Dark Matter and Gauged Baryon Number

Sebastian Ohmer

Collaborators: Pavel Fileviez Pérez and Hiren H. Patel

P. Fileviez Pérez, SO, H. H. Patel, Phys.Lett.B735(2014)[arXiv:1403.8029]
P.Fileviez Pérez, SO, Phys.Rev.D90(2014) [arXiv:1405.1199]

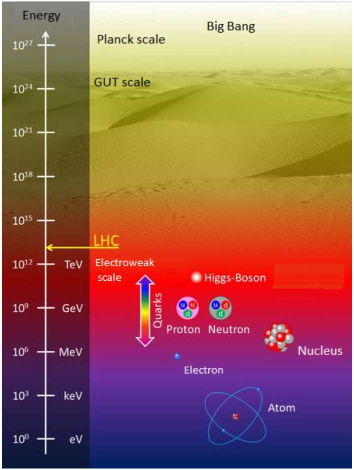
SO, H. H. Patel, [arXiv:1506.00954]

MPIK Heidelberg

12. June 2015

Motivation

- Baryon and lepton number classical symmetries in standard model



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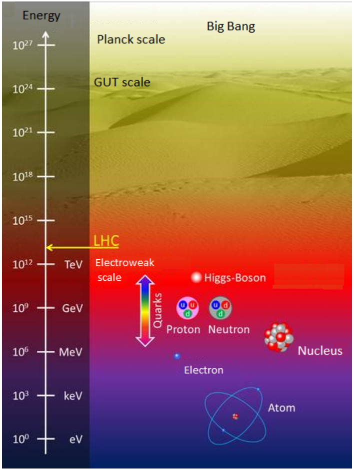

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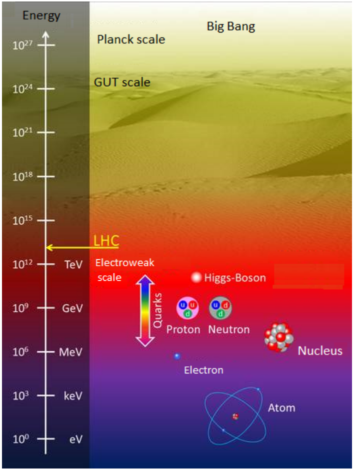
- Great desert $M_{\text{GUT}} \gtrsim 10^{14-16}$ GeV



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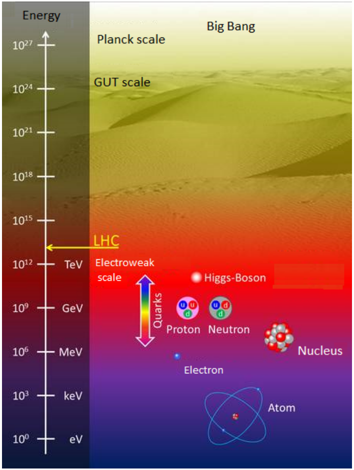
Low scale unification possible!

P.Fileviez Pérez, SO, Phys.Rev.D90(2014)



Gauging Baryon and Lepton Number

- Promote global symmetries to local symmetries

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

P.Fileviez Pérez, M.B.Wise, Phys.Rev.D82(2010) [arXiv:1002.1754]

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- Theory with right-handed neutrinos not anomaly-free

$$\mathcal{A}_1^{SM}(SU(2)_L^2 \otimes U(1)_B) = 3/2, \quad \mathcal{A}_2^{SM}(U(1)_Y^2 \otimes U(1)_B) = -3/2$$
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- Minimal number of new fermionic degrees of freedom: 8

Leptobaryons $\sim (SU(2)_L,\ U(1)_Y,\ U(1)_B,\ U(1)_\ell)$

Leptobaryon model VA

M. Duerr, P. Fileviez Pérez, M. B. Wise
Phys.Rev.Lett.110(2013)

[arXiv:1304.0576]

$$\begin{aligned}
\Psi_L &\sim (2,\ \pm 1/2,\ -3/2,\ -3/2)\,,\\
\Psi_R &\sim (2,\ \pm 1/2,\ 3/2,\ 3/2)\,,\\
\eta_L &\sim (1,\ \pm 1,\ 3/2,\ 3/2)\,,\\
\eta_R &\sim (1,\ \pm 1,\ -3/2,\ -3/2)\,,\\
\chi_L &\sim (1,\ 0,\ 3/2,\ 3/2)\,,\\
\chi_R &\sim (1,\ 0,\ -3/2,\ -3/2)
\end{aligned}$$

