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Investigation of the nature of a massive vector mediator for Dark Matter through e^+e^- collisions

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INTRODUCTION

Several studies have been proposed to investigate the dark matter (DM), trying to uncover its origin and nature. Distinct approaches aims to understand how DM interacts and what are the possible mechanisms for detecting it. Theories beyond the Standard Model of the Elementary Particles (SM) investigate the possible couplings of DM with conventional matter in order to measure its interaction in the laboratory.

This work aims to investigate the interaction between fermions and particles of DM by interaction through vector bosons, which would be the mediators of some kind of interaction of DM. Thus, our goal is to establish new exclusion limits for the differential and total cross sections for the coupling this vector boson to conventional matter, specifically employing three possible candidates (fermion, scalar, and vector) for relic DM.

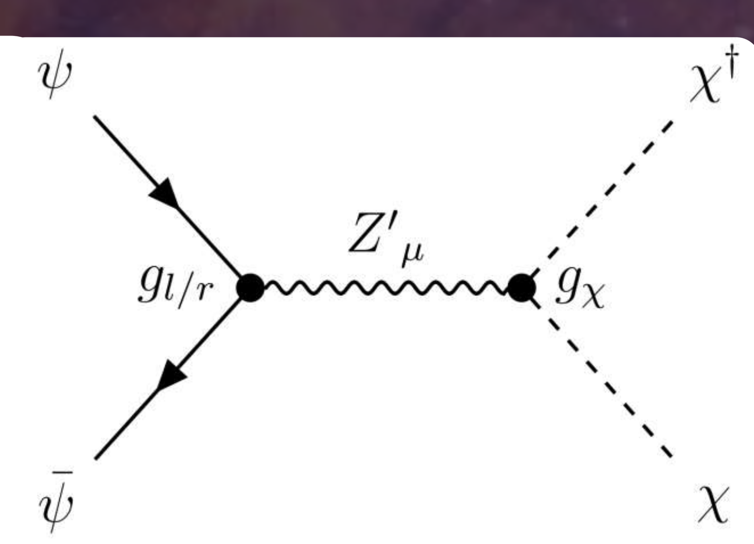
OBJECTIVES

The main goal of this study is to probe the limits and analyze parameters for the thermal production of DM, through a process that involves an interaction of the standard model with the dark sector mediated by a **new** massive boson mediator (Z'_μ) as a Breit-Wigner resonance peak.

METHODS

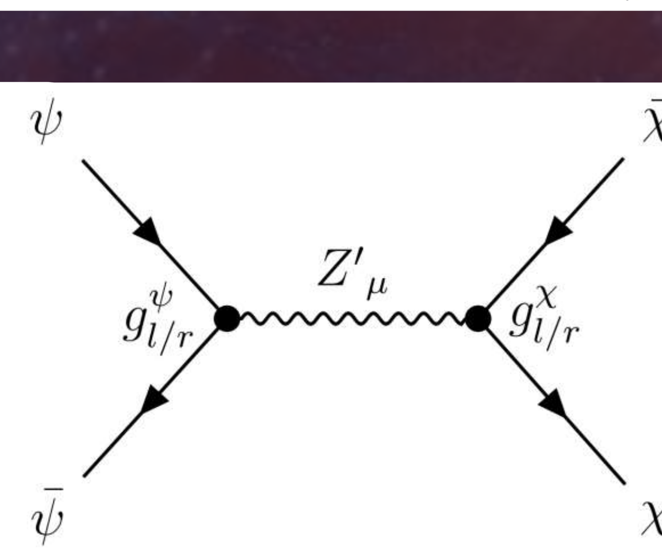
In this work we investigate three possible DM candidates, i.e. scalar, fermion, and vector DM particles. Making use of the Feynman rules, we compute the total cross sections for the following diagrams and its respective Lagrangians [1]:

