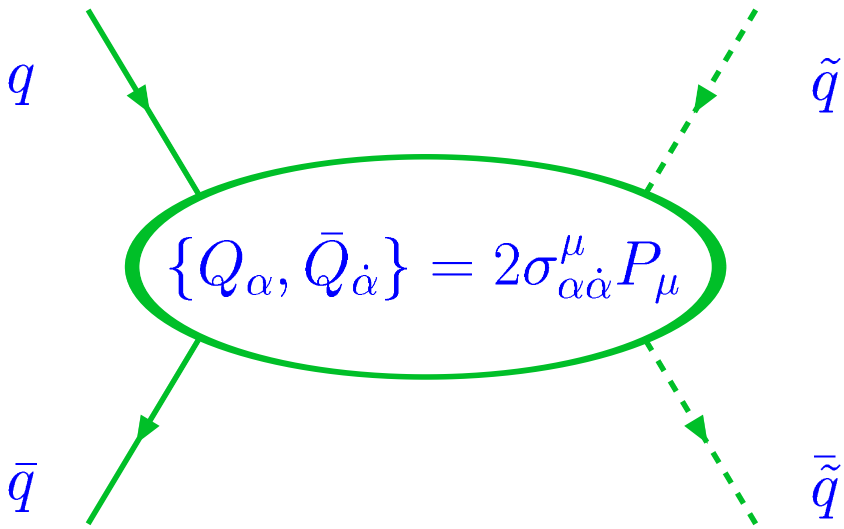
“Modelos Supersimétricos Left-Right.”



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Motivação para estudar SUSY

1. Unifica bósons e férmions Gerador Q

$$Q|\text{bóson}> = |\text{férmion}>$$
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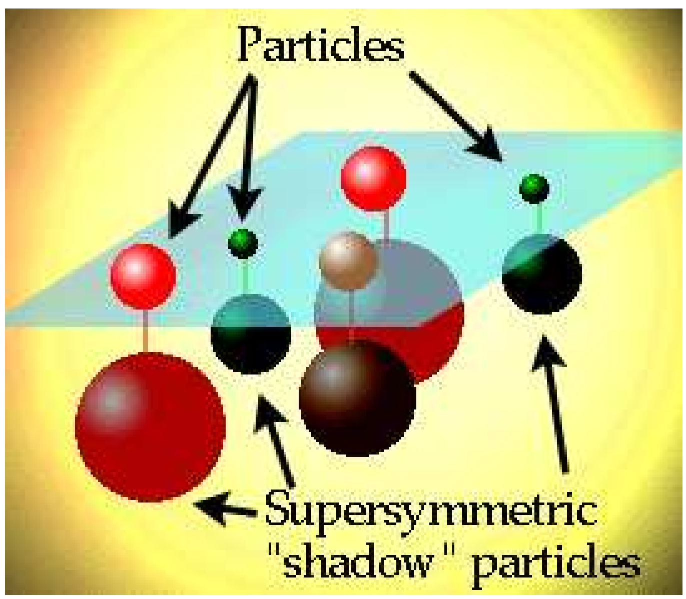


As sombras do parceiros supersimétricos das partículas conhecidas

2. SUSY local unifica com a Gravidade (Supergravidade)

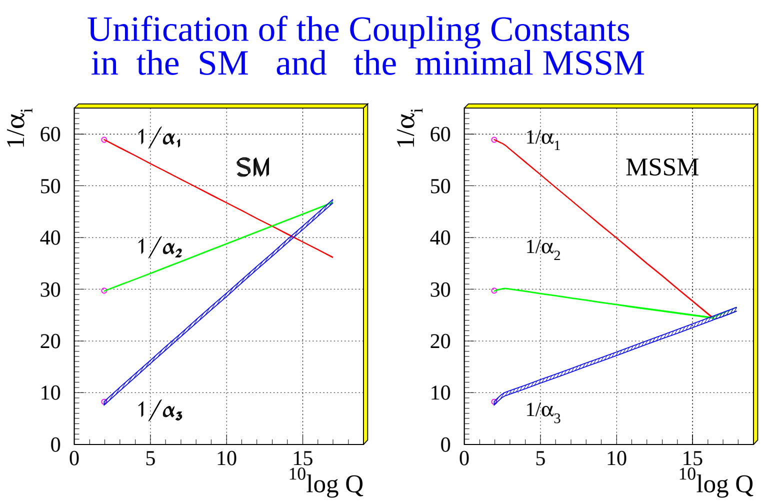
   - *idéia geral* é a unificação de todas as forças da natureza

