Run II Operational Status and Plans

Run II Meeting

October 28, 2004

Dave McGinnis

Outline

- Goals
- Performance
- Major Accomplishments
- Machine Issues
- FY05 Outlook
- Summary

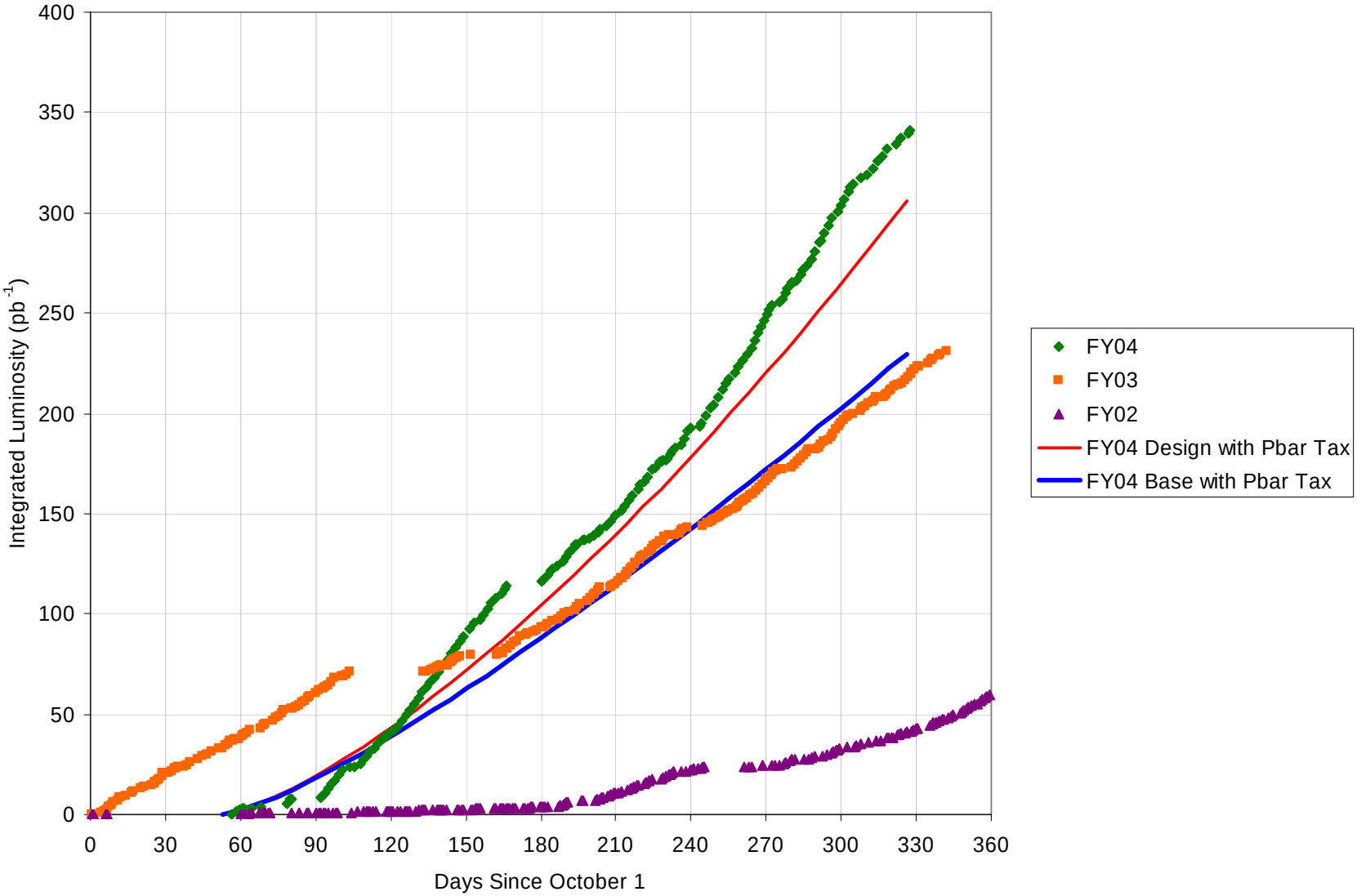
Goals

Major FY04 Goals

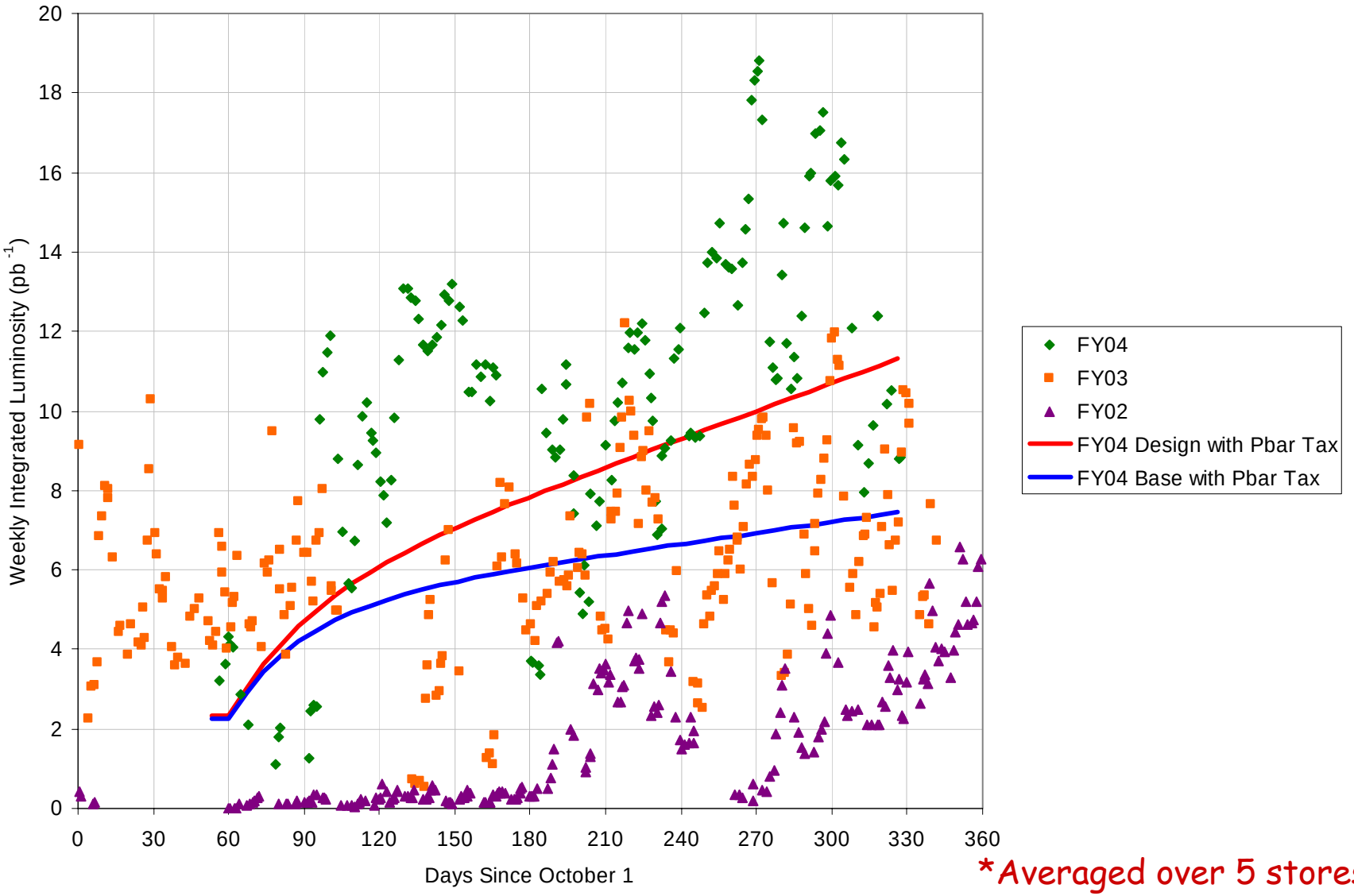
- Operate the Collider at the Main Injector project luminosity design goals
  - 80% Antiproton transfer efficiency from the Accumulator to Low Beta
  - 260×10^{9} protons per bunch at low beta
  - 18×10^{10}/hour antiproton zero stack stacking rate
  - Peak Luminosity of $80 \times 10^{30} cm^{-2} sec^{-1}$
- Integrate over $300 pb^{-1}$ in 39 weeks
- Prepare the Collider for implementation of the initial stages of the Run II Upgrades
  - Slip Stacking
  - AP2-Debuncher Aperture
- Commission the Recycler for electron cooling

