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The Type III Inverse See-Saw:

the model and updated constraints

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See-saw vs. Inverse See-saw

Neutrinos are massive and light, but why?

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: either *M* big
or *Y* small

Difficult to test!

$\Rightarrow$ Inverse see-saw:

M small (o(TeV))
Y big
m_ν small because *L* is an approximate symmetry

Type III See-saw

We study type III see-saw $\Longrightarrow$ We add fermion triplets $\vec{\Sigma} = \left(\Sigma^-,\ \Sigma^0,\ \Sigma^+\right)$

~ Coefficient of the dim. 6 operator

Σ^0 behaves like ν_R $\Longrightarrow$ $U_{PMNS} \to N = (1+\eta)\, U_{PMNS}$

$\Sigma^\pm$ mixes with charged leptons $\Longrightarrow$ FCNC at tree-level!

We study 3 cases:

Free parameters:

General case:
(all triplets integrated out)
- all entries of η (9 parameters)

3 triplets:
(inverse see-saw)
- Lepton Number gives 1 more constraint
$\Rightarrow$ 8 parameters

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

2 triplets:
(inverse see-saw)
- many more constraints
$\Rightarrow$ only 3 parameters!

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

Observables:

Goal: find constraints on $\eta = \frac{v^2}{2} Y^\dagger M^{-2} Y$ or on $\theta = \frac{v}{\sqrt{2}} M^{-1} Y$

43 observables as functions of $\alpha,\ M_Z,\ G_F$:

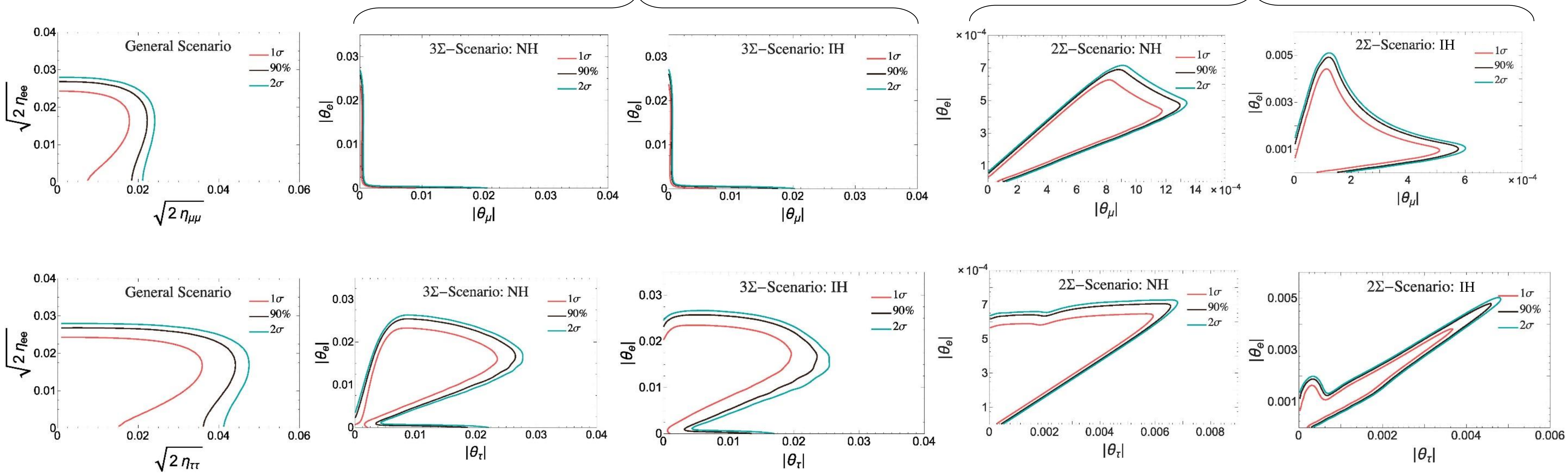
- W mass
- ratios of Z fermionic decays
- invisible width of Z
- Z asymmetry parameters
- ratios of weak decays constraining EW universality
- weak decays constraining CKM unitarity
- LFV processes: $\mu \to e\,(\mathrm{Ti})$, μ and τ to 3 charged leptons decays, lepton radiative decays, Z LFV decays

Results: Plots

General scenario

3 triplets

2 triplets



Results & Conclusions:

		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	$< 2.4 \cdot 10^{-3}$	$< 1.5 \cdot 10^{-3}$

- Low-scale see-saws with approximate Lepton Number symmetry are very interesting scenarios
- We studied the type III see-saw both in general and with approximate L-symmetry with 2 and 3 triplets
- We found new bounds on the parameters of these models

Thank you!

3 triplets:

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

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

By evaluating m_ν explicitly, one gets a set of 6 relations.
By eliminating the unknown parameters ε/Λ, one gets an additional constraint on θ_α and $(m_\nu)_{\alpha\beta}$.

2 triplets:

$$m_D = \frac{v}{\sqrt{2}} \begin{pmatrix} Y_{\Sigma_{1e}} & Y_{\Sigma_{1\mu}} & Y_{\Sigma_{1\tau}} \\ \varepsilon_1 Y_{\Sigma_{2e}} & \varepsilon_1 Y_{\Sigma_{2\mu}} & \varepsilon_1 Y_{\Sigma_{2\tau}} \end{pmatrix}, \qquad M = \begin{pmatrix} \mu_1 & \Lambda \\ \Lambda & \mu_2 \end{pmatrix}$$

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

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