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

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Presentation Outline

Motivations

- Left-Right symmetric model: arXiv:1510.07872,512090
  - 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
- Same sign leptons have small SM backgrounds.

  2SSL: WZ,$t\bar{t}W$,$t\bar{t}$

  3SSL: $t\bar{t}W$,$t\bar{t}t\bar{t}$,$t\bar{t}b\bar{b}$
- $S/\sqrt{b}$ overestimates if the background is very small. An approximation for the median expected discovery significance and exclusion is used.

  G. Cowan, K. Cranmer, E. Gross and O. Vitellsv, (arxiv:1007.1712)
- There can be uncertainty in backgrounds.

Presentation Outline

Left Right Symmetric Model

- Doublet quarks and leptons Q_L, Q_R, l_L, l_R.
- Additional $SU(2)_R$ vector-like fermion quintuplet to accommodate a DM candidate χ^0.
$$\chi = (\chi^{4+}, \chi^{3+}, \chi^{2+}, \chi^{1+}, \chi^0)^T$$
- Scalar Doublet H_R, required for symmetry breaking,
$$< H_R^0 >= v_R$$
- bi doublet Φ, required to give masses to fermions,
$$< \phi_1^0 >= v_1, \qquad < \phi_2^0 >= v_2$$
- A scalar S and fermion singlet N to give neutrino mass.

$$SU(2)_L \times SU(2)_R \times U(1)_Y \xrightarrow{v_R} SU(2)_L \times U(1)_Y \xrightarrow{v_1, v_2} U(1)_{EM}$$

Couplings

- Quintuplets, couples to $SU(2)_R$ gauge bosons.

$$\boxed{g_R C_{2m}\overline{\chi}^{Q+1} W'^{\mu}\gamma_\mu \chi^Q + \sqrt{g_R^2 - g_Y^2}\left[Q - \frac{g_R^2 Q_{B-L}}{2(g_R^2 - g_Y^2)}\right]\overline{\chi} Z'^{\mu}\gamma_\mu \chi}$$

- The mass degeneracy of χ are lifted at 1 loop order and they decay via off shell W'. arXiv:1607.03878
  Mass spectrum:

M_χ^i GeV
200,205,216,233,257
400,409,428,456,494

- Also couples to photon and Z

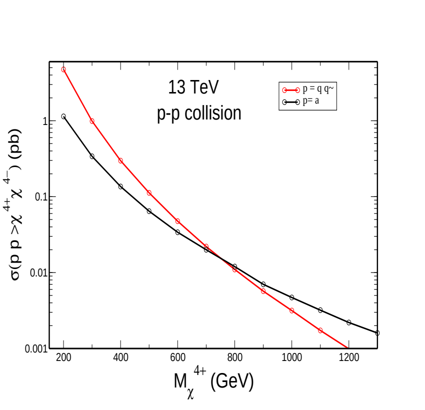
$$\boxed{e\ Q\ \overline{\chi} A^{\mu}\gamma_\mu \chi - g_Y s_W Q \overline{\chi} Z^{\mu}\gamma_\mu \chi}$$

- Coupling to photon is proportional to Q, the cross-sections are enhanced by a factor Q^4.

Presentation Outline

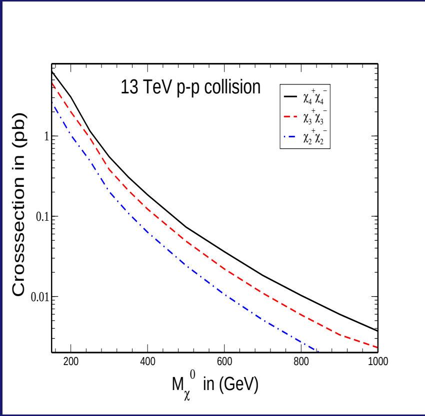
Photon Photon Fusion

- Photon density is significantly smaller than the quark and gluon densities.
- Being a t(u)-channel process, falls slowly with $\sqrt{s}$ compared to the s-channel DY process.
- Therefore, for larger masses significant contribution than DY production.

