STUDIES OF BEAM PROPERTIES AND MAIN INJECTOR LOSS CONTROL USING COLLIMATORS IN THE FERMILAB BOOSTER TO MAIN INJECTOR TRANSFER LINE

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Abstract

High intensity operation of the Fermilab Main Injector has resulted in increased activation of machine components. Efforts to permit operation at high power include creation of collimation systems to localize losses away from locations which require maintenance. As a first step, a collimation system to remove halo from the incoming beam was installed in the Spring 2006 Facility Shutdown [1]. We report on commissioning studies and operational experience including observations of Booster beam properties, effects on Main Injector loss and activation, and operational results.

OPERATIONAL NEEDS

The Fermilab HEP program uses an increasing intensity from the Main Injector. After the Tevatron Fixed Target run, operation has used one Booster batch for antiproton production (PBar), then added 5 batches for Neutrinos at the Main Injector (NuMI), added a second (slip-stacked) batch for PBar and is preparing to slip-stack an additional 4 batches for NuMI. Unsurprisingly, the residual radiation in the tunnel has been rising. In anticipation of increased demands for beam, the program of residual radiation measurements for personnel protection has been supplemented by additional measurements designed to diagnose losses and benchmark performance.

Figure 1. Collimator C836B, bellows, marble mask, Loss Monitor LM8C1 beside 836 marble mask with loss monitor LM8C3 above on wall, position monitor HP837, gradient magnet.

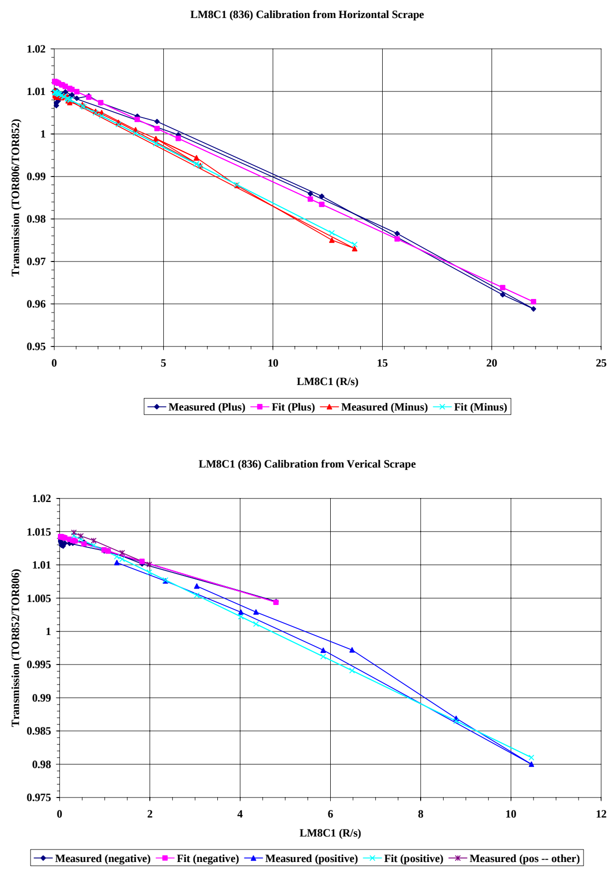

Figure 2. Calibration of loss monitor LM8C1 using transmission changes measured by beam toroids. Measurement from scraping horizontal edges above, vertical edges below.

A concern raised by these measurements was that the number of places with significant radiation was large enough as to make diagnoses more difficult. Since many locations showed activation which was associated with injected beam halo, a collimation system [1] in the Booster to Main Injector beam transport line (MI8) was installed during the Spring 2006 Facility Shutdown to provide a more well-defined beam. Measurements and operational results from use of this system are described.

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Table 1. Sensitivity of LM8C1 to losses due to C836A. Sensitivity of LM8C3 to losses due to C838A.

