Proton Plan
Main Injector Upgrades
Temple Review
August 2005

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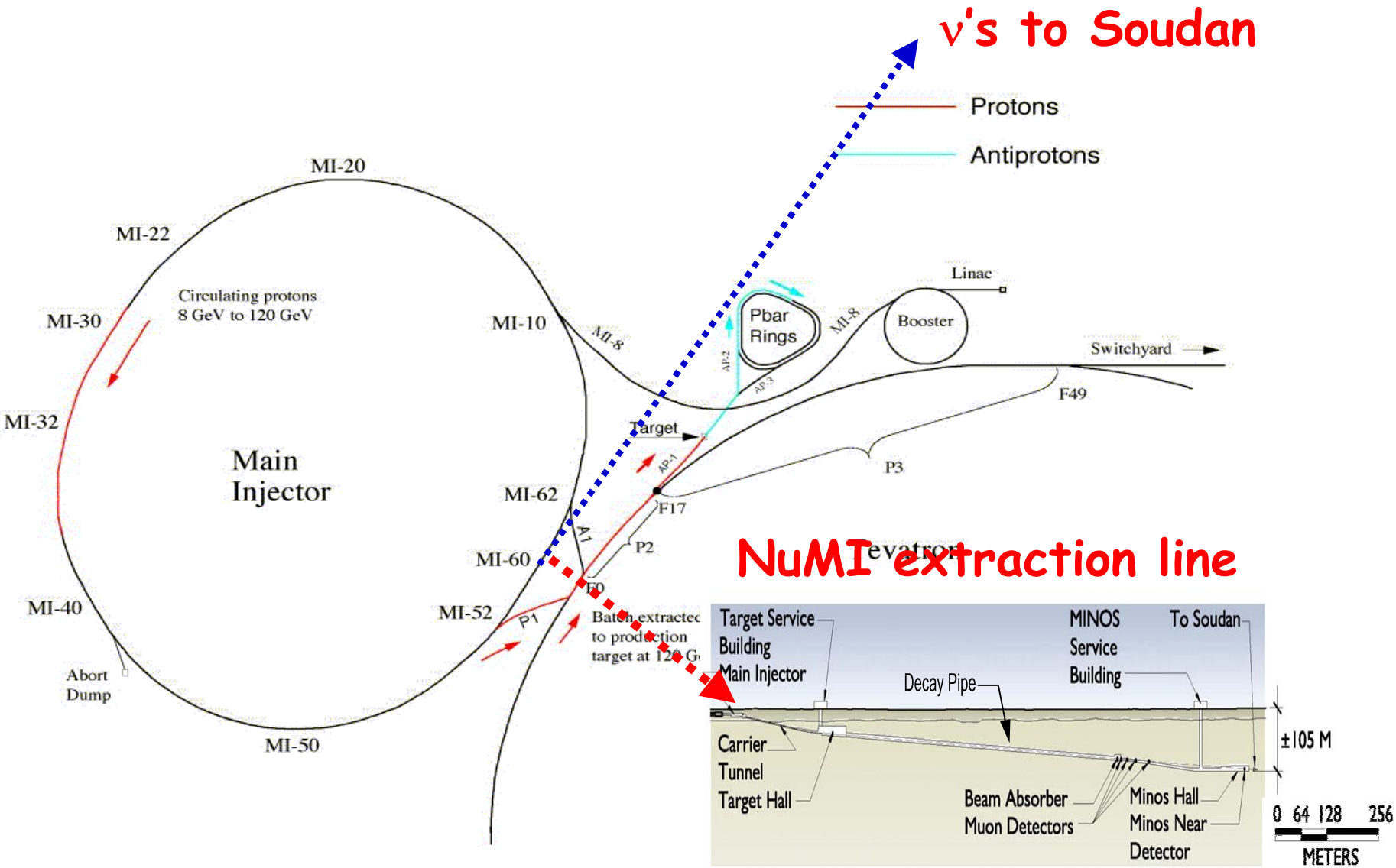
Outline

- Current MI operation
- MI multi batch stacking schemes
- Large Aperture Quads (WQB)
- MI-8 Collimation system
- MI collimation
- Kicker upgrades
- Cost and Schedule tables

