The Higgs of Baryon Number and Dark Matter

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with Pavel Fileviez Perez, Elliot Golias and Clara Murgui

[arXiv: 2003.09426] JHEP 07 (2020) 087
[arXiv: 2012.06599] JHEP 02 (2021) 163

PHENO 2021 - University of Pittsburgh
May 24, 2021

Aim of the talk

Discuss the Higgs and dark matter phenomenology in minimal gauge extensions of the SM that predict dark matter

1. $U(1)_B$

[Fileviez Perez, Golias, Li, Murgui, ADP 1904.01017]

[Fileviez Perez, Murgui, ADP 2003.09426]

[Fileviez Perez, ADP 2008.09116]

Gauging baryon number

- Baryon number is an accidental global symmetry in the SM
- Only broken by non-perturbative effects - SU(2) instantons
- Anomalous in the Standard Model

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$$\underbrace{\mathrm{U}(1)_B}$$

Local gauge symmetry

gauge boson: Z_B

$$\langle S_B \rangle \neq 0$$

- Spontaneous breaking of baryon number
- Consistent completion of simplified models of dark matter

[Pais 1973]

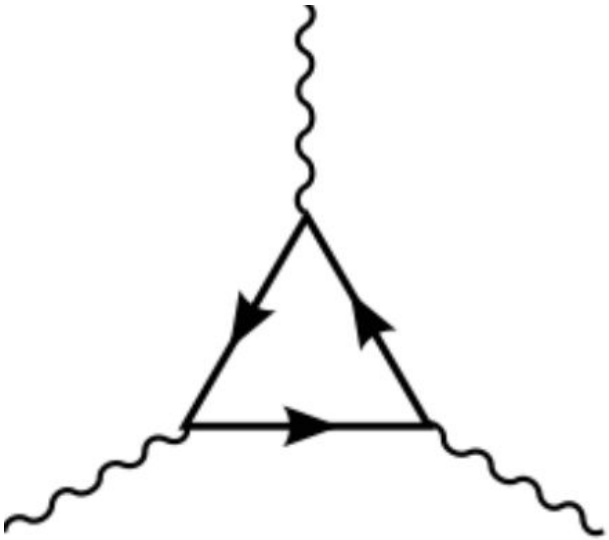
[Fileviez Perez, Wise 2011]

Anomaly cancellation

- Baryon number broken in 3 units: $\Delta B = \pm 3$ interactions

  ➡ No proton decay

- Need to add new fermions to cancel anomalies



$$\mathcal{A}_1(\mathrm{SU}(3)^2 \otimes \mathrm{U}(1)_B), \quad \mathcal{A}_2(\mathrm{SU}(2)^2 \otimes \mathrm{U}(1)_B),$$
$$\mathcal{A}_3(\mathrm{U}(1)_Y^2 \otimes \mathrm{U}(1)_B), \quad \mathcal{A}_4(\mathrm{U}(1)_Y \otimes \mathrm{U}(1)_B^2),$$
$$\mathcal{A}_5(\mathrm{U}(1)_B), \quad \mathcal{A}_6(\mathrm{U}(1)_B^3),$$

In the SM the non-zero values are:

$$\mathcal{A}_2 = -\mathcal{A}_3 = 3/2$$

Anomaly-free model

[Fileviez Perez, Ohmer, Patel 1403.8029]

Fields	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	$U(1)_B$
$\Psi_L = \begin{pmatrix} \Psi_L^+ \\ \Psi_L^0 \end{pmatrix}$	**1**	**2**	$\frac{1}{2}$	$\frac{3}{2}$
$\Psi_R = \begin{pmatrix} \Psi_R^+ \\ \Psi_R^0 \end{pmatrix}$	**1**	**2**	$\frac{1}{2}$	$-\frac{3}{2}$
$\Sigma_L = \frac{1}{\sqrt{2}} \begin{pmatrix} \Sigma_L^0 & \sqrt{2}\Sigma_L^+ \\ \sqrt{2}\Sigma_L^- & -\Sigma_L^0 \end{pmatrix}$	**1**	**3**	0	$-\frac{3}{2}$
χ_L^0	**1**	**1**	0	$-\frac{3}{2}$

- Neutral fermion required for anomaly cancellation
- Automatically stable from remnant $U(1) \longrightarrow Z_2$ symmetry

DM Candidate

Simplified Dark Matter

χ: Majorana DM

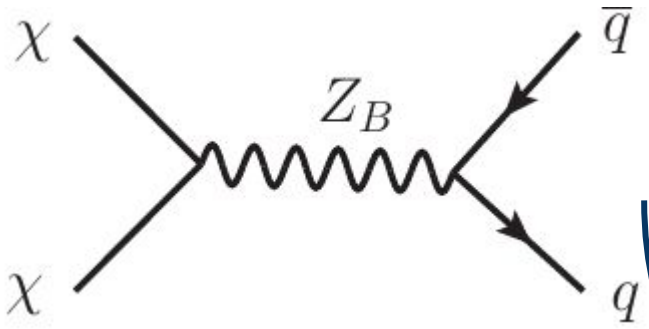
Z_B : Leptophobic mediator

$$\mathcal{L} \supset \frac{3}{4} g_B \bar{\chi} \gamma^\mu \gamma^5 \chi Z_\mu^B - \frac{1}{3} g_B \bar{q} \gamma^\mu q Z_\mu^B + \frac{M_\chi}{2 v_B} \sin\theta_B \bar{\chi}\chi h_1 - \frac{M_\chi}{2 v_B} \cos\theta_B \bar{\chi}\chi h_2$$

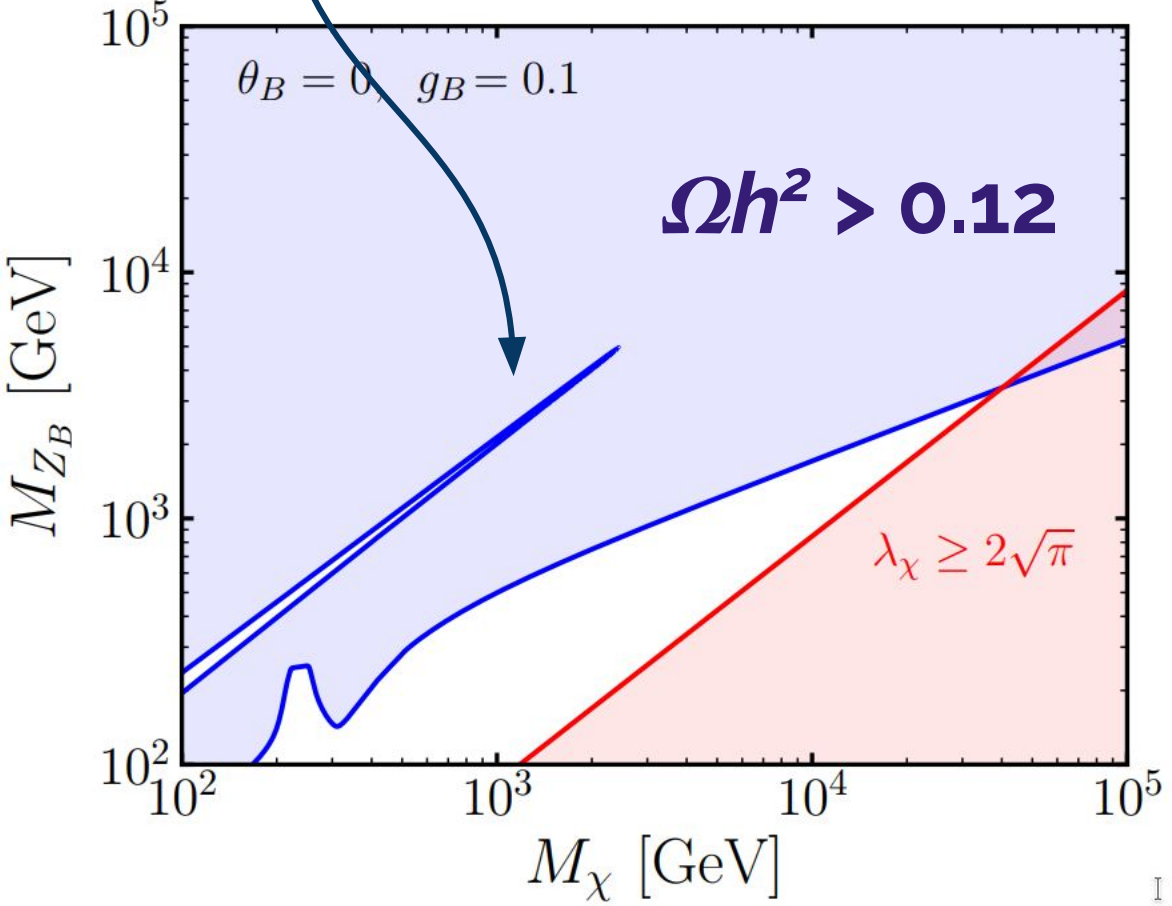
Axial **Vector**

the free parameters in the model are:

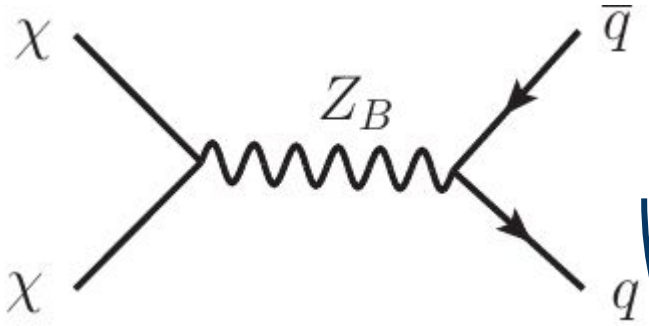
$$M_\chi, \quad M_{Z_B}, \quad M_{h_2}, \quad \theta_B, \quad g_B.$$



$$M_\chi \approx M_{Z_B}/2$$



[Fileviez Perez, Golias, Li, Murgui, ADP 1904.01017]



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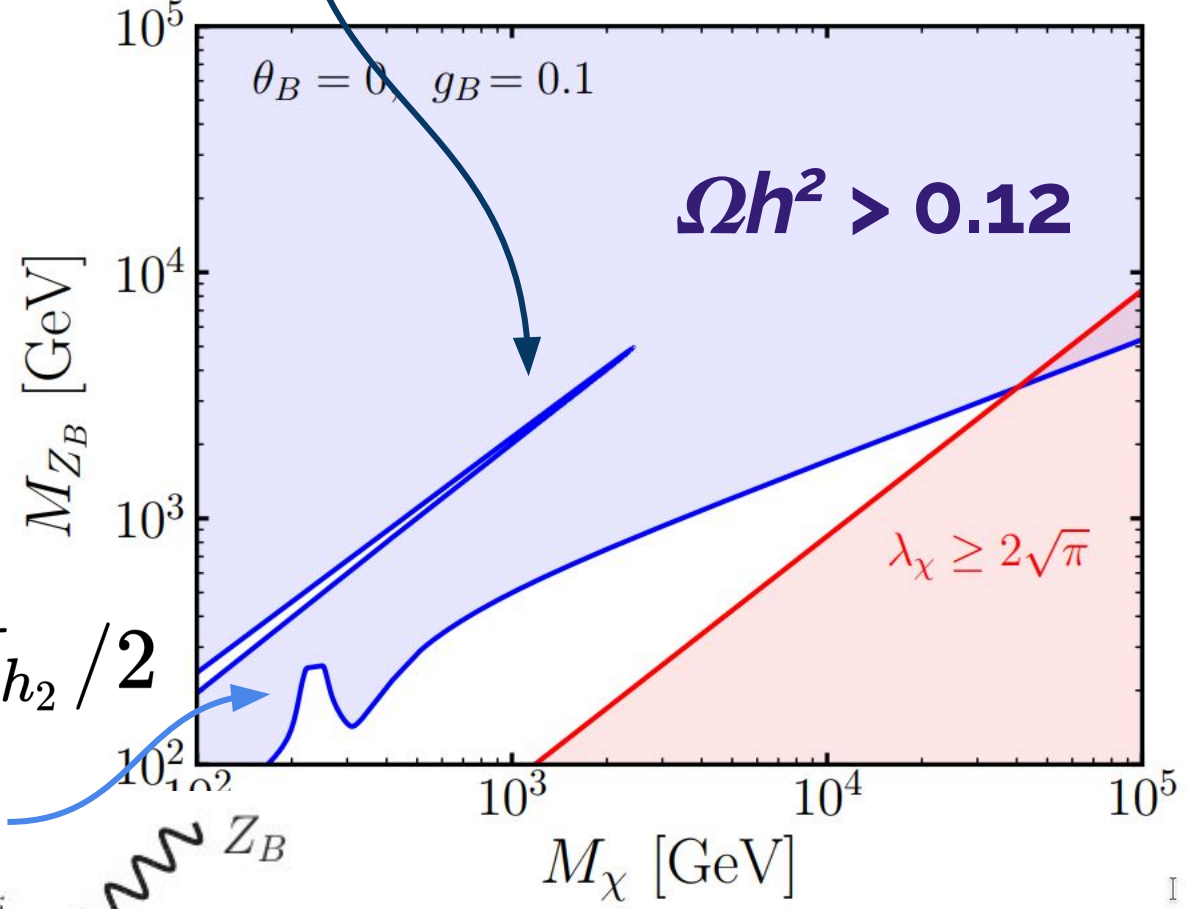
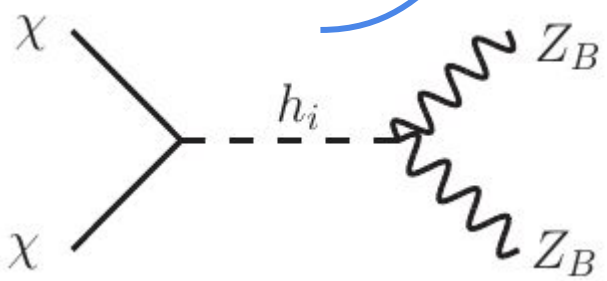
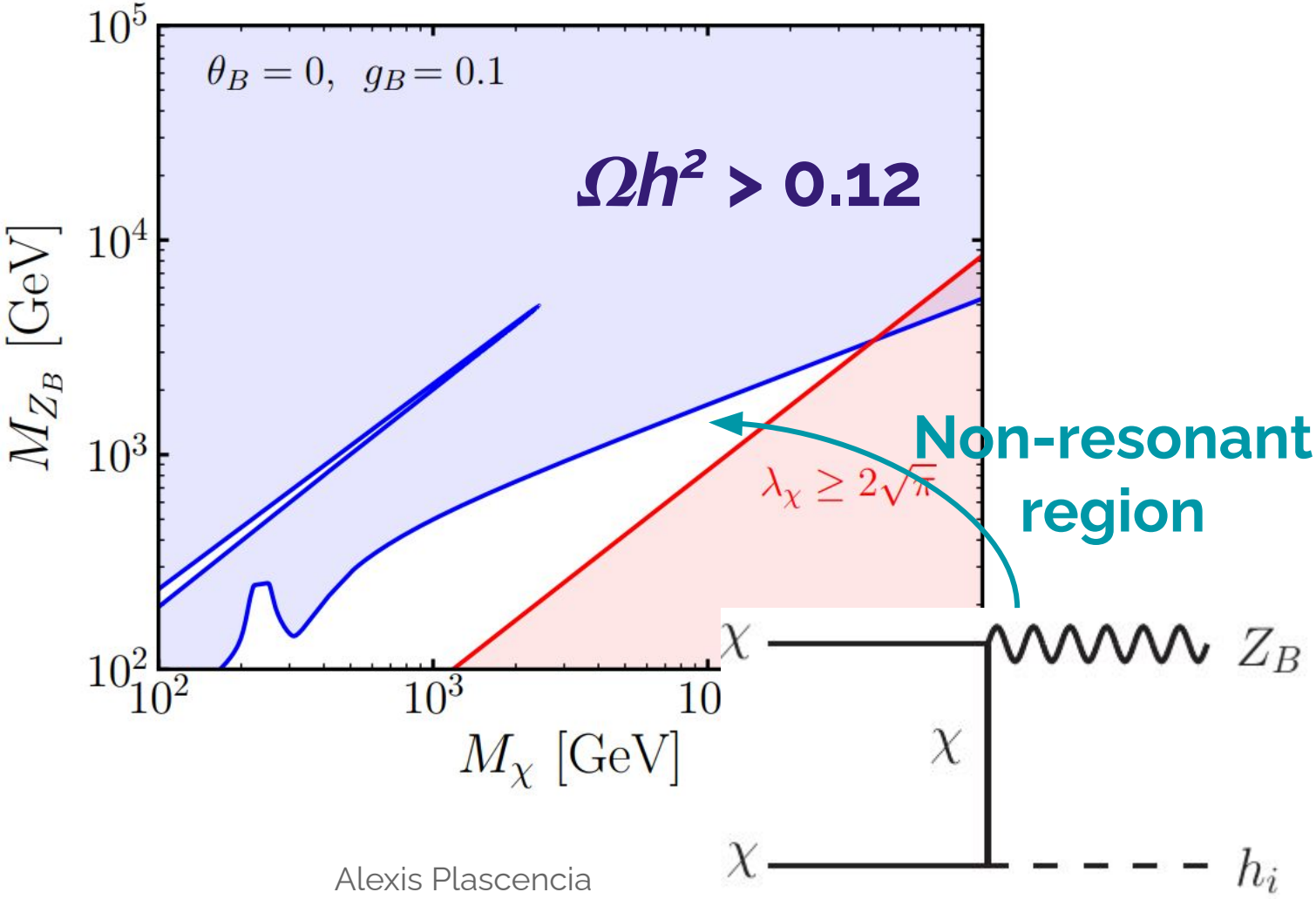
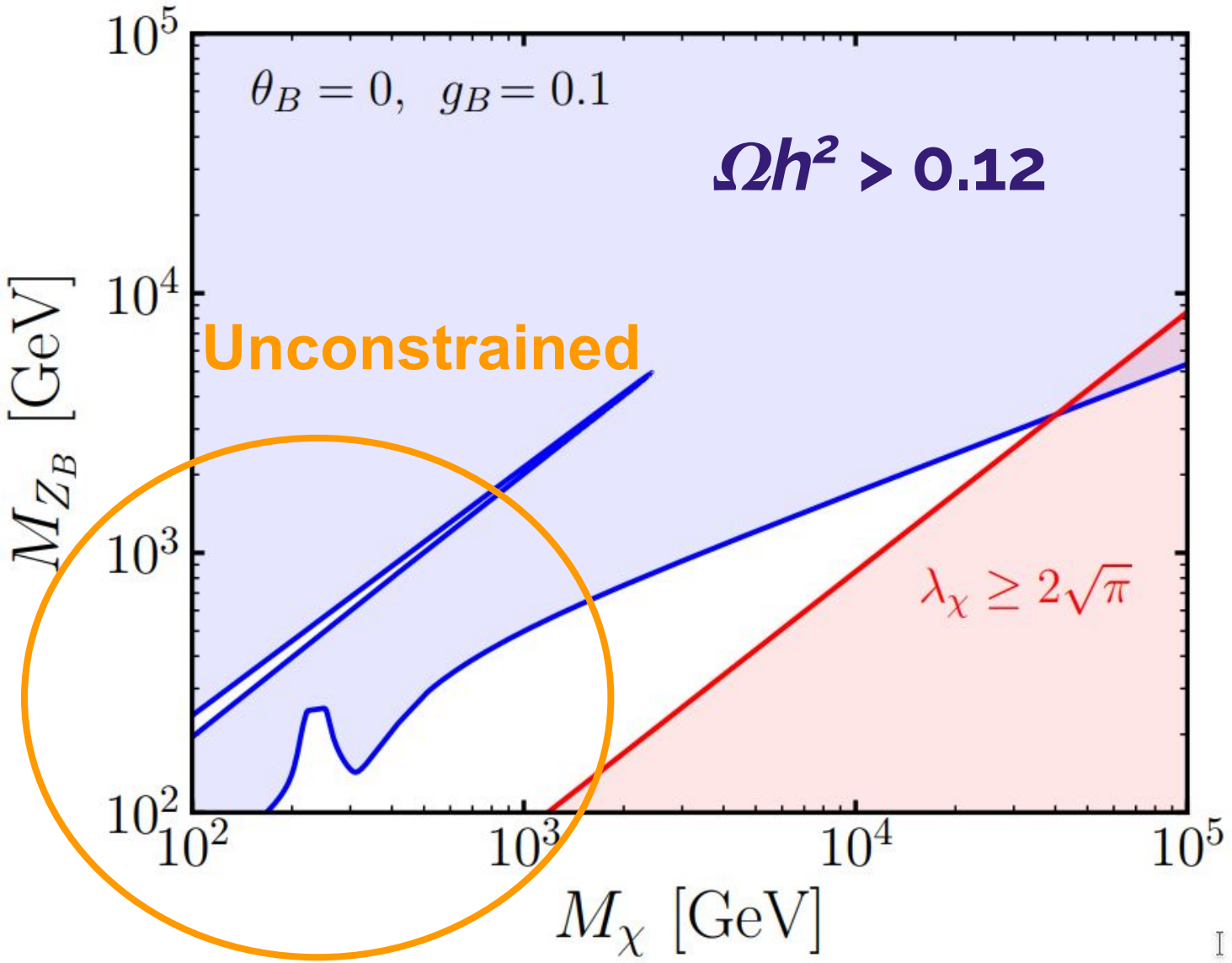


$$M_\chi \approx M_{h_2}/2$$




$\theta_B = 0, \quad g_B = 0.1$
$\Omega h^2 > 0.12$
M_{Z_B} [GeV]
M_χ [GeV]
10^5
10^4
10^3
10^2
10^2
10^3
10
$\lambda_\chi \geq 2\sqrt{\pi}$
Non-resonant region
χ
Z_B
χ
χ
h_i

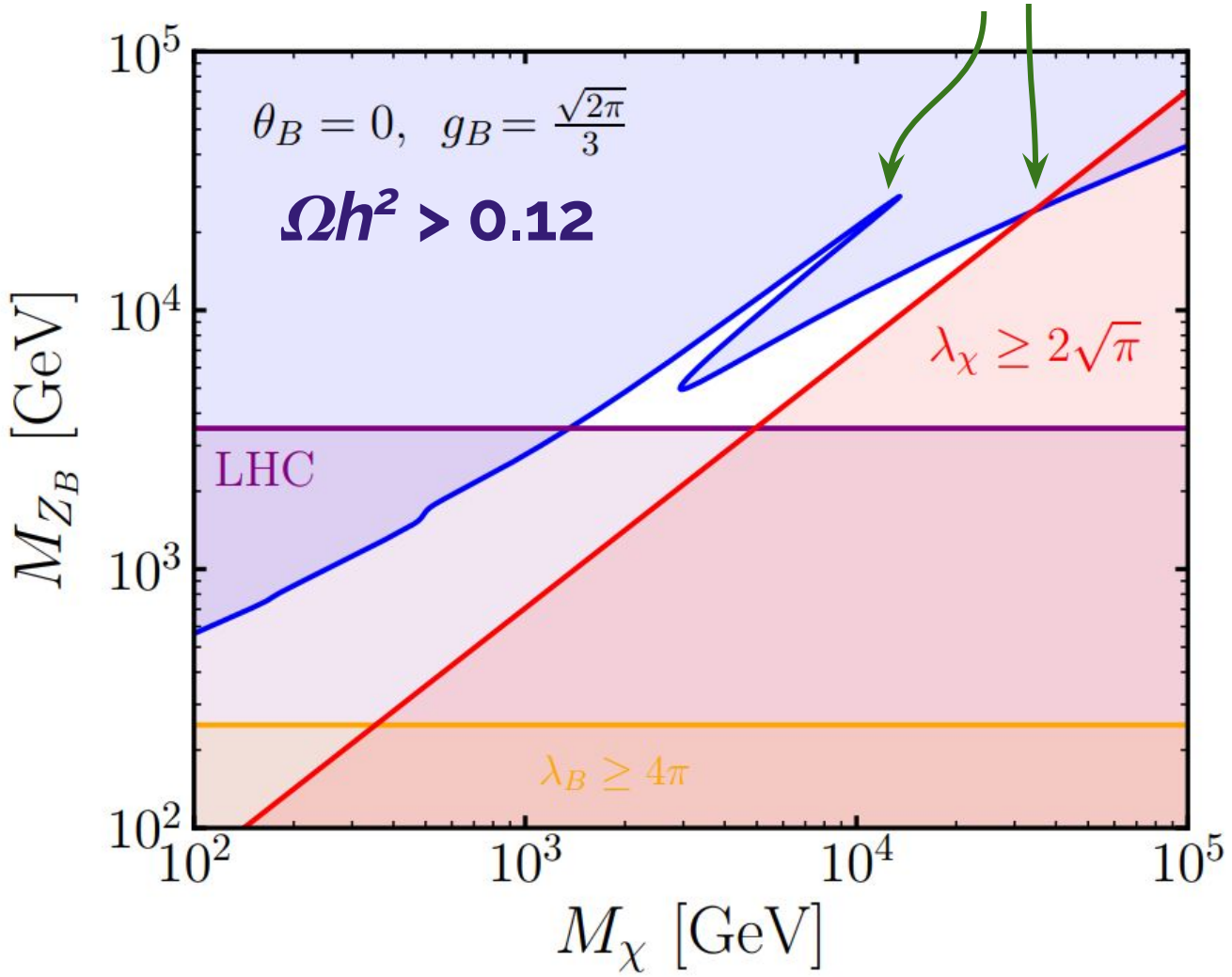
Results



[Fileviez Perez, Golias, Li, Murgui, ADP 1904.01017]

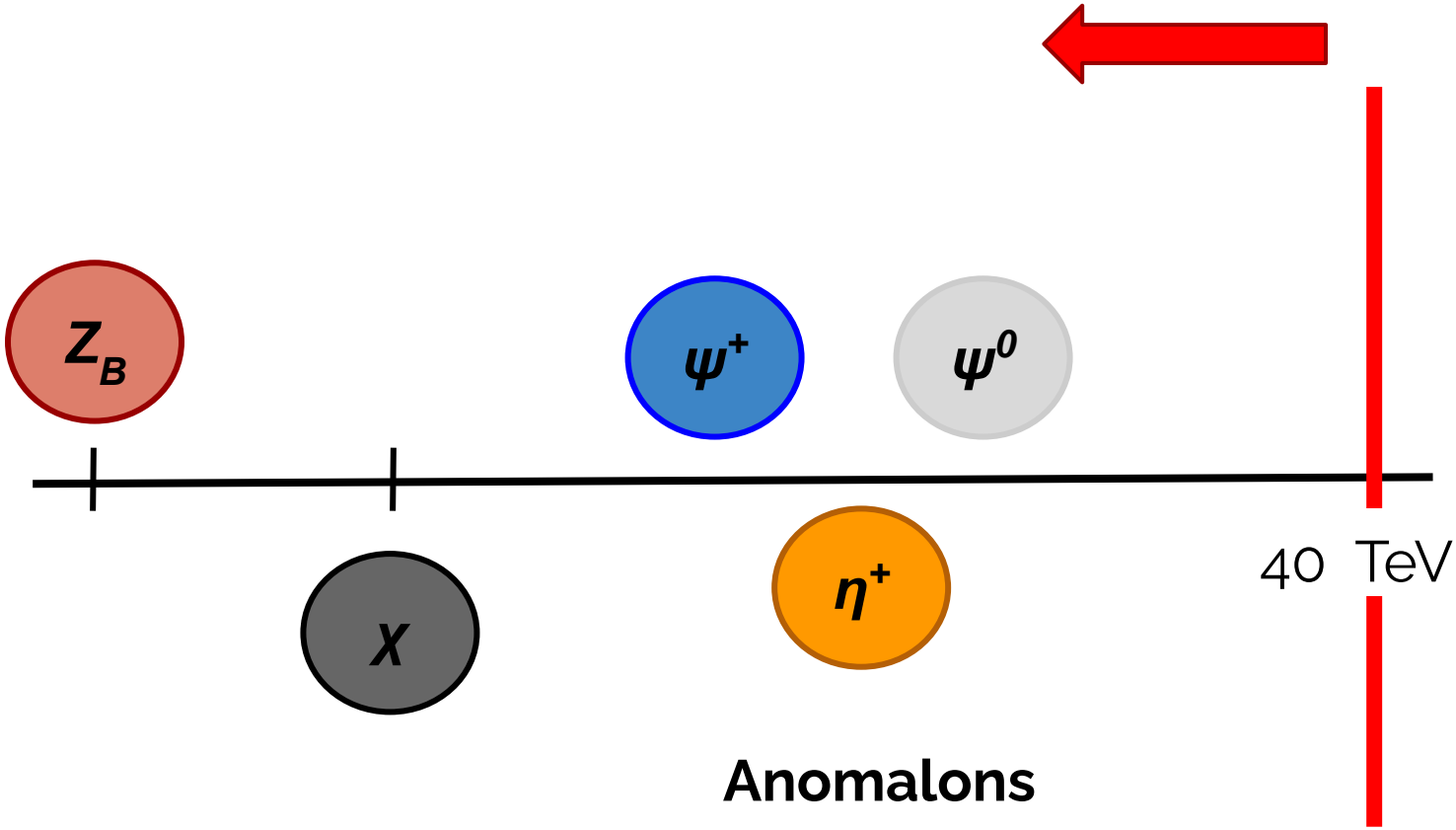
Perturbativity $g_B \leq \frac{\sqrt{2\pi}}{3} \approx 0.84$ and $\Omega h^2 \leq 0.12$

Give an upper bound on the scale



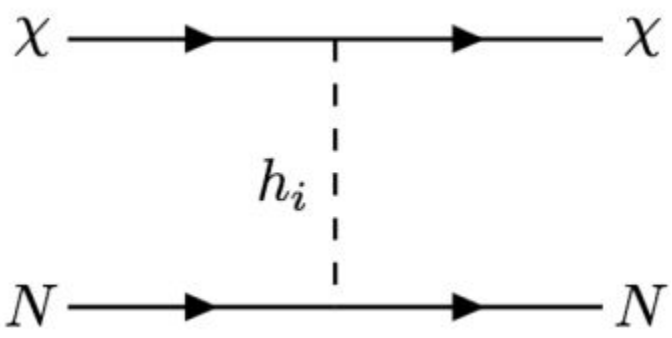
Upper bound on baryon number breaking scale

All masses connected to v_B , and hence, there is an upper bound for the full model



Direct Detection

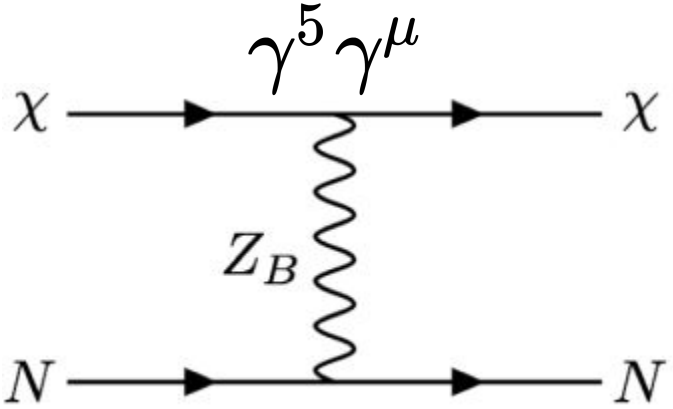
$$\sigma_{\chi N}^{\mathrm{TOT}} = \sigma_{\chi N}(h_i) + \sigma_{\chi N}^{0}(Z_B)v^2$$



suppressed by Higgs mixing

$\theta < 0.3$ for $M_{H_2} > 200$ GeV

For lighter M_{H_2} stronger bound



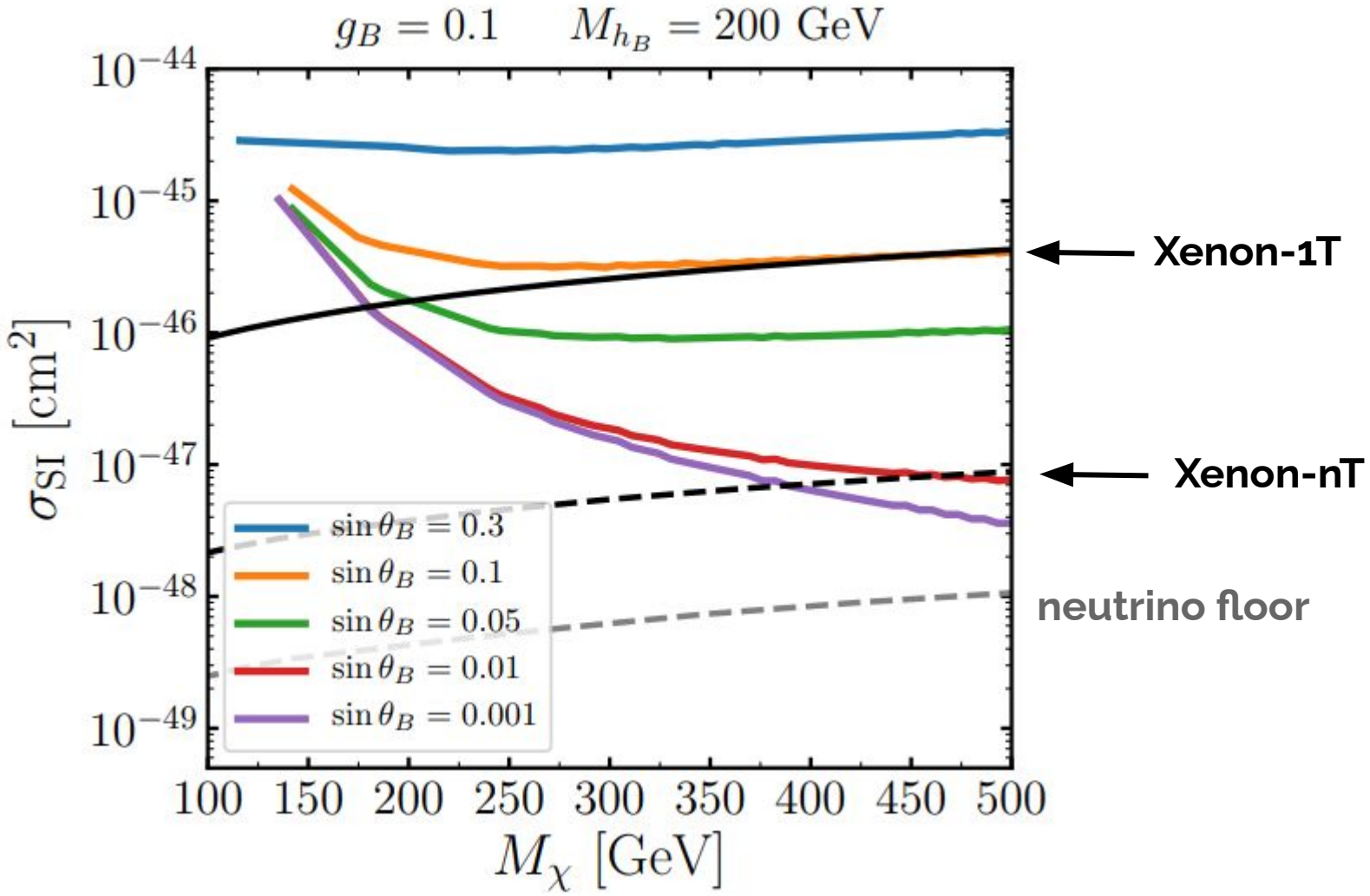
Due to axial coupling,

velocity suppressed $v \sim 10^{-3}$

[Ilnicka, Robens, Stefaniak 2018]

Direct Detection

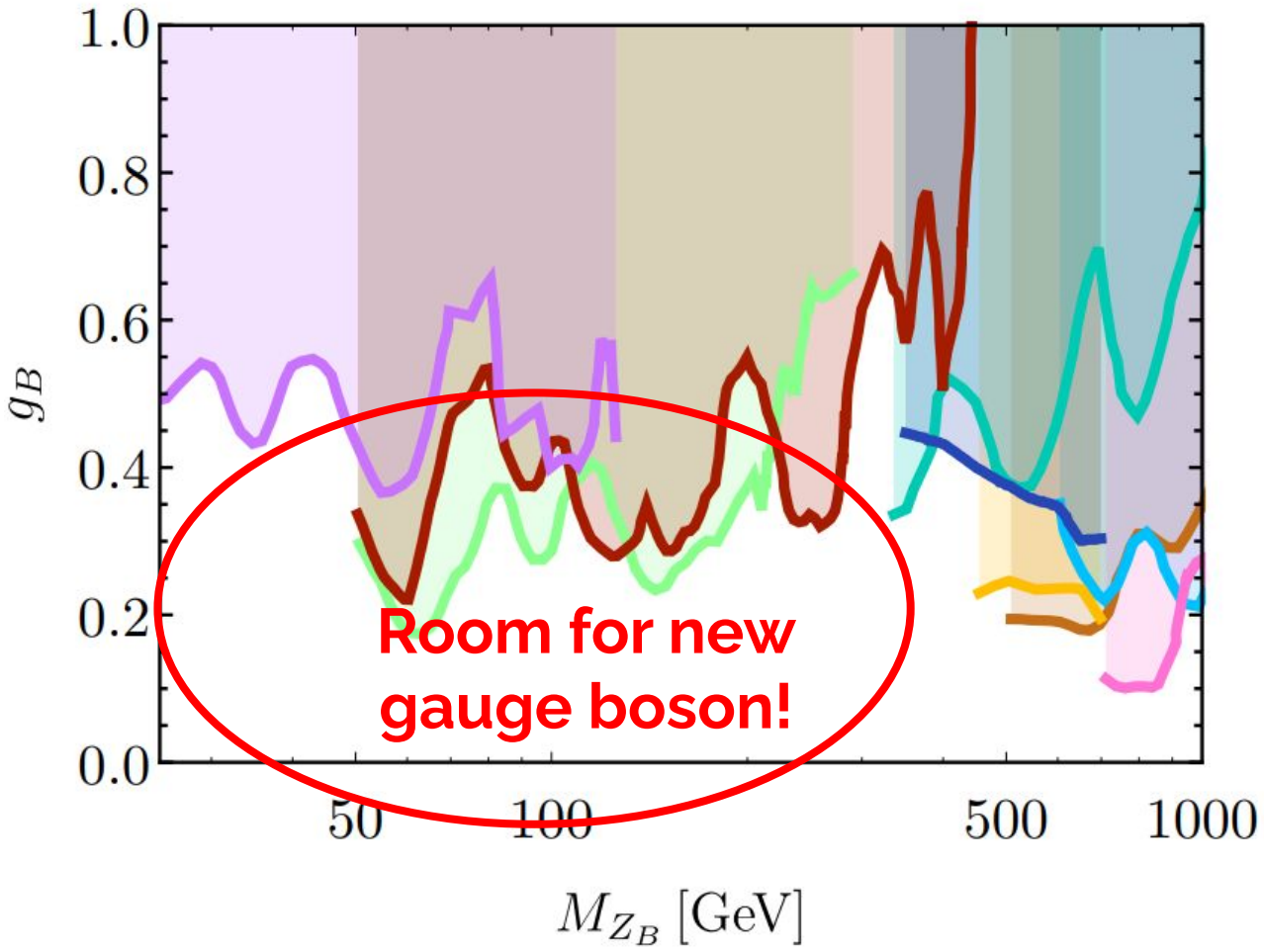
All points satisfy: $\Omega h^2 = 0.12 \pm 0.0022$



2. LHC Phenomenology

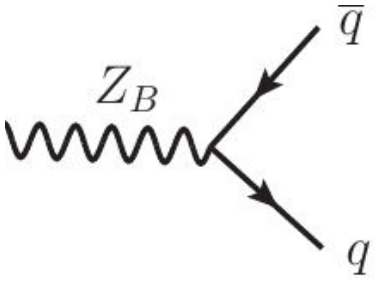
LHC bounds on leptophobic gauge boson

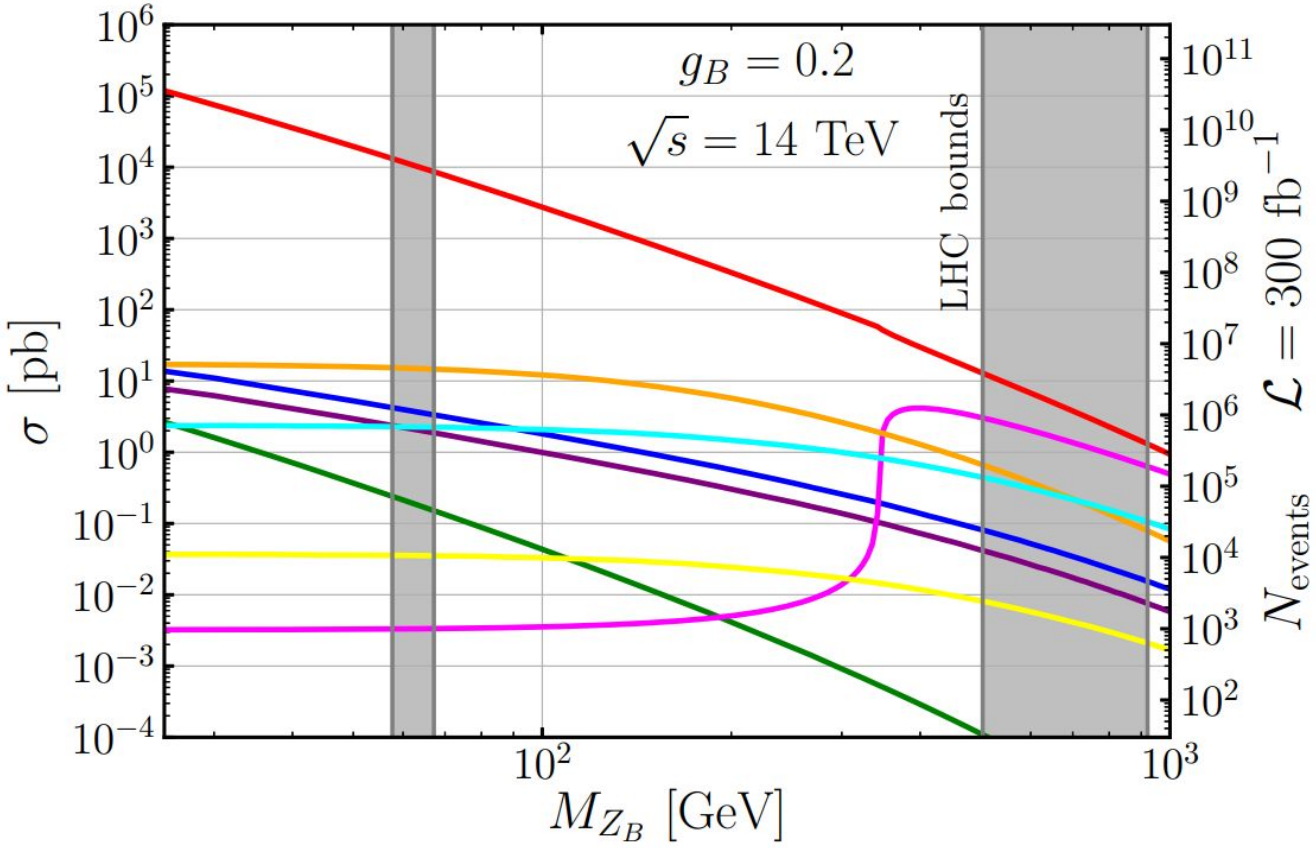
- Di-jet searches at CMS and ATLAS - Run I & II

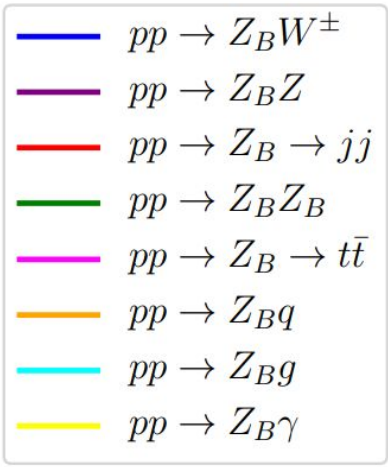


[Fileviez Perez, Murgui, ADP 2003.09426]

LHC production cross-sections



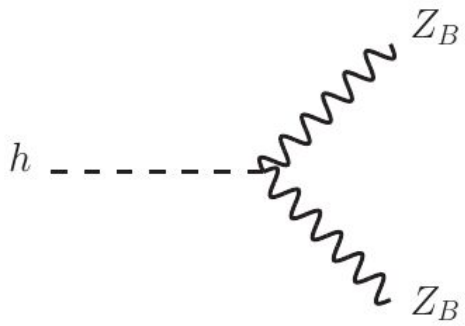




[Fileviez Perez, Golias, Murgui, ADP 2003.09426]

Exotic Higgs decays

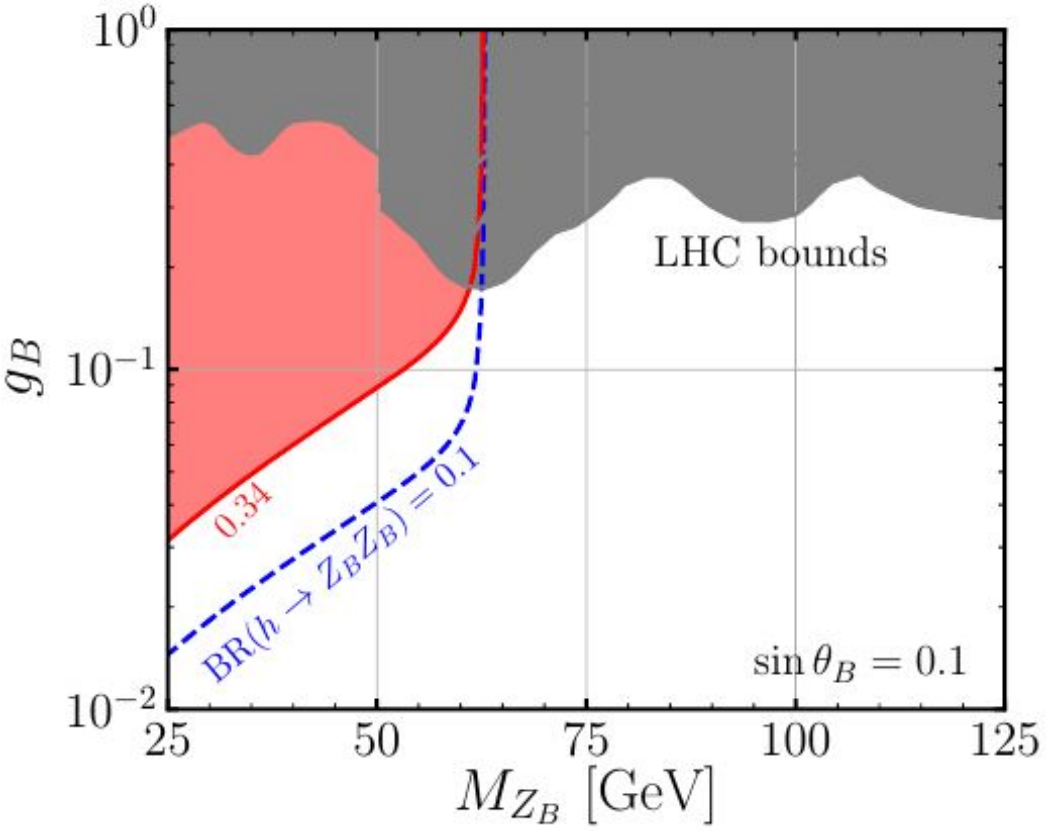
When $M_{Z_B} \leq M_h/2$:



$$hZ_B^\mu Z_B^\nu : \; 2i\frac{M_{Z_B}^2}{v_B} g^{\mu\nu} \sin\theta_B,$$

$$\mathrm{BR}(h \to \mathrm{BSM}) \leq 0.34$$

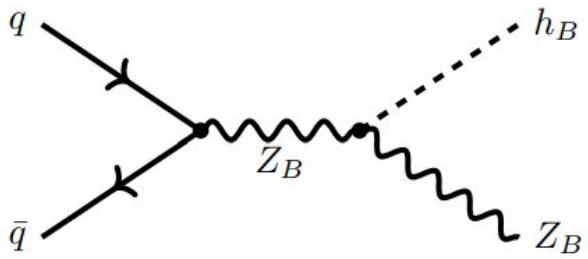
[ATLAS & CMS 1606.02266]

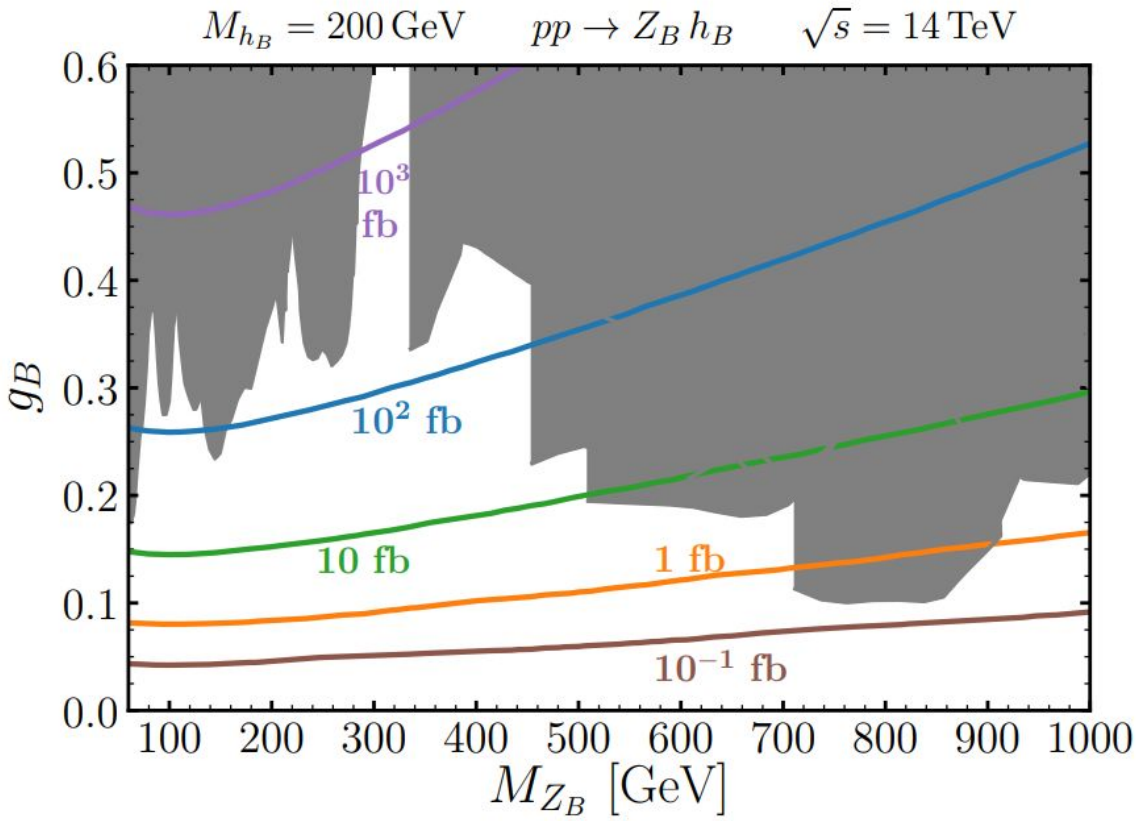


[Fileviez Perez, Golias, Murgui, ADP 2020]

The Higgs of Baryon Number h_B

Associated production does not depend on scalar mixing





[Fileviez Perez, Murgui, ADP 2012.06599]

The Higgs of Baryon Number h_B

We calculate full one-loop decays

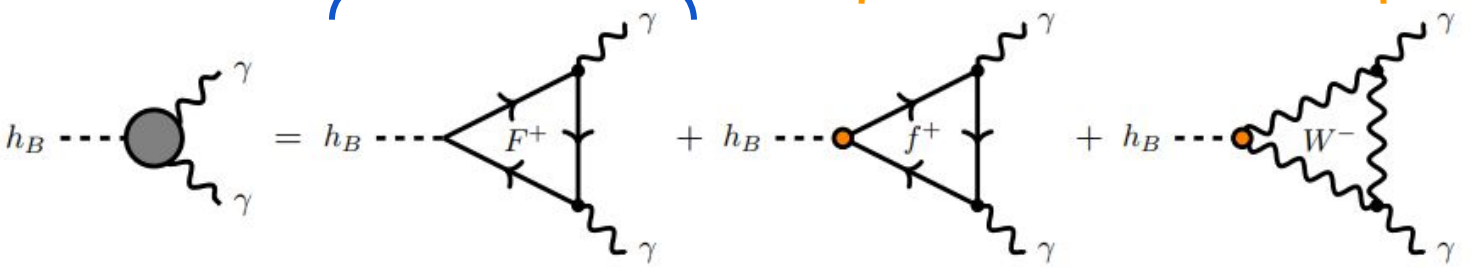
Second Higgs can have a large branching ratio into pair of photons

Anomaly-canceling fermions run in the loop!

small mixing

large mixing with SM *h*

- $h_B \to \gamma\gamma$:



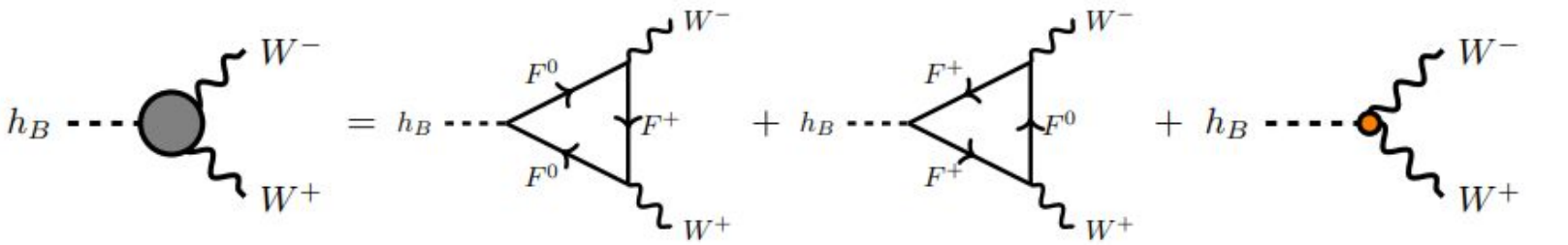
$$\Gamma(h_B \to \gamma\gamma) = \frac{\alpha^2}{64\pi^3 M_{h_B}^5} \left| \cos\theta_B \sum_{F^+} \frac{3 g_B M_{F^+}^2}{M_{Z_B}} F_{F^+} + \frac{\sin\theta_B}{v_0} \left(\sum_{f^+} N_c^f Q_f^2 m_{f^+}^2 F_{f^+} - F_W \right) \right|^2 .$$

[Fileviez Perez, Murgui, ADP 2012.06599]

The Higgs of Baryon Number h_B

small mixing with SM h — large mixing

- $h_B \to WW$:

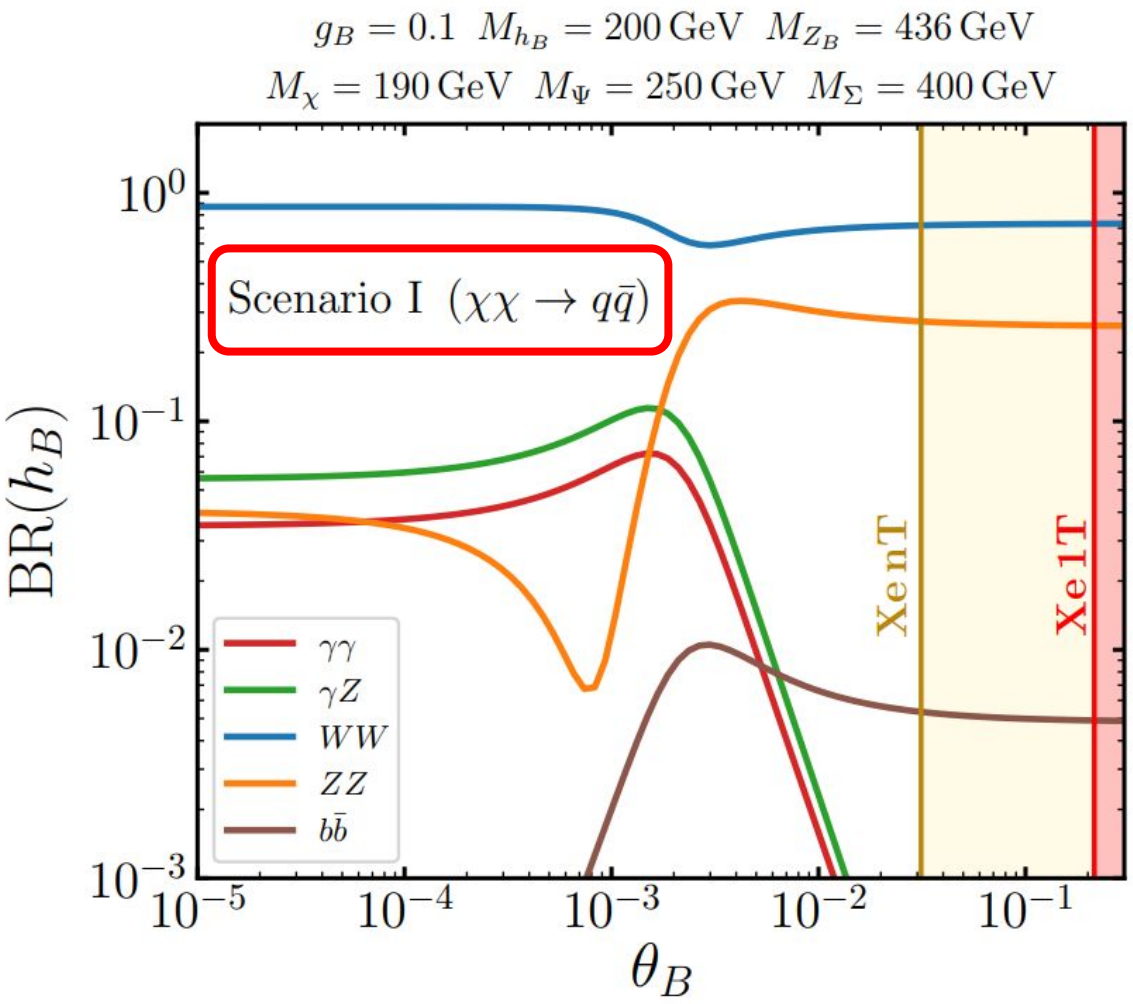


$$\Gamma(h_B \to WW) = \frac{\sqrt{M_{h_B}^2 - 4M_W^2}}{16\pi M_{h_B}^2 M_W^4}\left(\cos^2\theta_B \frac{9g_B^2}{M_{Z_B}^2}\left|\sum_F g_{WF}^2 B_F[W]\right|^2 + 2(M_{h_B}^2 - 2M_W^2)\times\right.$$
$$\mathrm{Re}\left\{\cos\theta_B \frac{3g_B}{M_{Z_B}}\sum_F g_{WF}^2 B_F[W]\left(\cos\theta_B \frac{3g_B}{M_{Z_B}}\sum_F g_{WF}^2 C_F^*[W] + \frac{\sin\theta_B}{v_0}M_W^2\right)\right\}$$
$$\left. + \left|\cos\theta_B \frac{3g_B}{M_{Z_B}}\sum_F g_{WF}^2 C_F[W] + \frac{\sin\theta_B}{v_0}M_W^2\right|^2 (M_{h_B}^4 - 4M_{h_B}^2 M_W^2 + 12M_W^4)\right).$$

[Fileviez Perez, Murgui, ADP 2012.06599]

The Higgs of Baryon Number h_B

Correlation between dark matter and the properties of the second Higgs



$$\Omega_{\text{DM}} h^2 = 0.12$$

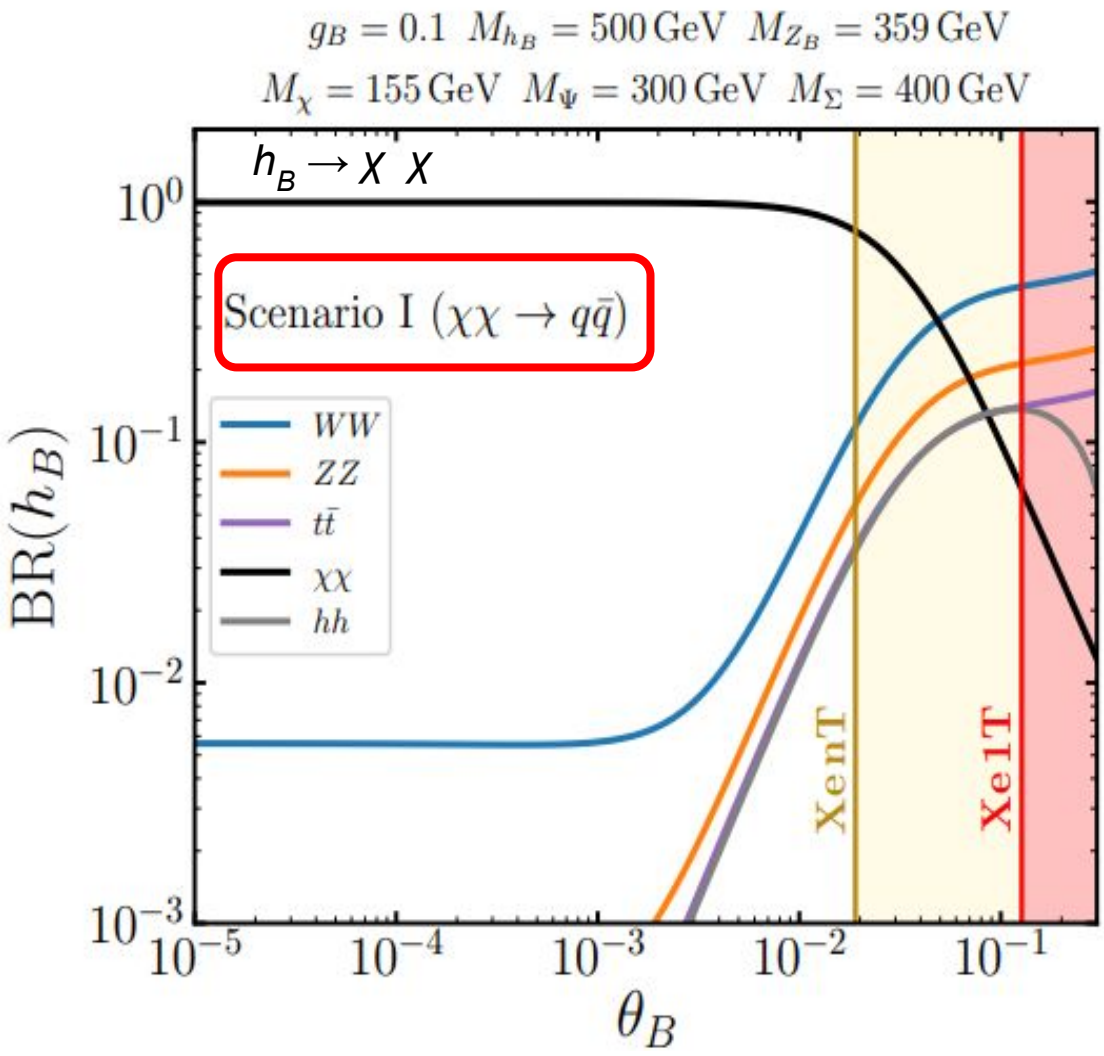
$$\text{Br}(h_B \to \gamma\gamma) \simeq 5\%$$

Large di-photon decay!

0.1% for SM Higgs

[Fileviez Perez, Murgui, ADP 2012.06599]

$M_\chi < M_{h_B}/2$ **Dominant invisible decay**

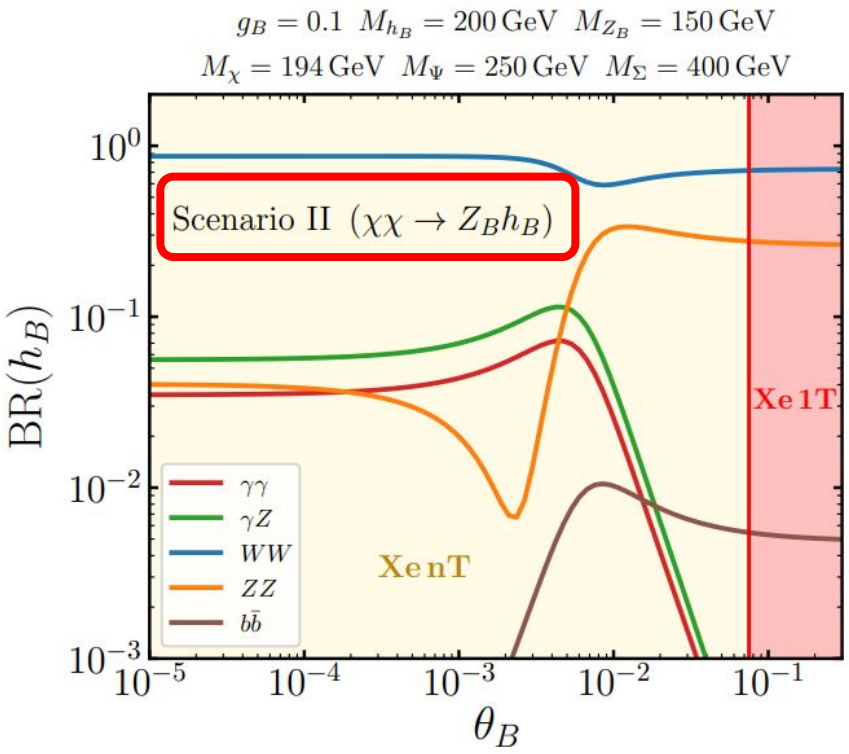


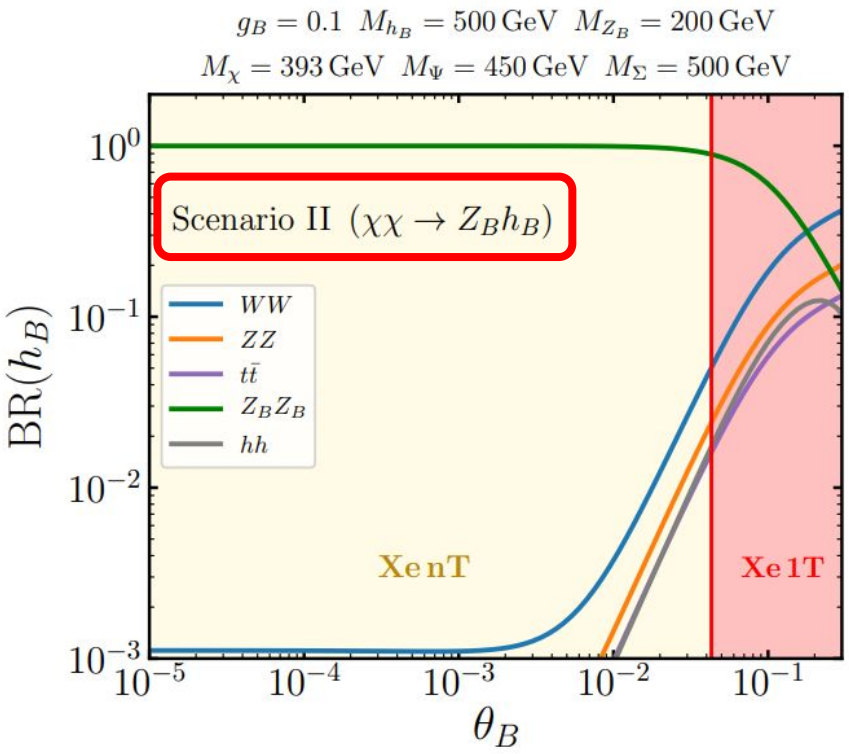
[Fileviez Perez, Murgui, ADP 2012.06599]

The Higgs of Baryon Number h_B

Correlation between dark matter and the properties of the second Higgs

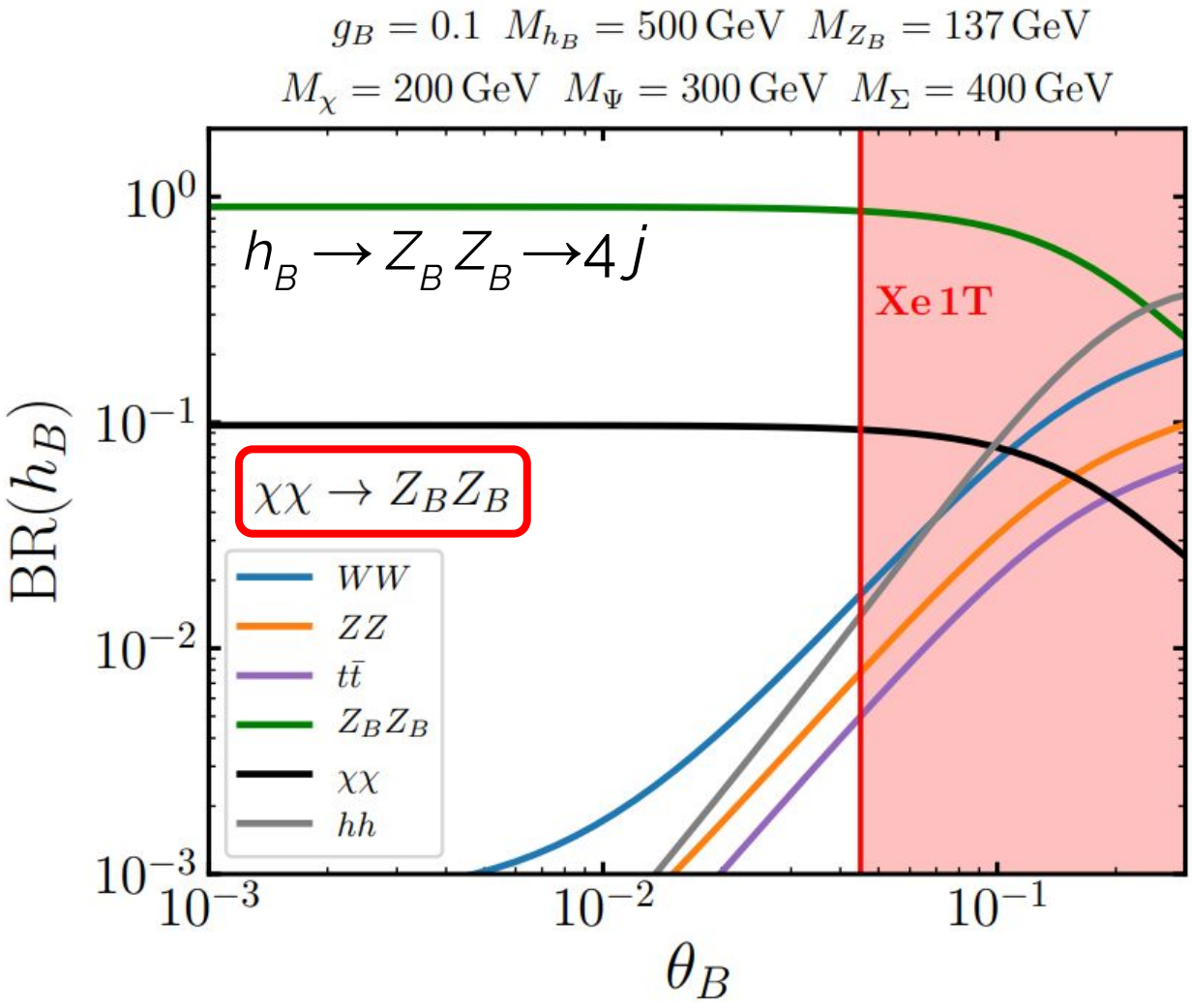
$$h_B \to Z_B Z_B$$





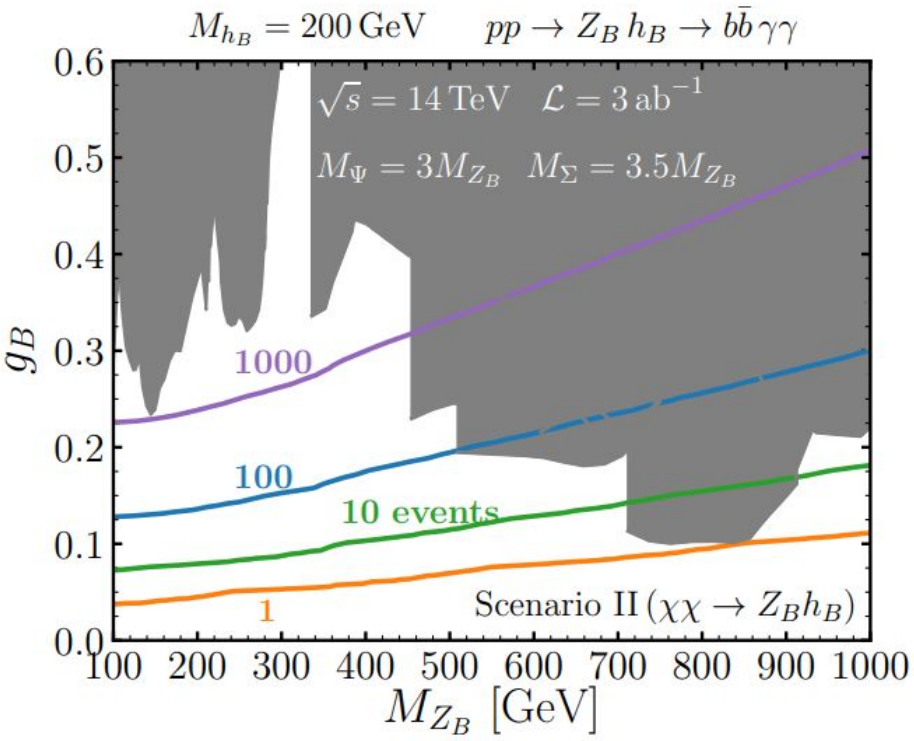
[Fileviez Perez, Murgui, ADP 2012.06599]

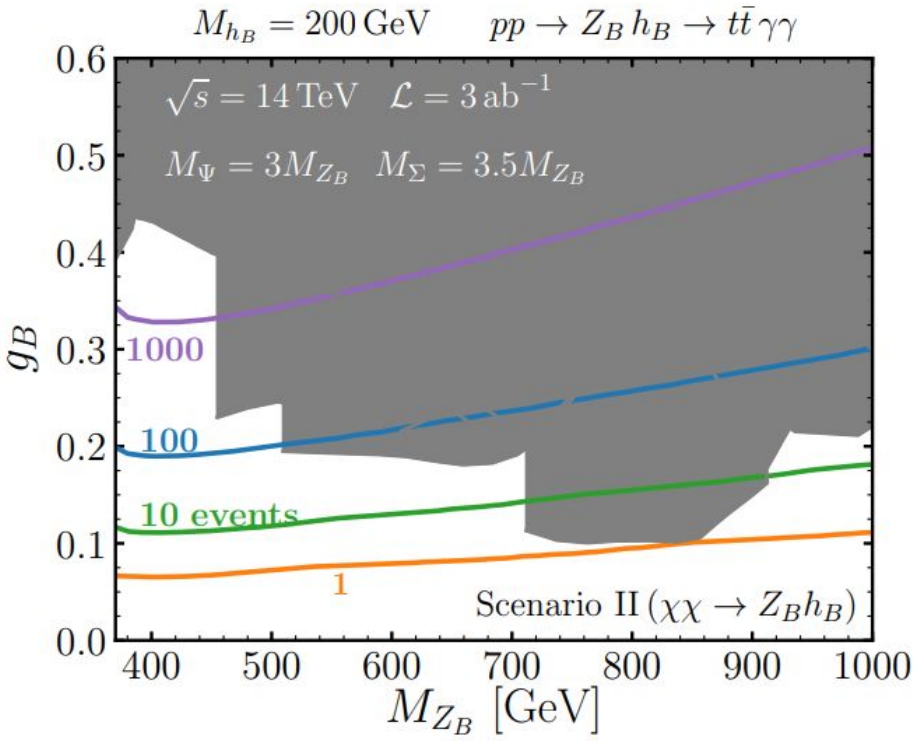
The Higgs of Baryon Number h_B



[Fileviez Perez, Murgui, ADP 2012.06599]

The Higgs of Baryon Number h_B





[Fileviez Perez, Murgui, ADP 2012.06599]

Conclusions

- Promoting baryon and/or lepton number to local symmetries predicts a new sector from anomaly cancellation

- Leptophobic mediator and second Higgs leads to interesting phenomenology at the LHC

- These new fermions lead have implications for the properties of the second Higgs $\mathbf{Br}(h_B \to \gamma\gamma) \simeq 5\%$

- Not overproducing dark matter gives an upper bound on the full theory at the multi-TeV scale

Thank you!


рахмат
danke
謝謝
ngiyabonga
teşekkür ederim
spas
Баярлалаа
mersi
kia ora
barka
welalin
tack
mahalo
tapadh leat
спасибо
faafetai lava
vinaka
спасибі
blagodaram
dank je
misaotra
matondo
paldies
grazzi
gracias
thank you
kiitos
dankie
nanni
nandri
dhanyavad
хвала
asante
manana
obrigada
tenki
bedankt
bayarlalaa
gràçie
hvala
mauruuru
köszönöm
dankon
akun
djiere dieuf
tau
mochchakkeram
murakoze
enkosi
dziękuję
дякую
mamnun
chokrane
chnorakaloutioun
gratias ago
gràcies
sulpáy
go raibh maith agat
sobodi
děkuji
sagolun
sukriya
kop khun krap
taiku
arigatô
takk
dakujem
trugarez
obrigado
mèsi
didi madloba
najis tuke
ありがとう
tanemirt
grazie
shukriya
mercé
мерси
kam sah hamnida
rahmat
terima kasih
rahmet
ευχαριστώ
diolch
dhanyavadagalu
merci
তোমাকে ধন্যবাদ
감사합니다
xièxie

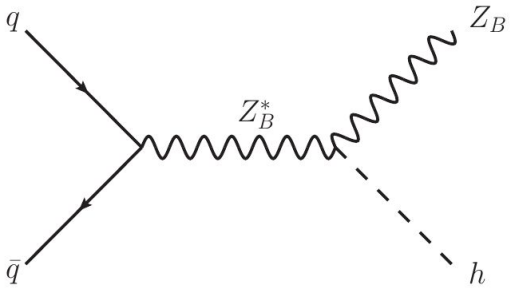
Back-up

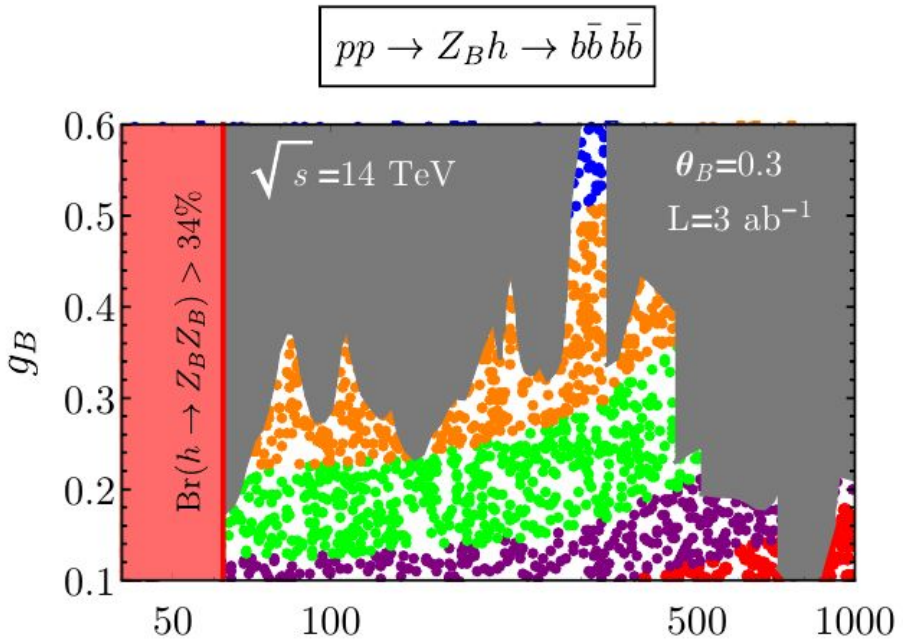
Model II

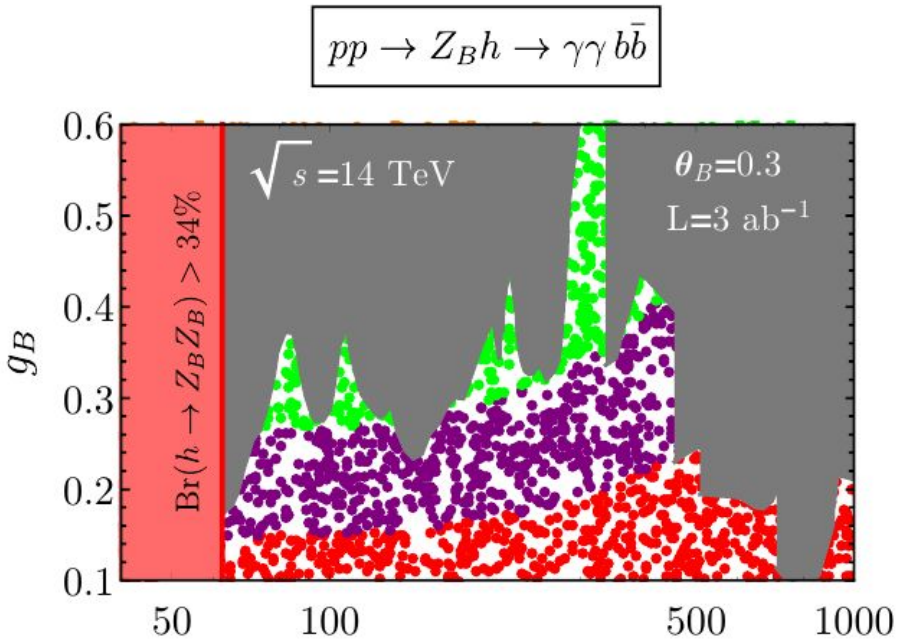
Fields	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	$U(1)_L$
$\Psi_L = \begin{pmatrix} \Psi_L^0 \\ \Psi_L^- \end{pmatrix}$	1	2	$-\frac{1}{2}$	$-\frac{3}{2}$
$\Psi_R = \begin{pmatrix} \Psi_R^0 \\ \Psi_R^- \end{pmatrix}$	1	2	$-\frac{1}{2}$	$\frac{3}{2}$
η_R^-	1	1	-1	$-\frac{3}{2}$
η_L^-	1	1	-1	$\frac{3}{2}$
χ_R^0	1	1	0	$-\frac{3}{2}$
χ_L^0	1	1	0	$\frac{3}{2}$

[Duerr, Fileviez Perez & Wise 2013]

Associated Higgs HB HB!! Production







- $N_{\text{events}} > 10^5$
- $10^4 < N_{\text{events}} < 10^5$
- $10^3 < N_{\text{events}} < 10^4$
- $10^2 < N_{\text{events}} < 10^3$
- $10 < N_{\text{events}} < 10^2$
- $N_{\text{events}} < 10$

[Fileviez Perez, Murgui, ADP 2003.09426]