Crystal Ball Single Event Display

CB-97-010

D. Grosnick,¹ C. Allgower,² J. Alyea,^{1,2} and A. Gibson¹

¹ Department of Physics and Astronomy, Valparaiso University, Valparaiso, IN 46383
and

² High Energy Physics Division, Argonne National Laboratory, Argonne, IL 60439

October 15, 1997

The Single Event Display (SED) is a routine that is designed to provide information graphically about a triggered event within the Crystal Ball. The SED is written entirely in FORTRAN and uses the CERN-based HIGZ graphing package. The primary display shows the amount of energy deposited in each of the NaI crystals on a 'Mercator-like' projection of the crystals. Ten different shades and colors correspond to varying amounts of energy deposited within a crystal. Information about energy clusters is displayed on the crystal map by outlining in red the thirteen (or twelve) crystals contained within a cluster and assigning each cluster a number. Additional information about energy clusters is provided in a series of boxes containing useful data about the energy distribution among the crystals within the cluster. Other information shown on the event display include the event trigger type and data about π^0 's and η 's formed from pairs of clusters as found by the analyzer.

A description of the major features is given below, along with some information on how to install the SED into the analyzer.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

DTIC QUALITY INSPECTED 1

The submitted manuscript has been authored by a contractor of the U. S. Government under contract No. W-31-109-ENG-38. Accordingly, the U. S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U. S. Government purposes.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Event Number 27

Neutral Trigger

Cluster 1	Cluster 2	Cluster 3
Peak=(19;3;6)	Peak=(6;2;4)	Peak=(3;2;7)
E(tot) =316.8	E(tot) =290.8	E(tot) = 46.8
E(1:4) =0.896	E(1:4) =0.615	E(1:4) =0.728
E(1:13)=0.834	E(1:13)=0.411	E(1:13)=0.728

π^0 η
 1 155.22 (2, 3) 1 521.29 (1, 2)

Figure 1: Sample View of the Single Event Display (Event 27 from Run 50).

1. Crystal Display

The Crystal Ball detector, with each of the 672 NaI crystals displayed as a triangle, is shown in the fold-out view of Figure 1, similar to a Mercator map of the world projecting a globe. In this view, the crystals on the left side of the display are actually attached to those on the right side; they are split apart only to display them in two dimensions. In the display, the twenty major triangles are outlined in the thickest black lines, the four minor triangles within each major triangle are outlined with thick black lines, and the nine crystals of each minor triangle (thirty six crystals per major triangle) have thin black lines. (Note: The Single Event Display figures in this note are in color, and should be printed accordingly, if at all possible.)

In the crystal display of Figure 1, the regular hexagons, shown as blank areas

Figure 2: Major Triangle Numbering Scheme

where there are no NaI crystals, are due to the entrance and exit of the beam into the Crystal Ball detector. These hexagons are labeled 'Beam In' and 'Beam Out.' Note that the 'Beam Out' hexagon is drawn on the left side of the display, and most of the energy from an interaction will be showered around that location.

A diagram of the numbering scheme for the major triangles is shown in Figure 2. The first major triangle is displayed in the upper left, the second major triangle below it (rotated 180 degrees from the first), the third next to it, and the fourth major triangle below the third. This group of four major triangles is then repeated four more times, totaling twenty major triangles. The numbering scheme for the minor triangles within a major one is shown in Figure 3. There are two different orientations of the major triangles rotated 180 degrees from each other. The minor triangles within both of the major triangle orientations are displayed in Figure 3.

Finally, there are nine crystals within each minor triangle, and the numbers for each of these crystals are shown in Figure 4. Again, there are two different orientations of the minor triangles, so the crystal numbers corresponding to both orientations are shown.

2. Colors and Shades

There are seven different colors and three different shades to represent the amount

Figure 3: Minor Triangle Numbering Scheme Within a Major Triangle

Figure 4: Individual Crystal Numbering Scheme Within a Minor Triangle

of energy deposited in a particular NaI crystal. Within the crystal display, the lowest amount of energy, corresponding to < 1 MeV, remains in white, while two shades of gray correspond to small amounts of energy (< 5 MeV and < 10 MeV) deposited in a NaI crystal. Thus any energy deposited in a crystal below 10 MeV will be in a shade of gray and not in color. The seven colors range from blue (cool), for energies in the range 10 to 20 MeV, to red (hot), for energies in a single crystal greater than 100 MeV, in a manner similar to the electromagnetic spectrum. A key to the energies associated with each color is provided for each event in the bottom left corner of the crystal display.

