Disclaimer

A Study of Hot Cells and Jets:
Should We Add Hotcells Back into Events?

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D0Note #[redacted]
March 10, 1995

Abstract
D0 uses the subroutine (AIDA) to remove jets caused by single calorimeter cells firing randomly in an event. This subroutine has been used both on-line and off-line to remove "noisy" cells from the data. In this note, typical run 1A QCD trigger data (which has the hotcells removed) was analyzed. The sample was separated into typical good QCD events and bad QCD events. For these two sets of data, the effects of the removal of the hot cells was investigated. It was discovered that ~5% of the good QCD events have at least one hot cell and often (86% of the time) the hotcell is within the cone of a good jet. In those cases (3.6% of all good events), 67% of the time the E_T of the event would decrease if the hot cell were added back into the event. A routine to allow for such corrections is being constructed.

1 Introduction

The sample used for this study was a set of QCD DST data from typical run 1A QCD triggers kept on disk (D0$DATA$DST:*.*DST*U11*QC*). From this set of runs, ranging from 50004 to 65981, a subset of good runs was compiled. The bad run list was obtained from the file PRJ$ROOT236:[QCD_14.MDST.DOCS]BAD_RUNS_1A.LIST. In this note:

Central = inclusive triggers with at least one central jet (non-JET_END triggers)
Forward = inclusive triggers with at least one forward jet (JET_END triggers)
Jet_Max = highest jet E_T trigger (does not use the main ring veto)
$\overline{\text{Jet\_Max}}$ = all triggers except Jet_Max
Central, $\overline{\text{Jet\_Max}}$ = inclusive non-Jet_Max triggers with at least one central jet

The energy of a jet is expected to be spread over a number of cells. Thus electronic noise is suspected if the energy of a jet is concentrated only in one cell. Marc Paterno wrote a "Hot Cell Killer Routine" AIDA which is used in the reconstruction program (RECO 11 and on) and on-line in L2 for some triggers in order to remove such hotcells from events. This routine looks at a completed CAEP bank and a cell is removed if its $E_T \geq 10$ GeV and:

$$\left(\frac{E_T(up) + E_T(down)}{N * E_T(candidate)}\right) \leq 0.05 \qquad (1)$$

Here E_T(candidate), E_T(down) and E_T (up) are the candidate hotcell (HC) and its radial neighbors and N is the number of radial neighbors (generally 1 or 2). A maximum of 100 candidates is allowed, where a candidate is a cell with $E_T \geq 10$ GeV. Events which pass the E_T cut and the cut in equation (1) are identified as hotcells and information concerning them is put into the CAID bank. The CAEH bank is then modified by multiplying all the energy variables for these hotcells by 1×10^{-9}. After this, general reconstruction for the event is done.

For this study the hotcell information was obtained from the CAID bank, the jets information from the JETS bank, the missing E_T information from the PNUT2 bank and trigger tower information from ESUM bank. Vertex corrections were done using the first vertex listed in INFO from the VERTEX_INFO subroutine.

I wanted to determine how often hotcells were present in events and how often they are associated with a jet (other than the hotcell itself) and perhaps aren't noise, but a fluctuation in the jet. By dividing the data sample into good QCD events and bad QCD events, I hoped to see a difference in the way that the hotcells manifest themselves. For good QCD events one expects the removal of the real hotcell not to effect the event. Thus the correlation between the removed real hotcell energy and the event E_T should be negligible. For bad QCD events one expects the event to have very little left in it once the hotcell(s) are removed, on the grounds that the hotcell(s) caused it to trigger. As an aside I looked at the correlation between trigger towers and hotcells and the efficiency ratios of hotcell events to all events as a function of Jet E_t and eta.

2 The Data Sample

After the bad runs were removed, as stated above, the data sample consisted of approximately 205,000 events. Originally the idea was to divide the sample into "typically" good and bad QCD events in order to study the effects of hotcell removal on each sample. In the process it was discovered that there are distinctly different subsets of these two categories with respect to hotcell effects. Thus, to some extent, the data sample was separated into two subsets for some studies. These two subsets were JET_MAX and $\overline{\text{Jet\_Max}}$ triggers, and central and non-central triggers. For this analysis a cone size of 0.7 was used.

2.1 Good and Bad QCD Events

The data sample was divided into what one might typically call good QCD events (GEs) and bad QCD events (BEs). For the good QCD events, the two leading jets are good jets (as defined by the routine QCD_BAD_DST) and they are back to back ($\Delta\phi$ between the two leading jets is $\pi \pm 0.2\pi$). The QCD_BAD_DST BAD_FLAG defines a jet as good if the energy of the jet is distributed such that the:

- CH fraction < 0.4 and
- EM fraction cut: 0.05 < EMF < 0.95 and
- Ratio of hottest cell to second hottest cell < 10

For the bad QCD events at least one of the leading jets does not pass the QCD_BAD_DST cuts <u>and</u> the leading jets are not back to back (as defined above) if there are at least two jets in the event <u>and</u>:

- $abs\left(\frac{Missing\ E_T}{leading\ jet\ E_T}\right) > 0.75$

In the 205K data sample, 76% are good QCD events and 3% bad QCD events. The remaining 21% fall in neither category. Table 1 provides a summary of the data sample, divided into trigger subsets. In this table GE $\geq$ 1 HC (or BE $\geq$ 1 HC) refers to good (bad) QCD events with at least 1 hotcell in the event. The values in parenthesis under $\overline{\text{Jet\_Max}}$ include bad QCD events that had zero jets, all other values do not. Similarly, $\geq$ 1 HC means all events with at least one hotcell. Figure 1 shows the number of jets per event for $\overline{\text{Jet\_Max}}$ triggers. As expected the GE distribution peaks at two to three jets per event whereas the BE distribution peaks at one jet per event.

Table 1: The Data Sample

Trigger	All	Jet_Max	Central	$\overline{\text{Jet\_Max}}$	Central, $\overline{\text{Jet\_Max}}$
All Events	205,408	59,965	198,376	145,443	141,189
$\geq$ 1 HC	9%	26%	9%	2%	2%
Good QCD	76%	76%	76%	76%	76%
Bad QCD	3.3%	10%	3.4%	0.4% (0.5%)	0.4%
GE $\geq$ 1 HC (% of GE)	5.5%	16%	5.5%	1.3%	1.3%
BE $\geq$ 1 HC (% of BE)	89%	95%	89%	26% (40%)	26%

2.3 Jet_Max and $\overline{\text{Jet\_Max}}$ Trigger Events

Most triggers are $\overline{\text{Jet\_Max}}$ triggers (71%). This is fortunate as the Jet_Max trigger does not have the main ring veto in it and thus events from this trigger have many more hotcells as shown in Table 1. Some events have up to 75 hotcells as shown in Figure 2 where the distribution of events with hotcells is shown versus the number of hotcells for BEs and GEs from Jet_Max (Figure 2a) and $\overline{\text{Jet\_Max}}$ (Figure 2b) triggers . Almost all of the hot cells in the Jet_Max trigger bad events show up in layer 10, the End Cap (EC) massless gap, or layer 15, the Coarse Hadronic 1 (CH1), around the Main Ring. It is prevalent on some DSTs (where the Main Ring was probably on the entire time). It is interesting to look at the hotcell energy for GEs and BEs for Jet_Max and $\overline{\text{Jet\_Max}}$ triggers as shown in Figure 3. The energy distribution for the BEs in the Jet_Max triggers (Figure 3a) is relatively flat, versus that of the $\overline{\text{Jet\_Max}}$ trigger BEs (Figure 3b). The spike in the GE sample at 45 GeV is from two tapes of data and thus most likely from a noisy cell which was not removed from the readout. This is approximately a 10% contamination in our GE sample with hotcells. When these two runs were removed from a smaller subsample of data, the peak at 45 GeV disappeared and all the results stated in this paper remained the same within 1%.

2.4 Central and Forward Trigger Events

Most triggers are from the central region of the calorimeter (97%). For forward triggers the number of events with hotcells will be suppressed due to the 10 GeV E_T requirement. This is clearly shown in Figure 4. Figure 4a shows the distribution of jets with hotcells versus eta and one can see the depletion of events for |eta| > 1, especially when compared to Figure 4b which shows the same distribution for all GEs with jets. In the central region 9% of the events have at least one hot cell and half of these events have only one hot cell. In 82% of these events there are no bad jets (as defined by QCD_BAD_DST) and in 14% there is only one bad jet.

3 Discussion

3.1 General

Most triggers in this data sample are from the central region (97%) and thus the statistics for "All Events" is essentially that for the central region. The central events have more events with hotcells in them (9%) due to the fact that that is where all the noise from the main ring lies. If one looks only at $\overline{\text{Jet\_Max}}$ triggers, then the number of events with hotcells is reduced greatly (2%) since the main ring noise is mostly removed. For this reason most figures show $\overline{\text{Jet\_Max}}$ data only unless otherwise stated.

