Main Injector Status and Plans

Shekhar Mishra
MID/BD

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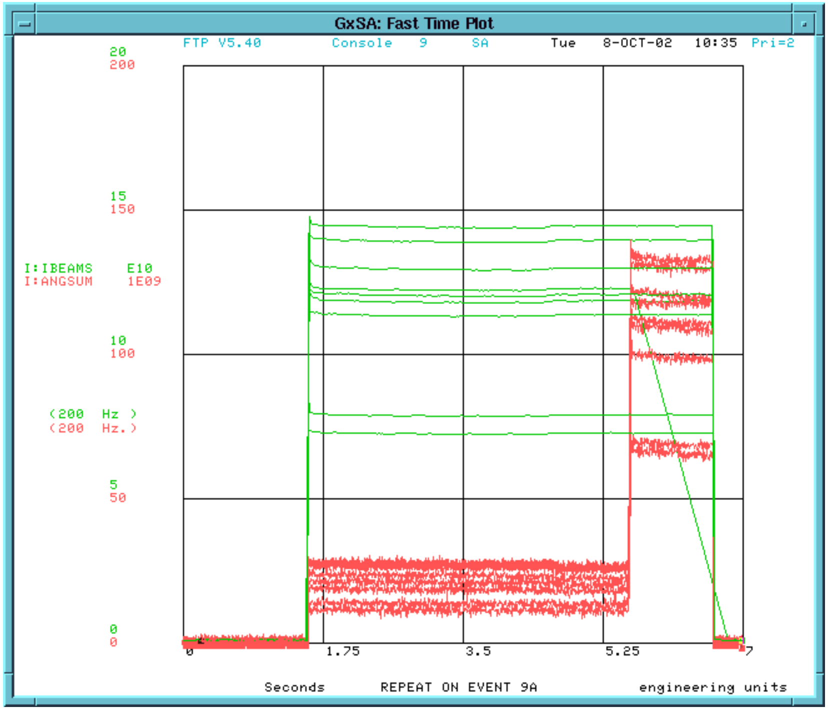
DOE Review

- Main Injector operation and performance goals
- Lattice
- Proton and Antiproton Coalescing
- Antiproton production cycle
- Slip Stacking
- Summary



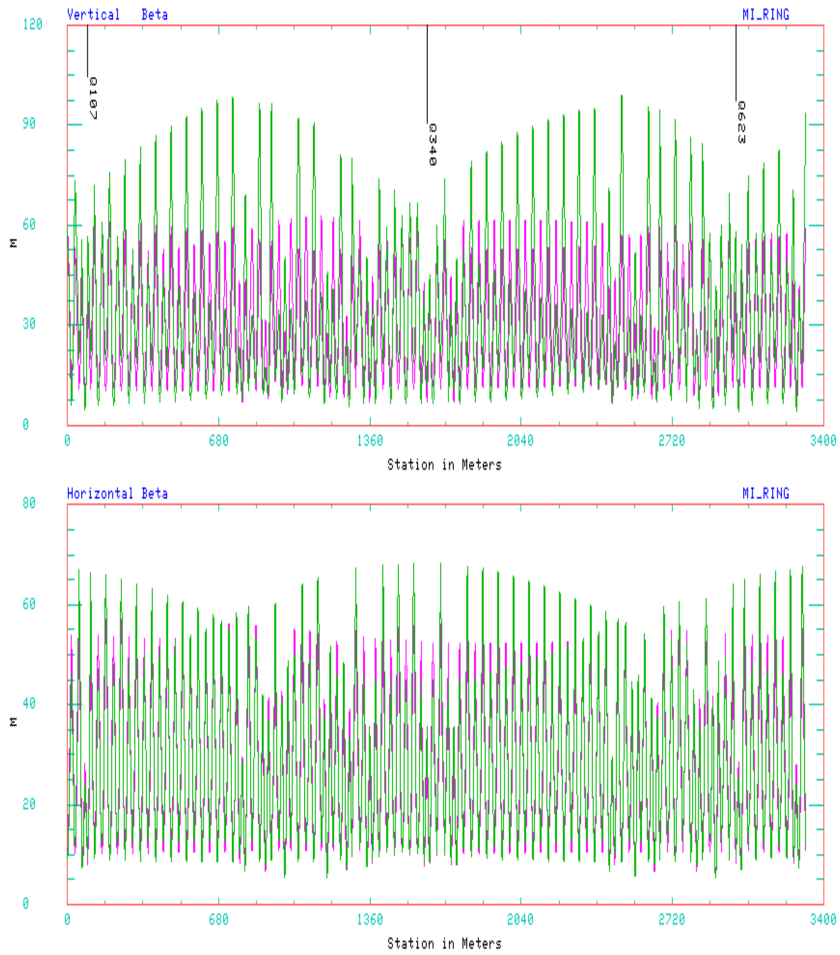
Main Injector Operation

- 8.9 - 120 GeV/c Proton for antiproton production
- 8.9 - 150 GeV/c proton for TeV collider operation
- 8.9 - 150 GeV/c antiproton for TeV collider operation.
- 8.9 GeV proton
    - Reverse tune up of the Accumulator
    - Reverse tune up of the Recycler
    - MiniBooNE beam
- Support of SY120 and NUMI activities
- R&D for Run-II

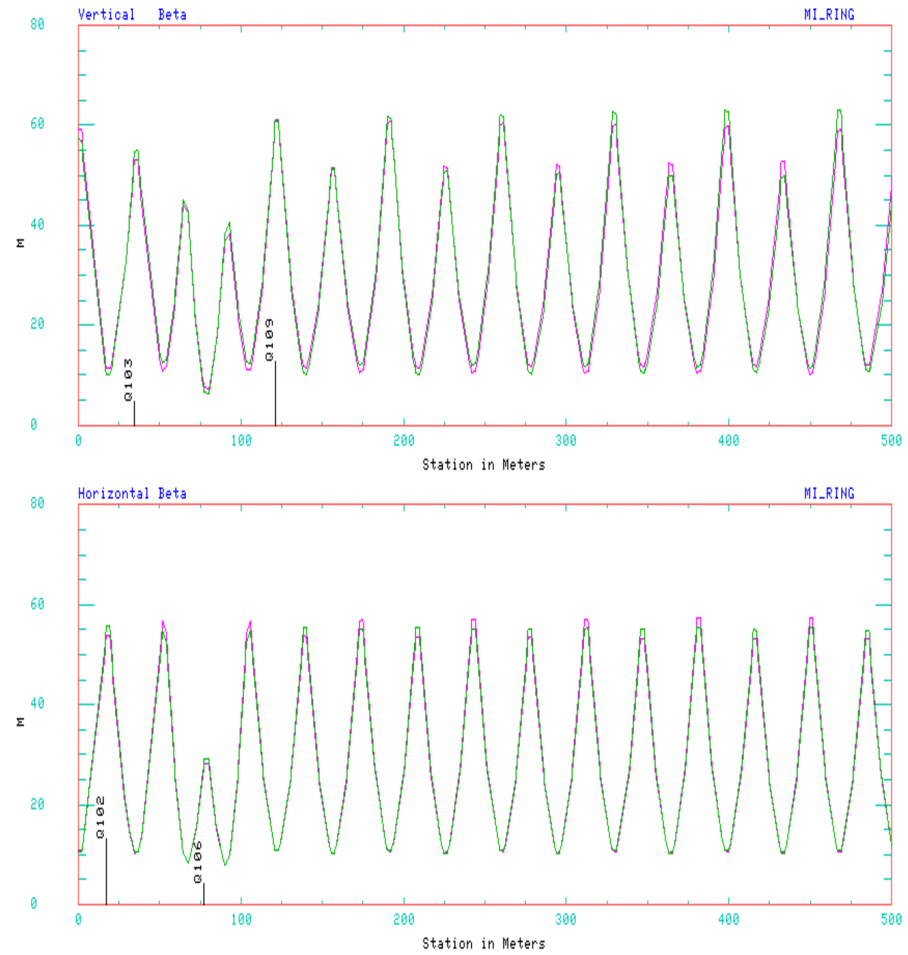
Main Injector Recent Developments

- Lattice match between Injection lines(MI8) and Main Injector.
- Beam Loading compensation and tune up of the proton coalescing for collider program.
- Multi batch Beam Loading compensation and tune up of the pbar coalescing for the collider program.
- Studies to understand the longitudinal emittance growth in the Main Injector and R&D its solution.
- Slip stacking studies
- 8 GeV Coalescing studies to reduce longitudinal emittance of protons.
- Development of Recycler pbar extraction and acceleration.

