Gamma Lines and Dark Matter from Anomaly Cancellation

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Gamma Lines and Dark Matter from Anomaly Cancellation

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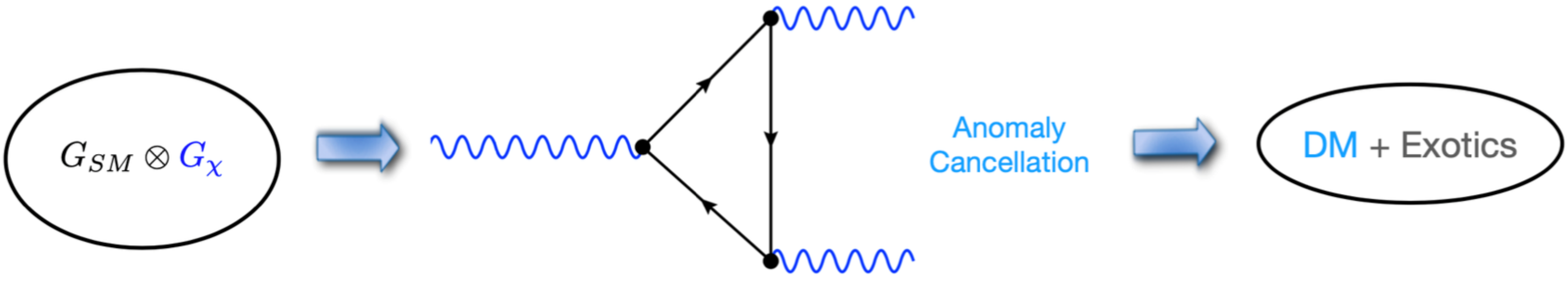
We discuss a simple theory for physics beyond the Standard Model where a Majorana dark matter is predicted from anomaly cancellation. We discuss in detail the minimal theory where the baryon number is a local symmetry spontaneously broken at the low scale. The correlation between the cosmological constraints on the dark matter relic density, the direct detection and collider bounds is investigated. We discuss in great detail the gamma lines from dark matter annihilation showing the possibility to test these predictions in the near future at gamma-ray telescopes such as CTA. We investigate all processes contributing to the total photon flux from dark matter annihilation and point out the unique features that can be used to test this theory for dark matter.

https://arxiv.org/pdf/2409.17976

Main Goal

P. Fileviez Perez, M. B. Wise, 2011

Dark Matter from Anomaly Cancellation



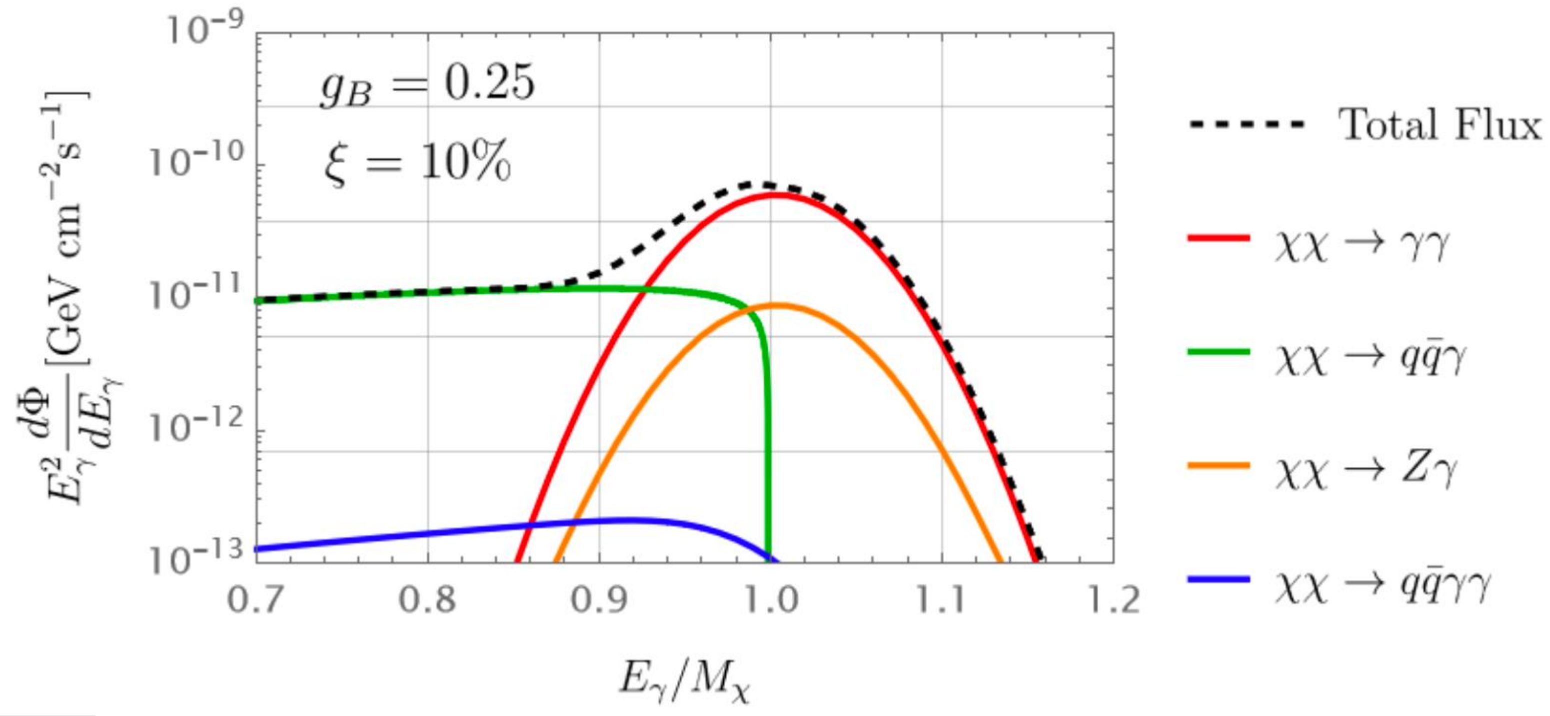
Relic Density Constraints

Direct Detection

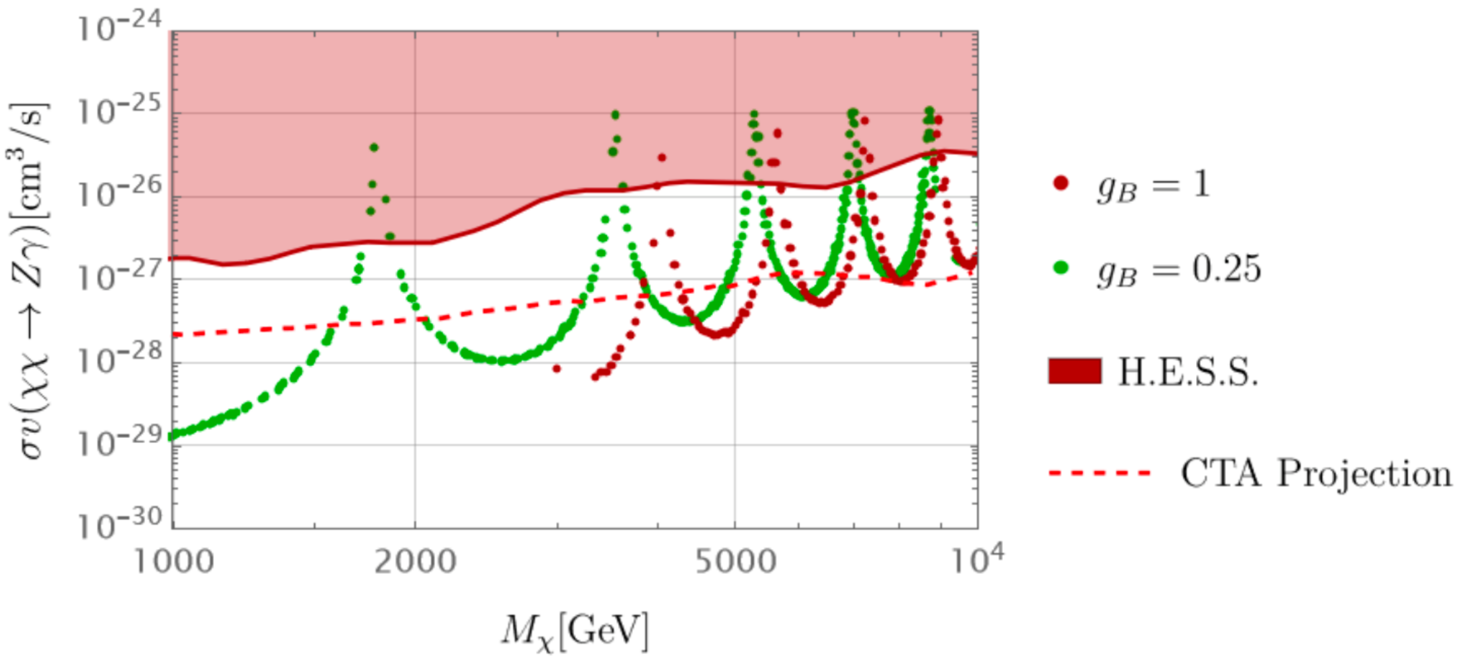
Indirect Detection

Gamma Lines !

Gamma Lines !

