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Data Cleaning: The In-time Channel (ITC) Cut

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Abstract

In this report, a time spread cut independent of PMT hit geometry is developed for the data cleaning group. The cut is primarily designed to tag so-called "flat-TAC" events occurring in the detector. This is a cut based on the fraction of in-time hits in an event, using an appropriately constructed sliding time window to count the number of in-time channels in the hit PMT spectrum. The cut was tested on ^{16}N calibration data and flat-TAC events from a burst in production neutrino run 10700 and found to tag $\sim 99\%$ of the flat-TAC data with only minimal sacrifice of ^{16}N events (fewer than 0.04% inside 8 m). It was also tested on the standard data cleaning set to determine how much of the benchmarking data is tagged by the cut.

1 Introduction

The majority of hit PMTs in Cerenkov light events are "close" in time due to the short duration of the Cerenkov light pulse for electron energies relevant to solar neutrinos. This suggests that a time spread analysis of events may be useful in discriminating between events from Cerenkov light and certain types of instrumental background. The Fitterless Time Spread (FTS) Cut uses as a cut statistic the median time difference between hit PMTs which are close to each other in the detector to reject events due to flasher light that are not easily identified by other cuts. As a blind flasher cut, the FTS cut uses specific time spread and PMT hit geometry criteria to cut a large fraction of these events without a significant sacrifice of good Cerenkov physics data. However, for identifying other types of background, this cut is too restrictive and a simpler time spread cut which is independent of hit PMT geometry is required. This is particularly true to cut so-called "flat-TAC" events which tend to get missed by the FTS cut despite their large time spread because the hits are diffuse in the detector and therefore do not typically contain enough "close" hit PMT pairs to calculate a meaningful median time difference. The In-time Channel (ITC) Cut uses as a simple statistic the maximum fraction of hits in a sliding time window of suitable width to identify events having a time spread significantly larger than is characteristic of events from Cerenkov light in the detector.

This report is organized in the following way. The ITC cut is motivated and described in Section 2. The standard data sets used by the data cleaning group are described in Section 3 and the results of applying the ITC cut to these data are presented in Section 4. The final results are summarized in Section 5 along with some conclusions and recommendations about the cut. Finally, Appendix A contains a description of how to use the cut as a hardwired filter within SNOMAN.

2 Description of the ITC cut

2.1 Motivation

In events from Cerenkov light, the vast majority of hits occur in a time window which is comparable to the transit time of light across the detector. The fact that most hits are "in-time" for "good" physics events is simply a consequence of the sharpness of the Cerenkov light pulse and because most PMT hits are due to direct or small angle scattered photons. However, the study of a large number of Cerenkov physics events (using 6 MeV γs from the ^{16}N calibration source) suggests that this simple characteristic can be turned into a powerful way of rejecting some background events based on their PMT time spectra alone.

The fact that the majority of hits in Cerenkov light events are in-time is shown in Figure 1, which contains "ITC ratio" distributions for the ^{16}N calibration source at the center of the detector and at z = - 6 m. The ITC ratio is ratio of the maximum number of hits in a sliding "in-time" window to the NHIT of the event. The width of the in-time window used in this

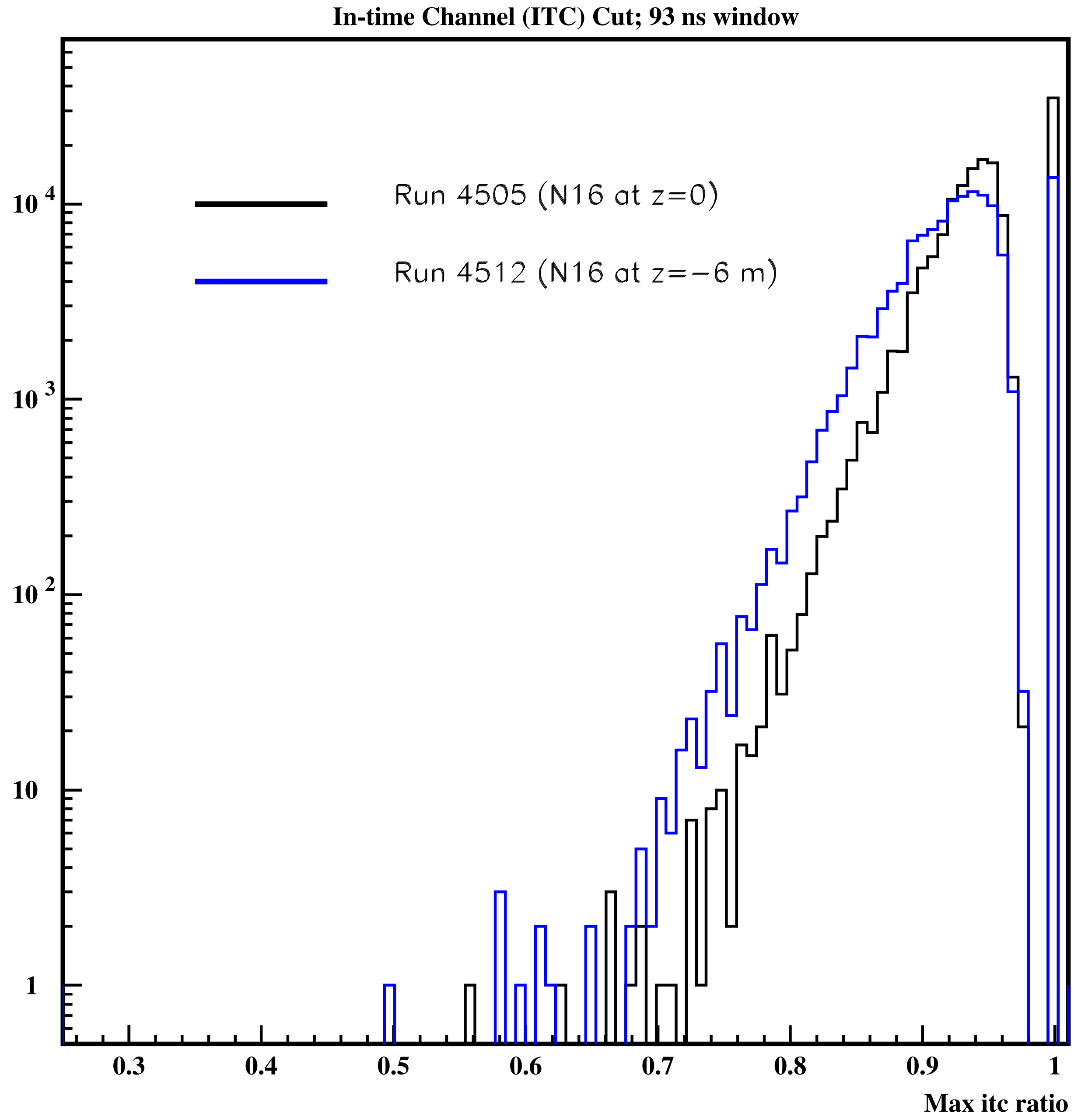

Figure 1: Distribution of ITC ratio for the ^{16}N calibration source at the center of the detector and at z = - 6 m.

section is 93 ns, which corresponds to the NHIT trigger coincidence time determined by the average width of the analog trigger primitives summed together in the system. This width is used as a reasonable example to motivate the cut, and the sensitivity of the ITC ratio to the choice of in-time channel width is investigated later in this section.

