Heavy ISS Neutrinos @LHC

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Motivation

Neutrino oscillations and masses => New Physics, Majorana neutrinos?

Low scale seesaws:
- Accommodate light neutrino data
- Allow large Yukawa couplings $Y_\nu \sim \mathcal{O}(1)$
- with heavy Neutrino masses at $M_N \sim \mathcal{O}(1\text{TeV})$

New Phenomenology:
- LFV: radiative decays, H decays, ...
- Heavy neutrinos reachable at the LHC

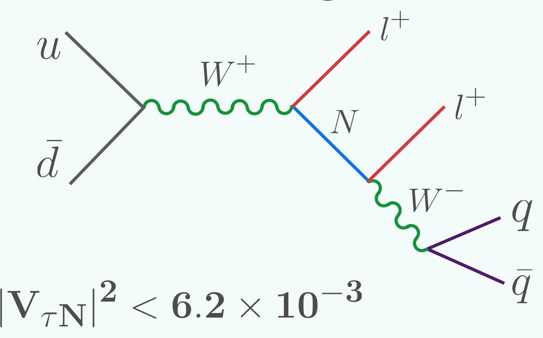
CMS excess for $H \to \tau\mu$: possible indication of LFV

Usual Heavy N Search†

Main N production at LHC: Drell-Yan. Also γW fusion

Smoking gun signature for Majorana neutrinos: same-sign leptons

Lepton Number Violation



Bounds from EW precision data:

$|V_{eN}|^2 < 3\times10^{-3}$, $|V_{\mu N}|^2 < 3.2\times10^{-3}$, $|V_{\tau N}|^2 < 6.2\times10^{-3}$

Also searches of tri-lepton signals, mainly for Dirac neutrinos

Our New Proposal*

We study the production and decay of heavy M_N in the TeV range at LHC and explore the connections with LFV

We look for singular/exotic signatures of heavy neutrinos with leptons of different flavors in the final state

Inverse Seesaw model (ISS)

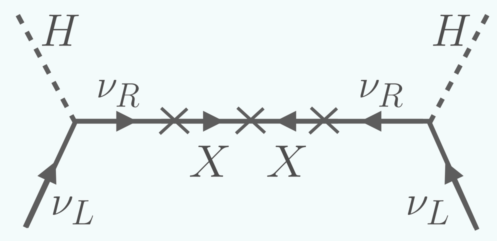
Extend the SM with fermionic singlets: $\nu_{R_i}(L=+1)$ & $X_i(L=-1), i=1\dots3$

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

Light neutrino masses related to small LNV parameter $\mu_X \ll M_R, m_D$

In contrast to type-I seesaw, we can have $M_R \sim \mathcal{O}(1\text{TeV})$ and still $Y_\nu \sim \mathcal{O}(1)$

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



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

$$N_{1/2}, N_{3/4}, N_{5/6} \quad \text{with} \quad \mathrm{M_{N_i}} \sim \mathcal{O}(\mathrm{M_R}) \sim \text{TeV range}$$