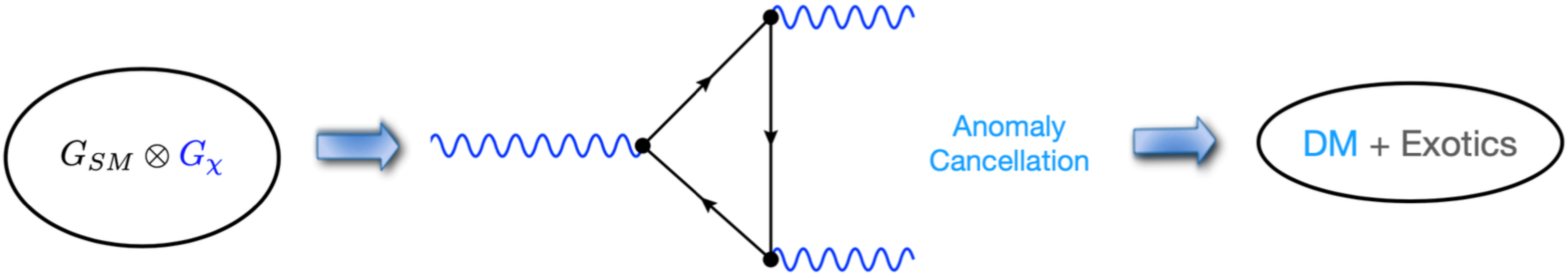


$g_B = 0.25$
$\xi = 10\%$
$E_\gamma^2 \frac{d\Phi}{dE_\gamma}$ [GeV cm^{-2}s^{-1}]
E_γ / M_χ
Total Flux
$\chi\chi \to \gamma\gamma$
$\chi\chi \to q\bar{q}\gamma$
$\chi\chi \to Z\gamma$
$\chi\chi \to q\bar{q}\gamma\gamma$



$\sigma v(\chi\chi \to Z\gamma)$[cm^3/s]
M_χ[GeV]
$g_B = 1$
$g_B = 0.25$
H.E.S.S.
CTA Projection

Dark Matter from Anomaly Cancellation



- Pavel Fileviez Pérez, Physical Review D 110, 035018 (2024)

- Pavel Fileviez Pérez, Sebastian Ohmer, Hiren H. Patel, Physics Letters B735 (2014) 283-287.
- Michael Duerr, Pavel Fileviez Pérez, Mark B. Wise, Physical Review Letters 110 (2013) 231801.

Pavel Fileviez Pérez, Physical Review D 110, 035018 (2024)

Theoretical Framework

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

Fields needed for anomaly cancellation !

$$\Longrightarrow \quad \begin{aligned} \Psi_L &\sim (\mathbf{1}, \mathbf{1}, -1, 3/4), \ \Psi_R \sim (\mathbf{1}, \mathbf{1}, -1, -3/4), \\ \chi_L &\sim (\mathbf{1}, \mathbf{1}, 0, 3/4), \ \text{and } \rho_L \sim (\mathbf{1}, \mathbf{3}, 0, -3/4). \end{aligned}$$

Yukawa interactions:

$$-\mathcal{L} \supset \lambda_\rho \mathrm{Tr}(\rho_L^T C \rho_L) S + \lambda_\Psi \bar{\Psi}_L \Psi_R S + \lambda_\chi \chi_L^T C \chi_L S^* \; + \; \mathrm{h.c.}.$$

$$\Longrightarrow \qquad S \sim (\mathbf{1}, \mathbf{1}, 0, 3/2),$$

$$\lambda_e \bar{\Psi}_L e_R \phi \qquad \Longrightarrow \qquad \phi \sim (\mathbf{1}, \mathbf{1}, 0, 3/4)$$

Physical States:

- Z_B is the new gauge boson associated to the local baryon number. The Z_B mass is given by $M_{Z_B} = 3 g_B v_S / 2$ in the case where the ϕ field does not acquire a vacuum expectation value.

- h is the SM-like Higgs boson defined as: $h = h_0 \cos\theta_B - h_S \sin\theta_B$.

- h_B is the new CP-even Higgs defined as: $h_B = h_0 \sin\theta_B + h_S \cos\theta_B$.

- ϕ is a complex scalar field

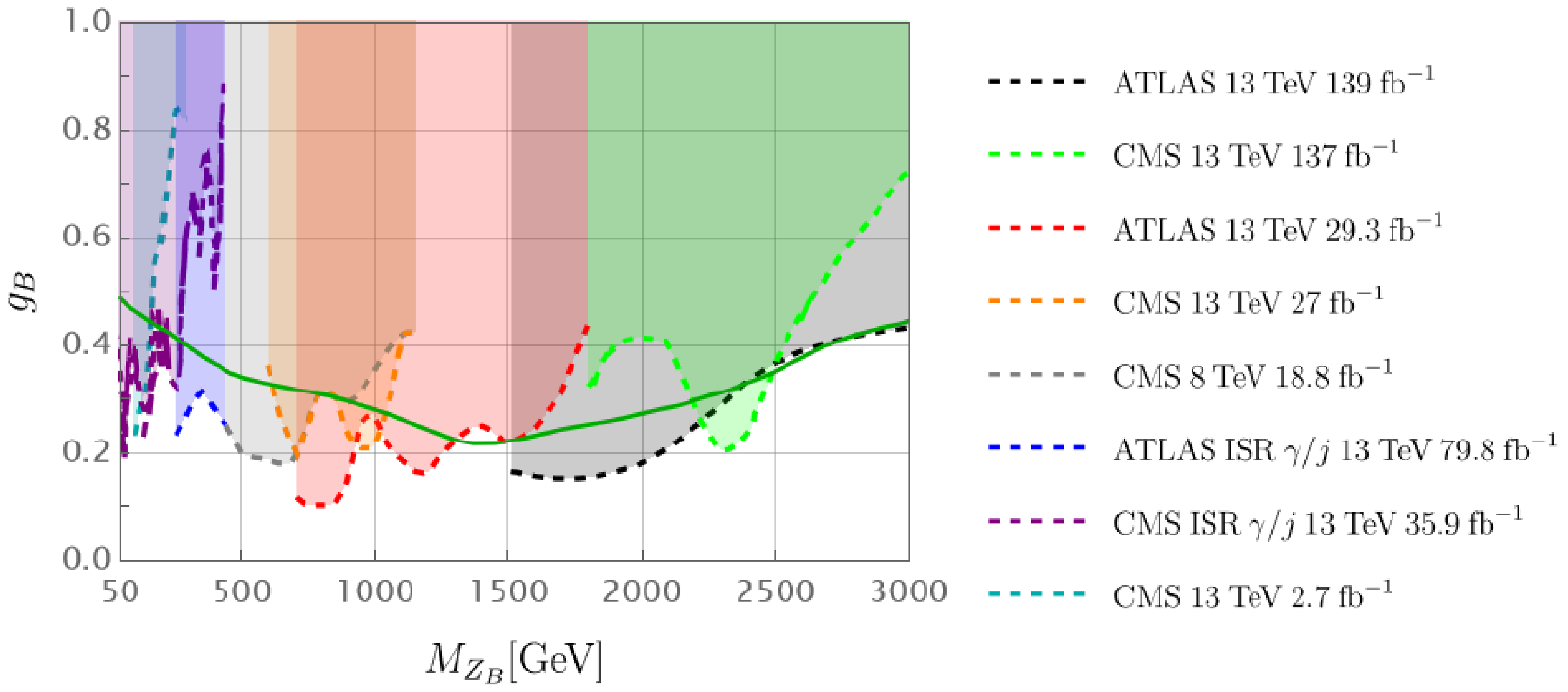
- Two Majorana fermionic fields: $\chi = \chi_L + (\chi_L)^C$ and $\rho^0 = \rho_L^0 + (\rho_L^0)^C$ with masses

$$M_\chi = \sqrt{2}\lambda_\chi v_S \text{ and } M_{\rho^0} = \sqrt{2}\lambda_\rho v_S.$$

- Two charged fields: $\Psi^- = \Psi_L^- + \Psi_R^-$ and $\rho^- = \rho_L^- + (\rho_L^+)^C$ with masses given by

$$M_{\Psi^-} = \frac{1}{\sqrt{2}}\lambda_\Psi v_S \text{ and } M_{\rho^-} = M_{\rho^0} + \delta M,$$

Collider bounds



$$h_B = h_0 \sin\theta_B + h_S \cos\theta_B .$$

"Cucuyo" Higgs decays

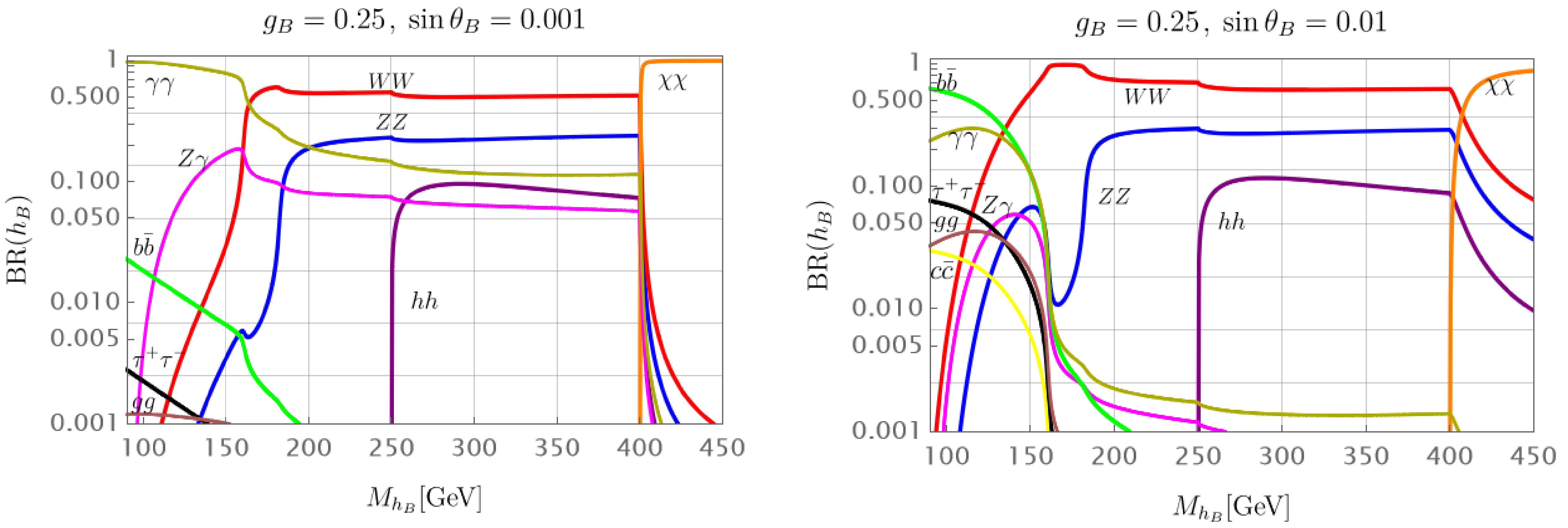


FIG. 2: Branching ratios for the h_B decays. Here we use $M_\chi = 200$ GeV, $M_{Z_B} = 300$ GeV, $M_{\Psi^-} = 1.2 M_\chi$, $M_{\rho^-} = 3 M_\chi$, and $g_B = 0.25$.

