MI High Power Operation and Future Plans

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(presented by Bruce Brown)

HB2008

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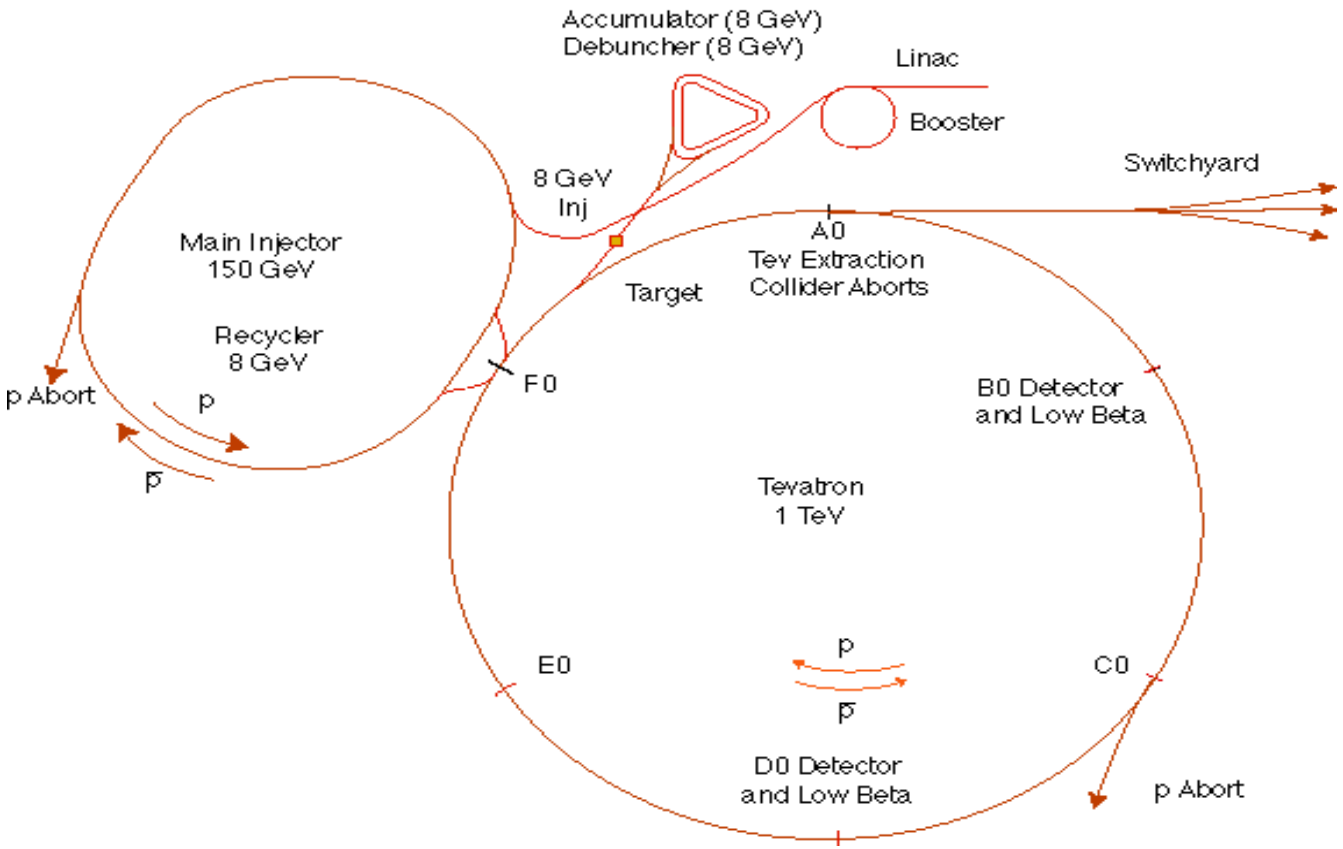
Outline

- Fermilab Accelerator complex and MI operations
- Status of the 400KW operation
- Future Plans
- Conclusions

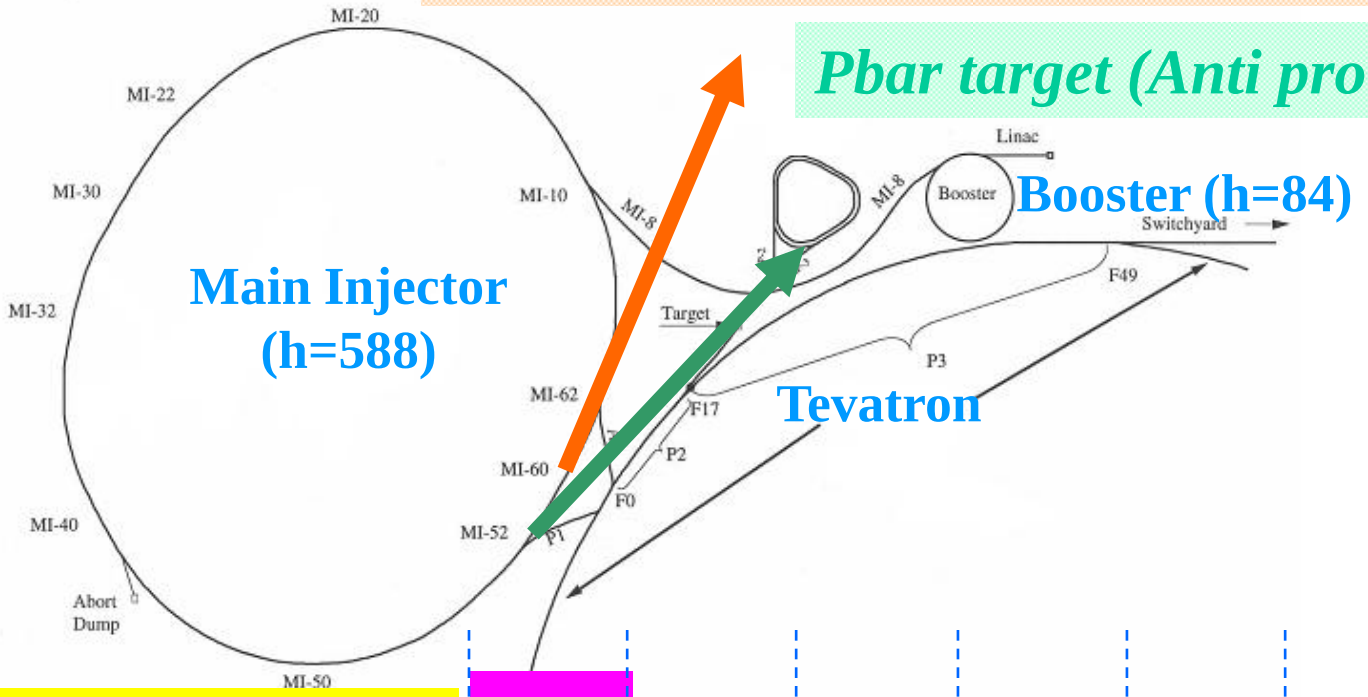
Fermilab Accelerators



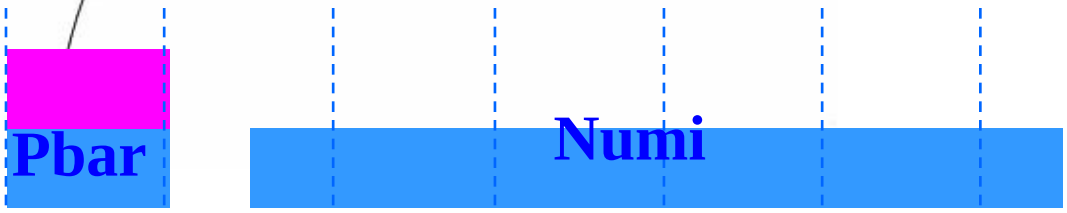
MI mixed mode operations

Numi target (MINOS Neutrino experiment)

Pbar target (Anti proton production)

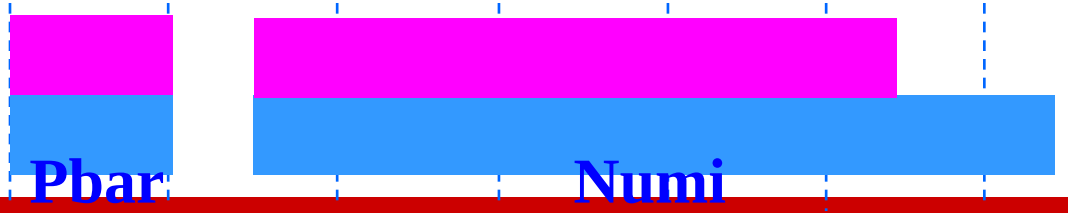


2 + 5 operation



7 batches

2 + 9 operation

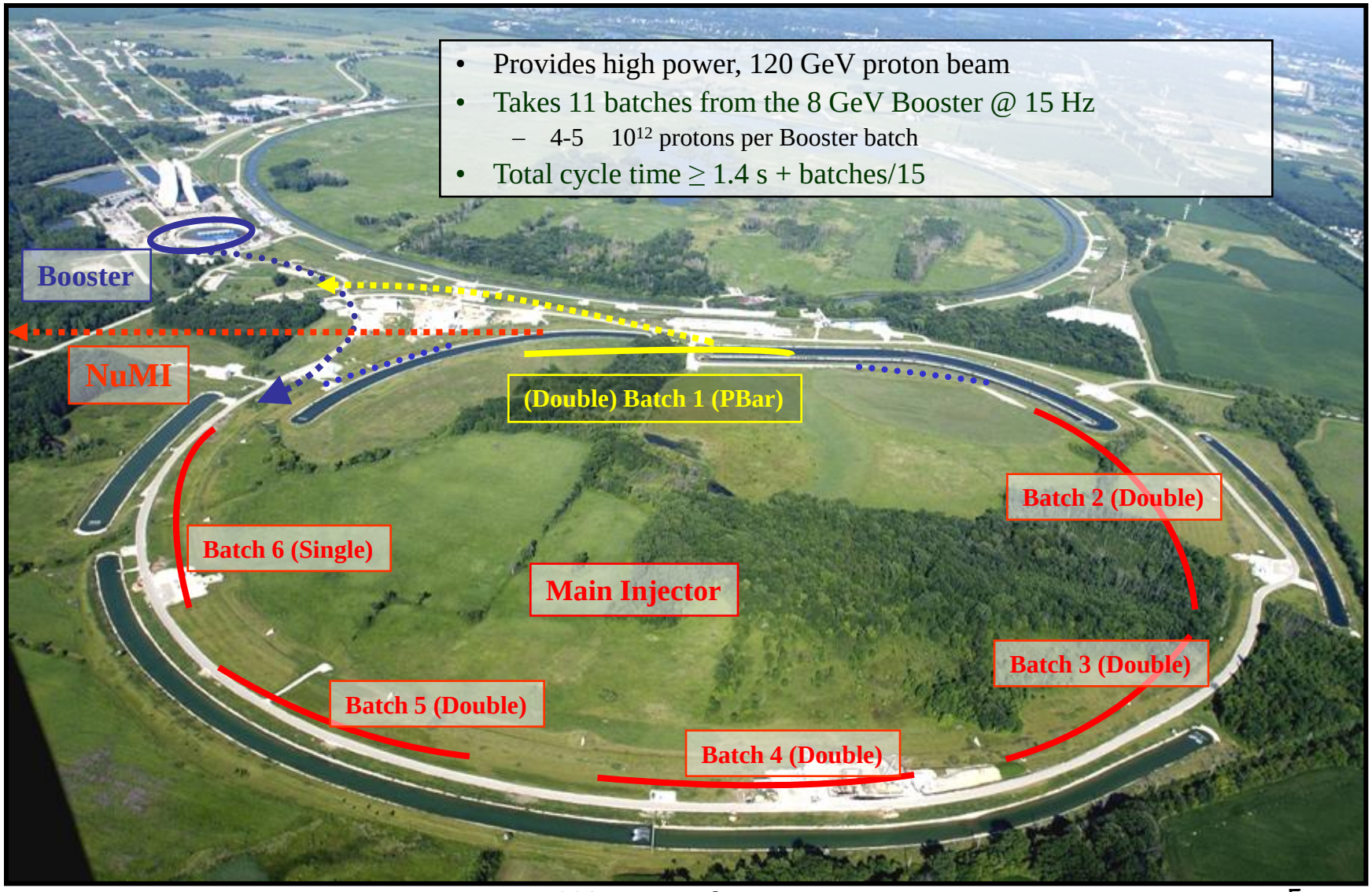


11 batches

Bucket # 0

588

The Main Injector Today (Mixed Mode)



