On anomaly-free dark matter models

Alexis Plascencia

with Pavel Fileviez Perez, Elliot Golias, Rui-Hao Li and Clara Murgui

[arXiv: 1904.01017]

CASE WESTERN RESERVE UNIVERSITY EST. 1826

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WIMP paradigm

- Initially, dark matter particle in thermal equilibrium with plasma. Later on, due to weak interactions dark matter freezes-out

- Current experiments already impose strong constraints on the simplest WIMPs scenarios, where dark matter is coupled to Standard Model gauge bosons or the Higgs

- However, it is natural to expect new mediator between the SM and the Dark Sector

- In recent years, there has been a strong interest in studying simplified models for dark matter, where the new particles in the spectrum are only the DM and the mediator **Review: [1506.03116]**

GOAL: Study the phenomenology of consistent completions of simplified models.

Spin-1 mediator: New gauge boson that couples to SM fermions

One motivation, is to promote the global symmetries in the SM to gauge symmetries

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

This talk

$$\underbrace{\mathrm{U}(1)_L \qquad \mathrm{U}(1)_{B-L}}_{\text{See Clara Murgui talk Tuesday 15:30}}$$

Dark matter is predicted by anomaly cancellation and its stability is guaranteed by remnant U(1)$\longrightarrow Z_2$ symmetry

Simplified Dark Matter

χ: Majorana DM

Z_B : Leptophobic mediator

Motivated by gauging baryon number, we choose

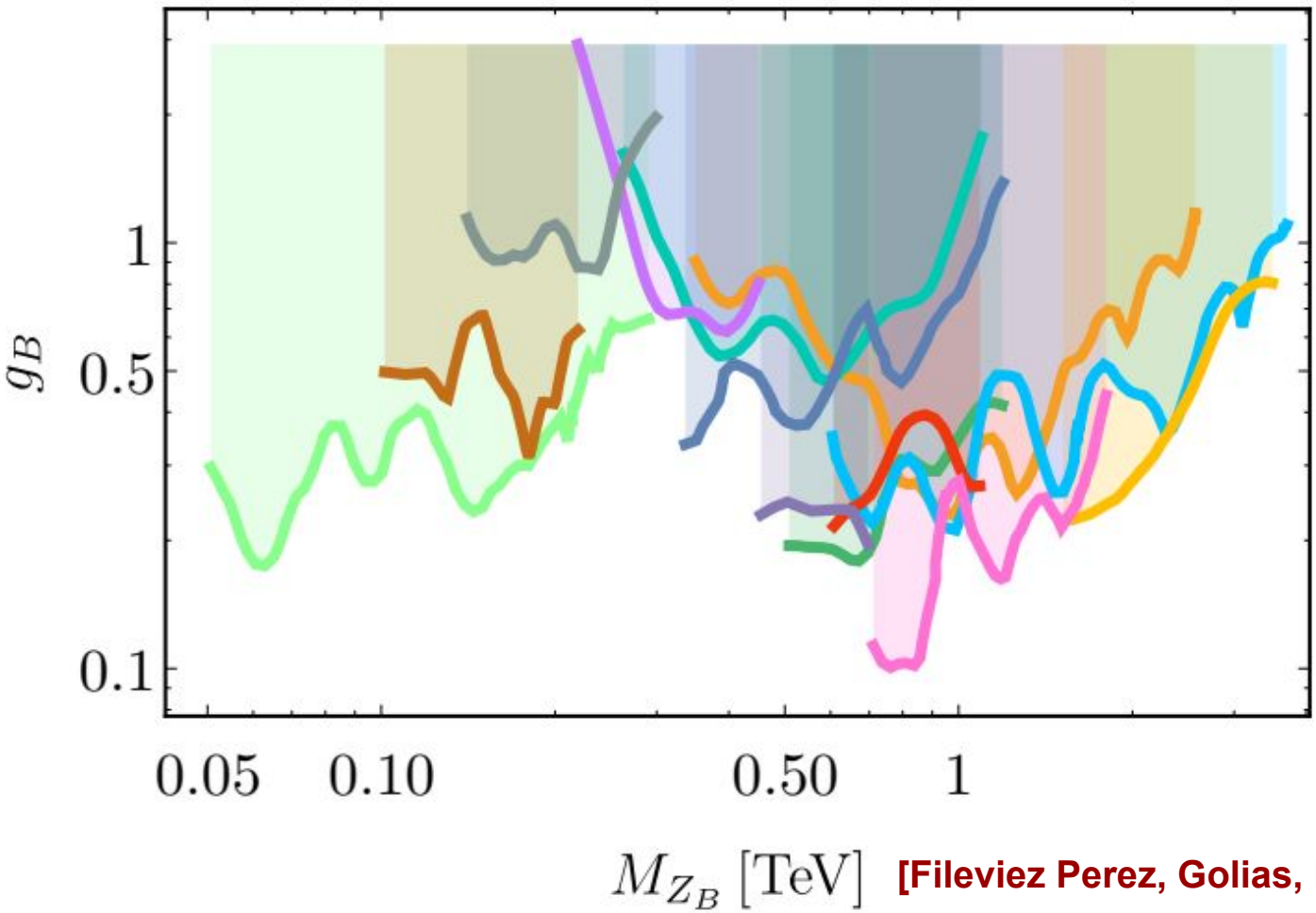
$$\mathcal{L} \supset \underbrace{\frac{3}{4} g_B \bar{\chi} \gamma^\mu \gamma^5 \chi Z_\mu^B}_{\textbf{Axial}} - \underbrace{\frac{1}{3} g_B \bar{q} \gamma^\mu q Z_\mu^B}_{\textbf{Vector}} + \frac{M_\chi}{2 v_B} \sin\theta_B \bar{\chi} \chi h_1 - \frac{M_\chi}{2 v_B} \cos\theta_B \bar{\chi} \chi h_2$$

the free parameters in the model are:

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

LHC bounds on leptophobic gauge boson

- No LEP bound for this scenario
- Di-jet searches at CMS and ATLAS - Run I & II



[Fileviez Perez, Golias, Li, Murgui 2018]

