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A Second Look at Injection Turn by Turn

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Abstract

This document shows a second set of injection turn by turn measurements taken using the upgraded BPM electronics at BPMs VA33 and HA32.

1 The Data

The data shown here are from the first 8192 turns following the start of proton injection at about 7:19 AM on January 31, 2005, the start of an HEP store. The data were taken on BPMs HA32 and VA33. They were read out by Luciano, who e-mailed them to me. Only the proton data will be presented here. The BPM electronics were configured to make 8192 consecutive single turn measurements, triggered by a signal that injection is imminent.

The sum and position information were computed on the front end. The position is given by,

$$P = 26\frac{|A| - |B|}{|A| + |B|} \tag{1}$$

where $A = (I_A, Q_A)$ and $B = (I_B, Q_B)$ The sum is given by $|A| + |B|$.

The figures 1 through 5 show the same information as the corresponding plots in Beams-doc-1546. The remaining figures are new in this document. There was a change in the configuration of the Echotek filters between the data used in Beams-doc-1546 and the data presented here. Contact Jim Steimel if you need to know the details of these differences.

The red points in Figure 1 show the proton sum signal for the first few turns. The vertical scale for these points is on the right hand side of the plot. Each point corresponds to a measurement for one turn of the Tevatron. The upper plot shows information for BPM VA33 while the lower plot shows information for BPM HA32. The beam first arrives on turn 16. The blue data points show the proton position and the vertical scale for these points is on the left side of the plot

The gross features of these data are: the arrival of the beam at point 16; the sawtooth in the sum signal; the outliers in the position signal. At present the last two features are not understood. The pattern continues for all 8192 data points, modulated by beam motion.

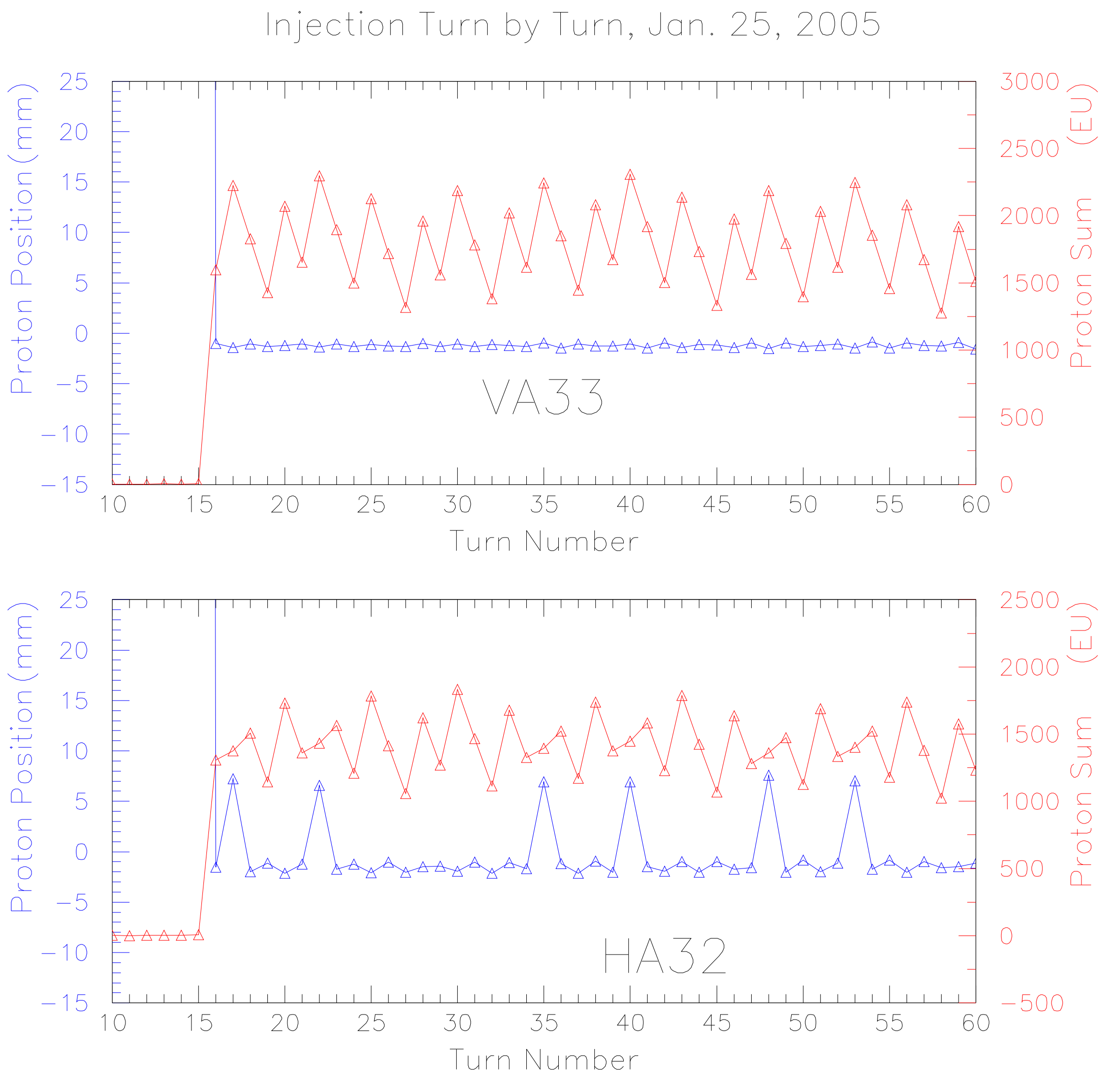

Figure 1: The red points show the measured proton sum signal at VA33 and HA32 as a function of turn number for the first few turns of the shot at about 7:19 AM, Jan. 31, 2005. The beam arrives at turn number 16. The blue points show the measured proton positions for the same turns.

1.1 Comparison with Beams-doc-1546

- In both data sets the beam arrives at turn 16.
- The old data has outlier positions for both HA32 and VA33, while the new data has outlier positions only for HA32.
- The pattern of how frequently outliers occur has changed between the old and new data.
- The structure in the sum signal has changed between the old and the new data.

2 Fixing the Outliers

In order to measure the frequency content of these data, the outliers were fixed by replacing them with the mean of their neighbors. I have not yet checked to see what sort of artifacts this will produce — but at low frequencies there should be few artifacts. Figure 2 shows the fixed beam positions as a function of turn number. In this figure, the data points before the beam arrived were dropped, leaving 8177 points.

3 Fourier Transforms

In order to look at the frequency content of the position data, the following transform was computed,

$$FT(f) \quad = \quad C(f) \sum_{n=0}^{N-1} (P_n - \bar{P}) e^{iwt_n} \tag{2}$$

where the sum runs over the N turns with beam present (8177), f is the frequency at which the transform is evaluated, $w = 2\pi f$, P_n is the measured position for the n^{th} turn, $t_n = nT_{\rm rot}$ is the time at the start of the n^{th} turn, $T_{\rm rot}$ is the rotational period of the Tevatron, $C(f)$ is a normalization factor to give the value of the transform in μm, and where $\bar{P}$ is the mean position, averaged over the N turns with beam present. When the turn by turn positions are given in mm, the normalization factor is given by,

$$C(f) \quad = \quad \frac{2000\ T_{\rm rot}}{N\ T_{\rm rot} + \frac{1}{2\omega}\left[\sin 2\omega(t_n + \delta) - \sin 2\omega(t_0 - \delta)\right]} \tag{3}$$

where $\delta = T_{\rm rot}/2$. The purpose of subtracting $\bar{P}$ is to remove the alias of the digitizing frequency which appears at 0 Hz and would dominate the transform.

