Tevatron Recent Successes & Prospects

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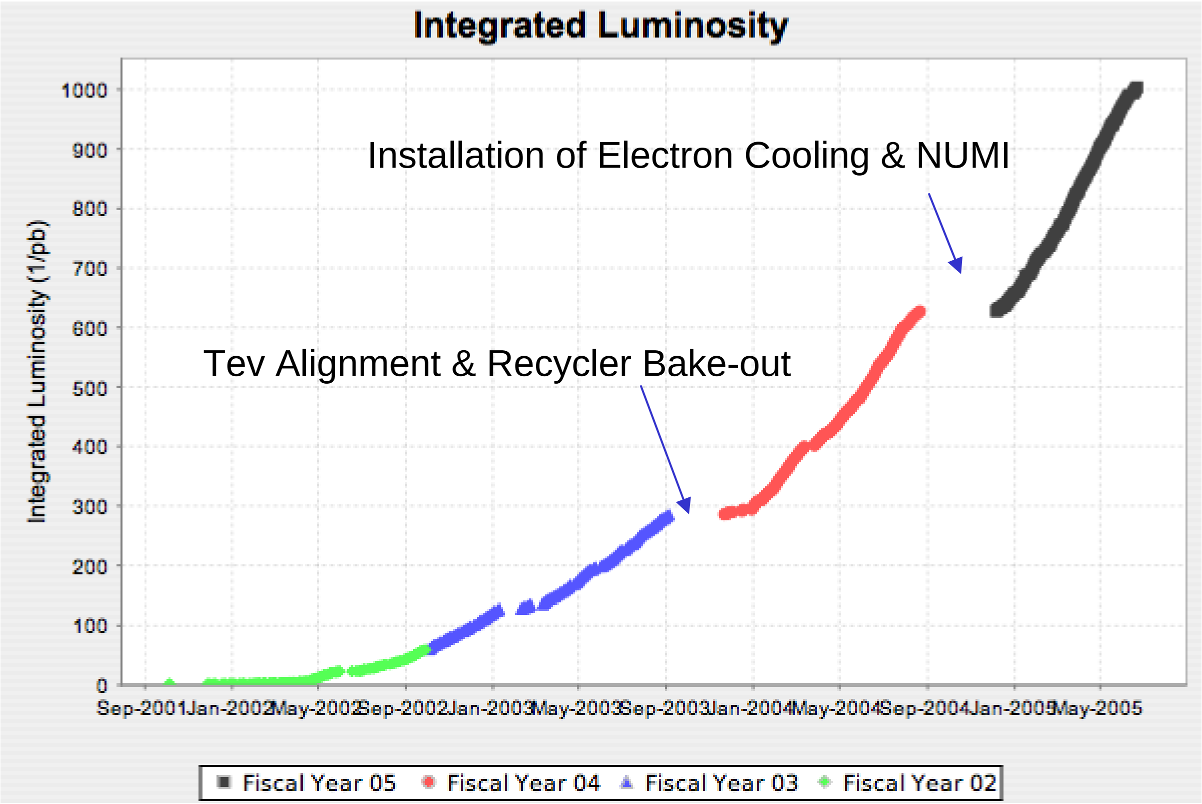
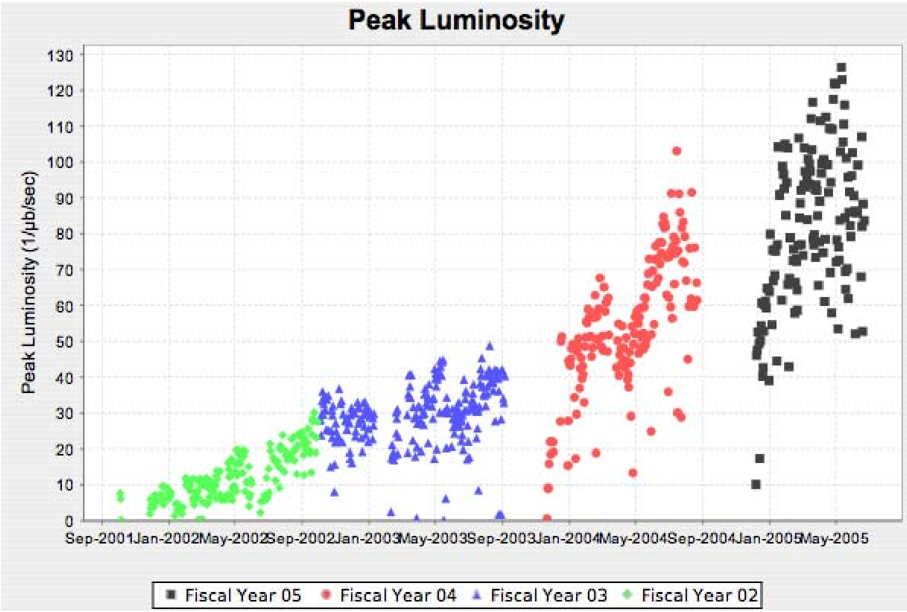
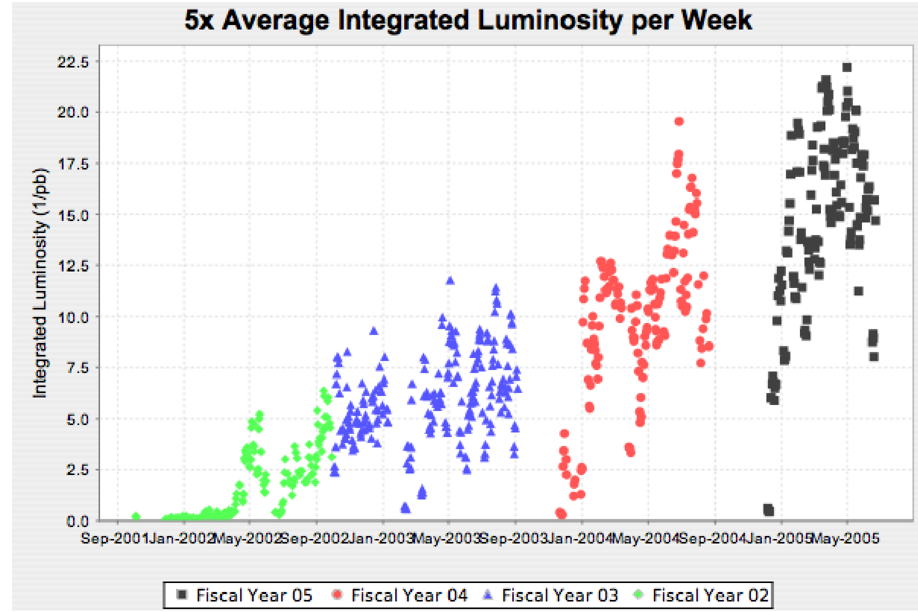
Integrated Luminosity



- Since June in 2003, the Tevatron has seen a 3-fold increase in
  - Peak luminosity
  - Integrated luminosity per week
  - Total integrated luminosity

