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Project X Project Collaboration Meeting
11/21/08

REVIEW OF MI ISSUES FOR PROJECT X

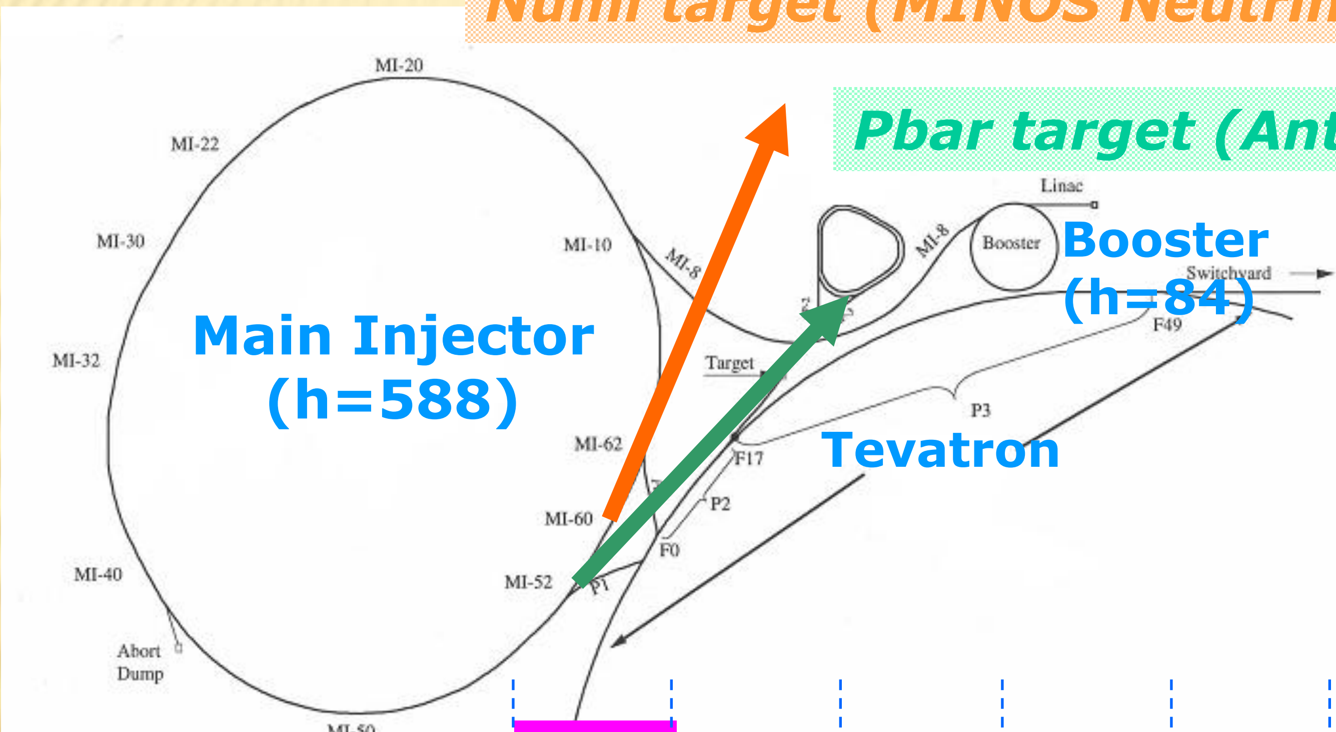
OUTLINE

- Present MI 120 GeV operations
- Evolution of MI beam power through NOvA
- Current MI performance
- MI requirements for Project X
- Major Issues
  - RF Systems
  - Transition crossing
  - E-cloud
  - Loss control and machine protection

CURRENT MI MIXED MODE OPERATIONS

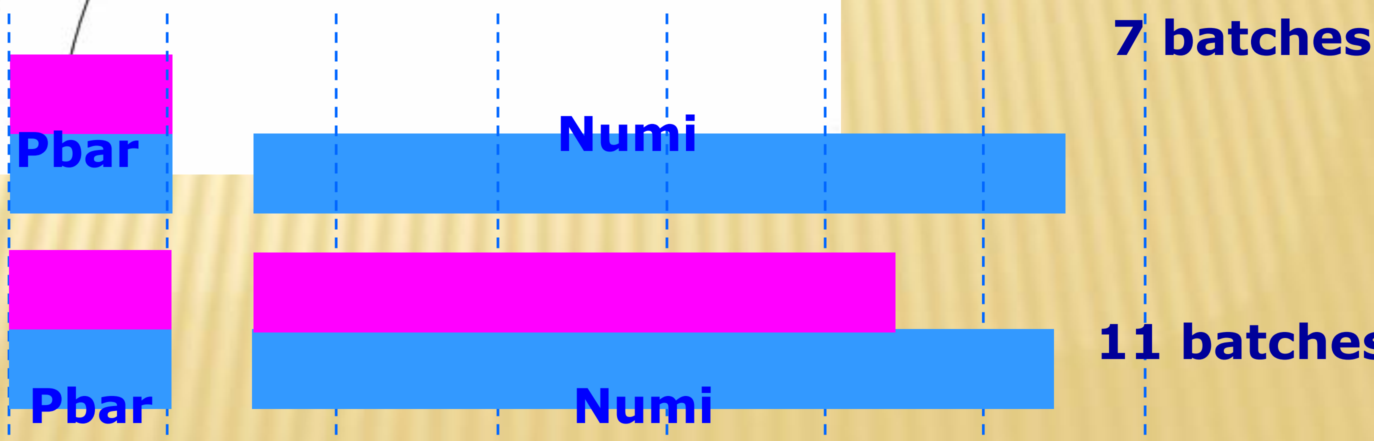
Numi target (MINOS Neutrino experiment)