In this analysis I used a nominal RF frequency,

$$f_{RF} \quad = \quad 53.104 \text{ MHz} \tag{4}$$

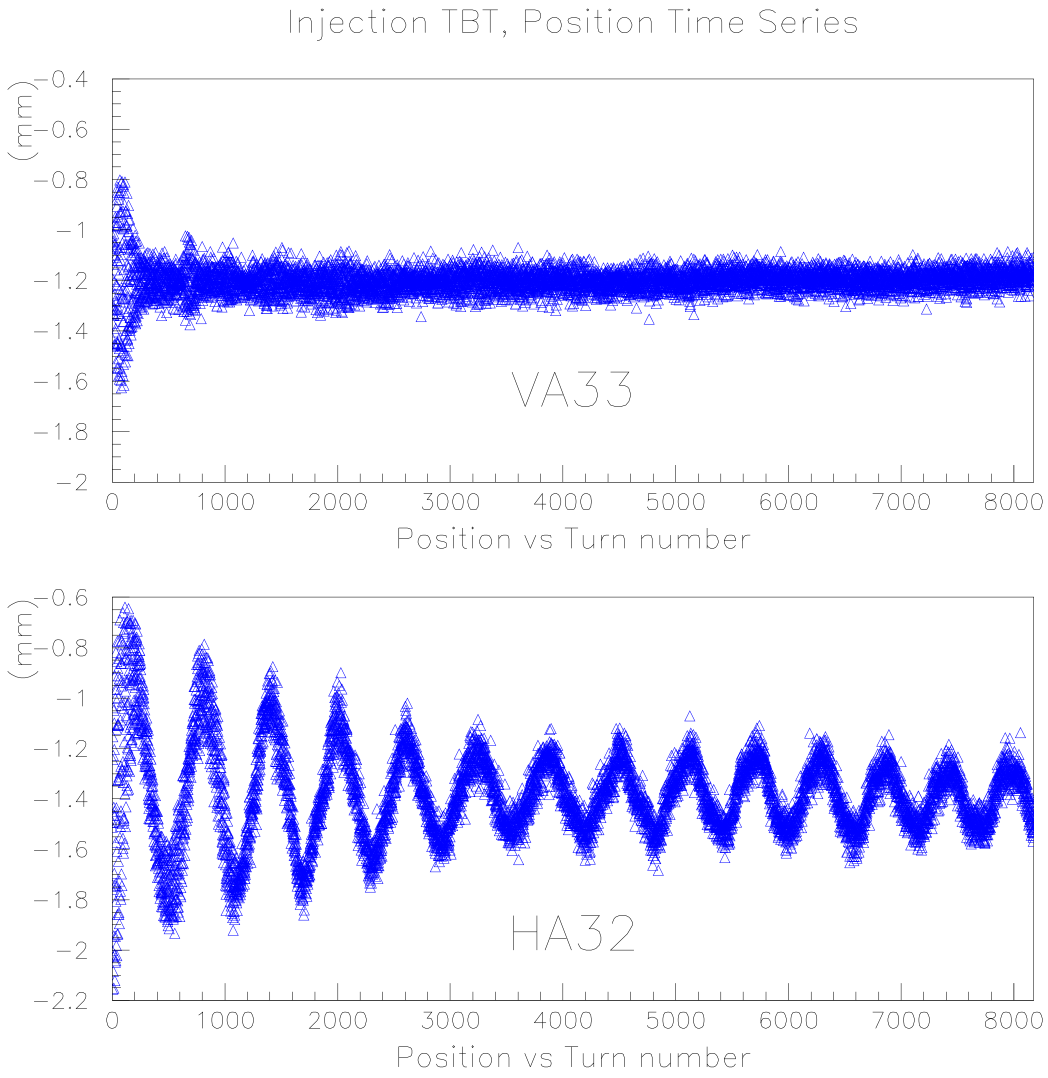

Figure 2: Measured proton positions at VA33 and HA32 as a function of turn number for the full 8177 turns. This plot was made after the outliers were repaired, as described in the text. On both plots the full vertical scale is 1 mm. Clear oscillations can be seen in the data for HA32.