The energies that are shown are taken from the 'ecryst' array, as determined in subroutine PedGain/CB_ADC2Energy.F. This array includes a pedestal subtraction and gain multiplication.

3. Cluster Information

Considerable information about each cluster located within the Crystal Ball is provided by the SED. These include: (a) a red outline of the thirteen (or twelve) NaI crystals contained within the cluster; (b) the cluster number shown on the cluster's highest-energy crystal; and (c) above the crystal display, a box containing information about the cluster, such as the peak-energy crystal location and the energy distribution within the cluster.

Each cluster of thirteen (or twelve) crystals is found by the algorithm located in subroutine Physics/find_clusters.F. Normally, a cluster contains the peak-energy (highest energy) crystal and its twelve closest neighbors, making a total of thirteen NaI crystals in the pattern of a hexagon. An exception to this is for peak-energy crystals located near the vertices of each of the major triangles, where there are only eleven nearest neighbors, making a total of twelve NaI crystals. Each cluster found by the algorithm is outlined in red to be easily distinguishable from the other crystals. Since all crystals for each cluster are outlined in red, individual clusters that overlap may sometimes be difficult to distinguish.

The clustering algorithm currently finds the highest-energy crystal in the detector and forms the cluster around it along with its nearest neighbors. The second highest-

energy crystal is then located with its nearest neighbors, and so on. The cluster numbers that are shown on the crystal display in the SED are formed from this method, and are *NOT* necessarily listed from the highest-energy cluster to the lowest-energy cluster. The cluster number is displayed at the location of the peak-energy (or highest-energy) crystal within the cluster.

Additional cluster information is provided within a box above the crystal display. An example of this is shown below:

Cluster 2 Peak = (14;4;9) E(tot) = 116.7 E(1:4) = 0.827 E(1:13) = 0.508

The information contained in this box includes:

a.) **Cluster number:**

The cluster number for a displayed event is shown and corresponds to the cluster number used in the crystal display.

b.) **Peak-energy crystal:**

The location of the peak-energy NaI crystal of the cluster is displayed in the form of the major and minor triangle numbers and the crystal number. Crystal numbers are found in the 'peak' array which is located in subroutine 'find_clusters' in file 'find_clusters.F.'

c.) **Total energy within the cluster:**

The sum of energy deposited within the cluster of thirteen (or twelve) NaI crystals is shown in units of MeV. The total energy values are stored in array 'e_cluster' in subroutine 'sed2find_clusters' in file 'cluster.f.'

d.) **Energy ratio between peak-energy crystal and three nearest neighbors:**

On the fourth line of the cluster information box is the energy ratio

of the highest-energy crystal (E_1) in a cluster to the sum of that crystal and its nearest three neighbors, $E_1/(E_1 + E_2 + E_3 + E_4)$. This ratio is calculated in subroutine 'peak_ratios,' and is stored in variable 'ratio1' of subroutine 'display_cluster' in file 'se_display.f.'

e.) Energy ratio of the peak-energy crystal to all nearest neighbors:

The energy ratio of the highest-energy crystal (E_1) in a cluster to the sum of that crystal and the twelve (or eleven) crystals nearest it in the cluster (total energy), $E_1/(E_1 + E_2 + \dots + E_{13})$, is displayed for each cluster. This ratio is calculated in subroutine 'peak_ratios,' and is stored in variable 'ratio2' of the subroutine 'display_cluster' in file 'se_display.f.'

The displays of the energy ratios provide information about the energy distributions within clusters, and perhaps can be used to identify photon clusters from neutron clusters.

Up to ten cluster boxes are displayed in two rows of five boxes each. If more than ten clusters are found in an event, only the first ten (ordered by the peak energy of the cluster) are displayed; the remaining clusters do not appear.

