Fermilab Collider Upgrade: Recent Results and Plans

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Abstract

The Fermilab collider program has entered its first physics run with two major detectors, CDF and D0. Recent results on the performance of the accelerators are presented, along with plans to improve the luminosity of the collider. The peak luminosity routinely exceeds the goal of 5×10^{30} cm^{-2}sec^{-1}, and the integrated luminosity routinely exceeds 1 pb^{-1} per week to each detector. The Tevatron has been successfully upgraded to include electrostatic separators which provide helical orbits which overcome the beam-beam tune shift limitations of previous runs by only allowing bunch crossings at the two detectors. The installation of two matched low beta inserts in the Tevatron has allowed for the simultaneous operation of two high luminosity interaction regions. The Antiproton Source has increased its performance over the previous run as measured by stack size and stacking rate. The Linac will be upgraded from 200 MeV to 400 MeV in order to lessen the space charge tune shift upon injection into the Booster. Additional improvements to the Antiproton Source are required to meet the luminosity projections. Higher luminosity requires more bunches in the Tevatron in order to keep the number of interactions per bunch crossing acceptably small. The present plan is to increase the number of bunches from 6 to 36 per beam. Until it is replaced with the Main Injector, the Main Ring will remain as the most significant bottleneck on the performance of the collider.

Current Performance

Initial and Integrated Luminosity

The initial luminosity delivered to the detectors has routinely exceeded 5×10^{30} cm^{-2} sec^{-1} which is the goal for the present run. This is demonstrated in Figure 1 which shows the initial luminosity for both the present run and the previous run. The "10X Running Average" means that the initial luminosities for a particular store and the nine previous stores are summed, divided by ten, and plotted. This averaging removes much of the scatter from store to store and presents a clearer picture of the actual accelerator performance. Some of the variations in the average are due to various failure modes - particularly those which result in dropping the antiproton stack - and some are due to differences in emphasis between operating for peak luminosity and other machine improvements. For the present run, the initial luminosity is taken after scraping which is done on the beams to reduce the backgrounds at the two detectors. The peak initial luminosity for the run has been 8.79×10^{30} cm^{-2}sec^{-1}. The luminosity displayed is for CDF; the luminosity for D0 is comparable. The luminosity lifetime at the beginning of a store is typically 12 to 16 hours. It increases about 0.2 hours per hour during the store.

Figure 2 shows the integrated luminosity for the present and previous runs for each week and for the entire run. The figure shows the integrated luminosity for the present run approaching 30 pb^{-1}. The goal for the run is 25 pb^{-1}. The plateau near week 22 is due to a scheduled shutdown. The goal for the run of 1000 nb^{-1} per week has been exceeded several times, and one week exceeded 2 pb^{-1}.

Figure 2 shows the integrated luminosity delivered to CDF. Approximately 70% of this is logged to tape. D0 logs about 20% less than this primarily due to the blanking required when Main Ring beam passes through the D0 detector during antiproton stacking. The concern that the D0 detector may not be able to run at all during stacking has been put to rest.

Beta* and the CDF SVX

The design for the minimum beta function at the interaction regions (beta*) is 50 cm. However, for the nominal current settings of the low beta

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quadrupoles, a beta beat is created which results in an effective beta* of about 35 cm at both interactions regions. This beta beat appears to be the result of errors in the field gradient of the low beta quadrupoles of about 1 part in 1000. This has been corrected with trim supplies on individual quadrupoles. The power supplies and low beta quadrupole magnets are designed to provide a beta* of 25 cm. The initial measurements with the 25 cm beta* lattice have produced the expected increase in the specific luminosity. (Specific luminosity is the luminosity divided by the product of the number of protons and antiprotons.) In addition, the length of the luminous region decreased to an rms of about 26 cm as measured by the CDF SVX (Silicon Vertex Detector).

