Beams-doc-1863-v1
June 8, 2005

Anti Proton Positions in the Tevatron

Rob Kutschke, CD/EXP

Abstract

This note compares the anti-proton position measurements, taken just after anti-proton injection, with with the proton position measurements, taken just before and after the helix opens. This provides a sanity check that the anti-proton positions make sense. It also provides a way to look for swapped anti-proton cables.

1 Introduction

During anti-proton injection, there is no intentional motion of either the proton or anti-proton helices. Therefore a check of the anti-proton calibration can be done by making three measurements:

- p_C Proton central orbit: obtained by measuring the proton position just before the helix is opened.
- p_H Proton helix: obtained by meausuring the proton position just after the helix is opened.
- $\bar{p}_H$ Anti-proton helix: obtained by meausuring the anti-proton position just after the end of end of anti-proton injection.

If everything is working as planned, then

$$p_H - p_C \quad = \quad -(\bar{p}_H - p_C) \tag{1}$$

This note will also discuss a fourth measurement,

- p_{H2} Proton position meausured just after the end of anti-proton injection.

The quantity $(p_{H2} - p_H)$ measures the sum of two contributions: the anti-proton contamination on the proton signals and any unplanned orbit change. It is believed that the latter is small so the difference is a direct measure of the former.

In an email from May 31, 2005, Mike Martens showed a plot of $p_H - p_C$ vs $p_C - \bar{p}_H$. This plot showed a main body of points which lay along the expected line but a significant number of outliers. This note examines the outliers and does some analyses with the outliers removed.

2 Data

The upper left part of Figure 1 shows a plot of $p_H - p_C$ vs $\bar{p}_H - p_C$. The main body of the data points lie, as expected, along the negative diagonal. This plot has many fewer outliers than did Mikes'. The main reason is that Mikes' plot included HE19, which has no cables connected at all, and 8 BPMs from the A0 and F0 houses, which have no anti-proton cables connected. Those points were simply noise.

The magenta points have $|p_H - p_C| < 0.5$ mm. For these points there is a short lever arm for computing the cancellation coefficients; therefore there can be a large measurement error on the anti-proton position. The plot shows that these points do indeed have a large scatter in the horizontal coordinate.

Of the remaining BPMs, those that are within 3 mm of lying on the negative diagonal are colored blue. Specifically, a point is blue if it satisfies,

$$\Delta^+ \quad = \quad |(p_H - p_C) + (\bar{p}_H - p_C)| \quad < 0.5\,\text{mm}. \tag{2}$$

The one yellow point will be discussed later.

This leaves the red and green points, which come in pairs. For every BPM that has anti-proton cables connected, and that is not colored magenta, yellow or blue, there are two points, a red one and a green one. The red points show $p_H - p_C$ vs $\bar{p}_H - p_C$, the same quantity as plotted for all other points. The green points are plotted after changing the sign of $\bar{p}_H$; this is equivalent to swapping the anti-proton A and B cables. For four of these BPMs, the green points fall within the main body of the data on the negative diagonal: HF17, HF26, VD33 and HD34.

Marv checked these BPMs he reports that HF26, VD33 and HD34 indeed had swapped anti-proton A and B cables. He fixed them. Because there are splitters in the signal path for HF17 Marv could not tell if the anti-proton cables for HF17 were swapped. HF17 will be discussed some more in two paragraphs.

This leaves two outliers, HC49 and VF14, both marked on the plot. Marv checked these too. He reports that HC49 and VC49 have their anti-proton cables swapped. He fixed this. VC49 is marked on the plot as the yellow point. Because the IQ data for these BPMs were not saved, it is not possible to fix this error in software and verify that the cable swap is the full story. So we will have to wait for another shot shot to see if this solves the problem.

Marv reports that VF14 is correctly cabled and the plot shows that swapping the anti-proton cables does not significantly improve the agreement. I will ask that Marv investigate the possibility that VF14 has its anti-proton cables swapped with one of the other cables in the crate. In particular HF17, mentioned above, is in the same crate. So two possibilities to check out are: 1) VF14 and HF17 have their anti-proton cables swapped and 2) HF17 has its own antiproton cables swapped and there is a different problem with VF14.

