Dark Matter searches with the ATLAS Detector

Lomonosov 2021

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on behalf of the ATLAS collaboration

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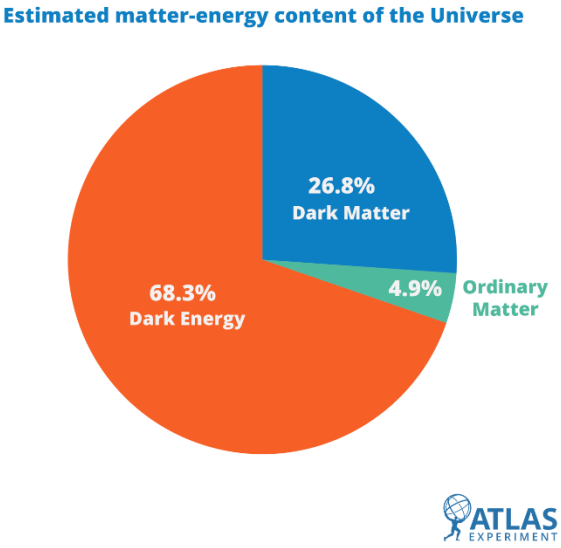
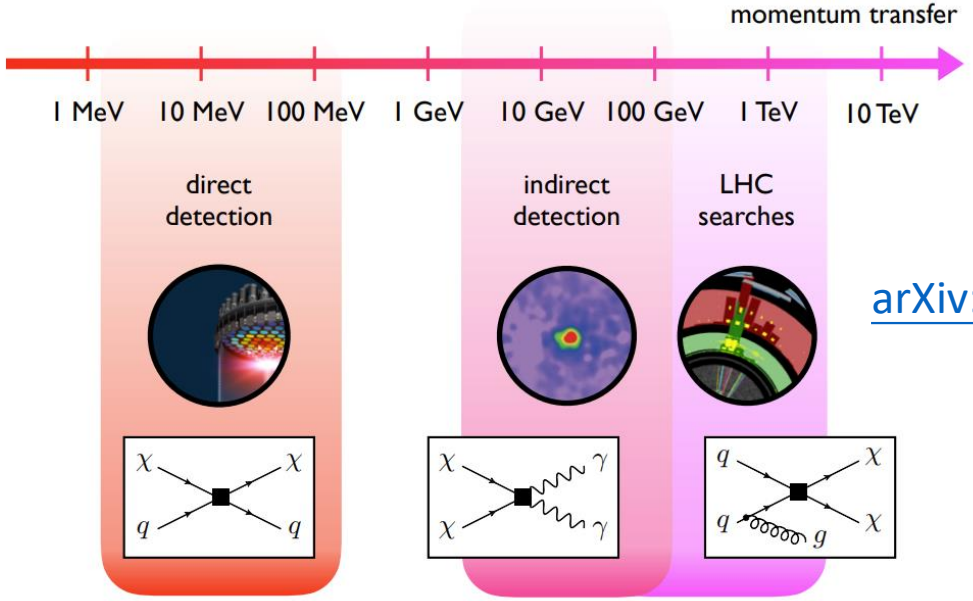
ATLAS EXPERIMENT

UNIVERSITY OF MICHIGAN

Introduction

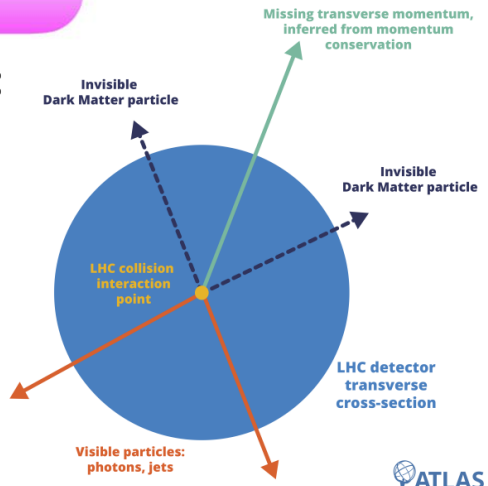
- Empirical evidence of DM from astrophysical observations at different scales
  - Most of the matter content of the universe is transparent
  - Appealing scenario: DM is a Weakly Interacting Massive Particle





arXiv:1810.09420

- **Assuming DM-SM weak interaction enables different searches:**
  - direct detection, nuclear recoils from DM-nuclei scattering
  - indirect detection, products from DM annihilation
  - colliders, DM production in high-energy collisions
- **DM production at colliders**
  - No direct trace in the detector, but could create a pT imbalance (MET) ⇒ associated production of **dark matter** and SM particles



Outline

- **Overview of Dark Matter models**
- Recent Dark Matter searches *
  - Jet + MET
  - H(bb) + MET
  - H(γγ) + MET
  - Z(ll) + MET
  - tW/tj + MET
- Combinations of Dark Matter searches
  - s-channel mediator
  - 2HDM + a
  - Higgs portal

*Caveat: Only a small selection of full Run 2 analyses presented today

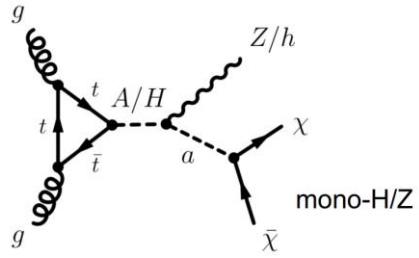
Overview of dark matter models

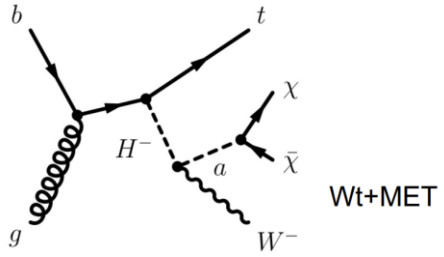
For DM searches, **theoretical benchmarks** are necessary to sharpen the regions of interest

- To **optimize searches** and characterize a possible discovery
- Define a theoretical framework for **comparison with non-collider results**

Simplified s-channel mediator model

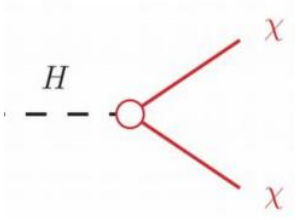
Small set of free parameters. Interesting interplays between Mono-X searches and resonance searches.





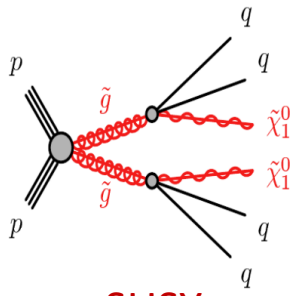
2HDM+a

Two-Higgs doublet extensions with a pseudo-scalar a. Gauge-invariant. Richer kinematics + phenomenology



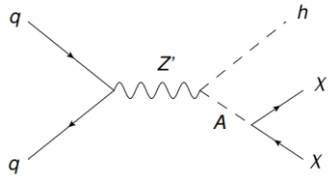
Higgs portal models

Search for enhancement of invisibly decays which increase BR(H→inv) (~0.1% in SM).



