The Higgs and Leptophobic Force at the LHC

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With Pavel Fileviez Pérez (CWRU), Alexis Plascencia (CWRU), Clara Murgui (IFIC)
• This talk is based on

  • P. Fileviez Perez, EG, C. Murgui, and A. D. Plascencia, *The Higgs and Leptophobic Force at the LHC*, arXiv: 2003.09426
Main Goals

• Investigate novel decays of the Standard Model Higgs boson into leptophobic gauge bosons in a simple gauge theory at the low scale.

• Study the associated production of the SM Higgs and leptophobic gauge boson.

• We focus on $U(1)_B$ theory because it is the simplest gauge theory that can live at the low scale without assuming a very small gauge coupling.
Theory for Local Baryon Number: $U(1)_B$

- Gauge Group:

\[
SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_B
\]
\[
\downarrow \langle S_B \rangle \quad \text{New Higgs}
\]
\[
SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes \mathbb{Z}_2
\]
\[
\downarrow \langle H \rangle \quad \text{SM Higgs}
\]
\[
SU(3)_C \otimes U(1)_{EM} \otimes \mathbb{Z}_2
\]

- Anomaly free theory which predict proton stability.

- Cold dark matter candidate with mass defined by the symmetry breaking scale

- SSB at the low scale compatible with experimental bounds

P. Fileviez Perez and M. B. Wise, *Baryon and lepton number as local gauge symmetries*, Phys. Rev. D82 (2010) 011901
P. Fileviez Perez and M. B. Wise, *Breaking Local Baryon and Lepton Number at the TeV Scale*, JHEP 08 (2011) 068
M. Duerr, P. Fileviez Perez and M. B. Wise, *Gauge Theory for Baryon and Lepton Numbers with Leptoquarks*, Phys. Rev. Lett. 110, (2013) 231801
Leptophobic Gauge Boson at the LHC

• Simple extensions of the SM with Baryon number as a local symmetry predict the existence of a leptophobic gauge boson:

\[ Z_B \]

• Coupling between SM quarks and leptophobic gauge boson:

\[ Z_B^\mu \bar{q} q : -i \frac{g_B}{3} \gamma^\mu \]

• \( Z_B \)-Higgs Couplings:

\[ h Z_B^\mu Z_B^\nu : 2i \frac{M_{Z_B}^2}{v_B} g^{\mu\nu} \sin \theta_B \]
Leptophobic Gauge Boson at the LHC

\[ M_{Z^B} \] [GeV]

\[ \Gamma_{Z^B} \] [GeV]

\( g_B = 0.5 \)
\( g_B = 0.3 \)
\( g_B = 0.2 \)
\( g_B = 0.1 \)

\[ M_{Z^B} = 2m_t \]

LHC bounds

\[ \Gamma_{Z^B = 0.5} \]
\[ \Gamma_{Z^B = 2} \]
\[ \Gamma_{Z^B = 5} \]
\[ \Gamma_{Z^B = 10} \]

LHC bounds
Exotic Decays of the SM-like Higgs

\[ h \to Z_B Z_B \]

\[ h Z_B^\mu Z_B^\nu : 2i \frac{M^2_{Z_B}}{v_B} g^{\mu\nu} \sin \theta_B \]

\[ \Gamma_h = \cos^2 \theta_B \Gamma_{SM} + \Gamma_{BSM} \]
Exotic Decays of the SM-like Higgs

$g_B = 0.2 \quad \sin \theta_B = 0.05$

$g_B = 0.2 \quad \sin \theta_B = 0.1$

$BR(h \rightarrow BSM) \geq 0.34$

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Higgs-$Z_B$ Associated Production

\[ q \rightarrow q \bar{q} Z_B \]

\[ Z_B^* \rightarrow Z_B h \]

\[ \sigma(pp \rightarrow Z_B^* \rightarrow Z_B h) \]

\[ \sqrt{s} = 14 \text{ TeV} \]

\[ \theta_B = 0.3 \]

\[ \text{Br}(h \rightarrow Z_B Z_B) > 34\% \]

\[ M_{Z_B} \text{ [GeV]} \]

- $\sigma < 0.1$ fb
- $0.1 < \sigma < 1$ fb
- $1 < \sigma < 10$ fb
- $10 < \sigma < 100$ fb
- $\sigma > 100$ fb
\[ N_{\text{events}}(\bar{x}\bar{y}y) = \mathcal{L} \times \sigma(p p \to Z_B^* \to Z_B h) \times \text{Br}(h \to \bar{x}\bar{y}) \times \text{Br}(Z_B \to \bar{y}y) \]

\[ pp \to Z_B h \to j j \bar{b} \bar{b} \]

\[ \sqrt{s} = 14 \text{ TeV} \]

\[ \theta_B = 0.3 \]

\[ L = 3 \text{ ab}^{-1} \]

