Considerations for Collider Run 3

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Prologue

- Given the LHC's lower initial √s and slower ramp up in luminosity, especially relative to P5 assumptions, it is sensible to consider running the Tevatron collider longer
  - Make the most of the continuing physics opportunity
  - Tevatron and rest of complex operating at peak performance
  - Opportunity to revisit capabilities of existing accelerator complex

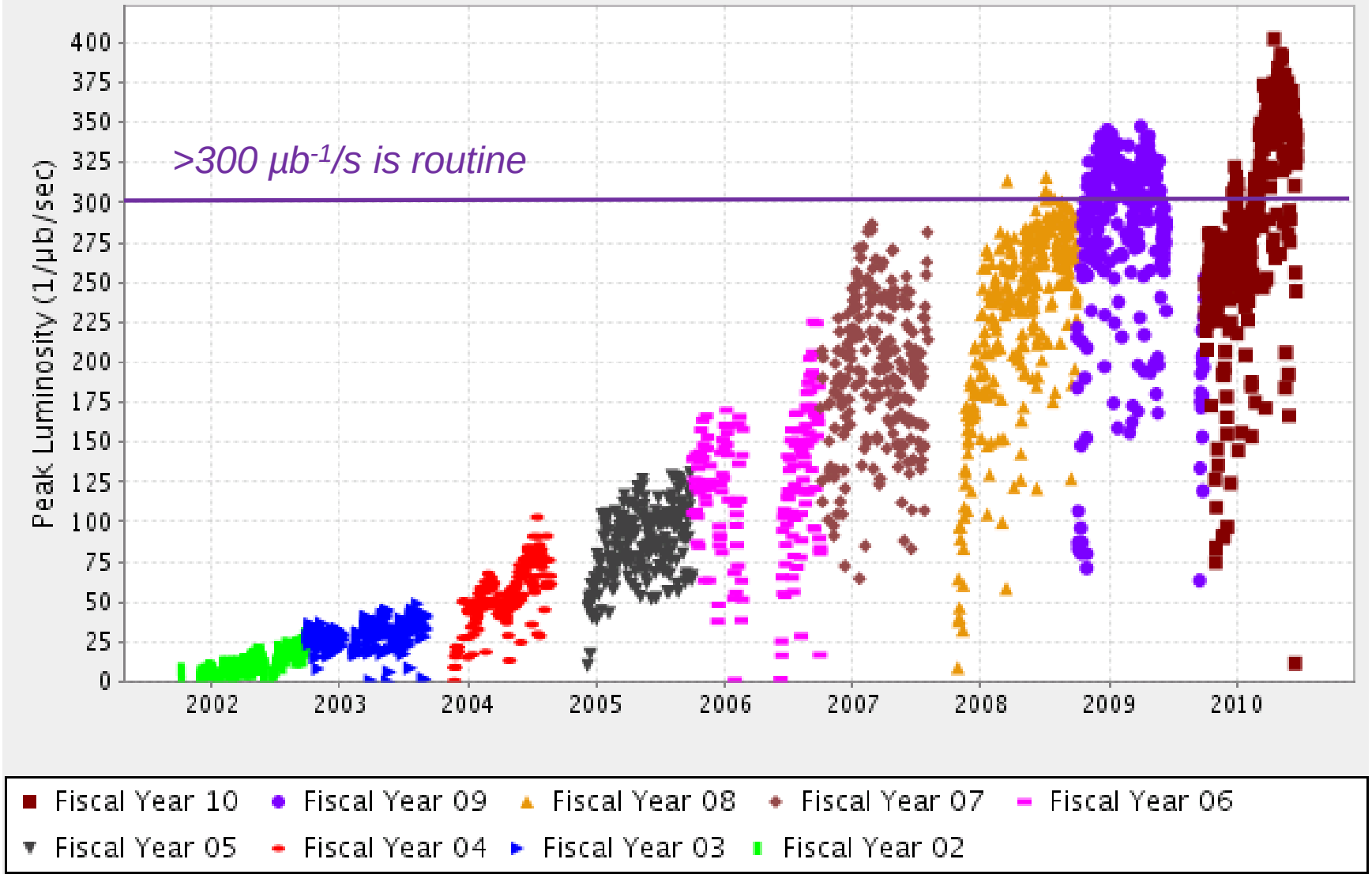
- "Run 3" document given to Directorate
  - http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=3617
  - physics case and detector operations *(see later talks by CDF & D0)*
  - outlines a possible accelerator operating scenario

