Relating Beam Loss, Activation and Residual Radiation for 400 kW Operation of the Fermilab Main Injector

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Outline

• Goal – Determine Loss and Activation
• Collimation and Loss Control Scheme
• Toroid Measurements (and limitations)
• Beam Loss Monitors (BLM’s) and Data
• Al Tag Activation
• Residual Radiation Monitoring
• Loss Determination using BLM Calibration
Fermilab Main Injector Operation

- Commissioning Began September 1998
- Loss rate experiences large increase
  - 2 batch Slip stacking for antiprotons - 2004
  - Neutrinos in Main Injector (NuMI) – May 2005
  - 11 batch Slip stacking for PBar Plus NuMI – 2008
  - 120 GeV beam delivered at 2.2 second cycle time/~400 kW
- Collimation System /Dampers - control loss –2008
- Gap Clearing Kickers 2010
- Tevatron and PBar operation end Sept 30, 2011
- Shutdown for Upgrade to stack in Recycler 2012-3
Weekly Beam Delivered to PBar (black) and NuMI
Beam Intensity Measurements

• Toroids measure beam intensity on injection, in the abort line and before the PBar and NuMI targets. Fully reliable injection intensity record was only available after adding additional micro-processor systems in 2011 for the 15 Hz rate of injected beam.

• DC Current Transformers (DCCT) measured beam intensity. Micro-processor for that added in 2006.
Transmission

Discontinuities are from Long Maintenance/Upgrade Periods
Collimator Loss Recorded by BLM system with Calibration

4/16/2015
Fermilab Main Injector Beam Loss
Beam Loss Monitor System

• Argon-filled glass detectors (Tevatron style) installed on outer wall and above beam height on downstream end of each quadrupole. (Multiple detectors at each transfer point)

• Electronics and display software upgraded in 2006 to provide control room display and data recording for each 2.2 Sec Main Injector cycle.
Activation Measurements

- Residual Radiation measured with Geiger Counter at 142 Bar-coded locations on more than 50 tunnel accesses.
- Activation of Al Tags measured at 15 locations in MI Collimator Region. Removed tags after one year, two years and three years.
- Studied activation of Steel and Cu Samples
- Software provides simple fit of activation to half life weighted BLM history.
Residual Radiation

was fit to the BLM measurements weighted by the half life of 3 Mn isotopes.

The history at Each collimator is Shown here.

Half Life
Mn-54 312 Day
Mn-52 5.59 Days
Mn-56 2.58 Hours
Residual Radiation During Shutdown

Here we show the residual radiation and fit for the last year of operation and the two years of shutdown.

Either fit activation or measured activation can be used to allocate the protons loss measured by the toroids.
BLM Calibration from Al Tag Activation

Al Tag measurements were normalized to nearby BLM measurements weighted by the half life of the Na-22 which was observed.

Tags removed after 1 yr, 2 yr and 3 yr

We see consistent results for first three collimators while 4 collimator experienced higher activation until masks protected those tags from activation by 3rd collimator

Third year activation (normalized to BLM nearly the same for all collimators.)
Proton Loss from Toroids or BLM
Results Average over 4 Week Periods.
Periods with no beam (shutdown) show as 1 or 0.
Calibration Results

<table>
<thead>
<tr>
<th>Loss Monitor</th>
<th>Al Tag Calibration</th>
<th>Residual Calibration</th>
<th>Calibration from Fit</th>
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</table>

Loss Calibration gives BLM Rads / Protons Lost
Status

The MARS simulations require as input the number of protons lost. Using the programs which provide accurate BLM history, one can use the tools developed here to provide a calibration for BLM Rads per proton lost. These results will be reviewed and summarized for comparisons with final MARS simulations.
Upgrade Result and Plans

After 2012-13 shutdown, Booster beam can be sent to Recycler. Main Injector cycle time reduced from 2.2 second to 1.3 seconds.

2+6 Recycler slip stacking commissioned and achieved >400 kW beam power at 120 GeV.

With Booster upgrades and further Recycler upgrades expect 6+6 slip stacking within the next year. Goal is ~700 kW of 120 GeV beam.