SUSY

Simplified R-parity conserving model



2HDM+Z'

Two-Higgs doublet extensions with a vector Z'

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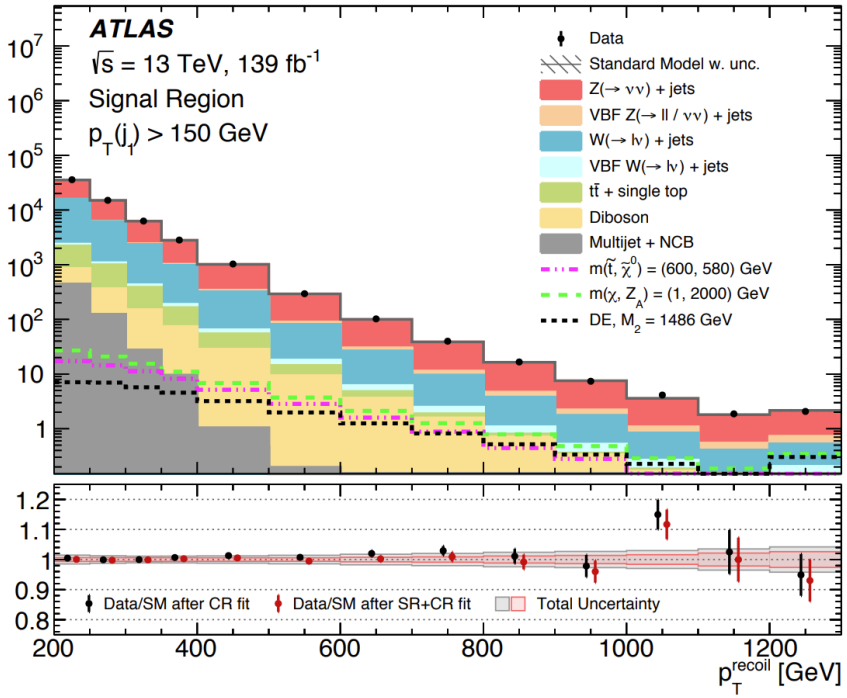
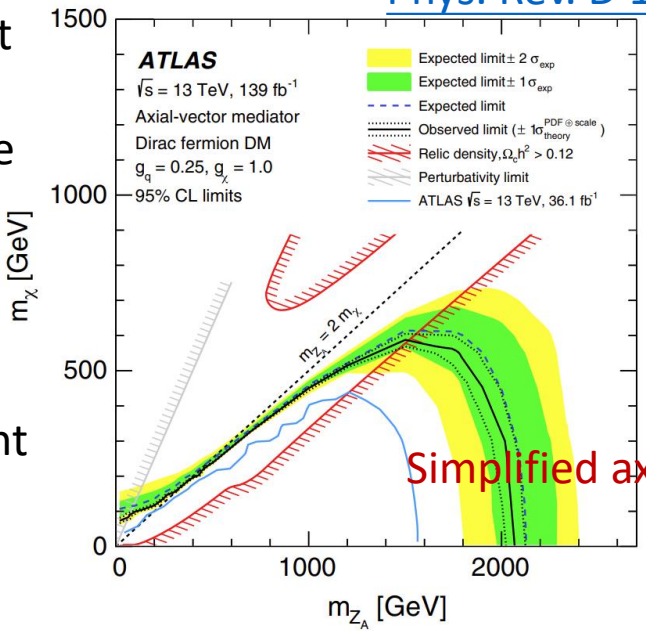
  - s-channel mediator
  - 2HDM + a
  - Higgs portal

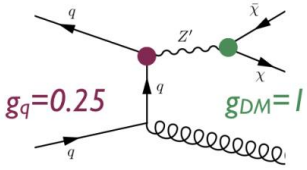
Jet + MET

Phys. Rev. D 103 (2021) 112006

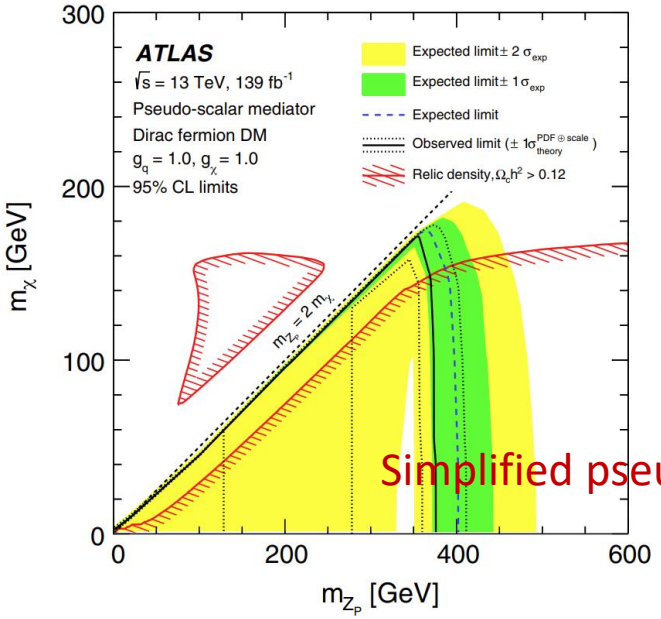
- **Selection:** MET> 200 GeV, $\Delta\Phi$(jet, MET) cut to reduce the multijet contribution.
- Dedicated control regions (**CRs**) to estimate *V+jets, ttbar* and single-top processes.
- **Results:** simultaneous fit to the p_T^{recoil} (hard component of MET) distributions in SR and CRs.
  - Uncertainties reduced to a few percent level in each bin for SM predictions.

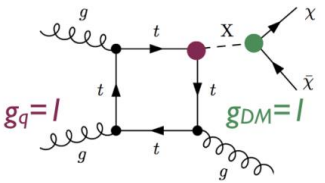






Simplified axial-vector model



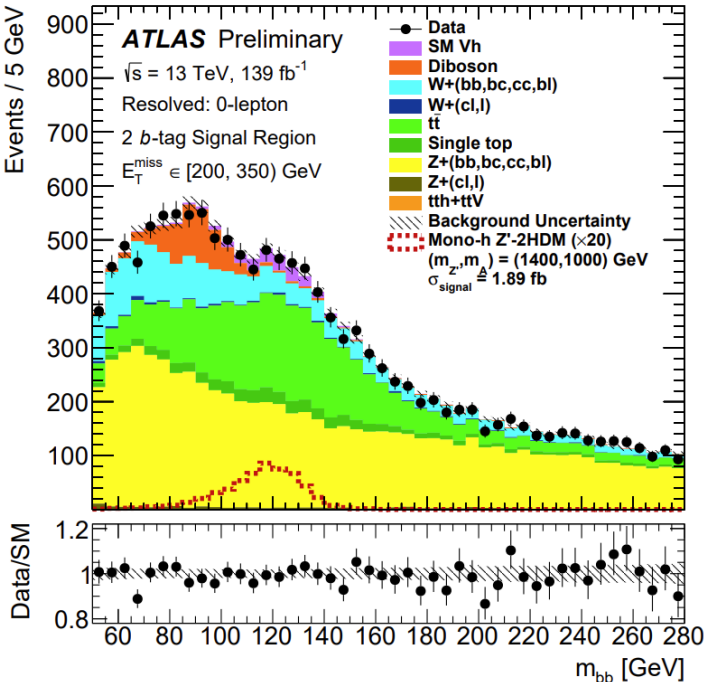


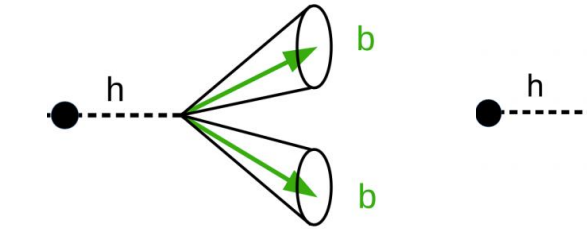
Simplified pseudo-scalar model

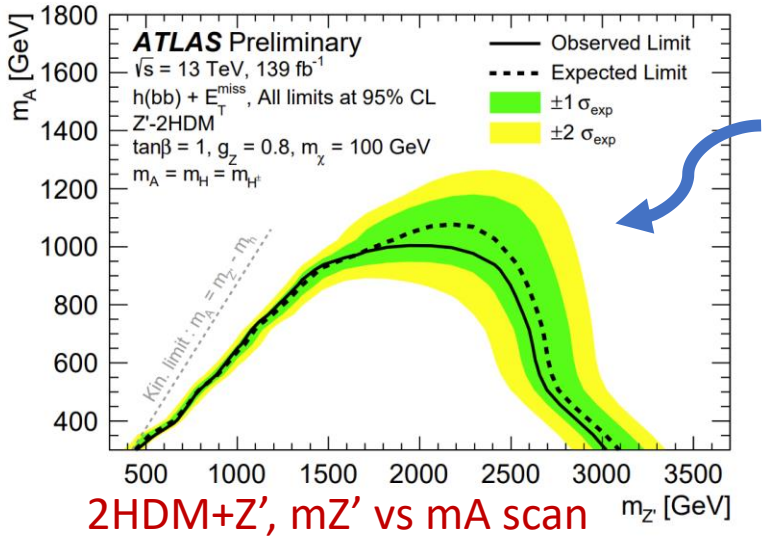
Mono-H(bb)

- Associated production of Dark Matter and a Higgs boson ⇒Larger production rate than ISR-based production mode.
- Both resolved and merged topologies with different *H→bb* reconstructions employed.
- **Results:** simultaneous fit to the Higgs mass distributions in SR and CRs.