SCALAR DM



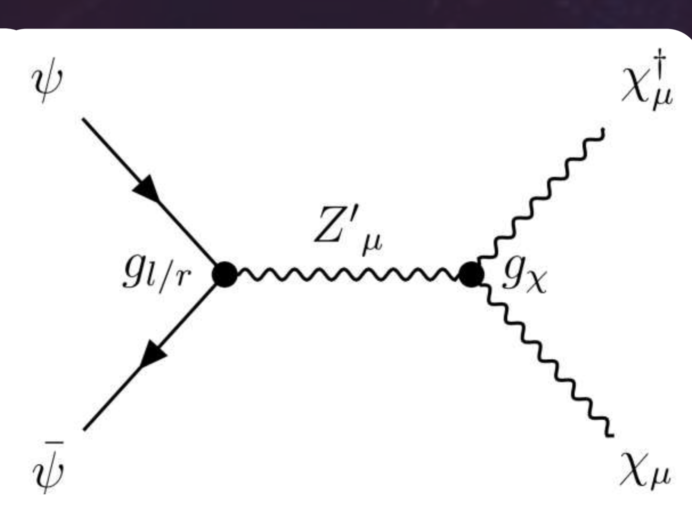
$$\mathcal{L}_{\text{int}} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \frac{1}{2}M_\Omega^2 Z'^\mu Z'_\mu + \bar{\psi}\gamma^\mu\left(g_l P_L + g_r P_R\right)\psi Z'_\mu + g_\chi\left(\chi^\dagger\partial_\mu\chi - \chi\partial_\mu\chi^\dagger\right)Z'^\mu$$

FERMION DM



$$\mathcal{L}_{\text{int}} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \frac{1}{2}M_\Omega^2 Z'^\mu Z'_\mu + \left[\bar{\psi}\gamma^\mu\left(g_l P_L + g_r P_R\right)\psi + \bar{\chi}\gamma^\mu\left(g_l P_L + g_r P_R\right)\chi\right]Z'_\mu$$

