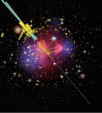


Discussion: t-channel studies for the White Paper in the spirit of the LHC DM WG



Oleg Brandt
for the LHC DM WG organisers





Overview of t-channel studies

- Focus of the talk: How do we see the t-channel studies evolving?
 - Ultimate goal:
 - White Paper with recommendations for interpretations of DM searches using models with t-channel mediators
 - Step-by-step review of what was done in the previous White Paper
 - “LHC Dark Matter Working Group: Next-generation spin-0 dark matter models”, [1810.09420](#), Phys.Dark Univ. 27 (2020) 100351
 - Kudos: strong collaboration between theory & experimental community on phenomenology/sensitivity studies/scans!
 - [Hands-on session will hopefully facilitate that!]
 - *First ideas about model parameter scans & pheno scans → next talk*
 - *Main kinematic parameters of the model?*
 - *Differences between scalar/Dirac/Majorana/vector DM?*
 - *Possible phenomenology studies (signatures etc)*



Final result:

[1810.09420](#), *Phys.Dark Univ.* 27 (2020) 100351

CERN-LPCC-2018-02

LHC Dark Matter Working Group: Next-generation spin-0 dark matter models

Abstract. Dark matter (DM) simplified models are by now commonly used by the ATLAS and CMS Collaborations to interpret searches for missing transverse energy (E_T^{miss}). The coherent use of these models sharpened the LHC DM search program, especially in the presentation of its results and their comparison to DM direct-detection (DD) and indirect-detection (ID) experiments. However, the community has been aware of the limitations of the DM simplified models, in particular the lack of theoretical consistency of some of them and their restricted phenomenology leading to the relevance of only a small subset of E_T^{miss} signatures. This document from the LHC Dark Matter Working Group identifies an example of a next-generation DM model, called 2HDM+a, that provides the simplest theoretically consistent extension of the DM pseudoscalar simplified model. A comprehensive study of the phenomenology of the 2HDM+a model is presented, including a discussion of the rich and intricate pattern of mono- X signatures and the relevance of other DM as well as non-DM experiments. Based on our discussions, a set of recommended scans are proposed to explore the parameter space of the 2HDM+a model through LHC searches. The exclusion limits obtained from the proposed scans can be consistently compared to the constraints on the 2HDM+a model that derive from DD, ID and the DM relic density.



