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A Simple Low Threshold Trigger

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Abstract
The major impediment to lowering the trigger threshold of Milagro is the rapid rise in trigger rate due to single muons. Milagro is currently triggering at a multiplicity of ~50 PMTs in the top layer, the point below which the rate from single muons becomes large. In order to substantially reduce the trigger threshold one must provide an intelligent trigger capable of vetoing triggers generated by muons. Here I describe a “dumb” intelligent trigger that will enable the lowering of the trigger threshold of Milagro to ~30 PMTs in the top layer. This trigger threshold should increase the number of gamma rays we trigger on (and fit) by ~50%, while keeping the total trigger rate below 2 kHz (the limit of the data acquisition hardware). However, these events have a substantially worse angular resolution than the current triggered events. This trigger could be implemented immediately.

Introduction

At the Irvine meeting in 1999 I described a trigger that incorporates information from the bottom layer of Milagro. This trigger is shown schematically in Figure 1.

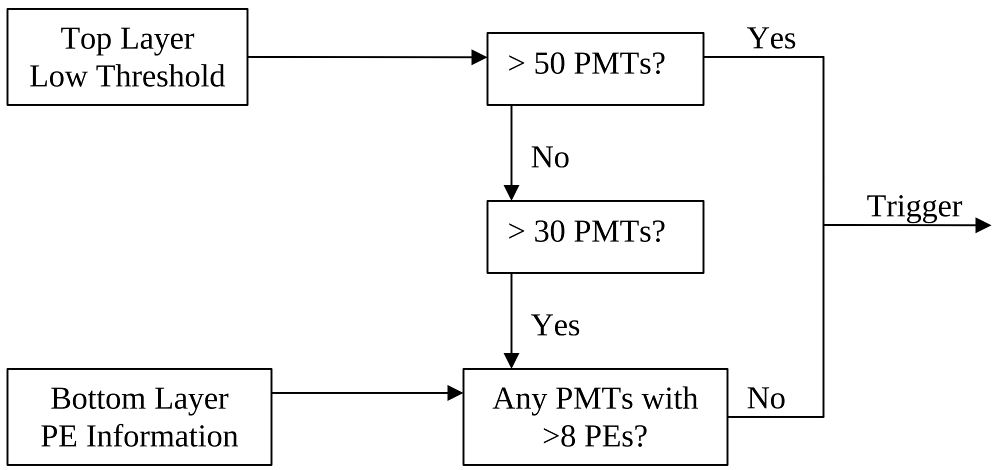

Figure 1 Old Proposed Intelligent Trigger

The difficulty with this trigger was the box marked “Any PMTs with >8 PEs?” This decision requires the manufacture of custom boards with variable discriminators to compensate for the different gains of the PMTs. David Noyes has also investigated this trigger and reported on its performance in a subsequent collaboration meeting. Here I propose an alternate trigger with comparable performance, but that does not require any specialized hardware. The new trigger is shown in Figure 2. The only difference is that we use the already present high threshold information instead of the 8 PE information.

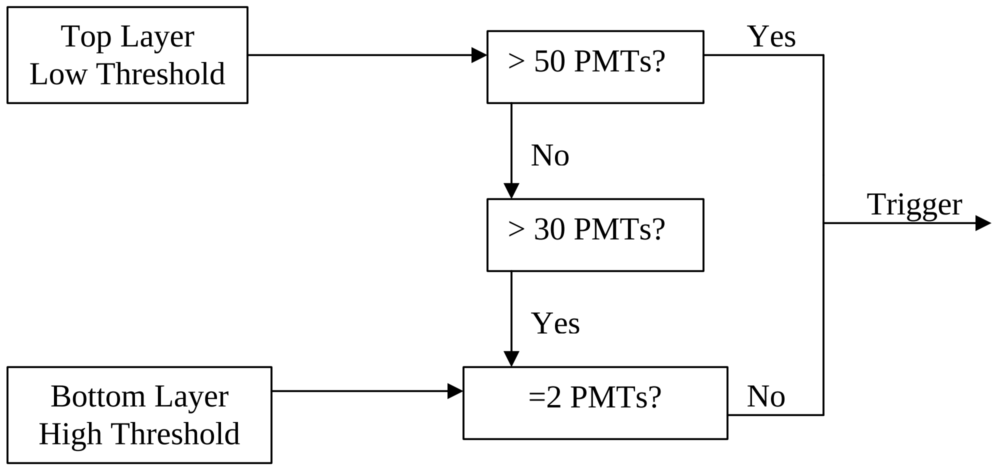

Figure 2 New Proposed Trigger

This new trigger can be easily formed by putting all of the high-threshold trigger outputs from the Santa Cruz boards into an analog sum unit whose output goes to a discriminator, that is used to veto the trigger (NOT signal from this discriminator ANDED with >30 PMT trigger from top layer). In the subsequent sections I describe how this trigger is simulated and show the performance, based on both Monte Carlo simulations and data taken at a low trigger threshold.

Trigger Simulation

The Monte Carlo reports the number of PEs in each PMT, but does not report the number of edges. To properly simulate the proposed trigger I used the data to determine the true value in PEs of the high threshold for each PMT in the pond. Figures 3 and 4 show the PE distributions for all 4-edge events for two typical channels. I take the peak in this distribution as being the PE threshold for the high discriminator of each channel. The distribution of high thresholds for all channels is shown in Figure 5. For dead and uncalibrated channels I assigned a value randomly selected from the distribution shown in Figure 5. Note for each live channel I used the *real* measured value of the high threshold, **not** an average value, **nor** a randomly assigned value based on the distribution in Figure 5. With this information I can use the Monte Carlo to simulate the trigger. To simulate the trigger in the data I used the raw (uncalibrated) PMT information in conjunction with the edge-finder (to make the timing requirement). This allows me to use uncalibrated tubes that will be present in the hardware. In Figure 6 I show the distribution of the number of 4-edge PMTs in each event for data and gamma ray simulations (for events with 30<nTop<50). For the top layer trigger in the data I use the raw information with the edge-finder (similar to finding the number of bottom layer

PMTs with 4-edges). For completeness in Figure 7 I show the relationship between the number of 4-edge PMTs and the number of PMTs with more than 8 PEs.

