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The Position Grid Study from Mar 11, 2004

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Abstract

On March 4, 2004 we were given study time to bump the beam in a grid pattern and measure the response of BPMs VA14 and HA15, instrumented with the modified recycler Echotek board. This note summarizes the data from that study; it supercedes the first version of this note which contained only a subset of the information.

1 Introduction

The study was originally designed to map out a 7x7 grid, with a step of 3 mm between grid positions in both horizontal (H) and vertical (V) directions. The study started by moving to one of the corners of the pattern and the beam was immediately lost. Mike modified the script to map a 5x5 grid and the study was restarted. Just as the study restarted, when the beam was again moved to an extreme position, about 10% of the beam intensity was lost but the study was able to continue.

The bumped beam was measured using BPMs VA14 and HA15, both instrumented with modified Recycler Echotek boards. The data were read out as an array device and, for each BPM, four (I,Q) pairs were data logged at 15 Hz.

The study was done at 150 GeV using a fill pattern of 12x0. The original plan was to use uncoalesced beam but that gave signals on the Pbar cables which were judged to be too small to be useful.

After completing the first 4x5 subset of the 5x5 study, the beam was lost again and we declared the study complete.

After the study was complete Mike Martens realized that the step size in the horizontal direction was about 2.2 times larger than intended.

2 First look

Figure 1 shows the proton sum and position signals for both BPMs. The grid pattern is clear in the position signals and the larger H step size is clear. To be specific the sum and position signals are defined as:

$$\text{Sum} = |\mathbf{A}| + |\mathbf{B}| \tag{1}$$

$$\text{Position} = 26\frac{|\mathbf{B}| - |\mathbf{A}|}{|\mathbf{B}| + |\mathbf{A}|} \tag{2}$$

where A and B are the complex numbers (I, Q) for the proton A and B cables and where || denotes the magnitude of the complex number. The values of I and Q were read from the data logger.

The interesting features of these plots are:

- In the vertical position signal there is a strong dependence, a few hundred microns, on the horizontal position.
- The horizontal sum signal depends strongly on the horizontal position.
- Shortly after injection, near t=14.133 hours, some of the beam was lost. This is clear on the V sum signal but less clear on the H sum signal. This can also be seen in Figure 2c) which shows the value of T:IBEAM during this time.

Figure 2a) shows a detail of the HA15 position signal covering the dwell time at the first grid point, (-12.97,-5.16) mm. To come up with one number to characterize these data, 200 points near the middle of the stable region were averaged. The vertical red lines denote the limits of the interval used in the average and the red dot shows the average value, drawn at the mid-time of the interval. This process was repeated for each of the points in the study and the resulting measured positions are plotted in Figure 2b) and are given in Table 1.

The interesting features of Figure 2b) are:

- The grid is not quite square. This could come from many sources.
  - The bumps are designed to give a square grid at VA14 but the H position is measured at HA15.
  - Various sorts of misalignment among correctors and BPMs.
  - The eigendirections of the transverse motion are not along the axes of the BPMs.

Figures 3a) and b) show the Pbar sum signals, defined by equation 2, but before cancellation of the proton contamination. These signals have a strong dependence on the proton position in both planes. To provide a time reference, Figures 3g) and h) show the proton position signals. The proton contamination was subtracted using the third model developed in Beams-doc-988-v1, section 3.3.

The model will be briefly summarized here using the horizontal BPMs as an example. It is assumed that the corrected Pbar signals, A_{Pbar} and B_{Pbar}, are given by the equation,

$$\mathbf{A}_{\text{Pbar}} = \mathbf{A}_{\text{Pbar,raw}} - \mathbf{A}_{\text{cor}} \tag{3}$$

$$\mathbf{B}_{\text{Pbar}} = \mathbf{B}_{\text{Pbar,raw}} - \mathbf{B}_{\text{cor}} \tag{4}$$

Horizontal (mm)	Vertical (mm)
-12.964 ± 0.018	-5.157 ± 0.006
-7.739 ± 0.024	-4.981 ± 0.006
-1.729 ± 0.027	-4.863 ± 0.006
4.578 ± 0.025	-4.792 ± 0.005
10.563 ± 0.021	-4.775 ± 0.006
-12.716 ± 0.018	-1.905 ± 0.006
-7.442 ± 0.022	-1.770 ± 0.006
-1.432 ± 0.023	-1.661 ± 0.005
4.838 ± 0.022	-1.578 ± 0.005
10.759 ± 0.020	-1.523 ± 0.006
-12.529 ± 0.018	1.452 ± 0.006
-7.247 ± 0.023	1.550 ± 0.005
-1.229 ± 0.022	1.652 ± 0.005
5.021 ± 0.024	1.759 ± 0.005
10.925 ± 0.020	1.864 ± 0.006
-12.429 ± 0.018	4.787 ± 0.005
-7.105 ± 0.020	4.838 ± 0.006
-1.074 ± 0.023	4.925 ± 0.006
5.176 ± 0.022	5.057 ± 0.006
11.079 ± 0.020	5.217 ± 0.006