Luminosity History





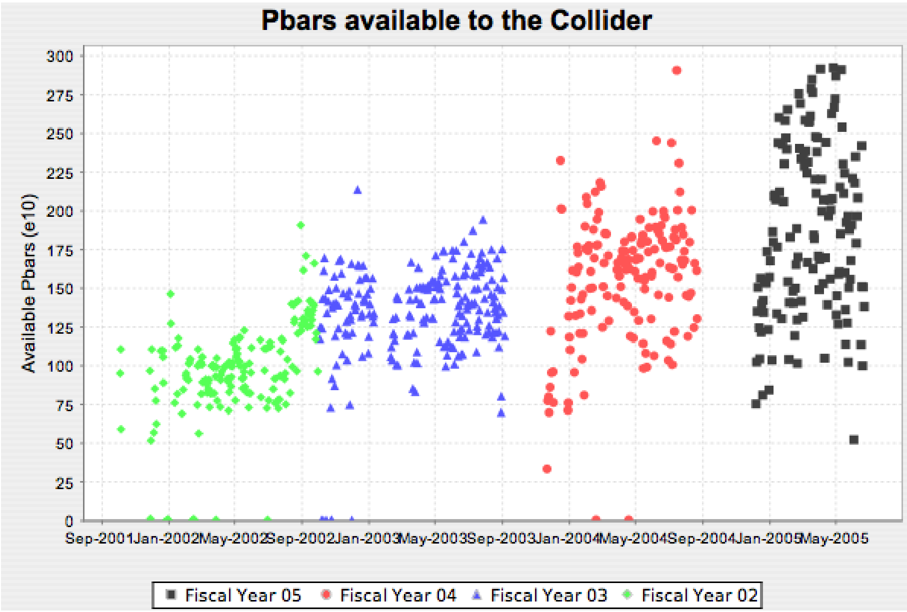
- Luminosity increase is mostly due to:
  - Better performance of the injector chain
  - Introduction of the Recycler into operations
  - Alignment of the Tevatron
  - Decision to "run" the Collider
    - Rigorous approach to attacking operational problems
    - De-emphasis of long periods of dedicated machine studies

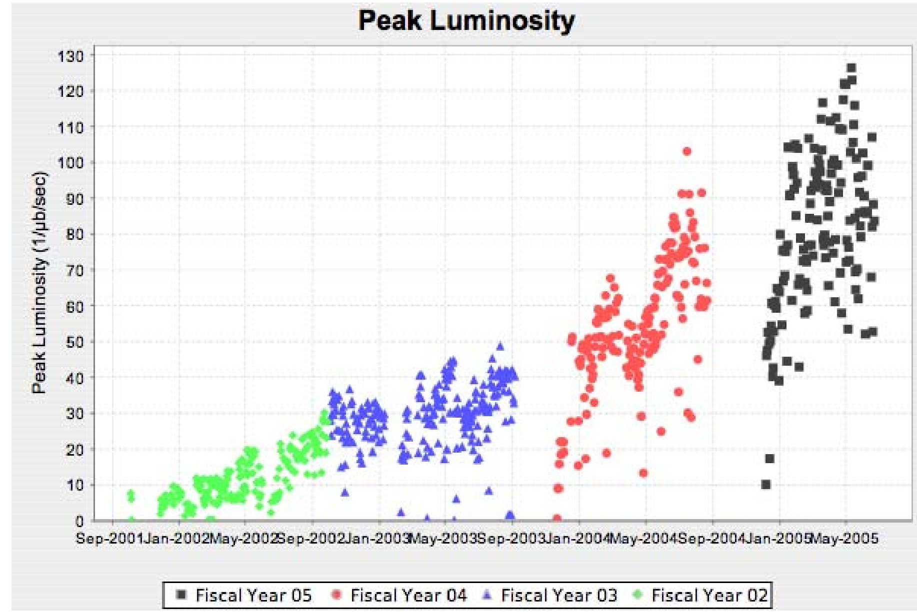
Luminosity

$$L = \frac{3\gamma f_0}{\beta^*}\left(BN_{\bar{p}}\right)\left(\frac{N_p}{\varepsilon_p}\right)\frac{F\left(\beta^*, \theta_{x,y}, \varepsilon_{p,\bar{p}}, \sigma^L_{p,\bar{p}}\right)}{\left(1+\varepsilon_{\bar{p}}/\varepsilon_p\right)}$$

- The major luminosity limitations are
  - The number of antiprotons (BN_{pbar})
  - The proton beam brightness (N_p/ε_p)
    - Beam-Beam effects
  - Antiproton emittance
  - F<1

Antiprotons and Luminosity





- The strategy to increasing luminosity in the Tevatron is to increase the number of antiprotons
  - Increase the antiproton production rate (Run 2 Upgrades)
  - Provide a third stage of antiproton cooling with the Recycler
  - Increase the transfer efficiency of antiprotons to low beta in the Tevatron

Collider Parameter Table

Parameter	Best Store	Last 10 Stores (Ave)	Best 10 Stores (Ave)	FY End Goal (Design)	
Luminosity Parameters					
Initial Luminosity	121.8	98.1	113.7	96.1	$x10^{30}cm^{-2}sec^{-1}$
Integrated Luminosity per Store	4806	4066.6	3977.5	3369	nb^{-1}
Luminosity per week	-	19	-	16.8	pb^{-1}
Store Length	27.3	29	24.4	20	Hours
Store Hours per week	-	135.5	-	100	Hours

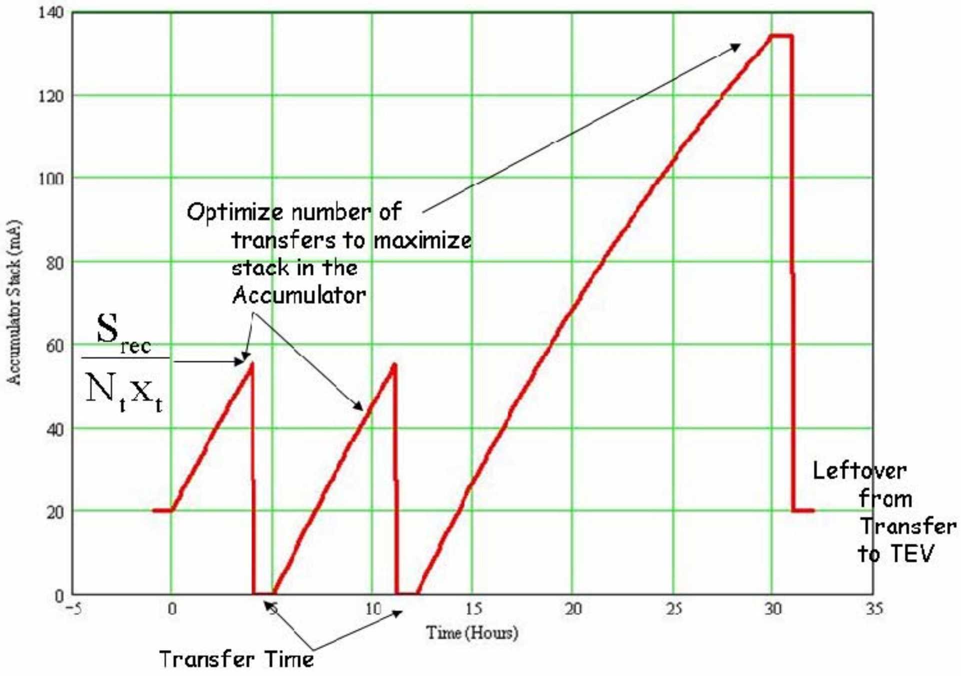
Parameter	Best Store	Last 10 Stores (Ave)	Best 10 Stores (Ave)	FY End Goal (Design)	
TEVATRON Parameters					
Energy	978	978	978	978	GeV
β^*	35	35	35	35	cm
Number of interaction regions	2	2	2	2	
Number of antiproton bunches	36	36	36	36	
Bunch spacing	396	396	396	396	nS
Protons per bunch	243.1	238.5	237.2	260	$x10^{9}$
Antiprotons per bunch	42.8	35.5	41.1	42	$x10^{9}$
Proton Efficiency to Low Beta	62.4	57.9	55.9	-	%
Pbar Transfer efficiency to Low Beta	68.1	62.3	60.9	76	%
HourGlass Factor	0.66	0.67	0.66	0.65	
Effective Emittance	13.9	14.3	14	18.5	π-mm-mrad

