Beams-doc-2004-v1
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TeV BPM Upgrade: Anti-Proton Position Resolution

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Abstract

Beams-doc-1752, page 9, showed data for which the closed orbit resolution for anti-protons was less than that for protons. This was a surprise. This note will show that this effect occurs in 6 of 25 BPMs studied. Most likely this indicates a true, but very small, difference in the behavior of the proton and anti-proton beams. This note will also characterize the behavior of several BPMs for which the anti-proton position measurements are unreliable; it will also recommend that the unreliable data be flagged.

1 Introduction

Beams-doc-1752, page 9, showed one store for which the closed orbit position resolution at HA32 for anti-protons was smaller than that for protons. This was a surprising result since all known instrumental effects, other than broken hardware, will yield a position resolution for anti-protons that is larger than that for protons. Indeed many people's first thought was that the result was simply a labeling error. I checked the raw data and code that produced the plot and the figure is indeed correct; the surprise is really there. This note will show that the effect occurs in six of the 25 BPMs that were investigated.

An additional two BPMs were originally included in the study but they have poorly determined cancellation coefficients, which leads to unreliable anti-proton data. For these BPMs, this note will present a time series that illustrates the unreliability of the data. It is recommended that these data be flagged as unreliable.

2 Data Selection

The data shown in this analysis cover 5 HEP stores, starting on October 12, 2005 and ending on October 21, 2005. Over this time period, 27 BPMs had both proton and anti-proton information logged to the lumberjack data logger; data from all 27 BPMs are shown in this note. For each store, for each BPM, the data from the lumberjack database was sampled, the first sample taken from a time just after the start of HEP collisions and further samples taken once per hour until the end of the store. Each sample consisted of 100 consecutive measurements of the closed orbit sum ($|A| + |B|$)and position information for both protons and anti-protons.[1] In the accompanying plots, the sum and position data points show the mean of the 100 measurements while the position resolution data points show the RMS spread of the 100 position measurements.

3 An Example: VA37

Figure 1, which shows the data taken from VA37, gives an illustrative example of these data. The bottom plot is the main figure of interest, while the other two plots provide background information. In the top plot, the sum signals (intensities) are shown for both the protons and the anti-protons. The five stores are delimited by vertical lines and are labeled by the day on which the store started; the store that started on October 19 ended on October 21. Within each store, each data point is separated from its neighbor by one hour but the time axis is discontinuous between stores. This data is unremarkable, showing the normal drop in intensity with time.

The middle plot in Figure 1 shows a set of position measurements, in one to one correspondence with the sum signal measurements in the top plot. Again the data is unremarkable, showing reasonably stable beam positions.

The bottom plot in Figure 1 shows the position resolution for both protons and anti-protons, each point in one to one correspondence with the sum and position measurements. In this figure, the position resolution for protons is always shown as a blue triangle. The position resolution for anti-protons is shown as a green square if it is larger than that for the protons; this is what one would normally expect. On the other hand, if the position resolution for anti-protons is smaller than that for protons, the anti-proton point is shown as a red cross; this is the circumstance that prompted this study. The reason for choosing VA37 as an example is simply that it has enough points of both colors to provide a good illustration; for most of the BPMs the anti-proton data points are almost entirely one color.

4 The Main Study

Figures 2 through 4 show the position resolution time series for 25 different BPMs. Each plot on these pages is made the same way as was the bottom plot in Figure 1. The BPMs are shown in alphabetical order, ignoring the leading H or V. The features of these data are:

1. To first order, the anti-proton and proton position resolutions track each other: if one is large then so is the other.

2. The effect that prompted this study (red data points which indicate an anti-proton resolution that is better than the proton resolution) occurs in about 1/4 to 1/3 of the BPMs:

[1] For most of the BPMs, the data were logged at 1 Hz but for six BPMs (HA32, VA33, HD32, VD33, HE32 and VE33) the data were logged at 15 Hz. This information is probably irrelevant for this study but it is included for completeness.

- For 6 BPMs all, or almost all, of the anti-proton data points are red.
- For 2 BPMs about 25% of the data points are red.
- The remaining 17 BPMs have, at most three or four red data points, usually none.

3. The effect occurs on 4 of 14 H BPMs and on 2 of 11 V BPMs. The statistics are not sufficient to conclude that it happens more on H than on V.

