Tevatron Physics

Fermilab Physics Advisory Committee – 3 November 2008

- Status and performance: accelerator and experiments
- Tevatron legacy measurements: top and W mass
- Indirect constraints on the Higgs mass
- Higgs searches and related SM measurements
- New b-physics and spectroscopy results
- New physics
Surpassed target integrated luminosity for FY08:
- increased stacking rate
- shorter turnaround time
- stability of machine (106 hours/week)
- improved luminosity lifetime

FY09 started well (1 week shutdown for work on powerlines to Fermilab)

More accelerator performance plots in the backup material
CDF and DØ Performance

CDF: 5.23 fb$^{-1}$ delivered
4.30 fb$^{-1}$ recorded

DØ: 5.20 fb$^{-1}$ delivered
4.54 fb$^{-1}$ recorded

Following up quickly with reconstruction, analysis and publication of results

Presented analyses with 3 fb$^{-1}$ at ICHEP this past summer

Analyses with over 4 fb$^{-1}$ of data to be presented at Winter 09 conferences
CDF and DØ Physics Results

2008 is already a record year for both experiments

5 plenary presentations at ICHEP
40 parallel talks

Both experiments are still attractive to new students/postdocs

80 PhD theses defended in 2007, 40 so far in 2008

Example: DØ - 22 new PhD students + 8 postdocs since January
Too many results for 20 minutes....

Example: CDF web pages with new results for Summer 2008: over 50 new results (similarly for DØ)

Will focus on a subset of new physics results since last PAC meeting
**Constraining $m_H : m_{top}$**

World average top quark mass (ICHEP 08)

$m_t = 172.4 \pm 0.7 \pm 1.0$ GeV

0.7 % precision

CDF: $m_t = 172.2 \pm 1.0 \pm 1.3$ GeV

DØ: $m_t = 172.2 \pm 1.0 \pm 1.4$ GeV
Constraining $m_H$: $m_W$

Current $m_W$ world average: precision 25 MeV (CDF best single experiment result)

CDF: working on 2.4 fb$^{-1}$ analysis
Expect to have measurement with precision equivalent to world average

DØ: publish 1 fb$^{-1}$ analysis soon
Constraining $m_H$: Electroweak Fits

$m_H = 84^{+34}_{-26}$ GeV

$m_H < 154$ GeV @ 95% CL

Impact of uncertainties on $M_H$:

- $\Delta M_t = \pm 1.2$ GeV
- $\Delta M_H = \pm 9/-8$ GeV
- $\Delta M_W = \pm 25$ MeV
- $\Delta M_H = \pm 13/+17$ GeV
- $\Delta \alpha^{(5)}_{\text{had}} = \pm 0.00035$
- $\Delta M_H = \pm 15/+17$ GeV
Diboson Processes at Tevatron

Both CDF and DØ combine ZZ→llνν and ZZ→llll channels to obtain 4.4σ and 5.7σ significance respectively.

Cross sections measured in agreement with SM prediction of 1.4 pb
... now also with Hadronic W/Z Decays

Select sample of qqlv events in 1.1 fb\(^{-1}\) of data

Cannot separate W and Z\(\rightarrow qq\), measure sum of two processes

Use Random Forest discriminant to separate signal (600 events) from background (27k events)

Measure \(\sigma = 20.2 \pm 2.8\text{(stat)} \pm 4.9\text{(syst)} \pm 1.1\text{(lum)}\) pb (4.4 \(\sigma\))

SM \(\sigma = 16.1 \pm 0.9\) pb

Main systematics: background (W+2jets) shape, jet energy scale, cross sections

With more data: observe Z\(\rightarrow bb\), separate W/Z contributions to signal
Single top Production

Both CDF and DØ now have evidence for single top production, reach 5 \( \sigma \) soon

Smallest cross section measured in final states containing jets
Higgs Searches (March 2008)

Tevatron combination limit/SM:

- 6.8 at $m_H = 120$ GeV/c$^2$
- 1.1 at $m_H = 160$ GeV/c$^2$

Since then: analyzed more data, improvement in the analyses, more channels added at low $m_H$
Higgs Searches (Low $m_H$)

- WH→ℓνbb  (most sensitive channel at low $m_H$)
- Signature: high $p_T$ lepton, MET and b jets

- Backgrounds: $W+bb$, $W+qq$(mistagged), single top, Non W(QCD)
- Key issue: estimating $W+bb$ background
- Shape from MC with normalization from data control regions

