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A List of Noisy MI BPMs

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Abstract

The upgrade MI BPM system has a problem with noise when measuring anti-protons in 2.5 MHz mode. It is believed that much of this noise can be removed by replacing old cables, which run from the tunnel to the houses, with new, better shielded cables. This note looks at anti-proton data from states 11 and 20 to identify identify the noisiest BPMs and produce a list of candidates for cable replacement.

Contents

1 Introduction

The data presented in this note are injection and extraction flash turn-by-turn data taken during anti-proton transfers in states 11 and 20. State 11 is a transfer from Recycler to TeV. State 20 is a transfer from Accumulator to Recycler. The times at which the data were taken are recorded in Table 1; these times can be used to look up the bunch intensities for these transfers. The data were taken with the standard MI BPM operating conditions for these states. Most of the data is taken with the BPM system set for 2.5 MHz operation. The exception is

State	Time
11	March 11, 2007 20:53:40
20	March 12, 2007 07:37:49

Table 1: The times at which the data for this report were taken. From this one can look up the intensity of the beams.

the extraction data for state 11, for which the BPM system was set for 53 MHz operation.

To estimate the noise level, the first step is to filter the position time series data to remove the betatron oscillation. The filtered position time series is then analyzed to determine the maximum deviation, positive or negative, from the mean position. The magnitude of this deviation is used as a measure of the noise. This note also considers other metrics for the noise level and shows that they all give an consistent picture.

2 Method

Figure 1 shows some low noise data that are used to illustrate the method. The upper left plot in Figure 1 shows the sum signal ($|A| + |B|$) as a function of turn number; here A and B are the complex numbers, (I, Q), produced by the Echotek board. In this plot. t he arrival of the beam at turn 34, counting from turn 0, is clear. The upper right plot shows the measured position as a function of turn number; when there is no beam in the machine the position is set to zero. The position was calculated in the front end computer using all available corrections. The middle left plot shows the magnitude of the FFT of the position time series, excluding the first turn with beam; the reasons for excluding the first turn with beam will be discussed later. In this data, a strong betatron line is present. The middle right plot shows the same FFT with the magnitude of the bins near the betatron line set to zero. Finally the filtered FFT is inverted to give a filtered time series, shown in red on the bottom plot; this is superimposed on the original position time series, shown in blue.

Here are a few additional details:

1. For all of this analysis, the knowledge of the first turn with beam was used a priori. Many attempts were made to automate the finding of the first turn with beam so that it could be used as a check of the timing; but all of the methods failed on at least some of the noisy BPMs.

2. Before computing the FFT, the mean position is subtracted from the time series data.

3. The FFT code produces both magnitude (middle left) plot and phase information that is not shown. The inverse FFT uses both the magnitude and phase information.

4. In the bottom plot, the bins with no beam and the first turn with beam have been removed.

5. I did the round trip test. When I invert the unfiltered FFT, I get back the original time series.

For hp100, the maximum deviation from the mean position is 0.65 mm, for the unfiltered time series, and 0.44 mm for the filtered time series. The RMS spread of the unfiltered position time series is 0.22 mm, while that of the filtered time series is 0.12 mm.

At a few BPM locations, those immediately following the injection point, the beam is not kicked onto the closed orbit until the second turn. An example of such a location is hp321, the first BPM after the injection point. The sum and position time series for this bpm are shown in the top row of Figure 2; the beam arrives on turn 34 and the position on the first turn is very different than that on the remaining turns. A similar situation exists for vp313, shown in the bottom row of Figure 2, which is a few locations past the injection point but before the kicker than moves the injected beam onto the closed orbit. This is a vertical BPM and I think I heard that the beam is supposed to be on axis vertically during injection. (Dave: do I have this right?) However the beam is far off axis horizontally and the BPM response is not properly calibrated when the beam is far off axis in the unmeasured coordinate. Therefore the measured position is incorrect for the first turn. Note that the vertical scales are very different in the two right plots. This effect also produces an artifact in the sum signal that is present on the first turn with beam, as seen in the bottom left plot.

Accounting for this in an automated way is more complicated than I want to deal with. So I discarded the position data for the first turn at all locations; this does not change the results in a significant way.

An example of the main class of noisy bpms is given by vp515, shown in Figure 3; in fact vp515 is the worst example of this class of noise. The upper row shows the time series of the sum and position data. Strong noise is present in both the sum and position data. The noise is present in the sum signal both with beam in the machine and without; the position was set to zero for turns with no beam in the machine. The bottom row of Figure 3 shows the FFT's of the sum and position time series; the noise has a strong periodic structure. For noise such as this, almost any metric will easily identify noisy BPMs.

Another class of noisy bpms is illustrated by hp322, for which the sum and position time series are shown in the top row of Figure 4. The disturbance near 200 turns is quite small in the sum time series but it is large in the position time series. This arises because the beam is far off axis, making the B signal very small, as is shown in the bottom row of plots; so a small noise signal has a small fractional effect on $|A|$ but a large fractional effect on $|B|$. This sort of noise is easy to find using the maximum deviation from the filtered position as a metric; if one uses the RMS spread of the filtered position, this sort of noise is more difficult to find in an automated way.

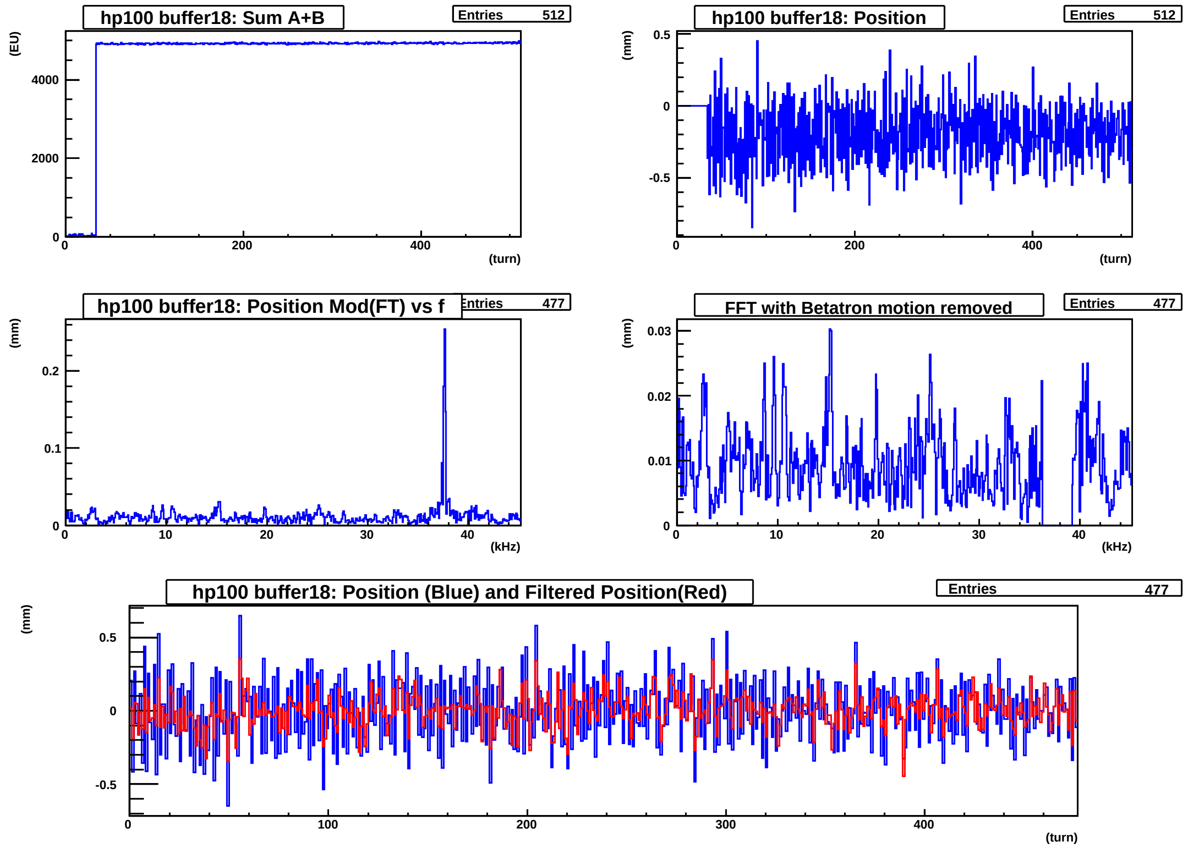

Figure 1: Data from hp100 for state 11, a location with low noise. The text refers to this data to describe the method. The vertical scale of the sum signal plot is echotek units (EU).

