Run II Luminosity Progress

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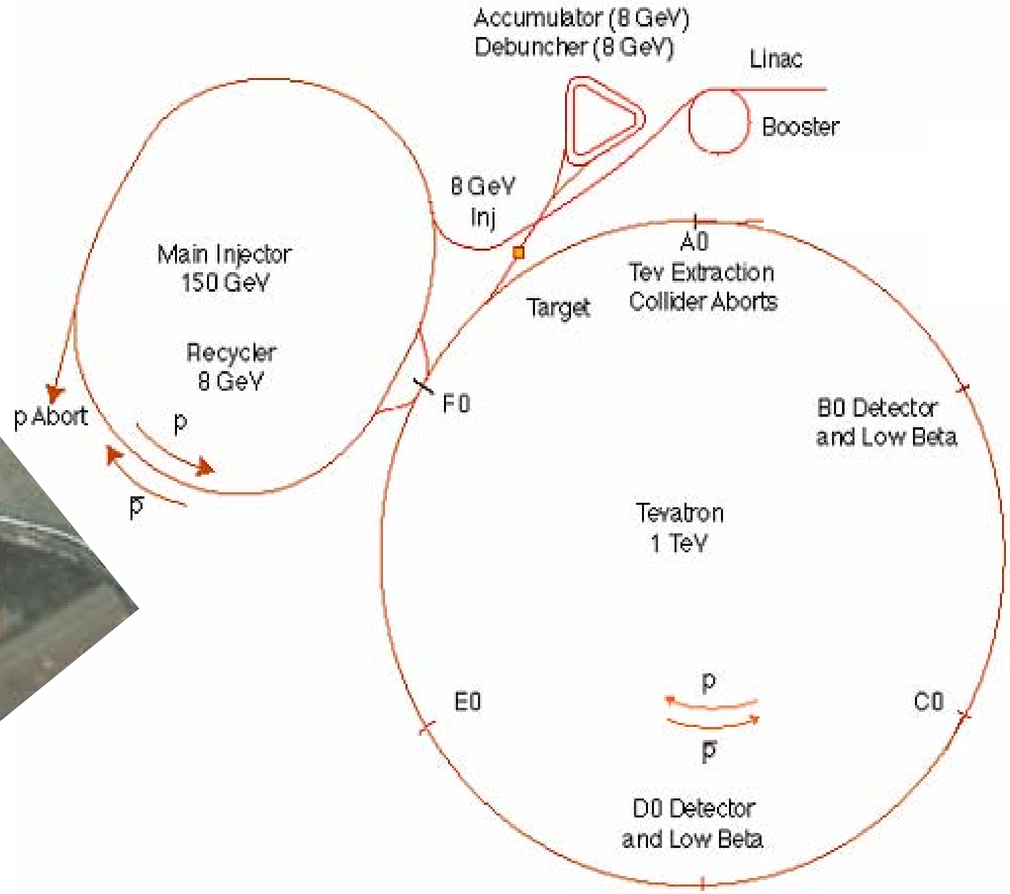

Accumulator (8 GeV)
Debuncher (8 GeV)
Linac
Booster
8 GeV
Inj
Main Injector
150 GeV
Recycler
8 GeV
A0
Tev Extraction
Collider Aborts
Target
p Abort
p
p̄
F0
B0 Detector
and Low Beta
Tevatron
1 TeV
E0
C0
p
p̄
D0 Detector
and Low Beta

Overview

- Collider Run 2
  - Tevatron 36×36 proton-antiproton collisions to CDF & D0
  - Design goal = 8 fb^{-1} by end FY09
  - Over 3 fb^{-1} delivered so far
  - Antiproton production is key factor for increasing luminosity
  - Operates in parallel with MiniBoone, NuMI, SY120/Test Beam

- Tevatron
  - 1 km radius superconducting synchrotron at 980 GeV beam energy
  - 3 trains of 12 bunches each with 396 ns separation
  - Protons and antiprotons circulate in single beam pipe
    - Electrostatic separators keep beams apart except where/when desired
    - Beam-beam interactions (head-on & long range) play major role in performance

Luminosity

$$L = \frac{f N_p N_a}{2\pi(\varepsilon_p + \varepsilon_a)\beta^*} H\left(\sigma_z / \beta^*\right)$$

- The major contributors to determining the luminosity are:
  - Number of particles in each bunch (*N*)
  - The transverse emittance of the beams (ε)
  - Transverse beam optics at the interaction point (β^*)

Antiprotons are the key

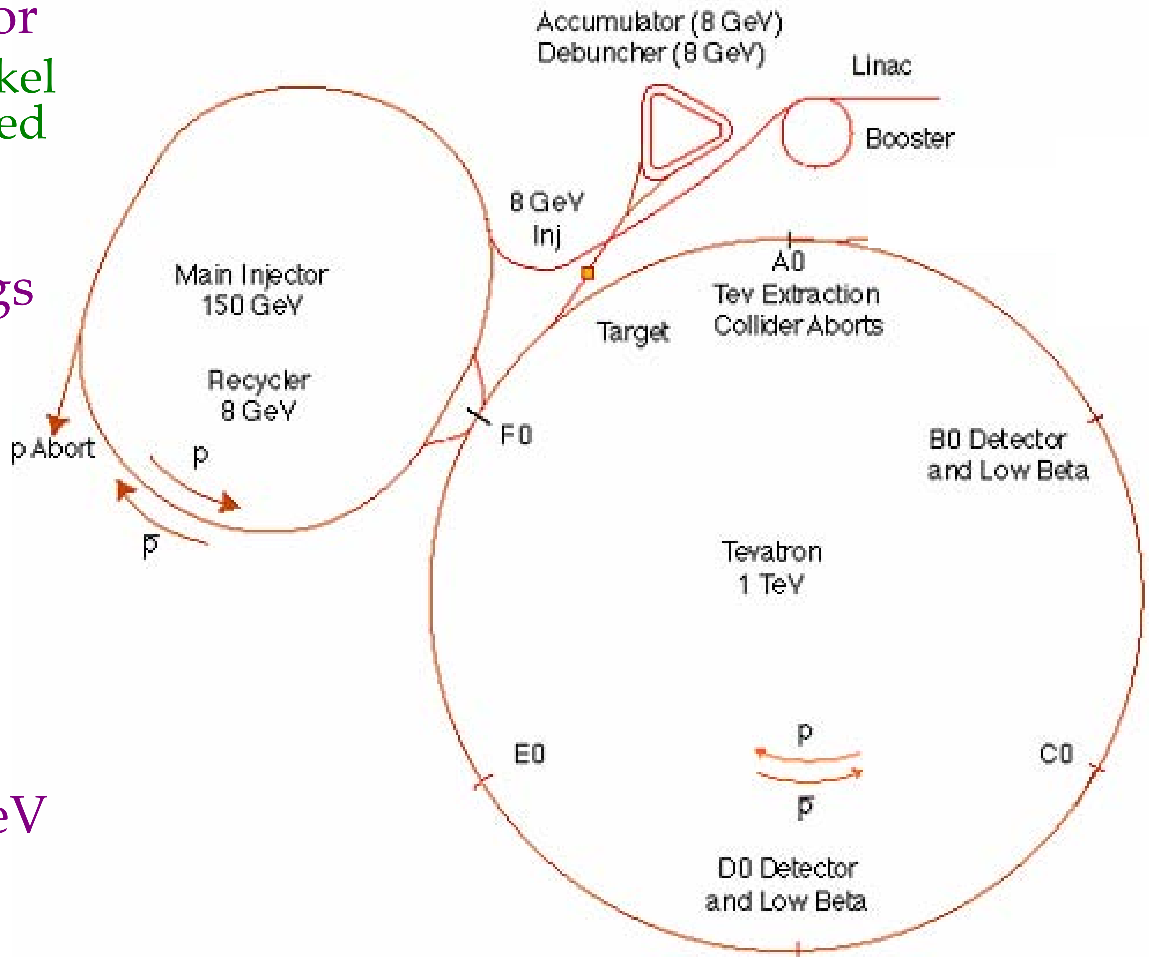
Antiproton Operations

- Accumulator Only (prior to Dec 2004)
  - Stack and store <2e12 pbars
  - Accumulation rate decreases as stack size increases
- Combined Shots (Dec 2004 to Oct 2005)
  - Together with Accumulator provide more pbars
- Recycler - Electron Cooling (since Oct 2005)
  - First time done with relativistic electron beam
  - Able to make denser pbar bunches
  - Routinely have >3e12 pbars available for Tevatron
  - Pbars to Tevatron come only from Recycler
  - Accumulator focus on stacking
    - Rate stays flat
    - Frequent transfers

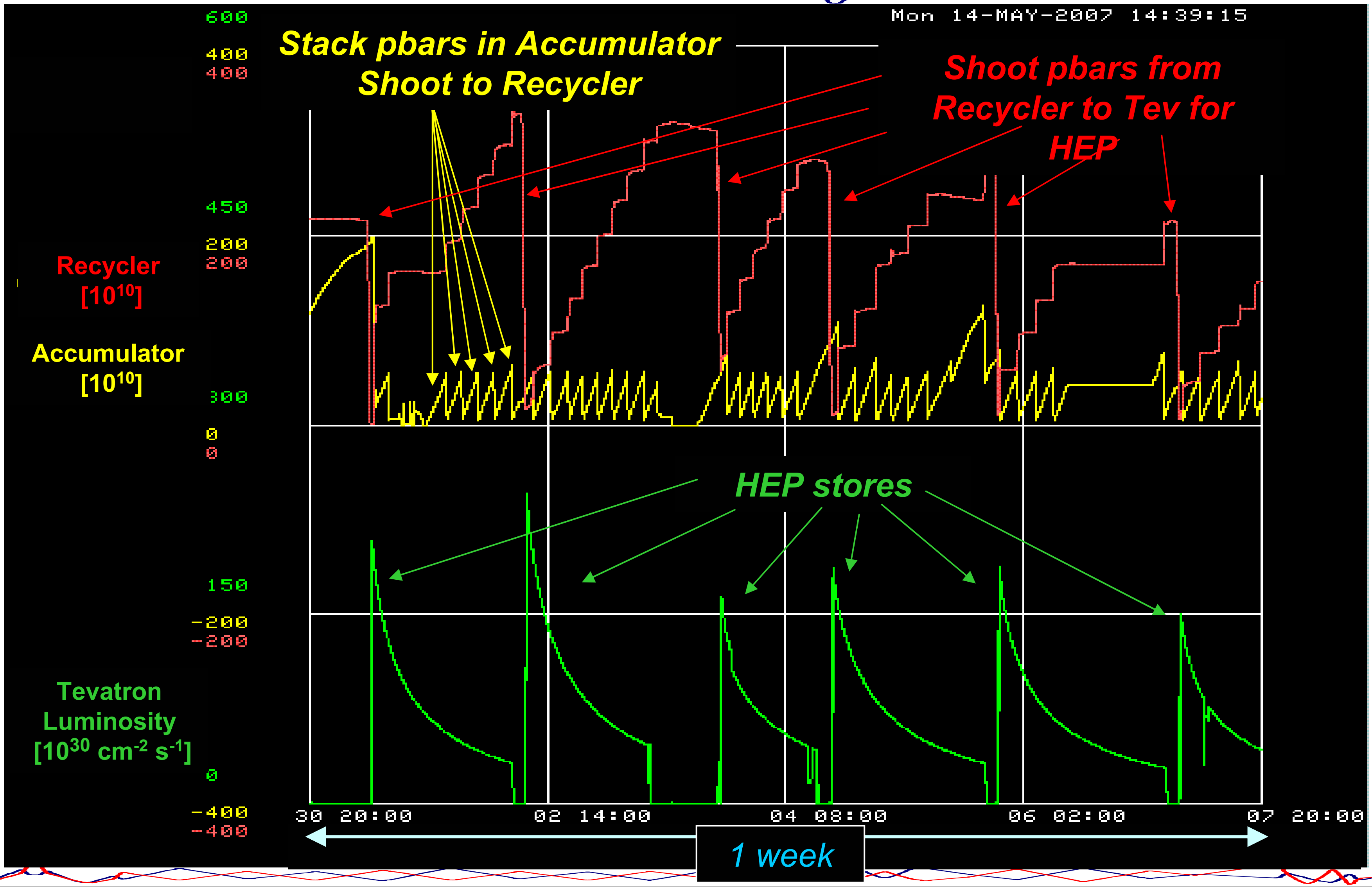
$$L = \frac{f N_p N_a}{2\pi(\varepsilon_p + \varepsilon_a)\beta^*} H\left(\sigma_z / \beta^*\right)$$

