Supersymmetric radiative corrections and CP-violation effects on supernova neutrinos

J. Gava, C.-C. Jean-Louis, arXiv:0905.????

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The experimental results on the oscillation parameters

3 masses (but experimentally only mass square differences)…

$$\Delta m^2_{32} = m_3^2 - m_2^2 = 1.9 \text{ to } 3.0 \times 10^{-3} eV^2 \qquad \Delta m^2_{21} = m_2^2 - m_1^2 = 8.0^{+0.4}_{-0.3} \times 10^{-5} eV^2$$

$$U = T_{23} S^\dagger T^0_{13} S T_{12} = \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}}_{T_{23}} \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & \boxed{e^{i\delta}} \end{pmatrix}}_{S^\dagger} \underbrace{\begin{pmatrix} c_{13} & 0 & s_{13} \\ 0 & 1 & 0 \\ -s_{13} & 0 & c_{13} \end{pmatrix}}_{T^0_{13}} \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & \boxed{e^{-i\delta}} \end{pmatrix}}_{S} \underbrace{\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{T_{12}}$$

In three flavours

Maki-Nakagawa-Sakata-Pontecorvo Matrix

3 mixing angles

θ_{12} $\quad sin^2 2\theta_{12} = 0.86^{+0.03}_{-0.04}$ (SNO, Kamland)

θ_{23} $\quad sin^2 2\theta_{23} > 0.92$ (Super-Kamiokande, Minos)

$\boxed{\theta_{13} \ ? \quad sin^2 2\theta_{13} < 0.19}$ (CHOOZ, but soon Double-CHOOZ, T2K…)

CP-violation effects & nu-nu interaction

J. Gava & C. Volpe, Phys.Rev.D78:083007(2008), arXiv:0807.3418

In the standard model, at the tree level, at the neutrinosphere:

$$\boxed{L_{\nu_\mu} = L_{\nu_\tau}}$$

$$\Downarrow$$

$$\boxed{\tilde{H}_{\nu\nu}(\delta) = S\tilde{H}_{\nu\nu}(\delta = 0)S^\dagger}$$

$$\boxed{P(\nu_e \to \nu_e, \delta \neq 0) = P(\nu_e \to \nu_e, \delta = 0)}$$

$$\boxed{\phi_{\nu_e}(\delta) = L_{\nu_e}\underbrace{P(\nu_e \to \nu_e)}_{\neq f(\delta)} + L_{\nu_\mu}(\underbrace{P(\nu_\mu \to \nu_e) + P(\nu_\tau \to \nu_e)}_{\neq f(\delta)})}$$

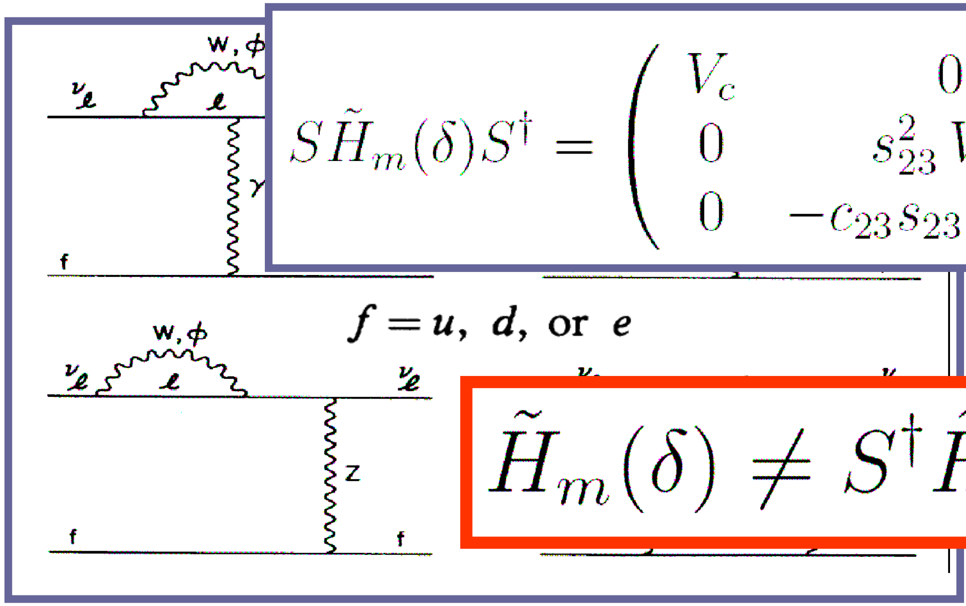
AT TREE LEVEL $\phi\nu_e$ *DOES NOT DEPEND ON* δ.

Radiative corrections on neutrino in Standard Model

Considering one loop corrections in the Standard Model on the neutrino interaction with matter:

$$H_m = \begin{pmatrix} V_c & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & V_{\mu\tau} \end{pmatrix} \quad \text{with} \quad V_{\mu\tau} = \varepsilon V_c = \sqrt{2} G_F \frac{3\sqrt{2} G_F m_\tau^2}{(2\pi)^2 Y_e} \left[\ln\left(\frac{m_W^2}{m_\tau^2}\right) + \frac{Y_n}{3} - 1 \right] N_e$$

