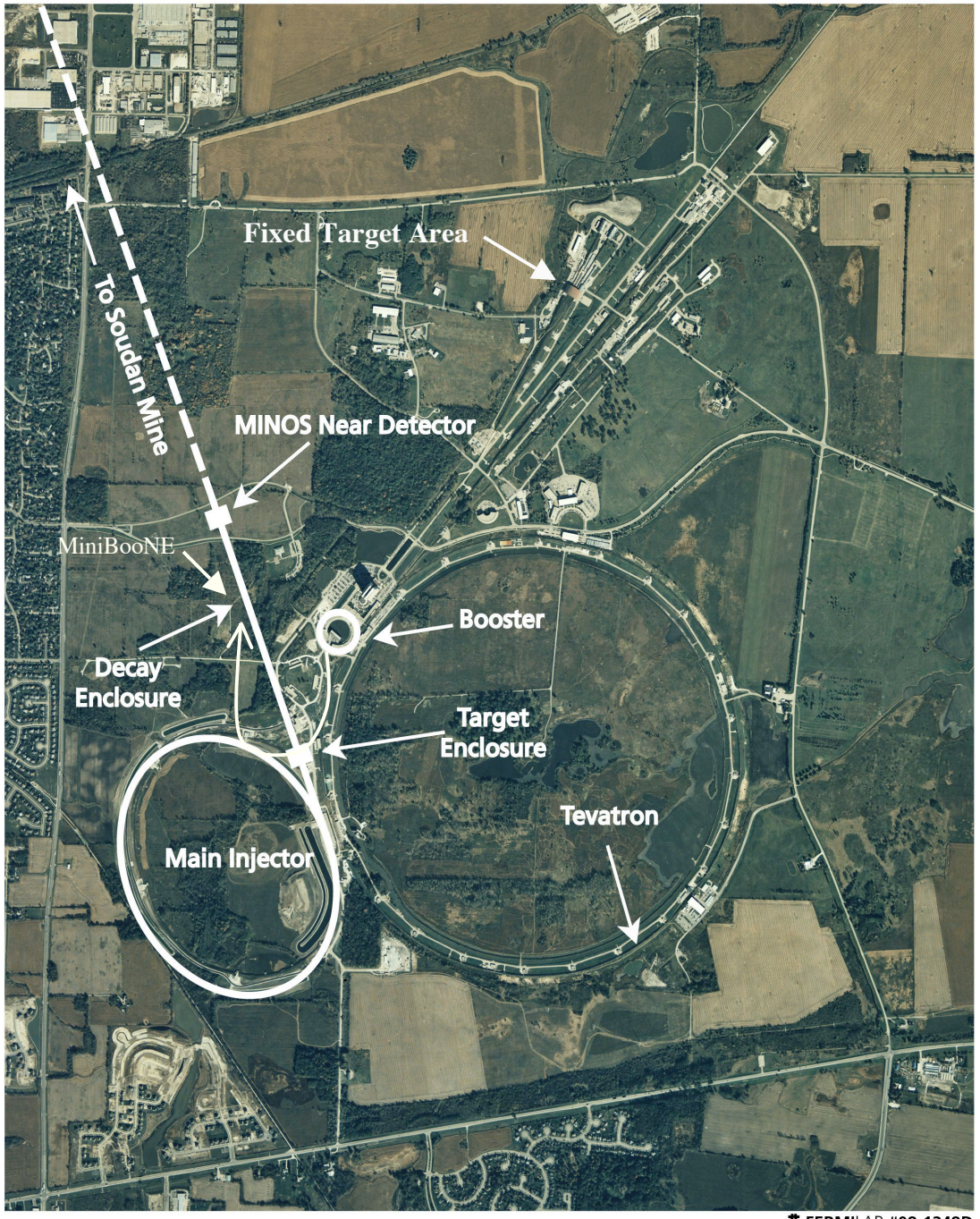
Run II and the Tevatron Collider

R. Dixon

Overview

- Run II History
- Run II Upgrade Plan
- Progress
- Outlook



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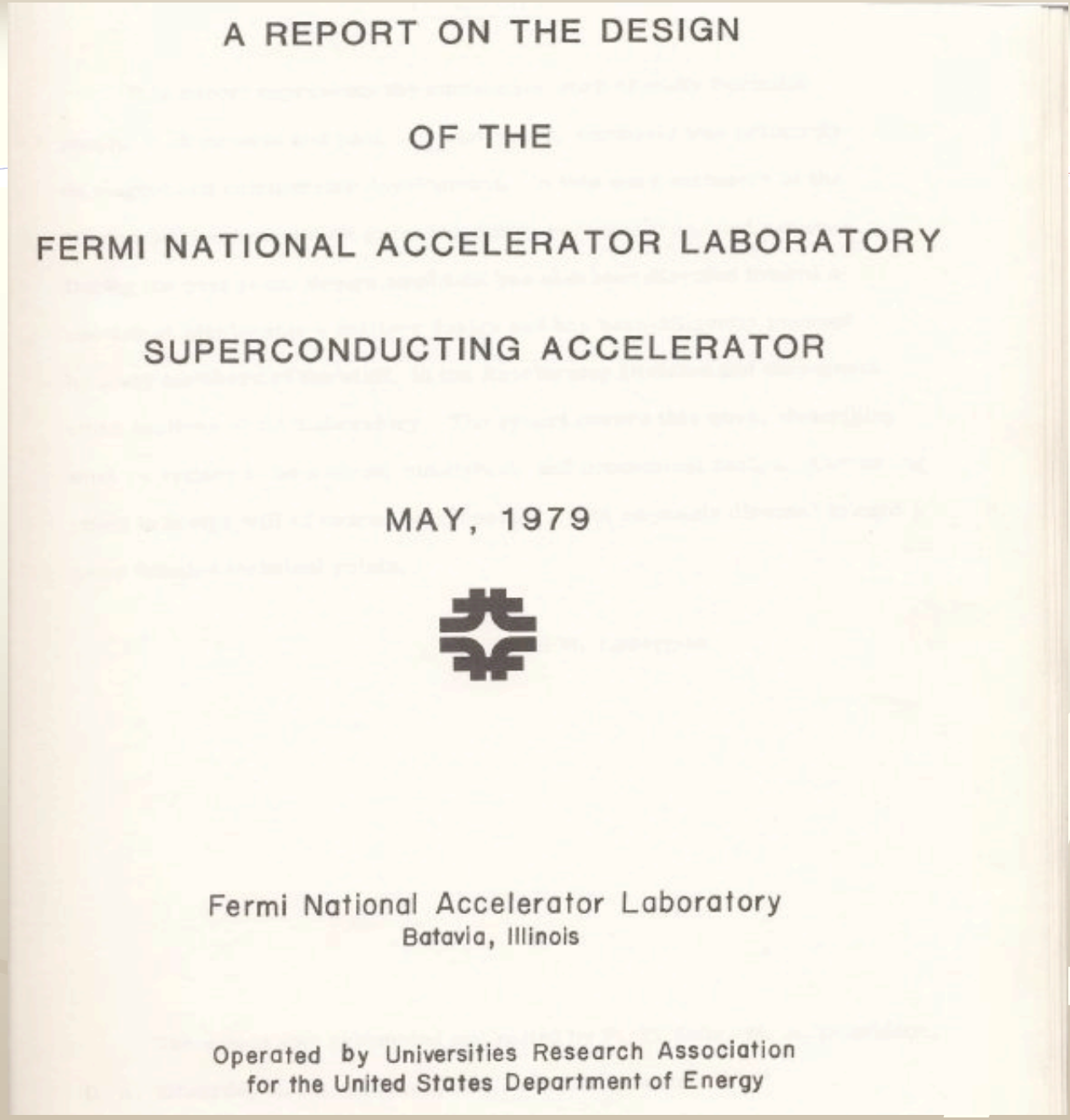


A REPORT ON THE DESIGN

OF THE

FERMI NATIONAL ACCELERATOR LABORATORY

SUPERCONDUCTING ACCELERATOR

MAY, 1979

Fermi National Accelerator Laboratory
Batavia, Illinois

Operated by Universities Research Association
for the United States Department of Energy

Initial Design Specifications

Table 1-II. $\bar{p}p$ Collider Specifications.

