Tevatron Collider Status and Prospects

Ron Moore

Fermilab – AD / Tevatron Dept.

Shameless outreach advertisement:

Follow the Tevatron on Facebook and Twitter!

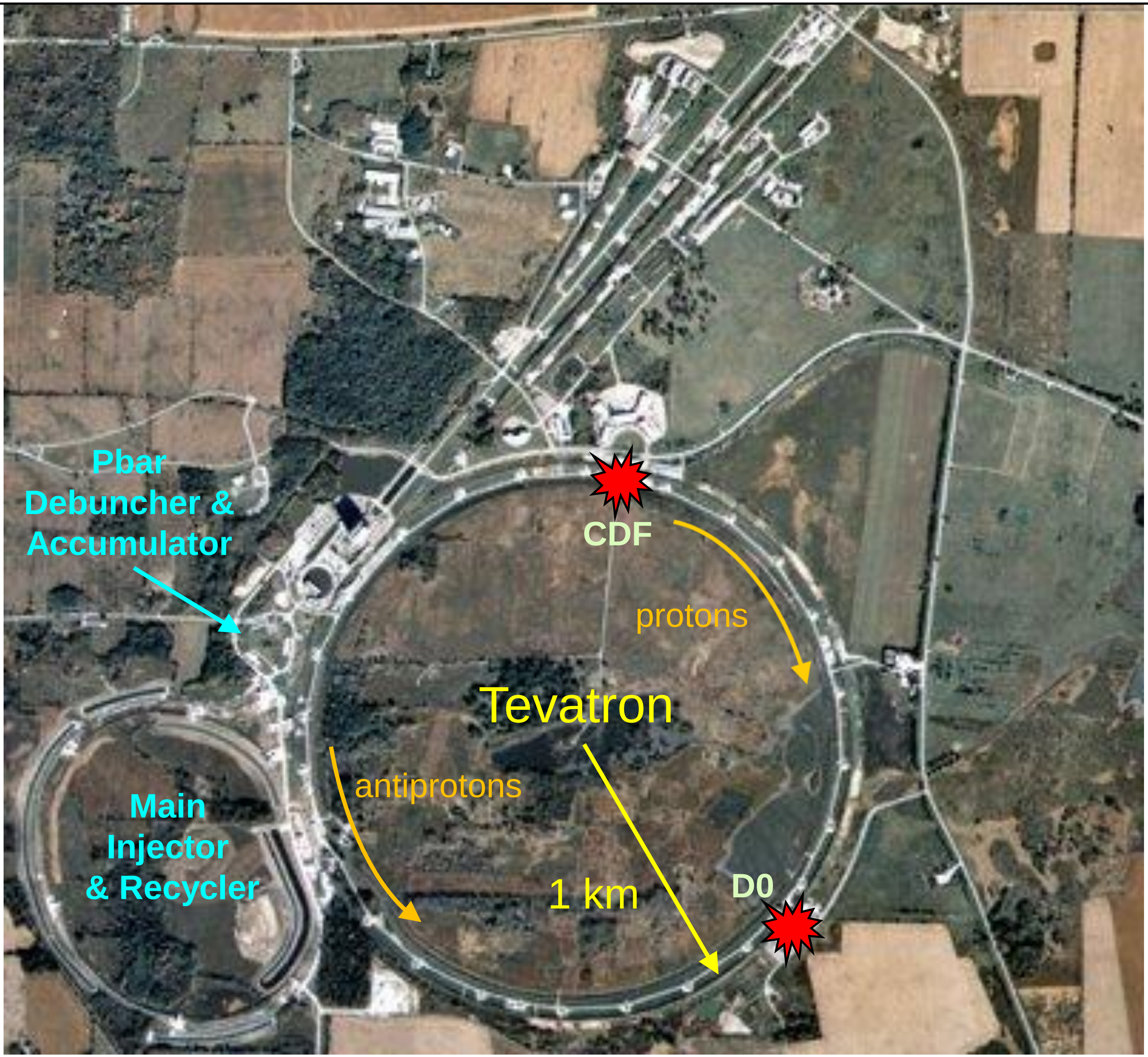
APS DPF 2009 – Wayne State University

Contents

- Overview
- Luminosity Evolution
- Operational Considerations
- Prospects and Projections

- References to other FNAL talks in the Accelerator sessions…
  - Vladimir Nagaslaev – *Antiproton Production at Fermilab* (Accelerator 3)
  - Sasha Shemyakin – *Antiproton Accumulation and Cooling at the Fermilab Recycler Ring* (Accelerator 1)
  - Phil Adamson – *Fermilab Main Injector* (Accelerator 3)
  - Mary Convery – *Optimization of Integrated Luminosity of the Fermilab Tevatron Collider* (Accelerator 1)

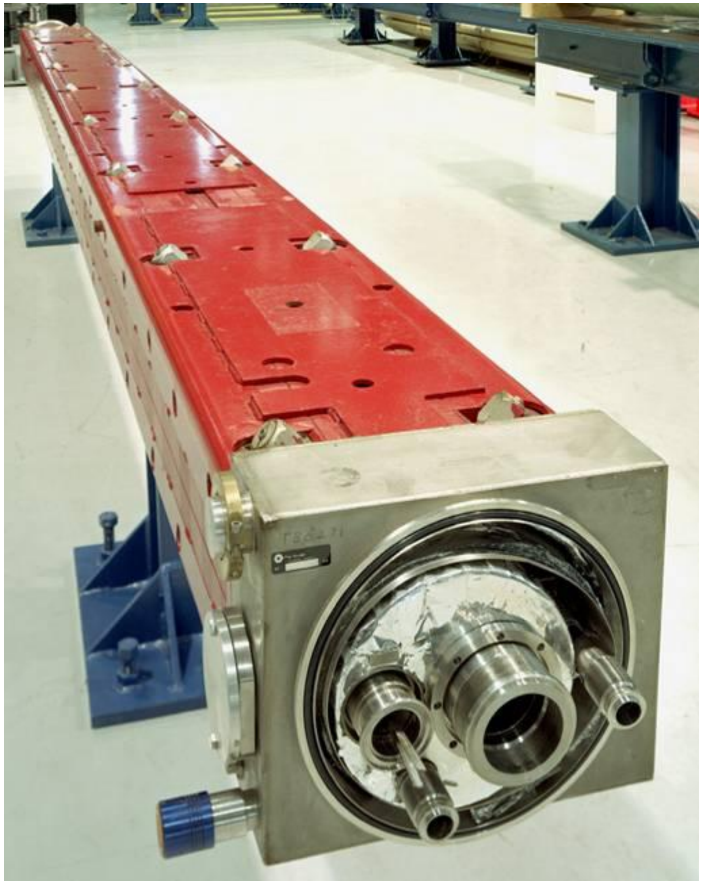
Looking Down on the Fermilab Accelerator Complex



Tevatron Overview

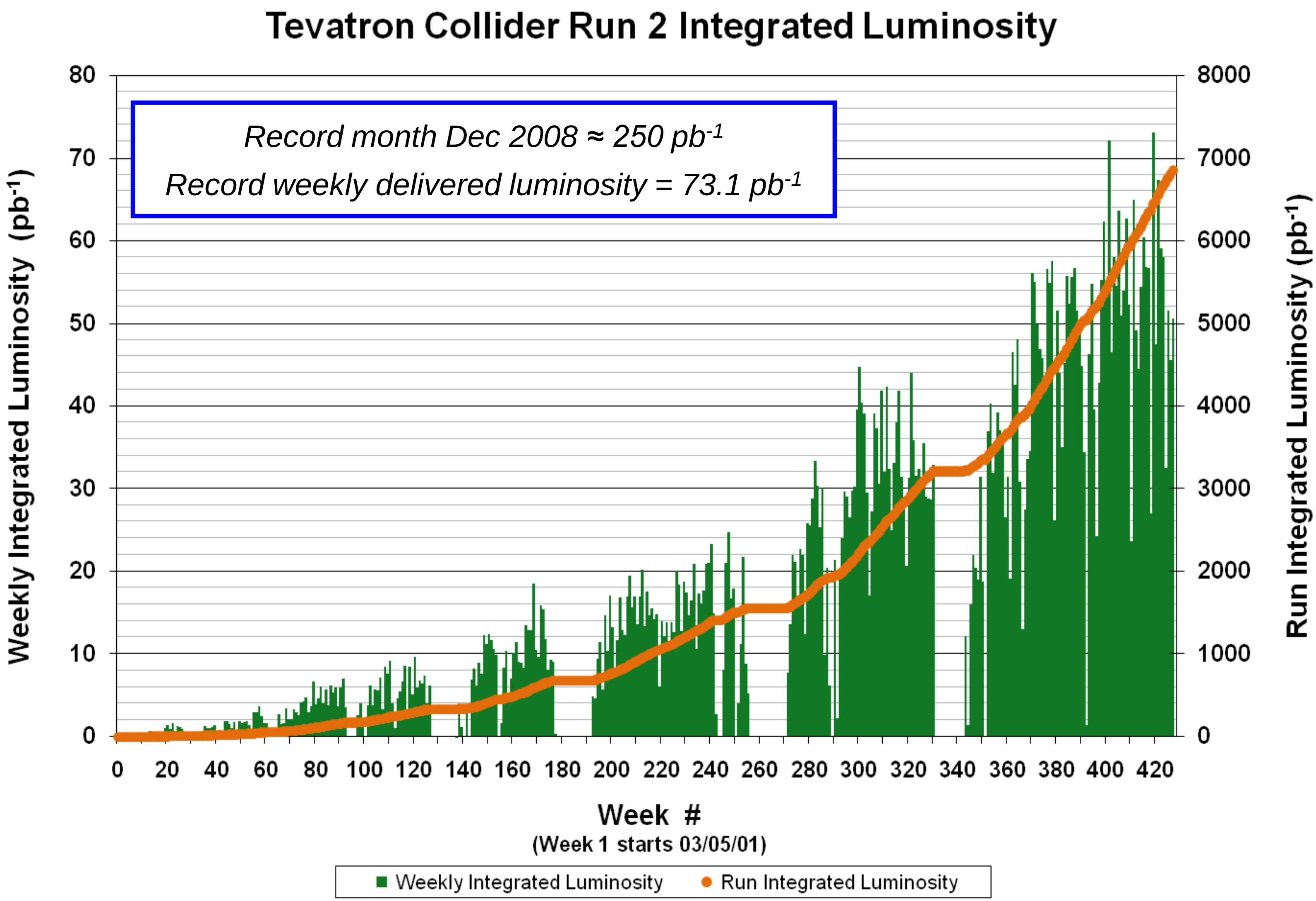
- Synchrotron providing proton-pbar collisions @ 980 GeV beam energy
  - Injection energy is 150 GeV
- Tevatron radius = 1 km $\Rightarrow$ revolution time ~ 21 μs
- Virtually all of the Tevatron magnets are superconducting
  - Cooled by liquid helium, operate at 4 K *fun fact: ≈350 MJ stored energy!*
- 36 bunches of proton and pbars circulate in single beampipe
  - 3 trains of 12 bunches with 396 ns separation
  - Electrostatic separators keep beams apart on helical orbits
- 8 Cu RF cavities to keep beam in bucket, provide acceleration
  - 1113 RF buckets (53.1 MHz $\Rightarrow$ 18.8 ns bucket length)
- 2 low β (small beam size) intersection points (CDF and D0)