Pbar target (Anti proton production



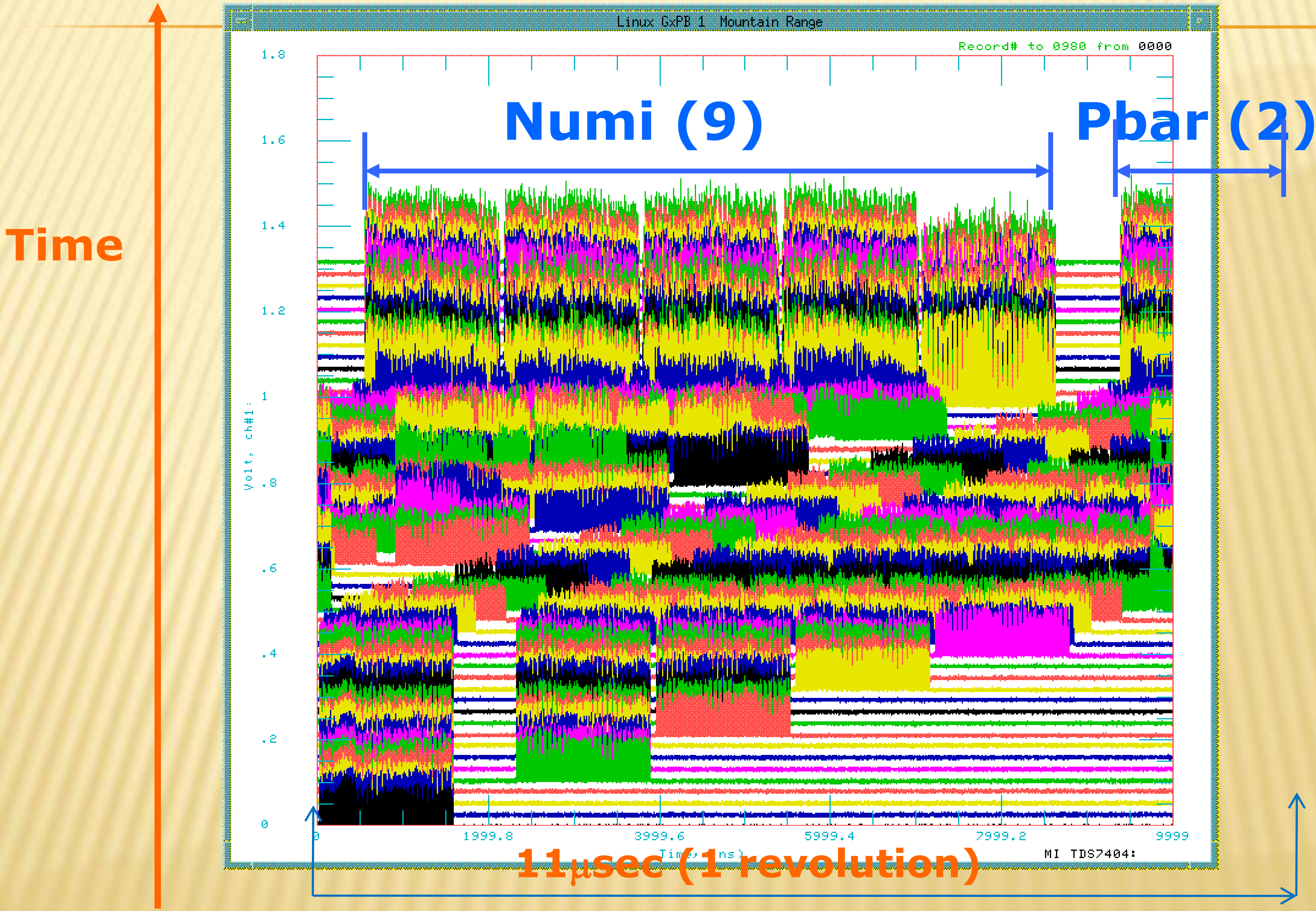
2 + 5 operation

2 + 9 operation



Bucket # 0 588

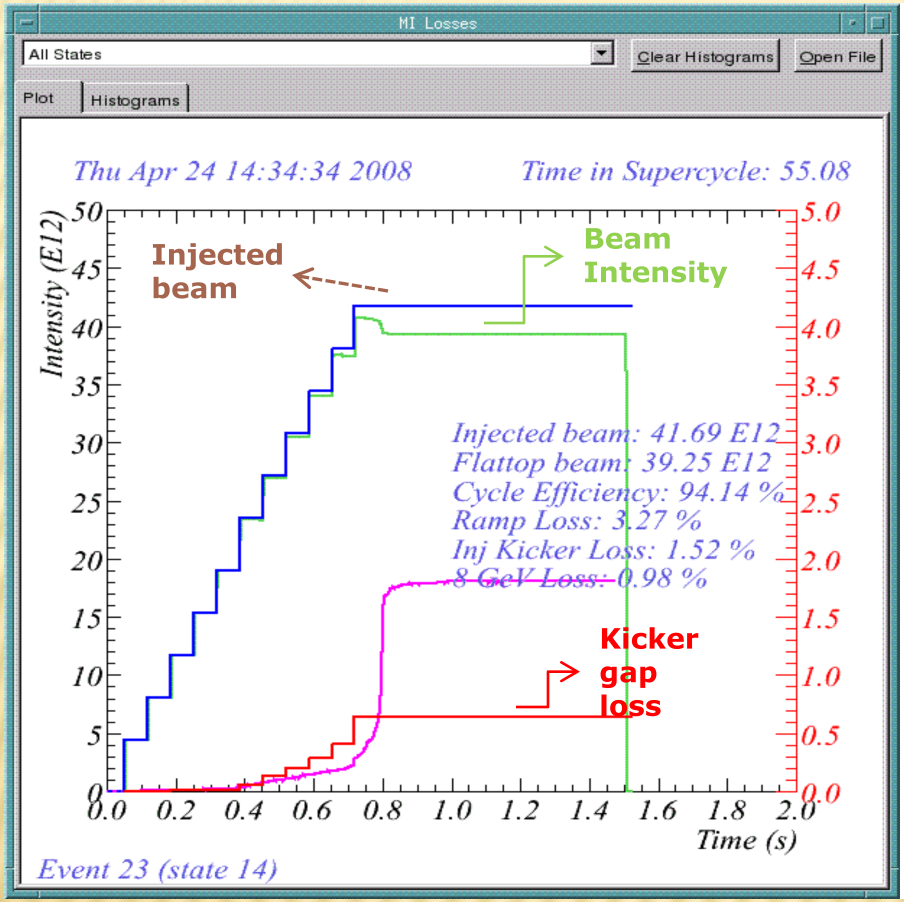
Mountain Range Picture of 11 Batch slip stacking

