Probing Radiative Neutrino Mass Models with Dilepton Events at the LHC

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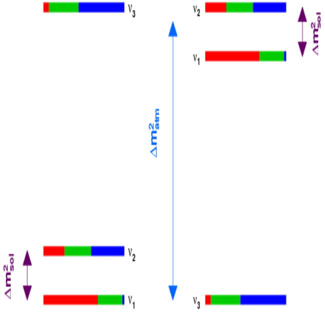
Introduction

- The Standard Model (SM) has been very successful in describing physics at $\mathcal{O}(100\,GeV)$
- The discovery of neutrino oscillation phenomenon $\Rightarrow$ Neutrinos should be massive.
- Necessary to go beyond the Standard Model for ν mass
  - Seesaw mechanism (Type I, Type II, Type III...)
  - Radiative models (1 loop [Zee, 1980, Ma, 2006], 2 loops [Zee, 1986, Babu, 1988], 3 loops [Aoki et al., 2009,KNT].



Three-Loop Model For Neutrino Masses

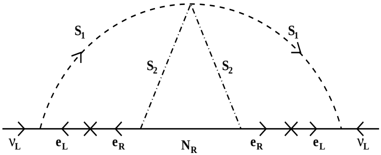
- Introduce a singly charged scalar ($S^{\pm}$), three generations of fermions $\mathcal{F}_i (i = 1 - 3)$ and one scalar multiplet, ϕ to Standard Model [**PRD90,015024**]

Lagrangian

$$\mathcal{L} = \mathcal{L}_{SM} + \{f_{\alpha\beta}\overline{L^c_\alpha}L_\beta S^+ + g_{i\alpha}\overline{\mathcal{F}^c_i}\phi^+ e_{\alpha R} + h.c\} - \frac{1}{2}\overline{\mathcal{F}^c_i}M_{ij}\mathcal{F}_j$$
$$-V(H,S,\phi) \quad / V(H,S,\phi) \supset \frac{\lambda_S}{4}(S^*)^2\phi^2 + h.c$$

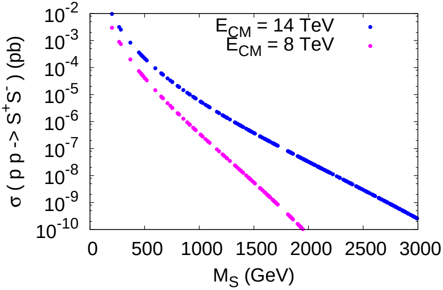
- Impose $\mathbb{Z}_2$ symmetry in order to forbid Dirac masses at tree-level.

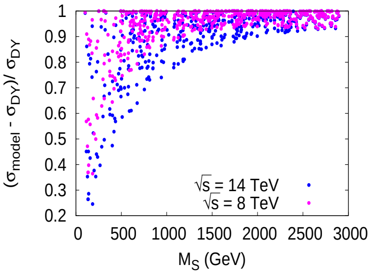
	$SU(2)_L$	$U(1)_Y$	$\mathbb{Z}_2$
S^+	**1**	1	1
ϕ_i	**1** or **2** or **3**	1	-1
$\mathcal{F}_i$	**1** or **2** or **3**	1	-1



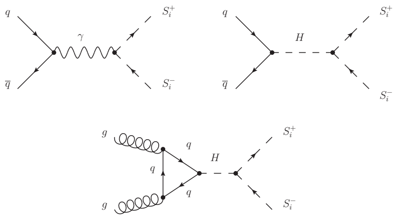
- Neutrino mass arises at three-loop.
- Lighetest of $\mathcal{F}_i$'s is a candidate for DM.

Production of the charged scalar $S^{\pm}$ at LHC collider





- Three-loop model files are generated using LanHEP
- cross sections of the charged scalar pair production at various CM energies were obtained by using CalcHEP package



LHC collider signatures

- Our signal consists of requiring di-leptons plus missing energy which it is defined as

$$pp \to l_\alpha^\pm l_\beta^\pm + E_{miss} \tag{1}$$

where $l_\alpha^\pm l_\beta^\pm = \{e^+e^-, \mu^+\mu^-, e^-\mu^+\}$

- The SM background is defined as

$$pp \to W^+W^- \to l_\alpha^\pm l_\beta^\pm \nu_\alpha \nu_\beta \tag{2}$$

$$pp \to ZZ(\gamma Z) \to l_\alpha^\pm l_\beta^\pm \nu_\alpha \nu_\beta \tag{3}$$

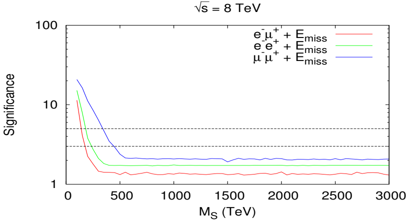
- set a Benchmark parameter which satifies FLV constraints.

