MI/RR Upgrades: Overview and Plans

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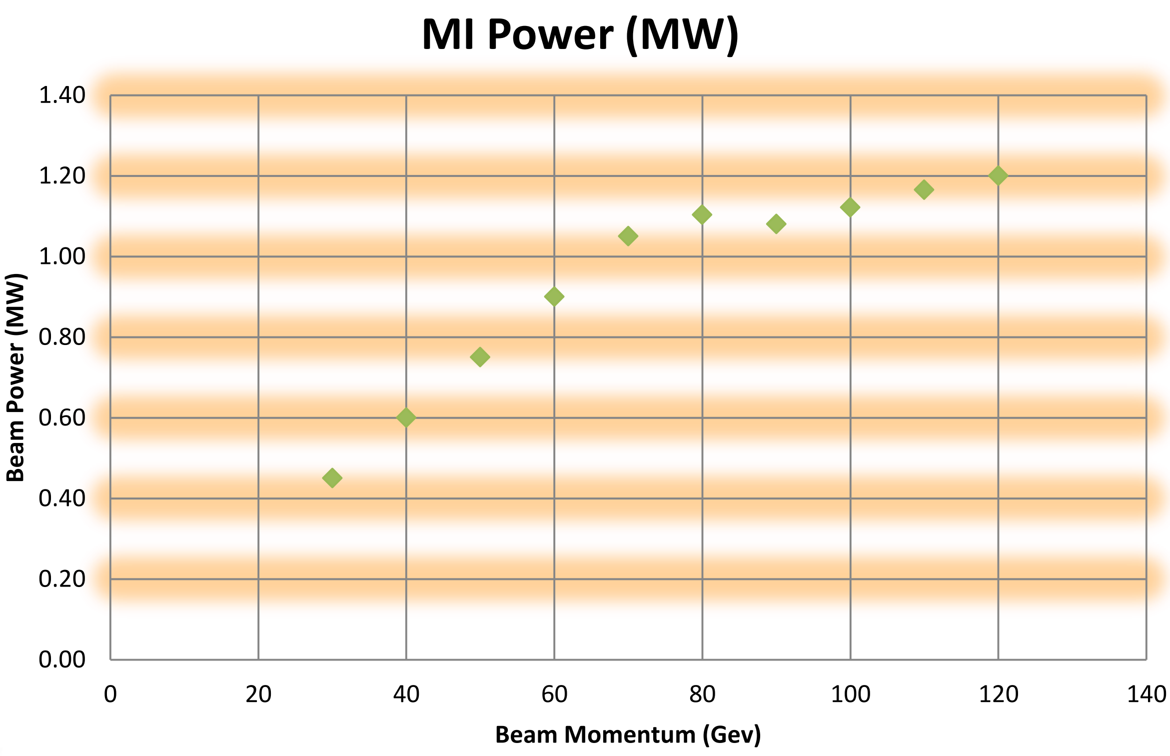
MI/RR Performance Requirements

Performance Parameter	Requirement	
Particle Species	Protons	
Injection Beam Energy (kinetic)	8.0	GeV
Extracted Beam Energy (kinetic)	60-120	GeV
Protons per Pulse (injected)	7.7×10^{13}	
Protons per Pulse (extracted)	7.5×10^{13}	
Slip-stacking Efficiency	97	%
Controlled 8 GeV losses to Abort	0.8	%
Controlled 8 GeV losses to Collimators	1.7	%
Uncontrolled 8 GeV losses	0.5	%
Transition Losses	0.2	%
Cycle Time	0.8-1.2	sec
Beam Power	0.9-1.2	MW
Beam Emittance (6σ, normalized)	20	π mm-mrad
Bunching Factor	0.5	
Laslett Tune Shift (Injection)	-0.06	