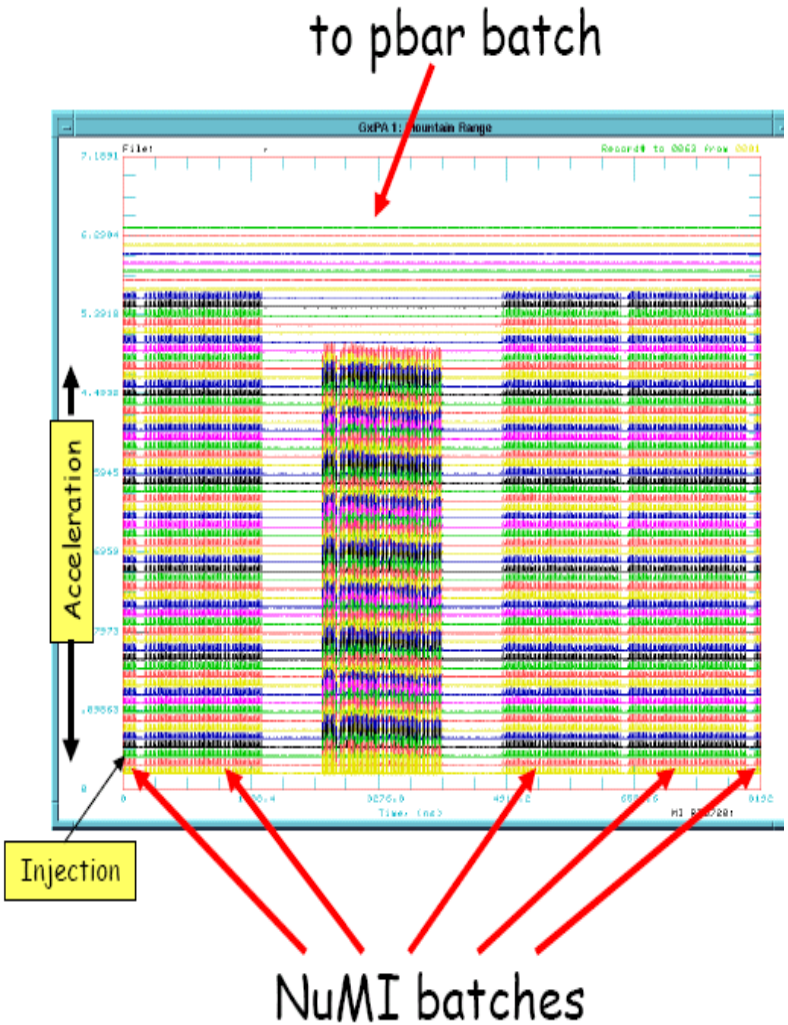
MI in 2005

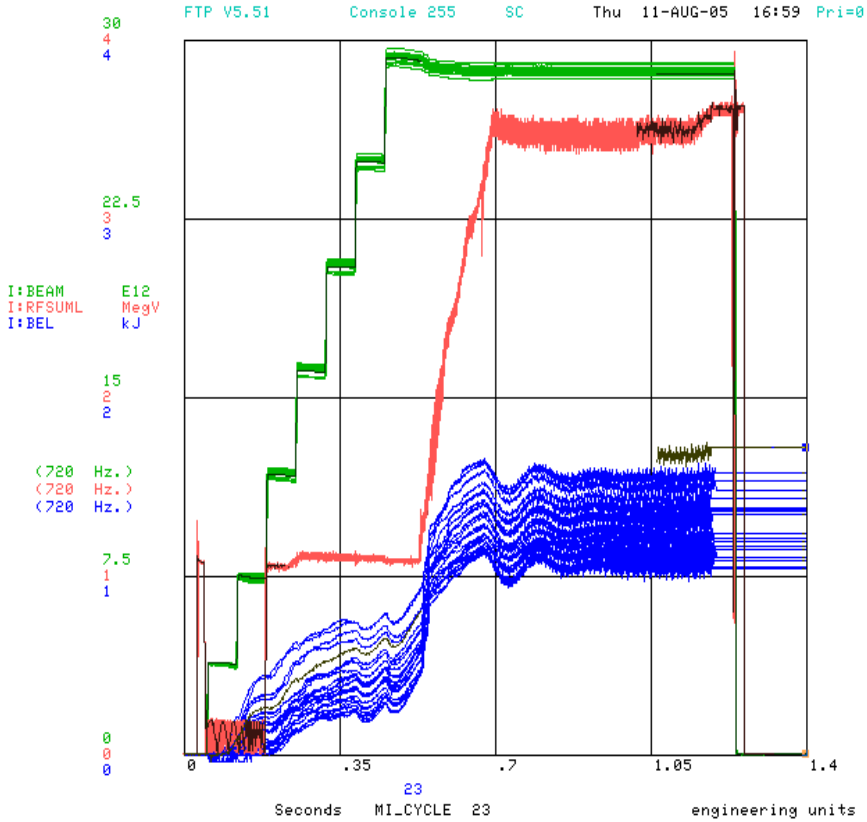

ν's to Soudan
Protons
Antiprotons
MI-20
MI-22
MI-30
MI-32
MI-40
MI-50
MI-52
MI-60
MI-62
MI-10
MI-8
Circulating protons
8 GeV to 120 GeV
Main
Injector
Abort
Dump
Pbar
Rings
Booster
Linac
Switchyard
F49
P3
Target
F17
P2
A1
P1
F0
Batch extracted
to production
target at 120 G
NuMI extraction line
Target Service
Building
Main Injector
Decay Pipe
MINOS
Service
Building
To Soudan
Carrier
Tunnel
Target Hall
Beam Absorber
Muon Detectors
Minos Hall
Minos Near
Detector
±105 M
0 64 128 256
METERS

Current MI Operation

- Main Injector is currently delivering beam to the pbar target(using slip stacking) and to NuMI on the same mixed mode (1.87 sec long).
- The total MI beam intensity can be as high as 3.5E13p/cycle and is expected to increase to about 4.4-5.5E13p/cycle with the implementation of beam stacking for NuMI.
- The MI cycle length is dominated by the injection time and the ramp has been optimized using a max acceleration rate of 205 GeV/sec.
- The power supplies can support a max acceleration rate of 280 Gev/sec but we only have enough rf to support acceleration rates up to 240 GeV/sec (bucket area).