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

Teoria menos divergente que a gravitação quântica

3. Unifica as constantes de gauge

- *hipótese*: Todas as interações conhecidas são diferentes ramificações de uma única interação associada a um único grupo de Gauge. A Unificação ocorre a altas energias



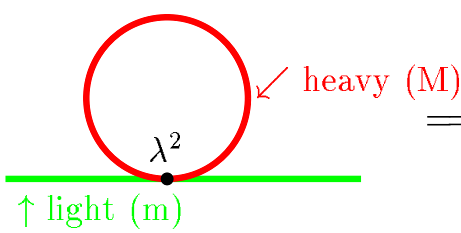
4. Soluciona o problema da hierarquia

O aparecimento de duas diferentes escalas $V \gg v$ em GUT leva a um problema conhecido como *problema da hierarquia*

$$\begin{array}{lllll} m_H & \sim & v & \sim & 10^2 \text{ GeV} \\ m_\Sigma & \sim & V & \sim & 10^{16} \text{ GeV} \end{array}$$

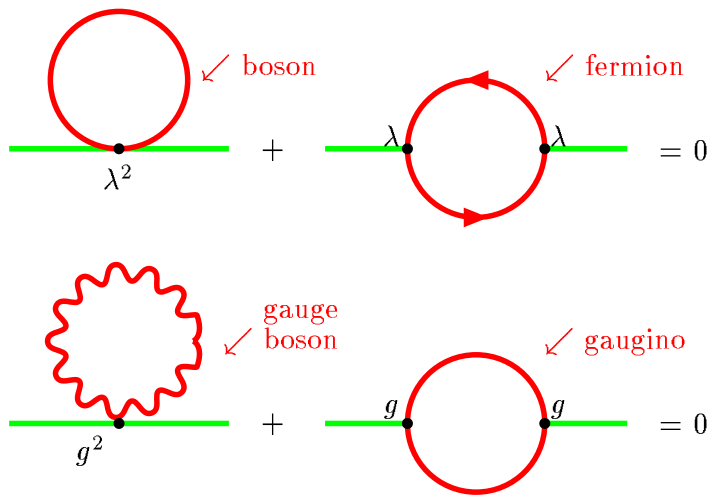
$$\frac{m_H}{m_\Sigma} \sim 10^{-14} \ll 1,$$

A correção na massa do Higgs do MP é



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

Mas em SUSY temos o higgsinos e teremos



Cancelamento das divergências para a massa do escalar

Motivation to study LR Models

1. Dynamical Explanation Parity Violation

2. $B-L$ Gauge Symmetry

3. Explain Lightness of Neutrinos Masses

4. Explain the milliweak Strength of CP Violation

Supersymmetric Left-Right Triplet Model (SUSYLRT)

$SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$

three generation of quarks and léptons $i = 1,2,3$

$$
\begin{aligned}
L_{iL} &= \begin{pmatrix} \nu_i \\ l_i \end{pmatrix}_L \sim (\mathbf{1},\mathbf{2},\mathbf{1},-1) \\
L^c_{iL} &= \begin{pmatrix} \nu^c_i \\ l^c_i \end{pmatrix}_R \sim (\mathbf{1},\mathbf{1},\mathbf{2},1) \\
Q_{iL} &= \begin{pmatrix} u_i \\ d_i \end{pmatrix}_L \sim \left(\mathbf{3},\mathbf{2},\mathbf{1},\frac{1}{3}\right) \\
Q^c_{iL} &= \begin{pmatrix} u^c_i \\ d^c_i \end{pmatrix}_R \sim \left(\bar{\mathbf{3}},\mathbf{1},\mathbf{2},-\frac{1}{3}\right)
\end{aligned}
$$

sleptons and squarks

$$\begin{aligned}
\tilde{L}_{iL} &= \begin{pmatrix} \tilde{\nu}_i \\ \tilde{l}_i \end{pmatrix}_L \sim (\mathbf{1}, \mathbf{2}, \mathbf{1}, -1)\,, \\
\tilde{L}^c_{iL} &= \begin{pmatrix} \tilde{\nu}^c_i \\ \tilde{l}^c_i \end{pmatrix}_R \sim (\mathbf{1}, \mathbf{1}, \mathbf{2}, 1) \\
\tilde{Q}_{iL} &= \begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix}_L \sim \left(\mathbf{3}, \mathbf{2}, \mathbf{1}, \frac{1}{3}\right) \\
\tilde{Q}^c_{iL} &= \begin{pmatrix} \tilde{u}^c_i \\ \tilde{d}^c_i \end{pmatrix}_R \sim \left(\bar{\mathbf{3}}, \mathbf{1}, \mathbf{2}, -\frac{1}{3}\right)
\end{aligned}$$

Higgs's sector

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

$$\Delta'_L = \begin{pmatrix} \frac{\delta_L'^-}{\sqrt{2}} & \delta_L'^{--} \\ \delta_L'^0 & \frac{-\delta_L'^-}{\sqrt{2}} \end{pmatrix} \sim (\mathbf{1},\mathbf{3},\mathbf{1},-2)$$

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

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

higgsinos

$$\tilde{\Delta}_L = \begin{pmatrix} \frac{\tilde{\delta}_L^+}{\sqrt{2}} & \tilde{\delta}_L^{++} \\ \tilde{\delta}_L^0 & \frac{-\tilde{\delta}_L^+}{\sqrt{2}} \end{pmatrix} \sim (\mathbf{1},\mathbf{3},\mathbf{1},2)$$

$$\tilde{\Delta}'_L = \begin{pmatrix} \frac{\tilde{\delta}_L^{\prime -}}{\sqrt{2}} & \tilde{\delta}_L^{\prime --} \\ \tilde{\delta}_L^{\prime 0} & \frac{-\tilde{\delta}_L^{\prime -}}{\sqrt{2}} \end{pmatrix} \sim (\mathbf{1},\mathbf{3},\mathbf{1},-2)$$

$$\tilde{\Delta}_L^c = \begin{pmatrix} \frac{\tilde{\delta}_L^-}{\sqrt{2}} & \tilde{\delta}_L^{--} \\ \tilde{\delta}_L^0 & \frac{-\tilde{\delta}_L^-}{\sqrt{2}} \end{pmatrix} \sim (\mathbf{1},\mathbf{1},\mathbf{3},-2)$$

$$\tilde{\Delta}_L^{\prime c} = \begin{pmatrix} \frac{\tilde{\delta}_L^{\prime +}}{\sqrt{2}} & \tilde{\delta}_L^{\prime ++} \\ \tilde{\delta}_L^{\prime 0} & \frac{-\tilde{\delta}_L^{\prime +}}{\sqrt{2}} \end{pmatrix} \sim (\mathbf{1},\mathbf{1},\mathbf{3},2)$$

two bidublets

$$\Phi = \begin{pmatrix} \phi_1^0 & \phi_1^+ \\ \phi_2^- & \phi_2^0 \end{pmatrix} \sim (\mathbf{1}, \mathbf{2}, \mathbf{2}, 0)$$

