A Portalino to Twin Sector – Cosmological and Flavor Physics

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arXiv:1905.00861

July 30, 2019

THM and Cosmic Problem

- Discrete Z_2 symmetry: $SM \leftrightarrow Twin$
- Applying to Higgs sector, Z_2 turns out to be approximately global $SU(4) : \mathcal{H} = (H_A, H_B)^T$

$$\langle \mathcal{H} \rangle = \begin{pmatrix} 0 \\ 0 \\ 0 \\ f \end{pmatrix}, \; f \sim 1 \text{ TeV}.$$

One of the pNGB is identified as phyiscal Higgs boson.

Naturalness w/. $\Delta N_{eff} \approx 5.6$

Cosmic observation: $\Delta N_{eff} < 0.3$ (95% C.L. Planck 2018)

Strategy

Might be resolved if,

- The Z_2 symmetry is somehow spontaneously broken.
- Twin mass spectrum is then lifted.
- Return twin entropy to us via portal.

SSB & Lift Twin Fermions

To be specific:
$[U(1)_Y]_A$: ϕ and $[U(1)_Y]_B$: Φ

$$\boxed{V = -m_\phi^2(|\phi|^2 + |\Phi|^2) + \lambda_\phi(|\phi|^4 + |\Phi|^4) + \kappa_\phi|\phi|^2|\Phi|^2}$$

- Z_2 SSB via $\langle\phi\rangle = 0$ and $\langle\Phi\rangle = v_\phi \sim$ few TeV.
- Twin photon (Γ) becomes massive.
- $Y_{\phi_3}\Phi L_1 \circ L_2$ and $Y_{E_{ii}}\Phi^\dagger E^c_{R_i} N_i$, $i = 1, 2, 3$ lift twin lepton masses.
- $N_i \leftrightarrow N_i$ under Z_2.

Neutrino Portal

$N_{1,2,3}$: RH neutrinos (portalino) , i.e. $(\ell_i H_A + L_i H_B) Y_{\nu_{ij}} N_j$

- One combination of ν_i and E_{R_i} is massive which turns out to be the Dirac partner of N_i and its orthogonal counterpart remains massless at tree level which is identified as physical SM neutrino.
- Integrate out heavy fermions: E_{R_3} and N_3. E_{L_3} and $\hat{\nu}_{L_3}$ are seesawed and share Dirac mass $M_{\hat{\nu}_\tau} \sim y_\tau Y_{\nu_3} f^2 / v_\phi \approx 0.1$ GeV (lighest twin state)
- Sizable tau-neutrino mixing, $U_{\nu_\tau \hat{\nu}_\tau} \equiv \sin(\alpha_3) \sim v_h / f \approx 0.17$

$$\boxed{\Gamma(\hat{\nu}_\tau \to 3\nu_{\text{SM}}) \simeq \frac{\sin^2(2\alpha_3)}{9 \times 10^{-6}\text{sec}}}$$

Entropy returned!

Mass Spectrum (Schematical)

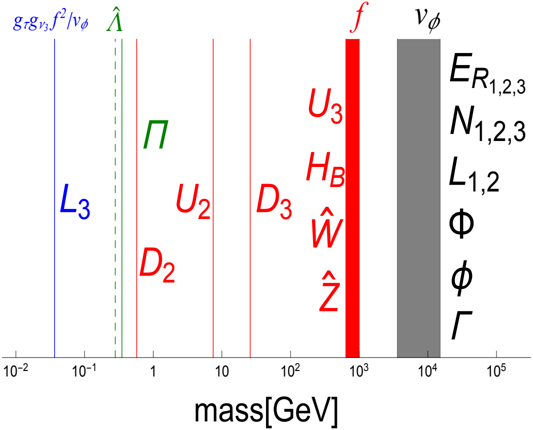


Figure: mass spectrum of the weak solution

But this is not the complete solution ...

