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Investigation of the STAR FEE Response to the FEE Pulser at the TPC System Test

Abstract

Comparisons between the response of the Front End Electronics (FEE) of the STAR TPC to the FEE pulser before and after the hardware modifications were made at the cosmic ray system test at LBNL. Indications are that the fix has had the desired effect. This is a small part of the work made possible by the collaborative effort of the TPC system test group at LBNL during August and September 1997.

1 Introduction

First indications at the cosmic ray test at LBNL during the month of August and September 1997 have shown that cross-talk between channels in the FEE boards have detrimental effects on space point resolution. This is shown in figure 1 where the average residuals to straight line fits of cosmic ray tracks show a systematic structure where points on odd pad rows are all pulled to one

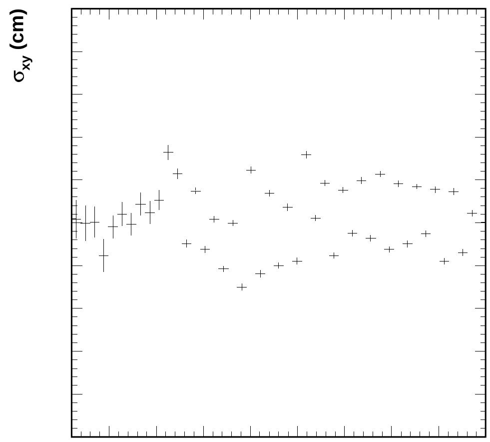

Figure 1: Average residual distribution in the x-y direction from a straight line fit to 2000 cosmic ray tracks in sector number 18. This is data integrated over all drift lengths. The odd-even structure is very striking.

side of the track and those on even pad rows are pulled to the other.[1] More seriously is the fact that the residuals are of the order of 1-2 mm which is roughly an order of magnitude more than expected from design considerations of the STAR TPC. The position or centroid of a charge cluster is calculated via the center of gravity method. In the case where a cluster has charge distributed over 3 pads and is Gaussian in profile, 20% of the integrated charge within a cluster must be distributed in the adjacent pad in order to shift the position of the cluster the order of 1 mm from its nominal centroid. This amount of charge is not observed in the tails of the clusters and so the distortion must come from something other than deformed cluster profiles.

A possible explanation for such an effect was suggested by E. Hjort and others. It lies in the layout of the electronics, how the pads are read-out, and a significant level of cross-talk between adjacent channels in the FEE cards. A FEE card instruments 32 pads, however, in the layout of the pad-plane read-out, adjacent channels in the FEE cards do not read out adjacent pads, but rather odd numbered channels read out pads on odd numbered pad rows and

[1] E. Hjort was the first to recognize this effect early in the system test.

even numbered channels read out pads on even numbered pad rows. This is shown schematically in figure 2. This explanation would account for the fact the “odd-even” effect in the track residuals is not seen at NA49 where the electronics design is similar but the read-out is such that adjacent electronics channels within a single FEE card read out adjacent pads in the same pad row. In the case of the STAR TPC electronics, cross-talk as illustrated in figure 2 between adjacent channels within a FEE card can affect the charge collected in neighboring pad rows! Such cross-talk can account for the pattern as seen in figure 1.

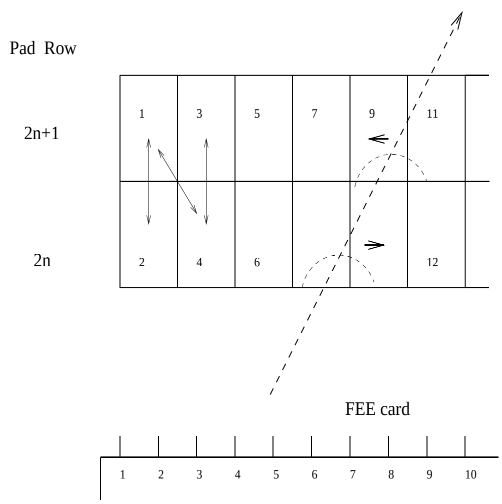

Figure 2: The structure of the read-out of the electronics channels and cross-talk between adjacent channels affects charge collected in adjacent rows. This pattern is shown by the double sided arrows on the left-most pads. This can pull the center of gravity of the charge distribution a non-negligible amount, and result in a pattern as seen in figure 1.

