Technicolor Assisted Leptogenesis with and Ultra-Heavy Higgs Doublet

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Introduction

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- Specifically, the hierarchy between the weak scale and potentially large scales of new physics can be alleviated by a dynamical EWSB mechanism based of the condensation of new fermion pairs.

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- Although the SM can accommodate the relevant phenomenology, Nature may realize EWSB in a more complicated manner.
- For example, different sectors may be responsible for the masses of the gauge bosons and fermions.
- Specifically, the hierarchy between the weak scale and potentially large scales of new physics can be alleviated by a dynamical EWSB mechanism based of the condensation of new fermion pairs.
- Although the $W^{\pm}$ and Z masses can be easily generated, fermion masses are a challenge in these models.
- One possible solution is the hybrid proposal Bosonic Technicolor.

Bosonic Technicolor

- The SM fermions obtain their masses via Yukawa couplings to a Higgs doublet, Φ

$$V_\Phi = m_\Phi^2 \Phi^\dagger \Phi - \lambda_\psi \Phi \bar{\Psi}_L \psi_R - \lambda_f \Phi \bar{F}_L f_R + \dots ,$$

    - ψ are technifermions, F, f are SM fermions.
    - L denote $SU(2)_L$ doublets, and R $SU(2)_L$ singlets.
- Upon condensation $\langle \bar{\Psi}_L \psi_R \rangle \neq 0$, a vev $\langle \Phi \rangle \neq 0$ is induced:

$$\langle \Phi \rangle = \lambda_\psi \frac{\langle \bar{\Psi}_L \psi_R \rangle}{m_\Phi^2}$$

    - $\langle \bar{\Psi}_L \psi_R \rangle \approx 4\pi f_{TC}^3$ and $\langle \Phi \rangle^2 + f_{TC}^2 \approx (246\ \mathrm{GeV})^2$

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- For $\mathcal{O}(1)$ parameters, $m_t \simeq 172$ GeV needs m_Φ to be a few hundred GeV to a TeV.
- For a somewhat heaver Higgs field $\langle \Phi \rangle \ll m_W$, and small Yukawa couplings are not needed to accommodate the light fermions.

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- If we treat the Higgs as a fundamental particle, we expect its mass to be quite large due to quadratic quantum corrections.
- For $m_\nu \sim 0.1$ eV and $\mathcal{O}(1)$ couplings, we need $\langle H \rangle \sim 0.1$ eV.
- Introduce interactions as before:

$$V_H = m_H^2 H^\dagger H - \lambda_\chi H \bar{X}_L \chi_R - \lambda_\nu H^* \bar{L} \nu_R + \ldots$$

  - X_L,χ_R are $SU(2)_L$ doublet and singlet technifermions.
- Now $\langle H \rangle = \lambda_\psi \dfrac{\langle \bar{\Psi}_L \psi_R \rangle}{m_H^2} \sim 0.1\ \mathrm{eV}$
- For $\langle \bar{X}_L \chi_R \rangle \sim (100\ \mathrm{GeV})^3$ and order on couplings, we find $m_H \sim 10^8$ GeV.

Leptogenesis

- This scenario is analogous to the standard seesaw mechanism: small (Dirac) neutrino masses are generated via the splitting between the fundamental Higgs and EW scales.
- Extend analogy to Leptogenesis: generate $B-L$ charge through

$$H \to X_L \bar{\chi}_R \text{ and } H \to \bar{L} \nu_R$$

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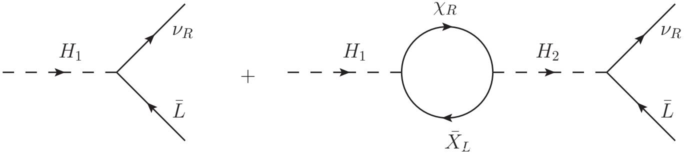
- Introduce H_2 with $m_2 > m_1$ to create asymmetry via CP violating decays:

$$V_H = m_a^2 H_a^\dagger H_a - \lambda^a_{\chi^D} H_a \bar{X}_L \chi_R^D - \lambda^a_{\chi^U} H_a^* \bar{X}_L \chi_R^U - \lambda^a_\nu H_a^* \bar{L} \nu_R + \dots$$

  - $a = 1, 2$



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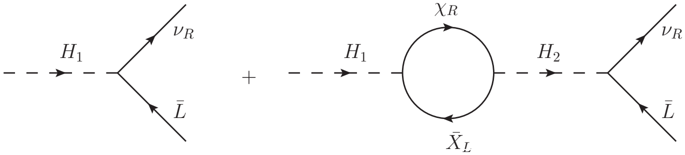

- Calculate Lepton asymmetry:

$$\varepsilon \equiv \frac{\Gamma(H_1 \to \bar{L}\nu_R) - \Gamma(H_1^* \to L\bar{\nu}_R)}{2\Gamma(H_1)}$$

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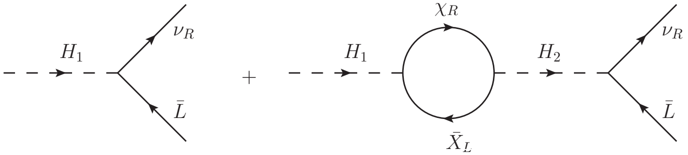

- Calculate Lepton asymmetry:

$$\begin{aligned}\varepsilon &\equiv \frac{\Gamma(H_1 \to \bar{L}\nu_R) - \Gamma(H_1^* \to L\bar{\nu}_R)}{2\Gamma(H_1)} \\ &\simeq \frac{N_{TC}}{8\pi}\frac{m_1^2}{m_2^2 - m_1^2}\frac{\sum_i \mathrm{Im}\left[\left(\lambda^{1*}_{\chi^D}\lambda^{2}_{\chi^D} + \lambda^{1}_{\chi^U}\lambda^{2*}_{\chi^U}\right)\lambda^{1}_{\nu_i}\lambda^{2*}_{\nu_i}\right]}{N_{TC}(|\lambda^1_{\chi^D}|^2 + |\lambda^1_{\chi^U}|^2) + \sum_i |\lambda^1_{\nu_i}|^2}\end{aligned}$$

- Can easily generate $\varepsilon \sim 10^{-2}$ with reasonable assumptions.