- **50% more beam intensity**
- **Operate at different energies**

MI Beam Power vs Momentum



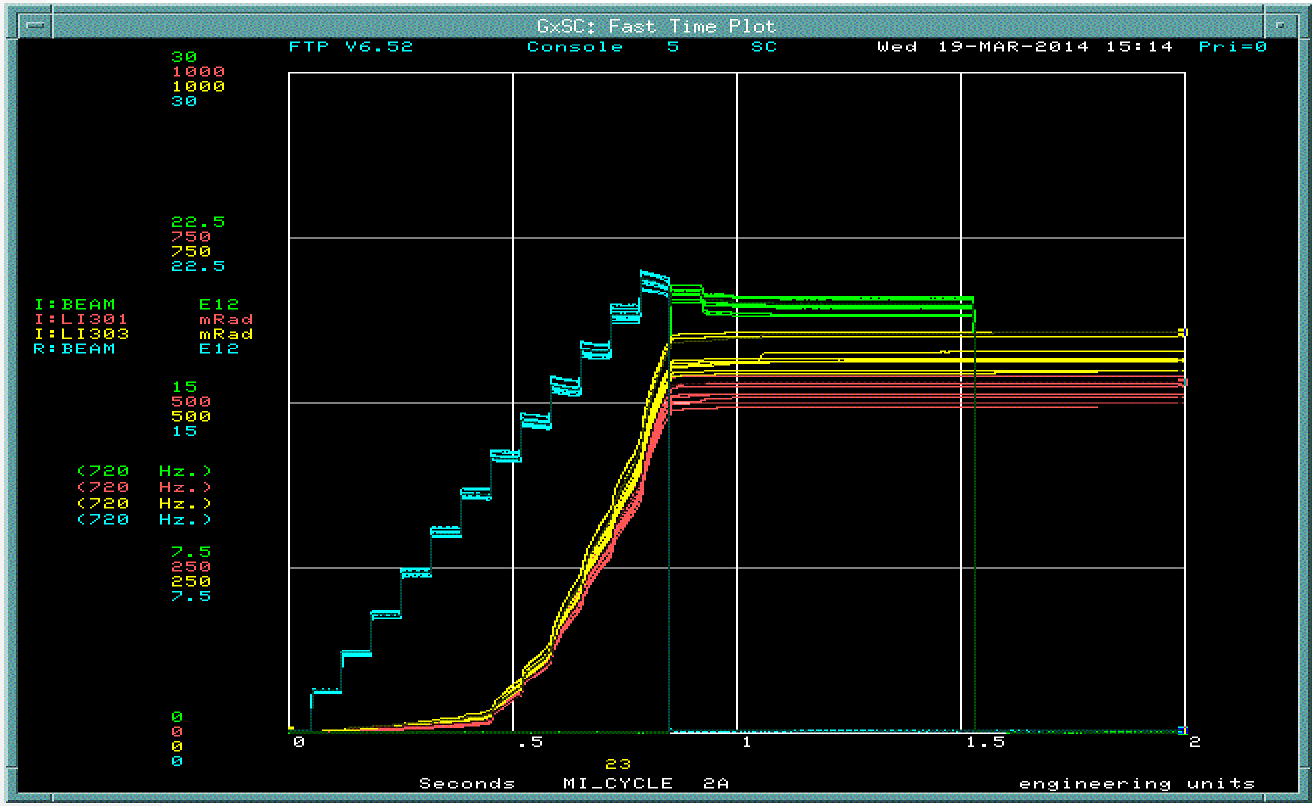
MI/RR Accelerator Issues

- Can we slip stack and accelerate 50% more intensity.
  - Power loss from slip stacking
  - RF Power
  - Transition crossing
- Electron cloud
- Beam loss control/mitigation
- Running Recycler 53 MHz Cavities CW

Slip Stacking in the Recycler

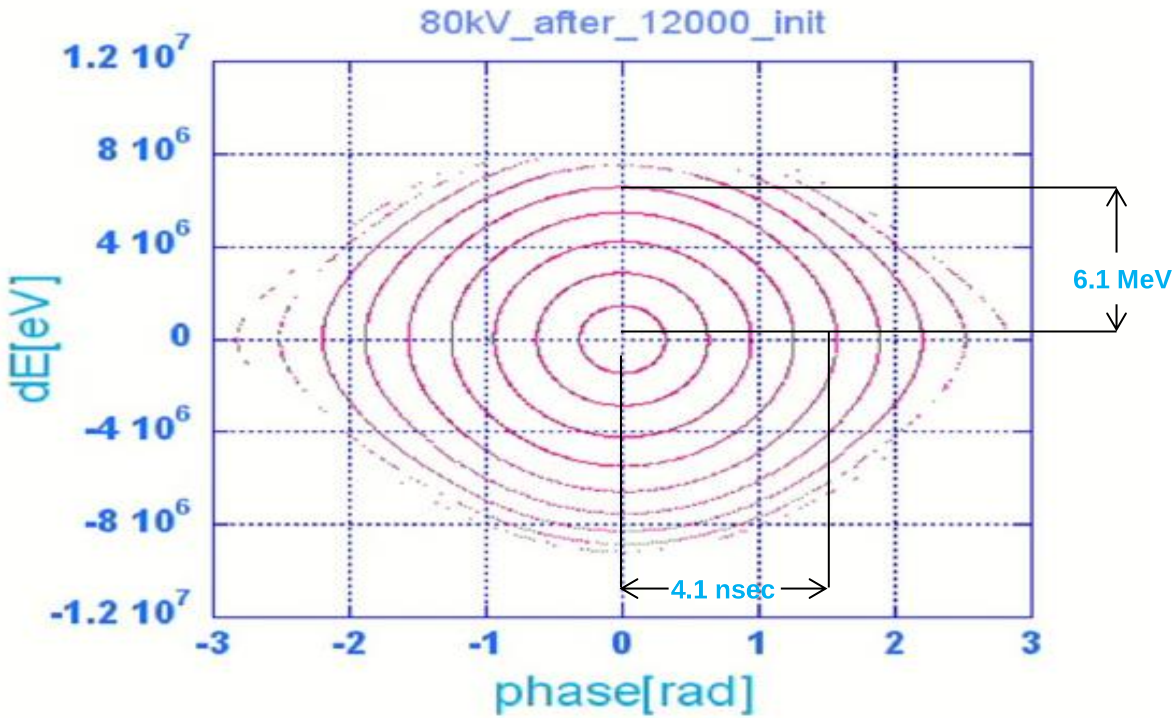
- We need to maintain the same power loss from slip stacking with 50% more intensity per bunch.
- Increase the slip stacking efficiency from 95% to 97%.
  - Tighter beam specifications out of Booster.
- Are there any longitudinal space charge issues in Recycler?
  - Demonstrate with realistic simulations that slip stacking in the Recycler works at the higher intensities.

Slip Stacking in the Recycler



Highest intensity achieved 23E12. Working on damper commissioning

Injected beam requirements for 97% efficiency.



97% emittance of 0.08 eV-sec matched to 80KV bucket in Recycler.

Particles on initial matching contours in an 80 KV bucket after 120 msec of slip stacking with 1,200 Hz separation.