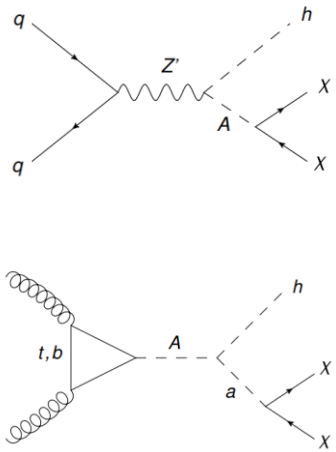
ATLAS-CONF-2021-006

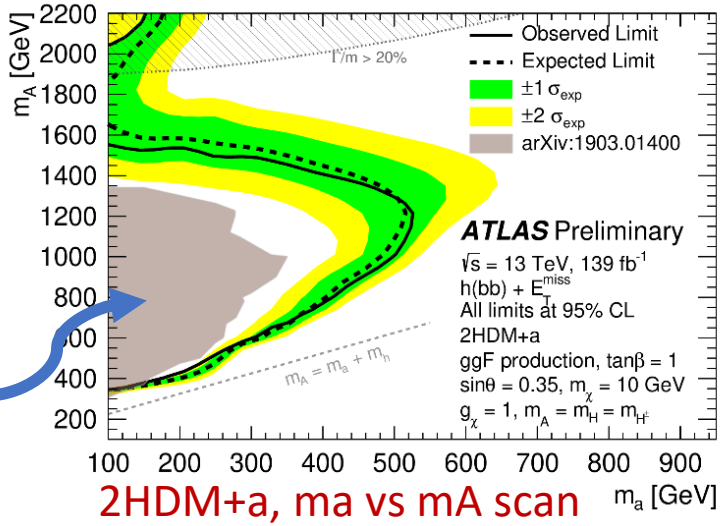






2HDM+Z', mZ' vs mA scan





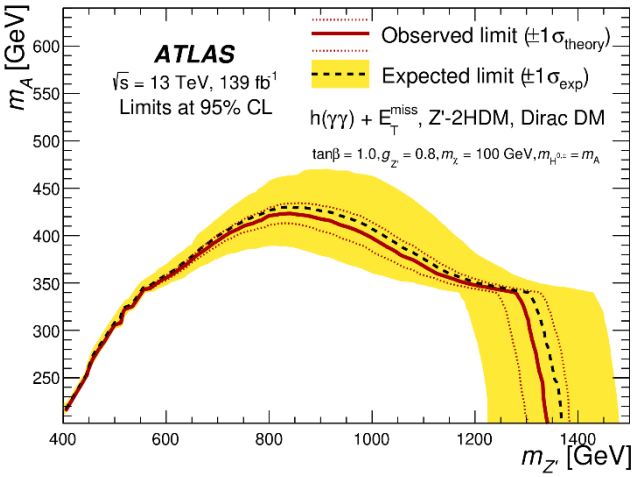
2HDM+a, ma vs mA scan

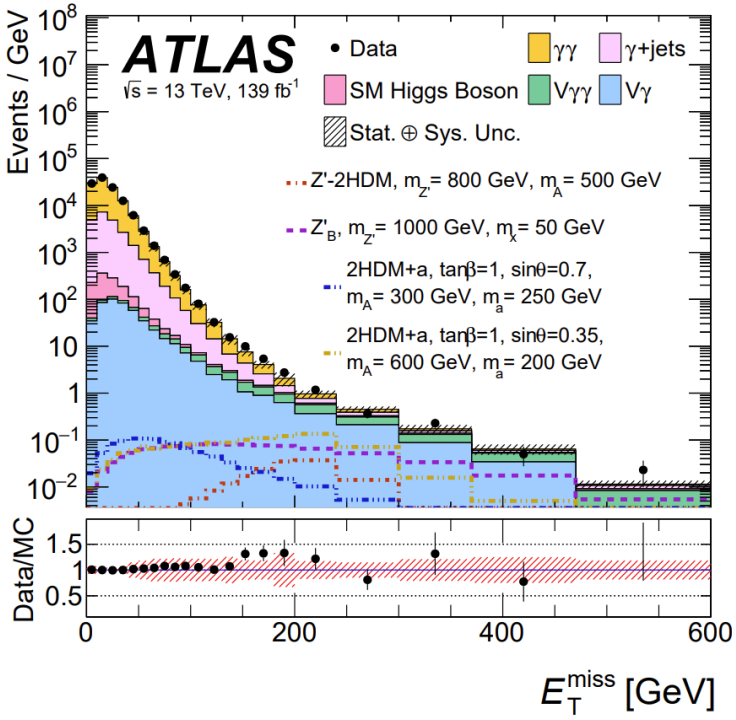
Mono-H(γγ)

- Comparing to mono-H(bb), **triggered using the photon pair**, allowing for much lower and better resolved MET in the event.
- S+B fits performed in analysis categories simultaneously.

