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A More Detailed Look at Raw Mode with the Upgraded MI BPM System

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Abstract

This note takes a more detailed look at raw mode data from the upgraded MI BPM system. The raw mode data look good but one significant issue was discovered when comparing the timing of raw mode to that of flash turn-by-turn mode. In flash mode, the Echotek "Receiver Data Skip" count has been set to a large value, so large that it exceeds one turn. We now need to understand if flash turn-by-turn is really turn-by-turn or every-other-turn.

Contents

1 Introduction

The raw mode data presented here were taken by Steve Foulkes on Tuesday February 7, 2006. They include all 11 BPMs from the new system in MI40, for locations V403 through V413 inclusive. The data were taken for MI state 5, mixed mode, slip-stacking plus NUMI. At the time these data were taken, all of the BPMs in were timed in so that, in proton flash turn-by-turn mode, the Echotek window captured front of each newly injected batch. It is estimated that the accuracy of this timing is about ± 10 buckets.

For the raw mode measurements, the data acquisition was triggered by the BES. The pre-trigger delay and the turn-by-turn half-bucket delay were counted down exactly as for the flash measurements. The only difference is that the I44 bucket delay, DATUM4, could, in principle, be different for the two cases. I believe, but am not 100% certain, that the I44 bucket delay was zero for both measurements.

In raw mode the Echotek data are just ADC counts, signed 14 bit integers, with a range of -8192 to +8191. Peter Prieto asked that the data be multiplied by 4, in order to match the representation used elsewhere, a range of -32768 to +32764. For the data presented here this change has been made. I checked that every ADC value returned is evenly divisible by 4; they are.

Data similar to this were shown at the project meeting on February 7, 2006. The differences are: the timing for data shown here is well understood but that is not the case for the other data; and the previous data did not include the factor of 4 discussed in the previous paragraph.

I do not know the transition board settings for this data.

2 V403 in Some Detail

Figure 1 shows the raw mode data from BPM V403. In this mode the quantities A and B are ADC counts, not complex numbers (I,Q). The upper plot in the figure shows A as a function of ticks of the $10/7\ f_{\mathrm{RF}}$ clock. In this data one can see a little more than a full turn with no beam, followed by the first pass of a batch and the second pass of the same batch. A single turn is 840 ticks of the $10/7\ f_{\mathrm{RF}}$ clock. The data fill approximately one quarter of the dynamic range of the digitizer.

The middle plot shows the same information but for the B channel. The same features can be seen in the data.

The bottom plot shows the sum signal, $|A| + |B|$.

Figure 2 shows two details of the same data. The left column shows a detail of the first pass of the batch. The right column shows the first 500 turns, during which there is no beam. In the noise data, a small DC offset can be see on both the A and B channels.

Using the data from right hand column, the noise in the sum signal was measured to have mean level of 131 counts and a maximum value of 408 counts. Based on this analysis a threshold of 816, twice the maximum count was chosen to define the presence of beam. One needs to be a little careful in looking for batches because isolated points in the middle of a batch sometimes fall below this threshold. This is not a very precise definition of a batch since it usually excludes small tails at both ends of the batch; delimiting these tails more precisely is complicated by the large fluctuations that arise from undersampling. But this definition of a batch is good enough for the purposes of this note.

Using this definition, the first batch extends from 904 to 1034 ticks, inclusive, and the second batch extends from 1774 to 1874 ticks, inclusive. This gives 840 ticks between turns, as expected. Using the same procedure on all 11 BPMs gives a turn length of 840 nine times and and 838 ticks twice. This is good.

The above analysis gives a batch length of 131 ticks both times that the batch passes the Echotek. Using the same procedure on all 11 BPMs gives an average bunch length of 125.9 ticks. This corresponds to $7/10 \times 125.9 = 88.1$ buckets.

This makes sense for a batch of length 80 buckets, plus the rise and fall time of the analog filters on the transition board.

Figure 3 shows the Fourier transforms of the A, B and sum signals, using only the data between ticks 911 and 1029, inclusive. This range corresponds to the first turn of the injected batch. Before computing a transform the mean value of the signal, over the range of the transform, was subtracted out. The colored vertical lines are drawn at frequencies of $2/7 f_{\mathrm{RF}}$ (green), $3/7 f_{\mathrm{RF}}$ (red), and $4/7 f_{\mathrm{RF}}$ (yellow). The A and B data show a strong line at $3/7\ f_{\mathrm{RF}}$, the expected position of the alias of f_{RF} with a $10/7 f_{\mathrm{RF}}$ sampling clock.

Because of the absolute value in the computation of the the sum signal, the Fourier transform of the sum signal contains power at all frequencies, with prominent spikes at baseband and at all even multiples of f_{RF}. The power is highest at baseband and decreases as the multiple increases. The main features in this plot are the alias of $2f_{\mathrm{RF}}$, that appears at $4/7 f_{\mathrm{RF}}$ and the alias of $4f_{\mathrm{RF}}$ that appears at $3(10/7) - 4 = 2/7$ of f_{RF}. The core of the alias at baseband has been suppressed by subtracting out the mean value of the data; the tail of this alias remains. Neither of the aliases at $(20/7 \pm 1) f_{\mathrm{RF}}$ lies within the domain of the plot. A simulation showed that the transform of the sum signal indeed has the expected shape.

2.1 The Arrival Time of the Raw Mode Signal

As noted above, the first tick with a sum signal above background is tick 904. This is more than a full turn after the start of data taking. It was stated earlier that the Echotek was timed in so that the Echotek gate samples the first part of the batch. The explanation is below.

In flash turn-by-turn mode the timing card receives the trigger, in this case the BES. It then counts down a pre-trigger delay, denominated in turns. It then counts down a turn-by-turn delay, denominated in half-buckets that is the sum of several contributions. Following this delay the timing card issues its first sync. Syncs are issued every 588 buckets thereafter. Once a sync is received, the Echotek begins to digitize and filter the data. Because it takes some time for the output of the digital filter to settle, the Echotek can be asked to skip the first points out of the filter. This is referred to as the "Receiver Data Skip" count. Peter Prieto tells me that there is a bug in the Echotek documentation and that, if the Receiver Data Skip is set to n, then the Echotek will actually skip $2n$ points. This was certainly the case with earlier versions of the Echotek and he believes, but is not 100% certain, that this is still the case the MI version of the board.