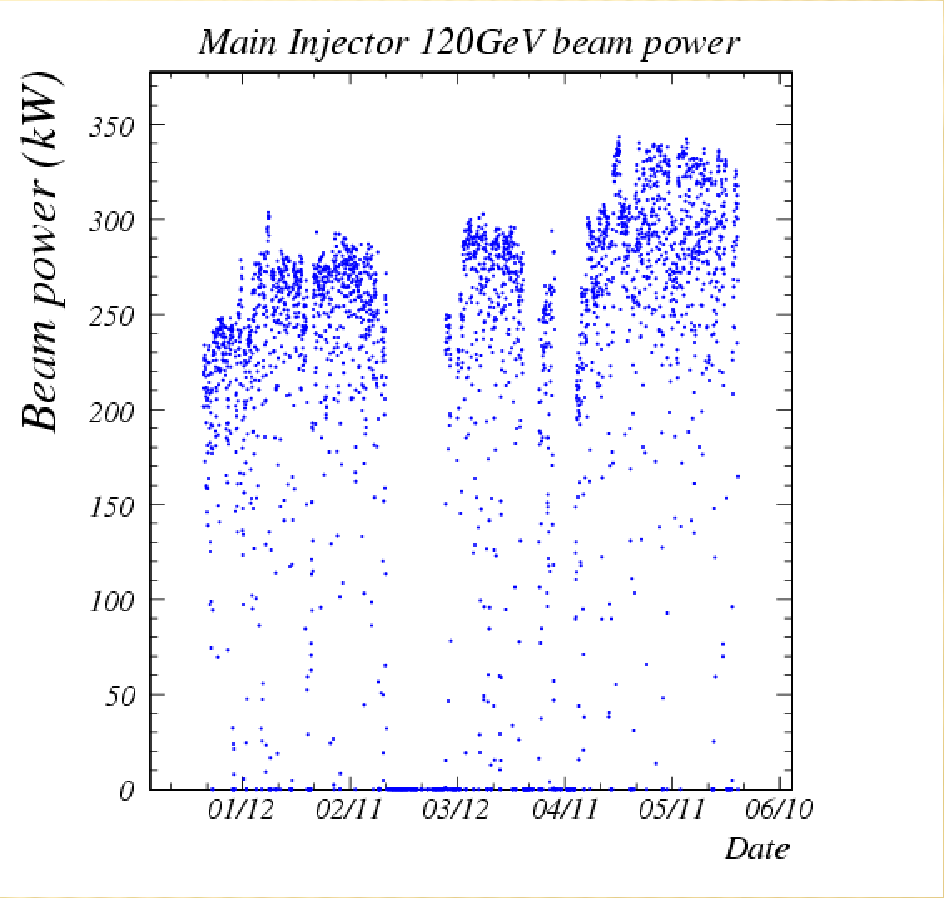


EVOLUTION OF MI BEAM POWER

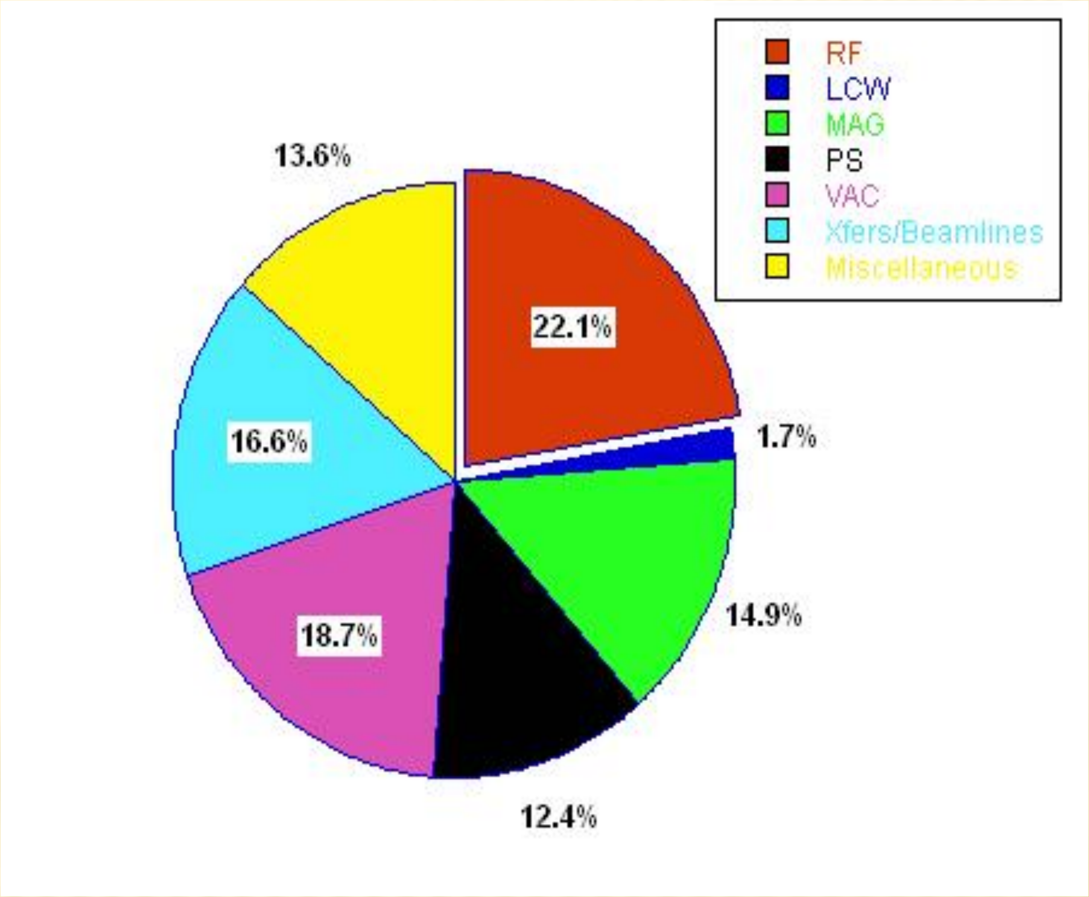
	Last Years' Conditions Two-batch slip-stacking in MI	**Proton Plan (Current conditions)** **Multi-batch slip-stacking in MI**	**NOνA** **Multi-batch slip-stacking in Recycler**
Booster intensity (protons/batch)	$4.3\text{-}4.5 \times 10^{12}$	4.3×10^{12}	4.3×10^{12}
No. Booster batches	7	11	12
MI cycle 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}

PRESENT MI BEAM INTENSITY AND POWER



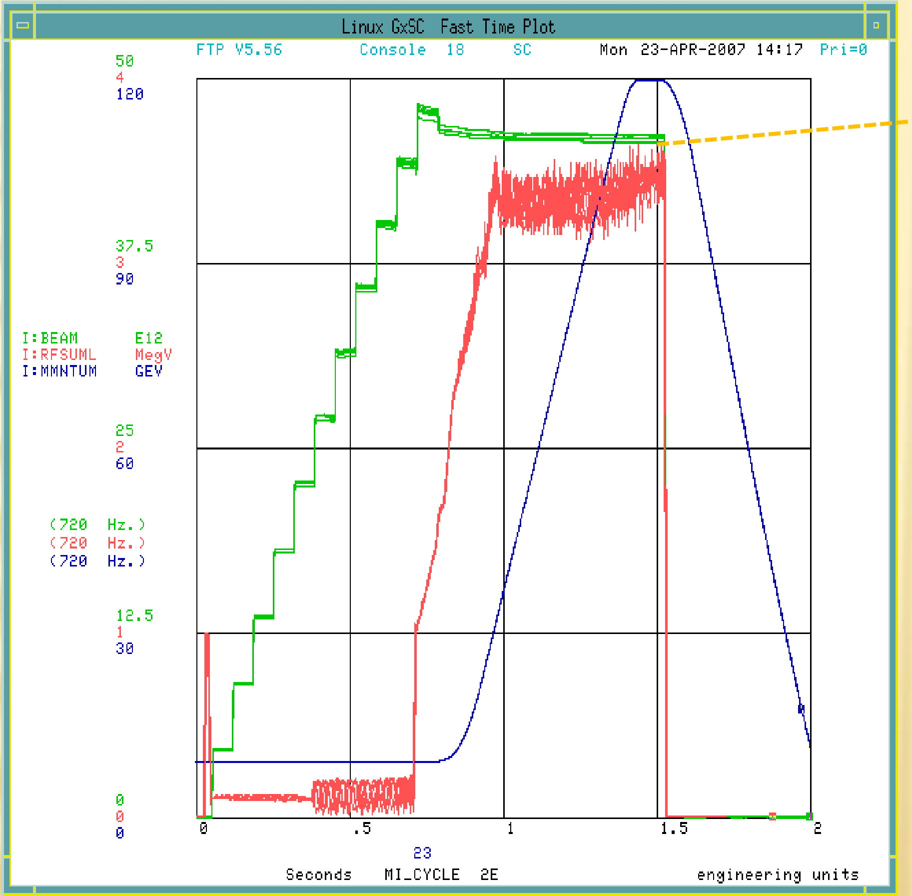


- From January1, 2008 to June 2, 2008 the total MI downtime was 143.6 Hrs, i.e 3.8% of the total time.
- The biggest source for downtime was the MI RF.
- The rf requirements are larger because of the amount of the beam-loading compensation required during slip stacking and the amount of beam that is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