Table 1: Measured positions for each of the 20 positions in the study. The central values are the mean of 200 individual measurements and the errors are the RMS of these same 200 measurements. See Figure 2a)

where all of the quantities are complex numbers. The corrections are given by,

$$\begin{aligned} \mathbf{A}_{\rm cor} &= \mathbf{a_1}(y)\mathbf{A_p} + \mathbf{b_1}(y)\mathbf{B_p} \\ \mathbf{B}_{\rm cor} &= \mathbf{a_2}(y)\mathbf{A_p} + \mathbf{b_2}(y)\mathbf{B_p}. \end{aligned} \tag{5}$$

where the complex functions $\mathbf{a}_i(y)$ and $\mathbf{b}_i(y)$ depend on the orthogonal coordinate, y, and must be determined from data.

In this model the real and imaginary parts of $\mathbf{a}_i(y)$ and $\mathbf{b}_i(y)$ are presumed to be linear in y,

$$\mathbf{a_1}(y) = \mathbf{m_{a_1}}y + \mathbf{b_{a_1}} \tag{6}$$

$$\mathbf{a_2}(y) = \mathbf{m_{a_2}}y + \mathbf{b_{a_2}}, \tag{7}$$

where $\mathbf{m_{a_i}}$ and $\mathbf{b_{a_i}}$ are complex constants. Similar equations hold for $\mathbf{b}_i$. Therefore it takes 4 points to calibrate the model. In Figure 3g) the points marked 1 and 2 were used to determine the values of the constants $\mathbf{a}_i$ and $\mathbf{b}_i$ for one fixed value of y. The two points marked 3 and 4 were used to determined $\mathbf{a}_i$ and $\mathbf{b}_i$ for a second fixed value of y. At other values of y the correction was interpolated from these values.

In Figure fig:cancelg), the calibration points were chosen not to be at extrema of the grid positions. As will be seen later, the extreme points are outside of the region in which the linear approximations work well.

A similar development, with x and y interchanged, gives the correction for the vertical BPM. In Figure 3h) the 4 points used to calibrate the model for VA14 are shown. Points 1 and 2 gave the coefficients for one fixed value of x while points 3 and 4 gave the coefficients for a second fixed value of x. The correction for other values of x was linearly interpolated from these. For these data, it turned was safe to use the grid points at the horizontal extrema.

Figures 3c) and d) show the Pbar sum signals after the correction described above and figures e) and f) show the same information expressed as a fraction of the uncorrected value. The interesting features of these plots are:

- Look at plots c) and d) before about t=14.3. The residual is only a very weak function of proton intensity.
- For both BPMs there is a strong pattern of residuals that follows proton horizontal beam position. The pattern is less pronounced in the vertical BPM but it is still there.
- Neither BPM shows a strong pattern of residuals which follows the vertical beam position.
- For the vertical BPM, the residual is less than 1.5% of the uncorrected data, except at very low intensities.
- For the horizontal BPM, the residuals are less than 2% of the uncorrected data for most times. There are dramatic exceptions for the grid points at the extrema of the horizontal bumps. These will be discussed later.

To investigate reasons for the poor cancellation at the extrema of the horizontal bumps the signals on the individual cables were examined. Figure 4 shows the magnitudes of the signals on the Pbar cables before and after cancellation. In parts f) and g) one can see that, for the vertical BPMs, the cancellation is of approximately equal quality at all times.

On the other hand there are several problems associated with the horizontal BPM.

- In plot a) everything looks OK until you realize that there is no suppressed zero. At the points with the smallest value of A, the beam is at about $x = +11$ mm; it is about half way from the center to the B plate. In this position the signal on the A plate is already almost at zero. What happens when the beam moves a little farther from A?
- In plot c) there is a glitch at the start of each cycle of 5 points. The first of these is marked by two red vertical lines at the horizontal axis. This point is the negative extremum of the horizontal position, when it is farthest from the B plate, near $x = 13$ mm. So now we have the answer to the question at the end of the last bullet. When you move a little closer to an electrode, the signal goes through zero and becomes large again! I am not yet certain how this happens or what it means.
- The anomolously large residuals for the corrected Pbar signal from plate A, plot b), occur when the beam is closest to plate A, when the magnitude of Pbar A is large and the magnitude of Pbar B is in the glitch discussed in the previous point. At this time the residuals for the corrected Pbar signal from plate B, plot d), are of normal size.
- The converse is true for the large residuasl for corrected Pbar signal from plate B, plot d), occur when the beam is closest to plate B, when the magnitude of Pbar B is large and the magnitude of Pbar A is almost at zero, as discussed in the first bullet. At this time the residuals for the corrected Pbar signal from plate A are of normal size.
- I can't yet tell if the anomalously large residuals should be blamed on the small signal on the opposite plate or the large signal on the same plate. Or both or neither.

From the above I conclude that, somewhere between 7 mm and 11 mm from the electrical center of the BPM the algorithm used to cancel the proton signal on the Pbar cables starts to fail.