Figure 1 shows that the majority of ^{16}N have an ITC ratio close to unity. There is a slight distortion in the ITC ratio distribution when the source is moved from the center of the detector to z = -6 m, which is due to geometric effects in the arrival time of the direct and reflected light. The gap in the distribution near ITC ratio = 1 is due to the fact the we are computing a ratio of integers where the denominator (i.e. NHIT) is within a finite interval, and will get filled in as the NHIT of the event increases. From the ITC ratio distributions shown in Figure 1 for ^{16}N data, we expect very few Cerenkov physics events to have an ITC ratio less than about 0.6 - 0.7 (for a 93 ns in-time channel window width). These values of the ITC ratio are significantly larger than the limit of $\sim$ 0.25 for a uniform TAC distribution, which is set by the width of the in-time channel window (93 ns) and the average length of GTVALID ($\sim$ 390 ns) for the channels, so we expect to be able to reject some types of instrumental background having broad TAC spectra with little sacrifice of Cerenkov physics data.

One such background which has caused problems in recent neutrino data taking is bursts of the so-called "flat-TAC" events. These events have been identified because they tend to come in bursts which can cause trigger rate instabilities, but no one actually knows whether they only happen in bursts or represent a more pervasive contribution to our neutrino background. As an example, a flat-TAC burst occurred in neutrino run 10700 and the associated rate instability can be seen in Figure 2. In scanning through the events during the burst period ($800000 < GTID < 1100000$), it is apparent that the data is dominated (during the burst) by events having single p.e. charge, indicating the hits are due to real light in the detector, and flat or nearly flat TAC spectra. The NHIT of the events in the run 10700 burst fall into the region which is interesting for solar neutrinos ($50 < NHIT < 150$) as shown in Figure 3. While a burst cut should identify a (probably large) fraction of these events, the fact that they have normal charges and occupancies in the middle of the solar neutrino region should cause some concern that flat-TAC events *not* associated with significant bursts may not be identified by other data cleaning cuts. This is actually not completely true, since

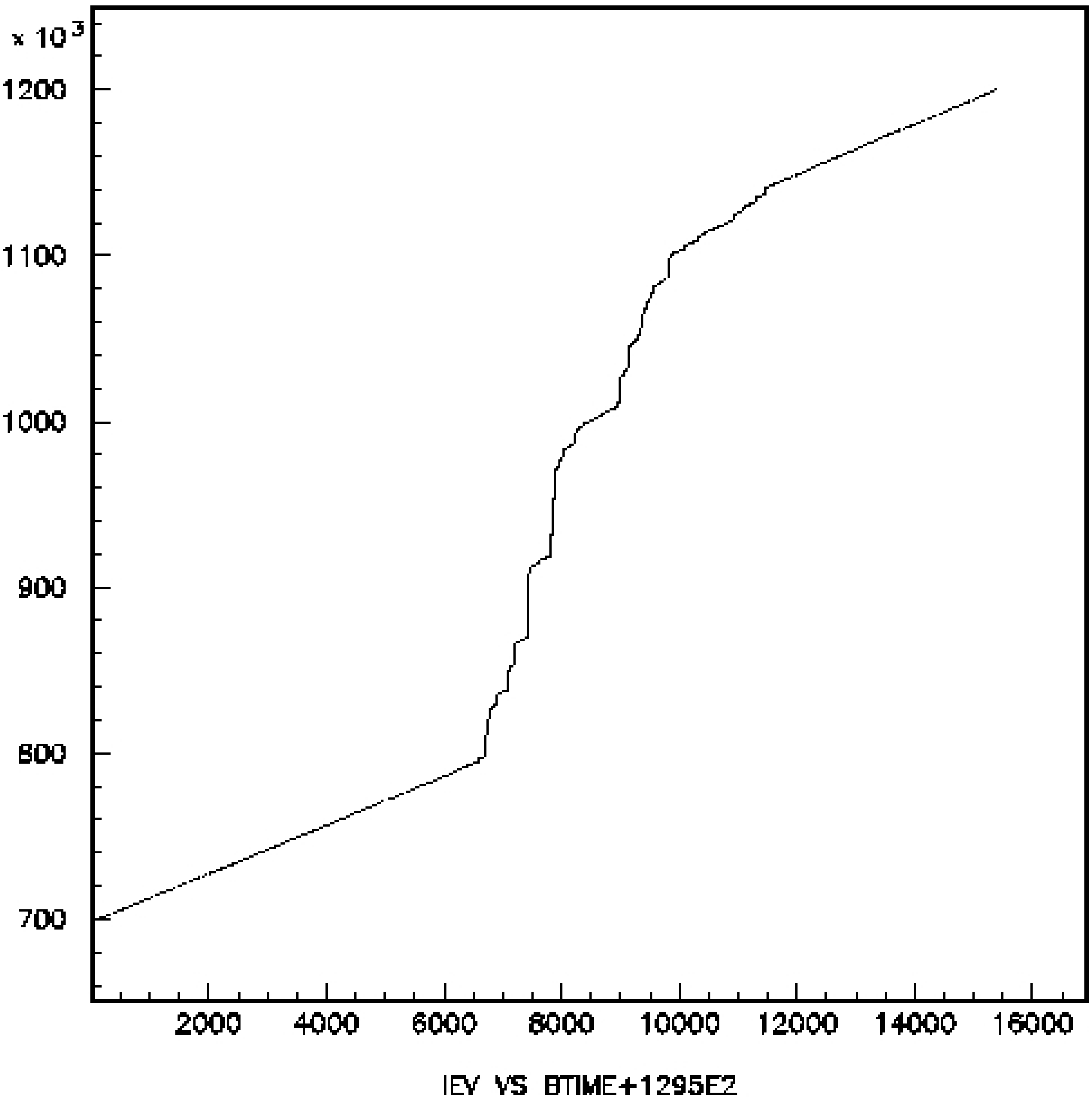

Figure 2: Global trigger ID number versus 50 MHz time (in nanoseconds) showing the burst of flat-TAC events which occurred during run 10700.

