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THE DUMAND MONTE CARLO: DUMXX
A USER'S MANUAL

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by

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I. INTRODUCTION

This text explains the structure and operation of the DUMAND Monte Carlo program. It is divided in sections so that additional material can be added as the program evolves, or as additional explanations or amplifications are written.

The DUMAND Monte Carlo program was originally developed by V. Stenger (1). It started from a program written by the author, called MUMC, which simulated the energy loss of high-energy muons in the ocean, and had been used to demonstrate the feasibility in principle of analyzing high-energy neutrino interactions in sea-water (2). That program survives as a subroutine in the general-purpose Monte Carlo, into which Stenger incorporated specification of the DUMAND array, calculation of the detected signal in each module, and reconstruction of the muon track or hadronic cascade from the observed module responses. The routine describing the transmission of Cerenkov light in the ocean, the calculation of light incident on the PMT and its response has been replaced by a more detailed and accurate one written by J.G.Learned (3).

The development of the Monte Carlo program has diverged in recent times; but now a new effort to unite on a single version is in progress. The combined executable program is known as DUMXX.EXE. DUMXX has been rather extensively commented, and the present manual is an attempt to make it usable to other members of the collaboration.

Programs like these are constantly subject to change and improvement; as is well known, the best way to handle such changes and improvements is to accumulate them for a period of time, and then to issue a new version. We will attempt to do so for DUMXX; if users will be so good as to send proposed changes to us, we will incorporate them. We will also maintain a list of revisions.

II. ACCESS TO PROGRAM FILES; LIST OF REVISIONS

The Fortran source files of the program can be accessed (read only) by signing in on the Hawaii VAX under the user code DUMAND, and then calling for the respective files, preceded by the directory [DUMCO.DUMXX]. Thus the command COPY [DUMCO.DUMXX]DUMXA.FOR XXX.FOR will copy the file DUMXA.FOR to a file in the DUMAND area called XXX.FOR.

Revisions can be defined by the version numbers of the component programs and the combined executable file. In the present version the executable file is DUMXX.EXE; and the program is compiled from object files of DUMXA, DUMYA, DUMZAX, DUMC1A, DUMC2A, DUMC3A, and DUMC4A. In addition the common storage file DUMCA.INC must be present before compilation. The command file DUMXA.COM does the linking.

LINKING: To link on UH VAX, the file DUMXA.COM calls:

```
$LINK/OUT=DUMXX.EXE [DUMCO.DUM]DUMXA -  
+DUMYA+DUMZAX+DUMC1A+DUMC2A+DUMC3A+DUMC4A -  
+CERNLIB:HBOOKL/LIB + CERNLIB:CERNLIB/LIB+XSYS:HEPLIB/LIB
```

Outside of UH you may not have these libraries. After compiling the object modules you can then say, using the UCIU example,

```
$LINK/OUT=DUMXX.EXE [DUMCO.DUM]DUMXA -  
+ DUMYA+DUMZAX+DUMC1A+DUMC2A+DUMC3A+DUMC4A -  
+SUBCERN.OLB/LIB+HBOOKL.OLB/LIB+GENSECLIB.OLB/LIB
```

The command file DUMXA.COM will contain the appropriate link command.

III. USE OF THIS GUIDE

This guide is intended to provide the user with sufficient information to use the DUMAND Monte Carlo program and to understand its contents and printout.

In the first section, the general nature of the program is outlined, and its capabilities discussed. The second section is concerned with how the program is constructed and operated; it gives instructions for using it. Section 3 is concerned with interpreting the printouts. The appendices contain detailed explanations of the printouts, for three different sets of data.

This discussion is by no means comprehensive; many more things can be done with the program. Further amplification will, we hope, be forthcoming in later revisions of this manual.

SECTION 1.

1A. Overview.

The DUMAND Monte Carlo program has three main parts. The first part is concerned with the generation of tracks; it will on command generate single or multiple tracks, of specified direction and spacing, with a specified energy or energy distribution, and originating at specified locations. In this part the array is not specified in detail, but a coordinate system for it is set up.

The tracks are usually simulated muon tracks, though hadron cascades may be generated instead. Interactions due to pair production, ionization, bremsstrahlung, and nuclear interaction are simulated in accordance with the probability of such interactions in sea-water for muons of the appropriate energy. Cascades produced by fast electrons are simulated, and the Cerenkov light produced by all these interactions is generated with the proper intensity and direction. Thus the illumination of each module in the array can be found, taking into account the wavelength-dependent attenuation of the Cerenkov light in the water. The PMT response is then calculated, taking into account the attenuation of the Benthos sphere and PMT envelope, the PMT cathode (wavelength-dependent) efficiency, and the Poisson distribution of the photoelectron yield.

The second part specifies water transparency as a function of wavelength. It then specifies the DUMAND array in detail: number and location of strings and modules, including random errors in string location; and PMT sensitivity (as a function of direction and wavelength). It then calculates the performance of the array in detecting the track; i.e. the time of arrival of the pulse on each module hit, its amplitude, and other possible information (such as closely spaced hits if the primary signal is not a single muon but a a bundle of muons.) The program takes due account of the Poisson fluctuations in signals.

In addition, the program generates background noise pulses of two sorts: tube noise and external illumination noise, which is lumped under the heading of K40 background, even though it may contain components due to bioluminescence. The program then is in a position to simulate the array response whether a muon is present or not.

In the absence of a muon signal, one can study background effects, such as simulation of muon tracks by random background, a potentially serious problem.

In the third part of the program, a track detection and analysis routine is introduced. Its purpose is to use the data on module hits to find tracks, whose direction can be determined.

The program also contains routines intended to find the energy of the muon or cascade, and to give an indication of the multiplicity in the case of muon bundles.

The track-finding part of the program is adapted, in part, from bubble-chamber routines, and its first pass (the space fit) resembles standard routines in structure. However, a second pass (the time fit) takes into account the time of each hit, a feature not available in bubble-chamber track-finding routines.

Finally, routines for histogramming, printing, or otherwise examining the data and results of the program are liberally provided.

1B. Structure of Program.

Since the Monte Carlo is a very long program, it is inconvenient to compile it as a single unit; it takes too long. It is therefore divided, somewhat arbitrarily, into seven sections of roughly equal length, so that changes are more limited in their effect on compilation time. These sections are called DUMXA, DUMYA, DUMZAX, DUMC1A, DUMC2A, DUMC3A and DUMC4A. These are linked together for execution. The entire program is in Fortran.

Following is a listing of all the subroutines in the different portions of the program.

<u>DUMXA</u>	<u>DUMYA</u>	<u>DUMZAX</u>	<u>DUMC1A</u>	<u>DUMC2A</u>	<u>DUMC3A</u>	<u>DUMC4A</u>
MAIN	ELINE	PHIDL	SMOOTH	MUMC	STATS	HADES
PASS1	POLYA	ROOSTST	WAVSHAPE	TRACK	DETECT	GSTRING
	SIGMA	CONTENTS	TLINE	HADMC	KPOI	STRING
	ROOSPR	TRACKLOOP	DELETE	PHOCAS	RAGU	RECT
	FILTER	DETLOOP	CHISQ	PHOMIZ	ROTATE	HEXAG
	ENMU	SORTLOOP	NSORT	DNDT	RFMU	SLIAQ
	INITL	BKGDDATA	(MINER)	ECAS	STAR	SLIME
	TRACKTEST	SORTMULT		MULTT	DEPROC	ORDER
				WAVPRT	LUMIN	POLAR
				GENT	TANQUE	
				FLINE	ARRAY	

These will be considered in detail in Section 2. In addition to the above, the program requires the presence of DUMCA.INC, an array of common statements included in many subroutines. DUMXA.COM is a command file that links together the object code generated by the FORTRAN compiler for the six program sections as well as the required HBOOK and other library routines. Its important content is the LINK command:

```
$LINK [DUMCO.DUM]DUMXA +DUMYA+DUMC1A+DUMC2A+DUMC3A+DUMC4A -
+CERNLIB:HBOOKL/LIB + CERNLIB:CERNLIB/LIB+XSYS:HEPLIB/LIB
```

This LINK format is for the VAX computer; it will take other forms on other machines.

MINER is an external library function that does least squares fitting. It is included in the library package XSYS:HEPLIB/LIB. We expect to package together all routines needed for DUMXA, for the convenience of users.

SECTION 2: OPERATING THE PROGRAM.

2.1 Command Files

The program is normally operated by means of a command file which includes both instructions to the computer concerning input and output, as well as the data for the Monte Carlo run. These are best explained by starting with a particular example and following it all the way through.

Following is a command file called AREA.COM;113.

FILE AREA.COM;113

```

100      $ASSIGN 'P1' FOR$print
200      $SET DEFAULT [DUMCO]
300      $SET WORKINGSET /LIMIT=300
400      $DIR/OUTPUT=[DUMCO]TEST.13B
[DUMCO.DUM]DUMXX.EXE;*,DUM*A.LIS;*,DUM*A.OBJ;*
500      $RUN [DUMCO.DUM]DUMXX
600      MUON GENR HMTS ROOS ION PLOT DUMB PAIR NPEF
650      11 12 14 15 46 56
700      100 1 2 0 0 0 5258963 3567864 0 10 2
800      2. 0 4.5 333 10 .6 .2 4 3 2
900      3 3 2.5 6. 3 40 15 2 202 168 0 0 0
1000     -20 -20 0 0 45 95 0 .2 .15 .25 350 3 -3 3 -3 1
1100     MUON GENR HMTS ROOS ION PLOT DUMB NPEF
1200     11 12 14 15 46 56
1300     100 1 2 0 0 2 5258963 3567864 0 10 2
1400     2. 0 4.5 333 10 .6 .2 4 3 2
1500     3 3 2.5 6. 3 40 15 0 202 168 0 0 0
1600     -20 -20 0 0 45 95 0 .2 .15 .25 350 3 -3 3 -3 1
1700     MUON GENR HMTS ROOS ION PLOT BKGD DUMB NPEF
1800     11 12 14 15 46 56
1900     500 1 0 0 0 1 5258963 3567864 -2 10 2
2000     20. 0 4.5 333 4 .6 .2 2 2 1
2100     3 3 2.5 6. 3 40 15 0. 201 168 1.5 0 0
2200     0 0 0 0 -20 -20 .75 .9 .1 .4 350 3 -3 3 -3 1
2300     STOP
2400     $PRINT AREA.COM;113, TEST.13B
2500     $APPEND TEST.13B 'P1'
2600     $PRINT 'P1'
2700     $SET WORKINGSET /LIMIT=200

```

Let us now go over this command file in detail. Line 100 tells the computer that the output print file will be identified as parameter 'P1' in the call to execute this command file, which will look like this on the VAX:

FASTBATCH/PAR=AREA113.PRT AREA.COM;113

The identifier /PAR in the calling sequence identifies the name AREAL13.PRT as parameter P1 in the FASTBATCH instruction, and therefore the output file will bear the name AREAL13.PRT.