A less egregious class of noisy bpms, is illustrated by hp404, for which the sum and position time series are shown in the top row of Figure 5. For this BPM, the beam arrives on turn 35 but there is a significant sum signal present in the last turn before beam. This noise is believed to be pickup from a kicker. In the position plot, the position for turn 34 was set to zero because the code knows that no beam is expected for that turn. Because of this sort of noise, the last turn before the expected injection is excluded from the set of points with no beam.

Two final bpms of note are vp403 and vp609 which have some unusual structures, as shown in Figure 6.

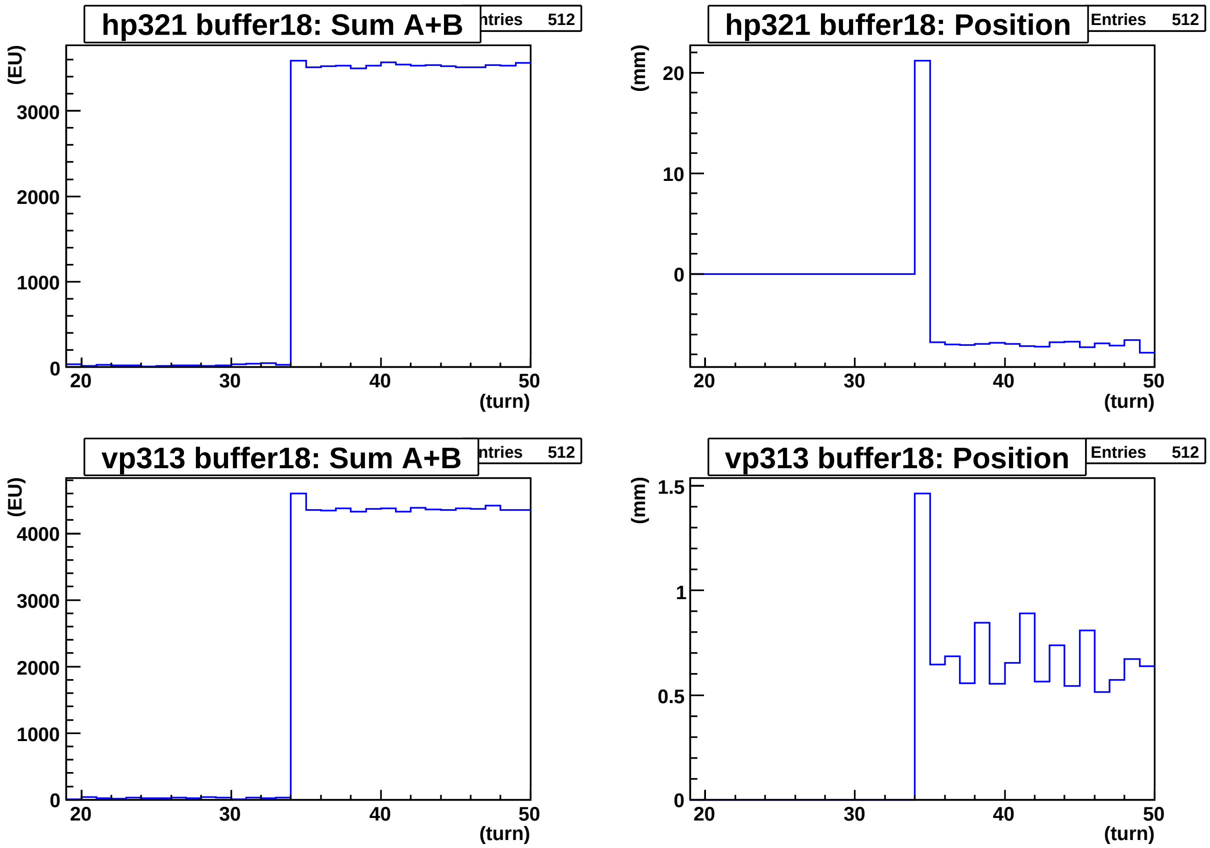

Figure 2: Data from hp321 and vp313 for state 11. The text refers to this data to describe the set of BPMs shortly after the injection point for which the beam is far from the closed orbit on the first turn with beam.

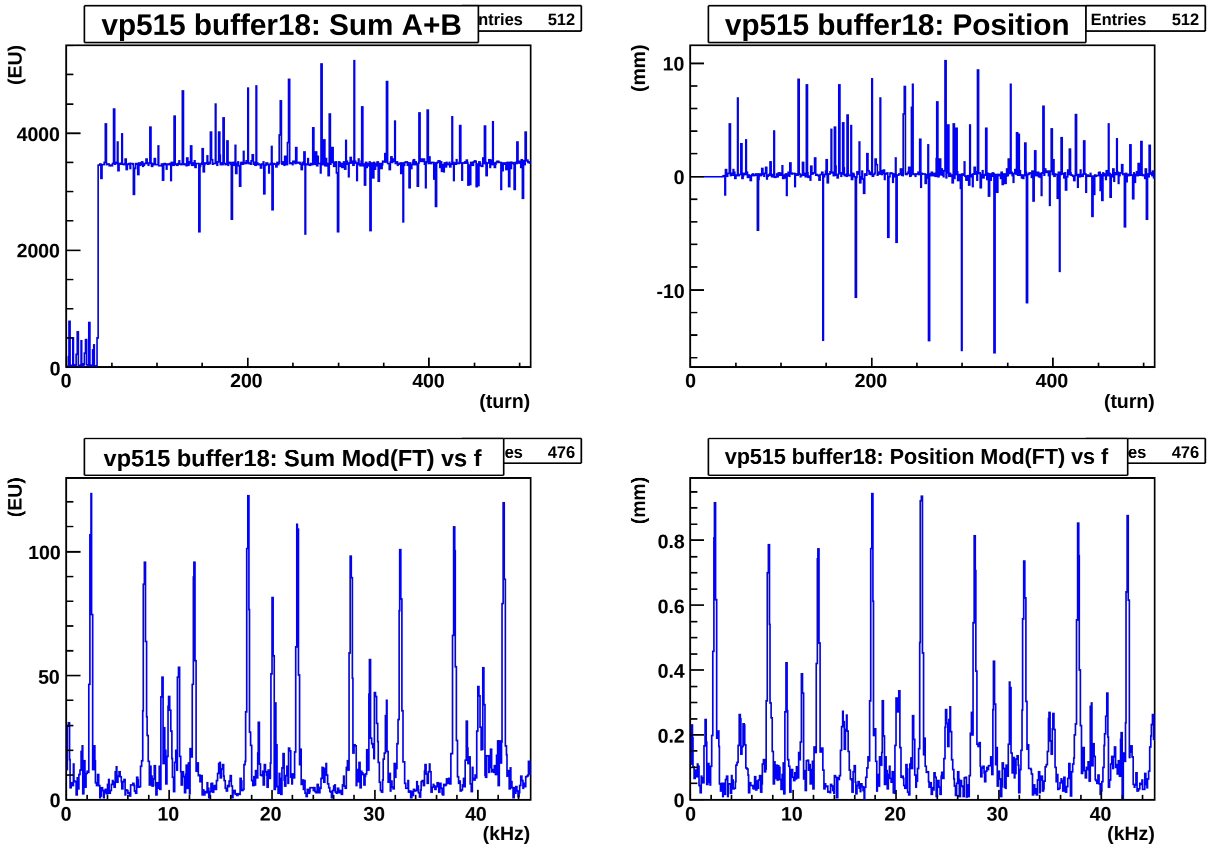

Figure 3: Data from vp515 for state 11. This is the noisiest BPM in the main class of noise. The text refers to this figure when discussing the main class of noise.