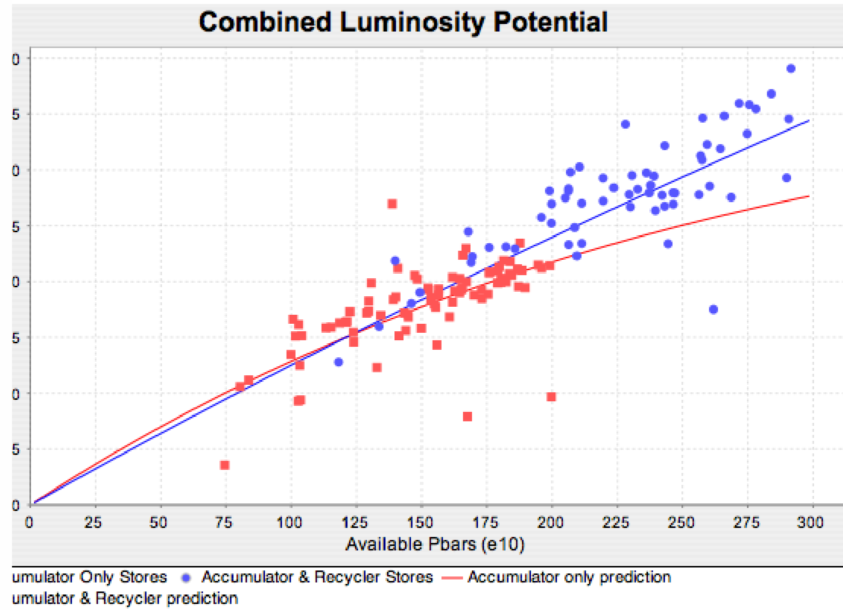
Parameter	Best Store	Last 10 Stores (Ave)	Best 10 Stores (Ave)	FY End Goal (Design)	
Antiproton Parameters					
Zero Stack Stack Rate	13.4	14.8	14.6	24.5	$x10^{10}$/hour
Normalized Zero Stack Stack Rate	2.2	2.3	2.3	3.1	$x10^{-2}$/hour
Average Stacking Rate	6.3	7.2	7.3	10.1	$x10^{10}$/hour
Stacking Time Line Factor	60.6	63.7	67.3	75	%
Stack Size at Zero Stack Rate	382.5	364.1	359.2	300	$x10^{10}$
Protons on Target	6.2	6.3	6.2	8	$x10^{12}$
Start Stack	266.3	219.7	260.8	216	$x10^{10}$
End Stack	40.5	31.2	42.6	15	$x10^{10}$
Unstacked Pbars	225.8	188.5	218.2	201	$x10^{10}$

Combined Shots

- Extracting antiprotons from both the Accumulator and the Recycler for the same store i.e.
  - Twelve bunches from the Recycler
  - Twenty four bunches from the Accumulator
- Combined Shot Operation
  - Proposed in February '04 by Brian Chase
  - Initial proposal presented at the April '04 Run II PMG
  - Dual energy ramps in the MI completed and tested by May '04
  - First Attempt 6/13/04
  - Record Luminosity
    - $103\times10^{30}cm^{-2}sec^{-1}$ recorded 7/16/04
    - $127\times10^{30}cm^{-2}sec^{-1}$ recorded May 2005
  - Routine Operations - January 2005
- Reasons
  - Flexibility in the Run II Upgrade schedule
    - Natural merging of commissioning of electron cooling
  - Push Recycler commissioning progress by plunging it into operations
  - Luminosity enhancement – larger amount of antiprotons for smaller emittances
    - Accumulator stack size limited to <200 mA
      - Stacking Rate
      - Transverse emittance vs Stack Size
- Ratio $I_{Recycler}/I_{Accumulator}$ is governed by:
  - Recycler phase space density (cooling)
  - Recycler transfer time (Rapid transfers)
- Obstacles
  - Stacking Rate
  - Injector Complex 8 GeV energy alignment
  - Longitudinal emittance in both the Accumulator and Recycler
  - Transfer time between Accumulator to Recycler

Combined Shots

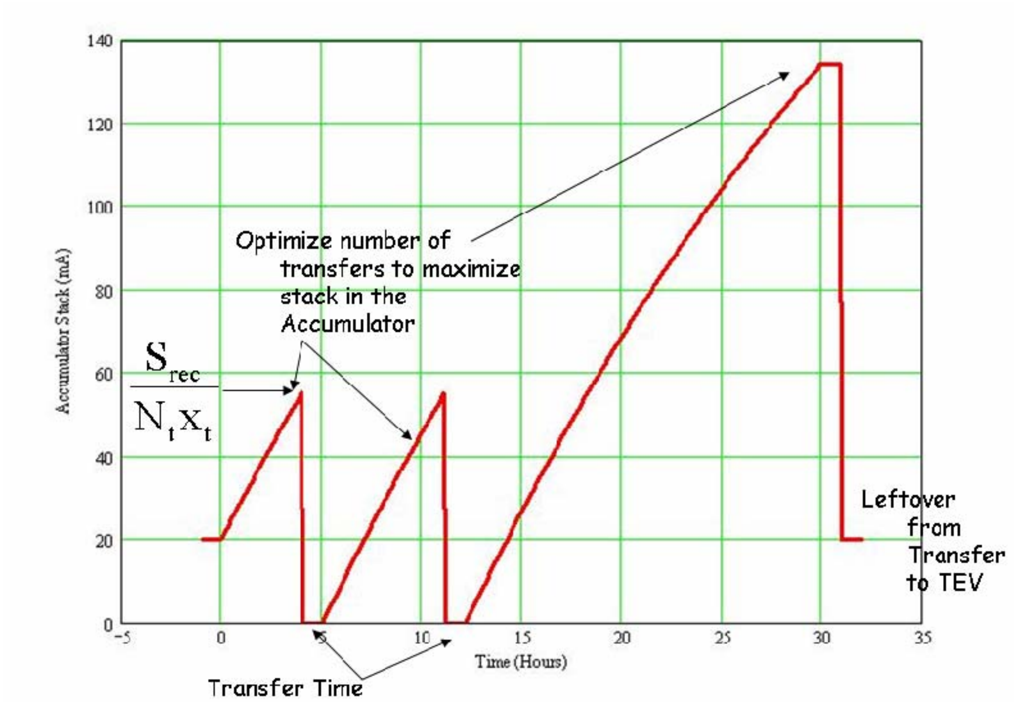


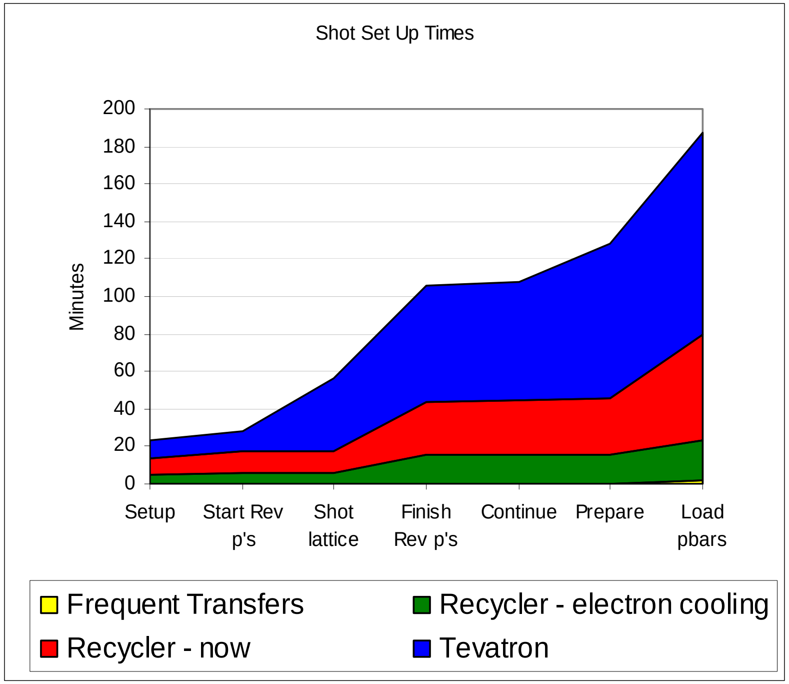


- Luminosity enhancement – larger amount of antiprotons for smaller emittances
  - Accumulator stack size limited to <200 mA
    - Stacking Rate
    - Transverse emittance vs Stack Size