Antiproton Production

- Created from 120 GeV Protons from Main Injector
  - Production Target is nickel alloy followed by a pulsed lithium collection lens
- Collected using three rings at 8 GeV
  - Debuncher (2.4s)
  - Accumulator (~3hr)
  - Recycler (~1day)
  - Cooling systems reduce the phase space and increase beam density
- Main Injector is used to accelerate pbars to 150 GeV for injection into the Tevatron



Antiproton Production Flow

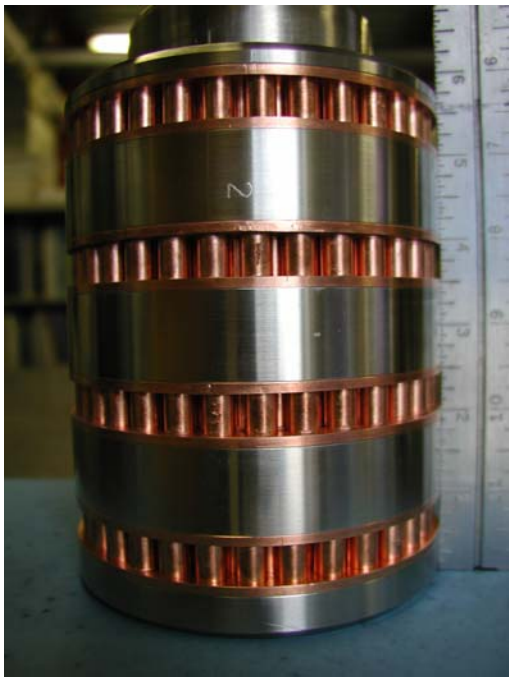


More Antiprotons

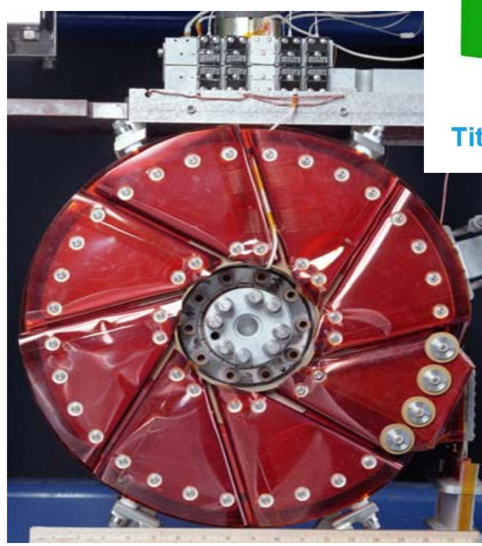
- Increase the Stacking Rate
  - The Accumulator's stochastic cooling systems configuration is a balance between the rate and maximum stack size.
    - With Recycler taking the "storage" role, the Accumulator is focusing on stacking rate
      - More protons on Production Target

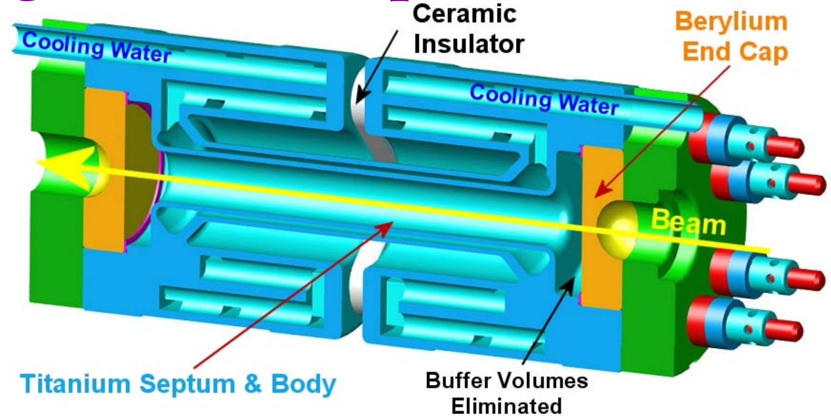
Protons and Target Station

- Slip Stacking in Main Injector: consistently 8-9e12 protons on target
- Balance of spot size and target consumption



