MODEL-INDEPENDENT STUDY OF LEPTOPHILIC DARK MATTER

{ HUGO PRAGER }   UNIVERSITY OF SOUTHAMPTON, HIGH ENERGY PHYSICS DEPARTMENT

UNIVERSITY OF Southampton

INTRODUCTION

A *Dark Matter* (DM) candidate is one of the main missing pieces in our understanding of the Universe.

In this study we will focus on a simplified model where the DM is a boson, either scalar or vector which is produced through the decay of a extra charged leptonic mediator (XL). Both of these new particles are odd under a $\mathbb{Z}_2$ symmetry which is needed to make the DM stable. These scenarios can be constrained by a large number of observables from cosmology, direct and indirect DM detection, SM lepton dipole moments, flavour and collider physics. We will discuss the constraints on the new parameters of the scenario (masses and couplings) and combine them to identify exclusion regions for some representative benchmarks characterised by how the extra lepton interacts with the SM leptons.

LAGRANGIAN AND INTERACTIONS

Lagrangian for singlet DM

$$\mathcal{L}^S = \sum_{f=e,\mu,\tau} \left[\lambda_{11}^f \bar{E} P_R e_f + \lambda_{21}^f (\bar{N}\bar{E}) P_L \begin{pmatrix} \nu_f \\ e_f \end{pmatrix} \right] S^0_{DM}$$

$$\mathcal{L}^V = \sum_{f=e,\mu,\tau} \left[g_{11}^f \bar{E}\gamma_\mu P_R e_f + g_{21}^f (\bar{N}\bar{E})\gamma_\mu P_L \begin{pmatrix} \nu_f \\ e_f \end{pmatrix} \right] V^{0\mu}_{DM}$$

Interactions between XLs and SM gauge bosons

$$\begin{aligned} \mathcal{L}_{AXL} &= -eA^\mu \bar{E}\gamma_\mu E \\ \mathcal{L}_{ZXL} &= Z^\mu \bar{E}\gamma_\mu \left(g_L^{ZEE} P_L + g_R^{ZEE} P_R \right) E \\ &+ Z^\mu \bar{N}\gamma_\mu \left(g_L^{ZNN} P_L + g_R^{ZNN} P_R \right) N \\ \mathcal{L}_{WXL} &= W^{+\mu} \bar{N}\gamma_\mu \left(g_L^{WLN} P_L + g_R^{WLN} P_R \right) E \end{aligned}$$

BENCHMARK POINTS AND CHIRALITIES

Benchmark points (BP)

Branching ratios						
BP1	*BP2*	*BP3*	*BP4*	*BP5*	*BP6*	*BP7*
100% e	100% μ	100% τ	50% e,μ	50% e,τ	50% μ,τ	33% e,μ,τ
Relic density, direct and indirect detection, EWPTs, corrections to Z width						
			FCNC Z decays into leptons			
$(g-2)_e$	$(g-2)_\mu$	$(g-2)_\tau$	$(g-2)_{e,\mu}$	$(g-2)_{e,\tau}$	$(g-2)_{\mu,\tau}$	$(g-2)_{e,\mu,\tau}$
			$\mu\to e\gamma$ $\mu\to 3e$	$\tau\to e\gamma$ $\tau\to 3e$	$\tau\to\mu\gamma$ $\tau\to 3\mu$	$\mu,\tau\to e\gamma$ $\tau\to\mu\gamma$ $\tau\to 3l$ $\mu\to 3e$

Chiralities

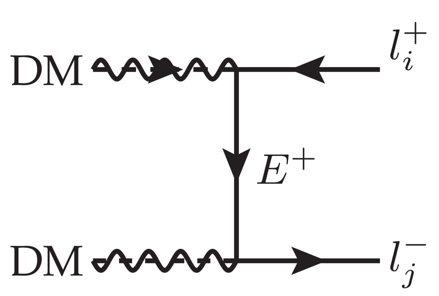
Scenario	Couplings
L	$\lambda_{11}^f = 0$
R	$\lambda_{21}^f = 0$
V	$\lambda_{11}^f = \lambda_{21}^f$
A	$\lambda_{11}^f = -\lambda_{21}^f$