Figure 5 continues the search for reasons for large residuals by looking at phases. Plot a) shows the phase of the HA15 proton B cable, relative to that of the HA15 proton A cable. It is reasonably constant with fine structure which follows both the horizontal and vertical bumps. Plot b) shows similar results for VA14. The remaining plots show the relative phases of the Pbar cables wrt the corresponnding Proton A cable. Observations on these plots:

- Plot f) looks almost as stable as VA14 proton B cable. Plot e) is not as good.
- Plot c) shows a large phase shift at the time that Figure 4d) shows a large residual.
- Plot d) shows its largest phase shift at the time that Figure 4b) shows a large residual.

This is not really enough to break the dilemma mentioned in the last bullet in the discussion of Figure 4.

3 Still to come

need a discussion about how a 2% error affects Pbar position and intensity measurements. Need to make these residuals signed.

4 Conclusions

Is the whole problem that we are out of the domain of the linear approximation? Or is it more.

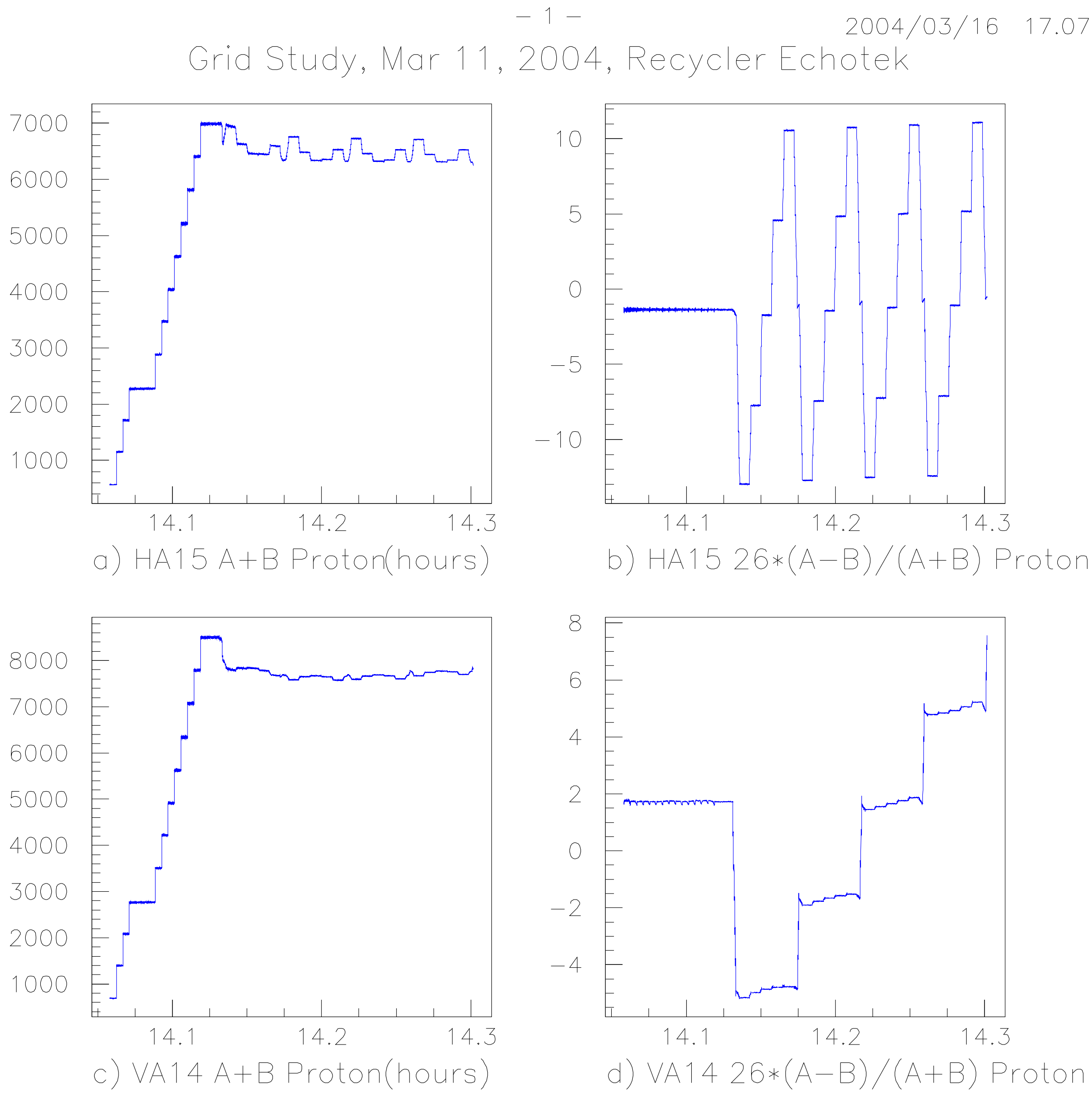

Figure 1: The proton sum and position signals for both BPMs in this study. In all plots in this study, unless otherwise stated, the horizontal axis is time, in units of hours since midnight on March 11.