MI DOWNTIME

MI RECORD INTENSITY

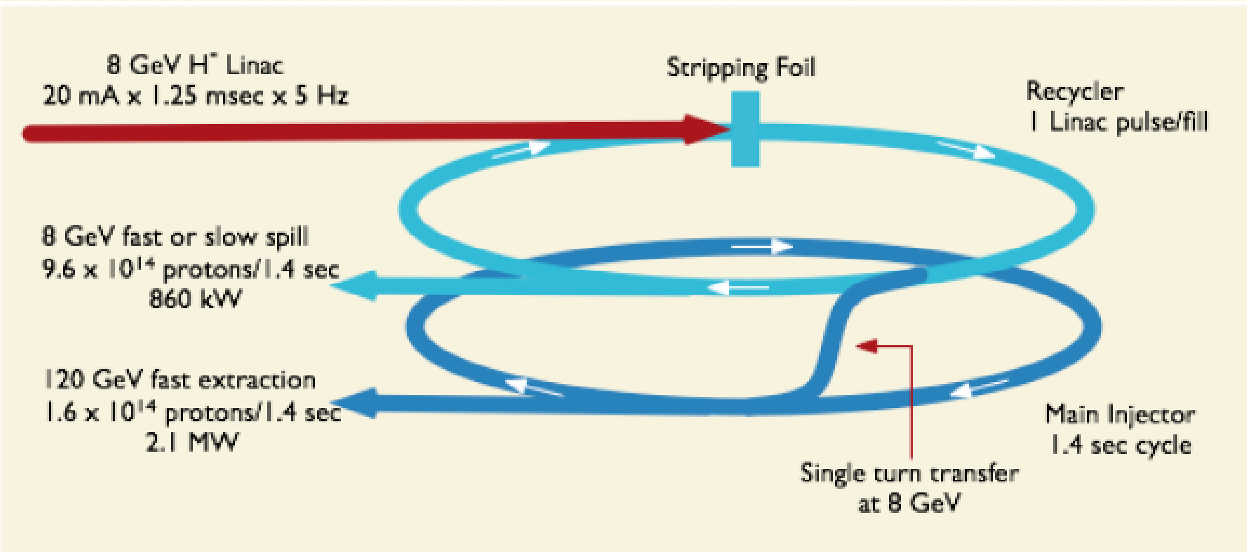


- 4.63E13 Protons to MI abort at 120 GeV.
- 92% Efficiency

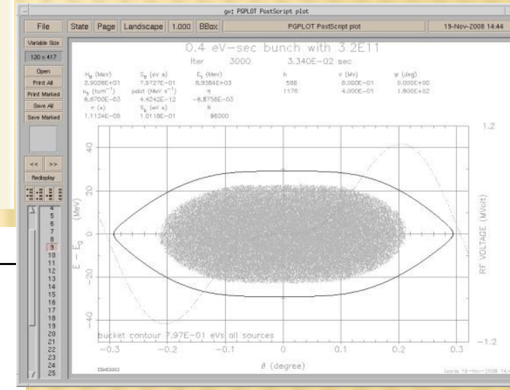
KEY ELEMENTS

- **Beam loading compensation**
- **Transverse and longitudinal bunch by bunch dampers**
- **Ring collimators**
- **Gap clearing kickers (under construction)**

MI IN PROJECT X



•One turn bucket to bucket transfer from RR



Req. No.	Description	Req.	Unit	Reference Requirements	
6.0	**Main Injector**				
6.1	120 GeV cycle Time	1.4	sec		
6.2	RF Frequency	53	MHz		
6.3	Abort Gap Length	700	nsec	1.2	
6.4	Acceleration Efficiency	99	%	1.6	
6.5	Main Injector Beam Current	2.356	A	2.3	
6.6	Final Energy	120	GeV	5.2	
6.7	120 GeV Beam Power	2.1	MW	5.6	
6.8	Availability	87	%	5.6	
6.9	Injection Energy	8	GeV	5.6	
6.10	Longitudinal emittance per Bunch	0.5	eV-Sec	5.6	5.12
6.11	Space Charge Tune Shift	0.05	0	6.1	
6.12	95% normalized transverse emittance	25	p-mm-mrad	6.2	
6.13	r.m.s. normalized transverse emittance	13	p-mm-mrad	6.3	
6.14	Bunching factor	2	0	6.5	