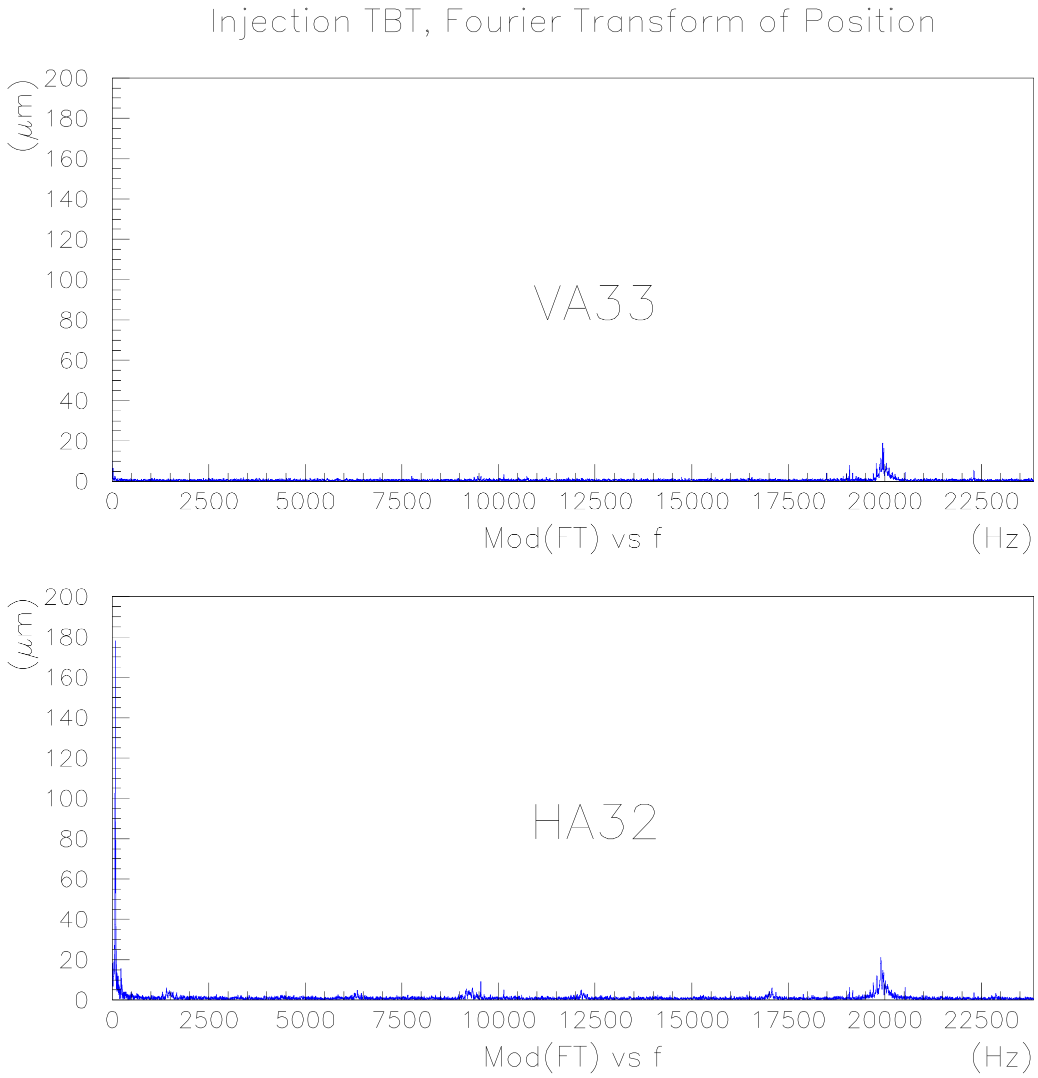

Figure 3: Frequency content of the position data shown in Figure 2. The vertical scale is arbitrary and the mathematics of the transform are described in the text. There is a prominent feature in the HA32 data near 80 Hz and there are prominent features in both plots near 20 kHz. The next plots will show these features in detail.

This value is not quite correct but the conclusions should stand when the correct value is used. From this I derived, a Tevatron rotational frequency of

$$f_{\rm rot} \quad = \quad f_{RF}/1113 = 47.712 \text{ kHz}, \tag{5}$$

and a Tevatron rotational period of,

$$T_{\rm rot} \quad = \quad 1/f_{RF} = 20.9589\ \mu\text{s}. \tag{6}$$

Figure 3 shows histograms of $|FT(f)|$ for VA33 and HA32 data; the transform for each bin was evaluated using the center frequency of the bin. Each transform was computed in N bins between 0 and half of the Tevatron rotational frequency. Therefore the width of a frequency bin is

$$\delta f \quad = \quad \frac{f_{\rm rot}}{2}\frac{1}{N} = 2.917 \text{ Hz} \tag{7}$$

In the two plots there are prominent features near frequencies of 80 Hz and 20 kHz. The following plots will focus on these features.

Figure 4 shows a detail of Figure 3 at low frequencies. There is a prominent feature near 80 Hz which is present in the HA32 data but absent in the VA33 data. These data were taken at injection when the energy of the Tevatron is 150 GeV. At this energy the synchrotron frequency is about 80 Hz. So it seems likely that the observed feature is the synchrotron line.

Figure 5 shows a detail of Figure 3 near 20 kHz, where the betatron lines are expected. At these frequencies, there could be artifacts of the procedure for fixing the outlying data points. I have not investigated what those artifacts might look like.

I have not yet determined the tunes for these data, as was done in Beams-doc-1546. That will be done in a later version of this document.

4 Time Dependence of the Frequency Spectrum

The next few figures show how the frequency spectrum evolves with time. The upper left plot in Figure 6 shows a detail, near 80 Hz, of the frequency spectrum that is obtained using the first quarter of the HA32 position data points. The plot is made with the bin width equal to the resolution bandwidth, about 12 Hz. This is the same detail was shown for HA32 plot in Figure 4, in which the resolution bandwidth, and the bin size, were about 3 Hz. The remaing plots in this figure show the same detail of the frequency spectrum for the other three quarters of the data. One can see that the amplitude of the synchrotron oscillation of the center-of-mass of the bunch is decaying with time, as is expected from inspection of Figure 2.

The four plots in Figure 7 shows the same detail of the frequency spectrum for the four quarters of the VA33 position data. These spectrum are all similar to each other and to the VA33 plot in Figure 4.

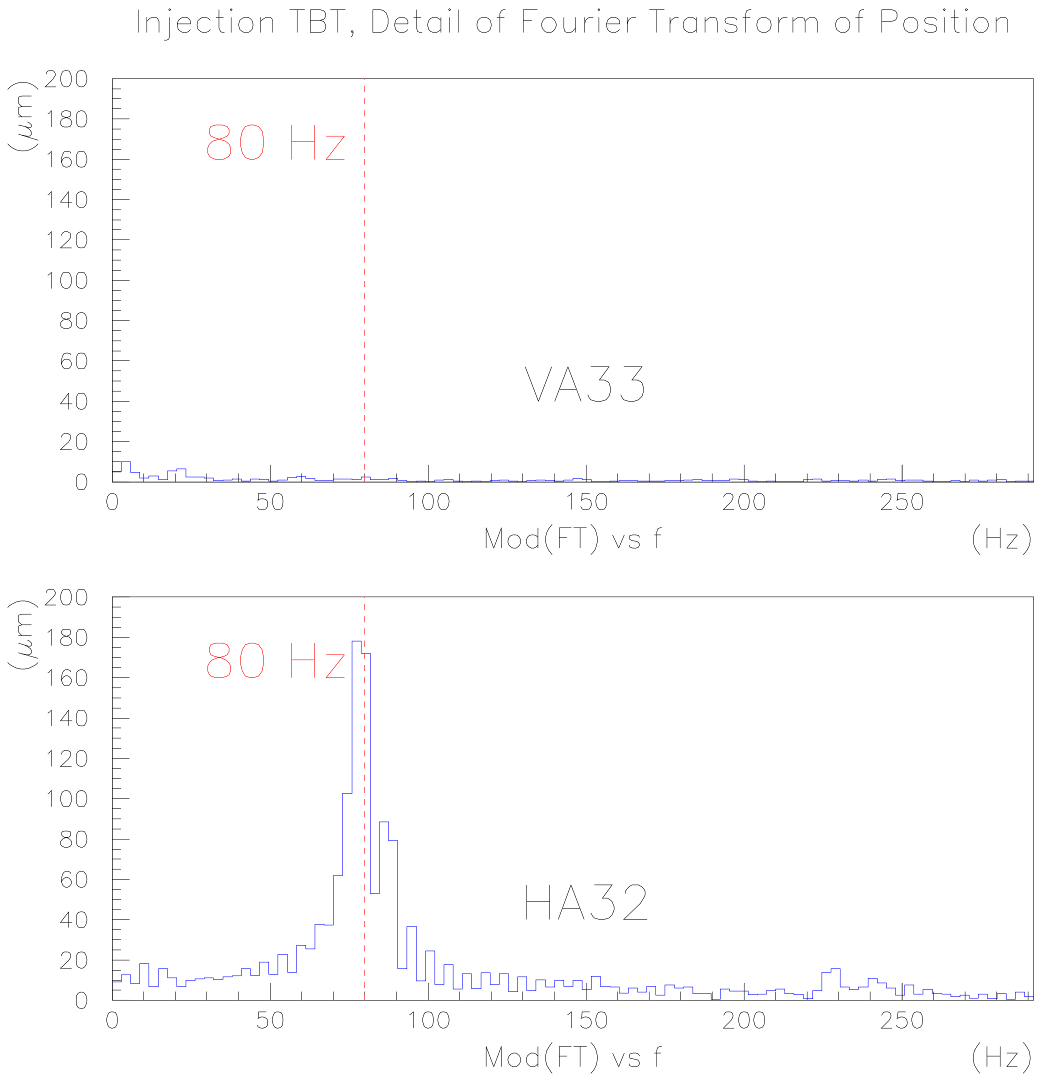

Figure 4: Detail of Figure 3 for low frequencies. The feature near 80 Hz in the horizontal data is likely the synchrotron line.

