Collider signatures of multicharged vectorlike leptons

Nilanjana Kumar

University of Delhi, India
(nilanjana.kumar@gmail.com)

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Vector-like leptons:some facts

- Vector like leptons occur in extensions of SM, TeV-scale see- saw neutrino masses, little Higgs, minimal technicolor....
- Can address anomaly in muon anomalous magnetic moment measurements [1305.3522] and LFU violation [1705.07007]...
- Neutral component of the VLL multiplet can be a DM candidate [1812.06505]
- Couples with SM vector bosons and leptons $\rightarrow$ Multilepton final states [1510.03456]

$$L^{\pm} \rightarrow (W^{\pm}\nu),\ (Zl^{\pm}),\ (Hl^{\pm})$$

- Current limit by CMS [1905.10853] Multilepton search

  VLL in the mass range of 120–790 GeV, is excluded at 95% confidence level if couples with third generation SM leptons.

Different VLL Models:

- Multicharged VLL appears in warped space [0806.0350] or models of Compositeness [1001.5151]
- Decays to a W boson and a charged lepton leading to a clean same-sign di-lepton final state[1404.2375].

$$L^{\pm\pm} \rightarrow (W^{\pm} l^{\pm})$$

- Presence of charged Higgs, different VLL signature [2002.12218].

$$L^{\pm\pm} \rightarrow (H^{\pm} l^{\pm}),\ ((\nu l^{\pm}) l^{\pm})$$

$\delta M(mH, L) \rightarrow$ small, implied from muon (g-2) $\rightarrow$ soft leptons.
If $(\mu - \tau)$ is a symmetry, final state is $(\mu^+\mu^-)(l^+l^-)$

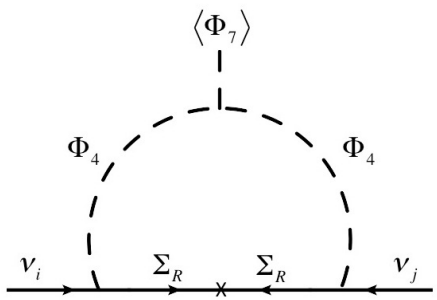
- Photon fusion is important for the multicharged VLL $\rightarrow$ increase in cross section.

A particular multicharged VLL Model:

	Lepton Fields			Scalar Fields			
	L_L	e_R	Σ_R	H	Φ_7	Φ_5	Φ_4
$SU(2)_L$	2	1	5	2	7	5	4
$U(1)_Y$	$-\frac{1}{2}$	-1	0	$\frac{1}{2}$	1	0	$\frac{1}{2}$

$$\Phi_4 = \left(\varphi^{++}, \varphi_2^{+}, \varphi^{0}, \varphi_1^{-}\right)^T, \qquad \Sigma_R = \left[\Sigma_R^{++}, \Sigma_R^{+}, \Sigma_R^{0}, \Sigma_L^{+c}, \Sigma_L^{++c}\right]^T$$

$\Phi_4$can be inert and hence the neutrino mass matrix is induced at one-loop level$\rightarrow$ small neutrino mass.



H, Φ_7 and Φ_5 have nonzero vev and satisfy $\rho = 1$

Couplings of doubly charged VLL's :

Gauge interaction:

$$\bar{\Sigma}_R \gamma^\mu i D_\mu \Sigma_R \supset \bar{\Sigma}^{++} \gamma^\mu \left(2eA_\mu + 2gc_W Z_\mu\right) \Sigma^{++} + \bar{\Sigma}^{+} \gamma^\mu \left(eA_\mu + gc_W Z_\mu\right) \Sigma^{+} + ..$$

Yukawa interaction:

$$-\mathcal{L} \supset (y_\nu)_{ij}\ \bar{\nu}_{L_i} \Sigma^{++}_{R_j} \varphi^{--} + \bar{\ell}_{L_i} \Sigma^{++c}_{L_j} \varphi^{+}_2 + ..$$

$\rightarrow$ explains LFV's and muon (g-2).

