# Main Injector Status and Plans

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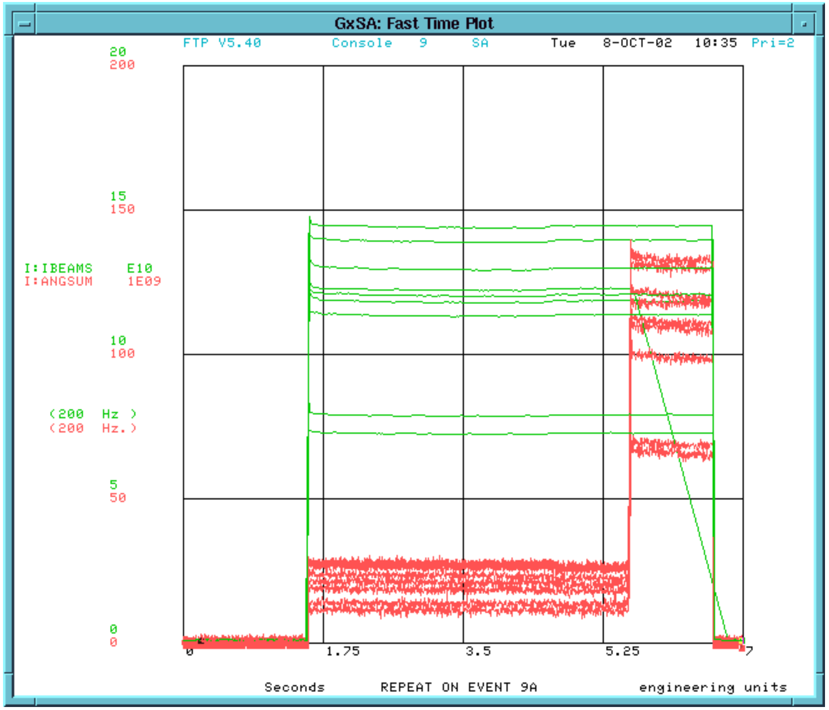
MID/BD
10/17/02
Director's review

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



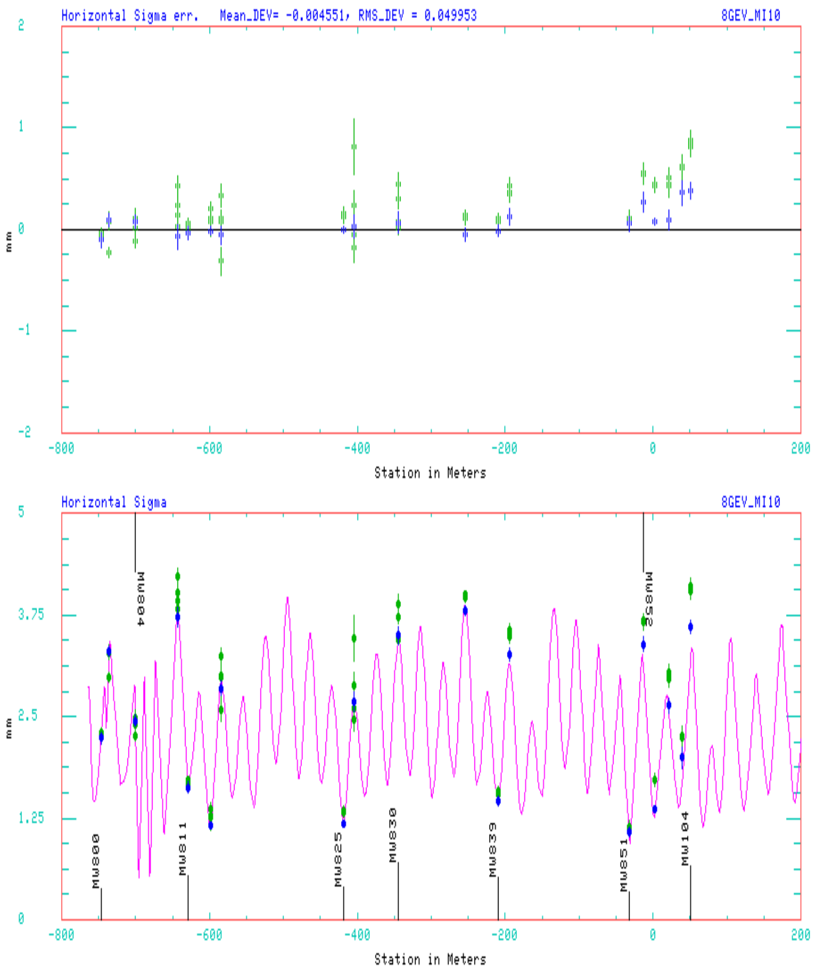
# Main Injector Operation

- 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

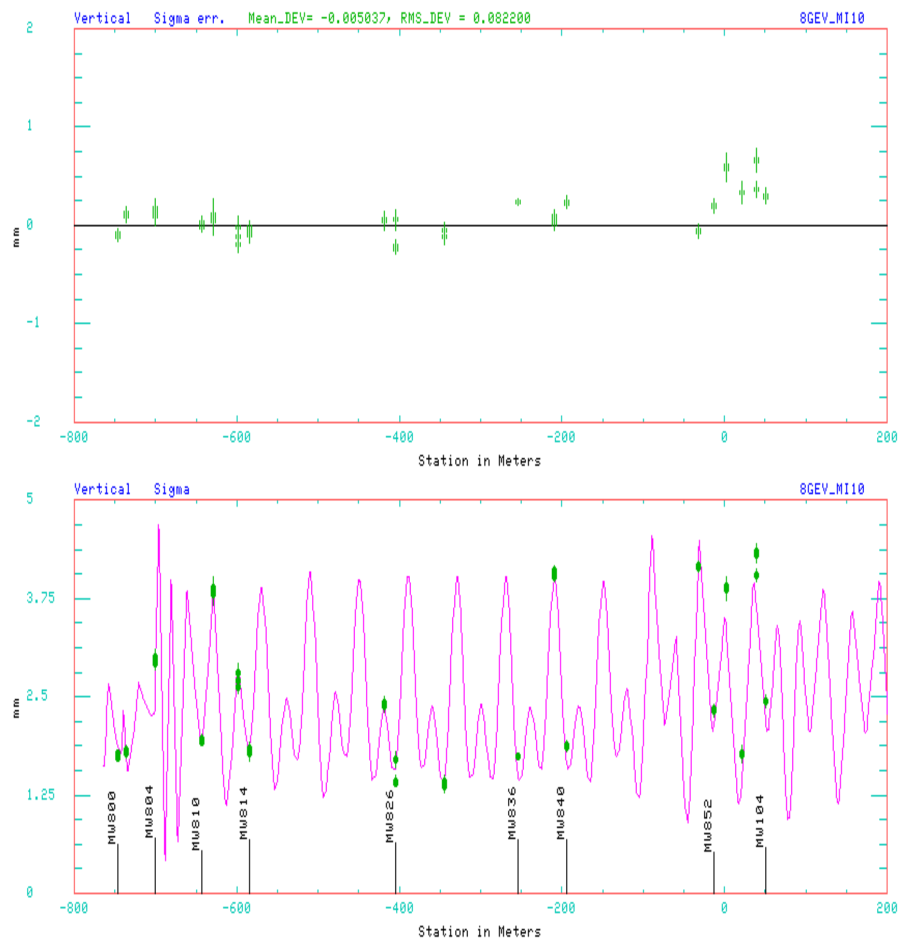
# Main Injector Recent Developments

- 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.

