EXPERIENCE WITH THE 1.7 GHZ SCHOTTKY PICK-UPS IN THE TEVATRON*

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Abstract

During a 2003 shutdown, new high-frequency Schottky pick-ups were installed in the Tevatron. These devices operate at 1.7 GHz (harmonic 36000 of the revolution frequency) and can in principle be used to measure tunes, chromaticities, momentum spread and transverse emittances of individual bunches. Only the transverse signal is used, as the longitudinal is dominated by coherent signal. The default mode of operation during a store is to sequentially acquire and analyze frequency data from different sets of bunches in the machine. This function is performed by an Open Access Client (OAC) written in Java/C++, running in the background. The resulting fit parameters are datalogged and can also be plotted in ”real time” during the store. With an alternative setup, data from select bunches can be acquired continuously during the entire ramp (and squeeze), for analysis off-line. This paper describes the evolution, current status and performance of the acquisition and analysis software, and presents measurements with comparison to predictions and other measurement techniques. One example of such a measurement is the variation of beam-beam tune shift as a function of intensity and bunch position within a train.

INTRODUCTION

Identical sets of 1.7 GHz slotted-waveguide Schottky pick-ups were built and installed in both the Recycler and the Tevatron during a 2003 shutdown[1]. As both the data acquisition system and the observations differs significantly between the machines, this paper covers the experience in the Tevatron only.

The signals from the pick-ups are combined in the tunnel to generate sum and difference. These signals are band-pass filtered and amplified before they are sent to the surface building. Upstairs, the signal is gated on the relevant bunches. The gating together with the directionality of the pick-up provides excellent separation between protons and pbars. It also reduces the background noise. After gating, the signals goes thru a narrow band pass filter and further amplification before being downconverted to base band using a 1.7GHz reference locked to the Tevatron RF. Single side-band downconversion is used to avoid aliasing and preserve the assymetry due to chromaticty.

Via an analog multiplexer, the signals can then be sent to an oscillosope or a vector signal analyzer (VSA), both of which are connected to the controls network via ethernet.

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ACQUSITION & ANALYSIS SOFTWARE

The initial application software was written as a Fermilab standard controls page capable of controlling the VSA, displaying and analysing the data. However, although useful for commissioning, the limited operational usefulness of this approach immediately became clear, as the page must be open on a control room console for the data to be read out and analysed. To fully utilize the potential of the Schottky pick-ups, the data should be continuously analysed and the results datalogged. This led to the development of an open access client (OAC) which serves as a virtual front-end.

The OAC controls most aspects of the data aquisition system, including the gates, the multiplexer settings and the VSA parameters. When active, it downloads the VSA data and sends it to one or more ”fitter” subprocesses, which are based on the ROOT HEP analysis package[2]. The results are output to the control system (ACNET), and are available for fast time plots and datalogging. While the the OAC itself is written in Java, the fitter is written in C/C++ for performance.

The OAC is essentially controlled by a single ACNET parameter, defining which of a large number of predefined modes of operation to use. The mode define the gate pattern (e.g. gate all bunches, loop over subsets of bunches etc) as well as which beam is considered (proton, pbar, or switch between both).

To facilitate the control of the OAC for the end-user, and to display the fits on-line, a Java GUI (Graphical User Interface) has been provided. In addition, the original VAX/VMS application page has been retained for special studies, and a special process initiated by the sequencer takes data during ramps and squeeze. When either of these programs run, they automatically pause the OAC to avoid interference.

MEASUREMENTS RESULTS

Measurements during stores

Even though the measurement is done at ≈ 36000 times the revolution frequency, theoretically way above the bunch spectrum of the beam, there is significant coherent signal at the revolution harmonics. The OAC has the capability to auto-range using the over-voltage and half-voltage of the VSA input register to find the optimum gain.

The exact harmonic where to perform the measurment can be chosen arbitrarily within a window of a few MHz. However, the signal quality varies between harmonics. In particular, in some cases spurious peaks are observed out-

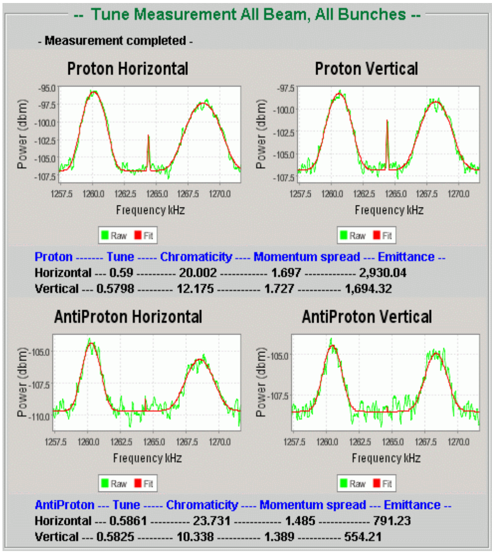

Figure 1: Online display of a randomly selected fit of the Schottky signals, for both proton and antiproton.

side of the betatron bands. These are believed to be intermodulation products coming from the strong revolution lines. The frequency for continuous operation was set to 1.265 MHz, although other harmonic numbers were also deemed suitable. It was verified that the extracted tune did not depend on the harmonic number, as long the spectra were acceptably clean.