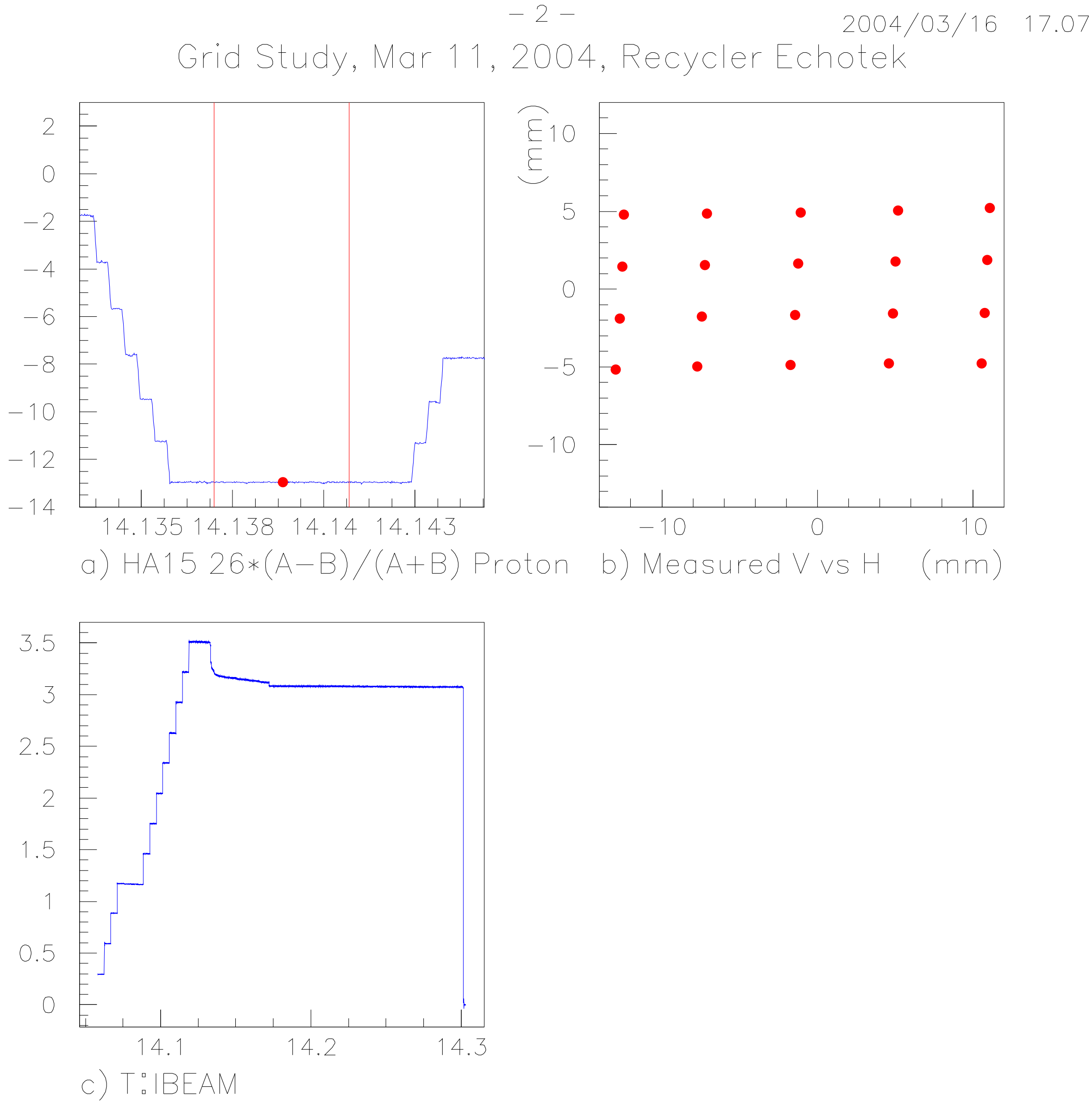

Figure 2: Part a) shows a detail of measuring the beam position at the first point in the study, (-5.16,-12.97) mm. Part b) shows the measured position for each grid point, in mm, vertical vs horizontal. Part c) shows the ACNET variable T:IBEAM during the study. The beam loss near t=14.133 is visible; it is followed by period of short beam lifetime before conditions settle down.

