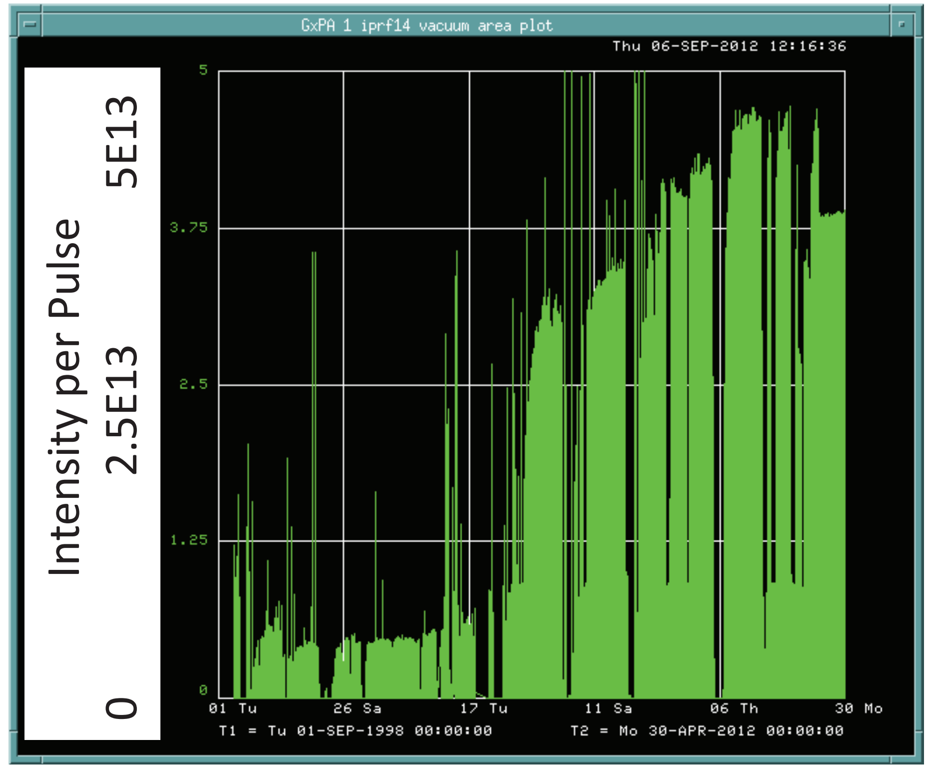
BEAM LOSS CONTROL FOR THE FERMILAB MAIN INJECTOR

Bruce C. Brown
Main Injector Department
Fermilab

Overview of Loss Control

- Intensity History
- Loss Mechanisms
- Collimation
- Aperture
- Gap Clearing
- Instrumentation
- Identifying Problems
- Successes

Per Pulse Intensity in Fermilab Main Injector



Sep-1998 2005 Apr-2012

Slip Stacking for High Intensity

- The Fermilab Main Injector is fed from the 1/7th size Fermilab Booster. Leaving room for injection magnet rise time => 6 injections.
- Booster loss and beam quality limit intensity to <5E12 protons/cycle (< 30E12 per MI cycle)
- Achieve 45E12/MI cycle with 11 injections of 4.3E12 and 95% acceleration efficiency.
- Major loss due to longitudinal emittance too large for capture in desired rf buckets.

Loss Mechanisms

Slip Stacking employs pairs of Booster batches which are captured in rf buckets of different frequency, slipped together for recapture.

Beam outside bucket:

- not captured => not accelerated => lost at low p
- or
- Captured in other bucket, perhaps in kicker gap

Some beam is lost for other reasons.

