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TUNE-SHIFT COMPENSATION USING THE TEVATRON ELECTRON LENS

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Abstract

The Tevatron Electron Lens was originally designed to alleviate the tune shift and spread induced in Tevatron antiproton bunches from interactions with the proton bunches. We report recent developments and successful results of such tune-shift compensation. Lifetime measurements are central to our data and the basis of our analysis. Future goals and possible uses for the lens are also discussed.

INTRODUCTION TO THE TEVATRON ELECTRON LENS

A description of the Tevatron Electron Lens (TEL) has been described in several previous articles, including a detailed motivation for tune-shift compensation of the TevatronÕs beam-beam interaction during Run II [1,2]. Antiproton bunches in the Tevatron suffer a tune shift due to their interaction with proton bunches at the collision points. In addition, parasitic crossings (long-range interaction points) and nonlinear fields cause a spreading of a bunchÕs tune. These two effects create a large, unwieldy tune footprint that encourages emittance growth and low average luminosity [3].

Overview of the TEL

The TEL consists of an electron gun placed in a solenoid that directs the low-energy electron beam along the field lines. A second, superconducting solenoid bends the beam along the path of the antiprotons, and a third bends the electrons back out where they are collected [4]. Figure 1 illustrates most of the hardware, with a rendering of the electron beam interacting with the antiproton bunches while avoiding the protons. The central magnet is two meters long, and beam position monitors (BPMs) are located near both ends to ensure that the electrons and antiprotons are collinear along the entire magnet length [5].

The goal of the TEL is to provide a radial space-charge force on the antiprotons during every pass that is opposite the tune shift caused by the protons. Adjusting the electron-beam current for each bunch will allow the space-charge force to mimic the linear forces caused by the protons. Creating nonlinear fields to decrease the tune spread within individual bunches is also being addressed [6].

The changing of the gun

At the beginning of the current year, the electron gun was replaced with one of a different geometry. The initial gun had a large measured perveance (possibly as high as 5.6 μP) and a flat transverse current distribution, both in accordance with its design goals. The ÒflattopÓ beam profile, illustrated in Figure 2, produced nicely linear focusing forces on the immersed antiproton bunches. However, the steep edges on the sides created extremely nonlinear forces on antiprotons with large betatron amplitudes. These forces excited oscillations until the antiprotons were lost.

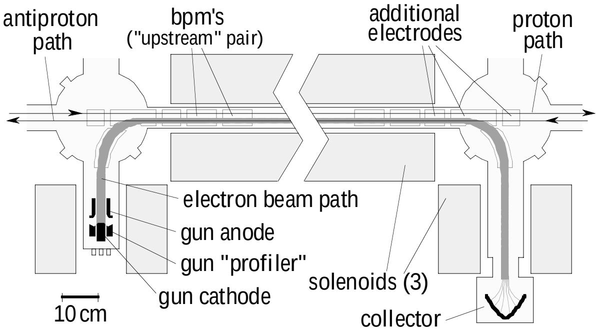

Figure 1: An approximate CAD drawing of the TEL apparatus. The electron beam as drawn interacts with the antiprotons.

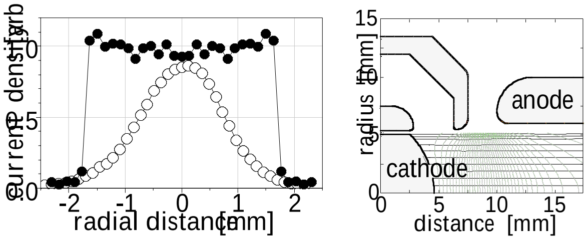

Figure 2: Comparison of the beam profiles of the Òflattop gunÓ and ÒGaussian gunÓ and a cross section of the latter.

This unfortunate effect spurred the design of a new gun with a very smooth, almost Gaussian-shaped profile. The perveance is only 1.8 μP, but the central current density is about the same than that of the Òflattop gun.Ó Figure 2 also shows a cross-section of the ÒGaussian gunÓ and its current profile, and more description of the changes can be found in another publication [5].