Stacking and NuMI mixed mode cycle





Beam Intensity and losses

MI Ramps

Present MI Ramp 1.87sec

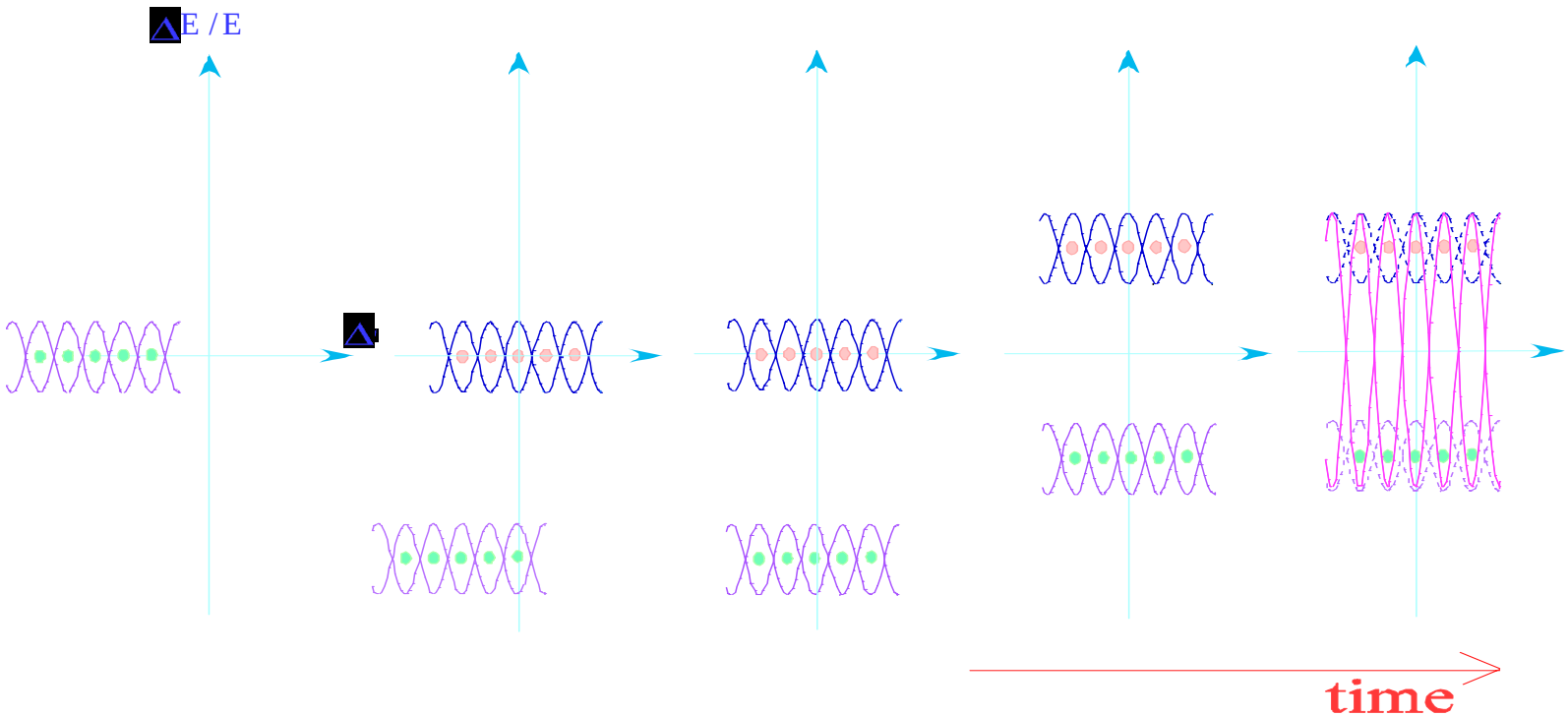
Minimum Cycle Ramp 1.75sec

Time for Sync. Injection

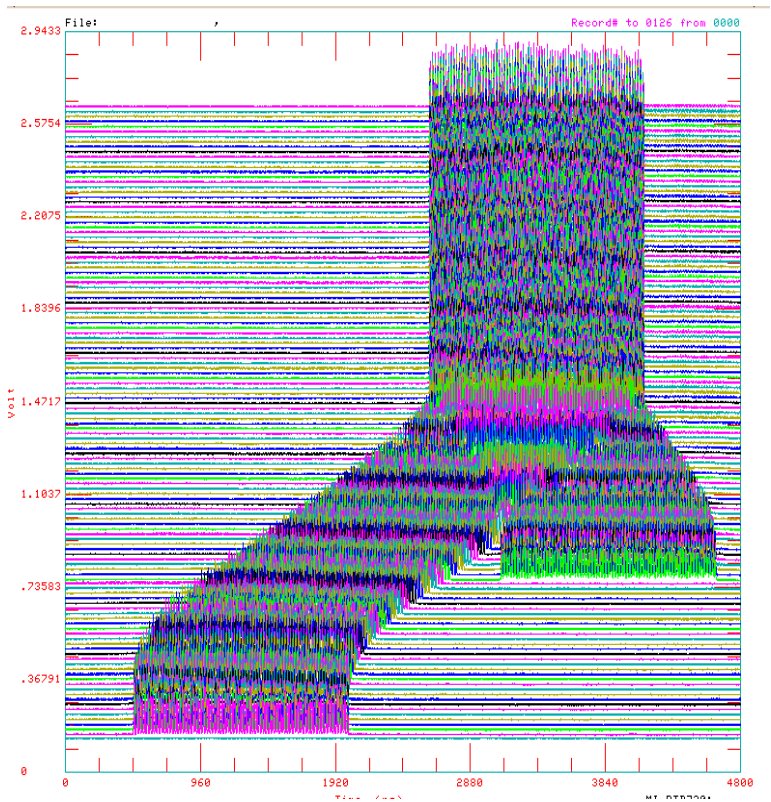
Delta t	Time	Momentum	Pdot
0.50000	0.50000	8.884	0.00
0.02533	0.52533	8.96	6.00
0.04154	0.56687	9.5	20.00
0.11111	0.67798	22	205.00
0.30732	0.98530	85	205.00
0.15385	1.13915	115	185.00
0.05081	1.18996	119.7	0.00
0.07000	1.25996	119.7	0.00
0.09800	1.35796	105	-300.00
0.15517	1.51313	60	-280.00
0.19600	1.70913	11	-220.00
0.04182	1.75095	6.4	0.00
0.06198	1.81293	7.7945	45.00
0.04842	1.86135	8.884	0.00
0.00500	1.86635	8.884	0.00

Delta t	Time	Momentum	Pdot
0.50000	0.50000	8.884	0.00
0.02533	0.52533	8.96	6.00
0.04154	0.56687	9.5	20.00
0.08333	0.65021	22	280.00
0.23774	0.88794	85	250.00
0.13636	1.02430	115	190.00
0.04947	1.07378	119.7	0.00
0.07000	1.14378	119.7	0.00
0.09639	1.24017	105	-305.00
0.15385	1.39402	60	-280.00
0.19600	1.59002	11	-220.00
0.04182	1.63184	6.4	0.00
0.06198	1.69381	7.7945	45.00
0.04842	1.74224	8.884	0.00
0.00500	1.74724	8.884	0.00

