TEVATRON IONIZATION PROFILE MONITORING*

A. Jansson, K. Bowie, T. Fitzpatrick, R. Kwarciany, C. Lundberg, D. Slimmer, L. Valerio, J. Zagel,
Fermilab, Batavia, IL 60510, U.S.A.

Abstract

Ionization Profile monitors have been used in almost all machines at Fermilab. However, the Tevatron presents some particular challenges with its two counter-rotating, small beams, and stringent vacuum requirements. In order to obtain adequate beam size accuracy with the small signals available, custom made electronics from particle physics experiments was employed. This provides a fast (single bunch) and dead-timeless charge integration with a sensitivity in the femto-Coulomb range, bringing the system close to the single ionization electron detection threshold. The detector itself is based on a previous Main Injector prototype, albeit with many modifications and improvements. The first detector was installed at the end of 2005, and the second detector during the spring shutdown. The ultimate goal is to continuously monitor beam size oscillations at injection, as well as the beam size evolution during ramp and squeeze. Initial results are very encouraging.

INTRODUCTION

To diagnose emittance blow up at injection and on the ramp, and Ionization Profile Monitor (IPM) has been developed for the Tevatron. The goal was to be able to detect beam size oscillations at injection of 10% or less for both protons and antiprotons. Timing is used to separate injected bunches from circulating ones, as well as to separate proton bunches from antiproton bunches. This required very sensitive electronics with good time resolution. Custom electronics developed for Particle Physics experiments was employed to achieve this. The rms noise level achieved for 60ns integration intervals is a little more than 1 ADC count (2.6fC). With a detector gain of 10,000 (provided by a microchannel plate), this corresponds to about 2 primary ionization electrons. A gas injection system is used to generate a local pressure bump, in order to have enough primary electrons for single bunch measurements. The details on the instrument and electronics design are described in [1].

INITIAL RESULTS

The first IPM detector, a vertical unit, was installed during an unscheduled downtime in December 2005, and the first measurements were made in early 2006 using a reduced read-out system (40 out of 128 channels) with a 1 cm active width. After solving some initial grounding issues, which caused the distributed clock and timing signal to couple into the input signal, clean single pass beam profiles were obtained both at injection and top energy. Small beam related parasitic signals were observed with no microchannel plate gain, but they could be removed by subtracting a reference measurement obtained, since they were very reproducible from turn to turn.

Due to a high voltage sparking problem, initially the detector could only be operated at ~25% magnetic field and 70% electric field. This caused a widening of the measured profiles, estimated to 0.5mm (added in quadrature). However, when correcting the result for this effect, the measured beam sizes were in good agreement with those measured with the flying wires.

A sizeable injection mismatch yielding beam size oscillations of ±20% in the vertical plane was also observed[1]. By chance, the phase of the oscillation observed by the IPM is such that the first two turns are nearly identical. Therefore, the mismatch could not be detected with the Optical Transition Radiation Monitor[2], since it can only resolve the two first turns because of its slow camera.

POST-SHUTDOWN RESULTS

After removing the vertical detector for modifications during the 2006 spring shutdown, both horizontal and vertical detectors were (re)installed in the machine. For initial commissioning, both detectors were fitted with a reduced readout system for commissioning. Up to this point, only the vertical system has been tested.

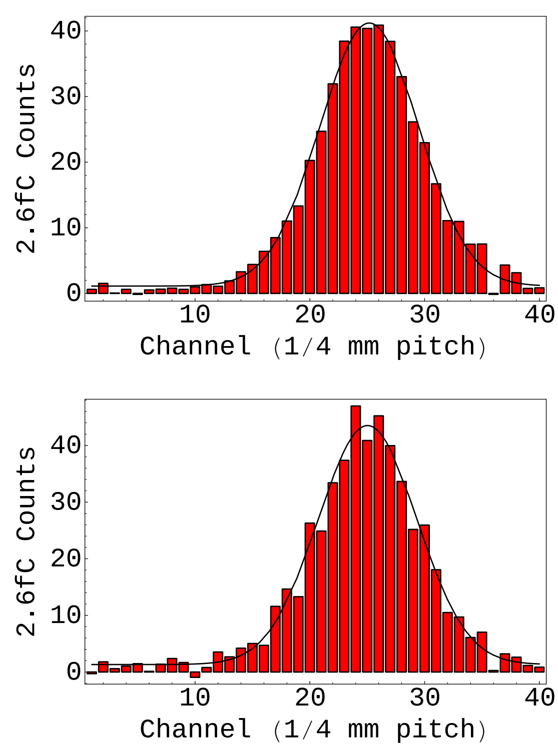

Figure 1. Single turn (bottom) and 30-turn average (top) profiles of a single proton bunch at 150GeV.

