Minimal Supersymmetric Standard Model

Collider physics, constrained MSSM,Neutrino masses

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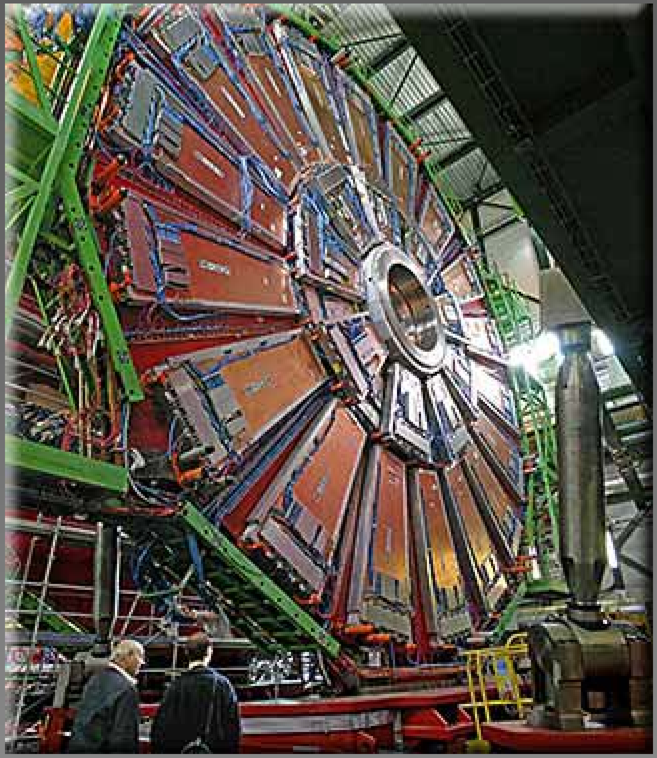
LHC

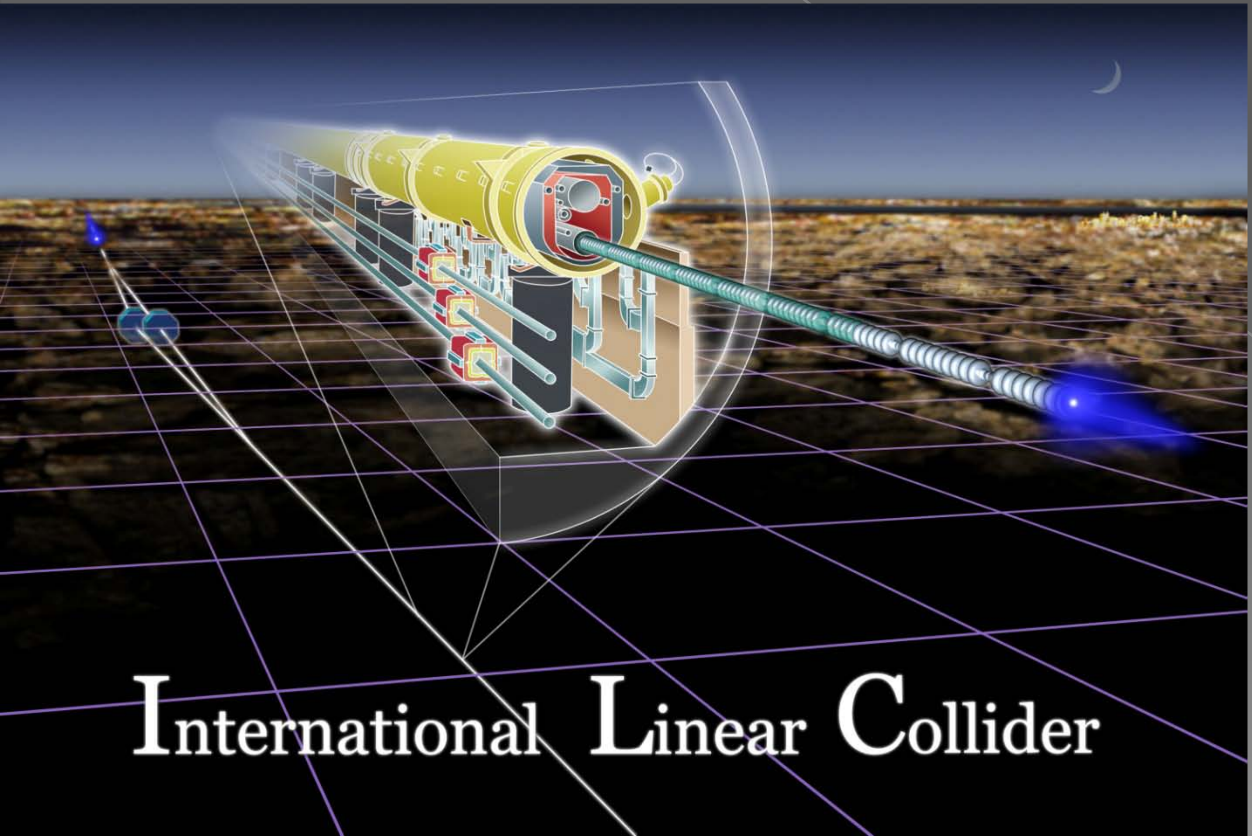
- Currently running: LHC
- Large Hadron Collider
- Proton Proton collider