4. Particle Information

Displayed to the right of the cluster information boxes are columns that show data about pairs of clusters. There are two sets of columns, one displaying information on π^0 's found by the analyzer, and the other on η 's. Within each particle column, the data supplied are: the number of the type of particle, the invariant mass of the particle, and the cluster numbers making up the particle. Up to five different π^0 's or five different η 's can be displayed per event. An example is shown below:

	π^0		η	
1	127.31 (1,4)	1	546.01 (1,2)	
2	114.43 (2,3)			

In the π^0 column, there are two pairs of clusters that form a candidate π^0 . For the first π^0 , cluster numbers 1 and 4 form an invariant mass of 127.31 MeV. Likewise, cluster numbers 2 and 3 form the second π^0 candidate with an invariant mass of 114.43 MeV. Similar data are displayed in the η column.

The information about the particles is taken from subroutines `Physics/find_pi0.F` and `Physics/true_pi0.F`, where all possible pairs of clusters are combined to form an invariant mass of the π^0 . A similar calculation is performed for the η . These invariant masses are compared with the real π^0 (η) mass and are identified as a π^0 (η) only if the experimental masses are within a given tolerance. If the invariant mass lies outside the tolerance, then the pair is not identified as either a π^0 or an η . Finally, the cluster numbers of all cluster pairs are compared so that no duplicate clusters are used to form another π^0 (η). No comparison is made to check that the pairs of clusters making a π^0 are the same as the cluster pairs for the η . Also, the information displayed comes from cluster pairs only; no information about the missing mass or calculation of η 's from three π^0 's is performed.

5. Miscellaneous Information on Display

At the top of the display, two additional pieces of information are provided. The first is the event number of the current run, which is located in the `Main/run_info.inc` file.

The other piece of information is the trigger type. There are nine physics trigger types: neutral, charged, elastic, $\pi - p$, beam, pulser, calibration, scaler, and cosmic ray triggers. There are also five CODA event triggers, a DIBBUK trigger, and begin and end of run triggers. One of these trigger types will be displayed to the right of the event number at the top of the display. Note that for some triggers, such as pulser and scaler triggers, the information about the event is NOT cleared from the previous event. This is a result of the arrays in the analyzer not being cleared for each new event, and therefore not being overwritten. The display for these trigger types will look the same as for the previous event, even though the trigger type at the top will change. The trigger type is found in the array 'event_type' in `Main/run_info.inc`.

6. Other Features of the SED

The CEBAF Test Package (CTP) can be used to cut on and display certain events with the SED. In the file, Analysis/ctp_skim.config, cuts on the data can be made using the same methods as other cuts on CTP variables. There are two variables in this file that must have given values, 'sedon' and 'sedtest.' The variable 'sedon' is a switch with two values:

0 = false turns the SED off, (sedtest = 0 also turns off the SED)

1 = true turns on the SED.

The second variable, 'sedtest', may contain other cuts appropriate to the analysis, and should be in the same format as other cuts on variables using CTP. For example, to view only those events that are neutral triggers (event.type = 1), sedtest should be written as:

```
sedtest = (event.type == 1)
```

A simple example of the ctp_skim.config file is:

```
sedon = 1
```

```
sedtest = (event.type==1)
```

To view all triggers, set: sedtest = 1 Another example could be to look at all neutral triggers that have three clusters with one pion (defined as 3cl_1pi0 in ctp-physics.config):

```
sedtest = 3cl_1pi0 && (event.type==1)
```

Particular event numbers may be found with the SED by cutting on the variable, 'event_number.' By adjusting the cuts on sedtest, only certain events may be displayed by the SED as required for the analysis.

The SED can only display events in increasing order of event number, or in a 'forward' direction. Moving backward through the events is not performed, just as in the case of analyzing events during replay. Event displays can be skipped, but only by using the cuts on the events through the CTP variables described previously or by repeatedly hitting RETURN.

A hardcopy of a particular event may be produced from the SED. The SED will write a PostScript file of that event when the 'p' key is typed along with the Return key in the non.SED window, which is the window not displaying the event. The file

name for that event includes in its format the run number and the event number of the event displayed on the SED, run_number-event_number.ps. For example, if run 50 was being analyzed and event number 37 was the event that looked particularly interesting, pressing the 'p' key and Return would create the file, 50-37.ps. This color PostScript file can then be printed out or viewed again later.

