

Performance and Future of the Tevatron

Ron Moore

Fermilab - Tevatron Dept.

- Tevatron overview and performance
- Antiproton source + Recycler overview and performance
- Plan for rest of Run 2

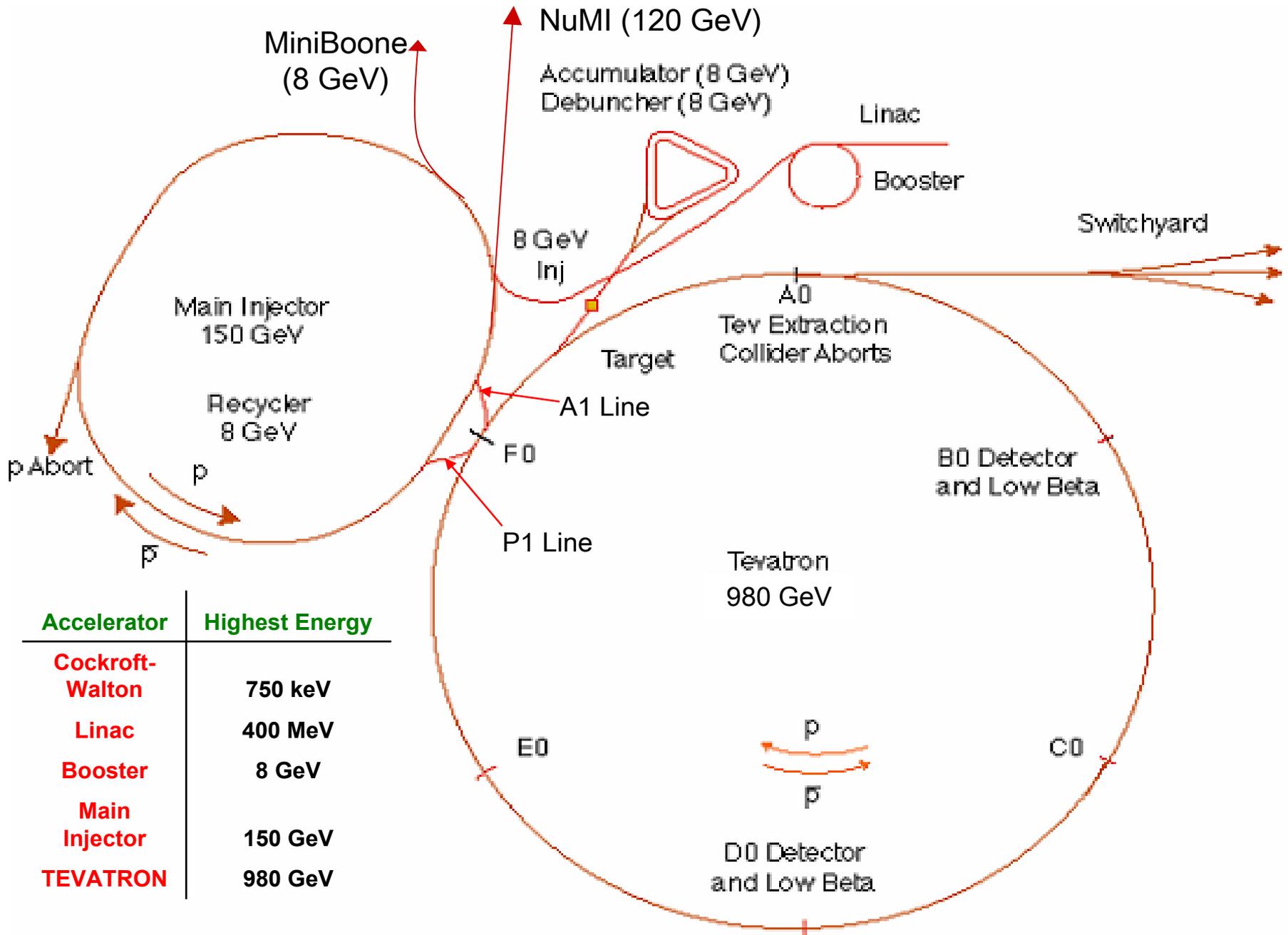


Overview



- Collider Run 2
 - Tevatron 36×36 proton-antiproton collisions to CDF & D0
 - Design goal = 8 fb⁻¹ by end FY09
 - Nearly 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

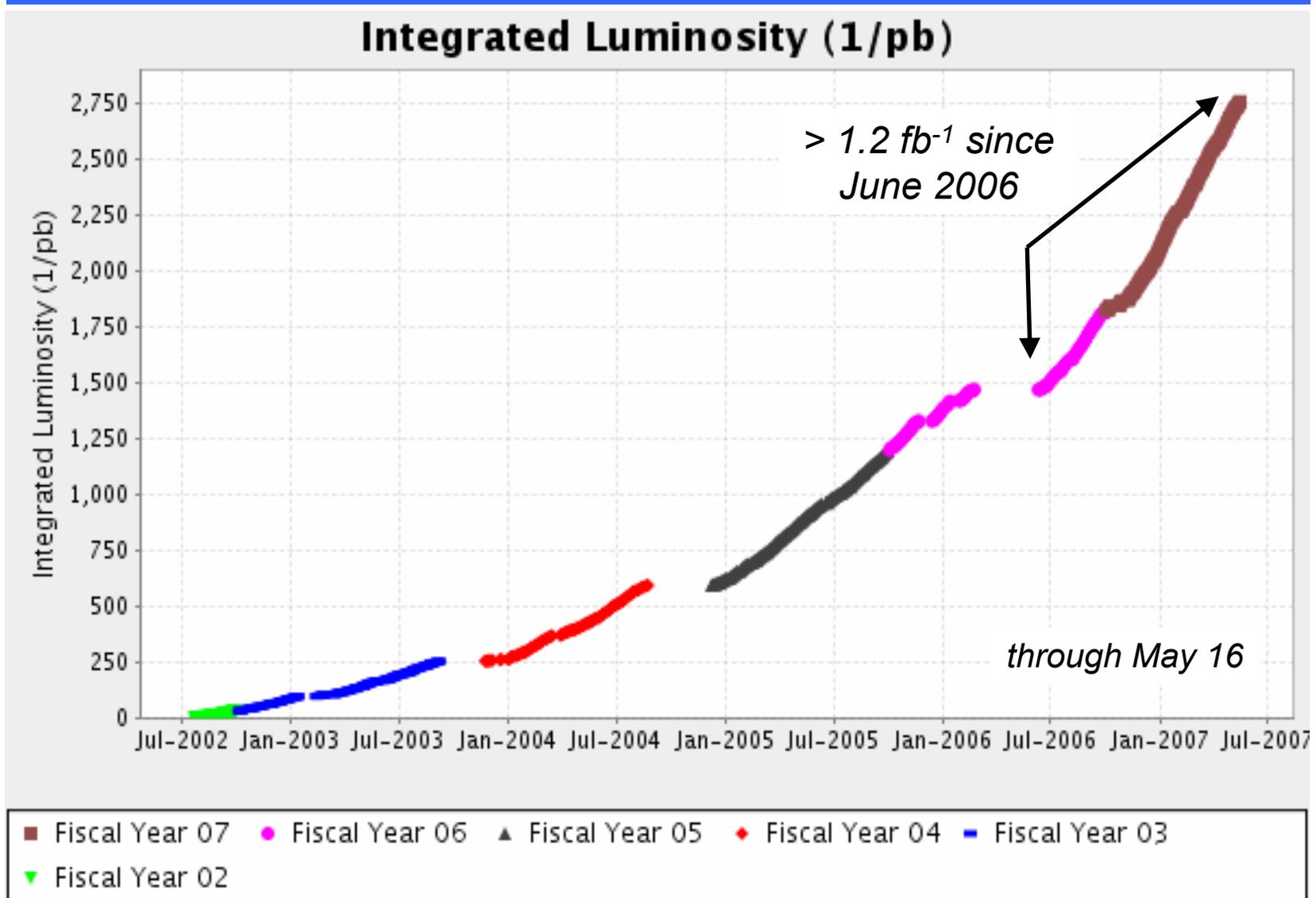
Fermilab Accelerator Complex

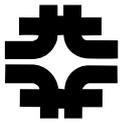


Accelerator	Highest Energy
Cockroft-Walton	750 keV
Linac	400 MeV
Booster	8 GeV
Main Injector	150 GeV
TEVATRON	980 GeV