Present and Required MI RF Capabilities

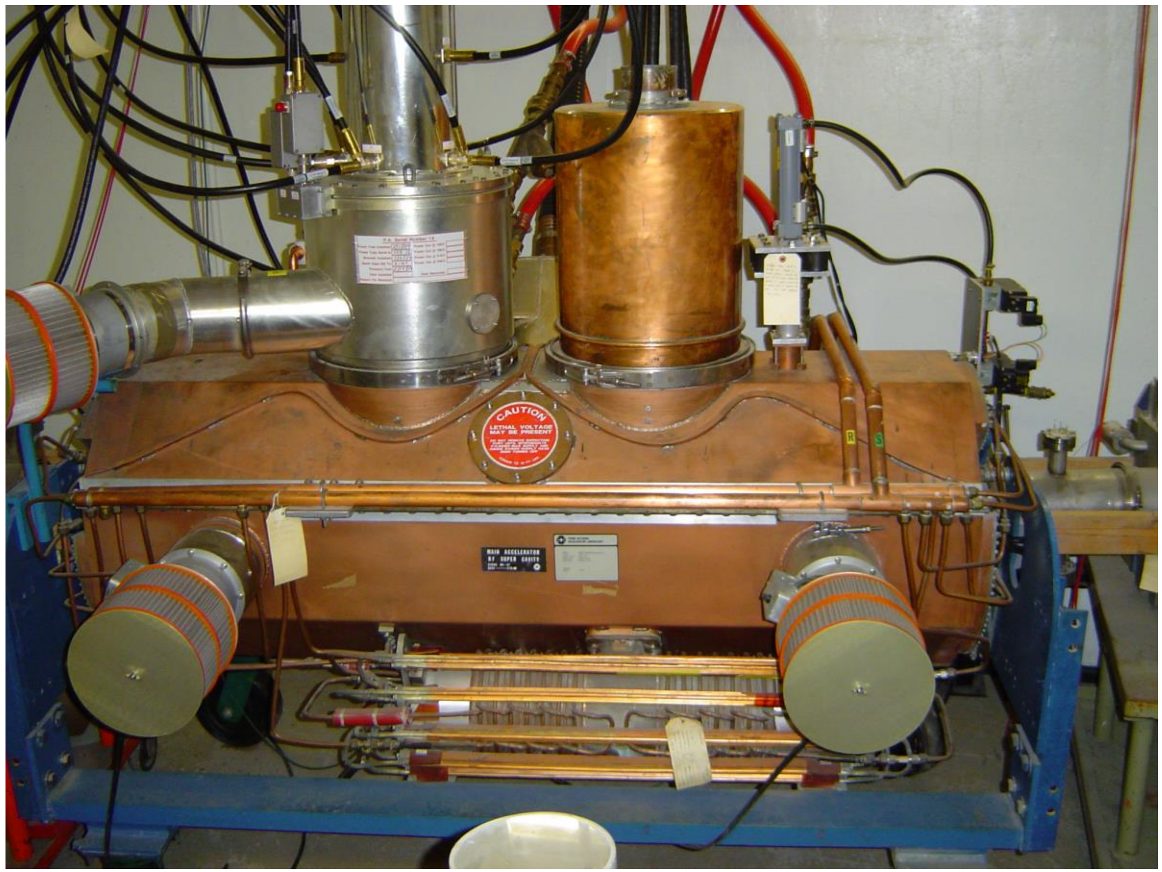
Performance Parameter	Present Capability	PIP-II Requirement	
Beam Intensity	6.2×10^{13}	7.5×10^{13}	
Harmonic Number	588	588	
Number of Filled Buckets	504	504	
RF Frequency Range	52.811-53.104	52.811-53.104	MHz
Acceleration Rate	240	240	GeV/s
Main Injector Ramp Rate:	1.2 s	1.2 s	
Accelerating Cavities	20	20	
Maximum Accelerating Voltage	235	235	kV/cavity
Total Available Accelerating Voltage	4.7	4.7	MV
Total Required Accelerating Voltage ($V\sin\phi_s$)	2.7	2.7	MV
Total Required Cavity Power	204	240	kVA/cavity
Robinson Stability Factor	4	4	

- **Present RF System does not have the power to accelerate the PIP-II Beam intensities**

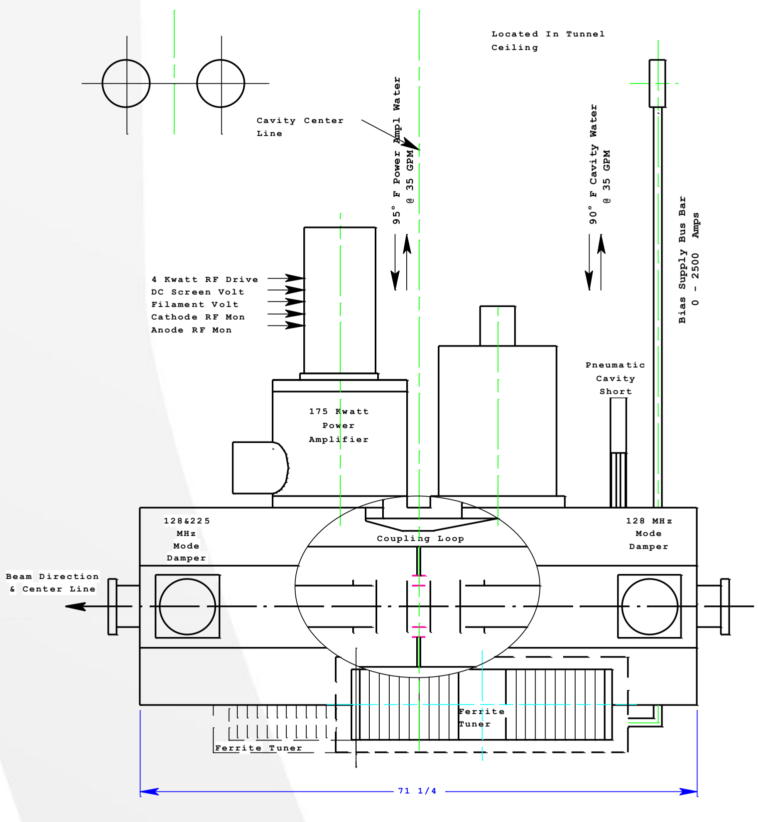
MI RF Options for higher power

- Operate the current RF cavities with two power tubes instead of one in a push-pull configurations.
  - Need to double the number of modulators and solid state drivers.
- Use a new more powerful power tube (EIMAC 4CW250,000B).
  - New mounting configuration (much longer tube).
  - New modulators and upgraded PA cooling.

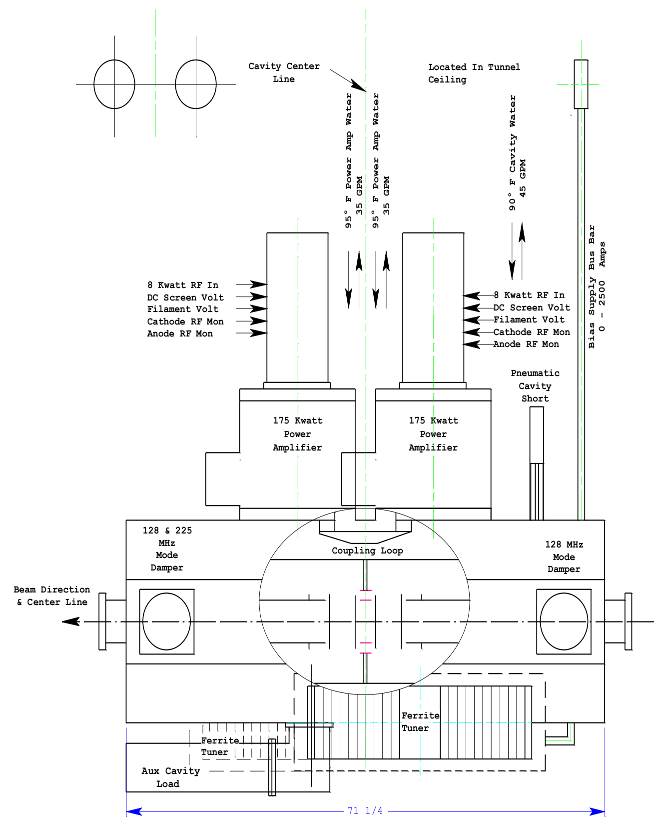
Standard MI RF Cavity



Present and future MI Cavity Configuration



Present Main Injector Cavity



Modified Main Injector Cavity for Two Power Amplifiers

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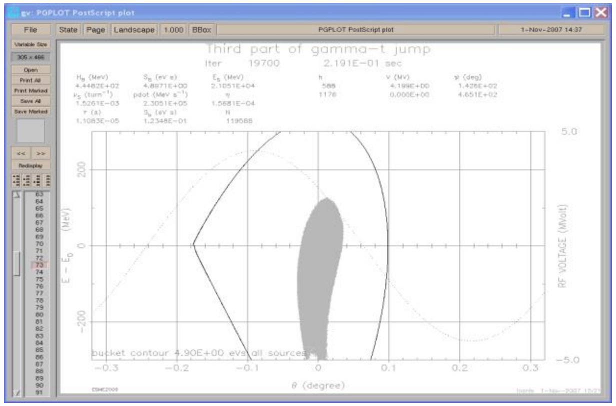
Transition crossing

