Fermilab Proton Source Report

Bob Webber

ICFA Mini-Workshop on High-Intensity, High Brightness Hadron Beams

Beam Halo and Scraping

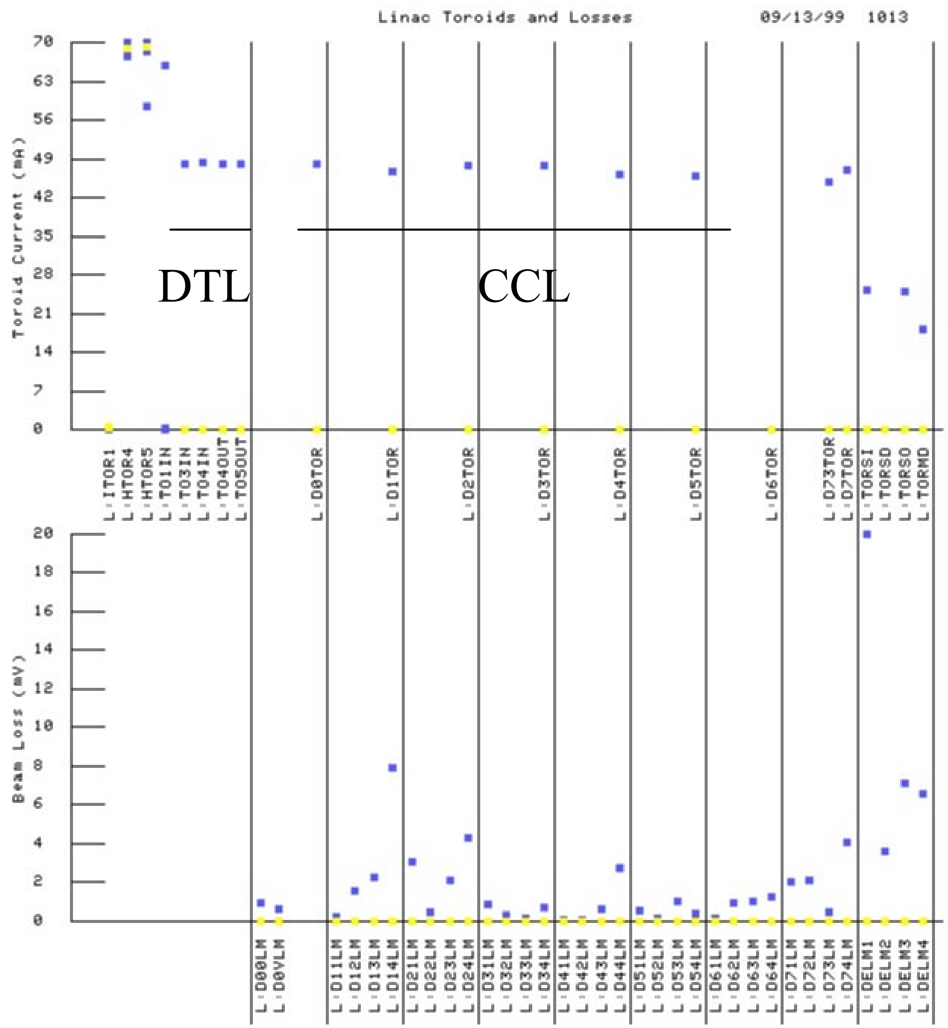
Lake Como, WI

9/14/99

Fermilab Linac Parameters

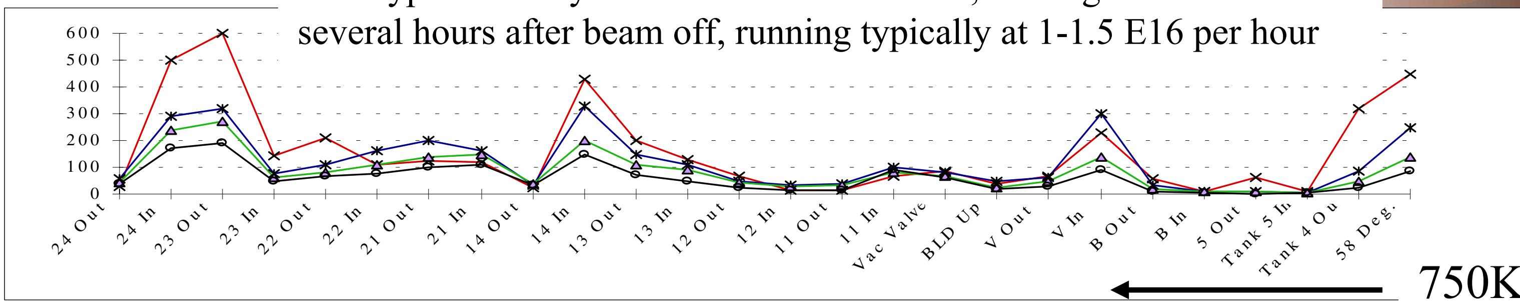
- 200 MeV proton Linac built ~ 1969
- H^- upgrade in 1977
- 400 MeV upgrade in 1992
- 15 Hz hardware capability, variable beam pulse rate
- 45mA pulse current typical at 400 MeV
- variable beam pulse length, typically 10-30 microsec
- typical efficiency 10 MeV to 400 MeV ~ >95%
- typical operation ~ .5µA for 0.2kW
- present normal 400 MeV capability ~ 20 µamp for 8kW
  - 45mA @ 15 Hz @30 microsec
- accelerated >90mA (protons) during Jan. 1999 test