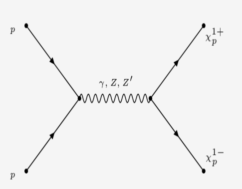


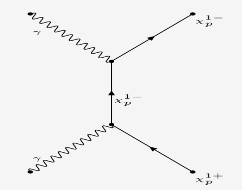
Cross Sections

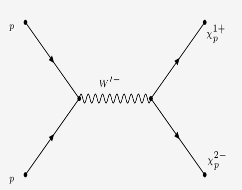
- $pp \to \chi^{4+}\chi^{4-}$
  $pp \to \chi^{3+}\chi^{3-}$
  $pp \to \chi^{2+}\chi^{2-}$
  $pp \to \chi^{1+}\chi^{1-}$
  $pp \to \chi^{0}\chi^{0}$
- $pp \to \chi^{4+}\chi^{3-}$
  $pp \to \chi^{3+}\chi^{2-}$
  $pp \to \chi^{2+}\chi^{1-}$
  $pp \to \chi^{1+}\chi^{0}$



Production and Decays of Quintuplets







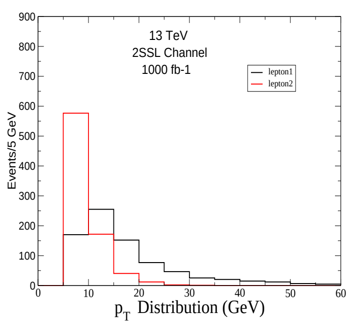
Decay:

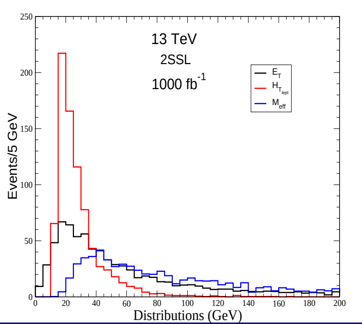
$$\chi^{Q+1} \to \chi^{Q} l \nu_l,\ \text{l=e},\mu$$
$$\chi^{Q+1} \to \chi^{Q} l q \bar{q}.$$

This can give rise to different multilepton signatures among which we will consider same sign leptonic signatures at LHC.
Note: soft leptons

Presentation Outline

Distributions in 2SSL





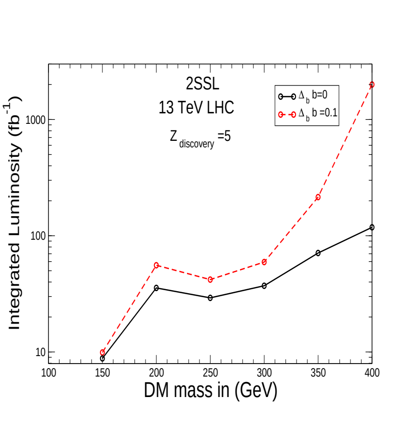
- S1: 2 Same sign $ee, \mu\mu, e\mu$
- S2:
  - $p_{T_{\ell_1}} < 35$ GeV, $p_{T_{\ell_2}} < 20$ GeV
  - $H_{T_\ell} < 60$, $E_T^{\rm miss} < 100$, $E_T^{\rm miss}/M_{eff} > 0.2$
- S3: $m_T < 40$ GeV

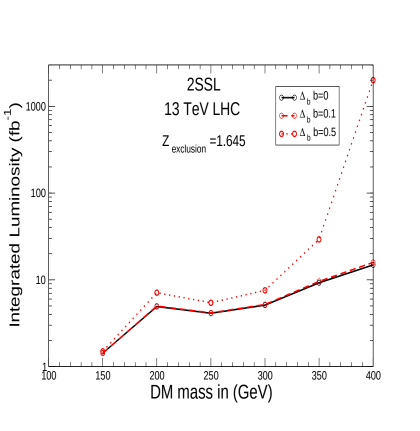
2SSL, 3SSL Signal and Backgrounds

Table : Effective cross sections of the signal in 2SSL in different selections.

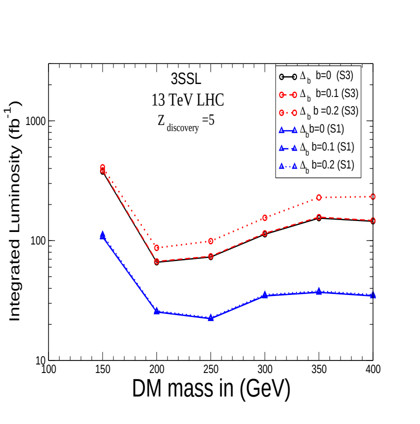
2SSL	$S1$ (fb)	$S2$ (fb)	$S3$ (fb)
M_{χ^0} =200 GeV	2.03	1.31	0.85
M_{χ^0} =400 GeV	1.69	0.95	0.44
WZ	98.89	4.45	0.77
$t\bar{t}$	36.9	0.028	< 0.0082
$t\bar{t}W$	9.89	0.043	0.00186
Total Back	160.76	4.78	0.78
3SSL	$S1$ (fb)	$S2$ (fb)	$S3$ (fb)
$M_{\chi^0} = 200$GeV	0.151	0.117	0.0556
$M_{\chi^0} = 400$GeV	0.119	0.0814	0.0275
Total Back	0.00221	< 0.00057	< 0.00057