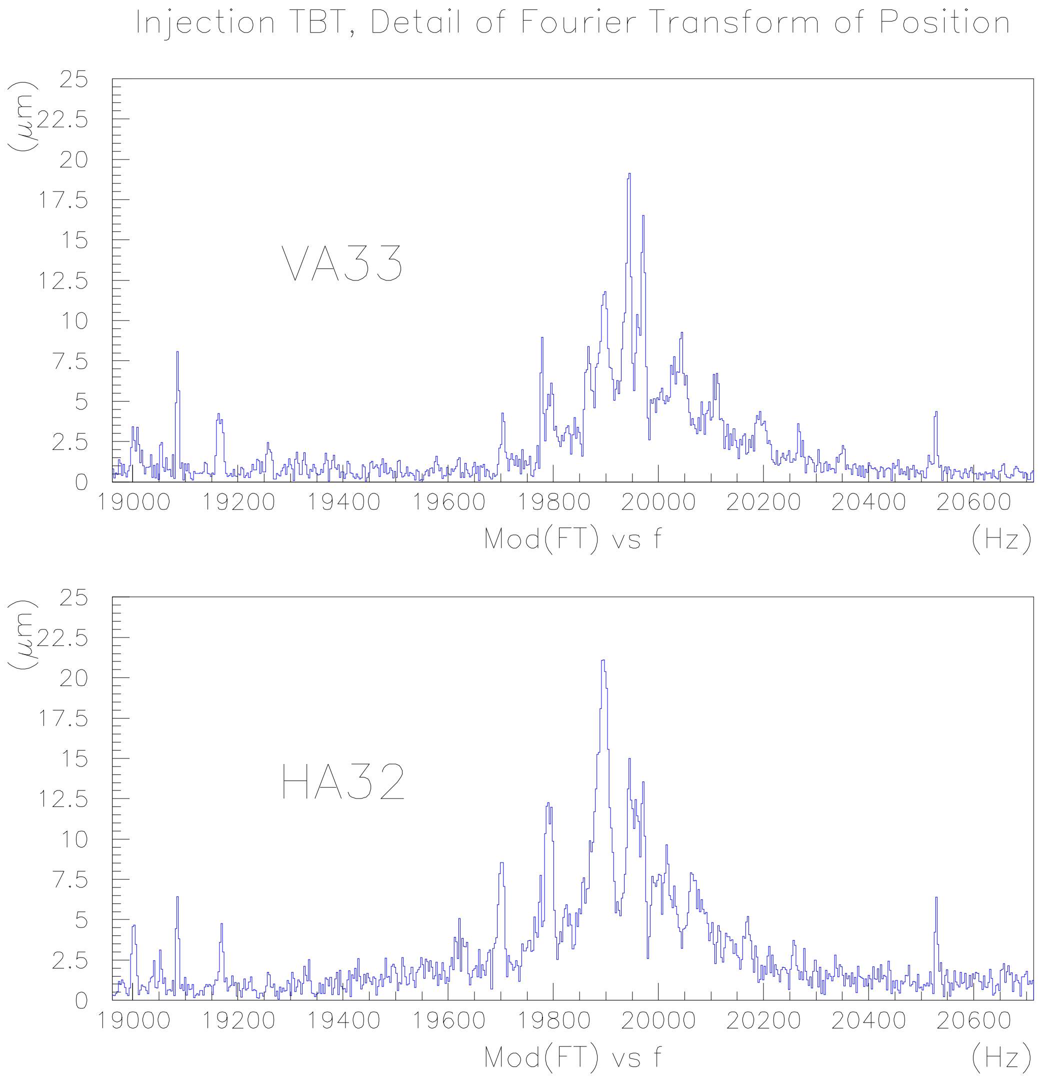

Figure 5: Detail of Figure 3 for frequencies hear the expected betatron lines. The vertical scales are the same on the two plots.