Botella, Lim, Marciano, Phys. Rev. D35:896,1987



$$S\tilde{H}_m(\delta)S^\dagger = \begin{pmatrix} V_c & 0 & 0 \\ 0 & s_{23}^2 V_{\mu\tau} & -c_{23}s_{23}e^{-i\delta} V_{\mu\tau} \\ 0 & -c_{23}s_{23}e^{i\delta} V_{\mu\tau} & c_{23}^2 V_{\mu\tau} \end{pmatrix}$$

$$\boxed{\tilde{H}_m(\delta) \neq S^\dagger \tilde{H}_m(\delta = 0) S}$$

Consequences for CP-violation effects

$$\boxed{\tilde{H}_T(\delta) \neq S^\dagger \tilde{H}_T(\delta = 0) S}$$

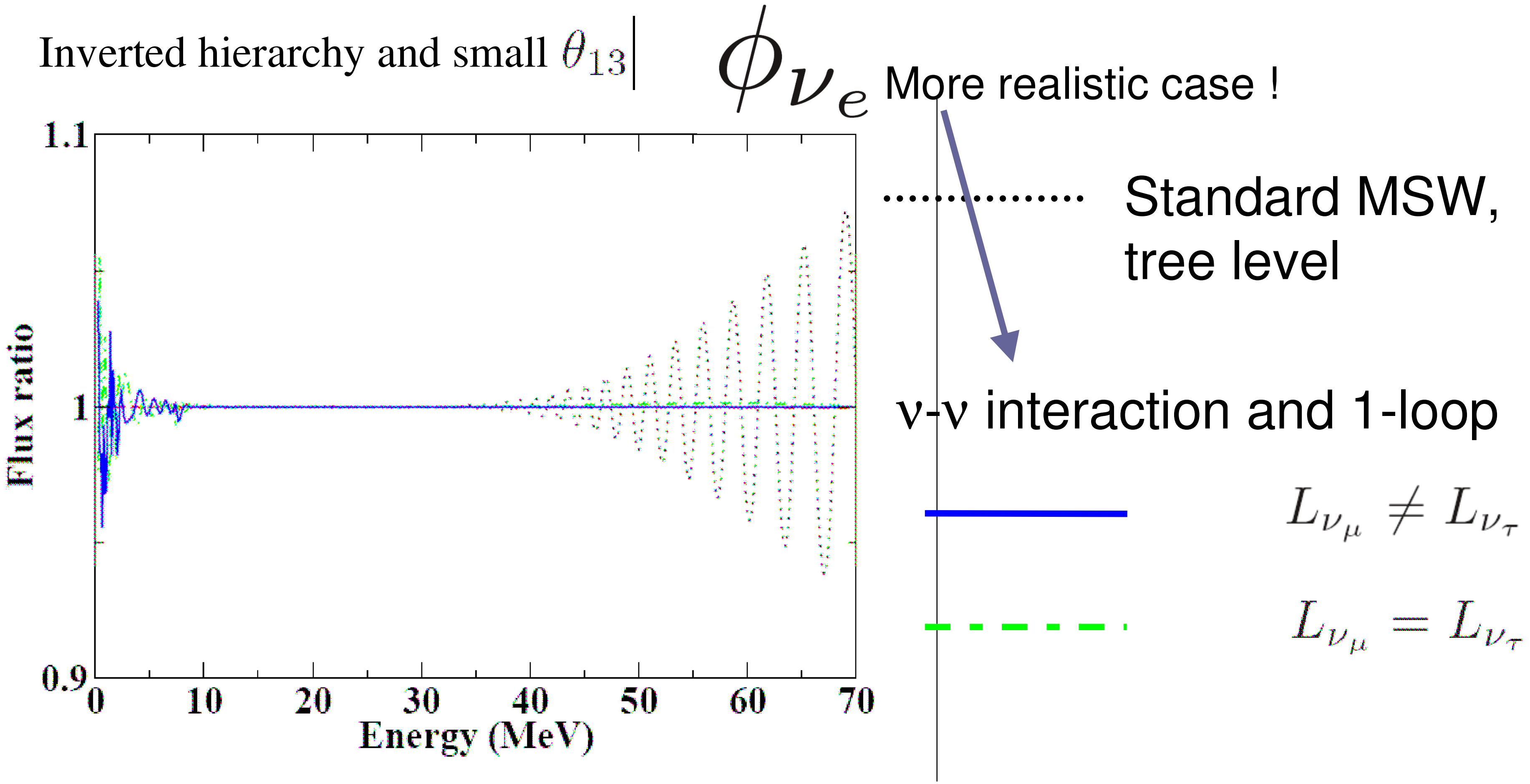
⇓

$$\boxed{P(\nu_e \to \nu_e, \delta \neq 0) \neq P(\nu_e \to \nu_e, \delta = 0)}$$

$$\begin{aligned}
\phi_{\nu_e}(\delta) &= L_{\nu_e} P(\nu_e \to \nu_e,\, \delta) + L_{\nu_\mu} \left(P(\nu_\mu \to \nu_e) + P(\nu_\tau \to \nu_e) \right) \\
&= L_{\nu_e} P(\nu_e \to \nu_e,\, \delta) + L_{\nu_\mu} \left(1 - P(\nu_e \to \nu_e,\, \delta) \right) \\
&= (L_{\nu_e} - L_{\nu_\mu}) P(\nu_e \to \nu_e,\, \delta) + L_{\nu_\mu}
\end{aligned}$$

AT ONE-LOOP LEVEL, $\phi\nu_e$ *DEPENDS ON* δ*.*

CP-violation effects inside the SN



Inverted hierarchy and small θ_{13}

ϕ_{ν_e}

More realistic case !

Standard MSW, tree level

ν-ν interaction and 1-loop

$L_{\nu_\mu} \neq L_{\nu_\tau}$

$L_{\nu_\mu} = L_{\nu_\tau}$

EFFECTS OF 5% ON THE ELECTRON NEUTRINO FLUXES.

Motivations to use Supersymetry

- Supersymmetry is a general symmetry between fermions and bosons
- Gauge couplings unification at GUT scale
- Supersymmetry solves the Hierarchy problem
- There is a supersymmetric particle which is a dark matter candidate

Superfields

There are two kinds of superfields :

. Chiral superfield : $\hat{\Phi} = (z, \psi, F)$

a) leptons → sleptons

b) quarks → squarks

c) higgs → higgsinos

. Vector superfield : $\hat{V} = (v^{\mu}, \lambda, \mathrm{D})$

a) U(1) gauge boson → bino

b) SU(2) gauge bosons → winos

c) gluons → gluinos

F and D are auxiliary fields, they don't have kinetic terms.

