Tests of Low-Scale Leptogenesis in Charged Lepton Flavour Violation Experiments

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International Workshop on
Feebly-Interacting Particles (FIPs 2022)
CERN, Geneva, Switzerland
17 - 21 October, 2022

The origin of the matter-antimatter (or baryon) asymmetry of the Universe is still a fundamental and unresolved problem in Particle Physics and Cosmology, i.e., in Astroparticle Physics. Its solution requires physics beyond that predicted by the Standard Model.

Leptogenesis offers a particularly appealing solution as it relates the generation and smallness of neutrino masses to the generation of the baryon asymmetry of the Universe (BAU).

In its simple realisation a lepton charge CP violating asymmetry is generated in the Early Universe in the CP and lepton charge non-conserving decays of the two or three heavy Majorana neutrinos N_j, $j = 1,2$ or 1,2,3, of the (type I) seesaw mechanism of neutrino mass generation. This asymmetry is converted into a BAU by (B+L) violating but (B-L) conserving sphaleron processes which exist in the SM and are effective at $T \sim (132 - 10^{12})$ GeV. The generation of BAU takes place approximately at $T \sim M_1$, assuming $M_1 < M_2 (< M_3)$, M_i being the mass of N_i.

One of the major problem - testability of the LG mechanism of generation of BAU.

A unique possibility to test experimentally the LG idea is provided by the low-scale scenarios based on the type I seesaw mechanism proposed in A. Pilaftsis, hep-ph/9707235 and hep-ph/9812256, in E. K. Akhmedov et al., hep-ph/9803255 and T. Asaka and M. Shaposhnikov, hep-ph/0505013.

In these scenarios vialble LG is possible for quasi-degenerate in mass heavy Majorana neutrinos: $0 < M_2 - M_1 << M_{1,2} \cong M$, **similary in the case of** $N_{1,2,3}$, $M_{1,23} \cong M$.

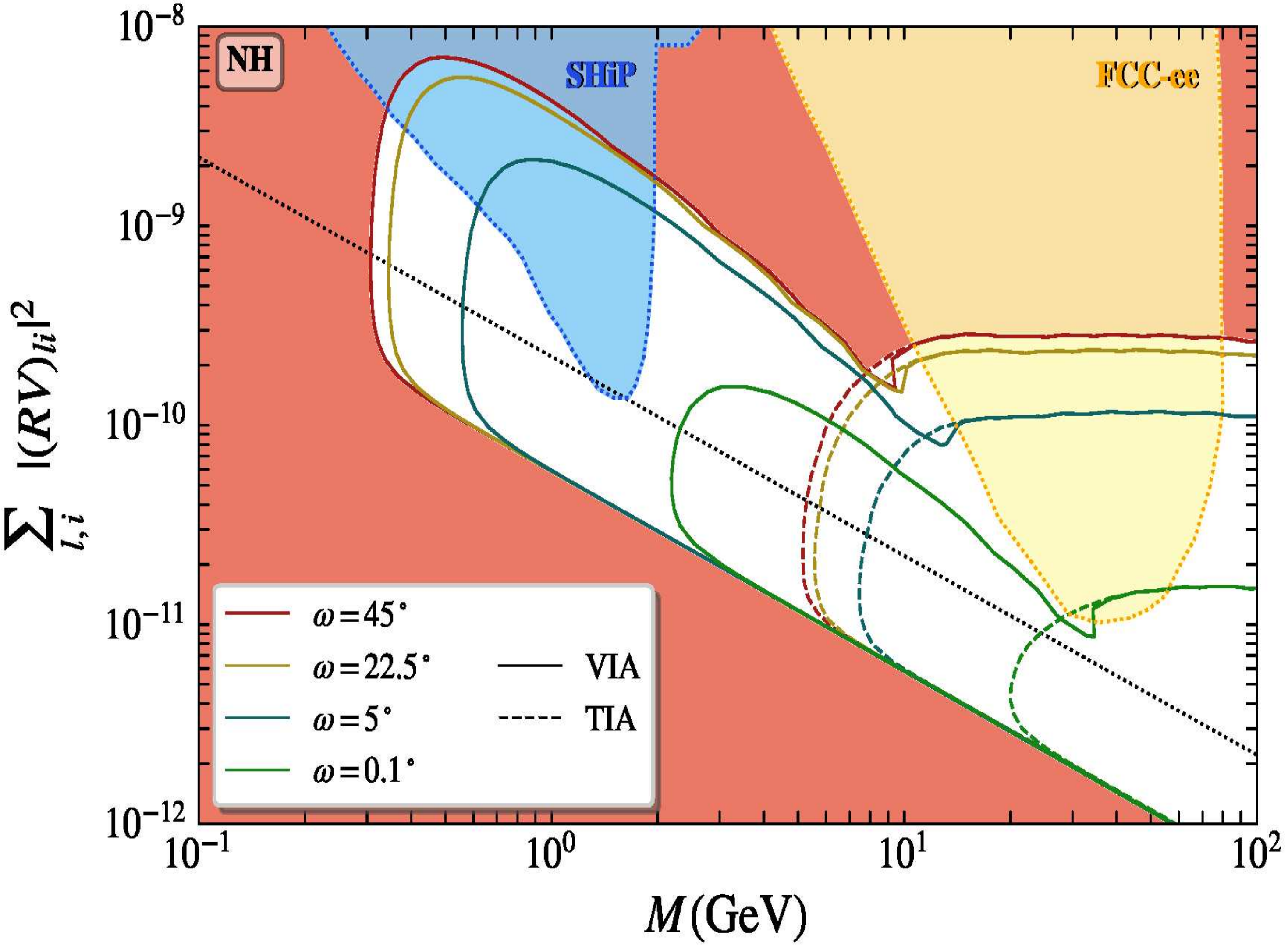
Of crucial importance for the low-scale LG experimental tests – the magnitude of the $N_{1,2,3}$ couplings in the charged and neutral currents in the weak interaction Langrangian, $(RV)_{\ell j}$, which ensure successful LG:

