Unique collider signatures of a left-right symmetric model with minimal dark matter

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Candles of Darkness
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Presentation Outline

Motivations

Model

Production of quintuplets at collider

Collider signatures

Conclusion

Motivations

- Discovery of scalar boson at 125 GeV does not solve other issues in Particle Physics: Nonzero neutrino mass, Dark Matter, Origin of Matter-antimatter symmetry.
- Left-Right symmetric model is one of the Beyond Standard Model theories:
  - Max parity violation $\rightarrow$ naturally light neutrino mass
  - Stable TeV scale Dark Matter, (Arxiv: 1607.03878,1510.07872)
  - If $SU(2)_R \times U(1)$ breaks at TeV$\rightarrow$ interesting collider signature
- In some models, Unique collider signatures of 5-8 leptons or 2-4 Same sign leptons. These channels are mostly background free.

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Model: $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)$

Particle content:

- Chiral fermions, scalar doublet H_R (H_R^+, H_R^0 gets vev v_R)
- Bi-doublet ϕ (ϕ_1, ϕ_2 gets VEV v_1 and v_2), required to break left-right (LR) symmetry,
- Additional $SU(2)_R$ vector-like fermion quintuplet to accommodate a DM candidate.
- Quintuplet with B-L $= 4$

$$\chi = (\chi^{4+}, \chi^{3+}, \chi^{2+}, \chi^{1+}, \chi^0)^T$$

Model

$$\mathcal{L} = -g_Y s_W Q\overline{\chi} Z^\mu \gamma_\mu \chi + eQ\overline{\chi} A^\mu \gamma_\mu \chi + \sqrt{g_R^2 - g_Y^2}\left(Q - \frac{g_R^2 Q_{B-L}}{2(g_R^2 - g_Y^2)}\right)\overline{\chi} Z'^\mu \gamma_\mu \chi$$

$$g_R C_{2m} \overline{\chi}^{Q+1} W'^{+\mu} \gamma_\mu \chi^Q$$

$$C_{2m} = \sqrt{(2+m+1)(2-m)/2} \qquad m = Q - Q_{B-L}/2$$

- Quintuplet fermions, being charged under the $SU(2)_R$ and $U(1)_{B-L}$, couple to photon, and $SU(2)_R$ gauge bosons.
- The components of χ are mass degenerate at tree-level, but radiative corrections remove this degeneracy
- The mass difference increases as we increase the masses. From heavier mass decays we can have energetic leptons (off shell w')
- But have to pay price for the low cross section; Considering initial state photons can boost up the cross section.

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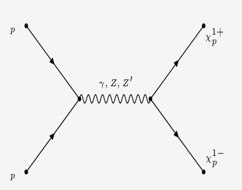
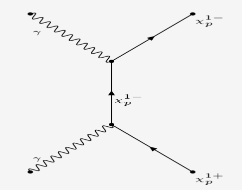
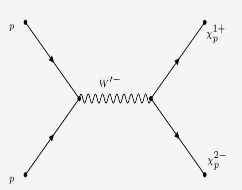
Production of Quintuplets







Quark -antiquark Drell Yan process (s channel) and photon-photon fusion (t(u) channel).

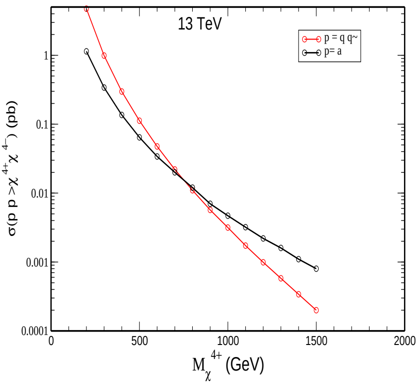
$\chi^0\chi^0$ and all possible combinations of $\chi^{Q+}\chi^{Q-}$ and $\chi^{(Q+1)+}\chi^{Q-}$ can be produced for Q= 4,3,2,1,0

Photon Photon fusion

- Photon density being significantly smaller than the quark and gluon densities, photon fusion contribution to the pair-production of charged fermions was neglected.
- Photon coupling to a pair of charged fermions being proportional to Q, the cross-sections are enhanced by a factorQ^4.
- Photon fusion being a t(u)-channel process, falls slowly with $\sqrt{s}$ compared to the s-channel DY process.
- Therefore, for larger masses of doubly, triply and quadruply charged fermions, photon fusion production could be significant compared to the conventional DY production.

Photon Photon fusion

Photon contribution gets larger at around 800 GeV.