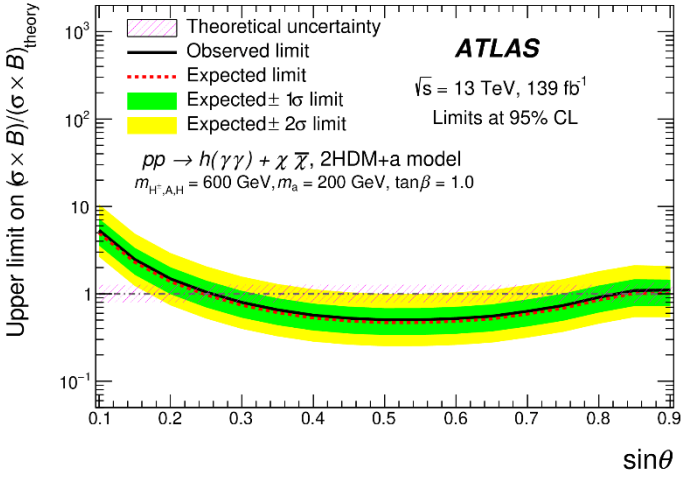
arXiv:2104.13240

2HDM+Z', mZ' vs mA scan





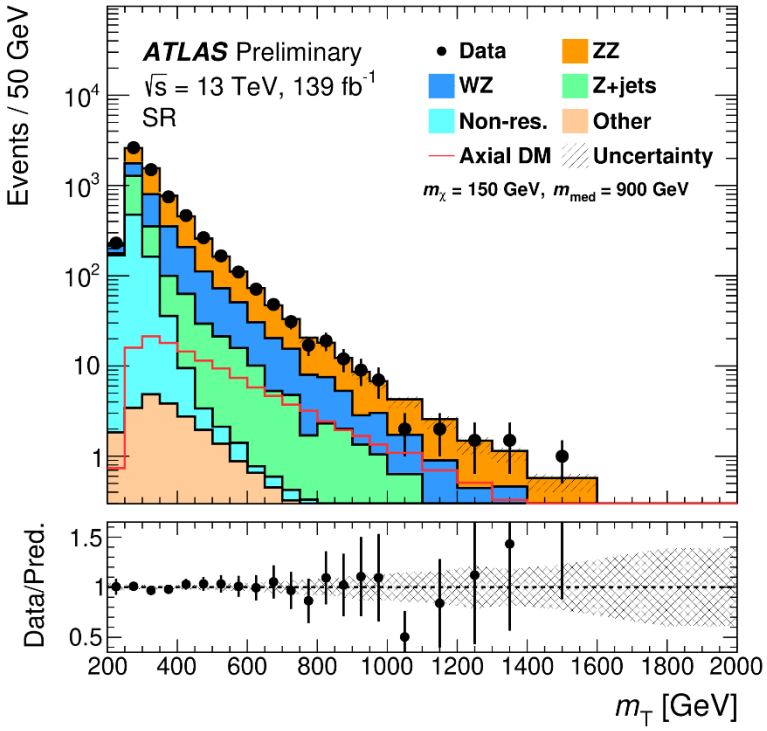
2HDM+a, sin θ scan



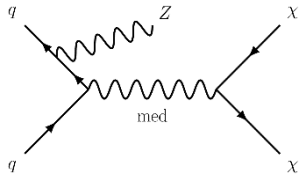
Mono-Z(ll)

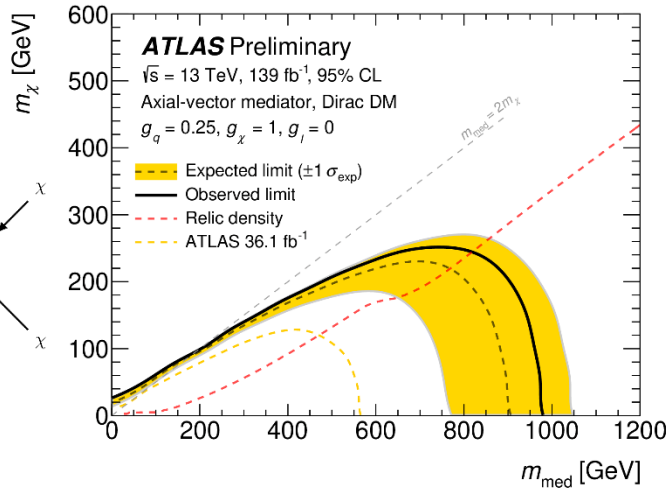
- Select events with a **leptonically-decaying Z against significant MET.**
- **Results:** simultaneous fit in SR and CRs.
- Observed BR(H→inv) < 0.18 @ 95% C.L.

ATLAS-CONF-2021-029

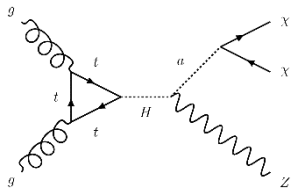


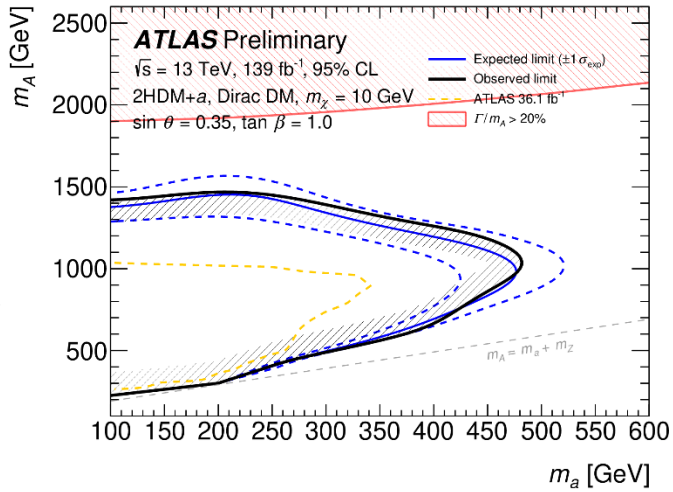
Simplified axial-vector model





2HDM+a, ma vs mA scan

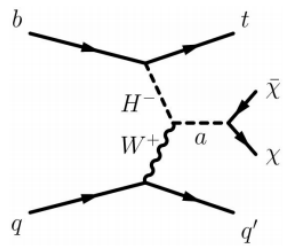




tW/tj + MET

- Search for dark matter in the context of **2HDM+a** arXiv:2011.09308

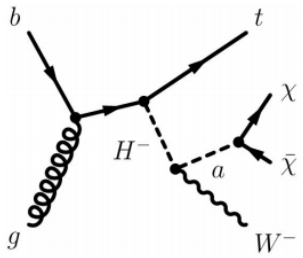
t-channel



tj_{1L}

- 1 isolated lepton
- N_{jets} ϵ [1,4]
- $N^{b\text{-jets}}$ ϵ [1,2]
- MET > 200 GeV
- BDT trained to improve sensitivity

tW-channel

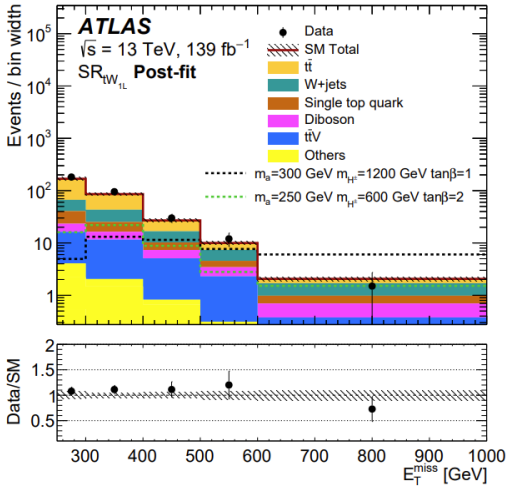


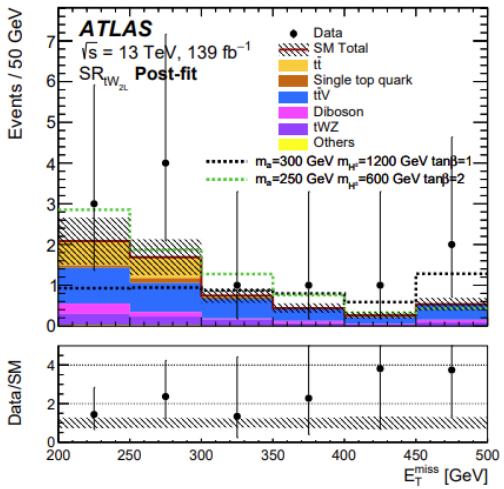
tW_{1L} (1 W decays leptonically)

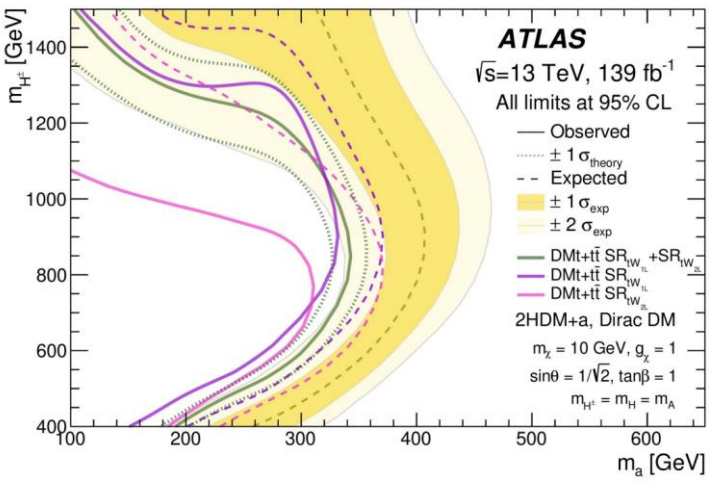
- 1 isolated lepton
- $N_{jets} \geq 3$
- $N_{b\text{-jets}} \geq 1$
- MET > 250 GeV

tW_{2L} (2 Ws decay leptonically)

