Tech Note #291
Trigger level 1.1 Study

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Abstract

The performance of the level 1.1 trigger was measured as a function of K_B rate during the 1994 run. The results are discussed herein. It was discovered that the $\pi\nu\overline{\nu}1$ and $\pi\nu\overline{\nu}2$ trigger rejections decrease as the K_B rate increases. Changes to the ASIC trigger logic are discussed which which will help improve the rejection of the trigger at high K_B rates.

1 Description of the Level 1.1 Trigger

The level 1.1 trigger is a muon filter system designed to tag events having the $\pi^+ \rightarrow \mu^+\nu_\mu$ decay chain signature. The is done by searching for a delayed 4 MeV excess energy pulse in the range stack stopping counter. The system components which comprise this trigger are:

- The Master Trigger which is used to select level 0 triggers. The trigger performs among others, a hextant cut. Aided by the hextant cut, it finds the stopping counter of the charged track in the range stack. The stopping counter information is passed to the level 1.1 trigger system via the System Master.
- The System Master is a gate generator used to gate 256 channels of 500MHz **T**ransient **D**igitizers (TD's). It is also used to do an 8bit to 7bit RS stopping counter address conversion which is broadcast to the ASICs via the stopping channel bus.

Level 1.1 Trigger System Schematic

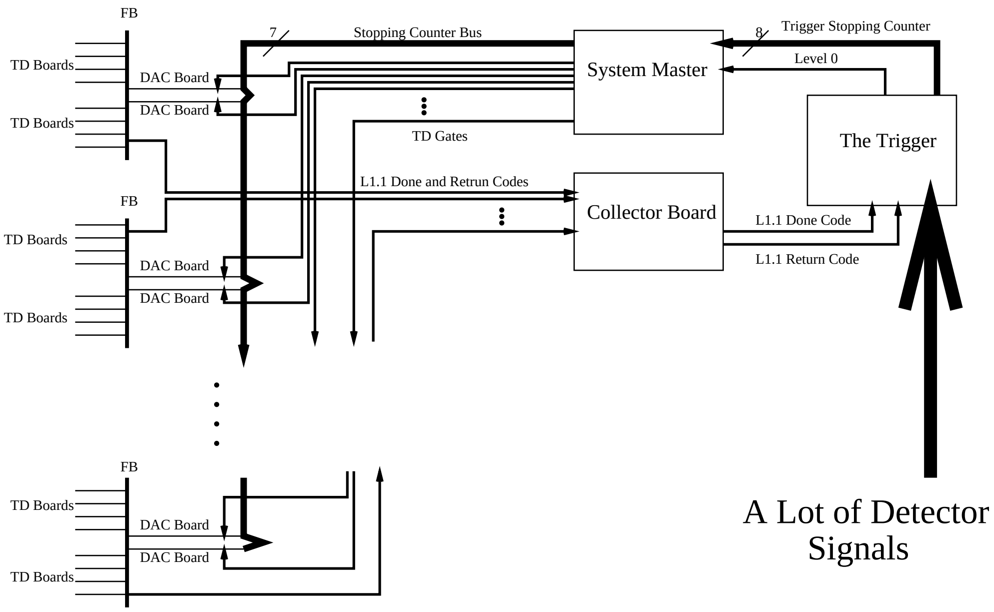

Figure 1: The level 1.1 trigger

- The level 1.1 ASIC is a custom designed chip used to read out the data from the TD's and perform both a height vs area and a detached pulse cut on the prompt stopping counter pulse digitized by the TD. There is one ASIC per TD channel.
- The Collector Board receives the crate summed level 1.1 return codes from the 8 TD RS fastbus crates. The return codes are then ORed into one signal and passed back to the Trigger.

See figure 1 for an abstracted schematic of the level 1.1 trigger system.

2 Measuring the Trigger Level 1.1 Performance

Measuring the level 1.1 trigger performance is simple, but subject to several systematic errors. There are two quantities that need to be measured: the level 1.1 rejection and the pion tagging efficiency. The level 1.1 $\pi\nu\overline{\nu}1$ rejection is defined by the ratio:

$$R_{\pi\nu\overline{\nu}1} = \frac{\text{No. } \pi\nu\overline{\nu}1 \text{ level 0 events}}{\text{No. } \pi\nu\overline{\nu}1 \text{ level 0 events which pass L1.1}} \tag{1}$$

Similarly the level 1.1 $\pi\nu\overline{\nu}2$ rejection is defined.

The measurement of the π^+ tagging efficiency is more complicated. For this purpose, $K_{\pi 2}(2)$ events whith the level 1.1 trigger removed are collected. When the charged track energy spectrum (RS+TT) is plotted for these triggers one can clearly see the energy peaks due to $K_{\mu 2}$ and $K_{\pi 2}$ decays. Underneath the two energy peaks lies a large background which must be subtracted. To measure the number of $K_{\pi 2}$ events in the $K_{\pi 2}(2)$ trigger sample, one fits a Gaussian distribution plus a constant background term to the $K_{\pi 2}$ energy peak.

$$\text{fit}(x) = a e^{-(\frac{(x-b)^2}{2\sigma^2})} + c \tag{2}$$

Using the three parameters measured by fitting the above function to the energy of the $K_{\pi 2}$ peak, one determines the number of pions by using the equation[1]:

$$\text{No of } \pi^+ \text{ tracks } = \sqrt{2\pi} a \sigma \tag{3}$$

With this procedure to measure the number of π^+ track events in the $K_{\pi 2}(2)$ trigger sample, one then determines the π^+ tagging efficiency by counting the number of π^+ track which pass the level 1.1 trigger and dividing it by the number of π^+ tracks which passe the level 0 trigger.

$$A_{\pi^+} = \frac{\text{No. } \pi^+ \text{ track events which pass L1.1}}{\text{No. of } \pi^+ \text{ tracks which pass L0}} \tag{4}$$

[1]There is a scale factor involved which normalizes the constant a to number of events/MeV. Since the histograms were booked with 1 MeV bins, the scale factor can be ignored.

