



Experimental bounds on t -channel models with heavy flavours

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(University of Wisconsin)

Roadmap of Dark Matter models for Run3

CERN, 13-17 May

Dark matter? signature and phenomenology at collider

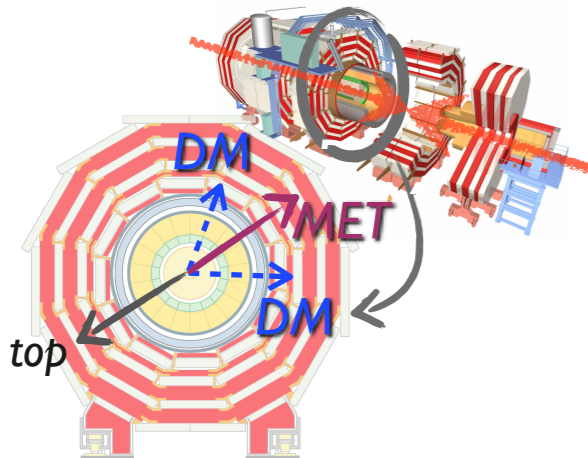
DM evidence



- ▶ Empirical evidence of DM from astrophysical observations at different scales
 - interacts gravitationally, long lived and neutral
 - *no information about its nature*

assume weak interactions with SM

DM production

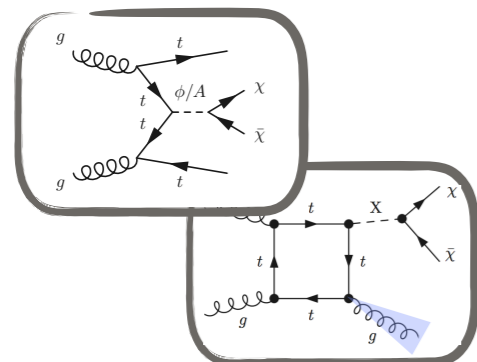


- * most studied class of theories: DM is a weakly interacting massive particle

- ▶ DM could be produced at colliders (rare process)
 - no direct trace in the detector, but could create a p_T imbalance (**MET**)
 - need *visible particle* to which DM particle recoils against
 - “mono-X searches”: X includes jets, vector bosons, top, ...

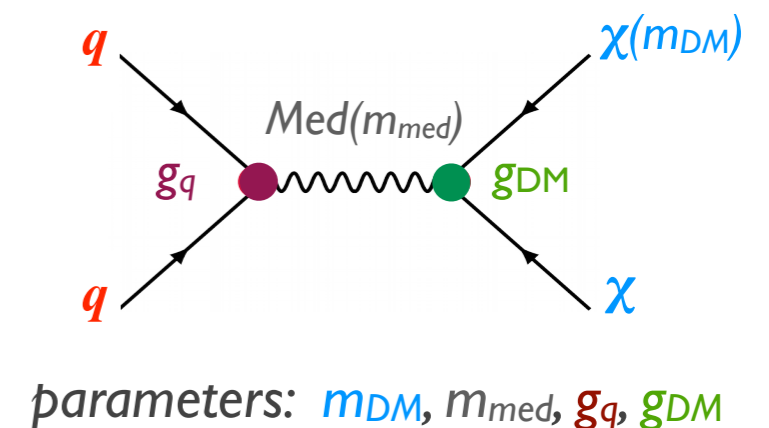
investigate specific interactions/final states

DM signature



- ▶ Which type of events do we study at colliders? can assume different interactions

	vector	axial-vector
spin-1	$g_q \sum_q V_\mu \bar{q} \gamma^\mu q$	$g_q \sum_q A_\mu \bar{q} \gamma^\mu \gamma^5 q$
	scalar	pseudoscalar
spin-0	$g_q \frac{\phi}{\sqrt{2}} \sum_f y_f \bar{f} f$	$g_q \frac{iA}{\sqrt{2}} \sum_f y_f \bar{f} \gamma^5 f$

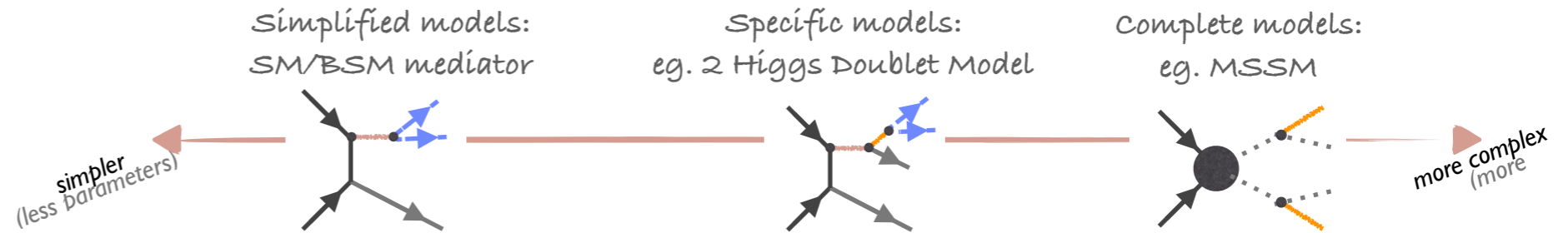


- * benchmark models: kinematically distinct set of model parameters

ATLAS/CMS DM forum
[arXiv:1507.00966]

Dark matter? phenomenology at colliders

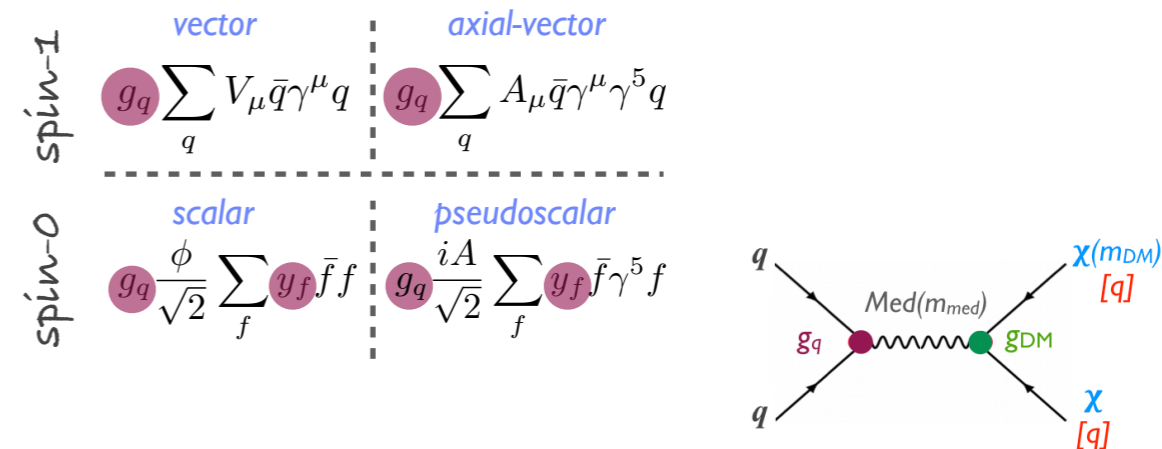
- ▶ Energy frontiers: GeV-TeV



- ▶ Which type of events do we study at colliders?

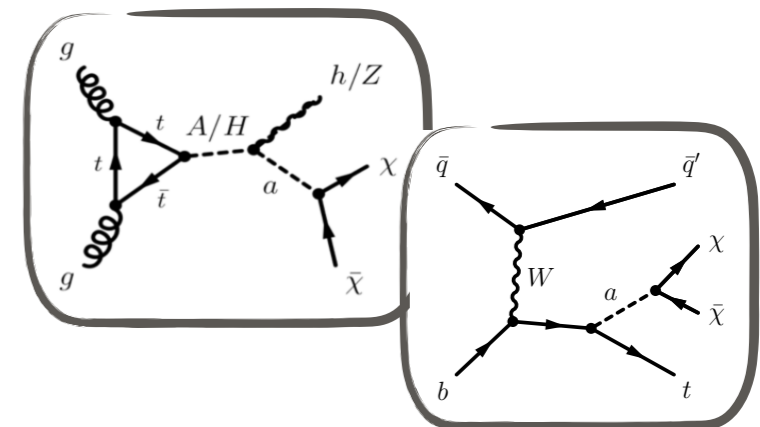
Simplified models

- ▶ one s-channel mediator (*t-channel med also possible*)
- * interaction type define most sensitive signatures
- * possible extensions with additional dark sector particles
- ▶ invisible and visible final states
- ▶ Higgs boson could be the SM-DM mediator



2HDM

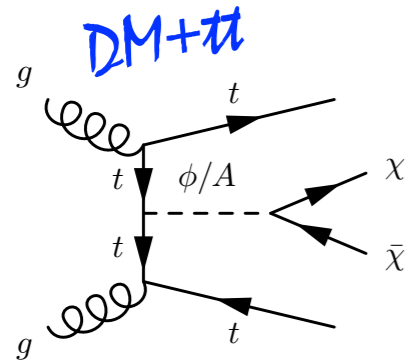
- ▶ two-Higgs doublet extensions with vector Z' or pseudo-scalar a
- ▶ couplings prioritize third generation and signatures with vector and Higgs bosons