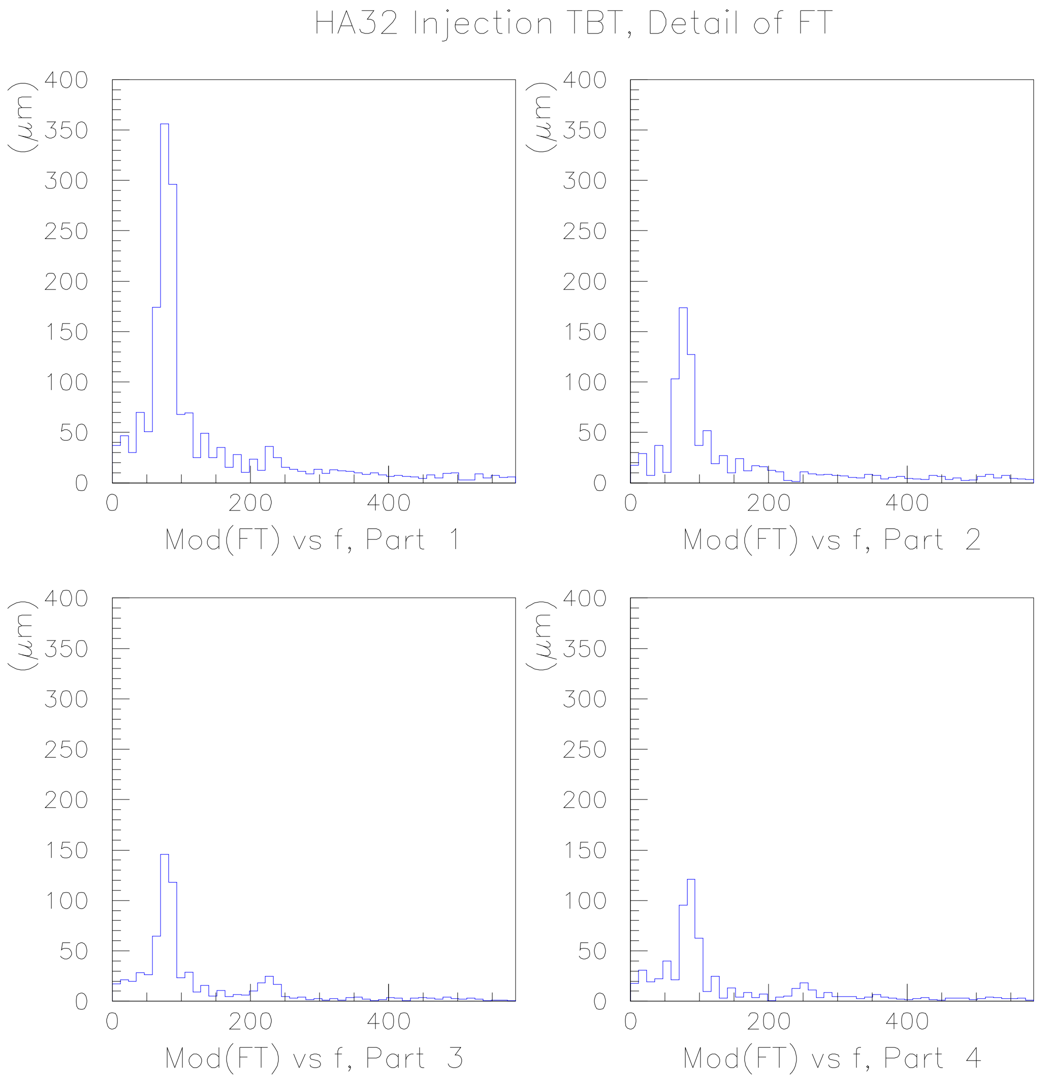

Figure 6: Same data as Figure 4

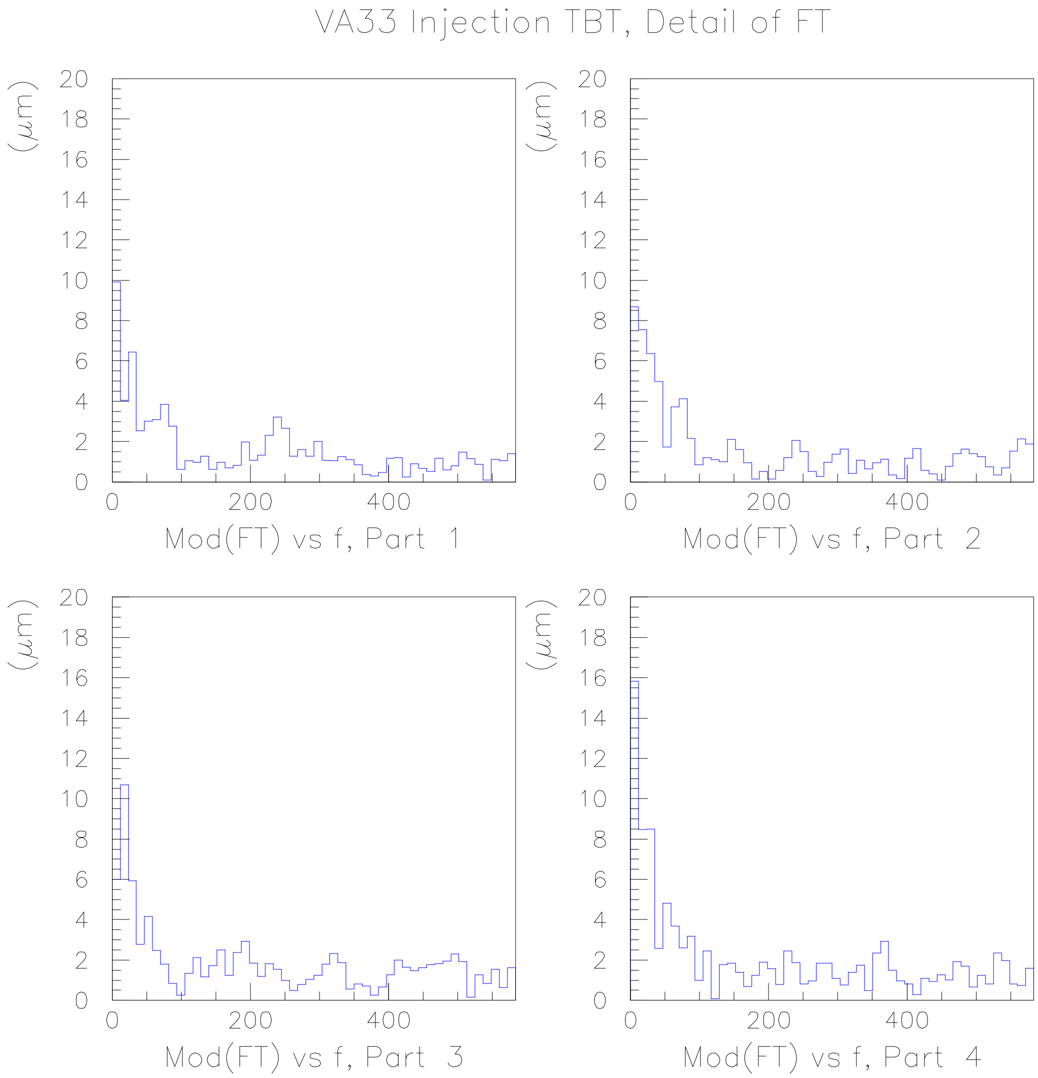

Figure 7: These plots show the frequency spectrum for four equal sized subsets of the data. Same data as Figure 4

Figures 8 and 9 show details of the frequency spectrum in the region near 20 kHz. Each plot is made using a quarter of the data. From these plots we see that the betratron oscillations of the center-of-mass of the bunch persist only during the first 2048 turns. I have not yet checked shorter time scales to see how long it really does persist.

5 Phase of the Transform

The upper two plots in Figure 10 show the same information as Figure 5, but with a slightly more restricted horizontal scale. That is they show the magnitude of the Fourier transform as a function of frequency. The bottom two plots show the corresponding phase of the transform.

It is a little hard to interpret the phase plots since they are very noisy when the magnitude of the transform is small. There is a step function jump in the phase near the tune line;but I think that this is an artifact of the choice of time=0 and does not contain useful information.