The upper left plot in Figure 1 has a dotted line along the main diagonal. The upper right histogram in this figure shows the projection of the blue data points onto the dotted line. From this we can read the quality of the agreement of the measured anti-proton position with the predicted position: it has a mean of 0.061 mm and a width of 0.94 mm. The error on the mean is roughly RMS/$\sqrt{N}$, where N is the number of entries in the histogram, 207. This gives an error on the mean of about 0.066 mm. Therefore the observed mean is consistent with zero.

The lower right histogram shows, for all blue points in the upper left plot, the difference $p_{H2} - p_H$; this histogram has a mean consistent with zero and an RMS of 0.73 mm. There are two candidate explanations for the observed width. Most probably it is due to anti-proton contamination on the proton cables. A second possible explanation is there that is unplanned beam motion during anti-proton injection; the Tevatron experts consider this less likely.

There is a clue in the data that favours the first explanation. With the available data, one can compute the size of the proton helix in two ways, using p_H or using p_{H2}. The lower left histogram shows the same information as the upper right but with the substitution of p_{H2} for p_H. In the event that there is signifcant contamination of the proton signal due to the anti-protons, then p_H is a better measure of the proton helix than is p_{H2}. In this scenario, the upper right histogram should have a smaller RMS than the lower left, as is observed. If the explanation for the width of the lower right histogram is actual, but unplanned, motion of the central orbit, then the lower left histogram should have the smaller RMS than the upper right and the lower left histogram should also have a non-zero mean value. Neither of these is not observed. If the explanation is that the central orbit stays the same, but the magnitude of the helix changes with time, then the lower left histogram should have the narrower RMS than the upper right and the upper right histogram should have a non-zero mean. This is not observed.

Figure 2 shows the same information as Figure 1 but using data from the shot on May 30, 2005. The same conclusions as above are reached with this data.

3 More Swapped Cables?

The histograms in the upper right of Figures 1 and 2 has a wide enough width that it might contain some more swapped cables. To search for these, I defined the quantities Δ^+ and Δ^-, where Δ^+ is define as above and where Δ^- differs by the sign in front of the $\bar{p}_H$.

$$\Delta^- \quad = \quad |(p_H - p_C) + (-\bar{p}_H - p_C)|; \tag{3}$$

that is, Δ^+ is the agreement between the measured and predicted anti-proton positions, while Δ^- is the agreement between the same two quantities if one swaps the anti-proton A and B channels. If $|\Delta^-| < |\Delta^+|$, then the data suggests that the anti-proton cables might be swapped and we should investigate. Figure 3 shows histograms of the quantity, $|\Delta^+| - |\Delta^-|$ for both data sets. The right hand bins of both histograms, colored red, are the bins which contain candidates for swapped cables; there are 10 candidates in each data set. These candidates are not well separated from the main body of the distribution so this is not a particularly sensitive test.

Table 1 gives some details of the properties of the candidates for swapped cables. Nine of the ten BPMs are common to the two data sets. The only BPM that seems very likely to have swapped anti-proton A and B cables is T:HPD48, for which $p_H - p_C$ and $\bar{p}_H - p_C$ have the same sign. Several other BPMs have $|\Delta^+| - |\Delta^-| > 1$ mm and I judge these as likely to have swapped cables; these are marked with a "Yes" in the righthand column. I think that those BPMs that have $0.5 < |\Delta^+| - |\Delta^-| < 1$ mm might well have crossed cables but I am not as sure; these are marked with a "Maybe" in the righthand column. I think that there is insufficient information in the Table 1 to make a judgement about the remaining BPMs; these are marked with a "?" in the right hand column.

I have asked Marv to check the cabling of BPMs marked Yes or Maybe in the right hand column of Table 1.

4 Fits to the Good Data Points

I computed the χ^2 that the data lie on lie on the negative diagnonal,

$$\chi^2 = \sum_i \left(\frac{\Delta^+}{\sigma}\right)^2, \tag{4}$$

where the sum runs over the 207 blue data points and where $\sigma = 0.95$ mm is the RMS width of the upper right histogram on both figures. From this χ^2 I computed the confidence level for 207 degrees of freedom; that is, no parameters were determined from the data. This gave 0.46 for the May 29 data and 0.43 for the May 30 data, both in excellent agreement with the hypothesis that that the data lie on the negative diagonal.

I also fitted the data points to a straight line using least squares fitter and equal weights of $1/\sigma^2$ for all points. For the May 29 data, this gave a slope of -1.02, an intercept of 0.06 mm and a confidence level of 0.16. For the May 30 data, this gave a slope of -1.03, an intercept of 0.06 mm and a confidence level of 0.43. The fitting package I used did not return an error on the slope or intercept. I can fix that if people would like to see it.