- Signatures:**
- *invisible*: production of DM through the decay of a portal/SM particles
 - *visible*: dark mediator particles can decay back to SM particles (especially if sector's lightest state)
 - *displaced (long-lived)*: production of dark sector particle with significant lifetime that decays visibly to SM

tt+MET search

1 - Selection: events categorized based on #leptons



0l

- * leptons veto: e, μ
 - * ≥ 4 jets
 - * ≥ 2 b-tagged jets
 - * large MET
- +categ based on large-cone jet mass

1l

- * 1 lepton: isolated e, μ
 - * ≥ 3 jets
 - * =1, ≥ 2 b-tagged jets
 - * large MET
- +NN techniques for had top reconstr. and improve sensitivity

2l

- * 2 OS leptons: e, μ
 - * ≥ 1 jets
 - * ≥ 1 b-tagged jets
 - * large MET
- +categ based on lepton flavour

1l, 2b

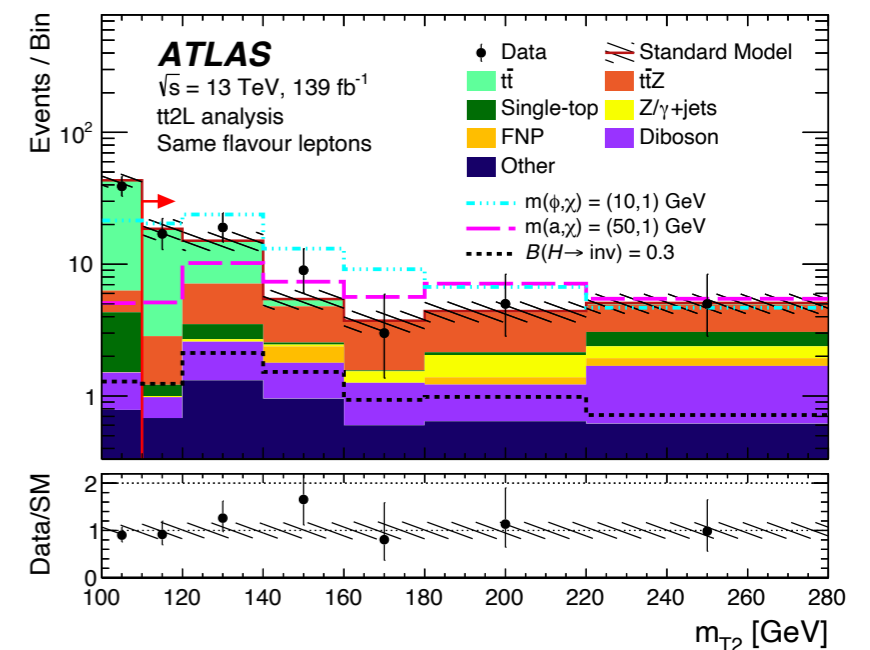
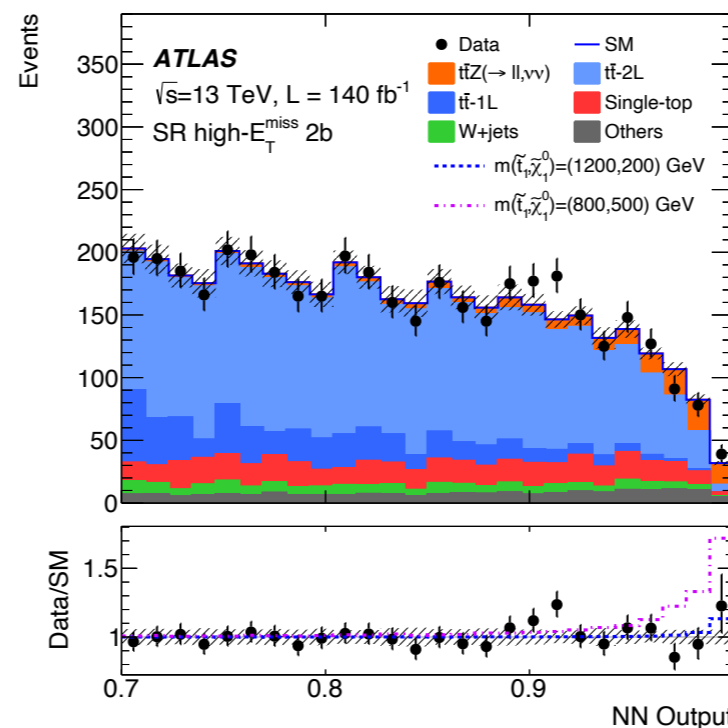
2l, same-flavour

2- Bkg:

- tt, ttV, V+jets main bkg, from CRs

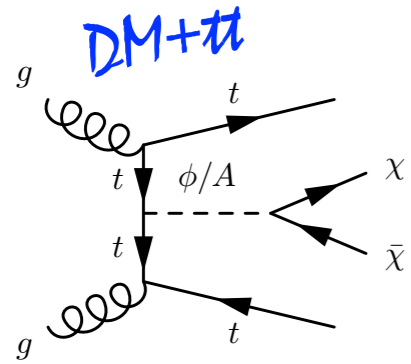
3- Results: combined fit of SRs and CRs

- systematic unc. included as nuisance parameters



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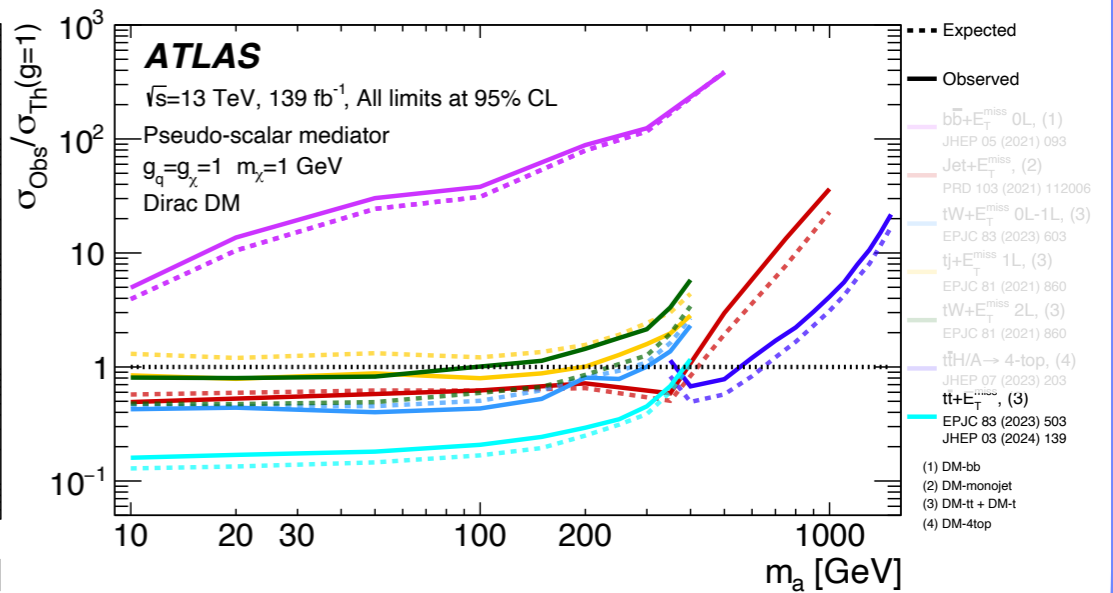
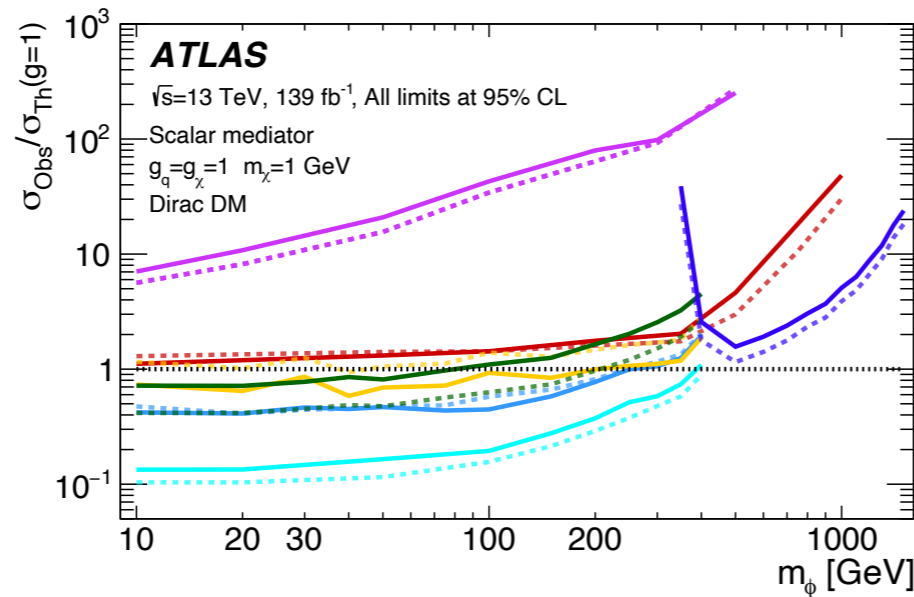
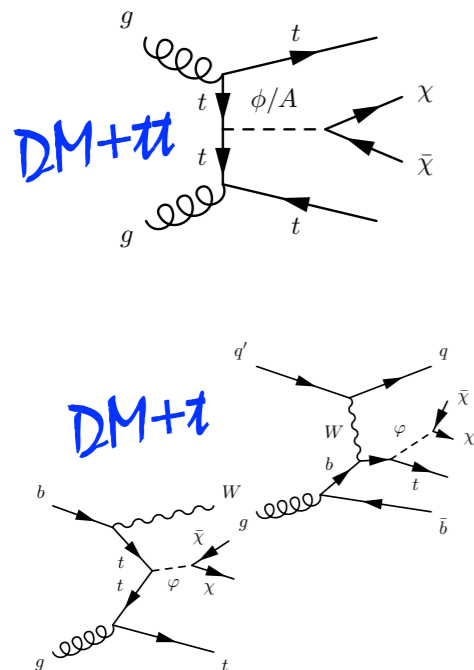
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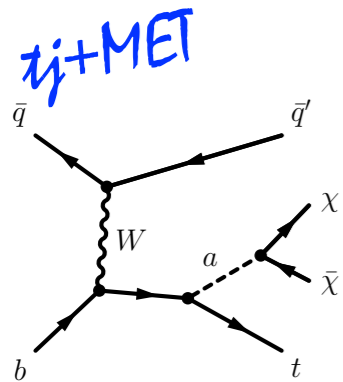
3- Results: interpretation in terms of DM model with Dirac DM upper limits at 95% CL on xsec