Collimation – Injection Line

- Collimation in the transfer line from Booster to Main Injector scrapes horizontally and vertically on both sides of the beam and at two locations separated by 90^o phase advance.
- Collimation is set for ~99% transmission
- Autotune using frequent feedback from BPM to trim dipoles keeps beam position at 0.1 mm level

Collimation – Uncaptured Beam +…

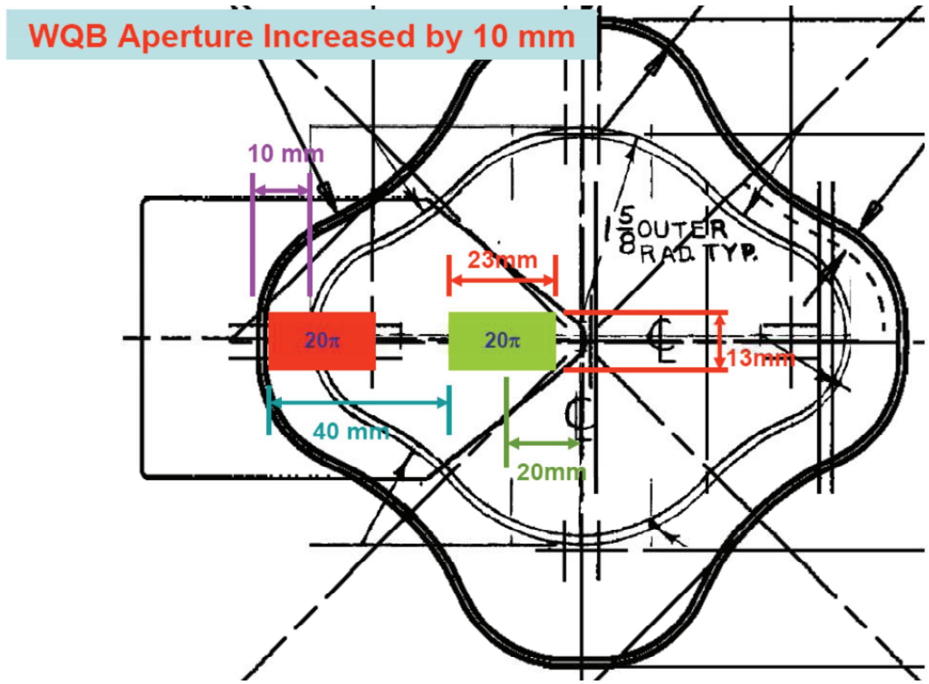
20 Ton Secondary Collimator

Unaccelerated Beam strikes
- primary collimator and products are captured in secondary collimator (99%)

Beam which slips into injection kicker gaps:
- Driven into magnets by kicker unless removed
- Removed by antidamping (moderately useful)
- Removed by gap clearing kicker (highly effective)

Aperture Improvements

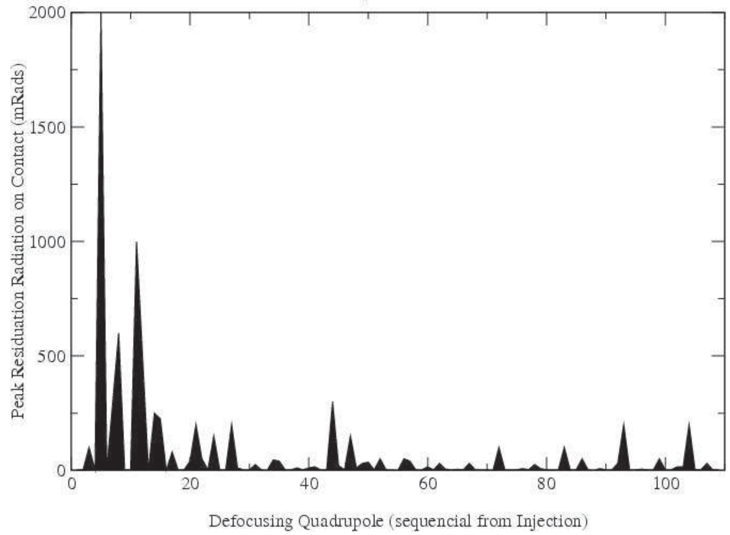
Added Wide Aperture Quadrupoles at 7 transfer locations.



