Determination of Z, A, and Initial Energy from Voyager HET Events

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SRL Internal Report 97

ABSTRACT

This report describes a method for determining Z, A, and the initial energy for a particle traversing a detector with at least two pulse height analyzed ΔE measurements. First there will be a brief general discussion of the method, followed by a detailed description of the analysis of Voyager High Energy Telescope (HET) events using this procedure. The three modes covered are HET high gain A-stopping (AS), HET high gain B-stopping (BS), and HET high gain penetrating (PEN). The analysis was done for H and He, including ^{2}H and ^{3}He where possible. A separate report will describe the use of the analysis method on high Z ($>$ 2) HET events when that analysis is completed.

February 9, 1989

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Introduction

For a particle of a given charge (Z), mass (A), and initial kinetic energy (E), going through a stack of n detectors, a point can be plotted in an n-dimensional space, where each coordinate (i) is the energy (ΔE_i) deposited in the i-th detector. When Z and A are fixed and E is varied, a track is traced out in this n-dimensional space. In reality, events are going to be spread in n-space about this track. Ideally, for any event of given Z and A, the most likely initial energy would be that energy corresponding to the point on the theoretical track closest to the point for the event, and the distance (r) between the point and the track, with each of the coordinates weighted by their respective fluctuations ($\sigma_{\Delta E}$), is a measure of how "good" the event is. Therefore, events on the track can be discriminated from background events by selecting events with r less than a certain value. This value may depend upon energy (i.e. the position along the track) because the fluctuations about the track vary with energy. One should note that certain regions of the track will have to be left out of the analysis due to ambiguities arising from crossing tracks. This crossing of tracks can occur between tracks of different Z and A, and for different energy regions of the same track.

There are also complications due to the shape of the dE/dx vs. E curve. After a steep decrease in dE/dx with increasing energy, there is a minimum value of the energy loss at the "minimum ionizing energy" and then a slow increase (the relativistic rise). Because of this shape, there is a region of incident energies from slightly less than minimum ionizing on up for which the track is completely ambiguous. This effect is what determines the upper limit for incident energies in this analysis.

In practice, determination of r and E are not this easy. Voyager's solid-state detectors contain "dead layers" in which the energy deposited is not added into the pulse height analysis. This causes an offset in the track for particles which penetrate the dead layer. Because the dead layers are thin ($\sim$ 150 μm), this problem only affects particles in a small energy range (a few MeV/n), smaller than the final energy resolution. However, these breaks do make the calculation of r and E analytically difficult. Instead, a computationally simpler procedure which roughly approximates this method is used.

If one differentiates between particles which stop in a given detector and particles which fully penetrate the detector, and if dead layers are neglected, then for a given Z and A, the energy deposited in the detector is a monotonic function of the initial energy with the ΔE monotonically increasing with increasing energy for stopping particles, and decreasing with increasing energy for penetrating particles, ignoring particles with incident energies more than the minimum ionizing energy. Therefore, taking each of these cases separately, the value of the initial energy is a direct function of the ΔE. The Voyager High Energy Telescopes (HETs) have three detectors (or stacks of detectors) which are pulse height analyzed for each event. Figure 1 shows a cross-section of a HET and shows the detectors or stack of detectors which pulse-height analyzed for each of the three modes. This gives three independent values of the initial energy, E, for each event, if Z and A are assumed. Then, the average of the three E_i (perhaps a weighted average) is approximately the closest E on the theoretical track, and the variance of the E_i, σ_E^2, as given by $\Sigma\,(E_i - E_{avg})^2$ gives a measure of how close the point is to the theoretical track, and so can be used to select events.

One problem with this is the breaks in the ΔE vs. E curves caused by the dead layers. This was resolved by artificially smoothing the curves so that the ΔE_i are always monotonic functions of E. This also allows the analysis to use a previously written fast spline interpolation routine which requires monotonic functions. This smoothing is acceptable because the energy region affected (stopping in the dead layers) is smaller than the final energy resolution.

Another problem arises due to the fact that, in regions where the slope, $\delta\Delta E_i \,/\, \delta E_i$, is small, a small fluctuation in ΔE_i causes a large shift in E_i, and therefore in E_{avg} and in the variance, σ_E^2. However, E_{avg} can be used to determine three $\Delta\epsilon_i$, the nominal theoretical values for ΔE_i given an initial energy E_{avg}, and another variance, $\sigma_{\Delta E}^2$, can be calculated from $\Sigma\,(\Delta\epsilon_i - \Delta E_i)^2$ which works well as a measure of how "good" the event is in the region where $\delta\Delta E_i \,/\, \delta E_i$ is small, but not in the region where it is large. But, by using a combination of both variances, σ_E^2 and $\sigma_{\Delta E}^2$, the appropriate events can be selected across the entire energy range. The cut using both variances was determined empirically and will be discussed later.

Selection Of Events And Preliminary Analysis

Several steps are required before calculating Z, A, and E. Figure 2 is a flow chart of these and subsequent steps in this analysis. The Voyager program, vrebox, is used to select the events to be analyzed. There are six different input files, three each for Voyager 1 and Voyager 2: A-stopping, B-stopping, and penetrating. Only high gain events are currently analyzed for H and He, and only events without the caution flag set are included. Also, for Voyager 1, only HET 2 is analyzed due to a PHA problem on HET 1, and on Voyager 2, only HET 1 is used because HET 2 is currently only in low gain mode. Although the other telescopes are usable early in the Voyager flights, the extra geometry is not at this point worth the time required to include their analysis. Wide window (boxes) on the raw pulseheights are also used to discriminate against particles far from the hydrogen and helium tracks. The slant cut is irrelevent, and the guard conditions are discriminated against at a later point in the process for penetrating and are set at $\overline{G1}$ for A-stopping and B-stopping.

Then the Voyager programs ecal#_lowz (where # is the space craft number, 1 or 2) are used to convert the three digital PHA values into ΔE_i in MeV using pre-flight calibration data. These programs also add a random number between 0 and 1 to the digital pulse height values in order to smooth out the events in ΔE space. This is done because it is easier to visually analyze such factors as event density when the events are spread out. This random number should have a negligible effect on the initial energy value calculated.

The two ecal programs also write a "tel" number for each event, which identifies the particular telescope and the range for each event. All of the information given by the tel number is also in the tag bits, but tel is used to discriminate between events for simplicity.

Initial Energy Determination

The main step in this analysis involves the three versions of a program "eincal": eincalas for A-stopping events, eincalbs for B-stopping events, and eincalpen for penetrating events. These programs and all the auxilliary files, and the fluxcal programs (which will be described later) are separated into directories according to the mode which they analyze. The three directories are Odin:/usr/erc/voyager/astop, Odin:/usr/erc/voyager/bstop, and Odin:/usr/erc/voyager/pen. The eincal programs take as input the chapter-verse format written out by ecal#_lowz, and output a chapter-verse format with all of the chapter 41s (individual event data) have been converted into chapter 39s in which the PHA data has been removed, and values for Z and EIN (initial energy per nucleon) are included for every event. The format of a chapter 39 is as follows:

Chapter 39 EINCAL Output		
Byte Number	Length	Name
0	2	KEY = 39 (Chapter Number)
2	2	Spare
4	2	NMVN = Number of Events ($\leq$40)
6	2	Spare
8	4 (long)	Itel
12	4 (float)	Y1 (ΔE_1) MeV
16	4 (float)	Y2 (ΔE_2) MeV
20	4 (float)	Y3 (ΔE_3) MeV
24	4 (float)	Z (Charge)
28	4 (float)	EIN (MeV/amu)
32 ...	Repeat last 24 bytes NMVN times (one set per event)	

The telescope numbers have also been modified to include such information as guard conditions, particle direction, and mass. The new telescope numbers are:

tel	HET	Gain	Guard	Direction	Mass
300	1	HG	G1*	A-Stop	Lighter Isotope (^{1}H or ^{3}He)
301	1	HG	G1*	A-Stop	Heavier Isotope (^{2}H or ^{4}He)
400	1	HG	G1*	B-Stop	Lighter Isotope (^{1}H or ^{3}He)
401	1	HG	G1*	B-Stop	Heavier Isotope (^{2}H or ^{4}He)
460	1	HG	G1·G2·G3*	A-Pen	all (isotopes inseparable)
461	1	HG	G1·G2·G3*	B-Pen	all (isotopes inseparable)
470	1	HG	G1·G2·G3	A-Pen	all (isotopes inseparable)
471	1	HG	G1·G2·G3	B-Pen	all (isotopes inseparable)
480	1	HG	G1*	A-Pen	all (isotopes inseparable)
481	1	HG	G1*	B-Pen	all (isotopes inseparable)
490	1	HG	G1·G2*	A-Pen	all (isotopes inseparable)
491	1	HG	G1·G2*	B-Pen	all (isotopes inseparable)
700	2	HG	G1*	A-Stop	Lighter Isotope (^{1}H or ^{3}He)
701	2	HG	G1*	A-Stop	Heavier Isotope (^{2}H or ^{4}He)
800	2	HG	G1*	B-Stop	Lighter Isotope (^{1}H or ^{3}He)
801	2	HG	G1*	B-Stop	Heavier Isotope (^{2}H or ^{4}He)
860	2	HG	G1·G2·G3*	A-Pen	all (isotopes inseparable)
861	2	HG	G1·G2·G3*	B-Pen	all (isotopes inseparable)
870	2	HG	G1·G2·G3	A-Pen	all (isotopes inseparable)
871	2	HG	G1·G2·G3	B-Pen	all (isotopes inseparable)
880	2	HG	G1*	A-Pen	all (isotopes inseparable)
881	2	HG	G1*	B-Pen	all (isotopes inseparable)
890	2	HG	G1·G2*	A-Pen	all (isotopes inseparable)
891	2	HG	G1·G2*	B-Pen	all (isotopes inseparable)

These programs ask for an "ascii control file name" which is an ascii file containing a table of points on the theoretical curves for each of the Z and A of interest. The format of each line is: EIN ΔE_1 ΔE_2 ΔE_3. The penetrating files are v1h2p.ein and v2h1p.ein and contain, in the following order, 27 lines for hydrogen A-penetrating (events coming from the A end of the detector), 27 lines for hydrogen B-penetrating, 27 lines for helium4 A-penetrating, and 27 lines helium4 B-penetrating. For A-stopping, the files are v1h2a.ein and v2h1a.ein and contain 27 lines each for ^{1}H, ^{2}H, ^{3}He, and ^{4}He. The B-stopping files are v1h2b.ein and v2h1b.ein and are in the same format as the A-stopping files.

These files were obtained with the program deltae.c which uses Rick Cook's spline fitting to energy loss curves from wrcspni.c. This requires knowing the thicknesses of all layers, including dead layers. Some work has been done on this (see Alan Cumming's Voyager notebooks), and I decided to use those derived thicknesses, which are noticeably different from detector to detector. The thicknesses include a factor of 1.026 which is approximately the average sec θ for incident particles.

		Thickness (μm)			
Label	Active	V1HET1	V1HET2	V2HET1	V2HET2
	no	50.00	50.00	50.00	50.00
A1	yes	150.30	150.70	146.20	151.50
A2	yes	149.30	149.70	142.30	150.20
C1	yes	3214.00	3040.00	3035.00	3168.00
	no	89.30	60.60	73.90	97.50
C2	yes	3594.00	3435.00	3109.00	3427.00
	no	157.00	176.50	149.80	142.70
C2	yes	3280.00	3177.00	2950.00	3427.00
C3	yes	3362.00	3301.00	3018.00	3309.00
	no	129.30	153.00	184.70	154.00
C3	yes	3362.00	3302.00	3018.00	3309.00
C4	yes	3000.00	3300.00	3000.00	3000.00
	no	155.95	153.90	152.87	176.60
C4	yes	3000.00	3000.00	3000.00	3000.00
	no	63.60	87.21	68.74	88.80
B2	yes	2246.00	2200.00	2200.00	2200.00
B1	yes	2238.00	2200.00	2200.00	2200.00
	no	87.20	60.53	88.24	76.60
	no	64.00	64.00	64.00	64.00

To first order, these thickness differences look the same as gain changes in the analog to digital conversion, but these differences affect the ranges of initial energy for which a particle stops in a detector, and have second order effects in the ΔE tracks. The second order effects were too small to be seen, so these thicknesses and their appropriate energy ranges were used throughout the procedure. It should be noted, however, that there may be systematic differences between the incoming energy and the calculated value on the order of a few percent.

However, using these thicknesses, and the standard gains from ecal#_lowz programs, gave a disagreement between the theoretical curve and the center of the distribution of events. This was corrected by using multiplicitive factors in the programs which modify the various ΔE_i so that they agree with the theoretical curves. These multiplicitive factors are input into the eincal programs in a gain file given as the required single argument to the programs. These gain files consist of three ascii numbers which are the gains for each of the three ΔE_i. These gains were obtained empirically by comparing ΔE_i vs. ΔE_j plots to the theoretical tracks. Figures 3 through 11 show the three ΔE_i vs. ΔE_j plots for each of the three modes with the theoretical tracks added in. These were generated with the programs eintesta, eintestb, and eintestp which read the ecal tapes and output the first 10000 events into three files, one for each ΔE_i vs. ΔE_j plot. The eintest programs also require a gain file as an argument, so the tracks match up unless the gains have shifted. The gain files are named v#gainaX.Y, v#gainbX.Y, and v#gainpX.Y where # is the spacecraft number (1 or 2) and X and Y are respectively the first and last CRS tapes for which these gains are appropriate (e.g. v1gainb1.31 is the V1 B-Stopping gain file for CRS tapes 1 through 31). The ΔE_i vs. ΔE_j plots for all tapes, and their matching theoretical tracks are in my file folders "HET A-Stopping H and He Final", "HET B-Stopping H and He Final", and "HET Penetrating H and He Final". If the gains are wrong by $\sim 2\%$ or less, the fluxes are different by only a few percent, and the gains obtained (by eyeball fit) can match the distribution to the theoretical tracks easily by less than 2%.

When a new ecal tape is ready, run the shell script gainbal#, where # is the voyager number. The gainbal scripts require one argument, the most recent gain file. The gainbal files are different in the different directories (astop, bstop, and pen), and so this step needs to be done 6 times (2 Voyagers $\times$ 3 modes). Two plots will be generated by each of these programs. These plots should be labelled with the CRS tape number and the gain file. They then have to be compared to the theorectical tracks by eye. If the theoretical tracks do not match up with the particles distributions, then the gains need to be changed. If the particles are higher (more Δ_E) than the theoretical tracks then the gains must be decreased, and vice versa. After setting up a new gain file, rerun gainbal to check the new gains.

Yet this was not always enough to get complete agreement. Although these gains successfully match the helium tracks, in some detectors the hydrogen tracks require a slightly different gain. I tried adjusting the thicknesses to see if the second-order effects from incorrect thicknesses could cause this problem, but it seems unlikely that the thicknesses are as far wrong (>25%) as are necessary to cause these 2% effects between hydrogen and helium. So I assume that this is caused by uncorrected non-linearities in the ADCs or shifts in the offsets of the ADCs. Ignoring the possible cause, the correction was empirically made in the input files to the eincal programs. Two of the theoretical ΔE_i had all of their hydrogen values decreased by hand by 2% to bring them into line with the event distributions: B1 in the file v1h2b.ein (B-Stopping), and B1 in the file v2h1b.ein (B-Stopping).

It should be noted that fragmentation taking place in the first detector is visible in the ΔE_3 vs. ΔE_2 plots. For Example, in Figure 4 you can clearly see the secondary deuterium and tritium which is not visible in Figure 3. These events will be spead out in the ΔE_1 coordinate and so will be off the theoretical track in the three dimensional space used in this analysis.

Since the exact analysis varied between the three different event modes, due to both program evolution and the tailoring of the programs to each of the modes, they will be treated separately in the following discussion of event discrimination and initial energy determination.

A Stopping

The program eincalas analyzes H, ^{2}H, ^{3}He, and ^{4}He for A-stopping events which penetrate as far as detector C1 (three-parameter events). In the analysis, $\Delta E_1 = \Delta E_{A1}$ (in MeV), $\Delta E_2 = \Delta E_{A2}$ (in MeV), and $\Delta E_3 = \Delta E_{C1+C2+C3}$ (in MeV). It first selects events by telescope (tel) number such that they are A-stopping: $300 \leq$ tel < 400 (HET 1) or $700 \leq$ tel < 800 (HET 2), and it also eliminates noise in low bins by requiring $\ln(\Delta E_1) > -2.3$, $\ln(\Delta E_2) > -2.3$, and $\ln(\Delta E_3) > 0$. Two-parameter events are eliminated by requiring that C1 triggers: ((tag & 04000) $\neq 0$). Since the hydrogen and helium tracks don't cross, the program does completely separate analyses of the two regions around the hydrogen and helium. Events with $0.2 < 0.58\times\ln(\Delta E_3) + \ln(\Delta E_2) < 2.4$ are possible hydrogen, and events with $0.58\times\ln(\Delta E_3) + \ln(\Delta E_2) \geq 2.4$ are possible helium. If $0.58\times\ln(\Delta E_3) + \ln(\Delta E_2) < 0.2$ then the events are background.

For the hydrogen section, three initial energies, E_i, are calculated from the table of E_i vs. ΔE_i read in from the input file Actually the table is stored in the program as $\ln(E_i)$ vs. $\ln(\Delta E_i)$) for the use of the cubic spline routine which does the interpolation.

Then the average initial energy, E_{avg} and the variance, σ_E^2, are calculated from:

$$E_{avg} = \sum_{i=1}^{3} \frac{E_i}{3} \qquad \sigma_E^2 = 1000 \times \sum_{i=1}^{3} \frac{(E_{avg} - E_i)^2}{E_{avg}^2}$$

E_{avg} is then used to calculate the $\Delta\epsilon_i$ from the inverse tables, ΔE_i vs. E_i, and the variance $\sigma_{\Delta E}^2$ is obtained from:

$$\sigma_{\Delta E}^2 = 1000 \times \sum_{i=1}^{3} \frac{(\ln(\Delta E_i) - \ln(\Delta\epsilon_i))^2}{E_{avg}^2}$$

The program uses $\ln(\Delta E_i)$ and $\ln(\Delta\epsilon_i)$ because that is what is returned by the interpolation subroutine. Figure 12 shows a plot of σ_E^2 vs. $\sigma_{\Delta E}^2$ in which it can be seen that the edge of the helium events is diagonal on the log-log plot. From this came the equation used for r which approximates the distance to the theoretical track: $r = 0.6 \times \ln(\sigma_{\Delta E}^2) + \ln(\sigma_E^2)$. Figure 13 shows the histograms of r for ^4He. For both hydrogen and helium the distance, r, is calculated independently for both isotopes. To be considered a good event, r must be less than the r obtained for the other isotope, and less than an empirically derived value, r_{max}, which is 4.0 for the hydrogen isotopes and 0.5 for the helium isotopes. Although Figure 13 appears to show that the cut of $r < 0.5$ is discriminating against good ^4He events, Figure 12 shows that this value is a reasonable cut, and indeed, to accept any events with larger r would prevent ^3He from being resolved. Good events are output with their correct Z value, and other events are assigned $Z = 0$. In Figures 14 through 19, the events plotted in Figures 3, 4, and 5 are separated into good events (Z, A, and EIN determined) and background.

B Stopping

For B-stopping events, the program eincalbs looks almost identical to eincalas. The values of cuts are changed, and in this case $\Delta E_1 = \Delta E_{B1}$, $\Delta E_2 = \Delta E_{B2}$, and $\Delta E_3 = \Delta E_{C2+C3+C4}$. If $4.6 \geq \ln(\Delta E_3) + 1.8\times\ln(\Delta E_2)$, or $\Delta E_i < 1$ MeV for any of the three detectors, the events are considered background. If $4.6 < \ln(\Delta E_3) + 1.8\times\ln(\Delta E_2) < 7.5$, the events are nominally hydrogen, otherwise they are nominally helium.

Again r is calculated by $r = 0.6\times\ln(\sigma_{\Delta E}^2) + \ln(\sigma_E^2)$ and the r_{max} is -5.0 for hydrogen and -8.0 for helium. Background events have been assigned $Z = 0$ as in A-Stopping. Figures 20 through 25 show the events of Figures 6, 7, and 8 separated into good events and background.

Penetrating

For several reasons the penetrating mode is much more difficult to analyze than either A-stopping or B-stopping. One problem is the bidirectional nature of this mode. At the lower energies, the slowing down of the particle is noticeable and so the direction of the event can be determined, but at higher energies the width of the track combines events from both the A side (particles which hit detector A1 first) and the B side (particles which hit B1 first). Also, for the penetrating mode the isotopes of both hydrogen and helium are indistinguishable, because the separation of the tracks is smaller than the width. Add to this the fact that the helium high-energy (minimum ionizing) particles blot out a noticeable portion of the hydrogen spectrum, and the penetrating procedure becomes much more difficult and complicated than either of the stopping modes. However, of the three, this is the one which was attempted first, and this is evident in the software. Several improvements could be made to the program eincalpen, and there are large sections of code which could be left out because they were not successful enough to allow the particles involved to be used. For example, calculations are made for particles which stop in the third detector, but this never worked very well, and the energy range (a few MeV) was small compared to the hundreds of MeV over which the analysis is sucessful for fully penetrating particles.

Penetrating high-gain events have tel numbers of 450 (HET 1) or 850 (HET 2), as given by the ecal program. The first thing that the eincalpen program does is to modify tel to include information about the guard conditions: tel=460 (860) is $G1 \cdot G2 \cdot \overline{G3}$, tel=470 (870) is $G1 \cdot G2 \cdot G3$, tel=480 (880) is $\overline{G1}$, and tel=490 (890) is $G1 \cdot \overline{G2}$. Then events with tels of 480, 490, 880, or 890 and with ($0.9 < \Delta E_1$ and $0.9 < \Delta E_2$) and ($\Delta E_1 < 18$ or $\Delta E_2 < 24$) are accepted and split into four regions of analysis, and several regions in which analysis is impossible (such as where the H and He tracks are mixed).

The region with (e1 > 6.0) and (e3 < 60.0) and ((9.091 × e1 − e3) > 18.182) contains the low energy (81 - 89 MeV) penetrating hydrogen coming from the A direction. If $\sigma^2_{\Delta E} < 0.02$ and $\sigma^2_E < 0.125$ then the particles are accepted.

