Recent results from EW and Top Quark Physics at DØ

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Gauge Boson Couplings

- The standard model makes very stringent predictions for (i.e. uniquely determines) the trilinear couplings of the gauge bosons: $W$, $Z$, and $\gamma$.
- These couplings can be investigated by measuring $W\gamma$ and $Z\gamma$ production, as well as $WW$, $WZ$, and $ZZ$ pair production.
- The presence of anomalous couplings would indicate physics beyond the standard model.
- Parameterized by an effective Lagrangian. Spin 1 boson will have four parameters.
Wγ Production

- Requires efficient photon identification.
- Event selection:
  - High $P_T$ isolated electron or muon,
  - Missing transverse energy,
  - Isolated photon with $E_T > 8$ GeV $|\eta| < 1.1$ and $\Delta R(l,\gamma) > 0.7$.
- Photon ID efficiency $= 81 \pm 1 \%$.
- Main background is $W$+jets production where the jet mimics a photon. Estimated from data.
- Background for important high $P_T$ analyses: $H \rightarrow WW$, top, trileptons.
• Theory cross section: $\sigma(pp\rightarrow W\gamma\rightarrow l\nu\gamma) = 16.0 \pm 0.4$ pb.
• Combined electron and muon cross section: 
  $L = 162 \ (134) \ pb^{-1}$
  $\sigma(pp\rightarrow W\gamma\rightarrow l\nu\gamma) = 14.8 \pm 1.6\,(\text{stat}) \pm 1.0\,(\text{syst}) \pm 1.0\,(\text{lumi})$ pb.
• In the absence of an excess of large $E_T$ photons, extract limits on the anomalous couplings.
Wγ Anomalous Couplings

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• Binned maximum likelihood fit to the photon $E_T$ spectrum.
• Limits on CP conserving couplings ($\Lambda = 2$ TeV):
  
  $-0.88 < \Delta \kappa_\gamma < 0.96 \quad -0.20 < \lambda_\gamma < 0.20$

• Limits on non-CP conserving couplings in progress.
• For $\cos \theta^*$, the angle between incoming quark and photon in the $W\gamma$ rest frame, equal to 1/3, the differential cross section goes to zero. This is a radiation amplitude zero.

• Endcap photon identification necessary to get a statistically significant signal. In progress…

• Background subtraction important ($M(W,\gamma) > 90 \text{ GeV/c}^2$).
Zγ Production

- Requires efficient photon identification.
- Event selection:
  - Two high P_T isolated electrons or muons (oppositely charged),
  - Isolated photon with P_T > 8 GeV, |η| < 1.1 and ΔR(l,γ) > 0.7.
- Photon ID efficiency = 81 ± 1 %.
- Main background is Z+jets production where the jet mimics a photon. Estimated from data.
**Zγ Production Cross Section**

**Zγ Event Yields**

<table>
<thead>
<tr>
<th></th>
<th>Electron</th>
<th>Muon</th>
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</thead>
<tbody>
<tr>
<td>SM</td>
<td>95.3 ± 4.9</td>
<td>126.0 ± 7.8</td>
</tr>
<tr>
<td>Bkgd</td>
<td>23.6 ± 2.3</td>
<td>22.4 ± 3.0</td>
</tr>
<tr>
<td>Data</td>
<td>138</td>
<td>152</td>
</tr>
</tbody>
</table>

- Theory cross section: $\sigma(pp\rightarrow Z\gamma\rightarrow ll\gamma) = 3.9 + 0.1 - 0.2$ pb.
- Combined electron and muon cross section: $L = 320(290)$ pb$^{-1}$
  $\sigma(pp\rightarrow Z\gamma\rightarrow ll\gamma) = 4.2 \pm 0.4$ (stat+sys) $\pm 0.3$ (lumi) pb.
• Limits on CP even and CP odd couplings for $ZZ\gamma$ ($\Lambda = 1000$ GeV):
  \[ |h_{10,30}^{Z}| < 0.23, \quad |h_{20,40}^{Z}| < 0.020 \]

• Limits on CP even and CP odd couplings for $Z\gamma\gamma$ ($\Lambda = 1000$ GeV):
  \[ |h_{10,30}^{\gamma}| < 0.23, \quad |h_{20,40}^{\gamma}| < 0.019 \]
• WW production is major background for searches (Higgs, SUSY).
• Provides another channel to search for anomalous couplings (WWγ and WWZ).
• Theoretical prediction:
  – $\sigma(WW) = 13.5\, \text{pb} @ 1.96\, \text{TeV}$
• Main backgrounds:
  – $Z/\gamma$, top pair production, WZ, ZZ, W+jet/γ, multijets.
• Event selection:
  – Two high $P_T$ isolated oppositely charged electrons or muons,
  – With $P_T > 20$ GeV and $P_T > 15$ GeV,
  – MET > 30, 40, 20 GeV in $ee, \mu\mu, e\mu$ to remove $Z/\gamma^*$.