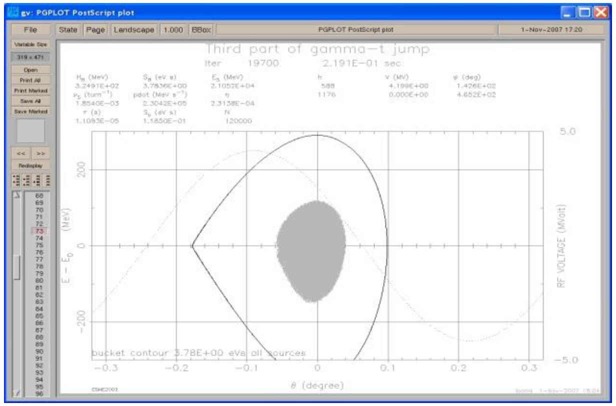
- A design of a first order gamma-t jump system for the Main Injector was completed as part of the Project X Reference design. This system is required for 2.3 MW operation.
- Further simulations are needed to verify if this system is required for 1.2 MW operation.

MI Gamma-t system

- A first order jump system with small dispersion increase (taking advantage of the dispersion free region)
- Design goal:
  - $\Delta\gamma_T = \pm 1$ within 0.5 ms
  - $d\gamma /dt = 4000$ 1/s
  - 16 times faster than the normal ramp (240 GeV/s)
- Components:
  - 8 sets of quad triplets
  - 8 sets of power supplies
  - Inconel beam pipe



