# Record luminosities at the Tevatron & Future potentiality

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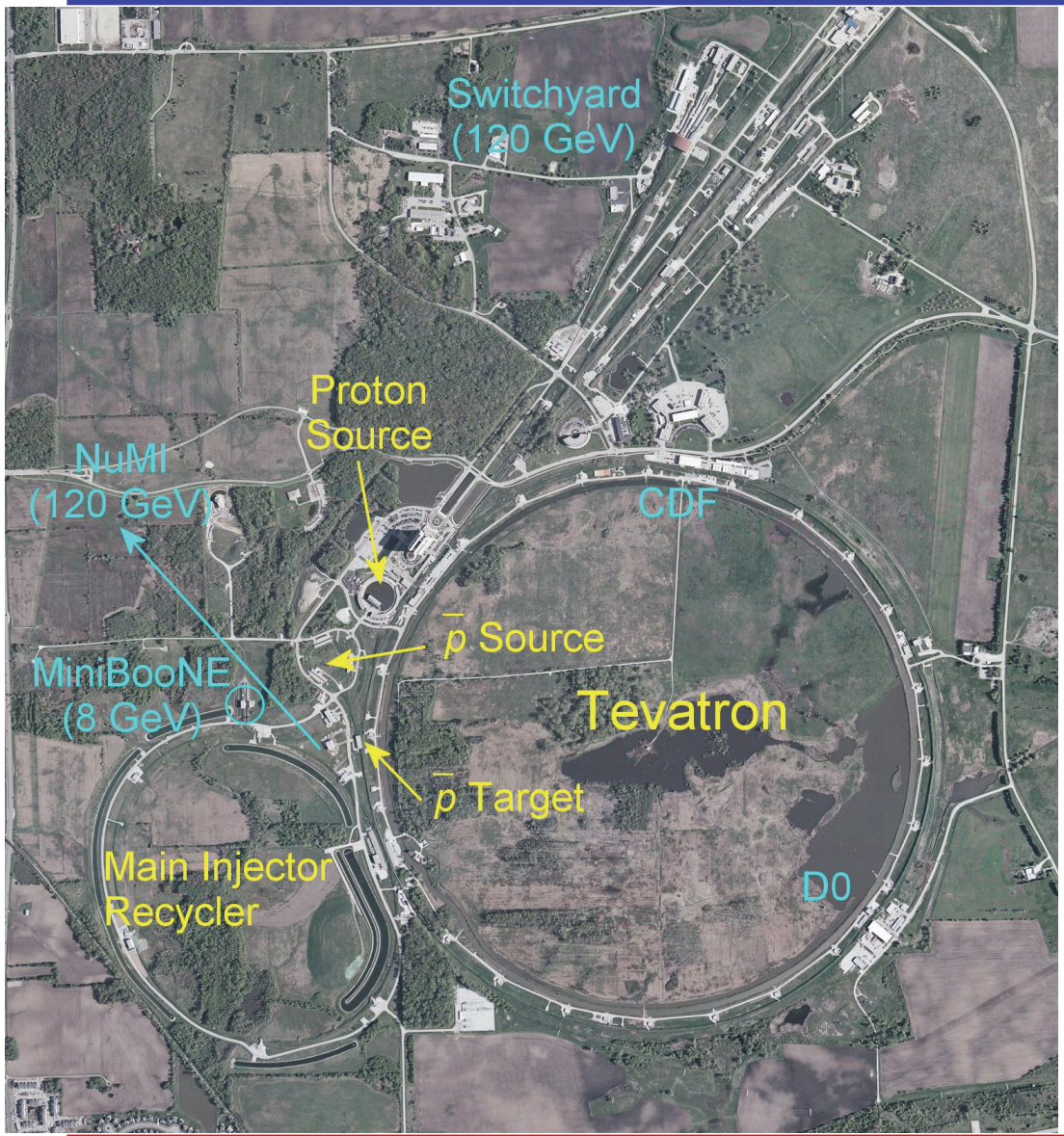
Asian Particle Accelerator Conference
Indore, India
January 30, 2007

# Outline

- Overview of Fermilab operations
- Major accomplishments
- Antiproton Production
- Recycler Only Operation
- Tevatron issues
- Conclusions

# Fermilab Accelerator Complex




Two Collider Experiments
- CDF
- D0

Two neutrino Experiments
- NuMI
- MiniBooNE

120 GeV Fixed Target Experiments

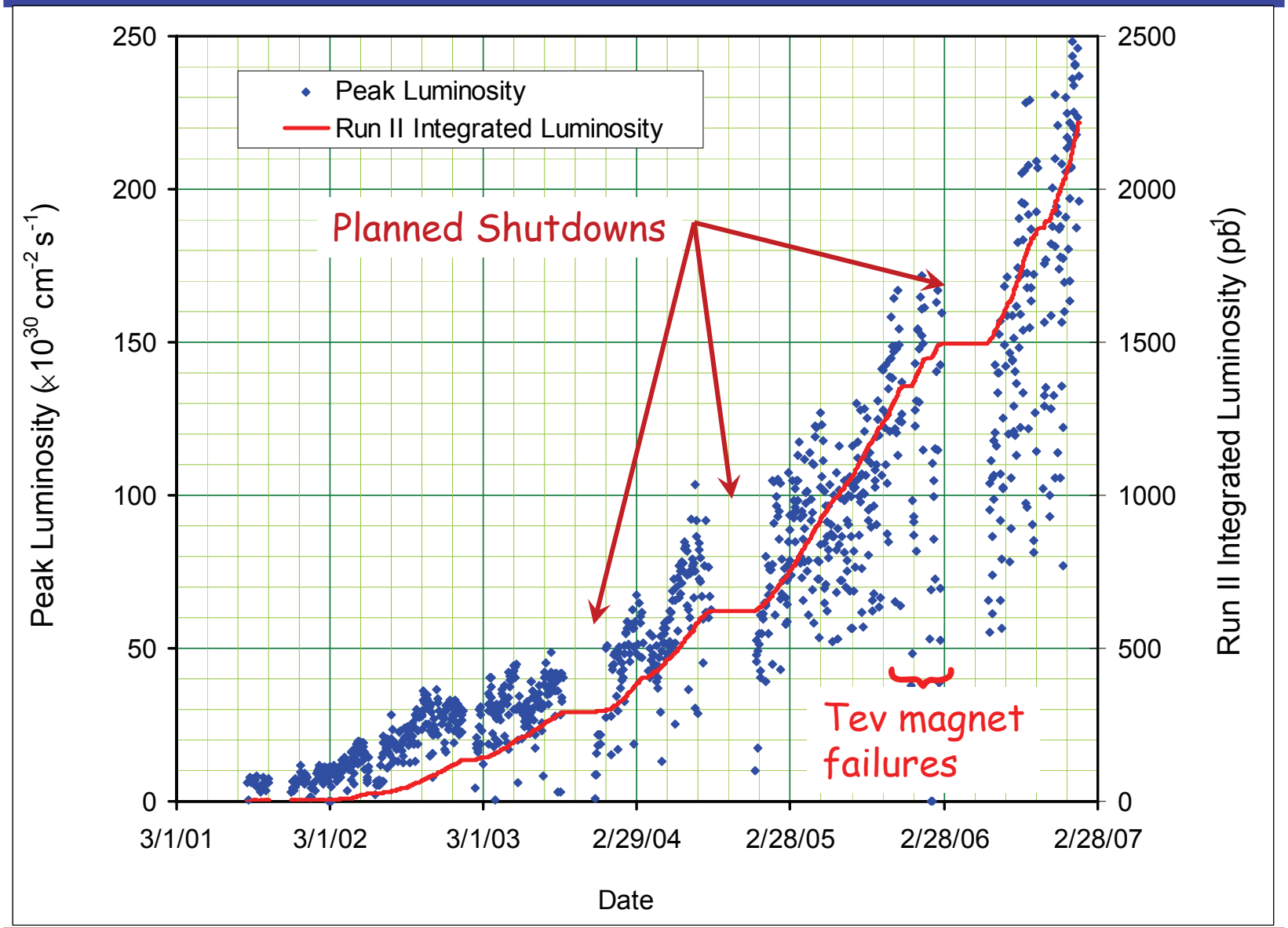
Ongoing program of
- Tevatron,
- $\bar{p}$ source,
- Main Injector, and
- Recycler upgrades

… One source of protons

# Collider Parameters

| Parameter | Present | Upgrade | Units |
|---|---|---|---|
| Peak Luminosity | 185 | 300 | $10^{30}$ cm$^{-2}$ s$^{-1}$ |
| Luminosity Lifetime | 8.5 | - | hr |
| Store hours per week | 97 | 105 | hr/wk |
| Integrated Luminosity | 5.1 | - | pb$^{-1}$/store |
| Total Run II $\int Ldt$ | 2.2 | 7 | fb$^{-1}$ |
| Protons per bunch | 250 | 270 | $10^9$ |
| $\bar{p}$ per bunch | 58 | 127 | $10^9$ |
| Number of bunches | 36×36 | 36×36 | |
| $\beta^*$ at IPs | 28 | 28 | cm |
| $\bar{p}$ stacking rate to Accumulator | 17.5 | 30 | $10^{10}$/hr |
| $\bar{p}$ stacking rate to Recycler | 12.0 | - | $10^{10}$/hr |

# Luminosity Progress



# Run II Milestones

| Milestone | Date |
|---|---|
| Start of Run II Commissioning | March 2001 |
| Collider Operational | July 2003 |
| Recycler Electron Cooling Operational | July 2005 |
| Slip Stacking Operational | August 2005 |
| Lower $\beta^*$ from 35 cm to 28 cm | September 2005 |
| Recycler Only Operations | October 2005 |
| Tevatron Separator Upgrade | Spring 2006 |

