Limits for NuMI Primary Beam Loss

November 11, 2003

NuMI Primary Sensitivity to Beam Loss

The combination of:

- very intense NuMI primary beam
  - 4E13 ppp, 120 GeV, 1.9 sec spill

and

- unshielded transport thru protected aquifer region
  - Nancy Grossman presentation

lead to requirement for a low beam loss NuMI primary transport line.

Have done detailed MARS modeling and beam loss study to understand beam loss limits

MARS Beam Loss Studies

- **Extensive MARS14 beam loss study by S. Striginov, I. Tropin, M. Kostin, N. Mokhov. Combined with study of groundwater flow near NuMI transport tunnel (N. Grossman,et.al), results set limits on allowed beam loss along NuMI primary beam**
- **Tunnel residual activity is also calculated for different beam loss modes**
- **Beam loss modes considered include loss along each component for normal transport with varying beam emittance, effects from power supply instabilities, and presence of wire scanners inserted into the beam**

Lambertson Region Component Modeling

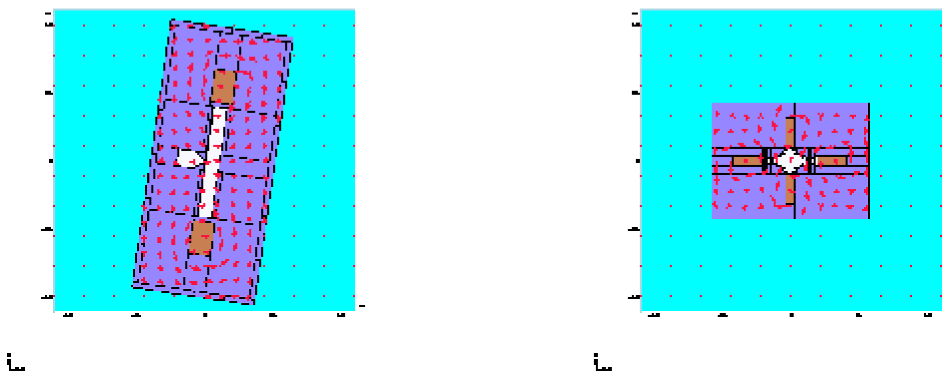


Figure 2.1: LAM60 (Lambertson) and Q608 (3Q84) magnets.

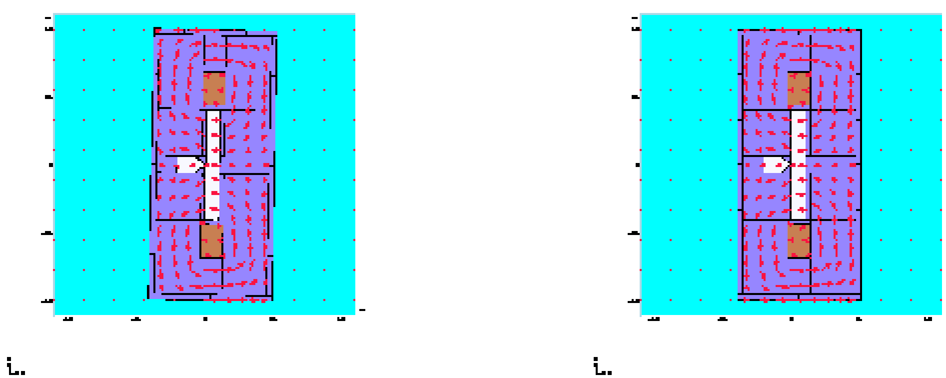


Figure 2.2: LAM61A and LAM61B (Lambertson) magnets.

Detail of Tunnel Geometry

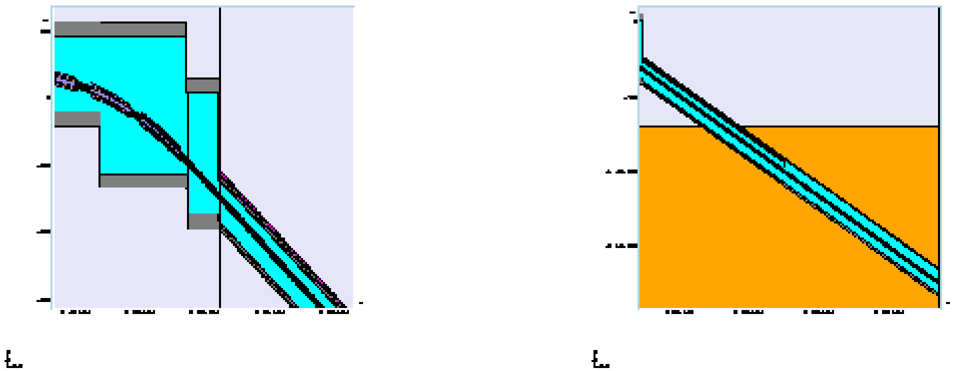


Figure 2.11: Extraction enclosure, extraction enclosure extension and carrier tunnel.

