Tevatron Measurements of Electroweak Boson Production

Ryan J. Hooper
On Behalf of the CDF and D0 Collaborations

PANIC 2011
July 25th, 2011
Outline

• The What
• The Why
• The Where
• The How
• The Results
• The End!
• Typically used as “standard candles” for searches
• Production cross sections well measured (circa 2000's)

Tevatron has produced millions of $W$s & hundreds of thousands of $Z$s!

• Large statistics allows detailed studies of properties
  • Boson's transverse momentum, decay product's angular dependencies, charge asymmetries ...
    • Sensitive to underlying physics
The Where: The Tevatron Accelerator

- The Tevatron Accelerator at Fermilab

- Tevatron collides protons and anti-protons at
  - Very efficient running for many years

\[ \sqrt{s} = 1.96 \text{ TeV} \]
The Where: The Detectors

• Both are typical collider detectors

CDF

• Silicon & drift chamber tracker in 1.4T solenoid
• Pb/Fe scintillating calorimeter
• Scintillating and drift chamber muon systems

DØ

• Silicon & scintillating fiber tracker in 2T solenoid
• U & liquid Ar calorimeter
• Scintillating and drift chamber muon systems
The How: Data Selections

- Focus on newest (2011) Z results & (2009 & prelim.) W results
- Both experiments use similar data selections
  - For Z's:
    - At least one high $E_T$ triggered lepton (CDF)
    - Fire one of a list of dilepton triggers (DØ)
    - One high $E_T$ (> 20 GeV) electron (e⁻)
    - One high $E_T$ (> 20 GeV) positron (e⁺)
  - For W's:
    - $\mu\nu$ final state
    - One of many single $\mu$ triggers
    - $\mu$ has matched central track
    - $\mu$ $p_T$ > 20 GeV
    - Isolated
    - Cosmic timing veto
    - $E'_T$ > 20 GeV
    - High transverse mass ($M_T^{\mu\nu}$ > 40 GeV)
  - For W's:
    - $e\nu$ final state
    - Combination of high $E_T/p_T$ and high $E_T'$ trigger
    - $e$ $E_T$ > 25 GeV (central)
    - $e$ $E_T$ > 20 GeV (end plug)
    - Isolated
    - $E'_T$ > 25 GeV
The Results: DØ's New $Z/\gamma^* \rightarrow e^+e^-$ Analysis

- Vector (V) & Axial (A) couplings to the $Z$
- Give rise to a forward-backward charge asymmetry ($A_{FB}$)

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

F=Forward: $\cos(\theta^*) > 0$
B=Backward: $\cos(\theta^*) < 0$

- Pythia leading order (LO) $A_{FB}$

- Due to $A_{FB}$ is sensitive to the weak mixing angle $\theta_W$

$$g_V^f = I_3^f - 2q_f \cdot \sin^2 \theta_W$$
$$g_A^f = I_3^f,$$
The Results: DØ's New $Z/\gamma^{*} \rightarrow e^+e^-$ Analysis

- Construct $A_{FB}$ vs. $M_{ee}$ from background subtracted data

- Analyze Z pole region ($70 < M_{ee} < 130$ GeV)

- Fit $A_{FB} (\sin^2(\theta_W))$ templates to extract measurement

- Comparable to the LEP c-quark result
- More precise than the LEP hadronic charge (Q) result!
• Construct an unfolded $A_{FB}$

• Fit templates of the $Z$-light quark (u,d) couplings

$Z$-$u$ couplings

$Z$-$d$ couplings

<table>
<thead>
<tr>
<th></th>
<th>$g^u_A$</th>
<th>$g^u_V$</th>
<th>$g^d_A$</th>
<th>$g^d_V$</th>
</tr>
</thead>
<tbody>
<tr>
<td>D0 (5.0 fb$^{-1}$)</td>
<td>0.502 ± 0.040</td>
<td>0.208 ± 0.014</td>
<td>-0.495 ± 0.037</td>
<td>-0.379 ± 0.027</td>
</tr>
<tr>
<td>SM</td>
<td>0.501</td>
<td>0.192</td>
<td>-0.502</td>
<td>-0.347</td>
</tr>
</tbody>
</table>

