
# Dark Matter searches with the ATLAS Detector

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on behalf of the ATLAS Collaboration

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# Overview

Introduction to the ATLAS dark matter strategy

Searches for DM production

Mediator-based searches

The SM Higgs as a mediator

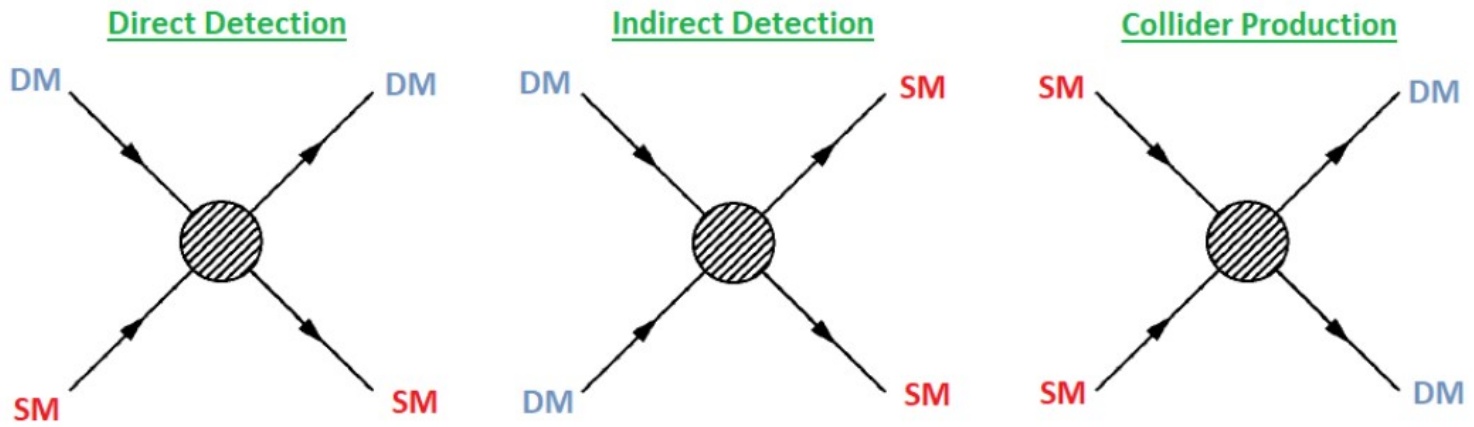
Making sense of it all

Conclusions

# Background

**WIMPs remain the “most popular” dark matter candidate.**

- Generally expected that there should be some (small) interaction with SM particles.




**For ~TeV masses and below, it should be possible to produce DM at the LHC.**

- If the cross section isn't too small, we can measure this.
- Complements other methods, which can have limited sensitivity at lower DM masses and for some DM-nucleon scenarios.

# Background

**3 broad classes of DM models:**


**Effective Field Theories**

- We don't know what the higher-scale physics is, but we can integrate it out.

**“Simplified Models”**

- We introduce a few additional degrees of freedom, but don't try to make statements about the complete theory.

**Complete Theories**

- We add a full set of new DoF's and expect them to explain everything (e.g. SUSY).

# Background

**3 broad classes of DM models:**


**Effective Field Theories**

EFTs often have validity issues at LHC energy scales.

- We don't know what the higher-scale physics is, but we can integrate it out.

**"Simplified Models"**

I'll focus mainly on simplified models.

- We introduce a few additional degrees of freedom, but don't try to make statements about the complete theory.

**Complete Theories**

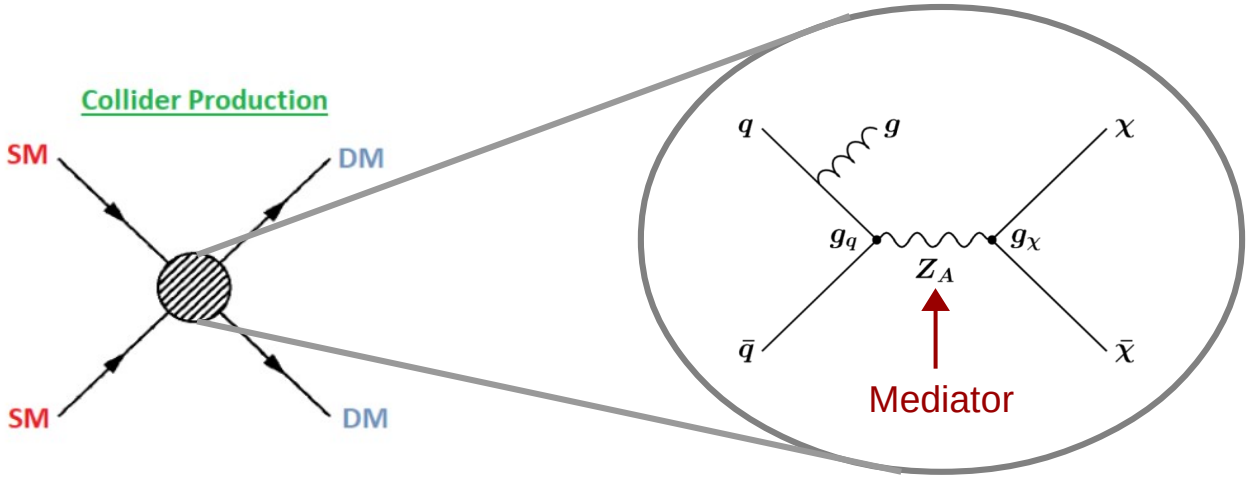
Typically require targeted model-specific searches. More details in the various ATLAS SUSY talks!

- We add a full set of new DoF's and expect them to explain everything (e.g. SUSY).

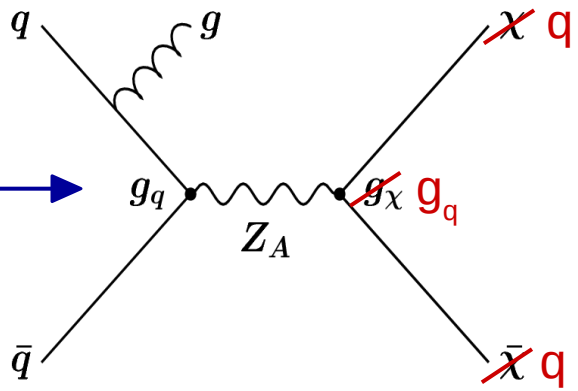
# ATLAS Strategy

**ATLAS has a broad program of searches for dark matter.**

- We often consider **"simplified models"** with an additional **mediator*.**




In many cases, it's easier to search for the mediator in visible channels.