As the betatron lines are to good approximation Gaussian, a Gaussian fit is performed to both the upper and lower sideband. Tunes are extracted from the position of the Gaussians, momentum spread from their average width, and chromaticity from the width difference. Since the downconversion frequency is locked to the RF, the revolution frequency can be fixed in the fit, which improves the stablity of the fitted tune value. An example of a fit as displayed by the GUI is shown on Figure 1.

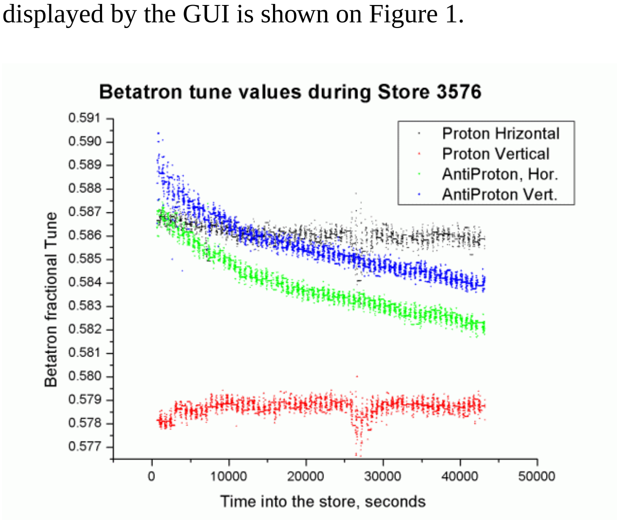

Figure 2: Proton and Antiproton fractional betatron tune during the store.

Under normal running conditions, the VSA performs 64 averages before the trace is read it out and the fit perfomed. This limits the rate to one fit every ≈ 20 seconds. The evolution of the tune during the store, shown in Figure 2, is dictated by two distinct phenomena: operational change to either the Tevatron base tune or feed-down circuitry to mitigate beam lossses, and the slowly decaying beam-beam tune shift imposed by the proton beam on the antiproton beam. As the proton emittance and intensities are monitored by other instruments during the store[4], the head-on beam-beam tune shift decay rate can be calculated, and compared to our measurement (See Figure 3) The comparison is not perfect, in part because the tune spread due to parasitic, long range, proton-antiproton collisions. This effect is large with respect to the statistical fulctuation shown in Figure 2.

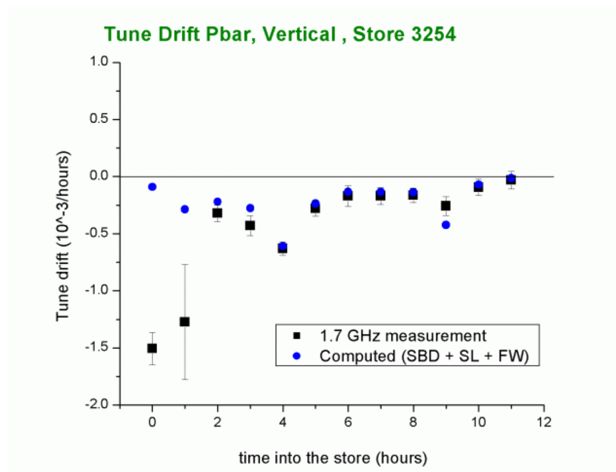

Figure 3: The antiproton tune drift during the store compared to expectation based on transverse and longitudinal emittance and intensity measurements

While the default mode of operation is to gate on all 36 bunches, and thereby averaging over all particles, the gate pattern can be arbitrarily chosen. In particular, since there is a three-fold symmetry due to the three bunch trains, it is interesting to gate on groups of three bunches with the same location within their train. In this way, one can study the tune shift due to parasitic crossing, which is expected to be different for bunches the extremities of the train. Results are shown in Figure 4, and agree with theory.

