Version 0.1 DRAFT

ATLAS+CMS DARK MATTER FORUM RECOMMENDATIONS

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1
Introduction

This is a citation test Harris and Kousouris [2011].

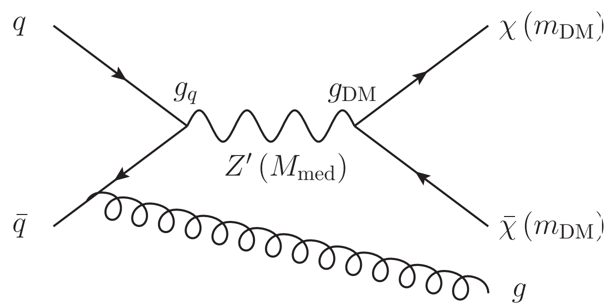

Figure 2.1: The diagram shows the pair production of dark matter particles in association with a parton from the initial state via an s-channel vector or axial-vector mediator. The process if specified by ($M_{\rm med}$, $m_{\rm DM}$, $g_{\rm DM}$, g_q), the mediator and dark matter masses, and the mediator couplings to dark matter and quarks respectively.

2

List of simplified models: choices and implementation

General topics:

- choice of Dark Matter type: Dirac (unless specified otherwise) and what we might be missing
- MFV and what we might be missing

2.1 Generic models for mono-jet signatures

Vector and axial vector mediator, s-channel exchange

- Matrix Element implementations (with references)
  - Production mechanism
  - Lagrangian We consider the case of a dark matter particle that is a Dirac fermion and where the production proceeds via the exhange of a spin-1 s-channel mediator. We consider the following interactions between the DM and SM fields including a vector mediator with:
    (a) vector couplings to DM and SM.
    (b) axial-vector couplings to DM and SM.

$$\mathcal{L}_{\text{vector}} = \sum_q g_q Z'_\mu \bar{q}\gamma^\mu q + g_{\text{DM}} Z'_\mu \bar{\chi}\gamma^\mu \chi \tag{2.1}$$

$$\mathcal{L}_{\text{axial}} = \sum_q g_q Z'_\mu \bar{q}\gamma^\mu \gamma^5 q + g_{\text{DM}} Z'_\mu \bar{\chi}\gamma^\mu \gamma^5 \chi \tag{2.2}$$

where the coupling extends over all the quarks and universal couplings are assumed for all the quarks. It is also possible to consider another model in which mixed vector and axial-vector couplings are considered, for instance the couplings to the quarks are vector whereas those to DM are axial-vector. As a starting point, we consider only the models with the vector couplings only and axial vector couplings only. Studies have been performed to see if the case of a mixed coupling can be simply extracted from the other models by some reweighting procedure to take account of the difference in cross section. This would assume that the difference between the pure and mixed couplings case does not affect the kinematics of the event.

- Definition of minimal width We assume that no additional visible or invisible decays contribute to the width of the mediator, this is referred to as the minimal width and it is defined as follows for the vector and axial-vector models.

$$\Gamma_{\text{min}} = \Gamma_{\bar{\chi}\chi} + \sum_q N_c \Gamma_{\bar{q}q} \tag{2.3}$$

where the individual contributions to this from the partial width are from,

$$\Gamma^{\text{vector}}_{\bar{\chi}\chi} = \frac{g^2_{\text{DM}} M_{\text{med}}}{12\pi} \left(1 + \frac{2m^2_{\text{DM}}}{M^2_{\text{med}}}\right) \sqrt{1 - \frac{4m^2_{\text{DM}}}{M^2_{\text{med}}}} \tag{2.4}$$

$$\Gamma^{\text{vector}}_{\bar{q}q} = \frac{3g^2_q M_{\text{med}}}{12\pi} \left(1 + \frac{2m^2_q}{M^2_{\text{med}}}\right) \sqrt{1 - \frac{4m^2_q}{M^2_{\text{med}}}} \tag{2.5}$$

$$\Gamma^{\text{axial}}_{\bar{\chi}\chi} = \frac{g^2_{\text{DM}} M_{\text{med}}}{12\pi} \left(1 - \frac{4m^2_{\text{DM}}}{M^2_{\text{med}}}\right)^{3/2} \tag{2.6}$$

$$\Gamma^{\text{axial}}_{\bar{q}q} = \frac{3g^2_q M_{\text{med}}}{12\pi} \left(1 - \frac{4m^2_q}{M^2_{\text{med}}}\right)^{3/2} . \tag{2.7}$$

- Couplings
- Parameter choices (for scan) Vary mediator mass and DM mass
- Generator implementation

Scalar and pseudoscalar mediator, s-channel exchange

Colored scalar mediator, t-channel exchange

2.2 *Specific models for signatures with EW bosons*

In this Section, we consider models with a photon, a W boson, a Z boson or a Higgs boson in the final state, accompanied by Dark Matter particles that either couple directly to the boson or are mediated by a new particle. The experimental signature is identified as *V+MET*.

These models are interesting both as extensions of models where the gluon provides the experimentally detectable signature, and as stand-alone models with final states that cannot be generated by the models in Section 2.1.

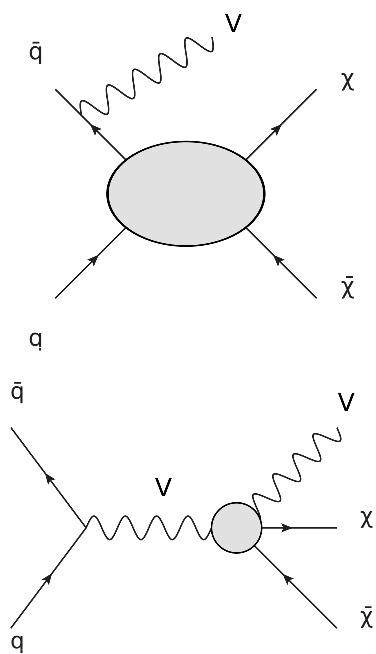

Figure 2.2: Sketch of EFT models for V+MET searches, adapted from [Nelson et al., 2014].

