Chargino and neutralino phenomenology in Left-Right supersymmetry

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Outline

Left-Right symmetry in particle physics: 1

General features

- Class of models based on Left $\leftrightarrow$ Right symmetry between fermions.
- Based on gauge group $SU(2)_L \times SU(2)_R \times G$ where G commutes with $SU(2)_L \times SU(2)_R$.

Non supersymmetric version

- Introduced in '70s for $\mathcal{P}$ and $\mathcal{CP}$ violation in Standard Model
- Many studies were done and many advantages found
  - Strong $\mathcal{CP}$ problem solved D. Guadagnoli, R.N. Mohapatra, I. Sung (JHEP 2011)
  - Neutrino masses via seesaw mechanism Pavel Fileviez Perez (JHEP 2009)
  - Warm dark matter from right-handed neutrino M. Nemevsek , G. Senjanovic, Y. Zhang (JCAP 2012)
  - Possible embedding in $SO(10)$ Grand Unified theories N.T. Shaban, W.J. Stirling (Phys.Lett. B291 1992)

Hierarchy problem still present

Left-Right symmetry in particle physics: 2

General features

- Class of models based on Left $\leftrightarrow$ Right symmetry between fermions.
- Based on gauge group $SU(2)_L \times SU(2)_R \times G$ where G commutes with $SU(2)_L \times SU(2)_R$.

Supersymmetric version

- Introduced in late '70s
- Inherits from non-supersymmetric version's advantages
- Brings new solutions to MSSM's issues
  - Susy $\mathcal{CP}$ problem Mohapatra and Rasin (Phys. Rev. D54 1996)

We are going to focus on the supersymmetric version.

1. Motivations
2. Model building
3. Preliminary results
4. Conclusion

Gauge, Quarks and Leptons

Gauge sector

- Gauge sector: $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$
  ($B-L$: Baryon number - Lepton number)
- Gauge fields: For each subgroup, one gauge superfield

$$\begin{array}{rcl} V_3 = (8,1,1,0) & \longrightarrow & (V_3, \tilde{V}_3) \\ V_{2L} = (1,3,1,0) & \longrightarrow & (V_{2L}, \tilde{V}_{2L}) \\ V_{2R} = (1,1,3,0) & \longrightarrow & (V_{2R}, \tilde{V}_{2R}) \\ V_1 = (1,1,1,0) & \longrightarrow & (V_1, \tilde{V}_1) \end{array}$$

Matter sector

- Only need to promote Standard Model's $SU(2)_L$ singlets to $SU(2)_R$ doublets

$$Q_L = (3,2,1,\frac{1}{3}) = \begin{pmatrix} u_L \\ d_L \end{pmatrix}, \quad Q_R = (\bar{3},1,2^*,-\frac{1}{3}) = \begin{pmatrix} u_R^c & d_R^c \end{pmatrix}$$

$$L_L = (1,2,1,-1) = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}, \quad L_R = (1,1,2^*,1) = \begin{pmatrix} \nu_R^c & e_R^c \end{pmatrix}$$

Higgs sector

Symmetry breaking pattern

1. Left-Right symmetry breaking

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

$\to$ can be done either with $SU(2)_R$ triplets or $SU(2)_R$ doublets.
$\to$ we choose triplets to break the symmetry

$\Rightarrow \delta_{\{1,2\}R} = (1, 1, \mathbf{3}, \pm 2), \quad \delta_{\{1,2\}L} = (1, \mathbf{3}, 1, \pm 2).$
$\Rightarrow$ **Automatic R-parity**.
$\Rightarrow$ **Doubly charged particles**.
$\Rightarrow$ **Seesaw mechanism**.

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2. Electroweak symmetry breaking

$$SU(3)_c \times SU(2)_L \times U(1)_Y \rightarrow SU(3)_c \times U(1)_{em}$$

$\rightarrow$ achieved with $SU(2)_L \times SU(2)_R$ bidoublets

$\Rightarrow \Phi_{\{1,2\}} = (1, \mathbf{2}, \mathbf{2}^*, \mathbf{0})$.
$\Rightarrow$ Masses for both **up**- and **down**-type fermions,
$\Rightarrow$ **non-trivial** CKM.