Peak energy	(800-1000 GeV) × (800-1000 GeV)
No. of bunches in each beam	1-12
Luminosity/bunch	$1\text{-}8 \times 10^{28}\,\mathrm{cm}^{-2}\,\mathrm{sec}^{-1}$
No. of interaction region	1-2
Longitudinal space for detector	> 10 m
Vacuum in warm regions	$< 10^{-8}$ Torr
Storage time	> 3 h
Injection	Forward and backward, single bunch
RF	Independent phase adjustments on $\bar{p}$ and p bunches
Abort	Forward and backward

$$\approx 10^{30}\,cm^{-2}\,\mathrm{sec}^{-1}$$

Table 1-I. Fixed-Target Accelerator Specifications.

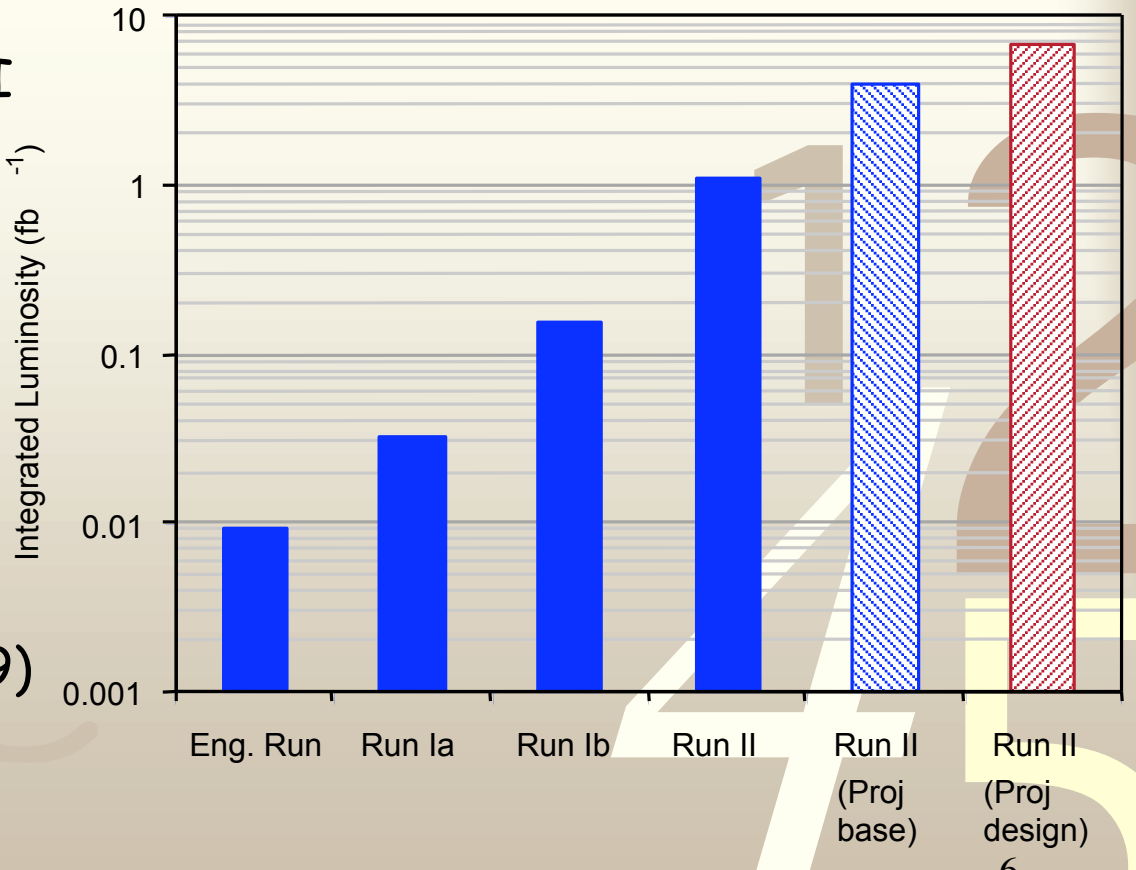
Peak energy	800-1000 GeV
Intensity	$> 2 \times 10^{13}$ ppp
Injection energy	150 GeV, single turn
Repetition rate	1-2 cycles/min
Acceleration rate	50-75 GeV/s
Flattop time	Variable to dc
Extraction	Slow: 1 to 10 s
	Fast: 1 ms
Beam abort system	Single - turn extraction

Events in History

- Energy Doubler completed March, 1983
  - First fixed target run at 800 GeV begins--1984
  - CDF approved 1982
  - E-691 approved (Witherell-- tagged photon)-- 1983
  - LAPDOG Rejected-- 1983
  - Dzero Approved as second collider detector-- 1984
  - E-743 Approved in 1983; completed in 1985
  - First Collisions observed at CDF-- 1985
  - First Collider Engineering Run-- 1986
  - Energy Doubler becomes the Tevatron-- 19??
  - Run I begins with Dzero and CDF-- 1992
  - Run II begins-- 2002

Collider Luminosity History (per detector)

- 1986-1987 Eng. Run I
  - .05 pb^{-1}
- 1988-1989 Eng. Run II
  - 9.2 pb^{-1}
- Run Ia (1992-1993)
  - 32.2 pb^{-1}
- Run Ib (1994-1996)
  - 154.7 pb^{-1}
- Run II (2002-2005)
  - 1100 pb^{-1}
- Projected (2006-2009)
  - 4000 - 8000 pb^{-1}



Run II Plan

- History
  - "Run II is a complex campaign of operations, maintenance, upgrades, R&D, and studies" Dan Lehman
  - Conceived in 2002 to enhance the performance of the Collider program
  - Plan written down in 2003
  - Major work began in 2003 and 2004 shutdowns and will continue through 2006

Run II Upgrade Plan Goals

- Increase Protons on antiproton target
  - Misc Booster improvements
  - Slip stacking in MI
- Antiproton Acceptance
  - AP2 aperture
- Antiproton Stacking and Cooling
  - Stacktail upgrade
  - Electron Cooling
  - Rapid Transfers
- Tevatron improvements
  - Alignment
  - Beam separation
  - Beam-Beam compensation
  - Improved Instrumentation

