Flavour and dark matter in a scoto/type-II seesaw model

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INVISIBLES'22 WORKSHOP

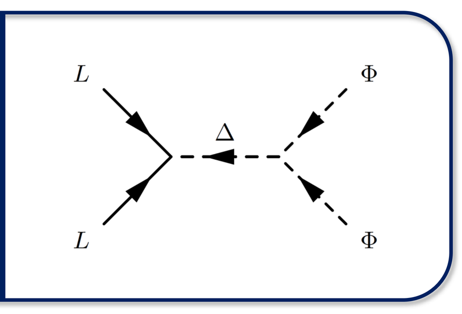
Motivation

The **Standard Model** cannot explain:

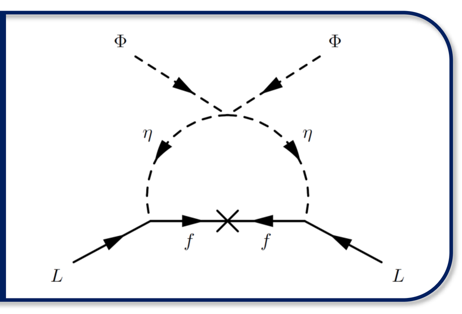
- **neutrino flavour oscillations** which imply nonvanishing neutrino masses and lepton mixing;
- observed **dark matter** abundance.

Straightforward and **elegant** solutions:

Type-II Seesaw Model



Scotogenic Model



Our approach:

Consider a model where **both mechanisms** contribute to neutrino masses with a **single discrete symmetry** to accommodate: **spontaneous CP violation**, **neutrino oscillation data** and **dark matter stability.**

Our model

Consider the **most restrictive** Yukawa coupling matrices realizable by **minimal discrete flavour symmetry** in order to maximize predictivity.

Particle content:

	Fields	$\mathrm{SU}(2)_L \otimes \mathrm{U}(1)_Y$	$\mathcal{Z}_8^{e-\mu} \to \mathcal{Z}_2$	$\mathcal{Z}_8^{e-\tau} \to \mathcal{Z}_2$	$\mathcal{Z}_8^{\mu-\tau} \to \mathcal{Z}_2$
Fermions	ℓ_{eL}, e_R	$(\mathbf{2},-1/2),(\mathbf{1},-1)$	$1 \to +$	$1 \to +$	$\omega^2 \to +$
	$\ell_{\mu L}, \mu_R$	$(\mathbf{2},-1/2),(\mathbf{1},-1)$	$\omega^6 \to +$	$\omega^2 \to +$	$1 \to +$
	$\ell_{\tau L}, \tau_R$	$(\mathbf{2},-1/2),(\mathbf{1},-1)$	$\omega^2 \to +$	$\omega^6 \to +$	$\omega^6 \to +$
	f	$(\mathbf{1},0)$	$\omega^3 \to -$	$\omega^3 \to -$	$\omega^3 \to -$
Scalars	Φ	$(\mathbf{2},1/2)$	$1 \to +$		
	Δ	$(\mathbf{3},1)$	$1 \to +$		
	σ	$(\mathbf{1},0)$	$\omega^2 \to +$		
	η_1	$(\mathbf{2},1/2)$	$\omega^3 \to -$		
	η_2	$(\mathbf{2},1/2)$	$\omega^5 \to -$		

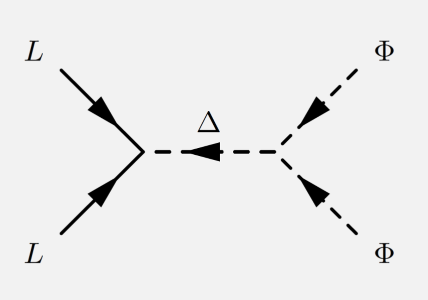
CP invariant Lagrangian:

$$-\mathcal{L}_{\text{Yuk.}} = \overline{\ell_L}\mathbf{Y}_\ell\,\Phi\,e_R + \overline{\ell_L}\mathbf{Y}_f^1\tilde{\eta}_1 f + \overline{\ell_L}\mathbf{Y}_f^2\tilde{\eta}_2 f + \overline{\ell_L^c}\mathbf{Y}_\Delta i\tau_2\Delta\ell_L + \frac{1}{2}y_f\,\sigma\overline{f^c}f + \text{H.c.}$$

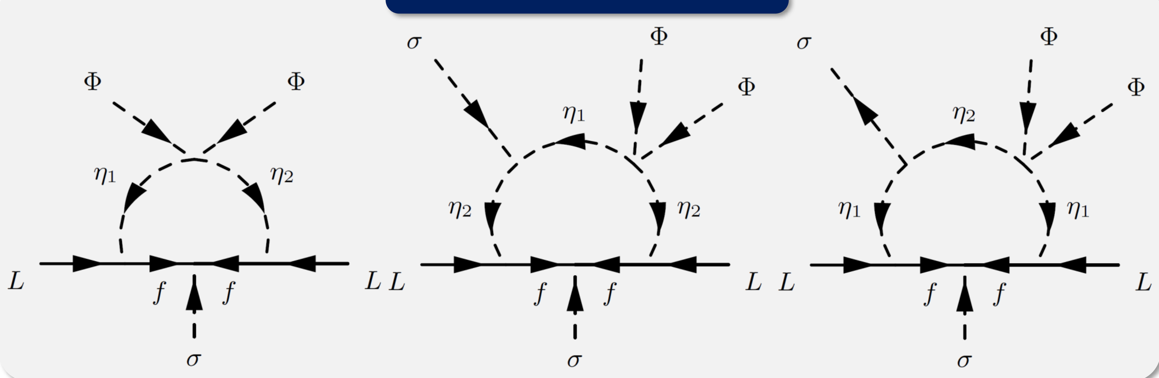
$$\text{with}\quad \langle\phi^0\rangle = \frac{v}{\sqrt{2}}\,,\ \langle\eta^0_{1,2}\rangle = 0\,,\ \langle\Delta^0\rangle = \frac{w}{\sqrt{2}}\,,\langle\sigma\rangle = \frac{u\,e^{i\theta}}{\sqrt{2}}$$

Some contributions to neutrino masses (dominant for $w \ll v \lesssim u$):

Tree level



Radiative level



Allowed Yukawa matrices by discrete symmetry $Z_8^{e-\mu}$:

$$\mathbf{Y}_\ell = \begin{pmatrix} \times & 0 & 0 \\ 0 & \times & 0 \\ 0 & 0 & \times \end{pmatrix},\ \mathbf{Y}_f^1 = \begin{pmatrix} y_e \\ 0 \\ 0 \end{pmatrix},\ \mathbf{Y}_f^2 = \begin{pmatrix} 0 \\ y_\mu \\ 0 \end{pmatrix},\ \mathbf{Y}_\Delta = \begin{pmatrix} y_1 & 0 & 0 \\ 0 & 0 & y_2 \\ 0 & y_2 & 0 \end{pmatrix} e^{-i\theta}$$

At the effective level:

$$\mathbf{M}_\nu = \sqrt{2}w\mathbf{Y}_\Delta + \mathcal{F}_{11}(M_f, m_{S_k})M_f\mathbf{Y}_f^1\mathbf{Y}_f^{1T} + \mathcal{F}_{22}(M_f, m_{S_k})M_f\mathbf{Y}_f^2\mathbf{Y}_f^{2T}$$

$$+\mathcal{F}_{12}(M_f, m_{S_k})M_f\left(\mathbf{Y}_f^1\mathbf{Y}_f^{2T} + \mathbf{Y}_f^2\mathbf{Y}_f^{1T}\right)$$

Type-II seesaw contribution

Scotogenic contributions

$$= \begin{pmatrix} \mathcal{F}_{11}M_f\,y_e^2 + \sqrt{2}w\,y_1\,e^{-i\theta} & \mathcal{F}_{12}M_f\,y_e y_\mu & 0 \\ \cdot & \mathcal{F}_{22}M_f\,y_\mu^2 & \sqrt{2}w\,y_2 e^{-i\theta} \\ \cdot & \cdot & 0 \end{pmatrix}$$

- New Z_8 symmetry leads to **low-energy predictions** for neutrino mass and mixing parameters.
- Presence of **dark particles** (odd under remnant Z_2 after SSB of Z_8): fermion f and scalars $\eta_{1,2}$.
- **Charged-lepton flavour violating** (cLFV) processes are allowed.

Spontaneous CP violation

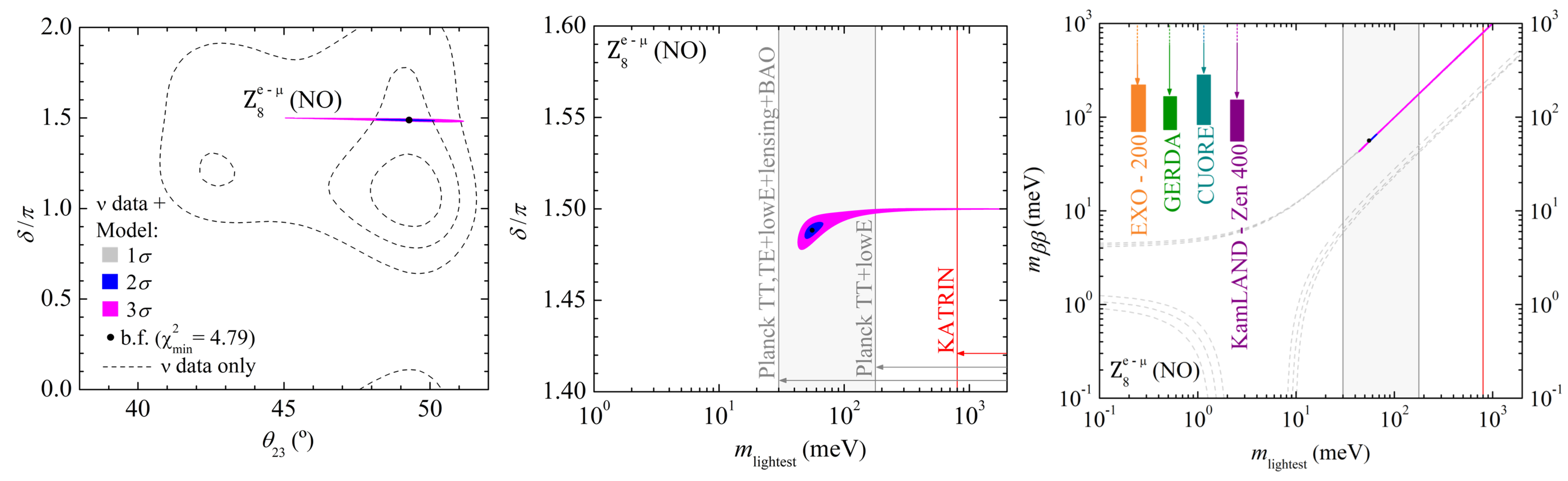
- We reduced the number of parameters by requiring **the Lagrangian to be CP symmetric.**
- CP is **spontaneously broken** by the **complex VEV** of σ and is **successfully** transmitted to the leptonic sector (see above).

$$V \supset\ m_\sigma^2\,|\sigma|^2 + \frac{\lambda_\sigma}{2}\,|\sigma|^4 + m_\sigma'^2\left(\sigma^2 + \sigma^{*2}\right) + \frac{\lambda'_\sigma}{2}\left(\sigma^4 + \sigma^{*4}\right)$$

CP violating solution to the minimisation conditions yields: $\cos(2\theta) = -\dfrac{m_\sigma'^2}{2u^2\lambda'_\sigma}$

Corresponds to the global minimum for $\left(m_\sigma'^4 - 4u^4\lambda_\sigma'^2\right)/(4\lambda'_\sigma) > 0$

Dirac phase, lightest neutrino mass and $m_{\beta\beta}$ predictions

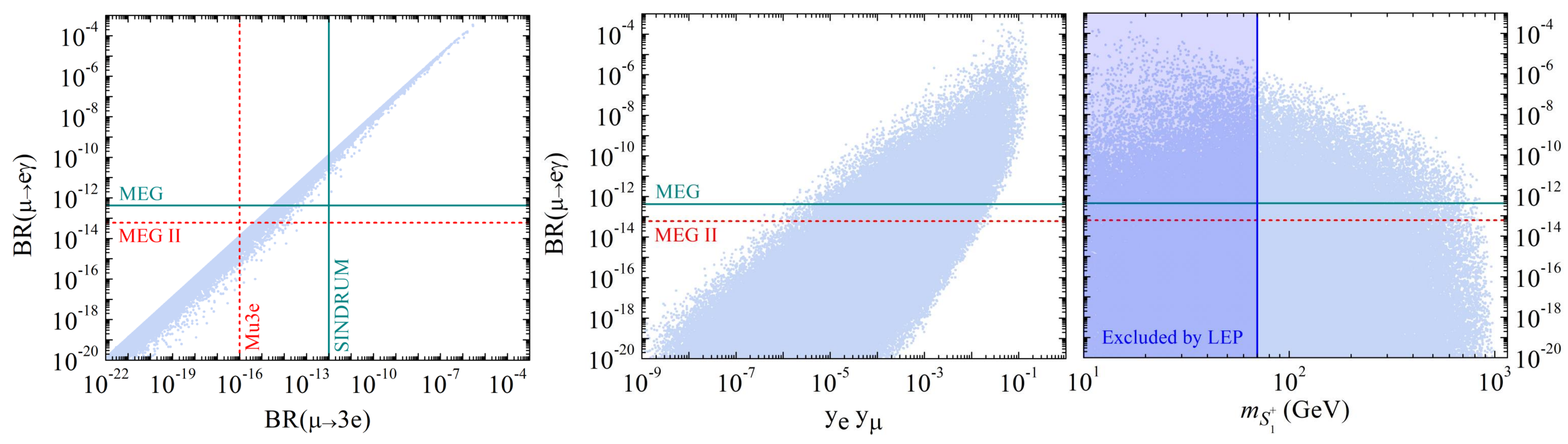


- Case $Z_8^{e-\mu}$ **selects one of the θ_{23} octants** and sharply **predicts $\delta \sim 3\pi/2$**; imposes a **lower limit on m_{lightest}** in the range probed by cosmology; and predicts **$m_{\beta\beta}$ within the sensitivity of current 0υββ experiments**. IO is strongly disfavoured by KamLAND-Zen 400.
- Case $Z_8^{e-\tau}$ is strongly disfavoured by KamLAND-Zen 400.
- Case $Z_8^{\mu-\tau}$ predicts $m_{\beta\beta} = 0$ leading to incompatibility with IO.

The **SCPV phase θ** is determined by **low-energy parameters**. For $Z_8^{e-\mu}$ and NO neutrino mass spectrum, **θ is fixed to 1.92π** for best-fit neutrino observables.

Charged-lepton flavour violation

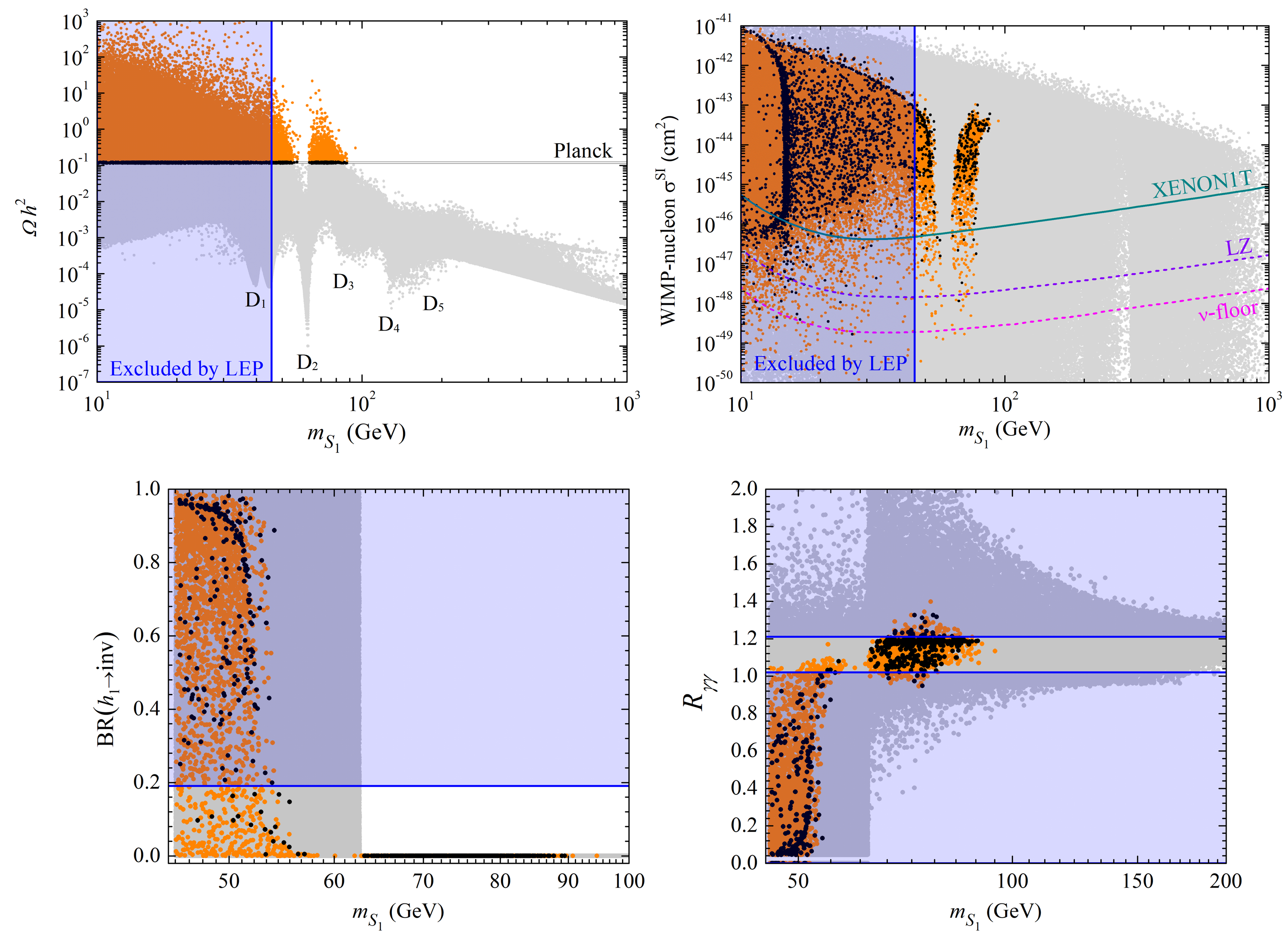
- For case $Z_8^{e-\mu}$ the only allowed **Δ-mediated process** (at tree level) is $\tau^- \to \mu^+ e^- e^-$. For best-fit neutrino observables and considering the LEP bound $m_{\Delta^{++}} \gtrsim 45.6$ GeV, the current Belle constraint requires $w \lesssim 15.98$ eV. For definiteness, we consider $w = 1$ eV.
- The **dark sector mediated processes** (at loop level) allowed for this case are: $\mu \to e\gamma$, $\mu \to 3e$, $\mu - e$ **conversion** in nuclei.



- Large region of the model's parameter space (blue dots) is **excluded by current cLFV bounds** (green solid lines). Future experiments (red dashed lines) will further constrain the parameter space.

Scalar dark matter

- WIMP DM candidate is the **lightest dark particle**: either the **lightest neutral scalar S_1** or the **fermion f**.
- Here we show the obtained results for DM **relic density**, Ωh^2, DM-nucleon **spin-independent cross section** at tree level, σ^{SI}, **Higgs invisible decay**, $\text{BR}(h_1 \to \text{inv})$, and **Higgs to photon-photon**, $R_{\gamma\gamma}$, for **scalar DM**.



- Two viable mass regions are compatible with the experimental interval for Ωh^2 (black dots), namely $m_{S_1} \lesssim$ **60 GeV** (low-mass region) and **68** $\lesssim m_{S_1} \lesssim$ **90 GeV** (intermediate mass region).
- The **lower mass region is excluded** by current DM **DD experiments** and by **collider constraints** (blue regions) from LEP on scalar masses and LHC Higgs data (invisible and diphoton decay).
- The **intermediate mass region is viable** and will be probed by future DD searches.
- For $m_{S_1} \gtrsim 90$ GeV (high-mass region), our model leads to underabundant DM (grey dots).

We propose a **hybrid scoto-seesaw model** which in spite of being based on a **very simple flavour symmetry** leads to significant constraints in light of present and future data coming from **neutrino**, **cLFV** and **DM experiments**.

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