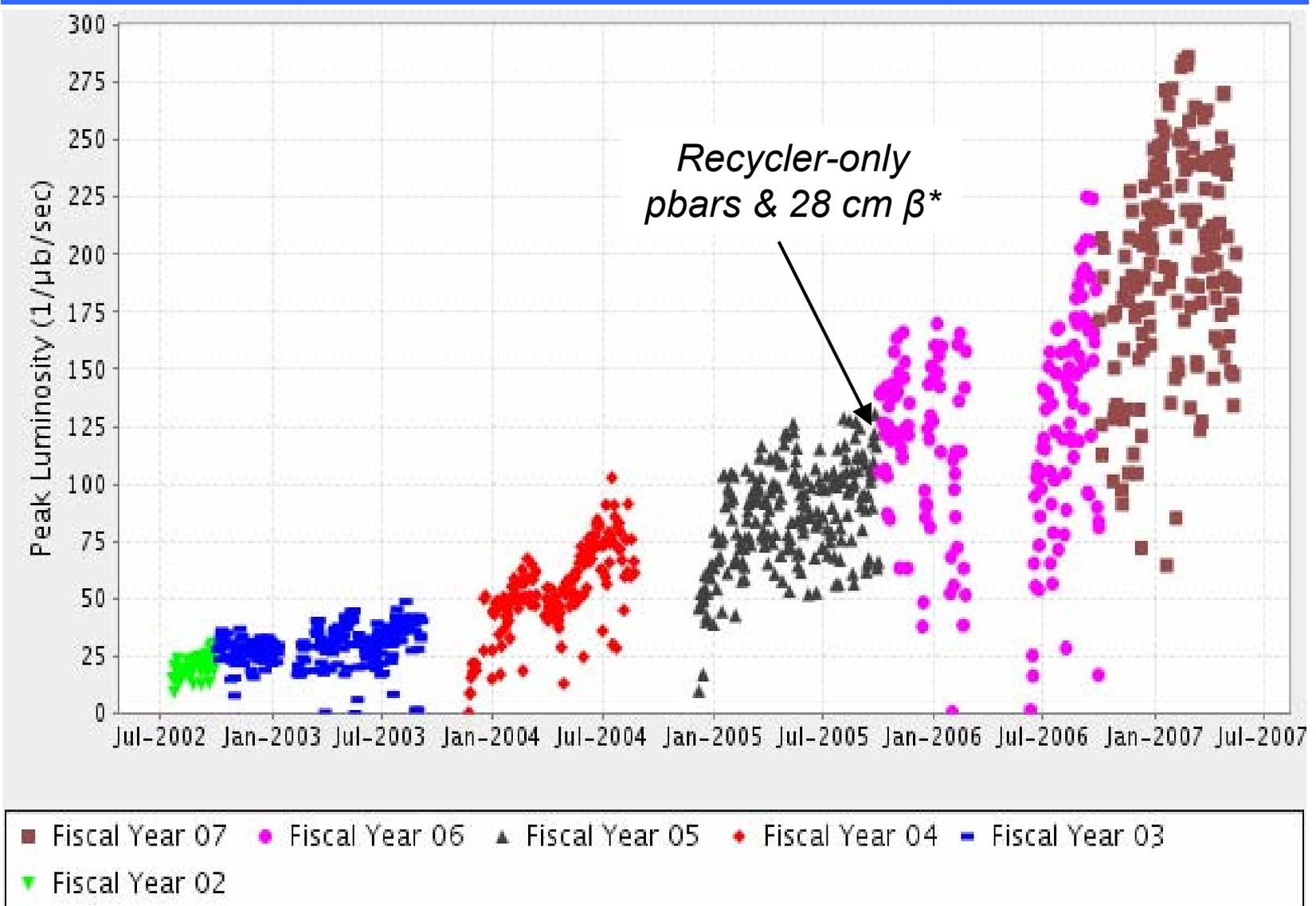


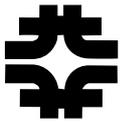
Tevatron Run 2 Delivered Luminosity





Tevatron Run 2 Peak Luminosities





Record Comparison Before/After 2006 Shutdown



- Peak luminosity increased 62% (180 → 292 $\mu\text{b}^{-1}/\text{s}$) 1 $\mu\text{b}^{-1}/\text{s} = 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$
- Weekly integrated luminosity increased ~75% (25 pb^{-1} → 45 pb^{-1})
- Monthly integrated luminosity increased ~95% (85 pb^{-1} → 167 pb^{-1})
- One hour antiproton stacking record -- 23.1 $10^{10}/\text{hr}$
- Antiproton accumulation for one week -- 2800 10^{10}

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

Big progress
this year

- N = bunch intensity, f = collision frequency
- ε = transverse emittance (size), σ_z = bunch length
- H = “hour glass” factor (<1 , accounts for beam size over finite bunch length)



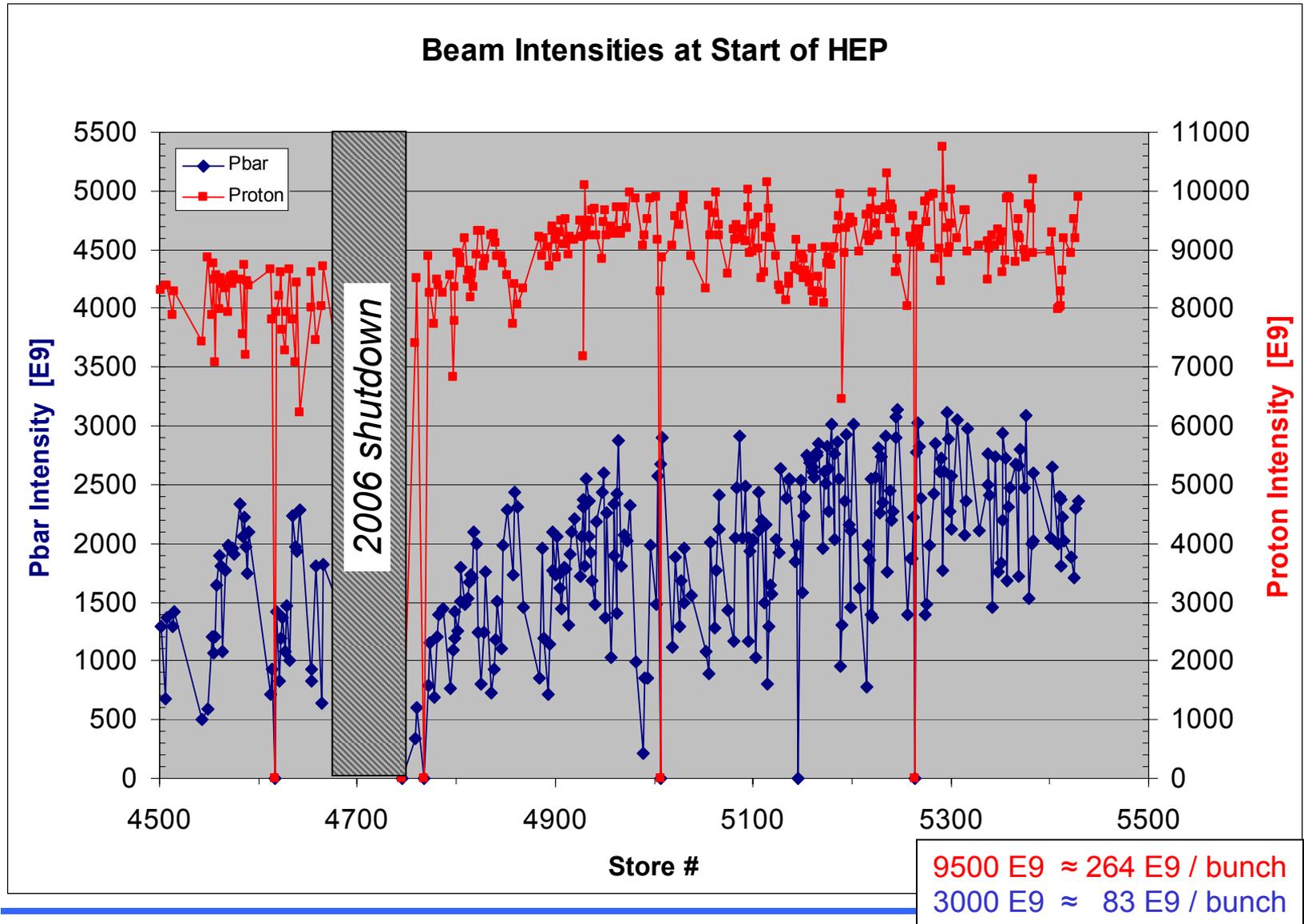
Recent Tevatron Highlights

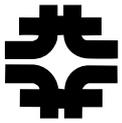


- More pbars with smaller emittances to HEP
 - Thanks to Antiproton Source and Recycler
- More protons to HEP
 - Injecting $\approx 10\%$ more protons
 - Better lifetime @ 150 GeV from new helical orbit, reduced beam-beam
- Improved luminosity lifetime
 - Additional separators increase separation (up to 20% at parasitic crossings)
 - Beam-beam effects reduced
- Reliability
 - Replaced all ≈ 1200 LHe Kautzky valves (cause of 2 FY06 dipole failures)
 - Modifying quench protection system to allow faster beam aborts
 - Cog pbars out of abort gap for acceleration – prevent needless quenches

