Accelerator Operations and Strategies

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Overview

- Tevatron Collider Highlights
  - Performance over the past year
  - Plans for improvements and strategies
  - Luminosity models and projections
- Neutrino Performance
  - Performance in 2006/2007
  - The path to future neutrino beams
- Test Beam

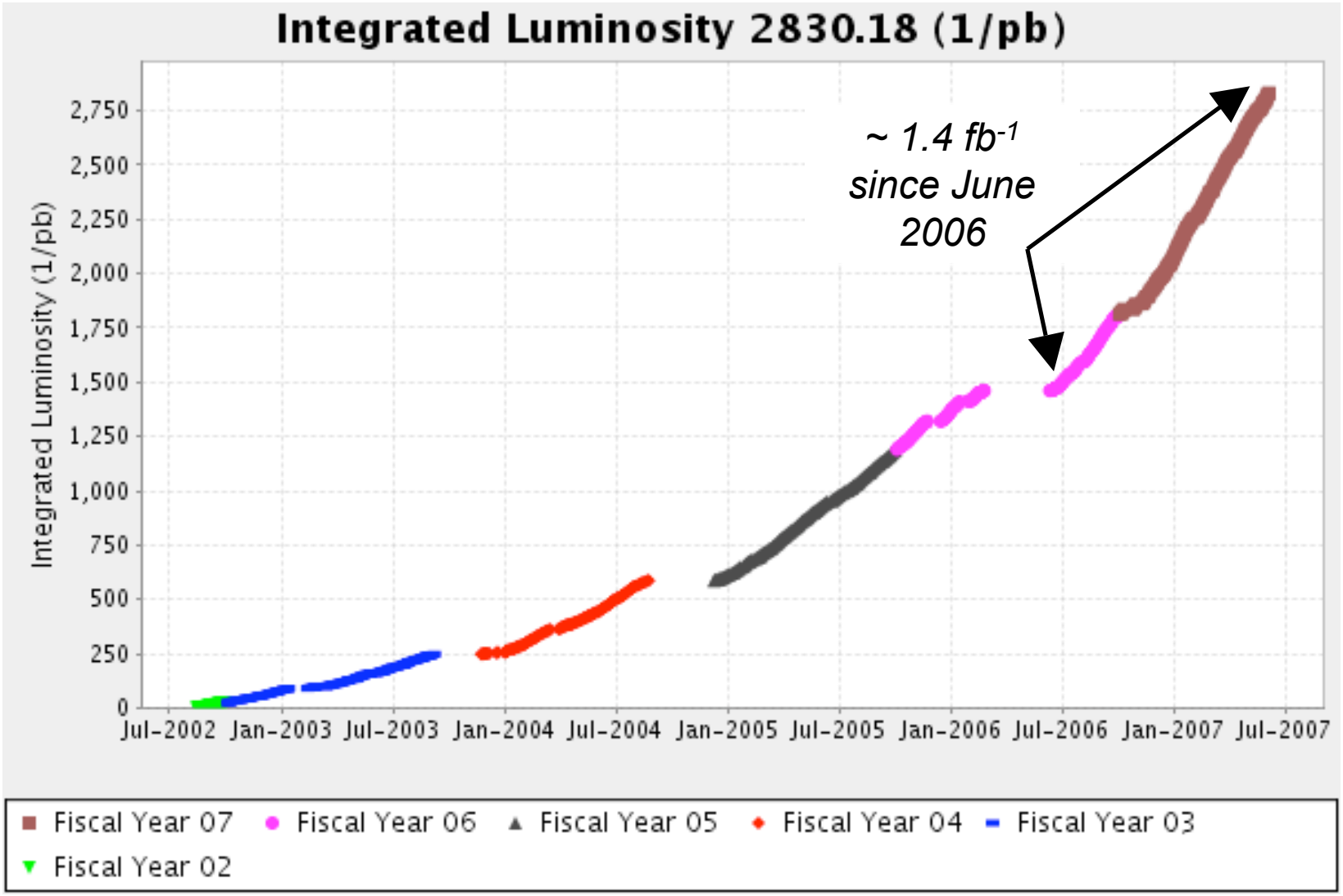
Accelerator Operations Overview

- Collider Run 2
  - Tevatron proton-antiproton collisions to CDF and D0
  - Design goal = 8 fb^{-1} by end FY09
  - Delivered > 2.8 fb^{-1} so far
  - Integrated luminosity has made dramatic increases during the past year

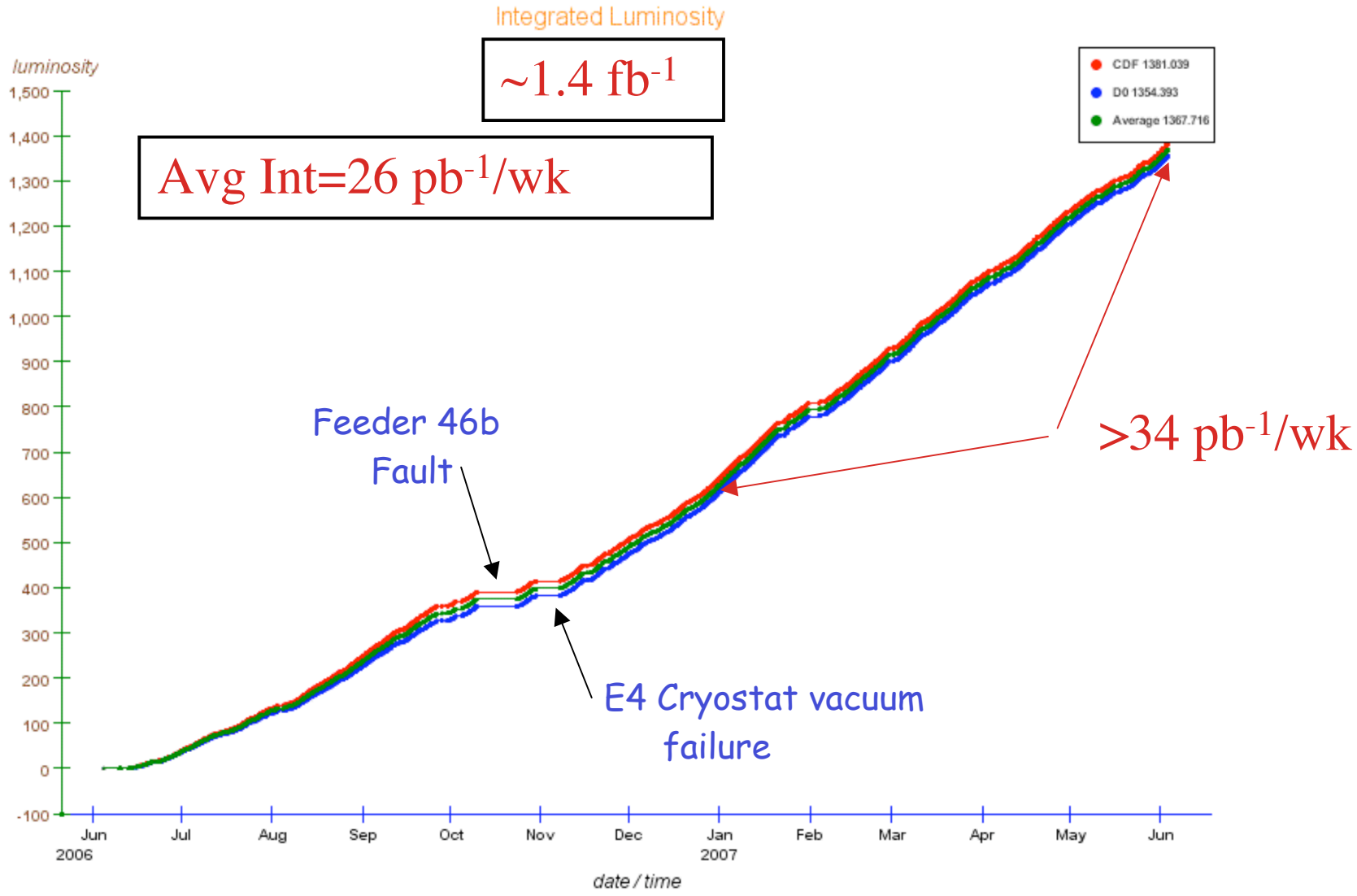
- Neutrino Program
  - MiniBooNE: 8 GeV protons from Booster
    - 8.9 E20 protons-on-target (neutrino/antineutrino modes combined)
  - NuMI: 120 GeV protons from Main Injector (MI)
    - 3.29 E20 protons-on-target
  - Proton Plan & beyond: increase proton beam power

