Long lived right-handed neutrinos, oscillations and leptogenesis

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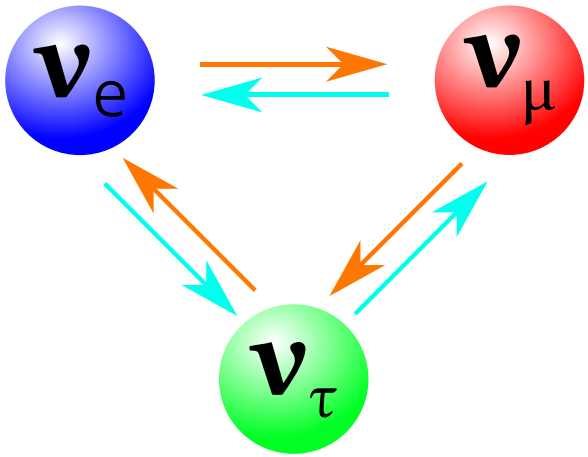
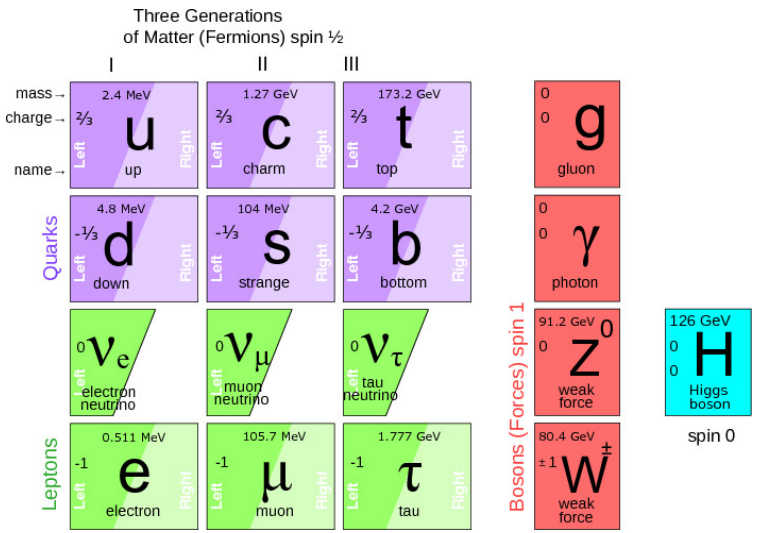
Neutrino oscillations & the Standard Model





courtsy M. Shaposhnikov

- No right-handed neutrinos in the Standard Model (SM).
- No mass matrix, no mixing of the neutrino flavour states.

$\Rightarrow$ Neutrino oscillations are evidence of physics beyond the SM.

Lowscale seesaw

Benchmark model, defined in Antusch, OF; JHEP **1505** (2015) 053

Similar to e.g.: Mohapatra, Valle (1986); Malinsky, Romao Valle (2005); Shaposhnikov (2007);

- Lowscale seesaw Lagrangian, two sterile neutrinos N_i with protective symmetry:

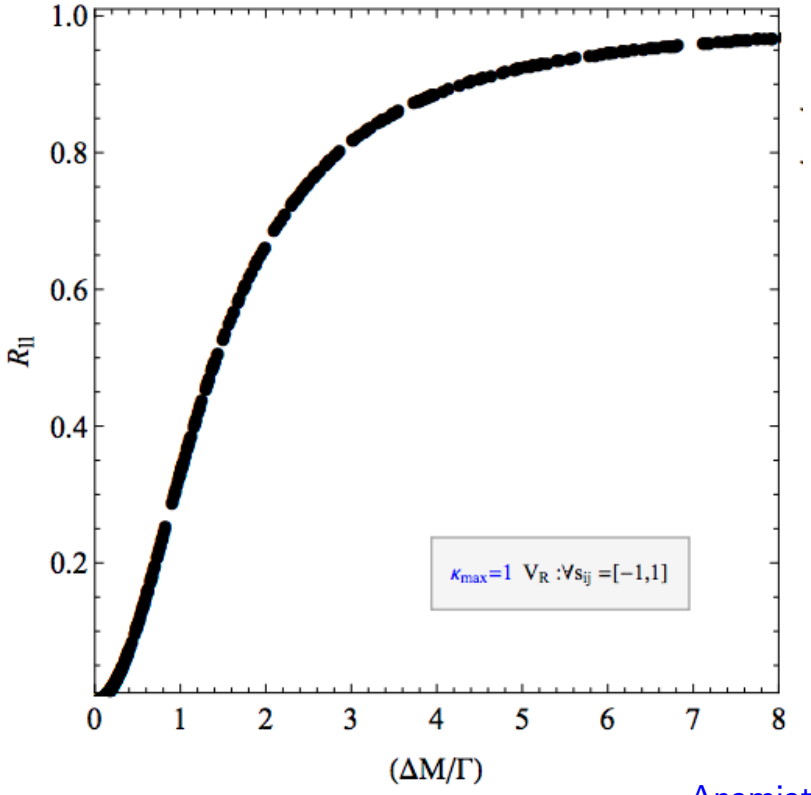
$$\mathscr{L}_N = -\frac{1}{2}\overline{N_R^1} M (N_R^2)^c - y_{\nu_\alpha} \overline{N_R^1} \widetilde{\phi}^\dagger L^\alpha + \mathrm{H.c.}$$