5.62

CiteScore

5.66

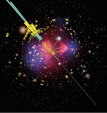
Impact Factor

LHC Dark Matter Working Group: Next-generation spin-0 dark matter models

List of contributions

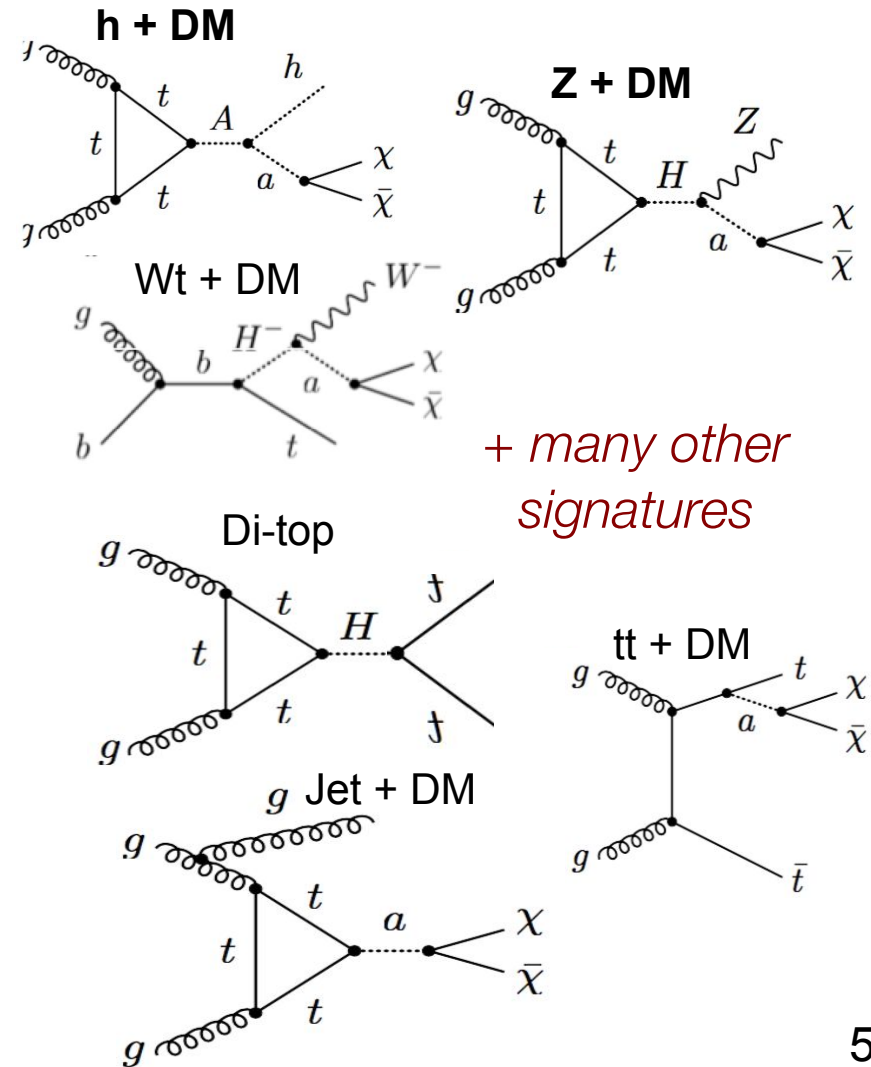
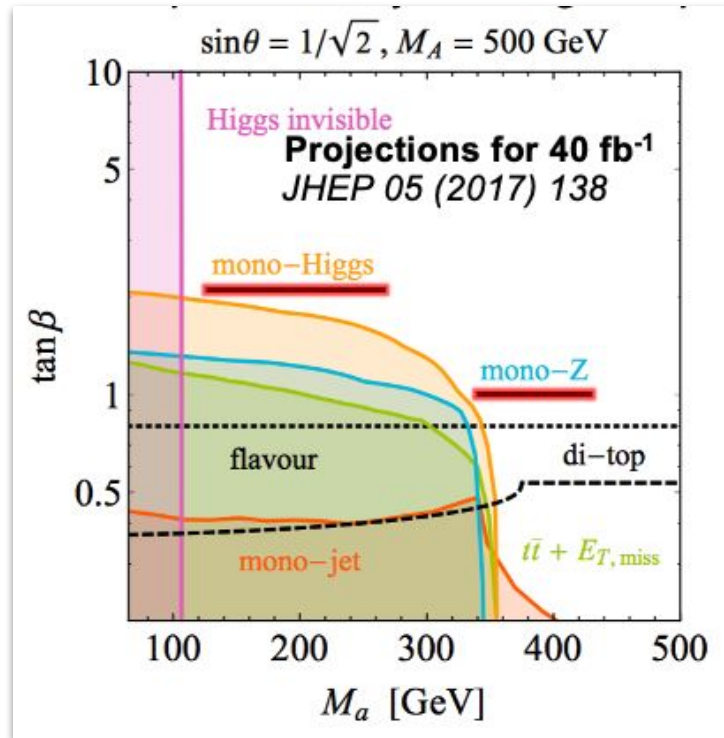
- **Tomohiro Abe**, Inputs on the direct detection part of the white paper.
- **Yoav Afik**, Studies of heavy flavor signatures (kinematic distributions, flavor studies, rescaling).
- **Andreas Albert**, Design of the 2HDM+a parameter scans; Kinematic distributions and cross-sections for mono-Z(lep); Relic density study.
- **Christopher R. Anelli**, Design of 2HDM+a parameter scans, kinematic distributions for mono-Z(lep), 2HDM+a cross-sections and sensitivity estimates for mono-Z(lep).

