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Performance of the Fermilab Main Ring During the 1988-89 TEVATRON Collider Operation *

Philip S. Martin
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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PERFORMANCE OF THE FERMILAB MAIN RING DURING THE 1988-89 TEVATRON COLLIDER OPERATION

Philip S. Martin
Fermi National Accelerator Laboratory*
P. O. Box 500
Batavia, Illinois 60510

Abstract

The Fermilab Main Ring serves as injector for the Tevatron at 150 GeV/c and as a source of 120 GeV/c protons for antiproton production. This paper discusses the Main Ring performance--intensity, reliability, and efficiency--during the present Collider run. Also discussed are questions related to emittance and emittance growth, both transverse and longitudinal, and the impact of Main Ring losses on the Collider experiments.

Intensity

The intensity of the Main Ring for antiproton production has averaged about 1.6×10^{10} protons per pulse over the past few months, with peak performance around 1.8×10^{10} ppp. This should be compared to operation during the 1987 Collider run of 1.2×10^{10} ppp typical, 1.4×10^{10} ppp peak. This increase is primarily due to the improvement in the vertical dispersion afforded by the reconfiguration[1] of the D0 overpass during the March-April, 1988, shutdown. A number of tight apertures have also been increased by magnet and beam pipe changes.

The cycle time for antiproton production has been reduced to 2.6 seconds (from 2.8 seconds in 1987). While it might be possible to reduce the cycle time to 2.4 seconds, there are difficulties in coping with remanent field problems and a number of ramped devices which presently do not recover as quickly as the main bus. Shortening the cycle time further would likely require substantial retuning when changing from antiproton production to setting up for filling the Tevatron for Collider operation. Therefore, the efforts toward increasing the antiproton production rate from the present 1385 cycles per hour are concentrated on accelerating more than one Booster batch in the Main Ring and targeting them one at a time at whatever rate the stochastic cooling systems in the Antiproton source will permit. Studies are being carried out towards this end; the operation is complicated by the rf bunch-narrowing manipulations carried out at extraction.

Reliability

The most significant downtimes caused by the Main Ring have been magnet failures, of which there were seven during the first seven months of this Collider run. Of these, five were of the newer B3 style dipoles which are essential parts of the overpasses at B0 and D0. These magnets are typically operating at twice the strength of normal dipoles, but the failures are attributed to construction problems rather than to the power dissipation. The magnet failures resulted in 130 hours of downtime during the 4200 calendar hours from June 20 to December 12, 1988. All other Main Ring downtimes combined to account for another 122 hours. Together, these were 16% of the total downtime for the accelerator.

Effects of Main Ring on Collider Experiments

There are presently four Collider experiments in place and one under construction. The major experiment, CDF, is sensitive to losses from the Main Ring in several ways. (The Main Ring overpass at B0 moves the Main Ring away from the Tevatron, but the Main Ring beam passes inside the B0 Collision Hall.) First, there is the possiblity of radiation damage to the detector from losses over long periods of time. This problem was solved during the 1987 run by opening apertures at the high loss points just upstream of the detector, which had the effect of lowering the radiation dose by five orders of magnitude. The second problem was the current drawn by the muon chambers at the top of the detector. The addition of two feet of iron shielding around the Main Ring pipe during the last shutdown has helped to keep those chambers active during normal operation. There are still occasional trips attributed to the Main Ring. The third problem is showers in the CDF calorimeter from Main Ring beam. At the beginning of this run, the CDF experiment simply gated off during the high-loss time of the Main Ring cycle, about 15% of the time in each cycle. Now it uses scintillation counters near the Main Ring to veto triggers from Main Ring backgrounds, with a resulting deadtime which is generally less than 1%.

Experiment E735 at C0 has concerns similar to CDF, but has no benefit from shielding or enlarged apertures. The reduced vertical dispersion, compared to that at B0, has enabled the losses to be reduced to acceptable levels during normal operation. Orbit control through the acceleration cycle, both horizontal and vertical, has also been essential to keeping the losses under control. (The present Main Ring correction elements are dc devices intended to smooth the orbit at injection only. Special dipoles with programmable supplies have been added at C0 and a few other locations.) Experiment E710 at E0 typically sees fairly low levels of losses. The D0 intersection region is presently occupied by the small experiment E713 searching for heavily ionizing particles. The nature of the apparatus makes it insensitive to Main Ring losses. That intersection region will be occupied by the larger E740 experiment in subsequent Collider runs, with the Main Ring passing through the detector with a smaller overpass than at B0. Investigations are underway to determine the effects of Main Ring losses on prototypes of detector components, and to reduce losses to acceptable levels.

Efficiency

The efficiency of the Main Ring is most important for the task of transferring antiprotons from the Accumulator to the Tevatron. The acceptance of the Main Ring is approximately 12π mm-mrad, and hence the transfer efficiency depends upon the emittance of the beam, as shown in Figure 1. The transverse emittance is correlated with the size of the antiproton core at the beginning of a transfer sequence. Figure 2 shows the Main Ring efficiency as a function of core size. The decreased transfer efficiency for larger cores is one of the limitations in increasing the luminosity of the Collider. Increasing the aperture at critical locations in the Main Ring has led to improved transfer efficiencies. The data shown span a period of time during which changes were being made; the more recent data, for example those at the largest core size, exhibit a higher efficiency.

