Present Status and Recent Results of Tevatron/CDF Run II

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CDF II Collaboration

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Tevatron/CDF Run II Upgrade
Present Status
Preliminary Physics Results
Prospects and Summary
Fermilab Accelerator Complex

CDF

Tevatron

Main Injector and Recycler

DØ
Fermilab Accelerator Complex (2)

Tevatron Run 2 Upgrade

- Higher Energy Collisions \( \sqrt{s} = 1.8 \text{ TeV} \rightarrow 1.96 \text{ TeV} \)
- Increased number of \( p \) and \( \bar{p} \) bunches \( 6 \times 6 \rightarrow 36 \times 36 \)
- Shorter bunch spacing \( 3.5 \, \mu\text{s} \rightarrow 396 \, \text{ns} \)
- Newly built \( \left\{ \begin{array}{l} 150 \text{ GeV Main Injector} \\ 8 \text{ GeV Recycler} \end{array} \right. \)
  for increasing luminosity at Tevatron
Tevatron Status

Tevatron Run 2 operation started in March 2001

Present Status
- Now achieving typical peak luminosity of $2.5 \sim 3.5 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$
- Run II Best: $3.8 \times 10^{31} \text{ cm}^{-2} \text{s}^{-1}$ on Nov. 08, 2002.
- 170 pb$^{-1}$ delivered, 125 pb$^{-1}$ recorded.
- 1 month shutdown from Jan. 13, 2003 → recovered on Feb. 10.

Luminosity goals for Run 2a
- Peak luminosity of $8 \times 10^{31} \text{ cm}^{-2} \text{s}^{-1}$
- Integrated luminosity of 2 fb$^{-1}$
CDF II Detector

- Central Hadron Calorimeter
- Central EM Calorimeter
- Solenoid
- Central Muon
- Forward Muon
- Endplug Hadron Calorimeter
- Endplug EM Calorimeter
- Tracking Chamber
- Silicon Detector
- TOF
- DAQ

* Japan group contributed in the Run 2 upgrade

New
Old
Partially New

$\vec{p}$
CDF II Detector (2)

Installing Silicon Detectors

Rolling into the Collision Hall
CDF II Tracking

All tracking detectors inside the solenoid are new.

- Solenoid magnet (1.4T)
- Drift chamber (Central Outer Tracker, COT) 30k sense wires
- Silicon detectors (SVXII, ISL, L00) 8 tracking layers (SVXII : 5, ISL : 2, L00 : 1)

\[
\delta p_T / p_T^2 \quad \text{(GeV}^{-1}) \quad \begin{cases} 
\sim 0.1\% \quad (|\eta|<1.0, \text{COT+ISL+SVXII}) \\
\sim 0.4\% \quad (1.0<|\eta|<2.0, \text{ISL+SVXII})
\end{cases}
\]
CDF II Calorimeters, Muon Detectors

- **Calorimeters**
  - EM (Central + End-Plug)
  - Hadron (Central + End-Wall + End-Plug)
  - New End-Plug Calorimeters \((|\eta| < 3.6)\)

- **Muon Detectors**
  - New forward detectors \((1.0 < |\eta| < 1.5)\)
CDF II Trigger Overview

Level 1:
- "Hardware" trigger
- Calorimeters, COT tracks(XFT), Muons
- 50kHz accept rate (currently ~12kHz)

Level 2:
- "Mostly hardware" trigger
- Trigger algorithms run on custom Alpha boards.
- Silicon track information added (SVT)
- 300Hz accept rate (currently ~300Hz)

Level 3:
- "Software" trigger
- ≈ 250 dual-CPU Linux boxes
- 50Hz accept rate (currently ~50Hz)

Typical event size : 250 ~ 300kB
Max logging rate : 20MB/sec
XFT (eXtremely Fast Tracker)