Loss Monitor	LM8C1	LM8C3
Units	Protons/(R/s)	Protons/(R/s)
From Hor. Positive	1.18E+10	7.03E+09
From Hor. Negative	1.30E+10	1.07E+10
From Vert. Positive	1.52E+10	1.10E+10
From Vert. Negative	9.56E+09	9.19E+09
Average	1.24E+10	9.49E+09

LOSS MONITOR CALIBRATION

Using loss monitor readings to measure the number of lost protons, one can set the collimators to provide a specified loss rate. By using only one collimator edge and by scraping enough beam to have a measurement of protons lost using upstream and downstream beam toroids, one can measure the beam profile and obtain a calibration for a loss monitor. Loss scans using all four faces of C836A and C838A were carried out. Figure 1 provides an illustration of the calibration process. Results of these measurements are shown in Table 1. LM8C4 responds almost proportionately with LM8C3 showing about 10% higher response at high loss. LM8C2 is less closely proportional to LM8C1 but is still well correlated. We find nominal calibrations of 1.02E+11 Protons/(R/s) for LM8C2 and 0.89E+11 Protons/(R/s) for LM8C4.

LOST BEAM PROFILES

By converting the loss monitor readings to lost protons and dividing by beam intensity, one has a measure of the integrated loss for that collimator location. The scraped beam scans were converted to integrated beam loss profiles using data sets with positions ranging from the center to positions which scrape several percent of the beam. Most of the data used Booster beam intensities of nearly 5E+12 protons/pulse. Loss signals due to upstream sources are independent of collimator position.

The integrated loss profile data is well-represented by an exponential beam halo plus a constant term. Both edges are measured and their separation is determined by the known collimator aperture and position. Measurements using the multiwire system are well-fit by a Gaussian. The width and center of the Gaussian can be related to the profile at the collimators using the known beam lattice functions. The match to the integrated loss profiles is satisfactory but not visually pleasing. Instead adjustments of the beta ratio and beam offset are applied to visually match the halo data. Data for C838 is shown in Figure 3. This data was measured without centering the beam on the beam position monitors.

The exponential fit is expressed by the formula in the Table 2 title. For Table 2, the offset is expressed as fitted, in collimator motion coordinates, and as related to beam position coordinates. The slope parameter, **a**, characterizes the halo shape. Note the asymmetry in the vertical shape as reported in Table 2.

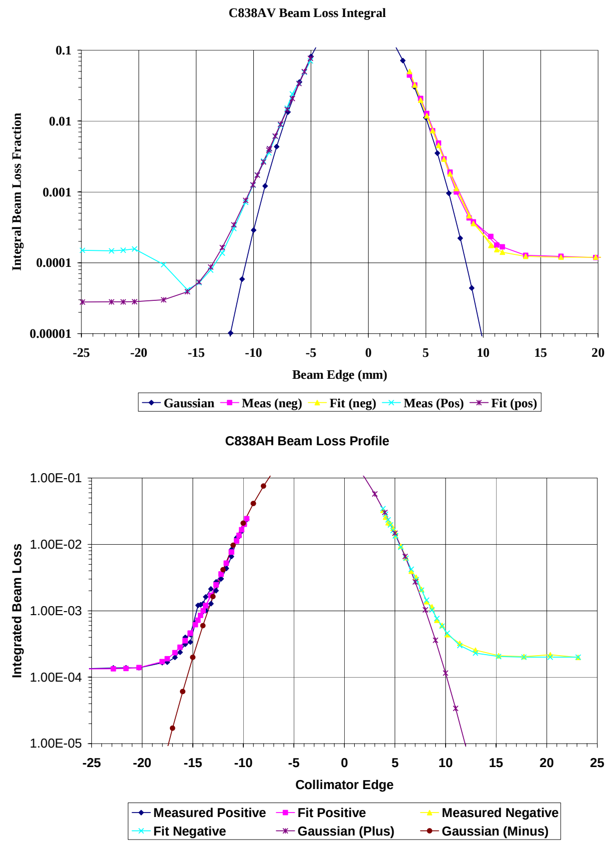

Figure 3. Integrated Beam Loss Profiles at C838A. Vertical profile show above and horizontal profile shown below. The data is shown with the exponential fit described in Table 2 and a Gaussian profile integrated from the beam edge on each side. Gaussian width adjusted to visually match halo data.

