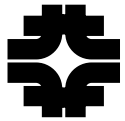


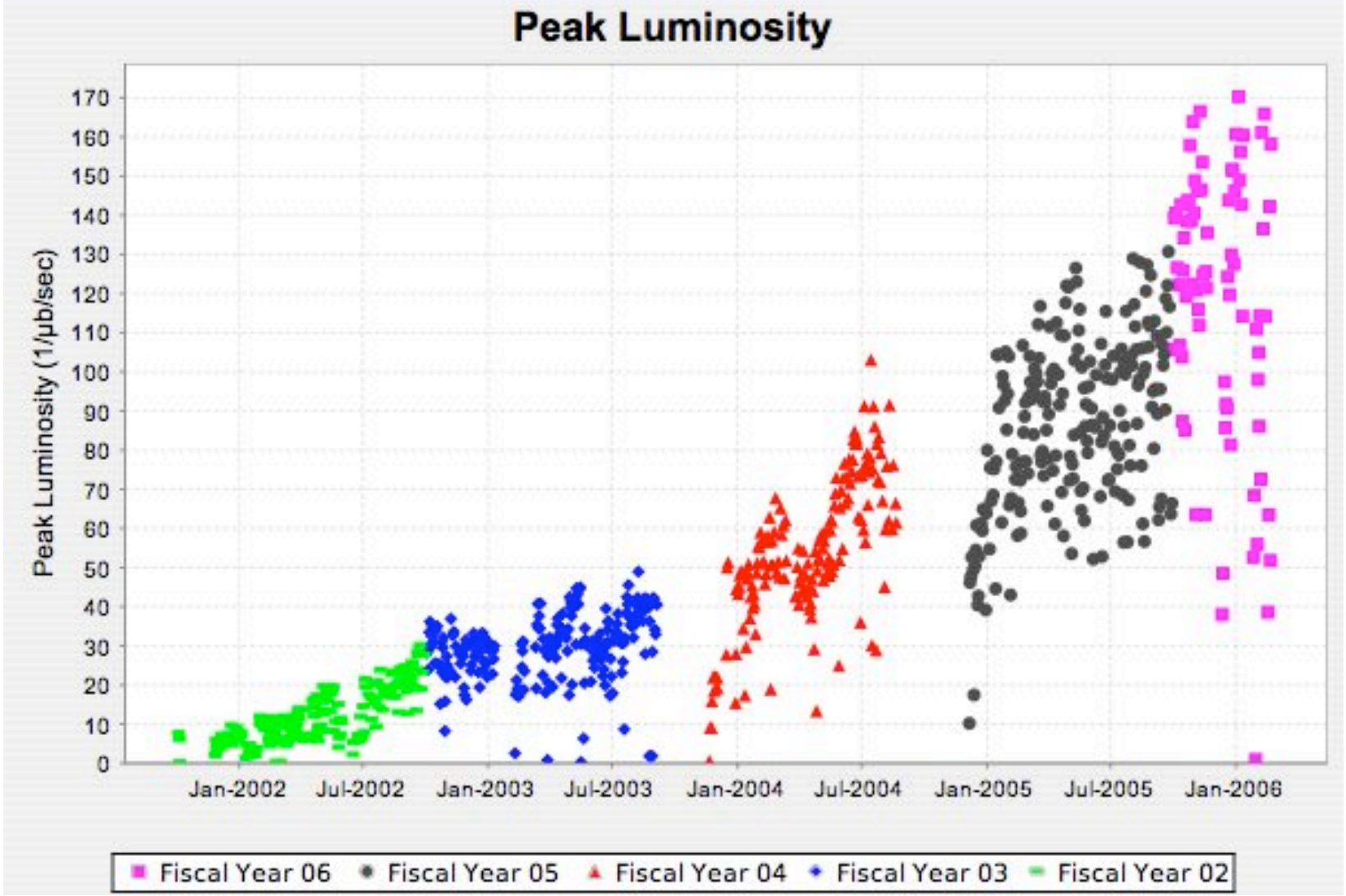
Accelerator Operations and Plans

R. Dixon

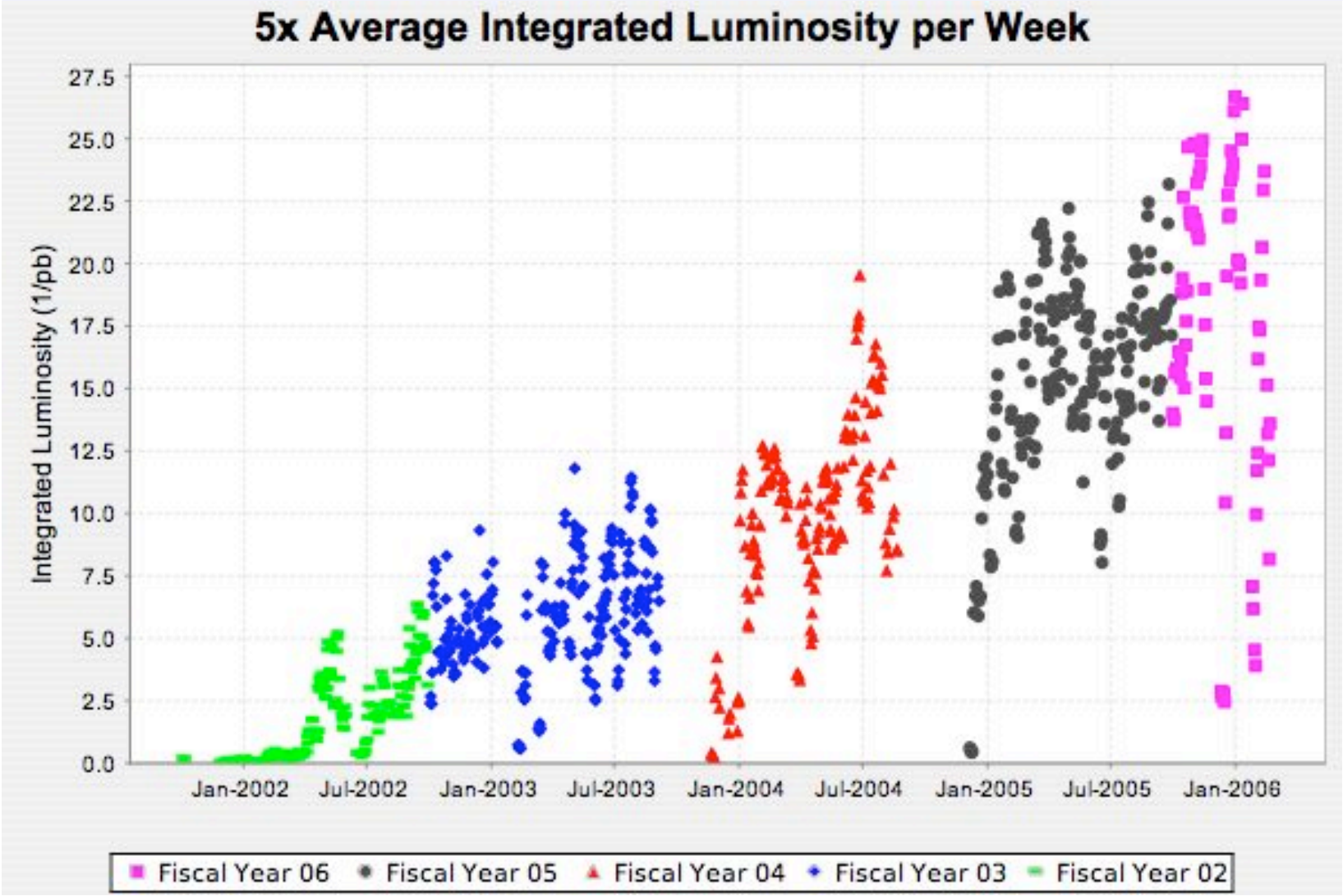
Major Accomplishments FY05-FY06

- Electron Cooling Demonstrated (July 2005)
- Recycler-Only Operations (October 2005)
- Peak Luminosity of $172 \times 10^{30} cm^{-2} sec^{-1}$ (average) (January 2006)
  - CDF Luminosity $185 \times 10^{30} cm^{-2} sec^{-1}$
- Weekly integrated luminosity of $24.4 pb^{-1}$ (December 2005)
  - CDF Luminosity $26 pb^{-1}$
- Antiproton Stack of 436×10^{10} in the Recycler (January 2006)
- Amount of antiprotons stacked in 1 hour 20.1×10^{10} (February 2006)