Innovations:

CDF: 20% acceptance gain from isolated tracks,
    ME with NN jet corrections
DØ:  20% acceptance gain from forward leptons,
    use 3 jet events

Results at $m_H = 115$ GeV: 95%CL Limits/SM

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Lum (fb⁻¹)</th>
<th>Higgs Events</th>
<th>Limit ($σ$/SM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDF NN</td>
<td>2.7</td>
<td>8.3</td>
<td>5.8</td>
</tr>
<tr>
<td>CDF ME+BDT</td>
<td>2.7</td>
<td>7.8</td>
<td>5.6</td>
</tr>
<tr>
<td>DØ</td>
<td>1.7</td>
<td>7.5</td>
<td>8.5</td>
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</tbody>
</table>
Other SM Higgs Searches

- CDF and DØ are performing searches in every viable mode
  - CDF/DØ: $WH \rightarrow WWW$: same sign leptons
    - Adds sensitivity at high and intermediate masses
    - Also fermiophobic Higgs search
  - CDF: $VH \rightarrow qqbb$: 4 jets mode
  - CDF: $H \rightarrow \tau\tau$ with 2 jets
    - Simultaneous search for Higgs in WH/ZH, VBF and $gg \rightarrow H$ production modes
    - Interesting benchmark for LHC
  - DØ: $H \rightarrow \gamma\gamma$
    - Also model independent and fermiophobic search
  - DØ: $WH \rightarrow \tau\nu bb$, new mode
    - Dedicated search with hadronic $\tau$ decays
  - DØ: $ttH$, new mode

Results at $m_H = 115$ GeV or 160 GeV: 95%CL Limits/SM

<table>
<thead>
<tr>
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<tbody>
<tr>
<td></td>
<td>Exp.</td>
</tr>
<tr>
<td>CDF $WH \rightarrow WWW$</td>
<td>33.0</td>
</tr>
<tr>
<td>DØ $WH \rightarrow WWW$</td>
<td>20.0</td>
</tr>
<tr>
<td>CDF $Vh \rightarrow qqbb$</td>
<td>37</td>
</tr>
<tr>
<td>CDF $H \rightarrow \tau\tau$</td>
<td>25</td>
</tr>
<tr>
<td>D0 $WH \rightarrow \tau\nu bb$</td>
<td>42</td>
</tr>
<tr>
<td>D0 $H \rightarrow \gamma\gamma$</td>
<td>23</td>
</tr>
</tbody>
</table>
Higgs Searches (High $m_H$)

- $H \rightarrow WW \rightarrow l\nu l\nu$
- **Signature:** Two high $p_T$ leptons and MET
  - Primary backgrounds: W pair production and top in di-lepton decay channel
  - Key issue: Maximizing lepton acceptance

**Innovations:**

- **CDF/DØ:** Inclusion of acceptance from WH/ZH(CDF) and vector boson fusion
- **CDF:** Combination of ME and NN approaches
- **DØ:** Reoptimized NN

Results at $m_H = 165$ GeV: 95%CL Limits/SM

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<tbody>
<tr>
<td>CDF ME+NN</td>
<td>3.0</td>
<td>17.2</td>
<td>1.6</td>
</tr>
<tr>
<td>DØ NN</td>
<td>3.0</td>
<td>15.6</td>
<td>1.9</td>
</tr>
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</table>
Single Experiment Combinations

- Limits calculating and combination
  - Using Bayesian and CLs methodologies.
  - Incorporate systematic uncertainties using pseudo-experiments (shape and rate included) (correlations taken into account between experiments)
  - Backgrounds can be constrained in the fit

Low mass combination challenging due to ~70 analyses
  - Expected sensitivity of CDF/DØ combined: <3.0*SM @ 115GeV
First Exclusion at High $m_H$

Exp. 1.2 @ 165, 1.4 @ 170 GeV
Obs. 1.0 @ 170 GeV

SM Higgs of 170 GeV excluded at 95%CL

Result verified using two independent methods (Bayesian/CLs)
MSSM Higgs Searches

$H \rightarrow \tau \tau$ main search channel

Use $b\Phi$ associated production to extend searches to $Z$ peak region ($b\bar{b}$ and $b\tau\tau$ final states)