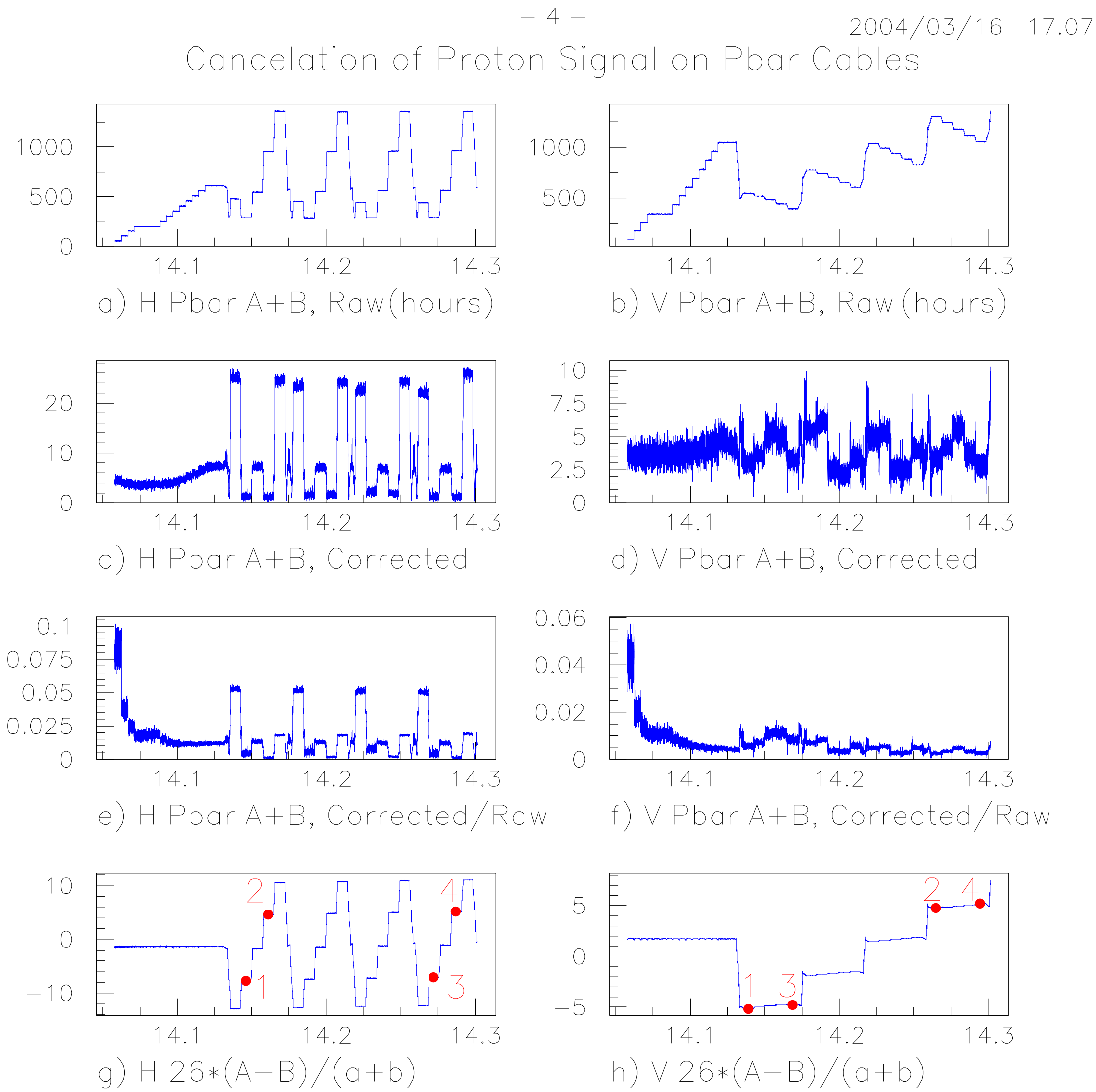

Figure 3: Study of the cancellation of the proton contamination on the Pbar cables. The plots in the left column show quantities for HA15 while those in the right column show quantities for VA14. The top two rows of plots show the Pbar sum signals before and after the correction. The third row shows the ratio of the corrected signal divided by the raw signal. The last row is provided as a time reference; it shows the proton position signals. The red dots and numbers are discussed in the text.