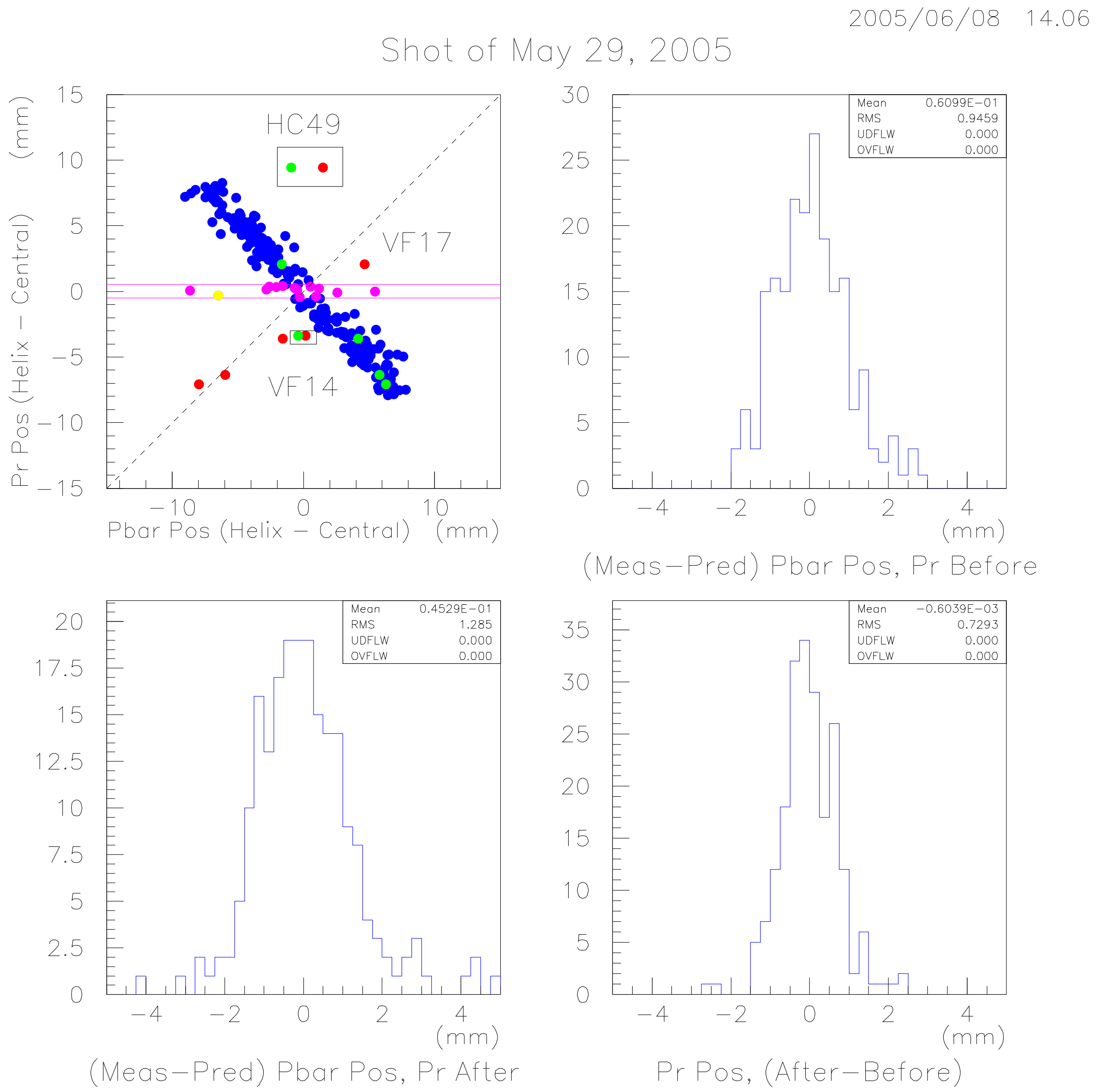

Figure 1: Data from the shot on May 29, 2005. The upper left plot shows a plot of $p_H - p_C$ vs $\bar{p}_H - p_C$. The different colors of points are described in the text. The upper right histogram shows a projection of the blue points onto the dashed line from the upper left plot; this is a measure of how well the measured anti-proton position agrees with the predicted position. The bottom left histogram shows the same information as the upper left but with p_H replaced by p_{H2}. The lower right histogram shows $p_{H2} - p_H$. The notation is described in the text.