The B direction low energy hydrogen region is (e2 > 8.0) and (e3 < 60.0) and ((6.071 × e2 − e3) > 12.143). Once again the variance cuts are $\sigma^2_{\Delta E} < 0.02$ and $\sigma^2_E < 0.125$.

The region in which $1.211 \times \ln(\Delta E_1) + \ln(\Delta E_2) > 3.44$ contains helium events with initial energy between about 80 MeV/n and 650 MeV/n. The EIN for the direction which gives the lowest value of the variance, $\sigma^2_{\Delta E}$, is assumed to be correct. This is acceptable because in the region where the A and B directions are indistiguishable the difference in EINs calculated for the two directions is smaller than the energy resolution. For the penetrating program, the two variances, σ^2_E and $\sigma^2_{\Delta E}$, are given by:

$$\sigma_E^2 = \sum_{i=1}^{3} \frac{(E_{avg} - E_i)^2}{E_{avg}^2} \qquad \sigma_{\Delta E}^2 = \sum_{i=1}^{3} \frac{(\Delta E_i - \Delta\epsilon_i)^2}{E_{avg} \times \Delta E_i}$$

which are slightly different from the stopping programs. Then, if 75 MeV/n $< E_{avg} <$ 650 MeV/n, and $\sigma_E^2 < 1$ and $\sigma_{\Delta E}^2 < 0.005$, the events are taken to be good helium.

The boundaries for high energy hydrogen events (called high energy because their intitial energies are above the energies for which minimum-ionizing helium mixes with the hydrogen track) are $0.759 < \ln(\Delta E_1) + 1.012 \times \ln(\Delta E_2) < 2.602$ and $\Delta E_3 < 23$. Although the variance σ_E^2 is calculated the same as for helium, $\sigma_{\Delta E}^2$ is now calculated as:

$$\sigma_{\Delta E}^2 = 1000 \times \sum_{i=1}^{3} \frac{(\Delta E_i - \Delta\epsilon_i)^2}{E^2}$$

with E being the minimum of E_{avg} or 375. This was done to prevent events having ridiculously high E_{avg} from having small $\sigma_{\Delta E}^2$. Acceptable high energy hydrogen events have 110 MeV < EIN < 375 MeV and $\sigma_E^2 < 1$ and $\sigma_{\Delta E}^2 < 0.30$. It was later determined that the energy range 110 MeV < EIN < 150 MeV suffers from too much helium contamination, and so these particles are left out of the flux calculations. Figures 26 to 31 show the particles selected and not selected from Figures 9, 10, and 11. Note that although the directional information is included in the tel number for every event (see table on page 5), it is only meaningful at the lower energies of the analysis, and only used in the 81 - 89 MeV hydrogen energy interval.

Flux Calculations

The three programs which calculate and plot the fluxes, fluxcala (AS), fluxcalb (BS), and fluxcalp (PEN), are mostly identical. They are run with the shell files runfluxa, runfluxb, and runfluxp which correctly pass the output to the plotter. The only important difference is which of the rates are used to calculated the flux. Since not all events of a given mode are pulse height analyzed, the number of events in a given energy bin has to be divided by a calculated livetime, not just the actual time. The formula for flux, F, (in particles/(m^2 sec sr MeV/nuc) is given by:

$$F = \frac{N \cdot \text{Rate}}{A\Omega \cdot \Delta E \cdot t \cdot \text{PHA}}$$

where N is the number of analyzed events in the energy bin ($E_{min} < E < E_{max}$), Rate is the total rate count for that mode as determined by a dead time free rate scalar, $A\Omega$ is the geometry factor (m^2 sr), ΔE is $E_{max} - E_{min}$ (MeV/nuc), t is the total time of detector operation (sec), and PHA is the PHA count for that mode. The major difference between the three programs is that each uses different values (locations) for Rate, t , and PHA. These values come from the chapter 48 rate summaries. If you assign the pointer value returned by doing a getvrs(1) on chapter 48 to a long (integer) pointer the offsets of the rate data are:

Mode Rate Label	A-Stopping AS		B-Stopping BSp		Penetrating PENH	
	HET 1	HET 2	HET 1	HET 2	HET 2	HET 2
Rate	41	83	47	89	51	93
t	42	84	48	90	52	94
PHA	361	368	364	371	367	374

These three programs plot each energy bin on a log-log plot of flux vs. energy/nuc, complete with statistical error bars in flux calculated from the number of particles in the bin, and error bars in energy which give the width of the bin.

The fluxcal programs read an input file with the following format:

NZ	The number of plots (one for each isotope)
Plot Title	| These twelve lines are repeated for each isotope
Z	| Charge
NBIN	| Number of energy bins
Z_{min} Z_{max}	| Charge range
$H1flag_1$ $\cdots$ $H1flag_{NBIN}$	| Flags for HET 1 (0 = don't use, 1 = use)
$H2flag_1$ $\cdots$ $H2flag_{NBIN}$	| Flags for HET 2 (0 = don't use, 1 = use)
$\Omega1_1$ $\cdots$ $\Omega1_{NBIN}$	| Geometry factors, HET 1 ($\times 10^5$)
$\Omega2_1$ $\cdots$ $\Omega2_{NBIN}$	| Geometry factors, HET 2 ($\times 10^5$)
$Emin_1$ $\cdots$ $Emin_{NBIN}$	| Minimum energy for energy bins
$Emax_1$ $\cdots$ $Emax_{NBIN}$	| Maximum energy for energy bins
NTEL	| Number of acceptable telescope values
Tel_1 $\cdots$ Tel_{NTEL}	| Acceptable telescope values
...	Repeat NZ times

The geometry factors used are calculated for particles which stop in the center of the range of stopping locations for that energy bin. In calculating these geometry factors, the areas of the detectors are multiplied by a factor, 0.94, to allow for the fact that 6% of the area of the detectors, at the edge, gives an incorrect value of of ΔE due to edge effects.

These programs also ask for the number of time periods to be used and the beginning and end of these time period given as volume numbers. This allows the removal of time periods in which rate spikes appear, which would invalidate the calculation of the fluxes. Figure 32 shows what the output of these programs looks like, in this case fluxcalp (PEN) for Voyager 1 helium. Figure 33 is the associated dump of all the values. In order to make it easier to get plots with all modes included (AS, BS, and PEN), the programs also output files which contain five values for each energy bin: the flux, and the endpoints of the error bars. One of these files is generated for each Z, and these files can be combined to give an overall plot with the program allflux. The files have names such as v1has.h.87a, v2hbs.he4.86c, and v2hpn.he3.85g depending upon Voyager, mode, Z, A, and time period.

There is a program allflux.c which is run by the shell file, runallflux, which combines the output files from the fluxcal programs onto one plot. It can combine up to 11 files, using a different plot character for each file. It first asks for a spacecraft number (0 means both) and a title for the plot. Then it requests the number of time periods of interest, and beginning and end volume numbers for each interval. It never actually uses these values, it just writes them to the plot so this information is not lost. Then it asks for the number of files to be combined and the names of each file. Figures 34 and 35 show the output for this program.

Conclusion

Although the programs work well as they stand now, there are still quite a few improvements which could be made. The program eincalpen was done first and so lacks some of the refinements of the later programs. Its selection cuts should be made diagonal in σ_E^2 and $\sigma_{\Delta E}^2$ like the A-stopping and B-stopping programs. Also, because of the large number of events in penetrating mode, the energy bins used in the fluxcalp program have been made quite small, smaller, in fact, than the actual energy resolution possible from the width of the the distribution, so that the energy resolution which appears on the plots is misleading.

All three programs still suffer from some common faults. The normalization of the variances is slightly different from mode to mode, and it is not exactly correct in any of them. They should be normalized by the width of their distribution, which is a function of energy. The normalization used only approximates these widths. Also, the calculation of E_{avg} should probably be a weighted mean (weighted by the slope of the EIN vs. ΔE curve, and the width of the distribution). The detector thicknesses and PHA gains are also still in question.

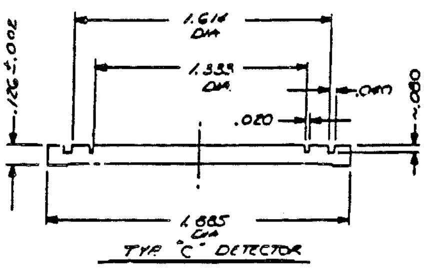
Yet all of these problems are at the couple of percent level or less and the programs still appear to work quite well, and so these problems have been left for future work. For more information on this work, there is a file folder titled "Determination of Z, A, and Initial Energy from Voyager HET Events" which contains copies of all programs, and their input and output files. There are also many other file folders filled with intermediate steps and test output. These can usually be referenced by the descriptions in my Voyager lab notebooks volumes I and II.

Figure 1 Cross-Section of HET

PHA Readout :

HET

Sum	AS	BS	P
A1 + LA3 + LB3	PHA3		
C2 + C3 + C4		PHA3	PHA3
A2 + B2	PHA2	PHA2	
C1 + LA2 + LB2			PHA2
C1 + C2 + C3	PHA1		
B1 + LA1 + LB1		PHA1	PHA1



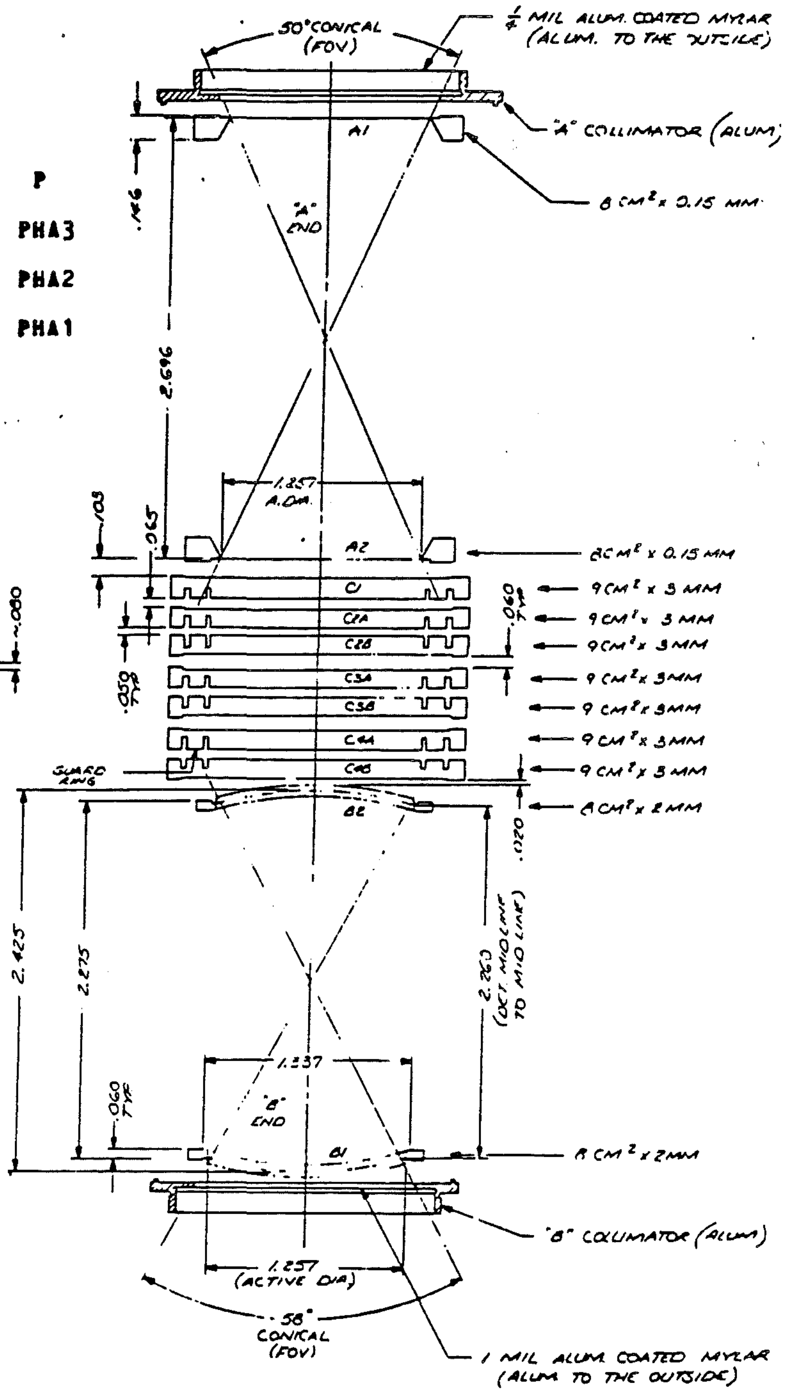
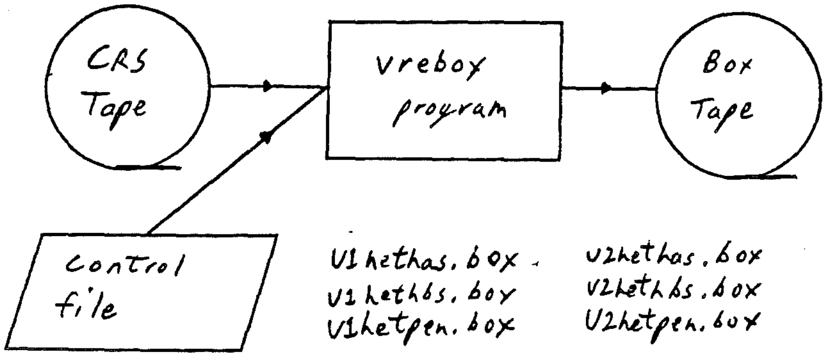
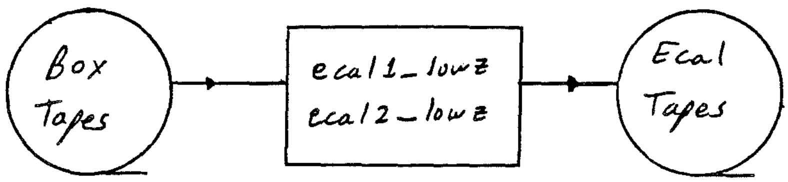


Figure 2 — Z, A, and Initial Energy Determination



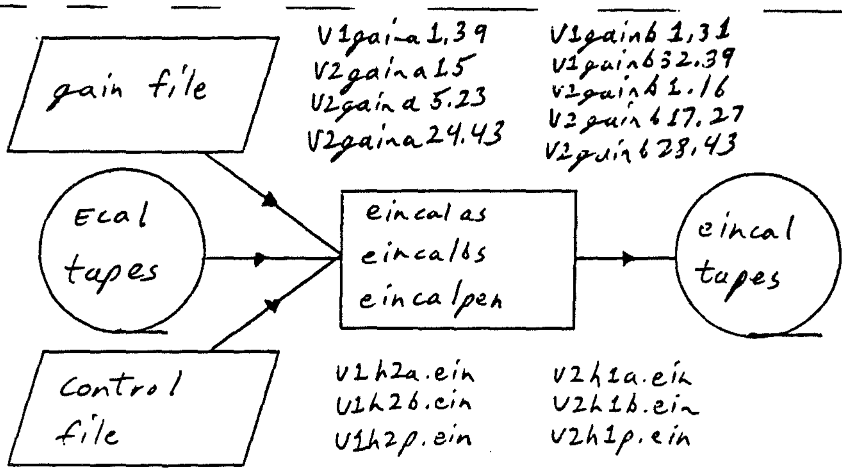
Vrebox selects events

All chapters stay the same



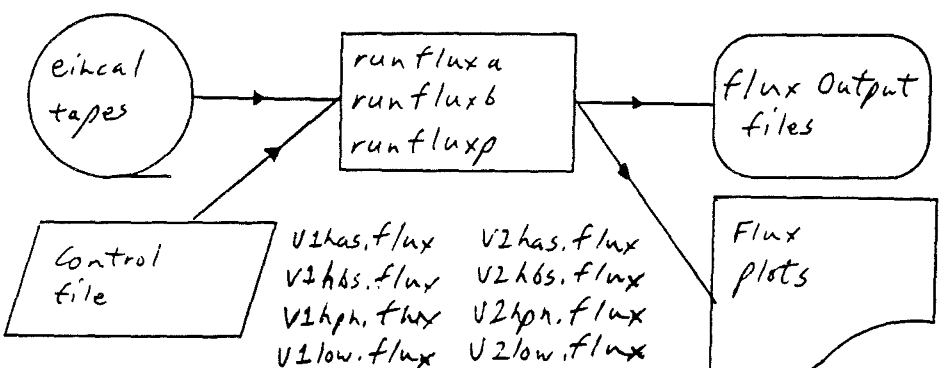
ecal converts PHA to MeV

Chapter 47 → Chapter 41



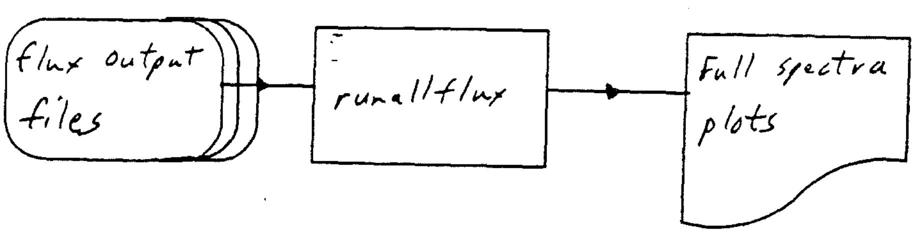
eincal calculates Z, A, and Initial Energy

Chapter 41 → Chapter 39



fluxcal calculates & plot fluxes

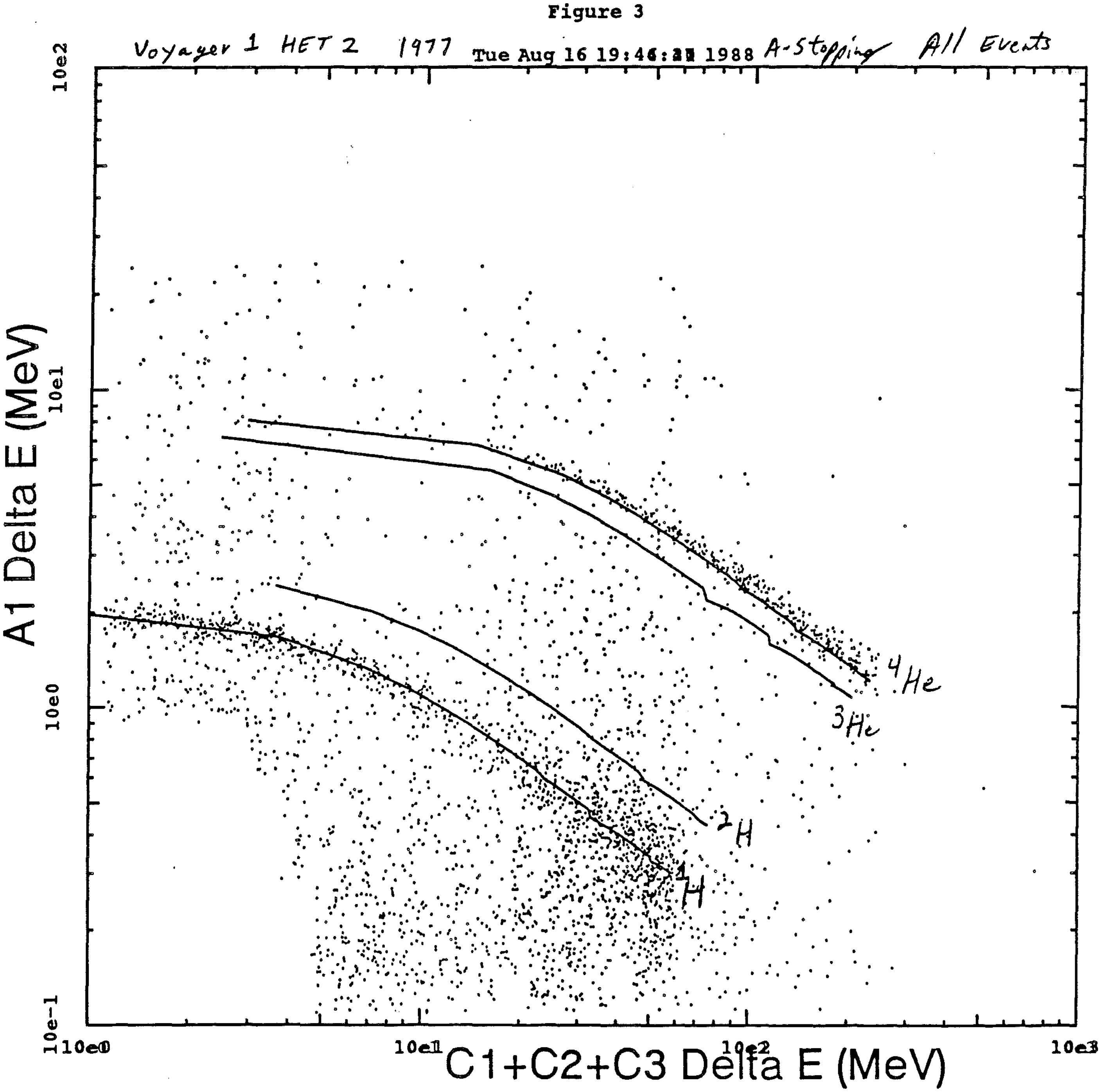
runflux sends output to plotter (Imagen)



allflux combines flux output files

runallflux sends output to plotter (Imagen)

Figure 3



Voyager 1 HET 2 1977 Tue Aug 16 1988 A-Stopping All Events
10e2
10e1
10e0
10e-1
A1 Delta E (MeV)
10e0
10e1
10e2
10e3
C1+C2+C3 Delta E (MeV)
4He
3He
2H
1H

