On Gauge Theories and the TeV Scale

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Collaborators

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Is there New Physics at the TeV Scale ?

The SM is a great effective field theory

$$\mathcal{L}_{\text{eff}}^{SM} \supset -m_H^2 H^\dagger H + \lambda_H (H^\dagger H)^2 + \frac{c_L}{\Lambda_{\not L}} l_L l_L H H$$

$$+ \frac{c_B}{\Lambda_{\not B}^2} Q_L Q_L Q_L l_L + \cdots$$

$$\delta m_H^2 \sim \Lambda^2$$

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Possible Scenarios:

i) $\Lambda \simeq \text{TeV}$ (The Higgs mass is protected)

ii) if $\Lambda = \Lambda_{\not B}$ or $\Lambda_{\not L}$ → huge fine-tuning if $\Lambda_{\not B}$ & $\Lambda_{\not L}$ are large !

iii) Maybe the fundamental Scale is Low.

Is there New Physics at the TeV Scale ?

New Gauge Theories at the TeV Scale !

New Gauge Theories at the TeV Scale

- Predict a New Sector needed for Anomaly Cancellation

- Predict a DM candidate from Anomaly Cancellation

- The new symmetry breaking scale must be below the multi-TeV scale to be in agreement with cosmology

- Predict new CP violating interactions needed for Baryogenesis

- One predicts unique signatures at the LHC

Baryon Number as Local Gauge Symmetry

Realistic Theories:

P. F. P., M. B. Wise, JHEP1108, 068

M. Duerr, P. F. P., M. B. Wise, Phys. Rev. Lett. 110, 231801

P. F. P., S. Ohmer, H. H. Patel, Physics Letters B735, 283

P. F. P., Physics Reports 597

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

P. F. P., S. Ohmer, H. H. Patel

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

$$\Sigma_L \sim (1,\, 3,\, 0,\, -3/2), \qquad \chi_L \sim (1,\, 1,\, 0,\, -3/2)\,.$$

$$\begin{aligned} -\mathcal{L} \;\supset\; & y_1 \bar{\Psi}_R H \chi_L + y_2 H^\dagger \Psi_L \chi_L + y_3 H^\dagger \Sigma_L \Psi_L \\ & + y_4 \bar{\Psi}_R \Sigma_L H + y_\Psi \bar{\Psi}_R \Psi_L S_B^* \\ & + \frac{y_\chi}{\sqrt{2}} \chi_L \chi_L S_B + y_\Sigma \mathrm{Tr}(\Sigma_L \Sigma_L) S_B + \mathrm{h.c.}, \end{aligned}$$

New Higgs: $S_B \sim (1, 1, 0, 3)$

$\Delta B = \pm 3$ → **Stable Proton !**

Gauge Theory for Proton Stability !

see also: M. Duerr, P. F. P., M. B. Wise, Phys. Rev. Lett.

Some Features:

P. F. P., Physics Reports 597

Dark Matter: χ

CDM Candidate from Anomaly Cancellation

Leptophobic Gauge Boson: $Z_B \to \bar{q}q, \bar{\chi}\chi$

New Higgs Boson:

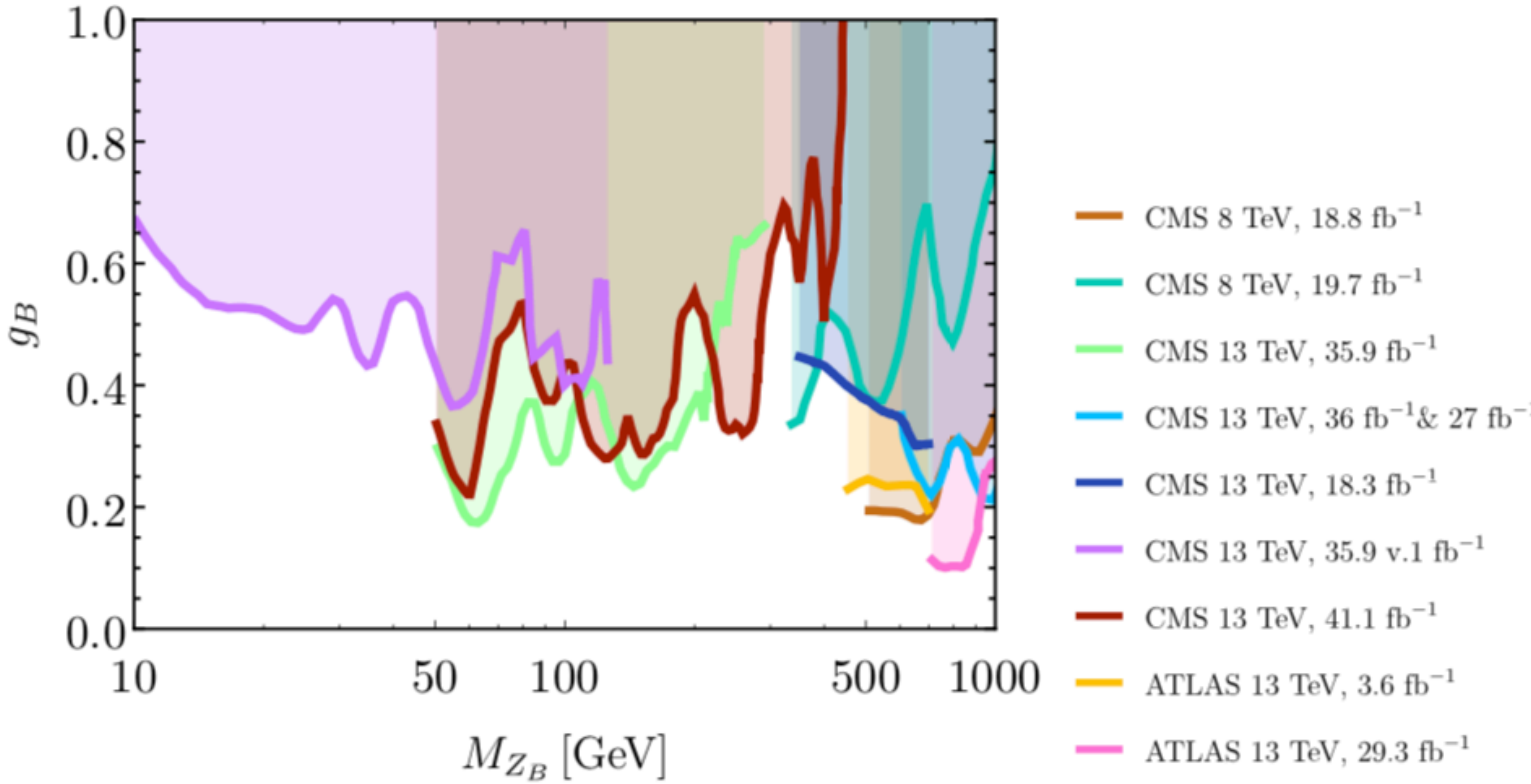
$$h_B \to \gamma\gamma,\ gg,\ \gamma Z,\ \gamma Z_B,\ ZZ,\ ZZ_B,\ Z_B Z_B,\ WW,\ \chi\chi,\ \overline{F_i}F_i,\ hh,\ \overline{f_i}f_i,$$