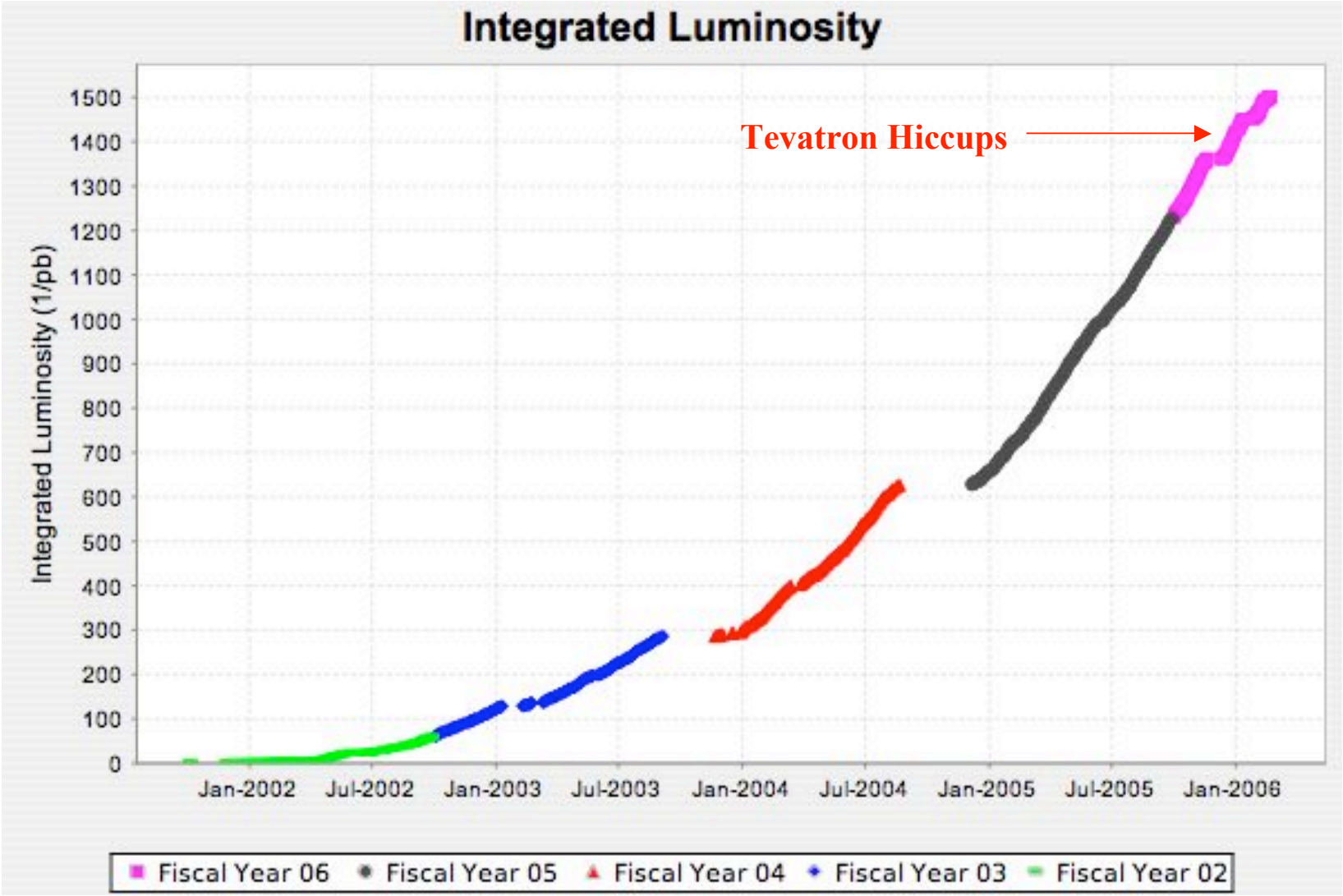
Peak Luminosity



Integrated Luminosity per Week

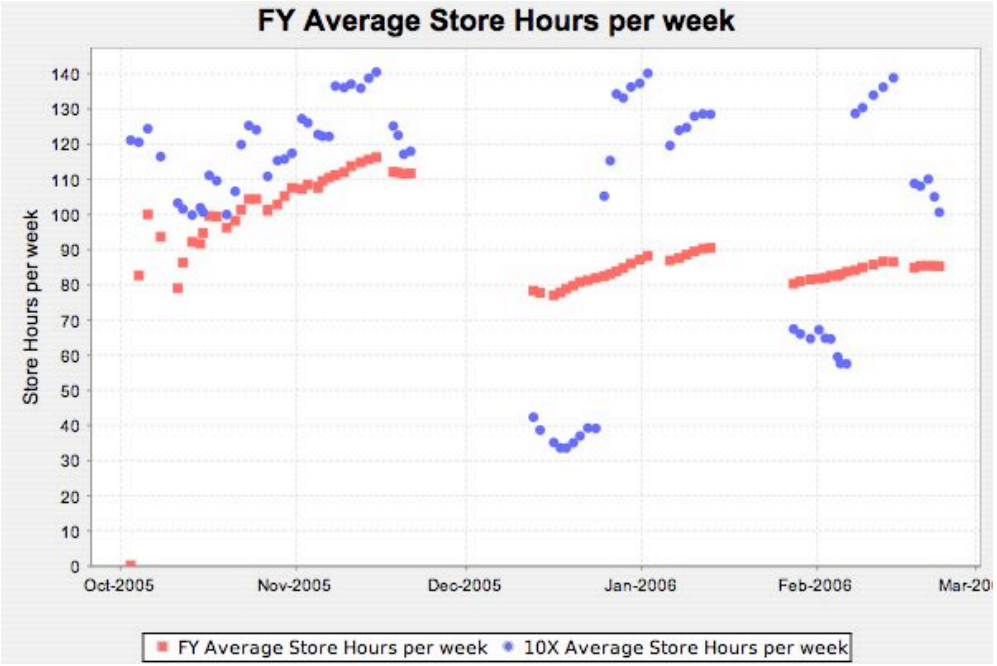


Integrated Luminosity



Tevatron Failures

- During the first 1/3 of FY06, Tevatron operations has been plagued by three Tevatron magnet failures
- The FY06 average number of store hours per week is 85 hours and is down by:
  - 21% from the FY06 goal (105 hours)
  - 30% from FY05 average (124 hours)
- This loss of running time accounts for most of the shortfall of the FY06 integrated luminosity



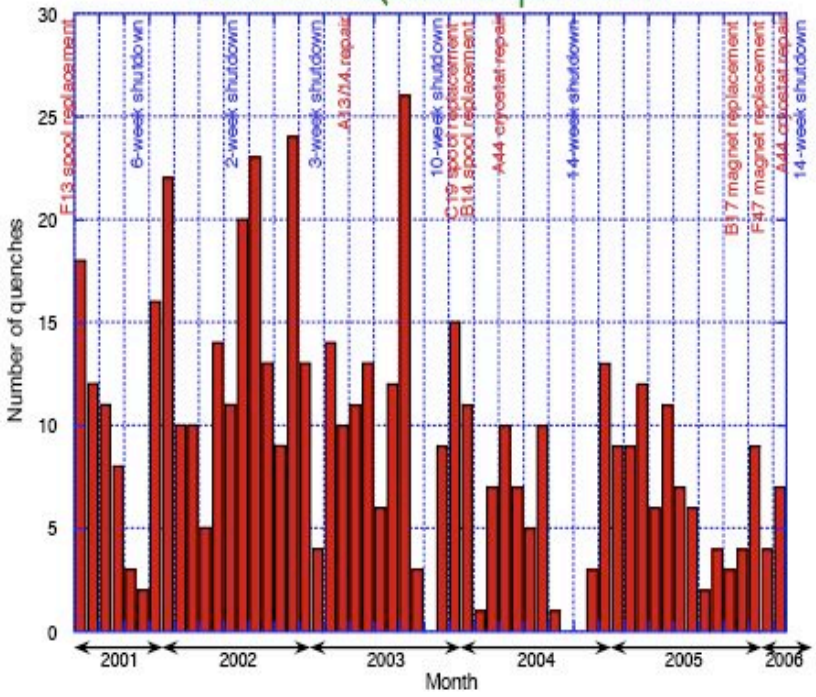
Tevatron Component Failures in Run II

Date	Description	Sector
29-Apr-01	Cryostat vacuum leak	D13
21-May-01	Helium leak at correction element feed-through	F13
8-Jul-01	Helium leak on spool	F47
18-Aug-01	Helium leak	F44
1-Mar-03	Safety lead ground fault	A13
5-Dec-03	Helium leak at correction element feed-through	C19
20-Dec-03	Cryostat vacuum leak	B14
15-Mar-04	Helium leak	A44
21-Nov-05	Helium leak caused by stuck Kautzky valve	B17
14-Jan-06	Cryostat vacuum leak (air)	A44
22-Feb-06	Helium leak caused by stuck Kautzky valve	F47

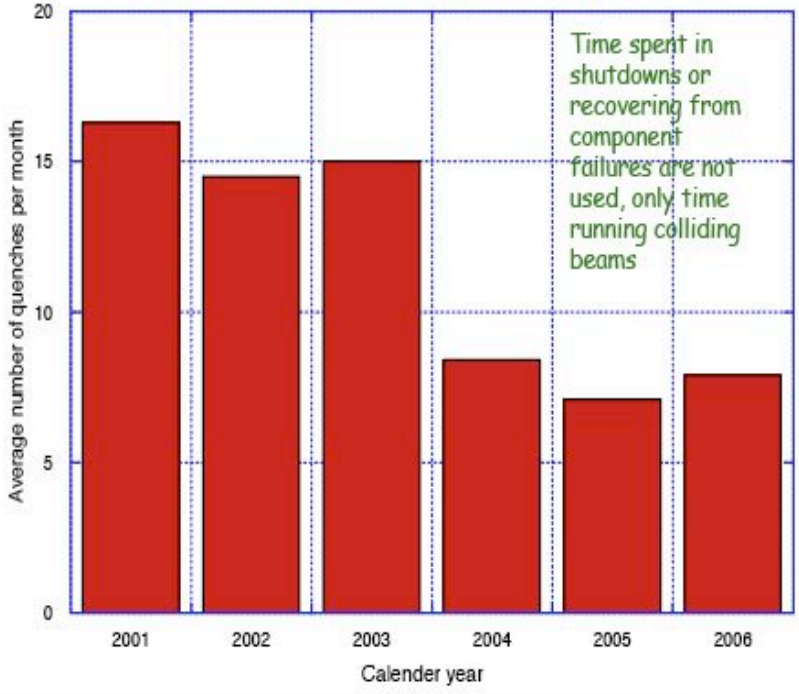
Tevatron Quenches

- All three Tevatron magnet failures where 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
- In July 2003, we declared the collider commissioned.
- We developed an operational attitude that emphasized focused and organized studies.
- Since then, the number of Tevatron quenches is down dramatically

