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Reducing Losses in Main Injector by MI8 Line Scraping

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Introduction

The increased demand for beam to be accelerated in the Main Injector for the neutrino program in addition to the slip-stacking to increase beam for pbar production has focused attention on the need to control activation in the Main Injector tunnel. Plans are being developed to provide a collimation system in the MI8 transfer line from the Booster to the Main Injector with the goal of removing beam halo. This is beam which is not destined to be accelerated in the Main Injector and extracted for the physics program. Studies of the residual radiation patterns around the Main Injector have suggested that this problem is most obvious in the vertical plane. This note will document some studies which suggest the value of scraping halo in the MI8 line to reduce beam loss in the Main Injector.

The studies were carried out since May 2005 by Dave Johnson. Bruce Brown is serving as scribe to provide a document for circulation. Figures and comments are extracted from the Main Injector E-Log .

Some Main Injector radiation issues are discussed in Beams-doc-1382.

Losses in the Context of E-Cool

The commissioning of the Fermilab electron cooling system began in Spring 2005. This system occupies space in the Main Injector tunnel at MI305 through MI307. Additional Loss monitors (same Tevatron style used throughout the Main Injector) have been added in the region of the electron cooling system to monitor for problems with the 4.3 MeV electron beam control. But these monitors are also sensitive to other losses in the tunnel. Among the loss points discussed in Beams-doc-1382 is one downstream of Q301 where residual radiation on the top of the bare beam pipe suggests beam is scraping on the top. Since there are no dipoles between Q301 and the E-Cool system, effects from losses at 301 can propagate from 302 through 307 and beyond.

These studies will explore losses in the MI300 straight section with special concern for Loss Monitor LMR04 which is on the E-Cool return beamline which is about 30 cm above Q305. We will explore aperture scans and time structure of losses and look for changes in these when the beam is scraped vertically in the MI8 line.

MI8 line Features

The MI8 line matches beam from the Booster lattice upstream into a FODO section in the middle for most of the transport. This is followed by a section downstream to match to the Main Injector. A portion of the line is made up of FODO sections where all the bending and focusing is created by gradient magnets (PGD) with one at the upstream and one at the downstream of each half-cell and 5.2 m of drift between. Collimation design is focusing on the region from 836 through 843 where this structure allows collimation to be added with minimal other impact.