Leptobaryon model A

P. Fileviez Pérez, SO, H. H. Patel
Phys.Lett.B735(2014)

[arXiv:1403.8029]

$$\begin{aligned}
\Psi_L &\sim (2,\ 1/2,\ 3/2,\ 3/2)\,,\\
\Psi_R &\sim (2,\ 1/2,\ -3/2,\ -3/2)\,,\\
\Sigma_L &\sim (3,\ 0,\ -3/2,\ -3/2)\,,\\
\chi_L &\sim (1,\ 0,\ -3/2,\ -3/2)
\end{aligned}$$

Introducing Leptobaryons

- New fermions with baryon and lepton number are introduced

$\Psi_L \sim (2, 1/2, 3/2, 3/2)$ $\Psi_R \sim (2, 1/2, -3/2, -3/2)$

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- Two new scalars needed to break $U(1)_B \times U(1)_L$

$$S_\mathrm{B} \sim (1, 0, 3, 3) \quad \text{and} \quad S_\mathrm{L} \sim (1, 0, 0, 2)$$

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$$S_\mathrm{B} \sim (1, 0, 3, 3) \quad \text{and} \quad S_\mathrm{L} \sim (1, 0, 0, 2)$$

- Here, $v_\mathrm{L} \gg v_\mathrm{B} \Rightarrow$ neglect $U(1)_L$

Stability of the proton

Gauging baryon number $\rightarrow$ proton stable
$\Rightarrow$ breaking $U(1)_B$ $\rightarrow$ proton unstable

Is the proton unstable after breaking $U(1)_B$?

Stability of the proton

Gauging baryon number $\rightarrow$ proton stable
$\Rightarrow$ breaking $U(1)_B \rightarrow$ proton unstable

- Only $\Delta B = \pm 3$ interactions
- Possible higher order operator that is allowed mediating proton decay

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

- Breaking $U(1)_B$ at low scales consistent with measured proton lifetime

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No desert is needed!

Leptobaryons as Dark Matter

$$\mathcal{L} = \boxed{-y_\Psi \bar{\Psi}_R \Psi_L S_\mathrm{B}^* - y_\chi \chi_L \chi_L S_\mathrm{B} - y_\Sigma \mathrm{Tr} \Sigma_L^2 S_\mathrm{B}}$$

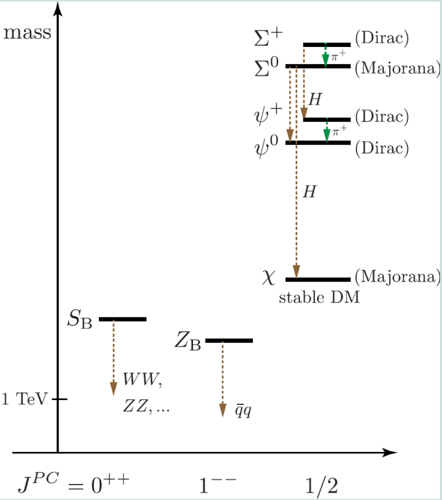
Leptobaryons as Dark Matter

$$\mathcal{L} = -y_\Psi \bar{\Psi}_R \Psi_L S_B^* - y_\chi \chi_L \chi_L S_B - y_\Sigma \mathrm{Tr}\Sigma_L^2 S_B$$

$$-\lambda_1 \bar{\Psi}_R H \chi_L - \lambda_2 H^\dagger \Psi_L \chi_L - \lambda_3 H^\dagger \Sigma_L \Psi_L - \lambda_4 \bar{\Psi}_R \Sigma_L H + \text{h.c.}\,,$$

Leptobaryon...