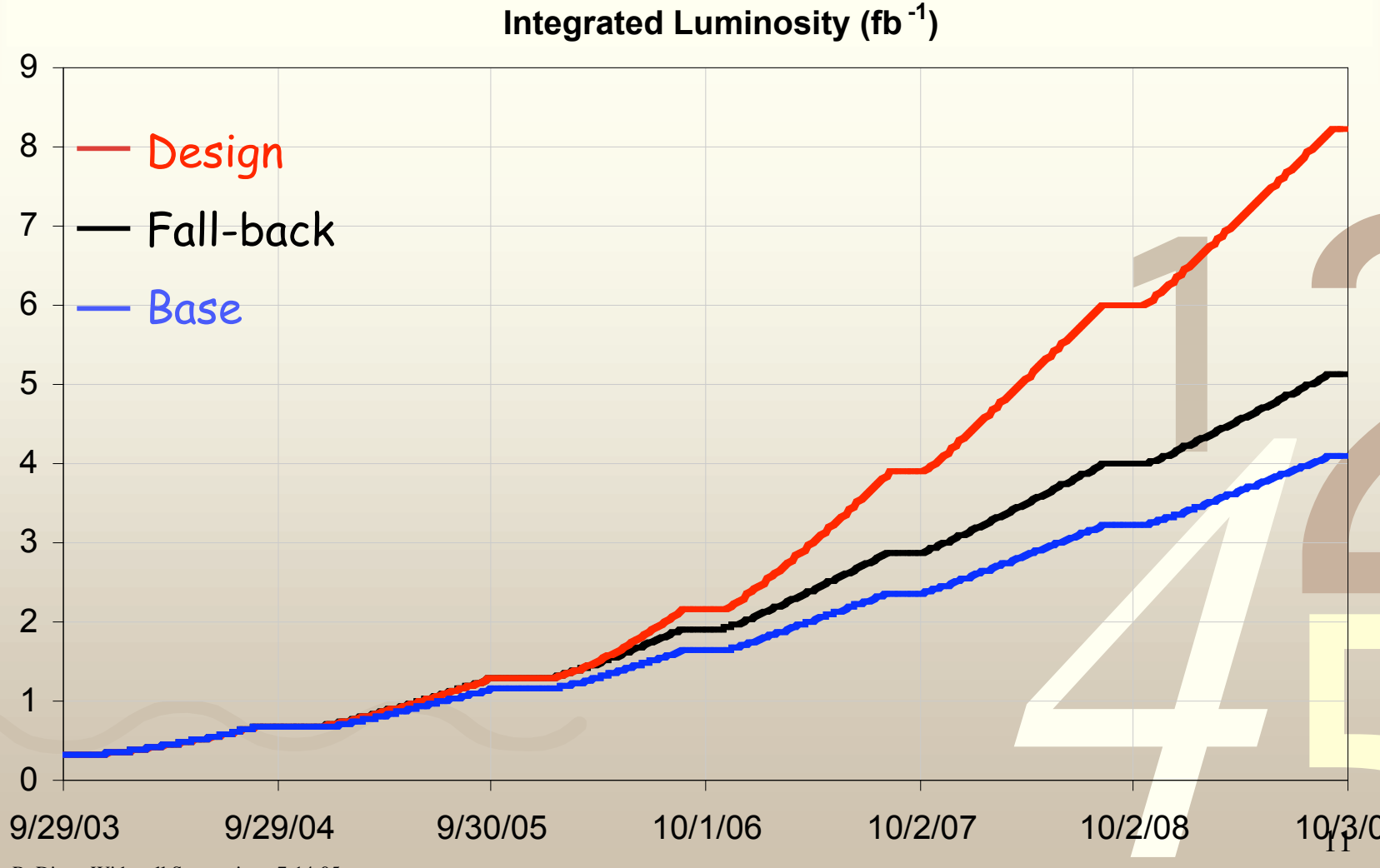
Major Reliability Improvements

- Linac Power Amplifiers
- MI Transformers
- Voltage to Frequency Converters for Quench protection
- Tevatron Abort
- Tevatron Stands

Run II Plan Goals

Parameter	Units	12/31/03-1/15/04	Run II *Design*
Peak Luminosity	$x10^{30}cm^{-2}sec^{-1}$	38	275
Store hours per week		112	99
Store Duration	hr	24	15
Integrated Luminosity	pb^{-1}/wk	7.7	47
Number of Bunches		36	36
Protons/bunch	$x10^{9}$	223	270
Antiprotons/bunch	$x10^{9}$	24	127
$\bar{p}^{*}$	Cm	40	35
Proton Transverse Emittance (at collision)	π-mm-mrad	28	25
Antiproton Transverse Emittance (at collision)	π-mm-mrad	12	15
Hourglass Form Factor		0.65	0.65
Pbar Transmission Efficiency to low beta	%	75	80
Stack Used	$x10^{10}$	113	569
Avg. Antiproton stacking Rate	$x10^{10}$ /hr	4.7	39

Integrated Luminosity



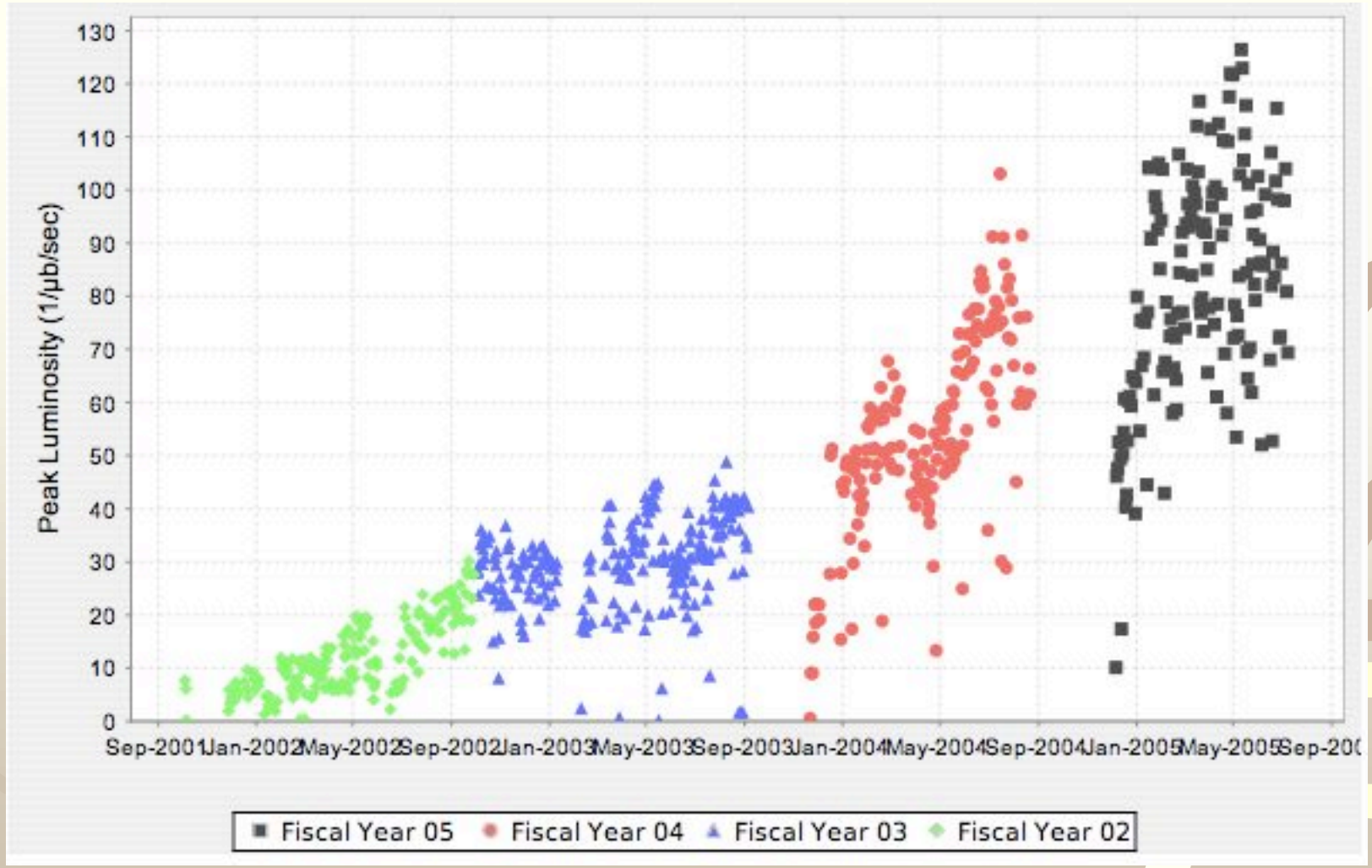
Major Improvements Completed

- Tevatron Alignment
  - Magnet Rolls
  - Smart Bolt Problem (Coupling)
  - Low Beta Optics
- Recycler Successful commissioned and integrated into operations
  - Combined shots from accumulator and Recycler
    - not planned initially
- Tevatron Beam Position Monitors
- Slip stacking in the MI

