Selected New Heavy Flavor, QCD and Electroweak Results from the Tevatron

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On behalf of DØ and CDF
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Overview

- Wide range of topics today, including:
  - CP violation parameters in $B \rightarrow J/\psi K^\pm$ and $B \rightarrow J/\psi \pi^\pm$
  - $D^0$-$\bar{D^0}$ mixing
  - Photon plus heavy flavor production
  - Anomalous quartic gauge coupling search
- Standard caveat: these are speaker's choice of topics, are many other interesting analyses not covered
Tevatron and Experiments

- Tevatron ~ 7km with 1.96 TeV p–p collisions
  - Operation ended September 2011
- DØ and CDF analyses use full data set, ranging from 8.7 to 10.4 fb⁻¹ depending on data quality requirements
- Both have inner tracker, magnet, calorimeter and muon system
  - DØ also regularly reverses magnet polarity
Direct CP Violation Parameters in $B \rightarrow J/\psi K^\pm$ and $B \rightarrow J/\psi \pi^\pm$

- Clean test of CP violation
  - Expect $\sim 0.3\%$ asymmetry from penguin loops in $B \rightarrow J/\psi K^\pm$, few percent allowed for $B \rightarrow J/\psi \pi^\pm$ in SM

\[
A^{J/\psi K}_{K^-} = \frac{\Gamma (B^- \rightarrow J/\psi K^-) - \Gamma (B^+ \rightarrow J/\psi K^+)}{\Gamma (B^- \rightarrow J/\psi K^-) + \Gamma (B^+ \rightarrow J/\psi K^+)}
\]

\[
A^{J/\psi \pi}_{\pi^-} = \frac{\Gamma (B^- \rightarrow J/\psi \pi^-) - \Gamma (B^+ \rightarrow J/\psi \pi^+)}{\Gamma (B^- \rightarrow J/\psi \pi^-) + \Gamma (B^+ \rightarrow J/\psi \pi^+)}
\]

- Measure raw asymmetry, then correct for reconstruction asymmetry of $K^+ K^-$ in the detector
  - Kaon asymmetry because $K^-$ can interact with detector to form hyperons, no equivalent for $K^+$
  - Because of DØ detector magnet polarity reversals, no track or pion asymmetry corrections are needed
Direct CP Violation Parameters in $B \rightarrow J/\psi K^\pm$ and $B \rightarrow J/\psi \pi^\pm$

- Maximum likelihood fit used to extract raw $A_{J/\psi K}$ asymmetry
- Kaon asymmetry from fit to $M(K\pi)$ in $K^*0(\bar{K}^*0) \rightarrow K^+\pi^-(K^-\pi^+)$
  \[
  A_K = [1.046 \pm 0.043 \text{ (syst)}] \%
  \]
- Dominant uncertainties statistical and Kaon asymmetry estimate
  \[
  A_{J/\psi K} = [0.59 \pm 0.36 \text{ (stat)} \pm 0.08 \text{ (syst)}] \%
  \]
  \[
  A_{J/\psi \pi} = [-4.2 \pm 4.4 \text{ (stat)} \pm 1.8 \text{ (syst)}] \%
  \]
- Results consistent with SM
- $A_{J/\psi K}$ most precise to date

D⁰ Mixing

• Study the ratio of the $D⁰ \rightarrow K^+ \pi^-$ and $D⁰ \rightarrow K^- \pi^+$ decay rates, where $D^* \rightarrow D⁰ \pi^+$. If no mixing, $x'=y'=0$.

$$R(t/\tau) = R_D + \sqrt{R_D} y' (t/\tau) + \frac{x'^2 + y'^2}{4} (t/\tau)^2$$

• Same selection applied to both $\pi^-$ (WS) and $\pi^+$ (RS) decay chains, chosen to optimize $\pi^-$ significance based on expected events and sideband information

• M(Kπ) selection (20 MeV around $D⁰$ mass peak) strongly reduces background to WS from RW due to $D⁰$ decay track mis-ID

• Additional selections for particle ID, decay topology

• Using world averages for $m_{D⁰}$ and tau in $t/\tau = m_{D⁰} L_{xy} / (p_T \tau)$
**D^0 Mixing**

- RW and WS separated into t/tau bins and $\Delta M = M(K^+\pi^-\pi^+) - M(K^+\pi^-) - M(\pi^+)$ bins
  - $M(K\pi)$ used to find $D^0$ yield, the $\Delta M$ is fit to get $D^*$ yield
- Measured WS to RS $D^*$ decay ratio diverges from no mixing hypothesis
  - No mixing excluded at 6.1 std. dev.