scalar/pseudoscalar interaction

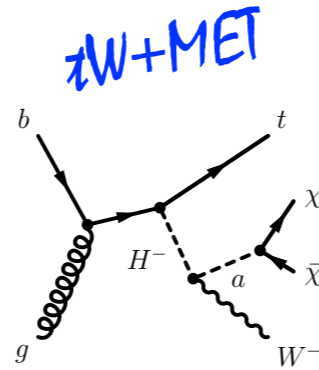


$tj(tW)+MET$ search

► 1 - Selection: events categorized based on #leptons



- 1l**
- * 1 lepton
 - * [1-4] jets
 - * [1-2] b-tagged jets
 - * MET > 200 GeV
 - * MVA techniques to improve sensitivity



- | | | |
|---|--|---|
| <p>0l</p> <ul style="list-style-type: none"> * 1 lepton: e, μ * ≥ 4 jets, ≥ 1 large-cone jet W-tagged * = 1 b-tag jet * MET > 250 GeV | <p>1l</p> <ul style="list-style-type: none"> * 1 lepton: e, μ * ≥ 3 jets, ≥ 1 large-cone jet W-tagged (had or lep) * = 1 b-tag jet * MET > 250 GeV | <p>2l</p> <ul style="list-style-type: none"> * 2 OS leptons * ≥ 1 jets * ≥ 1 b-tag jets * MET > 200 GeV |
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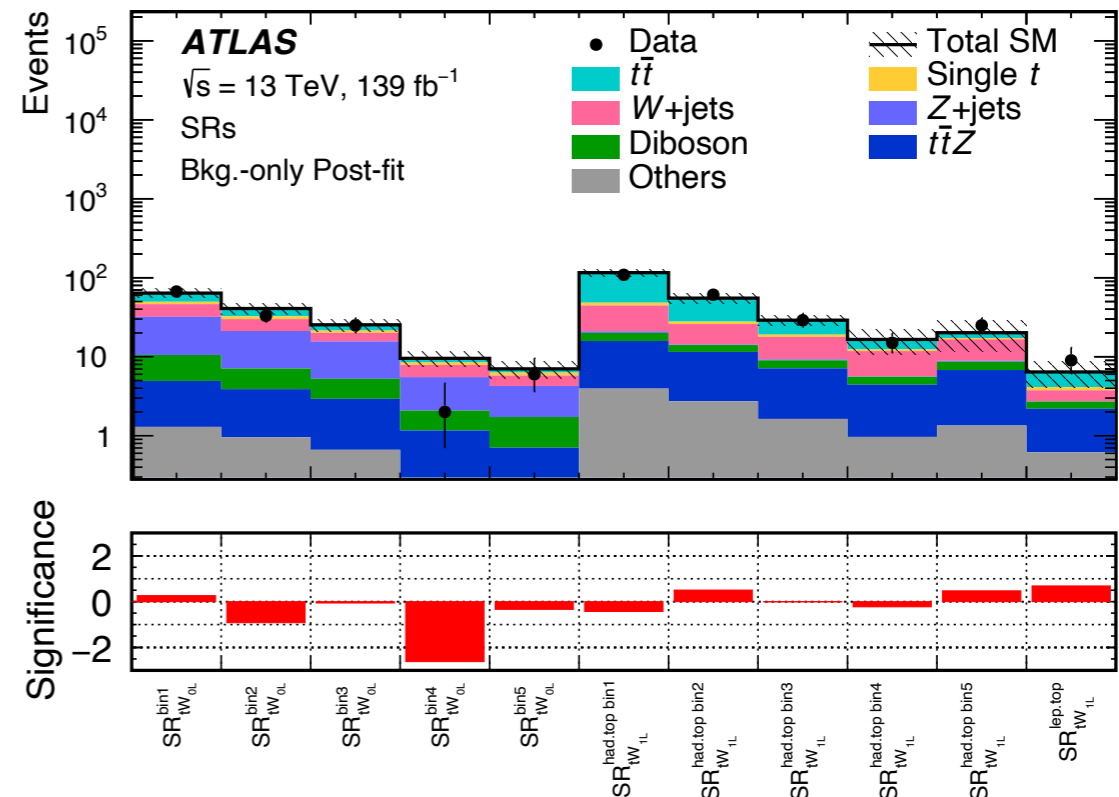
► 2- Bkg:

- tt , ttV , $V+jets$ main bkg, from CRs

► 3- Results: combined fit of SRs and CRs

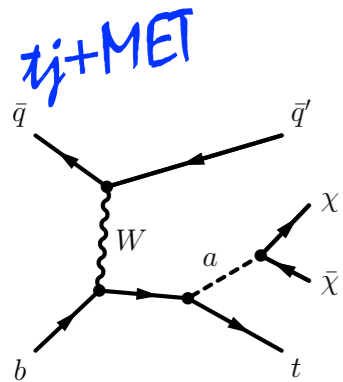
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$2tW+MET: 0l, 1l$