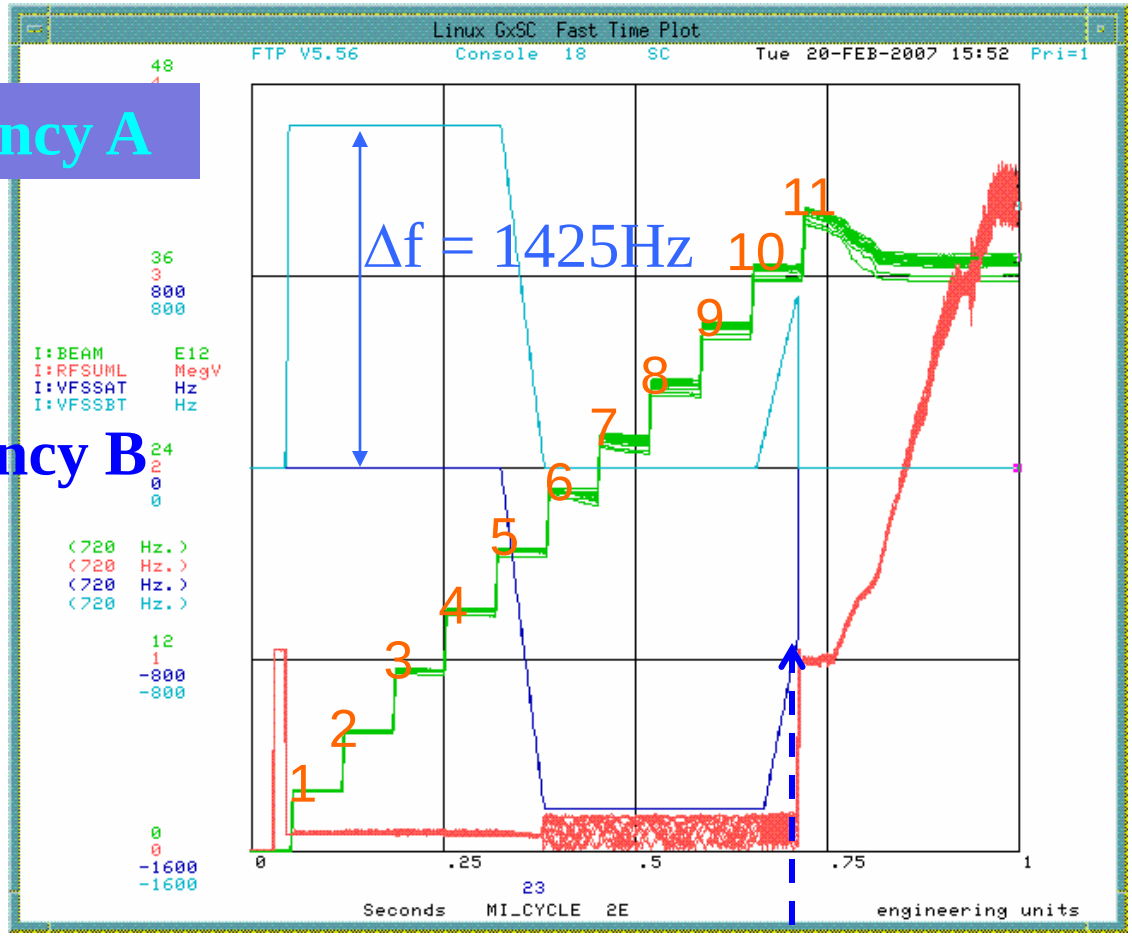
Evolution of MI Beam Power

	Last Years' Conditions Two-batch slip-stacking in MI	Proton Plan (Current conditions) Multi-batch slip-stacking in MI	NOvA Multi-batch slip-stacking in Recycler
Booster intensity (protons/batch)	$4.3\text{-}4.5\times10^{12}$	4.3×10^{12}	4.3×10^{12}
No. Booster batches	7	11	12
MI cycle time (s)	2.4	2.2	1.333
MI intensity (ppp)	3.3×10^{13}	4.5×10^{13}	4.9×10^{13}
To anti-proton source (ppp)	8.8×10^{12}	8.2×10^{12}	0
To NuMI (ppp)	2.45×10^{13}	3.7×10^{13}	4.9×10^{13}
NuMI beam power (kW)	192 (263)	320 (400)	700
PoT/yr to NuMI	2×10^{20}	3×10^{20}	6×10^{20}

MI 400KW Operation

- Since Jan. 08 we have switched to multi-batch slip stacking increasing the number of Booster batches in MI to 11.
- We are gradually increasing the beam intensity as we addressing the issues with beam loss.
- The allowable 5% loss happens mostly at 8 GeV corresponding to an average power loss of 1.5 KW or 0.5 W/m.
- The beam losses are not evenly distributed but are mostly localized and need to be controlled.
- Most of the losses are coming from the slip stacking process
  - Injection kicker gap loss
  - Un-captured beam loss
  - Extraction kicker gap loss