ILC

Proposal level

http://www.linearcollider.org



Electron positron collider

TESLA + NLC → ILC

Simple process at ILC

$$e^+e^- \to \widetilde{\mu}^+\widetilde{\mu}^-$$

$$\frac{d\sigma}{d\cos\theta} = \frac{\pi\alpha^2}{2s}\beta^3\sin^2\theta|f_{ab}|^2$$

$$f_{ab} = 1 + \frac{(I_e^3 + \frac{1}{2}s_w^2)(I_\mu^3 + \frac{1}{2}s_w^2)}{c_w^2 s_w^2}\frac{s}{s - m_Z^2}$$

$$I^3 = -\frac{1}{2}, 0 \text{ for } a, b = L, R$$

$$|f_{ab}|^2 = \begin{matrix} e_R^- \to \widetilde{\widetilde{\mu}} & : & 1.69 & e_R^- \to \widetilde{\mu} & : & 0.42 \\ e_L^- \to \widetilde{\widetilde{\mu}} & : & 0.42 & e_L^- \to \widetilde{\mu} & : & 1.98 \end{matrix}$$

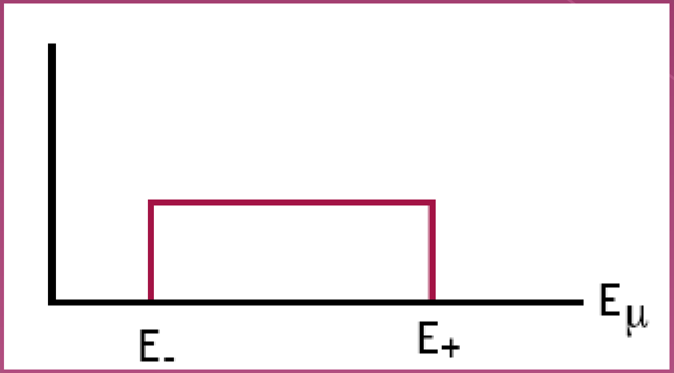
- What is the diagram?

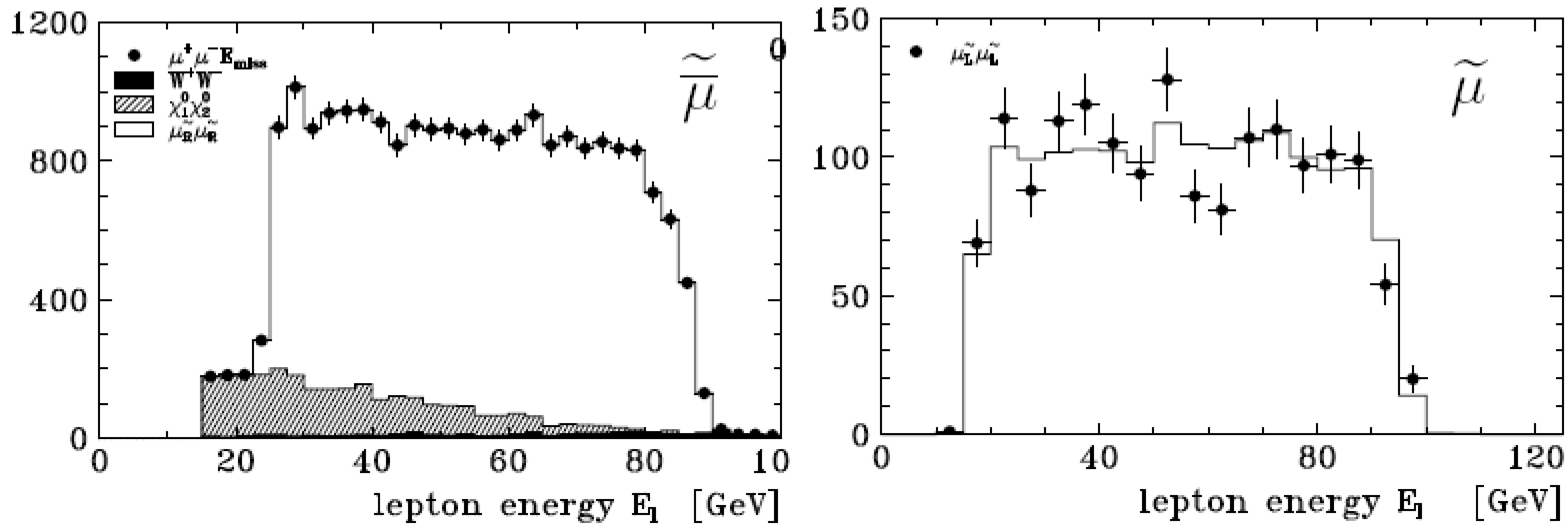
Signal

$$e^+e^- \rightarrow \widetilde{\mu}^+\widetilde{\mu}^-$$

$$\widetilde{\mu} \rightarrow \mu N_1^0$$

$$e^+e^- \rightarrow \mu^+\mu^- + (\text{missing E and } \ \text{p})$$





Blair and Martyn

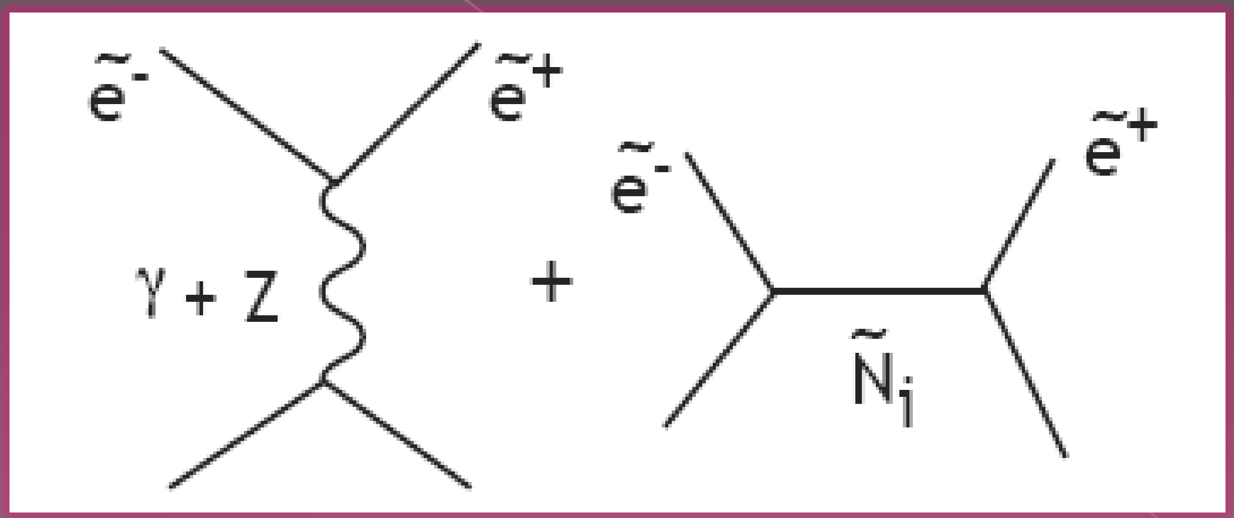
- How do you guess the argument will change?

$$e^+e^- \longrightarrow \widetilde{\tau}^+\widetilde{\tau}^-$$

How do you guess the argument will change?

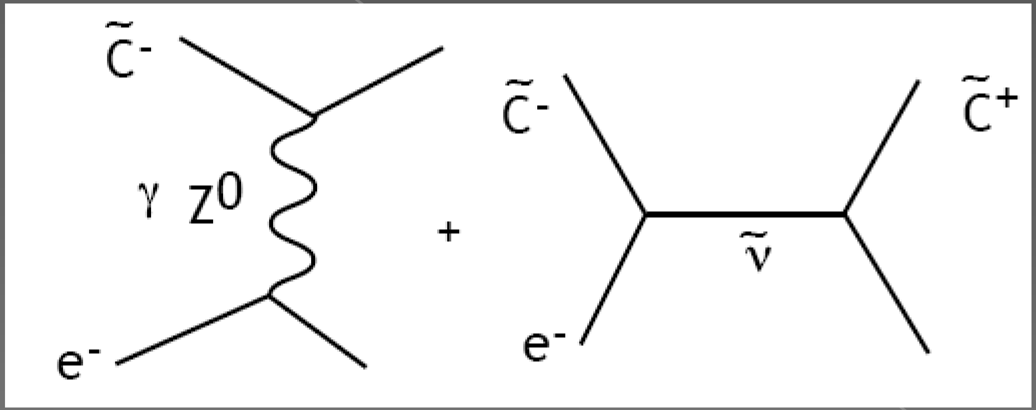
$$e^+e^- \longrightarrow \tilde{e}^-\tilde{e}^+.$$

Both s-channel and t-channel contributions



Chargino and neutralino pair production at ILC

$$e^+e^- \to C_k^+ C_\ell^- \ , \ N_i N_j$$



$$\widetilde{C}^+ \to \ell^+ \nu \widetilde{N}_1 \qquad \widetilde{C}^- \to q\overline{q} N_1$$

Supersymmetry at LHC

$$gg \longrightarrow \widetilde{g}\widetilde{g}\ ,\ \widetilde{q}\widetilde{q}^{*} \qquad gq \longrightarrow \widetilde{g}\widetilde{q}$$

$$\widetilde{\overline{q}} \longrightarrow \overline{q} N_1^0$$

$$\widetilde{q} \to q N_2^0 \to q(\ell^+\ell^-) N_1^0$$

$$\widetilde{g} \to u\overline{d}\; C_1^+ \to u\overline{d}\; W^+ N_1^0$$

Cascade decay

$$\tilde{q} \to q\tilde{\chi}_2^0 \to ql\tilde{l} \to qll\tilde{\chi}_1^0.$$

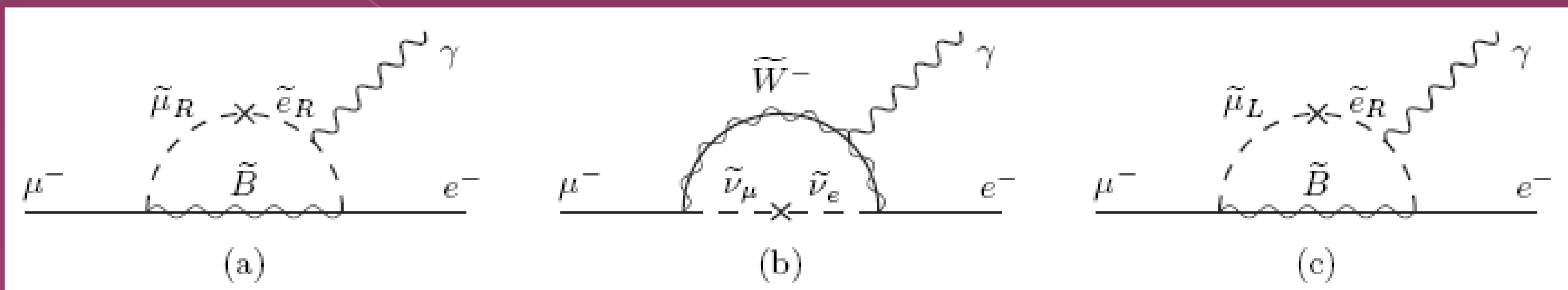
$$A \to XB \to XYC$$

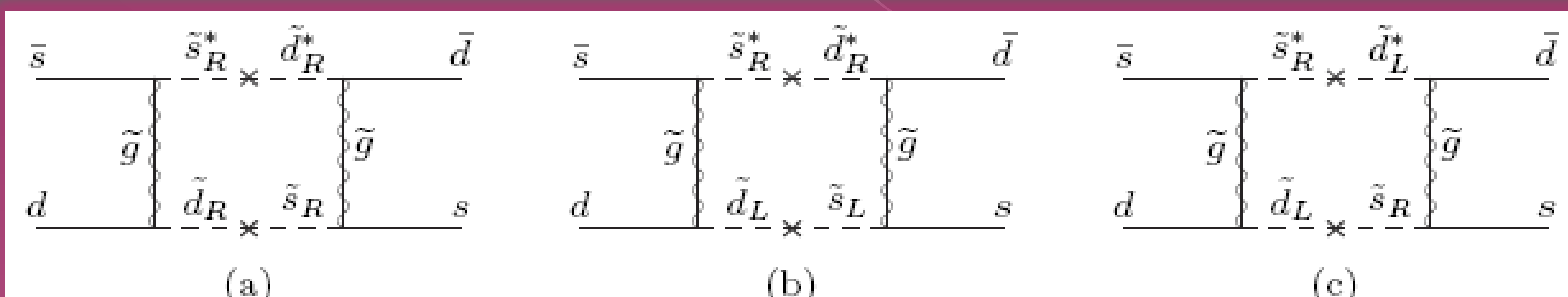
$d\Gamma_A/ds$, possesses a kinematic edge located at

$$s = \frac{(m_A^2 - m_B^2)(m_B^2 - m_C^2)}{m_B^2},$$

$$s \equiv (p_X + p_Y)^2$$

Flavor violation





$$K^0 \leftrightarrow \overline{K}^0$$

Bounds

No (significant) deviation from SM ⊙

$$b \longrightarrow s\gamma$$

$$K^0 \leftrightarrow \overline{K}^0$$

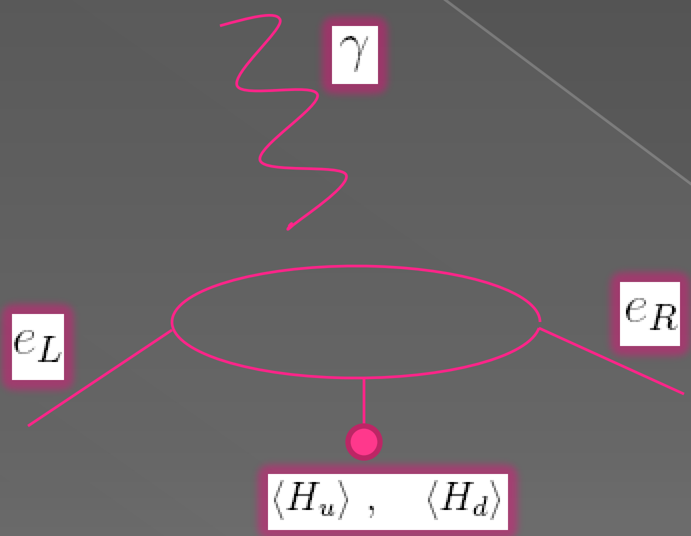
~~$\tau \longrightarrow e\gamma \quad \tau \longrightarrow \mu\gamma$~~

~~$\mu^- \to e^-\gamma \quad \mu^- \to e^-e^+e^-$~~

~~$\mu^-N \to e^-N \quad \tau^- \to e^-\gamma$~~

No new source of flavor violation

Electric dipole moment of the electron



$$d_e \propto \Im[\mathcal{M}]$$

$$d_e < 1.4 \times 10^{-27} \; e \; \mathrm{cm}$$

$$A_e \tilde{\bar{e}}_R \tilde{e}_L H_d \quad \mu \tilde{\bar{e}}_R \tilde{e}_L H_u^*$$

Bounds on the phases of A_e and μ

mSUGRA or Constrained MSSM

$$m_0 \quad m_{1/2} \quad a_0 \quad \mathrm{sgn}[\mu] \quad \tan\beta$$

$$M_1 = M_2 = M_3 = m_{1/2}$$

$$m^2_{\tilde{l}_R} = m^2_{\tilde{l}_L} = m^2_{\tilde{q}_R} = m^2_{\tilde{q}_L} = m_0^2 \mathbb{I}_{3\times 3}$$

$$m^2_{H_u} = m^2_{H_d} = m_0^2$$

$$A_\ell = a_0 Y_\ell \quad A_U = a_0 Y_U \quad A_D = a_0 Y_D$$

No source of flavor violation

No new source of CP-violation

No source of LFV

- How neutrino masses are supposed to be explained?
- In the context of SUSY:
- R-parity violation
- Seesaw mechanism embedded in SUSY

