Predictive Scotogenic Model with Flavor Dependent Symmetry

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Based on 1901.07798,1908.07192,1911.00819

Motivation

- BSM hints: Neutrino Mass and Dark matter $\rightarrow$ Scotogenic Model

  ✠hep-ph/0601225

- Flavor structure in M_ν $\rightarrow$ Texture-zeros (✠1108.4534)

  Discrete Flavor symmetry (✠hep-ph/0106291)

  $U(1)$ Gauge Symmetry (✠1203.4591)

- Scotogenic with Flavor structure
  - A_4 Model (✠1206.1570)
  - Texture C with $U(1)_{L_\mu - L_\tau}$ symmetry (✠1501.01530)
  - Texture A_1 with $U(1)_{xB_3 - xL_e - L_\mu + L_\tau}$ symmetry (✠1701.05788)
  - Two texture-zeros with $U(1)_{B-2L_\alpha - L_\beta}$ symmetry (✠1806.09957)

Classic Unflavored Scotogenic Model

- Three right-handed fermion singlets $N_{Ri}(i = 1 \sim 3)$
- An inert scalar doublet field $\eta = (\eta^+, \eta^0)$
- A discrete Z_2 symmetry is imposed for the new fields

The relevant interactions for neutrino masses generation

$$\mathcal{L} \supset h_{\alpha i}\overline{L}_\alpha \tilde{\eta} N_{Ri} + \frac{1}{2}M_N \overline{N}_R^c N_R + \frac{1}{2}\lambda(\Phi^\dagger \eta)^2 + \text{h.c.}. \tag{1}$$

If we assume $m_0^2 \equiv (m_R^2 + m_I^2)/2 \gg M_{Nk}^2$, M_ν are then given by

$$\begin{aligned}(M_\nu)_{\alpha\beta} &\simeq -\frac{1}{32\pi^2}\frac{\lambda v^2}{m_0^2}\sum_k h_{\alpha i}V_{ik}h_{\beta j}V_{jk}M_{Nk} \\ &= -\frac{1}{32\pi^2}\frac{\lambda v^2}{m_0^2}(hM_N h^T)_{\alpha\beta}\end{aligned} \tag{2}$$

The structure of M_ν is determined by Yukawa h and mass matrix M_N.

Classic Unflavored Scotogenic Model

The neutrino mass matrix M_ν is diagonalized as

$$U^T_{\text{PMNS}} M_\nu U_{\text{PMNS}} = \hat{m}_\nu \equiv \text{diag}(m_1, m_2, m_3), \tag{3}$$

where U_{PMNS} is the neutrino mixing matrix denoted as

$$U_{\text{PMNS}} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13} \\ -c_{12}s_{23}s_{13} - s_{12}c_{23}e^{-i\delta} & -s_{12}s_{23}s_{13} + c_{12}c_{23}e^{-i\delta} & s_{23}c_{13} \\ -c_{12}c_{23}s_{13} + s_{12}s_{23}e^{-i\delta} & -s_{12}c_{23}s_{13} - c_{12}s_{23}e^{-i\delta} & c_{23}c_{13} \end{pmatrix}$$

$$\times \text{diag}(e^{i\rho}, e^{i\sigma}, 1) \tag{4}$$

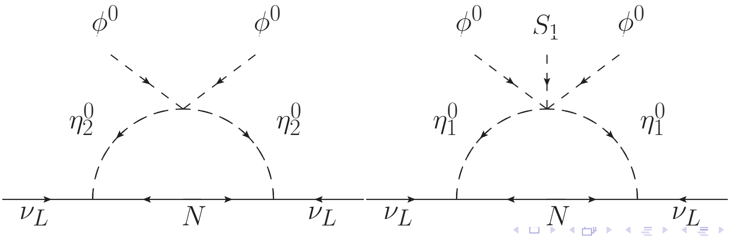
Here, we define $c_{ij} = \cos\theta_{ij}$ and $s_{ij} = \sin\theta_{ij}$ ($ij = 12, 23, 13$) for short, δ is the Dirac phase and ρ, σ are the two Majorana phases. One can denote U_{PMNS} as $U_{\text{PMNS}} = U \times P$. The neutrino mass matrix is then

$$M_\nu = U_{\text{PMNS}} \hat{m}_\nu U^T_{\text{PMNS}}. \tag{5}$$

Gauged $U(1)_{B-2L_\alpha-L_\beta}$ Scotogenic Model(1901.07798)