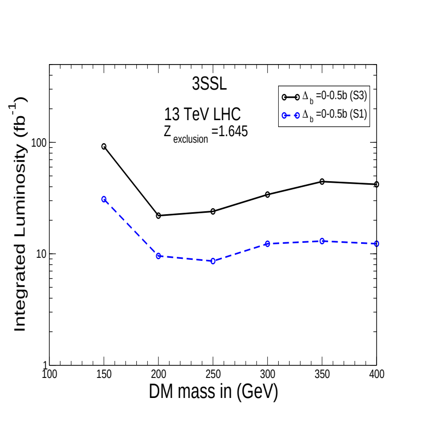
2SSL Channel





3SSL Channel





Presentation Outline

Conclusion

- 4SSL will be background free but small crosssection is challenging.
- For 400 GeV DM mass the cross section to pass is 0.007 fb, so minimum 2040 fb^{-1} is required.
- For 2SSL and 3SSL DM mass upto 400 GeV can be excluded by a very small luminosity but for discovery 100 fb^{-1} luminosity is required.
- Overall there might be a glimpse of light of BSM physics in multilepton channels, so LHC searches for multilepton channels should be a priority in the future

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 $= 4$

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

Cross section $\times$ Br before selection

M_{χ}	σ(2SSL) (fb)	σ(3SSL) (fb)	σ(4SSL) (fb)
200,205,216,233,257	214.4	71.88	11.55
300,307,322,345,377	75.83	11.23	2.0
400,409,428,456,494	24.73	3.7	0.7

Selections in 2SSL and 3SSL

- Selection1: 2 Same sign ee,$\mu\mu$,$e\mu$
- Selection 2:
  - $pT_{l1\,max} = 35$ GeV
  - $pT_{l2\,max} = 20$ GeV
  - $ET/M_{eff} > 0.2$
  - $HT_{lept} < 60$
  - $HT_{jets} < 200$
  - $ET < 100$
  - $ET/M_{eff} > 0.2$
- Selection 3
- $m_T < 40$ GeV

For 3SSL additionally we have imposed, $pT_{l3\,max} = 15$ 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:

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

$$Z_{disc} = \left[2\left((s+b)\ln\left[\frac{(s+b)(b+{}^2)}{b^2+(s+b){}^2}\right] - \frac{b^2}{2}\ln\left[1+\frac{{}^2 s}{b(b+{}^2)}\right]\right)\right]^{1/2}$$

If $\Delta_b = 0$,

$$Z_{disc} = \sqrt{2[(s+b)\ln(1+s/b)-s]}$$

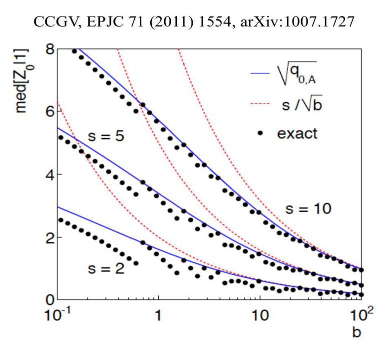
We will use > 5 corresponding to $p < 2.86 \times 10^{-7}$ and $\Delta_b = 0.1b$, $0.2b$, and $0.5b$.

$$Z_{exc} = \left[2\left\{s - b\ln\left(\frac{b+s+x}{2b}\right) - \frac{b^2}{\Delta_b^2}\ln\left(\frac{b-s+x}{2b}\right)\right\} - (b+s-x)(1+b/\Delta_b^2)\right]^{1/2}$$

If $\Delta_b = 0$,

$$Z_{exc} = \sqrt{2(s - b\ln(1+s/b))}$$

For a median expected 95% confidence level (CL) exclusion ($p = 0.05$), we will use > 1.645, and $\Delta_b = 0.1b$, $0.2b$, and $0.5b$.


CCGV, EPJC 71 (2011) 1554, arXiv:1007.1727
med[Z_0|1]
$\sqrt{q_{0,A}}$
$s/\sqrt{b}$
exact
s = 5
s = 10
s = 2
b