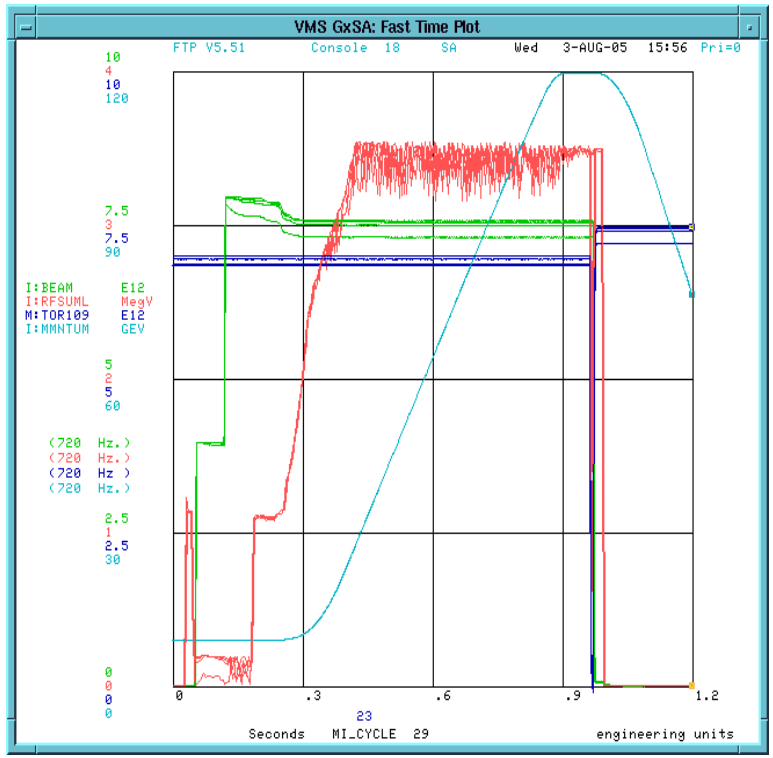
Slip Stacking Principle



Slip Stacking for pbar Production



Mountain Range Picture

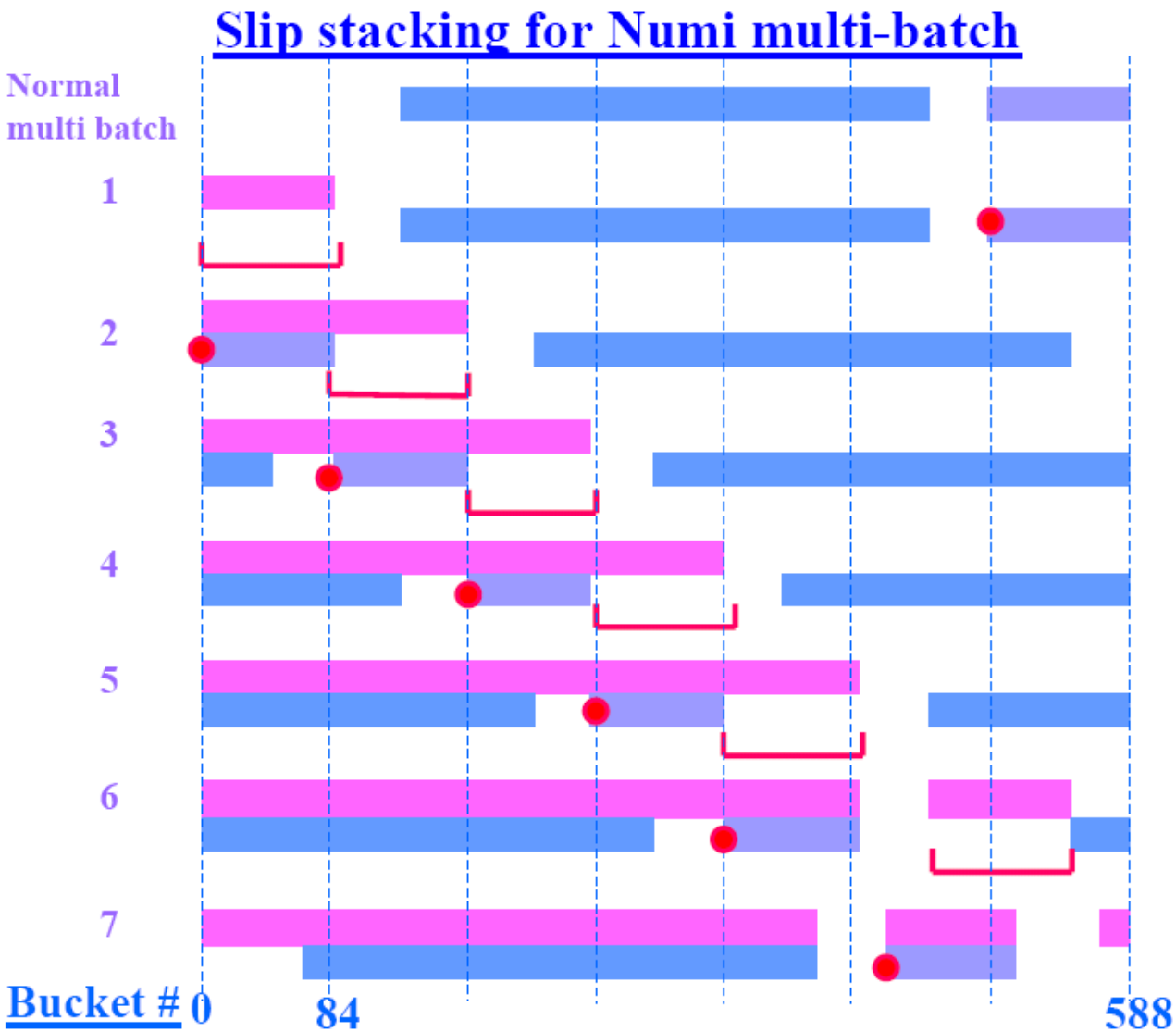


Beam Intensities (Efficiency ≥ 95%)

MI Multi-batch Stacking

- We have developed a plan to increased the proton Intensity for NuMI based on slip stacking. It turns out that we can increase the number of Booster batches from 5 to 9 in a mixed mode cycle using slip stacking and increasing the total cycle time by 0.3 sec.
- After injecting four batches for NuMI and one batch for stacking in the center of MI aperture using one rf system (60-100KV), the beam is decelerated by almost 1300Hz by the first rf system while the frequency of the second rf system is ramped down by 1300Hz.
- Five additional batches for NuMI are injected at the beginning of the injection gap which moves by one batch every Booster tick and captured by the second rf system.
- After the fifth injection a sixth batch is injected at the end of the injection gap.
- The whole 11 batches are then accelerated by 650Hz and when they overlap are recaptured with 1MV of rf at the center frequency.

Cartoon of multi-batch slip stacking in MI



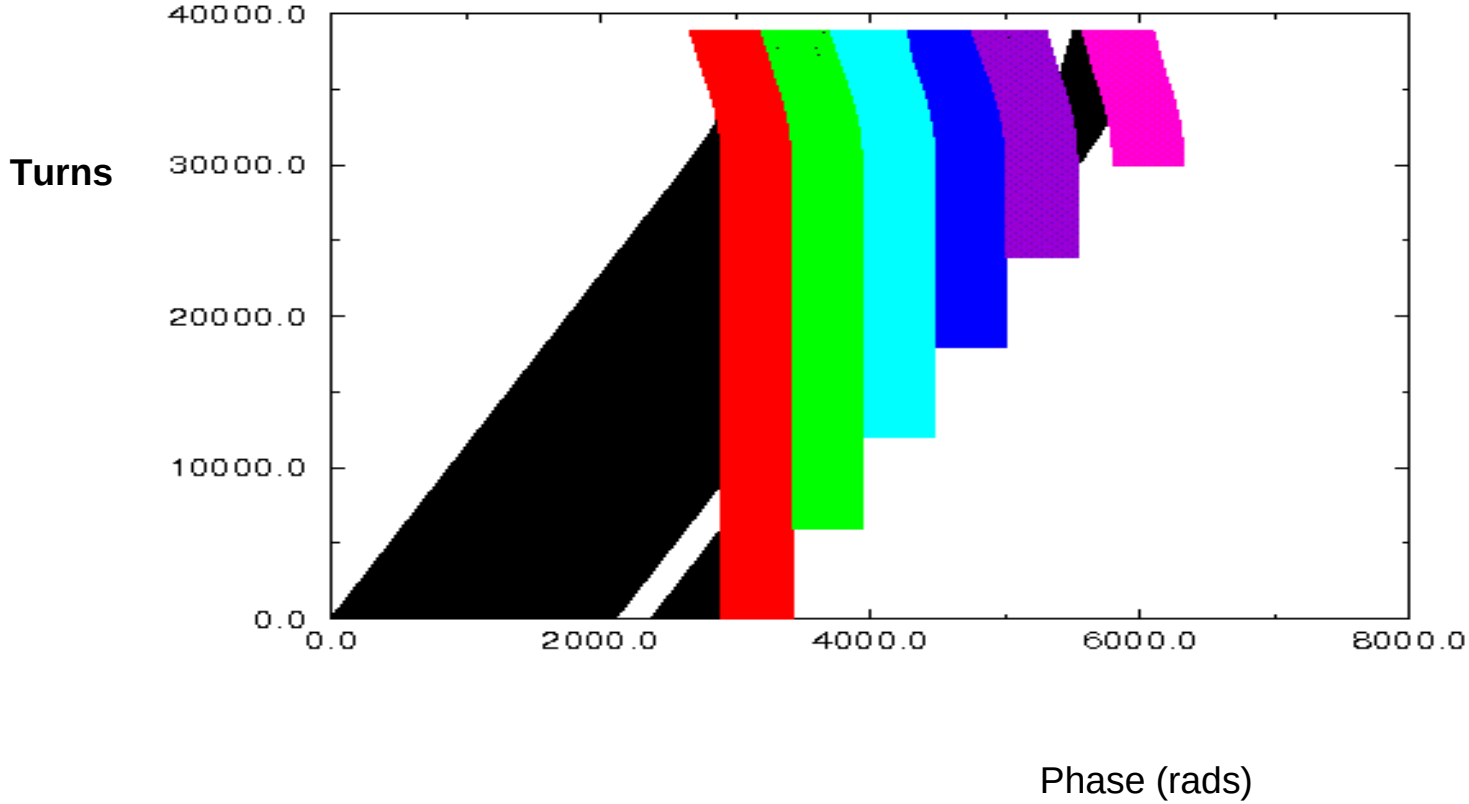
5 Booster batches are injected in the center using RF1

The 5 batches are decelerated by 1300Hz with RF1 and a sixth batch in injected in the center using RF2