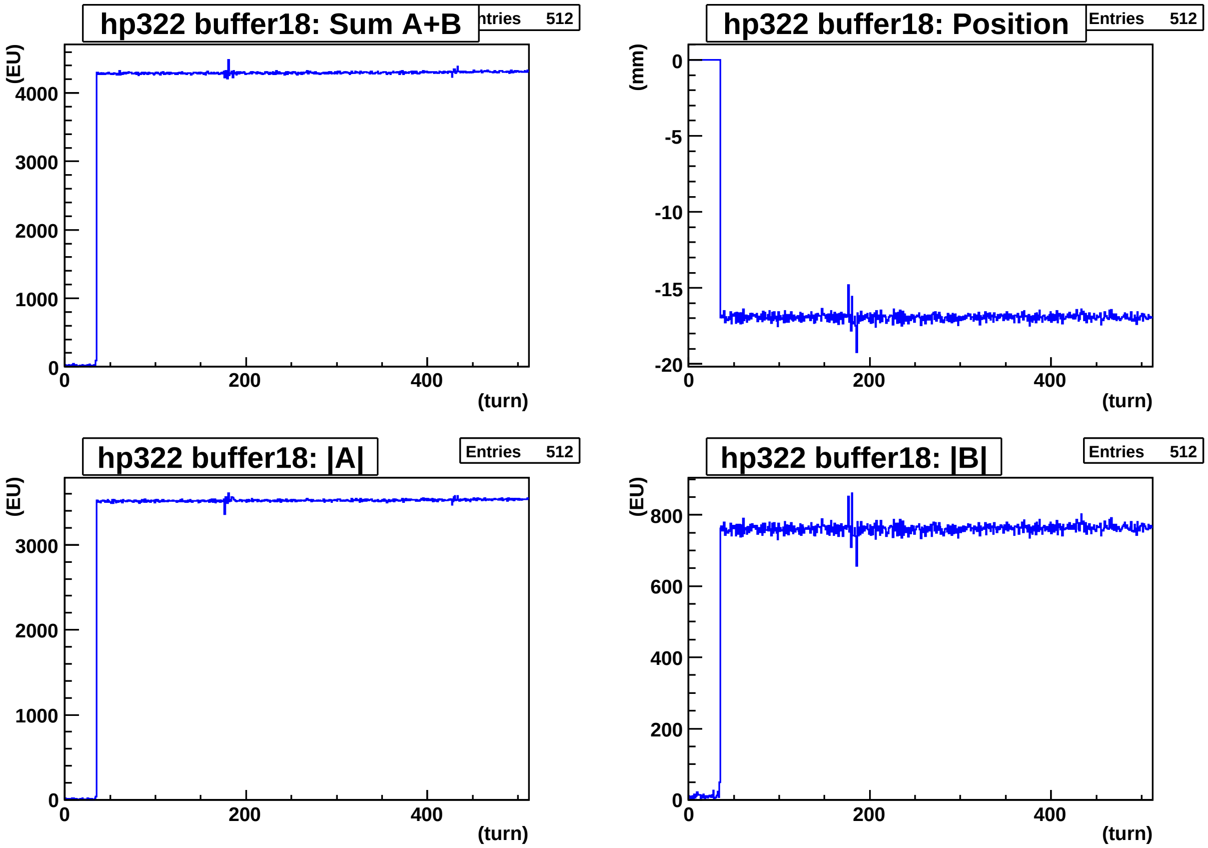

Figure 4: Data from hp322 for state 11. The text refers to this figure when discussing a second class of noise. Note that the position is far off axis.

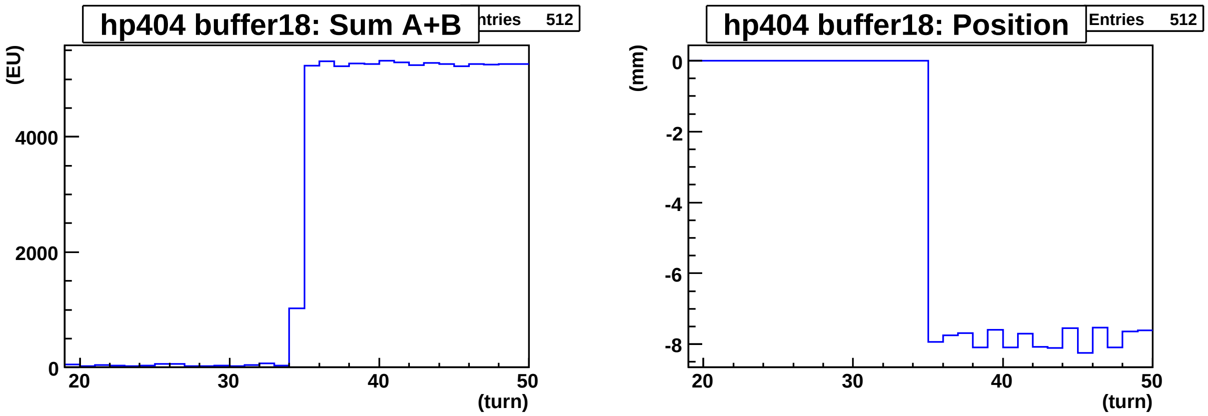

Figure 5: Data from hp404 for state 11. The text refers to this figure when discussing the pickup from kickers that occurs on some bpms on the last turn without beam.

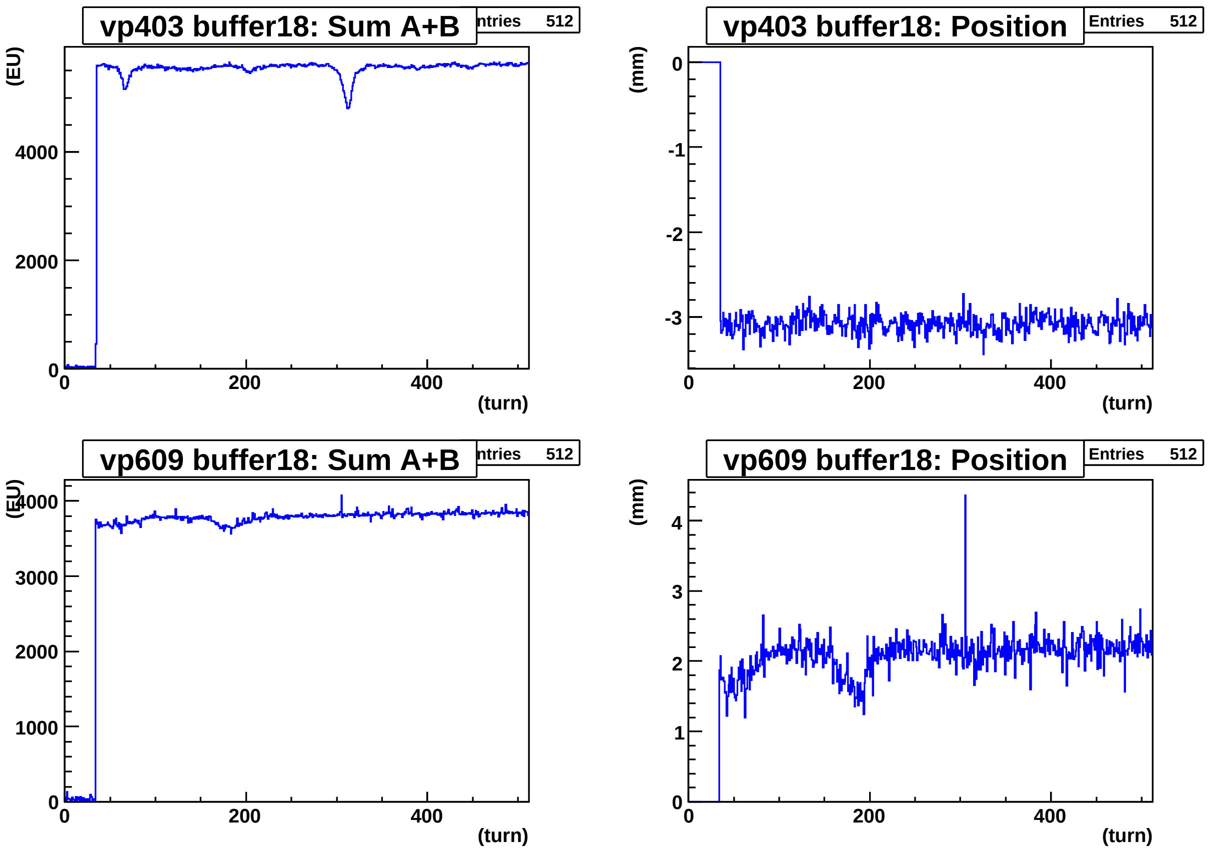

Figure 6: Data from vp403 and vp609, for state 11. These figures are included because of some unusual structures.

