_o$ is the most probable separation of a muon from the core and that measurable OM arrival time differences around 10 ns are common.

I have generated 30,000 multiple muons ($n \geq 2$) and run them through all the same triggers, cuts, and fitting procedures for single muons. The direction of the core of the bundle was generated with the same zenith angle distribution as single muons, in the range $\cos\theta_Z > 0.2$. The muon bundle was given an energy selected from the single muon spectrum with the individual muons energies randomly assigned within this total. The result is an effective area for fitted events of $A_{eff}^{(m)} = 2770 \pm 80\ m^2$, comparable to single muons

Of 1082 fitted events, 5 were reconstructed with $\cos\theta_Z < 0.2$, thus appearing as a neutrino event. An estimate of the mis-identified event background from multiple muons is:

$$M = \frac{\delta\Omega}{\Omega} F_{\mu}^{(m)} A_{eff}^{(m)} \epsilon_m = 0.15 \pm 0.07 \quad y^{-1} \tag{5}$$

where $F_{\mu}^{(m)} = 3\text{x}10^{-6}\ m^{-2}s^{-1}$ is the multimuon flux measured by Frejus at about DUMAND equivalent depth[6] and $\epsilon_m = 5/1082 = 0.0046$ is the fraction of multiple cosmic ray muons which are mis-identified neutrino events. Note that this is the same as for single muons.

## Mis-identified Events from Atmospheric Neutrinos

A new estimate of the atmospheric neutrino background has been made, in light of recent work indicating that the efficiency for DUMAND II to detect low energy events is better than anticipated.[7] While this is good news for those who regard atmospheric neutrinos as a signal, it could be bad news for those who worry about it as a background for point sources.

A Monte Carlo run was made in which 10,000 events with the expected atmospheric neutrino spectrum were generated, with $-1 \leq \cos\theta_Z \leq 0.2$. The triggers and cuts were as in the other analyses above. The neutrino energy range for this run was $1 \leq E_\nu \leq 100$ GeV. Of 661 triggers, only 17 passed the cuts and 5 gave $\nu_\mu$ fits. Previous calculations have found that 40,000 triggers above 1 GeV are expected from atmospheric neutrinos per year. Thus we expect 303 fitted events per year from atmospheric neutrinos below 100 GeV, when the cuts used to optimize for VHE neutrinos are used. (Different cuts to study low energy events can be simultaneously applied).

For events above 100 GeV, the expected atmospheric flux was folded in with the effective area of the detector, with all cuts applied, as a function of energy. The result is 2,500 events per year for atmospheric neutrinos above 100 GeV. Adding the 300 low energy events, and dividing by the number of pixels, we get $0.35 \pm 0.01$ events per year per pixel as the background to extraterrestrial events.

## Conclusions

The mis-identified event rates from random triggers, cosmic ray muons, and atmospheric neutrinos have been recalculated using the Monte Carlo program DUMC and the current assumptions, parameters, and algorithms for triggering, software cuts, background filters, and track fitting. Random noise at the expected rate is included. The result for a $1^{\circ}$ circular pixel over $2.4\pi$ sr (8,000 total pixels) for the three backgrounds is as follows:

| | |
|---|---|
| Random OM noise | 0.40 ± 0.08 per year |
| Single cosmic ray muons | 0.63 ± 0.36 |
| Multiple cosmic ray muons | 0.15 ± 0.07 |
| Atmospheric neutrinos | 0.35 ± 0.01 |
| Sum | 1.53 ± 0.38 per year |

Thus the goal of one event per year per pixel appears to be attainable; a signal of 10 events per year in a given pixel should still be detectable with these backgrounds.

**References**

1. V.J. Stenger, Proc. DUMAND Optical Module Workshop, Sendai 1990, p. 110.
2. J.G. Learned, DIR-12-90; J.G. Learned and A. Okada, Proc. DUMAND Optical Module Workshop, Sendai 1990, p. 110.
3. DUMAND II Proposal, 1988.
4. V.J. Stenger, HDC-1-90.
5. V.J. Stenger, HDC-1-88.
6. C. Berger et al., Phys. Rev. D40, 2163 (1989).
7. V.J. Stenger, HDC-12-91, to be published in the Proceedings of the Workshop on Long-Baseline Neutrino Oscillations, Fermilab, 1991.