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PHYSICS AT THE TERA SCALE
Helmholtz Alliance

Enhanced corrections to neutrino mixing for quasi-degenerate neutrinos

in collaboration with Ulrich Nierste

Wolfgang Gregor Hollik | Dec 3, 2013

INSTITUT FOR THEORETICAL PARTICLE PHYSICS — KARLSRUHE INSTITUTE OF TECHNOLOGY (KIT)

Why quasi-degenerate neutrinos?

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- Oscillations:
  - $\Delta m^2_{21} = 7.54^{+0.26}_{-0.22} \times 10^{-5}\,\mathrm{eV}^2$
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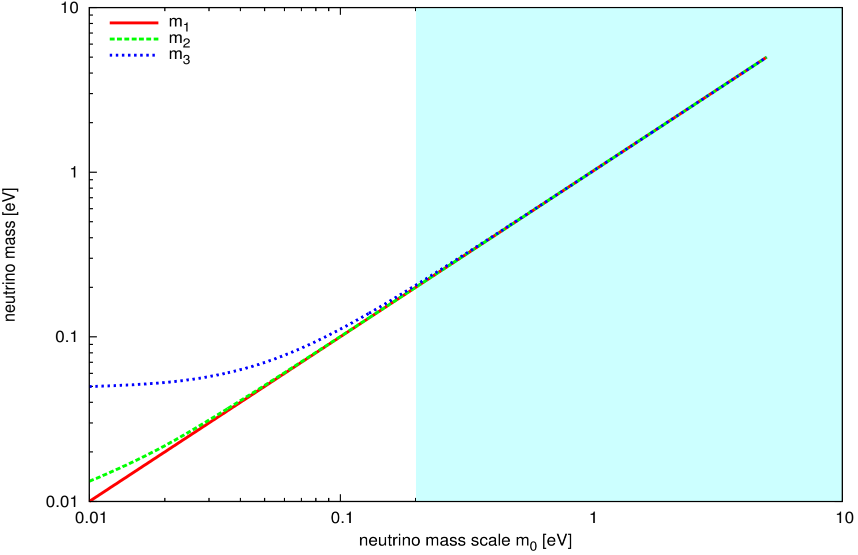
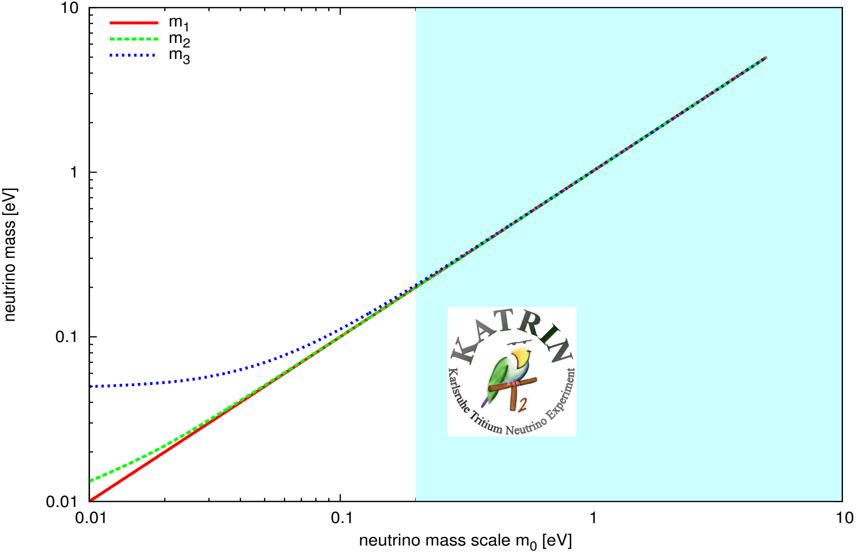
[global fit by Fogli et al. 2012]

- Unknown: Absolute neutrino mass scale → KATRIN
- possible upper limit: **0.2 eV**, discovery: **0.35 eV**

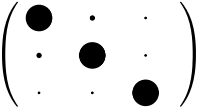
Quasi-Degeneration

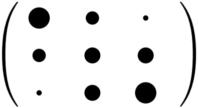


Quasi-Degeneration



Quark and Neutrino Mixing

$V_{\mathrm{CKM}} =$ 

$U_{\mathrm{PMNS}} =$ 

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

- large mixing angles
- no hierarchy
- get mixings from symmetries?

