"Exotic quark production at LHC in the Minimal Supersymmetric 3-3–1 Model"

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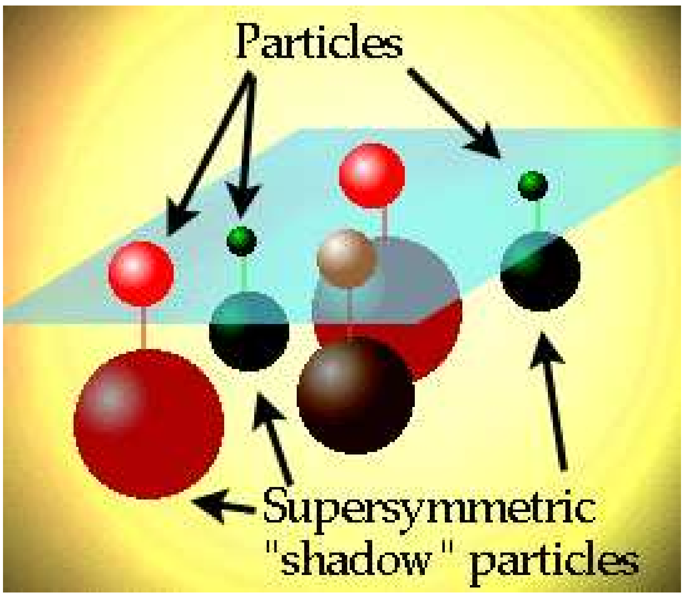
Motivation to study SUSY

- Unify bosons and fermions

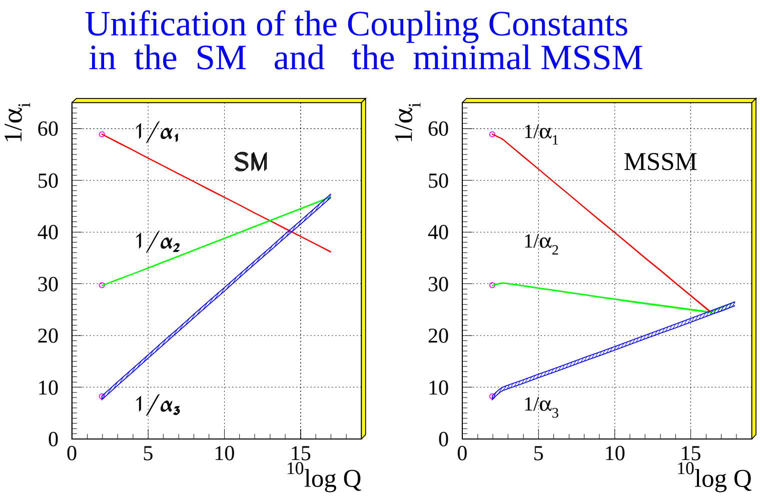
$$Q|\text{boson}> = |\text{fermion}>$$
$$Q|\text{fermion}> = |\text{boson}>$$



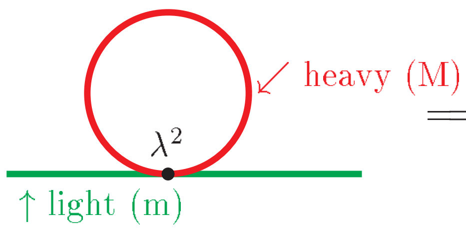
- SUSY local unify with Gravity (Supergravity)

$$\text{spin}2 \rightarrow \text{spin}\frac{3}{2} \rightarrow \text{spin}1 \rightarrow \text{spin}\frac{1}{2} \rightarrow \text{spin}0$$

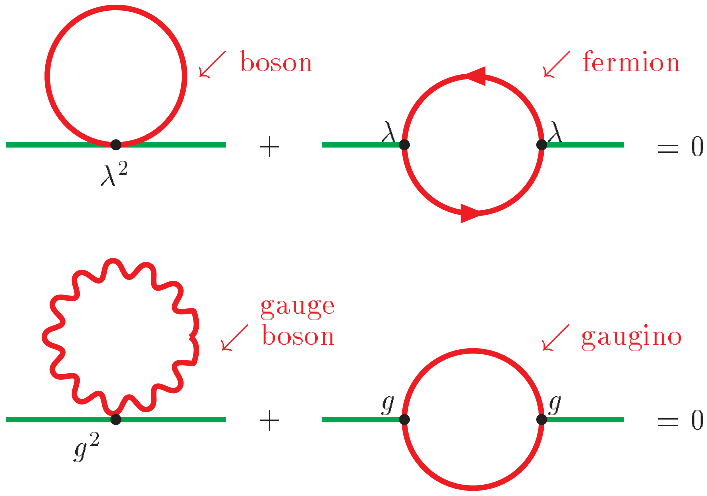
- Unify all the gauge constants



- Solve the hierarchy problem



$$\Longrightarrow \quad \begin{array}{cccc} \delta m^2 & \sim \lambda^2 & \cdot & M^2 \\ \wr & \wr & & \wr \\ 10^2 & 10^{-1} & & 10^{16} \end{array}$$