3 Results for Injection for State 11

The above procedure was repeated for each BPM to compute the maximum deviation from the mean filtered position. This is shown as the top plot in Figure 7. In this plot the horizontal axis is BPM location, in the order that they would be encountered by a bunch of anti-protons; that is the orbit moves left to right, with the first BPM on an orbit at hp532 and the last at hp601; this is the standard position for the seam. The houses are delimited by green, vertical, dashed lines and the houses are labeled in green text; house 60S is spread across the seam. Upon injection the first bpm to be encountered is hp/vp321, which is indicated by a vertical, solid red line.

In the top plot, the histogram shows, for each BPM, the maximum deviation from the mean filtered position. A dashed, red horizontal line is drawn at a level of 1.5 mm and all BPMs with an entry above this line are deemed to be noisy. There are three clusters of noisy BPMs, two very noisy clusters at either end of the plot and one less noisy cluster in the middle.

The next two plots show alternate measures of noise that lead to similar results. Entries in the second plot are obtained by computing the mean sum signal, from the second turn with beam to the end of the time series; the quantity plotted is the maximum deviation from this mean value. Entries in the third plot are obtained by finding the maximum value of the sum signal for turns in which no beam is present; the last turn without beam is excluded from this calculation. This exclusion is required to avoid BPMs which are quiet except for pickup on the last turn before injection; see the discussion of Figure 5. Again dashed, red, horizontal lines are drawn to denote the nominal level at which a BPM is declared noisy, at a level of 200 Echotek units (EU) for the second plot and 150 EU for the third.

Both of these plots are qualitatively the same as the top plot, with only a handful of BPM locations that show up as noisy in one plot but not in the other two. Two of the indicated locations, hp222 and vp101, are the extra wide bpms installed last shutdown. The other location, vp403, is has some unusual structures, shown in Figure 6.

The fourth plot looks to identify those BPMs that have significant pickup on the last turn without beam. The quantity plotted is the ratio of the sum signal in the last turn without beam to that in the first turn with beam. In this plot two clusters stand out. In house 40, all but vp403 show as quiet in the top 3 plots but all show as noisy in the bottom plot; so it is clear that all of house 40 suffers from this noise source. The other cluster of noisy BPMs is more difficult to interpret: a visual inspection of the sum signal for each BPM suggests that this noise source is not present for these BPMs, but the robustness of this conclusion is lessened by the high ambient noise level for these BPMs.

Table 2 summarizes the results for injection for state 11. The table is an ordered list of BPMs, sorted by the maximum deviation from the mean of the filtered position. The noisiest BPM is at the upper right corner of the table and list the proceeds down the first column, down the second column and so on. Only the first 36 entries qualify as noisy. The entries in bold face are not

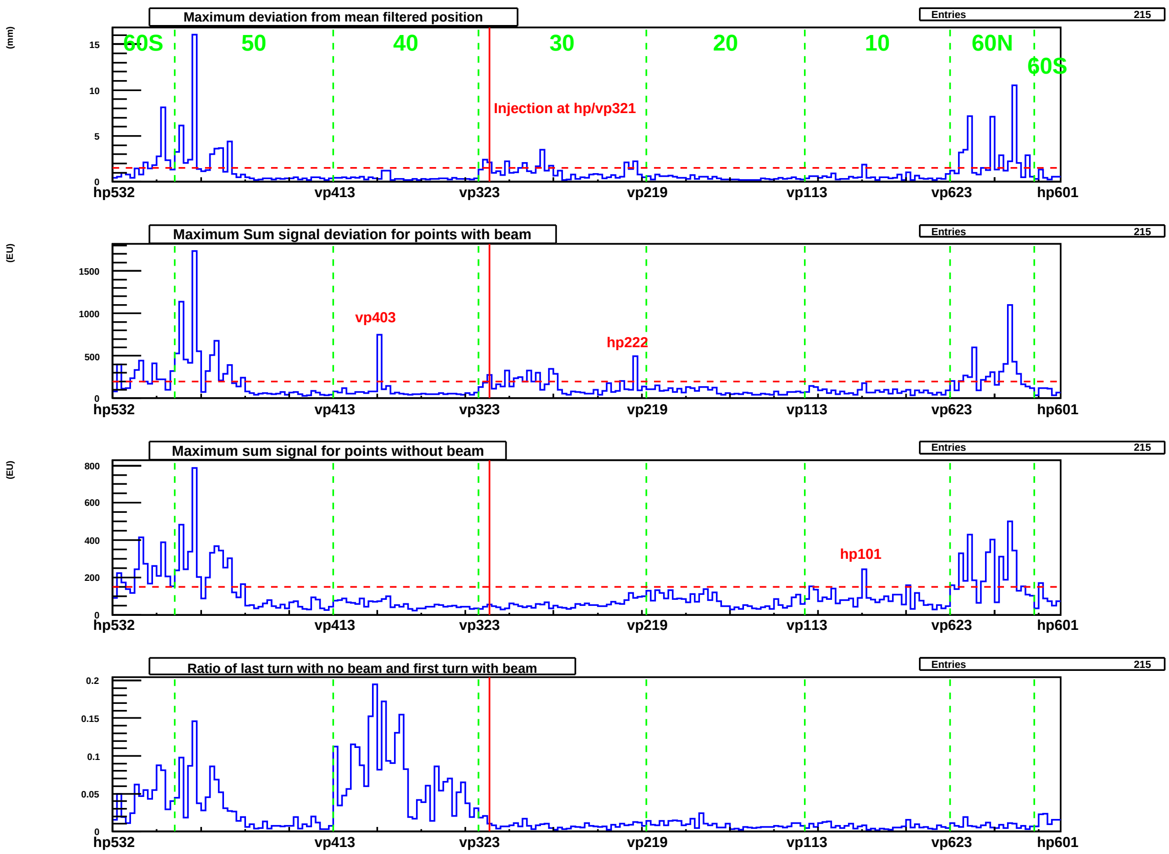

Figure 7: Summary of different measures of BPM noise for injection for state 11. The plots are described in the text.

classified as noisy by this criterion but they do have an entry above the dashed horizontal line in either the second or third plots of Figure 7.

The file Injection_11.pdf included in this document shows sum and position time series for all BPMs, sorted as in Table 2. The noisiest BPM is in the upper left of the page, the next in the upper right, the next in the middle left and so on. The entries that are in bold face in Table 2 are shown in red in the pdf file. In the file the position time series for all BPMs are shown with a full scale of 6 mm, centered on the mean position. The position plots show the original measured position while the sorting was done based on the filtered position.

4 Results for Extraction State 11

For extraction measurements, the method is a little simpler than used for extraction. First, the betatron oscillations of the bunch center have long since damped out so there is no need to remove them. Moreover there are too few measurements, typically 50 or 51, to get an FFT with good resolution. So the chosen metric is the maximum deviation from its mean value of the original position time series, starting at the first measured turn and ending one turn before the last turn with beam in the machine. I don't have a plot to show why the last turn is excluded but I have a vague memory of seeing some unusual behavior in the last turn in the past; I forget which state had this behavior.

In Figure 8, the top plot shows the maximum deviation of the position from its mean value, plotted as a function of BPM location. The bpms are ordered in the same was as for Figure 7. Again the houses are indicated in green and the last location with beam during extraction is shown as the red vertical line. There are no significant features in this data. The second plot shows the maximum deviation of the sum time series from its mean value, for points with beam. Again there are no significant features. The third plot shows the maximum value of the sum signal for turns with no beam in the machine; there is a sharp feature include vp605, hp604, vp603. The bottom plot shows the mean value of the sum signal for turns with no beam in the machine; the same few bpms near vp605 are noisy.

The first row in Figure 9 shows the sum and position time series for a typical good bpm, vp603. The bottom row shows the time series from vp605, the one bad outlier in Figure 8.

This data is much quieter than that for injection. The reason is that the beam structure has been changed to 53 MHz. For the extraction the MI BPM was programmed to measure at 53 MHz, which is much quieter the 2.5 MHz band used in the injection measurements.

The only anomalies in this data are the DC background levels seen at locations vp605, hp604, and hp602.

The file Extraction_11.pdf shows the sum and position time series for each bpm for the extraction for state 11. Because there is no interesting noise structure to follow, the BPMs are shown in anti-proton beam order, from hp532 to hp601.

