Tevatron Status

Engineering Run
Start of Run II
$10^{32}$ and higher

M Church  2/02/01
Chronology of "Interesting" Events

3/ 1 Circulating beam established in Main Injector
   Circulating beam established in Recycler
3/ 4 Antiproton stacking established
3/13 Stack rate > 1E10/ hr
4/ 8 Stack rate > 4E10/ hr
5/15 C4 vacuum failure during cooldown (1st Tev failure)
5/27 C4 vacuum failure during cooldown (2nd Tev failure)
6/ 7 C4 vacuum failure during cooldown (3rd Tev failure)
6/ 9 B0 low beta quad high energy tests start
6/13 1st circulating antiprotons in the Main Injector
6/20 E47 splice failure (4th Tevatron failure)
6/29 F11 ground fault (voltage taps) (5th Tevatron failure)
6/30 Antiprotons accelerated to 150 GeV in Main Injector
7/14 B0 coupling problem discovered (see figure)
7/15 Protons circulating in Tevatron
7/30 1010 GeV test of Tevatron at low beta (no beam)
7/31 Start A150 commissioning
8/ 2 Protons to 980 GeV
8/13 Protons to low beta
8/23 Antiprotons to low beta in Tevatron
8/25 1x8 store in the Tevatron (central orbit)
8/26 4.4E12 protons/ pulse on pbar production target
9/ 21 B0 aperture restriction found (see figure)
10/ 8 1st luminosity to CDF detector
10/30 1st 36x36 store
11/ 6 Antiprotons circulating in Recycler
Bad Splice at E47
B0 Coupling - A4Q3 rolled by 8.5 mrad
A4Q4 rolled by 4.0 mrad

1st turn difference orbit with 50 μrad horizontal bump at F17. Injection is at F0.
Handdrawn plot shows vertical orbit differences as a function of longitudinal distance from B0 at loss points for different bumps.
## Summary of the Commissioning Run

<table>
<thead>
<tr>
<th>Date (hrs)</th>
<th>bunches</th>
<th>Init. L (cm$^{-2}$ s$^{-1}$)</th>
<th>Tot L (nb$^{-1}$)</th>
<th>CDF accomplishment</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/08 (21)</td>
<td>1 x 8</td>
<td>6E27 (0.2)</td>
<td></td>
<td>Commission CLC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CLC based min bias trigger</td>
</tr>
<tr>
<td>10/13 (17)</td>
<td>1 x 8</td>
<td>2E27 (0.1)</td>
<td></td>
<td>Min bias, Calor. triggers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CLC, Calor timing-in</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Observed first COT, Silicon tracks</td>
</tr>
<tr>
<td>10/23 (30)</td>
<td>1 x 8</td>
<td>2E28 (1.0)</td>
<td></td>
<td>Min bias + Calor trigger</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Silicon, Calor timing-in</td>
</tr>
<tr>
<td>10/27 (4)</td>
<td>1 x 8</td>
<td>2E28 (0.3)</td>
<td></td>
<td>Min bias + Calor trigger</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Silicon, Calor timing-in</td>
</tr>
<tr>
<td>10/30 (34)</td>
<td>36 x 36</td>
<td>4E29 (27)</td>
<td></td>
<td>Timing-in : fine adjustment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Establish operating points (COT, Silicon, CLC)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~1 milion &quot;high Et&quot; (an object with Et or Pt &gt; 2 GeV) events on tape</td>
</tr>
<tr>
<td>11/02 (18)</td>
<td>36 x 36</td>
<td>2E29 (11)</td>
<td></td>
<td>Min bias + mu-stub, mu-stub + track trigger</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Timing-in : fine adjustment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Establish operating points (COT, Silicon, CLC)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~1 milion &quot;high Et&quot; (an object with Et or Pt &gt; 2 GeV) events on tape</td>
</tr>
<tr>
<td>11/04 (35)</td>
<td>36 x 36</td>
<td>3E29 (18)</td>
<td></td>
<td>Track trigger</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L2 processor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L3 reconstruction including COT tracking</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>read out TOF, SOC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~2 milion &quot;high Et&quot; (an object with Et or Pt &gt; 2 GeV) events on tape</td>
</tr>
</tbody>
</table>