If one looks at events where there are no jets (in the BE sample), one finds that all these events have a hotcell. One could assume that this hotcell(s) caused the trigger and once it was removed, there were no longer any jets in the event. Of all BE in the $\overline{\text{Jet\_Max}}$ sample, 50% have no jets and a hotcell(s). These are events were the hotcell killer works perfectly by removing a hotcell and thus removing the event as no jets remain. For events with at least on jet in them, the minimum distance in eta/phi space between a hotcell and a jet in an event (shown in Figure 5, denoted as "min eta/phi(nrhc-jet)") was determined. If that distance was less than 0.4, the hotcell was defined as associated with that jet since it was within the cone of the jet. Interestingly for both the GEs and BEs, there is usually a hotcell within the cone of a jet when a hotcell (and a jet) is present: 86% of the time for GEs and 96% of the time for BEs. In GEs this suggests that often times "hotcells" are jet fluctuations. In the remaining 50% of the BEs that have at least one jet even after the hotcells have been removed, it appears that the noise creates more than one cell of energy and not all the noise cells are identified as hotcells and thus a jet(s) remains in the event. Table 2 illustrates these results. The zero jet BE sample where the hotcell killer works best is not included in the Figures. The investigation is confined to determining the correlations within the GE and BE samples where jets remain and thus where physics results may be effected.

Table 2: Hotcell and Jet Correlation

eta/phi nearest hotcell-jet within 0.4	Good QCD Events	Bad QCD Events
All Events	86%	96%
Central	86%	96%
Jet_Max	93%	60%
$\overline{\text{Jet\_Max}}$	67%	73%
Central, $\overline{\text{Jet\_Max}}$	67%	73%

In plots of the phi of the hotcell versus the phi of it's associated jet, the correlation is high for both GEs and BEs, but when one looks at the phi of the hotcell versus the phi of the E_t there is high correlation for GEs and anti-correlation for BEs. This is illustrated well by Figure 6 which shows the difference between the phi of the hotcell associated with a jet and the phi of the E_T denoted as DPHI(nrhc-met) on the plots. One expects the GEs with hotcells to not have any hotcell energy $\not{E}_T$ correlation if the hotcells are noise, but Figure 6 shows that often the hotcell and the $\not{E}_T$ are in the same space in phi for GEs. This suggests that the hotcell was not noise but a jet fluctuation and that it should not have been removed from the event. In the BE sample the hotcell is usually opposite the $\not{E}_T$ in phi, suggesting that the noise often (~50% of the time) distributes itself over more than one cell and thus when one removes a hotcell, there is still enough energy left to form a jet and then the $\not{E}_T$ points opposite the noise jet that remains and opposite the hotcell that was removed from the noise jet. Both these results are unexpected. The hotcell routine was written to remove real noise (hotcells): from GEs without "harming" any real jets and from BEs eliminating the noise jet (and hopefully eliminating the event). This appears to not always be the case.

3.2 Adjusting the Missing E_T

For GEs most hotcells were within the cone size of a jet and the $\not{E}_T$ was highly correlated with the hotcell in phi. This indicated that the hotcells are often jet fluctuations for GEs and thus the $\not{E}_T$ should often decrease if the hotcell were added back into the event. If the minimum distance in eta/phi space between a hotcell and a jet in an event was less than 0.4, the hot cell energy was added back into the $\not{E}_T$. This adjusted $\not{E}_T$ was less than the original $\not{E}_T$ in 67% of the GEs, for both Jet_Max and non-Jet_Max triggers. For BEs the adjusted $\not{E}_T$ nearly always got worse. The scenario above of several noisy cells of which only one gets identified as a hotcell agrees with the fact that the $\not{E}_T$ generally increases when the hotcell is added back into an event. Figure 7 shows the adjusted $\not{E}_T$ (NMET) divided by the original $\not{E}_T$ (MET) for GEs and BEs with at least than one hotcell (M1HC). The adjusted $\not{E}_T$ is determined by adding the hotcell back into an event if it is within 0.4 of a jet and if the $\not{E}_T$ decreases, thus one expects the $\not{E}_T$ to improve. Figure 8 shows the adjusted and original $\not{E}_T$ distributions for GEs and BEs, and Figures 9a and b show these distributions for all hotcell events and all QCD good events respectively. The adjusted $\not{E}_T$ distribution is shown with a dotted line and the original $\not{E}_T$ distributions shown with a solid line. In Figure 9a, the adjusted $\not{E}_T$ distribution is significantly better as shown the Table 3. In the plots of BEs, the adjusted $\not{E}_T$ distribution is hardly discernible from the original $\not{E}_T$ distribution due to the fact that few BEs have their $\not{E}_T$ adjusted since it nearly always gets worse when "corrected". In Figure 9b, the plot for all good QCD events, the difference between the adjusted and original $\not{E}_T$ distributions can hardly be seen due to the fact that only a small percentage of all events have hotcells in them and thus only a small percentage are adjusted.

Table 3: Missing E_T Distributions for All Events with Hotcells

	Mean	RMS	Overflow	Number of Entries
Original E_T distribution	14.56	11.66	19	2634
Adjusted E_T distribution	11.36	10.22	19	2634

3.3 Efficiency Studies

It was of interest to determine the "efficiency" for hotcells in E_T and eta. For this I analyzed good QCD events from $\overline{\text{Jet\_Max}}$ triggers. The ratio of the E_T of a central jet with a hotcell to that of all central jets is shown in Figure 10b, where central is defined as $-0.9 \leq \text{eta(jet)} \leq 0.9$. The hotcell rate is $\leq 2\%$ independent of E_T for $E_T > 45$ GeV. Figure 10a shows the E_T distribution of central jets with a hotcell. A similar comparison is made in eta for jets with 30GeV< E_T<70GeV. Figure 11a shows the eta distribution of jets with an associated hotcell and 30GeV< E_T<70GeV. Figure 11b shows the ratio in eta of the jets in 11a to that of all jets with 30GeV< E_T<70GeV. The hotcell rate in this energy region is ~1.4% for all events $-1 < \eta < 1$.

These distributions in E_T and eta are relatively flat in the central region ($-1 < \eta < 1$) and thus the dependence on eta and E_T is minimal.

3.4 Trigger Tower Comparison Results

Another issue of interest was the relationship between trigger tower cells and hotcells from the reconstruction program. One wished to check that the trigger and the reconstruction were both picking out the same cells as noisy. At the DST level the information I had was the hotcell (0.1 x 0.1) and the trigger tower (0.2 x 0.2) in eta/phi space. I identified hotcells and checked to see if they were within a trigger tower. The hotcell and trigger tower matched 80% of the time, where I defined matching as within 0.1 in eta/phi space. This is good agreement considering the difference in time scales between the trigger and the acquired data. Figure 12 shows the ratio of the hotcell energy to the trigger tower energy (for GEs and BEs) where the noisy cells matched. The hotcell to trigger tower energy ratio peaks at one, which is good, but does have a large tail out to 5 or 6. Upon looking at Figure 12, one might consider a cut at 2. Such a cut would keep 86% of the GEs and remove 52% of the BEs. Perhaps this option should be studied in more detail. A better comparison could be made if one used all the cells in the trigger tower when determining the energy within the trigger tower instead of the hotcell energy only.

The distribution of GE and BE in layers of the calorimeter (ILYR) is somewhat unexpected and is quite different between GEs and BEs. It is shown in Figure 13. For good QCD events most hotcells are in Fine Hadronic 1 (FH1, 63%) and Coarse Hadronic 1 (CH1, 23%), whereas for QCD bad events most are in FH1 (34%), FH2 (29%) and FH3 (30%).

4.0 Conclusions

For typical QCD events, 4% have at least one hotcell in them. If one looks only at $\overline{\text{Jet\_Max}}$ triggers in the central region only 2% have hotcells. The main ring is the main contributor to hotcells, and thus triggers without the main ring veto (Jet_Max) greatly bias the data sample.

For both the GEs and BEs with hotcells, the hotcell is within the cone of a jet: 86% of the time for GEs and 96% of the time for BEs (see Table 2). In the BE sample this may be due to the fact that the noise creates more than one cell of energy and not all the noise cells are identified as hotcells. The remaining energy is then enough to be identified as a jet. When looking at the zero jet BE sample for $\overline{\text{Jet\_Max}}$ triggers, one finds that all zero jet events have a hotcell. This points to the fact that the event was only one cell (jet) and once this hotcell was removed the event was insignificant. This occurs in 50% of the BE sample for $\overline{\text{Jet\_Max}}$ triggers, pointing to the fact that the hotcell killer routine does what it was intended to do ~50% of the time in BEs. In GEs often times "hotcells" are jet fluctuations since the E_T often decreases when the hotcell is added back into the event.

These results are surprising. It was thought that hotcells were real noise in most cases, thus the reason for removing them. It was also thought that real noise manifested itself as a single hotcell. According to this study, often neither of these statements are true. It seems that what we define as hotcells are usually jet fluctuations and should not be removed from the jet and that when we do have real noise it often causes several cells to have energy above threshold. In the real noise case we may often not identify the noise as a hotcell due to the fact that it is several cells. What does appear to be true is that when we do identify a hotcell in what appears to be a bad QCD event, the removal of the hotcell does not always eliminate the event as the remaining energy is identified as a jet.

The above observations suggest that one might wish to add some hotcells back into events. Adding hotcells back into events often decreases the $\not{E}_T$ for good QCD events. A routine is being written which allows a user to remove all events with hotcells, put all hotcells back into events (adjusting the MET, JETS...) or only puts those hotcells within 0.4 eta/phi of a jet (which decrease the $\not{E}_T$ of the event) back into events.