# Antiproton Production

- Beam on target – Slip Stacking
- Consequences
- Lithium Lens & Aperture upgrades
- Stacktail Cooling Issues

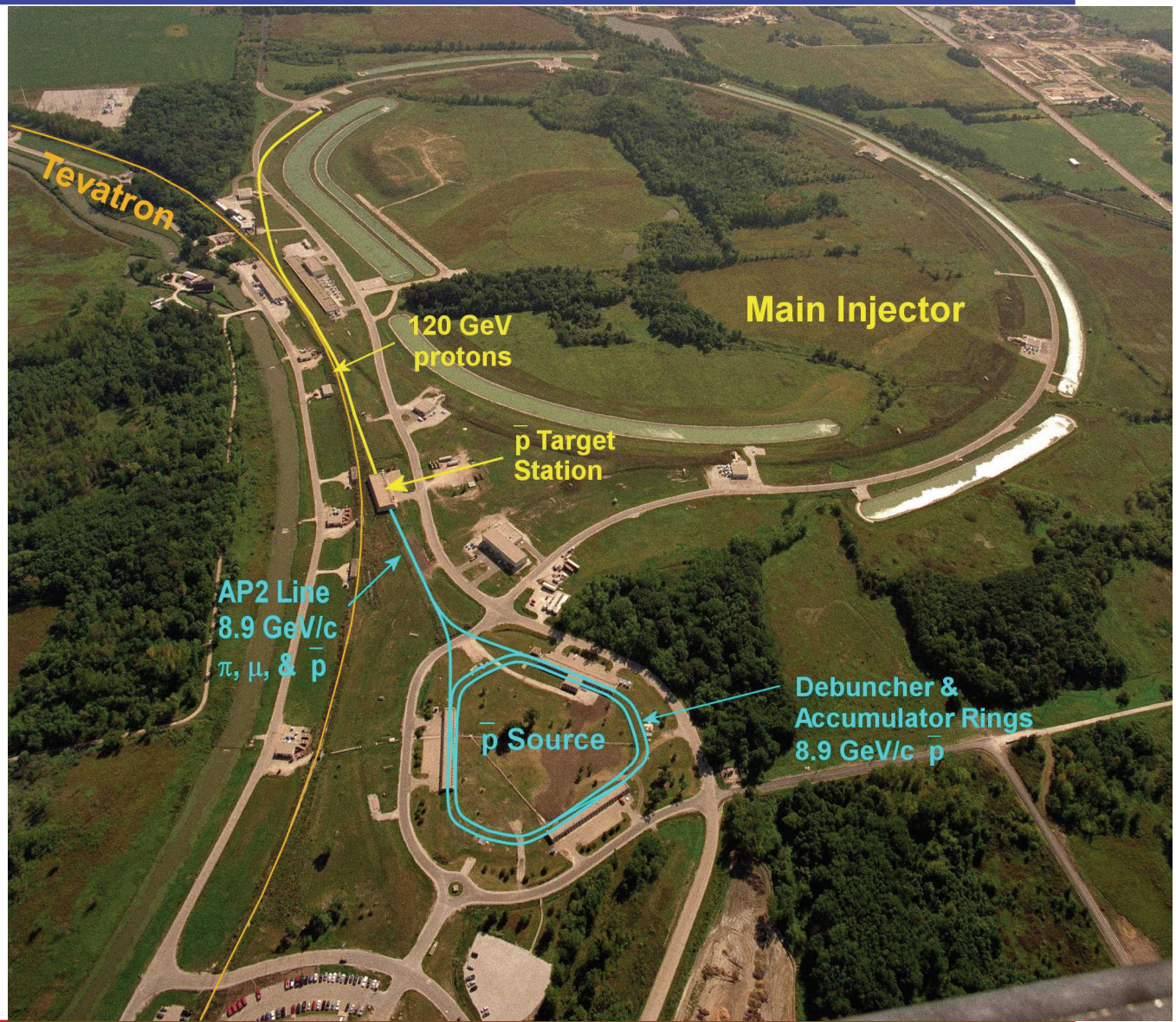
# Collider Operation - $\bar{p}$ Stacking

120 GeV protons ($8\times10^{12}$) on target

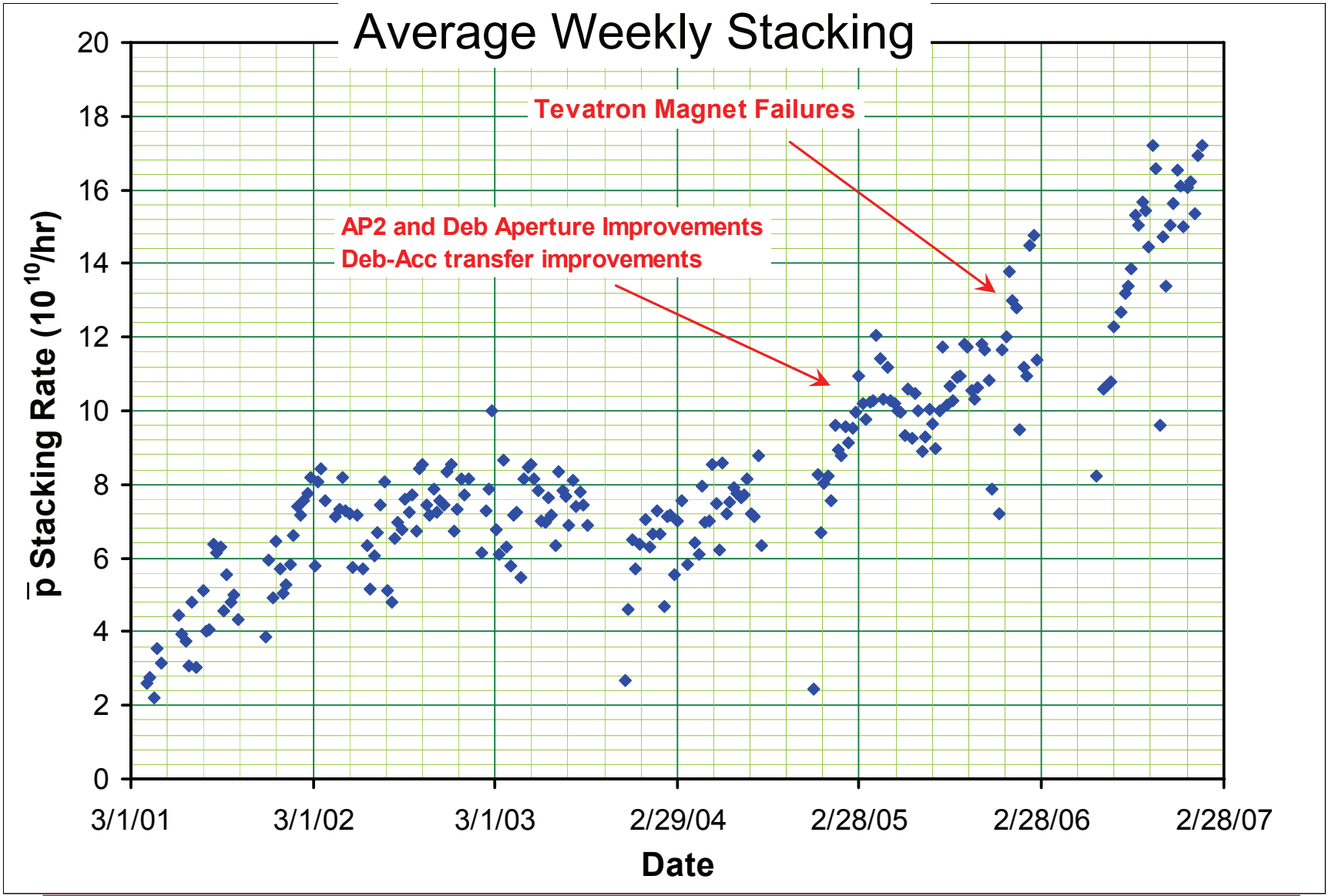
8 GeV $\pi$, $\mu$, & $\bar{p}$ in AP2 line

Debunch and cool in Debuncher for 2.4 sec.

