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PERFORMANCE AND FUTURE OF THE TEVATRON

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ABSTRACT

Fermilab's Tevatron continues Run 2 operation as a 36x36 bunch proton-antiproton collider at a center-of-mass energy of 1.96 TeV. Progress throughout the Fermilab accelerator complex that has led to recent advances in luminosity will be highlighted. The goals for the remainder of Run 2, currently scheduled to end in 2009, will be discussed.

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1. INTRODUCTION

In March 2001, Fermilab's Tevatron began Run 2 operation as a proton-antiproton collider at $\sqrt{s}$ = 1.96 TeV. At present, the Tevatron has delivered nearly 3 fb^{-1} of luminosity to both of the CDF and D0 experiments – see Fig. 1. The goal is to deliver 8 fb^{1} to CDF and D0 before the end of Run 2 which is currently scheduled for October 2009.

Recent advances in Tevatron peak and integrated luminosity have come largely from increased antiproton intensities with smaller emittances injected into the Tevatron. Since the last long shutdown ended in June 2006 until May 2007, over 1.2 fb^{-1} have been delivered while the rest peak luminosity has increased from 180 to 292 $\mu b^{-1}/s$ (1 $\mu b^{-1}/s$ = 10^{30} cm^{-2} s^{-1}). Over that period, the best weekly integrated luminosity increased ≈75% to 45 pb^{-1} while the highest weekly antiproton accumulation total increased ≈60% to 2800 10^{10}. Antiproton production continues to be the key factor for increasing Tevatron luminosity.

2. TEVATRON OPERATION

The Tevatron is a 1 km radius synchrotron with maximum beam energy of 980 GeV. The 36 proton and antiproton bunches are distributed into 3 trains of 12 bunches each with 396 ns bunch spacing. The beams circulate within a single beam pipe and electrostatic separators are used to kick the beams onto distinct helical orbits to keep the beams separated except at the collision points. Detrimental beam-beam effects from both head-on collisions and long-range interactions at the parasitic crossing points play a major role in the overall machine performance [1].

The recent increases in peak luminosity have arisen from the greater beam intensities reaching the start of high-energy physics (HEP) stores. Although the gains in antiprotons are greater, the proton intensities have increased ≈10%. The proton efficiency at 150 GeV during antiproton injections has increased by 50% thanks to a new helical orbit design that reduces beam-beam effects by increasing separation at a particularly bad long-range crossing point. Luminosity lifetime increased ≈15% from two additional separators installed during the 2006 shutdown; those separators provide up to 20% more separation at the parasitic crossings closest to the interaction points. Emittance growth of the beams is the dominant source of luminosity lifetime, especially early in a store. Ideally, the beam intensity lifetime should be dominated by luminosity. Typically, that is true for antiprotons, but more than 50% of the protons lost during stores are lost by other "non-luminous" processes driven by beam-beam effects from head-on collisions with the much smaller (~ factor 3) antiprotons. Overall, beam-beam effects can cause more than 10% loss of integrated luminosity over the course of an HEP store.

There are ongoing efforts to improve reliability in order to maximize Tevatron up-time for delivering luminosity. Before the last shutdown, there were two dipole failures that were caused by helium relief valves which did not open during quenches; each failure caused more than 1 week of downtime. After identifying the likely culprit, all ≈1200 such valves were replaced during the subsequent planned shutdown. In addition, the quench protection system is being modified to allow faster beam aborts upon detecting a quench in the superconducting magnets; the improvement should allow the beam to be aborted ≈350 μs (17 turns) after a quench. Finally, to help prevent needless quenches, antiprotons are now "cogged" (moved longitudinally relative to the protons) out of the abort kicker gap prior to acceleration.

All major Tevatron upgrades are complete, but there are smaller improvements to be tried to increase luminosity. First, we are implementing a correction of second-order chromaticity for the low-beta optics using sextupole elements that are now powered independently from the existing sextupole circuits. Simulations show improved lifetimes during HEP stores, particularly for protons, by reducing the tune spread of off-momentum particles. This second-order chromaticity correction is also a prerequisite for investigation of a possible new working point nearer to the ½ integer resonance. Other possible luminosity increases may arise by: scraping higher intensity protons after injection to give "brighter" proton bunches; the use of electron lenses to improve the lifetime of particular proton bunches during collisions by shifting their tunes away from the 7/12 resonance; and improved transfer line matching and reducing times for shot-setups.

