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DARK MATTER IN THE SUPERSYMMETRIC LEFT-RIGHT MODEL

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OUTLINE

- ***Motivation***
- ***Supersymmetric left-right (SUSYLR) model, $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$***
- ***Dark Matter***
- ***Benchmarks and Detection at the LHC***
- ***Conclusions***

A. Chatterjee, M. Frank, B. Fuks, KH, S. Mondal, S.K. Rai, H. Waltari, PRD 99 (2019) 035017;
M. Frank, B. Fuks, KH, S.K. Rai, H. Waltari, JHEP 1705 (2017) 015;

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MOTIVATION

Dark matter remains well established but completely unknown.
Supersymmetric models have many candidates (neutralino, sneutrino, gravitino,…).

Dark matter in MSSM is strongly constrained.
→ In supersymmetric left-right model consider candidates, which are not present in MSSM

Consider also setups where several states are light and nearly degenerate leading to coannihilations

Devise a set of benchmark points which satisfy all constraints → signals

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Why supersymmetric left-right model?

Based on $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ → $SU(3)_c \times SU(2)_L \times U(1)_Y$

Dynamical parity breaking, neutrinos massive, strong CP-violation ok, …

$R_{parity}=(-1)^{3(B-L)+2s}$ breaking would violate gauge symmetry
→ LSP stable and dark matter candidate

Note new gauge bosons: W_L, W_R, Z, Z', γ

Pati, Salam PRD (1974); Mohapatra, Pati PRD (1975); Mohapatra, Senjanovic PRL (1980);
Kuchimanchi, Mohapatra PRD 48 (1993); Martin PRD 46 (1992);
KH, Maalampi PLB (1995); Mohapatra, Rasin, PRL (1996), PRD (1996); Babu, Mohapatra PLB 668 (2008);
Frank, Korutlu PRD 83 (2011); …

Why in HPNP?

For the dark matter, the Higgs content essential

SUSYLR-specific dark matter candidates:

twelve neutralinos (gaugino- or Higgsino-dominated);
the Higgsino dominated especially interesting because of natural coannihilations

Always three right-handed sneutrinos present in the model;
annihilate through Higgses

SUPERSYMMETRIC LEFT-RIGHT MODEL (SUSYLR): $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

The Higgses in SUSYLR

$$Q = I_{3L} + I_{3R} + \frac{B-L}{2}$$

$$\Phi_1 = \begin{pmatrix} \Phi_{11}^+ & \Phi_{11}^0 \\ \Phi_{12}^0 & \Phi_{12}^- \end{pmatrix} \sim (\mathbf{1},\mathbf{2},\mathbf{2}^*,0)\,, \qquad \Phi_2 = \begin{pmatrix} \Phi_{21}^+ & \Phi_{21}^0 \\ \Phi_{22}^0 & \Phi_{22}^- \end{pmatrix} \sim (\mathbf{1},\mathbf{2},\mathbf{2}^*,0)\,,$$

$$\Delta_L = \begin{pmatrix} \frac{1}{\sqrt{2}}\Delta_L^- & \Delta_L^0 \\ \Delta_L^{--} & -\frac{1}{\sqrt{2}}\Delta_L^- \end{pmatrix} \sim (\mathbf{1},\mathbf{3},\mathbf{1},-2), \qquad \delta_L = \begin{pmatrix} \frac{1}{\sqrt{2}}\delta_L^+ & \delta_L^{++} \\ \delta_L^0 & -\frac{1}{\sqrt{2}}\delta_L^+ \end{pmatrix} \sim (\mathbf{1},\mathbf{3},\mathbf{1},2)$$

$$\Delta_R = \begin{pmatrix} \frac{1}{\sqrt{2}}\Delta_R^- & \Delta_R^0 \\ \Delta_R^{--} & -\frac{1}{\sqrt{2}}\Delta_R^- \end{pmatrix} \sim (\mathbf{1},\mathbf{1},\mathbf{3},-2), \qquad \delta_R = \begin{pmatrix} \frac{1}{\sqrt{2}}\delta_R^+ & \delta_R^{++} \\ \delta_R^0 & -\frac{1}{\sqrt{2}}\delta_R^+ \end{pmatrix} \sim (\mathbf{1},\mathbf{1},\mathbf{3},2)$$