FY04 Performance

Integrated Luminosity

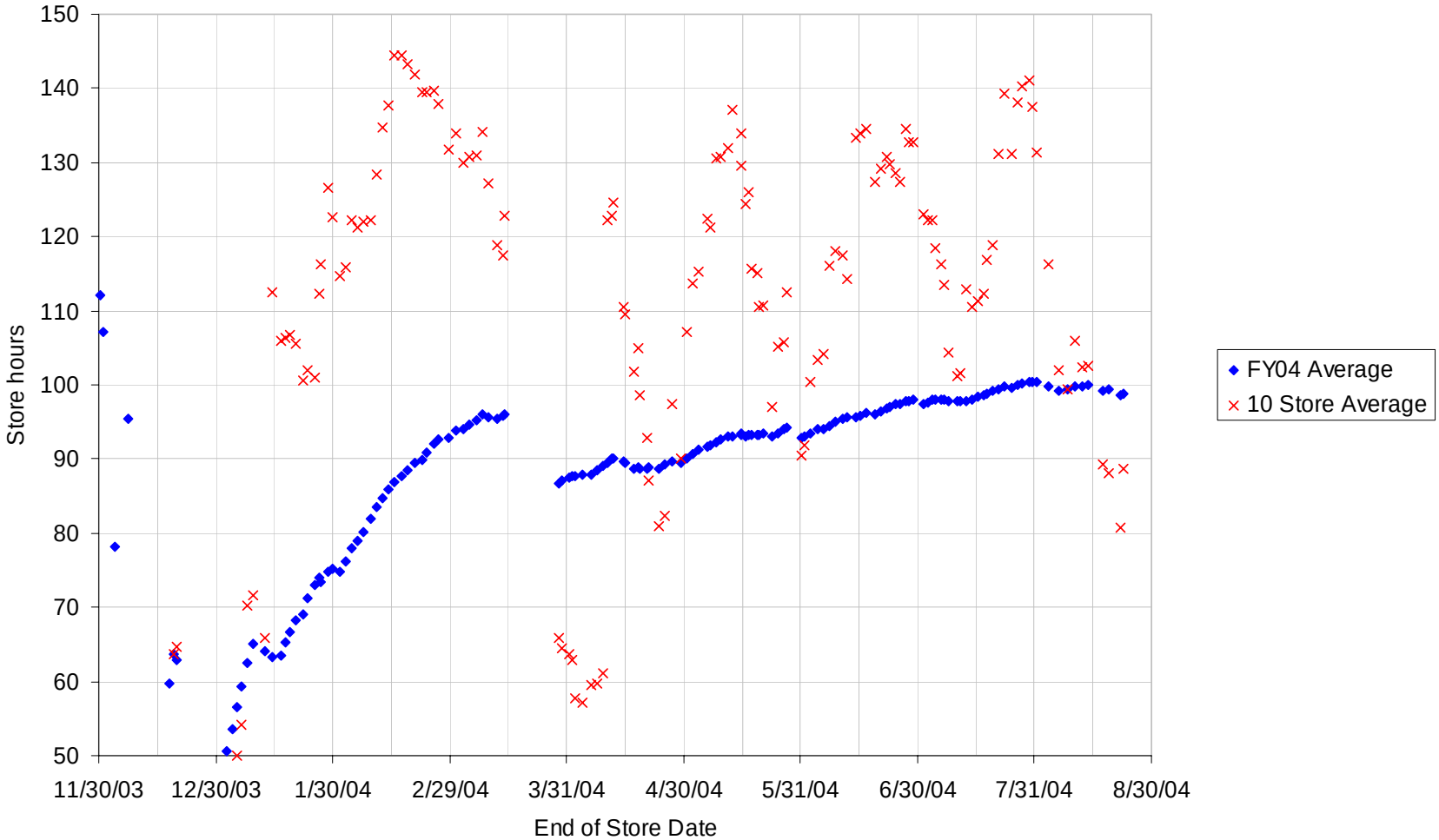


Weekly Integrated Luminosity*

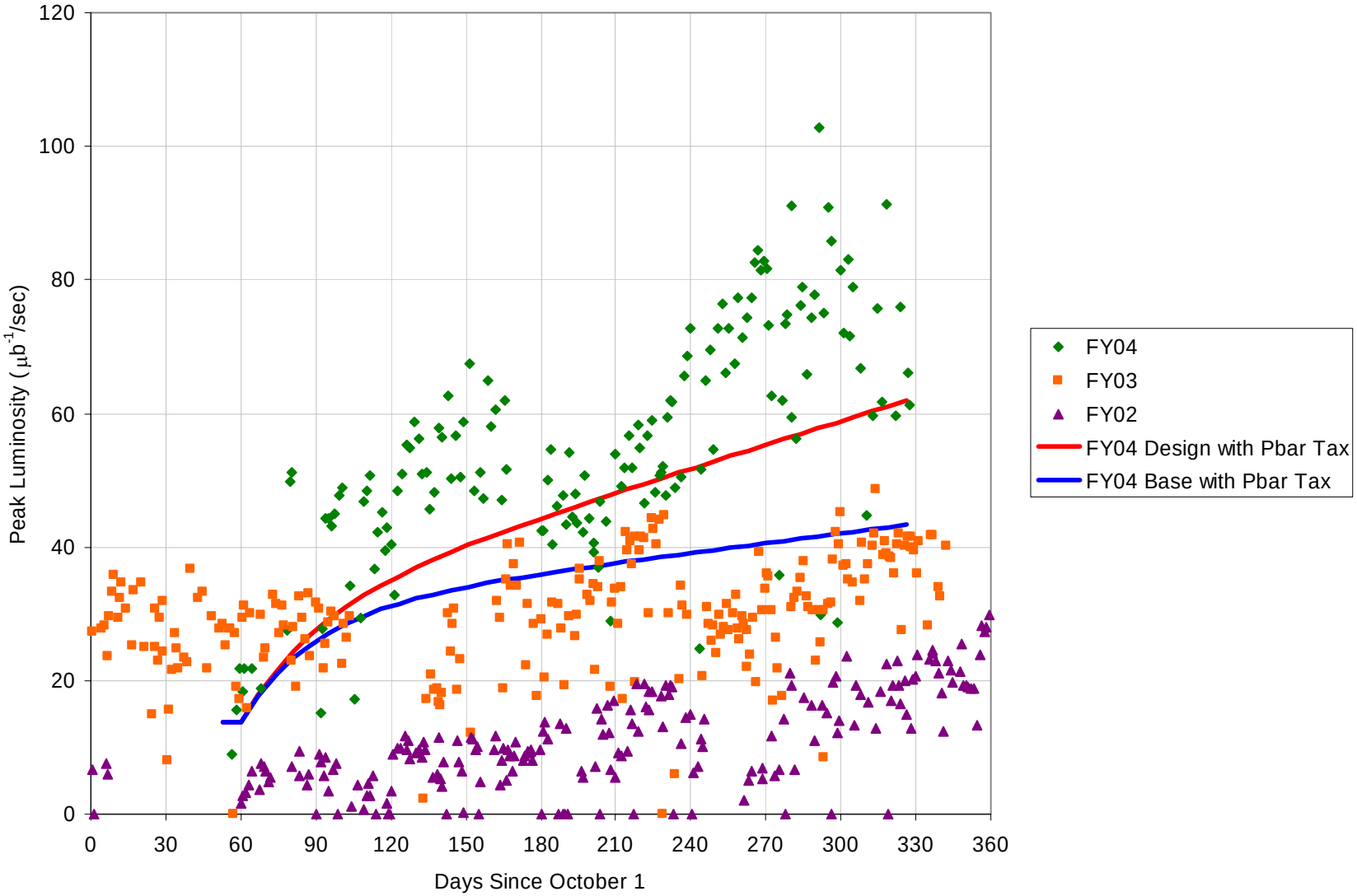


*Averaged over 5 stores

FY04 Average Store Hours per Week



Peak Luminosity



Data Summary Table

		Luminosity Parameters				
Parameter	Best Store	Best of FY04	Best of FY03	FY04 (End) Design	FY04 (End) Base	
Initial Luminosity (Average)	102.8	87.6	43.7	61.9	43.3	$x10^{30}cm^{-2}sec^{-1}$
Integrated Luminosity per Store (Averaged)	4241	3221	1518.5	2000	1300	nb^{-1}
Luminosity per week (Averaged)	-	-	-	11.3	7.4	pb^{-1}
Store Length	32.4	26.7	17.8	15.0	15.0	Hours
Store Hours per week	-	-	-	85	84	Hours
Shot Setup Time	2.4	2.6	2.1	2.2	2.2	Hours
		TEVATRON Parameters				
Parameter	Best Store	Best 10 stores Average	Best of FY03	FY04 (End) Design	FY04 (End) Base	
Protons per bunch	246	249	241.2	260	260	$x10^{9}$
Antiprotons per bunch	43	36	25.6	31	25	$x10^{9}$
Proton Efficiency to Low Beta	85	77	54.8	-	-	%
