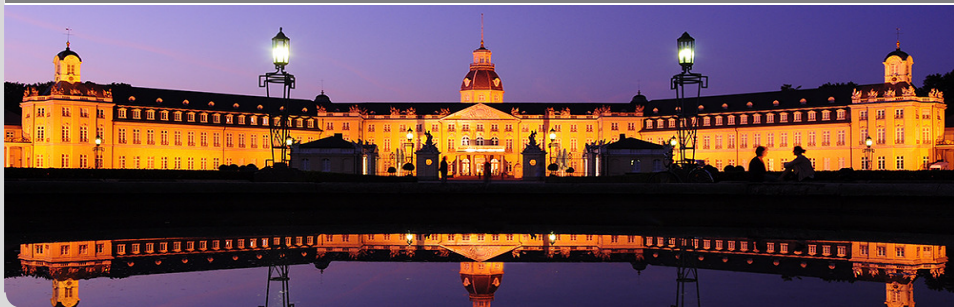


(Quasi-)Degeneration, Quantum Corrections and Neutrino Mixing

in collaboration with Ulrich Nierste

Wolfgang Gregor Hollik | Feb 14, 2014

INSTITUT FÜR THEORETISCHE PARTIKELPHYSIK — KARLSRUHE INSTITUTE OF TECHNOLOGY (KIT)



Why quasi-degenerate neutrinos?

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Why not?

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- Oscillations:

- $\Delta m_{21}^2 = 7.54^{+0.26}_{-0.22} \times 10^{-5} \text{ eV}^2$

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[global fit by Fogli et al. 2012]

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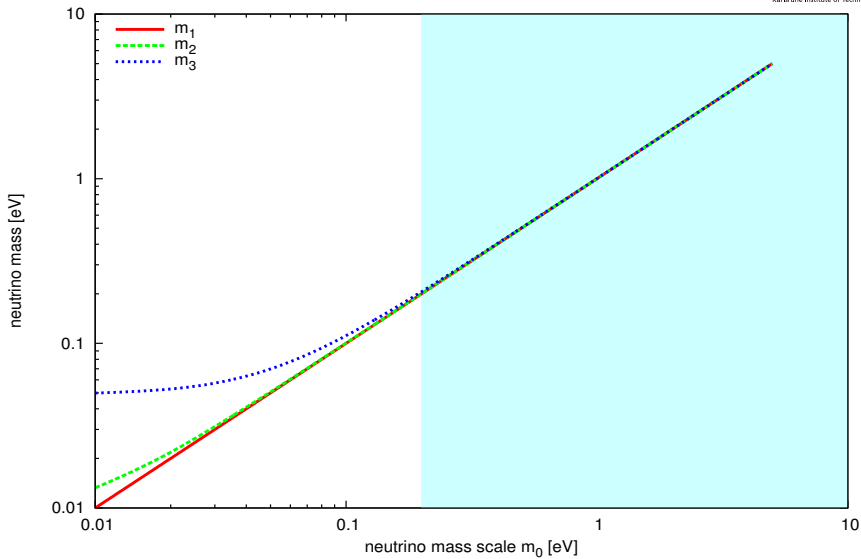
[global fit by Fogli et al. 2012]