Cancellation is true SUSY breaking scale

$$\sum_{bosons} m^2 - \sum_{fermions} m^2 = M^2_{SUSY} \leq 1\text{TeV}$$

Higgs Boson

$$\delta M_h^2 \sim g^2 M^2_{SUSY} \sim M_h^2$$

Motivation to study 331 Models

1. At low energies they coincide with the SM;

2. These sort of model are anomally free only if the family number is 3 or any multiple of 3;

3. They have bileptons charged vector bosons;

4. They have doubly charged vector bosons;

5. They have new heavy quarks;

6. It explains why $\sin^2\theta_W < \frac{1}{4}$ is observed;

7. It solves the strong CP problem;

8. The model has several sources of CP violation;

9. Since one generation of quarks is treated differently from the others this may lead to a natural explanation for the large mass of the top quark;

Some Phenomenological studies at 3-3-1 Model

- Assymetries can probe vector bosons and Scalars at ILC (Phd Thesis);

- Studies from UERJ (J. Sa Borges) and UFRJ (Yara Do Amaral Coutinho)

  1. Extra Neutral Gauge Boson $e^{+}+e^{-} \longrightarrow \mu^{+}+\mu^{-}$ and $e^{-}+e^{+} \rightarrow e^{+}+e^{+}+e^{-}+e^{-}$

  2. 3-3-1 exotic quark search at CERN LEPII-LHC

- M. D. Tonasse and J.E. Cieza Montalvo

  1. Doubly charged Higgs in 3-3-1 model at the CERN LHC and ILC

  2. Neutral Higgs bosons in the SU(3)(L) x U(1)(N) model

Why study MSUSY

- We don't need the anti-sextet or an extra lepton singlet in order to all the leptons in the model get their masses at tree level;

- Due the mixing $\widehat{L}\widehat{\eta}$ two neutrinos get their masses at tree level as in the MSSM model with break R-Parity;

- The Neutrinoless double beta decay is allow;

- The nucleon are stable (Therefore the proton is stable and the neutron antineutron oscillation is forbideen);

- Scalar sector have only three triplets otherwise the non supersymmetric model;

- The lightest scalar Higgs has a mass upper limit given by 112 GeV;

- There is also a good candidate for Self Interacting Dark Matter (SIDM);

- New Signal to lepton and baryon number violation;

Original references

- T. V. Duong and E. Ma, Phys. Lett. **B316**, 307 (1993) (preliminar analyses in scalar sector)

- H. N. Long and P. B. Pal, Mod. Phys. Lett. **A13**, 2355 (1998) (proton decay)

- J. C. Montero, V. Pleitez and M. C. Rodriguez, *Phys. Rev.* **D65**, 035006 (2002) (Construction of the Model using superfields formalism)

- M. Capdequi-Peyranère and M.C. Rodriguez, *Phys. Rev.* **D 65**, 035001 (2002) (Production of double charged charginos at ILC)

- M. C. Rodriguez, to appear in Journal of Modern Physics (mass spectrum of this model)

leptons

$$L_l = \begin{pmatrix} \nu_l \\ l \\ l^c \end{pmatrix}_L \sim (\mathbf{1}, \mathbf{3}, 0), \quad l = e, \mu, \tau.$$

quarks

$$Q_{\alpha L} = \begin{pmatrix} d_\alpha \\ u_\alpha \\ j_\alpha \end{pmatrix}_L \sim \left(\mathbf{3}, \mathbf{3}^*, -\frac{1}{3}\right) \quad \alpha = 1, 2$$

$$Q_{3L} = \begin{pmatrix} u_3 \\ d_3 \\ J \end{pmatrix}_L \sim \left(\mathbf{3}, \mathbf{3}, \frac{2}{3}\right)$$