Accumulator to Recycler Antiproton Transfers

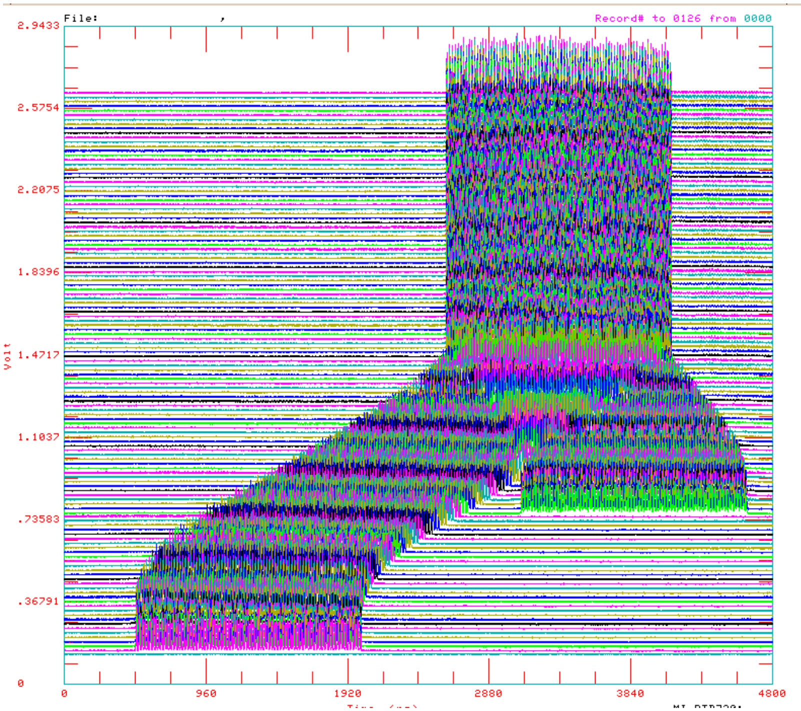
- Transfers between the Accumulator to the Recycler take about 1 hour to accomplish
  - Transfers frequency every 6-8 hours
- To realize the full potential of electron cooling, in the Recycler, this time needs to be reduced to less than 15 minutes
- Adopt a philosophy of being willing to lose a pbar transfer occasionally
  - Transfers frequency faster than every 2 hours

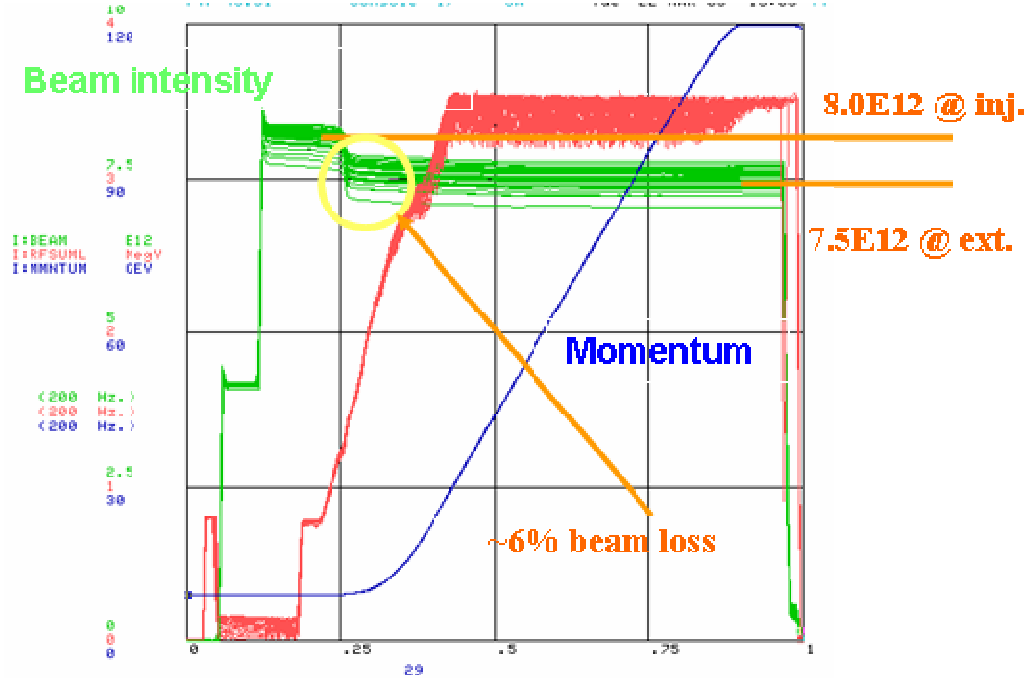




Antiproton Production - Slip Stacking

- Slip Stacking is the process of combining two Booster batches at injection into in the Main Injector to effectively double the amount of protons on the antiproton production target