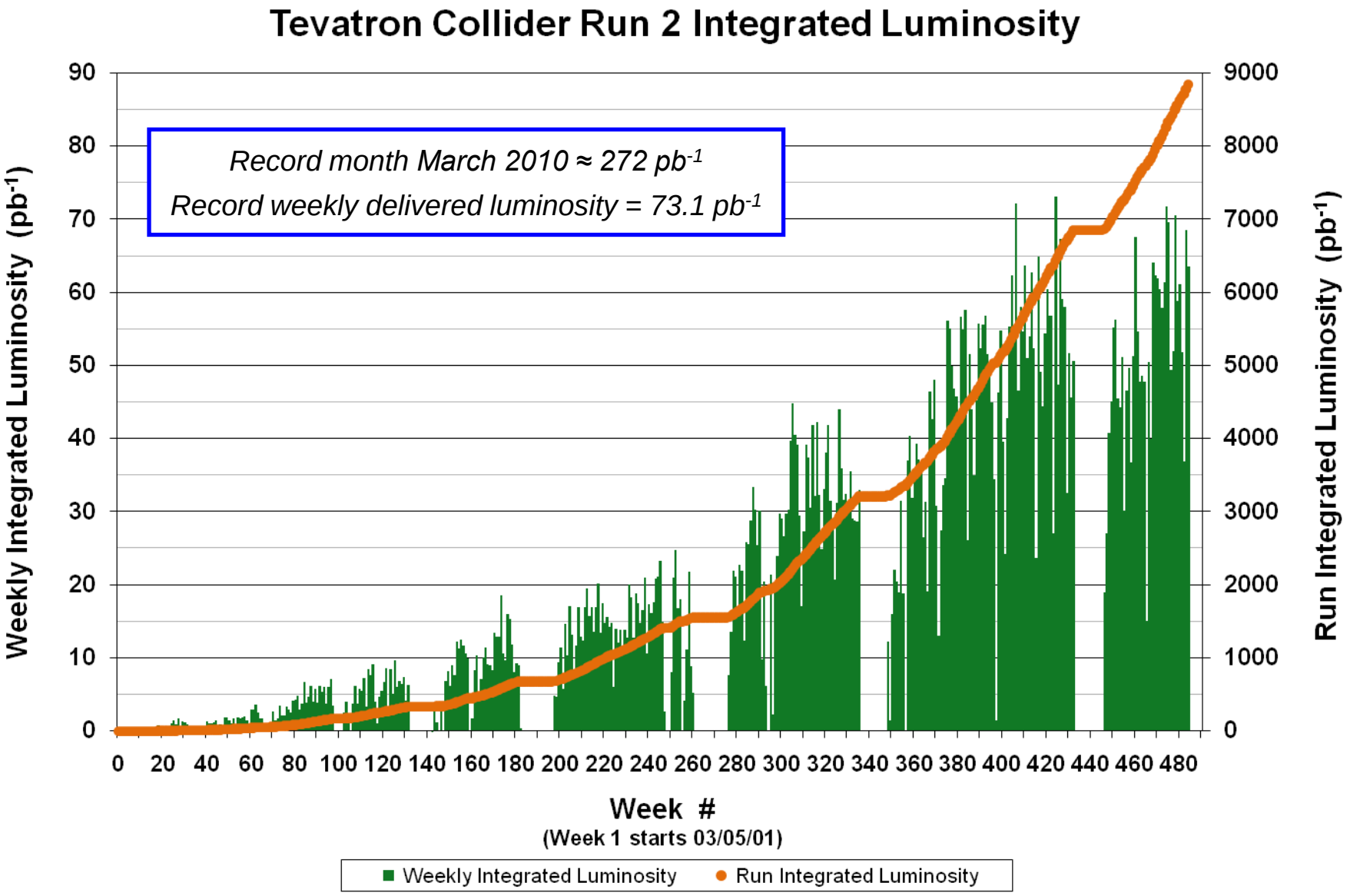
- Motivation: keep collider until it's really out of the energy frontier game
  - Bolster lab's planned physics program before Project X

