A possible new method to measure the betatron tunes at the TEVATRON

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Abstract

A new diagnostic to measure bunch-by-bunch betatron tunes for the TEVATRON is under development at Fermilab. The first results obtained with this diagnostic in its first stage are presented here. These results concern a coalesced proton bunch at 150 GeV and 980 GeV and an anti-proton bunch at 980 GeV.

1 Introduction

The TEVATRON collides 36 proton bunches against 36 anti-proton bunches at an energy of 1.96 TeV at the center of mass. The particles of each species are divided in 3 trains of 12 bunches. Each bunch is separated by 21 RF buckets (396 ns) and each train by 139 RF buckets (abort gap of 2.617 μs). During the revolution around the ring, the beam interacts with its environment which modifies the transverse tune of the trains and of the individual bunches. Three tune monitors (described in Ref. [1]) are presently available at the TEVATRON : a 21.4 MHz Schottky, a 1.7 GHz Schottky and a 3D-BBQ detector (Direct Diode Detector Base Band Q). The 21.4 MHz Schottky is mainly used to measure the horizontal and vertical tunes of the 36 proton bunches without the possibility to gate on individual bunches. The 1.7 GHz Schottky measures the horizontal and vertical tunes of a single proton and anti-proton bunch but needs a long averaging time ($\sim$20 minutes) to get to a precision of $\sim 10^{-4}$. The 3D-BBQ detector (Direct Diode Detector Baseband Q) is under development and allows to gate on proton and anti-proton bunches. This monitor showed promising results (individual proton and anti-proton tunes have been observed without the need of an external beam excitation) and is presently used to cross check the tunes measured by the two other monitors.

The new diagnostic described in this paper has the potential to give the tunes of each proton and anti-proton bunch without the need of an external excitation of the beam, at a 1 Hz repetition rate and with a high precision (10^{-4}). The monitor in its first stage is presented in the following.

2 Experimental setup

The new diagnostic relies on a simple idea : sampling the vertical position of each proton and anti-proton bunch for N turns ($N > 10^4$) and inspecting the power spectrum of the stored data computed by an FFT.

The experimental setup used to measure the beam motion is presented in Figure 1. A displaced beam produces non-equal current distributions when passing by stripline electrodes. The signals from the top and bottom electrodes (resp. A and B in Figure 1) is summed and subtracted using an RF hybrid box [1]. Comparing these two signals allows to compute the bunch vertical position. As indicated in Figure 1, before entering the hybrid box, the A and B signals pass through a phaser and a variable attenuator which are manually and carefully adjusted to remove the DC position offset which allows us to get to higher precision for our setup. At the exit of the hybrid box, the signals are sent to an oscilloscope [2] where 2.5 GS/sec of datas are recorded by an 8-bits ADC. The oscilloscope is triggered to gate on a proton or anti-proton bunch on a turn-by-turn basis.

The vertical striplines used for the measurements presented here are located in the F0 hall and have 1 meter long plates. Previous calibration [2] showed that the vertical displacement y_c for this stripline is related to the A-B and A+B signals according to :

$$y_c \simeq 27 \cdot \frac{A-B}{A+B} \quad \text{[mm]} \tag{1}$$

Since the stripline is terminated with the same characteristic impedance $Z_0 = 50\ \Omega$ at both ends, the voltage pulse splits into two parts, one traveling through the upstream port and the other one downstream the stripline. The stripline is not long enough to separate these two pulses, therefore the output pulse from the stripline is the sum of

[1]M/A-Com H-9 Hybrid Junction
[2]Tektronix TDS7154B

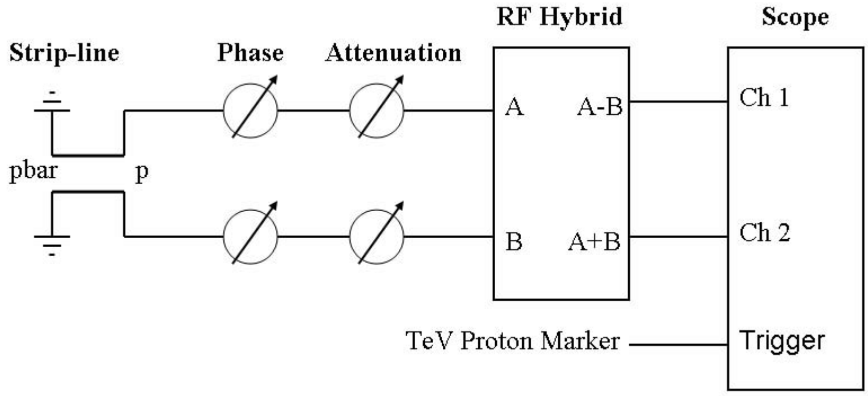


Figure 1: Schematic of the tune monitor.

the upstream and downstream pulse. A deconvolution of the output signal is necessary to separate these two pulses and get the correct A+B and A-B signals for Equation 1. The deconvolution is realized by delaying the output signal by a round-trip along the stripline (~ 6.6 ns) and by summing this signal with the initial signal. The data analysis was realized offline using MATLAB.