NMSSM

We will consider here a supersymmetric model called NMSSM and we give here the fermionic part of the lagrangian:

$$L \;=\; h_t \psi_Q . H_u \psi_{T_R^c} - h_b \psi_Q . H_d \psi_{B_R^c} - h_\tau \psi_L . H_d \psi_{L_R^c} + \lambda S \psi_{H_u} . \psi_{H_d} + \kappa S \psi_S \psi_S + \dots$$

Here L just contains the matter particles.

In supersymmetry we need 2 Higgs bosons to give masses to the other particles.

We will note $\mu = \lambda < S >$ in the following.

Supersymetry breakdown

- Experimental limits on supersymmetric particle masses obviously shows that SUSY has to be broken.
- Thus, the supersymmetric particle masses will be different from Standard Model particle masses.
- The soft breaking terms in NMSSM are :

a) mass terms for scalar particles :

$$\boxed{\begin{gathered} m_{H_u}^2|H_u|^2 + m_{H_d}^2|H_d|^2 + m_S^2|S|^2 + m_Q^2|Q|^2 \\ +m_T^2|T_R|^2 + m_B^2|B_R|^2 + m_L^2|L|^2 + m_\tau^2|L_R|^2 \end{gathered}}$$

b) mass terms for gauginos :

$$\boxed{\frac{1}{2}M_1\lambda_1\lambda_1 + \frac{1}{2}M_2\overrightarrow{\lambda_2}.\overrightarrow{\lambda_2} + \frac{1}{2}M_3\overrightarrow{\lambda_3}.\overrightarrow{\lambda_3}}$$

c) soft terms associated to the superpotential :

$$\boxed{\begin{gathered} (\lambda A_\lambda S H_u.H_d + \frac{\kappa}{3}A_\kappa S^3 \\ +h_t A_t Q.H_u T_R^c - h_b A_b Q.H_d B_R^c - h_\tau A_\tau L.H_d L_R^c + h.c) \end{gathered}}$$

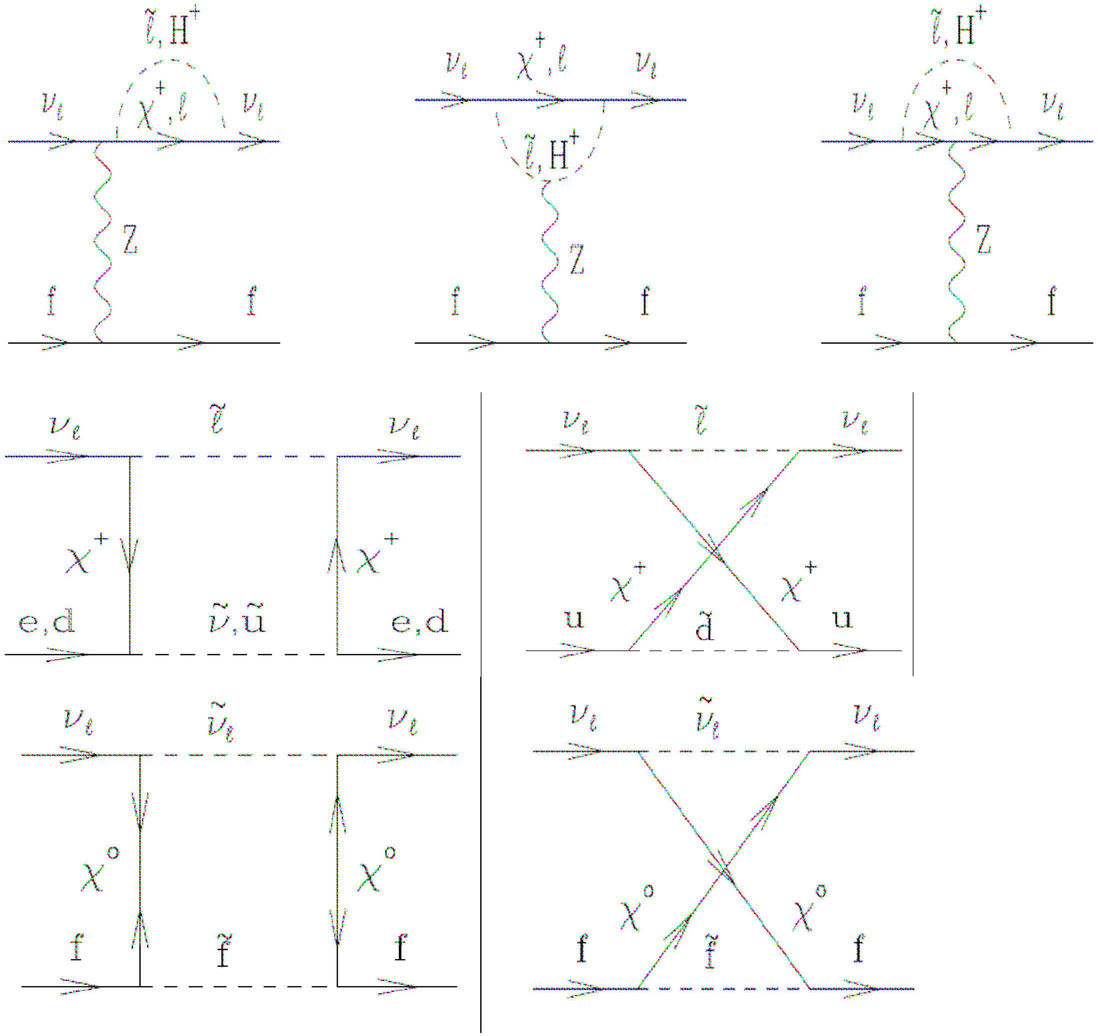
NMSSM Phenomenology

In this model, there are :