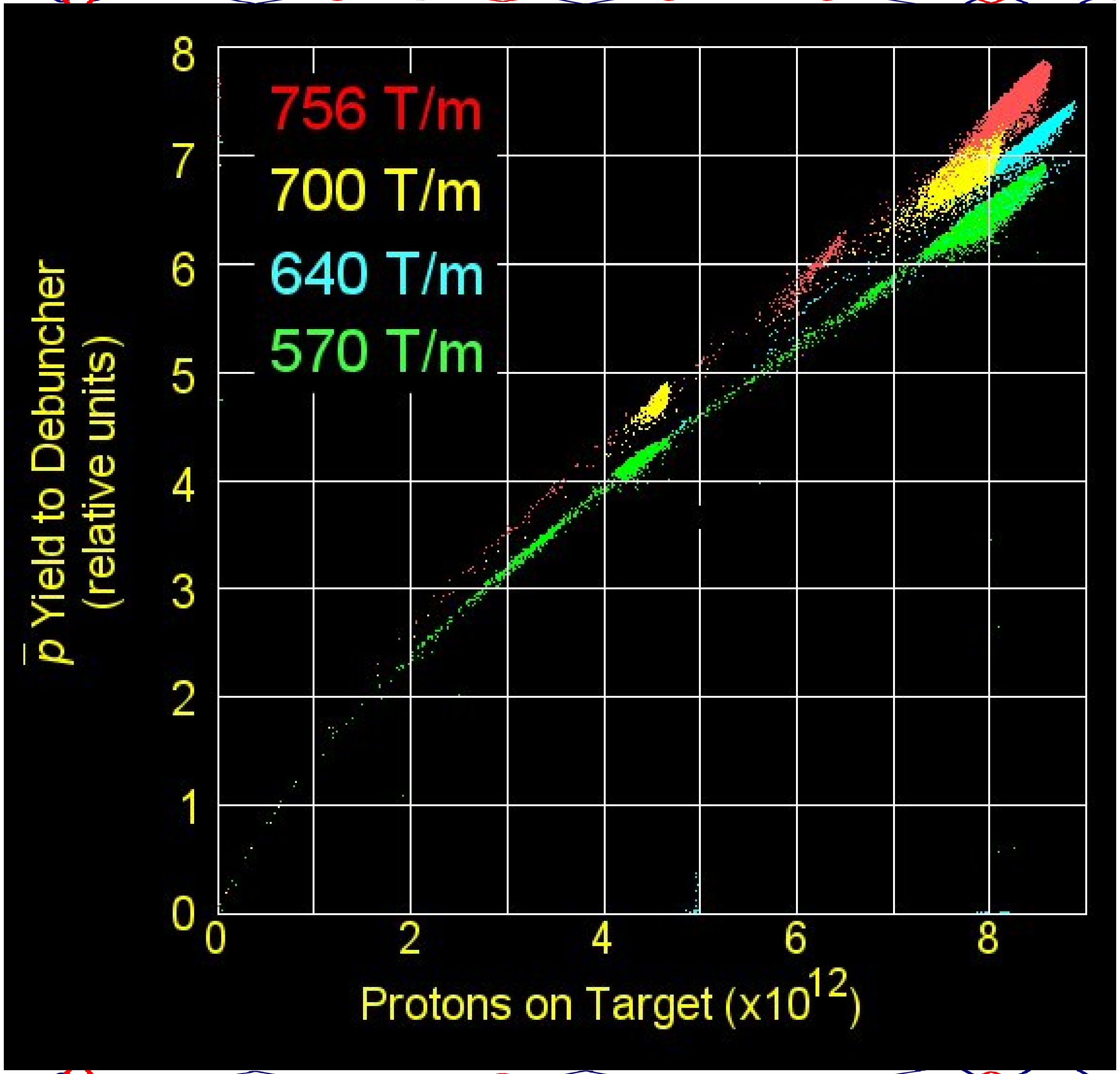
Spot ~150μm





New Lithium Lens allows an increase in collection gradient

Measured Yield Increase with Gradient



First new Lens module failed due to radiation damage to transformer

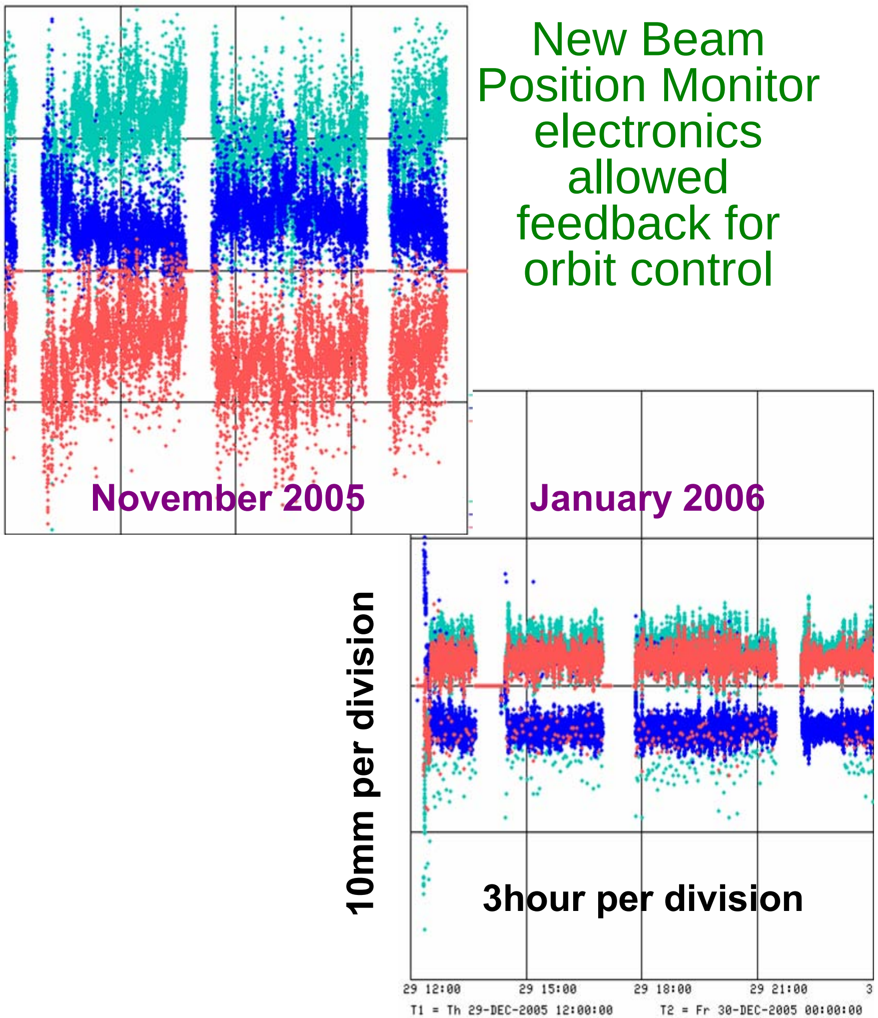
Second transformer developed ground fault after one week of service due to water leak

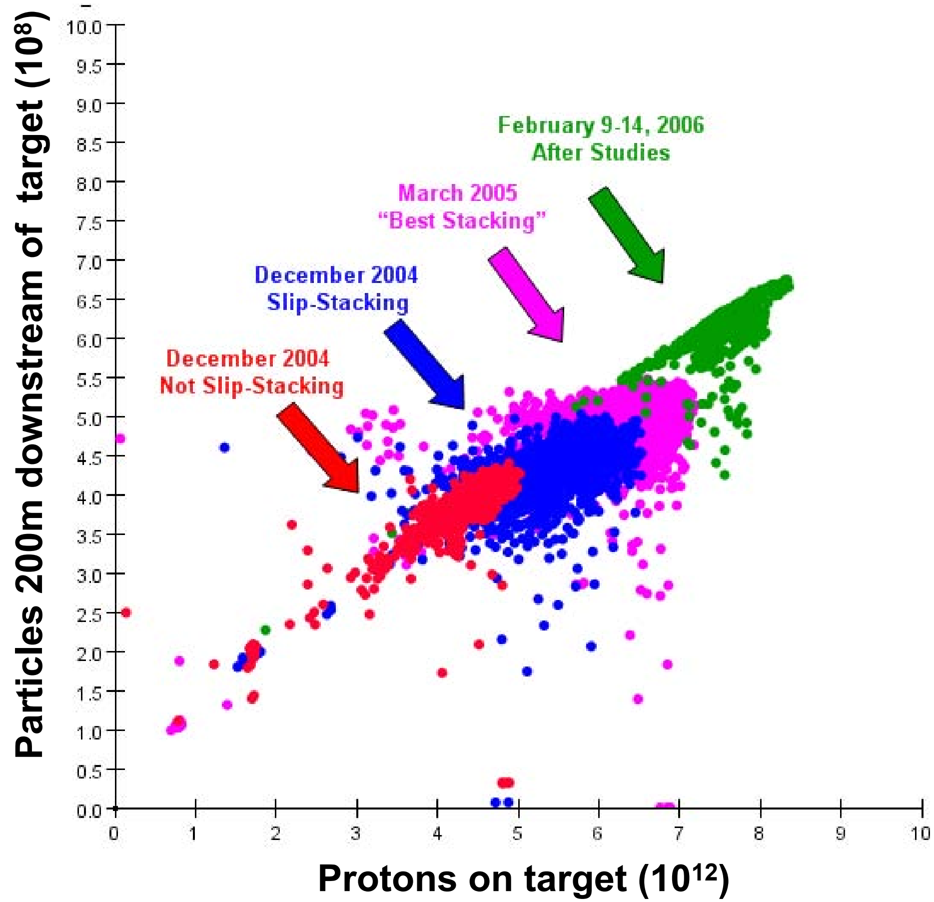
Hope to repair

Third lens module will be ready in August

Orbits & Protons for Antiproton Production

New Beam Position Monitor electronics allowed feedback for orbit control





More Antiprotons

- Increase the Stacking Rate
  - The Accumulator's stochastic cooling systems configuration is a balance between the rate and maximum stack size.
    - With Recycler taking the "storage" role, the Accumulator is focusing on stacking rate
      - More protons on Production Target
      - Antiproton collection efficiency (aperture of the beam line from the target to the Debuncher)

Debuncher Admittance

- Nearly all admittance upgrades are complete
  - Removal & Modifications of limitations
    - One remaining kicker beam tube to be replaced
  - Added orbit control
    - Dipole trims
    - Motorized quad stands
  - Motorized stands of components with tight apertures
  - Modified lattice to decrease beam size in small apertures
- Admittance has increased from ~23π mm-mrad to almost the goal of 35π mm-mrad
  - The goal admittance accepts ~320π mm-mrad beam emittance

More Antiprotons

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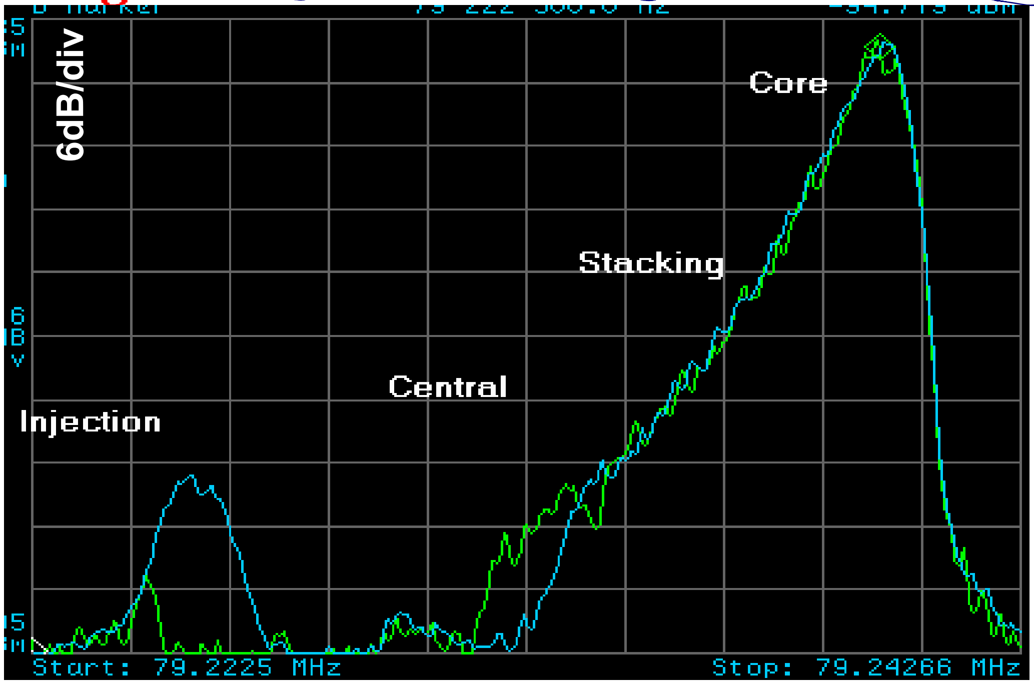
      - More protons on Production Target
      - Antiproton collection efficiency (aperture of the beam line from the target to the Debuncher)
      - Speed of the Debuncher and Accumulator Stochastic cooling systems
      - Accumulator stochastic cooling systems configuration

Accumulator



Energy

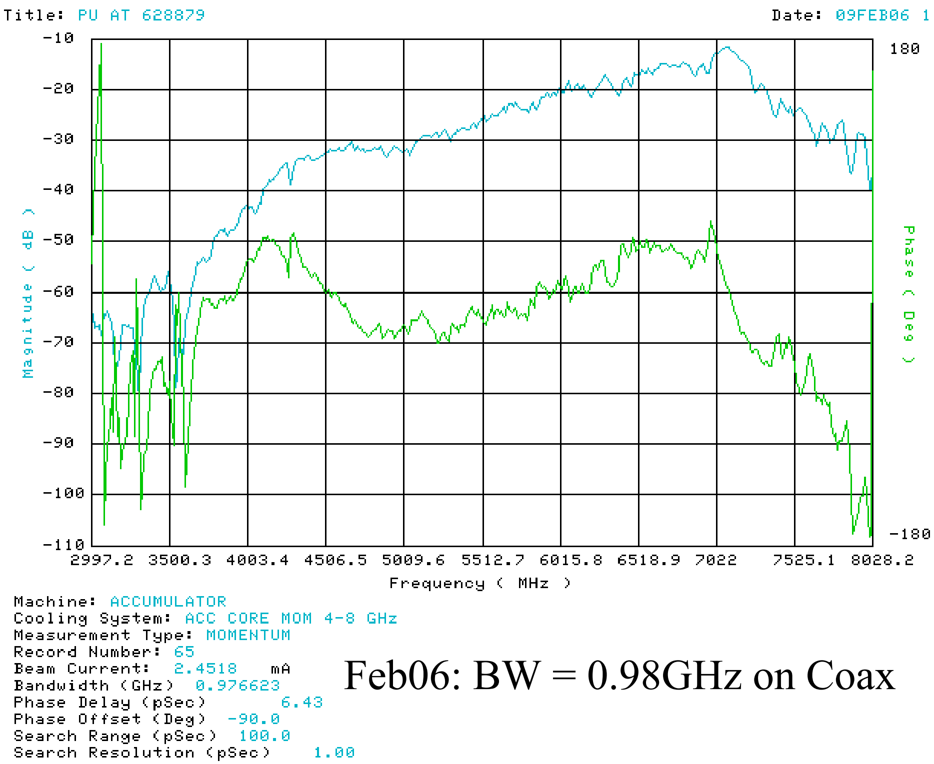
Stacking

1. ~2e8 pbars injected from Debuncher
2. RF capture on injection orbit
3. Move beam to central orbit
4. De-bunch beam
5. Stochastic cooling stacks beam onto core