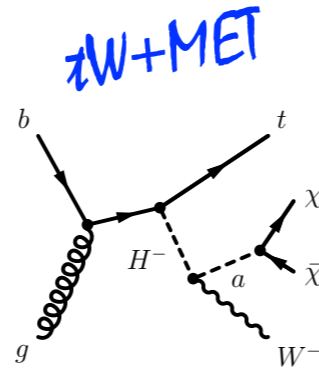


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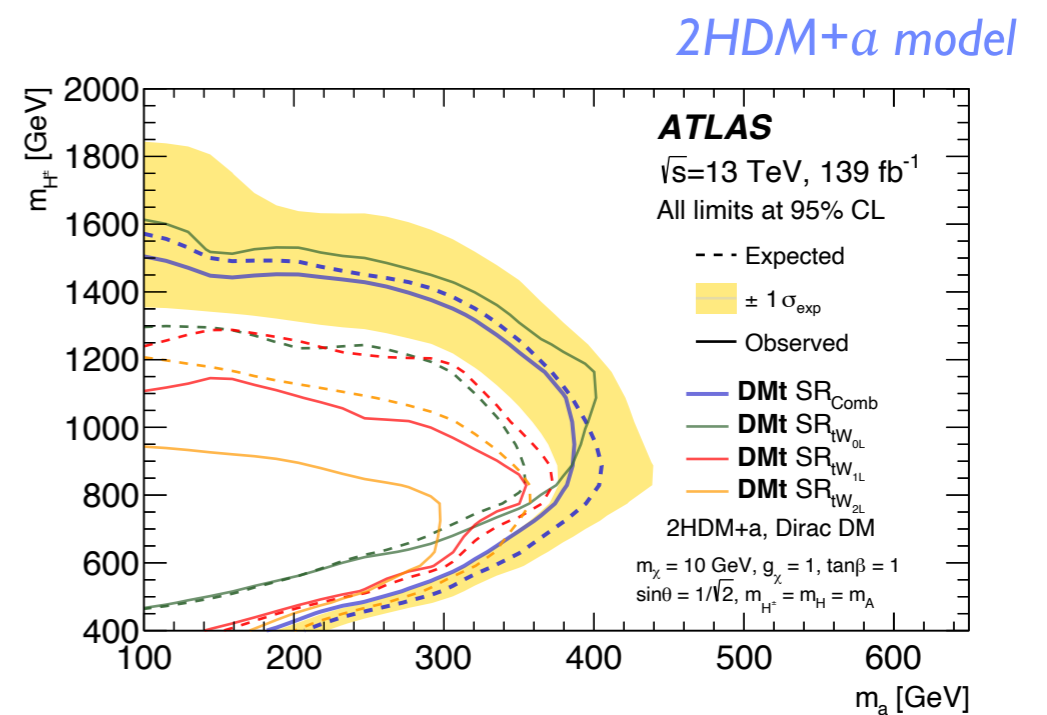
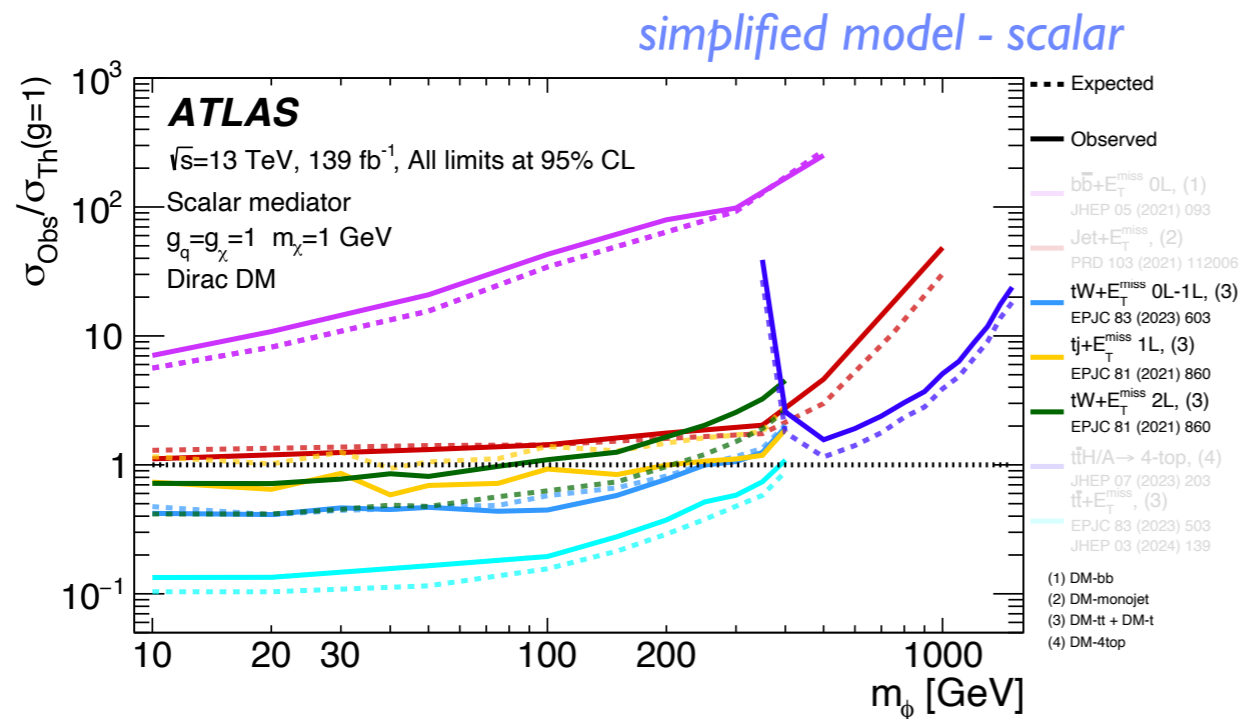


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|---|--|---|

► 3- Results: interpretation in terms of DM model with Dirac DM upper limits at 95% CL on xsec



* Analysis sensitive also to DM+tt processes: low H^\pm masses \rightarrow DM+t dominates, high $m(H^\pm)$ \rightarrow DM+tt dominates

DARK MATTER

Reminder:

$$g_q \frac{\phi}{\sqrt{2}} \sum_f y_f \bar{f} f \quad \left| \quad g_q \frac{iA}{\sqrt{2}} \sum_f y_f \bar{f} \gamma^5 f$$

scalar
pseudoscalar

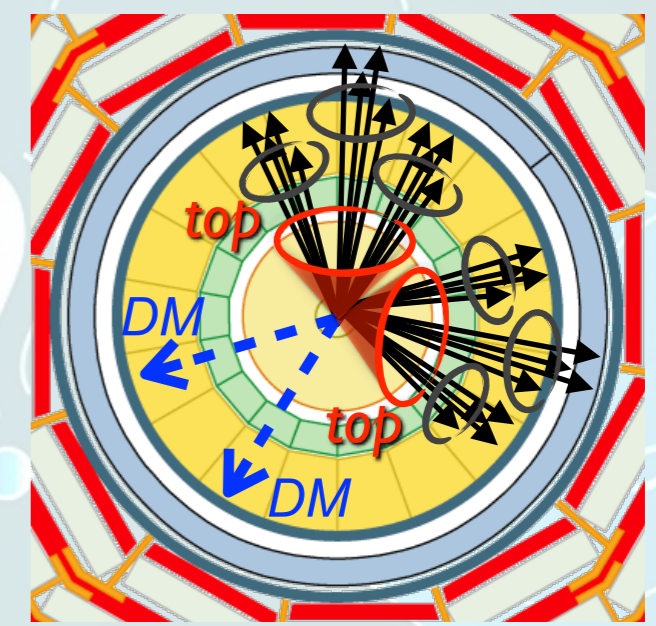
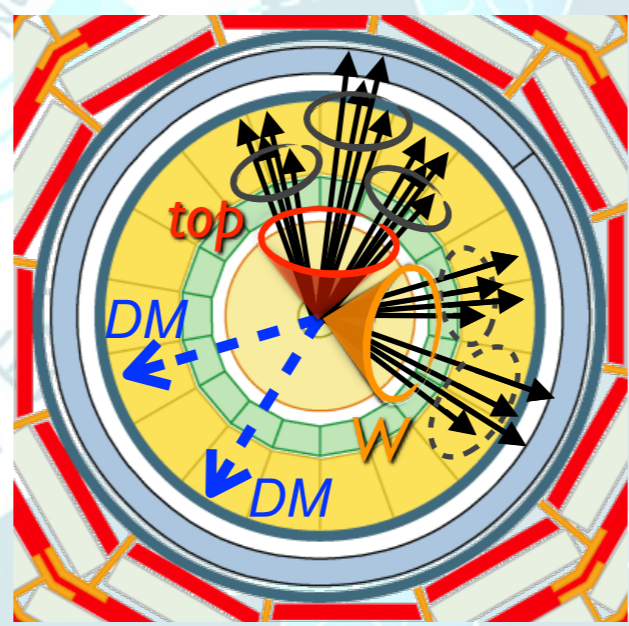
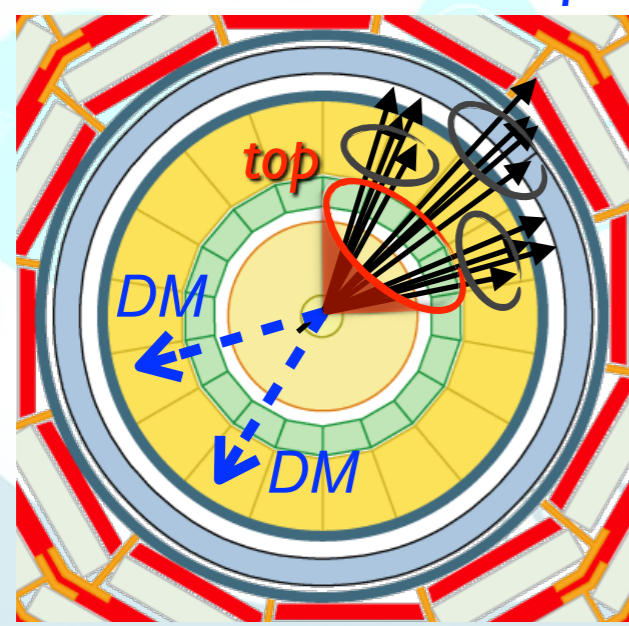
* choose X to exploit coupling \propto to quark mass (or increase xsec)

Spin-0 mediator: simplified models

Signature: large MET and 1(2) top quarks

DM+top: t/tW-channel

DM+tt



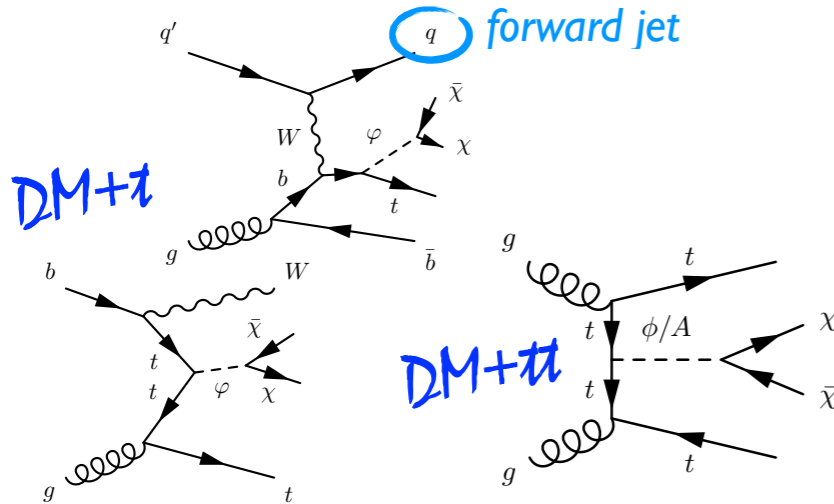
*

CMS: [EXO-22-014](#)