- 2 OS isolated leptons
- $N_{jets} \geq 1$
- $N_{b\text{-jets}} \geq 1$
- MET > 200 GeV







2HDM+a, ma vs mH± scan

Outline

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- Recent Dark Matter searches
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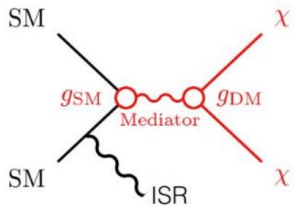
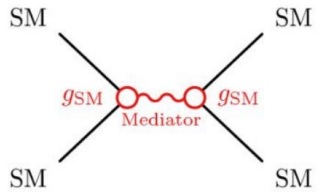
- **Combinations of Dark Matter searches**
  - **s-channel mediators**
  - **2HDM + a**
  - **Higgs portal**

S-channel – spin 1 mediators

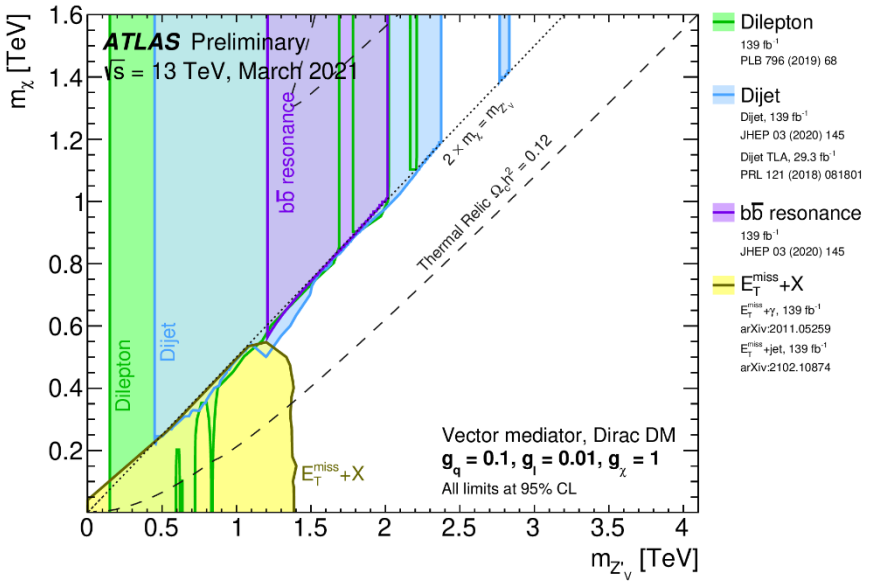
- Searches use simplified models with a **spin-1 particle** as the mediator
  - **Vector** and **axial vector mediator**
- Resonance searches and MonoX searches with sensitivities varied as a function of different coupling values of the model.



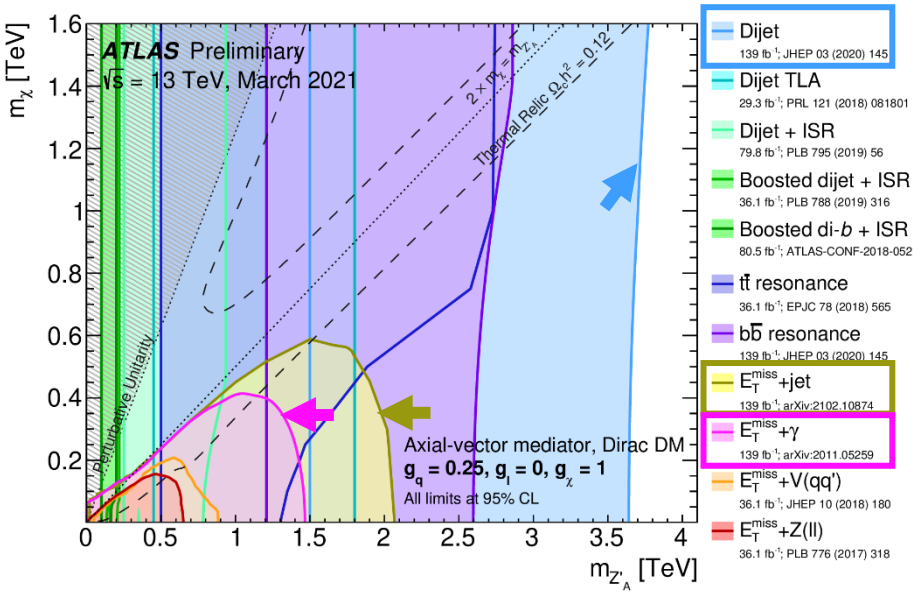
MonoX searches



Resonance searches



Simplified vector model



Simplified axial-vector model

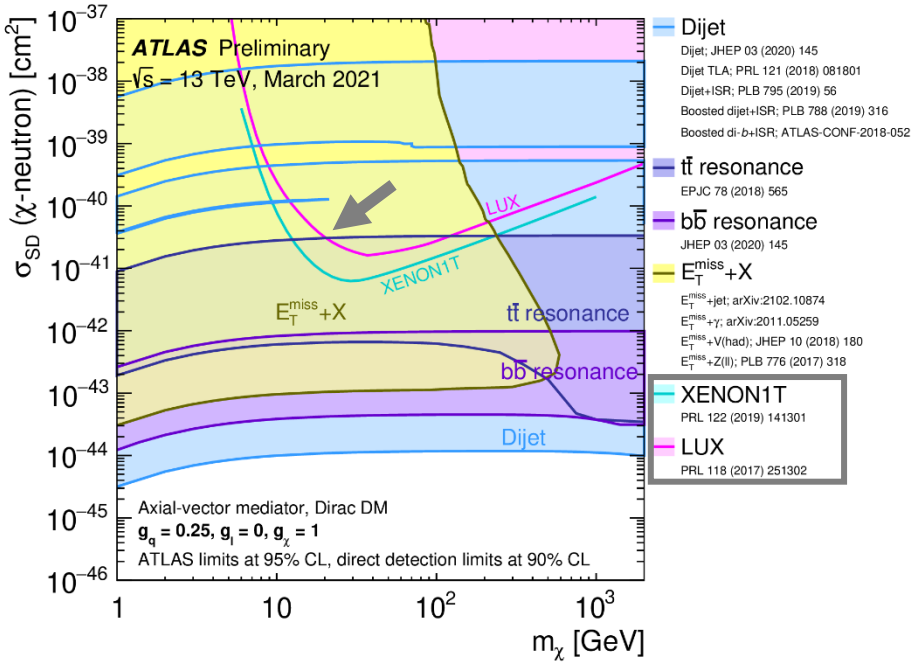
- Analyses dominating the sensitivity are:
  - **MET signatures**: Mono-jet and mono-photon
  - **Non-MET signatures**: High-mass di(b)-jet resonances, TLA di-jet, Dijet+ISR (boosted and resolved), Dilepton resonances