Number of Quenches per Month



AVERAGE Number of Quenches per Month

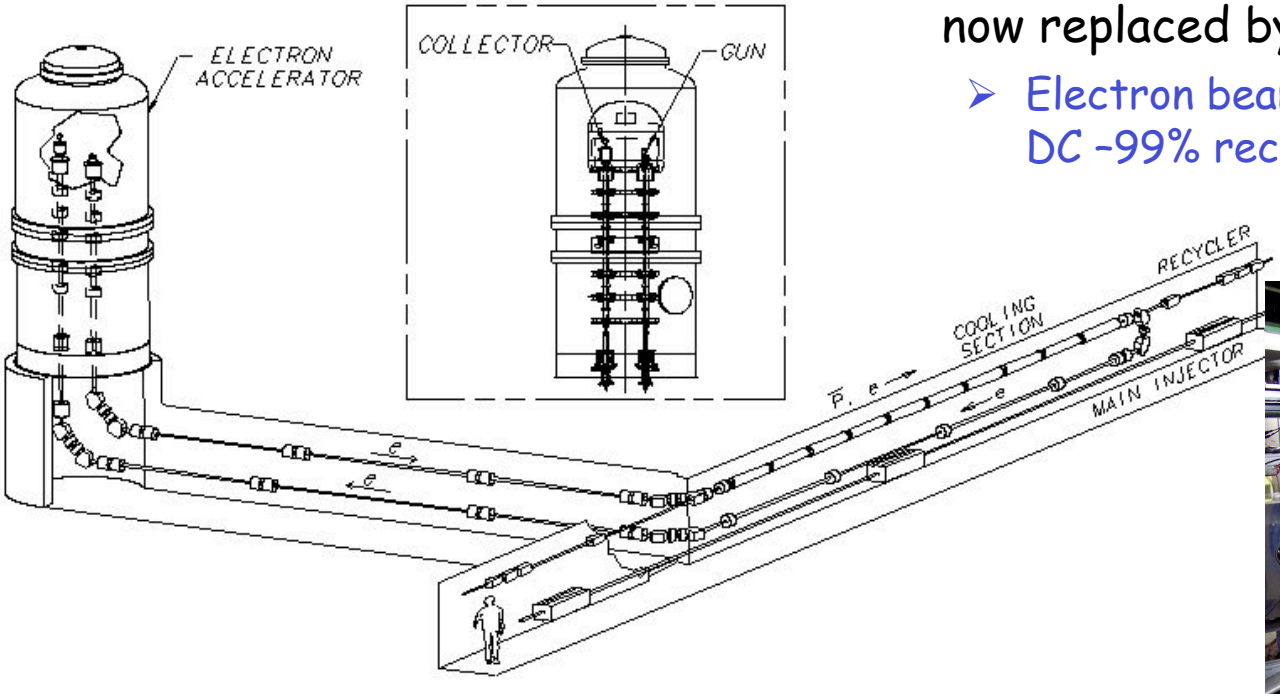


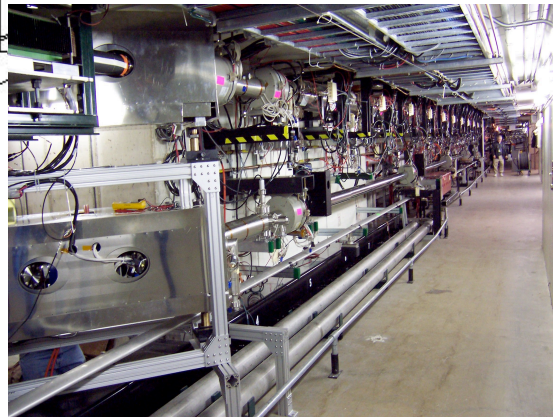
Tevatron Repairs

- Two of the magnet failures were the result of failed "Kautzky" (pressure relief) valves.
  - We view this as a systematic failure
  - We are replacing the failed part in all of the Tevatron Kautzky valves (~1200) during this shutdown
- We have also added a second shift during the shutdown to replace (or repair) all known cold leaks (F4, E2, A3, B4)

Major Accomplishments - Recycler Electron Cooling

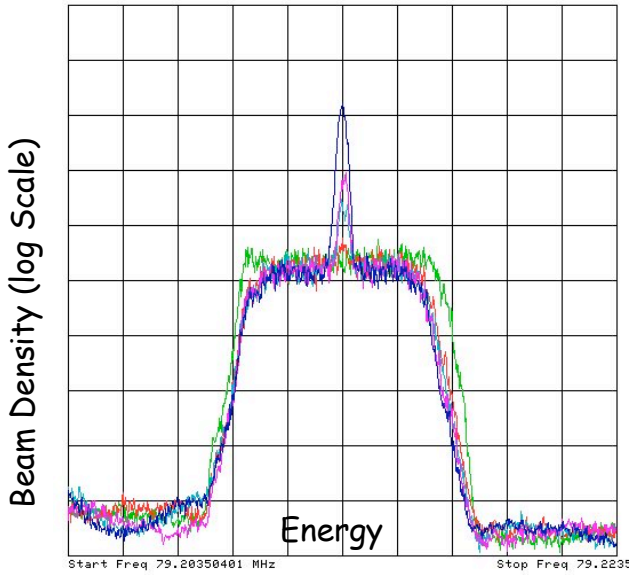
- The maximum antiproton stack size in the Recycler is limited by
  - Stacking Rate in the Debuncher-Accumulator at large stacks
  - Longitudinal cooling in the Recycler
- Longitudinal stochastic cooling of 8 GeV antiprotons in the Recycler is now replaced by Electron Cooling
  - Electron beam: 4.34 MeV – 0.5 Amps DC –99% recirculation efficiency

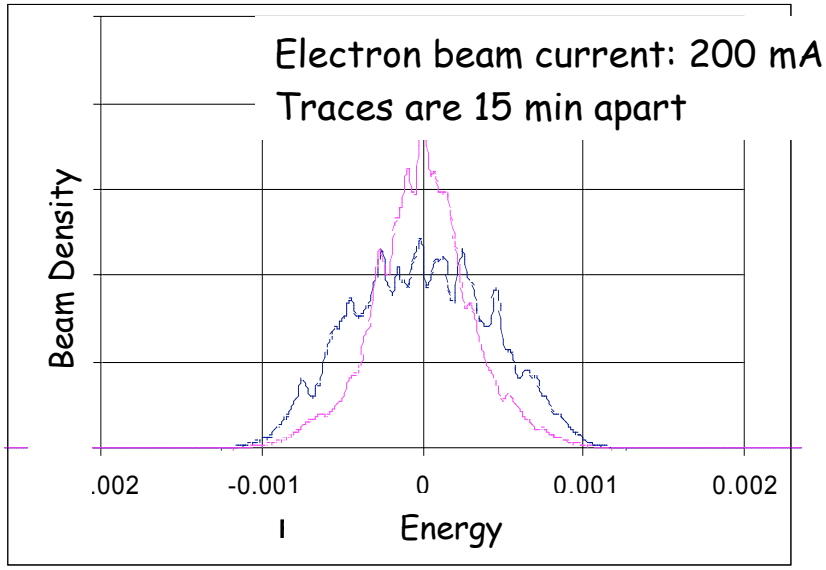




Recycler Electron Cooling

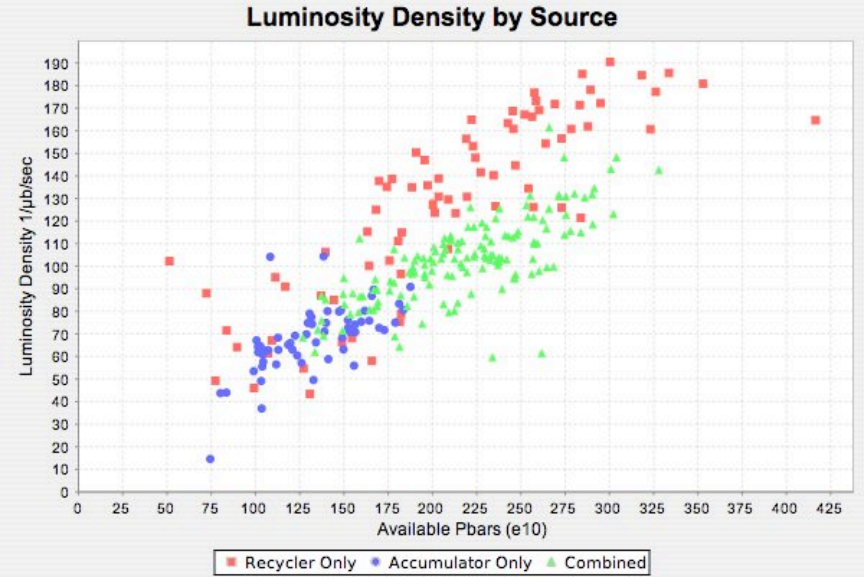
- Electron cooling commisioning
  - Electron cooling was demonstrated in July 2005 two months ahead of schedule.
  - By the end of August 2005, electron cooling was being used on every Tevatron shot
- Electron cooling goals
  - Can presently support final design goal of rapid transfers (30eV-Sec/2hrs)
  - Can presently reliably support stacks > 400×10^{10}
    - FY06 design goal = 250×10^{10}
  - Have achieved 1850 mA of electron beam (500mA final design goal.)





