Beams-doc-1205-v3
August 11, 2004

Tevatron BPM Upgrade Calibration Specifications: Part II

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Abstract

This note describes the calibration information which is needed for the commissioning period in August 2004. It includes enough information to compute the positions and intensities for both protons and anti-protons for both long gate and short gate mode.

1 Change Log

v1 First release.

v2 Reorganization following suggestions from Steve Wolbers. Add plots to show what the data should look like. Started section on how to determine a, b, c, d.

v3 Finish section on a, b, c, d. Provide initial values for these for HA34.

2 Introduction

Beams-doc-1161 discusses the computation of position and intensity starting from the raw (I, Q) values from the 4 cables at one BPM location. In the first tests to be done at the A3 house, many of the calibration contstants will not yet have been determined and they should be set to zero or one, as appropriate. A few other approximations will also be necessary for the early studies. After these changes, the equations simplify considerably and they are given in the body of this document. The derivation of the simplified equations from those in Beams-doc-1161 is given in Appendix A.

3 Notation Conventions

I decided that we have too many meanings for the symbols A and P. In this document I will try to clean this up by using the convention that the distinction proton vs anti-proton will always be made in subscripts $_P$ and $_A$, never by P or A as normal text.

When A does appear as normal text refers to the signal on the A plate, as opposed to the signal on the B plate.

I will also denote position by D, for displacement, instead of the traditional P.

I considered using $\bar{P}$ to denote anti-proton, which would allow A to mean, uniquely, a signal on the A plate. However the bar gets too easily lost on a computer screen or a photocopy of printout.

4 The Equations for Intensity and Position

The equations in this section are valid for long gate sampling mode, either turn by turn or closed orbit. They are valid when there are only protons in the machine or when there are both protons and anti-protons in the machine. The cases of only anti-protons in the machine and of short gate sampling mode will be discussed in their own sections.

The raw measurements produced by the Echotek card will be denoted by A_P and B_P, for the proton cables, and by A_A and B_A, for the anti-proton cables. Each of these is a complex number (I, Q).[1] The units of these measurements will be called Echotek units.

The equations which correct for the imperfect directionality of the pickups are,

$$A'_P = A_P \tag{1}$$

$$B'_P = B_P \tag{2}$$

$$A'_A = A_A - aA_P - bB_P \tag{3}$$

$$B'_A = B_A - cB_P - dA_P \tag{4}$$

where the unprimed symbols are the raw measurements and the primed symbols are the corrected measurements. Here a, b, c, d are dimensionless complex constants which will be specified during the commissioning period. Until they are determined, these constants should be set to (0.,0.). Table 1 gives initial values of these constants for HA34 and HA35. If meta-data exists, it should record when these constants have been zeroed. It is possible that these will change with time and will need to be versioned. But that can be ignored for the work in August 2004.

The proton and anti-proton intensity signals are given by:

$$I_P = f\left(|A'_P| + |B'_P|\right) \tag{5}$$

$$I_A = f\left(|A'_A| + |B'_A|\right) \tag{6}$$

where $||$ denotes the magnitude of a complex number and where f is a real constant which I have introduced here for the first time. Until otherwise specified, set $f = 1$. It seems likely that f may never be changed from 1.

[1] See section 8 for a discussion of the choice (I, Q) instead of (Q, I).

Parameter	Value
g	26 mm
f	1. (dimensionless)
t_P	50 Echotek units
t_A	100 Echotek units
HA34 a	(0.269853121240,-0.404472112702)
b	(-0.127801720502, 0.210281108014)
c	(0.147995115376,-0.368643350288)
d	(-0.123232471244, 0.241124984116)
VA35 a	(-0.230800209035,-0.0065327539274)
b	(0.0885953561502, 0.0147368606098)
c	(-0.125648289547,-0.015472249013)
d	(0.064846237889,-0.00477222266894)
Other a, b, c, d	complex (0.,0.) (dimensionless)

Table 1: Starting values for parameters which appear in these equations.