4. The data suggest that the effect does not occur when the proton position resolution is at its best, around 5 μm; however the statistics on this statement are weak.

5. In Beams-doc-1752 the effect was shown for HA32 and was present for all of the data points. In this study the effect is also present for HA32 but only for most, not all, of the data points. When it is present, the effect is about the same size as it was in Beams-doc-1752 but there is more scatter to the data points in these data so, at first glance, the effect appears smaller.

6. The BPM for which the effect is most pronounced is HF17. The sum and position data for HF17 look OK. For HF17 the step size of the protons at the helix opening is about 2.1 mm; this is safely above the value of of 0.25 mm that is needed to ensure a good determination of the cancellation coefficients.

7. There are a few wild outlier data points, in HC11, VF11, and HF17, for example. I am not certain how to explain these but they are all the first points in a store; so it is possible that I took the first sample too close to the start of collisions when the final Tevatron adjustments were not yet complete.

8. In some of the BPMs with very small proton position resolution, the anti-proton resolution gets larger as the store progresses. This is most dramatic on VE33 and VF11, for which the proton resolution is about 5 μm. One candidate explanation is that this is due to the least count of the ADC; however I have not done the work to test this hypothesis and I do not intend to.

5 Towards an Explanation

I have some ideas towards an explanation of this effect but they are not yet fully formed.

- The proton position resolution varies by more than a factor of 2 around the ring. This is true separately for H BPMs and for V BPMs. I have not seriously looked for any pattern to in this variation.

- Look at page 24 of Beams-doc-1752. This shows that, for the 8 BPMs investigated, the proton position resolution is explained by the magnitude of the "15 Hz" noise that is measured in hand triggered turn-by-turn measurements during HEP running.
- I don't understand how the source of the 15 Hz noise couples to the beam. But somehow it is creating a standing pattern of oscillations around the ring. The various BPMs are at different locations with respect to the necks and anti-necks of this pattern.
- I guess that there is a similar standing pattern of oscillations for the anti-protons. But it is only similar, not exactly the same, presumably because the anti-proton orbit is different than that of the protons and because the emittances of the beams differ.
- If the previous bullet is correct, then the differences in the "15 Hz" noise can explain the data.

6 BPMs with Unreliable Anti-proton Measurements

Figure 5 shows the same information as Figure 1 but for VC11. A glance at the bottom plot shows several dramatic changes in the resolution for the anti-proton position. At first I wondered if this could be correlated with changes to the Tevatron: did tuning of the Tevatron improve the resolution? Inspection of the VC11 position data, however, shows completely unbelievable changes in the anti-proton position: the measured anti-proton position changes between 4 mm and 15 mm when the proton position is stable to less than 1 mm and there are no corresponding changes in the anti-proton position at other BPMs.

It turns out that VC11 belongs to a class of BPMs for which the anti-proton position information is not reliable. In this class of BPMs, the step of the proton beam when the helix opens is less than 0.25 mm, which provides insufficient lever arm to reliably determine the cancellation coefficients. For VC11 the step size of the proton beam when the helix opens is about 0.20 mm. If we take the full spread of the data as an estimate of the systematic error due to this effect, then we conclude that, at this BPM, the anti-proton position measurement could easily be wrong by 10 mm!

The list of BPMs that belong to this class are given in Table 1.

In the dataset studied here, there is one other BPM that belongs to this class, HA38, for which the step size of the proton beam when the helix opens is about 0.16 mm. The middle plot in Figure 6 shows a similar, unbelievable variation in the anti-proton position at HA38. Although the full spread of the position variation is smaller, it is still large, about 5 mm.

This effect was documented before, as the blue points in Figure 1 of Beams-doc-1925. The present study makes it even more clear that one should not trust any anti-proton position information from BPMs in this class. Therefore we

BPM	Helix Step (mm)
HC26	-0.041
HB49	-0.045
VC18	-0.073
HB36	-0.151
HA38	-0.155
VB33	-0.174
VC11	-0.199
HF48	-0.258
VB14	-0.286
VA29	0.299

Table 1: The BPMs above the line have unreliable anti-proton information, while those below the line have reliable anti-proton information but small changes in the orbit could cause their anti-proton information to become unreliable. The information is unreliable when the step in the proton position when the helix opens is less than about 0.25 mm; this provides too small a lever arm to reliably determine the cancellation coefficients. The second column gives the size of the step in the proton position when the helix opens; this number is the mean step size from about 30 shots and the RMS spread of each step size is about 0.04 mm.

should modify the behavior of the BPM system to flag these data as unreliable. I propose that this be done in two steps:

1. When the front end returns a data structure with a status word, the problem can be indicated in the status word.

2. When the front end returns only the position, an offset can be added to the position to move the data outside of the reasonable range of (-26,26). It is desirable that this offset not conflict with the value of 999 that is returned when the sum signal is below threshold. So I propose an offset of 2000; if desired, one can recover the original value by subtracting the offset.

