Introduction and scope of the meeting

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LHC Dark Matter Working Group

Web site

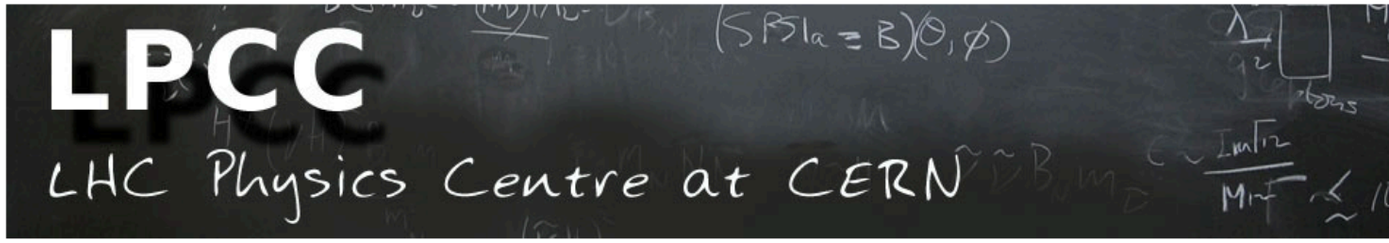
Previous meetings:

10–11 December 2015: presenting results from mono-X searches CERN-LPCC-2016-001 (arXiv:1603.04156)

22 June 2016: planning for future work

19–20 September 2016:

- Comparison of collider results from MET and non-MET channels (draft circulating to lhc-dmwg-contributors@cern.ch)
- Improvements to DMF simplified models (scalar sector continues today)
- Precision V+jet(s) background predictions (report today)
- Review of ICHEP results
- Future topics



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Useful links

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LHC DM WG:
WG on Dark Matter Searches at the LHC

To subscribe to the general WG mailing list, used to distribute announcements about meetings and available documents, go to
http://simba3.web.cern.ch/simba3/SelfSubscription.aspx?groupName=lhc-dmwg

A second mailing list is used for more technical exchanges related to the ongoing work of the WG. To subscribe, go to
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The LHC Dark Matter Working Group (LHC DM WG) brings together theorists and experimentalists to define guidelines and recommendations for the benchmark models, interpretation, and characterisation necessary for broad and systematic searches for dark matter at the LHC. As examples, the group develops and promotes well-defined signal models, specifying the assumptions behind them and describing the conditions under which they should be used. It works to improve the set of tools available to the experiments, such as higher- precision calculations of the backgrounds. It assists theorists with understanding and making use of LHC results.
The LHC DM WG develops and maintains close connections with theorists and other experimental particle DM searches (e.g. Direct and Indirect Detection experiments) in order help verify and constrain particle physics models of astrophysical excesses, to understand how collider searches and non-collider experiments complement one another, and to help build a comprehensive understanding of viable dark matter models.

The WG activity builds on the experience of the previous ATLAS-CMS Dark Matter Forum, whose findings are documented in this paper

WG documents and meeting agendas: see links in the right menu

Topics currently under discussion:

- Recommendations for the definition of further simplified models, to be used in the analyses in preparation for the Winter 2017 conferences.

Conveners:

- ATLAS: C. Doglioni and A. Boveia
- CMS: O. Buchmueller and K. Hahn
- TH: U. Haisch and T. Tait
- LPCC: M. Mangano

WG links

WG meetings
WG documents

LHC Dark Matter Working Group Organizers—Update

Organizers to guide discussions toward useful conclusions:

- Two ATLAS and two CMS organizers appointed by the experimental collaborations for fixed terms

  Caterina Doglioni and Antonio Boveia (ATLAS); Kristian Hahn and Oliver Buchmueller (CMS)

- Similarly, two theory organizers invited by the LPCC (Uli Haisch and Tim Tait)

Everyone welcome to participate in discussions, point out where work is needed, contribute (or criticise)

Thanks Oliver!

Exotica convener as of September

Welcome (back) Steven Lowette!