Group	Lepton Fields								Scalar Fields				
	L_α	$\ell_{\alpha R}$	L_β	$\ell_{\beta R}$	L_γ	$\ell_{\gamma R}$	N_{R1}	N_{R2}	Φ	η_1	η_2	S_1	S_2
$SU(2)_L$	2	1	2	1	2	1	0	0	2	2	2	1	1
$U(1)_Y$	$-\frac{1}{2}$	-1	$-\frac{1}{2}$	-1	$-\frac{1}{2}$	-1	1	1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0	0
Z_2	$+$	$+$	$+$	$+$	$+$	$+$	$-$	$-$	$+$	$-$	$-$	$+$	$+$
$U(1)_{B-2L_\alpha-L_\beta}$	-2	-2	-1	-1	0	0	-1	-2	0	-1	0	2	3

TABLE I. Particle content and corresponding charge assignments.



• The relevant scalar interactions for the loop-induced neutrino masses is given by

$$\mathcal{L}_S \supset \frac{\lambda}{\Lambda}(\Phi^\dagger \eta_1)^2 S_1 + \lambda'(\Phi^\dagger \eta_2)^2 \quad (6)$$

One can achieve the effective operator by simply adding a new scalar singlet $\rho \sim (1, 0, 1, -)$ so that in scalar sector $\mathcal{L}_S \supset \mu(\Phi^\dagger \eta_1)\rho^\dagger + \mu' \rho^2 S_1$ is allowed.

•Under $U(1)_{B-2L_e-L_\tau}$, the flavor dependent Yukawa interactions are given by

$$\begin{aligned} -\mathcal{L}_{\mathrm{Y}} \;=\; & h_{\mu 1}\bar{L}_\mu \tilde{\eta}_1 N_{R1} + h_{\tau 2}\bar{L}_\tau \tilde{\eta}_1 N_{R2} + f_{\tau 1}\bar{L}_\tau \tilde{\eta}_2 N_{R1} + f_{e2}\bar{L}_e \tilde{\eta}_2 N_{R2} \\ & + y_{11}\overline{N^c_{R1}} N_{R1} S_1 + y_{12}(\overline{N^c_{R1}} N_{R2} + \overline{N^c_{R2}} N_{R1}) S_2 + \text{h.c.}. \end{aligned} \quad (7)$$

• The texture of above Yukawa couplings are

$$h = \begin{pmatrix} 0 & 0 \\ h_{\mu 1} & 0 \\ 0 & h_{\tau 2} \end{pmatrix}, \quad f = \begin{pmatrix} 0 & f_{e2} \\ 0 & 0 \\ f_{\tau 1} & 0 \end{pmatrix}, \quad y = \begin{pmatrix} y_{11} & y_{12} \\ y_{12} & 0 \end{pmatrix}. \quad (8)$$

Assuming $\Lambda = \langle S_1 \rangle$, $\lambda/m^2_{\eta_1} = \lambda'/m^2_{\eta_2}$, and all the element in M_N to be equal, then

$$M_\nu \propto \begin{pmatrix} 0 & 0 & f_{e2}f_{\tau 1} \\ 0 & h^2_{\mu 1} & h_{\mu 1}h_{\tau 2} \\ f_{e2}f_{\tau 1} & h_{\mu 1}h_{\tau 2} & f^2_{\tau 1} \end{pmatrix}. \quad (9)$$

Texture of M_ν	Group	Texture of M_ν	Group	Status
$A_1: \begin{pmatrix} 0 & 0 & \times \\ 0 & \times & \times \\ \times & \times & \times \end{pmatrix}$	$U(1)_{B-2L_e-L_\tau}$	$A_2: \begin{pmatrix} 0 & \times & 0 \\ \times & \times & \times \\ 0 & \times & \times \end{pmatrix}$	$U(1)_{B-2L_e-L_\mu}$	Allowed
$B_3: \begin{pmatrix} \times & 0 & \times \\ 0 & 0 & \times \\ \times & \times & \times \end{pmatrix}$	$U(1)_{B-2L_\mu-L_\tau}$	$B_4: \begin{pmatrix} \times & \times & 0 \\ \times & \times & \times \\ 0 & \times & 0 \end{pmatrix}$	$U(1)_{B-2L_\tau-L_\mu}$	Marginally Allowed
$D_1: \begin{pmatrix} \times & \times & \times \\ \times & 0 & 0 \\ \times & 0 & \times \end{pmatrix}$	$U(1)_{B-2L_\mu-L_e}$	$D_2: \begin{pmatrix} \times & \times & \times \\ \times & \times & 0 \\ \times & 0 & 0 \end{pmatrix}$	$U(1)_{B-2L_\tau-L_e}$	Excluded

TABLE I. Two texture-zeros and corresponding $U(1)_{B-2L_\alpha-L_\beta}$ symmetry. Here, $\times$ denotes a nonzero matrix element.