- Unknown: Absolute neutrino mass scale \rightarrow KATRIN

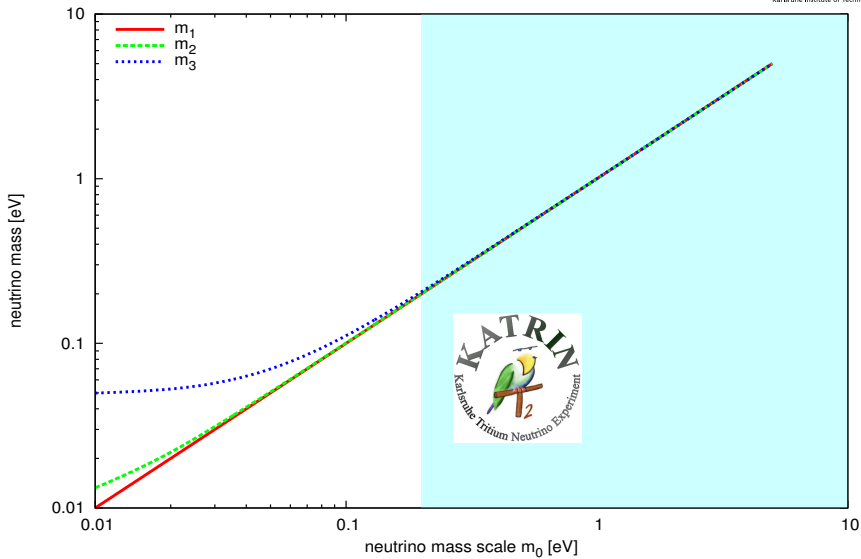


- possible upper limit: **0.2 eV**, discovery: **0.35 eV**

Quasi-Degeneration



Quasi-Degeneration



Quark and Neutrino Mixing

$$V_{\text{CKM}} = \begin{pmatrix} \bullet & \cdot & \cdot \\ \cdot & \bullet & \cdot \\ \cdot & \cdot & \bullet \end{pmatrix}$$

- small mixing angles
- close to unit matrix
- get mixings from loops?

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Radiative Flavour Violation

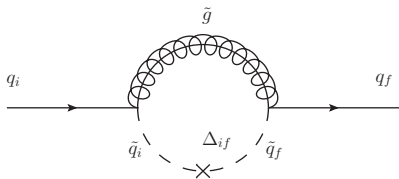
Theories with Additional Sources of Flavour Violation

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- e.g. non-minimal flavour violating MSSM
- arbitrary flavour structure in the soft breaking terms?

$$\mathcal{M}_{\tilde{Q}}^2, \mathcal{M}_{\tilde{U}}^2, \mathcal{M}_{\tilde{D}}^2, \mathcal{M}_{\tilde{\ell}}^2, \mathcal{M}_{\tilde{e}}^2, \quad A^u, A^d, A^e$$

- additional flavour mixing in fermion–sfermion–gaugino interaction
- especially non-CKM-like: e.g. quark–squark–gluino and lepton–slepton–neutralino



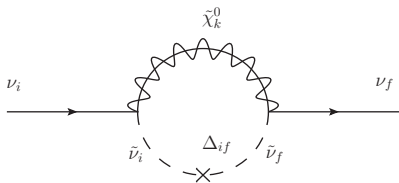
[Crivellin, Nierste 2009]

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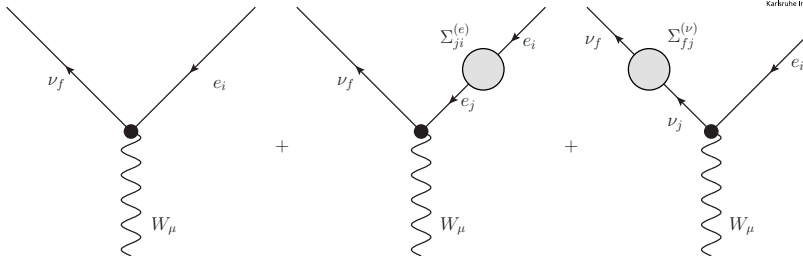
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Do the same for sleptons and sneutrinos!

Neutrino Corrections



mixing matrix renormalization

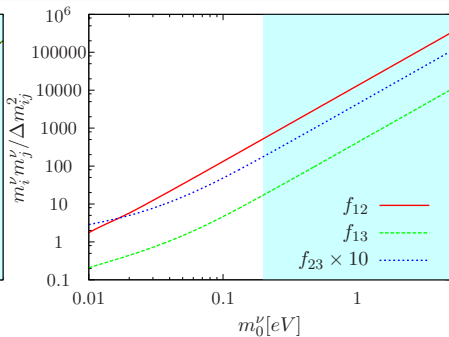
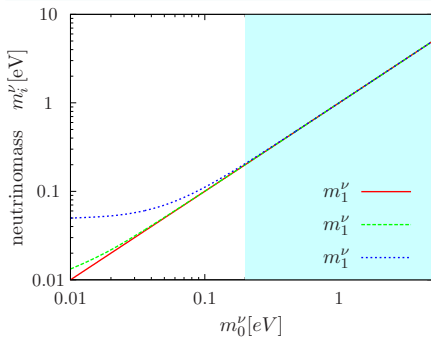
$$i \frac{g}{\sqrt{2}} \gamma^\mu P_L U_{\text{PMNS}}^\dagger \rightarrow i \frac{g}{\sqrt{2}} \gamma^\mu P_L \left(U^{(0)\dagger} + \Delta U^e U^{(0)\dagger} + \Delta U^\nu U^{(0)\dagger} \right),$$