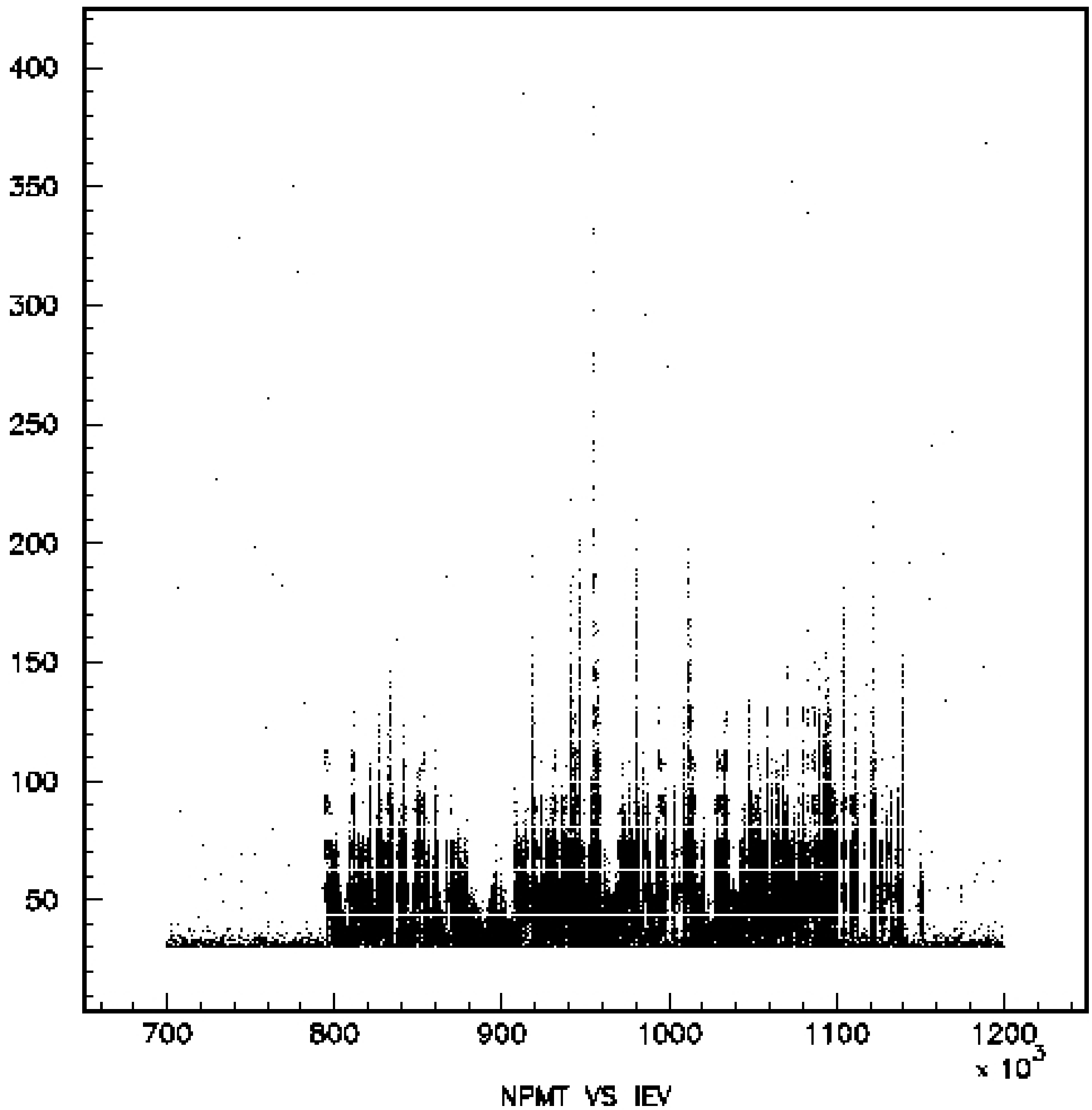

Figure 3: NHIT versus Global trigger ID number during the burst of flat-TAC events occurring in run 10700. Only events with NHIT > 30 are shown.

it turns out that most of the flat-TAC events also light up a number outward-looking tubes and so the OWL cut may have some non-negligible efficiency for identifying these events as well, however it is still important to have a cut to take advantage of the broad TAC spectra of these events.

The fact OWLs light up during the flat-TAC bursts is a interesting clue toward understanding the source of these events. An additional clue was provided by a recent flat-TAC burst caught by Noel on 2/29/2000 during run 11384 which actually caused the HV on crate 0 to trip. It was then found that 0/5/ch21 had no CMOS rates or base current under HV (i.e. was dead), which suggests that flat-TAC bursts are probably associated with light coming from a PMT base during its demise.

Figure 4 shows a plot of ITC ratio versus GTID for a portion of run 10700 (N100MED triggered, NHIT > 30) which contained the flat-TAC burst. It is clear from the figure that the ITC ratio distribution changes abruptly during the flat-TAC burst period toward lower ratios indicating a flatter overall TAC spectrum of hits.[1] It also appears that just after GTID $= 1000 \times 10^3$ there is a small gap and then a short period where the ITC ratio goes up to between 0.6 and 0.9. It was originally conjectured that this was due to some seismic flasher burst interleaved with the flat-TAC burst, but this does not appear to be the case from hand scanning these events. Instead, these large ITC ratio events appear to be part of the flat-TAC burst events since they typically have several OWL tube hits and occur at a much higher rate than the nominal rate before and after the burst. This points out that the ITC cut alone will not remove all the flat-TAC events and so we need to be sure that some combination of the other pass 0 cuts can remove these high ITC ratio events. As previously mentioned, the flat-TAC events are dangerous in terms of their NHIT and normal charge characteristics, so while a burst cut should identify a large fraction of the obvious events, an intermittent sprinkling of these events could pose a serious problem for data cleaning.

Figure 5 shows ITC ratio distributions for the events in run 10700 around the flat-TAC burst and for ^{16}N calibration data. Notice that while the ITC ratio distribution in run 10700 before the burst resembles the ^{16}N distributions, during the burst the ratio is greatly

[1] It should be noted that a small value of the ITC ratio does not necessarily imply that the underlying TAC spectrum is flat. For example, consider a bimodal distribution with the peaks separated by a time greater than the in-time channel width, which would have a ratio of 0.5. In the case the run 10700 burst, however, XSNOED scanning indicates that the TAC spectra really are nearly uniform.

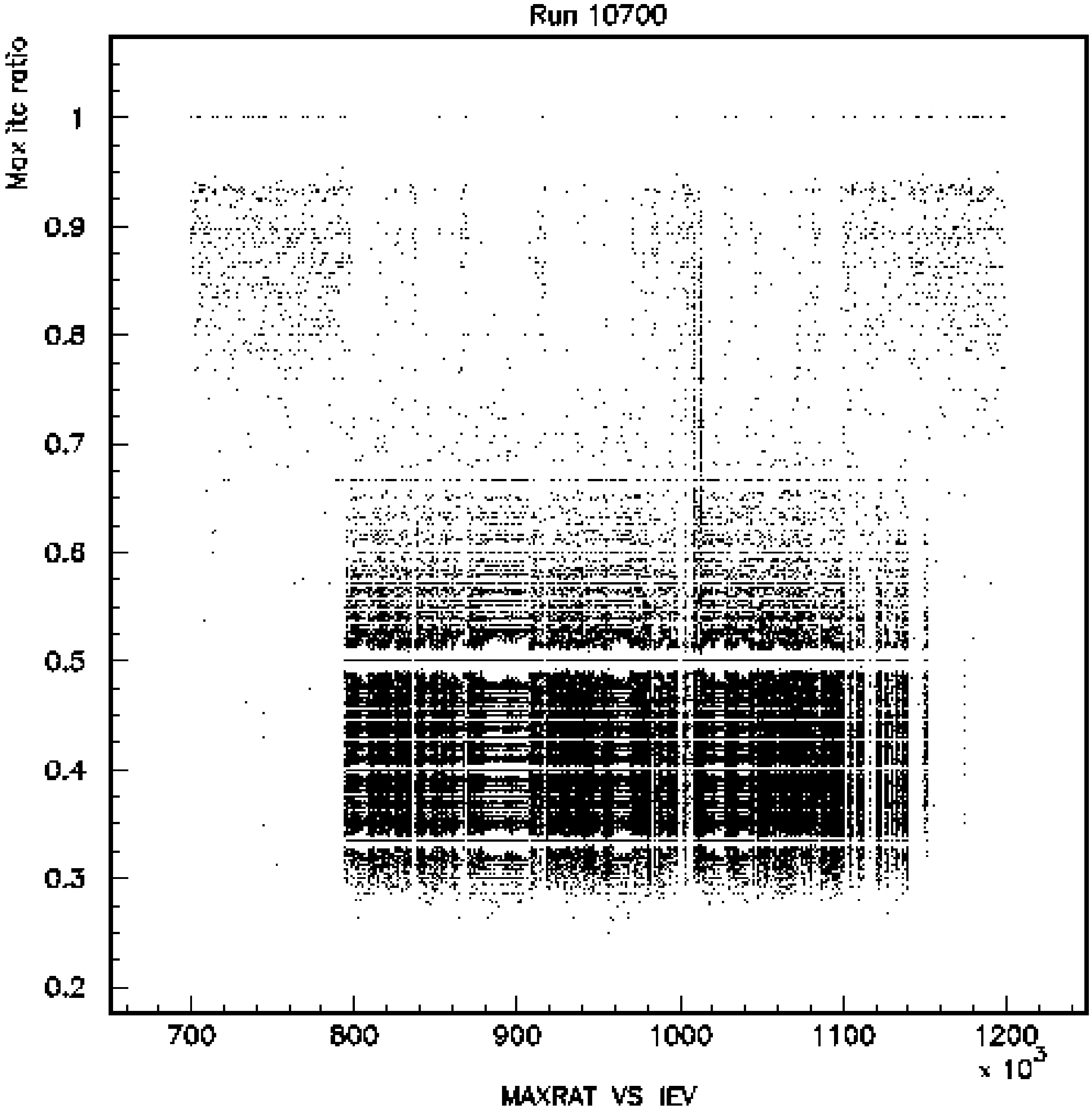

Figure 4: Plot of ITC ratio versus global trigger ID number, showing the much smaller value of the ITC ratio for events in during the flat-TAC burst.