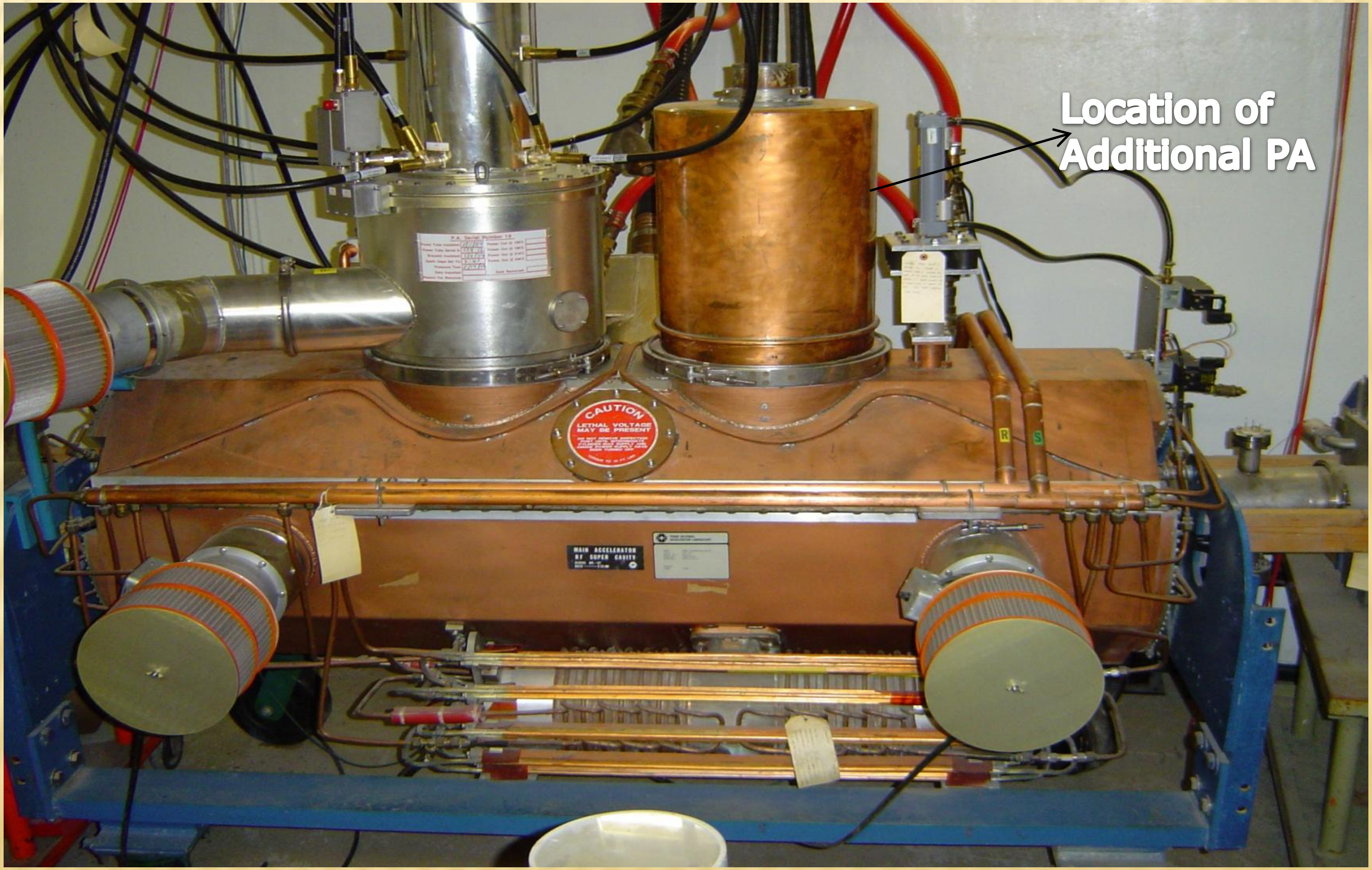
MI REQUIREMENTS FOR PROJECT X

- Accelerate 1.6E14 protons to 120 GeV every 1.4 sec with 99% acceleration efficiency for a total power of 2.1 MW.
  - 4.4 times the current intensity.
  - Three times the bunch intensity we can currently achieve.
  - 6 times the current 120 GeV beam power (x3 the NOvA power)
- The major upgrades that will be required in order MI to meet the above requirements include:
  - RF Systems
  - Improved transition crossing scheme
  - Mitigations for e-cloud instabilities

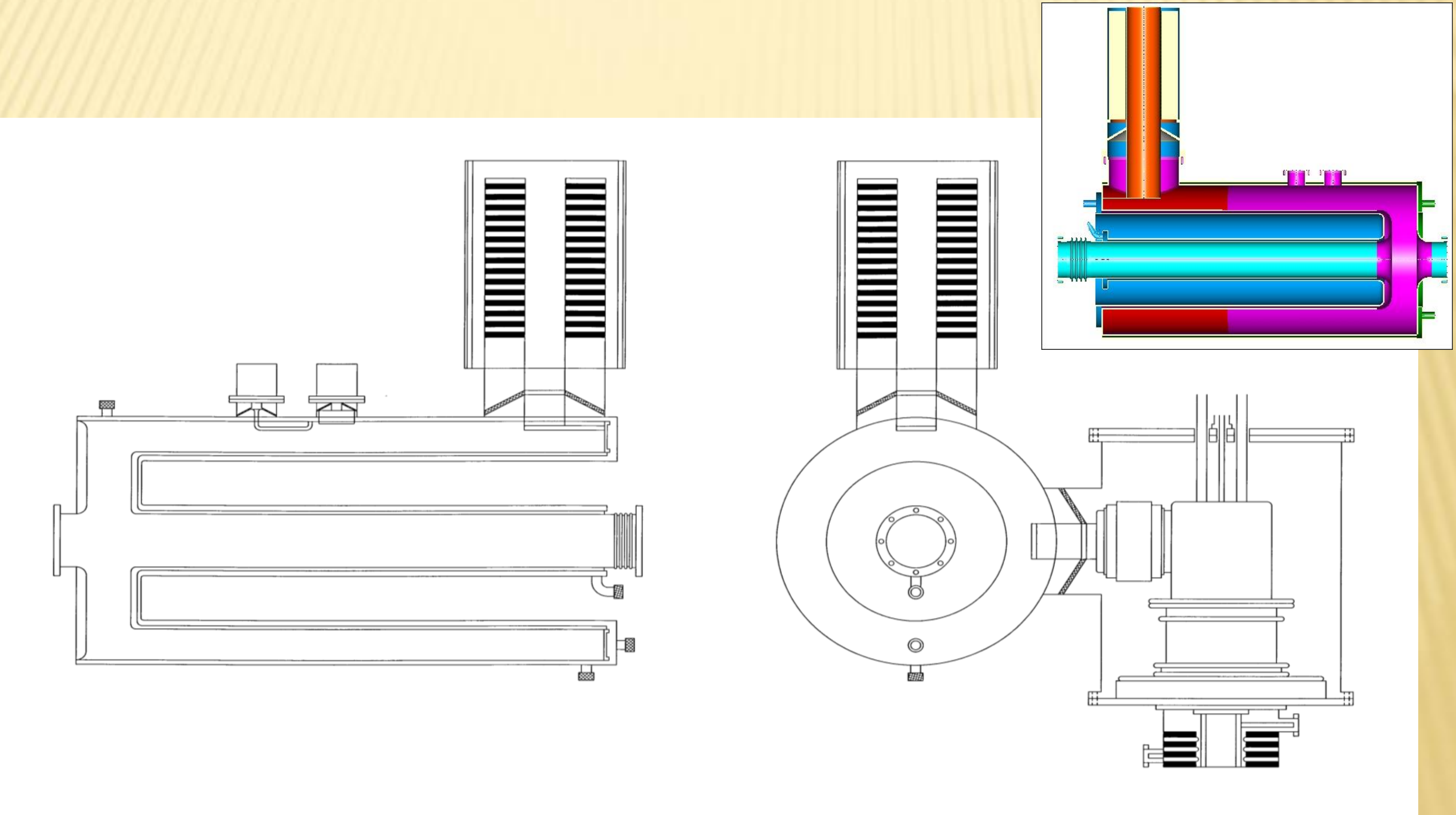
MI RF SYSTEM(S)

- Currently MI rf system uses the old Main Ring cavities (more than 30 years old). It does not have enough power to accelerate 1.6E14 protons at 240 GeV/sec.
  - At least 385KW per cavity are required (20 Cavities) while the power tube is rated at 175KW.
- There is a design for a new MI RF system that meets the power and voltage requirements.
  - Very conservative design uses a lot of power to guarantee stability. Is this design optimal?
- In order to achieve the large bunching factor required we need a second harmonic RF system.
  - No design exists.
- We have developed an R&D Plan for finalizing the design of both cavities and building prototypes.