Table 2: Fit Results for Exponential (10-2 exp(-(x-x0)/a)

	Collimator Position a		Collimator Position x_0		Beam Edge Position X-0		Width (98%)	Center
	mm	mm	mm	mm	mm	mm	mm	mm
	Negative	Positive	Negative	Positive				
836AH	1.527737	-1.41537	-21.9094	12.58068	3.490604	-12.8193	16.30993	-4.66436
838AH	1.30119	-1.29762	-19.9798	14.5959	5.420246	-10.8041	16.22435	-2.69193
836AV	0.93456	-1.30073	-16.7922	22.45753	8.607842	-2.94247	11.55031	2.832687
838AV	1.041336	-1.21198	-20.1474	17.87796	5.252579	-7.52204	12.77462	-1.13473

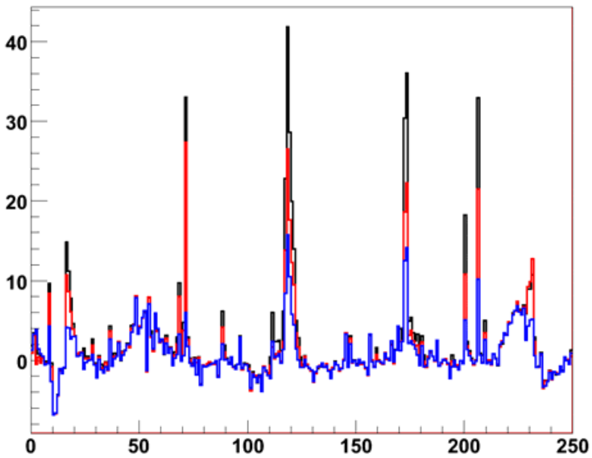

Figure 4. Loss just after injection on sequential Main Injector loss monitors. The black trace is with all MI-8 collimators in the out position, the red trace has the horizontal collimators in, and the blue trace has both H and V collimators in.

MAIN INJECTOR LOSS CONTROL WITH MI8 COLLIMATION

To establish the effects on Main Injector losses of removing halo in the MI8 Line, a study established the horizontal and vertical positions for each collimator which would produce ½% beam loss when used alone. The collimators were then placed such that opposite sides were collimated with the ½% loss setting on one horizontal and one vertical side of both the A Collimator and the B Collimator at 836 and 838. The losses indicated that 3.5% of the beam was removed as halo (compared with 4% expected). Figure 4 shows the result for losses just after injection in the Main Injector. The locations with high loss are at beam transfer locations where Lambertson magnets restrict the aperture.

Operational limits have been set at about 1% loss at 836 and 1% loss at 838. Typical operation is at one half of the per pulse limit. The average repetition rate is also held well below the design limit of 10 Hz by other considerations. Following operation for a few months, we find that the most radioactive Lambertson magnet locations are not as radioactive. Improved loss monitor readout has contributed to other tuning improvements but reduced halo may contribute to this improvement. Limits on the losses at MI8 Collimators have brought timely attention to beam tuning issues in the Booster. The optimal use of these collimators is still being explored.

CONCLUSIONS

The transfer line collimators in the Booster to Main Injector transfer line have been in operation for a few months. While scraping a modest fraction of the beam, we have experienced no problem with maintaining beam position using auto-tune steering. Typically, when beam delivery is interrupted due to losses at the collimators, we have found issues in the Booster operation. Radiation levels at the collimators are in line with predictions.

The halo from the Booster beam has been measured. We find the beam has an exponential distribution from above 1% to about 0.01% of the beam. The halo is symmetric in the horizontal plane but shows substantial up-down asymmetry. Nearby multiwire profile monitors find a symmetric Gaussian profile for the beam core.

REFERENCES

[1] B. C. Brown et al., “Collimation system for the Fermilab Booster to Main Injector transfer line,” PAC07.