The measured positions, in mm, are given by,

$$D_P = g\frac{|B'_P| - |A'_P|}{|B'_P| + |A'_P|} \quad (7)$$

$$D_A = g\frac{|B'_A| - |A'_A|}{|B'_A| + |A'_A|} \quad (8)$$

where the nominal value of g is 26. The initial values of the parameters are summarized in table 1. See section 8 for a discussion about the sign convention in these equations.

5 Validity of Data

The proton and anti-proton position information should be considered valid if the intensity signals satisfy:

$$|A'_P| + |B'_P| \geq t_P \quad (9)$$

$$|A'_A| + |B'_A| \geq t_A \quad (10)$$

where t_P and t_A are thresholds, in Echotek units, introduced here for the first time.

It would be prudent to keep these thresholds easy to change during the commissioning period. As an initial value use $t_P = t_A = 100$. This is motivated by studies using the Recycler Echotek boards in which the noise level, with no beam in the machine, is usually less than about 30 and the signal level, after the first bunch of either species is injected, at least a few hundred. See, for example, the discussion of Figure 2.

When the new boards are installed, the band between the noise and the signal may change because of changes to the filters and attenuators in the signal paths. It can also be affected by the gain of the filtering algorithm in the Grey chip.

It is possible for there to be valid data for one beam species but not for the other.

When raw (I, Q) is requested, it should be returned even if it fails the validity test above. Data below threshold is needed to study the quality of the cancellation of the non-directional components of the signal.

6 Anti-proton Only Stores

This section will discuss anti-proton position and intensity measurements during an anti-proton only store. It will be presumed that, during the commissioning period, one is not interested in the proton data for such a store.

For an anti-proton only store, the anti-proton data can be computed using the above formalism with $a = b = c = d = (0., 0.)$. In this case the data for the proton signals will contain uncanceled contamination from the anti-protons. This cancellation will be dealt with at a later time.

If one just uses the above formalism, without zeroing the cancellation coefficients, the result will probably remain qualitatively correct.

7 Short Gate Mode

For short gate mode, the above formalism applies with the exception that $a = b = c = d = (0., 0.)$. Unlike the discussion in the previous section, one must do this or else the anti-proton measurements are completely meaningless.

Remember that, in short gate mode, the anti-proton measurements are only valid for one cogging state.

8 Phase Conventions

There are two phase conventions which we will need to verify are correct.

1. In the configuration currently used for the studies with the modified Recycler Echotek board, the sign of the position is given by $|B| - |A|$. The configuration includes the cabling, the lumberjack data logger, and everything in between. The sign could change if the configuration of the new system changes relative to that of the existing one. We will ultimately determine this sign by bumping the beam and measuring the change in position. For the very first tests this sign is of minor importance but we should get it right before we make any PR plots.

2. I have used $A = (I, Q)$, not (Q, I). I have no idea if this is the standard usage or even if there is a standard. This convention has observable consequences only for equations 3 and 4. It is important that the convention

used to calculate a, b, c, d be consistent with that used when applying the correction. The correct choice can be verified by seeing if the corrected anti-proton intensity signal stays small when there are only protons in the machine.

9 Expected Signals

Figures 1 through 5 show some details of what the data should look like for about the first hour of a normal shot setup. The data shown in these figures is the same data described in Beams-doc-1197.

10 Deriving the Coefficients a, b, c, d

Refer to figure 5. At the two indicated times we have two raw measurements, $(A_{P1}, B_{P1}, A_{A1}, B_{A1})$ and $(A_{P2}, B_{P2}, A_{A2}, B_{A2})$, where the seccond subscript denotes one of the two times. There are no anti-protons in the machine at this time. Therefore the corrected values A'_{A1}, B'_{A1} A'_{A2}, B'_{A2} must all be zero. This constraint can be plugged into equation 3 to give two equations in the two unknowns a and b:

$$(0., 0) = A_{A1} - aA_{P1} - bB_{P1} \tag{11}$$
$$(0., 0) = A_{A2} - aA_{P2} - bB_{P2}. \tag{12}$$