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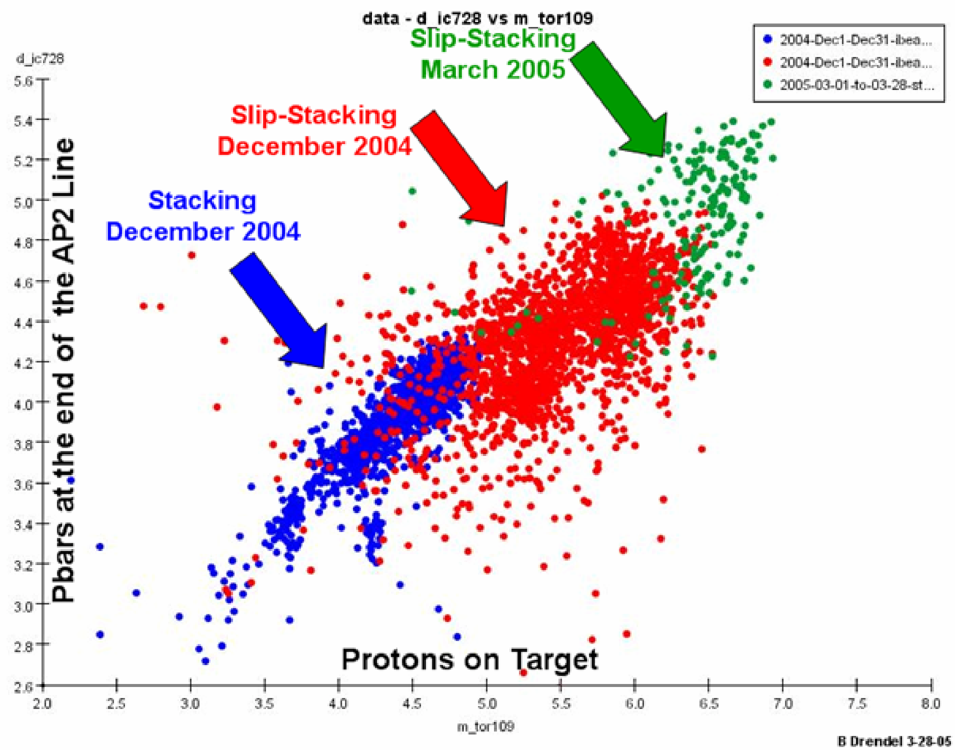
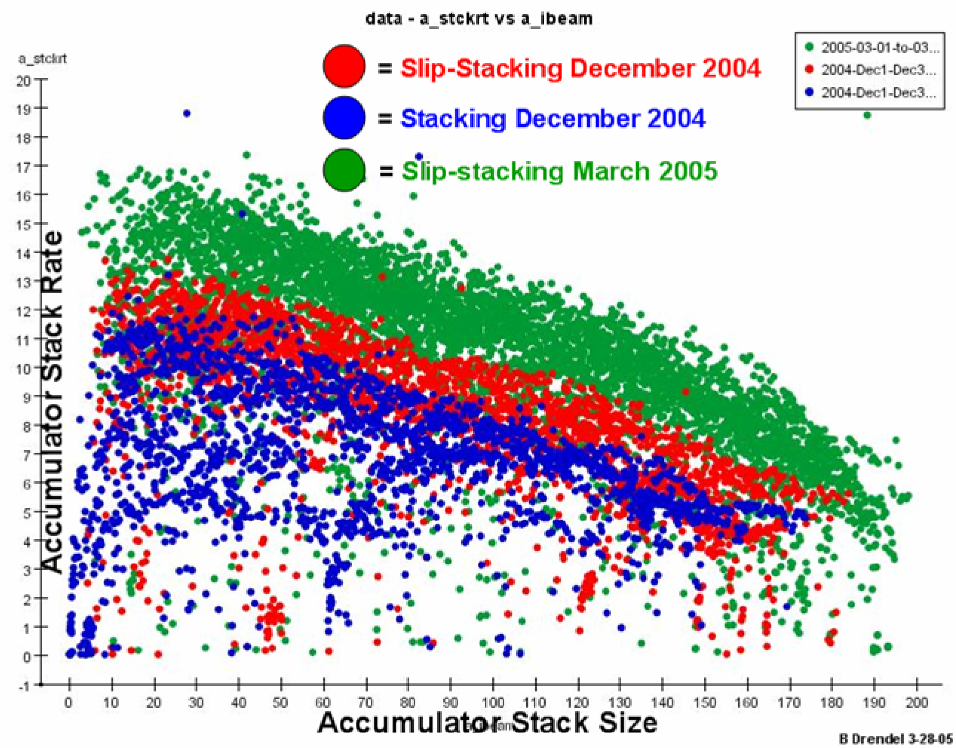
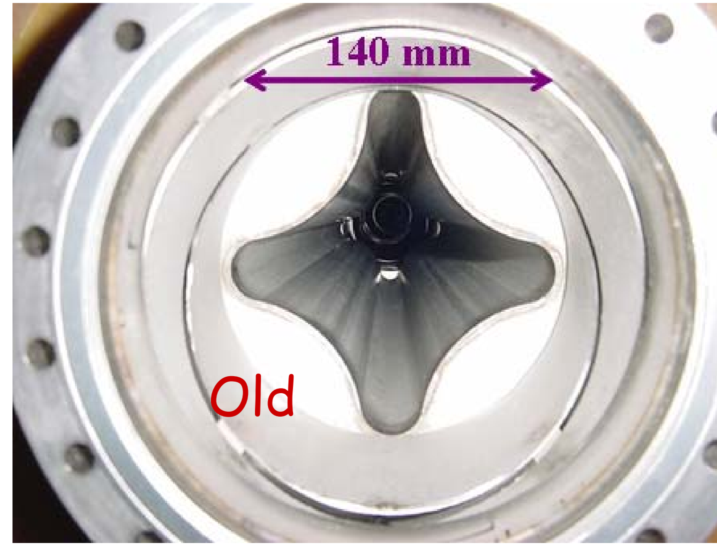




Antiproton Aperture - Pbar Production

- The measured aperture of the initial stages of the antiproton production chain is about 70% of the available physical aperture.
- An aggressive beam-based alignment program is under development to bring the measured aperture to the physical aperture.
  - Would increase the stacking rate by a factor of 2
- The beam based alignment scheme consists of 5 major components
  - Independent control of the quad gradients (done)
  - Beam position measurement system to measure orbit distortion due to varying quad gradients (in-progress)
  - Orbit control devices to center the beam through the quads (done)
  - Moveable control of tight apertures (stochastic cooling arrays) (in progress)
  - Loss monitor system to measure losses at tight apertures (done)
- Most of the recent focus has been to complete the instrumentation upgrade
  - Extremely small beam currents ~10μAmps
- The goal for this year is to increase the aperture for each plan to 78% of the available physical aperture which would result in a 25% increase in antiproton production rate



Stacking Progress

- The cornerstone of the Run II upgrades is antiproton production.
- The FY05 goal for the zero-stack stack rate is 24×10^{10} pbars/hour.
- Our best value to date is 17×10^{10} pbars/hour and recently we have not been able to reach above 15×10^{10} pbars/hour.
- There has been very little progress in increasing the stacking rate since February 2005.

Stacking Rapid Response Team

- We have formed a Stacking Rate Rapid Response team.
- The goal of the rapid response team is to:
  - Document the current state of the complex for antiproton stacking.
  - Formulate a study plan and needed instrumentation to reach 24×10^{10} pbars/hour
  - Successfully execute the plan by October 2005.
- The people on the Stacking Rapid Response Team are assigned to the team 100% of the time until the goals are accomplished.
  - Members of the rapid response team cannot be machine coordinators, so the departments will have to pick up the slack.
  - The Booster, Main Injector, and Antiproton Source departments will focus on operational aspects and other programs
    - Booster: MiniBoone and NUMI
    - Main Injector: NUMI and SY120
    - Antiproton Source: Rapid transfers to the Recycler.

Stacking Rapid Response Team Groups

- Management
  - Team:
    - Dave McGinns, Valeri Lebedev
    - Leader: Dave McGinnis
      - Jim Morgan will run the collider complex
        - Brian Drendel and Saleh Chaurize serving as his deputies
  - Goal:
    - The team meets twice a week at Tuesdays and Thursdays at 9 am in the Huddle to discuss overall progress and integration with collider operations.
      - This team will most likely identify and correct deficiencies in some of the operational aspects of the Run II Upgrades.
      - Some of these corrections might require re-scoping the Run II upgrades.
- Booster Extraction
  - Team:
    - Jim Steimel, C. Y. Tan, X. Yang, F. Garcia
    - Leader: – Jim Steimel
  - Goal:
    - 4.5e12/batch with a longitudinal emittance of 0.12 eV-sec/bucket and a momentum spread of 18 MeV

