

A Portalino to Twin Sector – Solutions to Cosmological Problem of THM

Di Liu and Neal Weiner

NYU CCPP

dl2522@nyu.edu

arXiv:1905.00861

May 7, 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 physical 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,

- Lift twin mass spectrum.
- Return twin entropy to us via portal.

Lift Twin Fermions

To be specific:

$[U(1)_Y]_A$: ϕ and $[U(1)_Y]_B$: Φ

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

- $\langle\phi\rangle = 0$ and $\langle\Phi\rangle = v_\phi \sim \text{few TeV} \Rightarrow$ massive twin photon (Γ)
- $Y_\phi\Phi L_1 \circ L_2$ and $Y_E\Phi^\dagger E_{R_i}^c N_i$, $i = 1, 2, 3$ lift twin lepton masses.
- $N_i \leftrightarrow N_i$ under Z_2

Y_ϕ is restrained from the SM counterpart $\phi\ell_1 \circ \ell_2$, e.g. muon decay requires $Y_\phi < 0.1m_\phi/\text{TeV}$.

Neutrino Portal

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

- Integrate out heavy fermions: E_{R3} and N_3 . E_{L3} and $\hat{\nu}_{L3}$ are seesawed and shares Dirac mass $M_{\hat{\nu}_\tau} \sim m_\tau Y_{\nu_3} f / v_\phi \approx 0.1$ GeV (lightest twin state)
- Sizable tau-neutrino mixing, $U_{\nu_\tau \hat{\nu}_\tau} \equiv \sin(\alpha_3) \sim v_h / f \approx 0.17$

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

Entropy returned!

Mass Spectrum (Schematical)