$$S \sim (\mathbf{1},\mathbf{1},\mathbf{1},0)\;,$$

with VEVs

$$\langle\Phi_1\rangle = \begin{pmatrix} 0 & 0 \\ \frac{v_1}{\sqrt{2}} & 0 \end{pmatrix}, \quad \langle\Phi_2\rangle = \begin{pmatrix} 0 & \frac{v_2}{\sqrt{2}} \\ 0 & 0 \end{pmatrix}, \quad \langle\Delta_R\rangle = \begin{pmatrix} 0 & \frac{v_R}{\sqrt{2}} \\ 0 & 0 \end{pmatrix}, \quad \langle\delta_R\rangle = \begin{pmatrix} 0 & 0 \\ \frac{v'_R}{\sqrt{2}} & 0 \end{pmatrix}$$

$$\langle S\rangle = \frac{v_S}{\sqrt{2}}\,.$$

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Superpotential:

$$W = Q_L^T \mathbf{Y}_Q^{(i)} \Phi_i Q_R + L_L^T \mathbf{Y}_L^{(i)} \Phi_i L_R + L_L^T \mathbf{h}_{LL} \delta_L L_L + L_R^T \mathbf{h}_{RR} \Delta_R L_R + \lambda_L \; S \; \mathrm{Tr}\left[\Delta_L \delta_L\right]$$
$$+\lambda_R \; S \; \mathrm{Tr}\left[\Delta_R \delta_R\right] + \lambda_3 \; S \; \mathrm{Tr}\left[\tau_2 \Phi_1^T \tau_2 \Phi_2\right] + \lambda_4 \; S \; \mathrm{Tr}\left[\tau_2 \Phi_1^T \tau_2 \Phi_1\right]$$
$$+\lambda_5 \; S \; \mathrm{Tr}\left[\tau_2 \Phi_2^T \tau_2 \Phi_2\right] + \lambda_S \; S^3 + \xi_F \; S \; ,$$

Problems with potential:

to preserve R-parity conservation in the vacuum, add

- non-renormalizable terms
- additional B-L triplets
- include radiative corrections → scale at most ~10 TeV → hopes to find at the LHC

Kuchimanchi, Mohapatra, PRD 48 (1993); Babu, Mohapatra, PLB 668 (2008);
Basso, Fuks, Krauss, Porod, JHEP 07 (2015)

Neutralinos in SUSYLR

$(\tilde{\delta}_L^0, \widetilde{\Delta}_L^0)$ $\quad$ $(\widetilde{\Phi}_{22}^0, \widetilde{\Phi}_{11}^0)$

$$M_{\tilde{\chi}_\delta} = \begin{pmatrix} 0 & \mu_L \\ \mu_L & 0 \end{pmatrix} \quad \text{and} \quad M_{\tilde{\chi}_\Phi} = \begin{pmatrix} 0 & -\mu_{\rm eff} \\ -\mu_{\rm eff} & 0 \end{pmatrix}$$

$(\widetilde{\Phi}_{12}^0, \widetilde{\Phi}_{21}^0, \tilde{\delta}_R^0, \widetilde{\Delta}_R^0, \tilde{S}, \tilde{B}, \widetilde{W}_L^0\ \widetilde{W}_R^0)$

$$M_{\tilde{\chi}^0} = \begin{pmatrix} 0 & -\mu_{\rm eff} & 0 & 0 & -\mu_d & 0 & \frac{g_L v_u}{\sqrt{2}} & -\frac{g_R v_u}{\sqrt{2}} \\ -\mu_{\rm eff} & 0 & 0 & 0 & -\mu_u & 0 & -\frac{g_L v_d}{\sqrt{2}} & \frac{g_R v_d}{\sqrt{2}} \\ 0 & 0 & 0 & \mu_R & \frac{\lambda_R v_R'}{\sqrt{2}} & g' v_R & 0 & -g_R v_R \\ 0 & 0 & \mu_R & 0 & \frac{\lambda_R v_R}{\sqrt{2}} & -g' v_R' & 0 & -g_R v_R' \\ -\mu_d & -\mu_u & \frac{\lambda_R v_R'}{\sqrt{2}} & \frac{\lambda_R v_R}{\sqrt{2}} & \mu_S & 0 & 0 & 0 \\ 0 & 0 & g' v_R & -g' v_R' & 0 & M_1 & 0 & 0 \\ \frac{g_L v_u}{\sqrt{2}} & -\frac{g_L v_d}{\sqrt{2}} & 0 & 0 & 0 & 0 & M_{2L} & 0 \\ -\frac{g_R v_u}{\sqrt{2}} & \frac{g_R v_d}{\sqrt{2}} & -g_R v_R & -g_R v_R' & 0 & 0 & 0 & M_{2R} \end{pmatrix}$$

$$\mu_{\rm eff} = \lambda_3 \frac{v_S}{\sqrt{2}},\ \mu_S = \lambda_S \frac{v_S}{\sqrt{2}},\ \mu_{L,R} = \lambda_{L,R} \frac{v_S}{\sqrt{2}} \text{ and } \mu_{u,d} = \lambda_3 \frac{v_{u,d}}{\sqrt{2}}$$