Parameters and constrains

Parameters used

$g_L = 0.653, g_R = g_L, B-L = 4, v_R = 13\,TeV, v = v_1^2 + v_2^2 = 246\,GeV,$
$g_Y = 0.356$

$$M_{W'}^2 = \frac{g_R^2(v_R^2+v^2)}{2}$$

$$M_{Z'}^2 = \frac{(g_R^2+g_{B-L}^2)(v_R^2+g_R^2 v^2)}{2(g_R^2+g_{B-L}^2)}$$

$$g_Y = \frac{g_R g_{B-L}}{\sqrt{g_R^2+g_{B-L}^2}}$$

$M_{W'} = 6.003\,TeV, M_{Z'} = 7.15\,TeV$

Mass spectrum:

$M_\chi^0 = 400\,GeV,\ M_\chi^{1+} = 410\,GeV,\ M_\chi^{2+} = 428\,GeV,\ M_\chi^{3+} = 457\,GeV,$
$M_\chi^{4+} = 495\,GeV$

Cross section of different production channels

Table : Total cross section in pico barn when $M_\chi^0 = 400$ GeV, when initial state partons and photons are considered

Process	cross section (pb)
$pp \to \chi^{4+}\chi^{4-}$	0.1847
$pp \to \chi^{3+}\chi^{3-}$	0.1225
$pp \to \chi^{2+}\chi^{2-}$	0.0631
$pp \to \chi^{1+}\chi^{1-}$	0.0174
$pp \to \chi^{0}\chi^{0}$	7.8×10^{-6}
$pp \to \chi^{4+}\chi^{3-}$	0.2204
$pp \to \chi^{3+}\chi^{2-}$	0.3317
$pp \to \chi^{2+}\chi^{1-}$	0.3313
$pp \to \chi^{1+}\chi^{0}$	0.2208
Total cross section	1.4919

Branching ratios

$\text{Br}(\chi^{Q+1} \to \bar{e}\nu\chi^{Q})$=11.11%
$\text{Br}(\chi^{Q+1} \to \bar{\mu}\nu\chi^{Q})$=11.11%
$\text{Br}(\chi^{Q+1} \to \bar{\tau}\nu\chi^{Q})$=11.11%
$\text{Br}(\chi^{Q+1} \to \bar{d}u\chi^{Q})$=33.33%
$\text{Br}(\chi^{Q+1} \to \bar{s}c\chi^{Q})$=33.33%

Contribution of different production channels in 3SSL channel:

$$\sigma(pp \to \chi^{4+}\chi^{4-}) \times 2 \times 4 \times [Br(\chi^{(Q+1)+} \to l^{+}\nu_{l}\chi^{Q+}]^{3} \times [Br(\chi^{Q+1-} \to q\bar{q}\chi^{Q-}]^{5}$$
$$+\sigma(pp \to \chi^{3+}\chi^{3-}) \times 2 \times [Br(\chi^{Q+1+} \to l^{+}\nu_{l}\chi^{Q+}]^{3} \times [Br(\chi^{(Q+1)-} \to q\bar{q}\chi^{Q-}]^{3}$$
$$+\sigma(pp \to \chi^{4+}\chi^{3-}) \times 2 \times 8 \times [Br(\chi^{(Q+1)+} \to l^{+}\nu_{l}\chi^{Q+}]^{3} \times [Br(\chi^{(Q+1)-} \to q\bar{q}\chi^{Q-}]^{4}$$
$$+\sigma(pp \to \chi^{3+}\chi^{2-}) \times 2[Br(\chi^{(Q+1)+} \to l^{+}\nu_{l}\chi^{Q+}]^{3} \times [Br(\chi^{(Q+1)-} \to q\bar{q}\chi^{Q-}]^{2}$$

$\sigma \times Br(3SSL)$= (2.12+0.785+3.168+7.57) fb = 13.643 fb

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Interesting collider signatures

Table : Effective cross section $\times$ BR from different processes, when initial state partons and photons are considered

M_{χ}^{4-}	Cross section$\times$ Br (fb)
4SSL	0.485
3SSL	13.643
2SSL	133.57
8L	0.001
7L	0.014
6L	0.512
5L	3.956

Multilepton channels with more leptons have smaller cross-section but they are background free.

Backgrounds

- $t\bar{t} \to$ 2SSL
- $ZZ \to$ 2SSL
- $t\bar{t}W \to$ 2SSL
- $t\bar{t}Z \to$ 2SSL
- $t\bar{t}h \to$ 2SSL
- $t\bar{t}WW \to$ 2SSL
- $t\bar{t}t\bar{t} \to$ 2SSL
- $WWZ \to$ 2SSL, 3SSL
- $ZZW \to$ 2SSL, 3SSL,5l
- $ZZZ \to$ 2SSL, 3SSL, 5l,6l
- $WWjj$
- $Z + jets$

Background contribution will be very small if require b-jet veto and Z veto.