their singlets

$$u^c_{iL} \sim \left(\mathbf{3}^*, \mathbf{1}, -\frac{2}{3}\right) \qquad d^c_{iL} \sim \left(\mathbf{3}^*, \mathbf{1}, \frac{1}{3}\right)$$

$$j^c_{\alpha L} \sim \left(\mathbf{3}^*, \mathbf{1}, \frac{4}{3}\right) \qquad J^c_L \sim \left(\mathbf{3}^*, \mathbf{1}, -\frac{5}{3}\right)$$

the gauge bosons

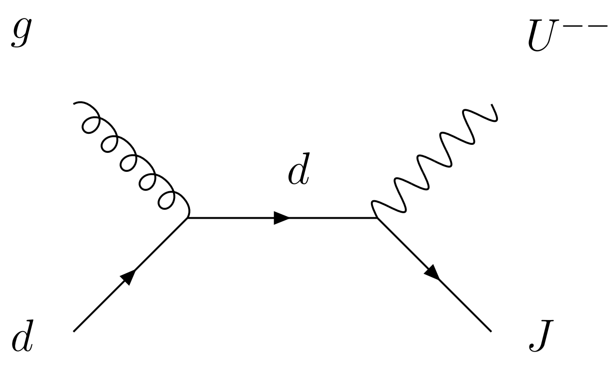
$$
\begin{aligned}
W_m^{\pm}(x) &= -\frac{1}{\sqrt{2}}(V_m^1(x) \mp iV_m^2(x)) \\
V_m^{\pm}(x) &= -\frac{1}{\sqrt{2}}(V_m^4(x) \pm iV_m^5(x)) \\
U_m^{\pm\pm}(x) &= -\frac{1}{\sqrt{2}}(V_m^6(x) \pm iV_m^7(x)) \\
A_m(x) &= \frac{1}{\sqrt{1+4t^2}}\left[(V_m^3(x) - \sqrt{3}V_m^8(x))t + V_m\right] \\
Z_m^0(x) &= -\frac{1}{\sqrt{1+4t^2}}\left[\sqrt{1+3t^2}V_m^3(x)\right. \\
&+ \left.\frac{\sqrt{3}t^2}{\sqrt{1+3t^2}}V_m^8(x) - \frac{t}{\sqrt{1+3t^2}}V_m(x)\right] \\
Z_m'^0(x) &= \frac{1}{\sqrt{1+3t^2}}(V_m^8(x) + \sqrt{3}tV_m(x))
\end{aligned}
$$

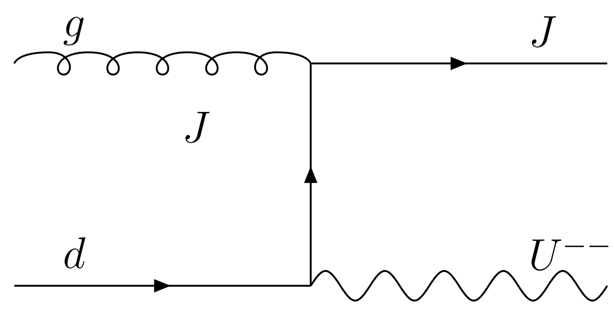
$\mathcal{L}_{qqV}$: U^{--} and V^{-} are called bileptons

$$\begin{aligned}\mathcal{L}_q^{CC} &= -\frac{g}{2\sqrt{2}}\left[\overline{U}\gamma^m(1-\gamma_5)V_{\text{CKM}}DW_m^+\right.\\ &+ \overline{U}\gamma^m(1-\gamma_5)\zeta_1\mathcal{J}\mathcal{V}_m\\ &+ \left.\overline{D}\gamma^m(1-\gamma_5)\zeta_2\mathcal{J}\mathcal{U}_m\right] + \text{H. c.}\end{aligned}$$