Similar definition for g_{ij}^f

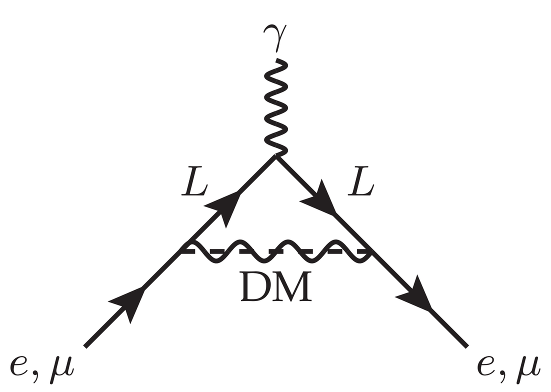
We will only study 7 benchmark points and 4 different chiralities. On this poster only representative plots are shown, the one for the other BP and chiralities can be found in annexe.

CONSTRAINTS

Relic density An important observable constraining our model is the relic density of DM. The value of this relic density is driven by the annihilation cross section of two DM particles which is described by the diagram on the right. The value of Ω_{DM} can be numerically computed using MadDM.The favoured region is a strip in the $M_E - M_{DM}$ plain which exclude the region in the high mass range but not the underabundant region if we allow multicomponent DM. The preliminary results are showed in red in the Numerical Results section.



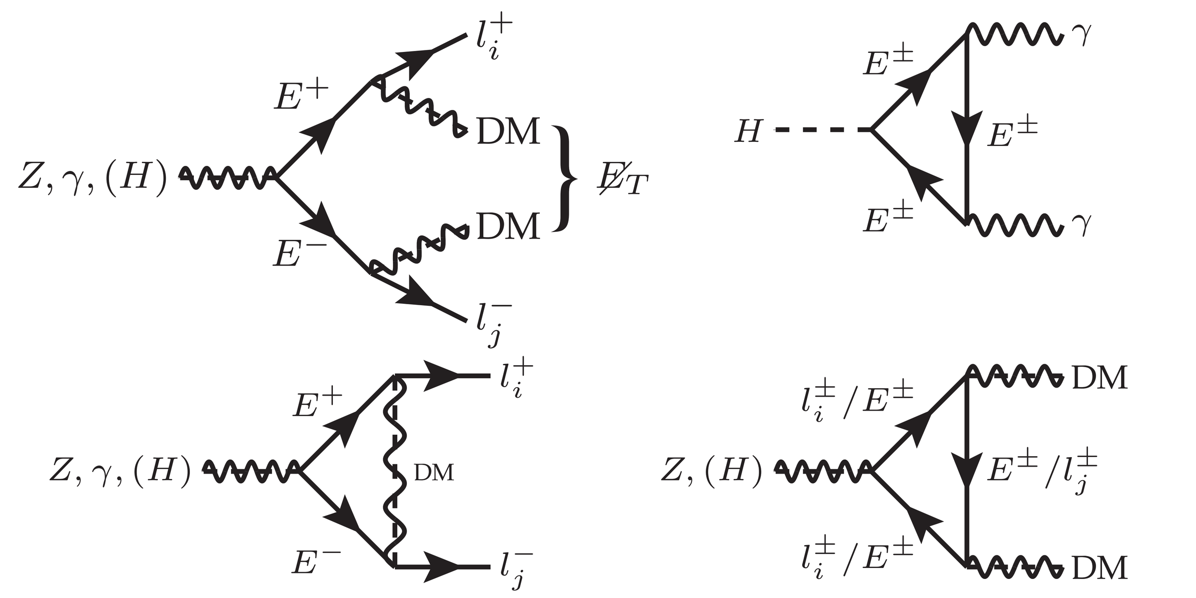
g-2 correction A stringent bound on the couplings of the DM particle and on the heavy lepton is given by the measurement of the electron and muon anomalous magnetic moments. The contribution to the anomalous magnetic moment is given in the diagram on the right and can be computed analytically.The preliminary results are showed in green in the Numerical Results section. Considering our preliminary results. the limits are typically quite strong, the only case which is not much constrained is the Scalar singlet DM in the *Vector-like XL* scenario.



