Neutrino Masses in the Lepton Number Violating MSSM

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12-17 June, SUSY 2006, California, Irvine

Outline

- $\not{L}$-MSSM : Introduction and Motivation, mSUGRA
- Fermion masses and Mixings at Tree level
- Anatomy of the 1-loop corrections to ν-masses
- Neutrino masses and mixings - Results
- Correlations - An example
- Conclusions

*Based on :

B. Allanach, A.D., H. Dreiner, PRD 69 115002 (2004)

A.D., S. Rimmer, J. Rosiek, M. Schmidt-Sommerfeld, PLB 627 (161) 2005

A.D., S. Rimmer, J. Rosiek, hep-ph/0603225, JHEP to appear

A.D., S. Rimmer, J. Rosiek, work in progress.

Introduction and Motivation

There are two discrete “gauge" symmetries that are anomaly free[a]:

- Z_2-R-parity symmetry : L and H_d are different fields
- Z_3- discrete symmetry : L and H_d are the same fields

$$\mathcal{W}^{\not{L}} = Y^e_{ij}\, L_i H_d \bar{E}_j + Y^d_{ij}\, L_i H_d \bar{D}_j + Y^u_{ij}\, Q_i H_u \bar{U}_j + \mu\, H_u H_d$$
$$+\lambda_{ijk}\, L_i L_j \bar{E}_k + \lambda'_{ijk}\, L_i Q_j \bar{D}_k + \kappa_i\, L_i H_u$$

$$\mathcal{L}^{\not{L}}_{SOFT} = (B_i\, \tilde{L}_i H_u + H.c) + \ldots.$$

[a] Ibanez and Ross ’95; Nilles and Polonsky ’96; H. Dreiner, C. Luhn, M. Thormeier, ’05

- A priori there is no preference for or against $\not{L}$-MSSM in Supersymmetric GUT's

$\rightarrow$ $SU(5)$[a] : $\lambda_{ijk}\bar{\mathbf{5}}_i\bar{\mathbf{5}}_j\mathbf{10}_k + \kappa_i\bar{\mathbf{5}}_i\mathbf{5}_H$

$\rightarrow$ $SO(10)$[b] :

$$\mathbf{16}_i \cdot \mathbf{16}_j \cdot \mathbf{16}_k \quad \text{not invariant}$$

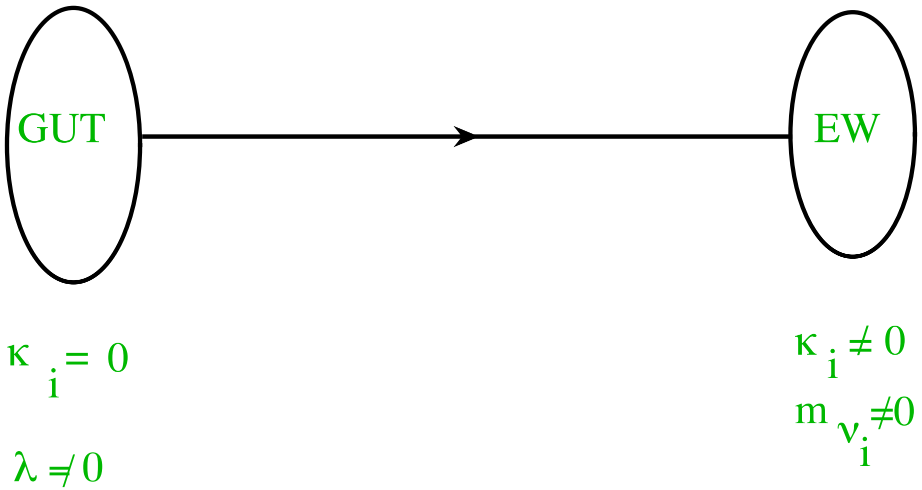
However, after breaking $SO(10)$

$$\mathbf{16}_i \cdot \mathbf{16}_j \cdot \mathbf{16}_k \cdot \mathbf{16}_H \cdot G(H)$$

[a] Hall and Suzuki'84; Smirnov and Vissani'95; Tamvakis'96

[b] Guidice and Rattazzi'97; G. Senjanovic et.al '99, '01

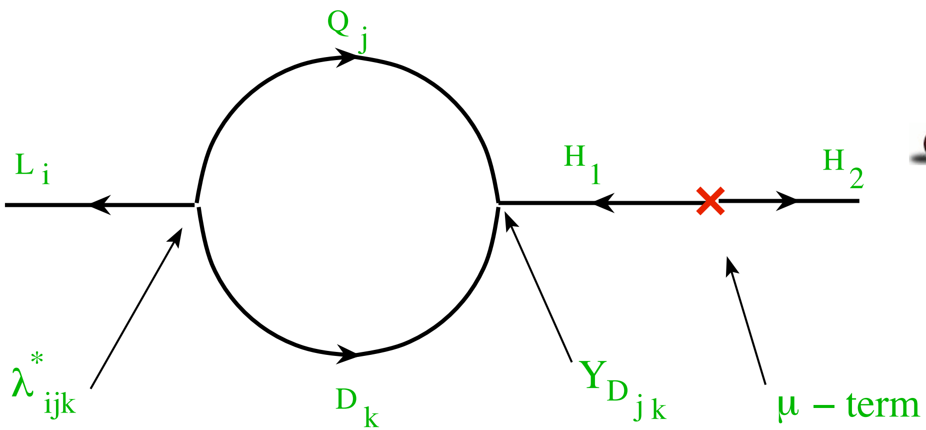
mSUGRA $\not{L}$-MSSM



- In SUGRA with minimal Kähler potential we can always rotate away the κ_i-term before SUSY breaking[a].