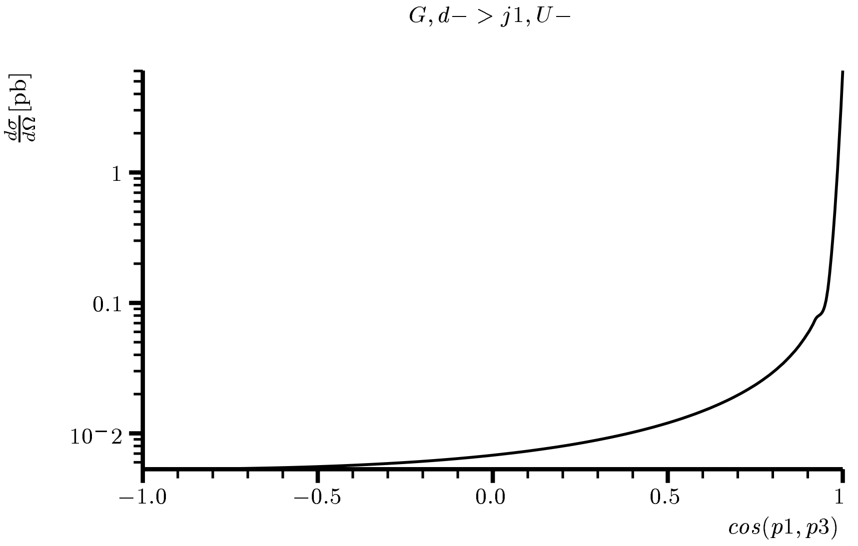
Processes: $pp \to j + X$

$$\begin{aligned} g + d &\to U^{--} + J \\ g + u &\to U^{++} + j_\alpha \end{aligned}$$

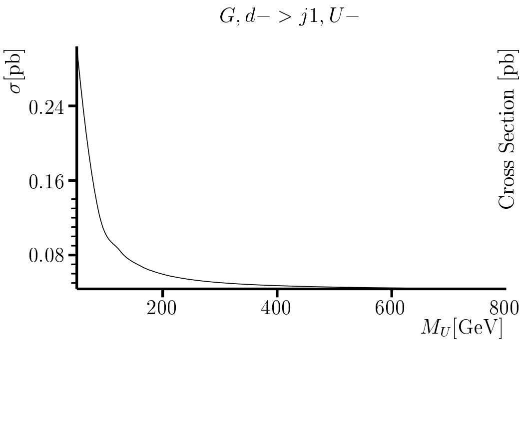


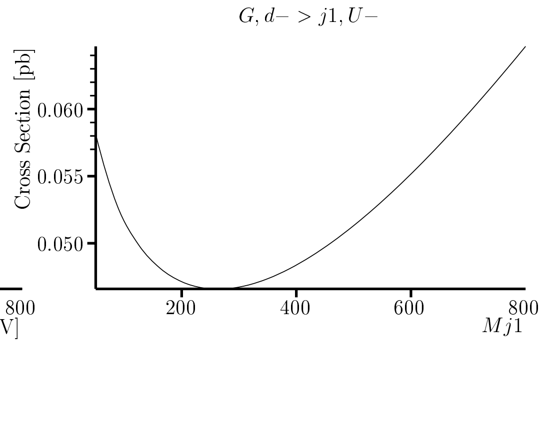


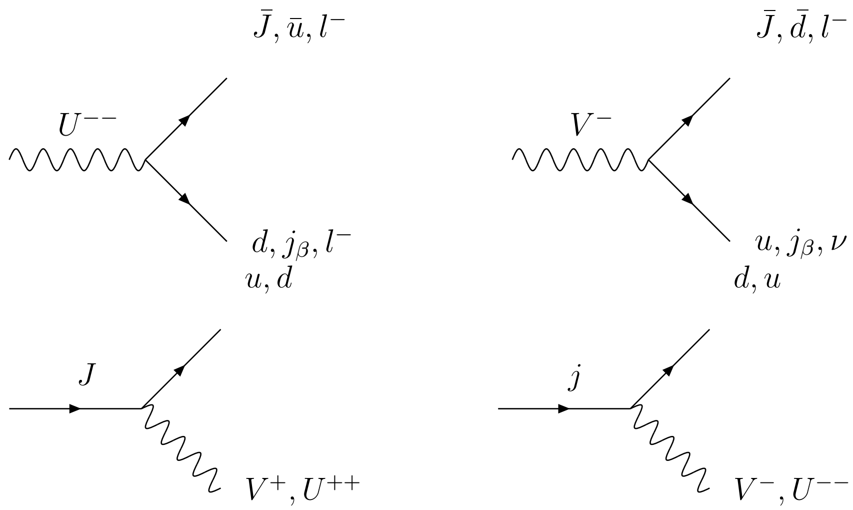
Differential Cross Section $gd \to JU^{--}$



Total Cross Section $gd \to JU^{--}$ as function of M_U (left) and M_J (right)