The FEE card is responsible for the pre-amplification, shaping, and the digital conversion of the signals induced on the pad-plane. These tasks are split between two Integrated Circuits (IC); the pre-amp and shaper (SAS) and switched capacitor array (SCA), both of which are 16 channel devices. A single FEE card instruments 32 pads and as such, is made up of two sets of each chip. The pre-amp and shaper chip (SAS) contains a charge injector which makes it possible to inject a known (setable) amount of charge into any specified channel(s) within the chip. This allows the possibility to isolate purely electronic effects from those that are inherent to processes within the chamber and allows the possibility to answer the question: Is cross-talk a function of the number of channels hit or rather a function of the amplitude of the pulses? Each case would require a different correction algorithm if this cannot be corrected at the hardware level.

2 Investigation with the FEE Pulser

Using the FEE pulser, all the odd numbered channels were pulsed in one chip (denoted chip 1) on the FEE card while only the first 4 odd numbered channels in the adjacent chip (denoted chip 2) were pulsed. This is shown schematically in figure 3. In these first tests, no even number channel was pulsed and since

	chip 1	chip 2
odd channels	X X X X X X X X	X X X X 0 0 0 0
even channels	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0

X denotes pulsed channel

O denotes non-pulsed channel

Figure 3: Pattern which channels are pulsed in FEE pulser test.

no charge is injected into these channels, any signal must be due solely to cross talk. In order to quantify this, the ADC value over pedestal of the time bin in the even channels which corresponds to the time bin where the pulse reaches its maximum amplitude in the *odd* channels will be recorded as a function of the charge injected. In the case of the FEE pulser, it is time bin 256. In order to increase the statistical power, an average over all even channels within a single chip was calculated. The data does not have the pedestal suppressed such that the complete pulse shape can be observed; particularly the undershoot that occurs in the tail of the pulse.

Two sets of data were taken at LBNL during the cosmic ray testing; one before the modifications to the FEE boards (in the initial board configuration), and one after. The run taken before the modifications to the FEE cards was not written to tape. Both runs were taken when sector 18 was instrumented.

The left panel of figure 4 shows the amplitude of the cross talk as a function of the pulser amplitude in the two chips before the modifications to the electronics were carried out. It is believed that there are two components to the cross-talk: (*i*) an amplitude independent component intrinsic to the architecture of the ICs which is a function of the number of channels which fire and (*ii*) an amplitude dependent part that is simply a function of the pulse height.

It is expected that the amplitude of the cross-talk or induced signals should be a factor of two less in chip number 2 than in chip number 1 because only half of the number of channels are being pulsed. This is not what appears to be happening. Instead the signals induced in chip 1 seem to increase much faster than linearly with increasing pulser amplitude, while the induced signals in chip 2 seem to saturate when the pulse is at a level of $\sim$700 ADC counts. The