*

$t(tt)+MET$ search

► 1 - Selection: events categorized based on #leptons, # b-jets and #forward jets



0l

- * leptons veto: e, μ
- * ≥ 3 jets, =1, ≥ 2 b-tagged jets
- * MET > 250 GeV
- + 0 or ≥ 1 forward jets

1l

- * 1 lepton
- * ≥ 2 jets, =1, ≥ 2 b-tagged jets
- * MET > 250 GeV
- + categ based on topness
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2l

- * 2 OS leptons
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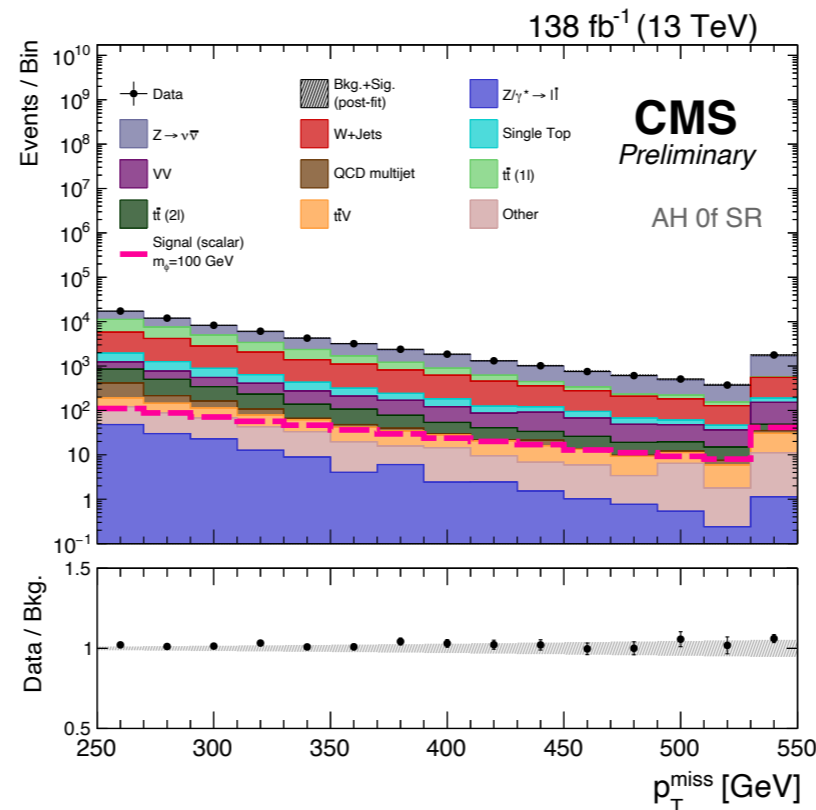
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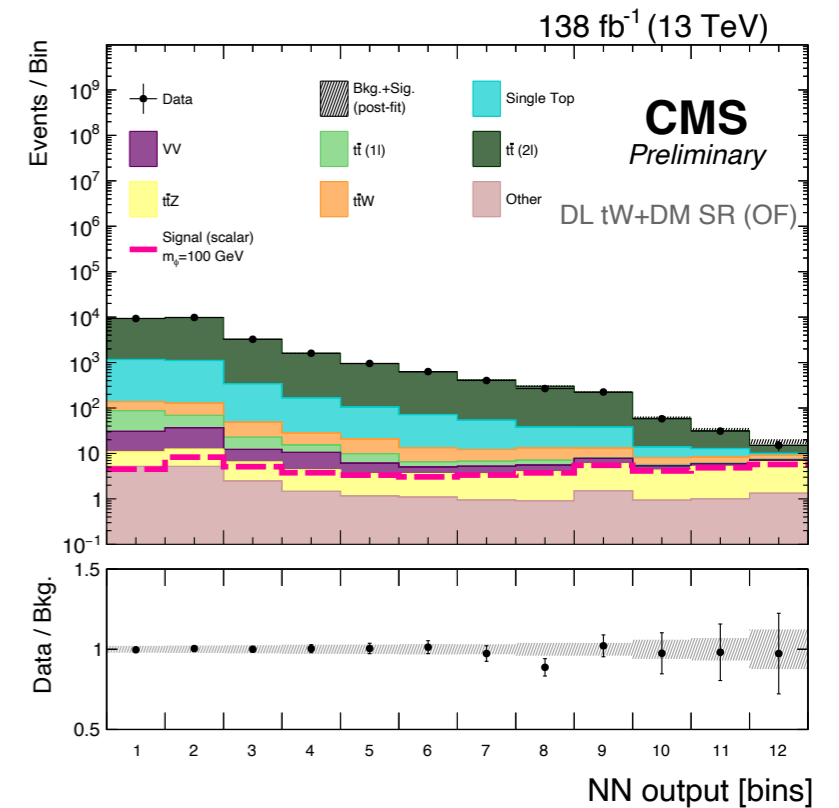
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0l, 1b, 0 forw. jets