3 First Results : protons at 150 & 980 GeV, anti-protons at 980 GeV.

Using the experimental setup described in the previous section, we gated one proton bunch at injection and flat-top and one anti-proton bunch at flat-top. The flat-top studies were undertaken at the end of stores. The proton bunch was selected randomly among the 36 bunches. The anti-proton bunch had to be the first in the train because of contamination from the proton signals.

Figure 2 and Figure 3 show the A+B signal, A-B signal, beam centroid and power spectrum for a 150 GeV coalesced proton bunch with VTICK respectively OFF and ON. The power spectrum was computed using $N = 5 \cdot 10^5$ turns of datas. The A+B signal and A-B signal is the average over the first $N = 3 \cdot 10^4$ turns. The beam centroid is represented as well for the first $N = 3 \cdot 10^4$ turns only. VTICK is a vertical kicker connected to a noise source which excites the beam at a frequency around the tune frequency, with a 5 kHz bandwidth and a power of 5 Watts. It is clear from the power spectrum (Figure 2(d) and Figure 3(d)) that without external beam excitation the betatron tunes can not be observed with this setup.

Figure 4 and Figure 5 lead to the same conclusion for a 980 GeV proton bunch: without external excitation (VTICK OFF), there are no signs of betatron tunes in the power spectrum (Figure 4(d)), while the betatron tunes appear clearly with VTICK turned ON (Figure 5(d)). Figures 6(a) and 6(b) show the horizontal and vertical tunes from the 21.4 MHz Schottky monitor for VTICK ON and OFF. Figure 6(c) compares the 21.4 MHz Schottky signals with the signal from our setup (Figure 3(d)) for VTICK ON: from this figure it appears clearly that the 21.4 MHz Schottky monitor gives a much wider signal.

Figure 7 presents the results from the 980 GeV anti-proton bunch without external excitation: no betatron tunes have been observed in the power spectrum (Figure 7(d)). Furthermore, the background in the power spectrum is larger for the anti-proton bunch without external excitation than for the proton bunch with external excitation (5(d)). Therefore, it is not surprising that the betatron tunes were not observed in the power spectrum for the anti-proton case even when we did excite the anti-proton beam.

Table 1 shows a summary of the experiment and reports the RMS beam motion and RMS noise for each scenario. The RMS square noise was found by integrating the spectral density. From the results reported in this table, the RMS beam motion is larger for a 980 GeV beam than for a 150 GeV. In fact, since the bunches are longer at injection energy than at flat-top energy, the damping of the transverse oscillations might be more effective at injection energy.

	150 GeV proton		980 GeV proton		980 GeV pbar
	VTICK Off	VTICK On	VTICK Off	VTICK On	VTICK Off
Tunes ?	No	Yes	No	Yes	No
RMS motion [μm]	2.01	2.11	3.27	3.29	4.71
RMS noise [μm]	1.04	1.06	2.14	2.14	4.14

Table 1: Summary of the tune observations, RMS beam motion and RMS noise for the different experiments.

4 Next step : a 100 MHz, 14-bits ADC board

The results obtained with the monitor in its first stage (as described in Figure 1) indicate that the tunes of a proton bunch can be observed at injection and flat-top energies only if the beam is externally excited. Therefore, for the monitor to operate in a parasitic mode, the signal-to-noise ratio of the electronic needs to be improved.

To do so, a 100 MHz, 14-bits ADC board is under development at Fermilab. This board will supplement the present experimental setup. We hope with this 14-bits ADC to get a larger signal-to-noise ratio than with the 8-bits ADC from the oscilloscope which will allow us to observe the betatron tunes of each proton and anti-proton bunches without the need of an external excitation of the beam. This board should be available in August 2005 and will be first tested using a signal generator that gives simulated 53 MHz beam structure.