J decay $l^+l^+d, l^+\nu u$ while j $l^-\nu d.l^-l^-\bar{u}$

Case number	Mass relation	decay mode
1	$M_U > M_J$, $M_U > M_j$	$\bar{J}d$, $\bar{u}d$, l^-l^-
2	$M_U < M_J$, $M_U > M_j$	$\bar{J}d$, l^-l^-
3	$M_U > M_J$, $M_U < M_j$	$\bar{u}d$, l^-l^-
4	$M_U < M_J$, $M_U < M_j$	l^-l^-

Experimental signal is $gd \to JU^{--} \to lllX$

$\underline{l^+l^+d}\ \underbrace{l^-l^-\bar{d}d}$	$\underline{l^+\bar{\nu}u}\ \underbrace{l^-l^-\bar{d}d}$
$\underline{l^+l^+d}\ \underbrace{l^-\nu\bar{u}d}$	$\underline{l^+\bar{\nu}u}\ \underbrace{l^-\nu\bar{u}d}$
$\underline{l^+l^+d}\ \underbrace{l^-l^-\bar{u}u}$	$\underline{l^+\bar{\nu}u}\ \underbrace{l^-l^-\bar{u}u}$
$\underline{l^+l^+d}\ \underbrace{l^-l^-}$	$\underline{l^+\bar{\nu}u}\ \underbrace{l^-l^-}$

J-quark is heavier than $j_{1,2}$ quarks and their masses are in TeV scale

$M_U = 734,63$ GeV $M_V = 730,28$ GeV

$pp \to jU \to l^{\pm}l^{\pm}l^{\mp}X$

background

- SM $W^\star Z^\star$, $W^\star\gamma^\star$,$Z^\star Z^\star$ and $\bar{q}q$

- MSSM $\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 l^{\pm}\nu_l$ and $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 l^+l^-$

U has superpartner double charged charginos

$$\begin{aligned}\lambda_W^{\pm}(x) &= -\frac{1}{\sqrt{2}}(\lambda_A^1(x) \mp i\lambda_A^2(x)) \\ \lambda_V^{\pm}(x) &= -\frac{1}{\sqrt{2}}(\lambda_A^4(x) \pm i\lambda_A^5(x)) \\ \lambda_U^{\pm\pm}(x) &= -\frac{1}{\sqrt{2}}(\lambda_A^6(x) \pm i\lambda_A^7(x)) \\ & \quad \lambda_A^3 \;\; \lambda_A^8 \;\; \lambda_B \;\; \text{(neutral gauginos)}\end{aligned}$$

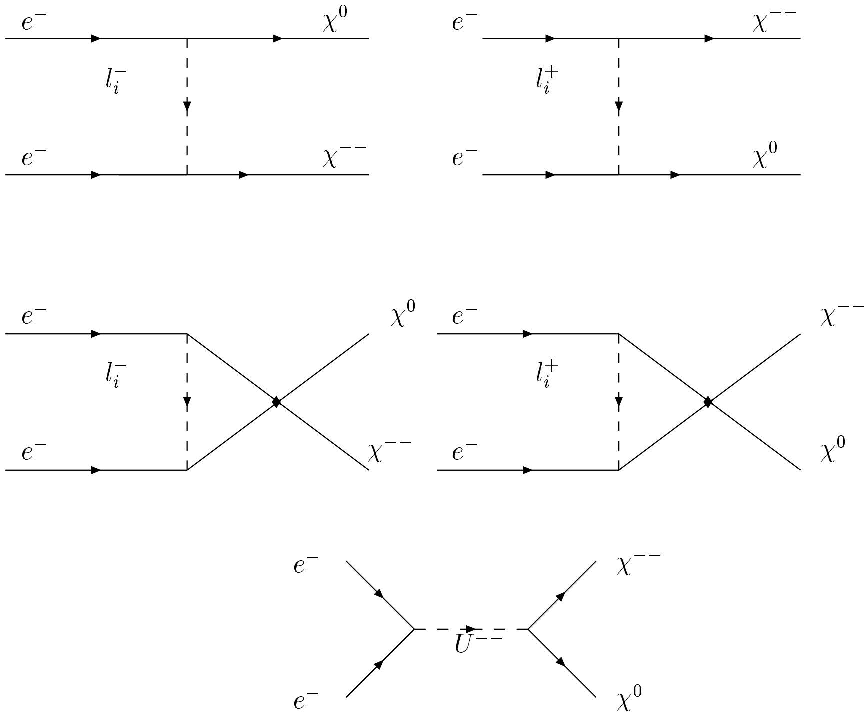
$\mathcal{L}_{H\tilde{H}\tilde{V}}$ mixing gauginos higgsinos