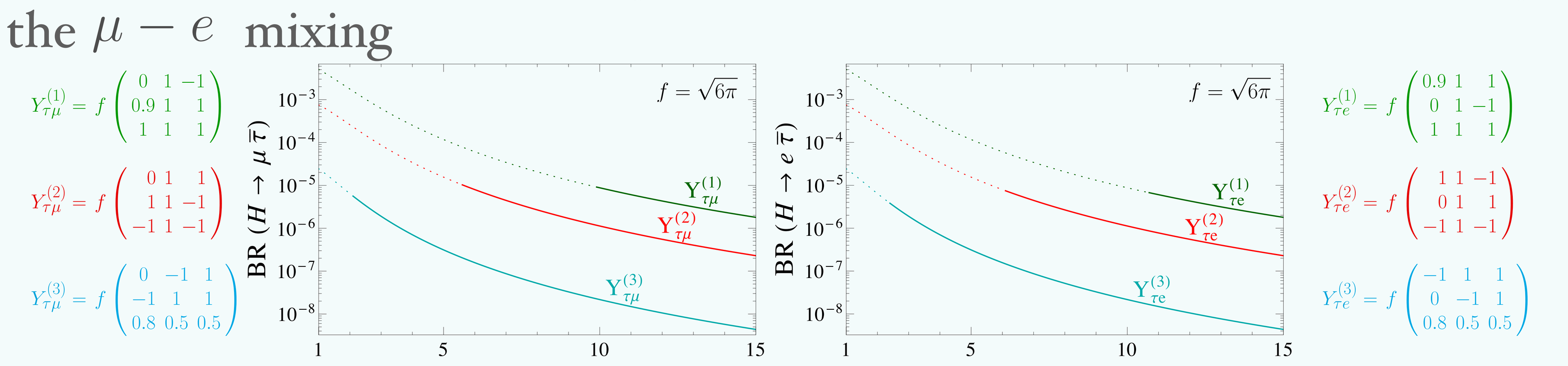
Accommodate ν data by adjusting the parameters of the ISS

Input: M_R & $\mu_X \implies vY_\nu^T = V^\dagger\sqrt{M_N^{\text{diag}}}R\sqrt{m_\nu^{\text{diag}}}U_{\text{PMNS}}^\dagger$

Input: M_R & $Y_\nu \implies \mu_X = M_R^T m_D^{-1} U_{\text{PMNS}}^* m_\nu U_{\text{PMNS}}^\dagger m_D^{T-1} M_R$

Maximum allowed LFV

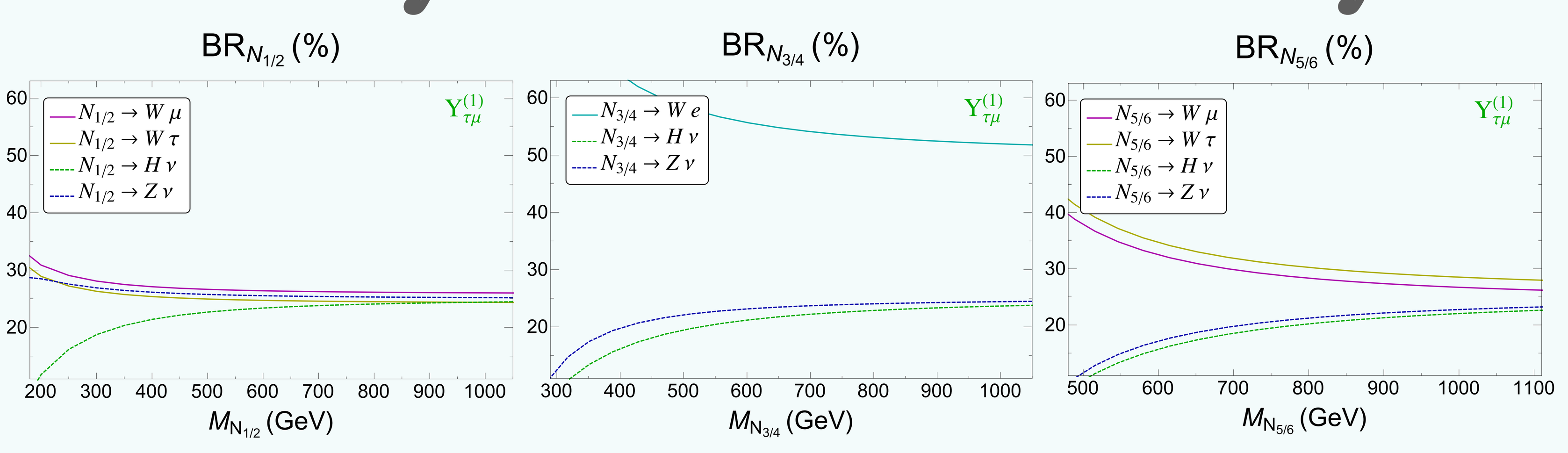
Examples of textures allowing for maximal LFV in ISS and suppressing the $\mu - e$ mixing



