LHC DM WG meeting, 10-11 December 2015

Agenda: https://indico.cern.ch/event/459037/other-view?view=standard

Thursday morning

Introduction and summary

M. Mangano - Introduction to WG

Mandate:

* building on ATLAS/CMS DM Forum (1507.00966)
* topics:
  * guidelines and recommendations for presentation of results
  * tools
  * signal models
  * reinterpretation

LHCb invited, will add a representative.

WG focused on topical efforts - this meeting: dedicated to presentation of results for Moriond.

S. Lowette - ATLAS/CMS Dark Matter Forum summary

Summary of ATLAS/CMS DM Forum:

* recommendations for basis of models for Dirac fermion DM to be used by early (<5/fb) 13 TeV searches
* SVN repository for model UFOs
* couplings chosen as benchmarks (vector/axial: gSM=0.25, gDM=1; scalar: gSM=1, gDM=1)
* description of state-of-the-art tools
* models for future searches
* suggestions for presentation of results

Q&A:

Choice of Dirac fermion: simplification, but the results can often be extended trivially.

Suggested that the LHC DM WG keeps maintaining the list of state of the art tools and SVN repositories up to date.

P. Pani - ATLAS results on searches for Dark Matter

Many results at 8 TeV, looking for WIMP DM in the MET+X channel.

General search strategy:

* background estimation in signal-enriched regions comes from control regions: transfer factors derived from control regions to obtain data-driven normalization
* background estimation checked in validation region for the transfer factor.

Highlights on 8 TeV monojet, monophoton, heavy flavor+MET, Higgs->invisible, recent 13 TeV dijet results using DM benchmark from ATLAS/CMS DM Forum (axial vector).

Q&A:

Relevant point for later discussion: coupling of up- and down-type quarks:

* choice of equal or opposite couplings changes presentation of results when comparing to direct detection

* enhances sensitivity for mono-W, but that could be due to violation of gauge invariance (see N. Bell's talk)

Importance of standardizing presentation of results and adding all information to HEPData.

N. Wardle - CMS results on searches for Dark Matter

A number of results from 8 TeV are presented: mono-jet, mono-V (leptonic and hadronic w/substructure), combination of H->invisible searches, full combination of searches for DM Forum simplified models. Introduction of the formula to conversion of collider to DM-nucleon xsec used in CMS-PAS-EXO-12-055.

For Run-2: shape-based analyses, need a grid that is finer than the DM Forum: start from high-statistics generator level samples, and use key analysis variables to reweight for changes at the reconstructed level.

Q&A:

CMS-PAS-EXO-12-055 includes a spin-0 scenario, where the use of heavy quarks only should be discussed.

Issue when including the direct detection results: these plots assume the observed relic density. However, the models shown for colliders don't reproduce the relic density and the contours can change dramatically.

U. Haisch - Theory summary

Summary of EFTs and simplified models used so far:

* EFTs are still theories that are useful within assumptions.
* Simplified models also have criteria:
    * simple enough as credible unit within more complicated model
    * complete enough to describe accurately LHC energy phenomena
    * satisfy other low-energy constraints in most of its parameter space

Simplified models used so far: colorless vectors, scalars, squarks. NLO corrections can be important.

Constraints on couplings:

* Universal SM couplings lead to minimal flavor violation (respects=ing flavor constraints).
* Lagrangian allows to make mediators decay into leptons and light quarks, and dileptons can constrain low-mass DM mediators.

What can one do to distinguish chirality in case of discovery? E.g. correlation of final state objects, azimuthal angle difference.

Q&A:

Applying dijet and dilepton constraints to DM: one needs to make the same assumptions for the various searches with different couplings, but all signatures belong to the model at the LHC and could be shown on the same plot.

No plans from the WG to specifically pursue and interpret signals from other collaborations (e.g. gamma-ray excess).

Thursday afternoon

Proposal

O. Buchmueller - Summary of the proposal

Summary of the proposal that will be shaped by the next two talks:
* main plot for presentation of collider results: plane of DM mass - mediator mass, fixed couplings, show limit on signal strength
* well-defined procedure to translate non-collider results into collider results on mass-mass plane, and collider results into non-collider on other planes
* showing line for relic density on collider plot

Idea: take simplified models, define limits in mDM, mMed, fix couplings, then we can plot it in the DD/ID planes (1 to 1 relationship anyways)

F. Kahlhoefer - mass-mass plots for s-channel mediators

Focus on spin-1 mediators for the discussion.
Introduction to the mass-mass plots: mMed vs mDM
Three regions:
* high mMed: EFT limit, well-understood regime, only two couplings
* mMed > 2mDM: on-shell mediator, can use narrow-width approximation in some cases but not necessarily possible
* mMed < 2mDM: off-shell mediator, cross-section almost independent of mediator mass, only depends on product of couplings and DM mass

Consequence: naive cross-section rescaling does not work. How to present results without rescaling?