Majorana Dark Matter

$$\chi = \chi_L + (\chi_L)^C$$

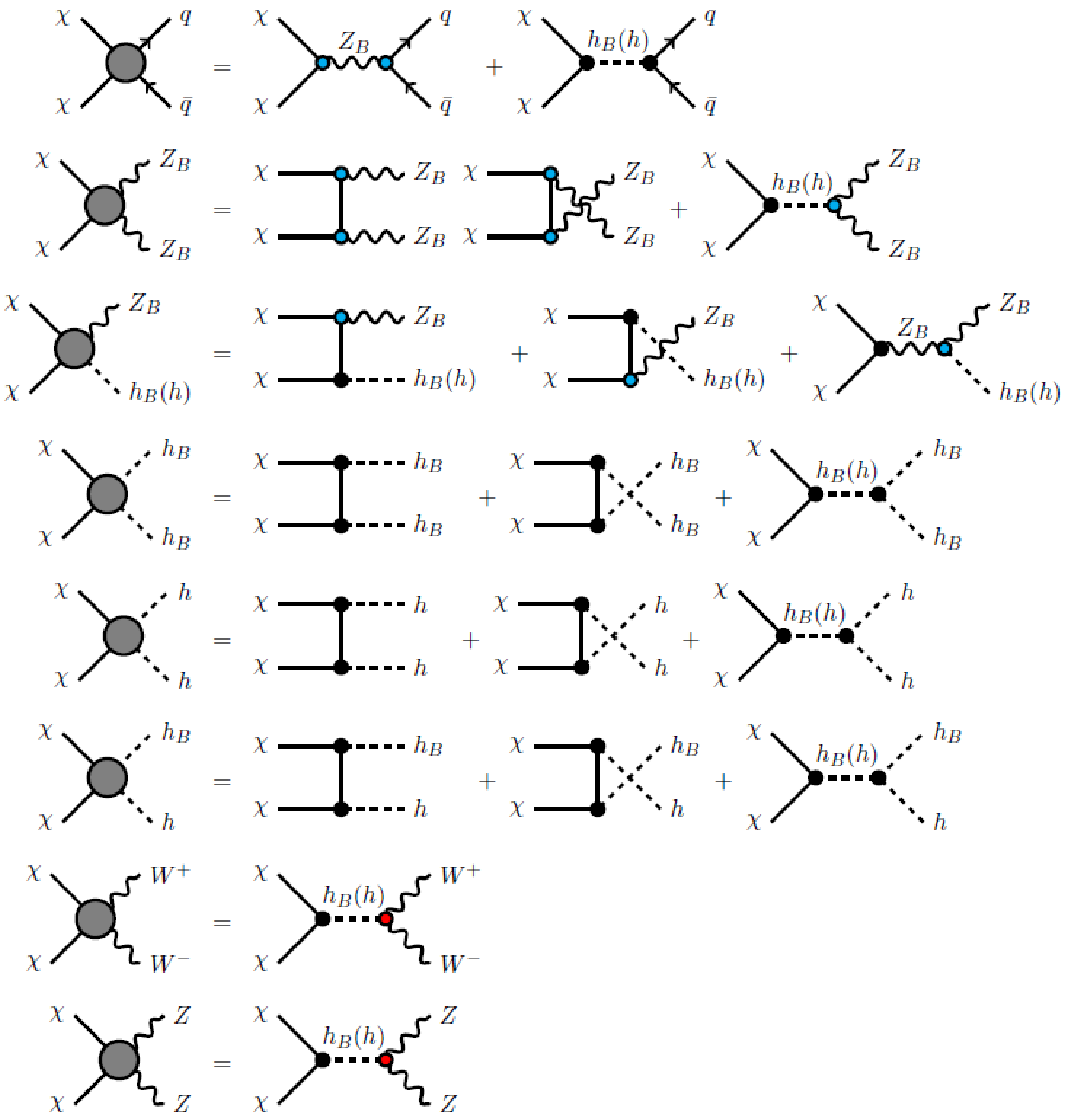
Neutral and Stable

$$\mathbb{Z}_2 : \chi \rightarrow -\chi$$

More relevant free parameters of the theory:

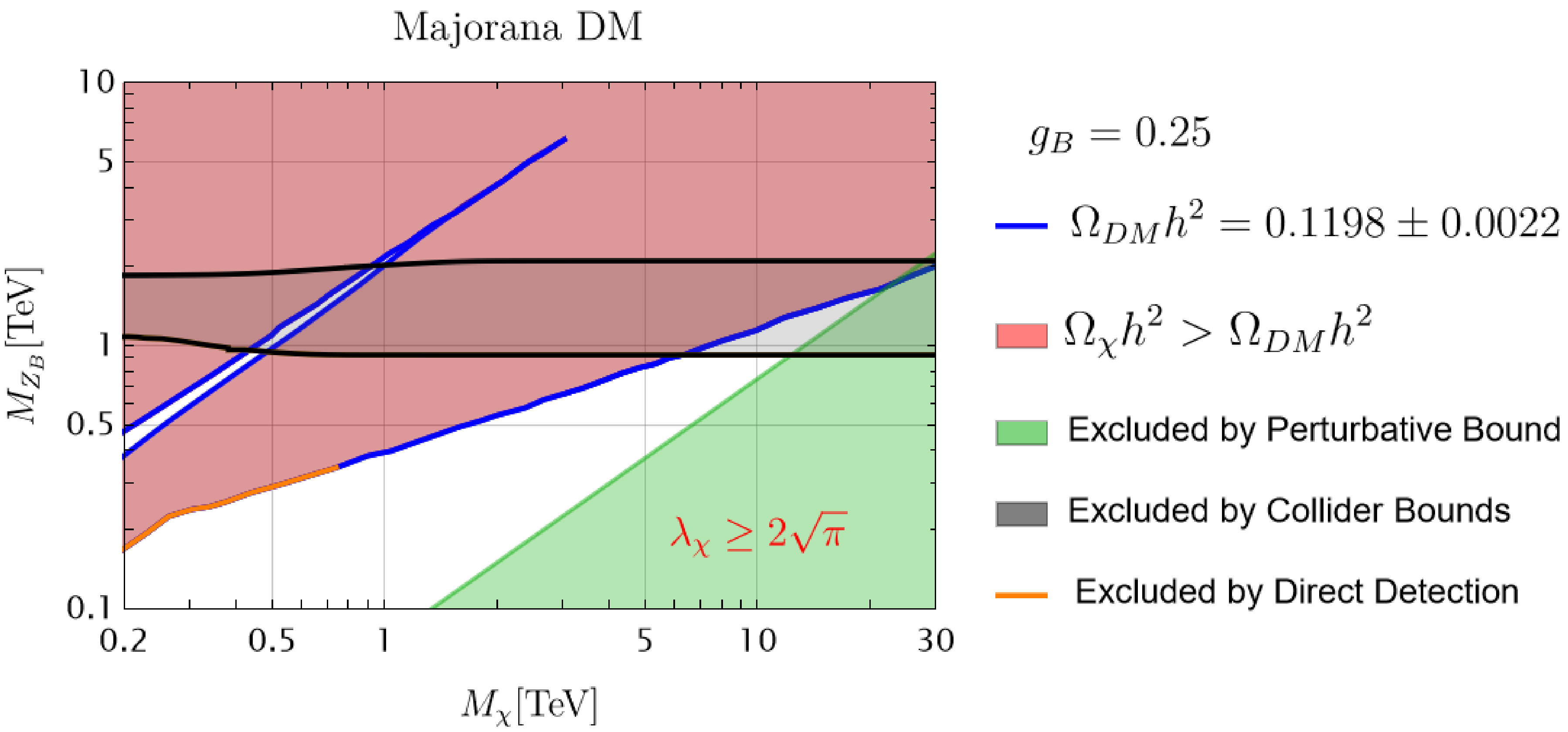
$$g_B, M_\chi, M_{Z_B}, M_{h_B} \ and \ \theta_B.$$