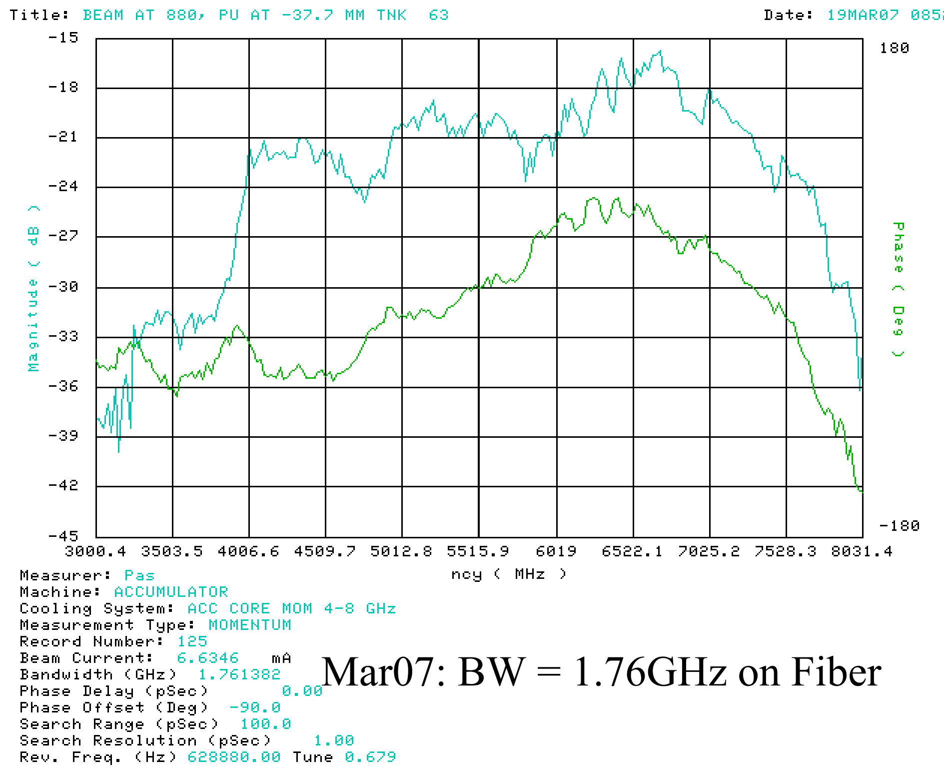
- Longitudinal cooling is the key
  - Stacktail moves beam from Central to Core
  - Core systems hold beam in place
  - Each system is "noise" to the other
- Improvements
  - Core Configuration
  - Lattice change
  - Bandwidth upgrades

4-8GHz Core Trunk Changed

- Trunk changed from Coax to fiber
  - Increase Bandwidth results in more effective cooling