1- Fix both couplings, quote upper bound on signal strength => proposal
   * pro: fixed width through fixing couplings, only scan masses, easy to use other constraints
   * con: changing couplings changes kinematics and relationship between collider and non-collider significantly

2- Fix one of the coupling (or their ratio), quote upper bound on other couplings
   * pro: more intuitive
   * con: width-dependent so not always valid

Add relic density and perturbative unitarity (1510.02110) as guidance as well.
Other constraints (including direct mediator searches) can also be shown easily to show what regions of the parameter space are allowed.

Q&A:

We could also consider other planes, fixing one of the other parameters of the simplified model and projecting the limits.
The mass-mass plane results change significantly when changing the couplings, so strong caveats and clear coupling statements are needed.
Should we have the DM mass on the x (non-collider-like) or y axis (SUSY-like)?

Chris McCabe - Comparison of LHC, DD and ID

Message of the talk: Translating results is always well defined as long as the assumptions are clear. Assumptions already written up, will be circulated soon.
Planes for direct and indirect detection:
DD: WIMP-nucleon cross-section
ID: cross-section*velocity
Important to state all simplified model assumptions clearly
* couplings
* kind of interaction (vector, axial...)

* add 'Dirac DM'

Translation to and from DD plane, WIMP-nucleon

Inconsistency in the CL of collider/non-collider results, 90% vs 95% CL
Cross-section to scatter off a nucleon shown:
* spin-independent: WIMP-nucleon
* spin-dependent: difference between neutron and proton scattering

Easier to compare nucleon cross-section, but needs assumption (SI: coupling to p=coupling to n, SD: only coupling to proton or neutron)
In general, keep gq equal for all quarks to start with.
Open question: How to convey the strong assumption that a single DM particle makes up for the full relic abundance?
Vector operator:
* keep couplings to proton and neutron equal

Scalar operator:
* contains form factors given from other papers (e.g. 1310.1114) - those need to be kept updated, also in light of discussion of strange content
* all quark couplings should be considered (change for non-collider experiments)

Axial operator:
* open question: which couplings to choose? difference in non-collider whether gu=gd and gu=-gd

Translation to and from ID plane, cross-section/velocity

Open issue for pseudoscalar: the calculation of the 2->2 cross section shows some difficulties:
* limit should be divided per final state (Fermi only has bbar)
* contribution of 2->3 channels if DM can decay to mediators (e.g. DMDM->3med->6bb)

Q&A:

The basis of operators in DD/ID is the leading order one, we can expand it later for more.
Direct detection assumes a specific relic density value, so when shown on the same planes the collider limits should do the same.

Discussion on proposal

It should be made clear what analyses have to do and provide in practice, and if anything can be produced centrally by this WG.
Discussion on whether, for more complicated searches (and whenever we want to profile the couplings across searches) one should generate MC or could rescale the limit plot. Experimentalists doing shape-based searches seem to go for producing more MC.
Putting too many lines on a plot is not necessarily helping the conference speakers: plots should be kept simple.
The relic density in these plots is not consistent between collider and non-colider.
Avoidance of the problem: keep the DD planes so nothing needs to be done by the DD results, and translate collider limit in there. The relic density line should

also be clearly labeled. Furthermore, one does not want to bind the non-collider search to restrict itself with a parameter that has unknows.

Relic density

G. Belanger - MicrOMEGAs

MicrOMEGAs: Tool for DM studies that can calculate relic density in various models.
Baseline assumption: DM is a WIMP -> many models, with a stable DM particle (some R-parity symmetry) that is weakly interacting. Coannihilation complicates the picture, so the process needs to be automated via CalcHEP. Other models can also be chosen: extended non-Z2 discrete symmetries, asymmetric DM.