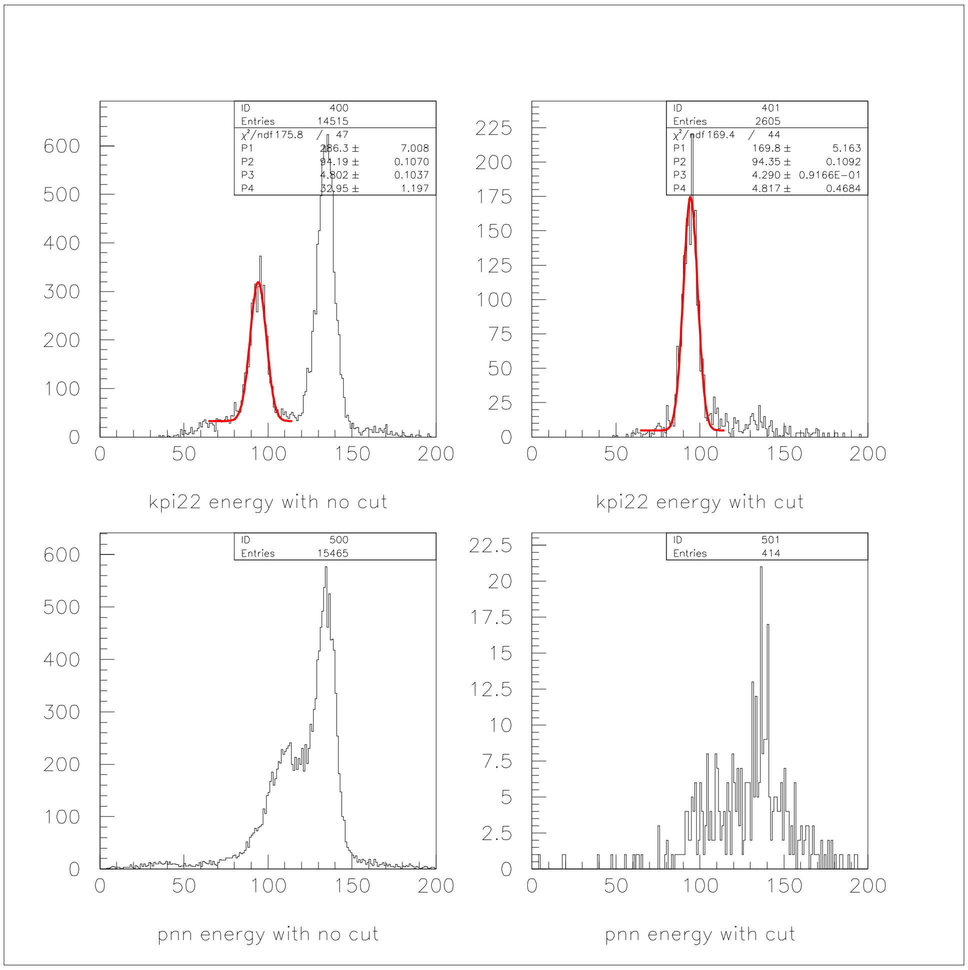

Figure 2: Kinetic energy spectra for $K_{\pi 2}(2)$ and $\pi\nu\overline{\nu}1$ triggers before and after the application of the level 1.1 trigger cut for K_B = 100K/spill.

The top two histograms of figure 2 give a graphical representation of the π^+ track counting procedure. These two histograms are plots of the charged track kinetic energy spectra for events which pass level 0 (left) and which pass both the level 0 and level 1.1 trigger (right). Both histograms are fitted with the Gaussian plus background term function described above. The bottom two histograms are charged track kinetic energy spectra for $\pi\nu\overline{\nu}1$ triggers which pass the level 0 trigger (left) and both the level 0 and level 1.1 cuts (right).

3 Beam Rates

The purpose of this analysis is to measure how well the level 1.1 trigger performs at different beam rates. To do this, data was taken at three beam intensities, $K_b =$ 100K, 500K and 1200K per spill. Reference Figure 3 and 4 for plots of the scaler values of K_B and C_k/C_π for the three data taking runs. During these runs, several triggers were recorded. They were $K_{\pi2}(2)$, $\pi\nu\overline{\nu}1$ and $\pi\nu\overline{\nu}2$. In all three triggers, the level 1.1 trigger requirement was dropped so that it could be applied offline. Also, there were no $\pi\nu\overline{\nu}2$ triggers recorded at $K_B = 100$K.

4 Trigger Level 1.1 Performance for the 1994 AGS Run

The results of measuring the trigger level 1.1 π^+ track tagging acceptance and $\pi\nu\overline{\nu}1$ and $\pi\nu\overline{\nu}2$ event rejections are listed in table 1. Reference Figure 5 for a graphical representation of this data. To summarize, the pion tagging efficiency was found to be independent of K_B rate. The $\pi\nu\overline{\nu}1$ and $\pi\nu\overline{\nu}2$ rejection factors did show a strong dependence on the K_B rate. The data indicate that the rejection power of the level 1.1 trigger decreases as the K_B rate goes up. The $\pi\nu\overline{\nu}1$ trigger rejection factor dropped from 37 to 18 as K_B rose from 100K to 1200K/spill. The $\pi\nu\overline{\nu}2$ rejection factor dropped from 14 to 10 as K_B rose from 500K to 1200K/spill.