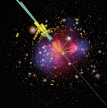
... (showing only first four here)



- Starting point similar to t-channel effort:
 - Interest in community for interpretations of models with spin-0 mediators and extended Higgs sectors
 - Series of LHC DM WG meetings
 - Review of different models on the market
 - Richness of phenomenology:
 - Diverse palette of experimental signatures?
 - Important role of h +MET and Z +MET signatures?
 - Main model for interpretations identified (next slide)
 - *(this is where we are now with t-channel studies)*

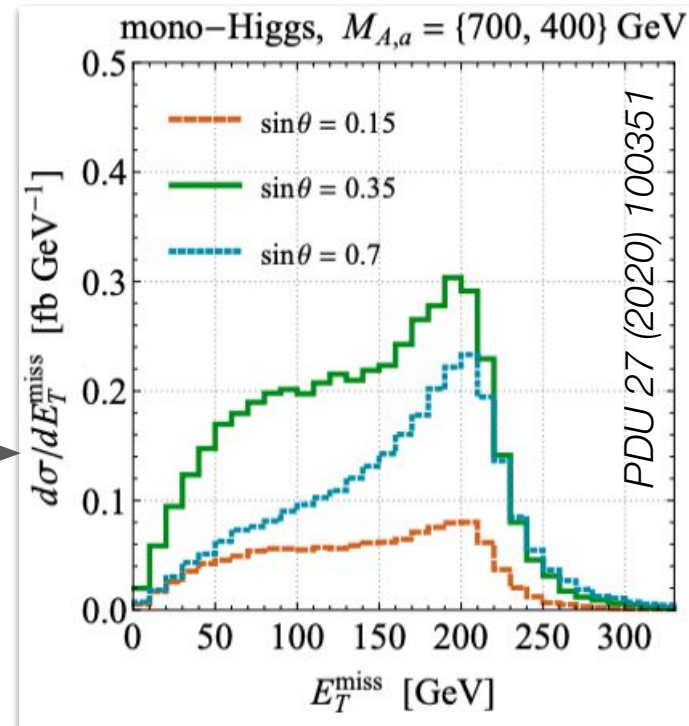
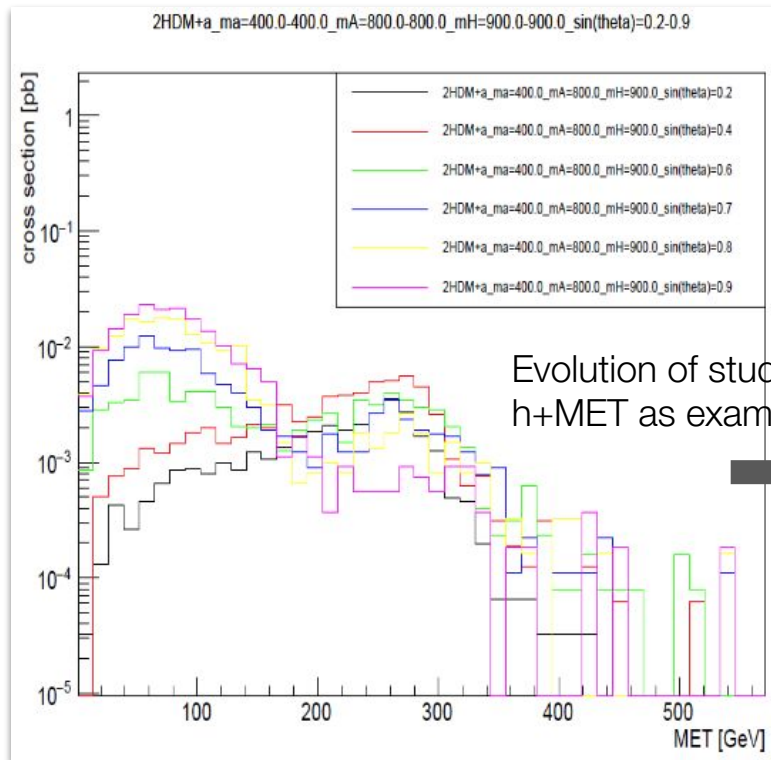
- 2HDM+a model [JHEP 05 (2017) 138]
 - Simplified, but UV-complete
 - Diverse palette of signatures
 - Z+MET, h+MET resonant

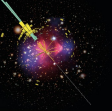




Representative pheno studies

- Identified main handles to promote resonant production of h+MET, Z+MET:
 - Model kinematics (mediator masses, not shown)
 - $\sin\theta$
 - → snapshots of studies: [2HDM+a rolling agenda](#)