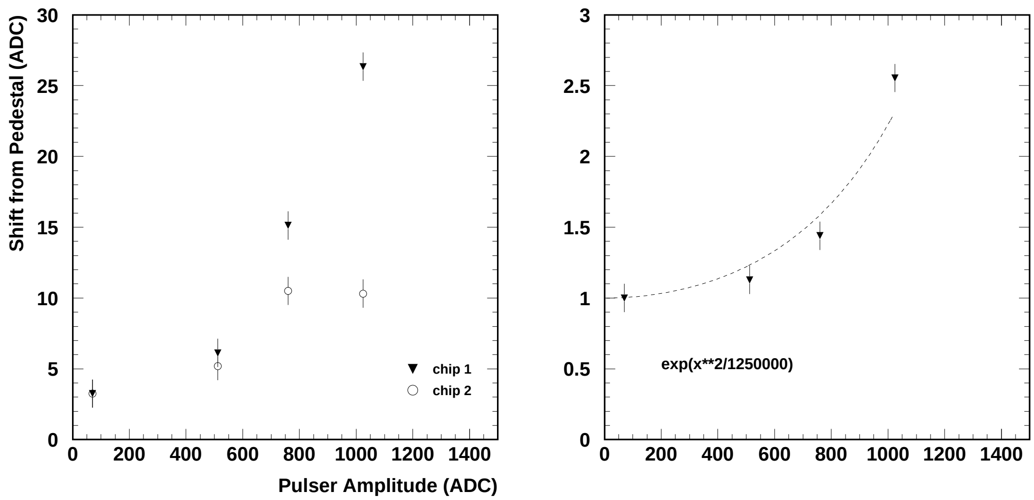

Figure 4: Effects of cross-talk before the modifications to the FEE boards. Shown at left is the average pulse height in the 256^{th} time bucket above the pedestal for the two chips on a single FEE board where the channels pulsed are shown in figure 3. Shown at right is the ratio of the heights of the pulses between the two different chips.

right panel of figure 4 shows the ratio of the induced signals (in time bucket 256) in the two different chips. This seems to indicate that the dominant component of the cross talk comes from the amplitude independent part.

A hardware solution to the problem was implemented by S. Klein and C. Vu during the system test and data was taken with the modified FEE boards under the same conditions. Shown in the left panel of figure 5 is the response of the electronics. In comparison to figure 4 it appears that the level of cross-talk does not appear to saturate at large pulsing amplitudes in chip 1 but rather continually increases as a function of the pulser amplitude, independent of the number of channels that are pulsed. The ratio of the pulse height between the two chips is shown in the right panel of figure 5. It appears that the cross-talk does not appear to be reduced in magnitude or at least not in chip 1 where all the odd channels are being pulsed. This is seen in comparing the left-most panels of figures 4 and 5. However, it appears that the behavior changes quite drastically in the second chip where only half the number of odd channels are pulsed. In this case, the electronic modifications remove the saturation and the cross talk becomes a smoothly increasing function of the amplitude of the pulser. This implies that the amplitude-independent component of the cross-talk is reduced considerably. The effect of this is seen in the right panel of figure 5 where the ratio of the pulses due to cross-talk in the two chips is essentially constant. Although there is no evidence for a reduced amount of cross-talk, it appears that the dominance of the amplitude-dependent cross-talk decreases the residuals in