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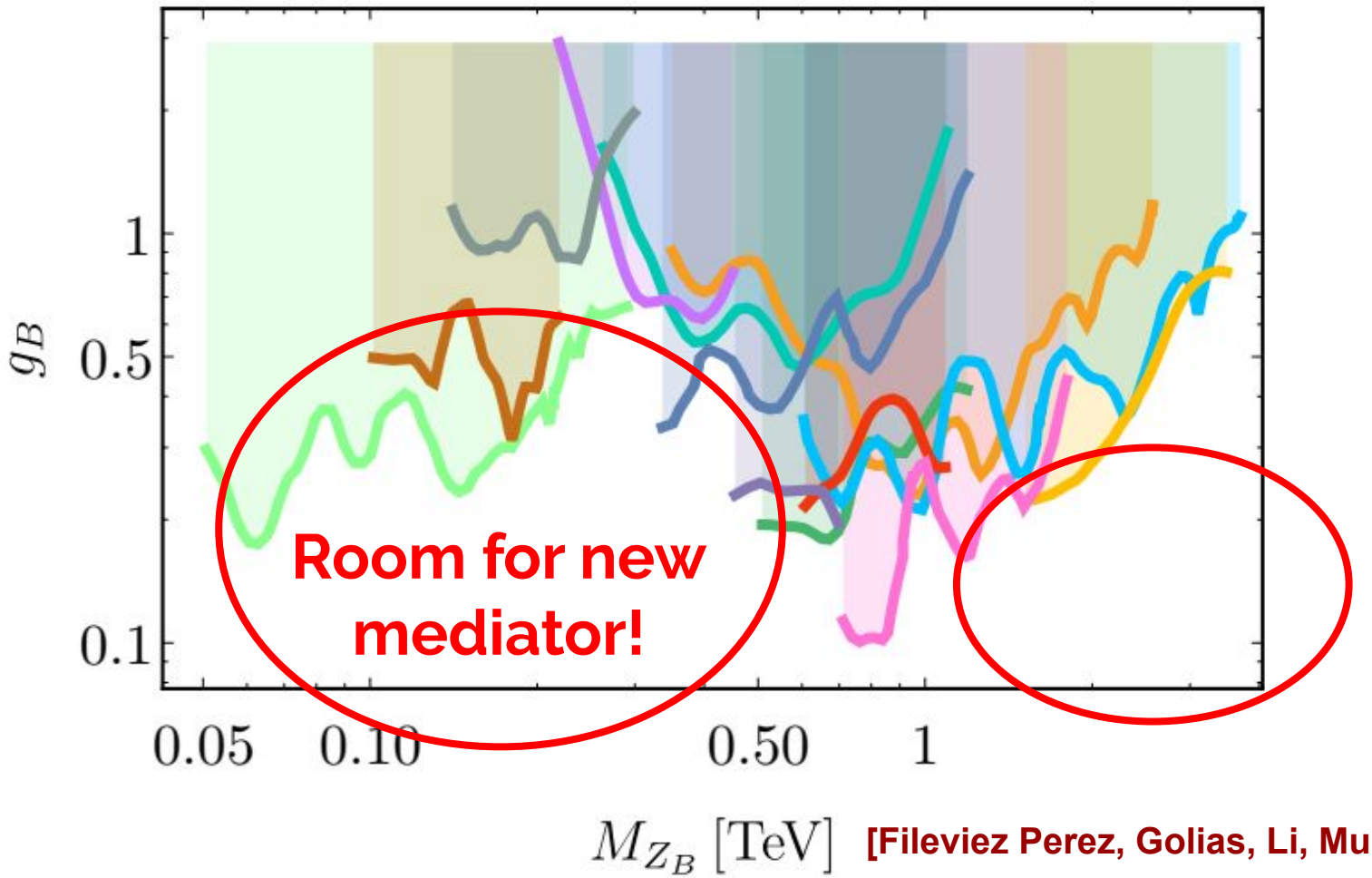
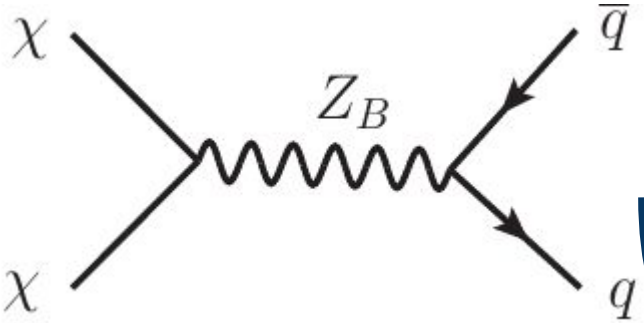
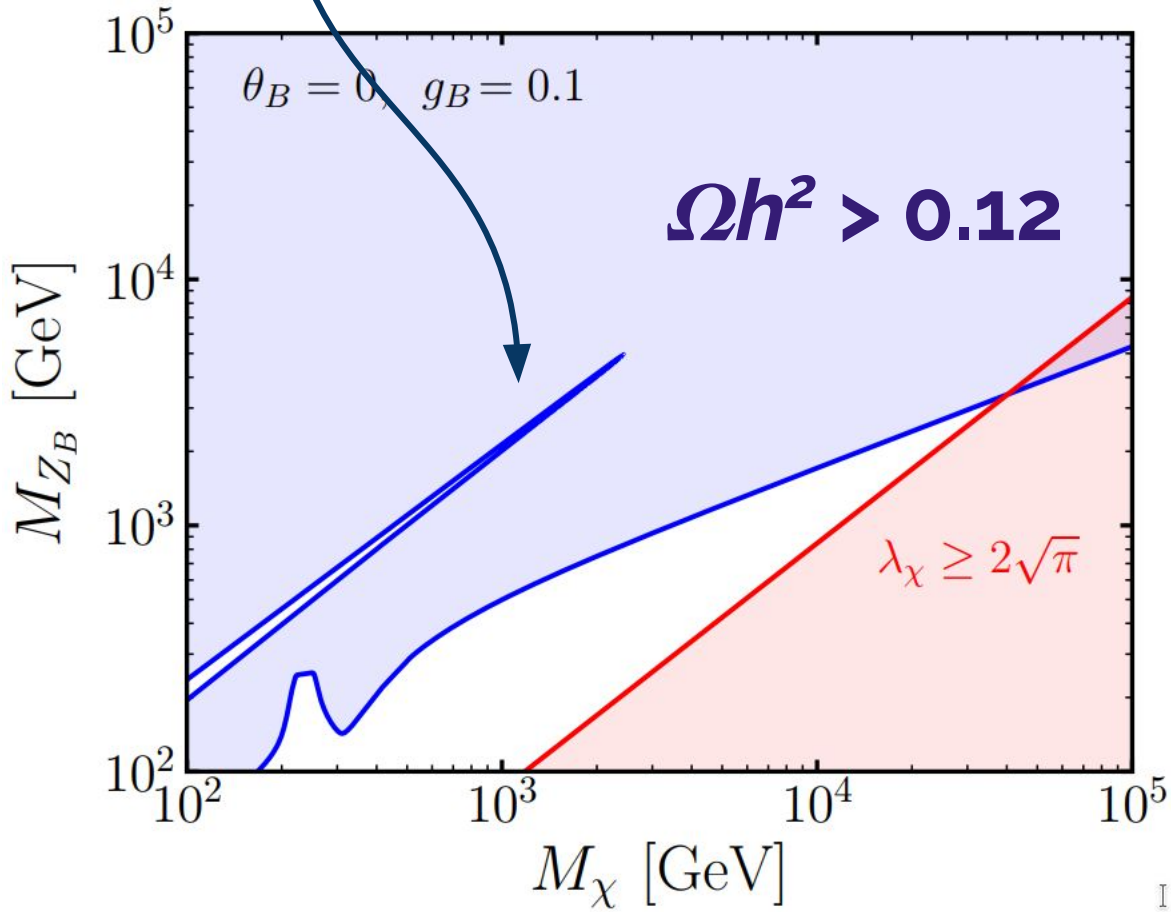
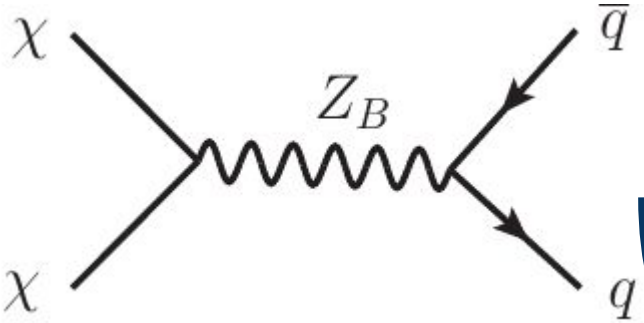