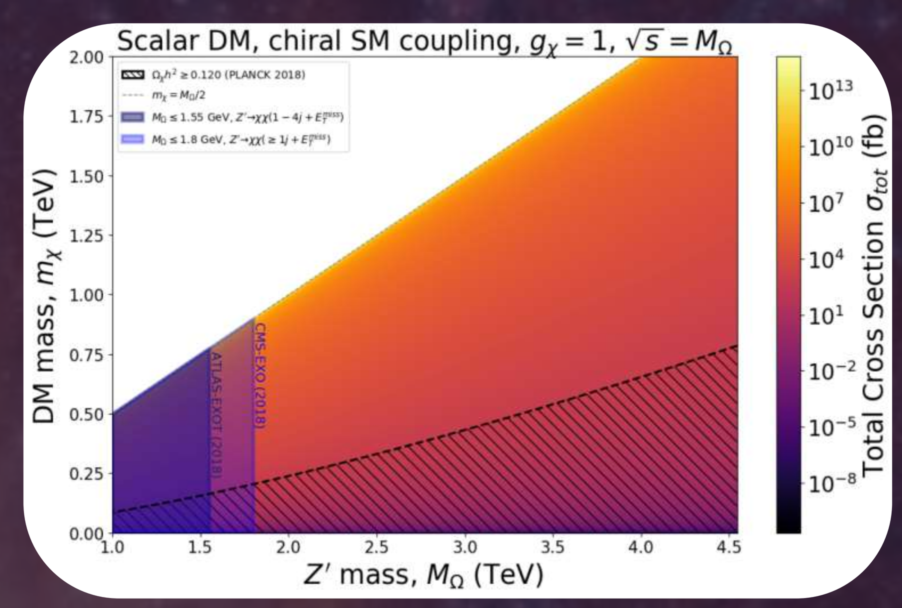
VECTOR DM

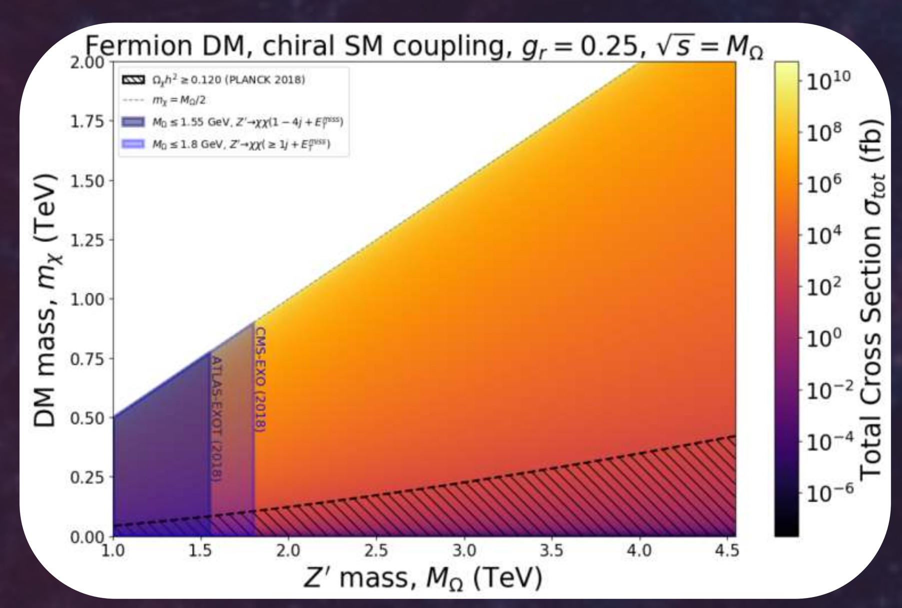


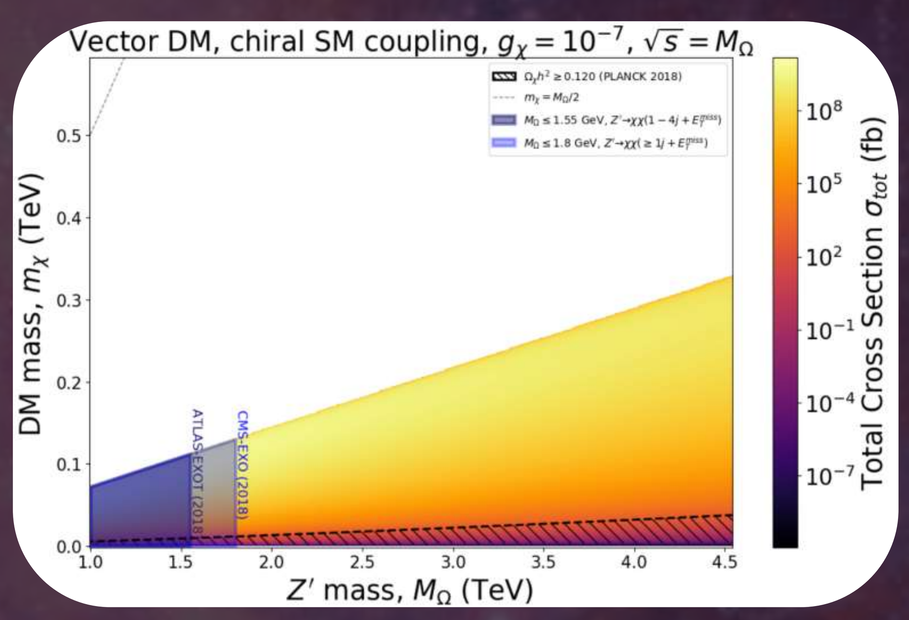
$$\mathcal{L}_{\text{int}} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \frac{1}{2}M_\Omega^2 Z'^\mu Z'_\mu + \bar{\psi}\gamma^\mu\left(g_l P_L + g_r P_R\right)\psi Z'_\mu - ig_\chi Z'_\mu \chi^\dagger_\nu\left(\partial^\mu\chi^\nu - \partial^\nu\chi^\mu\right)$$
$$+ ig_\chi Z'^\mu\chi^\nu\left(\partial_\mu\chi^\dagger_\nu - \partial_\nu\chi^\dagger_\mu\right) - ig_\chi\left(\partial^\mu Z'^\nu - \partial^\nu Z'^\mu\right)\chi^\dagger_\mu\chi_\nu,$$