FIGURE 1: JET_MAX Triggers

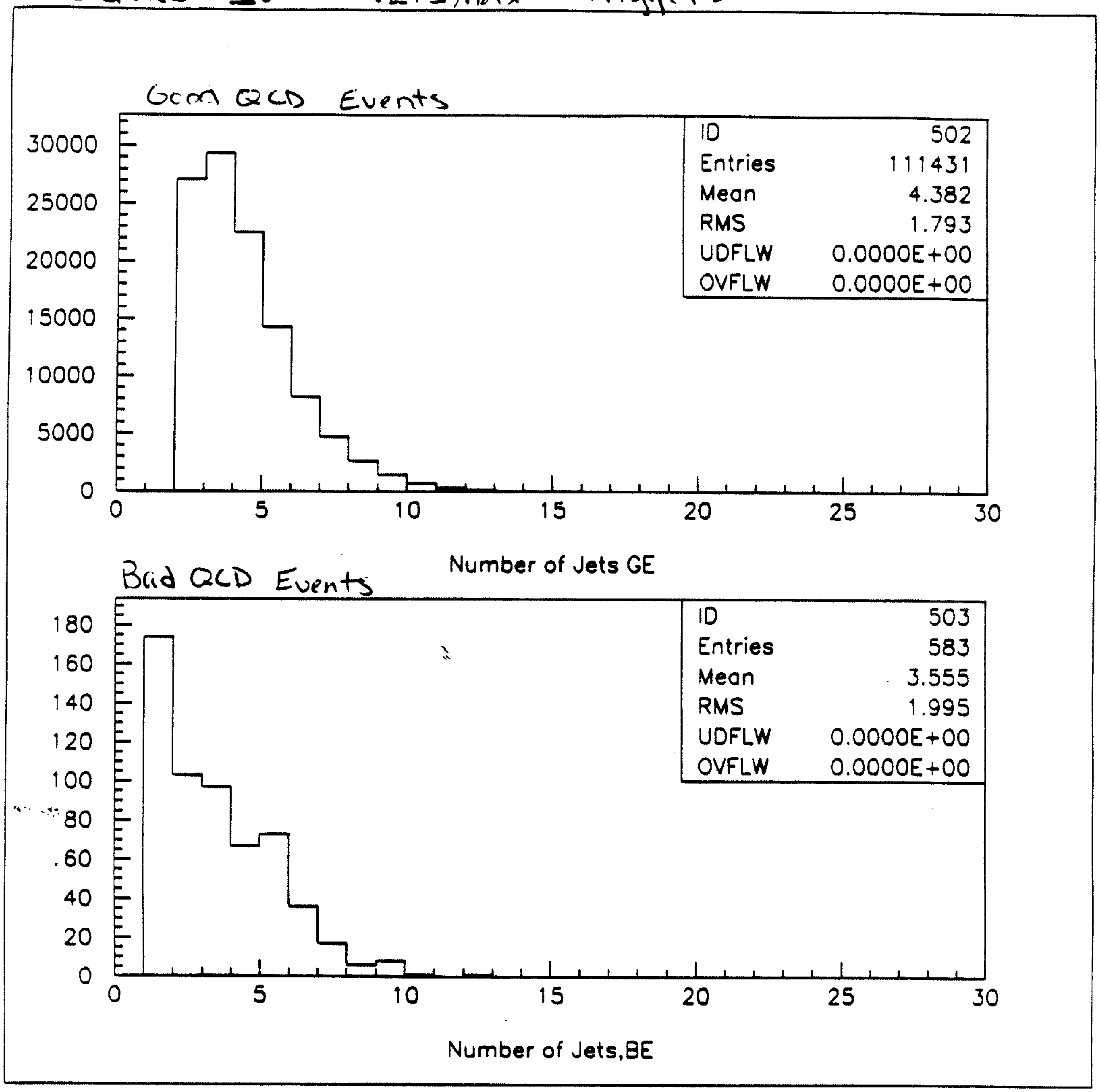


FIGURE 2a: JET_MAX Triggers, Events w/at least 1 HC

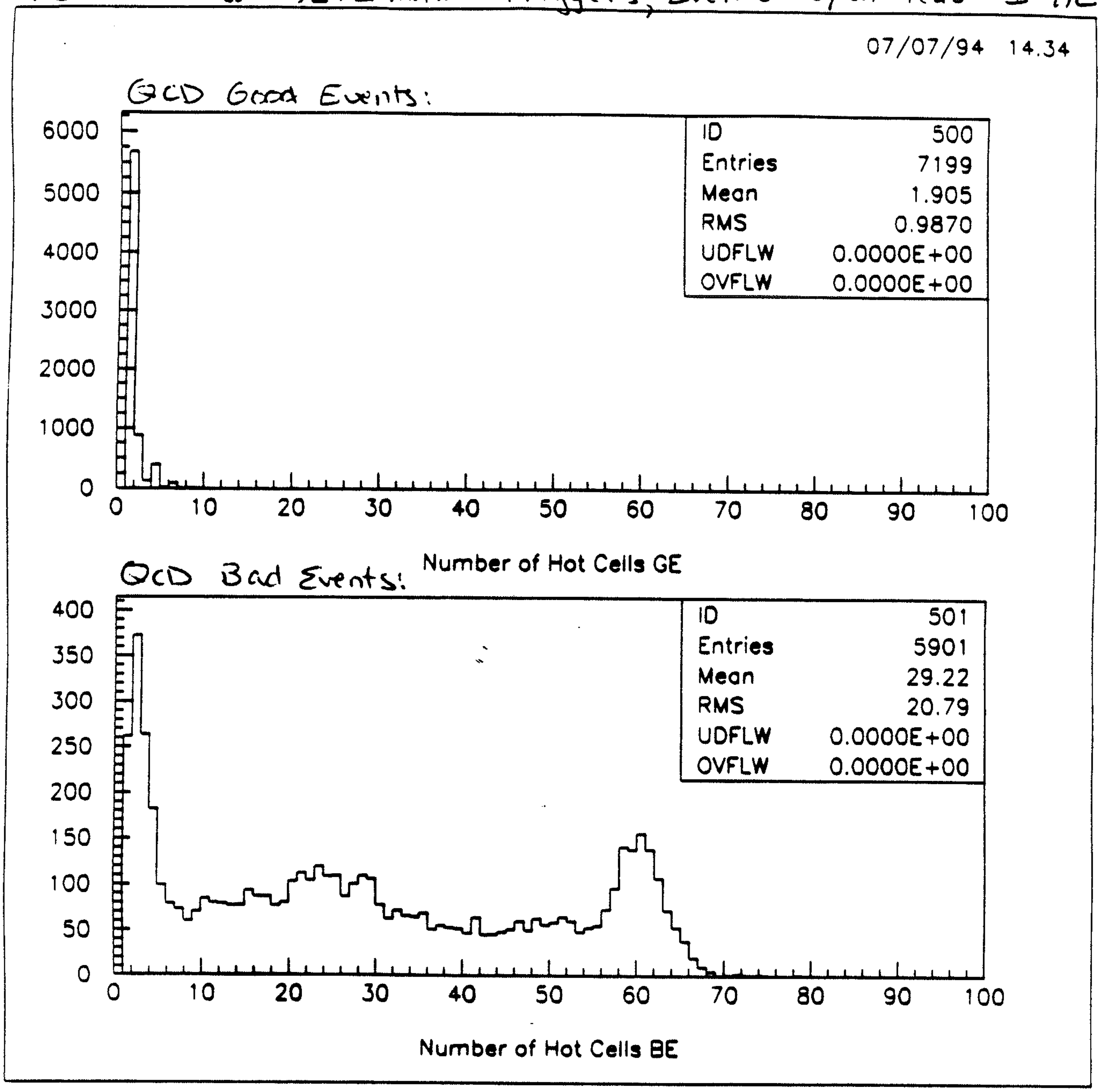


FIGURE 2b: JET-MAX Triggers, Events w/at least 1 HC