# Proton beam sigma before the injection lattice match

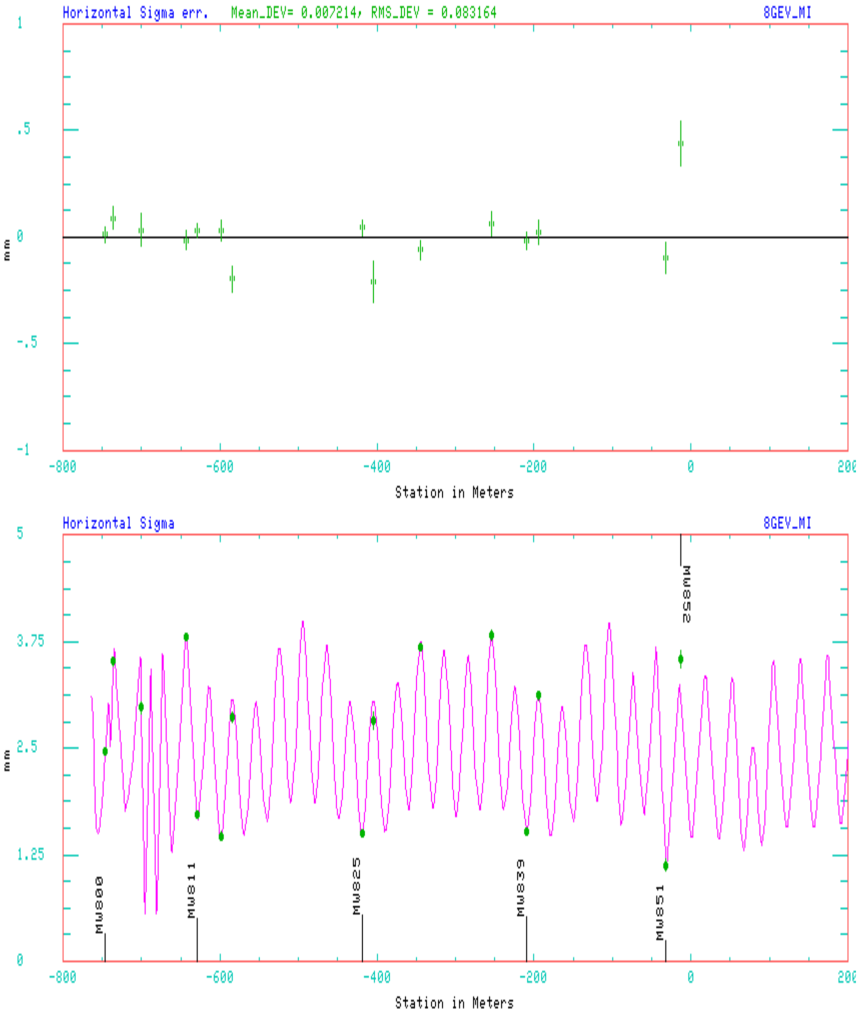



Horizontal Plane

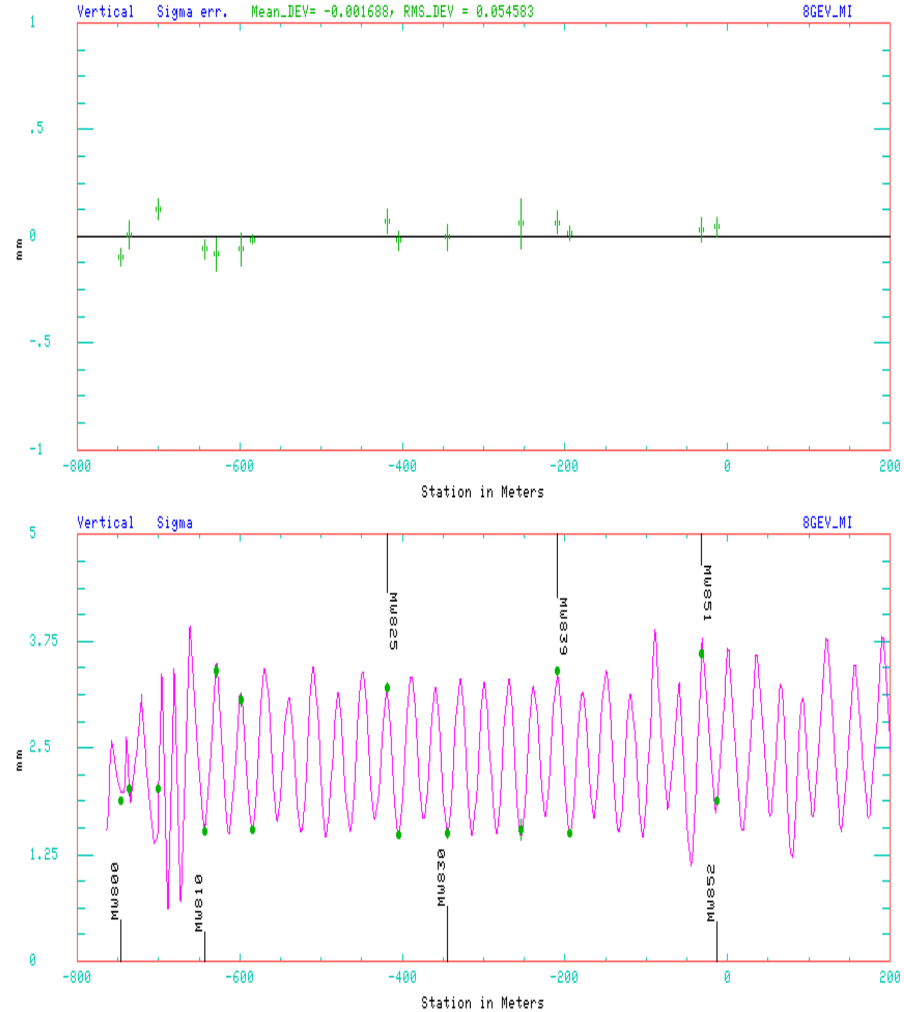



Vertical Plane

# Proton beam Sigma after injection lattice match

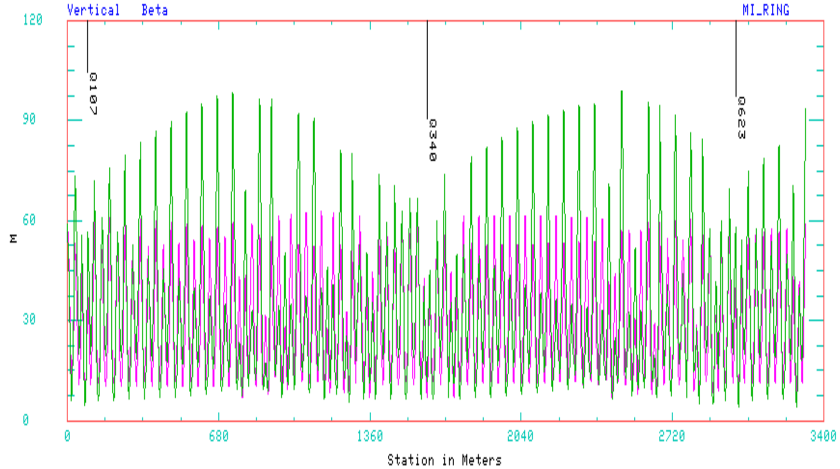


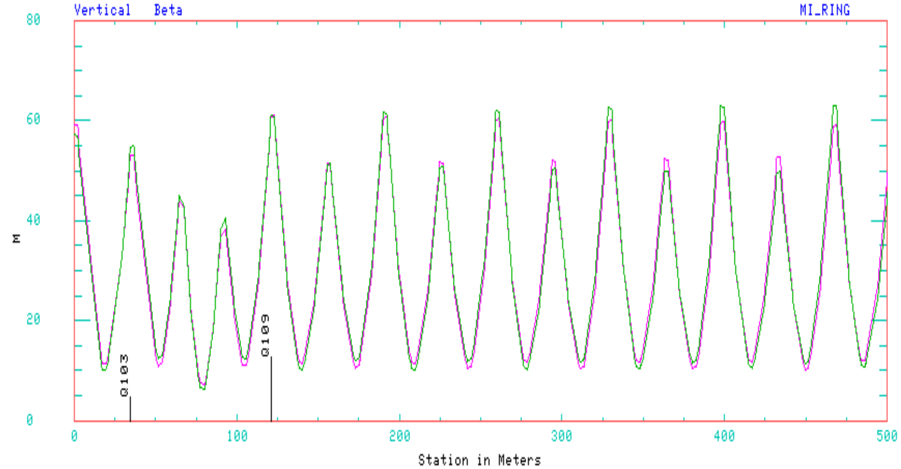

Horizontal

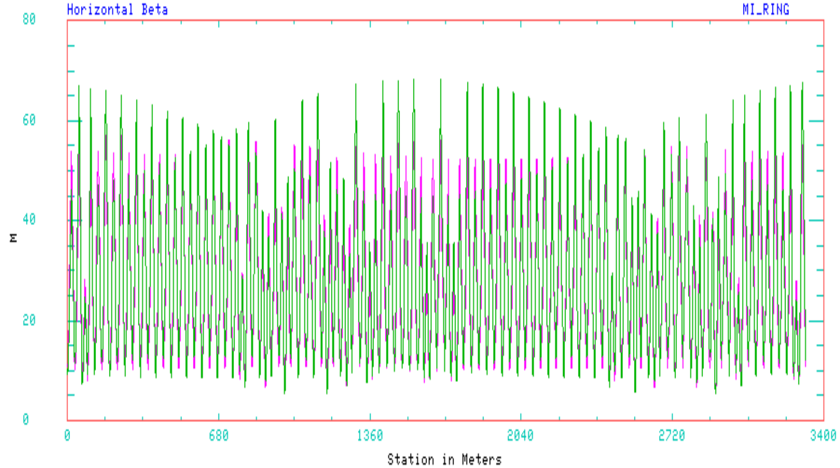


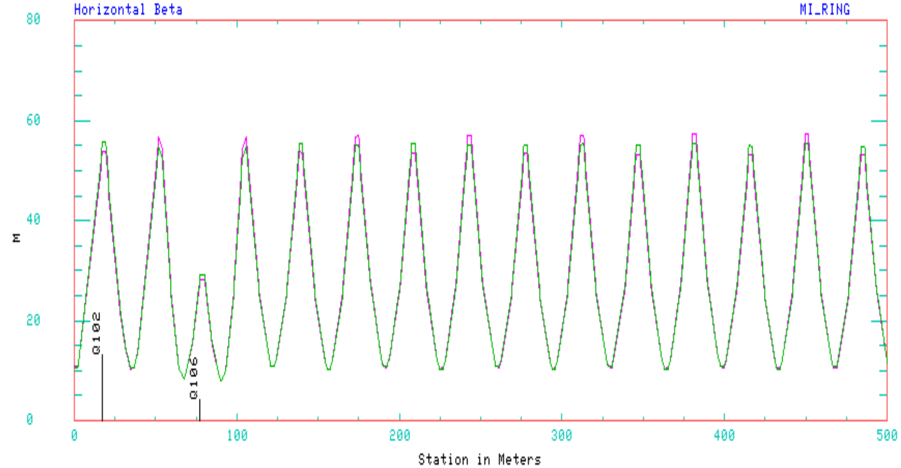

Vertical

# Projected Main Injection beta vs. calculated MI beta



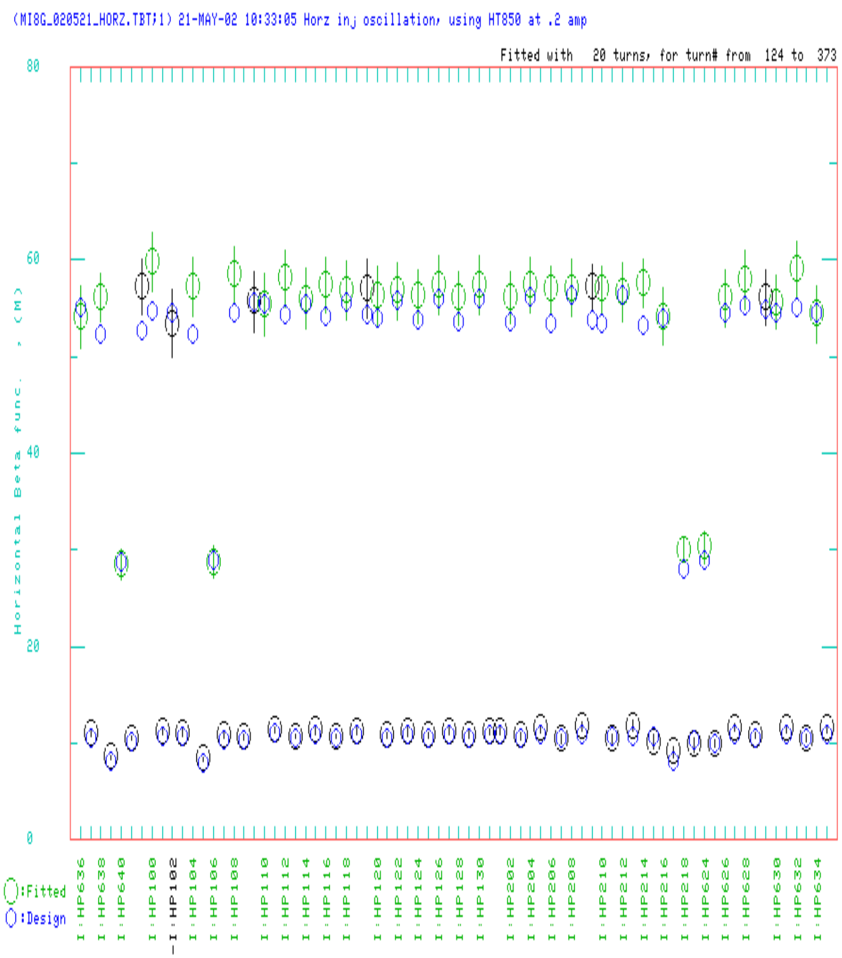



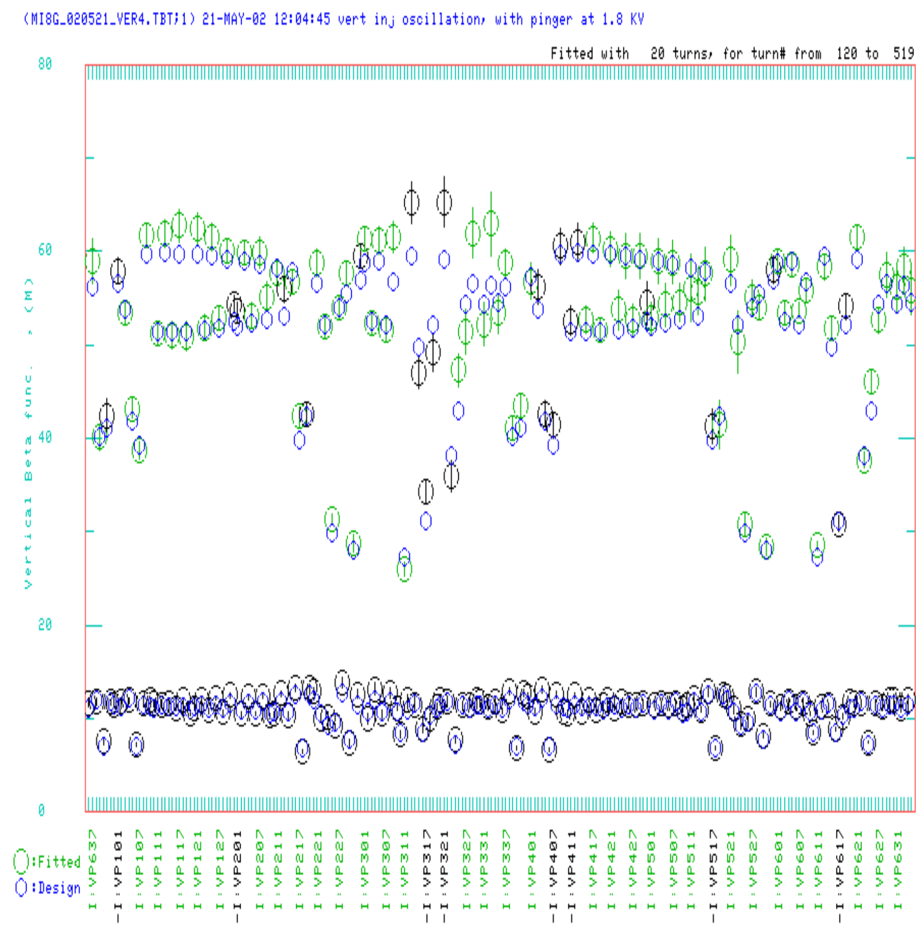

Before Injection match

After Injection Match

# Circulating beam Beta function in the Main Injector at 8.9 GeV

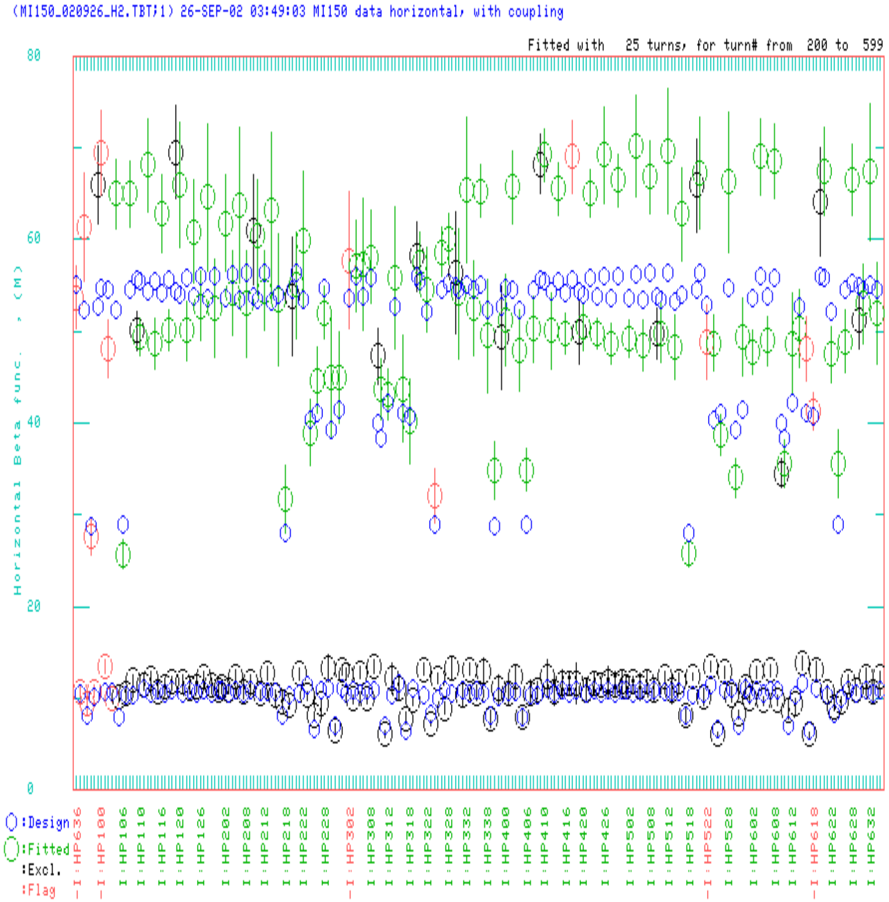


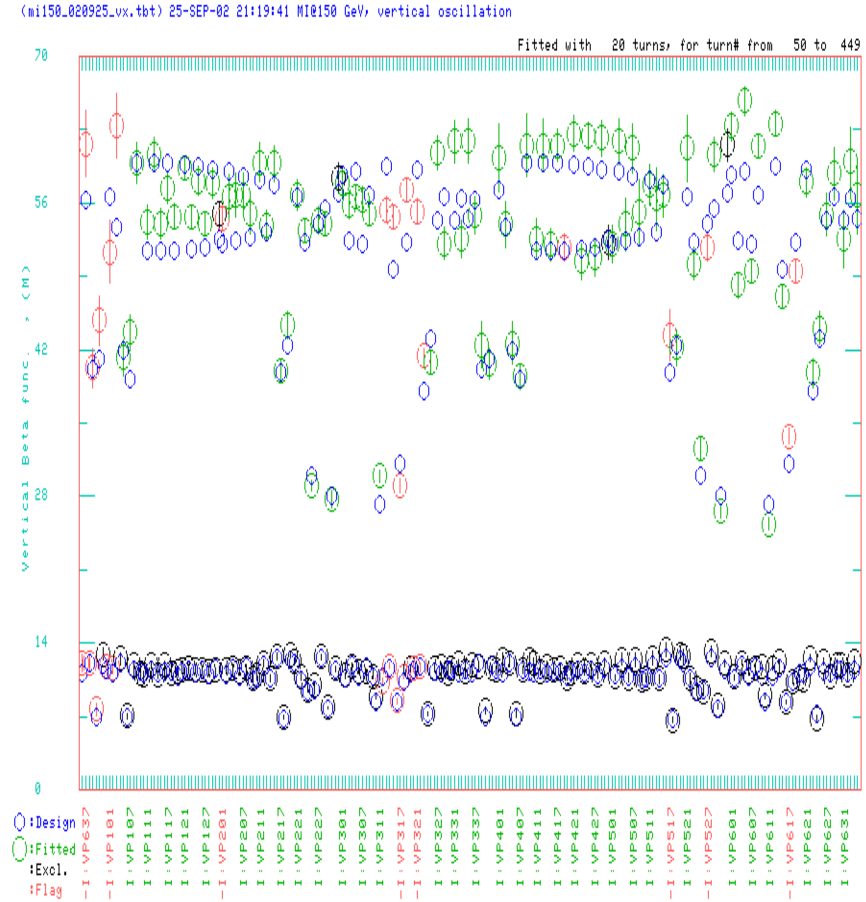

Horizontal