$$\Phi' = \begin{pmatrix} \chi_1^0 & \chi_1^+ \\ \chi_2^- & \chi_2^0 \end{pmatrix} \sim (\mathbf{1}, \mathbf{2}, \mathbf{2}, 0)$$

their higgsinos

$$\tilde{\Phi} = \begin{pmatrix} \tilde{\phi}_1^0 & \tilde{\phi}_1^+ \\ \tilde{\phi}_2^- & \tilde{\phi}_2^0 \end{pmatrix} \sim (\mathbf{1}, \mathbf{2}, \mathbf{2}, 0)$$

$$\tilde{\Phi}' = \begin{pmatrix} \tilde{\chi}_1^0 & \tilde{\chi}_1^+ \\ \tilde{\chi}_2^- & \tilde{\chi}_2^0 \end{pmatrix} \sim (\mathbf{1}, \mathbf{2}, \mathbf{2}, 0)$$

Their superfield

$$\begin{aligned}
\hat{L}_{iL} &\sim (\mathbf{1}, \mathbf{2}, \mathbf{1}, -1)\,, \quad \hat{L}^c_{iL} \sim (\mathbf{1}, \mathbf{1}, \mathbf{2}, 1) \\
\hat{Q}_{iL} &\sim \left(\mathbf{3}, \mathbf{2}, \mathbf{1}, \frac{1}{3}\right), \quad \hat{Q}^c_{iL} \sim \left(\bar{\mathbf{3}}, \mathbf{1}, \mathbf{2}, -\frac{1}{3}\right) \\
\hat{\boldsymbol{\Delta}}_L &\sim (\mathbf{1}, \mathbf{3}, \mathbf{1}, 2)\,, \quad \hat{\boldsymbol{\Delta}}'_L \sim (\mathbf{1}, \mathbf{3}, \mathbf{1}, -2) \\
\hat{\boldsymbol{\Delta}}^c_L &\sim (\mathbf{1}, \mathbf{1}, \mathbf{3}, -2)\,, \quad \hat{\boldsymbol{\Delta}}'^c_L \sim (\mathbf{1}, \mathbf{1}, \mathbf{3}, 2) \\
\hat{\Phi} &\sim (\mathbf{1}, \mathbf{2}, \mathbf{2}, 0)\,, \quad \hat{\Phi}' \sim (\mathbf{1}, \mathbf{2}, \mathbf{2}, 0)\,.
\end{aligned}$$

The Gauge sector is written as

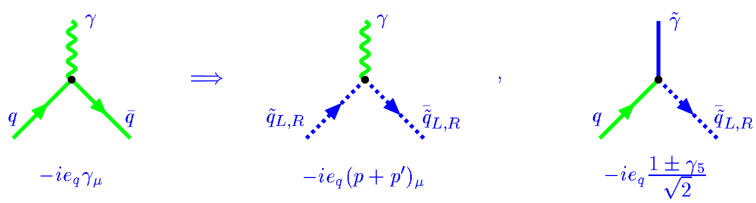
$$
\begin{array}{llll}
g_m^a & \sim (\mathbf{8},\mathbf{1},\mathbf{1},0)\,, & \tilde{g}^a \sim (\mathbf{8},\mathbf{1},\mathbf{1},0) & \to V_c^a \\
V_L^i & \sim (\mathbf{1},\mathbf{3},\mathbf{1},0)\,, & \lambda_{AL}^i \sim (\mathbf{1},\mathbf{3},\mathbf{1},0)\,, & \to V_L^i \\
V_R^i & \sim (\mathbf{1},\mathbf{1},\mathbf{3},0)\,, & \lambda_{AR}^i \sim (\mathbf{1},\mathbf{1},\mathbf{3},0)\,, & \to V_L^i \\
V^m & \sim (\mathbf{1},\mathbf{1},\mathbf{1},0)\,, & \lambda_B \sim (\mathbf{1},\mathbf{1},\mathbf{1},0) & \to V'
\end{array}
$$