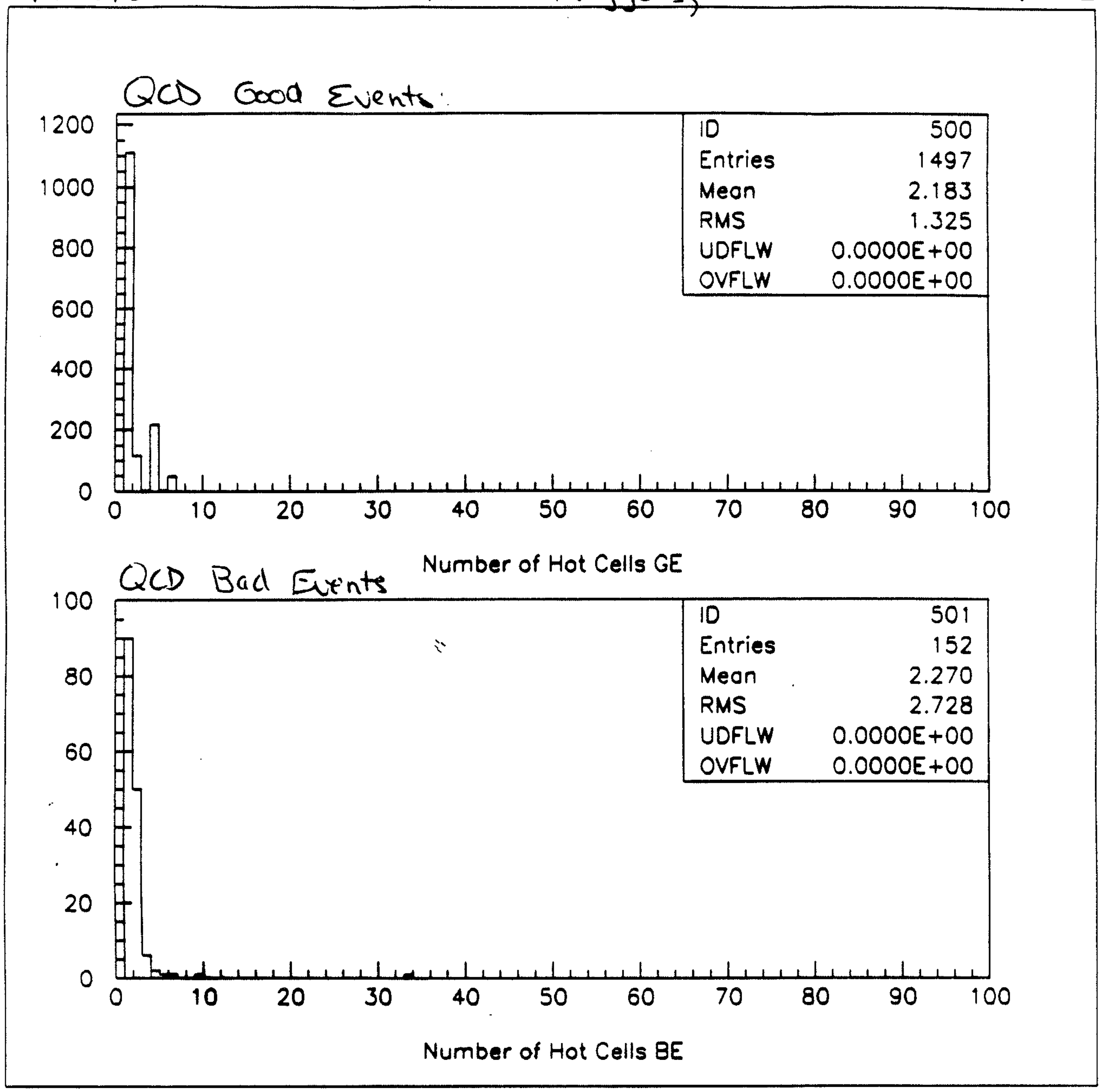


FIGURE 3a: JET-MAX Triggers, Events w/at least 1 HC

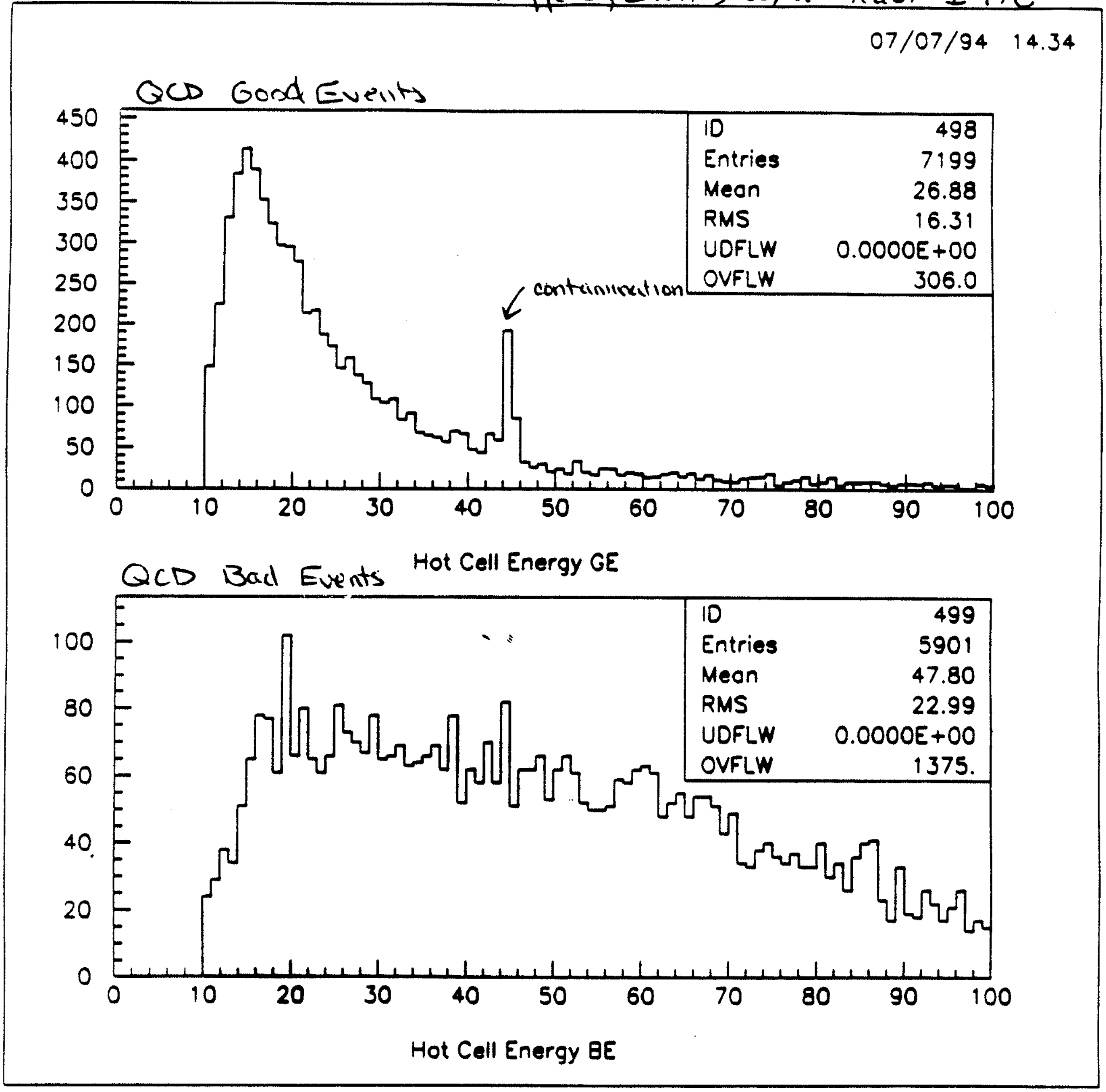


FIGURE 3b: Jet_Max Triggers, Events w/at least 1 HC