Relic Density



Relic Density

H. Debnath, P. Fileviez Perez, K.G.Q, arXiv:2409.17976

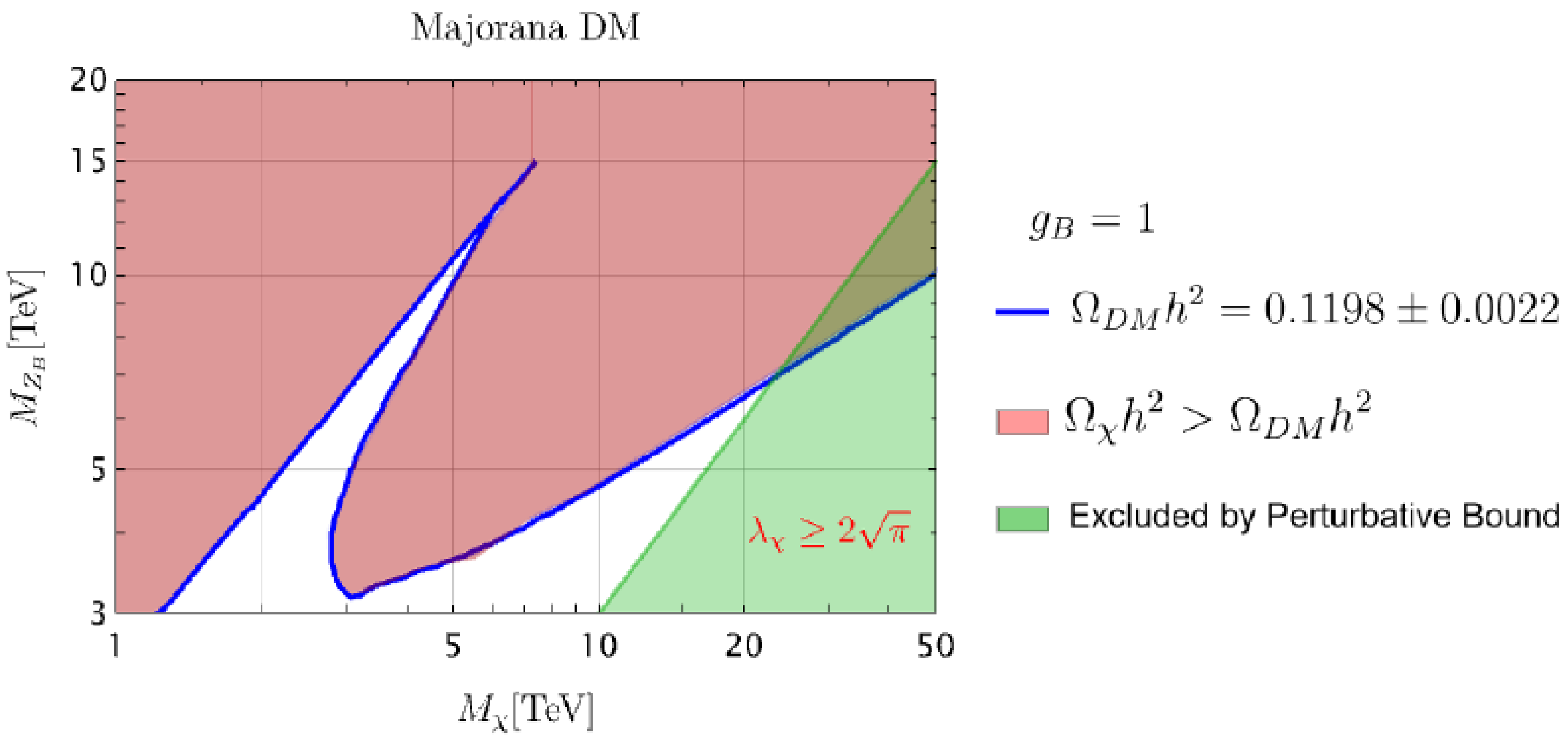


The scale for spontaneous BNV must be below the multi-TeV scale

For the collider bounds see: Jon Butterworth, H. Debnath, P. Fileviez Pérez, Y. Yeh, 2405.03749

Relic Density

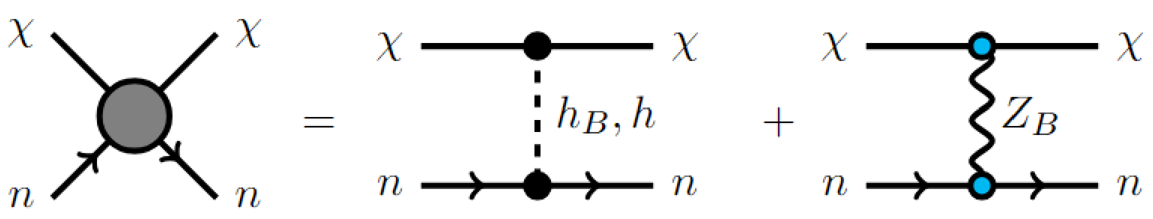
H. Debnath, P. Fileviez Perez, K.G.Q, arXiv:2409.17976

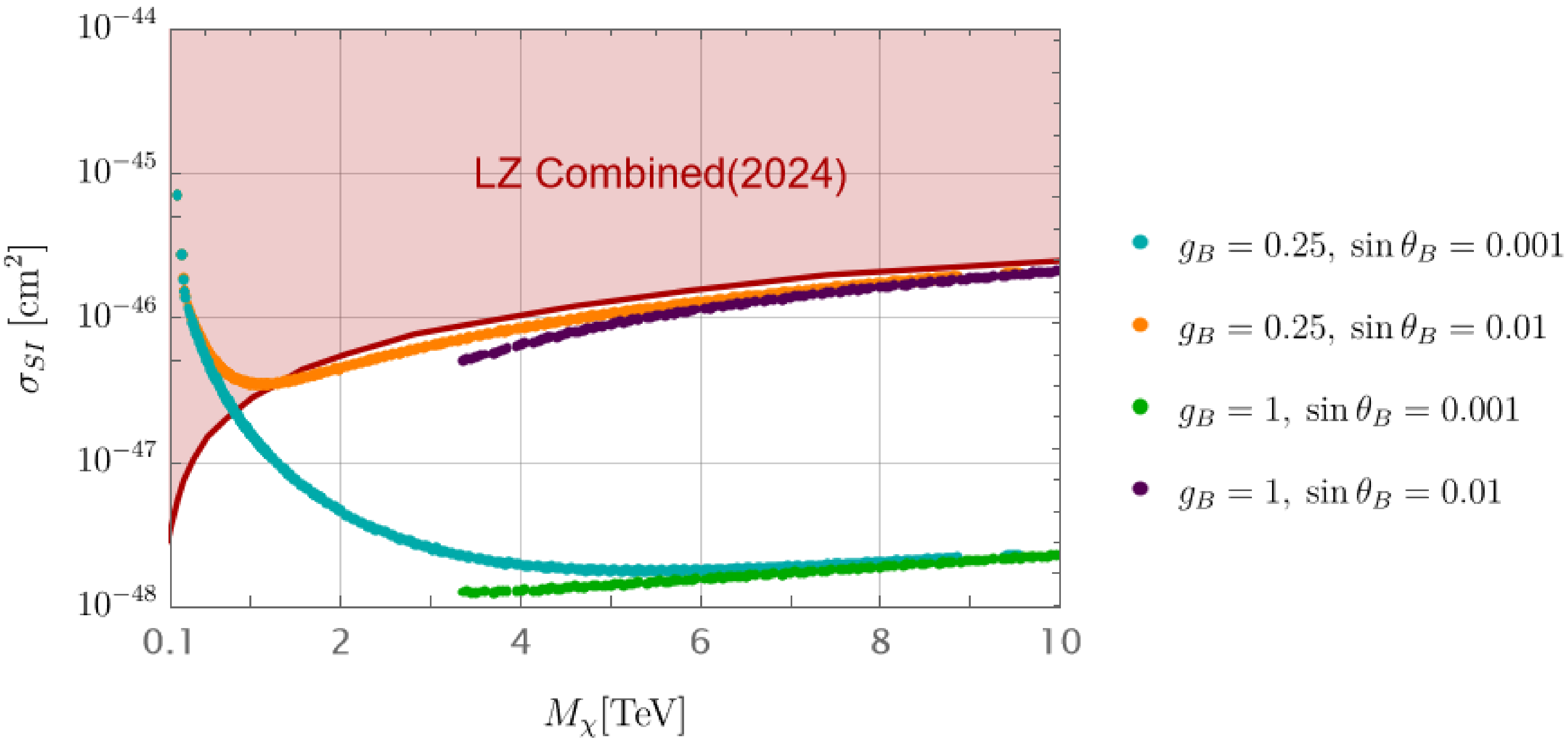


The scale for spontaneous BNV must be below the multi-TeV scale

Direct Detection

H. Debnath, P. Fileviez Perez, K.G.Q, arXiv:2409.17976

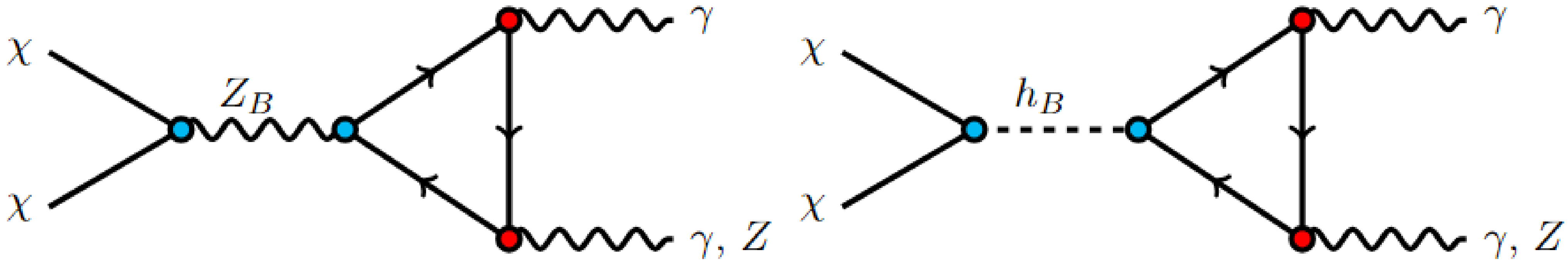




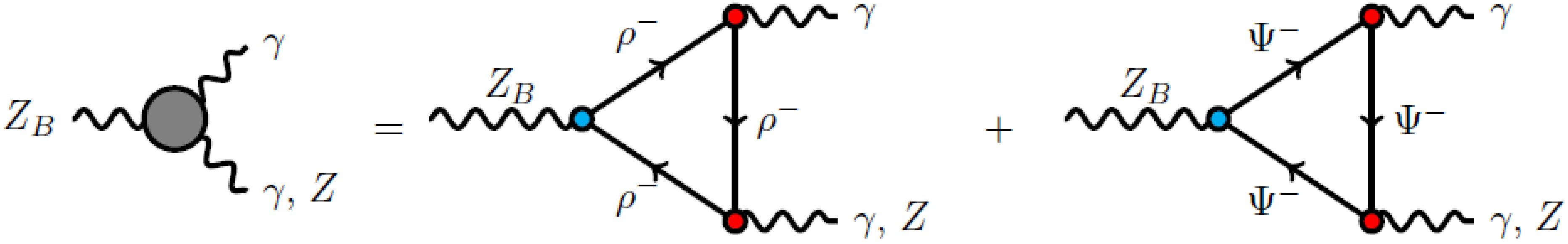
Gamma Lines from Dark Matter Annihilation

H. Debnath, P. Fileviez Perez, K.G.Q, arXiv:2409.17976

Gamma Lines



- Effective $Z_B\gamma\gamma, Z_B\gamma Z$ couplings:



$\chi\chi \to \gamma\gamma$

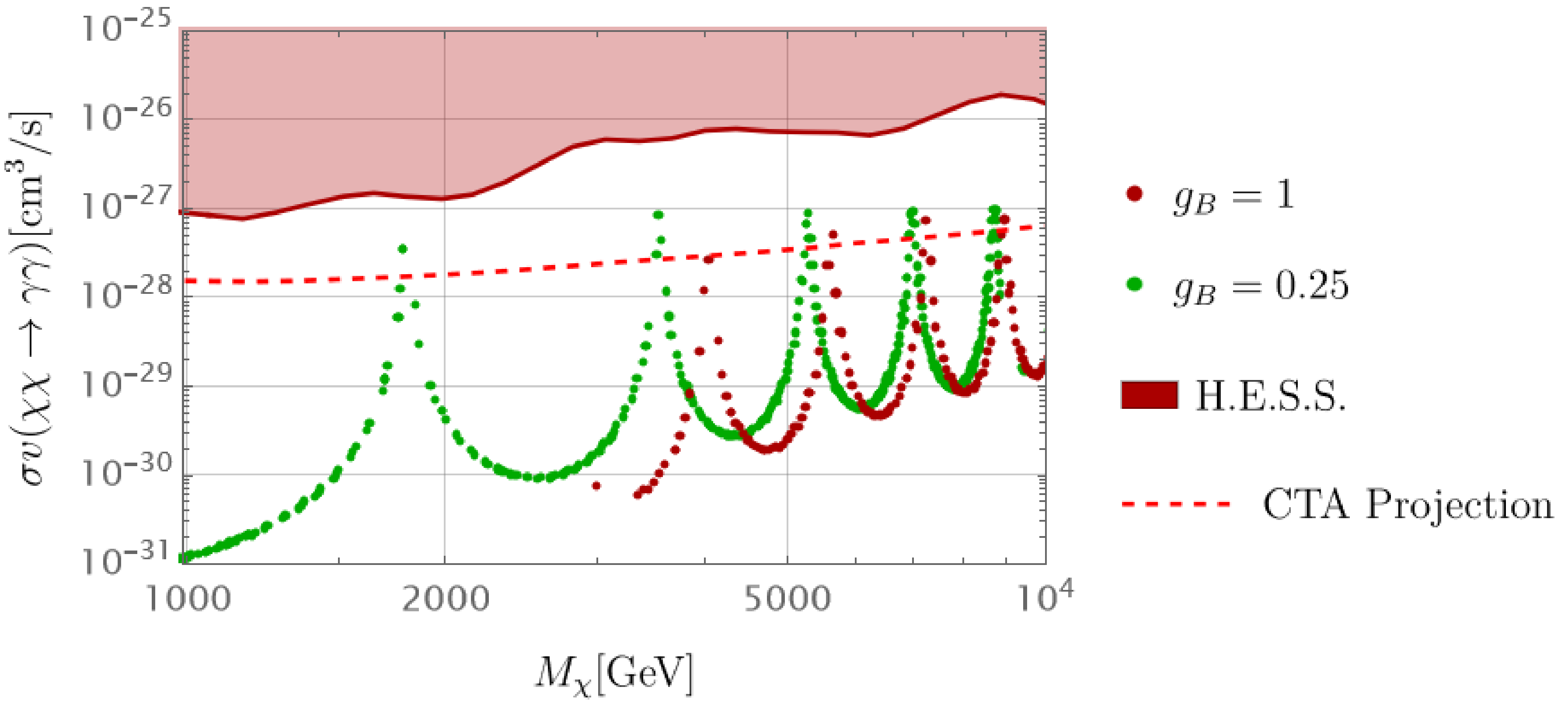


FIG. 9: Annihilation cross section $\sigma v(\chi\chi \to \gamma\gamma)$ as a function of M_χ for different values of g_B. Here we used the corresponding values of M_{Z_B} that satisfy the relic density constraints. Here we used M_{h_B}=150 GeV, $M_{\Psi^-} = 1.2 M_\chi$ and $M_{\rho^-} = 3 M_\chi$. The H.E.S.S bounds are shown in red, while the dashed red line shows the CTA [32] projected bounds.

H. Debnath, P. Fileviez Perez, K.G.Q, arXiv:2409.17976

$\chi\chi \to \gamma Z$

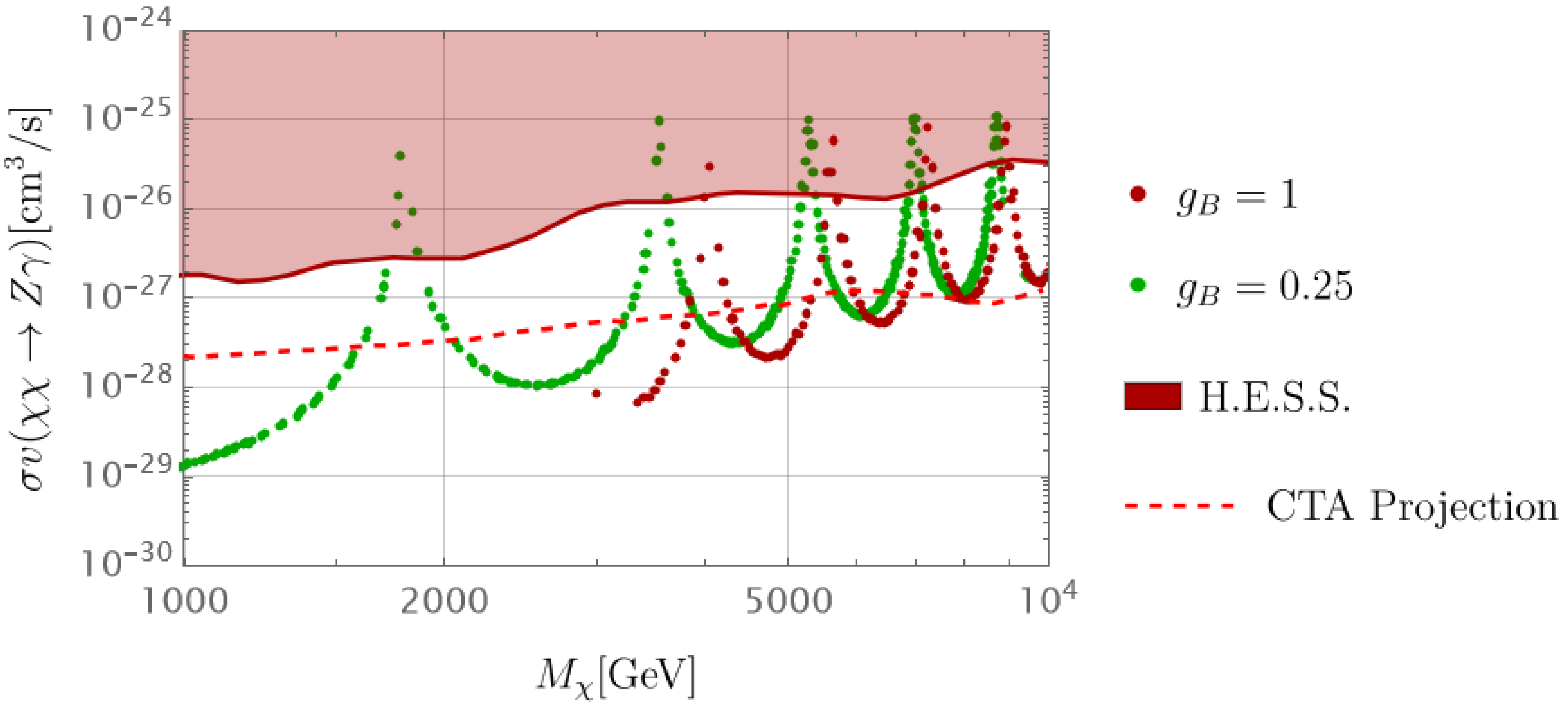


FIG. 11: Values of $\sigma v(\chi\chi \to Z\gamma)$ as a function of M_χ for different values of g_B. Here we used M_{h_B}=150 GeV, $M_{\Psi^-} = 1.2 M_\chi$ and $M_{\rho^-} = 3 M_\chi$.

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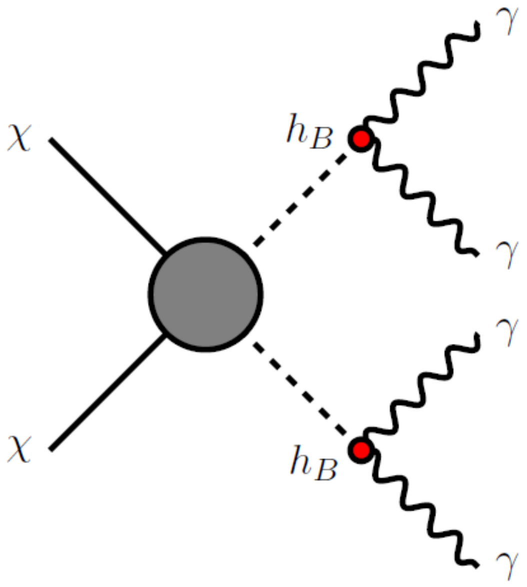
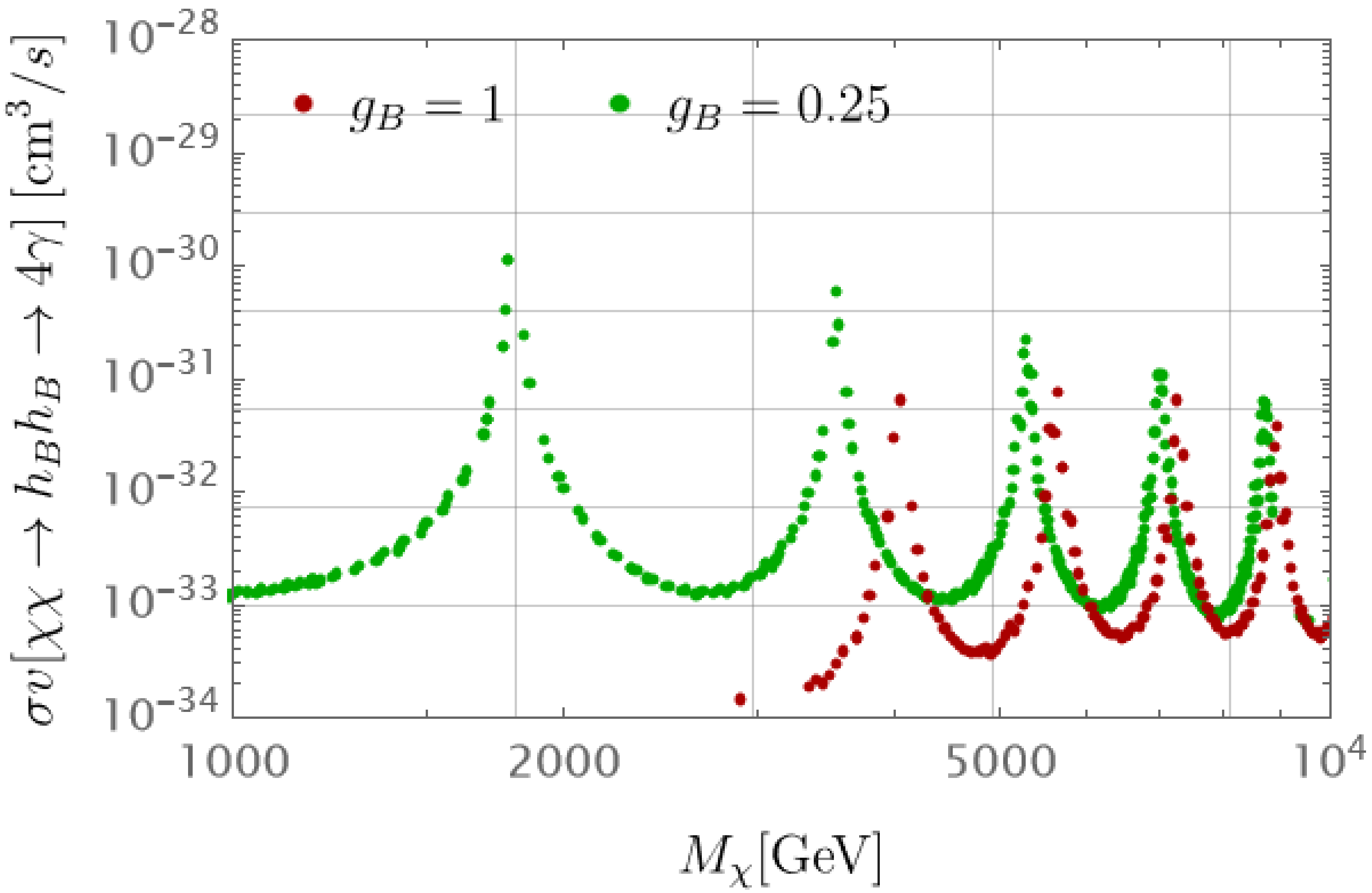
$\chi\chi \to h_B h_B \to 4\gamma$