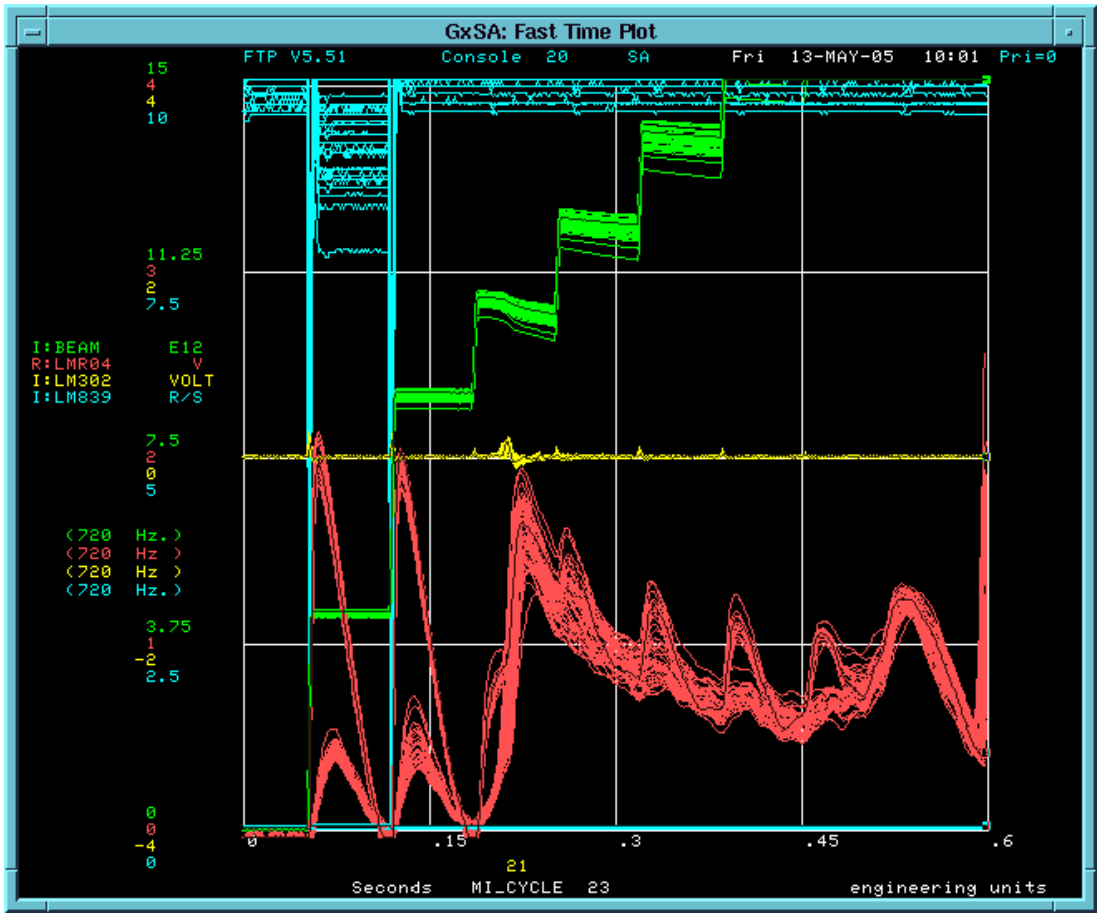
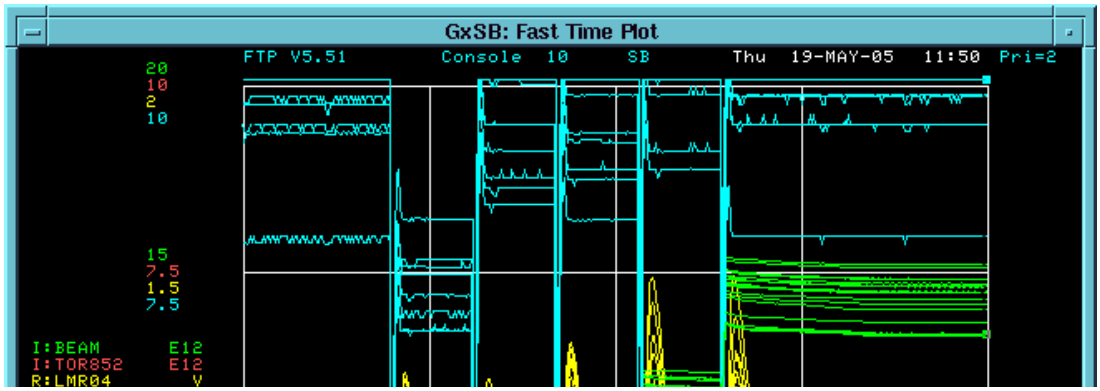
The field imperfections in the MP02 pulsed septum may be diluting the beam