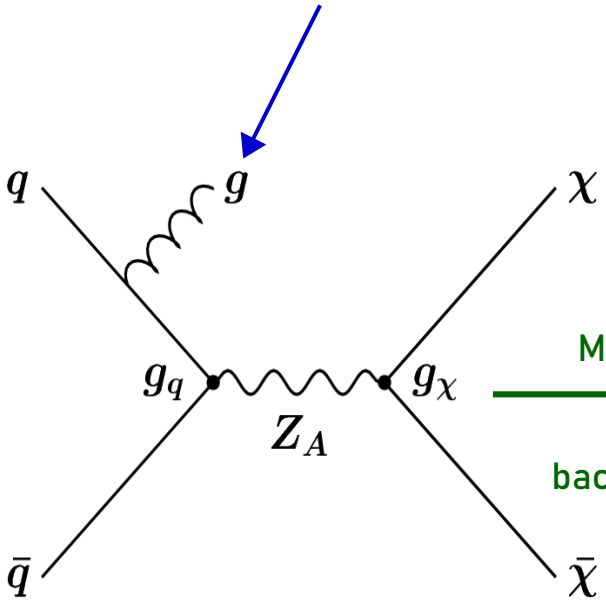

* The SM Higgs can be the mediator, more on this later.

# “Direct” Searches

# Jets + MET

**LHC makes lots of jets, this is the most obvious place to look!**

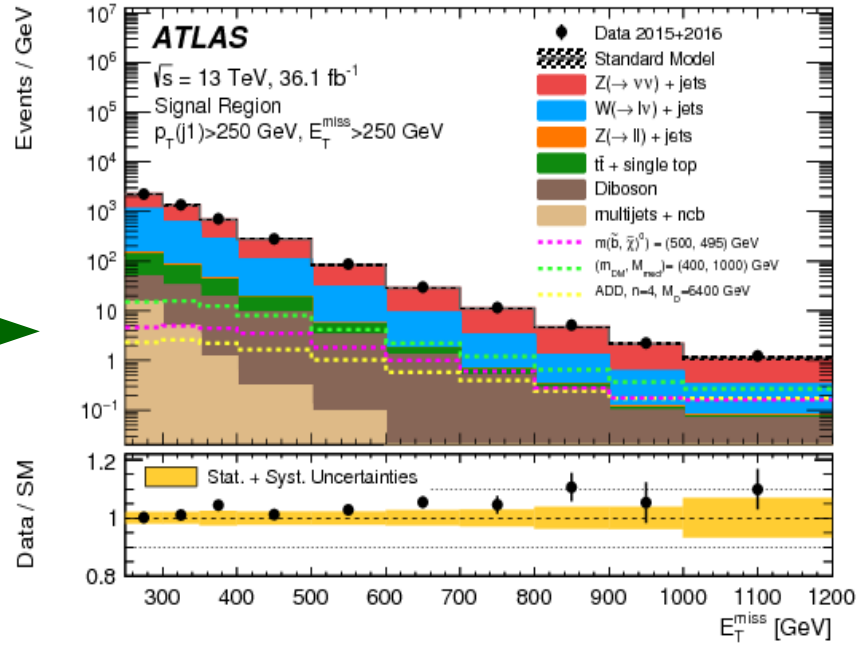
Jet required to boost the invisible system



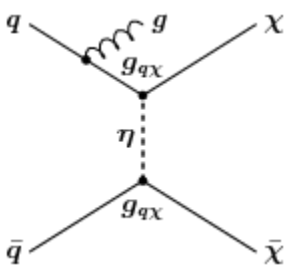

Measure MET spectrum

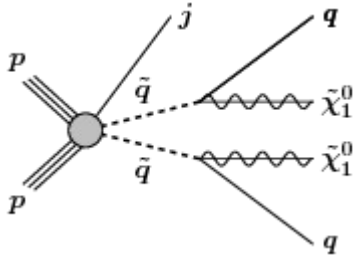
Constrain W and Z backgrounds using lepton control regions

JHEP 01 (2018) 126 (arXiv: 1711.03301)




Many models produce this signature!




Latest result is with 36.1 fb$^{-1}$ (2015+2016 dataset).

Full Run-2 (140 fb$^{-1}$) analysis in the works!

# Bosons + MET

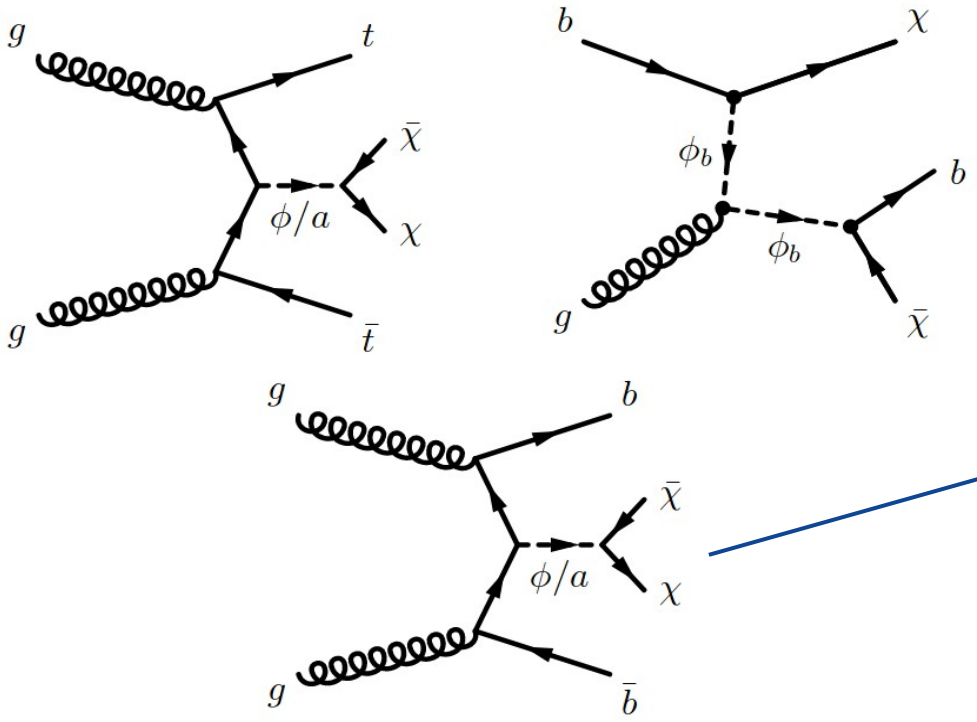

- γ — Eur. Phys. J. C 77 (2017) 393, arXiv: 1704.03848 — 36.1 fb$^{-1}$
- Z → ll — Phys. Lett. B 776 (2018) 318, arXiv: 1708.09624 — 36.1 fb$^{-1}$
- W, Z → qq — JHEP 10 (2018) 180, arXiv: 1807.11471 — 36.1 fb$^{-1}$
- H → bb — ATLAS-CONF-2018-039 — 80 fb$^{-1}$
- H → γγ — Phys. Rev. D 96 (2017) 112004, arXiv: 1706.03948 — 36.1 fb$^{-1}$