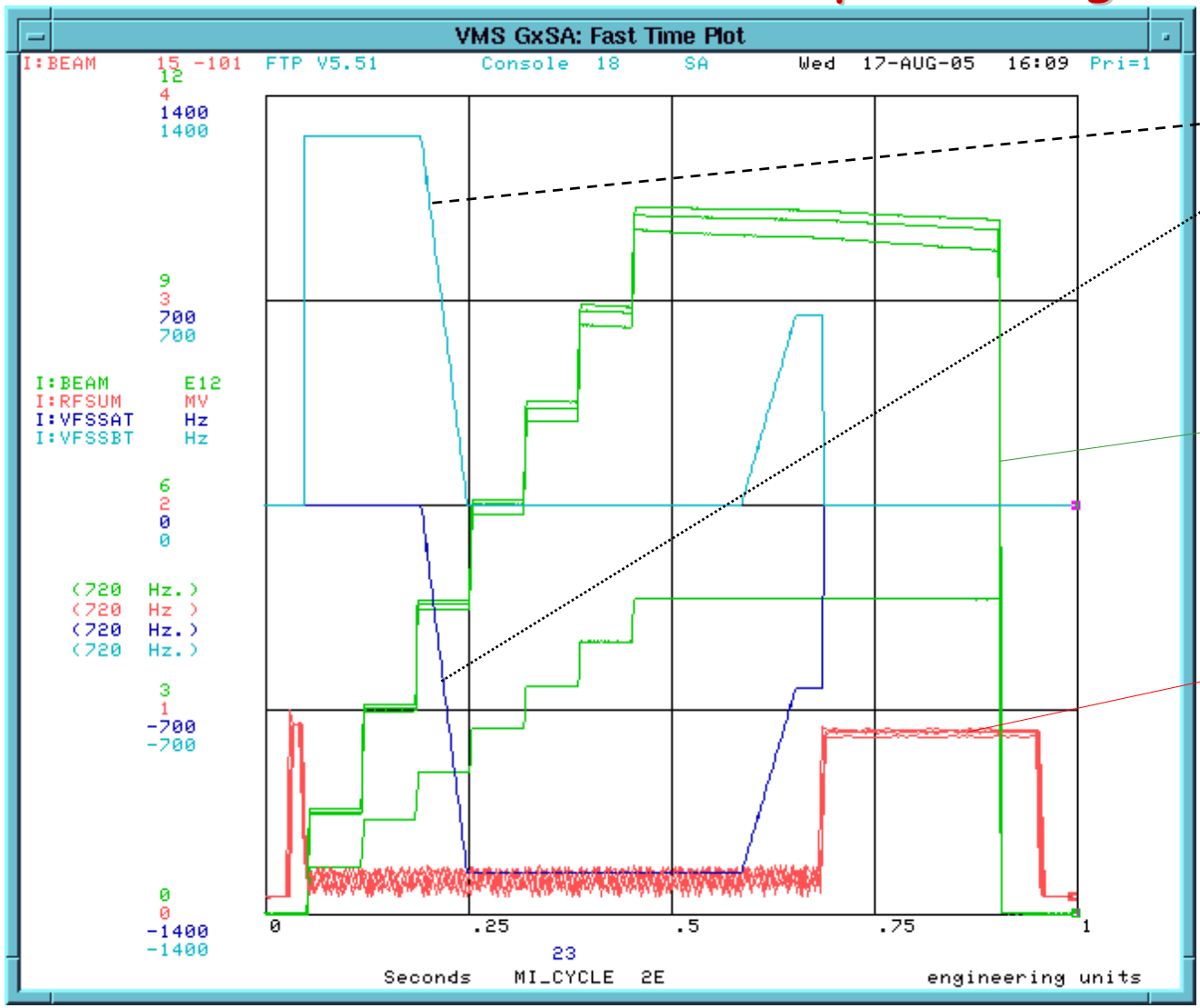
Five more batches are injected using RF2 while the two groups are slipping against each other.

Both groups are accelerated by 650Hz and recaptured

Mountain Range Simulation of multi batch slip stacking (K. Seiya)