Linac Toroid and BLM Plot

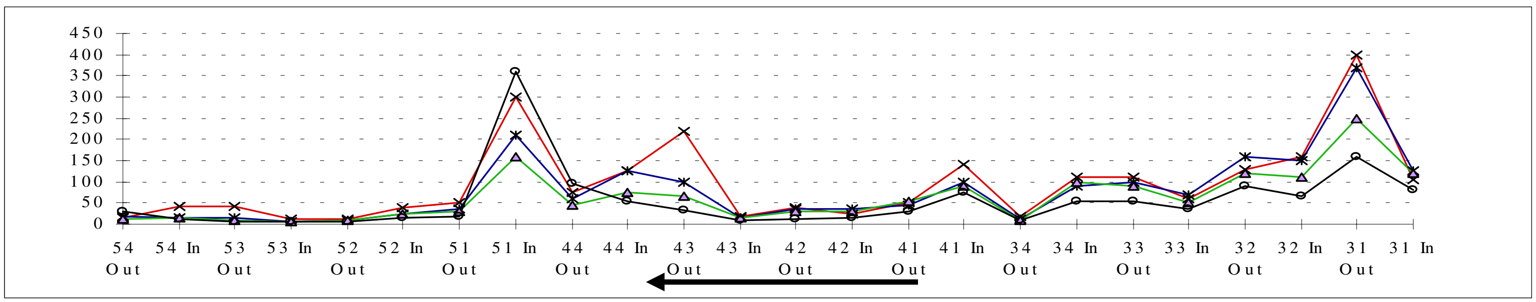


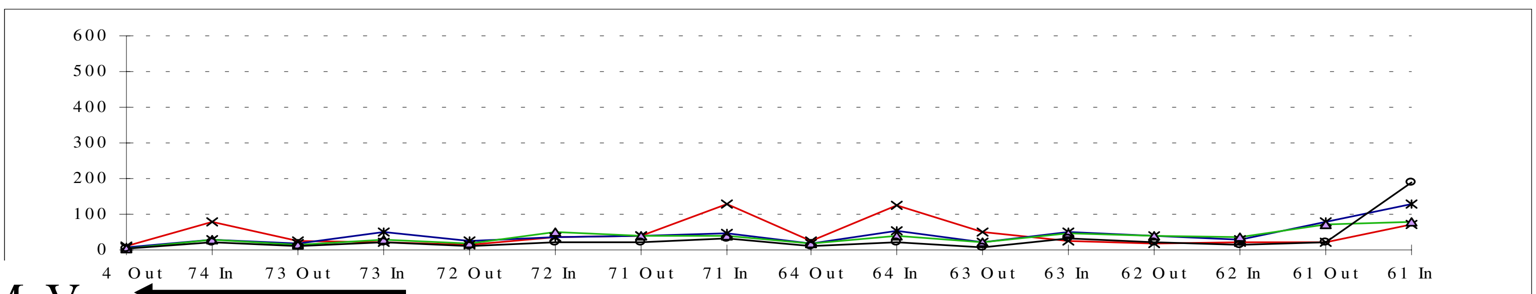
Linac Radiation Survey Data

Four typical surveys between 12/94 and 3/96, readings are ‘on contact’ several hours after beam off, running typically at 1-1.5 E16 per hour