	0	25	50	75	100	125	150	175	200
0	vp515	vp321	hp402	vp529	hp422	hp102	hp324	hp338	vp127
1	hp610	hp314	**vp313**	vp229	vp417	hp412	hp428	vp425	vp627
2	hp522	vp517	vp513	hp226	vp505	hp232	vp331	hp120	hp124
3	hp620	vp609	hp320	vp319	vp503	hp408	vp637	hp118	vp337
4	vp615	hp101	**hp508**	vp209	vp405	hp110	vp423	vp205	vp415
5	hp518	vp523	hp316	vp631	vp101	vp413	hp626	hp400	vp125
6	vp507	hp308	vp633	hp214	hp116	vp225	vp117	vp421	hp632
7	vp509	vp311	hp530	vp307	vp411	vp119	hp122	vp325	hp126
8	hp510	vp315	vp317	vp215	vp227	vp329	hp208	vp129	hp340
9	hp310	vp617	hp312	vp109	hp638	hp332	hp326	hp430	hp640
10	vp620	hp524	**vp619**	hp216	vp608	vp203	vp115	hp406	vp501
11	vp519	**vp527**	hp321	hp112	hp220	hp628	vp105	vp427	hp128
12	vp621	**hp514**	hp622	vp219	hp418	vp123	hp210	vp121	vp339
13	vp511	vp222	vp107	vp111	vp409	hp410	vp327	hp106	hp634
14	vp613	**hp520**	hp624	vp407	hp108	hp630	hp104	vp335	vp419
15	hp608	vp323	hp230	vp607	vp639	hp416	vp625	hp330	
16	vp522	vp605	hp506	hp206	vp641	hp426	hp606	vp603	
17	hp322	hp614	vp303	**vp531**	vp301	hp404	hp334	hp218	
18	hp516	**hp616**	vp635	vp207	hp212	vp113	hp328	hp202	
19	vp521	**hp512**	vp217	vp103	hp532	hp420	vp629	hp304	
20	hp222	**hp612**	hp618	hp602	hp100	hp414	vp333	vp201	
21	hp318	hp306	hp504	hp224	hp604	vp429	hp302	hp114	
22	vp611	vp309	vp221	vp601	hp636	hp228	**vp403**	hp130	
23	vp223	vp623	**hp526**	hp204	vp211	hp502	vp341	vp305	
24	vp525	vp402	vp231	vp213	hp528	hp424	hp336	vp401	

Table 2: For state 11, injection. Ordered list of BPMs, sorted by the maximum deviation from the mean filtered position, largest first. The first 35 BPMs have a deviation of more than 1.5 mm and are considered noisy. The list is to be read down the first column, down the second column and so on. The bpms in bold face are not considered noisy by the above criteria but are considered noisy by either one of the other two criteria: maximum deviation from mean sum signal or maximum sum signal when no beam is present. The plots in the file Injection_11.pdf are in the order given by this table.

Figure 8: Summary of different measures of BPM noise for extraction for state 11. The plots are described in the text. The only significant feature is at vp605 in the bottom two plots.

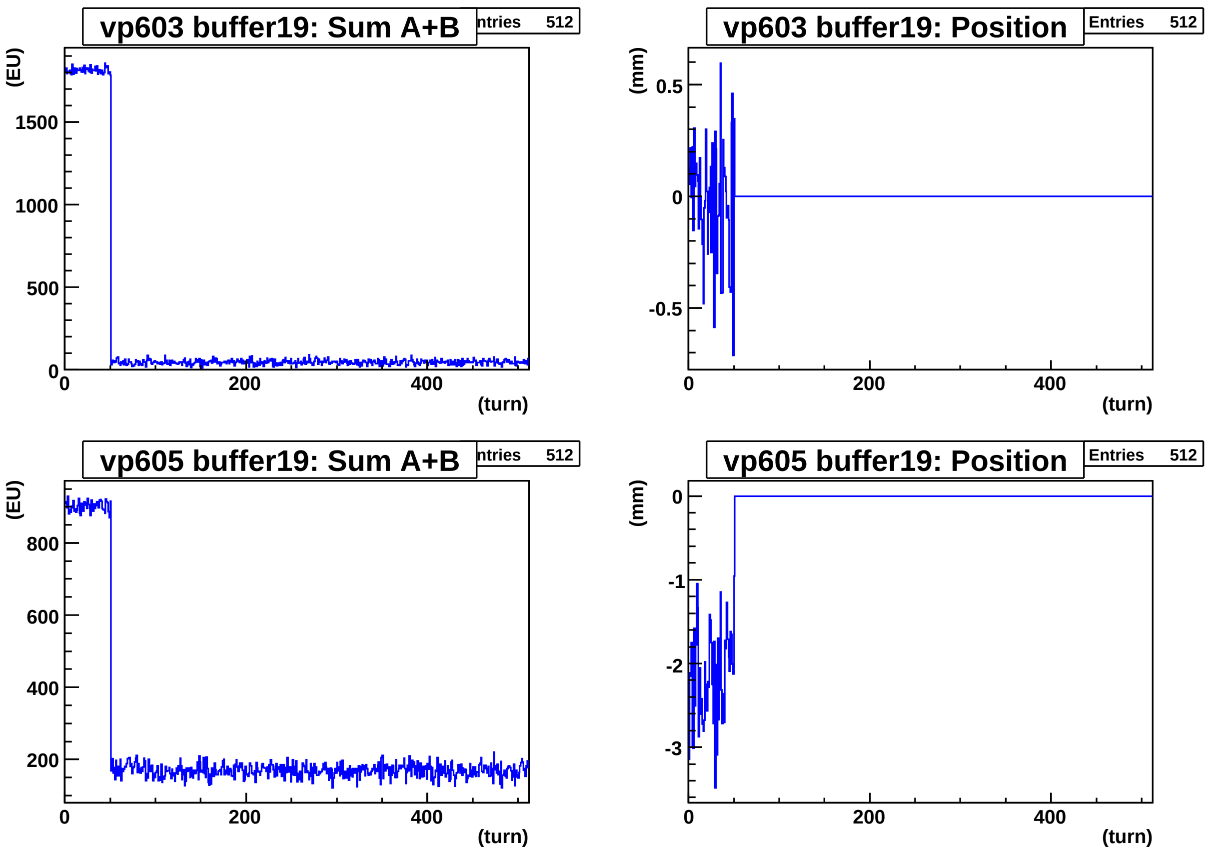

Figure 9: Sum and position time series for two BPMs for extraction from state 11. The BPM vp603 is a typical good bpm and vp605 is the one bad bpm. In both cases the position is set to zero when there is no beam in the machine.

5 Results from Injection for State 20

The file Injection_20.pdf shows sum and position time series data for the injection flash for all of the BPMs from state 20. The BPMs are ordered noisiest first, to quietest last, using the same method as described for the state 11 data. In this file, the position time series data are shown with a vertical full scale of 12 mm, centered on the mean position. This compares to a 6 mm full scale for the state 11 data. One observation is immediately clear: the signal to noise ratio is much poorer for the state 20 data. More careful inspection will show that that the sum signal is typically about 5 times smaller for the state 20 data compared to the state 11 data. It will be shown in the following that the noise level is about the same, hence the degraded signal to noise ratio.

Figure 10 shows the same information as Figure 7, but for data from a state 20 injection. The top plots on both pages show the maximum deviation from the mean filtered position. The main difference between the two is that the state 20 data has a much larger full scale; some BPMs have a deviation of as much as 30 mm from the correct position. The other difference is that the BPM's in house 30 are only marginally noisy in state 11 but they are very noisy for state 20. Other than the scale difference, the remaining features of the plot are remarkably similar; this is consistent with the explanation that the noise is constant but the signal level has been reduced.

The second plots on the two Figures are almost identical, including the scale; similarly for the third plots on the two Figures. This strongly suggests that the magnitude and pattern of the noise is the same for the two states.

The fourth plot in Figure 10 is designed to search for single turn noise on the last turn without beam. The two clusters of noise are consistent with the general noise and do not show evidence for this particular problem. So I conclude that this effect is not present in state 20. Recall that it was strong only in house 40 for state 11.

The state 20 injection data was processed as described for state 11 to identify the noisiest BPMs. Many more noisy BPMs were found. There was also no point in trying to identify BPMs that looked quiet in the position time series but had evidence of noise in the sum signal time series. Table 3 gives an ordered list of the noise levels on each BPM for state 20 injection. The plots in the file Injection_20.pdf are in the same order as the entries in Table 3.