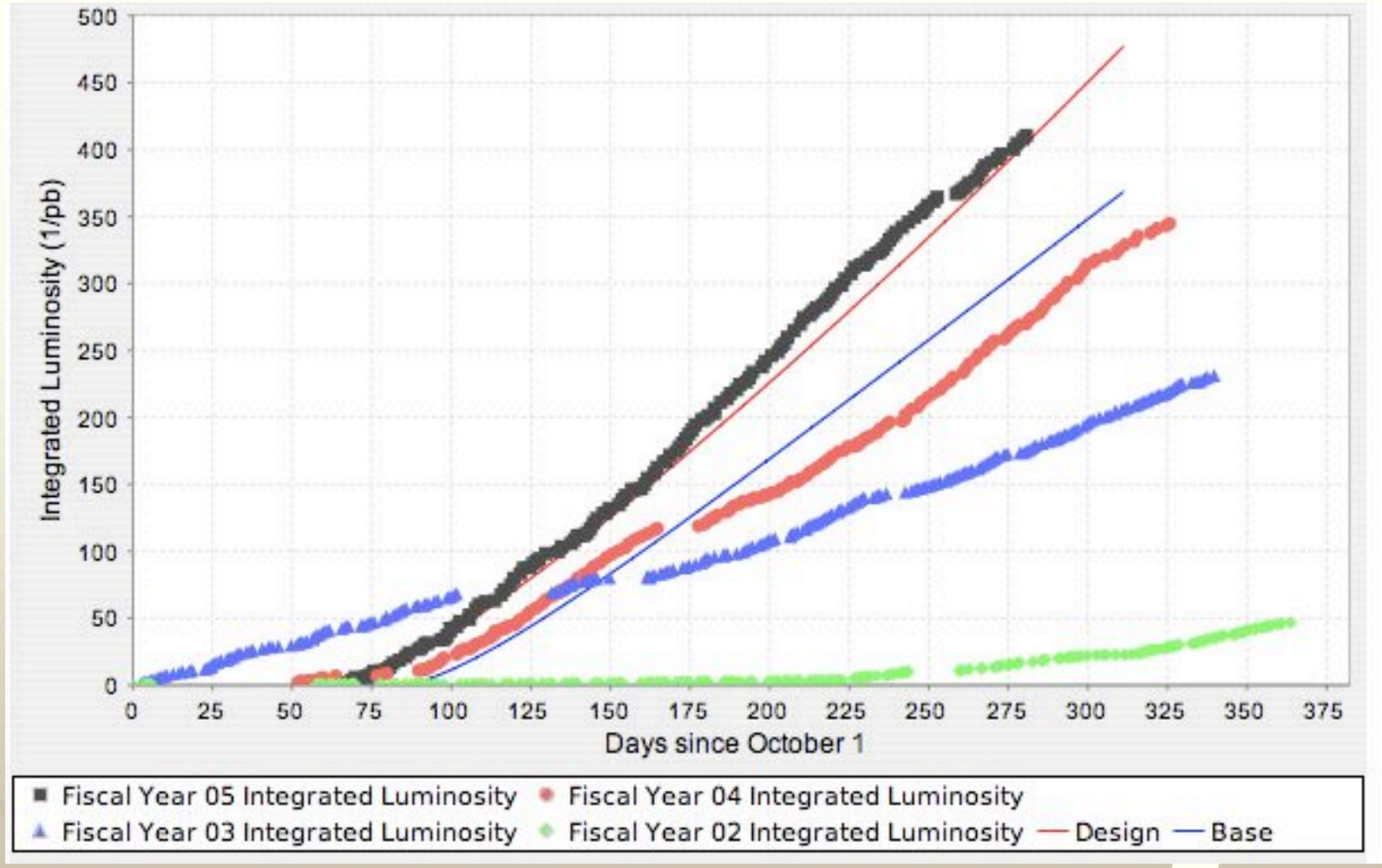
Major Improvements Expected

- Antiproton Stacking improvements
  - AP2 and Debuncher Apertures
  - Electron Cooling
  - Stacktail Upgrade
- Rapid Transfers
- Instrumentation (Ongoing)
- Improved Beam Separation in the Tevatron