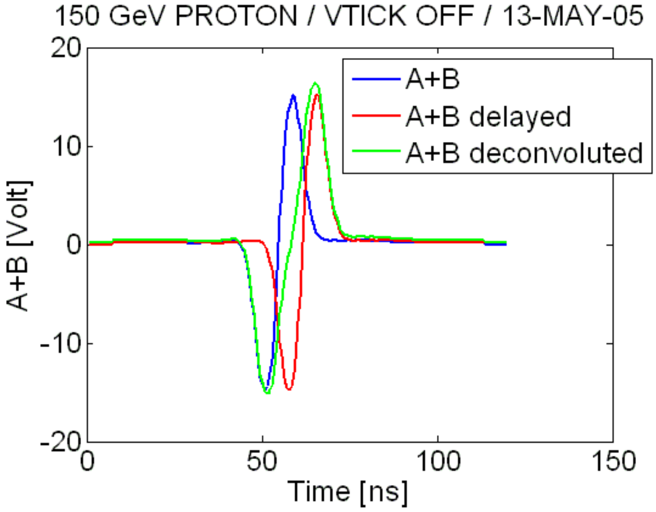
5 Conclusion

The results presented in this paper indicate the need of a larger signal-to-noise ratio of our monitor to get the betatron tunes of the proton and anti-proton bunches without an external excitation. A new board is under development that will allow us to look into this direction. How much will this card increase the signal-to-noise ratio ? Will it be sufficient to get the betatron tunes of the proton and anti-proton bunches without external excitation ? These questions will be answered as the board will become available in August 2005. We hope to complete our tests with beam before the next TEVATRON shutdown foreseen for three months, starting in November 2005.

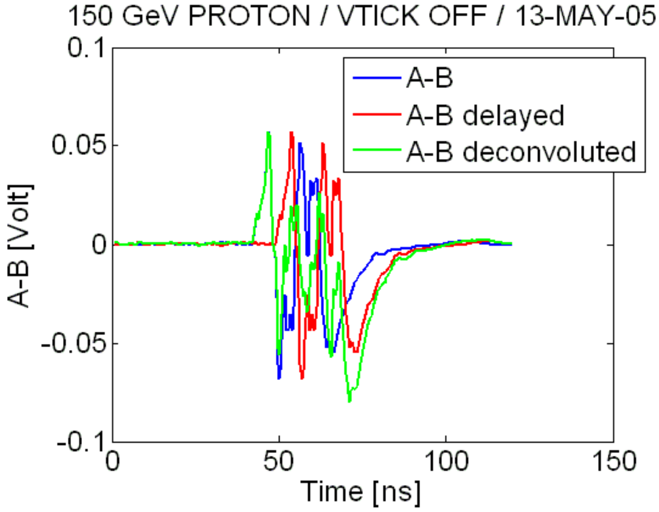
References

[1] C.Y. Tan, “Novel Tune Diagnotics for the Tevatron”, Proccedings of the Particle Accelerator Conference 2005.

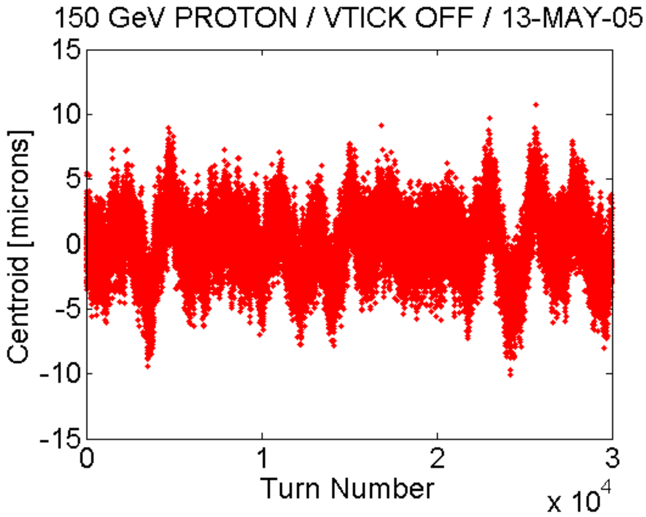
[2] J. Crisp, “Tevatron Stripline Turn by Turn Data Showing Differential Head-Tail Positions”, Fermilab-TM-2195, November 2002.