Contents

- Tevatron performance
- Improvements for NOvA Operation
- Simultaneous Collider and NOvA Operation
- Tevatron Luminosity in Run 3

Run 2 Peak Luminosities




Tevatron Collider Run 2 Integrated Luminosity
Record month March 2010 ≈ 272 pb-1
Record weekly delivered luminosity = 73.1 pb-1
Weekly Integrated Luminosity (pb-1)
Run Integrated Luminosity (pb-1)
0 10 20 30 40 50 60 70 80 90
0 1000 2000 3000 4000 5000 6000 7000 8000 9000
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400 420 440 460 480
Week #
(Week 1 starts 03/05/01)
Weekly Integrated Luminosity
Run Integrated Luminosity

Tevatron Reliability

Year	Stores	Normal Terminations	%Normal Terminations	Avg Store Hrs/Week (outside of planned shutdowns)
2003	186	55	30%	-
FY04	162	106	65%	100
FY05	211	145	69%	110
FY06	163	101	62%	100
FY07	235	187	80%	110
FY08	304	242	80%	106
FY09	293	253	86%	108
FY10	311	268	86%	123

Improving Reliability

The Tevatron is running better than ever.

Run 2 Luminosity Improvements

- Long campaign of improvements across the complex
  - Proton Source & MI = deliver more beam to pbar production target
  - Antiproton Source = higher stacking rate, stochastic cooling pick-ups, target and lens production improvements
  - Tevatron = new diagnostics, improved lattices with smaller β*, increased beam separation, better shot-to-shot reproducibility
  - Recycler + electron cooling = higher pbar intensity with smaller emittances (higher brightness)
  - Other: improved diagnostics, SDA (shot data analysis), faster Accumulator → Recycler transfers, faster HEP shot-setups

⇒ Without Recycler + e-cooling as part of collider operations, integrated luminosity would be down > 50% per year

Current Plan for 700 kW to NOvA

- No sharing protons with pbar production
  - 2 more proton batches/cycle available (9 → 11 batches)
- Proton stacking in Recycler
  - Recycler can accommodate 1 more batch than MI slip-stacking
  - Negligible filling time from Recycler allows faster MI cycle time
- Decreasing Main Injector ramp time
  - Upgrade quadrupole bus power supply + 2 additional RF stations
- Increasing Booster flux to get 14×10^{16}/hr (NOvA alone)
  - Current total flux = 11×10^{16}/hr @ ≈7 Hz (NuMI + pbar + MiniBoone)
  - NuMI: 4.3×10^{12}/batch @ 5 Hz → NOvA: 4.3×10^{12}/batch @ 9 Hz
- *See also Roger Dixon's proton source upgrade talk*

Simultaneous Collider & NOvA Operation

- Retain Recycler solely for Collider – need high pbar brightness
  - 2012 accelerator shutdown could be shortened *(less work in MI tunnel)*
  - Run collider while NuMI target hall work goes on
- Assume 11×10^{16}/hr (current total Booster flux) for (NOvA + pbar)
- Implement improvements for faster MI ramp time
- Interleave pbar production cycles (9 NOvA+2 pbar batches every other MI cycle)
  - Pbar stochastic cooling less efficient for shorter ramp cycles
  - NOvA can take all 11 proton batches on non-pbar cycles
  - Already do this occasionally when stuck with large pbar Accumulator stack
  - *Pbar stacking rate will be lower; discuss impact on luminosity later*

⇒ Can achieve 500 kW for NOvA in this scenario
  - All modifications within already planned costs for NOvA upgrades
  - Additional proton source improvements would contribute also

Proton Flux Allocation

	NuMI	NOvA	Run 3	units
Booster Cycle Rate	5.00	9.00	5.89	Hz
NuMI/NOvA Booster Batches	9	12	10	
NuMI/NOvA Booster Batch Intensity	4.30	4.30	5.10	$\times 10^{12}$
Antiproton Booster Batches	2	N/A	1	
Antiproton Booster Batch Intensity	4.60	N/A	5.50	$\times 10^{12}$
Main Injector Fill Time	0.67	0.00	0.67	sec
+ Main Injector Ramp Time	1.53	1.33	1.20	sec
= Main Injector Cycle Time	2.20	1.33	1.87	sec
Main Injector Efficiency	95	95	95	%
Main Injector 120 GeV Intensity	45.51	49.02	53.68	$\times 10^{12}$
Main Injector Loss Rate	1.39	2.48	1.94	kW
Antiprotons Used in the Recycler	Yes	N/A	Yes	
Antiproton Cycles Interleaved	No	N/A	Yes	
Antiproton Cycle Time	2.20	N/A	3.73	sec
Booster Flux	7.84	13.93	10.90	$\times 10^{16}$/hour
Antiproton 120 GeV Proton Flux	1.43	0.00	1.01	$\times 10^{16}$/hour
NuMI/NOvA Beam Power	**321**	**706**	**498**	**kW**