Stochastically stack in Accumulator



# Stacking Rate History

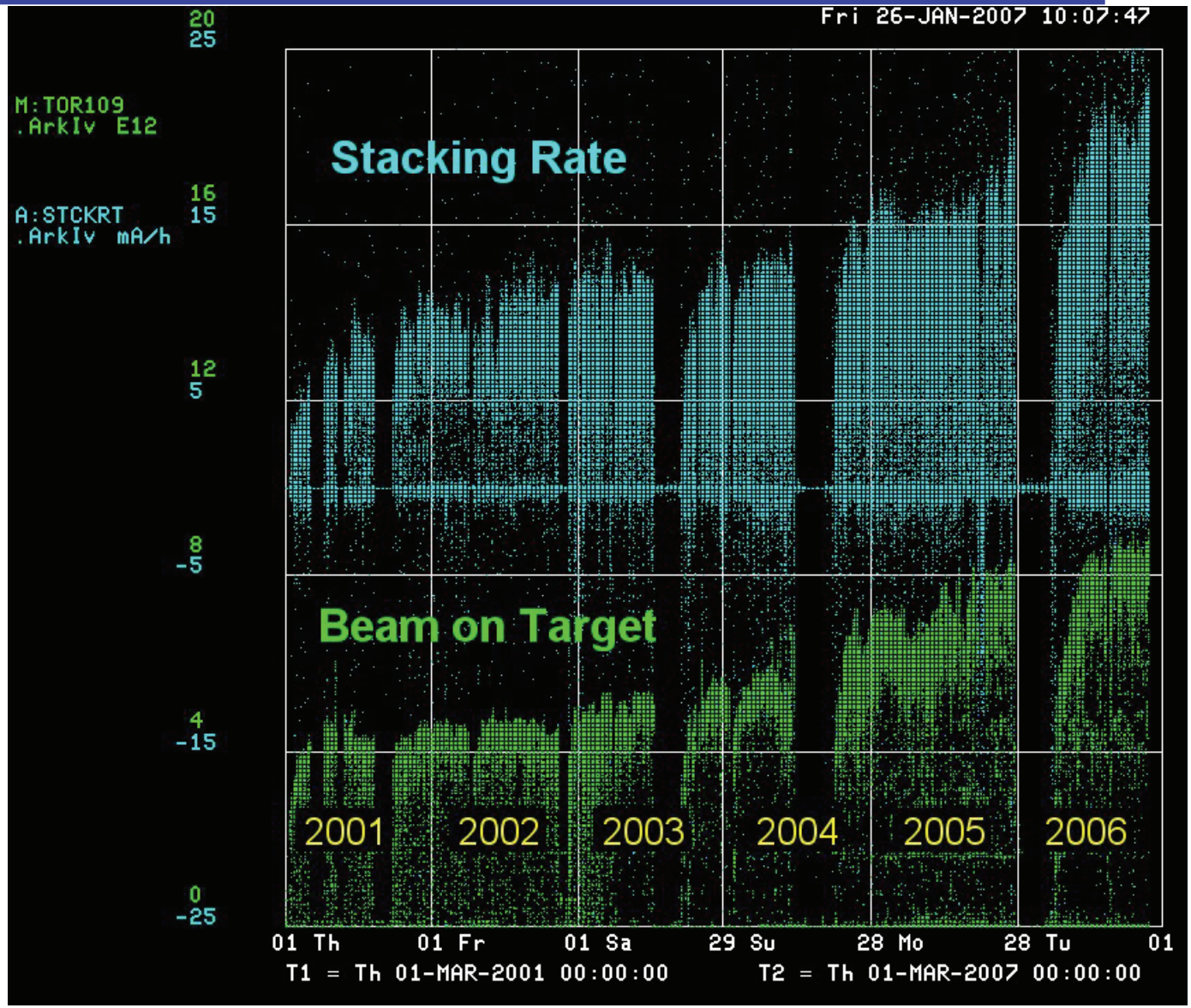


# $\bar{p}$ Stacking – Beam on Target

Stacking rate increases have generally followed the increases in beam on target.

The steady increase after the 2004 shutdown is due to Slip Stacking.

Presently $8.2 \times 10^{12}$ protons per cycle are routinely targeted.

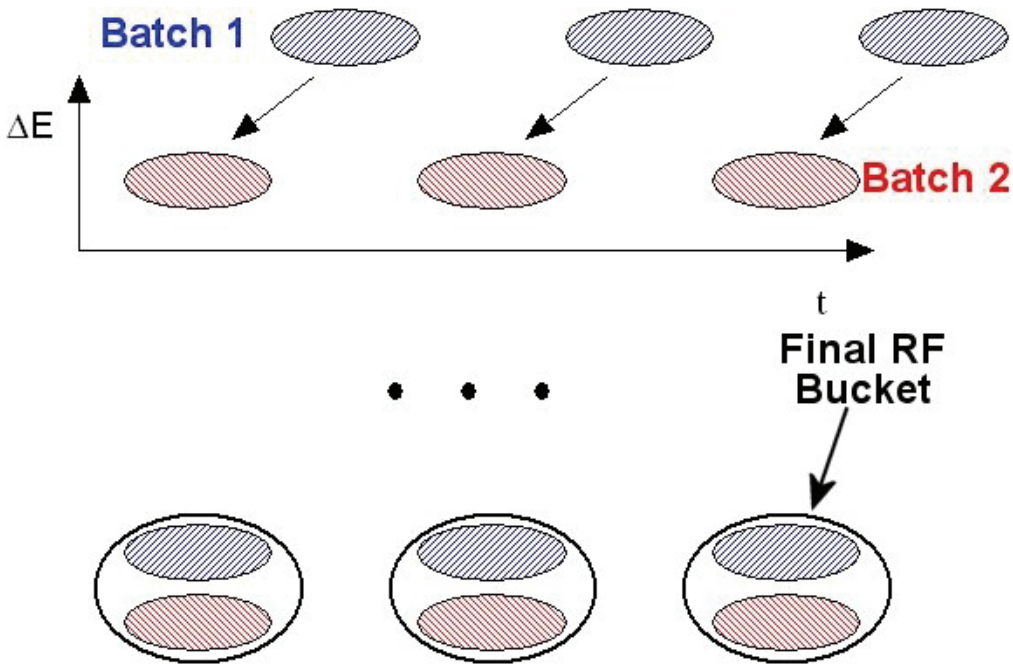


# Slip Stacking

Two proton batches are injected into the Main Injector on different radial orbits. They will have different momenta and revolution frequencies.

Since the revolution frequency of these two batches are different they will slip longitudinally relative to one another.

When the two batches are azimuthally aligned they are captured in a common RF bucket and accelerated to 120 GeV.



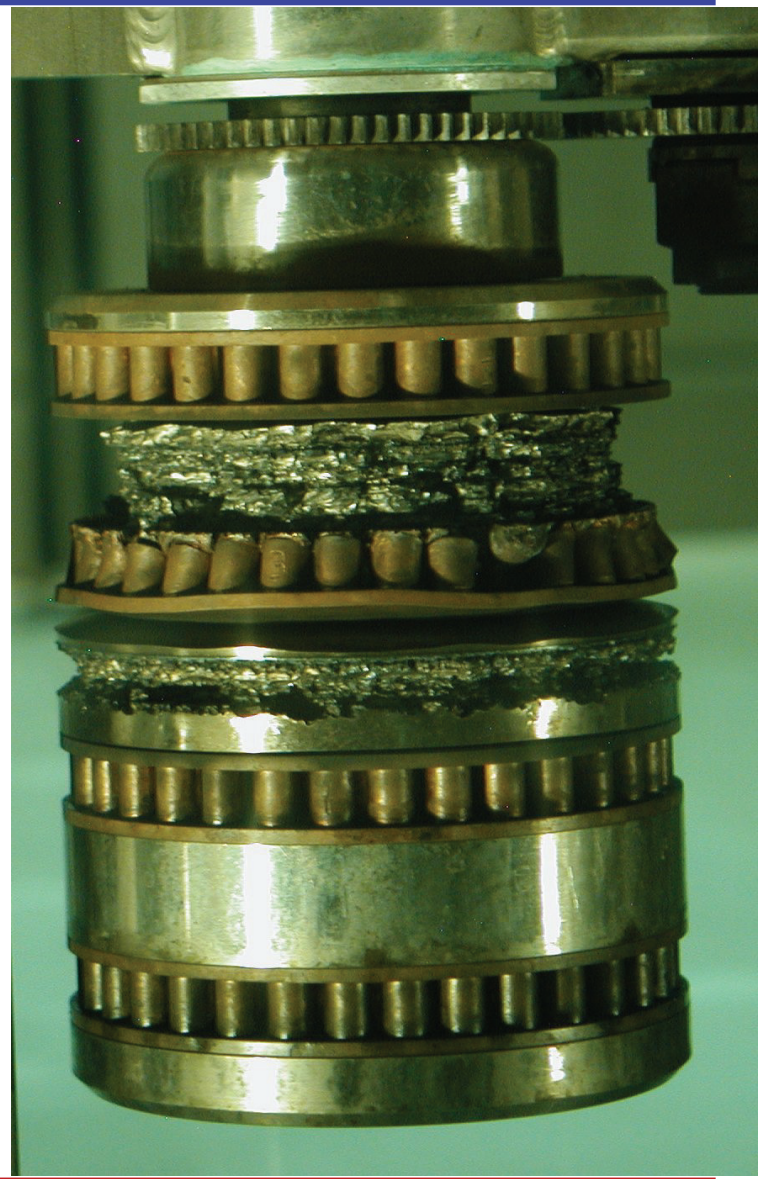
# Consequences – Target Damage

3 Nickel disks

- Diameter: 11.43 cm
- Height: 2.15 cm
- Air Cooled

Capacity: $6 \times 10^{18}$ protons/disk

- Takes ~ 5 weeks to consume one disk
- Yield degraded by ~5% after this
- Target lifetime is ~3 months