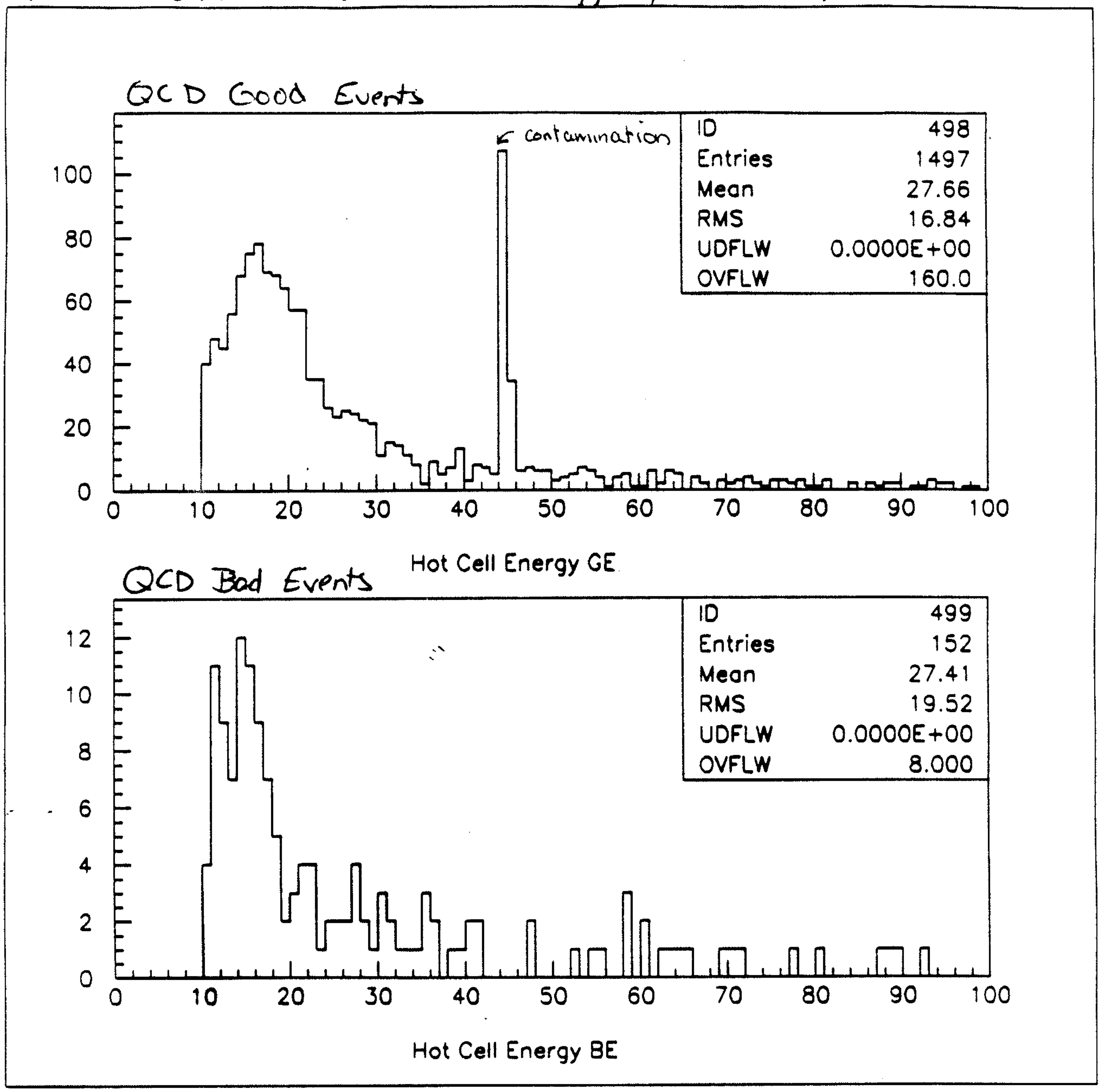


FIGURE 4: JET_MAX Triggers

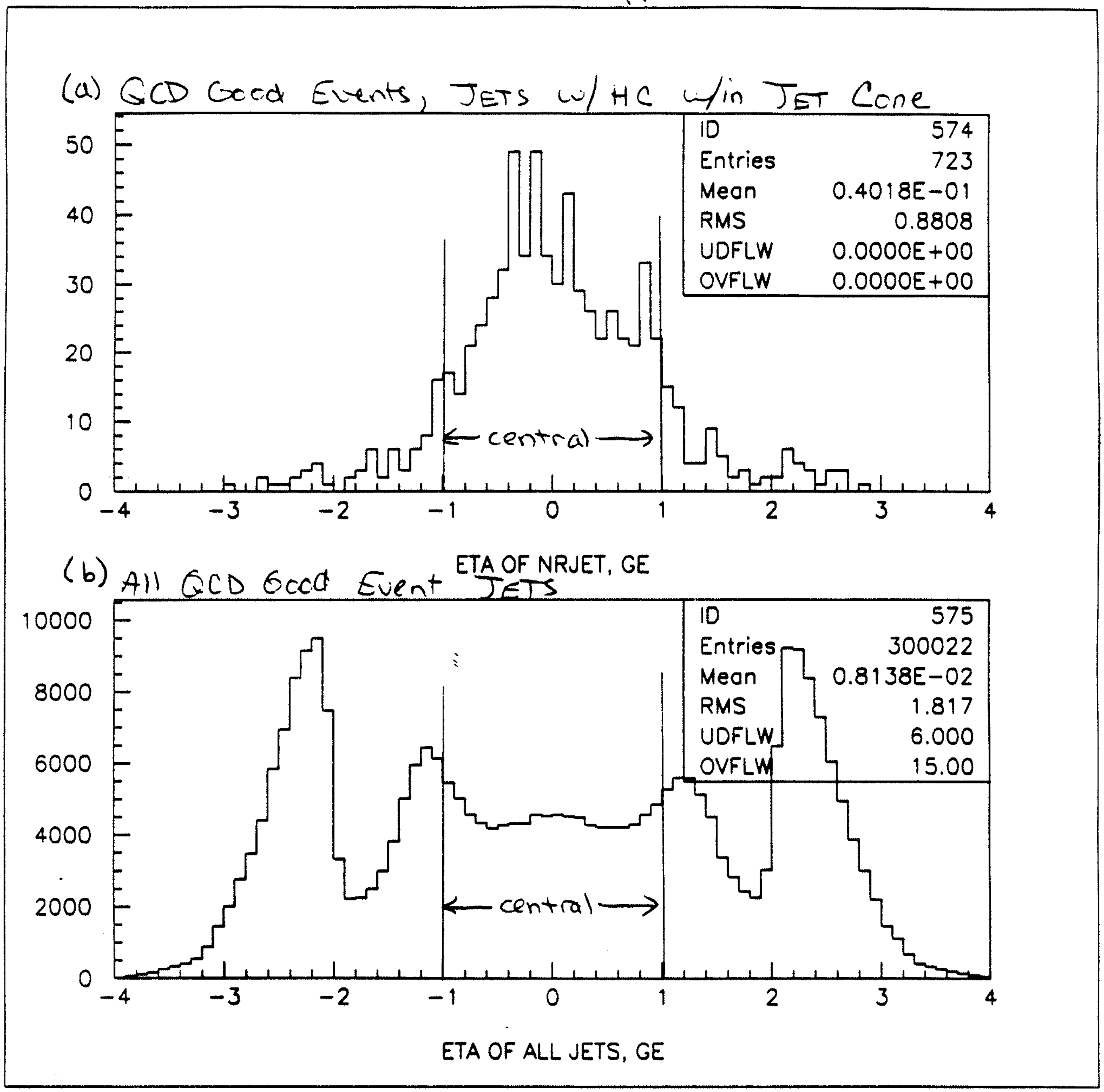


FIGURE 5: Jet_Max Triggers

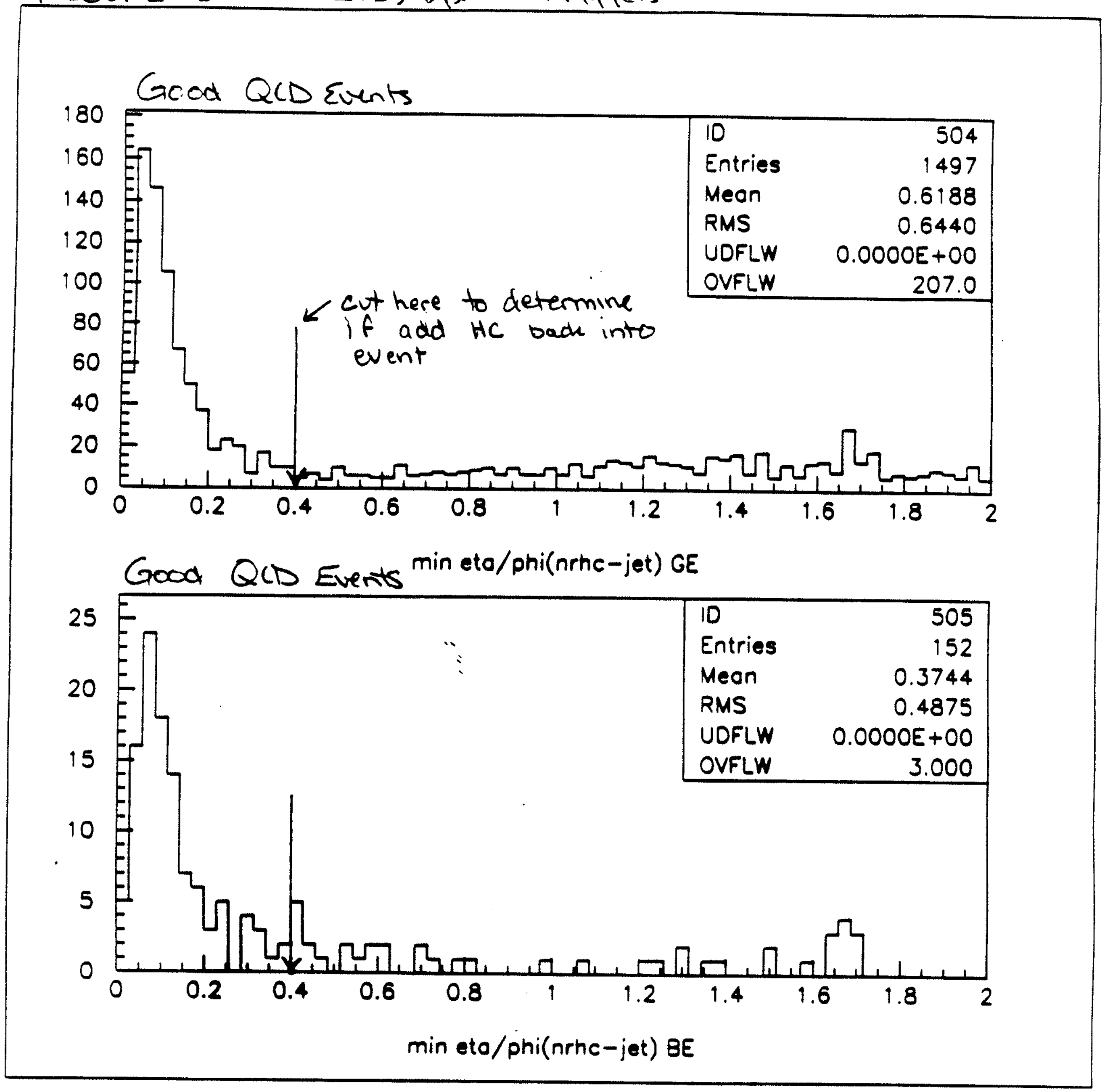
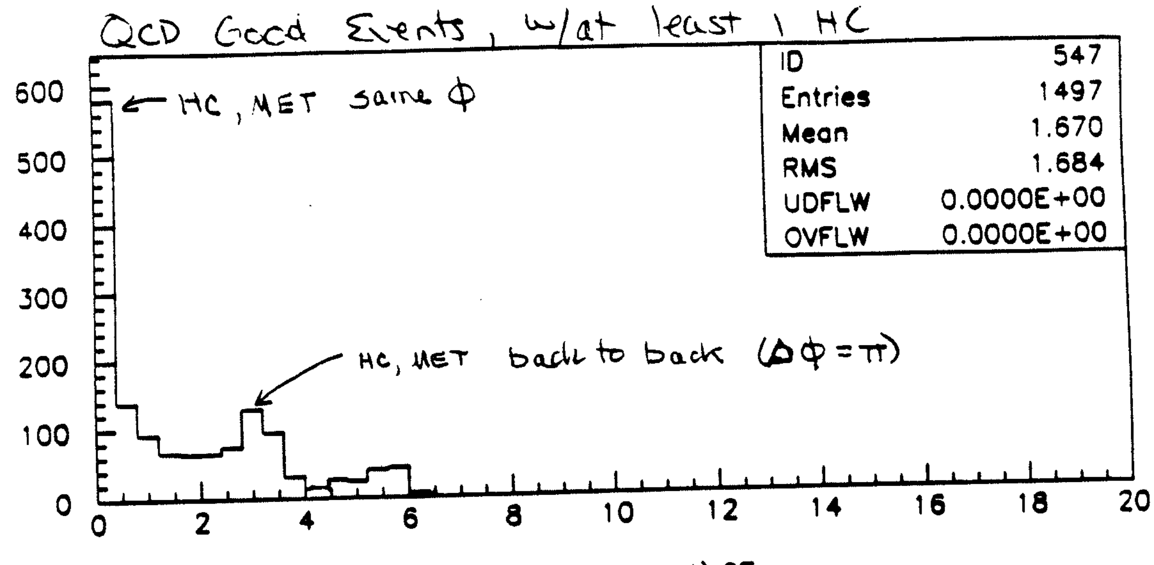