ν_τ Mixing Angle

$$U_{\nu_\tau n} = v_h/f \approx 0.17, \; M_{\hat{\nu}_\tau} \approx 0.1 \text{ GeV}$$

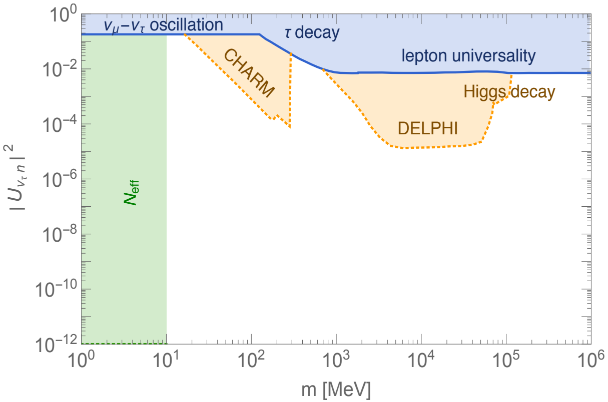


Figure: Experimental limit on $U_{\tau n}$

M. Schmaltz, N. Weiner arXiv: 1709.09164

ν_τ Mixing Angle

Extend the model by introducing another pair of HD (σ, Σ), and couple to leptons. In the twin sector, $\Sigma^\dagger L_3 E^c_{R_3}$ and $\Sigma L_3 N_3$ extra mass terms are provided if $\Sigma = \begin{pmatrix} \gamma \\ \theta \end{pmatrix} f$ and will reduce the tau-neutrino mixing angle with an additional factor,

$$\boxed{U_{\nu_\tau n} = \frac{\mu_\sigma^2}{m_\sigma v_\phi} \frac{v_h}{f}}$$

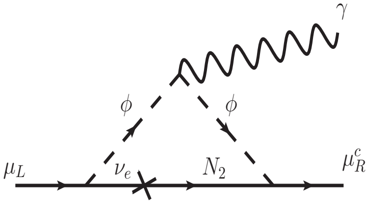
New HD get VEVs from potential:
$M_\Sigma^2 |\Sigma|^2 - \mu_\sigma^2 H_B^\dagger \Sigma + m_\sigma \Phi^\dagger H_B \Sigma + Z_2$.

Constraints and Signals

- Uncertanty of G_F measured from muon deccay allows $Y_{\phi_3} < 0.57 M_\phi/\mathrm{TeV}$.
- LFV decay. $\mathrm{BR}(\mu \to e\gamma) \propto Y_{\nu_{11}}^2 Y_{E_{11}}^2 + Y_{\nu_{22}}^2 Y_{E_{22}}^2$ requires $|Y_{\phi_3} Y_{\nu_{aa}} Y_{E_{aa}}| < 4.5 \times 10^{-7} (M_\phi/TeV)^2$ for $R_\mu^{e\gamma} < 4 \times 10^{-13}$.
- $g-2$ discrpancy: $a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} \simeq 287(80) \times 10^{-11}$. Can provide further information about the interactions between ϕ and leptons.

Anomalous Magnetic Dipole Moment

Without the advent of portalino, $\phi - \nu_e$ loop only generates negative AMDM, i.e. $\Delta a_\mu^\nu \propto -Y_{\phi_3}^2 m_\mu^2 / M_\phi^2$. In our model, Δa_μ could be either sign by virtue of the novel contribution,



$$\Delta a_\mu^N \simeq -\frac{Y_{\phi_3} Y_{\nu_{12}} Y_{E_{22}} v_h m_\mu}{16\pi^2 M_\phi^2}\ , \text{ for } M_\phi \gg M_{N_2}$$

Portalino signal may show up. While reproducing the sizable Δa_μ discrepancy, muon mass becomes logarithm sensitive to cutoff scale Λ which implies a UV complification is needed. For $\Lambda = 5$ TeV, $M_\phi = 600$ GeV, $Y_{\phi_3} = 0.15$ we have,

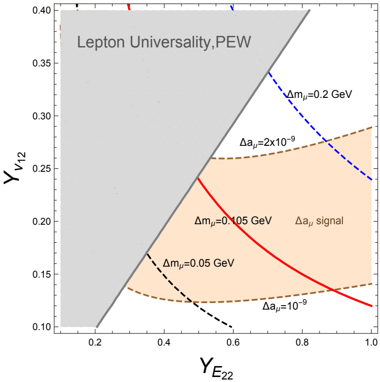


Figure: Muon mass radiative correction

Alternative Approach

The strong solution: twin $SU(3)_c$ is fully broken via QCD charged scalars, i.e. twin $\tilde{X} \in (\bar{3}, 1, 1/3)$, $X \in (3, 1, -1/3)$ and Z_2 partners $\tilde{x}$ and x

$$\langle \tilde{X} \rangle = \begin{pmatrix} 0 \\ 0 \\ v_{\tilde{X}} \end{pmatrix}, \quad \langle X \rangle = \begin{pmatrix} 0 \\ v_{X_2} \\ v_{X_3} \end{pmatrix}, \quad \langle \tilde{x} \rangle = \langle x \rangle = \vec{0}$$

The colored scalars are regarded as leptoquark and diquarks.