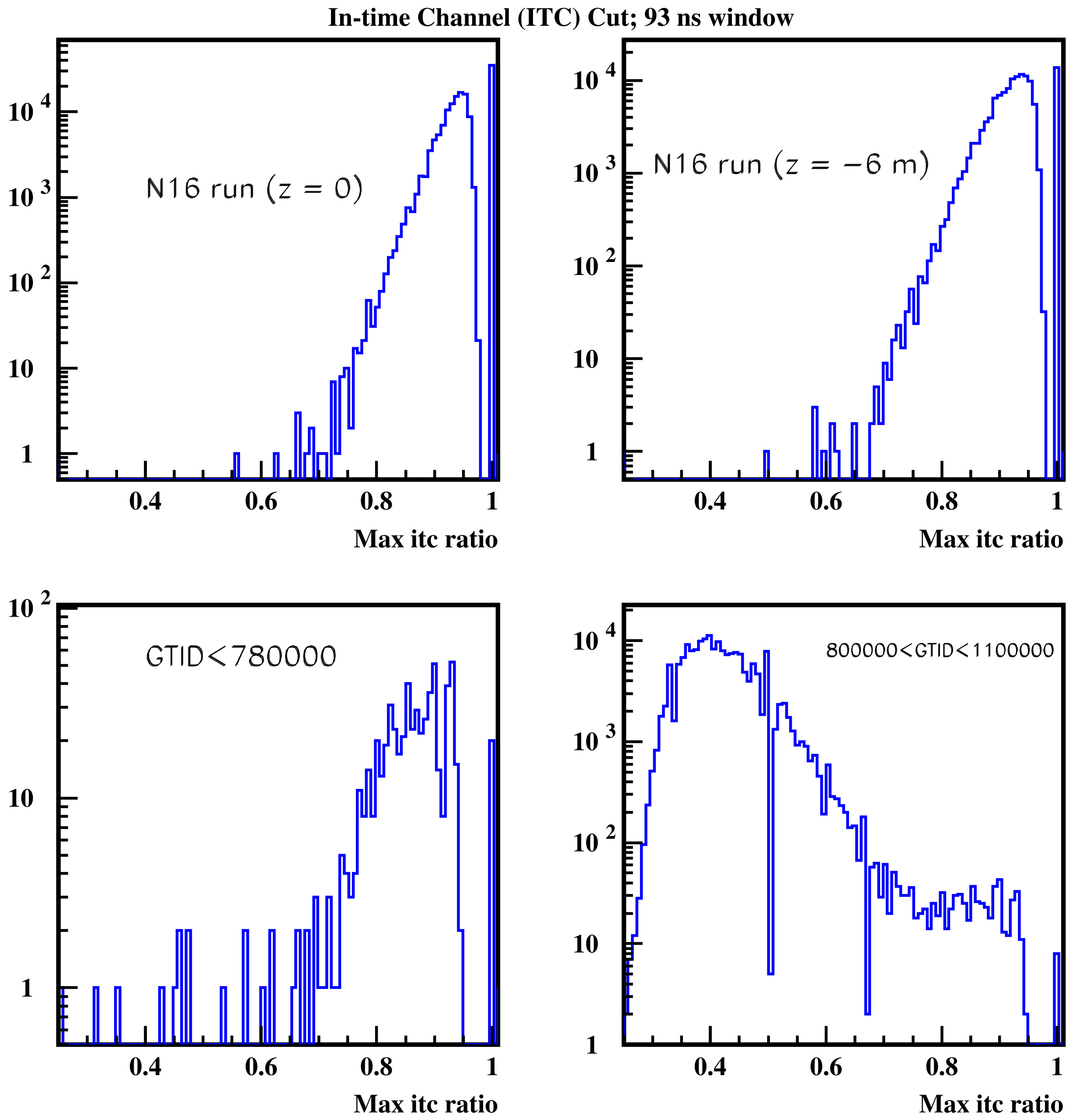

Figure 5: Distribution of ITC ratio for ^{16}N calibration data (top) and events in run 10700 before (bottom left) and during (bottom right) the flat-TAC burst.

reduced, suggesting this in-time channel method is a feasible way of rejecting the majority of flat-TAC events with minimal sacrifice of Cerenkov light events.

2.2 Cut Algorithm

In this section, a brief outline of the cut algorithm as currently implemented in SNOMAN (version 3.0192) is given. A more detailed description with specifics about how to run the cut and alter cut parameters is given in appendix A.

The algorithm of the ITC cut is very simple. There is a loop over all the hits in the event which stores all successfully PCA calibrated channel into an array for processing. Therefore, the ITC cut in its current form relies on the ECA and PCA constants applied for timing calibration of the channels, although in principle it should be less sensitive to PCA calibration than the FTS cut. A sliding window of appropriately chosen width is applied to the PMT times of the event to count the maximum number of hits in any time position of the window. This is considered the number of "in-time" channels in the event. The step size used in sliding the in-time channel window is by default 1 ns, but this is a parameter in the cut which can be changed by the user, if so desired. The cut statistic is the "ITC ratio", which is the fractional number of in-time channels in the event,

$$\text{ITC ratio} = \frac{\#\ in-time\ channels}{\#\ hits\ passing\ ECA + PCA\ calibration}$$

Events are *failed* (i.e. tagged as *bad*) if their ITC ratio is less than a user-defined value, otherwise they are *passed*.

2.3 Estimation of Optimal Cut Parameters

In this section, the optimal values of the main ITC cut parameters are estimated using ^{16}N calibration data and events from the run 10700 flat-TAC burst previously described in Section 2.1. The current implementation of the ITC cut has only two parameters worth optimizing - the width of the sliding in-time channel window and the cut threshold for the ITC ratio. Figure 6 shows the ITC ratio distributions for ^{16}N data and the run 10700 flat-TAC burst using in-time channel widths of 33, 93, 163, and 243 ns. Note that the position dependence of the ITC ratio gets stronger as the in-time window width is reduced, particularly for the 33 ns window which is considerably smaller than the transit time of light