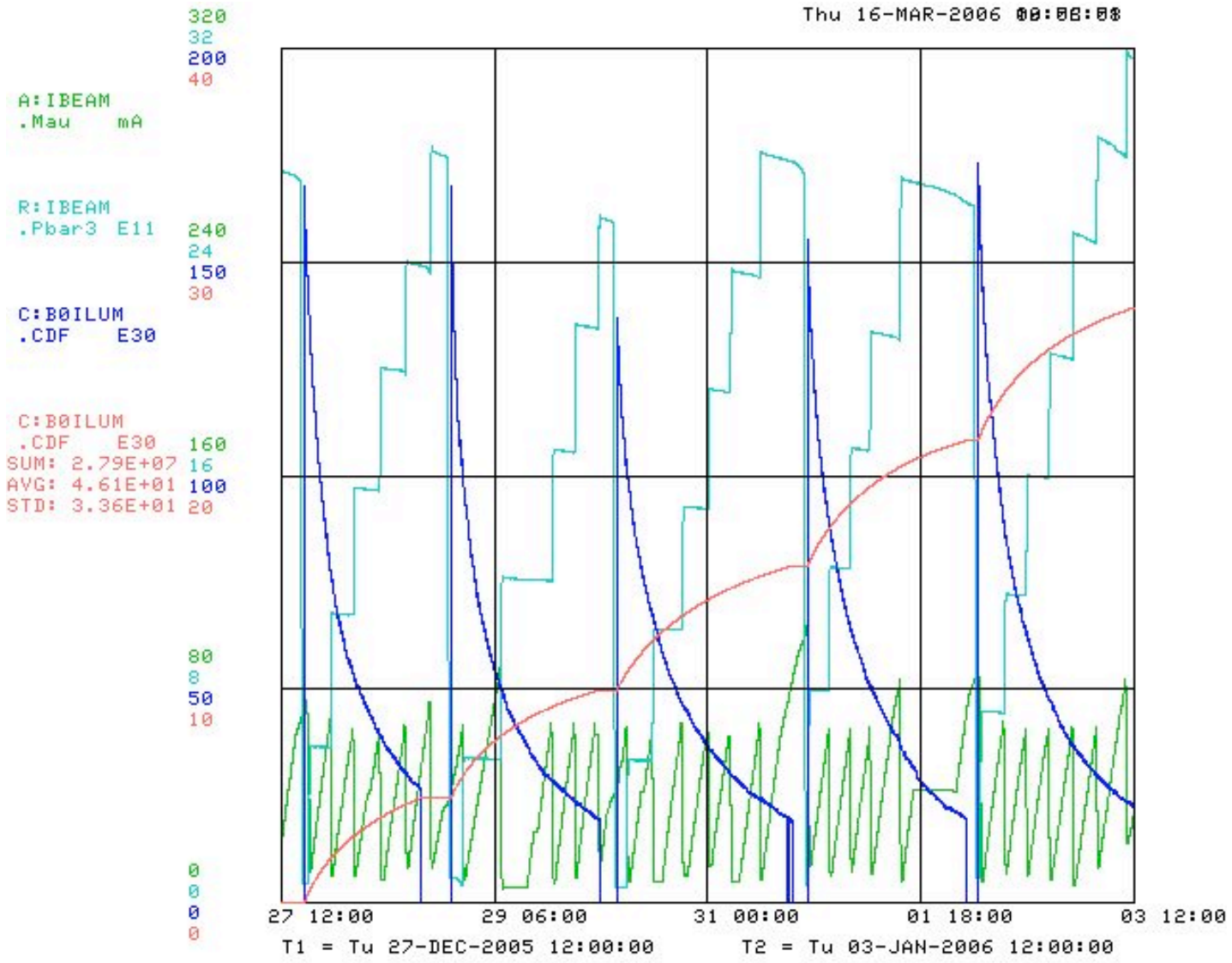
Recycler-Only Operations

- Recycler had been participating in Collider Operations in the Combined Shot mode because the Recycler Stack size has been limited to ~120x10^{10} pbars
  - Longitudinal Cooling
  - Transverse Stability
- With Electron Cooling operational and the transverse dampers commissioned, the Recycler stack size can now be increased to over 400x10^{10} pbars

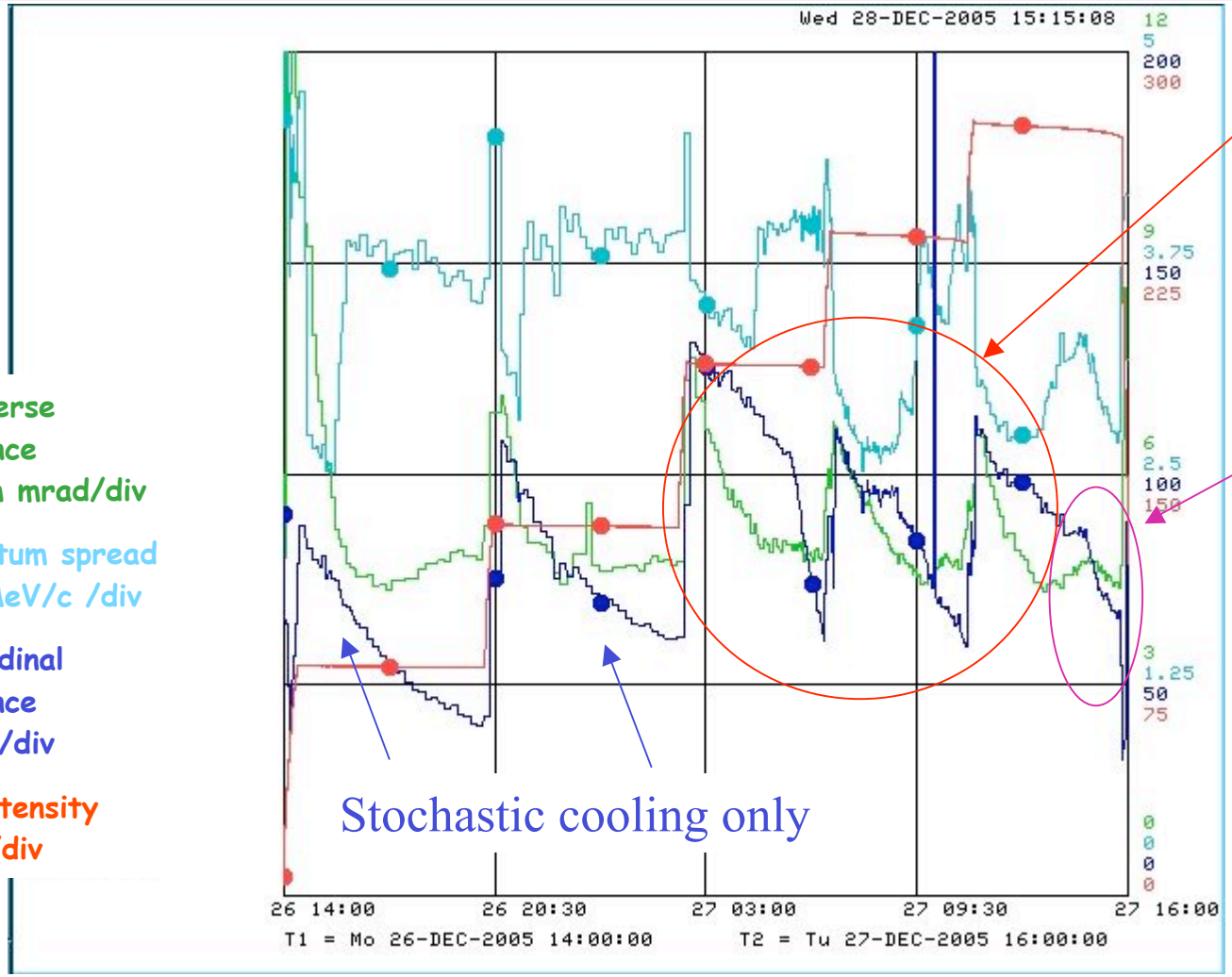


- The Collider complex has transitioned from Combined Shot mode to Recycler-Only mode
  - Faster average stacking.
  - Smaller pbar emittances in the TEV
  - In Recycler-Only mode we no longer need
    - The Accumulator shot lattice
    - Pbar-Tev shot setup
    - Dual energy ramps in the Main Injector
    - Complicated RF states
  - In addition, the Neutrino program benefits because the Accumulator will spend most of the time with small stacks, hence fast cycle times.
- Transition was completed by October 1, 2005 – 1 month ahead of schedule

Recycler-Only Operations



Recycler Cooling Sequence



Transverse emittance
3 π mm mrad/div

Momentum spread
1.25 MeV/c /div

Longitudinal emittance
50 eVs/div

Pbar intensity
75e10/div

Electron cooling between transfers

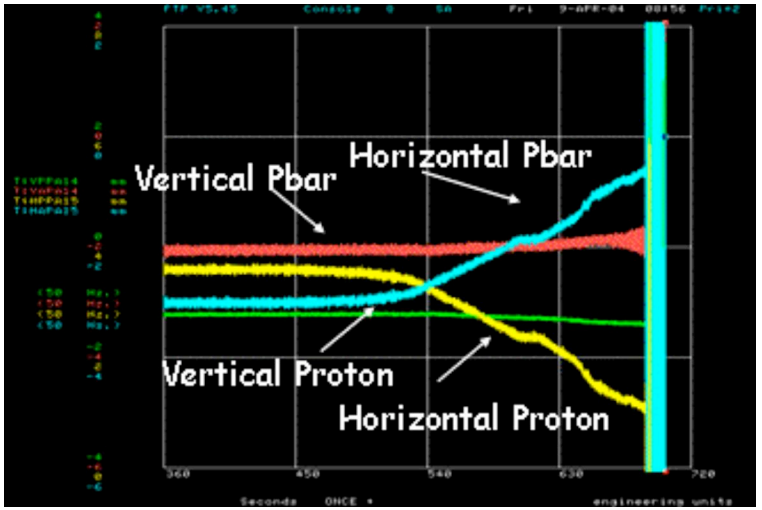
Electron cooling prior to extraction

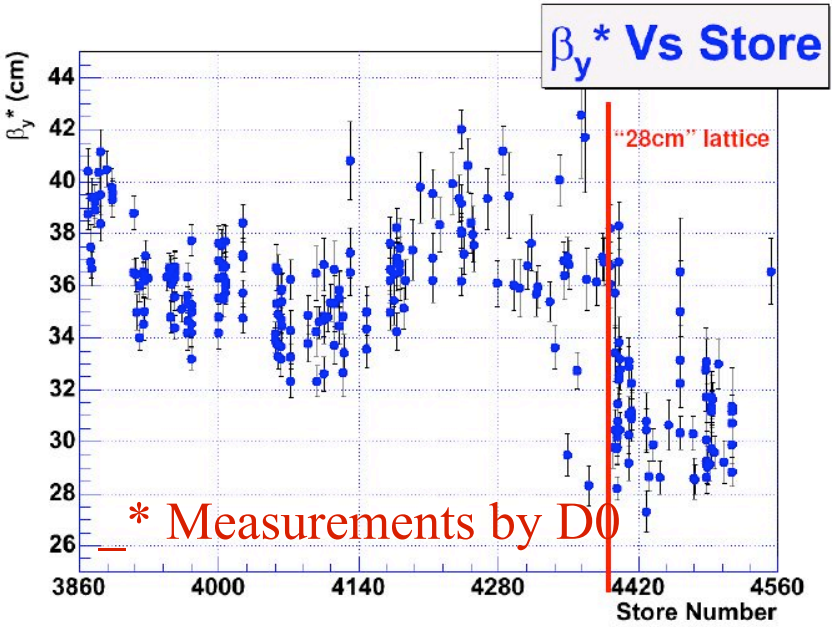
Recycler Shutdown Tasks

- Flying Wire upgrade
  - Reduce the Carbon Fiber wire diameter from 33 to 5 microns
- Damper upgrade (80 MHz Damper system)
  - Shorter kickers installed at higher beta
  - Switch to VME board designed for damper
- Vacuum maintenance
  - Firing of TSP's ring wide
  - Leak Check
- RF upgrade
  - Water cooling for RF amplifiers
- Installation of a ground bypass around the cooling section
  - Connect low reactance cable to the Recycler beam pipe
  - Should reduce induced currents by a factor of ~10 (from ~100 mA to ~10 mA)
- Shielding for cameras in the MI tunnel
  - CCD cameras to be used with Optical Transition Radiation instrumentation
- Upgrade of the SF_6 gas recirculation system