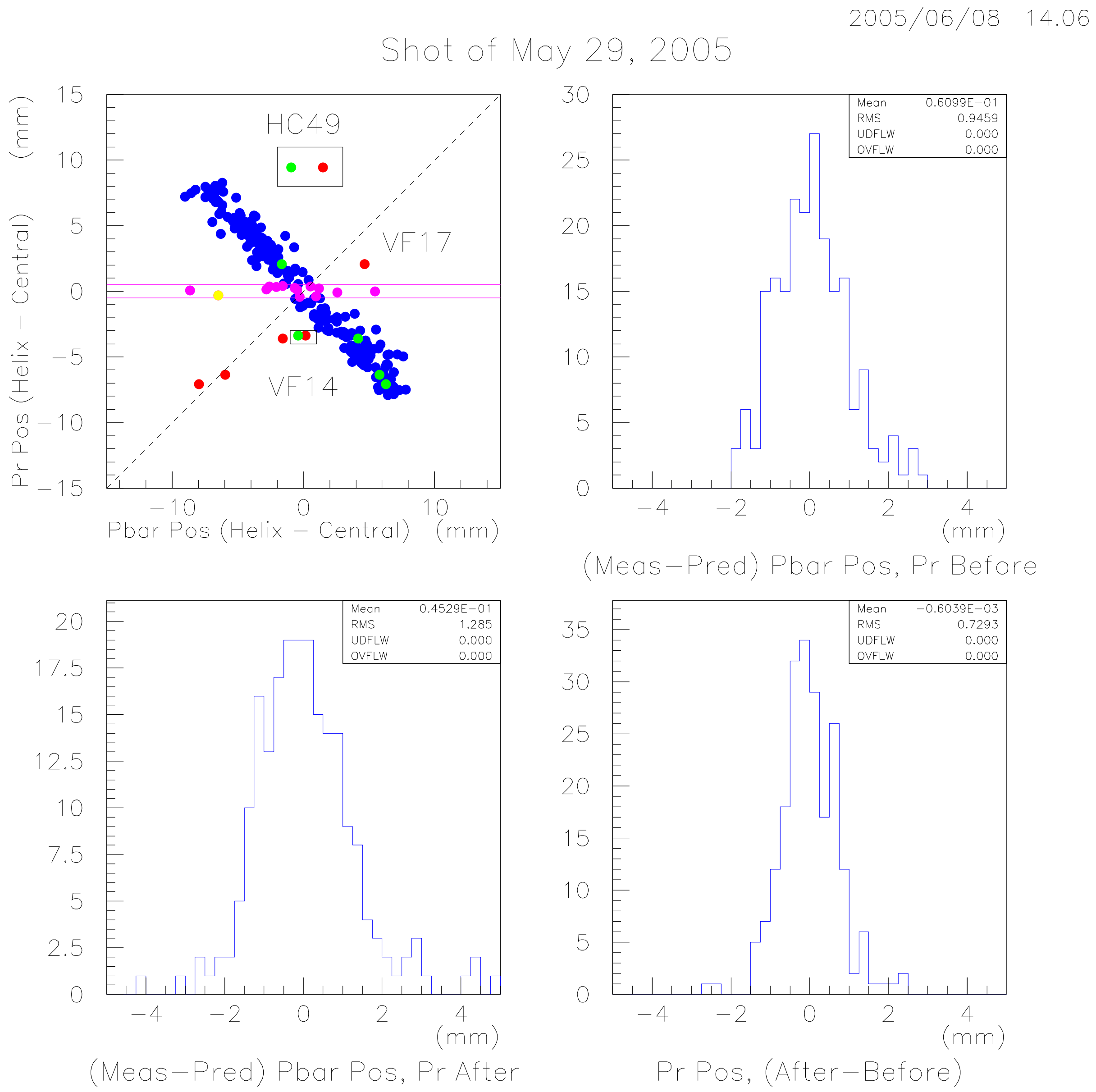

Figure 2: The same information as the previous figure but for data from the shot on May 30, 2005.

