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Tevatron BPM Upgrade: Cancellation of Proton Signal on Anti-proton Cables

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Abstract

This note presents the anti-proton positions at HA34 and VA35 using three different datasets to calibrate the subtraction of the proton contamination on the anti-proton cables. The best results are obtained when data from a shot is used to calibrate itself. When data from an earlier shot is used for calibration, the quality of the cancellation is much poorer. During HEP running, the different calibrations give anti-proton positions which differ by as much as 220 μm. The calibrations derived from earlier shots give rise to a severe instrumental artifact: the anti-protons appear to move by as much as 1.5 mm during the 9 steps of anti-proton injection. The note also presents some thoughs on how to improve the calibration. Finally it presents the ratio of the proton sum signals for HA34/VA35.

1 The Data

The data shown in figures 2 to 6 were taken on August 18, 2004 during the shot which took place around 3:00 AM. The data in figures 7 to 9 were taken on August 22, 2004, during the shot which took place around 2:30 PM. In all cases the data shown here started from the I and Q values data logged at 15 Hz to the Lumberjack data base using logger TevSA. Positions and intensities were computed offline from these I and Q values.

For all data shown here the proton contamination on the anti-proton cables was subtracted using model 2 described in Beams-doc-988-v2. This is the standard method which has been used for the past few months to subtract the proton contamination. The point of this note is to explore how the quality of the cancellation depends on the data used to calibrate the coefficients used in this algorithm.

2 The HA34 Data

The top two plots and the middle left plot in figure 1 show the anti-proton sum signal (A+B) on HA34 for the same data but for three different calibrations of the algorithm used to cancel the proton contamination on the anti-proton cables. All three plots are on the same vertical and horizontal scales. These data were taken during proton injection, just before and just after. Throughout this period there were no anti-protons in the machine so a perfect cancellation algorithm would produce an anti-proton sum signal which is zero at all times shown in the plots. None of these calibrations gives perfect cancellation but some are clearly much better than others. The best cancellation is obtained by using the data from one shot to calibrate itself; this is shown in the middle left plot. The top right plot shows the anti-proton sum signal using a calibration derived from the previous shot, two days earlier. And the top left plot shows the anti-proton sum signal using a calibration derived from a shot one week earlier; this is the worst of the three calibrations.

In all three plots the spikes at times between 2.8 and 2.95 hours are due to real proton motion during the proton injection bumps.

The remaining two plots are present to set the scales of interest. The middle right plot shows, for the same time interval as the first three plots, the raw signal from the anti-proton cables, without subtraction of the proton contamination. If there were no contamination this plot would be all zero. And the bottom plot shows, during anti-proton injection, the corrected anti-proton sum signal using the best available calibration; this signal is supposed to be non-zero. Note the change in vertical scale for these last two plots, relative to the first three plots.

From these five plots one sees that, for the first few steps in the anti-proton injection, the proton contamination dominates the true anti-proton signal. Even when anti-proton injection is complete, the proton contamination is about one third of the true anti-proton signal. The best calibration reduces the proton contamination to less than 1% of the true anti-proton signal from the first four bunches. When anti-proton injection is complete, the residual proton contamination with the best algorithm is less than 1 per thousand of the true anti-proton signal. On the other hand, with the one week old calibration, the residual contamination is about 6% of the true anti-proton signal from the first four bunches, falling to about 1% when all 9 groups of anti-protons have been injected. We will see in the following that this produces a significant error in the position.

Figure 2 shows the anti-proton position, as a function of time, for the same time interval used on the previous page. The four traces on this plot are for the four different calibrations of the algorithm used to subtract the proton contamination on the anti-proton cables. The green trace shows the antiproton position using the data from this shot for calibration. This is the best available calibration. The anti-proton position is stable throughout the anti-proton injection. The large beam motion near a time of 3.35 hours occurs during the ramp, squeeze and start of collisions. Real beam motion is expected during this time but it is not yet clear if all of the observed motion is all real or if some of the observed motion is an instrumental artifact. The stable beam position after a time of about 3.5 hours marks the start of HEP running.

In figure 2, the red trace is the anti-proton position computed using the calibration derived from the previous shot and the blue trace is the position computed using the calibration derived from the shot one week earlier. For reference, the magenta trace in figure 2 shows the antiproton position computed without subtracting the proton contamination at all.

The main observation on this plot is that the old calibrations give a very different answer than the best calibration. The most visible difference is that the old calibrations show a large apparent motion of the anti-proton beam during anti-proton injection. This apparent motion is an instrumental artifact which comes from the incomplete cancellation of the proton contamination. Early in the injection, the residual proton contamination is a moderate fraction of the true anti-proton signal, which produces a significant shift in the measured position. As the anti-proton current increases, the residual contamination is a smaller and smaller part of the total signal and the measured position approaches an asymptote, in smaller and smaller steps. This effect is also present in the green trace but with a full scale effect of a few hundred microns. See, for example, page 6 from the file Feb27.ps in Beams-doc-1059.

The other important difference among the three calibrations is that during HEP running they give significantly different values for the mean measured beam position. To illustrate this better, the data between the vertical black lines in figure 2 were projected onto the position axis and the projections are shown in figure 3. These projections show that the one day old calibration has a shift of $+70$ μm with respect to the best calibration while the one week old calibration has a shift of -218 μm. The errors on these shifts are less than 1 μm.

3 The VA35 Data

Figures 4 through 6 show the same information for the same shot but for BPM VA35. The only significant difference is that the calibration derived during the previous shot (August 16) is almost identical to the calibration derived from the current shot (August 18). I don't yet know if this is an accident or if it is a systematic difference between the horizontal and vertical beam properties.

4 Details of Other Features

Figure 7 shows a detail of the proton sum signal, the proton position and the anti-proton sum signal for a time interval starting near the end of proton injection and ending just after the helix is opened. There is a lot of structure during this time and the reason for looking at this is to see any of the structures can be used to improve the algorithm for canceling the proton contamination on the anti-proton cables.