Higgs sector

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3. Gauge singlet $S = (1, 1, 1, 0)$
$\Rightarrow$ Succeed in conserving both R-parity and electric charge.

Babu and Mohapatra, (Phys.Lett. B668 2008).

Higgs sector: Summary

- Triplets

$$\delta_{1\{L,R\}} = \begin{pmatrix} \delta^1_{1\{L,R\}} \\ \delta^2_{1\{L,R\}} \\ \delta^3_{1\{L,R\}} \end{pmatrix} \rightsquigarrow \Delta_{1\{L,R\}} = \begin{pmatrix} \frac{\Delta^-_{1\{L,R\}}}{\sqrt{2}} & \Delta^0_{1\{L,R\}} \\ \Delta^{--}_{1\{L,R\}} & -\frac{\Delta^-_{1\{L,R\}}}{\sqrt{2}} \end{pmatrix}$$

$$\delta_{2\{L,R\}} = \begin{pmatrix} \delta^1_{2\{L,R\}} \\ \delta^2_{2\{L,R\}} \\ \delta^3_{2\{L,R\}} \end{pmatrix} \rightsquigarrow \Delta_{2\{L,R\}} = \begin{pmatrix} \frac{\Delta^+_{2\{L,R\}}}{\sqrt{2}} & \Delta^{++}_{2\{L,R\}} \\ \Delta^0_{2\{L,R\}} & -\frac{\Delta^+_{2\{L,R\}}}{\sqrt{2}} \end{pmatrix}$$

- Bidoublets

$$\Phi_1 = \begin{pmatrix} \phi^0_1 & \phi^+_1 \\ \phi'^-_1 & \phi'^0_1 \end{pmatrix}, \quad \Phi_2 = \begin{pmatrix} \phi^0_2 & \phi^+_2 \\ \phi'^-_2 & \phi'^0_2 \end{pmatrix}$$

- Singlet S

At the end, we have:

- 4 pairs of doubly charged Higgs bosons,
- 8 (of which 2 Goldstones) pairs of singly charged,
- 18 (of which 9 scalars, 7 pseudo-scalars and 2 Goldstones) neutral fields.

Higgs sector: Summary

At the minimum of the potential, neutral scalars get a vacuum expectation value

- Triplets

$$\langle \Delta_{1\{L,R\}} \rangle = \begin{pmatrix} 0 & v_{1\{L,R\}} \\ 0 & 0 \end{pmatrix}, \quad \langle \Delta_{2\{L,R\}} \rangle = \begin{pmatrix} 0 & 0 \\ v_{2\{L,R\}} & 0 \end{pmatrix}$$

- Bidoublets

$$\langle \Phi_1 \rangle = \begin{pmatrix} v_1 & 0 \\ 0 & v_1' e^{i\alpha_1} \end{pmatrix}, \quad \langle \Phi_2 \rangle = \begin{pmatrix} v_2' e^{i\alpha_2} & 0 \\ 0 & v_2 \end{pmatrix}$$

- Singlet $\langle S \rangle = v_s e^{i\alpha_s}$

Symmetry breaking pattern
Kaon systems
Neutrino data

$$\left.\begin{array}{l} \text{Symmetry breaking pattern} \\ \text{Kaon systems} \\ \text{Neutrino data} \end{array}\right\} v_{\{1,2\}R} \gg v_{\{1,2\}} \gg v_1' \simeq v_2' \simeq v_{1L} \simeq v_{2L}$$

Superpotential

- General superpotential

$$
\begin{aligned}
W &= y_Q^1\ \tilde{Q}_L\hat{\Phi}\tilde{Q}_R + y_Q^2\ \tilde{Q}_L\hat{\Phi}_2\tilde{Q}_R + y_L^1\ \tilde{L}_L\hat{\Phi}\tilde{L}_R + y_L^2\ \tilde{L}_L\hat{\Phi}_2\tilde{L}_R \\
&+ y_L^3\ \hat{\tilde{L}}\Delta_{2L}\tilde{L}_L + y_L^4\ \hat{\tilde{L}}_R\Delta_{1R}\tilde{L}_R \\
&+ (\mu_L + \lambda_L S)\Delta_{1L}\cdot\hat{\Delta}_{2L} + (\mu_R + \lambda_R S)\Delta_{1R}\cdot\hat{\Delta}_{2R} + (\mu_3 + \lambda_3 S)\Phi_1\cdot\hat{\Phi}_2 \\
&+ \frac{1}{3}\lambda_s S^3 + \mu_s S^2 + \xi_S S.
\end{aligned}
$$