Figure 6: JET-MAX Triggers



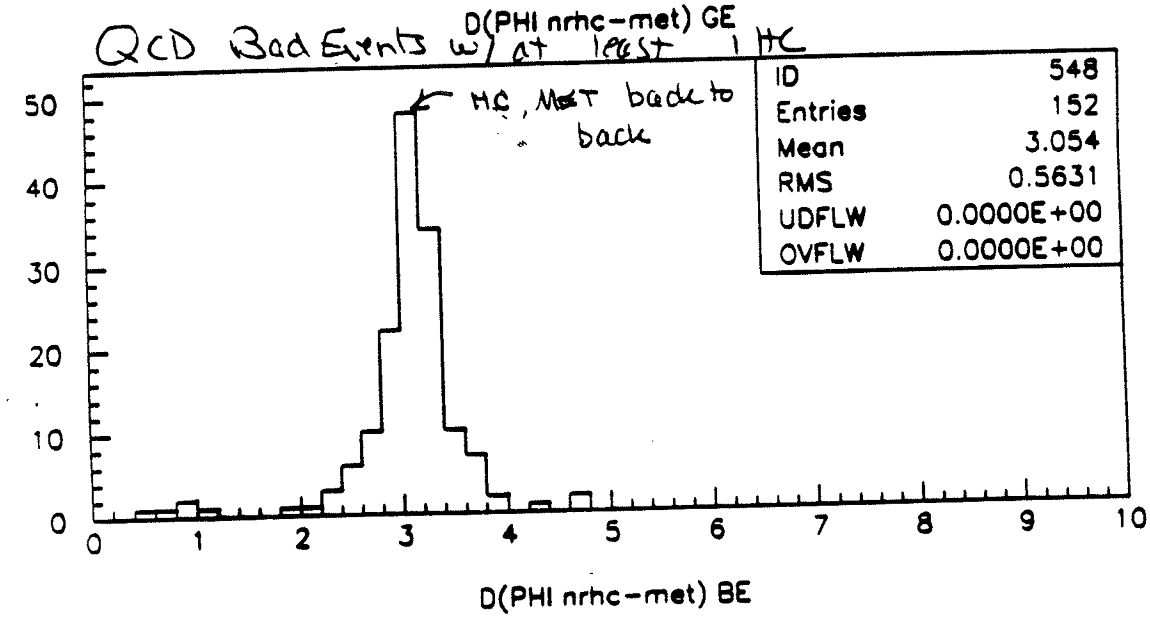


FIGURE 7: JET_MAX Triggers

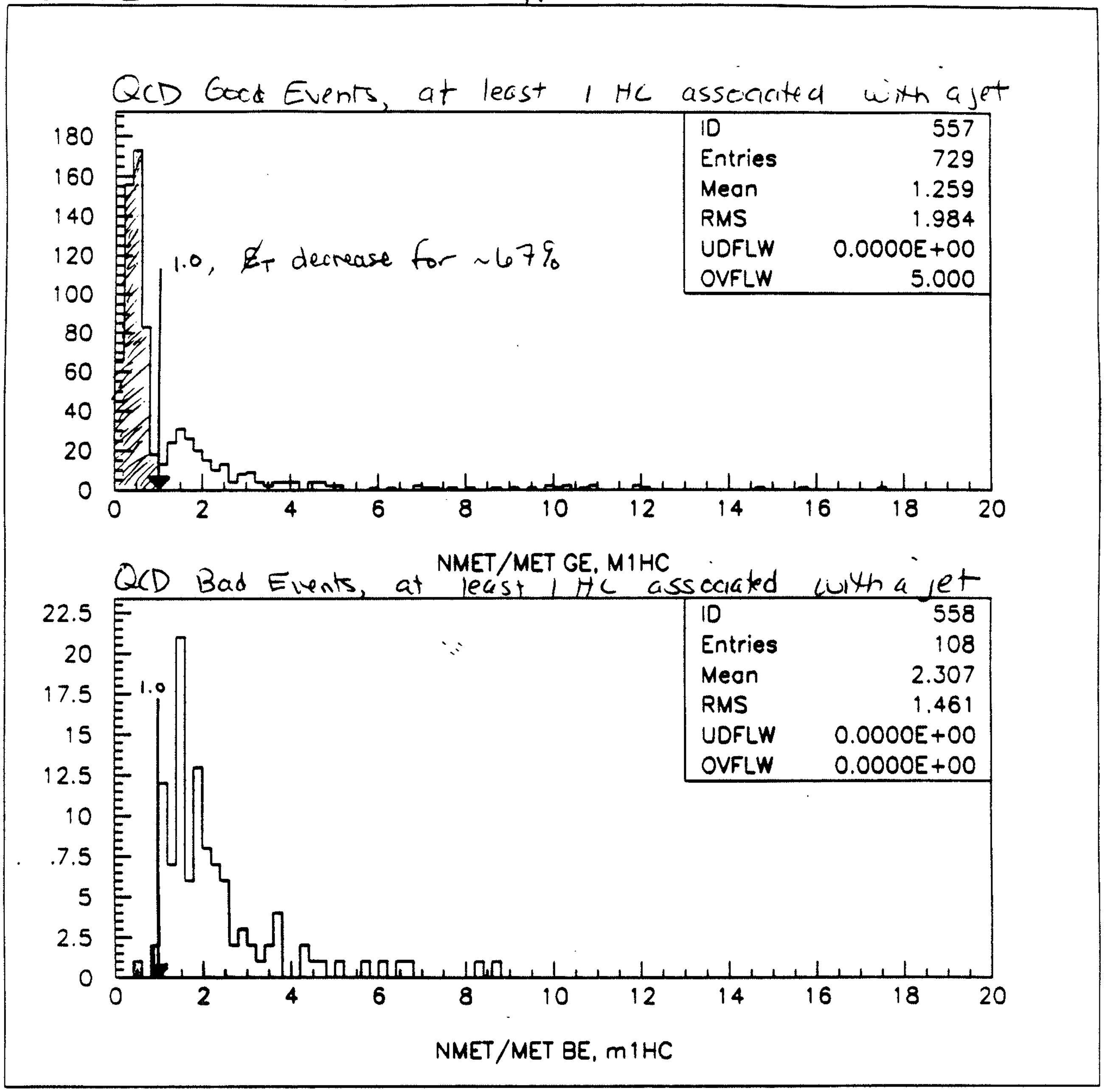
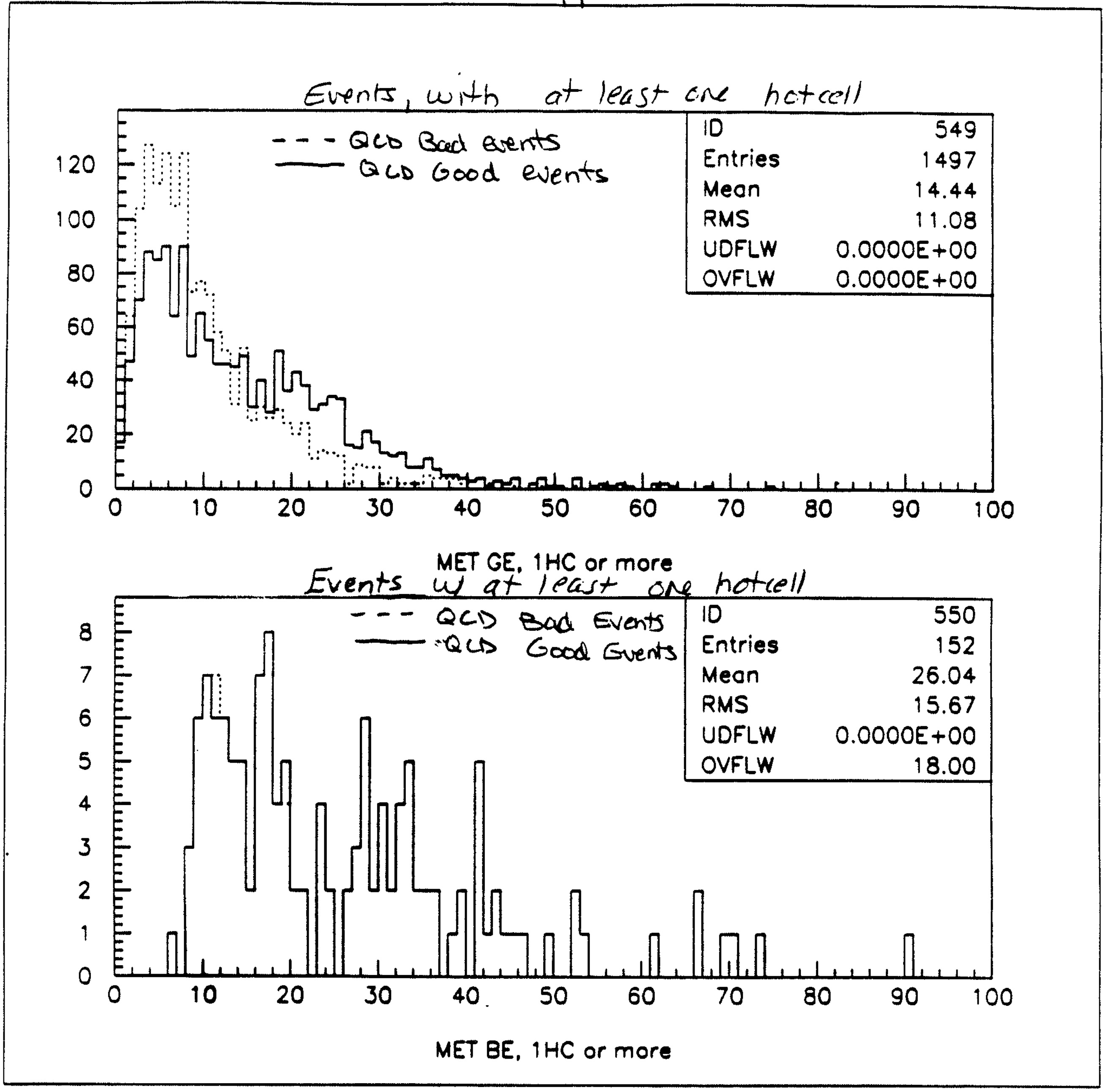