For proton data, the 53 MHz wideband filter as been programmed as follows:

- Decimations in the CIC, CFIR and PFIR of (8,2,2). This means that a new data point comes out of the digital filter every 32 ticks of the 10/7 clock.
- The Echotek gate corresponds to twice this, or 64 ticks. This corresponds to $7/10 \times 64 = 44.8$ buckets, as advertised.

- The Receiver Data Skip is set to 15. This means that 31^{st} point out of the Echotek is retained as the measurement of a single turn. The value of 15 seems too high given that there are only four non-zero taps in the PFIR; it is probably a remnant of an old, closed orbit configuration and needs to be revisited.

With this configuration, the recorded measurement samples the beam that arrived during an interval starting after the expiry of tick 29. This corresponds to a delay of $29 \times 32 = 928$ ticks of the 10/7 clock, relative to the arrival of the timing board sync at the Echotek.

In raw mode, the timing card receives the BES, counts down the pre-trigger delay, counts down the aggregate turn-by-turn delay (denominated in half-buckets) and issues a single sync. Following this sync, the Echotek digitizes 2048 samples, stores these samples without filtering them and stops. The above analysis predicts that the first beam should arrive at tick 928 in all data samples. For V403 it was noted that the beam arrives at tick 904. For the other 11 BPMs in the crate, the beam arrives between ticks 901 and 907. This difference is larger than the expected 10 bucket difference. My guess is that we guessed wrong about the accuracy of timing in the BPMS and that this analysis really is self consistent.

2.2 Is there a Problem?

In the above section, it was described that the delay from the Echotek sync to the recorded data point corresponds to 31 points out of the Echotek filter. This is $31 \times 32 = 992$ ticks of the 10/7 f_{RF} clock. This is longer than one turn, 840 ticks. According to Peter Prieto, the Echotek ignores any syncs received during an ongoing operation.

This leaves a big question. Is turn-by-turn mode really every-other-turn mode? If so, why do we get the expected 512 points not 256 points? Also if so, every-other-turn mode would shift the measured synchrotron and betatron frequencies. We have not yet made any measurements of these frequencies that are careful enough to exclude this scenario. These measurements will be made.

There is another complication that I have not yet thought through. If flash turn-by-turn mode the delays are configured so that there is one turn with no beam, followed by 511 turns with beam. I am not sure what this does to the above analysis since I don't know enough about what boards actually do.

3 Summar of All 11 BPMs

Figures 4 and Figures 5 show the sum signal for all 11 BPMs in this sample. All are timed in so that the beam arrives at about the same time. The red and green superimposed lines are described in the discussion of the subsequent figures. For each BPM, the noise level was measured as described above for V403; these noise levels are recorded in Table 1. The tick numbers that mark the start and end of the two turns of the injected batch are also recorded in the table.

Figures 6 through 9 show details of the sum signals for all 11 BPMs. The first two pages show details at the start of the first turn of the injected batch. The last two pages show details at the end of the first turn of the injected batch. In these figures, the superimposed red and green dashed lines show the mean noise level and the threshold used to indicate the presence of beam. The vertical red line marks the nominal edge of the batch, where the threshold intercepts the data.

One can see from these figures that the nominal definition of a batch truncates the tails a little; this does not change any of the conclusions in this note.

I have made Fourier transforms for all 11 BPMs but they all look so much like Figure 3 that this is no reason to include them in this note.

Finally, figure 10 shows the various measures of the noise level, as recorded in Table 1 plotted vs increasing BPM number. The BPMs to the left of the plot have short cable runs from the BPM to the house while those on the right edge have long cable runs. There is no significant structure as a function of cable length.

4 Summary and Conclusions

We need to understand what, if any problems, have been caused by the large value of "Receiver Data Skip Count". I believe that we understand the value of the delay from the start of the raw data to the arrival of the first beam; but there is still one issue to check. Otherwise all of the data looks good. In particular there is no evidence for increased noise for long cables.

BPM	Noise (ADC Counts)			Batch Turn 1 (Tick)		Batch Turn 2 (Tick)	
	Mean	RMS	Max	Start	End	Start	End
v403	130	72	408	904	1744	1034	1874
v403	131	72	408	904	1034	1744	1874
h404	120	61	368	905	1035	1745	1875
v405	161	74	384	905	1035	1745	1875
h406	156	72	436	901	1031	1741	1871
v407	113	59	300	902	1025	1742	1870
h408	127	66	364	904	1025	1742	1874
v409	132	71	528	907	1025	1747	1867
h410	127	65	388	904	1024	1744	1864
v411	118	63	324	903	1026	1743	1864
h412	116	62	380	905	1025	1743	1865
v413	176	84	468	906	1026	1746	1866

Table 1: Summary information about the raw data from each BPM. The first noise column gives the mean level of the sum signal, measured in the first 500 turns, during which there is no beam. The error on the mean is a few ADC counts. The second noise column gives the RMS of the same data sample. The third noise column gives the value of the maximum sum signal in the first 500 turns. The next two columns give the tick numbers that mark the extent of the the first turn of the injected batch. The last two columns give the tick numbers that mark the extent of the second turn of the injected batch.

