Status of Preparations for Tevatron Collider Run II:
Main Injector/Tevatron, CDF, and DO

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I. Collider Run IB (1993–96) Performance

II. Run II Goals

III. Accelerator Status

IV. Detector Status

V. Longer Term Prospects
COLLIDER RUN IB PERFORMANCE

The last Tevatron Collider Run was completed over the period 1993-96. An integrated luminosity of approximately 150 pb\(^{-1}\) was delivered to each detector @ E\(_{cm}\) = 1800 GeV

- Delivered luminosity = 2 pb\(^{-1}\)/week (end of run)
- Typical initial luminosity = 1.6x10\(^{31}\) cm\(^{-2}\)sec\(^{-1}\) (end of run)

Record initial luminosity = 2.5x10\(^{31}\) cm\(^{-2}\)sec\(^{-1}\)
Record monthly integrated luminosity = 18 pb\(^{-1}\)
Collider Performance Limitations

Under current operating conditions, the most important factor influencing Tevatron luminosity performance is the total number of antiprotons in the ring, $BN_p$. The second most important factor is the proton phase space density, $Np/\varepsilon_p$.

$\Rightarrow$ Beam-beam interaction precludes a large increase in $Np/\varepsilon_p$.

For Run II the Fermilab complex will be required to support:

- More protons in collision
- Many more antiprotons in collision
- A significant increase in the antiproton stacking rate
- A capability for recovering antiprotons at the end of stores

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Fermilab's
ACCELERATOR CHAIN

MAIN INJECTOR

TARGET HALL
ANTIPROTON SOURCE
BOOSTER LINAC
COCKCROFT-WALTON

TEVATRON
DZERO
CDF

PROTON
MESON
NEUTRINO

Antiproton Direction Proton Direction

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The Main Injector is designed to support:
- a three-fold increase in the antiproton production rate.
- good antiproton transmission efficiency from the Recycler to Tevatron.
- a modest increase in coalesced proton bunch intensity.

The Recycler is designed to:
- relieve the Antiproton Source of responsibility for maintaining high stacking rate at high stacks
- double the effective stacking rate via antiproton recovery
- provide a platform for further performance enhancements

The Antiproton Source is being reconfigured to:
- Achieve a factor of three increase in the achievable antiproton production rate.
- Accommodate future improvements leading to an additional factor of four increase in performance.

The Tevatron has been reconfigured to:
- Accommodate 36 bunch operations.
- Achieve collider operations at 2000 GeV in the center-of-mass.
RUN II GOALS

The Fermilab Tevatron is the highest energy collider operating in the world today. The aim of upgrade projects currently nearing completion is to exploit the capabilities of the Tevatron to the fullest extent possible while it retains this unique position.

Collider Performance Goals

The initial Run II goal is to deliver an integrated luminosity of $>2 \text{ fb}^{-1}$ by about the end of 2002.

$\Rightarrow$ Run II Luminosity Goal: $>8-20 \times 10^{31} \text{cm}^{-2}\text{sec}^{-1}$

