HDC 82-1. Multiple Muons

RECOGNITION OF MULTIPLE MUON EVENTS IN DUMAND.

by
A. Roberts, Hawaii DUMAND Center

ABSTRACT

The possibility of distinguishing single muon tracks from multiple muon events in DUMAND would be valuable, since the abundance of high-energy multiple-muon events relative to single muons yields information concerning the primary cosmic-ray composition at energies up to 10^{18} to 10^{19} eV. We find from Monte Carlo simulations that the most promising procedure is to analyze the individual sensor waveforms, looking for multiple hits by signals from tracks at different distances from the sensor. On reasonable assumptions about PMT waveforms, such distinction appears to be feasible; but the Monte Carlo simulation must be verified by studies of actual PMT waveforms.

INTRODUCTION.

The recognition of multiple muons is of considerable potential importance to DUMAND, since it affords information relevant to the primary cosmic ray composition. With detectors spaced 25 to 50m apart, the resolution of closely spaced parallel muon bundles is not easy. However, because of multiple scattering in the 4 km of ocean above the array, the average spacing of the muons is several meters in the array. It is possible to use timing information to distinguish single muons from multiple tracks. In principle, as shown by Monte Carlo studies, it should even be possible to distinguish between one, a few, and many, where a few means two or three, and many means more than three. A better idea of how many is many can perhaps be obtained from the total signal strength. For many purposes this degree of accuracy may be sufficient.

In this paper we discuss the methods used to distinguish single muons from multiple tracks, as investigated by Monte Carlo simulations. We have not concerned ourselves with widely separated muons, a rare and interesting case, but only with muons a few meters apart, which will be recognized as a single track by conventional track-finding algorithms.

1.0 PRINCIPLES USED IN DISTINGUISHING SINGLE FROM MULTIPLE TRACKS.

If we consider the Cerenkov light reaching a single detector in the neighborhood of a multiple muon event, we note that the light reaching it will not all arrive at the same time. This contrasts with a single muon event, in which the light arrives within a very short time interval characteristic of the detector dimensions - 1 to 2 nsec for a 16-20" diameter phototube. In a multiple track event, if one muon is five meters further from the detector than another, its light will arrive about 20 nsec later. Since the characteristic time spread of the pulses from a PMT of the type envisioned has an overall spread of about 8-10 nsec, two light pulses separated by a larger time difference can be recognized as such. We use this feature to help distinguish single from multiple tracks.

Most parameters differ, on the average, from single to multiple muon events; these include goodness of fit, the number of photoelectrons detected, the average ionization density, etc. Unfortunately, for ultra-high energy muons, these parameters have such broad dispersions even for single muons that it is difficult to use them to make the desired distinction.

1.1 ACCURACY OF IDENTIFICATION REQUIRED.

Table 1, from data of Elbert[1], shows the relative abundance of various multiplicities of events.

Table 1. Relative abundance of multiple muon events.

Multiplicity	Number
1	100,000
2	2330
3	250
4	83.3
5	33.
6-10	34.7
>10	8.1

We see that to eliminate single muons to an accuracy of 999 parts in 1000 would leave a background of 100 events per 100,000, enough to seriously perturb all identifications of high multiplicities, and even to perturb the numbers of 2- and 3-fold events, if their efficiency is impaired too much by the selection procedure. We require an identification procedure for single muon tracks which will be correct to at least one part in 10,000, and preferably better. At that level only events with five or more tracks are rare enough to run the risk of being appreciably diluted by unrecognized singles. It is likely that such events will have sufficiently recognizable characteristics to rule out such errors.

In order to assess the possibility of mistaking a small fraction of single tracks for a multiple track event, it is necessary to know the actual properties of signals from real phototubes, rather than assuming some standard waveform. In the absence of real data on phototubes, which we hope to obtain on prototype PMT's, we have been forced to make somewhat arbitrary assumptions about photomultiplier behavior, and to use Monte Carlo techniques to investigate possible procedures.

1.2 The Shape Deviation Parameter.

Neglecting electronic jitter, the shape of the output pulse from a PMT illuminated by photons from a single muon track will be determined by the time spread in arrival of photons at the photocathode, plus variations in transit time of the photoelectrons from cathode to first dynode, plus a small contribution from time spreads in the multiplier structure. The importance of these will depend also on the total number of photoelectrons produced. Except for the occasional large fluctuations in energy loss, the Cerenkov light production by the muon is localized in the track and relatively short delta-rays. Higher energy losses produce small cascades, which do not spread very far from the main track. Thus large variations in time spread are not too likely; unfortunately we are concerned with improbable events in the region one part in 10^{-4}.