Collider signatures

XL are mainly produced via the exchange of a Z or a photon, or through a Higgs in the s-channel; and then decays into SM leptons and DM.

LEP The main constraints from LEP come from the correction to the $Z - l - l$ vertex (flavour conserving and flavour changing decays constraints). At loop level, the XLs also contribute to Z and Higgs decays. The contributing diagrams are shown below.



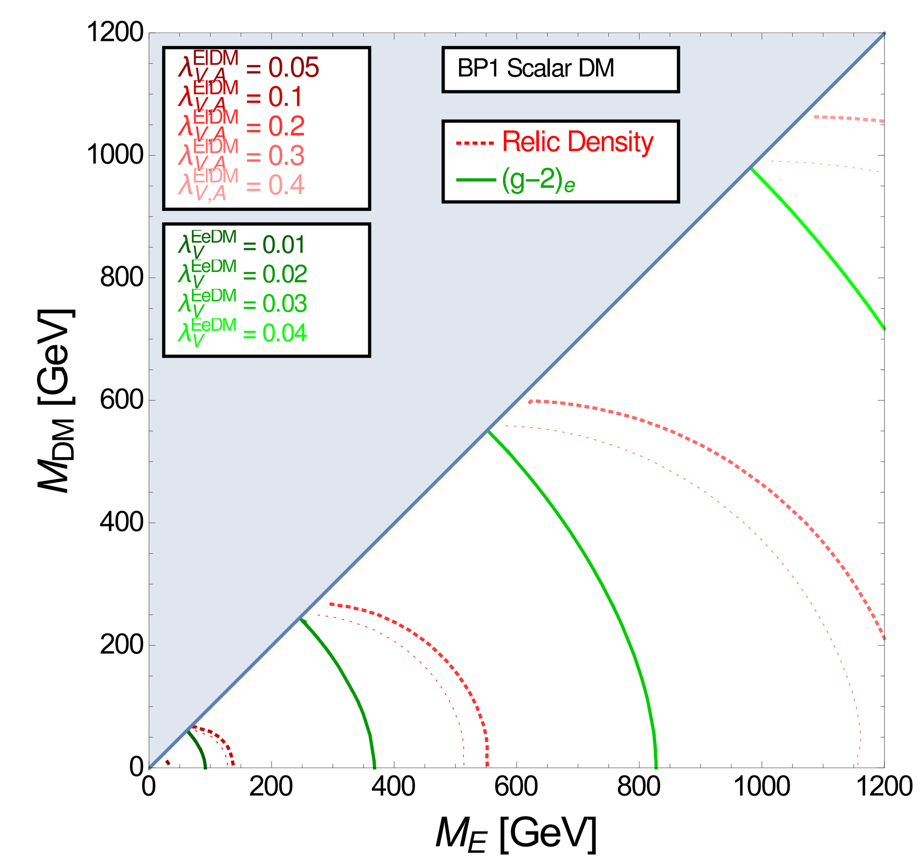
A further constraint is given by the cross-section for the W-pair production and for the χ^+-pair production where the χ^+ decays to a 2-body $\tilde{\nu}$-l final state.

LHC To obtain the LHC constraints at tree level we have performed a scan over the XL and DM masses and over their couplings with the SM states using MadGraph5 (parton level), Pythia (hadronisation and parton shower) and CheckMATE (Atlas and CMS searches).

The results for the scalar DM case are shown in the Numerical Results section. For fixed XL and DM masses, the coupling between the heavy lepton and the SM Z determines the cross-section, while the coupling between the heavy lepton, the DM and the SM leptons determines the width of the heavy lepton.