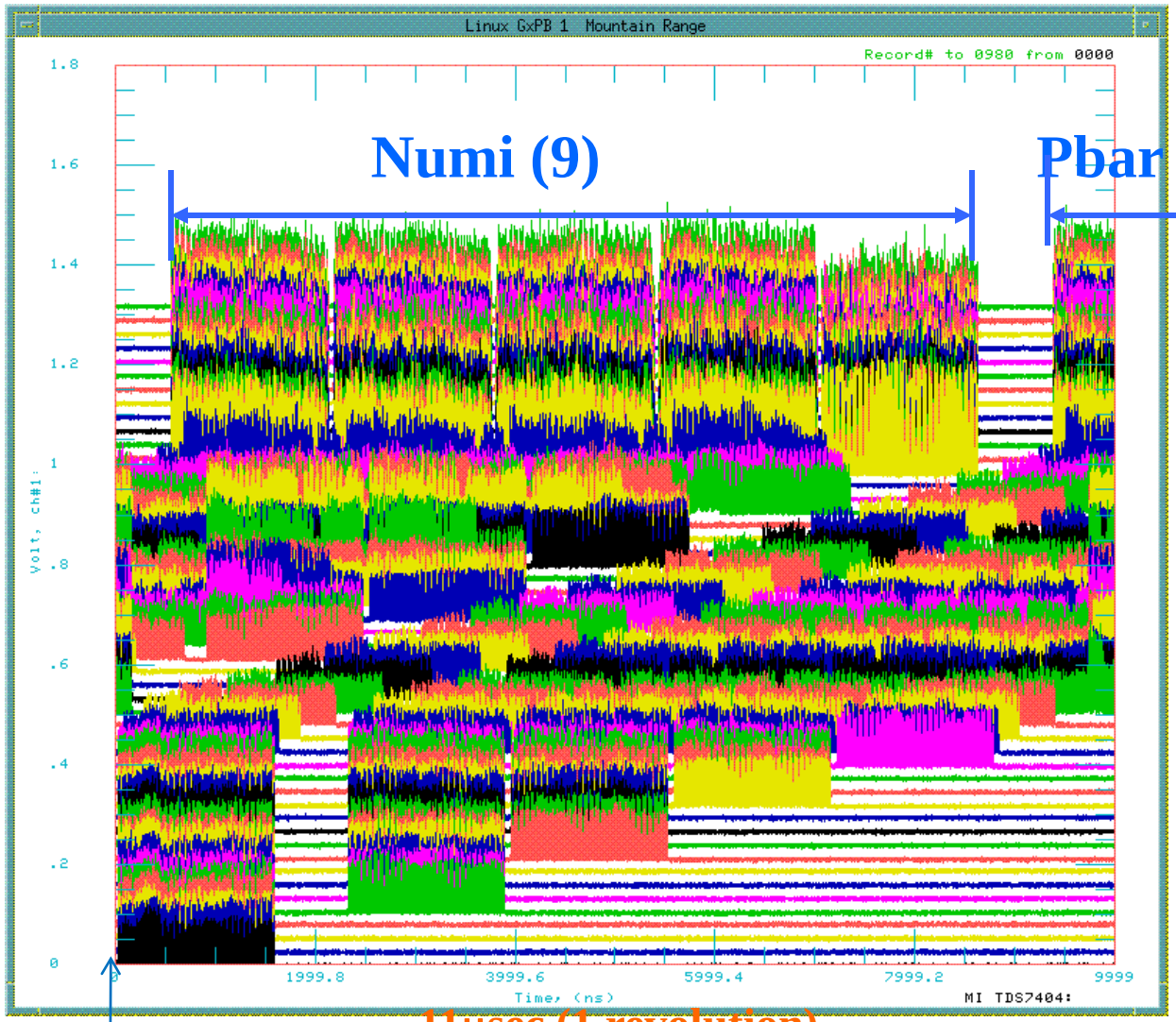
11 batch Slip stacking



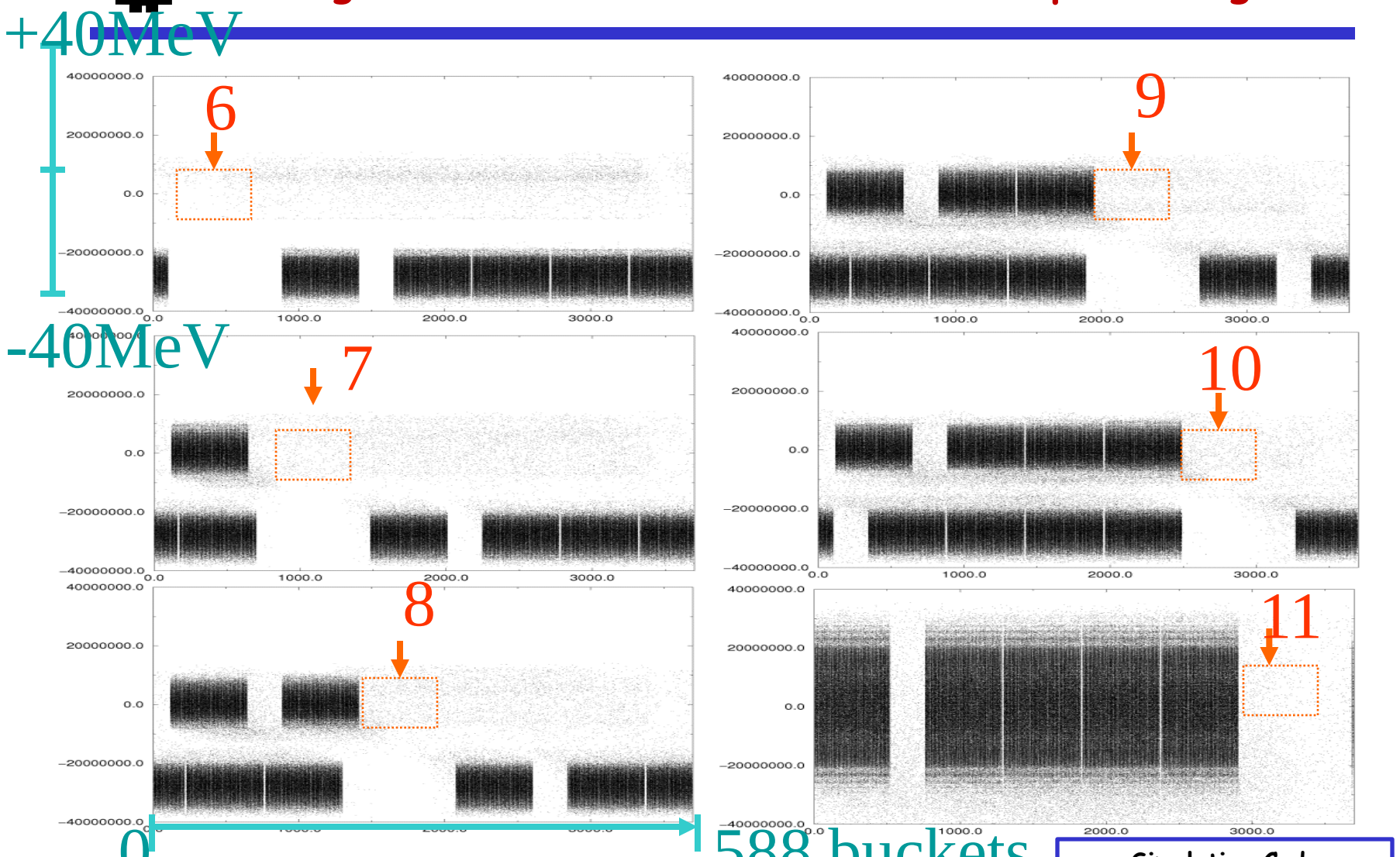
Slipping with 100kV rf

Recapture with 1MV rf

Mountain Range Picture of 11 Batch slip stacking



Longitudinal simulation for 11 batch slip stacking

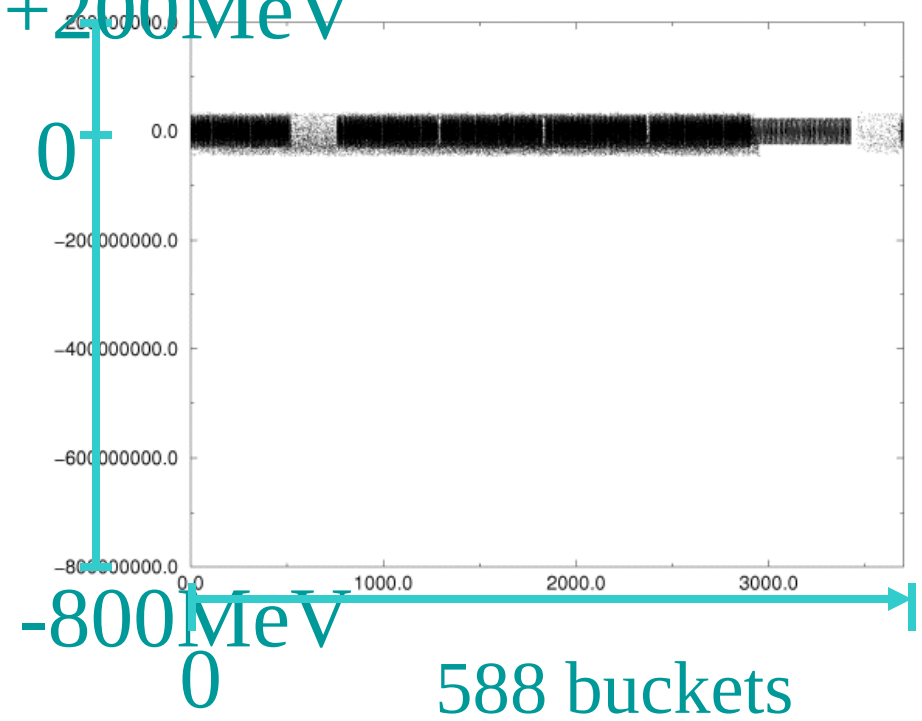


Simulation Code developed by K. Seiya

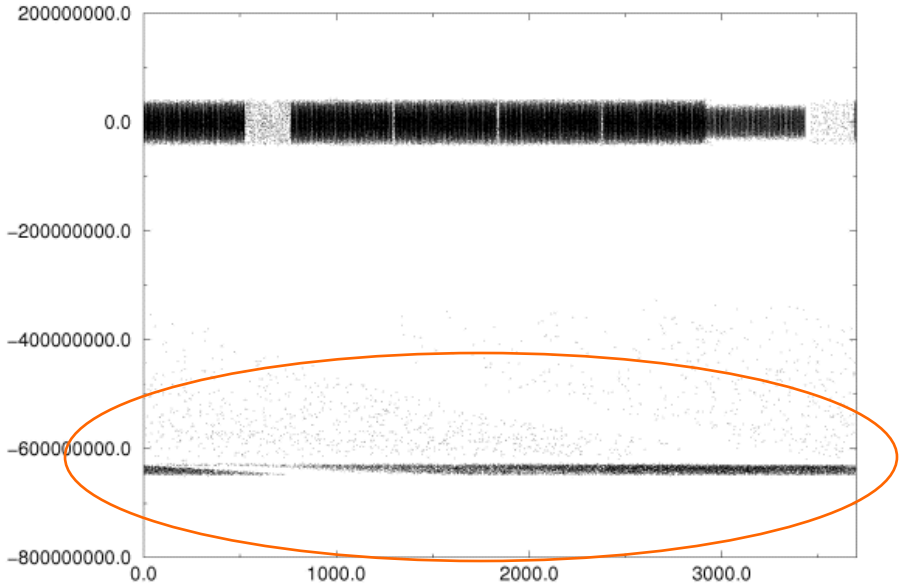
Un-Captured beam Loss

Some of the beam that spilled out during slip stacking is never captured and gets lost early during acceleration. This loss is concentrated at the high dispersion points and at the injection/extraction magnets (Lambertsons).

Before acceleration



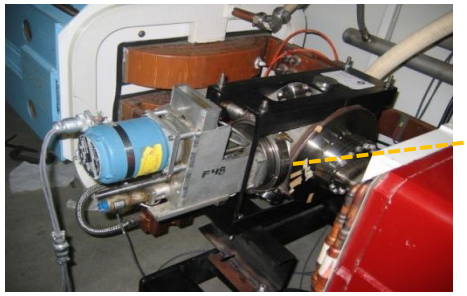
After acceleration



MI collimators have being built to address this loss

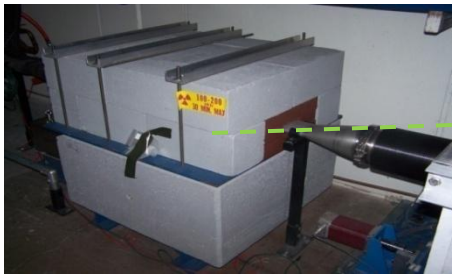
MI Collimators

- Define momentum aperture using primary collimator (.25 mm W) placed in regular cell with normal dispersion.
- Capture scattered beam in massive (20ton) steel blocks to control radiation.
- Cover aisle side and ends with marble.
- Add masks for out-scatter and tails.