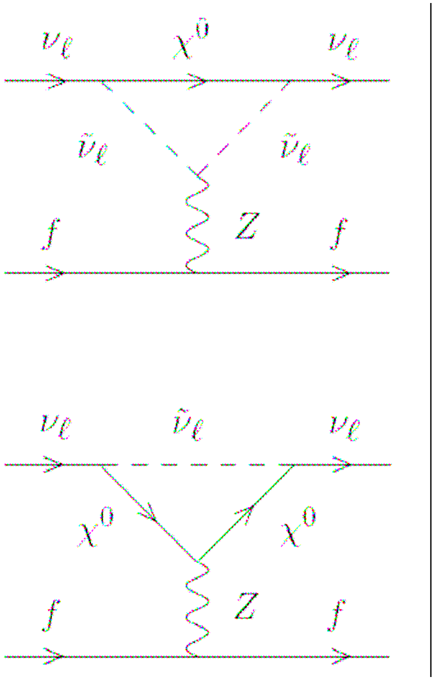
- Standard Model fermions and their scalar supersymmetric partners (sfermions)
- Standard Model gauge bosons
- 3 neutral scalar Higgs (h, H^0, S_R)
- 2 neutral pseudo-scalar Higgs (A^0, S_I)
- 1charged Higgs ($H^{\pm}$)
- 2 charginos ($\chi^{\pm}_{1,2}$) originally from mixing between charged gauginos and charged fermionic super-partners of Higgs bosons (higgsinos)
- 5 neutralinos ($\chi^0_{1...4}$, χ^0_S) of which the lighest called lighest supersymmetric particle (LSP) is gererally stable and is thence a natural candidate for Dark Matter. They come from the mixing between neutral gauginos et neutral higgsinos.

The supersymmetric contributions to $V_{\mu\tau}$ are :

E.Roulet, Phys.Lett.B356:264-272,1995



and:



Numerical analysis

- The analysis of these supersymmetric contributions has been possible by making a routine in the Low-Energy Fortran code called NMHDECAY accessible on the web page :

  www.th.u-psud.fr/nmhdecay/nmssmtools.html.
- U. Ellwanger, J. F. Gunion and C. Hugonie, JHEP 0502(2005) 006
- U. Ellwanger and C. Hugonie, Comput. Phys. Commun. 175 (2006) 290
- G. Belanger, F. Boudjema, C. Hugonie, A. Pukhov, A. Semenov, JCAP 0509 :001 (2005)
- U. Ellwanger and C. Hugonie, Comput.Phys.Commun.177 :399-407,2007
- U. Ellwanger, C.-C. Jean-Louis, A.M. Teixeira, JHEP 0805 :044 (2008)

Input parameters

- We fix some parameters:

. $M_1 = 66GeV, M_2 = 133GeV, M_3 = 500GeV$

. $\lambda = 0,4$

. $\kappa = 0,5$

- We allow some other parameters to vary:

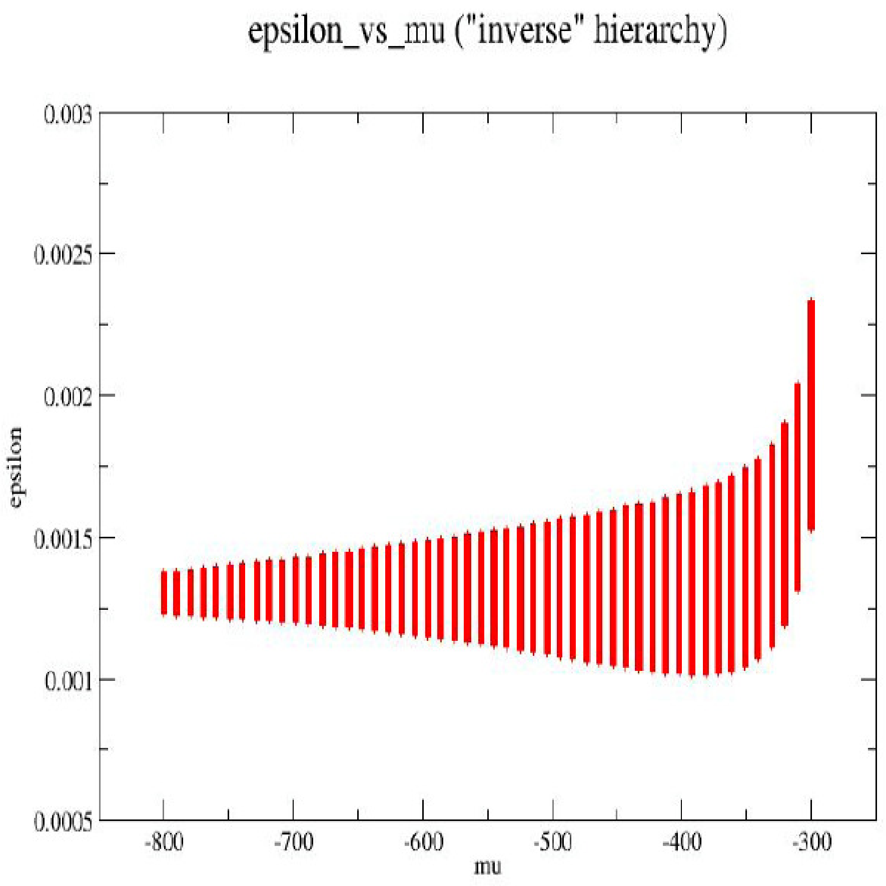
. $tan\beta = 2 \rightarrow 40$

. $M_A = 640 \rightarrow 2000GeV$

. $\mu = -800 \rightarrow -300GeV$

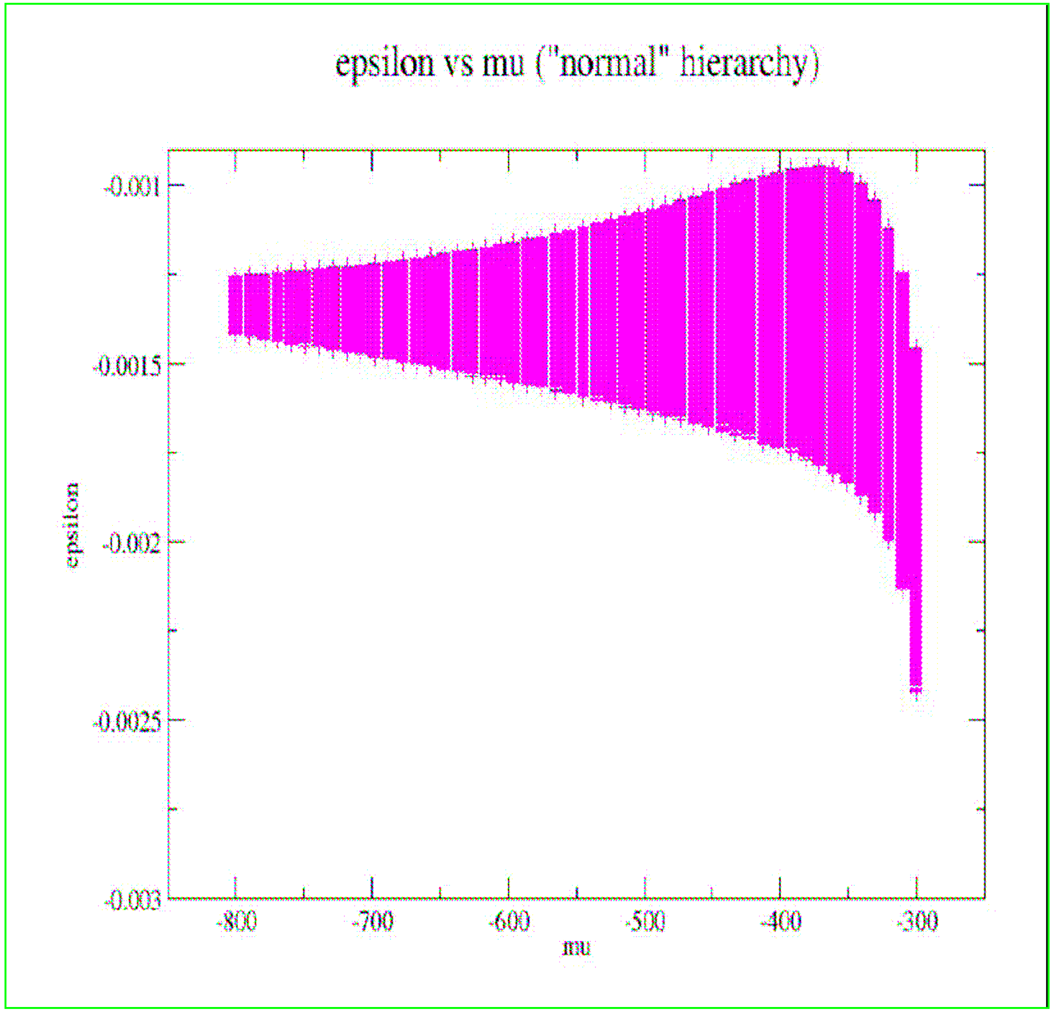
Examples of scans for epsilon

$$M_{\tilde{l}_3} = 200GeV,\, M_{\tilde{l}_{2,1}} = 300GeV$$



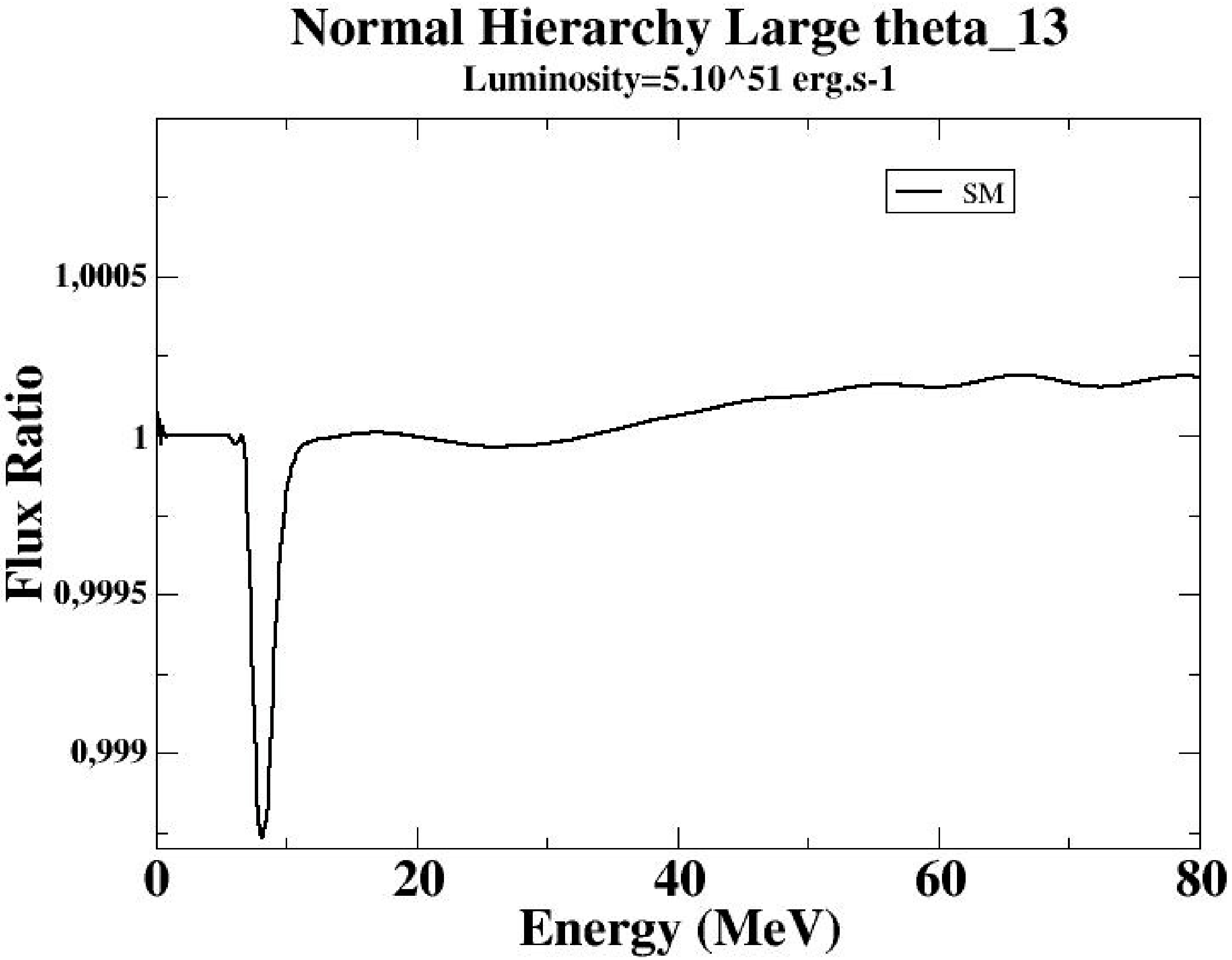