For the short term, the list of BPMs in this class should be stable. It remains to be discussed how to keep the list current in the longer term.

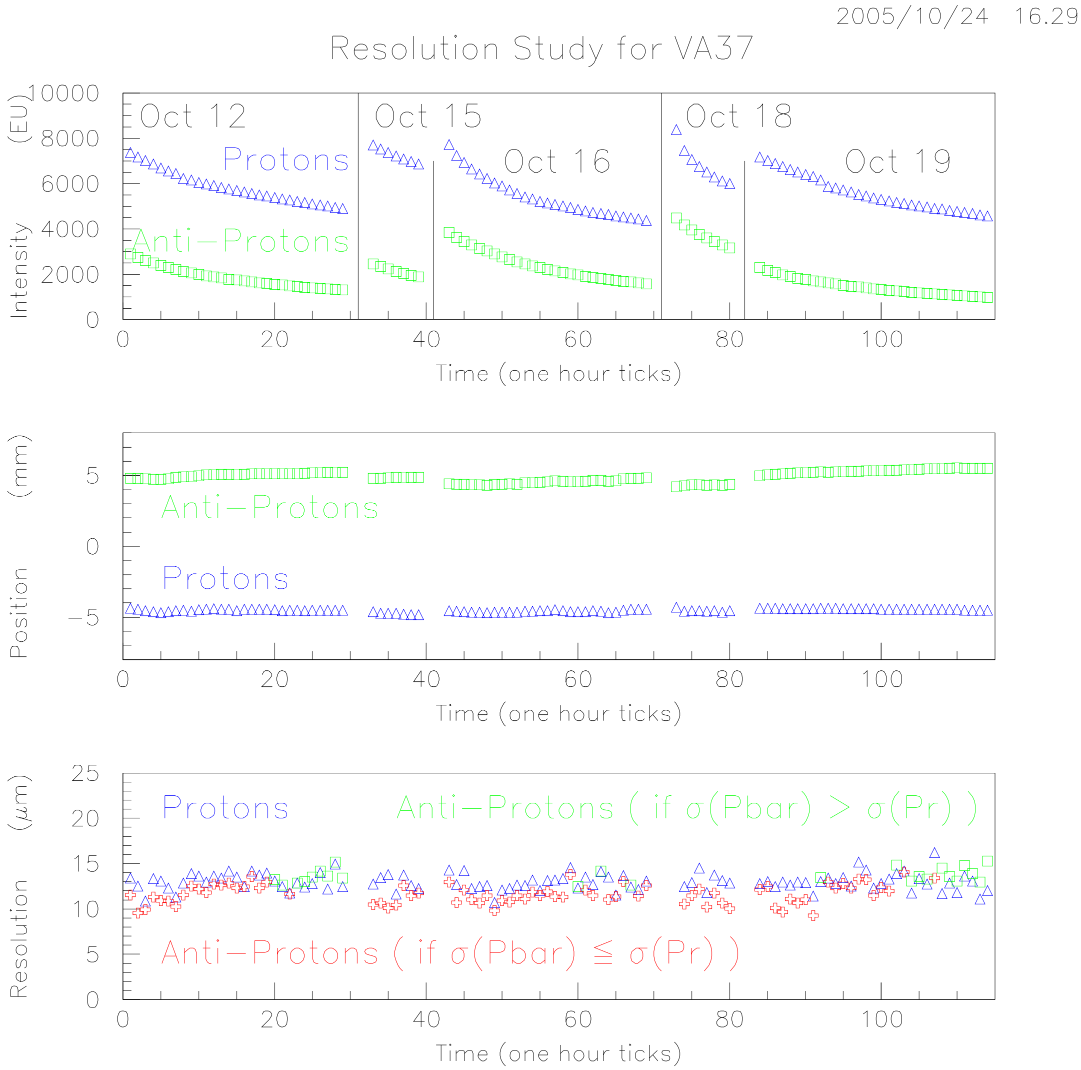

Figure 1: In the upper plot the blue triangles and green squares show, respectively, the proton and anti-proton sum signal ($|A| + |B|$) for the five stores included in this study. Within each store the points are separated by one hour but there is a discontinuity in the time axis between stores. The stores are labeled by the day on which they began. The middle plot shows the proton and anti-proton positions for this same time period. The