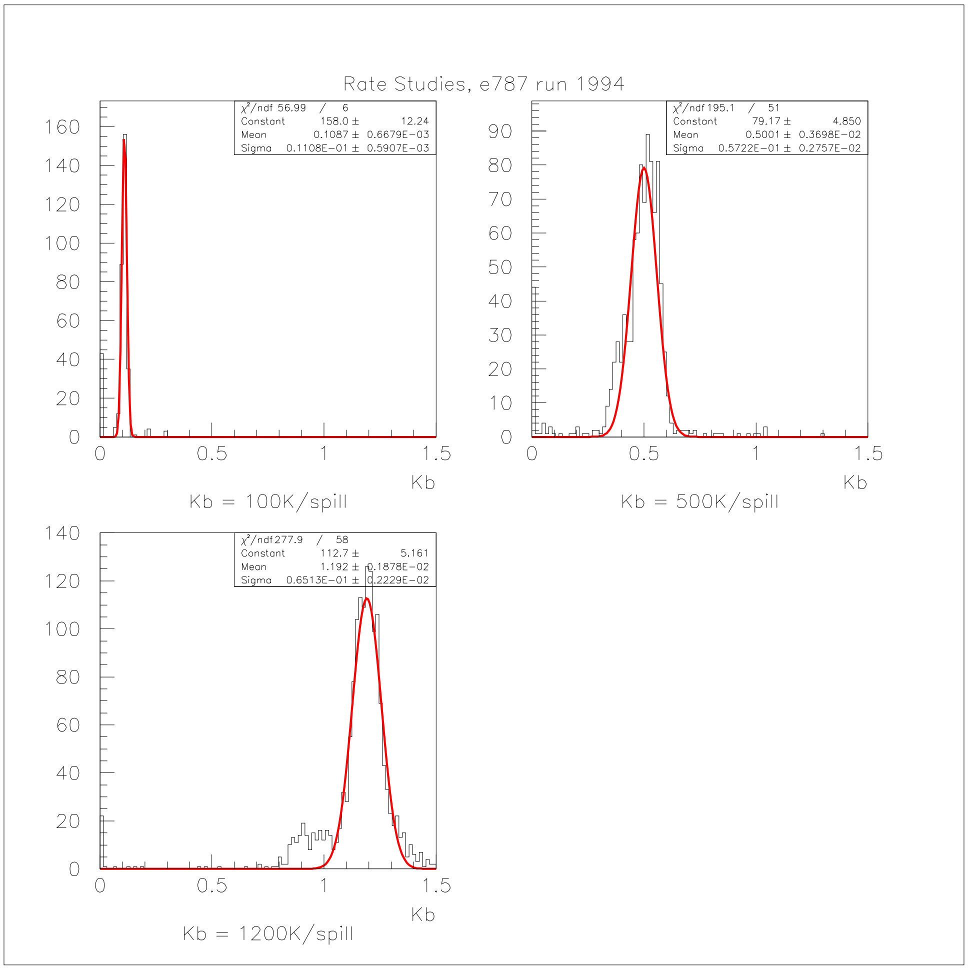

Figure 3: Histogram plots of the scalar value K_B for the three data taking runs.

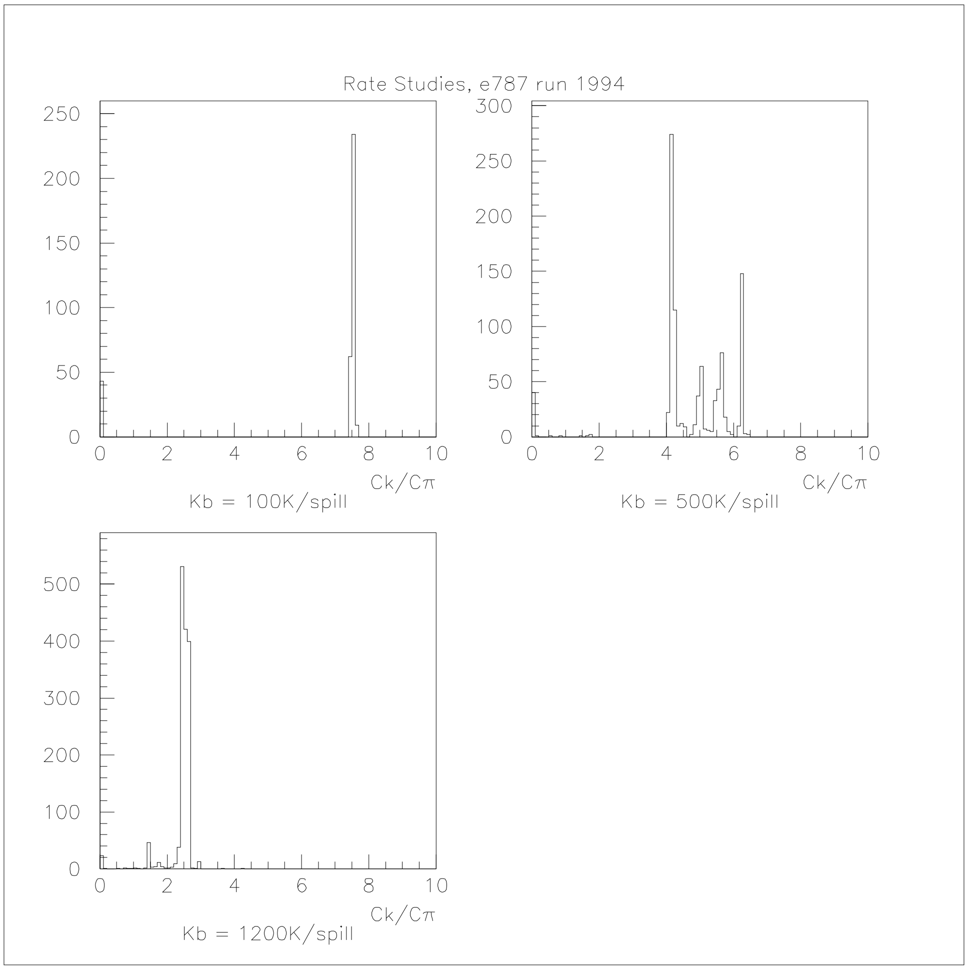

Figure 4: Histogram plots of the scalar value C_k/C_π for the three data taking runs.