$\Rightarrow$ Dirac mass terms for neutrinos
$\Rightarrow$ Majorana mass terms for neutrinos
} Seesaw mechanism

- Discrete symmetry $\mathbb{Z}_3$

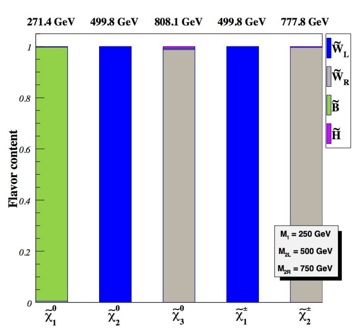
$\Rightarrow$ All μ terms set to 0

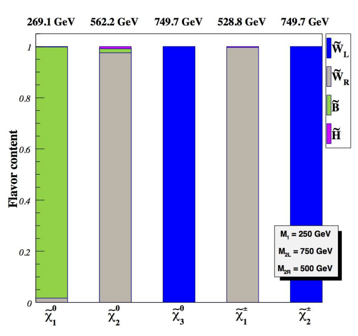
$\Rightarrow$ Domain wall issues eluded with higher-dimensional, non-renormalizable, Planck-scale suppressed operators

Setup for the phenomenological study

- Singlet vacuum expectation value v_s **much bigger** than any other *vev*
  - $\Rightarrow$ Shift all the higgsino fields to a higher scale.
  - $\Rightarrow$ Focus on the 3 lightest neutralinos and 2 lightest charginos (*gauginos*.)
- Organizing principle based on unification at high energy
  - $\Rightarrow$ Decouple squarks and gluinos at low scale.
- Universal masses for right- and left-handed sleptons at low scale.
- **Scan** of the parameter space defined by $(M_{\tilde{W}_L}, M_{\tilde{W}_R}, M_{\tilde{B}})$
  - $\Rightarrow$ Different hierarchies in the mixings of the *gauginos*
  - $\Rightarrow$ Constraints: the lightest neutralino is the dark matter

Four scenarios

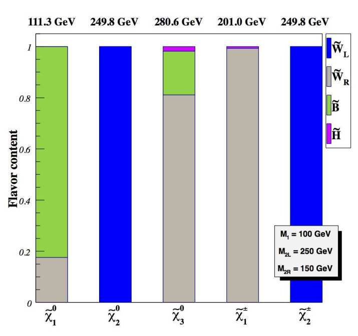


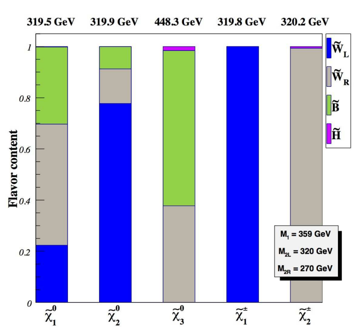


Two "pure" scenarios with no mixings

$\Rightarrow$ Lightest Supersymmetric Particle = bino
$\Rightarrow$ Small mass splittings between charginos and neutralinos
$\Rightarrow$ Expected Cascade decays to at most 2 leptons and MET

Four scenarios





Two "mixed" scenarios with maximum mixings

$\Rightarrow$ Lightest Supersymmetric Particle = mix between wino and bino
$\Rightarrow$ Very small mass splittings between charginos and neutralinos
$\Rightarrow$ Expected Cascade decays to at most 2 leptons and large MET