Pending the obtaining of true pulse shape measurements on PMT's similar in design to those we expect to use, we have simulated the shape of the output pulse by methods to be outlined below. Then we have asked: how would that shape be affected if there were two (or more) muon tracks simultaneously, so that photons would strike the PMT cathode at distinguishable times from the two tracks. We then find mathematical descriptions for the waveforms in the several cases, and simulate the digitization of these waveforms by a fast sampling device, such as a flash encoder. The task is then to determine whether the waveforms are distinguishable.

2.0 RESULTS OF MONTE CARLO COMPUTATIONS.

In generating the Monte Carlo waveforms for all events, we used the following procedure for each sensor triggered.

1. The waveform is represented by an initial rise, followed by an exponential decay of mean life 3*TRES, where TRES is the standard deviation of the (Gaussian) rise. The decay is followed for a period specified by the program data called DEADTIME. Sample values are TRES = 6nsec, DEADTIME = 50nsec.

2. To measure waveform, the signal amplitude is sampled at five equally spaced intervals of time, starting at 0.1*DEADTIME, at intervals of 0.2*DEADTIME. A standard waveform is taken with precisely these values (i.e. with no jitter).

3. Signals of single tracks are simulated by adding a slight jitter to the time at which the samples are taken; it is varied around the mean value defined above by a random gaussian error of one-third TRES. Fig. 1 shows a set of sensor samples so taken, for single-track events.

4. The amplitude samples thus taken are normalized to a maximum value of 100.

5. An average waveform for the track is obtained by averaging, over all sensors struck, all the first samples, the second, etc..., to the fifth.

6. The shape deviation parameter (S.D.) is defined by the sum of the squares of the deviation from unity of the ratios of the average sample values to the standard ones. For the sample values cited above, this results in a mean S.D. parameter for single tracks of 0.0164. In 10,000 single track events, the largest value encountered was 0.23.

7. In multiple track events, the sensors will experience successive hits by signals from different tracks. Each of these will be represented by a waveform similar to that from a single track, and they will be superposed on each other. Sampling of such complex waveforms will then result in waveforms departing considerably from the standard, and will yield larger values of the S.D. parameter. Fig. 2 shows such an average waveform for a multiple track event.

Thus, following the same procedure with events with two tracks, we find an average S.D. of 0.660. Of 500 events, 474 gave good track fits. Of these, 296 had an S.D. greater than 0.24, for a detection efficiency of 0.624.

With three tracks per event, the mean S.D. was 1.57; and the efficiency of identification was 433 out of 485 events, or 0.893. For more tracks, the efficiency would be even higher.

Other parameters show variation with the number of tracks, but nothing as distinctive as the S.D. parameter.

2.1 Variation of Jitter.

The amount of jitter suitable for representing the waveform of a single track is obviously an important parameter. If the jitter, instead of being one-third the rise time (TRES), is equal to it, then we find that the mean S.D. for single tracks rises to 0.22, and distinction between one track and more is no longer possible on the basis of the S.D. alone. It is clear that to evaluate the usefulness of this procedure, we will have to work with real PMT waveforms. However, from what we know of the behavior of standard PMT's, there is reason to hope that a satisfactory identification procedure can be achieved. For real waveforms, all we have to go on at present is the way noise pulses from phototubes look on an oscilloscope. On the basis of such observations, the values we have assumed for the residual jitter appear to su to be conservative: i.e. large. Thus, the spread of the shape deviation parameter of single tracks is, if our assumptions are correct, being somewhat exaggerated. Since, in spite of that, we obtain good separation of single tracks from multiples, that is as far as the Monte Carlo can take us for the present.

REFERENCES.

1. J. Elbert, "Multiple Muons Produced by Cosmic-Ray Interactions", Proc. 1978 DUMAND Summer Study, A. Roberts, ed., Vol. 2, p. 101. Hawaii DUMAND Center, Honolulu,HI., 1979.