Signatures at the LHC:

$$pp \to Z_B h_B \to t\bar{t}\chi\chi \to t\bar{t}E_T^{miss}$$

$$pp \to Z_B h_B \to t\bar{t}\gamma\gamma$$

Collider Bounds - Leptophobic Gauge Boson



P. F. P., E. Golias, C. Murgui, A.D. Plascencia, 2020

Dark Matter from Anomaly Cancellation

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

P. F. P., S. Ohmer, H. H. Patel

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

$$\Sigma_L \sim (1,\ 3,\ 0,\ -3/2), \qquad \chi_L \sim (1,\ 1,\ 0,\ -3/2)\,.$$

$\Rightarrow$ $\langle S_B \rangle \neq 0$ $\Rightarrow$ $U(1)_B \to \mathcal{Z}_2$

$$\{\Psi_L \to -\Psi_L,\ \Psi_R \to -\Psi_R,\ \Sigma_L \to -\Sigma_L, \chi_L^0 \to -\chi_L^0\}.$$

$(\chi_L^0, \Sigma_L^0, \Psi_{1L}^0, \Psi_{2L}^0)$

$$\mathcal{M}_0 = \begin{pmatrix} y_\chi v_B & 0 & \frac{y_2 v}{\sqrt{2}} & \frac{y_1 v}{\sqrt{2}} \\ 0 & \sqrt{2} y_\Sigma v_B & -\frac{y_3 v}{2} & -\frac{y_4 v}{2} \\ \frac{y_2 v}{\sqrt{2}} & -\frac{y_3 v}{2} & 0 & \frac{y_\Psi}{\sqrt{2}} v_B \\ \frac{y_1 v}{\sqrt{2}} & -\frac{y_4 v}{2} & \frac{y_\Psi}{\sqrt{2}} v_B & 0 \end{pmatrix},$$

Majorana Leptophobic DM

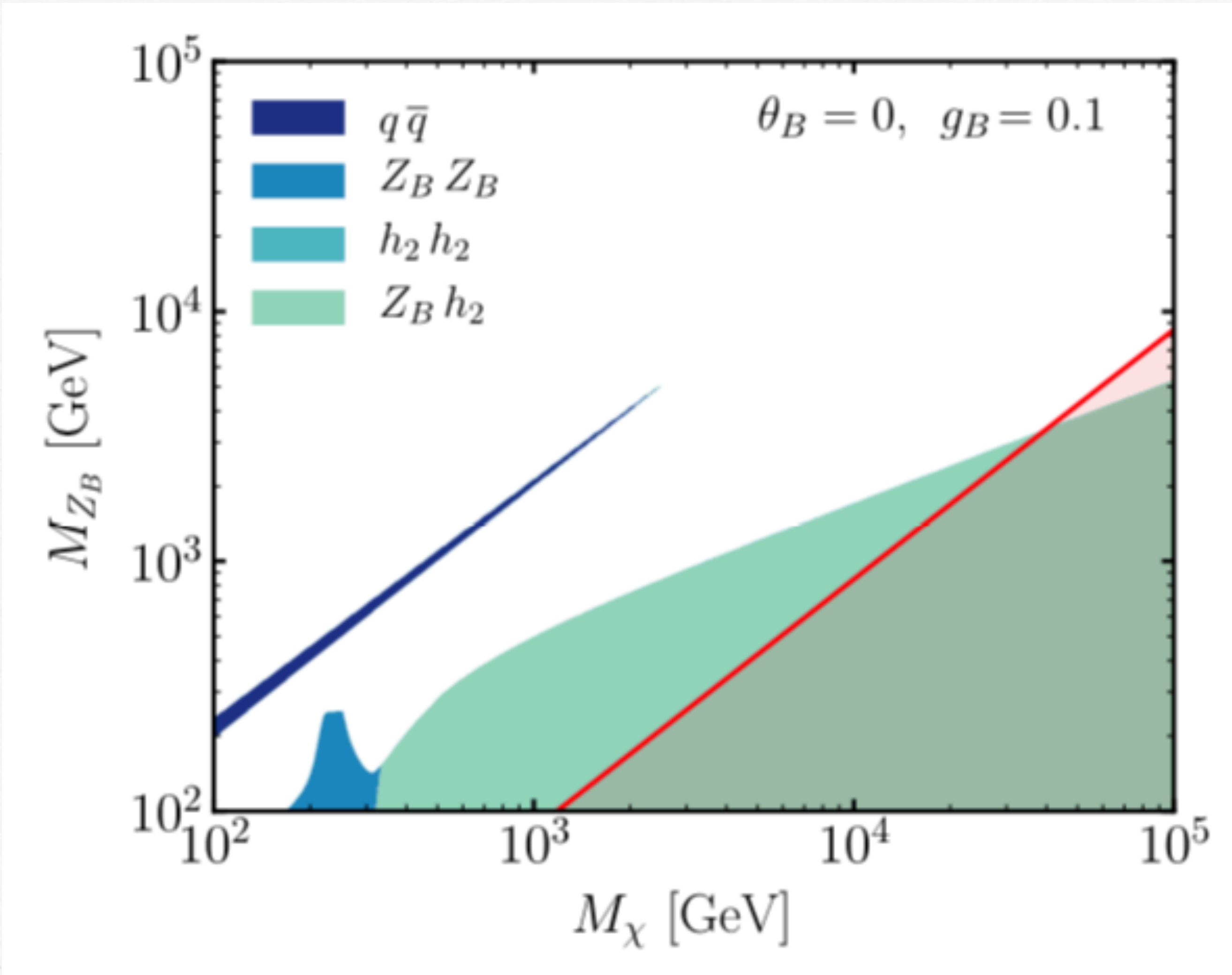
$$\mathcal{L} \supset \frac{3}{4} g_B \bar{\chi} \gamma^\mu \gamma^5 \chi Z_\mu^B - \frac{1}{3} g_B \bar{q} \gamma^\mu q Z_\mu^B$$