Projected Main Injection beta vs. calculated MI beta

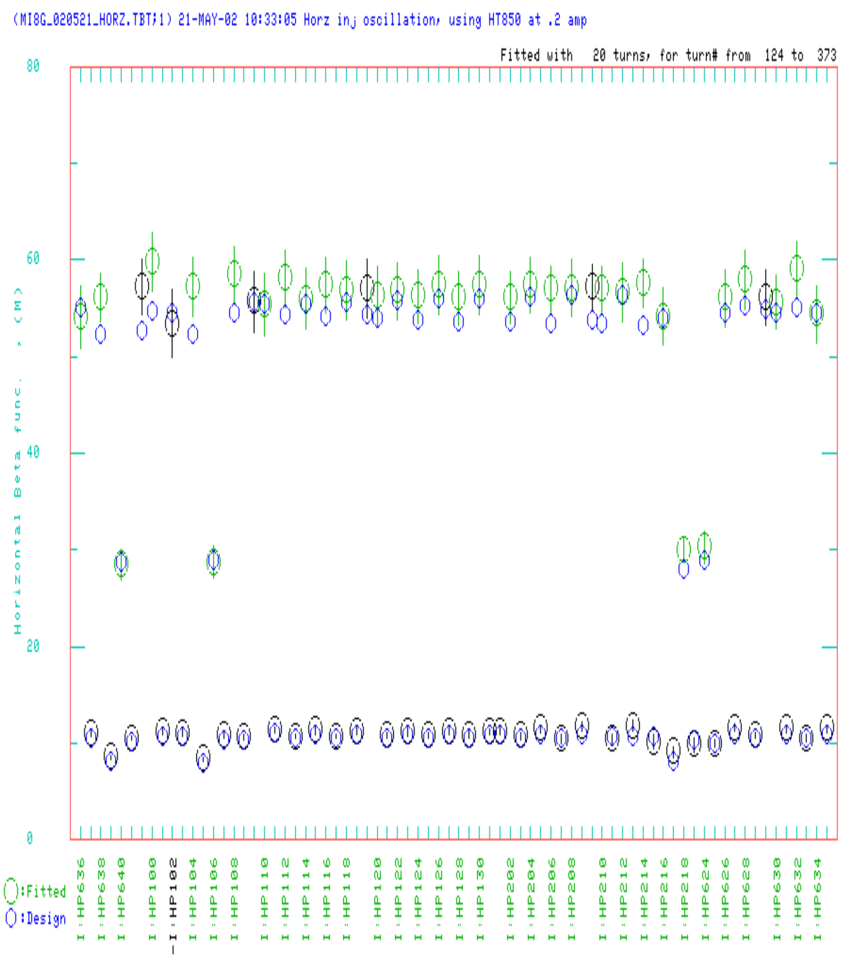


Before Injection match

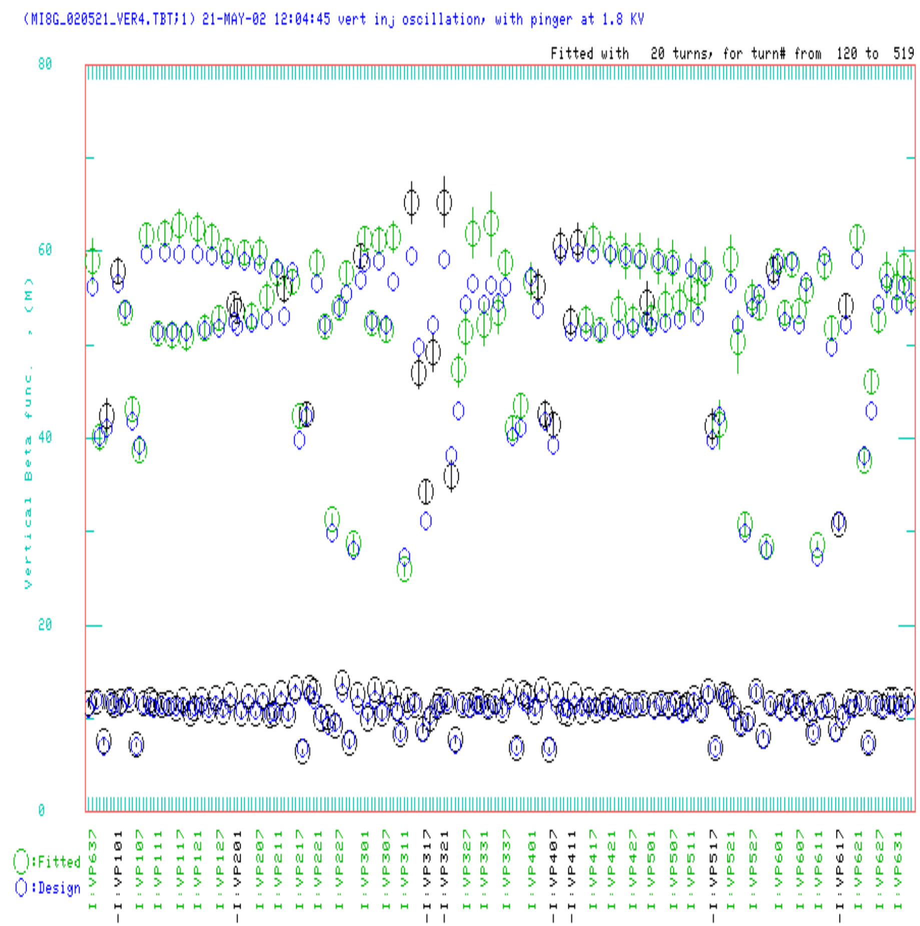


After Injection Match

Circulating beam Beta function in the Main Injector at 8.9 GeV

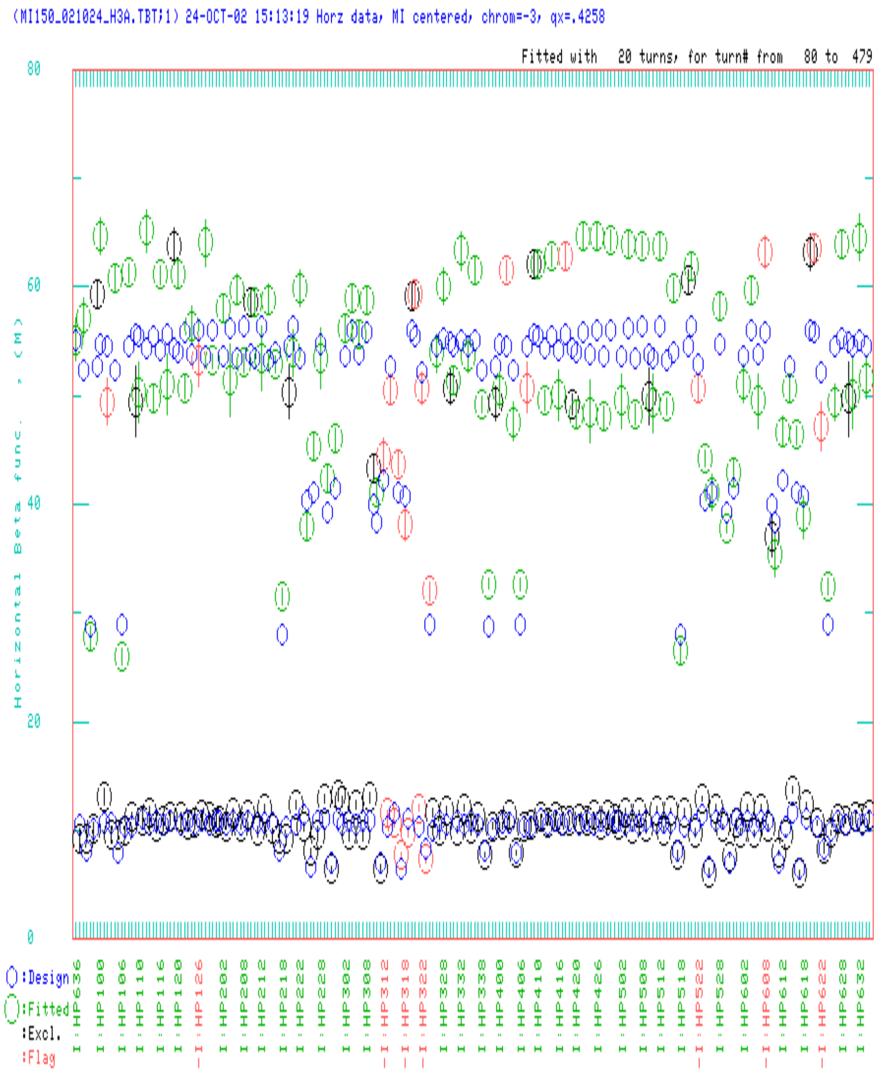


Horizontal

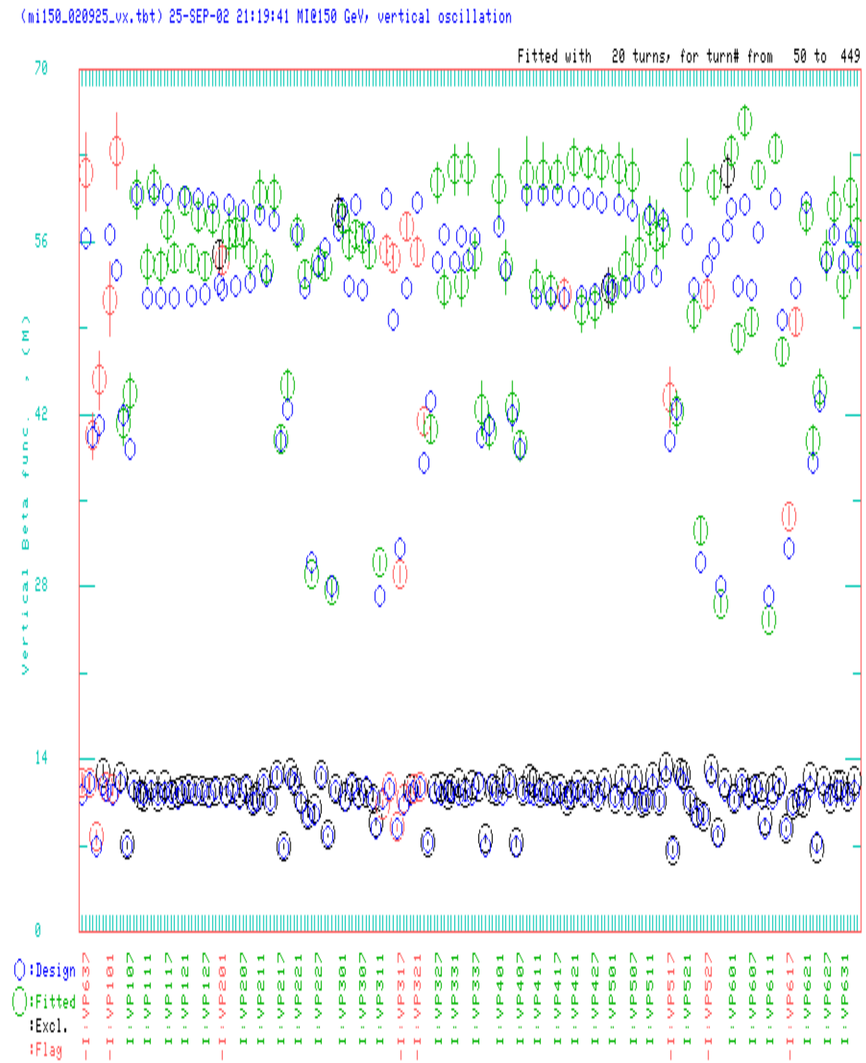


Vertical

Beta Function of Main Injector at 150 GeV



Horizontal Plane

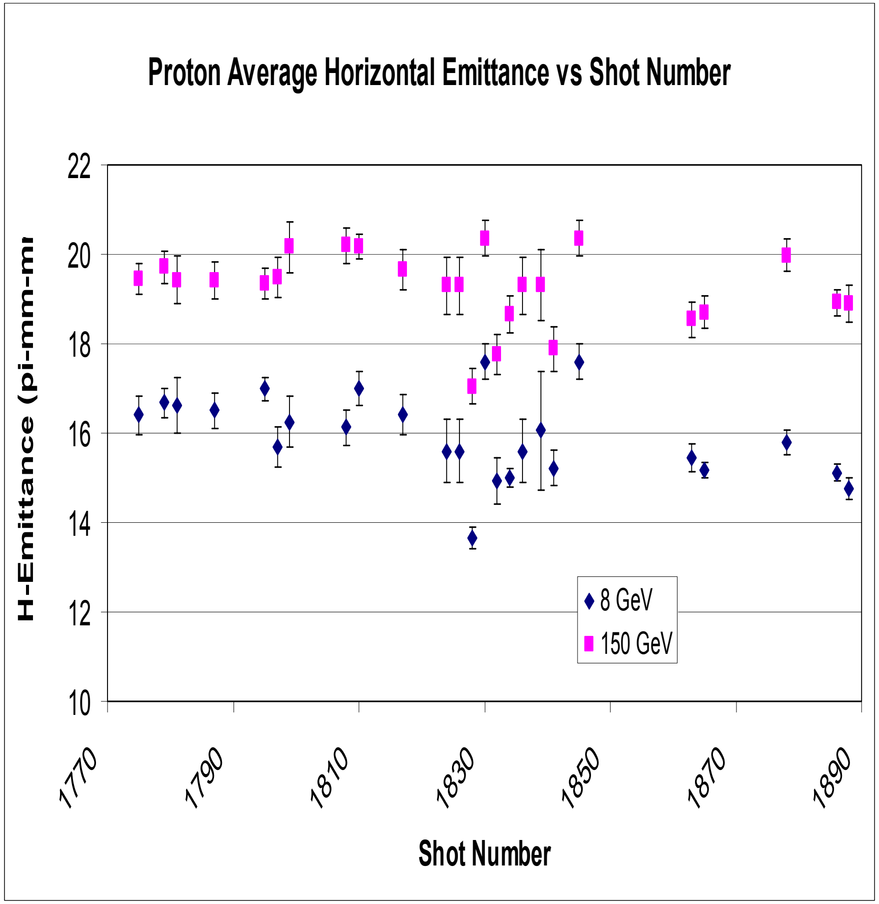


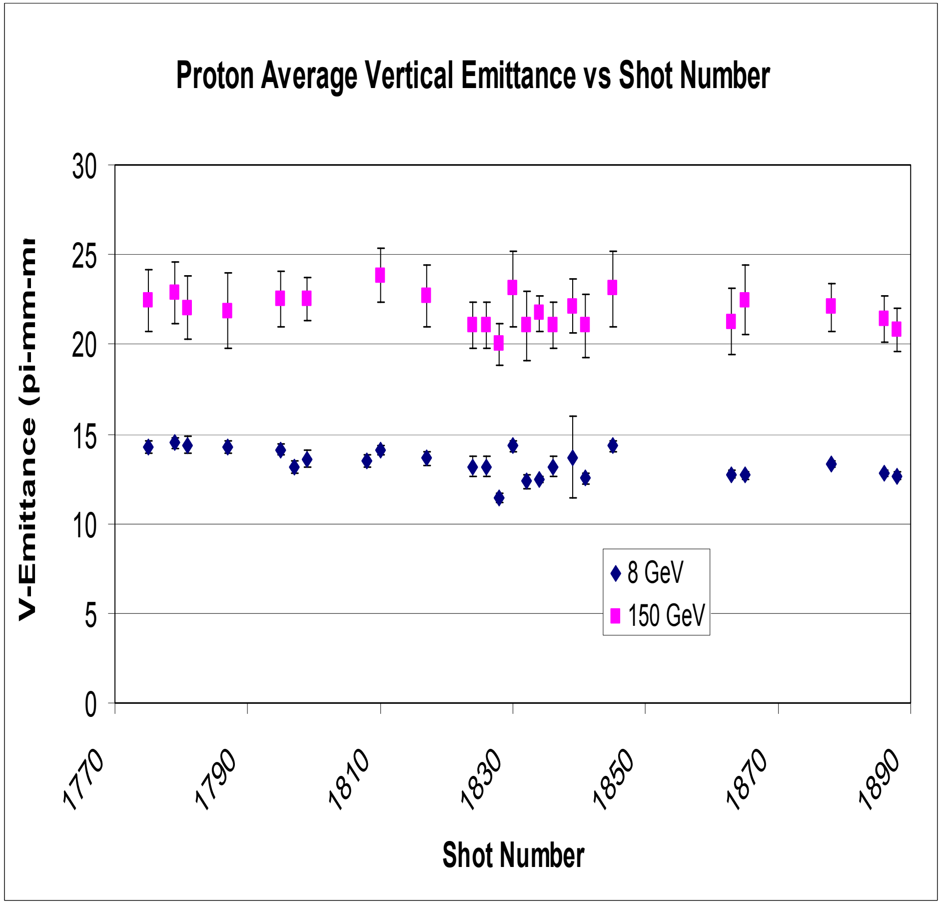
Vertical Plane

Performance Goals for proton Coalescing

- Coalesce 300-330e9 ppb with 7 Booster bunches
  - This intensity is required to achieve 270E9 ppb at TeV Low beta.
  - It requires the Booster to run at intensities >4.5E12 ppp
  - Requires coalescing efficiencies >80-85%
- The coalesced bunches should have longitudinal emittances smaller than 2.8 eV-sec