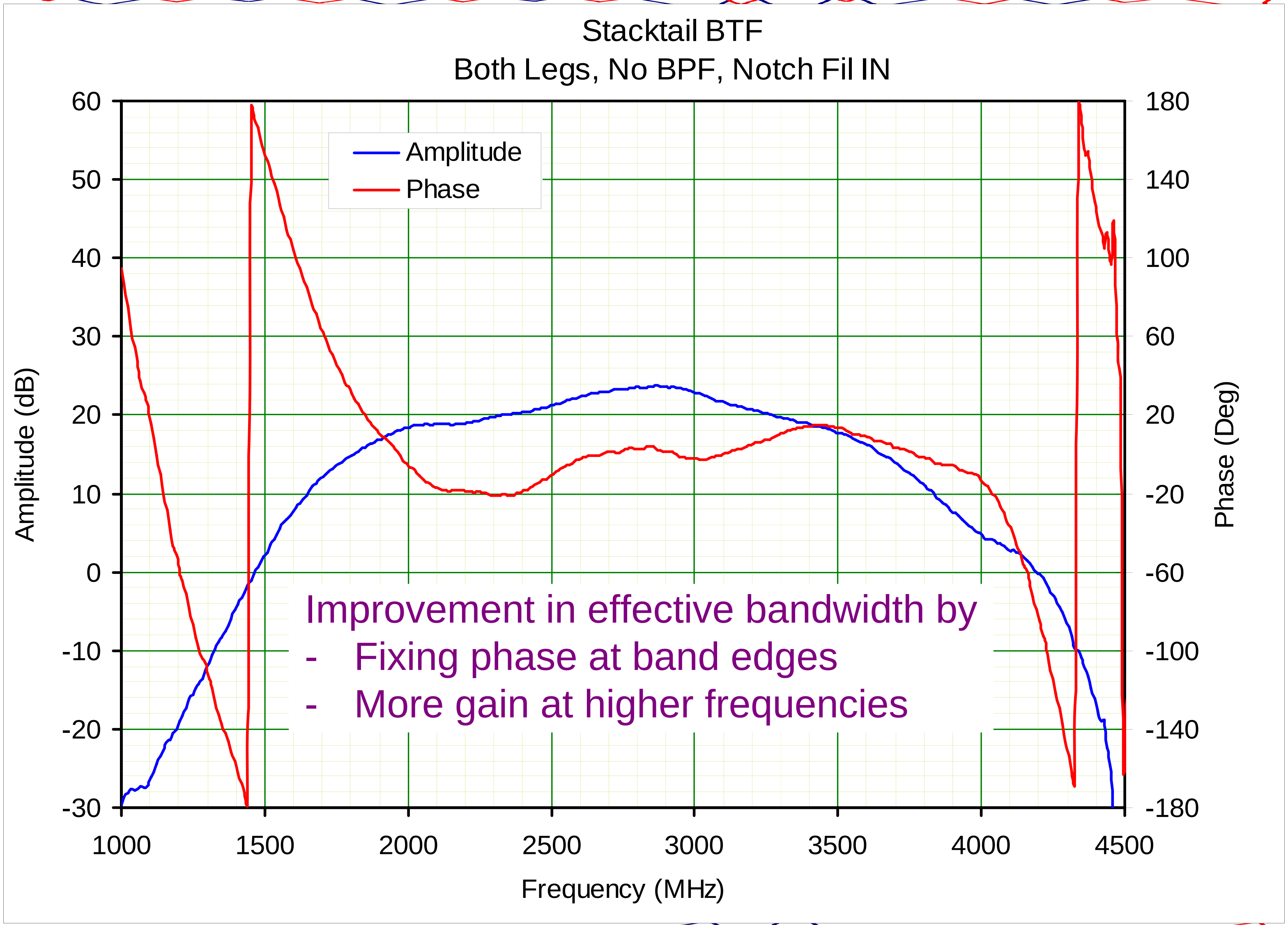


Feb06: BW = 0.98GHz on Coax

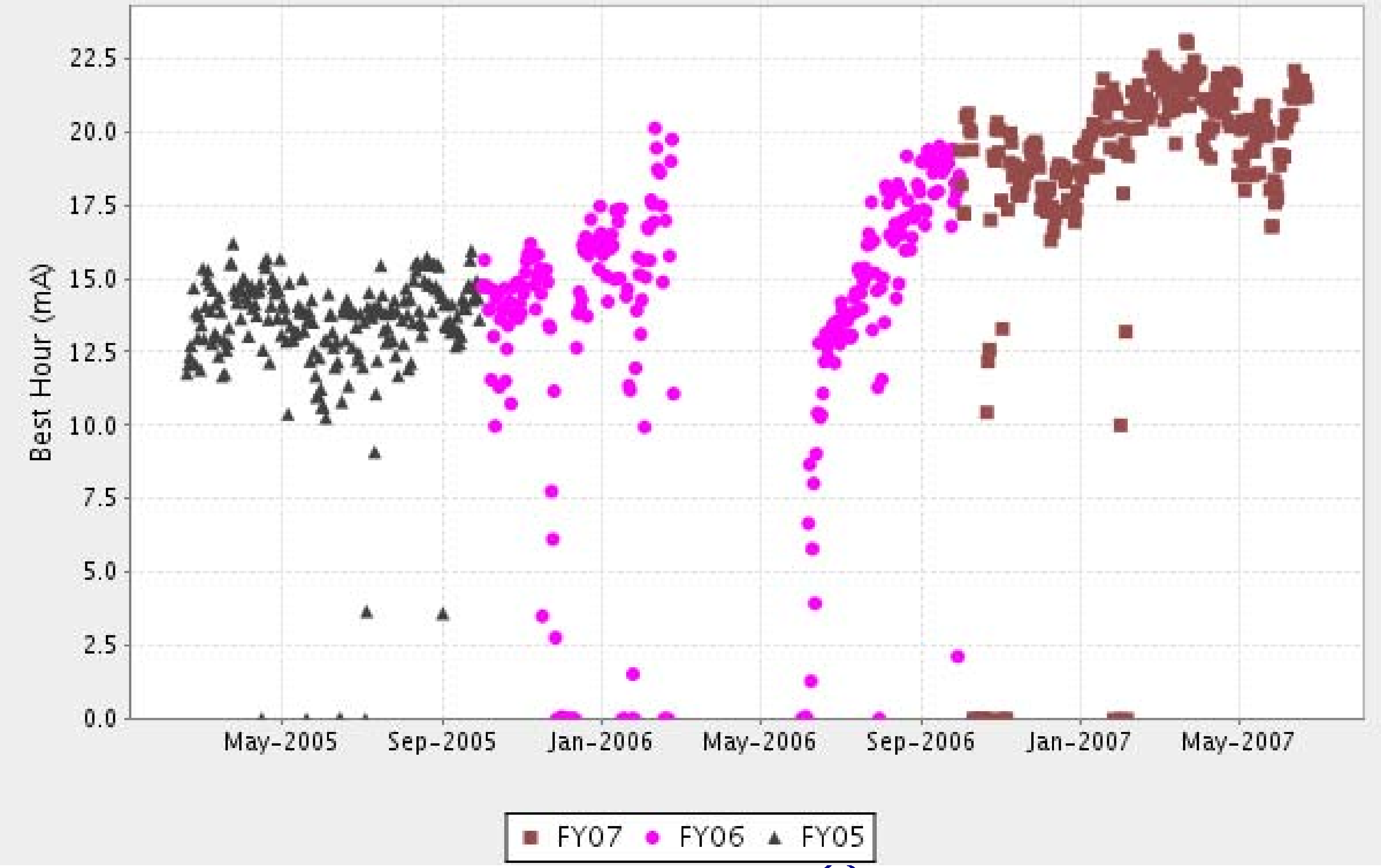


Mar07: BW = 1.76GHz on Fiber

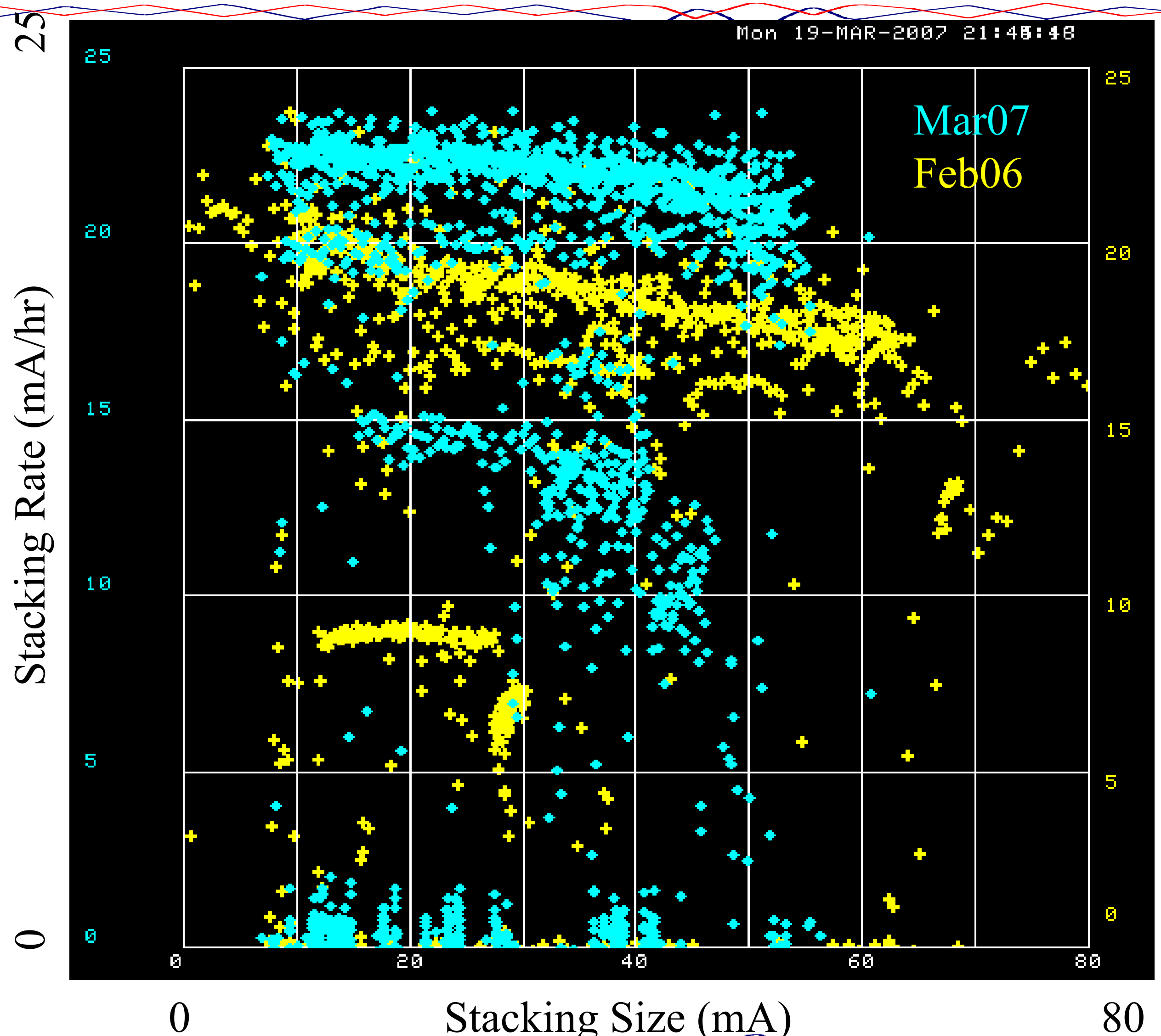
Stacktail Bandwidth Improvement



Best Stacking Hour Each Day



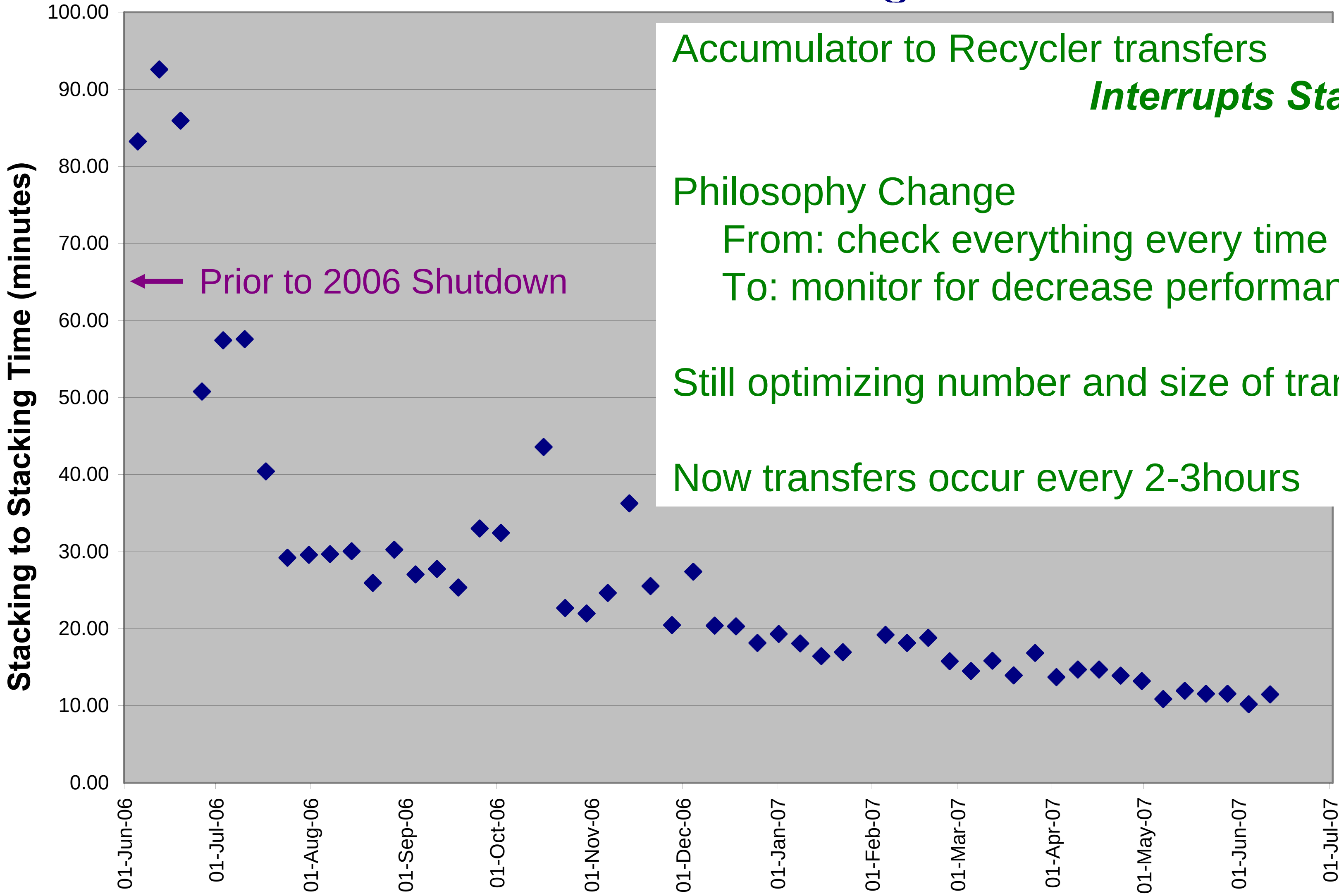
Performance Comparison



More Antiprotons

- Increase the Stacking Rate
  - The Accumulator's stochastic cooling systems configuration is a balance between the rate and maximum stack size.
    - With Recycler taking the "storage" role, the Accumulator is focusing on stacking rate
      - More protons on Production Target
      - Antiproton collection efficiency (aperture of the beam line from the target to the Debuncher)
      - Speed of the Debuncher and Accumulator Stochastic cooling systems
      - Accumulator stochastic cooling systems configuration
  - More stacking hours due to decreasing time it takes to transfer from Accumulator to Recycler

Decreasing Time to do Transfers



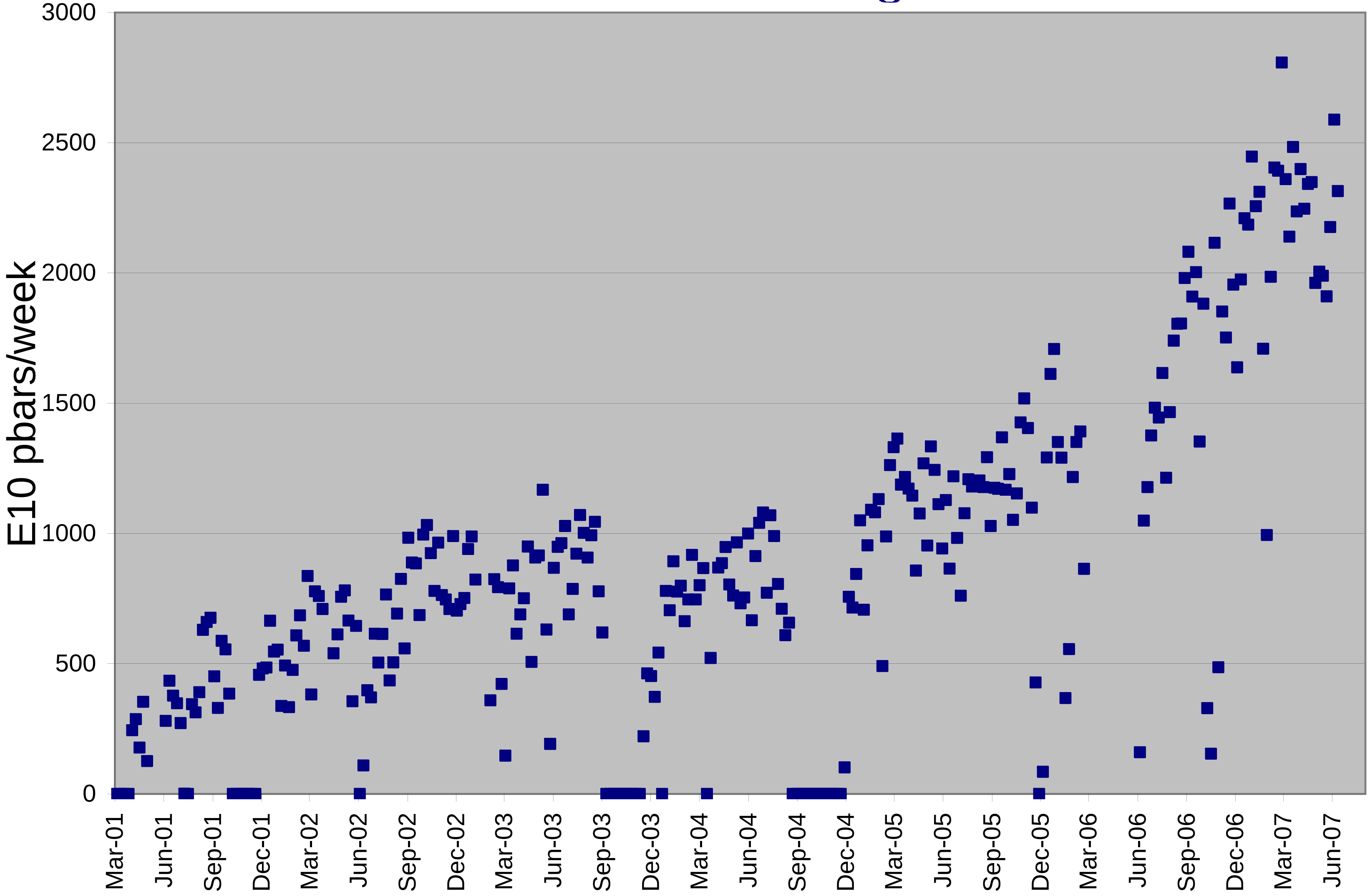
Accumulator to Recycler transfers
Interrupts Stacking