Draft of ‘Summary Plot’ recommendations

On 8 December, we circulated a version of arXiv draft to the lhc-dmwg-contributors list that summarizes a portion of our 19–20 September meeting

Please read and comment (ideally before winter break!)

We also ask you to indicate if you would like to sign this document as an author.

Next slides: main points and feedback so far

CERN-LPCC-2016-XXX

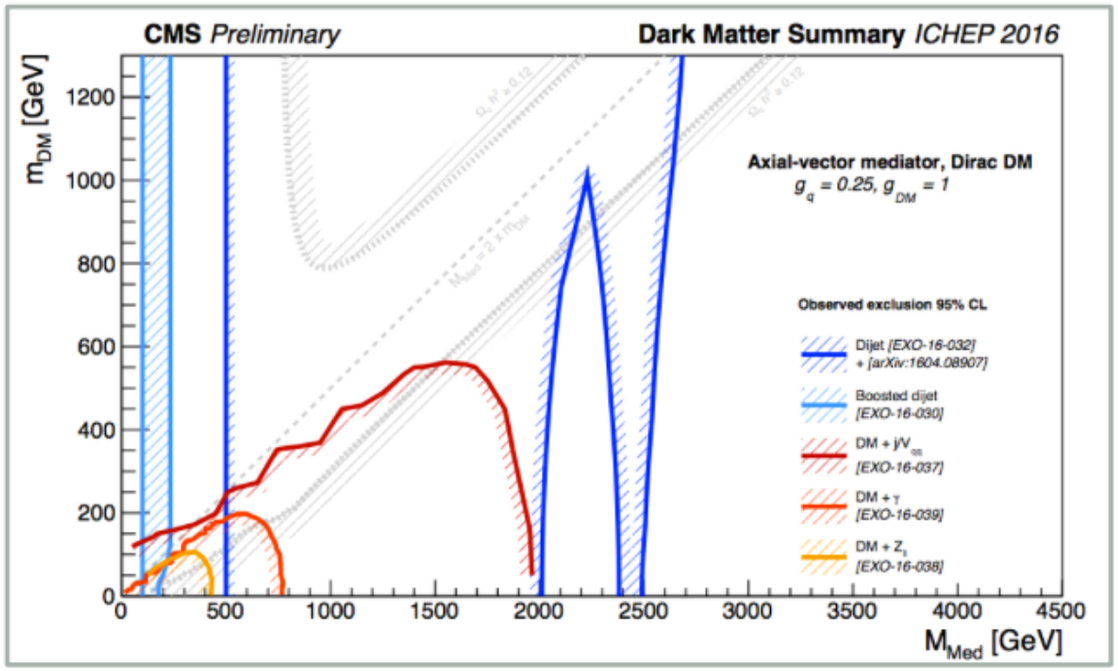
Recommendations of the LHC Dark Matter Working Group: Comparing LHC searches for heavy mediators of dark matter production in visible and invisible decay channels