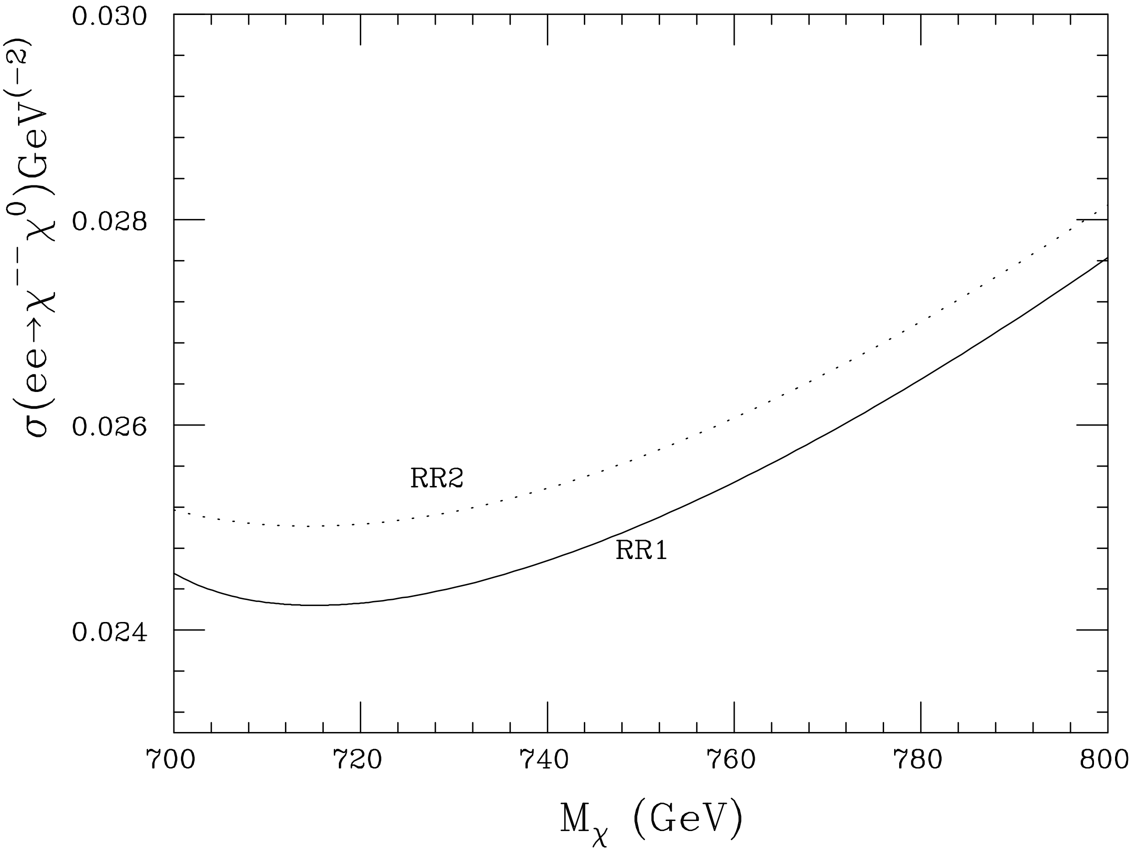
- $(\lambda_U^{++}\tilde{\rho}^{++}\tilde{\rho}'^{--}\tilde{\chi}'^{++}\tilde{\chi}^{--})$ to $\tilde{\chi}^{\pm\pm}$

- $(e^c, \mu^c, \tau^c, -i\lambda_W^+, -i\lambda_V^+, \tilde{\eta}_1'^+, \tilde{\eta}_2^+, \tilde{\rho}^+, \tilde{\chi}'^+)$ to $\tilde{\chi}^{\pm}$

- $(\nu_e\nu_\mu\nu_\tau - i\lambda_A^3 - i\lambda_A^8 - i\lambda_B\tilde{\eta}^0\tilde{\eta}'^0\tilde{\rho}^0\tilde{\rho}'^0\tilde{\chi}^0\tilde{\chi}'^0)$ to $\tilde{\chi}^0$

$$e^-e^- \to \tilde{\chi}^{--}\tilde{\chi}^0 \to U^{--}\tilde{\chi}^0 l^+\tilde{l}^- \to l^-l^-\tilde{\chi}^0 l^+\nu_l d\bar{u}$$





$$m_{\tilde{\chi}_1^{\pm\pm}} = 194.4 \quad m_{\tilde{\chi}_2^{\pm\pm}} = 343.3 \quad m_{\tilde{\chi}_3^{\pm\pm}} = 452.2$$