  - The longitudinal emittance per bunch before coalescing should be 0.2 eV-sec or less (0.2 ev-sec x 7 bunches x 2 coalescing)
- Transverse proton emittances at 150 GeV should be about 20 π-mm-mrad.
  - Less than 15% transverse emittance growth is allowed through the cycle
- Run II requirement of 2 eV-sec longitudinal emittance can be achieved with 5 Booster bunches. Requires Booster intensity to MI larger than 5e12, which is difficult to achieve.

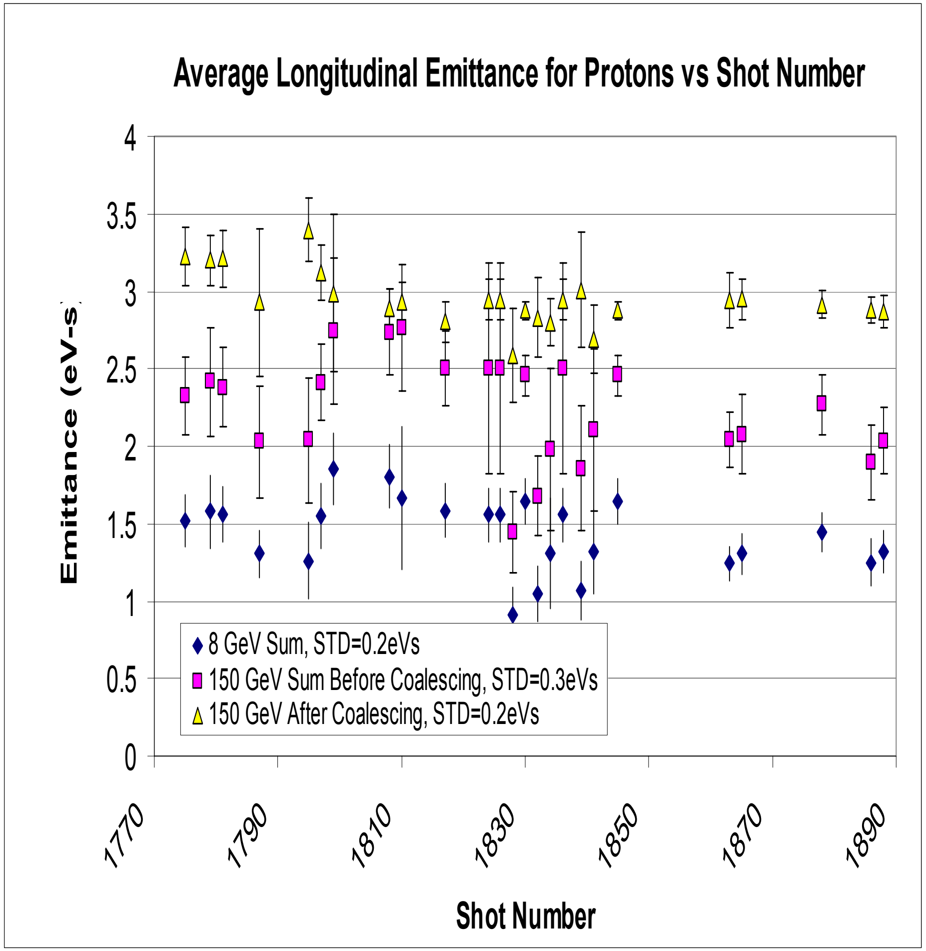
Transverse Emittance of proton beam

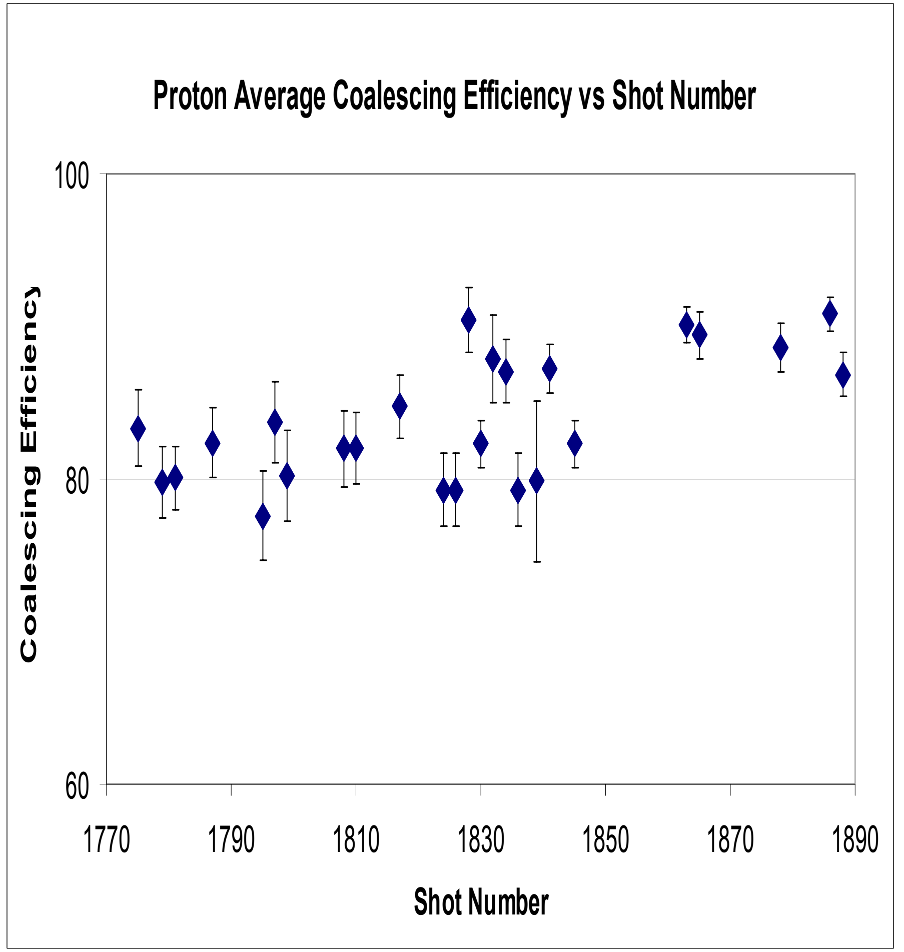




- Horizontal data include dispersion effects, and should be 1.5 pi smaller (dispersion correction). This plane shows small emittance growth.
- We need to understand vertical plane emittance growth and minimize it.