- Track trigger on Level 1
- Momentum resolution $\Delta p_T/p_T^2 = 1.65\% \text{ GeV}^{-1}$ (using data)
- Angular resolution $\Delta \phi = 5.1 \text{ mrad}$ (using data, better than design)

- Plateau efficiency $> 96\%$
  for $p_T > 1.5 \text{ GeV/c}$
Silicon Vertex Trigger (SVT)

- Track-based trigger on Level 2
- Combines COT tracks (from XFT) with silicon hits
- Allows triggering on displaced impact parameters/vertices
CDF II Collaboration

North America
United States
  3 Natl. Labs
  28 Universities
Canada
  1 University

Europe
Italy
  1 Research Lab
  6 Universities
Germany
  1 University
United Kingdom
  4 Universities
Russia
  2 Research Labs
Spain
  1 University
Switzerland
  1 University

Asia
Korea
  3 Universities
Taiwan
  1 University
Japan
  5 Universities
    1 Research Lab
    Univ. of Tsukuba
    KEK
    Waseda Univ.
    Osaka City Univ.
    Hiroshima Univ.
    Okayama Univ.

Totals
11 countries
58 institutes
581 physicists
$Z \rightarrow e\ e$

- Reconstruction of high $E_T$ electron pairs
  (Inclusive high-$E_T$ central electron trigger: $E_T > 18$ GeV, $P_T > 9$ GeV/c)

- $\sigma(Z) \cdot B(Z \rightarrow ee) = 269.0 \pm 6.3$(stat) $\pm 15.1$(sys) $\pm 26.9$(lum) pb
  
  NNLO prediction: 250.2 pb
Forward-backward Charge Asymmetry

\[ \overline{q}q \rightarrow Z/\gamma \rightarrow e^-e^+ \]

\[ A_{FB} = \frac{N_F^e - N_B^e}{N_F^e + N_B^e} \]

- Probe of relative strengths of vector and axial couplings over \( Q^2 \) range
- Probe for additional heavy neutral gauge bosons

\( Z \rightarrow e^-e^+ (2) \)
\[ W \rightarrow e \nu \]

- Isolated electron
- Large \( E_T \) and \( \not{E}_T \)

\[ E_T = 35 \text{ GeV}, \; \not{E}_T = 38 \text{ GeV} \]
Cross section measurement (preliminary)

\[ \sigma(W) \cdot B(W \rightarrow ev) = 2.69 \pm 0.01 \text{(stat)} \pm 0.09 \text{(sys)} \pm 0.27 \text{(lum)} \text{ nb} \]

NNLO prediction : 2.73 nb ( \( \sqrt{s} = 1.96 \text{TeV} \))

\[ R = \frac{\sigma(W) \cdot B(W \rightarrow ev)}{\sigma(Z) \cdot B(Z \rightarrow ee)} = 9.93 \pm 0.24 \text{(stat)} \pm 0.58 \text{(sys)} \]

- W mass is extracted from a fit to transverse mass distribution (combined with \( \mu \nu \) mode).

\[ \Delta M \sim 30 \text{MeV/c}^2 \text{ with } 2 \text{fb}^{-1} \]

(competitive with combined LEP2 result : 39MeV/c^2)
W and Z Measurements with Muons

- Inclusive high-$P_T$ muon trigger sample ($P_T > 18$ GeV/c)

Transverse mass of $W \rightarrow \mu\nu$

Inclusive high-$P_T$ muon trigger sample ($P_T > 18$ GeV/c)

\[
\sigma(W) \cdot B(W \rightarrow \mu\nu) = 2.70 \pm 0.04 \, \text{(stat)} \pm 0.19 \, \text{(sys)} \pm 0.27 \, \text{(lum)} \, \text{nb}
\]

\[
R = \frac{\sigma(W) \cdot B(W \rightarrow \mu\nu)}{\sigma(Z) \cdot B(Z \rightarrow \mu\mu)} = 13.66 \pm 1.94 \, \text{(stat)} \pm 0.14 \pm 0.13 \, \text{(sys)}
\]