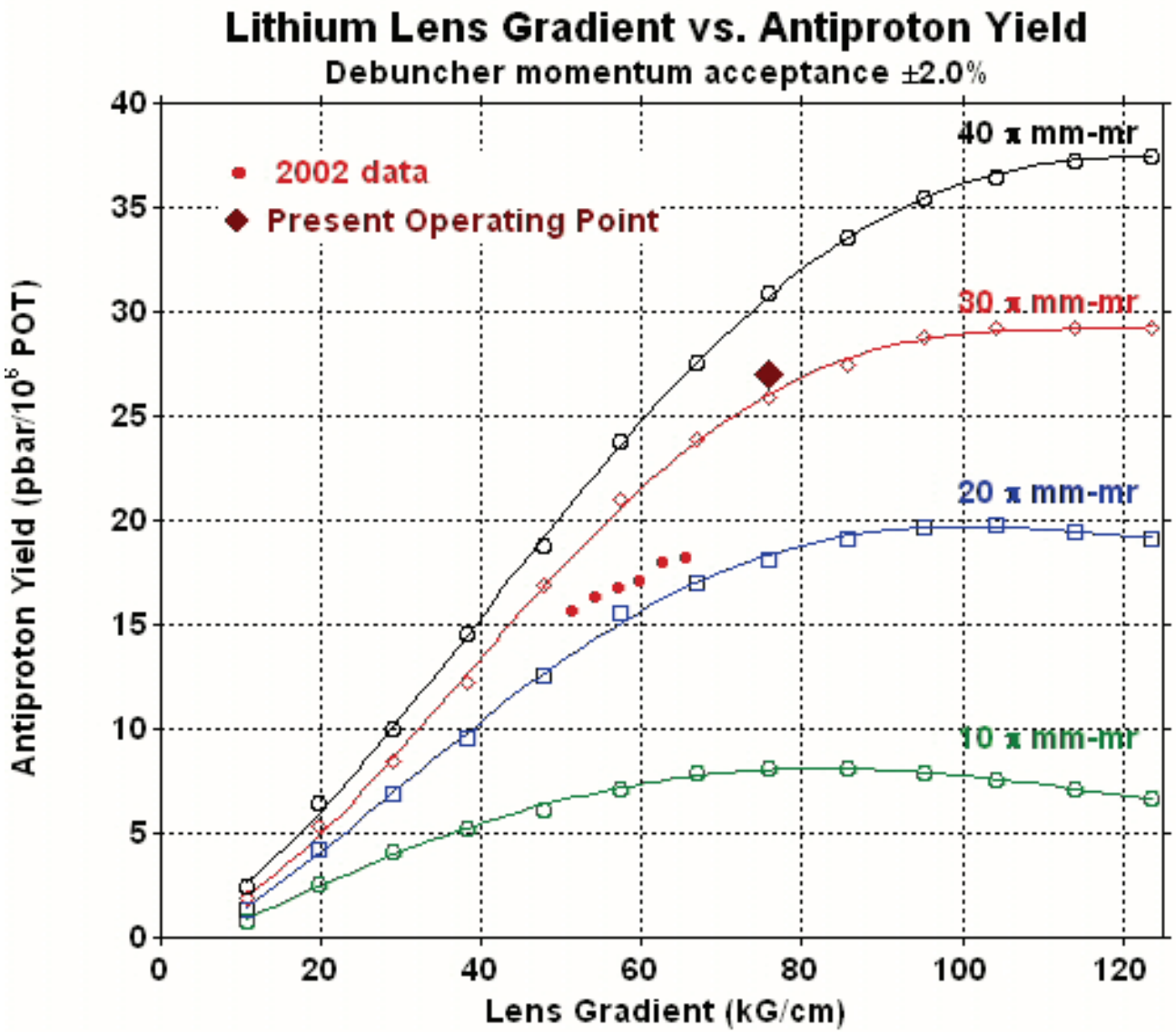


# $\bar{p}$ Production – Collecting beam from the target

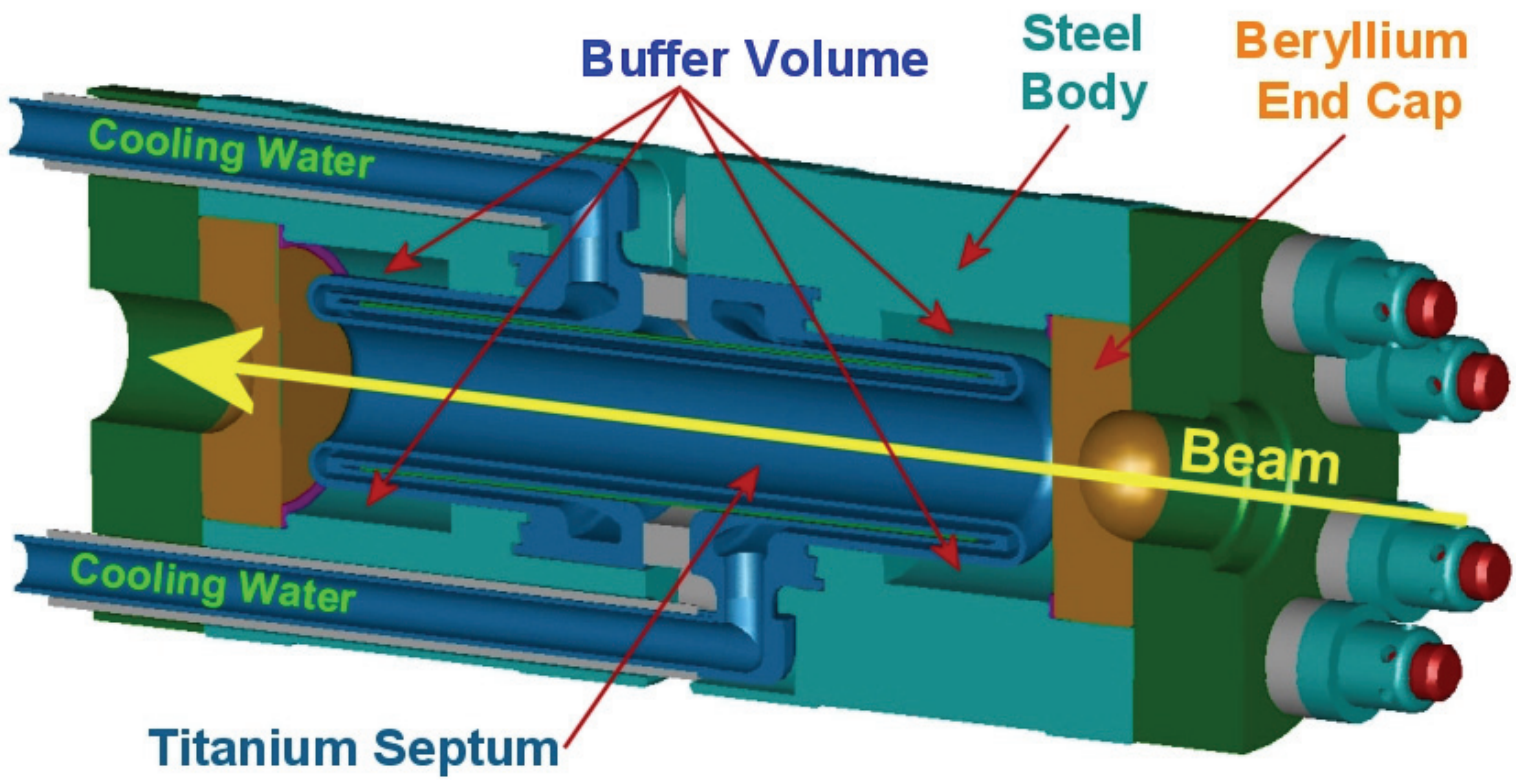
Two upgrade projects have increased the $\bar{p}$ yield by 60%:

Li Lens gradient upgrade

AP2 & Debuncher acceptance upgrade



# Old Li Lens Design



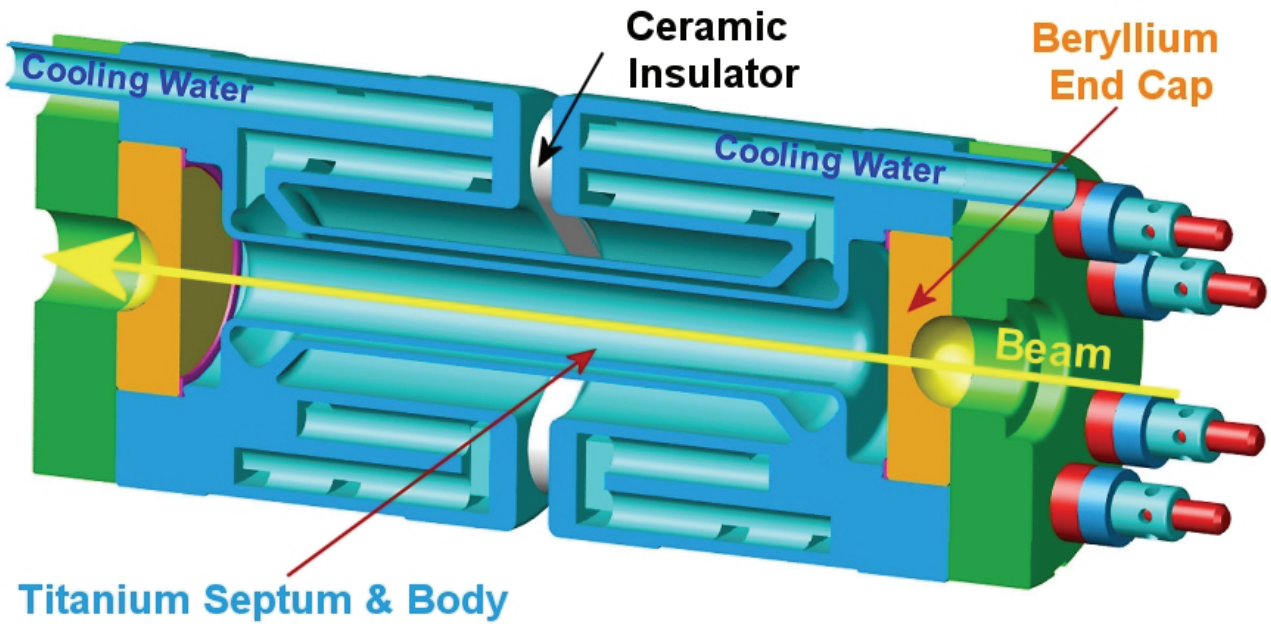

Note:

- No cooling of steel body
- Only septum is made of titanium

# High Gradient Lithium Lens – New Design

## Features:

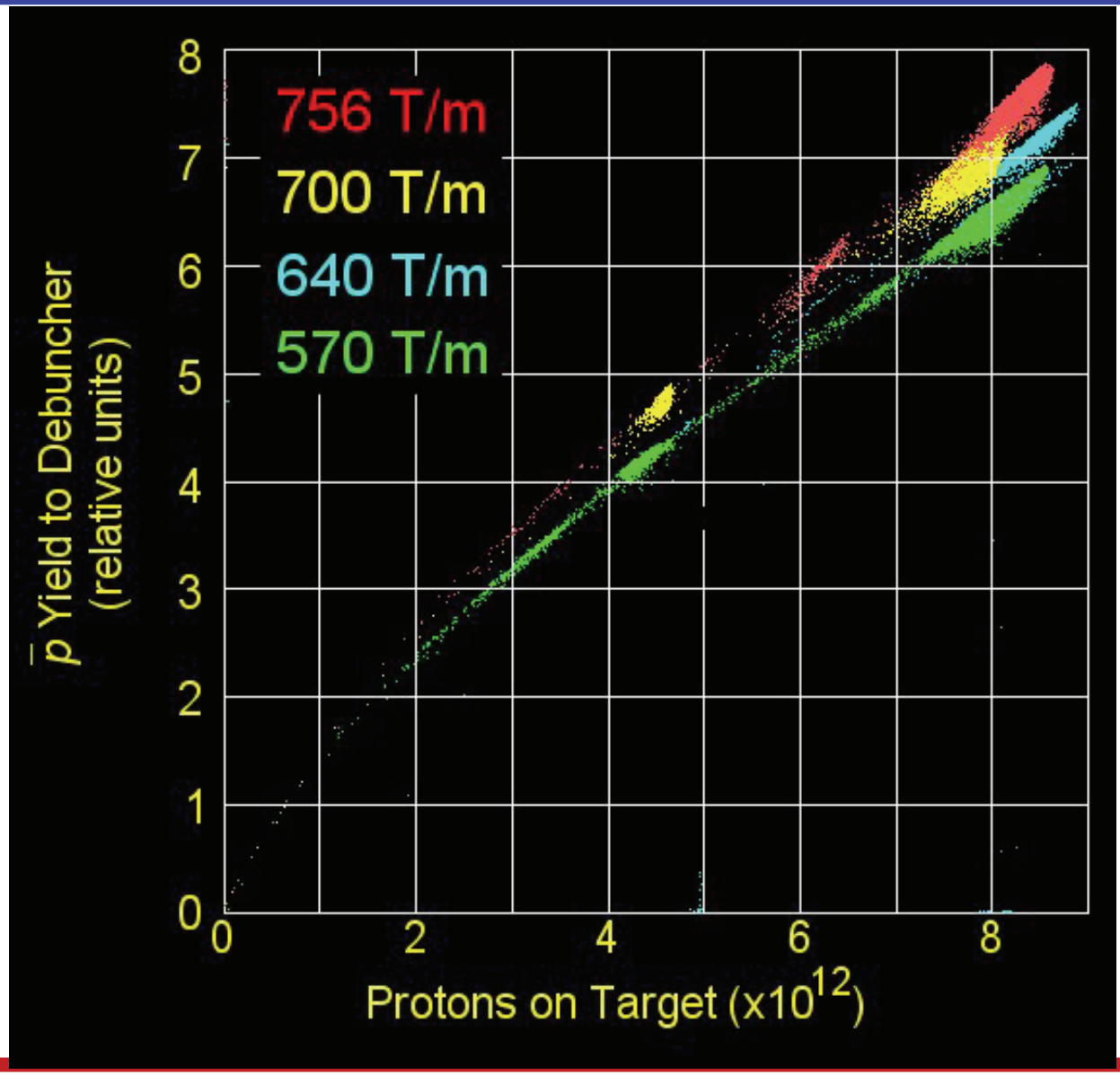
- Diffusion bonded titanium body
- Improvec cooling
- Li buffer volumes eliminated




## Diffusion Bonding:

- Better, more uniform cooling of lens body
- Allows use of new Ti alloy (Ti 10V-2Fe-3Al)
- Simplified lens fabrication
- Elimination of weld joints on septum

# Measured Yield Increase with Gradient

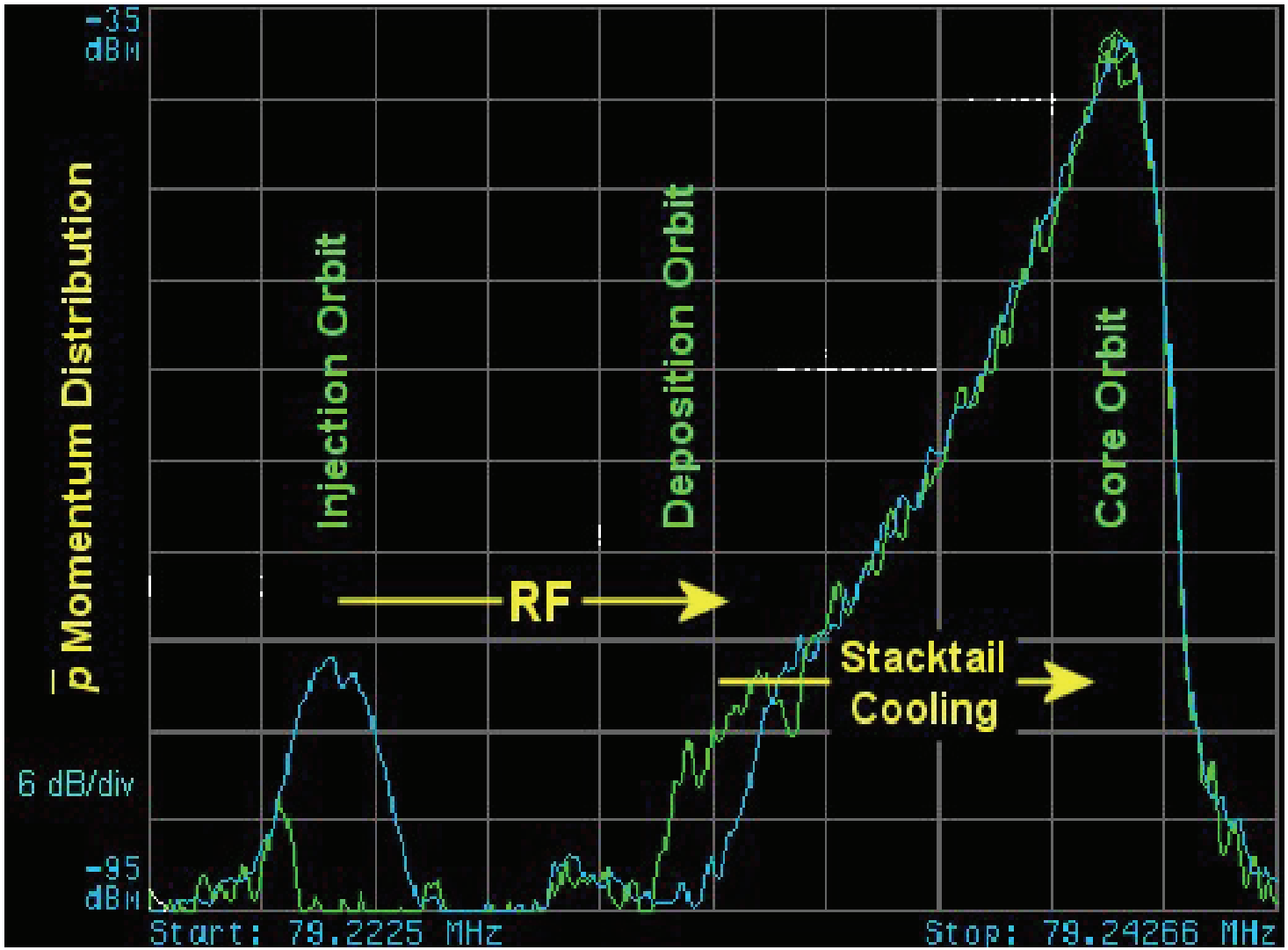


# Accumulator Stacking

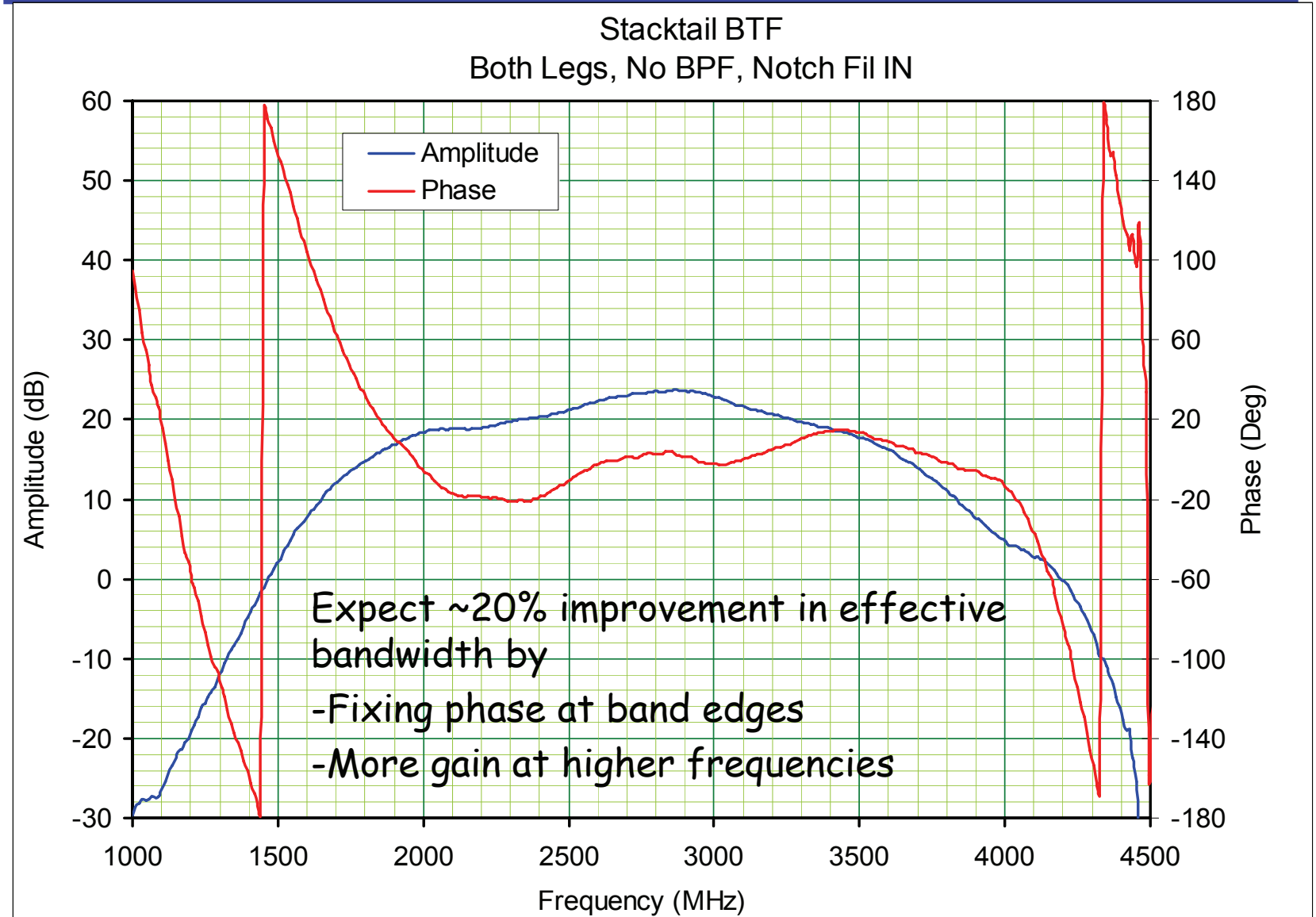
Injected beam is moved by RF to Deposition Orbit.