Pbar Transfer efficiency to Low Beta	86	81	63.5	80	77	%
HourGlass Factor	0.66	0.67	0.6	0.65	0.65	
Initial Luminosity Lifetime	5.2	6.0	8.9	8.3	7.0	hours
Asymptotic Luminosity Lifetime	17.7	19.3	23.7	25.0	25.0	hours
Effective Emittance	16.9	17.0	22.4	21.0	23.0	π-mm-mrad
		Antiproton Parameters				
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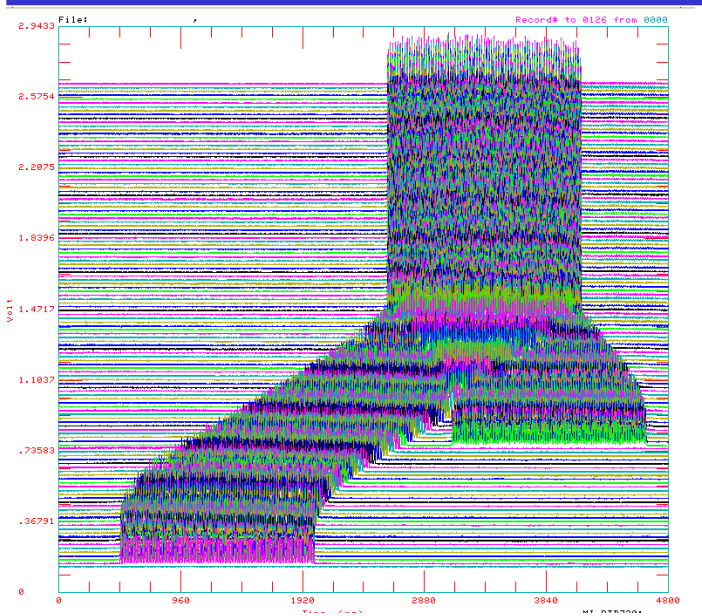
Zero Stack Stack Rate	13.2	12.7	12.0	18.0	13.7	$x10^{10}$/hour
Normalized Zero Stack Stack Rate	2.5	2.4	2.4	3.6	2.7	$x10^{-2}$/hour
Average Stacking Rate	6.8	6.4	7.8	9.3	7.6	$x10^{10}$/hour
Stacking Time Line Factor	86	78	94.8	75	75	%
Stack Size at Zero Stack Rate	309	321	299.7	300	300	$x10^{10}$
Protons on Target	5.3	5.2	5.1	5.0	5.0	$x10^{12}$
Start Stack	198	179	158.8	155	130	$x10^{10}$
End Stack	17	18	12.9	15	15	$x10^{10}$
Unstacked Pbars	181	161	145.9	140	115	$x10^{10}$

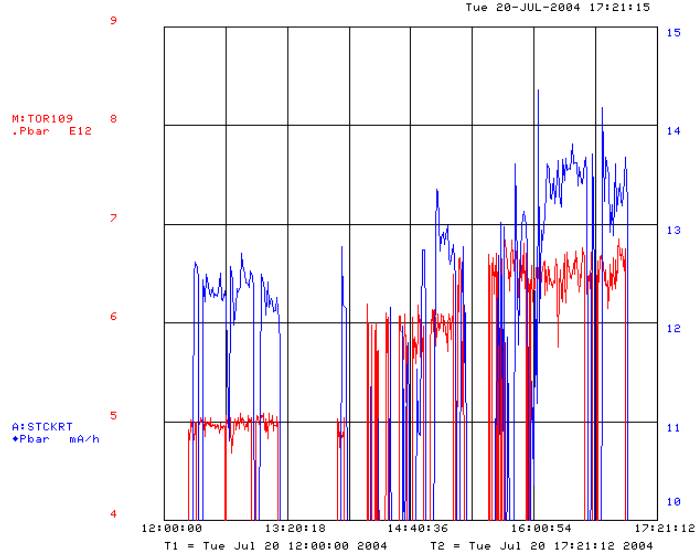
Major Accomplishments

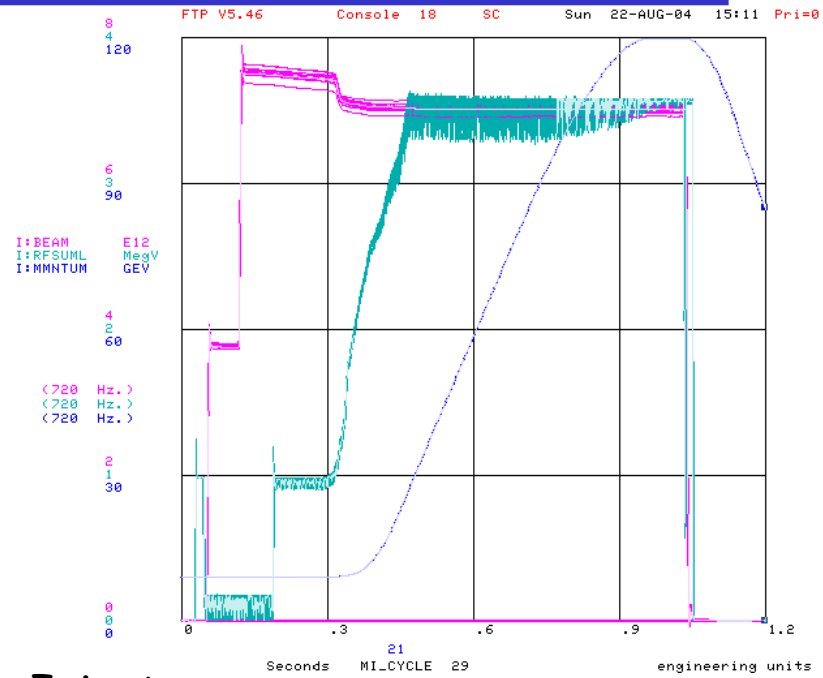
Major Accomplishments for the Collider in FY04