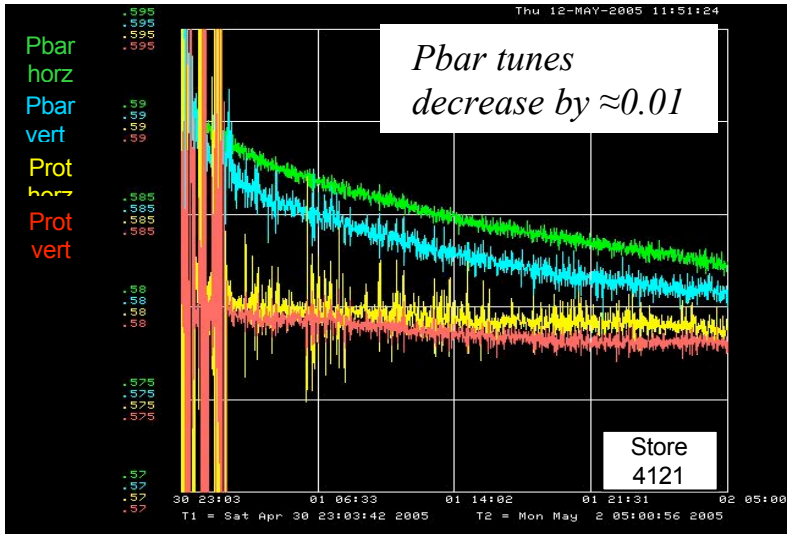
Tevatron Improvements

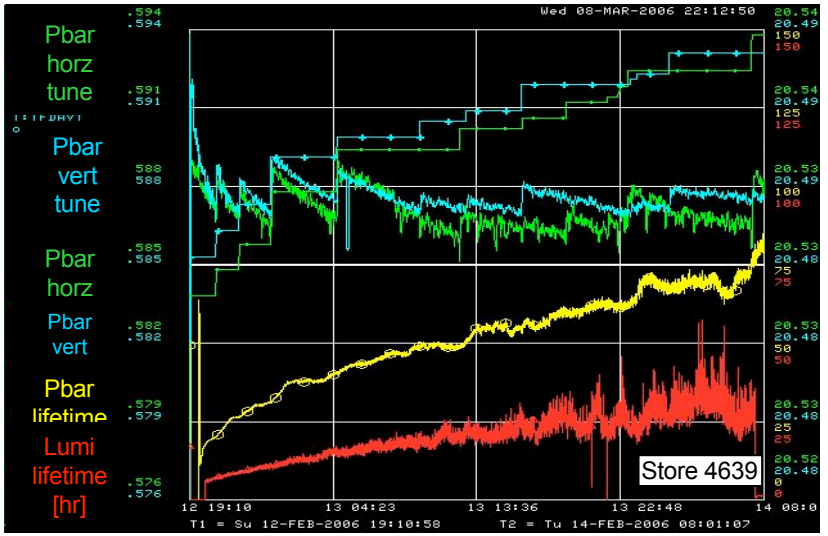
- Completed Tevatron BPM system installation and commissioning
  - ¬ An order of magnitude improvement in proton position measurements and new for pbars
  - ➢ Position resolutions in the range of ~10-25 μm
- 28 cm _* + optics correction
  - ➢ Lattice measurements exploited new BPM electronics
  - ➢ Tested at end of stores; implemented in September
- Pbar tune stabilization during HEP
  - ➢ Keep pbar tunes > 7/12 as beam-beam tune shift decreases over a store
  - ➢ Helps maintain pbar lifetime
- Orbit stabilization during HEP
  - ➢ Compensate for "fast" low-beta quad motion
  - ➢ Eliminate halo spikes @ CDF & D0, maintain lifetime

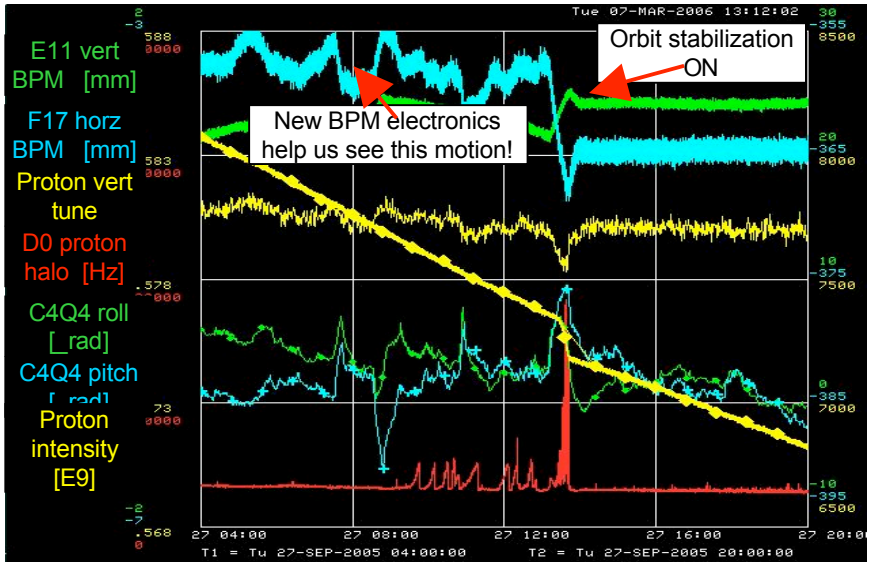




Tevatron Tune and Orbit Compensation







Tevatron Work Highlights in 2006

- Shutdown Tasks
  - Fix known cold leaks (F4, E2, A3, B4)
  - Replace poppets on He Kautzky valves (≈1200)
  - Re-shim remaining 228 dipoles
  - Unroll magnets
    - Quads in D1, A3 > 5 mrad
    - Various magnets > 1 mrad since 2004 shutdown
  - Replace 3 separators @ A49
  - Install new separators @ A17, B48 (1 each)
  - Install TEL-2
  - Pull cables for new sextupole circuits (chromatic compensation)
  - Complete IPM installation
  - Install new crystal collimator-- Awaiting parts
  - Infrastructure maintenance (feeders, cryo, etc.)
- Commissioning Tasks
  - Re-commission with beam…lots of changes
    - Adjust coupling following the dipole re-shimming, unrolls
    - Implement new helices for injection and HEP
  - Adjust IP positions
    - Already aware of low-_ quad + detector motion
  - Commission TEL-2
  - Continue commissioning of IPM and OTR
  - Complete chromatic compensation (split sextupole circuits)
    - Finish constructing new power supplies
    - Connect new cables to sextupoles, run with existing settings
    - Machine studies to implement lattice corrections
  - **Commission new BLM electronics**
  - Conduct machine studies on new working points (1/2, 2/3)

Antiproton Production

- The cornerstone of the Run II upgrades is antiproton production.
- In June 2005, we realized that antiproton production was falling behind expectations.
- We formed a team of twenty people divided into four groups dedicated to increasing the antiproton production rate.
  - Booster Extraction – Goal: 4.5e12/batch with a longitudinal emittance of 0.12 eV-sec/bucket and a momentum spread of 18 MeV
  - Main Injector Slip Stacking – Goal - 8e12 protons on target with a 1.5 nS bunch length and an acceleration efficiency of 95% and single point Rad limit of 1 Rad/hr in the MI tunnel.
  - Antiproton Source – Goal - 8e12 protons on target every 2.0 secs with a production of 17e-6
  - Instrumentation
- The team met twice a week at Tuesdays and Thursdays at 9 am in the Huddle to discuss overall progress and integration with collider operations.

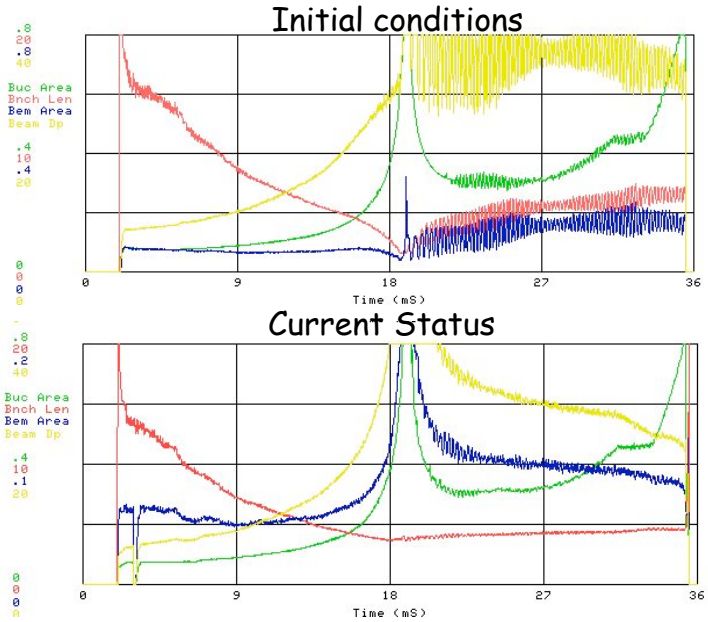
Protons on Target

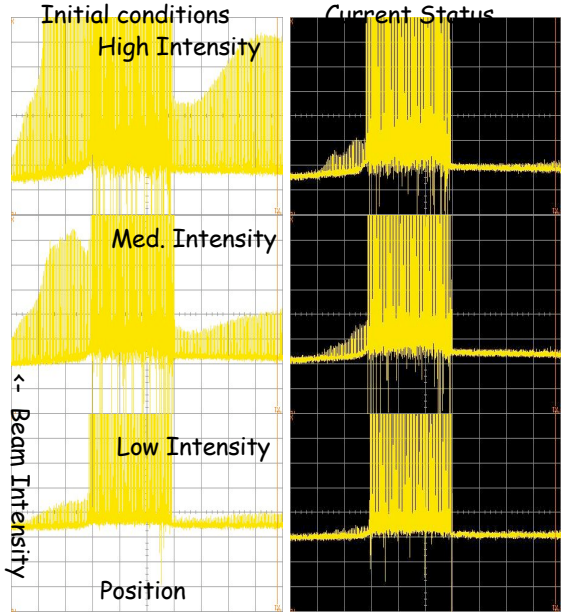
- Booster
  - Longitudinal Dampers
    - Dipole Mode 0, 1, 2, 52
    - Quadrupole Mode 1
  - RF Cavity balancing

