Heavy ISS Neutrinos @LHC

Xabier Marcano
in collaboration with E. Arganda, M.J. Herrero and C. Weiland
Instituto de Física Teórica, Universidad Autónoma de Madrid/CSIC
`xabier.marcano@uam.es`

June, 23rd 2015

Motivation

Low scale seesaw models

- Accommodate light neutrino data
- Allow large neutrino Yukawa couplings, $Y_\nu^2/4\pi \sim \mathcal{O}(1)$
- with heavy neutrino masses at $M_N \sim \mathcal{O}(1\text{ TeV})$

New phenomenology

- Lepton Flavor Violation (LFV): radiative decays, H decays, ...
- Heavy neutrinos reachable at LHC

Usual Heavy neutrino searches at colliders

- Majorana neutrinos: same-sign lepton signals
- Dirac neutrinos: tri-lepton signals

The Inverse Seesaw Model

SM extended with 6 fermionic singlets: $3 \times \left\{ \nu_R(L=+1) \& X(L=-1) \right\}$

$$\mathcal{L}_{ISS} = -Y_\nu^{ij} \overline{L_i} \tilde{H} \nu_{R_j} - M_R^{ij} \overline{\nu_{R_i}^C} X_j - \frac{1}{2} \mu_X^{ij} \overline{X_i^C} X_j + h.c.$$

$$M^\nu = \begin{pmatrix} 0 & m_D & 0 \\ m_D^T & 0 & M_R \\ 0 & M_R^T & \mu_X \end{pmatrix}$$

$$\begin{aligned} m_\nu &= \frac{m_D^2}{m_D^2 + M_R^2} \mu_X \\ M_{N_1,N_2} &= \pm\sqrt{M_R^2 + m_D^2} + \mathcal{O}(\mu_X) \end{aligned}$$

New particle content

6 heavy Majorana neutrinos, quasi degenerate in (pseudo-Dirac) pairs

$$N_{1/2}, N_{3/4}, N_{5/6}$$

whose masses,driven by M_R, can be in the TeV range for $Y_\nu^2/4\pi \sim \mathcal{O}(1)$

LFV in the ISS

E. Arganda, M.J. Herrero, XM, C. Weiland, PRD91(2015)1,05001

Full 1-loop computation of $H \to \mu\tau$ rates, but the result can be understood using some approximate expressions

Approximate formulas in the large Y_ν limit

$$
\begin{aligned}
\mathrm{BR}(l_m \to l_k \gamma) &\approx 4 \times 10^{-17} \, \frac{m_{l_m}^5 \ (\mathrm{GeV}^5)}{\Gamma_{l_m} \ (\mathrm{GeV})} \, \frac{v^4}{M_R^4} \left| (Y_\nu Y_\nu^\dagger)_{km} \right|^2 \\
\mathrm{BR}(H \to \mu\bar{\tau}) &\approx 10^{-7} \, \frac{v^4}{M_R^4} \left| (Y_\nu Y_\nu^\dagger)_{23} - 5.7 \, (Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger)_{23} \right|^2
\end{aligned}
$$

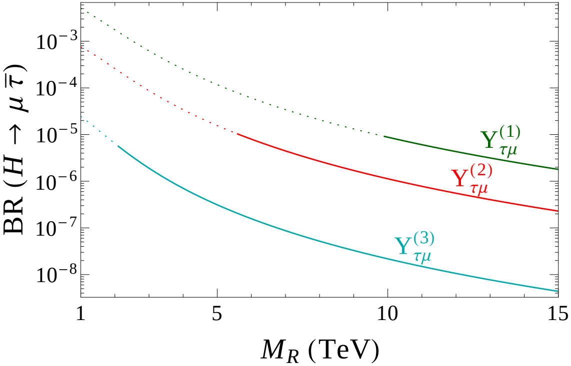
They behave differently. Large rates, $\mathrm{BR}(H \to \mu\bar{\tau}) \sim 10^{-4}$, but they are bounded by the upper limits on radiative decays, especially by $\mu \to e\gamma$

$$
\begin{aligned}
\mathrm{BR}(\mu \to e\gamma) &\leq 5.7 \times 10^{-13} \\
\mathrm{BR}(\tau \to e\gamma) &\leq 3.3 \times 10^{-8} \\
\mathrm{BR}(\tau \to \mu\gamma) &\leq 4.4 \times 10^{-8}
\end{aligned}
$$

Maximum allowed LFV in the ISS

Scenarios in the ISS allowing for maximun LFVHD rates and being compatible with the LFV radiative decays

$$\mathrm{BR}(H \to \mu\bar{\tau})^{\mathrm{ISS}}_{\mathrm{max}} \sim 10^{-5}$$



Examples suppressing μe mixing

$$Y^{(1)}_{\tau\mu} = f\begin{pmatrix} 0 & 1 & -1 \\ 0.9 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}$$

$$Y^{(2)}_{\tau\mu} = f\begin{pmatrix} 0 & 1 & 1 \\ 1 & 1 & -1 \\ -1 & 1 & -1 \end{pmatrix}$$