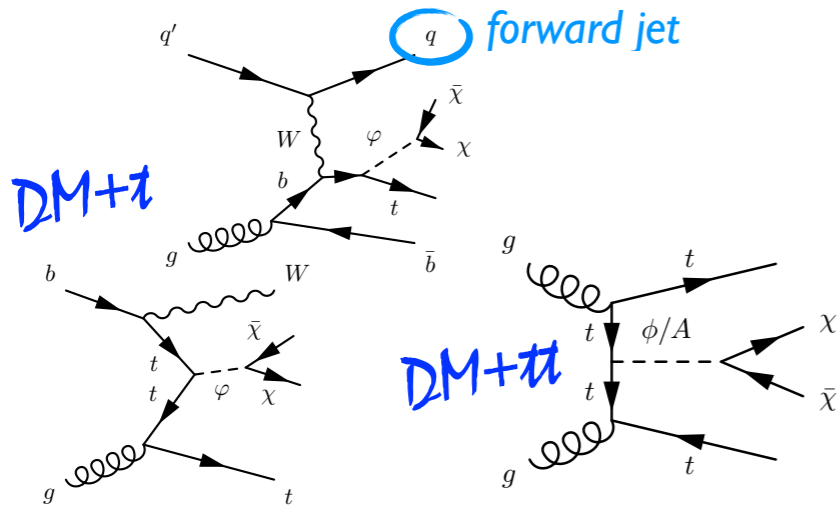


2l, 1b



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1l

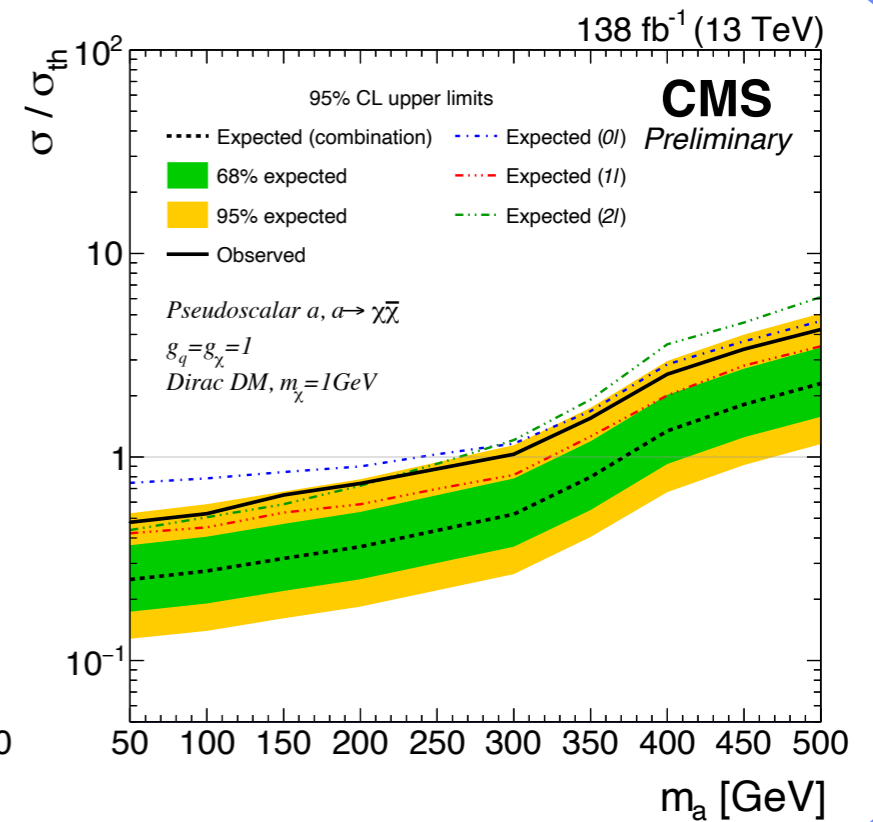
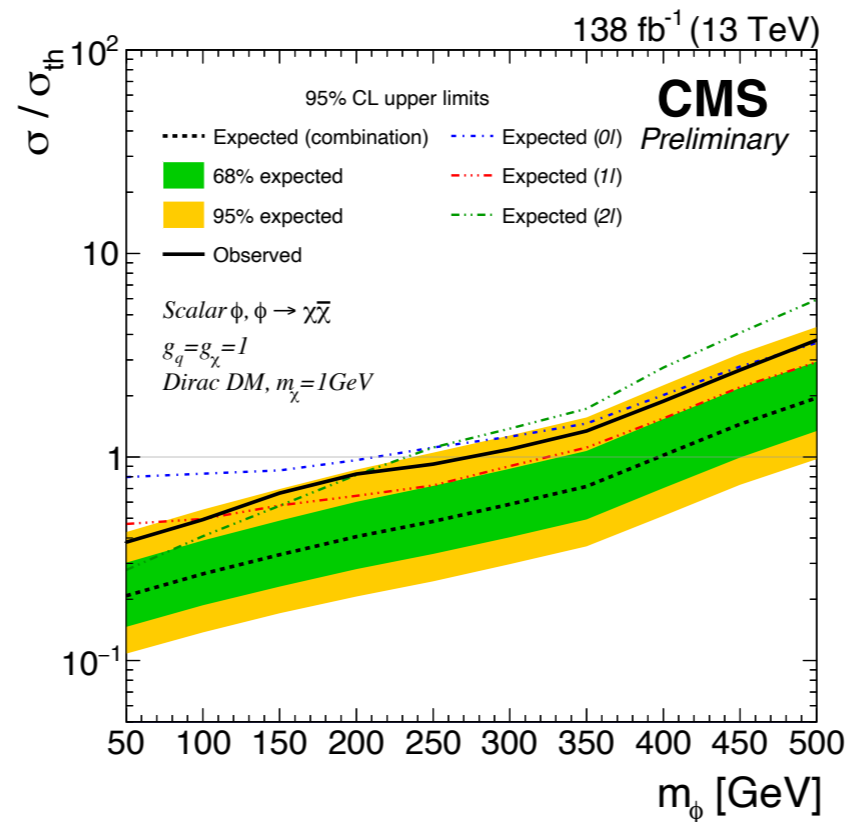
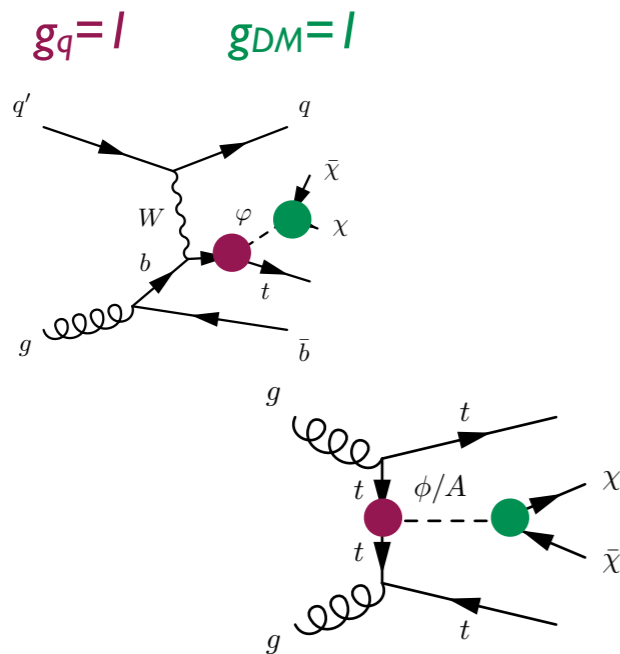
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scalar/pseudoscalar interaction



DARK MATTER

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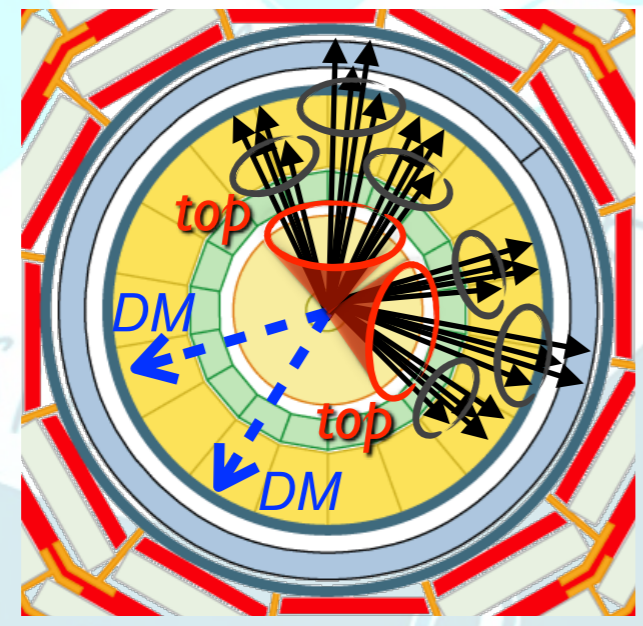
$$\begin{array}{c} \text{scalar} \\ g_q \frac{\phi}{\sqrt{2}} \sum_f y_f \bar{f} f \end{array} \left| \begin{array}{c} \text{pseudoscalar} \\ g_q \frac{iA}{\sqrt{2}} \sum_f y_f \bar{f} \gamma^5 f \end{array} \right.$$

* choose X to exploit coupling \propto to quark mass (or increase xsec)

Spin-0 mediator: simplified models

Signature: large MET and 2 bottom quarks

DM+bb



- *
- *

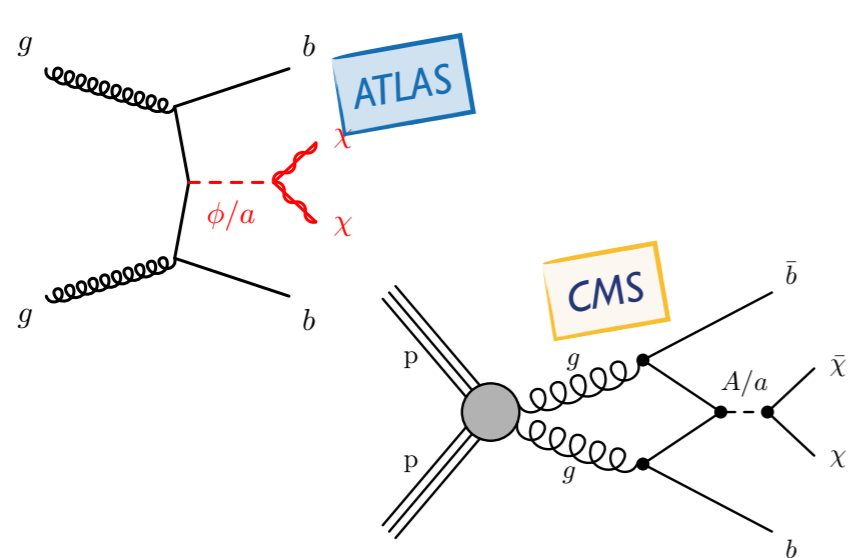
ATLAS: [arXiv:2404.15930](https://arxiv.org/abs/2404.15930)

CMS: [SUS-23-008](https://arxiv.org/abs/2308.008)

Wimp

bb+MET search

1 - Selection:



- ATLAS**
- * leptons veto
 - * [2-3] jets, = 2 b-tagged jets
 - * MET > 180 GeV
 - * MVA techniques to improve sensitivity
 - +categ based on med. mass range

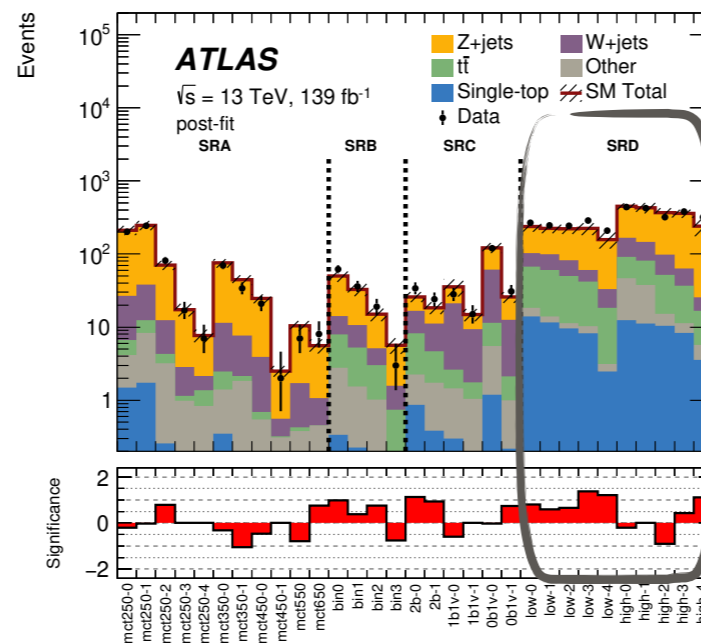
- CMS**
- * leptons veto
 - * ≥ 1 jets, $p_T(j) > 100$ GeV
 - * ≥ 1 b-tagged jets
 - * MET > 250 GeV
 - +categ based on b-jets multiplicity