Missing transverse energy after event selection.
**WW Production Cross Section**

- **eµ channel:**
  - no third lepton such that $61 < M(l^+l^-) < 121$ GeV/$c^2$.
  - minimal transverse mass $> 20$ GeV/$c^2$.
  - $H_T$ (jets $w/E_T > 20$ and $|\eta| < 2.5$) $< 50$ GeV.

- **Summary:**
  - 6 $ee\nu\nu$ candidates, exp. signal/background: 3.4 and 2.3.
  - 4 $\mu\mu\nu\nu$ candidates, exp. signal/background: 2.1 and 1.9.
  - 15 $e\mu\nu\nu$ candidates, exp. signal/background: 11.1 and 3.8.

- **Anomalous coupling extraction in progress:**
  - $|\Delta \kappa| < 1.2$ $|\lambda| < 1.0$ 95% C.L. $\Lambda = 1000$ GeV (Run I).

**P(background fluctuation) = 2.3 \times 10^{-7}**

Corresponds to 5.2 $\sigma$ significance.

$$\sigma(WW) = 13.8_{-3.8}^{+4.3} (\text{stat.})_{-0.9}^{+1.2} (\text{sys.}) \pm 0.9(\text{lum.}) \text{ pb}$$
Trilepton events:
- At least two high $P_T > 15$ GeV/c isolated electrons or muons that make a $Z$ boson,
- A third isolated $e$ or $\mu$ with high $P_T$,
- Missing transverse energy $> 20$ GeV.

$\sigma (WZ) \sim 4.0$ pb @ 1.96 GeV.

Only sensitive to WWZ coupling.
Main background is $Z+X$ ($X = j, \gamma, \text{or } Z$).

- 2 $\mu\mu\nu\nu$ and 1 $eee\nu$ candidates.
- $P(0.71 \text{ bkgd}) \rightarrow 3$ signal events is 3.5%.

Cross section $\sigma(WZ) = 4.5^{+3.5}_{-2.6} \text{ pb}$

Standard model cross section:
- $\sigma(WZ) = 3.7 \pm 0.1 \text{ pb}$
Best limits in WZ final states.
First 2-d limits in $\Delta \kappa_Z$ vs $\lambda_Z$ using WZ.
Best limits available on $g_1^Z$, $\Delta \kappa_Z$, and $\lambda_Z$ from direct, model independent measurements.
Factor of 2-3 improvement of Run I.
Z Boson Rapidity Distribution

- Complimentary measurement to high-momentum jet spectrum PDF’s.
- Advantage: Z/DY process rapidity distributions calculated at NNLO.
- Measure at high $Q^2$, large and small Bjorken $x$ in the initiating quark and antiquark.
- Can be used to constrain the parton distribution functions.
- Two high $P_T$ isolated electrons that make a Z boson:
  - $71 \text{ GeV}/c^2 < M(\gamma^*) < 111 \text{ GeV}/c^2$
- Integrated luminosity = 337 pb$^{-1}$
- Good agreement with prediction.
W Boson Width

- W boson width is predicted precisely to be $\Gamma_W = 2.090 \pm 0.008$ GeV (Hagiwara et al. D66 (2002)).
- High values of $M_T$ are sensitive to the width of the W boson (Breit-Wigner lineshape).
- Integrated luminosity = 177 pb$^{-1}$
- Event selection:
  - High $P_T$ electron
  - Missing transverse energy
- Backgrounds:
  - Multijets
  - $Z \rightarrow ee$, one electron undetected
  - $W \rightarrow \tau \nu \rightarrow e\nu\nu\nu$
- Binned maximum likelihood fit:
  - $100 \text{ GeV} < M_T < 200 \text{ GeV}$

$\Gamma_W = 2.011 \pm 0.093 \text{ (stat)} \pm 0.107 \text{ (syst)}$

Calorimeter calibration in progress.
One inverse femtobarn can give $\sim 25 \text{ GeV} \text{ (stat.)}$ and $\sim 45 \text{ MeV} \text{ (syst.)}$ totaling $\sim 50 \text{ MeV}$.
• At Tevatron, top pair production mainly from qq (85%) and gg (15%).
• In standard model, top decays 99.9% of the time to Wb. It decays before it hadronizes.
• Event classification:
  all hadronic (all jets), lepton plus jets, dileptons.
• Need to identify and reconstruct:
electrons, muons, jets from b-quarks, jets from light quarks, missing transverse energy.
Top Quark Event Signatures