Quark and Neutrino Mixing

$$V_{\mathrm{CKM}} = \begin{pmatrix} \bullet & \cdot & \cdot \\ \cdot & \bullet & \cdot \\ \cdot & \cdot & \bullet \end{pmatrix} \qquad U_{\mathrm{PMNS}} = \begin{pmatrix} \bullet & \bullet & \cdot \\ \bullet & \bullet & \bullet \\ \cdot & \bullet & \bullet \end{pmatrix}$$

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different or similar?

Let's see...

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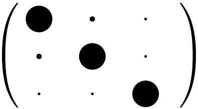
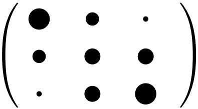
$V_{\mathrm{CKM}} =$ 

$U_{\mathrm{PMNS}} =$ 

- small mixing angles
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Radiative Flavour Violation

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Theories with Additional Sources of Flavour Violation

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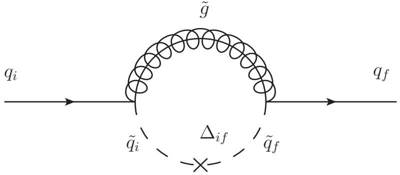
- e.g. non-minimal flavour violating MSSM
- arbitrary flavour structure in the soft breaking terms?

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

- 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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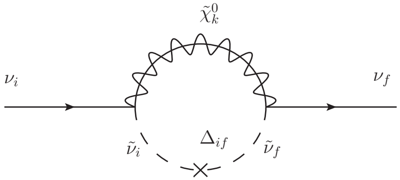
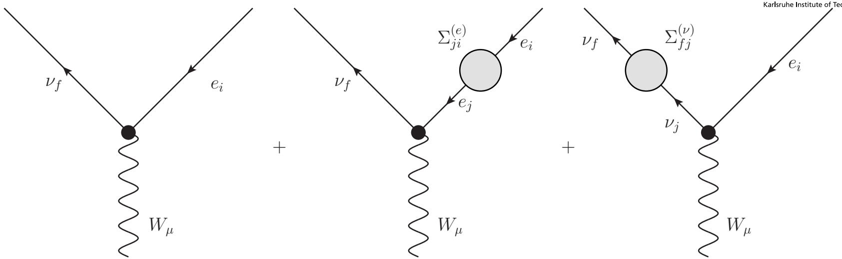


Do the same for sleptons and sneutrinos!

Neutrino Corrections



[Denner & Sack 1990]

mixing matrix renormalization

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

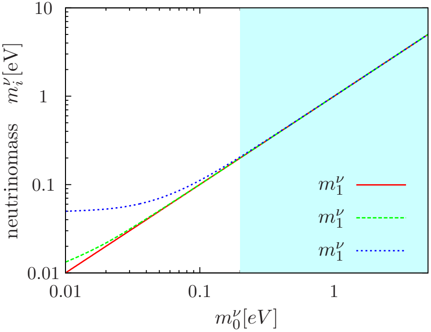
sensitivity to neutrino mass

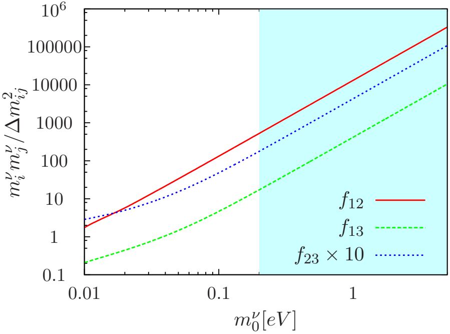
$$\Delta U^\nu_{fi} \sim \frac{m_{\nu_f}\Sigma_{fi}}{\Delta m^2_{fi}}$$

enhanced corrections

enhancement by degeneracy of neutrino mass spectrum

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





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

The MSSM with righthanded neutrinos

Superpotential of the νMSSM

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

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

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

Interlude: Seesaw

Standard Model + righthanded Neutrinos = Seesaw Type I

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

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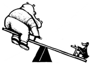
$$\mathcal{M}_\nu = \begin{pmatrix} 0 & m_D \\ m_D^T & m_R \end{pmatrix}$$

