Physics Result from the Tevatron

Kazu Hanagaki / Fermilab for CDF/DØ collaborations
The Collaborations

12 countries, 59 institutions
767 physicists

More than 50% non-US
Outline

• Physics capability at the Tevatron
• Overview of experiment
• Detectors
• Recent results plus prospects
  – Higgs search
  – Top and electroweak (W/Z)
  – QCD
  – B
  – Search for new phenomena
• Conclusions

✓ All results shown in this talk are preliminary (though I don’t label “preliminary” on all the plots)
Physics Potential at the Tevatron

• The world’s highest energy ($\sqrt{s}=1.96\text{TeV}$) p-pbar collider
  – [Various kinds of particle] factory, i.e. the following events have been produced at each detector in run 2 (delivered integrated luminosity ~ 280 pb$^{-1}$)
    - $n$ Gravitons from Extra Dimension
    - $m$ Charginos, Neutralinos, gluinos…
    - 48 (or 0) $H_{\text{SM}}(120\text{GeV})+W$ events
    - 2300 t-tbar events
    - $2.5 \times 10^6$ Z+X events
    - $8.4 \times 10^6$ W+X events
    - $42 \times 10^9$ b-bbar events
    - $17 \times 10^{12}$ q-qbar (inelastic scattering) events

  ➔ Provide unique opportunity to cover wide range of physics
A CDF + DØ joint study has updated the famous Higgs reach plot

- Concentrated on low mass region
- Higgs reach at the Tevatron appears to be at least as good as was projected four years ago
- (The silicon upgrade was assumed here)
Experimental Challenges

• Capability to produce tons of various particles ➣ high physics potential, however, many experimental difficulties
  – In most case, (people’s interests) × (cross section) is a constant ➣ most events are background
    ➢ Background rejection by O(10^{10})
  – Very high rate ➣ e.g. 1Hz W(→lν)+X @L=2×10^{32}
    ➢ Detector operation in high occupancy condition
    ➢ High radiation
    ➢ Trigger and DAQ
    ➢ Data size huge
    ➢ Many new technologies

• High luminosity is crucial
• Detector maintenance/calibration also crucial…
  but many people loves only physics analysis
  ➣ detector operation is also a challenge!!
Accelerator Complex

- 980 GeV p and p-bar
- 36 × 36 bunches
- 396ns bunch crossing

Fermilab’s Accelerator Chain

150 GeV

8 GeV
Luminosity

Collider Run IIA Peak Luminosity

2001  2002  2003
Data Collection Status

- Both CDF and DØ experiments are operating well and recording physics quality data with ~85% efficiency
- Data are being reconstructed within a few days
2T magnetic field for momentum measurement
**DØ Trigger**

- **Level-1**
  - Mainly single-detector-based
  - Operating rate ~ 1.5 kHz

- **Level-2**
  - Extensive correlations
  - Physics objects out (e, µ, τ, jet…)
  - Operating rate ~ 800 Hz

- **Level-3**
  - Software reconstruction
  - Operating rate ~ 50 Hz
CDF Trigger

1.7 MHz bunch crossing rate

Detector

L1 trigger

Hardware tracking for \( p_T \geq 1.5 \text{ GeV} \)

Muon-track matching

Electron-track matching

Missing \( E_T \), sum-\( E_T \)

L1 buffers

L2 trigger

Silicon tracking

Jet finding

Refined electron/photon finding

L2 buffers

L3 trigger

Full event reconstruction

30 kHz L1 accept

present: 25 KHz

4 L2 buffers

300 Hz L1 accept

present: 250 Hz

300 CPU’s

300 CPU’s

46 L1 buffers

70 Hz L3 accept

present: 50 Hz

tape

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Detector Performance

- Emphasis different in CDF and DØ
  - CDF
    - Larger tracking volume
    - Higher rate capability of trigger
  - DØ
    - Larger acceptance for muon
    - Calorimeter with better energy resolution
B-jet tagging

**Secondary Vertex (Impact parameter) Tag**
- Signature of a b decay is a displaced vertex:
  - Long lifetime of b hadrons ($c\tau \sim 450 \mu m$) + boost
  - B hadrons travel $L_{xy} \sim 3mm$ before decay with large charged track multiplicity

**Soft Lepton Tag**
- Exploits the b quarks semi-leptonic decays
  - $b \rightarrow \ell v c$ (BR $\sim 20\%$)
  - $b \rightarrow c \rightarrow \ell v s$ (BR $\sim 20\%$)
  - These leptons have a softer $p_T$ spectrum than W/Z leptons
  - They are less isolated

---

CDF

Important tool in top analysis and Higgs search
Higgs Hunting at the Tevatron

- The Higgs boson
  - Last piece of the SM
  - Key to understanding beyond-the-SM physics like supersymmetry: a light Higgs is a basic prediction of SUSY

