Unification and Local Baryon Number

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P.Fileviez Pérez, SO, Phys.Lett B768 (2017), [arXiv:1612.07165]

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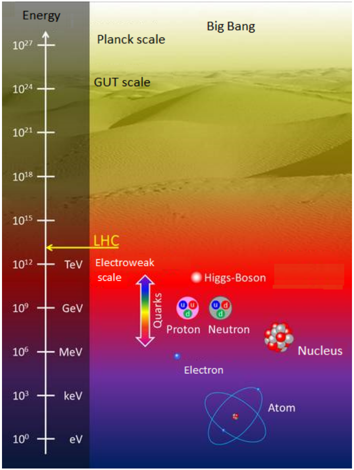
8. May 2017

Motivation

- Standard Model of Particle Physics

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$$



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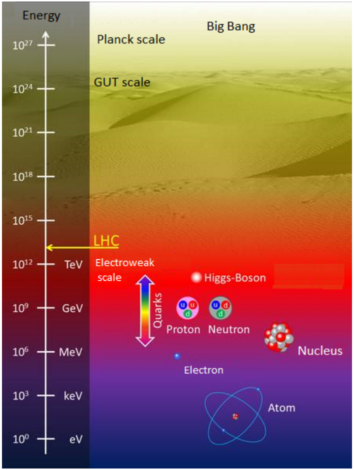

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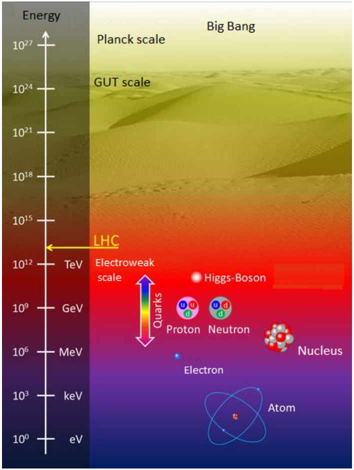
- Grand Unified Theories (GUTs)

Georgi, Glashow (1974)



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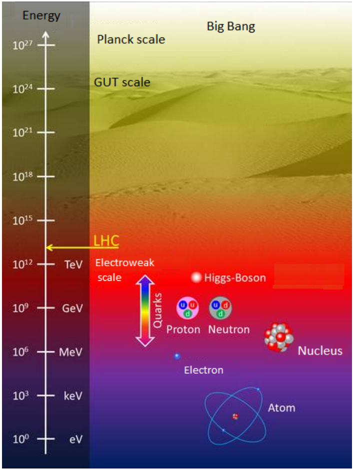

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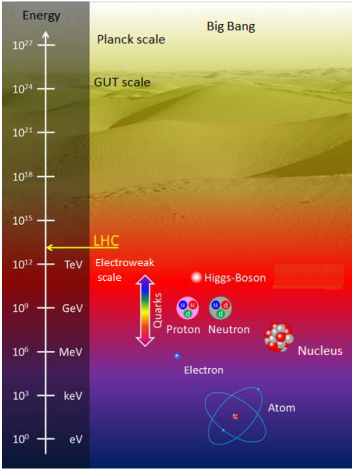
Untestable!



Gauging Baryon Number

How can we lower the GUT scale?

Gauging Baryon Number

Make the proton stable again!

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Make the proton stable again!

- Promote global symmetries to local symmetries

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_B$$

Fileviez Pérez, Wise (2010)

Gauging Baryon Number

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- Bottom-up approaches: Leptobaryons

Duerr, Fileviez Pérez, Wise (2013), Fileviez Pérez, SO, Patel (2014)

Gauging Baryon Number

Leptobaryons

- Proton decay suppressed

$$\frac{c_B}{\Lambda^{15}}(QQQL)^3 S_{\mathrm{B}}^*$$

- Inherently stable cold dark matter candidate
- Dark matter asymmetries linked to matter-antimatter asymmetry
- Predict leptophobic gauge boson Z_B
- Enable low scale unification

Gauging Baryon Number

Make the proton stable again!