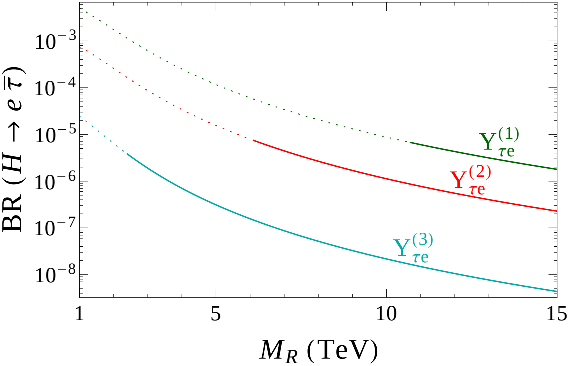
$$Y^{(3)}_{\tau\mu} = f\begin{pmatrix} 0 & -1 & 1 \\ -1 & 1 & 1 \\ 0.8 & 0.5 & 0.5 \end{pmatrix}$$

Solid lines: allowed by all radiative decays

Maximum allowed LFV in the ISS

Scenarios in the ISS allowing for maximun LFVHD rates and being compatible with the LFV radiative decays

$$\mathrm{BR}(H \to e\overline{\tau})^{\mathrm{ISS}}_{\mathrm{max}} \sim 10^{-5}$$



Examples suppressing μe mixing

$$Y^{(1)}_{\tau e} = f \begin{pmatrix} 0.9 & 1 & 1 \\ 0 & 1 & -1 \\ 1 & 1 & 1 \end{pmatrix}$$

$$Y^{(2)}_{\tau e} = f \begin{pmatrix} 1 & 1 & -1 \\ 0 & 1 & 1 \\ -1 & 1 & -1 \end{pmatrix}$$

$$Y^{(3)}_{\tau e} = f \begin{pmatrix} -1 & 1 & 1 \\ 0 & -1 & 1 \\ 0.8 & 0.5 & 0.5 \end{pmatrix}$$

Solid lines: allowed by all radiative decays

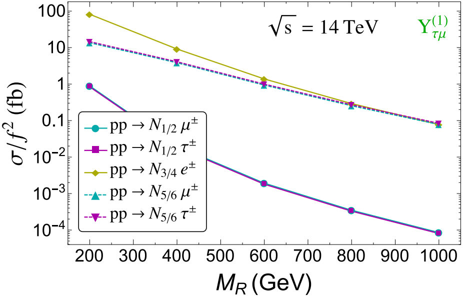
Heavy neutrino production and decay at LHC

Large production $\sigma \sim \mathcal{O}(fb)$,
reachable @LHC for $M_R \leq 500\text{GeV}$

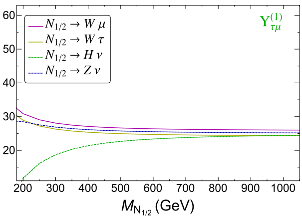
Distinct rates for diff flavors
For $Y^{(1)}_{\tau\mu}$, max. couplings between:

$$\begin{array}{ccc} N_{1/2} & \longleftrightarrow & \mu, \tau \\ N_{3/4} & \longleftrightarrow & e \\ N_{5/6} & \longleftrightarrow & \mu, \tau \end{array}$$

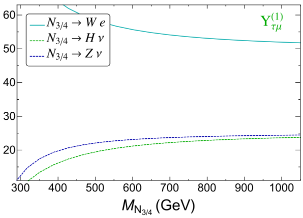
We focus on the $N_j \to W l_i$ decay



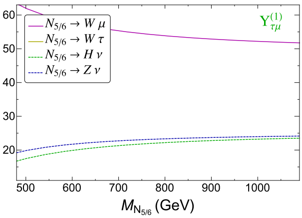
BR$_{N_{1/2}}$ (%)



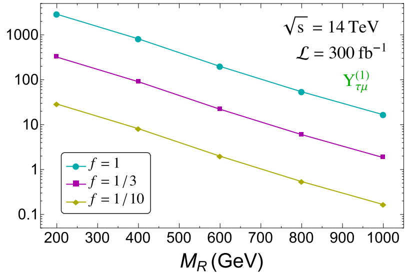
BR$_{N_{3/4}}$ (%)

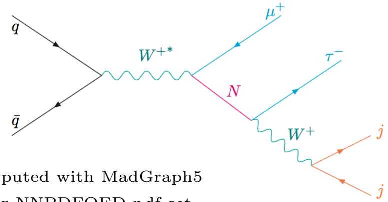


BR$_{N_{5/6}}$ (%)



Exotic events at LHC: $p\,p \to l^- l'^+ jj,\ l \neq l'$


Total exotic events pp → $\mu\tau$jj @LHC



Computed with MadGraph5
Using NNPDFQED pdf set
Degenerate M_{R_i} entries

Conclusions

We predict detectable number of singular events with no $\not{E}_T$, two different lepton flavors and two jets with $M_{jj} \sim M_W$, naively background free

Work in progress:

- Explore other singular signals: $pp \to e^\pm \tau^\mp jj$ or $pp \to e^\pm \mu^\mp jj$
- Estimate realistic signal/background ratio
- Add γW fusion, rates approximately 2 times larger