Beam Pipe Distortions

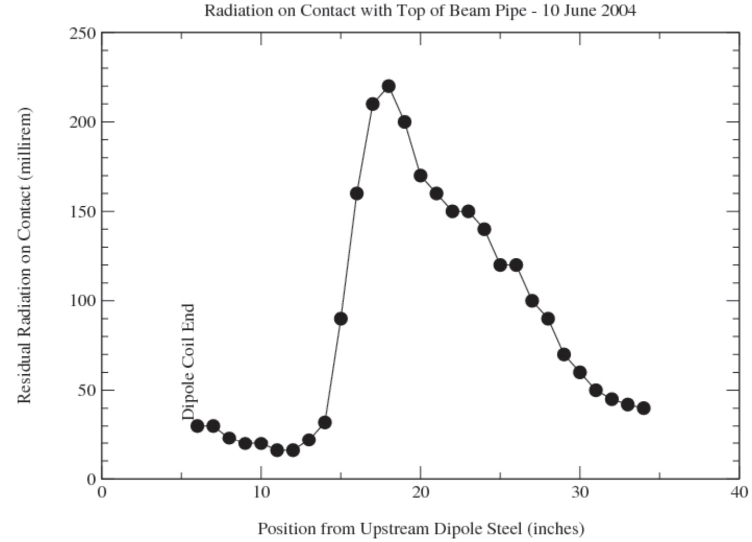
Residual Radiation on MI Defocusing Quads

Survey 11 June 2004

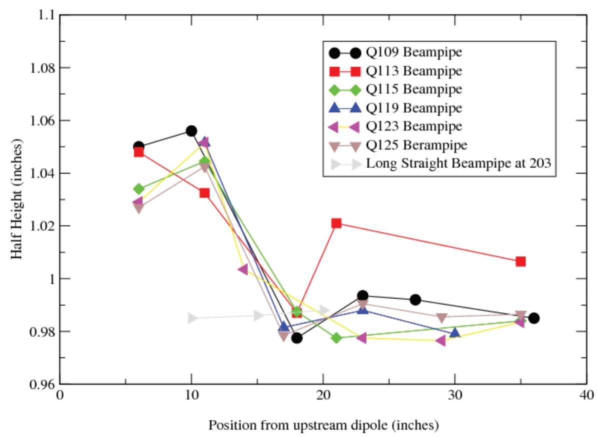


Q209 Radiation Distribution

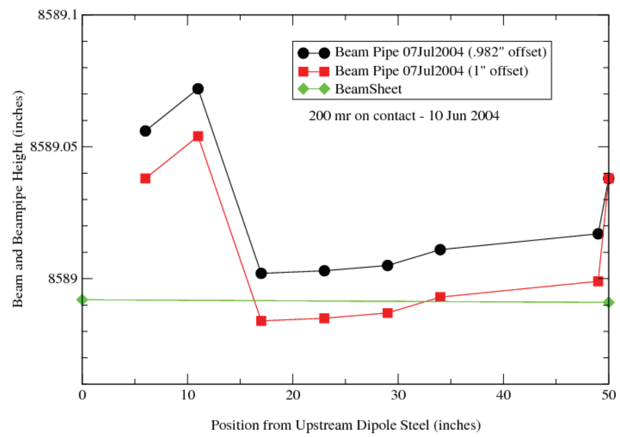
Radiation on Contact with Top of Beam Pipe - 10 June 2004