750KeV





400 MeV

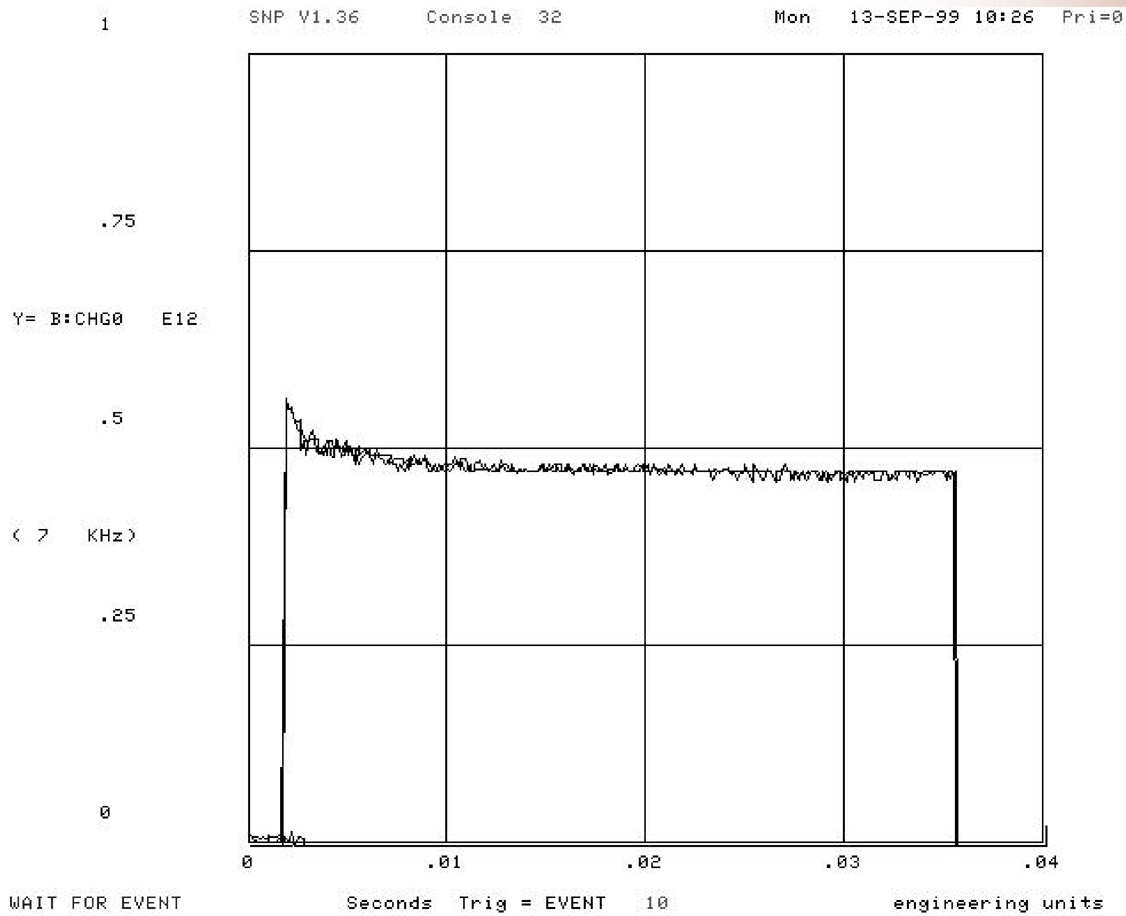
Linac Radiation and Activation Issues

- Linac radiation limits
  - several interlocked detectors for accident conditions
  - trips rarely encountered
- Linac activation
  - not a serious issue at typical levels
  - 400MeV "switchyard" is important

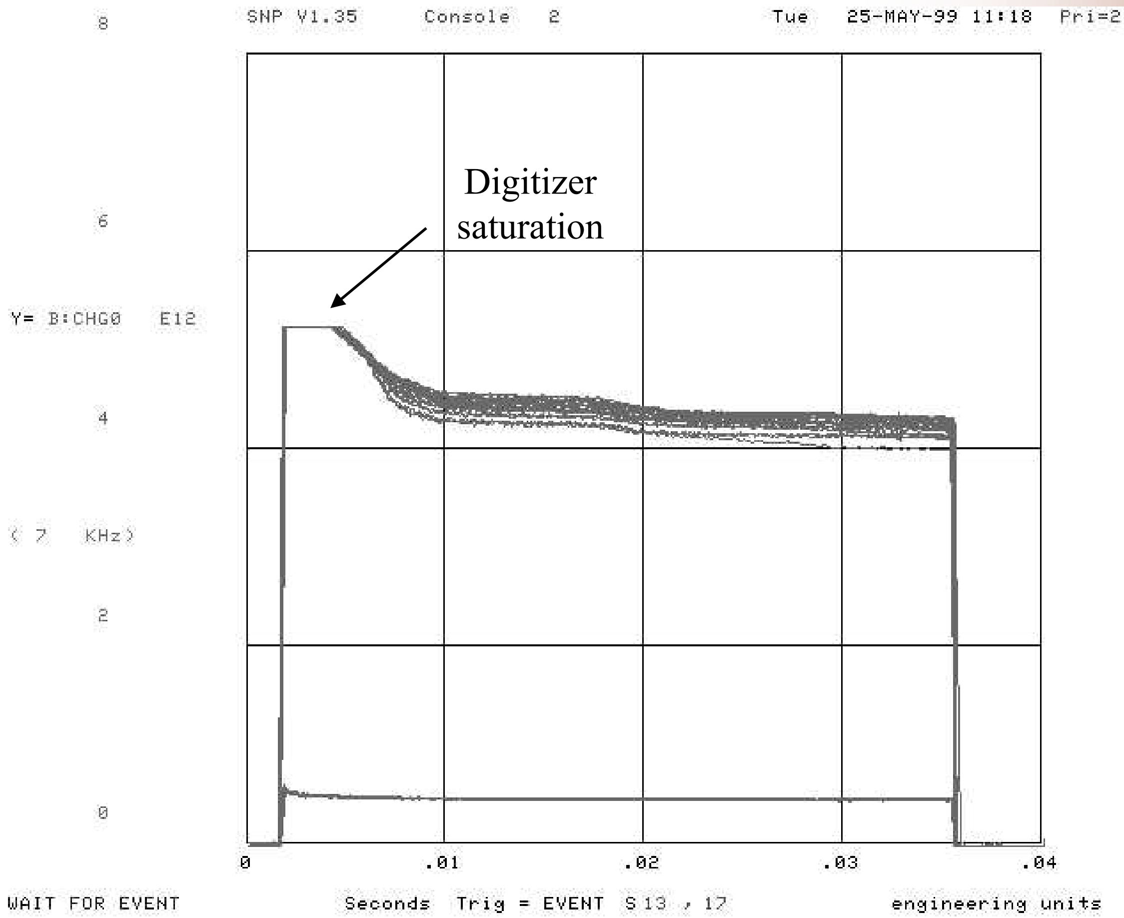
Fermilab Booster Parameters

- 400 MeV -- 8 GeV proton synchrotron built ~ 1970
- 15Hz sinusoidal magnet cycle with transition at $\gamma = 5.4$
- H- charge exchange injection, typically <12 turns
- adiabatic capture of injected beam by Booster RF
- 38 - 53 Mhz RF frequency, h=84
- typical 8 GeV beam current (1E16 pph = 0.44 μA)
  - historical high 3E12ppp @ 2.5Hz ~ 1.3μA for 10kW (8 GeV)
  - currently 2E12ppp @ 0.5Hz ~ 0.16μA for 1.3kW
  - Run II demand (2000) 5E12ppp @ .7 Hz ~ .55μA for 4.3kW
  - Year 2002 demand 5E12ppp @ 8 Hz ~ 6.4μA for 51kW
- typical efficiency 80% @ 1E12ppp to 60% @4E12ppp

Booster Low Intensity Charge Snapshot



Booster High Intensity Charge Snapshot



Booster Radiation and Activation Issues

- Fermilab HEP program, within the coming year, will be limited by allowed radiation around Booster
  - demand for proton throughput will rise order of magnitude in next three years relative to historic levels in 90’s
  - recent office and beamline constructions and tightened radiation exposure regulations exacerbate original situation
  - little option for additional shielding
- Component activation will be a serious concern at NUMI/MiniBooNE levels
- Booster beam loss reduction and control key to entire future planned Fermilab high energy physics program!

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Fermilab
ACCELERATOR DIVISION

Record File

BOOSTER SURVEY SHEET

#-A/B #-B/1 #-1/2 #-3/4
R.F. R.F.
#-A ION PUMP #-B #-1 ION PUMP #-2 #-C #-3 ION PUMP #-4

PURPOSE: initial entry survey
TIME BEAM WAS TURNED OFF: 2/14/95 0800
HIGHEST DOSE RATE FOUND: 150 mR/hr

SURVEYOR: Busch / Fulgham
DATE: 2/15/95 TIME: 0615
INSTRUMENT/SERIAL NUMBER: LSM 23
BATTERY CHECK (SAT/UNSAT): SAT
SOURCE CHECK (SAT/UNSAT): SAT
DATE CALIBRATED: 1/6/95

		WIPE NUMBERS			
		COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 4
LOCATION OR PERIOD	DOSE RATE AT 1 FOOT (SEE NOTE 1)	BELLOWS, MAGNET OR DEVICE	UPSTREAM	DOWNSTREAM	FLOOR
20-4/A	25	1			
21-4/A	20	2			
21-B/1	70	9	8	10	
2-C	80	12	11	13	
3-C	150	23	22	24	25
7-C	40	30			
12-3/4	70	31	32	33	
~~12-4/5~~					
13-C	30	45			
13-4/A	30	46			

