Dark matter and neutrino mass in the radiative seesaw model

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Contents

Model

It contains (i) a real scalar singlet (S), (ii) a vectorlike charged fermion singlet E_S^- and (ii) a vectorlike fermion doublet, $F_D = (X_1^0 \;\; E_D^-)^T$. Nucl.Phys.B 964 (2021) 115307, arXiv:2001.04070

Symmetries	S	F_D	E_S
$SU(2)$	1	2	1
$U(1)_Y$	0	-1	-2
Z_2	-1	-1	-1

$$\mathcal{L}_S = \frac{1}{2}|\partial_\mu S|^2 - \frac{1}{2}kS^2\phi^2 - \frac{1}{4}m_S^2S^2 - \frac{\lambda_S}{4!}S^4$$

$$\mathcal{L}_\mathcal{F} = \overline{F_D}\gamma^\mu D_\mu F_D + \overline{E_S}\gamma^\mu D_\mu E_S - M_{ND}\overline{F_D}.F_D - M_{NS}\overline{E_S}.E_S \;\; \& \;\; \mathcal{L}_{int} = -Y_N\overline{F_D}\phi^\dagger E_S - Y_{fi}\bar{L}_i F_D S + h.c.$$

$$\mathcal{M} = \begin{pmatrix} M_{ND} & M_X \\ M_X^\dagger & M_{NS} \end{pmatrix}, \; M_X = \frac{Y_N v}{\sqrt{2}}, \; \tan 2\beta = \frac{2M_X}{M_{NS} - M_{ND}}$$

$$M_{NS} - M_{ND} \gg M_X, \;\; M_{E_1^\pm} = M_{ND} - \frac{2(M_X)^2}{M_{NS} - M_{ND}}, \;\; M_{E_2^\pm} = M_{NS} + \frac{2(M_X)^2}{M_{NS} - M_{ND}}.$$

$$M_{X_1^0} = M_{ND}, \; M_S^2 = \frac{m_S^2 + kv^2}{2}, \; M_H^2 = 2\lambda v^2.$$

$M_{E_1^\pm} < M_{X_1^0} < M_{E_2^\pm}$, S for $M_S < M_{E_1^\pm}$ can serve as a viable DM candidate.

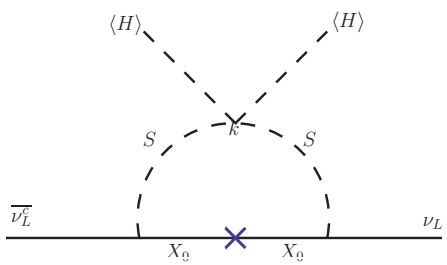
CONSTRAINTS ON THIS MODEL

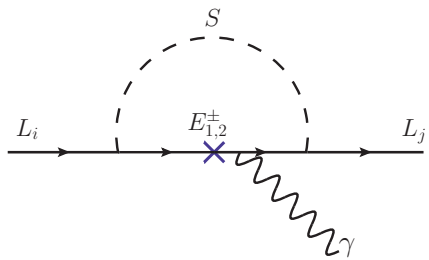
- Stability: $\lambda(\Lambda) > 0, \quad \lambda_S(\Lambda) > 0 \quad \text{and} \quad \kappa(\Lambda) + \sqrt{\frac{2\lambda(\Lambda)\lambda_S(\Lambda)}{3}} > 0$
- Unitarity: $\lambda \leq 8\pi \quad \text{and} \left| 12\lambda + \lambda_S \pm \sqrt{16\kappa^2 + (-12\lambda + \lambda_S)^2} \right| \leq 32\pi$
- LHC di-photon signal strength $\mu_{\gamma\gamma} = \frac{\Gamma(H\to\gamma\gamma)_{BSM}}{\Gamma(H\to\gamma\gamma)_{SM}}$,
  $\Gamma(H \to \gamma\gamma)_{BSM} = A \left| \sum_i Q_i^2 Y_{Ni} F_{1/2}(\tau_{E_i^\pm}) + C_{\rm SM} \right|$
  $Y_{N1} = \sqrt{2}\cos\beta \sin\beta\, Y_N$ and $Y_{N2} = -\sqrt{2}\cos\beta \sin\beta\, Y_N$
- EWPT: $\Delta S_{BSM} < 0.05 \pm 0.11$, $T_{BSM} < 0.09 \pm 0.13$ and $\Delta U_{BSM} < 0.011 \pm 0.11$
- Lepton flavor violation $\mathrm{BR}(\mu \to e\gamma) < 4.2 \times 10^{-13}$ at 90% CL. MEG-II Collaboration: EPJC 78, 380 (2018)

