TEVATRON COLLIDER STATUS AND PLANS*

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Abstract

Tevatron is currently the world's highest energy collider operating at 980 GeV per beam. Peak luminosity attained during the collider Run II is 2.05×10^{32} $cm^{-2}s^{-1}$ at the time of publication. In this report a summary of the collider performance is presented, accelerator physics issues and future plans are discussed.

COLLIDER OVERVIEW AND STATUS

Tevatron Collider complex consists of the following main elements: proton source; antiproton source with target station, Debuncher, Accumulator and Recycler; Main Injector and Tevatron. In the Tevatron, 36 bunches of protons collide with 36 bunches of antiprotons at two interaction points where CDF and D0 experiments are located. Protons and antiprotons move in a common vacuum chamber being separated with electrostatic separators to avoid parasitic interactions [1-3].

Tevatron Collider Run II began in the spring of 2001, and since then the luminosity of the machine was steadily increasing. During the year of 2005 the collider has been running well with only one major component failure. The planned 3-month shutdown in spring of 2006 was used to perform maintenance work and implement improvements. Changes of the collider ring include replacement of all pressure relief valves, un-rolling of three quadrupole magnets, removal of skew-quadrupole field component in the remaining ~200 dipoles, installation of two new electrostatic separators and new electron lens. Recovery from the shutdown was successful with first luminosity obtained on June, 13.

ACCOMPLISHMENTS IN 2005-2006

Peak Luminosity Records

In July 2005 the electron cooling of antiprotons in the Recycler has been demonstrated. It was put in routine operation in August and gave rise to the amount of pbars available for collisions as well as to their quality [4].

Prior to commissioning of Recycler antiprotons have been stacked in the Accumulator and then transferred to the Tevatron. When Recycler became operational the collider was filled in the so-called mixed mode when part of the pbars came from the Accumulator and part came from the Recycler. In October of 2005 the complex switched to Recycler-only operation which resulted in immediate improvement of the peak luminosity (Fig. 1) because of the smaller emittance of antiprotons coming from the Recycler.

At the same time as the Recycler-only operation was implemented the collider optics has been changed with the aim of smaller β-function at the Interaction Points [5]. Figure 2 shows the value of vertical β* measured by D0 detector. Red line marks the moment of switching to the new (β*=28 cm) optics. The resulting change of the peak luminosity is about 10%. Further decrease of the β-function value is limited by hourglass factor.

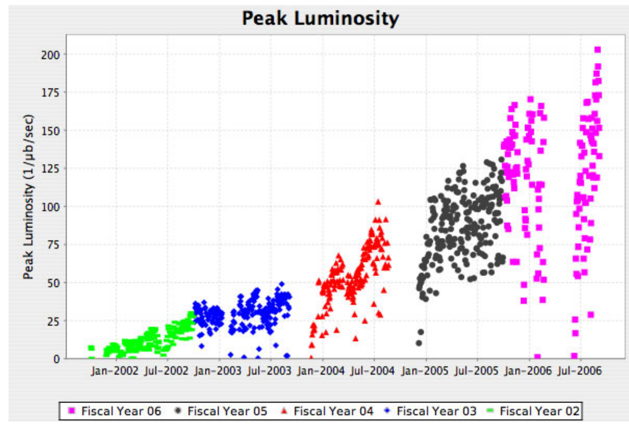

Figure 1: Peak luminosity (10^{30} $cm^{-2}s^{-1}$) vs. time.

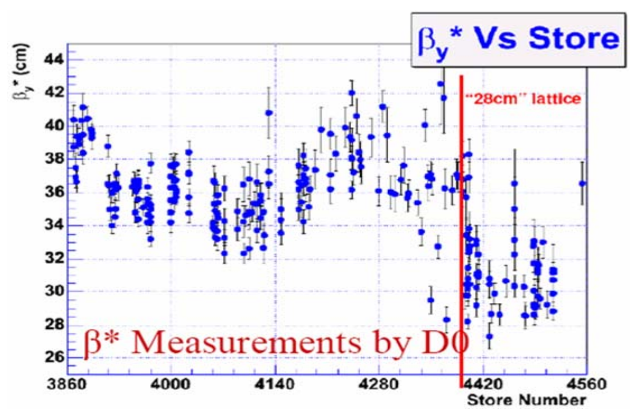

Figure 2: Value of vertical β* as measured by D0.