Young-Kee Kim (www-cdf.fnal.gov/upgrades/collisions/summary_comm.html)
Luminosity - head-on, round beams, no crossing angle

\[ L \approx \frac{0.01 fBN_p N_B}{2 \left( \frac{r_p}{r_p} \right)} F(\frac{r_p}{r_p}^*) \cdot 10^{31} \text{ cm}^2 \text{ sec}^{-1} \]

revolution frequency: \( f \approx 47.7 \text{ KHz} \)

# bunches: \( B \approx 36 \)

# protons/bunch: \( N_p \approx 40 \cdot 10^9 \) 15% Run II Handbook

# pbars/bunch: \( N_B \approx 2.4 \cdot 10^9 \) 8% Run II Handbook

hourglass factor: \( F(\frac{r_p}{r_p}^*) \approx 0.63 \) 85% Run II Handbook

\[ A_p \approx 5.0 \text{ ev sec} \quad A_B \approx 3.0 \text{ ev sec} \]

beam size: \( r_p \approx 45 \mu m \quad r_p \approx 45 \mu m \)

\( r_p \approx 36 \mu m \quad \mu m \quad \text{mrad} \) 180% Run II Handbook

\( r_p \approx 36 \mu m \quad \mu m \quad \text{mrad} \) 240% Run II Handbook
Proton Intensity  (goal is 270E9)

- Shots for stores were done with 65E9 (at injection).
- MI acceleration efficiency and MI Tev transfer efficiency are very good.
- Proton-only stores of 110E9 have been successfully demonstrated. Transverse dampers will be installed for Run II for higher intensities.
- Reasonable proton coalescing in the MI has been demonstrated up to intensities of 200+E9.
- Proton lifetime in Tevatron at 150 GeV was (often) poor Proton acceleration and squeeze efficiency is ~95% (see figure).
- Proton loading into the Tevatron is routine and 1 coalesced bunch every ~12 seconds.
Start of 2nd 36x36 Store

**Blue:** DC beam intensity

**Red:** Proton bunched beam intensity

**Green:** Dipole bus current

**Yellow:** Antiproton bunched beam intensity
Antiproton Intensity  (goal is 30e9)

Where do all the antiprotons go?

For a "typical" shot:
•  $50E9/4 = 12.5E9$ extracted from Accumulator
•  80% efficiency to 150 GeV in MI (see figure):  $10E9$
•  50% coalescing/ transfer efficiency to Tevatron:  $5E9$
•  50% efficiency to low beta in Tevatron:  $2.5E9$

Why?

• The amount of beam which can be usefully extracted from the Accumulator was limited by longitudinal emittance.

• The unstacking process blows up the longitudinal emittance by a factor of $\sim4$. Improving this procedure should allow us to unstack $\sim3$ times as many antiprotons/bunch.  (For comparision, in Run I the unstacking process increased longitudinal emittance by $\sim30\%$.)
Antiproton Acceleration Efficiency in MI

Antiproton acceleration efficiency in the MI showing transition crossing losses

red = beam intensity; green = bunch length monitor; yellow = RF voltage
Antiproton Intensity Why (continued)

- Transfer efficiency to 150 GeV in the MI has been as good as 90%. This is better than Run I.

- A serious problem is the "non-repeatability" of the AP3/AP1/P2/P1 transfer line. (Beamline is longer. Many elements are run by PS which have to ramp from 8 GeV to 120 or 150 GeV.) This should get better with practice.

- Another problem is the "non-repeatability" of transition crossing in the MI. This should get better with practice, smaller longitudinal emittance, higher intensity, and a more sensitive pickup for MI RF feedback systems.
Antiproton Intensity Why (continued)

- Transfer efficiency for reverse coalesced protons (Tevatron → MI) is typically 98%.

- Transfer efficiency for uncoalesced antiprotons (MI → Tevatron) is 90%. This could be made to be 100% with some tuning and better diagnostics (closure, for example).

- Poor MI → Tevatron coalesced antiproton transfer efficiency is mainly due to poor antiproton coalescing.