- The mass matrix:

$$M_\nu = \begin{pmatrix} 0 & m_D & m'_D \\ (m_D)^T & 0 & M \\ (m'_D)^T & M & \mu \end{pmatrix},$$

- Perturbations $\Rightarrow$ m_ν and HNL mass splitting (ΔM)
- m'_D: Linear seesaw, $\Delta M^{\mathrm{NO}} = 0.0416\,\mathrm{eV}$, $\Delta M^{\mathrm{IO}} = 0.000753\,\mathrm{eV}$
- μ: inverse seesaw, $\Delta M \sim \frac{m_{\nu_i}}{|\theta|^2}$.

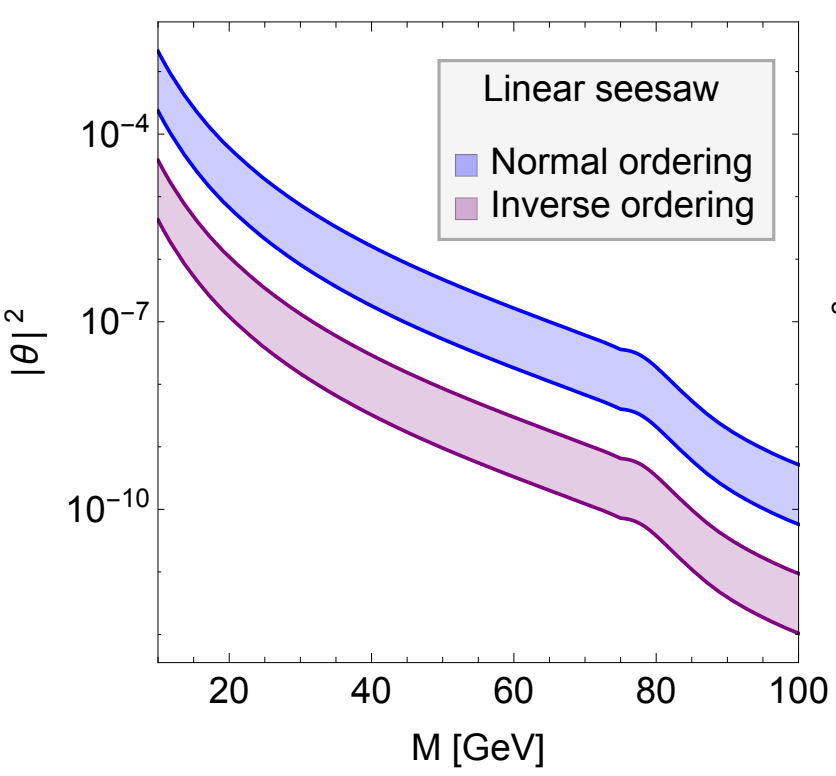
Lepton number violation and ΔM

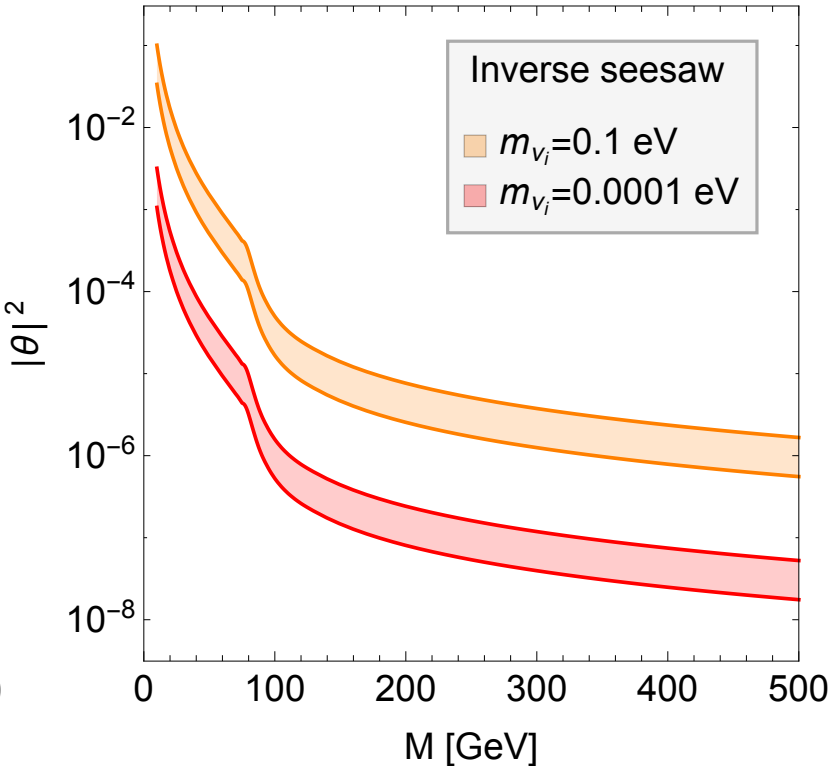


Anamiati, Hirsch, Nardi; 1607.05641

- $R_{\ell\ell}$ = ratio of LNV/LNC dilepton events.
- $R_{\ell\ell}$ is a function of mass splitting and decay width of N.
- For mass splitting $\sim$ decay width, $R_{\ell\ell} \in [0, 1]$.
- Zero mass splitting $\Rightarrow$ zero LNV.