- Mass below ~140 GeV
  - \((qq \rightarrow HW, HZ) + (H \rightarrow bb)\)
  - \((qq \rightarrow H) + (H \rightarrow bb)\)
  - overwhelmed by large QCD background (see page 4)

- Mass above ~140 GeV
  - \((gg \rightarrow H) + (H \rightarrow WW)\)

Dominant decay mode: \(H \rightarrow WW\)
Higgs Search

- $H(\rightarrow bb)W(\rightarrow ev)$
  - Look for dijets in $W+X$ events

- $H(\rightarrow bb)W(\rightarrow e\nu)$
  - Look for dijets in $W+X$ events

- $H \rightarrow WW$
  - Two high $P_T$ isolated leptons
  - Large missing $E_T$
  - Angle between two leptons
Higgs Search - cont’d

- $H^{++/--) \rightarrow \mu^\pm \mu^\pm$
  - Left-right symmetric model
  - Higgs triplet

- Similar results in $e\mu$ channel (CDF)

- $bb(h/H/A)$ enhanced at large $\tan \beta$:

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What if we see nothing?

- Exclusion of Higgs itself would be very important
  - LEP’s hint in the SM framework (~2fb\(^{-1}\))
  - Most probable mass range (~5fb\(^{-1}\))
  - Almost all the allowed range (~10fb\(^{-1}\))
- Special importance for minimal SUSY Higgs
  - can be excluded almost all parameter space with 5-10fb\(^{-1}\)

Note: the plot do not yet take account of the Higgs reach update
Top quark

- Why does the top quark strongly couple to the Higgs field?
  - Special role in EW symmetry breaking?
  - Window to the origin of fermion mass?
- The Tevatron is the only source of top quarks in the world
Top Production and Decay

- at Tevatron energies, top quarks are primarily produced in pairs
- 85% $qq$ and 15% $gg$
- $\sigma = 5.8 - 7.4 \text{ pb}$
  [hep-ph/0303085]

- $\text{Br}(t \rightarrow Wb) \sim 100\%$
- Both W’s decay via $W \rightarrow lv$ ($l=e$ or $\mu$; 5%)
  dilepton $\leftarrow$ clean
- One W decays via $W \rightarrow lv$ ($l=e$ or $\mu$; 30%)
  lepton+jets $\leftarrow$ less clean
- Both W’s decay via $W \rightarrow qq$ (44%)
  all hadronic $\leftarrow$ not clean

- Lepton ID
- Jet ID and its energy scale
- Missing Et
- b tagging
- all detector elements
Event Display

CDF

Lepton + jets

Jet 1

Jet 2

dilepton

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Cross Section - lepton + jet

1 high $p_T$ lepton ($e, \mu$)
Large Missing $E_T$
$\geq 3$ central jets

$H_T$: scalar sum of all the measured "objects" $E_T$'s (leptons, jets)

CDF Preliminary (126 pb$^{-1}$)

N$_{jet} \geq 4$

jet multiplicity

no. of tagged events

CDF Preliminary

D0 Run II preliminary

Data  QCD  $W$+light  $W_c$  $W_{cc}$  $W_{bb}$  error on Bgr

error on Bgr

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Cross Section - dilepton

- 2 high $p_T$ leptons ($e, \mu, \tau, \text{iso track}$)
- Large Missing $E_T$
- 2 central jets

CDF Run II Preliminary

- $126 \text{ pb}^{-1}$
- $97.7 \text{ pb}^{-1}$

Number of jets, $p_T > 15 \text{ GeV}$

$H_T$ [GeV]
Top Cross Section - Summary

**CDF**

**Top Cross Section – Summary**

1. **CDF Dileptons 90-107 pb⁻¹**
   
   \[8.7^{+6.4}_{-4.7} (stat)^{+2.7}_{-2.0} (syst) \pm 0.9 (lum)\]

2. **CDF Dileptons 126 pb⁻¹**
   
   \[7.6^{+3.8}_{-3.1} (stat)^{+1.5}_{-1.9} (syst)\]

3. **CDF L+Track 126 pb⁻¹**
   
   \[7.3 \pm 3.4 (stat) \pm 1.7 (syst)\]

4. **DØ Dileptons 90-107 pb⁻¹**
   
   \[7.4^{+4.4}_{-3.6} (stat)^{+2.1}_{-1.8} (syst) \pm 0.7 (lum)\]

5. **DØ L+jets/CSIP 45 pb⁻¹**
   
   \[10.8^{+4.9}_{-4.0} (stat)^{+2.1}_{-2.0} (syst) \pm 1.1 (lum)\]

6. **DØ L+jets/SVT 45 pb⁻¹**
   
   \[4.6^{+3.1}_{-2.7} (stat)^{+2.1}_{-2.0} (syst) \pm 0.5 (lum)\]