- Switchyard 120 – Meson Test Beam Facility (MTBF)
  - Deliver 120 GeV protons and 1-64 GeV secondaries π, K, p, e, μ
  - Run in parallel with Run 2 and neutrino program
  - 1 slow/fast spill from MI every 60 seconds ~12 hr/day

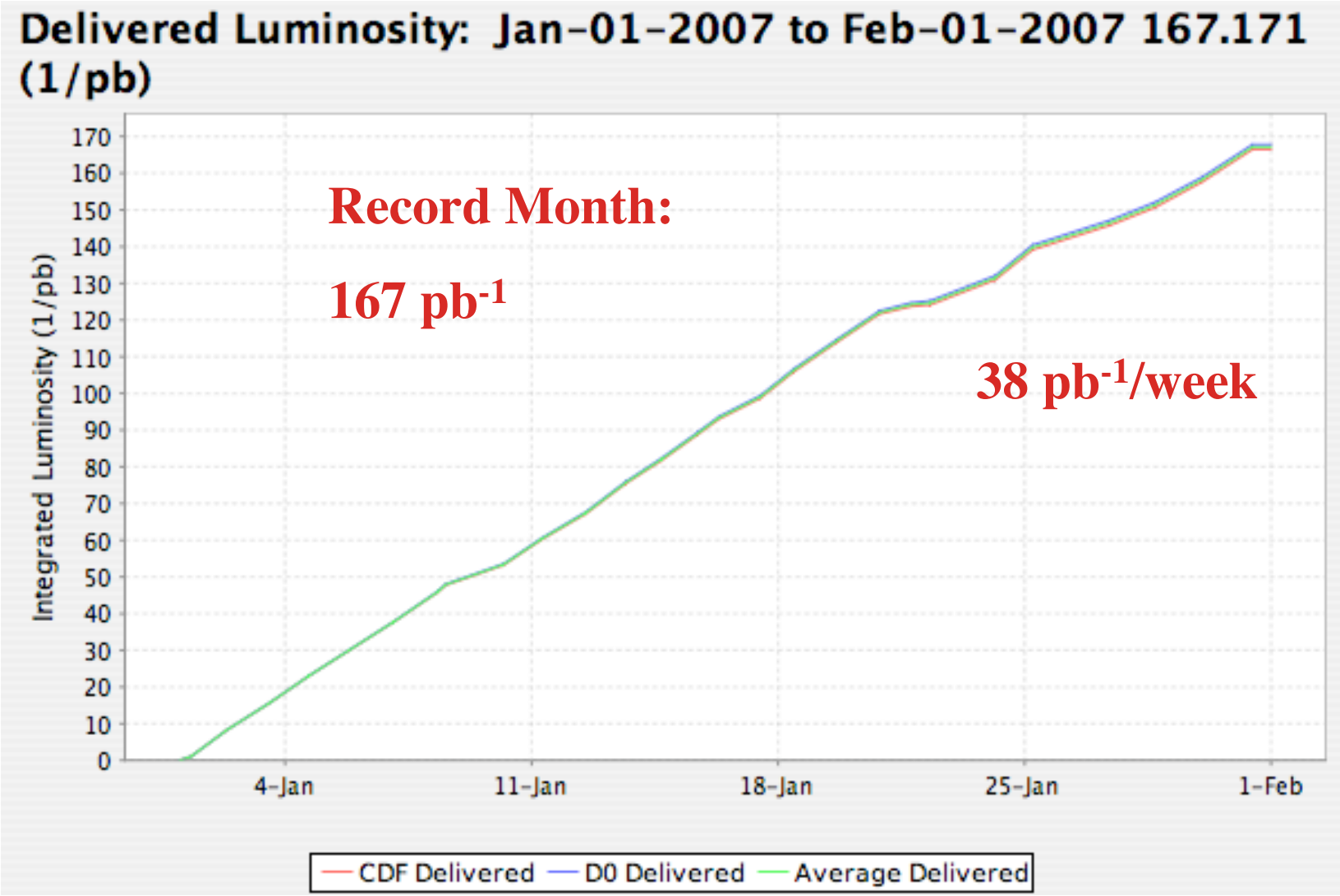
Total Run II Luminosity



Run II
Delivered Luminosity June 06 to June 07



Integrated Luminosity for January 2007



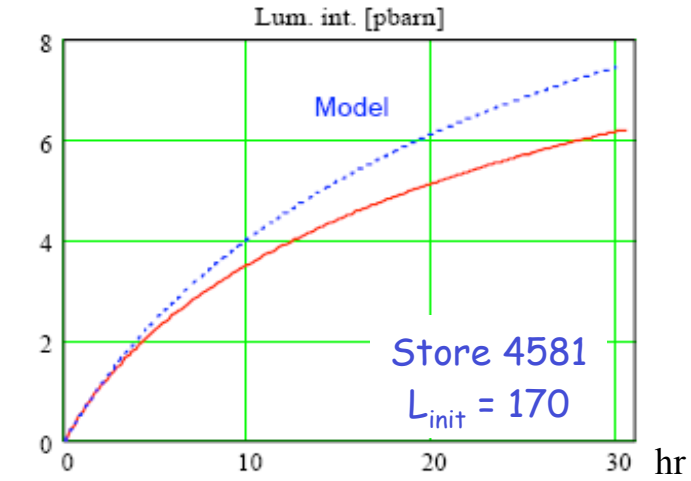
Records

- Comparing before and after 2006 shutdown data
  - Peak Luminosity increased by 62% (180 E30 --> 292 E30)
  - Weekly integrated Luminosity Record increased by ~ 75% (25 pb^{-1} --> 45 pb^{-1})
  - Monthly integrated luminosity increased by ~ 95% (85 pb^{-1} --> 167 pb^{-1})
  - Numerous peak luminosity records were set during this period
  - One hour stacking record-- 23.1 ma/hr
  - Antiproton accumulation for one week-- 2800 E10