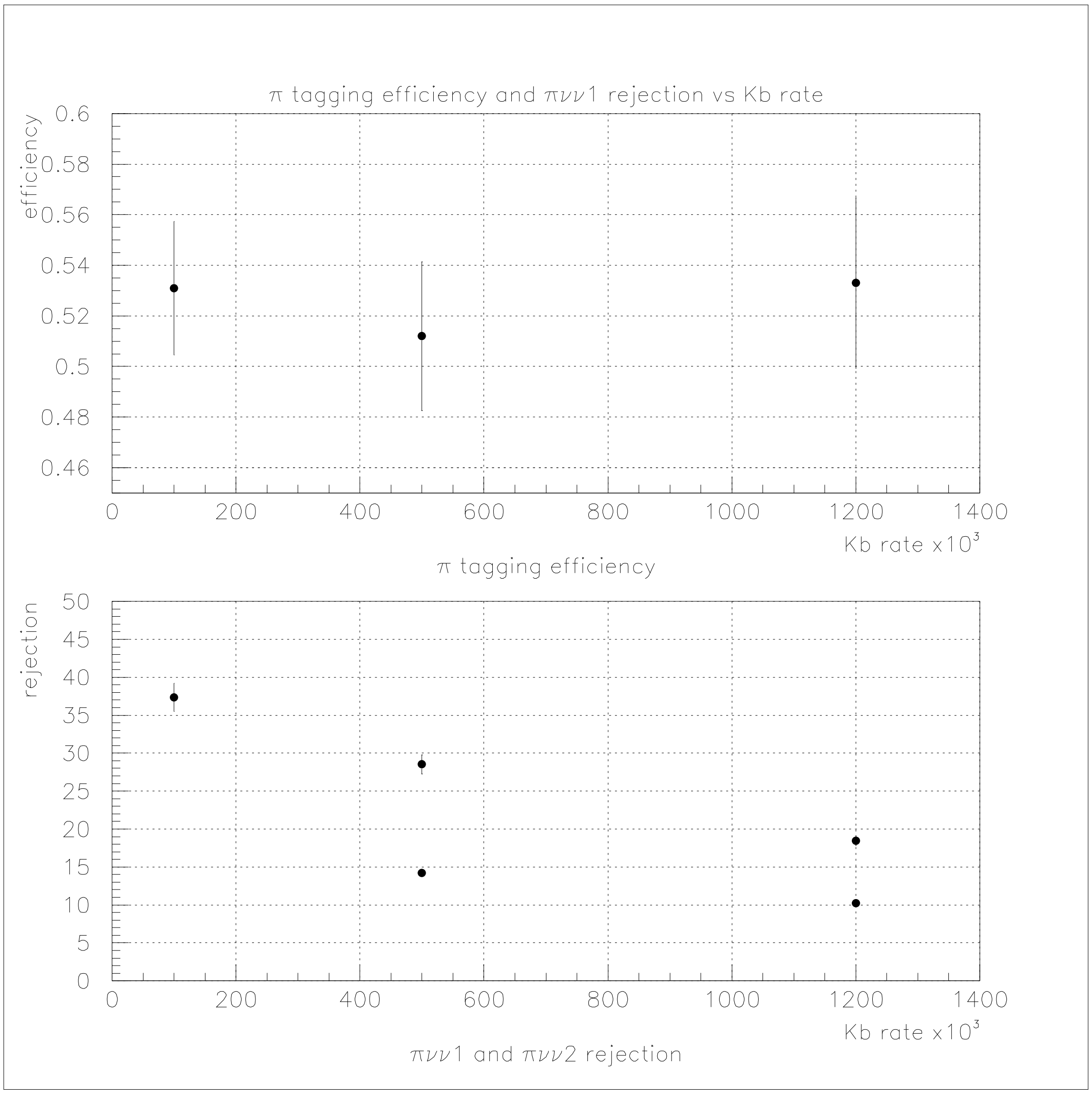

Figure 5: Trigger level 1.1 performance for the 1994 AGS run

K_b rate	trig type	rejection	π^+ eff
100K	$\pi\nu\overline{\nu}1$	37 ± 2	$.53 \pm .03$
500K	$\pi\nu\overline{\nu}1$	29 ± 1	$.51 \pm .03$
1.2M	$\pi\nu\overline{\nu}1$	18 ± 1	$.53 \pm .03$
500K	$\pi\nu\overline{\nu}2$	$14.2 \pm .4$	
1.2M	$\pi\nu\overline{\nu}2$	$10.2 \pm .3$	

Table 1: Trigger level 1.1 performance summary for the AGS run 1994

5 Issues Concerning Measuring the Trigger Level 1.1 Performance

There is no error in measuring the level 1.1 trigger rejection since the definition of rejection is to blindly count the events which are presented to the level 1.1 trigger divided by the number of events which pass the trigger. Measuring the pion tagging acceptance is a different issue. In this case, one is trying to measure in an independent way, how many π^+ track events pass the level 1.1 trigger vs how many π^+ tracks are presented to the level 1.1 trigger before applying its cut. The problem in this case is to be able to generate a 'pure' sample of pion track events. This cannot be done with the software analysis tools we have now: Fitpi, range/momentum, photon π^0 reconstruction etc. Therefore I rely on fitting the kinetic energy $K_{\pi2}$ peak found in sample of $K_{\pi2}(2)$ triggers before and after the level 1.1 cut. This method is not perfectly accurate and subject to several systematic errors such as:

- How well does the software identify the π^+ track in the target.
- How well does the software identify the charged track in the range stack.
- How well does the software find the stopping counter of the charged track in the range stack.
- Once a charged track in the target and range stack are found, how well does their energy sum give the true kinetic energy of the particle in question.