R-parity violation

$$\mathcal{W}_Y = \epsilon_{\alpha\beta}\left(Y_U^{ij}\widehat{Q}_i^\alpha\widehat{u}_j^c\widehat{H}_u^\beta + Y_D^{ij}\widehat{Q}_i^\beta\widehat{d}_j^c\widehat{H}_d^\alpha + Y_l^{ij}\widehat{L}_i^\beta\widehat{l}_j^c\widehat{H}_d^\alpha\right)$$

$$\mathcal{W}_{b\not{R}_p} = \mathcal{W}_Y + \epsilon_{\alpha\beta}\left[\epsilon_i\widehat{L}_i^\alpha\widehat{H}_u^\beta - \mu\widehat{H}_d^\alpha\widehat{H}_u^\beta\right]$$

$$\mathcal{W}_{\mu\nu\mathrm{SSM}} = \mathcal{W}_Y + \epsilon_{\alpha\beta}\left[Y_\nu^i\widehat{L}_i^\alpha\widehat{\nu}^c\widehat{H}_u^\beta - \lambda\widehat{\nu}^c\widehat{H}_d^\alpha\widehat{H}_u^\beta\right] + \frac{1}{3}\kappa\widehat{\nu}^c\widehat{\nu}^c\widehat{\nu}^c$$

Stefan Liebler and Werner Porod, hep-ph/1106.2921

Neutrino mass at tree level

$$(\psi^0)^T = \left(\tilde{B}^0, \tilde{W}_3^0, \tilde{H}_d^0, \tilde{H}_u^0, \nu^c, \nu_1, \nu_2, \nu_3\right)$$

$$\mathcal{M}_n = \begin{pmatrix} M_H & \hat{m} \\ \hat{m}^T & 0 \end{pmatrix}$$

$$M_H = \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g'v_d & \frac{1}{2}g'v_u & 0 \\ 0 & M_2 & \frac{1}{2}gv_d & -\frac{1}{2}gv_u & 0 \\ -\frac{1}{2}g'v_d & \frac{1}{2}gv_d & 0 & -\mu & -\frac{1}{\sqrt{2}}\lambda v_u \\ \frac{1}{2}g'v_u & -\frac{1}{2}gv_u & -\mu & 0 & -\frac{1}{\sqrt{2}}\lambda v_d \\ 0 & 0 & -\frac{1}{\sqrt{2}}\lambda v_u & -\frac{1}{\sqrt{2}}\lambda v_d & \sqrt{2}\kappa v_c \end{pmatrix}$$

$$\hat{m}^T = \begin{pmatrix} -\frac{1}{2}g'v_1 & \frac{1}{2}gv_1 & 0 & \epsilon_1 & \epsilon_1\frac{v_u}{v_c} \\ -\frac{1}{2}g'v_2 & \frac{1}{2}gv_2 & 0 & \epsilon_2 & \epsilon_2\frac{v_u}{v_c} \\ -\frac{1}{2}g'v_3 & \frac{1}{2}gv_3 & 0 & \epsilon_3 & \epsilon_3\frac{v_u}{v_c} \end{pmatrix}$$

Seesaw mechanism

- Adding right-handed neutrino: N

Superpotential:

$$W = -Y_\nu^{ij}\epsilon_{\alpha\beta}H_{u\alpha}N_iL_{j\beta} + \frac{M_{ij}}{2}N_iN_j$$

New terms in the soft susy breaking potential

Sneutrino mass term: $m_0^2 \tilde{N}_i^\dagger \tilde{N}_i$

Neutrino A-term: $a_0 Y_\nu^{ij} \epsilon_{\alpha\beta} H_{u\alpha} \tilde{N}_i \tilde{L}_{j\beta}$

Neutrino B-term: $\frac{B_\nu M_i}{2} \tilde{N}_i \tilde{N}_i$

One should worry about LFV again.