bottom plot shows the closed orbit position resolution for protons and anti-protons for this same time period; the anti-proton points have been plotted as red crosses if $\sigma(\bar{p}) \leq \sigma(p)$ and green squares otherwise.

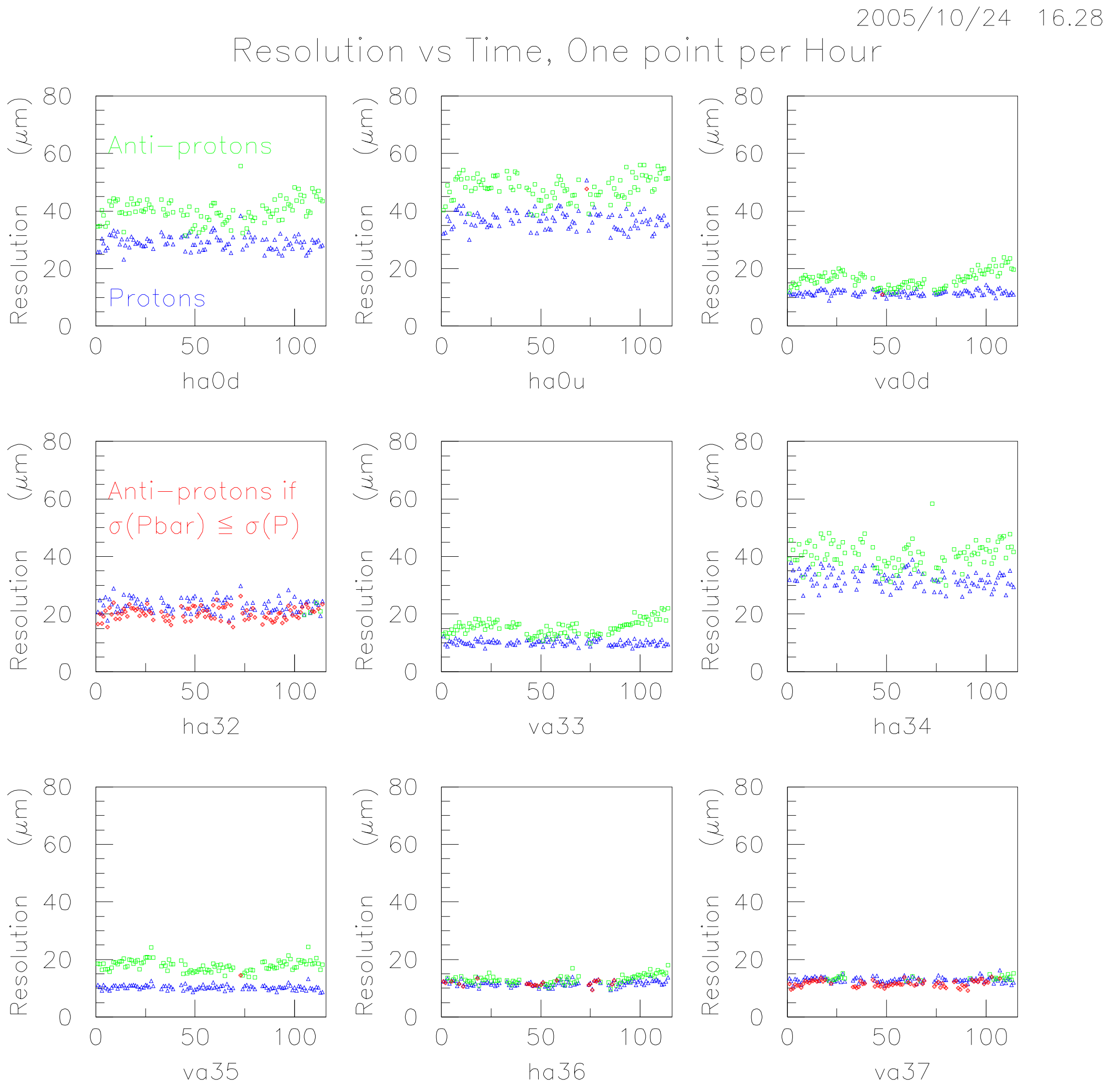

Figure 2: The same information as the bottom plot of Figure 1 for nine BPMs. The blue points show the closed orbit position resolution for protons, measured once per hour during HEP running. The green and red points show the same for anti-protons; an anti-proton point is shown as a red cross if $\sigma(\bar{p}) \leq \sigma(p)$ and as a green square otherwise.