Figure 4

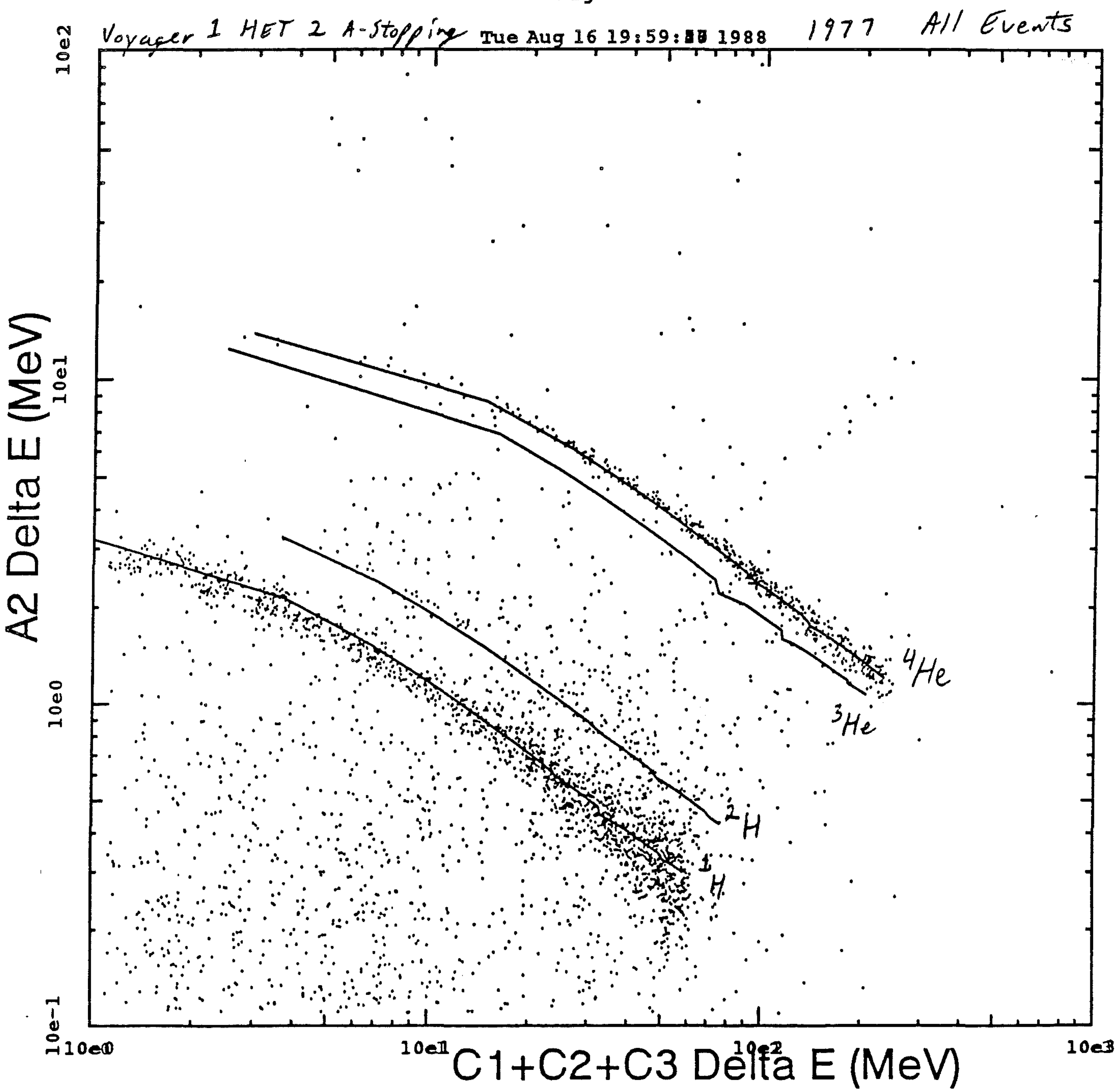

Voyager 1 HET 2 A-Stopping Tue Aug 16 19:59:33 1988 1977 All Events
A2 Delta E (MeV)
C1+C2+C3 Delta E (MeV)
10e-1
10e0
10e1
10e2
10e3
4He
3He
2H
1H

Figure 5

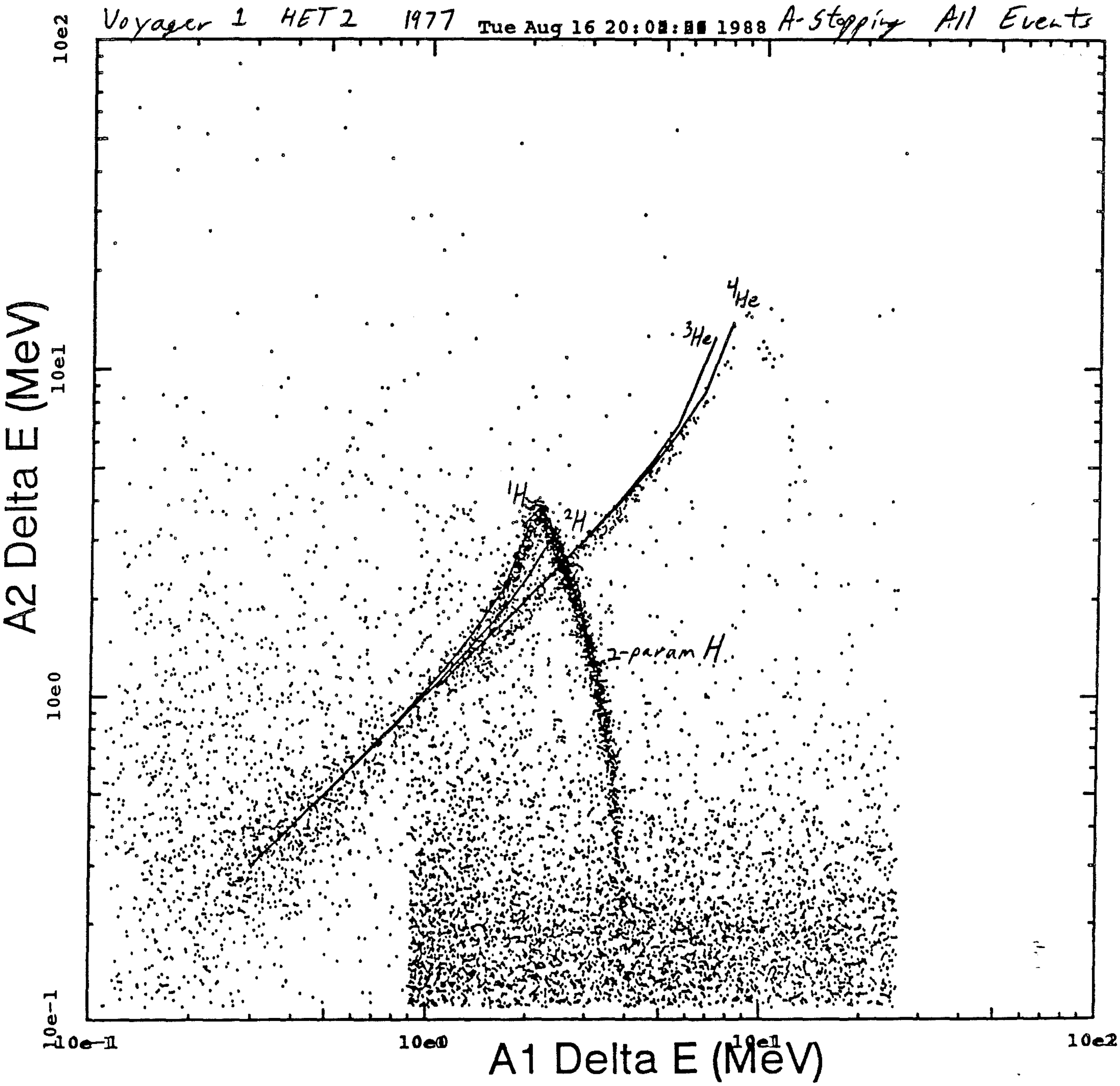

Voyager 1 HET 2 1977
A-Stopping All Events
A2 Delta E (MeV)
A1 Delta E (MeV)
10e-1
10e0
10e1
10e2
4He
3He
1H
2H
2-param H

Figure 6

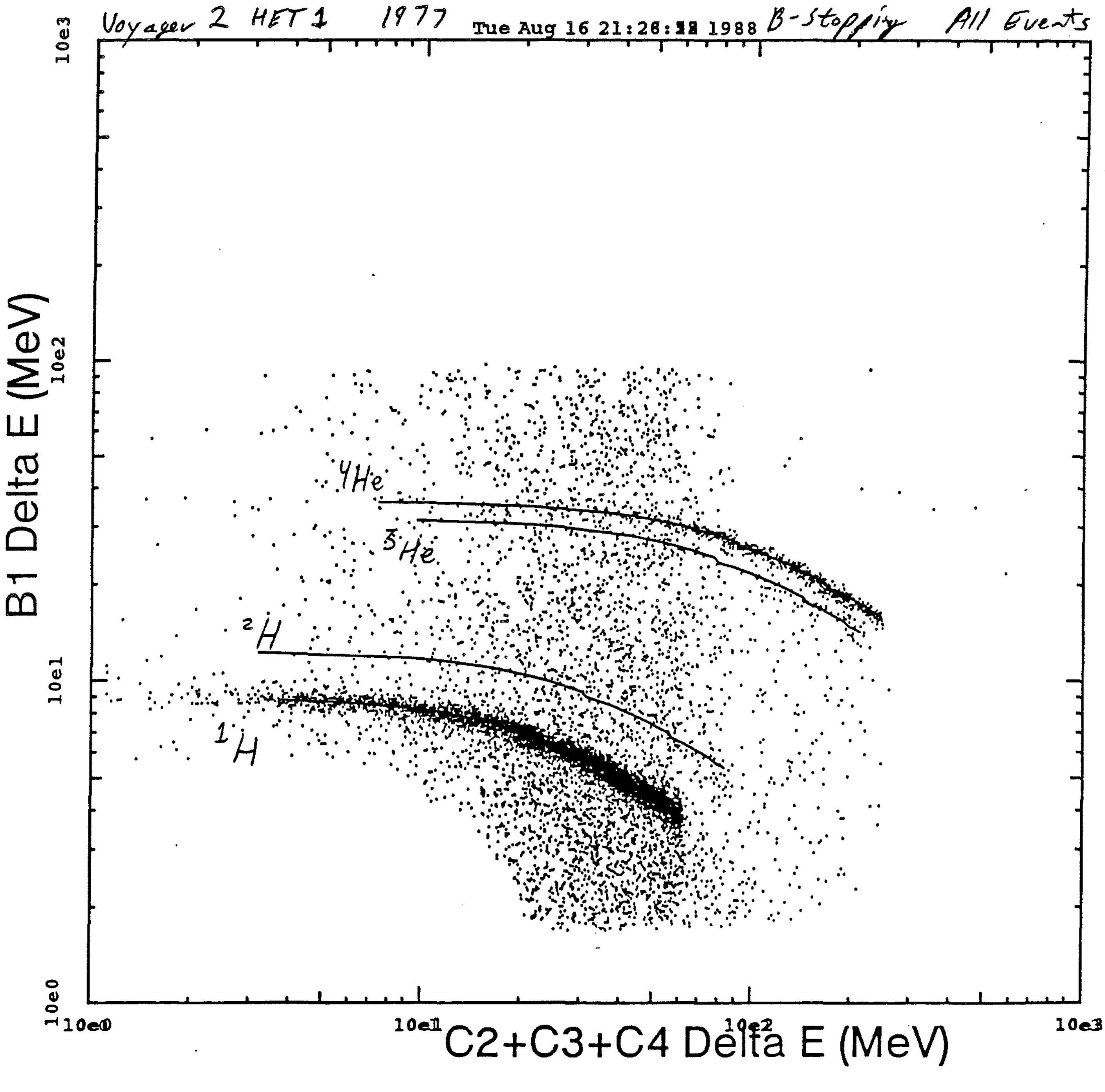
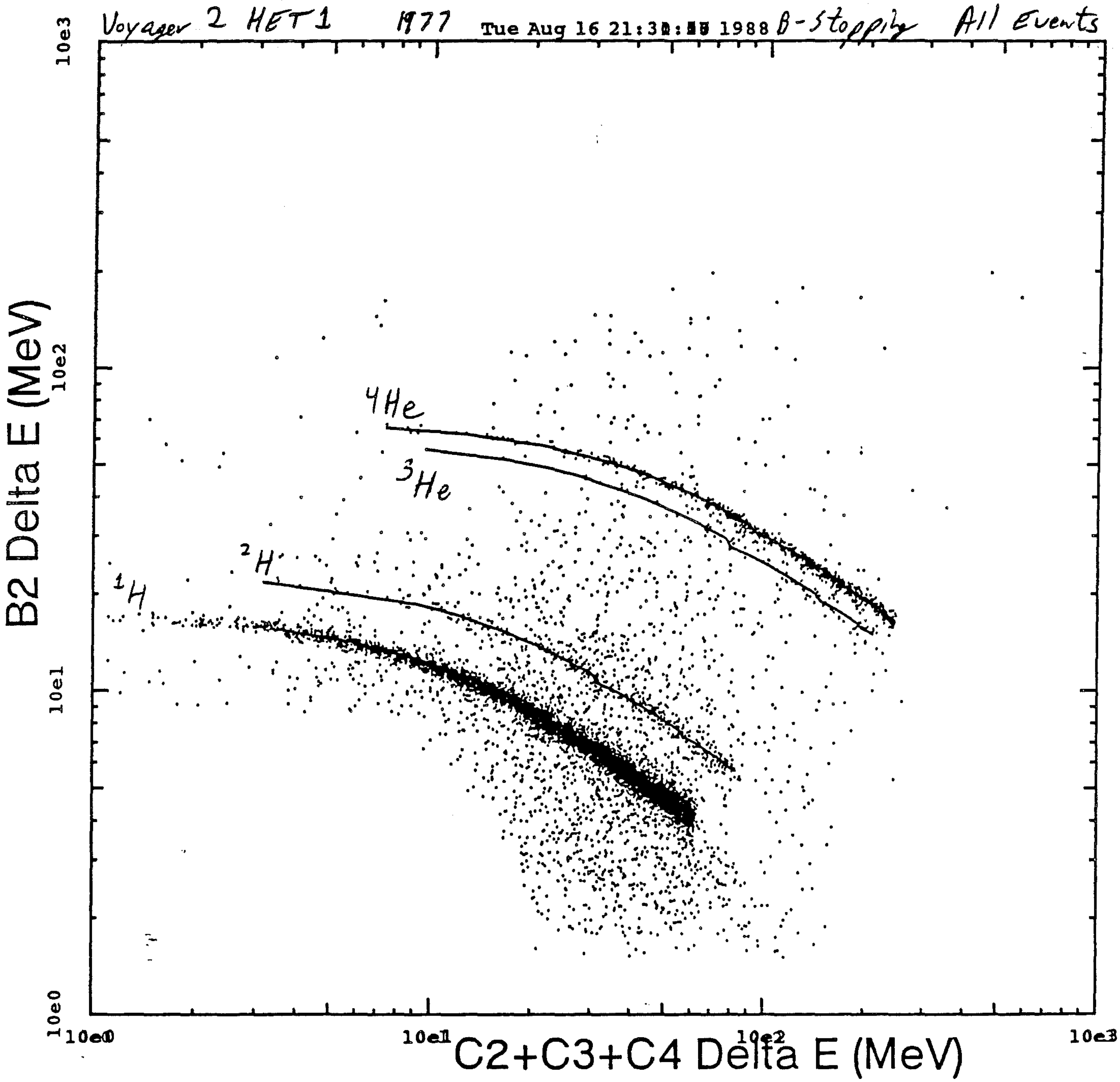

Voyager 2 HET 1 1977
Tue Aug 16 21:26:12 1988
B-Stopping All Events
B1 Delta E (MeV)
C2+C3+C4 Delta E (MeV)
10e0
10e1
10e2
10e3
4He
3He
2H
1H

Figure 7



Voyager 2 HET 1
1977
Tue Aug 16 1988
B-Stopping
All Events
4He
3He
2H
1H
B2 Delta E (MeV)
C2+C3+C4 Delta E (MeV)
10e0
10e1
10e2
10e3

Figure 8

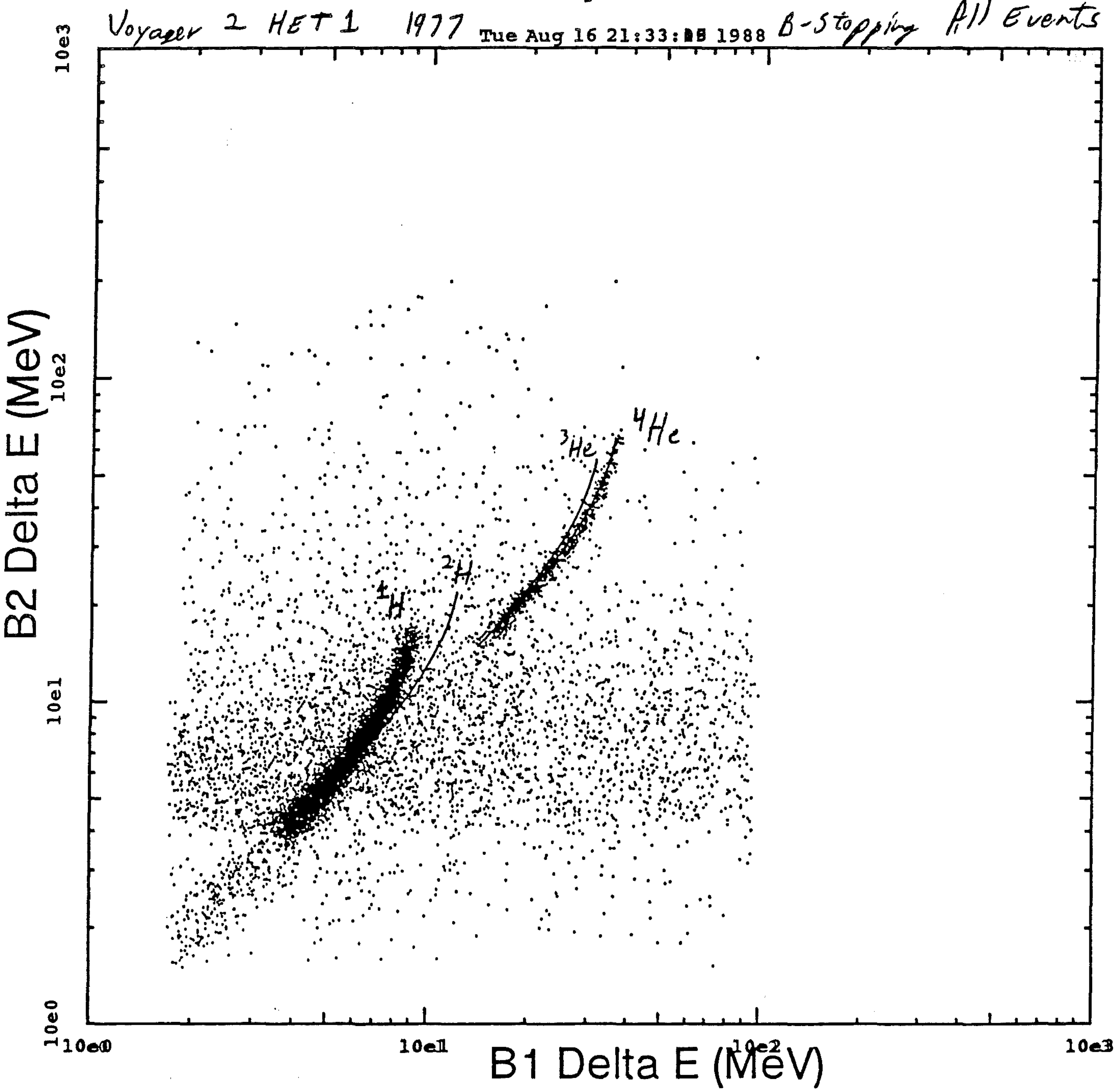
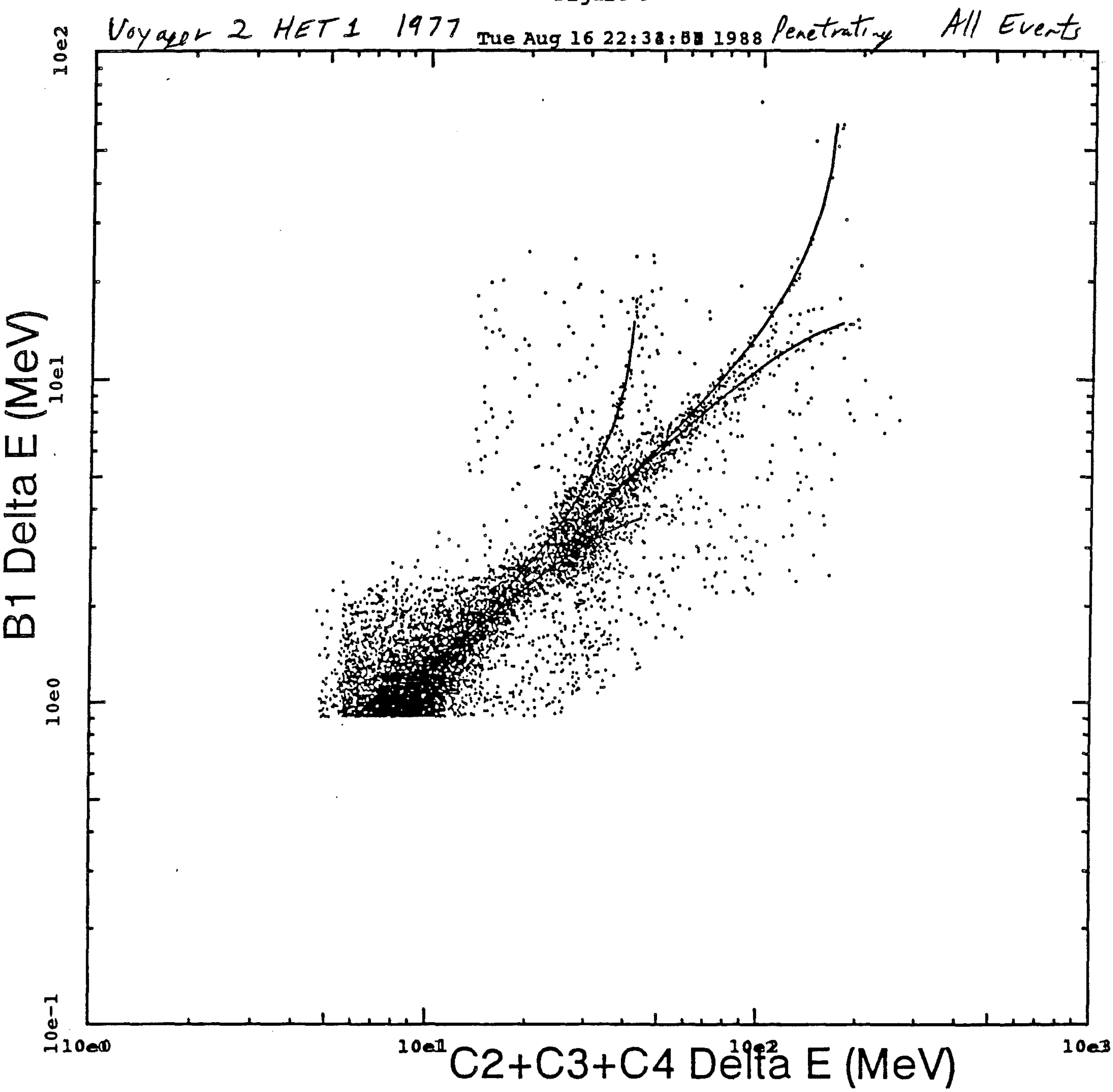
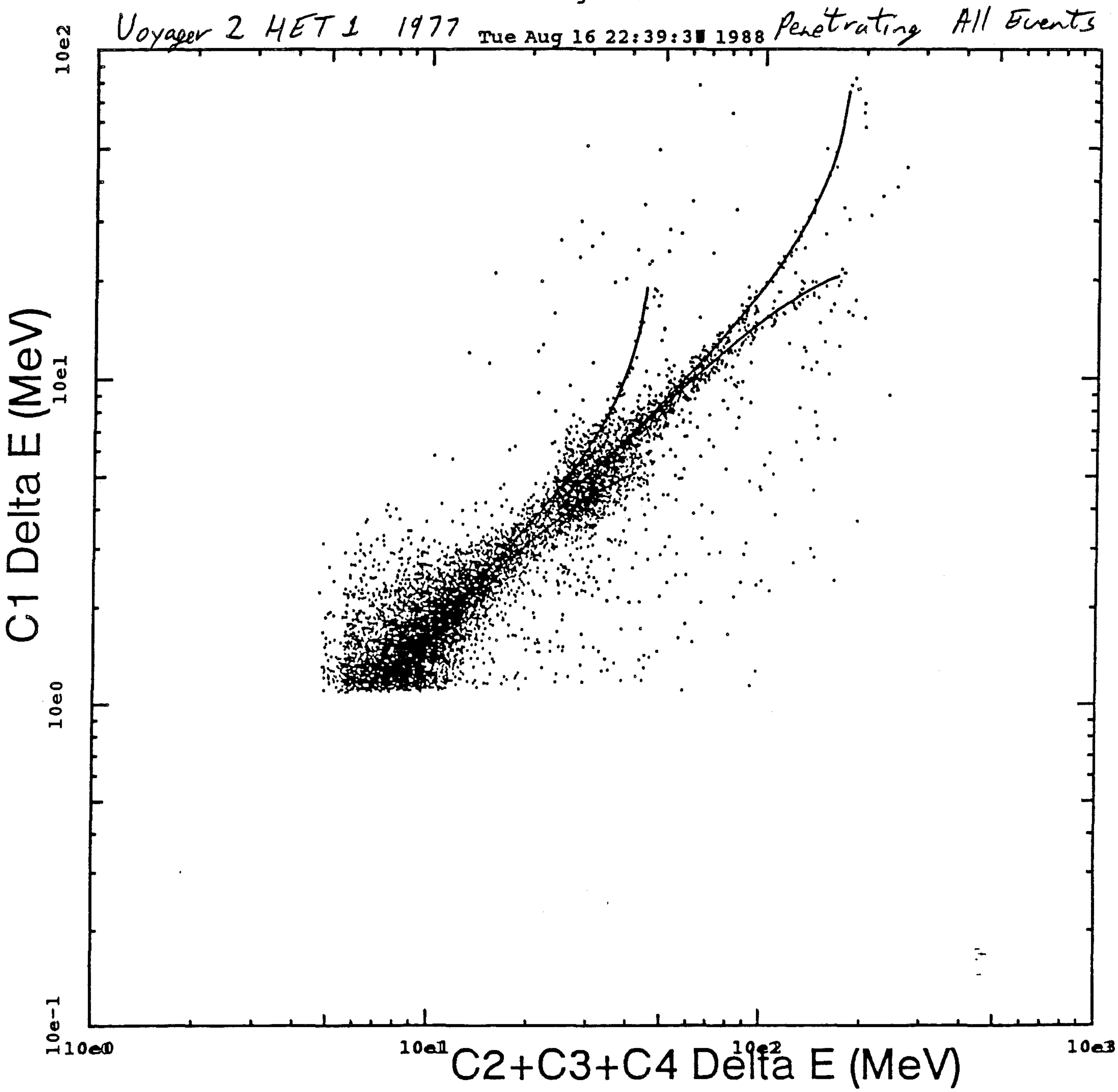