Note that there are a few features of the HIGZ graphics package that are included in the SED. One is that all commands must be executed in the window in which the analyzer is running, NOT the one where the SED event occurs. Nothing should happen if this is done. Another feature is that there is a lack of redraw capability with HIGZ.

7. How to Run the SED

The SED is contained in a single package, called from subroutine `usr_event.F` in the Main directory. As mentioned previously, both the variables 'sedon' and 'sedtest' must be 'true' for the SED to be called. The SED package is currently available and the installation instructions may be found in the SED Release Notes (see README). The necessary files can be retrieved via anonymous ftp to kepler.valpo.edu in /pub/E913/sed, and are named sed.tar, README, and INSTALL.

The SED currently operates in the analyzer only in 'replay' mode. The current v1.0 analyzer does not handle the Monte Carlo data in the same manner as data runs, and consequently the SED does not operate in -m mode. The SED is also not currently operational in the online analyzer.

Any comments or further suggestions about additions to the SED are welcome, but several things must be kept in mind. First, there is limited space to include additional information. Second, an attempt was made to make the display as general as possible, with particular cuts delegated to the CTP. Lastly, an attempt was made to make this available for online use and consequently as fast as possible, so long calculations per event will not be viewed on with favor. This version of the SED is constructed mainly for analysis using real data, using the variables associated with it. The Monte Carlo data format is not the same, so some differences may be present.

Event Number 545

Neutral Trigger

Cluster 1	Cluster 2	Cluster 3
Peak=(1;2;8)	Peak=(18;2;5)	Peak=(3;4;7)
E(tot) =358.3	E(tot) =229.4	E(tot) =161.0
E(1:4) =0.887	E(1:4) =0.874	E(1:4) =0.893
E(1:13)=0.838	E(1:13)=0.874	E(1:13)=0.857

 π^0
 1 131.71 (1, 2)

Figure 5: A possible good $n \pi^0$ event. (Event 545 from Run 50).

8. Examples of Different Types of Events in the SED

The power of the SED as an analysis tool is demonstrated in this section, which contains examples of SED pictures of several different types of events encountered in data taken during the running of E913/E914 in 1997. Specifically, the figures shown here are from run 50, which was taken with a pion beam tune, and run 141, which was taken with the beam tuned for kaon production. The pictures from run 50 were generated with the SED using raw data from the incident pion beam (i.e. no TOF cut), and the pictures from run 141 were generated using a time-of-flight cut corresponding to that expected for incident kaons.

Event Number 227

Neutral Trigger

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	π^0
Peak=(18;3;2)	Peak=(2;1;8)	Peak=(1;2;6)	Peak=(9;2;4)	Peak=(6;1;9)	1 137.34 (2, 3)
E(tot) =194.6	E(tot) =263.7	E(tot) =106.6	E(tot) = 31.0	E(tot) = 24.0	2 131.71 (1, 4)
E(1:4) =0.855	E(1:4) =0.543	E(1:4) =0.801	E(1:4) =0.918	E(1:4) =1.000	
E(1:13)=0.790	E(1:13)=0.464	E(1:13)=0.775	E(1:13)=0.918	E(1:13)=1.000

Figure 6: A possible good $n2\pi^0$ event. (Event 227 from Run 50).

Beginning with the pion data, Fig. 5 shows a candidate event for the reaction $\pi^- p \rightarrow n \pi^0$. In this example, the neutron was most likely detected in the NaI crystals near the 'Beam Out' hole as cluster number 3, because clusters 1 and 2 reconstruct to an invariant mass of a π^0 .

Figure 6 shows a likely candidate for the reaction $\pi^- p \rightarrow n 2\pi^0$. In this example, cluster 5 is very likely the neutron, and clusters (2,3) and (1,4) correspond to the two π^0 's.

Event Number 591

Neutral Trigger

Cluster 1	Cluster 2
Peak=(6:2:7)	Peak=(19:3:6)
E(tot) =341.4	E(tot) =279.7
E(1:4) =0.830	E(1:4) =0.698
E(1:13)=0.747	E(1:13)=0.620

 η
 1 537.34 (1, 2)

Figure 7: A possible good $n\eta$ event. (Event 591 from Run 50).