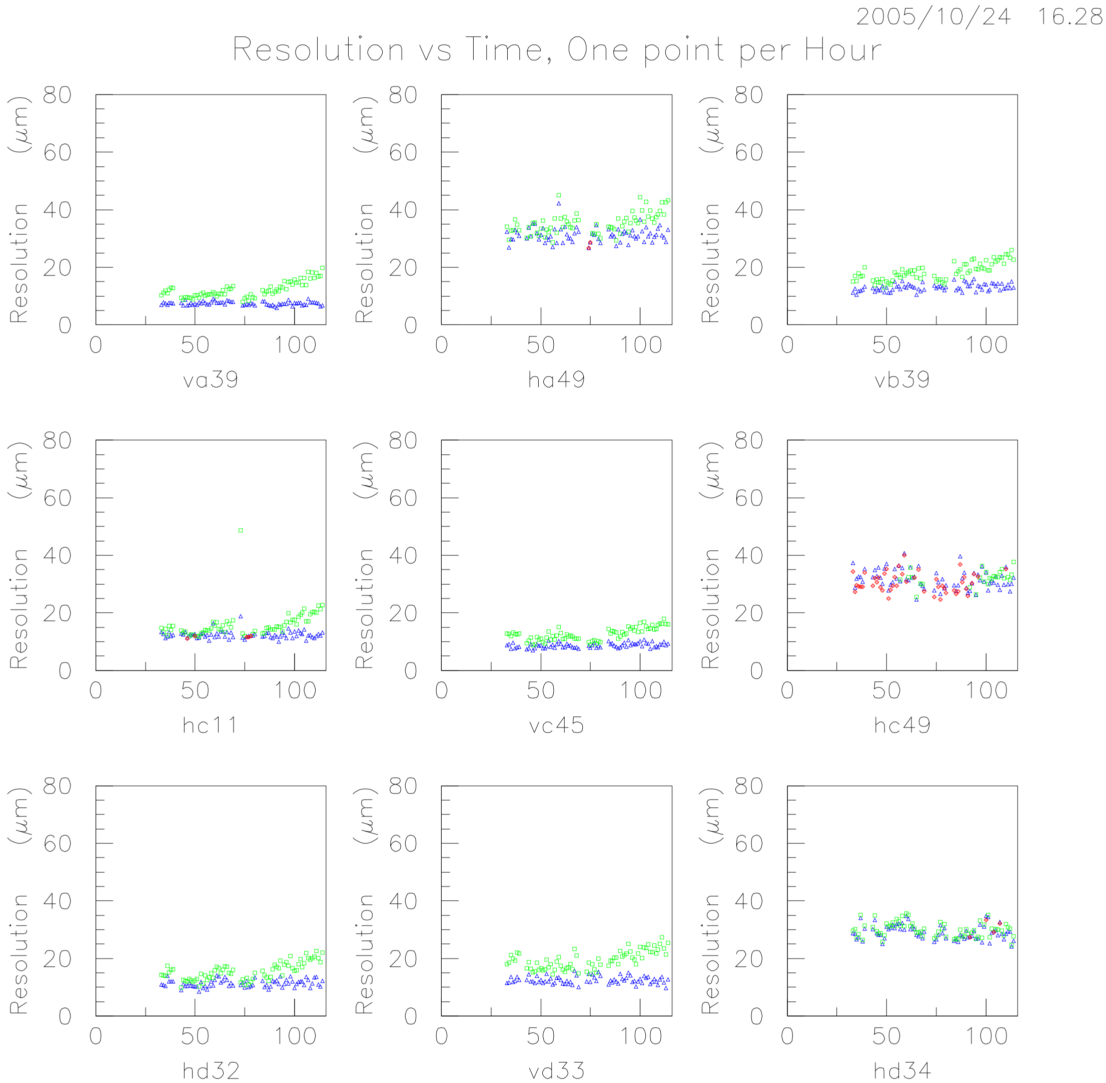

Figure 3: The same information as the bottom plot of Figure 1 for another nine BPMs. The blue points show the closed orbit position resolution for protons, measured once per hour during HEP running. The green and red points show the same for anti-protons; an anti-proton point is shown as a red cross if $\sigma(\bar{p}) \leq \sigma(p)$ and as a green square otherwise. For some of the BPMs, the data from the first store is missing.