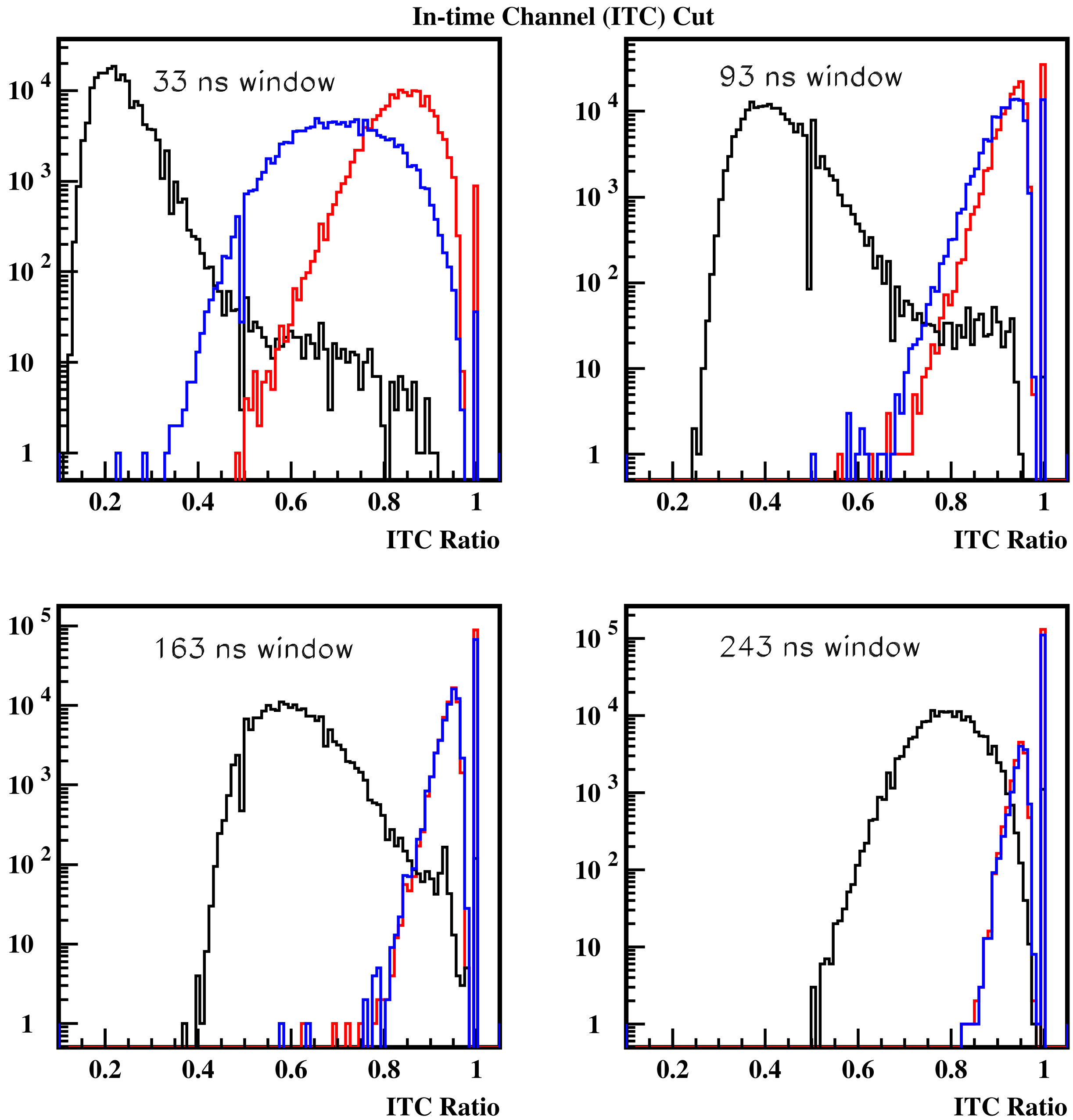

Figure 6: Distribution of ITC ratio for ^{16}N data (z = 0 in red, z = -6 m in blue) and events during the flat-TAC burst of run 10700 (in black), shown for several values of the sliding in-time channel window width.

across the detector ($\sim$ 70 ns). It is also evident from the figure that the distributions shift toward unity as the window width is increased (for obvious reasons) and that this effect is stronger for the flat-TAC events than it is for ^{16}N events which are already near unity.

These qualitative observations from Figure 6 can be made more quantitative by looking at the fraction of flat-TAC events which would be tagged by the ITC cut if the ITC ratio threshold was set to tag a small fraction of ^{16}N events. This is shown in Figure 8 for values of the ITC ratio threshold set to tag 0.1% and 0.05% of the ^{16}N data in runs 4505 (z = 0) and 4512 (z = -6 m). First notice that the fraction of tagged events during the flat-TAC burst is very high - 98% to 99.9% over the large range in in-time window widths shown in the plot. Therefore, in trying to optimize the ITC cut parameters, the emphasis should be placed on the structure in the plot rather than the absolute fraction of tagged events in the burst. It is clear from the figure that the discriminatory power of the cut is reduced as the in-time channel width is increased past about 123 ns. This is because the ITC ratio distribution gets shifted toward unity as the width of the in-time channel window widens and to a larger degree for the flat-TAC burst events. At the small window width end of the figure, notice that the z = 0 and z = - 6 m ^{16}N source position curves begin to diverge at 53 ns. This suggests that an ITC cut with an in-time channel window width much below this value will have a substantial radial bias. The region between 53 ns and 123 ns is fairly flat in terms of the number of flat-TAC burst events cut, so it included that using the trigger coincidence time of 93 ns as the in-time channel window width is a nearly optimal value for this ITC cut parameter and that the cut performance is fairly insensitive to changes in the window width.

Now that we have estimated the optimal in-time channel window width (93 ns), we can turn our attention to the ITC ratio threshold upon which events are either passed or failed. Figure 8 shows the fraction of ^{16}N events tagged as well as the fraction of flat-TAC burst events missed versus the ITC ratio threshold using 93 ns as the width of the in-time channel window. Note that the cut misses fewer 1% of run 10700 flat-TAC burst events for ITC ratio values anywhere in the region that more than a handful of the ^{16}N events are cut (0.6 and above). So we pick an ITC ratio of 0.6 as an estimate of the optimal value which cuts the most flat-TAC events with smallest sacrifice of good Cerenkov physics data. At this ITC ratio threshold, the ITC cut tags fewer than 0.004% of ^{16}N events within 6 m and