ATL-PHYS-PUB-2021-006

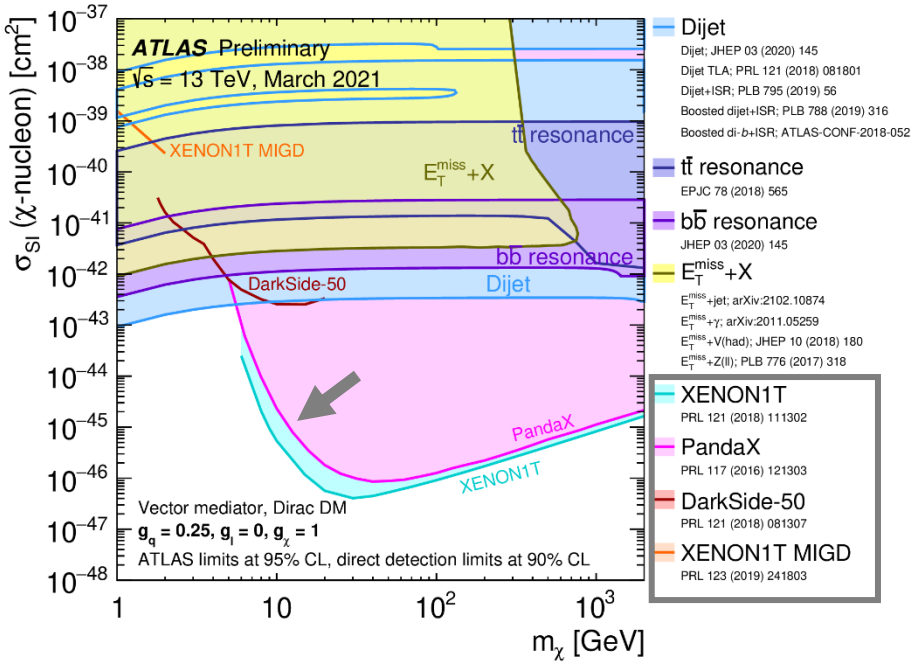
Compare to direct detection

Results translated into spin-dependent and spin-independent DM-nucleon elastic scattering cross-section limits ⇒ compared to direct searches

ATL-PHYS-PUB-2021-006



Axial-vector mediator leads to a SD interaction



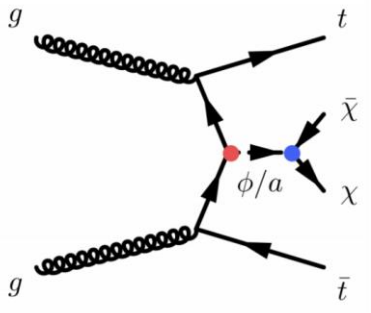
Vector mediator leads to a SI interaction

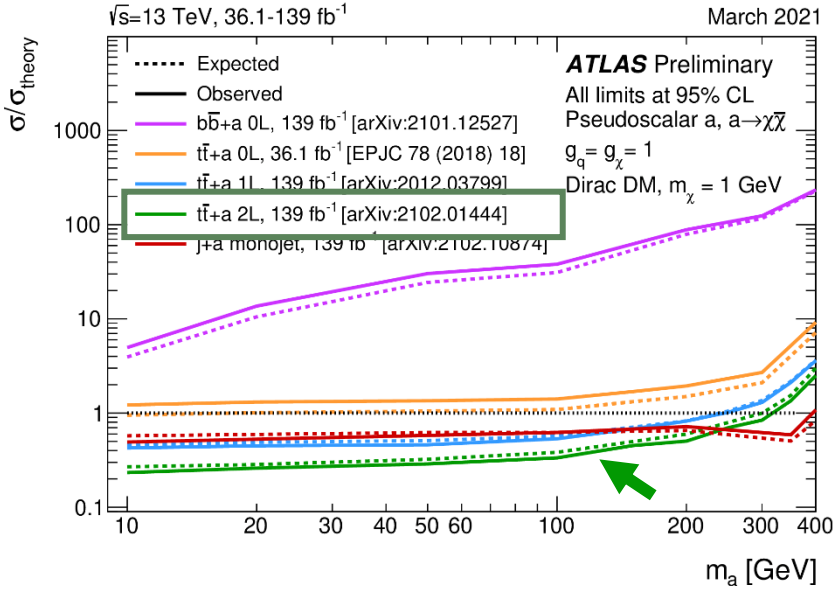
- ATLAS results are particularly competitive for low DM masses.
- Translation is **model-dependent**. LHC limits hold exclusively for considered models.

s-channel – spin 0 mediators

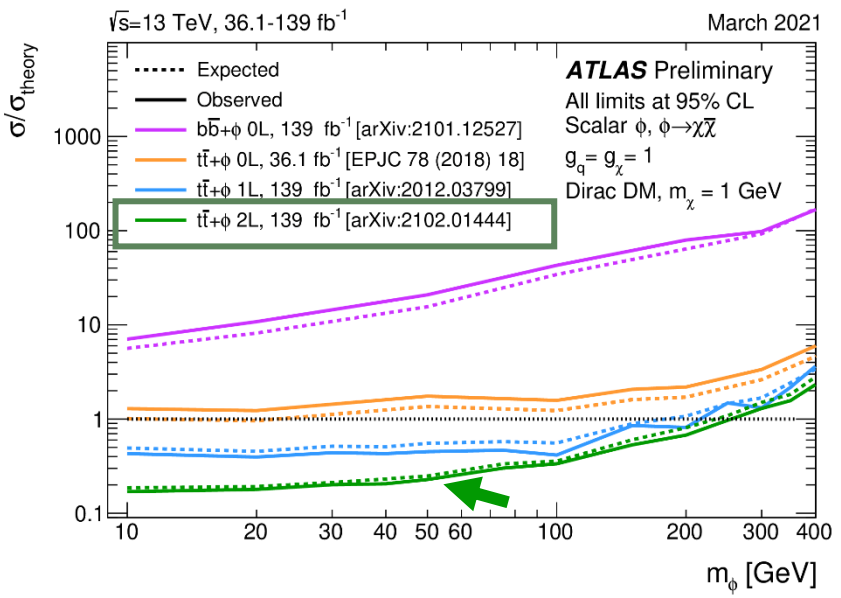
ATL-PHYS-PUB-2021-006

- Searches with **scalar (ϕ)** and **pseudoscalar (a)** as the mediator
  - Dark Matter production via (pseudo)scalar mediator in association with **HF**
  - Mediator decays into two dark matter particles X, with MET signature.
- Dominated by t/tt/bb+MET analyses, mono-Jet, and tt resonances.
- The strongest limits are placed by **tt+MET 2L** final state.