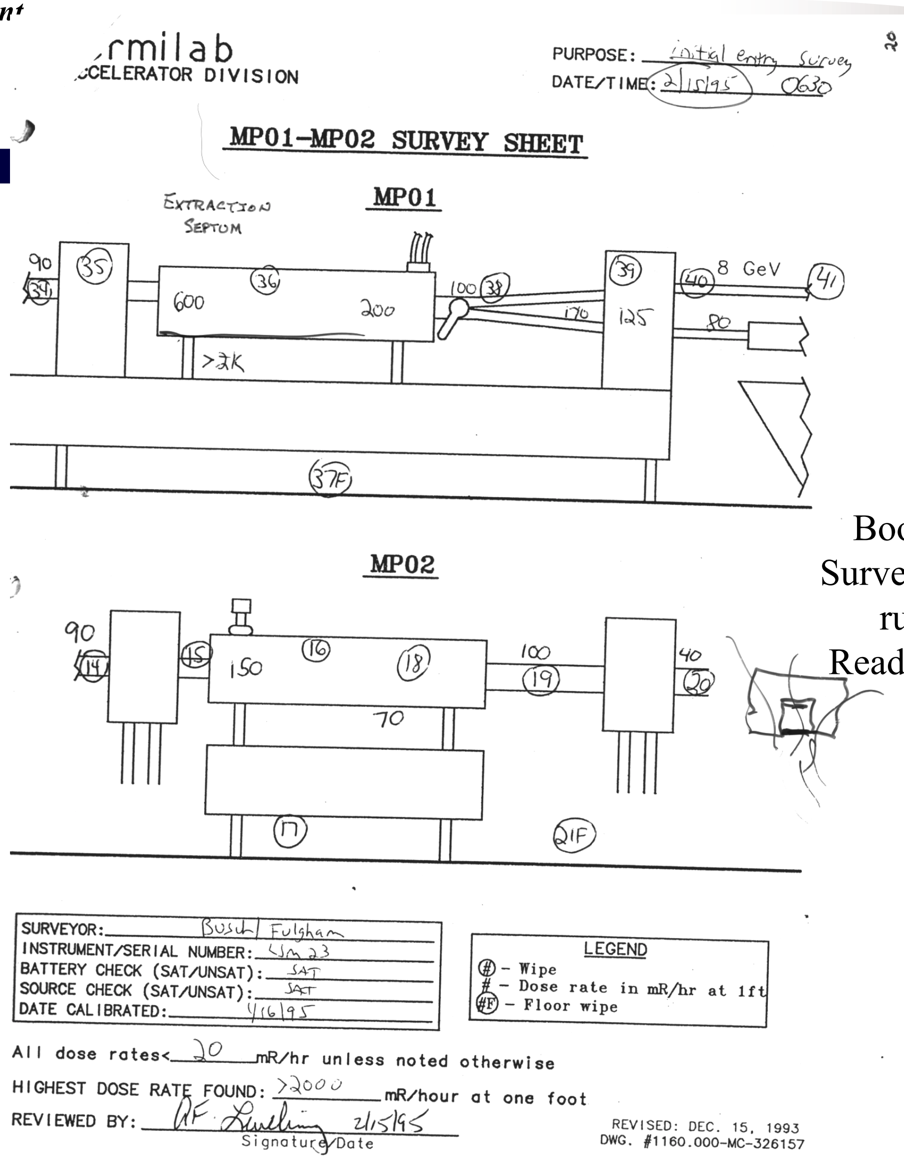
COMMENTS: All dose rates < 20 mR/hr unless noted otherwise

Note 1: If ≥ 20 mR/hr complete column 1.
If ≥ 50 mR/hr complete columns 1, 2 and 3.
If ≥ 100 mR/hr complete columns 1, 2, 3 and 4.

REVIEWED BY: [signature] 2/15/95
Signature/Date

REVISED: DEC. 15, 1993
DWG. #1160.000-MC-326161

Booster Ring Radiation Survey
24 hrs after extended running
at 7.5E15/hr

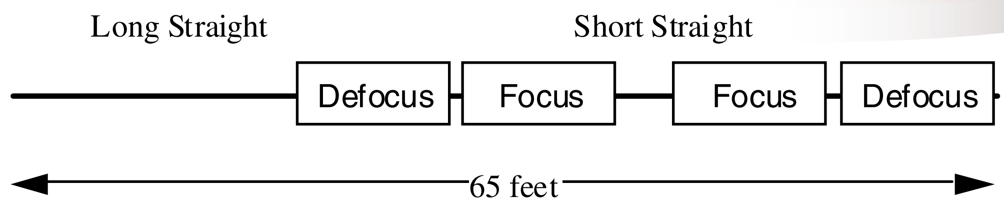


Booster Extraction Area
Survey 24 hrs after extended running at 7.5E15/hr
Readings are mR/hr @ 1 ft.