(Run 2 preliminary)
Measurements with Low $p_T$ Muons

- Di-muon trigger sample ($P_T > 1.5$ GeV/c)

\[ J/\psi \rightarrow \mu \mu \quad \text{and} \quad Y \rightarrow \mu \mu \]

- Large sample of $J/\psi$ is a good tool of physics analysis and tracking calibration.
Measurements of B Masses

- Cross check of tracking calibration using $J/\psi$ decay channels

$$m(B^+) = 5280.6 \pm 1.7\text{(stat)} \pm 1.1\text{(sys)} \text{ MeV}/c^2 \quad (\text{PDG : } 5279.0 \pm 0.5 \text{ MeV}/c^2)$$

$$m(B^0) = 5279.8 \pm 1.9\text{(stat)} \pm 1.4\text{(sys)} \text{ MeV}/c^2 \quad (\text{PDG : } 5279.4 \pm 0.5 \text{ MeV}/c^2)$$

Starting to be competitive . . .

$$m(B^{0}_S) = 5360.3 \pm 3.8\text{(stat)} +\frac{2.1}{2.9}\text{(sys)} \text{ MeV}/c^2 \quad (\text{PDG : } 5369.6 \pm 2.4 \text{ MeV}/c^2)$$

$B^+ \rightarrow J/\psi \ K^+$

$B^0 \rightarrow J/\psi \ K^{*0}$

$B^0_\psi \rightarrow J/\psi \ \phi$

$\int L = 18.4 \text{ pb}^{-1} \quad N(B^+) = 152.7 \pm 14.0$

$N(B^0) = 82.4 \pm 11.5$

$N(B^{0}_S) = 14.4 \pm 4.0$
Fully Hadronic B Signals with the SVT Trigger

- Hadronic triggers are working!!
- First step to find $B_s^0 \rightarrow D_s^- \pi^+$ towards $B_s^0 - \bar{B}_s^0$ mixing
B Physics Projections

- measurement of $\sin 2\beta$

  \[ B^0 \rightarrow J/\psi K_S \]

  \[ \sigma(\sin 2\beta) \sim 0.05 \text{ with } 2 \text{ fb}^{-1} \]

- $B_s^0 - \bar{B}_s^0$ mixing (unique at Tevatron)

  \[ B_s^0 \rightarrow D_s \pi, \ D_s \pi \pi \pi \]

  CDF sensitivity at 5$\sigma$ for $x_s < 60$

  \[ (x_s = \Delta m_s / \Gamma_s) \]

  Latest LEP limit: $x_s > 21$ ($\Delta m_s > 14.4 \text{ ps}^{-1}$)

  SM expectation: $x_s < 35$
Measurements of Charm Mesons

- SVT trigger collects charm events as well as bottom events.

- Ratios of Cabibbo suppressed $D^0$ decays

\[
\Gamma(D^0 \to KK)/\Gamma(D^0 \to K\pi) = 11.17 \pm 0.48\text{(stat)} \pm 0.98\text{(sys)}\% \quad \text{(PDG : 10.83 \pm 0.27 \%)}
\]
\[
\Gamma(D^0 \to \pi \pi)/\Gamma(D^0 \to K\pi) = 3.37 \pm 0.20\text{(stat)} \pm 0.16\text{(sys)}\% \quad \text{(PDG : 3.76 \pm 0.17 \%)}
\]

already competitive with CLEO2 results
starting to be competitive with PDG averages
Measurements of Charm Mesons (2)

- $D_s^\pm - D^\pm$ mass difference

  Reconstructed $D_s^\pm (D^\pm) \rightarrow \phi \pi$ ($\phi \rightarrow KK$)

  $M(D_s^\pm) - M(D^\pm) = 99.28 \pm 0.43({\text{stat}}) \pm 0.27({\text{sys}})$ MeV/c^2