Peak Luminosity History

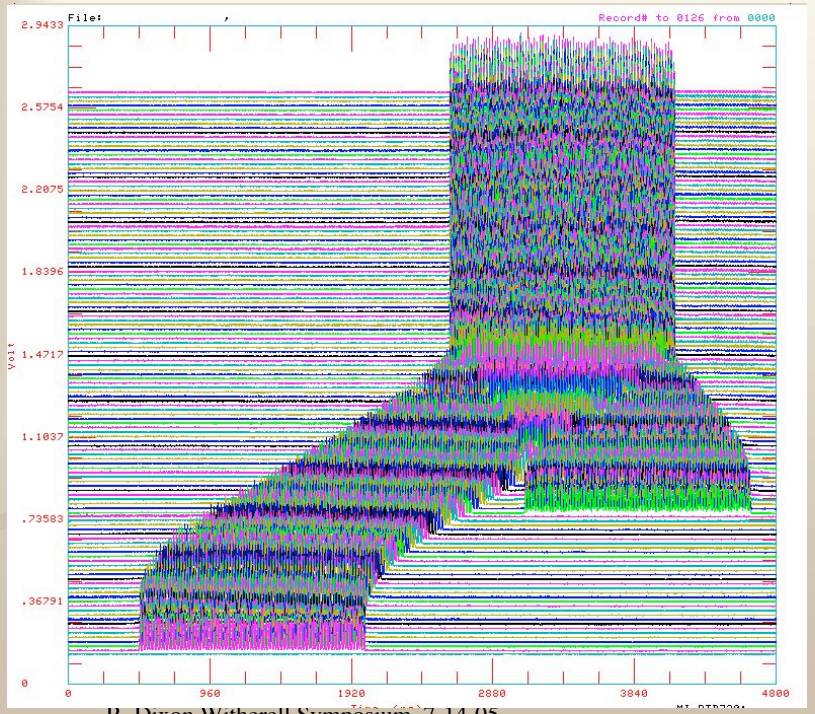


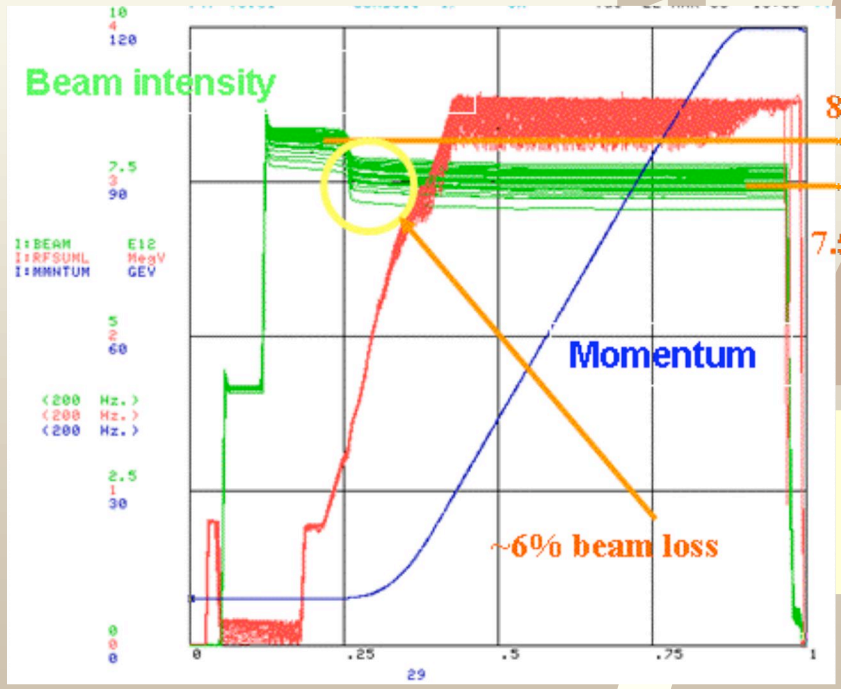
Integrated Luminosity vs Projections



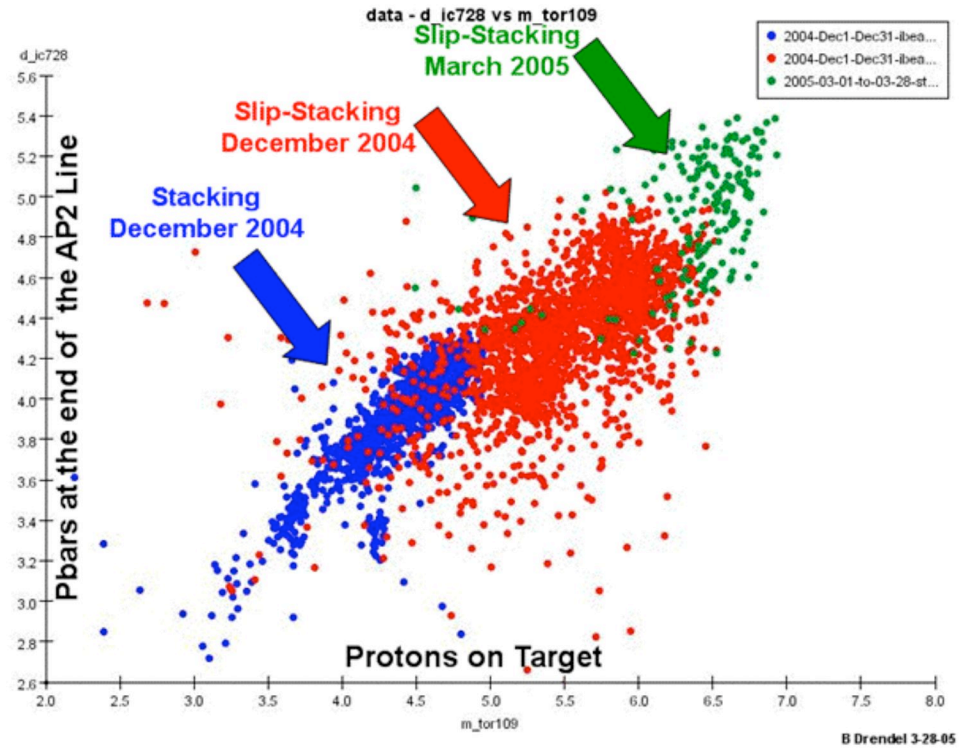
Antiproton Production – Slip Stacking

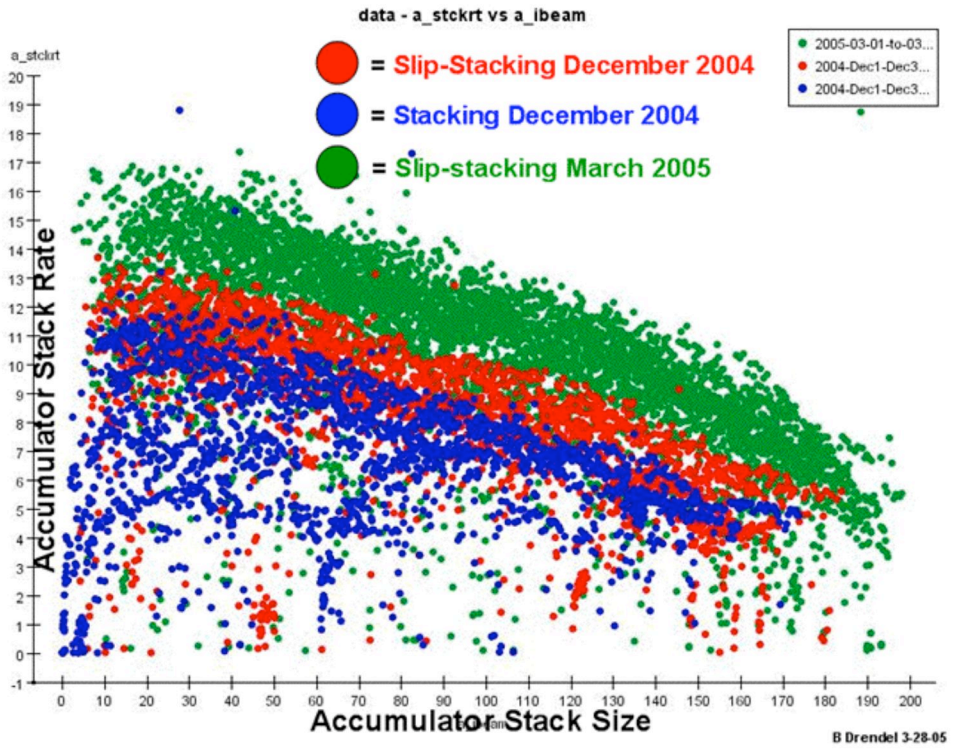
- Slip Stacking is the process of combining two Booster batches at injection into in the Main Injector to effectively double the amount of protons on the antiproton production target