D. McGinnis

Tevatron Luminosity

- Run 3 interleaved pbar cycles decrease stacking rate 12%
  - Corresponding reduction in luminosity
- Mitigate by increasing proton intensity at collisions
- Need to change working point to near ½ integer
  - Increase available tune space for protons
  - Considered several years ago, not implemented due to limited time for payoff when Run 2 being extended only year-by-year
  - Simulations already developed (A. Valishev)
- Can regain integrated luminosity lost by reduced stacking rate
  - ½ integer working point, ≈30% higher proton intensity, longer stores

½ Integer Working Point

- Used at B-factories

- Advantages
  - 50% more tune space than current point ⇒ 50% higher proton intensity
  - 20% smaller beam-beam tune shift for same intensities/emittances

- Challenges
  - Increased beta-beating in lattice
    - Necessary correction circuits already exist in Tevatron
  - Greater sensitivity to magnet, orbit errors
    - Quadrupole gradient stability already known to be sufficient
    - Need improved orbit stabilization scheme

- Not trivial - few months dedicated studies to develop & implement
  - Entire cycle: injection, ramp, squeeze, collisions

Luminosity Projection

- Proponents suggest 3 more years beyond FY11
- Expect similar rates of delivered luminosity: >200 pb^{-1}/month
  - Our current "red line" rate = 52.5 pb^{-1}/week
- Assume 8-week shutdown each year for maintenance

12 fb^{-1} delivered by end FY11

+ 52.5 pb^{-1}/week for 44 weeks/year over 3 years = 6.9 fb^{-1}

= nearly **19 fb^{-1}** delivered to each CDF and D0 total Run 2 + 3

Tevatron Spare Components

- Spares pool remains acceptable over past several years

- Tunnel component replacement history since 2006
  - 3 dipoles, 4 spool packages (leaks or electrical faults)
    - 2 other dipoles fixed in tunnel, reinstalled
  - 2 injection kickers (leaking fluorinert, replaced with rebuilt units)
  - 2 feed cans (cryogenic distribution with superconducting bus)

- Ready-to-use
  - Dipoles: 14 TB, 15 TC (various grades: ~ ½ are “superior”)
  - Quads: 5 QF, 4 QD (all but one are “excellent”)
  - Spool packages: 50 among 26 different types
    - Some spools can replace other types if needed
  - Low-beta: 1 ready-to-use spare for each of the major components