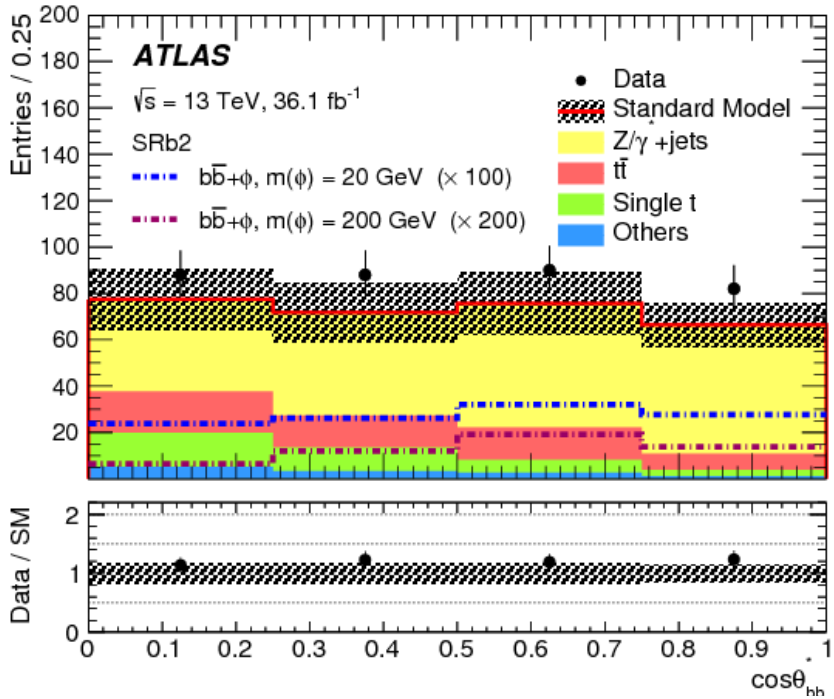
# Heavy Flavor + MET

**Dedicated search for cases where the mediator couples preferentially to heavy-flavor quarks**

Latest result (36.1 fb$^{-1}$): Eur. Phys. J. C 78 (2018) 18, arXiv: 1710.11412

- Set limits on scalar/pseudoscalar models



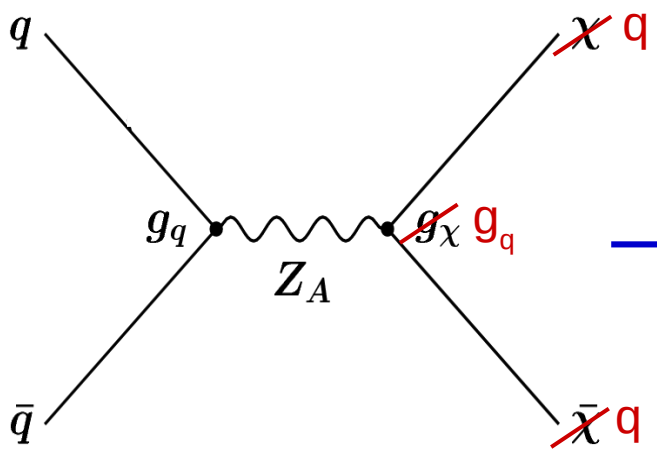



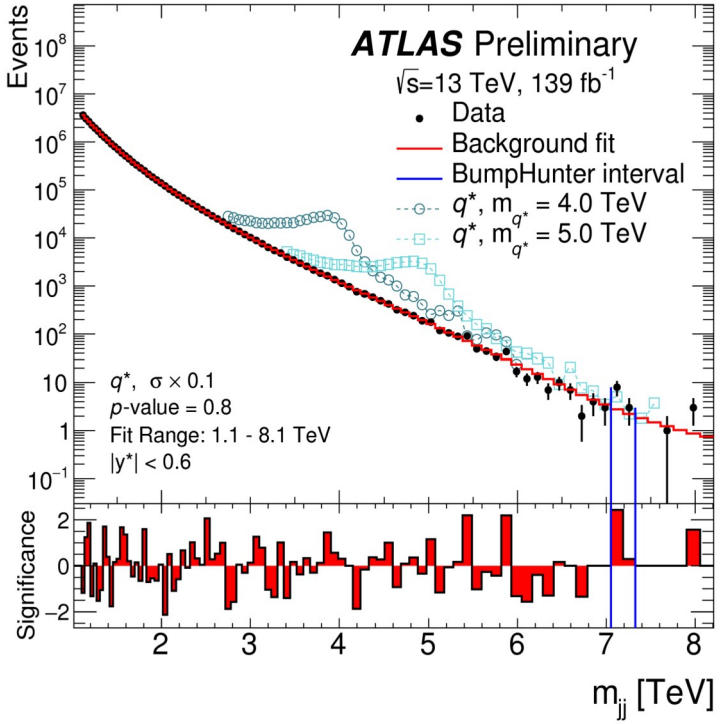
# Mediator Searches

# Dijets

**Most obvious place to look for mediators is the dijet final state.**

New 140 fb$^{-1}$ resonant result now public (ATLAS-CONF-2019-007)




**Also, in previous results:**

- Angular analysis for signals that aren't narrow resonances (Phys. Rev. D 96 (2017) 052004)
- b-jet-specific channel (Phys. Rev. D 98 (2018) 032016)

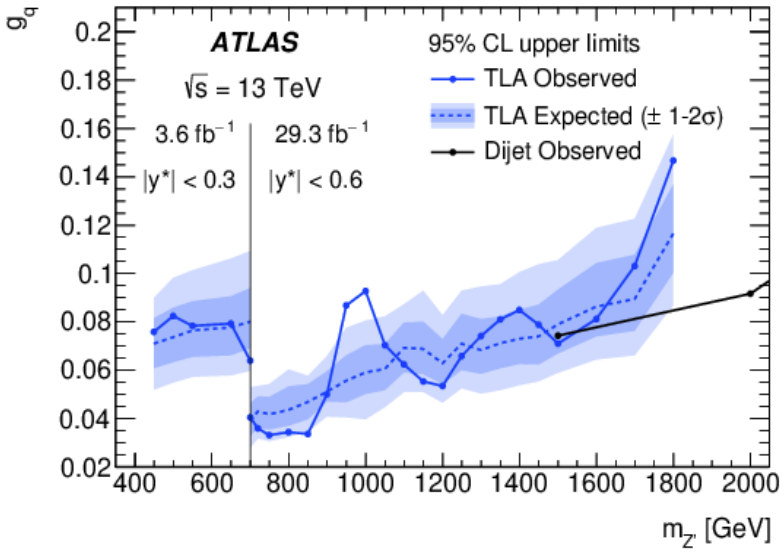
# Dijets – Probing lower masses

**Standard dijet search is limited to high masses by trigger thresholds.**

→ We use 2 methods to access lighter mediators:

## Trigger-Level Analysis

Save only trigger-level jet information to allow recording more events!