Separators and Feeddown Sextupoles

In the previous run, with no separators and 6 bunches per beam, the beams collided 12 times per revolution. This resulted in a beam-beam tune shift which severely limited the proton brightness, and consequently the luminosity. (Brightness is the intensity divided by the emittance.) The implementation of separators in the Tevatron allow the beams to collide only at the two detector locations. The subsequent increases in the proton brightness and the luminosity are given in the table. (The previous run is "1989" and the present run is IA.) The separators in the Tevatron provide two-dimensional helical orbits, not one-dimensional pretzel orbits (in the horizontal plane only) as in other accelerators. The separators have been used to scan the beams through one another, and a summary of these results is presented at this conference by D. Siergiej et al.

The presence of the helical orbits allow the use of families of trim sextupoles (both normal and skew) for adjusting the tunes and coupling of the proton and antiprotons beams independently. When sextupoles are used in this manner, they are called "feeddown sextupoles".

Pbar Improvements

The improvements in the Antiproton Source - especially the Accumulator stacktail system - have resulted in increased stacking rates. The production rate exceeds 14 antiprotons per 10^6 protons on target. The stacking rate is typically 4.5×10^{10} antiprotons / hour at modest stacks and 3.5×10^{10} antiprotons / hour at stacks exceeding 10^{12}.

The development of techniques for stabilizing large antiproton stacks has been necessary. Clearing electrodes have been used to help expel trapped ions which are the primary problem. However, the clearing electrodes alone are not enough. Counter circulating protons, and bunching of the antiproton core have also been found to have a stabilizing influence. P. Zhou and P. Colestock, S. Werkema et al., and A. Gerasimov, all have presented at this conference some of the observations of the effects of trapped ions in the Antiproton Source.

Coalescing Improvements

Longitudinal instabilities in the Main Ring limit the efficiency of coalescing. (Coalescing is the process by which several - typically 11 - bunches are combined into a single high intensity bunch.) By speeding up the process of coalescing, so that the instability does not have time to develop, the intensity of the coalesced bunches has been increased from 80×10^9 to greater than 125×10^9. The "speeded up process" is called "snap coalescing". Refer to X. Lu and G. Jackson, and I. Kourbanis et al., at this conference, for details.

Collider Upgrade Plans

Overview

The table presents the overall plan for the upgrade of the collider. The previous run (called 1989 in the table) provided 0.32 inverse picobarns per week on the average, with a typical initial luminosity of 1.6×10^{30} cm^{-2} sec^{-1}, which exceeded the Tevatron I design goal of 1×10^{30} cm^{-2} sec^{-1}. As noted previously, the present run (Run IA) provides 1 inverse picobarn per week at each detector, with a typical initial luminosity in excess of 5×10^{30} cm^{-2} sec^{-1}. Run IA is scheduled to end June 1, 1993 to allow the final installation and commissioning of the Linac upgrade, and the installation of the cold compressors in the Tevatron. The integrated luminosity per week is expected to double in Run IB which is scheduled to begin in the fall of 1993. Run II is not expected to provide much more integrated luminosity per week, but the energy of the Tevatron will be raised and number of interactions per crossing will be greatly reduced. Finally, a factor of five increase in the integrated luminosity will be provided by the Main Injector.

The form factor in the table describes the reduction in the luminosity which occurs when the bunch length is comparable to the beta function. It approaches 1.00 if the beta function is much larger than the bunch length. However, this is not the case for the actual case presented in the Tevatron as seen in the table where typically one only obtains about 2/3 of the luminosity one would naively expect from the bunch intensities, emittances and crossing rate.

Linac Upgrade

This summer, the Linac upgrade project will be completed. The kinetic energy of the H^- ions provided by the Linac will be increased from 200 MeV to 400 MeV. This is accomplished by replacing the last four sections of the present drift tube linac with seven side coupled cavity sections. The first 100 MeV of energy will still be provided by the original (20+ year-old) drift tube linac tanks. The beam will be transported to the Booster with a new 400 MeV beam transfer line. The calculated reduction in the space charge tune shift limit for injection into the Booster decreases by a factor of 1.75 which in principle allows for an equivalent increase in the proton intensity delivered by the Booster. However, the full realization of this factor is not expected to be attained until the Main Ring is replaced with the Main Injector.

