Run II Luminosity Progress

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Overview

• Collider Run 2
  – Tevatron 36×36 proton-antiproton collisions to CDF & D0
  – Design goal = 8 fb⁻¹ by end FY09
  – Over 3 fb⁻¹ delivered so far
  – Antiproton production is key factor for increasing luminosity
  – Operates in parallel with MiniBoone, NuMI, SY120/Test Beam

• Tevatron
  – 1 km radius superconducting synchrotron at 980 GeV beam energy
  – 3 trains of 12 bunches each with 396 ns separation
  – Protons and antiprotons circulate in single beam pipe
    • Electrostatic separators keep beams apart except where/when desired
    • Beam-beam interactions (head-on & long range) play major role in performance
Luminosity

\[ L = \frac{\int N_p N_a}{2\pi(\varepsilon_p + \varepsilon_a)\beta^*} H(\sigma_z/\beta^*) \]

- The major contributors to determining the luminosity are:
  - Number of particles in each bunch \((N)\)
  - The transverse emittance of the beams \((\varepsilon)\)
  - Transverse beam optics at the interaction point \((\beta^*)\)

Antiprotons are the key
Antiproton Operations

- Accumulator Only (prior to Dec 2004)
  - Stack and store <2e12 pbars
  - Accumulation rate decreases as stack size increases
- Combined Shots (Dec 2004 to Oct 2005)
  - Together with Accumulator provide more pbars
- Recycler - Electron Cooling (since Oct 2005)
  - First time done with relativistic electron beam
  - Able to make denser pbar bunches
  - Routinely have >3e12 pbars available for Tevatron
  - Pbars to Tevatron come only from Recycler
  - Accumulator focus on stacking
    - Rate stays flat
    - Frequent transfers

\[ L = \frac{fN_p N_a}{2\pi(\varepsilon_p + \varepsilon_a)\beta^*} H\left(\frac{\sigma_z}{\beta^*}\right) \]
Antiproton Production

- Created from 120 GeV Protons from Main Injector
  - Production Target is nickel alloy followed by a pulsed lithium collection lens

- Collected using three rings at 8 GeV
  - Debuncher (2.4s)
  - Accumulator (~3hr)
  - Recycler (~1day)
  - Cooling systems reduce the phase space and increase beam density

- Main Injector is used to accelerate pbars to 150 GeV for injection into the Tevatron
Antiproton Production Flow

Stack pbars in Accumulator
Shoot to Recycler

Shoot pbars from Recycler to Tev for HEP

HEP stores

Recycler \( [10^{10}] \)
Accumulator \( [10^{10}] \)

Tevatron Luminosity \( [10^{30} \text{ cm}^{-2} \text{ s}^{-1}] \)

1 week
More Antiprotons

• Increase the Stacking Rate
  – The Accumulator’s stochastic cooling systems configuration is a balance between the rate and maximum stack size.
  • With Recycler taking the “storage” role, the Accumulator is focusing on stacking rate
    – More protons on Production Target
Protons and Target Station

• Slip Stacking in Main Injector: consistently $8-9 \times 10^{12}$ protons on target

• Balance of spot size and target consumption

New Lithium Lens allows an increase in collection gradient

Spot $\sim 150 \mu m$
First new Lens module failed due to radiation damage to transformer

Second transformer developed ground fault after one week of service due to water leak

Hope to repair

Third lens module will be ready in August
Orbits & Protons for Antiproton Production

New Beam Position Monitor electronics allowed feedback for orbit control

November 2005

January 2006

10mm per division

3 hour per division

Protons on target \(10^{12}\)

Particles 200m downstream of target

February 9-14, 2006 After Studies

March 2005 "Best Stacking"

December 2004 Stip-Stacking

December 2004 Not Stip-Stacking

June 27, 2007

Gollwitzer - Run II Luminosity Progress
More Antiprotons

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• With Recycler taking the “storage” role, the Accumulator is focusing on stacking rate
  – More protons on Production Target
  – Antiproton collection efficiency (aperture of the beam line from the target to the Debuncher)
Debuncher Admittance

- Nearly all admittance upgrades are complete
  - Removal & Modifications of limitations
    • One remaining kicker beam tube to be replaced
  - Added orbit control
    • Dipole trims
    • Motorized quad stands
  - Motorized stands of components with tight apertures
  - Modified lattice to decrease beam size in small apertures

- Admittance has increased from $\sim 23\pi$ mm-mrad to almost the goal of $35\pi$ mm-mrad
  - The goal admittance accepts $\sim 320\pi$ mm-mrad beam emittance
More Antiprotons

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  – More protons on Production Target
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  – Speed of the Debuncher and Accumulator Stochastic cooling systems
  – Accumulator stochastic cooling systems configuration
Accumulator

• Longitudinal cooling is the key
  – Stacktail moves beam from Central to Core
  – Core systems hold beam in place
  – Each system is “noise” to the other