Lagrangiana

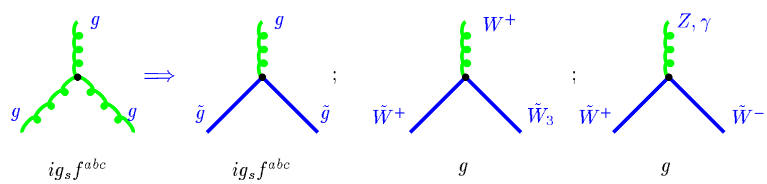
$$\mathcal{L}_{SUSYLR} = \mathcal{L}_{SUSY} + \mathcal{L}_{soft}$$

$$\mathcal{L}_{SUSYLR} = \mathcal{L}_{Lepton} + \mathcal{L}_{Quarks} + \mathcal{L}_{Gauge} + \mathcal{L}_{Higgs}$$

$$
\begin{aligned}
\mathcal{L}_{Quarks} &= \int d^4\theta \left[\hat{\bar{Q}}_{\alpha L} e^{2g_s T^a \hat{V}_c^a + 2gT^i \hat{V}^i + g'\left(\frac{1}{3}\right)\hat{V}'} \hat{Q}_{\alpha L} \right. \\
&+ \left. \hat{\bar{Q}}^c_{\alpha L} e^{2g_s T^a \hat{V}_c^a + 2gT^i \hat{V}^i - g'\left(\frac{1}{3}\right)\hat{V}'} \hat{Q}^c_{\alpha L} \right] \\
&= \mathcal{L}^{Quarks}_{qqV} + \mathcal{L}^{Quarks}_{\tilde{q}\tilde{q}V} + \mathcal{L}^{Quarks}_{q\tilde{q}\tilde{V}} \\
&+ \mathcal{L}^{Quarks}_{\tilde{q}\tilde{q}VV} + \mathcal{L}^{Quarks}_{cin} + \mathcal{L}^{Quarks}_{F} \\
&+ \mathcal{L}^{Quarks}_{D}
\end{aligned}
$$



$$
\begin{aligned}
\mathcal{L}_{Lepton} &= \int d^4\theta \left[\hat{\bar{L}}_{aL} e^{2gT^i\hat{V}^i_L + g'(-1)\hat{V}'} \hat{L}_{aL} \right. \\
&+ \left. \hat{\bar{L}}^c_{aL} e^{2gT^i\hat{V}^i_L + g'(1)\hat{V}'} \hat{L}^c_{aL} \right] \\
&= \mathcal{L}^{Lepton}_{llV} + \mathcal{L}^{Lepton}_{\tilde{l}\tilde{l}V} + \mathcal{L}^{Lepton}_{l\tilde{l}\tilde{V}} \\
&+ \mathcal{L}^{Lepton}_{\tilde{l}\tilde{l}VV} + \mathcal{L}^{Lepton}_{cin} + \mathcal{L}^{Lepton}_{F} \\
&+ \mathcal{L}^{Lepton}_{D}
\end{aligned}
$$



$$\begin{aligned}\mathcal{L}_{Gauge} &= \frac{1}{4}\int d^2\theta\ \Big[W_s^{a\alpha}W_{s\alpha}^a + W_L^{i\alpha}W_{\alpha L}^i + W_R^{i\alpha}W_{\alpha R}^i \\ &+ W'^{\alpha}W'_{\alpha} + h.c.\Big] \\ &= \mathcal{L}_{cin}^{Gauge} + \mathcal{L}_{\lambda\lambda V}^{Gauge} + \mathcal{L}_{D}^{Gauge}\end{aligned}$$

