https://indico.cern.ch/event/563066/timetable/

Simplified model discussion

0. General simplified models

Since publication of the Dark Matter Forum report, NLO implementations of many of the DMF models have started to appear, and we now recommend that signal models be generated at NLO wherever possible. This can be achieved by using packages such as DMSimp. Using a consistent model basis will facilitate analysis cross-checks in the future.

1. t-channel models

The t-channel models produce different signals than the s-channel models. The dijet and dilepton resonance signals are absent. Any such model must take care to respect EW symmetries and flavor constraints.

The t-channel model discussed in the DMF report has not yet been studied to the same degree as the s-channel models. In parallel with another line of discussion at the June WG meeting, Millie McDonald and Maria-Giulia Ratti have picked up where the DMF left off, comparing the kinematic distributions of the DMF t-channel model with an MSSM squark benchmark model. They find that the DMF t-channel model produces kinematic distributions that strongly resemble the MSSM benchmark when the mediator-quark-DM coupling g~0.1. In this case, the cross section is dominantly mediator pair production. When increasing g to larger values, diagrams involving near-s-channel-like single-mediator exchange become important and lead to signal distributions with lower average MET and lower jet multiplicities. For modest couplings (~0.1<g<~1?), the mediator decay to quark+DM can produce a broad Jacobian peak in the jet pT and MET distributions. Millie and Maria-Giulia also presented calculations of the relic density from DM-DM annihilation in this model, and found that there are regions in the mDM-mMediator plane accessible to the LHC that match the observed relic abundance.

The simulation of this signal followed the Papucci et al. prescription for splitting/merging/matching N-parton final states. It was pointed out that more commonly used schemes may be better and simpler, and some oddities in the MadGraph cross sections for certain N-leg contributions were noticed, such as that the "pp>dmdm 2j" contribution is much lower than "pp>sq sq 0-j". The discussion of this is continuing on the lhc-dmwg-contributors list.

After these studies, the t-channel signals remain an interesting avenue to explore. Work on them will continue. Given that mediator pair production remains a large component of the total cross section even with large coupling values, the sensitivity of SUSY multijets+MET searches to this signal should be understood. This work is expected to have a longer timescale with respect to the MC timeline for Moriond 2017, but the collaborations should continue working on it to converge.

Discussion and action items:

- Millie and Maria-Giulia place updated model in the central model repository (DMF repository)
- The WG should continue to discuss and clarify details of the studies
- The WG should understand the reach of existing SUSY searches from mediator pair production via reinterpretation

2. Scalar simplified model with mixing proposed as extension of current Dark Matter Forum benchmarks (SMM)

The proposal of a scalar model that includes mixing with the SM Higgs through a portal interaction and described in [1607.06680] was presented by Kristian Hahn.

The parameter of this model are:

- DM mass (mDM)
- Mass of the scalar mediator (h2)
- Mixing angle of the scalar mediator with the SM Higgs (θ)
- DM-scalar coupling (yDM)
- A quartic h^2h2^2 coupling (b)

This has a correspondence with the coupling structure of the previous model:

- Coupling of the scalar with SM particles: sinθ
- Coupling of the scalar to DM particles: yDM*cosθ

The phenomenology of this model includes monojet, monoV, monoH, multijet (heavy flavor)+MET, VBF+MET channels. This model allows for a consistent combination of searches that are be essentially unrelated in the existing simplified models and that this by itself should be more than sufficient motivation. Also, it provides an important missing link between UV-complete models and simplified models: many other models can be mapped onto the SMM, and this was not the case for the DMF scalar model.

This model is related to mono-Higgs scalar model from Section 3.1.2 of the DMF report, originally from arXiv:1312.2592, but not any other models in the report, and provides one additional interpretation for the mono-X searches (once sensitive). In particular, this proposal would not change the DMF recommendation on the four mono-X vector, axial, scalar, and pseudoscalar models. The overlap in kinematic distributions could be studied by the two collaborations during the definition of the parameter scan. It is to be seen whether this model will be the recommendation for the Moriond 2017 timescale, or we proceed directly with developing a 2HDM recommendation, see below.

In the case of the SMM, the parameter scan would have to be defined broadly enough to probe at least the following phenomenological scenarios:

A) h2 (new heavy scalar) on-shell and h1 (SM Higgs) off-shell, with similar kinematics as the mono-H heavy scalar model from Section 3.1.2 of the DMF report
B) h1 on-shell and h2 off-shell, with a harder MET distribution and and higher cross-section with respect to A)
C) heavy h2, light DM, where the decay of SM Higgs to DM is resonantly enhanced and the kinematics maps the SM Higgs boson one
D) light h2, lighter DM, where mixing starts having an impact.

The parameter sin(θ) would be fixed to a value allowed by current experimental constraints. At the time of the DMF report, the corresponding value for the scalar model (Sec. 3.1.2) was 0.4, but this may need to be lowered. The scan in mediator and DM mass could follow that of the current scalar model, possibly adding some heavier DM mass point to explore scenario B with the increased sensitivity with a larger dataset.

3.2HDM models

The discussion of more general 2HDM+DM models should take place within the DMWG, on a longer timescale wrt this year's winter conferences. The motivation and timelines are sketched in the following bullet points:

- 2HDMs are gauge invariant & unitary, thus like the SMM, they are a consistent basis for channel comparison/combination.
- 2HDMs are generally less restrictive than the SMM, and could therefore provide more complex phenomenology for scalar mediators
- These models can also naturally incorporate pseudoscalar mediators
- They can also help connect our spin-0 searches more directly with the SUSY paradigm
- There is overlap between the SMM, 2HDM+DM, the DMF 2HDM proposal, and the 2HDMs recommended elsewhere (e.g. the LHCXSWG, SUSY). This overlap should be understood and used to set out a compact and minimal set of interpretations that are useful across each experiment.