Leptobaryon Spectrum



$\mathcal{L} = - y_\Psi \bar{\Psi} \ldots$

$- \lambda_1 \bar{\Psi} \ldots {}_L H + \text{h.c.}\,,$

Leptobaryons as Dark Matter

$$\mathcal{L} = - y_\Psi \bar{\Psi}_R \Psi_L S_{\mathrm{B}}^* - y_\chi \chi_L \chi_L S_{\mathrm{B}} - y_\Sigma \mathrm{Tr} \Sigma_L^2 S_{\mathrm{B}} \\ - \lambda_1 \bar{\Psi}_R H \chi_L - \lambda_2 H^\dagger \Psi_L \chi_L - \lambda_3 H^\dagger \Sigma_L \Psi_L - \lambda_4 \bar{\Psi}_R \Sigma_L H + \mathrm{h.c.}\,,$$

- Breaking $U(1)_B$ induces Z_2 symmetry

$$\Psi_L \to -\Psi_L\,, \\ \bar{\Psi}_R \to -\bar{\Psi}_R\,, \\ \Sigma_L \to -\Sigma_L\,, \\ \chi_L \to -\chi_L$$

Leptobaryons as Dark Matter

$$\mathcal{L} = - y_\Psi \bar{\Psi}_R \Psi_L S_{\mathrm{B}}^* - y_\chi \chi_L \chi_L S_{\mathrm{B}} - y_\Sigma \mathrm{Tr} \Sigma_L^2 S_{\mathrm{B}}$$
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$$\Psi_L \to -\Psi_L\,,$$
$$\bar{\Psi}_R \to -\bar{\Psi}_R\,,$$
$$\Sigma_L \to -\Sigma_L\,,$$
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- Lightest leptobaryon **automatically** stable

Dark Matter Annihilation

<u>Resonant annihilation channels</u>

$\chi\chi \to \bar{q}q$

velocity suppressed **veleocity + mixing suppressed**

- Both velocity suppressed due to Majorana nature of χ

Dark Matter Annihilation

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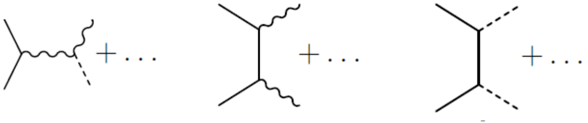
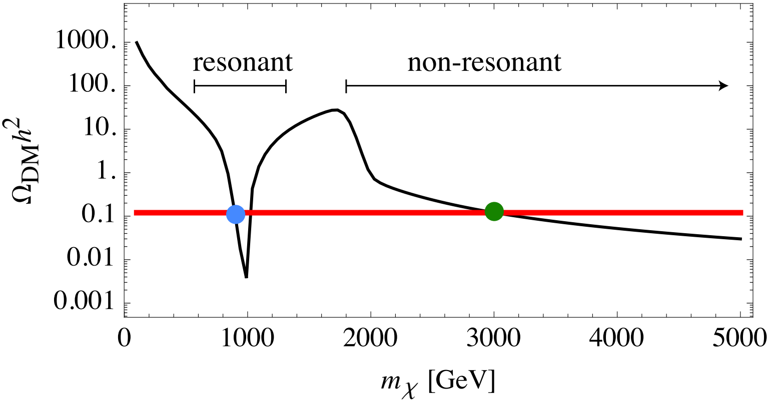
Non-resonant annihilation channels

$\chi\chi \to Z_{\rm B} S_{\rm B}$ $\chi\chi \to Z_{\rm B} Z_{\rm B}$ $\chi\chi \to S_{\rm B} S_{\rm B}$



velocity unsuppressed **velocity suppressed**

Dark Matter Thermal Abundance

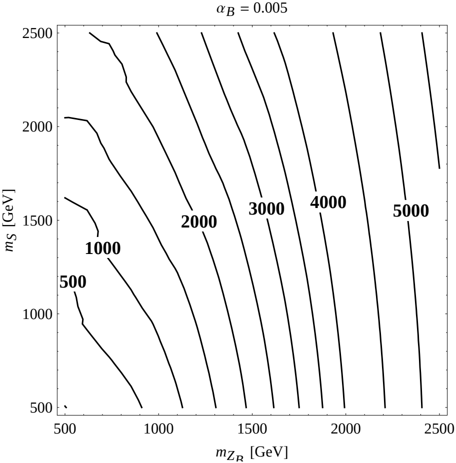


- Resonant annihilation → light dark matter
- Non-resonant annihilation → heavy dark matter