Examples of scans for epsilon

$$M_{\tilde{l}_3} = 300GeV, M_{\tilde{l}_{2,1}} = 200GeV$$



Flux ratio on Earth :

$$R_{\nu_i}(\delta) = \frac{\phi_{\nu_i}(\delta)}{\phi_{\nu_i}(\delta = 0^\circ)}$$



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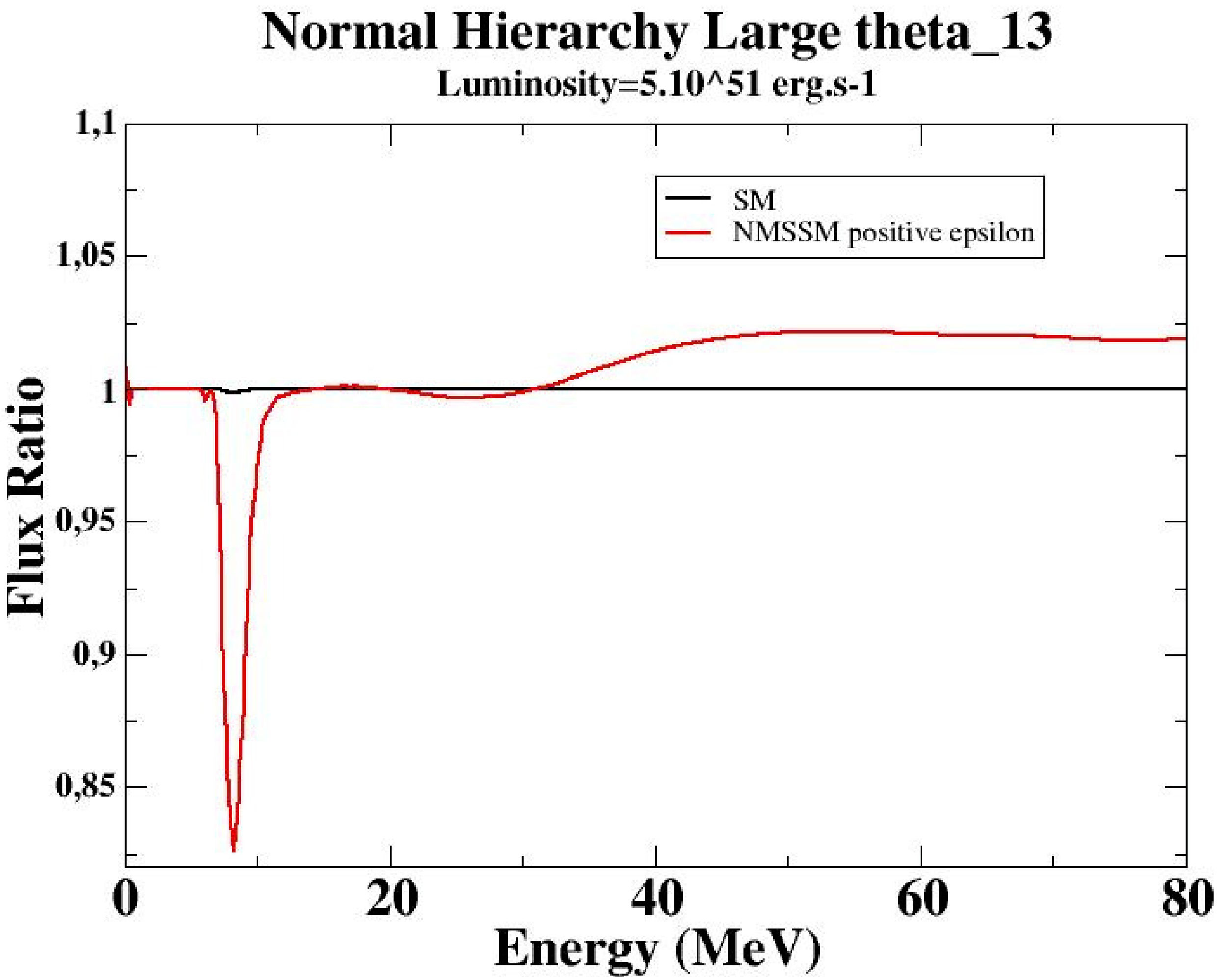