Simplified pseudo-scalar model



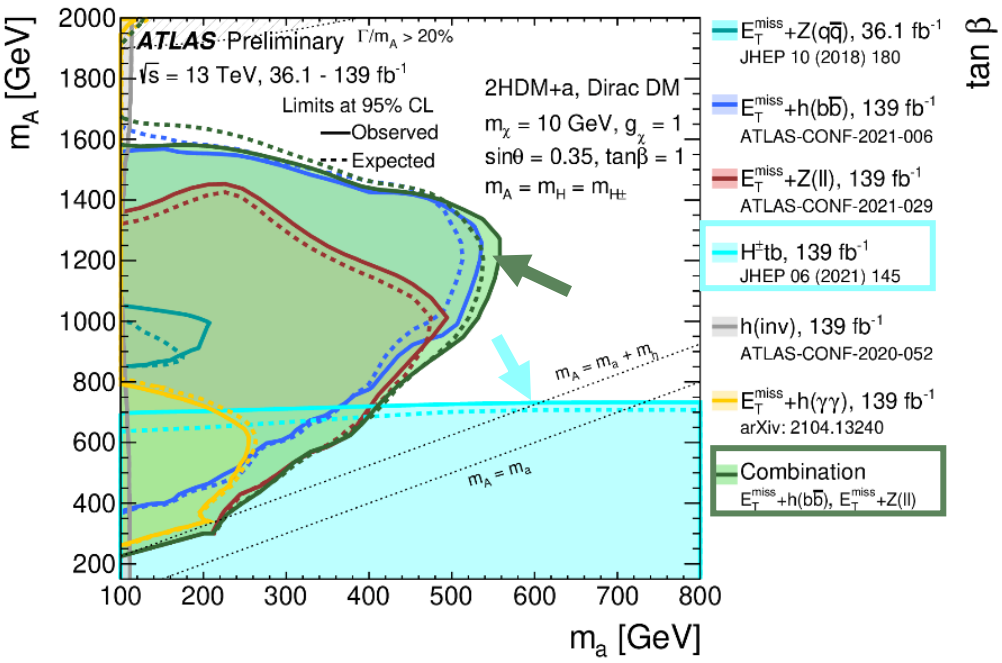
Simplified scalar model

Combination of 2HDM+a

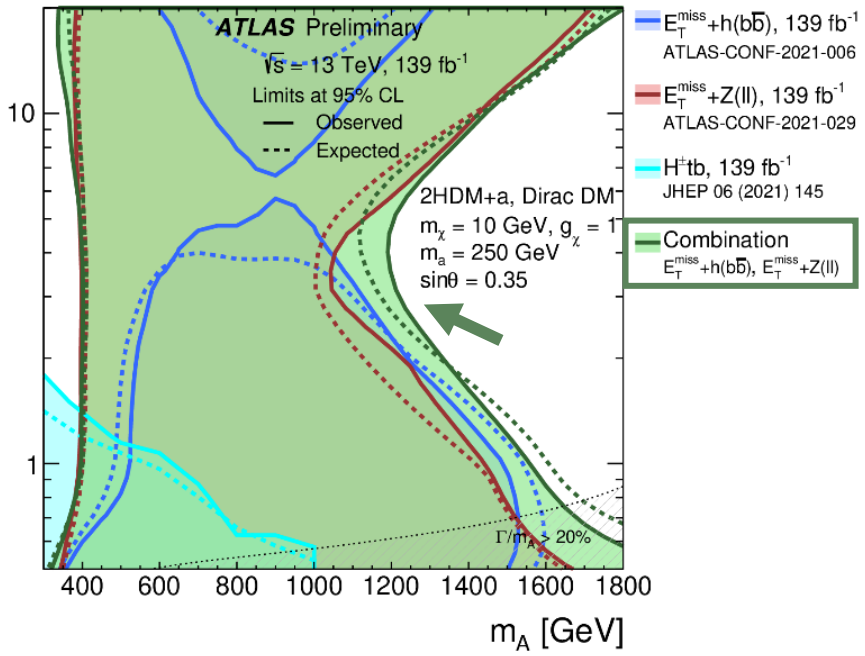
- Most sensitive searches updated to full Run 2 luminosity
- Statistical combination of MET+h(bb) and MET+Z(ll) analyses, which improves the sensitivity.
- Significant complementarity from different channels.

ATLAS-CONF-2021-036

ma vs mA scan



mA vs tanβ scan



Combination of 2HDM+a

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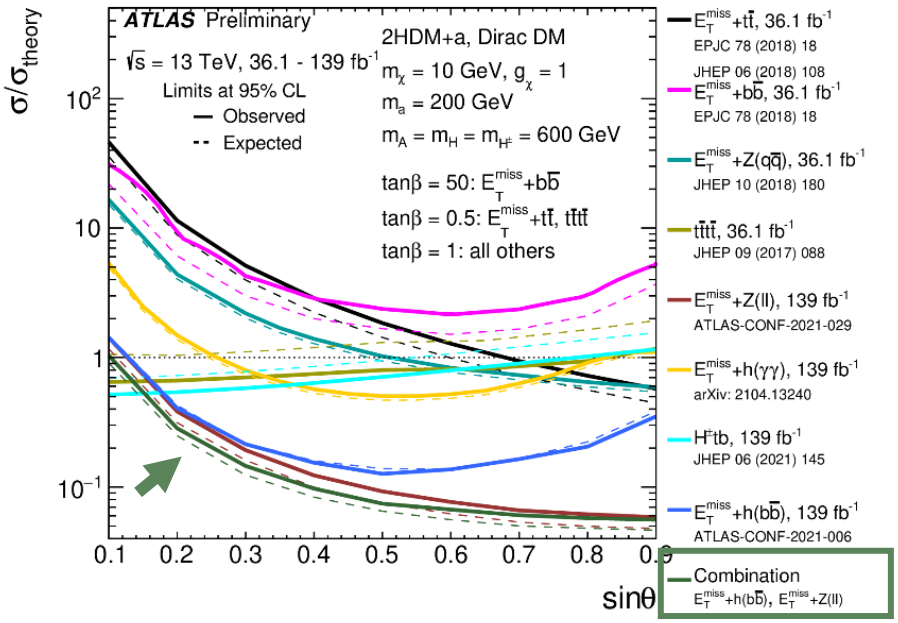
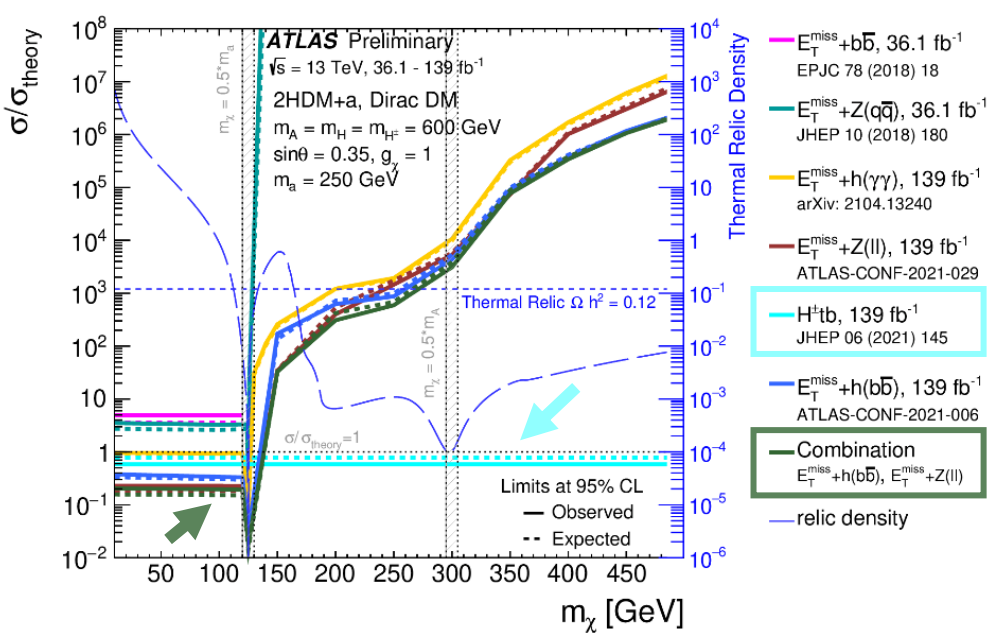
ATLAS-CONF-2021-036