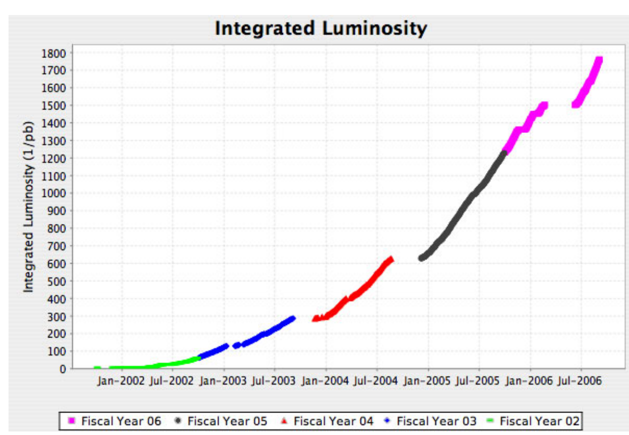

Figure 3: Run II integrated luminosity vs. time.

*Work supported by the Universities Research Assos., Inc., under contract DE-AC02-76CH03000 with the U.S. Dept. of Energy.

Integrated Luminosity

In February, 2006 the antiproton stacking rate in the Accumulator exceeded $20\text{x}10^{10}$ per hour which is a major achievement crucial for integrating luminosity because amount of pbars available for collisions is now the main limiting factor.

Among other milestones are

- Peak antiproton stack of $4.36\text{x}10^{12}$ in the Recycler (January 2006)
- Luminosity integral of 33 pb^{-1} per week in August, 2006
- Good operational reliability with the average weekly integral of 22 pb^{-1}

A very important modification of the collider was the installation of two new electrostatic separators and subsequent commissioning of new helical orbits in the Tevatron. Long-range (or parasitic) beam-beam effects are detrimental to the beam life time and emittance growth rate both at injection energy and at collisions. Hence, it is important to maintain the separation of protons and antiprotons as large as possible everywhere except the main IPs. Installation of the new separators allowed to increase separation of the beams at first long-range collision points by about 20% at collisions (Table 1).

Table 1: Separation of the beams (in beam σ) at parasitic collision points nearest to main IPs. “u.s.” is upstream, “d.s.” is downstream.

	CDF u. s.	**CDF** d. s.	**D0** u. s.	**D0** d. s.
Before	5.4	5.6	5.0	5.2
After	6.4	5.8	6.2	5.6

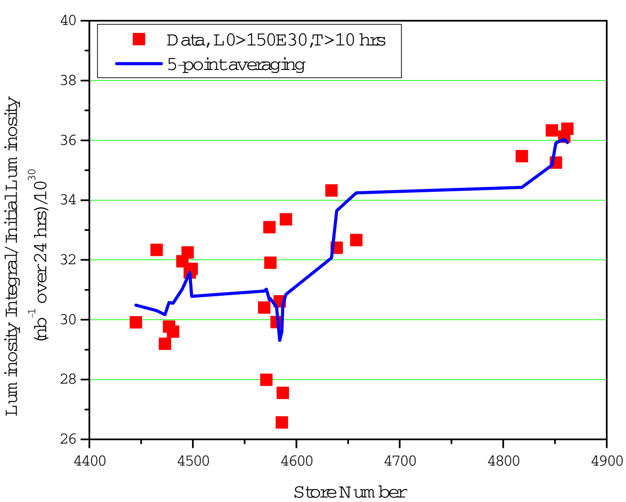

Figure 4: Luminosity integral over 24hrs per initial luminosity vs. collider store number.