2- Bkg:

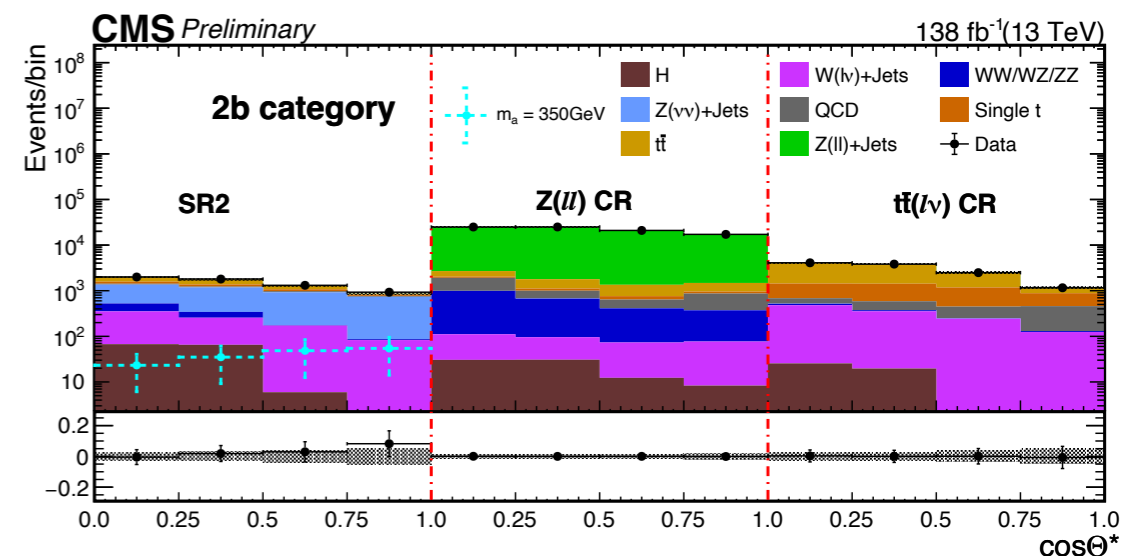
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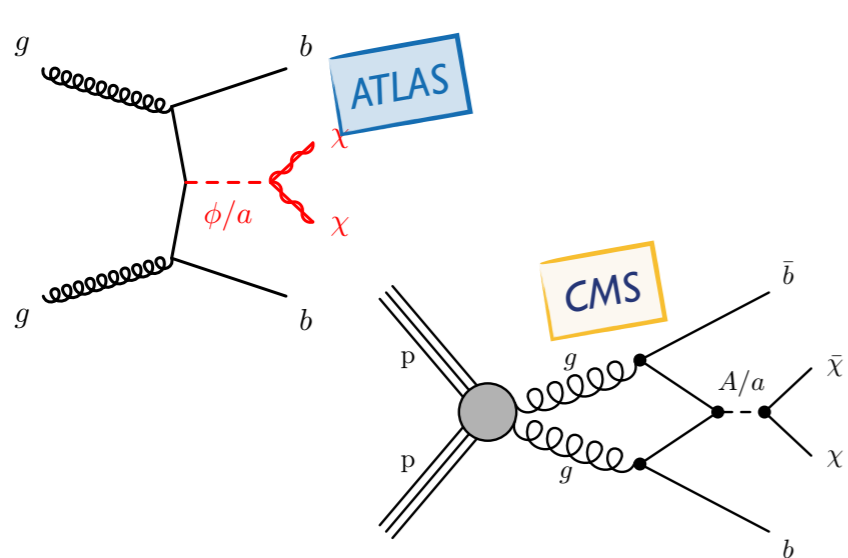


2b category



bb+MET search

1 - Selection:



ATLAS

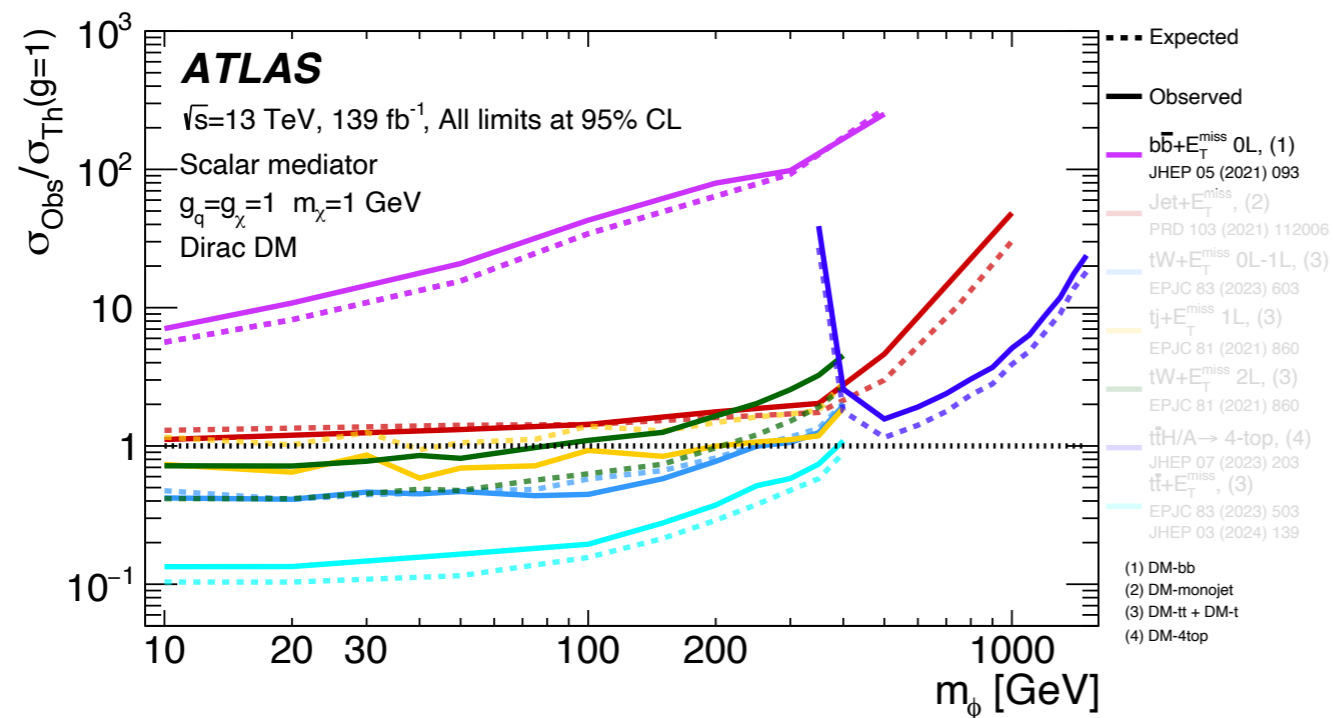
- * leptons veto
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- * MET > 180 GeV
- * MVA techniques to improve sensitivity
- +categ based on med. mass range

CMS

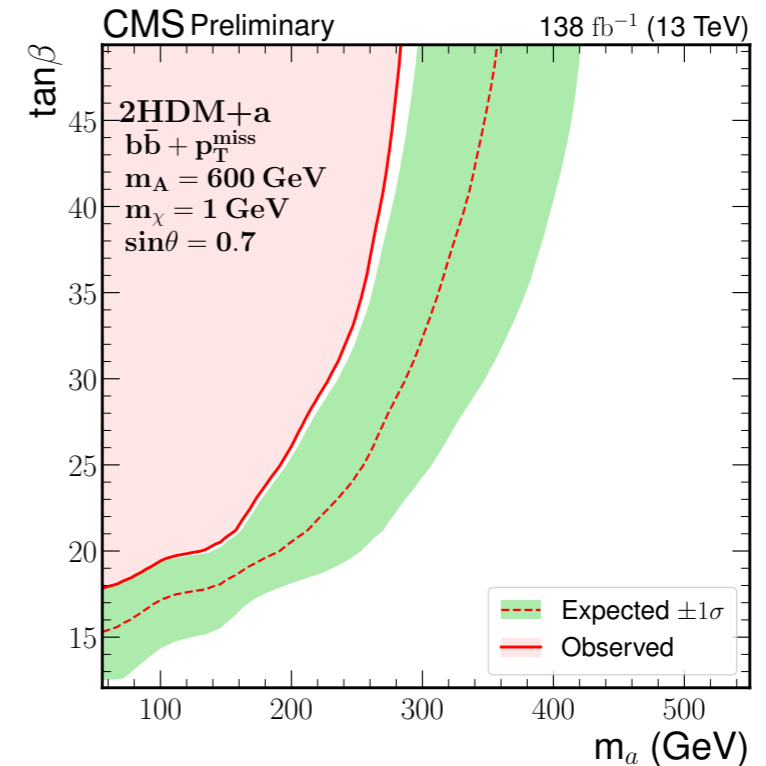
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simplified model - scalar



2HDM+a model



**Heavy-flavour +MET:
can we go from s- to t-channel?**



$t(b)+MET$: can we go from s- to t-channel?