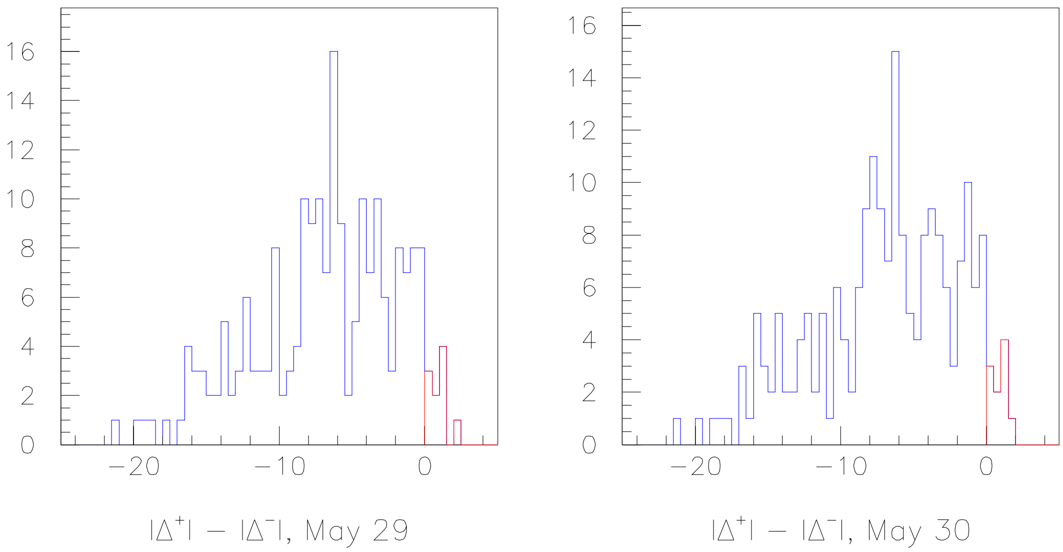

Figure 3: $|\Delta^+| - |\Delta^-|$ for both data sets. The bins in red have values > 0 and are candidates for investigation to see if the anti-proton cables are swapped. Details of the BPMs from the red bins are given in Table 1.

BPM	$p_H - p_C$ (mm)	$\bar{p}_H - p_C$ (mm)	$-\bar{p}_H - p_C$ (mm)	Δ^+ (mm)	Δ^- (mm)	Swapped?
T:HPA19	1.664	-2.318	-1.970	-0.654	-0.306	?
T:HPD48	-0.565	-0.650	0.415	-1.215	-0.150	Yes
T:VPE18	0.549	-1.294	-0.487	-0.745	0.062	Maybe
T:VPE23	3.299	-2.933	-2.978	0.367	0.321	?
T:VPF35	-4.067	5.865	3.519	1.799	-0.548	Yes
T:VPF37	-4.950	7.610	4.469	2.659	-0.482	Yes
T:VPF47	-2.932	5.547	4.247	2.615	1.315	Yes
T:VPB45	1.449	-0.070	-1.368	1.380	0.081	Yes
T:VPC16	1.739	-0.616	-1.298	1.123	0.442	Maybe
T:VPE12	1.968	-2.114	-2.015	-0.145	-0.046	?
T:HPA19	1.637	-2.372	-2.099	-0.734	-0.462	?
T:HPD48	-0.597	-0.786	0.536	-1.383	-0.062	Yes
T:VPE18	0.557	-1.269	-0.456	-0.712	0.101	Maybe
T:VPE23	3.305	-2.860	-3.122	0.445	0.182	?
T:VPF35	-4.119	5.915	3.380	1.796	-0.739	Yes
T:VPF37	-5.011	7.678	4.314	2.667	-0.697	Yes
T:VPF47	-2.977	5.586	4.105	2.609	1.128	Yes
T:VPB45	1.454	-0.028	-1.346	1.426	0.108	Yes
T:VPC16	1.745	-0.569	-1.225	1.176	0.520	Maybe
T:VPA11	-1.988	1.525	1.555	-0.463	-0.433	?

Table 1: Details for those BPMs which have $|\Delta^+| - |\Delta^-| > 0$, that is for the points that fall into the red bins in Figure 3. The entries above the double middle line are for the shot of May 29 while those below the line are for the shot of May 30. Within each of these data sets, the nine entries above the single line are common to both data sets, while the tenth entry is unique to that data set. The righthand column contains my judgement, as described in the text, whether or not the anti-proton A and B cables are swapped; for the entries marked "?" I cannot tell from this data whether or not the cables are swapped.