Stacking Rapid Response Team Groups

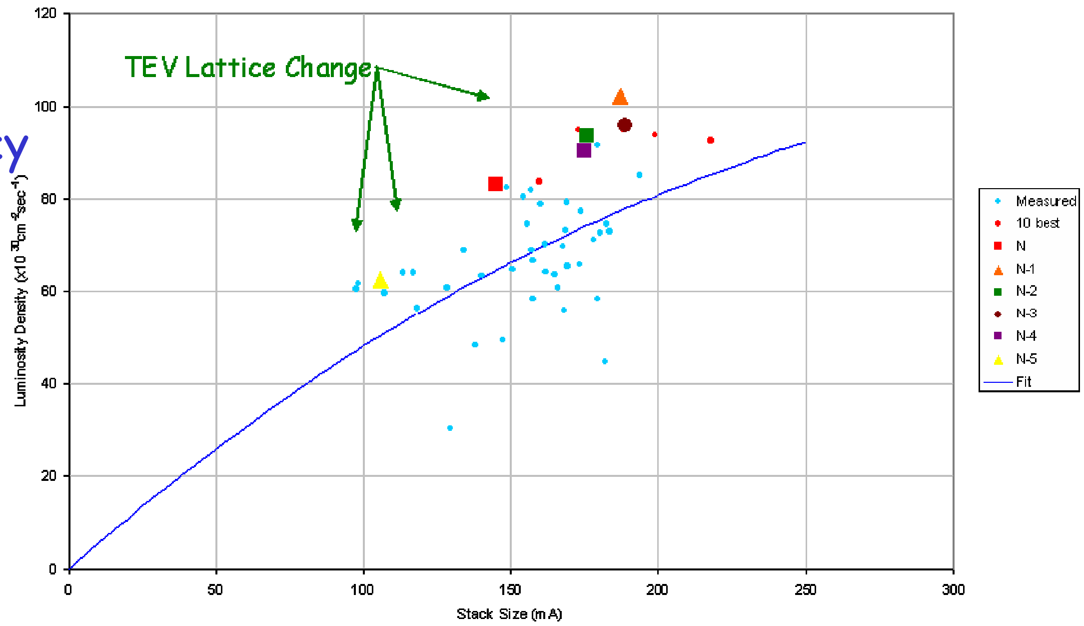
- Main Injector Slip Stacking
  - Team:
    - K. Seiya, P. Adamson, V. Wu, J. Dey
    - Leader: K. Seiya
  - Goal:
    - 8e12 protons on target with a 1.5 nS bunch length and an acceleration efficiency of 95% and single point Rad limit of 1 Rad/hr in the MI tunnel.
- Antiproton Source
  - Team:
    - K. Gollwitzer, S. Werkema, P. Derwent, D. Vander Meulen, D. Broemmelsiek
    - Leader: K. Gollwitzer
  - Goal:
    - 8e12 protons on target every 2.0 secs with a production of 17e-6
- Instrumentation
  - Team:
    - W. Ashmanskas, D. Peterson, N. Eddy, Sten Hansen (PPD), C. Drennan
    - Leader: W. Ashmanskas

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 to be replaced by Electron Cooling
  - Electron beam: 4.34 MeV – 0.5 Amps DC – 200μrad beam spread – 99% recirculation efficiency
- Installation of e-cool equipment in MI-31 and the Recycler tunnel complete
- Commissioning of electron cooling in progress
  - Electron beam circulated in cooling section
  - Commissioning due to be completed by September 2005

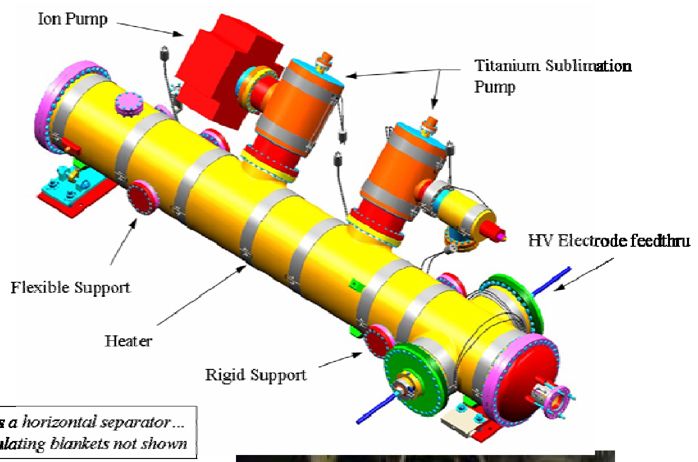
Tevatron Major Accomplishments

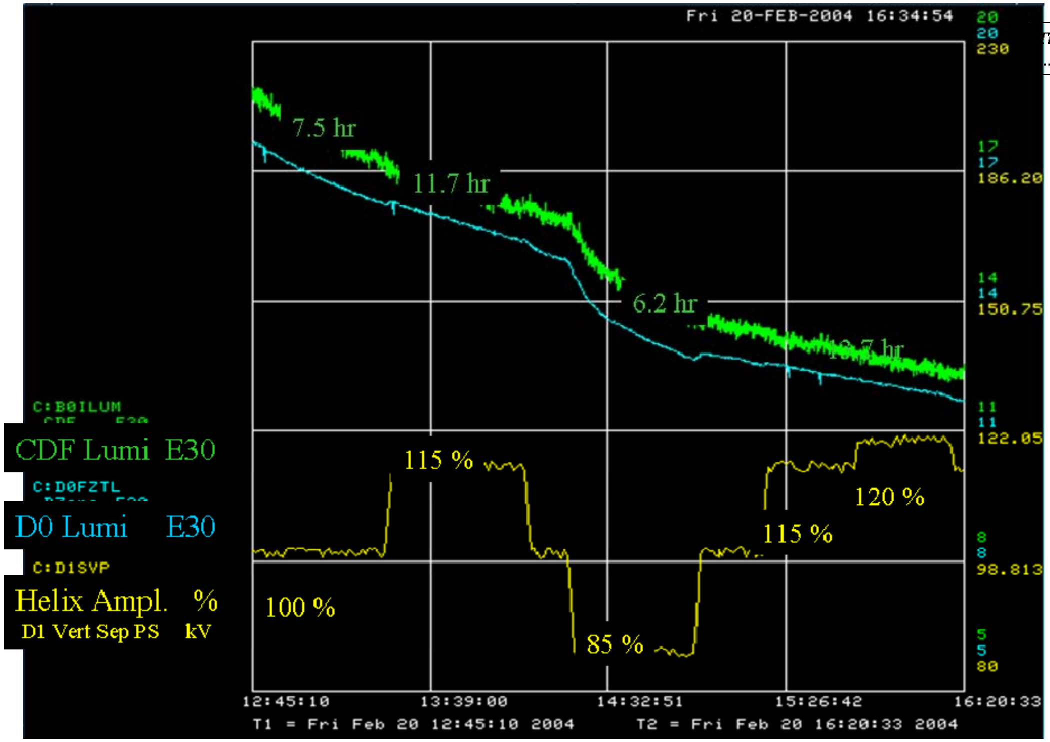
- Alignment Projects
  - Tev-Net
  - Smart bolt retro-fit
  - Dipole Un-Rolls
  - P1 Line roll
  - IP low-beta regions
  - Tight aperture areas
- Alignment Results
  - Better injection efficiency
  - Smaller emittance at collisions
  - Better ramp efficiency
  - Better store-store reproducibility
- New Low Beta optics (April 04 – June 04)
  - 20-30% increase in luminosity
  - Smaller beta*
  - Smaller emittance



Tevatron Helical Orbit Separation

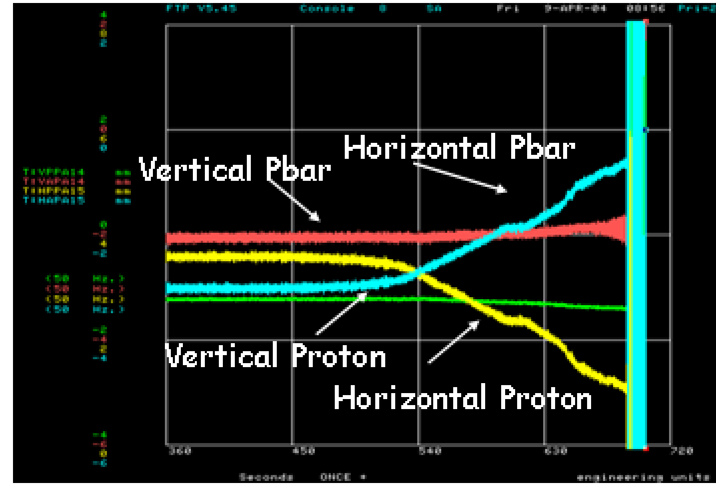
- More separators
- Higher separator voltage
  - Separator R&D
- Different separator configuration
  - Polarity switches