Tevatron

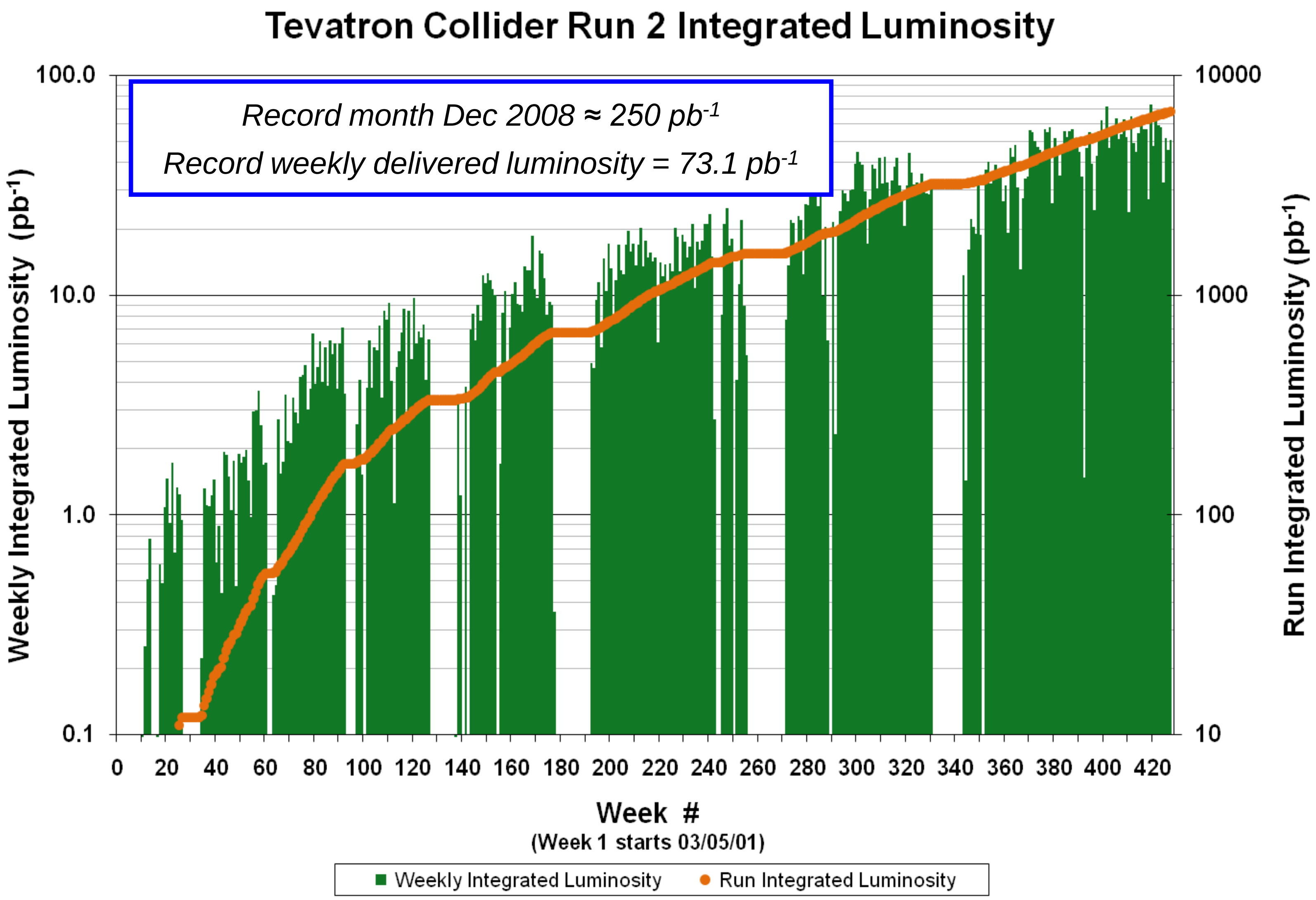


Tev dipole

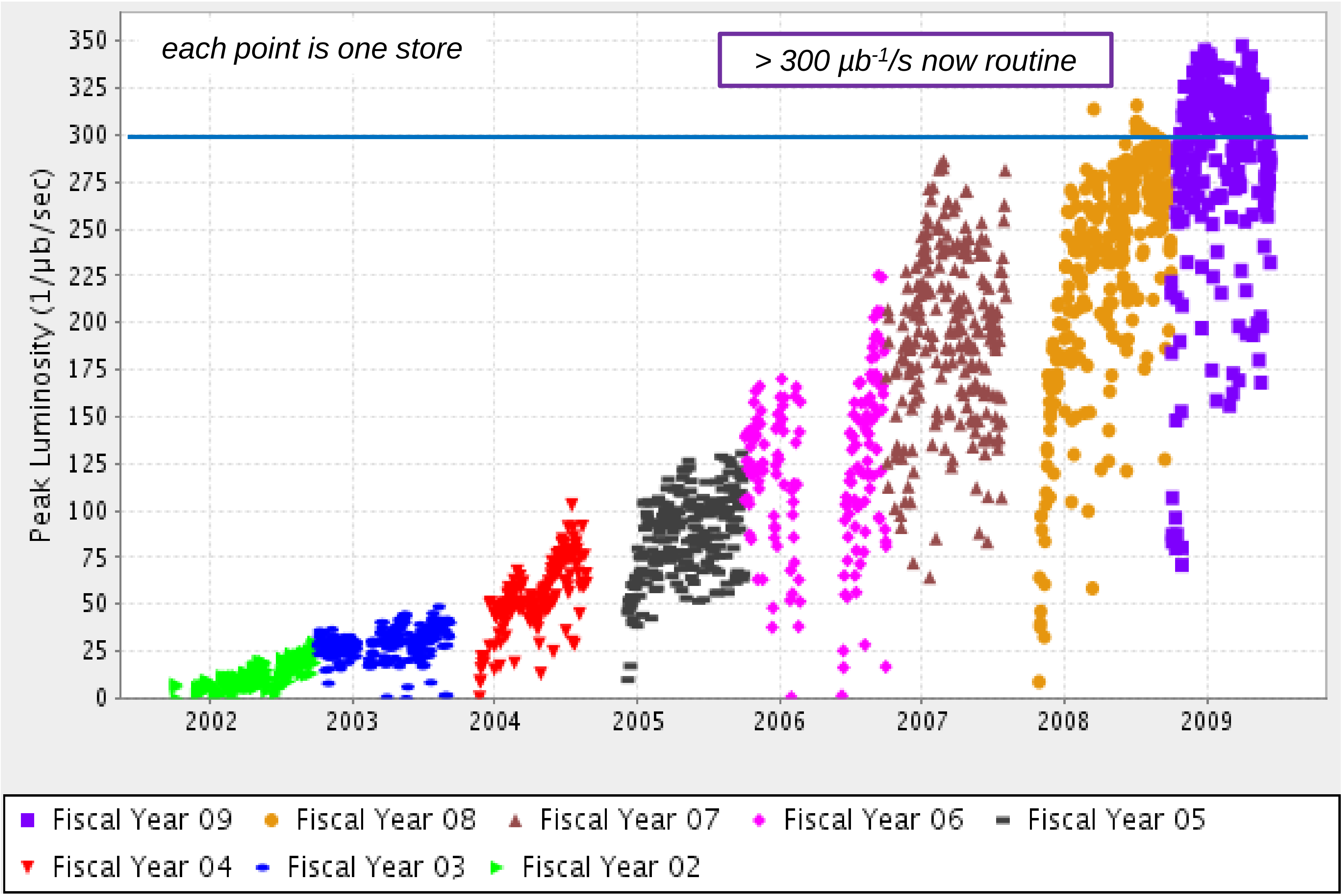
The Big Picture



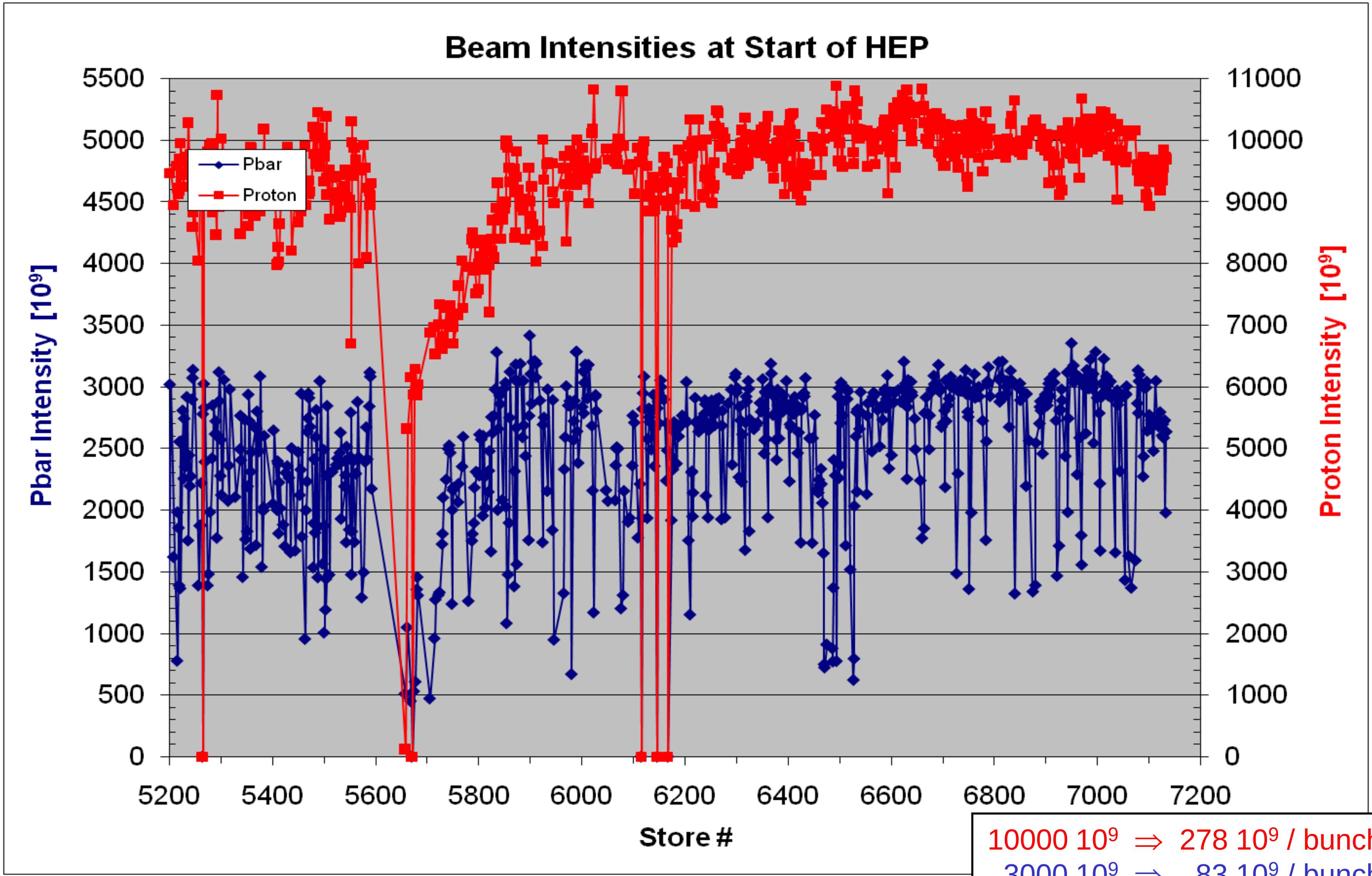
The Logarithmic Big Picture



Tevatron Peak Luminosity



Beam Intensities



$10000\ 10^9 \Rightarrow 278\ 10^9$ / bunch

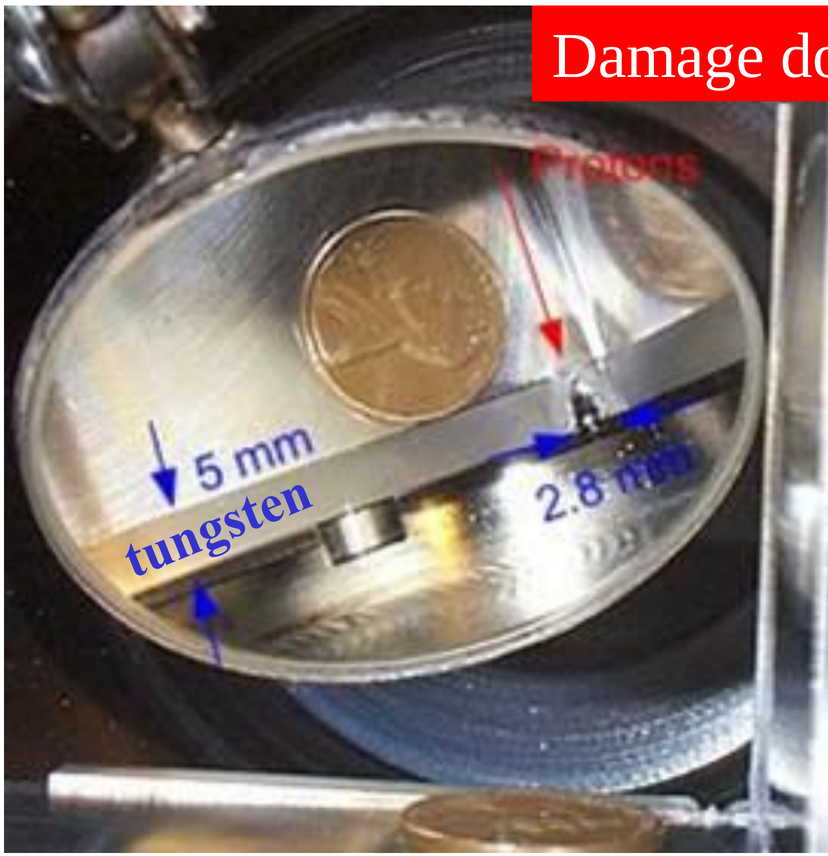
$3000\ 10^9 \Rightarrow 83\ 10^9$ / bunch

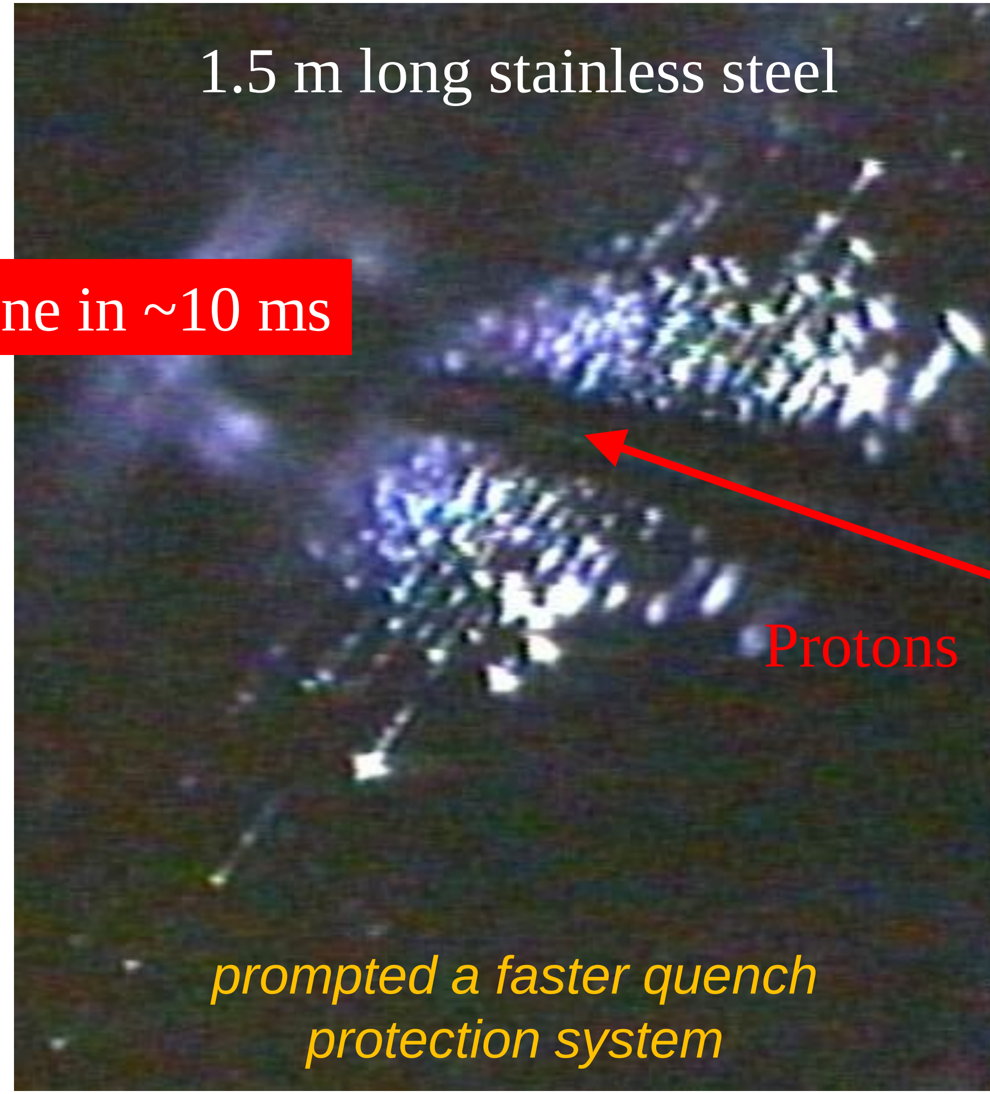