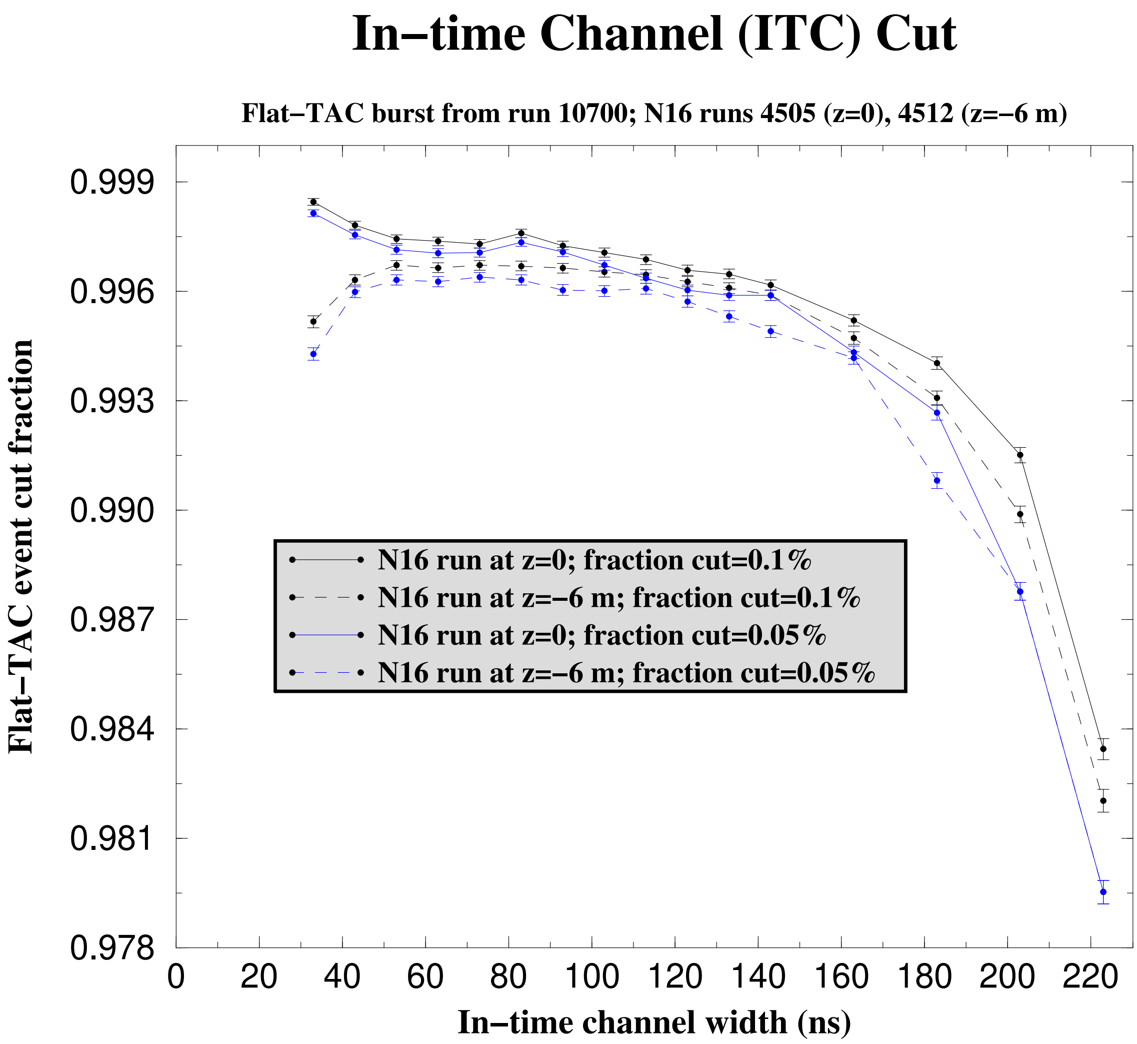

Figure 7: Fraction of run 10700 flat-TAC burst events tagged by the ITC cut versus the width of the sliding in-time channel window, when the ITC ratio threshold is set to tag 0.1% and 0.05% of the ^{16}N calibration data.

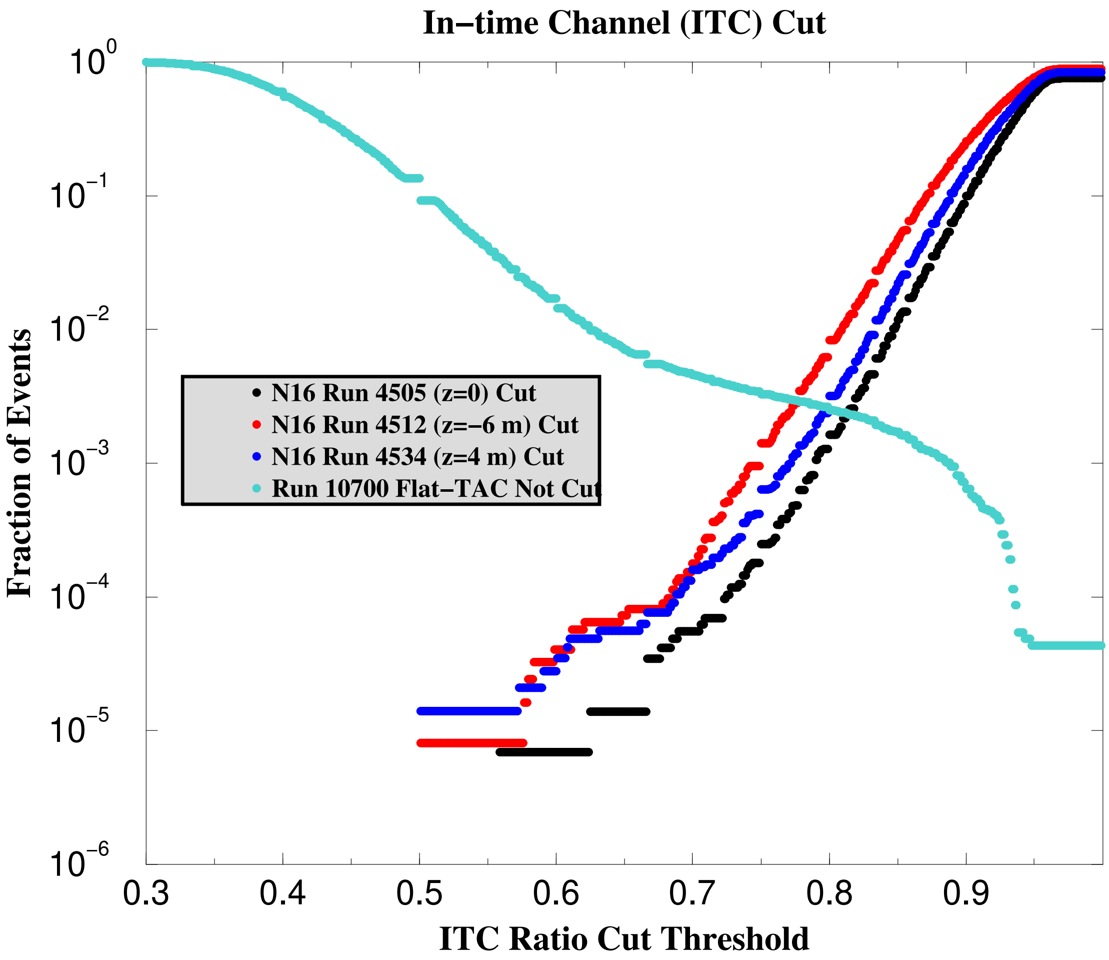

Figure 8: Fraction ^{16}N events tagged and the fraction of run 10700 flat-TAC burst events missed by the ITC cut versus the ITC ratio threshold value, using 93 ns as the width of the in-time channel window.

approximately 99% of flat-TAC events (based on the admittedly low statistics of the run 10700 burst).

3 Standard data sets

In order to test and compare the performance of the various data cleaning cuts, standard data sets have been produced. The main idea is for these sets to provide a sample of Cerenkov physics events as well as the known types of instrumental backgrounds which pose a worrisome background to the neutrino signal. A brief description of the standard data sets is provided below:

- ^{16}N **Runs**

  These are runs taken with the ^{16}N calibration source, which is a triggered source of 6.13 MeV γ-rays. Relativistic electrons are produced near the source ($\lambda_c \sim 35$ cm at this energy) through Compton scattering of the γ-ray. This source provides us with a triggered sample of "good" physics events and we expect the data cleaning cuts to pass the vast majority of these events. In terms of electrons, multiple Compton scatters can complicate things by producing more than one electron over Cerenkov threshold within an event. This is expected to be a very small effect for the low level (so called "pass-0") data cleaning cuts but could be relevant for higher level cuts based on hit PMT angular distributions as well as for testing reconstruction algorithms. For this reason, as well as to get more energy coverage to test NHIT scaling of the cuts, it would be valuable to have other source data such as the ^{8}Li electron source and the pT 19.8 MeV γ-ray source in the near future.

  The three data files correspond to runs at different source z-position (x = y = 0 for these runs, see Table 1), where only the first sub-run was included in each file. All events over an NHIT of 20 which had the ^{16}N PMT (cr/ca/ch = 17/15/1) in the event were included as well as any PERM banks (run header, trigger headers, calibration headers, etc.).

- **Laser Runs**

  These are low occupancy ($\sim 4-6\%$) laser calibration runs at three different z-positions (x = y = 0 for these runs, see Table 1). While low intensity laser ball light is approximately isotropic and hence not representative of Cerenkov light, it does have sharp timing and produces $\sim$ 1 pe charge in the PMTs like real Cerenkov events, so it is expected that cuts *not* based angular information should pass a large fraction of these events. The ability to vary the light intensity over a large range may also prove useful for getting a rough estimate of the energy scaling of the cuts, although an electron source or a high energy γ-ray source would of course be preferable.