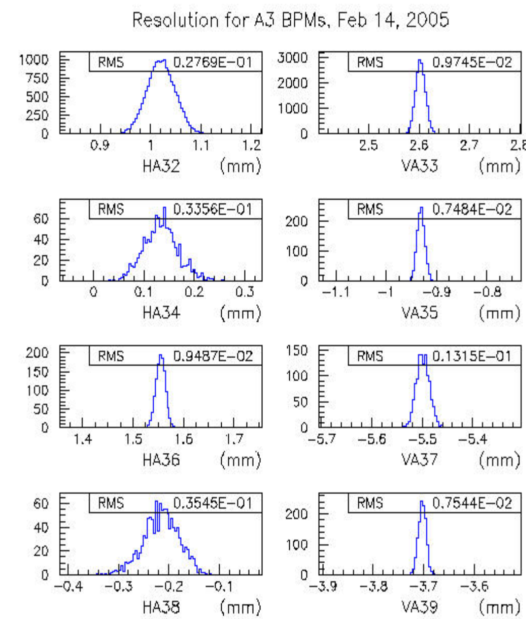




Tevatron Instrumentation

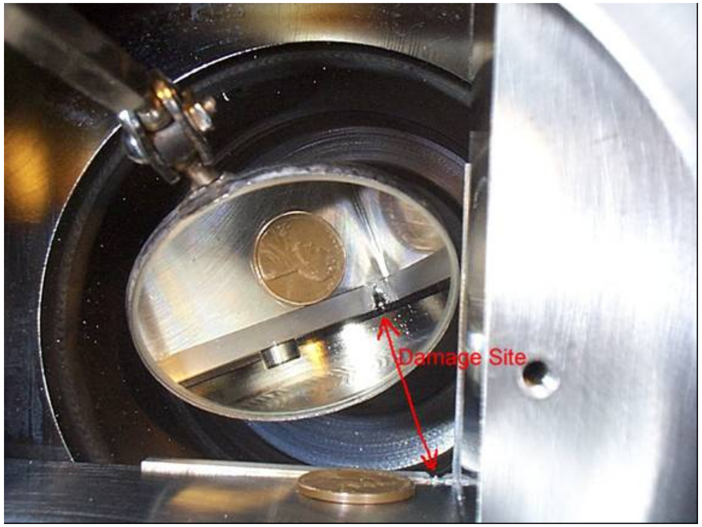
- Tevatron BPM Project
  - Joint CD/AD effort
  - A major success
  - Project making very good progress though completion date has slipped by a few months
  - An order of magnitude improvement in proton position measurements and new for pbars
  - Position resolutions in the range of ~10 - 25 μ
  - Will be extremely useful in understanding beams
    - Can see synchrotron and betatron lines, quadrupole oscillations, H-V coupling, etc.
  - 85% installed
    - ~ 50% connected/ commissioned
- New Beam loss monitor system
- New Ion Profile Monitor



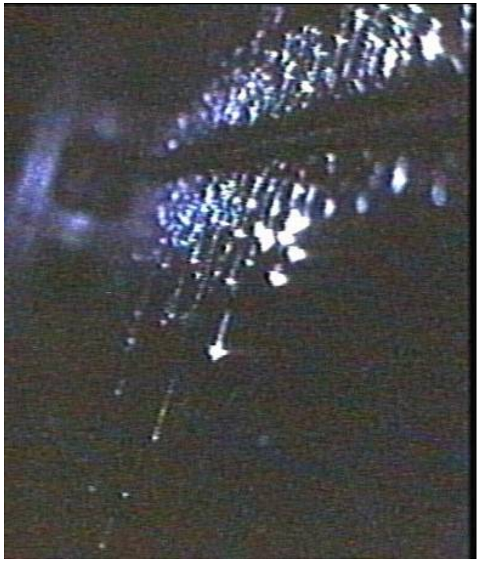


Tevatron Beam Power

$$L = \frac{3\gamma f_0}{\beta^*}\left(BN_{\bar{p}}\right)\left(\frac{N_p}{\varepsilon_p}\right)\frac{F\left(\beta^*, \theta_{x,y}, \varepsilon_{p,\bar{p}}, \sigma^L_{p,\bar{p}}\right)}{\left(1 + \varepsilon_{\bar{p}}/\varepsilon_p\right)}$$



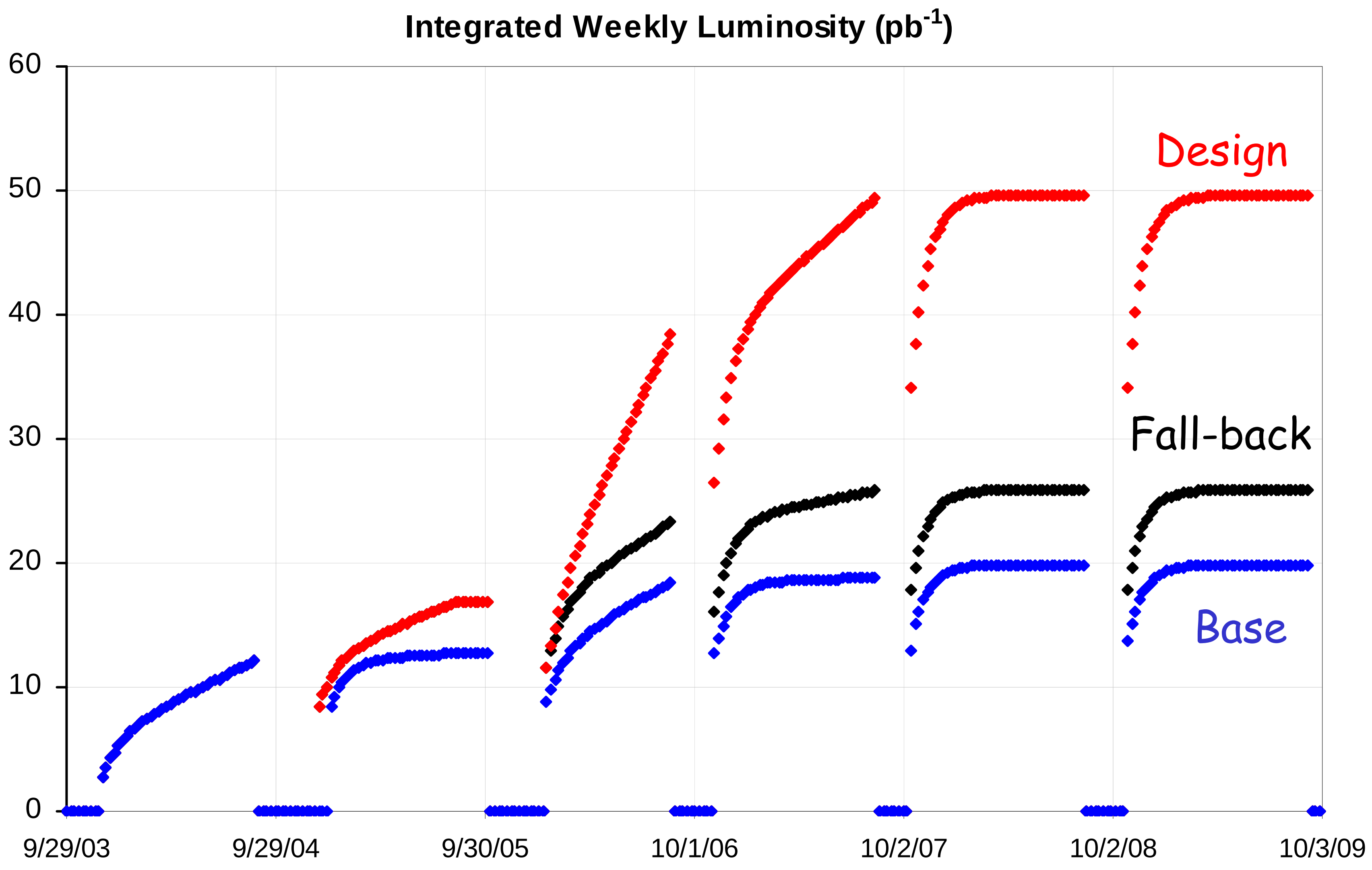
- Proton Beam Current
  - Luminosity is proportional to the number of protons **per bunch** (N_p)
  - The proton beam current is proportional to BN_p
- Fast Beam Loss - can cause serious damage to the detector or the accelerator
  - Run II example: fast beam loss incident initiated by misbehavior of roman pot → losses → fast trip of correctors →beam mis-steer
  - Each proton/pbar bunch is a bullet – in Russian roulette
  - Add collimator protection where possible
  - Assertions:
    - Every serious beam incident should be fully diagnosed
    - Implication digested by the experiments.
    - Any corrective action will likely involve work on the accelerator
  - Unmasking of inputs for protection
  - New BLM system as abort input
  - Kicker Pre-fires
    - Collimator design
    - Abort block reconfiguration