- Proton Source
  - Operational Improvements
    - Booster Aperture
      - Alignment of Booster cavities and Magnets
      - Long 3 septa
    - New dogleg magnets at Long 3
      - Reduction of beta wave
      - Less tune shift
    - Damper mode number and Power increase
    - Matching of the 400 MeV Line
    - Harmonic Correction
    - Two stage collimation system
    - Cogging of batches for Slip Stacking and NUMI
  - Record intensities- 6.0×10^{12} protons/pulse for stacking
  - Record efficiencies > 85%
  - Record throughput > 1.0×10^{19} protons/week for Miniboone
- Antiproton Source
  - Stacking rate 13.65×10^{10} pbars/hour
  - Largest stack 246×10^{10}
  - Longest sustained stack > 2 months
  - Debuncher Aperture Increase
  - Main Injector – Debuncher Phase alignment system
    - Aperture Increase
    - 8 GeV alignment across the injector complex now possible

Main Injector Accomplishments







- Main Injector
  - Bunch Length reduction from dampers and beam loading compensation
    - 20% for coalescing
    - 50% for stacking
  - 2.5 MHz transfers – 95% pbar coalescing efficiency
  - Slip Stacking for Pbar Stacking
    - Done operationally for the last 7 days of running
  - Slow Spill to SY120
    - Mixed Mode Pbar Stacking and Slow spill on the same cycle

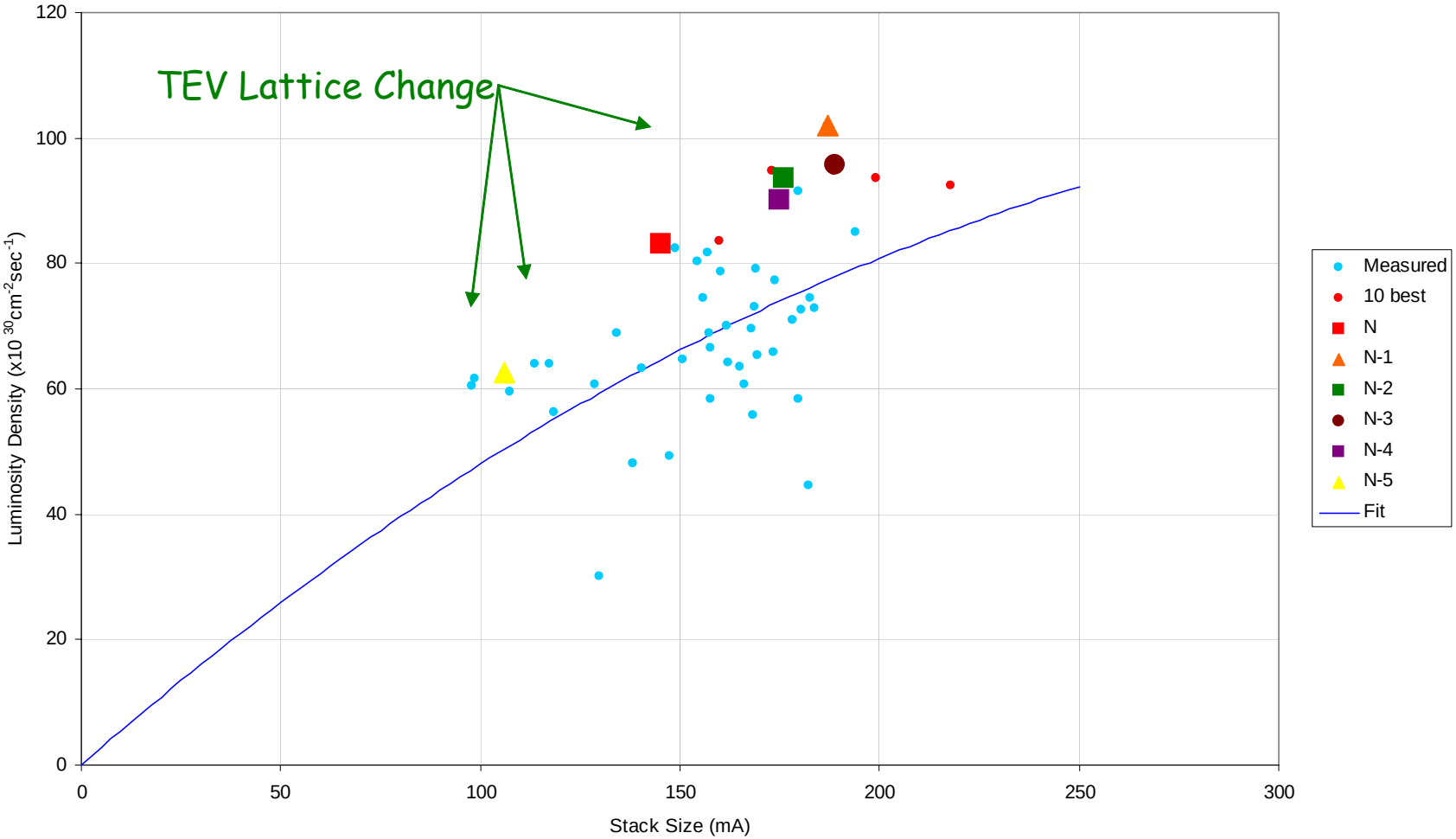
Tevatron Major Accomplishments

- Tevatron
  - Alignment
    - Projects
      - Tev-Net
      - Smart bolt retro-fit
      - Dipole Un-Rolls
      - P1 Line roll
      - IP low-beta regions
      - Tight aperture areas
    - Results
      - Better injection efficiency
      - Smaller emittance at collisions
      - Better ramp efficiency
      - Better store-store reproducibility

Tevatron Major Accomplishments

- CDF IP
  - Location of IP was 4-5 mm too high vertically
  - Significant impact on CDF's
    - Silicon tracking efficiency
    - SVX longevity due to radiation damage
  - Rapid response team was organized during the 1 week shutdown in early December (due to the 16 house quench) to find a solution to move the CDF IP down by 4 mm
    - Within 1 week: designed, installed, and commissioned a series of low beta quad moves that
      - » Moved the IP down by 4mm
      - » Put the beam through the center of the low beta quads
      - » Better aligned the quadrupoles
- New Low Beta optics (April 04 – June 04)
  - 20-30% increase in luminosity
  - Smaller beta*
  - Smaller emittance