NUMERICAL RESULTS

Relic density and g-2

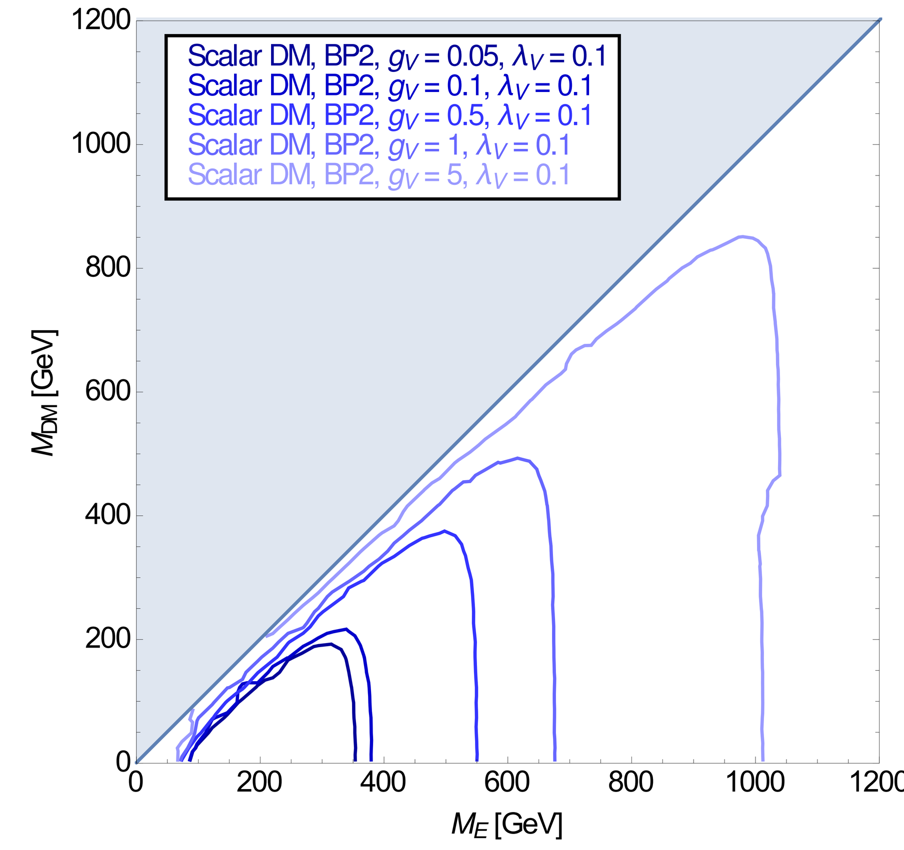


Preliminary results considering relic density and $g-2$ constraint seem to rule out BP1 for scalar DM. The results for the other BP can be find on the annexe pages, we see that they impose strong constraints on the free parameters when they don't completely exclude the model.

Collider signatures

LEP Unfortunately LEP constraints didn't give very useful results, they only exclude XL with mass below 100 GeV, and only for large value of the coupling with the Z ($g^{ZEE} = 5$).

LHC (here $g = g^{ZEE}$)



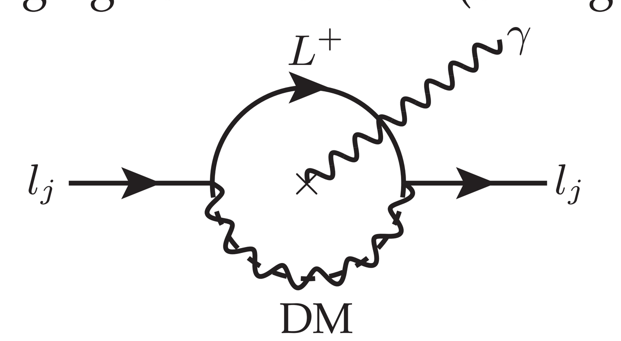
We observe that a recasting of 8TeV LHC data using CheckMATE for BP2 and scalar DM can exclude a large part of the parameter space depending on the value of the coupling with the Z.

CONCLUSION

We considered several different observables to constraints a toy model including a XL and a DM candidate. Preliminary results from relic density and $g-2$ correction allows us to rule out a lot of models, or at least to impose strong constraints on the free parameters. Conversely the results from LEP doesn't give us much exclusion, unless the coupling with the Z is very large. Finally the results from the LHC signature give us interesting constraints depending on the value of the coupling with the Z.

FURTHER RESEARCH

To complete this preliminary study, more constraints have to be included: relic density including brehmsstrahlung and loop effect, $(g-2)_\tau$ corrections, EWPTs (only for lepton doublets), direct and indirect detection of DM as well as flavour changing neutral current (cf diagram below).



REFERENCES

Based on a work in progress with D. Barducci, A. Deandrea, S. Moretti and L. Panizzi.