FIGURE 8: Jet_Max Triggers



JET-MAX Triggers

Figure 9a: Missing E_T for All events w/ at least 1 HC

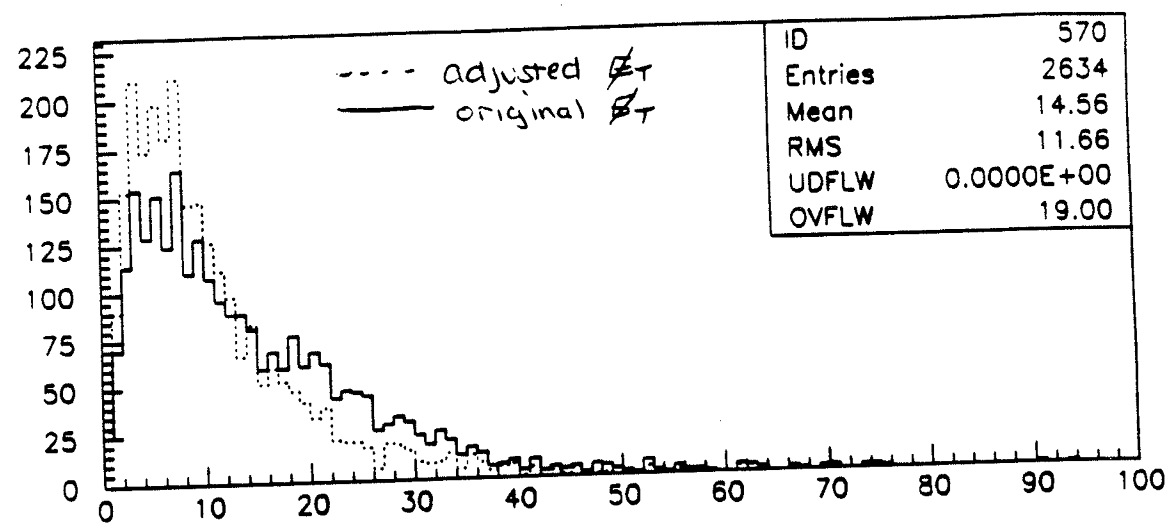


Figure 9b: Missing E_T for all Good QCD Events

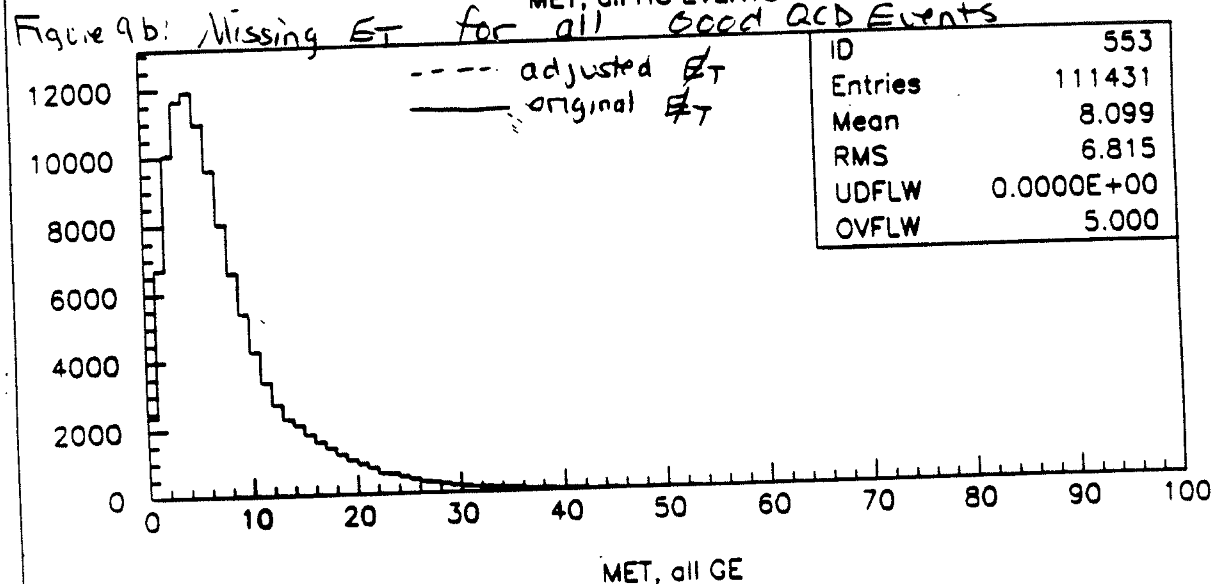


FIGURE 10: JET-MAX $-0.9 \le \eta_{jet} \le 0.9$