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$\Rightarrow$ **Now: UV complete top-down approach**

$SU(4)_C \otimes SU(3)_L \otimes SU(3)_R$

- Partial Unification

$$SU(4)_C \otimes SU(3)_L \otimes SU(3)_R$$

- Standard Model fermions

$$Q \sim (4, \bar{3}, 1)\,, \quad Q^c \sim (\bar{4}, 1, 3)\,, \text{and} \quad L \sim (1, 3, \bar{3})$$

- Anomaly cancellation

$$\Psi^c \sim (1, 3, 1) \quad \text{and} \quad \eta \sim (1, 1, \bar{3})$$

$SU(4)_C \otimes SU(3)_L \otimes SU(3)_R$

- Partial Unification

Matrix Notation

- Standard Model fermions

$$Q = \begin{pmatrix} d_r & u_r & D_r \\ d_b & u_b & D_b \\ d_g & u_g & D_g \\ \Psi_d & \Psi_u & \Psi_D \end{pmatrix} \quad Q^c = \begin{pmatrix} d^c_{\bar{r}} & d^c_{\bar{b}} & d^c_{\bar{g}} & \eta^c_d \\ u^c_{\bar{r}} & u^c_{\bar{b}} & u^c_{\bar{g}} & \eta^c_u \\ D^c_{\bar{r}} & D^c_{\bar{b}} & D^c_{\bar{g}} & \eta^c_D \end{pmatrix} \quad L = \begin{pmatrix} N_1 & E^+ & \nu \\ E^- & N_2 & e^- \\ \nu^c & e^+ & N_3 \end{pmatrix}$$

- New fermions

$$\Psi^c = \begin{pmatrix} \Psi^c_d & \Psi^c_u & \Psi^c_D \end{pmatrix} \quad \text{and} \quad \eta = \begin{pmatrix} \eta_d \\ \eta_u \\ \eta_D \end{pmatrix}$$

Symmetry Breaking

- Idea: baryon number as fourth color

Fileviez Pérez, Wise (2013), Fornal, Rajaraman, Tait (2015)

$$SU(4)_C \to SU(3)_C \otimes U(1)_B$$

- Scalar sector

$$\Sigma \sim (15, 1, 1) \quad \text{with} \quad \langle \Sigma \rangle = v_C T_C^{15}$$
$$\phi \sim (4, 1, 1) \quad \text{with} \quad \langle \phi \rangle = (0, 0, 0, v_B/\sqrt{2})^T$$

- Masses new fermions

$$-\mathcal{L} \supset y_\Psi \phi^\dagger Q \Psi^c + y_\eta \phi Q^c \eta + h.c.$$
$$\Rightarrow \quad M_\Psi = y_\Psi \frac{v_B^*}{\sqrt{2}} \quad \text{and} \quad M_\eta = y_\eta \frac{v_B}{\sqrt{2}}$$

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$\Rightarrow$ **proton decay suppressed** $QQQL\Phi\Phi\phi^\dagger/\Lambda^5$

Trinification and Gauged Baryon Number

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$$SU(3)_C \otimes SU(3)_L \otimes SU(3)_R \otimes U(1)_B$$

- Symmetry breaking to Standard Model

$$\Phi_i \sim (1, 3, \bar{3}) \quad \text{with} \quad i = 1, 2, 3 \quad \Rightarrow \quad \Phi_i = \begin{pmatrix} \varphi^0_{1i} & \varphi^+_i & H^0_{Li} \\ \varphi^-_i & \varphi^0_{2i} & H^-_i \\ H^0_{Ri} & H^+_i & S^0_i \end{pmatrix}$$

- Standard Model masses

$$-\mathcal{L} \supset QQ^c\left(y_1\Phi_1 + y_2\Phi_2 + y_3\Phi_3\right) + \frac{1}{2}LL\left(k_1\Phi_1 + k_2\Phi_2 + k_3\Phi_3\right) + h.c.$$

Symmetry Breaking

$$\boxed{SU(4)_C \otimes SU(3)_L \otimes SU(3)_R}$$

$$\langle \Sigma \rangle \neq 0$$

$$\boxed{SU(3)_C \otimes SU(3)_L \otimes SU(3)_R \otimes U(1)_B}$$

$$\langle \Phi_{33} \rangle \neq 0$$

$$\boxed{SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \otimes U(1)_B}$$

$$\langle \Phi_{23} \rangle \neq 0$$

$$\boxed{SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_B}$$

Leptophobic Gauge Bosons

- $SU(4)_C$ gauge boson: $A_\mu = \begin{pmatrix} G_\mu & X_\mu/\sqrt{2} \\ X_\mu^*/\sqrt{2} & 0 \end{pmatrix} + Z_{B\mu} T_C^{15}$

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- Massless Standard Model gluons $G_\mu \sim (8, 1, 1)$
- Massive leptophobic gauge boson $X_\mu \sim (3, 1, 1)$

$$M_X^2 = \frac{2}{3} g_C^2 v_C^2 + \frac{1}{4} g_C^2 v_B^2 \quad \text{and} \quad X_\mu \to q\bar{\Psi}, \eta^c \overline{q^c}$$