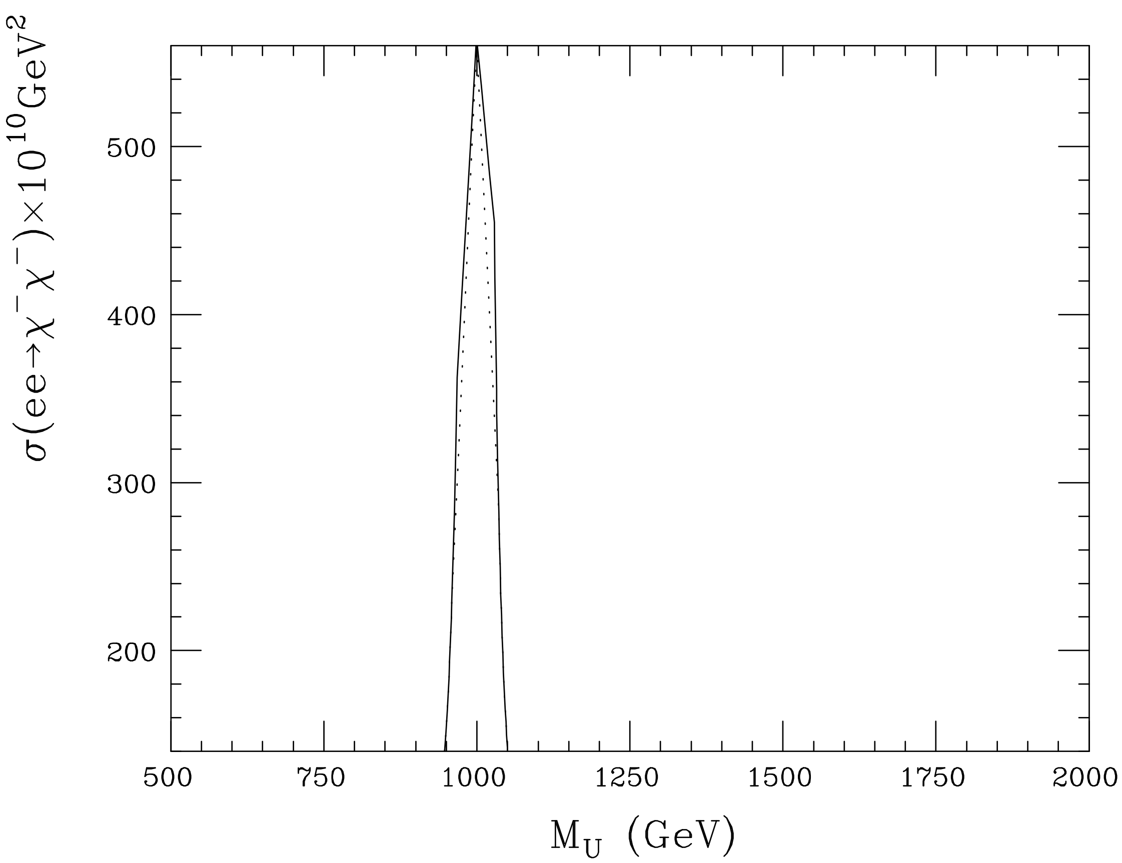
$$m_{\tilde{\chi}_4^{\pm\pm}} = 652.1 \quad m_{\tilde{\chi}_5^{\pm\pm}} = 3187$$

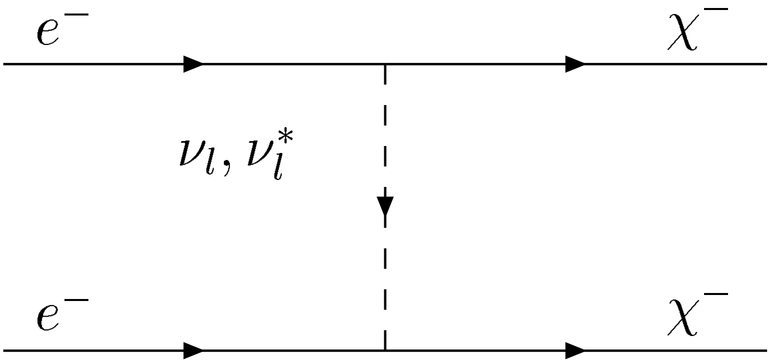
$$m_{\tilde{\chi}_{12}^0} = -4162.22 \quad m_{\tilde{\chi}_{11}^0} = 3260.48 \quad m_{\tilde{\chi}_{10}^0} = 3001.1$$