Line 200 says that if not otherwise specified, files called by the command program will come from the directory [DUMCO]. Line 300 is an instruction to the VAX concerning memory allocation.

Line 400 asks for a printout of the directory, giving files with .EXE, .OBJ or .LIS extensions. The listings are assigned to a new file TEST.13A which is to be printed out. The purpose of this instruction is to record the actual versions of the program files used, an important record when the program is frequently modified.

Line 500 finally requests that the program be run; the executable file called is DUMXX.EXE. All following lines up to STOP are data for the program. We now look at these in detail. They represent three different passes or independent tests.

Codes. -- The first line (600) lists the codes used in the first pass. MUON tells us we are dealing with muon tracks. GENR says we generate the tracks, rather than reading them off a tape. HMTS invokes a function that describes PMT sensitivity as a function of angle; without it isotropic sensitivity would be assumed. It uses the experimental sensitivity function

$$S = 0.6 + 0.4\cos A$$

where A is the angle with the symmetry axis of the PMT.

ROOS tells us the ROOS algorithm for selecting pairs of adjacent hits is to be included. ION specifies that only minimum-ionizing tracks will be considered; it turns off the MUMC routine that generates muon interactions, and ignores the muon energy specified. Conservative estimates for detection efficiency for muons will generally include ION. PLOT restricts the histograms to those whose numbers are given in the line 0650, in this case 10,11,30,31. Only these will be printed; omitting PLOT would print all histograms automatically, unless all histograms are cancelled by the code NOOK. DUMB refers to the PMT, and allows the definition of the response of the PMT to single electrons to be specified by the parameters of a Polya distribution, specified in line 800. The program will print out the PMT response explicitly.

PAIR says that the unit detector module is a doublet, or pair of 16" PMT's, whose spacing is specified later. The output of the PAIR PMT's is in coincidence, for the purpose of reducing background. PAIR will give good data with wider detector unit separations along the string, and will tolerate at least an order of magnitude more background. The first two passes explicitly compare operation with and without PAIR.

NPEF is a parameter that determines least-square-fit procedure; its presence gives somewhat higher efficiency and higher angular accuracy.

The order in which these codes appear has no significance; any order is permissible. The format for each code is A5.

Data. -- The next line (700) starts actual data. The variables are those requested in statement no. 710 of MAIN: MC MAX, MTK, MPR, NPRI, IPRT, MP IX, ISEED, JSEED, NKEY, CHIMAX, NSTRMN. They are as follows:

MC MAX	No. of events to be generated
MTK	No. of tracks per event (1 unless multiple muons wanted.)
MP R	No. of events to receive full printout Σ !
NP RI	Set = 1 to print out full details of muon track generation. WARNING: VERY EXTENSIVE PRINTOUT!
IP RT	Provides printout in MINER error minimization routine.
MP IX	Number of events for which tracks will be plotted
I SEED	Random number seed
J SEED	Random number seed for auxiliary routines
N KEY	number of events to receive full printout in track-forming and filter routines. If negative, number of data-controlled events to be printed.
CHI MAX	Maximum chisquare for an acceptable event (usually 8-10)
N STR MN	Minimum number of strings allowed for acceptable trigger.

Line 800 is in a format that depends on the code used. There are four possible formats, depending on whether the codes DUMB and ROOS are present or not. They are described in lines 11300-13400 of MAIN. In our case ROOS is true, DUMB true. The format then calls for EMIN, GAMMA, AVX, SPER, SPER1, AVPOL, BPOL, NROOS, NTMIN, MINTHR, which are interpreted as follows:

EMIN	Minimum incident muon energy, TeV. Unused if ION is true.
GAMMA	Muon energy spectrum exponent (neg. sign omitted). If zero, all muons have energy EMIN.

The next three parameters refer to noise and K40 signal parameters.	
AVX	Mean no of photoelectrons in a noise count. Must have the decimal fraction .5 added in order to activate ROOS.
SPER	Mean interval between noise counts in microseconds. E.g. if noise rate is 5 kHz, SPER = 200.
SPER1	Mean interval between K40 counts, in microseconds. If the K40 rate is 50 kHz, SPER1 = 20.
AVPOL	Mean value of a Polya distribution.
BPOL	B-parameter of a Polya distribution (describes deviation from exponential or Poisson distribution.)
NROOS	Number of ROOS pairs required for a trigger.
NTMIN	Minimum number of photoelectrons required for at least one member of a ROOS pair to trigger.
MINTHR	Minimum number of triggers required, in which a single module satisfies the threshold requirement THRES. Needed only when ROOS pairs are used.

The next line, 900 (called in MAIN statement no. 740) requests the following:

MINDET	Minimum number of modules triggered for valid event.
THRES	Minimum no. of photoelectrons for trigger, for triggers not belonging to a ROOS pair.
ADET	Sensor sensitivity, in units of photoelectrons produced in a photon flux of 100 quanta/sq. m. For the 16" Hamamatsu PMT, on axis, the conventional value is 2.5.
TRES	Resolving time of PMT -- separation required to see two distinct pulses, in nsec. For the 16" Hamamatsu PMT, we have been using, on the basis of information received from the manufacturers, 6 nsec., as the assumed S.D. of the distribution.
IAT	Code to describe water attenuation length; 1 means 20m, 2 25m, and 3 30m. The latter value is now "standard".
DELTA	Three entries: DELTA(1) = x,y array spacing for rectangular array; DELTA(2) is z-spacing; and DELTA(3) is the doublet spacing, all in meters. The latter is unused unless the code PAIR is in use, but it must always be present.
XMAX	Two entries: XMAX(1) is the overall array x- or y- dimension, XMAX(2) the overall array z-dimension. Taken together with the module spacings DELTA, these determine the number of modules in the array. In this case, XMAX(1) = 201 and DELTA(1) is 40; so there will be six rows and strings in each (the first is located at zero.) XMAX(2) is 221, and DELTA(2) is 20.; therefore there are 12 modules per string.
POSER	Two entries: POSER(1) is random error of location in x,y; POSER (2) random error in z. Both are std deviations for gaussian error distributions.
ELCUT	Rarely used parameter to define electron threshold for acceptable events in cascade energy determination. Set to zero.

Line 1000, the last data line, is called in MAIN statement 750. It asks for:

XFID	Three pairs of numbers: minimum and maximum values of x, y, and z, at entry point of track. In the example given, the x points are both -20, so that all entering tracks have the same x value, -20; similarly, they all enter at y = 0. They enter between z = 45 and z = 95. Values of x, y, z at entry are random between limits given. (N.B. When KODE OUT is used, the significance of the XFID parameters is changed; see subroutine RECT for their values.)
CTHMIN	Minimum value of cos of polar angle of track at entry.
CTHMAX	Maximum value of same cos. Value random between limits.
PHMIN	Min value of azimuthal angle of track
PHMAX	Max value of azimuthal angle. Angles in radians.
TIMAX	Maximum length of track to be followed. This is rounded off in the program to the next highest multiple of 100m. This number is set not to exceed the longest track expected, to avoid wasting computer time.

KPOL(4) Polarization axes for 4 adjacent modules. By polarization axis is meant the symmetry axis of the PMT, which is nominally axially symmetric. The polarization axis specifies which way it is oriented. 1, 2, and 3 represent the x, y, and z-axes respectively; at present the program can handle only z-axis polarizations, so 3 is the only permissible value. +3 means the axis points upward, -3 means downward. The four values are repeated along each string. The sequence 3 -3 3 -3 has been found to be the most uniform in sensitivity. When PAIR is used, the values refer to two adjacent doublets.

KPLSET Index for setting polarization choice in subroutine POLAR
Possible values 0 to 3; see POLAR for details. Values 0, 1 are the best. 1 is the de facto standard.

This completes the data for the first pass. A similar set of data cards is needed for each additional pass. In our example, we have removed PAIR for the second pass, and decreased the z-spacing; the first two passes thus compare results with single modules and pairs. The third pass is a background run; we have added BKGD. This means that no true tracks are present, and we are searching for spurious tracks concocted from random triggers. It is therefore useful to set NKEY negative, so that printout will occur only if a spurious track has been found. In addition, we have lowered the trigger requirements and increased the noise rate to 250K/sec (SPER1 = 4), to generate spurious tracks at a higher rate.

Following the three passes requested, the code STOP is encountered. This ends the computation and causes the final data collection and printout file to be prepared. The subsequent computer instructions do the following:

Line 2400 prints out the command file and the list of files used in the program embodied in TEST.110. Line 2500 adds the TEST module to the standard printout. Line 2600 requests the final data printout, with the title given in the FASTBATCH parameter, AREAL13.PRT, replacing 'P1'. The last line, 2700, releases the additional memory requested.

SECTION 3: THE PRINTOUT

3.1. Array Fits.

On running the above program, an extended printout is obtained. At this point we will discuss only that printout which is always present, and leave for an appendix a discussion of the extended printout called for in this demonstration program.

The first page, of which we give an example (Fig. A0-1) taken from pass 1, reprints many parameters, including those that pertain to background (SPER, SPER1) and "dumb" PMT parameters (AVPOL, BPOL.) TX and TX1 are the respective probabilities of a tube noise count and a K40 count in a module in a time interval (TMEV) determined by the size of the array; in this case it is about 1 microsec.

Since the code DUMB is present, we are dealing with dumb PMT's, in which single-photoelectron counts are not uniquely recognized, but only with the probabilities defined by the Polya distribution. These are shown in Fig. A0-1, in a table just above the error messages indicated by IER. That table shows, for the Polya distribution parameters used, the probability $p(i)$ that a single electron pulse will be recognized as an i -electron pulse instead; in our case, $p(1) = .7027$, $p(2) = .2259$, etc.; thus there is a 70% chance that a single-electron count will be so recognized. The Polya distribution parameters that give this result, which duplicates the behavior of contemporary dumb tubes, are AVPOL=0.6, BPOL=0.2. Had we used smart tubes (no code DUMB), all single-electron counts would have been recognized as such.