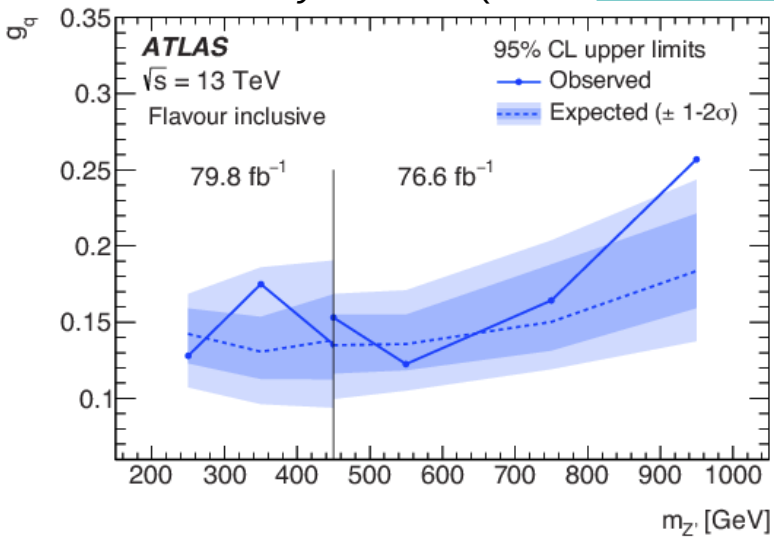

One Run-2 result so far with 29.3 fb$^{-1}$

Phys. Rev. Lett. 121 (2018) 081801 (arXiv: 1804.03496)

## Boosted dijet system

The latest: photon+dijet with 80 fb$^{-1}$
- includes new b-tagged channel

Submitted to *Phys. Lett. B* (arXiv: 1901.10917)




SM physics provides the boost, so the recoiling object is model-independent.

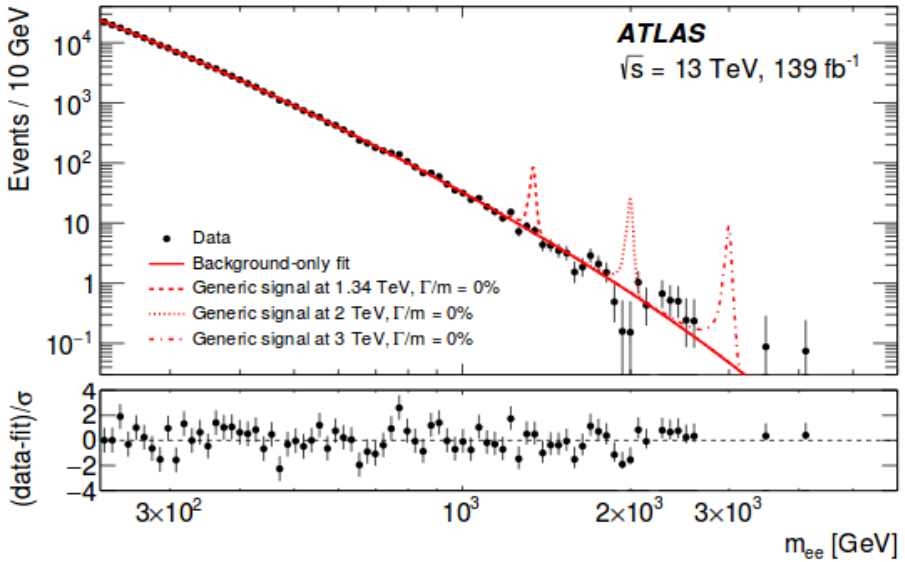
See also: jet+di-bjet with 80 fb$^{-1}$ (ATL-CONF-2018-052)

# Dileptons

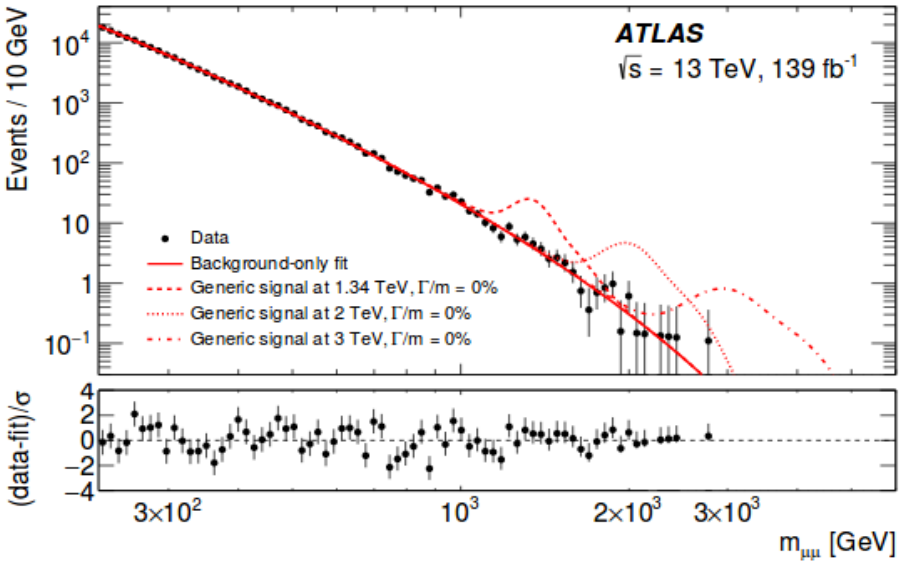
**Search for generic resonances which couple to leptons.**

- Not “traditionally” thought of as a DM mediator search, but easy to reinterpret.
- New 140 $fb^{-1}$ result submitted to *Phys. Lett. B* (arXiv: 1903.06248)

Electrons




Muons




**Explore dilepton spectrum from 250 GeV – 6 TeV**

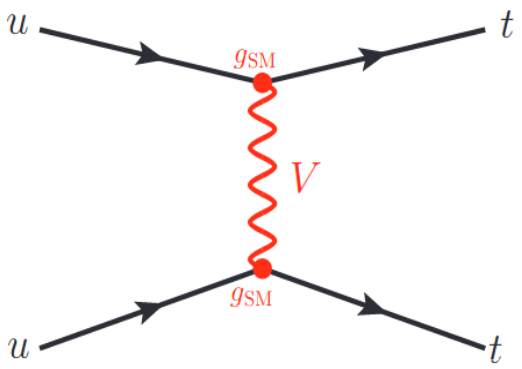
- Earlier versions have gone down to 80 GeV.

