# BEAM LOSS HANDLING AT TEVATRON: SIMULATIONS AND IMPLEMENTATIONS

A.I. Drozhdin and N.V. Mokhov*, Fermilab, P.O. Box 500, Batavia, IL 60510 USA

*Abstract*

Summary of studies is presented towards minimization of beam loss in the critical locations at the Fermilab Tevatron to reduce background rates in the collider detectors and to protect machine components. Based on detailed Monte-Carlo simulations, measures have been proposed and incorporated in the machine to reduce accelerator-related instantaneous and residual background levels in the DØ and CDF detectors. Recent measurements are in good agreement with the predictions. A re-alignment of the electrostatic deflector and the Lambertson magnet and the addition of shielding in the AØ straight section has resulted in reduction of beam induced energy deposition in the superconducting magnets, which allowed an increase in the extracted beam intensity. Using the same simulation technique, it has been calculated that the total beam of $10^{13}$ protons can be removed from the Tevatron at the end of the store, leaving the antiproton beam in the machine for recycling. Using the EØ collimator with attached scattering targets, this process will require about 100 seconds to keep the power deposition in the superconducting magnets below the quench level.

## 1 INTRODUCTION

Tevatron is the world's first superconducting and most powerful hadron collider. Enormous efforts at Fermilab, reliably provided 900 × 900 GeV $p\overline{p}$ collisions with the peak luminosity up to $2.5\times10^{31}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, recently resulted in the discovery of the top quark, among many other important achievements. The current fixed target run, begun in May 1996, exhibits the impressive performance of both the machine and experiments. At the same time, work progresses to upgrade the accelerator and detectors into even more powerful research tools [1]. The high performance of Tevatron both in the fixed target and collider modes is achievable only with a dedicated beam cleaning system embedded in the lattice [2, 3, 4].

## 2 BEAM LOSS HANDLING

In the Tevatron, as in any other accelerator, the creation of a beam halo is unavoidable: proton (antiproton) scattering in the IPs, in beam-gas interactions and on the limiting apertures, the diffusion of particles due to various nonlinear phenomena out of the beam-core, as well as various hardware and software errors – all result in emittance growth and eventually in beam loss in the lattice [2, 5, 6]. This causes irradiation of conventional and superconducting (SC) components of the machine, an increase of background rates in the detectors, possible radiation damage, quench, overheating of equipment and even a total destruction of some units. A very reliable multi-component beam collimation system is the main way to handle beam loss and is mandatory at any SC accelerator, providing [4, 5, 6]:

- reduction of beam loss in the vicinity of IPs to sustain favorable experimental conditions;
- minimization of radiation impact on personnel and environment by localizing beam loss in the predetermined regions and using appropriate shielding in these regions;
- protection of accelerator components against irradiation caused by operational beam loss and enhancement of reliability of the machine;
- prevention of quenching of SC magnets and protection of other machine components from unpredictable abort and injection kicker prefires/misfires and unsynchronized abort.

At the early Tevatron days the first collimation system was designed [2] on the basis of the MARS/STRUCT [7, 8] full-scale simulations of beam loss formation in the machine. The optimized system, consisted of primary and secondary collimators about 1 m long each, was installed in the Tevatron which immediately made it possible to raise by a factor of 5 the efficiency of fast resonant extraction system and intensity of the extracted 800 GeV proton beam. The data on beam loss rates and on their dependence on the collimator jaw positions were in an excellent agreement with the calculational predictions.

Later, we have refined the idea of a primary-secondary collimator set and shown that this is the only way to use such a system in the TeV region with a length of a primary collimator going down to a fraction of the radiation length. The whole system should consist then of a primary 'thin scattering target', followed immediately by 'a scraper' with a few 'secondary collimators' in the appropriate locations in the lattice [5, 6]. The purpose of a thin target is to increase amplitude of the betatron oscillations of the halo particles and thus to increase their impact parameter on the scraper face on the next turns. This results in a significant decrease of the outscattered proton yield and total beam loss in the accelerator, scraper jaws overheating and mitigating requirements to scraper alignment. Besides that, the scraper efficiency becomes independent of accelerator tuning, there is only one drastic restriction of accelerator aperture and only the scraper region needs heavy shielding and probably a dogleg structure. The method would give

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an order of magnitude in beam loss reduction at multi-TeV machines, but even at the Tevatron we have got a noticeable effect. Recently the existing scraper at AØ was replaced with a new one with two 2.5 mm thick L-shaped tungsten targets with 0.3 mm offset relative to the beam surface on the either end of the scraper (to eliminate the misalignment problem), resulting in reduction of beam loss rate upstream of both collider detectors [3]. A few other recent studies are described in the following sections.