Frequency Curves and Intensity for Multi-batch Slip Stacking Experiment

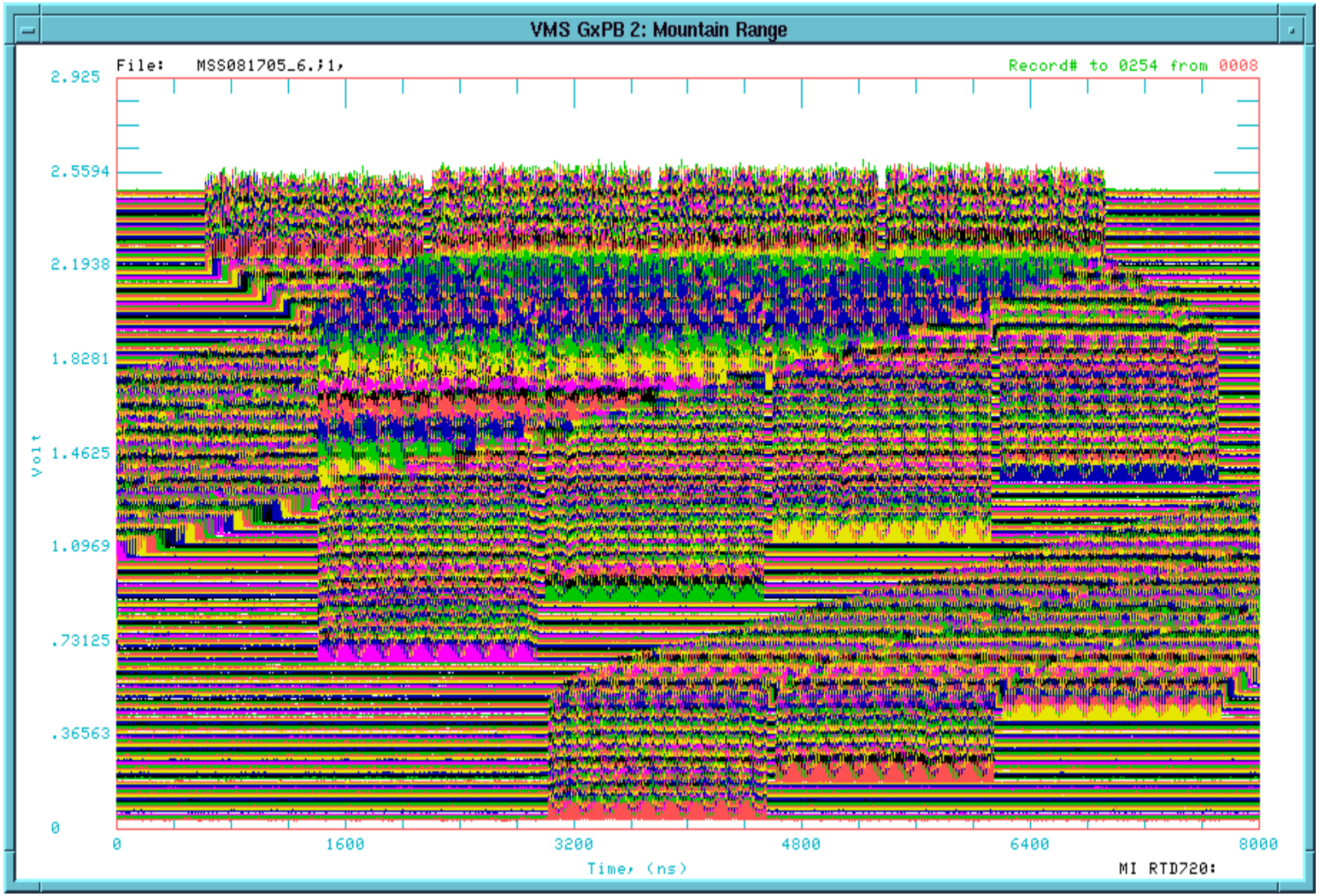


Frequency Curves

Beam Intensity

RF Voltage

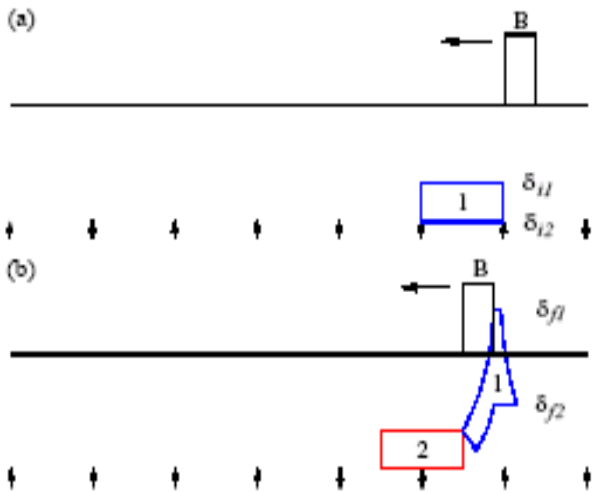
Mountain Range of Multi Batch Slip Stacking



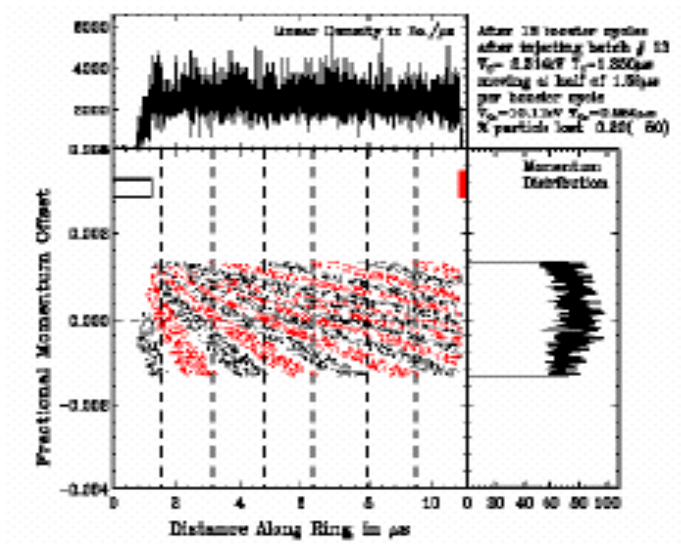
Barrier Bucket Stacking

- In parallel with slip-stacking we plan to study fast momentum stacking using barrier buckets.
- The scheme first proposed by Griffin uses a system of two RF barriers (one stationary one moving) and continuous Booster Injections with negative momentum offset.
- The barrier systems are using Finemet cavities and a pair of bipolar high voltage fast switches.
- One barrier RF system has been installed and we plan to install the second one during the next shutdown.

Fast Barrier Bucket Illustrations (B. Ng)



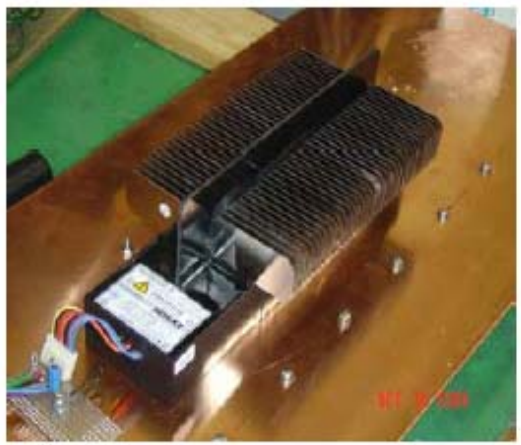
Principle of the method



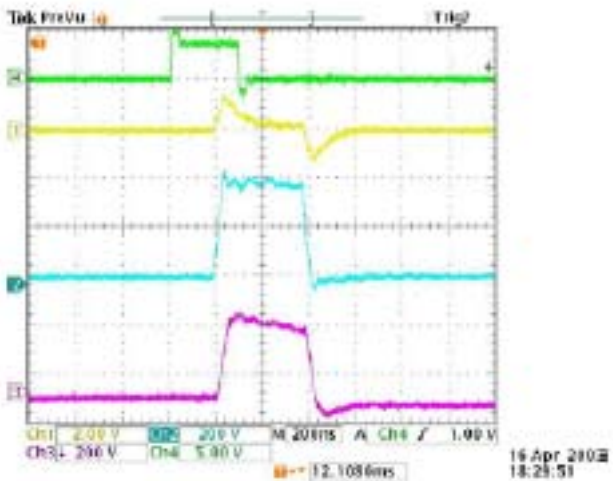
Simulation picture after 12 Booster Injections

Barrier RF System

Barrier RF Cavity in MI



High voltage SS fast switch made by Behlke

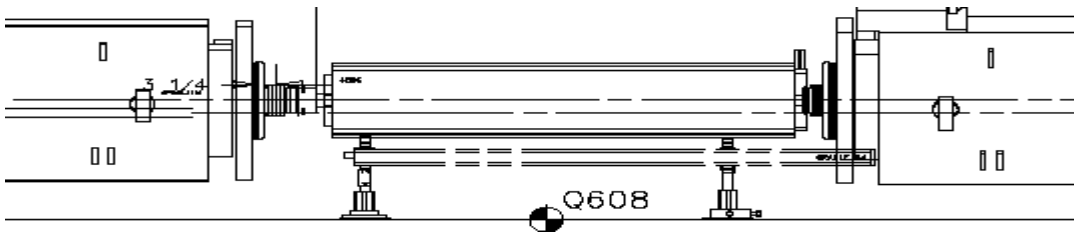


Primary (light blue) and secondary voltages (purple)