7. **DØ L+jets/topo 92 pb⁻¹**
   
   \[11.4^{+4.1}_{-3.5} (stat)^{+2.0}_{-1.8} (syst) \pm 1.1 (lum)\]

8. **DØ L+jets/soft muon 92 pb⁻¹**
   
   \[8.0^{+2.4}_{-2.1} (stat)^{+1.7}_{-1.5} (syst) \pm 0.8 (lum)\]

9. **DØ L+jets combined 92 pb⁻¹**
   
   \[5.3 \pm 1.9 (stat) \pm 0.9 (syst)\]

10. **CDF L+jets/SVX 57 pb⁻¹**
    
    \[5.1 \pm 1.8 (stat) \pm 2.1 (syst)\]

11. **CDF L+jets/HT 126 pb⁻¹**
    
    \[8.1^{+2.2}_{-2.0} (stat)^{+1.6}_{-1.4} (syst) \pm 0.8 (lum)\]

12. **DØ Combined 90-107 pb⁻¹**
    
    \[8.1^{+2.2}_{-2.0} (stat)^{+1.6}_{-1.4} (syst) \pm 0.8 (lum)\]
Single Top Production

- With $\sim1\text{fb}^{-1}$ should be able to see signals for both $s$ and $t$-channel production

\[ \sigma_t(t\text{-channel}) < 15.4 \text{pb} @95\% \text{ C.L.} \]
\[ \sigma_t(\text{combined}) < 17.5 \text{pb} @95\% \text{ C.L.} \]
Electroweak

- Top and W mass measurements help to constrain Higgs mass
  \[ \delta M_W \propto \{ M_t^2, \ln(M_H) \} \]

\[ dm_H/dm_t \sim 50 \text{ GeV}/4 \text{ GeV} \]
\[ dm_H/dm_W \sim 50 \text{ GeV}/25 \text{ MeV} \]

[hep-ph/0111217 (2001)]
[hep-ph/0202001 (2002)]
Likelihood method using most available information

\[
P(x; \alpha) = \text{Acc} (x) \times \frac{1}{\sigma} \int d^n \sigma(y; \alpha) \ dq_1 \ dq_2 \ f(q_1) \ f(q_2) \ W(x, y)
\]

Likelihood definition:
estimate signal and background fractions and \( m_t \)

\[
P_0(x; c_1, c_2, \alpha) = c_1 P_{t\bar{t}bar}(x; \alpha) + c_2 P_{W+jets}(x)
\]

LO ME used, 4 jets required exclusively, additional cut on background probability (to improve purity) \( \rightarrow 22 \) events
Top Mass in DØ Run I – cont’d

\[ m_{\text{top}} = 179.9 \pm 3.6 \text{ (stat) GeV}/c^2 \]

large improvement on the statistical uncertainty (~2.4× stats)

<table>
<thead>
<tr>
<th>Jet Energy Scale</th>
<th>5.6 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal model</td>
<td>1.5 GeV</td>
</tr>
<tr>
<td>Background model</td>
<td>1.0 GeV</td>
</tr>
<tr>
<td>Multiple interactions</td>
<td>1.3 GeV</td>
</tr>
</tbody>
</table>

The application of this technique to many other measurements would be possible
Top Mass in CDF Run II

CDF RunII preliminary, 108 pb\(^{-1}\)

- **Data 22 evts**
- **Signal + Bkgd**
- **Bkgd only (6.5 evts)**

Reconstructed Top Mass, Tagged Events (GeV/c\(^2\))

- **Mass in lepton+jets channel**
- **Mass in dilepton channel**

**CDF RunII preliminary, 126 pb\(^{-1}\)**

- **6 events**

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Mass in lepton+jets channel with a b-tagged jet

\(177.5^{+12.7}_{-9.4} \text{ (stat)} \pm 7.1 \text{(syst)} \text{ GeV/c}^2\)

Mass in dilepton channel

\(175.0^{+17.4}_{-16.9} \text{ (stat)} \pm 7.9 \text{(syst)} \text{ GeV/c}^2\)
Prospects of Mass Measurements

(per experiment)

<table>
<thead>
<tr>
<th></th>
<th>$\Delta m_W$</th>
<th>$\Delta m_t$</th>
<th>$l + \text{jets}$</th>
<th>dilepton</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 fb$^{-1}$</td>
<td>$\pm 27$ MeV</td>
<td>$\pm 2.7$ GeV</td>
<td>$\pm 2.2$ GeV</td>
<td>$\pm 2.8$ GeV</td>
</tr>
<tr>
<td>5 fb$^{-1}$</td>
<td>$\pm 22$ MeV</td>
<td>$\pm 2.2$ GeV</td>
<td>$\pm 2.2$ GeV</td>
<td>$\pm 2.2$ GeV</td>
</tr>
</tbody>
</table>