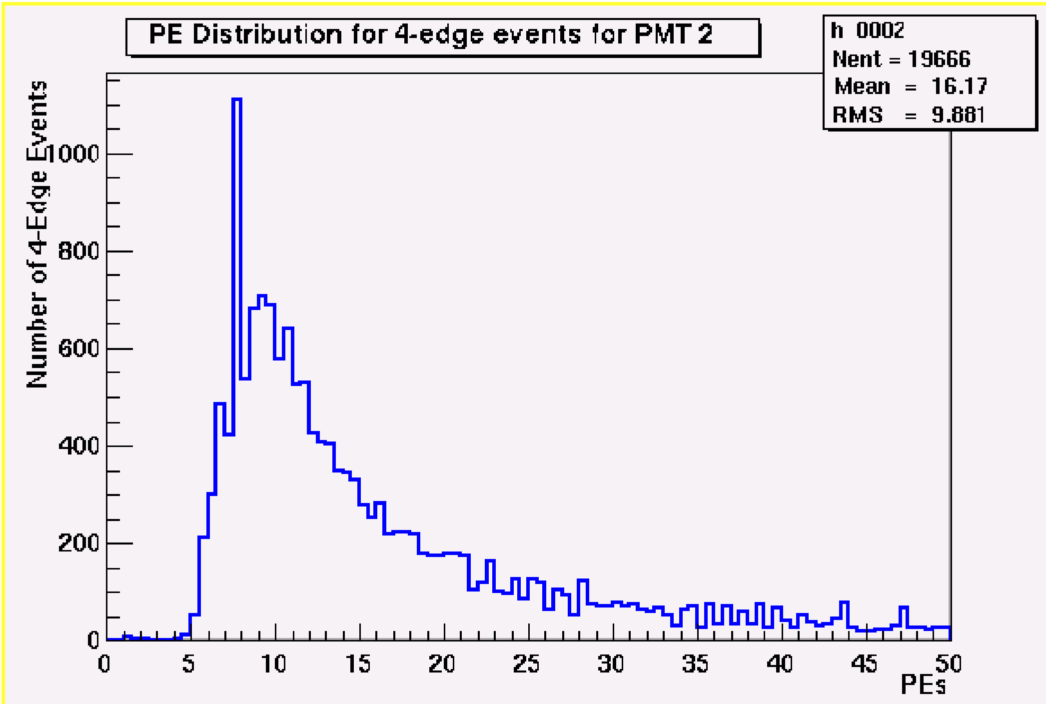

Figure 3 PE distribution of 4-edge events for channel 2.

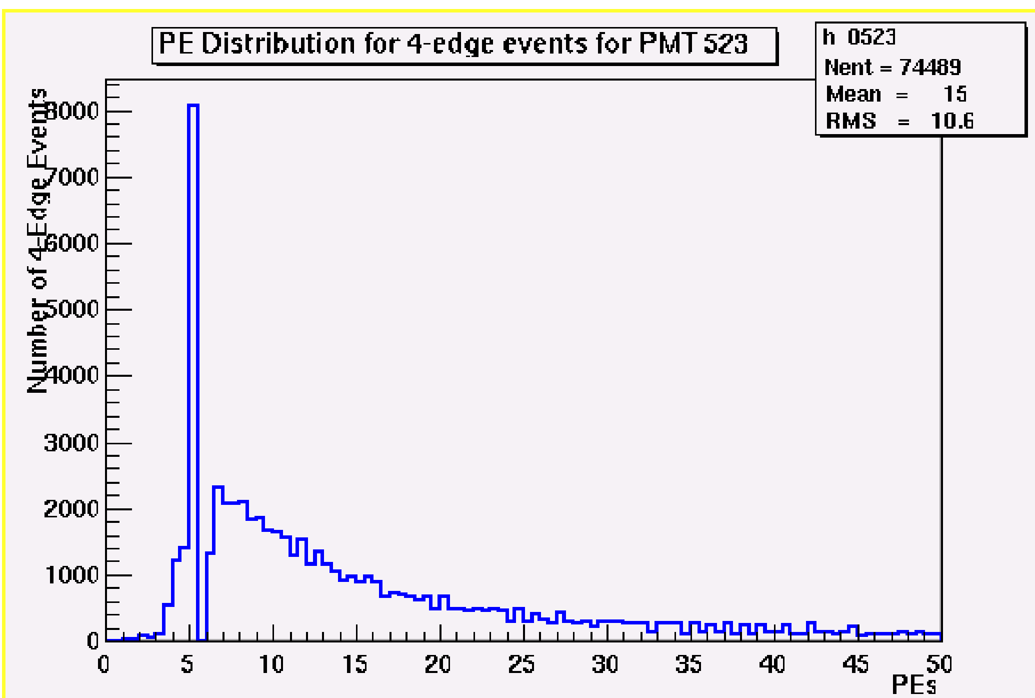

Figure 4 PE distribution of 4-edge events for channel 523.

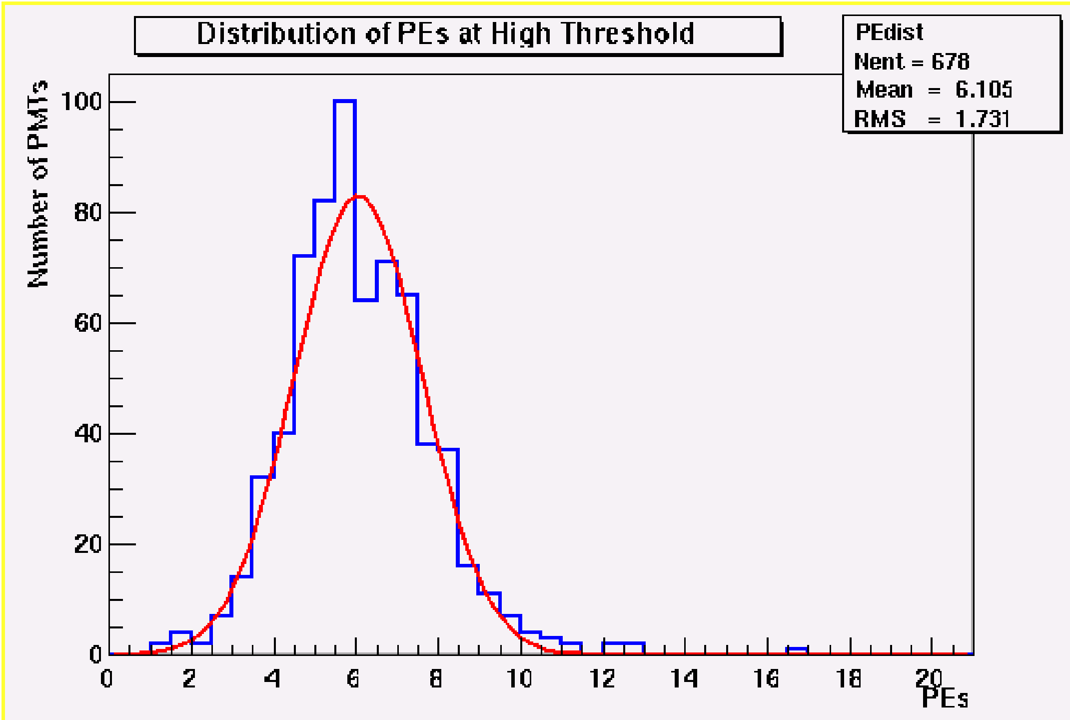

Figure 5 Measured values of high threshold (in PEs) for all PMTs in the pond. The red line is a Gaussian fit to this distribution.