brightness and creating halo (see Beams

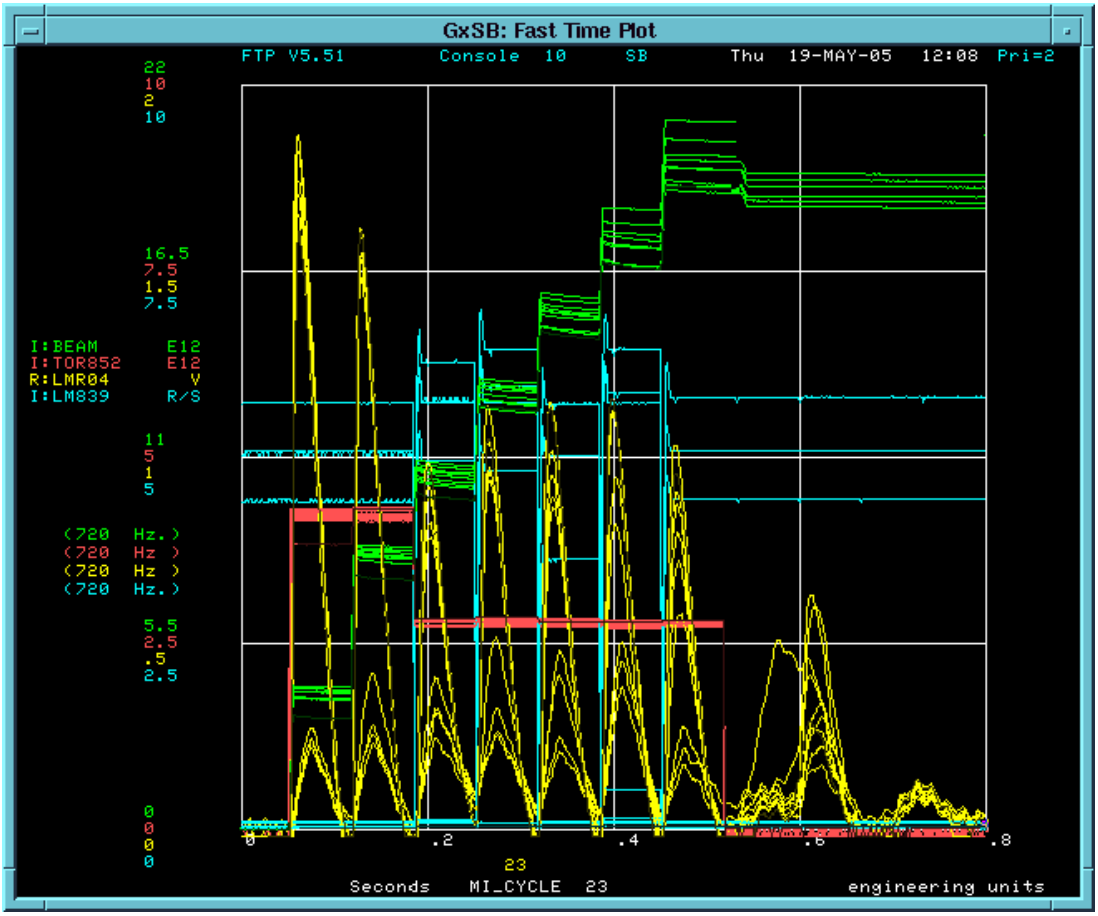
Document 1573-v1). Studies of the losses will try to explore this possibility.

