Mapping the viable parameter space for testable leptogenesis

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based on work in collaboration with M. Drewes and J. Klaric
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UCLouvain

Heavy neutral lepton (HNLs)

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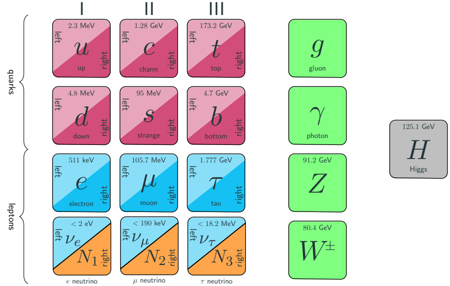

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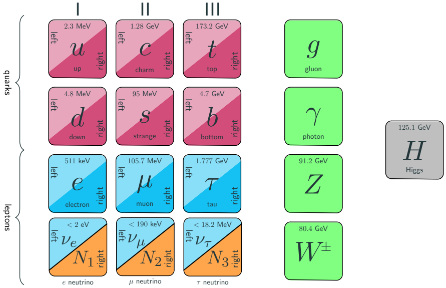

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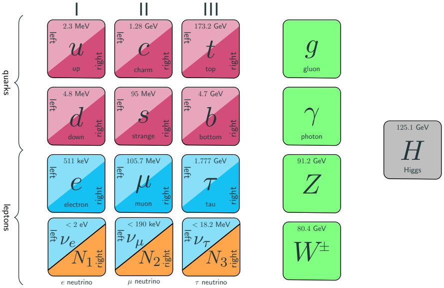
- Non-zero mass of the Standard Model (SM) neutrinos via the **type-I seesaw** mechanism. (P.Minkowski, 1977)
- Overabundance of matter with respect to antimatter through **leptogenesis**. (M. Fukugita, T. Yanagida, 1986)



Seesaw type-I

- Seesaw mass term

$$\mathcal{L} \supset F_{ai}(\bar{\ell}_a\tilde{\phi})\nu_{Ri} + \frac{1}{2}\bar{\nu}^c_{Ri}(M_M)_{ij}\nu_{Rj} + \text{h.c.}$$

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- Strength of the mixing with SM neutrinos parametrised by

$$U^2 = v^2 \sum_{a,i} |(F \cdot M_M^{-1})_{ai}|^2 \equiv \sum_{a,i} |\theta_{ai}|^2.$$

B-L approximate symmetry

B-L approximate symmetry allows to avoid the naive seesaw bound

$$U_i^2 \sim \frac{\sqrt{\Delta m_{atm}^2 + m_{light}^2}}{M} \lesssim 10^{-10} \frac{\text{GeV}}{M_i}$$

Majorana mass:

$$M_M = \bar{M} \cdot \begin{pmatrix} 1-\mu & 0 & 0 \\ 0 & 1+\mu & 0 \\ 0 & 0 & \mu' \end{pmatrix}$$

Yukawa coupling matrix

$$F = \frac{1}{\sqrt{2}} \begin{pmatrix} f_e(1+\epsilon_e) & if_e(1-\epsilon_e) & f_e\epsilon_e' \\ f_\mu(1+\epsilon_\mu) & if_\mu(1-\epsilon_\mu) & f_\mu\epsilon_\mu' \\ f_\tau(1+\epsilon_\tau) & if_\tau(1-\epsilon_\tau) & f_\tau\epsilon_\tau' \end{pmatrix} .$$

B-L approximate symmetry when $\mu, \epsilon, \epsilon' \ll 1$.

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   $\longrightarrow$ TeV-scale HNLs allowed if small HNLs mass splittings

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$\hookrightarrow$ Two regimes of the same mechanism ! Represented by the same set of equations. (cfr. B.Garbrecht 1812.02651)

Quantum kinetic equations

$$i\frac{\mathrm{d}\delta\rho}{\mathrm{d}t} = -i\frac{\mathrm{d}\rho_{eq}}{\mathrm{d}t} + [H,\delta\rho] - \frac{i}{2}\{\Gamma,\delta\rho\} - i\sum_{a\in\{e,\mu,\tau\}}\tilde{\Gamma}_a\frac{\mu_a}{T}f_F(1-f_F)$$

