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Improved Measurement of Main Injector Collimation Efficiency for Uncaptured Beam

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Abstract

Initial commissioning efforts for the Main Injector Collimation System have reported[1] that about 93% of the loss due to uncaptured beam was deposited in the collimation region (LM229 - LM309) with an additional several percent in the region just beyond the pre-defined collimation region (LM310 - LM315). This was based on the integrated loss for $23 cycles (mixed mode PBar and NuMI) between 0.755 seconds and 0.829 seconds (74 ms). This document reports on measurements which explore the time structure in this region and find that slow losses (8 GeV lifetime) are significant. Measurements during the ~12 ms of uncaptured beam loss show an efficiency of about 97% in the collimation region with an additional 2% in the next few loss monitors. We obtain this result either by determining the slow loss and subtracting it or by simply focusing on the appropriate time interval when the background is almost negligible. We conclude that further collimation optimization needs to emphasize stable operation for uncaptured beam while exploring better collimation efficiency for injection and 8 GeV lifetime processes.

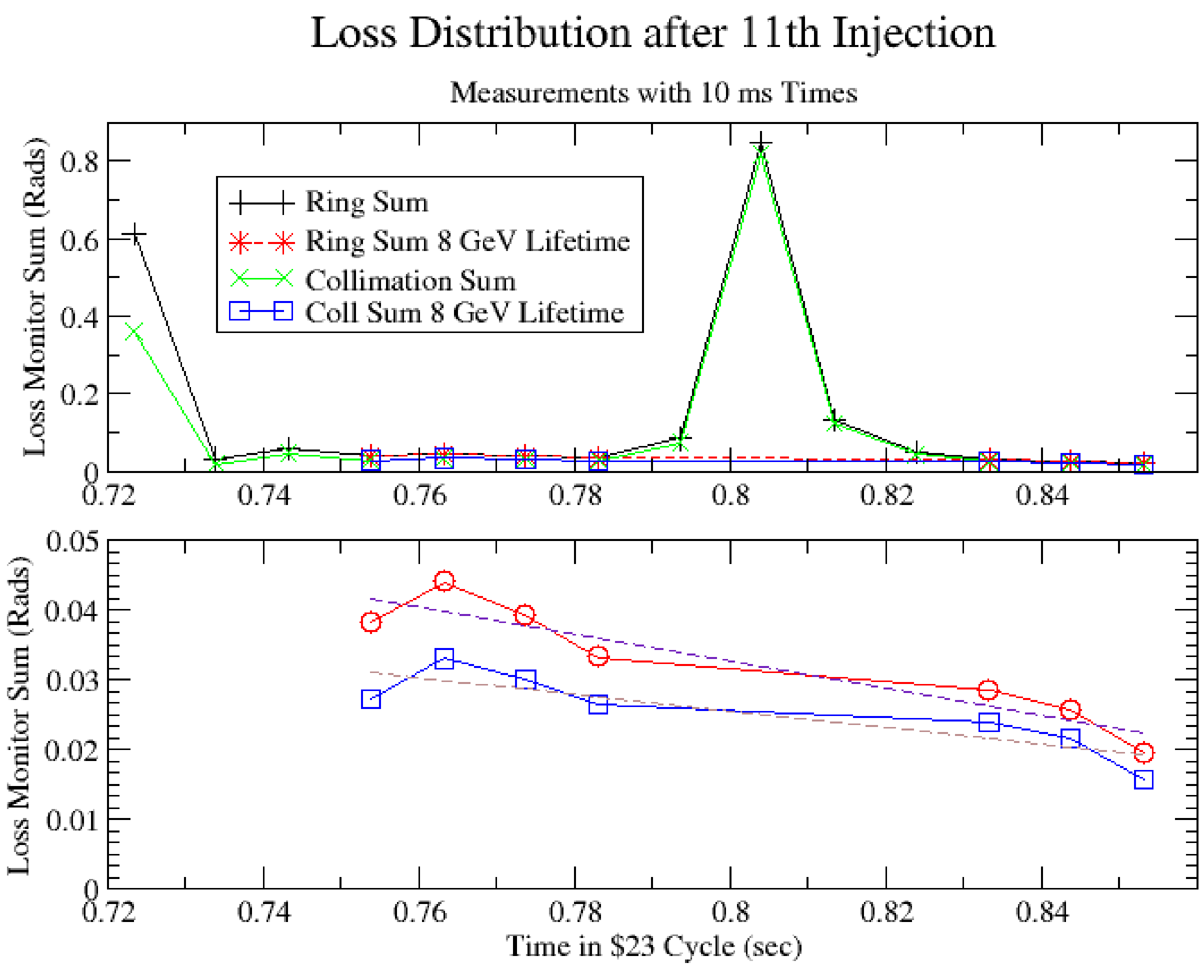
Introduction

As we add more convenient tools for measurement of losses using the Main Injector Beam Loss Monitor (BLM) system, we are exploring the losses for various time periods. Except for the losses at extraction, no large loss is normally observed after the uncaptured beam hits a momentum aperture and is lost. We are exploring losses during the injection period, separating them into kicker losses and lifetime losses. We noted that the lifetime losses continue after the last injection, even extending during the early acceleration period following the uncaptured beam loss. This encouraged a more careful look at the loss distribution for the uncaptured beam. Previous studies reported on the losses for $23 cycles (mixed mode PBar and NuMI) between .755 seconds and .829 seconds so as to emphasize the loss of beam which was not captured at the end of slip-stacking. These times are the 'break point' times which are normally maintained as the PROFILE time settings for normal physics operation of the Main Injector. Using more convenient loss measurement tools (I129 modifications still under development), the loss from .725 to .845 seconds has been explored with 10 ms and 4 ms time resolution. These measurements show that the uncaptured beam loss duration is only about 12 ms (as previously reported) but a slow loss (8 GeV lifetime) continues through this period. Subtracting the loss contribution from the slow loss from all groups of loss monitors shows that the loss distribution from uncaptured beam is different from that for the slow losses. We can re-evaluate our tuning procedures so that separate optimization can be attempted for these different lost particles.