(1806.06785)

The corresponding Yukawa coupling h and mass matrix M_N are

$$h = \text{diag}(h_e, h_\mu, h_\tau), \quad \mathcal{M}_N = \begin{pmatrix} M_{ee} & \frac{v_S}{\sqrt{2}}h_{e\mu} & \frac{v_S}{\sqrt{2}}h_{e\tau} \\ \frac{v_S}{\sqrt{2}}h_{e\mu} & 0 & M_{\mu\tau}e^{i\theta_R} \\ \frac{v_S}{\sqrt{2}}h_{e\tau} & M_{\mu\tau}e^{i\theta_R} & 0 \end{pmatrix} \tag{10}$$

M_ν has same structure with M_N, i.e., Texture C.

We consider this model to explain two anomalies simultaneously:

• If Z' also has flavor violating $b-s$ coupling, then Z' would contribute to the transition $b \to s\mu^+\mu^-$, hence explain the $R_{K^{(*)}}$ anomaly.

•Annihilation channels $NN \to Z'Z'$ and $NN \to Z'H_0(\to Z'Z')$ channel could be used to interpret the AMS-02 positron excess.

Gauged $U(1)_{B-3L_\alpha}$ Scotogenic Model(1911.00819)

The interactions relevant to lepton mass generation are given by

$$-\mathcal{L} \supset f_{\alpha\beta}\bar{L}_\alpha \Phi \ell_{\beta R} + h_{\alpha i}\bar{L}_\alpha \eta^c N_{Ri} + \frac{M_{Nij}}{2} N_{Ri} N_{Rj} + \frac{1}{2}\lambda (H^\dagger \eta)^2 + \text{hc.} \quad (11)$$

Under $U(1)_{B-3L_\tau}$ gauge symmetry, the texture of lepton Yukawa couplings are given by

$$f = \begin{pmatrix} f_{ee} & f_{e\mu} & 0 \\ f_{\mu e} & f_{\mu\mu} & 0 \\ 0 & 0 & f_{\tau\tau} \end{pmatrix} h = \begin{pmatrix} h_{e1} & h_{e2} & 0 \\ h_{\mu 1} & h_{\mu 2} & 0 \\ 0 & 0 & h_{\tau 3} \end{pmatrix} M_N = \begin{pmatrix} M_{11} & M_{12} & \frac{v_S}{\sqrt{2}} y_{13} \\ - & M_{22} & \frac{v_S}{\sqrt{2}} y_{23} \\ - & - & 0 \end{pmatrix}$$

The texture structure of M_l and M_ν are of the form

$$M_l \propto \begin{pmatrix} f_{ee} & f_{e\mu} & 0 \\ f_{\mu e} & f_{\mu\mu} & 0 \\ 0 & 0 & f_{\tau\tau} \end{pmatrix} \qquad M_\nu \propto \begin{pmatrix} (M_\nu)_{11} & (M_\nu)_{12} & (M_\nu)_{12} \\ - & (M_\nu)_{22} & (M_\nu)_{23} \\ - & - & 0 \end{pmatrix}. \quad (12)$$

Pattern	Group	Texture of M_l	Texture of M_ν
A	$U(1)_{B-3L_e}$	$\begin{pmatrix} \times & 0 & 0 \\ 0 & \times & \times \\ 0 & \times & \times \end{pmatrix}$	$\begin{pmatrix} 0 & \times & \times \\ \times & \times & \times \\ \times & \times & \times \end{pmatrix}$
B	$U(1)_{B-3L_\mu}$	$\begin{pmatrix} \times & 0 & \times \\ 0 & \times & 0 \\ \times & 0 & \times \end{pmatrix}$	$\begin{pmatrix} \times & \times & \times \\ \times & 0 & \times \\ \times & \times & \times \end{pmatrix}$
C	$U(1)_{B-3L_\tau}$	$\begin{pmatrix} \times & \times & 0 \\ \times & \times & 0 \\ 0 & 0 & \times \end{pmatrix}$	$\begin{pmatrix} \times & \times & \times \\ \times & \times & \times \\ \times & \times & 0 \end{pmatrix}$

Table: Possible mass textures of charged leptons (M_l) and neutrinos (M_ν), where $\times$ denotes a non-zero entry.