## 3 FORWARD PROTON DETECTOR

The detector [9] consists of four Roman Pot units placed in the DØ straight section upstream and downstream of the separators, and of three units at the C48 location. Each unit consists of two square 2×2 $cm^2$ detectors placed from both sides of the closed orbit.

Particle background in the Roman pot detectors is originated in proton and antiproton interactions with the primary and secondary collimators. The primary collimators are positioned at $5\sigma$ while secondary ones at $8\sigma$. The Roman pot detectors are at $8\sigma_x$ for proton beam and $9.4\sigma_x$ for antiprotons. Moreover, antiproton intensity intercepted by the collimation system is 3.6 times lower compared to the proton intensity. Therefore, antiproton background in the Roman pots amounts only 2% of the total background, and backgrounds in the DØ detector due to Roman pots on the proton side about two orders of magnitude higher compared to the antiproton side.

Total background hit rates in Roman pots are (2.3-3.3)$\times 10^6$ p/s for detectors at $8\sigma_x$ and (0.87-1.09)$\times 10^6$ p/s for detectors at $9\sigma_x$, i. e. the rates are three times lower for the detectors at larger distance from the closed orbit. Beam loss distributions in Tevatron with the Roman pot detectors at $8\sigma_x$ are presented in Fig. 1.

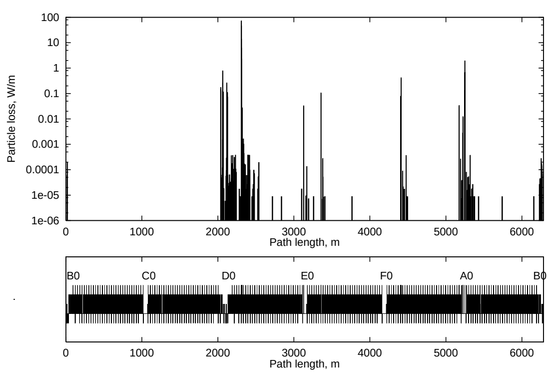


Figure 1: Beam loss distributions in Tevatron for D17 collimation with Roman pots at $8\sigma_x$.

## 4 FAST RESONANT EXTRACTION

Our recent simulations have shown that with the appropriate collimation, additional shielding in AØ and electrostatic deflector and Lambertson magnet realignment, one could reduce beam loss rates in Tevatron and increase the extracted intensity without quenches. It was found that in a narrow region of resonance phases used for extraction, the angle of the Lambertson magnet alignment depends mostly on the septa position, not on the resonance phase. This angle is equal to x'=-0.330 mrad for the septa at 20 mm from the beam orbit. Any misalignment can drastically increase the effective septum thickness and thus beam loss.

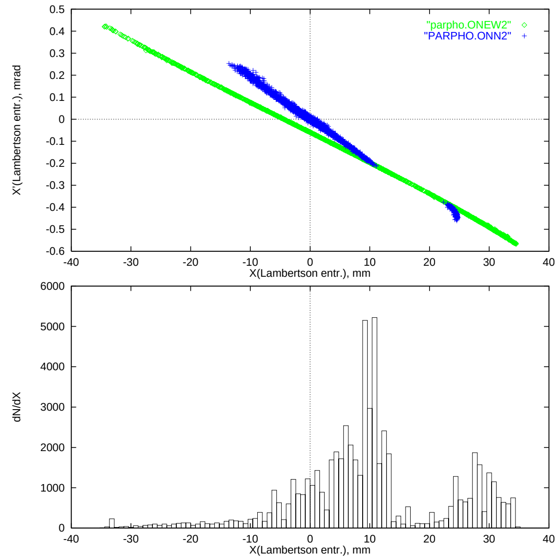


Figure 2: Fast extraction phase space at the AØ Lambertson magnet entrance. Top – extracted beam (black crosses) and protons outscattered from the DØ deflector (grey squares). Bottom – transverse distribution of outscattered protons.

Proton distributions at AØ are shown in Fig. 2 with proton beam kicked by the DØ electrostatic septum. Protons outscattered from the septum wires are intersepted by the Tevatron collimators. The EØ straight section is a very convenient place for the absorption of scattered protons, but unfortunately, there is no collimator in this location. It was found that the antiproton injection Lambertson magnet can be used as a collimator with particles catched by the normal conducting magnet yoke. Fast resonant extraction related beam losses (in SC magnets only) with and without collimation are presented in Fig. 3. Collimation system reduces beam losses in the superconducting magnets downstream of D17 by one order of magnitude. The DØ collimator right after the septum, catching the low-energy debries from the wires, unfortunately doesn't protect the DØ - D17 region.

Calculations show that a 1 m long collimator ($r_{in}$=15 mm) upstream of the extraction line superconducting skew dipoles will protect them from the secondaries produced in the Lambertson magnet. Similar collimator with a round aperture of $r_{in}$=20 mm upstream of the first and second quadrupoles will protect them and other ring superconducting magnets.