A Measurement with 10 ms Resolution

Many cycles of high intensity operation were observed. Data was recorded for both 10 ms and 4 ms PROFILE time sets.

This note will report on a single measurement. The data from the group table which was immediately reported as a .csv file was studied. It is typical of the operations which were measured. The following graph (upper) shows the data for 14 PROFILE times (uniformly spaced). The uncaptured beam induced the large loss at 0.804 seconds. The momentum begins to change at 0.755 seconds and about 1% of acceleration has occurred by the time of the loss. The first time point shows the integrated injection and slow loss through injection of 11 batches. Red and black data is the integral of all MI loss monitors while the blue and green data are for LM229 through LM309 (collimation region). Red and Blue data sets exclude the 4 measurements nearest the uncaptured beam loss. The lower graph shows the losses excluding the four data sets.along with linear fits to the slow loss data. It is apparent that the loss of beam from processes which are likely unrelated to the uncaptured beam loss contribute losses throughout this time period.



One can examine this measurement for a collimation efficiency result. We show three new analyses for this data to demonstrate that the essential conclusion is not strongly dependent on the details of the slow loss. The results for the 'break point' measurement which is and will remain the basis for the "comfort" display from I38 is Analysis A. Analysis B measures the efficiency in a 10 ms interval without subtraction. We use a linear fit to the background and Analysis C uses that for the same 10 ms interval while Analysis D subtracts background from the measured results for the 40 ms period which appears to have signal from the uncaptured beam.

Analysis	A	B	C	D
Loss from 229 through 309 (rads)	1.476	.817	.789	.946
Loss from 310 through 315 (rads)	0.055	.018	.015	.023
Sum Loss around Ring (pfsum rads)	1.586	.847	.813	.976
Fraction from 229 through 309	.931	.964	.971	.969
Fraction from 310 through 315	.035	.018	.019	.023
Fraction from 229 through 315	.966	.985	.990	.993

Analysis	Description
A	Results for loss between break points at .755 seconds and .829 seconds
B	Results for 10 ms measurement of peak loss including slow loss
C	Results for 10 ms measurement of peak loss subtracting slow loss
D	Results for 40 ms measurement of loss subtracting slow loss
Note	Analysis B, C, D are of the same cycle while A is from a different MI Cycle

The essential new result is clear from any of these new analyses. Losses due to uncaptured beam are well captured by the collimation system with 97% going to the region indicated by the simulations and another 2% falling a bit further along the ring. With 10 ms bins, the result is apparent even without correcting for some slow loss which occurs throughout this time period.

For uncaptured beam, progress in operations now can focus on stable operation and perhaps reduction of losses in the ECOOL region (LM305A,B LM306A,B). Clearly this will require examining an appropriately short time interval. One must be careful in defining such an interval, however, since the tuning can change the loss time by moving the omentum aperture limit using the primary collimator position and the orbit at that location.

Caveats

As we seek to understand loss measurements at the 1% level, we must note that a few effects would have to be evaluated to provide the ability to determine particle loss distributions from the ionization-based beam loss monitor measurements. I particularly note that the collimation system is designed to absorb lost beam and the products produced as it interacts. One should hope that the BLM response to a particle lost in the collimators will be lower than the response in the general case of losses around the ring. This would suggest that these measurement results could underestimate the collimation efficiency. More generally, the loss monitor response is a complex function of the ring geometry and the orbit employed. Since the orbit in the MI300 straight section where we collimate is significantly modified during the uncaptured beam loss time, we may have different loss response functions for slow losses and for the uncaptured beam loss. At present we expect that this issue will remain to be explored at a later time.

We also note that the loss monitor system, as currently configured, has an offset which integrates to a negative loss response for many of the loss monitor channels. We have employed the data by setting any negative loss result for a time interval to zero. We expect that this is not significant for result at the loss levels we currently consider, but would need to be evaluated to assure accuracy for more refined studies.

Conclusions

The MI Collimation system collects the losses due to uncaptured beam in about a 12 ms interval just after the beginning of acceleration. We have shown that loss in the pre-defined collimation region is about 97% with an additional 2% being observed in the adjacent 6 half-cells. This is to be compared with a predicted 99.7% capture efficiency predicted for the collimation region. For this accuracy we find that we must focus on the loss interval or subtract the background but either of these produces a similar result. We believe that this level of loss capture is sufficient. Efforts will be directed toward stable operation, reduction of losses in ECOOL and better capture of injection and 8 GeV lifetime losses.

References

[1] Bruce C. Brown, Collimation system for beam loss localization with slip stacking injection in the Fermilab Main Injector, 42nd ICFA Advanced Beam Dynamics Workshop on High-Intensity, High-Brightness Hadron Beams (HB 2008), Nashville, Tennessee, 25-29 Aug 2008, Also available as FERMILAB-CONF-08-392-AD.