SO, H. H. Patel, [arXiv:1506.00954]

Non-Resonant Dark Matter

- Five free parameters: m_χ, m_{Z_B}, α_B, m_S, θ
- Calculate dark matter abundance in limit $\theta \to 0$



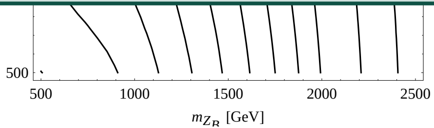
Non-Resonant Dark Matter

- Fiv
- Ca

Vacuum Metastability

- Leptobaryons destabilize vacuum in S_{B} direction
- Solve one-loop $\overline{\mathrm{MS}}$ renormalization group equation for the baryonic Higgs quartic self-coupling
- Demand self-consistency

$$m_{\psi,\Sigma,\chi} \lesssim 0.86 \left(\frac{m_{Z_{\mathrm{B}}} m_S}{g_{\mathrm{B}}} \right)^{1/2}$$



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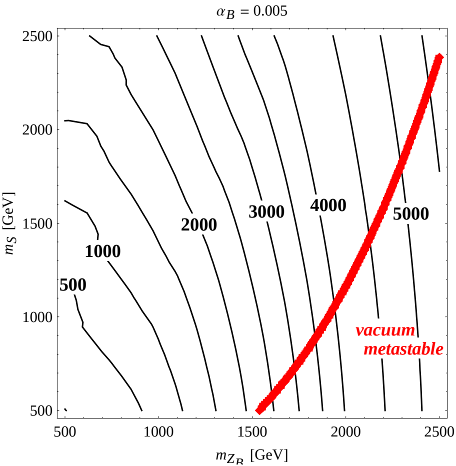
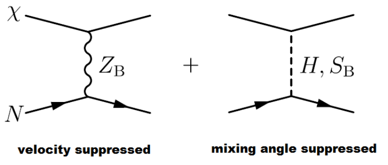
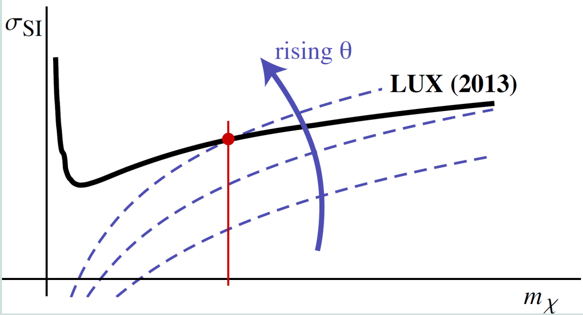


Non-R

- Fiv
- Ca

Direct Detection Bounds on θ





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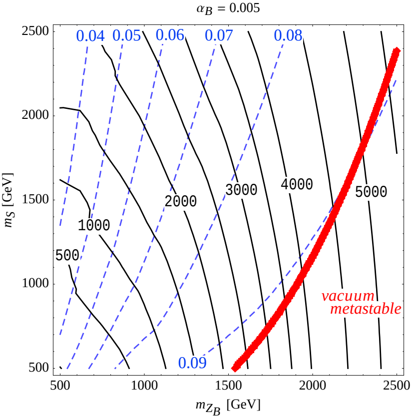


- Constrain mixing angle by direct detection experiments
- Find bound $\theta \lesssim 0.09$
- LHC Higgs signal strength measurements $\theta \lesssim 0.35$