  (PDG average: $99.2 \pm 0.5$ MeV/c^2)

  already competitive

- Expect $O(10^7)$ fully reconstructed D meson decays in 2 fb^{-1}

  Foresee a quite interesting charm physics program
  
  CP asymmetries and mixing in D sector, rare decays, . . .
Top Event Candidate

\begin{itemize}
\item $800 \, \bar{t}t$ events with $b$-tagging are expected with 2 fb$^{-1}$
\item Expect preliminary $\sigma_{\bar{t}t}$ and $M_{\text{top}}$ by Spring 2003
\end{itemize}

\begin{itemize}
\item $e^+$ \quad $E_T = 73$ GeV
\item $e^-$ \quad $E_T = 56$ GeV
\item Jet 1 \quad $E_T = 35$ GeV
\item Jet 2 \quad $E_T = 34$ GeV
\item MET \quad $E_T = 43$ GeV
\item $M(e^+e^-) = 118$ GeV
\end{itemize}
Higgs at the Tevatron

Low-mass SM Higgs ($\lesssim 130\text{GeV/c}^2$)

$q\bar{q}' \rightarrow Wh \rightarrow \ell\nu b\bar{b}$

$q\bar{q} \rightarrow Zh \rightarrow \ell^+\ell^- b\bar{b}, \nu\bar{\nu} b\bar{b}$

High-mass SM Higgs ($130\text{GeV/c}^2 \sim 190\text{GeV/c}^2$)

$gg \rightarrow h \rightarrow W^*W^* \rightarrow \ell^+\ell^- \nu\bar{\nu}$

$q\bar{q}' \rightarrow Wh \rightarrow \ell^+\ell^- W^*W^* \rightarrow \ell^+\nu\ell^±\nu j j$

$q\bar{q} \rightarrow Zh \rightarrow \ell^±\ell^± W^*W^* \rightarrow \ell^±\ell^± \ell^±\nu j j$
Higgs at the Tevatron (2)

- Sensitivity reevaluation in progress using fine-tuned full detector simulation

![Graph showing integrated luminosity/expt. vs. Higgs mass (GeV/c^2)]

- LEP excluded
- 2 fb^{-1}: exclude $M_h = 115$ GeV/c^2, if not there
- 5 fb^{-1}: $3\sigma$ signal for $M_h = 115$ GeV/c^2
- 10 fb^{-1}: $3\sigma$ signal for $M_h = 115 \sim 125$, $155 \sim 175$ GeV/c^2
Top / Electroweak Projections

- $\sqrt{s} = 1.96\text{TeV}$
  - $\sigma(W), \sigma(Z) \sim 10\%$ higher
  - $\sigma(t\bar{t}) \sim 30\%$ higher
- With 2 fb$^{-1}$ (Run 2a)
  - $\Delta M_W \sim 30\text{ MeV}/c^2$
  - $\Delta M_{top} \lesssim 3\text{ GeV}/c^2$
  - $\Rightarrow \Delta(\log M_h) \sim \log 1.6$
    - $(1/1.6 M_h < M_h < 1.6 M_h)$
- With 10 fb$^{-1}$
  - $\Delta M_W \sim 20\text{ MeV}/c^2$
  - $\Delta M_{top} \lesssim 2\text{ GeV}/c^2$
  - $\Rightarrow \Delta(\log M_h) \sim \log 1.3$

\[ 
\begin{align*}
\text{Higgs Mass (GeV}/c^2) & \quad \text{M}_W \quad \text{M}_{top} \\
130 & \quad 140 & \quad 150 & \quad 160 & \quad 170 & \quad 180 & \quad 190 & \quad 200 \\
\text{LEP2 + Tevatron Run-I} & \quad \text{RUN-IIa} & \quad \text{LEP1+SLD+vN} \\
100 & \quad 250 & \quad 500 & \quad 1000
\end{align*} 
\]
- From Run I Results -  

**Direct $J/\psi$ Production**

- Observed large excess of direct production of $J/\psi$ and $\psi(2S)$ compared with QCD prediction with color singlet model (CSM).