$\lambda_{R,L}$ large,
v_R, v'_R, v_S large
→
most states heavy

Possibly light:
gauginos,
bidoublet Higgsinos

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Constraints on spectrum

Strict limits on doubly charged Higgses

fix $BR(H^{\pm\pm} \to \tau^{\pm}\tau^{\pm})$=92%, $BR(H^{\pm\pm} \to \mu^{\pm}\mu^{\pm}/e^{\pm}e^{\pm})$=4%, $m_{H^{\pm\pm}} >$ 350 GeV

$(m_N)_{\mathrm{ij}} = (h_{RR})_{\mathrm{ij}}\, v_R$ → m_{N_τ} ≈750 GeV, $m_{N_e} \approx m_{N_\mu} \approx$ 150 GeV

Impose m_h=125.1±0.3 GeV;

tan $\beta \geq 5$, stop masses ≈a couple of TeV and stop mixings

$m_{H_2^0} \approx m_{A_1^0} \approx m_{H_1^\pm}$ constrained by $B_s \to \mu\mu$, which favors moderate tan β

$m_A^2 \approx g_R^2\, v_R^2(tan^2\beta_R - 1)$ around (650 GeV)^2; assume $tan\,\beta_R$ ≈1.05

Other Higgs masses several TeV (≈ v_R or v_S)

Decays to superpartners around 20% → $m_{W_R} \geq$ 3.3 TeV → $m_{Z_R} \geq$ 5.6 TeV

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DARK MATTER

Candidates specific for SUSYLR

The correct amount of relic density can be achieved by:

Sneutrinos:

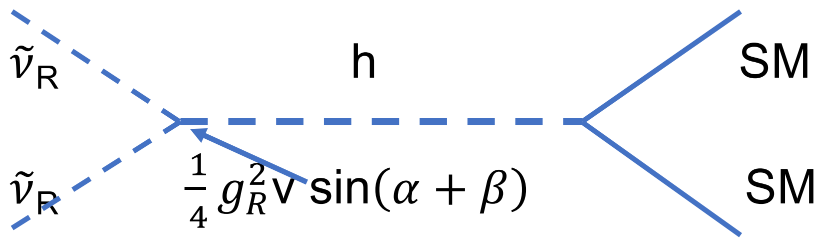
- Right sneutrino LSP with annihilations through Higgs: $\tilde{\nu}_R$ mass 200-250 GeV
- Right sneutrino LSP with coannihilations with another sneutrino or neutralinos: $\tilde{\nu}_R$ mass up to ~ 700 GeV

Neutralinos:

- Dominantly bino-like neutralino with mass $m_h/2$
- Bidoublet Higgsino – four degenerate neutralinos+two charginos → with coannihilations 700 GeV Higgsino

Right-sneutrino without coannihilation

Right-sneutrino annihilation through the Higgs boson: since right-sneutrinos belong to doublets, they couple to the Higgs boson via gauge coupling:



The coupling is strong enough to reach the measured values

Right-sneutrino mass is the only free parameter

→ relic density determines the sneutrino mass

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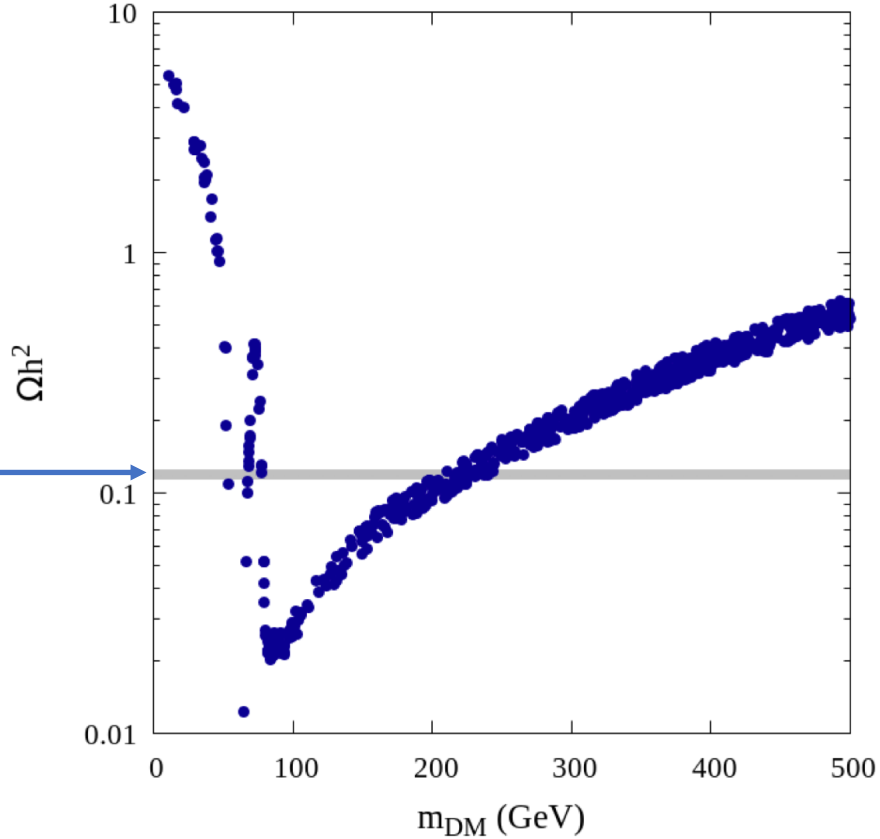
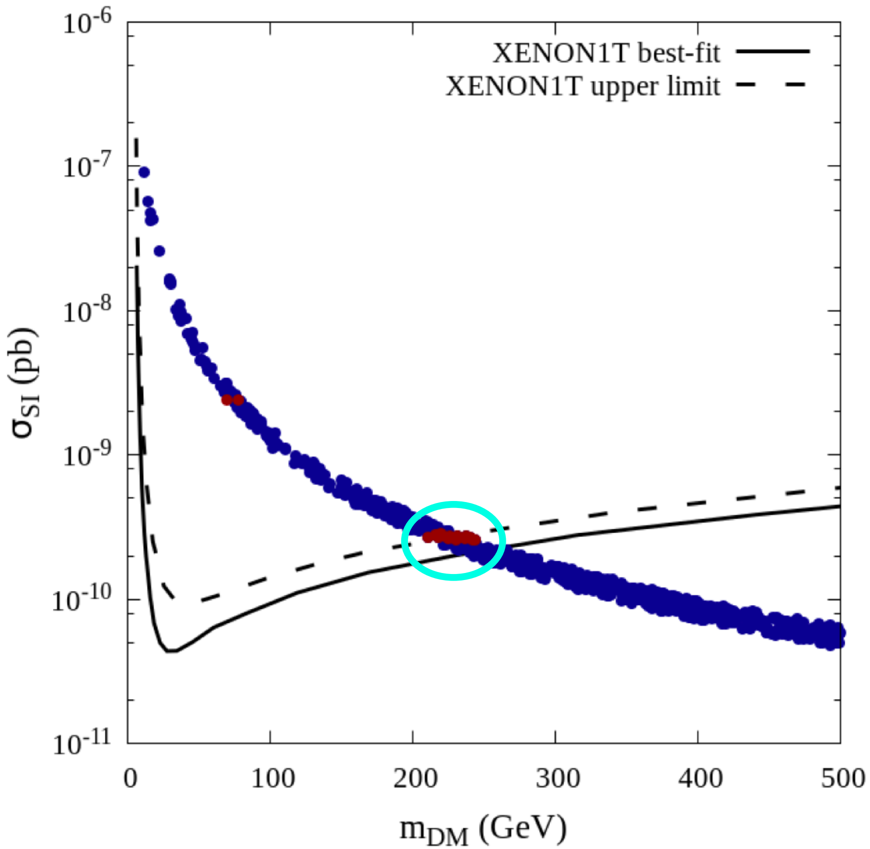
[0.1163, 0.1217]