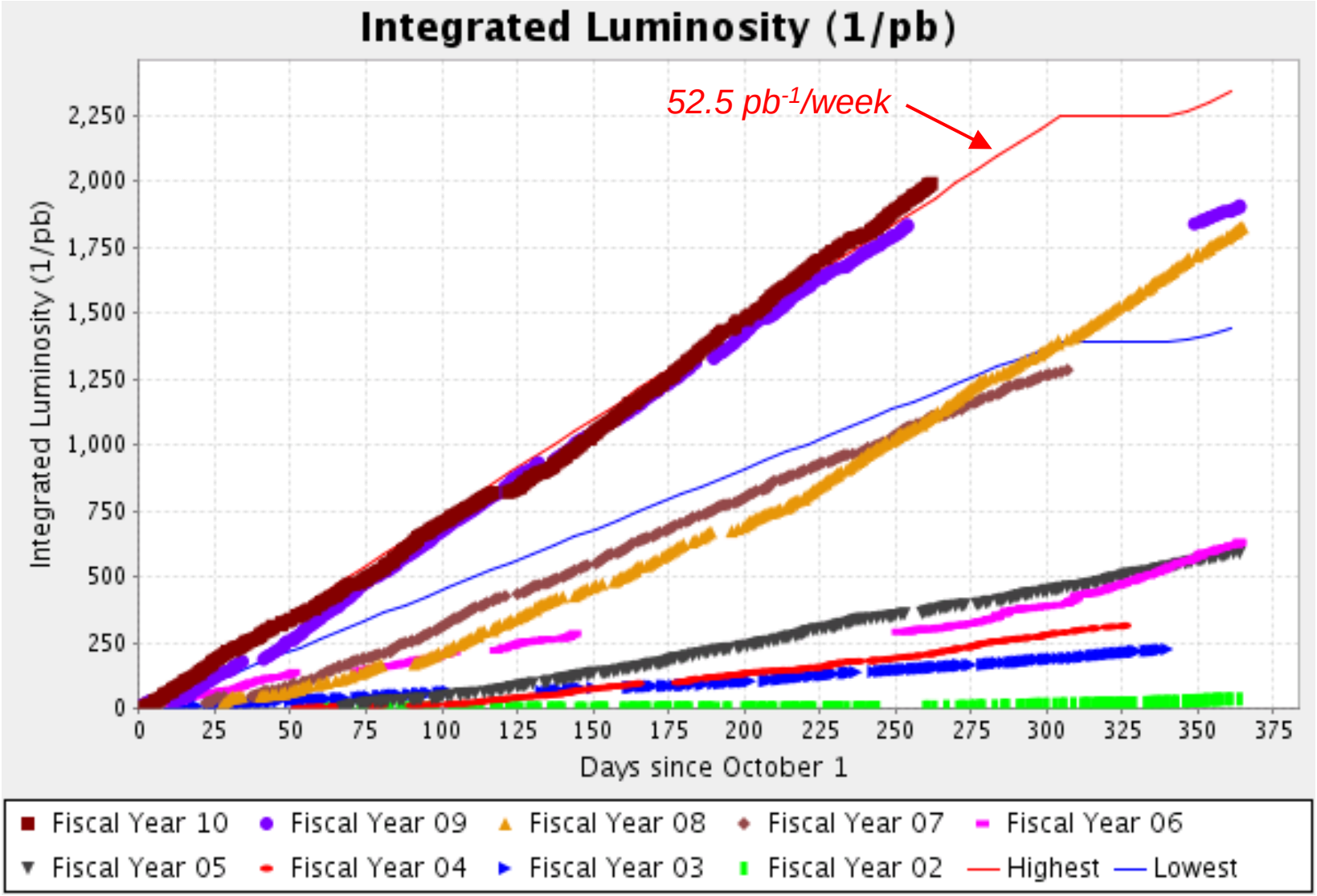
Other Considerations

- Pbar source needs
  - Maintain production of target hall station components
    - Targets, Li lens + transformers, pulsed magnets
    - Lens transformer current priority
    - Dump water system needs maintenance (leaks)
  - Continue procurement of various tubes for RF systems
- Recycler + Pelletron OK if maintain same level of support
- NOvA scavenging from Tevatron
  - Significant parts of RF system would be used in Recycler for NOvA
  - No Issue for Run 3
- Recycler can move on to proton operation after Run 3
  - As envisioned for NOvA