Voyager 2 HET 1 1977
B-Stopping All Events
B2 Delta E (MeV)
B1 Delta E (MeV)
10e0
10e1
10e2
10e3
1H
2H
3He
4He

Figure 9



Voyager 2 HET 1 1977
Tue Aug 16 22:38:58 1988
Penetrating
All Events
B1 Delta E (MeV)
10e2
10e1
10e0
10e-1
10e0
10e1
10e2
10e3
C2+C3+C4 Delta E (MeV)

Figure 10


Voyager 2 HET 1 1977
Tue Aug 16 22:39:3▮ 1988
Penetrating All Events
10e2
10e1
10e0
10e-1
C1 Delta E (MeV)
10e0
10e1
10e2
10e3
C2+C3+C4 Delta E (MeV)

Wed Aug 17 13:02:18 1988
File: eincalas.out2

Figure 12 Voyager 2 HET 1 A-Stopping 1977 He4

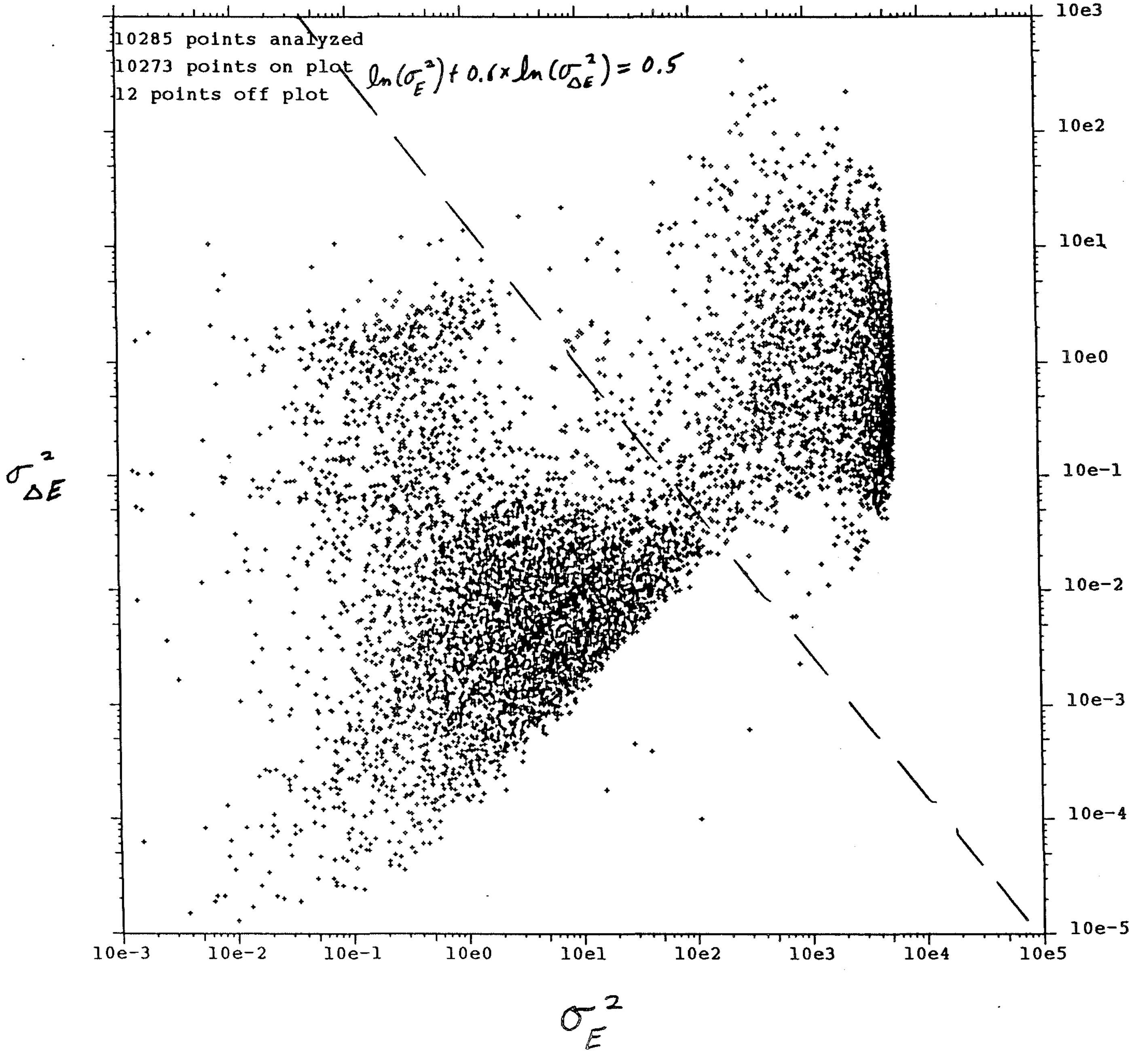


Figure 13   Voyager 2 HET 1   A-Stopping   1977   He4

Wed Aug 17 13:07:30 1988
File: eincalas.out3

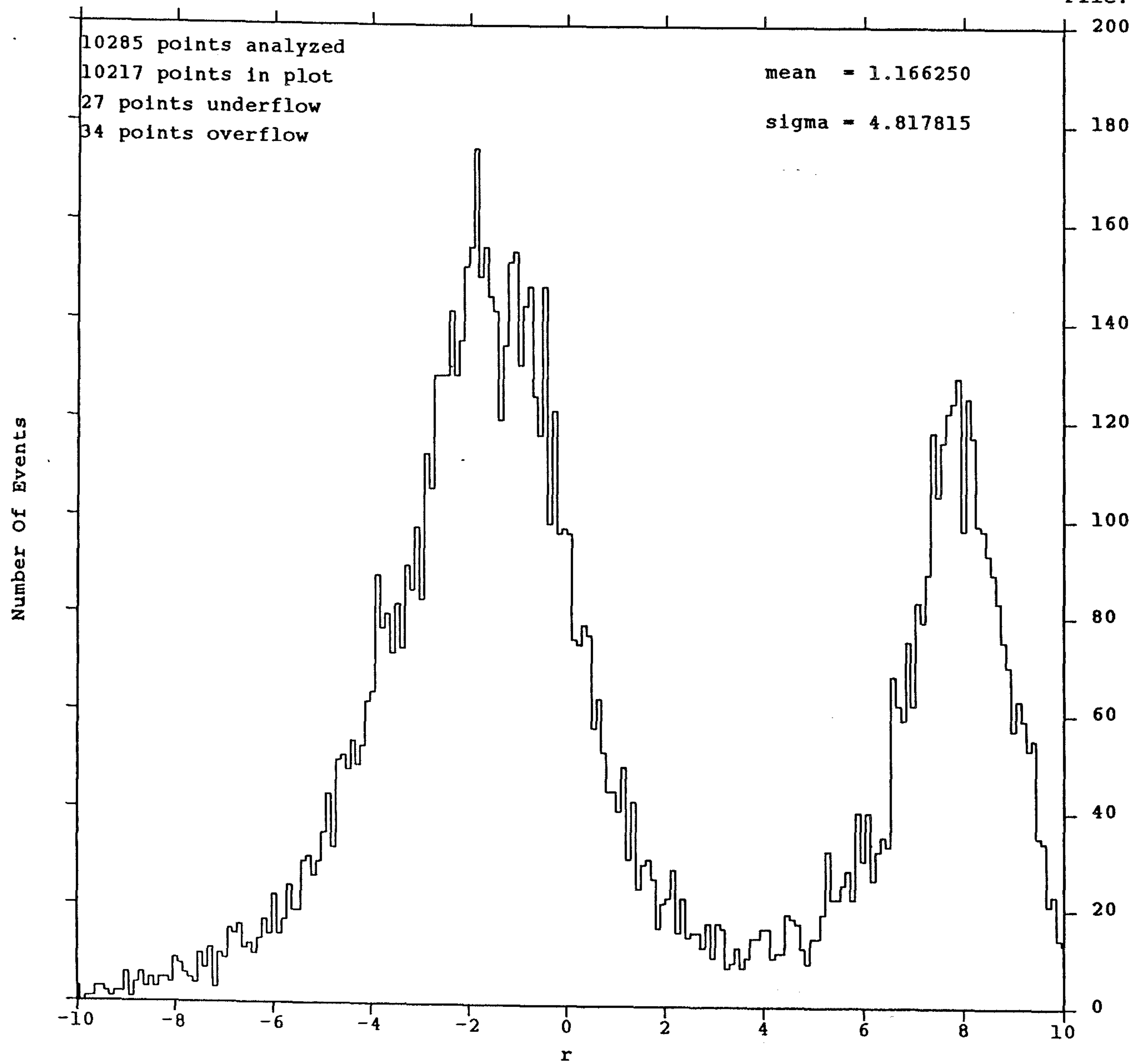


Figure 14 Voyager 1 HET 2 A-Stopping 1977 Bad Events

Tue Aug 16 10:32:42 1988
File: eincalas.out6