Kinetic term:

$$|D_\mu \Phi_4|^2 \supset i\sqrt{\frac{3}{2}} g W^-_\mu (\partial^\mu \varphi^-_2 \varphi^{++} - \partial^\mu \varphi^{++} \varphi^-_2)$$
$$+ i\sqrt{2} g W^-_\mu (\partial^\mu \varphi^{0*} \varphi^+_2 - \partial^\mu \varphi^+_2 \varphi^{0*}) + ...$$

Potential:

$$\mathcal{V} \supset \lambda_0 [H^\dagger \tilde{\Phi}_0 H H] + ...$$

Decay channels of VLL's:

$$\Sigma^{\pm\pm} \to \ell^{\pm}\varphi_2^{\pm} \to \ell^{\pm}W^{\pm *}\varphi^0 \to \ell^{\pm}W^{\pm *}hh$$

$$\Sigma^{\pm\pm} \to \nu\varphi^{\pm\pm} \to \nu W^{\pm *}\varphi_2^{+} \to \nu W^{\pm *}W^{\pm *}\varphi^0 \to \nu W^{\pm *}W^{\pm *}hh$$

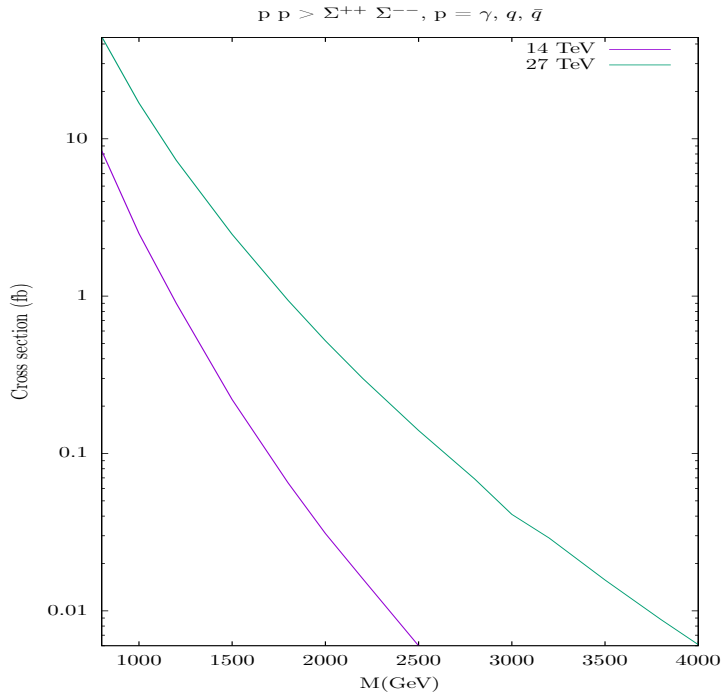
BP's after satisfying the LFV, neutrino mass and also muon (g-2).

-	BP1	BP2	BP3
v_5	1.44	1.44	1.44
v_7	0.748	0.748	0.748
$(y\nu)_{11}$	$-0.424903 - 0.433832i$	$-0.211747 + 0.0786788i$	$0.451545 + 0.281382i$
$(y\nu)_{21}$	$-0.515018 + 0.294156i$	$-0.174239 - 0.404063i$	$-0.455368 - 0.660787i$
$(y\nu)_{31}$	$-0.674845 + 0.282308i$	$0.218317 - 0.045373i$	$1.17154 - 0.229787i$

Simplified scenario, $\text{BR}(\Sigma^{\pm\pm} \to \ell^{\pm}\varphi_2^{\pm}) = (\Sigma^{\pm\pm} \to \nu\varphi^{\pm\pm}) \sim 50\%$

Production Cross section:

The inclusion of the photon PDF increases the signal cross section significantly as the coupling is proportional to the charge of the fermion.