Deposited pulse is moved of the deposition orbit and stacked by the stacktail cooling system.

Deposition orbit must be cleared off prior to next pulse.



# Stacktail Bandwidth Improvement



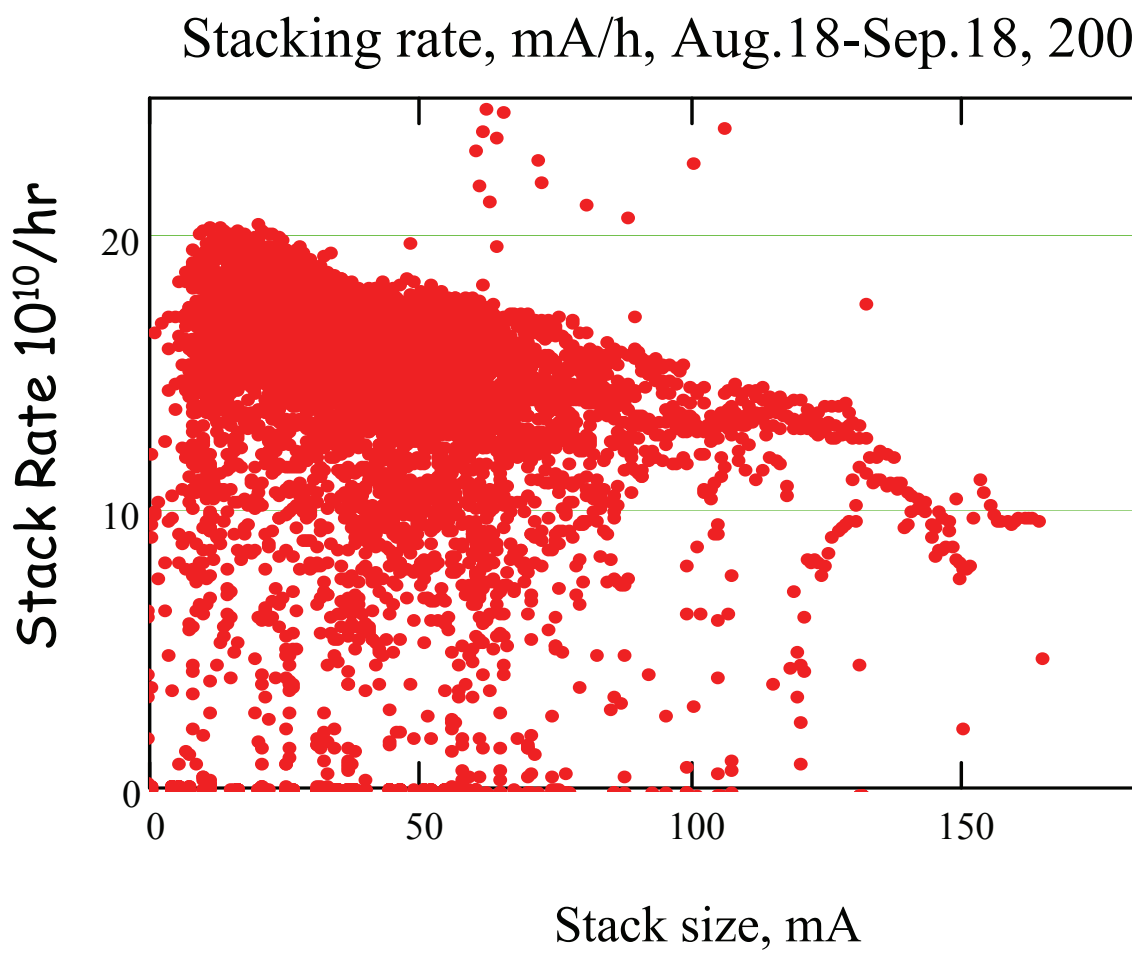
# Recycler Only Operation (1)

Stacking Rate in the accumulator is stack-size dependant.

As the core grows its signal on the stacktail pickups grows also.

The result is core heating by the stacktail. Thus, as the core grows the stacktail gain must be lowered ⇒ stacking rate decreases.

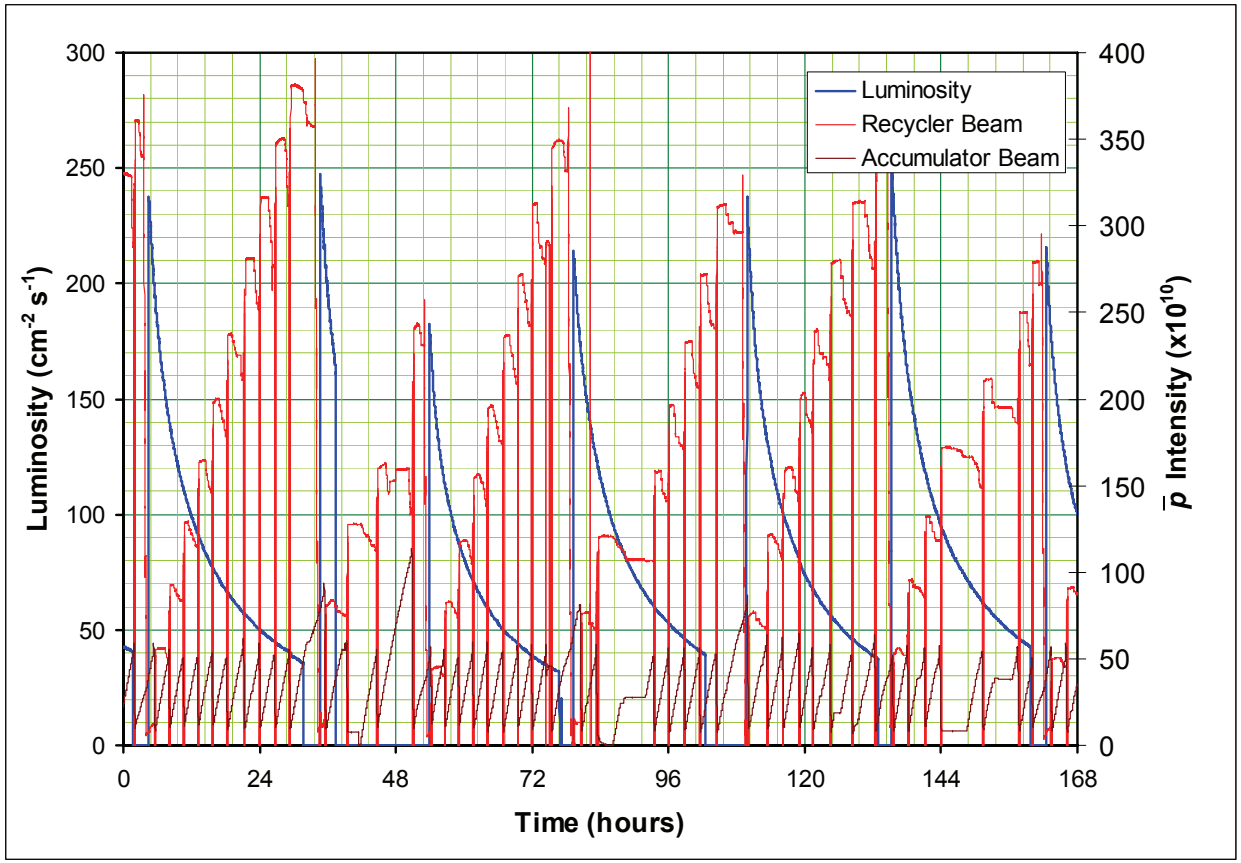
**Solution**: Transfer the beam to the Recycler before the core grows too large.