Lower Temperature

This summer, cold compressors and new valve boxes are to be installed in the 24 helium refrigerators for the Tevatron. These allow for subatmospheric operation of the helium system and a subsequent reduction of the temperature of the superconducting cable in the Tevatron magnets from 4.5 ^{o}K to 3.5 ^{o}K. This is expected to raise the short sample limit of the cable and allow the beam energy of the Tevatron to be raised from 900 GeV to 1 TeV for collider operations. Run IB will be used to gain experience with lower temperature operation, and the increase in energy is expected to become operational for Run II as shown in the table.

Multibunch Kickers

As the table shows, the Main Injector will result in typical initial luminosities in excess of 5×10^{31} cm^{-2} sec^{-1}. The present collider operates with 6 proton and 6 antiproton bunches colliding at the two detectors, CDF and D0. For the present configuration, the minimum spacing between bunches is 185 buckets. For the present typical initial luminosity, 5×10^{30} cm^{-2} sec^{-1}, the number of interactions in the detectors per bunch crossing is 0.79 (assuming a cross section of 45 mbarns). For the upcoming collider run, typical initial luminosities are expected to exceed 1×10^{31} cm^{-2} sec^{-1}. Since the number of bunches per beam will remain at 6 for that run, the number of interactions per crossing will exceed 1.57. Certain types of physics - not including the discovery of the top quark - are done more efficiently if the number of interactions per crossing is kept below one. The number of bunches per beam will be increased to 36, in order to reduce the number of interactions per crossing to 0.26. For this configuration, the minimum spacing between bunches will be 21 buckets.

With the Main Injector, the typical initial luminosity will exceed 5×10^{31} cm^{-2} sec^{-1}, and the number of interactions per crossing will exceed 1.31, again exceeding one. If necessary for the types of physics to be done, some modest improvements to the Antiproton Source and the Tevatron can provide 99 bunches per beam with 7 bucket spacing. This would keep the number of interactions per crossing near one for luminosities of 1×10^{32} cm^{-2} sec^{-1}.

Additional details of bunch loading schemes can be found in J. Holt et al., this conference.

Antiproton Source

There are several improvements needed in the Antiproton Source to realize the upgrades given in the table. An h=4 rf system in the Accumulator will allow the delivery of 36 rather than 6 bunches. Improvements in Debuncher cooling include rebuilding the pickups to allow for 2 - 4 GHz operation and cooling the pickups to 20 ^{o}K. Increases in the apertures of the Accumulator, Debuncher and the beam transfer lines are also being considered. Finally, the Main Injector will deliver sufficient intensity at 120 GeV to the antiproton production target that the target is not expected to survive the shock. R&D on a beam sweeping system has begun.

Table of Fermilab Collider Upgrade Parameters

	1989	IA	IB	II	Main Injector	
Protons/bunch	7.0×10^{10}	1.2×10^{11}	1.5×10^{11}	1.5×10^{11}	3.3×10^{11}	
Pbars/bunch	2.9×10^{10}	3.6×10^{10}	4.5×10^{10}	7.5×10^{9}	3.7×10^{10}	
Proton emittance	25	16	16	16	30	mm-mrad
Pbar emittance	18	16	16	16	22	mm-mrad
Beta at IP	0.55	0.50	0.35	0.35	0.5	m
Beam Energy	900	900	900	1000	1000	GeV
Number of Bunches	6	6	6	36	36	
Bunch length (rms)	0.65	0.5	0.5	0.5	0.65	m
Form Factor	0.71	0.76	0.65	0.65	0.68	
Luminosity*	1.60×10^{30}	5.37×10^{30}	1.03×10^{31}	1.15×10^{31}	5.60×10^{31}	$cm^{-2}sec^{-1}$
Integrated Luminosity	0.32	1.08	2.08	2.31	11.28	pb^{-1}/week
Bunch spacing	3000	3000	3000	396	396	nsec
Interactions / crossing (@ 45 mbarn)	0.25	0.84	1.62	0.30	1.47	
Antiproton tune shift	0.025	0.011	0.014	0.014	0.016	
Proton tune shift	0.014	0.003	0.004	0.001	0.002	
What's New?		Separators, D0 Detector, Pbar Improvements	Linac	Faster Kickers and Cold Compressors	Main Injector	

*Typical luminosity at the beginning of a store; translates to integrated luminosity with a 33% duty factor.