$$+ \frac{M_\chi}{2 v_B} \sin\theta_B \chi\chi h - \frac{M_\chi}{2 v_B} \cos\theta_B \chi\chi h_B - \frac{1}{2} M_\chi \chi\chi + \dots$$

$$\chi\chi \to \bar{q}q,\ Z_B Z_B,\ Z_B h,\ Z_B h_B,\ hh,\ h h_B,\ h_B h_B,\ WW,\ ZZ.$$

P. F. P., E. Golias, RH. Li, C. Murgui, A. D. Plascencia, Phys. Rev. D 100, 015017 (2019)

$$\Omega_{DM} h^2 \leq 0.12$$



P. F. P., E. Golias, RH. Li, C. Murgui, A. D. Plascencia, Phys. Rev. D 100, 015017 (2019)

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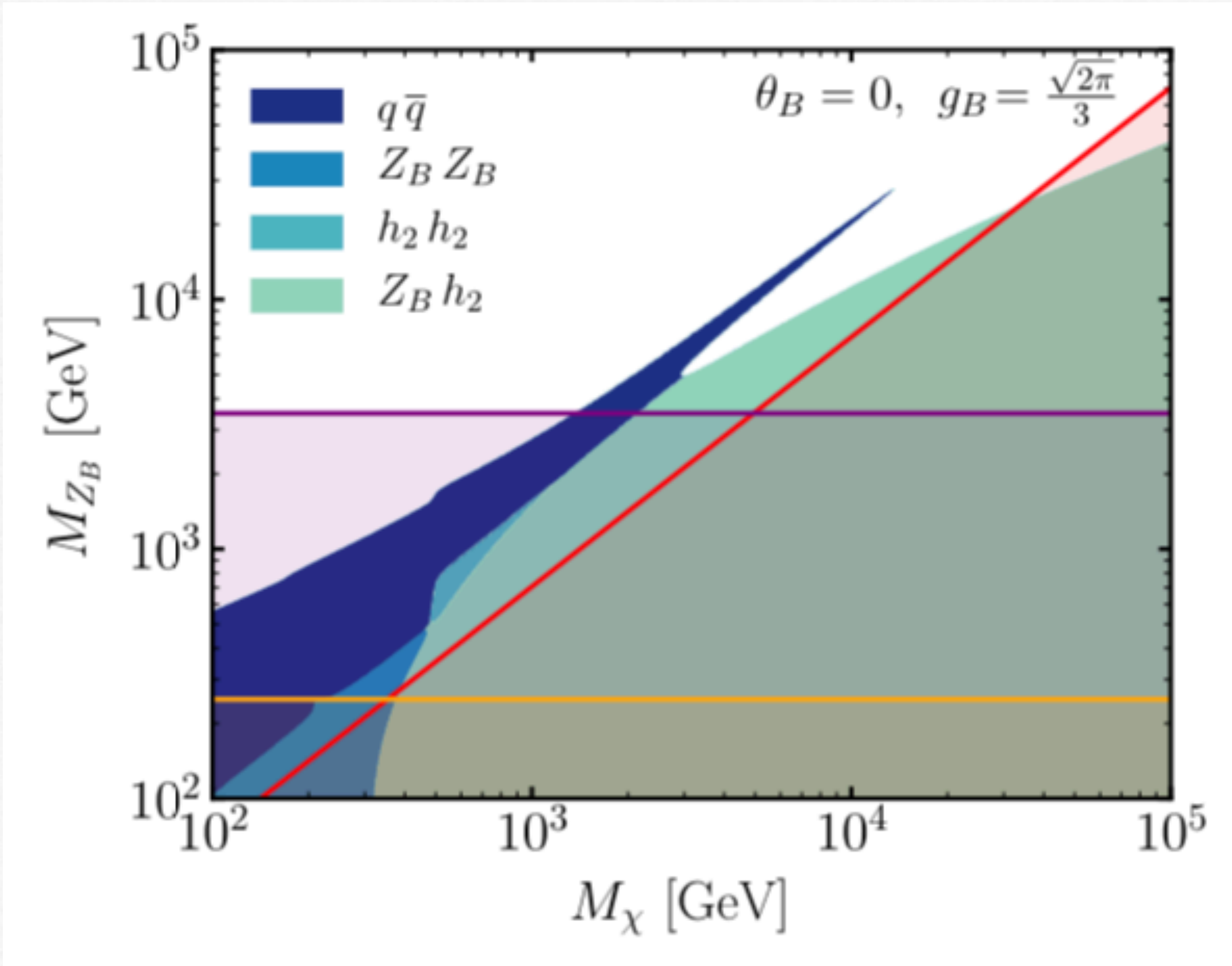
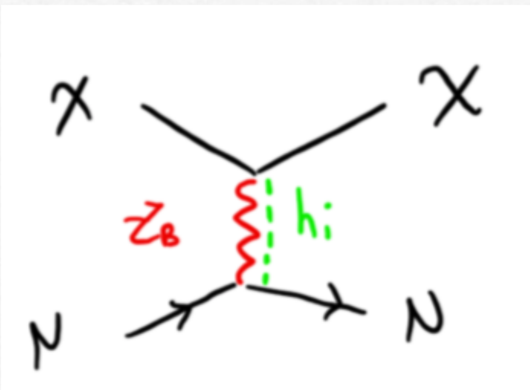