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Coasting beam

Measurements were made on coasting beam at both injection and top energy. At injection (see Figure 1), the observed vertical beam size was about 1.1mm, and the rms fluctuation of the single-turn beam size measurement was about 60µm between consecutive measurements. At 980GeV (see Figure 2), the observed beam size was about 0.55mm, and the fluctuations between consecutive measurements was 20µm. This gives an idea of the sensitivity. In both cases, the total observed signal per bunch profile was about 1300fC, corresponding to about 750 primary ionization electrons.

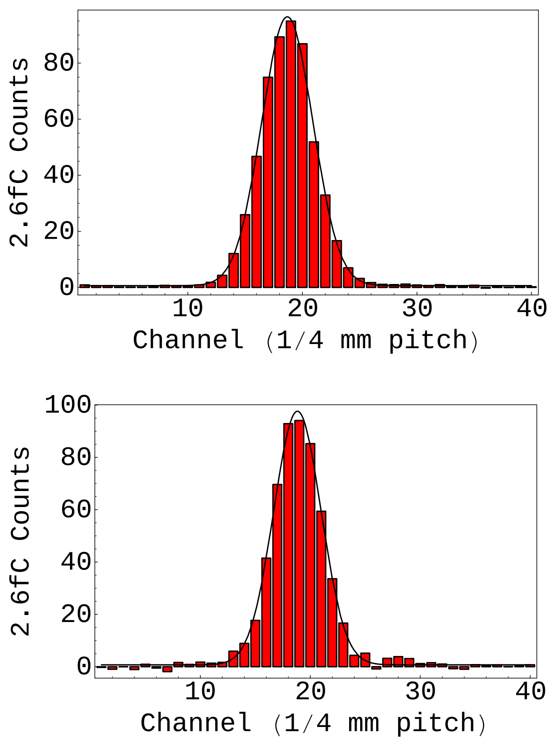

Figure 2. Single bunch (bottom) and and 30-turn average (top) profiles of a single proton bunch at 980GeV

Injection

Measurements were also made at injection. These measurements confirmed the previous observation of an injection mismatch yielding vertical beam size oscillations of ±20% (see Figure 3). Theoretically, this should result in an emittance blow-up of 10%, and a corresponding loss of luminosity. Efforts are underway to correct this optics mismatch.

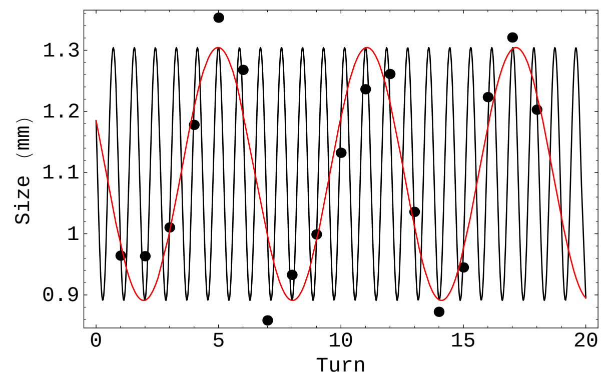

Figure 3. Turn-by-turn beam size measurement at injection, taken during a collider shot. The oscillation frequency is twice the tune (black line), but due to aliasing it appears to be lower (red line).

Sensitivity to operating conditions

The sensitivity of the measurement to the operating conditions has been studied by varying some input parameters.

As expected, the measured beam size scales with the magnetic field as

$$\sigma_{measured} = \sqrt{\sigma_{real}^2 + \frac{k}{B^2}} \qquad (1)$$

with a resolution of 0.1mm at the nominal field of 0.2T (see Figure 4). Since the effect adds in quadrature, this is only a 2% effect for a 0.5mm beam size. Some increase in total profile signal was also observed as a function of magnetic field. This is most likely due to increased detection efficiency. Although the pulse height distribution of the MCP is exponential, on average a little bit more than one primary electron is needed per channel to give a detectable signal. Hence, as the electrons are focused onto fewer channels, more of the primary electrons are detected.