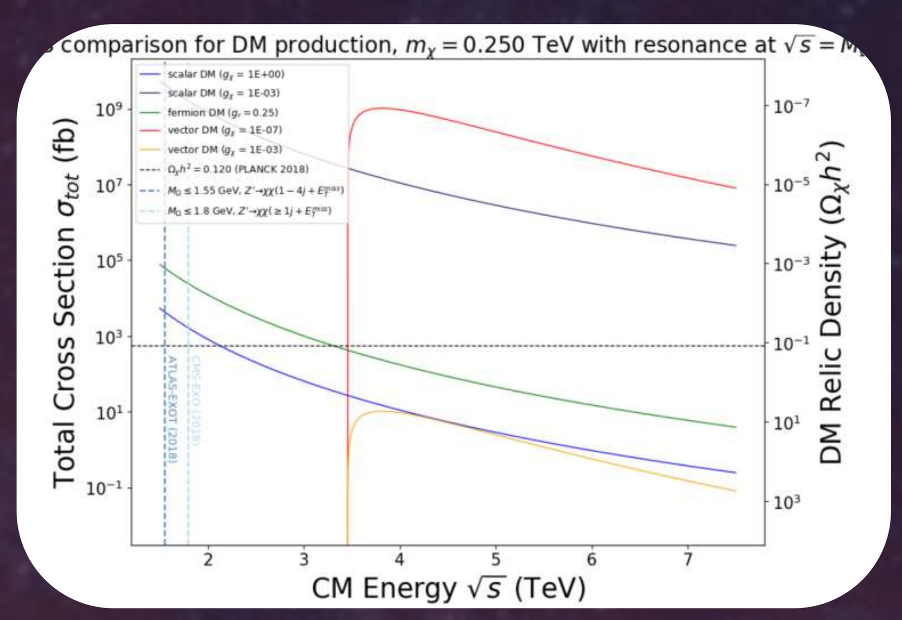
DISCUSSION AND CONCLUSION

With the analytical results obtained, we have developed a Python code to evaluate the total cross section in DM (m_χ) and mediator (M_Ω) mass ranges as employed in the literature. Using data from Refs. [3-4], we are able to estimate exclusion limits for the proposed models. For observed DM density, we assume a scenario, with being the mass of the DM cold relic density.









For these evaluations, we used some recommendations of [2-4] and adopted the parameters described below in Table 1.

Table 1 – Some of the parameters utilized

Parameter [2-4]	Value
SM fermion mass	$m_e = 511\ keV$
SM coupling (left)	$g_l = 0.25$
SM coupling (right)	$g_r = 0$
DM coupling (scalar and fermion DM)	$g_\chi = 1$
DM coupling (vector DM)	$g_\chi = 10^{-7}$
Dimensionless Hubble parameter	$h = 0.678$
Present day CMB temperature	$T_0 = 2.7255$ K
Critical density	$\rho_{crit} = 1{,}05371 \times 10^{-5}\ h^2\ GeV\ cm^{-3}$
Cold DM relic density	$\Omega_\chi = 0{,}120h^2$

Therefore, these results show that our models are within the parameter space probed in the experimental and cosmological limits. Note that, to reproduce similar cross sections with the other models, the vector DM needs a much smaller coupling constant (10^{-7}) and a reduced mass range. This work aims to further stringe our parameter space, especially the mass range of the mediator mass, with both existing data and new experiments such as the Future Circular Collider (FCC) and International Linear Collider (ILC).

SOME REFERENCES

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[3] Planck Collaboration, *Planck 2018 results. VI. Cosmological parameters* (2018). arXiv:1807.06209v1 [astro-ph.CO]
[4] CMS Collaboration, *Physical Review D* **97** 092005 (2018). arXiv:1712.02345 [hep-ex]

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