# Top final states

**Some models have the mediator preferentially coupling to top quarks.**

- Interpret various top-related searches in terms of DM mediators.

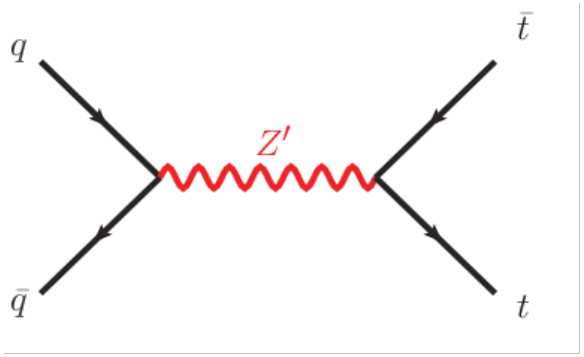
## same-sign tt




JHEP 12 (2018) 039
arXiv: 1807.11883

**36.1 fb$^{-1}$**

## $t\bar{t}$ resonance




Eur. Phys. J. C 78 (2018) 565
arXiv: 1804.10823

**36.1 fb$^{-1}$**

## 4-top production

**SUSY search re-interpreted in terms of non-minimal 2HDM mediator scenarios**

JHEP 09 (2017) 088
arXiv: 1704.08493

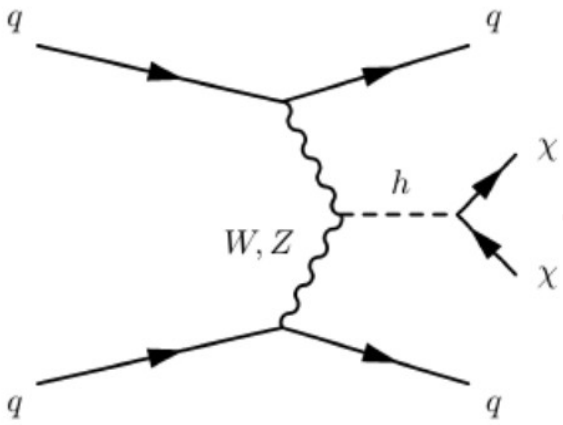
**36.1 fb$^{-1}$**

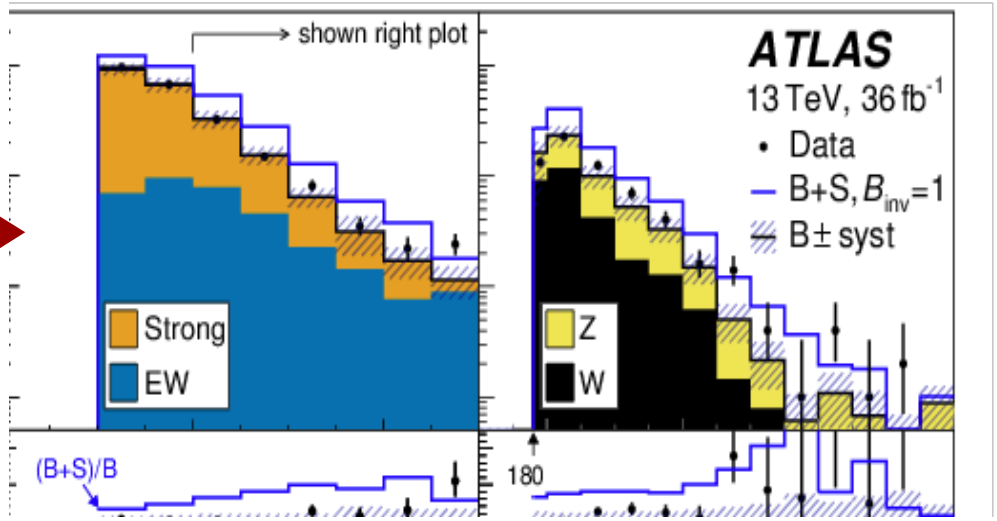
# Higgs As The Mediator

# Higgs → Invisible

If DM couples directly to the Higgs and is lighter than ~62 GeV, then H can decay into pairs of DM particles.

- VBF is currently the most sensitive channel for this at LHC.




Accepted by *Phys. Lett. B* (arXiv: 1809.06682)

Leverage VBF topology (forward jets) to discriminate against large SM backgrounds.

# Higgs → Invisible

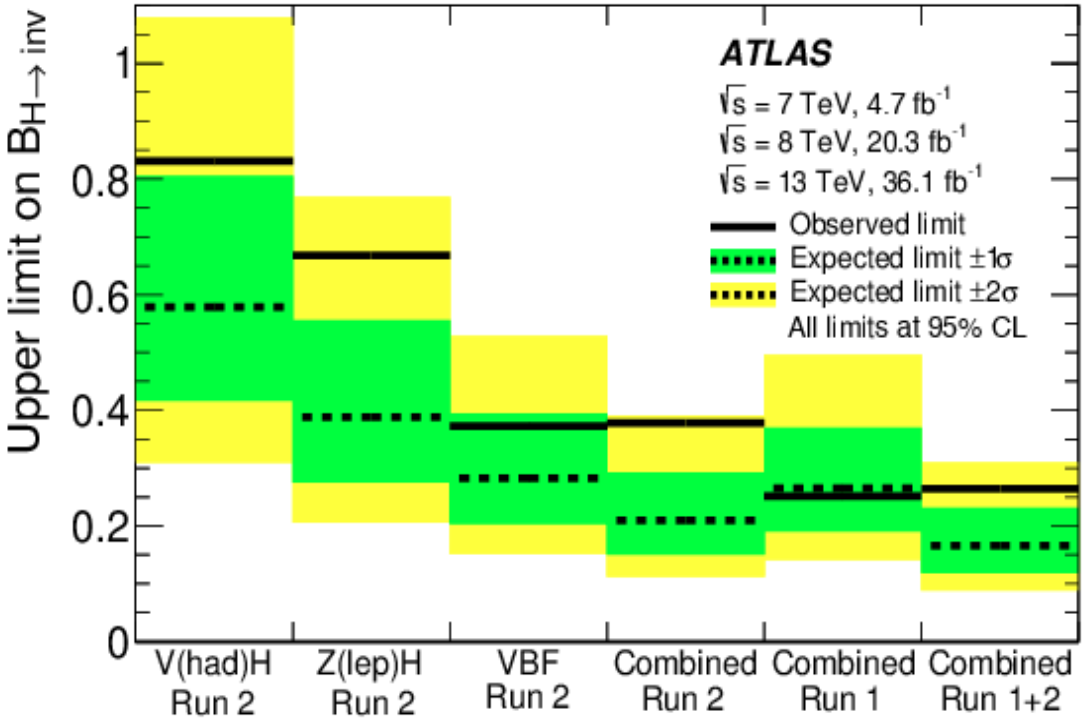
Also search using W/Z associated production.