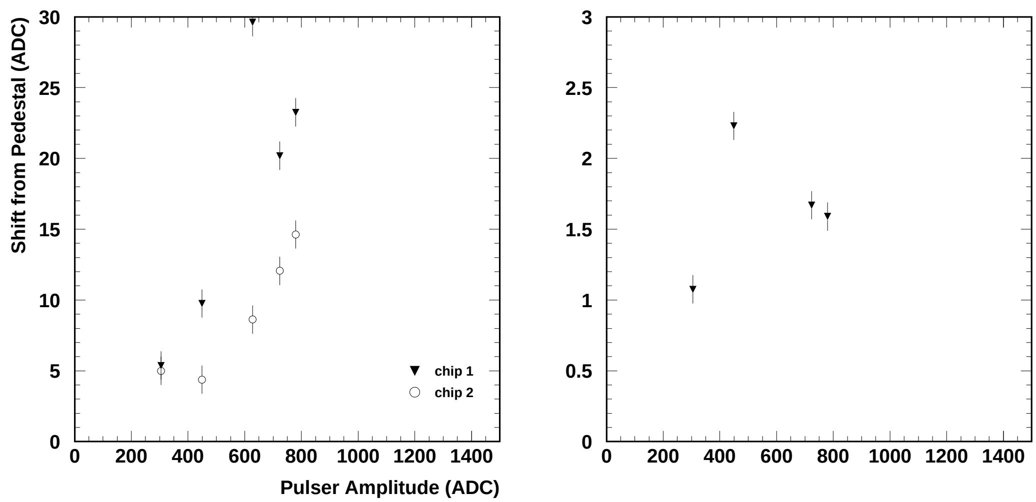

Figure 5: The same as figure 4 but after the electronics modifications. There is no evidence of saturation and it appears the degree of cross-talk is very similar in both chips, independent of the amplitude of the pulse.

track reconstruction. This is seen in figure 6 where the residuals are reduced to the level of several hundred microns.

3 Pulse Shape and Further Studies

Although the magnitude of the induced signals has not been substantially reduced by the modifications to the FEE boards, its character has changed which is directly seen in a large reduction in the track residuals. At this point it is necessary to understand the pulse shape as well as the effects of the gain calibration on cluster position. Currently the calibration constants are deduced via the pad pulser by normalizing the total integrated charge of a pulse in a single channel to the average pulse observed in a complete sector. This is in contrast to the method used in NA49 where the normalization is done to the peak channel. In the data there seems to be a variation of up to 40%[2] in the gain factors between different chips as deduced from the pad pulser data. An example of the gain constants from a single pad row is shown in figure 7. This is potentially serious for two reasons. First, if the calibration constants are not properly applied, this could compromise the calculation of cluster position over chip boundaries. Second, the shape of the gain profile is expected to be similar

[2] It was pointed out by S. Klein that the chips used in the system test did not go through a rigorous selection process and as such is a "worst case" scenario.

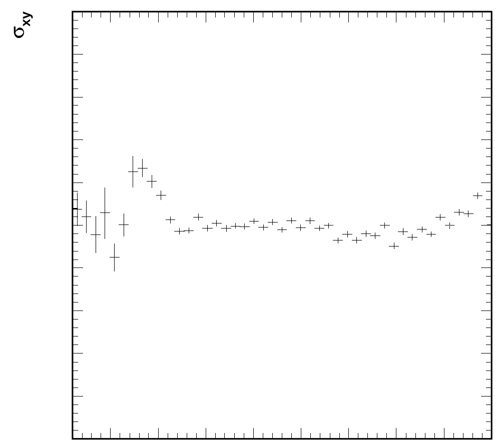

Figure 6: Average residual distribution in the x-y direction in sector number 18 for 1000 cosmic ray tracks after the electronics modifications. This data integrated over all drift lengths and can be directly compared with Figure 1.

for different chips as it is a property of the architecture of the chip,[3] and this does not seem to be the case. It is difficult to quantify the effects of gain variations within a chip in terms of track residuals, however, it should be possible to incorporate a criterion which restricts the gain variations between chips in the final chip (or FEE card) selection process.

In regards to the pulse shape, there appears to be an effect where the rise time of the pulse changes as the number of channels pulsed increases; i.e. the rise time of the input pulse seems to be reduced pushing the peak into the adjacent time bucket. This is shown in figure 8. In the top panel, the pulse shape from chip 1 where all odd numbered channels are pulsed is shown. The peak of the pulse occurs in time bin 256, whereas in the bottom panel, the pulse shape for chip 2 (where only the first 4 odd channels are pulsed) is shown. Here the peak channel shifts to time bin 255. It was suggested by S. Klein that this is simply a result of the rise time of the pulse decreasing as more channels are pulsed because of the increase in the amount of current that need be supplied. However this does*not* appear to be systematic in all chips! Perhaps this is not serious but if the pulse shape changes as a function of the number of channels hit in a single chip or as a function of the track density, corrections to the measured charge will have to be made at the chip level which will affect the total integrated cluster charge. Such corrections will impose an additional time penalty in the data analysis and affect the ultimate resolution of $\frac{dE}{dx}$ measurements used for particle identification. If this is not a systematic effect, *it should be incorporated*

[3] At least this was the case in NA49. For example see B. Lasiuk, *On the Specific Ionization Loss in the VTPCs*, NA49 Internal Note 120, January 1997.