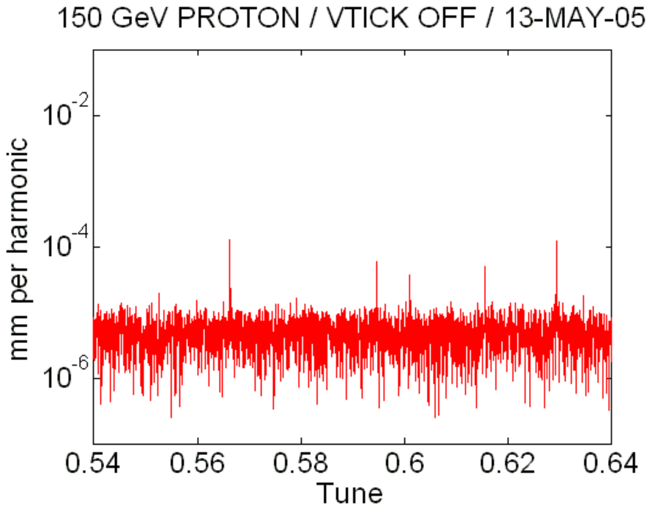
(a) A+B signals



(b) A-B signals

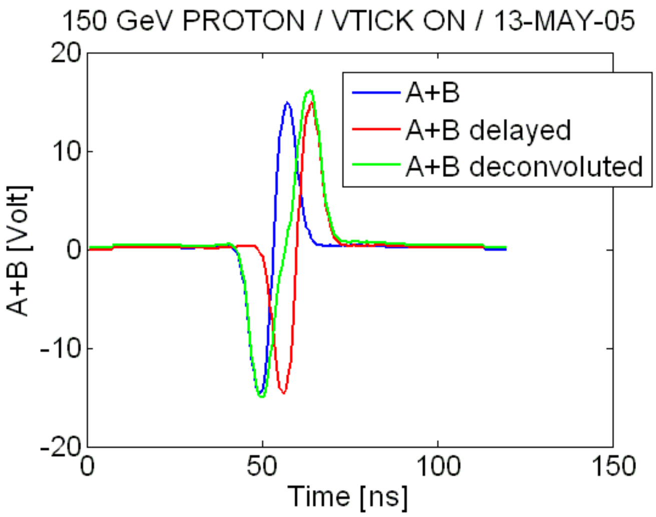


(c) Beam motion

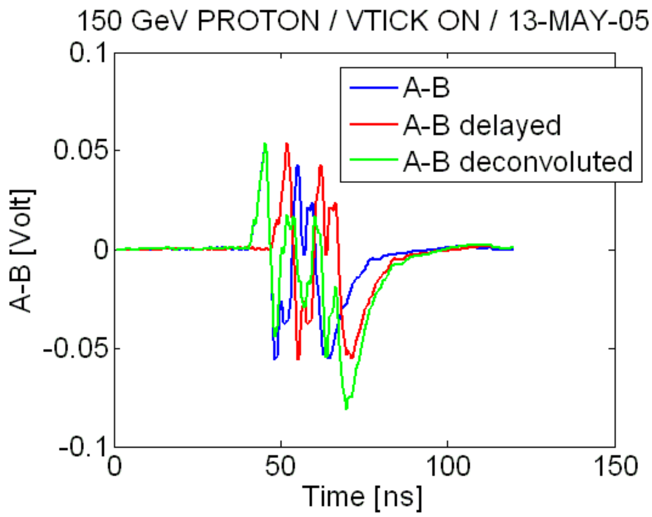


(d) Spectrum

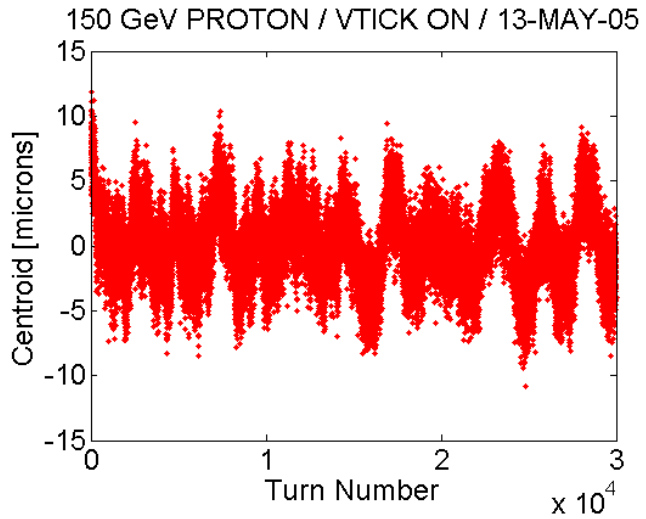
Figure 2: 150 GeV Proton / No Tickler



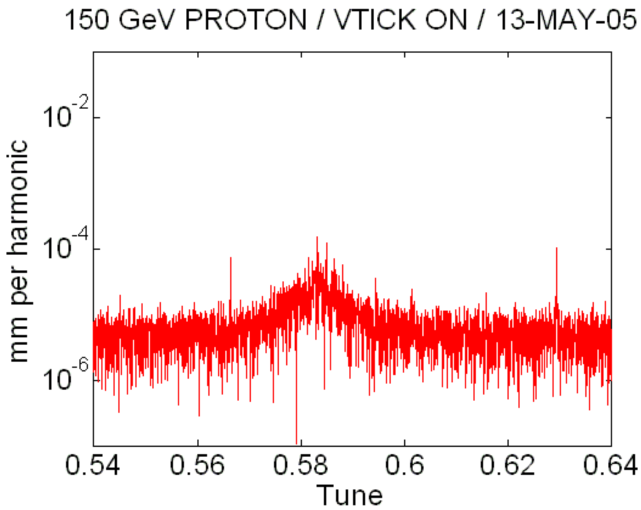
(a) A+B signals



(b) A-B signals