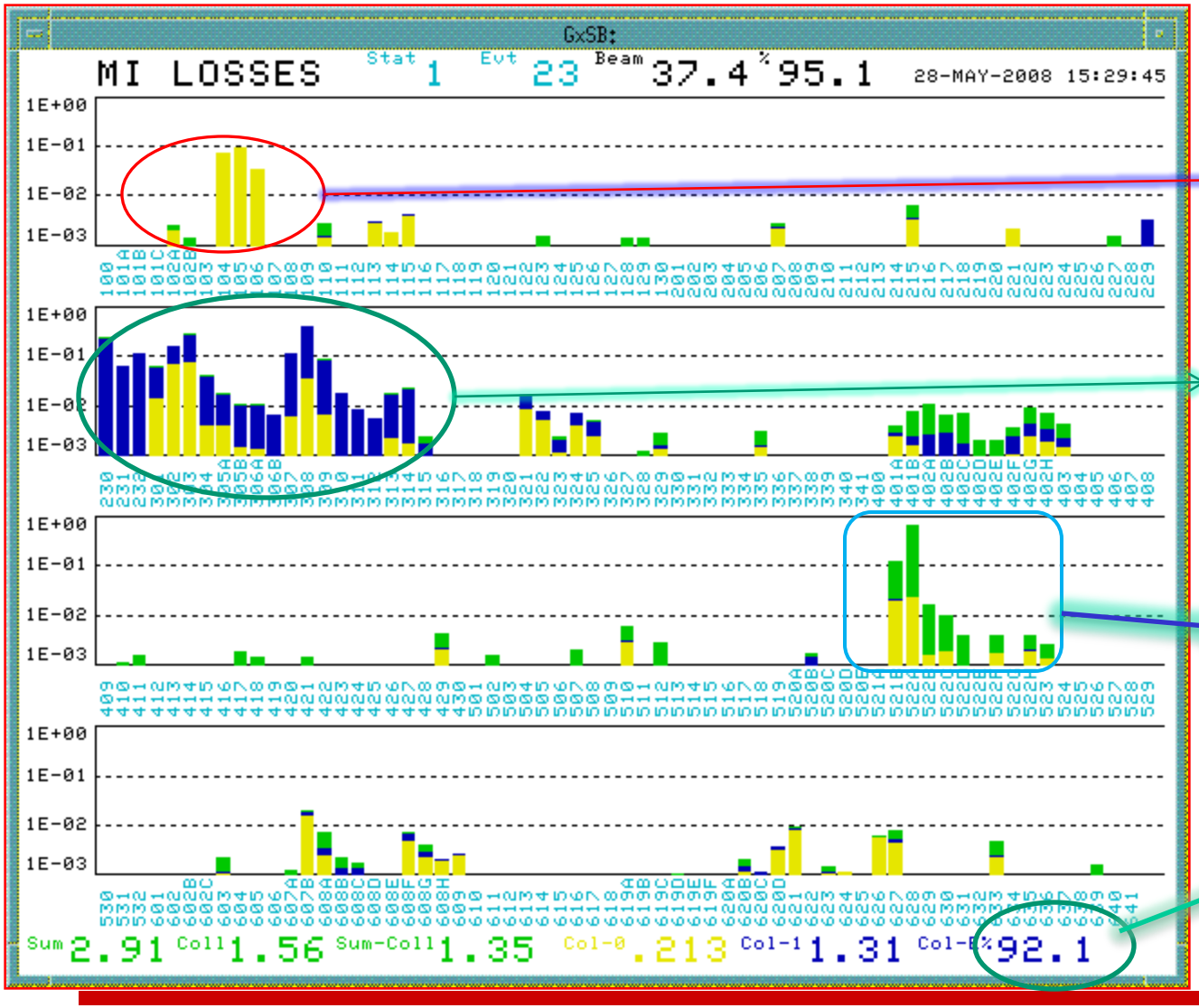
Primary Collimator

Secondary Collimator



Steel concrete mask

MI loss plot and Collimator efficiency



Injection Region

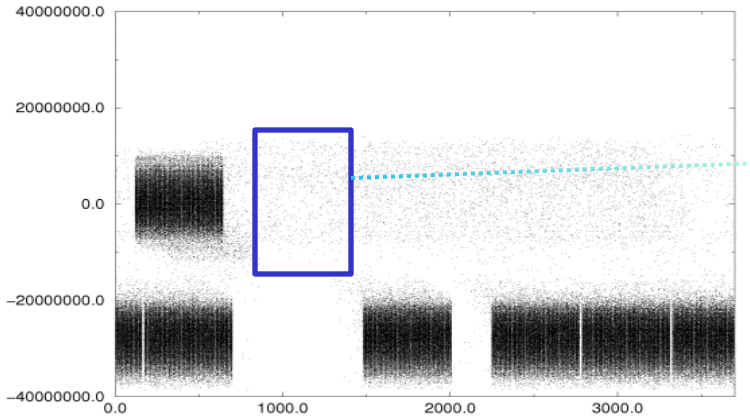
Collimator Region

Extraction to Pbar Target

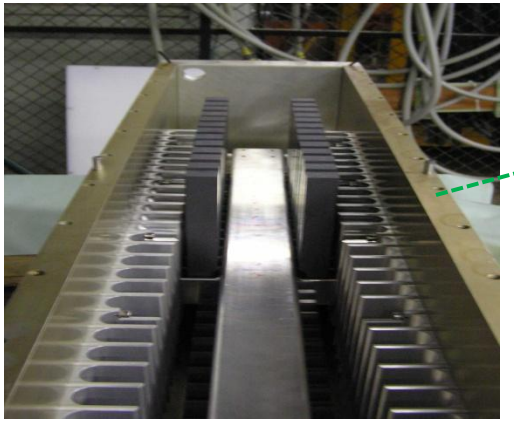
Collimator Efficiency

Injection Kicker Gap Loss

- During the injections of the second group there is beam accumulated in the injection kicker gap.
- Some of this beam come from the deceleration and some from the beating of the two rf frequencies.
- This loss is localized at the injection region.
- In order to dress this problem gap clearing kickers are to be built that will be fired before the injection kickers and send the beam left in the gap in the MI abort.



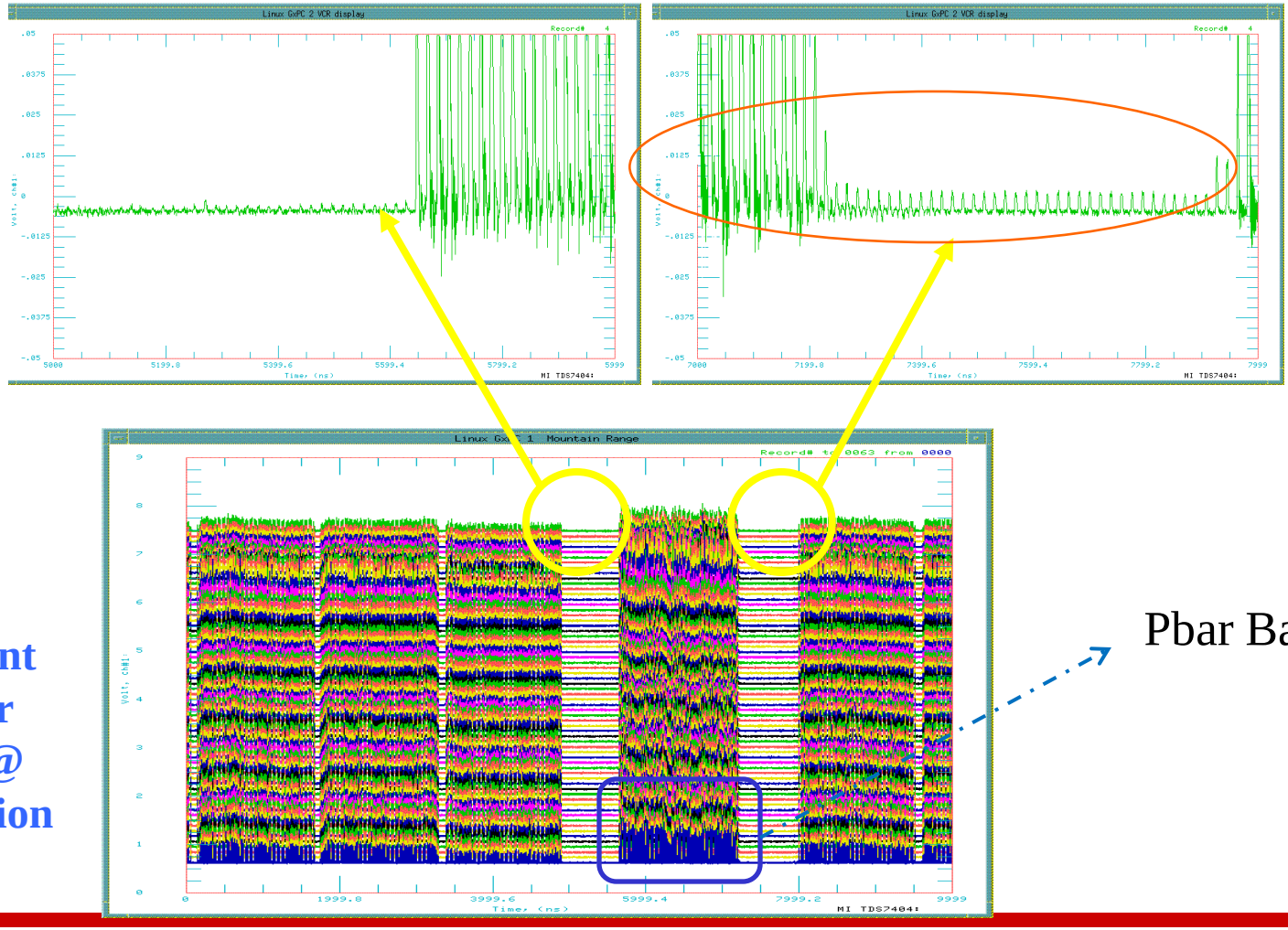
Beam in the injection kicker Gap



Gap Clearing kicker prototype

Extraction kicker gap loss (1)

Some of the spilled beam is captured in buckets between the pbar batch and the the NuMI group of batches .This beam gets accelerated to 120 GeV and gets kicked out by the pbar extraction kicker.



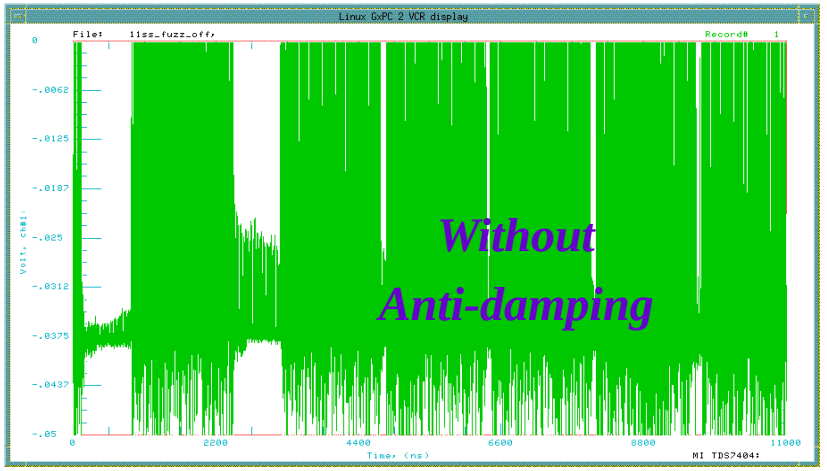
Wall current monitor signal @ extraction

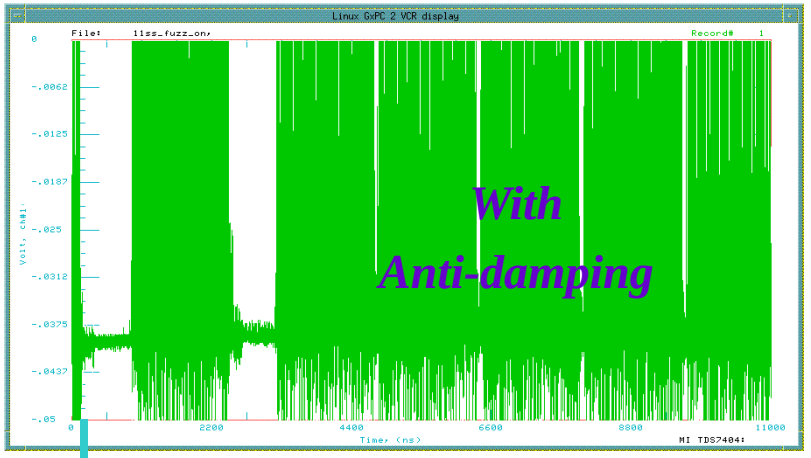
Pbar Batch

Extraction kicker gap loss(2)

The bunch by bunch MI transverse damper is used to reduce the beam in the extraction kicker gap for the pbar batch.

- The damper is used to anti-damp the beam around the pbar batch.
- Since the damper is limited in voltage the anti-damping is most effective at low energies.
- We are working to increase the damping power by adding another kicker.



