Colliders Signatures of LNV Higgs Sectors

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in collaboration with F. del Águila, A. Santamaria

and J. Wudka. Based on 1311.1510 and 1305.3904.

BLV2015, UmassAmherst, April 29, 2015
The Standard Model is very strong

Planck scale

valid up to

Renormalizable
Stable vacuum
Degrassi et al., 1205.6497

...
About Lepton Number Violation

Accidental symmetry broken by neutrino Majorana mass terms

\[ \sim m_\nu \bar{\nu}_L \nu_L^c \]

- \[ \mu^- (A, Z) \rightarrow \mu^+ (A, Z - 2) \]
- \[ K^+ \rightarrow \mu^+ \mu^+ \pi^- \]
- \[ 0\nu\beta\beta \] decay
The natural scale of LNV scalars

Planck scale valid up to TeV scale

$O^{(5)} = \frac{1}{\Lambda} (\overline{L_L^c} \tilde{\phi}^*) (\tilde{\phi}^\dagger L_L)$

Natural assumption

$\Lambda \gg \text{TeV}$
The natural scale of LNV scalars

Planck scale

valid up to

TeV scale

Natural assumption

$\mathcal{O}^{(5)} = \frac{1}{\Lambda} (\bar{L}_L \phi^* \phi^i L_L)$

del Águila et al, 1204.5986, 1111.6960

Gustafsson et al, 1212.4806

BLV2015, UmassAmherst, April 29, 2015
Outline

A generic approach to LNV scalars

Observing LNV scalar interactions at the LHC?

Distinguishing LNV scalars at the LHC RUN2
\begin{itemize}
  \item LNV extensions of the SM can accommodate \textit{neutrino} Majorana masses
  \item Only three scalar fields at the renormalizable level
\end{itemize}

$$\Delta = (\Delta^{++}, \Delta^+, \Delta^0)^T$$

$$\kappa^{++}, \pi^+$$
• LNV extensions of the SM can accommodate neutrino Majorana masses

• Only three scalar fields at the renormalizable level

Different doubly-charged scalar

at a lower scale can mix with $\Delta$, $\kappa$

$$\chi = \begin{pmatrix} \chi^{++} \\ \chi^+ \end{pmatrix}, \quad \Sigma = \begin{pmatrix} \Sigma^{++} \\ \Sigma^+ \\ \Sigma^0 \\ \Sigma^- \end{pmatrix}, \quad \Omega = \begin{pmatrix} \Omega^{++} \\ \Omega^+ \\ \Omega^0 \\ \Omega^- \\ \Omega^{--} \end{pmatrix}$$

$\Lambda$ scale

$$\Delta = (\Delta^{++}, \Delta^+, \Delta^0)^T$$

$\kappa^{++}, \pi^+$
After integrating out $\Lambda$ scale, higher multiplets $\chi, \Sigma, \Omega$ couple to same-sign leptons via Yukawa-like interactions.
<table>
<thead>
<tr>
<th>Representation</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triplet $\Delta$</td>
<td>$(\tilde{L}_L \tau^a L_L) \Delta^{-a}$</td>
</tr>
<tr>
<td>Singlet $\kappa$</td>
<td>$\tilde{l}_R^c l_R \kappa$</td>
</tr>
<tr>
<td>Quadruplet $\Sigma$</td>
<td>$(-1)^{\frac{1}{2} - b} C_{a,b}^{1 \times \frac{1}{2}} \rightarrow \frac{3}{2} (\tilde{L}_L \tau^a L_L) \phi^b \Sigma^{-a-b}$</td>
</tr>
<tr>
<td>Doublet $\chi$</td>
<td>$(-1)^{1-a} (\tilde{L}_L \tau^a L_L) (\phi^\dagger \tau^{-a} \chi), \tilde{l}_R^c l_R (\tilde{\phi}^\dagger \chi)$</td>
</tr>
<tr>
<td>Quintuplet $\Omega$</td>
<td>$C_{a,b}^{1 \times 1} \rightarrow 2 (\tilde{L}_L \tau^a L_L) (\tilde{\phi}^\dagger \tau^b \phi) \Omega^{-a-b}$</td>
</tr>
</tbody>
</table>

Either

$H^{++} \tilde{l}_R^c l_R$

or

$H^{++} \tilde{l}_L^c l_L$

What about

$D_\mu H (\overline{L}_L^c \gamma^\mu l_R)$

+ others?

Equivalent by the eq. motion and integration
After integrating out $\Lambda$ scale, higher multiplets $\chi, \Sigma, \Omega$ couple to same-sign leptons via Yukawa-like interactions.

$$\begin{align*}
H^- & \rightarrow l_i^- \\
& \rightarrow l_j^- \\
& 2i \left[ \alpha_{ij}^{L*} P_L + \alpha_{ij}^{R*} P_R \right] \\
H^- & \rightarrow l_i^- \\
& \rightarrow \nu_j \\
& 2i \beta_{ij}^{*} P_L
\end{align*}$$

$\alpha$ and $\beta$ suppressed by powers of $1/\Lambda$. 
What is the phenomenology of these scalars?

VS

What current analyses assume (see-saw II)?
Observing LNV interactions in simplest models can be really hard
Using current CMS three- and four-lepton analyses, set bounds on LNV processes mediated by doubly-charged scalars.
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<table>
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Can we discriminate among the different multiplets?

- LNV can be very difficult to be established at the LHC
- But doubly-charged scalars can be still present
- Discrimination is possible if two-body decays dominate

Measure the neutral cross section using four-lepton events

arXiv:1305.3904
\[
\sigma = \left( \sigma_{\ell\ell\ell\ell} + \frac{1}{2} \sum_{a \neq \ell\ell} \sigma_{\ell\ell a} \right)^2 / \sigma_{\ell\ell\ell\ell}
\]
Distinguishing the different four-lepton channels
Distinguishing the different four-lepton channels
Distinguishing the different four-lepton channels
Distinguishing the different four-lepton channels
How well can we discriminate among the different multiplets?

- Only light leptons
- Light leptons and taus
- Light leptons and Ws
- Light leptons, taus and Ws

Águila, MC, Santamaría, Wudka, '13
Singlet case

Doublet case

It is a background of

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Charged signals VS neutral current backgrounds

BLV2015, UmassAmherst, April 29, 2015
The SM describes nature to a very good accuracy, although there are still open questions: **neutrino masses**

**LNV** scalar interactions can be very difficult to be proved at the LHC

For the first time, **bounds on LNV** scalar interactions, and many other channels

Even if no LNV, doubly-charged scalars can be distinguished in a large run of LHC

Thank you!