Schottky detectors in the Tevatron are used to measure the tunes of the bunches. During one test of the lens, three proton bunches (without antiprotons) were injected into the Tevatron, and the observed (fractional) horizontal tune of all three bunches was 0.5795. Then the lens was pulsed such that it only intercepted one of the three bunches. The two spectra that were associated with the other two bunches

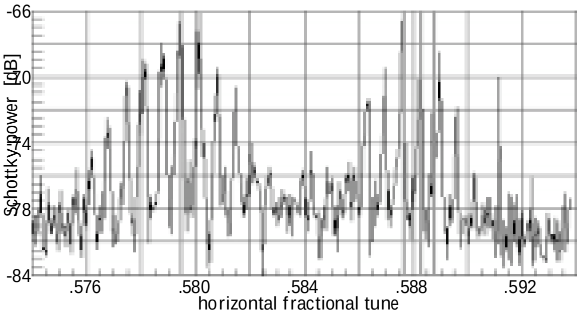

Figure 3: Schottky spectra while one bunch is tune-shifted.

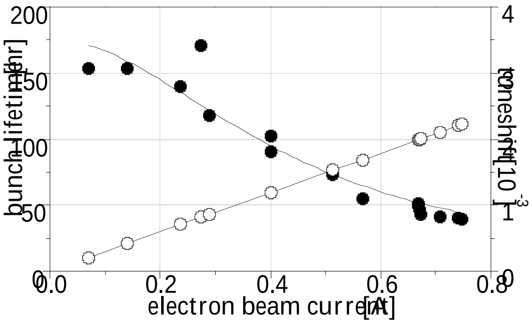

Figure 4: Tune shift (open circles) and lifetime (closed circles) depend on beam current.

remained unaltered, but the tune of the third shifted by 0.0082 to 0.5877, and its spectra appeared quite stable. Figure 3 shows the resulting spectra; the two untouched bunches produced the set of peaks on the left, and only after turning the TEL on did the third bunch produce the set on the right.

Changing the electron-beam current changes the observed tune shift and the losses of bunch particles. Figure 4 illustrates the nearly linearly increasing tune shift (open circles).

EFFECTS ON BUNCH LIFETIME

During most Tevatron operations, the antiproton and proton emittances have been larger than expected, especially toward the end of stores. Due to this, the Òflattop gunÓ always reduced bunch lifetime. The ÒGaussian gun,Ó however, was able to preserve the original lifetime of a bunch. Figure 4 shows how increasing the peak current from the latter gun decreased the observed lifetime; nevertheless, these values rival the typical lifetimes for the Tevatron and corroborate our belief that a smoother profile preserves the bunch emittance.

Another cause of bunch blowup could be turn-by-turn fluctuations of the electron beam current. During typical studies, these fluctuations were found to be approximately 0.1%. In order to assess the effect of , measurements of purposefully large current fluctuations were taken. Figure 5 presents this data, where 0.1% corresponds to less than 1 mA and therefore about 0.01 π-μm/hr emittance growth.

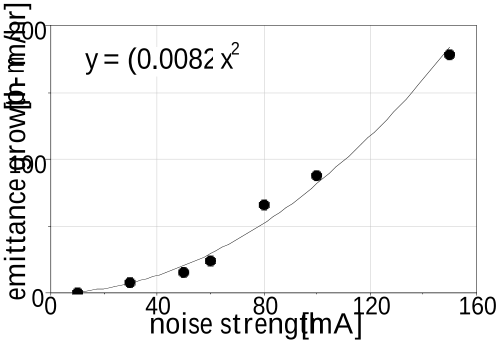

Figure 5: Emittance growth scales with the square of current fluctuations.

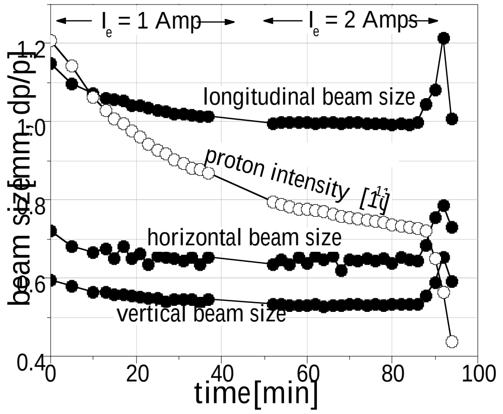

Figure 6: Bunch sizes stabilize after TEL collimates them.

TEL as a soft collimator

An interesting application of the Òflattop gunÓ is to slowly eliminate bunch particles with large betatron amplitudes, thereby leaving a lower-emittance bunch. Figure 6 shows the size of a particular bunch while it was collimated in this manner. One amp of electron-beam current was applied initially. Many particles were quickly lost, decreasing the beam size; however, the loss rate began to level off because the remaining core bunch was stable. To confirm our understanding, the beam current was doubled to two amps, but the beam size was still secure.