Destroyed Collimators in Tevatron (2003)

Stored beam energy

10^{13} protons @ 1 TeV ≈ 1.6 MJ

Damage done in ~10 ms





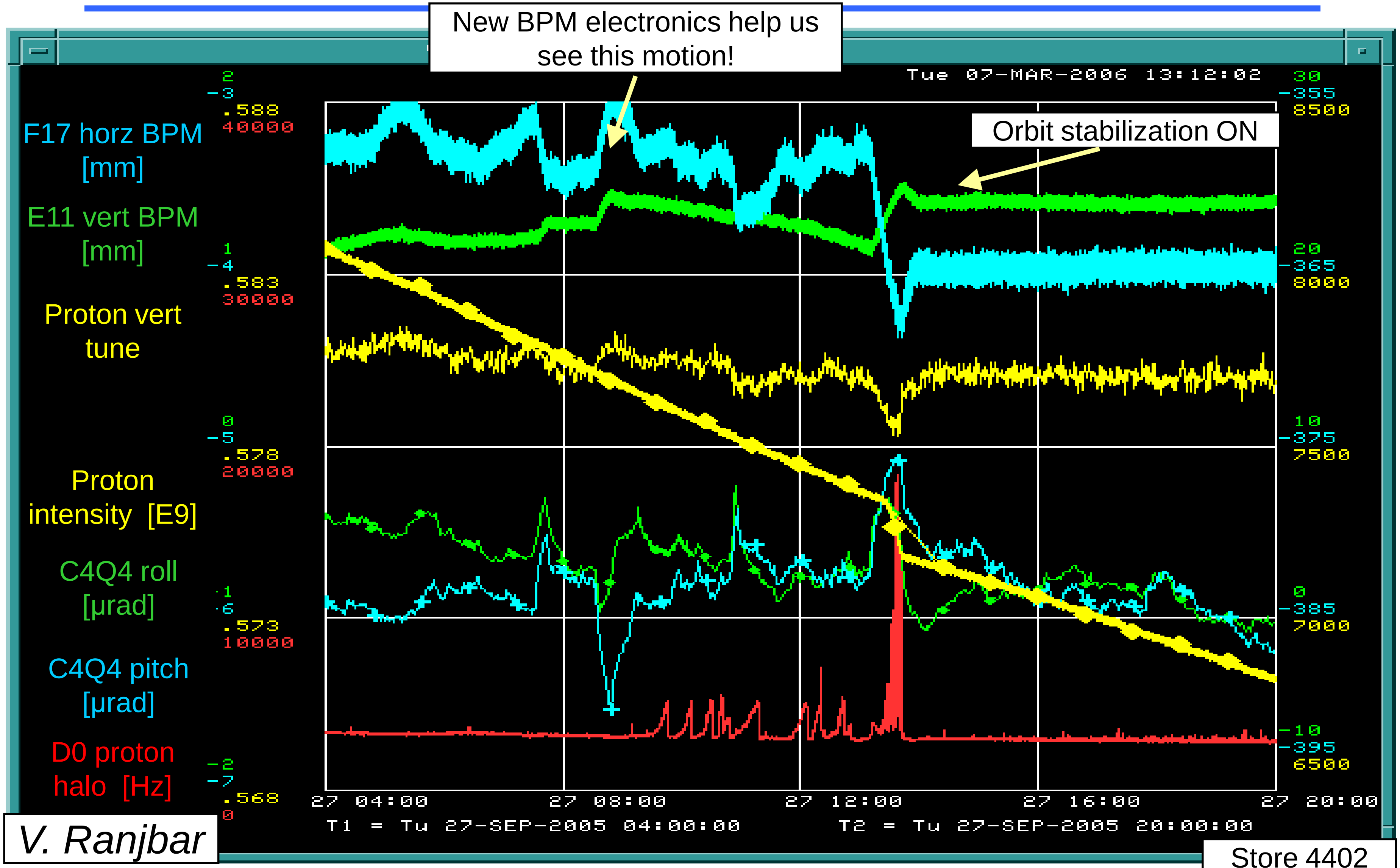
Increasing Tevatron Luminosity

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

- *N = bunch intensities, f = collision frequency*
- *ε = transverse emittance (size), σ_z = bunch length*
- *H = "hour glass" factor (~0.6 for finite bunch length)*