The effect of the electric drift field on the measured profile widths was found to be negligible at nominal B-field. However, the total signal peaks around 7kV of applied voltage (see Figure 5). This corresponds to a kinetic energy of the electrons striking the MCP of close to 3keV, which is where the MCP is advertised to have its highest detection efficiency for electrons.

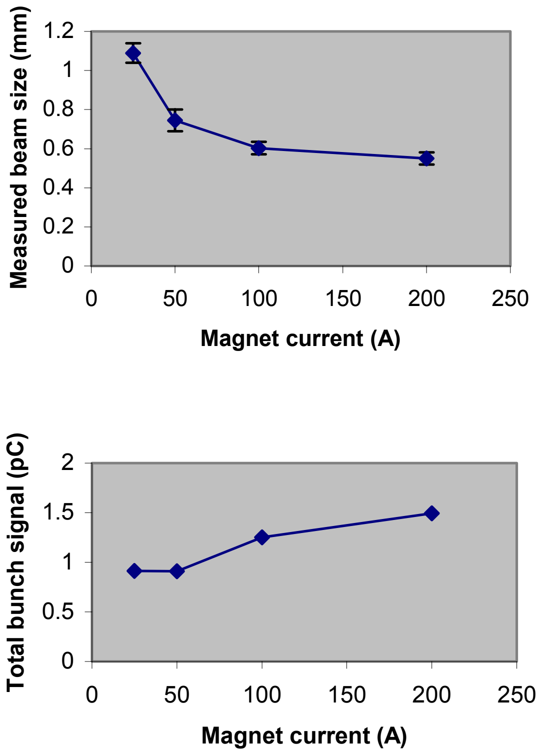

Figure 4. Measured beam size (top) and total signal (bottom) as a function of magnet current. 200A correspond to the nominal field of 0.2T.

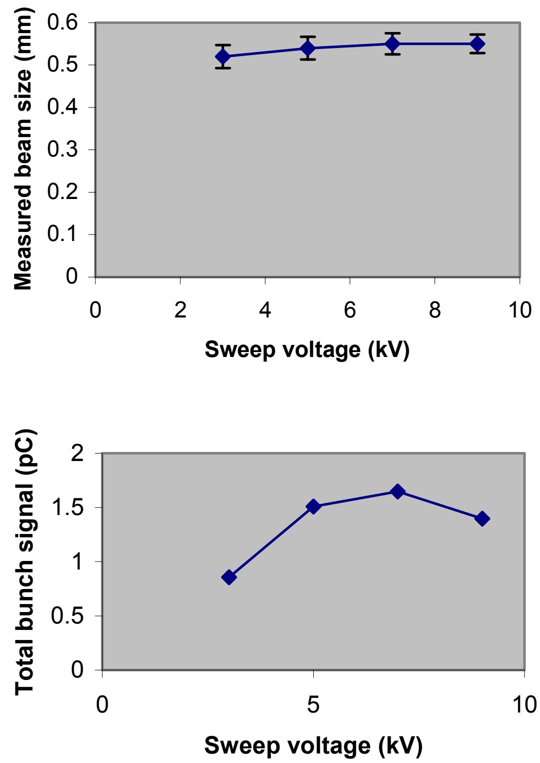

Figure 5. Measured beam size (top) and total signal (cyan) as a function of sweep voltage. 7kV correspond to a electron kinetic energy of about 3keV.

Comparative Measurements

The IPM measurement was compared to the flying wire data taken at 980GeV during one of the early stores after the shutdown (see Figure 6). Tuning of the abort gap cleaner timing had blown up certain bunches in this store, which is clearly seen by both detectors. On the whole, the relative agreement between the two instruments is quite remarkable. From the MAD lattice file, the expected relative difference in beam size seen by the two detectors should be 13%. The measured difference is only a few percent, but this discrepancy is well within the accuracy of the optics model. Comparisons have yet to be made with measured optics functions.

Antiprotons

With the reduced readout system and the resulting limited active width, only one beam can be measured at a time. So far, measurement have focused on protons, and no measurements have yet been made on antiprotons. Depending on the antiproton bunch intensity, it is possible that a slight increase in vaccum pressure may be needed to measure antiprotons with good accuracy at injection.

SUMMARY AND CONCLUSIONS

Single bunch turn-by-turn profile measurement using Ionization Profile Monitors have been demonstrated in the Tevatron. The observed sensitivity for nominal intensity proton bunches is 20μm at 980GeV and 60μm at 150GeV, and the accuracy (systematic error) is estimated to a few percent. The sensitivity can be improved by increasing the vacuum pressure, which may be needed for pbar measurements.