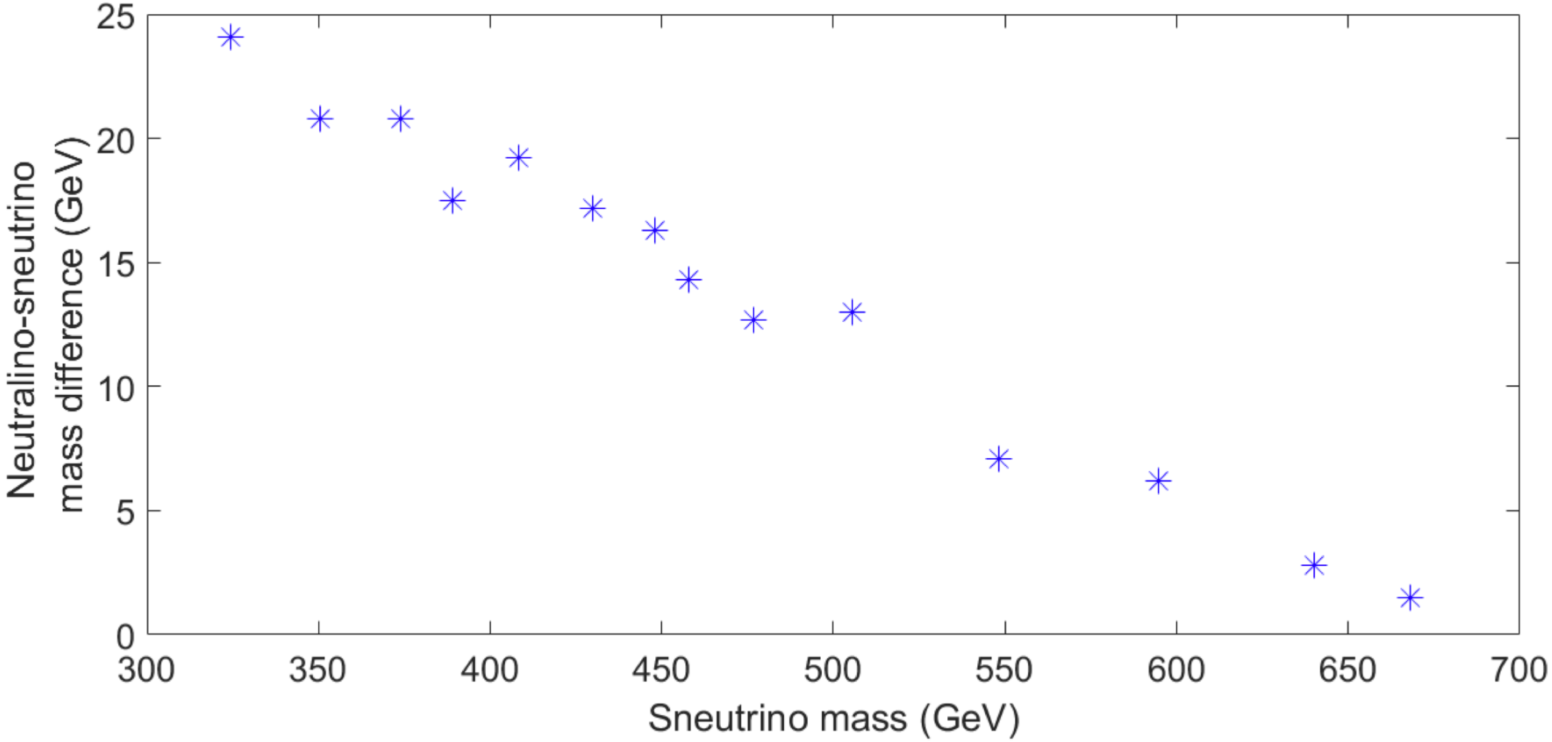




Barely allowed around 250 GeV

Add coannihilations:

Assume sneutrino LSP nearly degenerate with NLSP Higgsino
→ e.g. $\tilde{\nu}\tilde{\chi}^{\circ} \rightarrow \ell^{\pm}W^{\mp}$ via t-channel wino → sneutrino DM mass can be close to 700 GeV



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Higgsino LSP

Bidoublet Higgsinos form a nearly degenerate set of four neutralinos and two charginos

→

Coannihilations cannot be avoided, when the lightest Higgsino is the LSP

→ e.g. $\tilde{\chi}_i^0 \tilde{\chi}_j^\pm \to q\bar{q}'$ and $\tilde{\chi}_i^0 \tilde{\chi}_j^0 \to q\bar{q}\ \ ,\ \ VV \quad (V = W, Z)$ via t-channel wino;
the Planck-value for relic density is achieved with 750 GeV LSP Higgsino

Additional annihilations with sneutrinos decrease the effective annihilation cross section and LSP Higgsino mass would be around 675-700 GeV.

Note that in this case the spectrum is rather heavy, and difficult to detect.