- From Run I Results -  \( W + \text{heavy-flavor jets} \)

- Excess of \( W + 2,3 \text{ jet events} \) compared with SM

One of these was tagged by both
- displaced vertex tag (SECVTX)
- soft lepton tag (SLT).

<table>
<thead>
<tr>
<th>Source</th>
<th>( W + 1 \text{ jet} )</th>
<th>( W+2 \text{ jet} )</th>
<th>( W+3 \text{ jet} )</th>
<th>( W + \geq 4 \text{ jet} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>SECVTX mistags in events with SLT tags</td>
<td>0.28 ± 0.03</td>
<td>0.09 ± 0.01</td>
<td>0.07 ± 0.01</td>
<td>0.02 ± 0.00</td>
</tr>
<tr>
<td>Non-( W )</td>
<td>0.57 ± 0.05</td>
<td>0.13 ± 0.03</td>
<td>0.00 ± 0.00</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>( WW, WZ, ZZ )</td>
<td>0.02 ± 0.02</td>
<td>0.13 ± 0.06</td>
<td>0.01 ± 0.01</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>Single top</td>
<td>0.12 ± 0.04</td>
<td>0.24 ± 0.05</td>
<td>0.07 ± 0.02</td>
<td>0.02 ± 0.00</td>
</tr>
<tr>
<td>( Wc )</td>
<td>0.88 ± 0.29</td>
<td>0.24 ± 0.14</td>
<td>0.14 ± 0.10</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>( Wc\bar{c} )</td>
<td>0.41 ± 0.13</td>
<td>0.25 ± 0.09</td>
<td>0.13 ± 0.06</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>( Wb\bar{b} )</td>
<td>1.58 ± 0.33</td>
<td>1.07 ± 0.26</td>
<td>0.19 ± 0.09</td>
<td>0.01 ± 0.00</td>
</tr>
<tr>
<td>( Z\to\tau\tau )</td>
<td>0.00 ± 0.00</td>
<td>0.00 ± 0.00</td>
<td>0.00 ± 0.00</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>( Zc )</td>
<td>0.01 ± 0.00</td>
<td>0.00 ± 0.00</td>
<td>0.00 ± 0.00</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>( Zc\bar{c} )</td>
<td>0.01 ± 0.00</td>
<td>0.01 ± 0.00</td>
<td>0.01 ± 0.00</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>( Zb\bar{b} )</td>
<td>0.08 ± 0.02</td>
<td>0.05 ± 0.02</td>
<td>0.02 ± 0.01</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>( tt )</td>
<td>0.04 ± 0.02</td>
<td>0.48 ± 0.19</td>
<td>1.08 ± 0.40</td>
<td>1.42 ± 0.49</td>
</tr>
<tr>
<td>SM prediction (supertag)</td>
<td>4.00 ± 0.50</td>
<td>2.69 ± 0.41</td>
<td>1.71 ± 0.40</td>
<td>1.47 ± 0.51</td>
</tr>
<tr>
<td>Data (supertag)</td>
<td>1</td>
<td>8</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>

Need investigation with high-statistics data in Run II

- From Run I Results -  
Rapidity Distribution of $t\bar{t}$ Pair
Tevatron Plan and Luminosity Prospects

Run 2a

2003

- One month shutdown from January 13 → recovered on February 10
  - Increase C0 aperture
  - Others (dampers, MI, vacuum, etc.)
- During 2003
  - Complete Recycler work
  - Integrate Recycler into operation
  - Expect a delivered integrated luminosity of ~300 pb⁻¹

Run 2a goal

- Typical peak luminosity of $8 \times 10^{31}$ cm⁻²s⁻¹
- Integrated luminosity of 2 fb⁻¹ over 2 ~ 3 year period
Tevatron Plan and Luminosity Prospects (2)