Losses with and without Scraping

For simplicity of presentation, let us show various studies graphics in one column with information on conditions and comments on results in the adjacent column.

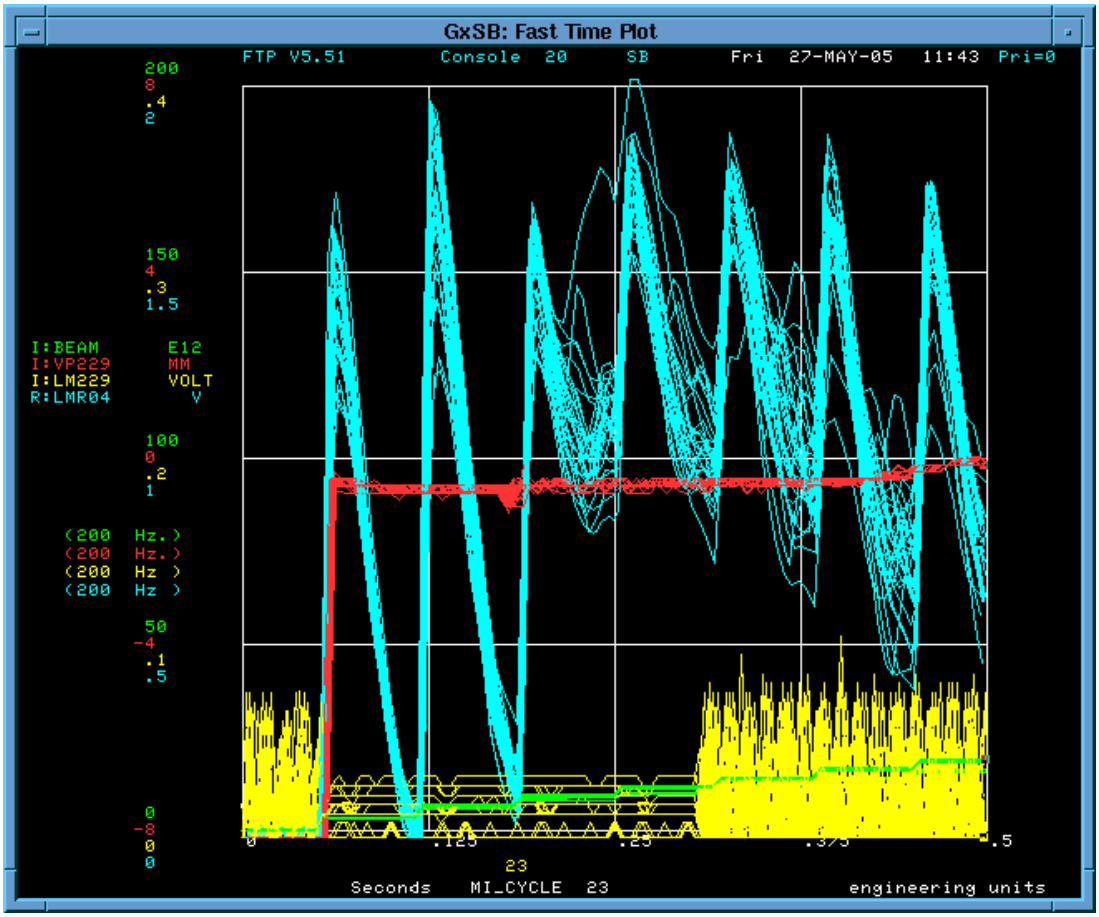
Studies Results -- Losses

Measurement	Conditions and Comments
	This plot shows the losses on the LMR04 with nominal injection and lower losses with a 17 mm vertical bump at 839 in the MI8 Line. Scraping reduces losses on both slip-stacking and NuMI cycles. Losses at LM839 increase as the loss in the 300 straight section goes down. Also recorded in the e-log with the data are measurements showing that the 3-bump is local including the MI8 orbit and the MI Injection flash.
	The 17 mm scraping bump at 839 was repeated here with NuMI-only cycles. Again, losses on the LMR04 monitor were reduced by about x5.

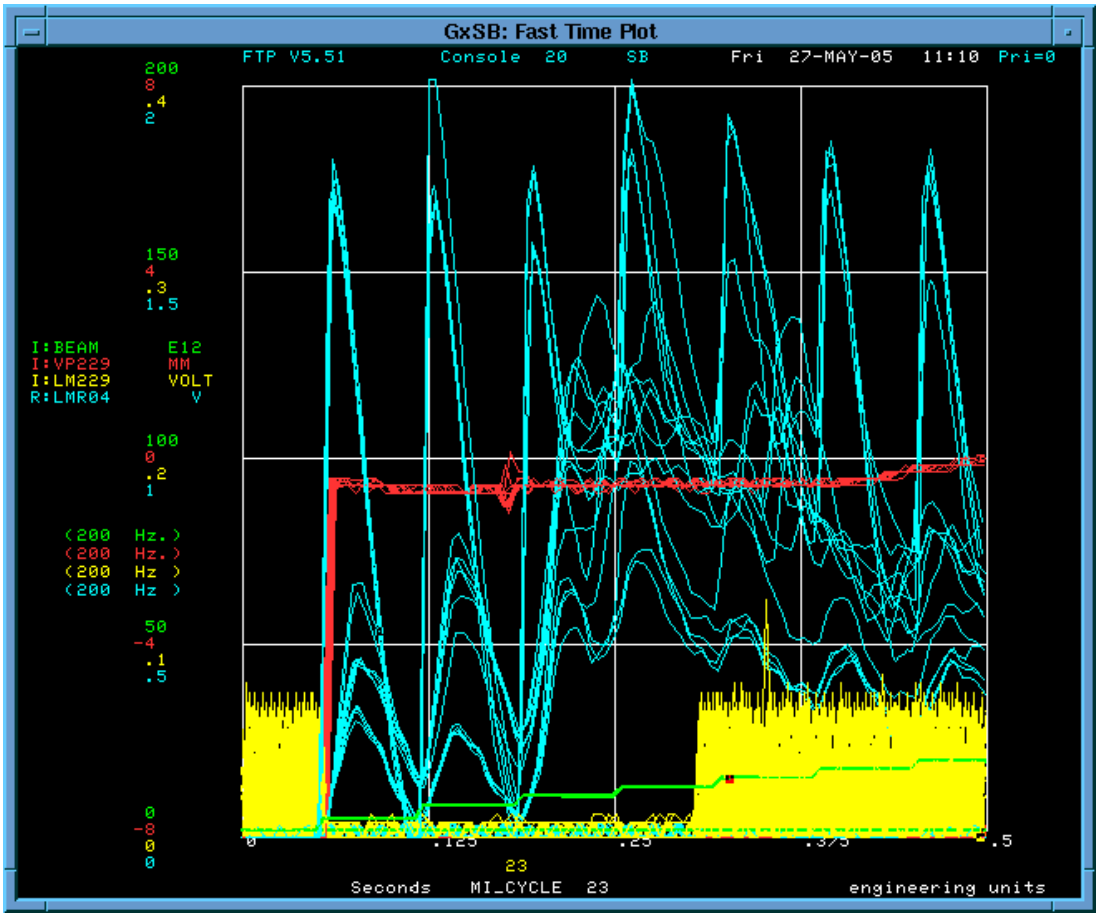
	Intensity in MI was not measurably reduced. Pulse-to-pulse variations in I:BEAM of many percent limit ones ability to see intensity changes at about the 1% level in many cases (and this case).
	With slip-stacking re-established, the loss comparison using a 17 mm bump at 839 was repeated, confirming a large change in the LMR04 losses.
Now we will explore the effect on losses at LMR04 with scraping at various locations in MI8.	We will explore vertical scraping from 829 through 837.
	