These can be solved for a and b. Similarly, the constraint can be applied to equation 4 to solve for c and d:

$$(0., 0) = B_{A1} - cB_{P1} - dA_{P1} \tag{13}$$
$$(0., 0) = B_{A2} - cB_{P2} - dA_{P2}. \tag{14}$$

Solving these equations gives,

$$b = \frac{A_{A1}A_{P2} - A_{A2}A_{P1}}{B_{P1}A_{P2} - B_{P2}A_{P1}} \tag{15}$$
$$a = \frac{A_{A1} - bB_{P1}}{A_{P1}} \tag{16}$$
$$d = \frac{B_{A1}B_{P2} - B_{A2}B_{P1}}{A_{P1}B_{P2} - A_{P2}B_{P1}} \tag{17}$$
$$c = \frac{B_{A1} - dA_{P1}}{B_{P1}} \tag{18}$$

A Proton Position and Intensity from Beams-doc-1161

This section is a copy of the information from Beams-doc-1161 which is included to make this document stand alone. Be sure to use version v2 of Beams-doc-1161, or later, which has a sign change relative to version v1.

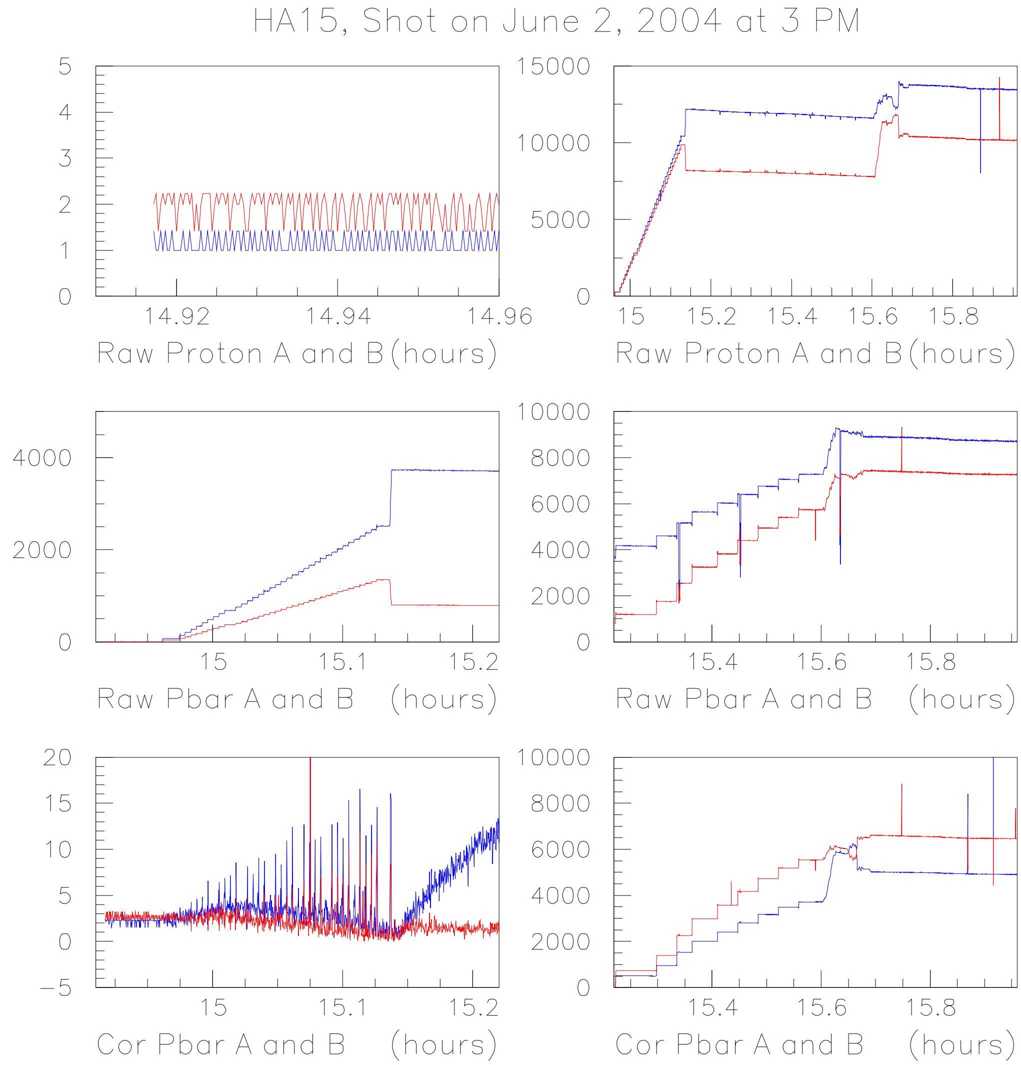

Figure 1: The top row shows the raw signals from the proton cables, A (red) and B (blue). The horizontal axis is time in hours of the day and the vertical axis is Echotek units. The two plots in the top row show one continous time series with no breaks. The first data point in the right hand plot is the first data point after the injection of the first bunch and the values of A and B are both about 280. The middle row shows the same information for the raw signals from Pbar cables. The bottom two plots show the same information for the corrected Pbar signals. In the middle and bottom rows the break between the two plots occurs at the time of the injection of the first Pbar bunch. The first data points on the right hand bottom plot have values of 535 for A and 723 for B.