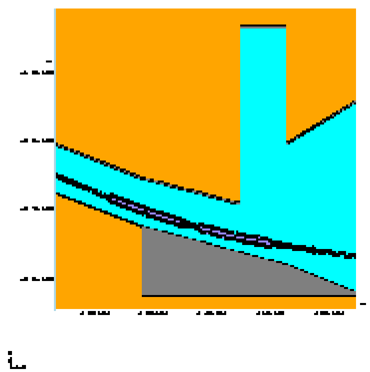
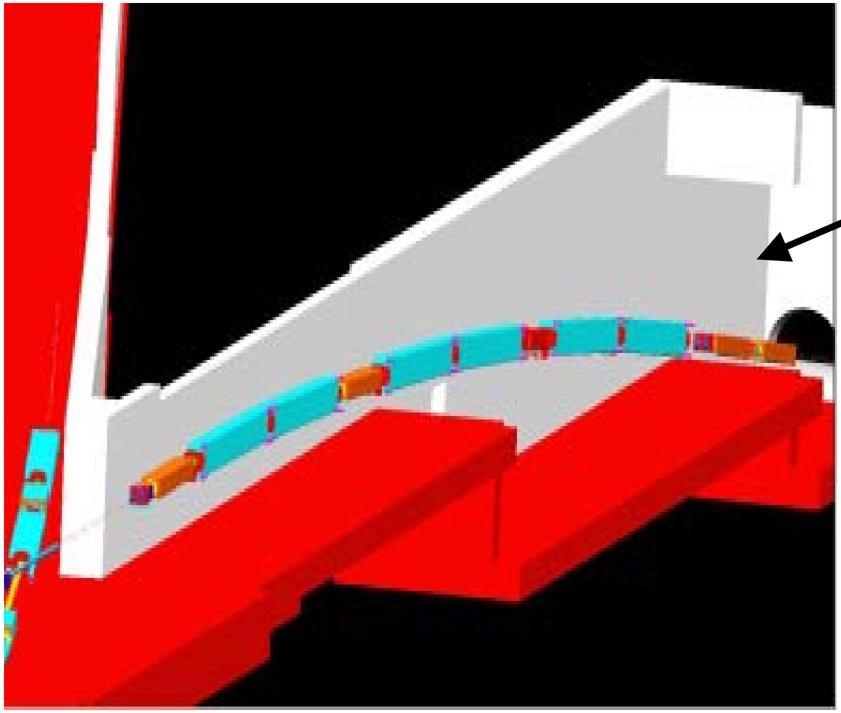


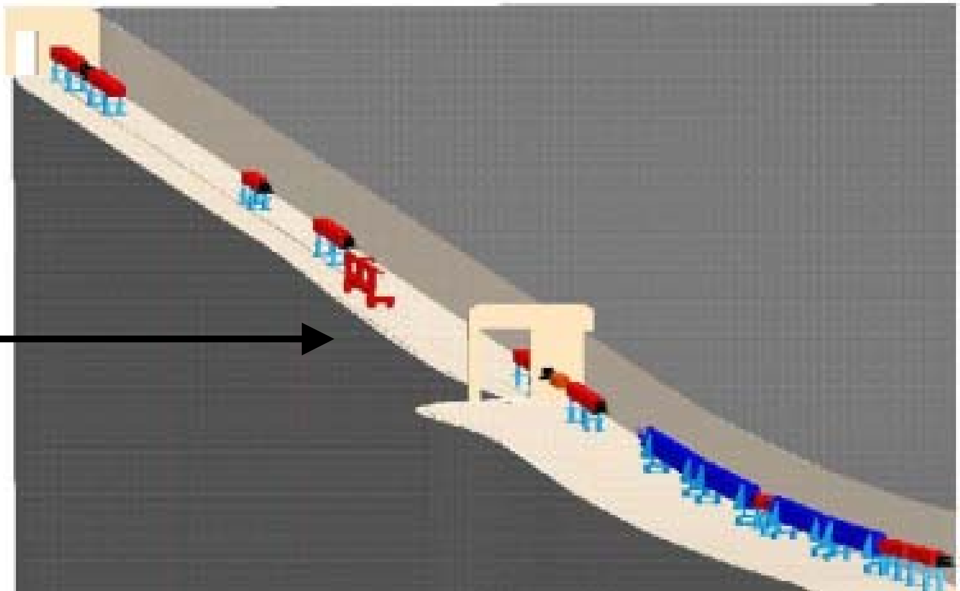
Figure 2.12: Pretarget hall.