• Improvements
  – Core Configuration
  – Lattice change
  – Bandwidth upgrades

Stacking
1. ~2e8 pbars injected from Debuncher
2. RF capture on injection orbit
3. Move beam to central orbit
4. De-bunch beam
5. Stochastic cooling stacks beam onto core
4-8GHz Core Trunk Changed

- Trunk changed from Coax to fiber
  - Increase Bandwidth results in more effective cooling

Feb06: BW = 0.98GHz on Coax
Mar07: BW = 1.76GHz on Fiber
Stacktail Bandwidth Improvement

Improvement in effective bandwidth by
- Fixing phase at band edges
- More gain at higher frequencies
Best Stacking Hour Each Day
More Antiprotons

• Increase the Stacking Rate
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      – More protons on Production Target
      – Antiproton collection efficiency (aperture of the beam line from the target to the Debuncher)
      – Speed of the Debuncher and Accumulator Stochastic cooling systems
      – Accumulator stochastic cooling systems configuration
  – More stacking hours due to decreasing time it takes to transfer from Accumulator to Recycler
Decreasing Time to do Transfers

Accumulator to Recycler transfers

*Interrupts Stacking*

Philosophy Change
From: check everything every time
To: monitor for decrease performance

Still optimizing number and size of transfers

Now transfers occur every 2-3 hours

Prior to 2006 Shutdown
Antiprotons per Week

E$10^9$ pbars/week

June 27, 2007
Recycler

- Electron Cooling has become operational
Electron Cooling in Recycler

- e⁻ beam for cooling
  - 4.34 MeV
  - 0.5 amp DC
  - 200 μrad angular spread

- Momentum exchange between e⁻ and antiprotons while overlapped in cooling section
- Cooling rate independent of antiproton intensity
After demonstration, time was spent learning how to control the cooling via electron current and relative beam positions.

Was brought into operations in 2.5 months.
Recycler

- Electron Cooling has become operational

- Improvements
  - Change in Working point:
    - Improvement in Lifetime at large stashes
    - Space charge tune shifts
      - $p_{\text{bar}}$ beam as function of intensity / density
  - Implementation of Adaptive Feed Forward RF Correction
    - Uniform bunch intensity for collider operation
Adaptive RF Correction

- Implementation of adaptive feed forward RF correction
  - Integral of barrier buckets gives a flat potential well
  - Flat potential well -> uniform time distribution
  - For extraction, grow additional barrier buckets to make 9 slices which are transferred to Tevatron
  - Uniform time distribution -> uniform bunch density in Tevatron
More Uniform Pbar Intensities from Recycler

Store 5008
Without correction:
100% variation
25% RMS

Large variations in tune shifts and luminosity

Intensities of 36 Pbar Bunches in Tevatron

Store 5245
With correction:
25% variation
7% RMS
Recycler

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  – Change in Working point:
    • Improvement in Lifetime at large stashes
    • Space charge tune shifts
      – pbar beam as function of intensity / density
  – Implementation of Adaptive Feed Forward RF Correction
    • Uniform bunch intensity for collider operation

• Optimization continues
  – Every time new record number of antiprotons has led to learning how to optimize the operation of the Recycler
Antiprotons for Collider Program
Improvements – Not Covered

• Protons
  – Better coalescing and transmission

• Recycler
  – Mining procedure
  – Electron Cooling Operations

• Tevatron
  – Decrease of $\beta^*$ + optics correction
  – Separation increase of beams
  – Lifetime

• Reliability

• Percents here and there add up
Peak Luminosity
Record Comparison Before/After 2006 Shutdown

- One hour antiproton stacking record
  - 32% (17.5 $10^{10}$/hr $\rightarrow$ 23.1 $10^{10}$/hr)

- Antiproton accumulation for one week
  - 64% (1710 $10^{10}$ $\rightarrow$ 2810 $10^{10}$)

- Recycler peak Stash
  - 43% (325 $10^{10}$ $\rightarrow$ 465 $10^{10}$)

- Peak luminosity increased
  - 62% (180 $\rightarrow$ 292 $\mu$b$^{-1}$/s)  \(1 \mu$b$^{-1}$/s = $10^{30}$ cm$^{-2}$ s$^{-1}$

- Weekly integrated luminosity increased
  - 80% (25 pb$^{-1}$ $\rightarrow$ 45 pb$^{-1}$)

- Monthly integrated luminosity increased
  - 95% (85 pb$^{-1}$ $\rightarrow$ 167 pb$^{-1}$)
Integrated Luminosity
Conclusions

• The Fermilab Tevatron complex has delivered \( \sim 3 \text{ fb}^{-1} \) to each experiment
  – Great progress in antiproton production and beam quality have lead to improvements in luminosity and the integrated luminosity delivered

• 4 \( \text{ fb}^{-1} \) should be achieved in 2009
  – Dependent upon Accumulator stacking rate
  – Optimization of the Recycler operations with electron cooling will continue