Loss at LMR04 with and without scraping using a 5 mm bump up at 829.

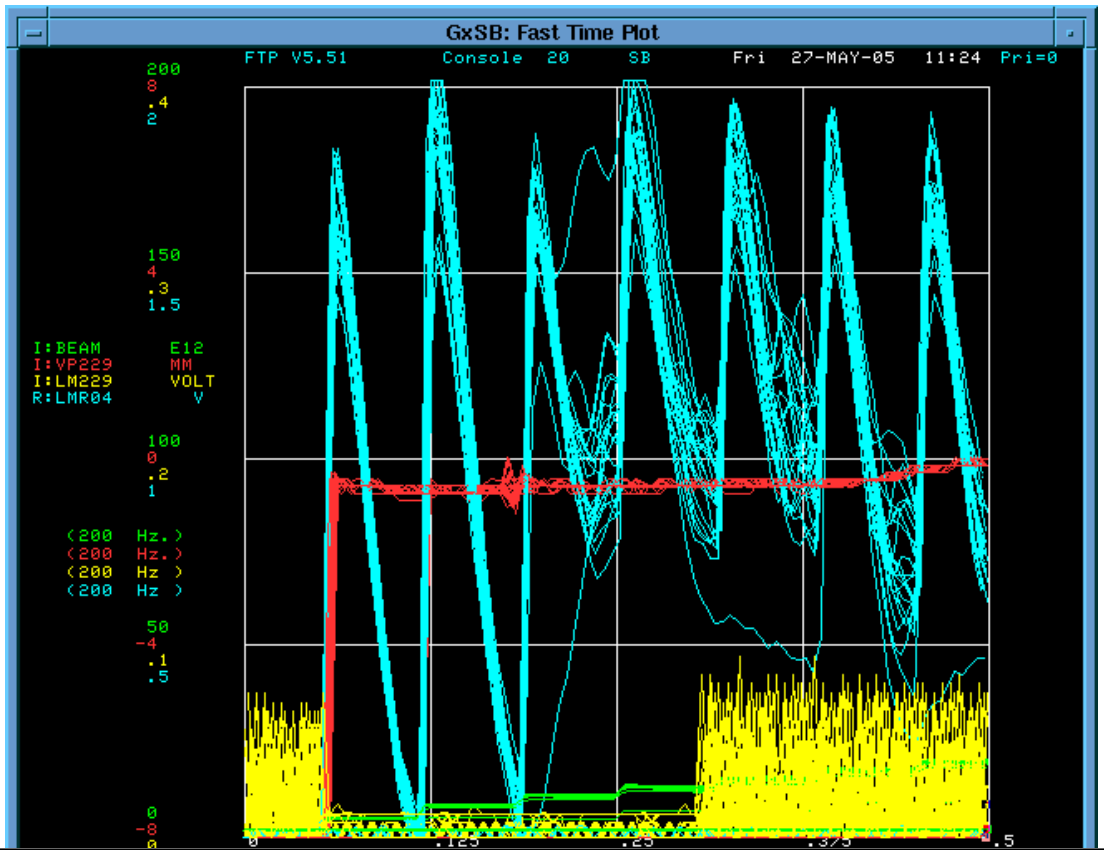
Loss with scraping is about 5 times lower.