The red trace shows the proton position signal, in which the injection bumps and the opening of the helix are clear. The blue trace shows the proton sum signal, in which the last three proton bunch injections can be seen. The blue trace also has a downward step at the time that the helix opens. The green trace shows the anti-proton sum signal. For most of the time the cancellation of the proton signal is excellent, with residual contamination less than 2.5 Echotek units. During the injection bumps, however the cancellation is much poorer. Also there is an interesting structure as the helix opens. There is also a small step up in the mean background level after the helix opens.

My guess is that the downward step in the proton sum signal, when the helix opens, is due to the quadratic effect described in beams-doc-1161. Perhaps it can be used to calibrate this effect? This is only true if there was, in fact, no change in beam current as the helix opened. This is explored in figure 8. The blue trace in figure 8 shows the same data as the blue trace in figure 7, the proton sum signal. The scale has been expanded to provide a better view of the down step when the helix opens. The red trace shows T:IBEAM and the green trace shows T:FBIPNG, both of which are measures of the proton beam current. The scales of these three traces have been set so that the step up at the last injection has about the same range for all traces. From these plots I conclude that the down step in the proton sum signal when the helix opens is due to the response of the BPMs, not due to an actual change in the beam current. Therefore this downward step can be used to improve the calibration.

Refer back to figure 7. The bumps in the anti-proton sum signal, the green trace, appear to have the same detailed shape as the bumps in the proton position signal. So it is likely that we can improve the cancellation algorithm to remove, or at least reduce, the residual bumps in the anti-proton sum signal. This will be investigated at a later date.

I don't yet understand the structure in the anti-proton sum signal which appears during the opening of the helix. The motion of the proton beam at this time is monotonically increasing but the structure in the anti-proton sum signal rises and then falls. So one explanation is that two effects are in play here. An alternative explanation is that this is a different sort of instrumental artifact: when the helix opens the orbits change which can introduce small changes in the revolution frequency. This can confuse the Echotek board which is programmed to process a stream of bunches arriving in a fixed pattern. If the pattern shifts in the middle of a measurement the meaning of the measurement changes. It will require further investigation before we can tell if we can learn useful calibration information from this feature.

5 Ratio of HA34 to VA35

During the meeting on August 25, Steve Wolbers wondered what the ratio of the proton sum signals looked like for the HA34 and VA35 BPMS. To test this I have computed the ratio,

$$R = \frac{(|A| + |B|)_{HA34}}{(|A| + |B|)_{VA35}}. \tag{1}$$

This ratio is plotted in figure 9, The top plot shows the ratio at full scale and it is indeed close to flat. The bottom plot shows the ratio using an expanded scale; the variation throughout the shot is about 3% of full scale.

I don't yet know if we learn anything useful from this plot.