$T^i = \sigma^i/2$ and $T^a = \lambda^a/2$ are $SU(2)$ and $SU(3)$ generator

$$
\begin{aligned}
\mathcal{L}_{Higgs} &= \int d^4\theta \; Tr \Big[\bar{\hat{\Delta}}_L e^{2gT^i \hat{V}_L^i + g'(2)\hat{V}'} \hat{\Delta}_L \\
&+ \bar{\hat{\Delta}}'_L e^{2gT^i \hat{V}^i + g'(-2)\hat{V}'} \hat{\Delta}'_L \\
&+ \bar{\hat{\Delta}}^c_L e^{2gT^i \hat{V}_L^i + g'(-2)\hat{V}'} \hat{\Delta}^c_L \\
&+ \bar{\hat{\Delta}}'^c_L e^{2gT^i \hat{V}^i + g'(2)\hat{V}'} \hat{\Delta}'^c_L \\
&+ \bar{\hat{\Phi}} e^{2gT^i \hat{V}_L^i + 2gT^i \hat{V}_R^i} \hat{\Phi} \\
&+ \bar{\hat{\Phi}}' e^{2gT^i \hat{V}_L^i + 2gT^i \hat{V}_R^i} \hat{\Phi}' \Big] \\
&= \mathcal{L}^{Higgs}_{HHV} + \mathcal{L}^{Higgs}_{\tilde{H}\tilde{H}V} + \mathcal{L}^{Higgs}_{H\tilde{H}\tilde{V}} \\
&+ \mathcal{L}^{Higgs}_{\tilde{H}\tilde{H}VV} + \mathcal{L}^{Higgs}_{cin} + \mathcal{L}^{Higgs}_{F} \\
&+ \mathcal{L}^{Higgs}_{D}
\end{aligned}
$$

Superpotential

$$
\begin{aligned}
W &= M_\Delta \hat{\Delta}\hat{\Delta}' + M_{\Delta^c}\hat{\Delta}^c\hat{\Delta}'^c + \mu_1\hat{\Phi}\hat{\Phi} + \mu_2\hat{\Phi}'\hat{\Phi}' \\
&+ \mu_3\hat{\Phi}\hat{\Phi}' + f\hat{L}\hat{\Delta}\hat{L} + f^c\hat{L}^c\hat{\Delta}^c\hat{L}^c \\
&+ h_l\hat{L}\hat{\Phi}\hat{L}^c + \tilde{h}_l\hat{L}\hat{\Phi}'\hat{L}^c + h_q\hat{Q}\hat{\Phi}\hat{Q}^c + \tilde{h}_q\hat{Q}\hat{\Phi}'\hat{Q}^c
\end{aligned}
$$

VEV

$$
\begin{aligned}
\langle\Phi\rangle &= \frac{1}{\sqrt{2}}\begin{pmatrix} k_1 & 0 \\ 0 & 0 \end{pmatrix}; \quad \left\langle\Phi'\right\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 0 \\ 0 & k_2' \end{pmatrix}; \\
\langle\Delta_L\rangle &= 0; \quad \left\langle\Delta_L'\right\rangle = 0; \\
\langle\Delta_L^c\rangle &= \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & \upsilon_R \\ 0 & 0 \end{pmatrix}; \quad \left\langle\Delta_L'^c\right\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 0 \\ \upsilon_R' & 0 \end{pmatrix}.
\end{aligned}
$$

$$
\begin{aligned}
M_{ij}^u &= \frac{h_{ij}^q}{\sqrt{2}}k_1(u_i u_j^c + hc), \\
M_{ij}^d &= \frac{\tilde{h}_{ij}^q}{\sqrt{2}}k_2(d_i d_j^c + hc), \\
M_{ab}^l &= -\frac{\tilde{h}_{ab}^l}{\sqrt{2}}k_2(l_i l_j^c + hc). \\
M_{ab}^\nu &= \frac{1}{\sqrt{2}}\left[k_1 h_{ab}^l + k_2'\tilde{h}_{ab}^l\right](\nu_a\nu_b^c + hc) \\
&+ \frac{\upsilon_R}{\sqrt{2}}f_{ab}^c(\nu_a^c\nu_b^c + hc) \\
&- \frac{\upsilon_L}{\sqrt{2}}f_{ab}(\nu_a\nu_b + hc)
\end{aligned}
$$