<table>
<thead>
<tr>
<th>RUN</th>
<th>IB</th>
<th>II (36 x 36)</th>
<th>II (140 x 121)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons/bunch</td>
<td>$2.3 \times 10^{11}$</td>
<td>$2.7 \times 10^{11}$</td>
<td>$2.7 \times 10^{11}$</td>
</tr>
<tr>
<td>Pbars/bunch</td>
<td>$5.5 \times 10^{10}$</td>
<td>$3.0 \times 10^{10}$</td>
<td>$3.0 \times 10^{10}$</td>
</tr>
<tr>
<td>Total Pbars</td>
<td>$3.3 \times 10^{11}$</td>
<td>$1.1 \times 10^{12}$</td>
<td>$3.6 \times 10^{12}$</td>
</tr>
<tr>
<td>Pbar Production Rate</td>
<td>$6.0 \times 10^{10}$</td>
<td>$2.0 \times 10^{11}$</td>
<td>$2.0 \times 10^{11}$ (pbar/hour)</td>
</tr>
<tr>
<td>Proton emittance</td>
<td>$23\pi$</td>
<td>$20\pi$</td>
<td>$20\pi$ (mm-mr)</td>
</tr>
<tr>
<td>Pbar emittance</td>
<td>$13\pi$</td>
<td>$15\pi$</td>
<td>$15\pi$ (mm-mr)</td>
</tr>
<tr>
<td>$\beta^*$</td>
<td>$0.35$</td>
<td>$0.35$</td>
<td>$0.35$ (m)</td>
</tr>
<tr>
<td>Energy</td>
<td>$900$</td>
<td>$1000$</td>
<td>$1000$ (GeV)</td>
</tr>
<tr>
<td>Bunches</td>
<td>$6$</td>
<td>$36$</td>
<td>$121$</td>
</tr>
<tr>
<td>Bunch length (rms)</td>
<td>$0.60$</td>
<td>$0.37$</td>
<td>$0.37$ (m)</td>
</tr>
<tr>
<td>Crossing Angle</td>
<td>$0$</td>
<td>$0$</td>
<td>$126$ (urad)</td>
</tr>
<tr>
<td>Typical Luminosity</td>
<td>$1.6 \times 10^{31}$</td>
<td>$8.6 \times 10^{31}$</td>
<td>$16.1 \times 10^{31}$ (cm$^{-2}$sec$^{-1}$)</td>
</tr>
<tr>
<td>Integrated Luminosity</td>
<td>$3.2$</td>
<td>$17.3$</td>
<td>$32.5$ (pb$^{-1}$/week)</td>
</tr>
<tr>
<td>Bunch Spacing</td>
<td>$-3500$</td>
<td>$396$</td>
<td>$132$ (nsec)</td>
</tr>
<tr>
<td>Interactions/crossing</td>
<td>$2.5$</td>
<td>$2.3$</td>
<td>$1.3$</td>
</tr>
</tbody>
</table>

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CDF-DO Physics Goals

QCD
- Precision measurements using W, Z, Photon in association with jets
- High $E_t$ jet production:
  - proton structure functions at high $x$ and $Q^2$
  - search for di-jet resonances and deviations from QCD at distance scales $< 10^{-17}$ cm

Bottom Physics
- $\sin 2\beta$, $\Delta \sin 2\beta < 0.08$
- $B_s$ Mixing, $x_s \rightarrow 60$
- CP Violation in $B_s$, $B_s \rightarrow J/\psi \phi$
- $\sin 2\alpha$, $\sin 2\gamma$ might be feasible
- Rare Decays
- High Mass States Accessible! ($B_c$, $\Lambda_b$)

Top Physics
- top production: $\sigma_{tt}$, $P_t^{\text{top}}$, resonance searches, spin correlations, single top ($\sigma$, $V_{tb}$)
- top decay: branching ratios, W helicity, $V_{tb}$, rare decay modes
Electroweak

- Gauge Couplings, W-boson width
- W-boson mass, uncertainty ~ 40 MeV
- Top-quark mass, uncertainty ~ 2 GeV

Particle Searches

- Gauge Bosons:
  - 1 TeV - Direct
  - 6 TeV - Indirect
- Leptoquarks:
  - Technicolor > 500 GeV
- SUSY squarks, gluinos:
  - 300-400 GeV
- SUSY Gauginos:
  - 150-250 GeV

The Higgs

Possible reach of CDF/DO for Higgs search based on assumptions listed below:

**Combined channel thresholds**

- Gaussian approximation in combination
- 30% better $m_{\text{H}}$ resolution than Run 1
- Run 2 acceptance $\times 1.3$ NN improvement
- 10% systematic error on background
- all except $\ell^\pm\ell^\pm jj$