BND(I) gives the cumulative probability that a single electron yield an amplitude I or less; e.g., for I=2, it is .9286. Error messages and the codes for the hit parameter KZ are listed.

3.1.1. Pass 1

If individual event printouts and track plots are requested, they follow at this point. Figs. A1-1 to A1-4 show a printout of the first event. Then an abbreviated printout of the first 30 events is always printed. If the extended printout is data-controlled, it may occur after the first 30 events; but those are always shown. An example of the printout of the last of the 30 events and of the summary of the first pass is shown in Fig. A1-5.

The summary that ends the pass states the number of background events - i.e. the total number of modules with background or noise hits in all events, then gives a statistical summary of the pass. The table lists many parameters; the most significant ones are the number of space fits and time fits, and their mean angular error (in radians). The total average value of the total number of photoelectrons per fitted track is given; this is significant with respect to possible measurement of muon energy.

The next entry is a debugging aid; it shows the number of times the program has traversed certain locations indicated by the variable INQ; to date values up to INQ(7) are in use.

There follows a table showing the fraction of events in which ND detectors have at least NT counts, with ND and NT going from 1 to 10. The distribution of the number of ROOS pairs per event follows, and the distribution of the failure index IER; this gives an idea of why events fail. Both these tables are useful in monitoring the operation of the program.

If histograms have been requested, they follow here. Fig. A1-6 shows a plot of the distribution of angular error in the time fit; the units are milliradians.

3.1.2. Pass 2

In Pass 2 the pairs are replaced by single modules. The printout of one event (Figs. A2-1 to A2-5) is longer, since without the coincidence feature

of the pairs, there are far more single hits. The printout first lists all the hits -- 94 in this case. After the initial trigger requirements are satisfied, only 27 remain. Then FILTER begins; it applies the Roberts (causality) test, throwing out points that fail. At the end (bottom of A2-3), 22 hits remain, to which ELINE makes the initial space fit. TLINE then makes a time fit, calculating the CHISQ for each point; the hits are all listed. After all deletions of bad points (there are none in this case) TLINE prints its final fit, which in this case is the same as the original fit. Then a summary of the space and time fits is given.

3.1.3. Pass 3.

Pass 3 is a background run, as shown by the code BKGD. This means that although dummy input tracks are used, resulting in fictitious error values in the fits, no signals from them are recorded. Background runs are used to evaluate triggers, so that a trigger stringent enough to reduce the background to a satisfactorily low level, yet still capable of allowing adequate track efficiency, can be identified. Usually background rates are sufficiently low that high noise rates must be assumed to give a significant number to evaluate.

Since only a very small fraction of events will give fits - i.e. spurious events -- it is desirable to have a printout that will select such fits. The quantity NKEY does this; when it has a negative sign, as e.g. -3, it instructs three events that yield fitted tracks to repeat and print out their data. In pass 3, two such events are printed out; one is shown in Figs A3-1 to A3-3, and discussed in more detail in Appendix 1.

3.2 String Fits.

We now examine the set-up for investigating a single string. The simplest procedure is to follow an example. Following is a sample program for investigating string response.

```

STRING.COM;5

0100 $ASSIGN 'P1' FOR$print
0200 $SET WORKINGSET /LIMIT=300
0300 $DIR/OUTPUT=TEST.05A [DUMCO.DUM]DUMXX.EXE;*,DUM*A.OBJ;*,DUM*A.LIS;*
0400 $RUN [DUMCO.dum]DUMXX
0500 MUON GENR HMTS ROOS ION PLOT DUMB PRAR OUT ATMU STRI NPEF
0600   55 56 14 15
0700 100 1 3 0 0 1 1644856 67003958 0 10 0
0800 2. 0 4.5 333 10 .6 .2 5 2 2
0900 6 3 2.5 6. 3 50 5 0 50 30 0 0 0 0
1000 4.5 0
1100 10 25 25 25 15 0 0. 1. -1 1 80 3 3 3 3 0
1200 STOP
1300 $PRINT STRING.COM;5, TEST.05A
1400 $APPEND TEST.05A 'P1'
1500 $PRINT 'P1'
1600 $SET WORKINGSET /LIMIT=200

```

This program investigates a string 30m long with a vertical spacing of 5 meters; thus there are 7 detectors. These parameters are determined in line 900. There the string length (fifth from end) is given as 30m, while the vertical string spacing is the 5 three places earlier.

The code parameters in line 500 are different from those discussed earlier. OUT and ATMU signal a different method of specifying the incoming tracks than that hitherto used. OUT implies that incoming tracks are incident on the upper surface of a cylinder whose dimensions are specified by XFID(6), the first 6 entries in line 1100. The first entry (10) is the radius of the cylinder; the second (25) is its length; the origin of the coordinate system is at the center of the array. Since the array is presently a string, the coordinates of the center, as described by the entries in line 900, are 25,25,15. These are entered as XFID(3-5). XFID(6) is zero.

Code ATMU describes the incident cosmic ray atmospheric muon spectrum at an ocean depth in km given by the first entry in line 1000; in this case 4.5 km. The second entry, RDIR, is zero. The codes OUT and ATMU may be used independently.

The printout is basically similar to that discussed above; however, the filter routine is omitted, and the printout is consequently shorter. The code PRAR (PRInt ARray) prints out the x,y,z coordinates of all detector modules. A printout of an event from the above program is shown in Figs. S.1 - S.2.

The plot of the trajectories is different; a string fit gives no azimuthal information, and so the incident and fitted tracks are projected onto the same (XZ) plane. The string itself is the vertical line of +'s at 25m.

The summary of the pass is similar to that of a conventional array, although the items are somewhat different. The angular error of the string fit is given in degrees.

3.3 Multiple Muon Events.

Multiple muon events are likely to be of considerable interest in the full DUMAND array. They constitute several percent of the total muon rate, which is expected to be of the order 10-20 counts/sec. Thus the ability to distinguish them from single muon events is important. A considerable amount of work on the capability of the array to distinguish such events was carried out in 1981-2(refs). It showed that the array is capable of distinguishing between one muon, two, and many (i.e more than 2). The software for this is incorporated into the Monte Carlo program, and we discuss its use in the section on printout.

APPENDIX 1. DETAILS OF PRINTOUT: AREA.COM; 113

We now examine in detail printouts of the events for which it was requested; in pass 1 two event printouts are called for (MPR=2).

A1.1 First Pass. The printout of the first event is shown in Table P1-1 to P1-3. In general, the subroutine responsible for each section of the printout is named, to facilitate reference to the program. After a few parameters, a list of all detector hits is printed. Since in this run PAIR is activated, only coincidences are shown, both true and random; this event has no random coincidences, and 7 true ones. Then several printout tables from PASS1 show the status of all detectors hit, and finally those selected as satisfying trigger conditions. Note that the number of electrons in each PMT (SIG) is added for the pair to give EL for the first module; this is taken as the PAIR signal. These numbers are listed under WXYZ(5,K). Note that the 3 ROOS pairs declared are the last 6 hits; No. 1 is not a ROOS pair member, and therefore must satisfy the THRES requirement of 3 photoelectrons. Since it does not, it is assigned the value KZ=0 in ROOSPR, and dropped.

The remaining six hits are now subject to the Roberts criterion in FILTER. An extensive printout from subroutine FILTER shows the detailed applications of the Roberts criterion, in which hits not satisfying the causality condition are progressively eliminated. In this case none are; the 6 hits survive unchanged. The results of a space fit of these points (not including time data) follows, and a table showing all the parameters of the six hits. It is instructive here to compare the estimated and observed times of the hits.

Next, tests on the plausibility of the intensities indicate no anomalies; thus we are told that no points have been deleted because RHO, the PMT distance from the track, is too large (for the observed intensity).

The next entries, from TLINE, show the time fit. The largest chi-squared, CHIMAX, 21.65, is outside the bound given by the input parameter CHIMAX, which was 10. Accordingly, point 6 is deleted, and a new fit made to the remaining 5 points. The next table reveals that the largest chisq (listed under UNWTD) is 15.44, still above the cutoff; so point 2 is deleted. The remaining 4 points now make a good fit; but alas, - there now remains only 1 ROOS pair. The event fails for insufficient number of ROOS pairs; so the failure index IER=2 is assigned.

Had the event been fitted, a plot of the x-z and y-z projections of the track would have been printed; this was requested when MPIX was set equal to 2.

A similar printout for event No. 2 is obtained; we will not examine it.

Short summaries of the remaining events in the first thirty follow; page P1-4 shows a sampling of these summaries. Finally, on page P1-5, a summary of the results of the entire first pass is given. We note that of 100 events, 73

gave successful space fits, and 72 successful time fits. The mean angular error of the space fits was .0615 radians, of the time fits 0.0397. The average number of photoelectrons detected in the 72 successful timefits was 69.2.

The distribution of the number of events with IROOS pairs is printed out, as also the distribution of the failure index IER. The histograms requested follow at this point, bringing us to the end of Pass 1.

A1.2 Second pass. The second pass is similar to the first, except that the detector modules are now single modules rather than pairs. The vertical spacing between modules is still 15m. Again we print out the first event; it is shown in Table P2-1 to P2-5. We note that all hits in which the PMT has one or more photoelectrons are printed out. Most of them show the track signal SIG = 0, and BG, the background, not equal to zero; this is a consequence of the 100-kHz K40 rate. When SIG is not zero, the incident light intensity in quanta on the PMT is printed out in PHOT. There are a total of 116 hits, and the track-fitting program must extract the true hits from the background.

The first step is to examine adjacent hits to see whether they are ROOS pairs. If they do not meet the time criterion, they are printed out: see the printouts for II=15, I=16, for II=35, I=36, and II=82, I=83; all rejected. PASS1 prints out the hit parameter KZ for all 116 hits; this is obtained by applying the trigger parameters to them. Most are assigned KZ=0, which results in their being dropped. The remaining hits, with KZ not zero, are then listed; there are 14, including 9 ROOS pairs. FILTER accordingly starts work on the remaining 14. The first printout of NTOT shows many negative numbers. This indicates a point whose timing is inconsistent with a majority of the other points. FILTER deletes points, starting with a criterion NCRIT strongly negative, and increasing until a final value for NCRIT is achieved. In this way the number of points is reduced to nine, with 6 ROOS pairs.