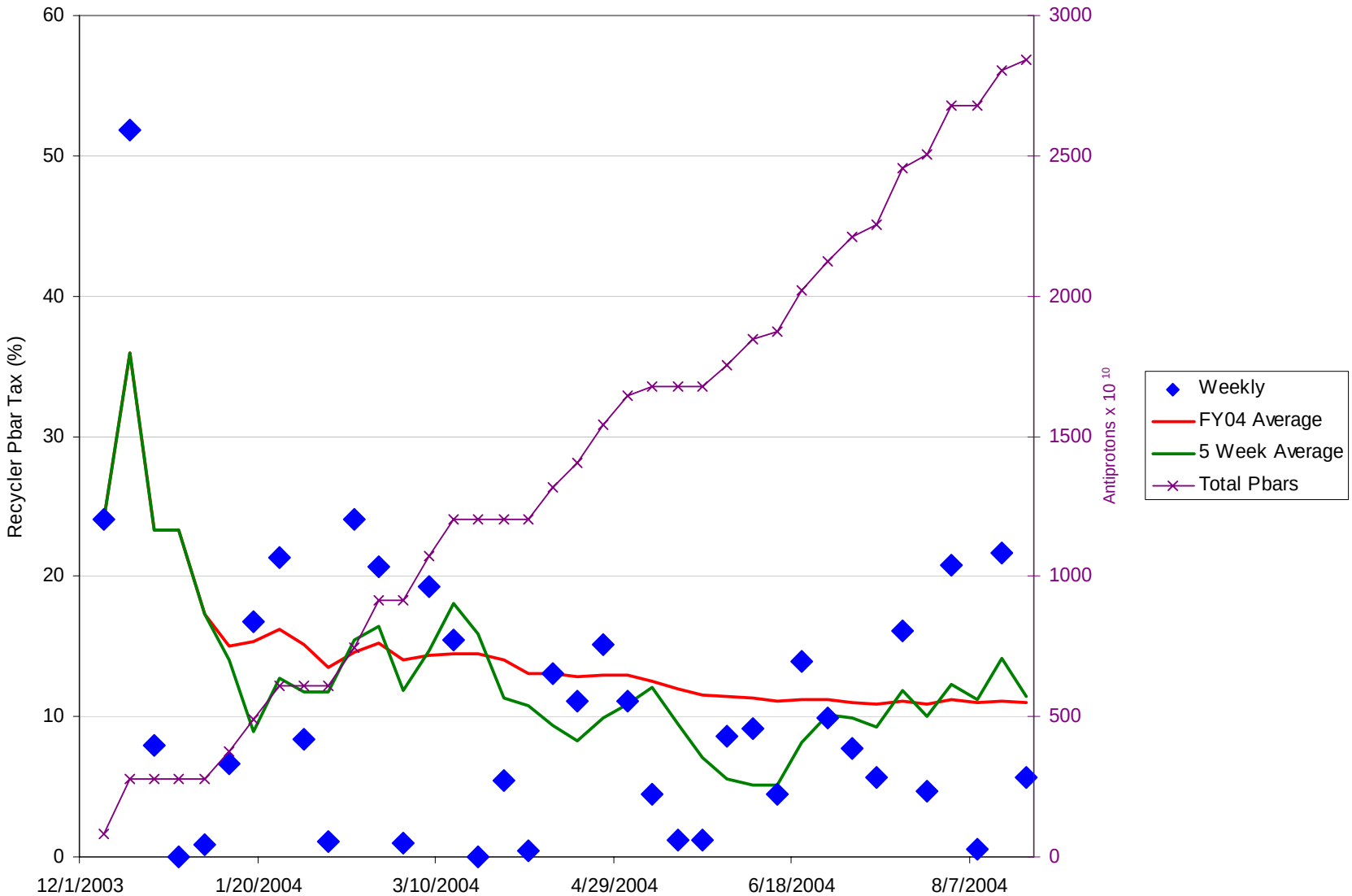
TEV Lattice Change



Major Accomplishments

- Recycler
  - At the end of FY03
    - The Recycler was "on the ropes"
      - Lifetime was < 60hrs
      - Transverse emittance growth was 12π-mm-mrad/hr
    - Took drastic measures
      - Re-organized the department (broke it away from Main Injector)
      - Lengthened the Fall 03 shutdown to bake the entire Recycler
      - Instituted the Pbar Tax (Investment) to guarantee the Recycler adequate study time and access to the tunnel
      - Re-organized the Accelerator Physics Dept. to give the Recycler and Tevatron more accelerator physicists
  - Recycler bake-out was extremely successful
    - Transverse emittance growth reduced by a factor of 5-8
    - Lifetime > 300 hours
  - Recycler commissioning has progressed rapidly
    - Stand alone Recycler shots to the Tevatron (Jan. '04)
      - Initial Luminosity > $17 \times 10^{30} cm^{-2} sec^{-1}$
      - Integrated useable luminosity
    - Stack of $>150 \times 10^{10}$ pbars in the Recycler
  - Using the Recycler in Mixed Pbar operations makes it a luminosity enhancement
    - The top 4 luminosity stores were done with using the Recycler
  - Recycler is ready for Electron Cooling

Recycler Pbar Tax for FY04



Major Accomplishments

- Operations
  - Long Stores
    - More integrated luminosity
    - More reliability - minimize ramping & shot setup
    - Better able to integrate machine studies
  - Better Planning
    - Permanent run coordinator (Jim Morgan)
    - Daily 9 am operations meetings
    - Focused control of machine studies

Machine Studies

- Over a year ago, we made the strong statement that we are leaving the commissioning phase of Run II behind and entering an operations phase in which we incorporate the Run II Upgrades.
- Although it has taken us awhile to come up with the right way to blend in studies with operations, we have achieved that balance during the second half of FY04.
- The success of this strategy comes from the following points (in order of importance)
  - Accelerator basics are the most important studies. The aperture, orbit, tune, and chromaticity must receive the highest attention.
  - The studies must be focused. That is, when possible, we do one study at a time and finish the studies to a conclusion.
  - Studies are embedded into operations. We follow the rhythm of the machine and use the machine performance as a reality check to the control and benefit of the studies. A natural result of this strategy is that study periods are often short. It is rare for us to schedule more than two study shifts in a row.
  - Injector chain studies have the highest priority (Recycler, MI slip stacking, AP2 aperture, Pbar production). To permit efficient coordination of injector chain studies, we run very long stores.