- 50% antiproton beam loss in Tevatron is not understood.
  - poor physical aperture?
  - poor dynamic aperture - wrong tunes?
  - poor lifetime?
  - DC beam?
  - Beam-Beam interaction?
Longitudinal Emittance (goal is 2 ev-sec)

- Proton coalescing in the MI is good at low intensity: \(~3\) ev-sec \(@\ 100E9\). Needs work at high intensity: \(~4\) ev-sec at \(200+E9\). Satellites are \(~2\)% at low intensity (see figure).

- Feedback systems were implemented on the MI RF cavities to compensate for fundamental beam loading. (Transient beam loading compensation is in progress.)

- Antiproton coalescing is poor. \(~5+\) ev-sec. Satellites are \(~20-50\)% (see figures).
  - large longitudinal emittance from the Accumulator
  - phase lock between MI and Accumulator
  - longitudinal emittance blowup in MI
  - MI coalescing not yet adequately tuned up
Proton bunch and satellite @ Collisions - F0 Resistive Wall Monitor
Antiproton Coalescing in the Main Injector

Pbar coalescing in the MI - top trace is at 8 Gev, bottom trace is at 150 GeV
Antiproton Bunch @ Collisions

Pbar bunch and satellite @ Collisions - F0 Resistive Wall Monitor
**Transverse Emittance** (goal is 15-20 ?-mm-mrad)

- Proton and pbar emittances at low beta are deduced from measured beam intensities and measured luminosity. (FW’s weren’t commissioned.) Emittances are large!

- Proton emittances in MI at 150 GeV are 10-15 ?-mm-mrad. Emittance growth is entirely in Tevatron.
  - tunes and coupling not adjusted well enough?
  - chromaticity too small?
  - transverse dampers required?

- Pbar emittances in MI at 150 GeV are ~25 ?-mm-mrad.
  - 8 GeV injection oscillations
  - large emittances in Accumulator (?)
  - emittance growth during acceleration is ~3-5 ?-mm-mrad

- Pbar emittance growth during Tevatron acceleration and low beta squeeze is entirely unknown. 150 GeV injection oscillations are undoubtedly large.
Stacking Issues

• Maximum stacking rate during Engineering Run was ~4.5E10/ hr goal is 20E10/ hr. What's wrong?

• Yield into the Debuncher is down by a factor of 2 from Run I
  - targeting (quad steering from lithium lens has been observed)
  - AP2 steering/ aperture
  - lattice mismatch into the Debuncher (vertical dispersion)
  - Debuncher aperture smaller by ~20% from Run I

• Beam on target is down by a factor of 2 from Run II goal
  - mostly repetition rate (typically 3 sec instead of 1.5 sec).
  - only 1/2 the Debuncher cooling has been installed
  - poor common mode rejection on Debuncher hybrids
  - transverse heating in stacktail - 3.2 GHz transverse resonance in stacktail momentum system prevents delta kickers from being used
  - Accumulator instabilities - ions (?)

• Can accumulator core cooling keep up with 20E10/ hr?
Shutdown Work

• Tevatron - warming up 6 houses
  - removal and reinstallation of CDF detector
  - removal of D0 LB quads; installation of D0 detector;
    reinstallation of D0 LB quads
  - installation of Beam-Beam Compensation Experiment at F48
  - magnet swapping; installation of HTS spool;
    installation of recoolers; replace bad correctors
  - transverse dampers
  - miscellaneous magnet alignment
  - miscellaneous vacuum repair

• Main Injector
  - installation of new pickup for RF feedback
  - installation of 7.5 MHz cavity
  - transient beam loading compensation on RF cavities
  - rework of kicker magnets
  - NUMI and MiniBooNE beamline work
- installation of new lithium lens module
- completion of installation of Debuncher cooling bands 3 and 4
- installation of new hybrids for Debuncher cooling bands 1 and 2 (?)
- fix of 3.2 GHz resonance in stacktail cooling system
- removal of E835 (charmonium production)
- repair of A60 vacuum leak

- installation of stochastic cooling systems
- removal of high beta lattice insert
- continuing realignment
- installation of more dipole correctors
- addition of ramp cards to dipole corrector PS's
- installation of more magnetic shielding
- installation of trim quads in transfer lines
**MI ↔ RR proton transfer efficiency**

- **Green:** circulating MI beam
- **Yellow:** circulating RR beam
Start of Run II

There are a lot of requirements during startup!