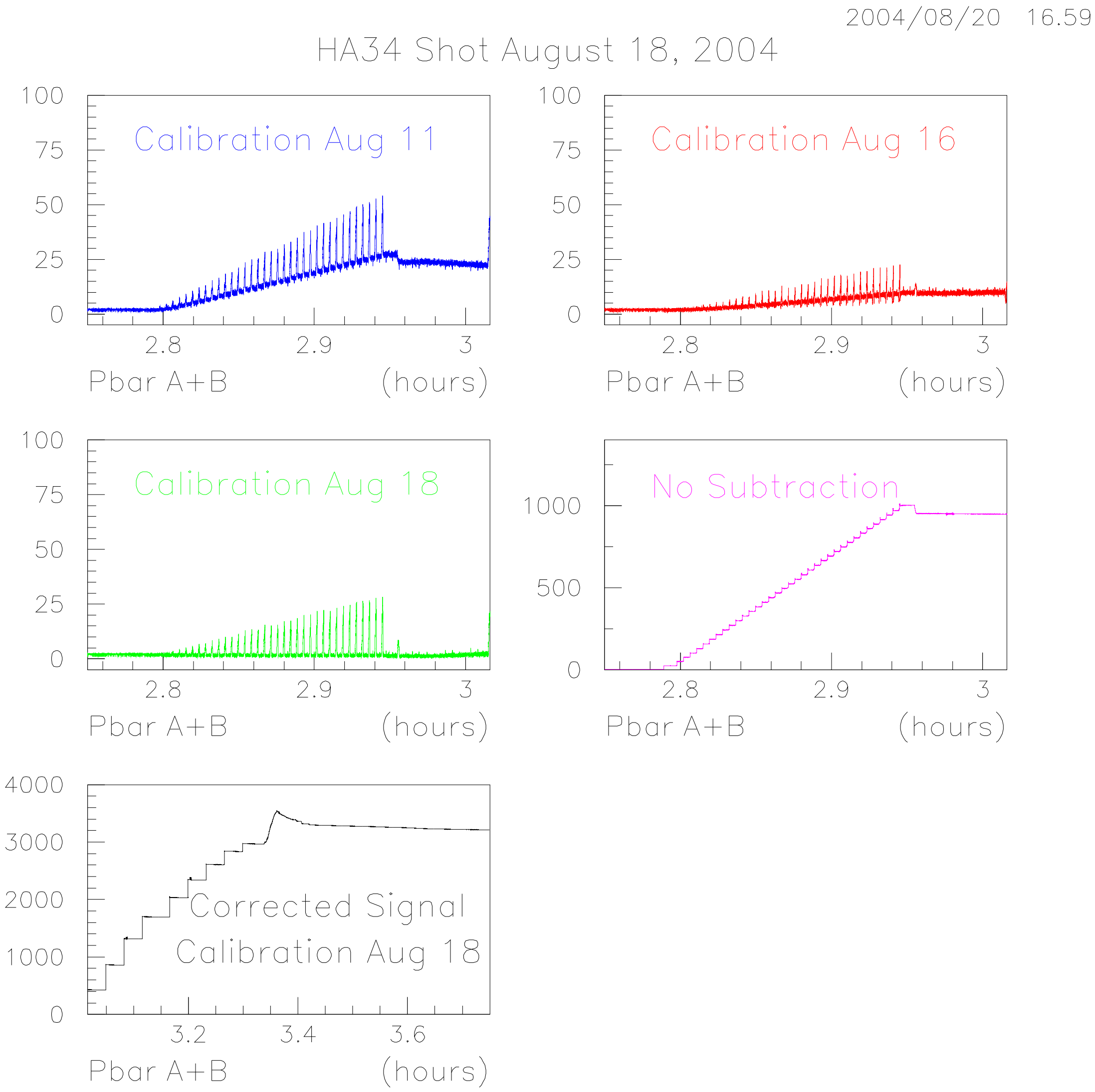

Figure 1: The top four plots show the HA34 anti-proton sum signal vs time during a time with no anti-protons in the machine. The four plots differ in the calibration used to subtract the proton contamination on the anti-proton cables. Three of the plots are on the same vertical scale while the fourth, with no subtraction, is on a very different scale. The bottom plot shows the anti-proton sum signal when there are antiprotons are in the machine; it is provided for reference.

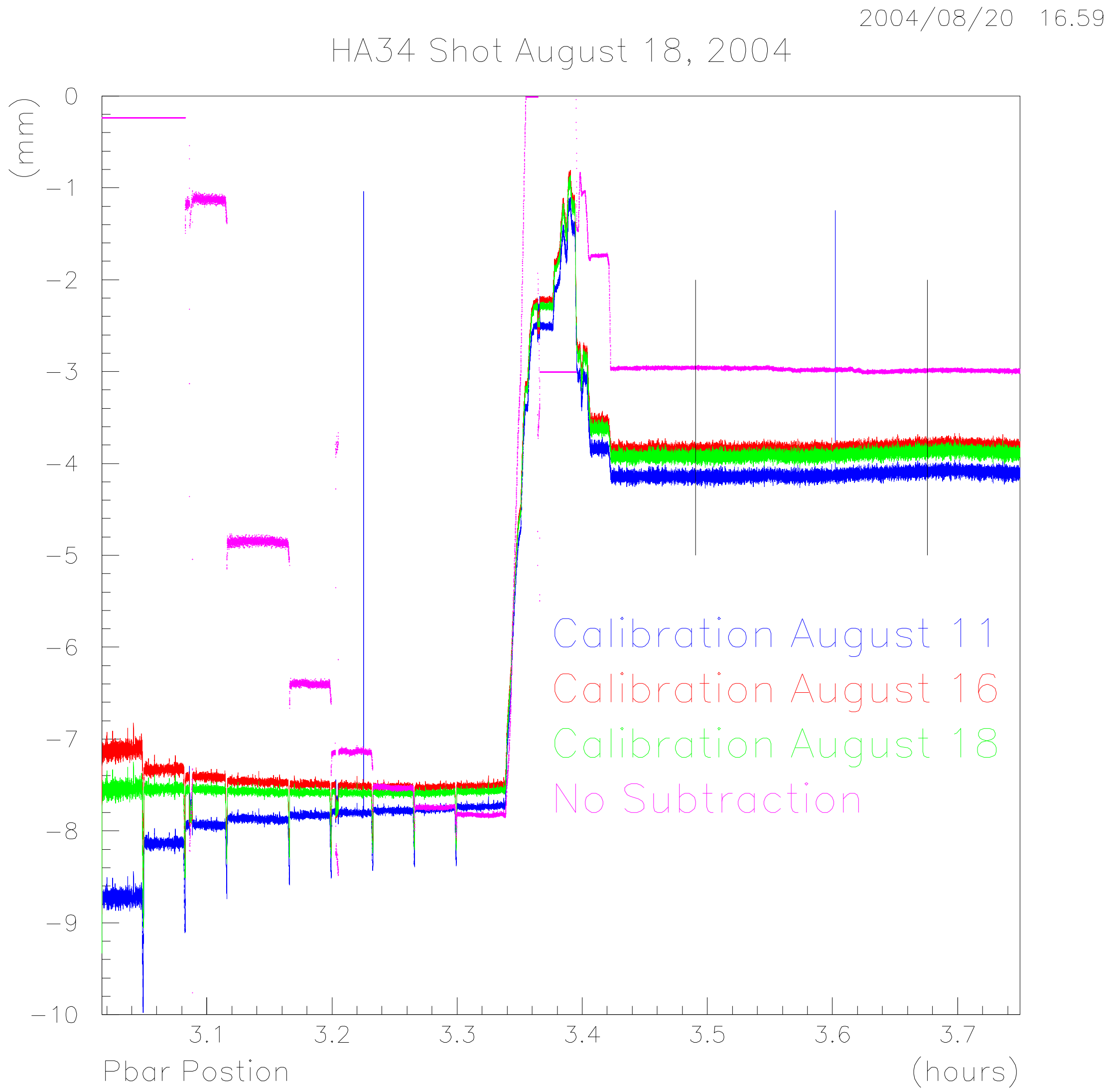

Figure 2: The four traces show the anti-proton position vs time for BPM HA34. The four traces are all made from the same data but use different calibrations to subtract the proton contamination. The vertical black lines denote the time interval used for the projections which are shown in the next figure.

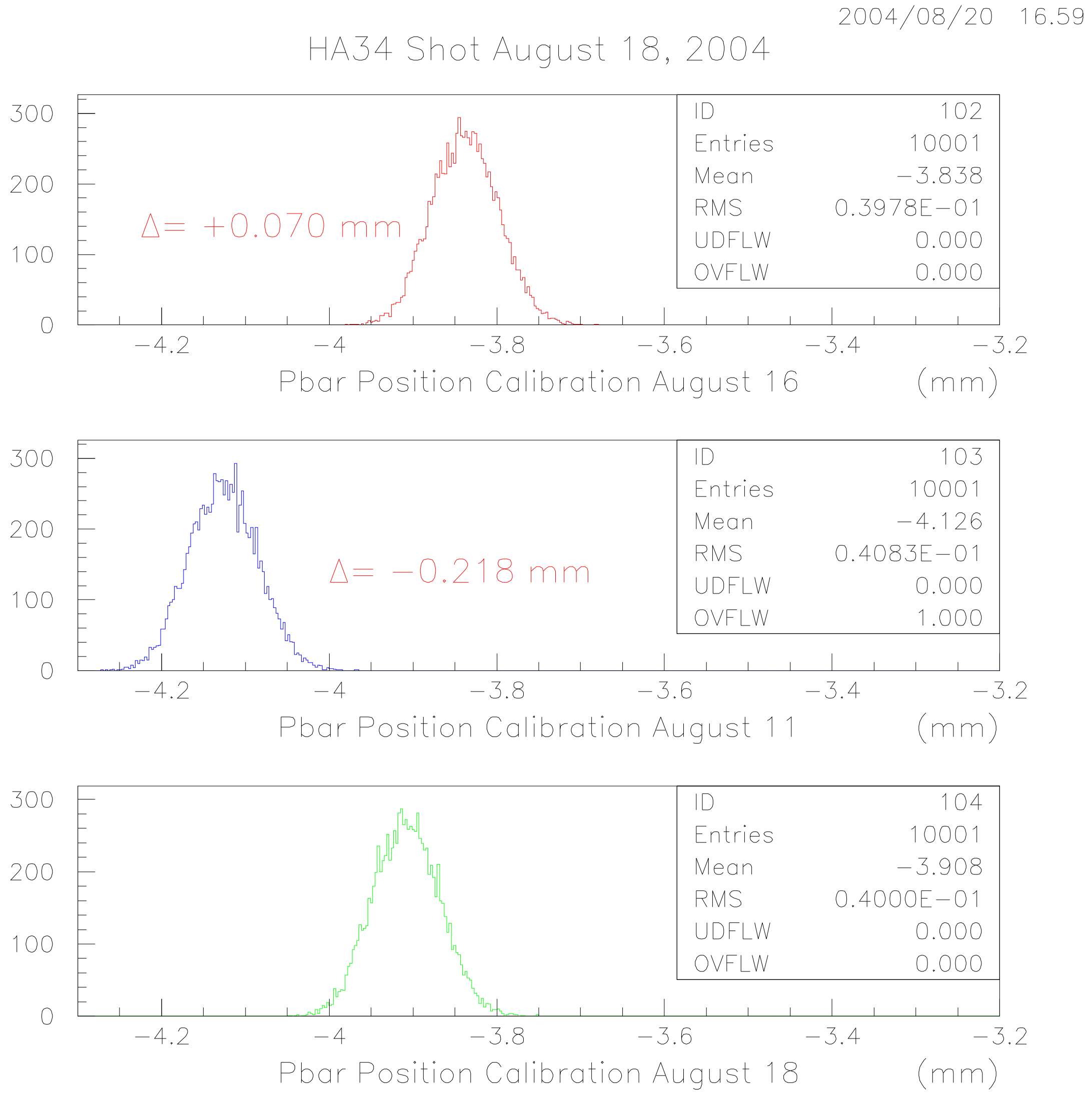

Figure 3: Projections onto the position axis of three of the traces from the previous figure (data from HA34). The vertical black lines in that figure show the time interval used to make these projections. The bottom plot is the projection for the best available calibration and the top two plots show other calibrations. The fourth trace on the previous page is for uncalibrated data and its projection is not shown here. On the top two plots, the notation Δ indicates the shift in measured mean beam position, relative to that measured in the bottom plot. The error on Δ is less than 0.001 mm.

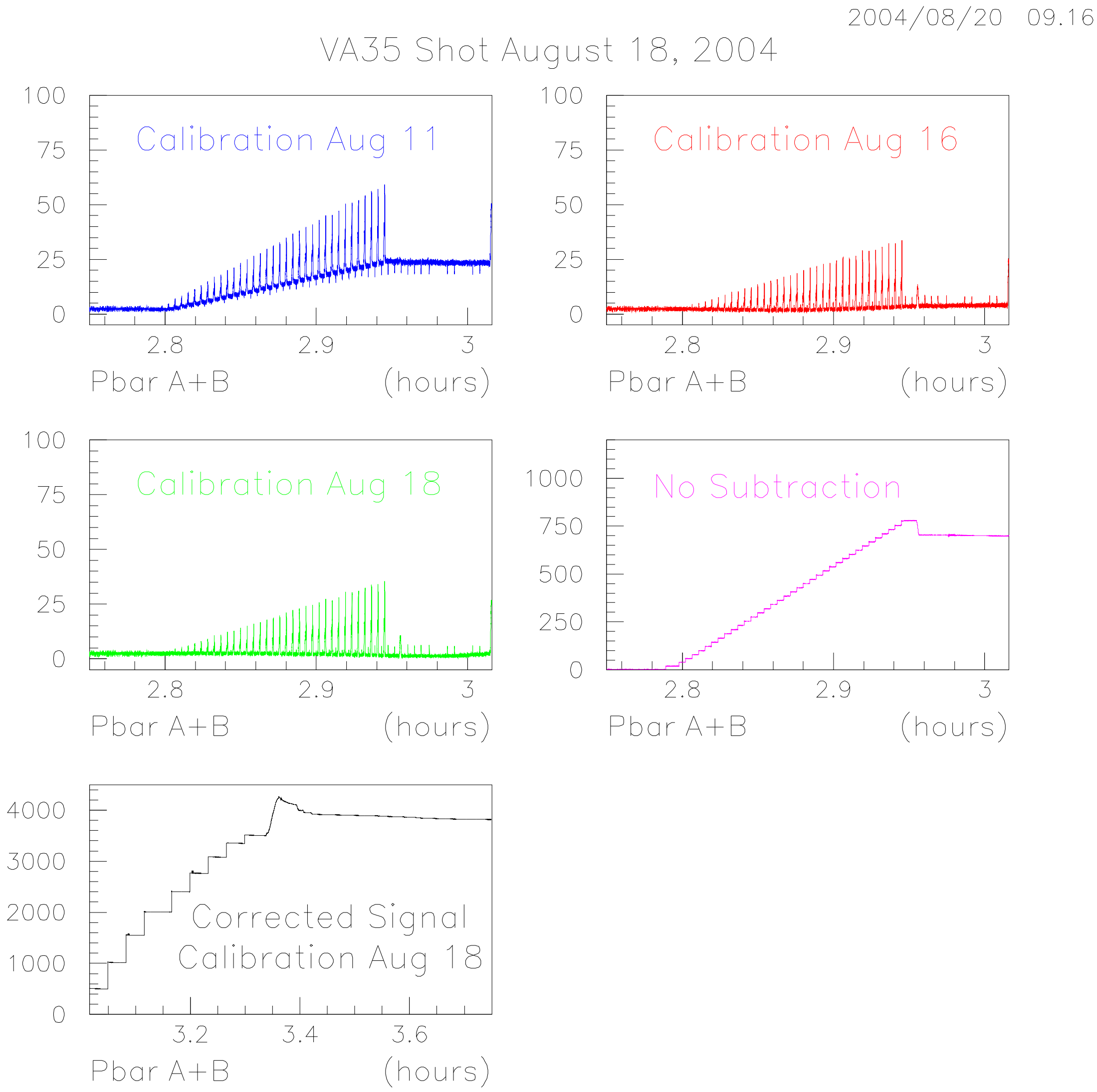

Figure 4: The top four plots show the VA35 anti-proton sum signal vs time during a time with no anti-protons in the machine. The four plots differ in the calibration used to subtract the proton contamination on the anti-proton cables. Three of the plots are on the same vertical scale while the fourth, with no subtraction, is on a very different scale. The bottom plot shows the anti-proton sum signal when there are antiprotons are in the machine; it is provided for reference.

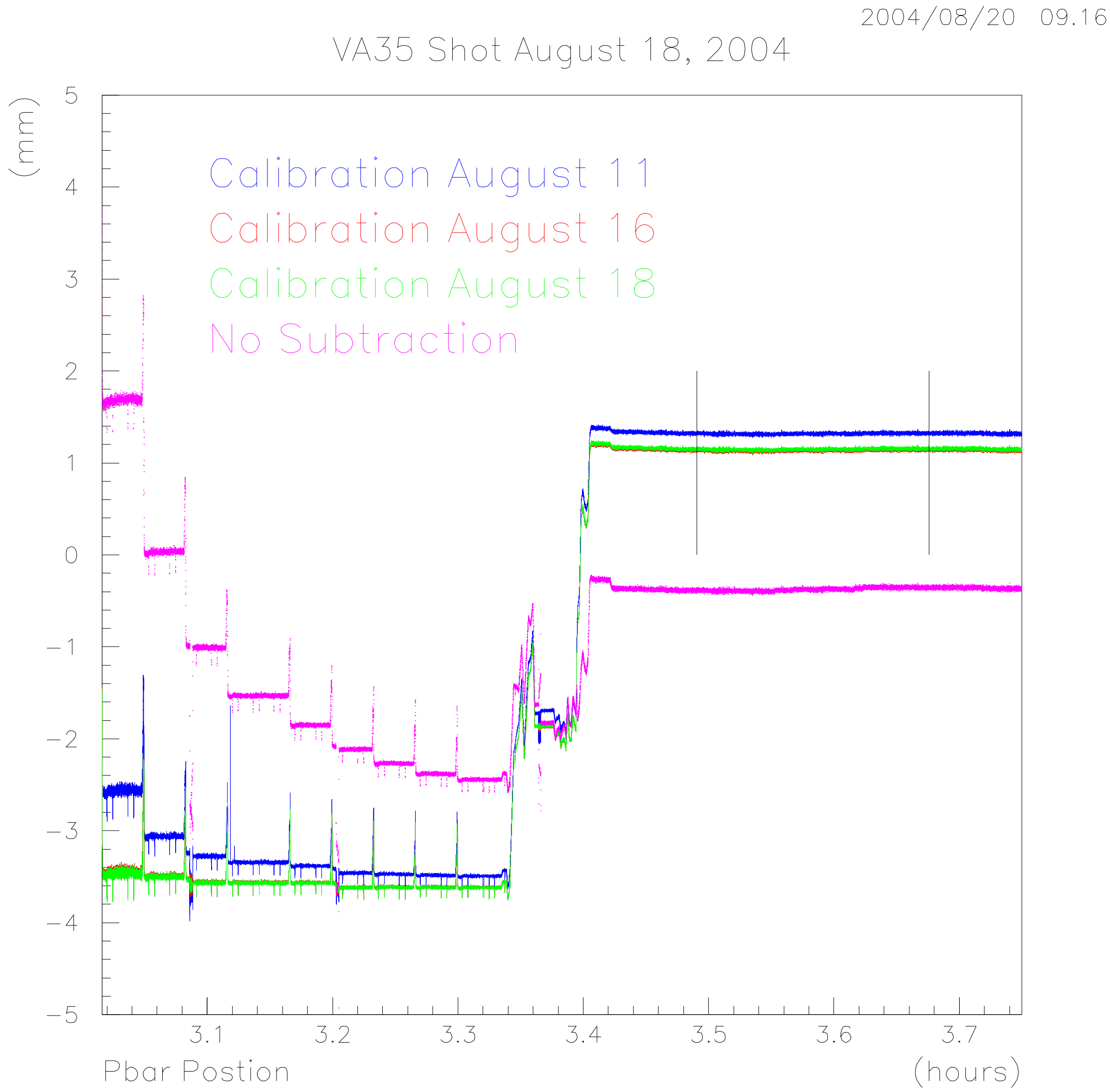

Figure 5: The four traces show the anti-proton position vs time for BPM VA35. The four traces are all made from the same data but use different calibrations to subtract the proton contamination. The vertical black lines denote the time interval used for the projections which are shown in the next figure. The red trace is lies almost exactly underneath the green one.

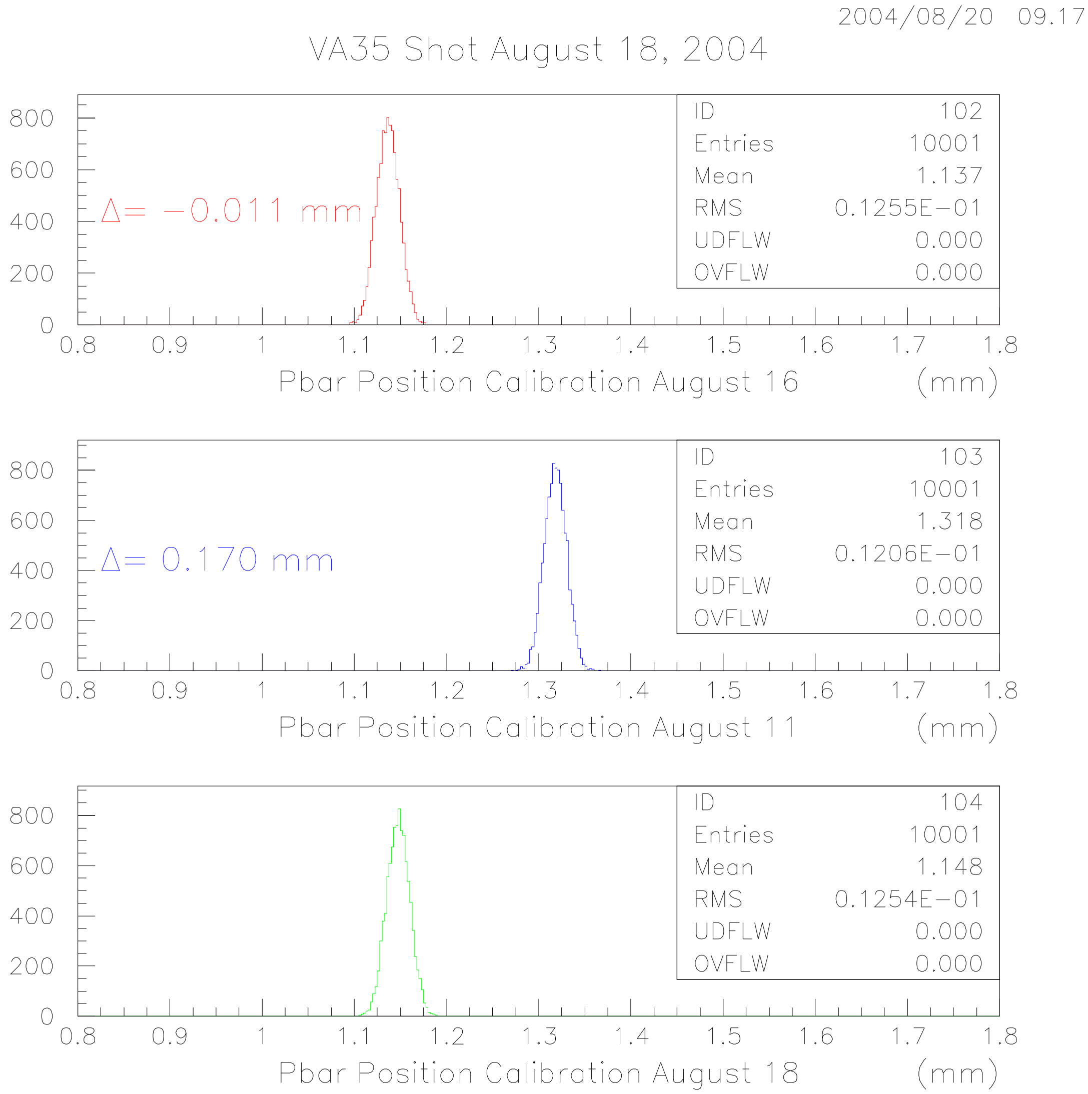

Figure 6: Projections onto the position axis of three of the traces from the previous figure (data from VA35). The vertical black lines in that figure show the time interval used to make these projections. The bottom plot is the projection for the best available calibration and the top two plots show other calibrations. The fourth trace on the previous page is for uncalibrated data and its projection is not shown here. On the top two plots, the notation Δ indicates the shift in measured mean beam position, relative to that measured in the bottom plot. The error on Δ is less than 0.001 mm.