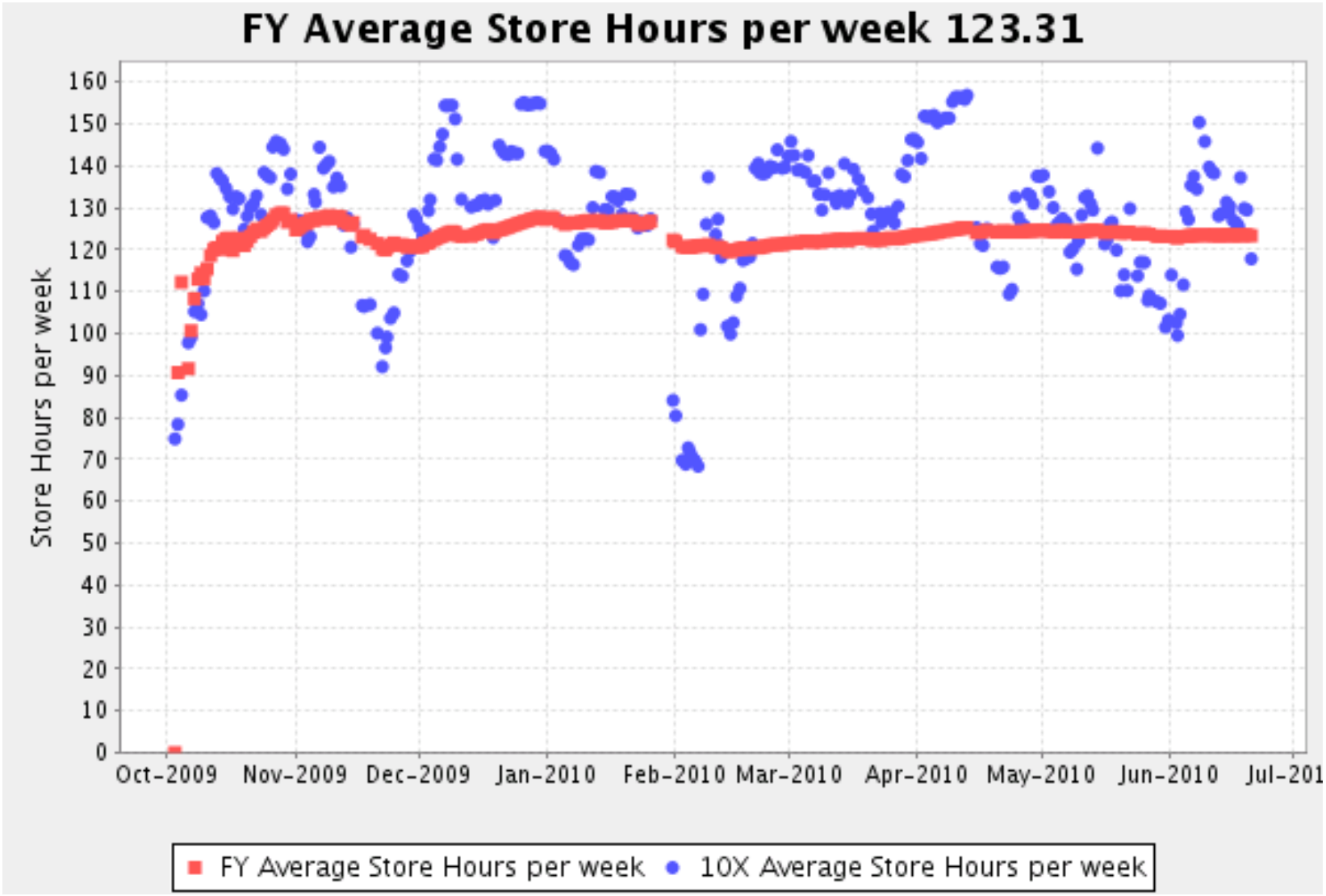
Summary

- Slow LHC turn-on begs the question “Should Tevatron run longer?”
  - Folks across the lab and CDF/D0 have been thinking diligently about it
- Can support delivering > 2 fb^{-1}/year and 500 kW to NOvA
  - Recycler stays with collider, keep pursuing other upgrades
  - Assumes current Booster proton flux = 11×10^{16}/hr (for NOvA + pbar)
  - Must implement new Tevatron working point to allow more protons
  - 3 more years of collider can deliver ≈19 fb^{-1} total Run 2 + 3
- No show-stoppers at this point
- Helps maintain strong operational program prior to Project X