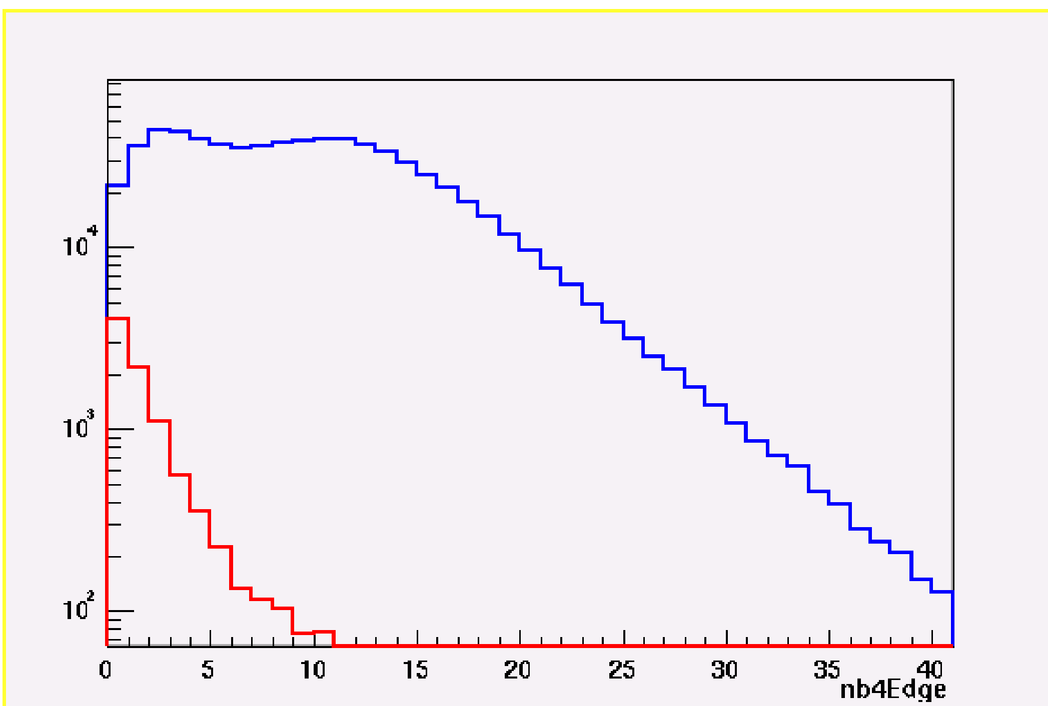

Figure 6 Distribution of number of 4-Edge PMTs for events with 30<nTop<50. Blue line is data, red line is gamma Monte Carlo.

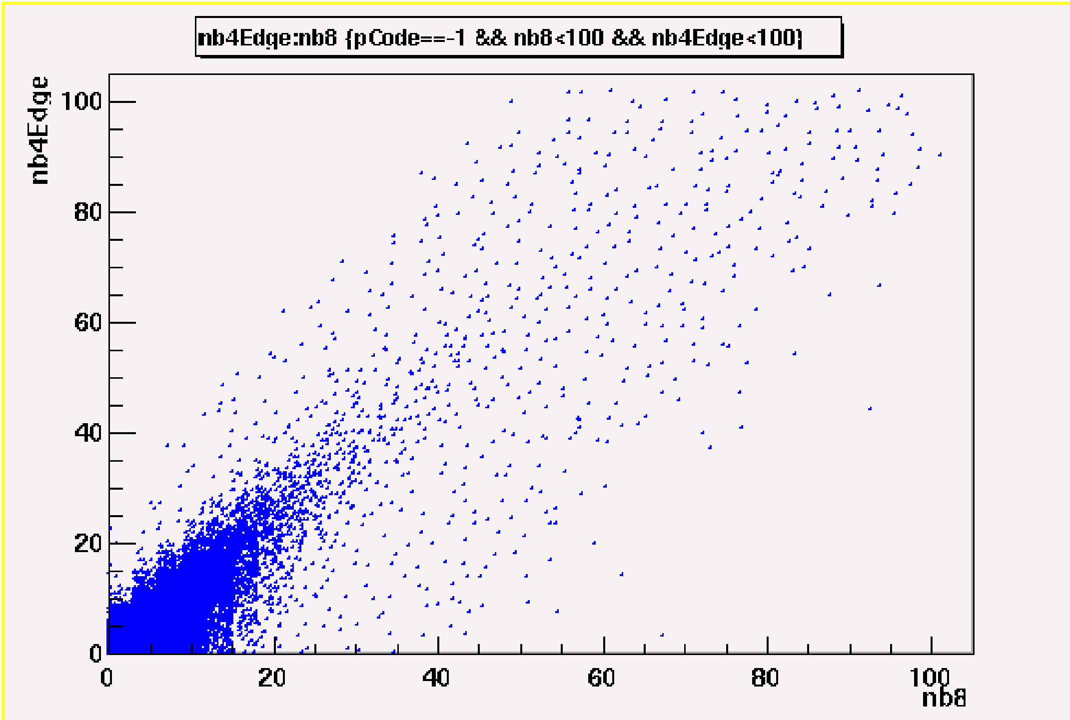

Figure 7 Number of 4-edge pmts vs. number of pmts with 8 or more PEs.

While there is a nice correlation between NB8 and N4EDGE, there is also a large spread due to the different gains of the PMTs.

<u>The New Trigger</u>

From Figures 6 and 7 one can see that simply replacing the 8 PE cut with a requirement that there be no 4-edge PMTs in the event will not work. Some PMTs have such high gains, that this would be a rather low cut on pulse height and remove many of the gamma rays that we are trying to keep. The next step is to investigate the requirement that there be fewer than 2 PMTs in the bottom with 4 edges. This trigger, shown in Figure 2 is the subject of the rest of this memo.

The first requirement is that the trigger rate be less than ~2 kHz, the limit of the data acquisition system. Figure 8 shows the trigger rate for as a function of multiplicity for the current “simple” trigger and for the proposed trigger. While the current trigger quickly rises below 50 PMTs, the proposed trigger remains below 2 kHz down to a top layer multiplicity of 30 PMTs. Figure 9 shows the ratio of the trigger rates for the two triggers.

The next question is the effect on the efficiency for triggering on gamma rays. Figure 10 shows the number of gamma ray triggers as a function of energy for the current trigger (nTop>50) and for the proposed new trigger. In both cases I only show triggers that were successfully fit (nFit>=5) by the reconstruction. Figure 11 shows the ratio of the number of triggers (for the two triggers) as a function of energy. The gamma rays were thrown on an $E^{-2.4}$ spectrum. So the new trigger increases our effective area for gamma rays by ~45%.

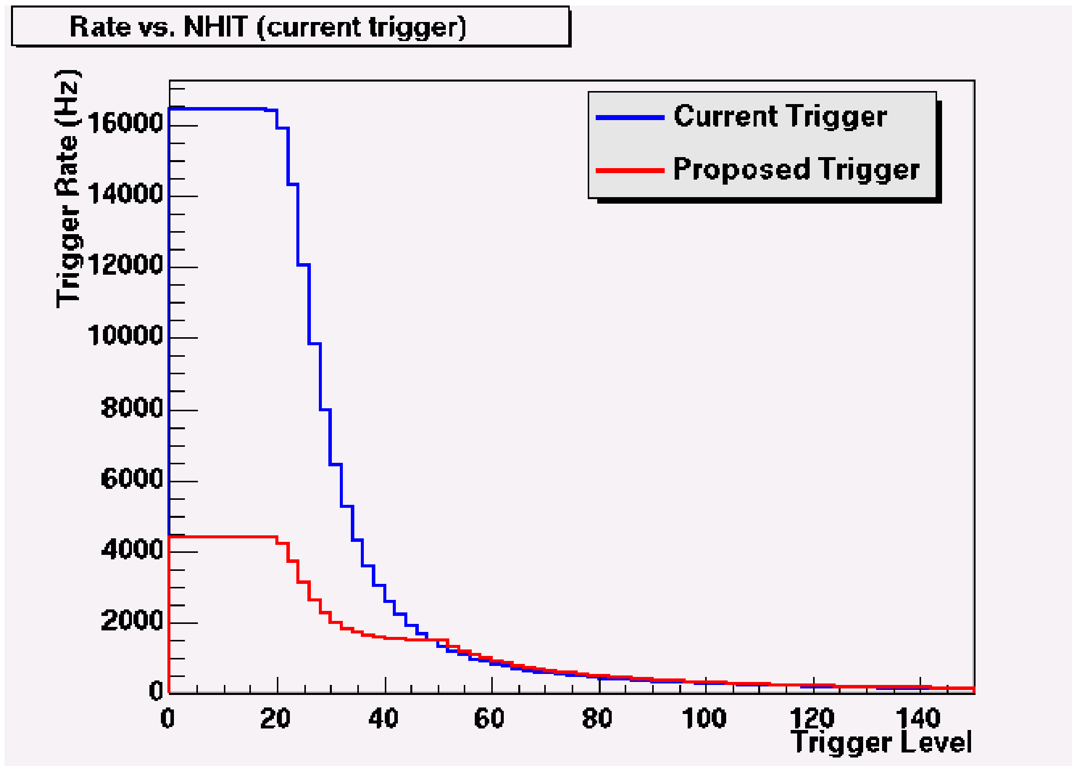

Figure 8 Trigger rate as a function of nTop for the current trigger (blue) and the propose trigger (red).

