The Type III Inverse See-Saw: the model and updated constraints

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See-saw vs. Inverse See-saw

We know that neutrinos have a tiny mass, but we don't know why.

We know however that if they had a big Majorana mass *M*, the see-saw mechanism would be a natural explanation:

$$m_\nu = -\frac{v^2}{2} Y^T \frac{1}{M} Y$$

But the standard see-saw requires either *M* very big, or *Y* very small, thus making signals of new physics very difficult to test!

One possible solution is the so-called inverse see-saw: in this case, one can have at the same time

M relatively small (o(TeV)), and
Y big,

while m_ν is small because *L* is an approximate symmetry of the model.

The Type III See-saw

We studied the inverse see-saw for the type III see-saw models, in which one adds to the SM fermion triplets $\vec{\Sigma} = \left(\Sigma^-,\ \Sigma^0,\ \Sigma^+\right)$.

The neutral component Σ^0 behaves exactly like a right-handed neutrino, therefore, just like in type I see-saw, the neutrino mixing matrix receives a non-unitary correction η:

$$U_{PMNS} \to N = (1+\eta)\, U_{PMNS}$$

Roughly speaking, η corresponds to the coefficient of the dimension-6 operator.

The fundamental difference from type I see-saw is that the charged components $\Sigma^\pm$ mix with the charged leptons, inducing FCNC already at tree-level and thus making this kind of model much more constrained.

We studied 3 cases of type III see-saw.

General Case

In the **General Case** an arbitrary number of triplets is integrated out. In this case, we have 9 free parameters: all entries of η.

3 Triplets Case

In the **3 Triplets Case** of inverse see-saw, the Lepton Number approximate symmetry forces the mass matrices to have the following structure:

$$m_D = \frac{v}{\sqrt{2}} \begin{pmatrix} Y_{\Sigma_{1e}} & Y_{\Sigma_{1\mu}} & Y_{\Sigma_{1\tau}} \\ \varepsilon_1 Y_{\Sigma_{2e}} & \varepsilon_1 Y_{\Sigma_{2\mu}} & \varepsilon_1 Y_{\Sigma_{2\tau}} \\ \varepsilon_2 Y_{\Sigma_{3e}} & \varepsilon_2 Y_{\Sigma_{3\mu}} & \varepsilon_2 Y_{\Sigma_{3\tau}} \end{pmatrix}, \qquad M_M = \begin{pmatrix} \mu_1 & \Lambda & \mu_3 \\ \Lambda & \mu_2 & \mu_4 \\ \mu_3 & \mu_4 & \Lambda' \end{pmatrix}$$

with ε_i, μ_i small LNV parameters. If we define the entries of the neutrino mass matrix as

$$m_\nu = -\frac{v^2}{2} Y^T \frac{1}{M} Y \equiv \begin{pmatrix} m_{ee} & m_{e\mu} & m_{e\tau} \\ m_{\mu e} & m_{\mu\mu} & m_{\mu\tau} \\ m_{\tau e} & m_{\tau\mu} & m_{\tau\tau} \end{pmatrix}$$

we get a set of 6 relations. By eliminating the unknown parameters ε/Λ, one gets an additional constraint:

$$Y_\tau = \frac{1}{m_{e\mu}^2 - m_{ee}m_{\mu\mu}} \left(Y_e \left(m_{e\mu}m_{\mu\tau} - m_{e\tau}m_{\mu\mu}\right) + Y_\mu \left(m_{e\mu}m_{e\tau} - m_{ee}m_{\mu\tau}\right) \right.$$
$$\left. - \sqrt{Y_e^2 m_{\mu\mu} - 2Y_eY_\mu m_{e\mu} + Y_\mu^2 m_{ee}} \times \sqrt{m_{e\tau}^2 m_{\mu\mu} - 2m_{e\mu}m_{e\tau}m_{\mu\tau} + m_{ee}m_{\mu\tau}^2 + m_{e\mu}^2 m_{\tau\tau} - m_{ee}m_{\mu\mu}m_{\tau\tau}} \right)$$

and therefore the number of free parameters reduces to 8.

2 Triplets Case:

Once again, in the **2 Triplets Case** of inverse see-saw, Lepton Number induces a lot of additional constraints:

$$Y_\mu = \frac{m_{e\mu} \pm \sqrt{m_{e\mu}^2 - m_{ee}m_{\mu\mu}}}{m_{ee}} Y_e \qquad Y_\tau = \frac{m_{e\tau} \pm \sqrt{m_{e\tau}^2 - m_{ee}m_{\tau\tau}}}{m_{ee}} Y_e$$

$$m_{ee}m_{\mu\tau} = m_{e\mu}m_{e\tau} - s_\mu s_\tau \sqrt{\left(m_{e\mu}^2 - m_{ee}m_{\mu\mu}\right)\left(m_{e\tau}^2 - m_{ee}m_{\tau\tau}\right)}$$

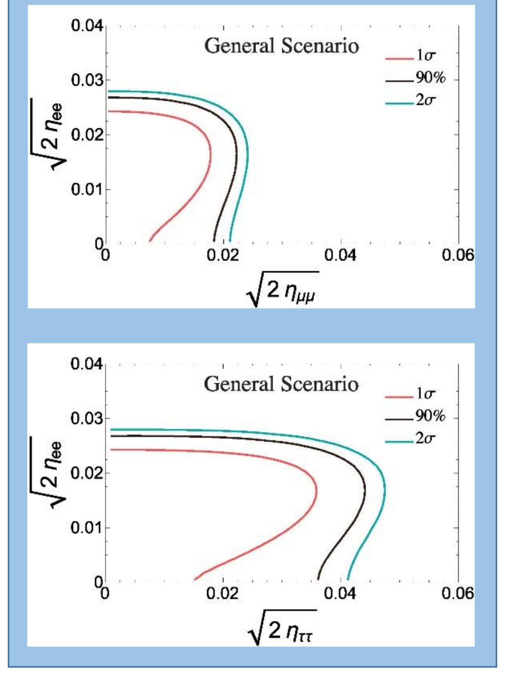
thus reducing to 3 the number of free parameters.

Observables:

Our goal was to find constraints on $\eta = \frac{v^2}{2} Y^\dagger M^{-2} Y$ or on $\theta = \frac{v}{\sqrt{2}} M^{-1} Y$. To do so, we used 43 observables as functions of $\alpha,\ M_Z,\ G_F$: the W mass, ratios of Z fermionic decays, the invisible width of Z, ratios of weak decays constraining EW universality, weak decays constraining CKM unitarity, and the following LFV processes: $\mu \to e\,(\mathrm{Ti})$, μ and τ to 3 charged leptons decays, lepton radiative decays and finally Z LFV decays.

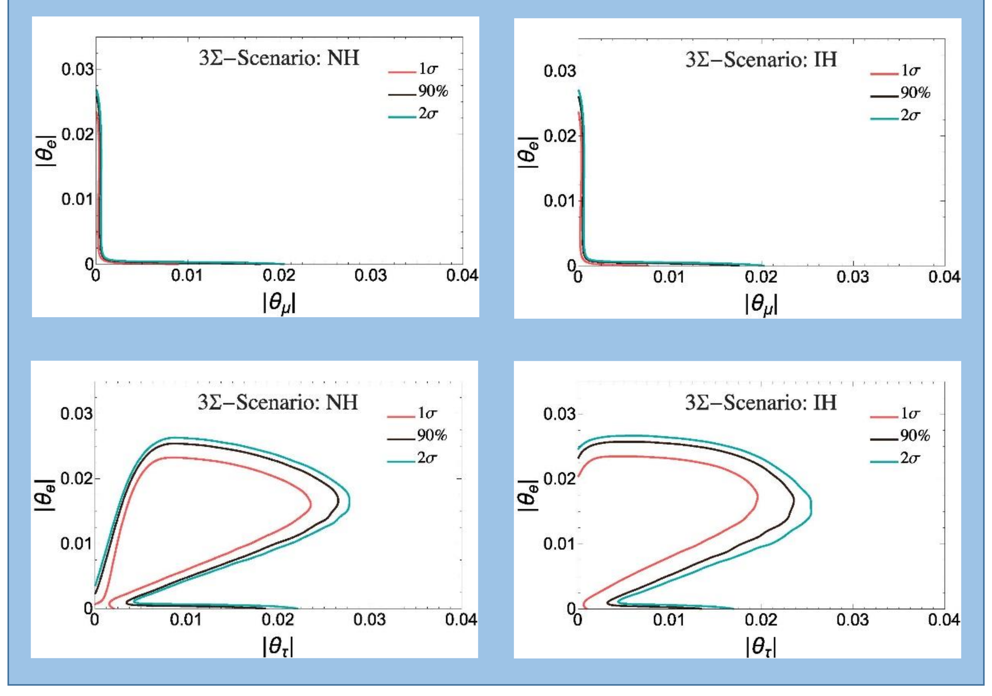
Preliminary Results:

General Case:



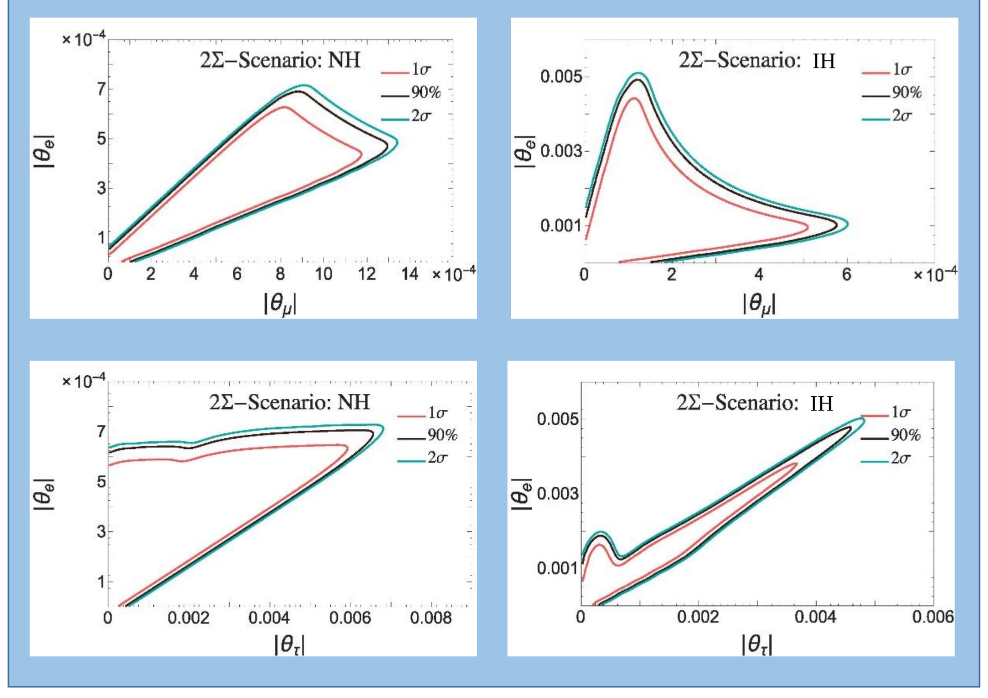
3 Triplets Case:

NH: IH:



2 Triplets Case:

NH: IH:



Numerical results:

		General	3 triplets		2 triplets	
			NH	IH	NH	IH
$\sqrt{2\eta_{ee}}$	1σ	$0.016^{+0.005}_{-0.007}$	$0.015^{+0.007}_{-0.006}$	$0.017^{+0.005}_{-0.007}$	$< 5.8 \cdot 10^{-4}$	$< 3.7 \cdot 10^{-3}$
	2σ	< 0.026	< 0.025	< 0.025	$< 6.9 \cdot 10^{-4}$	$< 4.4 \cdot 10^{-3}$
$\sqrt{2\eta_{\mu\mu}}$	1σ	< 0.013	$< 3.1 \cdot 10^{-5}$	$< 3.0 \cdot 10^{-5}$	$< 1.1 \cdot 10^{-3}$	$< 5.4 \cdot 10^{-4}$
	2σ	< 0.021	< 0.016	< 0.016	$< 1.3 \cdot 10^{-3}$	$< 6.5 \cdot 10^{-4}$
$\sqrt{2\eta_{\tau\tau}}$	1σ	< 0.027	$0.008^{+0.014}_{-0.005}$	< 0.018	$< 5.6 \cdot 10^{-3}$	< 0.014
	2σ	< 0.041	< 0.032	< 0.029	$< 6.6 \cdot 10^{-3}$	< 0.016
$\sqrt{2\eta_{e\mu}}$	1σ	$< 6.5 \cdot 10^{-4}$	$< 6.5 \cdot 10^{-4}$	$< 6.5 \cdot 10^{-4}$	$< 6.5 \cdot 10^{-4}$	$< 6.5 \cdot 10^{-4}$
	2σ	$< 7.7 \cdot 10^{-4}$	$< 7.7 \cdot 10^{-4}$	$< 7.7 \cdot 10^{-4}$	$< 7.7 \cdot 10^{-4}$	$< 7.7 \cdot 10^{-4}$
$\sqrt{2\eta_{e\tau}}$	1σ	< 0.019	$0.011^{+0.007}_{-0.006}$	$0.006^{+0.011}_{-0.006}$	$< 1.8 \cdot 10^{-3}$	$< 7.2 \cdot 10^{-3}$
	2σ	< 0.023	< 0.022	< 0.022	$< 2.1 \cdot 10^{-3}$	$< 8.5 \cdot 10^{-3}$
$\sqrt{2\eta_{\mu\tau}}$	1σ	< 0.015	$< 6.7 \cdot 10^{-4}$	$< 5.4 \cdot 10^{-4}$	$< 2.0 \cdot 10^{-3}$	$< 1.3 \cdot 10^{-3}$
	2σ	< 0.021	< 0.016	< 0.015	$< 2.4 \cdot 10^{-3}$	$< 1.5 \cdot 10^{-3}$

We can see that the bounds in the **3 Triplets Case** are of the same order as in the **General Case** (some percent), but the additional constraint greatly reduces the allowed parameter space. This is especially true also for the **2 Triplets Case**: here, the many additional constraints massively reduce the allowed parameter space, to the point that the bounds are improved by a whole order of magnitude.

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