[Fileviez Perez, Golias, Li, Murgui 2018]



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





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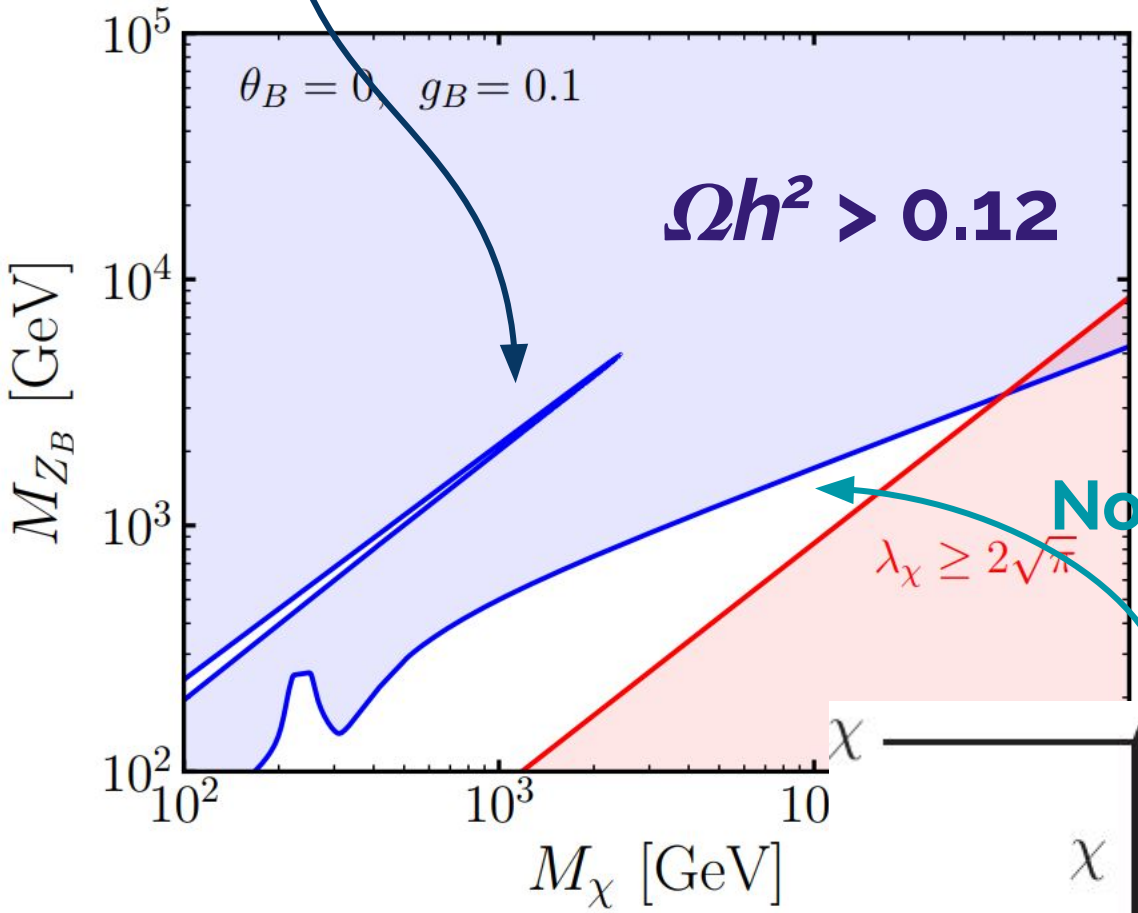
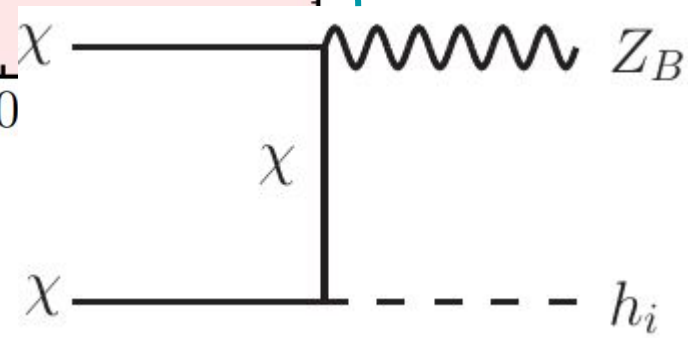
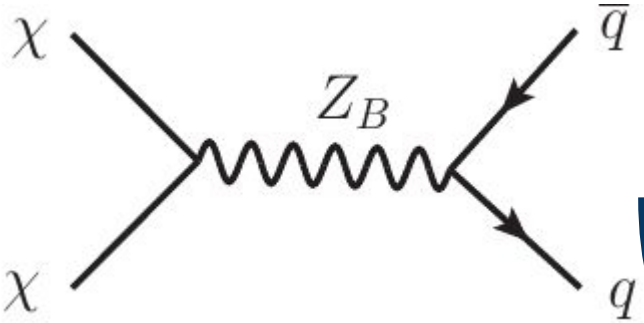