Main Injector

The purpose of the Main Injector is to remove the Main Ring bottleneck in the delivery of high intensity proton and antiproton beams to the Tevatron. The Main Injector will remove backgrounds from the CDF and (especially) the D0 detector, since the Main Ring - which shares the tunnel with the detectors - will no longer be used. The Main Injector will allow for test beams and fixed target physics year round.

Most of the wetlands mitigation has been completed. Civil construction for the MI-60 enclosure and service building has begun. This building is at the point of tangency between the Tevatron and the Main Injector and will contain the rf for the new accelerator. This building also services the principle access point to the Main Injector tunnel. The R&D for the project has produced several dipoles which have met the required field quality.

The funding profile in the President's FY94 Budget Request allows initiation of operations with the Main Injector in the summer of 1998.

Final Note

The author wishes to thank all the many accelerator and high energy physics collaborators who have contributed to the work summarized in this paper, although only a few of their contributions are mentioned by name. Each individual's professional contributions to the team effort have made it a pleasure to describe an ongoing success story as stunning as the Fermilab Collider.

Figure 1.1992 &1988 Initial Tevatron Luminosity
(10X Running Average)

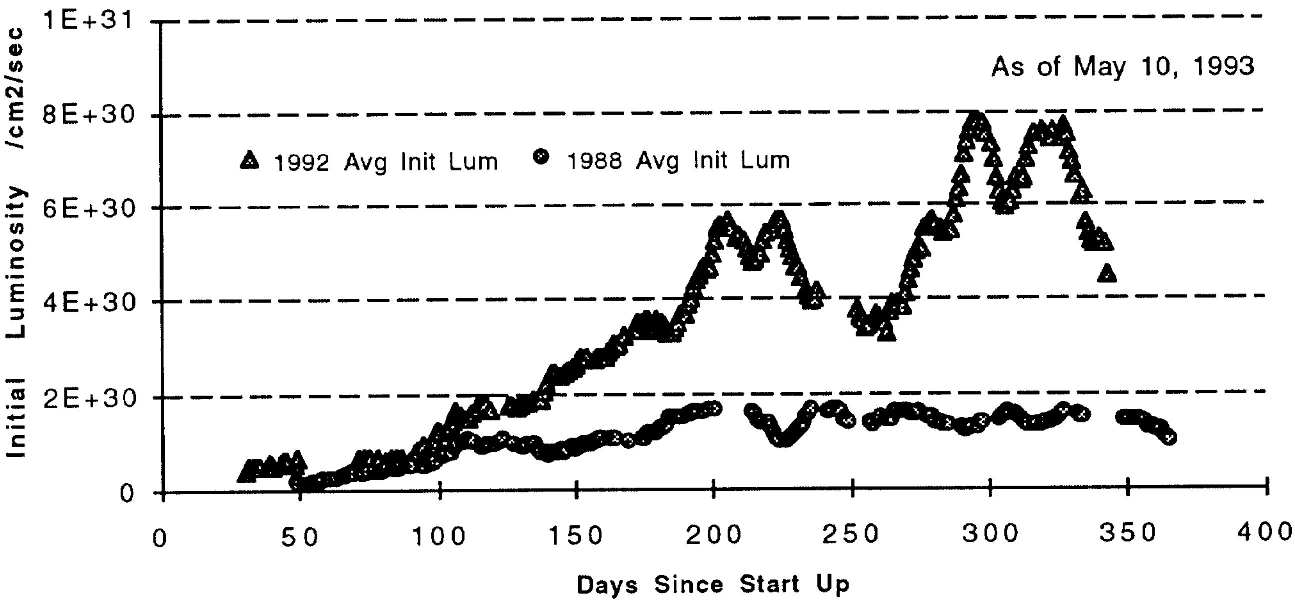

Figure 2. 1992 & 1988 Tevatron Integrated Luminosity