$$\mathrm{BR}(\mu \to e\gamma) = \frac{3\alpha_{em}}{64\pi G_F^2} \left| \cos^2\beta\, Y_{f1}^\dagger Y_{f2} \frac{F(M^2_{E_1^\pm}/M_S^2)}{M_S^2} + \sin^2\beta\, Y_{f1}^\dagger Y_{f2} \frac{F(M^2_{E_2^\pm}/M_S^2)}{M_S^2} \right|^2$$

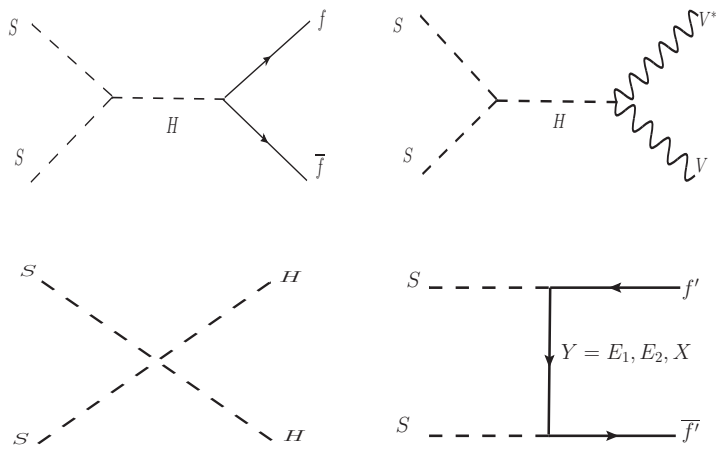
- Neutrino mass: $(M_\nu)_{ij} = \frac{1}{16\pi^2}(Y_{fi}^\dagger Y_{fi})(\kappa v^2)\, I(M_N, M_{DM})$

$$I(M_N, M_{DM}) = 4M_N \frac{M_{DM}^2 - M_N^2 + M_N \log(\frac{M_N^2}{M_{DM}^2})}{(M_{DM}^2 - M_N^2)^2}$$