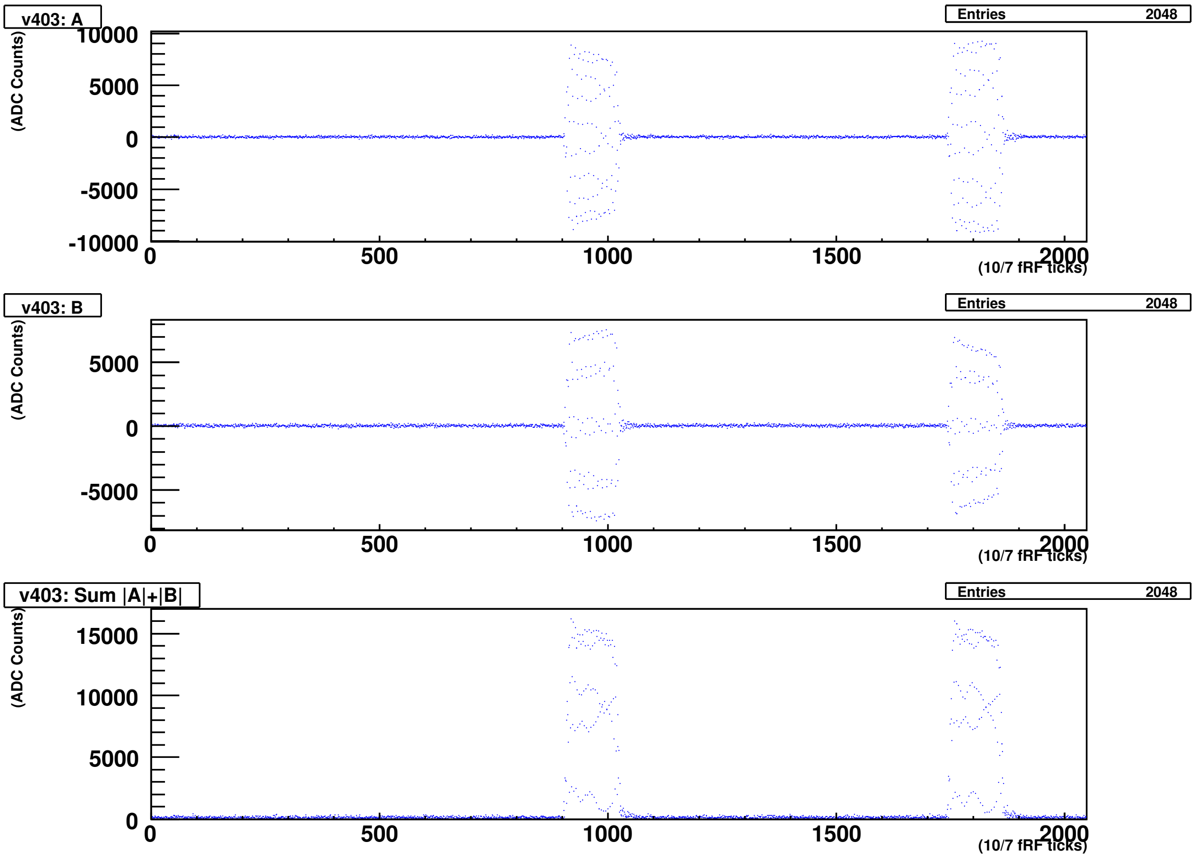

Figure 1: The raw mode data from BPM V403. The upper plot shows the digitized pulse height on the A channel, while the middle plot shows the digitized pulse height on the B channel. The bottom plot shows the sum signal $|A| + |B|$. In all three plots the horizontal axis is time, in ticks of the $10/7\ f_{\mathrm{RF}}$ clock. The features of the plots are discussed in the text.

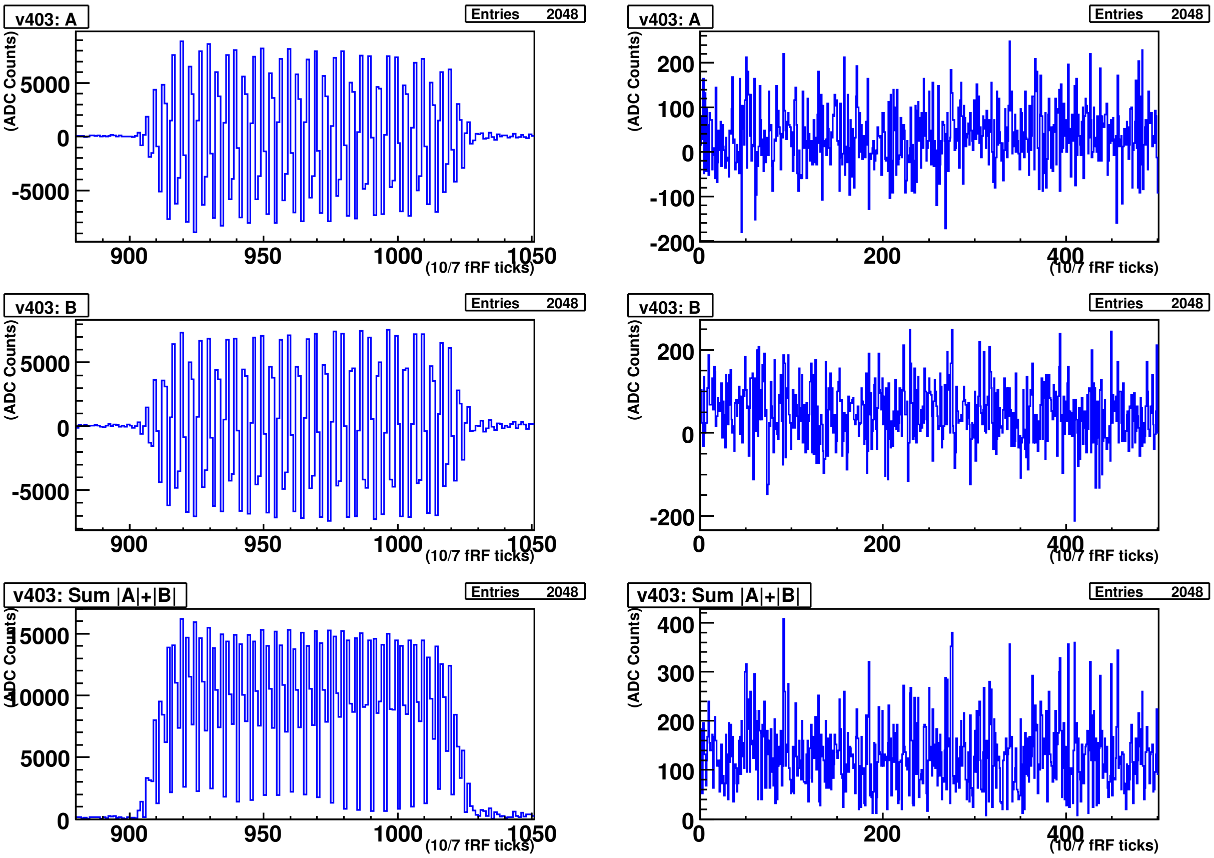

Figure 2: Two details of Figure 1. The left column shows a detail of the first turn of the injected batch. The right column shows a detail of the first 500 ticks, during which there is no beam; this provides a noise measurement.