Let us look at the first few deleted points in the original list. They are detectors 2, 27, 40, 43, 49. We see that they are all noise signals of less than 3 photoelectrons; they have been eliminated by the application of the threshold requirement THRES = 3. Detector 229, on the other hand, with 7 noise photoelectrons, survives the first winnowing. The final result of FILTER is 9 points, including 6 ROOS pairs.

The program now makes a fit to the track, in ELINE. Next, LUMIN looks at the track and decides that there are no points which are too far from the fitted track to show the number of photoelectrons they do (the criterion is a probability of less than .001). It therefore tells us that no points are deleted because RHO, the distance from the track, is too large to allow the observed number of photoelectrons.

A satisfactory space fit having been achieved, a time fit is tried. This is expected to be better, since it takes into account not only the locations of hits and their intensities, but the times at which they occur. TLINE tries a fit, and calculates the chisq for each point on the track. None are excessive, and a good time fit is obtained. Final results of errors: space fit 62, time fit 34 mrad. The original and fitted parameters are printed out. A

printout of the event trajectory, in X-Z and Y-Z projections, is shown in Fig. A2-6. The numbers indicate summed photoelectron numbers normal to the plane. The true trajectory is marked by dots, the fitted one by X's; in a good fit like this one, few dots remain, since superposed X's erase them.

A1.3 Third Pass. The parameters of this pass describe a BKGD run - i.e., no signals, only background; the purpose is to seek events simulated by the background.

The print code sets NKEY=-2; thus the printout is data-controlled, and calls for two events to be printed out when a successful fit is made. The printout shows that the first track fit occurs for event no. 16 (Figs. A3-1 to A3-2).

In event 16, 127 modules are triggered; this is because we have raised the background rate to 250K/sec. (When printed by a call from NKEY, the individual hits are not printed out.)

The initial application of the trigger parameters by PASS1 gets rid of most of the hits. The FILTER routines must winnow the remaining data to find any grains of wheat among the chaff. The subroutine NSORT does thus when the number of points is very large, systematically eliminating those points whose NTOT is most negative, then making a new fit and repeating the process. In this case, 18 iterations bring the number of points left down to 10. Further application of FILTER eventually leaves 7 points. ROOSDEL now takes over, eliminating the orphans in ROOS pairs left by deletion of the partner; there are then 4 points left, making up 2 ROOS pairs. The space fit, ELINE, lists them and finds the fit satisfactory. TLINE applies the time fit, and finds it poor but passable. Thus we have finally an acceptable event.

In order to demonstrate how BKGD operates, we have intentionally set the threshold requirements low: 3-3-2-1-1-2. In the operating program they must be set high enough so that the rate of generation of spurious background events is much lower: one in 10^8 is a reasonable goal.

In background runs the stated angular errors are meaningless; there is no true track from which to measure angles.

At the very end of the printout are appended two useful summaries; one is a listing of the subroutines of each segment of the program. The other is a directory giving the version numbers of each segment used in the current compilation of DUMXX.

APPENDIX 2. MULTIPLE MUONS

DUMXX treats multiple muons as follows. The number of tracks, MTK, is set at the desired value. The program requires the code ENV (for envelope). If ENV is used, an additional line of input data is required after the line specifying XFID, etc. This line reads in four quantitites, defined as follows:

DISL	Parameter describing distance between tracks; it is the S.D. of a Gaussian, in meters.
DISTH	Parameter describing distribution of tracks in polar angle; a constant to be added to the initial angle THIN.
DISPH	Parameter describing distribution of tracks in azimuth, phi; a constant to be added to phi.
DEADTIME	The minimum time interval at which two different signals on the same PMT can be resolved, in nsec.

The code ENV first becomes effective in SORTLOOP, which calls subroutine MULTT. SORTLOOP determines whether there are multiple hits on each detector, and sorts them in time order. MULTT generates and stores a waveform of the individual detectors from the multiple hits, sends it to WAVPRT for storage and optional printout, and returns the data to SORTLOOP, which compares the waveform with the standard one for a single hit, COLSTD. If the waveforms are significantly different from the standard, further action can be taken.

The printout is significantly different when ENV is true. To illustrate we run the following test program:

FILE MULTI.COM;1

```

00100 $ASSIGN 'P1' FOR$print
00200 $SET DEFAULT [DUMCO]
00300 $SET WORKINGSET /LIMIT=300
00400 $DIR/OUTPUT=TEST.01A [DUMCO.DUM]DUMXX.EXE;*,DUM*A.OBJ;*,DUM*A.LIS;*
00500 $RUN [DUMCO.dum]DUMXX
00600 MUON GENR HMTS DUMB ION ROOS PLOT ENV
00700      55 56 14 15 12 11 46
00800 10 5 1 0 0 0 1644856 67003958 0 10 2
00900 2. 0 4.5 333 10 .6 .2 2 2 2
01000 3 3 2.5 6. 3 40 15 0 122 303 0 0 0
01100 0 0 0 0 -20 -20 .75 .9 .1 .4 600 3 -3 3 -3 1
01200 5 0 0 50
01300 $PRINT MULTI.COM;1, TEST.01A
01400 $APPEND TEST.01A 'P1'
01500 $PRINT 'P1'
01600 $SET WORKINGSET /LIMIT=200

```

We now examine the printout from this program.

A partial printout of one event is shown in Figs. M-1 to M-9, and the

summary of the other events and of the entire pass in M-9 and M-10. Multiple track events are inherently much more complicated; and in the present case we have specified five parallel tracks, displaced from each other randomly, with a Gaussian separation of S.D. 5.0m. The beginning of the printout lists these five tracks. The hits produced by each of the five tracks are then listed. Background counts are added only to the first track; the others are simultaneous. We show part of the hits on track one, and the hits on tracks 4 and 5; the total number is 203. These hits are all sorted by detector number, and then listed so that all hits on the same detector appear together: thus detector No. 1 has six hits, no. 23 four. Multiple hits on some detectors are printed out, and histograms in which individual waveforms are plotted are listed.

Now the trigger requirements are applied, and FILTER does its job. When we get to ELINE, only 63 hits remain, as we see in the tail end of the ELINE printout (Fig. M-6). Two points are now rejected, in succession, by LUMIN, on the ground that they are too far from the track for the number of photoelectrons reported to be plausible. We thus reach TLINE with 61 hits, printed out by TLINE (M-6, M-7).

DELETE now deletes points whose fit to the track gives a CHISQ value larger than the value specified in CHIMAX. The worst point is deleted, and the track refitted. This process continues until all points are satisfactory, too few points remain, or a maximum number of deletions exceeded. In this case a satisfactory fit is attained, and TLINE prints out the final values, with 51 points (M-8, M-9). The final fit is then summarized and printed out.

Brief summaries of remaining events (up to 30, but there are only 10 in this run) now appear, and then the final summary at the end of pass 1. We note a persistent bug in multiple-track events which gives wrong numbers of events in lines 4 and 5 (32 listed, when the total number is 10). The corresponding averages are also wrong; the correct number of good events is the number for which IER = 0, which is 10. The angular distribution of time fits, the average value and the RMS deviation are given correctly in the histogram, No. 12. From this we see that the mean angular error is 19.2 mrad.

APPENDIX 3. SINGLE STRING FITS.

A printout of a single string event is given in Figs. S-1 and S-2. It is much shorter than a full array printout, since the FILTER routine is not called, and the amount of data is down by an order of magnitude. Three events are printed out; but the first two do not result in fits, and so we examine the third.

It is a straightforward, simple case. All the hits are good; none are eliminated, and the resulting fit is a good one. The distribution of angular fitting errors is found in histogram no. 55 (not shown), indicating an RMS error of 9.9 degrees for 47 fits. The mean error, from entry no. 8 in the end of pass summary, is 6.84 degrees.

REFERENCES

1. A. Roberts, A Monte Carlo Study of the Measurement of the Energy of Muons and of cascades in a DUMAND Optical Array, Proc. 1978 DUMAND Summer Workshop, A. Roberts, ed., Vol. 1, p. 275. DUMAND, Scripps, 1978.
2. V.J. Stenger, G.N.Taylor and A. Roberts, "Angular and Energy Resolution of the DUMAND Optical Array," Proc. 16th Intl Cosmic Ray Conference, Kyoto, 1979, Vol. 10, p 373.
3. J. G. Learned, DUMAND Internal Report HDC 81-10, "Attenuation of Cerenkov Photons in the Ocean.", Apr. 1981.

Following is a list of recent DUMAND reports that concern the Monte Carlo program in a significant way.

HDC-2-84, March 1984. "Experimental Confirmation of Monte-Carlo Generated Distribution of Cerenkov Light from a Muon Track." The light distribution observed by the IMW proton-decay collaboration is narrower than the theoretical value used in the Monte Carlo program.

HDC-4-84, June 1984. V. Stenger, "Operation of the DUMAND Array in the Presence of High Background."

HDC-5-84, June 1984. A. Roberts, "Effect of Introducing Doublet Coincidence Detectors in DUMAND."

HDC-6-84, Sept. 1984. A. Roberts, "Progress Report on DUMAND Array Studies."

