

Mike Williams - RF6 (rare & precision) plans for dark matter / dark sector plots

RF6 not yet restarted

Plan prior to the break: 3 solicited whitepapers, each for one idea (see report outline document).

1. Dark matter particle production: invisible decays
2. Dark sector (looking for the mediator): visible decays
3. Rich structures, new flavors...

Plan to collect all results (not plots!) using the DarkCast format

(<https://gitlab.com/philtten/darkcast>) to allow re-making plots at all stages.

Table of benchmarks in final state (x) portal by Natalia Toro, not yet finalized:

Benchmarks in Final State x Portal Organization			
	DM Production	Mediator Decay Via Portal	Structure of Dark Sector
Vector	m_χ vs. y [$m_\chi/m_\chi=3, \alpha_D=5$] m_χ vs. y [$\alpha_D=0.5, 3$ m_χ values] m_χ vs. q_D [$m_\chi/m_\chi=3, y=y_\chi$] m_χ vs. m_A [$\alpha_D=0.5, y=y_\chi$] <i>Millicharge m vs. q</i>	m_χ vs. ϵ [decay-mode agnostic] m_χ vs. ϵ [decays]	iDM m_χ vs. y [$m_\chi/m_\chi=3, \alpha_D=5$] (anom connection) SIMP-motivated cascades [slices TBD] $U(1)_{B-L/\mu-\tau/B-3t}$ (DM or SM decays)
Scalar	m_χ vs. $\sin\theta$ [$\lambda=0$, fix $m_\chi/m_\chi, g_D$] (thermal target excluded 1512.04119, should still include) Note: excluded DM relevance of $S \rightarrow SM$ of mediator searches	m_S vs. $\sin\theta$ [$\lambda=0$] m_S vs. $\sin\theta$ [$\lambda=3.1, Br(H \rightarrow \phi\phi) \sim 10^{-2}$]?	Dark Higgs-sstrahlung (w/vector) scalar SIMP models? Leptophilic/leptophobic dark Higgs?
Neutrino	$e/\mu/\tau$ a la 1709.07001?	m_N vs. U_e m_N vs. U_μ m_N vs. U_τ Think more about reasonable flavor structures	Sterile neutrinos with new forces?
ALP	m_χ vs. $f_{q/l}$ [$\lambda=0$, fix $m_\chi/m_\chi, g_D$] (thermal target excluded) What about f_ν, f_G ?	m_a vs. f_γ m_a vs. f_G m_a vs. $f_q=f_l$ (separate?) Think more about reasonable coupling relations including $f_{W/Z}$	FV axion couplings

+ Neutron portal (See e.g. 2003.02270)? Hidden valleys (or are these out-of-scope?)?

Bold = BRN benchmark, italic=PBC benchmark, others are new suggestions. Underline=CV benchmarks that were not used in BRN

More-or-less finalized/already studied: vector portal, while other categories will be more about new ideas.

Bold has already been used in Basic Research Needs (BRN) report, italic in Physics Beyond Collider (& European Strategy).

Usually specific of model don't matter too much for limits → don't absolutely have to know the models as the sensitivity is driven by certain kinds of decays (e.g. penguins) so the idea is to recast.

Q from Liantao: the structure of DM is less defined - idea is to talk about more structure in the dark sector?

A: some of them have more structure / more concrete connections to DM, others have a more vague link to dark matter.

Liantao: one can have an infinitely rich structure (ie hidden valley), will you focus on something specific?

A: we still need to discuss these and get to a conclusion.

Liantao: a lot of these results are already available, focusing on e.g. lower energy collider searches / fixed target.

A: yes, if you're dealing with low-mass particle in penguin decays then it's easy to recast different models. Kinematics set by the mass, and decay region drives sensitivity, so there's a direct translation between lifetime in different models. So we can usually take one result and recast it.

There is a discussion on 'what is the most useful way to do this'? Minimal dark photon is the usual search target, but there are different models just by changing the fermion couplings → what does this tell you about the future of what you should do experimentally? Should we do all the possible couplings?

Liantao: you want to have a priority plot (high level document) and then more in whitepapers.

Mike: yes, we're going to have some plots with more emphasis and then others as well.

Number of efforts from people who are going to produce plots for similar models.

Caterina:

Before the break, discussion about DM complementarity with a group of people. Cross frontier topic, get different communities together.

RF06, focusing on portals not DM interpretations.

EF10: DM connection. Not just mediator with a lot of visible decays.

Can't try all the models, pick a few to show complementarity.

Vector portal, example plot in paper out in 2020. Can we work together on a similar one? Using darkcast perhaps?

Another example: scalar mediator 1512.04119

Just initial ideas, more suggestions?

Tania:

Scalar mediator plots typical for many models, such as susy. What exp to include? Many DM detection + HEP collider options.