• Most precise measurement to date!
**CDF's Z/\gamma^* + X Angular Coefficients Analysis**

- Analyze dielectron data around the Z peak (66 GeV < M_{ee} < 116 GeV)
- Compare to the expected Drell-Yan +X differential cross sections
  \[
  \frac{d\sigma}{d\cos\theta} \propto (1+\cos^2\theta) + \frac{1}{2} A_0(1-3\cos^2\theta) + A_4 \cos\theta
  \]
  \[
  \frac{d\sigma}{d\phi} \propto 1 + \frac{3\pi A_3}{16} \cos\phi + \frac{A_2}{4} \cos^2\phi
  \]
- Includes $q\bar{q} \rightarrow Z/\gamma^* + \text{gluon (annihilation)}$ and contributions
- Includes $qg \rightarrow Z/\gamma^* + q$ (Compton)
- Analyze $e^+e^-$, $P_T$, $\cos(\theta')$, and $\phi$ data

- 2.1 fb^{-1} of data
CDF's $Z/\gamma^* + X$ Angular Coefficients Analysis

- Fit coefficients templates versus dielectron $P_T$
• Lan-Tung relation predict $A_0 = A_2$ ($A_0 - A_2 = 0$) for spin 1 gluons
• Violations could indicate something new

<table>
<thead>
<tr>
<th>$e^+e^- P_T$ bin (GeV)</th>
<th>$A_0 - A_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 10</td>
<td>$(0.005 \pm 0.314) \times 10^{-1}$</td>
</tr>
<tr>
<td>10 - 20</td>
<td>$(0.434 \pm 0.458) \times 10^{-1}$</td>
</tr>
<tr>
<td>20 - 35</td>
<td>$(0.341 \pm 0.706) \times 10^{-1}$</td>
</tr>
<tr>
<td>35 - 55</td>
<td>$0.023 \pm 0.105$</td>
</tr>
<tr>
<td>&gt; 55</td>
<td>$0.014 \pm 0.139$</td>
</tr>
</tbody>
</table>

Uncertainties are stat. + syst.

Published: PRL 106, 241801 (2011)

• Clearly the data favors spin 1 gluons!
**W Charge Asymmetry**

- $u$-quarks carry more of the proton's momentum than $d$'s
- $W^+$'s tend to get boosted along $p^+$ direction
- Leads to a charge asymmetry with direct connections to PDFs

\[
A(y_W) = \frac{d\sigma(W^+)/dy_W - d\sigma(W^-)/dy_W}{d\sigma(W^+)/dy_W + d\sigma(W^-)/dy_W} \approx \frac{u(x_1)d(x_2) - d(x_1)u(x_2)}{u(x_1)d(x_2) + d(x_1)u(x_2)}
\]

- However, it's the lepton we see!
- Assuming SM (V-A) couplings and using $e\nu W$-mass constraint, can recover $W$ asymmetry (CDF)

![Graph showing data points and curves for W Charge Asymmetry and Lepton Charge Asymmetry](image)
W Charge Asymmetry Results

D0's $W \rightarrow \mu\nu$ preliminary
$\mu$ asymmetry result
D0 Note 5976-CONF

Note experimental uncertainties smaller than PDF uncertainties

Constrain/give feedback on PDFs!

CDF's $W \rightarrow e\nu$ result

D0 Note 5976-CONF
Accelerator and detector running very smoothly for ~10 years

Millions/Hundreds of thousands of $W$'s and $Z$'s to study

$Z$'s to extract/confirm several SM parameters
- Weak mixing angle ($\theta_w$), really $\sin^2(\theta_w)$
- $Z$-light $(u,d)$ quark couplings
- Angular coefficients ($A_0, A_2, A_3, A_4$) and more gluon spin-1 evidence

$W$'s charge asymmetry used to constrain/improve PDF's

Even though Tevatron turns off September 30th we are not done yet
… still have ~5fb$^{-1}$ of data yet to analyze

Stay tuned for even more high(er) precision results!