sensitivity to neutrino mass

$$\Delta U_{fi}^\nu \sim \frac{m_{\nu_f} \Sigma_{fi}}{\Delta m_{fi}^2}$$

enhancement by degeneracy of neutrino mass spectrum

$$\Delta U_{fi}^{\nu} \sim \frac{m_{\nu_f} \sum_{fi}}{\Delta m_{\nu}^2} \sim \frac{m_{\nu_f} m_{\nu_i}}{\Delta m_{\nu}^2} \leq 5 \times 10^3 \text{ for } m_{\nu}^{(0)} \sim 0.35 \text{ eV and } f, i = 1, 2$$



$$f_{ij} = m_{\nu_i} m_{\nu_j} / \Delta m_{ij}^2$$

The MSSM with righthanded neutrinos

Superpotential of the ν MSSM

$$\mathcal{W}^\ell = \mu H_d \cdot H_u - Y_\ell^{IJ} H_d \cdot L_L^I E_R^J + Y_\nu^{IJ} H_u \cdot L_L^I N_R^J + \frac{1}{2} m_R^{IJ} N_R^I N_R^J,$$

with $L_L = (\ell_L, \tilde{\ell}_L) \in SU(2)_L$ and $E_R = (e_L^c, \tilde{e}_R^*)$, $N_R = (\nu_L^c, \tilde{\nu}_R^*)$.

Soft-breaking terms

$$\mathcal{V}_{\text{soft}} = (\mathcal{M}_{\tilde{\ell}}^2)^{IJ} \tilde{L}_L^I \tilde{L}_L^J + (\mathcal{M}_{\tilde{e}}^2)^{IJ} \tilde{e}_R^I \tilde{e}_R^{J*} + (\mathcal{M}_{\tilde{\nu}}^2)^{IJ} \tilde{\nu}_R^I \tilde{\nu}_R^{J*} \\ - \left[(B_\nu)^{IJ} \tilde{\nu}_R^I \tilde{\nu}_R^{J*} + A_e^{IJ} H_1 \cdot \tilde{L}_L^I \tilde{e}_R^{J*} - A_\nu^{IJ} H_2 \cdot \tilde{L}_L^I \tilde{\nu}_R^{J*} + \text{h.c.} \right].$$

Standard Model + righthanded Neutrinos = Seesaw Type I

$$-\mathcal{L}_{\nu,\text{mass}} = \underbrace{\bar{\nu}_L m_D \nu_R}_{\text{Dirac mass}} + \frac{1}{2} \underbrace{\bar{\nu}_L^c m_R \nu_R}_{\text{Majorana mass}} + \text{h. c.}$$



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$$\mathcal{M}_\nu = \begin{pmatrix} 0 & m_D \\ m_D^T & m_R \end{pmatrix}$$

[Minkowski 1977]

What about m_R ?

- ν_R SM singlet \rightarrow no constraint for mass


- : $m_\nu = -m_D^T m_R^{-1} m_D \approx \mathcal{O}(0.1 \text{ eV})$

- assumption: Dirac mass of order EW scale ($\mathcal{O}(10 \dots 100 \text{ GeV})$):

$$m_R \sim \mathcal{O}(10^{13 \dots 14} \text{ GeV})$$

$$\Delta U^\nu = \Delta U^\nu(\mathcal{M}_\ell^2, \mathcal{M}_{\bar{\nu}}^2, A_\nu)$$