Antiproton Production – Slip Stacking





The Recycler

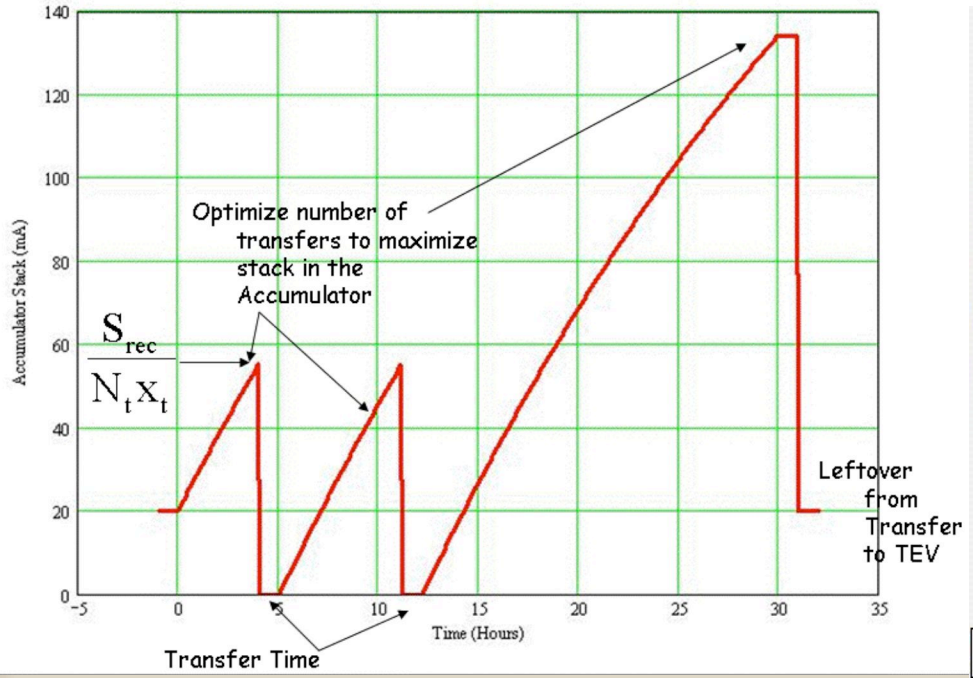
- Features
  - Designed to a be a third stage antiproton accumulator ring
    - Initially uses stochastic cooling
    - Eventually will use electron cooling
  - Shares the same tunnel as the Main Injector
  - Major magnetic elements are made from permanent magnets
- June 2003
  - The Recycler commissioning was not converging
    - Lifetime was < 60hrs
    - Transverse emittance growth was 12π-mm-mrad/hr
  - Took drastic measures
    - 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
    - Created Separate department for Recycler and electron cooling
    - 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 10-20
  - Lifetime > 600 hours
- Recycler commissioning has progressed rapidly
  - Stand alone Recycler shots to the Tevatron (Jan. '04)
  - Stack of >150x10^{10} pbars in the Recycler
- Using the Recycler in "Combined Shots" operations makes it a luminosity enhancement
- Recycler is ready for Electron Cooling

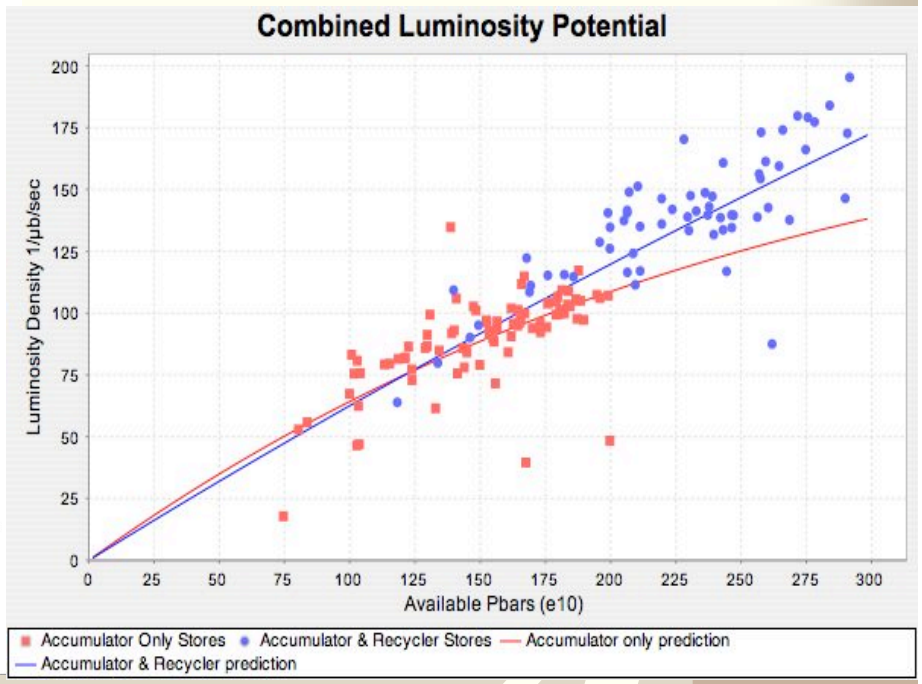
Combined Shots from Accumulator and Recycler

- Extracting antiprotons from both the Accumulator and the Recycler for the same store i.e.
  - Twelve bunches from the Recycler
  - Twenty four bunches from the Accumulator
- Combined Shot Operation
  - Proposed in February '04
  - Dual energy ramps in the MI completed and tested by May '04
  - First Attempt 6/13/04
  - Record Luminosity
    - $103 \times 10^{30} cm^{-2} sec^{-1}$ recorded 7/16/04
    - $127 \times 10^{30} cm^{-2} sec^{-1}$ recorded May 2005
  - Routine Operations - January 2005

- 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 antiprotons for 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

Combined Shots

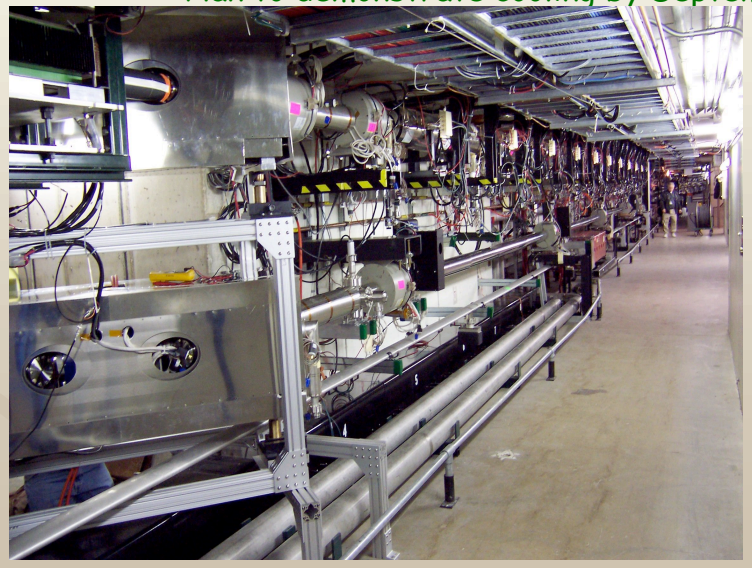




- Luminosity enhancement – larger amount of antiprotons for smaller emittances
  - Accumulator stack size limited to <200 mA
    - Stacking Rate
    - Transverse emittance vs Stack Size