[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 ($\mathcal{O}(10\ldots 100\text{ GeV})$): $m_R \sim \mathcal{O}(10^{13\ldots14}\text{ GeV})$

Some results

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

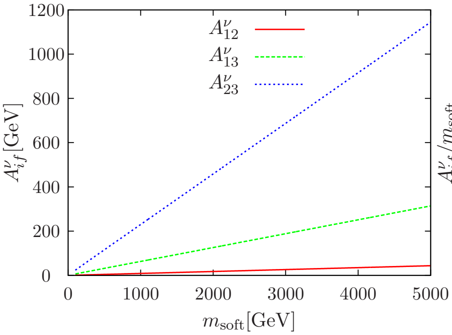
Assumptions:

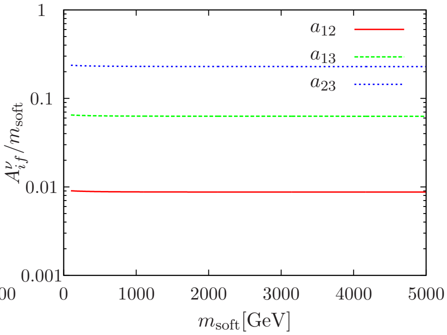
- $\mathcal{M}^2_{\tilde{\ell}} = \mathcal{M}^2_{\tilde{e}} = \mathcal{M}^2_{\tilde{\nu}} \equiv m^2_{\text{soft}}\,\mathbb{1}$
- $m_{\nu}^{(0)} = 0.35$ eV (possible KATRIN -discovery)
- only source of FV: A_{ν}^{ij} with $i \neq j$

$$\Rightarrow \Delta U^{\nu}_{ij} \propto A^{ij}_{\nu}$$

Some results

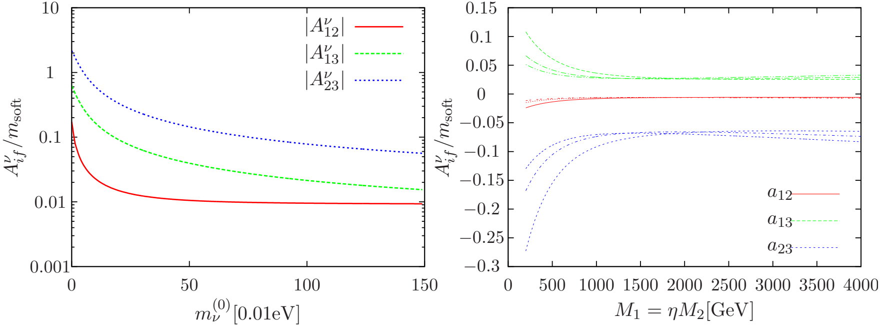
- non-decoupling effect





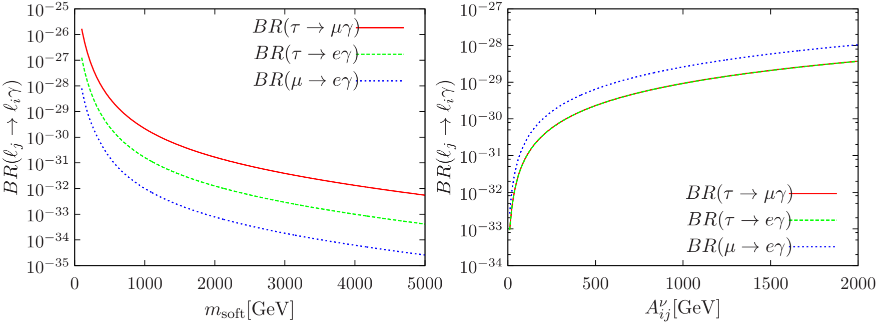
Some results

- 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 $\mathcal{BR}(\ell_j \to \ell_i \gamma)$ negligible



Conclusion

- enhancement for quasi-degenerate neutrinos
- general for generic Σ^ν_{ij}
- non-decoupling effect in νMSSM and general SUSY theories
- new flavour structure in sneutrino sector: no large $\mathcal{BR}(\ell_j \to \ell_i \gamma)$

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