3. ANTIPROTON PRODUCTION

Increasing the antiproton intensity delivered to the Tevatron has been a key factor for increasing luminosity. Antiprotons are stacked in the Accumulator for 2-3 hours and then transferred to the Recycler where antiprotons are stored until needed for transfers to the Tevatron. The electron cooling system in the Recycler [2-3] allows for smaller emittances, both transverse and longitudinal, than is possible from stochastic cooling alone. Since June 2006, the weekly antiproton production in the Accumulator has increased 45% thanks to a number of factors. The time needed to transfer antiprotons from the Accumulator to the Recycler has decreased from 68 minutes to less than 15 minutes, thus increasing the available time for stacking antiprotons. Other improvements include: increasing the gradient of the lithium lens that focuses the antiprotons coming out from the antiproton production target; improvements to the Accumulator stacktail stochastic cooling

system; a new working point in the Recycler that allows smaller emittances of the antiprotons delivered to the Tevatron; an RF feed-forward system in the Recycler that allows more uniform antiproton bunch intensities extracted to the Tevatron.

The Accumulator's stacktail stochastic cooling system remains a bottleneck in the production of antiprotons. During each production cycle (occurring ≈2.2 sec), this system is unable to sweep all of the incoming antiprotons toward the stack being built up on the Accumulator's core orbit. There is considerable ongoing effort to design and build new equalizers to mitigate the problem. In addition, a new Accumulator lattice was implemented recently to also help improve the stochastic cooling system's performance.

4. FUTURE PROJECTIONS

We have recently updated our luminosity projections made three years ago based on current conditions and machine performances. If the current antiproton stacking rate is maintained, we anticipate delivering a Run 2 total of at least 6 fb^{-1} to CDF and D0 before the scheduled end of the run in October 2009. Increased antiproton stacking rates are needed for higher integrated luminosities toward our 8 fb^{-1} goal.

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FIGURE CAPTIONS

Figure 1. Tevatron delivered luminosity over during Run 2 operation. .

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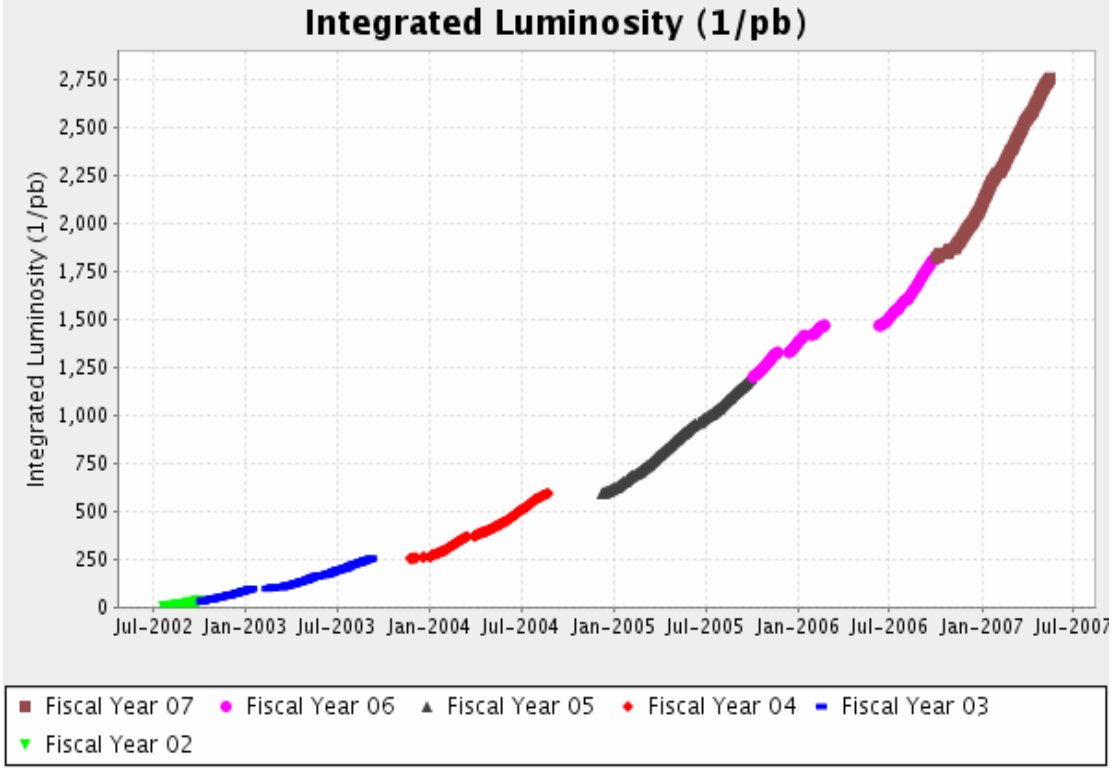
Integrated Luminosity (1/pb)
Integrated Luminosity (1/pb)
2,750
2,500
2,250
2,000
1,750
1,500
1,250
1,000
750
500
250
0
Jul-2002
Jan-2003
Jul-2003
Jan-2004
Jul-2004
Jan-2005
Jul-2005
Jan-2006
Jul-2006
Jan-2007
Jul-2007
Fiscal Year 07
Fiscal Year 06
Fiscal Year 05
Fiscal Year 04
Fiscal Year 03
Fiscal Year 02

Figure 1