The tune accuracy is estimated to be about $2\,10^{-4}$. The width of the betatron lines, when translated in to a momentum spread, match within $\approx 5\,\%$ the momentum spread derived from the bunch length. (see figure 5). Also, the chromaticities derived from the frequency spectrum, shown in figure 6, are reasonable compared to those expected from lattice studies (We do not have other independent measurements of the chromaticities during the store). In addition, one would expect the power in the betatron bands to be proportional to emittance, assuming that the signal is true Schottky noise. However, the measured proton band power

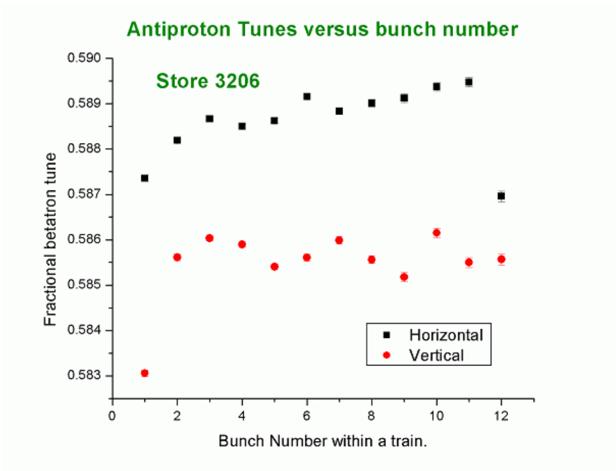

Figure 4: The antiproton tunes for all 12 bunches in the train, averaged over the three trains. The data was taken when tunes were fairly stable, staying only for a few minutes in a given gating configuration. The shift observed for the first and last bunches are signficantly larger than our statistic or systematic accuracy.

is showing large fluctuations, which seem to be related to fluctuations in the baseline of the spectrum. For antiproton signals, the band power does not fluctuate as much, but instead the baseline starts out higher, and 'decays' to an equalibrium value comparable to the proton channels on the time scale of a few hours. This effect, which has hampered attempts to measure emittance with the pick-ups, has yet to be properly understood.

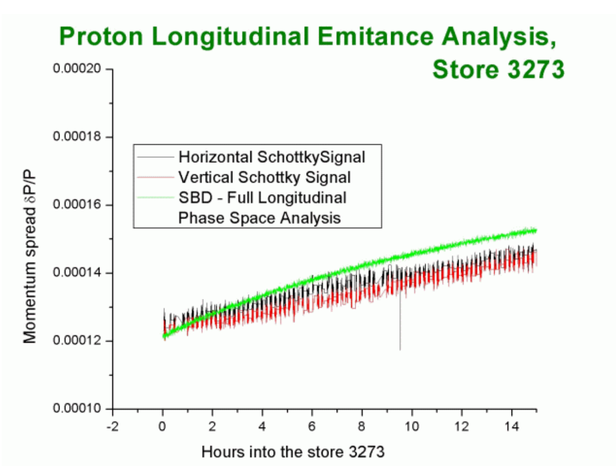

Figure 5: The momentum spread derived from the 1.7 GHz Schottky detector are consistent with those obtained from the Sample Bunch Display, which accurately measures the bunch length.

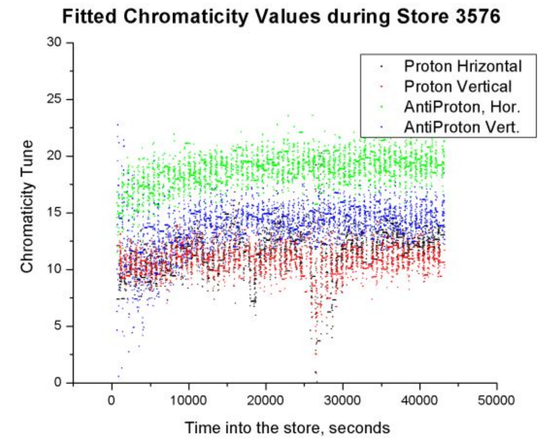

Figure 6: Proton and Antiproton chromaticities during the store.

Measurements during the ramp

During ramp and squeeze, the VSA is set up in buffer mode to aquire waterfall frequency spectra during the entire process. Is has been observed that the band power is fluctuating quite significantly. Also, the baseline is shifting in a reproducible manner. These effects need to be better understood before attempting to extract useful information (e.g. tune) from the data.

CONCLUSIONS AND OUTLOOK

The new 1.7 GHz Schottky has quickly become routinely used in operation, to a large extent due to the software that allows its results to be continuously both plotted on-line and saved for later analysis. The capability to distinguish clearly between protons and pbars have for example diagnose crossed tunes (the Tevatron is operating close to the diagonal in tune space), something that was difficult with the 'old' 21 MHz Schottky. The tune measurement is stable to about $2\,10^{-4}$, and the momentum spread and chromaticity results also agree with expectations. However, emittance measurement has ben hampered by issues with shifting baselines and the frequency spectrum on the ramp that have yet to be understood.

REFERENCES

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