Patten	Group	Hierarchy	Oscillation@3σ	Oscillation@1σ	$\sum_\nu < 0.12$ eV	M_{ee}(eV)
A	$U(1)_{B-3L_e}$	NH	$\surd$	$\surd$	$\surd$	0
		IH	$\times$	-	-	-
B	$U(1)_{B-3L_\mu}$	NH	$\surd$	$\times$	$\times$	$\gtrsim 0.05$
		IH	$\surd$	$\surd$	$\surd$	$\gtrsim 0.015$
C	$U(1)_{B-3L_\tau}$	NH	$\surd$	$\surd$	$\times$	$\gtrsim 0.033$
		IH	$\surd$	$\surd$	$\surd$	$\gtrsim 0.015$

Table: Some main results of the one texture-zeros in the $U(1)_{B-3L_\alpha}$ scotogenic model.

Neutrino Mixing

- The Method: Define $\lambda_1 = m_1 e^{2i\rho}$, $\lambda_2 = m_2 e^{2i\sigma}$, $\lambda_3 = m_3$.

Let $(M_\nu)_{ab} = (M_\nu)_{\alpha\beta} = 0$, then one can obtain

$$\frac{\lambda_1}{\lambda_3} = \frac{U_{a3}U_{b3}U_{\alpha 2}U_{\beta 2} - U_{a2}U_{b2}U_{\alpha 3}U_{\beta 3}}{U_{a2}U_{b2}U_{\alpha 1}U_{\beta 1} - U_{a1}U_{b1}U_{\alpha 2}U_{\beta 2}} \tag{13}$$

$$\frac{\lambda_2}{\lambda_3} = \frac{U_{a1}U_{b1}U_{\alpha 3}U_{\beta 3} - U_{a3}U_{b3}U_{\alpha 1}U_{\beta 1}}{U_{a2}U_{b2}U_{\alpha 1}U_{\beta 1} - U_{a1}U_{b1}U_{\alpha 2}U_{\beta 2}}, \tag{14}$$

from which two neutrino mass ratios are $\xi = \frac{m_1}{m_3} = \left|\frac{\lambda_1}{\lambda_3}\right|$, $\zeta = \frac{m_2}{m_3} = \left|\frac{\lambda_2}{\lambda_3}\right|$, and the two Majorana phases are $\rho = \frac{1}{2}\arg\left(\frac{\lambda_1}{\lambda_3}\right)$, $\sigma = \frac{1}{2}\arg\left(\frac{\lambda_2}{\lambda_3}\right)$.

The Dirac CP-violating phase δ is constrained by

$$R_\nu = \frac{\delta m^2}{|\Delta m^2|} = \frac{2(\zeta^2 - \xi^2)}{|2 - (\zeta^2 + \xi^2)|} \tag{15}$$

The neutrino mass spectrum is

$$m_3 = \sqrt{\delta m^2}/\sqrt{\zeta^2 - \xi^2}, m_2 = m_3\zeta, m_1 = m_3\xi \tag{16}$$

Neutrino Mixing

Following results are based on $U(1)_{B-2L_e-L_\tau}$

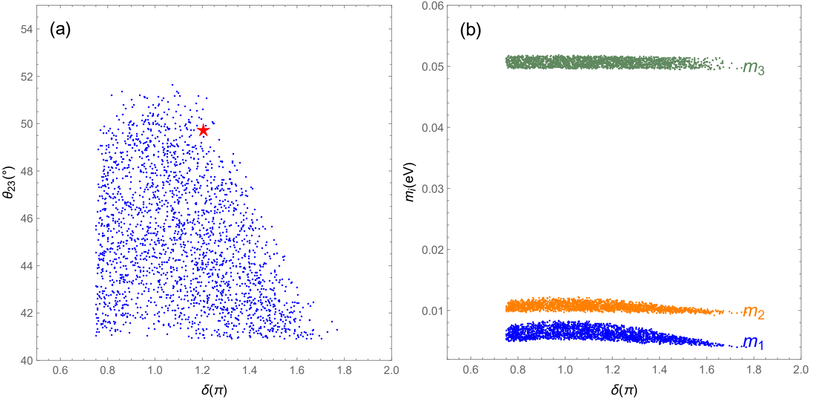


Figure: Allowed samples of A_1 texture with neutrino oscillation data in 3σ.