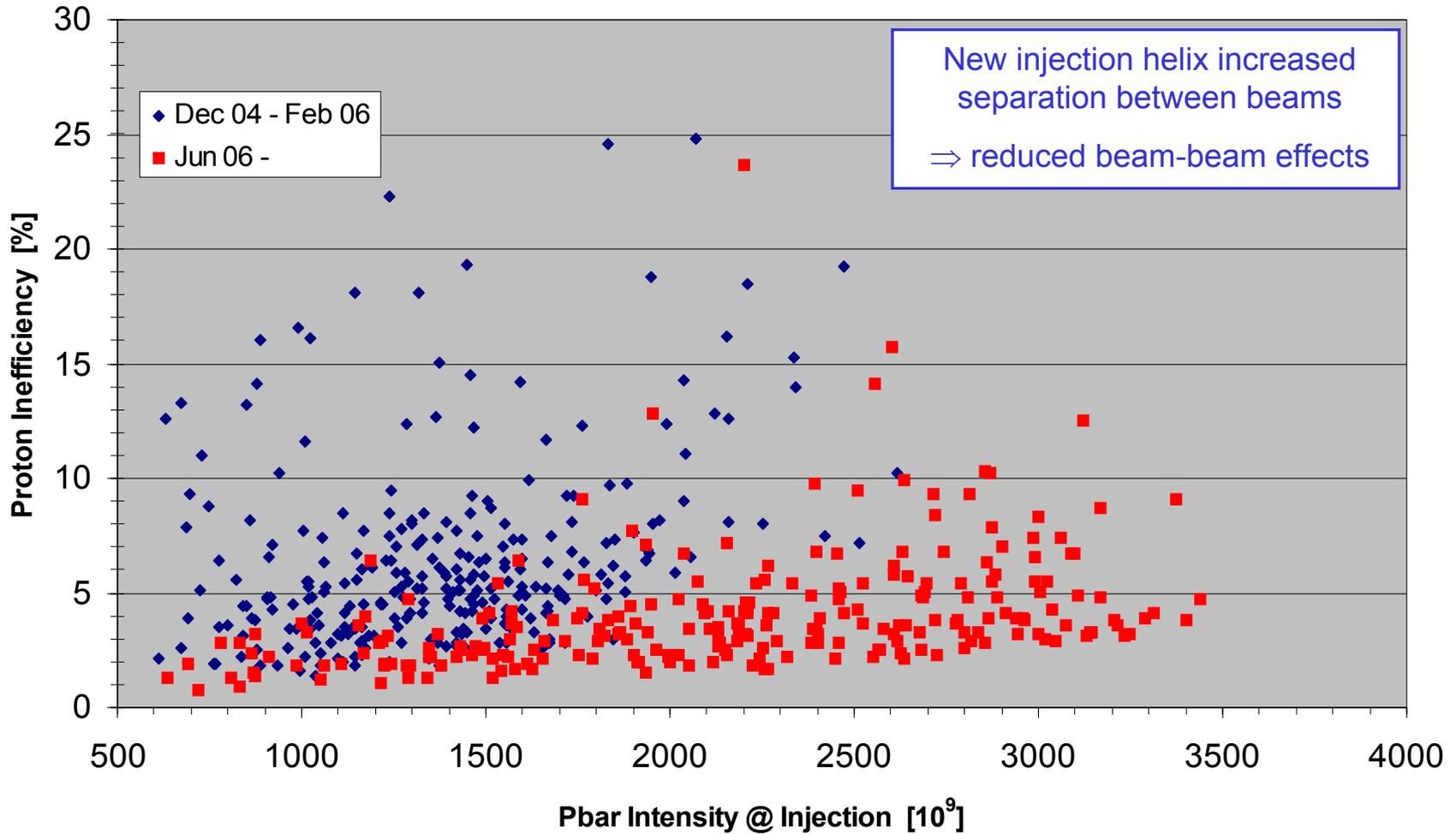


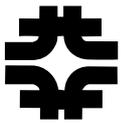
Higher Intensities to HEP





Proton Inefficiency @ 150 GeV

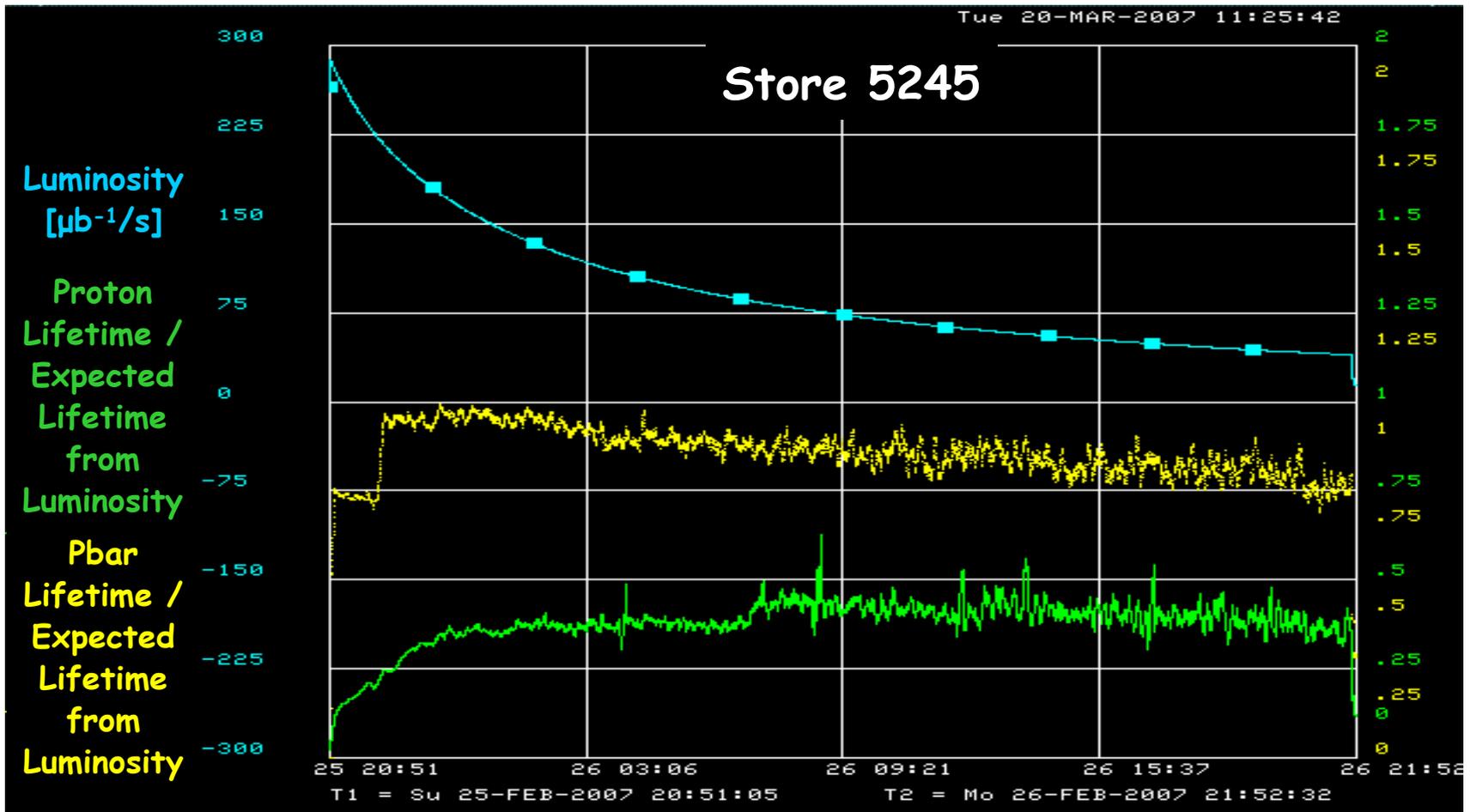


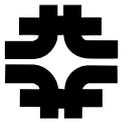


Beam Lifetimes during HEP

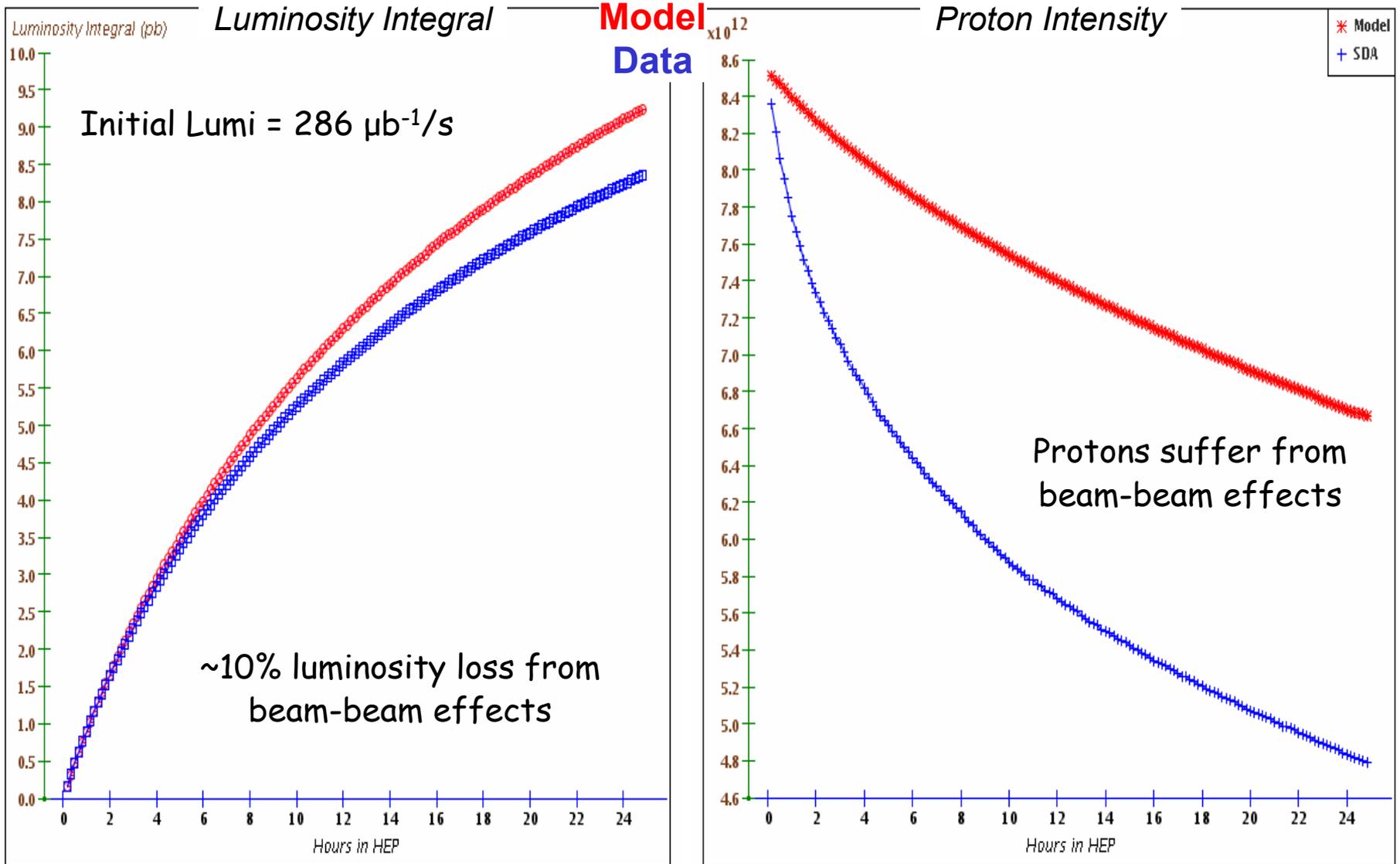


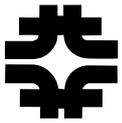
- Pbar lifetime dominated by luminosity – good
- Most protons lost in non-luminous processes – not so good
 - Beam-beam effects from smaller emittance pbars on protons





Store 5245 – Comparison to Model w/o Beam-Beam

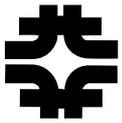




Looking Ahead in Tevatron



- All major Tevatron upgrades are complete
- Implement 2nd order chromaticity correction @ low β – in progress
 - Simulations show improved lifetimes during HEP
 - Also prerequisite to pursue possible new working point near $\frac{1}{2}$ integer
- Pursue other minor improvements (few % each) – they all add up!
 - Scrape (higher intensity) protons @ 150 GeV
 - Investigating new cogging between antiproton injections