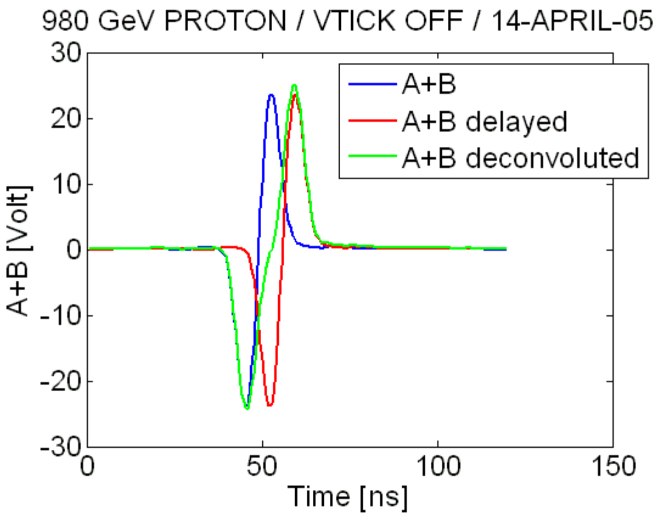


(c) Beam motion

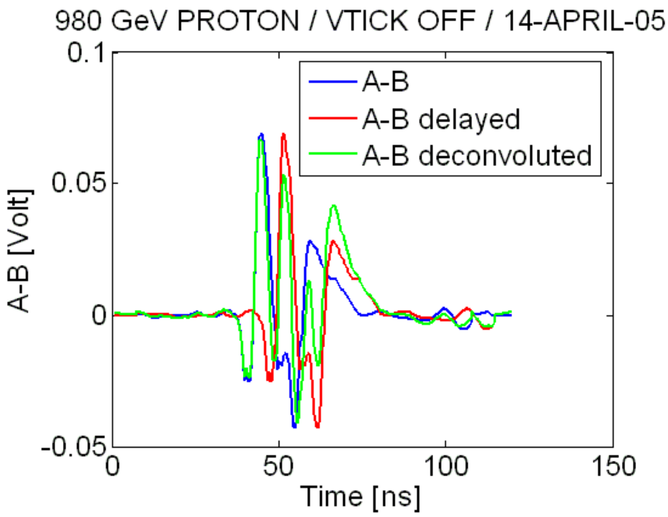


(d) Spectrum

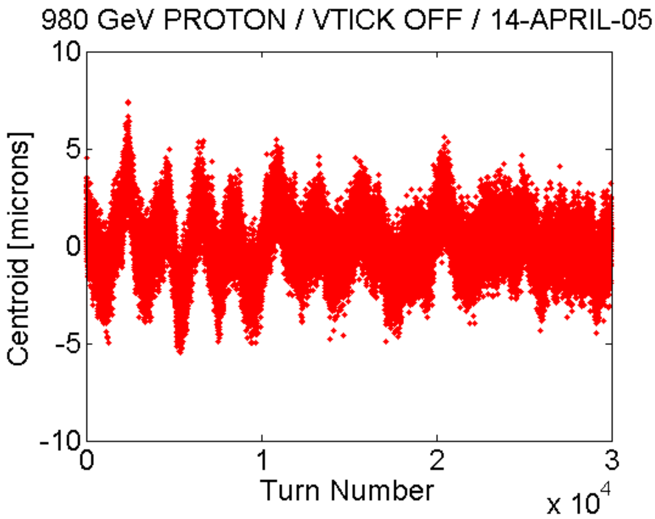
Figure 3: 150 GeV Proton / With Tickler



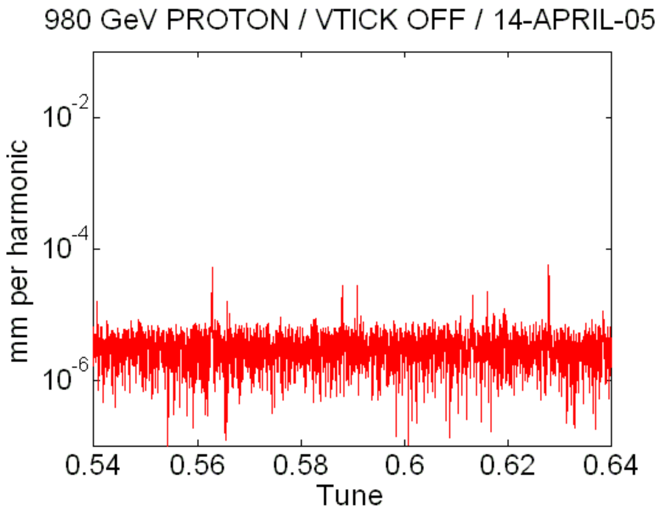
(a) A+B signals



(b) A-B signals

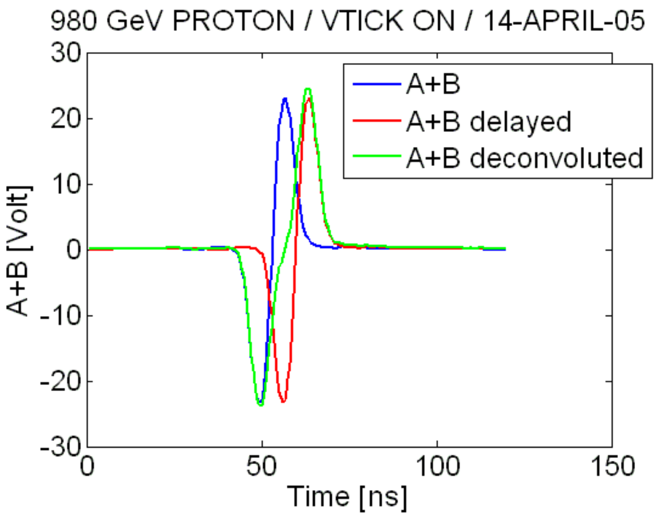


(c) Beam motion

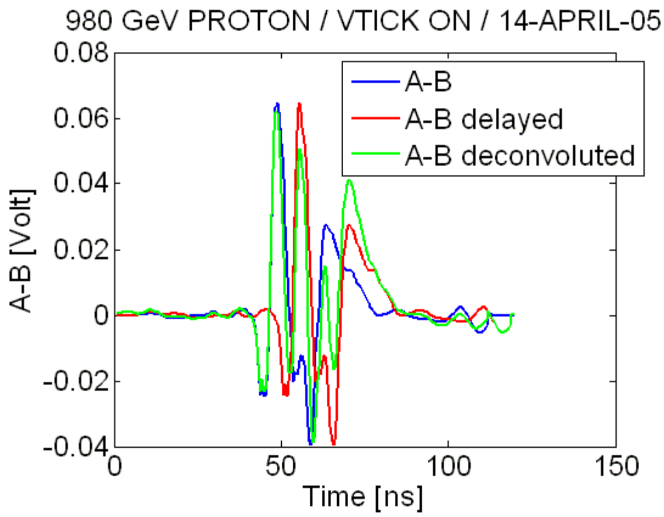