1 mA = $10^{10}$ $\bar{p}$

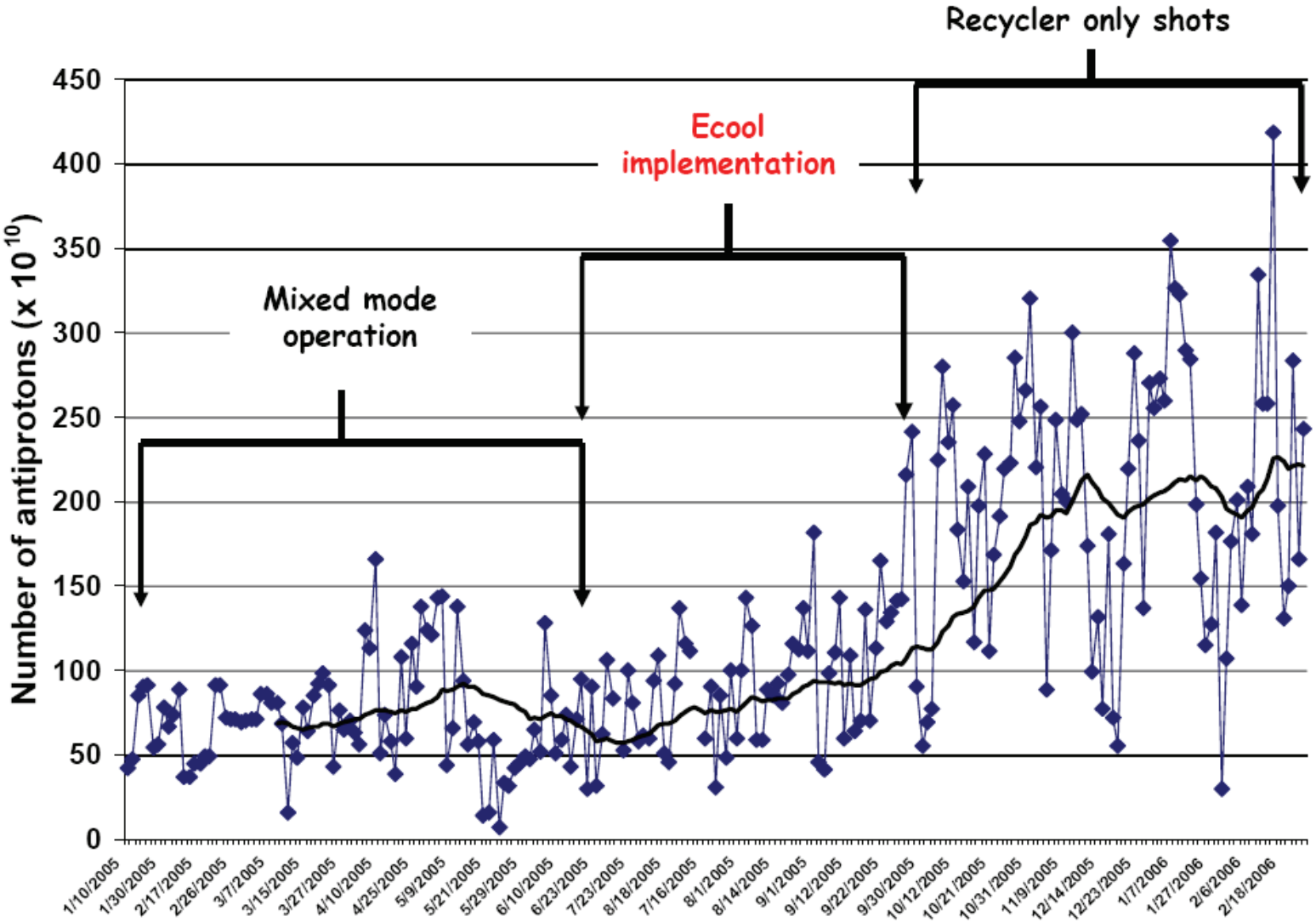
# Recycler Only Operation (2)

- Stack into Accumulator to 50 – 60 x $10^{10}$ $\bar{p}$
- Transfer all $\bar{p}$ from Accumulator to Recycler
- When Collider store is terminated, transfer $\bar{p}$ from Recycler to the Tevatron.




For more information on rapid transfers to the Recycler see V. Nagaslaev poster

# Shifting from Accumulator to Recycler Operation




Jan '05 Feb '06

# Tevatron Improvements

## Newly Operational

- BPM Upgrade
- Lower $\beta^*$
- Separator Upgrade

## Problems

- Magnet Failures

## Yet to Come

- Working point change

# Tevatron Improvements

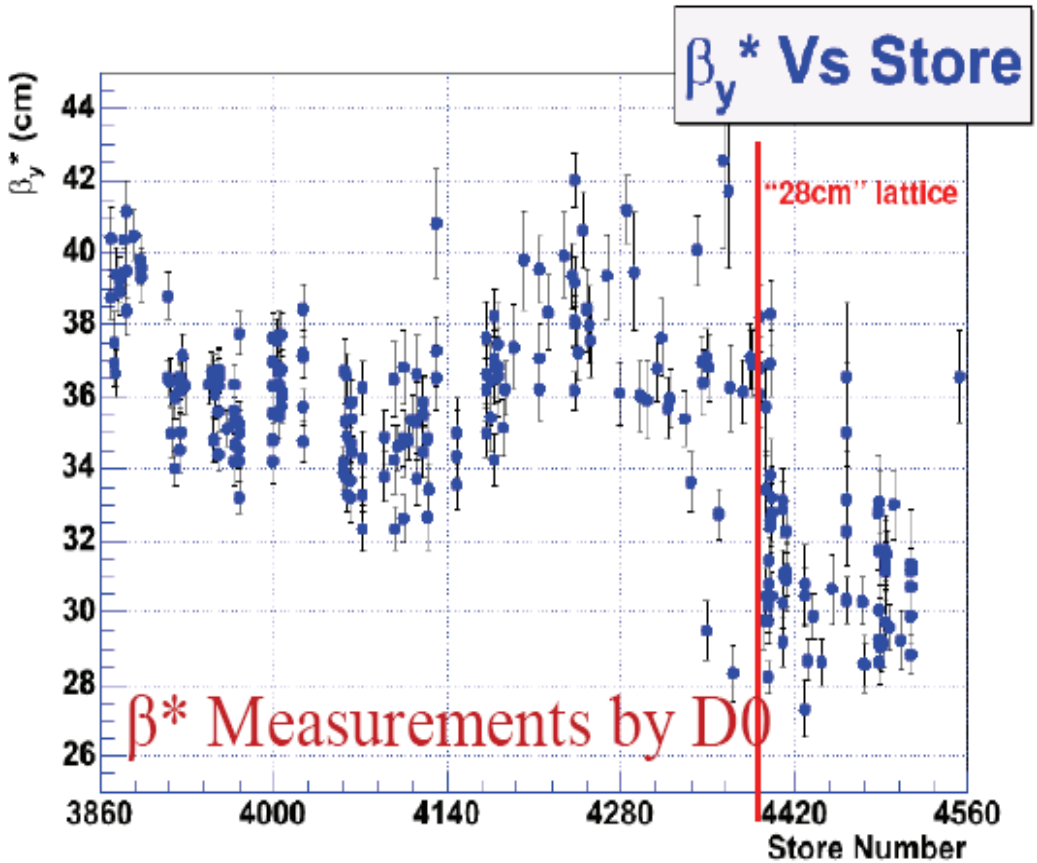
BPM upgrade

- 10 – 25 μm Resolution
- Accuracy of proton position measurement improved by order of magnitude.
- Ability to measure antiproton orbits for the first time

# Tevatron Improvements

## 28 cm $\beta^*$ Optics Change

- Lattice measurements exploited new BPM electronics.
- Tested after HEP prior to store termination.
- $\beta^*$ change implemented in September 2005.



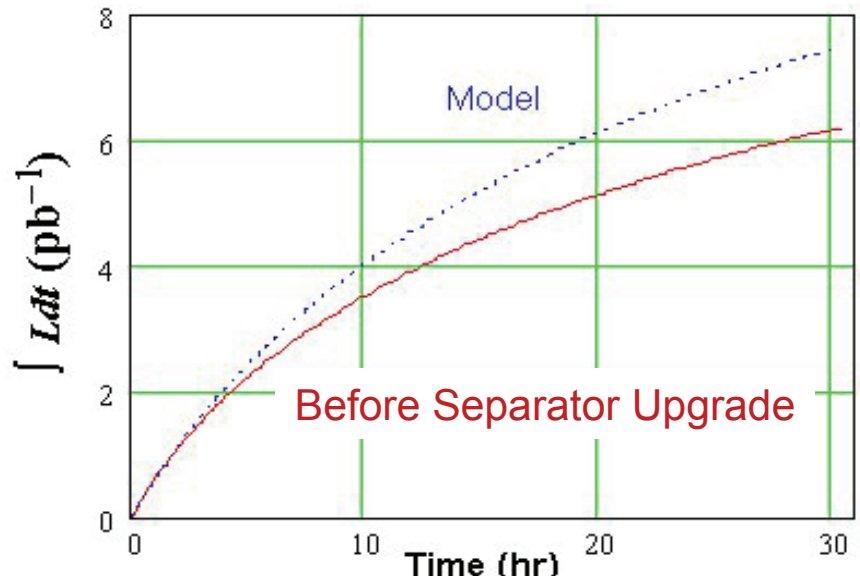
# Tevatron Improvements

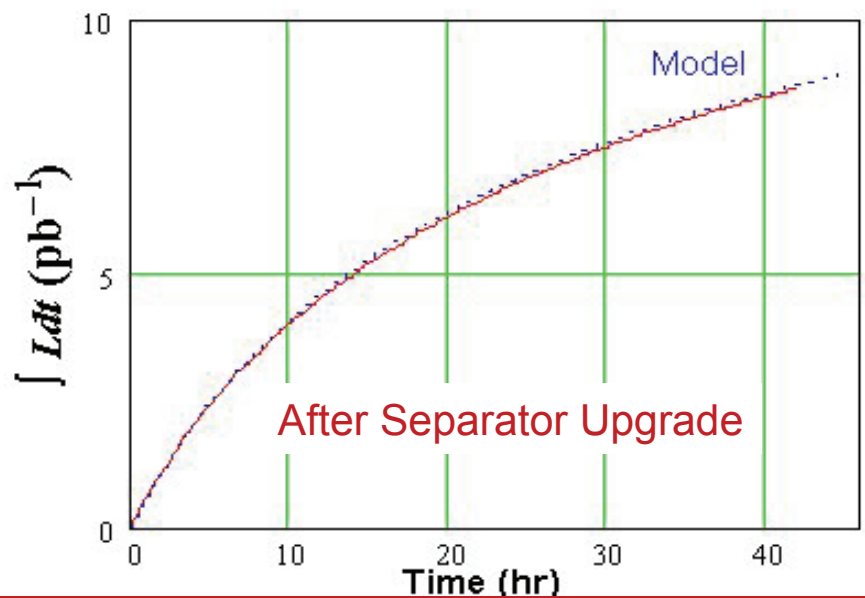
## Separator Upgrade

- Additional HV modules installed
- Polarity reversing switches
- Increased HV capacity

Comparison of luminosity evolution with model that does not include beam-beam effects.