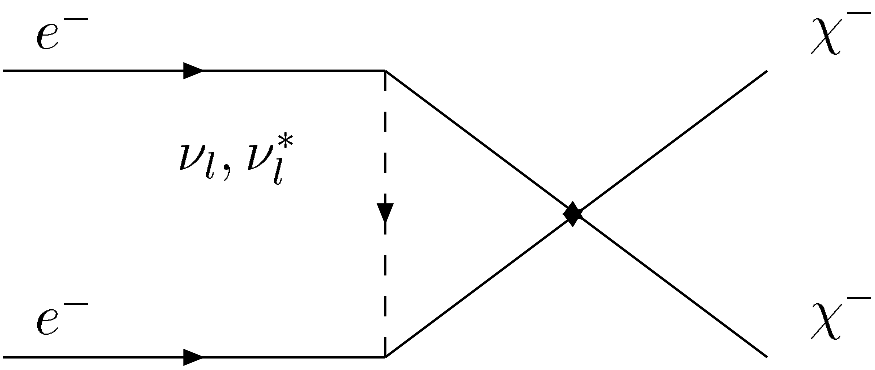
$$m_{\tilde{\chi}_9^0} = 585.19 \quad m_{\tilde{\chi}_8^0} = -585.19 \quad m_{\tilde{\chi}_7^0} = 453.22$$

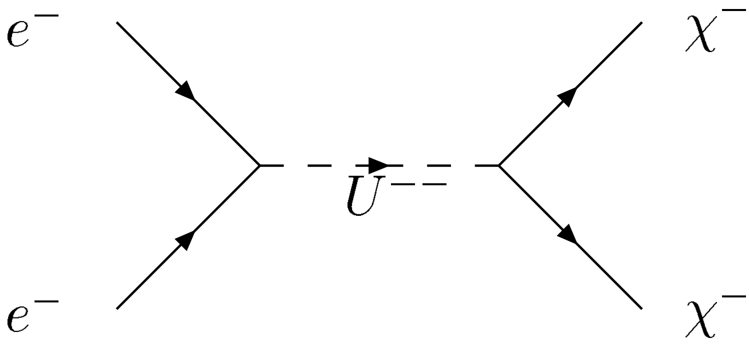
$$m_{\tilde{\chi}_6^0} = -344.14 \quad m_{\tilde{\chi}_5^0} = 283.14 \quad m_{\tilde{\chi}_4^0} = -272.0$$

$$e^- e^- \;\rightarrow\; \tilde{\chi}^- \tilde{\chi}^- \rightarrow l^- \tilde{\nu}_l V^- \tilde{\chi}^0 \rightarrow l^- \nu_l \tilde{\chi}_i^0 l^- \nu_l l^+ \bar{u}_j d_k$$




e^-
χ^-
ν_l, ν_l^*
e^-
χ^-


e^-
χ^-
ν_l, ν_l^*
e^-
χ^-


e^-
χ^-
U^{--}
e^-
χ^-

$$m_{\tilde{\chi}_9^\pm} = 3186.05 \;\; m_{\tilde{\chi}_8^\pm} = 3001.12 \;\; m_{\tilde{\chi}_7^\pm} = 584.85$$
$$m_{\tilde{\chi}_6^\pm} = 282.30 \;\; m_{\tilde{\chi}_5^\pm} = 204.55 \;\; m_{\tilde{\chi}_4^\pm} = 149.41$$

$$pp \to \tilde{\chi}^+\tilde{\chi}^+ \to \text{three leptons} + \text{jets} + \not{E}_T$$
$$pp \to \tilde{\chi}^{++}\tilde{\chi}^0 \to \text{three leptons} + \text{jets} + \not{E}_T$$

LHC can discover all charginos and neutralinos

Conclusion

- Heavy Exotic quarks J and j, M in TeV;
- Double Charginos
- Studying the processes $pp \to$ three leptons$+$ jets $+ \not{E}_T$ the new state as $\tilde{\chi}^{\pm\pm}_{1...5}$, $\tilde{\chi}^{\pm\pm}_{1...9}$, $\tilde{\chi}^{0}_{1...12}$, $j_{1,2}$ and J can be discovered by LHC or same ILC, if they really exist