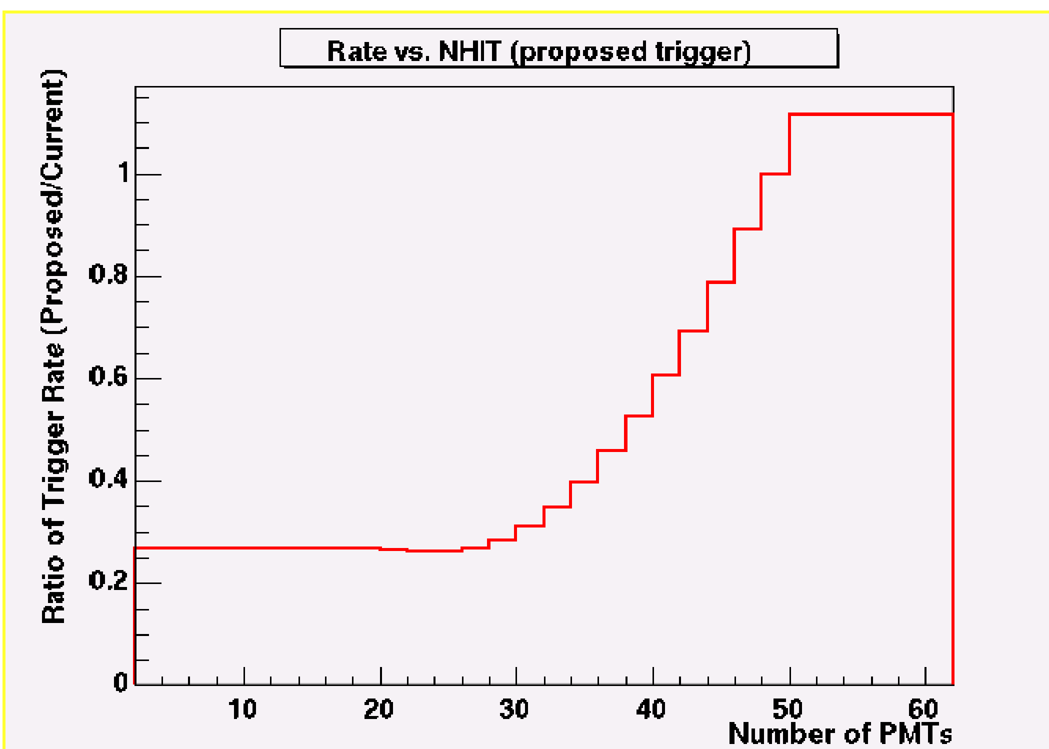

Figure 9 Ratio of trigger rates (proposed/current) as a function of nTop.

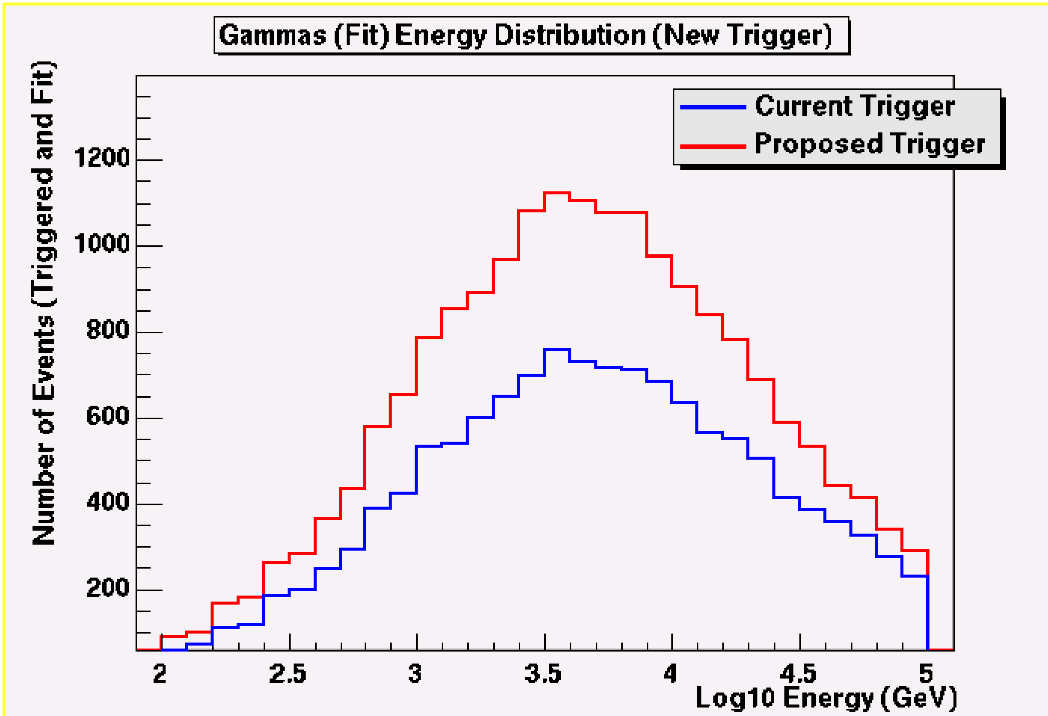

Figure 10 Number of triggers as a function of energy for the current trigger and the proposed trigger. The gamma rays were thrown on an $E^{-2.4}$ spectrum.