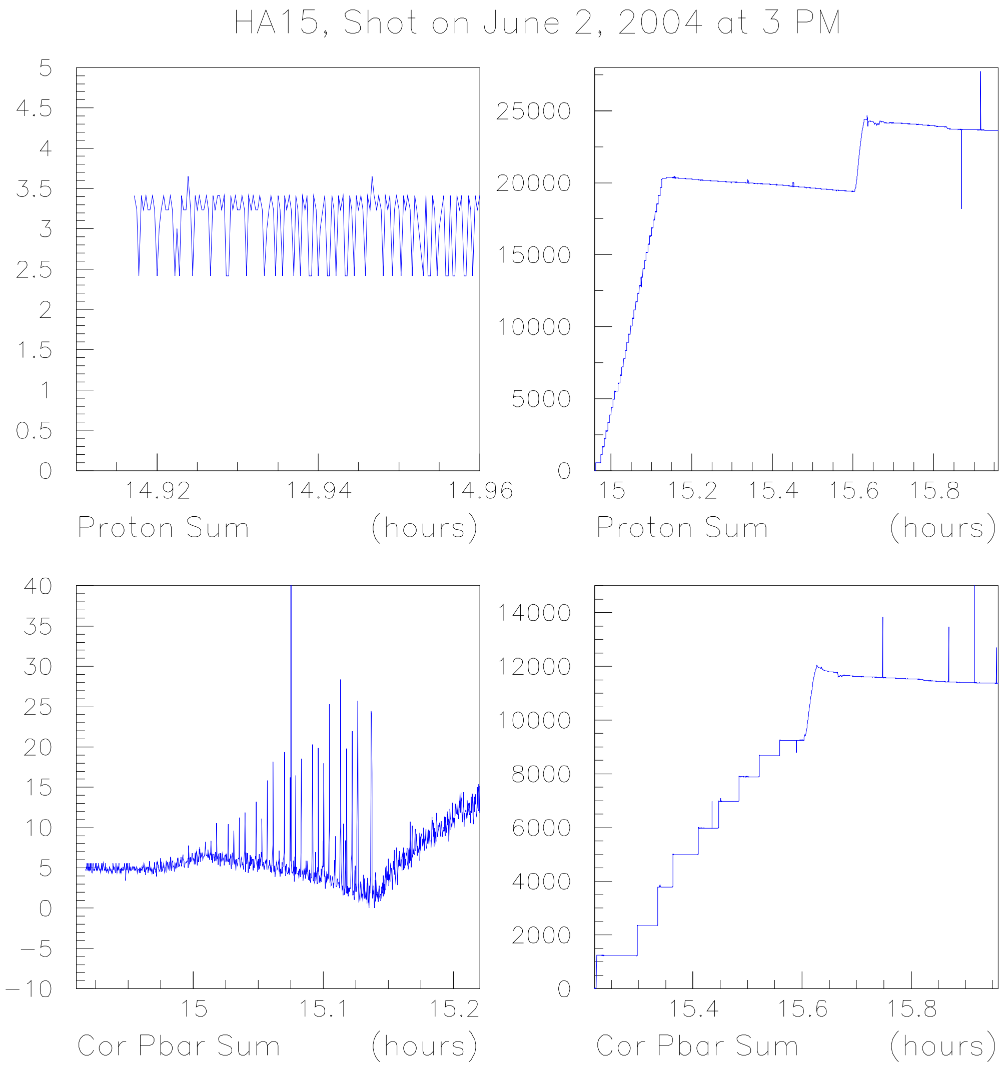

Figure 2: The top plot shows the raw proton sum signal, A+B. Again the two plots are for one continuous time series, with a break in the vertical scale at the time of the first proton injection. The bottom row shows the same information for the corrected Pbar signal, with the break at the time of the first Pbar injection. The off-scale points on the bottom left plot occur near t=15.075 hours and have a value of about 8000. We need to decide what to do with glitches like this. Except for this glitch, the right hand plots correspond to all data for which the A+B signal is above threshold as defined in section 5.