Caterina:

We need to prioritize. Take simple models. Scalar and simple vector models. Maybe need to go beyond that, more theory ideas. For EF, why do we need to go to high energy colliders?

Message of these plots is that better to have more than one exp cover one area, can be good motivation for certain collider option. 2nd message: HE collider can also go to higher mass, while low E exp can push for smaller coupling, complementary.

It would be nice to show something like these two plots. Perhaps as a minimal baseline. Depending on how many people/frontier would like to join.

For example, vector portal, do we have all the info?

Michael: yes. Caterina: for HE, need more work.

Natalia: off shell has not been studied, left of the plot. For invisible decay, HE not sensitive to decay, but beam dump maybe sensitive.

Michael: canonical plots showing the reach of dark photon? With mass range.

Caterina: for dark photon decaying into muons, how much room for dark matter? For visible decays, more of EF09.

Michael: scalar portal low mass: kaon. High mass: colliders. Many results available already.

Caterina: physics beyond collider group working on these topics as well.

Bottom line: let's keep working together towards summary plots & see how other frontiers join up and how many people are interested

Tania Robens - Complementarity for $H \rightarrow \text{invisible}$

Summary of what was done previously for:

- Higgs portal models (focused on HL-LHC)
- Inert Doublet Model
- THDMa = LHC dark matter working group

Part 1: Higgs portal models

Higgs portal models can be discovered via direct constraints OR modifications of SM branching ratios / Higgs couplings (see review on slides).

Direct searches

Indirect constraints via modifications of SM decays, including also loop-induced processes

General setup: SM BR is very small, so any deviation means new physics

Direct searches: ATLAS (+) CMS naive combination for HL-LHC: $< 2.5\%$

Couplings: use combined projections & study different systematic uncertainties

Then show, for $m_{DM} < m_H/2$:

1. Complementarity for SM decays and invisible BR
 2. Compare w/direct detection limits for different DM candidates
 3. Compare for specific models, singlet + additional scalar DM candidate
-
1. Use BR results vs k-framework for parameterisation, and check HL-LHC (3.3) / HL-LHC+LHeC (4.2)
 2. Take minimal Higgs portal and convert the decay width into DM-nucleon scattering cross-section $\rightarrow$ show complementarity between invisible Higgs searches and DM direct detection in a single plot

3. Singlet-scalar DM model: scalar DM candidate, where the mass of the scalar is fixed to m_H , and at this point one can change the coupling and enhance/suppress the invisible decays. This shows complementarity between direct / indirect searches.

Part 2: Inert doublet model

Model with 7 free parameters (where v , m_h are fixed) - the other Higgs is the DM candidate (inert).

Production modes in HH / HA / AA (with different charges), and decays into ZH / WH .

Colliders mainly test the masses since couplings with gauge bosons are coming from EW constraints.

Complementarity: interplay between astroparticle physics and collider searches: showing results excluding model parameters using direct detection as well.

Message: some parameters that can't be determined at colliders can be determined using direct detection.

Part 3: Two Higgs Doublet Model by LHC DM WG

[notes to be completed later based on slides]

Q&A

Liantao: general comment. If you consider light DM, there are good motivations from relic abundance to also consider a light mediator. Other dark sector states can also be light. So we could think about a very light particle that the Higgs decays into that can be the DM mediator.

Tania: this is investigated heavily at LHC (e.g. $H \rightarrow aa$), can you combine everything? In scans I've done, $m_{DM} < 65$ GeV then you don't have much room unless you fine tune the couplings. Discussed this also with people doing other extensions of the SM (e.g. complex singlets) and you can find it if you fine tune it.

What wasn't shown are the lines on slide for sensitivity, needed to reach N ($=1000$) events.

Liantao: many things to be discussing. We were planning a dedicated discussion on Higgs portals, with EF01-03.

Questions on Higgs portal:

4. Q1 CD: vector portal had a bit of controversy on validity.
 - a. A: probably OK? But may need to read Oleg's review above. We should show results and let others draw their own conclusions.
Comment from Tania: review is on scalar dm only I think... sorry.
 - b. We will need a longer discussion with other theorists about this.
5. Q2 CD: imposing the relic on the collider experiments as well leaves very little room for discovery already (Arcadi et al.). Does this make the model 'less appealing'?

- a. Liantao: choice of benchmarks here is important, the Higgs portal may be the most relevant coupling but not the only one. See earlier comment, maybe Higgs $\rightarrow$ new dark sector particles are interesting to think about.
- b. Tania: resonance-enhanced annihilation happens in many models.
- c. Liantao: richer dark sectors bring more possibilities, and relax this kind of requirement. But Higgs portal is the most relevant coupling to see this. Maybe we can also talk to cosmic frontier for alternative cosmologies.