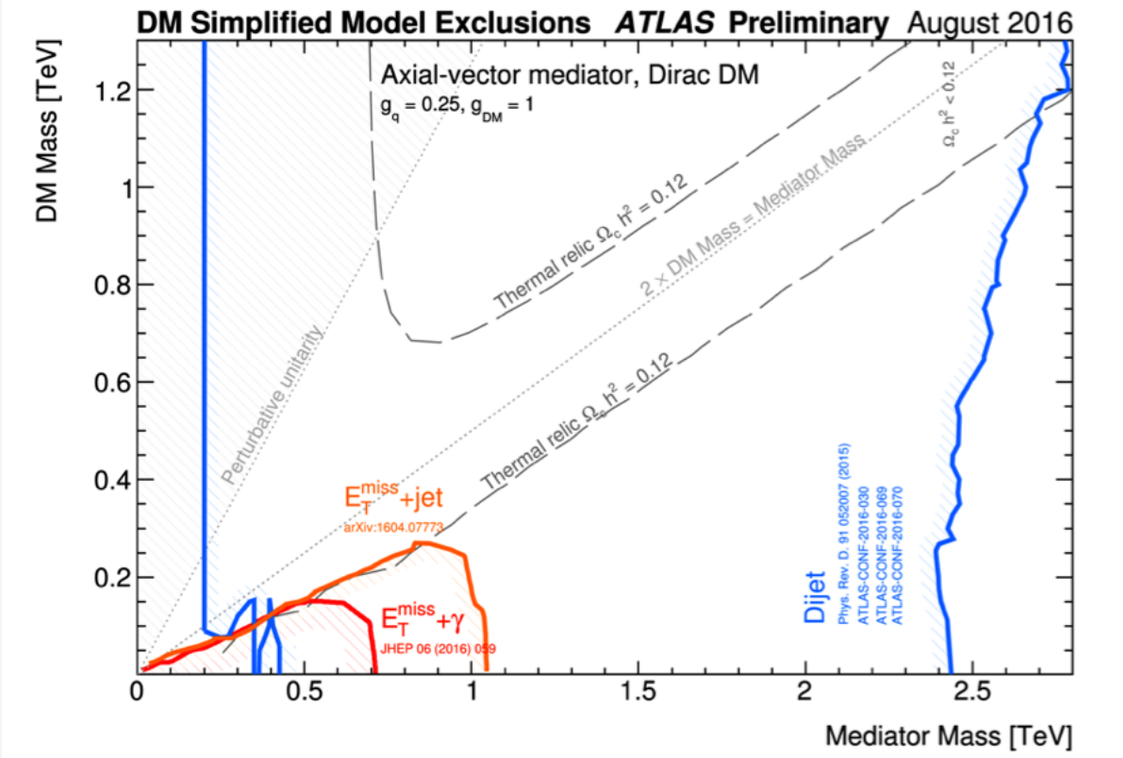
[Temporary contributor list] Mihailo Backović[0] Antonio Boveia,[1,*] Oliver Buchmueller,[2,*] Malcolm Fairbairn, [5] Patrick Tunney,[5] Caterina Doglioni,[7,*] Isabelle John,[7] Kristian Hahn,[9,*] Ulrich Haisch[10,11,*] Philip C. Harris,[1] Tristan DuPree,[1] Valerio Ippolito,[13] Emma Tolley,[13] Felix Kahlhoefer,[14,*] Tim M.P. Tait,[24,*] Bryan Zaldivar,[25,*] Kentarou Mawatari,[26,] Giuliano Gustavino,[27,] Andreas Albert,[28,] Dan Hayden,[29,*] Markus Zinser,[30,*] and You?[31,*]

Abstract. Weakly-coupled TeV-scale particles may mediate the interactions between normal matter and dark matter. If so, the LHC would produce dark matter through these mediators, leading to the familiar “mono-X” search signatures, but the mediators would also produce signals without missing momentum via the same vertices involved in their production. This document from the LHC Dark Matter Working Group suggests how to compare searches for these two types of signals, based on a workshop that took place on September 19/20, 2016 and subsequent discussions. These suggestions include how to extend the spin-1 mediated simplified models already in widespread use to include lepton couplings. This document also provides analytic calculations of the relic density in the simplified models and reports an issue that arose when ATLAS and CMS first began to use preliminary numerical calculations of the dark matter relic density in these models.