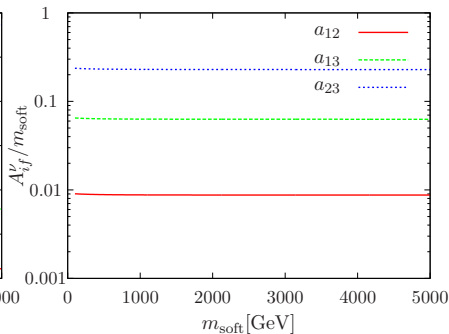
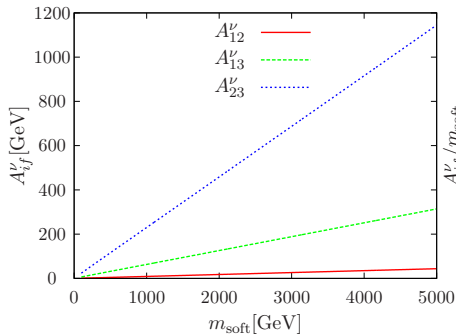
Assumptions:

- $\mathcal{M}_\ell^2 = \mathcal{M}_{\bar{e}}^2 = \mathcal{M}_{\bar{\nu}}^2 \equiv m_{\text{soft}}^2 \mathbb{1}$
- $m_\nu^{(0)} = 0.35 \text{ eV}$ (possible  -discovery)
- only source of FV: A_ν^{ij} with $i \neq j$

$$\Rightarrow \Delta U_{ij}^\nu \propto A_\nu^{ij}$$

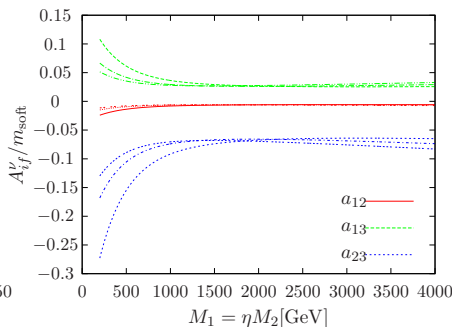
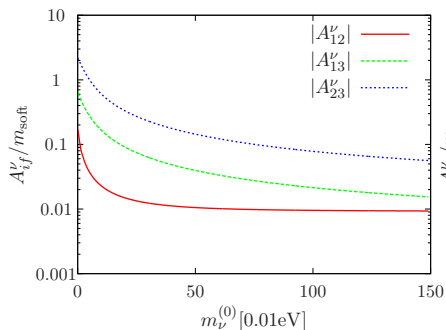
Some results

■ non-decoupling effect



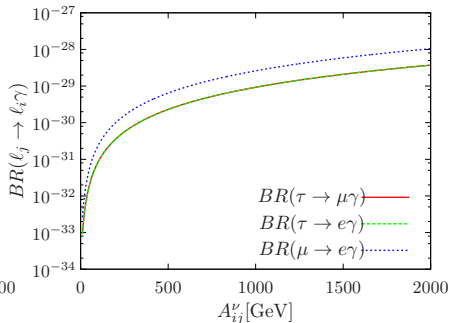
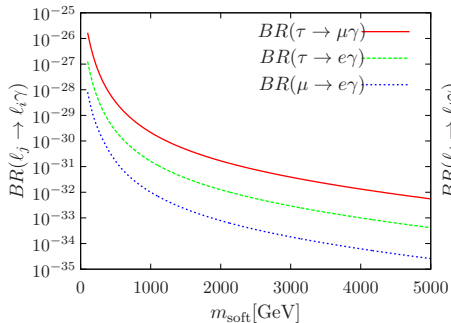
Some results

- basically no dependence on $m_\nu^{(0)}$ for “heavy” neutrinos
- basically no dependence on gaugino mass parameters M_1, M_2



Some results

- safe: contributions to $BR(\ell_j \rightarrow \ell_i \gamma)$ negligible



Conclusion

- mixing matrix corrections enhanced for quasi-degenerate neutrinos
- general for generic Σ_{ij}^ν
- non-decoupling effect in ν MSSM and general SUSY theories
- new flavour structure in sneutrino sector: no large $\mathcal{BR}(l_j \rightarrow l_i \gamma)$

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