1. Motivations
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3. **Preliminary results**
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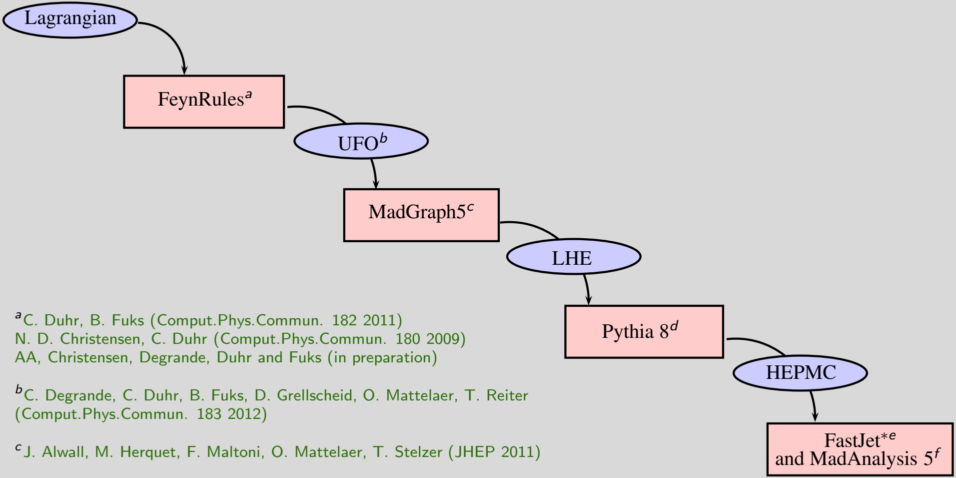
Tools chain



[a] C. Duhr, B. Fuks (Comput.Phys.Commun. 182 2011)
N. D. Christensen, C. Duhr (Comput.Phys.Commun. 180 2009)
AA, Christensen, Degrande, Duhr and Fuks (in preparation)

[b] C. Degrande, C. Duhr, B. Fuks, D. Grellscheid, O. Mattelaer, T. Reiter (Comput.Phys.Commun. 183 2012)

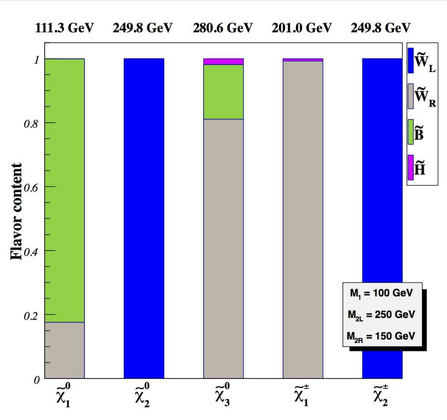
[c] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer, T. Stelzer (JHEP 2011)

[d] T. Sjstrand, S. Mrenna, P. Skands (Comput.Phys.Commun. 2008)

[e] M. Cacciari, G. P. Salam, G. Soyez (Eur.Phys.J. C72 2012) * Assume ideal detector

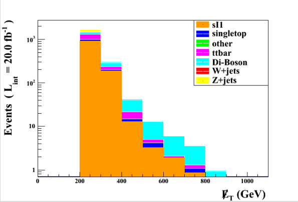
[f] E. Conte, B. Fuks, G. Serret (Comput.Phys.Commun. 184 2013)

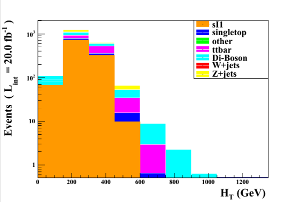
Scenario II: The setup

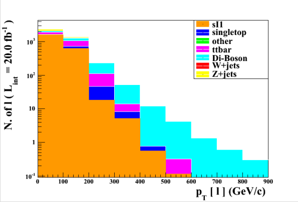


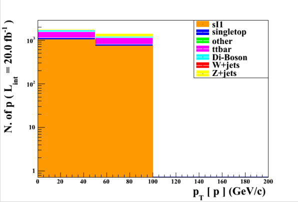
Process	xsection (fb) @ 8TeV
p p $\rightarrow \chi_2^0 \chi_1^\pm$	20.60
p p $\rightarrow \chi_3^0 \chi_3^\pm$	1.41
p p $\rightarrow \chi_1^+ \chi_1^-$	4.61
p p $\rightarrow \chi_2^+ \chi_2^-$	0.42

Preliminary results: 2 Leptons









Reject

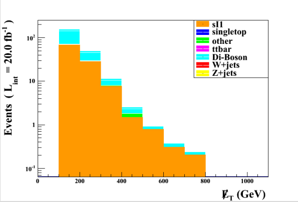
- Any lepton with PT < 10 GeV
- Any jet such as $\Delta_R(j, e^{\pm}) < 0.1$
- Any lepton such as $\Delta_R(j, l) < 0.4$
- Any jet with PT< 20 GeV
- Events with N(leptons) $\neq 2$