First Tevatron combination available soon

Exclude high tan$\beta$ region
CP Violation in J/ψ φ

First combination of CDF and DØ results without assumptions on strong phases: compatible at 2.2 standard deviations level with SM (p-value 0.031)

CDF: updated result with 2.8 fb⁻¹ Inconsistency with SM increased (p-value from 0.15 to 0.08, corresponding to 1.8 standard deviations)

More data to come, look also in other channels (asymmetry in semileptonic decays)
Reconstruct complicate decay chain

$\Omega^-$ candidates selected with multivariate technique to reduce background

Combine with $J/\psi$

Observe $17.8 \pm 4.9 \pm 0.8$ candidates

$m_{\Omega_b} = 6.156 \pm 0.010 \pm 0.013$ GeV

5.4 standard deviation observation

Another discovery in spectroscopy of $b$-hadrons
Physics beyond the SM

No evidence for new physics found in dedicated model driven analyses
Still room for surprises, few discrepancies at the 2-3σ level
Future Perspectives

Projections assume no further improvements
Over the weekend: 1\textsuperscript{st} and 3\textsuperscript{rd} highest peak luminosity for Tevatron
\((L=3.19\times10^{32}\text{ cm}^{-2}\text{ s}^{-1})\)

Real data for FY02-FY08

FY09 start

FY10 start

8.82 fb\textsuperscript{-1}

7.72 fb\textsuperscript{-1}

(7.2-8.6 fb\textsuperscript{-1} at March PAC)

Physics Advisory Committee

Tevatron Physics
Conclusions

- Strong motivation to continue running in 2010
- Could surpass current predictions for integrated luminosity
- Place strong constraints on / Obtain evidence for SM Higgs
- Improve top and W mass measurements
- Continue investigation of $B_s$ system
- Much room for improvement in channels where current analyses use only 1-2 fb-1 (reach 8 fb-1/experiment)
- More personnel available in both Collaborations than foreseen
Backup Transparencies

Weekly Integrated Luminosity (1/pb)

Days since October 1

- Fiscal Year 09
- Fiscal Year 08
- Fiscal Year 07
- Fiscal Year 06
- Fiscal Year 05
- Fiscal Year 04
- Fiscal Year 03
- Fiscal Year 02
- Design
- Base
Backup Transparencies

Peak Luminosity (1/μb/sec) Max: 317.5 Most Recent: 276.5

Days since October 1

- Fiscal Year 09
- Fiscal Year 08
- Fiscal Year 07
- Fiscal Year 06
- Fiscal Year 05
- Fiscal Year 04
- Fiscal Year 03
- Fiscal Year 02
Backup Transparencies

Run II Integrated Luminosity

19 April 2002 - 28 October 2008

Luminosity (/b)

Delivered
Recorded

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28
Higgs Searches (Low $m_H$)

- $ZH \rightarrow \nu\nu bb$, $WH \rightarrow l\nu bb$ (l not detected)
- Signature: MET and b jets
  - Primary backgrounds: QCD b jets and mistagged light quark jets
  - Key issue: Building a model of the QCD background
  - Shape from 0 and 1 b tagged data samples with tag and mistag rates applied

Innovations:
- CDF/DØ : Use of track missing $p_T$ to define control regions and suppress backgrounds
- CDF: Uses of H1 Jet Algorithm combining tracking and calorimeter information
  - 3 jet events including $W \rightarrow \tau\nu$ acceptance
- DØ also performs a dedicated $W \rightarrow \tau\nu$

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<td>3.7</td>
<td>8.4, 7.9</td>
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Higgs Searches (Low $m_H$)

- **ZH→llbb**
- **Signature: two leptons and two b jets**
  - Primary background: Z + b jets
  - Key issue: Maximize lepton acceptance and b tagging efficiency

**Innovations:**
- CDF/DØ: Extensive use of loose b tagging
- CDF: Use of isolated tracks and calorimeter only electrons
  - MET used to correct jet energies, New ME analysis
- DØ: Multiple advanced discriminates, NN and BDT

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<tr>
<td>CDF NN</td>
<td>2.4</td>
<td>1.8</td>
<td>11.8</td>
<td>11.6</td>
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<tr>
<td>CDF ME(120)</td>
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<td>1.4</td>
<td>15.2</td>
<td>11.8</td>
<td></td>
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<tr>
<td>DØ</td>
<td>2.3</td>
<td>2.0</td>
<td>12.3</td>
<td>11.0</td>
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