Searches for Lepton Flavour Violation in CMS: \(Z'\) & \(W'\)

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Introduction

**Standard Model**: Lepton Number and Flavour are not related to gauge symmetry
   **BUT** they might not be conserved

Fermions can change flavour
   - CKM matrix
   - PMNS matrix

Neutrino oscillations exists: BSM for neutrino masses

Do Charged leptons violate Lepton Flavor conservation??
1. Decays of SM particles ? Not observed yet !!!
2. Decays of BSM particles??
   **Not observed yet !!!**

Charged Lepton Flavour violation very strongly constrained due to GIM mechanism

Several BSM scenarios raise the branching ratios to levels reachable at the LHC

BSM + Massive $\nu \rightarrow$ Large LFV !!!

Any observation is discovery !!!
Lepton Flavour Violation @ CMS

- Muon decays: $\mu \rightarrow e\gamma$, $\mu \rightarrow eee$ and $\mu$-e conversion
- Tau Decays: $\tau \rightarrow e\gamma$, $\tau \rightarrow 3l$
- Meson decays: $B^0/D^0 \rightarrow e\mu$

Low energy results provide constraints (often with assumptions)

Z Boson
Search for $Z \rightarrow e\mu$ decays
(CMS PAS-EXO-13-005) 8 TeV

H Boson
Search for $H \rightarrow e\mu/e\tau/\mu\tau$ decays
PLB 763(2016) 472 (8TeV)
CMS PAS-HIG-17-001 (13 TeV)

Supersymmetry
RPV SUSY in dilepton channels (SUS-14-018)
RPV SUSY with displaced vertices (1610.05133)

Search for heavy neutrinos & right-handed W
1. Type I seesaw and Left-Right SM
2. Type III seesaw
PLB 775 (2017) 315-337
1803.11116

Analysis presented in the talk

Search for Heavy LFV resonances ($Z'$, RPV SUSY, QBH) into $e\mu$ @ 13TeV JHEP 04(2018)073
Search for Heavy LFV resonances decaying to dilepton final state

<table>
<thead>
<tr>
<th></th>
<th>2012 (8 TeV)</th>
<th>2015 (13 TeV)</th>
<th>2016 (13 TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ATLAS</strong></td>
<td><strong>eμ, eτ, μτ</strong> <strong>RPV,Z’</strong>&lt;br&gt;Phys Rev Lett. 115.031801</td>
<td><strong>eμ, eτ, μτ</strong> <strong>RPV, QBH,Z’</strong>&lt;br&gt;Eur. Phys. J. C76 (2016) 541</td>
<td>————</td>
</tr>
</tbody>
</table>
Selection Cuts and Background Estimation

**Analysis Strategy**

Single $\mu$ and single $\gamma$ triggers

$\mu$: $p_T > 53$ GeV, $|\eta| < 2.4$

$e$: $p_T > 35$ GeV, $|\eta| < 2.5$

No other selections to be model independent

Key variable: $e\mu$ invariant mass distribution

**Backgrounds**

- $t\bar{t}b$ar
- $WW$, $WZ$ and $ZZ$
- Jet background (QCD & $W$+jets)
- $DY$
- $W\gamma$

- Background with real leptons obtained from MC simulation
- Background with fake leptons using classic fake rate method
e\(\mu\) distribution in signal region

No excess over SM background predictions

Event yield

<table>
<thead>
<tr>
<th>Mass range (GeV)</th>
<th>(m_{\text{ej}} &lt; 500)</th>
<th>(500 &lt; m_{\text{ej}} &lt; 1000)</th>
<th>(1000 &lt; m_{\text{ej}} &lt; 1500)</th>
<th>(m_{\text{ej}} &gt; 1500)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet(\rightarrow\text{e misidentification})</td>
<td>3601</td>
<td>82.8</td>
<td>2.92</td>
<td>0.849</td>
</tr>
<tr>
<td>(W\gamma)</td>
<td>2462</td>
<td>56.2</td>
<td>2.76</td>
<td>0.562</td>
</tr>
<tr>
<td>Drell-Yan</td>
<td>2638</td>
<td>5.31</td>
<td>0.343</td>
<td>0.0145</td>
</tr>
<tr>
<td>Single (t)</td>
<td>9930</td>
<td>141</td>
<td>2.81</td>
<td>0.178</td>
</tr>
<tr>
<td>WW, WZ, ZZ</td>
<td>11126</td>
<td>239</td>
<td>13.0</td>
<td>2.03</td>
</tr>
<tr>
<td>(t\bar{t})</td>
<td>96754</td>
<td>971</td>
<td>18.5</td>
<td>1.01</td>
</tr>
<tr>
<td>Total background</td>
<td>126513</td>
<td>1495</td>
<td>40.3</td>
<td>4.64</td>
</tr>
<tr>
<td>Systematic uncertainty</td>
<td>23495</td>
<td>420</td>
<td>13.5</td>
<td>1.28</td>
</tr>
<tr>
<td>Data</td>
<td>123150</td>
<td>1426</td>
<td>41</td>
<td>4</td>
</tr>
</tbody>
</table>
Interpretation 1: Z’ model

- SSM-like Z’
- LFV decay to eμ allowed
- $\kappa_{12} = 1$, all other $\kappa_{ij} = 0$
- No Interference between SM Z and Z’
- $\text{BR}(Z’ \rightarrow e\mu) = 10\%$
- Relative width about 3%
Interpretation 2: RPV SUSY

- RPV SUSY scenario with tau-sneutrino is LSP
- $\lambda'_{311}$ (production) and $\lambda_{132}$ and $\lambda_{231}$ (decay)
- Other couplings set to zero

For $\lambda = \lambda' = 0.1$, limit is $1.7$ TeV
For $\lambda = \lambda' = 0.01$, limit is $3.8$ TeV
RPV SUSY parameter scan

\[
\sigma \cdot \text{BR}(\tilde{\nu}_\tau \rightarrow e\mu) = k(M_{\tilde{\nu}_\tau}) \cdot \frac{2(\lambda_{311}')(\lambda_{132})^2}{3(\lambda_{311}')^2 + 2(\lambda_{132})^2}
\]

\[
\lambda_{311}' \ll \lambda_{132}: \sigma \cdot \text{BR} \text{ independent of } \lambda_{132}
\]

Limit contour in \(M(\text{stau, } \lambda'_{311})\) parameter space for fixed values of \(\lambda_{132} = 0.07, 0.05, 0.01, 0.007\)
Extra spatial dimension(s) $\Rightarrow$ Fundamental Planck scale lowered to TeV region

- QBH can be produced if $\sqrt{s} > M_P$
- Spin-0, colorless, charge-neutral
- Cross section depends on threshold mass for QBH production ($M_{th} = M_P$) and number of extra dimensions ($n$)
  - $n=1$ : Randall-Sundrum (RS) model
  - $n=4, 5, 6$ : Arkani-Hamed-Dimopoulos-Dvali (ADD) model

Exclusion limits: 3.6, 5.3, 5.5, and 5.6 TeV for $n = 1, 4, 5$ and 6
Search for $L_\mu - L_\tau$ gauge boson (Z') using $Z \rightarrow 4\mu$ events

CMS PAS EXO-18-008

13 TeV, 77.3 fb$^{-1}$
(2016+ 2017 data)
Z→ 4 leptons

- Z’ predicted by extension of SM with additional U(1)’ symmetry (mass 5 - 70 GeV)
  - Model with (L_μ - L_τ) gauge symmetry
    - Anomaly free
    - Least constrained experimentally
    - Provides explanation to several anomalous experimental measurements
      - Muon magnetic moment by muon g-2 exp.
      - B→ K*±± decays etc

- Z’ produced as Final State Radiation product of a lepton from some process (i.e. Z boson)
- Z boson provides an extremely clean source, with Z’→ μμ process, in total four muons in final state
  - Excellent mass resolution
  - Higher reconstruction efficiency
  - Almost background free

Dominant background: q\bar{q}/gg → Z → 4μ
Analysis Strategy

- Four muons with $p_T > 5$ GeV with at least one muon having $p_T > 20$ GeV, at least 2 muons having $p_T > 10$ GeV
- Reconstruct Z candidates with $4 < m_{\mu^+\mu^-} < 120$ GeV
- For each ZZ ($Z_1Z_2$) candidate, $Z_1$ is selected having mass close to $m(Z)$
  $12$ GeV $< m(Z_1) < 120$ GeV
- $80$ GeV $< m(4\mu) < 100$ GeV

Key variables
$m(Z_2)$ for $Z'$ with mass 5-40 GeV
$m(Z_1)$ for $Z'$ with higher masses

Search window
$m(Z') + 2\% m(Z')$

No excess over SM predictions

Obs: 441
BG: 423 ± 39.2
Exclusion limits on production cross-section & BR

Exclusion limits on $Z'$ Leptophilic coupling

Assumption: $Br(Z' \rightarrow \mu\mu) = 0.33$

- Covers significant portion of parameter space
- Excludes $Z'$ coupling strength to muons above $0.004 - 0.3$ depending on $m(Z')$

First dedicated search @ LHC
Strong portfolio of LFV searches in CMS
Presented LFV decays of heavy mass resonances in this talk
BONUS: First LHC dedicated analysis “Search for L_μ - L_τ gauge boson (Z') using Z→4_μ events” using full 2016+2017 CMS data is presented
No excess over SM background prediction yet :( Expect more interesting updates with more data

So stay calm & keep looking....
Backup