Most of these issues are negligible or small when the detector is exposed to a low rate kaon beam. The problems start at the higher rates. One method of trying to estimate the systematic errors involved in selecting the number of pion track events in a $K_{\pi 2}(2)$ trigger data set is to compare the online and offline stopping counters. The idea is to see how many times the online and offline methods fail to find the same stopping counter. This data can be found in figure 6. The x axis on this plot is the absolute value of the difference between the stopping counter found by the trigger and by the offline software. The y axis is the number of times this absolute value is less than a given amount divided by the total number of tries.

The three histograms are the same data but measured for different K_B intensities. One can see that the agreement between the stopping counters found by the hardware and software gets worse as the K_B rate goes up. Table 2 give a summary of the number of times each method (hardware or software) was in error in finding the stopping counter.

The second part of table 2 gives a list of common reasons the hardware and software found different stopping counters. When the hardware fails to find the stopping counter, it is usually due to the presence of a detached cluster in the vicinity of the charged track. This detached cluster is a real, intime splash of energy, and looks very much like a photon shower in the RS where the photon emanated from a radiative decay process such as a radiative $K_{\mu 2}$ or $K_{\pi 2}$. The hardware then tags the deepest layer of the shower as the stopping counter. As for the software, the leading cause of failure in finding the correct stopping counter is due to one of the range stack counters in the charged track having a wrong time assigned to it by the TD timing software. For example, the fiducial pulse for that RS counter is overlayed with a random pulse, thus throwing off the correct time by many 10s of nanoseconds. Or the prompt TD pulse in the RS is a superposition of several pulses, due to randoms, many 10s of nanoseconds apart. This fools the TD timing software and assigns a wrong time to the prompt hit in that RS counter. This problem gets worse with the higher rates.

The number of times the hardware and software stopping counters disagree gives an estimate of the systematic error in measuring the pion tagging efficincy. When one misidentifies the stoping counter in software, then one mismessures the RS energy and what could have been a good pion track is thrown out. The times the hardware fails to find the stopping counter needs to be factored out since a wrong harware stoping counter has no effect on

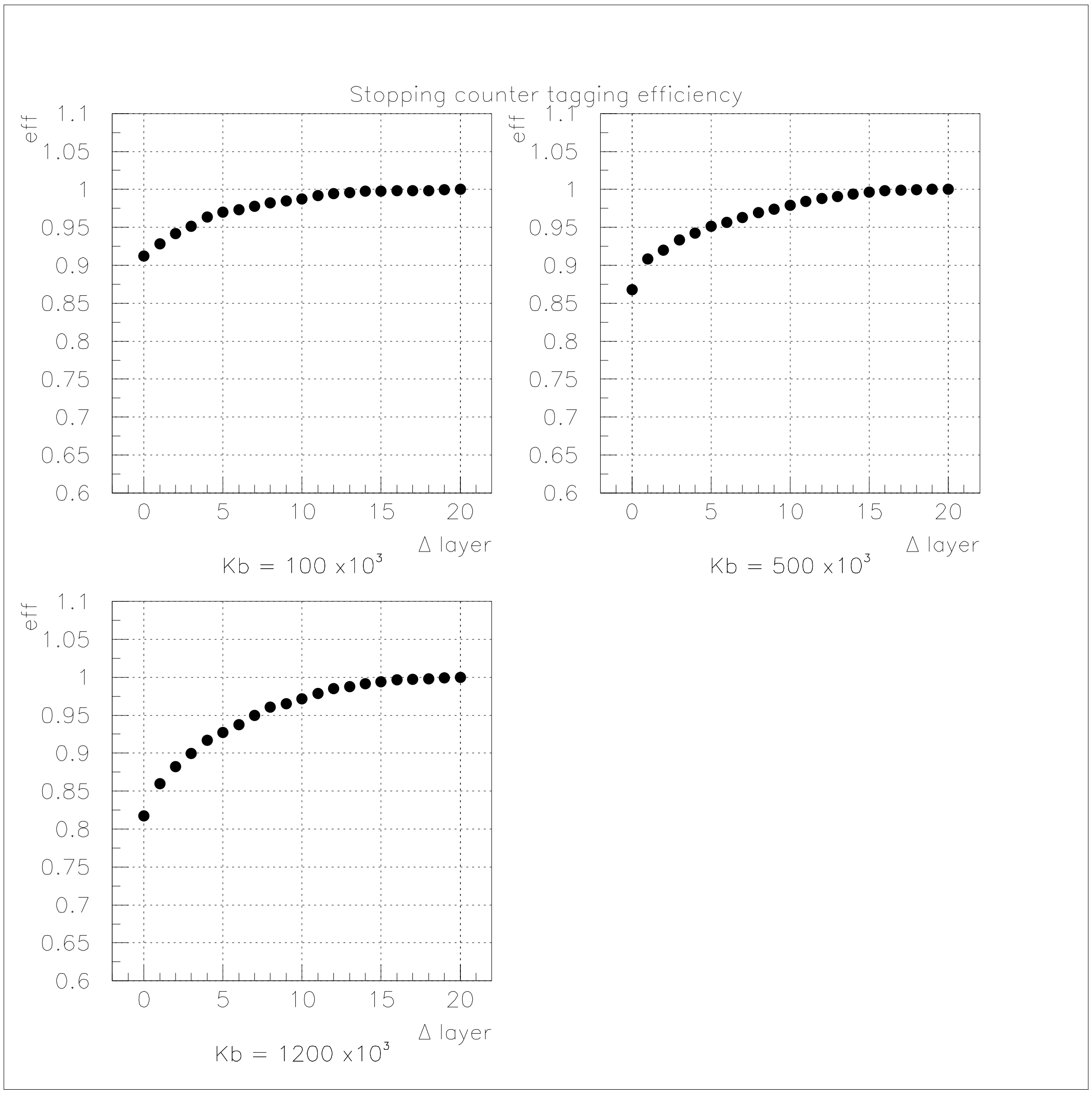

Figure 6: Stopping counter tagging efficiency

K_B rate	100K		500K		1200K	
	sw	hw	sw	hw	sw	hw
$K_{\pi 22}$	9	31	5	36	13	26
$\pi\nu\overline{\nu}1$	10	30	5	35	22	18
$\pi\nu\overline{\nu}2$			19	21	18	22