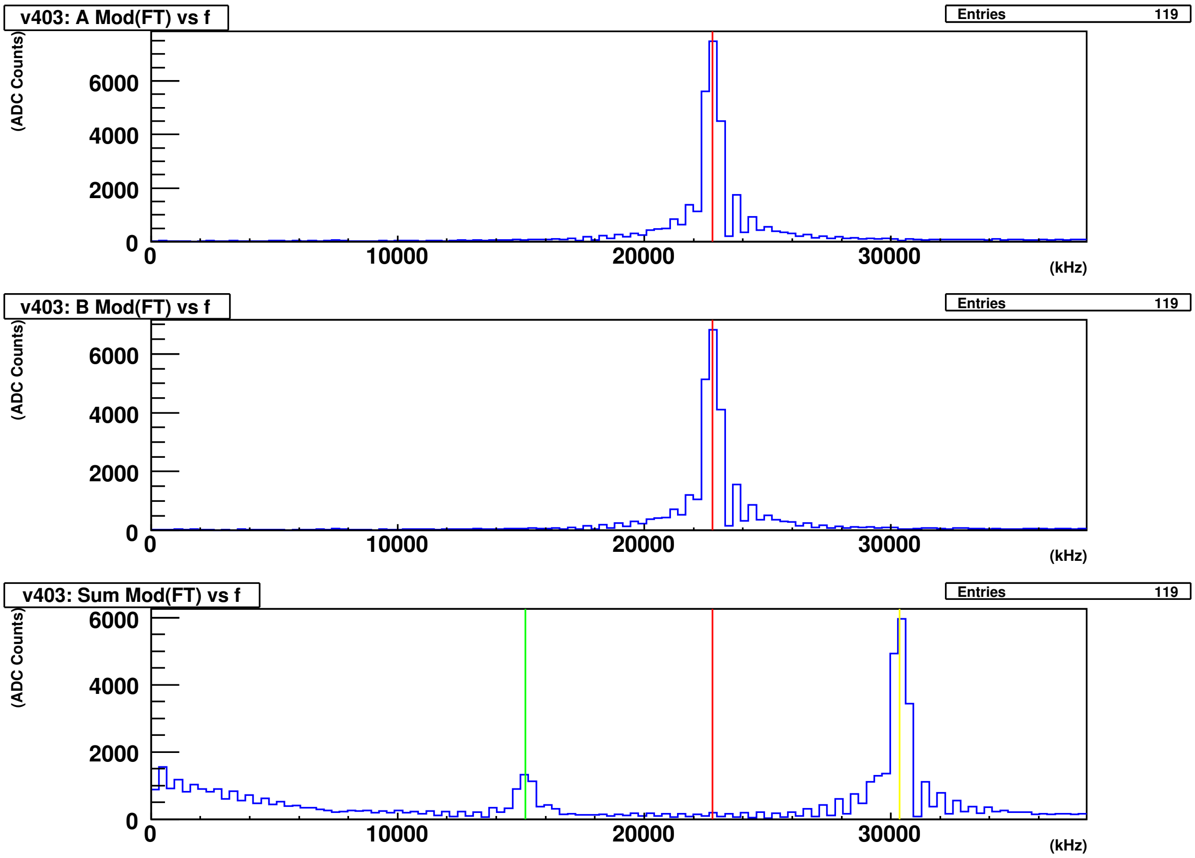

Figure 3: Fourier transforms of the signals from the first batch, ticks 911 through 1029 in Figure 1. In all plots the mean value of the data, averaged over the transform interval, was subtracted from each point. The upper plot shows the transform for the A signal, the middle for the B signal and the bottom for the sum signal. The structures in these plots are described in the text.