Vertical

# *Beta Function of Main Injector at 150 GeV*



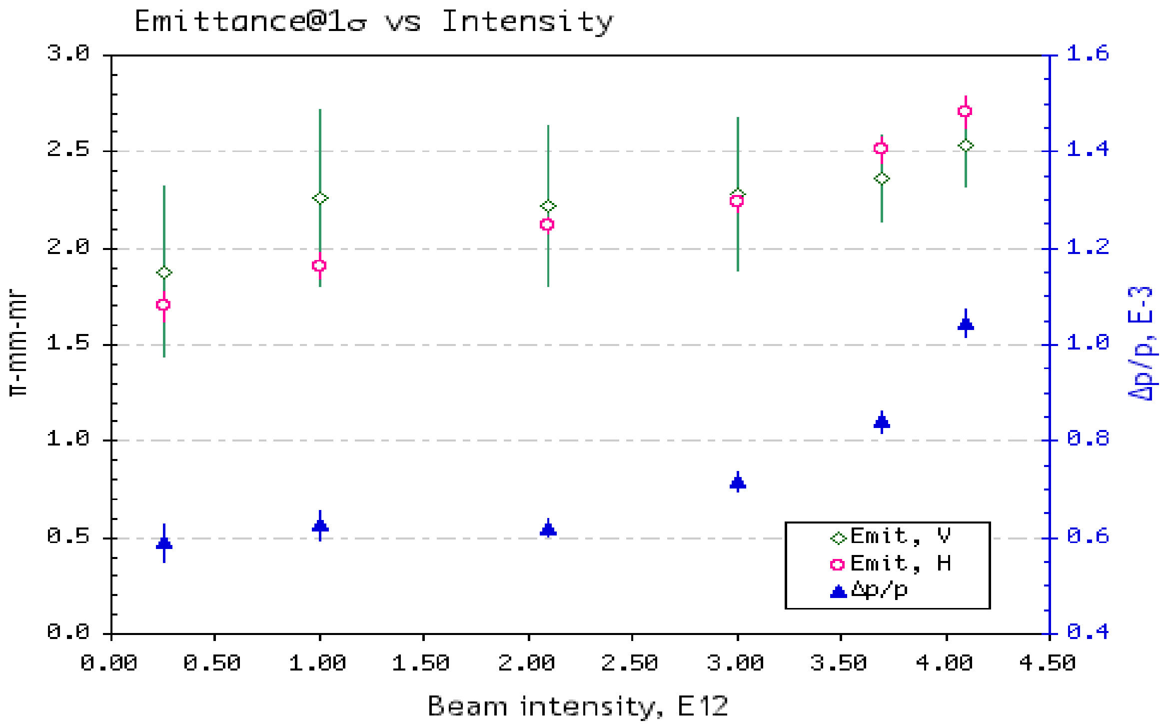

Horizontal Plane

Vertical Plane

* Data taken with substantial betatron coupling.

** Not on central orbit. Measured while phase locked to Tevatron at 150 GeV

# Proton Beam Emittance vs. Intensity

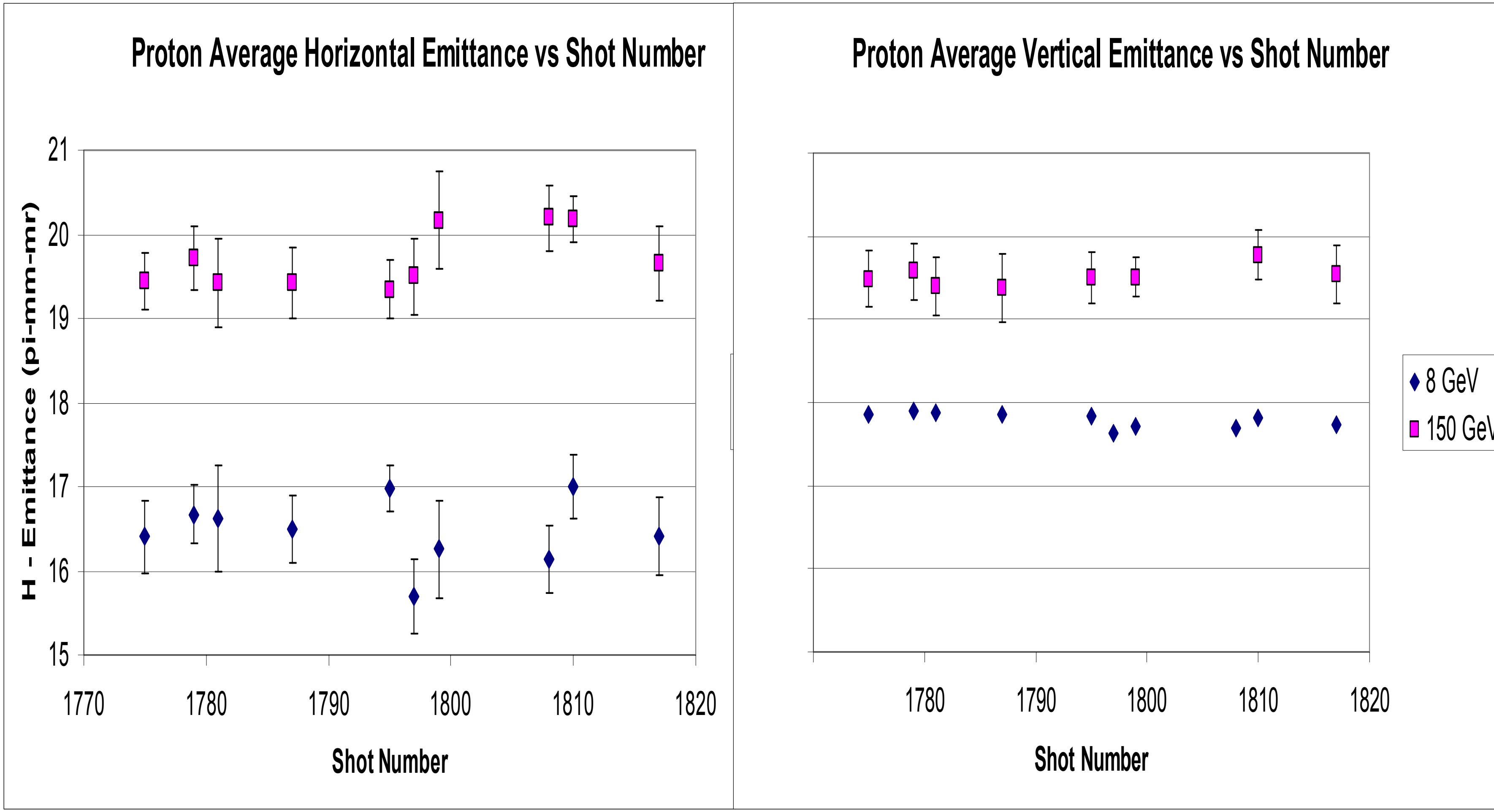



The horizontal flying wire measurement agree with the emittance measured by the Multiwires. Vertical is off by about 1 pi mm-mr. These are 1 sigma emittances.

# 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 $\pi$-mm-mrad.
  - Less than 15% transverse emittance growth is allowed through the cycle
- 2 eV-sec longitudinal emittance can only be achieved with 5 Booster bunches. This will require Booster intensity to MI >5e12.

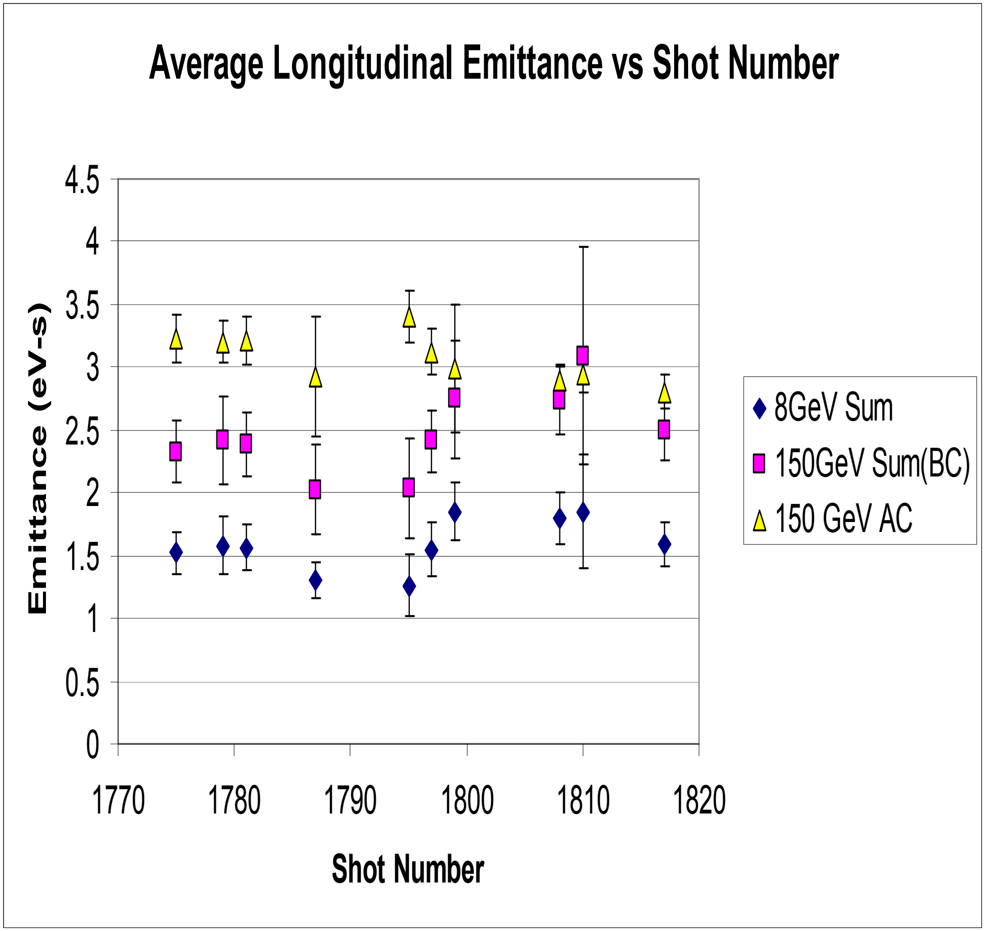
# Transverse Emittance of proton beam

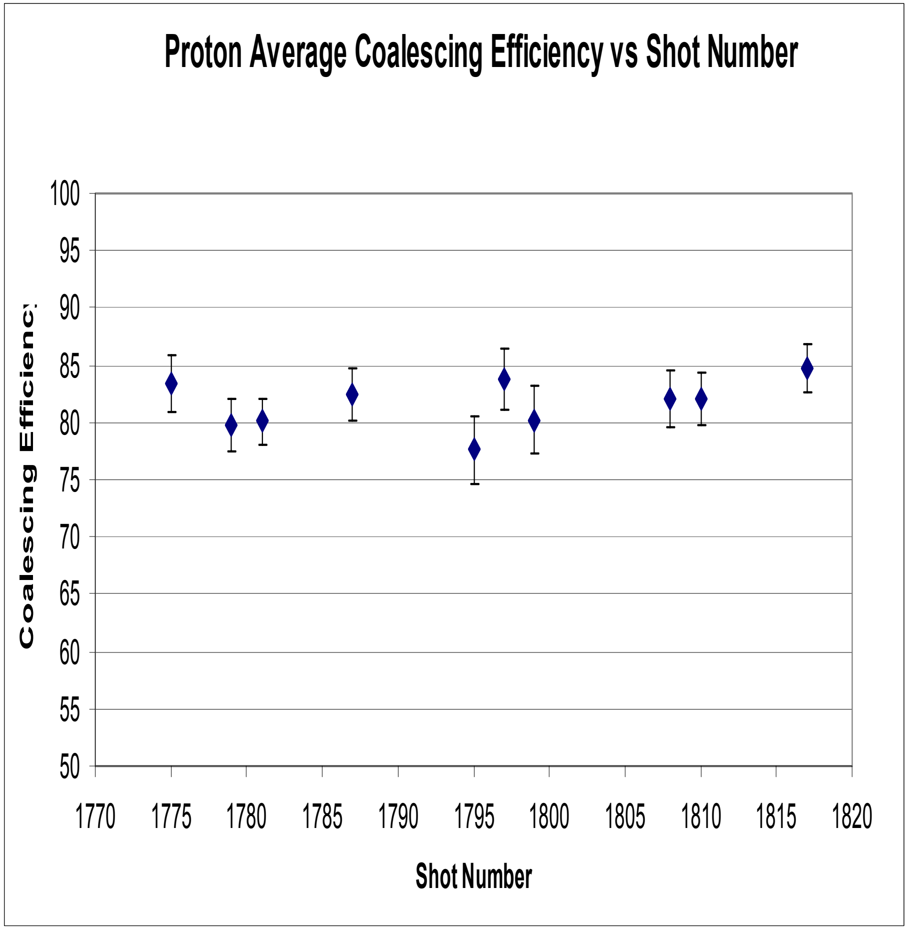



- We need to understand these emittance growth and minimize them.

Horizontal data include dispersion effects, and should be 1.5 pi smaller (dispersion correction).

# Proton coalescing

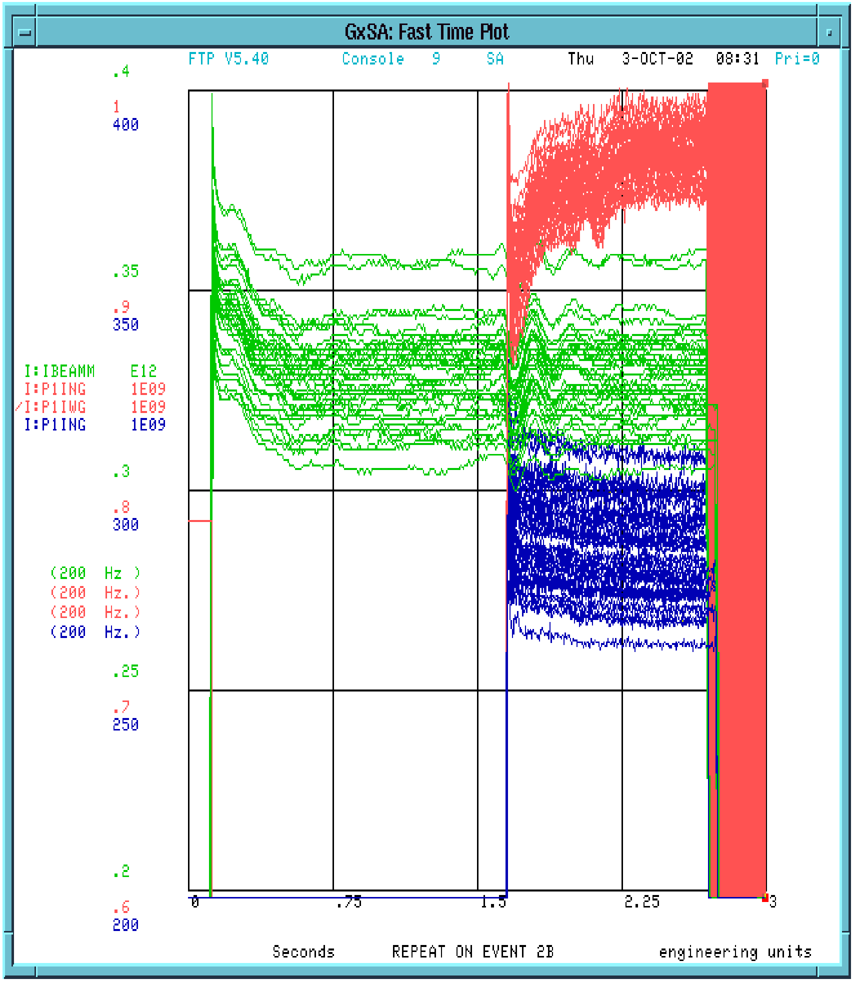


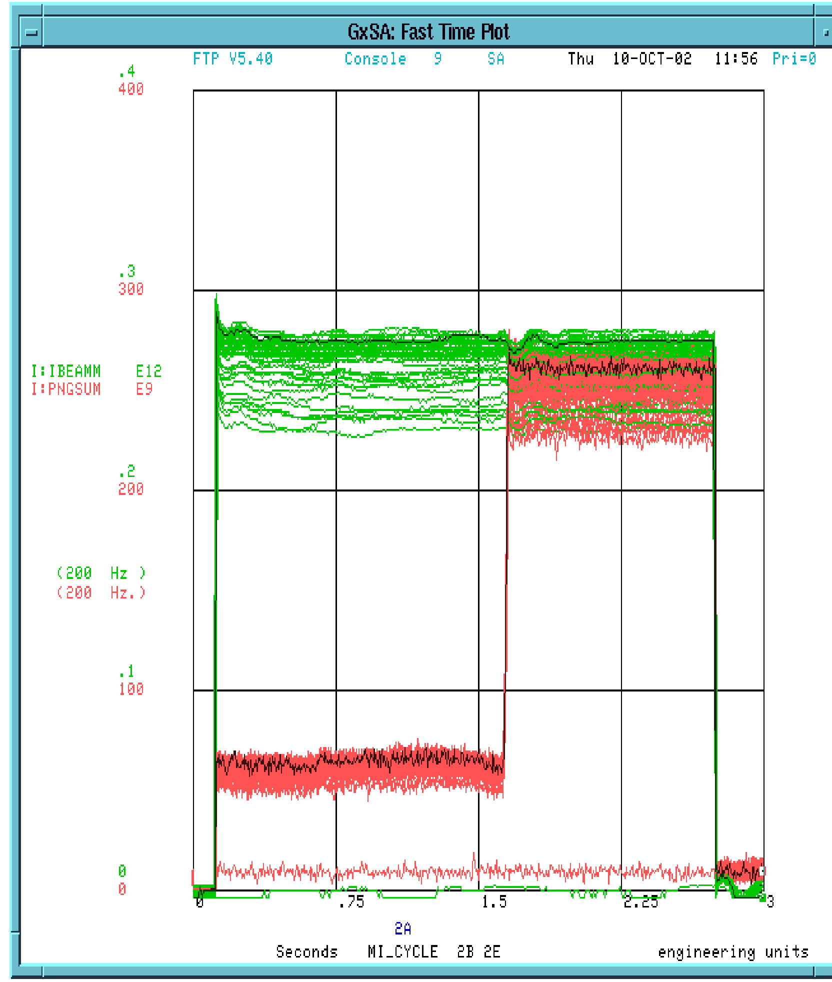

Longitudinal Emittance <3eV-sec for recent shots 7 bunches.

Efficiency >80% for 7 bunches.

# Proton coalescing




7 bunches, 80% efficiency, 2.8 ev-Sec

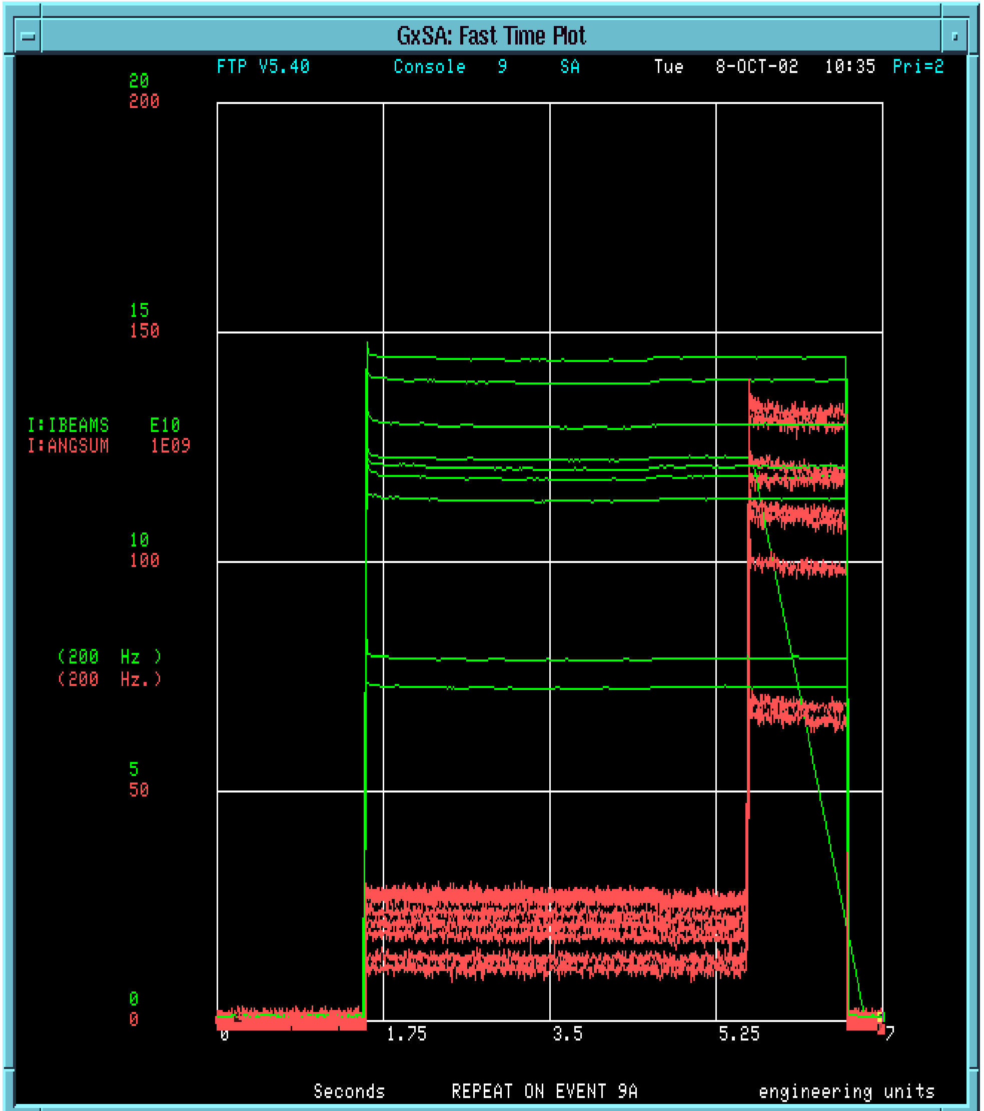



5 bunches, 95% efficiency, 2.2 eV-sec

# Performance of MI for pbar

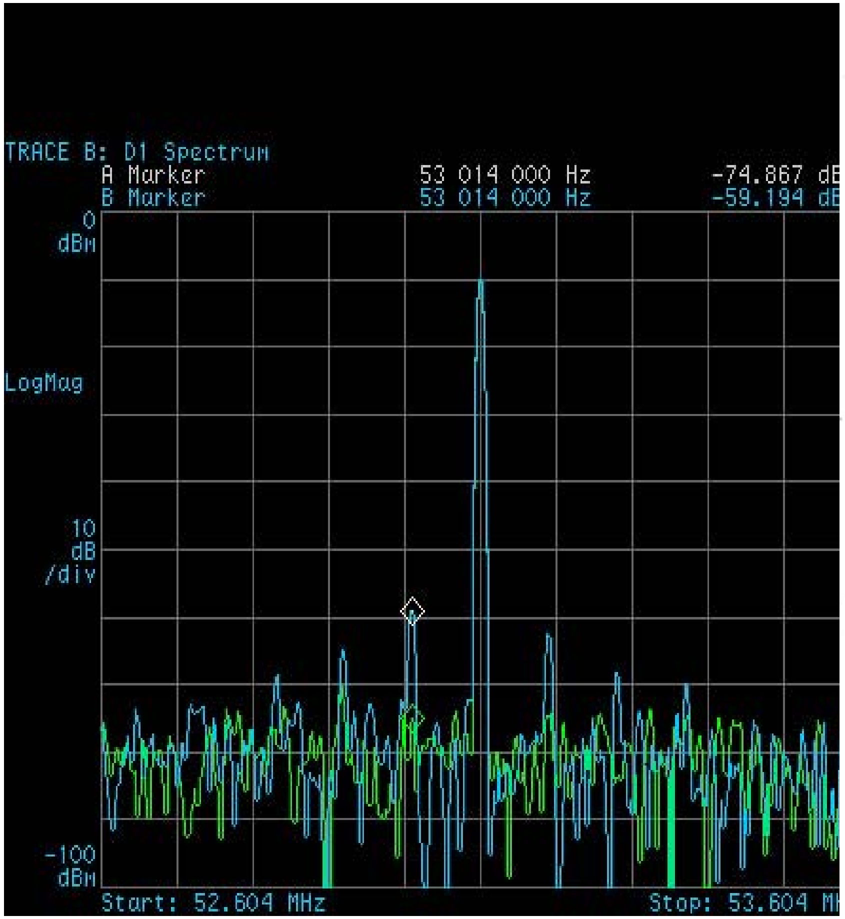
- During the Aug.-Sept. 02 we have commissioned the pbar feed forward beam loading compensation.
- The average pbar Coalescing efficiency is about 85% and has small dependence on the stack size in the accumulator.
  - The average Coalescing efficiency at the large stacks has been increased by 10-12% 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.

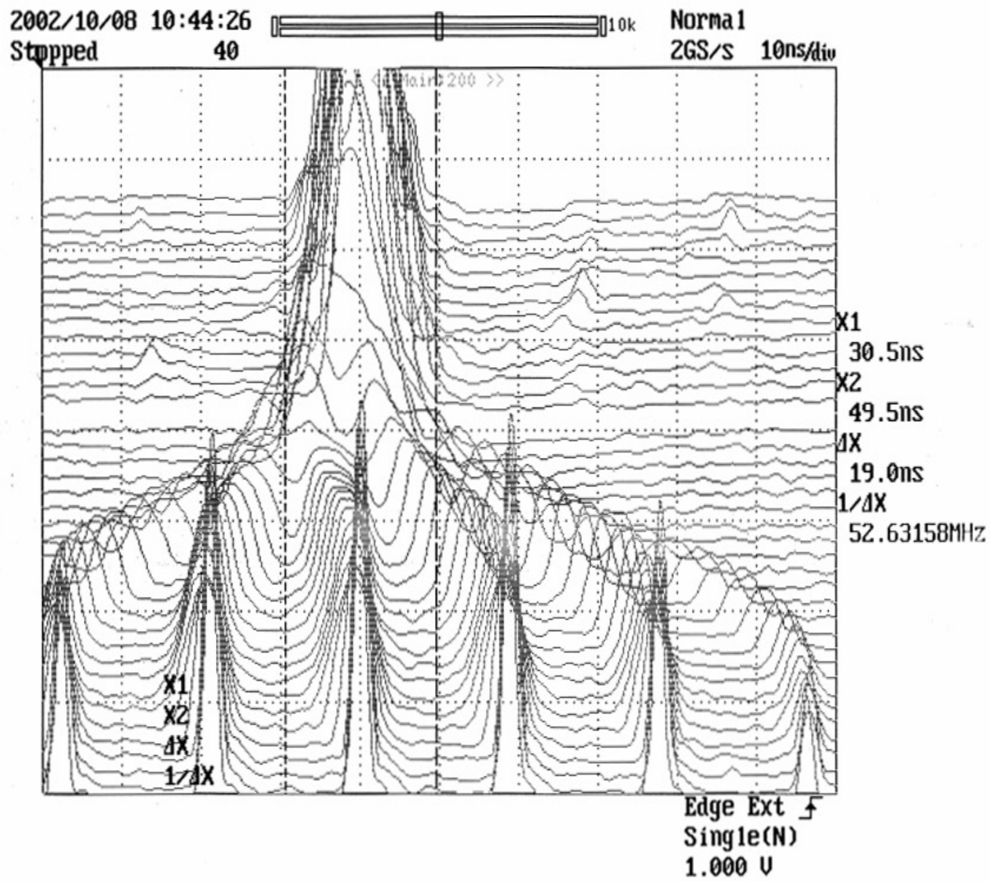
# *Pbar Acceleration and Coalescing Efficiencies*




- 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



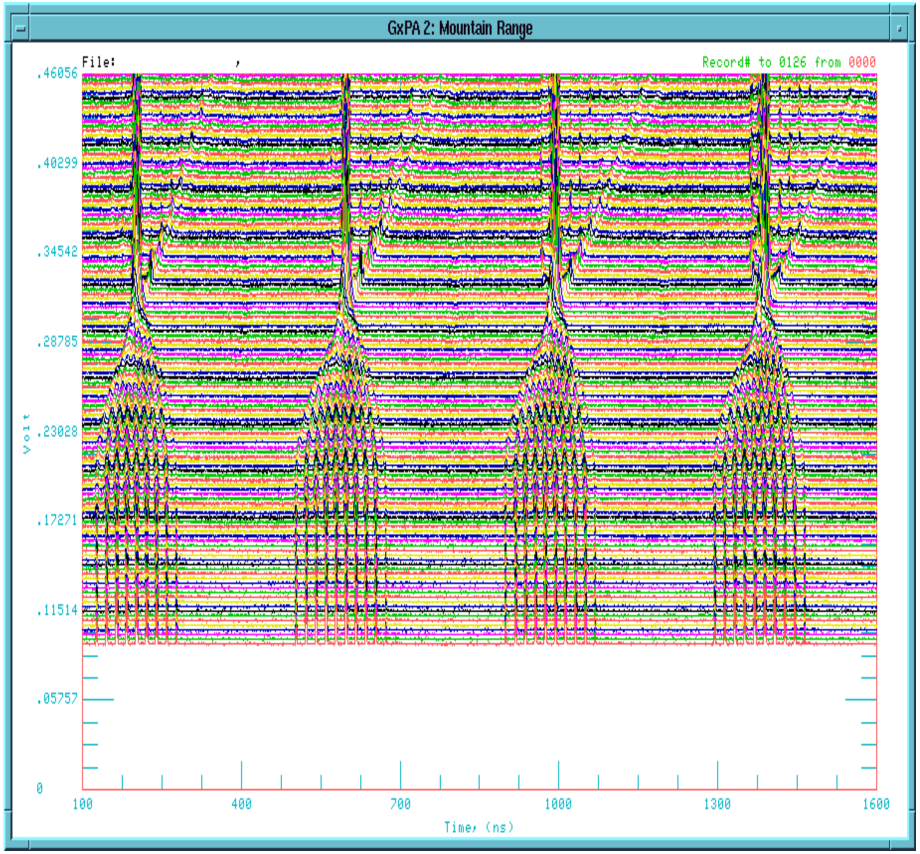



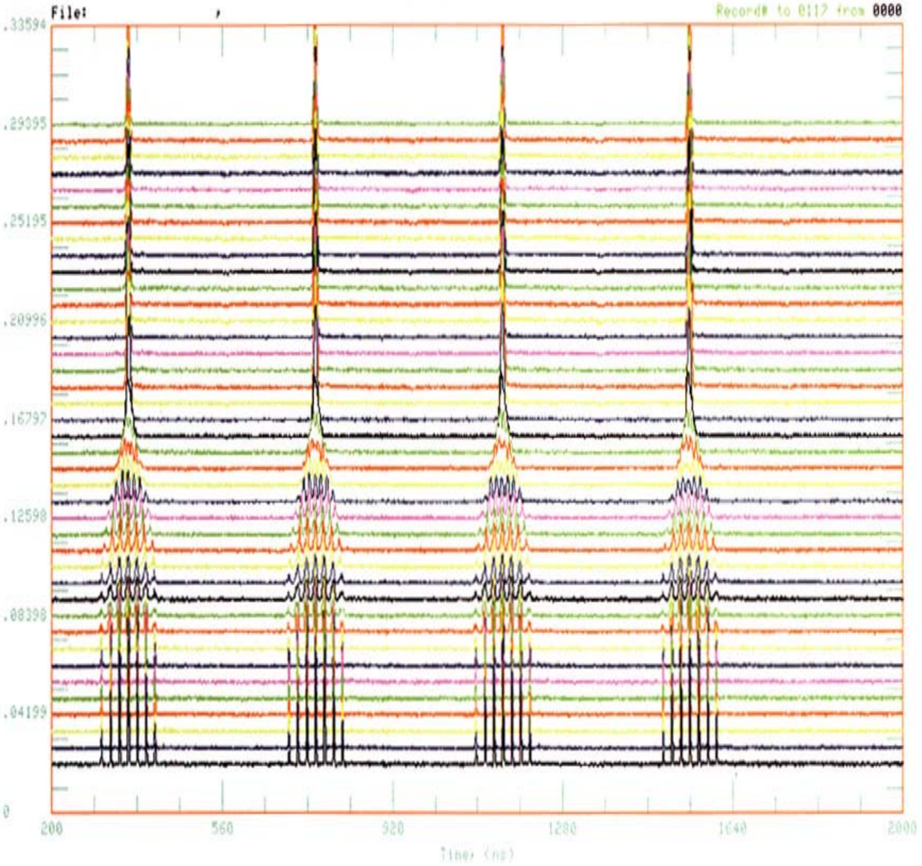

Green trace with beam loading compensation.

4th batch in the pbar transfer

Blue Without

# Pbar coalescing and beam loading compensation

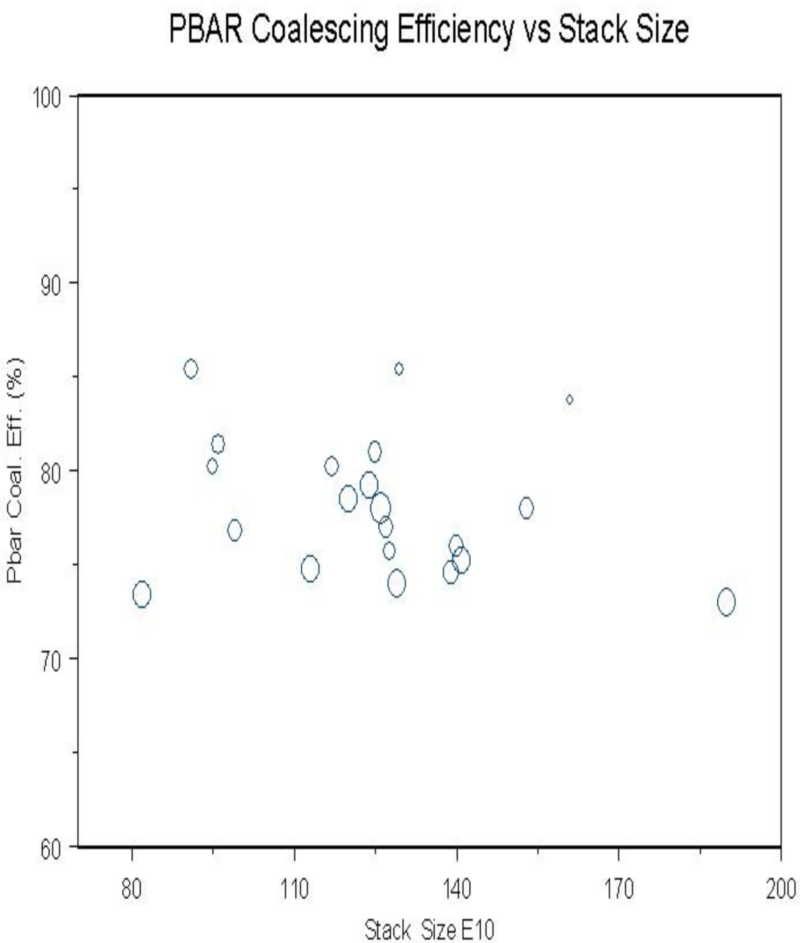


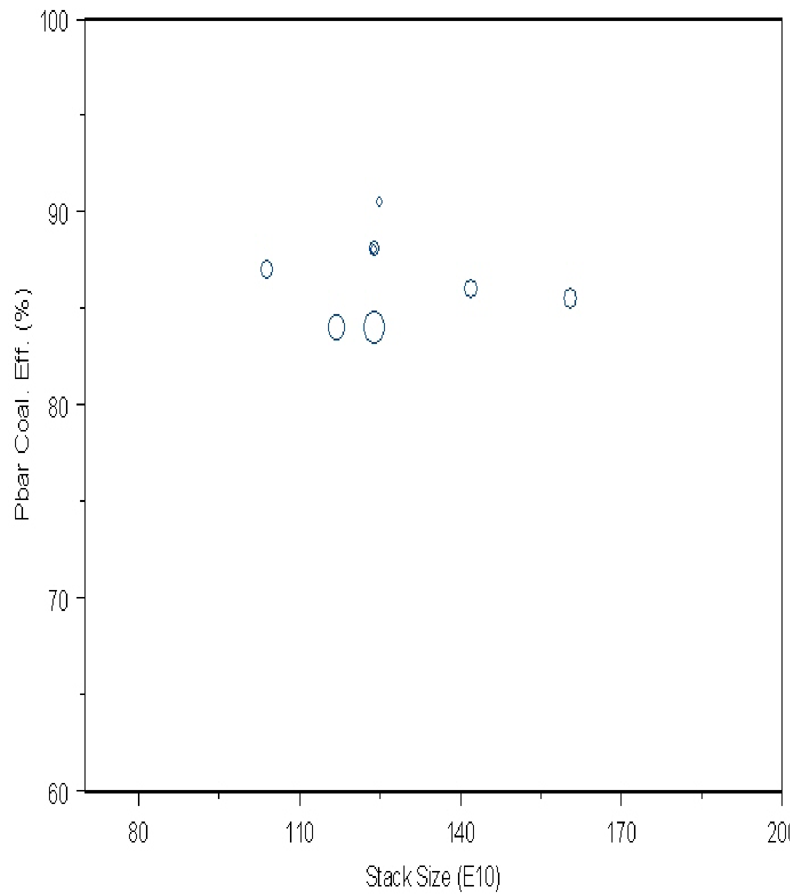

Without compensation

With compensation

# *Effect of Beam loading compensation on Pbar Coalescing Efficiency*

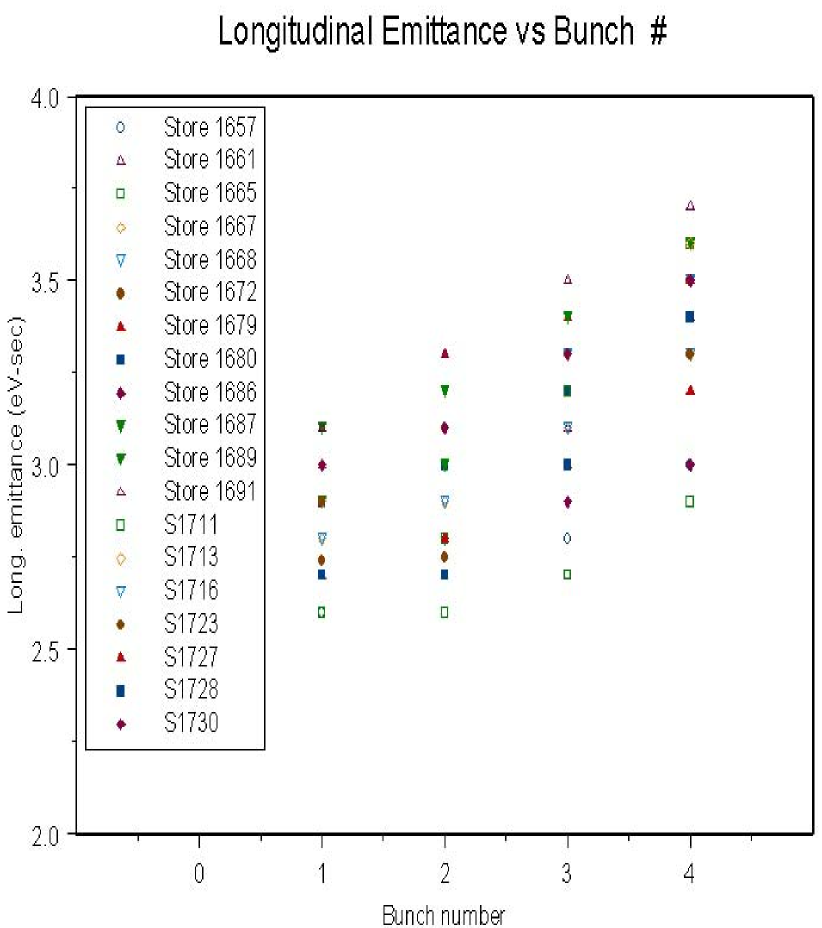



Without

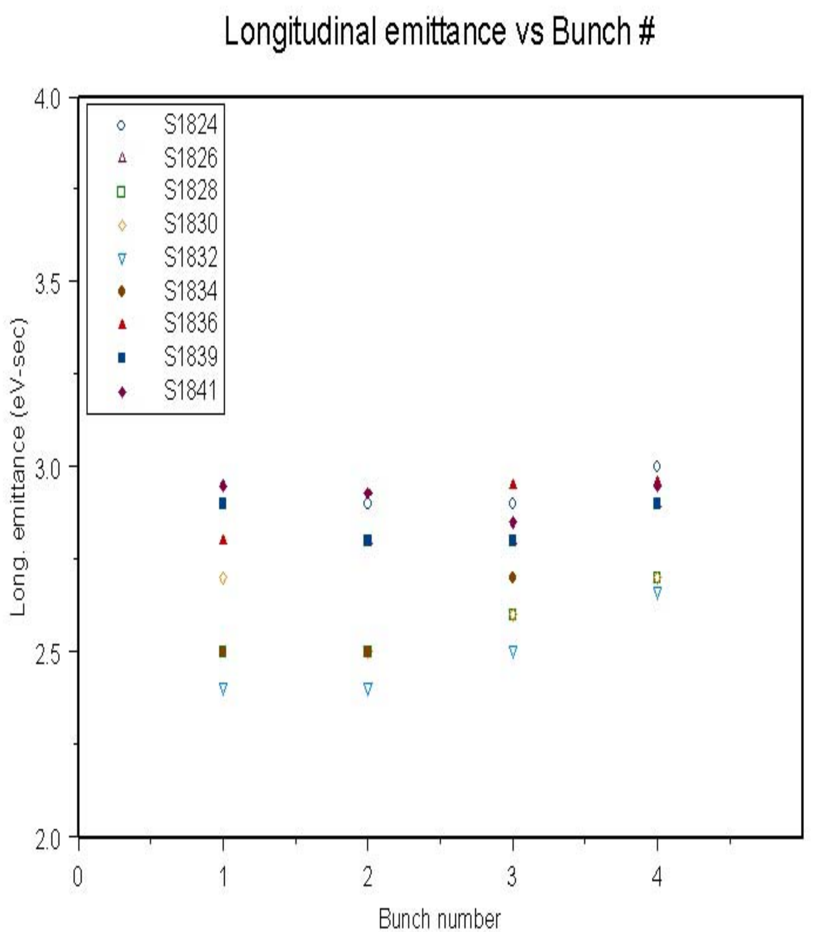



With

# *Effect of Beam loading compensation on Pbar longitudinal emittance*

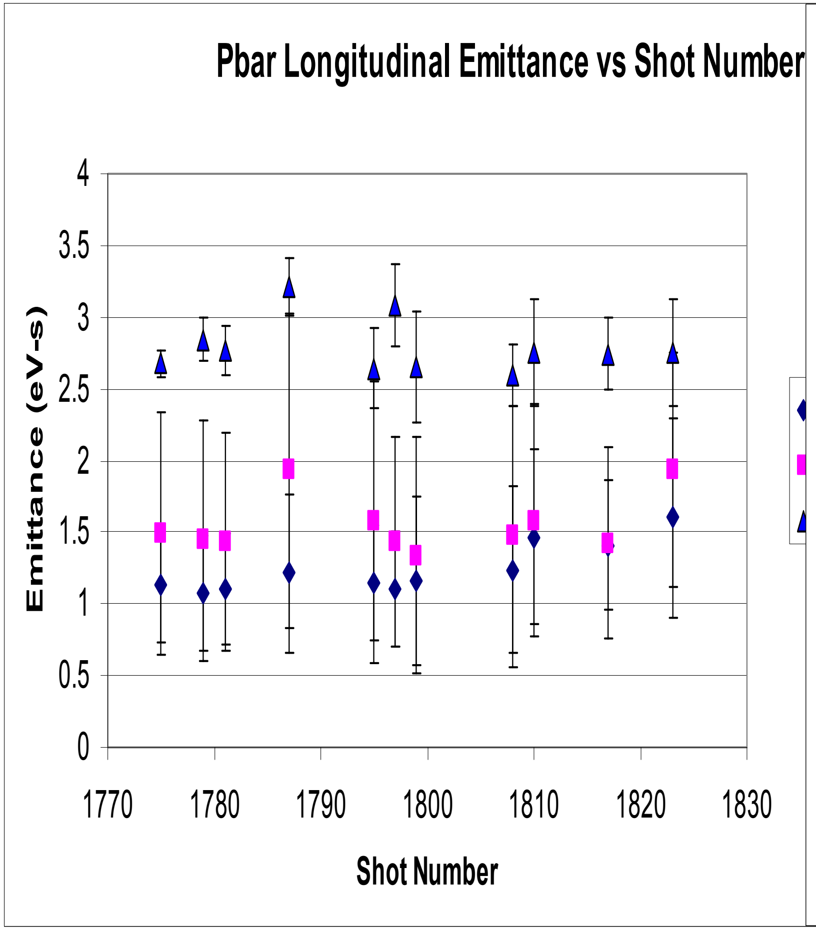


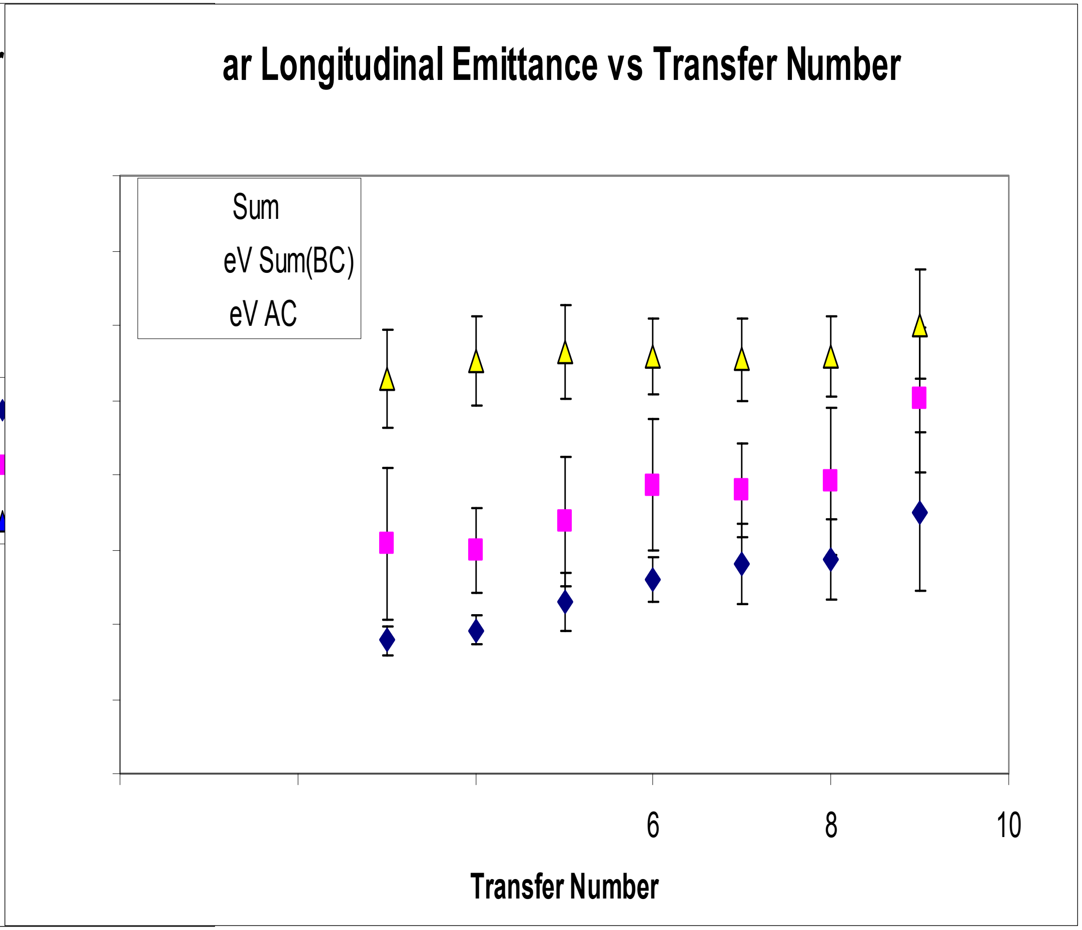

Without



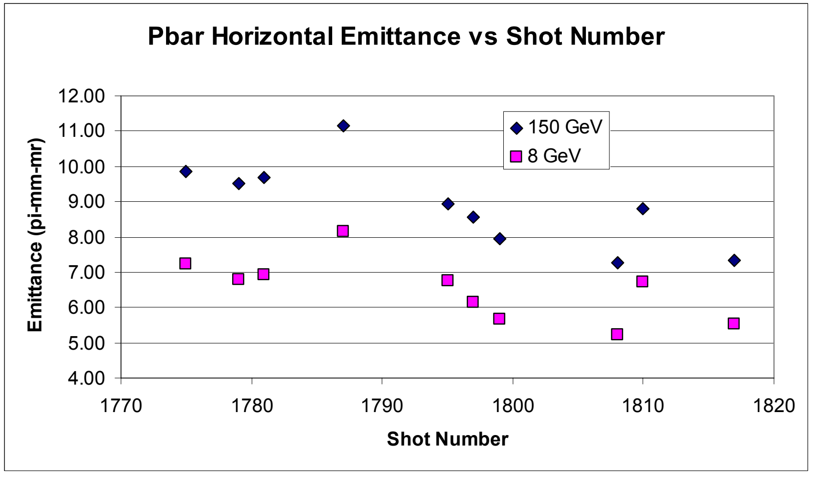

With

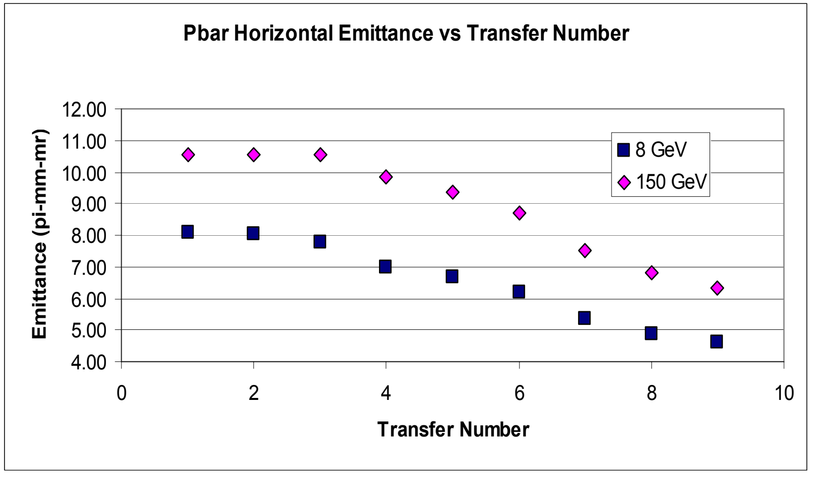
# *Longitudinal Emittance of pbar beam in MI*