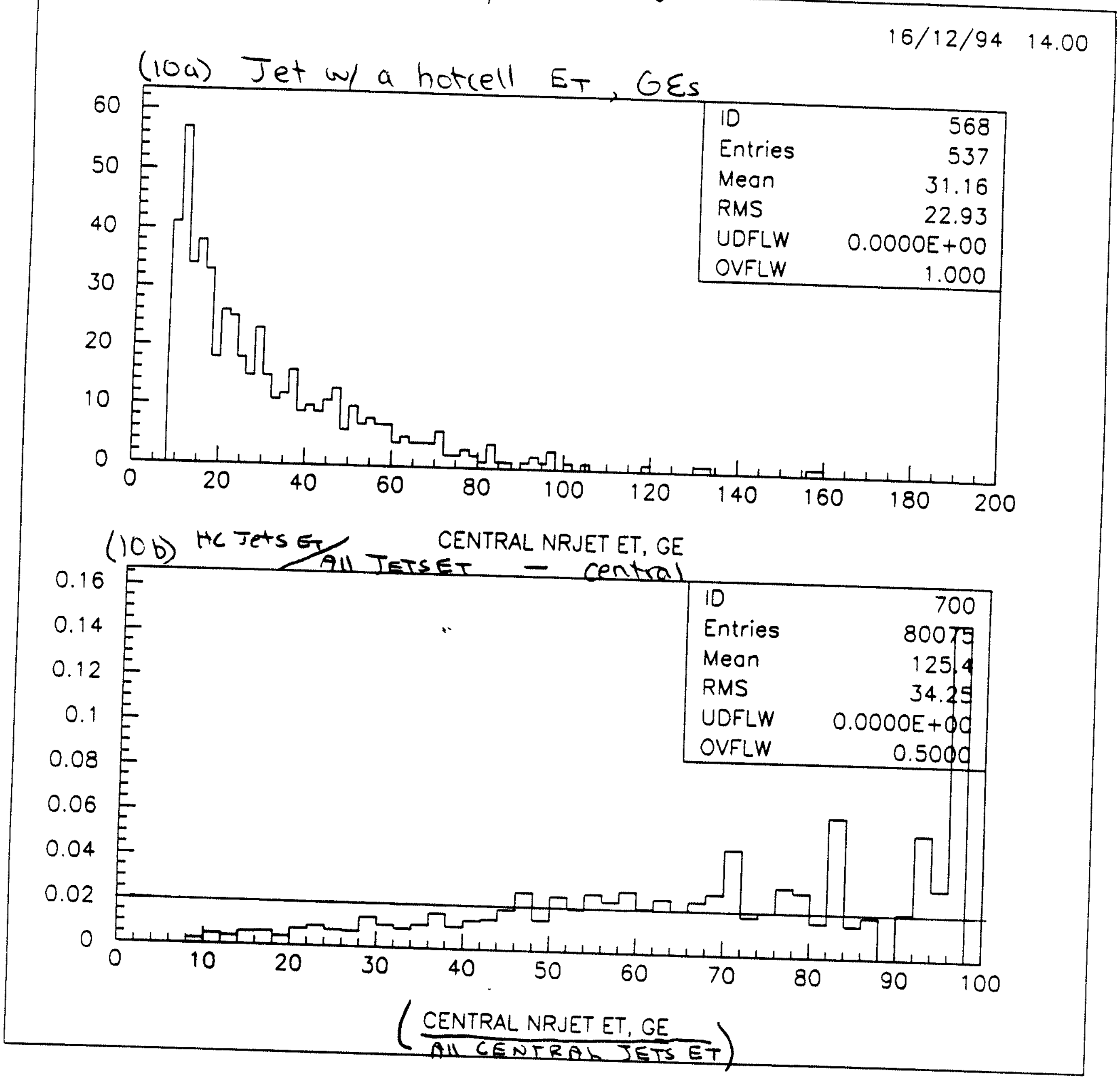


FIGURE 11: JET-MAX Triggers

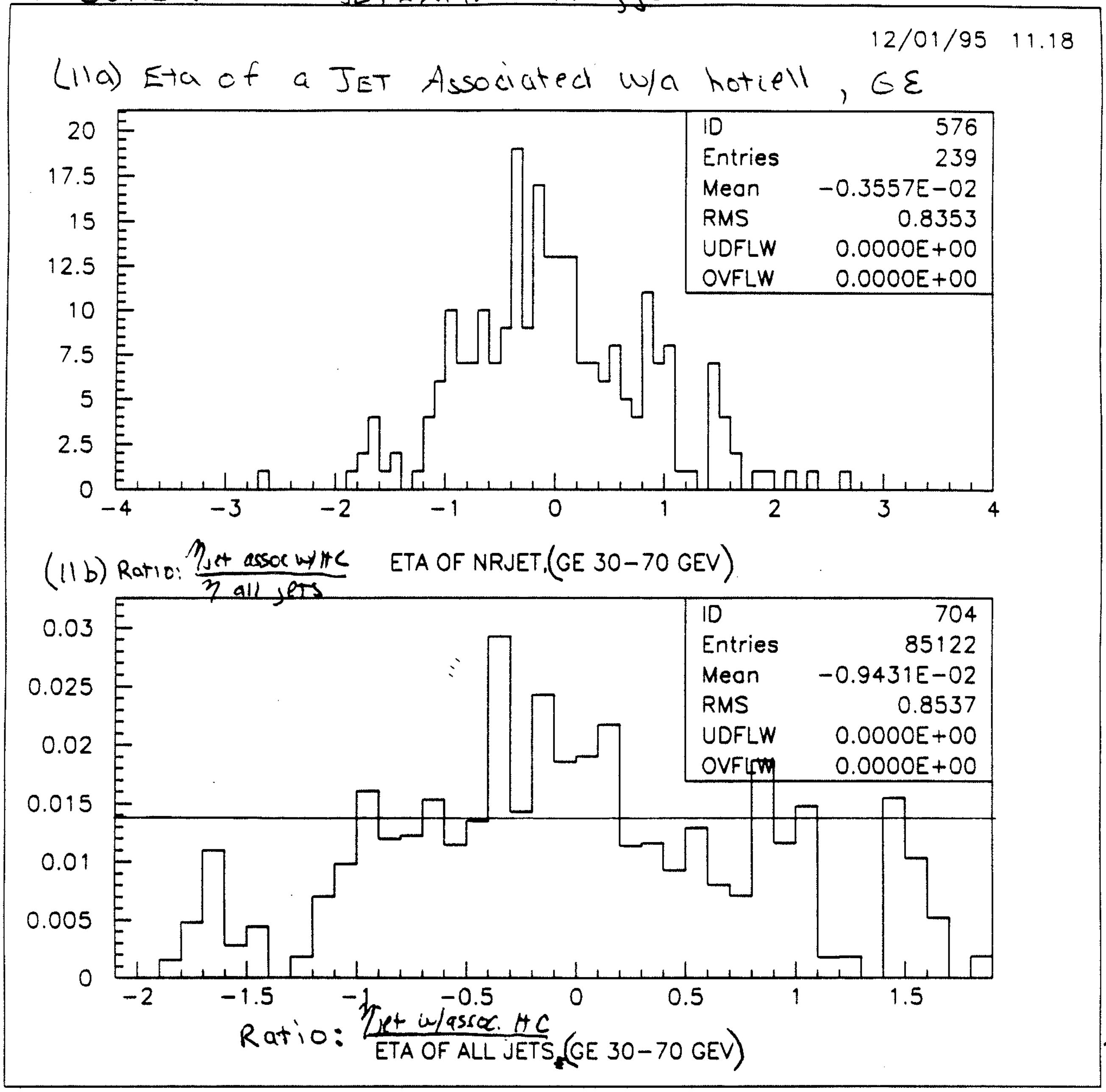


FIGURE 12: Ratio = (Hotcell energy / matching trigger tower energy)

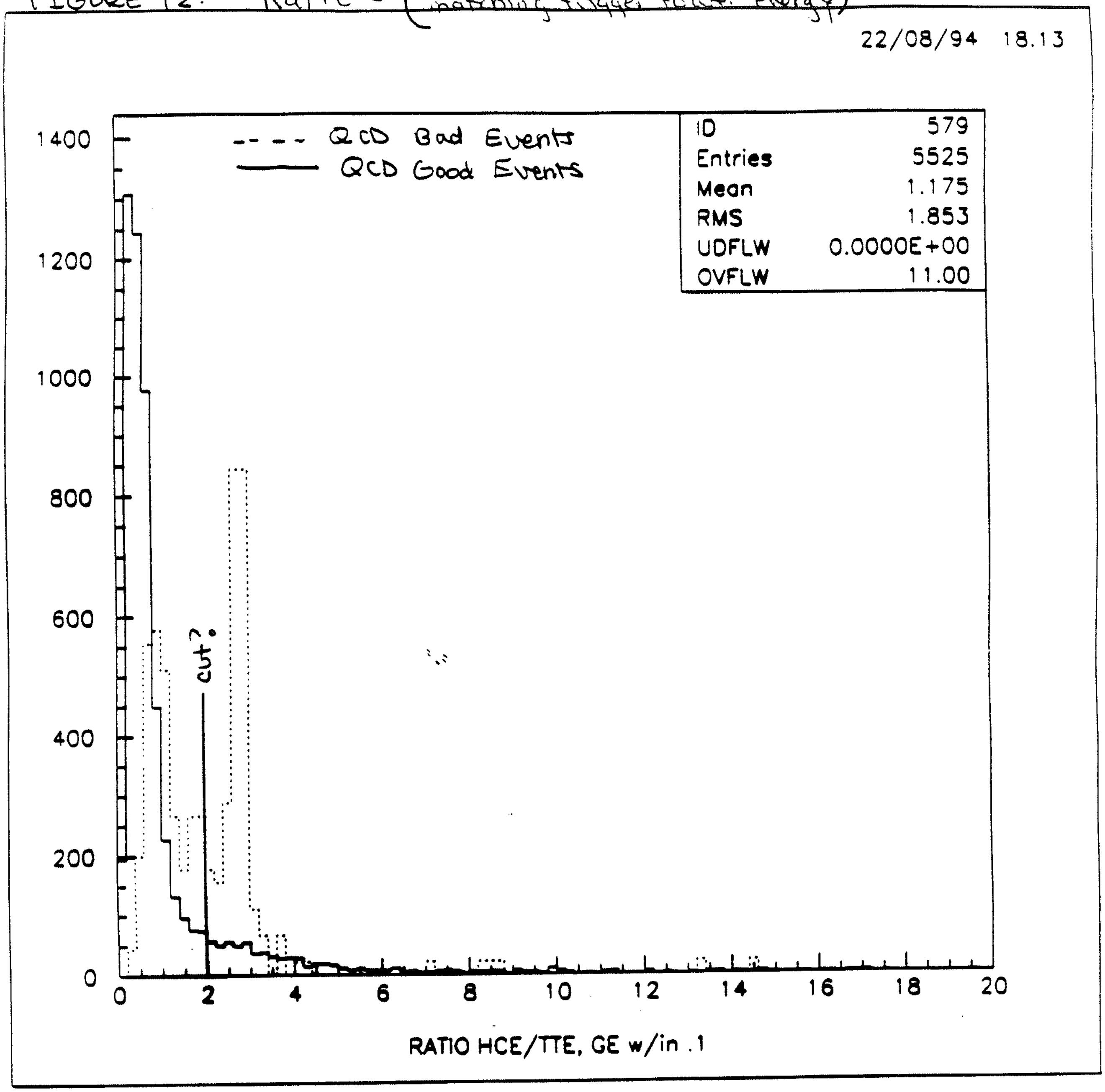


Figure 13: Events within 0.1 η/ϕ of a Trigger Tower