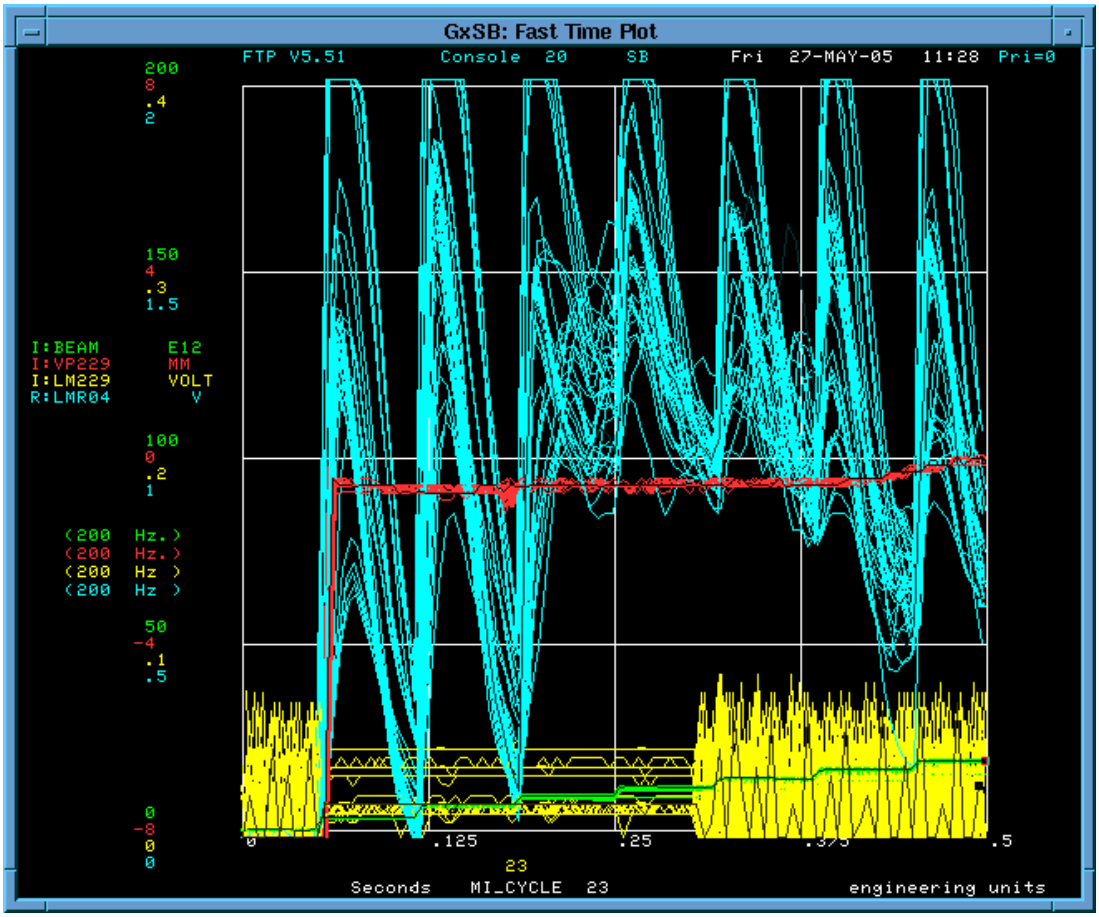
Scraping with a plus or minus 15 mm bump at 831 shows no effect on LMR04 losses.



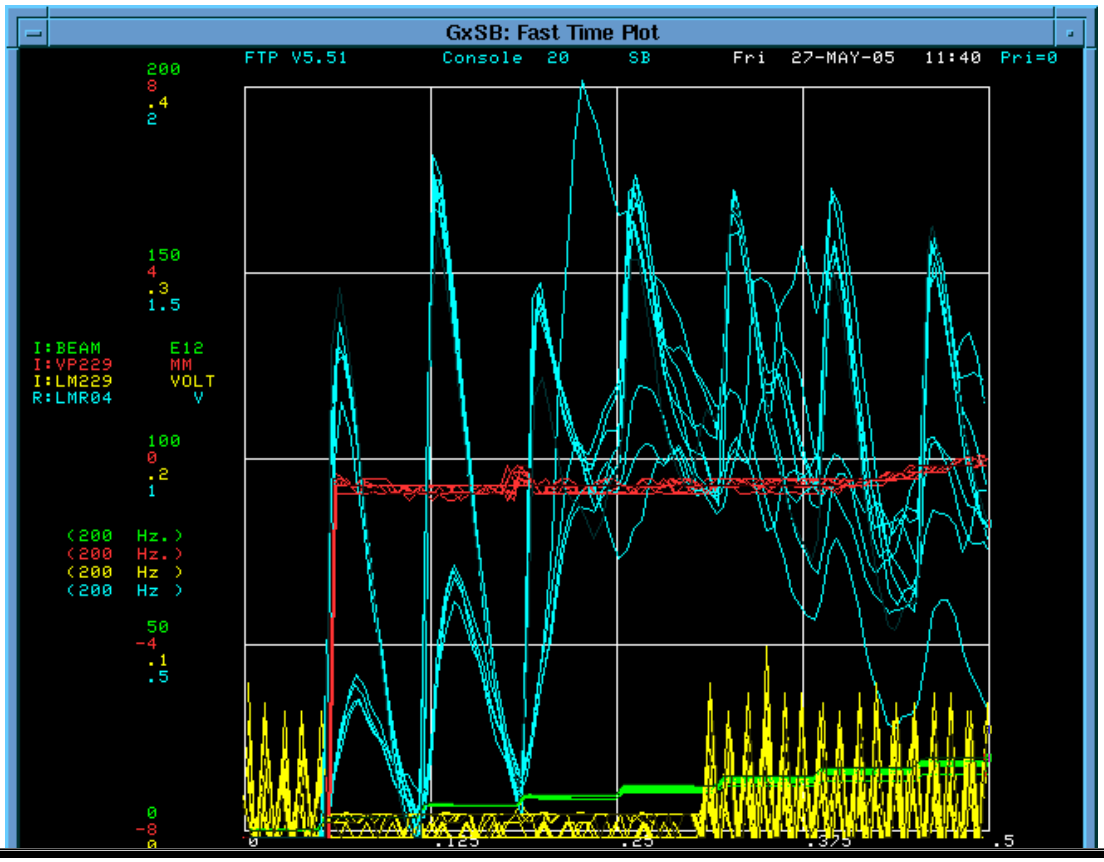
Pushing the beam up at 833 by 15 mm also reduces the losses at LMR04.