$$\nu_{\ell L}(x) = \sum_i (1+\eta) U_{\ell i} \nu_{iL}(x) + \sum_j (RV)_{\ell j} N_{jL}(x)\,,$$

The case of two heavy Majorana neutrinos $N_{1,2}$ forming a pseudo-Dirac pair, was investigated more recently in J. Klarić et al., arXiv:2008.13771, and A. Granelli et al., arXiv:2009.03166:

i) The observed BAU can be generated for $M_{1,2} \cong M \gtrsim 100$ MeV and up to the TeV scale;
ii) LG is effective in a broad range of the relevant parameters, including the couplings $(RV)_{\ell j}$ of $N_{1,2}$ which depend on the value of M.
In the region of viable leptogenesis parameter space

for $M \gtrsim 0.2$ GeV, one has:
$M \cdot U^2 \lesssim 5 \cdot 10^{-6}$ **GeV**, $U^2 \equiv \Sigma_{\ell i} \, |(RV)_{\ell i}|^2$ –
too small to be probed in low-energy experiments
the only exception could be the $\beta\beta0\nu$ experiments
for $\Delta M/M \gtrsim 10^{-3}$, and masses below 2 GeV
(M. Drewes and S. Eijima, arXiv:1606.06221, P. Hernandez et al., arXiv:1606.06719).
Could be probed in future colliders (e.g., FCCee) or potentially at the HL-LHC (I. Boiarska et al., arXiv:1811.10545; M. Drewes and J. Hajer, arXiv:1903.06100).



A. Granelli et al., arXiv:2009.03166

It was shown recently in M. Drewes et al., arXiv:2106.16226 and noticed earlier in A. Abada et al., arXiv:1810.12463: in the case of 3 quasi-degenerate in mass heavy Majorana neutrinos $N_{1,2,3}$, the range of $U^2 \equiv \sum_{\ell i} |(RV)_{\ell i}|^2$ (and thus $|(RV)_{\ell i}|^2$) of successful LG is by several orders of magnitude larger than the range in the scenario with 2 heavy Majorana neutrinos $N_{1,2}$, reaching at, e.g., $M = 100$ GeV values $\sim 5 \times 10^{-2}$ (TIA case).

This opens up the possibility to test directly the low-scale leptogenesis scenario with 3 N's in upcoming high precision experiments on charged lepton flavour violation (cLFV) searching for $\mu^{\pm} \to e^{\pm} + \gamma$ and $\mu^{\pm} \to e^{\pm} + e^{+} + e^{-}$ decays and for $\mu - e$ conversion in nuclei.

The best upper limits on these processes were obtianed in MEG, SINDRUM and SINDRUM II experiments:

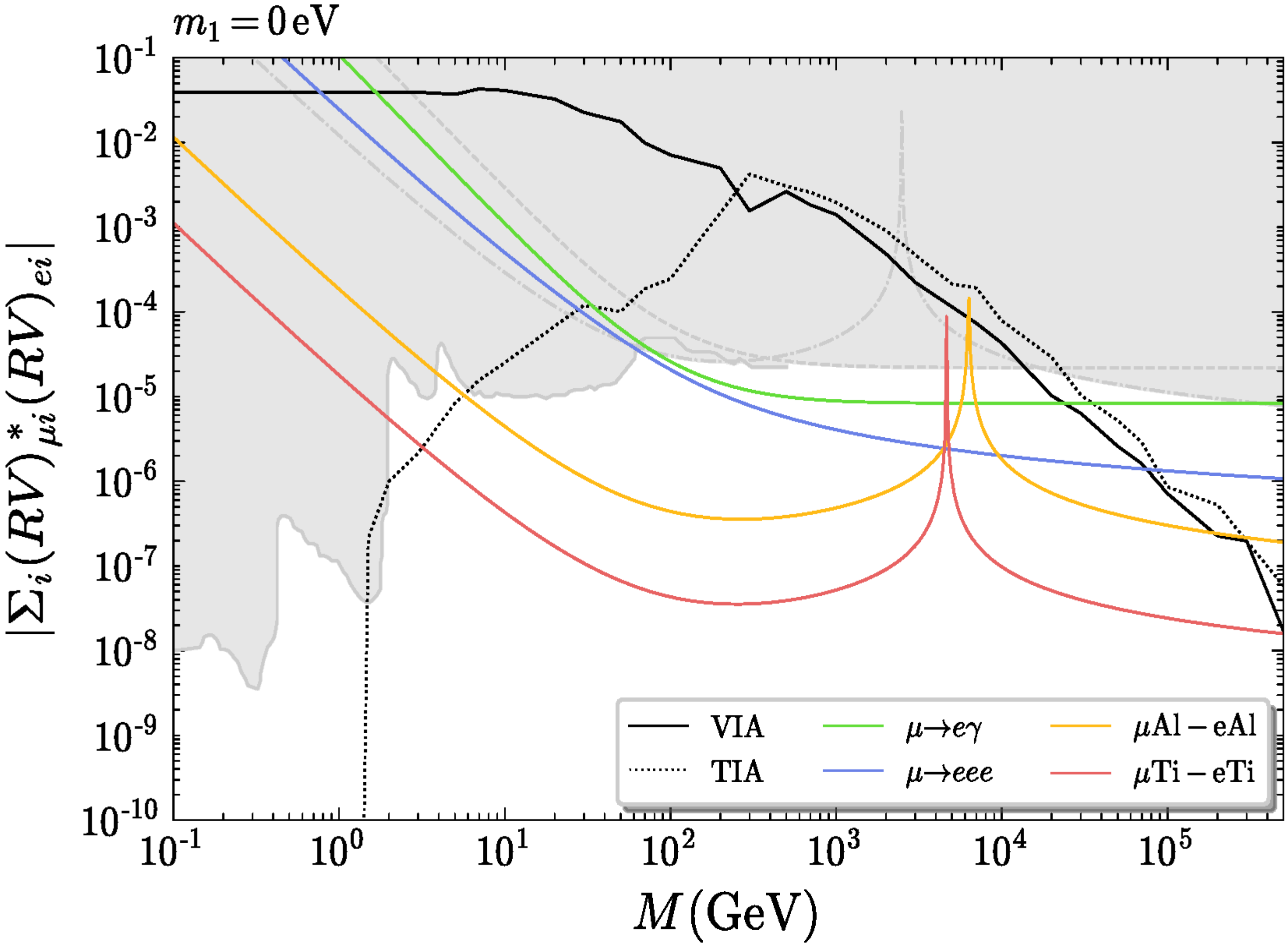
$$\mathrm{BR}(\mu \to e\gamma) < 4.2 \times 10^{-13}\ (90\%\ \mathrm{C.L.})\,,$$

$$\mathrm{BR}(\mu \to eee) < 1.0 \times 10^{-12}\ (90\%\ \mathrm{C.L.})\,,$$

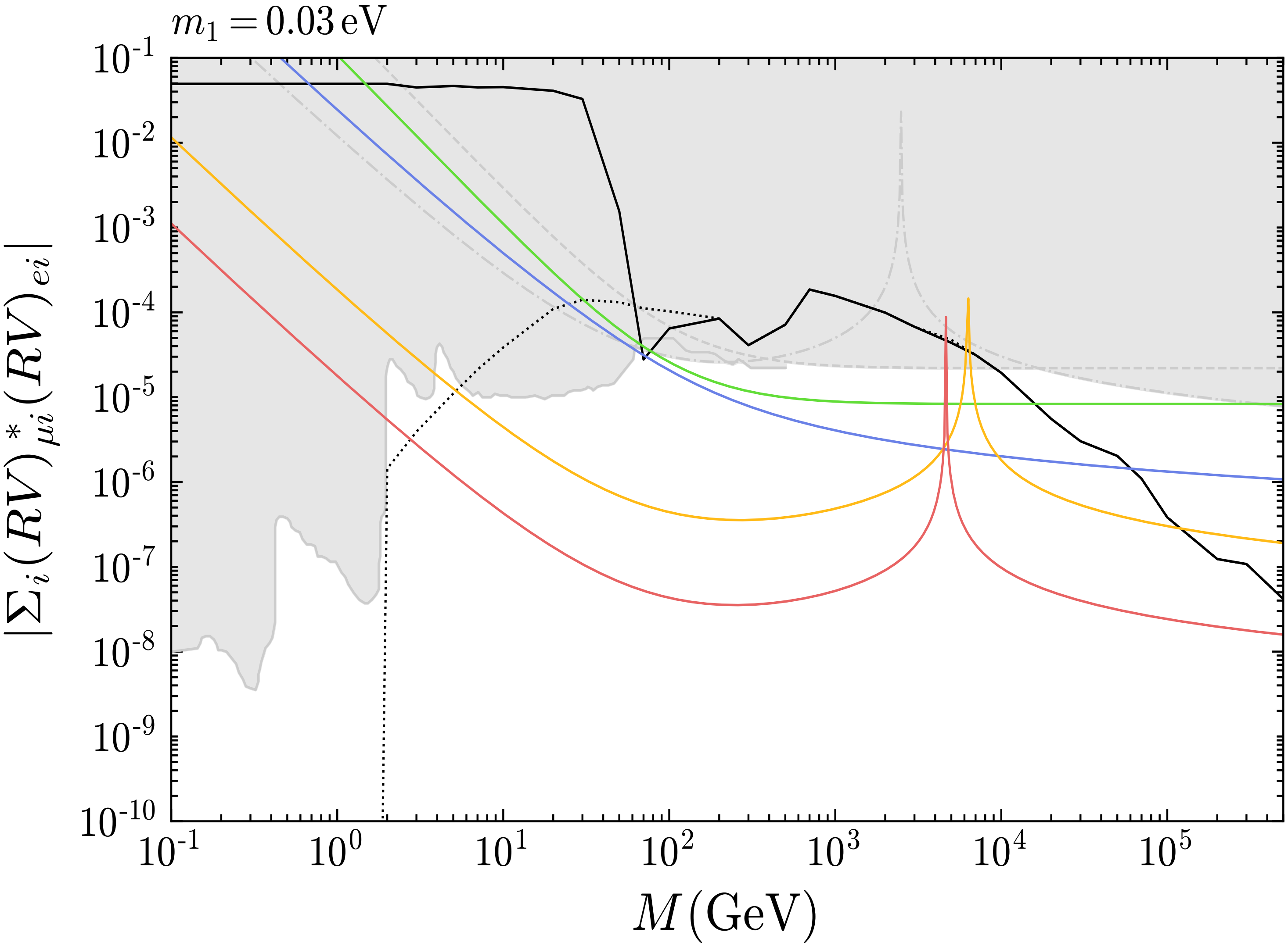
$$\mathrm{CR}(\mu\, {}^{48}_{22}\mathrm{Ti} \to e\, {}^{48}_{22}\mathrm{Ti}) < 4.3 \times 10^{-12}\ (90\%\ \mathrm{C.L.})\,,$$

$$\mathrm{CR}(\mu\, {}^{197}_{79}\mathrm{Au} \to e\, {}^{197}_{79}\mathrm{Au}) < 7.0 \times 10^{-13}\ (90\%\ \mathrm{C.L.})\,.$$

The planned MEG II update of the MEG experiment: $\mathrm{BR}(\mu \to e\gamma) \simeq 6 \times 10^{-14}$.
Mu3e Project: $\mathrm{BR}(\mu \to eee) \sim 10^{-15}\ (10^{-16})$.
Mu2e and COMET experiments on $\mu - e$ conversion in Al: $\mathrm{CR}(\mu\, {}^{27}_{13}\mathrm{Al} \to e\, {}^{27}_{13}\mathrm{Al}) \sim 6 \times 10^{-17}$.
The planned PRISM/PRIME experiment with Titanium: $\mathrm{CR}(\mu\, {}^{48}_{22}\mathrm{Ti} \to e\, {}^{48}_{22}\mathrm{Ti}) \sim 10^{-18}$, an improvement by six orders of magnitude of the current bound.



A. Granelli, J. Klarić, STP, arXiv:2206.04342



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To summarise, we have shown that the upcoming and planned experiments on charged lepton flavour violation with $\mu^{\pm}$, MEG II on the $\mu \to e\gamma$ decay, Mu3e on $\mu \to eee$ decay, Mu2e and COMET on $\mu - e$ conversion in aluminium and PRISM/PRIME on $\mu - e$ conversion in titanium, can probe ditectly significant regions of the viable parameter space of low-scale leptogenesis based on the type I seesaw mechanism with three quasi-degenerate in mass heavy Majorana neutrinos $N_{1,2,3}$, and thus test this attractive leptogenesis scenario with a potential for a discovery.

We are looking forward to the results of these very important experiments on beyond the Standard Model physics.