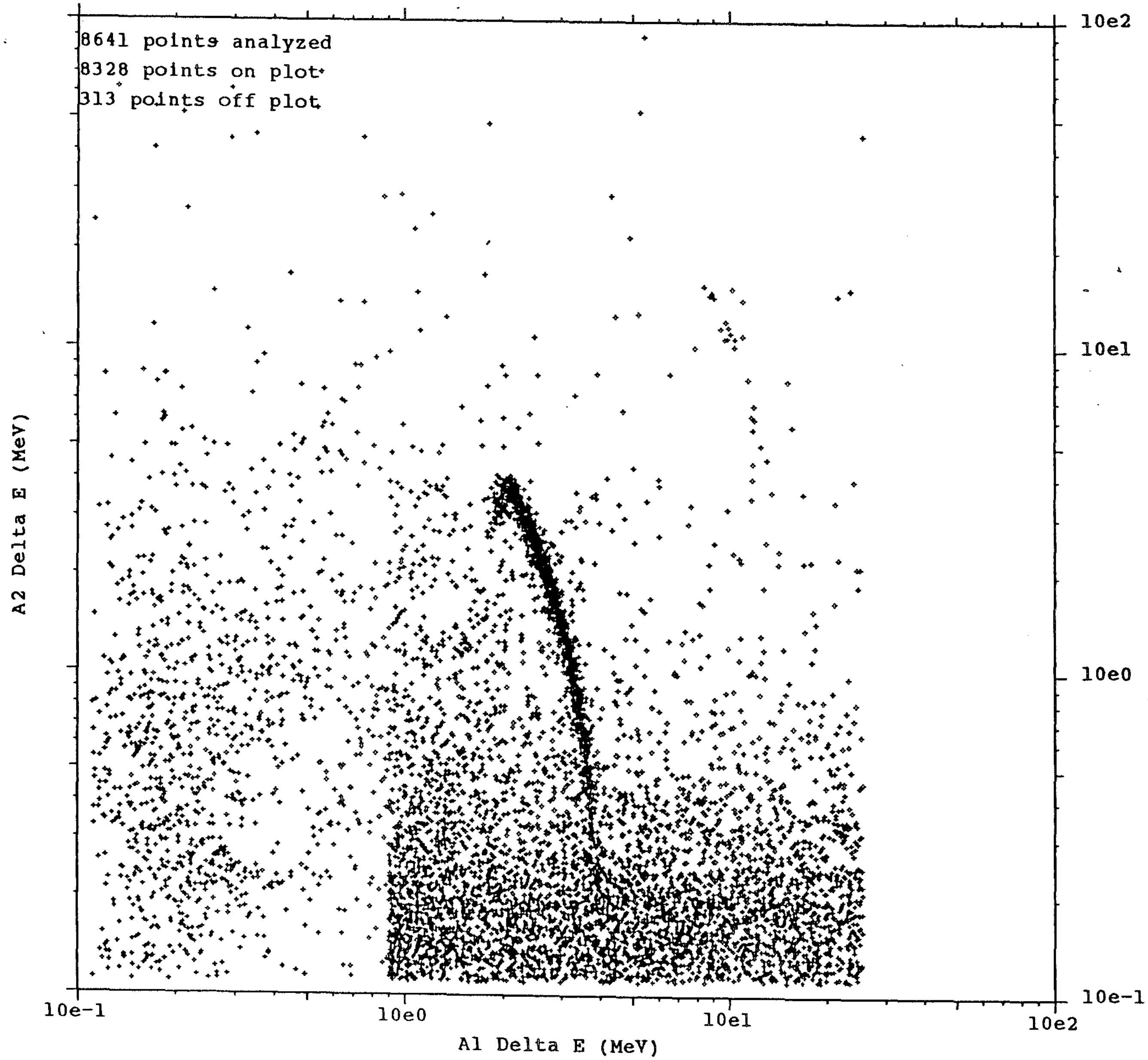


Figure 15 Voyager 1 HET 2 A-Stopping 1977 Bad Events

Tue Aug 16 10:31:32 1988
File: eincalas.out4

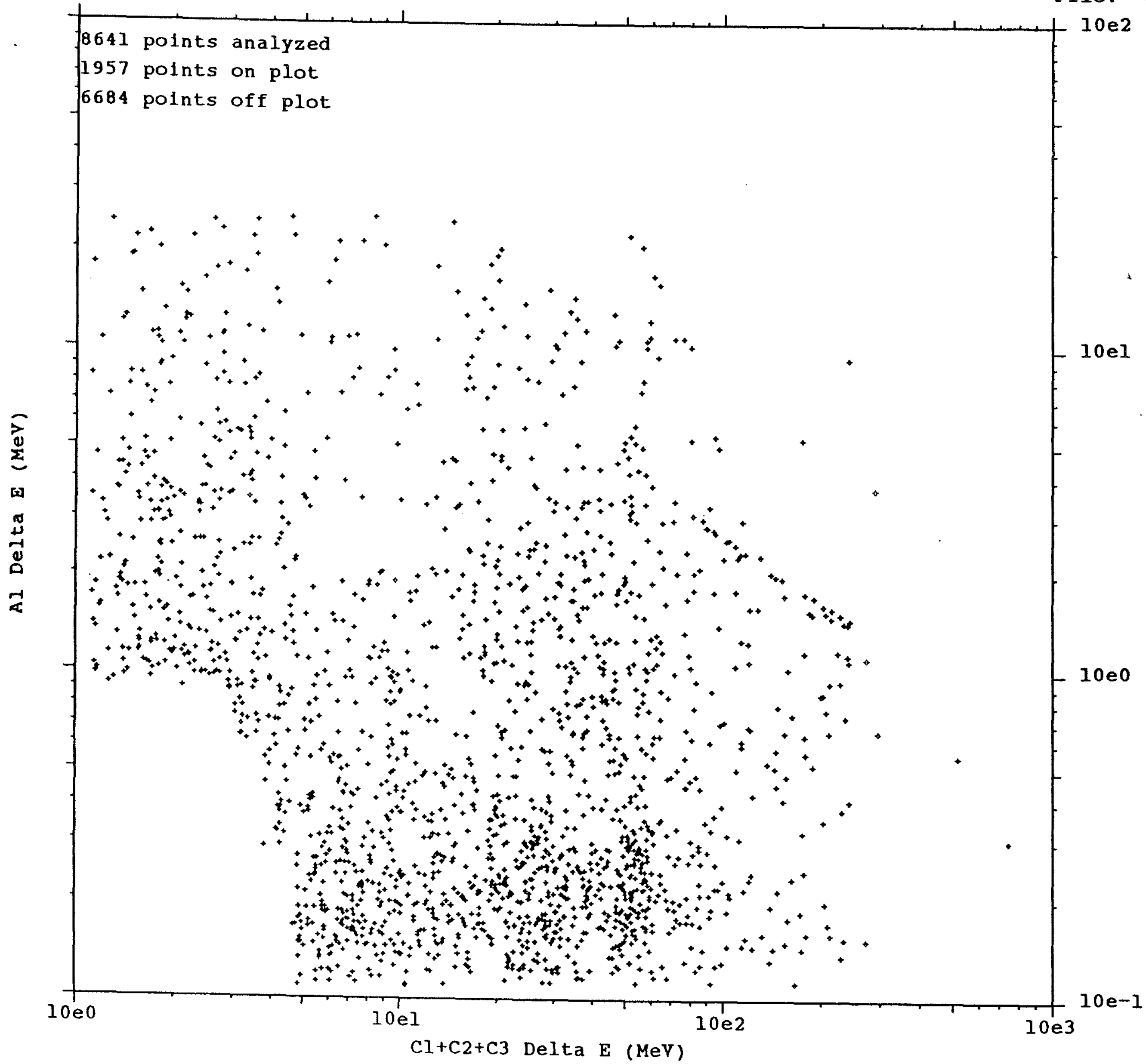


Figure 16 Voyager 1 HET 2 A-Stopping 1977 Bad Events

Tue Aug 16 10:32:04 1988
File: eincalas.out5

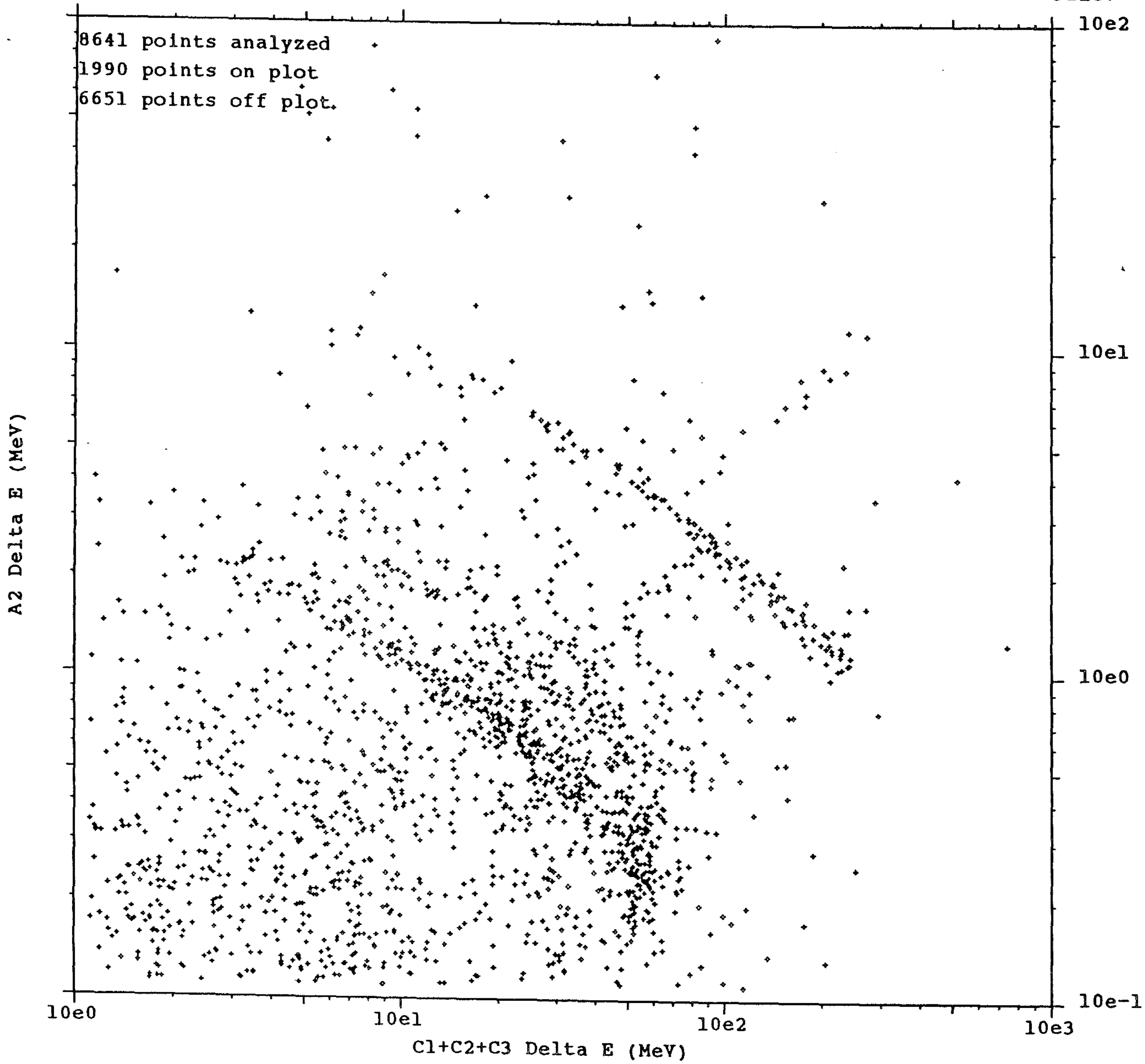
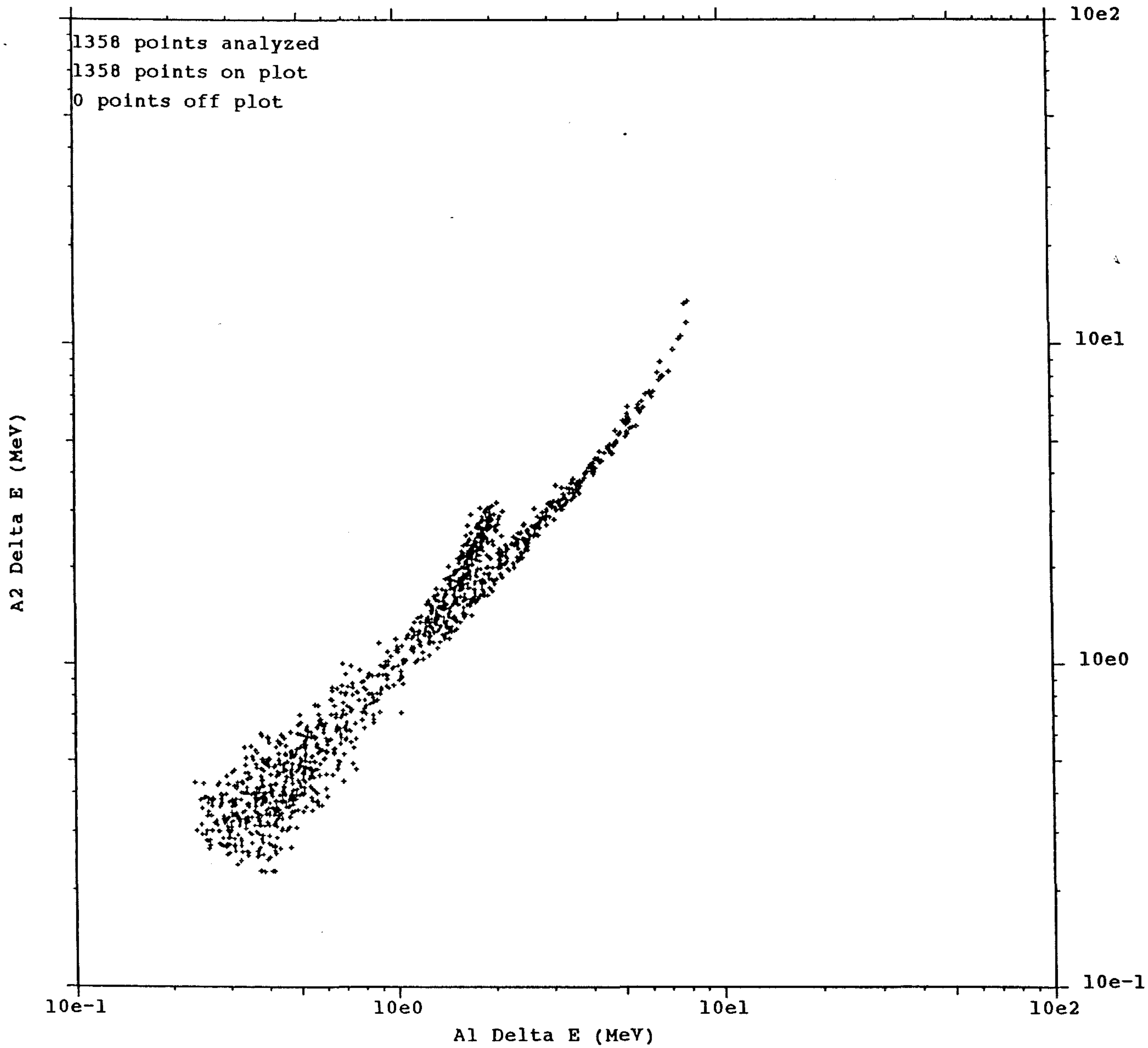


Figure 17 Voyager 1 HET 2 A-Stopping 1977 Good Events

Tue Aug 16 10:37:45 1988
File: eincalas.out9



Tue Aug 16 10:37:16 1988
File: eincalas.out7

Figure 18 Voyager 1 HET 2 A-Stopping 1977 Good Events

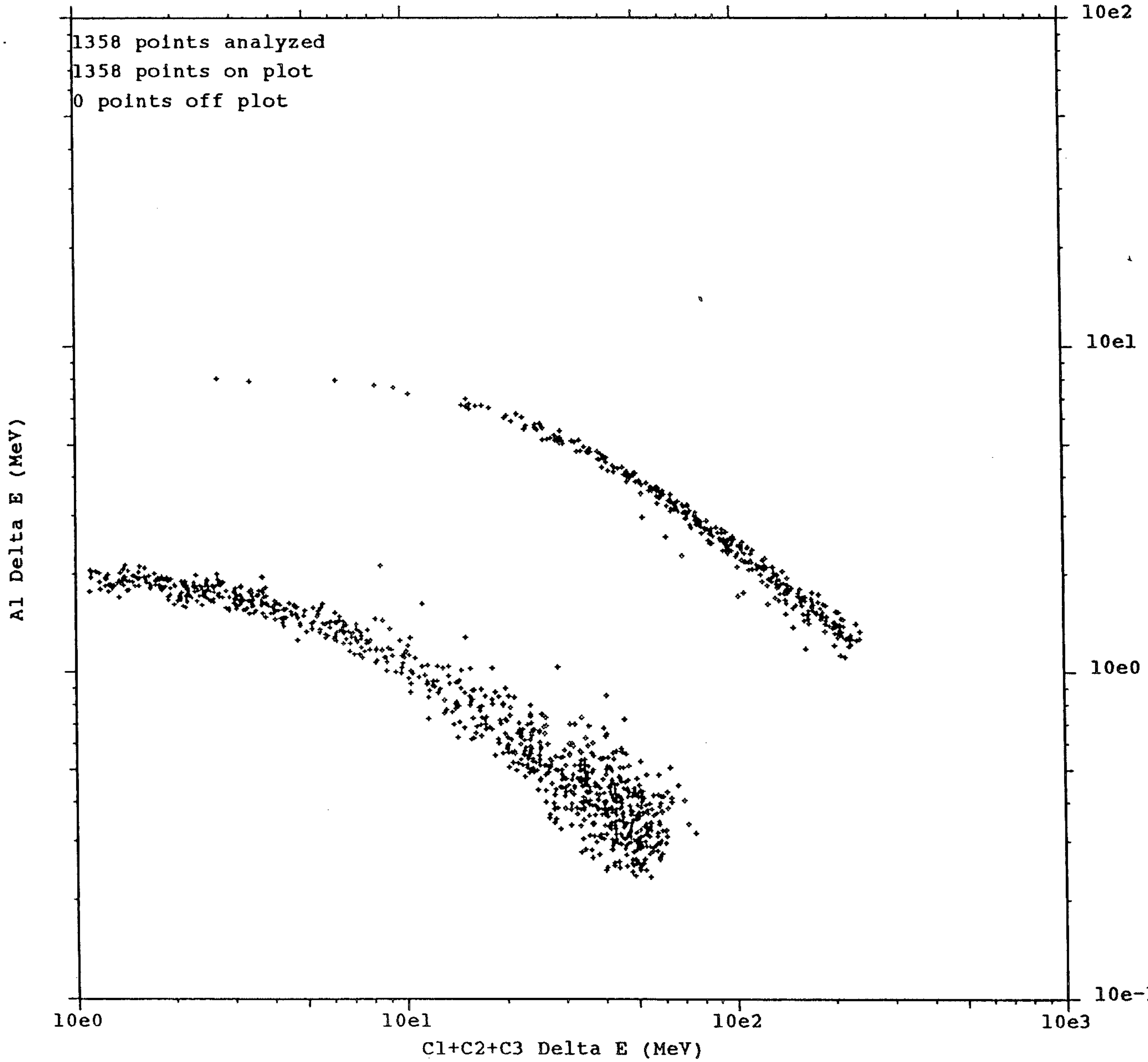


Figure 19 Voyager 1 HET 2 A-Stopping 1977 Good Events

Tue Aug 16 10:37:27 1988
File: eincalas.out8

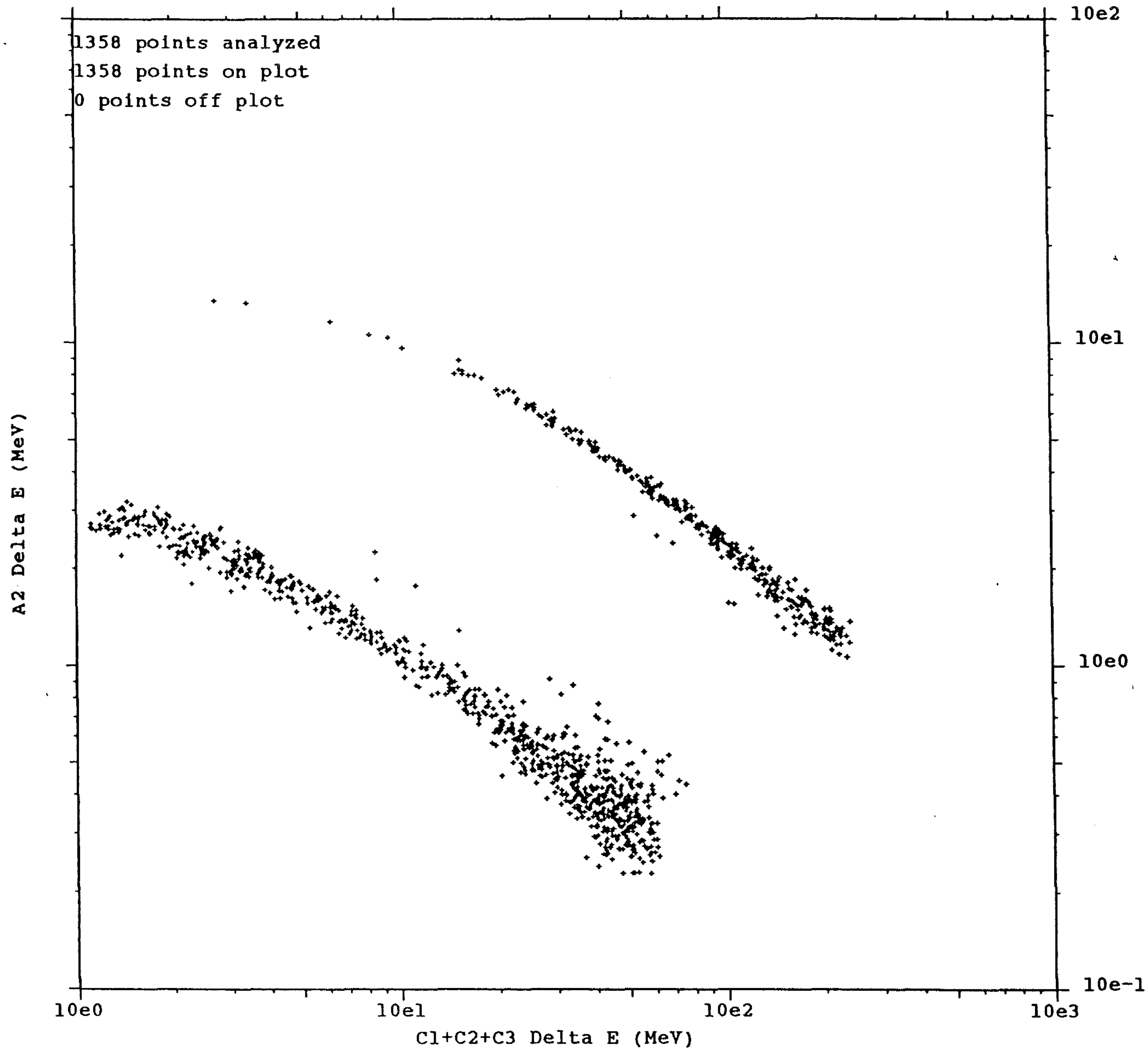
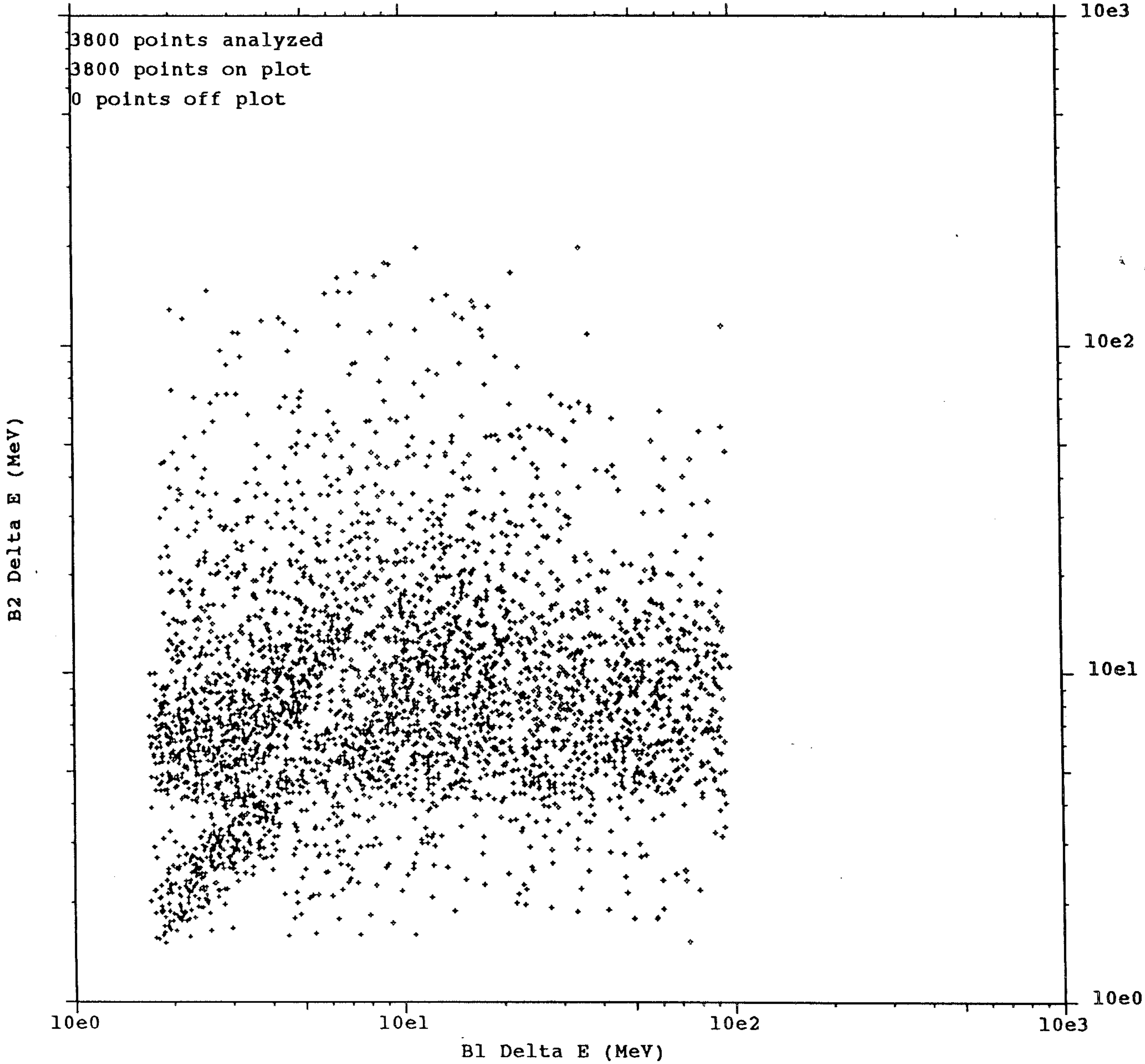