If VLL mass is 1 TeV,

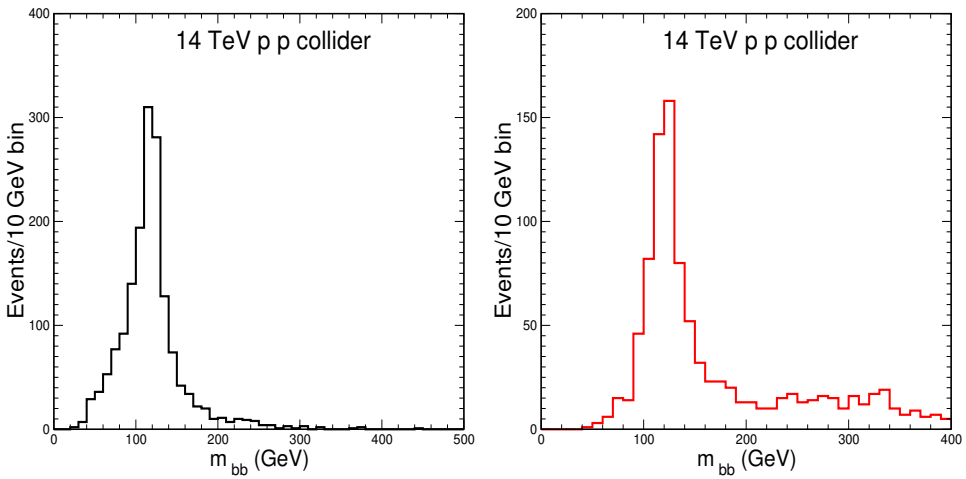
$\sigma \times BR(l^+W^+hh,\ l^-W^-hh) \rightarrow (l^+l^+)(l^-l^-)(hhhh) + MET \sim 0.06$ fb

Small cross section but background free.

Event Selection and Reconstruction:

At least 4 b-jets, coming from the Higgs and at least one of the two oppositely charged lepton pairs. Pairing of the b-jets to identify leading and subleading Higgs [1804.06174]

$$\frac{360}{m_{4b}} - 0.5 < \Delta R_{bb}(\text{leading}) < \frac{653}{m_{4b}} + 0.475$$
$$\frac{235}{m_{4b}} < \Delta R_{bb}(\text{subleading}) < \frac{875}{m_{4b}} + 0.35$$

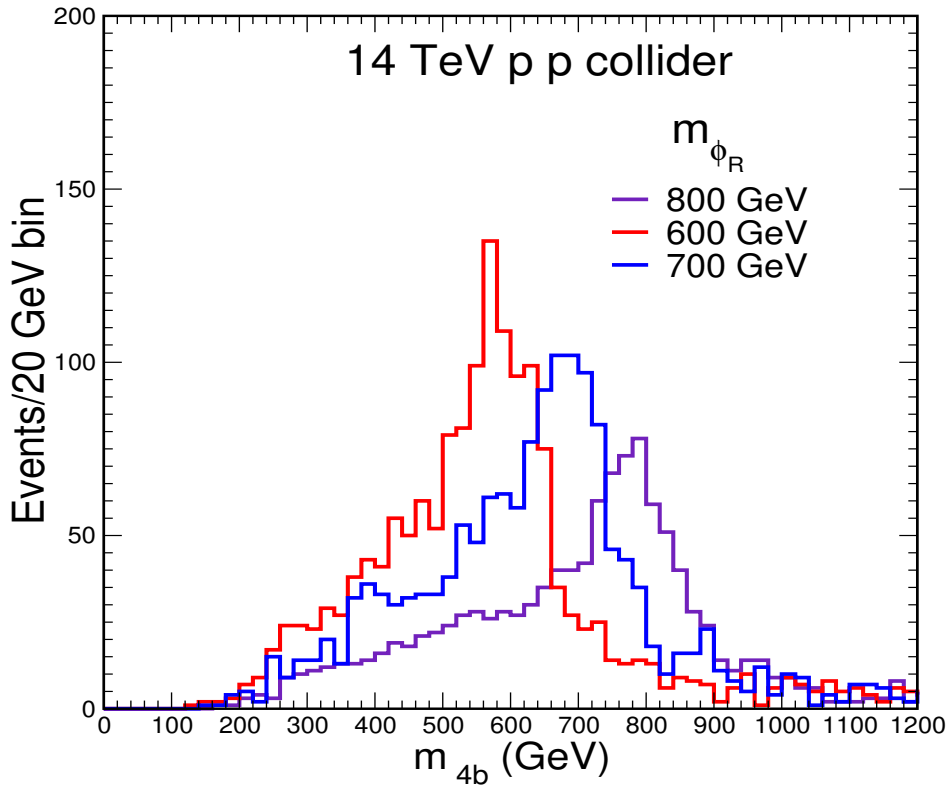


$p_{T_{\ell_1}} > 40$, $p_{T_{\ell_2}} > 20$, $\eta_\ell < 2.5$, $p_{T_b} > 40$, $\eta_b < 2.5$,$\Delta R(l, l) > 0.4$, $\Delta R(l, b) > 0.4$.