HDC-4-83, June 1983. A. Roberts, "Progress Report on Data Processing in DUMAND."

```

PASSING PROGRAMS CALLER BY PLUT:  MUCH GENEU HITS ROOT INH POINT NPER DUMB PAIR. 0 0
MAIN: REPRINT PRINT PARAMETERS: 1 KEY1= 0 KPP = 2 KKEY = 0
      NTH1      NPP1     NPP2      TPR1      MP1      JSEED      NKFY1      CHIMAX      EMIN GAMMA      NPP0      NTH3      NSTRNN
      100       52588963   3567864    0        10.0      2.000 0.0      4
      ATL      ANET DL(1) RL(2) DL(3) XM(1) XM(2) PE(1) PE(2) ELCUT TRES AVX_3 SUPER AVBC MDET3 THRES MINTH DEPTH RDIR
      30.0     2.50     40.0     15.0     202.0    168.0    0.0     0.0     6.0     4.5     333.0    0.00      3.0      3.0      2      0.0      0.000
FINDUCIAL VOLUME AND ANGULAR LIMITS
XF(1)= XF(2) XF(3) XF(4) XF(5) XF(6) CTHMAX CTHMIN PHMAX PHMIN TMAX KPOL(4) -3 KPLSET
-26.0 -50.0 0.0 0.0 45.0 95.0 0.000 0.000 0.200 0.471 0.785 350. 3 -3 -3
SPER1= 3.3 0.000 TX1= 1.1046970E+06 TX2= 3.3173086E+03 APOL1
SPER15= 10.00000 TX1= 0.1045863 APOL2= 0.6000000
PAIRS RESOLVING TIME TESTED 24.60000
AV= 0.660 A= 0.20000 BND(1)= 0.7027 P( 2)= 0.2259 BND(1)= 0.9286 P( 3)= 0.0565 BND(1)= 0.9851
P( 1)= 0.1027 BND(1)= 0.7027 P( 3)= 0.2259 BND(1)= 0.9286 P( 3)= 0.0565 BND(1)= 0.9851
P( 4)= 0.0121 BND(1)= 0.0000 P( 3)= 0.0023 BND(1)= 0.9495 P( 6)= 0.0004 BND(1)= 0.9999
P( 7)= 0.0001 BND(1)= 1.00000
ERROR MESSAGES INDICATED BY IER
IER          SIGNIFIES
0            EVENT ACCEPTED; TIME FIT.
-1           EVENT REJECTED; TOO MANY RAD POINTS IN CHISQ
1            NDEG & LT. 1. NROOTS; TOO FEW POINTS PAIRS
2            NDEG & LT. 1.500 AT START OF FILTER
3            TOO FEW POINTS, SPACE FIT
4            TOO FEW POINTS, TIME FIT
5            TOO FEW POINTS ABOVE THRESH
6            TOO FEW STRINGS SEPS IN SPACE FIT
8            TOO MANY CUT STEPS IN LFAST SQUARES ROUTINE
HITS ARE CHARACTERIZED AS FOLLOWS:
K2          NO HIT SIGNIFIES
0            NO HIT
1            MINOR MEMBER OF ROOTS PAIR
2            MAJOR MEMBER OF ROOTS PAIR
3            HIT ABOVE THRESHOLD THREHS
MAIN: PRINTING PARAMETERS: 0 KSINC= 1 KPP= 2 KKEY= 0 NKFY= 0 MPP= 2 MC= 1 NKEY1= 0 KTOT= 500

```

FIG. A0-1. First page of printout for each pass; enumerates data read in, data on Polya distribution, error messages, and hit characterizations.

Fig. A1-1. Printout for first event of pass 1. Initial track parameters, and list of hits. Since this is PAIR array, individual hits are coincidences, either true or random.


```

TIMEFIT. EVENT NO. 1 IRONS. NO. OF ROOTS PAIRS 6 IER = 0 KSIGN= 1 KTOT=500 MPRT= 2 NKEY1=
PASS1: RESULTS OF FITS. TIMING CHISQ/NDFIT = 0.710E-01
      XA      YA      ZA      THETA/PHI
TRUE   +20.0    0.0    47.8    1.4279  0.6507
SFIT   -16.0   -0.5    49.2    1.4175  0.6506
SEFF   -14.0   -0.5    41.4    0.0104  -0.0002
TEFF   -16.1   -0.3    48.7    1.4283  0.6545
TEQR   -13.9   -0.3    48.9    0.0004  0.0038
LOCATION ERROR 4.036 M.

PASS1: EVENT NO. 1 SPACE FIT. MR. = 500. TIME FIT = 4. TIR = 0
BKGD: PRINTING PARAMETERS
MATH: KRPTE 0 KSIGN= 2 KKEY= 0 NKFY= 0 MPRT= 2 NC= 2 NKFY1= 0 KTOT= 500

```

Fig. A1-4. Continuation. The final TLINE fit is thus identical with the initial one. A summary of the event completes the printout.

```

*****VINT NO. 25 FAILS! IEP = 3
TIMEFIT. EVENT NO. 26 IPONS, NO. OF ROOS PAIRS 8 IER = 0 KSIGN= 1 KTOT=500 MPRTE 2 NKEY1=
PASS1: EVENT NO. 26 SPACE FIT, MR. = 70.TMF FIT = 3. IEP = 0
TIMEFIT. EVENT NO. 27 IRONS, NO. OF ROOS PAIRS 4 IFR = 0 KSIGN= 1 KTOT=500 MPRTE 2 NKEY1=
PASS1: EVENT NO. 27 SPACE FIT, MR. = 12.TMF FIT = 12. IEP = 0
TIMEFIT. EVENT NO. 28 IRONS, NO. OF ROOS PAIRS 9 IER = 0 KSIGN= 1 KTOT=500 MPRTE 2 NKEY1=
PASS1: EVENT NO. 28 SPACE FIT, MR. = 34.TMF FIT = 13. IEP = 0
TIMEFIT. EVENT NO. 29 IPONS, NO. OF ROOS PAIRS 4 IFR = 0 KSIGN= 1 KTOT=500 MPRTE 2 NKEY1=
PASS1: EVENT NO. 29 SPACE FIT, MR. = 33.TMF FIT = 25. IER = 0
TIMEFIT. EVENT NO. 30 IRONS, NO. OF ROOS PAIRS 11 IER = 0 KSIGN= 1 KTOT=500 MPRTE 2 NKEY1=
PASS1: EVENT NO. 30 SPACE FIT, MR. = 39.TMF FIT = 36. IER = 0
END OF PASS 1. 100 EVENTS PROCESSED. 1328 BACKGROUND EVENTS
STATISTICS

```

COUNT	AVG(X)	RMS(X)	SD(X)	B3	B4	N
1533:	281.5	928.5	885.5	114.8	146.8	PHOT/M#2 AT DETECTOR
94:	132.5	134.5	124.5	13.6	13.6	DETector before space fit
94:	0.367E-01	0.367E-01	0.426E-01	0.217E-01	0.217E-01	ANGULAR ERROR - TIME FIT
94:	0.205E-01	0.205E-01	0.262E-01	0.164E-01	0.164E-01	ANGULAR ERROR - ALONG TRACK (GEV)
17675:	0.125E-02	0.2674E-02	0.2714	0.2714	0.2714	AVG RDE DX ALONG TRACK
17644:	0.000E+00	0.952E-02	0.200E+00	0.200E+00	0.200E+00	ANGULAR ERROR - STRIPPING FIT
94:	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	TOTAL PHOTOLELECTRONS
94:	0.142E-01	0.164E-01	0.200E-01	0.164E-01	0.164E-01	PE(MAX)
94:	0.555E-01	0.555E-01	0.666E-01	0.354	0.41	
94:	0.11E-01	0.11E-01	0.17E-01	0.11E-01	0.11E-01	

MAIN: NO. OF ARRIVALS AT SELECTED POINTS IN THE PROGRAM: INQ(1-50) = 0 0 0 0 0 0 0 0 0 0

ND	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
100	97	97	94	94	94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		

FRACTION OF EVENTS WITH AT LEAST ND DETECTORS HAVING AT LEAST NT COUNTS

NT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ND	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
10	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	

ROOS: NUMBER OF EVENTS IRONS(I) WITH I ROOS PAIRS

I	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
IRONS(I)=	0	0	1	0	1	3	15	15	20	18	8	10	13	12	12	13	14	15	16	17
NUMBER OF EVENTS IIER WITH FAILURE INDEX IER	-1	0	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
IIER=	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ND	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

FIG. A1-5. End of first pass. The last of the brief summaries of the first 30 events are shown, and the pass summary.

Following the summary, a list of INQ(I), a debugging aid, shows how many times the program reached a series of locations in the program. The distribution of the number of ROOS pairs per event is given, and the distribution of the failure index IER, which shows why events fail. In this case all 6 failures were due to too few ROOS pairs.

Fig. A1-6. Typical histogram: the angular error of the time fit. The units are milliradians.

Fig. A2-1. Printout of first event of pass 2. PAIR no longer being in use, all hits are single modules.

FIG. A2-2. Continuation. There are 94 hits. PASS1 lists the number of photoelectrons in each $\langle WXYZ(5,1) \rangle$.

EVENT NO. 1 IROUSE#16 ITRE 0 XSIGN = 1 FILTERS 500 MPRT = 2
 PASS1: RESULT OF SPACE FIT TO 22 POINTS:
 AVX 68.4 1.428 1.455 0.027 0.651 PPH STOPH RMS
 AYV 82.4 1.428 1.455 0.027 0.651 PPH STOPH RMS
 PASS2: MIDPOINT PROJECTION DISTANCE = 26.3 N

Fig. A2-3. Continuation. PASS1 characterizes each hit by KZ according to its satisfaction of the trigger conditions. After deleting the failures, 27 hits remain at the start of FILTER. After FILTER, 22 remain for BLINE.

-2M1N X20UT Y20UT Z220UT T2F0
-156.7 -37.0 -13.2 35.3 -44.4
E/INE

FIG. A2-4. Continuation. Printouts of ELINE (the space fit), and TLINE.

TURC:

20	415.	200.0	160.0	100.0	934.7	5.	3.3	0.67	929.4
21	416.	200.0	160.0	105.0	982.1	2.	3.0	1.92	974.4
22	417.	200.0	160.0	100.0	1035.1			3.03	1024.4
C	X4X	=	200.0	4.627658					

TIMEFIT.

		1 IRONS.	NO. OF ROOS PAIRS	16 IER = 0 KSIGN= 1 KTOT=500 MPRTE= 2 NKEY1=
PASS1:	RESULTS OF FITS.	CHISQ/DET = 0.582E-01		
	XA	ZA	PHI	
TRUE	-20.0	0.0	47.8 1.4479 0.6507	
SFIT	-27.0	-13.2	50.3 1.4455 0.6619	
SEFF	-30.3	-13.2	52.6 1.4427 0.6612	0.0111
TFIT	-30.3	-13.2	46.5 1.4298 0.6467	
TERR	-10.3	-7.0	47.5 1.4019 0.6040	0.0040
LOCATION				0.0040
	ERROR	12.528		
PASS1: EVENT NO.	1 SPACEFIT, MR. = 500			
BKGD= F KRPTE= 0 KTOT=				
PASS1: P EVENT NO.	1 IRONS, NO. OF ROOS PAIRS	16 IER = 0 KSIGN= 1 KTOT=500 MPRTE= 2 NKEY1= 0		
PASS1: KMAX = 25	DCZ(1),2ZZ(1),CTHEF,2ZF=	0.1424572 47.75882 0.1405674		
PASS1: 46.47845				

Fig. A2-5. Continuation. No deletions being necessary, the final TLINE printout is the same as the first. The final event summary completes the printout.