Also shown is the bunch intensity (open circles) in units of 10^{11} particles, and the linear attrition rate indicates that there was a uniform, slow diffusion of particles in phase space, which caused a small amount of continuous losses.

At the very end of the study, the electron beam was misaligned purposefully. The bunch, now passing through the highly nonlinear beam edge, quickly gained emittance and lost particles.

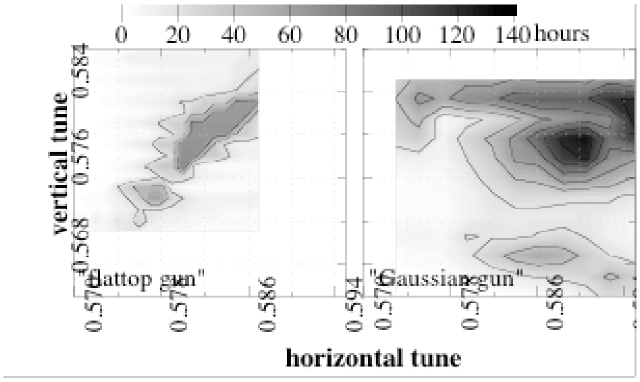

Figure 7: Working-point scans for the Òflattop gunÓ and the ÒGaussian gun.Ó

Dependence on working point

Figure 7 supplies cogent evidence that a smoother beam profile can preserve the bunch lifetime. Two working-point scans (measuring lifetime at various horizontal and vertical tunes) were conducted: the first with the Òflattop gun,Ó the second with the ÒGaussian gun.Ó While the two scans did not cover the exact same regions of tune space, most of the scans overlap each other. The plots have identical boundaries and color scales, and contours are drawn every 20 hours. The Òflattop gunÓ could not surpass eighty hours, and its highest lifetimes were confined to a small diagonal region. On the other hand, the ÒGaussian gunÓ offered decent lifetimes over a much broader area and sometimes exceeded 120 hours. Again, these values are indistinguishable from typical Tevatron lifetimes. The tune shift in both scans was set to about 0.004.

FUTURE GOALS

The TEL has a number of ongoing projects and upgrades under development. For the past 18 months, the lens has been needed to clean the abort gap of residual particles. Recent tests have pulsed the lens for this cleaning operation in addition to tune-shift compensation [5].

Improvements to the TEL

Currently we have additional solenoids that will be installed in the bends; at the same time, the gun and collector will be moved so that the beam needs only to bend about 53 degrees, instead of the current 90 degrees. These changes will stabilize current-dependent position changes and facilitate a larger beam diameter without scraping along the beam pipe.

The goal of extracting more current from the ÒGaussianÓ gun requires more voltage pulsed to the anode. A new pulse modulator will do this and hopefully provide quicker rise and fall times. In addition, the pulse-to-pulse fluctuations will hopefully be decreased further with a different design.

Ongoing work on a better BPM system has shown promising results. These BPMs have a significantly smaller frequency and intensity dependence than the previous model, and our hope is to install them within this year.

Lastly, new solenoids for an entire new lens are currently being fabricated.

Other uses for the TEL

The proton bunches in typical Tevatron stores suffer more beam-beam effects than expected, and the sheer number of protons makes their losses as problematic as the antiprotons. There are proposals to perform tune-shift compensation on protons instead [7].

Another source of emittance blowup in the Tevatron is a head-tail instability in proton bunches while the Tevatron is at low energy. An idea of stabilizing the effects of collective oscillations with the lens should alleviate this problem.

Integrating tune-shift compensation with Run II operations is our highest priority, but the number of other ideas by which the TEL can be useful to the Run II program is always increasing. Intense discussion of incorporating at least one into the LHC design and other accelerators is another tribute to our ongoing success.

ACKNOWLEDGEMENTS

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REFERENCES

[1] K. Bishofberger, et al., Advanced Accelerator Concepts Workshop Õ02, pp. 821-9.
[2] V. Shiltsev, et al., PAC Õ01, pp. 154, 8.
[3] T. Sen, et al., this conference.
[4] K. Bishofberger, et al., PAC Õ01, pp. 2076-8.
[5] X. Zhang, et al., this conference.
[6] V. Shiltsev, et al., Physical Review Special Topics Ð Accelerators and Beams, v. 2, pp. 071001.1Ð21. 1999.
[7] V. Shiltsev, et al., Beam-Beam Workshop Õ03, Brookhaven National Laboratory, 2003.