W-Boson Mass [GeV]

- $p\bar{p}$-colliders
- LEP2
- Average
- NuTeV
- LEP1/SLD
- LEP1/SLD/$m_t$

- LEP1, SLD Data
- LEP2, $p\bar{p}$ Data

CDF/D0
2 fb$^{-1}$ goal

$\Delta \alpha$

$H$ [GeV]

130 300 1000

Preliminary

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W/Z Physics

- Not only the mass measurement...
  - Indirect probe to new physics by measuring the SM parameters
    - $\gamma^*/Z$ interference
    - Triple gauge coupling
  - Constrain proton PDF
  - Probe effects of NLO QCD corrections
  - Better understanding of the experiments
  - Improve luminosity measurement
- Reconstructions from $\tau$
  - Lepton universality
  - Important as a baseline for many exotic searches including $\tau$
\( W/Z \) Cross Section

- **High \( P_T \) isolated lepton (e, \( \mu \)) + missing ET \( \rightarrow W \)
- **Two high \( P_T \) isolated leptons \( \rightarrow Z \)

**CDF**

\[ W^\pm \rightarrow e^\pm \nu_e \mu^- \nu_\mu, \text{ or } \tau^\pm \nu_\tau \]

\[ Z^0 \rightarrow e^+ e^-, \mu^+ \mu^-, \text{ or } \tau^+ \tau^- \]

\[ 68.5% \rightarrow q\bar{q}, \quad 20.0% \rightarrow \nu\bar{\nu} \]

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**D\( \phi \) and CDF Run2 Preliminary**

- \( p\bar{p} \rightarrow W+X \rightarrow N+X \)
- \( p\bar{p} \rightarrow Z+X \rightarrow l\bar{l}+X \)

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Forward-backward Asymmetry

- Forward-backward asymmetry $A_{FB}$ in $Z \rightarrow ee$
  - High mass reach unique in Tevatron

$$A_{FB} = \frac{d\sigma (\cos\theta > 0) - d\sigma (\cos\theta < 0)}{d\sigma (\cos\theta > 0) + d\sigma (\cos\theta < 0)}$$

CDF – Paper in preparation

Projection for 10 fb$^{-1}$

- Measure effective $\sin^2\theta_W$ to 0.0004 (5 fb$^{-1}$) and test $\gamma^*/Z$ interference at $\sqrt{s}$ much greater than LEP
**$W\gamma$ and $Z\gamma$ Couplings**

- Tests triple gauge couplings which are precisely predicted by SM
- Sensitive to anomalous couplings

<table>
<thead>
<tr>
<th>Process</th>
<th>Events</th>
<th>S/B</th>
<th>SM $\sigma$(pb)</th>
<th>meas. $\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W\gamma \rightarrow \gamma l\nu$</td>
<td>133</td>
<td>2.4</td>
<td>$18.6\pm1.3$</td>
<td>$17.2\pm1.8\pm2.2\pm1.0$</td>
</tr>
<tr>
<td>$Z\gamma \rightarrow \gamma ll$</td>
<td>47</td>
<td>15</td>
<td>$5.3\pm0.4$</td>
<td>$5.8\pm1.0 \pm0.4\pm0.4$</td>
</tr>
</tbody>
</table>

- Anomalous couplings limits coming soon

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• Important to understand the basic process
  – most of events at the Tevatron are created by the strong interaction
  – indirect probe to new physics
**B-Hadron inclusive cross section**

- Long standing puzzle – discrepancy between the data and theory (shape in high $P_T$ OK)

CDF recently measured the total cross section

$$\sigma(p\bar{p} \to bX, |y|<1) = 29.4 \pm 0.6\text{(stat)} \pm 6.2\text{(sys)} \, \mu b$$

- Total cross section MAY not be so inconsistent
**B Physics**

- Hadron collider – variety of B hadrons!

**CDF result:** \( M(B_s) = 5365.50 \pm 1.60 \text{ MeV} \)

**World average:** \( M(B_s) = 5369.6 \pm 2.4 \text{ MeV} \)

**CDF result:** \( M(\Lambda_b) = 5620.4 \pm 2.0 \text{ MeV} \)

**World average:** \( M(\Lambda_b) = 5624 \pm 9 \text{ MeV} \)

Ready for further step – \( \Delta m_S \), CP violation…

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Towards $B_s$ mixing

- Measurements of $\Delta m_S$ help to improve our knowledge of CKM triangle
- Current limit: $\Delta m_s > 14.4 \text{ps}^{-1} @ 95\% \text{CL}$
- $B_s$ oscillation much faster than $B_d$ because of coupling to top quark:
  $\text{Re}(V_{ts}) \approx 0.040 > \text{Re}(V_{td}) \approx 0.007$