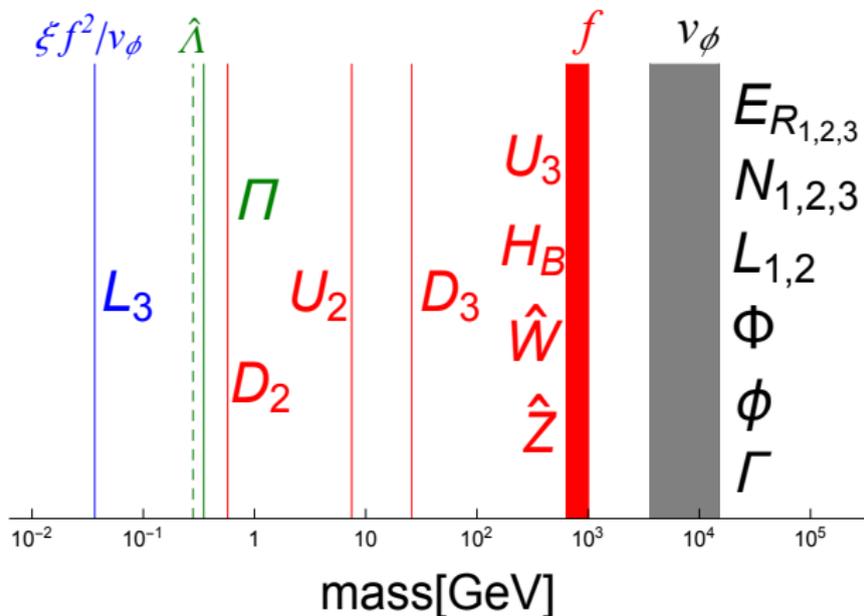


Figure: mass spectrum of the weak solution

ν_τ Mixing Angle

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

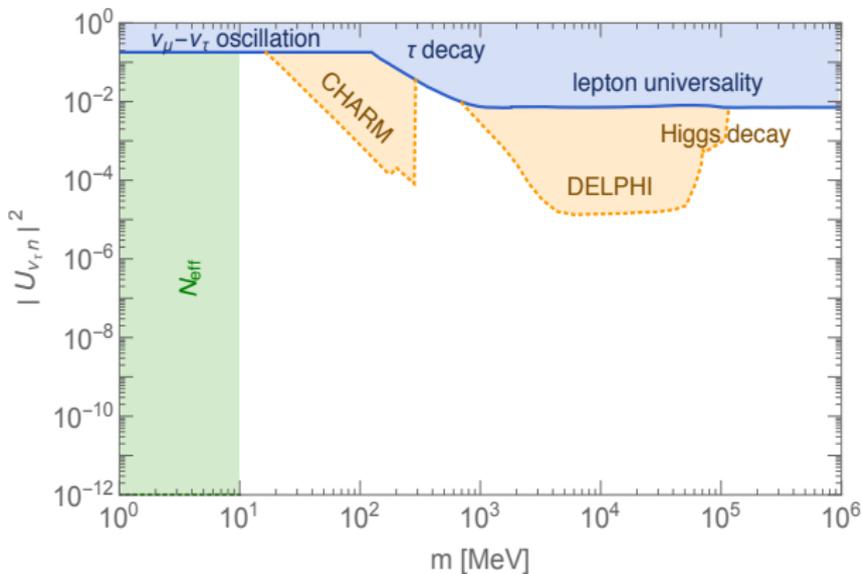


Figure: Experimental limit on $U_{\tau n}$

ν_τ Mixing Angle

Extend the model by introducing another pair of HD (σ, Σ), and couple to leptons. In the tau sector, $\Sigma^\dagger L_3 E_{R3}^c$ 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,

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

New HD get VEVs from potential:

$$M_\Sigma^2 |\Sigma|^2 - \mu_\sigma^2 H_B^\dagger \Sigma + m_\sigma \Phi^\dagger H_B \Sigma + Z_2.$$

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 desired VEVs of LQ and DQ,

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

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

Baryon number Z_2 SSB:

$$\langle S \rangle \simeq v_s, \langle s \rangle = 0$$

- 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

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

SM proton is stable for unbroken baryon number.

Schematical Mass Spectrum

Notice that twin top gets mass mainly from twin Higgs.

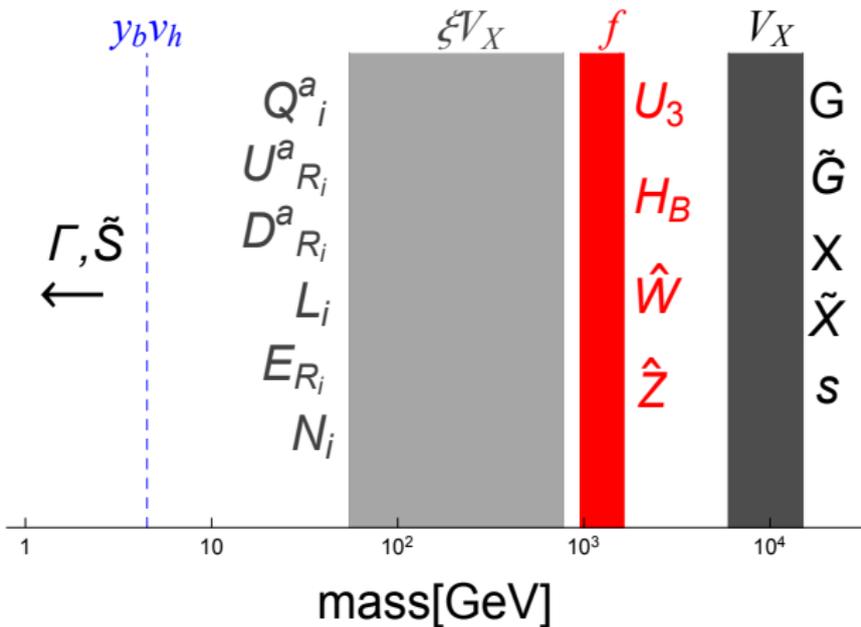


Figure: mass spectrum of the strong solution

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

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

Thank you!

Backup

- dijet leptoquark (insensitive to λ_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)