$Y_{\tau\mu}$: max $\tau\mu$ mixing $\qquad Y_{\tau e}$: max τe mixing

Solid lines: allowed by $\mu\to e\gamma, \tau\to e\gamma, \tau\to\mu\gamma$

Heavy Neutrino Decays



Which N_i maximally coupled to μ and/or τ :
$$\begin{cases} Y_{\tau\mu}^{(1)} : N_{1/2} \text{ and } N_{5/6} \text{ to } \mu, \tau \\ Y_{\tau\mu}^{(2)} : N_{3/4} \text{ and } N_{5/6} \text{ to } \mu, \tau \\ Y_{\tau\mu}^{(3)} : N_{1/2} \text{ to } \tau \text{ ; } N_{5/6} \text{ to } \mu \end{cases}$$

References

†Atre et al JHEP0905(2009)030, Alva et al. JHEP1502(2015)072, Das et at. PLB735(2014)364
Bhupal Dev et al. PRL112(2014)8,081801, Bambhaniya et al. PRD91(2015)9, 095007
*Arganda, Herrero, Marcano, Weiland, Phys.Rev. D91 (2015) 1, 015001 and work in progress

ISS and LFV

Large Yukawa couplings and heavy N at TeV range lead to interesting phenomenology, in particular Lepton Flavor Violation

Interesting CMS excess on $H \to \tau\mu$: LFV signal?

LFV radiative decays and Higgs decays behave different

$$\text{BR}(l_m \to l_k\gamma) \approx 4\times10^{-17}\frac{m_{l_m}^5\,(\text{GeV}^5)}{\Gamma_{l_m}\,(\text{GeV})}\frac{v^4}{M_R^4}\left|(Y_\nu Y_\nu^\dagger)_{km}\right|^2$$

$$\text{BR}(H\to\mu\bar{\tau}) \approx 10^{-7}\frac{v^4}{M_R^4}\left|(Y_\nu Y_\nu^\dagger)_{23} - 5.7\,(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger)_{23}\right|^2$$

Both can lead to sizable rates within ISS, but they are constrained by present data, mainly by $\mu \to e\gamma$

$\text{BR}(\mu\to e\gamma) \leq 5.7\times10^{-13}$

$\text{BR}(\tau\to e\gamma) \leq 3.3\times10^{-8}$

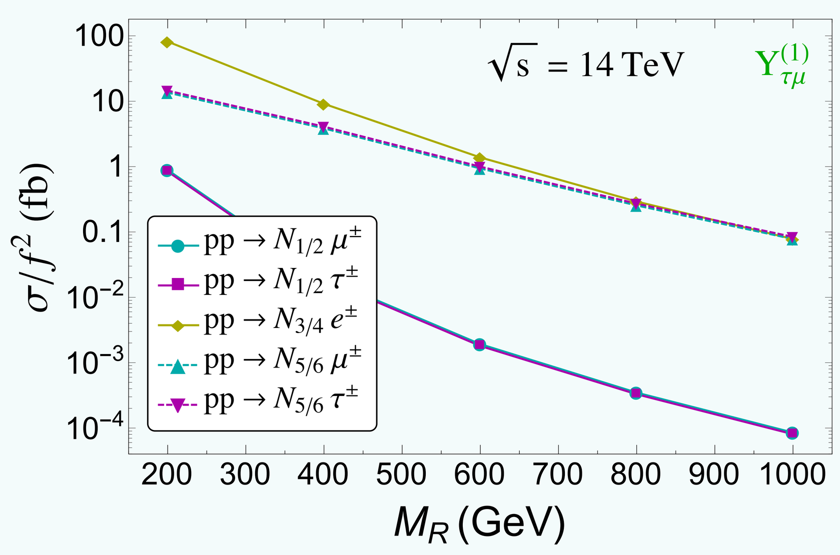
$\text{BR}(\tau\to \mu\gamma) \leq 4.4\times10^{-8}$

