Electroweak production with multileptonic final state in the CMS experiment

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  • CMS-SMP-16-002, submitted to *Phys. Lett. B*

• Search for electroweak SUSY production
  • CMS-PAS-SUS-16-024, presented in ICHEP2016
WZ cross section measurement
Motivation

- First measurement of WZ cross section at 13 TeV.
- Very important background source in multileptonic BSM searches.
- Potential tests for anomalous triple gauge couplings (aTGC).
Main background: *fake* leptons

Prompt lepton: lepton coming from the main interaction vertex, such as from a vector boson or some BSM process.
Non-prompt (*fake*) lepton: lepton contained in a jet, jet misidentified as a lepton, etc.

Data-driven approach: *tight-to-loose* method.
Efficiency of preselected (*loose*) prompt and non-prompt leptons passing the final selection (*tight*) is estimated from data in dedicated control regions.
Data events failing to pass lepton requirements enter the analysis region with a weight based on these probabilities.

\[ \begin{align*}
N_{\text{tightly}} & = N_{\text{loosely real}} + \epsilon_{\text{fake}} N_{\text{loosely fake}} \\
\text{Cut} & \begin{cases} 
N_{\text{loosely}} \\
N_{\text{tightly}} 
\end{cases}
\end{align*} \]
Selection

Fiducial region (selected at generator level):
- \( p_T^{\ell Z1} > 20 \) GeV, \( p_T^{\ell Z2} > 10 \) GeV.
- \( p_T^{\ell W} > 20 \) GeV.
- All leptons \(|\eta| < 2.5\).
- \( 60 < m_Z < 120 \) GeV.

Final event selection:
- Exactly 3 isolated leptons.
- \( 76 < m_Z < 106 \) GeV.
- \( m_{\ell\ell} > 4 \) GeV (all \( \ell\ell \) combinations).
- \( E_T^{\text{miss}} > 30 \) GeV.
- \( m_{3\ell} > 100 \) GeV.
- Veto on events with b-tagged jets.
Results

Fiducial region:
• $60 < m_Z < 120$ GeV
• $p_T^{Z_1} > 20$ GeV
• $p_T^{Z_2} > 10$ GeV
• $p_T^W > 20$ GeV
• $|\eta^{Z/Z_2/W}| < 2.5$

<table>
<thead>
<tr>
<th>Theoretical predictions</th>
<th>Fiducial</th>
<th>Total (in $60 &lt; m_Z &lt; 120$ GeV range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NLO (MCFM with NNPDF3.0 PDFs, dynamic QCD scales)</td>
<td>$274^{+11}_{-8}$ (scale) ± 4 (PDF) fb</td>
<td>$42.3^{+1.4}_{-1.1}$ (scale) ± 0.6 (PDF) pb</td>
</tr>
<tr>
<td>NNLO (MATRIX with NNPDF3.0 PDFs, fixed QCD scales)</td>
<td>—</td>
<td>$50.0^{+1.1}_{-1.0}$ (scale) pb</td>
</tr>
<tr>
<td>NNLO (MCFM with NNPDF3.0 PDFs, fixed QCD scales)</td>
<td>$291^{+16}_{-13}$ (scale) ± 4 (PDF) fb</td>
<td>$44.9^{+2.2}_{-1.8}$ (scale) ± 0.7 (PDF) pb</td>
</tr>
</tbody>
</table>

Measurement
Fiducial:
$$\sigma_{\text{fid}} \left( pp \rightarrow WZ \rightarrow \ell \nu \ell' \ell' \right) = 258 \pm 21 \ (\text{stat})^{+19}_{-20} \ (\text{syst}) \pm 8 \ (\text{lumi}) \ fb$$

Total (in $60 < m_{\ell^+ \ell^-} < 120$ GeV range):
$$\sigma \ (pp \rightarrow WZ) = 39.9 \pm 3.2 \ (\text{stat})^{+2.9}_{-3.1} \ (\text{syst}) \pm 0.4 \ (\text{theo}) \pm 1.3 \ (\text{lumi}) \ pb$$
Search for electroweak SUSY production
Guiding models

leading models: aim to improve sensitivity

CIN2→WZ
CIN2→SlepSneu (flavor-democratic decay)
CIN2→SlepSneu (tau-dominated decay)

subleading models: no or little sensitivity expected (or signal is not ready)

CIN2→WH
CIN2→SlepSneu (tau-enriched decay)
N2N3→ZZ
Final state channels

2 lepton

- 0 taus
  - same-sign
    - \( M_T, ME_T \) and \( p_T^{ll} \) bins

- 3 lepton final state
  - 0 taus
    - nOSSF\( = 1 \)
      - on \( Z \), off \( Z \), \( M_T \) bins
    - nOSSF\( = 0 \)
      - \( M_{ll}, M_T \) bins
  - 1 tau
    - SS\( \tau \)
      - \( M_{ll}, M_{T2} \) bins
    - nOSSF\( = 1 \)
      - \( M_{ll}, M_{T2} \) bins
  - 2 tau
    - \( \ell\ell\ell \)
      - \( M_{ll}, M_{T2} \) bins

- 4 lepton final state
  - 0 taus
    - nOSSF\( = 2 \)
      - \( ME_T \) bins
  - 1 tau
    - nOSSF \( \leq 1 \)
      - \( ME_T \) bins

Signals

- \( \chi^\pm \chi^0 \rightarrow WZ \)
- \( \chi^\pm \chi^0 \rightarrow \text{SlepSneu} \) (flavor-demonstrated)
- \( \chi^\pm \chi^0 \rightarrow \text{SlepSneu} \) (tau-enriched)
- \( \chi^0 \chi^0 \rightarrow \text{ZZ} \) (tau-dominated)

nOSSF = number of OSSF pairs (ee, \( \mu\mu \), \( \tau\tau \))
nOSOF = number of OS different flavour pairs (ee, \( \mu\mu \), \( e\mu \))
Lepton MVA

New MVA lepton identifier developed.