Stopping counter tagging failure modes:

- sw $\equiv$ Software Failure
  - td multi-hit problems
  - multi tracks
  - multi t.dot.2
  - out of time t.dot.a
- hw $\equiv$ Hardware Failure
  - multi tracks
  - negative track
  - multi t.dot.2
  - early $\mu^+ \rightarrow e^+$ decays

Table 2: Stopping counter efficiency

the measurement of the RS energy. A 0th order approximation in translating this stopping counter inefficiency into a systematic error gives a number on the order of a few percent. One starts by taking the data in Figure 6, and demanding that the hardware and software stopping counters disagree by more than two layers [2] . This figure is then corrected for only the times the software fails to find the stopping counter. With the K_B = 100K/spill rate data, one finds a disagreement of about 5% from Figure 6. Taking into account only the times the software failed to find the stopping counter, which was 9 out of 40 times, the 5% figure is reduced to 1%. For the K_B = 1200K/spill rate data, 12% of the time the two methods find stopping counters which differ by more than two layers. At this rate, 13 out of 39 times the software was wrong, which brings the 12% figure down to 4%.

To conclude, a 0th order estimate for the systematic error in measuring the number of pion tracks coming from $K_{\pi 2}$ decays varies from 1% at K_B = 100K/spill to 4% at K_B = 1200K/spill.

The statistical error in measuring the level 1.1 pion tagging efficiency is given in table 1 and is on the order of 6%. This error was found by propagating the errors measured in the two terms in equation 3.

6 Issues Concerning the Level 1.1 Rejection as a Function of K_B Rates

From the performance data listed in table 1, one can conclude that the $\pi\nu\overline{\nu}1$ and $\pi\nu\overline{\nu}2$ trigger rejection decreases as the K_B rate increases. The issue is to understand why this is happening and in doing so, find some way to modify the specific operation of the level 1.1 trigger/ASIC to make its rejection capacity less vulnerable to high K_B rates. The first step in this direction is to understand why the high rate data is causing the level 1.1 to lose its rejection power. In doing so, several issues emerge.

- High rates means random pulses are affecting the level 1.1 algorithm.

[2] Most of the times the hardware and software counter disagree by just one layer is due to energy leakage into the N+1 RS layer which is found by the software. The energy difference in the RS track by including or not including the N+1 RS layer is on the order of 1 MeV which does not affect the pion tagging efficiency measurement

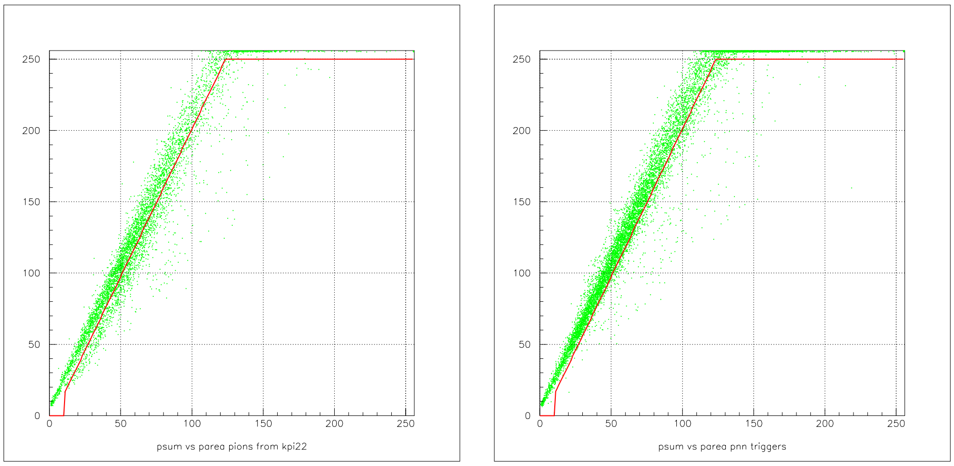

Figure 7: Single cut height vs area plot

- There may be something wrong with the pulses themselves which needs investigating.

The random pulse problem can be resolved by applying a second cut to the pulse height vs area cut. Currently, the level 1.1 trigger has a single cut used for the pulse height vs area. This can be visualized by examining the plot in figure 7. The line drawn on the plot is the lookup memory function used by the ASIC to determine the threshold for excessive area in a pulse. The plot on the left is a scatter plot of the prompt pulse height vs area for a sample of $K_{\pi 2}(2)$ triggers [3]. The plot on the right is the same scatter plot but for $\pi\nu\overline{\nu}1$ triggers. Notice in the $K_{\pi 2}(2)$ trigger sample, the region with excess pulse area due to the $\pi^+ \rightarrow \mu^+\nu_\mu$ decay signature. The key is that this excess area is limited to 4 MeV energy. When we compare the same region in the $\pi\nu\overline{\nu}1$ plot, one sees the absence of events with 4MeV excess area. Instead the whole region of excess area is uniformly populated. To help the level 1.1 trigger keep its rejection power at high rates, we need to limit this region of excess area such that only pulses with 4MeV excess area are allowed to pass the trigger. This can be accomplished by adding a second threshold which

[3] An additional cut on the $K_{\pi 2}$ energy peak was made to help enhance the π^+ track sample