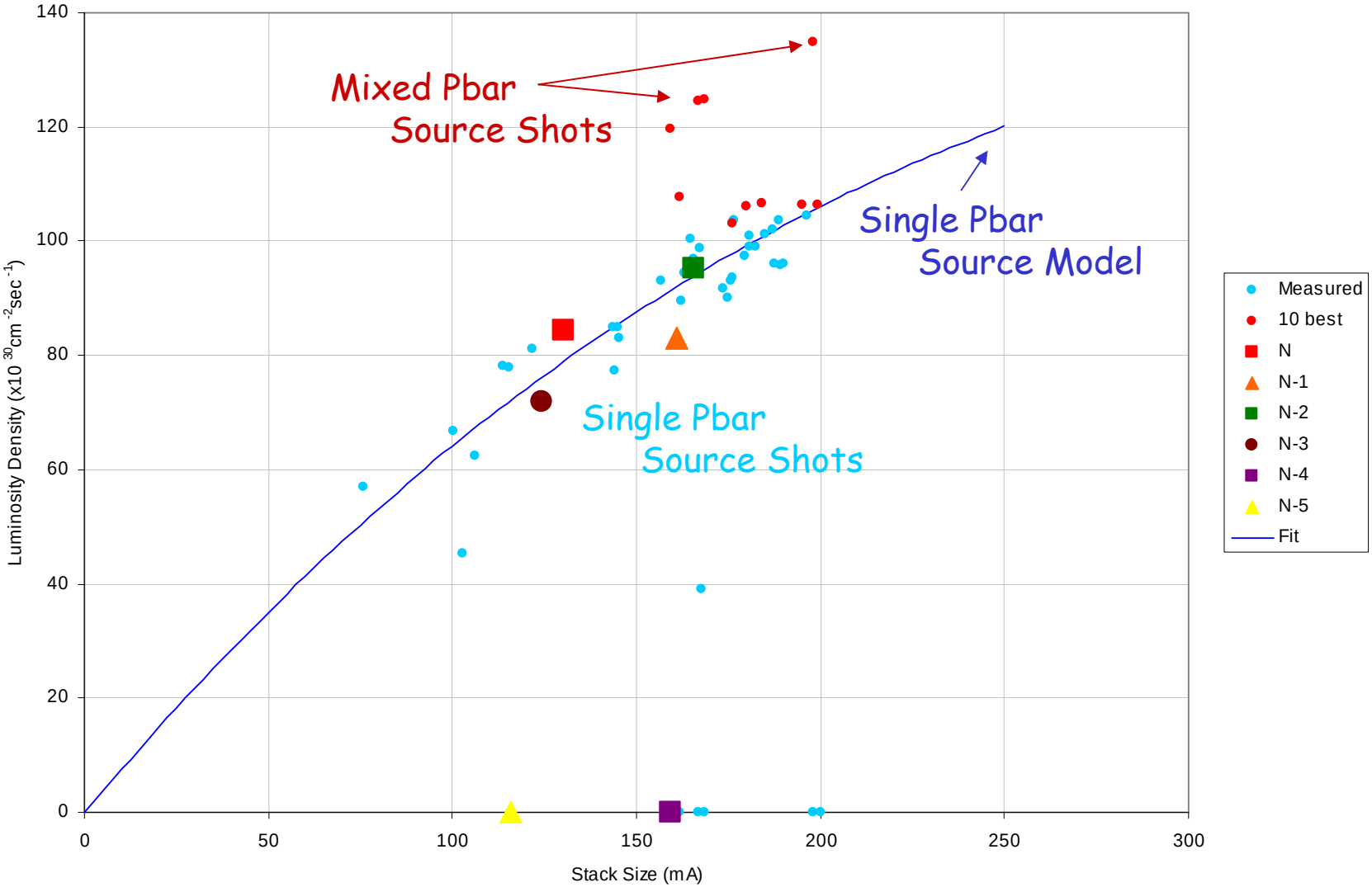
Major Accomplishments

- Operations (continued)
  - Mixed Pbar 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 of $103 \times 10^{30} cm^{-2} sec^{-1}$ recorded 7/16/04

Mixed Pbar Extraction

- Extracting pbars from both the Accumulator and the Recycler for the same store i.e.
  - Twenty four bunches from the Accumulator
  - Twelve bunches from the Recycler
- 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 pbars with 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
  - NEED TO UPDATE MIXED PBAR SOURCE OPERATIONS MODEL

Mixed Pbar Luminosity Potential



Machine Issues

Machine Issues

- Proton Source
  - Proton Demand
    - Collider with Slip Stacking, MiniBoone, SY120, NUMI
  - The Proton Plan (~$20M over the next 3 years)
    - Slip Stacking in the MI for NUMI
      - MI RF Power Upgrade
    - Reliability
      - Booster Solid State Drivers
      - What to do with the low energy Linac (long-term short term)
    - Booster Repetition Rate
      - Power availability
        - » Infrastructure
        - » Power Supplies
        - » Components
    - Booster Losses
      - Aperture upgrade
        - » Components
        - » Alignment
        - » Closed Orbit and tune control

Machine Issues

- Main Injector
  - Slip Stacking
    - Demonstrated 7×10^{12} protons on target
    - Bunch length on target within spec.
    - Need to get to 8×10^{12} stably
  - Running the Fixed target program
    - NUMI
      - Commissioning the NUMI beam line
      - Commissioning of high intensity NUMI multi-batch cycles
        - » Transverse and longitudinal dampers
      - Commissioning the 2 second cycle time
        - » Losses in the MI
        - » Pbar stacking at large stacks – reduced bucket area on ARF1
        - » Lithium Lens pulses
    - Switchyard 120 – Rep rate of Mixed Mode before NUMI turns on
  - Mixed Pbar Source Operation
    - 8 GeV Energy alignment

Machine Issues

- TEVATRON
  - More alignment work this shutdown
    - Over ½ of the dipoles have been re-shimmed during the past 2 shutdowns
    - Another round of dipole un-rolls has been performed
    - D0 separators have been re-aligned
    - Low Beta's at both IP's will be realigned
  - New Helix at low beta
    - 2 new separators have been installed
    - Will commission new helix before the start of operations
  - B2 Snapback Improvements
    - Will startup with new B2 snapback procedure
  - New Instrumentation
    - New BPMs
      - Will commission after startup
      - Automated Orbit smoothing ?
    - IPM and Crystal collimator
  - Octupoles
    - Beam Stabilization
    - Differential Chromaticity
  - TEV Abort
    - Unmasking of inputs for protection
    - New BLM system as abort input

Recycler

- Run the complex in Mixed Pbar operations
  - Stacks of 60-100x10^{10} in Recycler
    - 1-2 "super" transfers between Accumulator to Recycler
    - Transfer time between Accumulator to Recycler 20-45 minutes
  - Stacks of 140-200x10^{10} in the Accumulator
    - 3 transfers from the Recycler to the TEV, 6 transfers from the Accumulator to the TEV
  - Store Length of 20-25 hours
- Commission Electron Cooling
  - Commission the Pelletron
  - Commission beam transport through the U tube
  - Commission beam transport through the cooling beam line
  - Commission cooling of antiprotons

Stack Rate* (mA/hr)	Single Source Luminosity (ub^{-1}/sec)	Percent Increase (%)	Mixed Source Luminosity (ub^{-1}/sec)	Percent Increase (%)
24	90	29	105	50
18	82	17	96	37
12	70	0	76	9

Pbar Production

- Goal
  - Zero Stack Stacking Rate 18×10^{10} pbars/hr
    - Beam on target 5.0×10^{12} protons per cycle
    - Production 17×10^{-6} pbars/proton
    - Cycle time 1.7 sec
- Achieved
  - Zero Stack Stacking Rate 12.7×10^{10} pbars/hr*
    - Beam on target 5.2×10^{12} protons per cycle
    - Production 15×10^{-6} pbars/proton
    - Cycle time 2.2 sec
- Difference
  - Zero Stack Stacking Rate down 29%
    - Beam on target up 4%
    - Production down 12%
    - Cycle time up 29%

*Averaged over the 10 stores with the highest initial luminosity

Pbar Production

- The momentum spread extracted from the Debuncher into the Stacktail has been decreased by about 35% over the past year.
- The present Stacktail system with the bandwidth as measured should be capable of handling a static flux of 29mA/hr
  - At small stacks, the present Stacktail system can clear the deposition orbit as fast as 1.2 seconds
  - Note in the future, that the present 2-4 GHz Accumulator Core Momentum Cooling system will have to be replaced with either the present or modified 4-8 GHz Accumulator Core Momentum Cooling system if the Accumulator is going to have to continue support large stacks.
- In the range of cycle times of interest, the amount of beam reaching the injection orbit of the Accumulator is proportional to how long the transverse cooling is on in the Debuncher.
  - Indicates an aperture problem in the D-A line.
  - The transverse cooling was increased marginally by transverse gain ramping
    - Should be able to do better