- Many gradual improvements
- Higher antiproton stacking rate → more antiprotons faster
- Recycler + Electron Cooling → more pbars with smaller emittances
- Smaller β* at CDF and D0 → smaller beam size (now down to ≈30μm)
- Improved beam lifetimes in Tevatron
  - More separation between protons and antiprotons
- Better instrumentation, monitoring
- Better reliability, reproducibility

Magnet Motion / Orbit Stabilization



Strategy: Be Efficient, Be Consistent

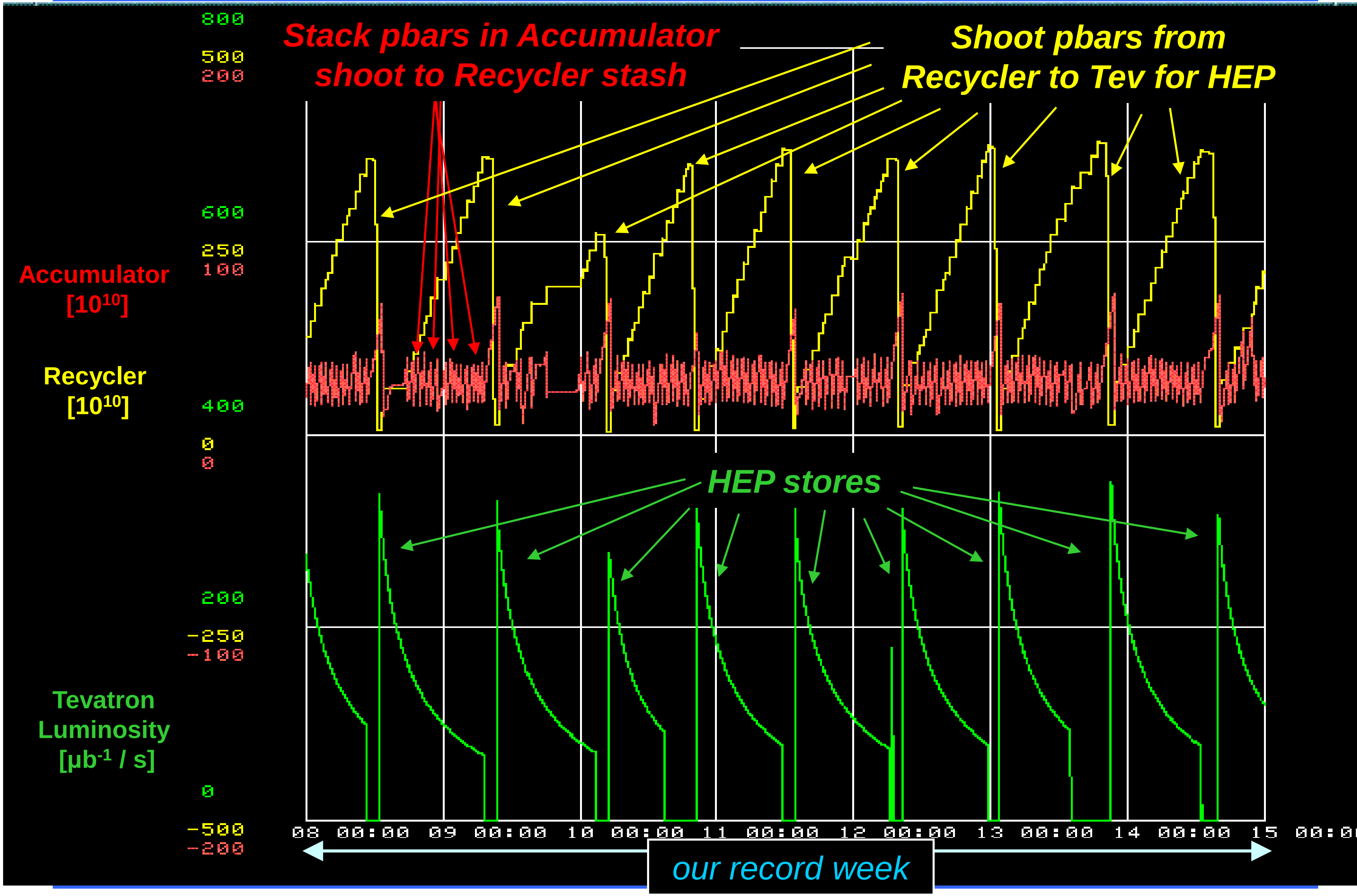
- Big upgrades are done ⇒ Make the most of what we've got!

- Make HEP shot-setup more efficient
  - "One-shots" for Tevatron injection when needed – allows more pbar stacking cycles
  - Automation of tune, coupling, chromaticity measurements/settings
  - Working on faster proton injection → 2 bunches per shot instead of 1

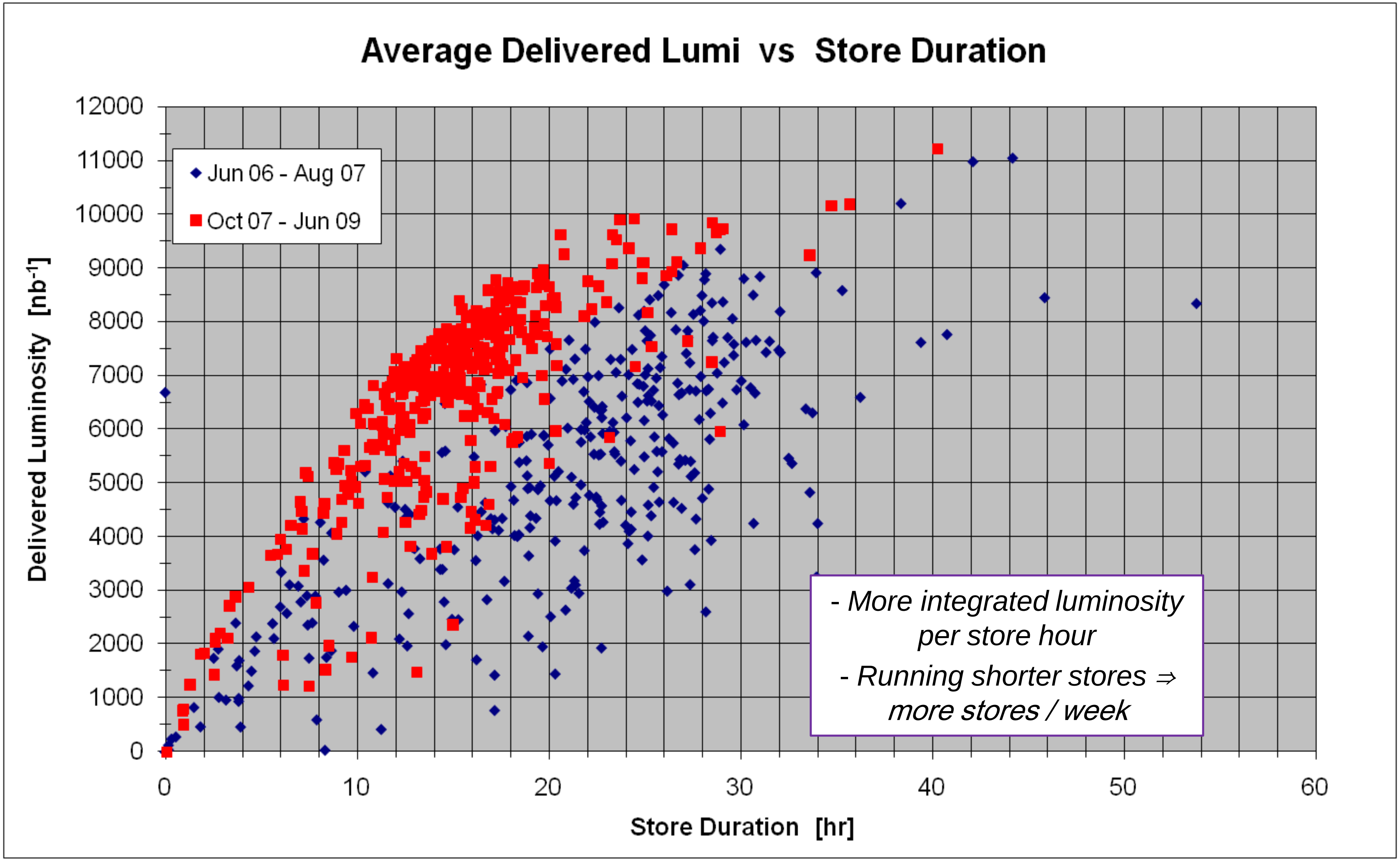
- Increased/improved automation
  - Tune, coupling, chromaticity measurements/settings during shot-setup
  - Orbit smooths during/between HEP stores
    - Reduce orbit drifts store-to-store, keeps optics consistent; sneak beam losses through IPs
  - Faster scraping/halo removal
  - Beam-beam tune shift control
    - Automated proton tune settings to account for varying pbar intensities shot-to-shot
    - Monitor decrease in beam-beam tune shift during store, alert operators to nudge up

- Shorter HEP stores
  - Higher average pbar stacking rate → shorter stores for ≈ same initial lumi
  - More stores with higher average luminosity over store duration

Stack, Stash, Store - Repeat



More Integrated Luminosity per Store



Beam-Beam Effects

- Recall both beams circulate within a single beam pipe!
  - EM fields from one beam disrupts the other when passing near/through it
- Head-on and long-range collisions (parasitic or "near-miss")
  - Would like > 5σ separation between beams prior to collisions
    - Not always possible
  - Affects all aspects of operation – injection, acceleration, squeeze,…
- Highest antiproton intensities are problematic
  - Antiprotons 3-4x smaller transversely than protons
  - High proton losses occasionally quench the Tevatron in squeeze
  - Early in HEP proton lifetime can dominate lumi lifetime
  - Occasionally back off beam intensities to sort out issues

Head-On Beam-Beam Effects

- Head-on collisions: each beam acts as (non-linear) focusing lens
  - Tune gets shifted up proportional to (N / beam size)
  - Tune footprint also spreads out – unavoidably crossing resonances