![combined CDF/DO thresholds](image)
Main Injector
The Main Injector was completed and commissioned in May, 1999. It is currently operating in support of the Tevatron fixed target run. Current performance:

- Up to $2 \times 10^{13}$ protons accelerated in 6 batches to 120 GeV
- $\sim 3 \times 10^{12}$ protons to 120 GeV every 2.5 seconds (antiproton production)
Recycler
The Recycler achieved circulating beam on May 18, 1999—and became the first ever permanent-magnet-based storage ring.
- Lifetime is limited by vacuum, aperture, and magnetic interference from the Main Injector.
- Vacuum bakeout, completion of magnetic shielding and corrector installation scheduled for October-November.
- Stochastic cooling installation scheduled for April ’00.

Antiproton Source
The antiproton accumulator has been recommissioned with upgraded (higher bandwidth) stochastic cooling systems. The Debuncher 4-8 GHz cooling systems are still under construction and will be installed in the winter of 99-00.

Tevatron
The Tevatron has been reconfigured to support:
- ~2 TeV collider operations
- 36x36 bunch operations. (140x121 ultimately)
- A new injection area

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Schedule

The Tevatron is currently running in 800 GeV fixed target mode. We expect to end the fixed target run at the end of January 2000. At that time the B-0 and D-0 straight sections be reconfigured for collider operations.

- Collider engineering run to start ~May 1, 2000
- Collider commissioning run will start when first detector(s) are ready to roll onto the beamline. (Summer/fall 2000)
- Run II will begin when the detectors in the complete configurations are on the collider beamline. (Winter 00-01).
Off-line Software
Infrastructure
Muon systems
DAQ system
Trigger (pipelined)
Front-end Electronics
Endplug Calorimeter
Central Outer Tracker
Intermediate Silicon Layers
Silicon Vertex Detector
Tracking

CDF II Detector Cross Section

New Detector Systems
CDF Upgrades
CDF Upgrade Progress -
Tracking Detectors

- Silicon detectors: Ladder production is beginning.
- "SVX3" custom monolithic chips digitize and acquire data at the same time.
- Readout electronics - mostly delivered.
- New Silicon Vertex Tracker - custom electronics to find tracks w/ large impact parameters in the trigger (Level 2).

Central Outer Tracker
- Consists of wire planes and field sheets between two precision endplates.
- Wire planes and field sheets all installed.
  - Now doing final QC.
- Next - gas seal, then HV installation and testing.
- Chamber will be read out with new custom TDCs.
- New trigger system includes COT track finding at Level 1.
CDF Upgrade Progress - Calorimeters and Muon Detectors

- New scintillating tile/fiber endplug calorimeters.
  - Construction complete; testing w/ sources.
- Central and plug calorimeters read out with new custom electronics - in production.
- New Trigger system for shorter bunch spacing.

- New muon steel shielding is finished.
- Intermediate muon chambers are complete.
- New scintillators will be installed for triggering.
- Muon detectors will be read out with new TDCs (like outer tracker).
  - TDCs are in production.
CDF Upgrade
Infrastructure and Schedule

**Infrastructure**
- Have removed old detectors.
- Lots of work on power distribution, cooling, gas system, etc.
- Commissioning solenoid.
- Building new luminosity monitor.

**Schedule**
- Calorimeters operational by ~ Jan, 2000.
- Central outer tracker complete ~ Feb, 2000.
- Most of electronics and trigger installed by Spring, 2000.
- Ready for commissioning with beam without full silicon system by Summer, 2000.
- Silicon detectors complete ~ Fall, 2000.
Upgrade Status

**Forward:** In production
- Central: Complete & installed
- VLPC
- Scintillator extrusions, VLS
- Shifter
- Preshower
- Installed and tested
- 2T superconducting
- Solenoid
- Produced 1st cylinder with 80K fibres w/ VLPC readout
- 80K fibres w/ VLPC readout
- Double sided
- Detector assembly starting
- along
- Detector production well
- SVXII readout
- 800K CH: Barrels & disks,
- Silicon
Upgrade Status