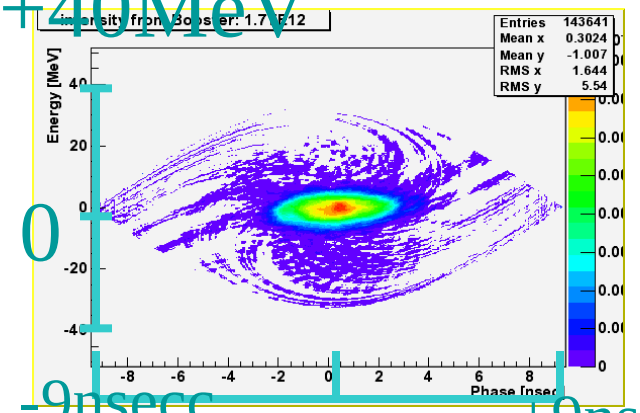


Properties of the Injected Beam

Longitudinal phase tomography with measurement results

The injected beam properties depend on the Booster Beam Intensity

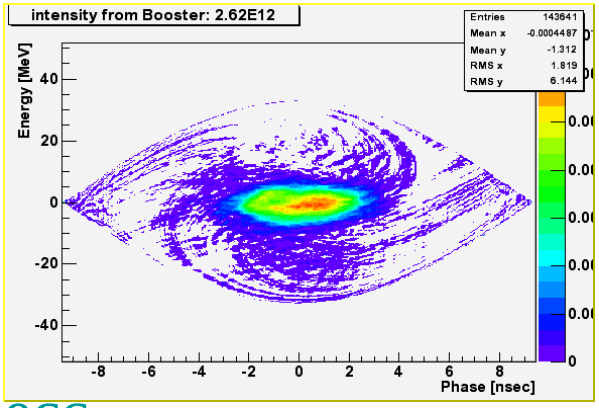
1.77E12 ppp



$\Delta\phi$: +/-1.47nsec

$\Delta p/p$: +/-6.88MeV

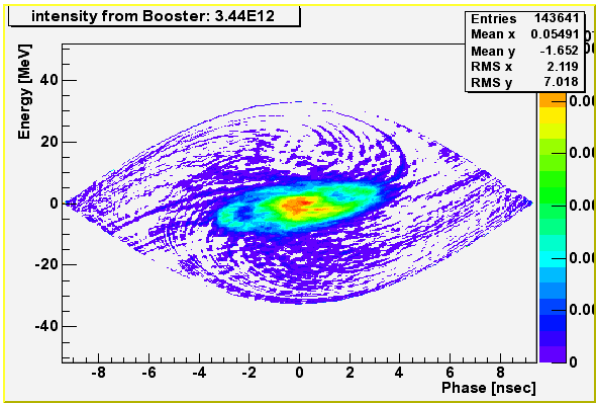
2.65E12 ppp



+/-1.68nsec

+/-7.62MeV

3.44E12 ppp

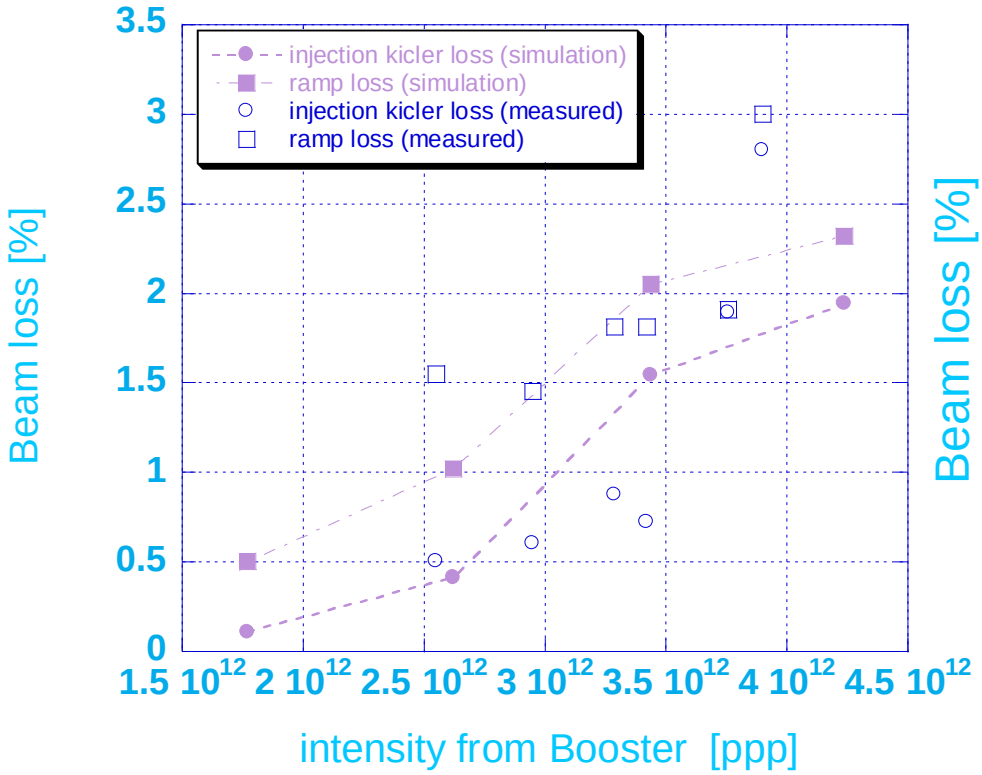


+/-1.78nsec

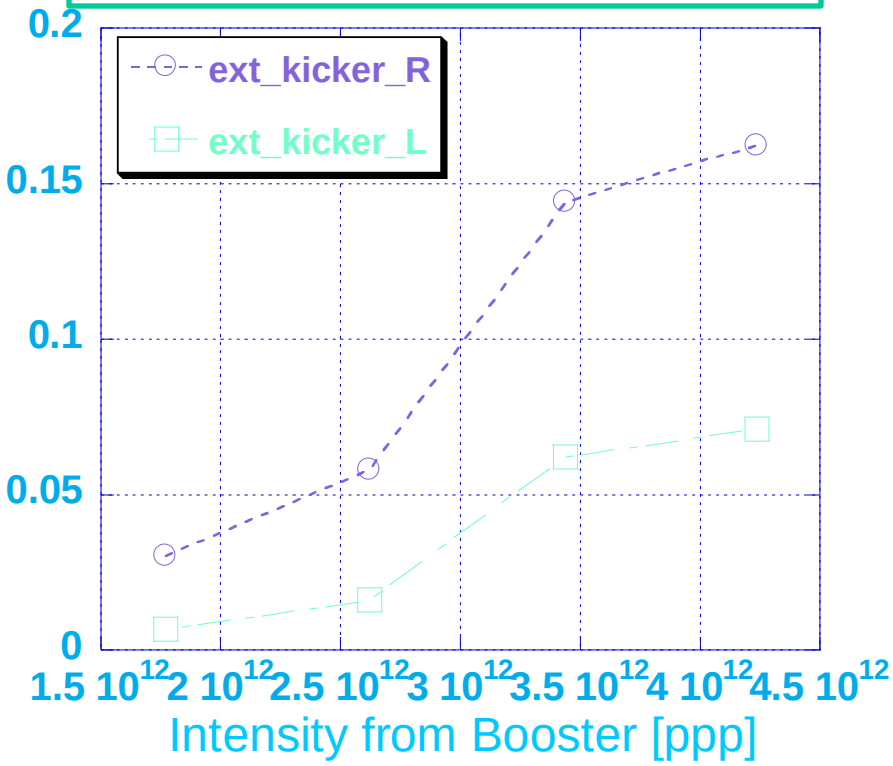
+/-8.99MeV

Comparison between measurements and Simulation

Injection kicker gap loss & Ramp loss



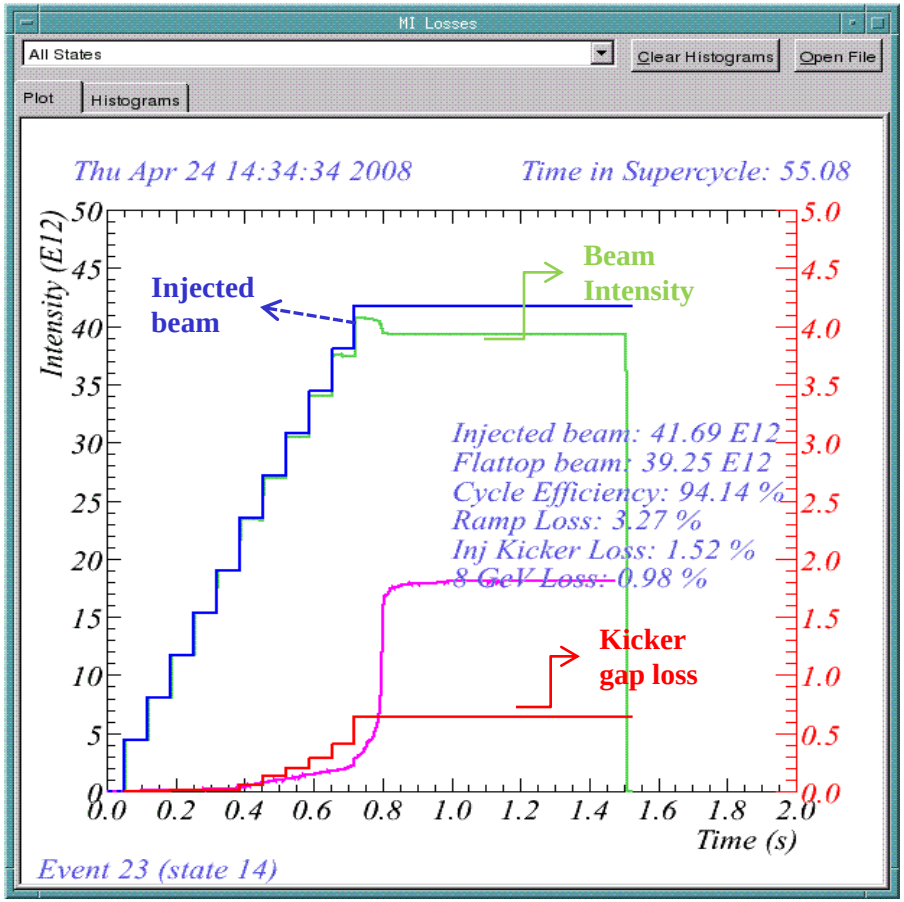
Extraction kicker gap loss

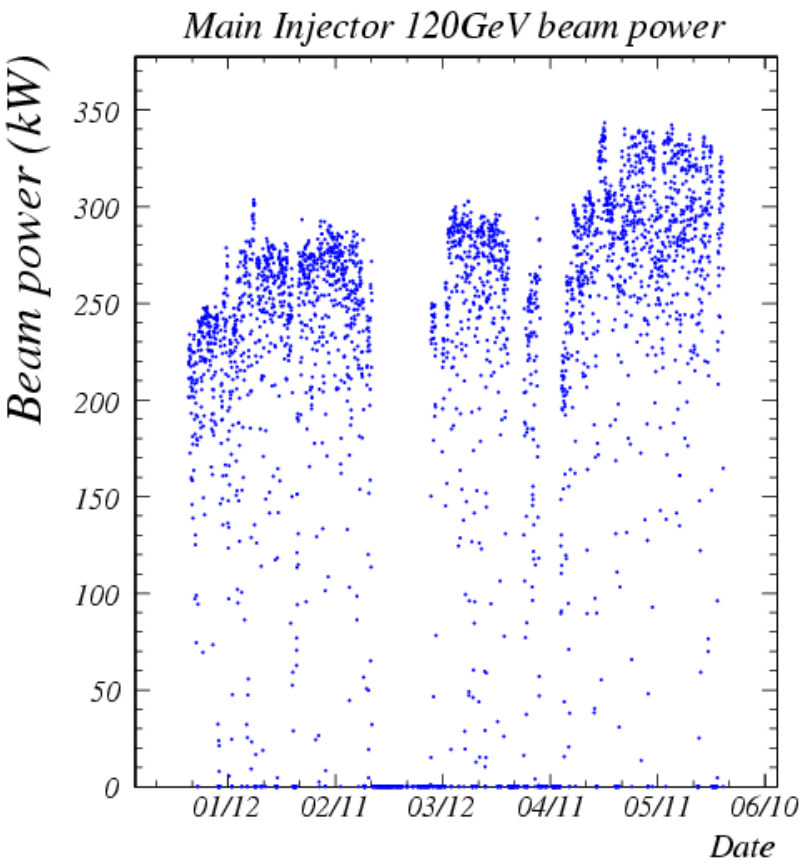


Status of the 400KW Operation

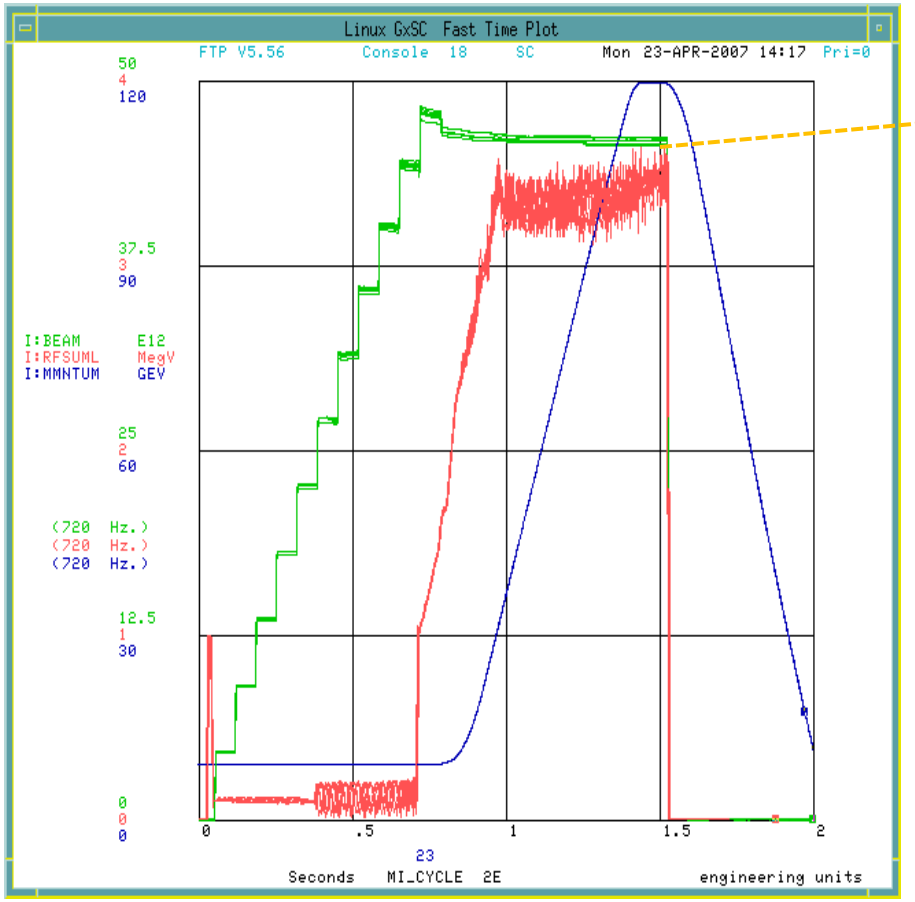
- The MI collimators were installed and have been commissioned.
- Since January 08 when we switched to multi-batch slip stacking the MI beam intensity to the NuMI target has been increased by 30%. The overall MI beam power at 120 GeV has reached 340 KW; 85% of the design goal of 400KW.