As the result, the luminosity life time has improved by about 16%. In the Tevatron, luminosity depends on time as

$$L = L_0\left(1+\tfrac{t}{\tau}\right)^{-1}$$

and luminosity integral normalized by initial luminosity can be expressed as

$$\int L dt = \tau \ln\left(1+\tfrac{t}{\tau}\right)$$

Hence, the luminosity integral over fixed period of time can be a good measure of luminosity life time. In Fig. 4, the improvement in integrated luminosity over 24 hours is shown. Store numbers above 4700 are when the new helix was implemented.

To prove that improvement came from mitigation of beam-beam effects we performed comparison of Tevatron model with actual store data before and after switching to the new helix [6]. The model takes account of the following phenomena:

- Particle losses because of luminosity.
- Emittance growth due to intra-beam scattering.
- Emittance growth due to scattering on residual gas.
- Emittance growth due to RF noise.

Figures 5-7 show the luminosity, proton intensity, and bunch lengths for store 4581. One can see that there is significant difference between the model and experimental data which indicates presence of beam-beam effects. However, for store 4859 the agreement is very good (Figs. 8-10). Free model parameters used in both cases were the same. It is remarkable that proton intensity decay was caused by losses of particles with large momentum deviations, which was predicted by simulations.

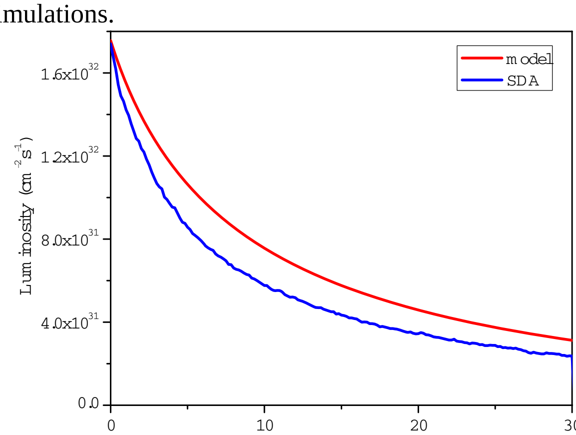

Figure 5: Luminosity vs. time (h) for store 4581.

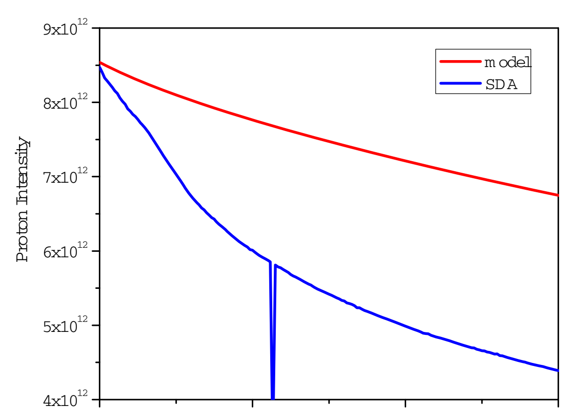

Figure 6: Proton intensity for store 4581.

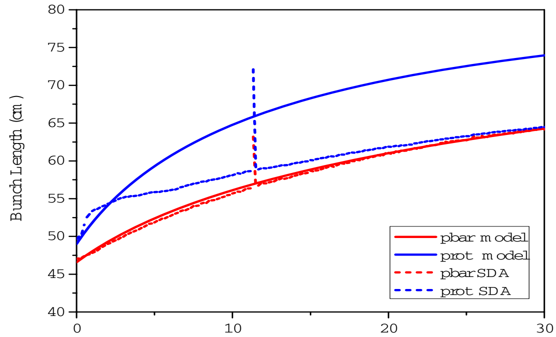

Figure 7: Bunch length for store 4581.