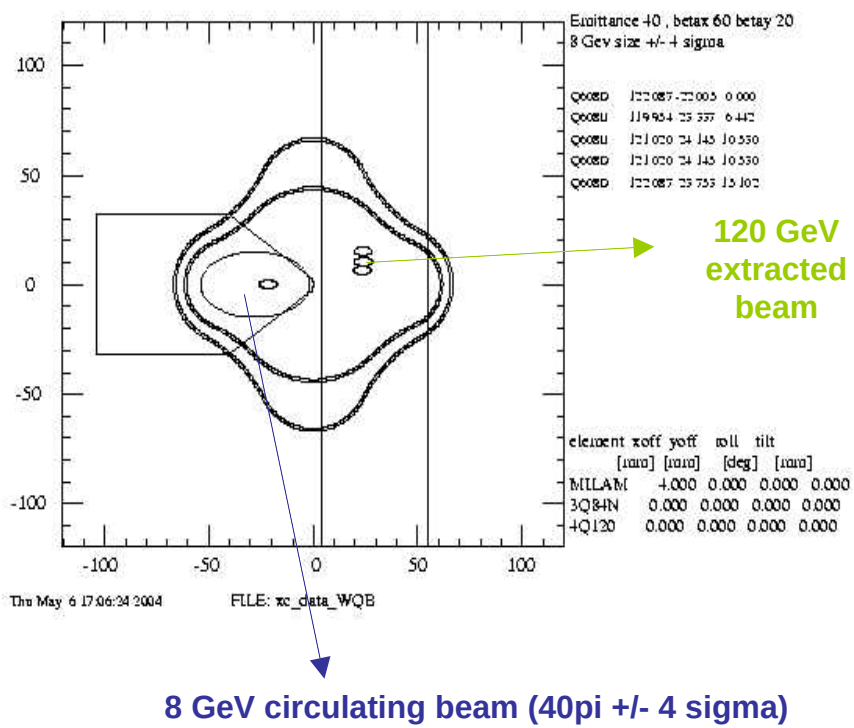
Large Aperture Quads (WQB)

- In all of the MI Extraction/Injection areas the quadrupole magnets in front of the Septa magnets are limiting the physical aperture leading to beam loss.
- We plan to replace all seven such quadrupoles with new magnets with larger aperture (4.4in instead of 3.3in).
  - The new magnets will be connected to the main Quad Buses.
  - Same length and integrated gradient as the old magnets.
  - Trim coils available for ±2% difference in saturation.
- Two of the new magnets are complete and in the process of being measured. A third magnet has been assembled and welded. All seven magnets are expected to be ready by 11/01/05.

Large Aperture Quads (cont.)



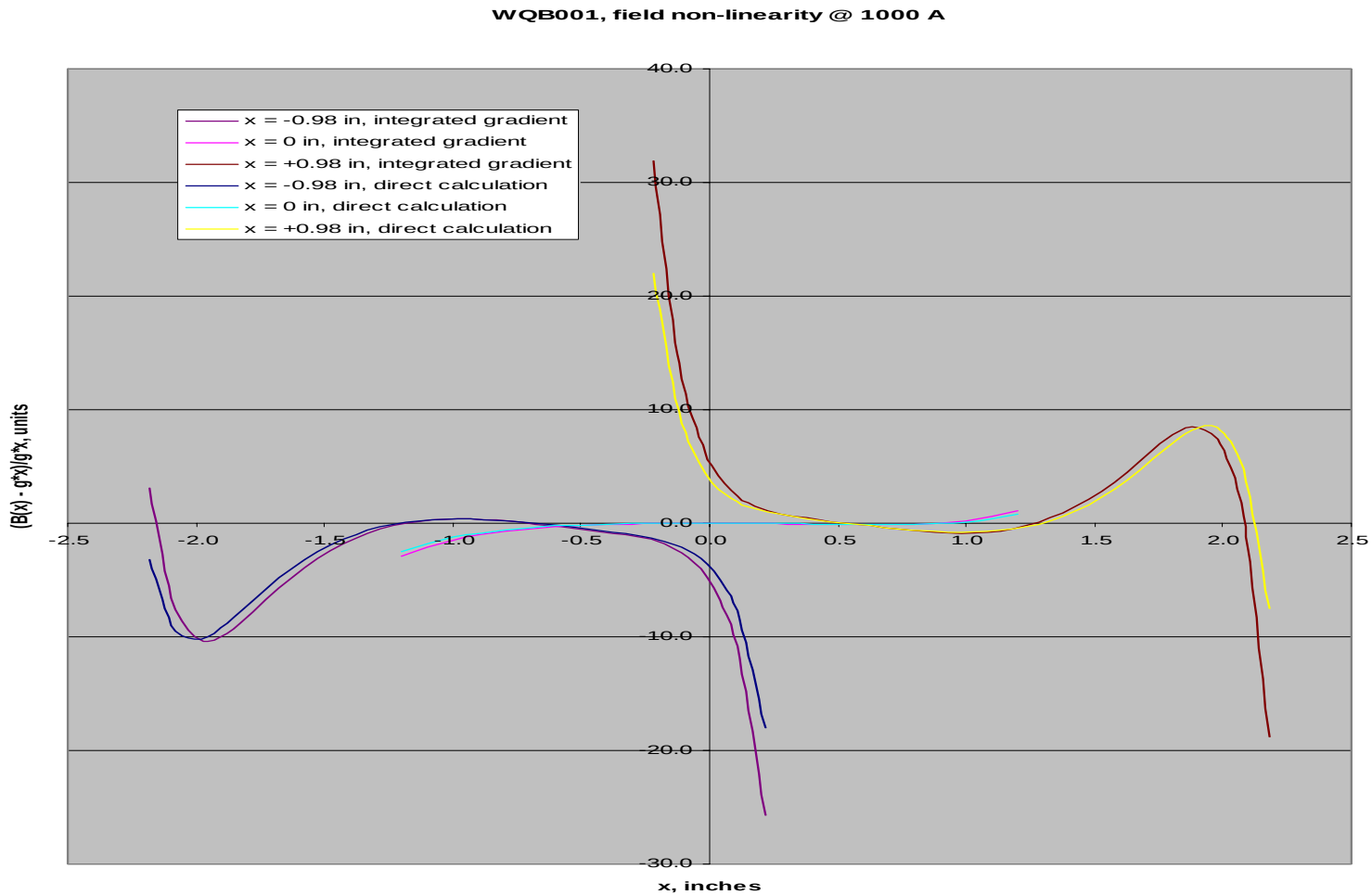
Typical MI extraction Area



Quad apertures and beam profiles at MI extraction area.

Pictures of the first two WQB Quads

Field non-linearity measurements (WQB001)