No gamma-t jump

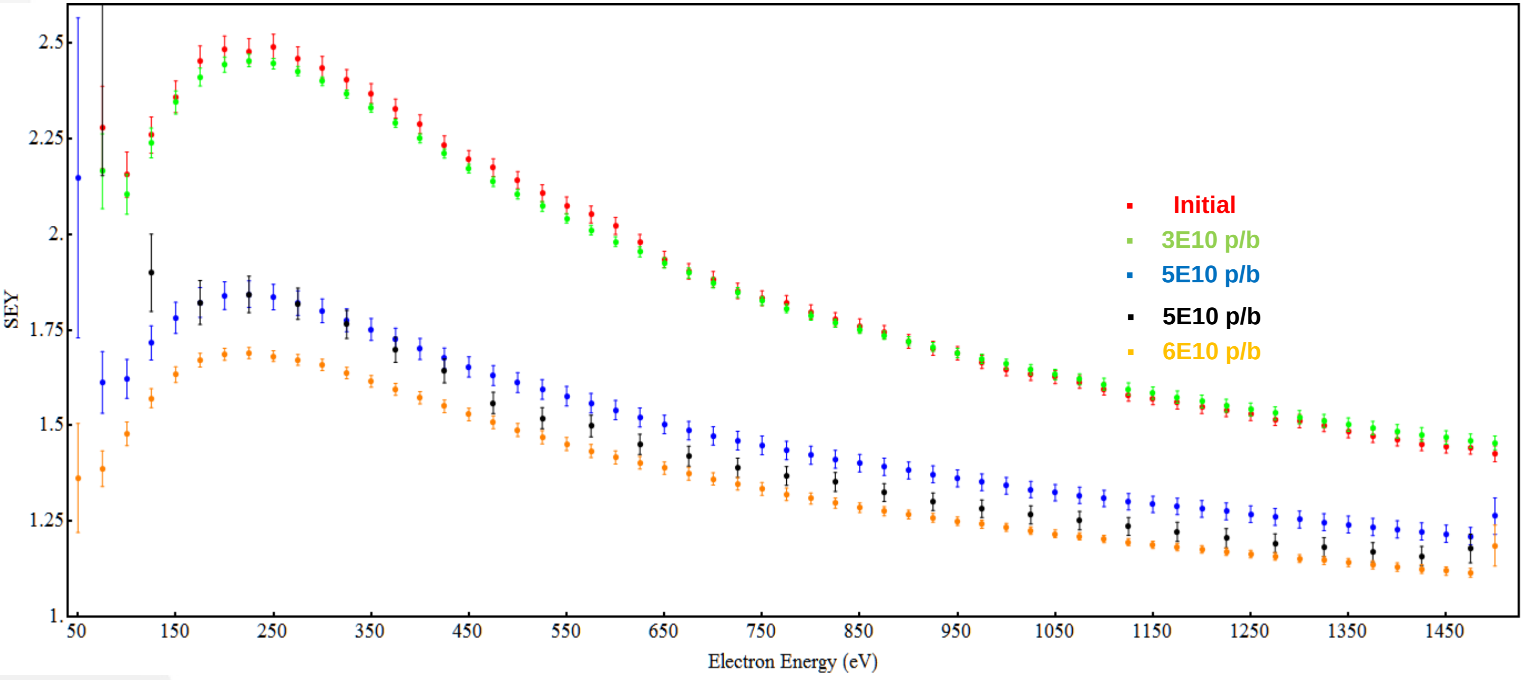


Gamma-t jump

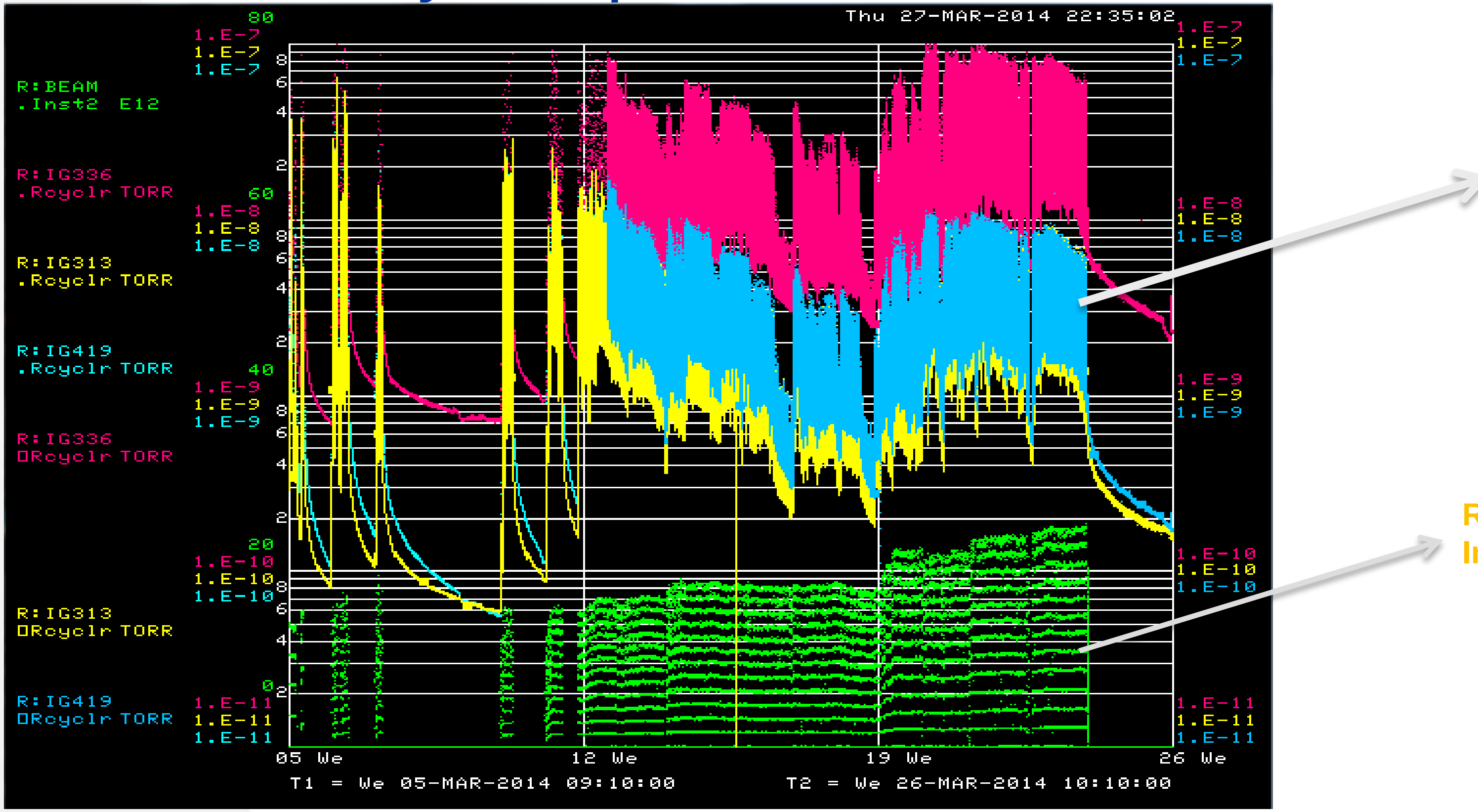
Electron Cloud

- Recent measurements in MI indicate that beam scrubbing is quite effective in reducing the SEY of the beam pipe so no electron cloud problems are anticipated.
  - Beam scrubbing has also been observed in Recycler during slip stacking commissioning.

MI SEY for different intensities



Recycler Beam Scrubbing with 1 and 2 $2A Cycles per minute



Pressure rises due to electron bombardment. The beam scrubbing effect characterizes a decrease of these pressure rises. This decrease results from both a cleaning of the surface (gas desorbsion and pumping) and a reduction of the electron cloud activity as a result of the decrease of the secondary electron yield of the inner chamber wall surfaces.

PIP-II, Collaboration Meeting, June 2014; Kourbanis

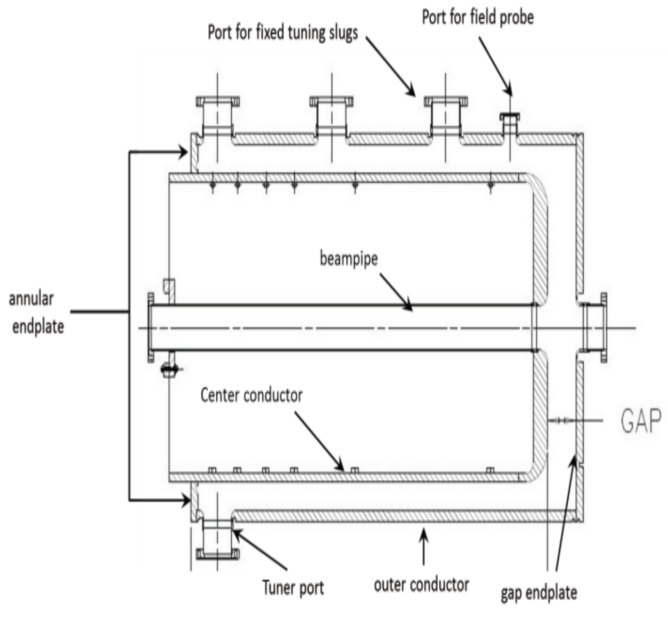
Loss control

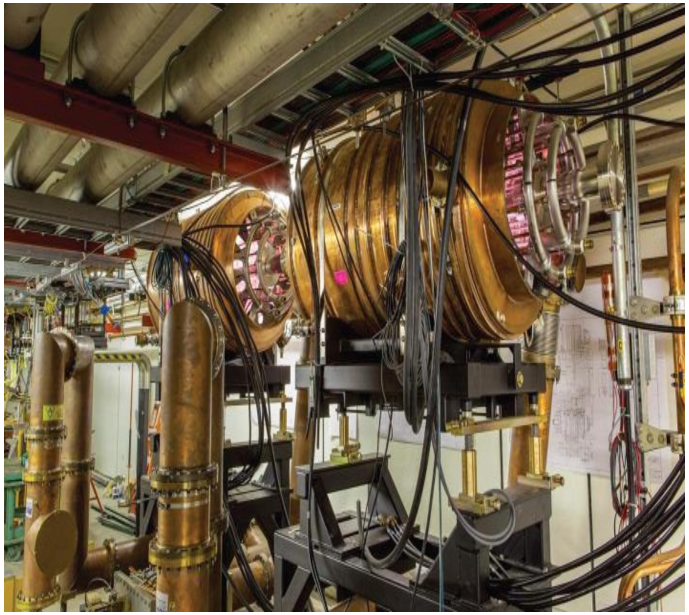
- Need to understand and control the space charge losses with the higher intensity beam in MI and Recycler.
  - We have generated single bunches with 3E11p in MI at 8 GeV
  - In MI the collimators intercept most of these losses.
  - Do we need collimators in Recycler?
- Realistic space charge simulations using SYNERGIA are under way.
- A full 3-d Recycler simulation including space charge and impedances will be required to fully understand losses.