1998 Booster Shielding Assessment

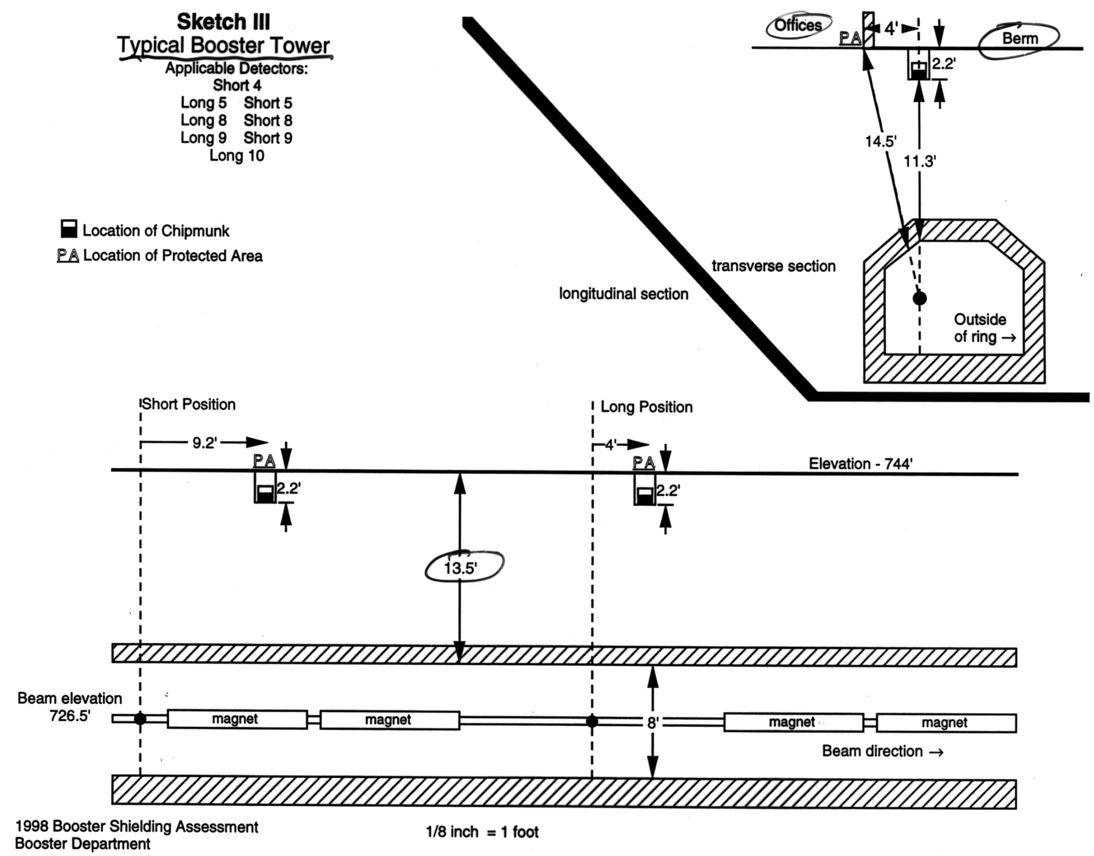
- Driving factors
  - old assessment inadequate for anticipated proton requirements
  - re-location of extraction point for beam to Main Injector
  - old assessment relied on loss signature at few locations limiting machine development flexibility, e.g. high energy orbit changes and magnet moves
- Numerous soil activation measurements
- Complete shielding geometry assessment for entire ring
- Many measurements to understand radiation patterns and levels for "normal" and "accident" conditions
- Resulted in array of ~50 interlocked radiation detectors

Typical Booster Lattice Period and Apertures



Location	Physical Aperture (inches)		**R** Value ($cm^{1/2}$)	
	Horizontal	Vertical	Horizontal	Vertical
Short-straight (BPM)	4.5	4.5	**0.197**	0.501
F-magnet (short-straight end)	4.5	1.64	**0.197**	0.181
F-magnet (D-magnet end)	8.0	1.64	0.457	**0.126**
D-magnet (F-magnet end)	8.0	2.24	0.467	0.164
D-magnet (long-straight end)	3.25	2.24	0.294	**0.126**
Long-straight (Beam pipe)	3.25	3.25	0.334	0.185
Long-straight (RF or Kicker)	2.24	2.24	0.231	0.128
Long-straight (Dog Legs)	2.31	3.25	0.237	0.185
Long-straight (Injection)	2.56	2.56	0.264	0.146