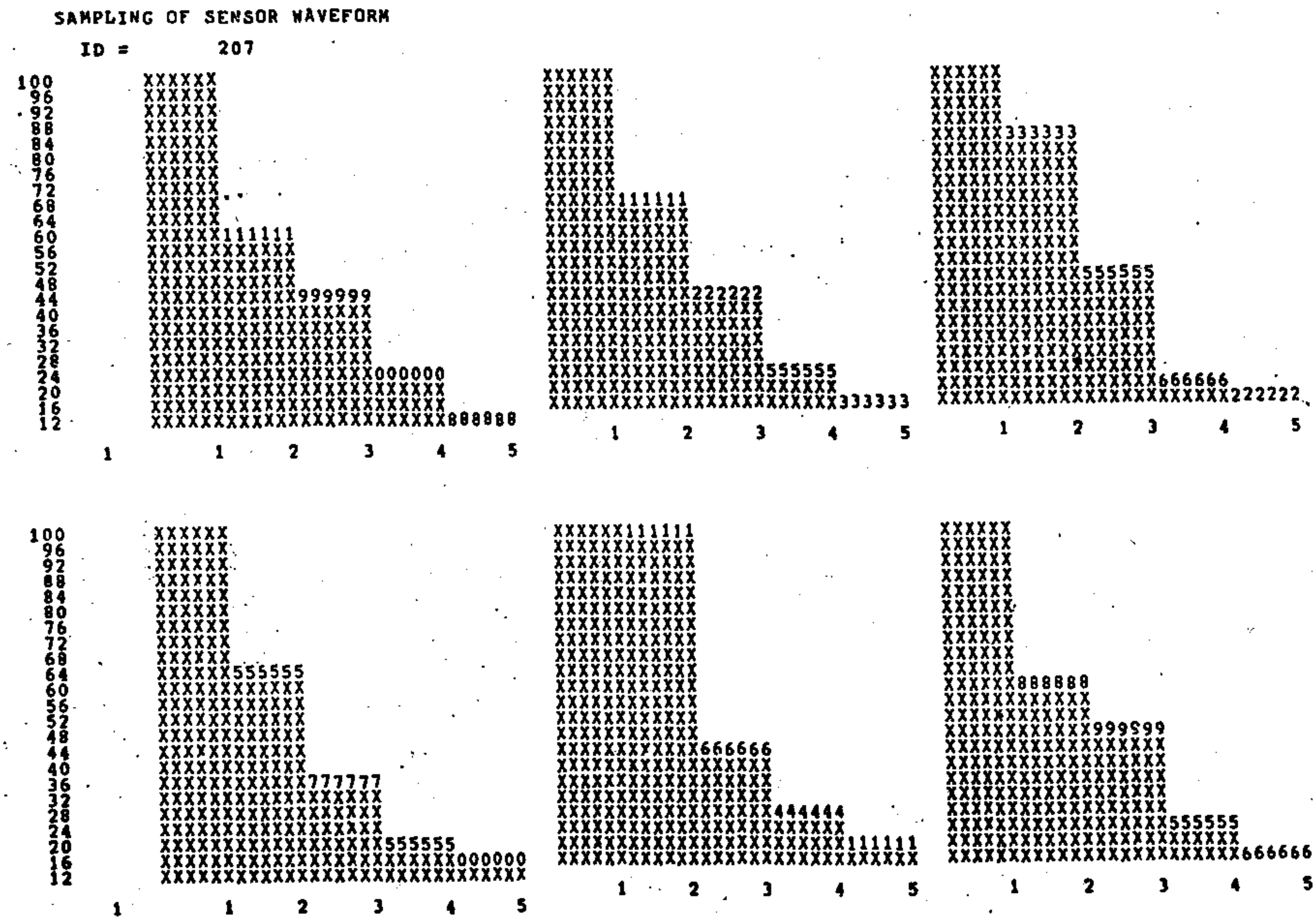
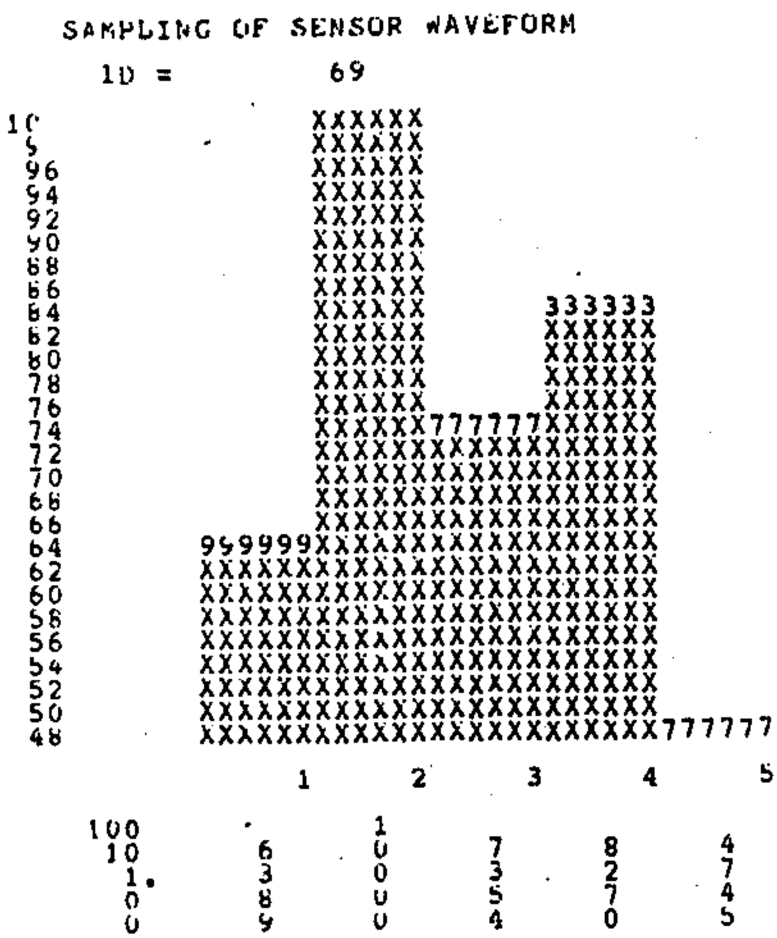