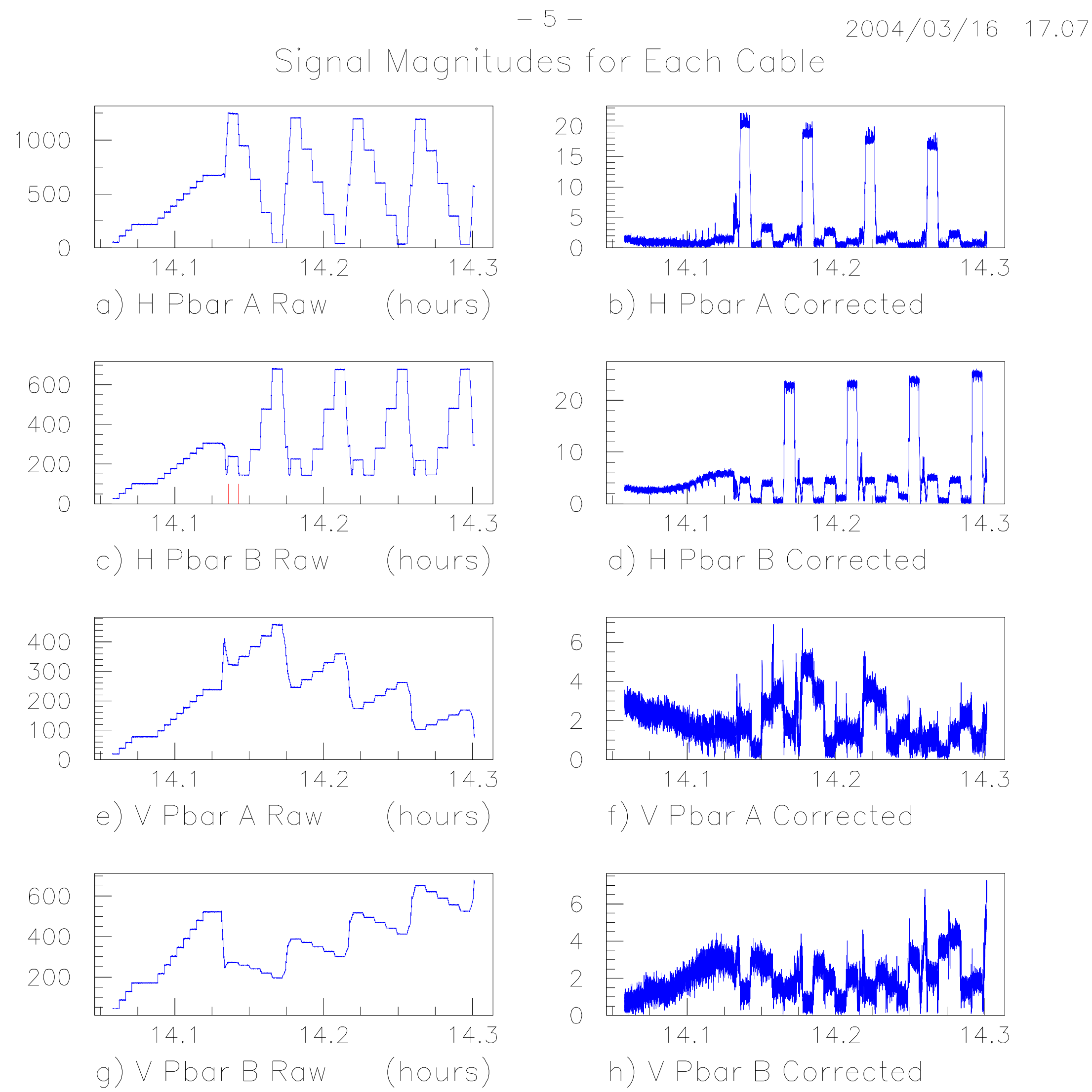

Figure 4: Magnitudes of the Raw and corrected Pbar signals for the A and B cables on HA15 and VA14. The figures are discussed in the text.