Booster Shielding at Period Long 9



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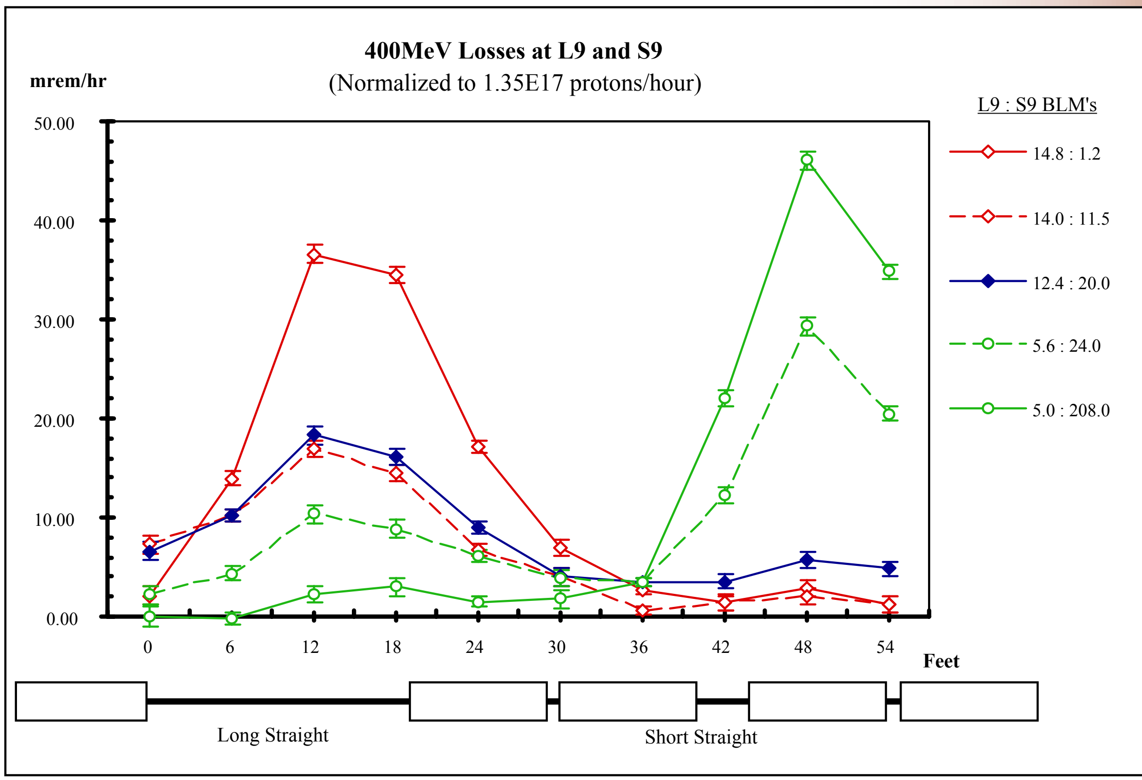
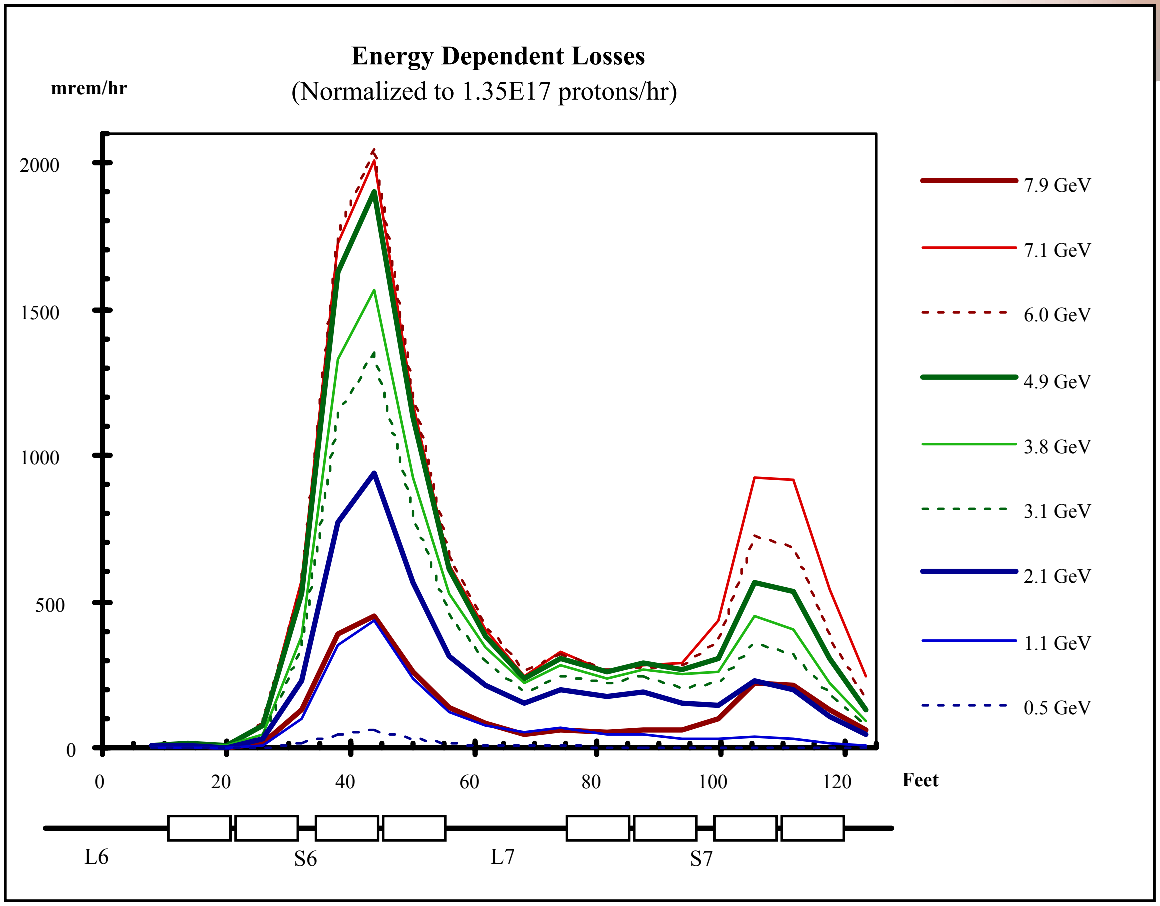
Injection Energy Radiation Patterns



Measured radiation levels at surface above Period 9 for different BLM ratios while attempting to lose all beam with dipole correctors.