Fig. A2-6. Printout of the event trajectory. Both X-Z plane projections are shown. Dots indicate the true track, X's the fitted ones; where they overlap, the dots disappear. In this case only one is left. The numbers indicate the sum of the number of photoelectrons in all modules with the same X,Z or Y,Z respectively.

FIG. A3-1. Start of event printout in third pass. This pass has data-controlled printout (NKEY negative). Only successfully fitted events are printed. Since this is a background run - no real tracks - very few events succeed, and thus data-control is required to see spurious tracks that are accepted. In data-controlled printouts, the hit list is omitted. There are 1127 hits, of which 13 survive trigger conditions.

END FILTERING
 FILTER NDET= 5 NPT(1)= 2 K=1,NDET = 4. 1. 2. 1. 3.
 -4 2
 ROOSDEL: ORPHAN PNT NO. 1 NDET = 15! DELETED; THEY ARE HITS NO.:
 ROOSDEL: 1 ORPHANS REMOVED; THEY ARE HITS NO.:
 HITS: 1

EVENT NO. 16 TROUSE PASS1: FINAL RESULTS OF FILTER.** -1 KTOTS = 16

PASS1: RESULT OF SPACE FIT TO 4 POINTS!
 AVX DTH PHOT RMS
 114.4 42.6 75.0 0.619 2.422 1.803 1.150-0.450-1.661-1.055 2.089
 ELINE: AVERAGE PROPAGATION DISTANCE = 7.7 M.
 ZMIN XZOUT YZOUT ZDOUT TZERO ELINE
 -281.9 65.8 86.1 236.6 -32.0

ELINE:
 1 NDET X TOBS PHEL RHO ETA PIN POUT
 1 176. 78.4 80.0 105.0 91.4 10.3 15.4 21.6 10.3 0.0 33.0 45.
 2 177. 78.4 80.0 129.0 19.7 1.1 10.4 21.2 14.6 0.4 0.0 0.0 0.
 3 178. 78.4 80.0 135.0 27.4 1.1 9.5 14.9 31.2 -35.3 -2.5 0.0 45.
 4 302. 162.4 39.4 155.0 554.1 3.1 0.6 161.5 510. -31.3 29.6 -0.6 0.0 12.0.

ELINE: RANGE ELOSS DEDX DNDX
 PASS1 PT. NO. 0 DELETED, RHO TOO LARGE

SPACEFIT EVENT NO. 16 IRONS. NO. OF ROOS PAIRS 2 IER = 0 KSIGN= -1 KTOTS = 16 NKEY1=

TLINE: EVENT NO. 16 TOTAL WTD. CHISQ = 27.97 NDET= 4 WXSUM= 7.

TLINE:

	X	Y	Z	TOBS	PHEL	CHIWT'D'	UNWT'D	TEST
1 NDET	78.4	80.0	105.0	91.4	1.1	8.7	8.72	10.91
2 176.	78.4	80.0	129.0	19.7	1.1	13.37	41.6	
3 177.	78.4	80.0	135.0	27.4	1.1	16.45	31.4	
4 302.	162.4	39.4	155.0	554.1	3.1	157.0	52.33	510.7
CHMAX=	162.4	39.4	155.0	554.1				
DELETE: CHSQ FOR 302	13.37	0.45						
ROOSDEL: 72 0 ORPHANS REMOVED; THEY ARE HITS NO.:								
HITS:								

TLINE: EVENT NO. 16 TOTAL WTD. CHISQ = 16 NDET= 3 WXSUM= 4.

TIMEFIT. EVENT NO. 16 IRONS. NO. OF ROOS PAIRS 2 IER = 0 KSIGN= -1 KTOTS = 16 NKEY1=

PASS1: RESULTS OF FITS. TIMING CHISQ/NDET = 0.673

	XA	YA	ZA	THETA	PHI
TRUE	0.0	0.0	-20.0	0.6190	1.502
SEFT	65.3	86.1	136.6	2.4222	0.4504
SEPR	65.8	85.5	156.6	1.8032	1.0548
TEFT	66.0	86.0	133.9	0.3699	0.4535
TERF	66.0	86.0	153.9	1.7609	1.184
LOCATION ERROR	168.280				

PASS1: EVENT NO. 16 SPACE FITTYPE MR. = 2089. TIME FITP=2078. 16 IER = 0 KTOTS = 1
 PASS1: KPTP1 KSIGN=-1 KPTP2 KKEY= 0 NKEY1= 1 KTOTS = 1
 8KGD= 1 KPTP1

PASS1: P EVENT NO. 16 IRONS. NO. OF ROOS PAIRS 2 IER = 0 KSIGN= -1 KTOTS = 1 MPRT= 0 NKEY1= 2
 PASS1: KMAX= 25 DCZ(1),222(1),CTHDF,ZZF= 0.8144776 -20.00000 -0.7167290
 LJJ3.9043

Fig. A3-2. Continuation. Five points survive FILTER; one is removed by ROOSDEL, which eliminates orphans — members of ROOS pairs that have lost their partners. ELINE lists the remaining four. TLINE fits these, and discards one with excessive Chsq. The remaining 3 survive to give an acceptable fit; the trigger conditions are so relaxed that 3 points are acceptable. The errors in the event summary are meaningless, since the "true" track is a fiction.

EVENT 3 ISEED = 320844568 ENERGY = 2.00 TeV
 *ATN TRACK PARAMETERS
 WTA 1 16.3 YZ 7Z YCYL 2.5 YCYL 2.5 PPH 0.451 0.000 DCX 0.436 0.000 DCL 0.900
 $T_X = \frac{1}{3} \cdot \frac{1}{2} \cdot 1295 \cdot 1.4$
 TRACK 1
 PHDI, DETECTOR RESPONSE. NON-ZERO SIGNALS SATISFYING INITIAL TRIGGER CONDITIONS
 INIT IDFT X Y Z ZETA RHO TIME PHOT PHION SIG RG EL
 TPR = 1 1 25.0 25.0 0.0 11.5 5.0 55.3 780.9 15.0 0.0 15.0
 2 2 25.0 25.0 5.0 16.0 3.4 58.0 1352.7 15.0 0.0 10.0
 3 3 25.0 25.0 10.0 20.5 2.9 67.0 1725.7 10.0 0.0 10.0
 4 4 25.0 25.0 20.0 29.5 2.5 110.4 674.8 30.0 0.0 30.0
 5 5 25.0 25.0 25.0 34.0 2.4 129.9 408.5 13.0 0.0 13.0
 6 6 25.0 25.0 30.0 38.5 2.3 150.3 264.6 16.0 0.0 6.0
 TRACKLOOP COMPUTED,
 PHDOL NHITES COMPUTED,
 SORTLDNP COMPUTED, EVENT NO. 6
 PHIDL COMPUTED, EVENT NO. 3
 NHITE= 6
 PASS1: EVENT NO. 3 IRONS, NO. OF ROOS PAIRS 7 IER = 0 KSIGN= 1 KTOT=500 MPRTE= 3 NKEY1= 0
 WXYZ(5,K) K=1 16.3 13.0 5.
 3 3 3 3
 PASS1: MDET: ID OF ALL DETECTORS WITH SIGNALS DIFFERENT FROM ZERO
 1 2 3 5 6
 PASS1: REMAINING DETECTOR HITS. DETECTORS NOT SATISFYING INITIAL TRIGGER REQUIREMENTS ELIMINATED. KZ:
 3 3 3 3
 PASS1: MDET: ID OF DETECTORS WITH SURVIVING HITS
 1 2 3 5 6
 PASS1: MDET= 6 IRONS = 7 HITS ABOVE THRESH 6
 PASS1: RESULT OF SPACE FIT TO 6 POINTS!
 AVY AYZ AVZ THOUT DTH PPH PHOUT STDPH RMS
 25.0 25.0 11.5 0.451 0.000-0.451 0.000 0.000 0.451
 ELINE: AVERAGE PROPAGATION DISTANCE = 0.0 m.
 ZMIN XZOUT YZOUT ZZOUT TZZERO ELINE
 -11.5 25.0 25.0 0.0 48.6
 ELINE: RANGE ELOSS DEDX DNDX
 30.0 0.0 0.0 2.611
 1: 25.0 25.0 0.0 2 TOBS PHEL PREL RHO R ZETA TEST DISP1 DISP2 XP YP ZP PIN POUT
 2: 25.0 25.0 5.0 55.3 15.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 3: 25.0 25.0 10.0 58.0 10.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 4: 25.0 25.0 20.0 67.0 20.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 5: 25.0 25.0 25.0 110.4 25.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 6: 25.0 25.0 30.0 129.9 30.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

Fig. S-1. Printout of string event. FILTER is not used for string fits, and there are few points, so printouts are short. ELINE retains all 6 points originally detected.