Figure 20 Voyager 2 HET 1 B-Stopping 1977 Background Events

Tue Aug 16 21:15:42 1988
File: eincalbs.out6



Tue Aug 16 21:13:18 1988
File: eincalbs.out4

Figure 21 Voyager 2 HET 1 B-Stopping 1977 Background events

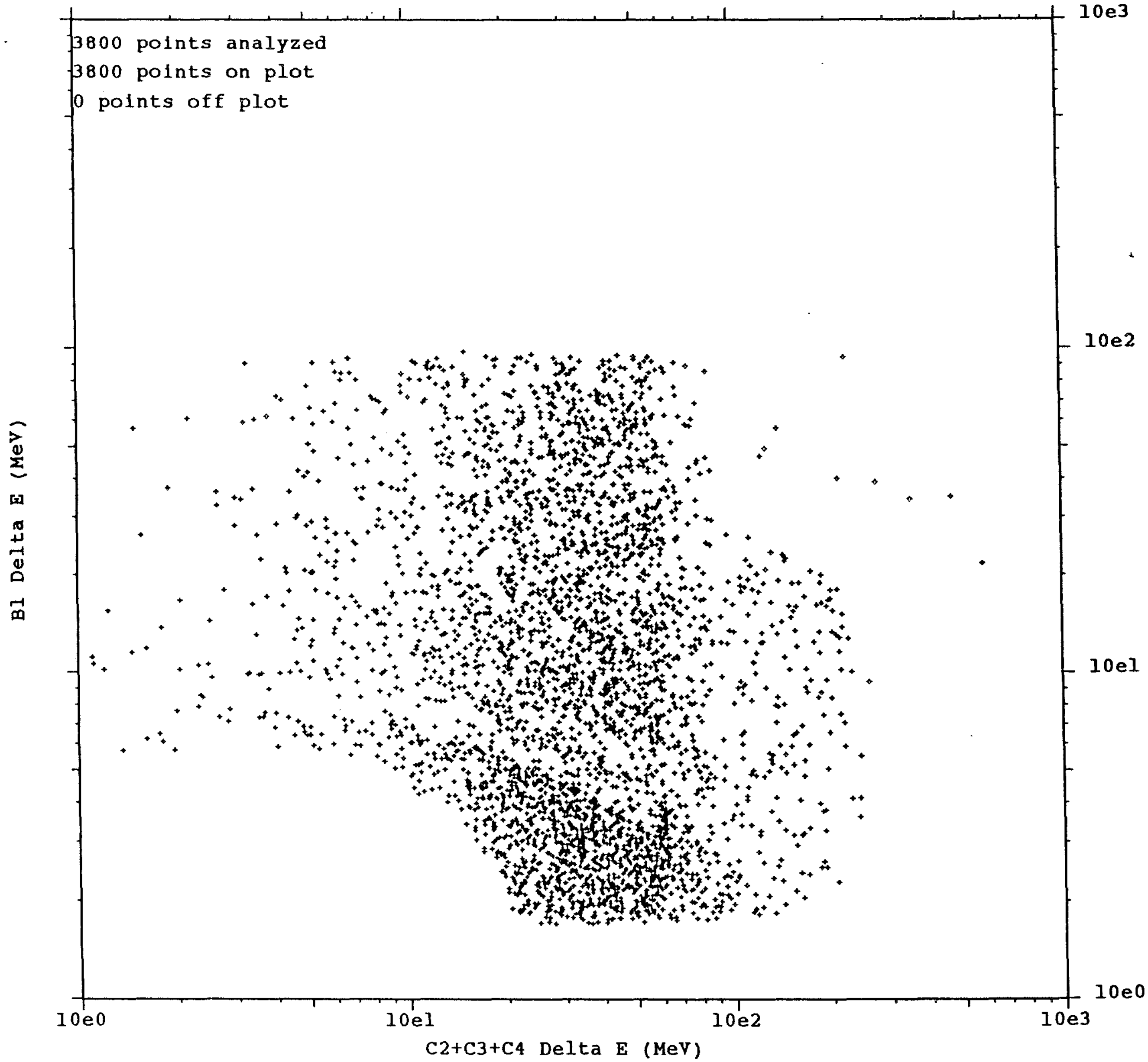


Figure 22 Voyager 2 HET 1 B-Stopping 1977 Background Events

Tue Aug 16 21:14:40 1988
File: eincalbs.out5

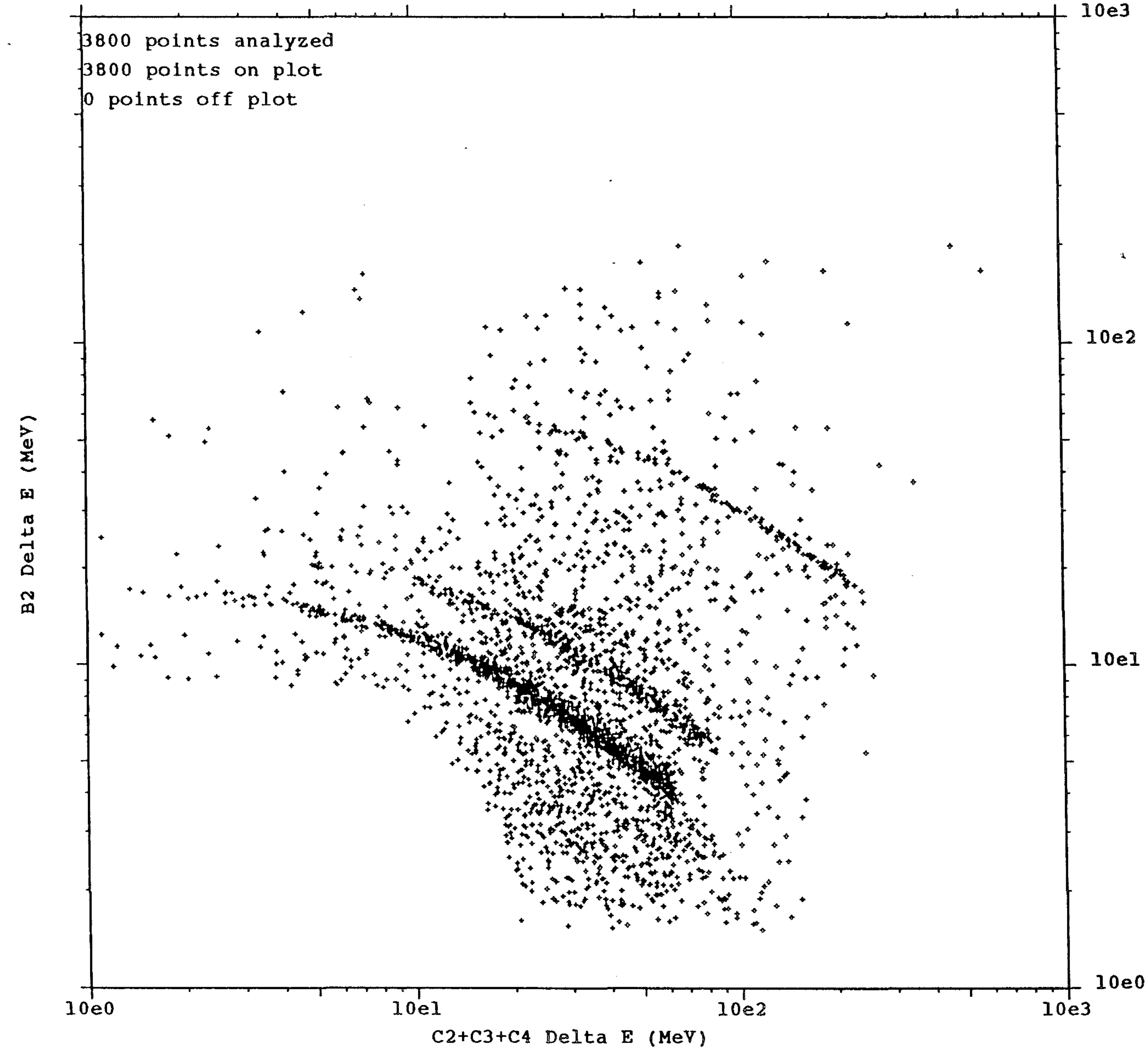


Figure 23 Voyager 2 HET 1 B-Stopping 1977 Good Events

Tue Aug 16 21:18:39 1988
File: eincalbs.out9

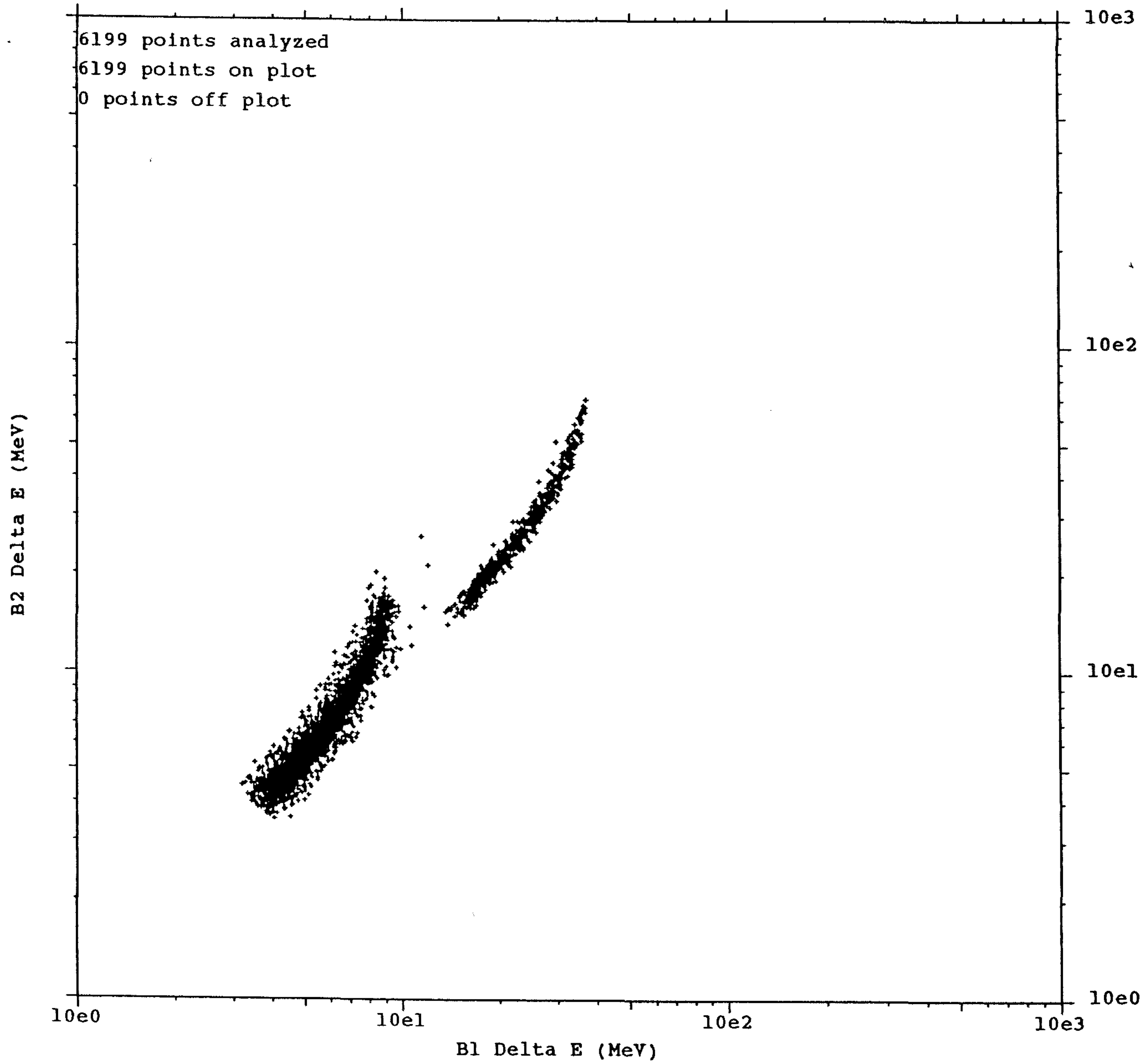
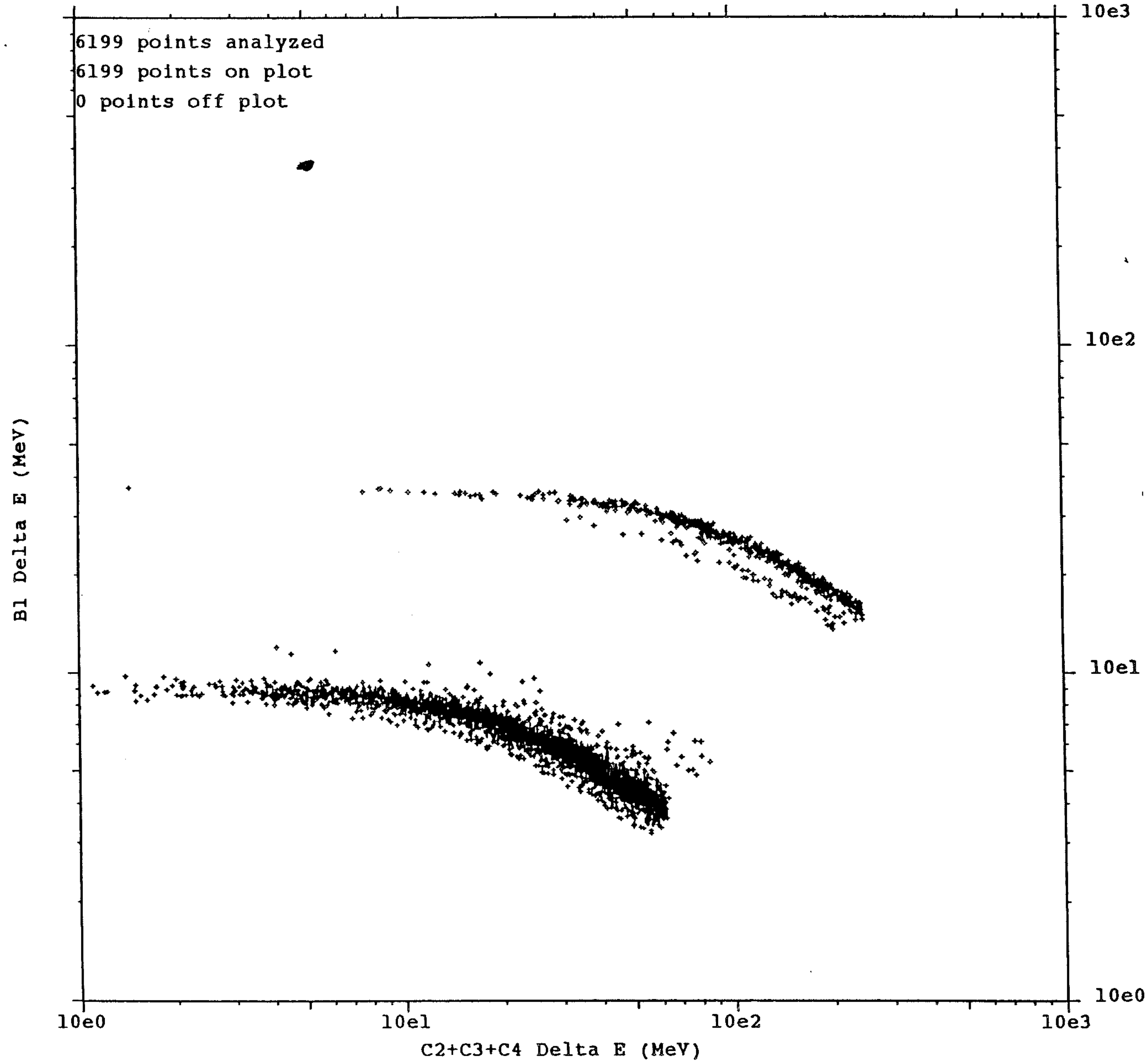


Figure 24 Voyager 2 HET 1 B-Stopping 1977 Good Events

Tue Aug 16 21:16:53 1988
File: eincalbs.out7



Tue Aug 16 21:17:52 1988
File: eincalbs.out8

Figure 25 Voyager 2 HET 1 B-Stopping 1977 Good Events

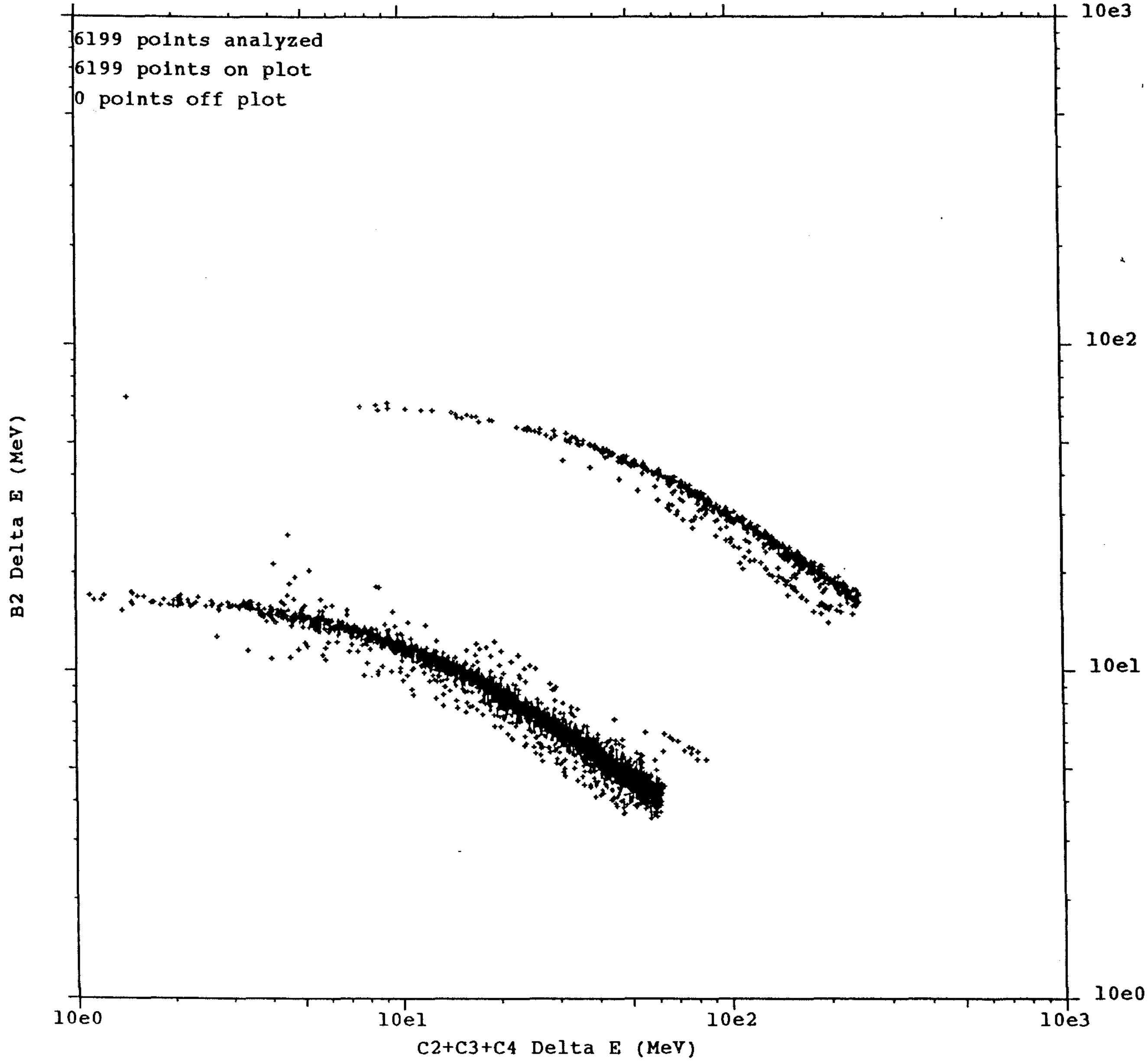
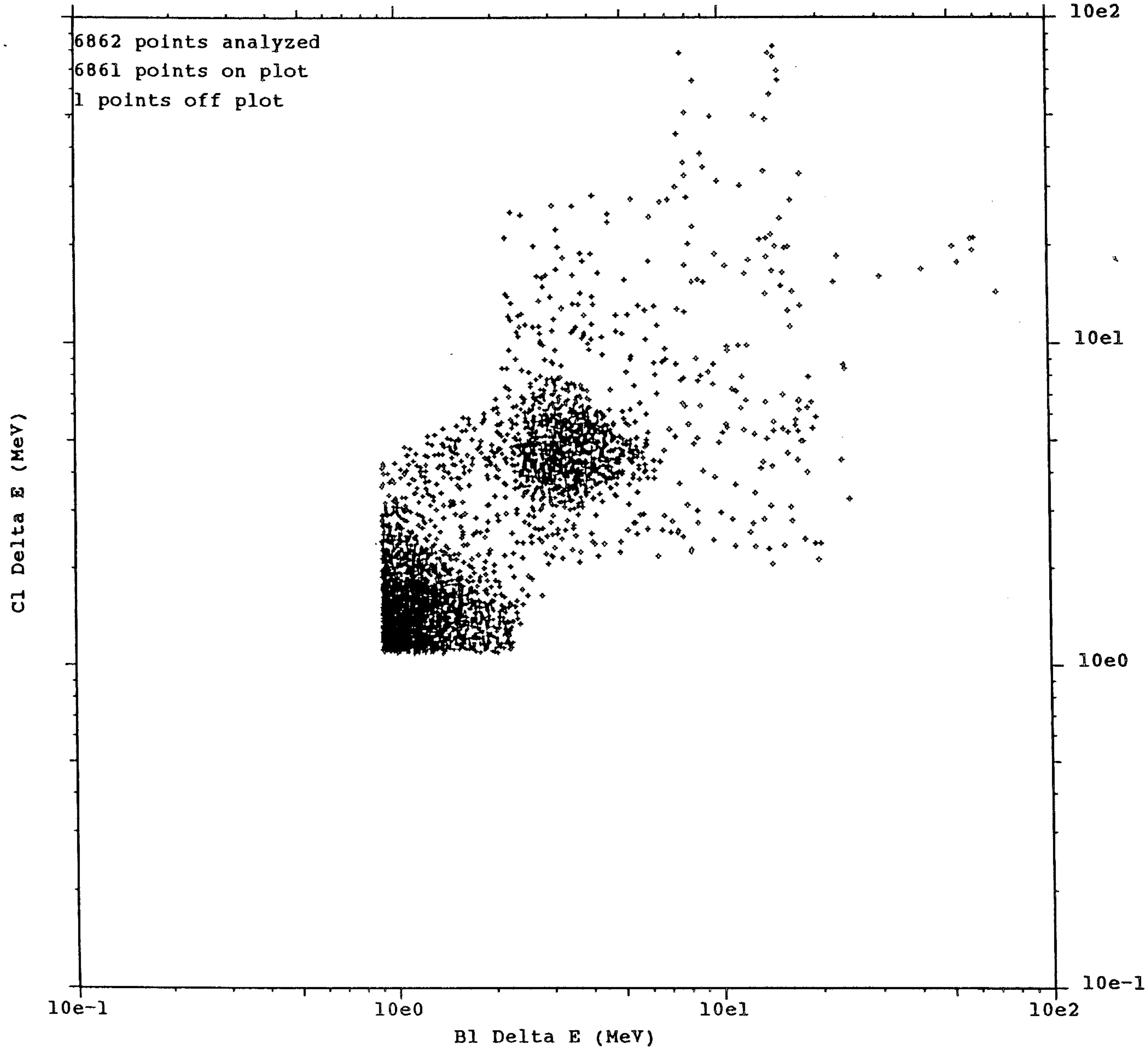


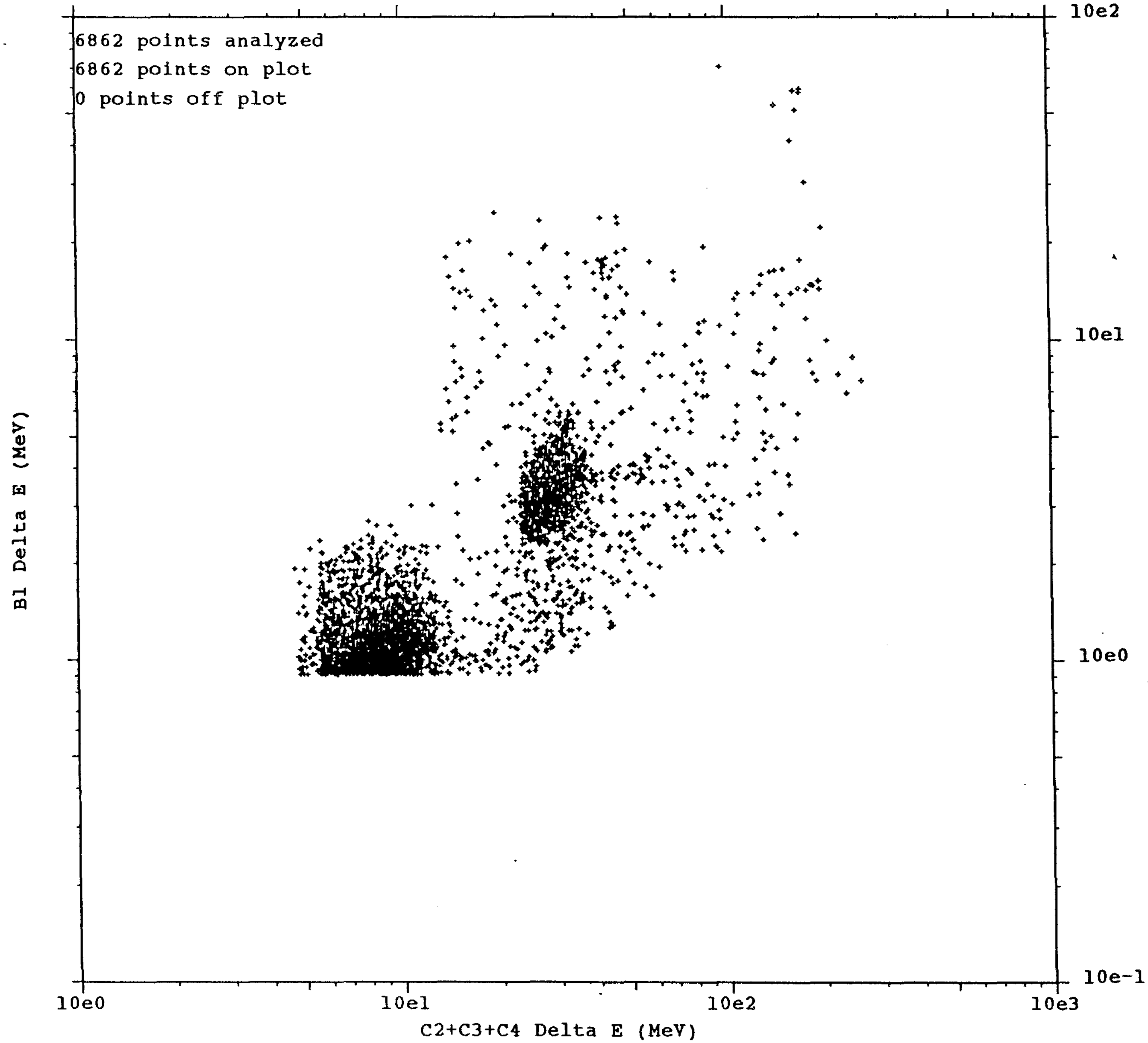
Figure 26 Voyager 2 HET 1 Penetrating 1977 Background Events