Energy Dependent Loss Patterns



Measured radiation levels above periods 6 and 7 at different beam energies obtained by shutting off RF while accelerating.

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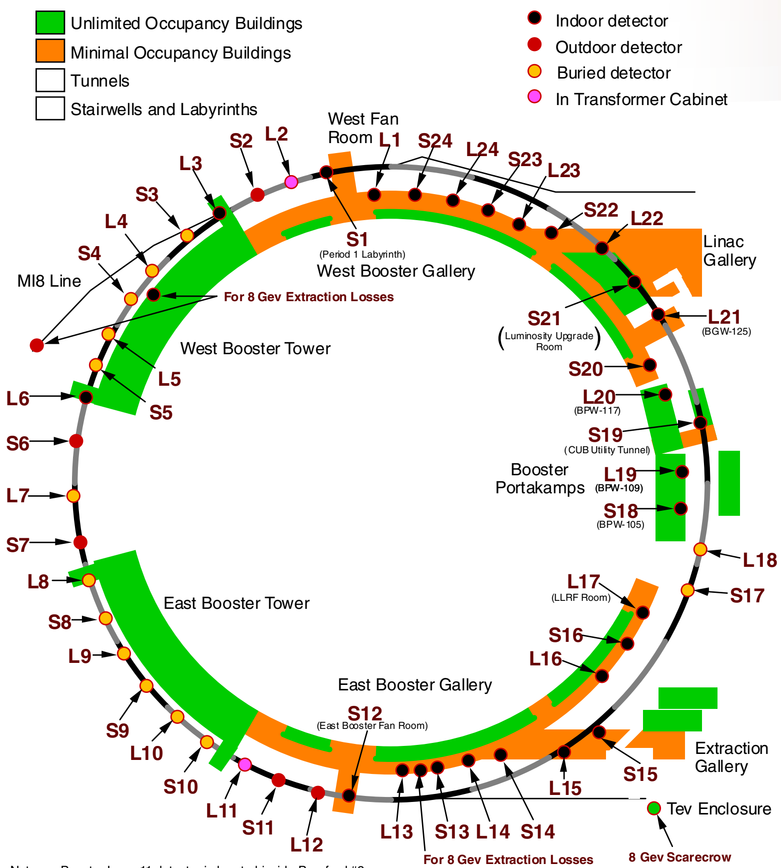
Booster Interlocked Radiation Detectors

Booster Interlock Detector Locations



Note: Booster Long 11 detector is located inside Brenford #3.
Booster Short 19 is located in the CUB Utility Tunnel on the West side of the LCW Piping.
Booster Short 12, located in the East Booster Fan Room, requires an AC-33 key.
Booster Long 21, located in BGW-125, requires an AC-2 key.
Booster Short 21, located in the Luminosity Upgrade Room, requires an AC-2 key.
Booster Long 7 located in a manhole in the road between the Booster Towers.
Booster Long 2 detector is located in the YBW1 transformer cabinet.
The 8 Gev Line Sarecrow is located in the Tev enclosure.

Causes of Beam Loss

- Poor orbit control
  - closed orbit changes dramatically vs. time in cycle
  - low field orbit is regularly modified by normal tuning
  - small dynamic apertures
- Historically no beam gap synchronized to extraction kickers -- systematic 2% beam loss at extraction septum
- Longitudinal instabilities after transition at high current
- RF capture inefficiencies
- Space charge blowup ?
- ??

Toward Control and Solution to Problem

- Continued aperture improvements
  - magnet moves to remove aperture constraints
  - study increased RF cavity aperture
  - improved orbit control
    - orbit adjustment program
    - ramped correctors w/ beam position feedback
    - improved main magnet control
- Create and synch beam gap with extraction kicker
  - presently able to create notch at 400 MeV after injection with short kicker
  - investigating laser neutralization gap creation
  - synchronization to circulating Main Injector beam is complicated and narrowly constrained by beam dynamics

Toward Control and Solution to Problem

- Improved longitudinal dampers
- Scraper/collimator
  - control loss of particles that cannot be retained
  - design is commencing based on new Booster model
- New BLM transducer and data acquisition system
  - ability to quantitatively see and record when and where beam losses occur under complicated operating scenarios is essential to facilitate and measure progress