Search for electroweak WZ vector boson scattering and new physics at CMS

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Introduction and Motivation

- WZ production via vector boson scattering
  - Important component of WZjj production proceeding entirely via EW interactions at tree level
  - Given SM Higgs, interactions with vector bosons, and V self-interactions precisely predicted
    - Deviations from predictions signal new physics in EW sector

- Low cross sections for VBS just becoming accessible
  - Does it occur with the rate predicted by the SM?
  - Do distributions show any signs of BSM physics?

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Radiation of vector bosons, lack of color flow between jets

- Distinct kinematic signature for VVjj EW component

- Forward and high momentum jets
- Low central jet activity
Why WZjj \(\rightarrow 3\ell vjj\)?
- Sensitive to charged resonances or couplings
- Less clean signature than ZZ, W\(\pm\)W\(\pm\), but cross section accessible with large dataset

Event selection
- Exactly 3 leptons with moderate \(p_T\) + \(p_T^{\text{miss}}\)
- Tight dijet kinematic cuts reduce QCD WZjj and significant nonprompt contributions
- Expected contributions in signal region
  - WZ/non-WZ \(\sim 3/1\)
  - EW WZ/other \(\sim 1/3\)
WZ VBS at 13 TeV: Results

- Measure WZjj EW+QCD cross section in VBS-enhanced phase space
  - Fit yields in signal region to reduce dependence on theory prediction

**Fiducial Regions**

<table>
<thead>
<tr>
<th></th>
<th>Tight fiducial</th>
<th>Loose fiducial</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_T^e$ [GeV]</td>
<td>$&gt; 25$</td>
<td>$&gt; 20$</td>
</tr>
<tr>
<td>$p_T^\mu$ [GeV]</td>
<td>$&gt; 15$</td>
<td>$&gt; 20$</td>
</tr>
<tr>
<td>$p_T^\tau$ [GeV]</td>
<td>$&gt; 20$</td>
<td>$&gt; 20$</td>
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<tr>
<td>$</td>
<td>\eta^e</td>
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<td>$</td>
<td>\eta^\mu</td>
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<tr>
<td>$</td>
<td>m_{ee} - m_Z</td>
<td>[GeV]$</td>
</tr>
<tr>
<td>$m_{3\ell}$ [GeV]</td>
<td>$&gt; 100$</td>
<td>$&gt; 100$</td>
</tr>
<tr>
<td>$m_{4\ell}$ [GeV]</td>
<td>$&gt; 4$</td>
<td>$&gt; 4$</td>
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<tr>
<td>$p_T^{miss}$ [GeV]</td>
<td>-</td>
<td>-</td>
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<tr>
<td>$</td>
<td>\eta</td>
<td>$</td>
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<tr>
<td>$p_T^{\ell}$ [GeV]</td>
<td>$&gt; 50$</td>
<td>$&gt; 30$</td>
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<tr>
<td>$</td>
<td>\Delta R(j, \ell)</td>
<td>$</td>
</tr>
<tr>
<td>$n_j$</td>
<td>$\geq 2$</td>
<td>$\geq 2$</td>
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<tr>
<td>$p_T^{\ell}$ [GeV]</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$n_b$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$m_{jj}$</td>
<td>$&gt; 500$</td>
<td>$&gt; 500$</td>
</tr>
<tr>
<td>$</td>
<td>\Delta R_{jj}</td>
<td>$</td>
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<tr>
<td>$</td>
<td>\eta^{3\ell} - \frac{1}{2}(\eta^h + \eta^j)</td>
<td>$</td>
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</tbody>
</table>

Compare tight fiducial to $\sigma_{\text{fid,MG}} = 3.27^{+0.39}_{-0.32}\text{ (scale)} \pm 0.15\text{ (PDF)}$
Simultaneously fit yield from background control region and 2D distribution of $m_{jj}$ and $\Delta\eta(j_1,j_2)$

- Fit 4 leptonic decay channels independently
- Uncertainties correlated across bins and with control region

EW contribution (purple dashed, stacked) rises with increasing $m_{jj}/\Delta\eta_{jj}$

Observed (expected) significance of EW WZ $1.9\sigma$ ($2.7\sigma$)

$$\mu_{EW} = \sigma_{EW, obs}/\sigma_{EW, theo} = 0.64^{+0.45}_{-0.37}$$
Limits on new physics: Procedure

- New WWZZ interactions likely modify the $m_T(WZ)$ spectrum
  - Sensitive center of mass energy of the scattering system
- Studied in specific and generic models
  - Charged Higgs bosons ➞ Resonance-like modification
  - Dimension-8 effective field theory operators ➞ Lead to excess of events at high $m_T$

No signs of new physics at high mass!
Limits on new physics: Results

- First dimension-8 operator constraints from WZ channel at 13 TeV
  - Limits complementary to SS WW analysis, competitive for several operators
- Charged Higgs limits improve from previous CMS study at 13 TeV, complement those from ATLAS

Limits on $\sigma_{H^{\pm}}$ and in parameters of GM model
Conclusions

- VBS measurements provide an important probe of a previously untested sector of the standard model.
- So far the standard model is withstanding these new tests.
  - Deviations could be subtle.
  - More data and improved techniques help look for cracks with increased precision and at higher energy scales.

![Graph showing CMS EWK measurements vs. expectation for different processes.](http://cern.ch/go/pNj7)
Backup
WZ VBS at 13 TeV: Backgrounds

- Nonprompt background
  1. Define “loose” ID with ID+isolation relaxed from “tight”
  2. Measure tight/loose ratio in Z+jet (dijet) events
  3. Apply $\text{loose} \rightarrow \text{tight}$ factors to events passing full analysis selection but failing analysis ID (tight)

- QCD WZjj background
  - Simulated with $\text{MG5\_aMC+Py8} \leq 3j@LO$
  - Compare to predictions from $\text{MG5\_aMC+Py8} \leq 1j@NLO$, each normalized to data in control region
  - Normalization constrained in control region
  - $m_{jj} > 100$ GeV, but fail dijet signal cuts
  - Uncertainty: LO scale+PDF+10% normalization from MC comparisons
Models of new physics

- Study deviations from SM from two perspectives
  - Explicit BSM models well-motivated by shortcomings in the SM
    - Example: charged Higgs bosons
    - Arise in extensions of the SM with extended Higgs sector, VBS production important when couplings to vector bosons dominant

- Generalized language for new physics in vector boson interactions
  - EFT expansion with Wilson coefficients $c_i$ and New Physics scale $\Lambda$

\[
\mathcal{L}_{SM} \rightarrow \mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{n=1}^{\infty} \sum_i \frac{c_i^{(n)}}{\Lambda^n} O_i^{(n+4)}
\]

- Observed as deviations at high mass

Approaches are complementary!