(d) Spectrum

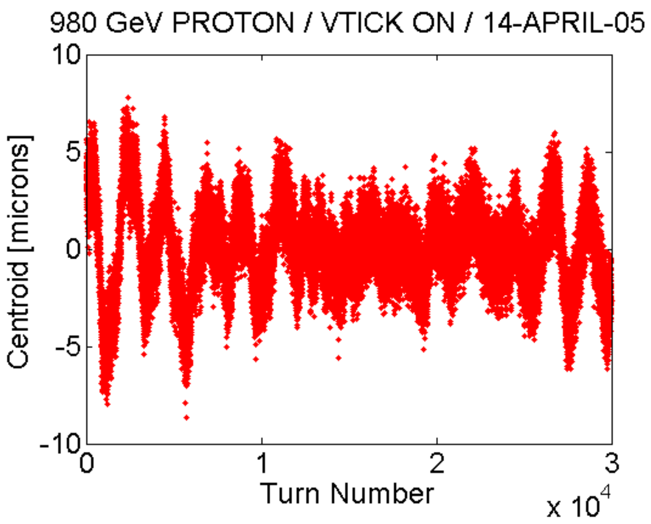
Figure 4: 980 GeV Proton / No Tickler



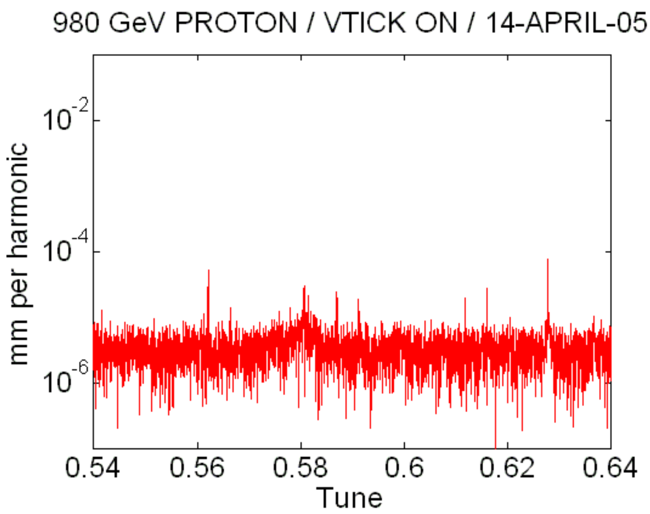
(a) A+B signals



(b) A-B signals

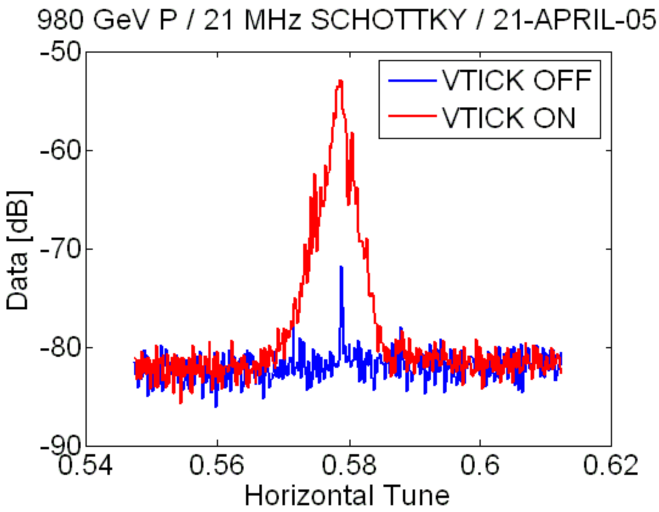


(c) Beam motion

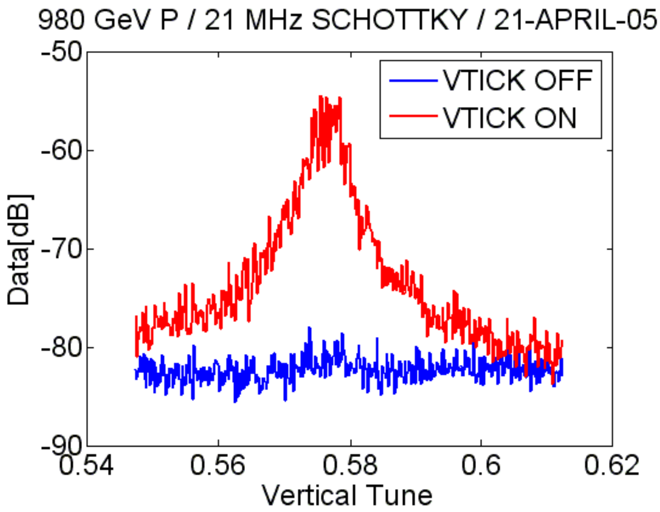


(d) Spectrum

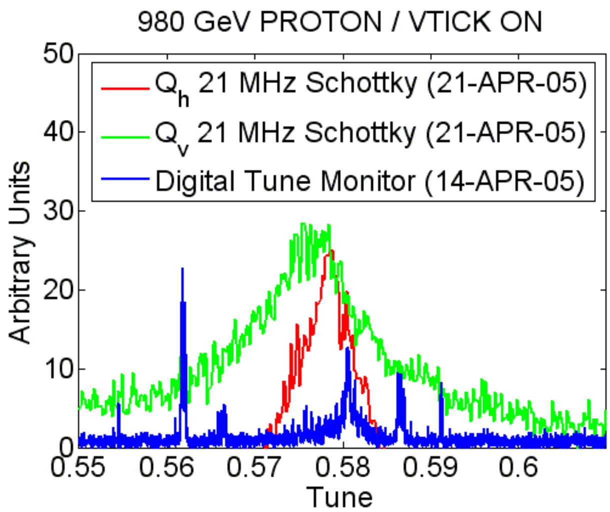