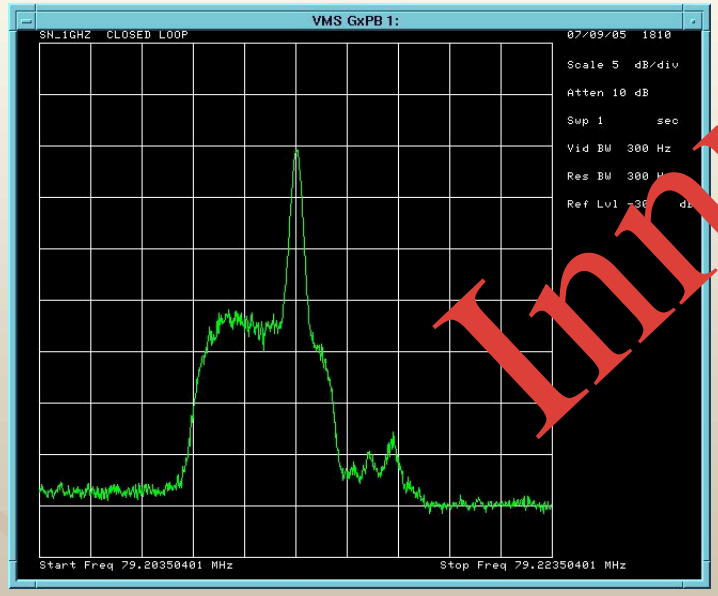
Electron Cooling

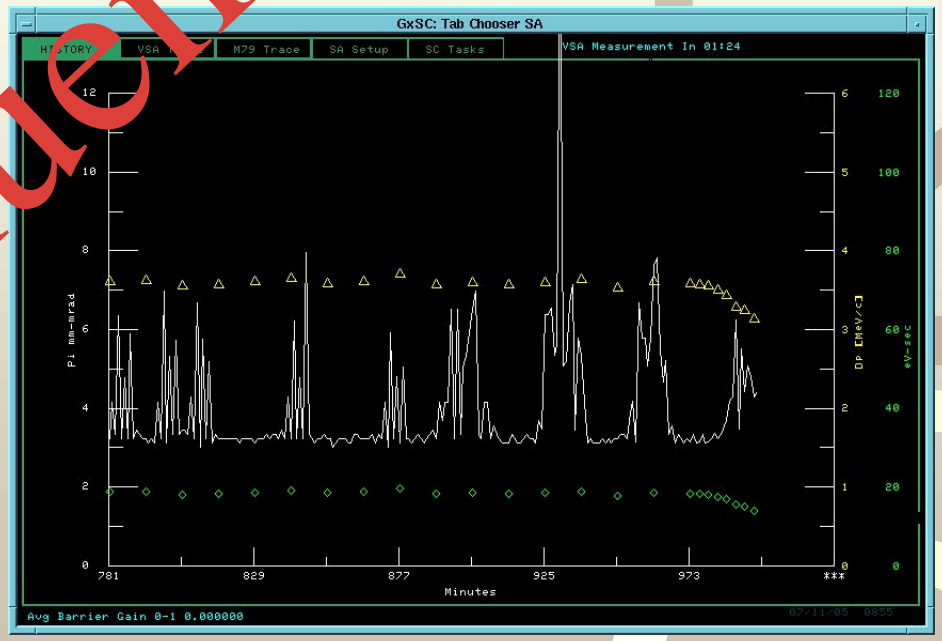
- The maximum antiproton stack size in the Recycler is limited by
  - Stacking Rate in the Debuncher-Accumulator at large stacks
  - Longitudinal cooling in the Recycler
- Longitudinal stochastic cooling of 8 GeV antiprotons in the Recycler is to be replaced by Electron Cooling
  - Electron beam: 4.34 MeV – 0.5 Amps DC – 200μrad beam spread – 99% recirculation efficiency
- Installation of e-cool equipment in MI-31 and the Recycler tunnel complete
- Commissioning of electron cooling in progress
  - Electron beam circulated in cooling section
  - Plan to demonstrate cooling by September 2005



Electron Cooling Rumors

- Recent studies and results
  - Evidence for electron interactions with the antiproton beam
  - Evidence for cooling
  - Verification is underway