Head-on beam-beam tune shift parameter

$$\xi = \frac{3r_0}{2}\frac{N}{\varepsilon}$$

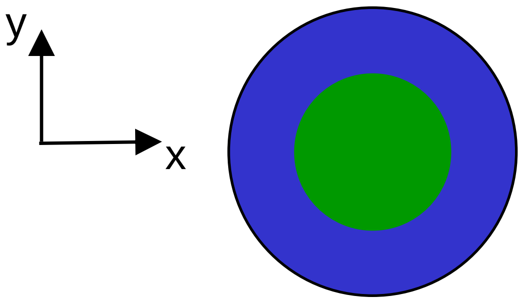
- *N = bunch intensity*
- *ε = transverse emittance*
- *r_0 = classical radius of proton*

2 collision points

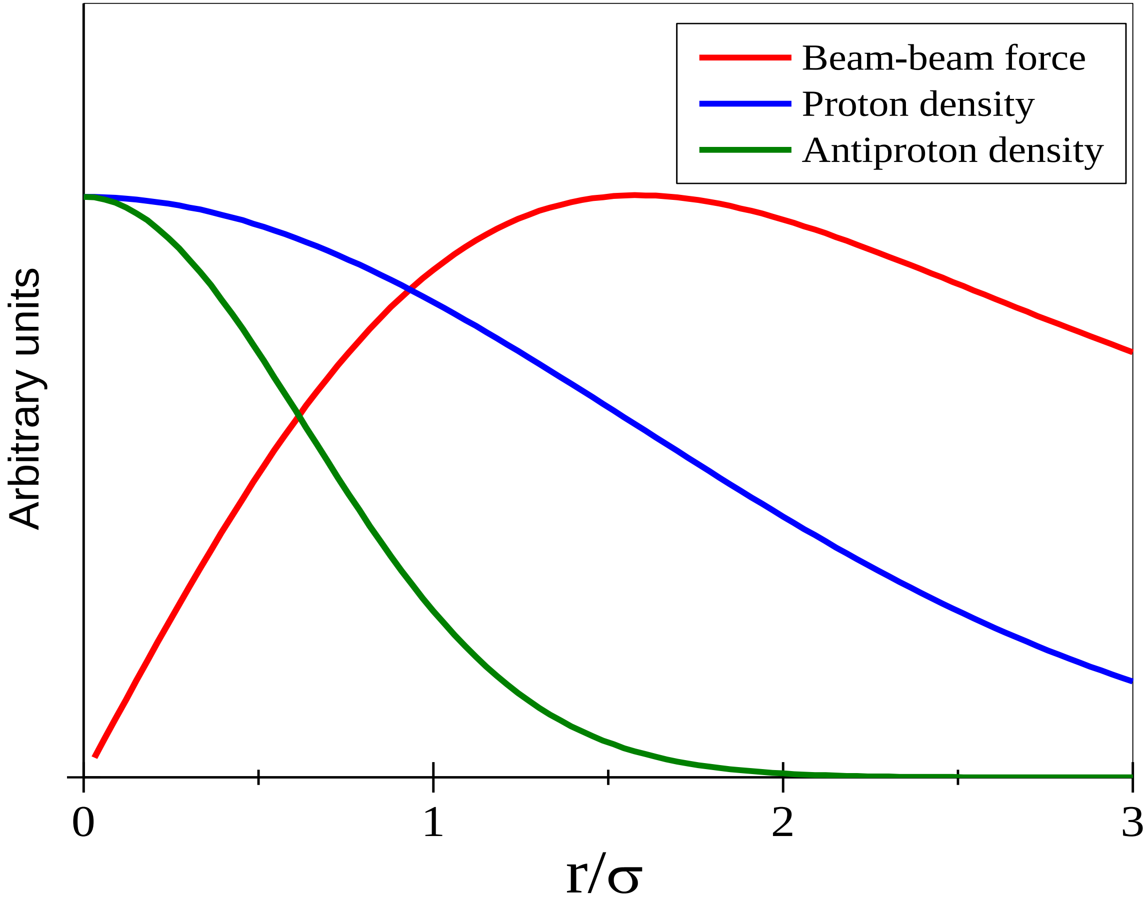
- $N_P \approx 250\ (10)^9$ $\varepsilon_P \approx 18\pi$ mm-mrad → $\xi_A \approx 0.020$ (pbar shift from protons)
- $N_A \approx 70\ (10)^9$ $\varepsilon_A \approx 5\pi$ mm-mrad → $\xi_P \approx 0.020$ (proton shift from pbars)

- **Beam-beam tune shift on protons ≈ pbars!**

Schematic of Beam-Beam Force on Proton Bunch

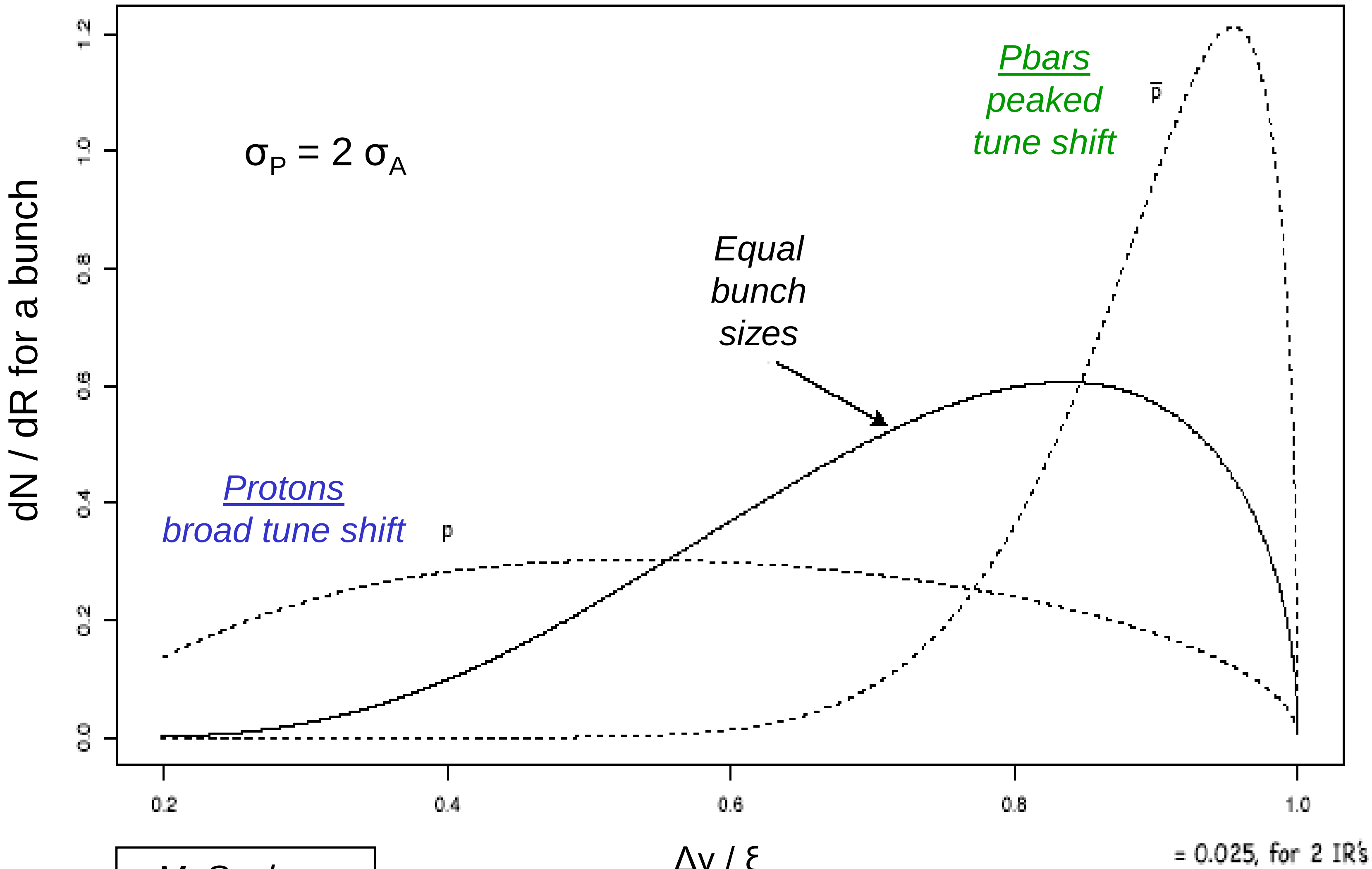


Round, gaussian bunches
proton pbar



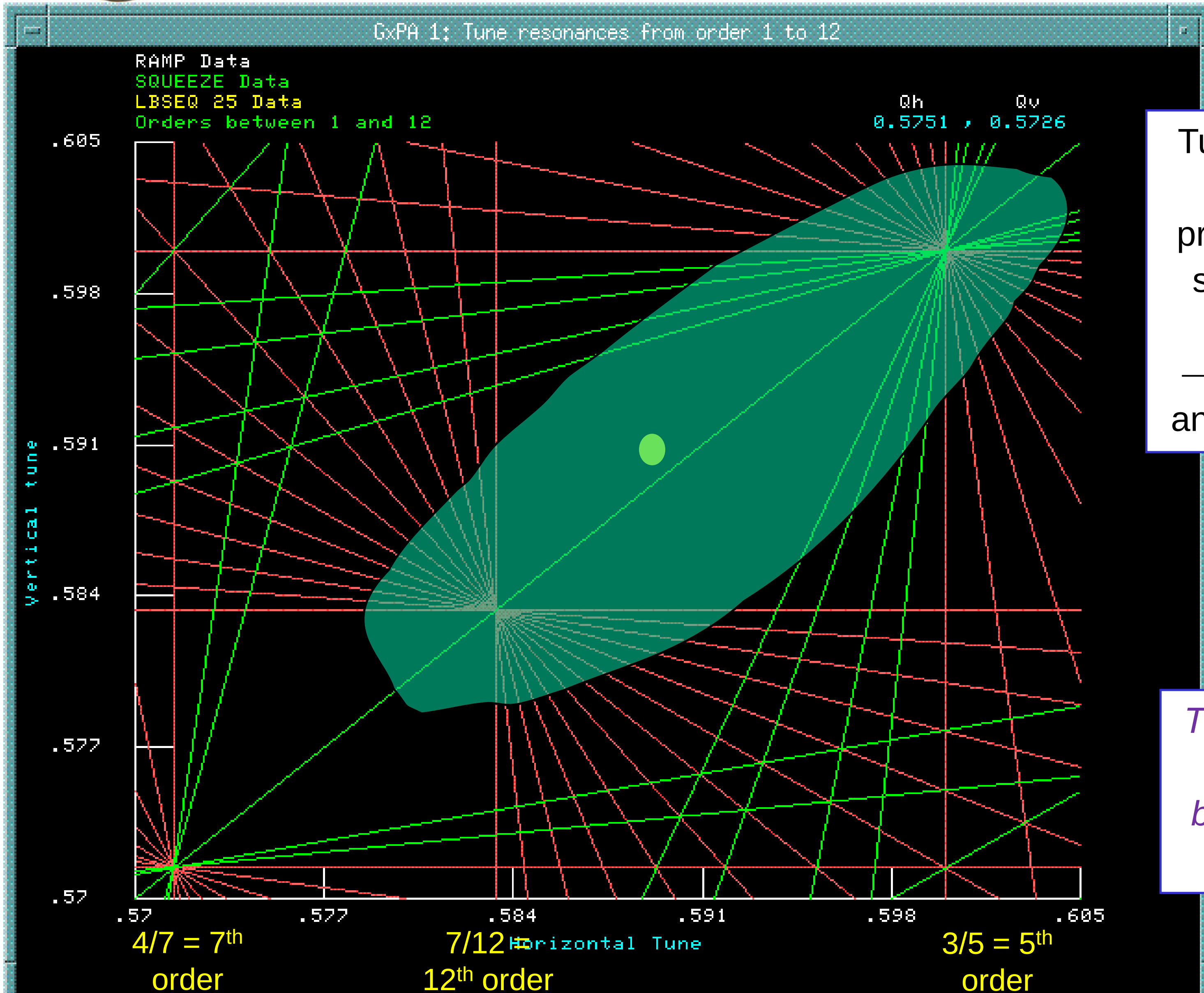
A significant fraction of the proton bunches feel the strongest, non-linear beam-beam force from the smaller pbars