Improved signal efficiency and background rejection wrt ID used in similar previous analyses.

Boosted Decision Tree:
Leptons from ttZ vs semileptonic tt
## Baseline selection

<table>
<thead>
<tr>
<th>selection</th>
<th>same-sign dilepton channel</th>
<th>trilepton channel</th>
<th>4-lepton channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>#leptons</td>
<td>2. same charge</td>
<td>3</td>
<td>&gt; 3</td>
</tr>
<tr>
<td>lepton $p_T$ for $e(\mu)$</td>
<td>25(20)/15(10)</td>
<td>25(20)/15(10)/10</td>
<td>25(20)/15(10)/10/10</td>
</tr>
<tr>
<td>#taus</td>
<td>0</td>
<td>0, 1, 2</td>
<td>≥ 0</td>
</tr>
<tr>
<td>lepton $p_T$ for $\tau_n(e/\mu)$</td>
<td>-</td>
<td>20(30/25)</td>
<td>20</td>
</tr>
<tr>
<td>#jets</td>
<td>0, 1</td>
<td>≥ 0</td>
<td>≥ 0</td>
</tr>
<tr>
<td>veto events with OSSF pair $M_{ll}$&lt;12</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>veto events with on-Z M3L</td>
<td>×</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>veto events with $&gt;0$ b-tagged jet</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>MET</td>
<td>&gt; 60</td>
<td>&gt; 50</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>overlap removal</td>
<td>no third lepton</td>
<td>no fourth lepton</td>
<td></td>
</tr>
</tbody>
</table>
Main background: WZ

- Exactly 3 light leptons (lepton MVA VT)
- 0 or 1 jet
- 0 b-tagged jets
- OSSF pair with $75 < M_{\ell^+\ell^-} < 105$ GeV
- $35 < E_T^{\text{miss}} < 100$ GeV
- $M_T^W < 120$ GeV

CR used to constrain WZ background. Negligible signal contamination, except for $\tilde{\chi}^\pm\tilde{\chi}^0 \rightarrow WZ$ models with $\Delta M \sim M_Z$ (WZ-like kinematics). Additional uncertainty. Overlap with SRA13 → substituted in the interpretation.
Most relevant signal regions

Categorization based on:
- \( p_T^{ll} \)
- \( M_T \)
- \( E_T^{miss} \)

Categorization based on:
- \( M_{\ell^+\ell^-} \)
- \( M_T \)
- \( E_T^{miss} \)
Flavor-democratic SlepSneu

CMS Preliminary 12.9 fb⁻¹ (13 TeV)

\[ \text{pp} \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow \ell^+ \ell^- \nu \bar{\nu}, \text{BR}(\tilde{\chi}_2^0 \rightarrow \ell^+) = 0.5, m = 0.5(m_\ell + m_{\nu}) \]

- Observed $\pm 1 \sigma_{\text{theory}}$
- NLO-NLL excl.
- Expected $\pm 1 \sigma_{\text{experiment}}$

CMS-SUS-13-006
Flavor-democratic SlepSneu

CMS Preliminary 12.9 fb\(^{-1}\) (13 TeV)

$pp \rightarrow \chi^0_1 \chi^0_2 \rightarrow \tilde{\ell} \tilde{\nu}$, $BR(\chi^0_2 \rightarrow \tilde{\ell} \tilde{\nu})=0.5$, $m_{\ell}=0.05 m_{\chi_1} + 0.95 m_{\chi_2}$

$\sigma$ [fb]

95% C.L. upper limit on cross section [pb]
\( \tau \)-dominated SlepSneu

**CMS Preliminary** 12.9 fb\(^{-1}\) (13 TeV)

pp \( \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_1^0 \rightarrow \tau \nu \tau \nu \), BR(\( \tilde{\chi}_2^0 \rightarrow \tau \nu \))=1, \( m_\tau = 0.5 (m_\tau + m_\tilde{\chi}_1^0) \)

- **Observed \( \pm 1 \sigma_{\text{theory}} \)** NLO-NLL excl.
- **Expected \( \pm 1 \sigma_{\text{experiment}} \)**

CMS-SUS-13-006
WZ

CMS Preliminary 12.9 fb⁻¹ (13 TeV)

pp → \tilde{\chi}_1^\pm \tilde{\chi}_2^0 → WZ\tilde{\chi}_1^0\tilde{\chi}_1^0

- Observed ± 1 \sigma_{theory}
- NLO-NLL excl.
- Expected ± 1 \sigma_{experiment}

CMS-SUS-13-006
Conclusions

- WZ cross section measurement with 13 TeV data (2015, 2.3 fb⁻¹)
  - Measured value noticeably lower than NNLO prediction: future measurements should shed some light on this.

- Electroweak SUSY production (2016, 12.9 fb⁻¹)
  - Expanded exclusion upper limits on several models with combination of same-sign dilepton and multileptons.
  - No SUSY found (otherwise you would probably know already).

Thank you for your attention!
WH

CMS Preliminary 12.9 fb⁻¹ (13 TeV)

pp → \tilde{\chi}_1^±\tilde{\chi}_2^0 \rightarrow WH\tilde{\chi}_1^0\tilde{\chi}_2^0

NLO+NLL exclusion

- Observed ± 1 σ_{theory}
- Expected ± 1 σ_{experiment}

CMS-SUS-13-006