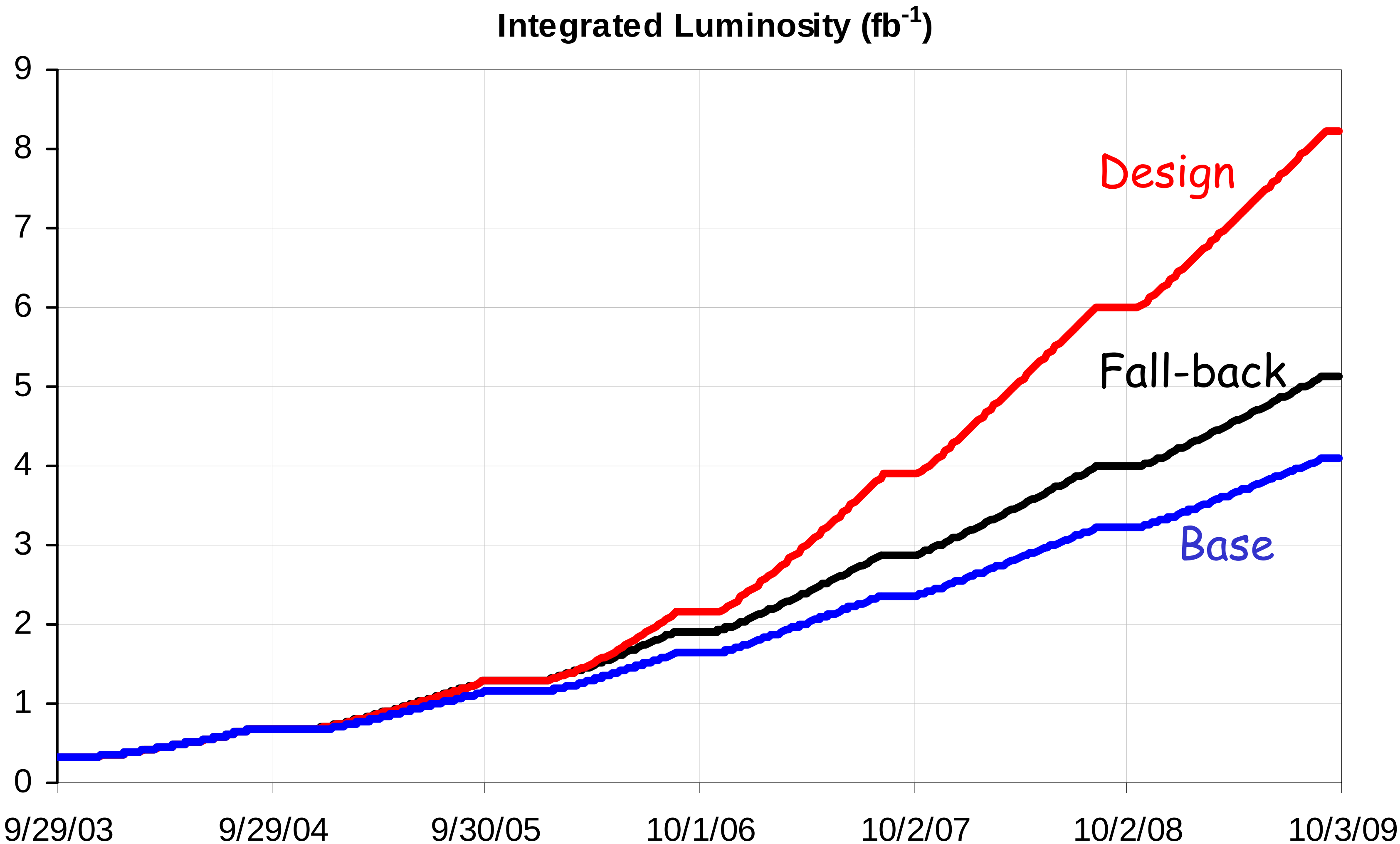
Luminosity Projections

- Our plan is to deliver the design projection,
  - but, develop an understanding of fallback scenarios
  - Combined-source operation and the phased Stacktail upgrade allow more natural introduction of key upgrades (e-cooling and Stacktail upgrades) and provide a more robust fall-back position
- Luminosity Scenarios
  - Design Projection: Electron cooling and Stacktail upgrade
  - Fall-back Projection: no Electron cooling, Combined-source operation beyond 05 (20% gain), Deb→Acc acceptance issues solved
  - Base Projection: no electron cooling, Deb-Acc acceptance only minor improvements and no gain from mixed-source
  - All assume slip stacking and 100 HEP hrs per week average long-term

Weekly Luminosity Projection



Integrated Luminosity



Other Business - Fixed Target FY05 Accomplishments

- Record throughput for MiniBoone
  - 8.0×10^{16} protons/hour
  - Delivered a over 5×10^{20} protons in under three years of running
- Routine running of Mixed Mode for SY120 with slip-stacking for pbar production
  - A factor of 7 more spill seconds then originally allocated
  - As NUMI takes the place of SY120 on the antiproton stacking cycles, a new long flattop ramp will keep most of the spill-seconds intact.
- NUMI commissioned
  - First beam on Dec. 4, 2004
  - Around the clock operations on March 14, 2005
  - Target problems April 2005
  - Have resumed operations in Mixed-Mode antiproton stacking cycles

Summary

- Since June 2003, the Tevatron has seen a 3-fold increase in:
  - Peak luminosity
  - Integrated luminosity per week
  - Total integrated luminosity
- Luminosity increase is mostly due to:
  - Better performance of the injector chain
  - Introduction of the Recycler into operations
  - Alignment of the Tevatron
  - Decision to "run" the Collider
    - Rigorous approach to attacking operational problems
    - De-emphasis of long periods of dedicated machine studies
- The Run II Upgrades are on track to provide over $8fb^{-1}$ by 2009
  - The Recycler is operational
  - Electron cooling is progressing well
  - Slip Stacking is operational
- The major challenge left in Run II is the increasing the antiproton production rate
  - AP2- Debuncher aperture upgrade
  - Debuncher to accumulator transfers
  - Stacktail Momentum cooling uprade
  - Rapid transfers between the Accumulator and Recycler