Soft supersymmetry breaking terms

$$
\begin{aligned}
\mathcal{L}_{soft} &= -\Big[m^2_{L_L}\tilde{L}^\dagger_L\tilde{L}_L + m^2_{L_R}\tilde{L}^\dagger_R\tilde{L}_R + m^2_{Q_L}\tilde{Q}^\dagger_L\tilde{Q}_L \\
&+ m^2_{Q_R}\tilde{Q}^\dagger_R\tilde{Q}_R + m^2_{\Phi\Phi}\Phi^\dagger\Phi + m^2_{\Phi\Phi'}\Phi^\dagger\Phi' \\
&+ m^2_{\Phi'\Phi'}\Phi'^\dagger\Phi'\Big] - \Big[M_1^2 Tr(\Delta\Delta') + M_5^2\Phi'\Phi' \\
&+ M_2^2 Tr(\Delta^c\Delta'^c) + M_3^2\Phi\Phi + M_4^2\Phi\Phi' + h.c.\Big] \\
&- \Big[A_{LL}Tr(\tilde{L}\tau_2\Delta\tilde{L}) + A^c_{LL}Tr(\tilde{L}^c\tau_2\Delta^c\tilde{L}^c) \\
&+ A_{LR}Tr(\tilde{L}\tau_2\Phi\tau_2\tilde{L}^c) + \tilde{A}_{LR}Tr(\tilde{L}\tau_2\Phi'\tau_2\tilde{L}^c) \\
&+ A_{QQ}Tr(\tilde{Q}\tau_2\Phi\tau_2\tilde{Q}^c) + \tilde{A}_{QQ}Tr(\tilde{Q}\tau_2\Phi'\tau_2\tilde{Q}^c) \\
&+ h.c.] - \frac{1}{2}\left(\sum_{i=1}^{8} m_{\tilde{g}}\tilde{g}^i\tilde{g}^i + \sum_{p=1}^{3} m_\lambda\lambda^p_A\lambda^p_A \right.\\
&+ \left. m'\sum_{i=1}^{3}\lambda^i_B\lambda^i_B + h.c.\right)
\end{aligned}
$$

We will consider processes like

$$e^- e^-$$

- in the SM is not interesting because

  1. Møller scattering

  2. bremsstrahlung events

- low background $\sigma \approx 10^{-3} nb$ at $\sqrt{s} = 500 GeV$

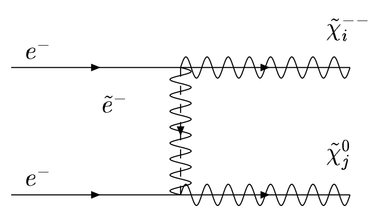
Can provide crucial information on exotic process

- lepton number violation

- fermion number violation

- K.Huitu, J.Maalampi, M. Raidal, NPB420, 449 (1994)

$$e^- e^- \to \tilde{\chi}^{--} \tilde{\chi}^0$$



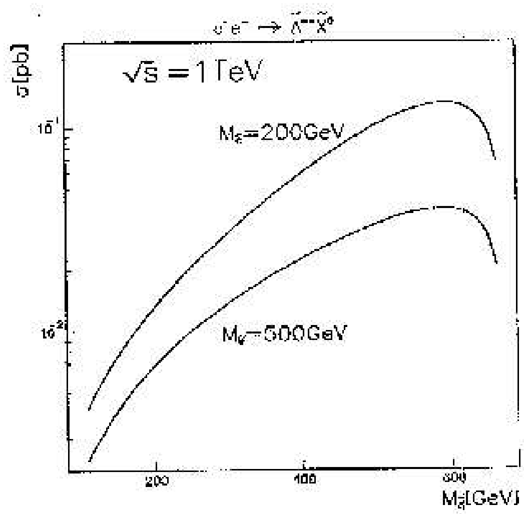


Figure 5: