SEARCH FOR HEAVY NEUTRINOS AT CMS

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University of Maryland
SUSY09, Boston, June 2009
THEORY / MODELS

D0 Run I Results
(PhysRevLett, Vol 76, Num 18)

- Left-Right Symmetric Model
- SU(2)_R with Z’ and W_R decaying to right handed, heavy neutrino (N).
- Mass of heavy neutrino related to light neutrino through see-saw mechanism
- Free model parameters: M(N), M(W_R), M(Z’)
- Limits from previous experiments:
  \( M(W_R) > \sim 700 \text{ GeV} \),
  \( M(N) > \sim 300 \text{ GeV} \)

FIG. 3. 95% CL excluded \( W_R \) mass region from the peak search. The lines represent the contours for different values of the LRM parameters. The diagonal line is the kinematic limit for the \( W_R \to eN_R \) decay.
REATIONS

- $pp \rightarrow Z' \rightarrow N + N$
  \[ \rightarrow \ell + q + q / \ell + \nu \]

- $pp \rightarrow W_R \rightarrow \ell + N$
  \[ \rightarrow \ell + \ell + \nu \]

- $pp \rightarrow W_R \rightarrow \ell + N$
  \[ \rightarrow \ell + q + q \]

- If $N$ is Majorana, equal prob. to have $\ell^+\ell^-$ as $\ell^+\ell^-/\ell^-\ell^-$ in final state (not used)

- Assume leptons have same flavor - no oscillation of $N$

- Assume no strong mixing, and coupling same in right and left sector

- This analysis assumes 100 pb$^{-1}$, 14TeV center of mass energy, $(M(W_R), M(N_\ell))$(GeV) = (2000,500), (1500,600), (1200,500), among others

- Analysis Summary: EXO-08-006
  S.N. Gninenko, M.M. Kirsanov, N.V. Krasnikov, A.N. Toropin
Two high energy leptons and two high energy jets (assuming $W$ decays to quarks)

Few irreducible standard model backgrounds:

$tt\bar{t}$, $Z + jets$, diboson
TRIGGERS

**Electron Channel:**
- 80 and 120 GeV EM trigger (Full Lum. trigger menu)
- 99% signal efficiency
- Loose isolation requirement, designed to be particularly effective for high energy electrons

**Muon Channel:**
- Low $p_T$ isolated muon trigger (Full Lum. trigger menu)
- 93% signal efficiency
- Trigger candidate $p_T$ cut at 80 GeV (nearly no effect on efficiency)
SELECTION CRITERIA

Event Selection

- **Exactly 2 leptons**
- **At least 1 lepton \( p_T > 80 \ \text{GeV} \), the other \( p_T > 20 \ \text{GeV} \)
- **Isolation of leptons in cone of radius 0.3**
- **At least 2 jets, \( p_T > 40 \ \text{GeV} \)**
- **Select 2 leading jets in \( p_T \). (Correct jets at least 90% of time)**

\[ M(W_R) \text{ reconstructed from 2 leptons and 2 jets,} \]
\[ M(N) \text{ reconstructed from lowest } p_T \]
\[ \text{lepton + 2 jets} \]

Wrong lepton for \( M(N) \) chosen up to 10% of the time, depending on mass hypothesis for \( N, W_R \).
Signal reconstruction

Signal mass distributions for electrons, muons.

Reconstructed mass for $W_R$ and N in muon channel.

Probability of event passing primary selection criteria:

$(M(W_R)=2\text{TeV}, N_e\rightarrow\text{eejj})$
- Dominant background: $t\bar{t}$
- Secondary: $Z + Jets$
- Small contributions from Diboson, $W+Jets$, Multi-Jet
- Cut on dilepton invariant mass to reduce $Z+Jets$ background

$M(N)=500 \text{ GeV}$,
$M(W)=2 \text{ TeV}$
## BACKGROUND CONTRIBUTIONS

<table>
<thead>
<tr>
<th>Step</th>
<th>Signal LRRP1</th>
<th>$t\bar{t}$</th>
<th>Z jets</th>
<th>W jets</th>
<th>$\gamma$ jets</th>
<th>QCD</th>
<th>WW jets</th>
<th>WZ jets</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial, $p_T &gt; 20$</td>
<td>49</td>
<td>83600</td>
<td>577 700</td>
<td>$5.8 \cdot 10^6$</td>
<td>$1.8 \cdot 10^7$</td>
<td>$10^{11}$</td>
<td>12800</td>
<td>5200</td>
<td>$10^{10}$</td>
</tr>
<tr>
<td>Primary selection</td>
<td>24.5</td>
<td>315</td>
<td>519</td>
<td>14.2</td>
<td>1.43</td>
<td>27</td>
<td>21.6</td>
<td>37.6</td>
<td>23.3</td>
</tr>
<tr>
<td>Two isolated $e^\pm$</td>
<td>23.7</td>
<td>136</td>
<td>504</td>
<td>8.7</td>
<td>1.31</td>
<td>24</td>
<td>8.16</td>
<td>31.2</td>
<td>20.7</td>
</tr>
<tr>
<td>$M_{ll}$ cut</td>
<td>22.6</td>
<td>34</td>
<td>11</td>
<td>3.3</td>
<td>0.73</td>
<td>0.23</td>
<td>3.2</td>
<td>0.56</td>
<td>1.4</td>
</tr>
<tr>
<td>$M_{WR}^{can} &gt; 600$ GeV</td>
<td>23</td>
<td>19</td>
<td>7.2</td>
<td>2.1</td>
<td>0.68</td>
<td>0.23</td>
<td>2.27</td>
<td>0.56</td>
<td>1.25</td>
</tr>
<tr>
<td>Under 2D peak</td>
<td>14</td>
<td>0.44</td>
<td>0.15</td>
<td>0.031</td>
<td>0</td>
<td>0</td>
<td>0.084</td>
<td>0</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Number of events remaining after selection (electron channel), scaled to integrated luminosity of 100 pb$^{-1}$
MASS “BUMP”, $M(W)=1500\,\text{GeV}$, $M(N)=600\,\text{GeV}$

Electron channel  
Muon channel

Number of events scaled to $100\,\text{pb}^{-1}$

Kirsanov, PANIC08
SIGNAL EXTRACTION

- 2-D fit with 2 free parameters: \( N_{\text{sig}}, N_{\text{bkgnd}} \)
- Assume width of \( W, N \) small compared to experimental resolution

\[
P(M_{W\text{cand}}, M_{N\text{cand}}) = N_{\text{sig}} \times BW(M_W, \Gamma_W, M_{W\text{cand}}) \times BW(M_N, \Gamma_N, M_{N\text{cand}}) + N_{\text{bkgnd}} \times P.Bkgnd(M_{W\text{cand}}, M_{N\text{cand}})
\]

\( BW = \) Breit-Wigner function,
\( P.Bkgnd = \) Probability of a background event (MC)
BACKGROUND ESTIMATES FROM DATA

- $t\bar{t}$:
  - Can study shape/size of $e\mu$ sample, deduce shape/size of $ee$ sample since kinematics identical
  - Compare with MC ($\sim$40 events) to calculate corrections

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<tr>
<td>Primary selection</td>
<td>604</td>
<td>1255</td>
<td>25</td>
<td>0.05</td>
<td>99</td>
<td>43.</td>
<td>84</td>
<td>266</td>
</tr>
<tr>
<td>$e - \mu$ pair</td>
<td>291</td>
<td>9.5</td>
<td>14</td>
<td>0.05</td>
<td>78</td>
<td>22.1</td>
<td>5.2</td>
<td>21</td>
</tr>
<tr>
<td>$M_{ll}$ cut</td>
<td>73</td>
<td>0.47</td>
<td>6</td>
<td>0</td>
<td>14</td>
<td>7.3</td>
<td>1.7</td>
<td>2.6</td>
</tr>
<tr>
<td>$M_{cand}^{WR} &gt; 600$ GeV</td>
<td>39</td>
<td>0.26</td>
<td>4</td>
<td>0</td>
<td>1.48</td>
<td>5.5</td>
<td>1.3</td>
<td>1.6</td>
</tr>
</tbody>
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- $Z + Jets$:
  - Relax $M_{ll}$ cut to 80 GeV (warning: shape of $M(W_R)$ could be different in this sample)
PDF Uncertainty:
largest deviation is 6%

Jet Energy Scale:
10% uncertainty leads to 5-10% change in mass measurement, increase in signal width by 2-3%

Luminosity:
Assume 10% uncertainty

Total: 15%
- Claim discovery if significance $\geq 5$

$$S = \sqrt{2 \ln \left( \frac{L_{s+b}}{L_{b}} \right)}$$

- Integrated Luminosity = 100 pb$^{-1}$

- Discover Neutrinos with masses up to $\sim 1$ TeV (with $M(W_R) < 2.2$ TeV)
EXCLUSION POTENTIAL

Virtual N

\[ M_{N_i} > M_{W_R} \]

Kirsanov,
PANIC08

Saturday, June 6, 2009
SUMMARY

- Discovery of heavy neutrino (N) up to a mass of ~1 TeV with $W_R$ up to a mass of ~2.2 TeV possible with 100pb-1
- Limit possible in similar mass ranges with 100pb-1
- If discovered, can determine if minimal LR symmetric model (Majorana, 50% same sign leptons) or something more complicated
- Signature not unique to this model - provides general search for many new particles beyond the SM
REFERENCES / ACKNOWLEDGMENTS

- M. Kirsanov, INR Moscow, PANIC08, "Detection of $W_R$ Bosons and Heavy Majorana Neutrinos in CMS"

- "Detection of heavy neutrinos and right-handed bosons of the left-right symmetric model", The CMS Collaboration, 2/2009


- "Search for Right-Handed $W$ Bosons and Heavy $W^0$ in pp Collisions at $\sqrt{s}= 1.8$ TeV", D-Zero collaboration, Phys Rev Letters, Volume 76, Number 18
BACKUP SLIDES
LIKE SIGN LEPTONS

Electron Channel

- Background smaller, but signal decreases by factor of 2 (Majorana).
- Good as cross check if signal is seen
- Absolute data correction from Z events
PSEUDO EXPERIMENTS

- 1000 pseudo-experiments
  - Generate unity-weighted events of signal and background with probability determined from weighted MC events

- Verified behavior of significance using statistical tools
  - Generated pseudo-experiments with $M(W)=2\text{TeV}$, $M(N)=1.2\text{ TeV}$,
  - Calculated probability of background to imitate signal (which had been estimated as $3\sigma$)
  - Found 6 out of 1000 pseudo-experiments had background fluctuate to fake signal -> consistent.
Construct control sample of $e\mu$ same sign events

- This largely dominated by fake leptons
- This should be ~5 times smaller than sample with no charge requirement. If much different introduce weight and tighten lepton selection.
- Warning - wrong charge measurement estimated at ~ 1.5% for electrons and ~ 0.01% for muons

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<td>0.6</td>
<td>0.77</td>
<td>0.64</td>
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</table>
Fit method highly sensitive to signal efficiency. Estimate signal efficiency from data:

**Leptons**

- Use “Tag and Probe” method to determine lepton effic. from Z sample
  - Lepton pairs in Z peak, one lepton well identified (“tag”), the other loose or no cuts (“probe”) provides efficiency measure.

**Jets**

- Study ttbar events in eμ and semi-leptonic channels to measure jet efficiency
LIMIT CALCULATIONS

- Calculated the representative likelihood ratio (RLR) as a median value of $S$ for background only pseudo-experiments.

- Found $N_{\text{signal}}$ that produces distribution with $5\%$ having $S$ below RLR.

- If $N_{\text{signal}}$ found is $< N$ predicted by cross section, assume $95\%$ confident that this mass pair excluded.

- Gaussian smearing of $\sim 10\%$ applied to pseudo-experiments.