- We have demonstrated that MI can run at the high intensity required for 400KW.
- Currently the injection kicker gap loss prevents us from further increasing the beam intensity.
- The gap clearing kickers will be ready for installation in MI in April 09.

MI Beam Intensity and Power



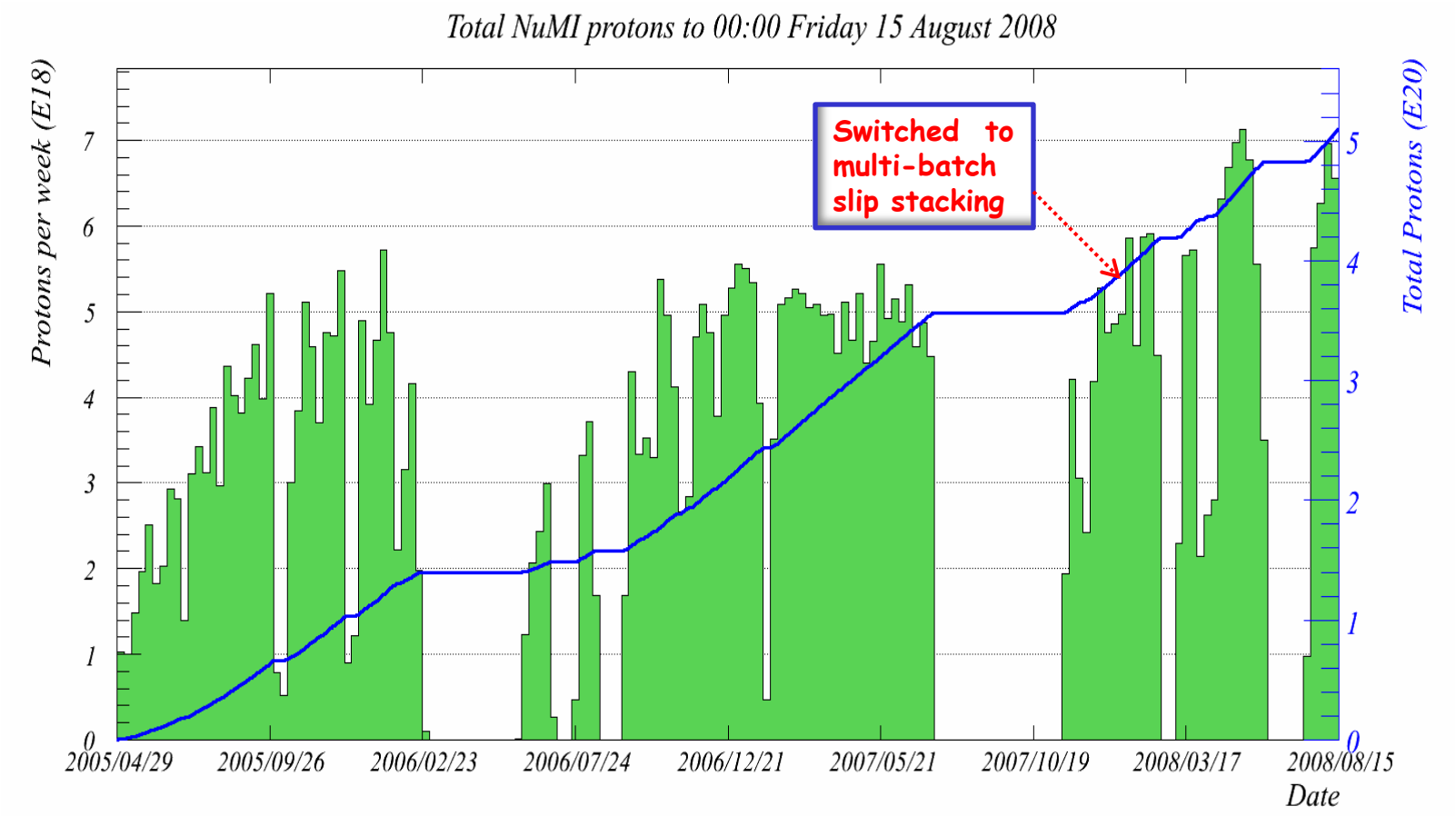


MI Record Intensity



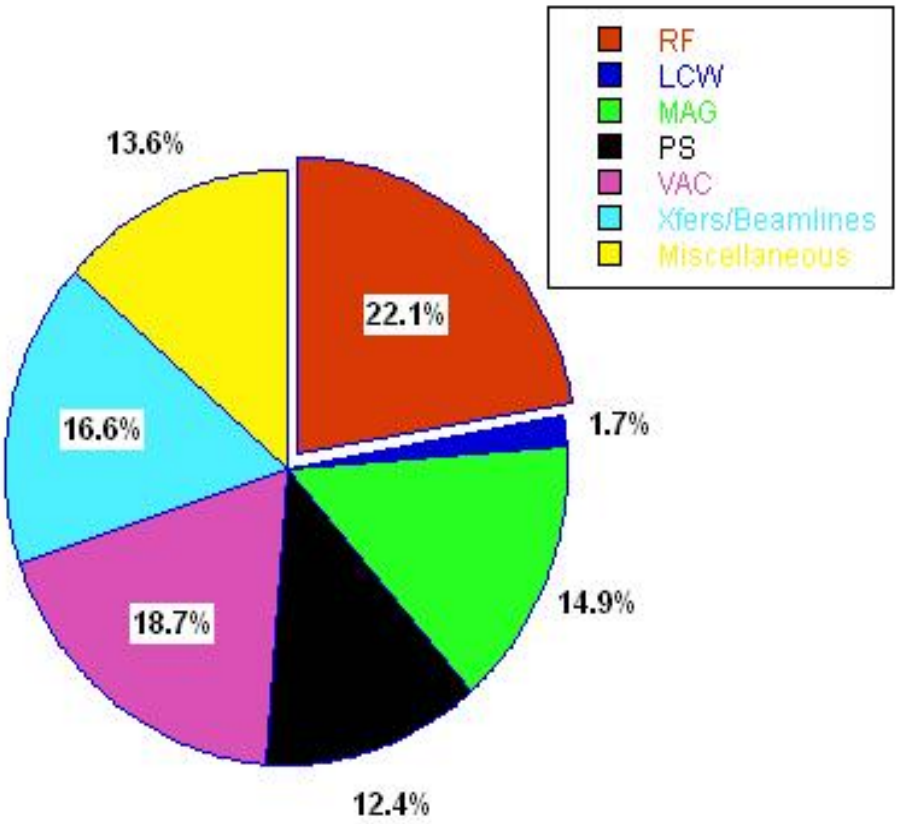
- 4.63E13 Protons to MI abort at 120 GeV.
- 92% Efficiency

Weekly protons to NuMI Target



MI Downtime

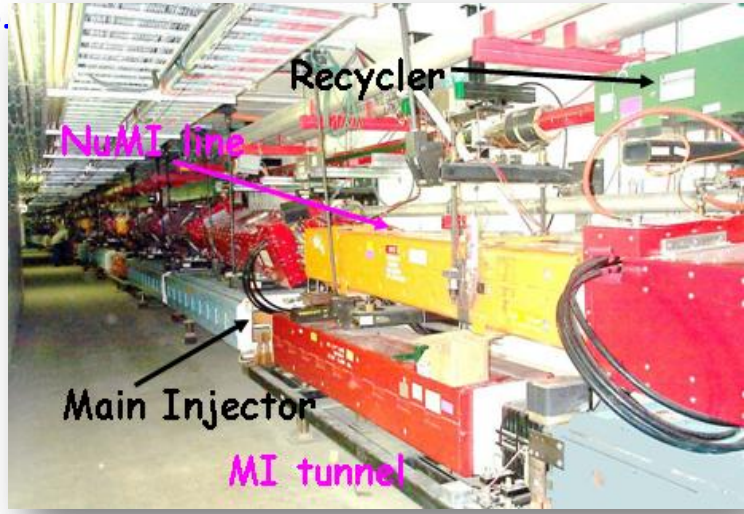
- From January1, 2008 to June 2, 2008 the total MI downtime was 143.6 Hrs, i.e 3.8% of the total time.
- The biggest source for downtime was the MI RF.
- The rf requirements are larger because of the amount of the beam-loading compensation required during slip stacking and the amount of beam that is accelerated.