Event Selection

- Used Feynrules to implement the model and then**Madgraph 5** to generate events, in p-p collisions at $\sqrt{s} = 13$ TeV.

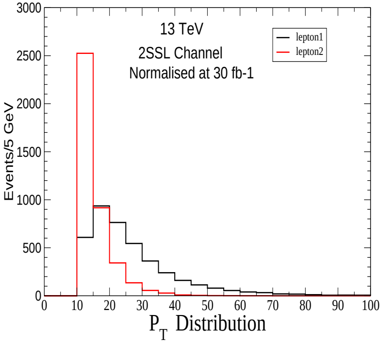
  We are looking for multilepton channels with or without jets.

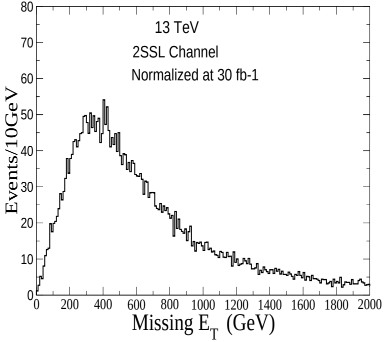
- ATLAS same sign leptons (1602.09058)
  ATLAS two or three leptons:ATLAS-CONF-2017-039

- Multilepton searches are motivated by supersymmetry so far.

- For leptons $\mathrm{p}_T > 10 GeV, \eta < 2.5$
  For jets $\mathrm{p}_T > 20 GeV, \eta < 2.8$

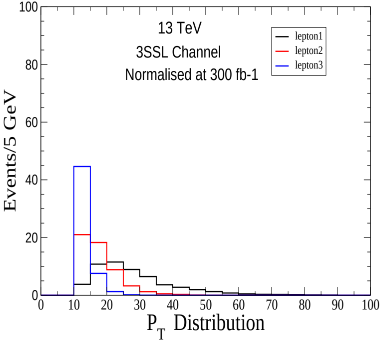
Distributions in 2SSL channel

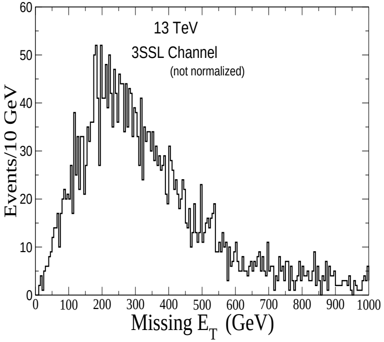




Sufficient events even if a strong selection is imposed at 30 fb^{-1}.

Distributions in 3SSL channel





Events survive even if a strong selection is imposed at 300 fb^{-1}.

Needs to generate more events for further study.

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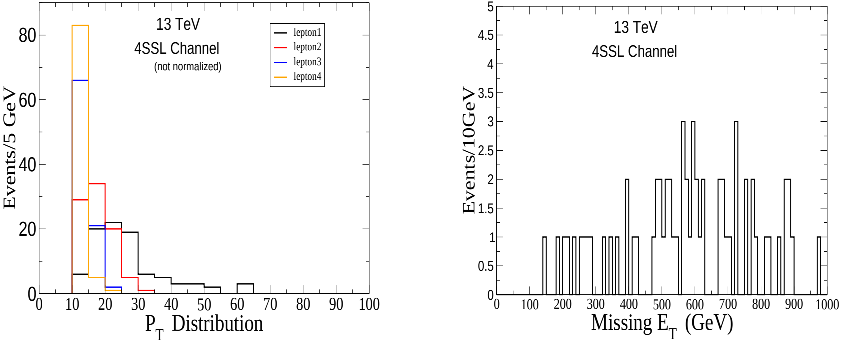
- LHC searches for multilepton channels should be a priority in the future, as a possible window to new physics.
- Due to the smallness of cross section $\times$ Br in multilepton channels one needs higher luminosities to observe an excess.
- To see moderate number of events, 300 fb^{-1} and $>$1000 fb^{-1} luminosities are required in 3SSL and 4SSL channels(current estimate).
- More precise collider study has to be performed yet, efficiencies are needed to be fixed as the detection efficiency have improved for leptons and jets.
- Overall there might be a glimpse of light of BSM physics in multilepton channels.

Distributions in 4SSL channel



p_T selection cuts off a lot of events.

Need a much higher luminosity to observe events ($> 1000\ \text{fb}^{-1}$).