  - What you need after event reconstruction:
    - Proper decay time
    - Flavor tagging

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**$DØ$ Results:**
- Jet charge: $\varepsilon D^2 = (3.3 \pm 1.1)\%$
- Muon tagging: $\varepsilon D^2 = (1.6 \pm 0.6)\%$

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**CDF Results:**
- Same-side ($B^+$): $\varepsilon D^2 = (2.1 \pm 0.7)\%$
- ($B^+/B^0/B_s$, correlations different)
- Muon tagging: $\varepsilon D^2 = (0.7 \pm 0.1)\%$
CDF $B_s$ Sensitivity Estimate

- **Current performance:**
  - $S=1600$ events/fb$^{-1}$ (i.e. $\sigma_{\text{effective}}$ for produce+trigger+recon)
  - $S/B = 2/1$
  - $\varepsilon D^2 = 4\%$
  - $\sigma_t = 67\text{fs}$
  - $2\sigma$ sensitivity for $\Delta m_s = 15\text{ps}^{-1}$ with $\sim 0.5\text{fb}^{-1}$ of data

- **With “modest” improvements**
  - $S=2000$ / fb$^{-1}$ (improve trigger, reconstruct more modes)
  - $S/B = 2/1$ (unchanged)
  - $\varepsilon D^2 = 5\%$ (kaon tagging)
  - $\sigma_t = 50\text{fs}$ (event-by-event vertex + L00)
  - $5\sigma$ sensitivity for $\Delta m_s = 18\text{ps}^{-1}$ with $\sim 1.7\text{fb}^{-1}$ of data
  - $5\sigma$ sensitivity for $\Delta m_s = 24\text{ps}^{-1}$ with $\sim 3.2\text{fb}^{-1}$ of data
  - $\Delta m_s = 24\text{ps}^{-1}$ “covers” the expected region based upon indirect fits.

- **DØ has the similar (but a little bit worse) sensitivity**
$\mathcal{B}_s \rightarrow \mu^+\mu^-$ Search

- SM prediction $\mathcal{B}r \sim 3.5 \times 10^{-9}$
- Can probe SUSY – enhancement by 1-3 order of magnitude (light Higgs and large $\tan\beta$) $\leftrightarrow g-2$

CDF: $\mathcal{B}r(\mathcal{B}_s \rightarrow \mu^+\mu^-) < 9.5 \times 10^{-7}$ @95% CL
DØ: $\mathcal{B}r(\mathcal{B}_s \rightarrow \mu^+\mu^-) < 1.6 \times 10^{-6}$ @90% CL
PDG: $\mathcal{B}r(\mathcal{B}_s \rightarrow \mu^+\mu^-) < 2.0 \times 10^{-6}$ @90% CL

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New Phenomena

- We know the Standard Model is incomplete
- What is dark matter?
  - SUSY LSP?
  - Extra dimensions?

- SUSY
  - Possible decay chains always end in the LSP
    - Jets + missing $E_T$
    - Photons + missing $E_T$
    - Trileptons

- Extra dimensions
  - Virtual graviton exchange
  - Direct graviton emission

CDF

matter: $27\pm4\%$
baryonic matter: $4.4\pm0.4\%$

WMAP, astro-ph/0302207
SUSY Searches

- No indications so far...

$$\tilde{g}\tilde{g} \rightarrow (bb_1)(bb_1) \rightarrow (bb\tilde{\chi}_1^0)(bb\tilde{\chi}_1^0)$$
3 or more Jets + missing $E_T$

$\gamma\gamma +$ missing $E_T$
- Gauge mediated SUSY breaking
Extra Dimensions - ADD Model

- Virtual graviton exchange modifies the SM dilepton or diphoton production

DØ results:
- dimuon 100 pb\(^{-1}\)
  - \(M_S(GRW) > 0.88 \text{ TeV} @95\% \text{ CL}\)
- diEM/\(\gamma\gamma\) 128 pb\(^{-1}\)
  - \(M_S(GRW) > 1.28 \text{ TeV} @95\% \text{ CL}\)
  - More stringent than Run I
  - Combined with Run I \(\Rightarrow 1.37 \text{ TeV}\)
- Probe up to 2 TeV with 2 fb\(^{-1}\)
ED Randall-Sundrum Model

- first graviton KK excitation $\rightarrow$ spin-2 resonance in dilepton mass
Other Searches

- \(Z' \rightarrow e\bar{e}, \mu\bar{\mu}\) – predicted by many models such as left-right symmetric model
  - \(M_{Z'} > 719\) GeV (DØ), > 665 GeV (CDF) @95% CL
  - probe up to 1 TeV with 2 fb\(^{-1}\)