R&D for RR RF Cavities required for running at lower MI Extraction Energy

- The Recycler 53 MHz cavities used for slip stacking have a high power dissipation (90 KW, 60% DF) because of the low R/Q (13 Ohms).
- Running MI at energies as low as 60 GeV will require the slip stacking cavities to run CW.
- We will need a different cavity design with higher R/Q and active beam loading compensation.

Recycler 53 MHz cavities





Conclusions

- We have identified the required MI/RR modifications required for running at the PIP-II Intensities.
  - More simulations will be required.
- Slip stacking loss requirements drive stringent specifications for the beam out of Booster.
- Loss control in the Recycler will be an issue that we need to address even during the NOvA running.
- The requirement of running MI at lower extraction energies drives a different RR 53 MHz cavity design.

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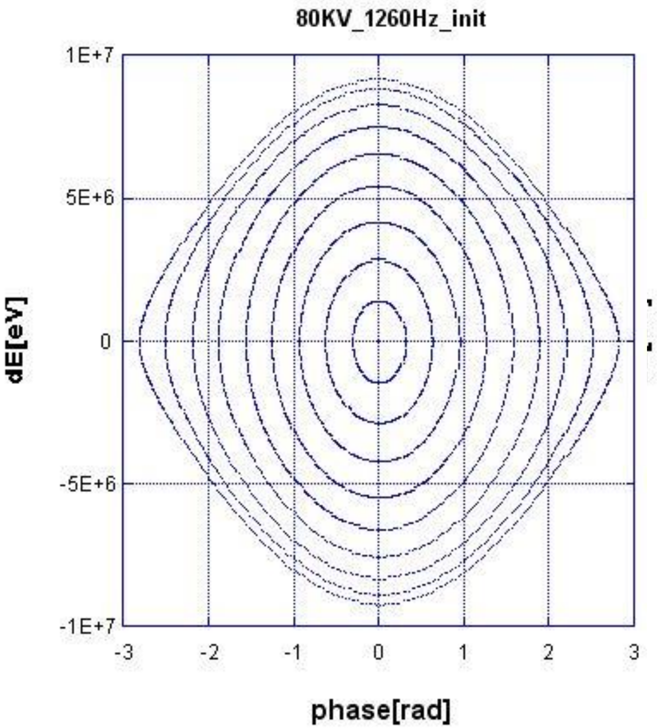
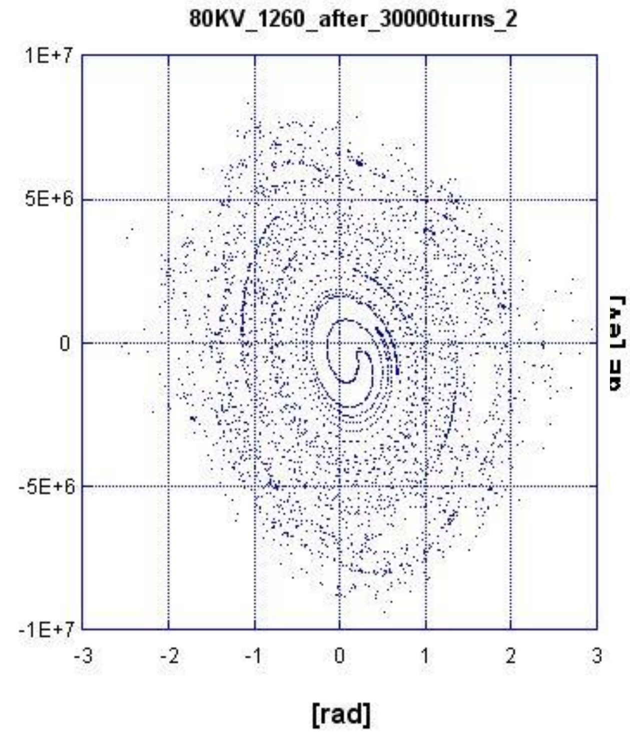
- **Extra slides**