D-A Line Plan of Work

- Alignment
  - Develop an accurate lattice and alignment model of the D-A line
  - Check model against alignment data
  - Adjust "D" pipe and extraction septum in Debuncher
  - Adjust beam pipe in D6Q6
  - Adjust bend centers of D:H807 if necessary
  - Adjust alignment of A:ISEP1 and A:ISEP2
- Fix or replace A:ISEP1
  - Have observed large ground current surge on beam pipe not seen on other septa
- Open up the D-A line for visual inspection during the shutdown
  - Will do when A:ISEP1 is removed from D-A line for fix
- Develop fix to control angle out of D6Q6
  - D:HT804 or new trim
- Maximize beam separation at D:ESEP
  - Install a Debuncher Extraction Ramped Bump
    - Optimizes maximum closed orbit aperture at injection
    - Optimizes extraction channel aperture
  - Design beam study to directly measure kicker separation
    - Will need SEMs working in Debuncher and Rev. Prot. TBT in Deb
- Build a forward Pbar BPM system in the D-A line
- Optimize Debuncher Transverse Cooling Gain Ramping
  - Looks very promising on paper
  - Initial experimental results show reduced emittances but ramps were not optimized
  - Need to first understand why higher static gains were not used in operations

FY05 Outlook

Plans for FY05

- Install electron cooling in the Recycler in Fall '04 shutdown
- Run Slip Stacking at 8×10^{12} protons/pulse every 2 secs
- Increase the pbar production aperture by 25%
- Stack at small stacks with a rate of 24×10^{10} pbars/hr
- Run the complex in Mixed Pbar operations
  - Assume the gain from Mixed Pbar operations is "break-even" (pessimistic?)
- Demonstrate electron cooling of antiprotons by the end of FY05
  - 25% Pbar Tax is still in effect
- Integrate $470 pb^{-1}$ in 34 weeks (average ~$14 pb^{-1}$/week)
- Run NUMI at a 2 sec. cycle time with 2.5×10^{13} protons/cycle by early Spring
  - Keep activation levels in Booster at the April 29, 2004 level.
  - Will need guidance from Program Planning on the priorities of NUMI, MiniBoone, SY120

FY05 Startup Guidelines

- Assume that it will take a maximum of 2 weeks from the day the TEV first sees beam to produce useable luminosity.
- Goal of commissioning plans should be to bring the machines to pre-shutdown level of performance
  - Proton source
    - 4.5 – 5.0x10^{12} protons/pulse for stacking
    - 4.0x10^{16} protons/hour for MiniBoone
  - Main Injector
    - 4.5 – 5.0x10^{12} protons/pulse for stacking
    - 2.4 sec. cycle time at small stacks
  - Pbar Source
    - 10-12 mA/hr at zero stacks
  - Recycler
    - Be ready for Mixed Source operations within 1 month after startup
  - Tevatron
    - Commission orbits, tunes, etc. with new alignment
    - Commission new helix at low-beta