Parameter space with LNV



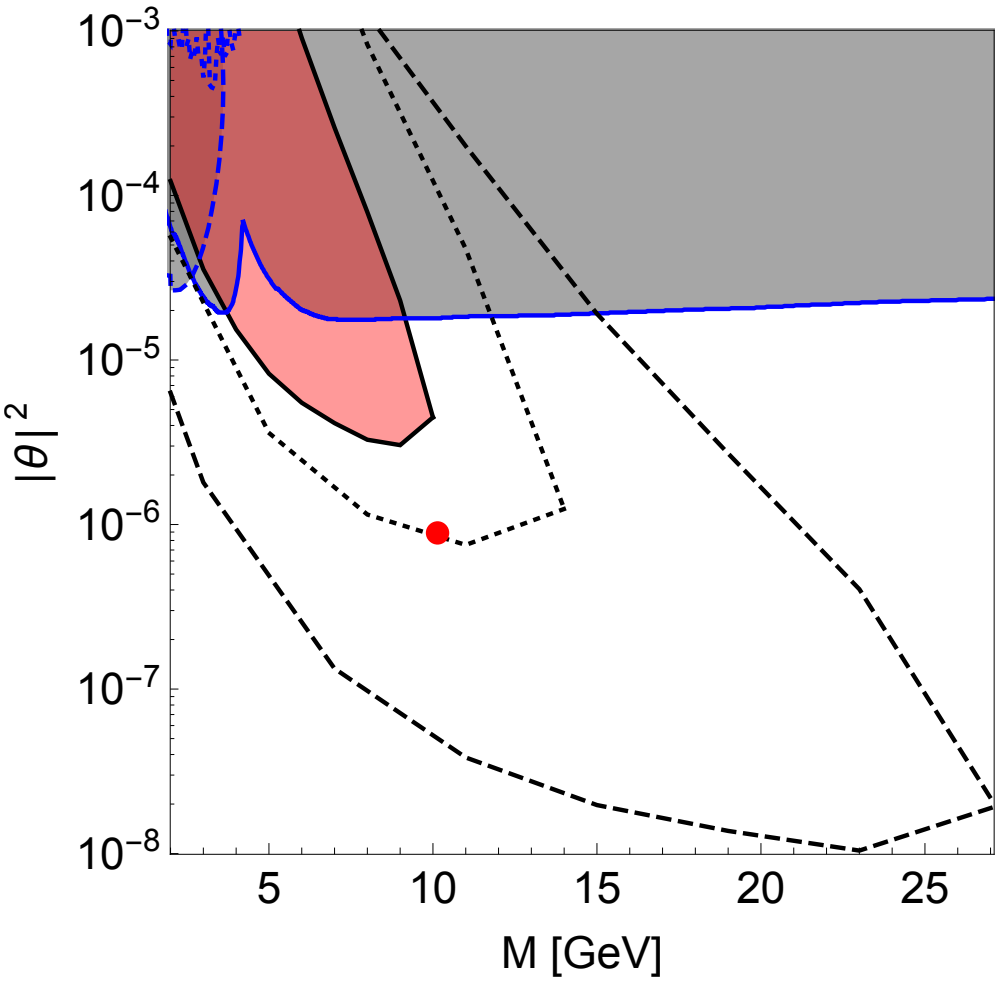


$$R_{\ell\ell} = \frac{\Delta M^2}{2\Gamma^2 + \Delta M^2}$$

- Upper contour: $R_{\ell\ell} = 0.1$
- Lower contour: $R_{\ell\ell} = 0.9$

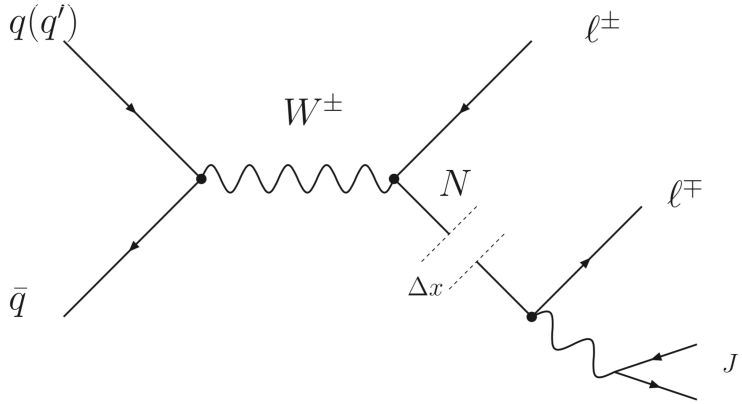
Observing Heavy neutrino-antineutrino oscillations