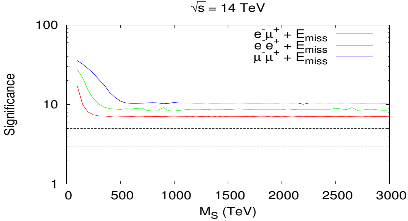
$$f_{e\mu} = -(4.97 + i1.91) \times 10^{-2}, \quad f_{e\tau} = 0.106 + i0.0859$$
$$f_{\mu\tau} = -(3.04 + i4.72) \times 10^{-6}, \quad M_S = 914.2 GeV$$

Signal Vs Background

- In order to optimize the signal significance, the event selection is performed in two steps:
  - The pre-selection : we use an accurate cut on M_{T2} ($M_{T2} > M_W$)
  - The final selection : deduce kinematic cuts

Process	cuts@8 TeV	cuts@14 TeV
$e^-\mu^+ + E_{miss}$	$80 < p_T^{e^-} < 250$ $\quad 80 < p_T^{\mu^+} < 270$ $-1.56 < \eta_{e^-} < 2.99$ $\quad -1.92 < \eta_{\mu^+} < 3$	$p_T^{e^-} > 180$ $\quad p_T^{\mu^+} > 170$ $1.1 < \eta_{e^-} < 2.89$ $\quad 1.2 < \eta_{\mu^+} < 3.02$
$e^-e^+ + E_{miss}$	$25 < p_T^l < 120$ $-2.09 < \eta_l < 2.89$	$30 < p_T^{e^-} < 80$ $-2.8 < \eta_{e^-} < 2.95$
$\mu^-\mu^+ + E_{miss}$	$30 < p_T^l < 155$ $-2.38 < \eta_l < 2.1$	$25 < p_T^{e^-} < 40$ $-0.13 < \eta_{e^-} < 3$





Numerical Results

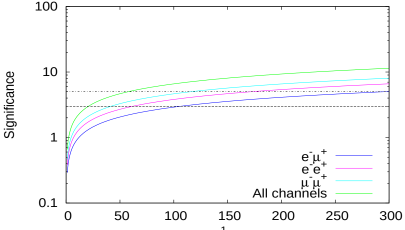
- In order to estimate the signal, the significance is given as (should be larger than 5σ)

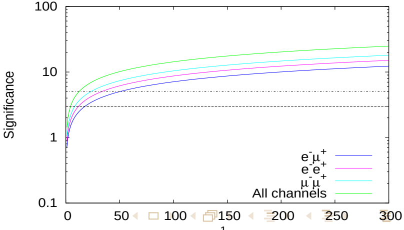
$$\mathcal{S} = \frac{N_{EX}}{\sqrt{N_{EX}+N_B}} \qquad N_{EX} = N_M - N_B = L \times (\sigma_M - \sigma_B) \tag{4}$$

$$\mathcal{S} \propto [2Re\left(\mathcal{M}^{\dagger}_{SM}\mathcal{M}_{non-SM}\right) + |\mathcal{M}_{non-SM}|^2] \propto |f_{\alpha\rho} f_{\beta\rho}|^2 \tag{5}$$

Process	σ^{EX} (fb)	σ^{B} (fb)	$\mathcal{S}_{100}$
$e^-\mu^+ + E_{miss}$	1.253	0.459	7.093
$e^-e^+ + E_{miss}$	44.45	38.65	8.699
$\mu^-\mu^+ + E_{miss}$	65.27	56.86	10.409

Process	σ^{EX} (fb)	σ^{B} (fb)	S_{20}
$e^-\mu^+ + E_{miss}$	13.03	11.98	1.301
$e^-e^+ + E_{miss}$	62.74	59.72	1.7051
$\mu^-\mu^+ + E_{miss}$	81.691	77.49	2.0786





Conclusion

- An observed deviation from the SM, if seen in the future, could be a very important hint that the SM right-handed neutrinos are Majorana fermions.
- We conclude that an inclusive cut on the M_{T2} event variable is vital and leads to an effective suppression of the large SM background.
- We found that at the LHC@8 TeV, the charged scalars effect can not be seen with luminosity $L = 20fb^{1}$, however, at LHC@14 TeV with luminosity $L = 100fb^{-1}$, this effect can be found in all channels.
- It has been shown that the signal significance decreases rapidly with the increasing charged scalar mass.

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