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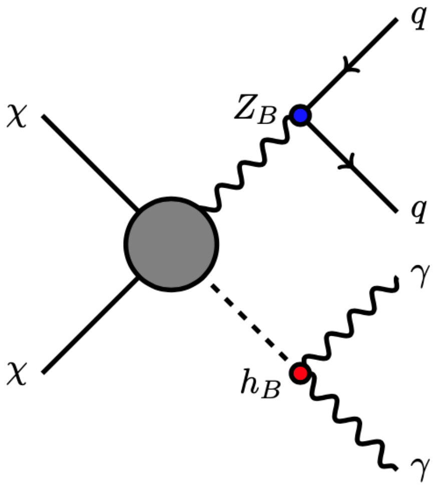
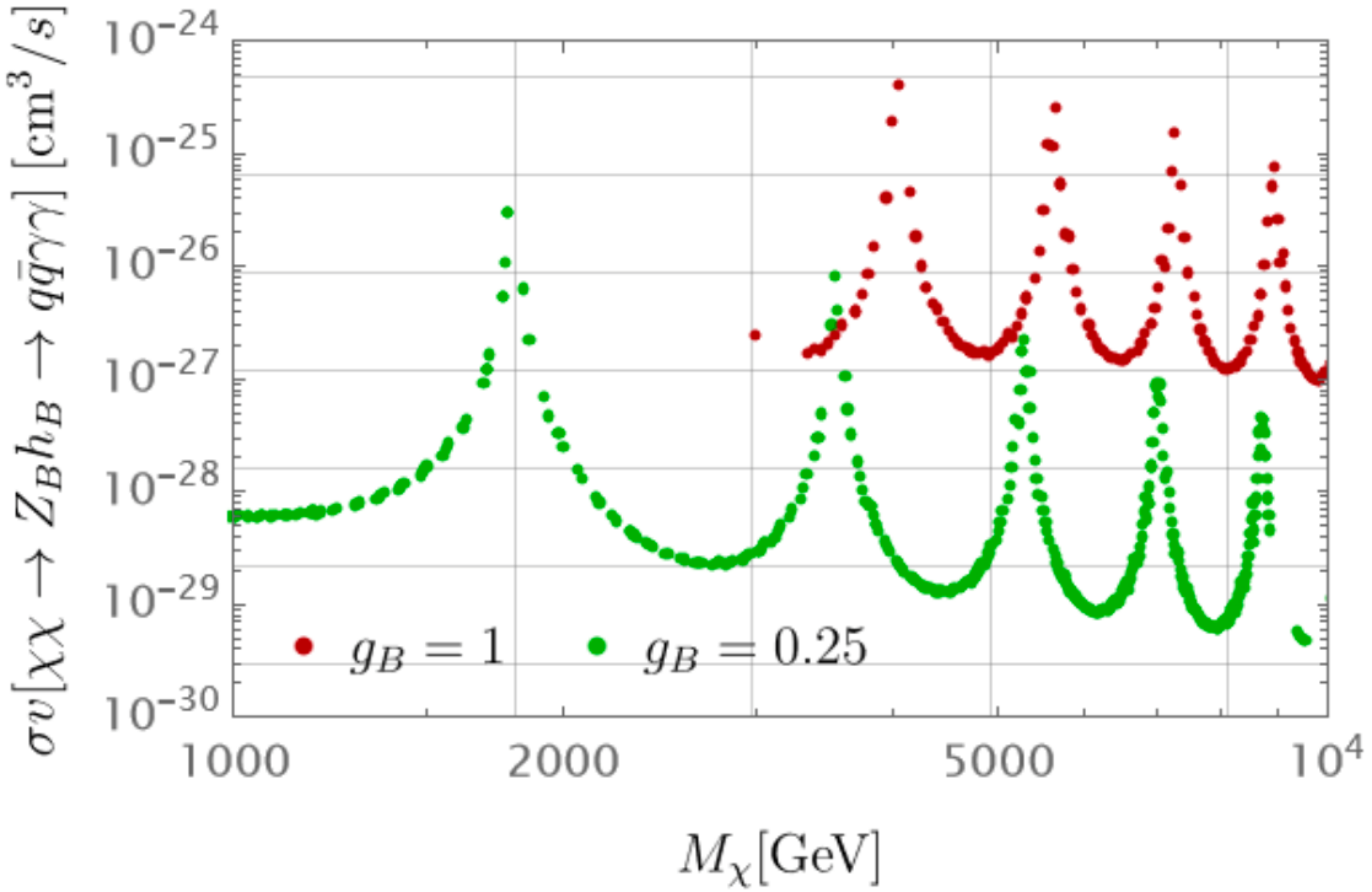
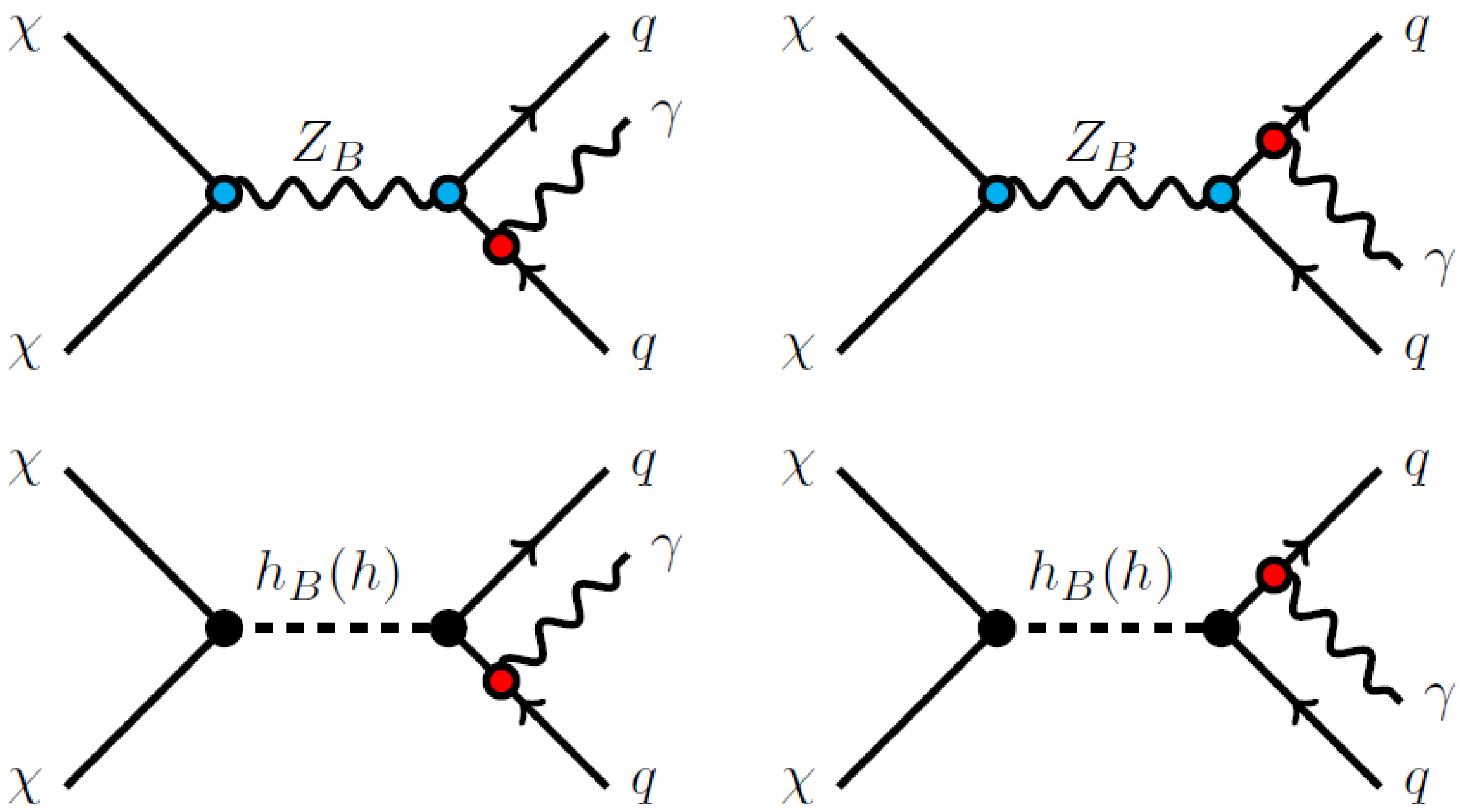




Final State Radiation



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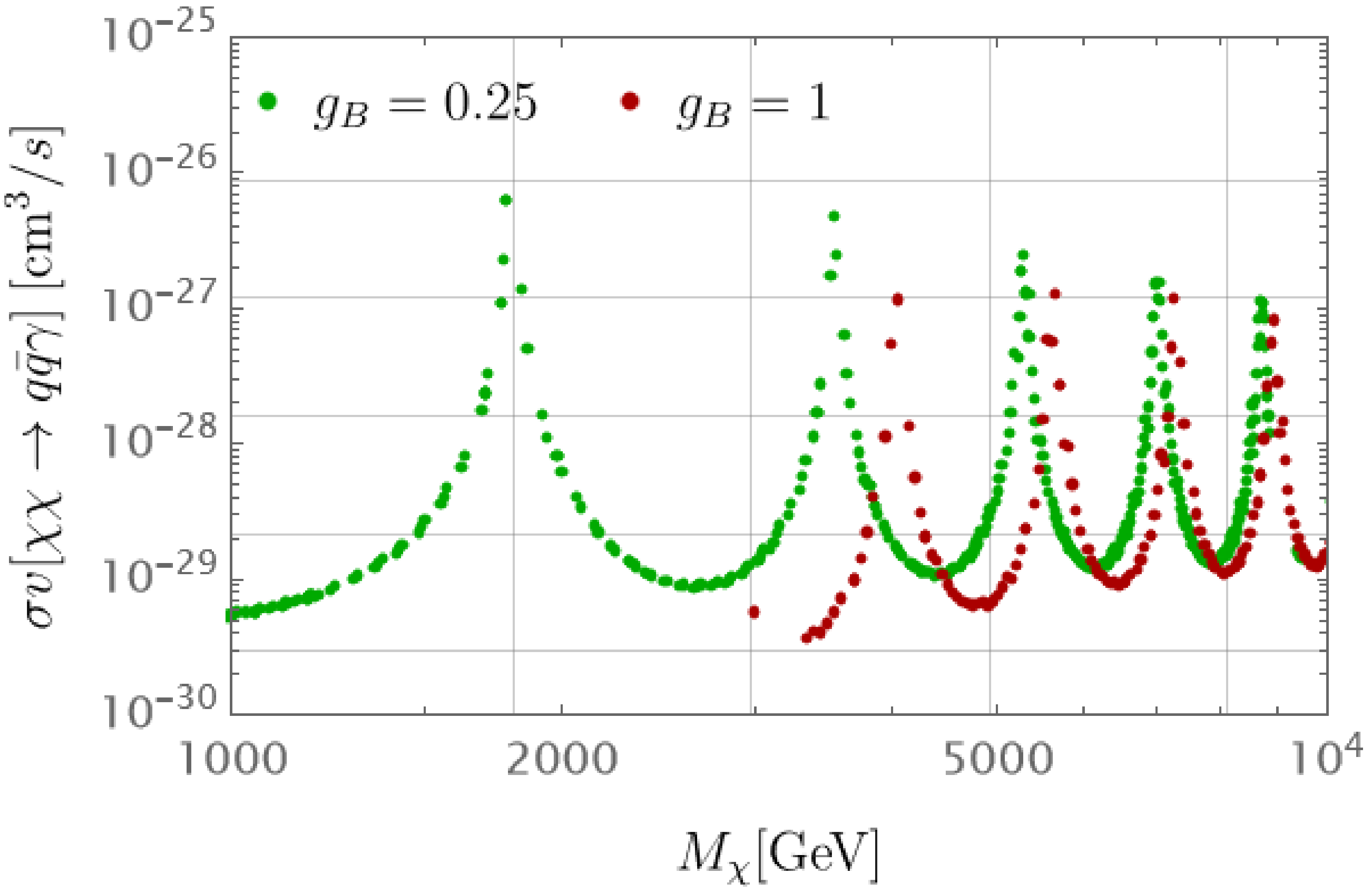
$\chi\chi \rightarrow q\bar{q}\gamma$



- The flux for the gamma lines is given by:

$$\frac{d\Phi_{\gamma\gamma}}{dE_\gamma} = \frac{n_\gamma}{8\pi M_\chi^2} \frac{d(\sigma v_{\rm rel}(\chi\chi \to \gamma\gamma))}{dE_\gamma} J_{\rm ann} = \frac{n_\gamma(\sigma v_{\rm rel}(\chi\chi \to \gamma\gamma))}{8\pi M_\chi^2} \frac{dN_{\gamma\gamma}}{dE_\gamma} J_{\rm ann}$$

$$\frac{dN_{\gamma\gamma}}{dE_\gamma} = \int_0^\infty dE_0 \, W_{\gamma\gamma}(E_0) \, G\left(E_\gamma, \frac{\xi}{\omega}, E_0\right)$$

Total Flux

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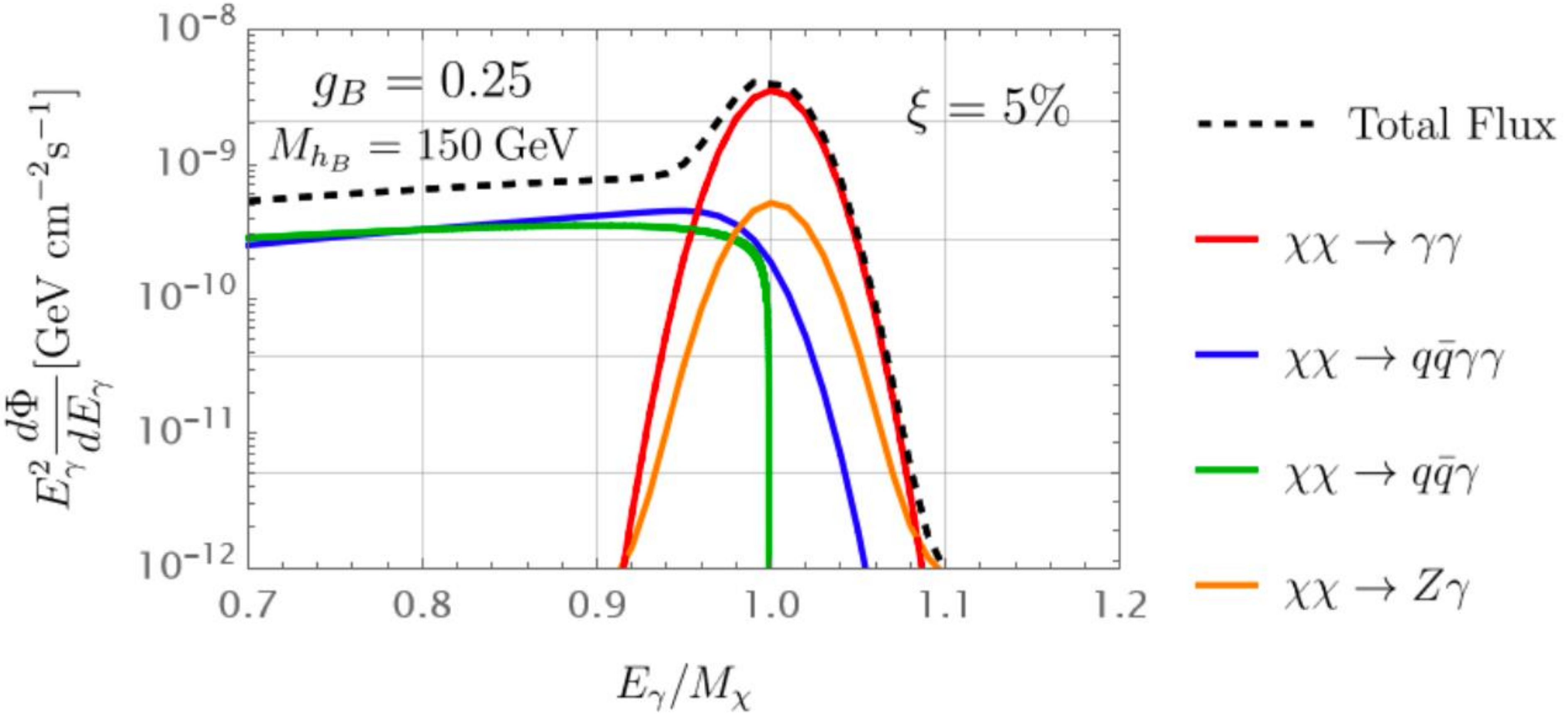