Figure 7 shows a candidate event for the reaction $\pi^- p \rightarrow n\eta$. In this event the neutron was not detected, either because it went forward through the 'Beam Out' hole, or because it failed to deposit energy in any of the crystals as it left the Crystal Ball.

Figure 8 shows a candidate event for the reaction $\pi^- p \rightarrow n3\pi^0$. The neutron was not detected, if this was indeed a $3\pi^0$ event, because the six clusters which were detected reconstruct pairwise to three π^0 's.

Event Number 67

Neutral Trigger

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	π^0
Peak=(7;1;1)	Peak=(7;2;9)	Peak=(17;4;3)	Peak=(19;4;7)	Peak=(2;4;8)	1 137.43 (2, 5)
E(tot) = 171.2	E(tot) = 93.0	E(tot) = 164.7	E(tot) = 74.4	E(tot) = 61.8	2 140.24 (3, 4)
E(1:4) = 0.531	E(1:4) = 0.901	E(1:4) = 0.478	E(1:4) = 0.872	E(1:4) = 0.916	3 116.12 (1, 6)
E(1:13) = 0.519	E(1:13) = 0.878	E(1:13) = 0.472	E(1:13) = 0.785	E(1:13) = 0.772	
Cluster 6					
Peak=(3;2;5)					
E(tot) = 28.5					
E(1:4) = 1.000					
E(1:13) = 0.749

Figure 8: A possible good $n3\pi^0$ event. (Event 67 from Run 50).

Event Number 170

Neutral Trigger

Cluster 1	Cluster 2	Cluster 3
Peak=(1;7;1;2)	Peak=(13;2;8)	Peak=(13;3;8)
E(tot) = 183.9	E(tot) = 162.8	E(tot) = 89.5
E(1:4) = 0.726	E(1:4) = 0.502	E(1:4) = 0.404
E(1:13) = 0.633	E(1:13) = 0.238	E(1:13) = 0.241

π^0
1 135.31 (1, 2)

Figure 9: A 'snake' event from a pion run. (Event 170 from Run 50).

Figure 9 shows a typical so-called 'worm' or 'snake' event. These events are ones where energy is deposited in a continuous line of crystals starting at the 'Beam In' opening of the Crystal Ball. Note that the large energy deposited at the 'head' of the 'snake' is due to the Bragg peak produced when the particle stopped.

Cluster 1	Cluster 2	Cluster 3
Peak=(12;2;5)	Peak=(14;1;2)	Peak=(11;1;5)
E(tot) = 501.6	E(tot) = 29.2	E(tot) = 21.4
E(1:4) = 0.626	E(1:4) = 1.000	E(1:4) = 1.000
E(1:13) = 0.479	E(1:13) = 1.000	E(1:13) = 1.000

Figure 10: A 'hot upstream' event from a pion run. (Event 41 from Run 50).

Figure 10 shows a so-called 'hot upstream' event, where a large amount of energy was deposited in the crystals near the 'Beam In' hole on the upstream side of the Crystal Ball. These events have kinematics inconsistent with any reaction which could have occurred in the target. In the case of the event shown in Fig. 10, the beam momentum was 750 MeV/c and the upstream crystals show an energy deposition of some 550 MeV. Most likely, both 'snakes' and 'hot upstream' events were caused by decay or scattering of incident beam particles just downstream of the upstream veto counters. The resulting scattered or decay particles then missed the barrel veto counters inside the Crystal Ball, entered the upstream crystals directly, and thereby satisfied the conditions of the neutral trigger.

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	π^0
Peak=(7;2;3)	Peak=(6;1;3)	Peak=(15;2;6)	Peak=(19;4;5)	Peak=(11;3;9)	1 133.29 (3, 5)
E(tot) =198.4	E(tot) = 84.1	E(tot) =143.7	E(tot) =146.0	E(tot) =103.3	2 139.90 (2, 7)
E(1:4) =0.779	E(1:4) =0.667	E(1:4) =0.666	E(1:4) =0.755	E(1:4) =0.729	3 152.33 (6, 8)
E(1:13)=0.488	E(1:13)=0.547	E(1:13)=0.532	E(1:13)=0.433	E(1:13)=0.512	
Cluster 5	Cluster 7	Cluster 8	Cluster 9	Cluster 10	
Peak=(16;2;8)	Peak=(20;4;6)	Peak=(7;3;6)	Peak=(10;1;7)	Peak=(15;2;9)	
E(tot) =105.4	E(tot) = 87.4	E(tot) = 68.7	E(tot) = 65.6	E(tot) = 38.3	
E(1:4) =0.638	E(1:4) =0.375	E(1:4) =0.626	E(1:4) =0.491	E(1:4) =0.462	
E(1:13)=0.366	E(1:13)=0.221	E(1:13)=0.310	E(1:13)=0.280	E(1:13)=0.201