- LQ: $\tilde{X} L \circ Q$, $\tilde{X} U_R^c E_R^c$ and $\tilde{X}^\dagger D_R^c N$, $(\lambda_{1,2,3})$
- DQ: $XQ \circ Q$ and $X^\dagger U_R^c D_R^c$, $(\lambda_{4,5})$

Twin color breaks at 10 TeV and Yukawa couplings $\lambda_i \sim 0.01$.

Twin sector decouples around 100 GeV.

limited contrb. to ΔN_{eff} & satisfies SM counterparts constraints.

To obtain deisred VEVs of LQ and DQ,

- $[U(1)_{\rm bn}]_B$ broken by S; while $[U(1)_{\rm bn}]_A$ is reserved by s.

$$V \supset \lambda_s \left(|s|^2 + |S|^2 - v_s^2\right)^2 + \eta_s |s|^2 |S|^2$$

Baryon number Z_2 SSB:

$$\boxed{\langle S \rangle \simeq v_s, \langle s \rangle = 0}$$

- Twin QCD vacuum alignment, e.g.

$$\left(|\tilde{X}|^2 - \xi_s |S|^2\right)^2 + \left(|X|^2 - \xi_s |S|^2\right)^2 + \kappa_b \left| X\tilde{X} - \mu_b S \right|^2 + Z_2$$

Resulting VEVs

$$\boxed{v_{\tilde{X}} \simeq \sqrt{\xi_s} v_s \,, \quad v_{X_3} \simeq \sqrt{1/\xi_s} \mu_b \,, \quad v_{X_2} = \sqrt{v_{\tilde{X}}^2 - v_{X_3}^2} \,, \ \langle \tilde{x} \rangle = \langle x \rangle = 0}$$

SM proton is stable for unbroken baryon number.

Schematical Mass Spectrum

Notice that twin top gets mass mainly from twin Higggs.

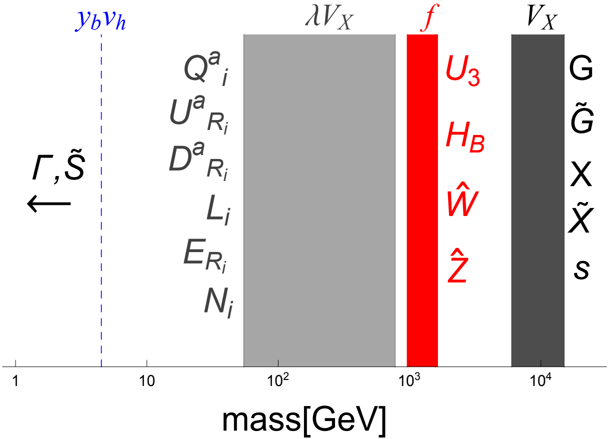


Figure: mass spectrum of the strong solution

Names	Σ	Φ	N_i
$[SU(2)_L \times U(1)_Y]_B$	$(2, +\frac{1}{2})$	$(1, 1)$	$(1, 0)$
Q_L	0	-2	-1

Table: Fields in the weak solution (sector B)

Names	$\tilde{X}$	X	S
$[SU(3)_c \times U(1)_Y]_B$	$(\bar{3}, \frac{1}{3})$	$(3, -\frac{1}{3})$	$(1, 0)$
$Q_{\mathrm{bn},B}$	$-\frac{1}{3}$	$-\frac{2}{3}$	-1
$Q_{\mathrm{bn},B} - Q_L$	$\frac{2}{3}$	$-\frac{2}{3}$	0

Table: new scalar fields for strong solution (sector B)

Thank you!

Backup

- dijet leptoquark (insensitive toλ_i; $M_{LQ} > 1.5$ TeV)
- dijet diquark narrow-width (large Yukawa, $M_{DQ} > 7.2$ TeV)
- 4-jet diquark (small Yukawa, $M_{DQ} > 400$ GeV)