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 $B^\pm \rightarrow J/\psi K^\pm$ and $B^\pm \rightarrow J/\psi \pi^\pm$
  • $D^0-\overline{D^0}$ mixing
  • Photon plus heavy flavor production
  • Anomalous quartic gauge coupling search
• Caveat: these are speaker's choice of topics, are many other interesting analyses not covered
Tevatron and Experiments

- Tevatron is $2\pi$ km with 1.96 TeV $p\bar{p}$ 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
- $p\bar{p}$ collisions mean CP symmetric initial states, which benefits certain analyses
- Different center of mass energy complements other experiments
Direct CP Violation Parameters
in $B^\pm \rightarrow J/\psi K^\pm$ and $B^\pm \rightarrow J/\psi \pi^\pm$

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

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

• 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 and symmetric detector, no track or pion asymmetry corrections are needed

Direct CP Violation Parameters in $B^\pm \rightarrow J/\psi K^\pm$ and $B^\pm \rightarrow J/\psi \pi^\pm$

- Maximum likelihood fit used to extract raw $A^{J/\psi K}$ asymmetry
- Kaon asymmetry from fit to $M(K\pi)$ in $K^{*0}(\overline{K}^{*0}) \rightarrow K^+\pi^- (K^-\pi^+)$

$$A_K = [1.046 \pm 0.043 \text{ (syst)}] \%$$

- 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 prediction
- $A^{J/\psi K}$ most precise to date

D⁰-\bar{D}⁰ Mixing

- Mixing slower than for B or K
- Occurs primarily through long range intermediate states but rate has large theoretical uncertainties (top)
- New physics could enhance short range rate, which is suppressed in SM (bottom)

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

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

- Using world averages for $m_{D⁰}$ and $\tau$ in $t/\tau = m_{D⁰} L_{xy}/(p_T \tau)$
• Same selection applied to both RS and WS decay chains, chosen to optimize WS significance based on expected events and sideband information

• $M(K\pi)$ selection (20 MeV around $D^0$ mass peak) strongly reduces background to WS from RW due to $D^0$ decay track mis-ID

• Additional selections for particle ID, decay topology
**D⁰-Ð⁰ Mixing**

- RS 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.**

\[
y' = (4.3 \pm 4.3) \times 10^{-3} \quad x'^2 = (0.08 \pm 0.18) \times 10^{-3} \]
\[
R_D = (3.51 \pm 0.35) \times 10^{-3}
\]

**CDF Public Note 10990**
**Photon plus Heavy Flavor**

- “Clean” process to study quark PDFs and rate of gluon splitting to quarks
- Compton-like scattering at low $\gamma E_t$ ($< \sim 100$GeV), $p\bar{p}$ annihilation with gluon splitting otherwise
- Selections require a central $\gamma$, using a NN to help to identify the $\gamma$. 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

![CDF Run II Preliminary](image)

![DØ, L = 8.7 fb$^{-1}$](image)
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

CDF Public Note 10818
Photon plus Heavy Flavor

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  - Uncertainties higher for $\gamma$ plus c but similar preference
- NLO disagrees for $E_T > 70$ GeV
- Pythia agrees better with x2 gluon splitting to heavy flavor

CDF Public Note 10818
• 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 $p_T$
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

Anomalous Quartic Gauge Couplings with WWγγ

- 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:

\[
\mathcal{L}_6^0 = -\frac{e^2}{8} \frac{a_0}{\Lambda^2} F_{\mu\nu} F^{\mu\nu} W^{+\alpha} W^{-\alpha}
\]

\[
\mathcal{L}_6^C = -\frac{e^2}{16} \frac{a_C}{\Lambda^2} F_{\mu\alpha} F^{\mu\beta} (W^{+\alpha} W^{-\beta} + W^{-\alpha} W^{+\beta})
\]

- Selection same as for Higgs but with extra jet veto
  - BDT trained for AQGC signal
  - Same BDT used for both \( a_0 \) and \( a_C \)
Anomalous Quartic Gauge Couplings with $WW\gamma\gamma$

- With cutoff scale of 0.5 TeV, limits are

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

- Factor of 4-8 better than best published results (OPAL)
  - For CMS result, see Jonatan's talk tomorrow afternoon

Fermilab-Pub-13-133-E, Submitted to Phys. Rev. D
Summary

- **Full data set analyses are ongoing at the Tevatron**
  - Precise $B^{\pm} \rightarrow J/\psi K^{\pm}$ and $J/\psi \pi^{\pm}$ CP violation measurements with DØ
  - Observation of $D^0 - \bar{D}^0$ 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


Measurement of sin²θ_w (or indirect M_w) (CDF), CDF Public Note 10952

ZZ Cross Section (lll'l'+llvv) (CDF), CDF Public Note 10957

Other Recent Results and Papers (2013)

- Search for the Rare Decay $B_s^0 \rightarrow \mu^+\mu^-$, (DØ), Phys. Rev. D 87, 072006 (2013)
- Measurement of the Semileptonic Charge Asymmetry using $B_s^0 \rightarrow D_s \mu X$ Decays (DØ), Phys. Rev. Lett., 110, 011801 (2013)
D⁰ Mixing (CDF)

CDF Run II preliminary L= 9.6 fb⁻¹
### AQGC, 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>$\Lambda_{\text{cutoff}} = 1$ TeV</td>
<td>0.00092</td>
<td>0.00089</td>
</tr>
<tr>
<td>$\Lambda_{\text{cutoff}} = 0.5$ 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.

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</tr>
</thead>
<tbody>
<tr>
<td>No form factor</td>
<td>0.0016</td>
<td>0.0015</td>
</tr>
<tr>
<td>$\Lambda_{\text{cutoff}} = 1$ TeV</td>
<td>0.0033</td>
<td>0.0033</td>
</tr>
<tr>
<td>$\Lambda_{\text{cutoff}} = 0.5$ 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
- 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

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