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BENCHMARKS AND DETECTION AT THE LHC

Typically $BR(W_R \to jj) \approx$ 50 %, $BR(W_R \to N\ell) \approx$ 16 %, $BR(W_R \to \tilde{\chi}\tilde{\chi}) \approx$ 22 %,

Benchmarks with

1. LSP $\tilde{\nu}_\tau$, no coannihilations ($\tilde{\nu}_\tau$ mass 278 GeV, hard leptons+$E_{T,miss}$)

3. Coannihilating $\tilde{\nu}_\tau$ and Higgsinos ($\tilde{\nu}_\tau$ mass 387 GeV, τ's +$E_{T,miss}$)

5. All light superpartners bidoublet Higgsinos (LSP neutralino mass 700 GeV, heavy spectrum, hard to detect at 13 TeV LHC)

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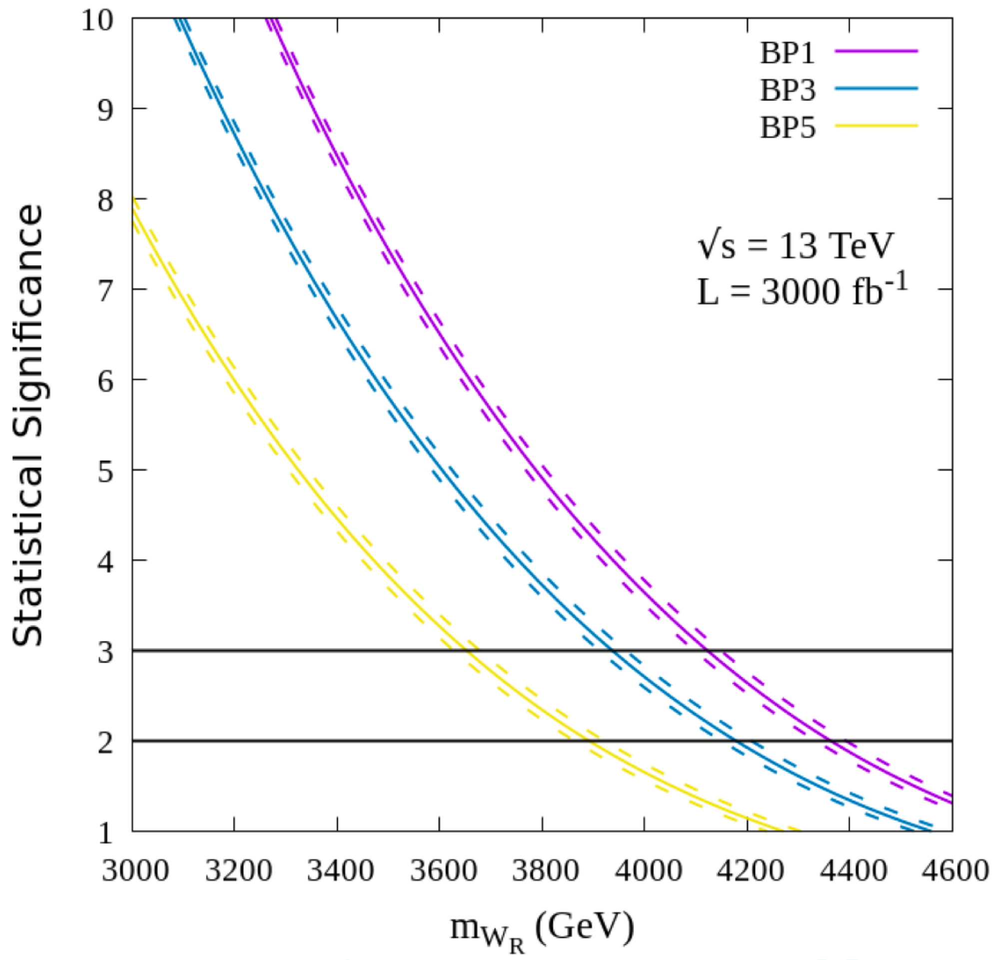
W_R production;
decay to neutralinos, charginos

→ Leptons and missing energy
→ Electroweakino searches are relevant

Signal significance $\mathcal{S} = \frac{S}{\sqrt{S+B+\sigma_B^2}}$



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CONCLUSIONS

In SUSYLR very interesting viable possibilities for supersymmetric dark matter, different from MSSM options

May need HE-LHC for detection
(preliminary results: good chances to detect Higgsinos at 27 TeV)

Thank You.