 - Reduce beam-beam effects by changing locations of long-range crossings
 - Use TELs (electron lenses) on protons for beam-beam compensation
 - Raise tunes of individual bunches away from 7/12 resonance to improve lifetime
 - Better helices, improved transfer line matching, faster shot-setups, etc.



Antiproton Production Overview

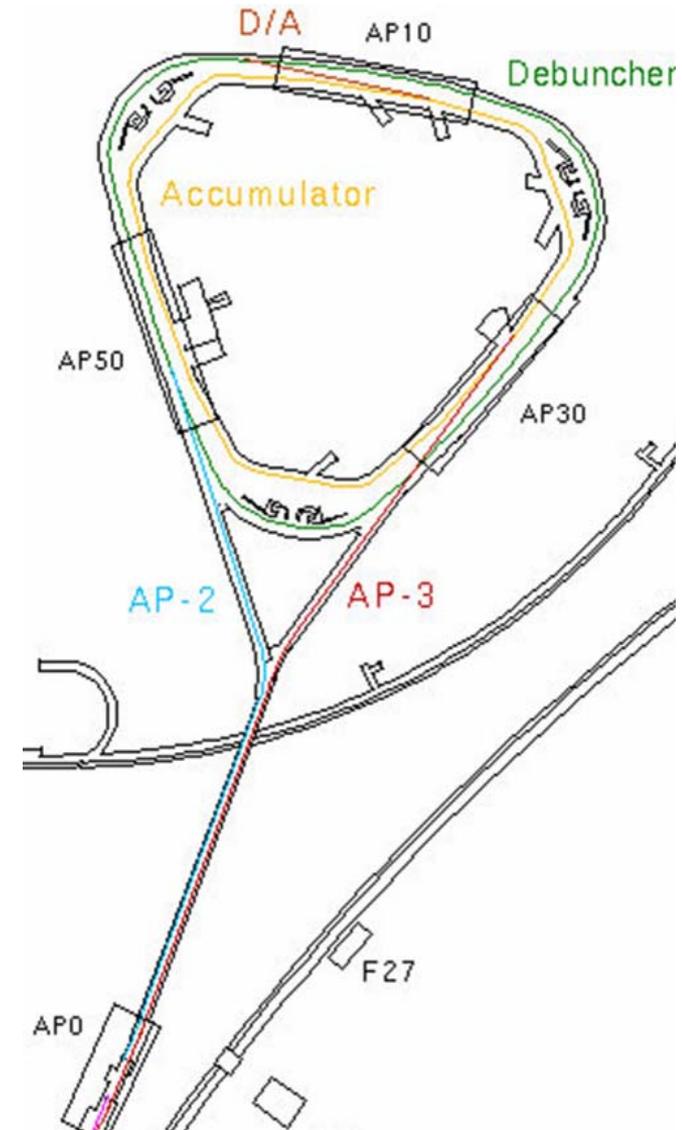


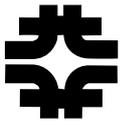
- Antiproton Source

- Every 2.2 sec, $\approx 8 \cdot 10^{12}$ 120 GeV protons from MI strike target
- Li lens + pulsed magnet focus/steer 8 GeV beam into AP-2 line
- Debuncher: bunch rotation + stochastic cooling shrink beam by factor 10 longitudinally, 7-10 transversely
- Accumulator: RF decelerates pbars from injection orbit; **stacktail momentum cooling** moves pbars to core; build up stack with additional stochastic cooling systems
- Typical stacking rates $\approx 20 \cdot 10^{10}/\text{hr}$ → **want to increase!**
- Every 2-3 hrs, transfer pbars from Accumulator → Recycler