Beam-Beam Tune Shift Distributions



M. Syphers

Beam-Beam Tune Spread



Tune spread caused by pbars causes proton tunes to span strong resonances

→ higher beam loss and/or poorer lifetime

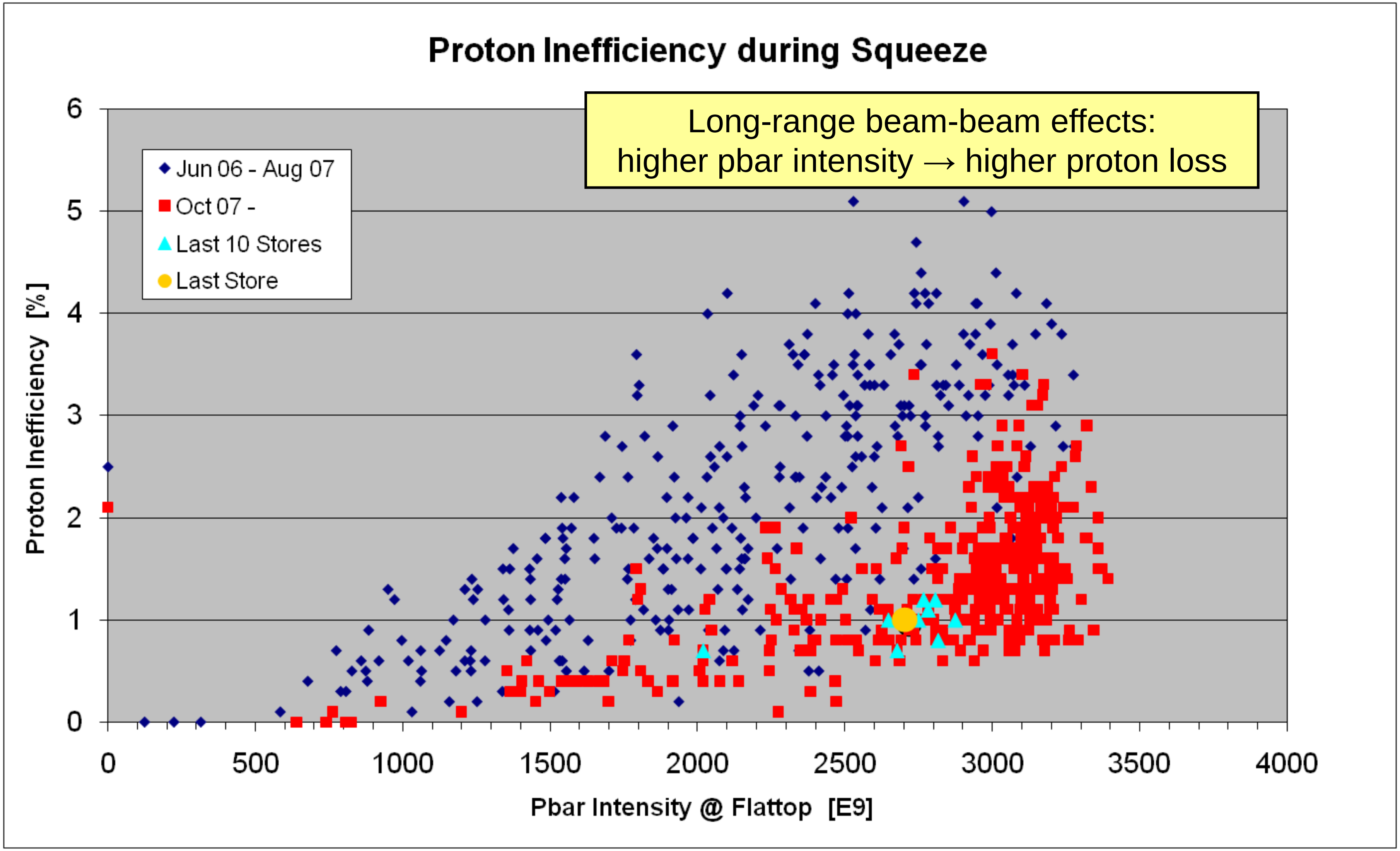
This is just an "artist's rendering" of the beam-beam induced tune spread…

Mitigating Beam-Beam Effects

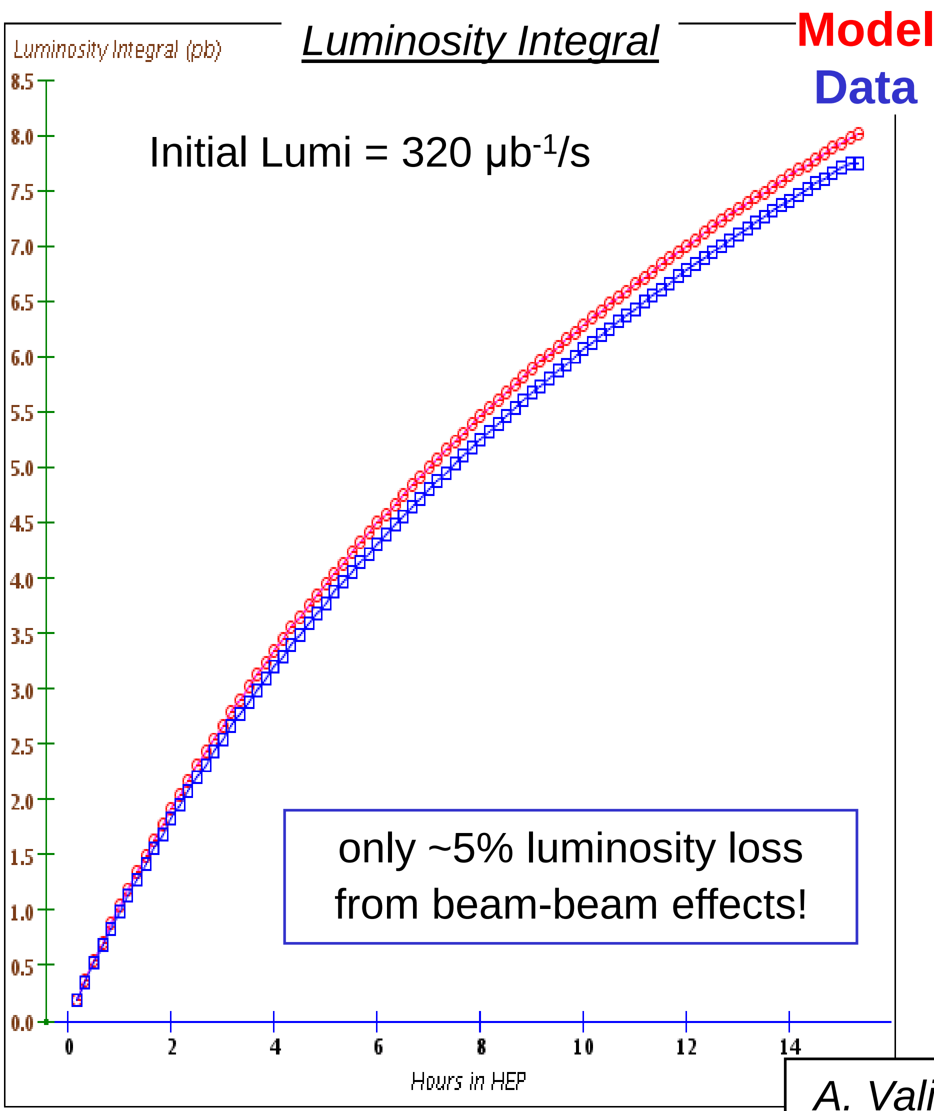
- Since ~Feb 08 deliberately “blowing up” antiprotons by ≈25% at flattop
  - Noise source on directional stripline
  - Reduce the emittance mismatch → proton tune spread
  - Helps beam losses in squeeze and in collisions
  - Would like to optimize the scheme, account for bunch-by-bunch differences