Baryon Number Asymmetry

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- Universe reheated via inflaton and H_1 decays.
- We find that for a $T_{\rm RH} \lesssim 5 \times 10^4$ GeV, the processes that could wash-out the asymmetry are decoupled.
- Since H_1 decays contribute to reheating, to maintain $T_{\rm RH} \ll m_1$ we must have $r = \dfrac{n_1 m_1}{g_* T_{RH}^4} \ll 1$
- Estimate H_1 abundance: $Y_1 = \dfrac{T_{\rm RH}}{m_1} r$

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- Estimate H_1 abundance: $Y_1 = \dfrac{T_{\rm RH}}{m_1} r$
- Assuming $T_{\rm RH} > T_c \gtrsim 100$ GeV, EW sphalerons will process the left handed lepton asymmetry into a baryon asymmetry.

Baryon Number Asymmetry

- For a minimal technicolor sector, i.e., $N_{TC} = 2$, a one generation each (X_L, χ_R) and (Ψ_L, ψ_R), and one EW scale Higgs doublet, the solution of the equilibrium equations gives the baryon number:

$$B = \frac{13}{67}(B-L) = -\frac{13}{67} L_{init}$$

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- Calculate BAU: $\eta \sim \frac{13}{67}\varepsilon Y_1 \sim 10^{-8}$
  - for typical values $r \sim 0.1$, $T_{\rm RH} \sim 10^4$ GeV, $m_1 \sim 10^8$ GeV, and $\varepsilon \sim 10^{-2}$
- Baryon number asymmetry observed to be 9×10^{-11}.

Technifermion Number

- H_1 decays and sphalerons also generate a technifermion number

$$B_\psi = \frac{13}{201}(B - L)$$

- If we assume the lightest technibaryon $S = \Psi^u \psi^d$ is electrically neutral, and that the processes that violate technibaryon number are sufficiently suppressed, S could make a good DM candidate.
- Since $\frac{\Omega_{\rm DM}}{\Omega_{\rm B}} \approx 5$, the ratio of B_ψ to B implies a mass of $m_S \sim 15$ GeV would make make a good DM candidate.
- However, with $\langle \bar{\Psi}_L \psi_R \rangle \sim (100 \text{ GeV})^3$, we expect $m_S \sim 1$ TeV, implying a suppression of $\mathcal{O}(10^{-2})$ is needed.

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- Sphalerons typically lead to suppressions in the technibaryon number of

$$\left(\frac{m_S}{T_c}\right)^{3/2} e^{-m_S/T_c} \sim 10^{-2}$$

for $m_S \sim 1$ TeV and $T_c \sim 200$ GeV.

Technibaryon Violation

- Technibaryon number may be violated by higher dimension operators.
- In such a case, the decay of technibaryons into light SM particles can lead to an increase in entropy.
- If these decays occur during big bang nucleosynthesis, they can strongly perturb abundances of the light elements. Two possibilities:
  - Decay before BBN
  - Long-lived on cosmological times

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- Decay before BBN, $\tau_{TB} \ll 1$ sec:
  - If decay is mediated via a dimension 6 operator, then

$$\frac{m_S^5}{M^4} \gtrsim 10^{-24}\ \mathrm{GeV}$$

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- Long-lived scenario, $\tau_{TB} \gtrsim 10^{26}$ sec:
  - For $m_S \sim 1$ TeV the scale of new physics is $M \gtrsim 10^{16}$ GeV, near the GUT scale.

Signatures

- Although mechanism of neutrino mass out of reach of current experiments, this model still falsifiable.
- First, we generate Dirac neutrino masses. Any observation of neutrinoless double $\beta-$decay would rule out this model.
- Generically, technihadrons are expected to emerge at the TeV scale.
- The EW scalar has suppressed coupling to $W^{\pm}$ and Z. Hence, at the LHC the measured Higgs branching ratios should be altered.
- It has been shown in a model similar to ours, LEP and EWP data constrain the technibaryon masses to be above 2 TeV and $f_{\rm TC} \lesssim$ 100 GeV Carone, Primulando, arXiv:1003.4720. In this case the Higgs like scalar may have signatures similar to the SM.
- This neutrino mass generation mechanism does not depend on how the other fermions obtain their masses, it can be coupled with any viable TC model.

Conclusions

- We investigated the possibility of generating Dirac neutrino masses via dynamical EWSB coupled with and ultra-heavy Higgs doublet, $m \sim 10^8$ GeV.
- Adopting the bosonic technicolor framework, we showed that CP-violating decays of the heavy Higgs can provide a mechanism for leptogenesis.
- Typical parameter values easily yield the correct cosmological baryon number.
- If the lightest technibaryon is electrically neutral and stable, it is a possible asymmetric dark matter candidate.
- Our model predicts
  - TeV scale technibaryons.
  - An EW scale scalar similar to the SM-Higgs, but with altered interactions.
  - The absence of neutrinoless double $\beta-$decay.