- **Tevatron** requires 5+ weeks of proton-only studies.
- **Pbar Source** requires \sim 100 shifts of studies to tune up stacking and antiproton extraction.
- **Recycler** will require commissioning time for orbit, aperture, beam line, RF, lattice studies, etc.
- **Recycler** will require antiprotons to commission stochastic cooling systems.
- **D0** requires 6 weeks of access time (I'm told).
- **CDF** requires 2 weeks of access time (I'm told).
- **MiniBooNE, NUMI, and SY120** will be asking for beam study time (I think).

I'm glad I'm not the Run Coordinator!
## Tevatron startup tasks

<table>
<thead>
<tr>
<th>Task</th>
<th>time (shifts)</th>
<th>Eng. Run (shifts)</th>
<th>required for 1x8 store</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>low intensity protons</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recommission P150 line</td>
<td>1</td>
<td>17.5</td>
<td>1</td>
</tr>
<tr>
<td>Establish 1st turn orbit</td>
<td>4</td>
<td>4.0</td>
<td>4</td>
</tr>
<tr>
<td>Establish circulating beam</td>
<td>2</td>
<td>4.0</td>
<td>2</td>
</tr>
<tr>
<td>Tune up C0 abort</td>
<td>1</td>
<td>1.4</td>
<td>1</td>
</tr>
<tr>
<td>Establish tune, chrom., coupling at 150 GeV</td>
<td>2</td>
<td>23.6</td>
<td>2</td>
</tr>
<tr>
<td>Optimize 150 GeV orbit</td>
<td>20</td>
<td>16.2</td>
<td>20</td>
</tr>
<tr>
<td>Establish acceleration ramp</td>
<td>6</td>
<td>17.7</td>
<td>6</td>
</tr>
<tr>
<td>Establish low beta squeeze</td>
<td>6</td>
<td>25.3</td>
<td>6</td>
</tr>
<tr>
<td>Establish injection helix</td>
<td>1</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Adjust fededown circuits at 150 GeV</td>
<td>1</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Adjust fededown circuits on ramp</td>
<td>6</td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td>Adjust fededown circuits on squeeze</td>
<td>10</td>
<td>15.0</td>
<td></td>
</tr>
<tr>
<td>Recommission A0 abort</td>
<td>2</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Optimize b2 correction</td>
<td>4</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>Measure and adjust lattice</td>
<td>4</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Recommission A150 line with reverse protons</td>
<td>6</td>
<td>20.2</td>
<td>6</td>
</tr>
<tr>
<td>Test collimators</td>
<td>2</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>10.4</td>
<td></td>
</tr>
<tr>
<td><strong>diagnostics/software</strong></td>
<td>15</td>
<td>9.8</td>
<td>12</td>
</tr>
<tr>
<td>Beam Position Monitors (BPM)</td>
<td>2</td>
<td>1.6</td>
<td>2</td>
</tr>
<tr>
<td>Flying Wires (FW)</td>
<td>6</td>
<td>3.4</td>
<td>6</td>
</tr>
<tr>
<td>Sampled Bunch Display (SBD)</td>
<td>2</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Fast Bunch Integrator (FBI)</td>
<td>2</td>
<td>2.5</td>
<td>2</td>
</tr>
<tr>
<td>Collision Point Monitors (CPM)</td>
<td>1</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Beam Line Tuner (BLT)</td>
<td>2</td>
<td>1.0</td>
<td>2</td>
</tr>
<tr>
<td><strong>high intensity protons</strong></td>
<td>6</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td><strong>antiproton only</strong></td>
<td>2</td>
<td>6.5</td>
<td>2</td>
</tr>
<tr>
<td><strong>magnet retraining</strong></td>
<td>6</td>
<td>13.5</td>
<td>6</td>
</tr>
<tr>
<td><strong>total shifts</strong></td>
<td>107</td>
<td>204.0</td>
<td>68</td>
</tr>
<tr>
<td><strong>total weeks</strong></td>
<td>5.1</td>
<td>9.7</td>
<td>3.2</td>
</tr>
</tbody>
</table>
Run II Parameter List
(official list from BD Web page)