$$m_1 \sim 0.007 \text{ eV}, m_2 \sim 0.01 \text{ eV}, m_3 \approx \sqrt{\Delta m^2} \sim 0.05 \text{ eV}, \sum m_i \sim 0.07 \text{ eV}.$$

Neutrino Mixing

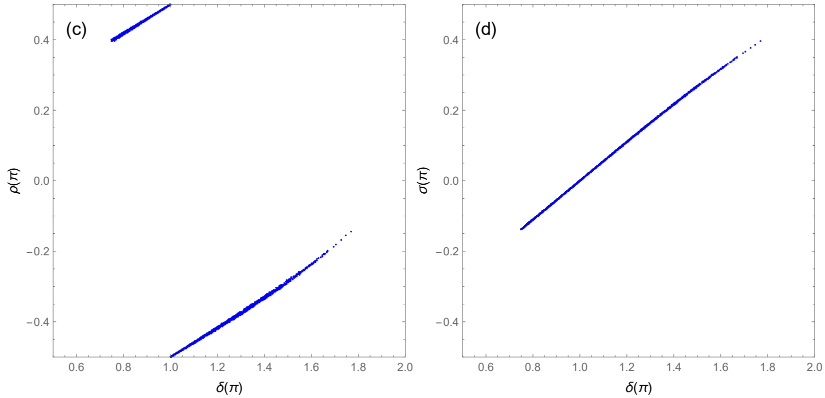


Figure: Allowed samples of A_1 texture with neutrino oscillation data in 3σ.

$$\delta \in [0.75\pi, 1.77\pi],\ \rho \approx \frac{\delta}{2}\ ,\ \sigma \approx \frac{\delta}{2} - \frac{\pi}{2}$$

Analytic and predicted neutrino mass matrixes are

$$M_\nu \propto \begin{pmatrix} 0 & 0 & f_{e2}f_{\tau 1} \\ 0 & h_{\mu 1}^2 & h_{\mu 1}h_{\tau 2} \\ f_{e2}f_{\tau 1} & h_{\mu 1}h_{\tau 2} & f_{\tau 1}^2 \end{pmatrix}, M_\nu = \begin{pmatrix} 0 & 0 & 0.0110 \\ 0 & 0.0293 & 0.0219 \\ 0.0110 & 0.0219 & 0.0256 \end{pmatrix} \text{eV}$$

The neutrino oscillation data requires

$$\frac{h_{\tau 2}}{h_{\mu 1}} : \frac{f_{\tau 1}}{h_{\mu 1}} : \frac{f_{e2}}{h_{\mu 1}} = \frac{(M_\nu)_{\mu\tau}}{(M_\nu)_{\mu\mu}} : \sqrt{\frac{(M_\nu)_{\tau\tau}}{(M_\nu)_{\mu\mu}}} : \frac{(M_\nu)_{e\tau}}{\sqrt{(M_\nu)_{\mu\mu}(M_\nu)_{\tau\tau}}} \simeq 0.745 : 0.933 : 0.401. \quad (17)$$

We can take $h_{\mu 1}$ as free parameters, and the overall neutrino mass scale is then determined by $\lambda v^2 M_N h_{\mu 1}^2/(32\pi^2 m_0^2) \approx 0.0293$ eV.

$(M_\nu)_{ee} = 0$, effective Majorana neutrino mass $\langle m \rangle_{ee} = 0$, only normal hierarchy is allowed.

Lepton Flavor Violation

The flavor dependent Yukawa interactions

$$-\mathcal{L}_{\mathsf{Y}} \supset h_{\mu 1}\bar{L}_\mu \tilde{\eta}_1 N_{R1} + h_{\tau 2}\bar{L}_\tau \tilde{\eta}_1 N_{R2} + f_{\tau 1}\bar{L}_\tau \tilde{\eta}_2 N_{R1} + f_{e2}\bar{L}_e \tilde{\eta}_2 N_{R2} \tag{18}$$

indicate no $\mu \to e\gamma$. $\tau \to \mu(e)\gamma$ is mediated by $\eta_1^\pm(\eta_2^\pm)$ with branching ratios

$$\text{BR}(\tau \to \mu\gamma) = \frac{3\alpha}{64\pi G_F^2}\left|\sum_{i=1}^{2}\frac{(h_{\mu 1}V_{1i})(h_{\tau 2}V_{2i})^*}{M_{\eta_1}^2}F\left(\frac{M_{Ni}^2}{M_{\eta_1}^2}\right)\right|^2 \text{BR}(\tau \to \mu\nu_\tau\bar{\nu}_\mu),$$

$$\text{BR}(\tau \to e\gamma) = \frac{3\alpha}{64\pi G_F^2}\left|\sum_{i=1}^{2}\frac{(f_{e2}V_{2i})(f_{\tau 1}V_{1i})^*}{M_{\eta_2}^2}F\left(\frac{M_{Ni}^2}{M_{\eta_2}^2}\right)\right|^2 \text{BR}(\tau \to e\nu_\tau\bar{\nu}_e),$$

where the loop function $F(x)$ is

$$F(x) = \frac{1 - 6x + 3x^2 + 2x^3 - 6x^2 \ln x}{6(1-x)^4}. \tag{19}$$

Lepton Flavor Violation

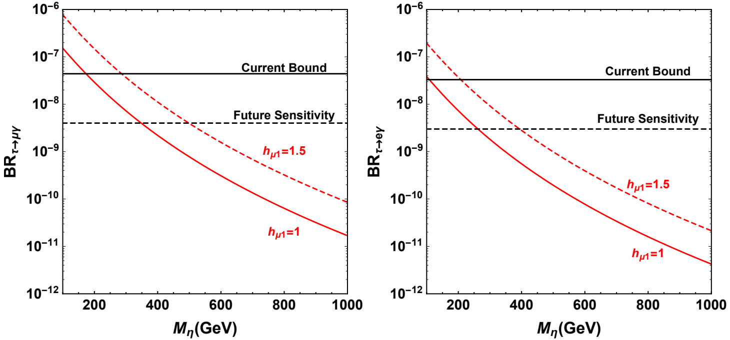


Figure: Predictions for $\tau \to \mu\gamma$ (left) and $\tau \to e\gamma$ (right) with corresponding current bound and future sensitivity. We have fixed $M_{N_1} = 200$ GeV.

In the limit of degenerate M_N, we have

$$\text{BR}(\tau \to \ell\gamma) \propto \left| \sum_{i=1}^{2} V_{1i} V_{2i}^* \right|^2 = |(VV^\dagger)_{12}|^2 = 0, \quad (20)$$

Muon Anomalous Magnetic Moment

$\bar{L}_\mu \tilde{\eta}_1 N_i$ contributes to Δa_μ as

$$\Delta a_\mu = -\sum_{i=1}^{2} \frac{|h_{\mu 1} V_{1i}|^2 M_\mu^2}{16\pi^2 M_{\eta_1}^2} F\left(\frac{M_{Ni}^2}{M_{\eta_1}^2}\right).$$

The total contribution is negative, but the observed discrepancy $\Delta a_\mu = a_\mu^{\text{EXP}} - a_\mu^{\text{SM}} = (261 \pm 78) \times 10^{-11}$ is positive.
We assume the contribution do not larger than EW uncertainty,i.e.,$|\Delta a_\mu| \lesssim 10^{-10}$.

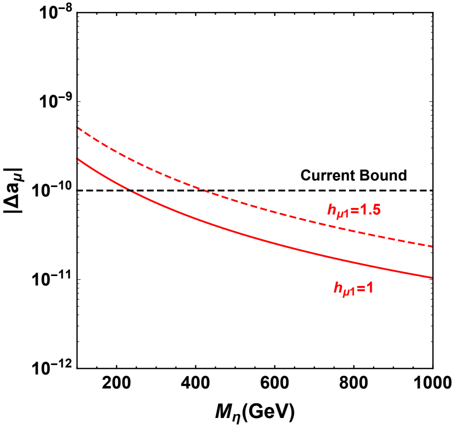


Figure: Predictions for $|\Delta a_\mu|$. In this figures, we have fix $M_{N_1} = 200$ GeV.

Dark Matter

In general annihilation channels $N_1 N_1 \to \ell^+\ell^-, \bar{\nu}\nu$ are tightly constrained by non-observation of LFV, especially $\mu \to e\gamma$.
The annihilation cross section

$$\sigma v_{\rm rel} = \sum_{\alpha,\beta} \left| h'_{\alpha 1} h'^*_{\beta 1} + f'_{\alpha 1} f'^*_{\beta 1} \right|^2 \times \frac{r^2(1-2r+2r^2)}{24\pi M^2_{N_1}} v^2_{\rm rel}.$$

$\langle \sigma v_{\rm rel} \rangle = a + 6b/x_f$. Freeze-out parameter $x_f = M_{N_1}/T_f$

$$x_f = \ln \left(\frac{0.038 M_{\rm Pl} M_{N_1} \langle \sigma v_{\rm rel} \rangle}{\sqrt{g_* x_f}} \right)$$

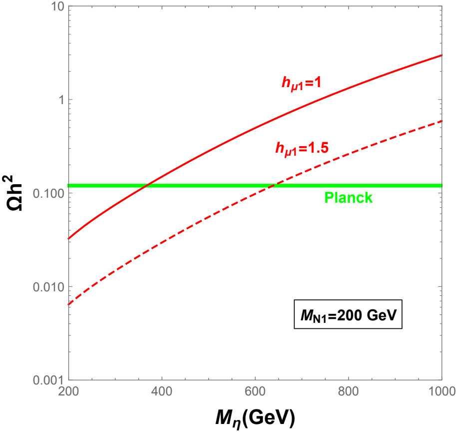


Figure: Predicted relic density as a function of m_η, where we have fix $M_{N_1} = 200$ GeV.

Dark Matter

The relic density

$$\Omega h^2 = \frac{1.07\times 10^9 \mathrm{GeV}^{-1}}{M_{\mathsf{Pl}}} \frac{x_f}{\sqrt{g_*}} \frac{1}{a+3b/x_f}, \tag{21}$$

The spin-independent DM-nucleon scattering cross section is dominantly mediated by scalars h, H_1

$$\sigma^{\mathsf{SI}} = \frac{4}{\pi}\left(\frac{M_p M_{N_1}}{M_p+M_{N_1}}\right)^2 f_p^2, \tag{22}$$

where M_p is the proton mass and the hadronic matrix element f_p

$$\frac{f_p}{M_p} = \sum_{q=u,d,s} f_{Tq}^p \frac{\alpha_q}{M_q} + \frac{2}{27}\left(1-\sum_{q=u,d,s} f_{Tq}^p\right)\sum_{q=c,b,t}\frac{\alpha_q}{M_q}. \tag{23}$$

Dark Matter

The effective vertex

$$\frac{\alpha_q}{M_q} = -\frac{y_{N_1}}{\sqrt{2}v} \sin 2\alpha \left(\frac{1}{M_h^2} - \frac{1}{M_{H_1}^2} \right),$$

the parameters f_{Tq}^p are evaluated as $f_{Tu}^p = 0.020 \pm 0.004$, $f_{Td}^p = 0.026 \pm 0.005$ and $f_{Ts}^p = 0.118 \pm 0.062$.
We have set $M_{H_1} = 500$ GeV and $v_S = 10$ TeV.

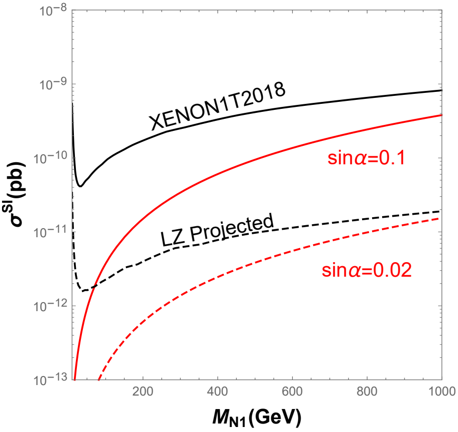


Figure: Spin-independent cross section as a function of M_{N_1}. The black solid and dashed line correspond to current XENON1T and future LZ limits.

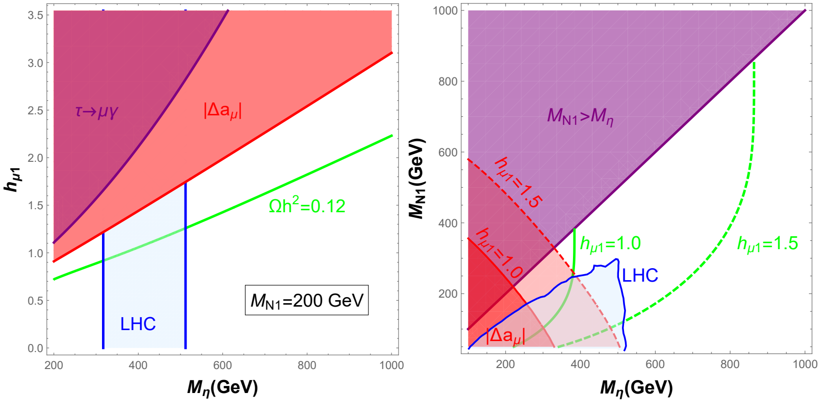


Figure: Combined results for the Yukawa-portal DM.

LHC constraint comes from $pp \to \ell^+\ell^- + \not{E}_T$.

Collider Signature

•The gauge boson Z' associated with $U(1)_{B-2L_e-L_\tau}$
Considering the heavy Z' limit, its partial decay width into fermion and scalar pairs are given by

$$\Gamma(Z' \to f\bar{f}) = \frac{M_{Z'}}{24\pi} g'^2 N_C^f (Q_{fL}^2 + Q_{fR}^2), \quad (24)$$

$$\Gamma(Z' \to SS^*) = \frac{M_{Z'}}{48\pi} g'^2 Q_S^2, \quad (25)$$

$q\bar{q}$	e^+e^-	$\mu^+\mu^-$	$\tau^+\tau^-$	$\nu\nu$	NN	H_1H_1
0.154	0.308	0	0.077	0.192	0.192	0.077

Table: Decay branching ratio of $U(1)_{B-2L_e-L_\tau}$ gauge boson Z', where we have show the lepton flavor individually.

$$\text{BR}(Z' \to b\bar{b}) : \text{BR}(Z' \to e^+e^-) : \text{BR}(Z' \to \mu^+\mu^-) : \text{BR}(Z' \to \tau^+\tau^-) = \frac{1}{3} : 4 : 0 : 1$$

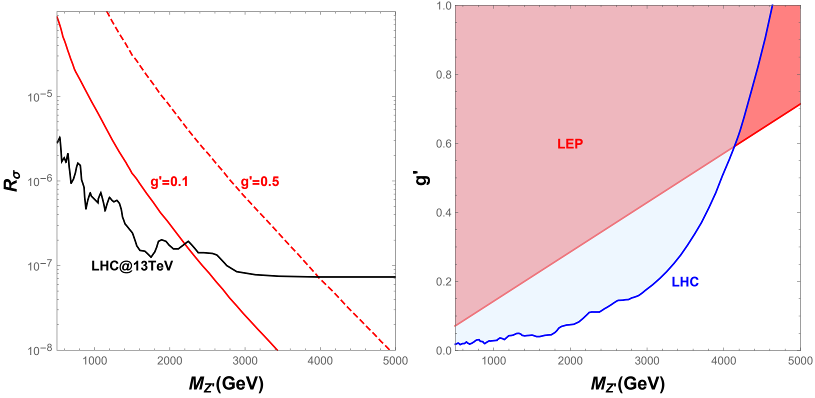


Figure: Left pattern: predicted cross section ratios in $U(1)_{B-2L_e-L_\tau}$ and corresponding limit from LHC. Right pattern: allowed parameter space in the g'-$M_{Z'}$ plane.

$$R_\sigma = \frac{\sigma(pp \to Z' + X \to e^+e^- + X)}{\sigma(pp \to Z + X \to e^+e^- + X)}. \tag{26}$$

Summary

• Texture-zeros in the scotogenic model can be realised with flavor dependent gauge symmetry.

$$U(1)_{B-2L_\alpha-L_\beta},\, U(1)_{L_\mu-L_\tau},\, U(1)_{B-3L_\alpha}$$

- Texture A_1 for $U(1)_{B-2L_e-L_\tau}$
  - $\langle m_{ee}\rangle = 0$, no neutrinoless double beta decay
  - $m_1 \sim 0.007$ eV, $m_2 \sim 0.01$ eV, $m_3 \approx\sim 0.05$ eV, then $\sum m_i \sim 0.07$ eV
  - Yukawa couplings are also predicted by neutrino oscillation

$$\frac{h_{\tau 2}}{h_{\mu 1}} : \frac{f_{\tau 1}}{h_{\mu 1}} : \frac{f_{e2}}{h_{\mu 1}} \simeq 0.745 : 0.933 : 0.401.$$

  - No $\mu \to e\gamma$, $\tau \to \mu(e)\gamma$ are suppressed.
  - Flavor dependent Z'

$$\text{BR}(Z' \to b\bar{b}) : \text{BR}(Z' \to e^+e^-) : \text{BR}(Z' \to \mu^+\mu^-) : \text{BR}(Z' \to \tau^+\tau^-) = \frac{1}{3} : 4 : 0 : 1$$