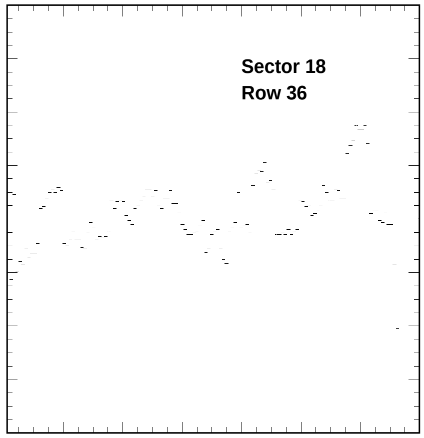

Figure 7: Gain constants deduced from the pad pulser across a single pad row. Such constants should remove any channel to channel (and chip to chip) fluctuations in gain characteristics. There are two notable effects; (*i*) the large variations between different chips and (*ii*) different gain profiles between different chips.

as a test for final chip selection.

Another subject that the FEE pulser is able to address is the degree of the undershoot in a typical pulse. This is evident in non-pedestal subtracted events. When the FEE pulser is set for zero amplitude, it in fact produces a negative pulse which is shown in figure 9. Because normal data taken necessarily requires pedestal subtraction, any undershoot will be registered as zero ADC counts, or worse, if a positive pulse is superimposed on the tail of an undershoot, the pulse will be artificially reduced in amplitude. As such it is important to understand under which circumstances the electronics will see a negative pulse such that it may be dealt with by an appropriate correction. It should be pointed out that the FEE pulser injects charge into a specific channel in the form of a delta function and the electronics has been optimized for the response of a signal generated by the amplification process which occurs over a much more extended period in time. A more realistic example would be the response to laser tracks of varying amplitude, but no laser data with pedestals seems to exist at this time.

The amount of undershoot appears to be a constant across a FEE card, *but* dependent on the positive pulse height. In figure 8 where the pulse was the order of 322 ADC counts, the undershoot was ~6% of the amplitude of the pulse and lasted for nearly 2 μs. The baseline shifted nearly 13% over this time interval. Figure 10 illustrates this in a quantitative manner. It appears that the amount of undershoot is linearly related to the amplitude of the pulse at a level of ~6.5%. Although the expected track density at STAR should not cause more

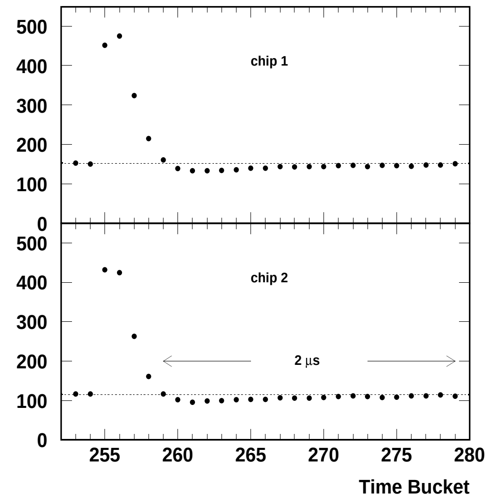

Figure 8: Pulse from FEE pulser seen on a single FEE card. This is an indication that the pulse shape changes as the current load on the SAS chip changes. Chip 1 has 8 of 16 channels being pulsed while chip 2 has only 4 of 16. It appears that chip 2 has a marginally faster rise time as seen in the shift in the peak pulse height by one time bin.

than several tracks crossing a single pad,[4] significant charge loss could occur if single electronics channels do not have at least $2\mu s$ to recover before another track crossing. Of course one must also emphasize that the operating point of the STAR TPC is such that a minimum ionizing particle has approximately 40 ADC counts over pedestal. A 6% effect represents a shift in the peak channels by only 2 ADC counts. Although this is probably not significant in terms of affecting position resolution, it is non-negligible in the quantification of specific energy loss or $\frac{dE}{dx}$ which is foreseen in the TPC. This gives some rough measure of the precision that exists for particle identification using $\frac{dE}{dx}$, and the required precision of the necessary corrections.