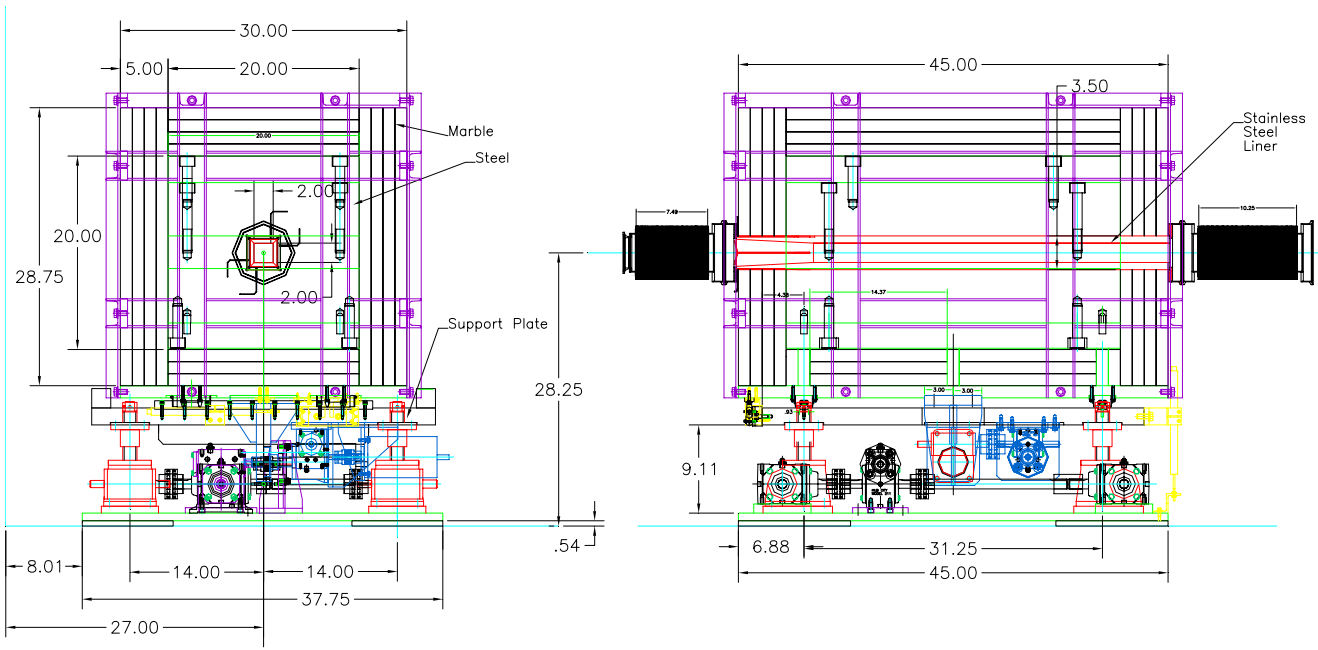


X, Inches

MI-8 collimation

- Plan to install a collimation system in the MI-8 injection line in order to get rid of Booster beam tails generated by the injection Septum.
- A total of four collimators will be build (two horizontal, two vertical) each designed of up to 1% of Booster beam lost without excessive residual radiation.
- Residual dose calculations and collimator design are complete.

MI-8 collimators



MI Collimation System

- We need to consider loss control collimation option for the MI
- Currently in MI he have no straight sections that are not used and they all have zero dispersion.
  - The last unused section (MI30) is now used for RR electron cooling.
- In collaboration with Nikolai Mokhov and his group we plan to carry out a study of aperture and loss mechanisms(mainly during slip stacking) with a goal of prescribing a set of collimators.
- We are also investigating ways to change the dispersion in an MI straight section in order to collimate the un-captured beam.

Kicker Upgrades

- The MI Injection kicker from Booster (MI-10) does not have enough cooling to support multi-batch operation for NuMI (6Hz average rate).
  - Build new load resistors.
  - Install a forced flow cooling system.

- We also plan to modify the MI-52 pbar extraction kicker in order to diminish the after pulse and reduce the effect on the first NuMI batch.
  - Changing the image strip termination is expected to diminish the after pulse by 30%.

Cost Tables

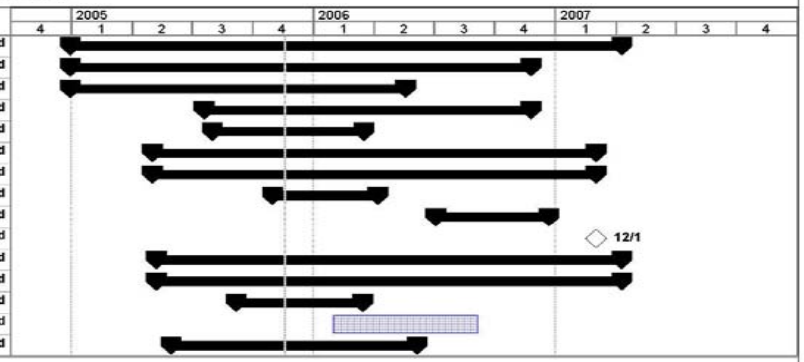
Uniq	WBS	Name	Esc SWF	Esc M&S	Cont %
4	**1.3**	**Main Injector Upgrades**	**$1,673,515**	**$1,295,240**	**53%**
19	**1.3.1**	**Large Aperture Quads - WQB**	**$1,086,224**	**$356,065**	**31%**
204	**1.3.1.1**	**WQB Fabrication**	**$932,752**	**$270,004**	**29%**
104	**1.3.1.2**	**WQB Install (AD)**	**$136,667**	**$64,463**	**40%**
206	**1.3.1.3**	**WQB Power Supplies**	**$16,806**	**$21,598**	**31%**
20	**1.3.2**	**Collimation Systems**	**$376,015**	**$634,695**	**86%**
218	**1.3.2.1**	**Collimation Systems Design**	**$149,997**	**$4,241**	**68%**
341	**1.3.2.2**	**MI-8 Collimation Syst Procure/Fab/Install**	**$29,800**	**$208,974**	**60%**
338	**1.3.2.3**	**MI Collimation Syst Procure/Fab/Install**	**$196,218**	**$421,480**	**100%**
126	1.3.2.4	Main Injector Loss Mitigation Complete	$0	$0	**0%**
21	**1.3.3**	**NuMI Multibatch Operation**	**$190,289**	**$302,481**	**50%**
219	**1.3.3.1**	**Multi-batch Studies**	**$85,857**	**$75,280**	**24%**
254	**1.3.3.2**	**Injection Kicker Modifications (Cooling System)**	**$82,963**	**$124,401**	**40%**
255	1.3.3.3	Extraction Kicker Modifications	$21,468	$102,800	**100%**
22	**1.3.4**	**Main Injector RF Upgrade**	**$20,988**	**$2,000**	**31%**

Schedule Tables

8/18/05

Proton Plan
Main Injector Upgrades
Schedule Information

Uniq	WBS	Name	St	Fin	%	Float
4	1.3	Main Injector Upgrades	9/30/04	1/9/07	43%	78 d
19	1.3.1	Large Aperture Quads - WQB	9/30/04	8/25/06	61%	25 d
204	1.3.1.1	WQB Fabrication	9/30/04	2/17/06	73%	72 d
104	1.3.1.2	WQB Install (AD)	4/20/05	8/25/06	5%	25 d
206	1.3.1.3	WQB Power Supplies	5/2/05	12/16/05	62%	14 d
20	1.3.2	Collimation Systems	2/1/05	12/1/06	35%	80 d
218	1.3.2.1	Collimation Systems Design	2/1/05	12/1/06	46%	80 d
341	1.3.2.2	MI-8 Collimation Syst Procure/Fab/Install	8/1/05	1/6/06	0%	3 d
338	1.3.2.3	MI Collimation Syst Procure/Fab/Install	4/4/06	9/21/06	0%	7 d
126	1.3.2.4	Main Injector Loss Mitigation Complete	12/1/06	12/1/06	0%	80 d
21	1.3.3	NuMI Multibatch Operation	2/7/05	1/9/07	21%	78 d
219	1.3.3.1	Multi-batch Studies	2/7/05	1/9/07	36%	78 d
254	1.3.3.2	Injection Kicker Modifications (Cooling System)	6/7/05	12/14/05	5%	16 d
255	1.3.3.3	Extraction Kicker Modifications	11/1/05	6/6/06	0%	82 d
22	1.3.4	Main Injector RF Upgrade	3/1/05	3/6/06	53%	61 d



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