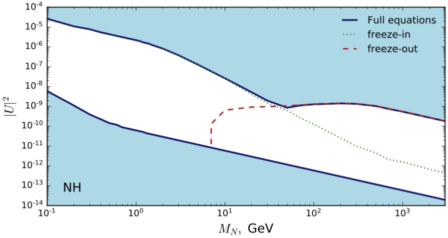
$$i\frac{\mathrm{d}\delta\overline{\rho}}{\mathrm{d}t} = -i\frac{\mathrm{d}\rho_{eq}}{\mathrm{d}t} - [H,\delta\overline{\rho}] - \frac{i}{2}\{\Gamma,\delta\bar{\rho}\} + i\sum_{a\in\{e,\mu,\tau\}}\tilde{\Gamma}_a\frac{\mu_a}{T}f_F(1-f_F)$$

$$\frac{\mathrm{d}}{\mathrm{d}t}n_{\Delta_a} = -\frac{2i\mu_a}{T}\int\frac{\mathrm{d}^3\vec{k}}{(2\pi)^3}\mathrm{Tr}[\Gamma_a]f_F(1-f_F) + i\int\frac{\mathrm{d}^3\vec{k}}{(2\pi)^3}\mathrm{Tr}[\tilde{\Gamma}_a(\delta\bar{\rho}-\delta\rho)]$$

- Rate equations for density matrices $\rho_N, \rho_{\overline{N}}$ and SM asymmetries n_{Δ_α}.
- Allow to cover the whole mass range 50 MeV- 70 TeV

n=2 leptogenesis

Large U^2
$\longrightarrow$ large washout
$\longrightarrow$ asymmetric Yukawa coupling needed to hide BAU from the washout



Klaric/Shaposhnikov/Timirsyasov 2008.13771

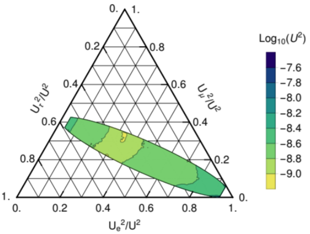
Asymmetry

$$f \simeq \frac{\min|F_a|}{\max|F_a|}$$

constrained by neutrino oscillation data

$$\Longrightarrow \quad f > 5 \cdot 10^{-3}$$

$\longrightarrow$ large U^2 not possible.



Antusch/Cazzato/Drewes/Fisher/Garbrecht/Gueter/Klaric 1710.03744

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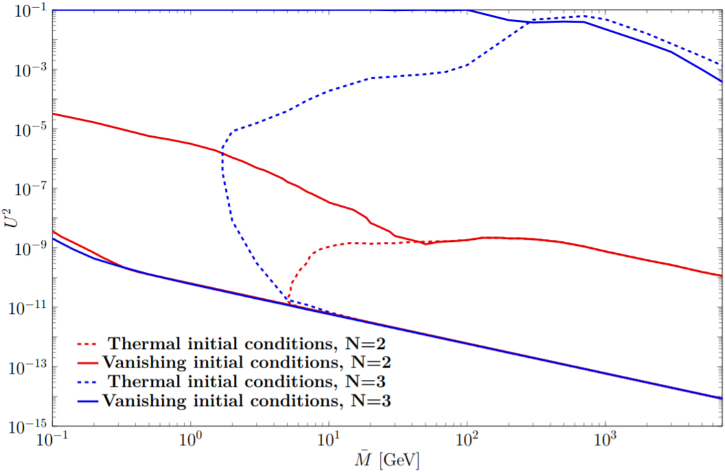
- Theoretical constraints:

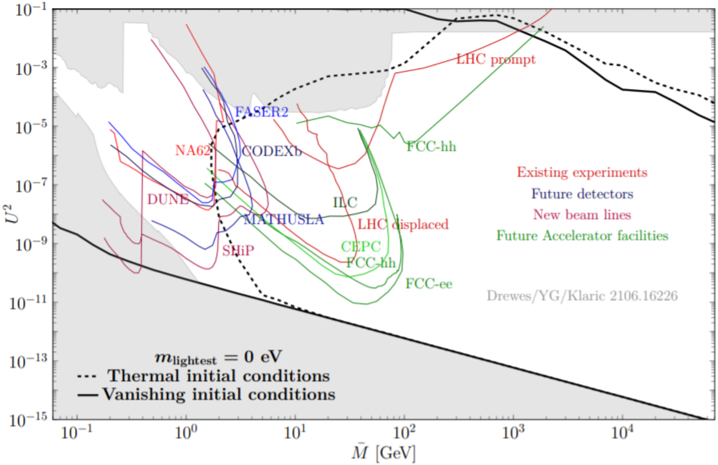
1. Perturbative unitarity $\Gamma < \frac{M}{2}$
2. Seesaw expansion $U^2 < 0.1$
3. No large radiative corrections $(1 - ||\frac{m_{tree}}{m_{loop}}||)^2 < \frac{1}{4}$.

Comparing $n = 2$ and $n = 3$.



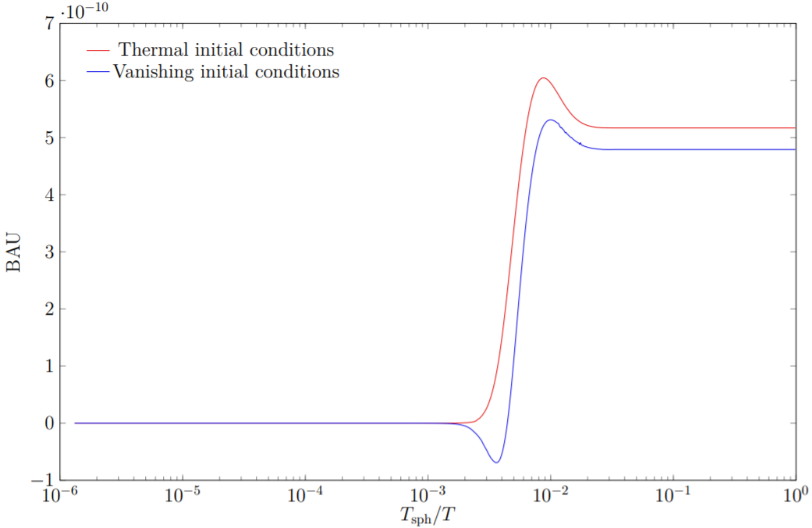
- Parameter space way larger than in the $n = 2$ scenario.
- Reaches theoretical constraint at low masses.
- Seesaw line reached as for n=2.

Results for $m_{\text{lightest}} = 0$ eV



- Experiments will cut deep into $n = 3$ parameter space.
- Can expect to produce thousands of displaced vertices at HL-LHC.
- Resonant leptogenesis working for masses as low as $\mathcal{O}(1.7)$ GeV: testable at *e.g.* NA62.

Thermal vs vanishing initial conditions



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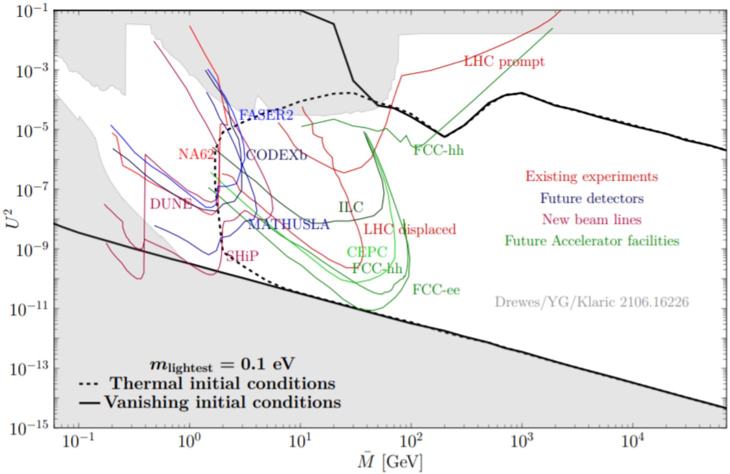

- Parameter space smaller for $m_{\text{lightest}} = 0.1$ eV.

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Conclusion

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- Leptogenesis with thermal initial conditions is possible for masses as low as 1.7 GeV.
- Larger parameter space for $m_{\text{lightest}} = 0$ eV.