RECENT TEVATRON OPERATIONAL EXPERIENCE *

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Abstract

Over the past year Tevatron has been routinely operating at initial luminosity over 3×10^{32} cm^{-2}s^{-1}. The high luminosity regime highlighted several issues that became the focus for operational improvements. In this report we summarize the experience in such areas as mitigation of particle losses, maintaining orbit and optics stability, and identification of aperture restrictions.

INTRODUCTION

The upgrade program of the Tevatron collider came to an end after the shutdown in 2007. Since this time the Tevatron has been operating in a stable configuration. Nevertheless, several operational changes implemented throughout 2008 allowed to increase the limit of attainable initial luminosity and improve the machine reliability thus providing higher rate of luminosity integration. For most of 2008 and the beginning of 2009, the Tevatron has been operated at initial luminosities above 3×10^{32} cm^{-2}s^{-1}, with a record of 3.5×10^{32} set in December of 2008. The luminosity integral per week reached the record of 72 pb^{-1}.

Arguably, stability is the key reason to the achieved high operational performance of the entire collider program. Many efforts were undertaken by the run coordinator team and throughout the collider complex to ensure that beams with repeatable properties are delivered to the collider from the upstream accelerators on a shot by shot basis [1]. By this an optimal tuning of the collider was established and the team was able to concentrate on improving efficiencies through the cycle as well as machine reliability.

One of the factors contributing to the increased luminosity integration rate was the reduction of time of shot setup in the collider cycle. For instance, the average shot setup which is the time between the termination of one high energy physics store and the beginning of the next was shortened from about 2 hours to below 1 hour.

In addition, increases in stability specific to the Tevatron operation including an analysis of existing limitations and details of these improvements implemented in 2008 will be discussed.

OVERVIEW OF COLLIDER OPERATION

The Tevatron is a superconducting proton-antiproton collider ring in which beams of the two species collide at the center of mass energy of 2×0.98 TeV at two experiments [2]. Each beam consists of 36 bunches grouped in 3 trains of 12 with 396 ns bunch spacing and 2.6 μs abort gaps between the trains. The beams share a common vacuum chamber with both beams moving along helical trajectories formed by electrostatic separators.

A collider cycle consists of the following stages:

1. Proton injection: Prior to January of 2009 proton bunches were injected into the Tevatron one by one. After the multibatch injection was commissioned, two proton bunches at a time are loaded in order to speed up shot setup.

2. Antiproton injection: During this phase antiproton bunches are injected in batches of four. Long-range beam-beam effects cause loss of 5 to 10% of the proton beam intensity. The proton loss rate depends strongly on the chromaticity. Hence, special attention was paid to accurate measurement of the chromaticity and compensation of the chromaticity drift at 150 GeV.

3. Energy ramp: The beams are accelerated to a flattop energy of 980 GeV. Particle losses of about 2% for both beams are caused by long-range beam-beam effects and aperture restrictions at locations with large dispersion. Maintaining orbit stability during this phase was found to be the most important factor allowing to avoid excessive losses. Upon reaching flattop the antiproton emittance is increased by ∼20% in order to reach the optimal proton/antiproton emittance ratio [3, 4].

4. Low-beta squeeze: During the low-beta squeeze two significant changes occur - the β^* value is being gradually decreased from ∼1.5 m to 0.28 m in 25 steps over 120 s (hence the name squeeze) and the helical orbits change their shape and polarity from injection to collision configuration. The latter poses a serious limitation since the beam separation at several long-range collision points briefly decreases from 5-6σ to $\sim2\sigma$. At this moment a sharp spike in losses is observed.

5. Initiate collisions: The beams remain separated at the main IPs until the head-on collisions are initiated by ramping up the separators adjacent to the collision points. Also, the chromaticity is lowered from 12 units in the low-beta squeeze to 5-6 in the collision mode.

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6. Remove halo: This is a rather lengthy process (8 min) during which the collimators are moved closer to the beams under feedback control from beam loss monitors. Better orbit repeatability provided opportunity to calculate desired collimator positions which allowed the process to be faster.
7. High energy physics run: Upon finishing the halo removal process the experiments start taking physics data. A typical store lasts for 16 hours.

The points of concern in Tevatron operations are:

- Particle losses that cause a controlled abort or a quench of superconducting magnets and consequently loss of the entire beam.
- Particle losses that decrease luminosity delivered to experiments.