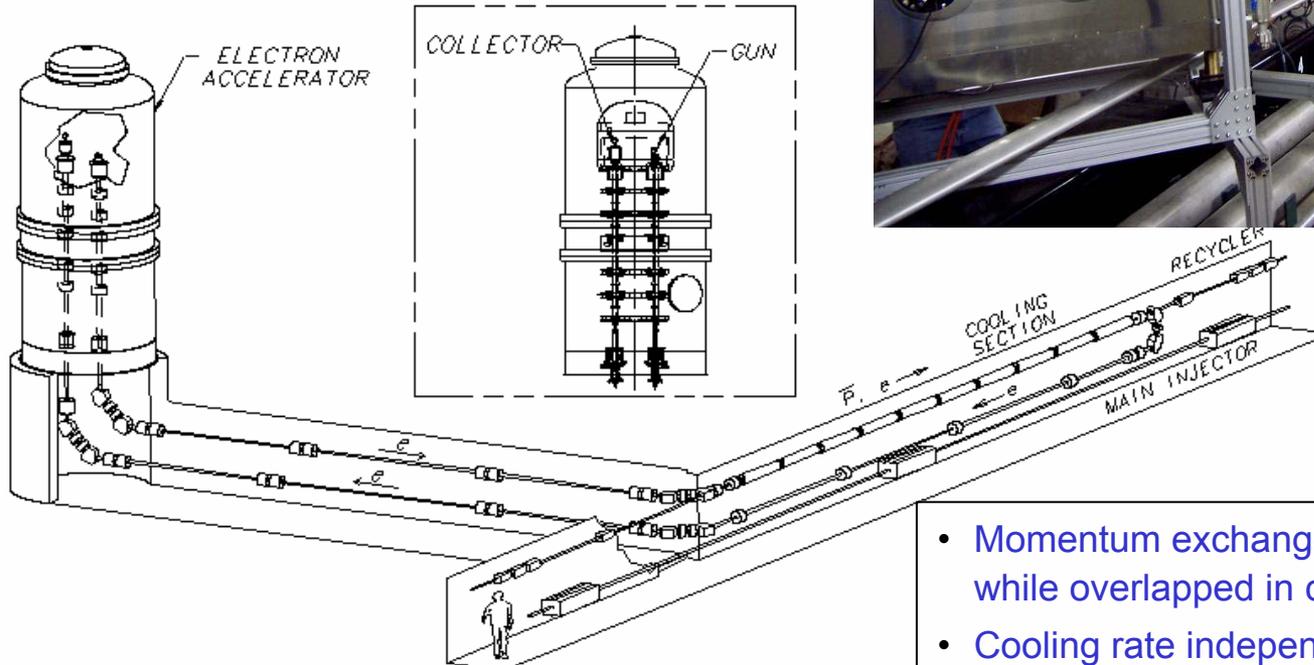
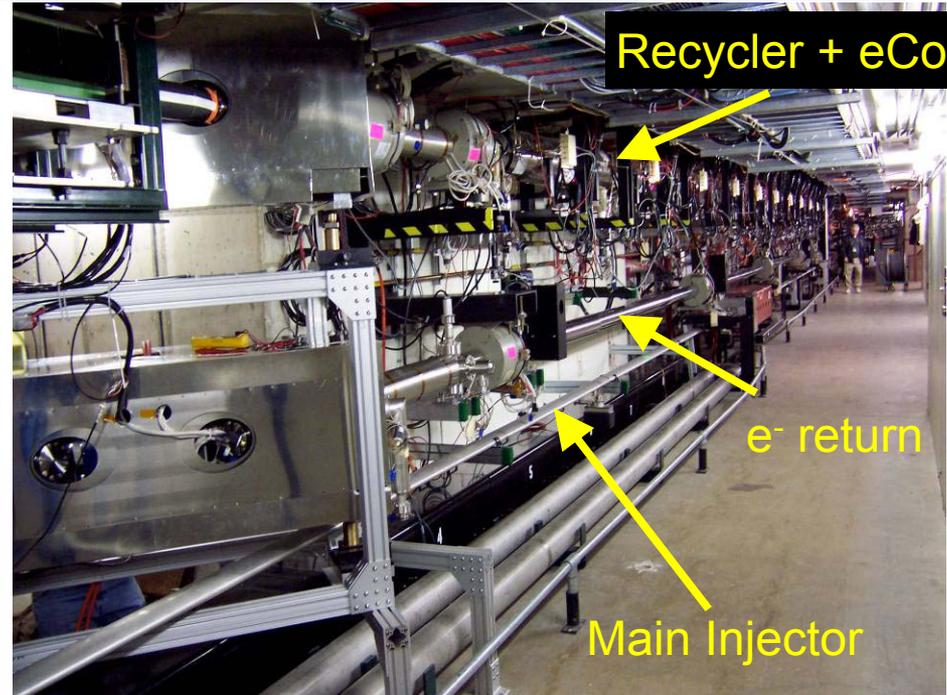
- Recycler

- 8 GeV (mostly) permanent magnet storage ring in MI tunnel
- Used as intermediate antiproton storage ring
- Exploit higher Accumulator stacking rates for small stacks
- Both stochastic and electron cooling are used
- Goal: $600 \cdot 10^{10}$ (best = $440 \cdot 10^{10}$, typical 350-400 $\cdot 10^{10}$)