SLINE: STRING FIT INITIALIZATION.
 1MAX 316AX 3.0 3.0
 1MAX 316AX 3.0 3.0
 SLINE: EVENT NO. 3 PTFUL WID. CHISU = 3 4.04
 SLINE:
 1 MDFT X 25.0 25.0 2 TORAS PHEL CHI TEST
 2 25.0 25.0 5.0 5.0 3 15.0 0.734 50.0
 3 25.0 25.0 10.0 10.0 4 10.0 1.034 69.1
 4 5.0 25.0 10.0 10.0 5 13.0 0.137 69.1
 5 25.0 25.0 20.0 20.0 6 13.0 0.157 112.8
 6 25.0 25.0 25.0 25.0 7 15.0 0.036 131.1
 7 25.0 25.0 15.0 15.0 8 5.0 0.001 150.0
 FX(151) 6.250, MDET= 1.8609610E-02 1.4934641E+03 0.000000E+00
 SLINE: EVENT NO. 3 CHMAX = 2.136869
 PASS 1 STRNG FIT. EVENT NO. 3 CHISU = 4.04
 TRUE 2.9 0.451 2.8 TB
 FIT 3.8 0.261 9.3 6.6 6.6
 EROR 1.670.190 1.2.6 -9.6 74.3
 LOCATIONN ERROR 2.943 N.
 PASS1 XZF, YZF, ZZF, THEF = 3.180 3.935 -9.605 0.261
 1 X Y Z T SIG TIME OF
 7 0.6 0.6 0.6 0.6 0.0 150.0 10.4
 PASS1: EVENT NO. 3 SPACE FIT. MR. = 451. TIME FIT = 190. IEP = 0
 PKGDF F KPTP= 0 KIOT= 500
 SLINE: EVENT NO. 4 CHMAX = 0.3306741
 PASS1: EVENT NO. 4 SPACE FIT. MR. = 290. TIME FIT = 371. IEP = 0
 SLINE: EVENT NO. 5 CHMAX = 2.623445
 PASS1: EVENT NO. 5 SPACE FIT. MR. = 180. TIME FIT = 29. IEP = 0
 SLINE: EVENT NO. 6 CHMAX = 6.184015
 PASS1: EVENT NO. 6 SPACE FIT. MR. = 278. TIME FIT = 59. IEP = 0
 SLINE: EVENT NO. 7 CHMAX = 1.346579
 PASS1: EVENT NO. 7 SPACE FIT. MR. = 89. TIME FIT = 231. IEP = 30
 SLINE: EVENT NO. 8 CHMAX = 2.407426
 PASS1: EVENT NO. 8 SPACE FIT. MR. = 164. TIME FIT = 36. IEP = 0
 SLINE: EVENT NO. 9 CHMAX = 0.54591176
 PASS1: EVENT NO. 10 CHMAX = 0.4151255
 SLINE: EVENT NO. 11 SPACE FIT. MR. = 384. TIME FIT = 36. IEP = 30
 PASS1: EVENT NO. 12 SPACE FIT. MR. = 447. TIME FIT = 42. IEP = 0
 SLINE: EVENT NO. 13 CHMAX = 2.692556

Fig. S-2. Conclusion. SLIME is the time fit for string events. All points survive; the summary gives the final fit. Some additional fits of the first 30 events are shown.

Fig. M-1. Selected parts of the printout of a multiple-track event. First the parameters of the five tracks specified are printed out. Since no angular deviation was specified, all tracks are parallel. The hit list shows hits in all five tracks serially. Background hits are all printed in track 1.

Fig. M-2. Continuation. The printout of hits for tracks 4 and 5.

HIT UN.	DET	MU.	SORTHIT	TIN
199				
321	120.0	14.7	663.4	
326	120.0	15.0	689.5	
200	120.0	15.6	881.2	
201	120.0	15.7	912.9	
202	120.0	15.9	986.1	
203	120.0	16.0	1119.9	
204	120.0	16.0	1191.1	
205	120.0	16.1	1591.0	
206	120.0	16.8	1416.8	
207	120.0	16.9	1167.5	
208	120.0	17.1	120.1	
209	120.0	17.8	1416.8	
210	120.0	18.0	1167.5	
211	120.0	18.1	120.1	
212	120.0	18.9	1119.9	
213	120.0	19.0	1191.1	
214	120.0	19.7	1591.0	
215	120.0	20.0	1416.8	
216	120.0	20.0	1167.5	
217	120.0	20.1	120.1	
218	120.0	20.8	1416.8	
219	120.0	21.0	1167.5	
220	120.0	21.1	120.1	
221	120.0	21.9	1119.9	
222	120.0	22.0	1191.1	
223	120.0	22.9	1591.0	
224	120.0	23.0	1416.8	
225	120.0	23.9	1167.5	
226	120.0	24.0	120.1	
227	120.0	24.5	1416.8	
228	120.0	25.6	1167.5	
229	120.0	25.7	120.1	
230	120.0	25.9	1119.9	
231	120.0	26.0	1191.1	
232	120.0	26.8	1591.0	
233	120.0	27.0	1416.8	
234	120.0	27.1	1167.5	
235	120.0	27.9	120.1	
236	120.0	28.0	1416.8	
237	120.0	28.1	1167.5	
238	120.0	28.8	120.1	
239	120.0	29.0	1119.9	
240	120.0	29.7	1191.1	
241	120.0	29.8	1591.0	
242	120.0	29.9	1416.8	
243	120.0	30.0	1167.5	
244	120.0	30.1	120.1	
245	120.0	30.8	1416.8	
246	120.0	30.9	1167.5	
247	120.0	31.0	120.1	
248	120.0	31.9	1119.9	
249	120.0	32.0	1191.1	
250	120.0	32.8	1591.0	
251	120.0	32.9	1416.8	
252	120.0	33.0	1167.5	
253	120.0	33.1	120.1	
254	120.0	33.8	1416.8	
255	120.0	33.9	1167.5	
256	120.0	34.0	120.1	
257	120.0	34.8	1119.9	
258	120.0	34.9	1191.1	
259	120.0	35.0	1591.0	
260	120.0	35.1	1416.8	
261	120.0	35.9	1167.5	
262	120.0	36.0	120.1	
263	120.0	36.8	1416.8	
264	120.0	36.9	1167.5	
265	120.0	37.0	120.1	
266	120.0	37.8	1119.9	
267	120.0	37.9	1191.1	
268	120.0	38.0	1591.0	
269	120.0	38.1	1416.8	
270	120.0	38.9	1167.5	
271	120.0	39.0	120.1	
272	120.0	39.7	1119.9	
273	120.0	39.8	1191.1	
274	120.0	39.9	1591.0	
275	120.0	40.0	1416.8	
276	120.0	40.1	1167.5	
277	120.0	40.8	120.1	
278	120.0	40.9	1119.9	
279	120.0	41.0	1191.1	
280	120.0	41.8	1591.0	
281	120.0	41.9	1416.8	
282	120.0	42.0	1167.5	
283	120.0	42.1	120.1	
284	120.0	42.8	1416.8	
285	120.0	42.9	1167.5	
286	120.0	43.0	120.1	
287	120.0	43.8	1119.9	
288	120.0	43.9	1191.1	
289	120.0	44.0	1591.0	
290	120.0	44.1	1416.8	
291	120.0	44.9	1167.5	
292	120.0	45.0	120.1	
293	120.0	45.8	1416.8	
294	120.0	45.9	1167.5	
295	120.0	46.0	120.1	
296	120.0	46.8	1119.9	
297	120.0	46.9	1191.1	
298	120.0	47.0	1591.0	
299	120.0	47.1	1416.8	
300	120.0	47.9	1167.5	
301	120.0	48.0	120.1	
302	120.0	48.8	1416.8	
303	120.0	48.9	1167.5	
304	120.0	49.0	120.1	
305	120.0	49.8	1119.9	
306	120.0	49.9	1191.1	
307	120.0	50.0	1591.0	
308	120.0	50.1	1416.8	
309	120.0	50.9	1167.5	
310	120.0	51.0	120.1	
311	120.0	51.8	1416.8	
312	120.0	51.9	1167.5	
313	120.0	52.0	120.1	
314	120.0	52.8	1119.9	
315	120.0	52.9	1191.1	
316	120.0	53.0	1591.0	
317	120.0	53.1	1416.8	
318	120.0	53.9	1167.5	
319	120.0	54.0	120.1	
320	120.0	54.8	1416.8	
321	120.0	54.9	1167.5	
322	120.0	55.0	120.1	
323	120.0	55.8	1119.9	
324	120.0	55.9	1191.1	
325	120.0	56.0	1591.0	
326	120.0	56.1	1416.8	
327	120.0	56.9	1167.5	
328	120.0	57.0	120.1	
329	120.0	57.8	1416.8	
330	120.0	57.9	1167.5	
331	120.0	58.0	120.1	
332	120.0	58.8	1119.9	
333	120.0	58.9	1191.1	
334	120.0	59.0	1591.0	
335	120.0	59.1	1416.8	
336	120.0	59.9	1167.5	
337	120.0	60.0	120.1	
338	120.0	60.8	1416.8	
339	120.0	60.9	1167.5	
340	120.0	61.0	120.1	
341	120.0	61.8	1119.9	
342	120.0	61.9	1191.1	
343	120.0	62.0	1591.0	
344	120.0	62.1	1416.8	
345	120.0	62.9	1167.5	
346	120.0	63.0	120.1	
347	120.0	63.8	1416.8	
348	120.0	63.9	1167.5	
349	120.0	64.0	120.1	
350	120.0	64.8	1119.9	
351	120.0	64.9	1191.1	
352	120.0	65.0	1591.0	
353	120.0	65.1	1416.8	
354	120.0	65.9	1167.5	
355	120.0	66.0	120.1	
356	120.0	66.8	1416.8	
357	120.0	66.9	1167.5	
358	120.0	67.0	120.1	
359	120.0	67.8	1119.9	
360	120.0	67.9	1191.1	
361	120.0	68.0	1591.0	
362	120.0	68.1	1416.8	
363	120.0	68.9	1167.5	
364	120.0	69.0	120.1	
365	120.0	69.8	1416.8	
366	120.0	69.9	1167.5	
367	120.0	70.0	120.1	
368	120.0	70.8	1119.9	
369	120.0	70.9	1191.1	
370	120.0	71.0	1591.0	
371	120.0	71.1	1416.8	
372	120.0	71.9	1167.5	
373	120.0	72.0	120.1	
374	120.0	72.8	1416.8	
375	120.0	72.9	1167.5	
376	120.0	73.0	120.1	
377	120.0	73.8	1119.9	
378	120.0	73.9	1191.1	
379	120.0	74.0	1591.0	
380	120.0	74.1	1416.8	
381	120.0	74.9	1167.5	
382	120.0	75.0	120.1	
383	120.0	75.8	1416.8	
384	120.0	75.9	1167.5	
385	120.0	76.0	120.1	
386	120.0	76.8	1119.9	
387	120.0	76.9	1191.1	
388	120.0	77.0	1591.0	
389	120.0	77.1	1416.8	
390	120.0	77.9	1167.5	
391	120.0	78.0	120.1	
392	120.0	78.8	1416.8	
393	120.0	78.9	1167.5	
394	120.0	79.0	120.1	
395	120.0	79.8	1119.9	
396	120.0	79.9	1191.1	
397	120.0	80.0	1591.0	
398	120.0	80.1	1416.8	
399	120.0	80.9	1167.5	
400	120.0	81.0	120.1	
401	120.0	81.8	1416.8	
402	120.0	81.9	1167.5	
403	120.0	82.0	120.1	
404	120.0	82.8	1119.9	
405	120.0	82.9	1191.1	
406	120.0	83.0	1591.0	
407	120.0	83.1	1416.8	
408	120.0	83.9	1167.5	
409	120.0	84.0	120.1	
410	120.0	84.8	1416.8	
411	120.0	84.9	1167.5	
412	120.0	85.0	120.1	
413	120.0	85.8	1119.9	
414	120.0	85.9	1191.1	
415	120.0	86.0	1591.0	
416	120.0	86.1	1416.8	
417	120.0	86.9	1167.5	
418	120.0	87.0	120.1	
419	120.0	87.8	1416.8	
420	120.0	87.9	1167.5	
421	120.0	88.0	120.1	
422	120.0	88.8	1119.9	
423	120.0	88.9	1191.1	
424	120.0	89.0	1591.0	
425	120.0	89.1	1416.8	
426	120.0	89.9	1167.5	
427	120.0	90.0	120.1	
428	120.0	90.8	1416.8	
429	120.0	90.9	1167.5	
430	120.0	91.0	120.1	
431	120.0	91.8	1119.9	
432	120.0	91.9	1191.1	
433	120.0	92.0	1591.0	
434	120.0	92.1	1416.8	
435	120.0	92.9	1167.5	
436	120.0	93.0	120.1	
437	120.0	93.8	1416.8	
438	120.0	93.9	1167.5	
439	120.0	94.0	120.1	
440	120.0	94.8	1119.9	
441	120.0	94.9	1191.1	
442	120.0	95.0	1591.0	
443	120.0	95.1	1416.8	