Non-resonant region





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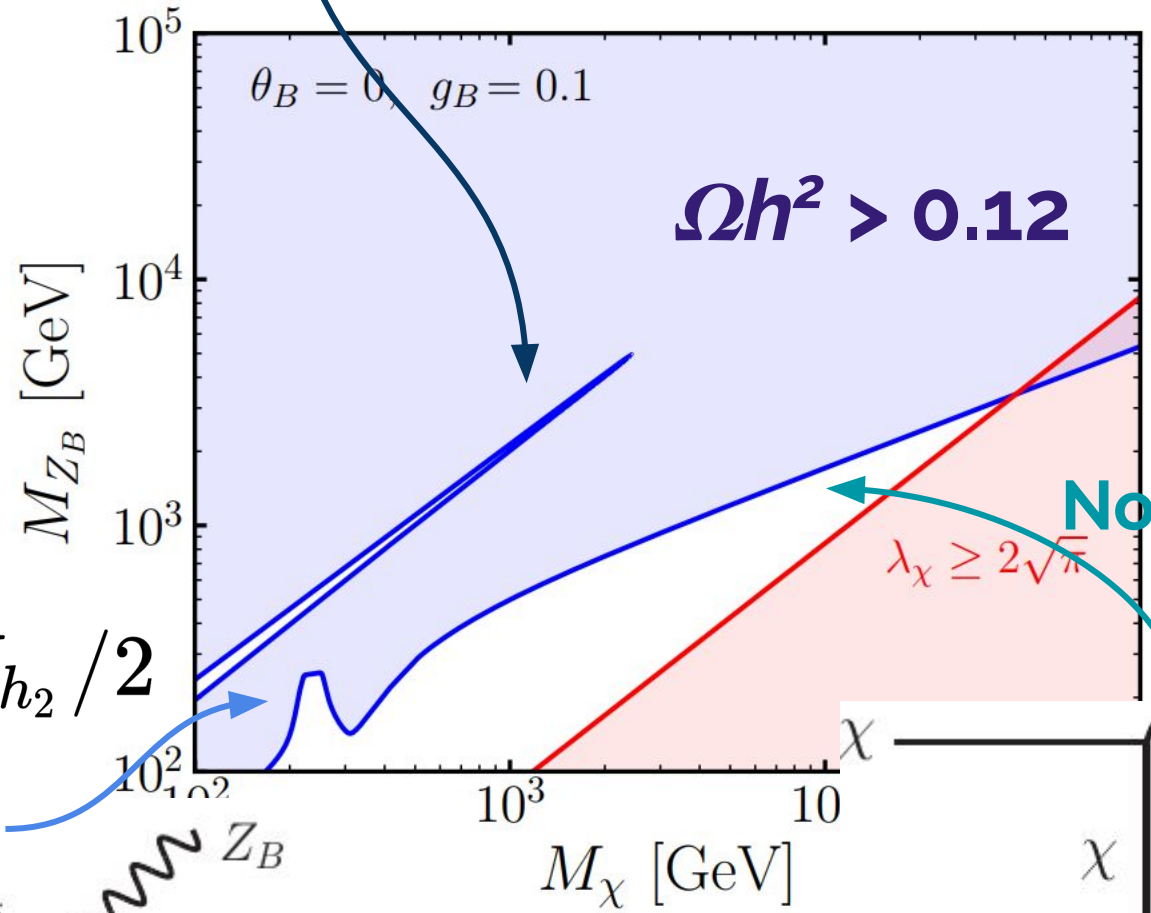
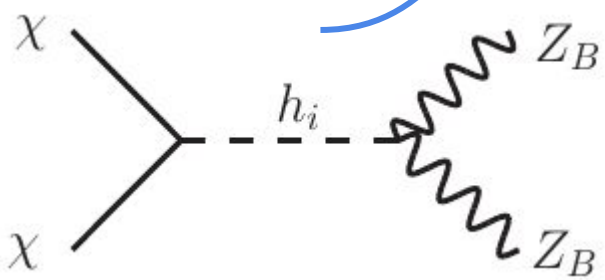
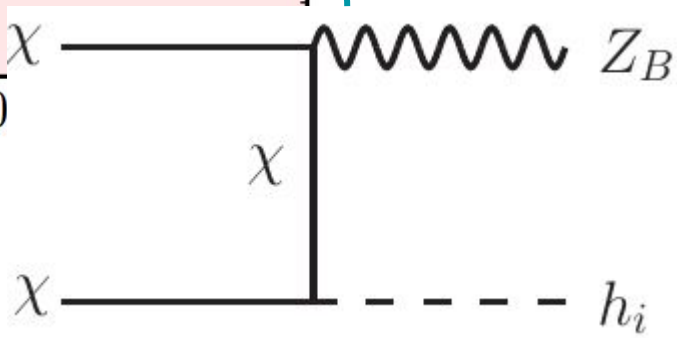


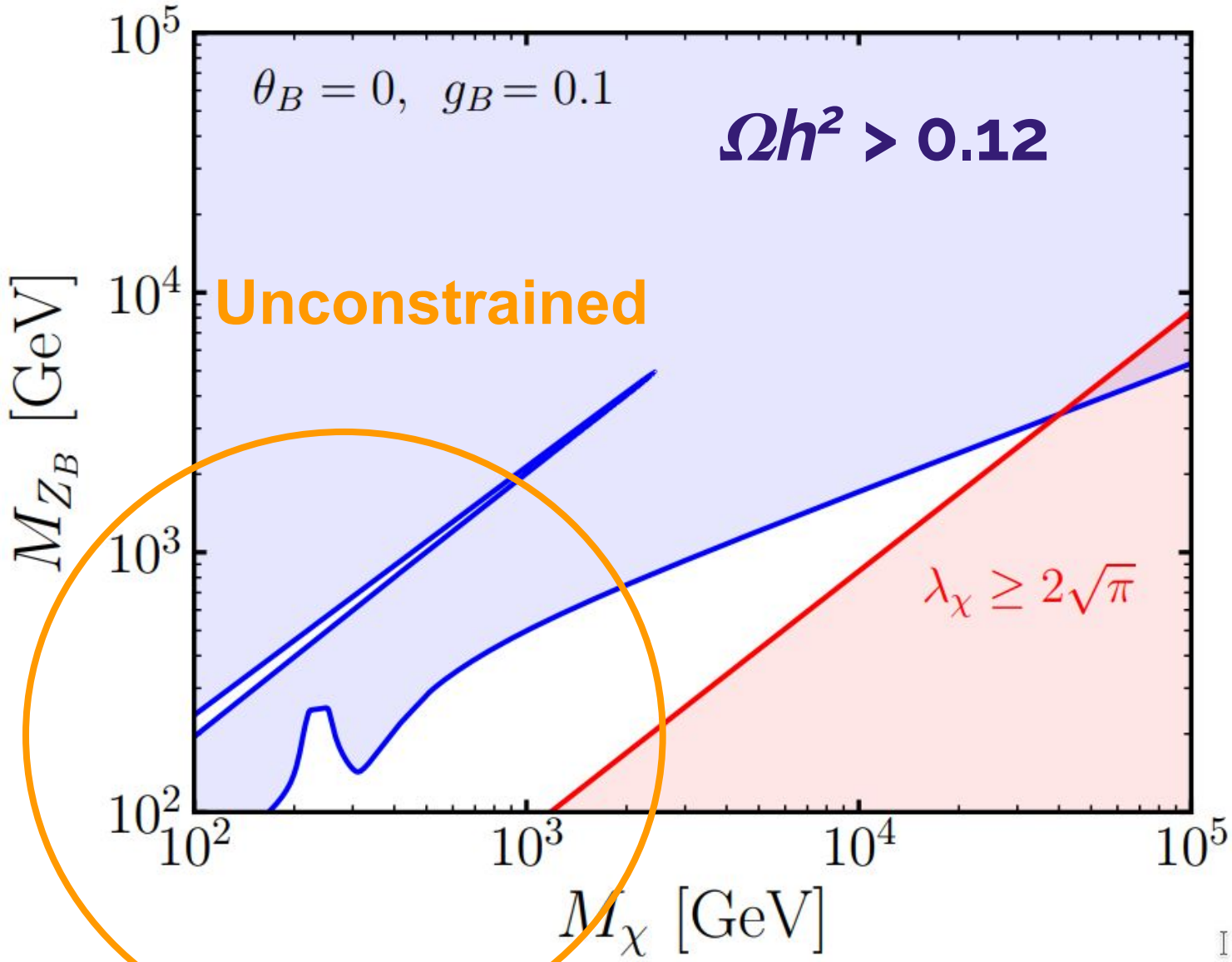
$$M_\chi \approx M_{h_2}/2$$



Non-resonant region

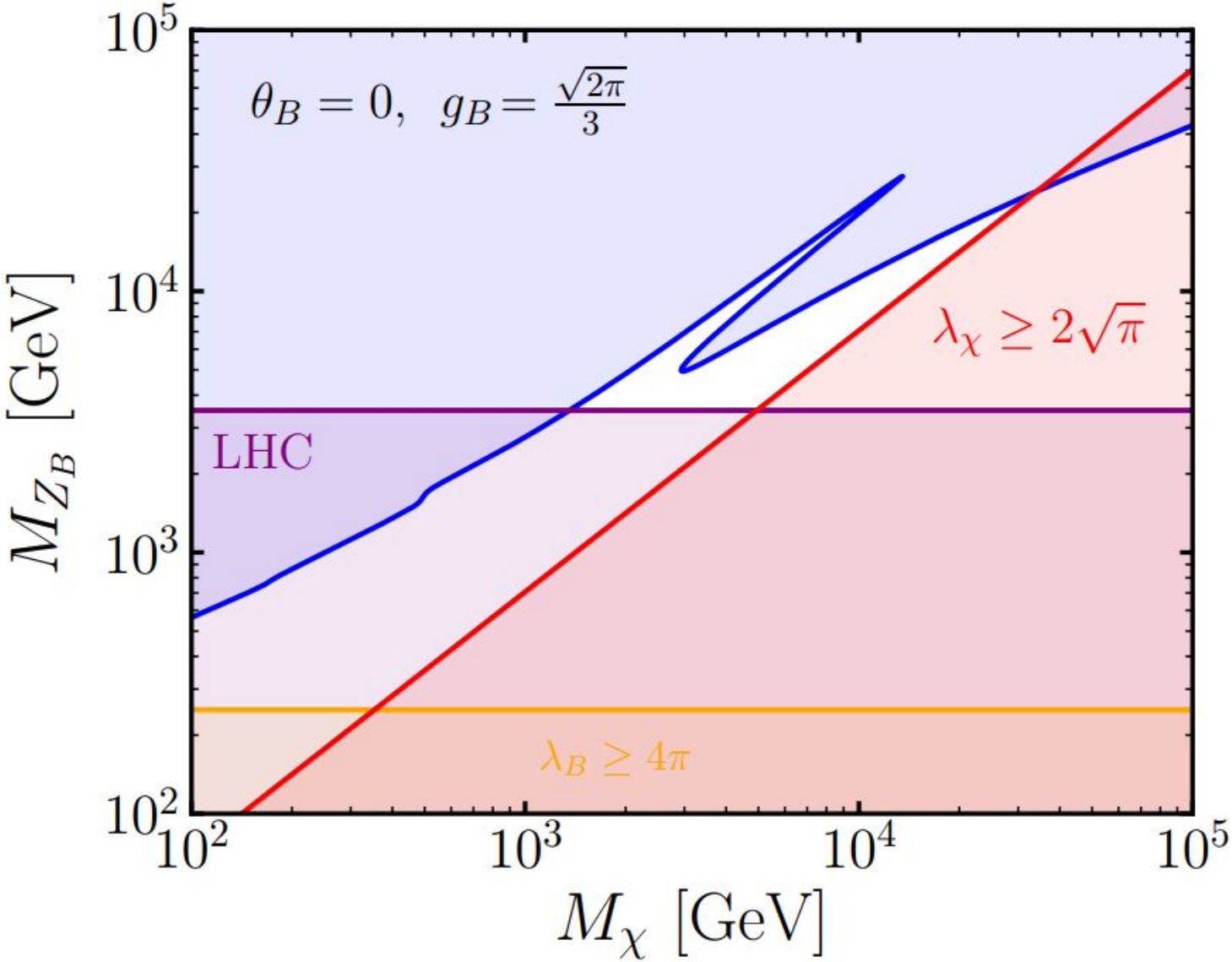


Results


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

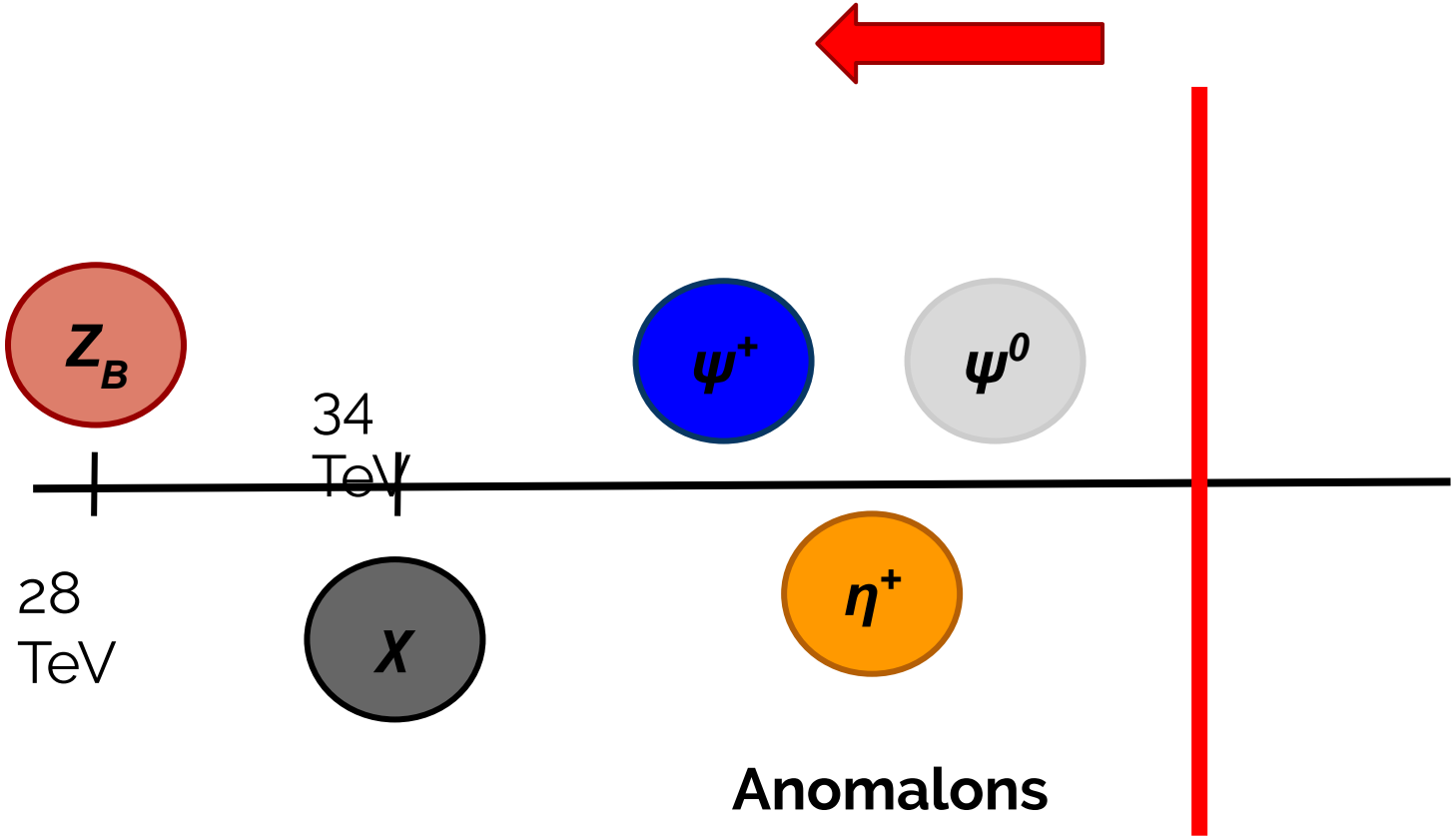
Perturbativity $g_B \leq \frac{\sqrt{2\pi}}{3} \approx 0.84$ and $\Omega h^2 \leq 0.12$

Give an upper bound on the scale



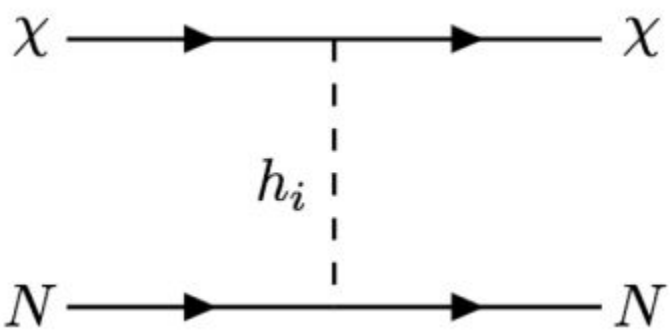
Upper bound on baryon number breaking scale

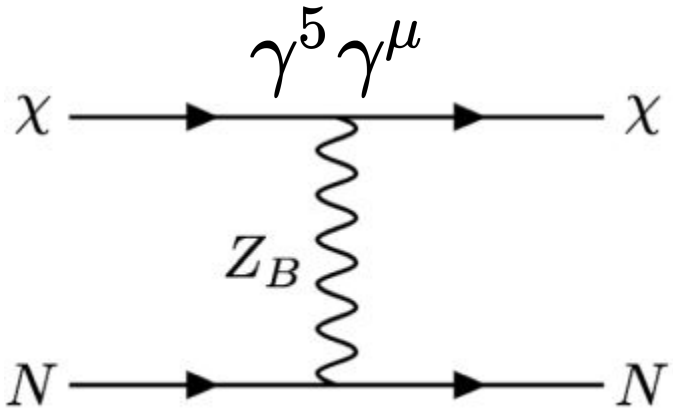
All masses connected to v_B and hence there is an upper bound for the full model



Direct Detection

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





Higgs mixing suppressed

$\theta < 0.3$ for $M_{H2} > 200$ GeV

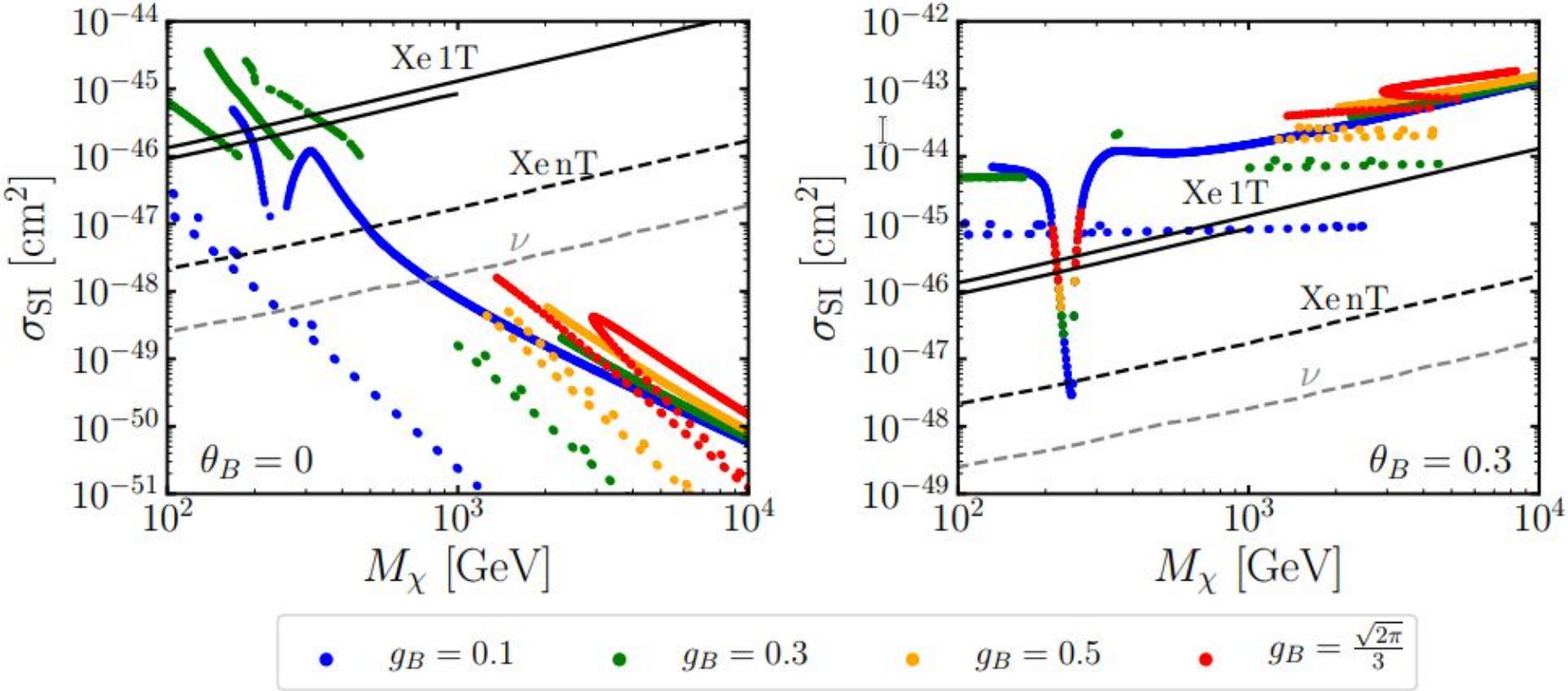
Due to axial coupling,

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

[Ilnicka, Robens, Stefaniak 2018]

Direct detection constraints can be avoided

Direct Detection



Gauging baryon number

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

$$\underbrace{\mathrm{U}(1)_B}_{\text{Local gauge symmetry}} \qquad \langle S_B \rangle \neq 0$$

gauge boson: Z_B

[Pais 1973]
[Fileviez Perez & Wise 2011]

Anomaly cancellation

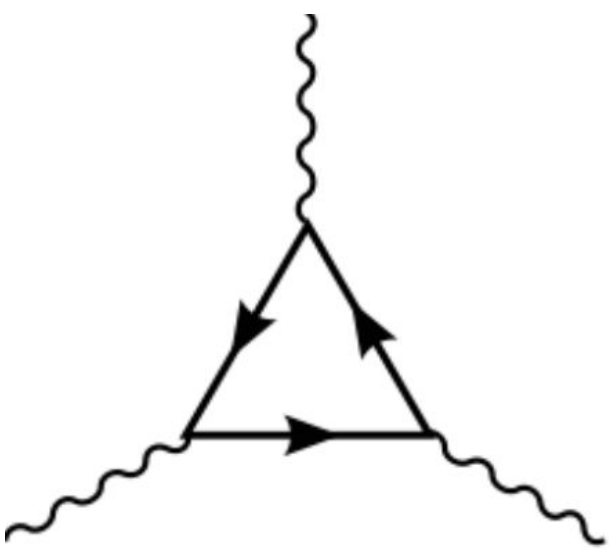
- Baryon number broken by 3 units: $\Delta B = \pm 3$ interactions

  → No proton decay

- Need to add new fermions to cancel anomalies

  Neutral fermion required for anomaly cancellation

  → DM Candidate



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

In the SM the non-zero values are:

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

Anomaly cancellation

[Duerr, Fileviez Perez, Wise 2013]

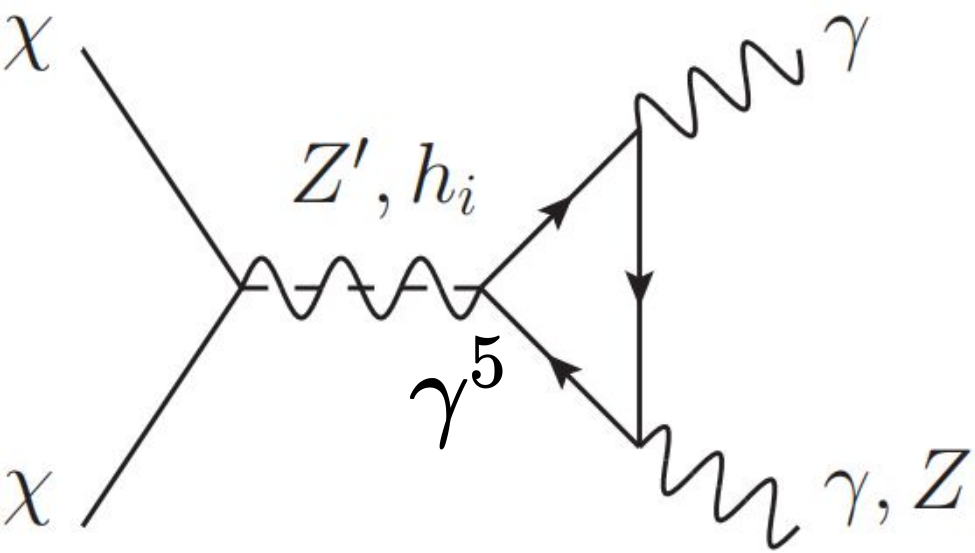
Fields	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	$U(1)_B$
$\Psi_L = \begin{pmatrix} \Psi_L^0 \\ \Psi_L^- \end{pmatrix}$	1	2	$-\frac{1}{2}$	$-\frac{3}{2}$
$\Psi_R = \begin{pmatrix} \Psi_R^0 \\ \Psi_R^- \end{pmatrix}$	1	2	$-\frac{1}{2}$	$\frac{3}{2}$
η_R^-	1	1	-1	$-\frac{3}{2}$
η_L^-	1	1	-1	$\frac{3}{2}$
χ_R^0	1	1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

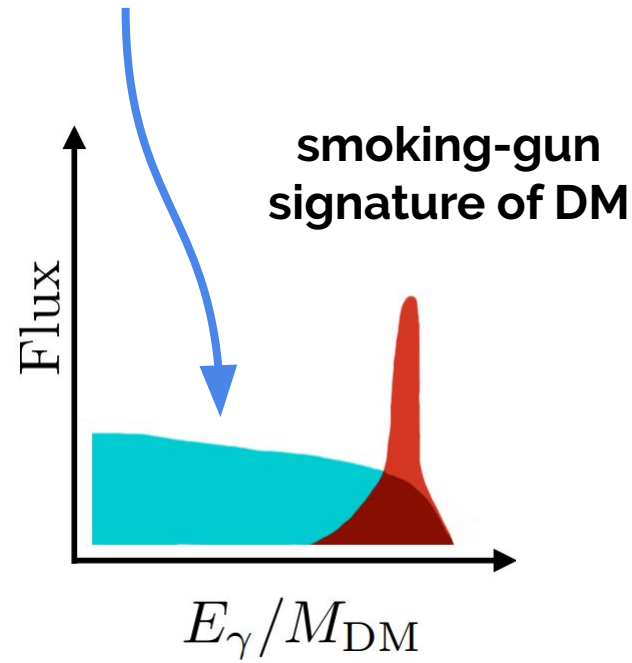
DM

For Model II see
[Ohmer, Fileviez Perez, Patel 2014]

Gamma lines

- Annihilation into $\gamma\gamma$ possible. New fermions required for anomaly cancellation in the loop.
- Peak at $E = M_{DM}$ in the gamma spectrum
- Continuum is velocity suppressed, because of axial coupling