Figure 11: A 'double-snake' event from a kaon run. (Event 460 from Run 141).

Figures 1 and 5-10 were all generated using data from Run 50, which had an incident pion beam of momentum 750 MeV/c. No time-of-flight cut was being used for the Single Event Display. Figures 11-13 were generated using data from run 141, which had a beam tune for 750 MeV/c kaon production, and a time-of-flight cut in the SED suitable for selecting events with incident kaons. The 'kaon' data of run 141 is dominated by 'snake' and 'hot upstream' events, however. Some of the 'snake' events reach almost 180° around the Crystal Ball, as in the event shown in Fig. 11. Figure 12 shows one of the 'hot upstream' events from the same run.

Event Number 227

Neutral Trigger

Cluster 1	Cluster 2	Cluster 3
Peak=(11;4;5)	Peak=(13;2;8)	Peak=(14;1;6)
E(tot) =253.4	E(tot) =359.7	E(tot) =163.8
E(1:4) =0.699	E(1:4) =0.635	E(1:4) =0.678
E(1:13) =0.628	E(1:13) =0.339	E(1:13) =0.588

π^0
1 133.56 (1, 3)

Figure 12: A 'hot upstream' event from a kaon run. (Event 227 from Run 50).

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	π^0
Peak=(7;1;9)	Peak=(19;4;4)	Peak=(9;3;3)	Peak=(16;2;1)	Peak=(1;2;6)	1 126.44 (1, 3)
E(tot) =263.0	E(tot) =172.9	E(tot) = 95.8	E(tot) = 81.4	E(tot) = 35.2	2 124.29 (2, 4)
E(1:4) =0.695	E(1:4) =0.698	E(1:4) =0.946	E(1:4) =0.832	E(1:4) =1.000	
E(1:13) =0.597	E(1:13) =0.635	E(1:13) =0.867	E(1:13) =0.832	E(1:13) =0.809

Figure 13: A (rare) good event from a kaon run. (Event 154 from Run 141).

Only occasionally does one find a 'kaon' event that seems likely to be reconstructable. Figure 13 shows what may be a good event for the reaction $K^- p \rightarrow n 2\pi^0$, where cluster number 5 would be the neutron.

In order to roughly compare the frequencies of the various types of events shown above, the first few events of runs 50 and 141 were viewed using the SED and tallied according to the type of event seen. The resulting counts of different types of events and the percentages of the total number of counts are summarized in Table I. The event category 'other bad' included events having cluster patterns which did not appear to reconstruct to good events based purely on viewing them with the SED. These included mostly events with several clusters where no pairs of clusters fell within either the pion or

eta invariant mass cuts. Undoubtedly there were good events in the 'other bad' category, such as events from the reaction $\pi^- p \rightarrow n \gamma$, where the neutron was not detected, or events for which one or more photons were lost out the upstream or downstream holes of the Crystal Ball. The second two columns of numbers in Table I are both from Run 141, but using the time-of-flight cuts in the SED appropriate for incident kaons and no cuts for pions, respectively.

TABLE I. Rough Estimates of Frequencies of Event Types.