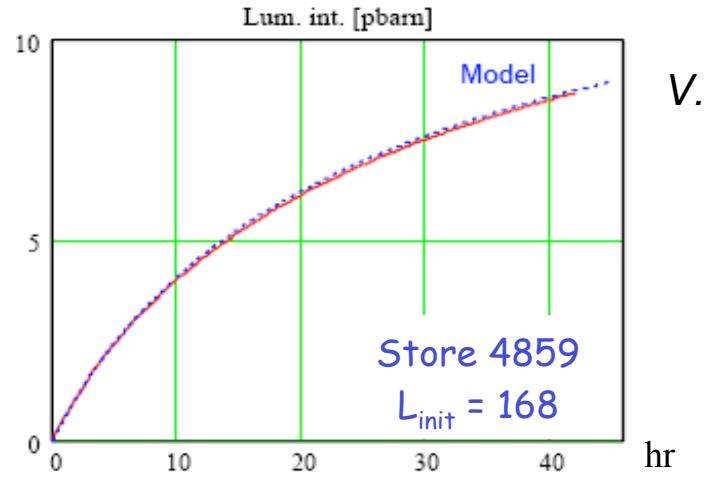
Tevatron Highlights

- Reliability
  - Replaced all ≈1200 LHe Kautzky valves (cause of 2 FY06 dipole failures)
  - Modifying quench protection system to allow faster beam aborts
  - Cog antiprotons out of abort gap for acceleration to prevent needless quenches
- More antiprotons with smaller emittances to HEP
  - Increased stacking rate in Antiproton Source
  - New working point in Recycler
  - Better antiproton lifetime @ 150 GeV from new helical orbit, reduced beam-beam
- Injecting ≈10% more protons
- Improved luminosity lifetime
  - Additional separators increase separation (20% at nearest parasitic crossings upstream of interaction points)
  - Beam-beam effects reduced – performance agrees better with model neglecting beam-beam

Comparing to Model without Beam-Beam Effects



Before shutdown (Jan. 6, 06)



After shutdown (July. 27, 06)

V. Lebedev

- After shutdown, luminosity evolution for similar stores agrees better to model without beam-beam effects
- Most pbars lost during HEP are burned in luminosity (good!)
- Protons suffering from head-on beam-beam due to brighter pbars
  - Limited tune space

Tevatron Plan

- Implement 2nd order chromaticity correction @ low ß
  - Installed and being commissioned
  - Will allow pursuit of a new working point
- Pursue other minor improvements (few % each)
  - Scrape (higher intensity) protons @ 150 GeV
  - Investigating new cogging between pbar 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
  - More reliable (bunch-by-bunch) tune measurements
  - Better helices, improved transfer line matching, faster shot-setups, etc.

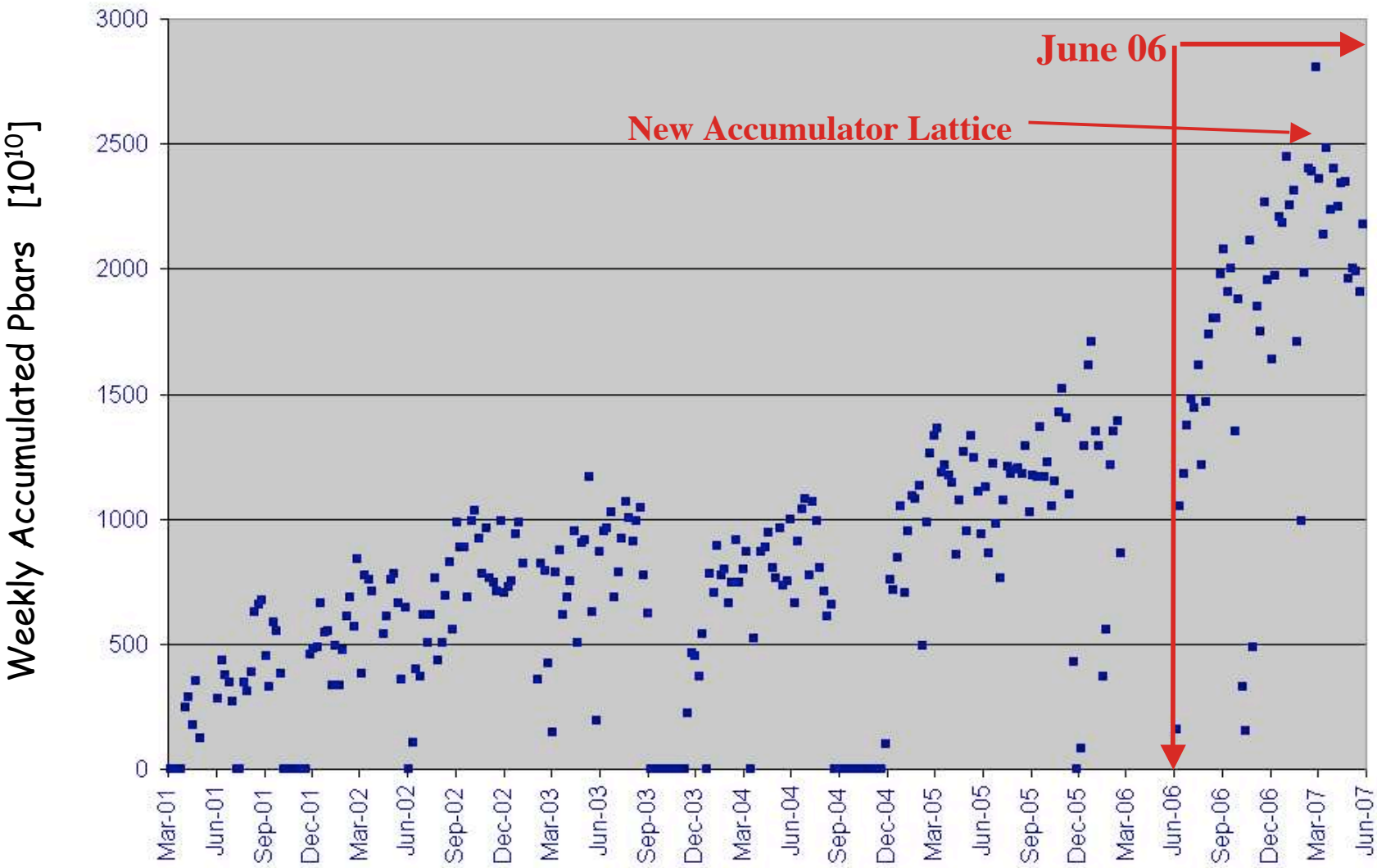
Antiproton Improvements

- Antiprotons delivered to Tevatron increased by 45%
  - Accumulator stacktail gain correction - 12%
  - Fast 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 AP2 line leading to Debuncher/Accumulator
  - Developed Model to understand stacktail -- good match to data (Lebedev)
    - Stacktail cooling in Accumulator 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 feed-forward system to reduce bunch-to-bunch variations
    - Helpful for Tevatron and experiments' trigger/DAQ systems