- \( N_{\text{events}} > 10^5 \)
- \( 10^4 < N_{\text{events}} < 10^5 \)
- \( 10^3 < N_{\text{events}} < 10^4 \)
- \( 10^2 < N_{\text{events}} < 10^3 \)
- \( 10 < N_{\text{events}} < 10^2 \)
- \( N_{\text{events}} < 10 \)
Higgs-$Z_B$ Associated Production

$pp \rightarrow Z_B h \rightarrow jj\gamma\gamma$

$pp \rightarrow Z_B h \rightarrow b\bar{b}b\bar{b}$

$pp \rightarrow Z_B h \rightarrow t\bar{t}b\bar{b}$

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Summary

• The SM Higgs boson can open a doorway to new physics and the chance to discover a new sector through the existence of new interactions.

• Higgs decays can have a large branching ratios into leptophobic gauge bosons.

• Associated Higgs-Leptophobic gauge boson production mechanisms may result in the large number of events allowed at the LHC.

• The leptophobic gauge boson may exist at the low scale, and it is possible to have a simple gauge theory where baryon number is a local gauge symmetry describing physics below the TeV scale.
Thank you!
Higgs-Leptophobic Gauge Boson Associated Production

\[ g_B = 0.2 \]
\[ \sqrt{s} = 14 \text{ TeV} \]

\[ pp \rightarrow Z_B W^\pm \]
\[ pp \rightarrow Z_B Z \]
\[ pp \rightarrow Z_B \rightarrow jj \]
\[ pp \rightarrow Z_B Z_B \]
\[ pp \rightarrow Z_B \rightarrow t\bar{t} \]
\[ pp \rightarrow Z_B q \]
\[ pp \rightarrow Z_B g \]
\[ pp \rightarrow Z_B \gamma \]

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arXiv: 2003.09426
• **Baryonic anomalies:**

\[ A_1(SU(3)^2 \otimes U(1)_B) \]
\[ A_2(SU(2)^2 \otimes U(1)_B) \]
\[ A_3(U(1)_Y^2 \otimes U(1)_B) \]
\[ A_4(U(1)_Y \otimes U(1)_B^2) \]
\[ A_5(U(1)_B) \]
\[ A_6(U(1)_B^3) \]

\[ A_2^{\text{SM}} = -A_3^{\text{SM}} = 3/2 \neq 0 \]

• **Nonzero anomalies require additional particle content.**

P. Fileviez Perez, *New Paradigm for Baryon and Lepton Number Violation*, Phys. Rept. 597 (2015) 1-30
Decay Widths: Higgs Boson

\[ \Gamma(h \rightarrow Z_BZ_B) = \frac{G_F M_h^3 \sin^2 \theta_W}{16\sqrt{2}\pi} \sqrt{1 - 4x} \left( 1 - 4x + 12x^2 \right) \]

\[ \Gamma(h \rightarrow Z_Bq\bar{q}) = \frac{1}{(2\pi)^3} \frac{1}{32M_h^3} \int_{p_{12}^{\text{min}}}^{p_{12}^{\text{max}}} dp_{12} \int_{p_{23}^{\text{min}}}^{p_{23}^{\text{max}}} dp_{23} \left| \overline{A}(h \rightarrow q\bar{q}Z_B) \right|^2 \]

\[ \left| \overline{A}(h \rightarrow q\bar{q}Z_B) \right|^2 = \frac{8 g_B^2}{3 v_B^2} \frac{M_{Z_B}^4 \sin^2 \theta_W}{\left( (p_{23} - M_{Z_B}^2)^2 + M_{Z_B}^2 \Gamma_{Z_B}^2 \right)} \times \left( p_{23} + \frac{(p_{12} - M_{Z_B}^2)(M_h^2 - p_{12} - p_{23})}{M_{Z_B}^2} \right) \]

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\[ \mathcal{L} \supset -\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{2} \text{Tr} \ W_{\mu\nu} W^{\mu\nu} - \frac{1}{4} B'_{\mu\nu} B'^{\mu\nu} - \frac{\sin \epsilon}{2} B_{\mu\nu} B'^{\mu\nu} \]

\[ + \frac{1}{8} (g_2 W_{3\mu} - g_1 B_\mu) (g_2 W_3^{\mu} - g_1 B^\mu) \nu_0^2 + \frac{1}{2} \mu_B^2 B'_\mu B'^{\mu} \]

\[ - \sum_i \bar{\psi}_i \gamma^\mu \left[ g_1 (Y_L^i P_L + Y_R^i P_R) B_\mu + g_2 P_L T^a W_{a\mu} \right] \psi_i + g_B \sum_i \bar{\psi}_i \gamma^\mu Q_B \psi_i B'_\mu \]