FIG. M-4. Continuation. End of sorted list; listing of multiple hits and sensor waveforms (for ENV, which identifies multiple-track events).


```

ELINE: RANGE ELOSS DEDX DNFX
        799.2    13     4.4   1.962
LUNIMINH NO. = 1 DTEST = 1 HIT(NC) = 18.9
LUNIMINH BAD POINT NO. = 40. DTEST = 1 HIT(NC) = 1.
LUNIMINH NO. = 26. DTEST = 29.8 HIT(NC) = 30.1
LUNIMINH BAD POINT NO. = 2 HIT(NC) = 26.
PT. NO. 26 DELETED. RHO TOO LARGE

ASSILI: RESULT OF SPACE FIT TO 62 POINTS! PHOUT DPH STOPH RMS
AVZ AYZ TTH THOUT DTW PHOUT DPH 0.037 0.021 0.027
75.3 75.6 116.0 0.632 0.616-0.016 0.740 0.777 0.037 0.021 0.027

ELTIME: AVERAGE PROPAGATION DISTANCE = 41.6 M.

ZMIN XZOUT YZOUT TZOUT TZZERO ELINE

```

```

ELINE: RANGE ELOSS DEDX DNDX
      79.9 3 11 3 4 2 1.962 1.962
LUMIN:HIT NO. # DTESI = 18.9 RHO(1) = 19.0 1
LUMIN: BAD POINT NO 1 HIT NO.
LUMIN: PT. NO. 1 DELETED, RHO 100 LARGE
PASS1.

```

PASS11: RESULT OF SPACE FIT TO 61 POINTS!
 AVE AVZ THOUT DPH PHOUT STDPH RMS
 76.9 79.3 123.6 0.632 0.592-0.040 0.740 0.714 0.034 0.019 0.044
 EELINE: AVERAGE PROPAGATION DISTANCE = 41.4 M.

ZWIN XZ001 YZR11 + ZZR11 + ZZR11 -4.0 ELINE

ELINE: RANGE ELOSS DEDX BNDX
298.1 1.2 460 1.969
PI. NO. 0 DELETED. RHO TON LARGE
PASSI. SPACEFIT EVENT NO. 1 IRONS. NO. OF ROOS PAIRS 52 IER = 0 KSIGN= 1 KTOT=500 MPRIS= 1 NKEY= 1

TIME!! EVENT NO. 1
TOTAL WTDS CHISQ = 3.02 NDET= 61 WXSUM= 269.

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Fig. M-6. Continuation. At end of ELINE, there are 63 hits. LUMIN now deletes points too far from track to have the observed signal; TLINE thus receives 61 hits.

Fig. M-7. Continuation. TLINE initial printout, start of deletion of points with excessive chisq.

FIG. M-8. Continuation. At end of DELETE, with all large chisq eliminated.

```

46 329: 120.0 120.0 120.0 195.0 912.9 20. 0.0 0.00 895.2
47 330: 120.0 120.0 210.0 225.0 953.5 50. 0.1 0.01 913.1
48 331: 120.0 120.0 225.0 1031.5 10. 0.2 0.02 960.8
49 332: 120.0 120.0 240.0 1093.2 6. 0.1 0.02 1025.7
50 333: 120.0 120.0 255.0 1156.4 2. 0.0 0.00 1092.3
51 334: 120.0 120.0 270.0 1214.3 3. 11.7 3.89 1159.2

TIMEFIT. EVENT NO. 1 IRONS. NO. OF ROOS PAIRS 41 IER = 0 KSIGN= 1 KTOT=500 MPRTE 1 NKEY1=
PASS1: RESULTS OF FITS. TIMING CHISQ/NDFT = 0.327E-01
XA YA THETA PHI
TRUE 3.1 11.8 -27.6 0.6321 0.7397
SFIT 6.4 8.4 -27.0 0.5244 0.7718
SERK 6.4 8.4 -27.0 0.0346 0.0340 0.0190
TEFIT -0.6 6.3 -22.2 0.6419 0.7297
TERRR -0.6 6.3 -22.2 0.0097 -0.0100 -0.0060
LOCATION ERROR 6.685 A.

PASS1: EVENT NO. 1 SPACE FIT, MR. = 44.TIME FIT = 500. IER = 0
RKGD= F KRPTE
KTOT= 0

TIMEFIT. EVENT NO. 2 IRODS. NO. OF ROOS PAIRS 28 IER = 0 KSIGN= 1 KTOT=500 MPRTE 1 NKEY1=
PASS1: EVENT NO. 2 SPACE FIT, MR. = 15.TIME FIT = 28. IER = 0
TIMEFIT. EVENT NO. 3 IRODS. NO. OF ROOS PAIRS 29 IER = 0 KSIGN= 1 KTOT=500 MPRTE 1 NKEY1=
PASS1: EVENT NO. 3 SPACE FIT, MR. = 43.TIME FIT = 13. IER = 0
TIMEFIT. EVENT NO. 4 IRONS. NO. OF ROOS PAIRS 21 IER = 0 KSIGN= 1 KTOT=500 MPRTE 1 NKEY1=
PASS1: EVENT NO. 4 SPACE FIT, MR. = 29.TIME FIT = 23. IER = 0
TIMEFIT. EVENT NO. 5 IRODS. NO. OF ROOS PAIRS 26 IER = 0 KSIGN= 1 KTOT=500 MPRTE 1 NKEY1=
PASS1: EVENT NO. 5 SPACE FIT, MR. = 76.TIME FIT = 15. IER = 0
TIMEFIT. EVENT NO. 6 IRONS. NO. OF ROOS PAIRS 36 IER = 0 KSIGN= 1 KTOT=500 MPRTE 1 NKEY1=
PASS1: EVENT NO. 6 SPACE FIT, MR. = 55.TIME FIT = 8. IER = 0
TIMEFIT. EVENT NO. 7 IRODS. NO. OF ROOS PAIRS 32 IER = 0 KSIGN= 1 KTOT=500 MPRTE 1 NKEY1=
PASS1: EVENT NO. 7 SPACE FIT, MR. = 15.TIME FIT = 26. IER = 0
TIMEFIT. EVENT NO. 8 IRODS. NO. OF ROOS PAIRS 20 IER = 0 KSIGN= 1 KTOT=500 MPRTE 1 NKEY1=
PASS1: EVENT NO. 8 SPACE FIT, MR. = 44.TIME FIT = 30. IER = 0
TIMEFIT. EVENT NO. 9 IRODS. NO. OF ROOS PAIRS 22 IER = 0 KSIGN= 1 KTOT=500 MPRTE 1 NKEY1=
PASS1: EVENT NO. 9 SPACE FIT, MR. = 179.TIME FIT = 17. IER = 0
TIMEFIT. EVENT NO. 10 IRONS. NO. OF ROOS PAIRS 32 IER = 0 KSIGN= 1 KTOT=500 MPRTE 1 NKEY1=
PASS1: EVENT NO. 10 SPACE FIT, MR. = 27.TIME FIT = 18. IER = 0
END OF PASS 1. 10 EVENTS PROCESSED. 358 BACKGROUND EVENTS
STATISTICS

```

Fig. M-9. Continuation. There are now 51 points, and a summary of the final fit is printed. After brief summaries of remaining events, we come to summary of the pass.

FRACTION OF EVENTS WITH AT LEAST ND DETECTORS HAVING AT LEAST NT COUNTS									
NUMBER OF UNCONDITIONAL SINGLES = 1.0000000000000000									
NUMBER OF NON-SINGLES. JER = 1 TO 6: 0.3000000000000000									
RONS: NUMBER OF EVENTS IROOS(I) WITH 1 ROOS PAIRS									
I= 1	0	1	2	3	4	5	6	7	8
TROUS(I)=	0	0	2	0	0	0	0	0	0
NUMBER OF EVENTS INTEP WITH FAILURE INDEX IFER = 0									
IERE= -1	0	2	3	4	5	6	7	8	9
NIER= 0	10	0	0	0	0	0	0	0	0
AVERAGE NUMBER OF ADJACENT KS-FOUND COINCIDENCES! ON THE SAME STRING WHEN ONE MNDUFL HAS AT LEAST NT COUNTS									
KS	-4.7000	2.4000	0.3000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000
I= 12	-9.0000	13.4000	1.5000	0.6000	0.1000	0.1000	0.1000	0.1000	0.1000
I= 13	-9.4000	15.5000	1.6000	0.6000	0.1000	0.1000	0.1000	0.1000	0.1000
I= 14	-9.4000	19.3000	1.5000	0.6000	0.1000	0.1000	0.1000	0.1000	0.1000
I= 15	-9.4000	19.4000	1.5000	0.6000	0.1000	0.1000	0.1000	0.1000	0.1000

Fig. M-10. Conclusion. The event summary shows all 10 events successfully fitted. A program bug gives an incorrect printout (32) of the number of space and time fits, and of the corresponding errors. These can be found correctly from a printout of histograms 11 and 12.