Proton coalescing

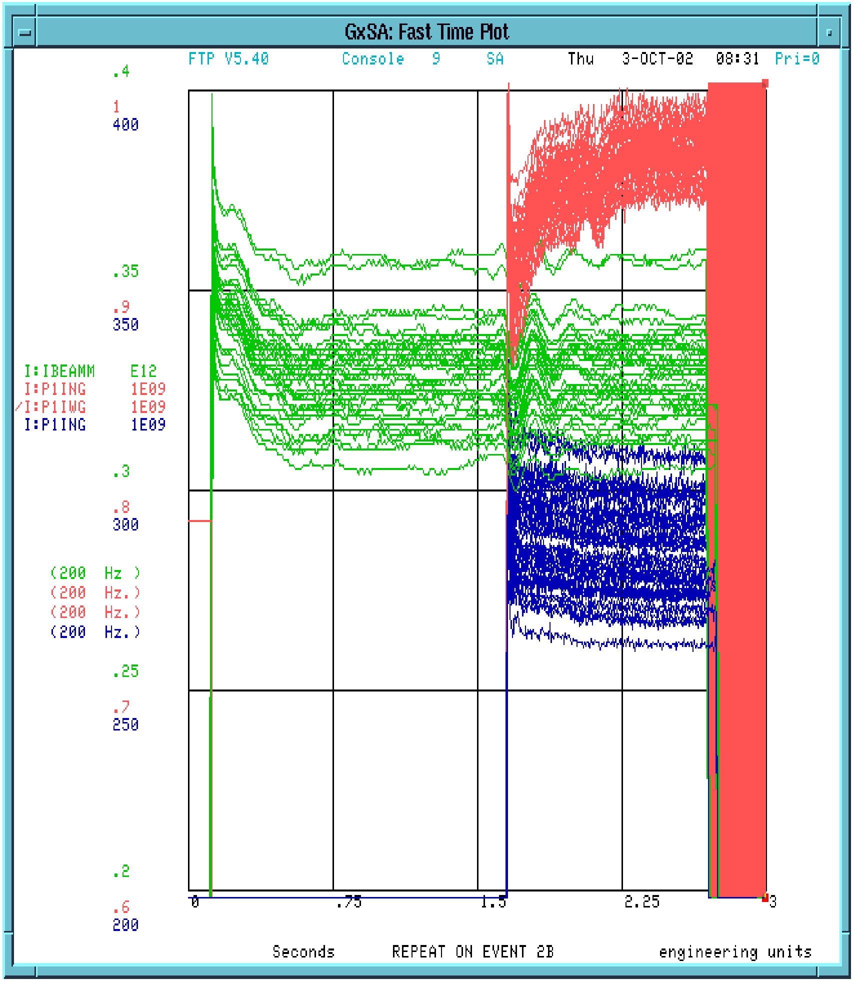


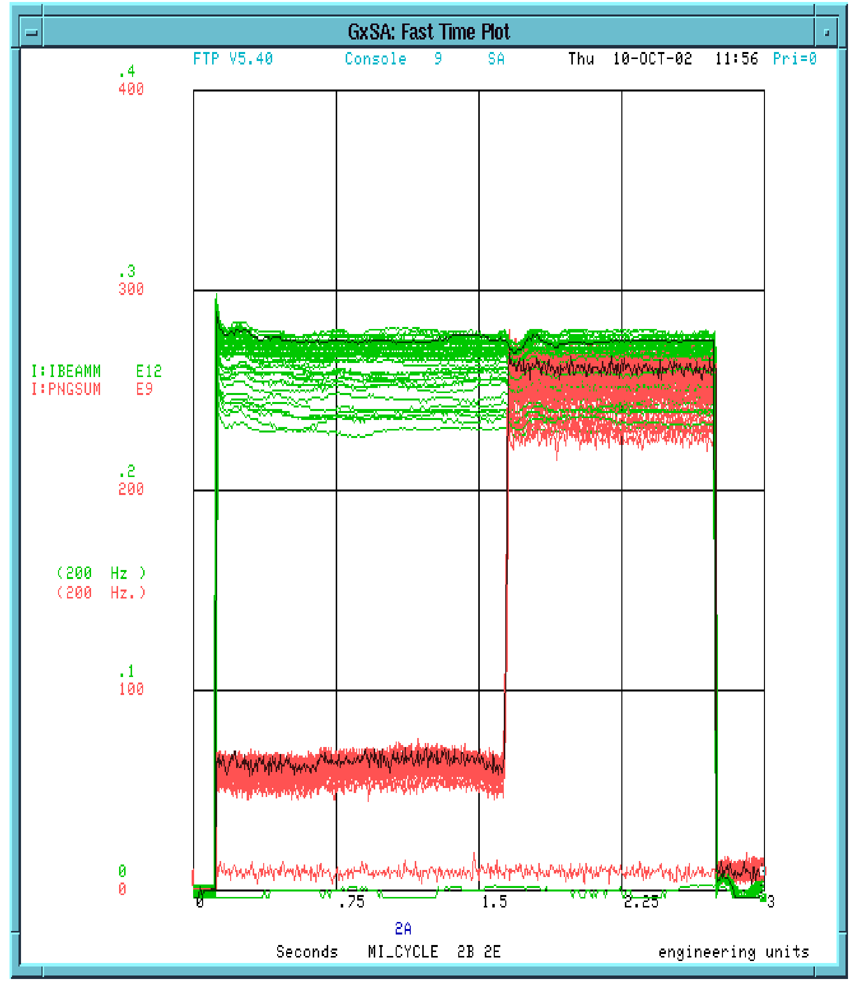


Longitudinal Emittance for recent shots (7 bunches).

Efficiency ~90% for 7 bunches.

Proton coalescing





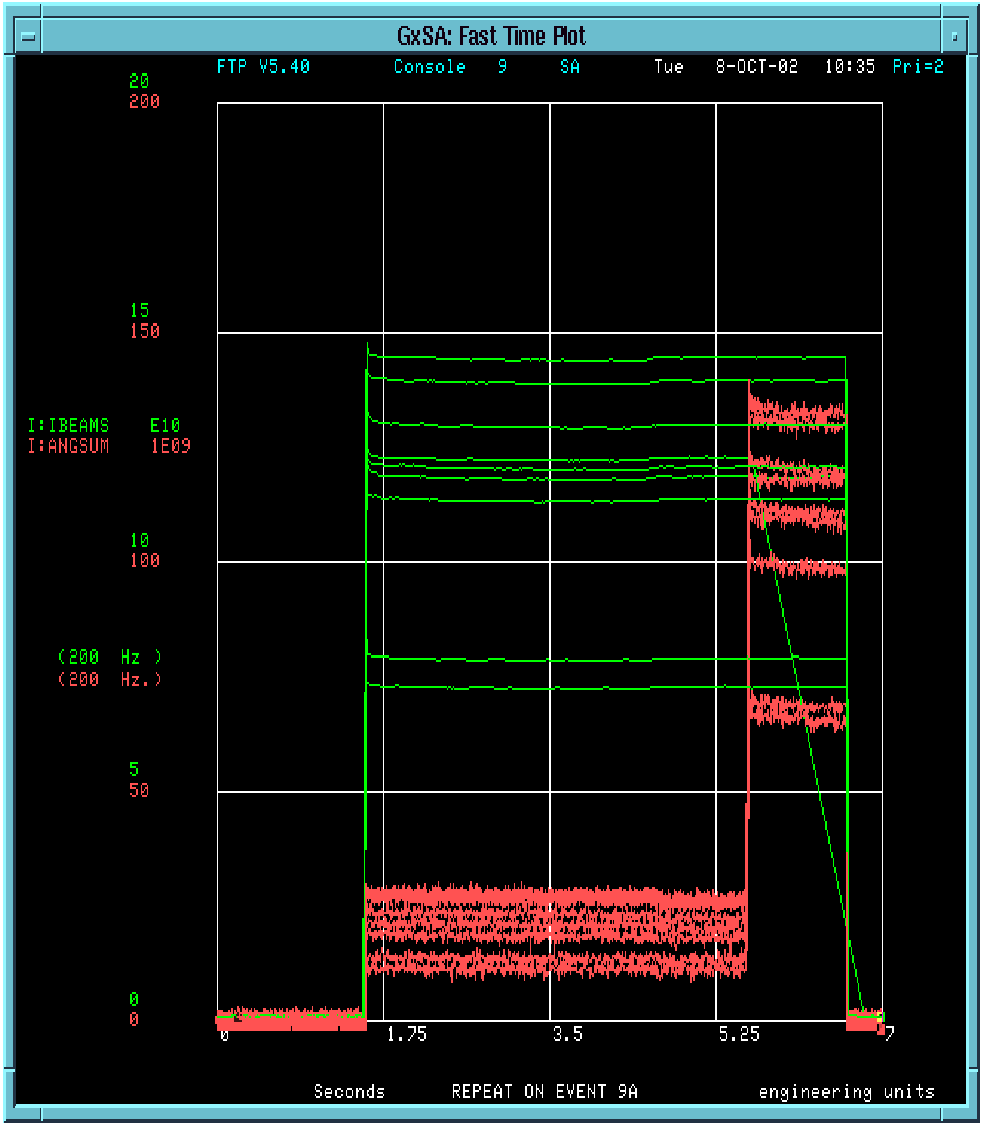
7 bunches, 85% efficiency

5 bunches, 95% efficiency

Performance of MI for pbar

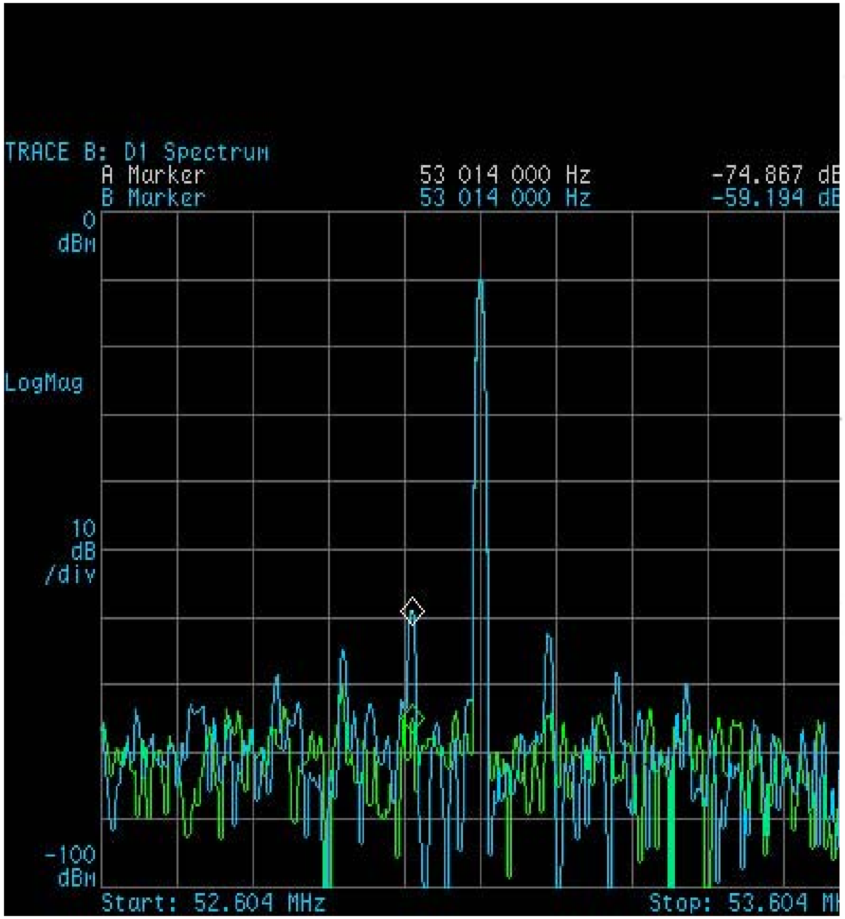
- During the Aug.-Sept. 02 we have commissioned the pbar feed forward beam loading compensation.
- The average pbar Coalescing efficiency is about 85% and has small dependence on the stack size in the accumulator.
  - The average Coalescing efficiency at the large stacks has been increased by 10-12% with the implementation of the feed-forward beam-loading compensation.
- The longitudinal emittance of the coalesced pbar bunches is on average 2.7 eV-sec
  - No significant dependence of the longitudinal emittance on the position of the bunch in the train is observed.

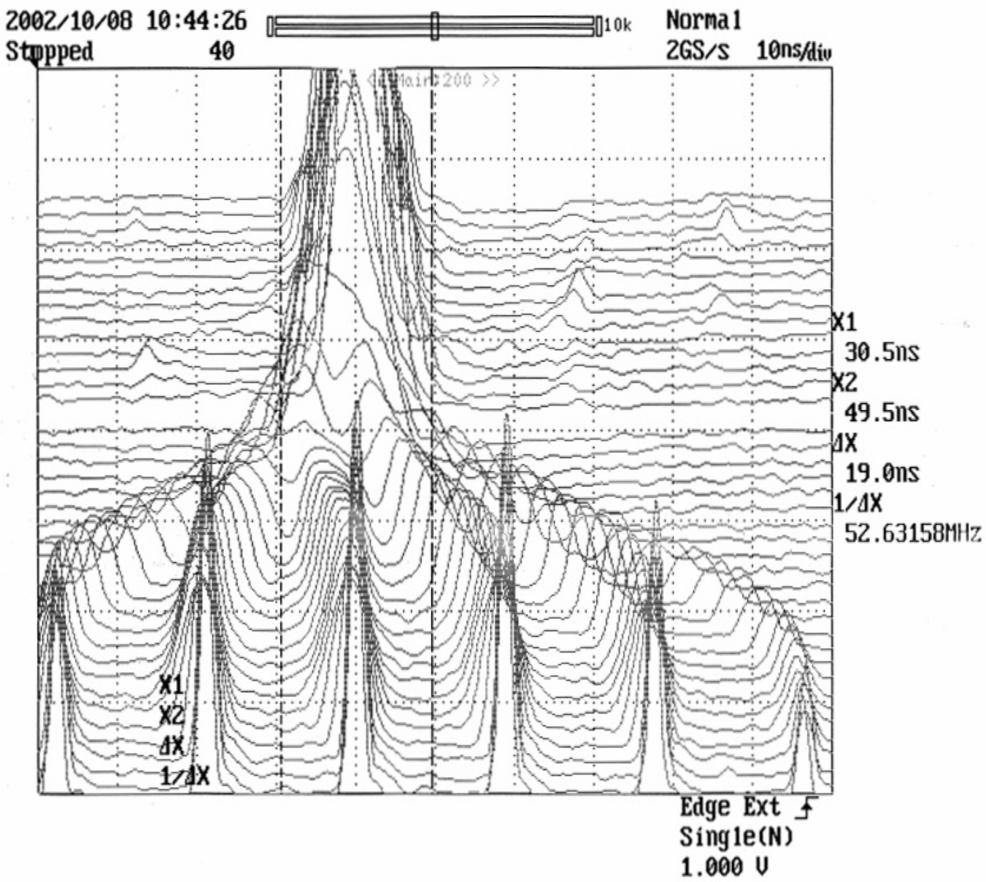
Pbar Acceleration and Coalescing Efficiencies



- After pbar beam loading compensation the pbar coalescing efficiencies are on average >85%.
- The DC beam is much smaller.
- The longitudinal emittance is smaller.