Q&A:

DM can be either Majorana or Dirac, as long as it's specified (annihilation changes depending on the type)
Plugging in simplified models is straight-forward via either FeynRules or CalcHEP

M. Backovic - MadDM

MadDM: tool for calculating relic density, accounting for co-annihilation, full treatment of s-channel resonances.
Inputs: same files and param cards as MadGraph (UFO), MadWidth module for width calculation, automated parameter scanning scripts available.
Status and future plans: want to integrate with MC_aMC@NLO to calculate amplitudes for loop induced processes, such as the box diagrams in gamma-ray excesses/lines.
For extremely small width (not reachable by colliders with standard assumptions), numerical instabilities need to be cured via longer integration time.
Also shown: 4D relic density scan for one of the available simplified models, only show allowed points by relic density - a model-dependent statement that can inspire searches.

Q&A:

Practical point for analyses: it's straight-forward to use those tools, and there can be a central repository of curves provided by members of the Working Group.
Connecting to earlier discussion about relic density: proposal to have both lines on mass-mass plot, one where relic density is enforced and one where it is not.

Mono-W

N. Bell - Mono-W and gauge invariance

Simplified models and EFT may violate SU(2). A sign of this is the cross-section growth in the case of constructive interference, pointing to the emission of longitudinally polarized Ws.
To prevent this, one can radiate a W from the mediator: s-channel model with Z/Z' mixing, t-channel model. EWSB can also introduce isospin-violating effects, but the enhancements in the cross-section are not big as there is a suppression in both models.

L. Carpenter - Simplified models for DM+V

Continuing effort in translating VVChiChi EFTs currently proposed in DM Forum to simplified models: adding loops of messengers with SU(3) quantum numbers. The implementation has been checked with an analytical calculation. More work to go beyond monojet (multijets is another signature) is ongoing.

Discussion

The constructive interference mode for the vector and axial vector simplified models has been exploited by colliders before, and drives the sensitivity of the Mono-W in the leptonic channel. It should be checked that the model is written in a gauge-invariant way (a thread will be started among the experts). This will be reported back at the WG since it is an important point when comparing results across experiments.

Heavy Flavors

B. Fuks - Monotop

Bottom-up strategy: start with single top signature, build benchmark models.
Monotop models:

* flavor-changing, three parameters, easy to reinterpret
* resonant (not necessarily connected to Dark Matter), six parameters, must be simplified -> CMS choices fix the width and make Narrow Width Approximation, ATLAS

Q&A (also discussed on Friday morning):

This model does not have a DMF recommendation - agreement should be reached before results become public for Moriond. Right now, theory preference would be with the CMS configuration, but discussions are ongoing with ATLAS analysers.

M. Buckley - Heavy flavor and scalars

If DM interactions mediated by scalar and we assume MFV, we need Yukawa couplings -> couplings to top and b dominate
Scalar simplified model:

* two production modes (gluon fusion loop and associated HF), gluon fusion dominates, but associated production measures tree-level couplings
* associated production targeted by both ATLAS and CMS

Even though they are not as sensitive, we should not deprioritize associated searches, as they would give us more information in case of discovery

Q&A:

Open point: how to treat combinations of monojet and ttbar, given that the reach of both is compatible? We will discuss combinations more thoroughly tomorrow.

EFT

N. Whallon - EFT truncation

Showing an overview of the EFT 'truncation' techniques to only retain valid events, with emphasis on methods used for Run-1 ATLAS analyses (not what ultimately recommended by DM Forum).
Truncation decreases sensitivity, as limits are rescaled based on the expected valid events.

Q&A:

It would be an interesting comparison to do a similar work as 1502.04701, comparing truncations to EFT completions, in case of models with loops.
The complications of the procedure should not be a showstopper, but discussion between experts in the two collaborations are encouraged.
As simplified models continue to appear to complete EFT-only models, truncation will not need to be implemented anymore.
It could still be useful to show results in the parameters of the EFT language.

Friday morning

Discussion on proposal

Proposal for presentation of results after yesterday's discussions:

* make mass-mass plots the main LHC result, only overlay relic density (line rather than shading) and perturbativity limit
* state assumptions very clearly
* choices of couplings: 0.25/1 for axial, 1/1 for scalar.
* only overlay collider to DD/ID in the DM-nucleon cross-section and velocity*cross-section planes. No need to show relic density line here, no rescaling done, add statement in the caption.