Tue Aug 16 22:28:00 1988
File: eincal.out6



Tue Aug 16 22:25:30 1988
File: eincal.out4

Figure 27 Voyager 2 HET 1 Penetrating 1977 Background Events



Tue Aug 16 22:27:07 1988
File: eincal.out5

Figure 28 Voyager 2 HET 1 Penetrating 1977 Background Events

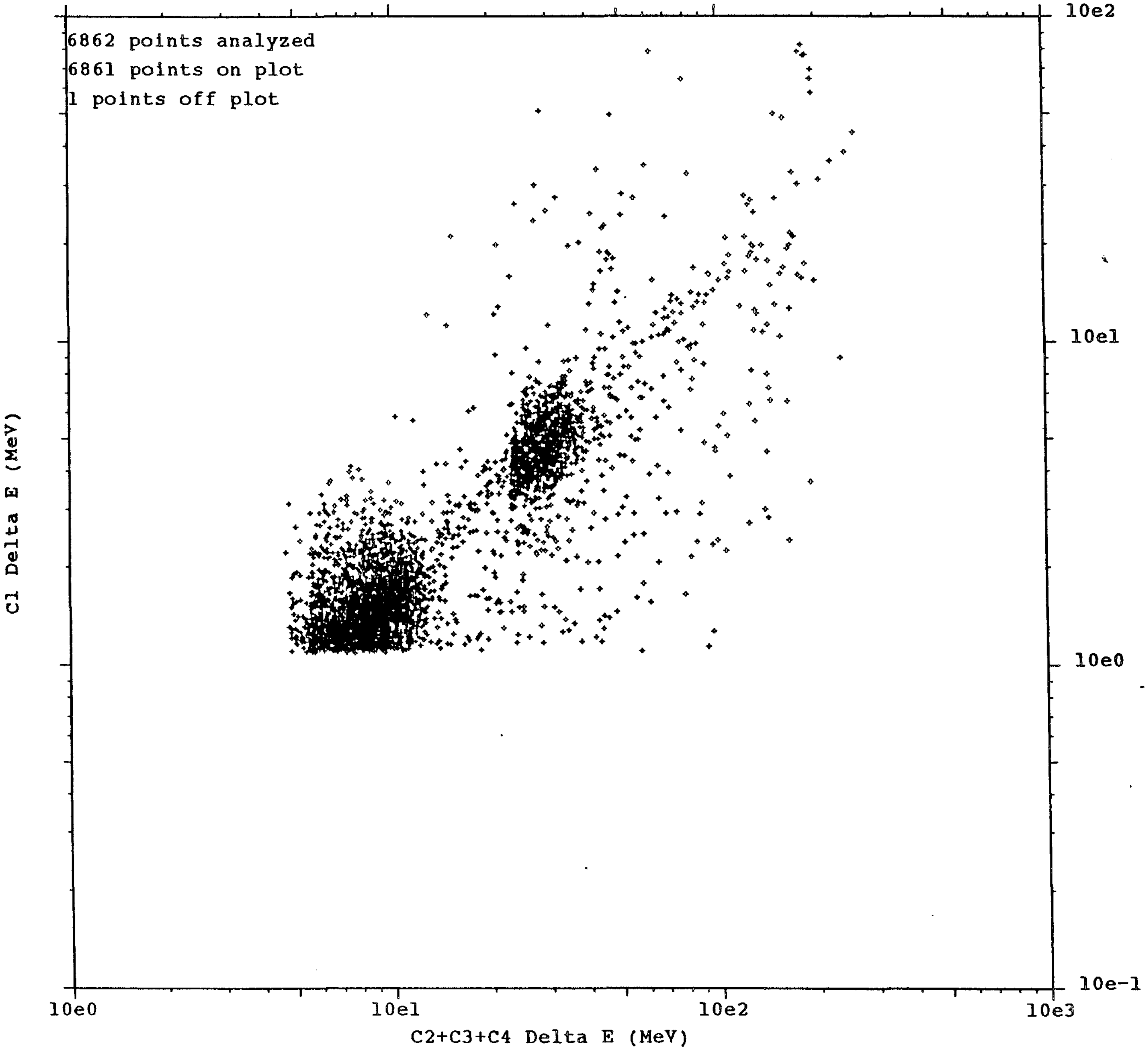


Figure 19 Voyager 2 HET 1 Penetrating 1977 Good Events

Tue Aug 16 22:31:21 1988
File: eincal.out9

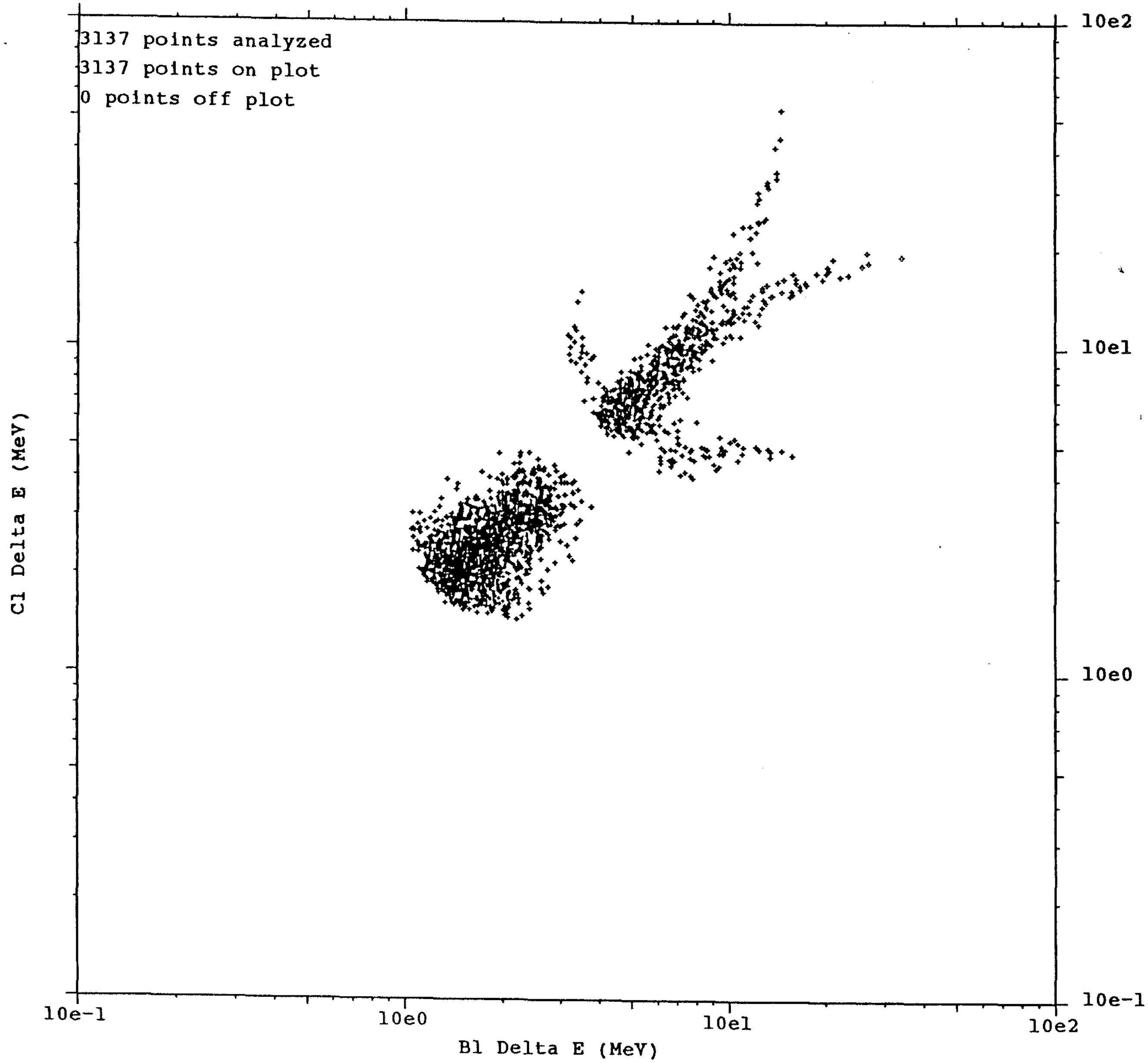


Figure 30 Voyager 2 HET 1 Penetrating 1977 Good Events

Tue Aug 16 22:29:30 1988
File: eincal.out7

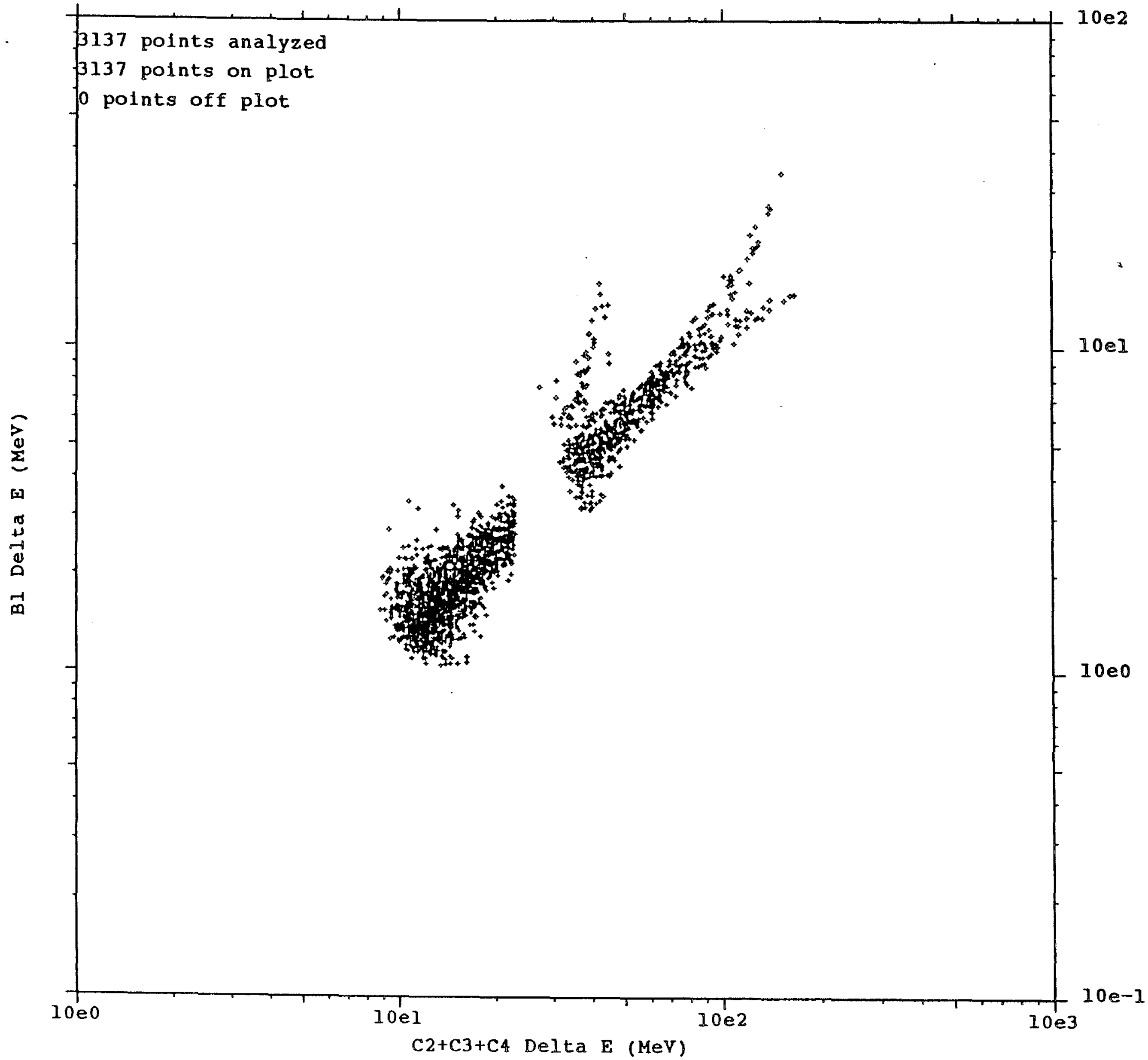


Figure 31 Voyager 2 HET 1 Penetrating 1977 Good Events

Tue Aug 16 22:30:36 1988
File: eincal.out8

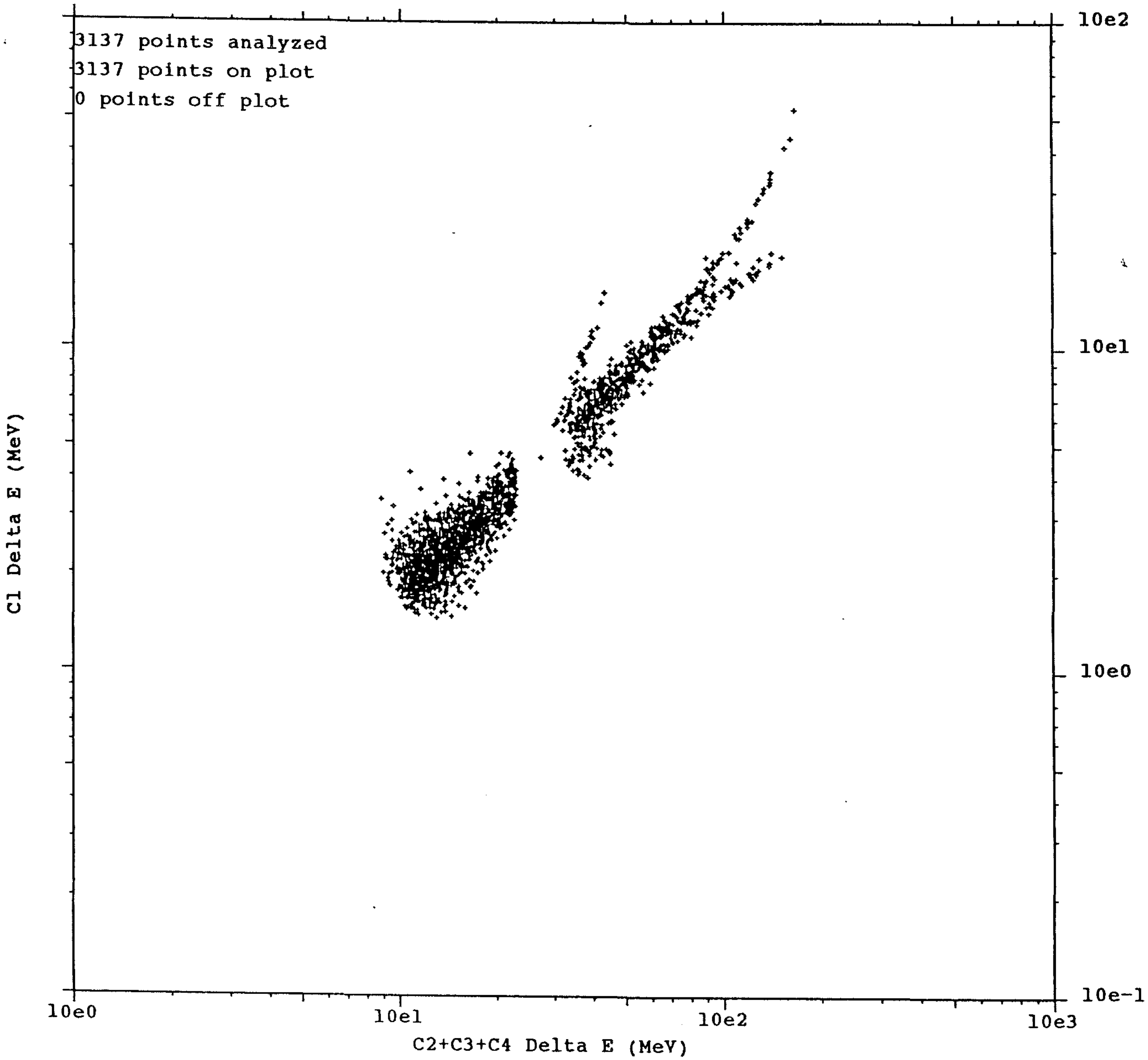


Figure 32

Voyager 1

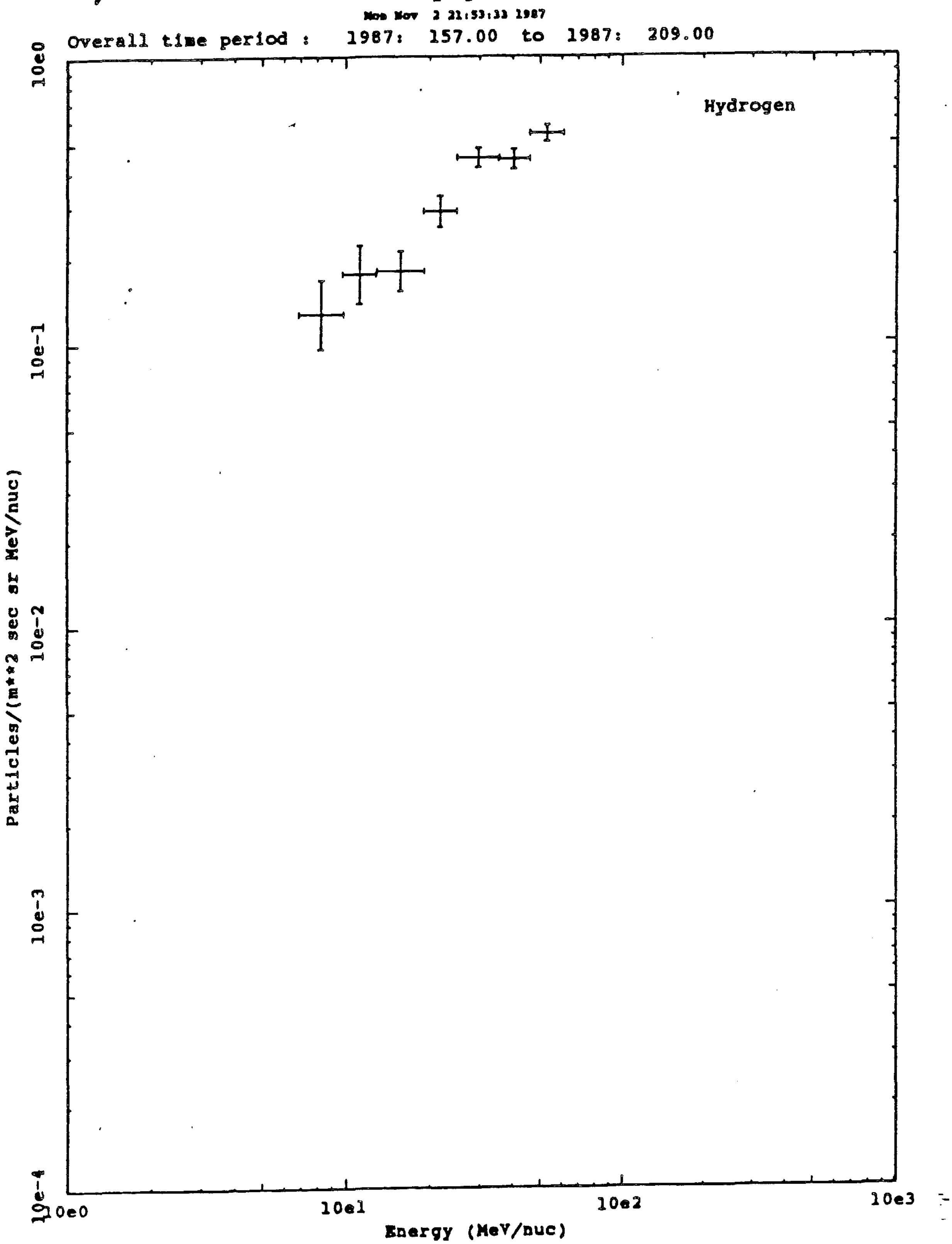


Figure 33

Voyager 1 Hydrogen

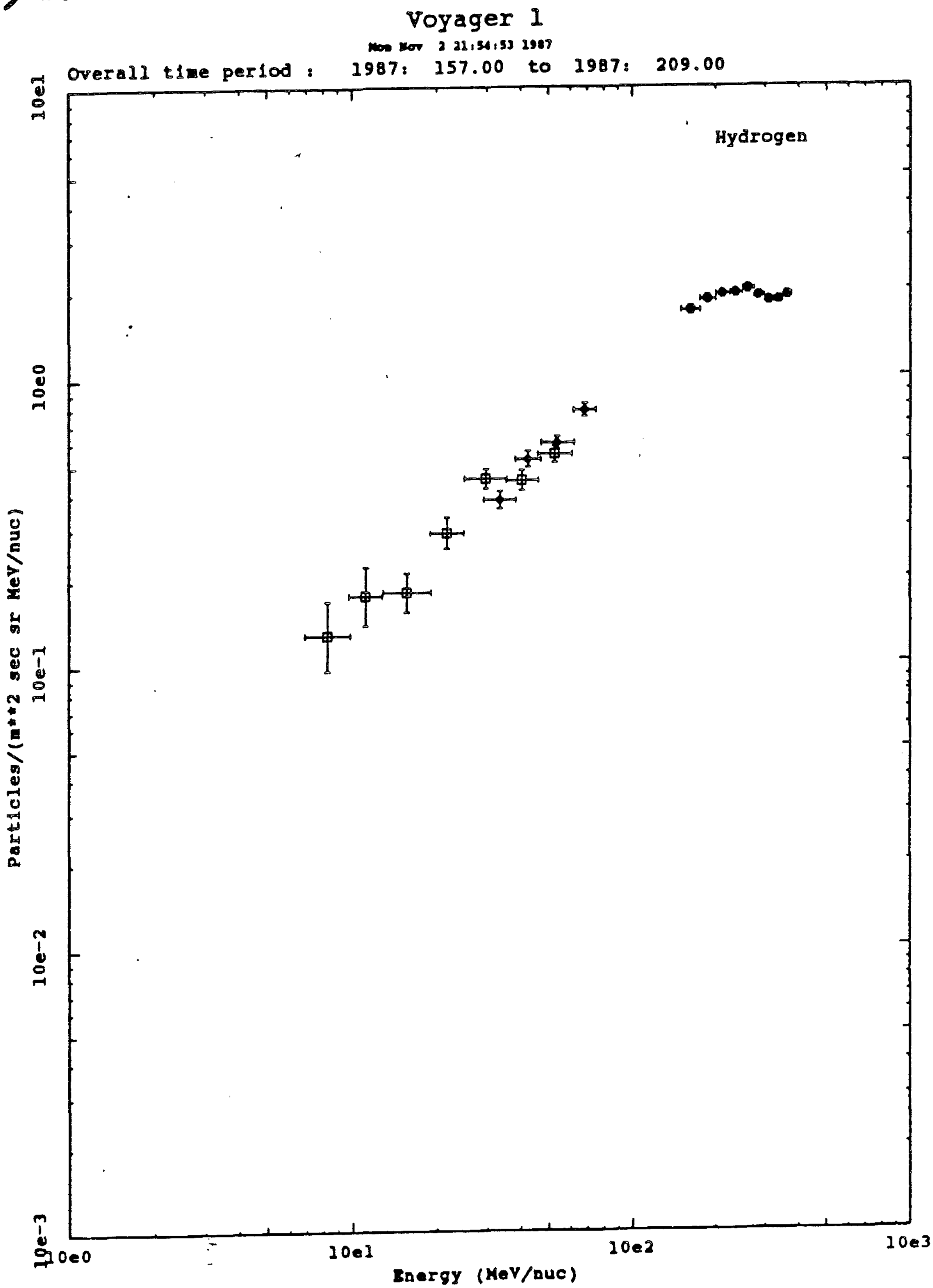
Mon Nov 2 21:53:33 1987

Overall time period :			1987: 157.00 - 1987: 209.00			
Intervals :	365569	369908	1987: 157.00 - 1987: 202.21	Actual vols :	365569	369908
	369913	369948	1987: 202.25 - 1987: 202.63		0	0
	369957	370012	1987: 202.71 - 1987: 203.29		369957	369967
	370025	370560	1987: 203.42 - 1987: 209.00		370025	370560

Energy	1	2	Tot	Flux	Lower	Upper	Avg Lt	Tot Geom
6.7 - 9.7	-	16	16	1.27e-01	9.54e-02	1.67e-01	3.84e+05	1.10e-04
9.7 - 12.7	-	22	22	1.74e-01	1.37e-01	2.20e-01	3.84e+05	1.10e-04
12.7 - 18.7	-	45	45	1.79e-01	1.52e-01	2.10e-01	3.84e+05	1.09e-04
18.7 - 24.7	-	72	72	2.89e-01	2.55e-01	3.27e-01	3.84e+05	1.08e-04
24.7 - 35.0	-	176	176	4.44e-01	4.11e-01	4.80e-01	3.84e+05	1.00e-04
35.0 - 45.4	-	163	163	4.40e-01	4.05e-01	4.77e-01	3.84e+05	9.28e-05
45.4 - 60.4	-	245	245	5.41e-01	5.07e-01	5.78e-01	3.84e+05	7.86e-05
	739							

Livetime Parameters :	1	2
Rate Counts :	173530	167814
Times :	850326	849960
PHA Counts :	77699	75818
Livetimes :	3.81e+05	3.84e+05
Geometry factors :	1.10e-04	1.10e-04
	1.10e-04	1.10e-04
	1.09e-04	1.09e-04
	1.08e-04	1.08e-04
	1.00e-04	1.00e-04
	9.28e-05	9.28e-05
	7.86e-05	7.86e-05

Figure 34



Voyager 1
Mon Nov 2 21:54:53 1987
Overall time period : 1987: 157.00 to 1987: 209.00
Hydrogen
Particles/(m**2 sec sr MeV/nuc)
10e1
10e0
10e-1
10e-2
10e-3
10e0
10e1
10e2
10e3
Energy (MeV/nuc)

Voyager 1 Hydrogen

Mon Nov 2 21:54:53 1987

Figure 35

Overall time period : 1987: 157.00 - 1987: 209.00
Intervals : 365569 370560 1987: 157.00 - 1987: 209.00

v1has.h.87d □

Energy	Flux	Lower	Upper
6.7 - 9.7	1.27e-01	9.54e-02	1.67e-01
9.7 - 12.7	1.74e-01	1.37e-01	2.20e-01
12.7 - 18.7	1.79e-01	1.52e-01	2.10e-01
18.7 - 24.7	2.89e-01	2.55e-01	3.27e-01
24.7 - 35.0	4.44e-01	4.11e-01	4.80e-01
35.0 - 45.4	4.40e-01	4.05e-01	4.77e-01
45.4 - 60.4	5.41e-01	5.07e-01	5.78e-01

v1hbs.h.87d ◇

Energy	Flux	Lower	Upper
29.1 - 37.9	3.76e-01	3.50e-01	4.03e-01
37.9 - 46.7	5.21e-01	4.89e-01	5.54e-01
46.7 - 61.4	5.92e-01	5.63e-01	6.22e-01
61.4 - 74.0	7.69e-01	7.30e-01	8.10e-01

v1hpn.h.87d ●

Energy	Flux	Lower	Upper
150.0 - 175.0	1.69e+00	1.63e+00	1.74e+00
175.0 - 200.0	1.84e+00	1.79e+00	1.90e+00
200.0 - 225.0	1.92e+00	1.86e+00	1.98e+00
225.0 - 250.0	1.93e+00	1.87e+00	1.99e+00
250.0 - 275.0	2.00e+00	1.94e+00	2.06e+00
275.0 - 300.0	1.89e+00	1.83e+00	1.95e+00
300.0 - 325.0	1.82e+00	1.76e+00	1.88e+00
325.0 - 350.0	1.82e+00	1.77e+00	1.88e+00
350.0 - 375.0	1.90e+00	1.84e+00	1.96e+00

Determination of Z, A, and Initial Energy from Voyager HET Events
Appendix A --- Voyager 1 A-Stopping

Boldface characters are computer output and *Italics* are comments. Standard Roman is your input.

cd /usr/erc/voyager/box	
vrebox	*ln'ed to /usr/voyager/crspro/box/vrebox*
Begin and end volumes : 1 900000	*for full tape*
ascii control file name : v1hethas.box	
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*

cd /usr/voyager/crspro/ecal	
ecal1_lowz	
Begin and end volumes : 1 900000	*for full tape*
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*

cd /usr/erc/voyager/astop	
gainbal1 v1gaina1.39	*Use appropriate or most recent gain file*
Begin and end volumes : 1 900000	*for full tape*
input? 1	*Input Tape Drive number*
<input?> -1	*Will only ask for second input on SHORT tapes*

Pick up the two plots generated by gainbal1 and label them with the CRS tape number and the gain file used. Match the plots with the theoretical track plots in the file folder "HET A-Stopping H & He Final". If the tracks line up rename the gain file to reflect the additional CRS tape (v1gaina1.39 => v1gaina1.40). If there is not a match, cp the gain file into a new file (cp v1gaina1.39 v1gaina40), and adjust the gains in the new file to get the tracks to match. THEN RERUN GAINBAL1. If it still doesn't work, then you'll have to do it again.

eincalas v1gaina1.40	*Note new gain file name*
Begin and end volumes : 1 900000	*for full tape*
ascii control file name : v1h2a.ein	
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*
1804 H, 32 H2, 47 Helium-3, 997 Helium-4	*Gives number of good events*

runfluxa
Number of time periods to sum : 2 — *The use of multiple time periods allows you to*
Beginning and end volumes for each time period :
405601 405792 — *avoid problems such as rate spikes*
405805 410592
ascii control file name : v1has.flux — *See Appendix G for file format*
input? 1 — *Input Tape Drive number*
<**input?**> -1 — *This will depend upon how many tapes are involved*
What is the output file name for Hydrogen? v1has.h.88e
What is the output file name for Deuterium? v1has.h2.88e
What is the output file name for Helium-3? v1has.he3.88e
What is the output file name for Helium-4? v1has.he4.88e

The program writes one output file for each of masses in the v1has.flux file. For more information on the v1has.flux file, how to use these output files, and the naming conventions for the output file, see the section on **Flux Calculation** pages 11-13.

Determination of Z, A, and Initial Energy from Voyager HET Events
Appendix B --- Voyager 1 B-Stopping

Boldface characters are computer output and *Italics* are comments. Standard Roman is your input.

cd /usr/erc/voyager/box	
vrebox	*ln'ed to /usr/voyager/crspro/box/vrebox*
Begin and end volumes : 1 900000	*for full tape*
ascii control file name : v1hethbs.box	
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*

cd /usr/voyager/crspro/ecal	
ecal1_lowz	
Begin and end volumes : 1 900000	*for full tape*
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*

cd /usr/erc/voyager/bstop	
gainbal1 v1gainb32.39	*Use appropriate or most recent gain file*
Begin and end volumes : 1 900000	*for full tape*
input? 1	*Input Tape Drive number*
<input?> -1	*Will only ask for second input on SHORT tapes*

Pick up the two plots generated by gainbal1 and label them with the CRS tape number and the gain file used. Match the plots with the theoretical track plots in the file folder "HET B-Stopping H & He Final". If the tracks line up rename the gain file to reflect the additional CRS tape (v1gainb32.39 => v1gainb32.40). If there is not a match, cp the gain file into a new file (cp v1gainb32.39 v1gainb40), and adjust the gains in the new file to get the tracks to match. THEN RERUN GAINBAL1. If it still doesn't work, then you'll have to do it again.

eincalbs v1gainb32.40	*Note new gain file name*
Begin and end volumes : 1 900000	*for full tape*
ascii control file name : v1h2b.ein	
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*
1804 H, 32 H2, 47 Helium-3, 997 Helium-4	*Gives number of good events*

runfluxb
Number of time periods to sum : 2 — *The use of multiple time periods allows you to*
Beginning and end volumes for each time period :
405601 405792 — *avoid problems such as rate spikes*
405805 410592
ascii control file name : v1hbs.flux — *See Appendix G for file format*
input? 1 — *Input Tape Drive number*
<input?> -1 — *This will depend upon how many tapes are involved*
What is the output file name for Hydrogen? v1hbs.h.88e
What is the output file name for Deuterium? v1hbs.h2.88e
What is the output file name for Helium-3? v1hbs.he3.88e
What is the output file name for Helium-4? v1hbs.he4.88e

The program writes one output file for each of masses in the v1hbs.flux file. For more information on the v1hbs.flux file, how to use these output files, and the naming conventions for the output file, see the section on **Flux Calculation**, pages 11-13.

Determination of Z, A, and Initial Energy from Voyager HET Events
Appendix C --- Voyager 1 Penetrating

Boldface characters are computer output and *Italics* are comments. Standard Roman is your input.

cd /usr/erc/voyager/box	
vrebox	*ln'ed to /usr/voyager/crspro/box/vrebox*
Begin and end volumes : 1 900000	*for full tape*
ascii control file name : v1hetpen.box	
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*

cd /usr/voyager/crspro/ecal	
ecal1_lowz	
Begin and end volumes : 1 900000	*for full tape*
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*

cd /usr/erc/voyager/pen	
gainbal1 v1gainp1.39	*Use appropriate or most recent gain file*
Begin and end volumes : 1 900000	*for full tape*
input? 1	*Input Tape Drive number*
<**input?**> -1	*Will only ask for second input on SHORT tapes*

Pick up the two plots generated by gainbal1 and label them with the CRS tape number and the gain file used. Match the plots with the theoretical track plots in the file folder "HET Penetrating H & He Final". If the tracks line up rename the gain file to reflect the additional CRS tape (v1gainp1.39 => v1gainp1.40). If there is not a match, cp the gain file into a new file (cp v1gainp1.39 v1gainp40), and adjust the gains in the new file to get the tracks to match. THEN RERUN GAINBAL1. If it still doesn't work, then you'll have to do it again.