Figure 5: 980 GeV Proton / With Tickler



(a) 21.4 MHz Schottky / Horizontal tune

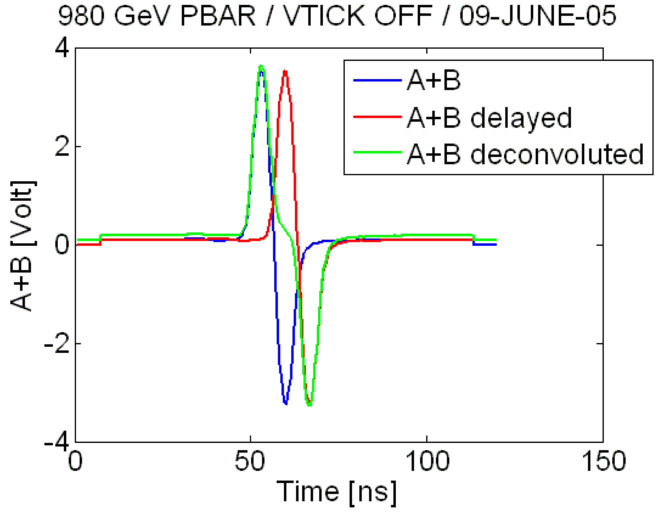


(b) 21.4 MHz Schottky / Vertical tune

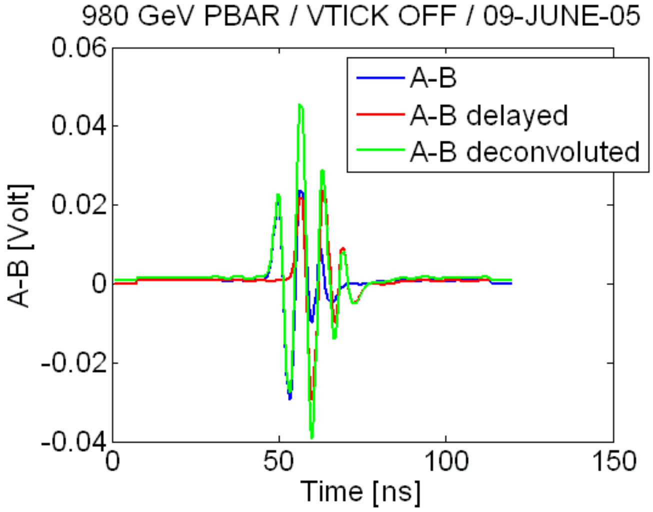


(c) Comparison 21.4 MHz Schottky / new diagnotic

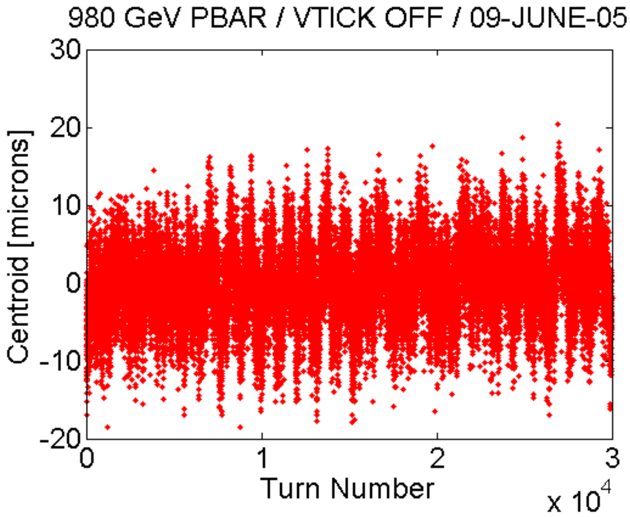
Figure 6: Signals from the 21.4 MHz Schottky monitor for a 980 GeV