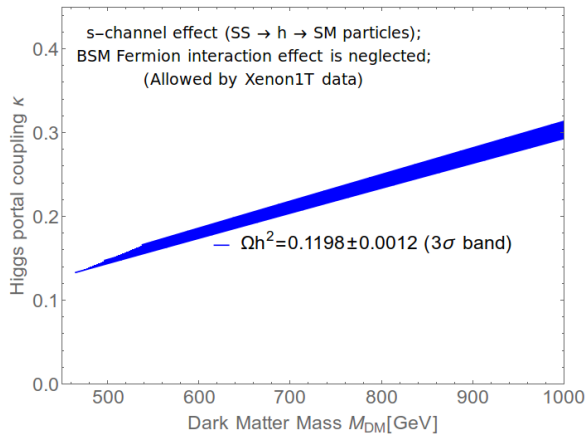


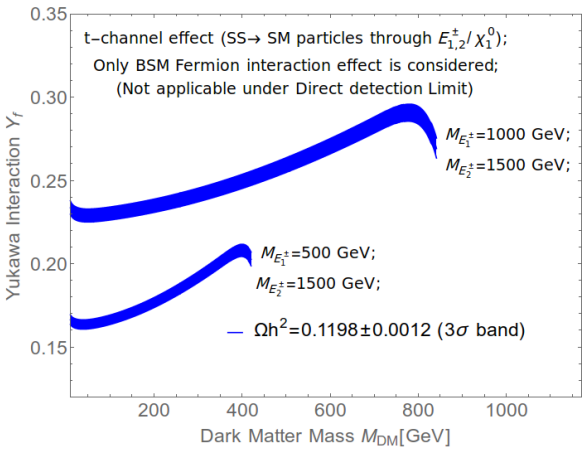


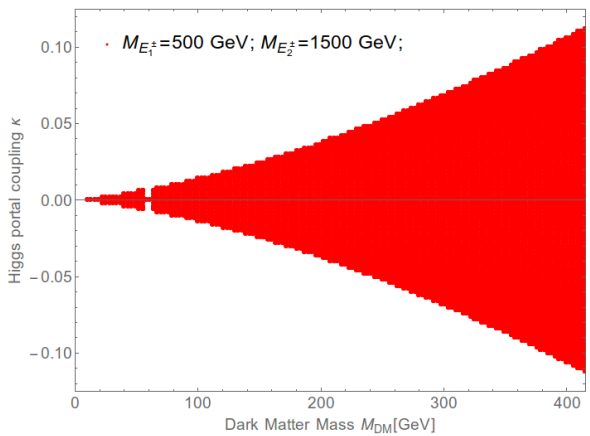
Dark Matter

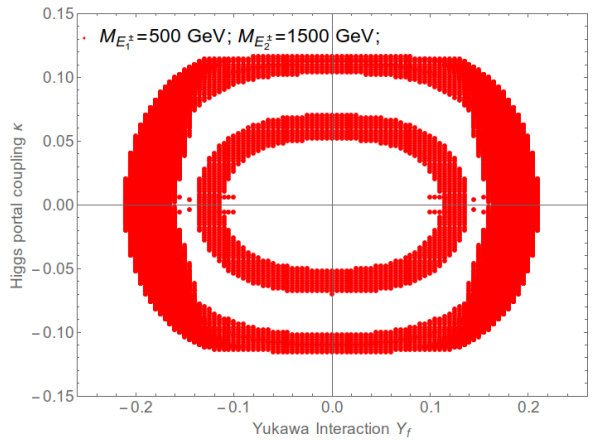


Annihilation diagrams









COLLIDER ANALYSIS

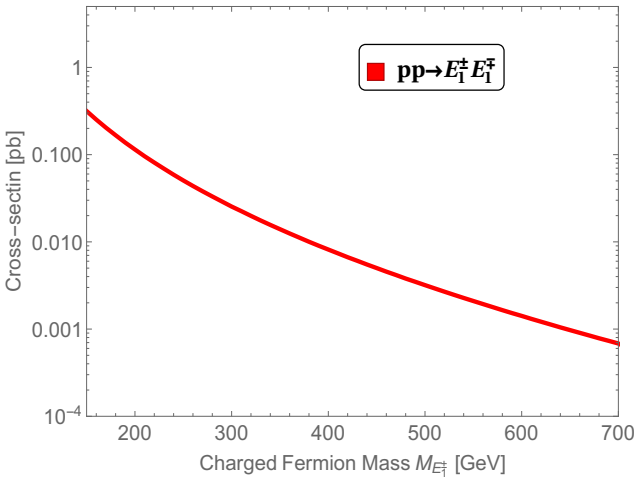
We perform a search for the lightest charged fermion $E_1^{\pm}$ in the context of 14 TeV LHC experiments with integrated luminosity of 100 fb^{-1} for event's process $pp \to E_1^{\pm} E_1^{\mp}$, where a SM leptons l is produced through decays of the charged fermion as $E_1^{\pm} \to l^{\pm} S$. Hence, in the final state, events have two same flavours opposite sign (SFOS) leptons, including significant missing transverse energy coming from the LSP S. Here, processes like $pp \to VV$ ($V = W, Z$) can add to the SM background.