Pbar beam loading compensation



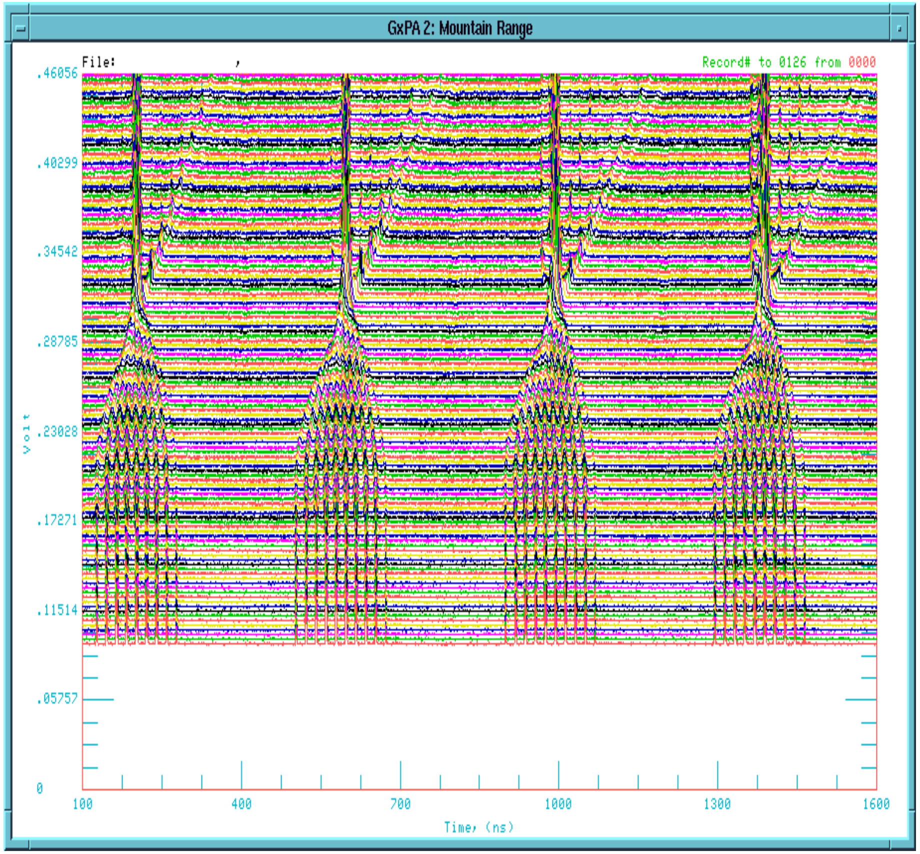


Green trace with beam loading compensation.