Future Plans: 700 kW for NOvA

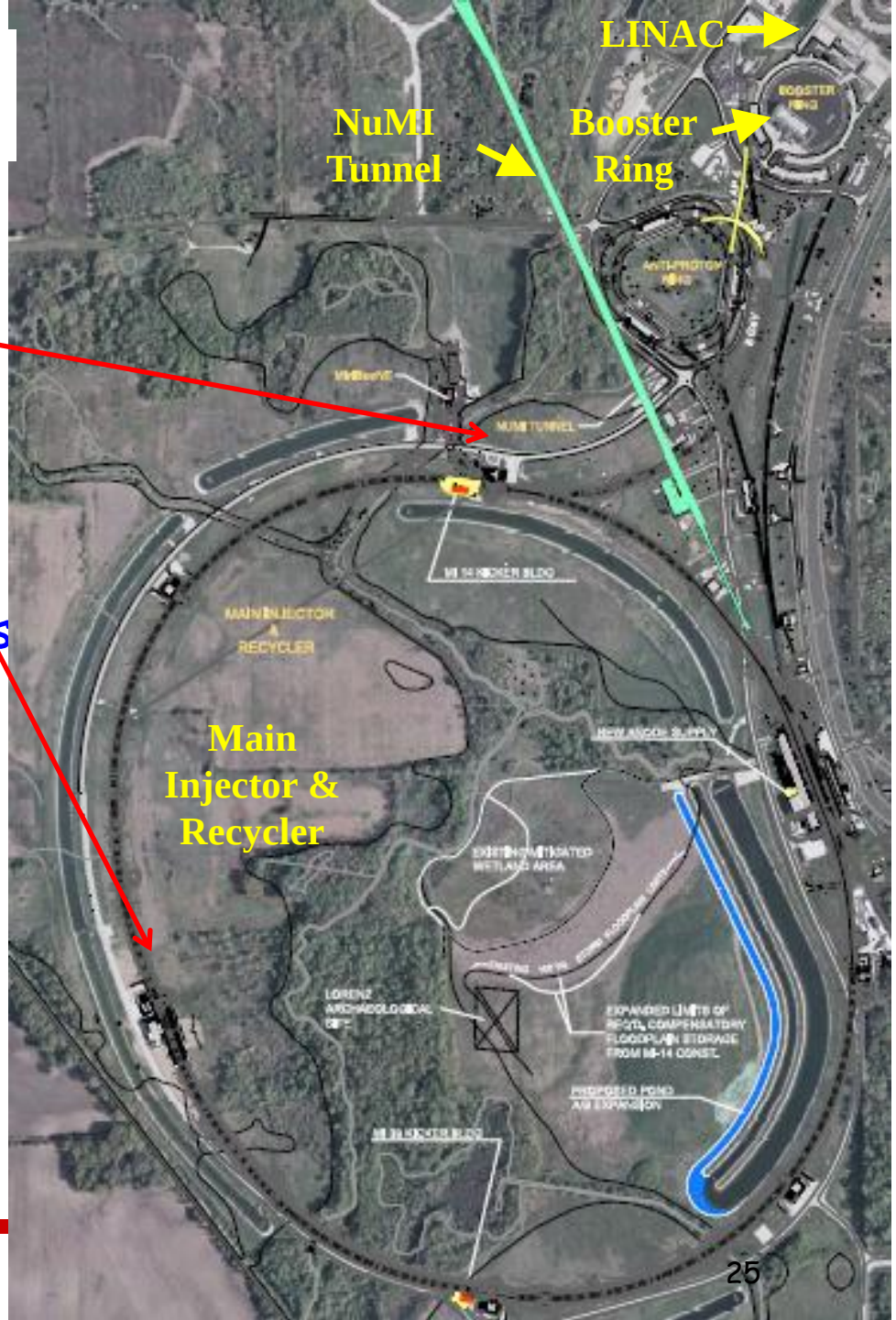
- When Collider program concludes, use the Recycler as a proton pre-injector
  - Use the Recycler to accumulate protons from the Booster while MI is accelerating
  - Can save 0.4 s for each 6 Booster batches injected
- Recycler momentum aperture is large enough to allow slip-stacking operation in Recycler, for up to 12 Booster batches injected
  - 6 batches are slipped with respect to the other 6 and, at the time they line up, they are extracted to MI in a single turn and there re-captured and accelerated
  - Main Injector will run at its design acceleration rate of 240 GeV/s (1.3s cycle time) (operates at 204 GeV/s presently)
  - 4.3 10^{12} p/batch, 95% slip-stacking efficiency
  - 4.9×10^{13} ppp at 120 GeV every 1.333 s

⇒ **700 kW**

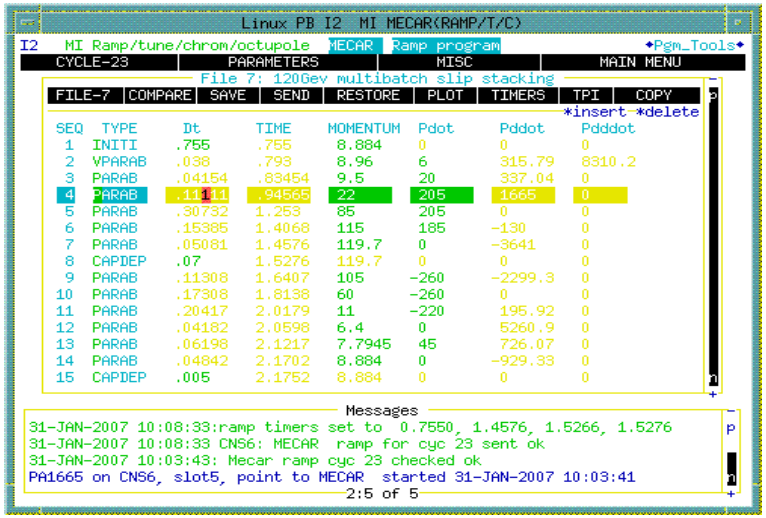


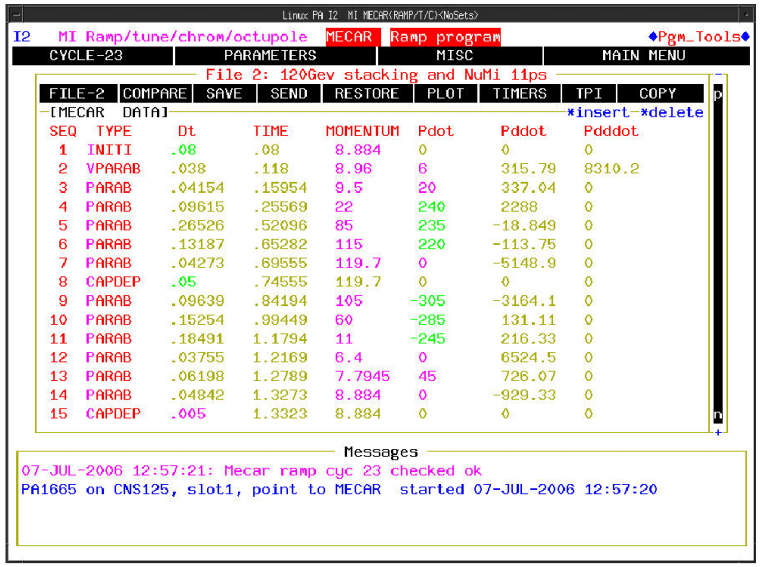
Main Accelerator Upgrades

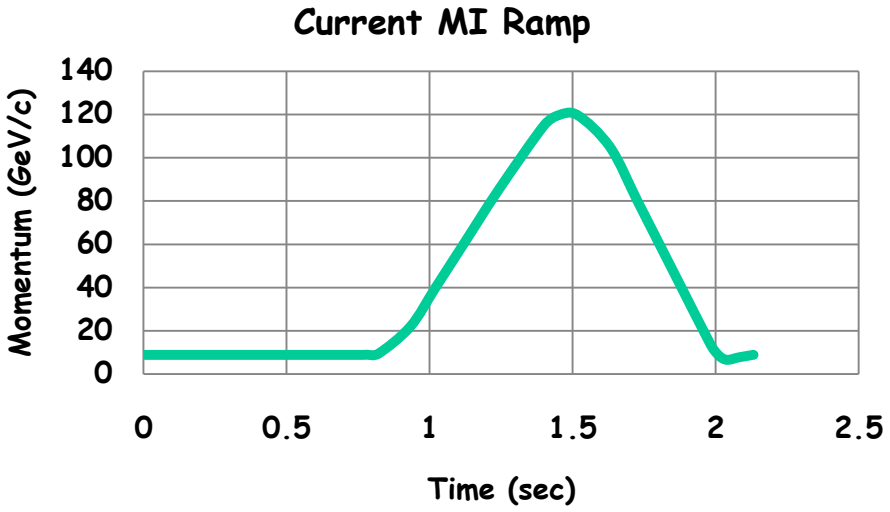
- Recycler Ring, RR
  - New injection line into RR
  - New extraction line from RR
  - New 53 MHz RF system
  - New low level RF system
- Main Injector
  - Two additional 53 MHz cavities (total 20 instead of 18)
  - Quad Power Supply Upgrade
- NuMI
  - Change to medium energy ν beam configuration (new target)
  - Cooling & power supply upgrades

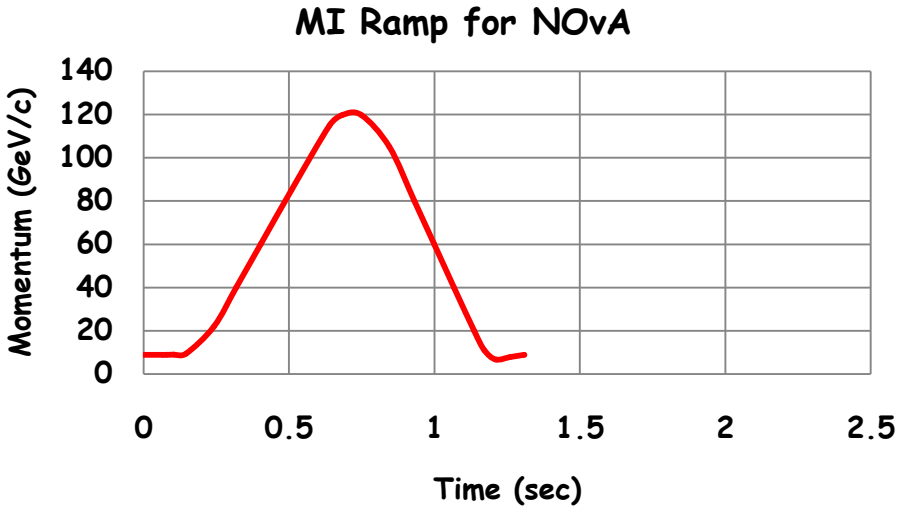


MI Ramp


Linux PB I2 MI MECAR(RAMP/T/C)
I2 MI Ramp/tune/chrom/octupole MECAR Ramp program ♦Pgm_Tools♦
CYCLE-23 PARAMETERS MISC MAIN MENU
File 7: 120Gev multibatch slip stacking
FILE-7 COMPARE SAVE SEND RESTORE PLOT TIMERS TPI COPY
*insert *delete
SEQ TYPE Dt TIME MOMENTUM Pdot Pddot Pdddot
1 INITI .755 .755 8.884 0 0 0
2 VPARAB .038 .793 8.96 6 315.79 8310.2
3 PARAB .04154 .83454 9.5 20 337.04 0
4 PARAB .11111 .94565 22 205 1665 0
5 PARAB .30732 1.253 85 205 0 0
6 PARAB .15385 1.4068 115 185 -130 0
7 PARAB .05081 1.4576 119.7 0 -3641 0
8 CAPDEP .07 1.5276 119.7 0 0 0
9 PARAB .11308 1.6407 105 -260 -2299.3 0
10 PARAB .17308 1.8138 60 -260 0 0
11 PARAB .20417 2.0179 11 -220 195.92 0
12 PARAB .04182 2.0598 6.4 0 5260.9 0
13 PARAB .06198 2.1217 7.7945 45 726.07 0
14 PARAB .04842 2.1702 8.884 0 -929.33 0
15 CAPDEP .005 2.1752 8.884 0 0 0
Messages
31-JAN-2007 10:08:33:ramp timers set to 0.7550, 1.4576, 1.5266, 1.5276
31-JAN-2007 10:08:33 CNS6: MECAR ramp for cyc 23 sent ok
31-JAN-2007 10:03:43: Mecar ramp cyc 23 checked ok
PA1665 on CNS6, slot5, point to MECAR started 31-JAN-2007 10:03:41
2:5 of 5