- Main Injector
  - Beam Loading
  - Longitudinal Matching
  - Bunch length on target during Mixed mode cycles

	Initial	3/1/2006	Final	Status	
Intensity	3.9	4.2	4.5	4.5	$x10^{12}$
Emittance	0.2	0.12	0.12	0.08	eV-Sec
Momentum Spread	18	18	18	12	MeV

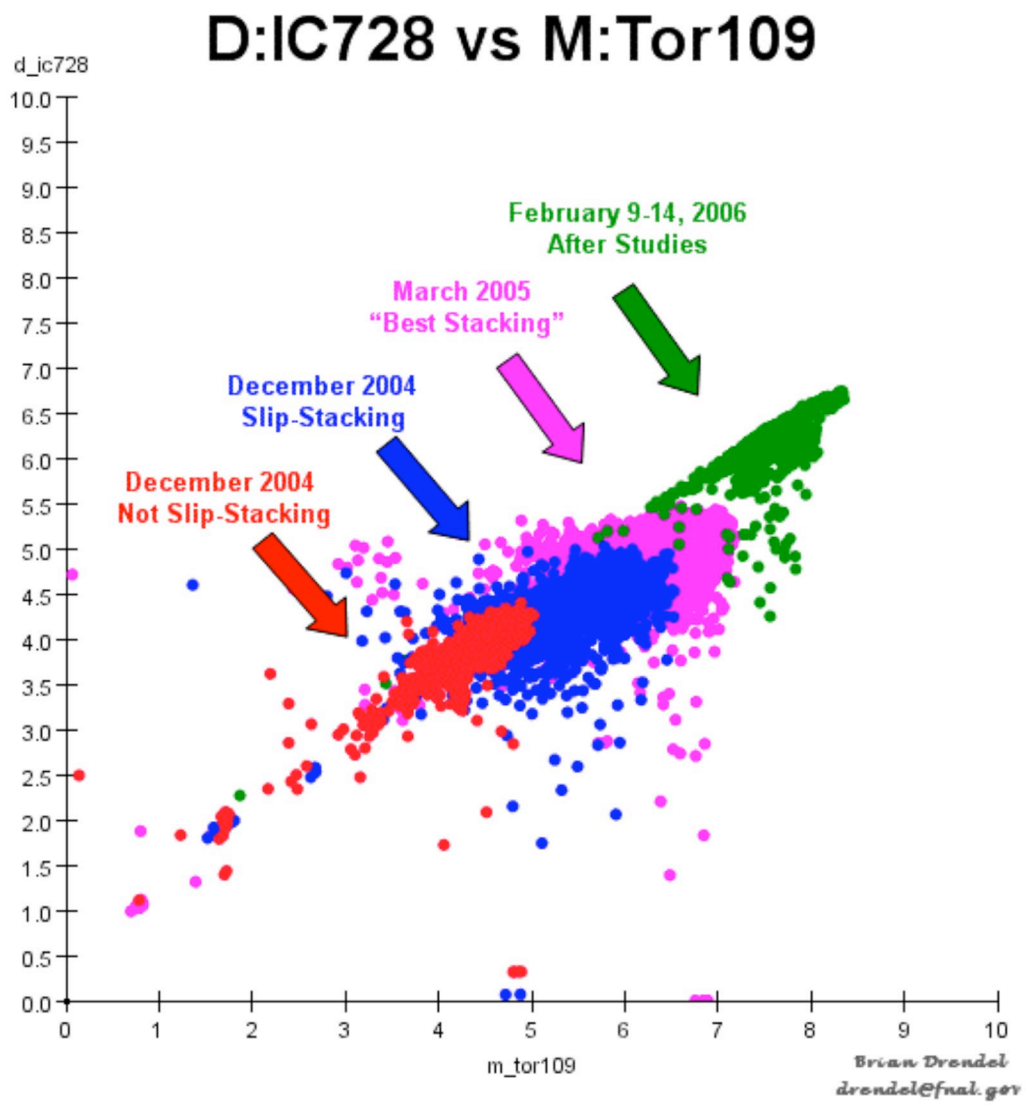
	Initial	3/1/2006	Final	Status	
Average Intensity	6.2	7.2	8	7.6	$x10^{12}$
Bunch Length	2	1.5	1.5	1.8*	nS
Efficiency	75	95	95	90	%





Antiproton Production and Protons on Target

- Average over 7.6×10^{12} protons on target
- Have achieved 8.5×10^{12} protons on target for sustained periods of time
- Reliability of Booster bunch rotation vs the number of Booster RF stations is the current key issue.



Studies, Studies, Studies

- Originally planned to dedicate 14 days of antiproton studies during low luminosity running
- First Tevatron Failure (B11 Separator)
  - Tue Nov 22 to Thu Dec 15
  - 23 days of dedicated studies
- Second Tevatron Failure (A44 vacuum)
  - Sun Jan 15 to Thu Jan 26
  - 12 days of dedicated studies
- Accumulator Aperture Work
  - Done during low luminosity running
  - Wed Feb 15 to Fri Feb 17
  - 3 days of dedicated studies

December Antiproton Study Period Statistics

- Length of Time: **Tue Nov 22 to Thu Dec 15**
- Number of Elog shift pages: **72**
- Number of Recorded Debuncher Orbits: **857**
- Number of Recorded AP2 Orbits: **775**
- Number of Commissioned items: **12**
- Number of Major Accomplishments: **$6+\frac{1}{2}+\frac{1}{2}$**
- Number of Confusions (at the time): **∞**
- Number of Other Things Done: **8+1**
- ♣ Number of "Next Times" Known Items: **$7\frac{1}{2}$**

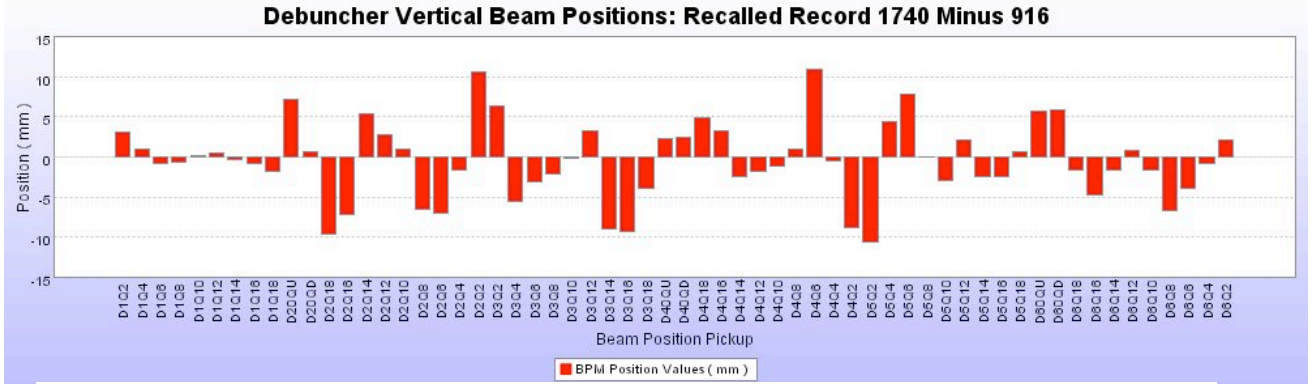
December Antiproton Study Period

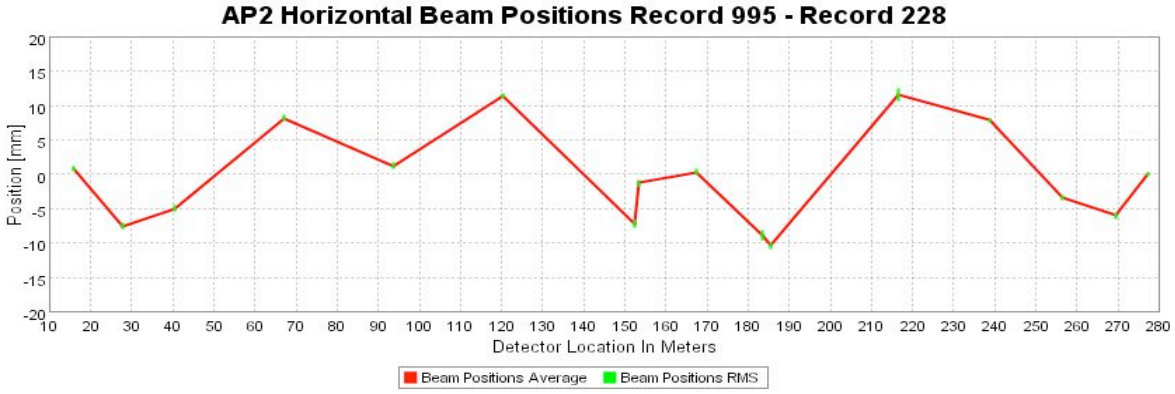
- Instrumentation Commissioned
  - Debuncher Reverse Proton Turn-By-Turn system
  - Debuncher Reverse Proton partial turn extraction up AP2
  - Debuncher Component Centering
  - Debuncher Orbit-Quad offset
  - AP2 Orbit-Quad offset
  - AP2 Beam Line Correction
  - One-Shot TLG for getting Debuncher beam
  - Admittance measurement from data-logger
  - "Deb Heat Rev p's to AP2" aggregate
  - AP2-Debuncher Injection region setup
  - Auto-tune 120 GeV orbit of P1-P2-AP1
- Scheduled Studies Accomplishments
  - Lattice measurements for Debuncher and AP2
  - Determine Debuncher Orbit/BPM-Quad offsets
  - Corrected Debuncher Vertical Orbit to Quad Centers
  - Centered Debuncher Components about orbit
  - Determine AP2 Orbit/BPM-Quad offsets
  - Set Orbit, Stands and Settings for AP2-Debuncher Injection Region
  - Corrected AP2 Orbit to near Quad Centers
  - Installed AP2 lattice that matches to current Debuncher Lattice