The models considered can be divided in four categories:

EFT models where the boson is radiated from the initial state As depicted in the top diagram of Figure 2.2, these models follow the nomenclature and theory for the EFT benchmarks commonly used by MET+X searches Goodman et al. [2010].

EFT models where the boson is directly coupled to DM Shown in the bottom of Figure 2.2, these models allow for an EFT vertex that directly couples the boson to Dark Matter.

Simplified models where the boson is radiated from the initial state These models follow those already described in Section 2.1, replacing the initial state gluon with a boson.

V-specific simplified models These models postulate direct couplings of new mediators to bosons, e.g. they couple the Higgs boson to a new scalar [Carpenter et al., 2014].

The following Sections describe the models within these categories, the parameters for each of the benchmark models chosen, the studies towards the choices of the parameters to be scanned, and finally point to the location of their Matrix Element implementation.

EFT models with ISR boson radiation Searches in the mono-jet final state are generally more sensitive with respect to final states including bosons, due to the much larger rates of jet+MET signal events with respect to radiation of bosons [Zhou et al., 2013]. The rates for the H+MET signature in these models are too low for EFT models to be considered a viable benchmark [Carpenter et al., 2014]. However, the presence of photons [Kha, 2014, Aad, 2014a], leptons from W and Z decays [Khachatryan et al., 2014, Aad, 2014a, Aad et al., 2014] and W or Z bosons decaying hadronically [Aad, 2014b] allow to reject the background more effectively, making Z/gamma/W+MET search results for simple EFT benchmarks still worth comparing with jet+MET. Furthermore, in the case of W boson radiation, the values of the couplings to up- and down-type quarks determine the interference between the radiation of a W from the up or from the down quark [Bai and Tait, 2013]. In case of constructive interference, the W+MET signature is more sensitive than the jet+MET signature (insensitive to the values of couplings).

EFT models with direct DM-boson couplings A complete list of effective operators with direct DM/boson couplings, up to dimension 7, can be found in [Cotta et al., 2013].

Simplified models with ISR boson radiation

Specific simplified models

2.3 *Specific models for signatures with heavy flavor quarks*

2.4 *SUSY-inspired simplified models*

3
Validity of EFT approach

4
Recommendations for expressing collider constraints

Bibliography

Robert M. Harris and Konstantinos Kousouris. Searches for dijet resonances at hadron colliders. *Int. J. Modern Phys.*, 26(30n31): 5005–5055, 2011. doi: 10.1142/S0217751X11054905.

Andy Nelson, Linda M. Carpenter, Randel Cotta, Adam Johnstone, and Daniel Whiteson. Confronting the Fermi Line with LHC data: an Effective Theory of Dark Matter Interaction with Photons. *Phys.Rev.*, D89(5):056011, 2014. doi: 10.1103/PhysRevD.89.056011.

Jessica Goodman, Masahiro Ibe, Arvind Rajaraman, William Shepherd, Tim M.P. Tait, et al. Constraints on Dark Matter from Colliders. *Phys.Rev.*, D82:116010, 2010. doi: 10.1103/PhysRevD.82.116010.

Linda Carpenter, Anthony DiFranzo, Michael Mulhearn, Chase Shimmin, Sean Tulin, et al. Mono-Higgs-boson: A new collider probe of dark matter. *Phys.Rev.*, D89(7):075017, 2014. doi: 10.1103/PhysRevD.89.075017.

Ning Zhou, David Berge, and Daniel Whiteson. Mono-everything: combined limits on dark matter production at colliders from multiple final states. *Phys.Rev.*, D87(9):095013, 2013. doi: 10.1103/PhysRevD.87.095013.

Search for new phenomena in monophoton final states in proton-proton collisions at $\sqrt{s}$ = 8 TeV. 2014.

Search for dark matter in events with a Z boson and missing transverse momentum in pp collisions at $\sqrt{s}$=8 TeV with the ATLAS detector. *Phys.Rev.*, D90(1):012004, 2014a. doi: 10.1103/PhysRevD.90.012004.

Vardan Khachatryan et al. Search for physics beyond the standard model in final states with a lepton and missing transverse energy in proton-proton collisions at $\sqrt{s}$ = 8 TeV. 2014.

Georges Aad et al. Search for new particles in events with one lepton and missing transverse momentum in pp collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector. *JHEP*, 1409:037, 2014. doi: 10.1007/JHEP09(2014)037.

Search for dark matter in events with a hadronically decaying W or Z boson and missing transverse momentum in pp collisions at $\sqrt{s} =$ 8 TeV with the ATLAS detector. *Phys.Rev.Lett.*, 112(4):041802, 2014b. doi: 10.1103/PhysRevLett.112.041802.

Yang Bai and Tim M.P. Tait. Searches with Mono-Leptons. *Phys.Lett.*, B723:384–387, 2013. doi: 10.1016/j.physletb.2013.05.057.

R.C. Cotta, J.L. Hewett, M.P. Le, and T.G. Rizzo. Bounds on Dark Matter Interactions with Electroweak Gauge Bosons. *Phys.Rev.*, D88:116009, 2013. doi: 10.1103/PhysRevD.88.116009.