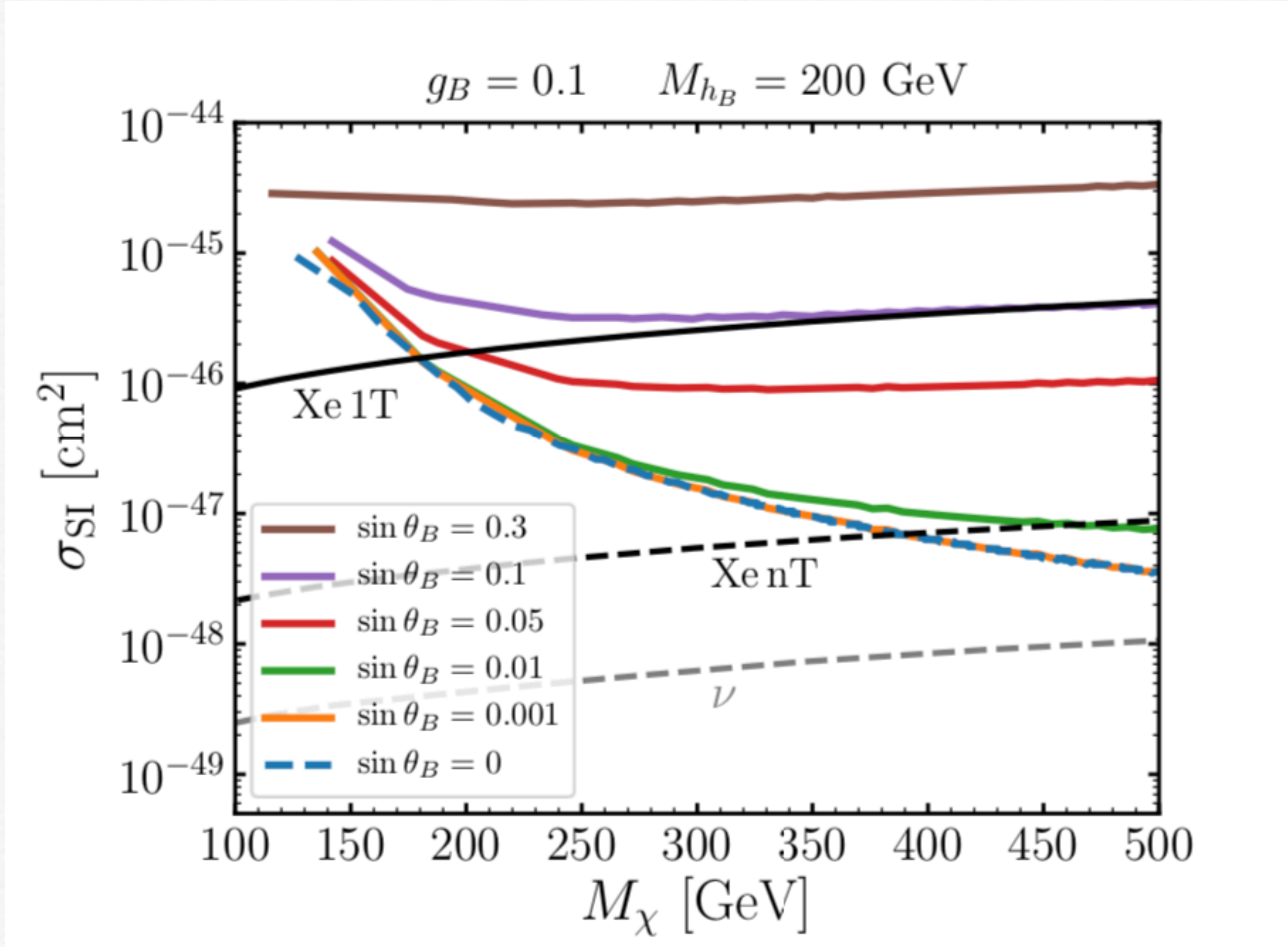


P. F. P., E. Golias, RH. Li, C. Murgui, A. D. Plascencia, Phys. Rev. D 100, 015017 (2019)





P. F. P., E. Golias, RH. Li, C. Murgui, A. D. Plascencia, Phys. Rev. D 100, 015017 (2019)

The theory for local baryon number at the TeV scale

$$M_{Z_B} \sim g_B v_B$$

$$M_X \sim \lambda_X v_B$$

$$M_{F_i^\pm} \sim \lambda_C v_B$$

$$M_{F_j^0} \sim \lambda_N v_B$$

$$M_{Z_B}, M_X, M_{F_i^\pm}, M_{F_j^0} \lesssim 10 \text{ TeV}$$

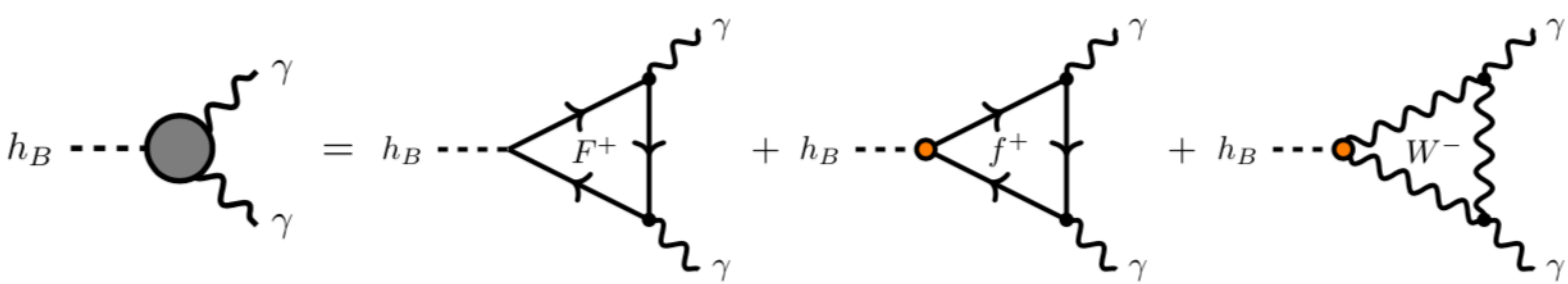
P. F. P., C. Murgui, A. D. Plascencia, JHEP 02(2021)163