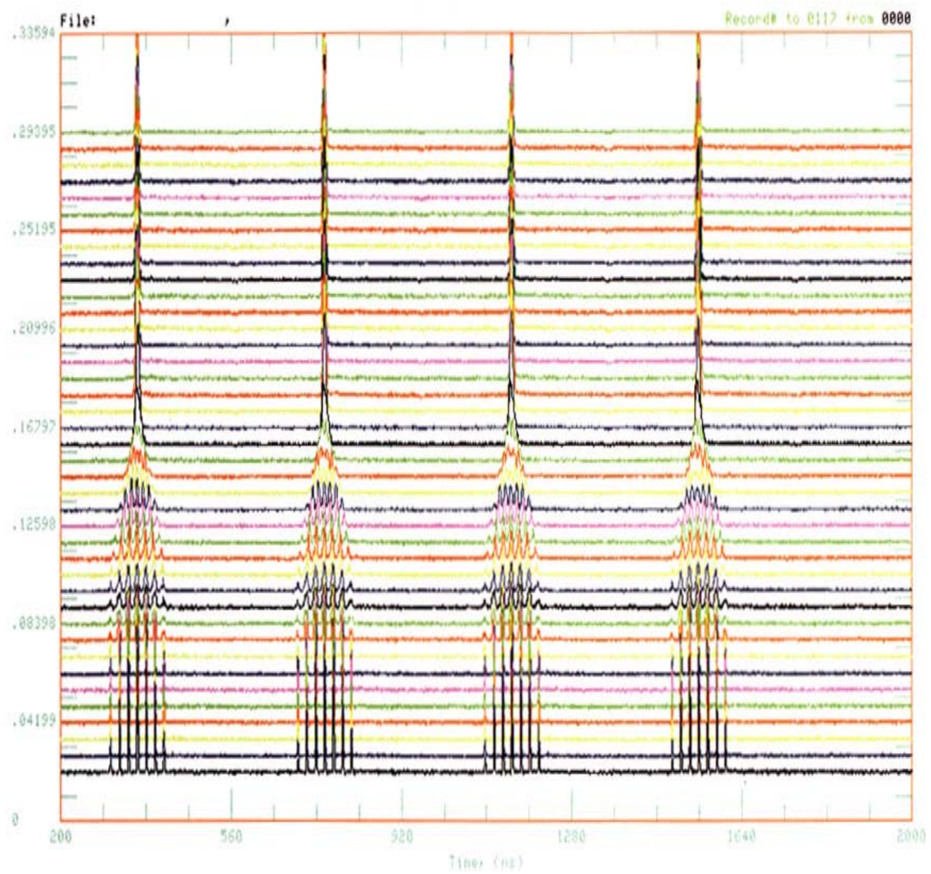
Blue Without

4^{th} batch in the pbar transfer

Pbar coalescing and beam loading compensation

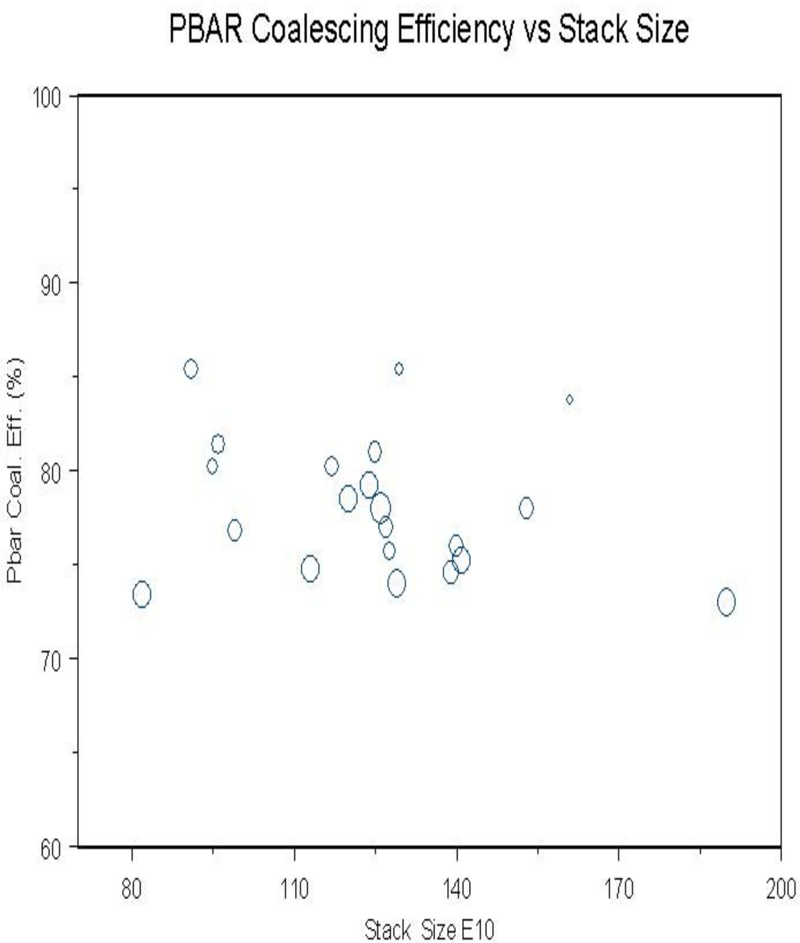


Without compensation

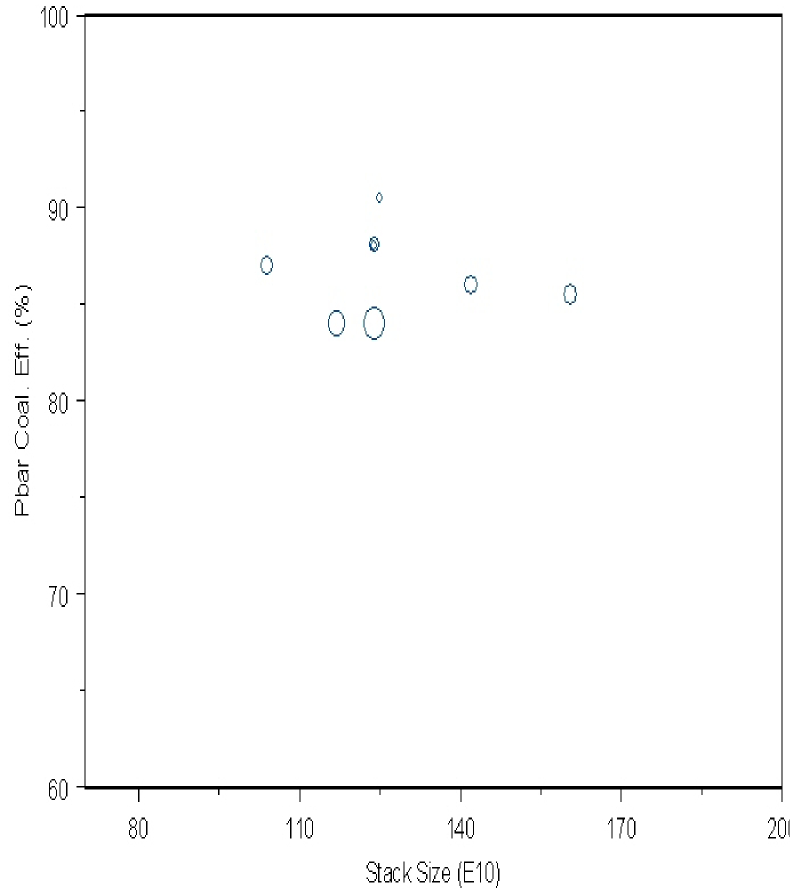


With compensation

Effect of Beam loading compensation on Pbar Coalescing Efficiency

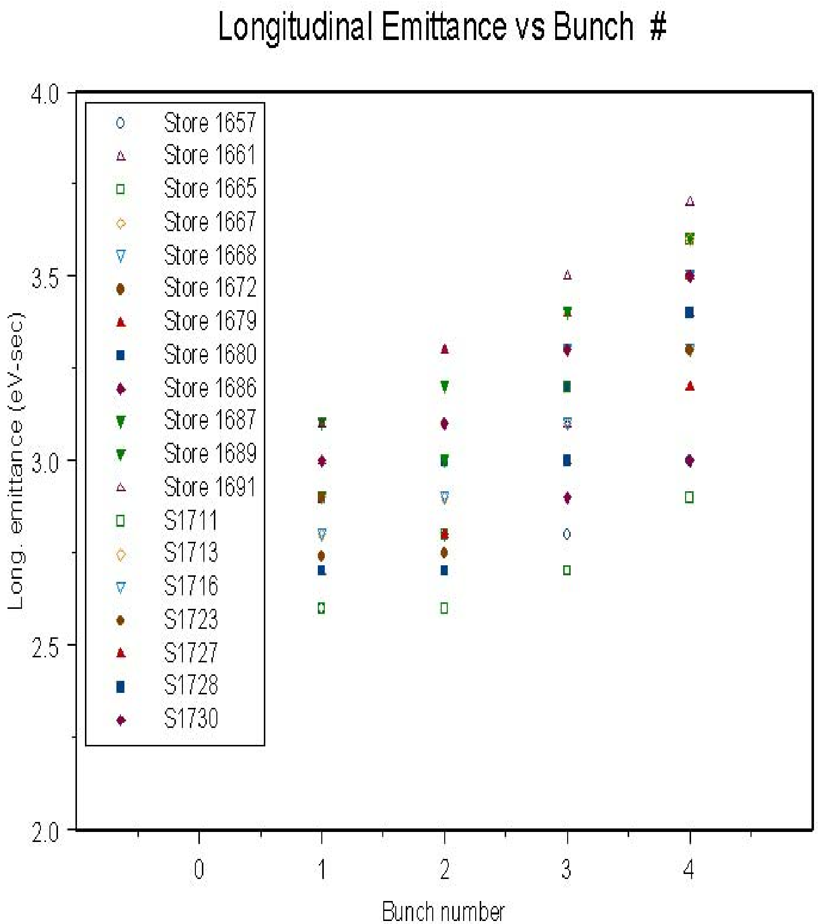


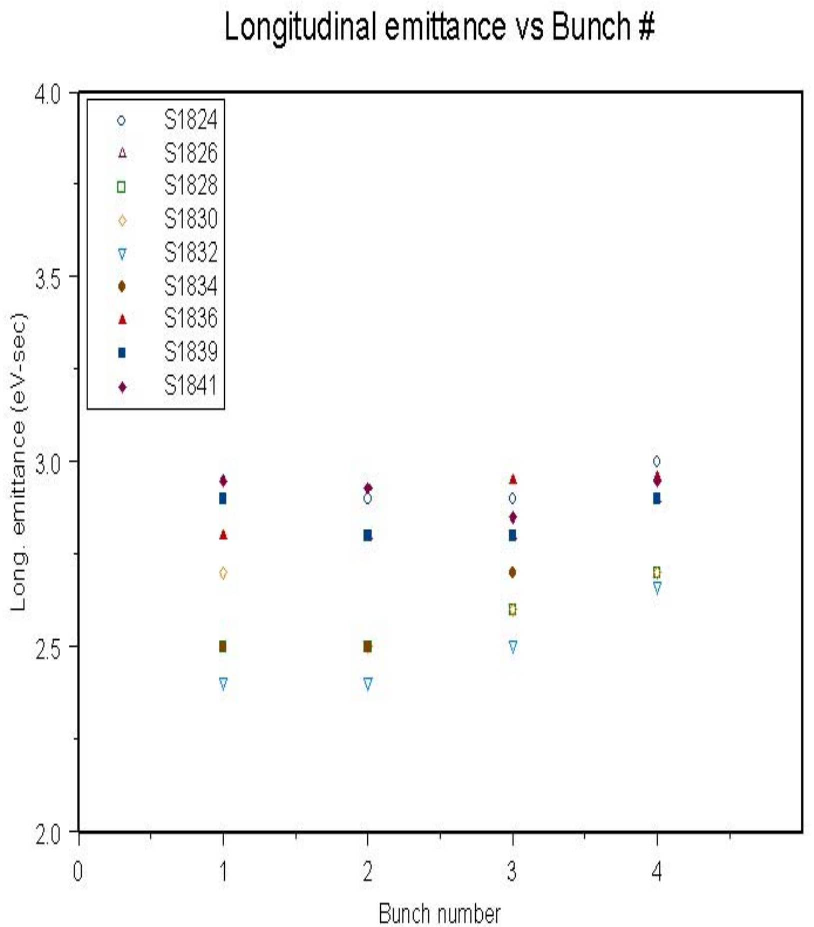
Without



With

Effect of Beam loading compensation on Pbar longitudinal emittance

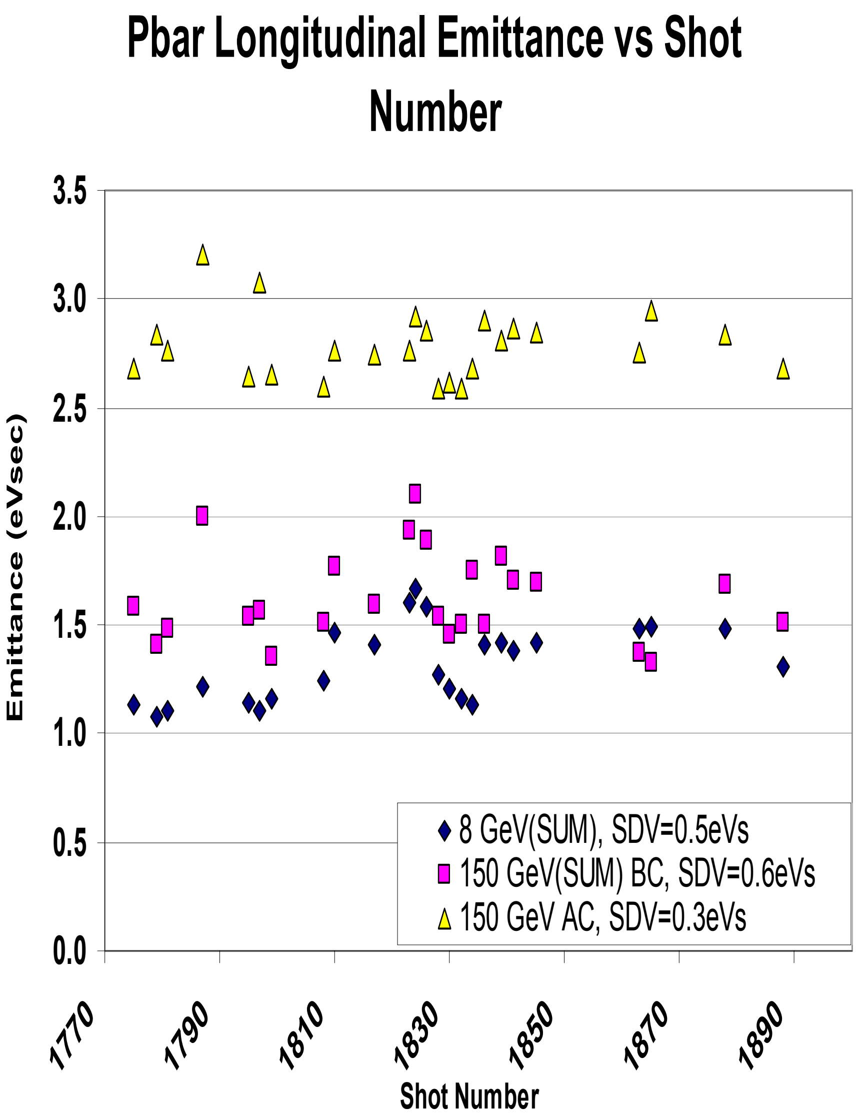


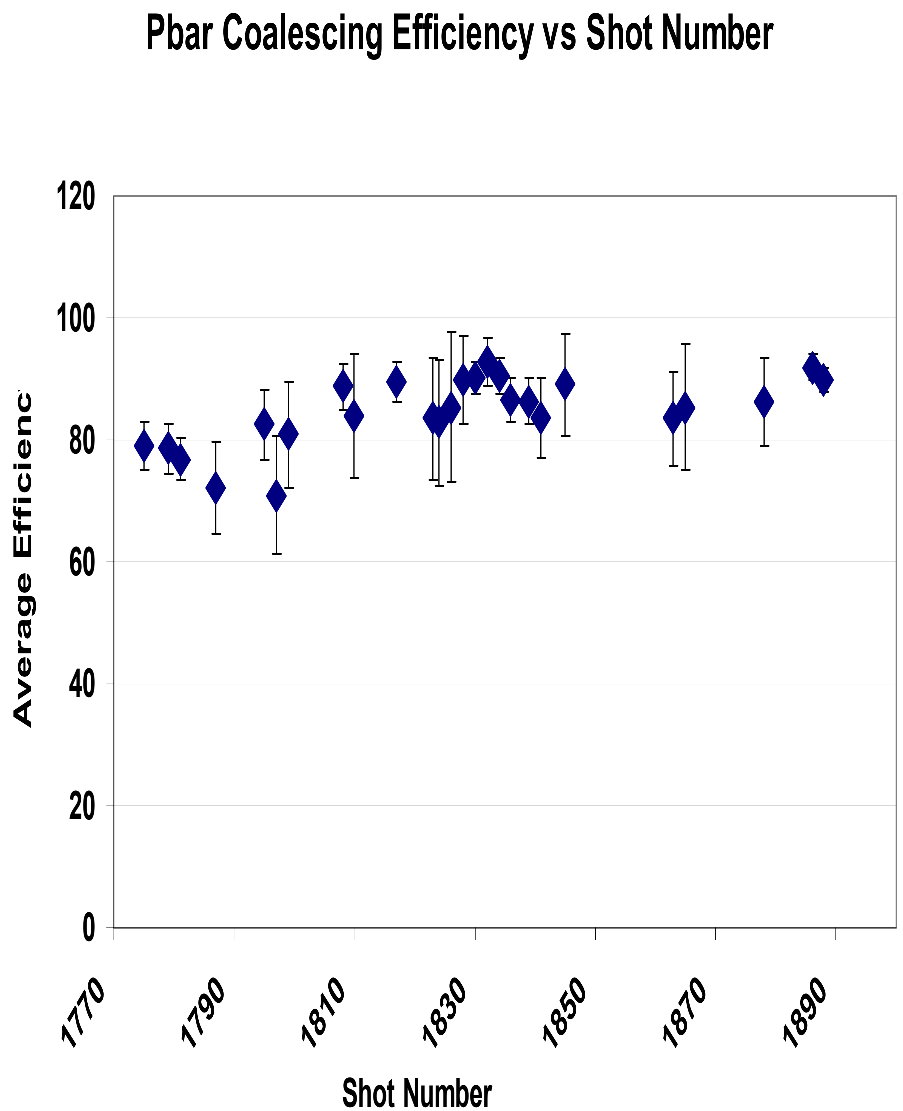


Without

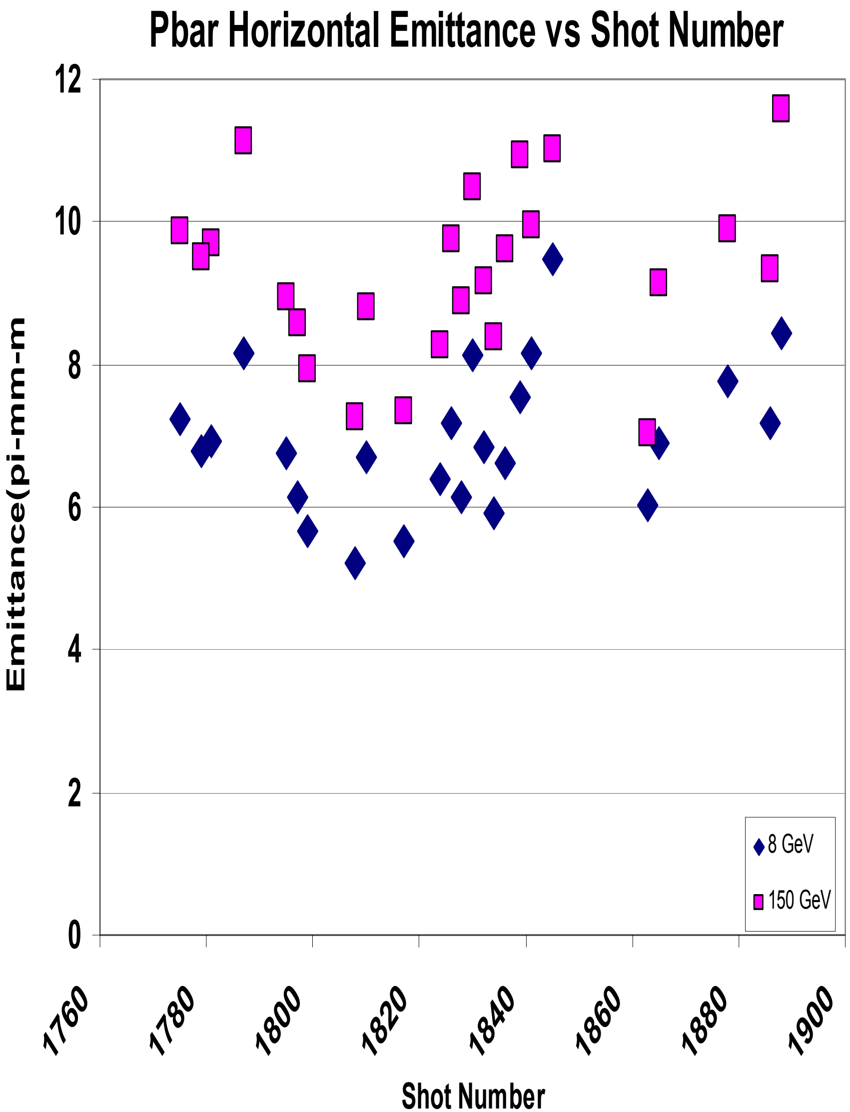
With

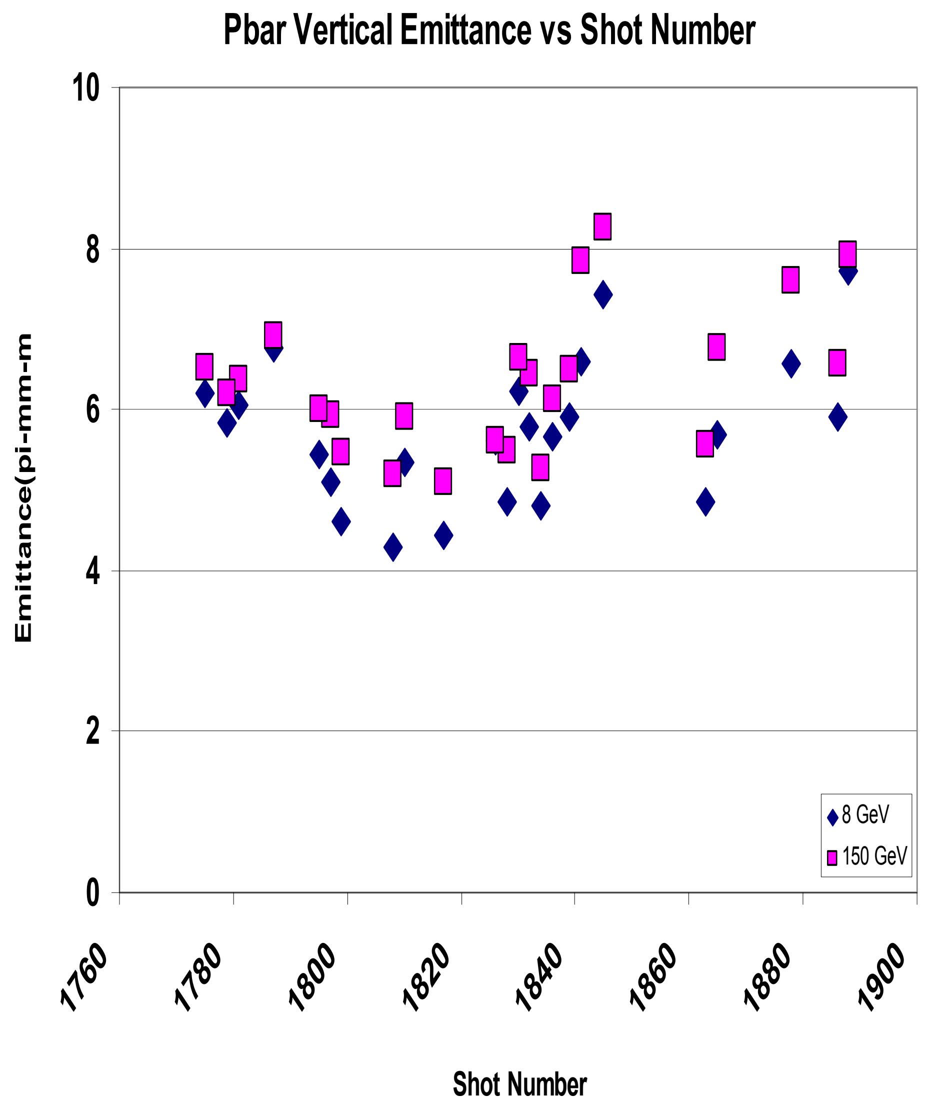
Longitudinal Emittance of pbar beam in MI





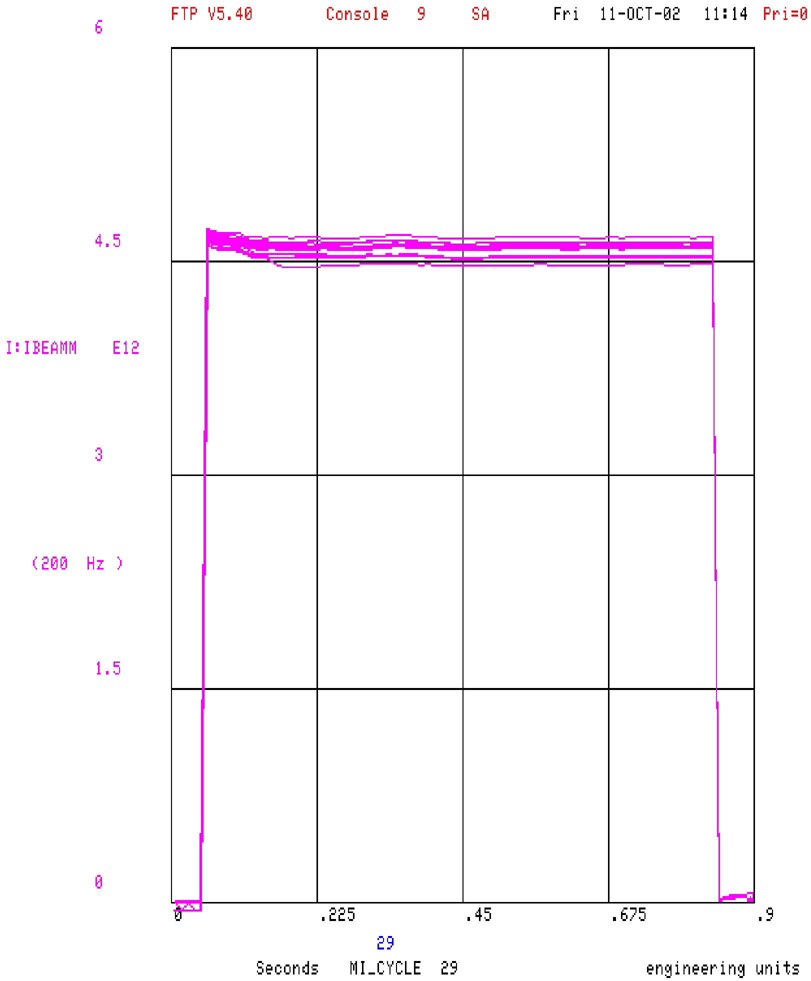
Pbar Transverse Emittance

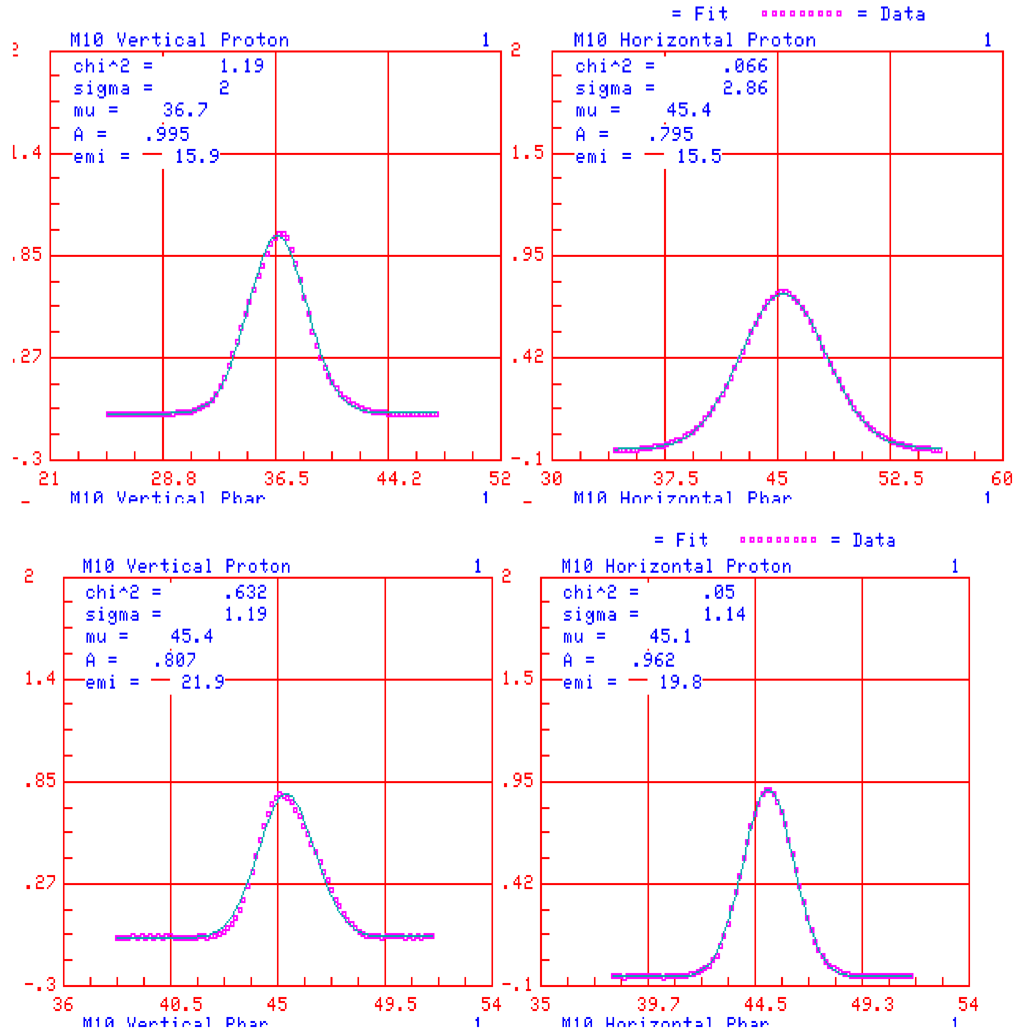




Dispersion correction of 1.5 pi mm-mr at 150 GeV not included.

120 GeV Anti-proton production cycle





1.46 sec cycle time

Parameter	Run IIa Goals	Current Performance (MI)
Protons/bunch	2.70E+11	3.00e+11 (7 bunches) 2.5e+e11 (5 bunches)
Proton coalesced Efficiency	0.90	0.85 (7 bunches) 0.95 (5 bunches)
Acc -> 150 GeV coalesced Efficiency	0.90	0.85-0.95%(Accumulator longitudinal emittance)
Proton emittance (95%, norm)	20	20 πmm-mr
Pbar emittance (95%, norm)	15	<10 πmm-mr
Longitudinal Emittance (proton, 95%)	3	2.8 eV-sec (7 bunches) 2.2 eV-Sec (5 bunches)
Longitudinal Emittance (pbar, 95%)	2	2.8 eV-sec (Accumulator longitudinal emittance)

Main Injector is working to improve on emittances of proton beam.

Main Injector Longitudinal emittance growth

Main Injector Injection

- Coupled-bunch motion (modes 16 & 36) observed on first turn in Main Injector.

  Solution: 1.) Check all existing passive dampers in Booster

  2.) Increase gain on mode 36 active damper (presently ≈ 20dB attenuation.)