MI CAVITY


Location of
Additional PA
CAUTION
LETHAL VOLTAGE
MAY BE PRESENT

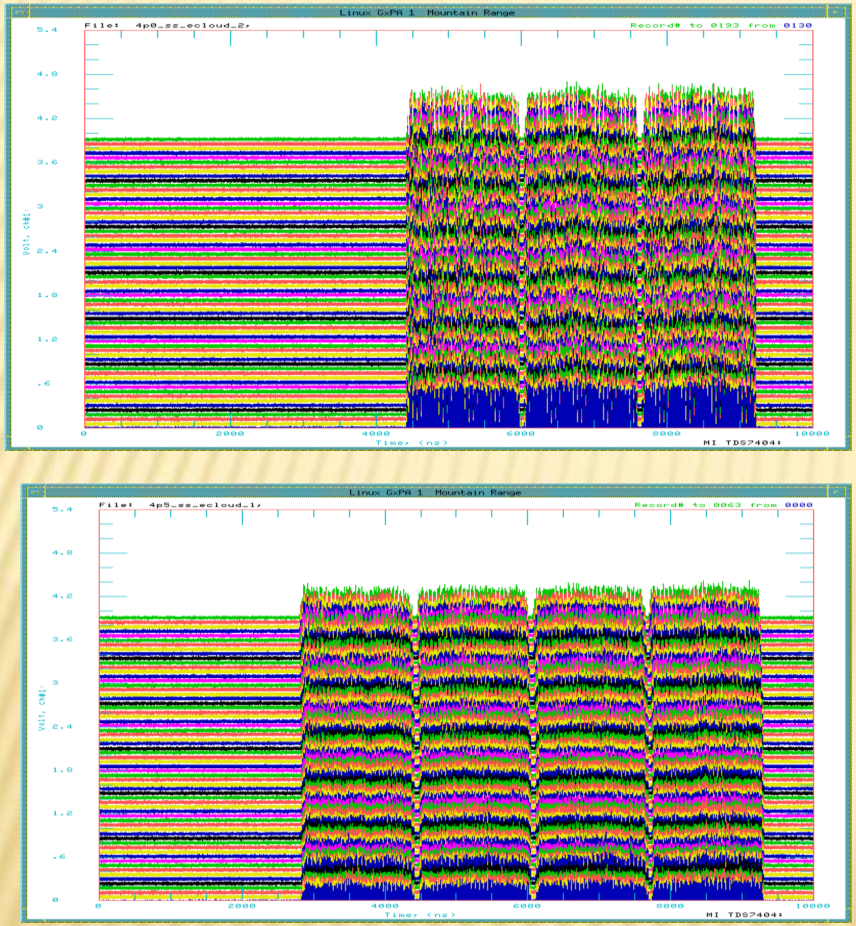
NEW CAVITY DESIGN SCHEMATIC (D. WILDMAN)



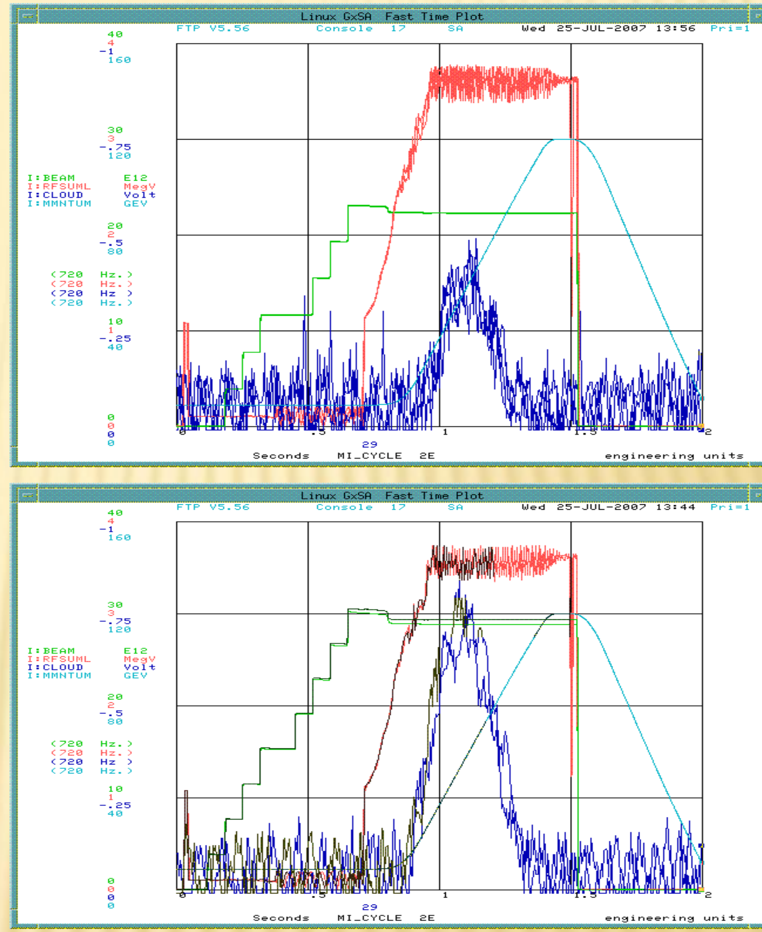
E-CLOUD INSTABILITIES

- The proposed increased in beam intensity would place MI in a parameter regime where other rings have seen a significant e-cloud effect.
- E-cloud signals have already been observed in MI. Measurements were done by using both an RFA detector and the microwave transmission method (in coll. with Berkeley)
  - No effects to the beam so far.
  - Strong dependence on beam conditioning.
- We have an ongoing program of e-cloud simulations.
- Medication schemes that we are considering include:
  - Higher RF frequency
  - Coating of the MI beam pipe

RFA E-CLOUD SIGNALS IN MI



Mountain range picture. Three/four slipped stacked batches with 9.1E10 p/bunch.



MI beam intensity, rf magnitude and e-cloud signal vs time.

E-CLOUD BUILD-UP SIMULATIONS

- There has been an extensive simulation effort since 2006 using the build-up code POSINST in order to understand the operational implications on the proposed MI intensity upgrades.
- Recently by combining the simulated results for the electron flux at the vacuum chamber with the corresponding RFA detector the peak secondary electron yield (SEY) of the MI pipe was predicted.
- Using the predicted value of SEY the simulation code was used to compared the EC build up with two different RF frequencies (53MHz,212 MHz).
- The results of POSINT need to be compared with at least another e-cloud build up code before doing beam dynamics simulations.