Bound $\dfrac{(Y_\nu Y_\nu^\dagger)_{km}}{M_R^2}$

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

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

Heavy N xsection at LHC



Generated with MadGraph5

NNPDF23QED set used

Similar results for CTEQ6L

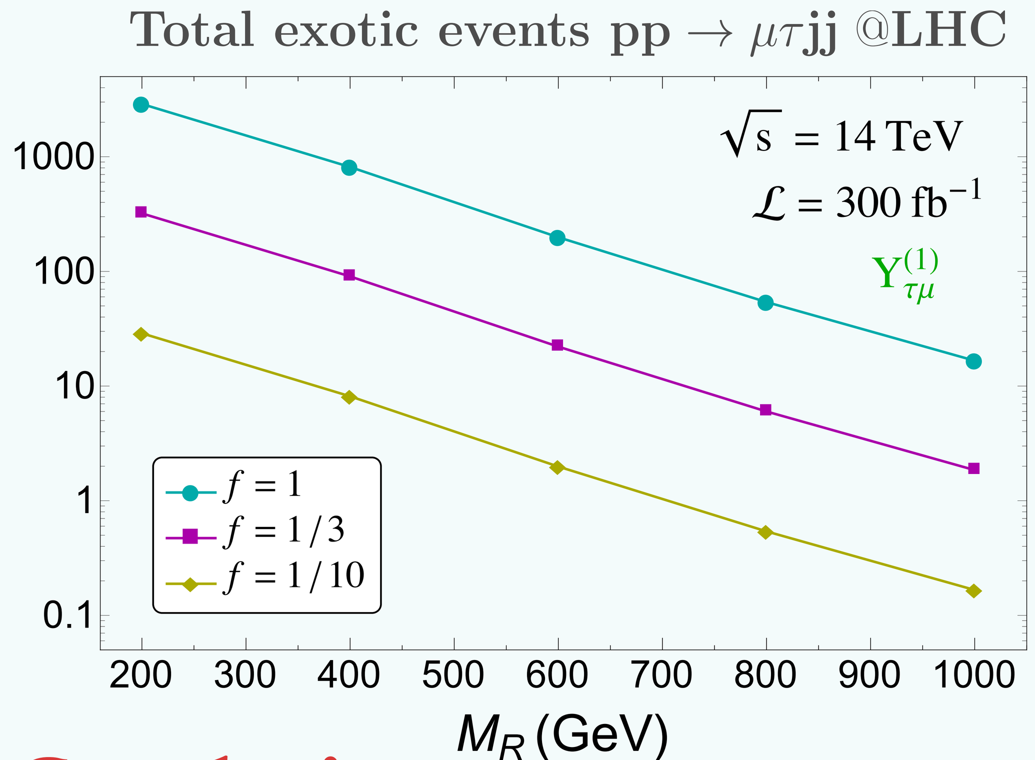
Suppressed channels not shown

Similar results for other $Y_{\tau\mu}$

Distinct rates for dif. flavors

Singular/exotic signals

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



Similar results for other $Y_{\tau\mu}$

Enhanced rates x 2 (approx) if γW fusion events added

Sizable rates for $f \sim \mathcal{O}(1)$

Conclusions:

We predict a detectable number of singular events with no $\not{E}_T$, two different lepton flavors ($\tau\mu$ in this plot) and two jets with $M_{jj} \sim M_W$, naively background free

Work in progress: Explore other singular signals: $\tau e jj$ and $\mu e jj$, estimate realistic signal/background and explore other ISS scenarios with non-degenerate M_{R_i}