**Dilepton:**
- **Signal selection:**
  - Two high $P_T$ leptons
  - Missing transverse energy
  - Two or more high $P_T$ jets
- **Backgrounds:**
  - Diboson (WW, WZ, ZZ)
  - Drell-Yan
  - $Z \rightarrow \tau\tau$
  - $W +$ jets with fake lepton

**Lepton plus jets:**
- **Signal selection:**
  - One high $P_T$ leptons
  - Missing transverse energy
  - Four or more high $P_T$ jets
- **Backgrounds:**
  - $W +$ jets
  - Multijet with fake lepton

Use $b$ tagging to increase S/B.
Top Quark Mass

Top mass measured in two channels with 0.25 fb⁻¹.

Currently improving measurement of jet energy calibration.

Expect improved results soon.
W Helicity Top Quark Decays

- In standard model, W helicity depends on the top quark and W boson masses:
  - Predicted 70% longitudinal, 30% left-handed, and 0% right-handed.
  - We measure right-handed fraction $f_+$ or $V+A$ component.

- Any deviation is a signal for new physics:
  - $SU(2)_L \times SU(2)_R \times U(1)_Y$ models [PRL 38, 1252 (1977)].

- Use the angular distribution $\cos \theta^*$:
  - Angle between the charge lepton and top quark direction in the W boson rest frame.

- Event selection:
  - High $P_T$ isolated electron or muon, $\geq$ four jets, missing $E_T$.
  - Two parallel analyses: topological, which uses only topological information, and b-tag, which requires at least one jet tagged by the SVT.
W Helicity in Top Quark Decays

- Analyses use binned maximum likelihood fit to extract $f_+: \cos \theta^*$ from data, $\cos \theta^*$ from signal and background contributions.
- Topological analysis (230 pb$^{-1}$):
  - 35 events observed in data
  - Expected yield for signal and background: 17 and 19, respectively.
- b-tag analysis (230 pb$^{-1}$):
  - 52 events observed in data
  - Expected yield for signal and background: 41 and 13, respectively.
W Helicity in Top Quark Decays

• Systematics include:
  • jet energy calibration,
  • top quark mass,
  • signal and background MC.

• Topological analysis:
  $f_+ < 0.25 \ @ \ 95\% \ Bayesian \ C.L.$

• b-tag analysis:
  $f_+ < 0.25 \ @ \ 95\% \ Bayesian \ C.L.$

• Dilepton analysis now under collaboration review.

Combined result:

$f_+ = 0.00 \pm 0.13 \ (stat) \pm 0.07 \ (syst)$

$f_+ < 0.25 \ @ \ 95\% \ Bayesian \ C.L.$
Single Top Quark Production

\[ \text{s-channel } \sigma_{\text{NLO}} \sim 0.88 \text{ pb} \quad \text{t-channel } \sigma_{\text{NLO}} \sim 1.98 \text{ pb} \]

- Event Selection:
  - One high \( P_T \) isolated lepton,
  - From 2 to 4 jets:
    - Leading jet > 25 GeV,
    - \( P_T > 15 \text{ GeV} \quad |\eta| > 25 \text{ GeV}. \)
  - s-channel 1 or more b-tagged jets,
  - t-channel 1 or more b-tagged jets and 1 or more untagged jets.
Single Top Quark Production

- Backgrounds:
  - W/Z + jets production,
  - Multijet production
  - Top pair production,
  - Diboson (WZ, WW).
- Use neural networks to improve sensitivity.
Single Top Quark Production

- No evidence for single top quark production.
- Set Bayesian 95% C.L. upper cross section limits:
  \[ \sigma_s < 6.4 \text{ pb} \quad \sigma_t < 5.0 \text{ pb} \]
- Presently, most sensitive limit in the world.
Summary

• This is just the beginning:
  – Electroweak analyses in progress:
    • W charge asymmetry in $e + \mu$, $Z$ $P_T$ distribution, $W \rightarrow \tau\nu$ cross section, etc…($Z \rightarrow \tau\tau$ cross section, $W \rightarrow \mu\nu$ and $W \rightarrow e\nu$ cross sections)
  – Top quark analyses in progress:
    • Top charge, top pair resonances, top decay to charged Higgs, anomalous kinematics ($P_T$ of top quark), top mass in all jets channel, etc…

•Reached one inverse femtobarn: $1 \text{fb}^{-1}$.

• For more details on results available:
  – http://www-d0.fnal.gov/Run2Physics/WWW/results.htm