I2 MI Ramp/tune/chrom/octupole MECAR Ramp program ♦Pgm_Tools♦
CYCLE-23 PARAMETERS MISC MAIN MENU
File 2: 120Gev stacking and NuMi 11ps
FILE-2 COMPARE SAVE SEND RESTORE PLOT TIMERS TPI COPY
[MECAR DATA]
*insert *delete
SEQ TYPE Dt TIME MOMENTUM Pdot Pddot Pdddot
1 INITI .08 .08 8.884 0 0 0
2 VPARAB .038 .118 8.96 6 315.79 8310.2
3 PARAB .04154 .15954 9.5 20 337.04 0
4 PARAB .09615 .25569 22 240 2288 0
5 PARAB .26526 .52096 85 235 -18.849 0
6 PARAB .13187 .65282 115 220 -113.75 0
7 PARAB .04273 .69555 119.7 0 -5148.9 0
8 CAPDEP .05 .74555 119.7 0 0 0
9 PARAB .09639 .84194 105 -305 -3164.1 0
10 PARAB .15254 .99449 60 -285 131.11 0
11 PARAB .18491 1.1794 11 -245 216.33 0
12 PARAB .03755 1.2169 6.4 0 6524.5 0
13 PARAB .06198 1.2789 7.7945 45 726.07 0
14 PARAB .04842 1.3273 8.884 0 -929.33 0
15 CAPDEP .005 1.3323 8.884 0 0 0
Messages
07-JUL-2006 12:57:21: Mecar ramp cyc 23 checked ok
PA1665 on CNS125, slot1, point to MECAR started 07-JUL-2006 12:57:20


Current MI Ramp
Momentum (GeV/c)
140
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
Time (sec)

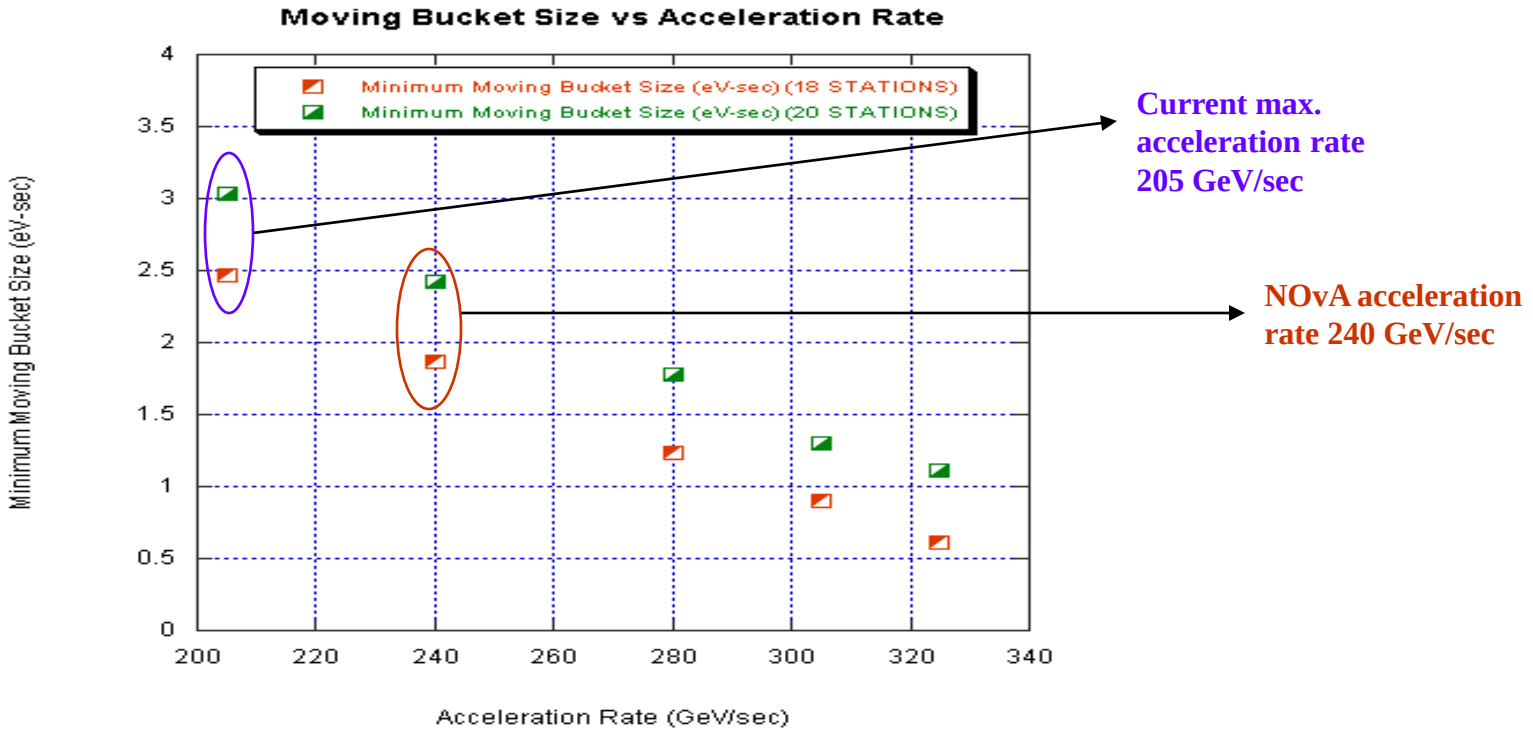

MI Ramp for NOvA
Momentum (GeV/c)
140
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
Time (sec)

Conclusions

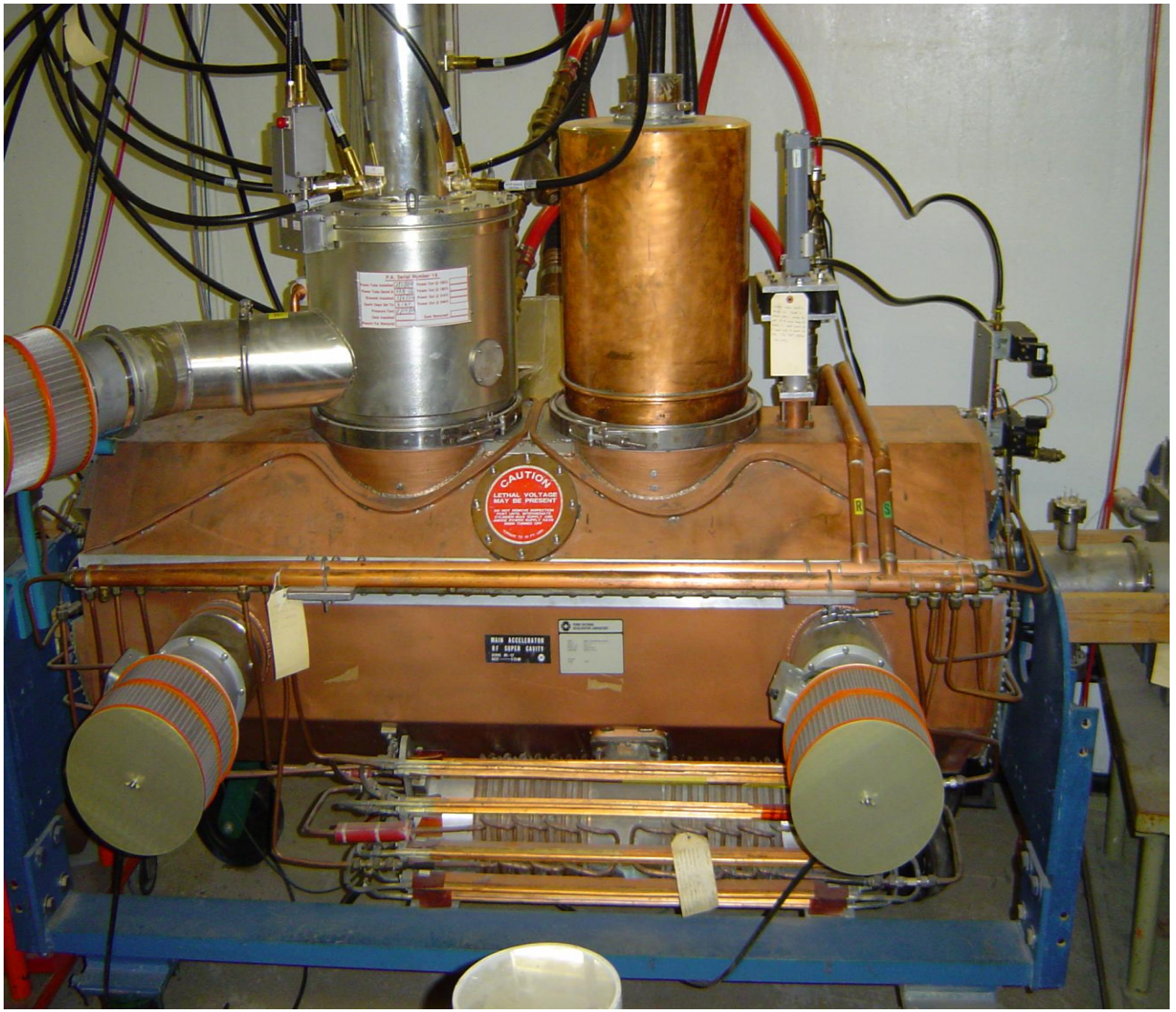
- We have successfully switched to multi-batch slip stacking in MI that would allow us to achieve 400KW beam power at 120 GeV.
- We have already achieved 85% of the design beam power and we are addressing the beam loss issues that are preventing us from reaching our goal.
- After the end of the Collider run we plan to use the Recycler as proton pre-injector allowing us to decrease the MI ramp by 40% reaching 700KW of beam power.
- Controlling the beam losses and limiting the activation of MI will continue to be our largest challenge.

Extra slides

Min. Bucket Area vs. Acceleration Rate



MI rf Cavity



MI Quad Bus Modifications

•During the NOvA ramp we are going to exceed the maximum available voltage of the defocusing (vertical) bus.

•We plan to increase the available voltage at the defocusing bus by replacing one of the transformers with a higher voltage one and modifying the corresponding supply.

•These modifications are similar to the ones done recently on the focusing quad bus in order to accommodate the installation of the wide aperture quads.