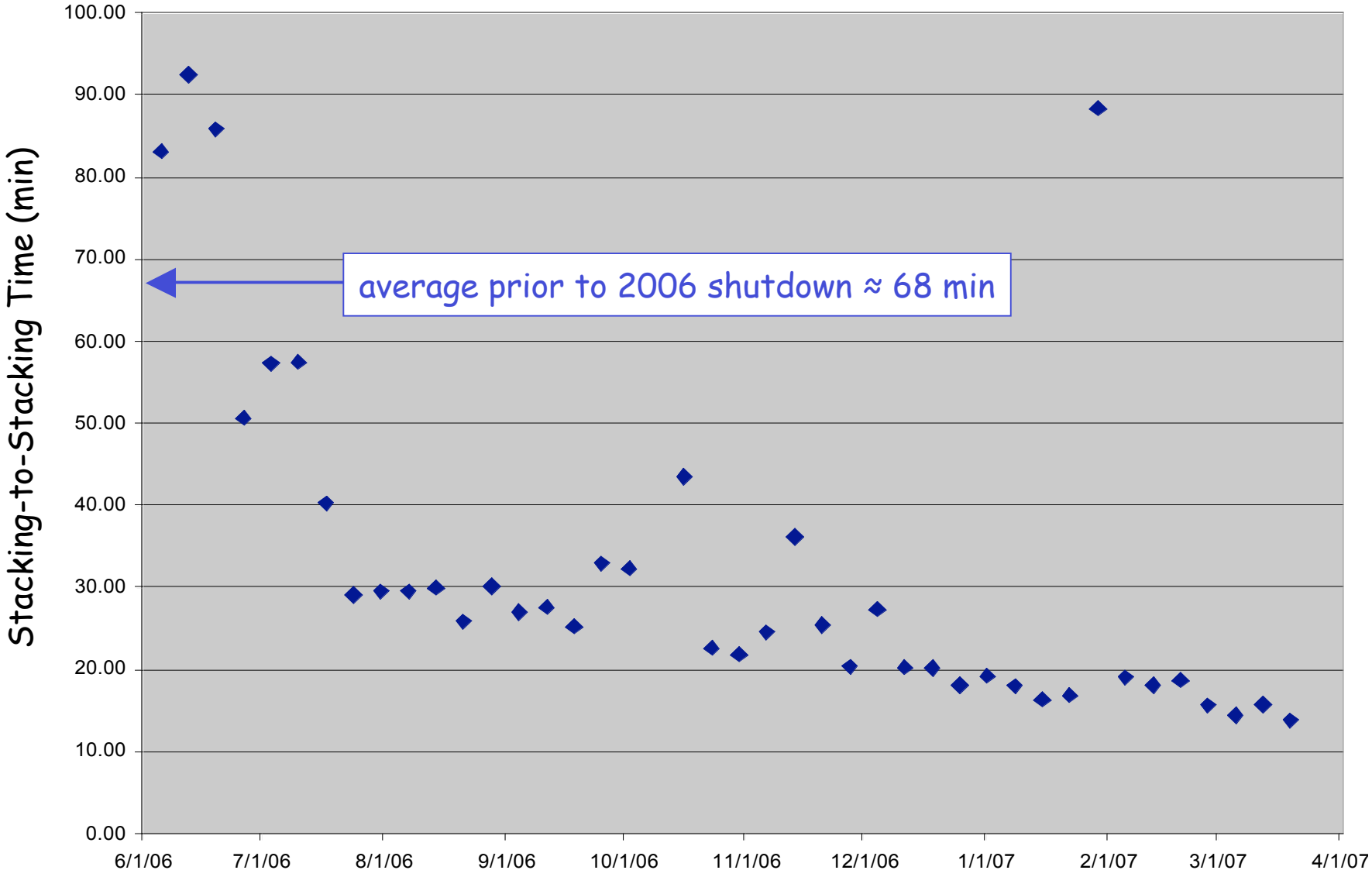
Antiproton Stacking Improvements

- Major items
  - New Stacktail Gain Equalizers
    - First installed in March
    - Second installed on past Monday
  - New Accumulator Lattice
    - Installed in May
- Other Items
  - Implementation of leg 3 stochastic cooling-- done
  - Improve Debuncher cooling-- in progress
  - Improve Debuncher and Accumulator orbits and matching optics-- in progress
- Misc
  - Re-install new style lithium lens with higher gradient
    - Improves flux into Debuncher
    - Two recent failures