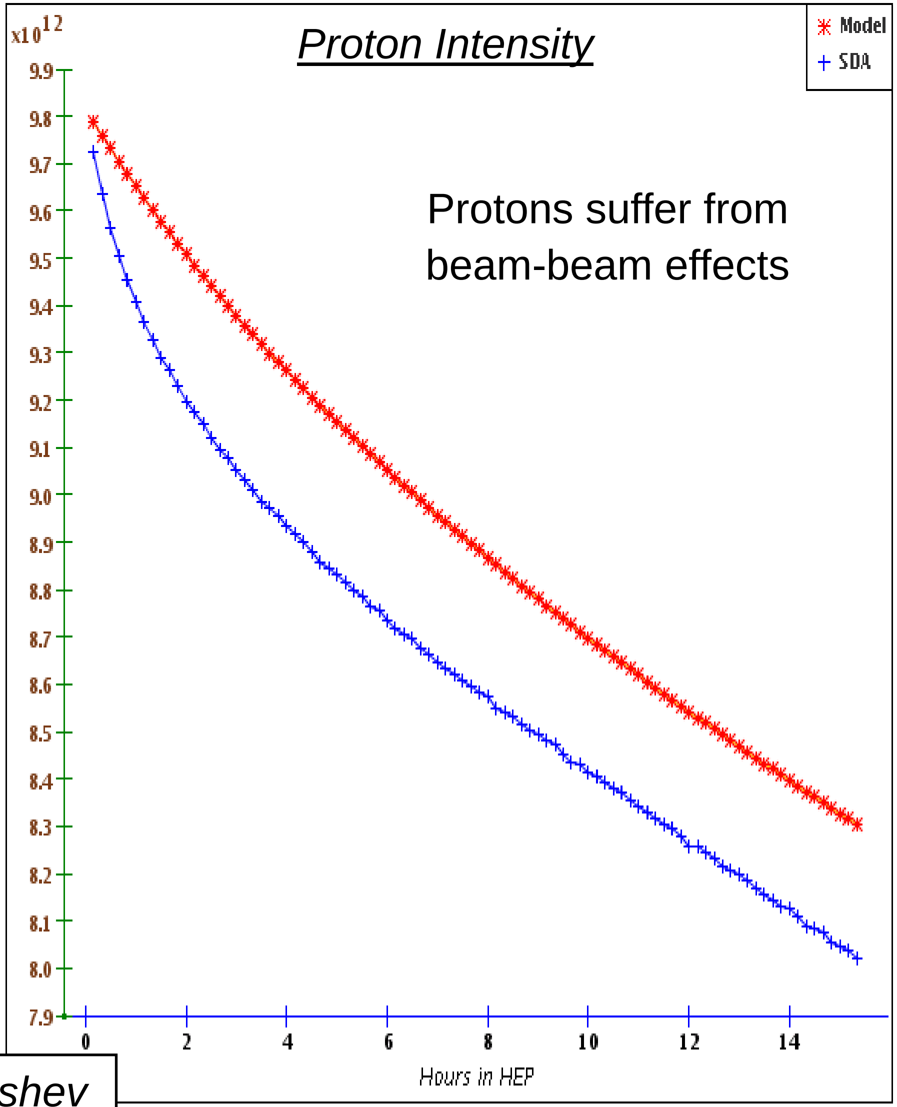
- Also testing scraping higher intensity protons @ 8 GeV in Main Injector
  - Bump beam into collimators, remove tails that would be lost in Tevatron

Proton Loss in Squeeze vs Pbar Intensity



Store 6908 – Comparison to Model without Beam-Beam Effects

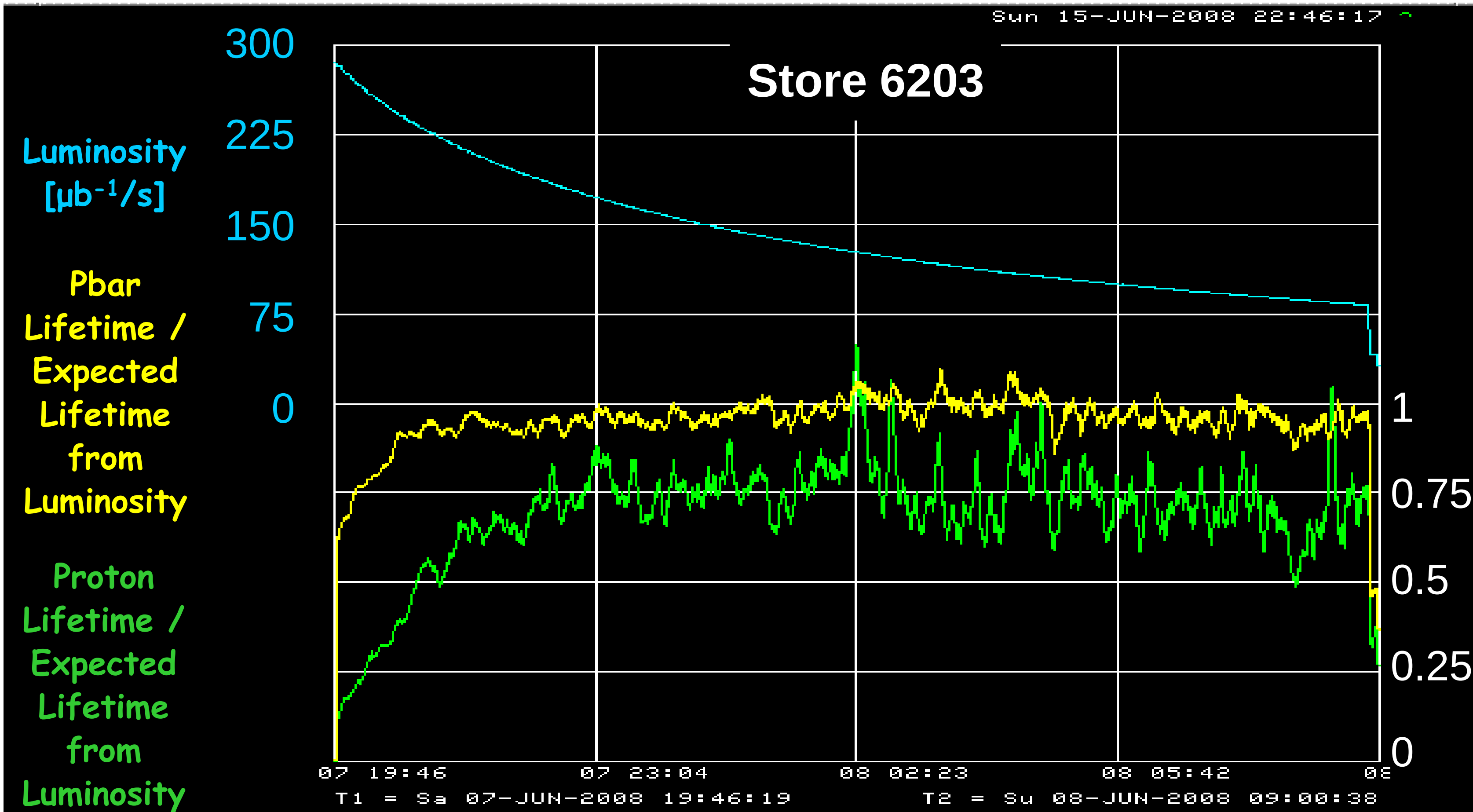




A. Valishev

Beam Lifetimes during HEP

- Pbar lifetime dominated by luminosity – good
- Most protons lost in non-luminous processes – but better with larger pbar emittances



Reliability

Year	Stores	Normal Terminations	%Normal Terminations	Avg Store Hrs/Week (outside of planned shutdowns)
2003	186	55	30%	-
2004	166	110	66%	100
2005	243	170	69%	110
2006	171	107	63%	100
2007	220	177	80%	110
FY2008	304	262	86%	106
FY2009	275	244	88%	110

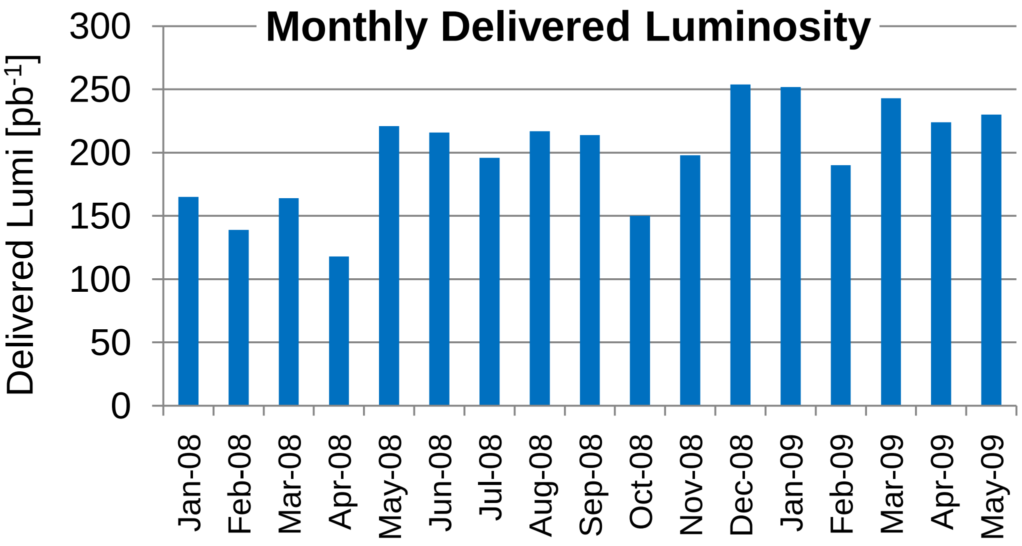
Improving Reliability

Prospects

- More pbars (faster) still most straightforward way to higher luminosity
- Believe Tevatron can deliver peak luminosity > 400 $\mu b^{-1}/s$
  - As a stunt, since integrated lumi would fall off @ current stacking rates
- Squeeze losses still a concern, so still blow up pbars @ flat-top
  - Identified aperture restriction on B-side of CDF (displaced beam pipe)
  - During Oct 08 shutdown, found pipe misaligned as expected
  - Moved pipe successfully to open up aperture (though not quite centered)
- All machines continue working on operational robustness, efficiency
- Quote from my boss (Roger Dixon) in Fermilab Today:
  - *"…the Accelerator Division has no shortage of innovative people who get an adrenalin rush from making unexpected improvements that could make our projections look silly."*