Dark Matter Summary plots by ATLAS and CMS

ICHEP 2016: axial-vector mediator, leptophobic scenarios





Goals for next (Moriond) iteration:

- add lepton couplings
- highlight complementarity
  —> introduce vector mediator as well

Implemented in DMSimp MG5aNLO

$$\mathcal{L}_{\text{vector}} = -g_{\text{DM}}\, Z'_\mu, \bar{\chi}\gamma^\mu\chi - g_q \sum_{q=u,d,s,c,b,t} Z'_\mu\, \bar{q}\gamma^\mu q - g_\ell \sum_{\ell=e,\mu,\tau} Z'_\mu\, \bar{\ell}\gamma^\mu \ell\,,$$

$$\mathcal{L}_{\text{axial-vector}} = -g_{\text{DM}}\, Z'_\mu\, \bar{\chi}\gamma^\mu\gamma_5\chi - g_q \sum_{q=u,d,s,c,b,t} Z'_\mu\, \bar{q}\gamma^\mu\gamma_5 q - g_\ell \sum_{\ell=e,\mu,\tau} Z'_\mu\, \bar{\ell}\gamma^\mu\gamma_5 \ell\,.$$

$$\Gamma^{\chi\bar{\chi}}_{\text{vector}} = \frac{g^2_{\text{DM}} M_{\text{med}}}{12\pi}(1-4z_{\text{DM}})^{1/2}(1+2z_{\text{DM}})\,,$$
$$\Gamma^{q\bar{q}}_{\text{vector}} = \frac{g^2_q M_{\text{med}}}{4\pi}(1-4z_q)^{1/2}(1+2z_q)\,,$$
$$\Gamma^{\ell\bar{\ell}}_{\text{vector}} = \frac{g^2_\ell M_{\text{med}}}{12\pi}(1-4z_\ell)^{1/2}(1+2z_\ell)\,,$$
$$\Gamma^{\nu\bar{\nu}}_{\text{vector}} = \frac{g^2_\ell}{24\pi} M_{\text{med}}\,,$$
$$\Gamma^{\chi\bar{\chi}}_{\text{axial-vector}} = \frac{g^2_{\text{DM}} M_{\text{med}}}{12\pi}(1-4z_{\text{DM}})^{3/2}\,,$$
$$\Gamma^{q\bar{q}}_{\text{axial-vector}} = \frac{g^2_q M_{\text{med}}}{4\pi}(1-4z_q)^{3/2}\,,$$
$$\Gamma^{\ell\bar{\ell}}_{\text{axial-vector}} = \frac{g^2_\ell M_{\text{med}}}{12\pi}(1-4z_\ell)^{3/2}\,,$$
$$\Gamma^{\nu\bar{\nu}}_{\text{axial-vector}} = \frac{g^2_\ell}{24\pi} M_{\text{med}}\,.$$

Neutrino couplings

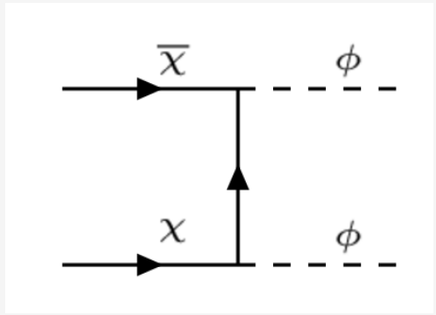
Summary plot scenarios

- addition of **lepton** couplings
  - dilepton searches will dominate if equal couplings to leptons and to quarks

- highlight **complementarity** of searches
  - introduce vector mediator, as UV completion of axial vector mediator models (= reasonable simplified models) require equal lepton and quark couplings

Goal of Scenario	Mediator type	g_q	g_{lep}	g_{DM}
V1: Highlight contribution of dijet searches in leptophobic case (close to current ATLAS/CMS benchmark)	Vector	0.25	0	1.0
V2: Highlight complementarity of DM/ dilepton/dijet searches	Vector	0.1	0.01	1.0
A1: Current ATLAS/CMS benchmark	Axial vector	0.25	0	1.0
A2: Highlight contribution of dilepton searches (close to current benchmark for dijets)	Axial vector	0.1	0.1	1.0