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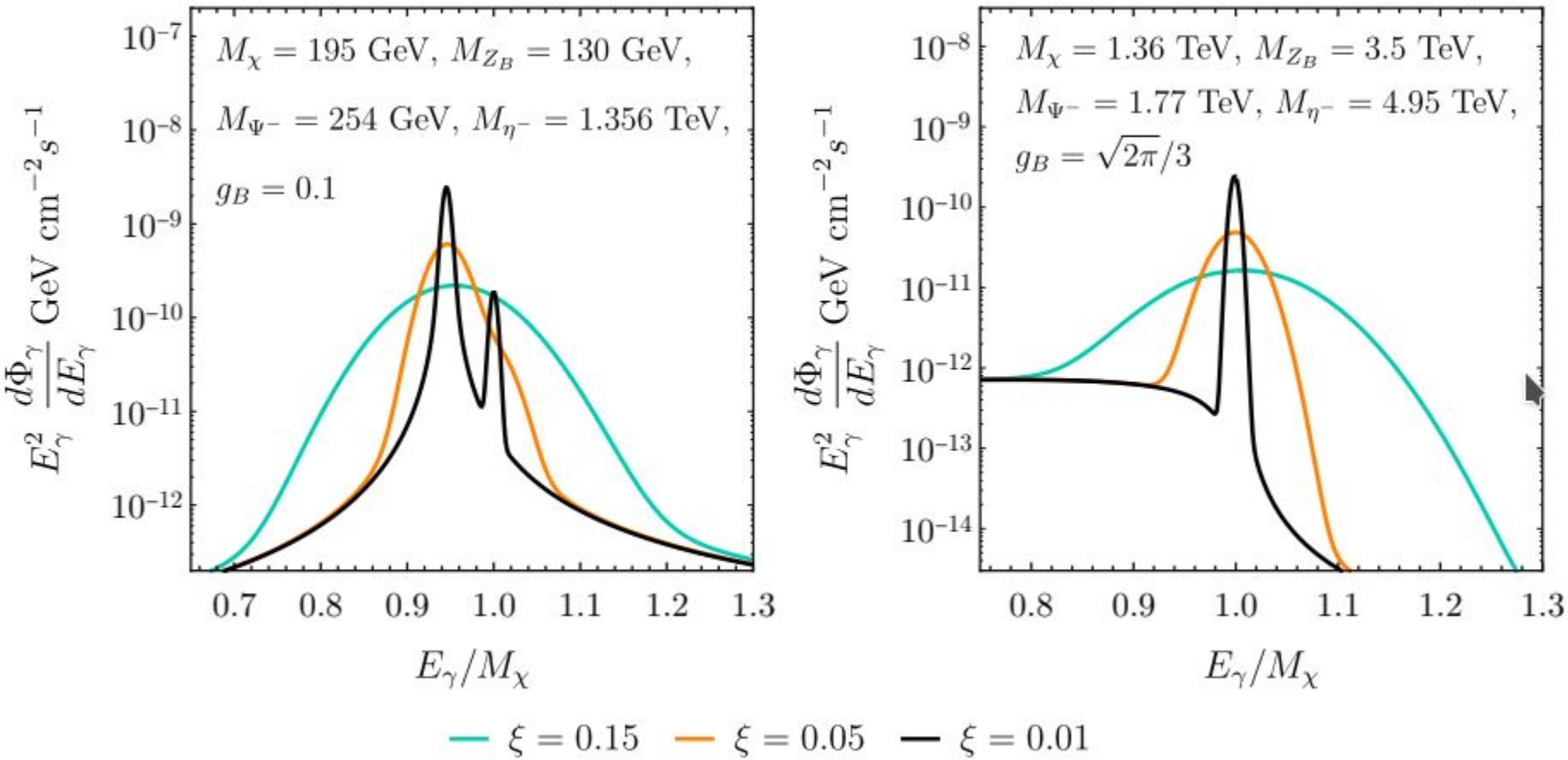
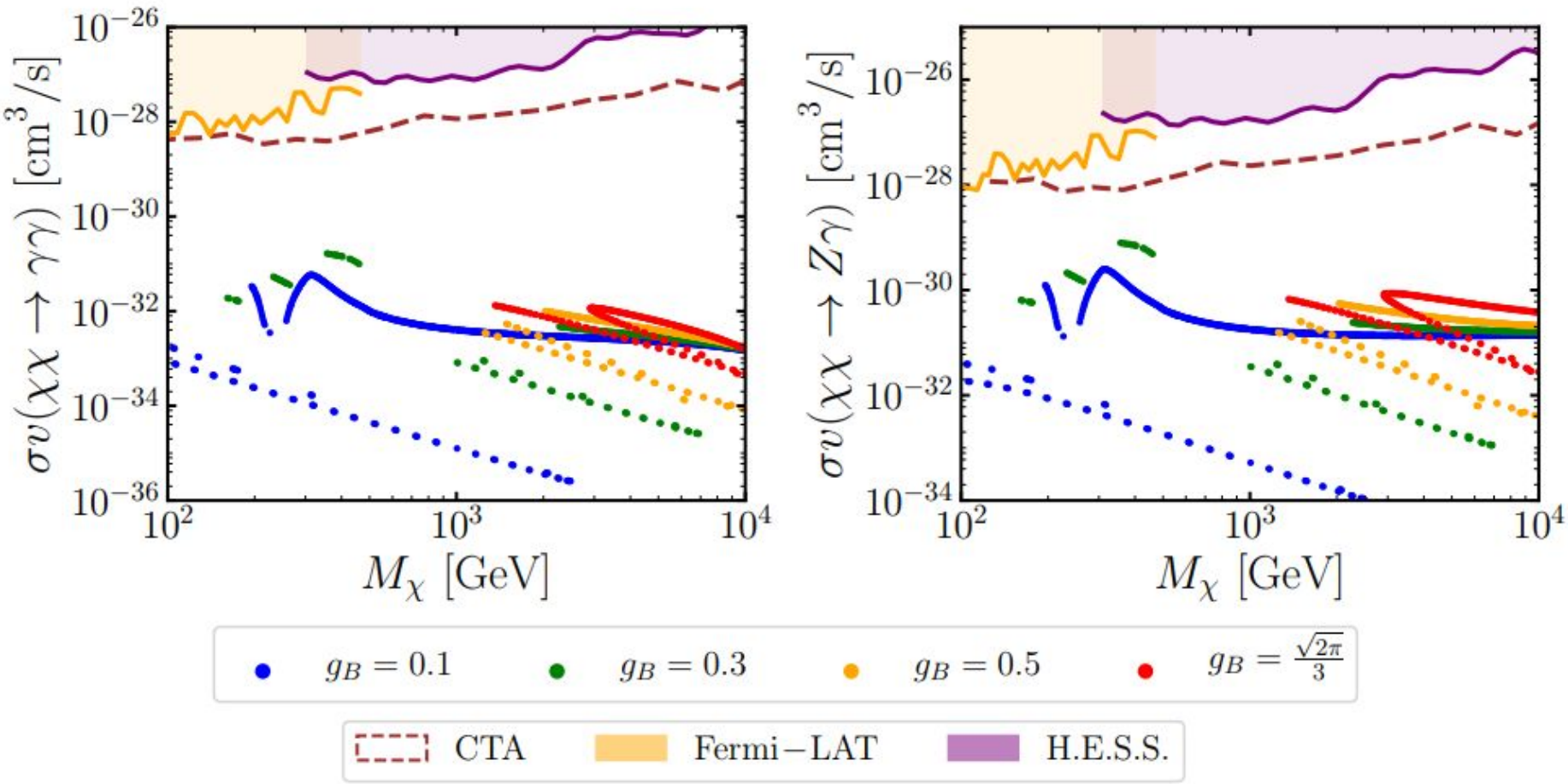

$M_\chi = 195$ GeV, $M_{Z_B} = 130$ GeV,
$M_{\Psi^-} = 254$ GeV, $M_{\eta^-} = 1.356$ TeV,
$g_B = 0.1$
$E_\gamma^2 \frac{d\Phi_\gamma}{dE_\gamma}$ GeV cm^{-2}s^{-1}
E_γ/M_χ
$M_\chi = 1.36$ TeV, $M_{Z_B} = 3.5$ TeV,
$M_{\Psi^-} = 1.77$ TeV, $M_{\eta^-} = 4.95$ TeV,
$g_B = \sqrt{2\pi}/3$
$\xi = 0.15$
$\xi = 0.05$
$\xi = 0.01$

Gamma lines


$\sigma v(\chi\chi \to \gamma\gamma)$ [cm^3/s]
10^{-26}
10^{-28}
10^{-30}
10^{-32}
10^{-34}
10^{-36}
10^2
10^3
10^4
M_χ [GeV]
$\sigma v(\chi\chi \to Z\gamma)$ [cm^3/s]
$g_B = 0.1$
$g_B = 0.3$
$g_B = 0.5$
$g_B = \frac{\sqrt{2\pi}}{3}$
CTA
Fermi−LAT
H.E.S.S.

Conclusions

- ☑ Consistent completions of simplified models of dark matter give rise to interesting phenomenology
- ☑ DM predicted from anomaly cancellation and stable from remnant $U(1)_B \longrightarrow Z_2$ symmetry
- ☑ Direct detection is velocity suppressed, Xenon nT will probe Higgs portal interaction
- ☑ Leptophobic gauge boson Z_B can appear as resonance in dijet searches at LHC
- ☑ Final state radiation velocity suppressed $\longrightarrow$ gamma-ray lines can be observed in future

Thank you!

Back-up

Model II

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	$-\frac{3}{2}$