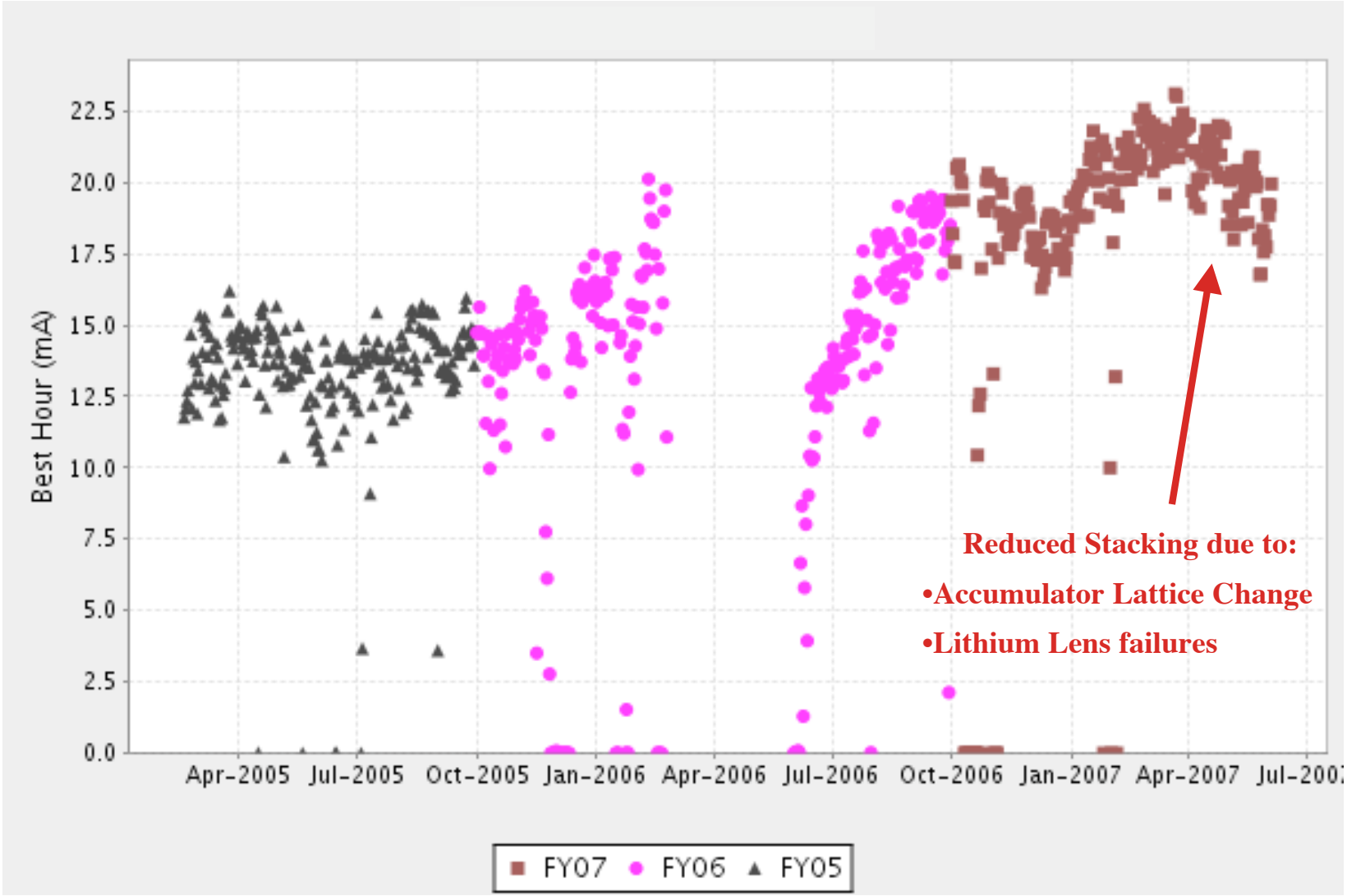
Run II Weekly Antiproton Accumulation



Reducing Time for Pbar Transfers to Recycler



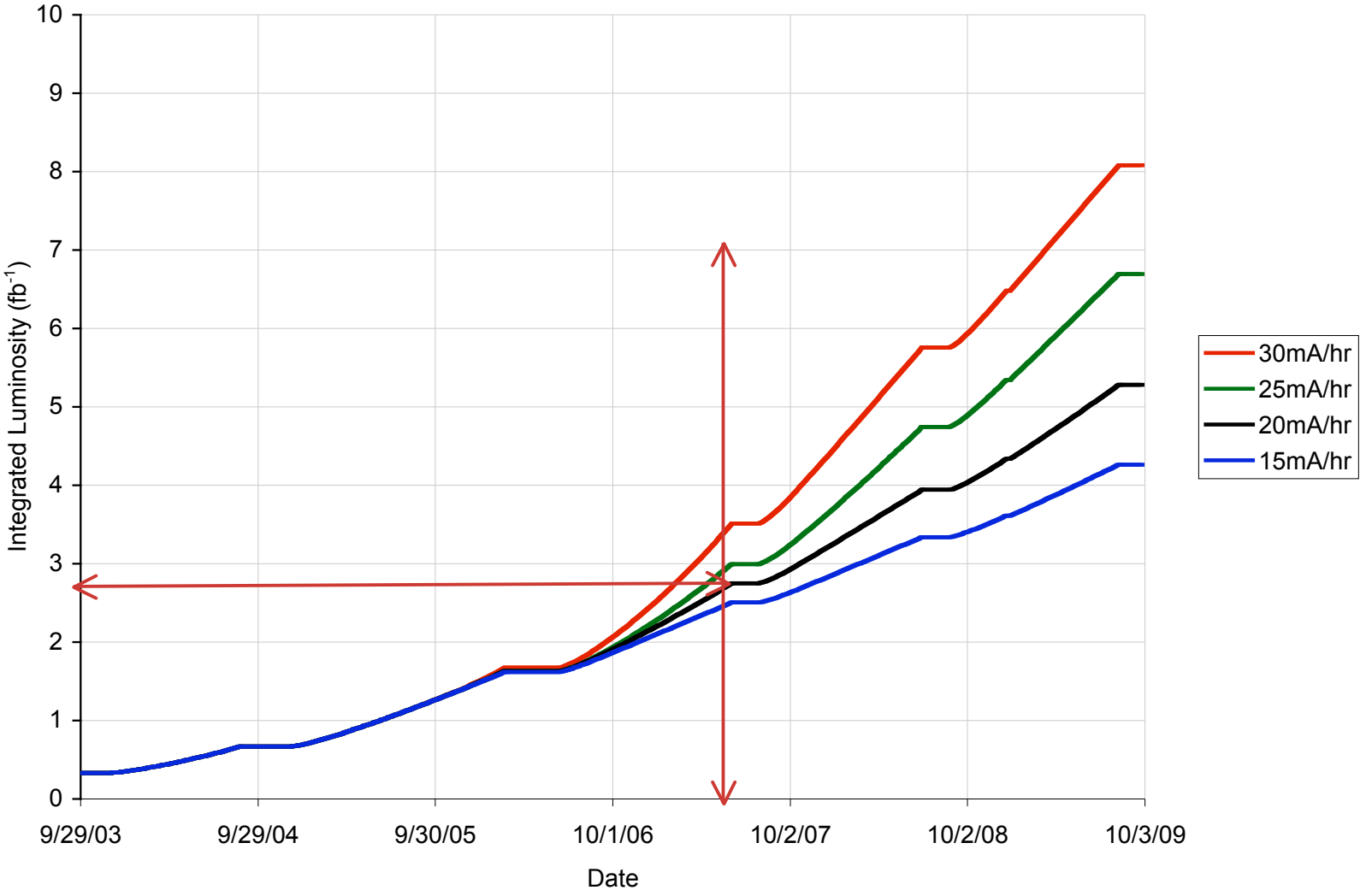
Best Stacking Hour in a Day



Present Collider Plan

- Increase pbar stacking rate
  - Change Accumulator Lattice to optimize stacktail-- done
  - Install second new equalizer for stacktail gain-- done
  - Tune stacking with improvements
  - Put new style lithium lens back in asap
- Slowly increase stash size in the Recycler
- Implement 2nd order chromaticity correction in Tevatron to improve lifetimes (New sextupole circuits)
- Optimize peak vs. integrated luminosity with experiments
  - Approaching design 320 pb^{-1}/s peak luminosity
- Continue to work on reliability in all machines
- Investigate new strategies