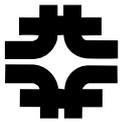


Electron Cooling in Recycler

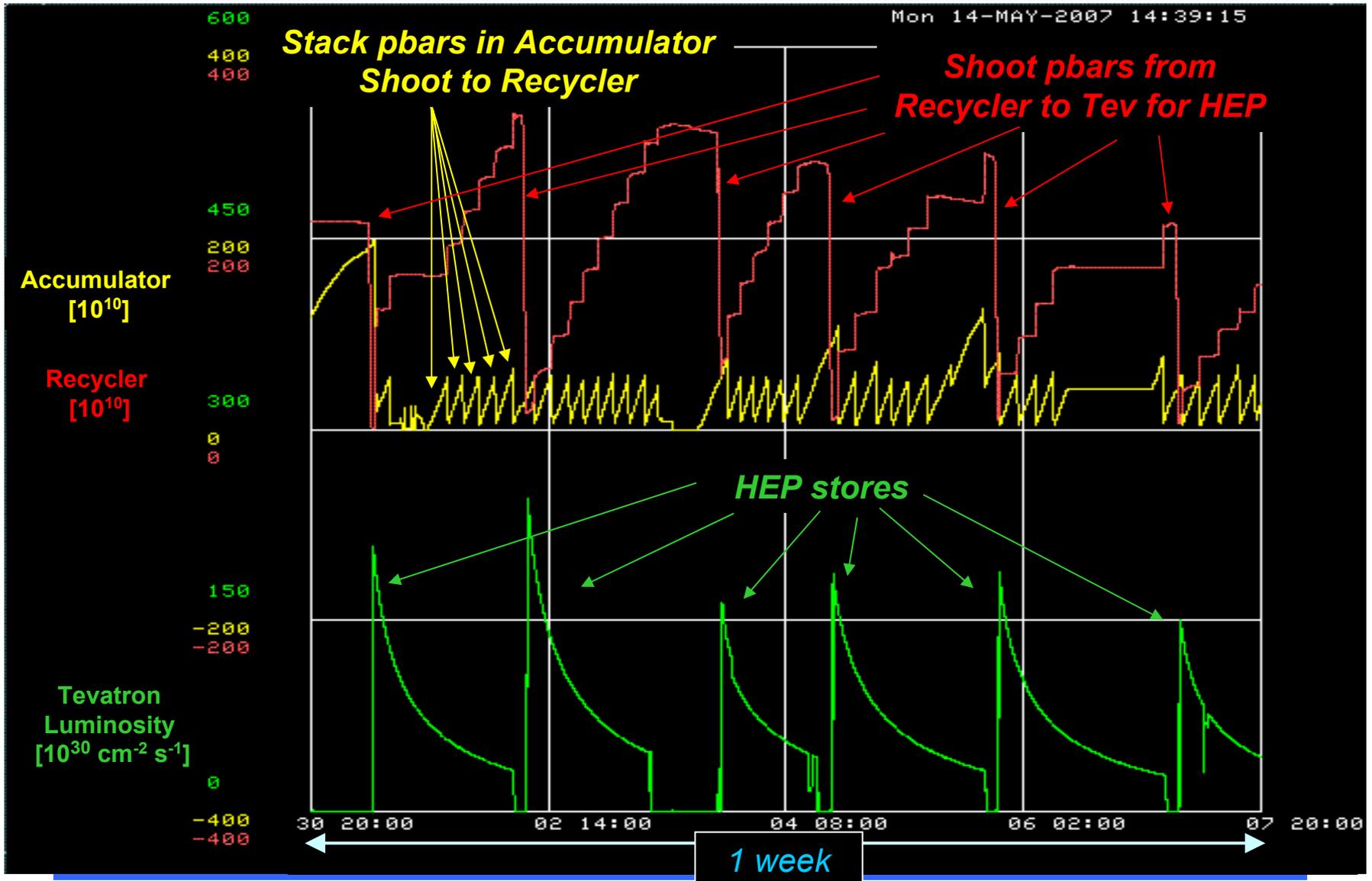


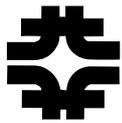
- e^- beam for cooling
 - 4.34 MeV
 - 0.5 amp DC
 - 200 μ rad angular spread

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



Antiproton Production Flow





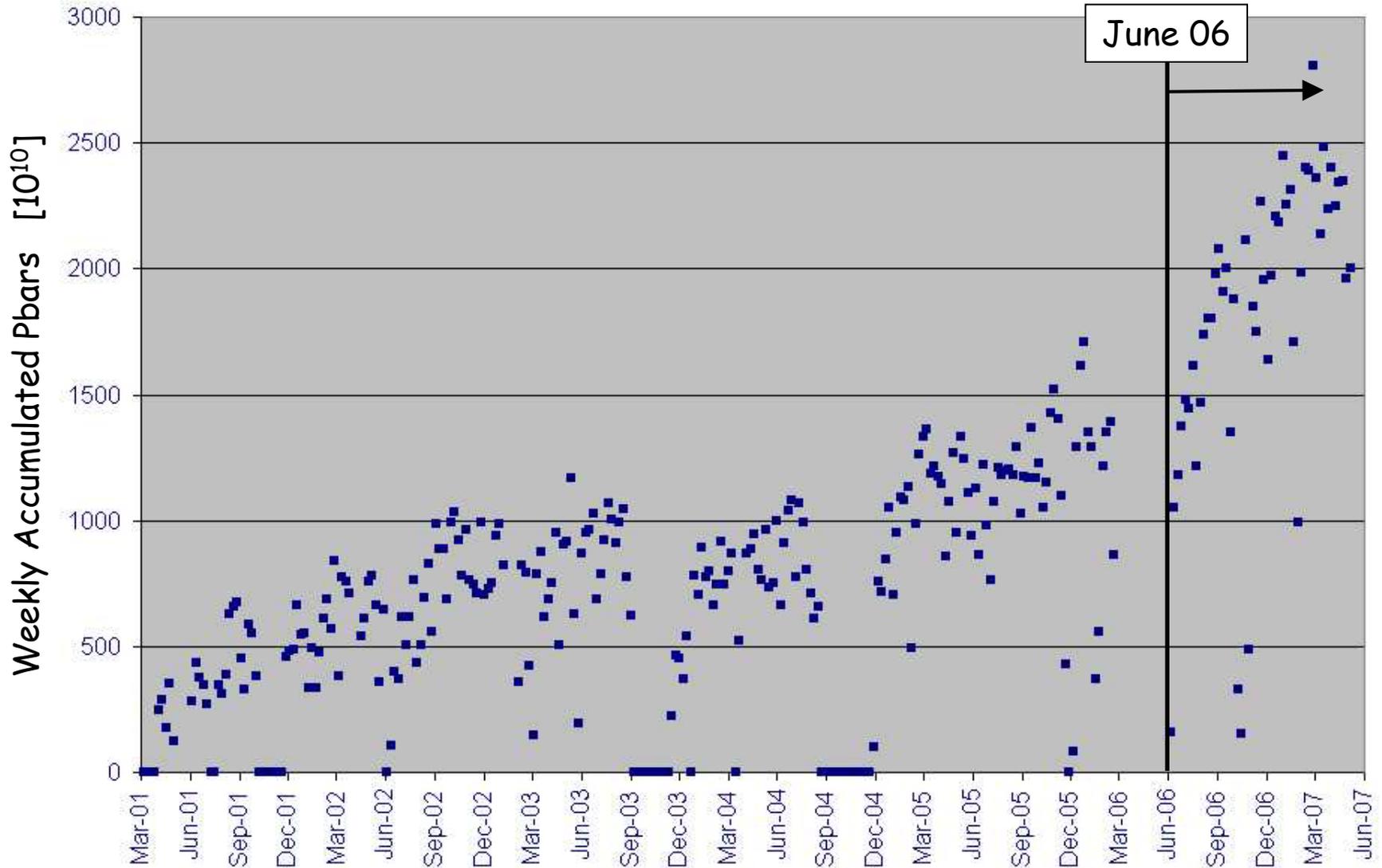
Recent Antiproton Improvements

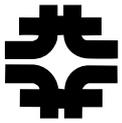


- Antiprotons delivered to Tevatron up 45%
 - Accumulator stacktail gain correction - 12%
 - Faster Accumulator-to-Recycler transfers - 10%
 - Recycler to Tevatron transfer efficiency - 6%
 - Misc. (reliability, etc.) - 11%
- Other factors
 - Lithium lens -- increasing gradient
 - Focus more pbars into transfer line leading to Debuncher/Accumulator
 - Improved model of Accumulator stochastic cooling
 - Stacktail identified as major bottleneck
 - New Recycler working point
 - Reduce impact of space charge tune shift; smaller emittances
 - Pbar bunch intensity leveling in Recycler
 - Uses RF feedforward system to reduce bunch-to-bunch variations
 - Helpful for Tevatron and experiments' trigger/DAQ systems