Extraction & Pretarget Enclosures



Extraction Enclosure

156 mrad down-bend



Pretarget Enclosure

98 mrad up-bend & target focus

Regions for Calculation of Star Density Distributions

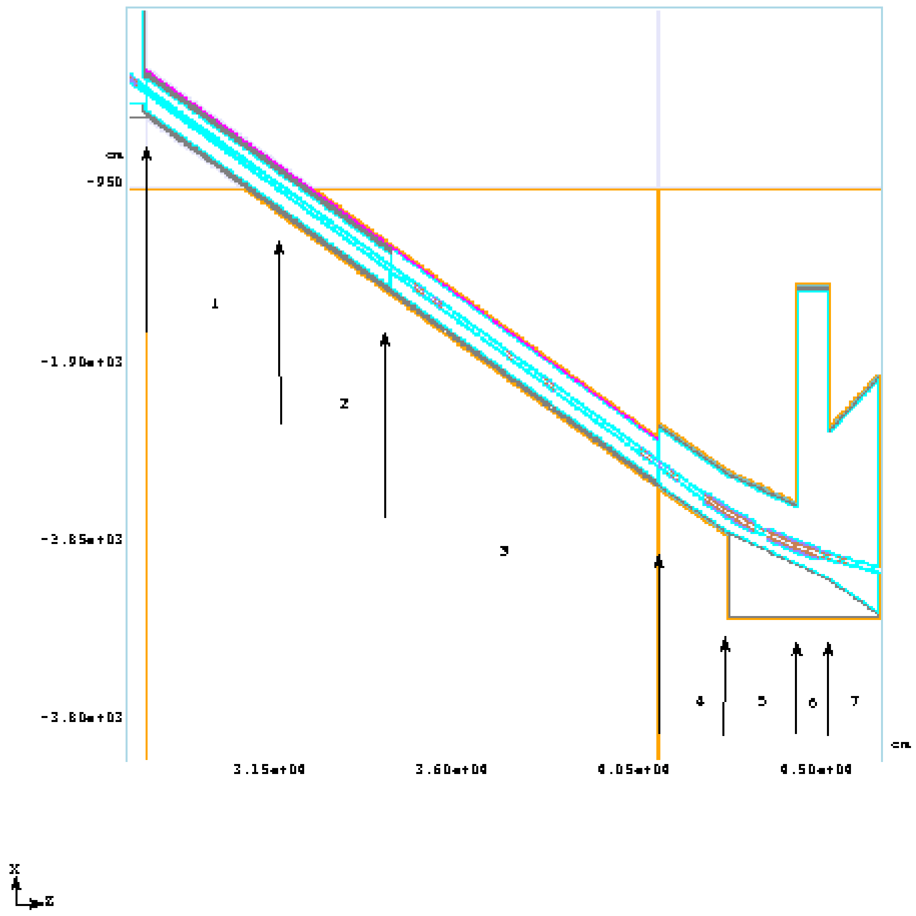


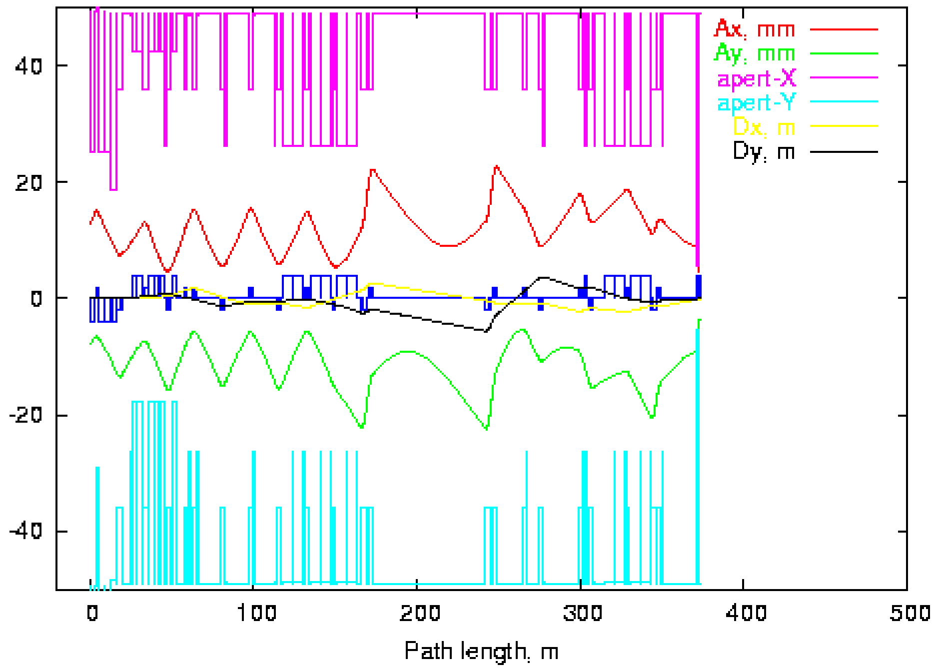