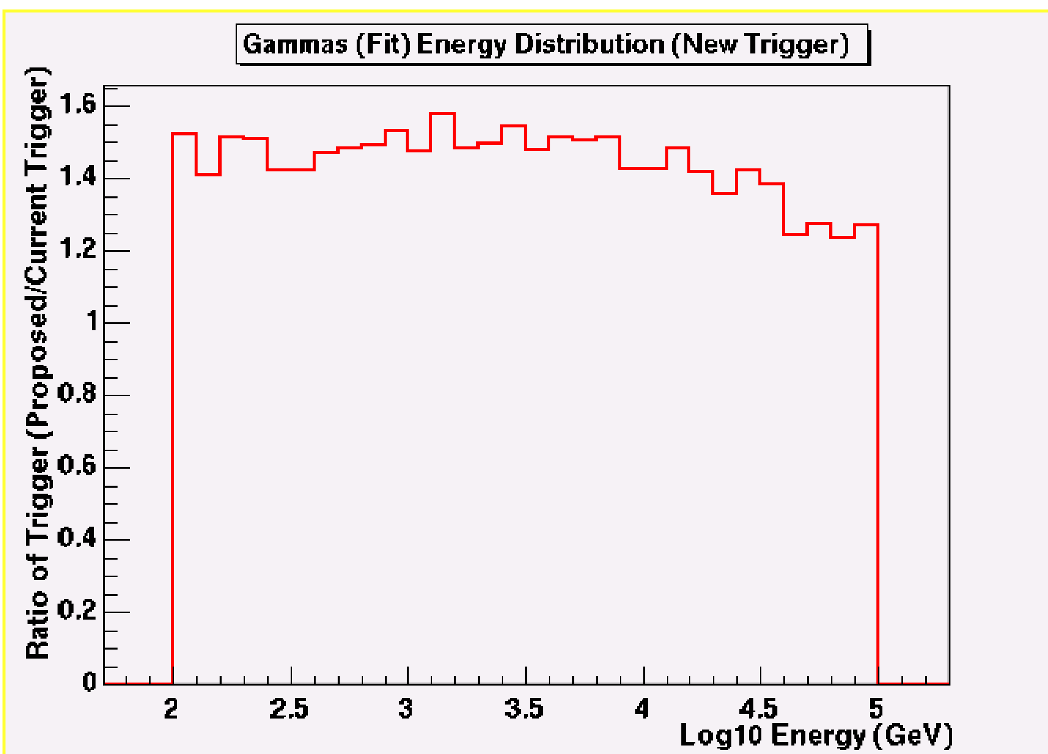

Figure 11 Ratio of the two curves in Figure 10. On average the new trigger increases the effective area for gamma rays by 45%.

Expected Performance Increase
This section is preliminary and is meant to give a feel for what we should expect in the effect of the proposed trigger to the sensitivity of Milagro. There are three factors to be considered: the increase in the number of signal events, the increase in the background, and the angular resolution of the new events. I believe these results are preliminary because I do not think that our current reconstruction is properly optimized for the lower trigger threshold. The increase in signal has already been shown. To find the increase in the background we need to see how many of the new triggers are successfully reconstructed. Figure 12 shows the increase in the fit background as a function of nTop for the proposed trigger. The plot is normalized to 1 at nTop=50 (the current trigger criteria). At nTop=30 the current trigger would increase the background level by ~2.3, while the proposed trigger only increases the background by a factor of 1.2. Therefore there is the *potential* to increase the sensitivity of Milagro by a factor of 1.32 (=1.45/v1.2).

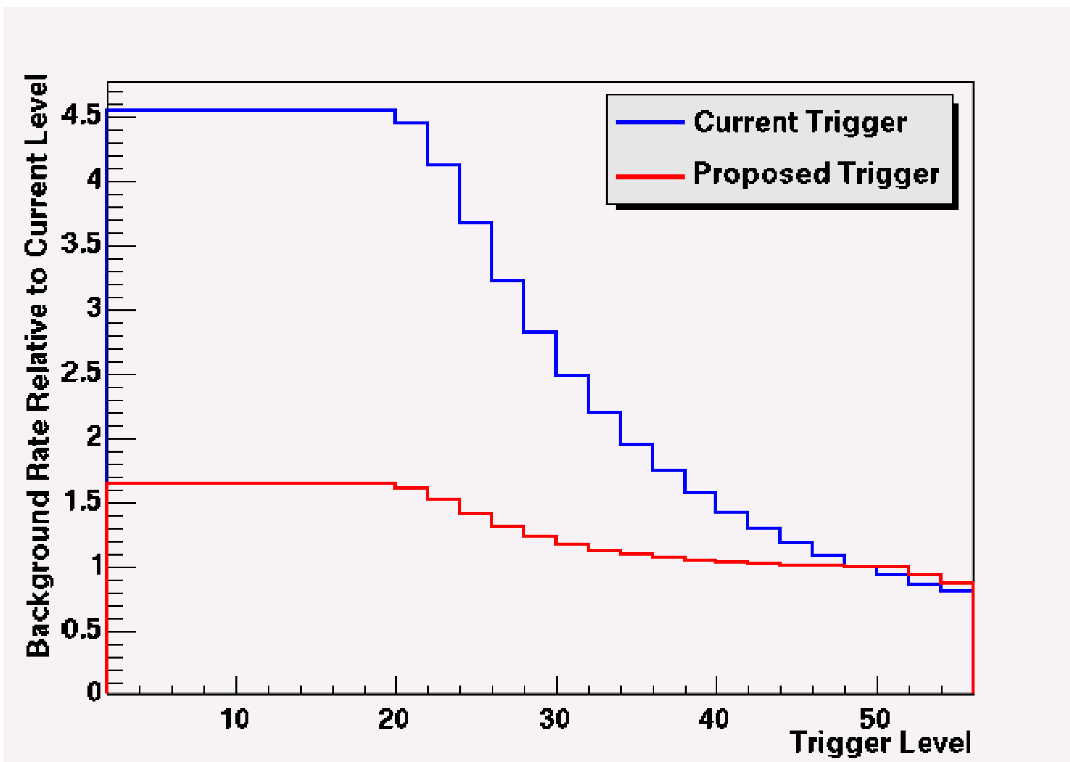

Figure 12 Relative (to current level) increase in fit background as a function of nTop.

The remaining factor is the angular resolution of the new events. Figure 13 shows the *delAngle* distribution of the current events and of the new events. Clearly the new events have significantly worse angular resolution. In fact, if one uses the current analysis bin-size of 1.2 degrees (radius circular bin), the number of signal events increases by a mere 18%. With the background increasing by 20%, the net gain in significance is only 8%. Before concluding that lowering the trigger threshold is not a useful endeavor I will investigate the problem a little further.

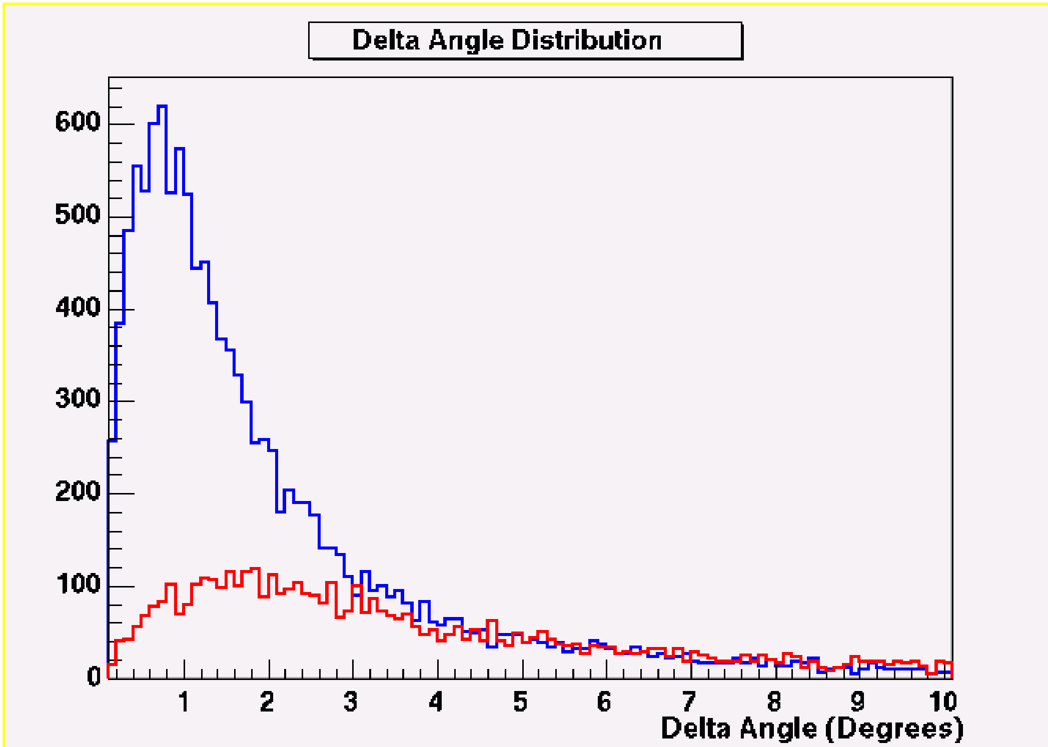

Figure 13 ***delAngle*** **distribution of current events (blue) and new events (red).** ***delAngle*** **is the space angle difference between the true direction and the reconstructed direction.**