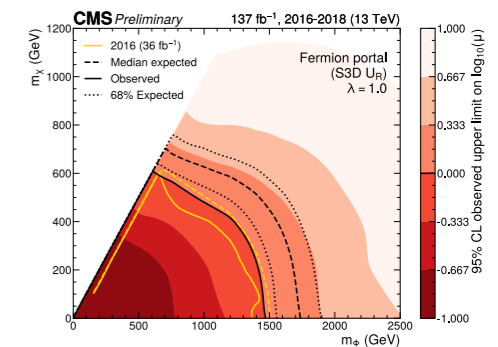
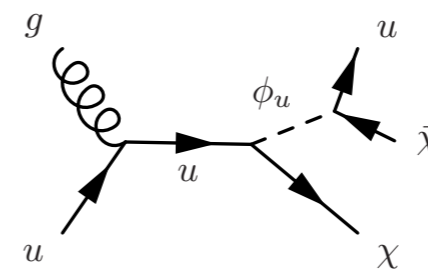
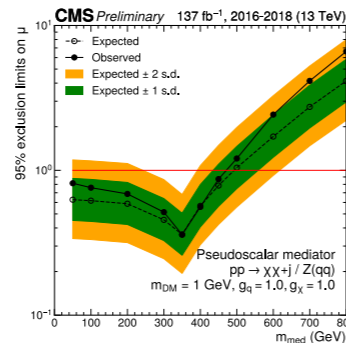
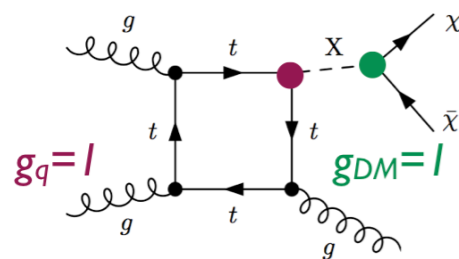
s-channel

mediator couples to pair of dark matter or SM particles

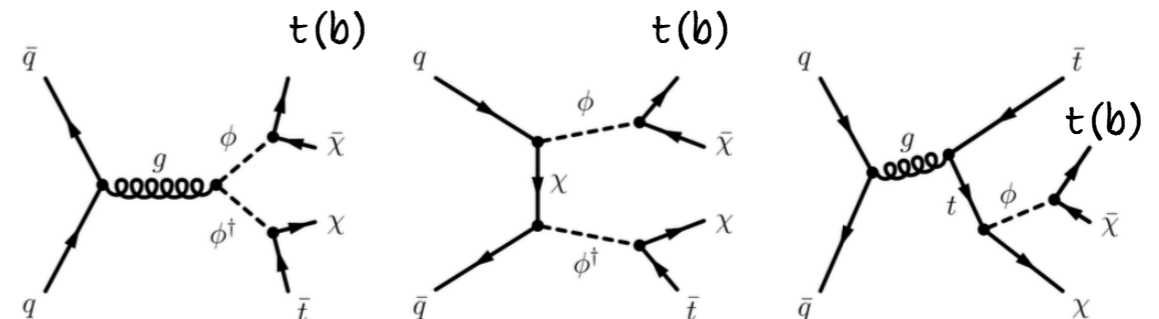
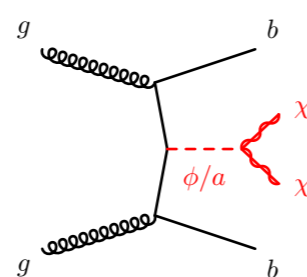
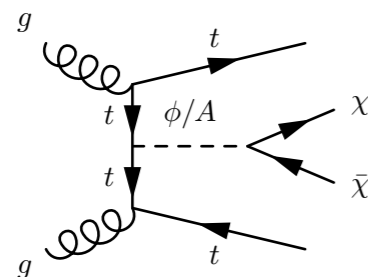
t-channel

mediator interacts with one SM state and the dark matter

t-channel models at LHC: mono-jet

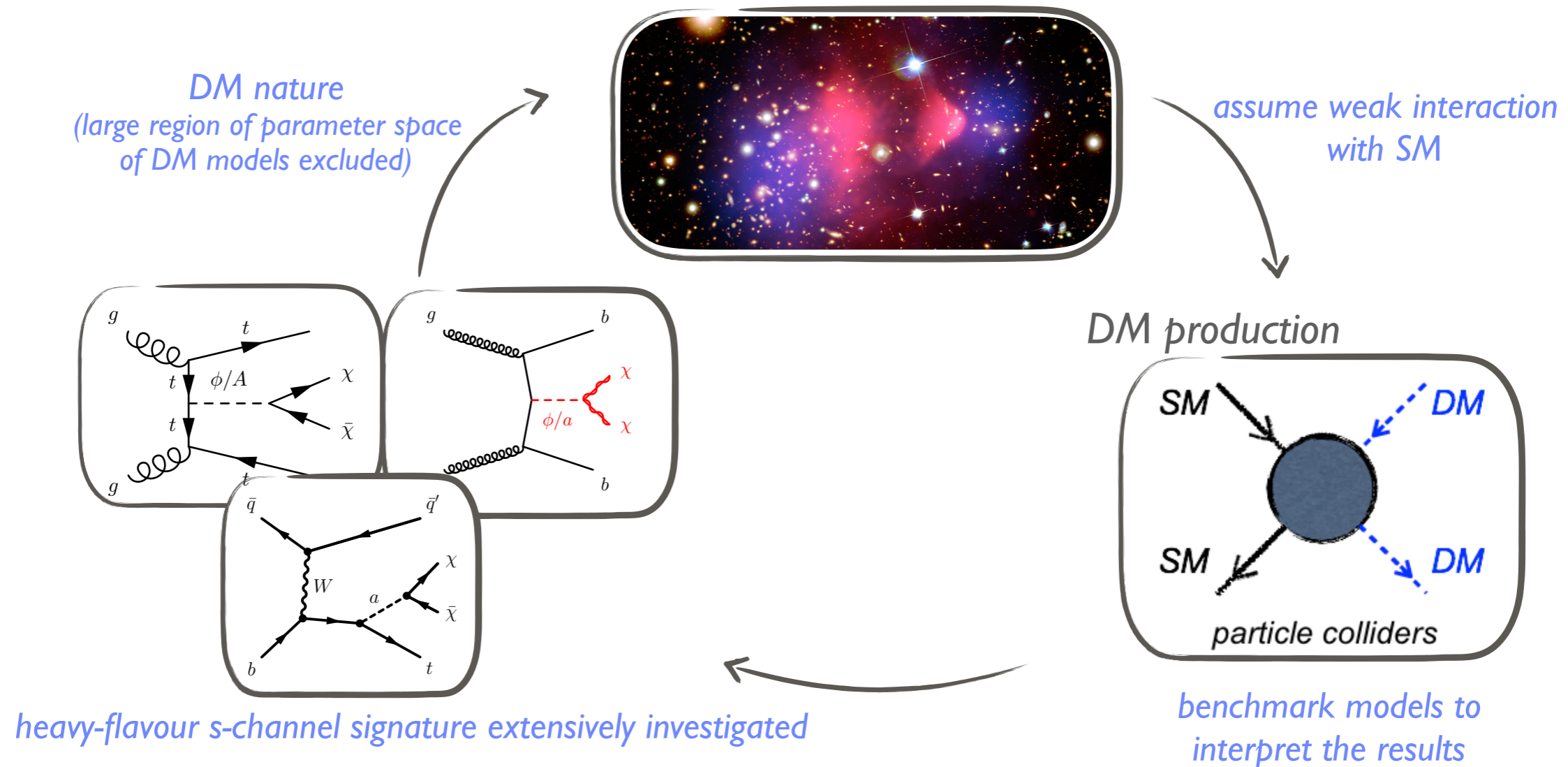


What about DM+heavy-flavour?



- existing literature shows that other flavor states could also contribute to LHC signals from t-channel mediators
- but such models have not been studied as extensively as others
- some signatures might be similar to already studied ones (eg. stop quarks production)
- other might give signatures covering different space-space, eg. is the request of large angular distance between MET and jets still valid?

Summary



* Rich DM+heavy flavour physics program at ATLAS and CMS

- s-channel signatures extensively investigated (simplified models, 2HDM+a)
- t-channel signatures not been studied as extensively
- what constraints we have from existing analyses?
- are there signature/phase-spaces currently not covered?

NEW SPEAKER.
DARK MATTER
TALK.

DARK
MATTER

MATTER

Thank you!

Dr
Gib
Bauer



DARK MATTER

Backup

PROTON

PHOTON

NEUTRINO

MUON

QUARK

VISIBLE MATTER

NEUTRALINO

AXION

AXION

GRAVITINO

Wimp