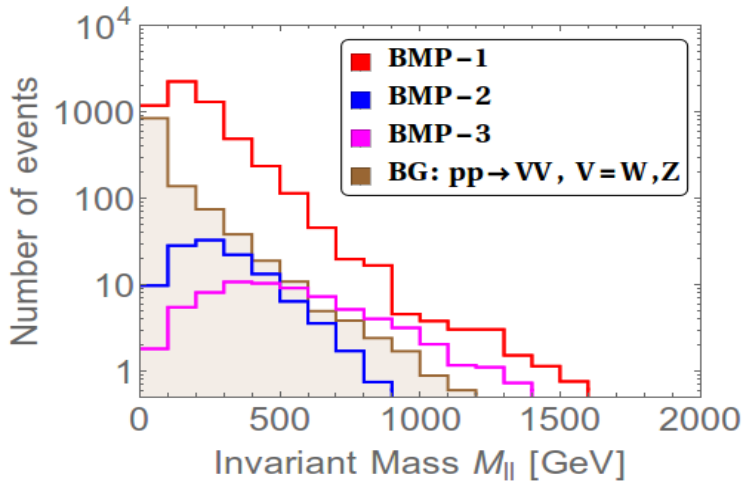
Signal Region	Various Cuts	
	M_{ll} [GeV]	$\not{E}_T$ [GeV]
SR-1	100.0	100.0
SR-2	110.0	140.0
SR-3	120.0	200.0

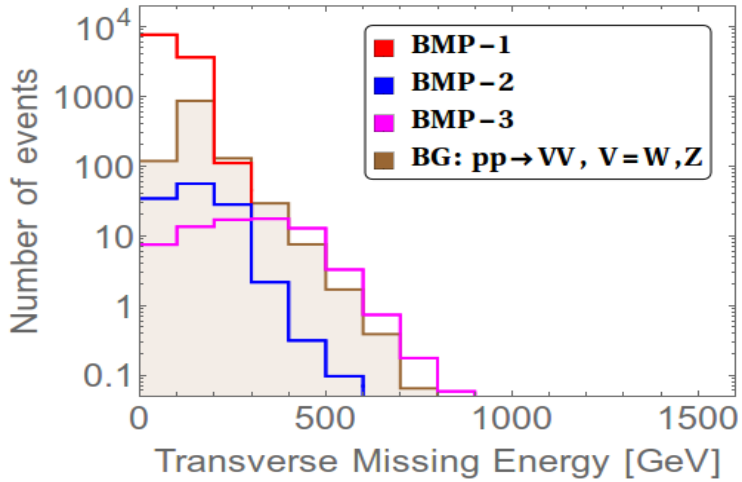
BMPs	Cross-Sections [fb]	Backgrounds	Cross-Sections [fb]
BMP-1	303.1	$pp \to WW$	28.2102
BMP-2	4.806	$pp \to WZ$	12.5581
BMP-3	2.91	$pp \to ZZ$	30.0432

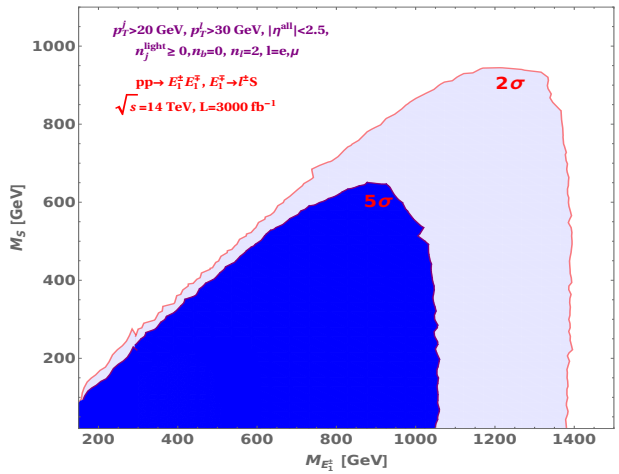
Signal Region	Total number of Backgrounds	Benchmark points: ($M_{E_1^{\pm}}$, M_S) in GeV					
		BMP-1 (150, 50)		BMP-2 (450, 300)		BMP-3 (500, 30)	
		# events	Significance	# events	Significance	# events	Significance
SR-1	243.759	1265.44	32.574	76.535	4.276	62.7682	3.585
SR-2	78.7281	344.017	16.732	53.7787	4.672	57.2691	4.912
SR-3	22.2838	63.6517	6.866	23.5256	3.476	48.8011	5.788

COLLIDER ANALYSIS









Conclusions

(**) We show the extended singlet scalar model with vector-like fermions have a viable dark matter and can be detected at LHC in the near future.