Reconstruction of the low nTop Events

Figure 14 shows the core distribution of the new events and of the current events. From this plot it seems plausible that the poor angular resolution of the new events is due to the fact that on average they fall at larger core distances. So the current core locator (which places all exterior cores at 50 meters) is poorly optimized for these events. Figure 15 demonstrates this point; here I plot the angle error as a function of core distance. A clear correlation is seen, with the events with cores on the pond being reconstructed comparatively well. One should also recall Ty's recent memo that showed that even for cores on the pond the current core locator does a rather poor job, since these events are smaller than our typical event it is not unreasonable to expect that the current core locator can be significantly improved for these new events with cores on the pond.

One might expect that the events with cores on the pond are the lower energy events. In fact this is the case. In Figure 16 I show the core distribution of the new events with primary energy less than 500 GeV. These events fall predominantly on the pond, and they also have significantly better angular resolution then the ensemble of new events. The *delAngle* distribution for the events with energy less than 500 GeV is shown in Figure 17. These events are reconstructed almost as well as the current set of events with nTop=50.

These results are summarized in Table 1, where I show the number of events as a function of binsize for our current trigger, the new trigger, and for the events with primary energy less than 500 GeV. Until the reconstruction is significantly improved for these low nTop events the proposed trigger will little impact on our analysis of Crab-like sources. However, for distant sources such as GRBs that have few (or no) high-energy events the trigger could gain is sensitivity is a little larger. However, the answer to this question is still uncertain, as I believe that one must re-optimize the entire analysis, from background rejection to binsize for these low energy searches.

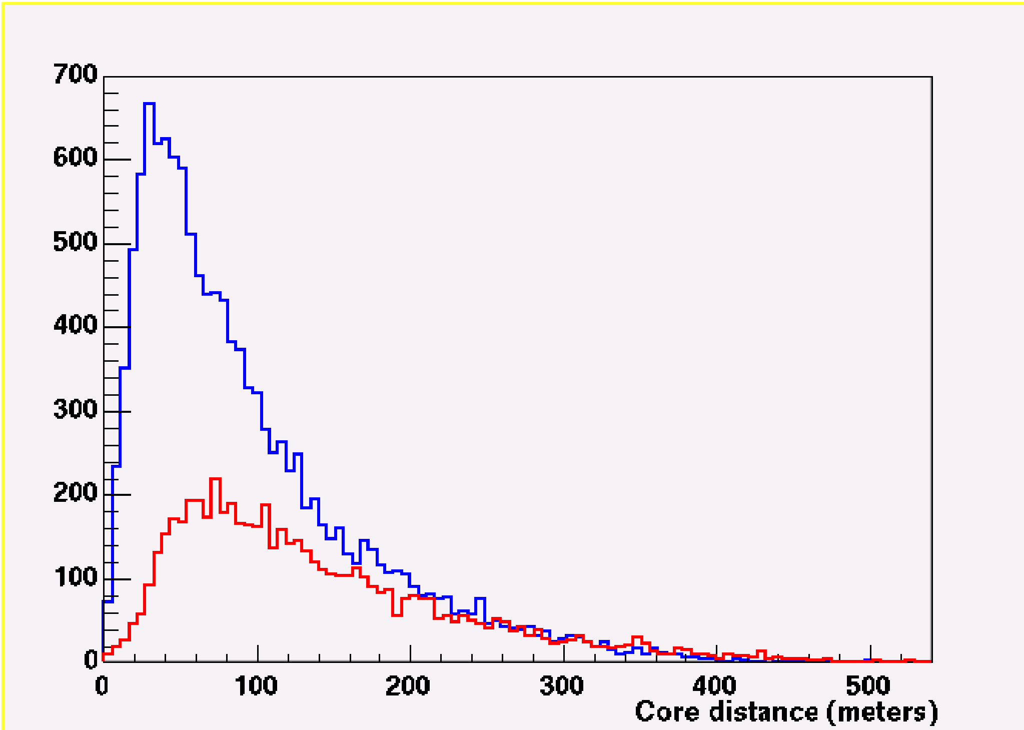

Figure 14 Core distance distribution for current events (blue) and new low threshold events (red).

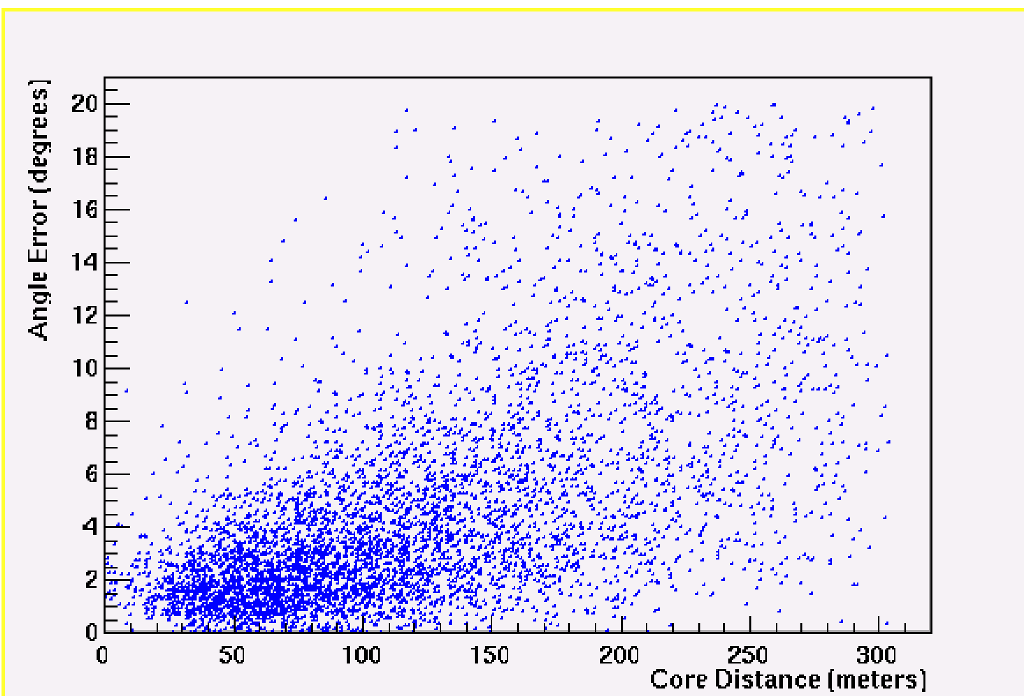

Figure 15 *delAngle* vs. core distance for the new events (nTop<50).