2006 Projection Curves



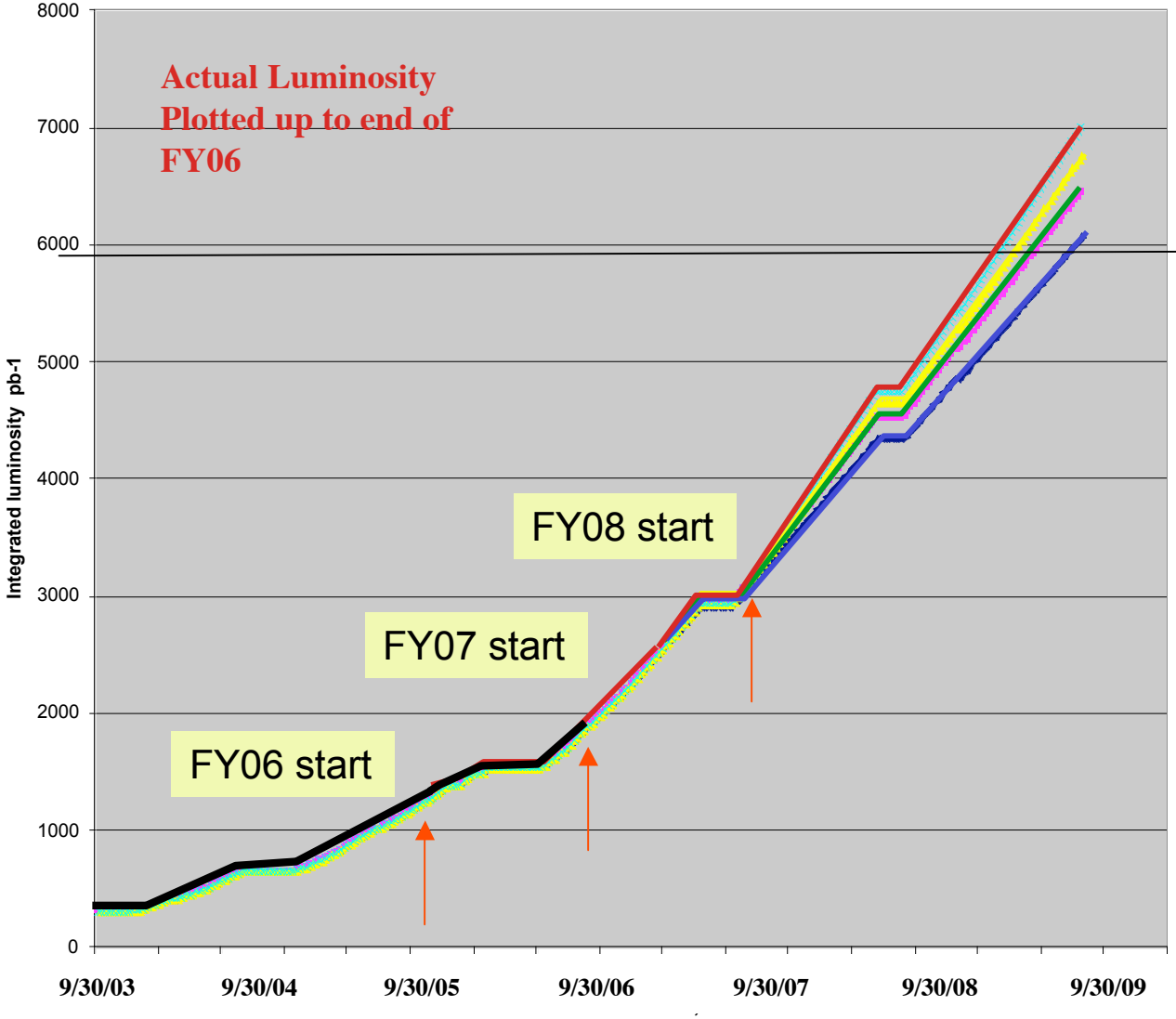
Parameters for Projections

- Number of protons per bunch
- Luminosity Density @ 100 x 10^{10}
- Luminosity Density @ 300 x 10^{10}
- Init Tevatron Lifetime @ 80 μb^{-1}/sec
- Init Tevatron Lifetime @ 160 μb^{-1}/sec
- HEP store hours per week
- Acc-Rec Transfer Efficiency @ 0x10^{10}
- Acc-Rec Transfer Efficiency @ 300x10^{10}
- Acc-Rec transfer time
- Recycler mining efficiency
- Recycler lifetime
- Initial Stacking Rate

- Half rate stack size
- Maximum stack size
- Timeline Utilization Factor
- Accumulator leftover factor

The output (initial, integrated lum.) depends on the average store length and the number of antiproton transfer shots between stores.