6 Summary

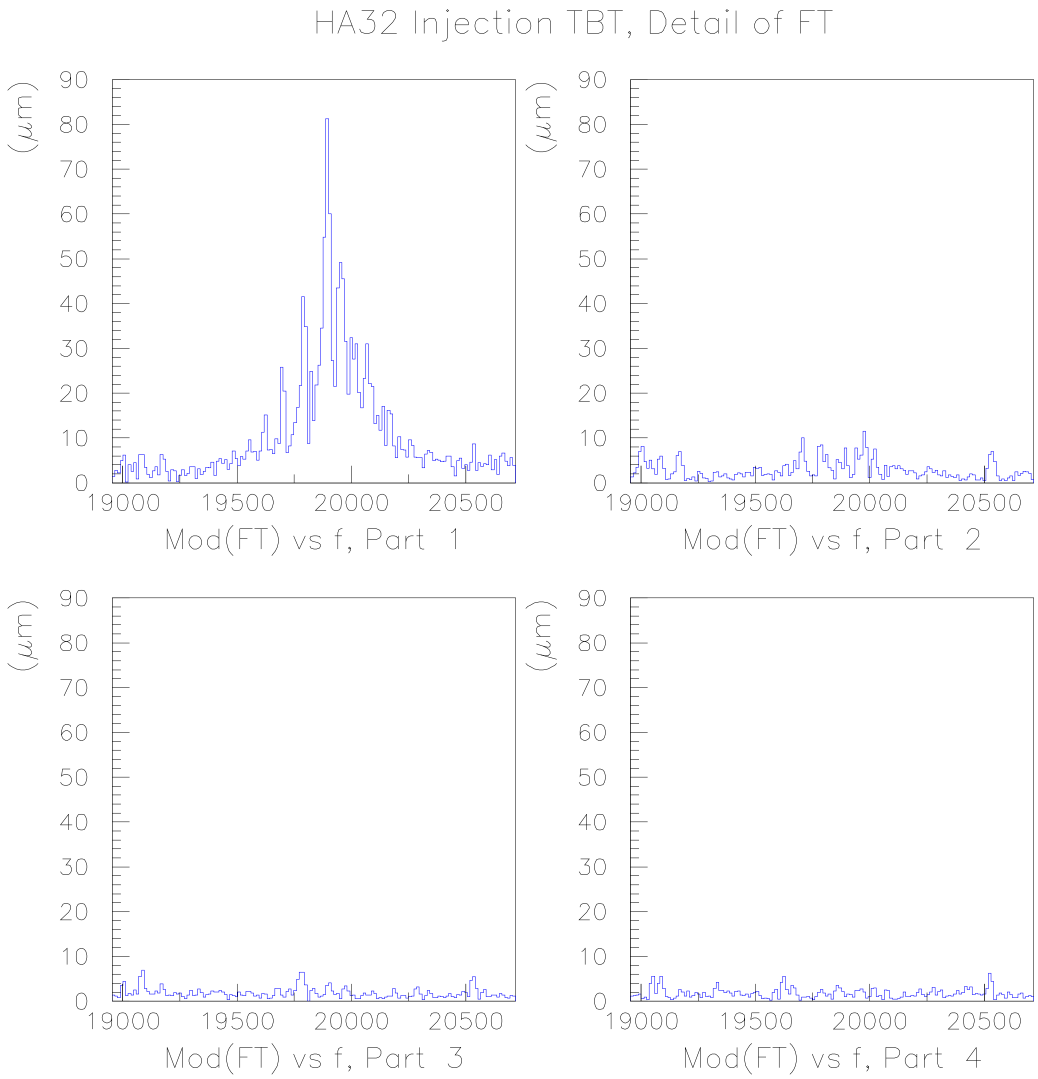

Figure 8: Same data as Figure 4

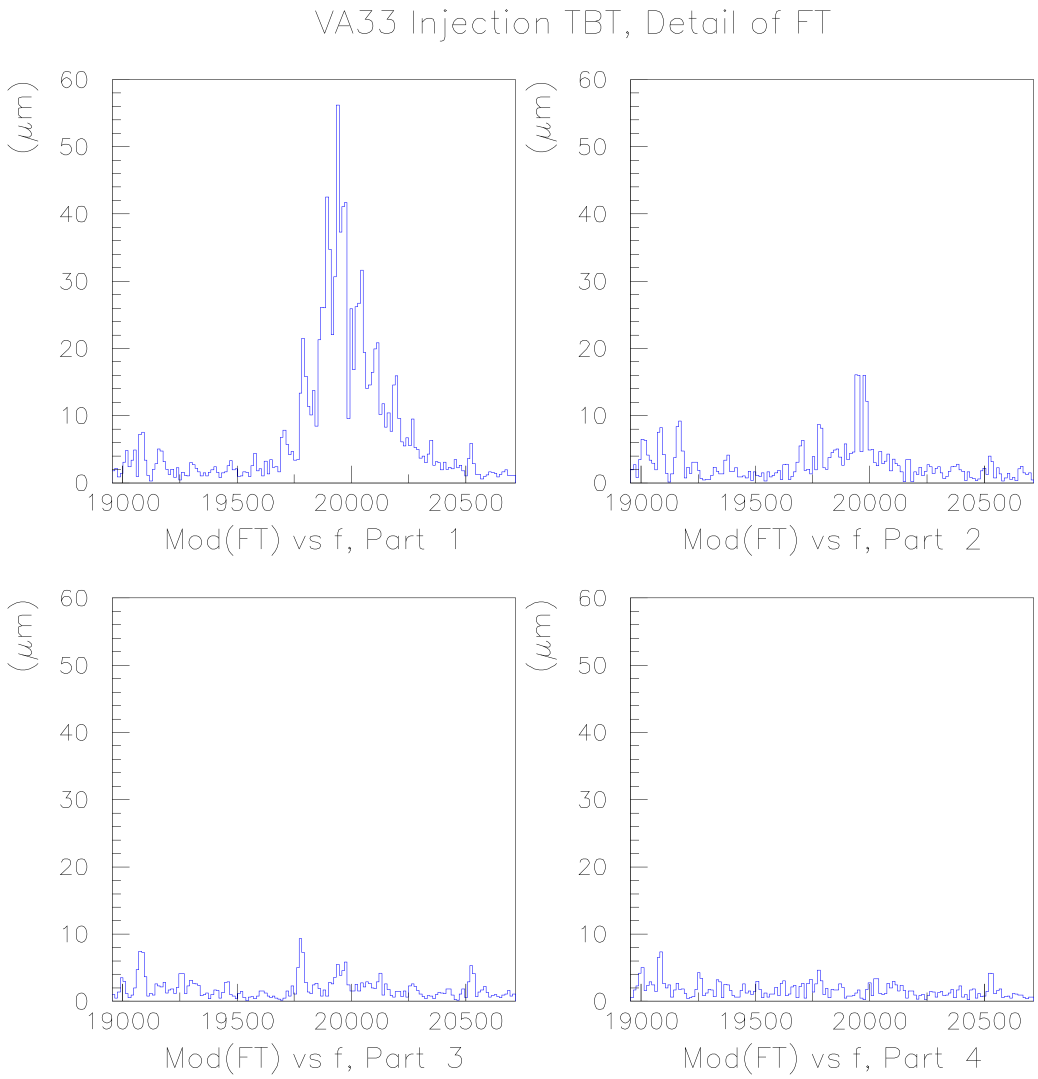

Figure 9: Same data as Figure 4

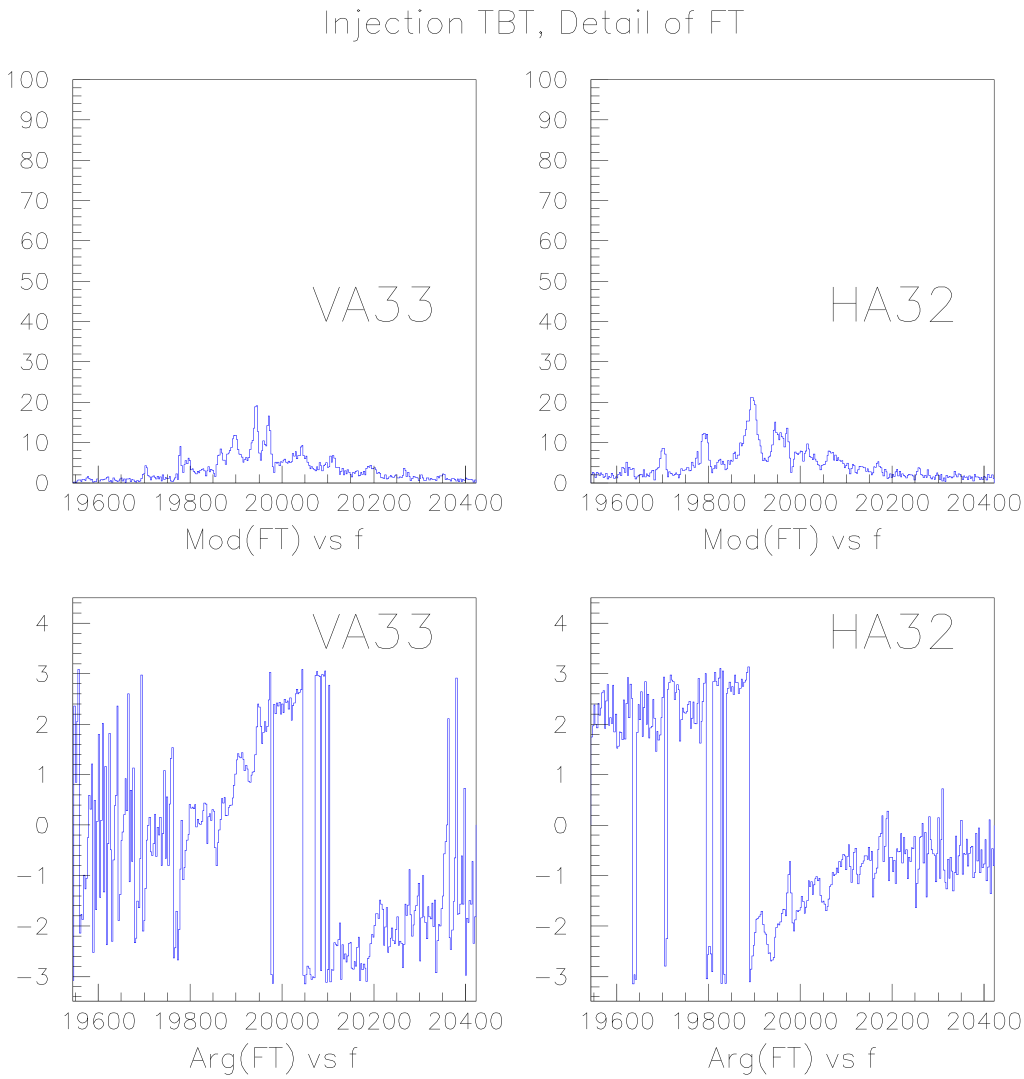