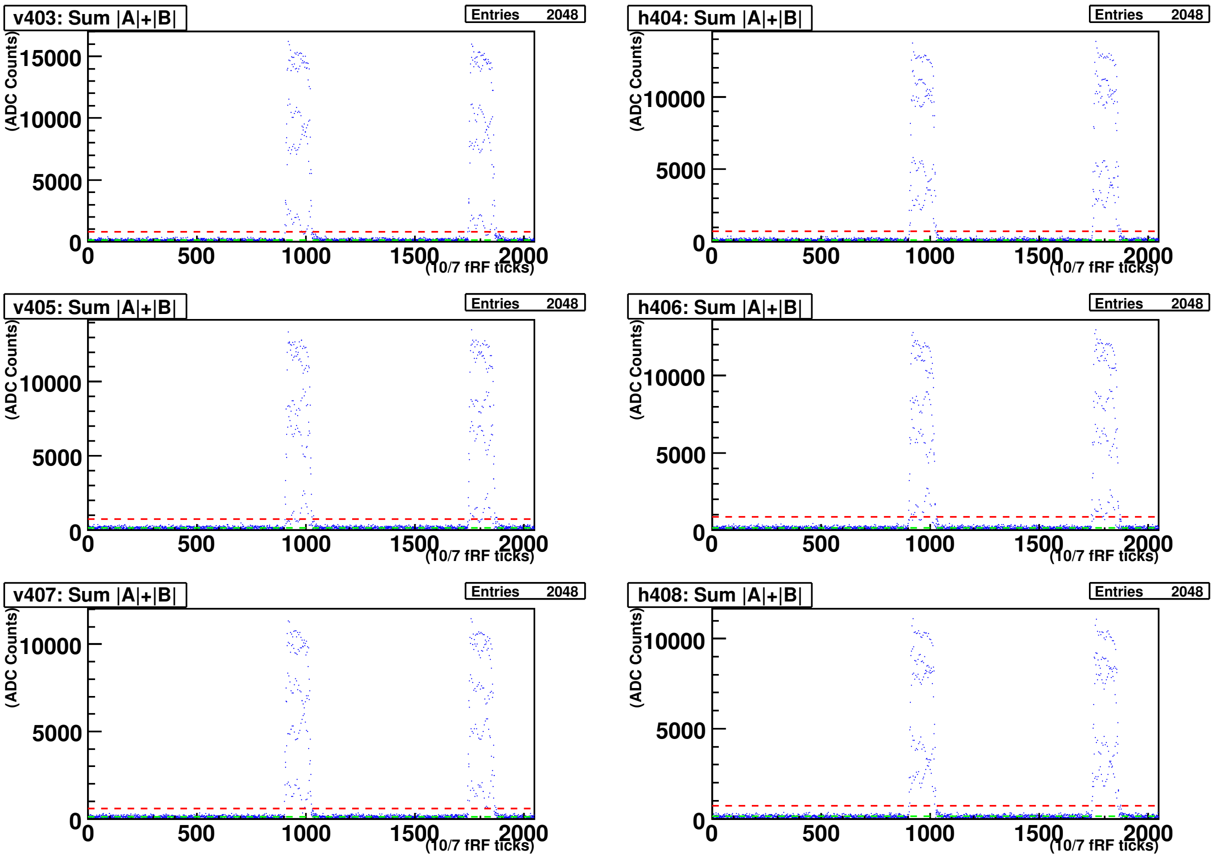

Figure 4: Sum signals from BPMs V403 through H408.

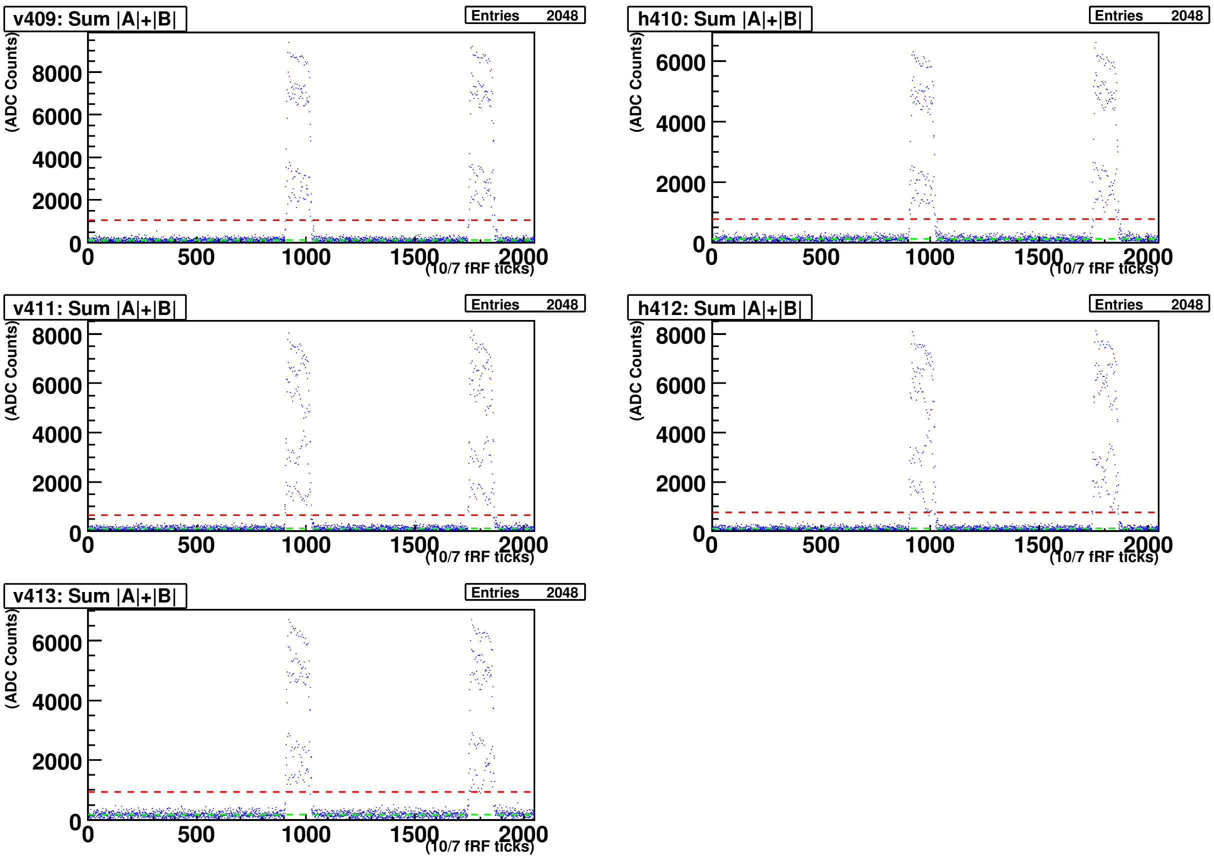

Figure 5: Sum signals from BPMs V409 through V413.