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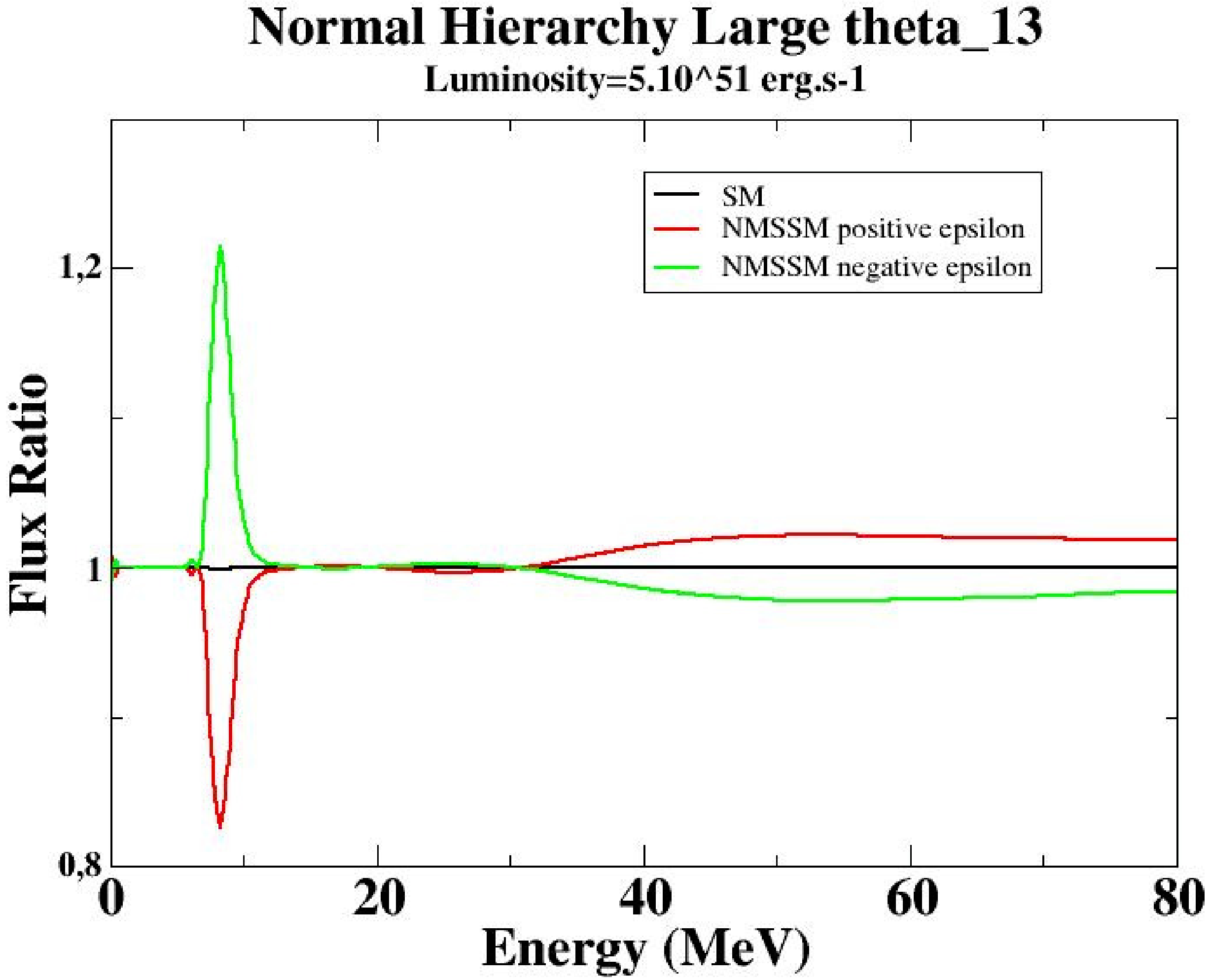