Philosophy Change
- From: check everything every time
- To: monitor for decrease performance

Still optimizing number and size of transfers

Now transfers occur every 2-3hours

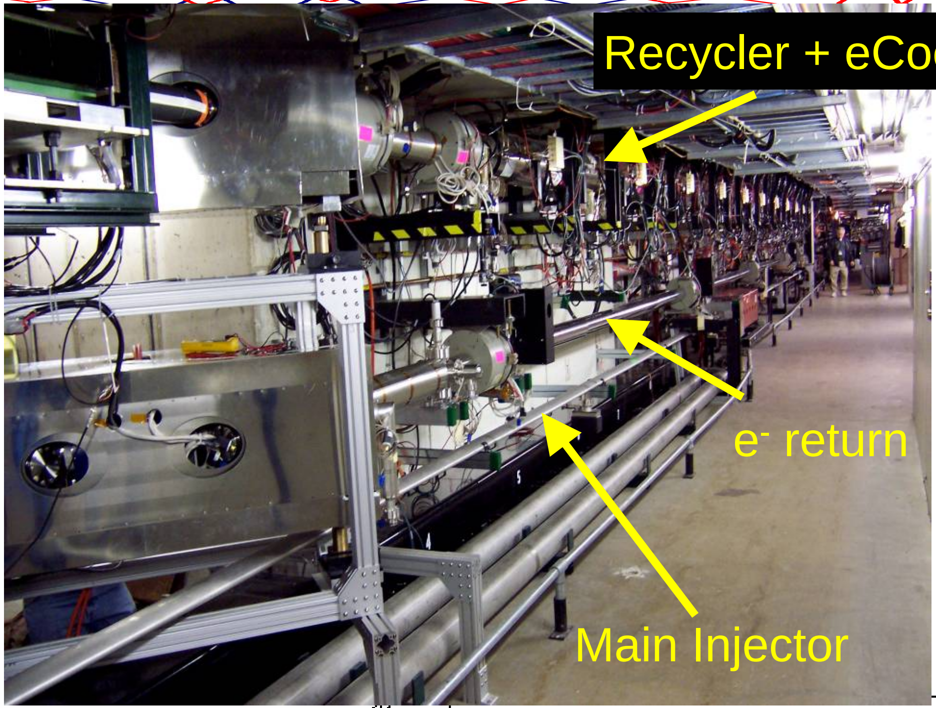
Antiprotons per Week

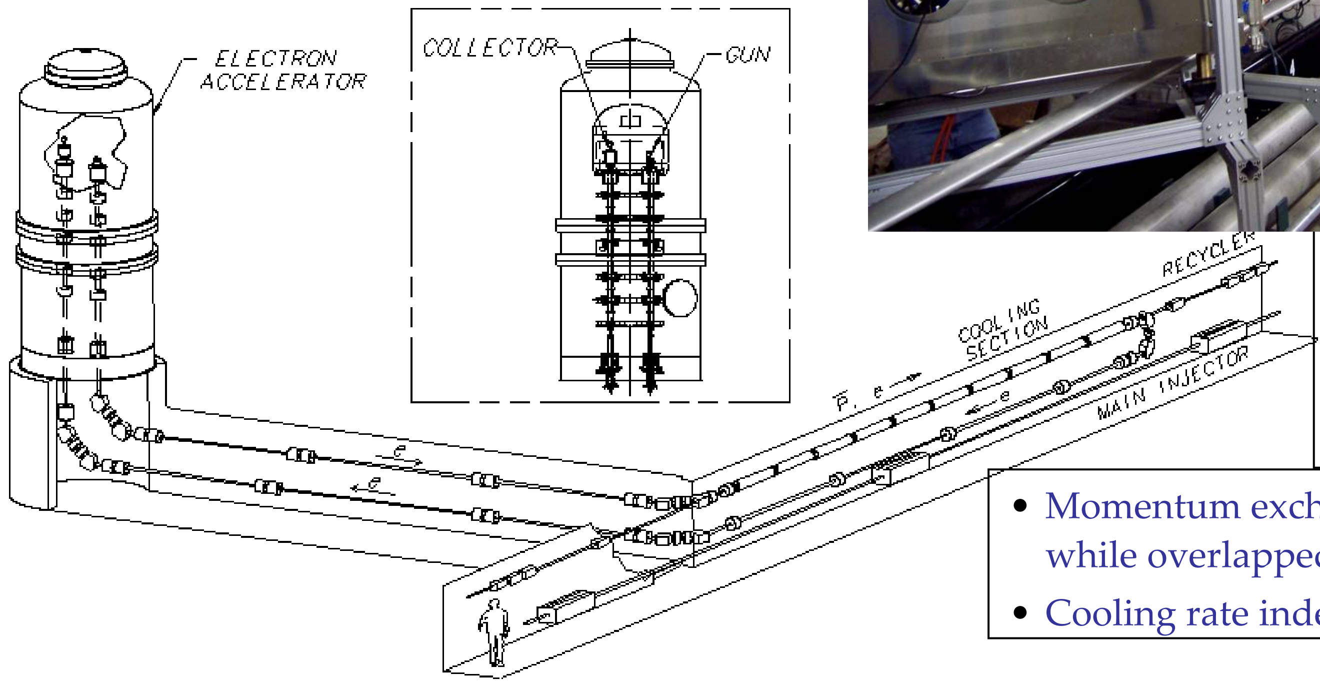


Recycler

- Electron Cooling has become operational

Electron Cooling in Recycler

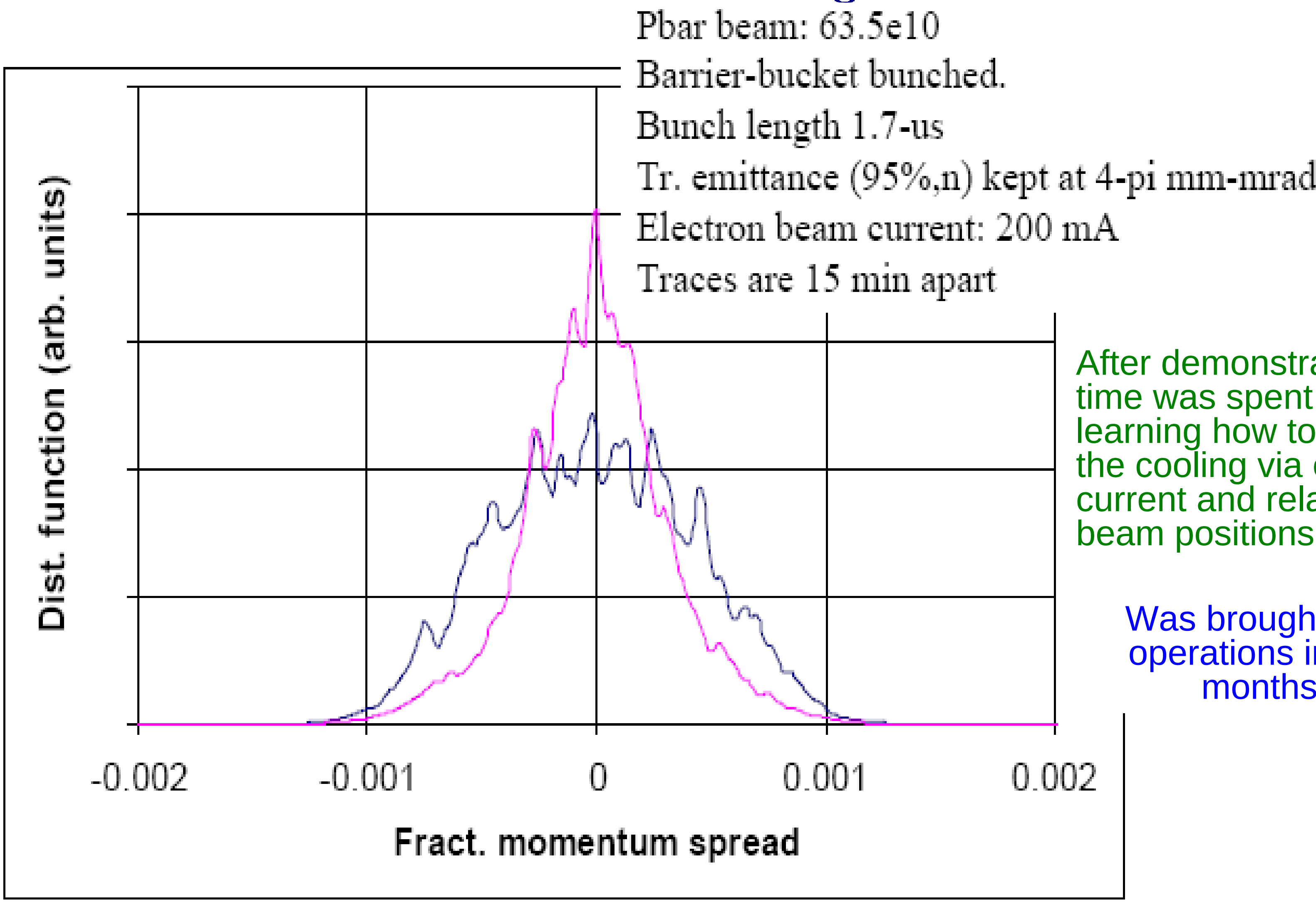




- e^- beam for cooling
  - 4.34 MeV
  - 0.5 amp DC
  - 200 μrad angular spread

- Momentum exchange between e^- and antiprotons while overlapped in cooling section
- Cooling rate independent of antiproton intensity

First Electron Cooling 07/15/05



After demonstration, time was spent learning how to control the cooling via electron current and relative beam positions.