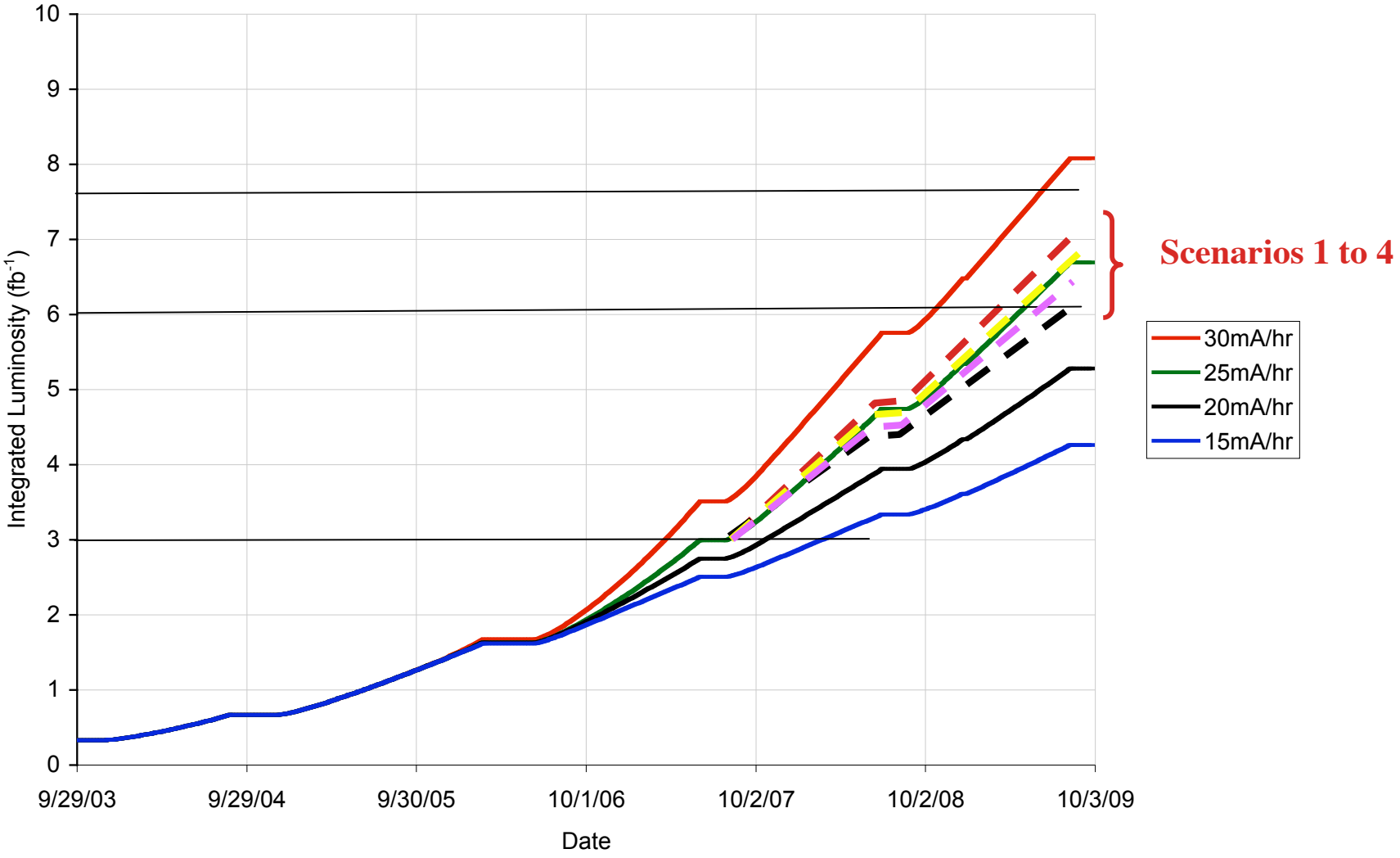
Projected Luminosity from Model



Four Scenarios Modeled

- **Scenario IV**
- **Scenario III**
- **Scenario II**
- **Scenario I**

All Projection Curves



Maximizing Investments

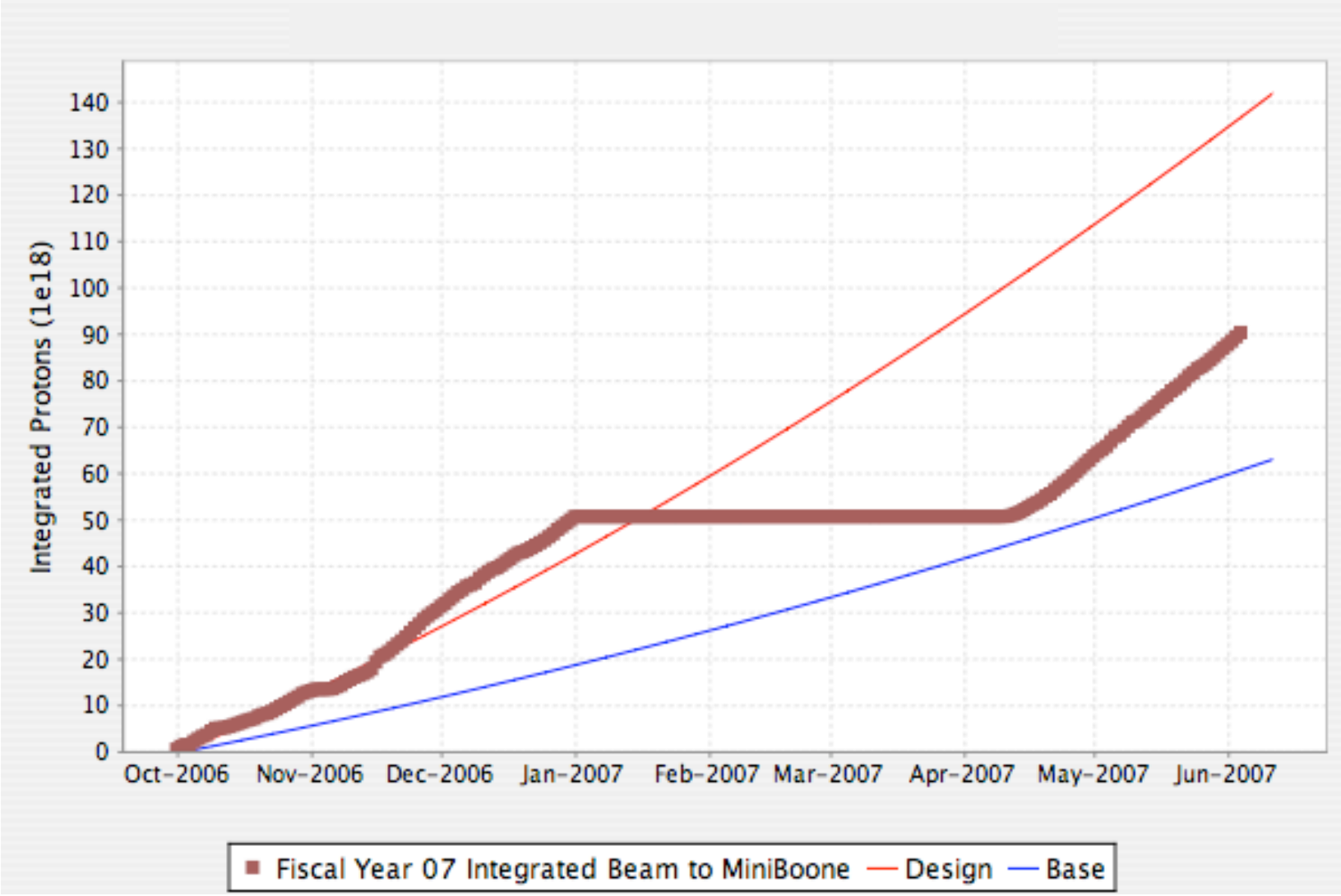
- Strategy Group
  - Charge
    - Maximize final integrated luminosity delivered to experiments
      - Investigate ongoing improvements to determine payoff
      - Explore new strategies with potential to increase luminosity
    - Continue the Development and use of models to make cost/benefit determinations

Neutrino Program

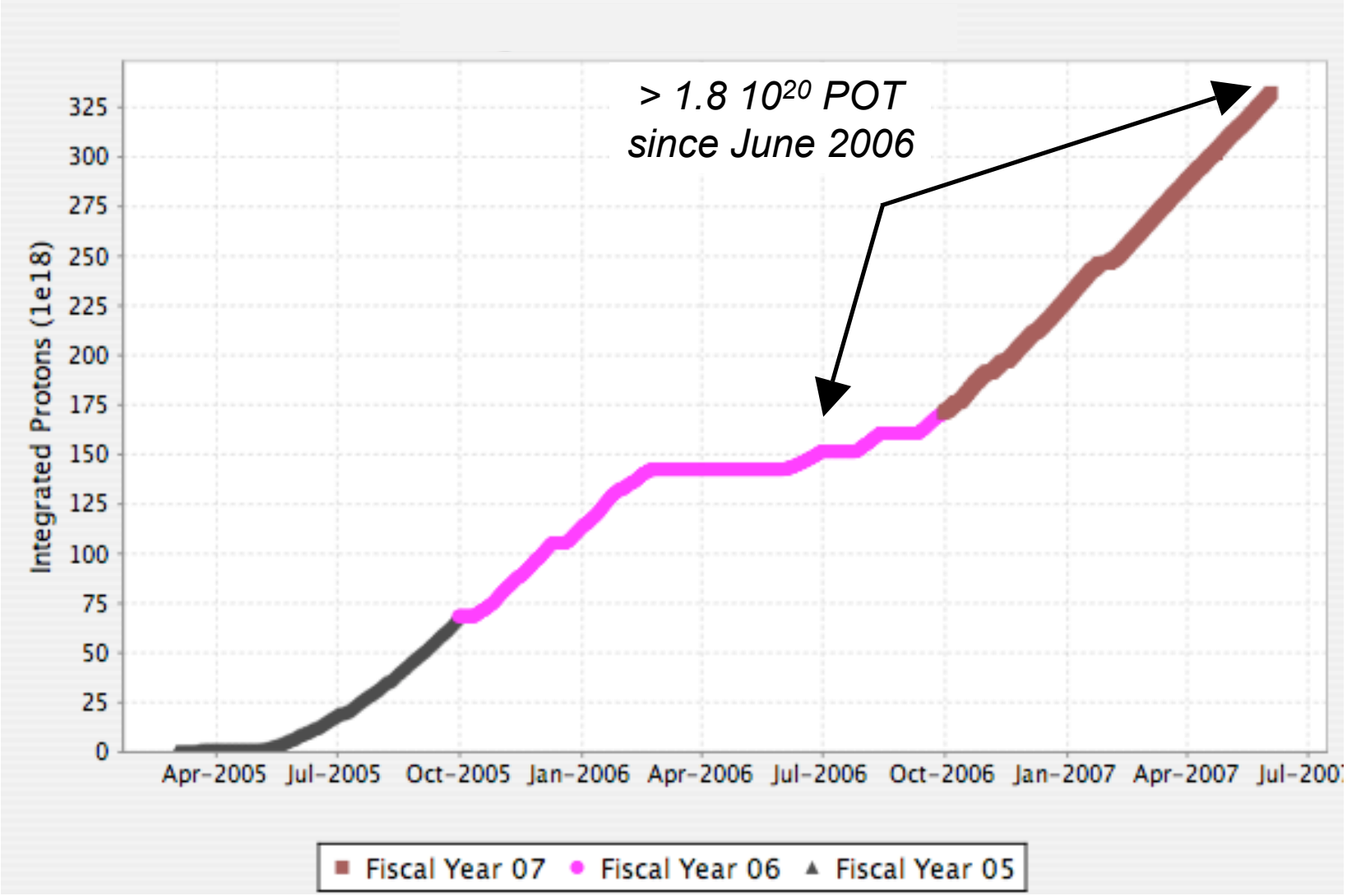
- MiniBooNE
  - Booster improvements during shutdown allowing higher throughput - exceeding design proton delivery rate
  - Resumed run after 14 week shutdown for absorber repairs

- NuMI
  - FY07 already best year: >1.2 E20 POT delivered
  - Improvements in slip-stacking
  - 2+5 mode operational
    - 180-200 kW beam power with pbar production
    - 250-300 kW running NuMI-only
  - 2+9 mode being developed for FY08 running
    - Single pulse record > 4 E13
  - Want to push pbar production cycle 2.4 _ 2.2 sec
    - Already @ 2.2 sec during pbar shots to Recycler