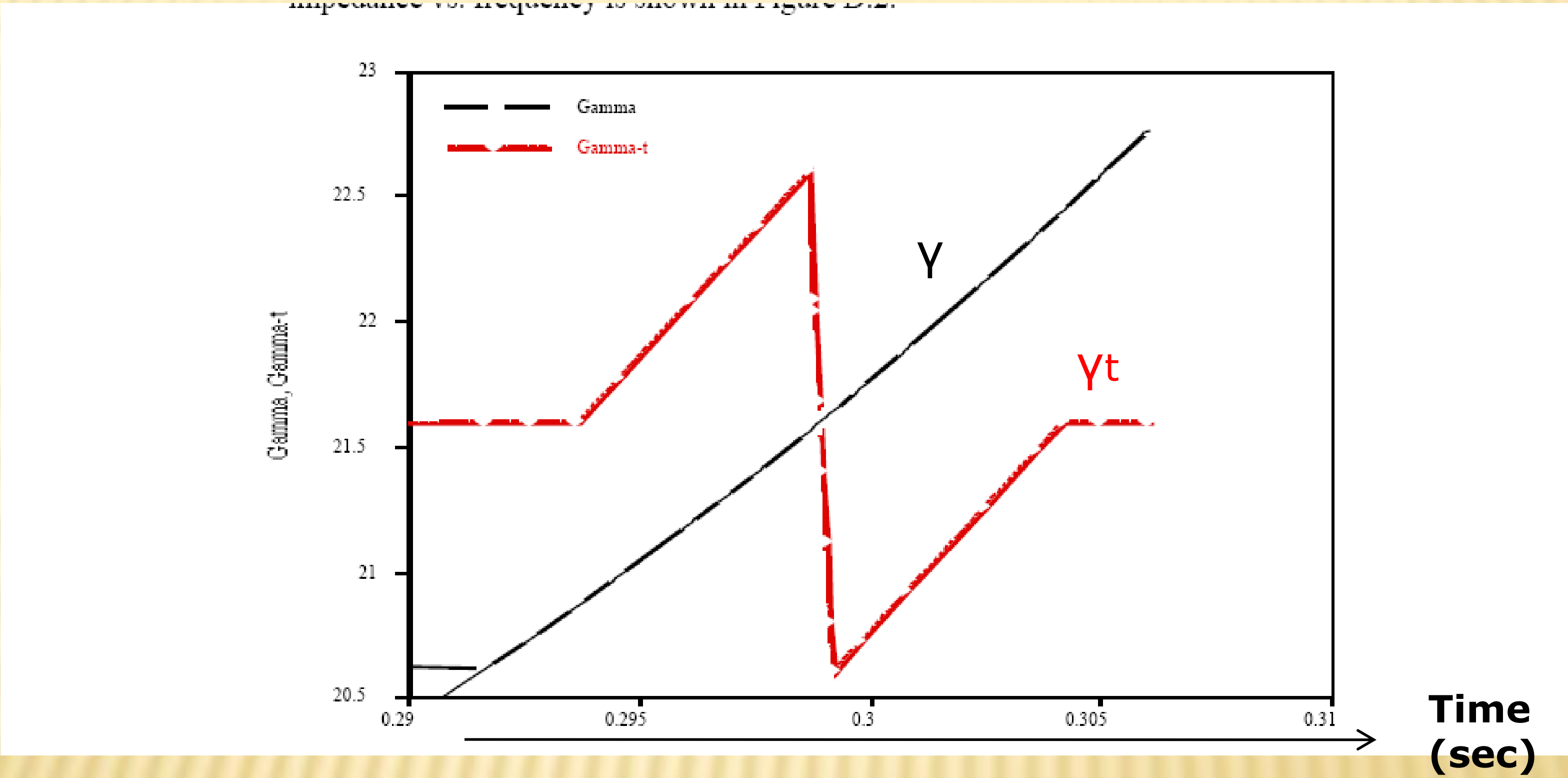
COATING OF THE MI BEAM PIPE

- Coating the MI beam pipe with TiN can reduce the SEY by about 40%.
- Since we cannot replace the MI beam pipe without cutting the magnets in half, the coating is only possible if can happen in situ.
- In order to evaluate the effectiveness of the TiN coating we plan to install a coated straight piece of pipe next to an un-coated piece and compare the RFA detector signals.
- We are developing an R&D plan to evaluate the possibility of coating the MI beam pipe in the tunnel.
  - We would like to utilize BNL and Argonne expertise

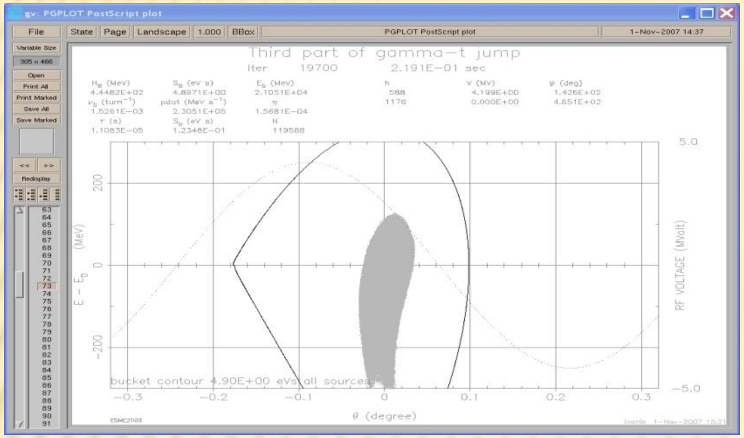
TRANSITION CROSSING

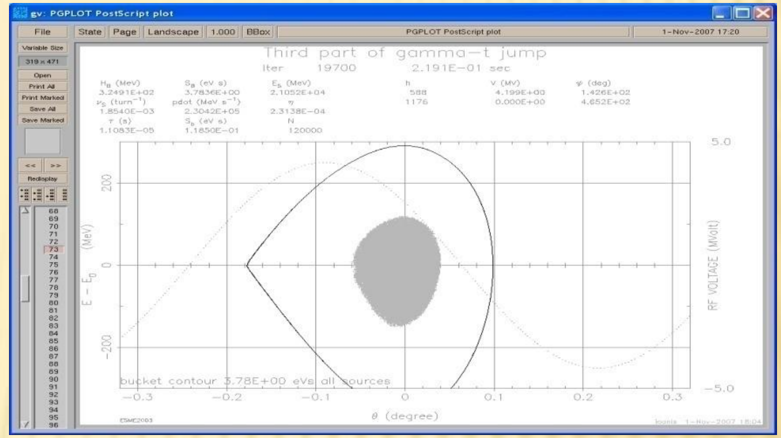
- For project X we will have to cross transition with bunch intensities 3 times larger than present. This can lead to beam loss and large longitudinal emittance blow-up.
- The most effective way to mediate the effects of crossing transition is a gamma-t jump.
  - Maintain a certain distance from gamma-t and crosses transition much faster than the ramp.
  - Can lead to large tune shifts, beta and dispersion waves.
- A design for a gamma-t jump in MI already exists (W. Chou et. al. PAC-1997).
  - First order matched transition jump.
  - Biggest issue is space in MI for quad placement.
  - Transverse instabilities during the jump?