[a] B. Allanach, A.D, H. Dreiner' 04; I. Jack, D.R.T Jones, A. Kord'05

mSUGRA $\not{L}$-MSSM



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- Non-zero κ_i are induced from the RGEs

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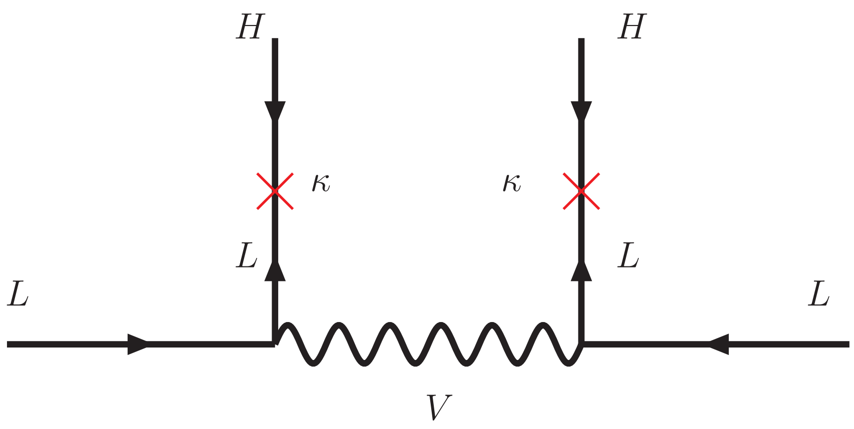

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- Non-zero κ_i are induced from the RGEs
- At low energies a tree level neutrino mass is generated

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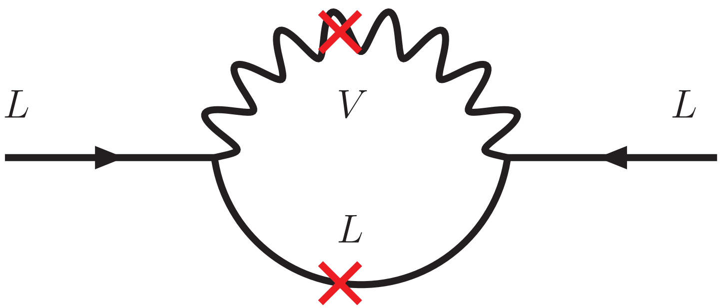
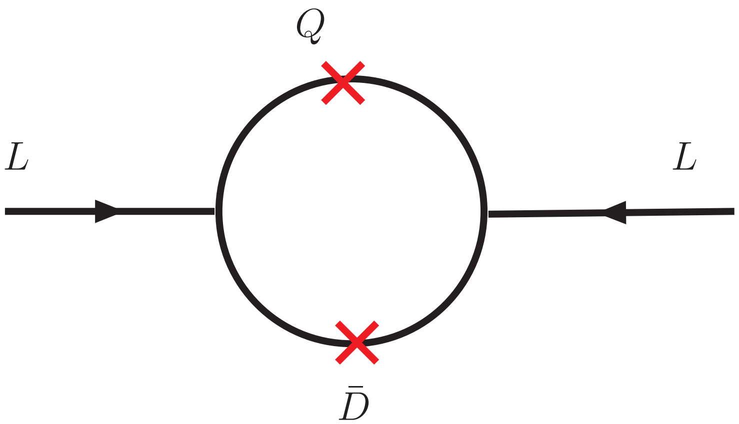
mSUGRA $\not{L}$-MSSM





- In SUGRA with minimal Kähler potential we can always rotate away the κ_i-term before SUSY breaking.
- Non-zero κ_i are induced from the RGEs
- At low energies a tree level neutrino mass is generated
- ν-masses are induced from finite thresholds

Fermion masses and Mixings

- Neutralino Mass matrix

$$\mathcal{M}_N = \begin{pmatrix} M_{N\,4\times4} & d_{N\,4\times3} \\ d^T_{N\,3\times4} & 0_{3\times3} \end{pmatrix} ,$$

$$M_{N\,4\times4} = \begin{pmatrix} M_1 & 0 & \frac{g v_u}{2} & -\frac{g v_d}{2} \\ 0 & M_2 & -\frac{g_2 v_u}{2} & \frac{g_2 v_d}{2} \\ \frac{g v_u}{2} & -\frac{g_2 v_u}{2} & 0 & -\mu \\ -\frac{g v_d}{2} & \frac{g_2 v_d}{2} & -\mu & 0 \end{pmatrix} ,$$

and

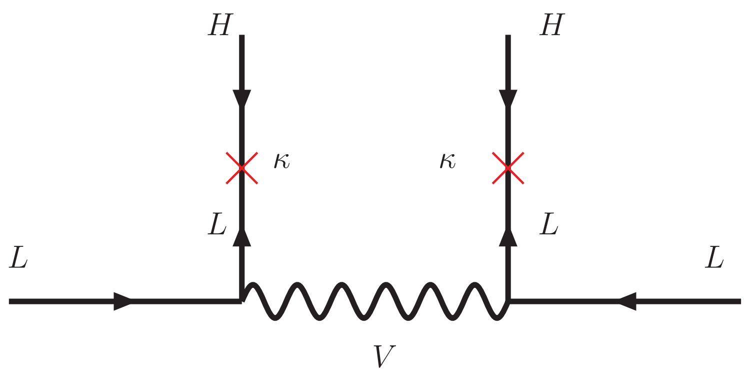
$$d_{N4\times3} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ -\kappa_1 & -\kappa_2 & -\kappa_3 \\ 0 & 0 & 0 \end{pmatrix} .$$

Fermion masses and Mixings

- Neutralino Mass matrix

$$\mathcal{M}_N = \begin{pmatrix} M_{N\,4\times4} & d_{N\,4\times3} \\ d^T_{N\,3\times4} & 0_{3\times3} \end{pmatrix} ,$$

$$m_\nu^{tree} = \left| \frac{v_d^2 (M_1 g_2^2 + M_2 g^2)}{4\text{Det}[M_N]} \right| (|\kappa_1|^2 + |\kappa_2|^2 + |\kappa_3|^2) , \quad 0 , \quad 0$$



Fermion masses and Mixings

- Neutralino Mass matrix

$$\mathcal{M}_N = \begin{pmatrix} M_{N\,4\times4} & d_{N\,4\times3} \\ d^T_{N\,3\times4} & 0_{3\times3} \end{pmatrix} ,$$

The neutralino mixing matrix at tree level is undefined. Quantum corrections are necessary to define neutrino masses and mixings

Towards the full 1-loop ν-masses

Our objective is to calculate the full 1-loop neutrino masses and compare with results from ν-oscillations[a]

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[a] Relevant literature :

Bilinear : T. Banks, Y. Grossmann, E. Nardi '95;

Josiphura and Nowakowski'95; Nowakowski and Pilaftsis'95;

R. Hempfling '96;

De Carlos and White '96; Nilles and Polonsky '96; Kaplan and Nelson, '00;

Hirsch, Diaz, Porod, Romao,Valle '00; Abada, Davidson, Losada '02

Trilinear : Chun, Kang, Kim, Lee '98; Haber and Grossman '99;

F. Borzumati and J.S. Lee, '02.

Towards the full 1-loop ν-masses

Our objective is to calculate the full 1-loop neutrino masses and compare with results from ν-oscillations

1. Not all parameters are physical – a good basis choice is needed[a]
   - Basis $< \tilde{\nu}_i >= 0$[b]
   - Soft breaking masses $m_{L_{ij}}$ are diagonal
   - No CP-violation at tree level
   - Simple Higgs sector – analytic results

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[a] A.D, S. Rimmer, J. Rosiek, M. Schmidt-Sommerfeld' 05

[b] M. Bisset, O. C. W. Kong, C. Macesanu and L. H. Orr, '98

Haber and Grossman' 02

Towards the full 1-loop ν-masses

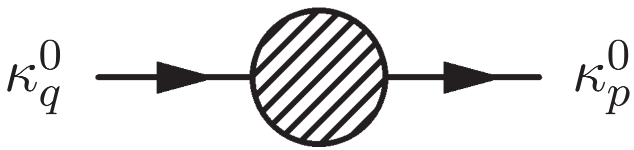
2. Relate the input parameters with the MNS matrix
   - $U_{\rm MNS} \simeq Z_\nu^\dagger \, Z_l^*$
3. Feynman Rules
   - The most general set
   - Fortran coded
4. Complete set of the 1-loop diagrams calculated[a]
   - Gauge invariance checked
   - Cancelation of infinities checked
   - Fortran coded $\times$ 2
     http://www.ippp.dur.ac.uk/∼dph3sr/rpv

[a] A.D., S. Rimmer, J. Rosiek '06

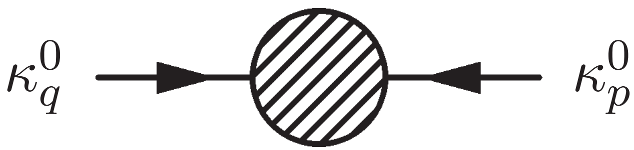
Anatomy of the one-loop corrections

- Physical neutrino masses

$$m^{\rm pole}_{N pq} = m^{\rm bare}_{Nq}(\mu_R)\delta_{pq} + \left[\Re e \Sigma^D_{N\,pq}(m^2_{Np}) - m_{Np}\,\Sigma^L_{N\,pq}(m^2_{Np})\right] \ ,$$

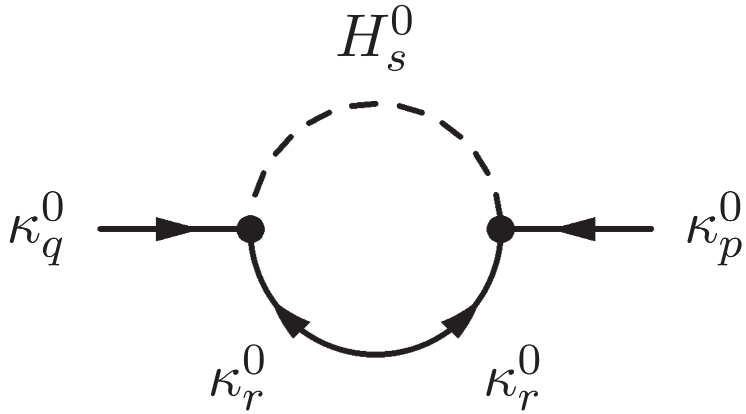


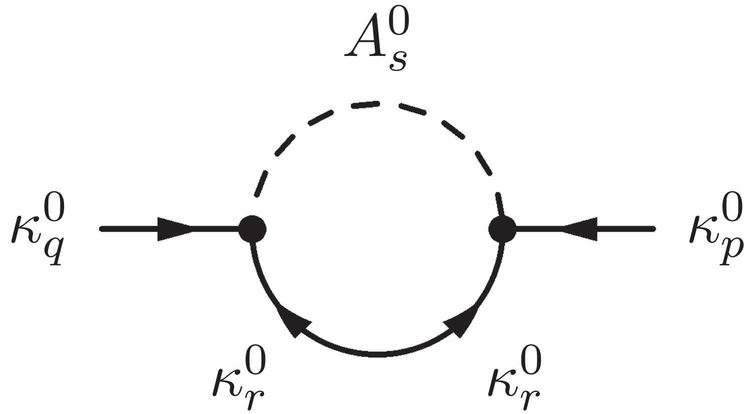
$$= i\,\bar{\sigma}^\mu\,q_\mu\,\Sigma^L_{Npq}(q^2)\ ,$$



$$= -i\,\Sigma^D_{Npq}(q^2)\ .$$

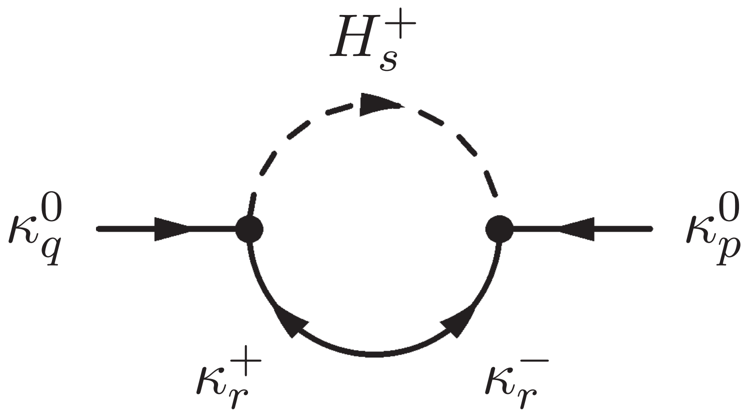
Neutral Scalar Contributions





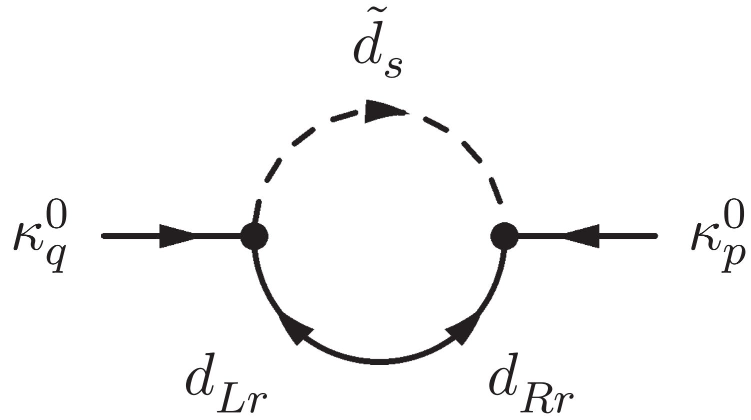
$$\Sigma^D \sim \left(\frac{\alpha}{4\pi}\right)\; m_{\kappa^0} \left(\frac{m_{\kappa^0}}{M}\right)^2 \; \frac{B_i^2\; \tan^2\beta}{(m_{\kappa^0}^2 - M^2)^2} \;,$$

Charged Scalar Contributions



$$\Sigma_N^D \sim \frac{\lambda^2}{16\pi^2} m_l^2 \, \frac{\mu \tan\beta + A_l}{M^2} \ ,$$

Colored Scalar Contributions



$$\Sigma_N^D \sim \frac{3\lambda'^2}{16\pi^2}\, m_d^2\, \frac{\mu \tan\beta + A_d}{M^2} \ ,$$

Experimental Data

The "pre-MINOS" combined neutrino data read (3σ) :

T. Schwetz, '05, see talk by C. Gonzalez-Garcia

$$\sin^2\theta_{12} = 0.24 - 0.40\ , \quad \sin^2\theta_{23} = 0.34 - 0.68\ , \quad \sin^2\theta_{13} \leq 0.046\ ,$$

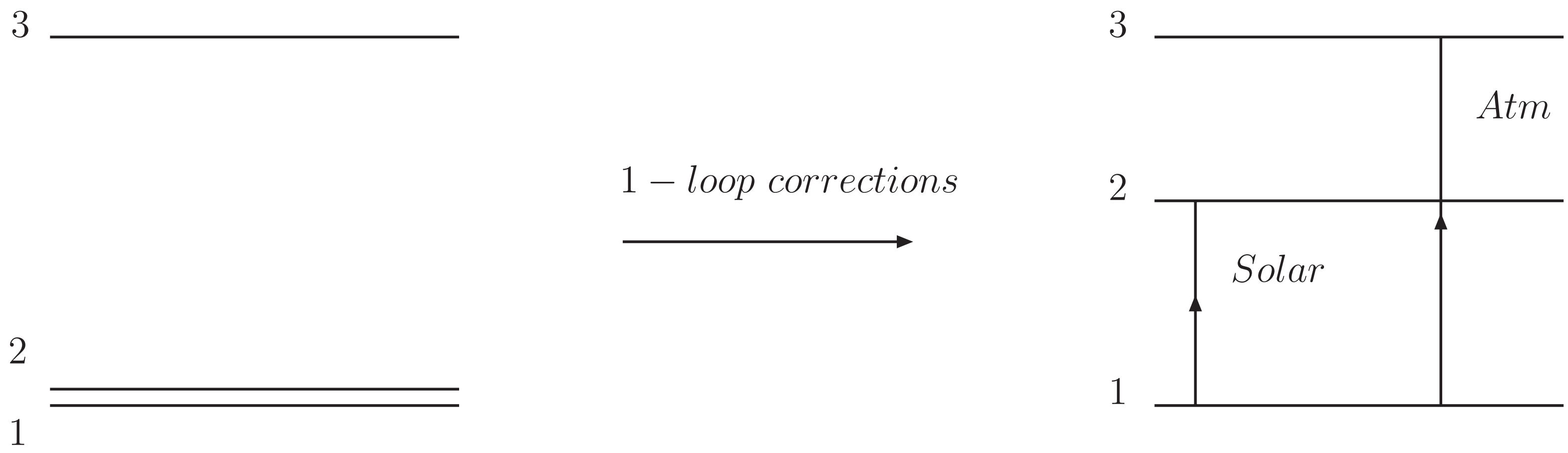
$$\Delta m^2_{21} = (7.1 - 8.9)\times 10^{-5}\ \mathrm{eV}^2\ , \quad |\Delta m^2_{31}| = (1.4 - 3.3)\times 10^{-3}\ \mathrm{eV}^2\ .$$

In our analysis LNV parameters are taken to reproduce the tri-bimaximal mixing scenario of Perkins et.al. ,

$$\sin^2\theta_{12} = \frac{1}{3}\ , \qquad \sin^2\theta_{23} = \frac{1}{2}\ , \qquad \sin^2\theta_{13} = 0\ .$$

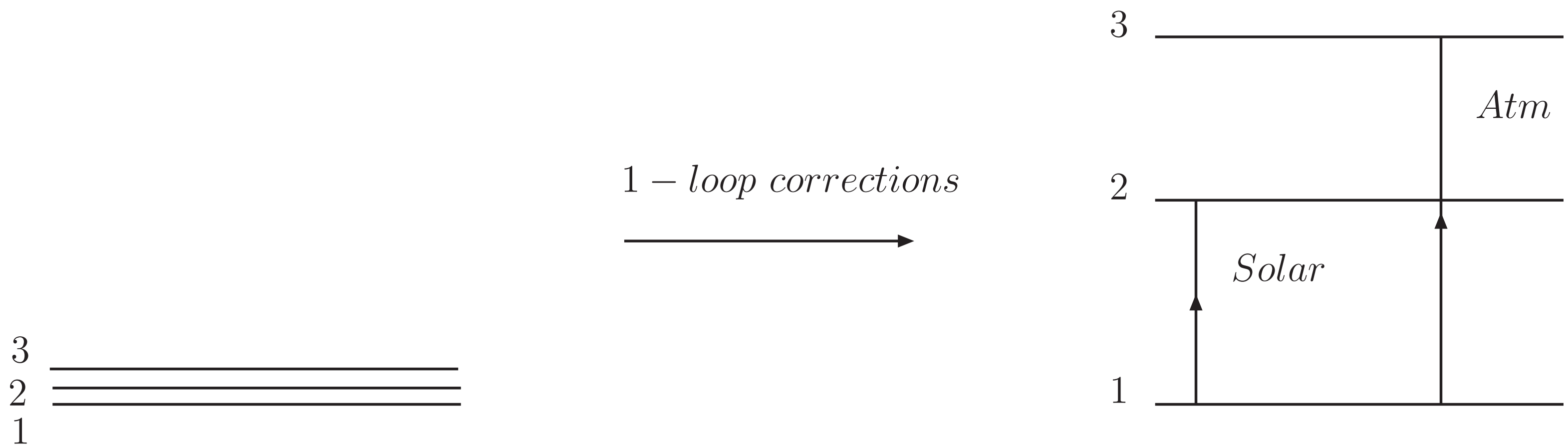
Scenarios

- Tree level dominance ($\kappa_i \neq 0$) : the atmospheric mass^2 difference originates from tree level contributions to neutrino masses



Scenarios

- Loop level dominance ($\kappa_i = 0$) : the atmospheric mass^2 difference originates from one-loop contributions to neutrino masses



Hierarchies

We obtain tri-bimaximal mixing scenario iff :

- Tree level dominance scenario :

$$\text{Hierarchy (A)} \;:\qquad \kappa_1 = \frac{\kappa_2}{\sqrt{2}} = \frac{\kappa_3}{\sqrt{3}}$$

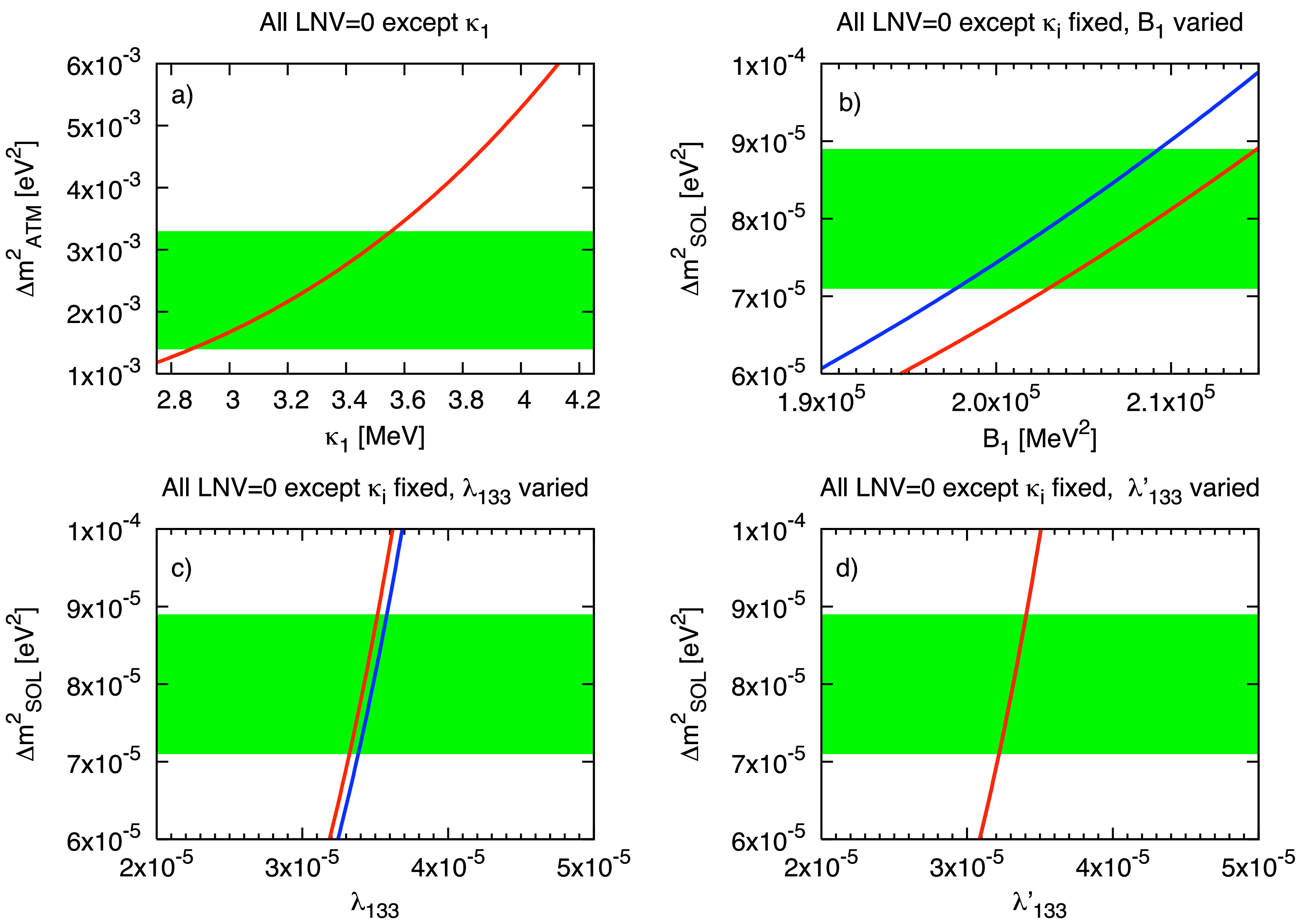
- Loop level dominace scenario :

$$\text{Hierarchy (B)} \;:\qquad \lambda'_{1jj} = \frac{\lambda'_{2jj}}{\sqrt{2}} = \frac{\lambda'_{3jj}}{\sqrt{3}}$$

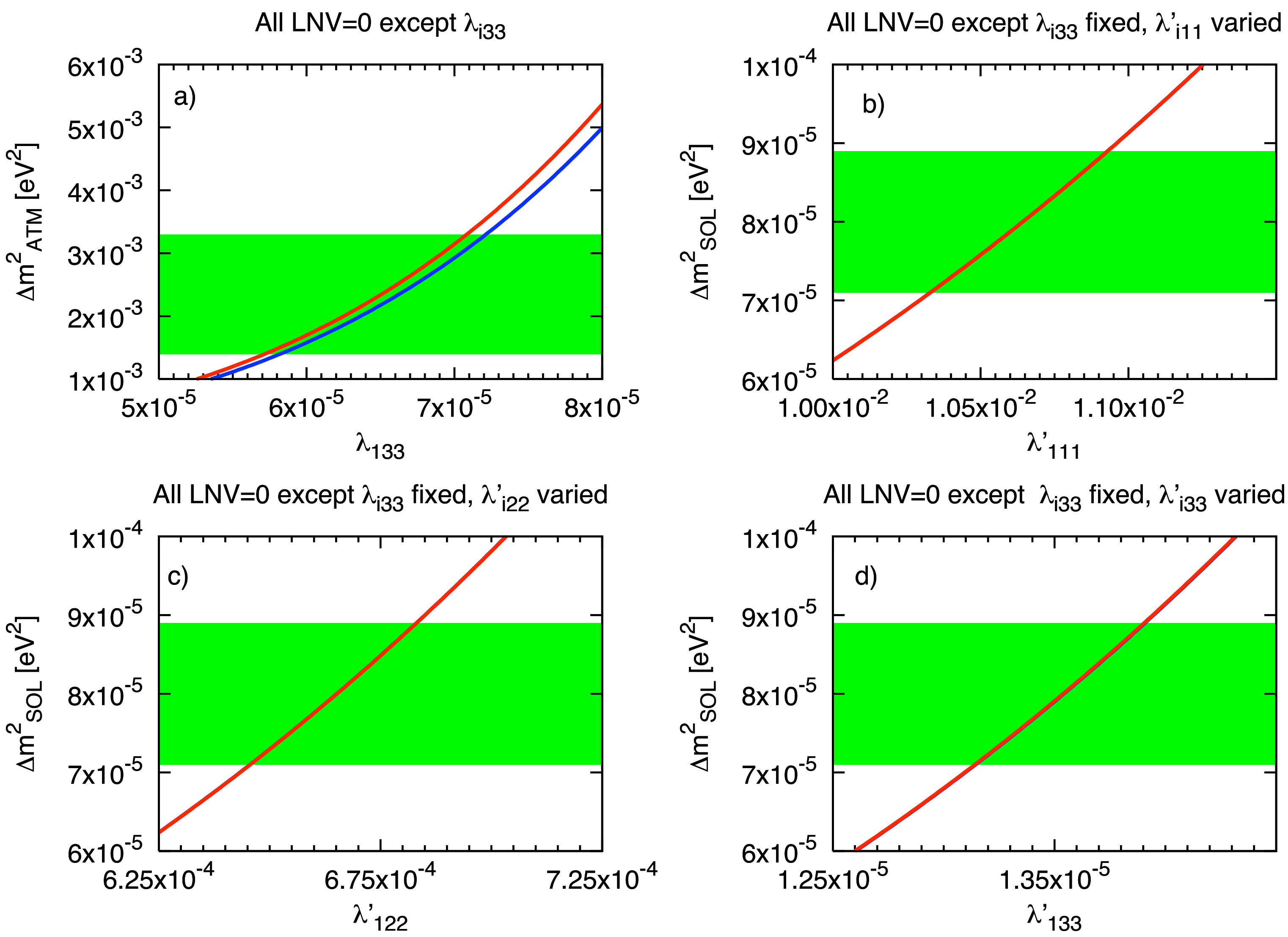
$$\text{Hierarchy (C)} \;:\qquad \lambda'_{1jj} = \frac{\lambda'_{2jj}}{\sqrt{2}} = -\frac{\lambda'_{3jj}}{\sqrt{3}}$$

$$\text{Hierarchy (D)} \;:\qquad \lambda_{1jj} = -\sqrt{2}\lambda_{2jj} \quad , \quad \lambda_{3jj} = 0 \; .$$

Tree level dominance



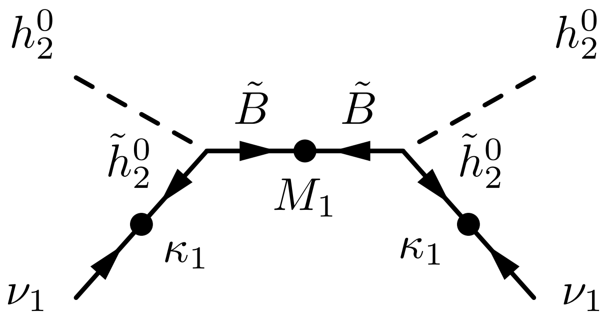
Loop level dominance

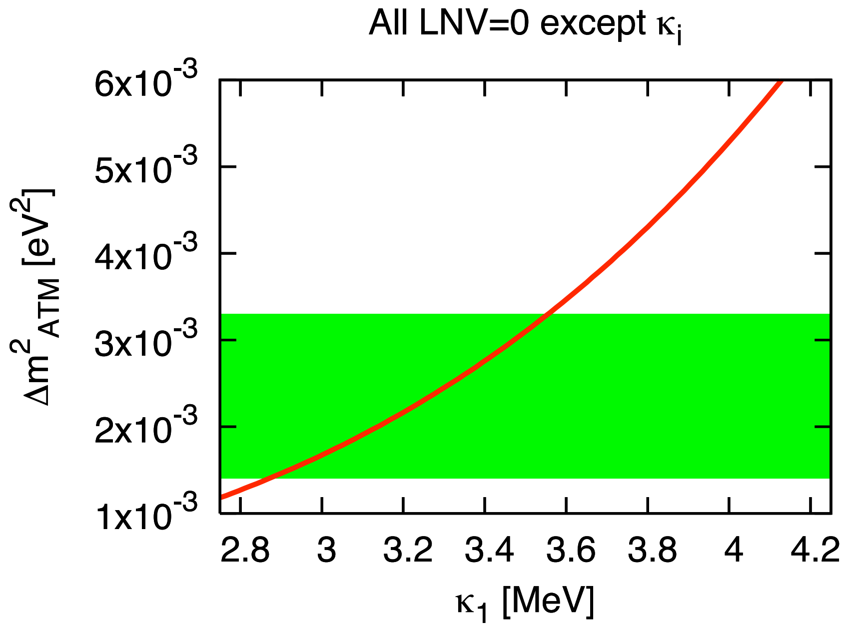


Correlations - An example

Consider the bilinear term κ_i and λ_{121} :

- Atmospheric ν-mass

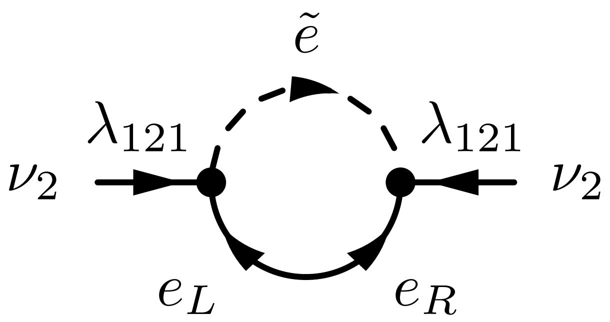


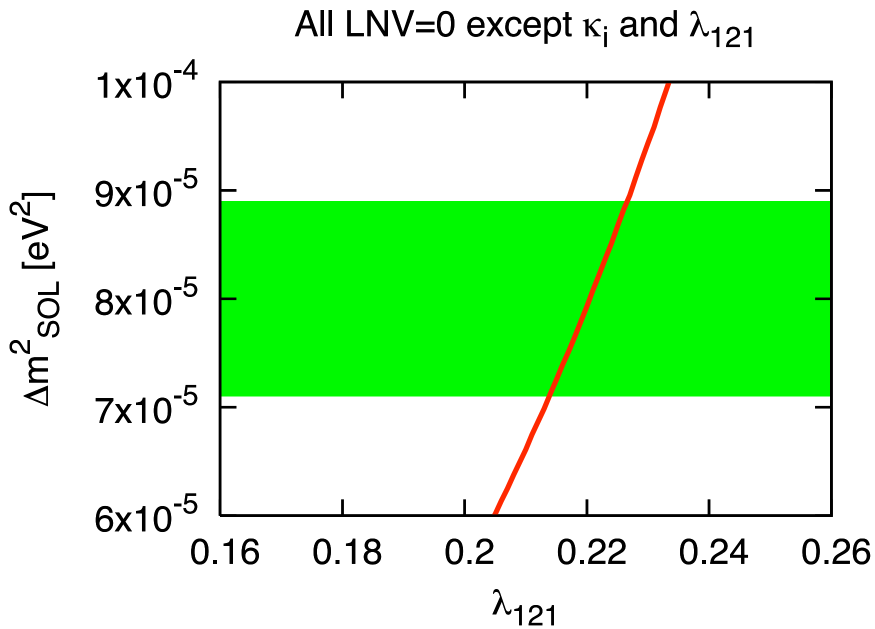


Correlations - An example

Consider the bilinear term κ_i and λ_{121} :

- Solar ν-mass

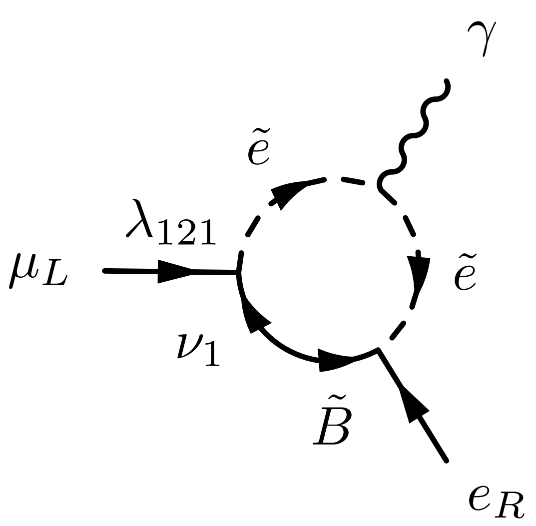


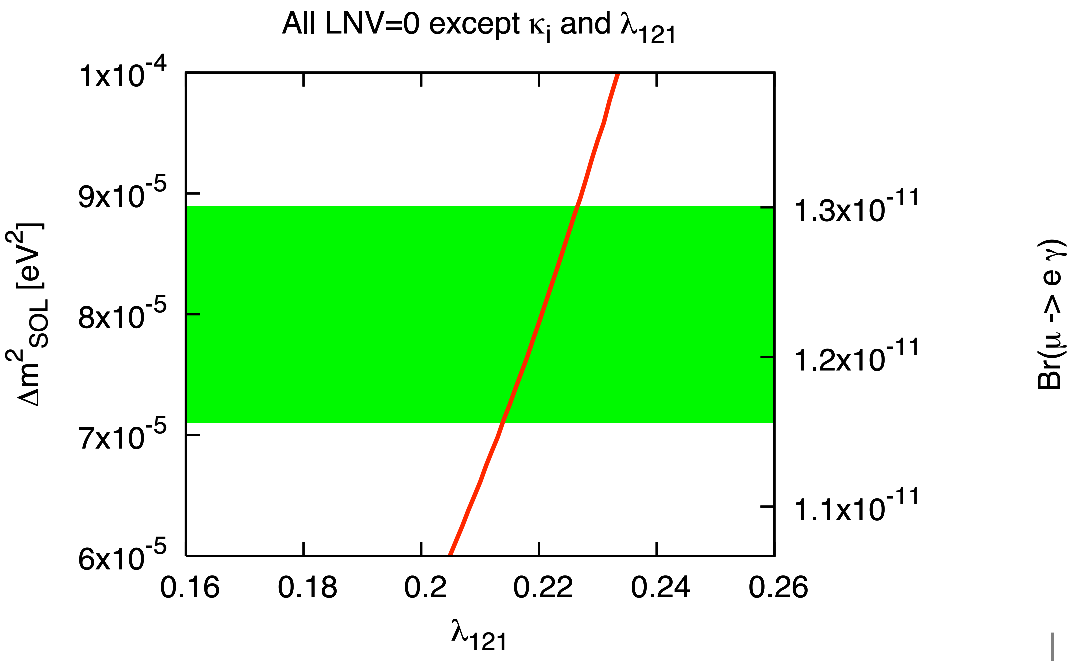


Correlations - An example

Consider the bilinear term κ_i and λ_{121} :

- $\mu \to e\gamma$ [A.D., S. Rimmer, J. Rosiek work in progress]



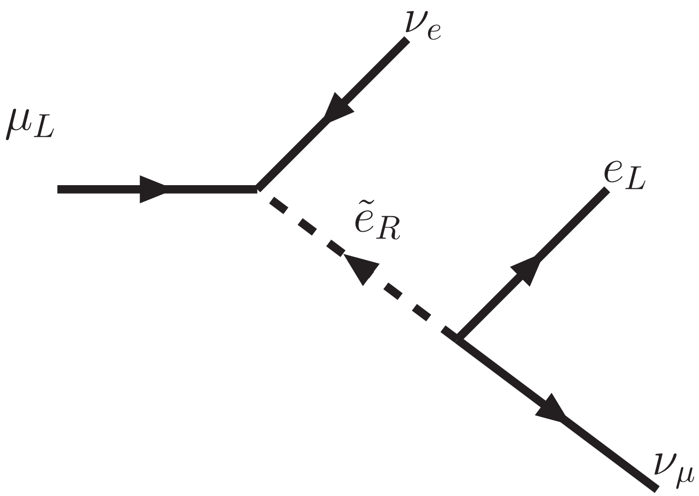


Correlations - An example

Consider the bilinear term κ_i and λ_{121} :

- Muon decay

  V. Barger, G. Giudice, T. Han, '89 ; B. Allanach, A.D., H. Dreiner '99

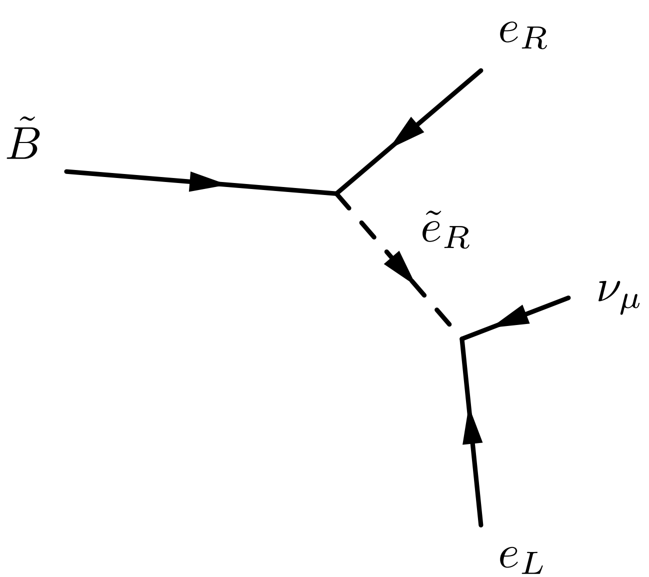


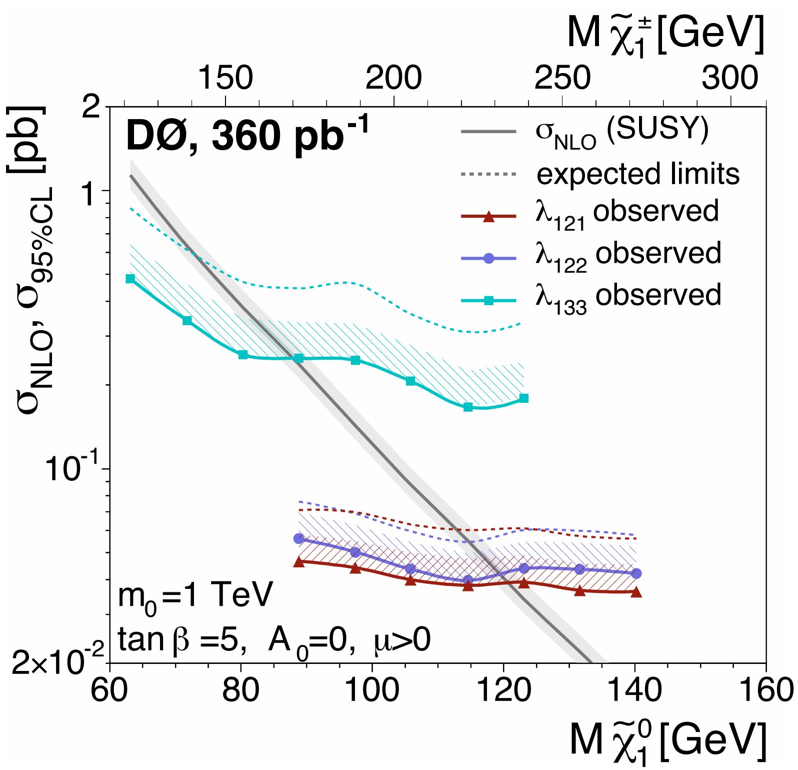
$$\Rightarrow \qquad \lambda_{121} \leq 0.049 \left(\frac{m_{\tilde{e}_R}}{100 \text{ GeV}} \right)$$

Correlations - An example

Consider the bilinear term κ_i and λ_{121} :

- Multilepton searches at Tevatron $p\bar{p} \to \kappa^{\pm}\kappa^{0} \to 3l + E_T$
  (D0-Collaboration,hep-ex/0605005 and talk by C. Autermann)





Conclusions

- After defining the low energy parameters of the $\not{L}$-MSSM , we performed a complete calculation of neutrino masses, and made predictions for neutrino masses and mixings.
- This model agrees with the experimental data when

$$\kappa_i \sim 1\ \mathrm{MeV}\ , \qquad B_i \sim (400\ \mathrm{MeV})^2\ , \qquad \lambda \simeq \lambda' \simeq 10^{-5} \sim y_e\ .$$

Exceptions exist i.e.,

$$\kappa_i \sim 1\ \mathrm{MeV}\ , \qquad \lambda_{121} \simeq \lambda'_{111} \simeq 10^{-1}$$

and have been classified. They lead to observable rates for $\mu \to e\gamma$ or neutrinoless double beta decay. They can be identified at Tevatron and LHC.