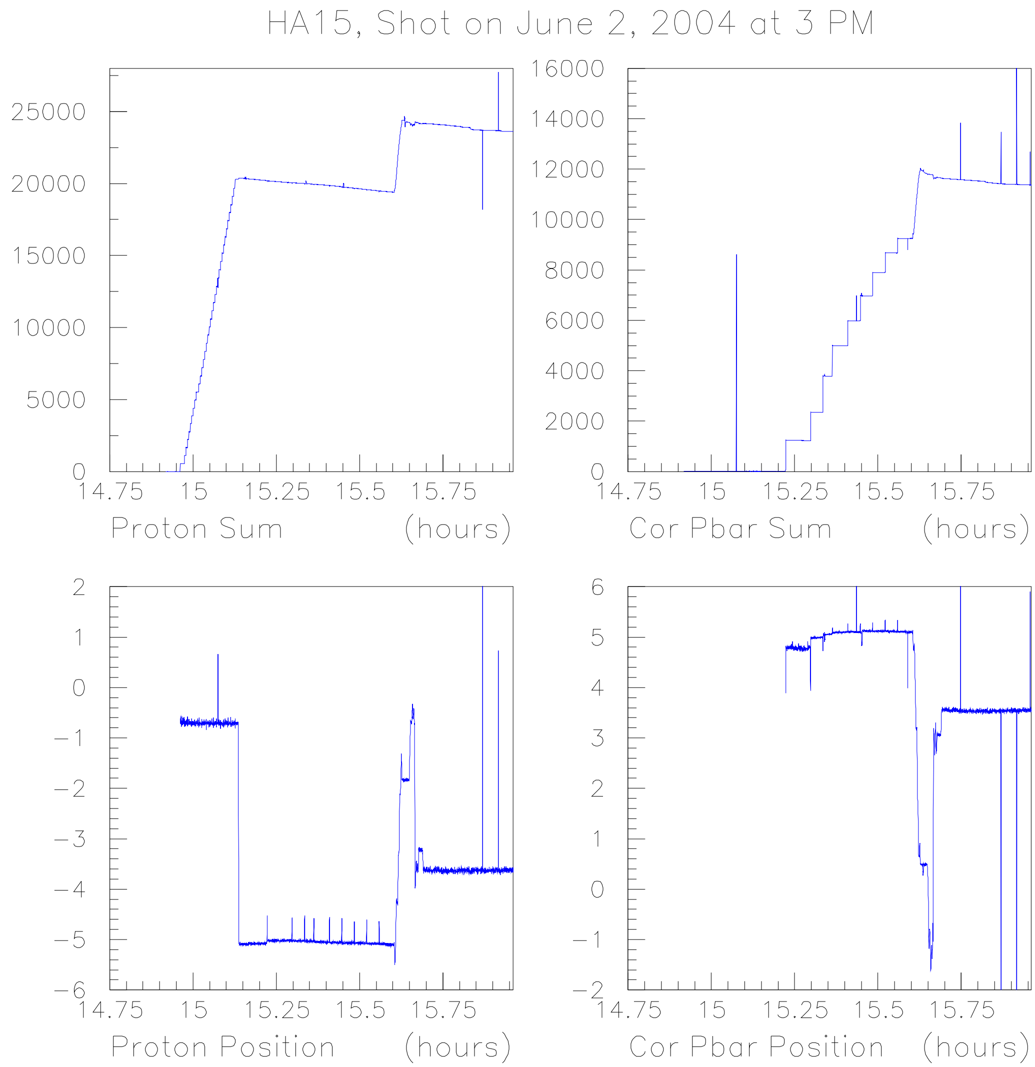

Figure 3: The top left plot is the proton sum signal from the previous page shown on a single plot. The top right plot is the corrected Pbar sum signal from the previous page shown on a single plot. The bottom left plot shows the proton position for times all times for which the proton $A+B$ signal is above 100 Echotek units. The bottom right plot shows the corrected anti-proton position signal for all times for which the anti-proton $A+B$ signal is above 100 Echotek units (with the one glitch near t=15.075 hours suppressed).

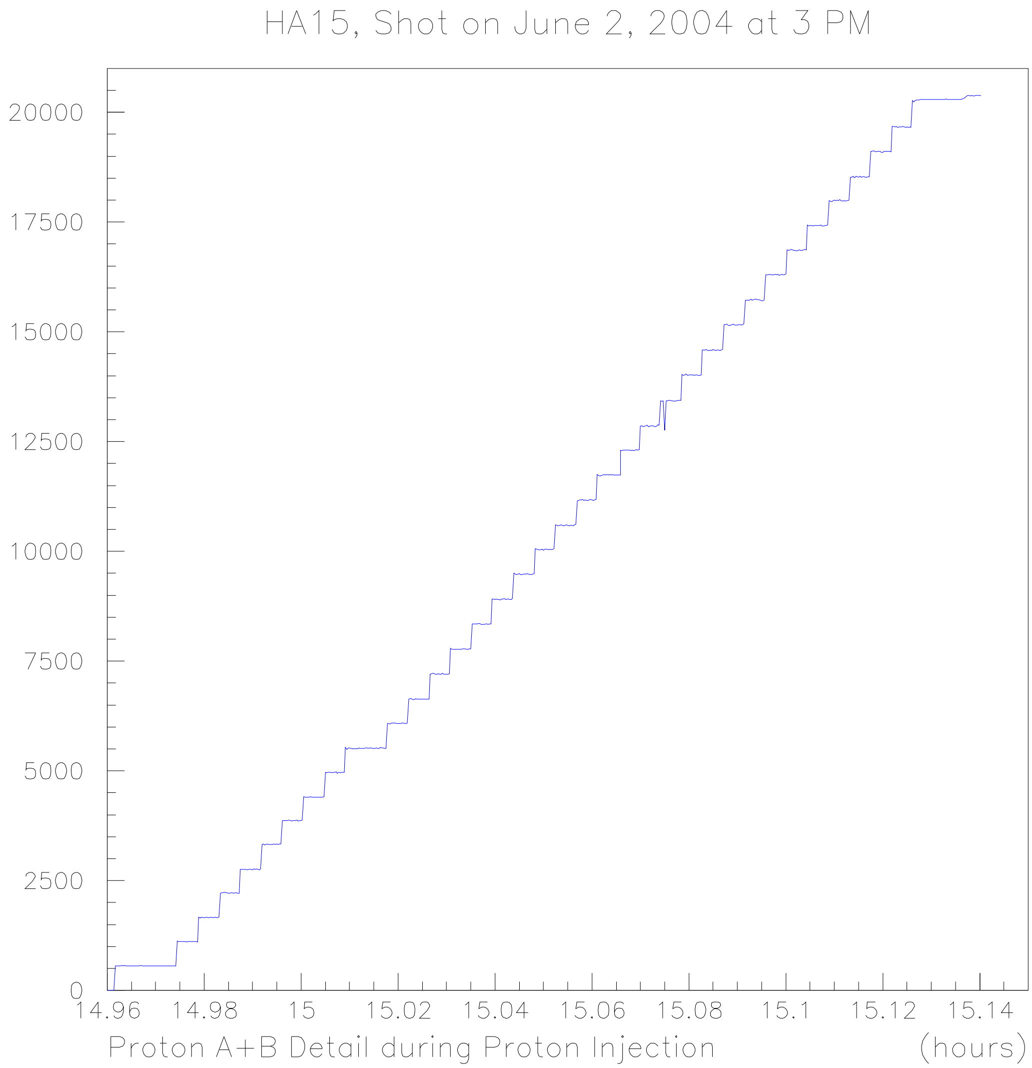

Figure 4: Detail of the proton sum signal during the time of proton injection. The 36 steps are visible. There is a glitch near t=15.075 hours which is in time with the off scale glitch in the corrected anti-proton position.

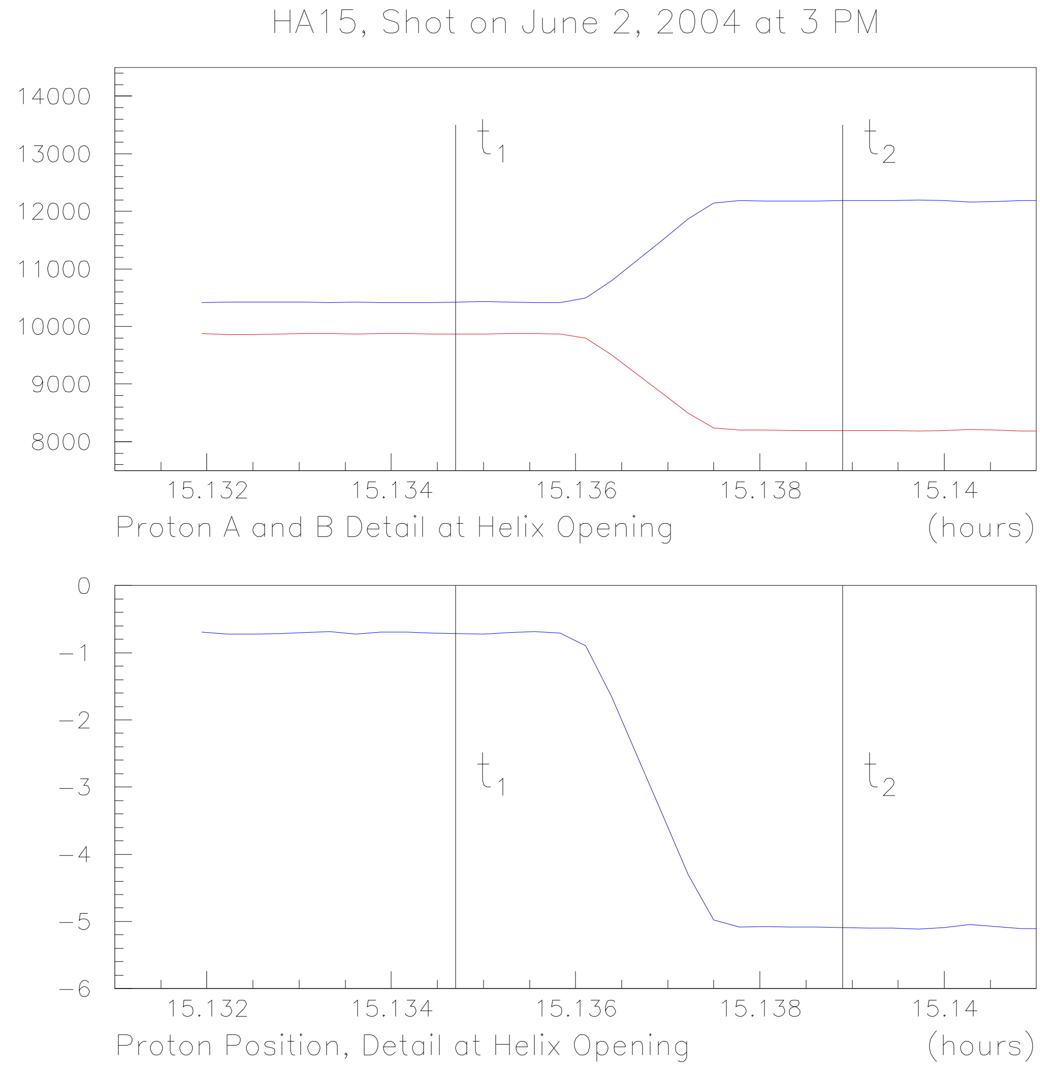

Figure 5: The top plot shows a detail of the proton A and B signals near the time that the helix opens. The bottom plot shows a detail of the proton position signal during the same time. At this time there are only protons in the machine. The two vertical lines labelled t_1 and t_2 mark the times chosen to compute the cancellation coefficients, a, b, c, d. This calculation is described in section 10.

Equations 4 and 5 of Beams-doc-1161 give a formula for the subtraction of anti-proton contamination on the proton signals. For purposes of this note, this correction will be ignored for measuring the properties of protons. The case of antiprotons will be discussed later. Therefore equations 4 and 5 from Beams-doc-1161 become,

$$A'_{HP} = A_{HP} \quad \text{and} \quad B'_{HP} = B_{HP} \tag{19}$$

where,

A_{HP}	Raw complex measurement of the A signal from the Echotek, (I, Q). Subscripts H and P refer to the BPM orientation (H for Horizontal, V for vertical) and species (P for protont, A for pbar).
B_{HP}	Raw complex measurement of the B signal from the Echotek, (I, Q).
A'_{HP}	Corrected complex value of the fundamental signal from the A plate.
B'_{HP}	Corrected complex value of the fundamental signal from the B plate.

In the following I will retain the distinction between primed and unprimed coordinates as a reminder that we will eventually need to deal with this.

Equations 1 through 3 from Beams-doc-1161 are,

$$\begin{aligned} P_{posraw} &= g\frac{|B'_{HP}| - |A'_{HP}|}{|B'_{HP}| + |A'_{HP}|} + E_{offset} && (20) \\ P_{Intensity} &= |A'_{HP}| + |B'_{HP}| - kP^2_{posraw} && (21) \\ P_{final} &= g\frac{|B'_{HP}| - |A'_{HP}|}{P_{Intensity}} + E_{offset} + Q_{offset} && (22) \end{aligned}$$

where,

P_{posraw}	Raw position
$P_{Intensity}$	Corrected intensity of beam fundamental frequency
P_{posraw}	Corrected position
g	Scale factor dictated by spacing between BPM plates. Normally 26.
E_{offset}	Electrical offset of measured zero displacement to actual center of BPM.
Q_{offset}	Offset of center of BPM to center of quadrupole correction element.
k	Quadratic correction parameter

This note will make the following approximations:

1. $E_{offset} = 0$.
2. $Q_{offset} = 0$.
3. $k = 0$.

I will also drop the subscripts H and V since the equations are the same for the two cases. With these approximateions, the equations for proton position and intensity simplify to:

$$\begin{aligned} P_{Intensity} &= |A'_P| + |B'_P| && (23) \\ P_{final} &= g\frac{|B'_P| - |A'_P|}{|A'_P| + |B'_P|} && (24) \end{aligned}$$

The anti-protons will now be discussed. For the case of the anti-protons it is important to subtract the proton contamination from the raw anti-proton measurements. For anti-protons, therefore, we keep the full equations 4 and 5 from Beams-doc-1161:

$$
\begin{aligned}
A'_A &= A_A - aA_P - bB_P && (25)\\
B'_A &= B_A - cB_P - dA_P && (26)
\end{aligned}
$$

where a, b, c, d are complex numbers to be determined.

Otherwise the same approximations are used for the anti-protons as for the protons and the equations for the anti-proton postiion and intensity simplify to:

$$
\begin{aligned}
A_{Intensity} &= |A'_A| + |B'_A| && (27)\\
A_{final} &= g\frac{|B'_A| - |A'_A|}{|A'_A| + |B'_A|} && (28)
\end{aligned}
$$