Figure 3.1: Regions for scoring star density distribution.

NuMI

MINOS

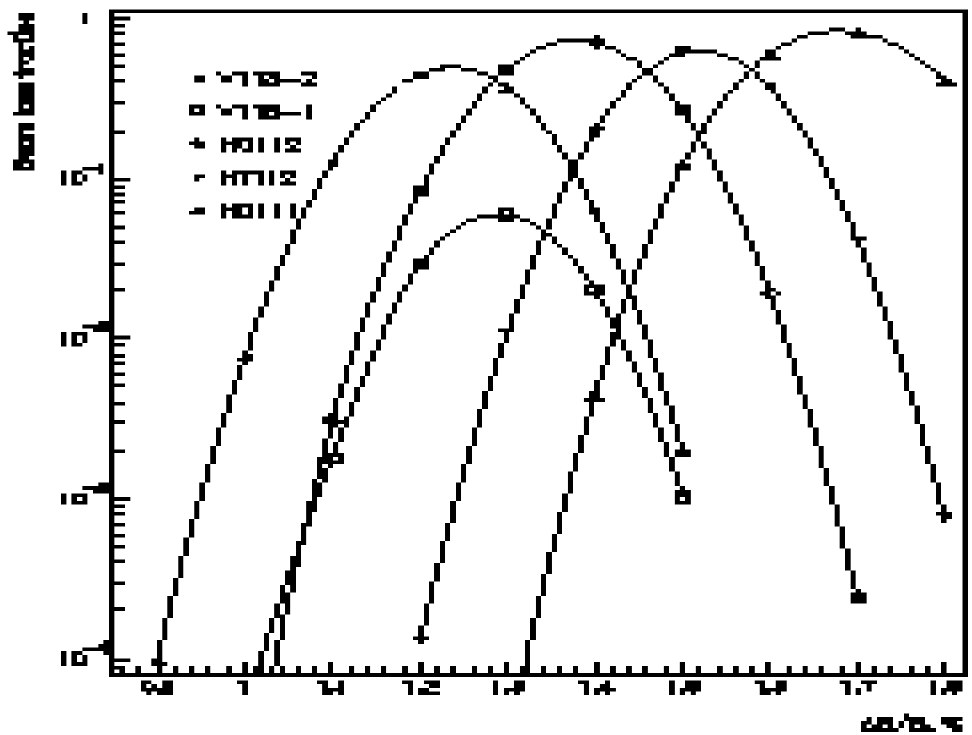
Bean Size (500 pi envelope) vs Apertures

NBI03
Nov. 7-11, 2003
MARS Primary Beam Loss
S. Childress (FNAL)



'igure 4.2: Beam size along NuMI beam-line. Maximum amplitude is 500 π mm mrad.