Scraping either on top or bottom at 835 has little effect on LMR04 losses



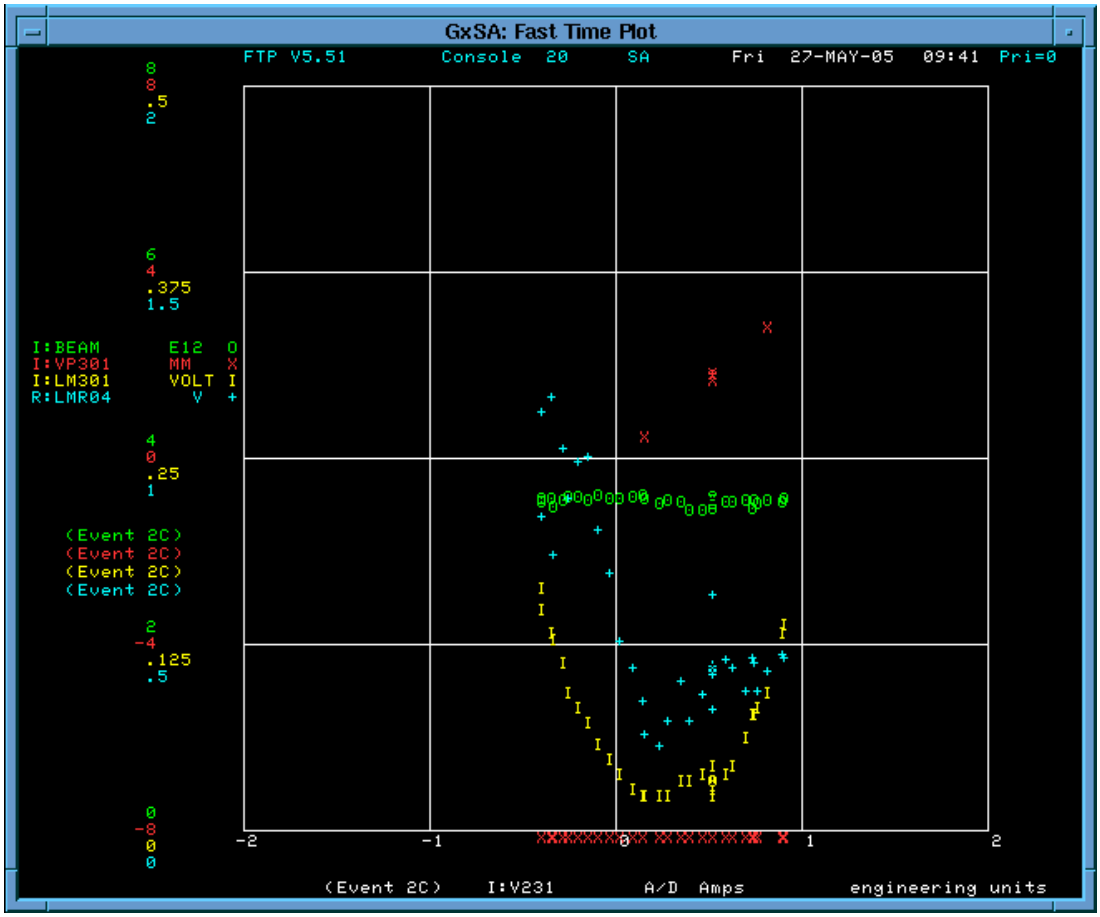
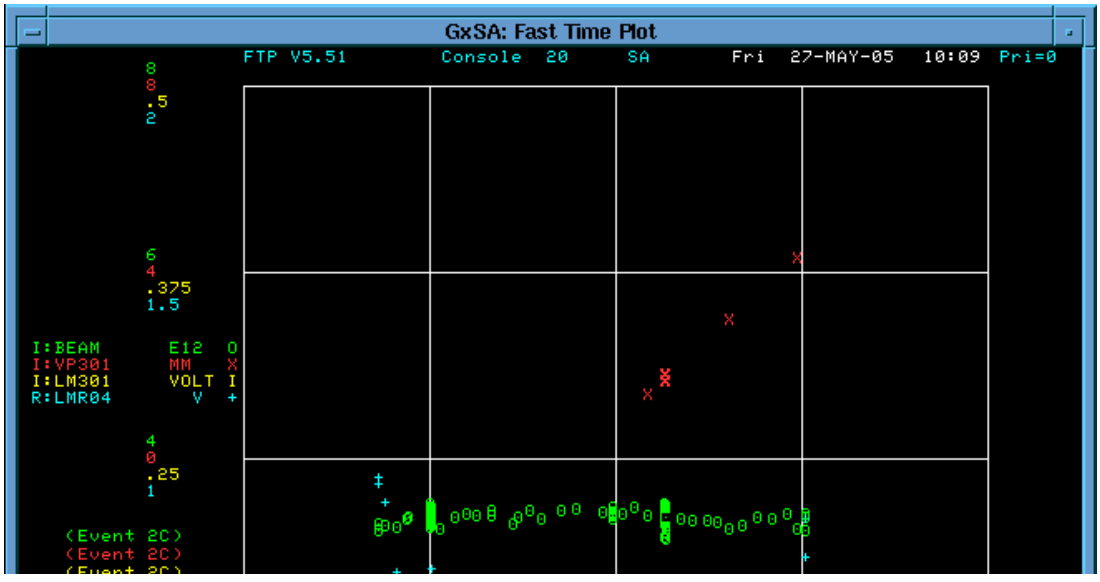
Positive to 10 mm at 837 reduces losses. Greater than 10 mm or moving negative increases losses.