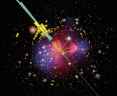




Overview of pheno studies

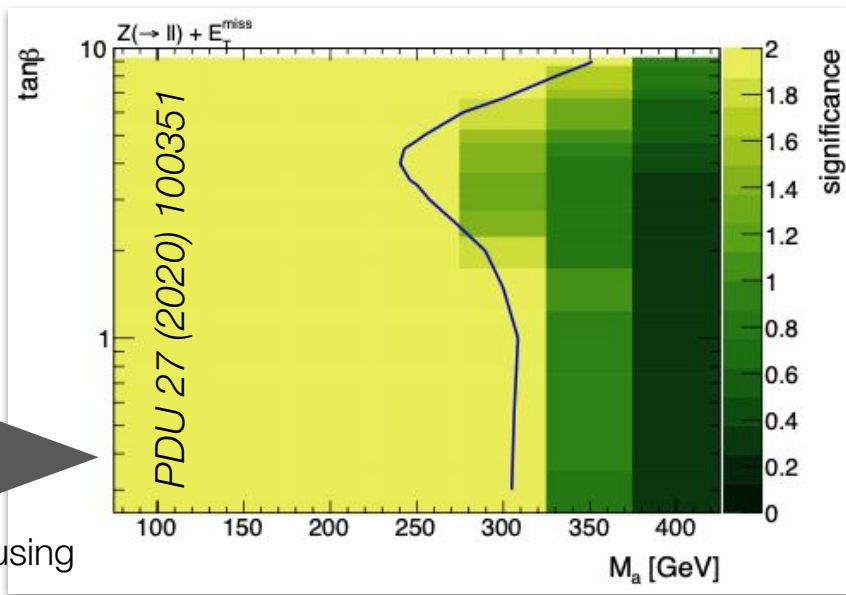
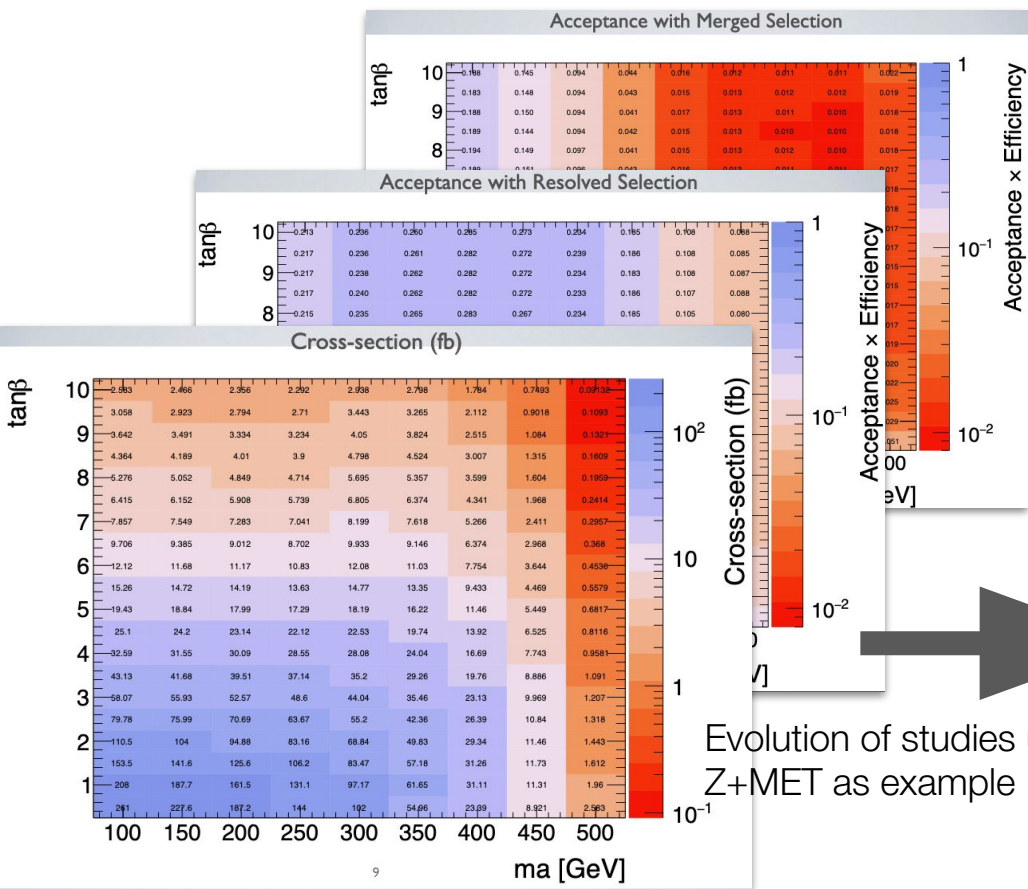
- A wealth of studies...