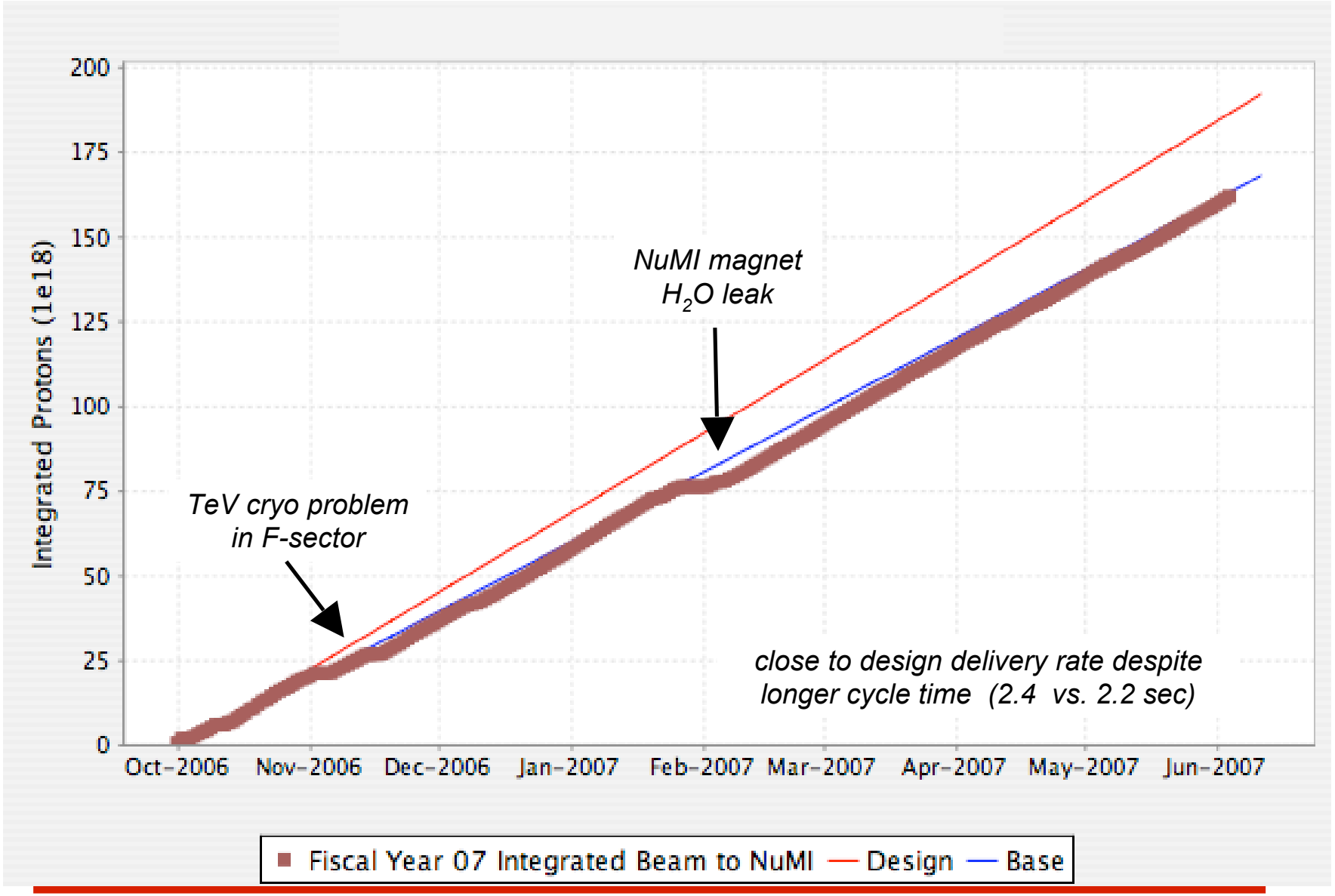
MiniBooNE Protons in FY07



Protons Delivered to NuMI



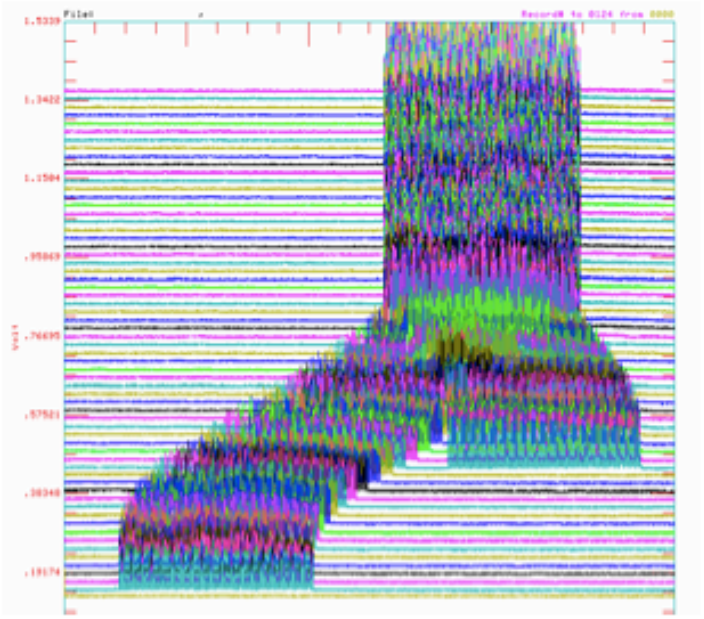
FY07 NuMI Delivered Protons



Slipping Stacking

- The Main Injector has six usable "slots", into which Booster batches may be placed.

- More batches may be loaded, using "slip stacking", in which an initial batch in the Main Injector is accelerated such that a subsequent batch will be at a slightly different energy.
- The two will then drift together and can be captured as a single batch (with at least twice the longitudinal emittance).



Slip Stacking in the Main Injector

- Space for 6 Booster batches + 1 empty slot

(1+5)

- Slip stacking allows (present operating scenario)

(2+5)

- Recent Successes in slip stacking lead to this possibility

(2+9)

NuMI Plan

- Slip Stacking Success has position us to implement (2+9) batch operation for NuMI
  - Presently running (2+5) mode
  - Conduct Studies on (2+9)-- In progress
  - Install collimators in Main Injector-- summer shutdown
  - Commission (2+9) batch operation after shutdown (up to 400KW)
  - Complete Proton Plan and Accelerator NuMI Upgrades (ANU)

Staged Neutrino Program

- Proton Plan
  - MI RF improvements and operational loading initiatives increase NuMI intensity to 4-5 _10^{13} protons per 2.2 second cycle (≈3_10^{20} protons/yr)
  - Ultimately 320 kW to NuMI (400 kW when not running pbar source)
  - Runs through end of collider program
- ANU ("Accelerator NuMI Upgrades", combined with NOvA as per DOE)
  - Use Recycler as pre-loader to save time injecting into MI
  - ~700 kW to NOvA
  - Presently being formalized and baselined
- Future Possibilities
  - SNuMI (formerly "SNuMI II")
    - Momentum-stack protons in Accumulator _ boxcar stacking in Recycler
    - Ultimately ~1.2 MW to NuMI
    - Still in early conceptual stage
  - HINS (formerly "Proton Driver")
    - New 8 GeV proton linac to Main Injector, exploit synergy with ILC
    - ≥2 MW to NuMI
    - Not part of our official planning at this point

Summary

- Significant Run II progress in the past year
  - Stacking Rate improvements continue
  - Developing Strategy to maximize integrated Luminosity
- NuMI and MiniBooNE have run well over the past year
- Improvements will continue for the neutrino beam
  - Slip stacking for (2+9) scenario
  - Completion of Proton Plan
  - Execution of ANU
  - Possible future upgrades