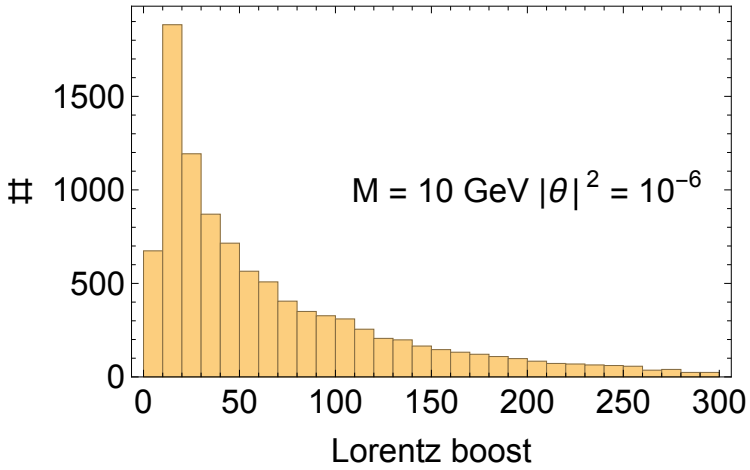
A best case scenario for LHCb

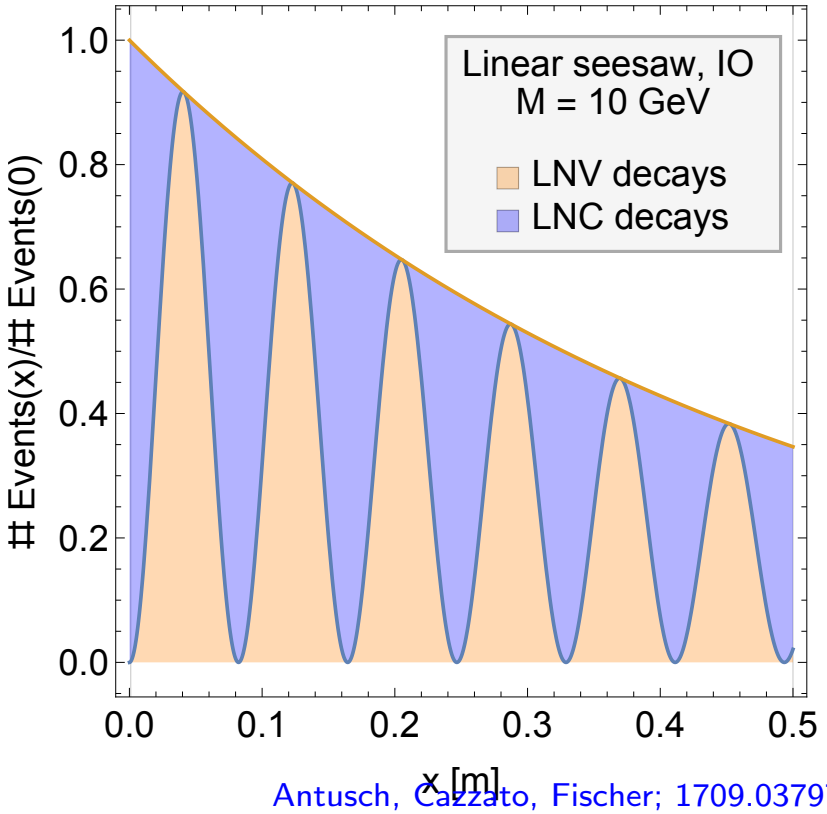


- Displacements 2 cm $\leq \Delta x \leq$ 50 cm.
- $\mathcal{O}(100)$ events with $\ell_\alpha(\ell_\beta + J)_{\text{displaced}}$ after run 5.

Oscillation: SS vs OS dileptons as function of displacement



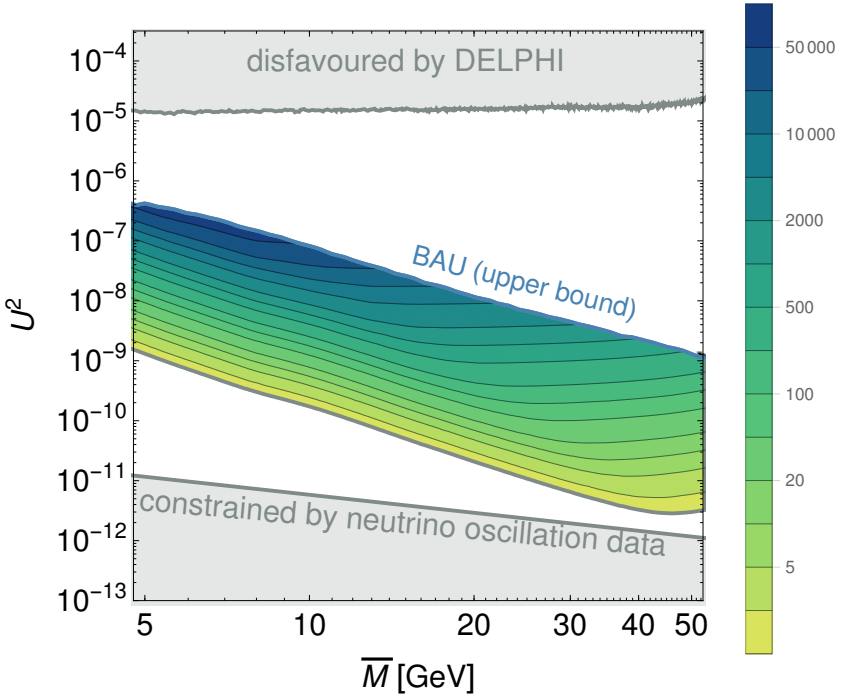




Antusch, Cazzato, Fischer; 1709.03797

- Proper oscillation length: $\lambda_{\rm osc}^{\rm lin,IO} = 3.29 \cdot 10^{-3} \sqrt{\gamma^2 - 1}$ m
- Proper lifetime: $c\tau = 0.0094$ m

Leptogenesis and the origin of neutrino masses



Antusch, Cazzato, Drewes, Fischer, Garbrecht, Gueter, Klaric; 1710.03744

- Active-sterile mixing angles θ_α fixed by the light neutrino data.
- Ratios of θ_α measurable at FCC-ee with sub-percent accuracy.
- Test minimal type I seesaw hypothesis.
- Together with ΔM also tests the compatibility with leptogenesis.

Conclusions!