Relic density updates



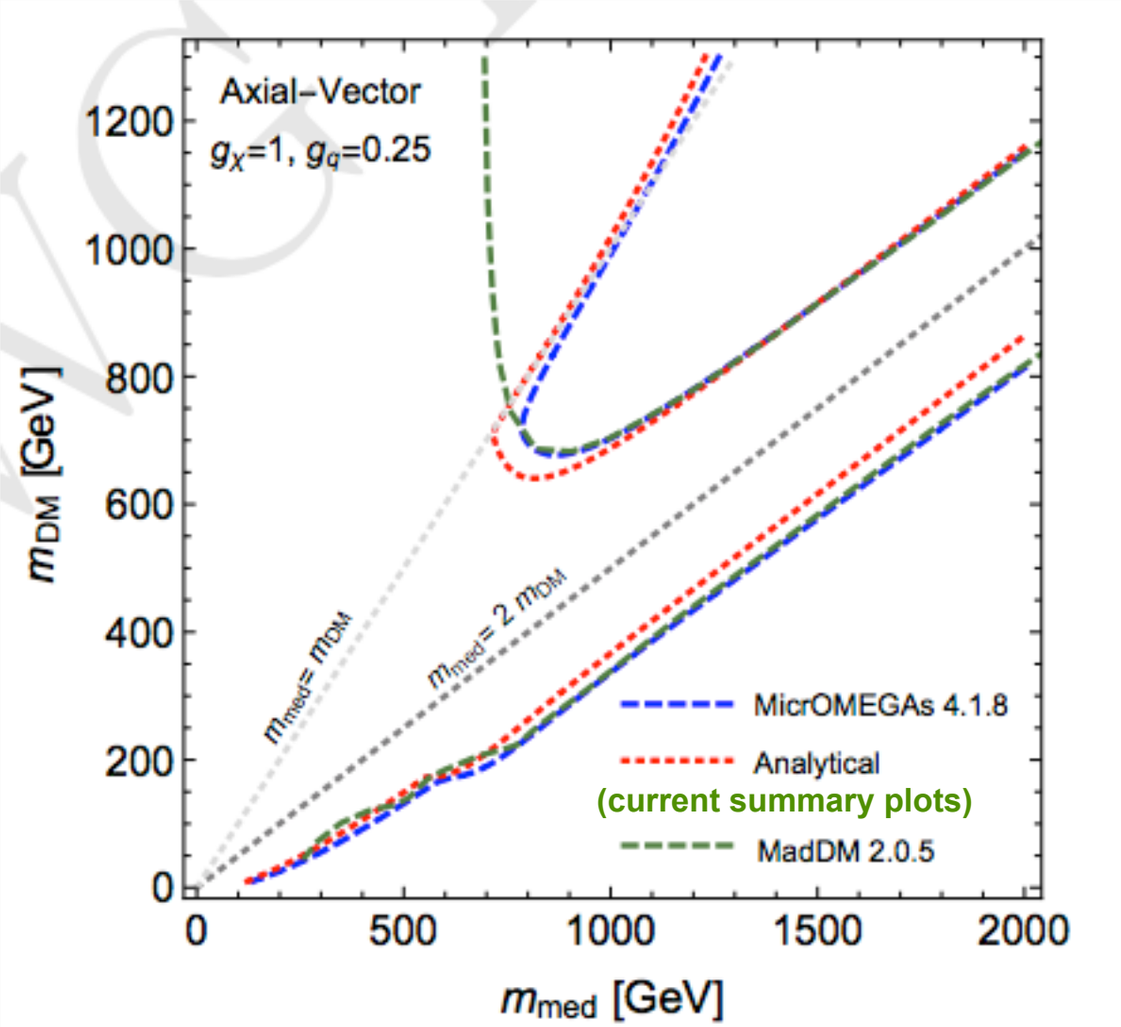
- Previous relic density calculation with MadDM: (bug) missing t-channel annihilation for $\chi\chi^{-} \to Z'Z'$

- Now fixed in MadDM 2.0.6

- New curves for summary plots will be provided centrally by DMWG

- Document contains comparison of numerical results (MadDM, MicrOMEGAs) with analytical calculation

[Full talk at DMWG September meeting here]