Beam Loss for Magnetic Field Variations



Normal Tune: Fractional Beam Loss

Table.4.1 : Beam loss for normal tune

95% emittance, $mm \cdot mrad$	60π	40π	60π	40π	25π
cuts, $mm \cdot mrad$	no	no	no	no	500π
$\delta p/p$	$4 \cdot 10^{-4}$	$2 \cdot 10^{-4}$	$4 \cdot 10^{-4}$	$2 \cdot 10^{-4}$	$4 \cdot 10^{-4}$
design	old	old	recent	recent	recent
HT107	$2.0 \cdot 10^{-3}$	$6.0 \cdot 10^{-5}$	0.	0.	0.
V110-1	$8.7 \cdot 10^{-4}$	0.	0.	0.	0.
HT108	$1.7 \cdot 10^{-3}$	$2.0 \cdot 10^{-3}$	0.	0.	0.
BAFFLE1	$4.0 \cdot 10^{-3}$	$1.8 \cdot 10^{-3}$	0.	0.	0.
BAFFLE2	$3.4 \cdot 10^{-3}$	$5.2 \cdot 10^{-4}$	$1. \cdot 10^{-4}$	$9. \cdot 10^{-7}$	0.
total	$1.2 \cdot 10^{-2}$	$4.4 \cdot 10^{-3}$	$1. \cdot 10^{-4}$	$9. \cdot 10^{-7}$	0.

Comparison of beam loss for original and current beam optics

Maximum Acceptable Loss in Different Regions – Groundwater

Table.4.12 : Maximum acceptable losses from operational beam loss limit.

region	star density limit star/cc/proton	beam loss limit particle/proton	place
1	$6.4 \cdot 10^{-4}$	1	HQ111,HQ112
2	$2.1 \cdot 10^{-12}$	$6.0 \cdot 10^{-4}$	HQ111
2	$2.1 \cdot 10^{-12}$	$4.0 \cdot 10^{-4}$	HQ112
3	$5.7 \cdot 10^{-10}$	$4.1 \cdot 10^{-3}$	HQ113
4	$4.8 \cdot 10^{-10}$	$5.7 \cdot 10^{-3}$	V118-1 or HT117
5	$6.4 \cdot 10^{-10}$	$2.3 \cdot 10^{-2}$	V118-2
6	$6.4 \cdot 10^{-10}$	$3.4 \cdot 10^{-2}$	V118-4
7	$6.4 \cdot 10^{-10}$	$3.6 \cdot 10^{-2}$	HT121

Beam Loss Limits from MARS14 Calculations

- Results indicate average beam loss fraction limits of several $\cdot 10^{-4}$ to $\cdot 10^{-3}$ of the high intensity primary beam flux, dependent on tunnel location. A loss fraction limit of 10^{-6} of the beam is seen in lined regions of the carrier tunnel. However, in this region geometry constraints preclude direct primary beam loss except for fault modes such as a vacuum pipe collapse or a magnet coil failure.
- Maintaining average beam loss fraction levels at ~ 10^{-4} or less is also well matched to need for control of component residual activity. Sustained localized beam loss of this level leads to ~ 1.50 mSv/hr readings on near magnet outside surfaces.

System for Beam & Beam Loss Control

- Most important is a well functioning beam transport line
  - Apertures / optics design enabling clean beam transmission, minimal sensitivity to normal variations of beam parameters - emittance, momentum spread, bunch rotation, etc.
  - Quantitative understanding of Main Injector extracted beam parameters.
- Power supply stability
  - Design for long term ~ 60ppm for major bends, 200ppm for smaller bends. (One supply at these limits gives < 1 mm change along transport, 0.25mm for targeting.) Pulse to pulse variations are much less.
- Comprehensive loss monitor coverage
  - Sensitivity to all beam loss modes, redundancy of loss coverage, continuous checks for loss monitor function, calibrated response and dynamic range for fractional beam loss from 10^{-5} of the high intensity beam to a full beam loss

System for Beam Control (cont)

- Capability for precise and rapid correction of beam position problems due to system drifts
  - AUTOTUNE beam position control
- Comprehensive alarms and limits monitoring
- Comprehensive beam permit system to preclude beam extraction to NuMI when an identifiable problem exists
  - Beam test prototyping of hardware ongoing in MiniBooNE and AP0 lines

All of these are patterned after previous successful efforts.