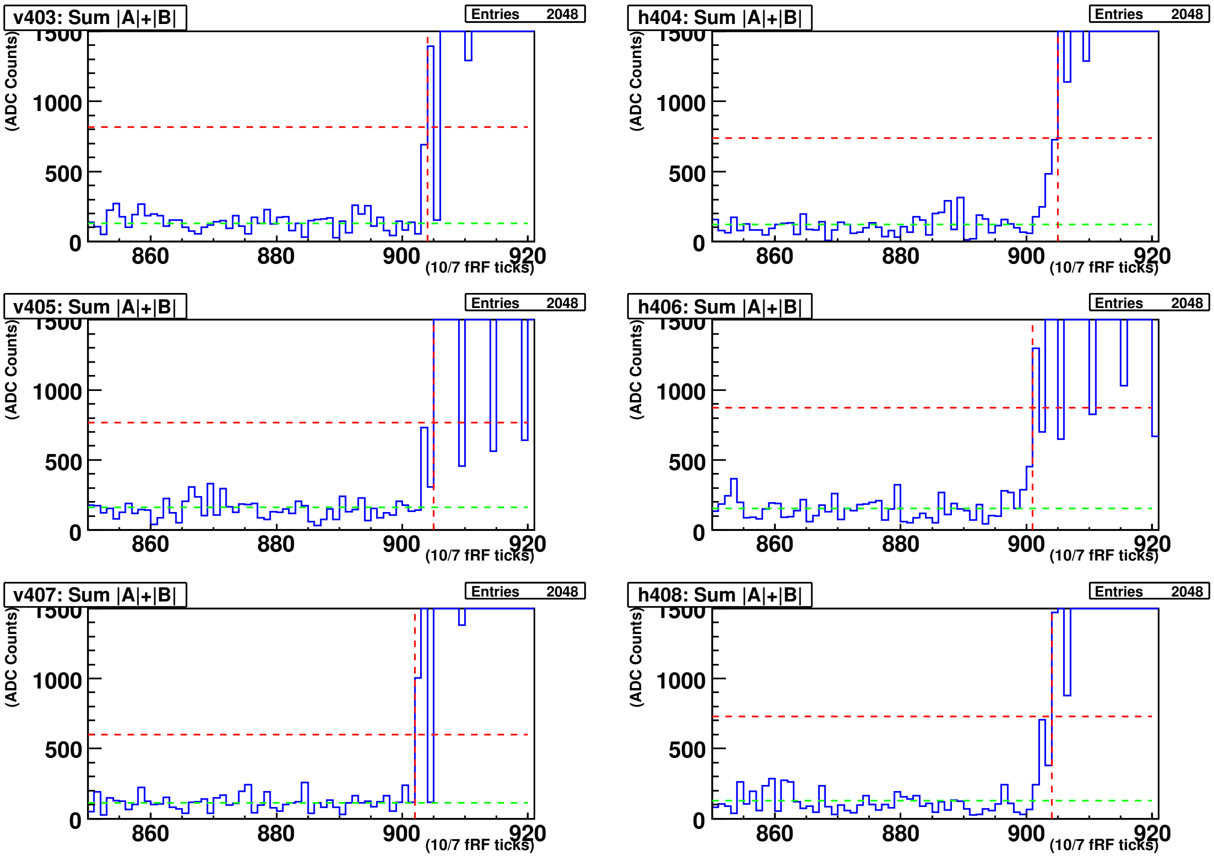

Figure 6: Detail of Figure 4, showing the time near the arrival of the first turn of the injected batch. The horizontal green line shows the mean noise level, measured using turns 0 through 499. The horizontal red line shows the threshold used to define the presence of a signal above threshold; it is twice the largest sum signal in turns 0 through 499. The vertical red line marks the nominal start of the batch, the intercept of the red horizontal line with the data.