6	E_T^{miss} signatures and parameter variations in the 2HDM+a model	15
6.1	Resonant E_T^{miss} signatures	15
6.1.1	Mono-Higgs signature	16
6.1.2	Mono- Z signature	18
6.1.3	Single-top signatures	19
6.2	Non-resonant E_T^{miss} signatures	20
6.2.1	Heavy-quark signatures	21
6.2.2	Mono-jet signature	22
6.3	Parameter variations	23
6.3.1	Variations of M_H and M_A	23
6.3.2	Variation of $\sin \theta$	24
6.3.3	Variation of $\tan \beta$	25
6.3.4	Variation of m_χ	26
7	Non-E_T^{miss} collider signatures in the 2HDM+a model	27
7.1	Di-top searches	27
7.2	Four-top searches	29
7.3	Other final states	31

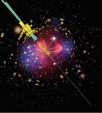


Sensitivity studies

- Studied sensitivity of ATLAS/CMS as function of model parameters
 - Showing only $(\tan\beta, M_a)$ dependence

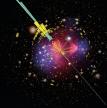


Evolution of studies using $Z+\text{MET}$ as example



- A wealth of studies:

8	Sensitivity studies	32
8.1	Mono-Higgs study	32
8.2	Mono- Z study	34
8.3	Sensitivity of other mono- X channels	36
9	Constraints from other DM experiments	37
9.1	DD experiments	37
9.2	ID experiments	39
10	DM relic density	41
10.1	Calculation	41
10.2	Scan results	42



Final recommendations:

- Previous slides: only few snapshots of many exciting studies
 - Strong collaboration between theory and experiment made this possible
 - Lots of work from ATLAS/CMS postdocs/graduates/undergraduates
 - Stimulating guidance from theory + studies
- Final recommendations:

Just one example:

11.2 Scan in the $M_a - \tan \beta$ plane

A 2D scan in the $M_a - \tan \beta$ plane with the common heavy 2HDM spin-0 boson masses fixed to $M_H = M_A = M_{H^\pm} = 600$ GeV is proposed. The remaining parameters should be chosen as in (4.5). Two examples of such a scan can be found in the lower panels of Figures 21 and 22. With 36 fb^{-1} of 13 TeV LHC data, mono-Higgs and mono- Z searches are already sensitive to $\tan \beta = \mathcal{O}(1)$ values for M_a values up to around 300 GeV. Other mono- X searches like $t\bar{t} + E_T^{\text{miss}}$ and $j + E_T^{\text{miss}}$ are at present only sensitive to $\tan \beta \lesssim 0.5$, which emphasises the special role that resonant E_T^{miss} signatures such as $h + E_T^{\text{miss}}$, $Z + E_T^{\text{miss}}$ and $tW + E_T^{\text{miss}}$ play in the 2HDM+a model (see Section 6.1). Like the mass-mass plane discussed before, also the $M_a - \tan \beta$ plane offers a nice way to compare and to contrast the LHC reach of E_T^{miss} and non- E_T^{miss} searches in the 2HDM+a context.