Total Flux

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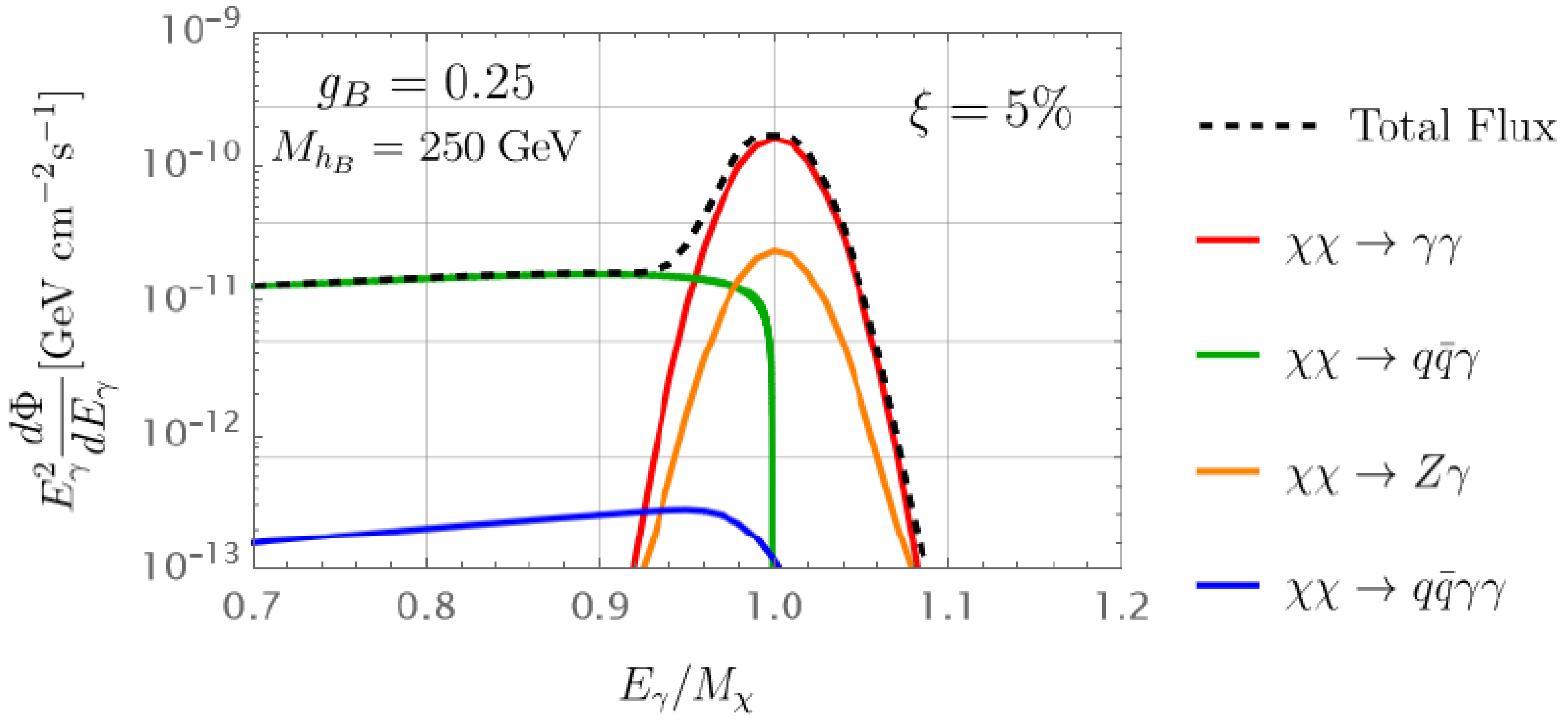


Summary

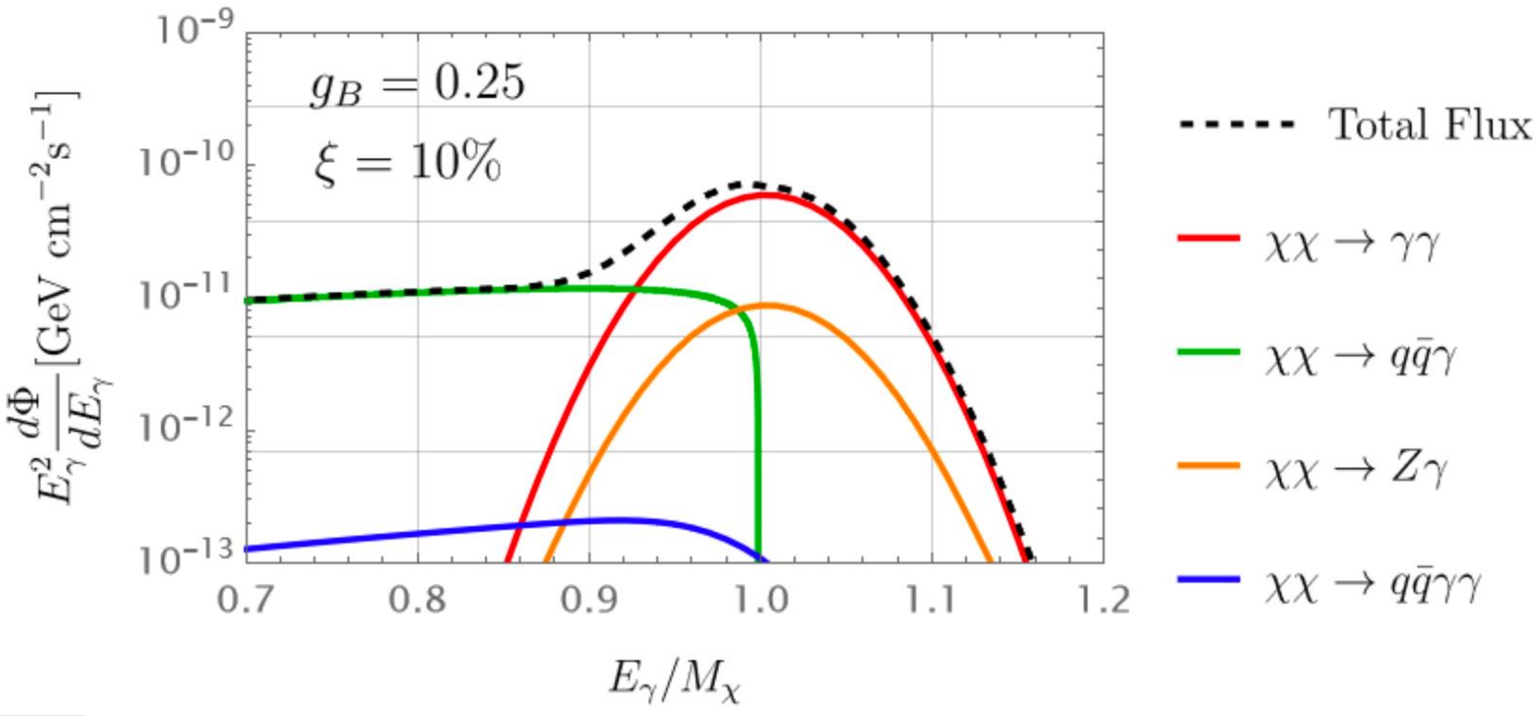
- We discussed a simple theory for physics beyond the Standard Model predicting a Majorana dark matter from anomaly cancellation. In this context the baryon number is a local gauge symmetry broken at the low scale.

- We have shown the constraints from the cosmological bounds on the dark matter relic density, the direct detection and collider constraints.

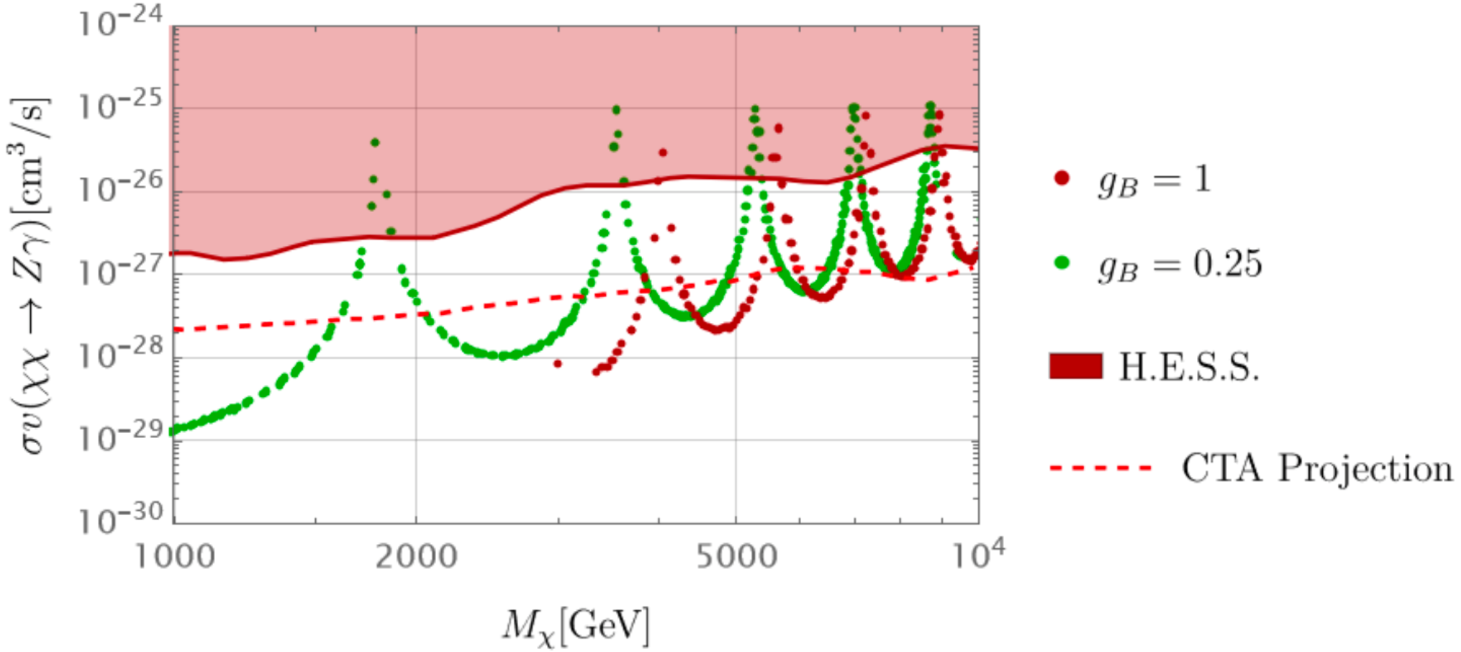
- We have discussed in detail the predictions for gamma lines and show that the predictions could be tested in the near future at gamma-ray telescopes such as CTA.

- We discussed all relevant processes to predict the photon flux from dark matter annihilation and shown that one can see the transition between the continuum and the gamma lines, I.e. the gamma lines visibility is not spoiled.

Gamma Lines !



$g_B = 0.25$
$\xi = 10\%$
$E_\gamma^2 \frac{d\Phi}{dE_\gamma}$[GeV cm^{-2}s^{-1}]
E_γ/M_χ
Total Flux
$\chi\chi \to \gamma\gamma$
$\chi\chi \to q\bar{q}\gamma$
$\chi\chi \to Z\gamma$
$\chi\chi \to q\bar{q}\gamma\gamma$



$\sigma v(\chi\chi \to Z\gamma)$[cm^3/s]
M_χ[GeV]
$g_B = 1$
$g_B = 0.25$
H.E.S.S.
CTA Projection