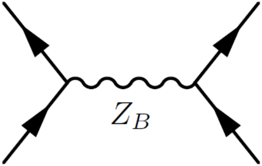
Gauged Baryon Number at the LHC

- Leptobaryons too heavy to produce at LHC

$$m_\chi \gtrsim m_{Z_\mathrm{B}} \simeq m_S$$

- Test baryonic symmetry breaking mechanism
- Search for Z_B via dijets resonances

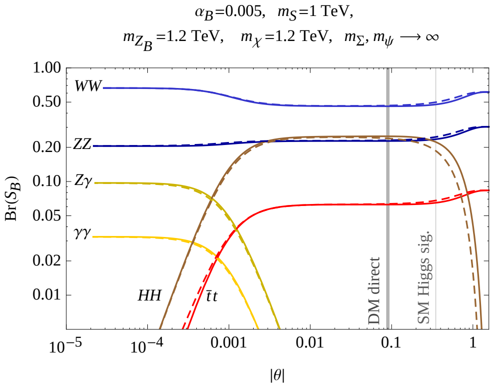
$$pp \to Z_\mathrm{B} \to jj$$



- Leptophobic $\Rightarrow$ absence of dilepton resonances

SO, H. H. Patel, [arXiv:1506.00954]

Baryonic Higgs Decays



- $|\theta| \geq 10^{-3}$ inherits standard model Higgs decays

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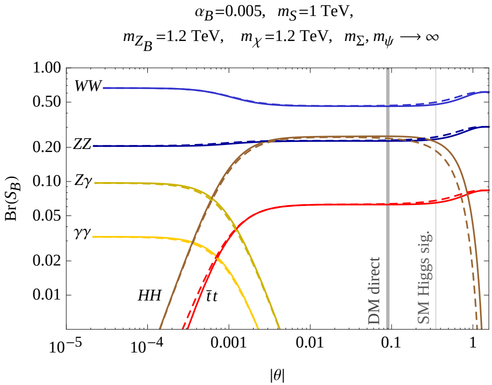

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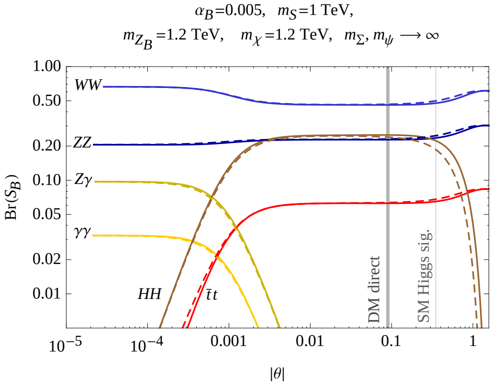

- $|\theta| \geq 10^{-3}$ inherits standard model Higgs decays
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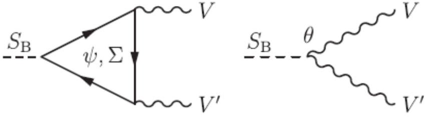
- Leptobaryons leave footprint in loops

Interplay of



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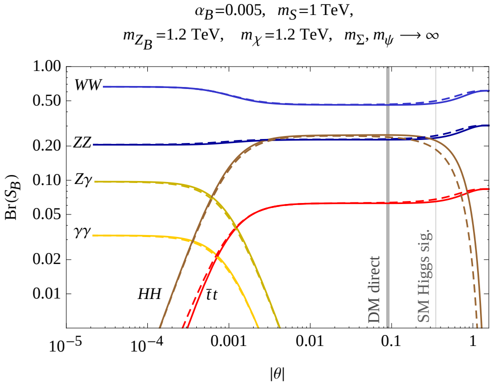
Baryonic Higgs Decays



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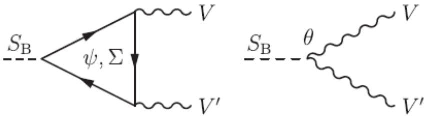
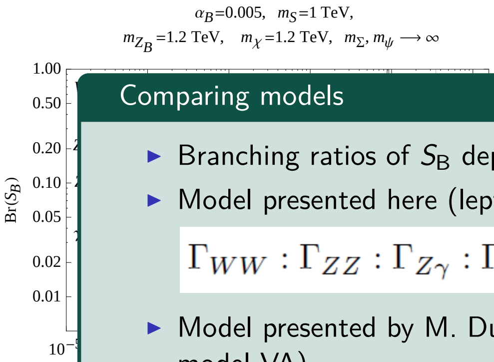


