Search for WW/WZ Resonant Production at DØ

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Motivation

• The standard model (SM) is widely believed to be a low-energy effective theory of physics
  – New physics expected at TeV scale
• New, heavy particles may decay to WW or WZ
  – See as resonances in SM diboson spectrum
• Look combine 3 different final states
  – $WZ \rightarrow l\nu ll$ in 4.1 fb$^{-1}$
  – $WW/WZ \rightarrow l\nu jj$ in 5.4 fb$^{-1}$
  – $WZ \rightarrow lljj$ in 5.4 fb$^{-1}$
BSM Models

• We compare data to SM expectations and to Beyond the SM (BSM) theories

• The sequential SM (SSM) with a $W' \rightarrow WZ$
  - Assumes additional SU(2) group having heavy resonances with SM-like couplings

• Randall-Sundrum (RS) Models w/graviton $G \rightarrow WW$
  - In RS Models, a warped extra-dimension exists that the graviton propagates through
  - Massive Kaluza-Klein Modes of the graviton may exist at the $\sim$TeV scale, observable at DØ
DØ Detector

- $p\bar{p}$ collisions
  - $\sqrt{s} = 1.96$ TeV
  - 1 bunch crossing per 396 ns
Signal and Background Modeling

- Principal backgrounds Z+jets, W+jets, t\bar{t}, single top, SM dibosons and multijet events
  - Z+jets, W+jets, t\bar{t} modeled using ALPGEN
  - Single top modeled with COMPHEP
  - SM diboson production modeled using PYTHIA
  - Multijets estimated using data

- Both SSM W' and RS graviton modeled w/ PYTHIA
  - No interference between W and W'
  - Signal normalized to NNLO
Lepton ID

- Electrons reconstructed in Central and Endcap Calorimeters (CC and EC)
  - > 95% in EM calorimeter
  - Calorimeter and Track Isolation
  - Multivariate discriminant to reject jets
  - Consistent with track from Primary Vertex

- Muons reconstructed by matching track in muon chambers to track in inner tracker
  - Calorimeter and Track Isolation
Jet ID and MET

- Jets reconstructed in CC and EC using iterative midpoint cone algorithm
  - Reject jets matched to electrons
  - Cone width $\Delta R = \sqrt{\Delta \eta^2 + \Delta \phi^2} = 0.5$
- Missing Transverse Energy (MET) found by taking vector sum of all calorimeter cell energies
  - Corrections for muon momentum, Jet and electron energy scales
WZ → lνll Selection Criteria

- The leptons must have $p_T > 20$ GeV
- MET $> 30$ GeV
- Dilepton mass consistent with $Z$
  - $80 \ (70) \ GeV < M_{ee(\mu\mu)} < 102 \ (110) \ GeV$
- Expect $W, Z$ boosted, so require
  - $\Delta R > 1.2$ between $W$ lepton and $Z$ daughters
WW/WZ → lνjj Selection Criteria

- Exactly one e or µ
- The lepton must have $p_T > 20$ GeV
- MET $> 20$ GeV
- $\Delta\phi(l,\text{MET}) < 1.5$ and $p_T$ of $l+$MET system $> 100$ GeV
- Either
  - Dijets with $70$ GeV $< M_{jj} < 115$ GeV and $\Delta R < 1.5$
  - Single jet with jet mass $= \sqrt{(E_j^2-p_j^2)} > 70$ GeV
WZ → lljj Selection Criteria

- Either ee or \( \mu \mu \) pair
- The leptons must have \( p_T > 20 \) GeV
- MET < 50 GeV
- \( 70 \text{ GeV} < M_{ll} < 110 \text{ GeV} \)
- \( \Delta R(l,l) < 1.5 \) and dilepton \( p_T > 100 \) GeV
- Either
  - Dijets with \( 60 \text{ GeV} < M_{jj} < 105 \text{ GeV} \) and \( \Delta R < 1.5 \)
  - Single jet with jet mass = \( \sqrt{(E_j^2 - p_j^2)} > 60 \) GeV
High/Low Mass Regions

- Divide W'/G samples for limit setting into low mass (≤ 450 GeV) and high mass (>450 GeV) regions
  - Low mass limits include all events passing cuts
  - High mass limit requires, for lνjj and lljj
    - $\Delta\phi(l,\text{MET}) < 1.0$ and $p_T$ of $l+$MET system > 150 GeV
    - $\Delta R(l,l) < 1.0$ and dilepton $p_T > 150$ GeV

High Mass Event Sample Composition

<table>
<thead>
<tr>
<th>Process</th>
<th>Single lepton sample</th>
<th>Dilepton sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z+$jets</td>
<td>3.6 ± 0.2</td>
<td>7.9 ± 0.8</td>
</tr>
<tr>
<td>$W+$jets</td>
<td>124.5 ± 20.3</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Top</td>
<td>22.9 ± 2.5</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Multijet</td>
<td>4.6 ± 0.3</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Diboson</td>
<td>27.6 ± 1.4</td>
<td>0.8 ± 0.1</td>
</tr>
<tr>
<td>Background sum</td>
<td>183.2 ± 24.5</td>
<td>8.7 ± 0.8</td>
</tr>
<tr>
<td>Data</td>
<td>174</td>
<td>8</td>
</tr>
</tbody>
</table>
Limits Setting

- Limits set using semi-frequentist method
- Log-Likelihood Ratio (LLR) based on Poisson statistics
  - Diboson mass distribution
  - Integrate over LLR in pseudo-experiments to set confidence limits for background (CL$_b$) and signal+background (CL$_{s+b}$)
- 95% C.L. exclusion limit set where CL$_{s+b}$/CL$_b$ = 0.05
W' Limit Setting

- Limits on WZ resonance use 50 GeV bin width
- In SSM, exclude 95% CL 180 GeV < M(W') < 690 GeV
- Assume linear relation between resonance mass and total W' width and that the intrinsic width is less than experimental resolution
  - Valid for W'WZ coupling strengths up to 10 times the SSM value
Graviton Limit Setting

- Limits on WW resonance also use 50 GeV binning.
- For RS graviton, assume $k/M_{Pl} = 0.1/\sqrt{8\pi}$, where $k$ is the curvature scale of the warped extra dimension and $M_{Pl}$ is the Planck mass.
- At 95% C.L, we exclude $300 \text{ GeV} < M(G) < 754 \text{ GeV}$
Summary

- Have set limits on WW and WZ resonances with 4.1-5.4 fb\(^{-1}\) of integrated luminosity at DØ

\[180 \text{ GeV} < M(W') < 690 \text{ GeV}\]

\[300 \text{ GeV} < M(G) < 754 \text{ GeV}\]