In this respect, a study to characterize the clusters of laser and cosmic ray tracks is necessary, and first evaluations of $\frac{dE}{dx}$ characterization using the hit finder will also begin. This is work in progress. More to come...

[4]H. Weiman, private communication at the system test August 1997.

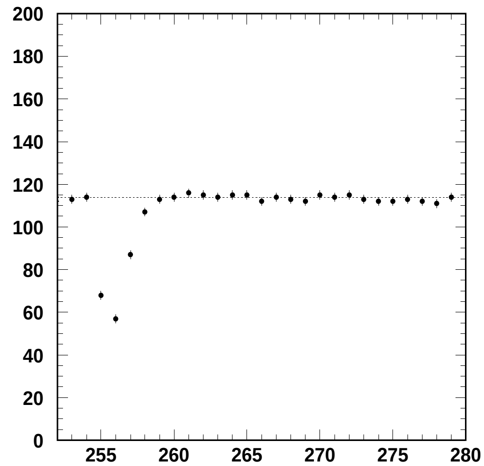

Figure 9: Indications that the electronics is able to handle pulses of negative polarity. This is the resulting signal when the FEE pulser is set to pulse with zero amplitude. If track densities are locally very high, the undershoot of pulses may be a significant source of charge loss in the TPC.

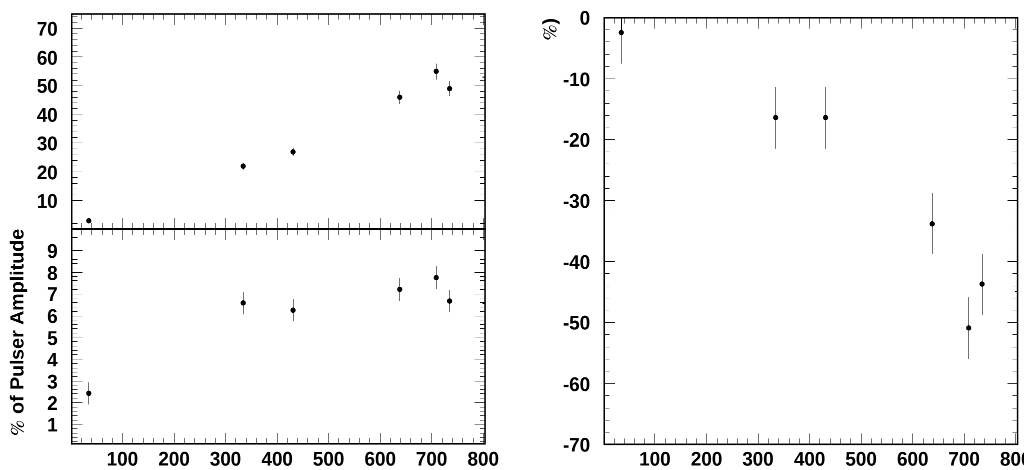

Figure 10: Quantification of the undershoot in the FEE cards. In the upper left panel is the magnitude of the undershoot in ADC counts versus the pulser amplitude which appear to be linearly related. At large pulsing amplitudes the undershoot is a constant fraction of the peak amplitude—approximately 6.5%. In the right panel, the shift from the baseline is shown. Although this is somewhat dependent on the magnitude of the pedestals, it is qualitatively consistent with the left panel.