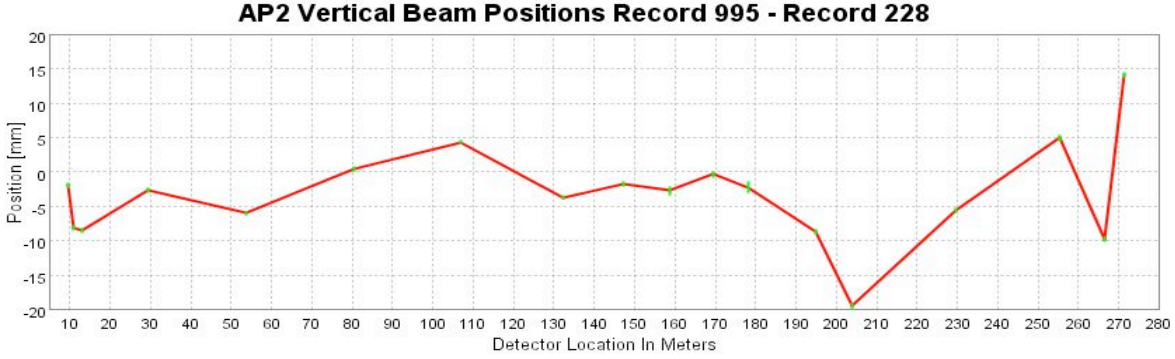
January Antiproton Study Period

- Quad Steering of the AP1 line
  - Not finished
- Alignment of the Debuncher horizontal orbit and moveable devices.
  - Did not do arcs
  - Need to Energy align the AP2-Debuncher-Accumulator
  - Horizontal Aperture up to 35π-mm-mrad!!!
- Installation and commissioning of Debuncher lattice modifications
  - First round done
  - Vertical aperture up to 34π-mm-mrad
- Removal of the Debuncher Schottkies
  - Completed
- Obstruction search of the AP2 line.
  - Completed – none found
- Installation of 4 additional AP2 trims
  - Two trims installed
  - Two trims staged
- D/A Beam based alignment
  - Completed to the Q3-Q6 straight section
- Accumulator orbit and aperture optimization
  - Backed out of orbit changes
    - Need to update quad centering software
    - Need to de-bug running wave software
  - Will only complete moveable devices
  - Quadrupole Pickup found to be an aperture restriction

Beam Based Alignment Orbit Changes







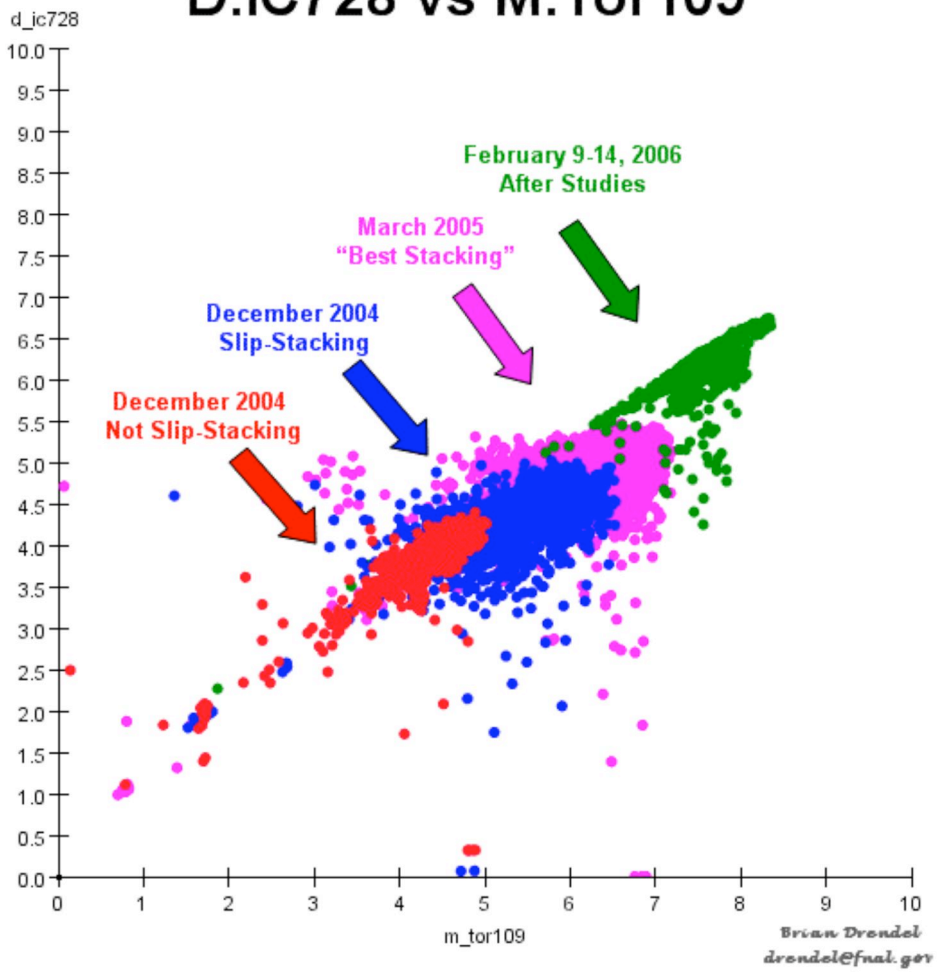
Antiproton Stacking – Stacktail System

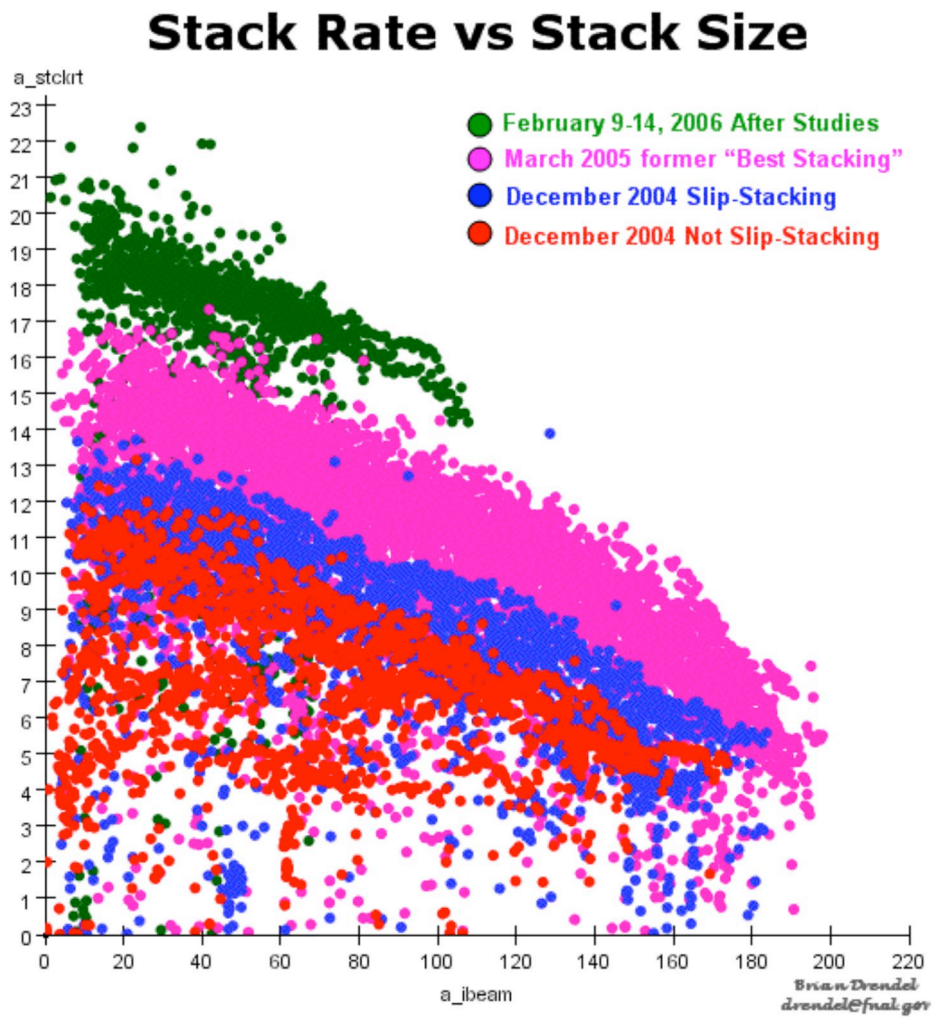
- The measured Accumulator 2-4 GHz Stacktail system can support a flux of 30mA/hr.
- The currently used 2-4 GHz core momentum system is the same frequency as the Stacktail system
  - At a flux of 15mA/hr, the core 2-4 GHz system can support a exponential gain slope that is a factor of two larger than the gain slope of the Stacktail.
  - As the number of particles in the core increases, the factor of 2 gain slope is exceeded and the core pushes back on the Stacktail and the flux must be reduced.
- For large fluxes into the Stacktail, the 2-4 GHz core momentum system cannot support a core.