Obviously, the biggest impact on the collider program is exerted by a loss of store due to a quench because of the subsequent lengthy cryogenic recovery process and the necessity to accumulate antiprotons for the next shot. Quench data from October 2007 has been analysed categorize the reasons for the quench during different portions of Tevatron collider cycle (Fig.1). Of the total 73 quenches, 31 happened during HEP runs, 21 in the low-beta squeeze, and 21 were almost evenly distributed over other stages. Note that only 1 of the HEP quenches was due to beam dynamics induced losses, the rest being caused by component, cryo, vacuum, or power failures. On the contrary, 18 of the quenches in the squeeze are attributed to the beam-beam related losses of protons. It is also important that a loss of store in the low-beta squeeze eliminates the entire stack of antiprotons that requires lengthy replenishment. Due to this reason much of the machine beam study time was targeting elimination of losses in the squeeze.

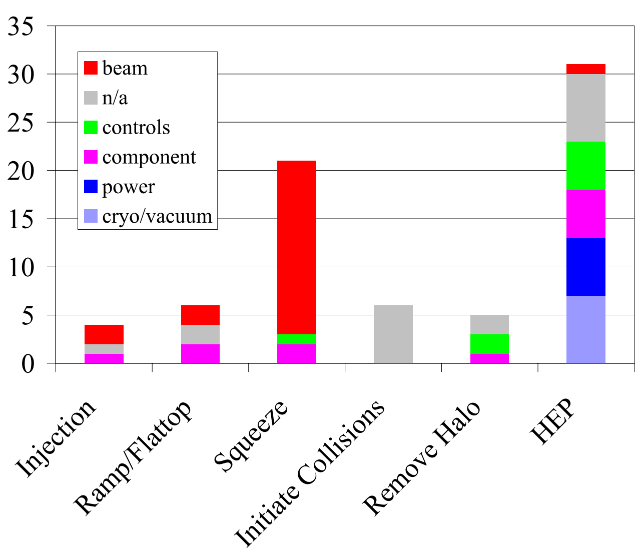

Figure 1: Occurrence of quenches over the Tevatron collider cycle.

ORBIT STABILIZATION

Orbit stabilization is a software process that uses ∼10 dipole correctors and all ring BPM to provide an orbit correction to reduce errors with respect to a standard BPM reference file. Most orbit errors are due to mechanical motion of the low-beta quadrupoles to environmental temperature effects. Orbits stabilization employs 2 types of orbit corrections. 1) Corrects orbits to BPM reference file when the Tevatron reaches lowbeta, collisions and at the end of a store. 2) During High Energy Physics (a store) data taking, the orbit is corrected every 30 sec to the orbit at the beginning of the store.

Fig. 2 shows the relative store-to-store changes of betatron tunes for a two year period. A remarkable reduction of frequency and magnitude of the tune changes is observed after implementation of the orbit stabilization.

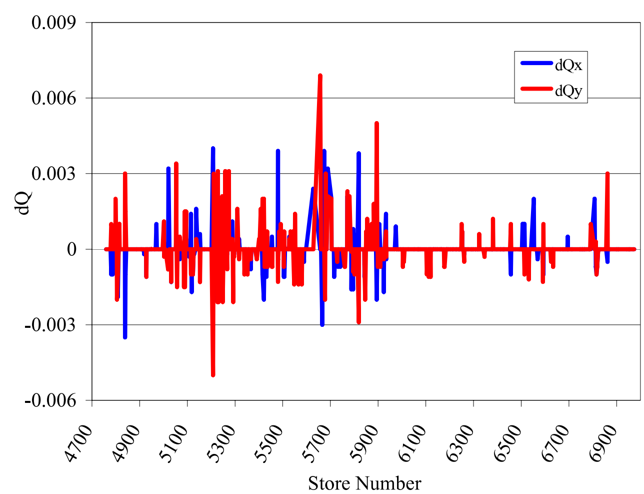

Figure 2: One year history of store to store betatron tune changes. Orbit smoothing procedure was implemented after store 5903.

LOW-BETA SQUEEZE

Aperture Restriction

Early in 2008 it was noticed that particle losses during the low-beta squeeze are very sensitive to the orbit through the CDF interaction region. This suggested the existence of an aperture restriction. Using specially designed orbit bumps the restriction was confirmed and located. It was caused by sagging of a section of the beam pipe immediately outside of the particle detector about 4 m from the interaction point. During a one week long shutdown in October 2008 the vacuum pipe was relocated and the restriction removed.