The three files contain only the events in the first sub-run of the corresponding run which have the EXT_ASYNC trigger bit set. This external trigger input is sourced by a discriminated PIN diode signal from the laser and is not synchronized to the 50 MHz clock on the MTC/D. All PERM banks are also included in the standard laser files.

- **Decay electrons**
  This is Christian's hand scanned data set of decay electrons from stopped muons, which contains events up to run 6005.

- **Detector junk**
  Unfortunate but quite expected, our detector does not just stream golden physics events from Cerenkov light to tape. In addition to signal and physics background, we have events from electronics pickup/noise, flashing PMTs, HV breakdown, etc. We have also had events from undesirable sources of light in our detector (in addition to flashers) such as "bubblers", "recirculight", "manipulight", and so called "neck events". Some of these sources of instrumental background have been quieted to very low levels with changes to our detector configuration in the commissioning process (e.g. breakdown with addition of N_2 into the H_2O, recirculight with the degasification/full-flow of the D_2O, and electronics pickup/noise with recent improvements in backplane/FEC shielding and grounding). Flashers, on the other hand, do not appear to be quieting away to zero (although there is evidence for limited conditioning after HV changes) nor are they isolated to a few tubes which would allow us to eradicate problem at the expense of a little efficiency. The flashing at an average rate of a few per week appears to be inherent to our PMTs, and it is likely SNO will have to deal with flasher events throughout the life of the experiment.

Below is a description of the standard detector junk files currently available to the data cleaning group:

- DC_golden_flashers_4025_5112.zdab

  This is a collection of $\sim 30k$ flasher events skimmed from selected runs between 4025 and 5112. The ID algorithm used was a simple cluster-type cut which looks for six or more consecutively hit channels. Some additional criteria was included to reject types of flasher background that also have clusters such as rings/slots of fire, muons, and muon retriggers. Specifically, events with a six channel cluster were rejected (i.e. a non-flasher not included in the file) if any one of the following were true:

  - There was more than one "big" cluster (6 or more consecutive channels)
  - There were more than 6 "small" clusters (3-5 consecutive channels not in a "big" cluster)
  - There were fewer than 20 total hits in the other crates not containing the "big" cluster.

  A hand scanning of the resulting file suggests a few percent contamination of non-flashers, the majority of which look like muon retriggers.

- DC_flash_burst_3887.zdab

  This file contains a portion of a 0.1 sec flasher burst which occurred in run 3887, probably due to some seismic activity in the mine. The reason the entire burst was not included is because many orphan events followed the burst and their parents make up the end part of that burst. The file not only includes flashers but also low NHIT events which are in many cases retriggers after flashers having the flasher tube (based on Q) and a few neighboring channels in the event. The flashers within this burst are complementary to the events in DC_golden_flashers_4025_5112.zdab since those flashers are biased in a different way than the burst flashers.

- DC_rings_of_fire_4782.zdab

  This is Josh Klein's file of "ring-of-fire" events, which are triggers due to electronic pickup from readout or external sources. The most susceptible channels at time this data was taken were those in slots 0 and 15 and channels 0 and 31 in all slots, so these events looks like rings on a crate display (don't ask me about the "fire" part). As previously mentioned, these types of events have been largely eliminated by recent improvements in shielding/grounding of the electronics. The possibility of these types of events resurfacing always exists - especially if we get more aggressive with channel thresholds - but its most likely that in future running, fires from rings and slots will be extinguished.

– DC_neck_10031_10040_10196.zdab, DC_neck_10779_10801_10922_11269.zdab
These are data sets of Neil's hand scanned neck events, corresponding to data taken *before* and *after* changes in the neck tube timing, respectively.

4 Performance on standard data

The performance of the ITC cut using the optimized cut parameters described in Section 2.3 on the standard data cleaning sets is summarized in Table 1. Notice that the sacrifice of Cerenkov light events based on ^{16}N calibration data is very small - fewer than 0.04% of events within 8 m - and essentially none of the laser data is tagged by the ITC cut. One decay electron event was tagged by the ITC cut, which is presumably due the contributions from afterglow tubes left over from the initiating muon event. These afterglow hits are present in some of the decay electron events, so one needs to be careful about making conclusions regarding cut performance for isolated high NHIT events based on the decay electron set.

4.1 Sensitivity to Timing Calibrations

Since the ITC cut depends solely on the properties of event time spectra, it is important to check how sensitive the results are to changes in the hit PMT timing. This is done by comparing ^{16}N and flat-TAC event tag fractions with and without PCA calibration constants applied to the data, which checks timing changes on the order of a few nanoseconds. It is observed that applying only ECA calibration constants to the standard ^{16}N data sets is a very small effect - typically adding or subtracting one or two events to the numbers of tagged events shown in Table 1. The effect on the fraction of run 10700 flat-TAC events tagged by the ITC cut is also found to be small - increasing this fraction by $\sim 0.5\%$ when only ECA

Category	Filename (.zdab)	Date(s) taken	# of events	Brief description	% (#) of events tagged
^{16}N runs	DC_n16_0000010353_000	11/30/99	157395	(0, 0.3, 100.1)	0.04 (7)
	DC_n16_0000010355_000	11/30/99	164297	(-0.17, 0.29, 200.01)	0.001 (2)
	DC_n16_0000010357_000	11/30/99	163976	(0.15, 0.23, 300.2)	0.001 (2)
	DC_n16_0000010359_000	11/30/99	158848	(0, 0.42, 400.5)	0.003 (4)
	DC_n16_0000010361_000	11/30/99	110127	(-1.42, 14.12, 498.23)	0.0 (0)
	DC_n16_0000010480_000	12/2/99	83894	(0, 0, -100)	0.002 (2)
	DC_n16_0000010482_000	12/2/99	74040	(0, 0, -200)	0.0 (0)
	DC_n16_0000010484_000	12/2/99	74696	(0, 0, -300)	0.0 (0)
	DC_n16_0000010486_000	12/2/99	70110	(0, 0, -400)	0.0 (0)
	DC_n16_0000010488_000	12/2/99	62676	(0, 0, -500)	0.0 (0)
	DC_n16_0000010490_000	12/2/99	36353	(0, 0, 0)	0.003 (1)
	DC_n16_0000010517_000	12/3/99	31620	(-10.56, 2.2, 600)	0.0 (0)
	DC_n16_0000010564_000	12/7/99	82101	(-586, 208, -100)	0.001 (1)
	DC_n16_0000010566_000	12/7/99	87234	(-586, 208, -200)	0.0 (0)
	DC_n16_0000010568_000	12/7/99	86337	(-586, 208, -300)	0.003 (3)
	DC_n16_0000010571_000	12/7/99	62142	(-586, 208, -400)	0.006 (4)
	DC_n16_0000010573_000	12/7/99	46220	(-586, 208, -500)	0.01 (6)
	DC_n16_0000010575_000	12/7/99	80759	(-586, 208, 0)	0.001 (1)
	DC_n16_0000010577_000	12/7/99	81016	(-586, 208, 100)	0.0 (0)
	DC_n16_0000010579_000	12/7/99	84861	(-586, 208, 200)	0.002 (2)
	DC_n16_0000010581_000	12/7/99	79458	(-586, 208, 300)	0.001 (1)
	DC_n16_0000010583_000	12/7/99	81729	(-586, 208, 400)	0.001 (1)
	DC_n16_0000010585_000	12/7/99	21966	(-586, 208, 500)	0.009 (2)
Laser runs	DC_laser_0000010626_000	12/9/99	51680	NHIT=120, (0, 0, 0)	0.0 (0)
	DC_laser_0000010628_000	12/9/99	49719	NHIT=80, (0, 0, 0)	0.0 (0)
	DC_laser_0000010630_000	12/9/99	43904	NHIT=25, (0, 0, 0)	0.0 (0)
	DC_laser_0000010632_000	12/9/99	34542	NHIT=25, (-3.98, 12.81, 549.9)	0.003 (1)
	DC_laser_0000010634_000	12/9/99	44316	NHIT=90, (-3.98, 12.81, 549.9)	0.0 (0)
Decay electrons	DC_decay_electrons_til_6005	- 10/30/99	59	Decay e^- from stopped muons	1.7 (1)
Detector junk	DC_golden_flashers_4025_5112	6/24 - 8/30/99	30526	Flashers from selected runs	2.1 (640)
	DC_flash_burst_3887	6/16/99	6532	Burst of flashers/retriggers	70.8 (4626)
	DC_rings_of_fire_4782	8/5/99	1230	Electronics pickup/noise	44.5 (490)
	DC_neck_10031_10040_10196	11/4 - 11/25/99	1490	Neck events before cable changes	24.8 (370)
	DC_neck_10779_10801_10922_11269	1/3 - 2/11/00	997	Neck events after cable changes	1.2 (12)