Delivered Luminosity by Fiscal Year

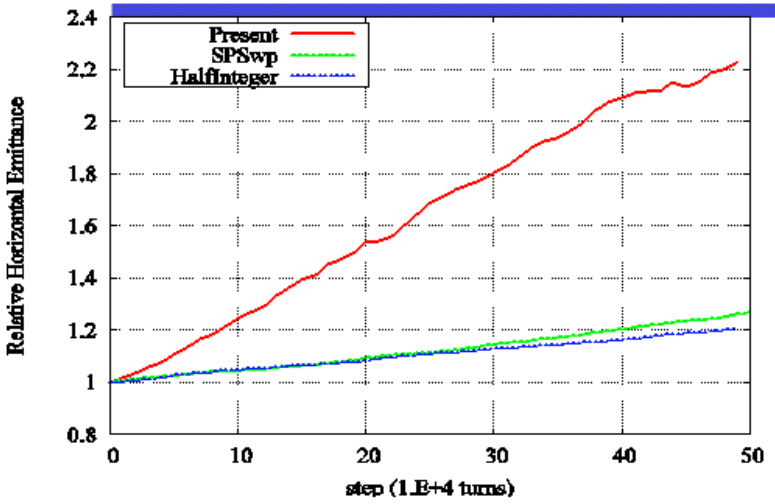


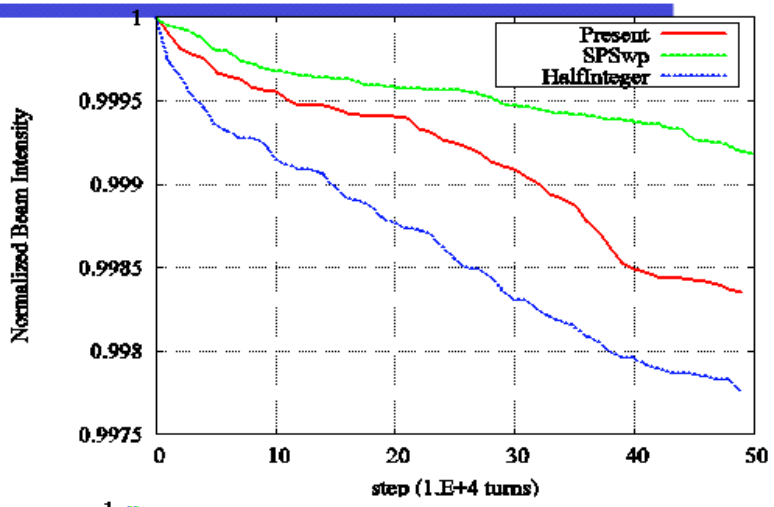
FY10 Average Store Hours/Week

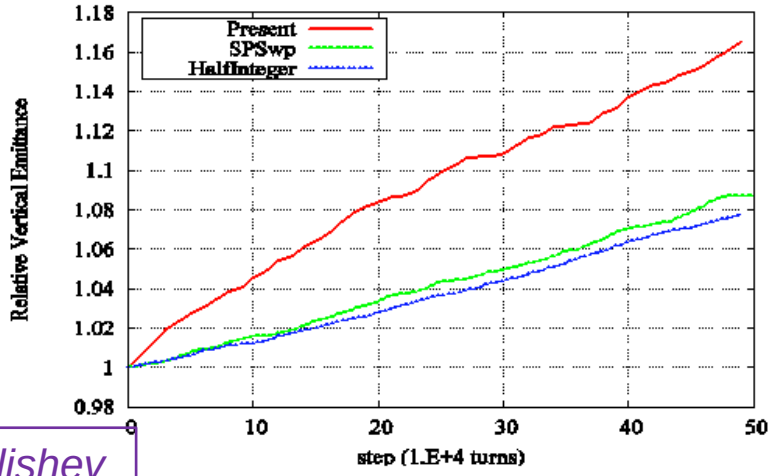


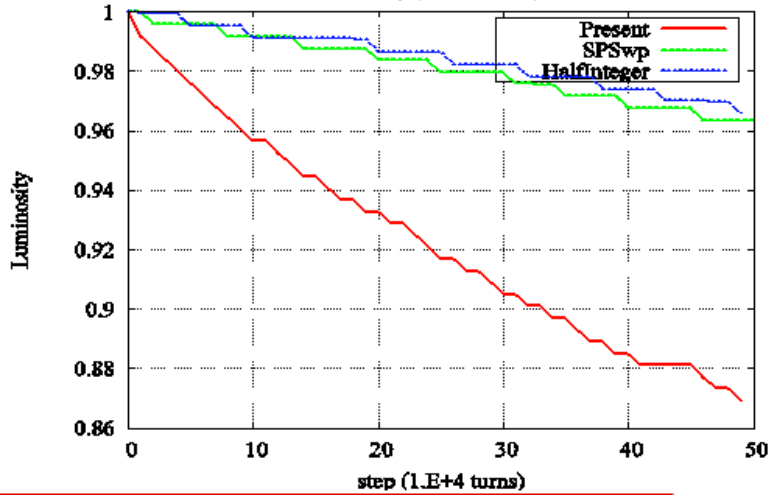
½ Integer Simulation

Weak-Strong Simulation: Proton Intensity Increased by 30%









A. Valishev