Low-scale leptogenesis with 3 right-handed neutrinos

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The Standard Model cannot account for the observed baryon asymmetry of the Universe (BAU)

$$Y_{\Delta B} = (8.6 \pm 0.01) \times 10^{-11}$$

BARYOGENESIS FROM STERILE NEUTRINO OSCILLATIONS: low scale (freeze-in) leptogenesis

Akhmedov, Rubakov, Smirnov (1998)

Type-I seesaw mechanism: SM + gauge singlet fermions N_I

$$\mathcal{L} = \mathcal{L}_{SM} + i\bar{N}_I \partial\!\!\!/ N_I - \left(F_{\alpha I} \bar{\ell}_\alpha \tilde{\phi} N_I + \frac{M_{IJ}}{2} \bar{N}_I^c N_J + h.c. \right)$$

After electroweak phase transition $< \Phi > = v \simeq 174$ GeV

$$m_\nu \simeq -\frac{v^2}{2} F^* M^{-1} F^\dagger$$ non-zero neutrino masses

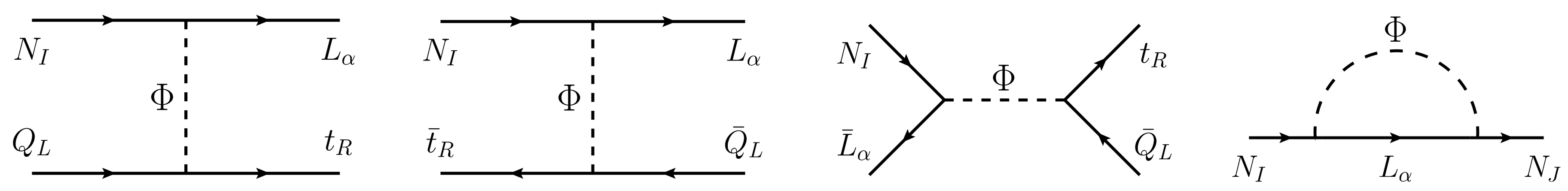
Sakharov conditions

- **Complex Yukawa** couplings *F* as a source of $\not{CP}$ ✓
- $\not{B}$ from sphaleron transitions until $T_{EW} \simeq 140$ GeV ✓
- sterile neutrinos deviations from thermal equilibrium ✓

Two kinds of $\not{CP}$ processes

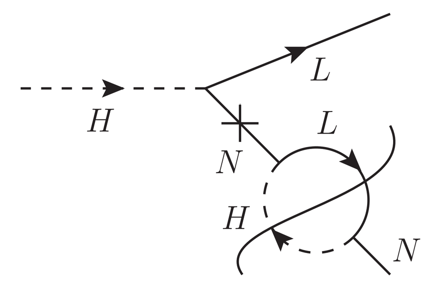
CP conjugation $F \leftrightarrow F^*$

Lepton number conserving (neutrino generation and oscillations)



Lepton number violating (thermal Higgs decay)

Hambye, Teresi (2016)