6 Results from Extraction for State 20

The file Extraction_20.pdf shows sum and position time series data for the extraction flash for all of the BPMs from state 20. The BPMs are ordered noisiest first, to quietest last, using the same method as described for the state 11 injection data. Unlike the state 11 extraction, this data is very noisy. The reason is that the state 20 data are taken at 2.5 MHz while the state 11 data were taken at 53 MHz.

Figure 11 shows the same information as Figure 8, but for data from a state

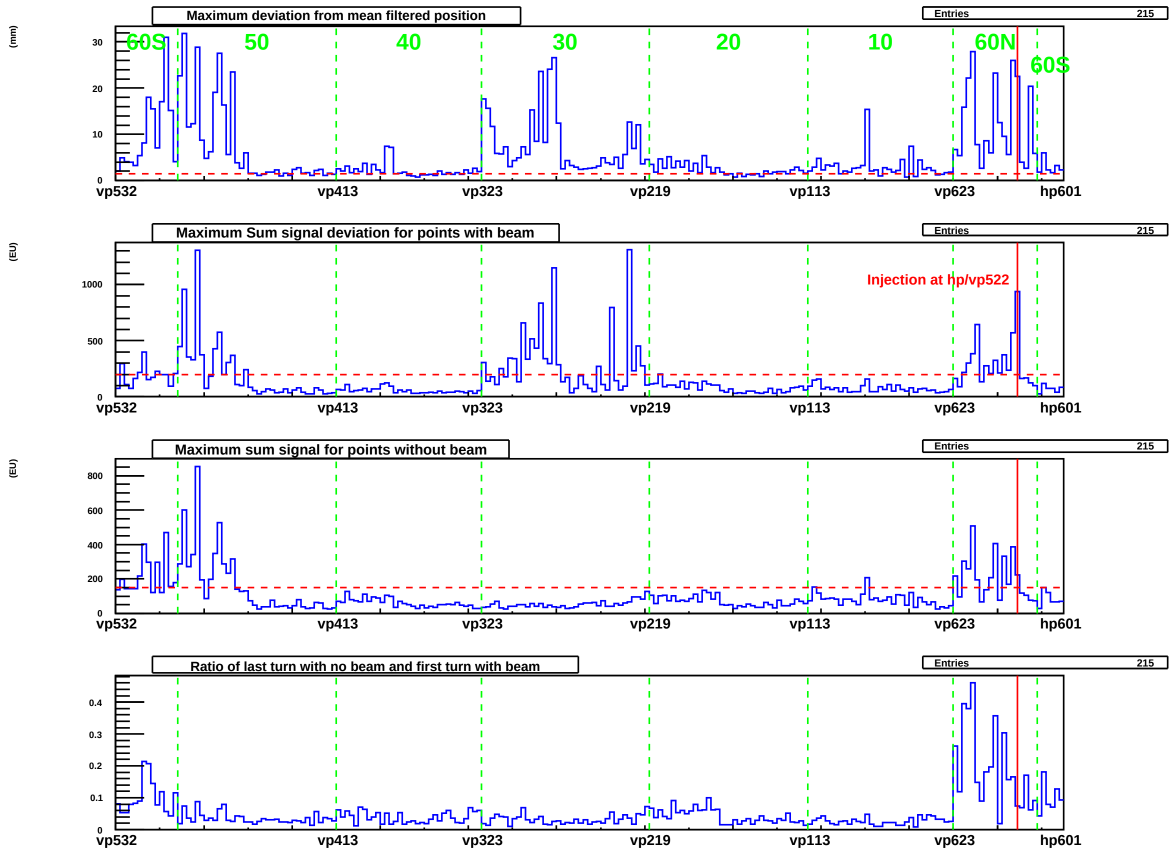

Figure 10: Summary of different measures of BPM noise for injection for state 20. The plots are described in the text. The plots have the same meaning as those for state 11 in Figure 7. The horizontal dashed red lines are drawn at the same levels there were in Figure 7.

	0	25	50	75	100	125	150	175	200
0	hp518	vp521	hp616	vp317	hp206	hp302	hp120	hp114	vp419
1	hp522	vp223	hp504	vp213	hp116	vp417	hp324	hp326	hp416
2	vp515	hp614	hp321	hp530	hp212	vp423	vp121	hp502	vp501
3	hp620	vp307	vp607	hp520	vp303	vp641	vp637	vp129	hp424
4	hp510	hp516	hp320	vp529	hp214	hp404	hp104	vp421	hp340
5	hp308	hp222	hp314	vp609	hp204	vp601	hp428	vp201	hp334
6	vp611	vp321	hp508	hp228	vp639	vp427	vp203	vp401	vp339
7	vp309	vp517	hp224	hp506	hp102	vp117	hp606	hp106	hp426
8	vp311	vp613	hp612	vp209	vp629	hp604	vp429	hp118	hp640
9	vp507	hp514	hp622	vp407	hp422	hp110	hp624	hp122	hp632
10	vp615	vp617	vp527	vp107	vp231	vp327	hp218	vp125	hp128
11	vp519	hp312	vp207	vp221	hp618	hp628	vp341	hp626	hp124
12	hp610	hp310	vp215	vp219	vp505	vp115	vp603	hp430	hp634
13	vp620	hp526	hp226	vp227	vp225	hp418	hp410	hp328	hp338
14	hp608	vp619	vp229	vp405	vp325	hp636	vp205	hp330	hp130
15	vp511	vp633	vp531	vp109	hp216	hp412	vp625	hp332	
16	vp525	vp402	hp316	hp528	vp103	vp105	vp331	hp406	
17	vp323	vp319	vp111	hp304	vp608	hp100	vp329	hp414	
18	vp522	vp315	vp513	vp101	hp232	vp333	hp208	vp335	
19	vp509	hp402	vp217	hp602	hp306	hp532	vp403	vp127	
20	vp621	vp523	hp220	vp411	vp413	vp113	hp420	hp126	
21	hp322	vp222	vp635	hp230	vp409	vp123	vp503	vp627	
22	hp524	vp623	vp631	hp108	vp301	hp210	hp400	vp337	
23	hp101	hp512	vp305	hp318	hp630	hp408	vp415	hp336	
24	vp313	vp605	vp211	hp112	hp638	vp119	vp425	hp202	

Table 3: For state 20 injection. Ordered list of BPMs, sorted by the maximum deviation from the mean filtered position, largest first. The list is to be read down the first column, down the second column and so on. The plots in the file Injection_20.pdf are in the order given by this table.