Half Height of Main Injector Minitube Beampipe



Q209 MiniTube Position



Failed Bellows rf Fingers

Good Bellows

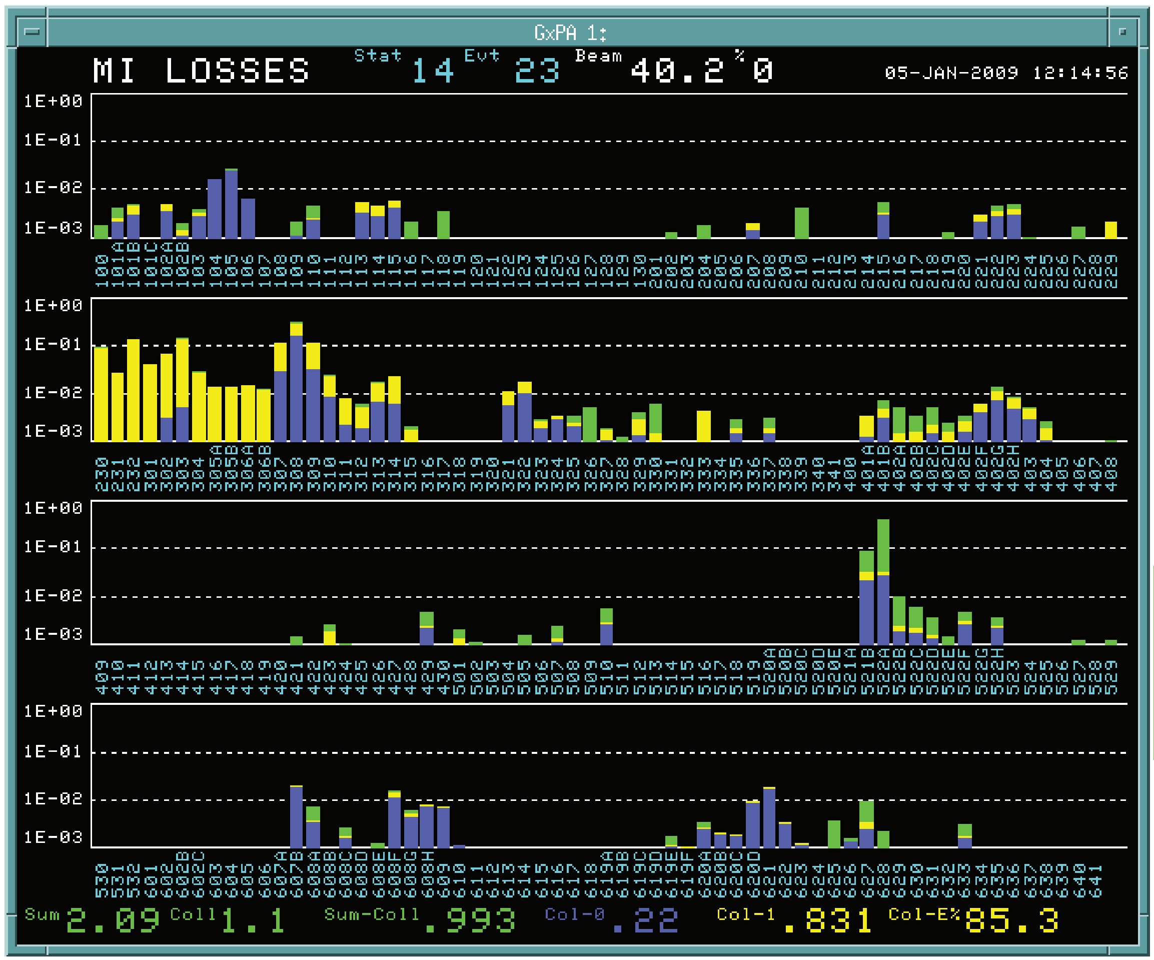
Failed Bellows

Clear Beam from Kicker Gaps

- Beam in injection gaps lost at 8 GeV when next batch arrives
  - Solution: Gap Clearing Kickers drive it to abort
  - Employed dampers in antidamping mode with limited success
- Beam in extraction gap lost at 120 GeV
  - Solution: Dedicated antidamping magnet
  - Antidamping with fast dampers mostly successful