Matching contours in 80 KV Bucket after 0.33 msec

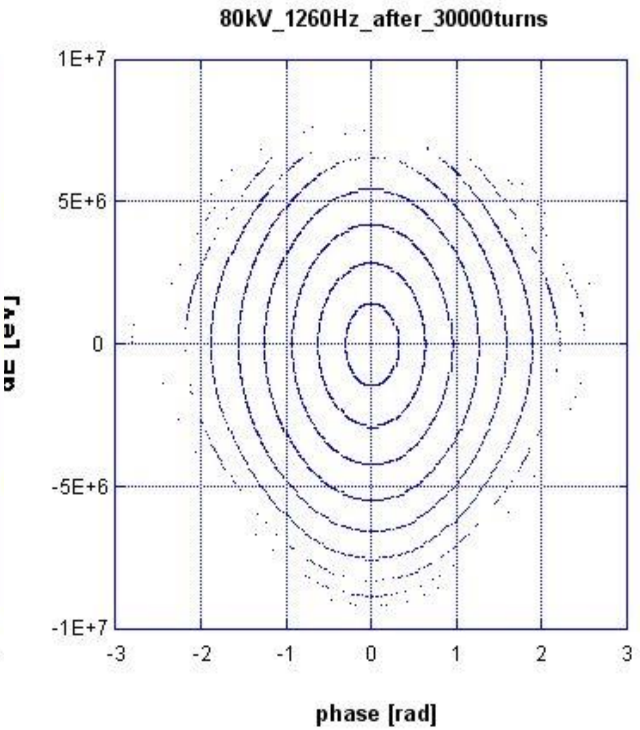
Initial



Final

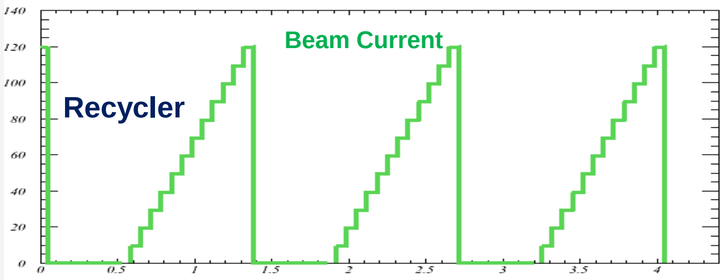


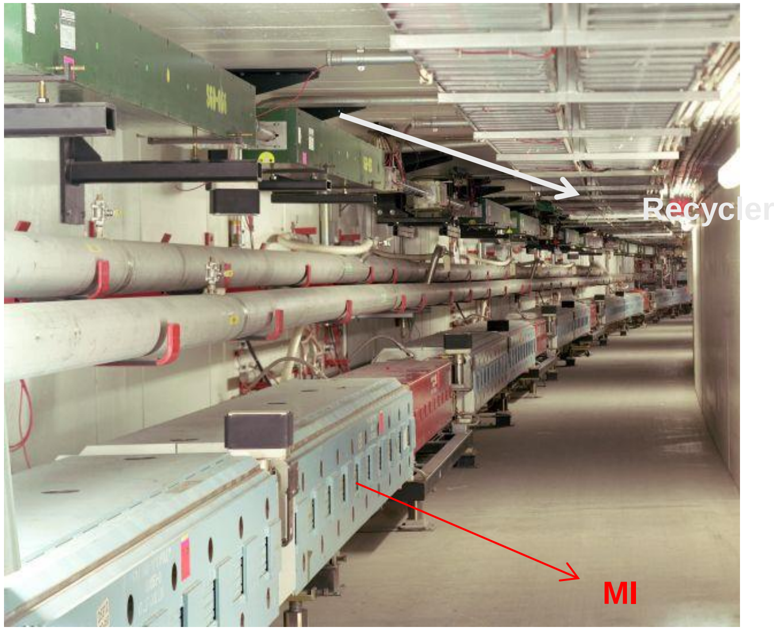
Acceptance

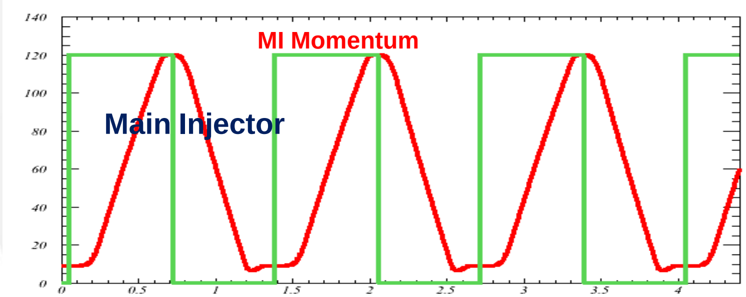


PIP-II Recycler Operation for NOvA

- Injection of 12 high intensity Booster Batches for slip stacking.