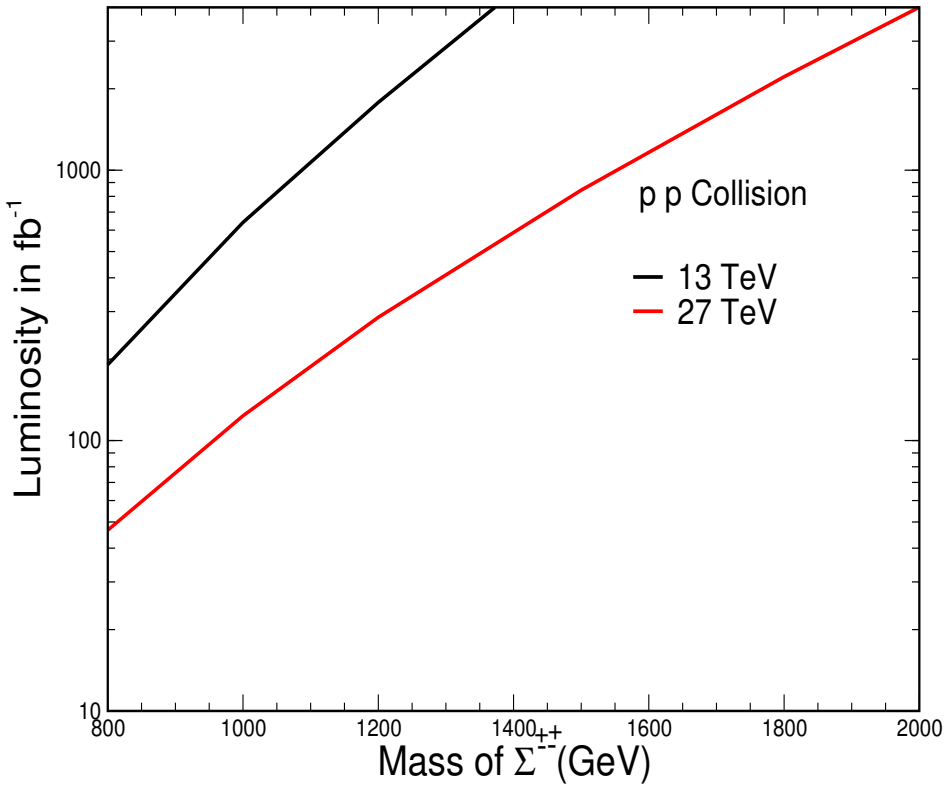
Event Selection and Reconstruction:

Finally we select the events that satisfy,

$$(M_H - 15)\text{GeV} < M_{2b} < (M_H + 15)\ \text{GeV}$$
$$(M_{\varphi^0} - 200)\ \text{GeV} < M_{4b} < (M_{\varphi^0} + 200)\ \text{GeV}$$



Prediction:



The required luminosity to observed at least 10 events in $4b + 1l$ channel. In $4b + l^+l^-$lepton the required luminosity is higher.

Conclusion:

- A more dedicated analysis is to be done in alternative channels of VLL's.
- The result highly depends on the b-tagging at the detector. At heavy VLL mass the objets will be highly boosted.
- Prospect for discovery and/or exclusion will be much better at 27 TeV.
- In general, study of VLL in different channels at LHC might give us glimpses of new physics.

extra1

Table: *Number of expected events at 150 fb^{-1}, 300 fb^{-1} and 3000fb^{-1} at 14 TeV p-p collision in different channels.*

$\geq$ 4 bjets $\geq$ 1 (l)	M_{φ_R} (GeV)	σ(fb)	N (150 fb^{-1})	300 fb^{-1}	3000 fb^{-1}
	600	5.1	4.9	9.7	97
	700	2.5	2.3	4.6	45
	800	1.6	1.4	2.8	28
$\geq$ 4 bjets + 1 (l^+l^-)					
	600	5.1	4	8	81
	700	2.5	2	4	40
	800	1.6	1.2	2.4	24