- $|\theta| \geq 10^{-3}$ inherits standard model Higgs decays
- $|\theta| < 10^{-3}$ loop mediated decays to electroweak standard model gauge bosons
- Leptobaryons leave footprint in loops
- Distinguish models with different fermionic content

SO, H. H. Patel, [arXiv:1506.00954]

Baryonic Higgs Decays



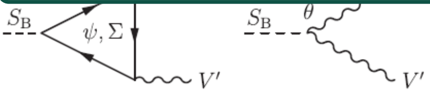
Comparing models

- Branching ratios of S_B depends on leptobaryons
- Model presented here (leptobaryon model A)

$$\Gamma_{WW} : \Gamma_{ZZ} : \Gamma_{Z\gamma} : \Gamma_{\gamma\gamma} = 20 : 7 : 3 : 1$$

- Model presented by M. Duerr (leptobaryon model VA)

$$\Gamma_{WW} : \Gamma_{ZZ} : \Gamma_{Z\gamma} : \Gamma_{\gamma\gamma} = 2 : 1 : 10^{-3} : 1$$



- $|\theta| > 10^{-3}$ inherits ... Higgs ... to ... dard ... ons ... ve ... s ... els with ... ic content

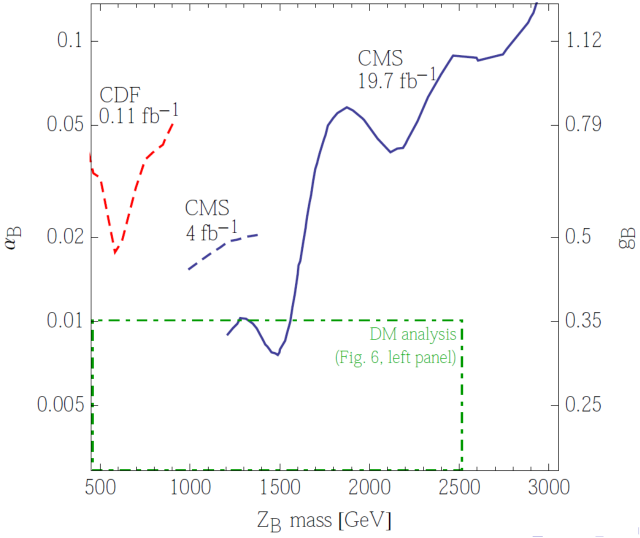
SO, H. H. Patel, [arXiv:1506.00954]

Conclusions

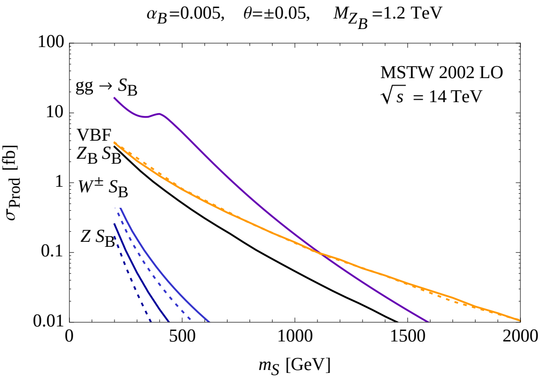
- Standard Model and proton stability as motivation for gauged baryon and lepton number
- Introduce model with minimal fermionic degrees of freedom and minimal number of multiplets (leptobaryons)
- Non-resonant dark matter annihilation ($m_\chi \gtrsim m_{Z_\mathrm{B}} \simeq m_S$)
- Bound on mixing angle from direct detection constraints ($\theta \lesssim 0.09$)
- Infer leptobaryons via loop decays at LHC