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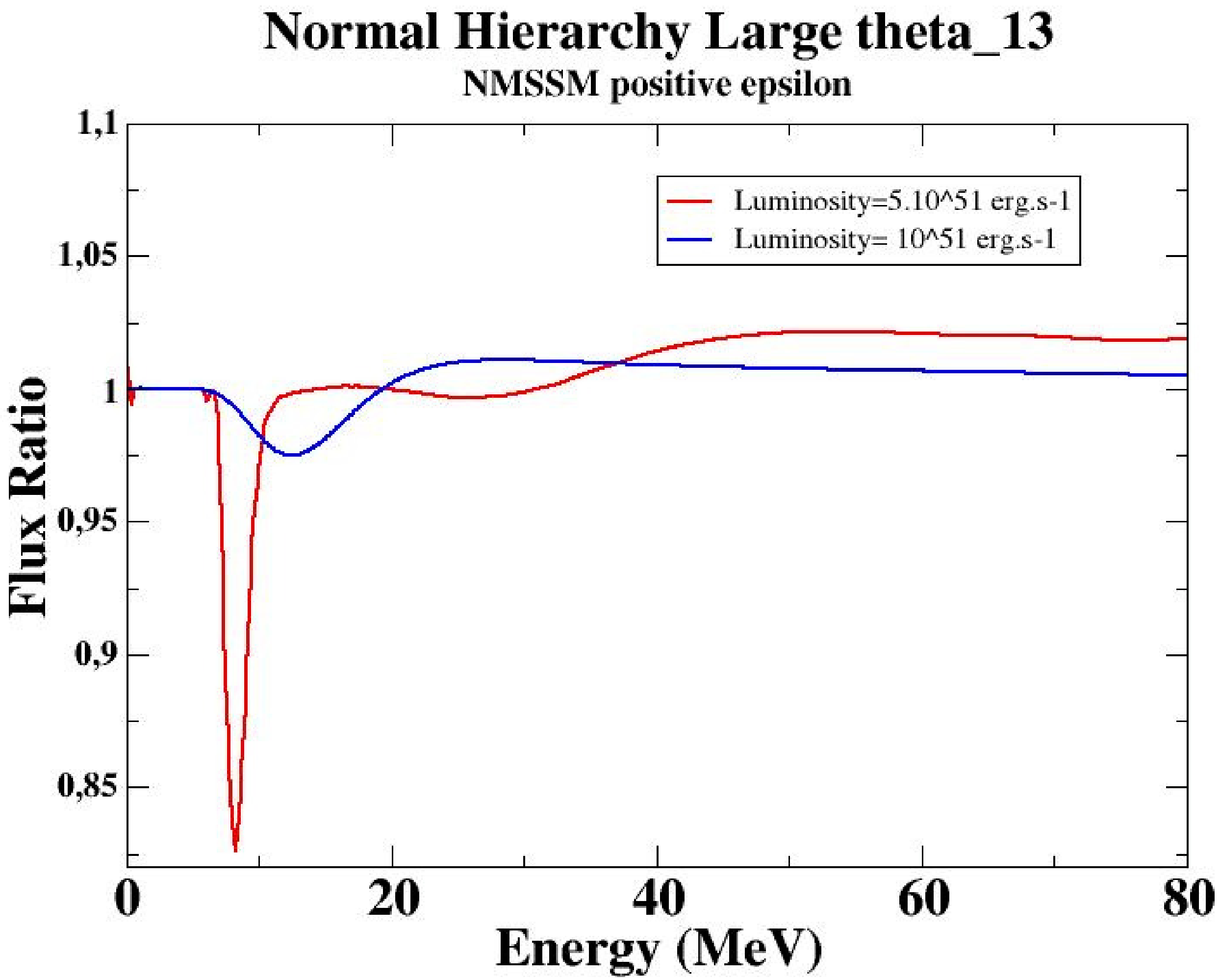
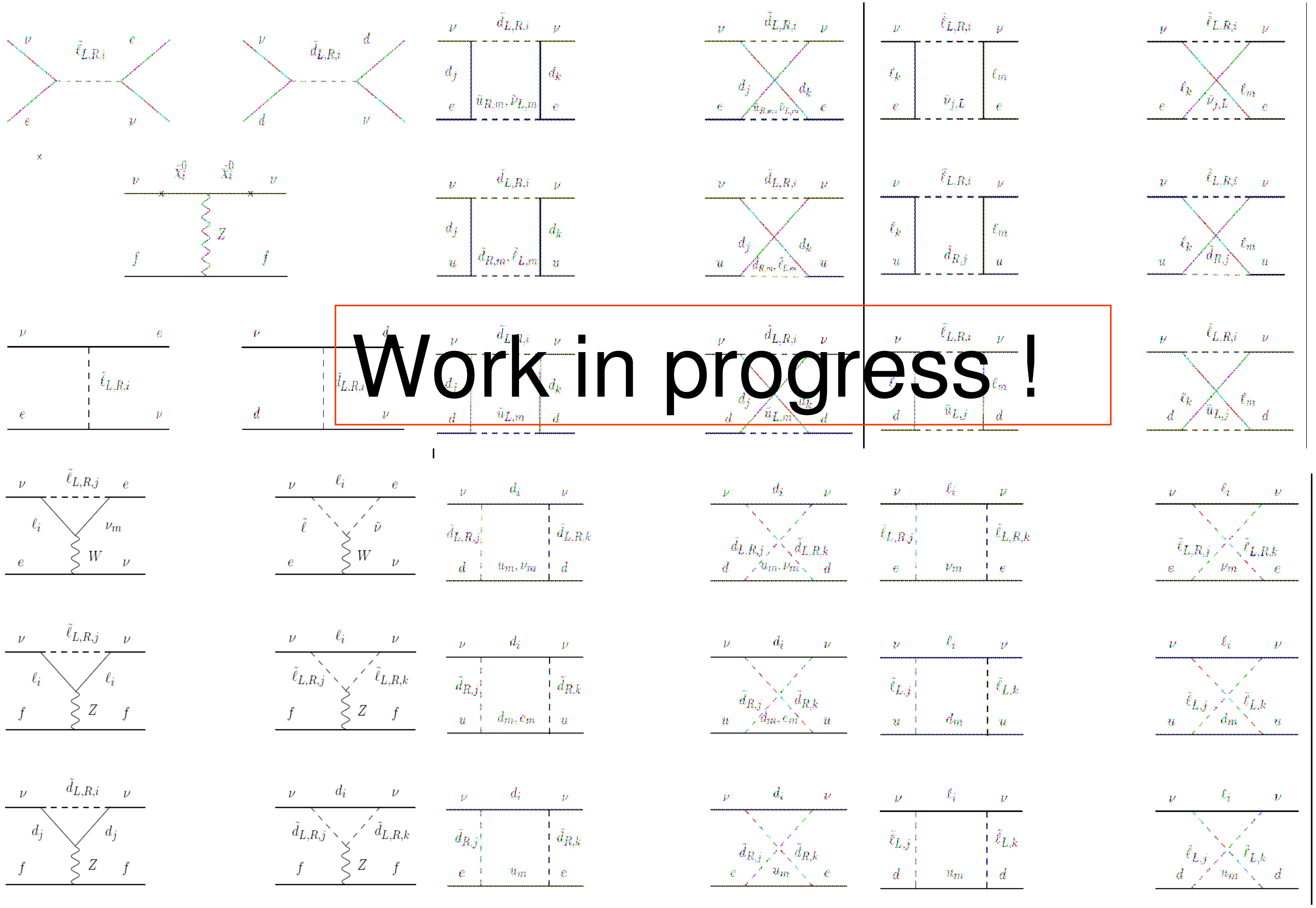


What 's about R-Parity violation ?



Work in progress !

Conclusions

IN THE STANDARD MODEL:

- Very small effect of the CP-violating phase on $\phi\nu_e$ on Earth.

BEYOND THE STANDARD MODEL:

- The one-loop radiative corrections on neutrino propagation can be much larger than in the Standard Model and can even be negative.
- In Normal Hierarchy, one can have about 20% effects on $\phi\nu_e$ on Earth.
- Consequently, it may lead to important constraints on SUSY parameters depending on the neutrino flux we will receive on Earth.
- We are currently investigating other cases and the possibility of R-parity Breaking which could give bigger effects.

GDR Neutrinos

27-28 April 2009 LPNHE, Paris

THANK YOU

GDR

neutrino