Loss Monitors – Loss Plots

5 Jan 2009



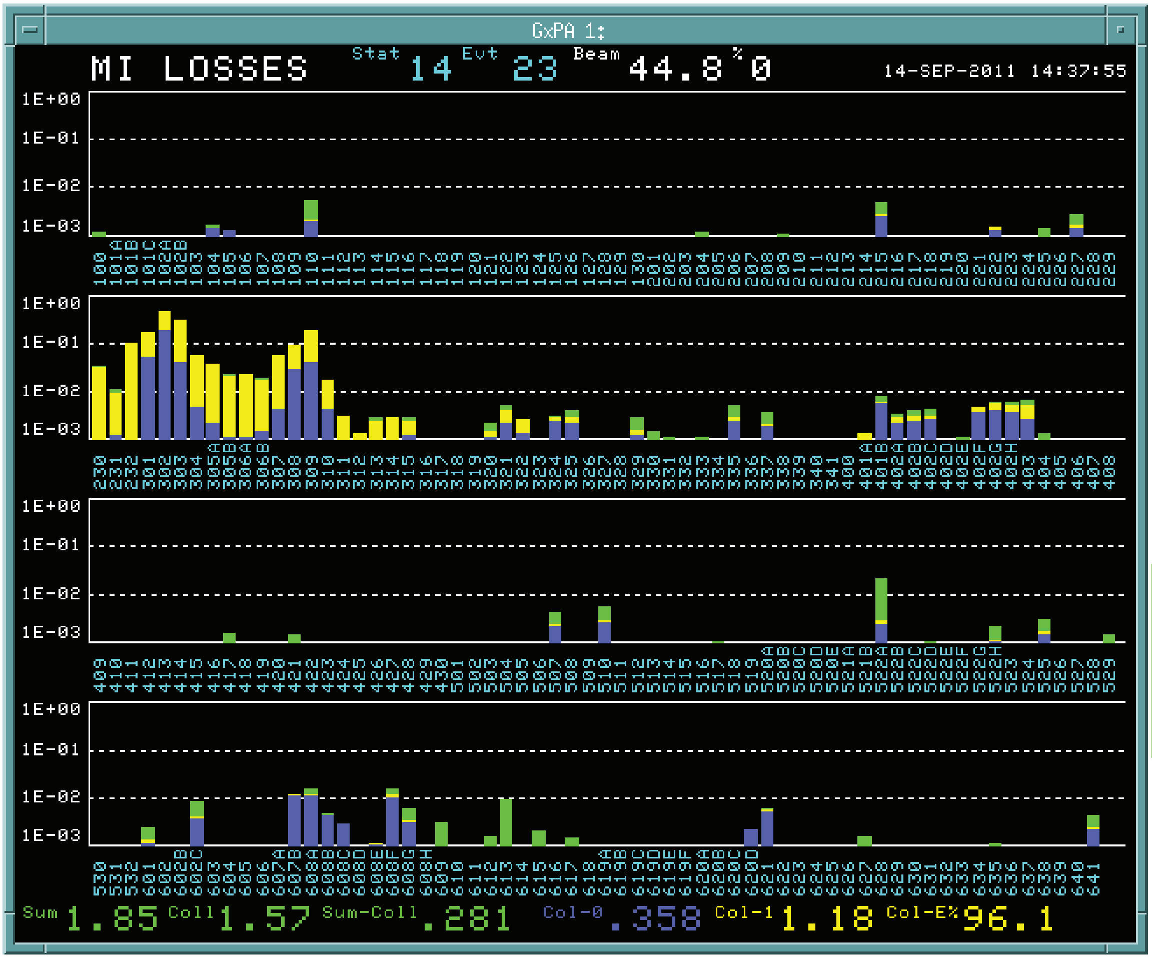
Injection Losses

Loss after 1% Accel

Total Loss for Cycle (inc. extraction)