Scraping at 839 (again) with a 15 mm positive bump reduces LMR04 losses.

Further information on the effects of scraping in MI8 is revealed by doing aperture scans in the Main Injector and examining the changes in loss patterns with position. Scans were carried out a a few locations. We will document only a few of these scans here.

Aperture Scans

Picture	Conditions and Comments
	LM301 Losses are shown vs. three-bump strength (proportional to position VP301). No Scraping in MI8 for this scan.
	As above, losses are shown vs. three-bump strength (proportional to position VP301). Scraping in MI8 using 3-

	bump at 839 which moves beam about 10 mm for this scan

Discussion

The MI8 line design creates a long FODO section where the beam envelope oscillates in a regular pattern of maxima and minima. It then matches into the Main Injector where, again, the design creates a repeating pattern of maxima and minima in the beam envelope. Achieving this pattern is the goal of the beam line tune up. Since the commissioning of the Main Injector, it has been approximately achieved by carefully studying the matching sections at the Booster and Main Injector ends of MI8. Recent studies have confirmed that a power supply replacement in early 2005 and associated changes in current control/readout devices resulted in a modest mismatch condition. Efforts are underway (early August 2005) to attempt to re-measure and rematch the MI8 line lattice.

Given this situation, we have difficulties in drawing quantitative conclusions about MI8 collimation and MI losses. We believe that the measurements presented above demonstrate that MI losses can be reduced by scraping tails in the MI8 line. However, statements about the quantitative effects and/or the optimal location for scraping are expected to be dependent on the lattice which is actually achieved. Quantitative studies will await matching of the MI8 line.

The patterns observed when scraping at locations from 829 through 839 show differences from cell to cell which suggest that the halo is not uniformly distributed in phase space (less useful scraping for LMR04 when scraping at 831 and 835). Losses at LMR04 are reduced when moving up at 839 but not down. These patterns may be related to the asymmetries of the halo or they may just reflect the phase relation between these MI8 locations and the locations in MI300 straight section. The MI8 collimation being designed will provide scraping on 4 sides at two phases which are separated by 90 degrees phase advance.

Conclusions

The ability to remove halo in the MI8 line using a vertical 3-bump to scrape the beam on the top of the beam pipe (inside a magnet) has been shown to reduce losses in the 300 straight section of the Main Injector. These observations support the concept that a properly designed and implemented collimation system which removes beam halo in the MI8 line can reduce the losses in the Main Injector.