  3.) Build active damper for mode 16.

- Residual coupled-bunch motion from the Booster drives the MIRF cavity modes at 128 MHz and 224 MHz

  Solution: Build a bunch by bunch longitudinal damper in the MI

Main Injector Longitudinal emittance growth…

Transition

- There is a 10 degree phase error on the $29 cycles crossing transition with heavy transient beam loading which results in dipole oscillations that persist throughout the remainder of the cycle.

Solution: The present high level transient feed-forward BLC system can reduce this phase error by a factor of three. The system needs to be modified before it can operate throughout the entire cycle.

Flattop

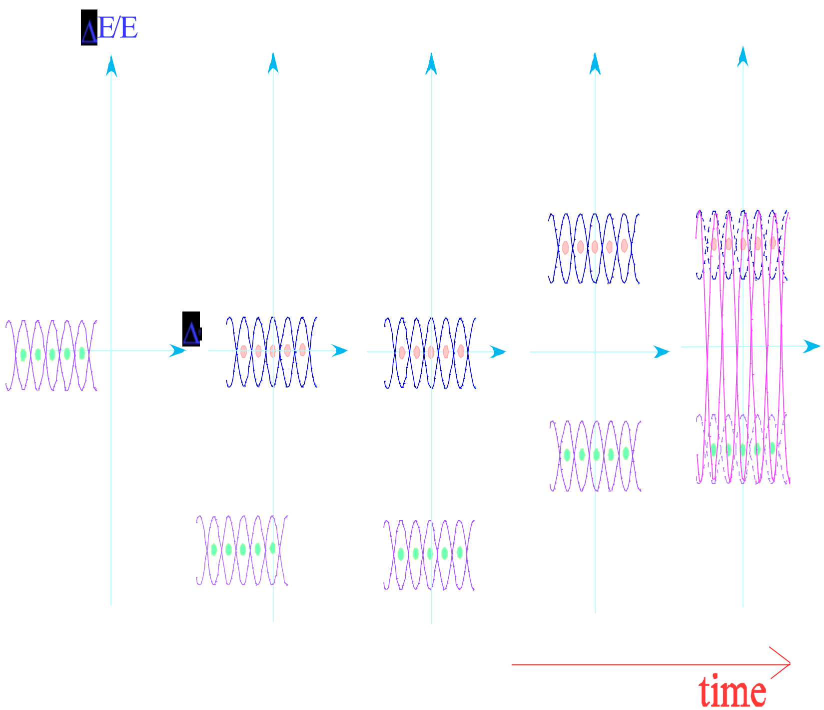
- The excitation of the MIRF cavity mode at 224 MHz is observed to grow throughout the acceleration cycle.

Solution: The new bunch by bunch damper should effectively damp these coupled-bunch oscillations.

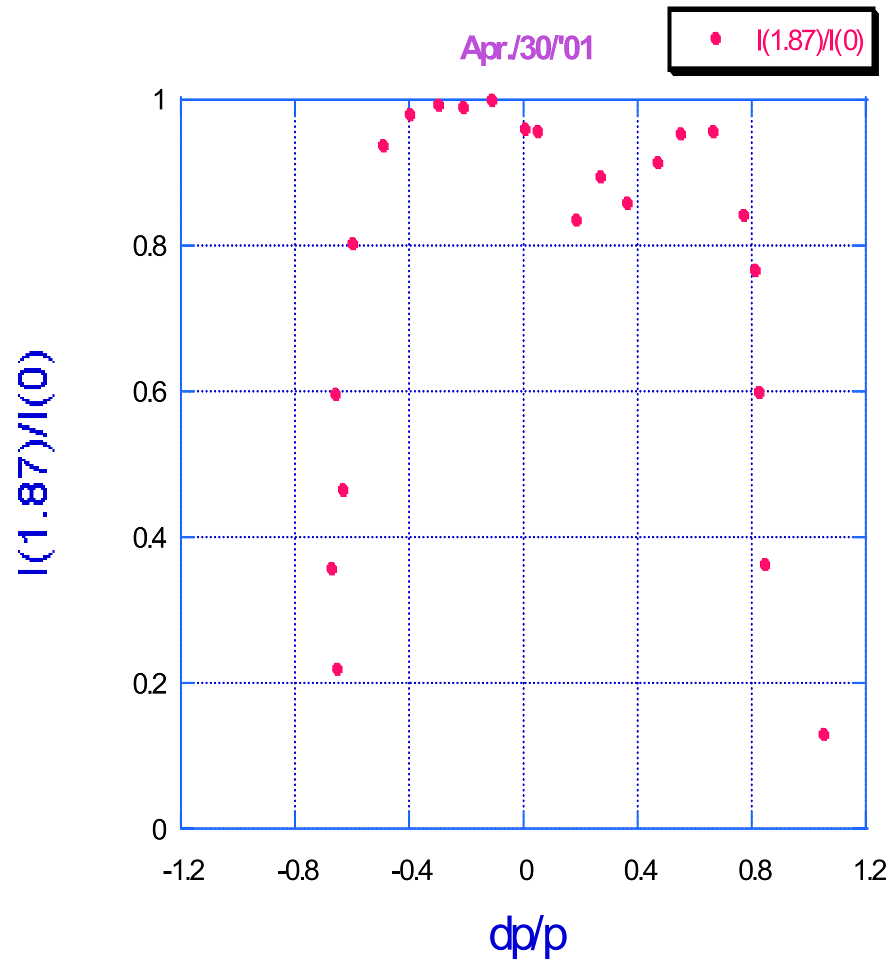
Dampers in Main Injector

- Longitudinal Dampers
  - Benefits to Bunch Coalescing for Collider
    - "Dancing Bunches" degrade Proton coalescing and ε_L
    - We are deliberately blowing ε_L in Booster
  - Benefits for Pbar Stacking Cycles
    - Bunch Rotation is generally turned off ! (x1.5 stack rate?)
    - Slip-Stacking etc. (Run IIb) will require stable bunches
  - Needed for eventual NUMI operation
- Transverse Dampers
  - Injection Damper
  - RW instability

Slip Stacking in MI (Run-IIb R&D project)

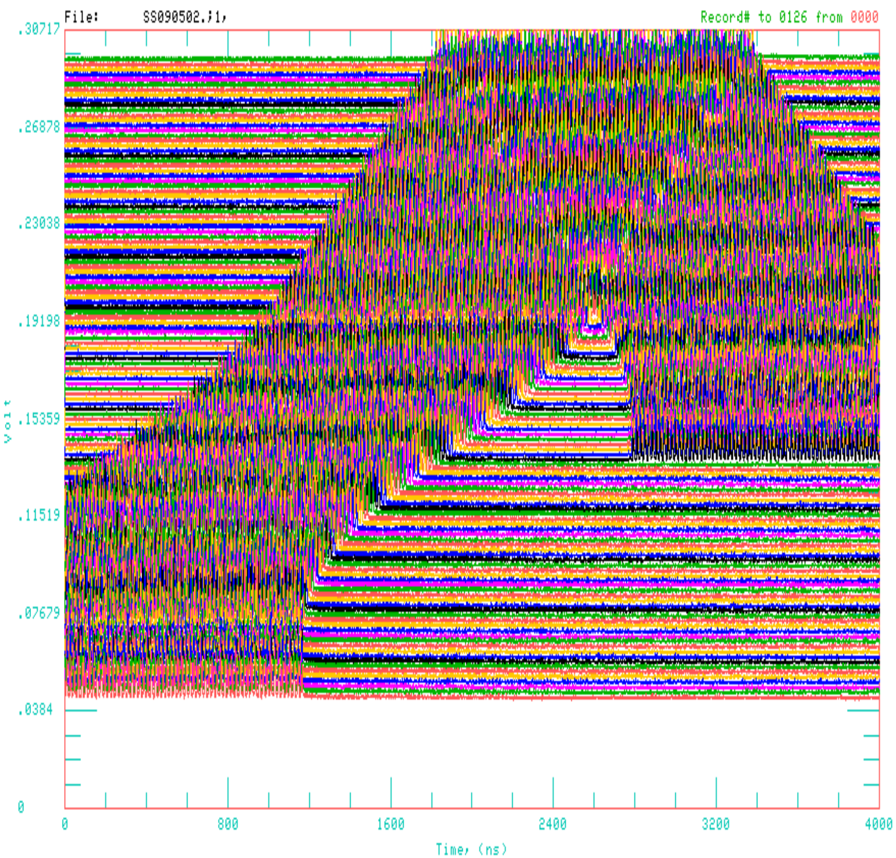


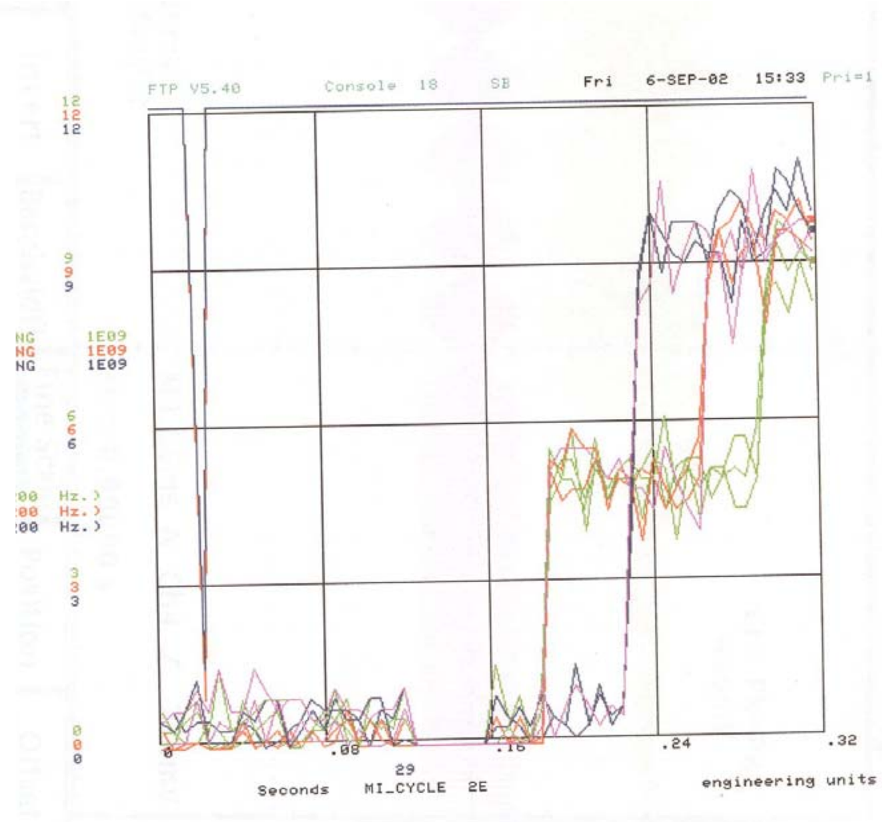
Slip Stacking Process



Momentum Aperture of MI

Slip Stacking…





- 'Slip Stacking' is working with low intensity.
- For high intensity operation, the development of the feedback and feed forward beam loading compensation system are under way.

Summary

• MI8 line and Main Injector lattice has been matched. Beta and dispersion is matched to better than a few %.

• Proton emittance growth is an issue we are investigating. The coalescing efficiency is about 85%.

• Antiproton beam from Accumulator→MI→TeV also has less than 2 pi mm-mr emittance growth. The longitudinal emittance growth is as expected.

• The antiproton coalescing efficiency is co-related with the pbar longitudinal emittance. For small emittances MI has achieved 95% coalescing efficiency. On average the coalescing efficiency is about 85%.

• Beam loading compensation has been implemented for protons and pbars. This has improved coalescing performance.

• An R&D for longitudinal and transverse dampers are under way .

• A R&D for slip stacking process is underway.

• An R&D for 2.5 MHz acceleration of pbar is also in progress.