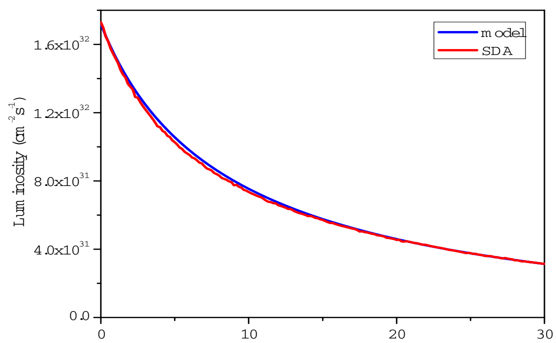

Figure 8: Luminosity for store 4859.

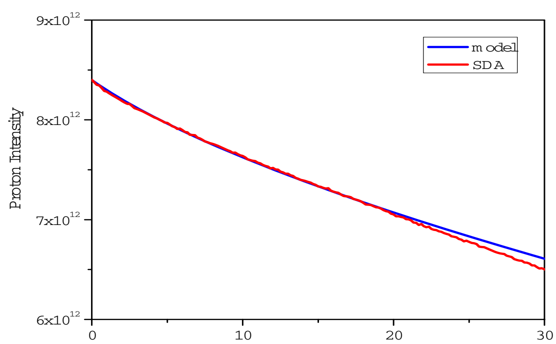

Figure 9: Proton intensity for store 4859.

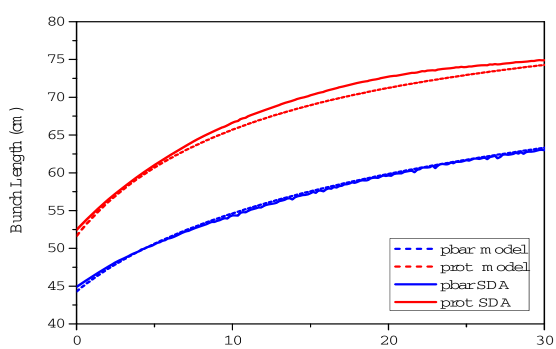

Figure 10: Bunch lengths for store 4859.

PLANNED IMPROVEMENTS

The upgrades being planned are mostly aimed at achievement of higher antiproton stacking rate. The only major change in the Tevatron ring is the proposed change of the betatron tune working point. At the present time the operating point is between the 7th order and 5th order resonances (Fig. 11). With the present proton beam intensity the beam-beam parameter for antiprotons ξ=0.011 per interaction point and the footprint occupies all available tune space. In order to increase the proton intensity by 20-30% one needs to open the tune space. The new Tevatron working point was chosen in the vicinity of half-integer resonance, where simulations predict stable operation with higher proton intensity. However, with approaching of the half-integer all focusing errors become more pronounced, and their careful compensation becomes essential. It is especially important to correct the β-function chromaticity. To accomplish that, the existing sextupole correctors were rearranged into new families. Commissioning of the new chromaticity correction scheme will start in October, 2006.

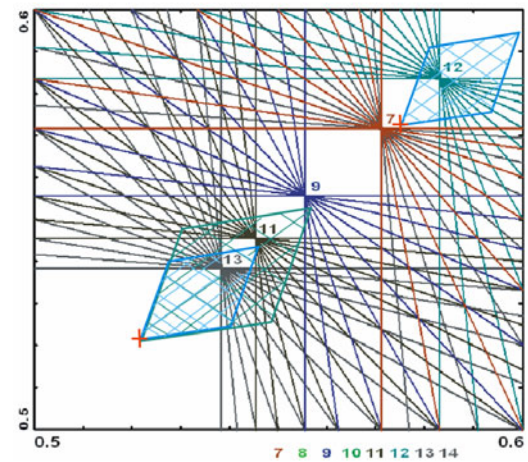

Figure 11: Betatron tune diagram

CONCLUSIONS

Excellent collider performance is the result of many machine improvements and reliable operation due to hard work of the team. A careful review of proposed changes and studies is important to balance the potential gain and impact on operations. The collider Run II program has promising future in what regards particle physics and accelerator physics. Some of the accelerator physics related questions to be answered:

- What is the nature of longitudinal instability at 980 GeV?
- Are there strong-strong beam-beam effects and beam-beam impedance?
- What is the actual dependence of beam life times on chromaticity?

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