## 5 PROTON BEAM REMOVAL

The upgrade plan requires to remove proton beam from Tevatron before the deceleration leaving antiproton beam for recycling. There are two main concerns with the intense

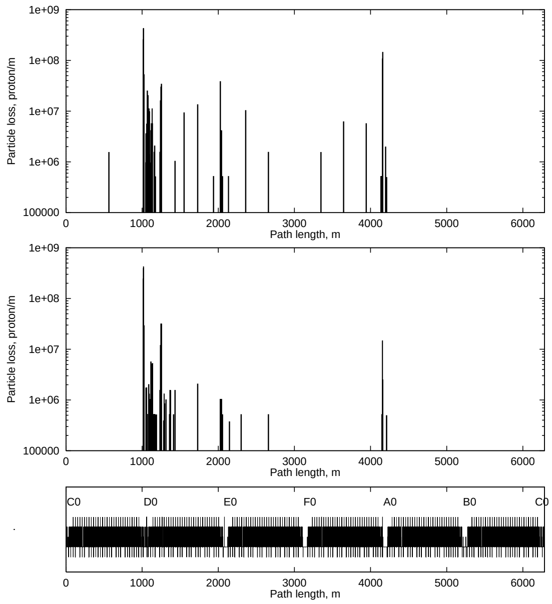


Figure 3: Fast resonant extraction losses without collimation (top), and with DØ , D17, F17, F49, AØ collimators and Lambertson magnet at EØ (bottom).

beam fast removal: superconducting magnet quenches caused by secondaries from a collimator and a target-collimator assembly overheating. A quench level of the Tevatron magnets at 1 TeV is about $3\times10^8$ p/m/s. This corresponds to about 50 W/m. A good practice is to keep a heat load to cryogenics below $\sim$ 1.5 W/m, or $1\times10^7$ p/m/s.

With the Main Injector, the EØ straight section becomes free of the magnets used for the beam injection into the Tevatron. With the first 15 m of EØ straight section reserved for RF, the rest 35 m can be successfully arranged for the proton beam removal (Fig. 4). Four DØ conventional bump-magnets are supposed to be used for the EØ dog-leg to protect the Tevatron magnets against neutral and low-energy charged particles out of a primary collimator. Two 1.5 m long L-shaped secondary collimators placed at $10\sigma$ downstream of the dog-leg at the entrance to the cold region intercept most secondaries. With such a system, the maximum beam loss in the Tevatron SC magnets is estimated to be 1.4 W/m. Moreover, the calculations show that it allows to get rid of other secondary collimators in the machine and, what is remarkable, reduce the beam loss level in the DØ - D17 region by about a factor of four.

The EØ target heating is a serious problem for short spills. An instantaneous target temperature rise is 10000°C. The target-collimator assembly cooling tremendously decreases this temperature. With this, for a 10 msec spill a stainless steel collimator edge is heated up to 1600°C, but already for a 1 sec spill, $\Delta T_{max}$ = 40°C, only. So, the target-scraper assembly overheating seams is not a restriction for the proton beam removal from Tevatron.

Calculations show that total beam intensity of $10^{13}$ can be removed from Tevatron during 100 s using EØ collimator. During the January 1997 experimental studies, proton

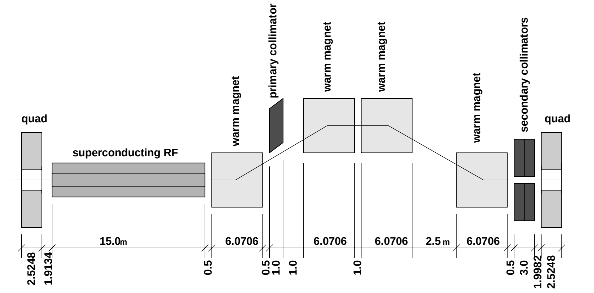


Figure 4: Dog-leg scheme for proton beam removal at EØ straight section.

beam was removed from Tevatron without problem until a SC magnet quench happened at the rate of $0.36\times10^{11}$ p/s. This is three times below of that was expected, what is easily explained by absence of a scattering target in the collimator and possible closed orbit displacement. Moreover, analysis of the spill at beam removal has shown peaks of losses at frequency of 1, 4.6, 13.9, 21, 37, 73 and 90 Hz, which are understood from the Main Ring and Central Helium Liquefier performance and the beam position oscillations with synchrotron frequency. The experiment has shown that a feed-back system from the Beam Loss Monitors to the dipole correctors used for the beam displacement is necessary. This system would provide rectangular spill shape and eliminate low-frequency peaks (1-37 Hz).

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