MI GAMMA-T JUMP

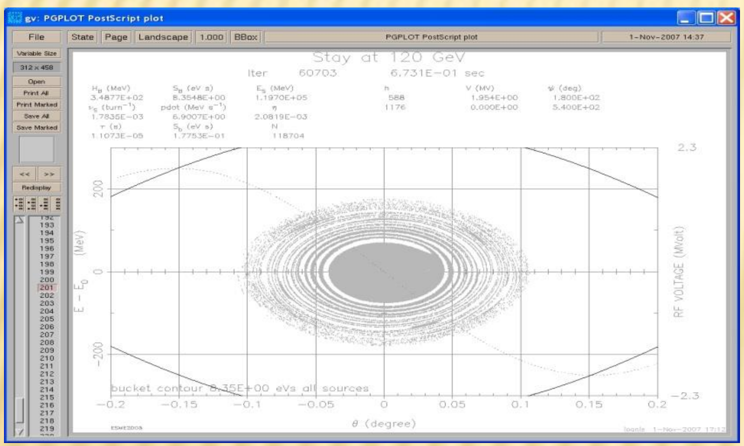


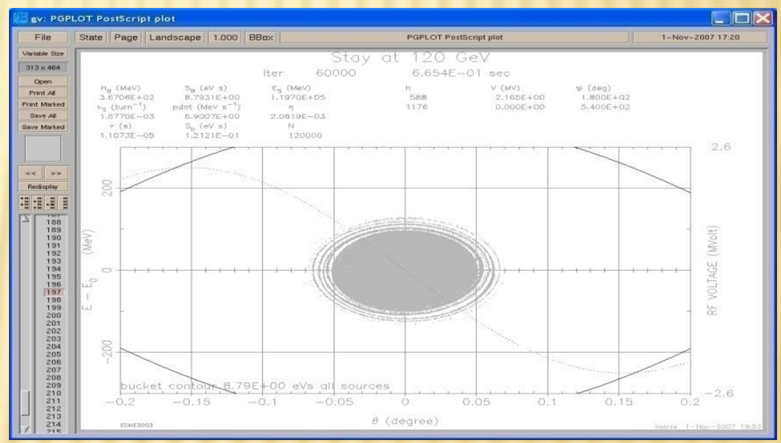
TRANSITION CROSSING SIMULATIONS





After Transition





At 120 GeV

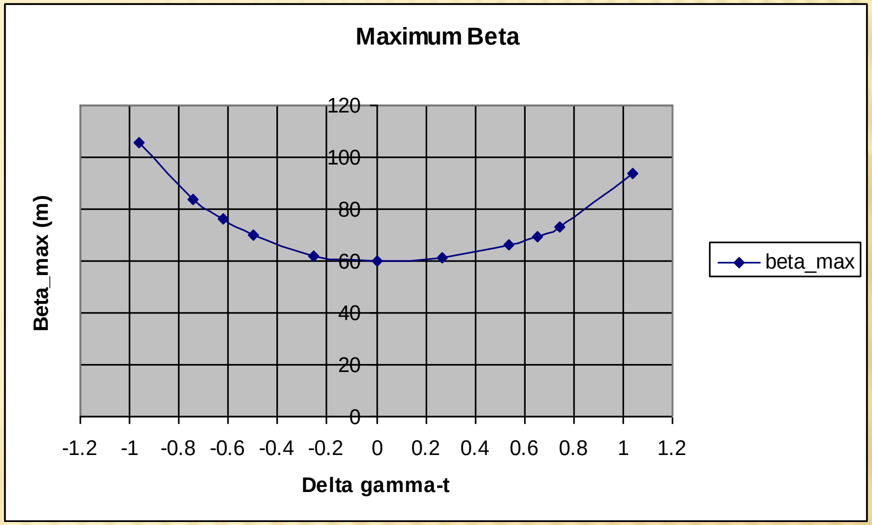
No gamma-t Jump

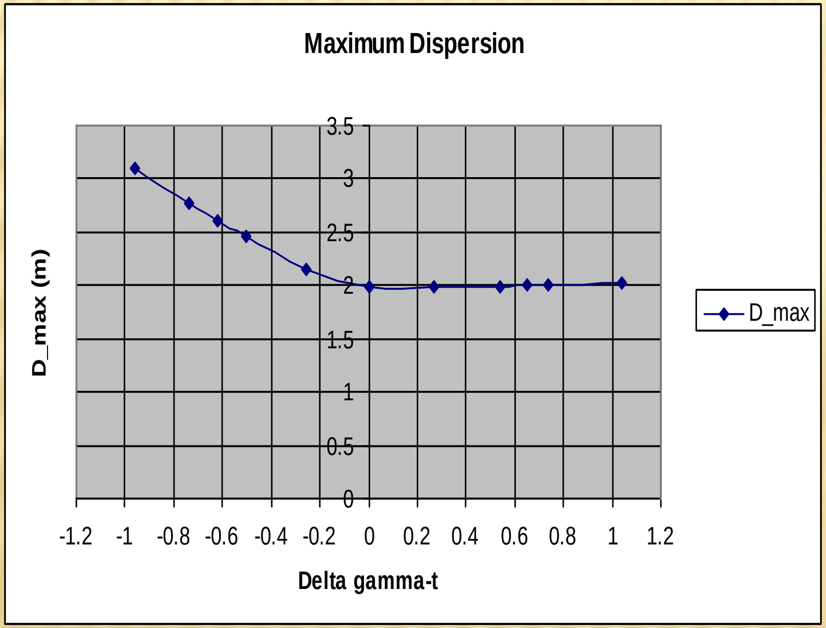
Gamma-t Jump

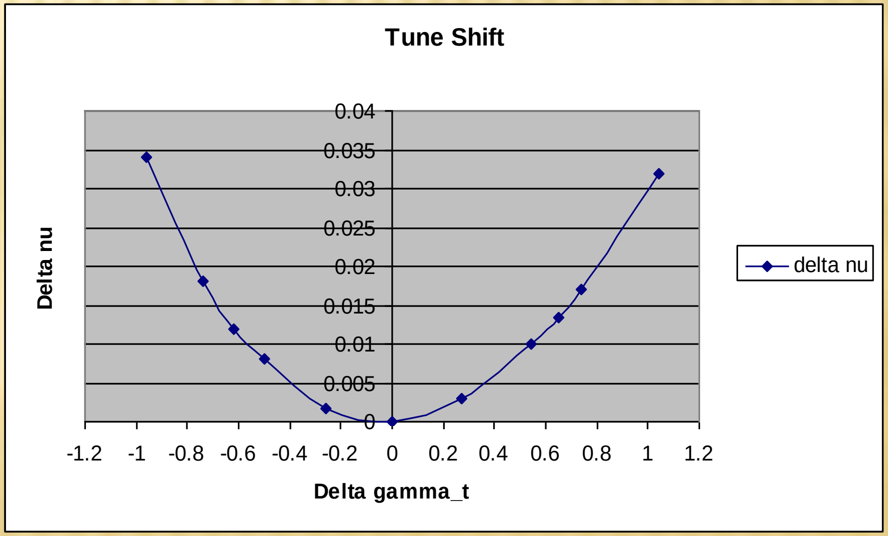
GAMMA-T JUMP SYSTEM FOR MI

- Pulsed quads:
  - 8 sets of quad triplets
  - Each triplet has two quads in the arc, one quad of twice strength in the straight section (where dispersion is zero)
  - Phase advance of π between each quad
  - Each triplet is optically independent from the others (i.e. the lattice perturbation is local)
  - Each triplet provides $\Delta\gamma_t$ = 0.25 (1/8 of the total jump)
  - Total amount of jump is adjustable, with maximum $\Delta\gamma_t$ = 2 (from +1 to -1)
- Pulsed power supplies:
  - 8 sets of power supplies
  - Using GTO as the switch
  - Resonant circuit with resonant frequency of 1 kHz
- Beam pipe:
  - Made of Inconel 718
  - Lower electrical conductivity and higher mechanical strength $\Rightarrow$ eddy current 4 times lower than stainless steel

LATTICE PERTURBATIONS DURING THE GAMMA-T JUMP





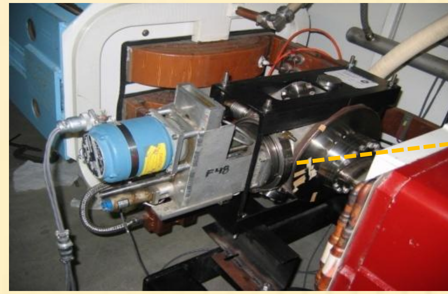


MI LOSS CONTROL

- We currently use a two stage collimation system in the horizontal plane to control the un-captured beam loss during slip stacking. This scheme should work for Project X.
  - Present secondary collimators can handle up to 1.5KW of power.
- The upgraded MI loss monitors are used for machine protection and to limit the tunnel activation.
- We are working on ways to understand the activation on machine components based on loss monitor readings and tunnel radiation measurements.

MI COLLIMATION

- 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

CONCLUSIONS

- There are a few major issues for MI in order to meet the Project X goals.
  - New rf system including a second harmonic
  - Understand and address the e-cloud problem
  - Gamma-t system for transition crossing
  - Loss control and activation

- Substantial R@D effort is required to resolve the issues and finalize the solutions.