Feedback so far

- Choice of wide resonance points: so far , all points chosen have a width of < 5%.
    - *The draft currently indicates that, since we haven't chosen any points where the width is very large, there isn't anything to worry about in dilepton searches. However, I thought one of the more interesting questions we raised was exactly what bounds do or don't apply in the case where we increase the dark matter coupling to the point where the resonance is wide. I still think this remains a very interesting question, and one we ought not to dismiss in such a summary way in a WG document. There is also the concern that the width effects might become important, not because of interference, so much as because of the effect they have on cuts applied or shapes fitted in the dilepton search.*

- Clarification on Fig. 1

Figure 1: Feynman graphs of s-channel (left) and t-channel (right) DM annihilation. While the s-channel process is dominant for $m_{\mathrm{med}}/2 > m_{\mathrm{DM}}$, the region $m_{\mathrm{med}} < m_{\mathrm{DM}}$ is dominated by the t-channel diagram.

- *What you call t-channel is in fact a double s-channel for the mediator, how is this favoured for light mediators? As an example e+e-→mu+mu- with single photon exchange has a much higher cross section than e+e-→4mu with two photons exchanged.*

    "annihilation into multiple mediators" dominates when kinematically open and $g_{DM} >> g_{SM}$

Feedback so far

- Concerns about relic density obtained with lepton couplings in benchmark scenarios
    - *What I see lacking in the document, are the relic density curves for the four proposed benchmark scenarios including lepton couplings. I'm particularly concerned about scenario A2, where the smallness of both lepton and quark couplings may result in overabundance.*

  => Provide numerical results for these benchmark scenarios?

    - *Similar comment goes toward the recommendation in the last full paragraph of P5: for g_q = 0.1 benchmark we should check first that there are still areas with correct relic abundance, which we could still probe with the diet searches. This is particularly important for the vector case, where the diet search reach typically ends above the Mme = 2 x mDM diagonal.*

  => Reiterate how relic density predictions depend on strong assumptions about cosmology

- Concerns about the small size of the couplings being probed
    - *Related tot he last point, also, there is a limit to how low once could go with the coupling to quarks and still be within a realistic simplified models. With the present coupling choice of 0.25, we effectively probe electromagnetic coupling strength (g_q = e = 0.3); going much lower in the coupling would require either a super-weak interaction or some kind of suppression, which could only comes from either mixing or loops, in both of these cases the particle content of the simplified model is probably not sufficient to capture physics. Personally, I think that for vector/axial-vector mediators we are already reaching ultimate coupling strength we would like to probe with this class of simplified models.*

  => Motivate lower couplings and cite examples (e.g., arXiv:1306.2629)

Today's focus: what 2HDM (or other scalar sector) provides a reasonably generic benchmark?

At the last meeting, discussion began converging on 2HDMs and extensions of the DMF scalar models.

We hope to converge on a recommendation by Spring 2017

From today, we would like to arrive at

- a map of the kinds of 'scalar sector'* DM models---the **ideas**, what **work** people have done, and **how the different models are related** to one another.

  do these motivate searches that are not yet being done?
  how different is the collider phenomenology (kinematic distributions…) w.r.t. the DMF models
  do they provide strong reasons to correlate searches in several channels?

- **what variants of 2HDMs** are appropriate benchmarks for the near future (Run 2 data)

- are there urgent reasons for **other self-consistent model(s)**, given present ATLAS and CMS searches?

- what is the collider phenomenology—if a given model provides a mechanism to connect the various DM search channels at the LHC, **how general is the mechanism**?

  e.g., is this the only way to make a gauge invariant version of the model?
  how 'simplified' is the model?

*By 'scalar sector' DM models, we mean models of how DM could be produced at the LHC, where key ingredients are extra (pseudo)scalars that may or may not be part of a multiplet with the SM Higgs. In some of the models we've considered so far (arXiv:1507.00966), the DM is an additional fermion, not a member of the scalar multiplet. The discussion so far is converging on 2HDMs, and we've designed the agenda of this meeting to focus on them.

Additional Slides