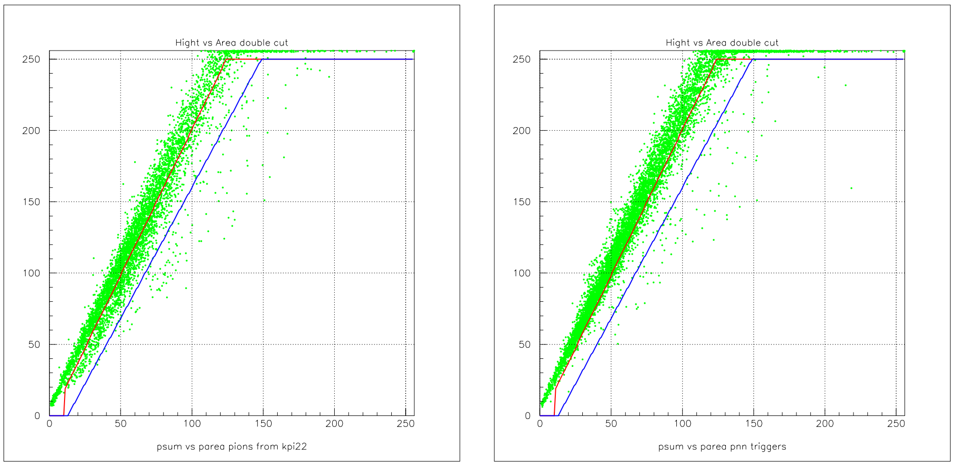

Figure 8: Double cut height vs area plot

can be graphically viewed in figure 8. The use of a minimum and maximum excessive area thresholds will decrease the probability of a random secondary pulse passing the hight vs area cut.

Another method of making the level 1.1 trigger more restrictive is to shorten the prompt time window in which the ASIC looks for the prompt pulse. Currently, this window is 184 ns wide. This large time window is due to two facts. First, the TD gate is driven by the System Master which runs on a 64 ns clock. This means that the prompt pulse time, as measured by the TD's, will be a flat distribution 64 ns wide. With the current System Master clock, the minimum prompt time window is 64 ns. There is also a requirement that restricts the detached pulse to lie inside the prompt time window. Since the current maximum detached time is set to 120ns, it is necessary to add another 120ns to the prompt time window, making it a total of 184 ns, to accommodate both the prompt and detached pulses.

A method which will reduce the prompt window time follows. First, one needs to eliminate the requirement that the detached pulse must be found within the prompt time window. With this change alone, one can reduce the prompt time window from 184 nanoseconds down to 64 nanoseconds. Second, one can increase the System Master's clock rate from 16Mhz up to

32Mhz or 64Mhz. By doing this, one can reduce the prompt time window from 64ns down to 32 or 16ns. This would apparently give one a factor of 5 to 10 in fighting the random problem. However one must be careful in this analysis. The only pulses which will be affected by reducing the prompt window time are early random pulses. The late random pulses are attached to the true prompt pulse will not throw the prompt pulse out of time as will a random attached early pulses. Therefore one needs to take the factor of 5 to 10 in improvement and scaling it down by 2, getting a factor of 2.5 to 5.

In order to get a better estimate of the improvement in rejection performance as a function of rate for the level 1.1 trigger, several plots related to the acceptance and rejection are found in figure 9. This figure contains 12 plots which deserve some comment. Each plot in the figure represents a different method of plotting the l1.1 performance at different K_B rates. Each method was measured twice, once with the single threshold height vs area cut (solid line) and once with the double threshold height vs area cut (dashed line). The first column corresponds to data taken at K_B = 100K, the middle column for K_B = 500K etc. The y axis for the first 3 rows of plots are rejection, acceptance and effective rejection respectively. The effective rejection is the acceptance multiplied by the rejection. The x axis in these first three rows of plots is a parameter which is adjusted during the calibration of the height vs area cut. What this parameter does is vary the slope of the line which is used to set the excess area threshold in the pulse height vs area scatter plot. (Reference figures 7 or 8.) With the y intercept of this line fixed, the slope is varied by $\pm 5\%$, and the acceptance, rejection and effective rejection are recorded. The last row is the most important one. This row plots the pion tagging acceptance vs $\pi\nu\overline{\nu}1$ trigger rejection for the three rates to which the detector was exposed. One should note that at low rates, the two lines are the same. At the higher rates, the double threshold height vs area cut provides better rejection for the same level of acceptance. This last row of plots best demonstrates the usefulness of the double threshold height vs area cut in having the level 1.1 trigger maintain high $\pi\nu\overline{\nu}1$ trigger rejection while the detector is exposed to a high rate kaon beam.

One last issue which could help the performance of the level 1.1 trigger is to analyze the pulse shapes themselves. The TD's work with a zero suppression circuit which breaks up the signal digitized by the TD's such that only pulses which rise above threshold are stored in memory. These pulses are later read out by the ASIC. One problem encountered, when hand