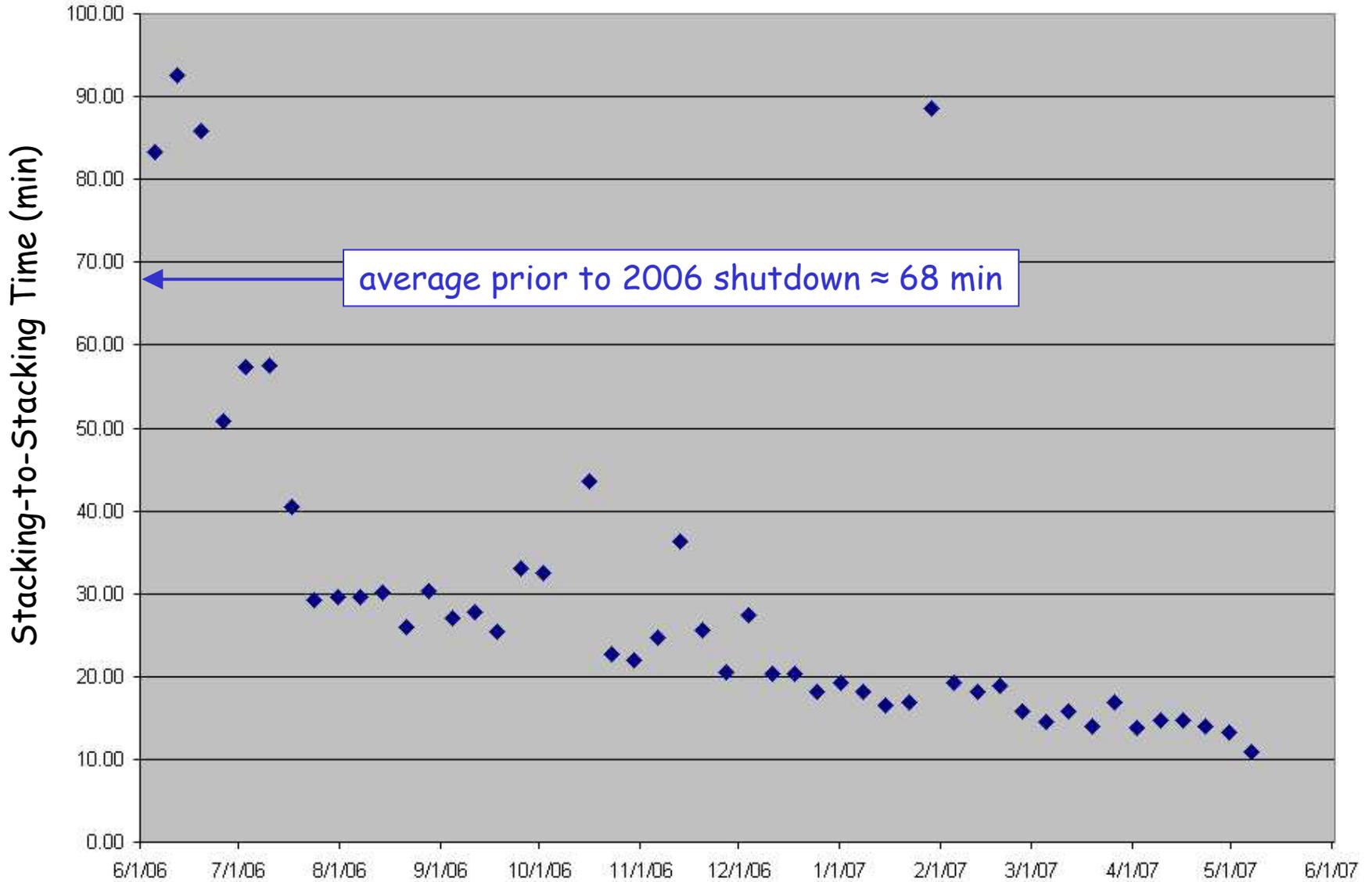


Run 2 Weekly Antiproton Accumulation





Reducing Time for Pbar Transfers to Recycler





More Uniform Pbar Intensities from Recycler



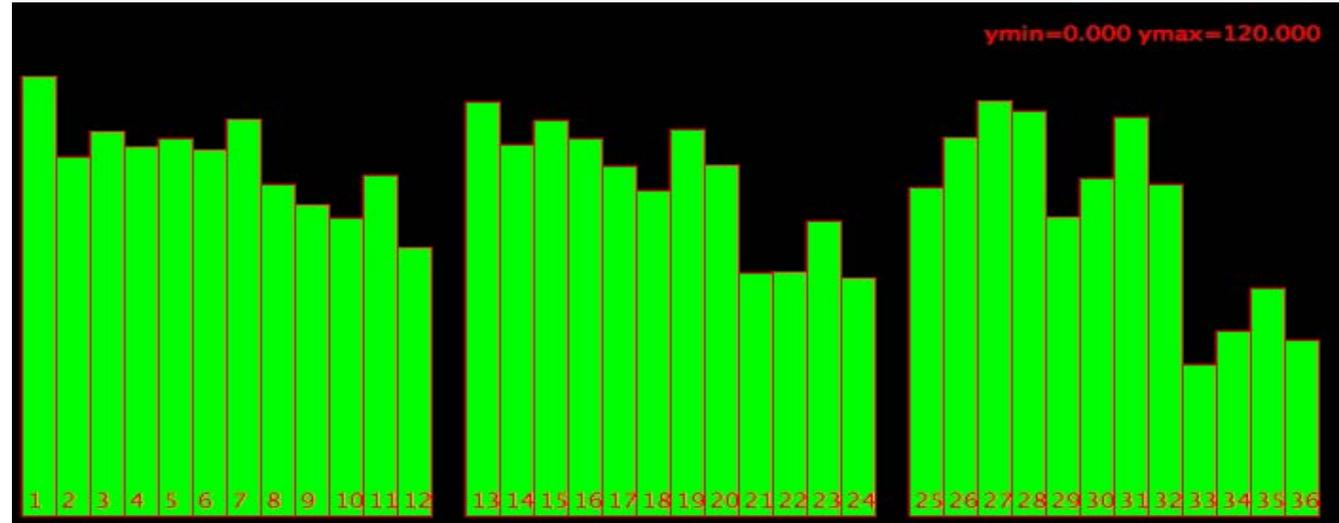
Store 5008

Without correction:

100% variation

25% RMS

*Large variations
in tune shifts and
luminosity*



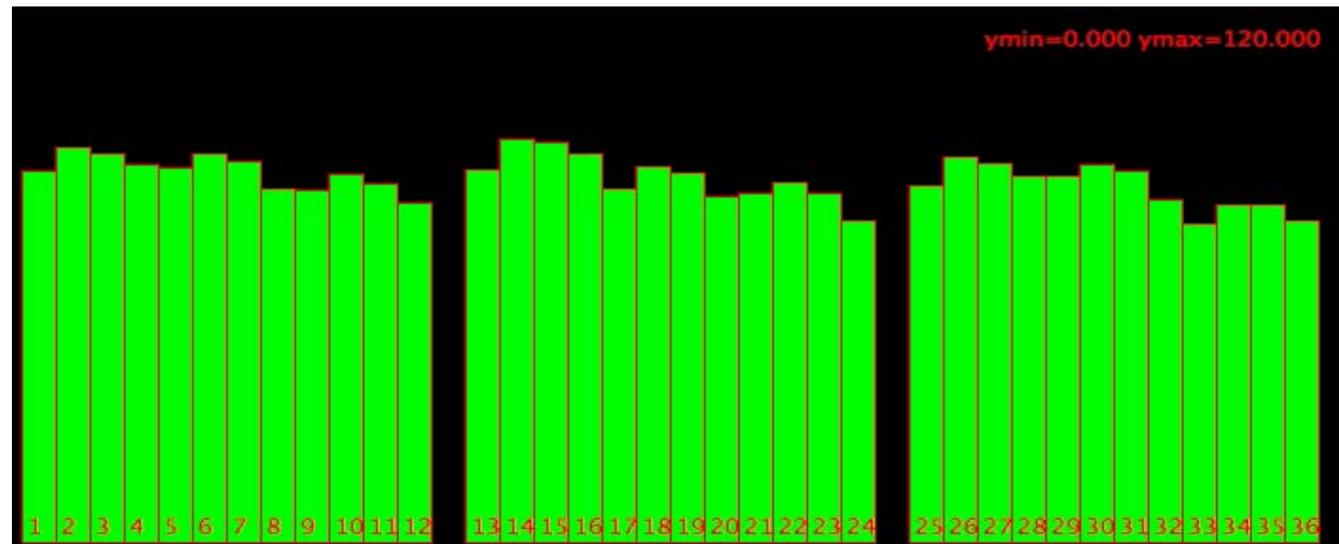
Intensities of 36 Pbar Bunches in Tevatron

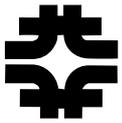
Store 5245

With correction:

25% variation

7% RMS





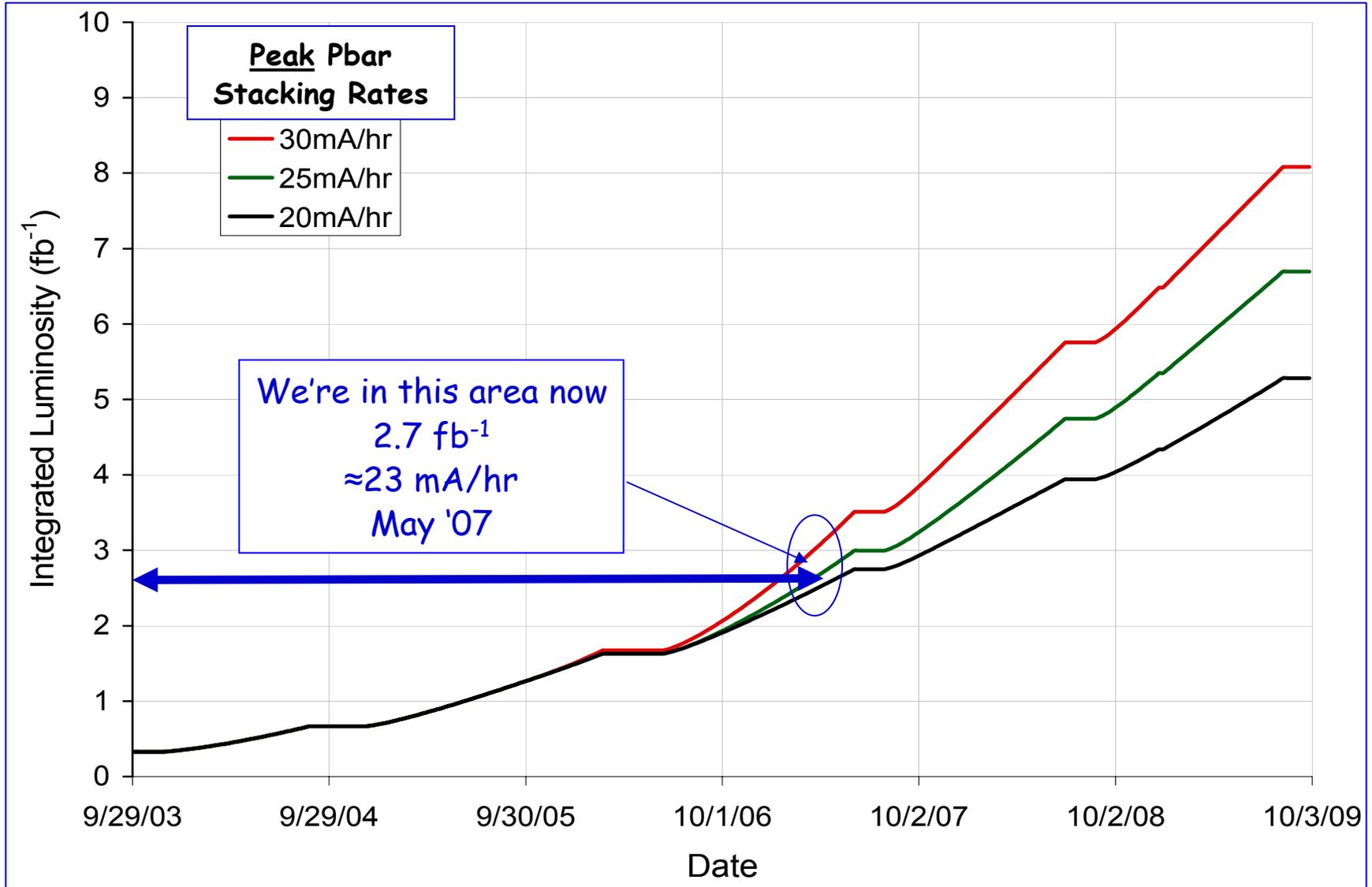
Collider Plan

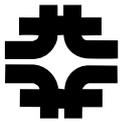


- Increase antiproton stacking rate
 - Design and build new equalizers for stacktail cooling
 - Implement new Accumulator lattice to help stochastic cooling
- Slowly increase stash size in the Recycler
 - Gain operational experience with highest intensities
- Implement 2nd order chromaticity correction in Tevatron
- Optimize peak vs integrated luminosity with experiments
 - Approaching design 320 $\mu\text{b}^{-1}/\text{s}$ peak luminosity
- Continue to work on reliability in all machines



Integrated Luminosity Projections

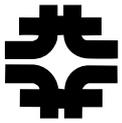




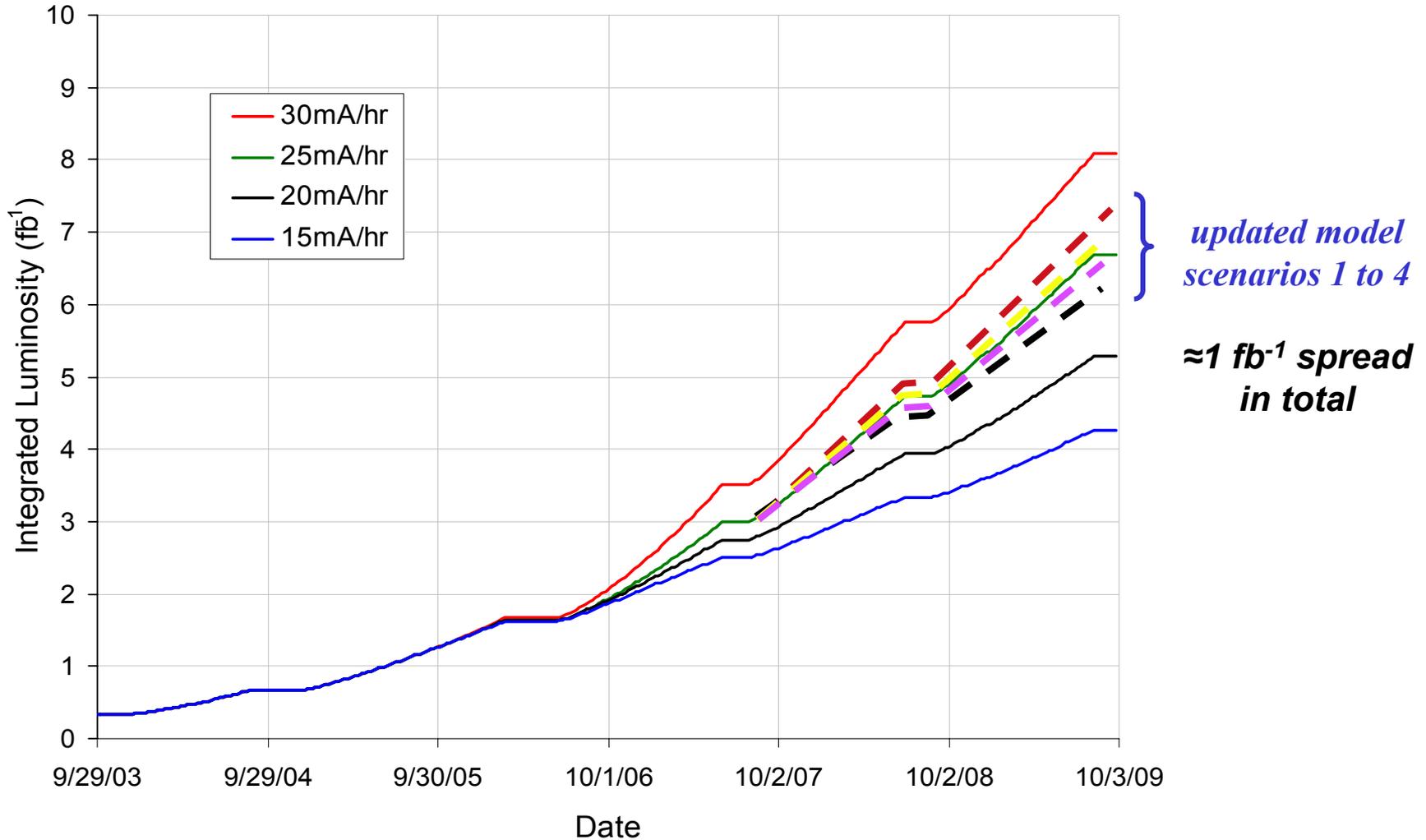
Projecting Luminosity



- Updated model based on current conditions and using various operational scenarios
 - Pbar stacking rate, store lengths, lifetimes, transfer efficiencies, etc
 - Vetted by reproducing FY 2006 numbers
- Based on current pbar stacking rate, on track to deliver 5.5-6.5 fb⁻¹ total
 - Need increased antiproton stacking rates to go higher
- Only ≈1 fb⁻¹ spread among various scenarios
 - Already run the machines in an optimal way
 - Limited time to take advantage of future benefits
- Goal is to maximize integrated luminosity on tape



Luminosity Projections with Updated Model Scenarios



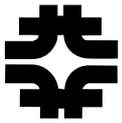


Summary



- Tevatron luminosity made great progress over past year
 - Higher antiproton intensities with smaller emittances
 - Improved luminosity lifetime from increased separation
 - Approaching 3 fb^{-1} delivered so far
- Can deliver $\approx 6 \text{ fb}^{-1}$ total through FY09 with current stacking rates
 - 8 fb^{-1} is still the goal
 - Need increased antiproton stacking rates for higher luminosity
 - Accumulator stacktail cooling system is bottleneck
- Goal is to maximize integrated luminosity to CDF and D0
 - Make the most of Run 2 before it's over – let's find the (SM?) Higgs!





FY07 Tevatron Performance



FY07 Integrated Luminosity 940.69 (1/pb)