eincalpen v1gainp1.40	*Note new gain file name*
Begin and end volumes : 1 900000	*for full tape*
ascii control file name : v1h2p.ein	
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*
1804 H, 997 Helium Analyzed	*Gives number of good events*

runfluxp
Number of time periods to sum : 2 — *The use of multiple time periods allows you to*
Beginning and end volumes for each time period :
405601 405792 — *avoid problems such as rate spikes*
405805 410592
ascii control file name : v1hpn.flux — *See Appendix G for file format*
input? 1 — *Input Tape Drive number*
<input?> -1 — *This will depend upon how many tapes are involved*
What is the output file name for Hydrogen? v1hpn.h.88e
What is the output file name for Helium? v1hpn.he4.88e

Then you have to do runfluxp again to get the low energy point (79-87 MeV) separated into A and B directions.

runfluxp
Number of time periods to sum : 2 — *The use of multiple time periods allows you to*
Beginning and end volumes for each time period :
405601 405792 — *avoid problems such as rate spikes*
405805 410592
ascii control file name : v1low.flux — *See Appendix G for file format*
input? 1 — *Input Tape Drive number*
<input?> -1 — *This will depend upon how many tapes are involved*
What is the output file name for Hydrogen-A? v1hpna.h.88e
What is the output file name for Hydrogen-B? v1hpnb.h.88e

The program writes one output file for each of masses in the .flux file. For more information on the .flux file, how to use these output files, and the naming conventions for the output file, see the section on **Flux Calculation**, pages 11-13.

Determination of Z, A, and Initial Energy from Voyager HET Events
Appendix D --- Voyager 2 A-Stopping

Boldface characters are computer output and *Italics* are comments. Standard Roman is your input.

cd /usr/erc/voyager/box	
vrebox	*ln'ed to /usr/voyager/crspro/box/vrebox*
Begin and end volumes : 1 900000	*for full tape*
ascii control file name : v2hethas.box	
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*

cd /usr/voyager/crspro/ecal	
ecal2_lowz	
Begin and end volumes : 1 900000	*for full tape*
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*

cd /usr/erc/voyager/astop	
gainbal2 v2gaina24.43	*Use appropriate or most recent gain file*
Begin and end volumes : 1 900000	*for full tape*
input? 1	*Input Tape Drive number*
<input?> -1	*Will only ask for second input on SHORT tapes*

Pick up the two plots generated by gainbal2 and label them with the CRS tape number and the gain file used. Match the plots with the theoretical track plots in the file folder "HET A-Stopping H & He Final". If the tracks line up rename the gain file to reflect the additional CRS tape (v2gaina24.43 => v2gaina24.44). If there is not a match, cp the gain file into a new file (cp v2gaina24.43 v2gaina44), and adjust the gains in the new file to get the tracks to match. THEN RERUN GAINBAL2. If it still doesn't work, then you'll have to do it again.

eincalas v2gaina24.44	*Note new gain file name*
Begin and end volumes : 1 900000	*for full tape*
ascii control file name : v2h1a.ein	
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*
1804 H, 32 H2, 47 Helium-3, 997 Helium-4	*Gives number of good events*

runfluxa
Number of time periods to sum : 2 *The use of multiple time periods allows you to*
Beginning and end volumes for each time period :
405601 405792 *avoid problems such as rate spikes*
405805 410592
ascii control file name : v2has.flux *See Appendix G for file format*
input? 1 *Input Tape Drive number*
<input?> -1 *This will depend upon how many tapes are involved*
What is the output file name for Hydrogen? v2has.h.88e
What is the output file name for Deuterium? v2has.h2.88e
What is the output file name for Helium-3? v2has.he3.88e
What is the output file name for Helium-4? v2has.he4.88e

The program writes one output file for each of masses in the v2has.flux file. For more information on the v2has.flux file, how to use these output files, and the naming conventions for the output file, see the section on **Flux Calculation**, pages 11-13.

Determination of Z, A, and Initial Energy from Voyager HET Events
Appendix E --- Voyager 2 B-Stopping

Boldface characters are computer output and *Italics* are comments. Standard Roman is your input.

cd /usr/erc/voyager/box	
vrebox	*ln'ed to /usr/voyager/crspro/box/vrebox*
Begin and end volumes : 1 900000	*for full tape*
ascii control file name : v2hethbs.box	
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*
cd /usr/voyager/crspro/ecal	
ecal2_lowz	
Begin and end volumes : 1 900000	*for full tape*
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*
cd /usr/erc/voyager/bstop	
gainbal2 v2gainb28.43	*Use appropriate or most recent gain file*
Begin and end volumes : 1 900000	*for full tape*
input? 1	*Input Tape Drive number*
<**input?**> -1	*Will only ask for second input on SHORT tapes*

Pick up the two plots generated by gainbal2 and label them with the CRS tape number and the gain file used. Match the plots with the theoretical track plots in the file folder "HET B-Stopping H & He Final". If the tracks line up rename the gain file to reflect the additional CRS tape (v2gainb28.43 => v2gainb28.43). If there is not a match, cp the gain file into a new file (cp v2gainb28.43 v2gainb44), and adjust the gains in the new file to get the tracks to match. THEN RERUN GAINBAL2. If it still doesn't work, then you'll have to do it again.

eincalbs v2gainb28.44	*Note new gain file name*
Begin and end volumes : 1 900000	*for full tape*
ascii control file name : v2h1b.ein	
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*
1804 H, 32 H2, 47 Helium-3, 997 Helium-4	*Gives number of good events*

runfluxb	
Number of time periods to sum : 2	*The use of multiple time periods allows you to*
Beginning and end volumes for each time period :	
405601 405792	*avoid problems such as rate spikes*
405805 410592	
ascii control file name : v2hbs.flux	*See Appendix G for file format*
input? 1	*Input Tape Drive number*
<input?> -1	*This will depend upon how many tapes are involved*
What is the output file name for Hydrogen? v2hbs.h.88e	
What is the output file name for Deuterium? v2hbs.h2.88e	
What is the output file name for Helium-3? v2hbs.he3.88e	
What is the output file name for Helium-4? v2hbs.he4.88e	

The program writes one output file for each of masses in the v2hbs.flux file. For more information on the v2hbs.flux file, how to use these output files, and the naming conventions for the output file, see the section on **Flux Calculation**, pages 11-13.

Determination of Z, A, and Initial Energy from Voyager HET Events
Appendix F --- Voyager 2 Penetrating

Boldface characters are computer output and *Italics* are comments. Standard Roman is your input.

cd /usr/erc/voyager/box	
vrebox	*ln'ed to /usr/voyager/crspro/box/vrebox*
Begin and end volumes : 1 900000	*for full tape*
ascii control file name : v2hetpen.box	
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*

cd /usr/voyager/crspro/ecal	
ecal2_lowz	
Begin and end volumes : 1 900000	*for full tape*
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*

cd /usr/erc/voyager/pen	
gainbal2 v2gainp35.43	*Use appropriate or most recent gain file*
Begin and end volumes : 1 900000	*for full tape*
input? 1	*Input Tape Drive number*
<input?> -1	*Will only ask for second input on SHORT tapes*

Pick up the two plots generated by gainbal2 and label them with the CRS tape number and the gain file used. Match the plots with the theoretical track plots in the file folder "HET Penetrating H & He Final". If the tracks line up rename the gain file to reflect the additional CRS tape (v2gainp35.43 => v2gainp35.44). If there is not a match, cp the gain file into a new file (cp v2gainp35.43 v2gainp44), and adjust the gains in the new file to get the tracks to match. THEN RERUN GAINBAL2. If it still doesn't work, then you'll have to do it again.

eincalpen v2gainp35.44	*Note new gain file name*
Begin and end volumes : 1 900000	*for full tape*
ascii control file name : v2h1p.ein	
input? 1	*Input Tape Drive number*
output? 2	*Output Tape Drive number*
What is name of output tape? <cr>	*Never used*
input? -1	*Ends chapter-verse input*
1804 H, 997 Helium Analyzed	*Gives number of good events*

runfluxp
Number of time periods to sum : 2 — *The use of multiple time periods allows you to*
Beginning and end volumes for each time period :
405601 405792 — *avoid problems such as rate spikes*
405805 410592
ascii control file name : v2hpn.flux — *See Appendix G for file format*
input? 1 — *Input Tape Drive number*
<input?> -1 — *This will depend upon how many tapes are involved*
What is the output file name for Hydrogen? v2hpn.h.88e
What is the output file name for Helium? v2hpn.he4.88e

Then you have to do runfluxp again for the low energy (79-87 MeV) point to separate it into A and B.

runfluxp
Number of time periods to sum : 2 — *The use of multiple time periods allows you to*
Beginning and end volumes for each time period :
405601 405792 — *avoid problems such as rate spikes*
405805 410592
ascii control file name : v2low.flux — *See Appendix G for file format*
input? 1 — *Input Tape Drive number*
<input?> -1 — *This will depend upon how many tapes are involved*
What is the output file name for Hydrogen-A? v2hpna.h.88e
What is the output file name for Hydrogen-B? v2hpnb.h.88e

The program writes one output file for each of masses in the .flux file. For more information on the .flux file, how to use these output files, and the naming conventions for the output file, see the section on **Flux Calculation**, pages 11-13.