FY05 Goals

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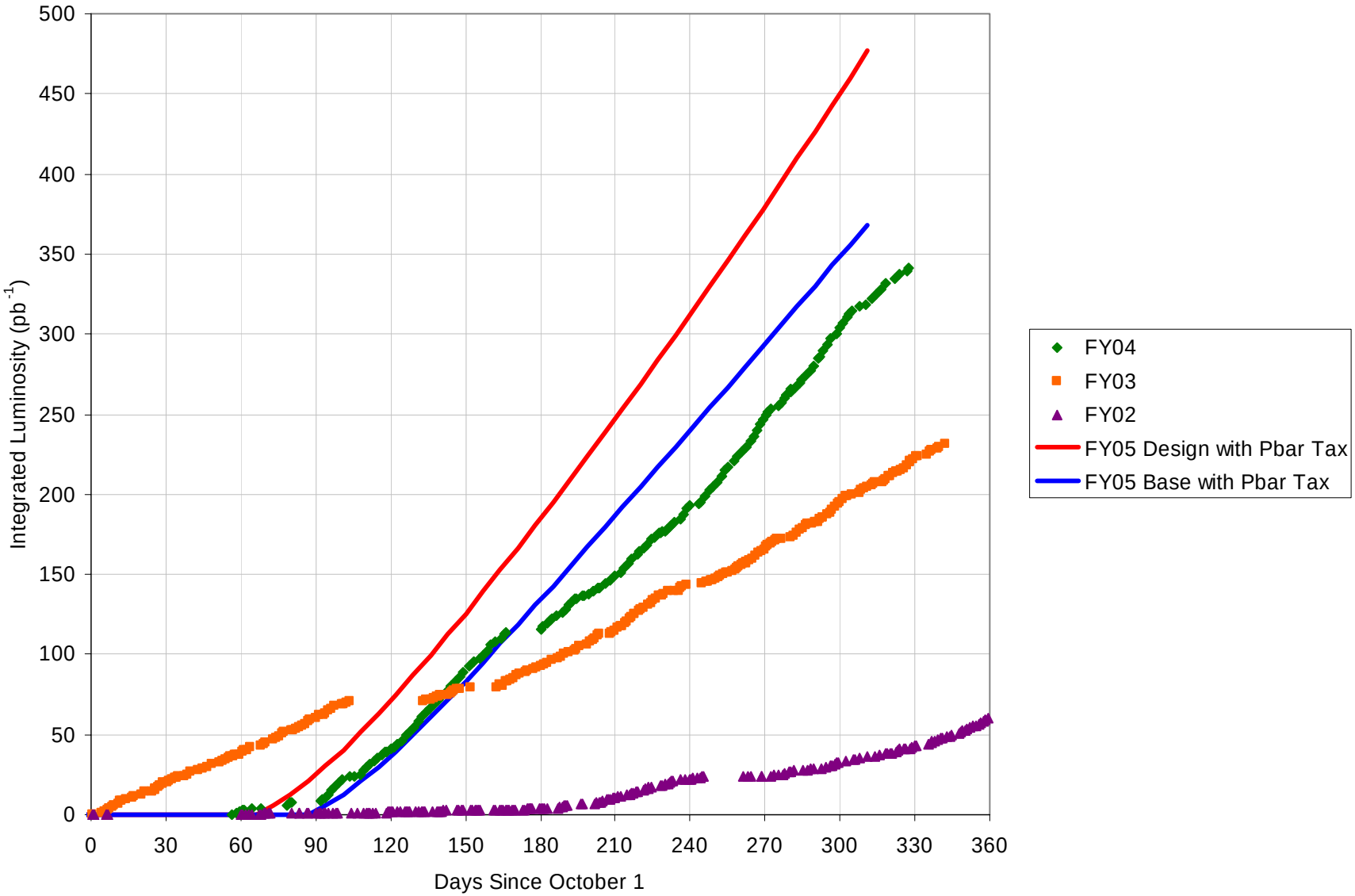
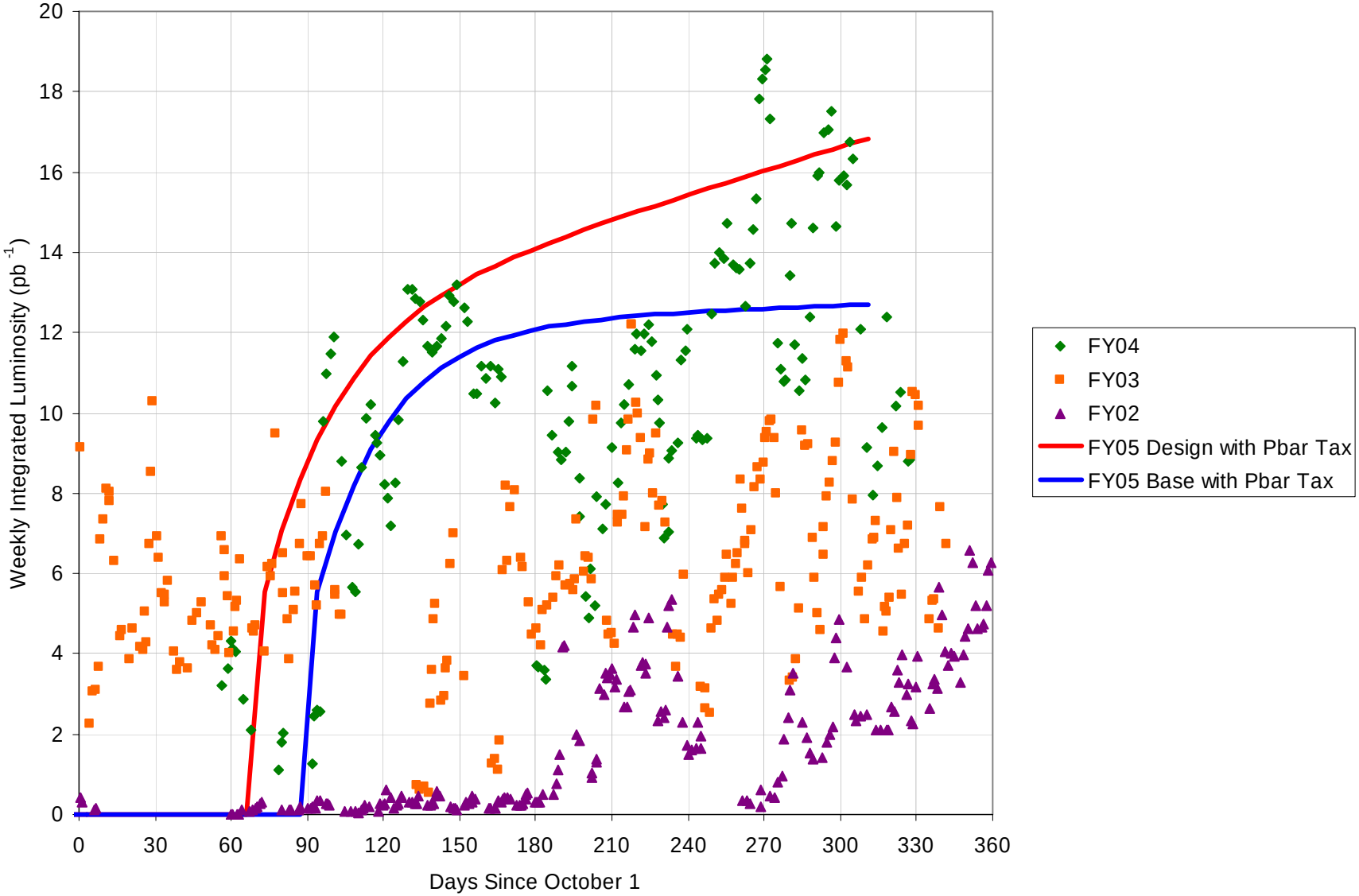
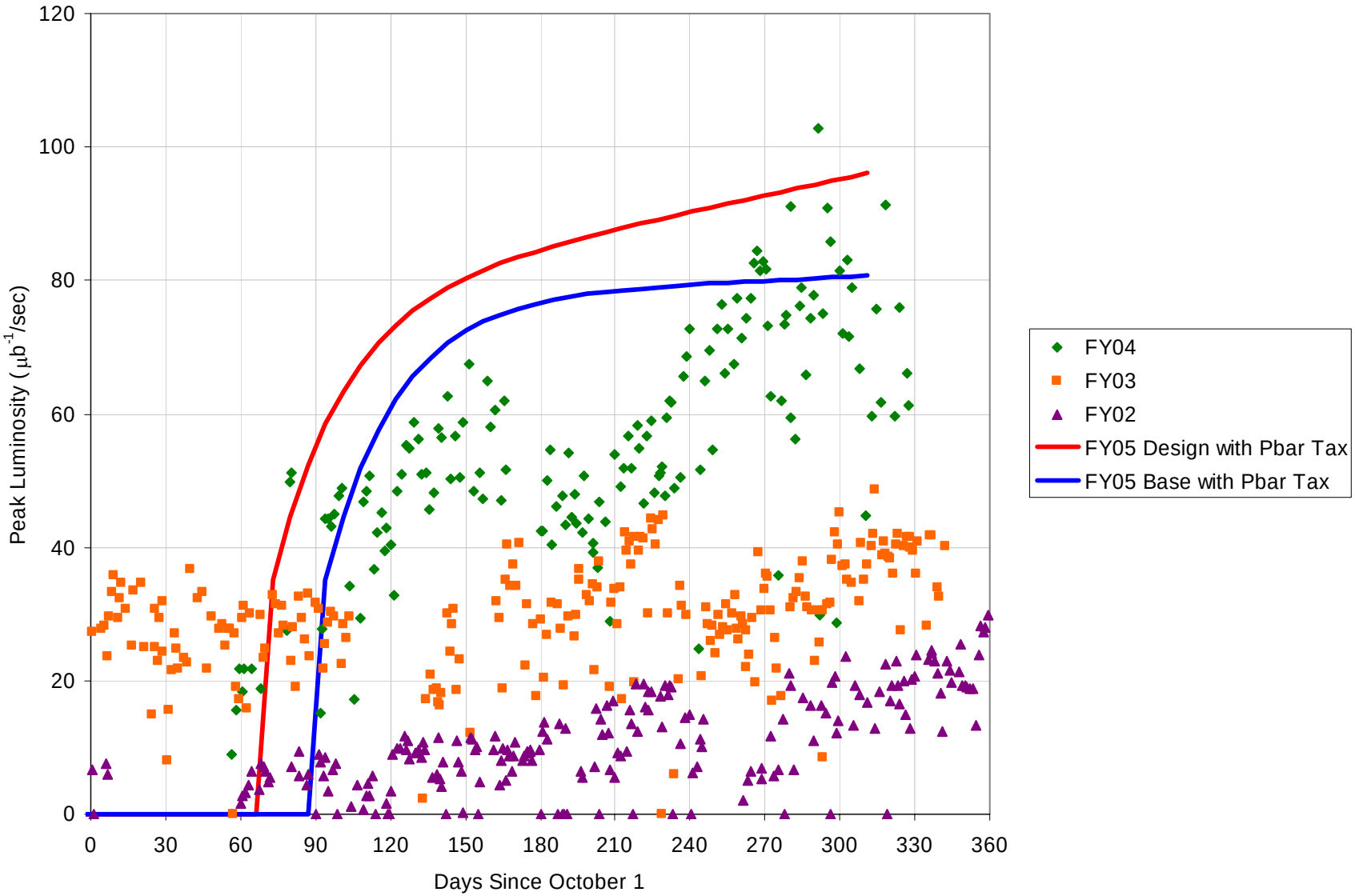


FY05 Goals Weekly Integrated Luminosity



FY05 Goals Peak Luminosity



Summary

- Collider performance in FY04
  - Exceeded the design FY04 design curve
  - The peak luminosity and the luminosity per week has doubled from FY03
  - Most of the Tevatron parameters are close to the design values
  - The Proton Source is operating at record intensities, efficiencies, and throughput.
  - Slip Stacking has been commissioned in the Main Injector
  - The Recycler is:
    - ready for electron cooling
    - Dramatically increases luminosity through mixed-pbar operations
  - Pbar production is well below the design parameters but the study plan executed over the summer indicates that the source of the shortfall is the result of a small effective aperture in the D-A line
- FY05 will be a pivotal year for the Run II Collider
  - Pbar stacking
  - Mixed Pbar operation
  - Electron cooling installation and commissioning
  - NUMI Commissioning and Running