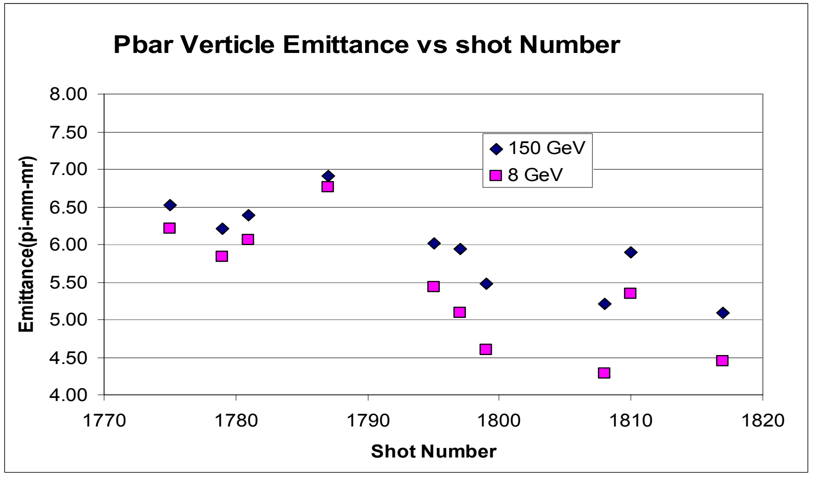


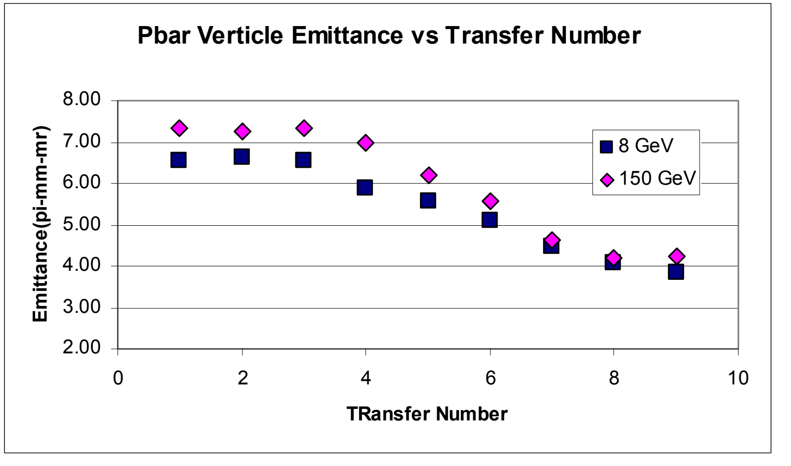



# Pbar Transverse Emittance



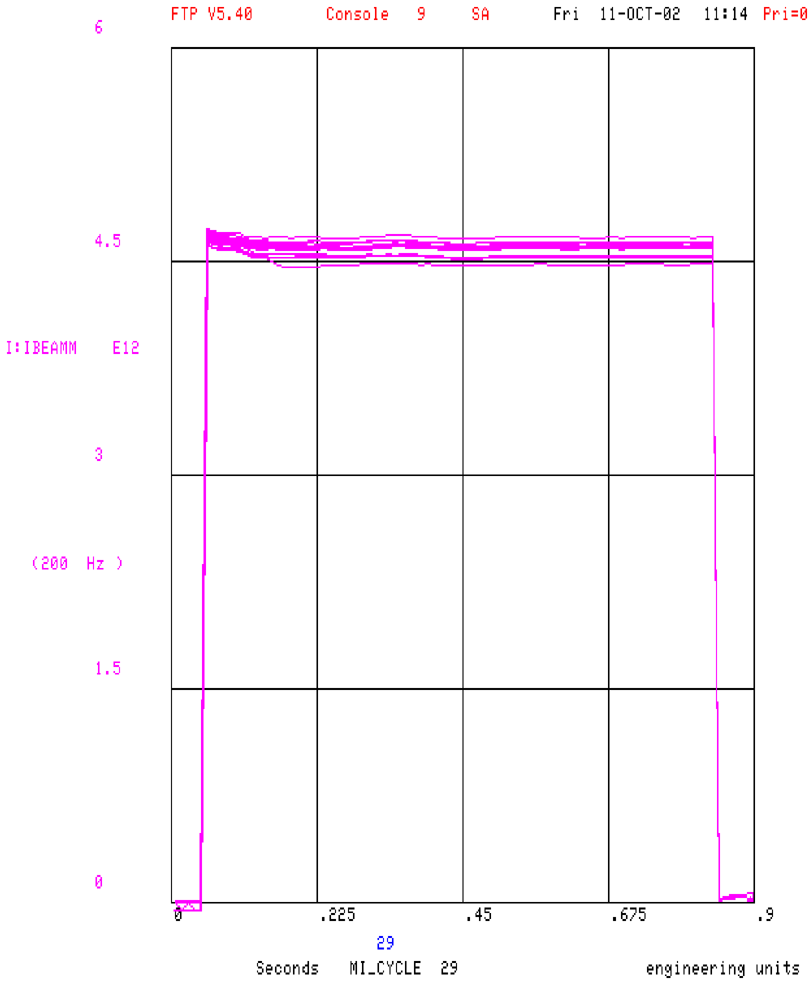



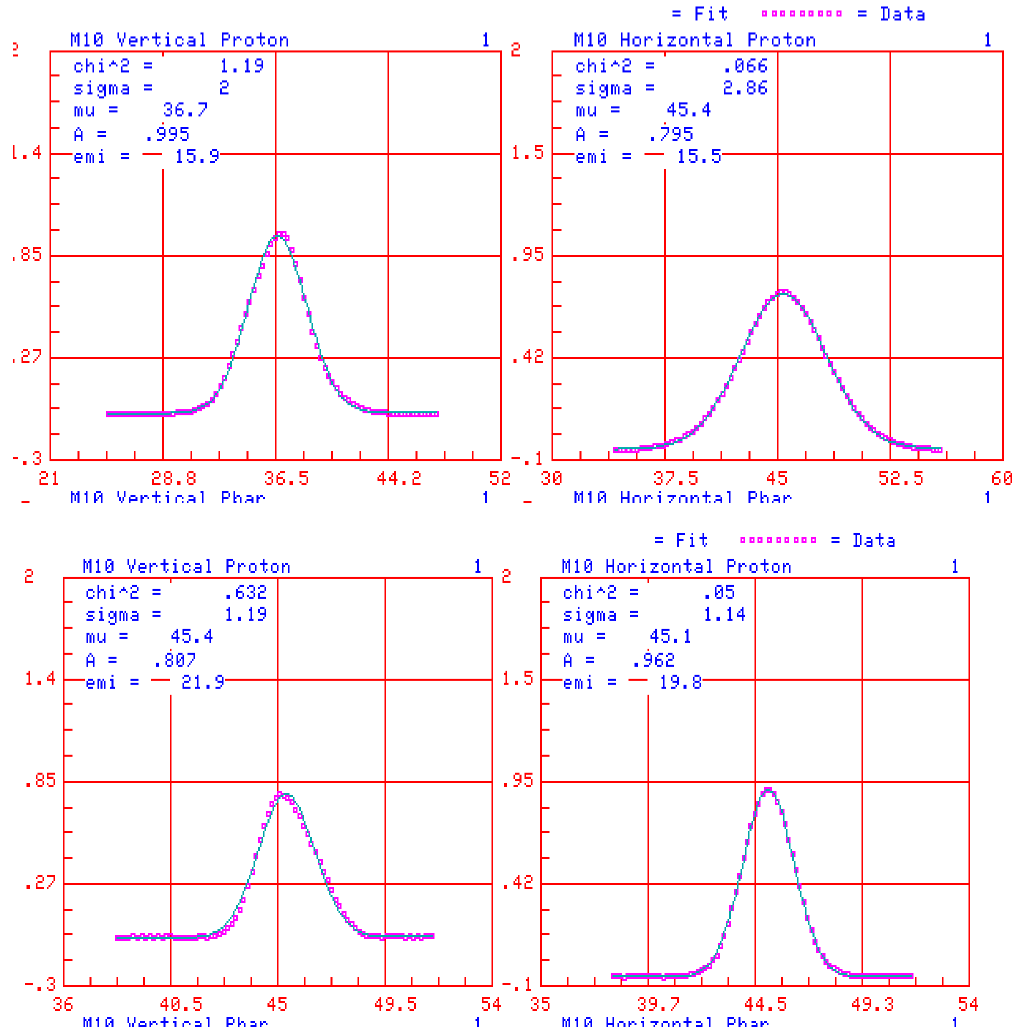




STD ≈ 1.5pi-mm-mr

STD ≈ 0.8 pi-mm-mr

# 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)<br>2.5e+e11 (5 bunches) |
| Proton coalesced Efficiency | 0.90 | 0.85 (7 bunches)<br>0.95 (5 bunches) |
| Acc -> 150 GeV coalesced Efficiency | 0.90 | 0.85-0.95%(Accumulator longitudinal emittance) |
| Proton emittance (95%, norm) | 20 | 20 $\pi$mm-mr |
| Pbar emittance (95%, norm) | 15 | <10 $\pi$mm-mr |
| Longitudinal Emittance (proton, 95%) | 3 | 2.8 eV-sec (7 bunches)<br>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

**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

- The Booster longitudinal quadrupole damper is being used in it's anti-damping mode as a bunch spreader to give consistent coalescing results. Here we are deliberately blowing up the initial emittance per bunch coming out of the Booster from 0.15 to 0.30 eV-sec.