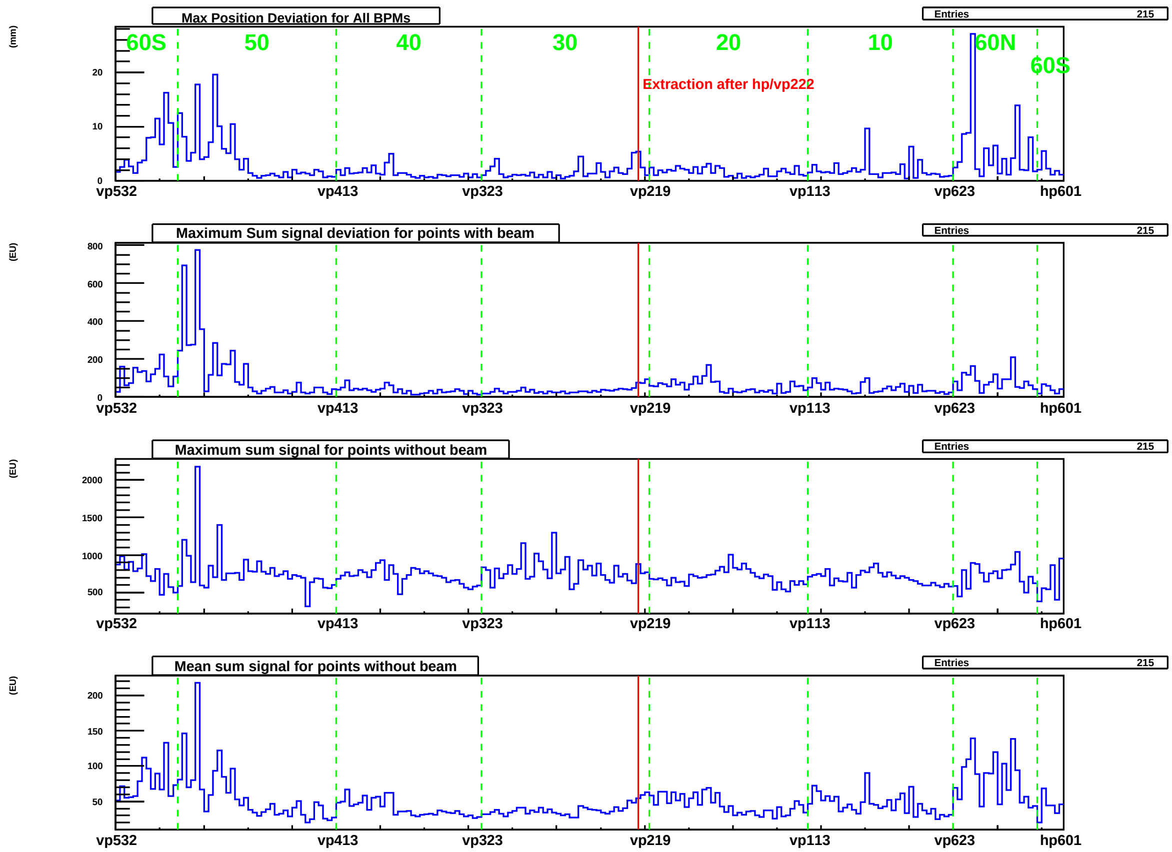

Figure 11: Summary of different measures of BPM noise for extraction for state 20. The plots are described in the text. The plots have the same meaning as those for state 11 in Figure 8.

20 injection. The top plots on both pages show the maximum deviation from the mean unfiltered position. Unlike the data for state 11, the state 20 data show lots of structure. Excluding house 30, this data is similar in shape to the top plot in Figure 10, the plot for state 20 injection. The second row shows the maximum deviation of the sum signal from its mean value for turns with beam in the machine. It is quieter than the corresponding plot for either of the injection data sets but it does show its peak activity at the usual place, in house 60 at the end near 60S. The remarkable feature of the third plot is that it shows a high level of noise for all BPMs, much higher than the corresponding plots for either injection dataset.

The state 20 extraction data was processed as described for state 20 injection to identify the noisiest BPMs. Again many noisy BPMs were found and there was also no point in trying to identify BPMs that looked quiet in the position

	0	25	50	75	100	125	150	175	200
0	vp515	vp619	hp306	hp126	vp423	hp634	vp329	vp625	vp620
1	hp510	vp611	hp530	hp618	vp229	hp208	vp509	hp114	hp304
2	hp308	hp532	hp310	hp104	vp637	vp421	hp330	hp116	vp119
3	hp518	vp603	hp408	hp508	hp412	hp332	vp223	hp414	hp326
4	vp315	hp318	vp405	vp307	hp334	hp214	hp106	vp215	hp604
5	hp610	hp402	vp613	vp507	vp231	vp309	vp117	vp627	vp121
6	hp312	hp226	hp322	hp616	vp409	hp418	hp524	vp629	hp118
7	hp526	hp512	vp621	vp335	vp427	hp124	hp632	hp514	hp520
8	vp201	hp232	vp101	vp337	vp525	hp320	vp115	hp108	vp608
9	vp517	vp203	hp204	vp221	vp209	hp636	vp617	hp630	hp400
10	vp531	hp100	hp528	vp429	hp110	vp107	vp609	hp324	vp522
11	vp305	vp323	hp336	vp111	vp635	vp217	hp212	vp623	hp622
12	vp601	hp130	vp503	vp319	hp410	hp614	vp105	vp519	hp602
13	hp504	hp428	vp425	hp522	vp333	vp341	vp331	vp211	hp606
14	vp403	vp339	vp615	hp224	hp122	hp314	hp120	hp624	hp420
15	hp302	hp321	hp502	vp401	hp422	hp424	vp419	vp325	
16	vp501	vp527	hp430	vp317	vp225	vp219	hp516	hp626	
17	vp311	hp316	hp101	vp123	hp608	vp417	vp213	vp521	
18	vp529	vp109	vp407	hp426	vp313	vp413	vp227	hp416	
19	hp620	vp523	hp220	hp210	vp113	hp218	hp628	vp513	
20	hp404	vp127	vp411	vp205	vp125	hp216	vp222	vp321	
21	hp128	hp338	hp638	hp102	vp639	vp505	vp607	vp103	
22	hp230	vp301	hp202	hp206	vp511	vp402	vp303	vp327	
23	vp641	hp612	hp506	hp112	vp207	hp228	vp631	vp415	
24	hp222	vp129	hp640	hp340	hp406	vp633	hp328	vp605	

Table 4: For state 20 extraction. Ordered list of BPMs, sorted by the maximum deviation from the mean filtered position, largest first. The list is to be read down the first column, down the second column and so on. The plots in the file Extraction_20.pdf are in the order given by this table.

time series but had evidence of noise in the sum signal time series. Table 4 gives an ordered list of the noise levels on each BPM for state 20 injection. The plots in the file Extraction_20.pdf are in the same order as the entries in Table 4.

7 Comparing States 11 and 20

Figure 12 collects a few plots from injection data for states 11 and 20. The top row of plots shows the standard noise metric, the maximum deviation from the mean of the filtered position data; except for the overall scale and the noisier data in house 30 for state 20, the shape of the data are quite similar.

The second row of plots shows the mean sum signal for turns with no beam in the machine, excluding the last turn before injection. Previous plots showed the maximum sum signal with no beam in the machine since that is a better metric for finding isolated noise spikes. The mean is a better metric for averaging over noise. The two plots are very similar, including the absolute scale.

To better illustrate how similar these plots are, they have been overlayed as the red and blue histograms in the top plot in Figure 13. The green histogram is the corresponding histogram for the state 20 extraction data. The three plots have been scaled to have identical integrals. All three shapes are a very close match.

The last row of plots in Figure 12 shows the mean sum signal for points with beam in the machine, again trying to average out the noise. These two plots have different absolute scales but very similar shapes. The bottom plot in Figure 13 shows these two plots overlayed as the red and blue histograms. The green histogram is the corresponding histogram for the state 20 extraction data. The three plots have been scaled to have identical integrals. All three shapes are a very close match.

From this I conclude that the MI BPM system has an almost identical response to states 11 and 20; the main difference is likely just the difference in bunch intensity. I also conclude that the system has almost identical noise properties for the two states. I did not expect this but it will make noise reduction easier.

To complete this I need to look at the mean position for the two states - but I am not sure if the orbits are really designed to be the same?

8 The Final List

To compute the final list of noisy bpms that are candidates for cable replacement, I used the following algorithm. For each bpm, I used the position in Table 2 as a rank, $0 \ldots 214$, with small values indicating noisy. Similarly I used the position in Table 3 as an independent rank. The two ranks are strongly correlated; if a bpm is noisy in one case it is likely to be noisy in the other. A total of 42 BPMs were among the noisiest 50 on both of the ranking lists.