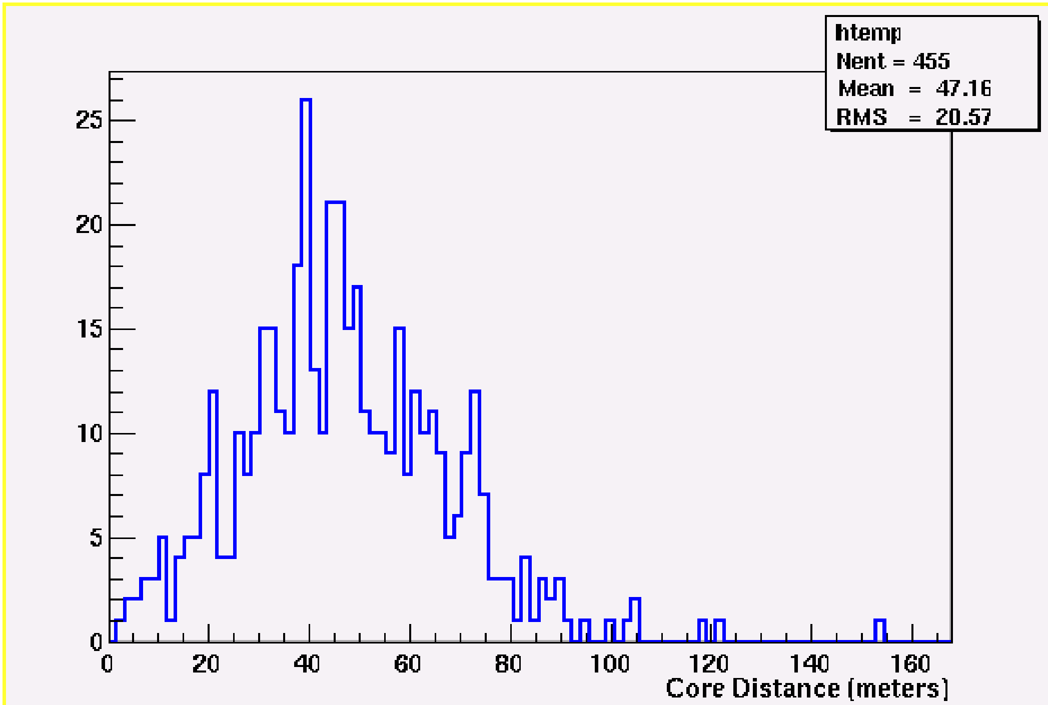

Figure 16 Core distance distribution for new events (nTop<50) with primary energy less than 500 GeV.

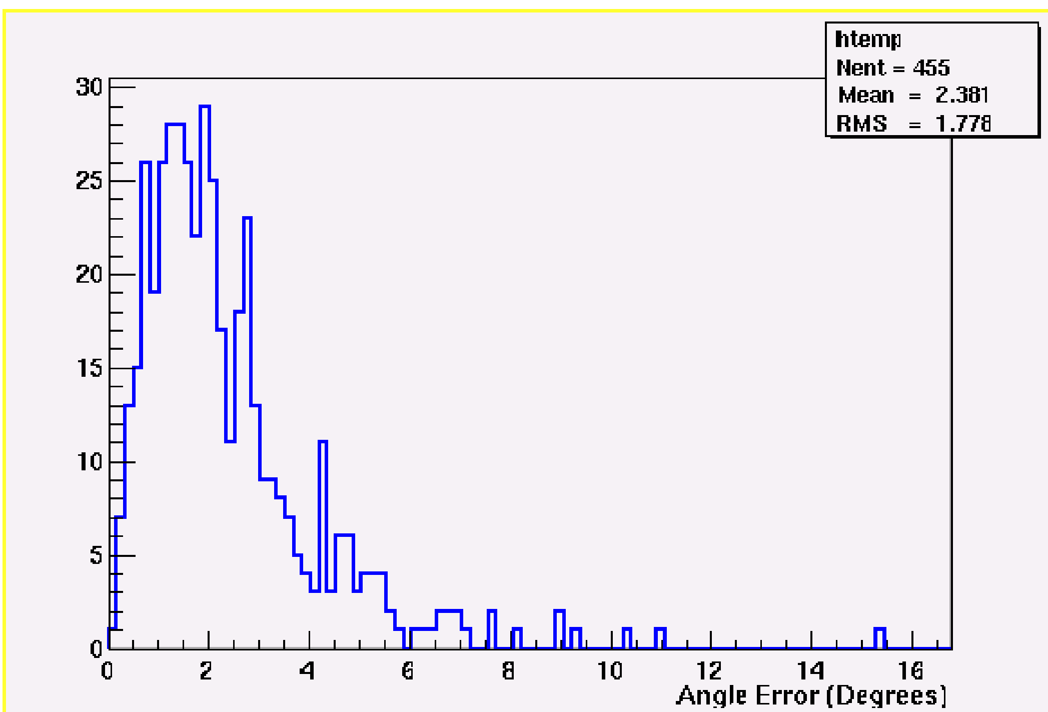

Figure 17 *delAngle* distribution for new events (nTop<50) with primary energy less than 500 GeV.

Table 1 Number of events for several angular bins for both the current trigger and the additional events included with the proposed trigger.

Angle Cut (radius)	Current Trigger	New Events	Current (E<500 GeV)	New (E<500 GeV)
All Events	12,809	5,811	991	452
$<2^o$	8,346	1,879	844	238
$<1.5^o$	6,850	1,342	699	160
$<1.2^o$	5,625	1,028	575	110

Conclusions:

I have demonstrated a simple extension to the current trigger that will allow us to lower the trigger threshold to 30 PMTs and does not require any additional hardware. While this will yield 45% more gamma ray triggers (for an $E^{-2.4}$ source spectrum) the additional higher energy events tend to fall farther from the pond and therefore have poorer angular resolution than the current triggered events. The background level will only rise by about 20% with this trigger. If no additional background rejection is performed and one utilizes a binned analysis with a binsize of 1.2 degrees, the sensitivity of Milagro will only improve by ~8%. However, for more distant sources, where all the gamma rays are below 500 GeV in energy the improvement should be closer to 20%. More work is needed to fully exploit these additional events. The current reconstruction algorithms, both the core finder and the angle fitter, need to be optimized for the smaller events and the background rejection needs to be extended to these events. However, one should always expect our angular resolution to degrade as nTop decreases, there fore to fully exploit these data we must develop an algorithm that fully exploits each event and its inherent angular resolution. For gamma-ray bursts, with no high-energy events, where Milagro is signal starved this is especially important.

Appendix:

I have appended several plots that are useful in understanding the reconstruction of these low threshold events. First is the nFit distribution (Figure 18). This is markedly different than our current nFit distribution, with ½ of the events having an nFit<20. Next I show a 2-d scatter plot (Figure 19) of the angle error vs. the energy of the primary gamma ray. One can see that even for these small events, we do a much better job fitting the lower energy events than we do with the higher energy events. The last plot shows the *delAngle* distributions for the low energy (<500 GeV) events. The blue histogram is the events with nTop=50 and the red histogram for events with 30<nTop<50. While the low threshold events still have worse resolution, they are relatively better than the ensemble shown in Figure 13.