Table 1: ITC cut performance on the standard data sets used for benchmarking cuts by the Data Cleaning Group.

calibration is performed. Therefore, it is concluded that ITC cut is robust against small changes in the hit PMT timing used by the cut.

4.2 NHIT Dependence of the ITC ratio

Although the ITC cut operating with its optimized parameters only tags a tiny fraction of ^{16}N events, it is still interesting to look at how the ITC ratio depends on the NHIT of events. Figure 9 shows the ITC ratio as a function of NHIT for ^{16}N calibration data at the center of the detector and at z = -6 m. The error bars in the figure represent the 1σ spread in the ITC ratio. It can be seen that with the optimal ITC ratio threshold of 0.6, the cut operates

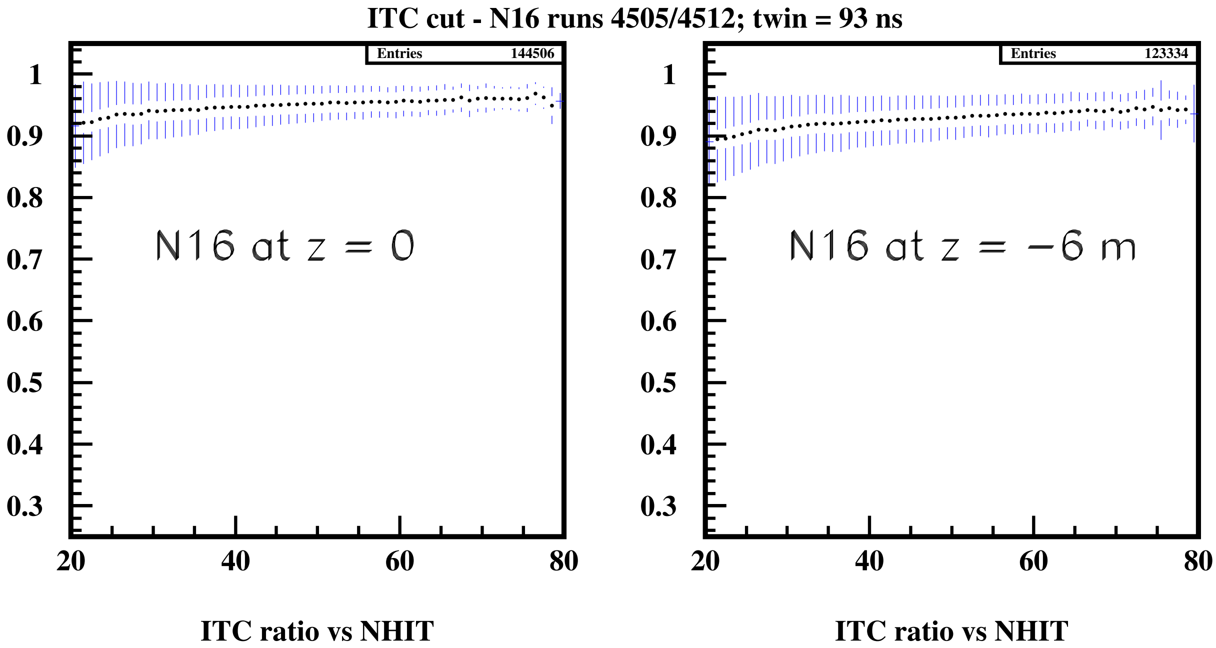

Figure 9: Plots of mean ITC ratio versus NHIT for ^{16}N calibration data taken at z = 0 (left) and z = -6 m (right), using 93 ns as the width of the sliding in-time channel window. The error bars in the figure represent the 1σ spread in the ITC ratio. The cut operates using 0.6 as the ITC ratio threshold value to determine which events are tagged by the cut.

several standard deviations from the ^{16}N data at all NHIT, although the mean ITC ratio is reduced and the spread is increased as the NHIT gets smaller. This is because random PMT noise is a constant contribution to the NHIT of events and has the effect of spreading the time distribution in a maximal way (uniform time distribution). Therefore, the fractional number of in-time channels is reduced by PMT noise hits to a larger extent for low NHIT events.

5 Conclusions and Recommendations

The ITC cut was developed by comparing the time spread characteristics of ^{16}N calibration data and flat-TAC events which dominated a burst period of data in the production neutrino run 10700. It was found that $\sim 99\%$ of these flat-TAC events could be tagged with minimal sacrifice of the ^{16}N data by using a 93 ns in-time channel window and 0.6 as the threshold for the fraction of in-time channels in the event. These results were found to be robust against the PCA timing calibration. The NHIT dependence of the ITC ratio was investigated and it was found that this ratio does have bias toward smaller values at low NHIT, presumably due to contributions from random PMT noise coincidences. However, the ITC cut tags such a small fraction of good events that this is expected to have a negligible effect on the NHIT spectrum of events passing the cut.

It is suggested that the ITC performance is tested on a few of the other flat-TAC bursts which have occurred over the production neutrino data taking period to verify the results of this report. Along these lines, it would probably also be useful to have some flat-TAC burst data in the standard sets to ensure that these events are rejected by the data cleaning pass 0 mask (aside from the burst cut), since they fall into a dangerous NHIT region in terms of solar neutrino background and some events (beyond expected numbers of Cerenkov physics events) in the burst are passed by the ITC cut.

A How to use the ITC cut

This section briefly reviews the cut algorithm and displays the ITC part of the titles file where the input parameters can be adjusted. The ITC cut was implemented in SNOMAN version 3.0191 as a hardwired filter and is invoked within the PEL by

```
call flt($itc_cut)
```

The cut algorithm is simply as follows, where words in bold/capitals are quantities that currently can be varied by the user and the corresponding word in the ITC_CUT part of the FLTH titles bank is shown in parentheses. There is a loop over all the hits in the event which stores the successfully PCA calibrated channels into an array for processing. A window of width **WINSIZE** (word 1) is slid through the spectrum of PMT times in **WINSTEP** (word 2) increments to count the maximum number of hits in any time position of the window, which is considered the number of "in-time" channels in the event. The cut statistic is the "ITC ratio", which is the fractional number of in-time channels in the event (considering only hits passing the full timing calibration). The ITC cut filter then returns 'false' if ITC ratio is less than **RAT_CUT** (word 3), otherwise 'true' is returned.

The cut parameters previously described which can be adjusted are contained in the titles file *filter_flth.dat*, the relevant part of which is shown below:

```
*DO   FLTH  23  -i(30I -F)            #.  FLTH: In-Time Channel time spread cut
#.
19750101        0 20380517 03331900   6*0   #.   Standard Database Header
19750101        0 20380517 03331900  16*0
#.
93.                          #. Sliding window size (in ns)
1.                           #. Step (in ns) of sliding window
0.6                          #. Cut value for in-time ratio
```