$$\propto \frac{M^2}{T^2}$$ relevant at late times

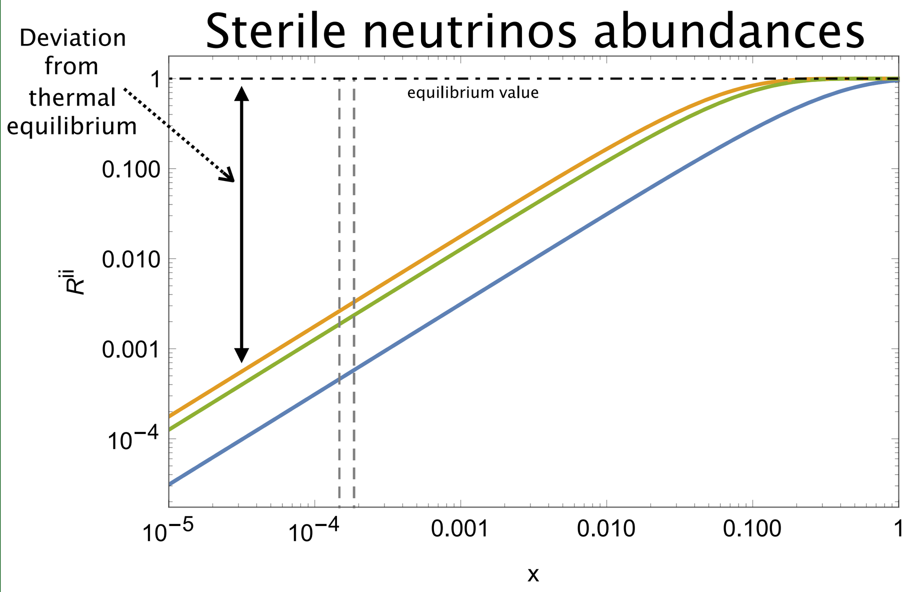
Asymmetry generation example

$x = \frac{T}{T_{EW}}$ $T_{EW} = 140$ GeV

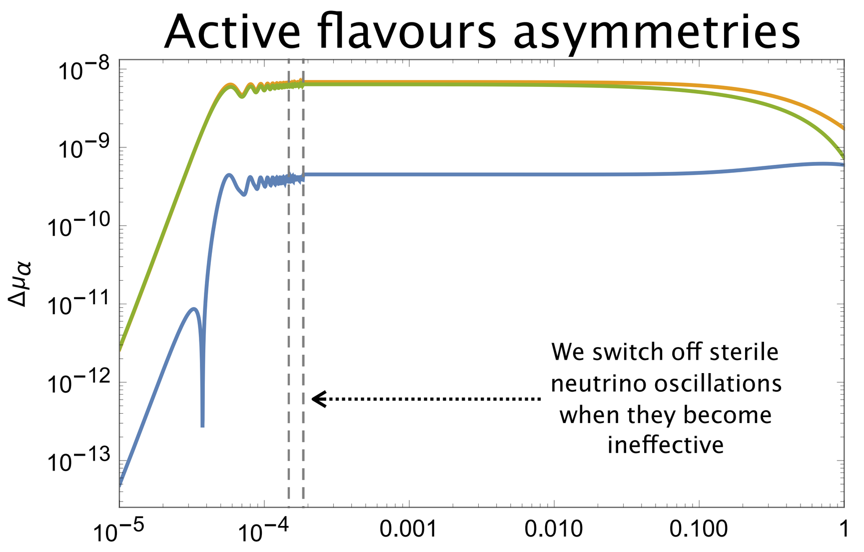
R : sterile neutrinos density matrix

μ_α : active flavours chemical potentials

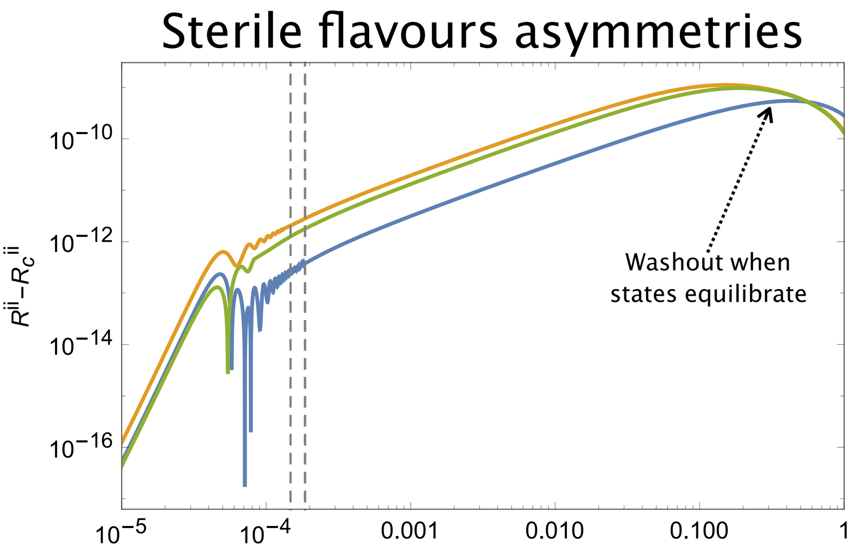
Sterile neutrinos abundances



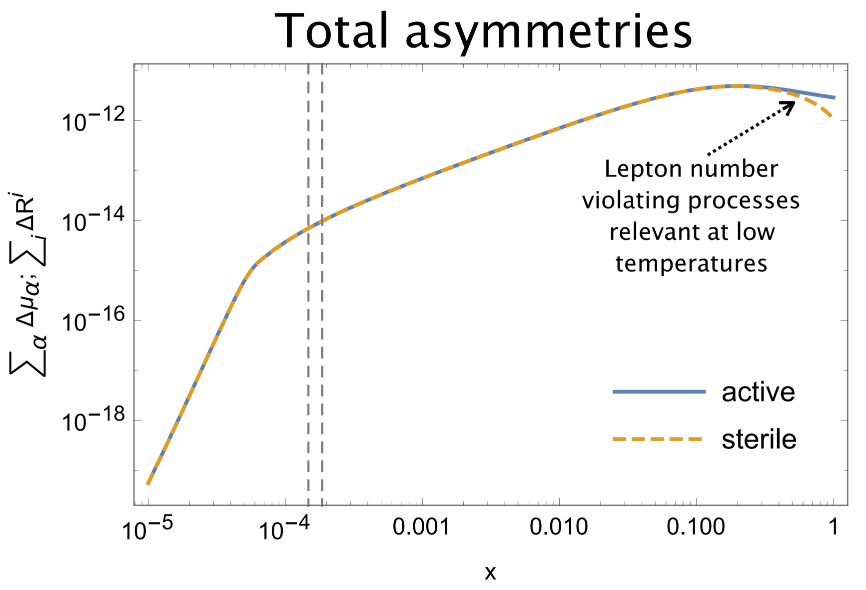
Active flavours asymmetries



Sterile flavours asymmetries



Total asymmetries



Parameters for this point

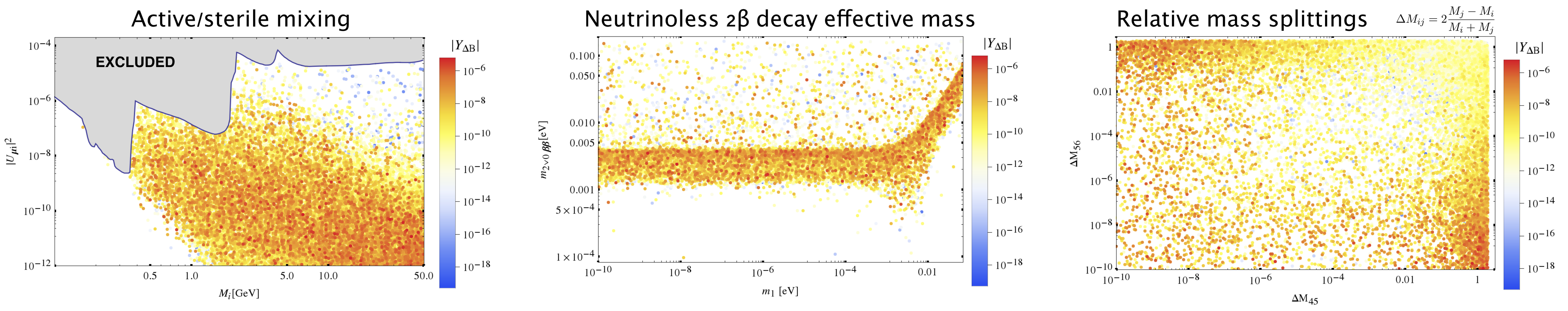
$$F = \begin{pmatrix} 2.5\times10^{-9} + 6.14\times10^{-8}\, i & 1.375\times10^{-7} - 1.30\times10^{-8}\, i & -8.0\times10^{-9} + 1.170\times10^{-7}\, i \\ -9.16\times10^{-8} - 5.67\times10^{-8}\, i & -1.96\times10^{-7} + 1.57\times10^{-7}\, i & -1.56\times10^{-7} - 1.51\times10^{-7}\, i \\ -6.4\times10^{-8} - 1.82\times10^{-7}\, i & -4.60\times10^{-7} + 6.7\times10^{-8}\, i & -2.1\times10^{-8} - 3.90\times10^{-7}\, i \end{pmatrix}$$

$M_1 = 18.3$ GeV $M_2 = 36.5$ GeV $M_3 = 48.1$ GeV

RESULTS:

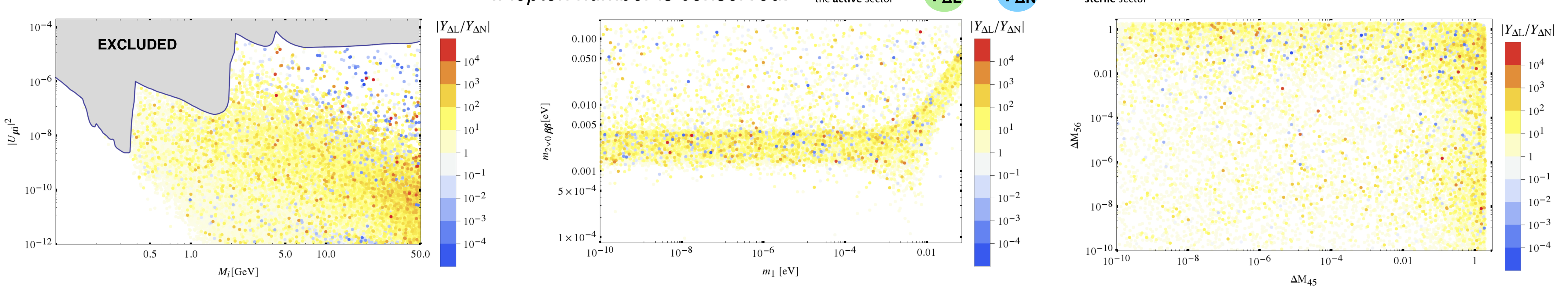
Allowed asymmetry values after imposing neutrino experimental constraints

Active/sterile mixing — Neutrinoless 2β decay effective mass — Relative mass splittings $\Delta M_{ij} = 2\frac{M_j - M_i}{M_i + M_j}$

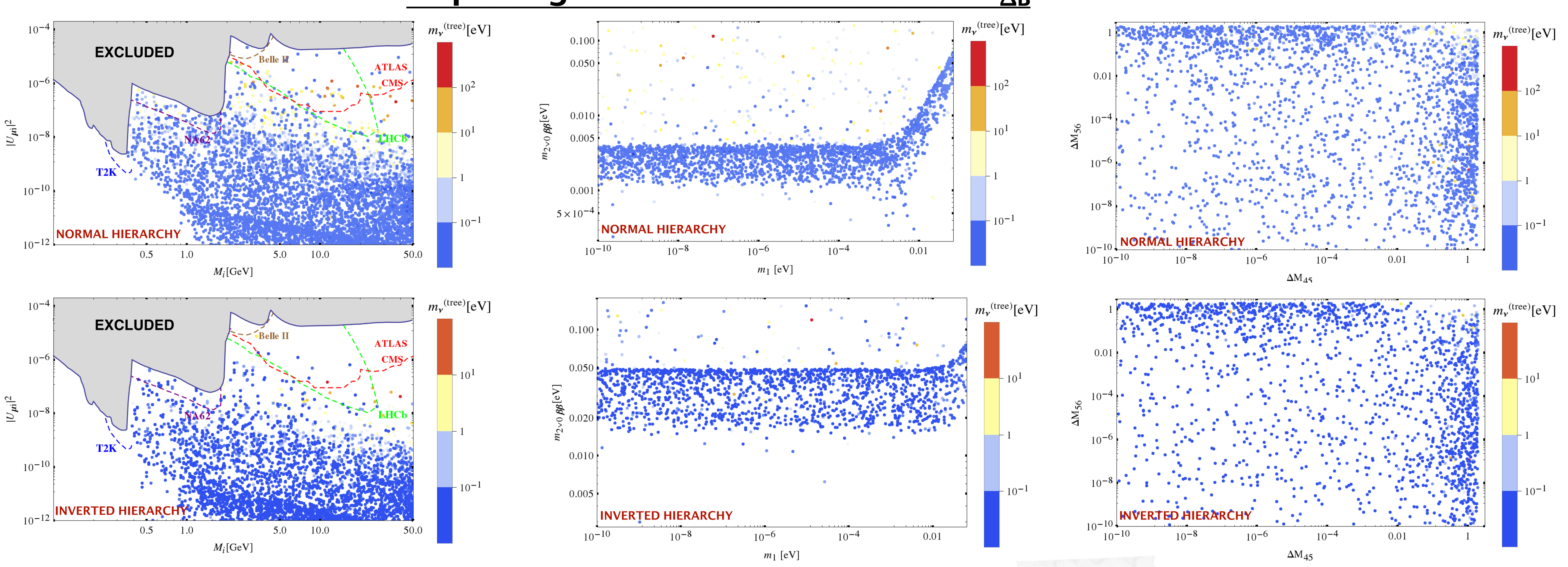


Lepton number violating processes are in general relevant

If lepton number is conserved: $Y_{\Delta L} = - Y_{\Delta N}$ (asymmetry in the active sector; asymmetry in the sterile sector)



Imposing the observed value for $Y_{\Delta B}$



Large mixing angles and low-scale seesaw: fine-tuning or symmetry?

We compute the neutrino mass matrix at 1-loop:

- ▶ If approximate lepton number symmetry, neutrino masses are protected at each perturbative order
- ▶ Conversely, accidental cancellations are unlikely to happen both at tree and 1-loop level

The tree-level neutrino mass scale is an indicator of the amount of fine-tuning of the solution

CONCLUSIONS

Low-scale leptogenesis solutions with **3 right-handed neutrinos testable** by **current experiments**

Sterile neutrinos contribution to **neutrinoless double beta decay** effective mass **within experimental reach**

A **degeneracy** in the **mass spectrum enhances** the **asymmetry, but it is not a necessary condition**

No fine-tuning is required

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