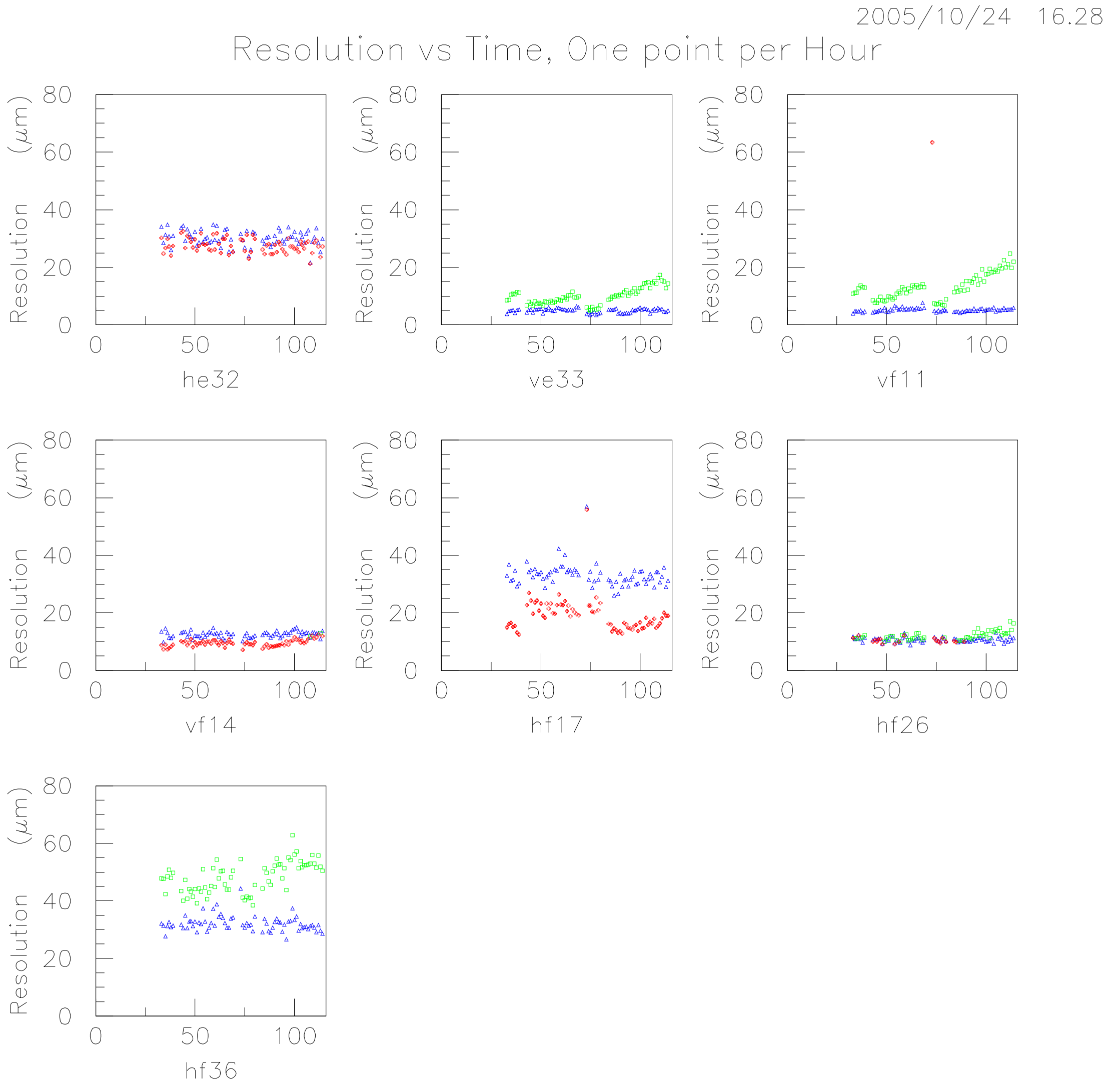

Figure 4: The same information as the bottom plot of Figure 1 for another seven BPMs. The blue points show the closed orbit resolution for protons, measured once per hour during HEP running. The green and red points show the same for anti-protons; an anti-proton point is shown as a red cross if $\sigma(\bar{p}) \leq \sigma(p)$ and as a green square otherwise. For some of the BPMs the data from the first store is missing.