- Software being written
- Central muon readout
- First systems purchased
- Online production in many systems
- 3 level trigger
- Trigger & DAG assembled
- Fabrication well along, module assembly begun
- Forward mini-drift tube fabricated, modules being assembled
- Forward scint pixeles
- Central scint tiles installed
- Muon System
- Production started
- 600 ch preamp & shaper, scint tiles for ICD
- Calorimeter Electronics & ICD
- Rolled in and hooked up Early 01
- Remove shield wall for roll in late Fall 00
- Silicon Tracker assembly complete Fall 00
- Muon Forward tracking MDT planes installed Summer 00
- Solenoid & CPS installed 9/98
- Muon central installed Summer 99
- Fiber Tracker assembly complete Spring 00
- Muon Forward tigger electronics fabricated Summer 00
- Calorimeter pixels installed Summer 00
LONGER TERM PROSPECTS

The initial Run II goal is achievement of a luminosity of \( \sim 1 \times 10^{32} \text{ cm}^{-2}\text{sec}^{-1} \), with 2 fb\(^{-1}\) delivered to each detector by the end of 2002. Further performance enhancements would be based upon:

- Improved antiproton availability
  - Electron cooling
  - Slip-stacking
  - Liquid lithium lens
  - Aperture improvements

- Controlling the antiproton (long-range) beam-beam interaction.
  - Electron beam compensation

R&D projects aimed at these areas are currently underway.

The expectation is that luminosity could rise into the mid-to-upper \( 10^{32} \text{ cm}^{-2}\text{sec}^{-1} \) with these improvements.
Possible Accumulation of Luminosity in the pre-LHC Era

<table>
<thead>
<tr>
<th>Year</th>
<th>Activity and Details</th>
<th>Luminosity (fb⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>Main Injector and Recycler</td>
<td>0.6</td>
</tr>
<tr>
<td>2002</td>
<td>Initiate antiproton recycling</td>
<td>1.2</td>
</tr>
<tr>
<td>2003</td>
<td>6 month shutdown to install e-cool, 132 nsec, and other intensity improvements</td>
<td>0.8</td>
</tr>
<tr>
<td>2004</td>
<td>Achieve $2 \times 10^{32}$ cm⁻²s⁻¹</td>
<td>2.0</td>
</tr>
<tr>
<td>2005</td>
<td>Achieve $3.5 \times 10^{32}$ cm⁻²s⁻¹</td>
<td>3.5</td>
</tr>
<tr>
<td>2006</td>
<td>Achieve $5 \times 10^{32}$ cm⁻²s⁻¹</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>6 month shutdown to install C-0.</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>Achieve $5 \times 10^{32}$ cm⁻²s⁻¹</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>Initiate Kaon program</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>~15fb⁻¹</td>
</tr>
</tbody>
</table>
SUMMARY

The Fermilab complex is being readied for the start of Collider Run II.

- Significant improvements to the accelerator complex have been completed including:
  - The Main Injector and Recycler Ring
  - Upgrades to the antiproton source stochastic cooling systems
  - Reconfiguration of the Tevatron to support 36 bunch operations
  → Tevatron collider changeover will be initiated in the winter of 2000, with a collider engineering run scheduled to start in spring 2000.

- Significant upgrades to the collider detectors are underway to capitalize fully on improved Tevatron collider performance:
  - A detector commissioning run, without silicon, is scheduled for fall 2000.
  - Startup of Run II with both completed detectors is expected in late winter/early spring 2001.
We expect to be able to deliver approximately 2 fb\(^{-1}\) of integrated luminosity to each detector by the end of 2002, with the potential for 15 fb\(^{-1}\) by the start of LHC operations.

Fermilab is currently uniquely positioned to make discoveries that could reshape our understanding of the physical world. We look forward to capitalizing on this opportunity during the pre-LHC era.