- **New combination with Run 1 + 2015 + 2016 data results!**

$BR(H \to inv) < 26\%$ $(17^{+7}_{-5}\ \%\ \text{expected})$

Constraints weaker than Run 1 due to excesses in every Run 2 channel.

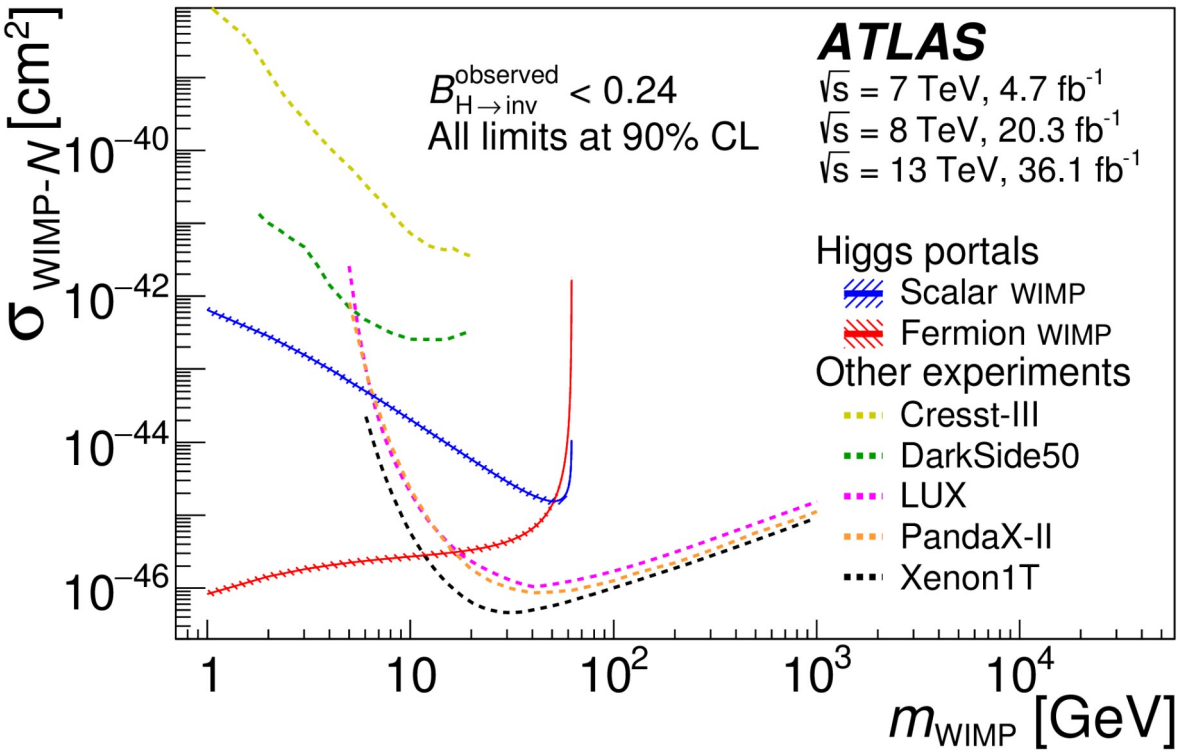
Full 140 $fb^{-1}$ analyses in the works, with final combination to follow.




Submitted to *Phys. Rev. Lett.* (arXiv: 1904.05105)

# Higgs → Invisible

**Sensitivity complements direct detection at low DM mass.**




**Note: We don't have any searches for DM over ~60 GeV with the SM Higgs as the mediator!**

# Putting It All Together

# Benchmark Models

**ATLAS's DM search program is really broad!**

- To help navigate, we've interpreted all of these in terms of a few benchmark scenarios:

| (Pseudo)scalar mediator | (Axial) vector mediator | Extended Higgs sector |
|---|---|---|
| • Neutral interaction | • Color-neutral interaction | • 2HDM + Vector |
| • Baryon-charged interaction | • Color-charged | • 2HDM + Pseudoscalar |
| • Flavor-changing interaction | | |

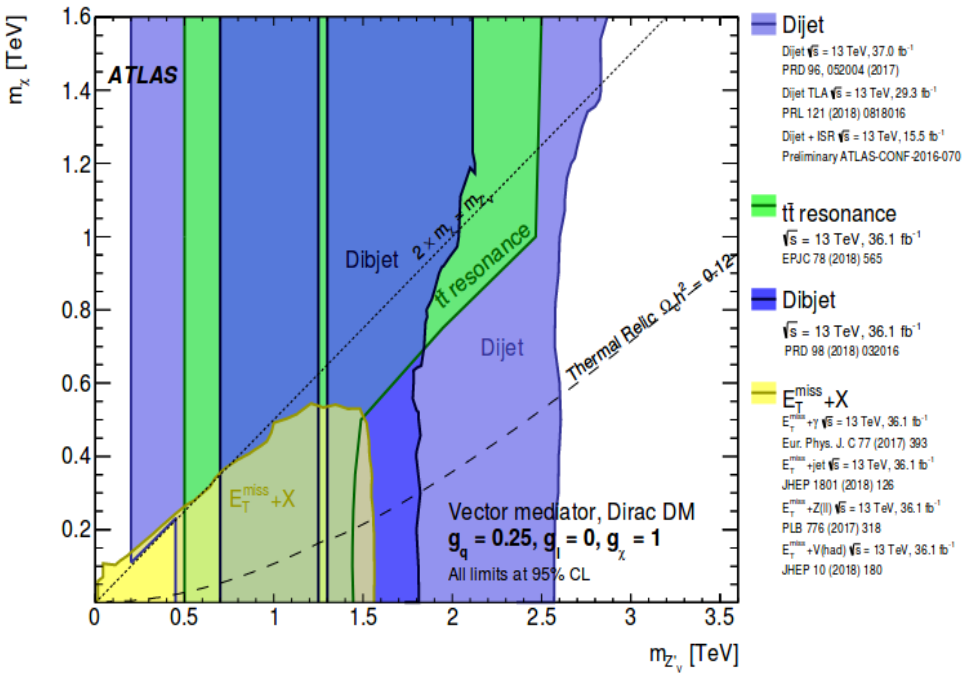
For full details, see our **new summary paper** (arXiv:1903.01400, accepted by *JHEP*)

# Vector Models

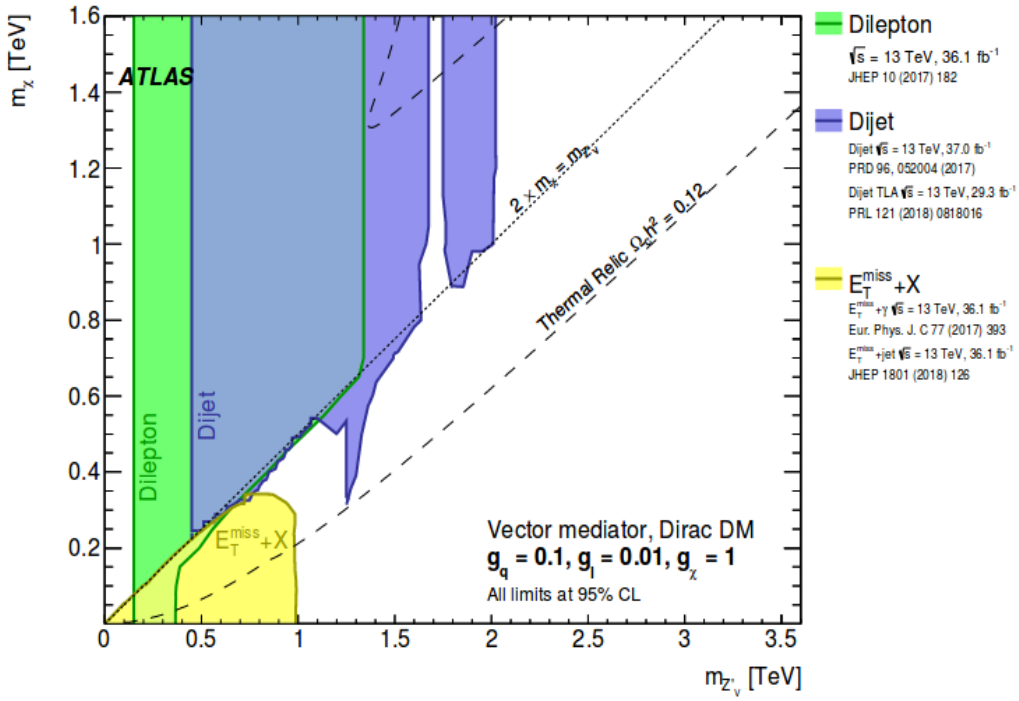
**We've re-interpreted existing searches in terms of these models.**

- Exclusion plots computed for a few representative parameter choices.

Leptophobic benchmark



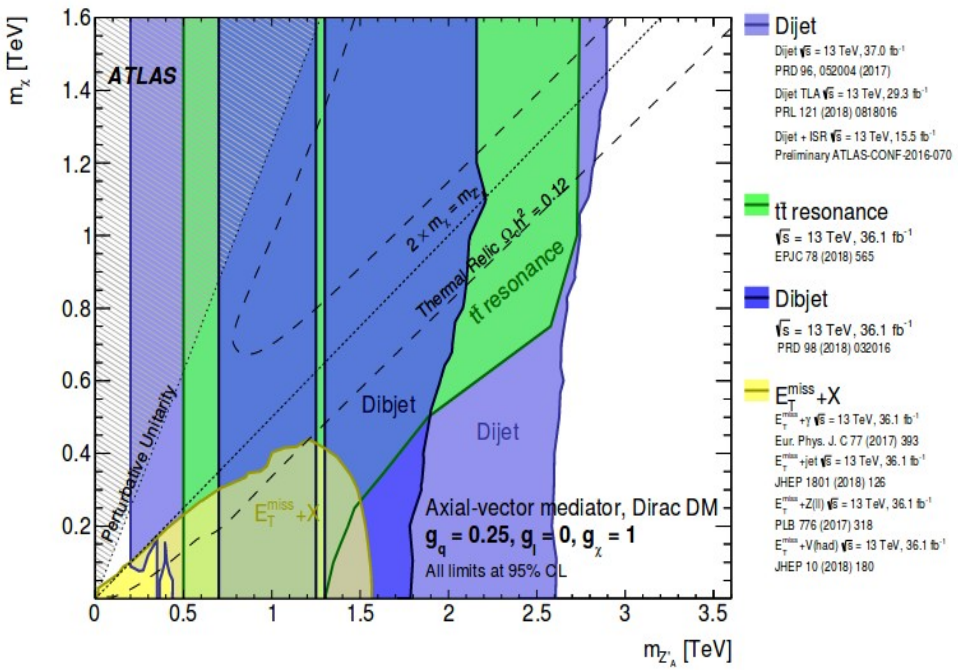

Leptophilic benchmark

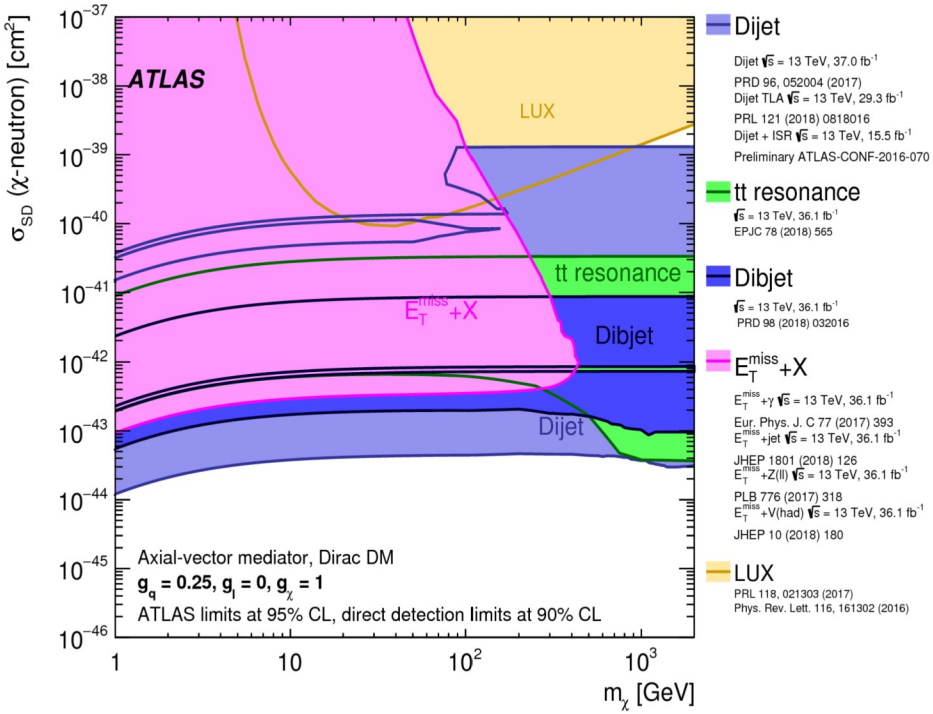


# Axial Vector Models

Collider limits generally much stronger than direct detection for spin-dependent interactions!