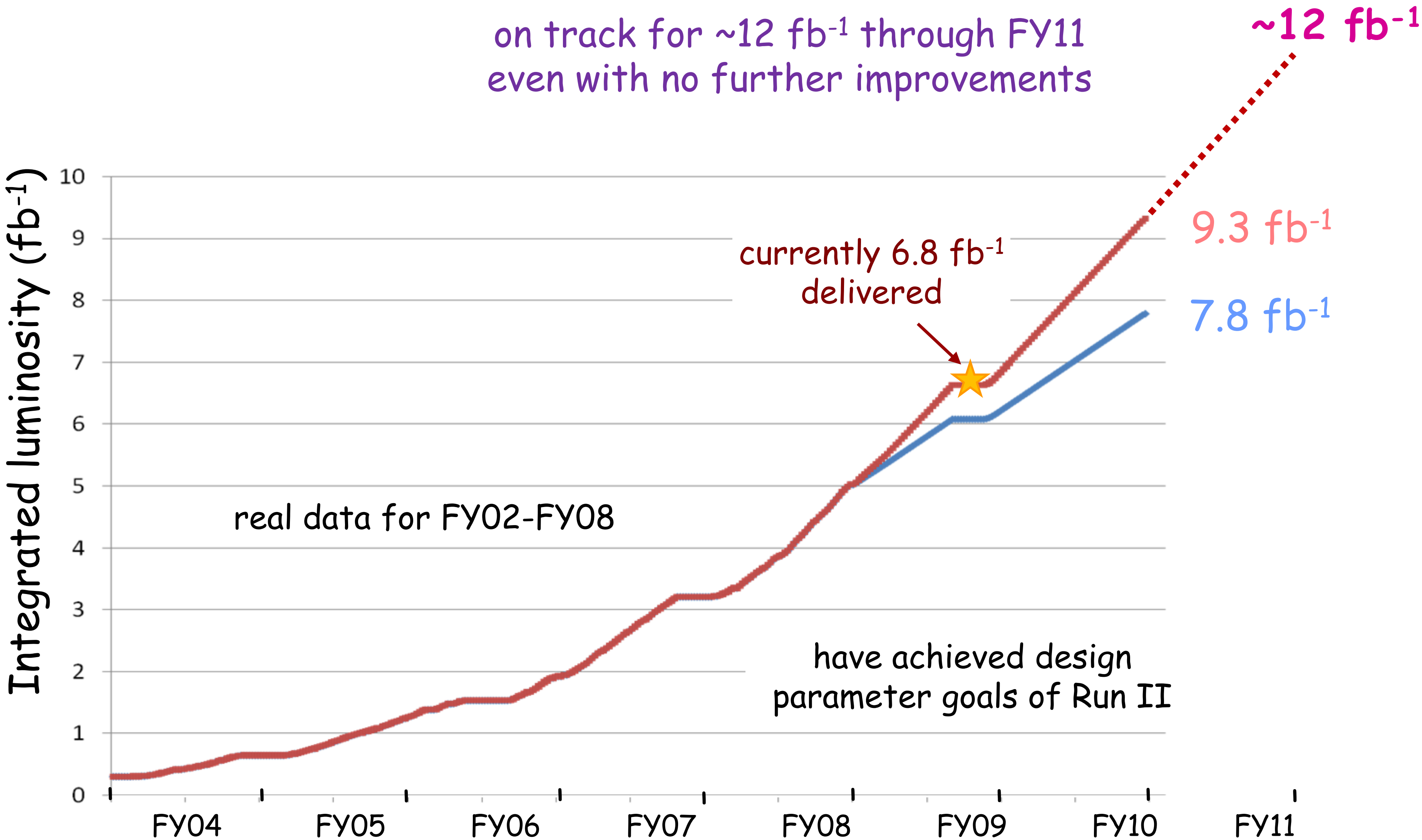
Luminosity Projections

- 200 pb^{-1} / month has become routine



- > 2.5 fb^{-1} / year is reasonable goal
  - No shutdowns, still need to be lucky
- 12 week shutdown began June 15
  - Install rest of new Booster correctors, poke holes in MI for NOvA
  - Find and fix known leaks in 8 of 24 Tevatron cryogenic houses

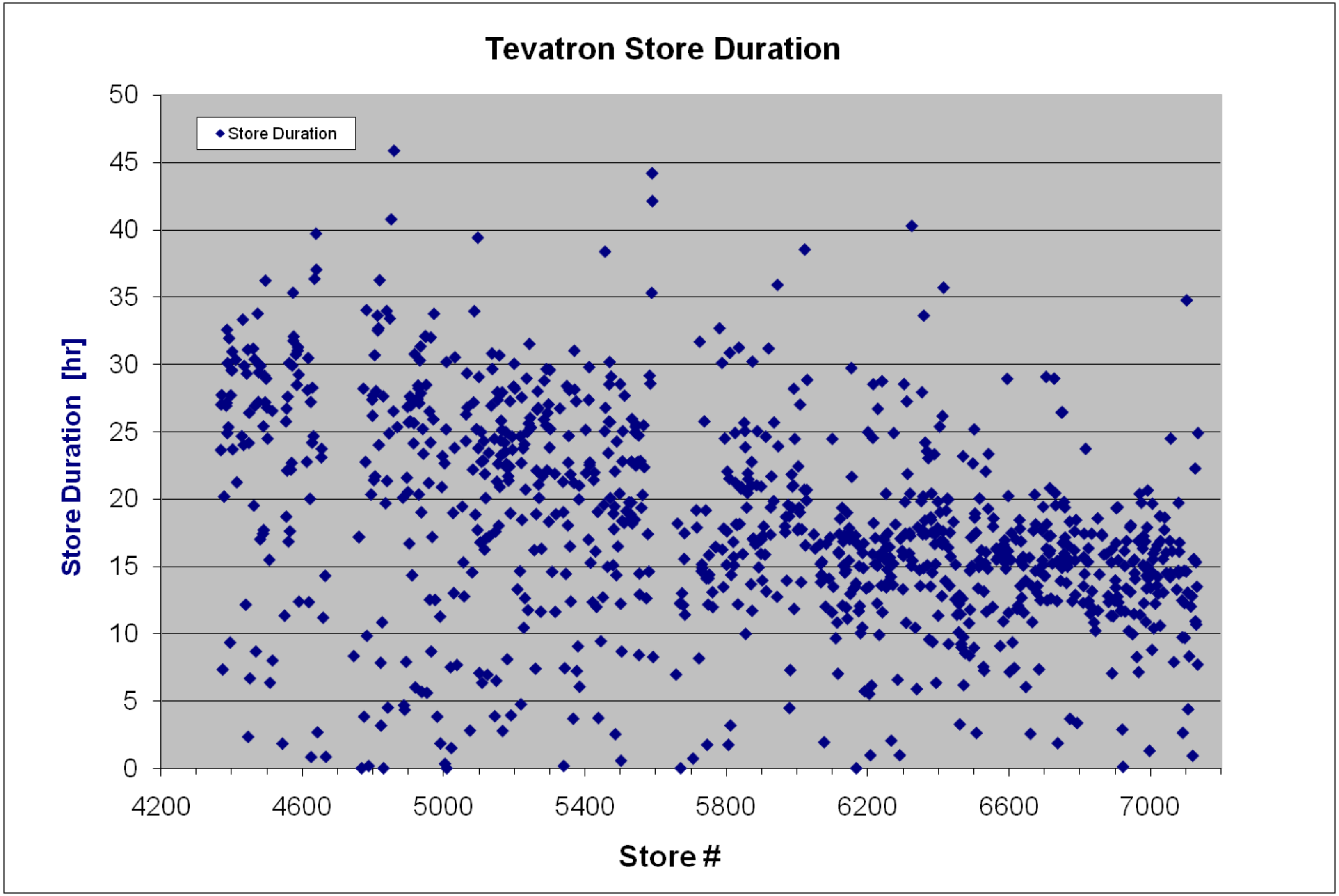
Luminosity Projection



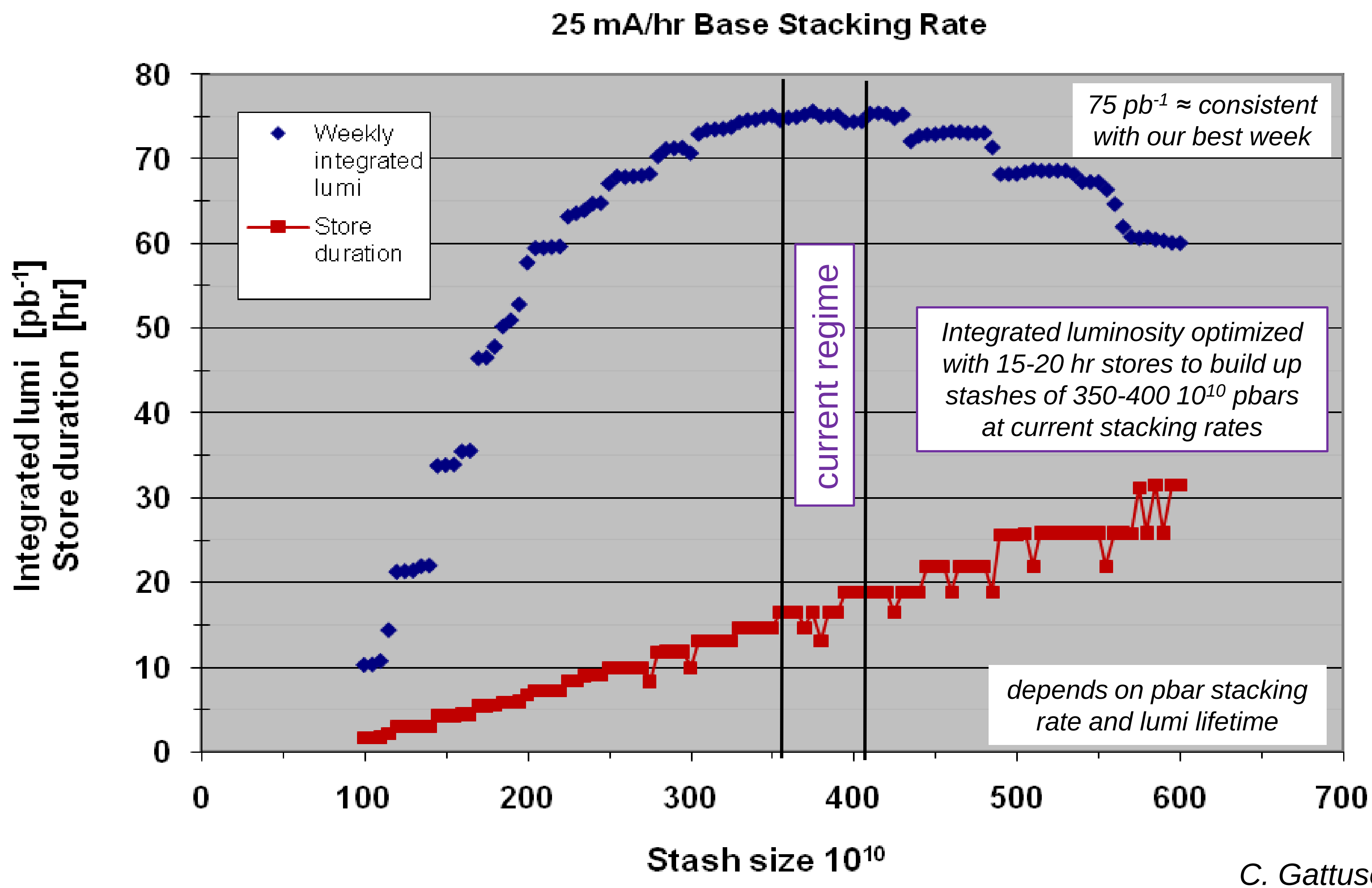
Summary

- Tevatron and whole accelerator complex running great
  - delivered ≈ 3.5 fb^{-1} over last running period (Oct 07-Jun 09)
  - now approaching 7 fb^{-1} total in Run 2
- Peak lumi > 300 $\mu b^{-1}/s$ and integrated > 200 pb^{-1}/month routine
- Ongoing efforts to improve operational efficiencies and get more pbars/week and HEP stores with greater lumi/hr
- Could deliver > 9 fb^{-1} by end FY10 and nearly 12 fb^{-1} by end FY11
  - *Let's go all the way through FY11!*
- Looking forward to physics results from both CDF and D0

Tevatron HEP Store Lengths



Collider Operational Model



C. Gattuso

Making HEP Shot-Setup Faster