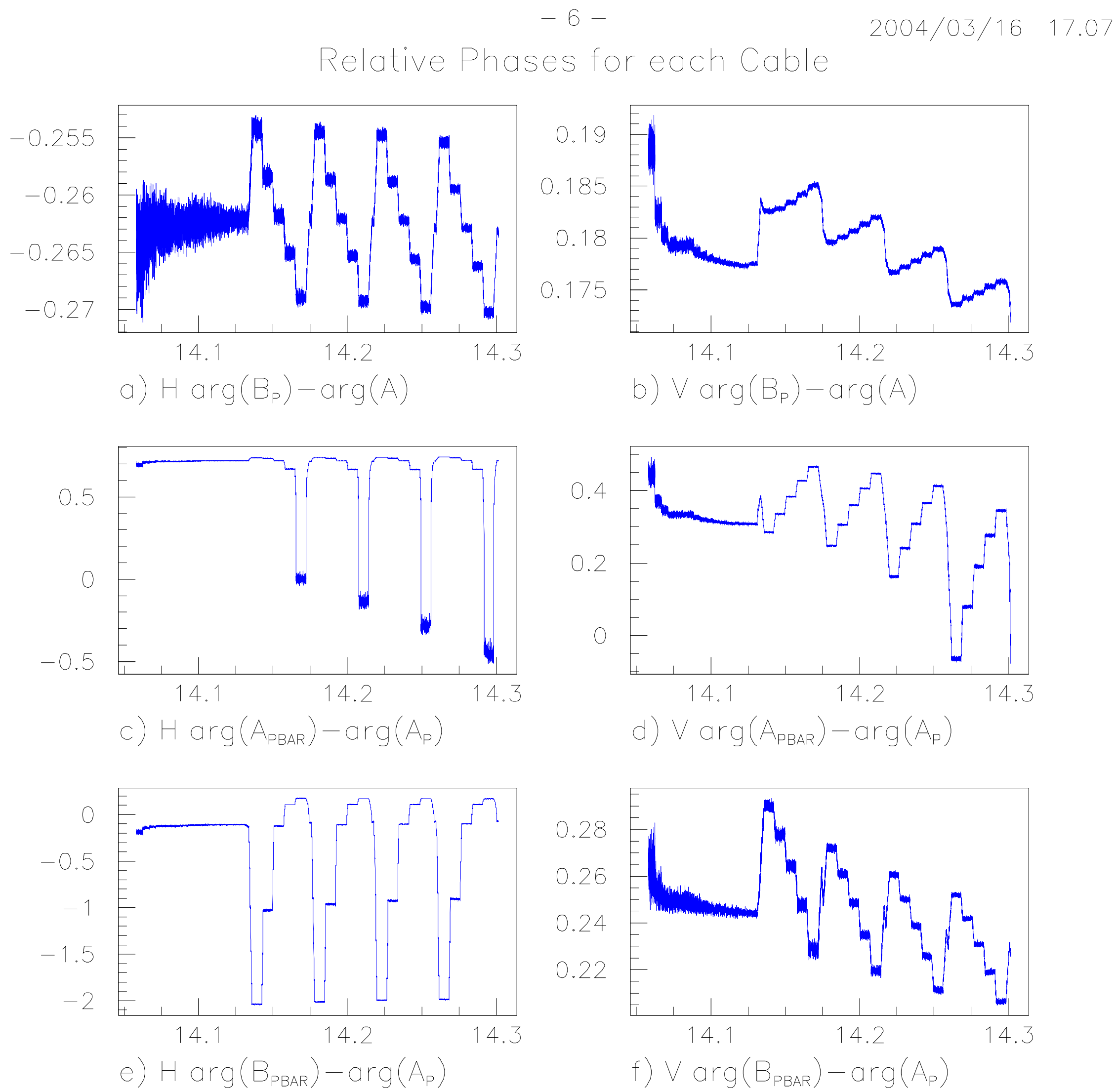

Figure 5: Phases of the signals on the Pbar cables and on the proton B cable, all relative to the phase of the proton A cable. The figures are discussed in the text.