Caveat: comparisons are model-dependent.



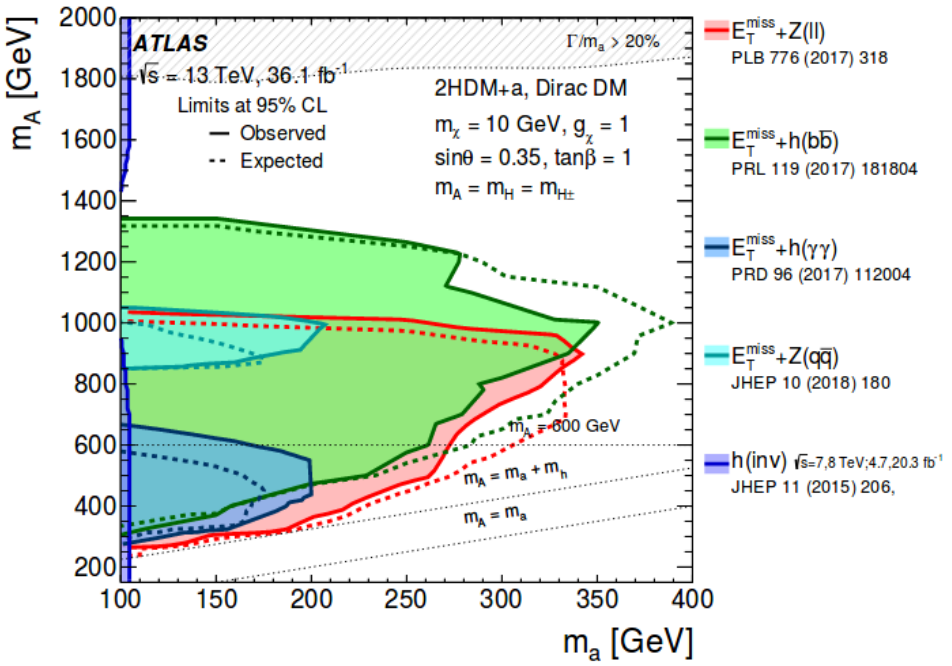



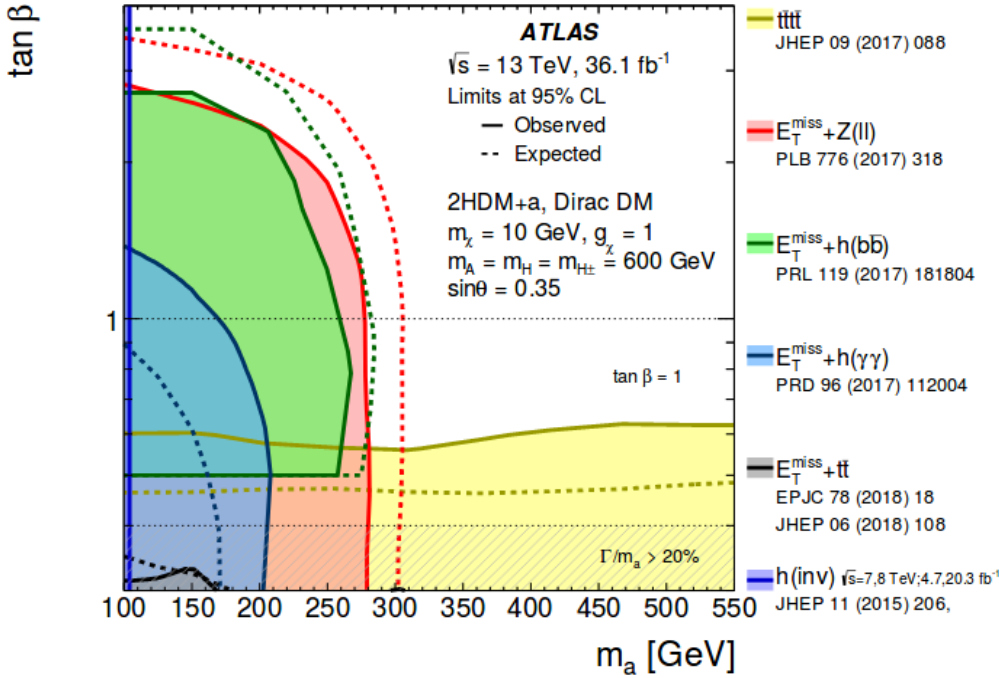

Shown here for DM-neutron interactions; protons look very similar.

# 2-Higgs-Doublet + Pseudoscalar Model

This model aims to be a little less “simplified” / more realistic.

Results in 3 new physical scalars (H, $H^+$, $H^-$), and 2 new pseudoscalars (a, A)



# Future Prospects

Many of the flagship dark matter searches are becoming systematics-limited now.

- Jet+MET, VBF H → invisible, etc.
- Taking full advantage of HL-LHC data will require improvements in reconstruction and analysis techniques (and in some cases, theoretical calculations).

A few DM searches automatically get a large benefit from statistics.

- Mainly channels which use EW or Higgs interactions (small cross sections)
- Z(→ll)H(→invisible), H(→γγ)+MET, etc.

We'll continue pursuing as broad a search program as we can through the end of the LHC lifetime.

- Have an interesting idea we haven't covered? Let us know!

# Summary

Collider searches provide complementary coverage with respect to other methods (like direct detection).

ATLAS has a very broad dark matter search program!

- Includes searches for DM production as well as for mediators.
- Recently beginning to include less minimal models in our interpretations.

We recently released a new summary paper combining everything into a few benchmark interpretations.

- Intended as the definitive reference for dark matter at ATLAS.

We're continuing to produce new results with the Run 2 dataset!