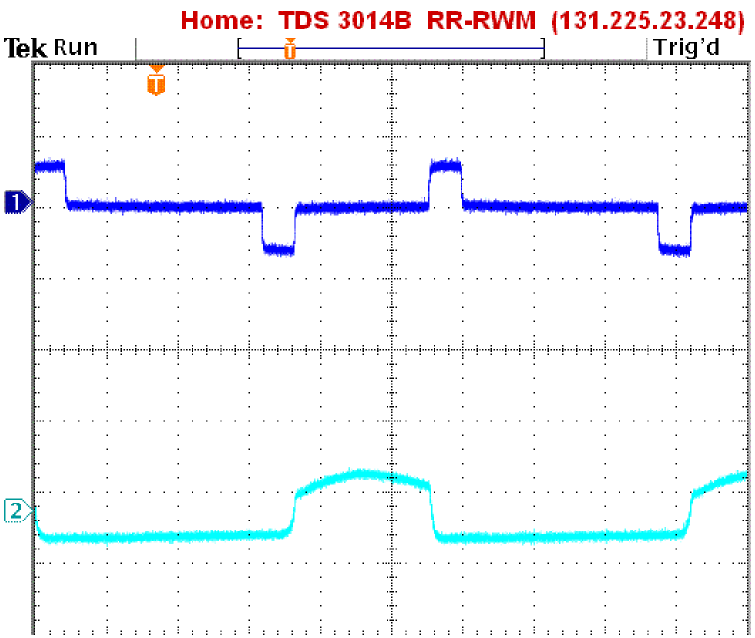
Was brought into operations in 2.5 months

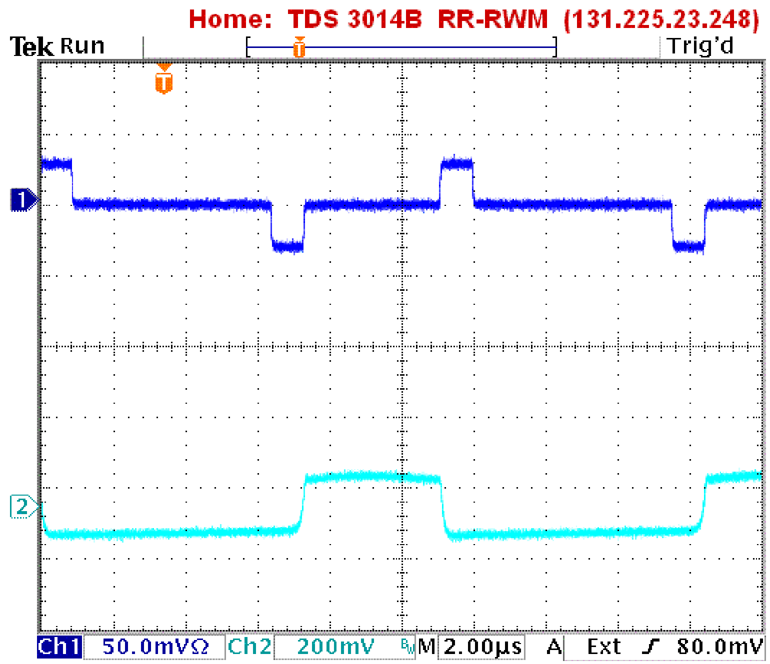
Recycler

- Electron Cooling has become operational
- Improvements
  - Change in Working point:
    - Improvement in Lifetime at large stashes
    - Space charge tune shifts
      - pbar beam as function of intensity / density
  - Implementation of Adaptive Feed Forward RF Correction
    - Uniform bunch intensity for collider operation

Adaptive RF Correction

- Implementation of adaptive feed forward RF correction
  - Integral of barrier buckets gives a flat potential well
  - Flat potential well -> uniform time distribution
  - For extraction, grow additional barrier buckets to make 9 slices which are transferred to Tevatron
  - Uniform time distribution -> uniform bunch density in Tevatron





More Uniform Pbar Intensities from Recycler

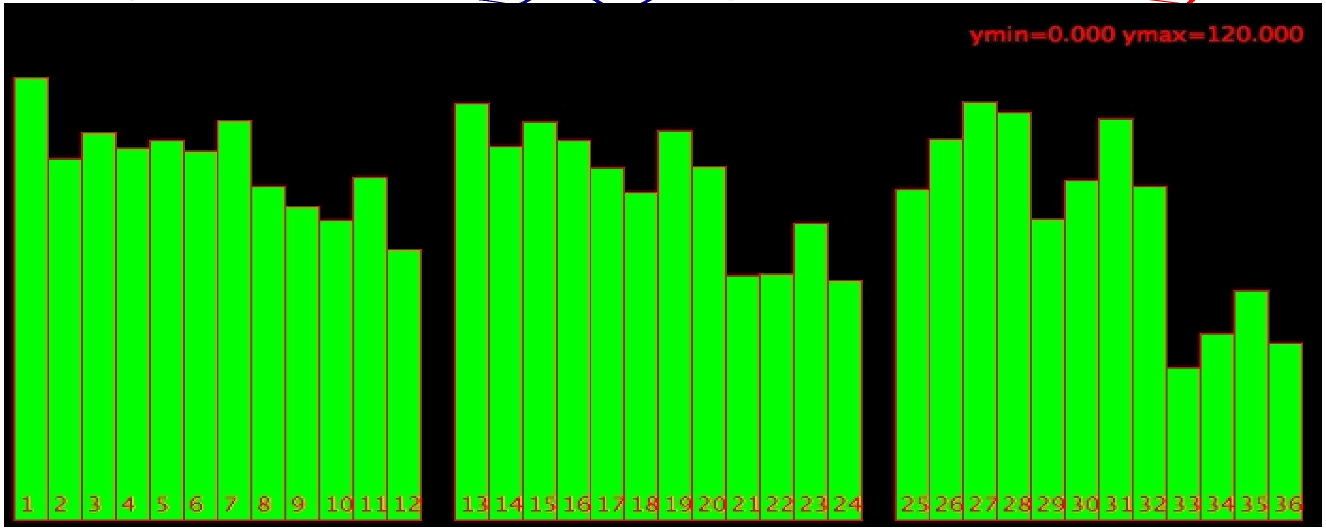
Store 5008

Without correction:

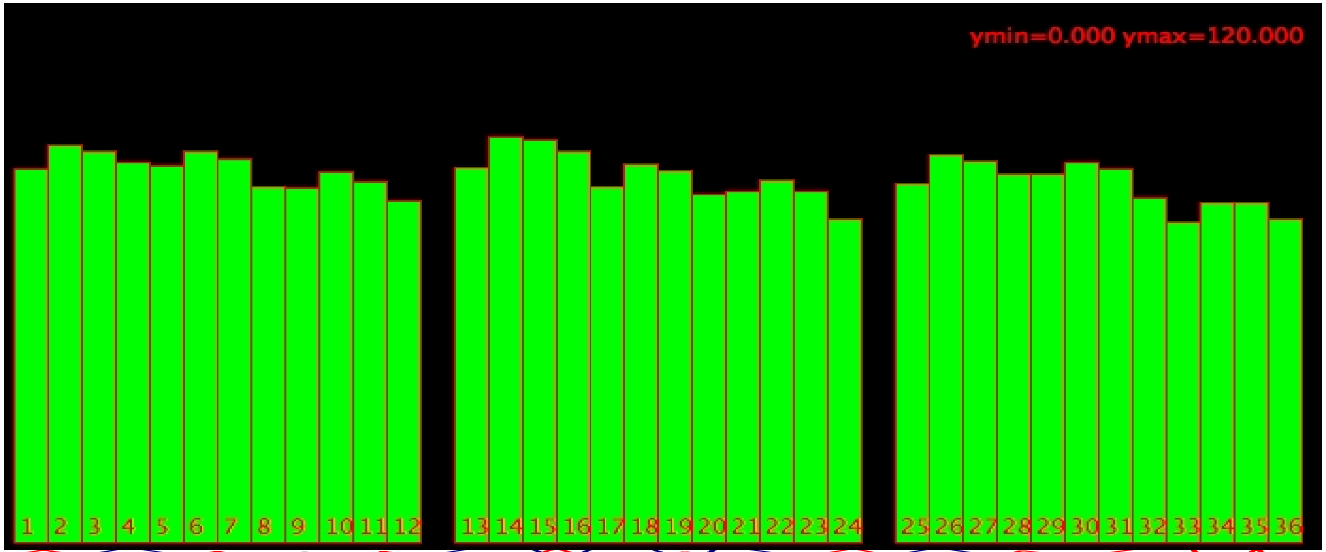
100% variation

25% RMS

Large variations in tune shifts and luminosity



Intensities of 36 Pbar Bunches in Tevatron



Store 5245

<u>With</u> correction:

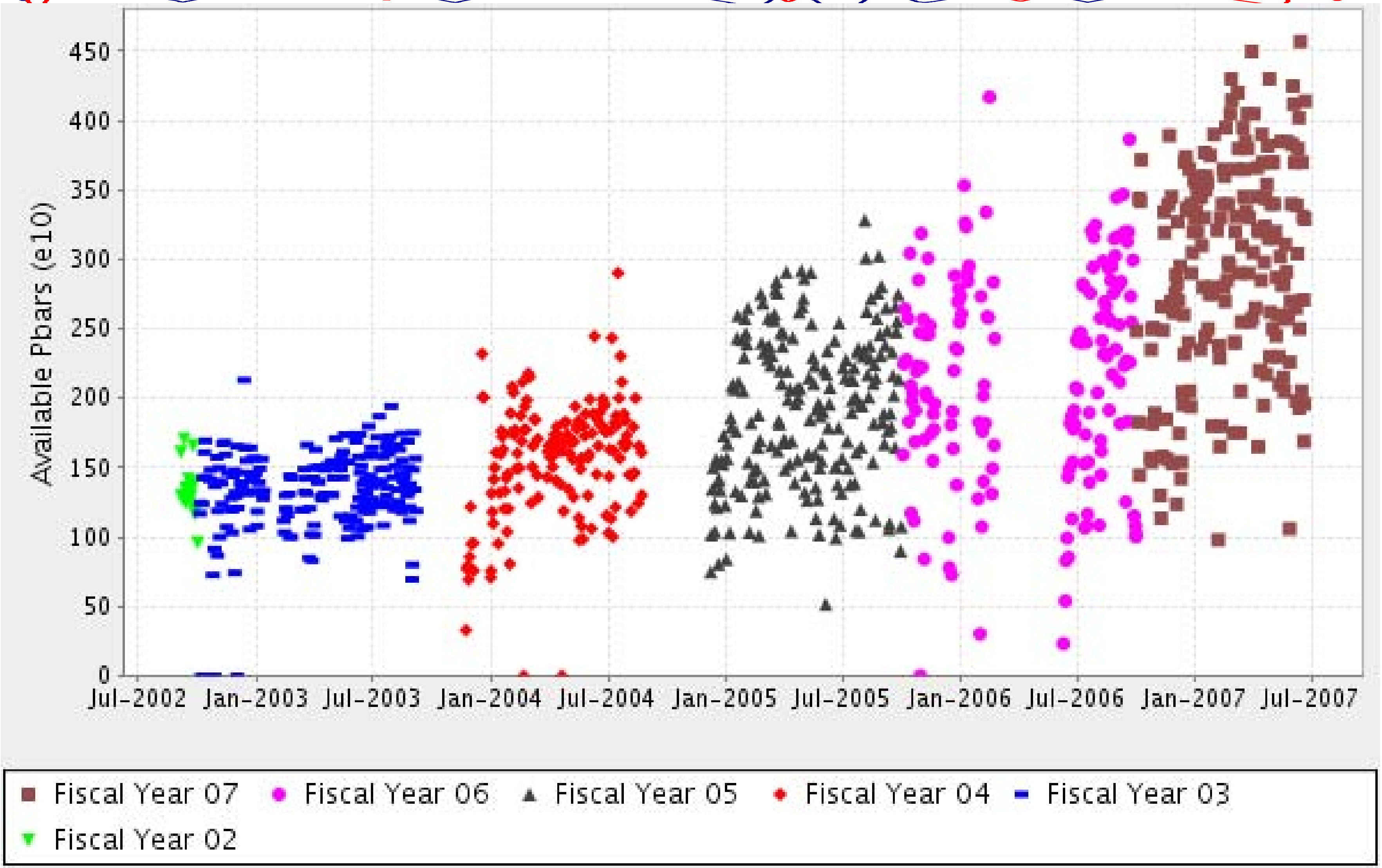
25% variation

7% RMS

Recycler

- Electron Cooling has become operational
- Improvements
  - Change in Working point:
    - Improvement in Lifetime at large stashes
    - Space charge tune shifts
      - pbar beam as function of intensity / density
  - Implementation of Adaptive Feed Forward RF Correction
    - Uniform bunch intensity for collider operation
- Optimization continues
  - Every time new record number of antiprotons has led to learning how to optimize the operation of the Recycler