What can be centrally given to community from LHC DM WG:

* relic density curves
* formulas to translate results (in C++ format)

Points from discussion:

* The perturbativity limit on these plots would appear because there is no Higgs mechanism regulating the theory. This however makes the situation equivalent to the 'EFT validity problem'. It would be best to add the necessary parameters for the model to be self-consistent -> kept for later searches.
* An extra plot that could be produced by the collaborations is with only one coupling fixed, or with the ratio of couplings, as it is more intuitive, but it requires the correct treatment for the width.
* To reinterpret, it will be necessary to also have detailed information on the efficiencies, fiducial x-sections in signal regions, cutflows for signal and background. This will be handled by the collaboration policies.
* Having too many lines on the mass-mass plot is not necessarily useful for conference speakers, and other information can be added by anyone later.
* Relic density: if put on the mass-mass plot add the caveat "We assume that the relic density is the one observed" in the caption and possibly also on the line as Omega=Omega_Planck. Remove the shading.
* State that the minimal width is the best case scenario
* State in plot the fixed mediator mass used for the conversion (so that one can see whether decay channels are open or not)
* Interpolation between the generated points is left to the experiments

Open points:

Open point #1: is the DM mass displayed in the x or y axis?
Open point #2: gu=-gd, equivalence to gu = gd needs to be checked in full phase

space available for early monojet searches, and mono-V interference vs SU(2) invariance issue needs to be understood.
Open point #3: The conversion between collider and non-collider needs to have its ingredients clearly stated (e.g. 2-mediator annihilation channel): once write-up available [now attached to agenda], cross-check annihilation cross-section.

Direct mediator searches

Bryan Zaldivar - Dilepton constraints

Direct probe of mediators: mono/di-signals. Di-signals may be less appealing for scalar mediators as MFV makes top loops more frequent (however, this is not the case for 2HDM).
Dijet or dilepton are narrow resonances -> upper limits to the couplings to fermions given simply by the narrow width approximation.
Using SSM W' and Z' as benchmarks for dileptons and dijets shows that the DM mass/branching ratio plane is spanned also by dilepton bounds from LEP.
There is complementarity between disignals and mono-signals, direct detection and relic abundance.

Q&A:

The SSM is only a phenomenology, but if you have B-L or E6, you'll have couplings to leptons -> hard to avoid completely. Suggestion is to ignore for simplified models though.

Matt McCullough - Dijet constraints

Starting point: use simplified models, with the hope that they are building blocks for more complete models.
Overlay different collider and non-collider searches, including mediator searches.
Example used: vector mediator, coupled to two fermions (DM), quarks, but not to leptons.
These processes and the couplings define the phenomenology of collider and non-collider experiments and the model width. A variety of dijet analyses for ATLAS, CMS and previous experiments, including ttbar searches and lepton-associated dijets, can probe the mass-mass plane.

Q&A:

Usual 'dijet' searches are bump searches for narrow resonance, but we can add angular information as well.
It would be valuable to produce a combined plot for mono-X / dijet searches from each of the collaborations (combinations will need more time and care)

Contributed and invited talks (short summaries)

Mathieu Pellen - NLO prediction for Madgraph5_aMC@NLO

FeynRules implementation and UFO publicly available for all simplified models in 1508.05327, including NLO QCD corrections and loop-induced processes. It can be used at LO/NLO in MadGraph5_aMC@NLO and at LO in both MicroMegas and MadDM. With MadDM incorporated in Madgraph5_aMC@NLO it would be possible to go to loop-level.

Felix Yu - Coannihilation codex

Propose a framework for bottom-up discovery: build a list of models characterizing all possible 2->2 DM coannihilation processes as simplified models, driven by known DM properties, then use the LHC to test how the relic density could have been produced.

D. Barducci - Reinterpretation tools

Recasting can be done using MadAnalysis5 PAD, to 'assist theorists with understanding and making use of LHC results': public analysis database available, where each analysis is validated and uploaded to INSPIRE, to be used in any searches.

Daniel Whiteson - new direction for DM searches

New unexplored data should guide the theory perspective: look everywhere and examine spectra very carefully in order to avoid missing something. One example of a new search is a Heavy resonance + MET. Backgrounds fall off because QCD does not peak, more unexplored models exist.

Jessie Shelton - Dark sector

What if our mediators don't couple to the SM directly, and there is no direct involvement of the DM in the thermal history of DM? This is a different class of models from the 'dark sector', where the couplings of the dark sector particles to the SM can be parametrically small. We could still use them as benchmarks, as they are a simple class of minimal models where the perturbative thermal relic leads to having the SM mass range for new particles. The signature at colliders would be the one produced by the mediator.

Summary and closing

Near future plan: write this into a document, circulate to the group, see to converge on open issues on relatively short timescale

- monoV: preserving unitarity
- how we portray things in the ID plane, are the relevant processes included in what we're including

Send proposal to the mailing list whenever ready, so everyone can give feedback.