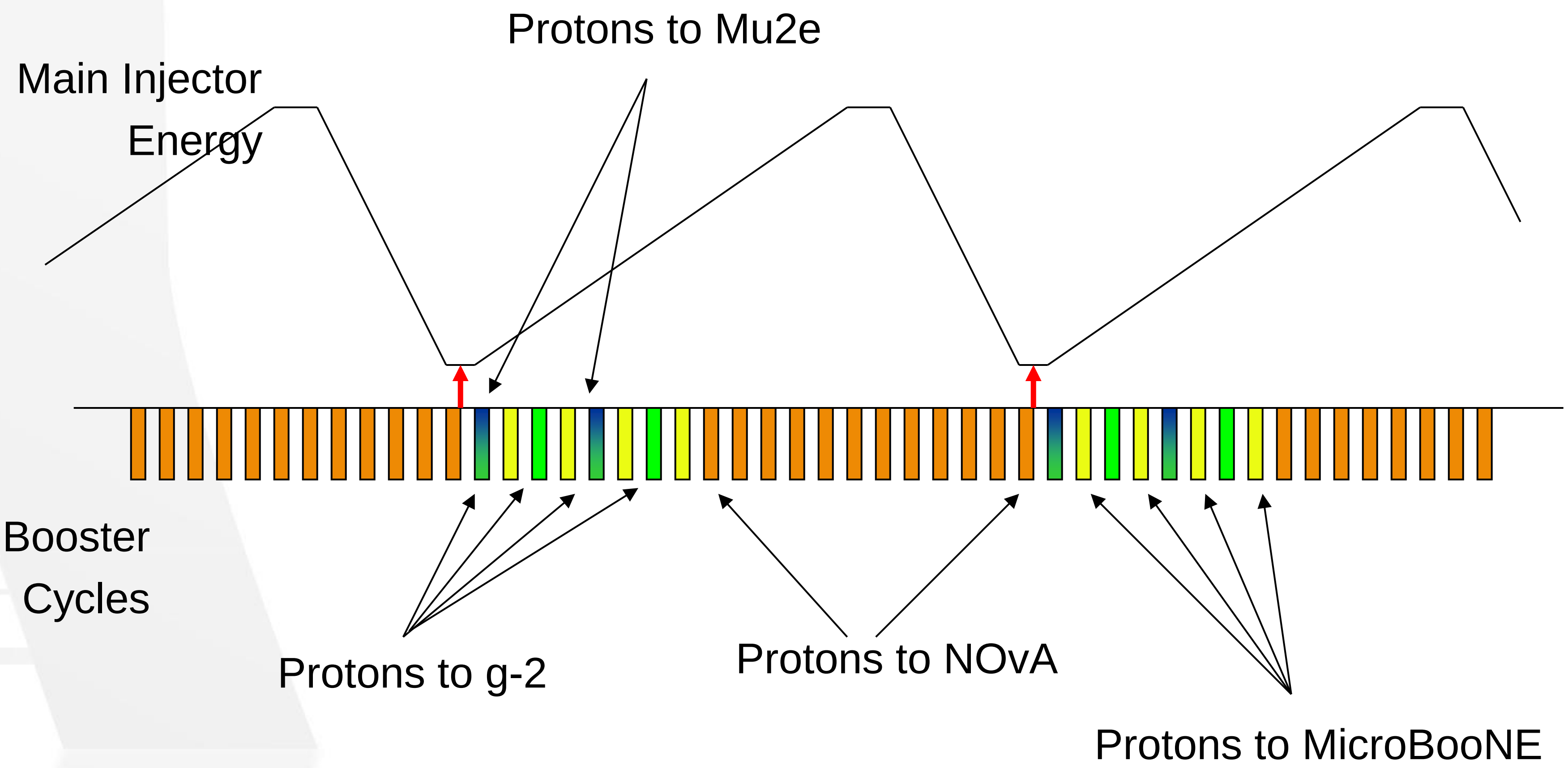




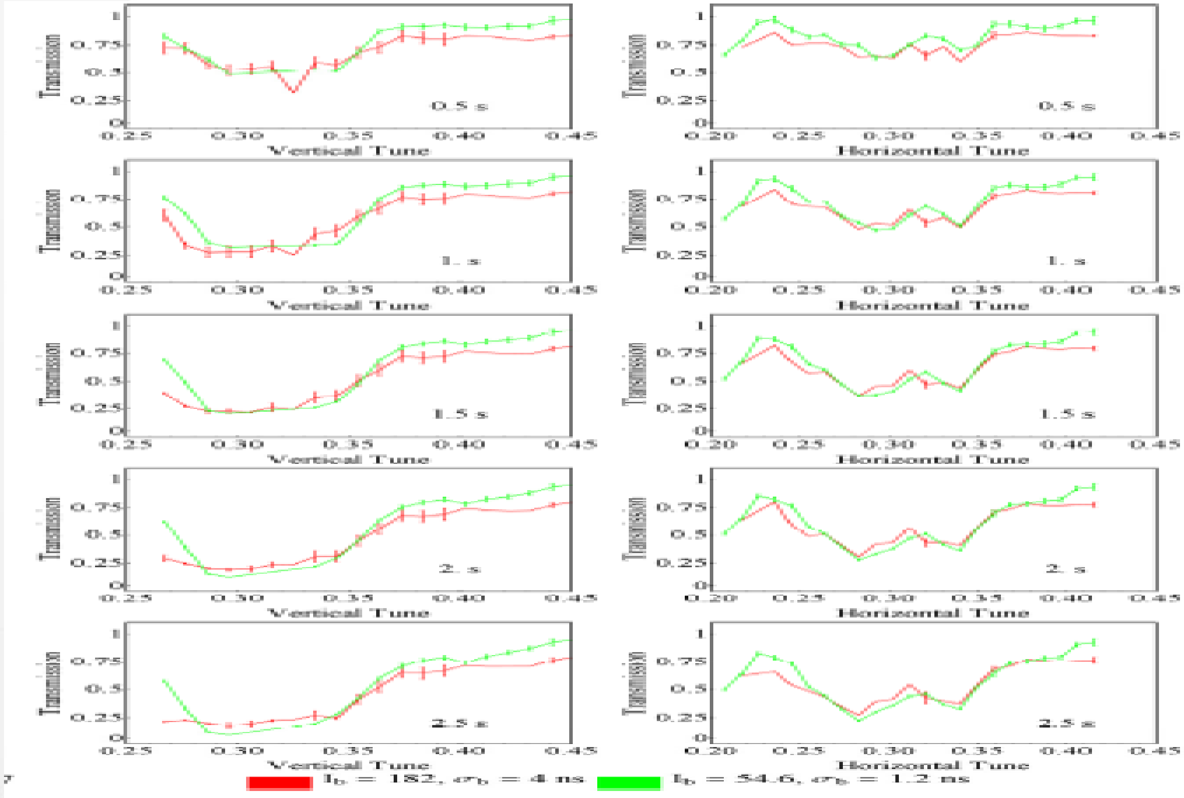


- Up to 8 additional Booster batches cab be injected in Recycler for delivery to the modified p-bar Rings (Mu2e, g-2 experiments)

Recycler operation for Mu2e and g-2



Transmission vs tune for two different intensity bunches in MI



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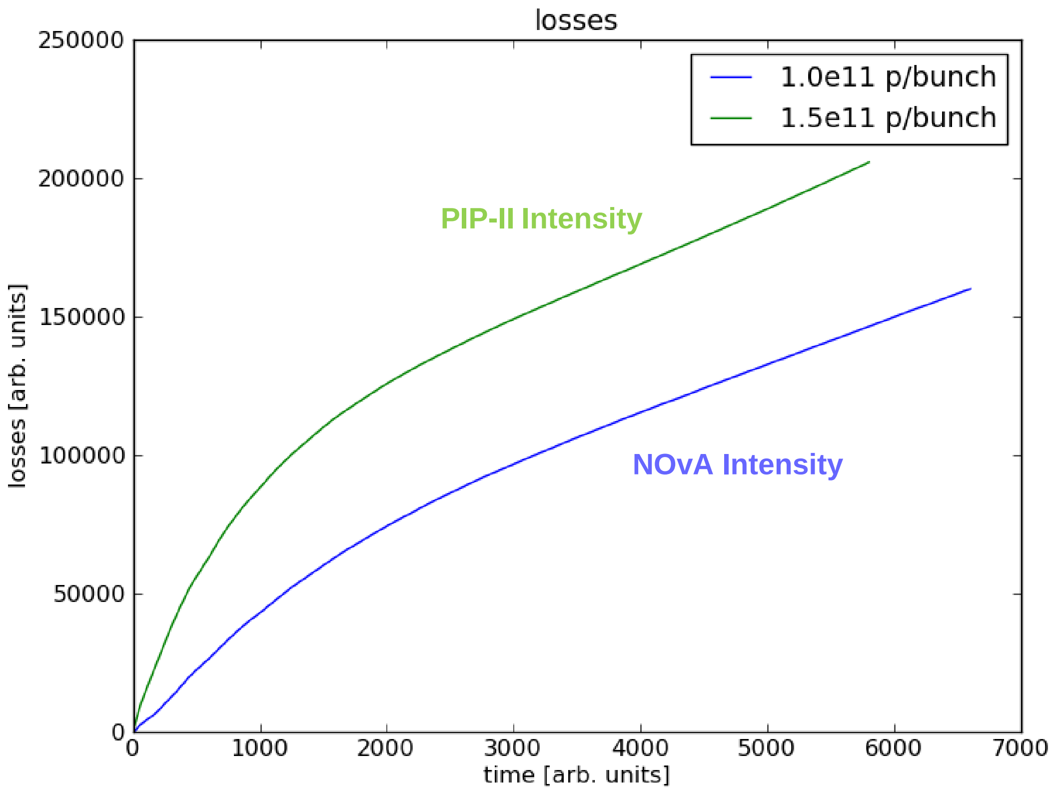
Recycler space charge simulations



Preliminary!