- Leptoquark
  - \(M(LQ_1) > 253\) GeV (DØ), > 230 GeV (CDF) @95% CL
  - \(M(LQ_2) > 186\) GeV (DØ) @95% CL

- Signature based searches – \(e\mu\) channel (DØ)
  - Model independent limit on production of new physics

- Many more…
Projected Integrated Luminosity
Conclusions

• The physics results started to come out
  – More data than Run I with higher CM energy and better detectors
• So many variety of new results
  – What’s shown here is only a fraction of all CDF/DØ results; much less than all new results
  – Top and EW measurements
    ➢ Top is rediscoverd!
  – World’s best limits on new phenomena
    ➢ Large extra dimensions, $B_s \rightarrow \mu^+\mu^-$, Mass limit on $Z'$…
    ➢ We have entered new territory in discovery potential for physics beyond the SM
  – QCD measurements
  – B physics ready for measuring $\Delta m_S$
• Please cross your finger for us to find some exotic events!
... Backup Slides
# Accelerator Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>May 03 Average</th>
<th>Run II Design</th>
<th>Ratio</th>
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<tr>
<td>Peak Luminosity</td>
<td>$x10^{31} \text{cm}^2 \text{sec}^{-1}$</td>
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<tr>
<td>Store hours per week</td>
<td>hr</td>
<td>75</td>
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<td>Store Duration</td>
<td>hr</td>
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<td>15</td>
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<tr>
<td>Integrated Luminosity</td>
<td>pb$^{-1}$/wk</td>
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<td>55</td>
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<td>Number of Bunches</td>
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<td>Protons/bunch</td>
<td>$x10^{10}$</td>
<td>22</td>
<td>27</td>
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<tr>
<td>Antiprotons/bunch</td>
<td>$x10^{10}$</td>
<td>2.2</td>
<td>13</td>
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<tr>
<td>$\beta*$</td>
<td>cm</td>
<td>35</td>
<td>35</td>
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<td>MI extraction Longitudinal Emittance</td>
<td>eV s</td>
<td>3.5</td>
<td>2.5</td>
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<tr>
<td>Bunch Length (rms)</td>
<td>m</td>
<td>0.6</td>
<td>0.5</td>
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<td>Proton Transverse Emittance (at collision)</td>
<td>$\pi$-mm-mrad</td>
<td>20</td>
<td>18</td>
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<tr>
<td>Antiproton Transverse Emittance (at collision)</td>
<td>$\pi$-mm-mrad</td>
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<td>Hourglass Form Factor</td>
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<td>Pbar Transmission Efficiency</td>
<td>%</td>
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<tr>
<td>Stack Used</td>
<td>$x10^{10}$</td>
<td>134</td>
<td>583</td>
</tr>
<tr>
<td>Avg. Antiproton Production Rate</td>
<td>$x10^{10}$/hr</td>
<td>8.3</td>
<td>40</td>
</tr>
</tbody>
</table>
# The Silicon Detector

<table>
<thead>
<tr>
<th>DØ</th>
<th>6 Barrels</th>
<th>F Disks</th>
<th>H Disks</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layers/planes</td>
<td>4</td>
<td>12</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Az</td>
<td>7.7 cm</td>
<td>48 cm</td>
<td>10 cm</td>
<td></td>
</tr>
<tr>
<td>Channels</td>
<td>387,120</td>
<td>258,000</td>
<td>1,474,56</td>
<td>792,576</td>
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<tr>
<td>Modules</td>
<td>432</td>
<td>144</td>
<td>192</td>
<td>768</td>
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<tr>
<td>Readout Length</td>
<td>12 cm</td>
<td>7.5 cm</td>
<td>14.9 cm</td>
<td></td>
</tr>
<tr>
<td>Inner Radius</td>
<td>2.7 cm</td>
<td>2.6 cm</td>
<td>9.5 cm</td>
<td>2.6 cm</td>
</tr>
<tr>
<td>Outer Radius</td>
<td>9.4 cm</td>
<td>10.5 cm</td>
<td>26 cm</td>
<td>26 cm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CDF</th>
<th>Layer 00</th>
<th>SVX II</th>
<th>ISL</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layers</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Length</td>
<td>0.9 m</td>
<td>0.9 m</td>
<td>1.9 m</td>
<td></td>
</tr>
<tr>
<td>Channels</td>
<td>13,824</td>
<td>405,504</td>
<td>303,104</td>
<td>722,432</td>
</tr>
<tr>
<td>Modules</td>
<td>48 SS</td>
<td>360 DS</td>
<td>296 DS</td>
<td>704</td>
</tr>
<tr>
<td>Readout Length</td>
<td>14.8 cm</td>
<td>14.5 cm</td>
<td>21.5 cm</td>
<td></td>
</tr>
<tr>
<td>Inner Radius</td>
<td>1.35 cm</td>
<td>2.5 cm</td>
<td>20 cm</td>
<td>1.35 cm</td>
</tr>
<tr>
<td>Outer Radius</td>
<td>1.65 cm</td>
<td>10.6 cm</td>
<td>28 cm</td>
<td>28 cm</td>
</tr>
<tr>
<td>Power</td>
<td>-100 W</td>
<td>1.4 kW</td>
<td>1.0 kW</td>
<td>1.5 kW</td>
</tr>
</tbody>
</table>
CDF Impact Parameter Resolution