Figure 10: Same data as Figure 4

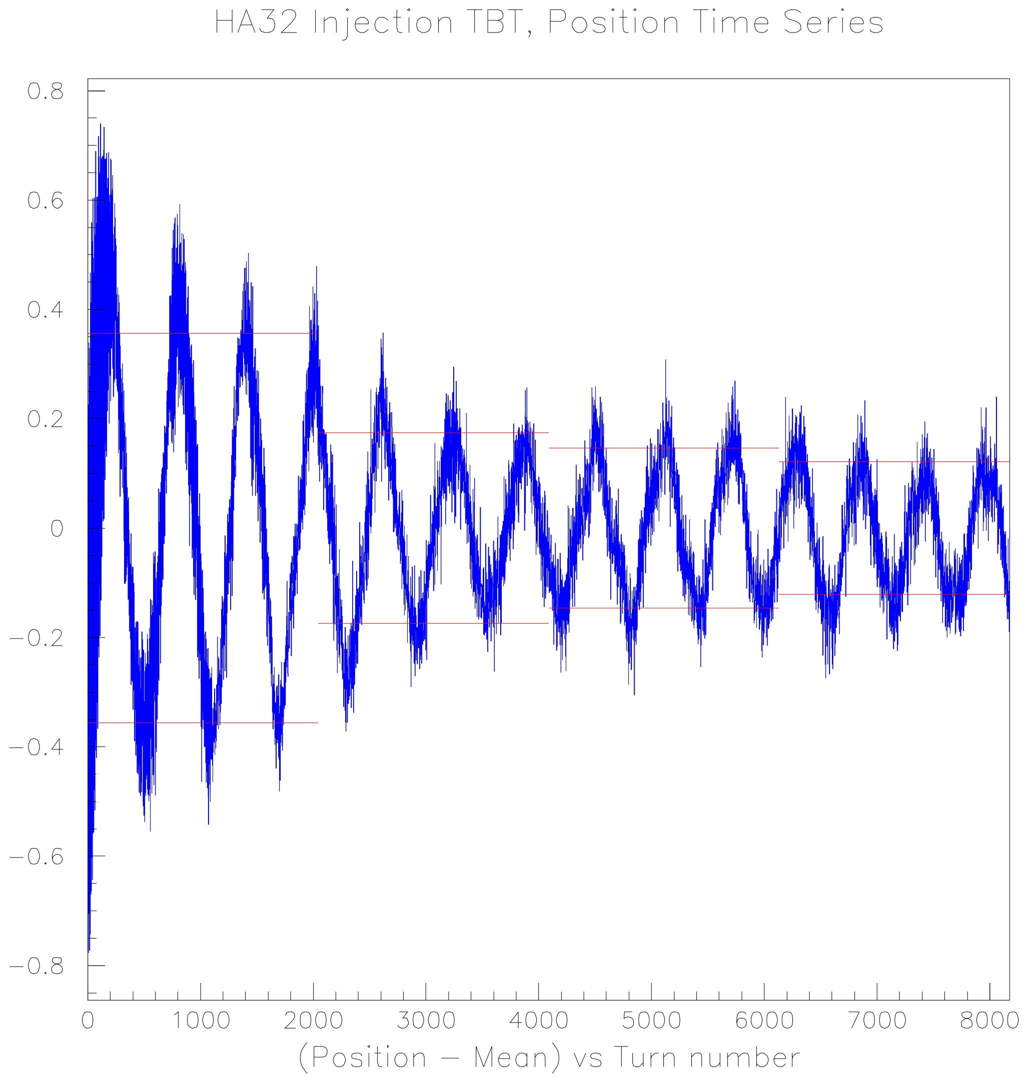

Figure 11: HA32 data froms Figure 2 with the magnitude of the 80 Hz component superimposed.