  **Solution:** Return the quad damper to the damping mode after other longitudinal problems are fixed.

# 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

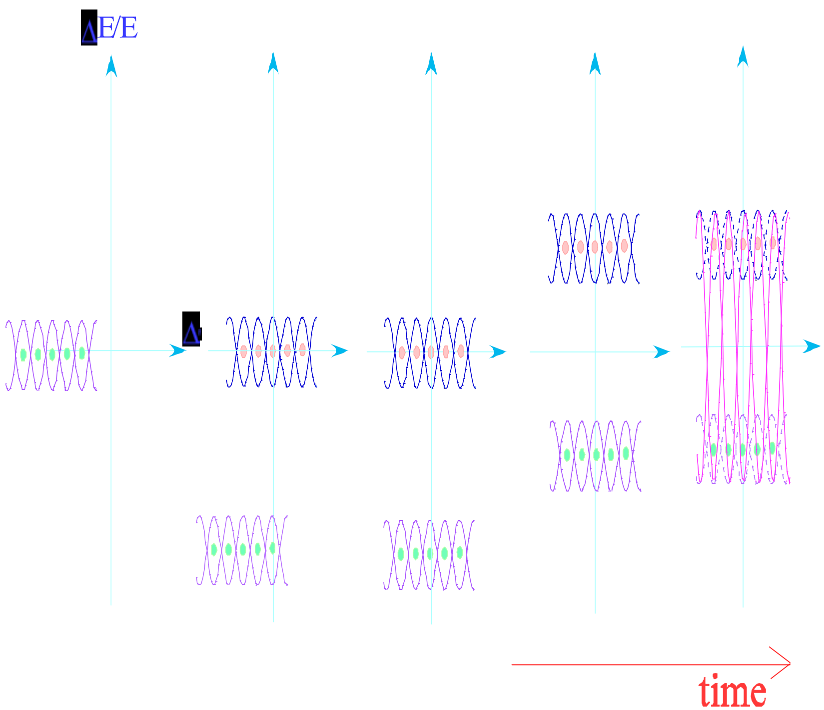
•The excitation of the MIRF cavity mode at 224 MHz is observed to grow throughout the acceleration cycle.

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

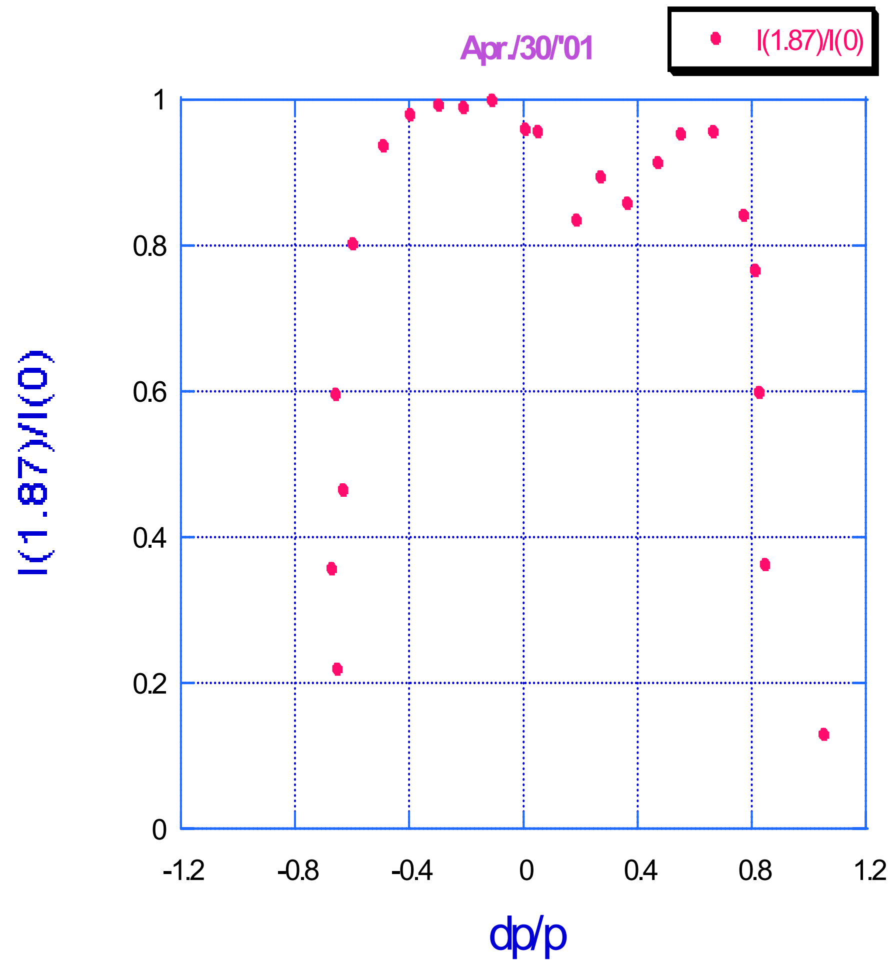
# Dampers in Main Injector

- Longitudinal Dampers
  - Benefits to Bunch Coalescing for Collider
    - "Dancing Bunches" degrade Proton coalescing and $\varepsilon_L$
    - We are deliberately blowing $\varepsilon_L$ 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)

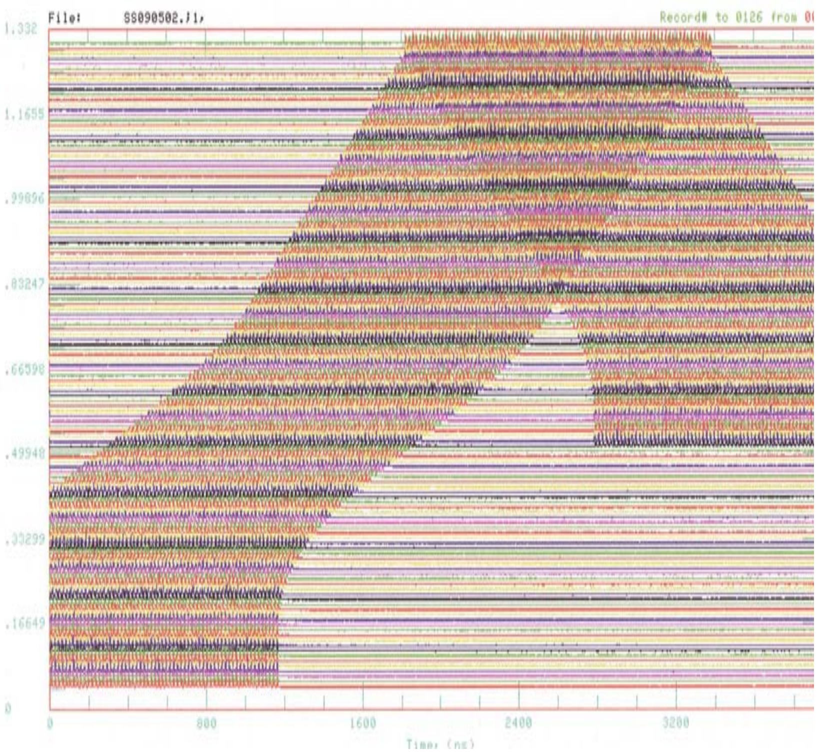


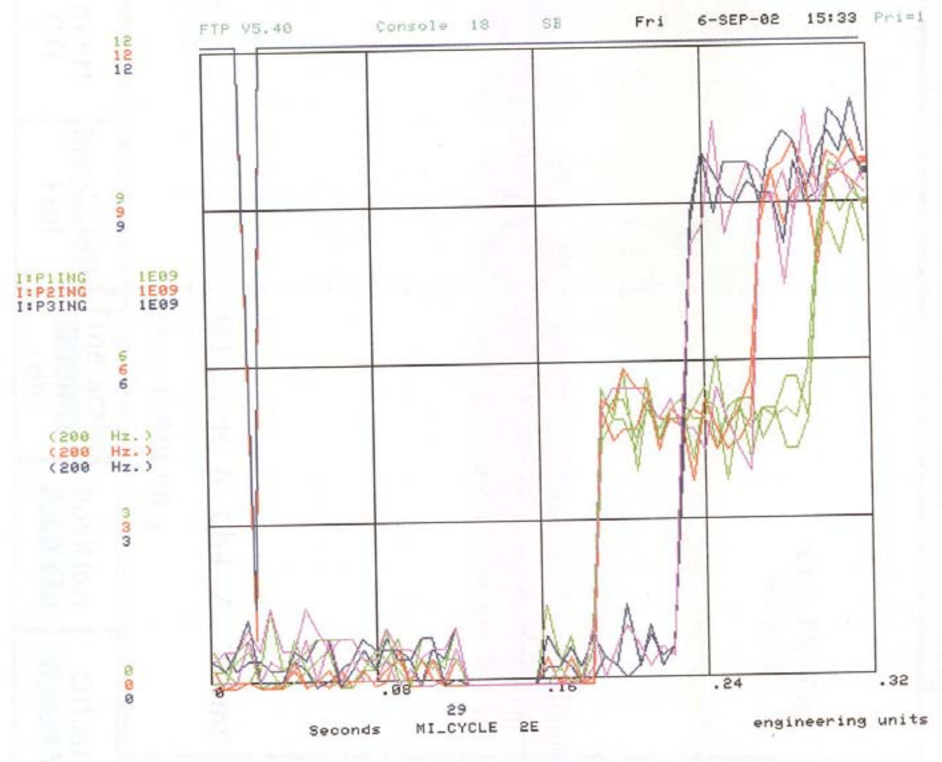

Slip Stacking Process




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 %.
- There are some lattice issue at 150 GeV between MI transfer lines and the Tevatron.
- 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 slip stacking process is underway.
- An R&D for 2.5 MHz acceleration of pbar is also in progress.