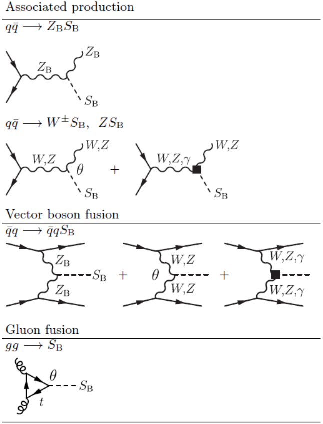
Future work: multicomponent dark matter, electroweak baryogenesis and low scale lepton number violation

Dijet Constraints



Baryonic Higgs Production

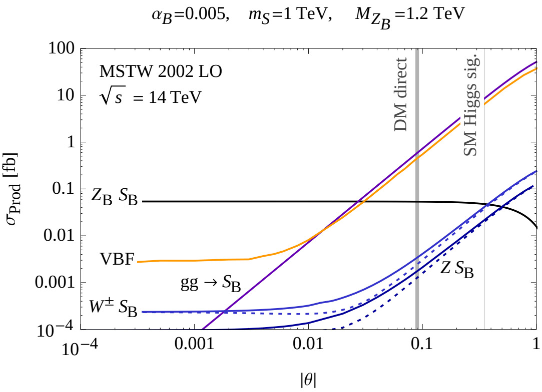


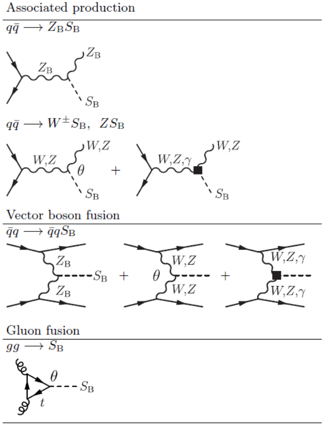


- S_B inherits standard model Higgs production channels

SO, H. H. Patel, [arXiv:1506.00954]

Baryonic Higgs Production



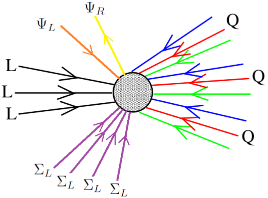


- For small mixing angles ($|\theta| < 0.02$) associated production dominates
- Loop suppressed contributions take over

SO, H. H. Patel, [arXiv:1506.00954]

Baryon Asymmetry with Leptobaryons

- Baryon asymmetry in the Universe → Leptogenesis
- Leptobaryons carry $SU(2)_L$ charge and modify sphalerons



- Final baryon asymmetry as function of initial $B-L$ asymmetry

$$B_f = \frac{32}{99}\Delta(B-L)_{\text{SM}} \approx 0.32\ \Delta(B-L)_{\text{SM}}$$

P.Fileviez Pérez, SO, H.H.Patel, Phys.Lett.B735(2014)

$$B_f^{\text{SM}} = \frac{28}{79}\Delta(B-L)_{\text{SM}} \approx 0.35\Delta(B-L)_{\text{SM}}$$

J.A.Harvey, M.S.Turner, Phys.Rev.D42(1990)

Low Scale Unification

- Standard Model as low energy effective theory

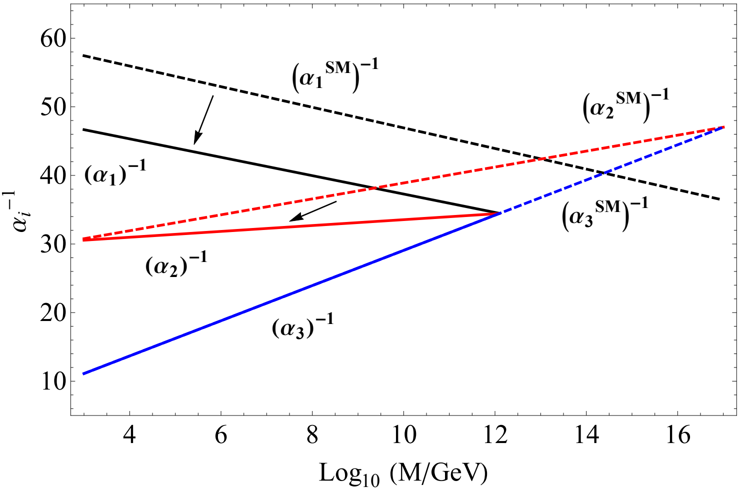
$$\mathcal{L} \supset \frac{c_L}{\Lambda_L}\ell_L\ell_L H^2 + \frac{c_B}{\Lambda_B^2} q_L q_L q_L \ell_L + \frac{c_F}{\Lambda_F^2}(\bar{q}_L\gamma^\mu q_L)(\bar{q}_L\gamma_\mu q_L) + \ldots,$$