<table>
<thead>
<tr>
<th>RUN</th>
<th>Run Ib (1993-95) (6x6)</th>
<th>Run IIa (36x36)</th>
<th>Run IIa (140x103)</th>
<th>Run IIb (140x103)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons/bunch</td>
<td>2.3x10^{11}</td>
<td>2.7x10^{11}</td>
<td>2.7x10^{11}</td>
<td>2.7x10^{11}</td>
</tr>
<tr>
<td>Antiprotons/bunch *</td>
<td>5.5x10^{10}</td>
<td>3.0x10^{10}</td>
<td>4.0x10^{10}</td>
<td>1.0x10^{11}</td>
</tr>
<tr>
<td>Total Antiprotons</td>
<td>3.3x10^{11}</td>
<td>1.1x10^{12}</td>
<td>4.2x10^{12}</td>
<td>1.1x10^{13}</td>
</tr>
<tr>
<td>PbAr Production Rate</td>
<td>6.0x10^{10}</td>
<td>1.0x10^{11}</td>
<td>2.1x10^{11}</td>
<td>5.2x10^{11}</td>
</tr>
<tr>
<td>Proton emittance</td>
<td>23?</td>
<td>20?</td>
<td>20?</td>
<td>20?</td>
</tr>
<tr>
<td>? *</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Energy</td>
<td>900</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Antiproton Bunches</td>
<td>6</td>
<td>36</td>
<td>103</td>
<td>103</td>
</tr>
<tr>
<td>Bunch length (rms)</td>
<td>0.60</td>
<td>0.37</td>
<td>0.37</td>
<td>0.37</td>
</tr>
<tr>
<td>Crossing Angle</td>
<td>0</td>
<td>0</td>
<td>136</td>
<td>136</td>
</tr>
<tr>
<td>Typical Luminosity</td>
<td>0.16x10^{31}</td>
<td>0.86x10^{32}</td>
<td>2.1x10^{32}</td>
<td>5.2x10^{32}</td>
</tr>
<tr>
<td>Integrated Luminosity \†</td>
<td>3.2</td>
<td>17.3</td>
<td>42</td>
<td>105</td>
</tr>
<tr>
<td>Bunch Spacing</td>
<td>~3500</td>
<td>396</td>
<td>132</td>
<td>132</td>
</tr>
<tr>
<td>Interactions/crossing</td>
<td>2.5</td>
<td>2.3</td>
<td>1.9</td>
<td>4.8</td>
</tr>
</tbody>
</table>

\* The typical luminosity at the beginning of a store has traditionally translated to integrated luminosity with a 33% duty factor. Operation with antiproton recycling may be somewhat different.
Integrated luminosity and "luminosity fraction" (luminosity within ±35cm of IR) during a recycled 36x36 store – "advanced" Run IIa. Comparison between 2 eV-sec and 3 eV-sec
Beam Intensity and transverse emittance during a recycled 36x36 store – "advanced" Run IIa
• Accumulator max. stack size = 250E10; stack rate is intensity dependent
• No Recycler max. stack size; stack rate is not intensity dependent
• 8% loss in Accumulator\ Recycler transfers
• Intensity dependent Recycler\ Tevatron transfer efficiencies
• Run II emittances and proton intensities; IBS only for growth rates
• Luminosity counted only within \pm 35\text{cm} from IR
• 70 mb cross section for luminosity
• 3ev-sec, 20? -mm-mrad pbars are recycled
• IR Xing angle is \pm 136? rad
• Luminosity levelled to =5 interactions/ crossing (@48mb cross section)
• 20% weekly downtime; 1 hour shot-setup time
(Brief) Summary

- Some problems have been solved
- Some more problems have been identified
- Many more unknown problems will challenge us