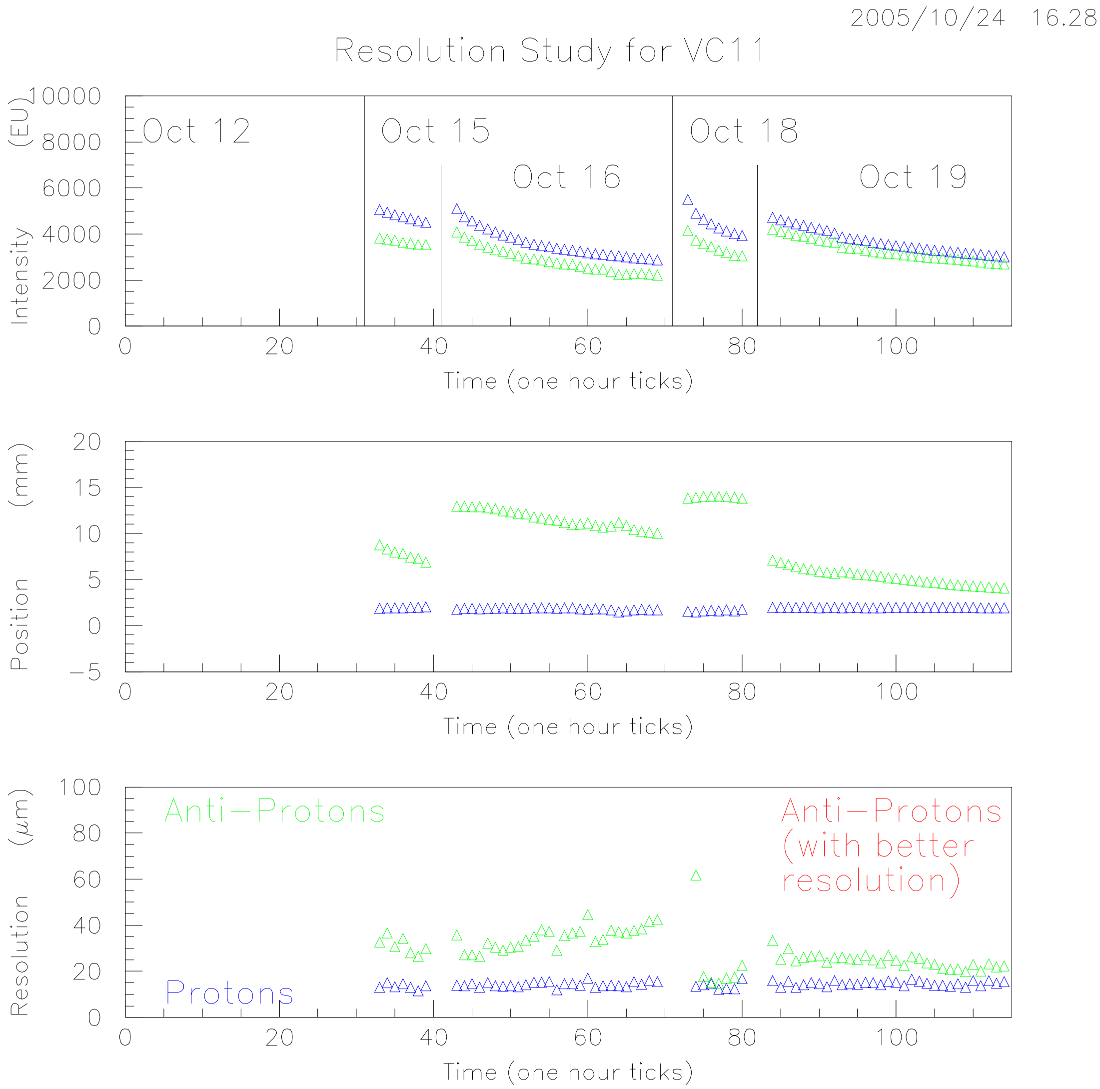

Figure 5: The same information as Figure 1 but for VC11. This BPM has poorly determined cancellation coefficients so the anti-proton information is unreliable.