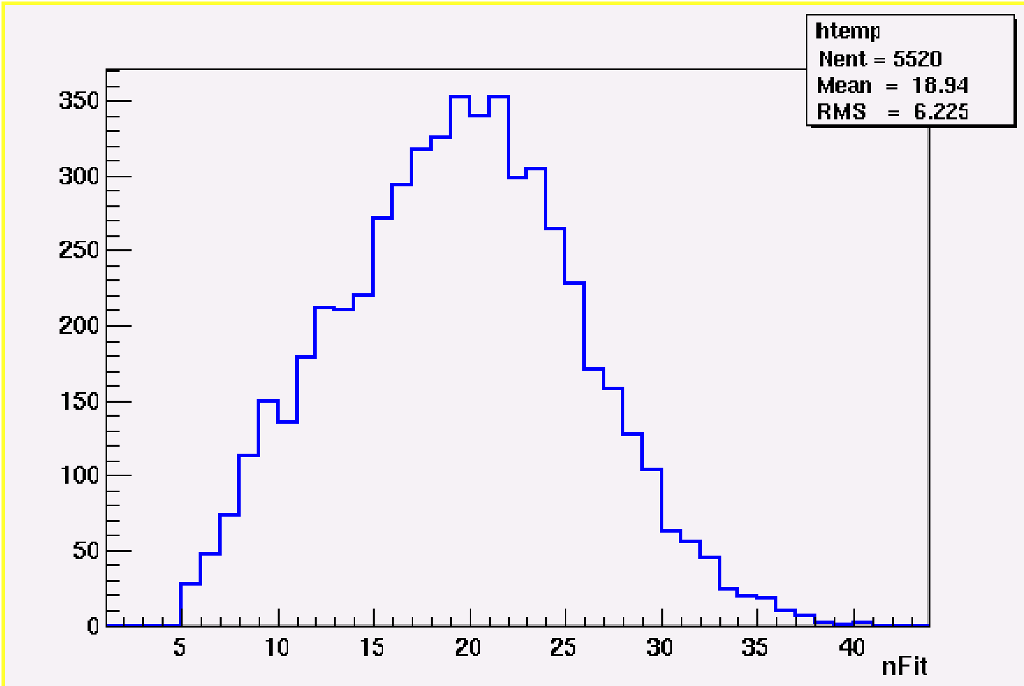

Figure 18 The nFit distribution for events with 30<nTop<50

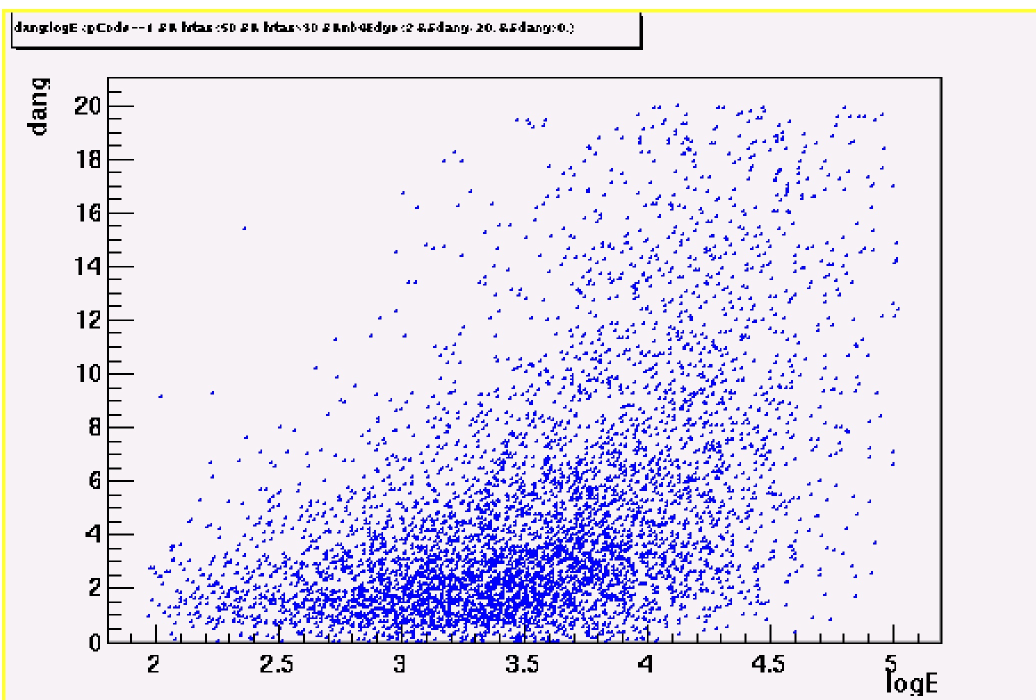

Figure 19 Angle error vs. primary energy for events with 30<nTop<50.

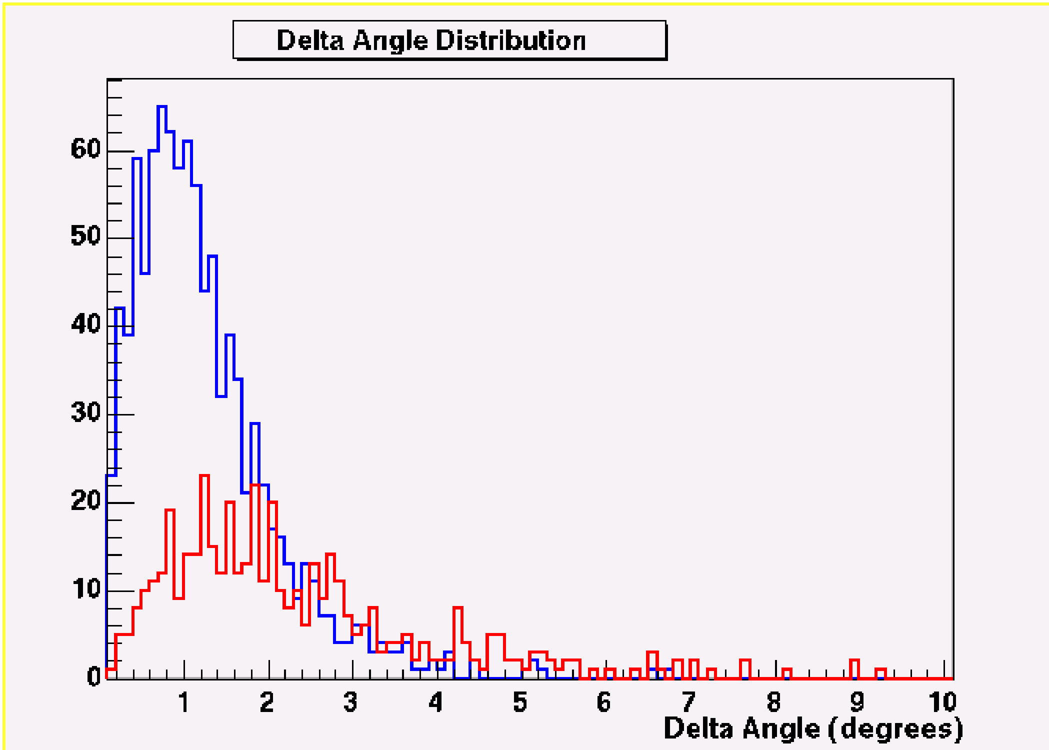

Figure 20 delAngle distribution for events with E<500 GeV. the blue histogram is for event with nTop=50 and the red histogram is for events with 30<nTop<50.