Loss Monitors – Loss Plots

13 Jun 2011

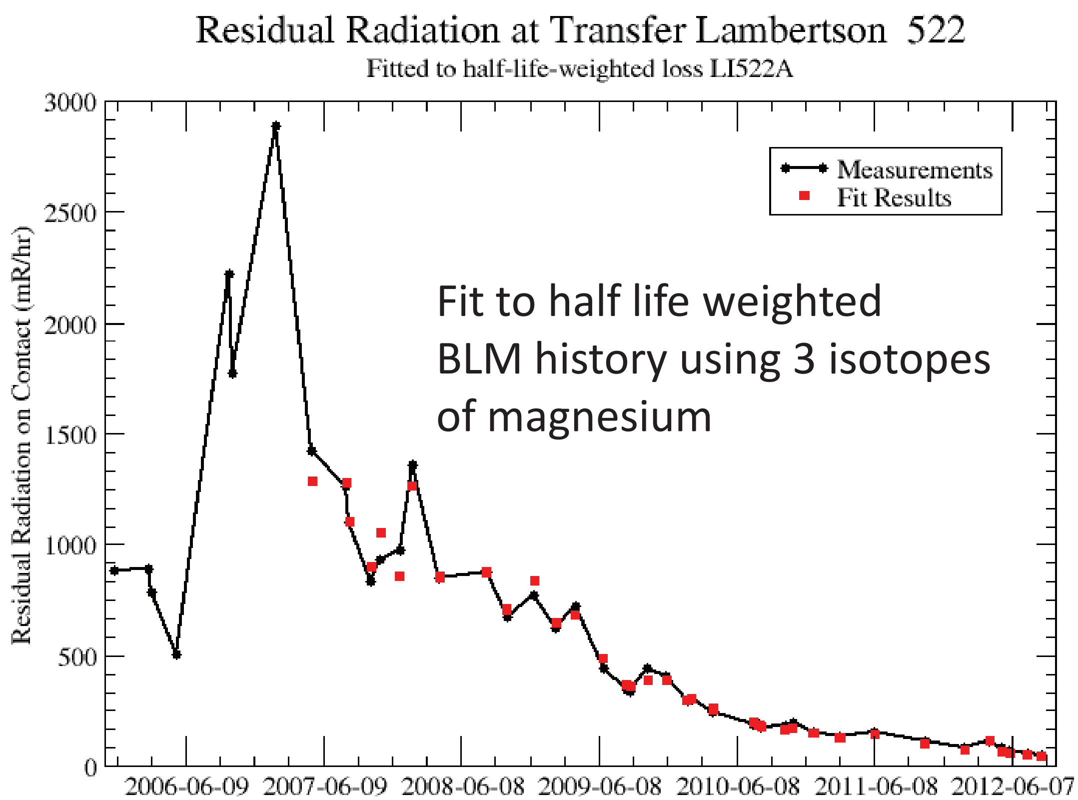


Injection Losses

Loss after 1% Accel

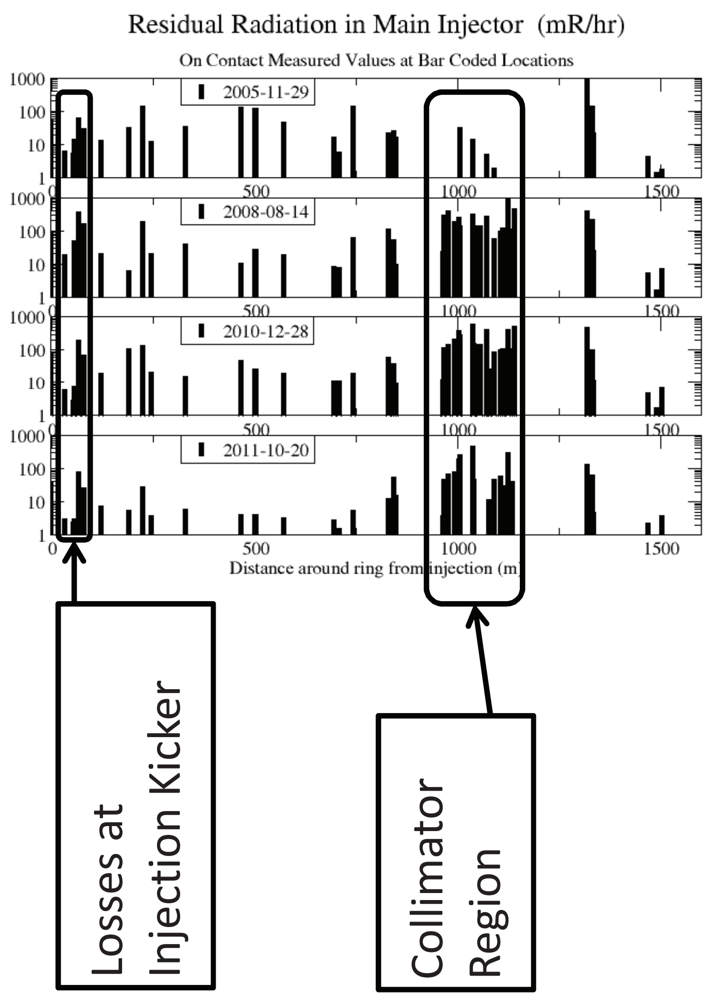
Total Loss for Cycle (inc. extraction)