Beam-Beam Effects and Chromaticity

One of the distinct features of proton beam dynamics during the low-beta squeeze is a noticeable bunch shortening at the moments of large losses, specifically around steps

14 and 15 when beams come within 2σ from each other at 3 long range collision points. This motivated the study of the dependence of long range beam-beam effects on chromaticity. Because of the absence of large tune spread caused by head-on beam-beam interaction the chromaticity was kept at 12-14 units to ensure coherent stability. Figure 3 shows the calculation of the tune chromaticity at step 14 for different values of beam-beam parameter. A large non-linear contribution is observed, which causes particles with large momentum deviation to approach the 3/5 resonance that is known to cause fast particle losses. A numerical simulation with the weak-strong beam-beam code LIFETRAC [5] predicted that lowering chromaticity would reduce the fast loss at steps 14 and 15 of the squeeze (Fig. 4). Simulation with strong-strong code showed that low chromaticity would not affect coherent stability of the beams [6].

The chromaticity at steps 14 and 15 was lowered to 5 units in December of 2008 and an immediate improvement in the beam loss was observed (Fig. 5).

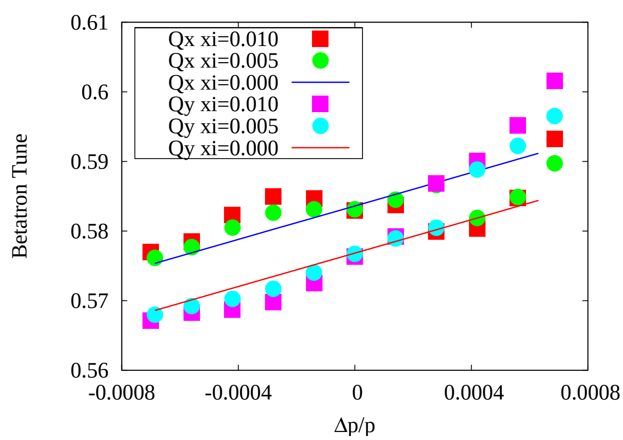

Figure 3: Tunes vs. momentum deviation for different values of beam-beam parameter.

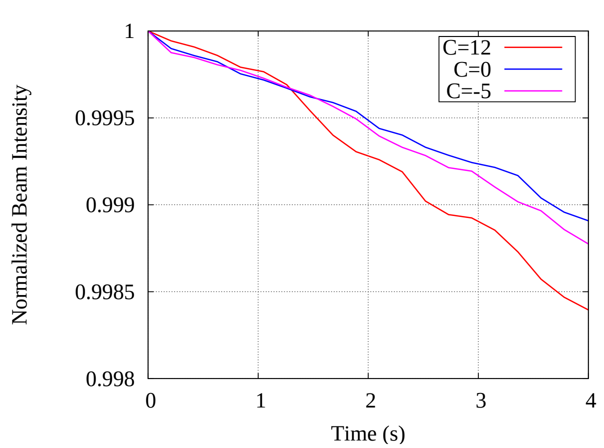

Figure 4: Beam loss at low beta step 14 vs. chromaticity.

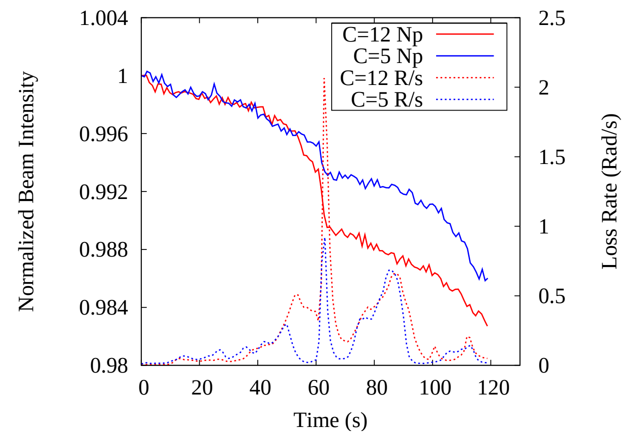

Figure 5: Comparison of proton intensity and loss rates in the low-beta squeeze before and after chromaticity change. Step 14 is at 60 s.

SUMMARY

Stable operation of the Tevatron in 2008 has been achieved by means of implementing a number of measures which include reduction of time of shot setup, better orbit correction and stabilization algorithm, and reduction of beam losses during certain stages of the collider cycle.

Categorization of reasons of quenches highlighted the importance of the low-beta squeeze. Even though the total amount of beam lost during this phase usually does not exceed 3%, the localization of losses can often cause quenches. Identification and elimination of an aperture restriction near the CDF collision point allowed stable operation at higher initial luminosities. Lowering betatron tune chromaticity in several steps of the low-beta squeeze was found instrumental in reduction of proton losses.

The focus of the future work will be on further reduction of proton losses during low-beta squeeze, improvement of the collider reliability, and preservation of the proton emittance through the collider cycle.

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