After 2 fb⁻¹ (Run 2b)

- Increase anti-proton intensity
  - More protons on target
  - Better collection and transfer efficiency
- Peak luminosity up to 4 x 10³² cm⁻²s⁻¹
- Silicon detector replacement at CDF and D0
  (Japan group is contributing to Run 2b silicon detector (SVXII-b) at CDF)
- Integrated luminosity of 6.5 ~ 11 fb⁻¹ during ~4-year running (~2008)

<table>
<thead>
<tr>
<th>FY</th>
<th>base</th>
<th>stretch</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>2003</td>
<td>0.2</td>
<td>0.32</td>
</tr>
<tr>
<td>2004</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>2005</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>2006</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>2007</td>
<td>1.5</td>
<td>3.0</td>
</tr>
<tr>
<td>2008</td>
<td>1.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Total</td>
<td>6.5</td>
<td>11.0</td>
</tr>
</tbody>
</table>
Fermilab accelerators and collider detectors were successfully upgraded. Run 2 started in March 2001.

Collider detectors are working well.

We are accumulating physics data of pp collisions. Data analyses are also in progress. Some preliminary results were presented. The updated results will be shown at the upcoming high energy conferences.

Luminosity of Tevatron is being improved. Hopefully, integrated luminosity of ~ 300 pb⁻¹ in 2003, 2 fb⁻¹ in 2 ~ 3 years, 6.5 ~ 11 fb⁻¹ in ~2008.
Backup Slides
# Tevatron Parameters and Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Run Ib</th>
<th>Now (Nov. 2002)</th>
<th>Run 2a Goals</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td># of bunches</td>
<td>6x6</td>
<td>36x36</td>
<td>36x36</td>
<td></td>
</tr>
<tr>
<td>Protons/bunch</td>
<td>230</td>
<td>200</td>
<td>270</td>
<td>$10^9$</td>
</tr>
<tr>
<td>Antiprotons/bunch</td>
<td>55</td>
<td>26</td>
<td>30</td>
<td>$10^9$</td>
</tr>
<tr>
<td>Total Antiprotons</td>
<td>330</td>
<td>900</td>
<td>1080</td>
<td>$10^9$</td>
</tr>
<tr>
<td>Peak Pbar production rate</td>
<td>60</td>
<td>130</td>
<td>200</td>
<td>$10^9$/hour</td>
</tr>
<tr>
<td>Proton emittance</td>
<td>23</td>
<td>20</td>
<td>20</td>
<td>$\pi$ mm-mr</td>
</tr>
<tr>
<td>Pbar emittance</td>
<td>13</td>
<td>18</td>
<td>15</td>
<td>$\pi$ mm-mr</td>
</tr>
<tr>
<td>Beam energy</td>
<td>900</td>
<td>980</td>
<td>1000</td>
<td>GeV</td>
</tr>
<tr>
<td>Bunch length (proton, rms)</td>
<td>0.6</td>
<td>0.61</td>
<td>0.37</td>
<td>m</td>
</tr>
<tr>
<td>Bunch length (pbar, rms)</td>
<td>0.6</td>
<td>0.54</td>
<td>0.37</td>
<td>m</td>
</tr>
<tr>
<td>Typical luminosity</td>
<td>0.16</td>
<td>3.2</td>
<td>8.1</td>
<td>$10^{31}$cm$^{-2}$s$^{-1}$</td>
</tr>
<tr>
<td>Integrated luminosity</td>
<td>3.2</td>
<td>5</td>
<td>16</td>
<td>pb$^{-1}$/week</td>
</tr>
</tbody>
</table>
- From Run I Results -  Direct $J/\psi$ Production (2)

- Inclusion of the color octet model seems to fit the spectrum, but . . .

- From Run I Results - Direct $J/\psi$ Production (3)

- Prediction of polarization disagrees with measurements at high-$p_T$.