	'pion' data (Run 50)	'kaon' data (Run 141)	'pion' data (Run 141)
N_{snk}	7	25	4
N_{hu}	10	15	4
N_{ok}	37	4	13
N_{ob}	46	7	6
N_{tot}	100	51	27
% Snake	7.0 ± 2.5	49.0 ± 7.0	14.8 ± 6.8
% Hot Upstream	10.0 ± 3.0	29.4 ± 6.4	14.8 ± 6.8
% Good	37.0 ± 4.8	7.8 ± 3.8	48.2 ± 9.6
% Other Bad	46.0 ± 5.0	13.8 ± 4.8	22.2 ± 8.0

From Table I, one sees that the pion run contained about fifteen percent snake and hot upstream events, and furthermore that the 'other bad' category outnumbers the 'good event' category. Apparently, only about fifty to sixty percent of the events may end up being reconstructable. The 'kaon' data of Run 141 is completely dominated by 'snake' and 'hot upstream' events, and probably about twenty percent of the events with good kaon time-of-flight were due to particles interacting in the target. Of these, less than half looked as though they were likely to reconstruct to good events. The 'pion' data of Run 141 had fewer 'snake' and 'hot upstream' events than the 'kaon' data from the same run, but a significantly higher incidence than 'pion' data from Run 50. The

cause of this is not yet understood. Curiously, the good events from the 'pion' data of Run 141 seem to outnumber the 'other bad' category, which is not the case for the 'pion' data of Run 50. This may be just due to the extremely limited statistics of this simple test, however.

Notwithstanding the limited statistics in Table I, it would appear that the beam tune for the 'kaon' running was poor, and that even after applying the time-of-flight cut for kaons, most of the surviving data were clearly not due to kaons, but rather were caused by stray beam particles that bypassed the barrel veto inside the Crystal Ball, and instead entered the crystals directly from the upstream side. While such events are probably not too difficult to reject in the offline data analysis, their presence indicates that a significant fraction of what one sees online is due to events that do not originate from the target. Improvements to both the beam tune and the trigger hardware could help eliminate this problem in the future, but at present more work needs to be done to better understand the origin of the stray particles and the mechanism by which they occur. Somehow they manage to be seen by the time-of-flight counters without being rejected by the upstream veto counter on a direct path to the upstream crystals. Once they reach the crystals, they leave a 'snake' trail that could only be produced by a high-energy charged particle such as a muon from a pion decay.

A possible explanation may be as simple as the timing having been slightly off for one or more of the four counters that comprise the upstream veto. In that case, a study of the phi distribution of the 'snake' events might reveal something, but the clusters from 'hot upstream' events seem to be relatively uniformly distributed around the upstream opening of Crystal Ball, as one can see by simply looking at Figs. 10 and 12. Of course, if the timing of all four of the upstream vetos was incorrect, then one would not expect a phi dependence in either the 'snake' or 'hot upstream' events.

Another possibility is that the 'snake' and 'hot upstream' events were leftover signals from previous charged-particle events that had not yet died away, and were triggered by beam particles that did not interact in the target. If this were the case however, one would not expect to see the very high energy depositions that one often sees. This possibility is not ruled out at this time, however.

9. Conclusions

A software package for displaying single events in the Crystal Ball has been developed by students and faculty at Valparaiso University. The Single Event Display package is compatible with the Crystal Ball analysis software, and should be incorporated in the online software for the benefit of the experimenters during the running. It is a very useful tool for visualizing events in the Crystal Ball, and can lead to significant insights which might not be immediately evident using other means.

A cursory look at data from the 1997 running period shows problems with stray particles entering the Crystal Ball from upstream and bypassing the target altogether. These problems are present in data from both pion and kaon running, and have serious implications for both offline analysis and possible improvements to the hardware for future running. The explanation of the origin of the stray particles is not immediately obvious, and so the initial use of the SED has already served as an aid for understanding the nuances of the Crystal Ball apparatus.

Acknowledgements

We wish to acknowledge Dr. H. Spinka of the High Energy Physics Division of Argonne National Laboratory for useful discussions and ideas. Also, the helpful guidance, suggestions, and ongoing review provided from the outset by Profs. Donald Koetke, Robert Manweiler, and Shirvel Stanislaus of Valparaiso University. The work was carried out at Valparaiso University and was supported by the U.S. Department of Energy, Division of Medium Energy Nuclear Physics Grant DE-FG02-88ER4016, and the U.S. Department of Energy, Division of High Energy Physics Contract W-31-109-ENG-38.

M98004783

Report Number (14) ANL-HEP-TR--97-86

Publ. Date (11) 19971015

Sponsor Code (18) DOE/ER, XF

UC Category (19) UC-414, DOE/ER

DOE