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- Massive leptophobic gauge boson $Z_{B\mu} \sim (1,1,1)$

$$M_{Z_B} = g_B v_B \quad \text{and} \quad Z_B \to \bar{q}q, \bar{\Psi}\Psi, \overline{q^c}q^c, \overline{\eta^c}\eta^c$$

Cosmology

- Stable fractional charged fermions $\Psi, \Psi^c, \eta, \eta^c$

$$
\begin{gathered}
Q(\Psi_u) = +2/3\,, Q(\Psi_d) = Q(\Psi_D) = -1/3, \\
Q(\Psi^c_u) = -2/3\,, Q(\Psi^c_d) = Q(\Psi^c_D) = +1/3, \\
Q(\eta_u) = +2/3\,, Q(\eta_d) = Q(\eta_D) = -1/3, \\
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\end{gathered}
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Is this a problem for cosmology?

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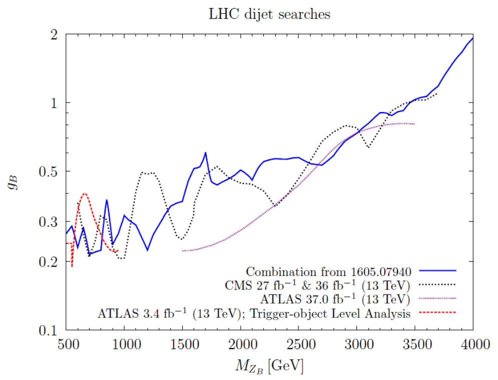
No! Reheating temperature below lightest stable exotic particle
$\Rightarrow$ Reheating temperature $\sim$ multi-TeV

433 @ Colliders

- Leptophobic gauge boson Z_B

Bounds leptophobic gauge boson Z_B



Duerr, Fileviez Pérez, Smirnov (2017)

433 @ Colliders

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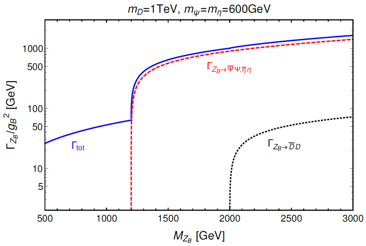
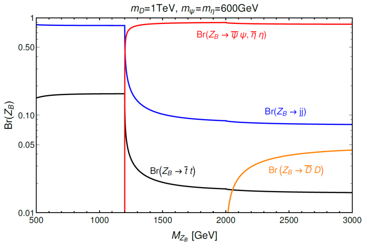
Properties leptophobic gauge boson Z_B

Decay Width Z_B



Branching Z_B



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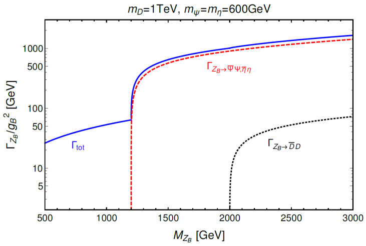

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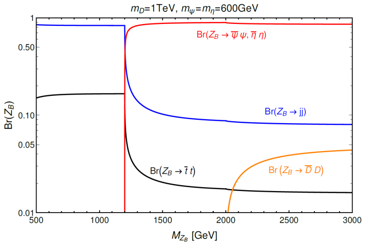

- Stable charged particles

$$pp \to \gamma^*, Z^*, Z_B^* \to \bar{\Psi}\Psi, \bar{\eta}\eta$$

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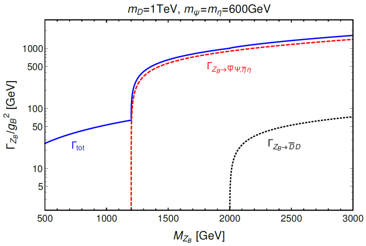

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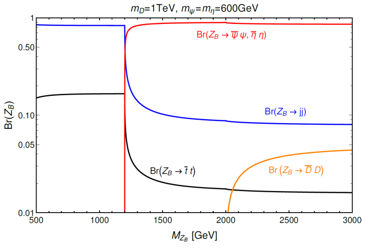

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$$pp \to \gamma^*, Z^*, Z_B^* \to \bar{\Psi}\Psi, \bar{\eta}\eta$$

- Stable colored particles $\Rightarrow$ R-hadrons

Conclusions

- UV completion of Standard Model at low scales

$$\Rightarrow \quad \text{proton decay suppressed} \quad QQQL\Phi\Phi\phi^\dagger/\Lambda^5$$

- Stable fractional charged and/or colored particles

$$\Rightarrow \quad \text{Reheating temperature multi-TeV regime}$$
$$\Rightarrow \quad \text{Exotic signatures at the LHC}$$