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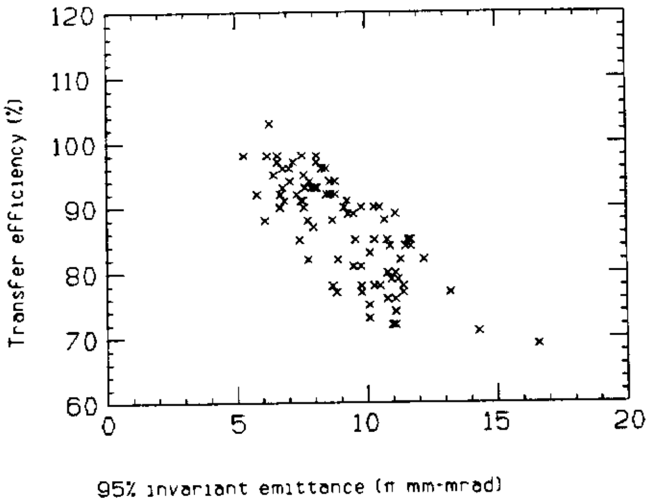

Figure 1. Efficiency (Accumulator core to 20 GeV in the Main Ring) as a function of the emittance measured at injection into the Main Ring.

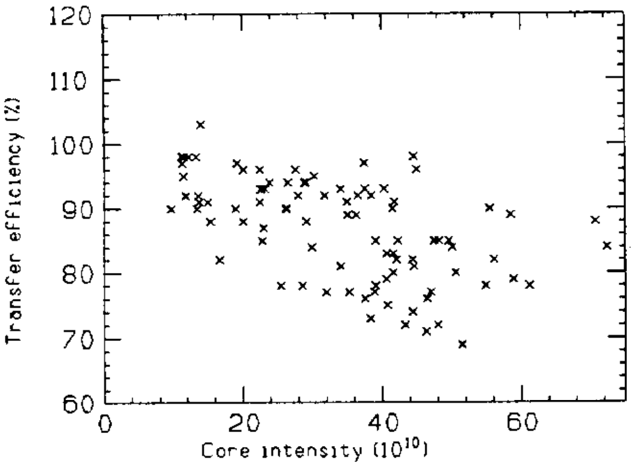

Figure 2. Efficiency (Accumulator core to 20 GeV in the Main Ring) as a function of antiproton core size.

Similarly, the longitudinal emittance of the beam extracted from the core affects the Main Ring efficiency due to the limited momentum aperture. The majority of the antiproton extractions from the core use a 1.0 eV-sec bucket area. For smaller buckets, less beam is extracted, while for larger buckets, the transfer efficiency drops. Figure 3 shows the beam intensity for the first 0.5 sec in the Main Ring for two transfers, one with a 1.0 eV-sec bucket, and another with 1.4 eV-sec. The ordinate scale is from 0 to 6×10^{10} antiprotons. The initial spike is partially instrumental (overshoot). These transfers were from a large core. For the 1.4 eV-sec transfer, the efficiency from the core to 20 GeV in the Main Ring, i.e. including transfer line efficiency, was only 48%; it rose to 81% for the 1.0 eV-sec transfer.

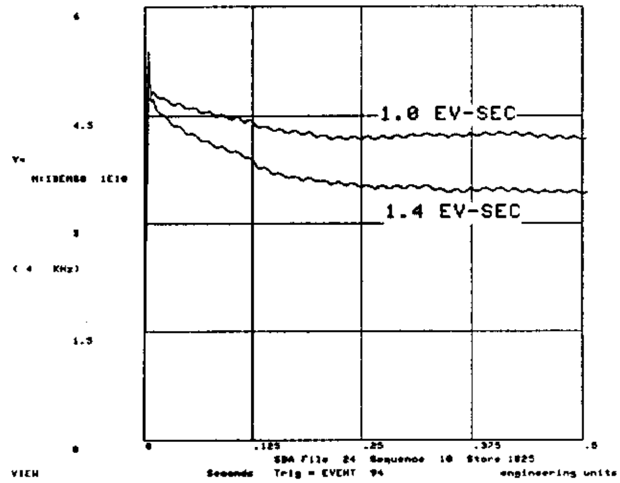

Figure 3. Antiproton intensity for the first 0.5 sec in the Main Ring for extractions of 1 and 1.4 eV-sec.

The overall Main Ring efficiency for transfers to the Tevatron must also include the coalescing efficiency. The coalescing efficiency for antiprotons is typically 90-100%; for protons, the efficiency is a strong function of how much beam is being coalesced. Another paper[2] discusses the coalescing performance in more detail.

Emittance Growth

There is some transverse emittance growth in the Main Ring. For protons which are injected into the Tevatron, the horizontal emittance almost doubles. This is not presently a concern, since it is desirable to have large proton emittances in the Tevatron[3,4]. The emittance growth of antiprotons is smaller, about 25%. Longitudinally, there is also some emittance growth; this growth is presently limiting the effectiveness of the bunch narrowing operation during the antiproton production cycles. It is not a significant factor in the coalescing for injection into the Tevatron.

Conclusions

The Main Ring efficiency and reliabilty during the 1988-89 Collider run have improved significantly relative to the previous run. The losses, while reduced, are still a concern for the experiments. The transfer efficiency for antiprotons, for large cores or when extracting more of the core, is limiting the Collider luminosity.

References

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