Antiprotons for Collider Program

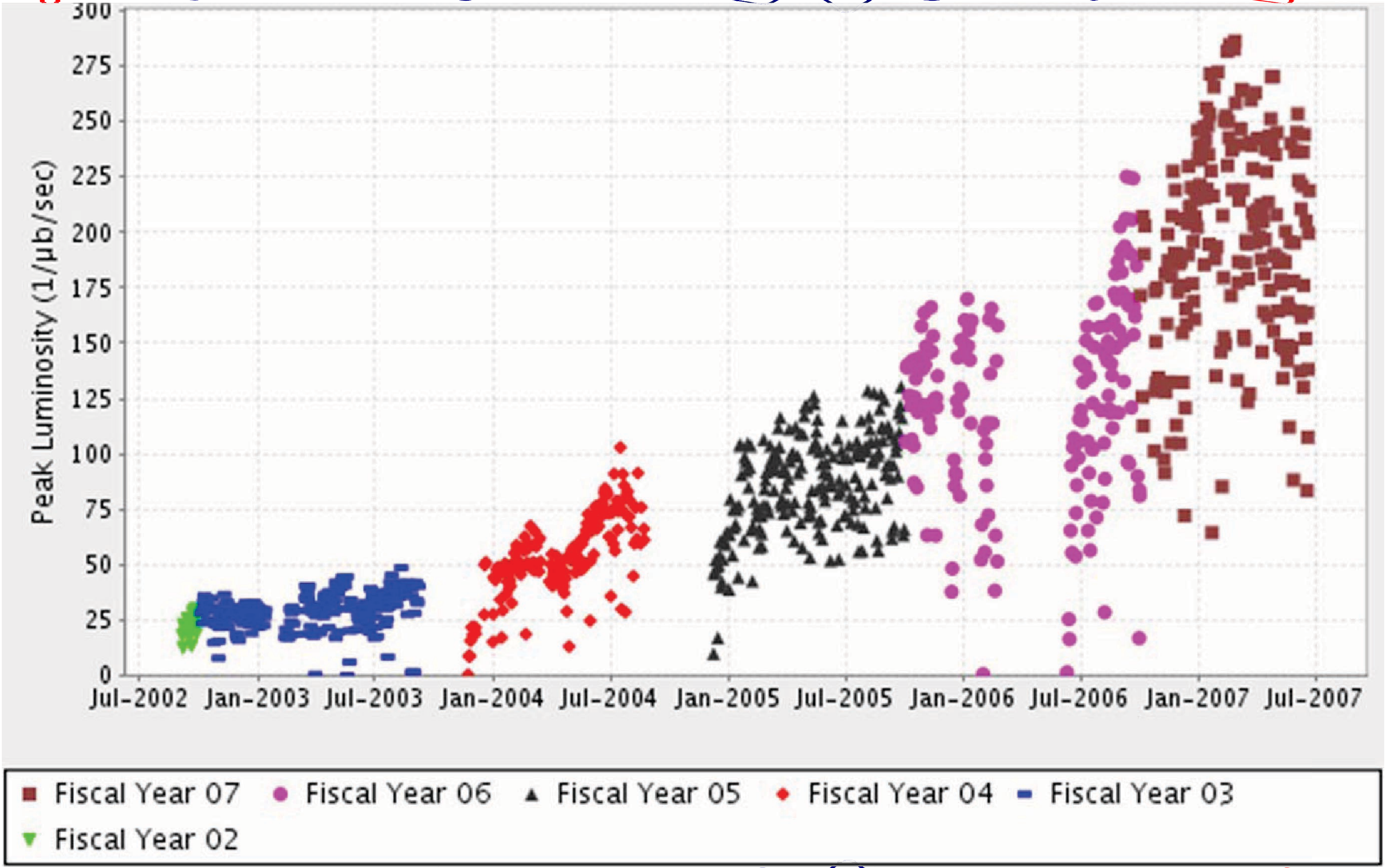


Improvements – Not Covered

- Protons
  - Better coalescing and transmission
- Recycler
  - Mining procedure
  - Electron Cooling Operations
- Tevatron
  - Decrease of β^* + optics correction
  - Separation increase of beams
  - Lifetime
- Reliability
- **Percents here and there add up**

Other Talks and Posters

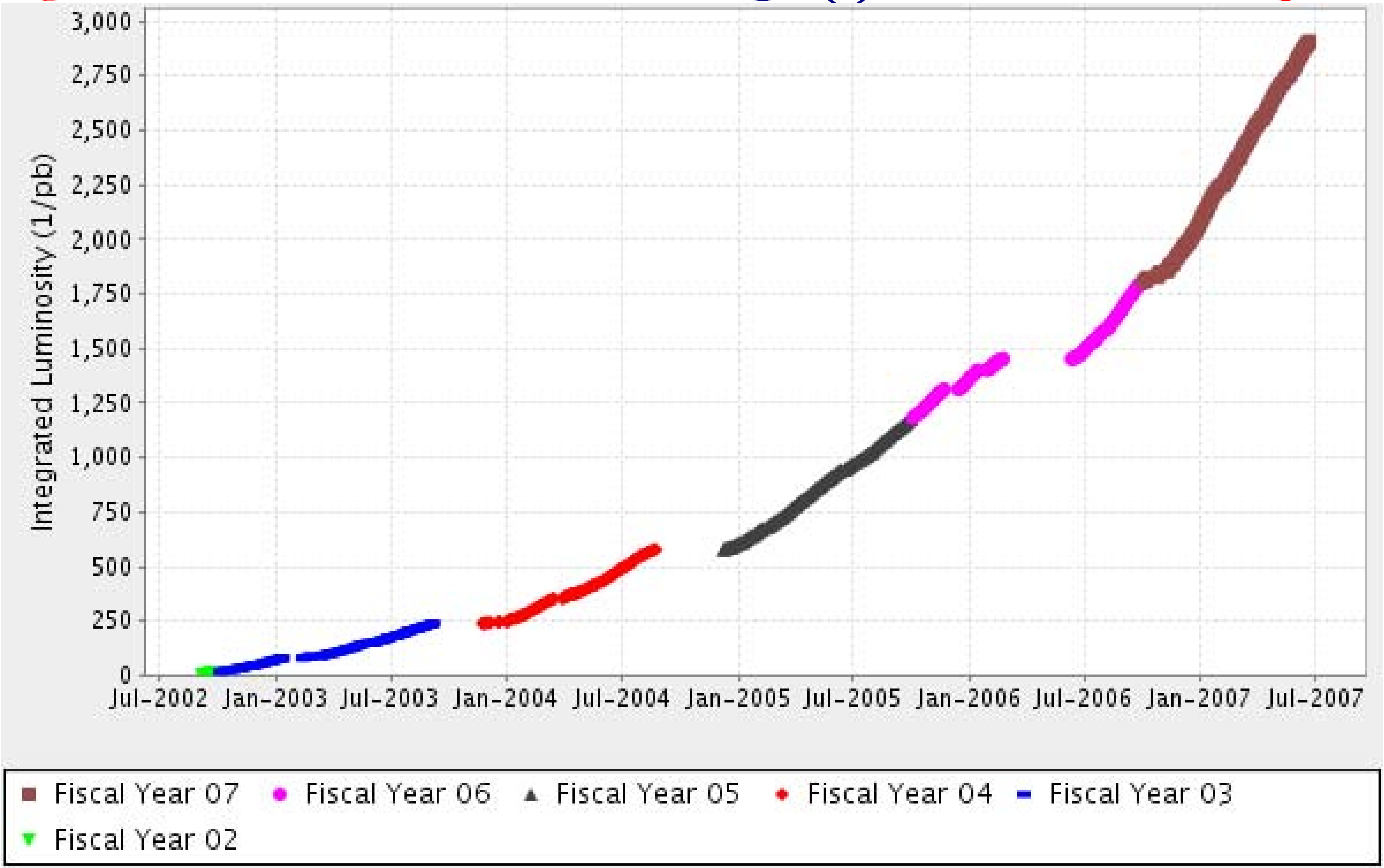
Peak Luminosity



Record Comparison Before/After 2006 Shutdown

- One hour antiproton stacking record
  - 32% ($17.5\ 10^{10}$/hr $\rightarrow$ $23.1\ 10^{10}$/hr)
- Antiproton accumulation for one week
  - 64% ($1710\ 10^{10} \rightarrow 2810\ 10^{10}$)
- Recycler peak Stash
  - 43%($325\ 10^{10} \rightarrow 465\ 10^{10}$)
- Peak luminosity increased
  - 62% ($180 \rightarrow 292\ \mu b^{-1}/s$) $1\ \mu b^{-1}/s = 10^{30}\ cm^{-2}\ s^{-1}$
- Weekly integrated luminosity increased
  - 80% ($25\ pb^{-1} \rightarrow 45\ pb^{-1}$)
- Monthly integrated luminosity increased
  - 95% ($85\ pb^{-1} \rightarrow 167\ pb^{-1}$)

Integrated Luminosity



Conclusions

- The Fermilab Tevatron complex has delivered ~3 fb^{-1} to each experiment
  - Great progress in antiproton production and beam quality have lead to improvements in luminosity and the integrated luminosity delivered
- 4 fb^{-1} should be achieved in 2009
  - Dependent upon Accumulator stacking rate
  - Optimization of the Recycler operations with electron cooling will continue