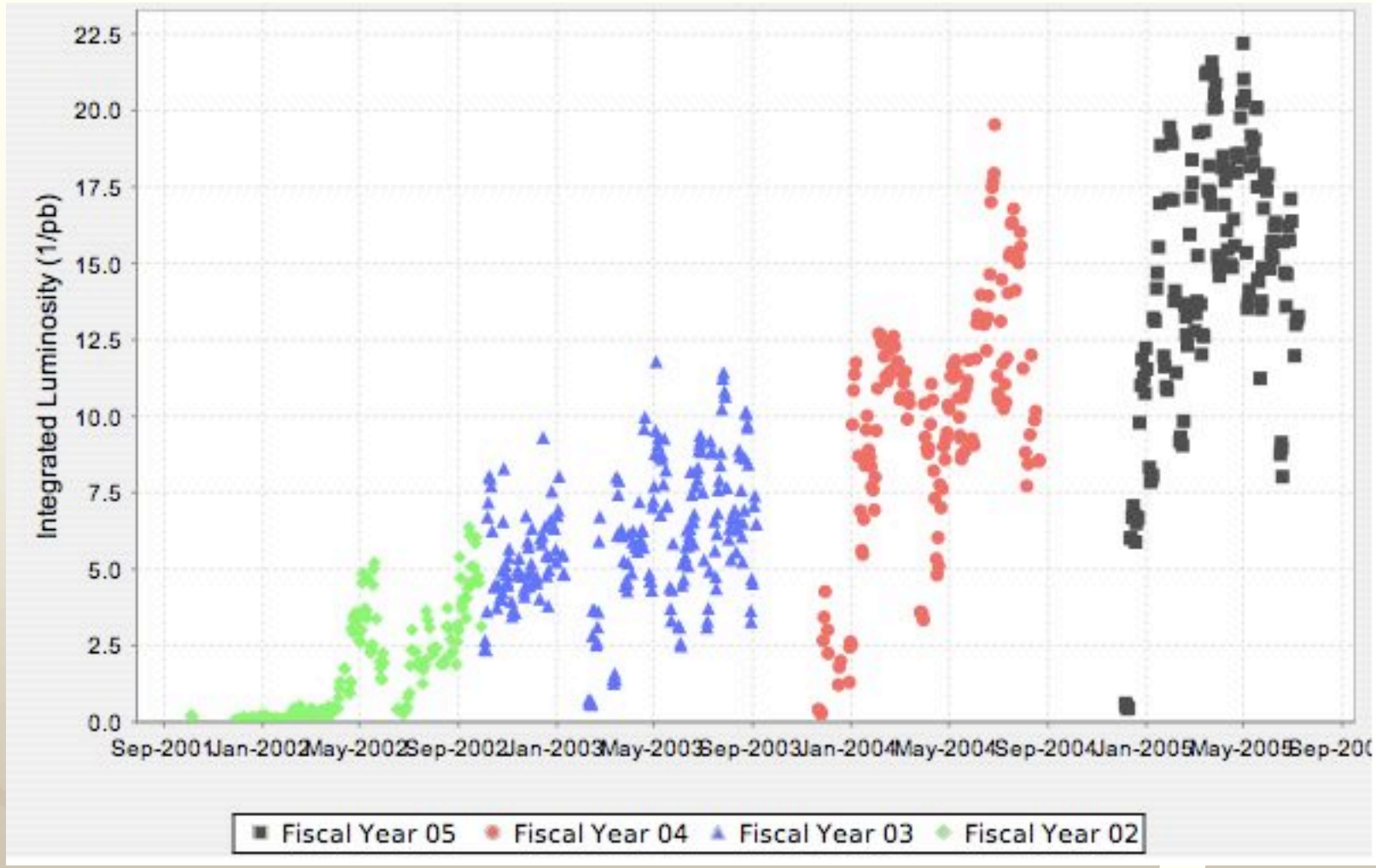




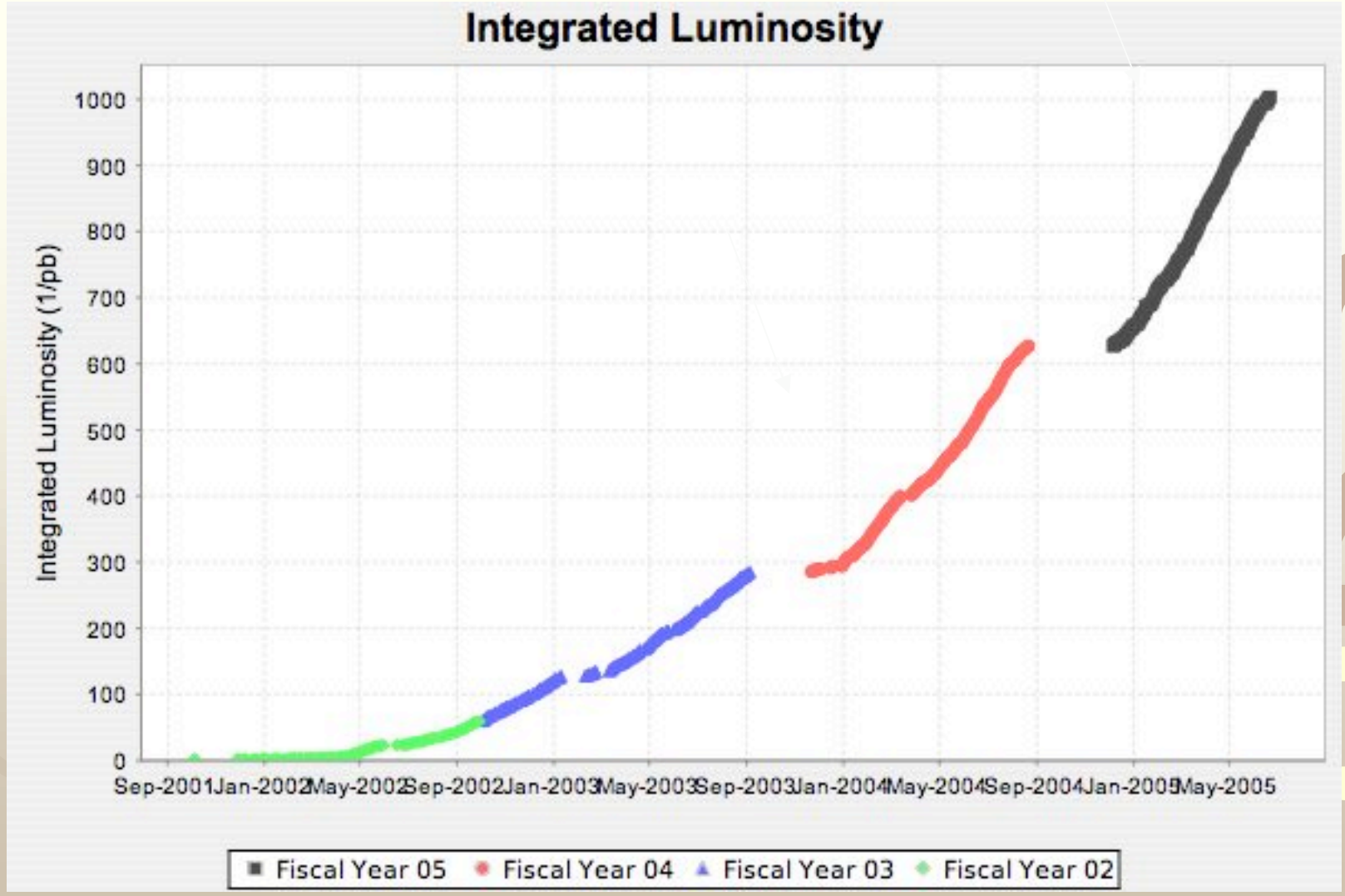
Summary

- Since June 2003, the Tevatron has seen a 3-fold increase in:
  - Peak luminosity
  - Integrated luminosity per week
  - Total integrated luminosity
- Luminosity increase is mostly due to:
  - Better performance of the injector chain
  - Introduction of the Recycler into operations
  - Alignment of the Tevatron
  - Decision to "run" the Collider
    - Rigorous approach to attacking operational problems
    - De-emphasis of long periods of dedicated machine studies
- The Run II Upgrades are on track to provide over 8fb^{-1} by 2009
  - The Recycler is operational
  - Electron cooling is progressing ahead of schedule
  - Slip Stacking is operational
- The major challenges left in Run II are
  - Increasing the antiproton production rate
    - AP2- Debuncher aperture upgrade
    - Debuncher to accumulator transfers
    - Stacktail Momentum cooling upgrade
    - Rapid transfers between the Accumulator and Recycler
  - Commissioning electron cooling

Weekly Integrated Luminosity

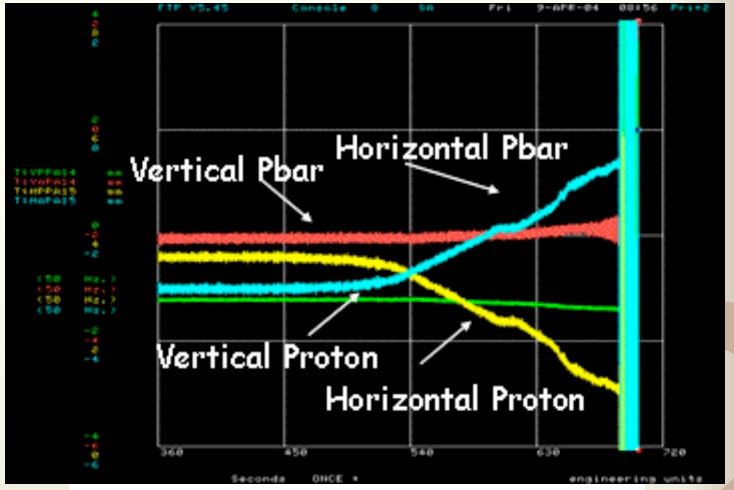


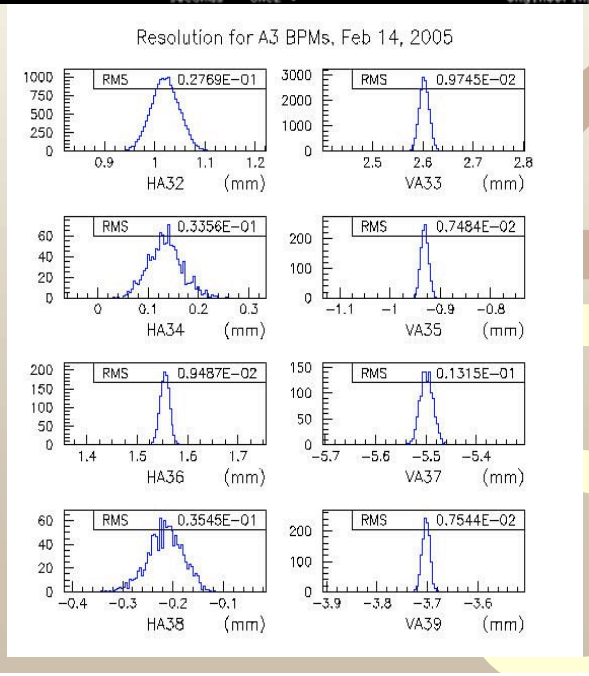
Integrated Luminosity History



Tevatron Instrumentation

- Tevatron BPM Project
  - Joint CD/AD effort
  - A major success
  - Project making very good progress though completion date has slipped by a few months
  - An order of magnitude improvement in proton position measurements and new for pbars
  - Position resolutions in the range of ~10 -25 μ
  - Will be extremely useful in understanding beams
    - Can see synchrotron and betatron lines, quadrupole oscillations, H-V coupling, etc.
  - 85% installed
    - ~ 50% connected/ commissioned
- New Beam loss monitor system
- New Ion Profile Monitor





Tevatron Major Accomplishments

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

- New Low Beta optics (April 04 – June 04)
  - 20-30% increase in luminosity
  - Smaller beta*
  - Smaller emittance