with $\Lambda_L < 10^{14}$ GeV, $\Lambda_B > 10^{15}$ GeV, and $\Lambda_F > 10^4$ TeV

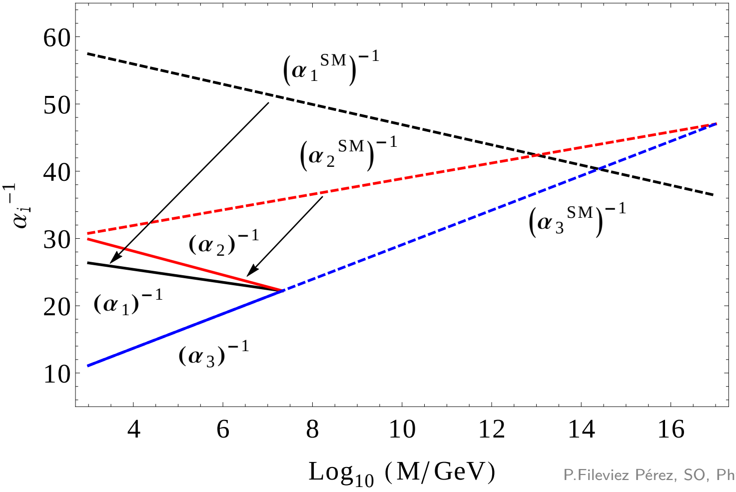
- Gauged baryon and lepton number forbid first two operators

Is unification of the gauge couplings at $\Lambda_{\mathbf{GUT}} \sim 10^4$ TeV possible?

Evolution of Gauge Couplings with Leptobaryons



Evolution adding four Generations of Leptobaryons



P.Fileviez Pérez, SO, Phys.Rev.D90(2014)

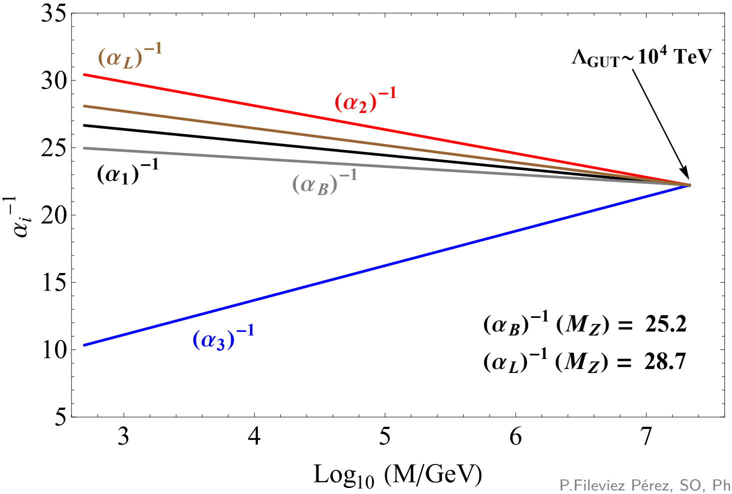
Unification Scales

n_F	$M_U\,(\mathrm{TeV})$	k_1
1	$1.24 \cdot 10^9$	2.05
2	$4.96 \cdot 10^6$	2.67
4	$2.14 \cdot 10^4$	3.62
5	$4.58 \cdot 10^3$	3.99

Table: Solutions for unification scale M_U with $M_F = 500$ GeV.

P.Fileviez Pérez, SO, Phys.Rev.D90(2014)

Low Scale Unification



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