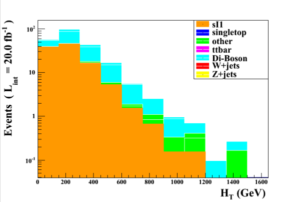
Reject events with

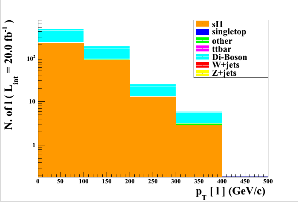
- MET < 200 GeV
- N(jets) > 3
- PT(jets) > 100 GeV
- PT(leptons) < 50 GeV

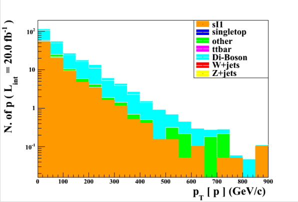
$$\mathbf{S = 1124,\ B = 1128,\ S/B = 0.99,\ S/\sqrt{S+B}} = 23.68$$

Preliminary results: 3 Leptons or more









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- Any lepton with PT < 10 GeV
- Any jet such as $\Delta_R(j, e^{\pm}) < 0.1$
- Any lepton such as $\Delta_R(j, l) < 0.4$
- Any jet with PT< 20 GeV
- Events with N(leptons) < 3

Reject events with

- MET < 100 GeV
- PT(lepton) > 400 GeV
- PT(lepton) < 50 GeV

$$\mathbf{S = 108\ events,\ B = 116,\ S/B = 0.93,}\ \ \mathbf{S}/\sqrt{\mathbf{S+B}} = 7.21$$

Conclusion

- Left-right supersymmetric models offer good theoretical motivations
- They also offer interesting phenomenological signatures (doubly charged particles)
- We chose to only focus on the charginos-neutralino sector
- Promising preliminary results
- ... but not for all scenarios
  $\rightarrow$ New cuts to find (b-veto for example)

Left-Right symmetry and Strong $\mathcal{CP}$ problem

Non susy version of L↔ R symmetric models

- See paper by Babu and Mohapatra, Phys.Rev.D41, 1286 (1990)
- The $\bar{\theta}$ parameter defined by

$$\bar{\theta} = \theta + Arg(Det(M_u M_d)) \sim 10^{-9}$$

with

  - $\frac{\theta}{32\pi^2}$ coefficient of $F\tilde{F}$ in the QCD lagrangian
  - $M_{\{u,d\}}$ mass matrix of the up- (down-) type quarks.
- Parity imposes $\theta = 0$

New vector like quarks and leptons
Or other discrete symmetries
} Hermiticity of yukawas $\Rightarrow Det(M_{\{u,d\}})$ is real

$$\boxed{\Rightarrow \bar{\theta} = 0}$$

Result holds for 1 loop level
Contributions start at 2 loop level.

Left-Right symmetry and Strong $\mathcal{CP}$ problem

In susy version of L$\leftrightarrow$ R symmetric models

- See paper by Mohapatra and Rasin, Phys.Rev.D54, 5835 (1996)
- The $\bar{\theta}$ parameter defined by

$$\bar{\theta} = \theta + Arg(Det(M_u M_d)) - 3Arg(m_{\tilde{g}}) \sim 10^{-9}$$

with

- $\frac{\theta}{32\pi^2}$ coefficient of $F\tilde{F}$ in the QCD lagrangian.
- $M_{\{u,d\}}$ mass matrix of the up- (down-) type quarks.
- $m_{\tilde{g}}$ Gluino mass.

$$\left.\begin{array}{l}\text{Parity}\\ \text{Supersymmetry}\\ \text{R-symmetry}\end{array}\right\} \Rightarrow \left\{\begin{array}{l}\theta = 0\\ \text{Superpotential parameters real}\\ \text{Gluino mass real}\\ \text{Singlet and bidoublets vevs real}\end{array}\right.$$

$$\boxed{\Rightarrow \bar{\theta} = 0}$$