- Prior to separator upgrade a model without beam-beam does not well represent the data
- After separator upgrade – beam-beam mitigated – model matches data



# Tevatron Failures

Three Tevatron magnet failures occurred in early FY 2006. Each were induced by components that failed to operate properly during "mild" quenches.

- Mild quench –10-15K magnet temperature, < 1 hour recovery
- Major quench –100k magnet temperature, multi-hour recovery

Two of the magnet failures were the result of failed "Kautzky" (pressure relief) valves.

- We view this as a systematic failure

**Shutdown 2006:**

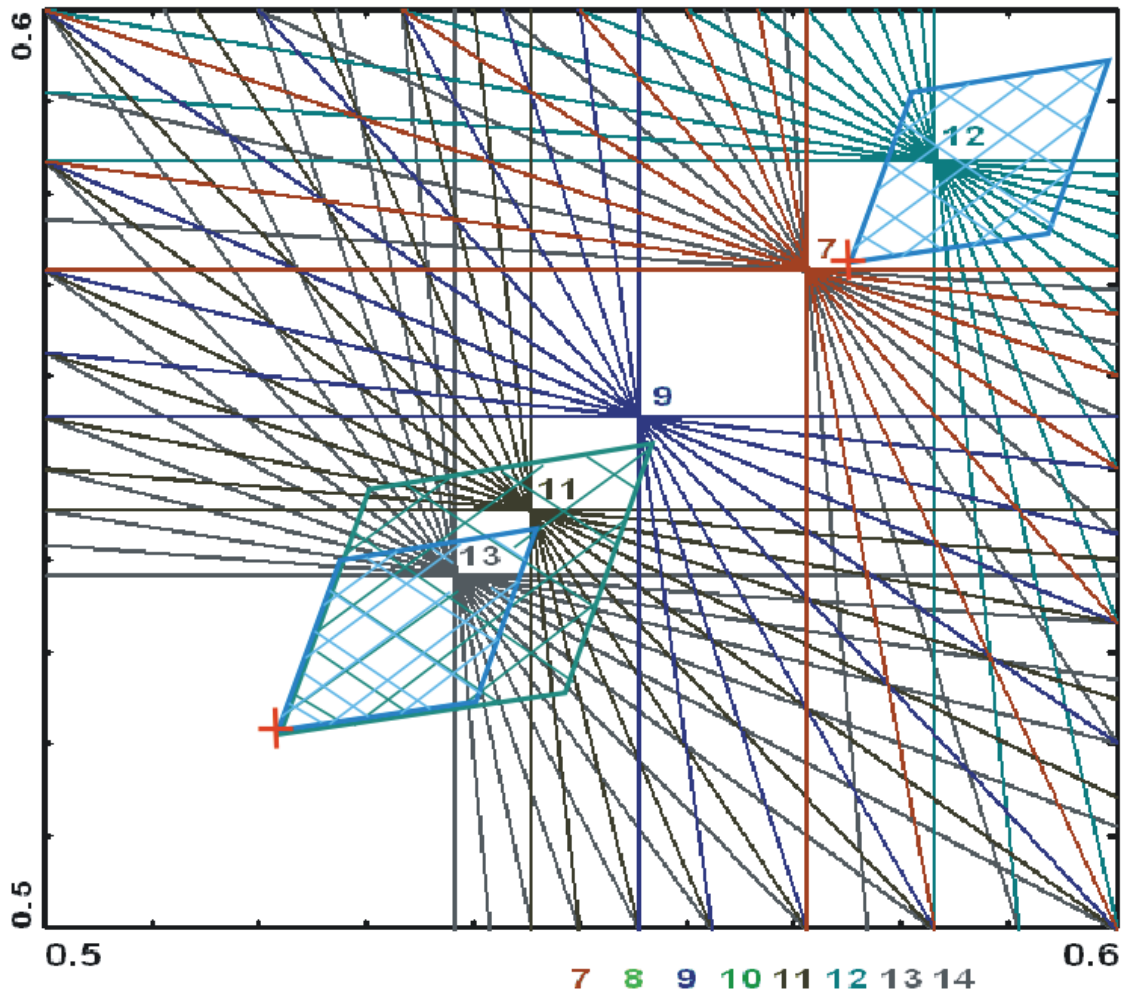
- Replaced the failed part in all of the Tevatron Kautzky valves (~1200) during this shutdown
- Repaired all known cold leaks (F4, E2, A3, B4)

# Tevatron – Yet to Come

Normal operating point between 4/7 and 3/5.

Plan to move working point to vicinity of $\frac{1}{2}$

- 40% more tune space
- Greater chromatic effects



# Conclusions

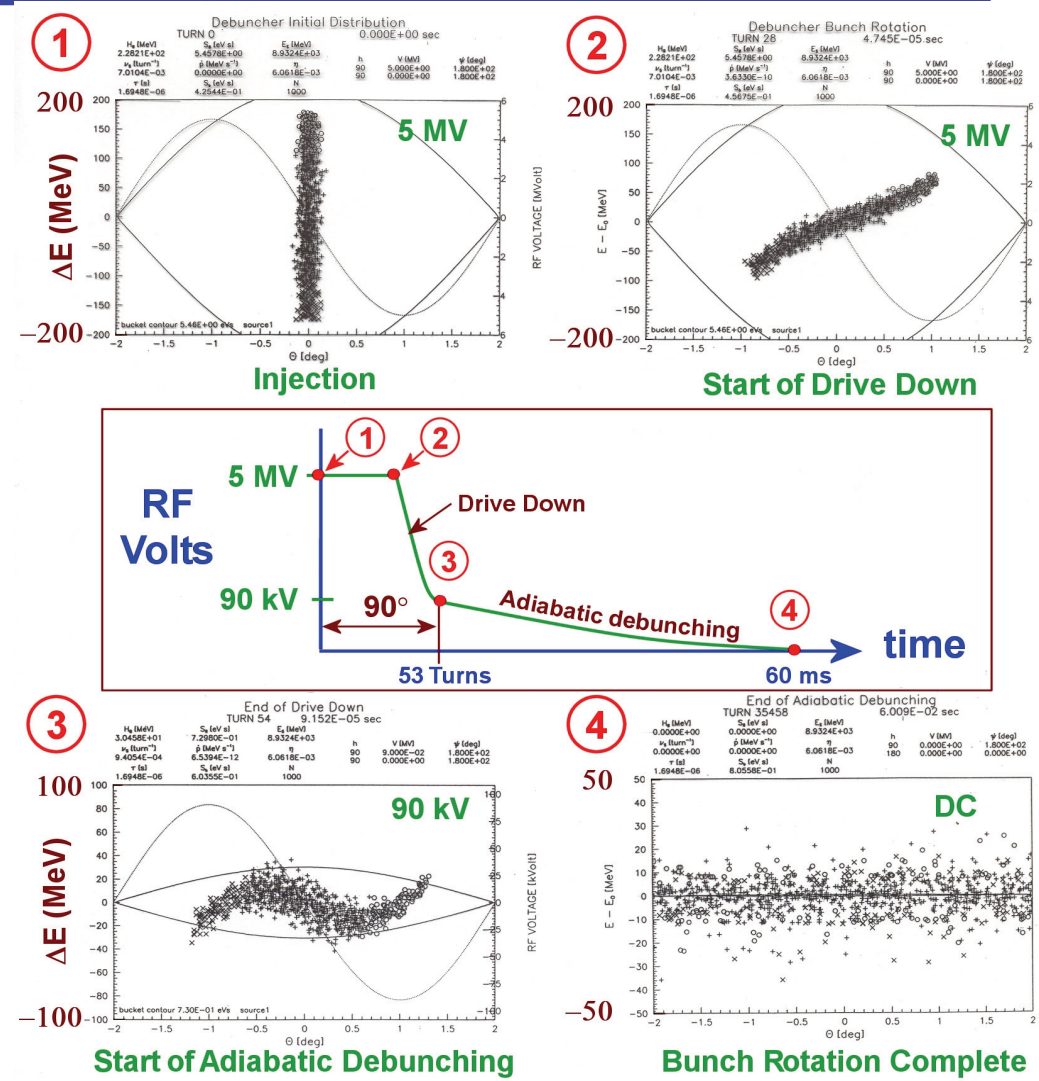
- Enormous progress in the last two years
  - Peak luminosity increase by factor of 2.5
  - 30-40 $pb^{-1}$/week integrated luminosity
  - 2x increase in $\bar{p}$ stacking rate since early 2005

- More is expected
  - $\bar{p}$ stacking rate increase to ~$30 \times 10^{10}$/hr
  - More protons, and antiprotons $\Rightarrow$ higher initial and integrated luminosity
    - $L_0 \sim 270 \times 10^{30}$ $cm^{-2}$ $s^{-1}$ (Last week had record $L_0 = 277 \times 10^{30}$ $cm^{-2}s^{-1}$)
    - $\int L dt \sim 6.4$ $pb^{-1}$/store ~ 32 $pb^{-1}$/week (my estimates – not official)
  - Run II total integrated luminosity of 7 $fb^{-1}$ is within reach

# Debuncher Operation

## Debuncher Operation

Bunch rotation

19 ns bunch structure → DC

3-D Cooling for 2.4 sec