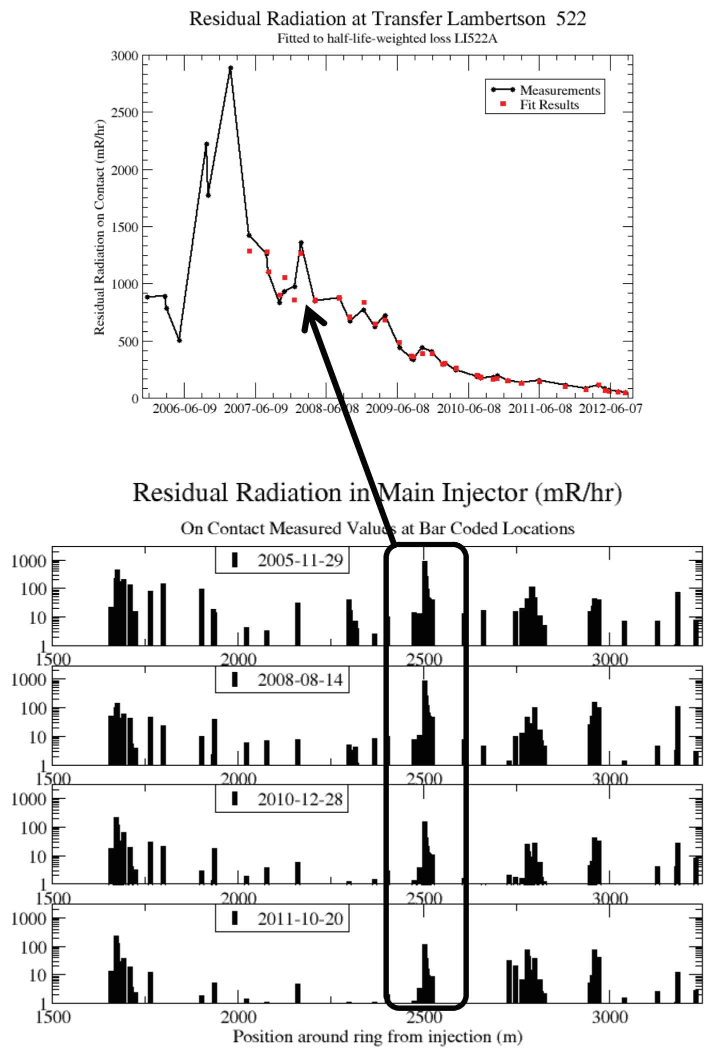
Residual Radiation History – LAM52A



See presentation on residual radiation at HB2010

History of Residual Radiation





Conclusions

A campaign of loss control for 400 kW operation of the Fermilab Main Injector has been successfully carried out.

- Wide Aperture Quadrupoles, Collimation,Gap Clearing with Kickers and Anti-damping
- Instrumentation Upgrades
- Attention to lesser losses to clear the view.

Clean Living is its own reward.