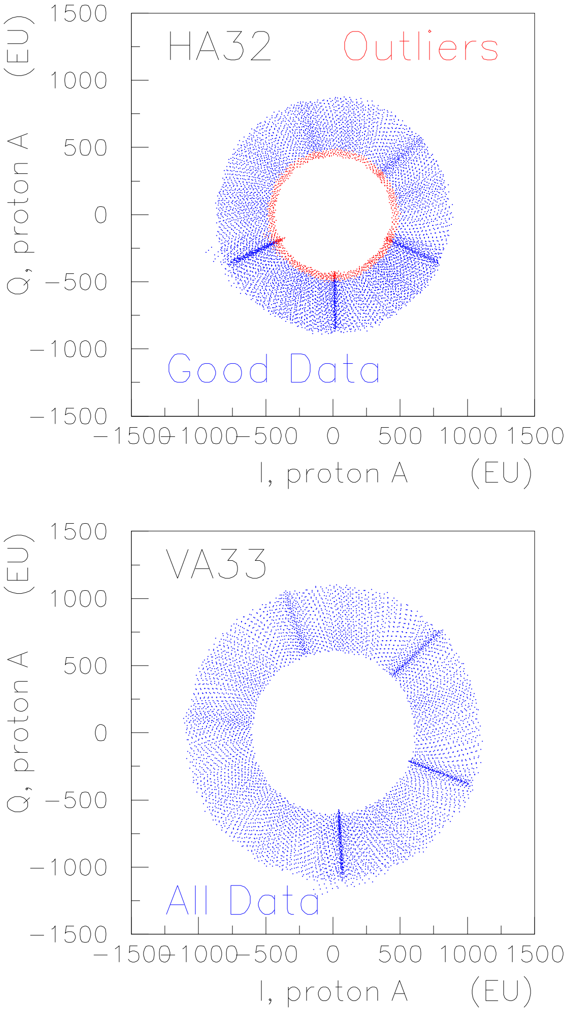

Figure 12: Phases Study

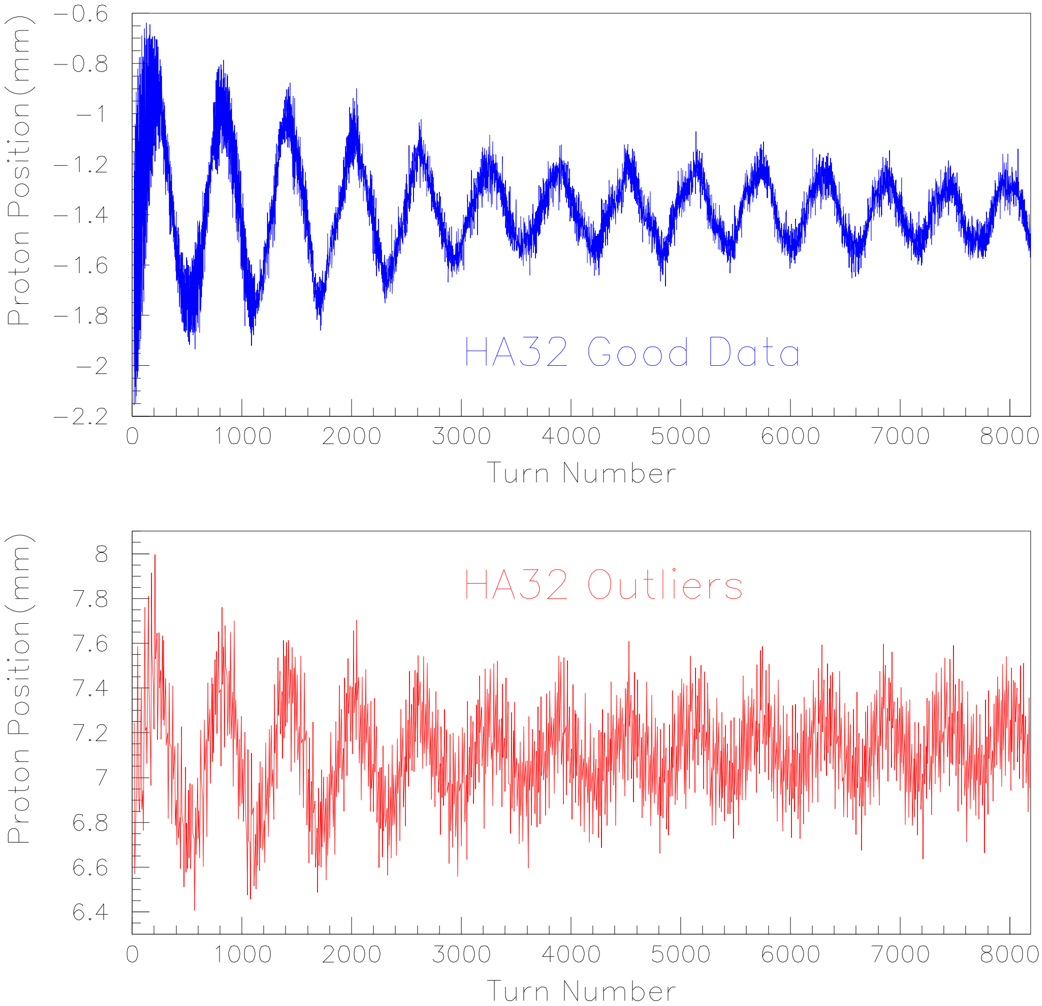

Figure 13: Phases Study

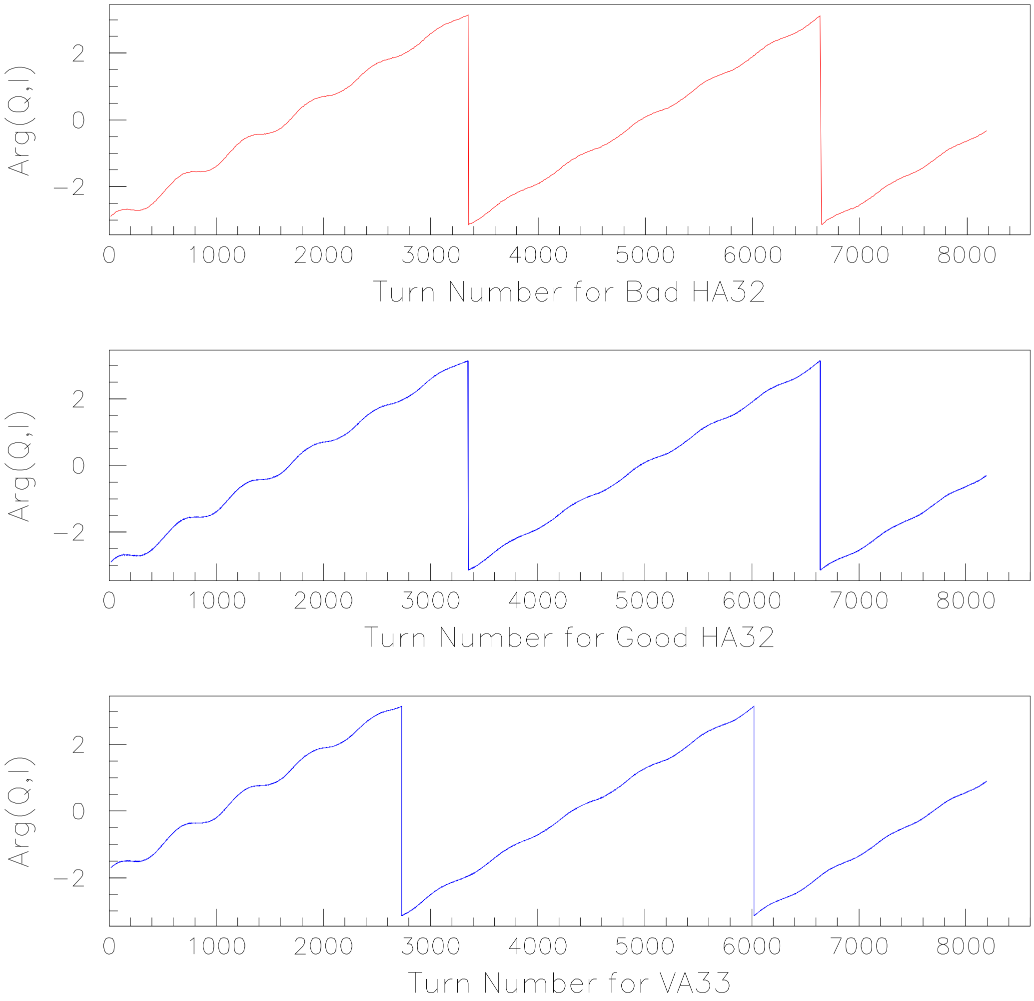

Figure 14: Phases Study