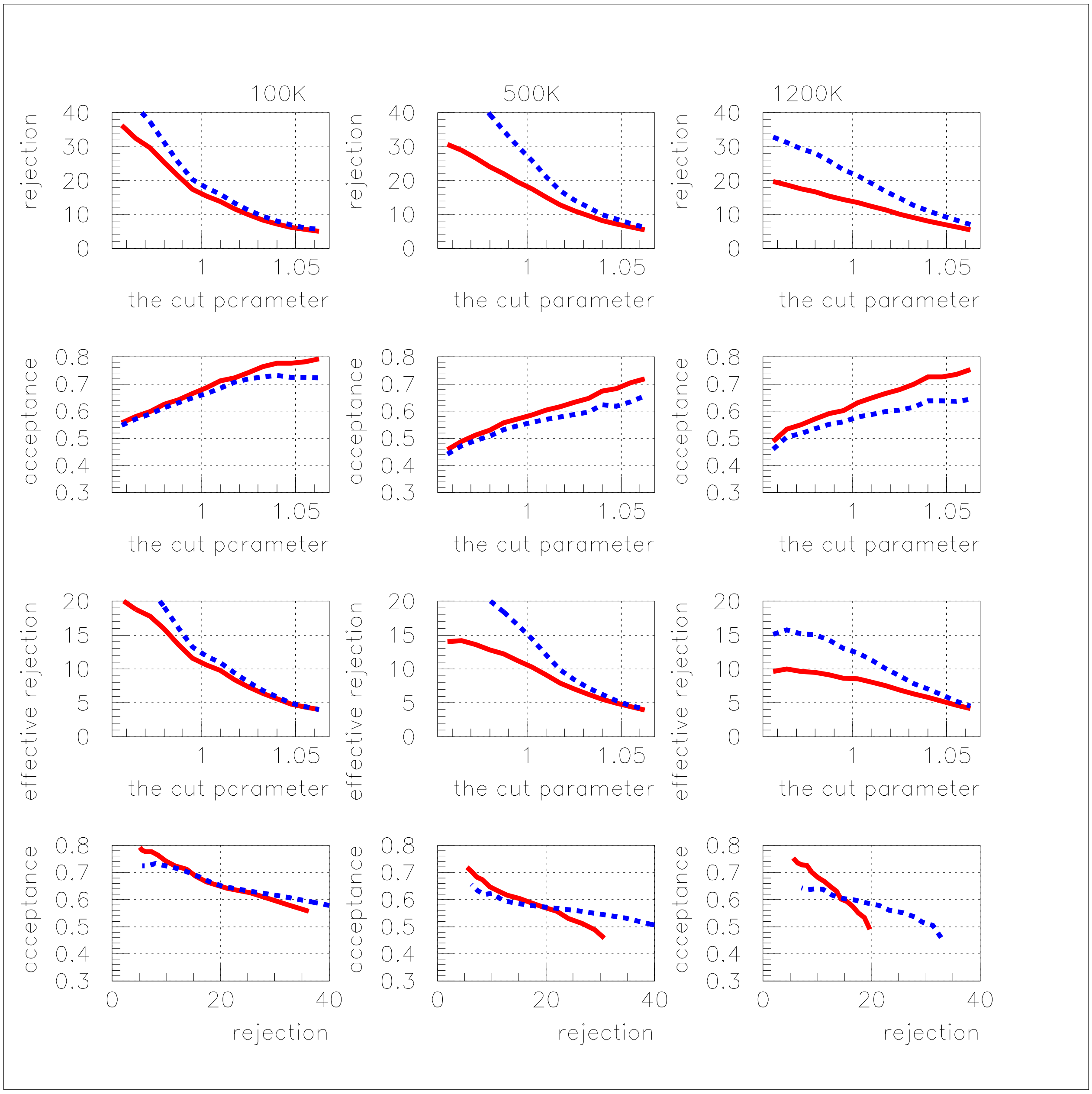

Figure 9: Trigger level 1.1 performance for the different beam rates. The solid line corresponds to the single threshold height vs area cut and the dashed line corresponds to the double threshold hight vs area cut.

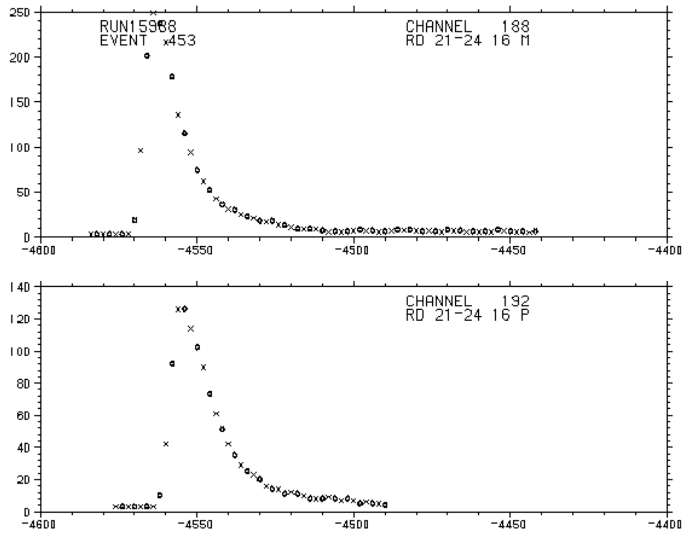

Figure 10: A long tailed TD pulse found in a $\pi\nu\overline{\nu}1$ trigger which passed the level 1.1 trigger

scanning many $\pi\nu\overline{\nu}1$ triggers which passed the level 1.1 trigger, were pulses which failed to return below threshold in a short time. An example of such a pulse is found in figure 10. This figure is a plot of a prompt stopping counter pulse. The feature to note in the pulse is it long baseline tail which seems to hover over threshold for about 60ns. The long tail has the effect of throwing the pulse height vs area cut into the excess area region, forcing the event to pass the level 1.1 trigger. An attempt needs to be made to make sure that the pulses promptly return below threshold to avoid this fake excess area problem.

7 Conclusion

The level 1.1 trigger was fully integrated into the E787 data acquisition system. This is a **major accomplishment**. The use of ASIC's to perform the height vs area cut and the detached pulse cut has reduced this trigger decision time by a factor of 10.

The performance of the level 1.1 trigger for the AGS run was measured and tabulated in table 1. The data indicate a problem with the current implementation of the hight vs area cut such that the rejection decreases as the beam rates increase. Two possible alterations to the ASIC implementation of the level l1.1 height vs area and detached pulse finding cut were discussed which will help reduce the dependence of the rejection as a function of rate. The rate dependent rejection data analyzed with the double threshold pulse height vs area cut show that the level 1.1 trigger is able to perform at is designed rejection level for beam rates expected in the '95 AGS run. Reducing the width of the prompt time window should add to the rejection capacity of the level 1.1 trigger, but by what amount was not investigated in this analysis.

Finally, there is evidence of long tailed pulses causing events to pass the level 1.1 trigger. A tail suppression circuit may be needed for future runs.