Discussion and action items:

- The WG should collect and solicit reasonably generic 2HDM+DM models, and focus on those able to provide signals in most of our MET+X channels.
- The WG should discuss the above 2HDM+DM models with other relevant experts, such as the Higgs working groups in the two collaborations.
- The WG should identify the parameter spaces that would lead to mainly a) scalar mediation b) pseudoscalar mediation c) maybe a mixed mediation scenario? Fix whatever parameters we can to current constraints from Higgs/Higgs invisible, precision EWK, SUSY searches, DD etc.
- The WG identifies which of the remaining parameters (holding out the mediator and DM masses, as those will be scanned) have a big impact on the DM phenomenology.
    - Gather all interested parties to study phenomenology with

this framework, scanning over the relevant parameters and masses. Compare results against the DMF models.

- Concretely identify if/how the existing DMF model can be used to emulate (at least for the scalar) the phenomenology of the 2HDM. If wide spaces of 2HDM parameter space can not be captured by the DMF model, then define a recommendation based on 2HDM that covers these gaps.

- The WG documents the contributions of its participants in a DM WG summary paper. We could aim for this to target the next DM WG meeting.

- The 2MDM (1606.07609) could also be studied as part of this effort, if time allows. Otherwise, this model should be explored in subsequent DMWG studies.

Summary plots discussion

Short summary

ATLAS and CMS (T. DuPree, C. Doglioni, A. Boveia) presented the current Dark Matter summary plots:

- [ATLAS and CMS] DM mass-axial vector mediator mass plane, overlaying dijet (high-mass, Data Scouting / Trigger-Level Analysis, dijet+ISR) and mono-X (mono-jet, mono-photon) searches. Coupling scenarios considered:
  - gDM=1.0, gq = 0.25 [ATLAS and CMS]
  - gDM=1.5, gq = 0.1 [ATLAS]
- [CMS] DM mass - scalar mediator mass plane, overlaying monojet and all DM+HF searches. CMS also has a vector mediator plot including mono-top searches.
- [ATLAS] mediator mass - SM coupling plane, overlaying all 13 TeV dijet searches, with mDM>>2mMed.

This was followed by another topical discussion on lepton couplings (B.

Zaldivar, F. Kahlhoefer). The two collaborations and the theory community agree that there should be an option to include constraints from dilepton searches. This is because there are many theoretically motivated scenarios where the mediator should also couple to leptons if it couples to quarks, even though this scenario is not as minimal as the leptophobic one for LHC searches. Many of these scenarios see the coupling to quarks (gq) equal to the coupling to leptons (gl) for axial vectors. In these scenarios, dileptons constraints would dominate the summary plots.

Discussion and action items:

- General treatment of spin-1 models:
    - We recommend that the signal models be generated at NLO wherever possible. This can be achieved by using packages such as DMSimp. Using a consistent model basis will facilitate analysis cross-checks in the future.
    - Action item: liaise with DMSimp authors to include leptons in the models
- How to treat top quarks
    - Top quarks should be included in the production and width side, but not in the decay (dijet searches are not optimally sensitive, so it's best to be conservative)
    - Action item: share a parameter card (in DMSimp, http://feynrules.irmp.ucl.ac.be/wiki/DMsimp) that includes the 5-flavor scenario in the initial state and no top quarks in the decay. Madgraph should be able to calculate the width automatically.
- How to best convey information about complementarity of searches
    - As arbitrary any scenario may be, the message of his plot should never be that one search dominates above others so that other searches shouldn't be done anymore, but that we should do all those searches as they all contribute
    - Action item: confirm consensus on a coupling scenario for the axial vector mediator plot beyond gDM=1.0, gq = 0.25 to convey complementarity: gDM = 1.0, gq = 0.1.

    - Longer timescale action item: reinterpret non-resonant searches for models where gDM is larger and the resonance is wider than the sensitivity of bump searches.

- Summary plot planes alternative to mass-mass:
    - Possible options: coupling ratio on the y axis, mediator mass on the x axis, for chosen dark matter mass points.
    - Longer timescale action item: propose and discuss plots with different planes.

- Dilepton couplings:
    - Both UV completion of the axial vector mediator (e.g. 1510.02110) and additional Higgs sectors (e.g. 1401.0221, 1607.06680) introduce lepton couplings in the leptophobic axial vector mediator simplified models used so far. The relative size of lepton to quark couplings can be more or less constrained depending on the specific model. How to best convey complementarity of collider searches?
    - Action items:
        - show dijet and dilepton searches separately in vector (no constraints on relative size of gq and gl, so set gl=0) and axial vector (gq=gl) respectively
        - converge on a scenario where glep << gq < gDM to highlight complementarity. Ideally, motivate the choice with a model, possibly with an additional Higgs sector, but still making the point that this coupling choice is one of many and engineered to benchmark various collider searches in the DM landscape.
            - The theory and MC experts will aid in updating the simplified models and write-up Lagrangians including lepton couplings
            - The two collaborations will study the expected sensitivity of their dijet and dilepton searches and propose benchmarks. More than one lepton coupling benchmark could be adopted if it does not overload the plot, see example below.

- The concrete proposal, including the coupling choices, will be written up and adopted by the collaborations for the next round of summary plot.