- L00 helps to improve the impact parameter resolution, especially in low momentum

![Graph showing impact parameter resolution with and without L00](image)

**excluding hybrid region**
- Without L00
- With L00

**average**
- Without L00
- With L00
Central Fiber Tracker in DØ

- ~8-11m long wave-guides to Visible Light Photon Counter (VLPC, solid state photo multiplier).
- VLPCs are operated at 9K.
- Quantum efficiency ~ 80%.
- 1 mip ~ 8 photo electrons
- High gain: 17k – 65k e per photon
Silicon Trigger in CDF

- **Lepton (e, μ) + displaced track trigger**
  - Lepton: p_T > 4 GeV
  - Track: p_T > 2 GeV, d_0 > 120 µm
  - Semi-leptonic B decays
- **Displaced two track trigger**
  - Tracks: p_T > 2 GeV, d_0 > 120 µm
  - Σp_T > 5.5 GeV
  - Fully hadronic B decays

![Graph showing SVT d_0 distribution](image)

- N(B^0 → Kπ) = 148 ± 17
- N(B^0 → ππ) = 39 ± 14
- N(B_s → KK) = 90 ± 17
- First observation!
- N(B_s → Kπ) = 3 ± 11

⇒ CDF is a charm/B factory
DØ Calorimeter

- 1 Barrel + 2 End Caps
- EM + Fine and Coarse Hadronic
- Liquid Argon
- U(EM)/Cu-Stainless steel (Had.)
- 5000 towers:
  - $\Delta \phi \times \Delta \eta = 0.1 \times 0.1$
- $\sim 50 \text{ cm} < r < \sim 250 \text{ cm}$
- Coverage $|\eta| < 4.2$
- 99.9% Active
- 4 EM read out layers
- 4/5 Had read out layers
  - $\sigma(\text{EM})/E \sim 15\% /\sqrt{E}$
  - $\sigma(\text{Had})/E \sim 45\% /\sqrt{E}$
Event Selection - top

CDF
- Two high $p_T$ isolated $\mu$ or e with opposite charge
- $\Delta \phi(E_T, l/j) > 20^\circ$
- $Z$ mass veto
- $E_T > 25$ GeV
- $\geq 2$ jets, raw $E_T > 10$ GeV & $|\eta| < 2.0$
- $H_T = \Sigma(E_T, E_{l_T}, E_{jet_T}) > 200$ GeV

DØ
- Two high $p_T$ isolated $\mu$ or e
- $E_T$ (Z mass) cut
- $\geq 2$ jets, $E_T > 20$ GeV & $|\eta| < 2.5$
- $H_T = \Sigma(E_{l_T}, E_{jet_T})$ cut
- Preselect a sample enriched in $W$ events (loose $e, \mu P_T > 20$ GeV, $E_T > 20$ GeV, veto soft $\mu$)
- $\geq 3$ jets
- $H_T > 110$ GeV
- Aplanarity > 0.04
- Soft muon within jet ($b \rightarrow \mu$, $b \rightarrow c \rightarrow \mu$) or
- $\geq 4$ jets
- $H_T > 180$ GeV (e)
- Aplanarity > 0.06
- $H_T(jets, p_W^T) > 220$ GeV (µ)

Lepton + jets
- One $e$ or $\mu$ with $P_T > 20$ GeV
- Veto $Z$'s, cosmics, and conversions
- $E_T > 20$ GeV
- $\geq 3$ jets with $E_T > 15$ GeV
- $\geq 1$ jet with secondary vertex tag (SVX)
Toy MC - top mass measurement

- Toy MC with 12 signals + 10 BG’s, $M_{\text{top}} = 175$ GeV

![Histograms showing $M_{\text{top}}$ distributions with pull and $S/(S+B)$ ratios]
Helicity of W in top Decays

\[ w(\cos \varphi_{lb}) = F_- \cdot \frac{3}{8} (1 - \cos \varphi_{lb})^2 + F_0 \cdot \frac{3}{8} (1 - \cos^2 \varphi_{lb}) + F_+ \cdot \frac{3}{8} (1 + \cos \varphi_{lb})^2 \]

• New DØ measurements for Run I data with LO matrix element (similar approach with mass measurement)
  – \( F_0 = 0.56\pm0.31 \) (22 events)
  – CDF RunI:
    \( F_0 = 0.91\pm0.39 \) (108 leptons)
B Hadrons