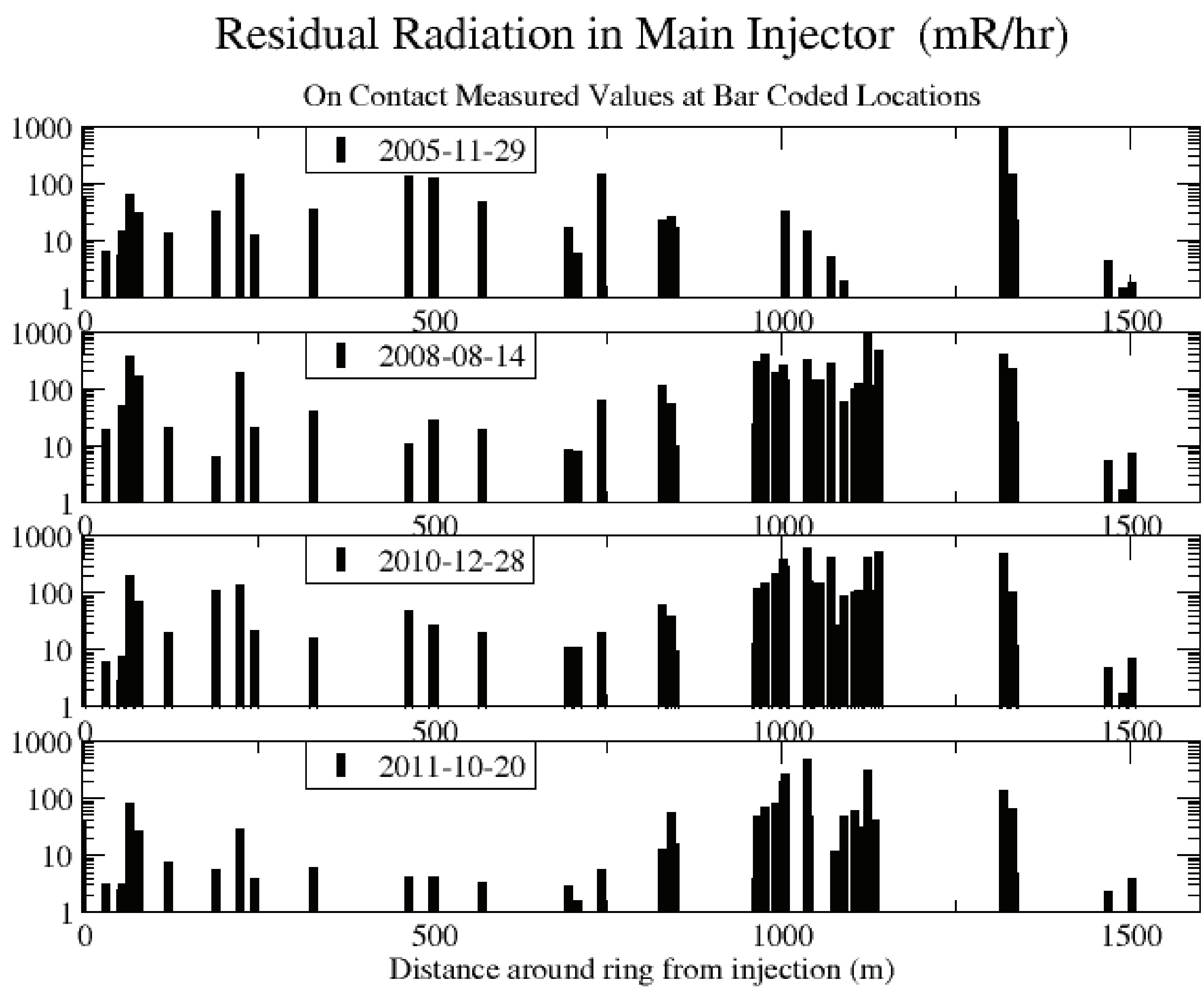
Acknowledgments

My thanks to the Fermilab Accelerator Division:

- Main Injector Department
- Mechanical Support Department
- Instrumentation Department
- Controls Department
- Operations Department
- Proton Source Department

This is to say…..**EVERYONE !!!**

Backup Slides



Residual Radiation in Main Injector (mR/hr)
On Contact Measured Values at Bar Coded Locations
2005-11-29
2008-08-14
2010-12-28
2011-10-20
1000
100
10
1
0
500
1000
1500
Distance around ring from injection (m)

Residual Radiation in Main Injector (mR/hr)