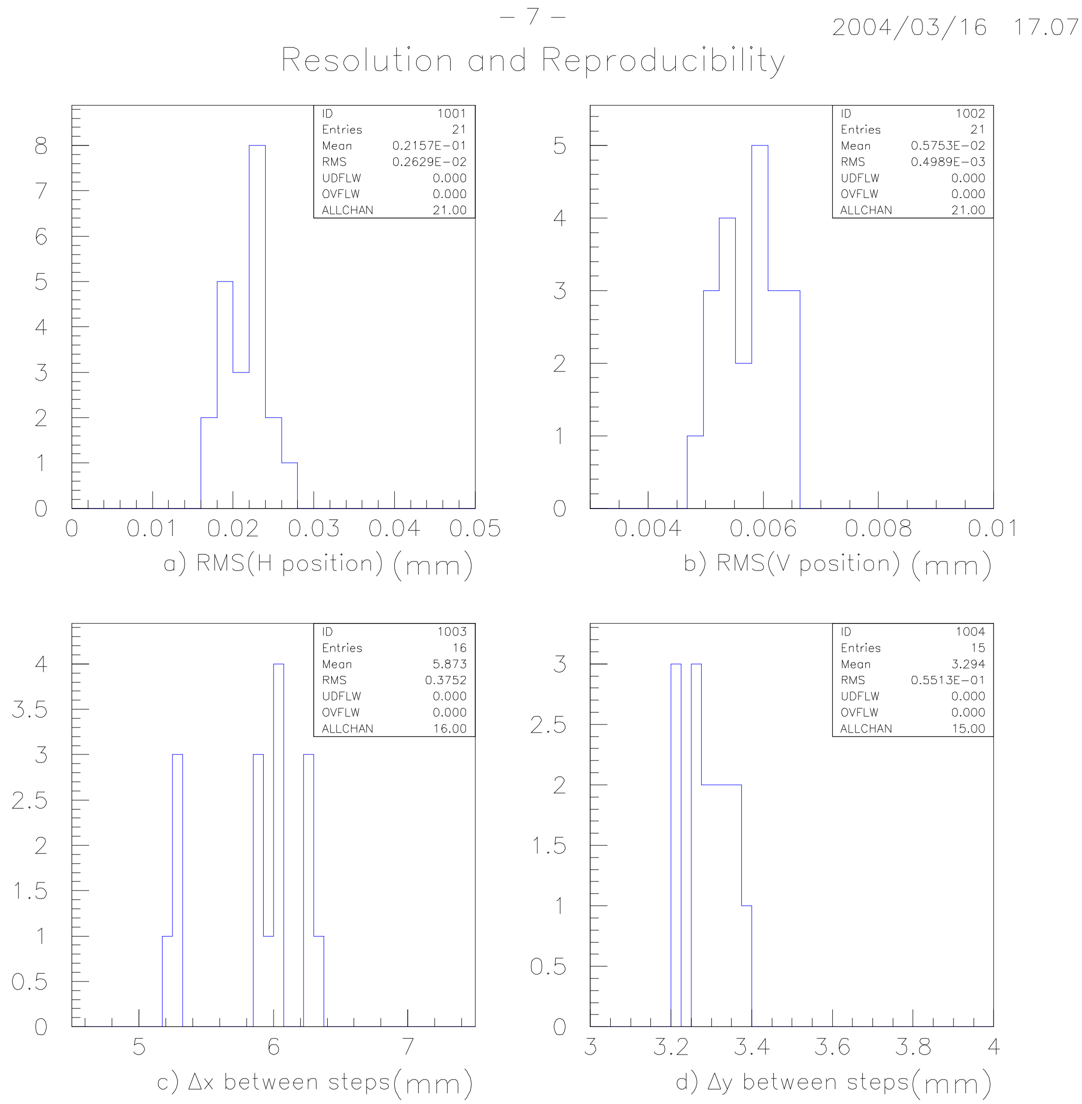

Figure 6: Plots a) and b) summarize the resolutions obtained for each of the 20 data points the study, plus a data point on the central orbit before the bumps began. For each of the 21 points, 200 measurements were averaged to give the mean value of the position. The quantity plotted is the RMS spread of these 200 points. Plots c) and d) show the step sizes from one point to the next in the grid. They are not very repeatable but I can't yet tell if this is an instrumental effect or a real difference in the orbit.

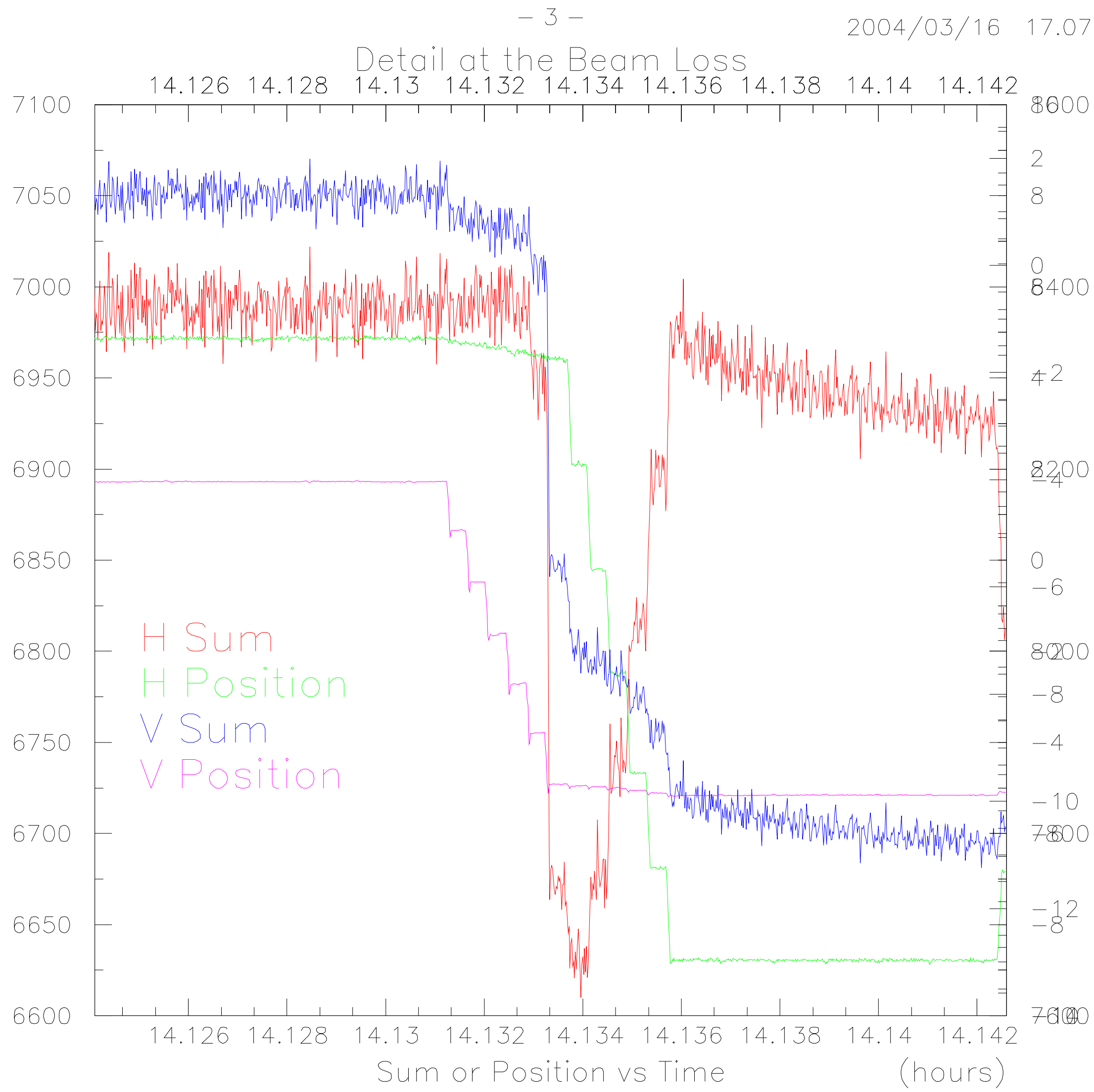

Figure 7: A detail of the proton sum and position signals near the time of the intensity loss.