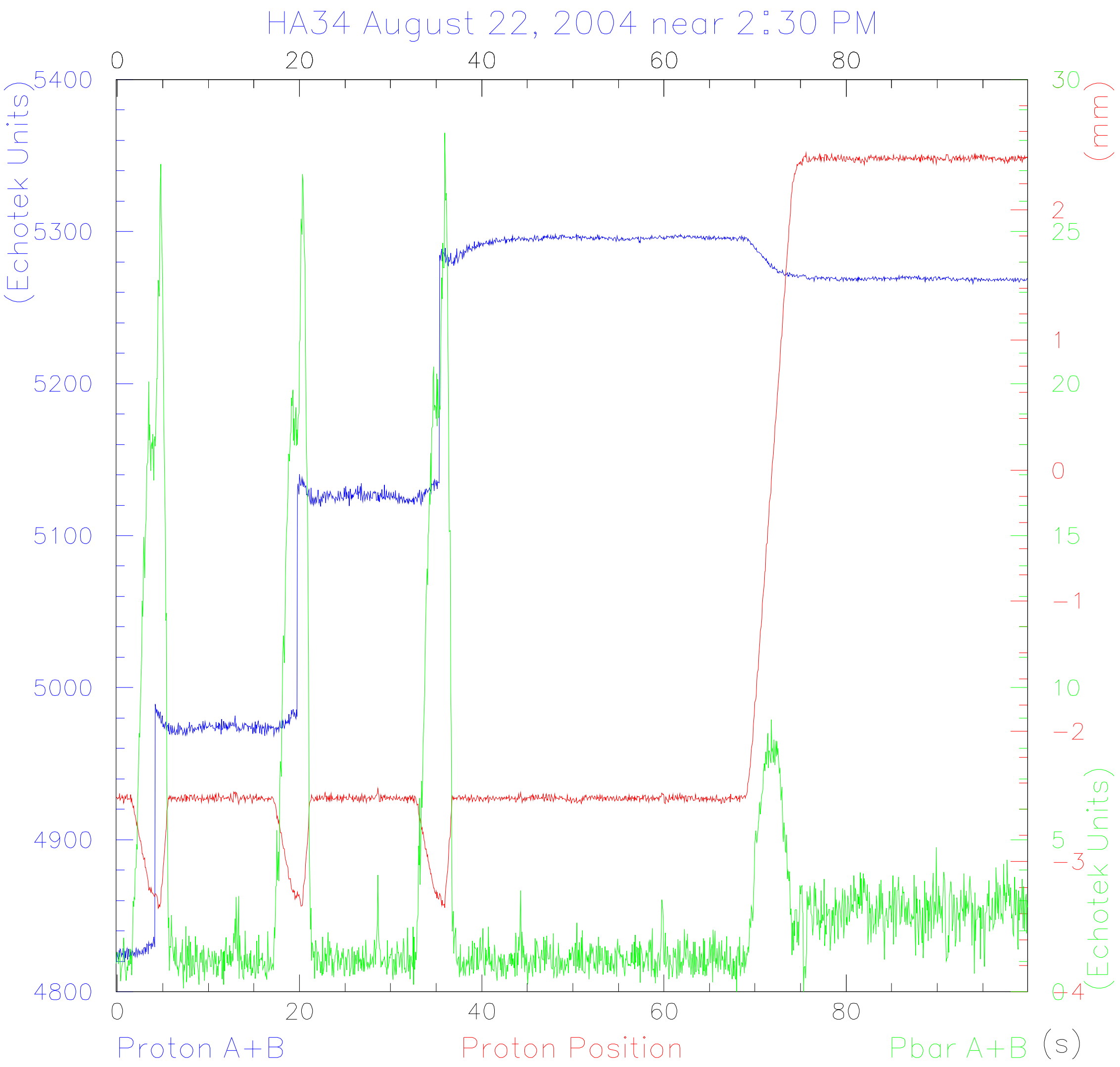

Figure 7: These traces show data from HA34 near the time of the helix opening during the shot taken on August 22, 2004 at about 2:30 PM. The horizontal axis is the time, in seconds, from the left edge of the plot. The blue trace shows the proton sum signal; the red trace shows the proton position and the green trace shows the antiproton sum signal, after subtraction of the proton contamination.