$y' = (4.3 \pm 4.3) \times 10^{-3}$

$x'^2 = (0.08 \pm 0.18) \times 10^{-3}$

$R_D = (3.51 \pm 0.35) \times 10^{-3}$
Photon plus Heavy Flavor

- “Clean” process to study quark PDFs and rate of gluon splitting to quarks
- Compton scattering at low $\gamma$ Et ($< \sim 100$ GeV), $p\bar{p}$ annihilation with gluon splitting otherwise
- Selections require a central $\gamma$, using a NN to help distinguish $\gamma$. NN is also used in template fit to determine rate of jets faking $\gamma$.
- Secondary vertex mass is used with a template fit to determine b and c quark fractions
Photon plus Heavy Flavor

- Sherpa or kT fact. closest to data for $\gamma$ plus b for high $E_T$
  - Uncertainties higher for $\gamma$ plus c but similar preference
- NLO disagrees for $E_T > 70$ GeV
- Pythia agrees better with x2 heavy flavor

CDF Public Note 10818
Photon plus Heavy Flavor

- Also see $\gamma$ plus c agrees best with $k_T$ fact or sherpa for larger $p_T$ values for $> 70$ GeV, $k_T$ underestimates for low $p_T$
- Pythia agrees better with 1.7 enhancement factor for cross-section ratio

• WWγγ study extension of higgs search with same final state
  • Look for anomalous quartic gauge couplings, SM too small to see
• Dimension 6 operator for Lagrangian, $a_0$ and $a_C = 0$ in SM:
  $\mathcal{L}_6^0 = \frac{-\alpha^2 a_0 W}{8 \Lambda^2} F_{\mu \nu} F^{\mu \nu} W^{+ \alpha} W^-_{\alpha}$
  $\mathcal{L}_6^C = \frac{-\alpha^2 a_C W}{16 \Lambda^2} F_{\mu \alpha} F^{\mu \beta} (W^{+ \alpha} W^-_{\beta} + W^{- \alpha} W^+_{\beta})$
• Selection same as for Higgs but with extra jet veto
  • BDT trained for aQGC signal
  • Same BDT used for both $a_0$ and $a_C$
With cutoff scale of 0.5 TeV, limits are

$$|a_0^W/\Lambda^2| < 0.0025 \text{ GeV}^{-2} \text{ and } |a_C^W/\Lambda^2| < 0.0092 \text{ GeV}^{-2}$$

Factor of 4-8 better than best published results (OPAL)
Summary

- Full data set analyses are ongoing at the Tevatron
  - Precise $B \rightarrow J/\psi K^\pm$ and $J/\psi \pi^\pm$ CP violation measurements with DØ
  - Observation of $D^0-D^{\bar{0}}$ mixing with CDF
  - Photon plus heavy flavor cross-sections have been measured by both experiments
    - NLO in particular disagrees with data at high $E_T$ values
  - aQCG search with DØ
- Overall, there is agreement with the standard model

Many topics not covered today, please see following pages for more results and more information about today's results

http://www-d0.fnal.gov/d0_publications/d0_pubs_list_runII_bytopic_byyear.html
D⁰ Mixing (CDF)

CDF Run II preliminary  L = 9.6 fb⁻¹
aQCD, Other Cut Off Values

**TABLE II:** Expected and observed 95% C.L upper limits on $|a_0^W/\Lambda^2|$, assuming $a_C^W$ is zero and for different assumptions about the form factor.

<table>
<thead>
<tr>
<th>Cutoff</th>
<th>Expected upper limit [GeV$^{-2}$]</th>
<th>Observed upper limit [GeV$^{-2}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>No form factor</td>
<td>0.00043</td>
<td>0.00043</td>
</tr>
<tr>
<td>$\Lambda_{\text{cutoff}} = 1 \text{ TeV}$</td>
<td>0.00092</td>
<td>0.00089</td>
</tr>
<tr>
<td>$\Lambda_{\text{cutoff}} = 0.5 \text{ TeV}$</td>
<td>0.0025</td>
<td>0.0025</td>
</tr>
</tbody>
</table>

**TABLE III:** Expected and observed 95% C.L upper limits on $|a_C^W/\Lambda^2|$, assuming $a_0^W$ is zero and for different assumptions about the form factor.

<table>
<thead>
<tr>
<th>Cutoff</th>
<th>Expected upper limit [GeV$^{-2}$]</th>
<th>Observed upper limit [GeV$^{-2}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>No form factor</td>
<td>0.0016</td>
<td>0.0015</td>
</tr>
<tr>
<td>$\Lambda_{\text{cutoff}} = 1 \text{ TeV}$</td>
<td>0.0033</td>
<td>0.0033</td>
</tr>
<tr>
<td>$\Lambda_{\text{cutoff}} = 0.5 \text{ TeV}$</td>
<td>0.0090</td>
<td>0.0092</td>
</tr>
</tbody>
</table>
Direct Diphoton Cross-section

- Major background for Higgs production and new physics processes, also implications for QCD, PDFs
- At Tevatron, dominant production is $p\bar{p} \rightarrow \gamma\gamma$ with gluon production as well
- Photons required to be central and pass photon ID requirements
- Backgrounds include gamma jet and jet jet production
  - CDF reduces this using matrix method, D0 uses a 2-D fit to NN
Diphoton Results

- Both groups see similar results, disagreement in the low delta phi region, best agreement with Sherpa.

- Agreement in Higgs mass region, but disagreements for low mass (not shown).

NNLO is Catani et al PRL 108, 072011 (2012)
NNLO is Catani & Grazzini, PRL 98, 222002 (2007)
CDF used SHERPA v1.3.1; D0 used v1.2.2; both with CTEQ6.6M.