Baryonic Higgs at the LHC

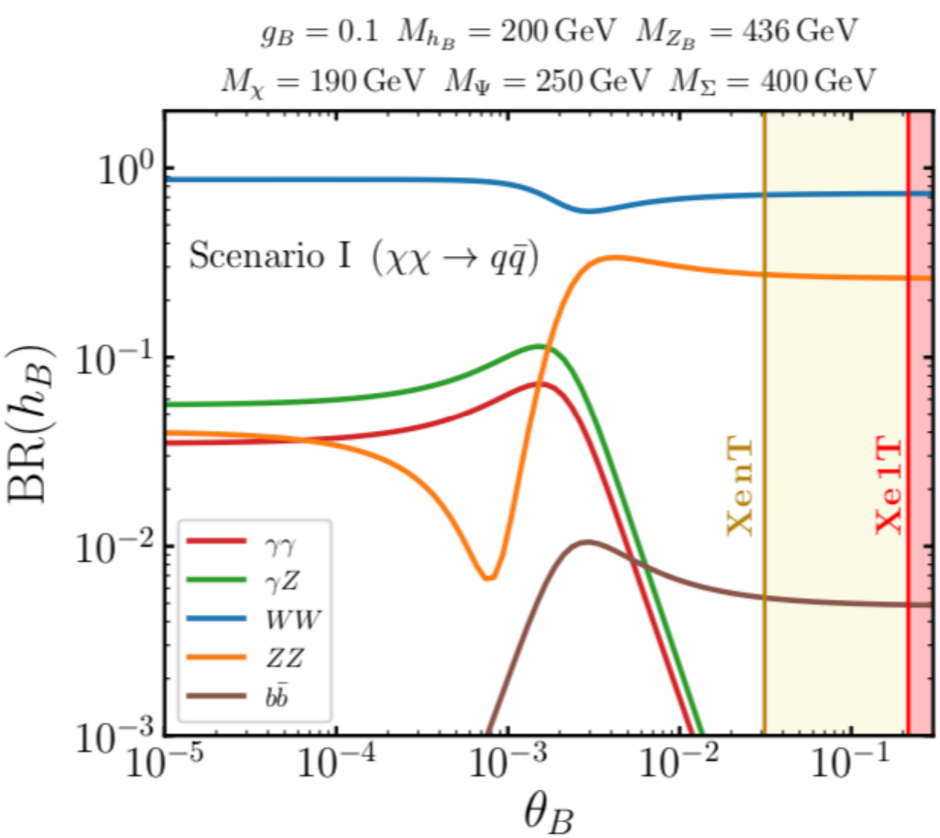
$$h_B \to \gamma\gamma,\ gg,\ \gamma Z,\ \gamma Z_B,\ ZZ,\ ZZ_B,\ Z_B Z_B,\ WW,\ \chi\chi,\ \overline{F_i}F_i,\ hh,\ \overline{f_i}f_i,$$

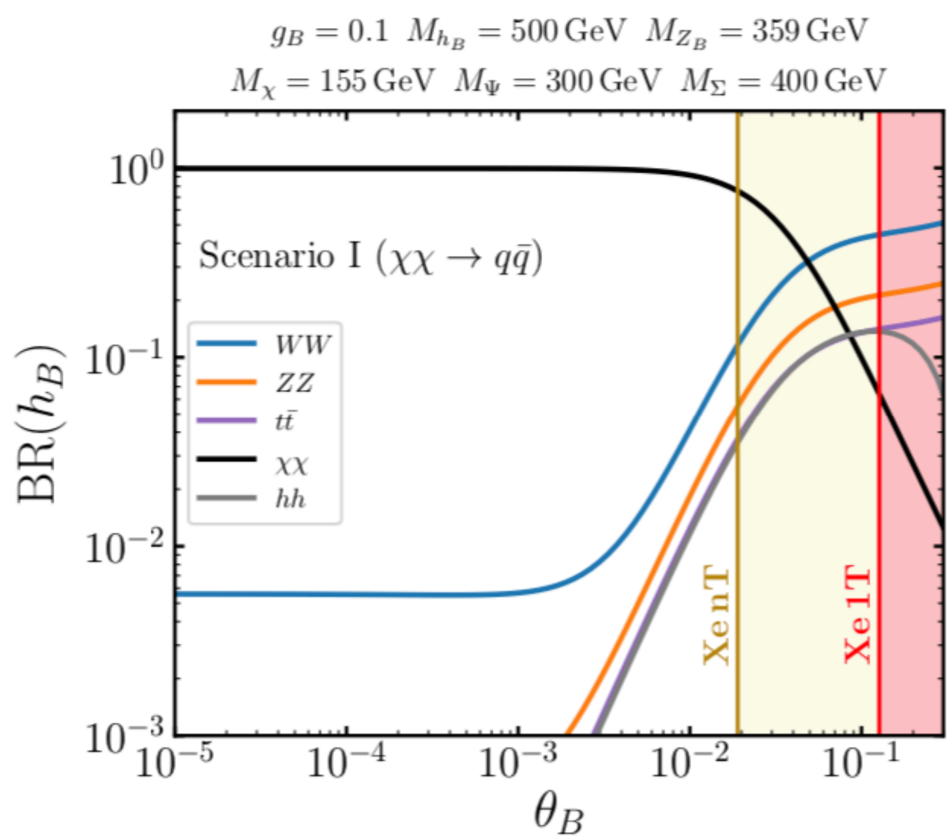
Label	Dominant annihilation channel	Properties
Scenario I	$\chi\chi \to \bar{q}q$	$M_\chi \simeq M_{Z_B}/2$
Scenario II	$\chi\chi \to Z_B h_B$	$2M_\chi > M_{h_B} + M_{Z_B}$
Scenario III	$\chi\chi \to Z_B Z_B$	$M_\chi > M_{Z_B}, \quad M_\chi \simeq M_{h_B}/2$