11 Proposed parameter scans

11.1 Scan in the $M_a, M_H = M_A = M_{H^\pm}$ plane

11.2 Scan in the $M_a - \tan \beta$ plane

11.3 Scans in $\sin \theta$

11.4 Scan in m_χ

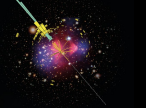
44

44

45

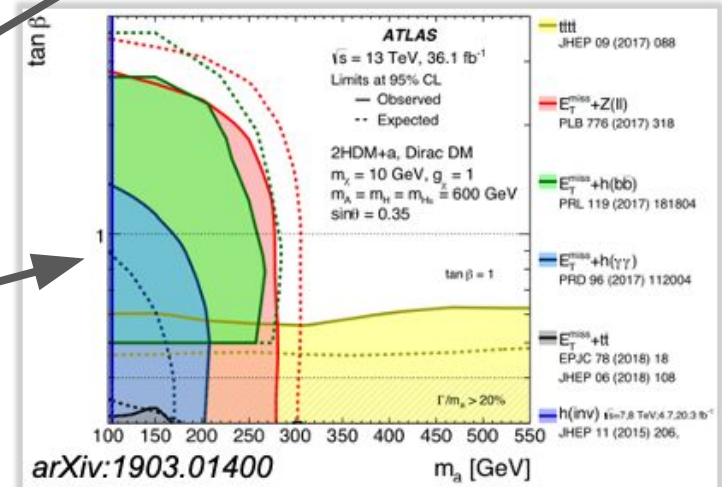
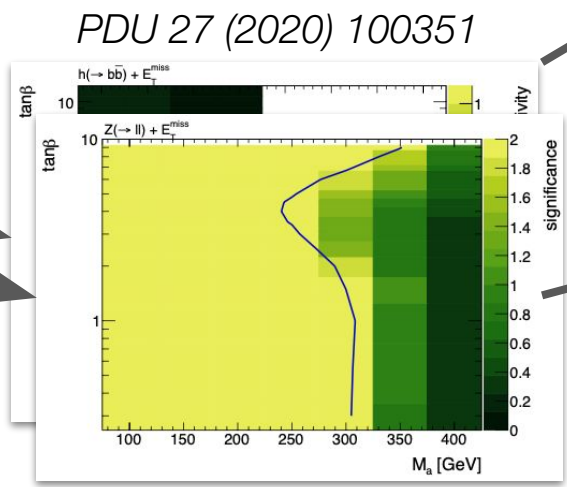
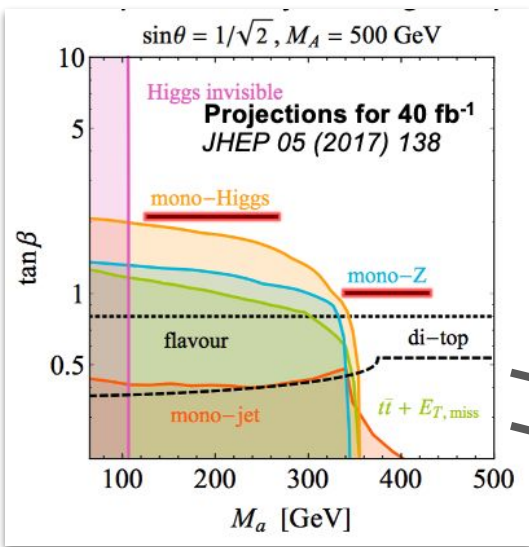
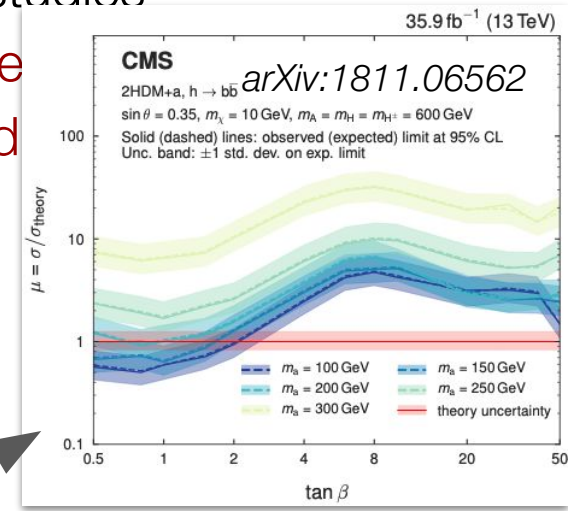
45

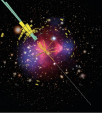
45



Final recommendations: outcome

- Previous slides: only few snapshots of many exciting studies
 - Strong collaboration between theory and experiment
 - Lots of work from ATLAS/CMS postdocs/grads
 - Stimulating guidance from theory + studies
- Final recommendations [only $(M_a, \tan\beta)$ shown]:





- Hopefully can take practices/enthusiasm on board for our Ultimate Goal:
 - White Paper with recommendations for interpretations of DM searches using models with t-channel mediators

- Next talk:
 - Some first thoughts about possible signal parameter scans

 - Aside: experimentalists think signatures
 - Motivation:
 - Did we miss a corner of phase space?
 - What is the most relevant phase space for this model?