Turn by turn measurements of beam size have revealed an injection mismatch of the proton bunches which is estimated to cause about 10% emittance increase.

In the near future, the horizontal detector will be commissioned and both detectors be fitted with full readout systems. Further work will include measuring antiprotons and correcting the detected mismatch. Some minor electronics problems also need to be worked out.

REFERENCES

[1] A. Jansson et al, The Tevatron Ionization Profile Monitors, 12th Beam Instrumentation Workshop, Fermilab, Batavia, IL, 2006.

[2] V. Scarpine et al, Initial OTR Measurements of 150 GeV Protons in the Tevatron at FNAL, 12th Beam Instrumentation Workshop, Fermilab, Batavia, IL, 2006.

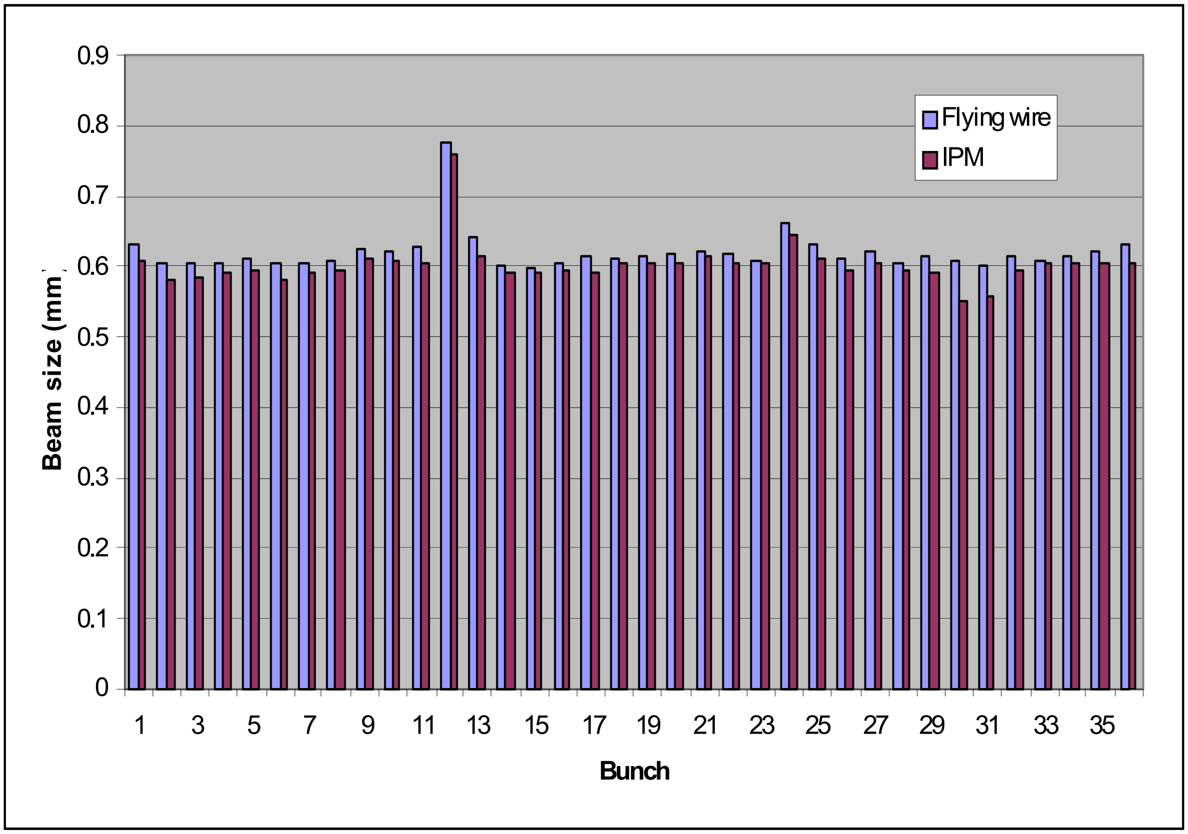

Figure 6: Comparison between beam sizes measured by Flying Wire and IPM at 980GeV, for all 36 bunches. The difference in ratio for bunches 30 and 31 is a known problem with the IPM electronics, causing the revolution marker to couple into the input signal.