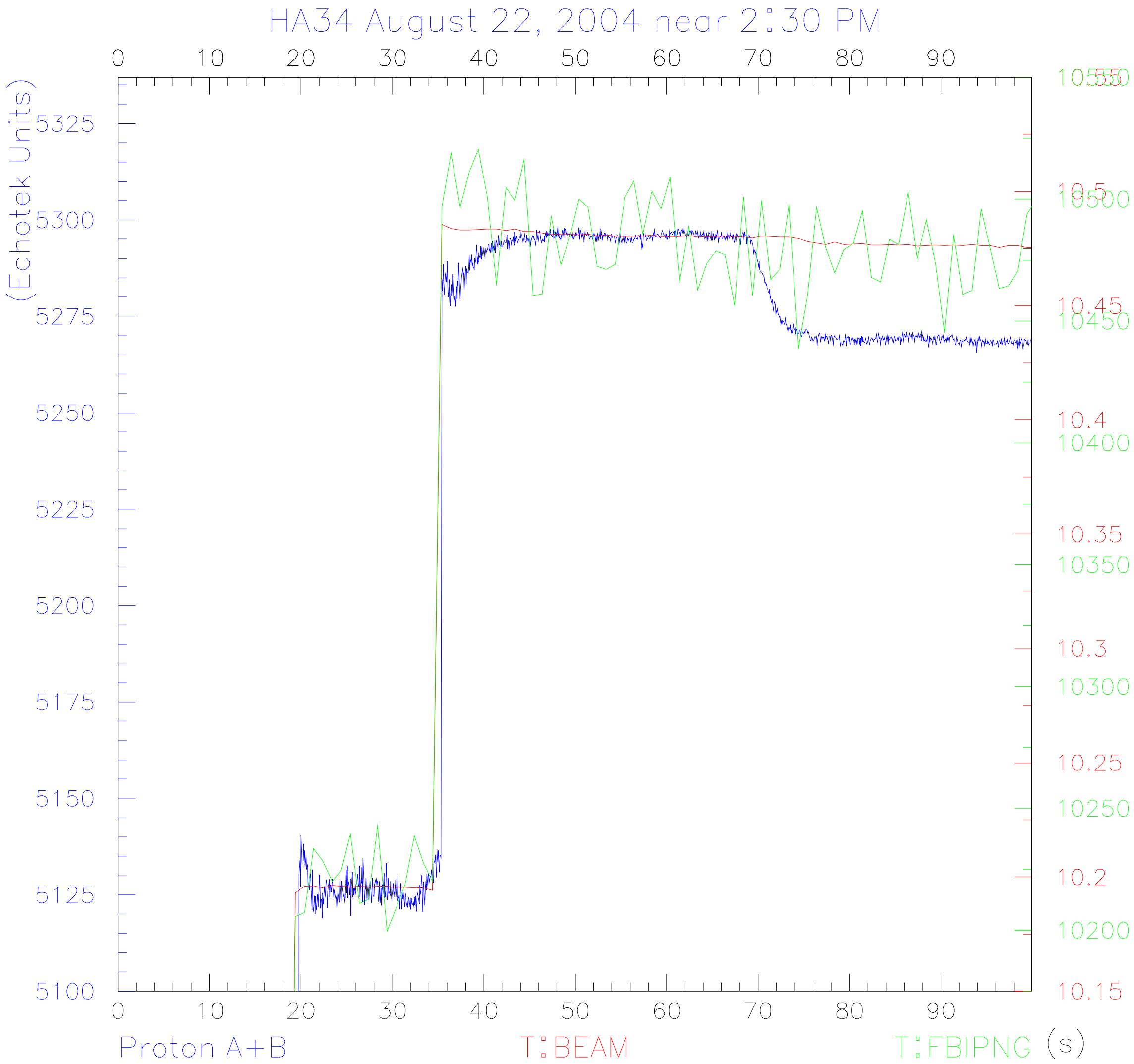

Figure 8: The blue trace shows the proton sum signal for the same data and same time as the blue trace on the previous plot. But the vertical scale has been expanded to give a better view of the down step near t=70 s, which occurs when the helix opens. The red trace shows T:BEAM and the green trace shows T:FBIPNG.

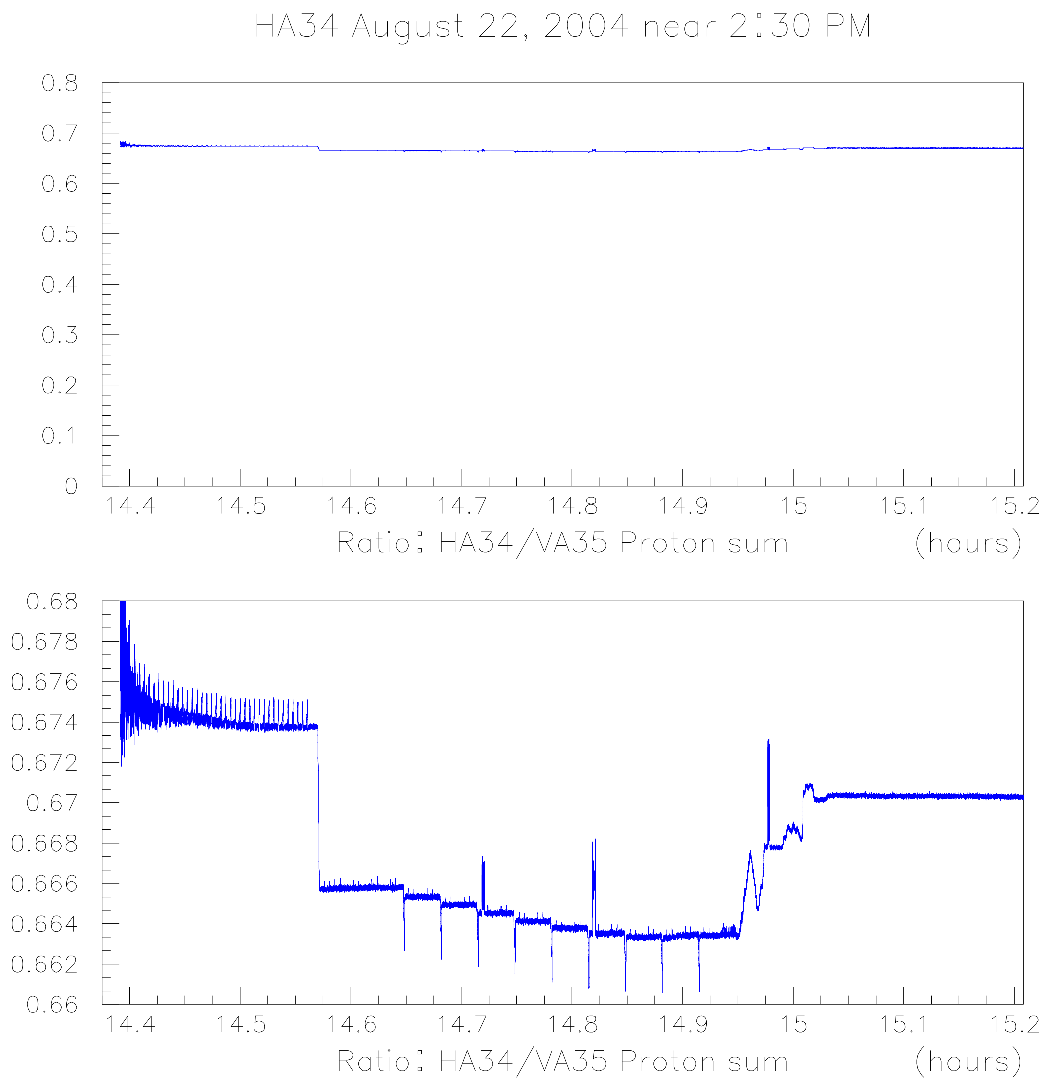

Figure 9: The top plot shows the ratio of proton sum signals, HA34/VA35, from the start of the shot to the start of HEP running. On this scale the ratio appears close to constant. The bottom plot shows the same data but on an expanded scale. The data shows lots of structure but all of the structure is less than 3% of the full scale.