$\boldsymbol{h_B \to \gamma\gamma}$:



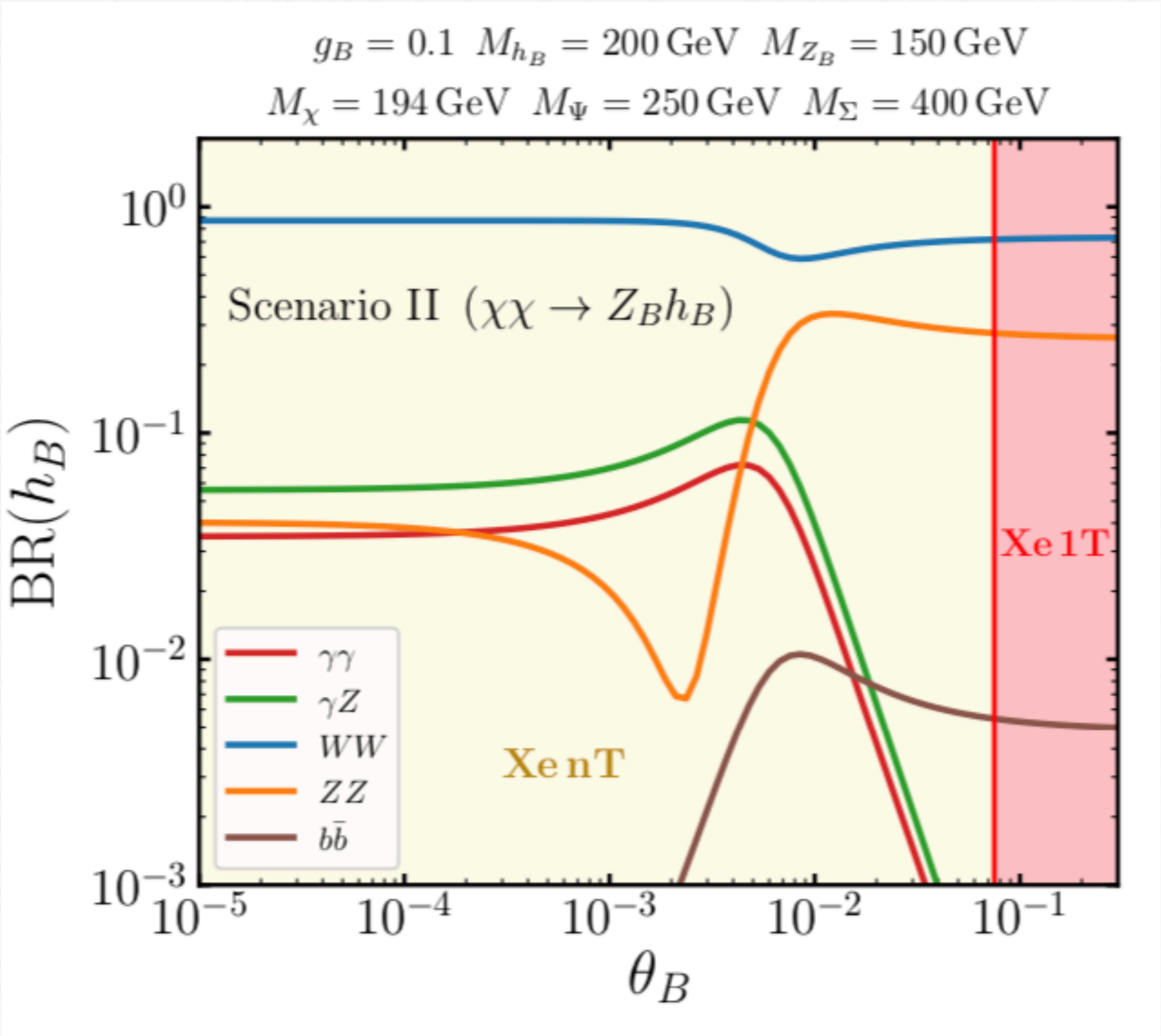
Baryonic Higgs Decays





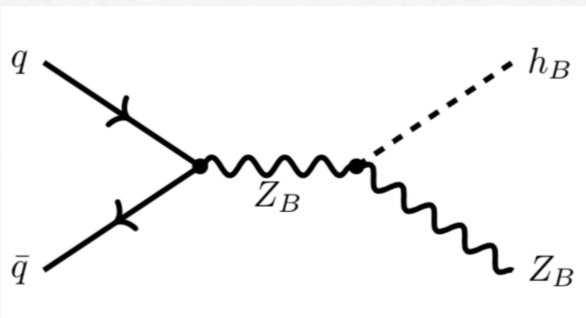
P. F. P., C. Murgui, A. D. Plascencia, JHEP 02(2021)163

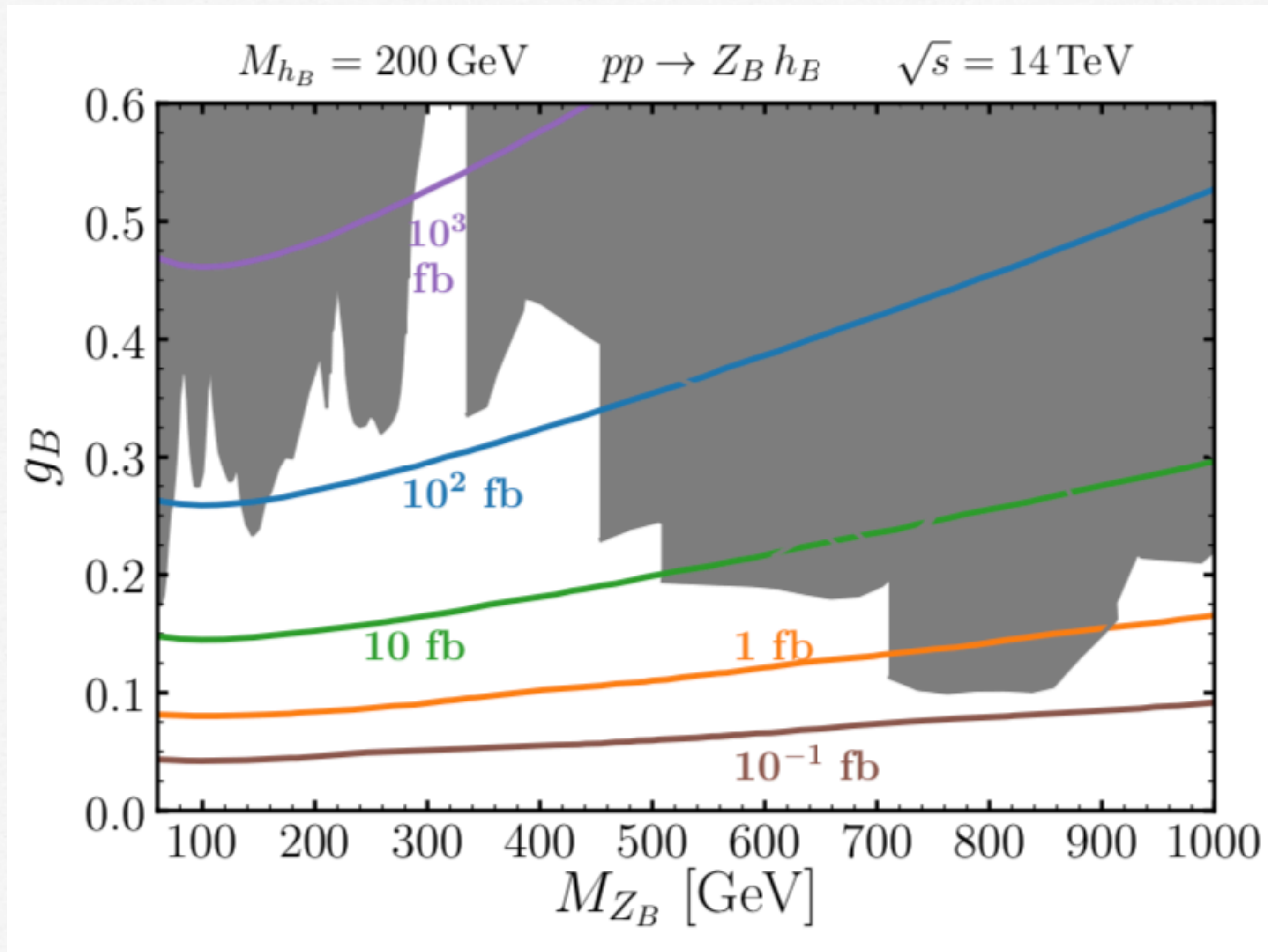
Baryonic Higgs Decays



P. F. P., C. Murgui, A. D. Plascencia, JHEP 02(2021)163

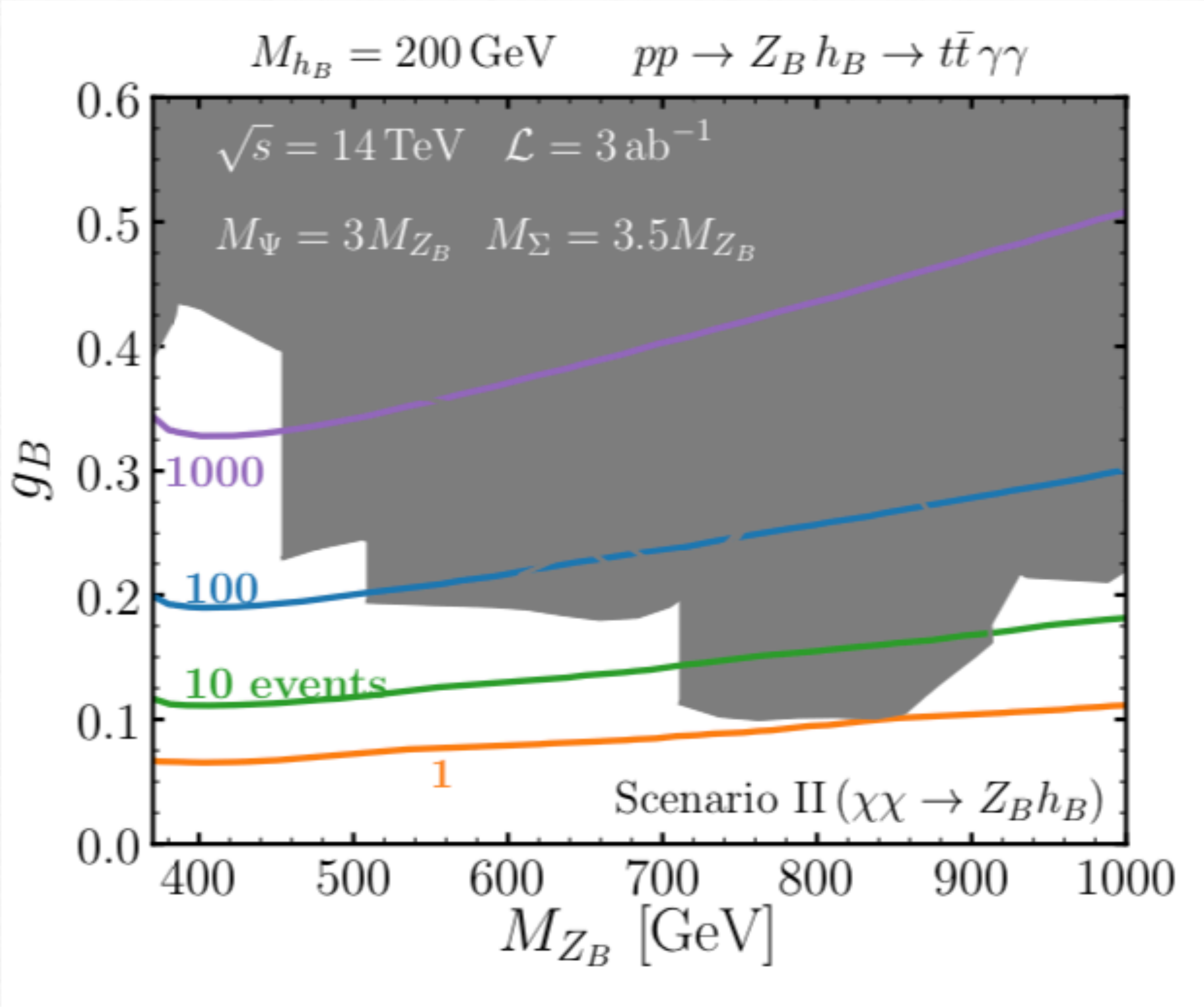
Baryonic Higgs at the LHC





P. F. P., C. Murgui, A. D. Plascencia, JHEP 02(2021)163

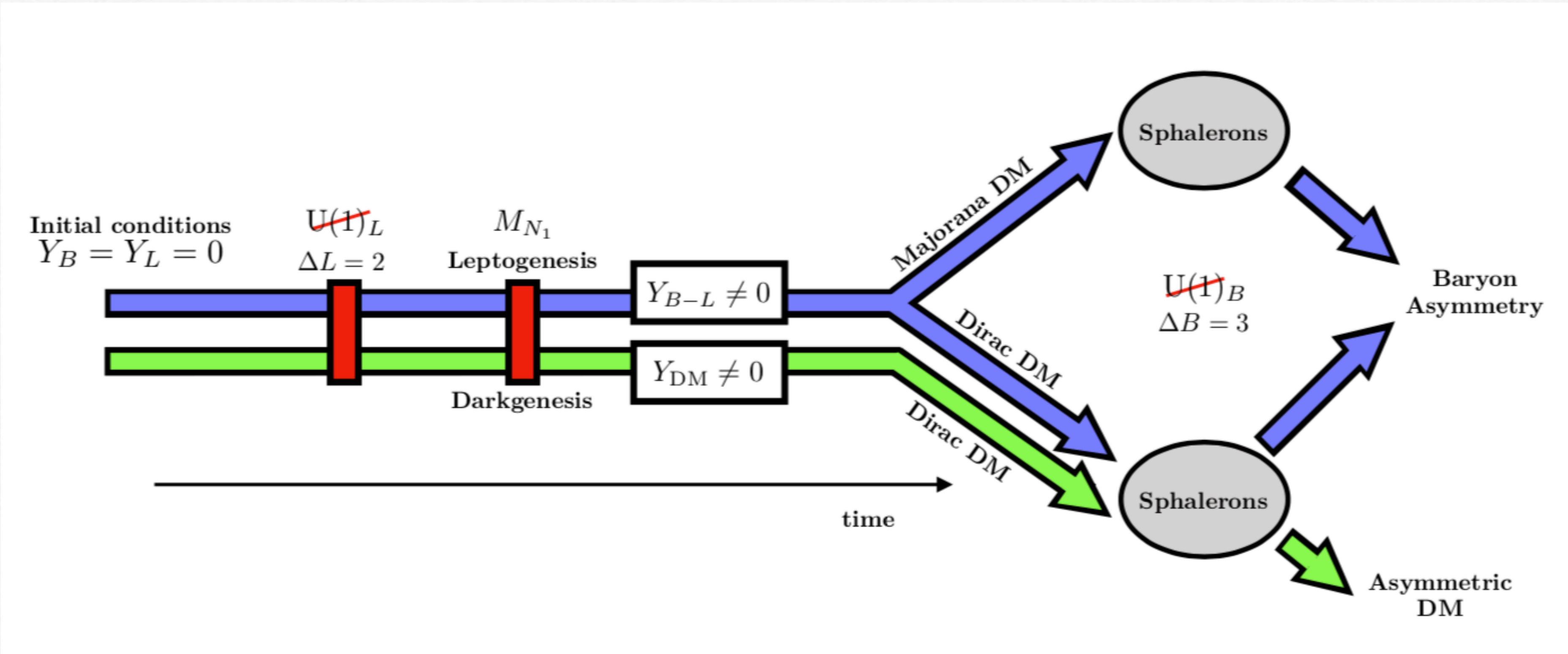
Baryonic Higgs at the LHC



P. F. P., C. Murgui, A. D. Plascencia, JHEP 02(2021)163

Baryogenesis via Leptogenesis

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



P. F. P., C. Murgui, A. D. Plascencia, 2103.13397

Fornal, Tait; P.F.P., Ohmer

Color and Baryon Number Unification

$$SU(4) \supset SU(3)_c \otimes U(1)_B$$

$$F = \begin{pmatrix} q_r \\ q_b \\ q_g \\ \psi \end{pmatrix}$$

Summary

One can have new gauge theories at the TeV Scale. The simplest theories for spontaneous baryon number violation predict new physics below the multi-TeV scale in agreement with cosmology.

The minimal theory for baryon number predicts the proton stability, a good cold dark matter from anomaly cancellation, and one can hope to test the predictions at the LHC.

The new Baryonic Higgs can have a large branching ratio into two photons or into dark matter. One can have unique signatures at the LHC.

Summary

The theories for spontaneous B and L violation provide an unique framework to understand the baryon asymmetry in the Universe.

One can have a simple mechanism to explain the baryon and dark matter asymmetries.

Maybe these theories are realized at the TeV scale and one can discover new physics at the LHC !

THANK YOU !