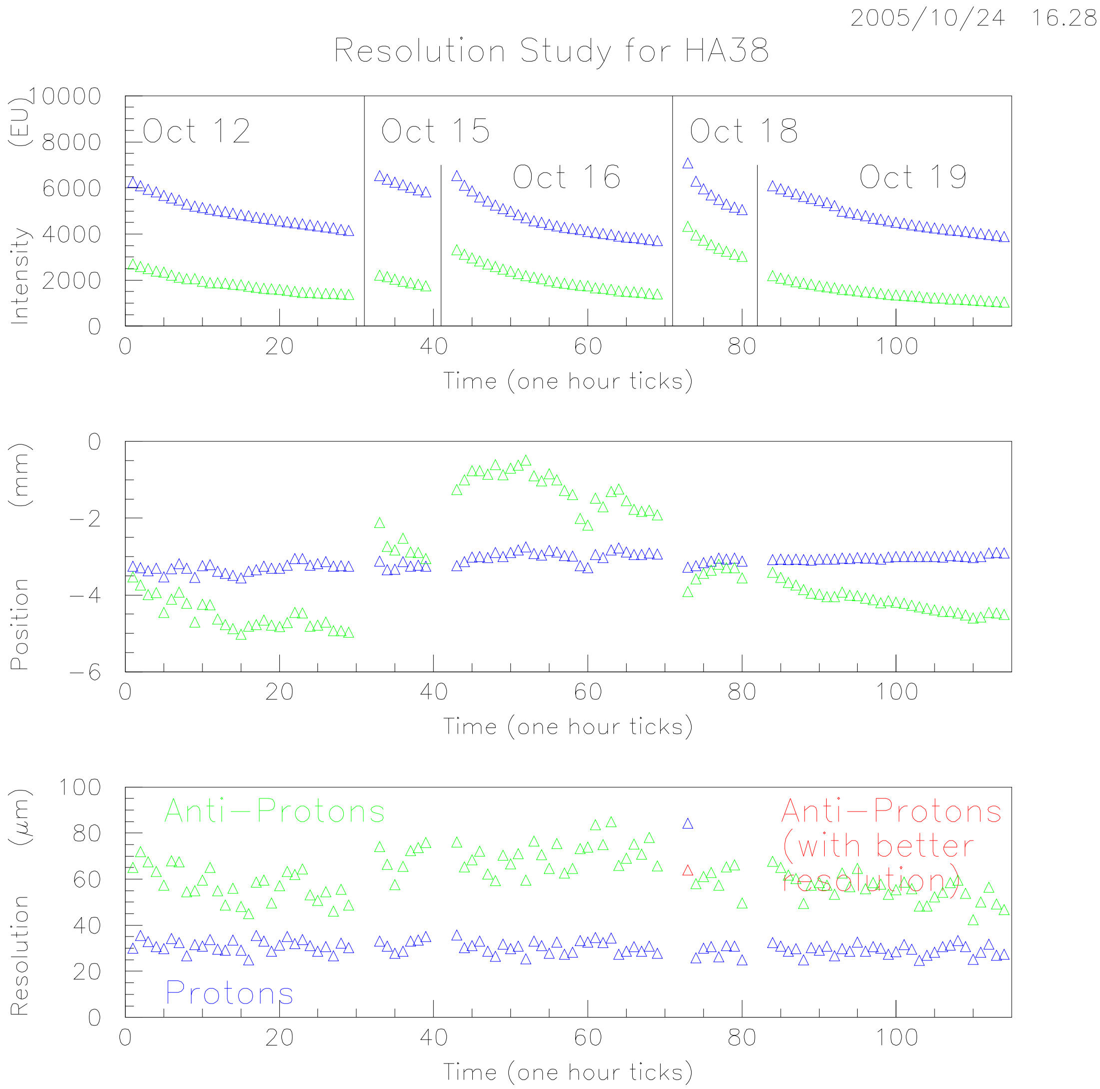

Figure 6: The same information as Figure 1 but for HA38. This BPM has poorly determined cancellation coefficients so the anti-proton information is unreliable.