Antiproton Stacking – Stacktail System and the Core 4-8 GHz System

- To support a core at high flux, the 4-8 GHz core momentum system must be used.
- Because the 4-8 GHz core system runs at twice the frequency, the electrodes are $\frac{1}{2}$ the size so the system has a factor of two smaller momentum reach.
- Moving the core closer to Stacktail to accommodate the smaller reach resulted in system instabilities at moderate stacks.
- We now :
  - Use the 2-4 GHz core momentum system to augment the hand-off between the Stacktail and the 4-8 GHz core momentum system
  - Run the 4-8 GHz core momentum system at MUCH larger gain.
  - Run the Stacktail during deposition debunching to pre-form the distribution to match the Stacktail profile

Stacking Performance





Antiproton Parameters

		Antiproton Parameters					
Phase	1	2	3	4	5	6	
Zero Stack Stacking Rate	13.0	16.0	18.9	30.2	30.2	30.2	$x10^{10}$/hour
	13.0	16.0	16.6	25.2	25.2	25.2	
	13.0	16.0	16.6	20.2	20.2	20.2	
	13.0	16.0	16.0	16.0	16.0	16.0	
Average Stacking Rate	6.3	7.4	9.6	21.7	21.7	21.7	$x10^{10}$/hour
	6.3	7.4	8.5	14.8	17.4	17.4	
	6.3	7.4	8.5	11.3	11.3	13.3	
	6.3	7.4	8.3	8.3	8.3	9.7	
Stack Size transferred	158.2	163.8	211.5	476.5	476.5	476.5	$x10^{10}$
	158.2	163.8	187.9	324.7	382.5	382.5	
	158.2	163.8	187.9	248.6	248.6	293.5	
	158.2	163.8	181.5	181.5	181.5	214.5	
Stack to Low Beta	117.1	124.5	169.2	381.2	381.2	381.2	$x10^{10}$
	117.1	124.5	144.7	253.3	298.3	298.3	
	117.1	124.5	144.7	191.4	191.4	226.0	
	117.1	124.5	138.0	138.0	138.0	163.0	
Pbar Production	16.0	15.0	16.0	21.0	21.0	21.0	$x10^{-6}$
	16.0	15.0	15.0	17.5	17.5	17.5	
	16.0	15.0	15.0	16.0	16.0	16.0	
	16.0	15.0	15.0	15.0	15.0	15.0	
Design (30mA/hr) **Fallback (25mA/hr)** **Fallback (20mA/hr)**	**FY04 Plan**	**Slip Stacking 8/8/2005**	**Recycler Ecool 2/27/2006**	**StackTail 5/14/2007**	**Helix 6/30/2008**	**Reliability 8/31/2009**	

Future Pbar Work

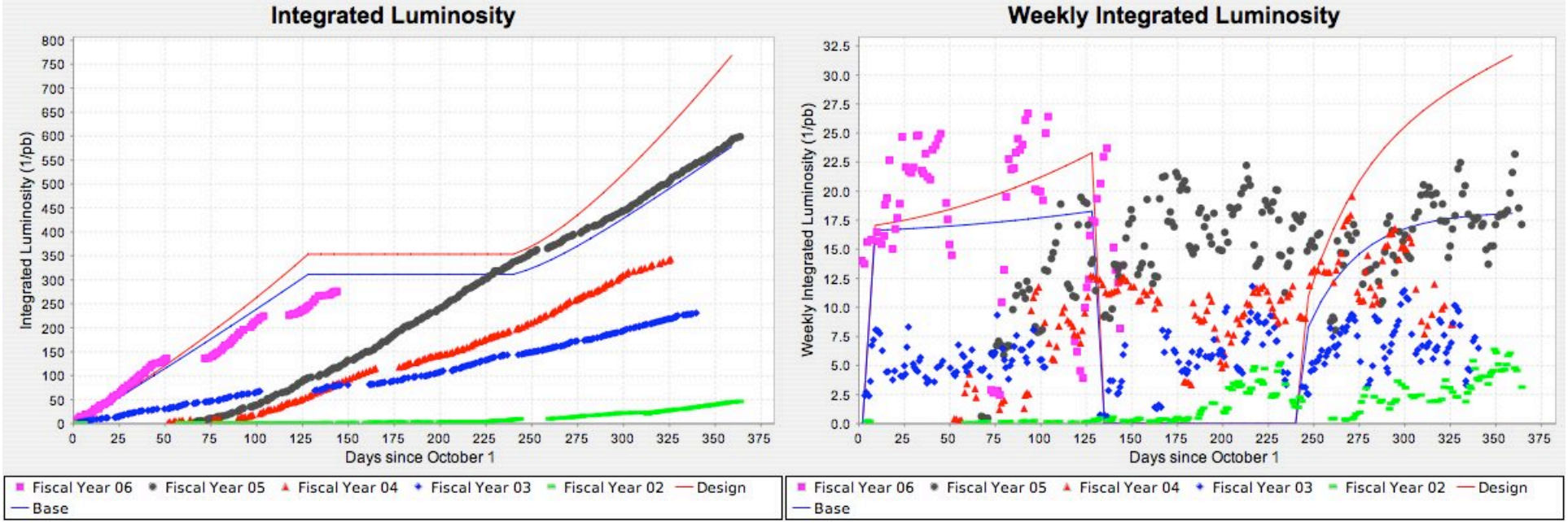
- Lithium Lens (0 – 15%)
  - Lens Gradient from 760T/m to 1000 T/m
- Slip Stacking (7%)
  - Currently at 7.5×10^{12} on average
  - Design 8.0×10^{12} on average
- AP2 Line (5-30%)
  - Lens Steering
  - AP2 Steer to apertures
  - AP2 Lattice
- Debuncher Aperture (13%)
  - Currently at 30-32um
  - Design to 35um
- DRF1 Voltage (5%)
  - Currently running on old tubes at 4.0 MEV
  - Need to be a t 5.3 MeV
- Accumulator & D/A Aperture (20%)
  - Currently at 2.4 sec
  - Design to 2.0 sec
- Stacktail Efficiency
  - Can improve core 4-8 GHz bandwidth by a factor of 2
- Timeline Effects
  - SY120 eats 7% of the timeline

Antiproton Production Prospects

- With the progress of the past studies, it is very likely that we will achieve 30x10^{10}/hr within the next year (Feb 07).
  - Using the conservative end of the range will give a 60% increase in stacking (32x10^{10}/hr).
  - Using the upper end of the range will give a 125% increase in stacking (45x10^{10}/hr – Run 2 Upgrade "stretch" goal)
- Goals
  - Achieve 25 x10^{10}/hr by September 2006
    - AP2 Line (5-30%)
    - Accumulator & D/A Aperture (20%)
  - Decide on the Stacktail Upgrade
    - To take advantage of the Stacktail upgrade,
      - a large antiproton flux is needed (>30mA/hr)
      - rapid transfers to the Recycler to keep the accumulator core small.
    - The Stacktail upgrade will remove our ability to go to even modest stack sizes.

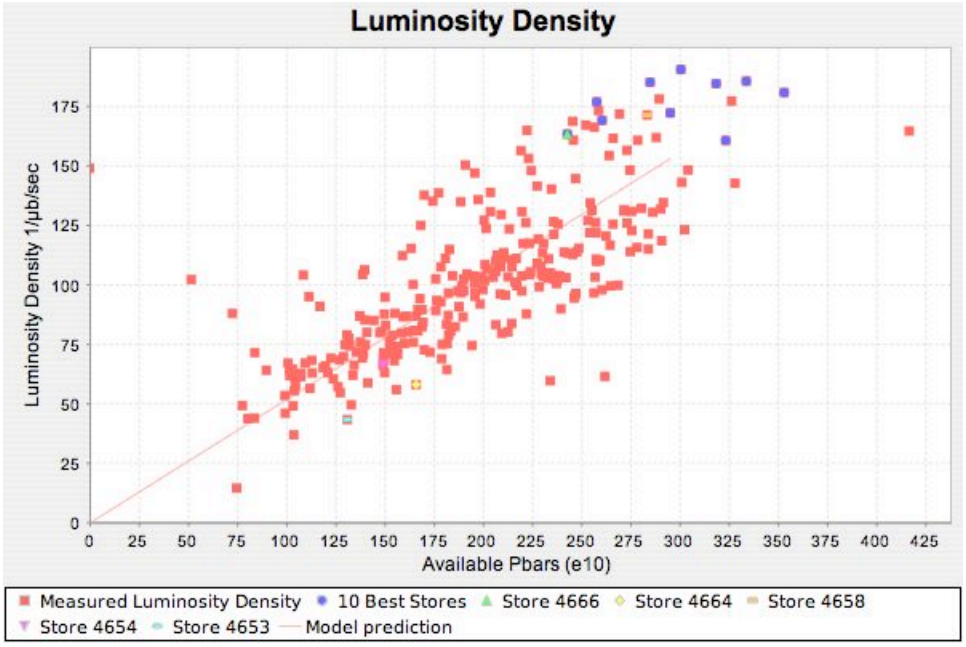
FY06 Goals

- To meet the FY06 design goal of 800pb^{-1}, we will have to run at the design curve parameters for 130 store hours per week after the shutdown.
  - FY06 original target was 105 store hours per week
  - FY05 averaged 124 store hours per week



Machine Study Priority

- The FY06 antiproton production rate goal is 24×10^{10}/hour
- The Run II Upgrade goal is to stack at 30×10^{10}/hour by May 2007
- Our goal is to achieve
  - 25×10^{10}/hour by September 2006
  - 30×10^{10}/hour by February 2007
- To achieve the antiproton production rate goal and the integrated luminosity goal, we will have to continue to carefully balance machine study time against running time
- Antiproton studies will continue to receive the highest priority
  - Average 2-3 shifts per week of dedicated & parasitic studies (25% pbar tax)
- Tevatron studies will be allocated to follow the natural rhythm of the machine
  - FY05-FY06 average >1 shift per week.



Summary

- Despite the rash of recent Tevatron failures, FY05-FY06 has been a spectacular year for Run II
  - Relativistic electron cooling commissioned
  - Recycler-only operations
  - Peak Luminosity of $172 \times 10^{30} cm^{-2} sec^{-1}$ (average)
  - Weekly integrated luminosity of $24.4 pb^{-1}$ (average)
  - Antiproton stack of 436×10^{10} in the Recycler
  - Antiproton production rate of 20.1×10^{10}/hour (average)
- We are taking well-defined steps to improve Tevatron reliability
  - Repair of all known cold leaks
  - Kautzky valve repair
- The FY06 integrated luminosity goal will be difficult <u>but</u> possible to achieve.
- The focus of accelerator studies for the remainder of FY06 will be antiproton production

Core 4-8 GHz Momentum Cooling System Bandwidth

- 1 GHz of bandwidth at 7 GHz is ~3x more powerful than 1 GHz of bandwidth at 2.5 GHz
- By replacing the trunk coaxial cable with optical fiber, the 4-8 GHz system will be 5.7x more powerful than the 2-4 GHz system