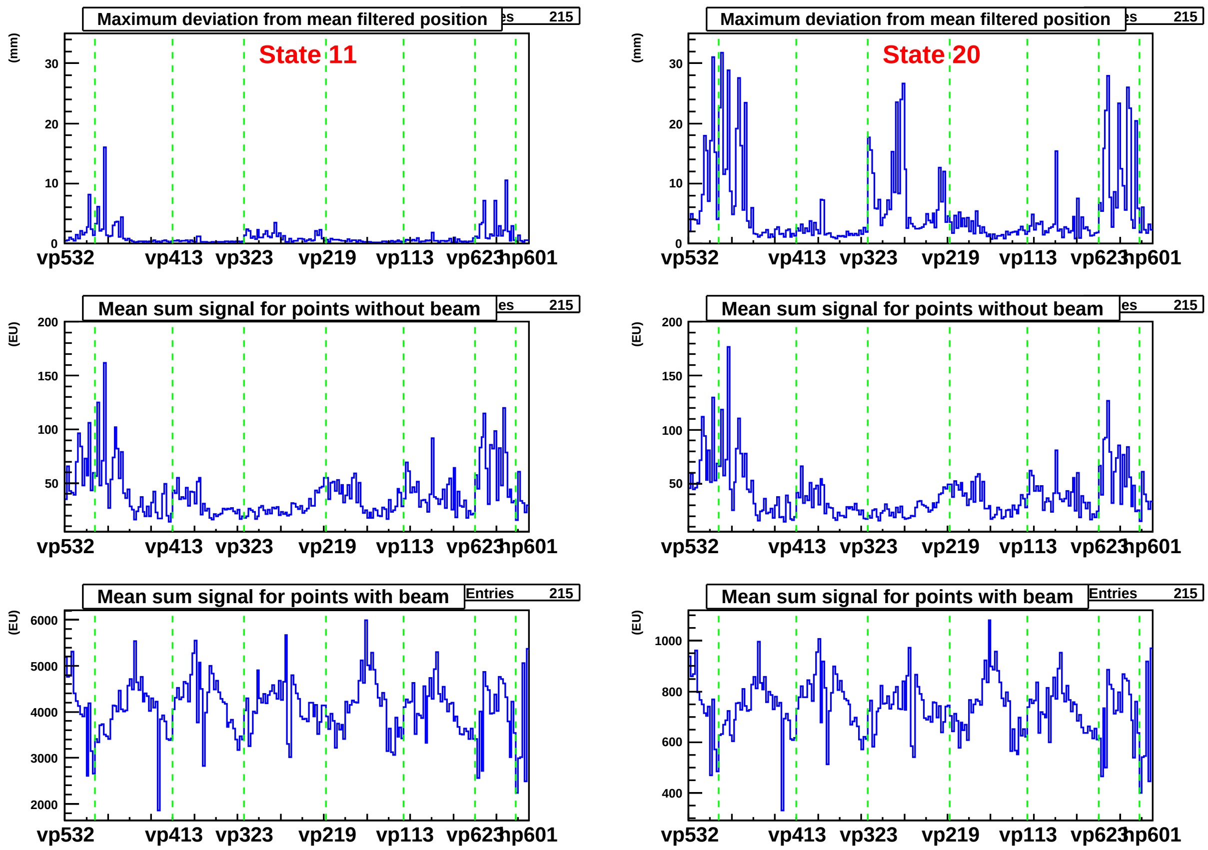

Figure 12: Comparison of three plots for injection for states 11 and 20. The plots in the top row are the noise level for each BPM as estimated using the method described in the text. The plots in the middle row are the mean sum signal for each BPM for turns without beam. The plots in the bottom row are the mean sum signal for each BPM for turns with the beam. In each of the bottom two rows, the plots are strikingly similar to each other.

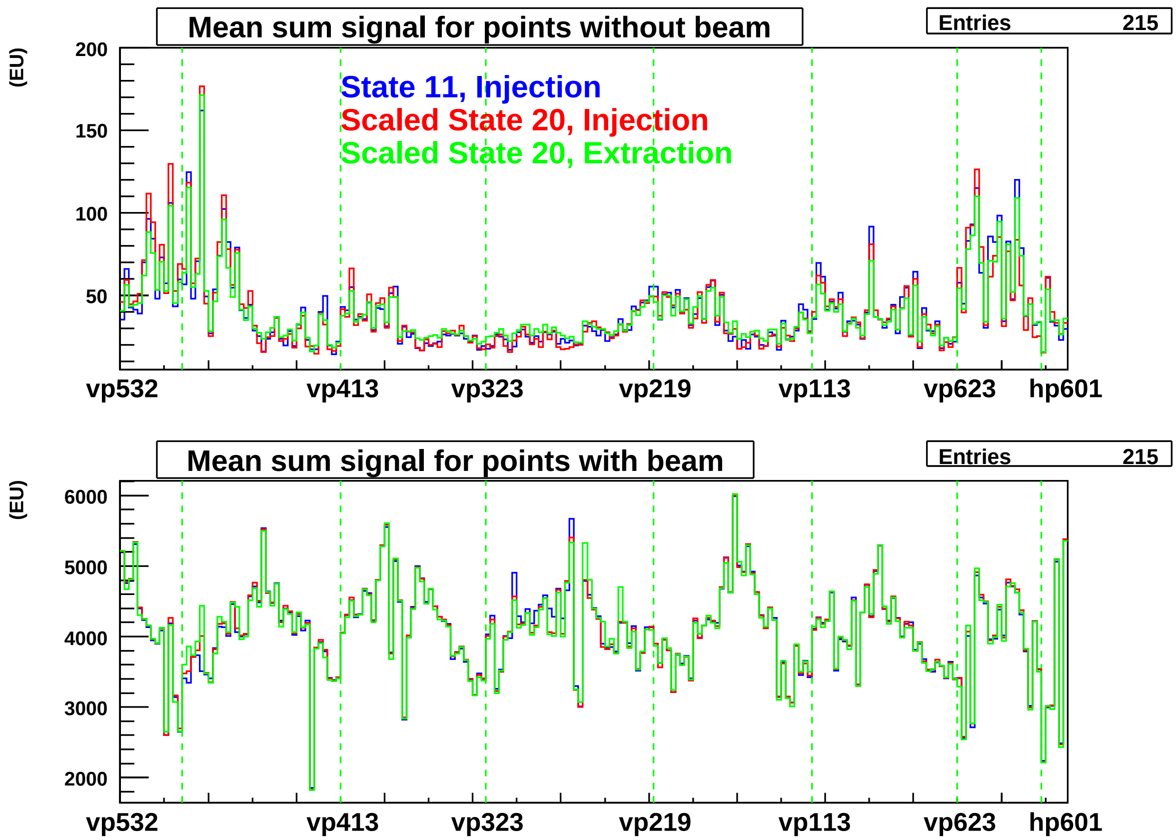

Figure 13: The blue histograms are the state 11 plots from the previous figure. The red histograms are the state 20 injection plots from the previous figure, scaled to have the same area under the histogram as does the corresponding state 11 injection plot. The green histograms are the corresponding histograms from the state 20 extraction data, scaled to have the same area. For both top and bottom, plots all three shapes match remarkably well.

I computed the combined rank as the sum of these two, again with a smaller number indicating noisier. The final order was based on combined rank. The noisiest 50 BPMs, based on the combined ranking are given in Table 5; that table also contains a few other BPMs that were not in the top 50 of the combined ranking but were in the top 50 of one or the other of the individual ranks.

	0				25				50			
0	vp515	0	0	2	hp222	25	20	30	hp612	50	45	58
1	hp522	1	2	1	hp101	26	29	23	vp609	52	28	80
2	hp518	2	5	0	vp309	27	47	7	vp307	53	82	28
3	hp620	3	3	3	vp321	28	25	31	hp526	55	73	38
4	hp510	4	8	4	vp323	29	40	17	hp520	57	39	78
5	hp610	5	1	12	hp524	30	35	22	hp318	58	21	98
6	vp615	6	4	10	vp517	31	27	32	vp319	60	78	42
7	vp507	7	6	9	hp614	32	42	27	hp306	83	46	119
8	vp519	8	11	11	vp617	33	34	35				
9	vp620	9	10	13	hp514	34	37	34				
10	vp509	10	7	19	vp313	35	51	24				
11	vp511	11	13	15	vp523	36	30	45				
12	vp611	12	22	6	vp315	37	33	43				
13	hp608	13	15	14	hp314	38	26	55				
14	vp621	14	12	20	vp222	39	38	46				
15	vp522	15	16	18	vp605	40	41	49				
16	hp308	16	31	5	vp402	41	49	41				
17	hp322	17	17	21	hp512	42	44	48				
18	vp311	18	32	8	hp616	43	43	50				
19	vp525	19	24	16	hp402	44	50	44				
20	vp521	20	19	25	hp312	45	59	36				
21	hp310	21	9	37	vp623	46	48	47				
22	hp516	22	18	29	vp633	47	56	40				
23	vp613	23	14	33	vp527	48	36	60				
24	vp223	24	23	26	vp619	49	60	39				

Table 5: Final list of noisy BPMs. The noisiest BPM is at the top left and the list is to be read down the first column, down the second column and so on. The list is given in the order of combined ranking using injection data from both states 11 and 20. The three numbers after the BPM name are the rank in the combined ranking, the rank in the state 11 list and the rank in the state 20 list. The noisiest BPMs have the lowest rank. This list includes all of the BPM's that appear in the noisiest 50, in either the combined list or in one of the individual lists.