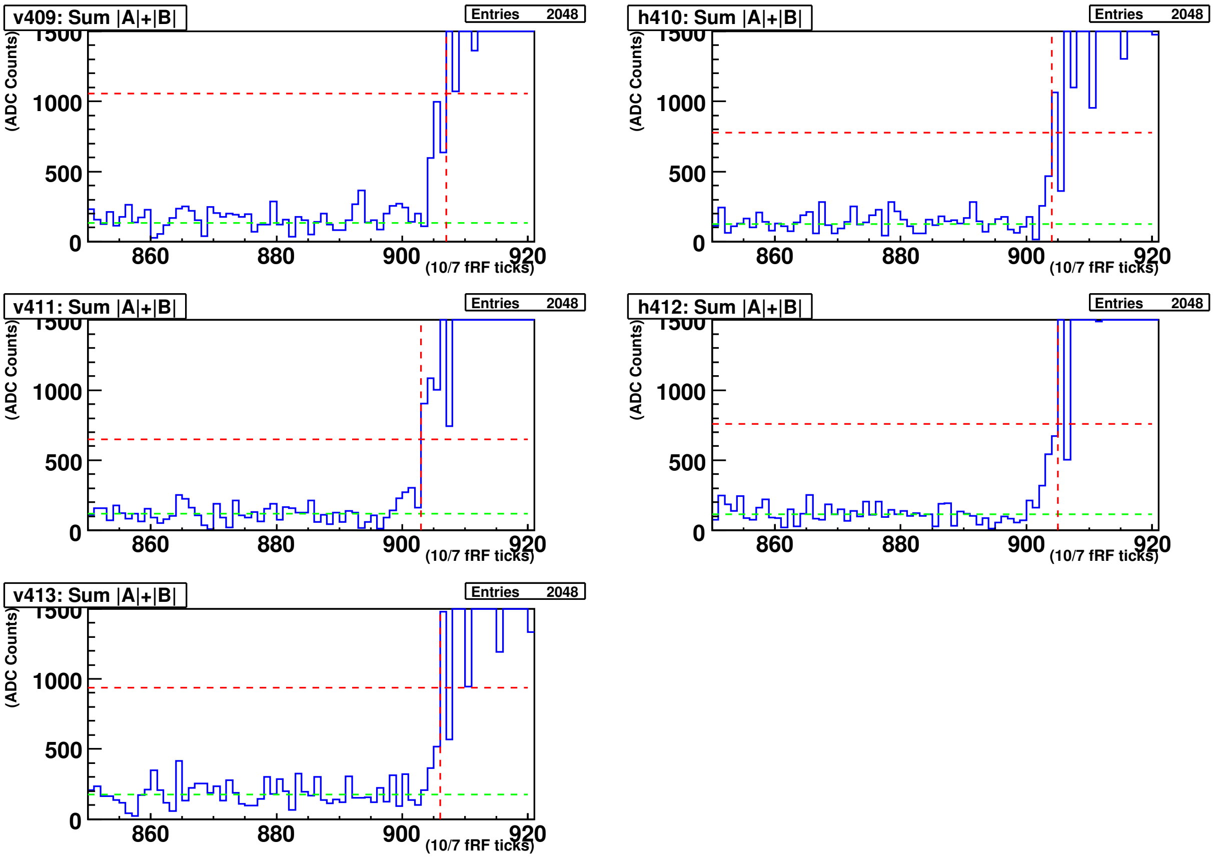

Figure 7: Detail of Figure 5, showing the time near the arrival of the first turn of the injected batch. The horizontal green line shows the mean noise level, measured using turns 0 through 499. The horizontal red line shows the threshold used to define the presence of a signal above threshold; it is twice the largest sum signal in turns 0 through 499. The vertical red line marks the nominal start of the batch, the intercept of the red horizontal line with the data.

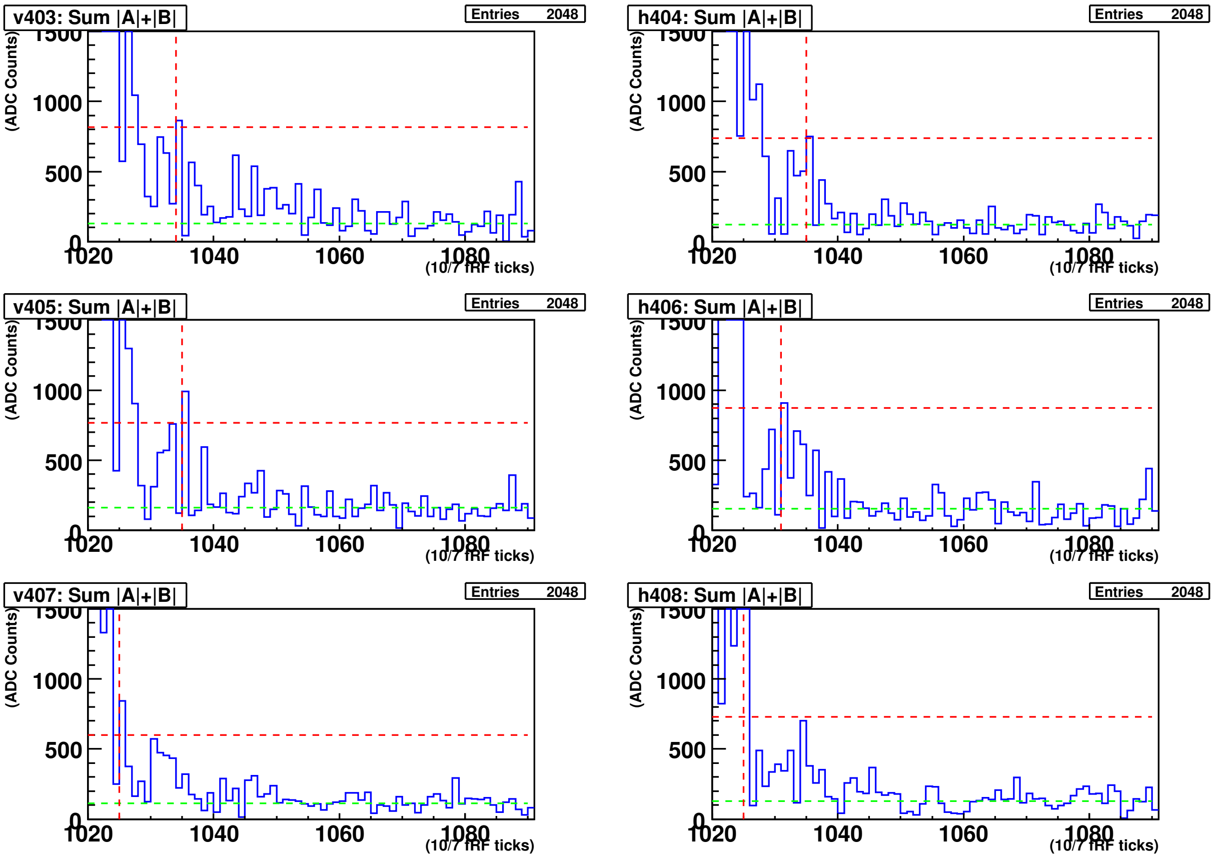

Figure 8: Detail of Figure 4, showing the time near the end of the first turn of the injected batch. The horizontal green line shows the mean noise level, measured using turns 0 through 499. The horizontal red line shows the threshold used to define the presence of a signal above threshold; it is twice the largest sum signal in turns 0 through 499. The vertical red line marks the nominal end of the batch, the intercept of the red horizontal line with the data.