proton beam at the end of a store with VTICK ON and OFF (a) horizontal tune and (b) vertical tune. Figure (c) compares the signals from the 21.4 MHz Schottky with the Digital Tune Monitor for VTICK ON.



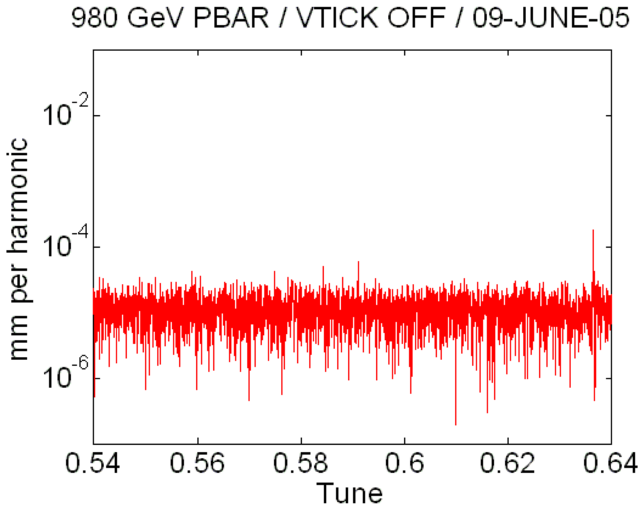
(a) A+B signals



(b) A-B signals



(c) Beam motion



(d) Spectrum

Figure 7: 980 GeV Anti-Proton / No Tickler