CDF Run II Preliminary

$B^0 \rightarrow J/\psi \ K_S$

$N(B_d) = 178 \pm 10$

CDF Run II Preliminary $80 \text{ pb}^{-1}$

$D_0$ Run II Preliminary, Luminosity = $114 \text{ pb}^{-1}$

$B_d \rightarrow J/\psi \ K_S^0$

$N = 157 \pm 20$
Lifetime of B Hadron

CDF: $\tau(\Lambda_B) = 1.25^{+0.26}_{-0.18} (\text{stat}) \pm (0.10) (\text{syst})$ ps

DØ: $\tau(\Lambda_B) = 1.25^{+0.26}_{-0.18} (\text{stat}) \pm (0.10) (\text{syst})$ ps
Lifetime of $B^-$ control sample

$D^0$ preliminary

47 pb$^{-1}$

$B^+$ lifetime

$D^0 \ 1.65 \pm 0.08 (\text{stat.}) ^{+0.10}_{-0.12} (\text{syst.}) \ \text{ps}$

$CDF \ 1.63 \pm 0.05 (\text{stat.}) \pm 0.04 \ (\text{syst.}) \ \text{ps}$

$D^0 \ 1.51 \ ^{+0.19}_{-0.17} \ (\text{stat.}) \pm 0.2 \ (\text{syst.}) \ \text{ps}$

$CDF \ 1.51 \pm 0.06 (\text{stat.}) \pm 0.02 \ (\text{syst.}) \ \text{ps}$
Luminosity Prospects
## Trigger Upgrade in DØ

- **Core trigger menu, simulated at L=2e32, Δt=396 ns**

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Example Physics Channels</th>
<th>L1 Rate (kHz) (no upgrade)</th>
<th>L1 Rate (kHz) (with upgrade)</th>
</tr>
</thead>
</table>
| EM (1 EM TT > 10 GeV) | $W \rightarrow e\nu$  
$WH \rightarrow e\nu jj$ | 1.3 | 0.7 |
| Di-EM (1 EM TT > 7 GeV, 2 EM TT > 5 GeV) | $Z \rightarrow ee$  
$ZH \rightarrow ee jj$ | 0.5 | 0.1 |
| Muon (muon $p_T > 11$ GeV + CFT Track) | $W \rightarrow \mu\nu$  
$WH \rightarrow \mu\nu jj$ | 6 | 0.4 |
| Di-Muons (2 muons $p_T > 3$ GeV + CFT Tracks) | $Z \rightarrow \mu\mu, J/\Psi \rightarrow \mu\mu$  
$ZH \rightarrow \mu\mu jj$ | 0.4 | <0.1 |
| Electron + Jets (1 EM TT > 7 GeV, 2 Had TT > 5 GeV) | $WH \rightarrow e\nu + jets$  
$t\bar{t} \rightarrow e\nu + jets$ | 0.8 | 0.2 |
| Muon + Jet (muon $p_T > 3$ GeV, 1 Had TT > 5 GeV) | $WH \rightarrow \mu\nu + jets$  
$t\bar{t} \rightarrow \mu\nu + jets$ | <0.1 | <0.1 |
| Jet+MET (2 TT > 5 GeV, Missing $E_T$ > 10 GeV) | $ZH \rightarrow \nu \bar{\nu} b\bar{b}$ | 2.1 | 0.8 |
| Muon + EM (muons $p_T > 3$ GeV+ CFT track + 1 EM TT > 5 GeV) | $H \rightarrow WW, ZZ$ | <0.1 | <0.1 |
| Single Isolated Track (1 Isolated CFT track, $p_T > 10$ GeV) | $H \rightarrow \tau\tau, W \rightarrow \mu\nu$ | 17 | 1.0 |
| Di-Track (1 isolated tracks $p_T > 10$ GeV, 2 tracks $p_T > 5$ GeV, 1 matched with EM energy) | $H \rightarrow \tau\tau$ | 0.6 | <0.1 |

**Total L1 bandwidth = 5 kHz**

**Additional headroom available from**
- topological cuts available in upgraded L1cal
- Higher mu $p_T$ threshold with upgraded CTT

**Total rate:** ~30 kHz  3.2 kHz
Higgs Sensitivity

![Graph showing Higgs Sensitivity](image)

- **5σ discovery**
- **3σ evidence**
- **95% CL exclusion**

**m_H (GeV)**

**integrated luminosity (fb⁻¹)**

**CDF**

**Higgs Sensitivity**

- **CDF Higgs Sensitivity Study ('03)**
- **SUSY/Higgs Workshop ('98-'99)**

Oct 21 2003 KEK seminar - Kazu Hanagaki 64