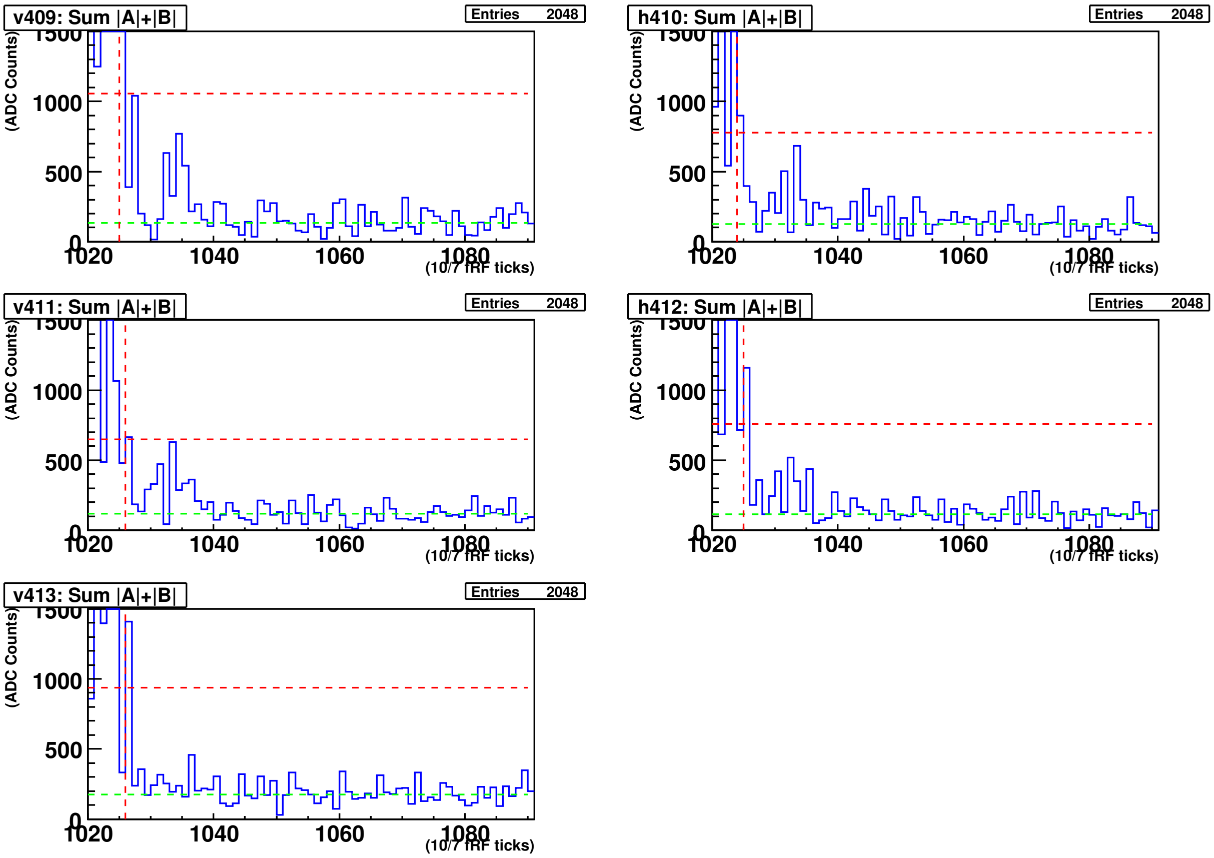

Figure 9: Detail of Figure 5, showing the time near the end of the first turn of the injected batch. The horizontal green line shows the mean noise level, measured using turns 0 through 499. The horizontal red line shows the threshold used to define the presence of a signal above threshold; it is twice the largest sum signal in turns 0 through 499. The vertical red line marks the nominal end of the batch, the intercept of the red horizontal line with the data.

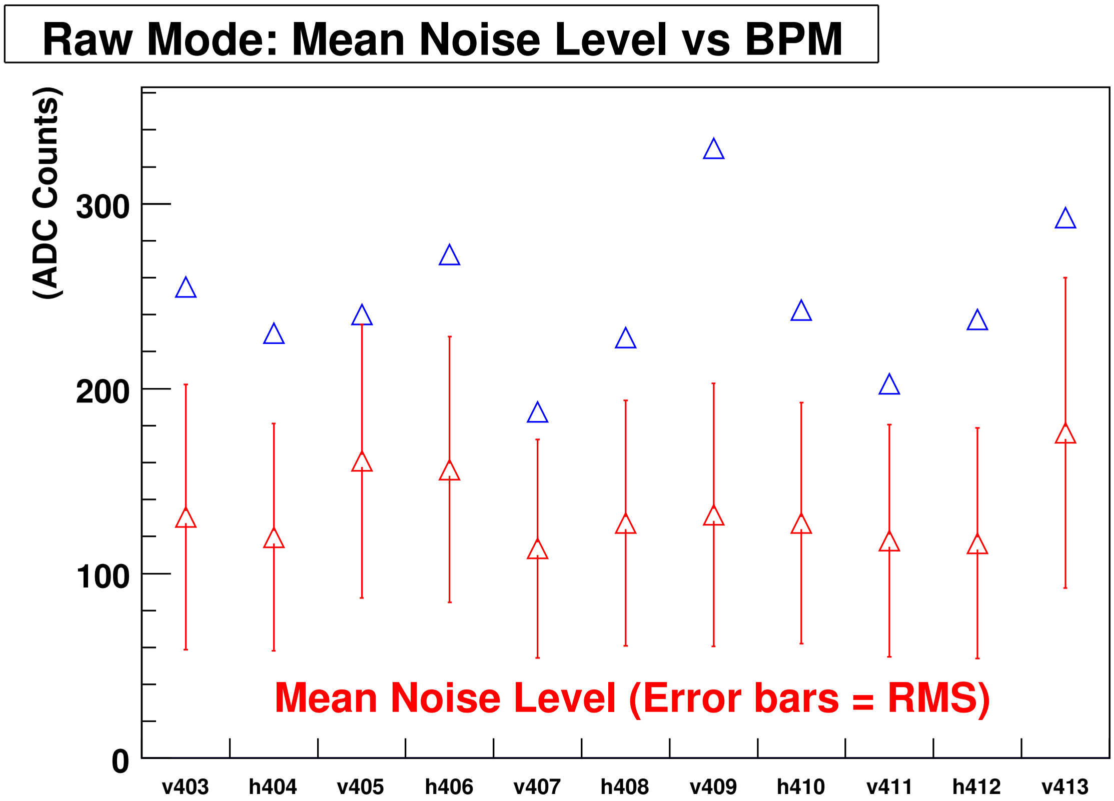

Figure 10: The noise level as a function of BPM. The red triangles show the mean sum signal, measured using the first 500 turns, during which time no beam is present. This provides one measure of the noise. The red error bars show the RMS spread of the sum signal about its mean. The error on the mean noise is a few ADC counts. The blue triangles show the maximum value of the sum signal in the first 500 turns; this is a second measure of the noise. The BPMs near the left end of the plot have short cables and those near the right end of the plot have long cables. No trend is seen as a function of cable length.