Fig. 1. Samplings of waveforms of six different sensors for the same single-track event. This shows the amount of variation of waveform to be expected with the parameters adopted.



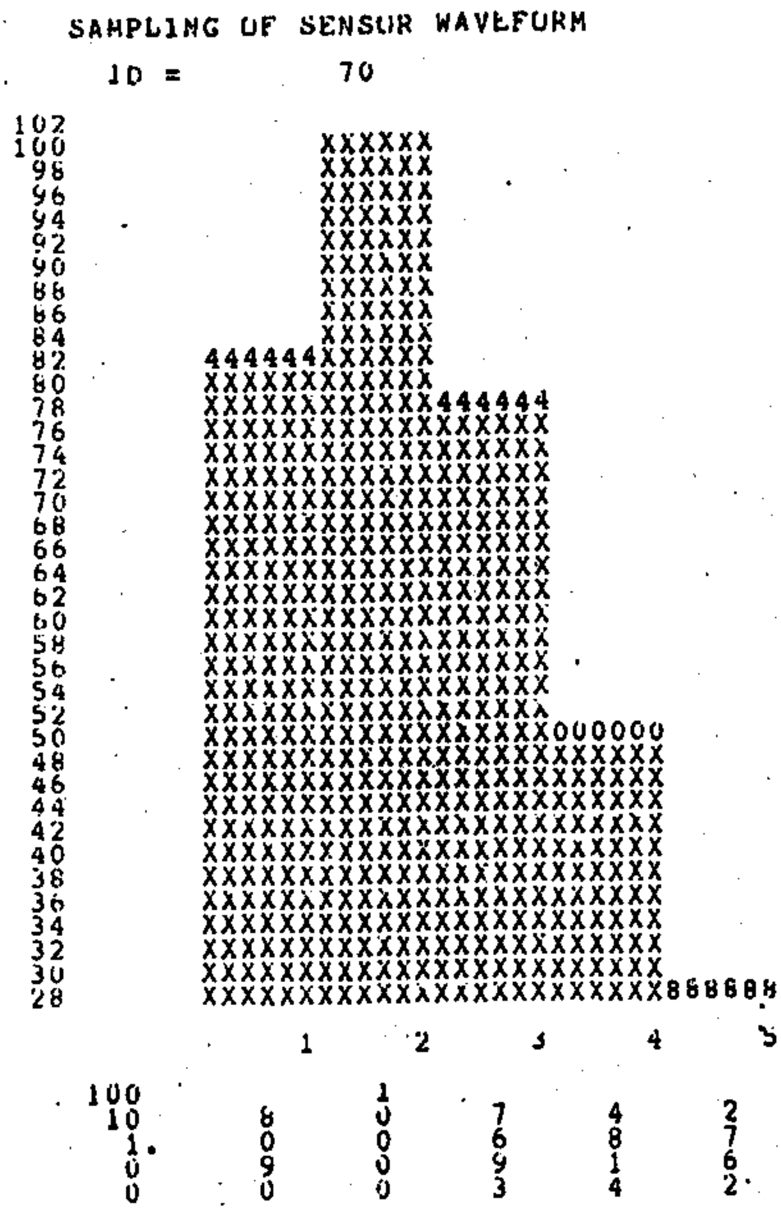


Fig. 2. Average waveforms for multiple hits on individual sensors. The left-hand waveform has three hits, the right hand two.