Sinθ scan

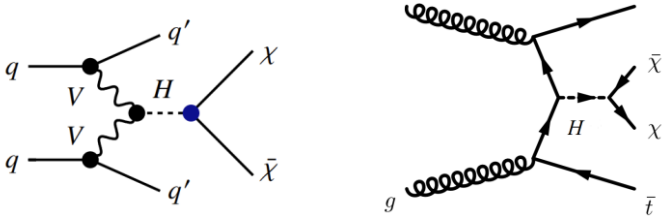


mχ scan



Higgs→invisible combination

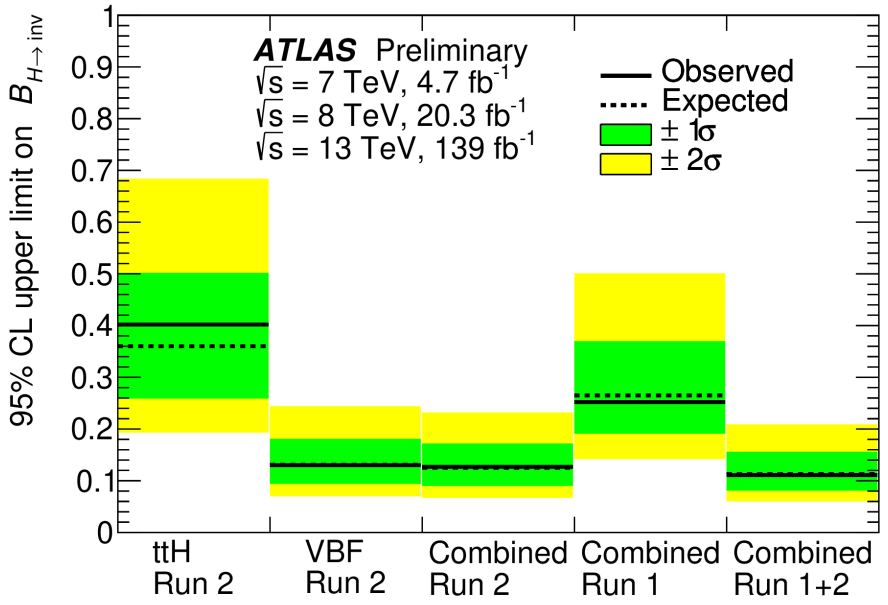
- Combining direct measurements to probe with higher sensitivity ⇒ Statistically combining **VBF+MET**, **tt+MET (tt2L + tt0L),** and **Run1 combination results**

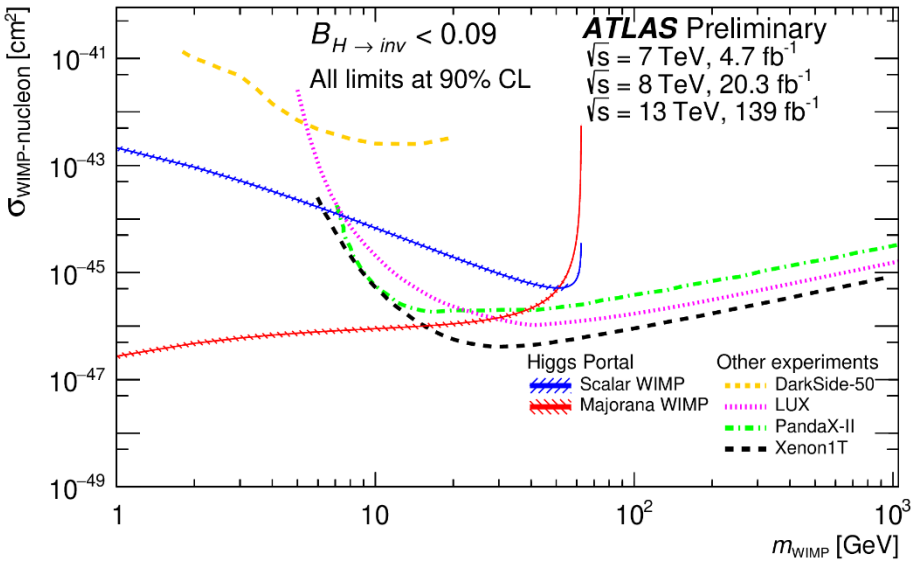


- Observed BR(H→inv) < 0.11 @ 95% C.L. (~0.1% in SM).
- Assuming DM particles are either scalar or Majorana fermions ⇒ Translate results into a DM-nucleon elastic scattering cross-section limit.
- **Significant complementarity** between LHC and direct detection experiments

- A preliminary combination ⇒ More results such as *Z(ll)*+MET, VBF+γ+MET to be added to the **final Run 2 combination.**

ATLAS-CONF-2020-052





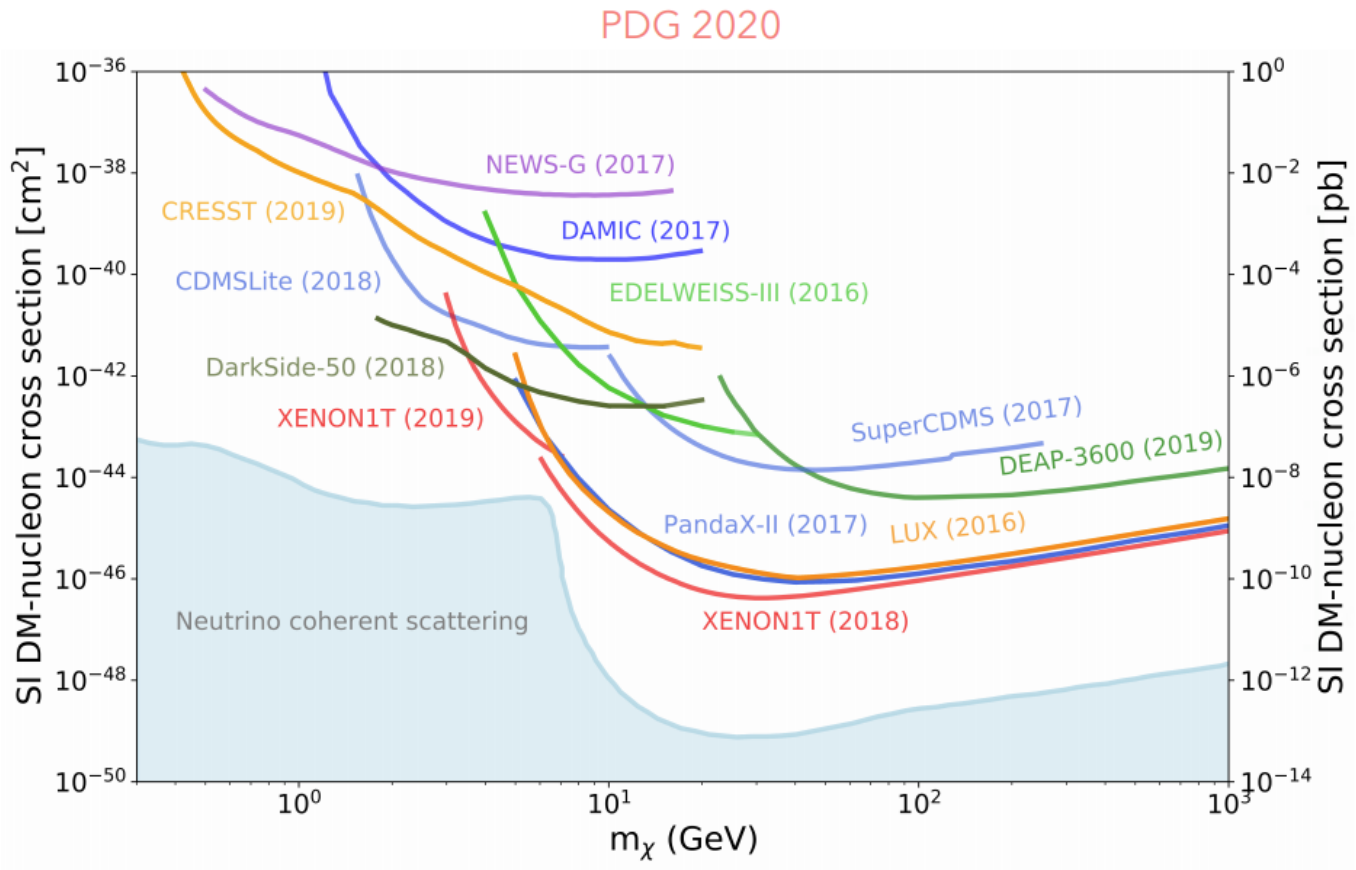
Summary

- A large number of searches for DM candidates has been performed by ATLAS. Selected full Run 2 searches and combination analyses presented.
  - Interpretation in view of **many different DM models**.
  - Complementarity from **different signatures** reached.
  - Complementarity with **non-collider searches** observed.
- There are still many more ATLAS full Run 2 results to be expected. Stay tuned for updates!

Thanks

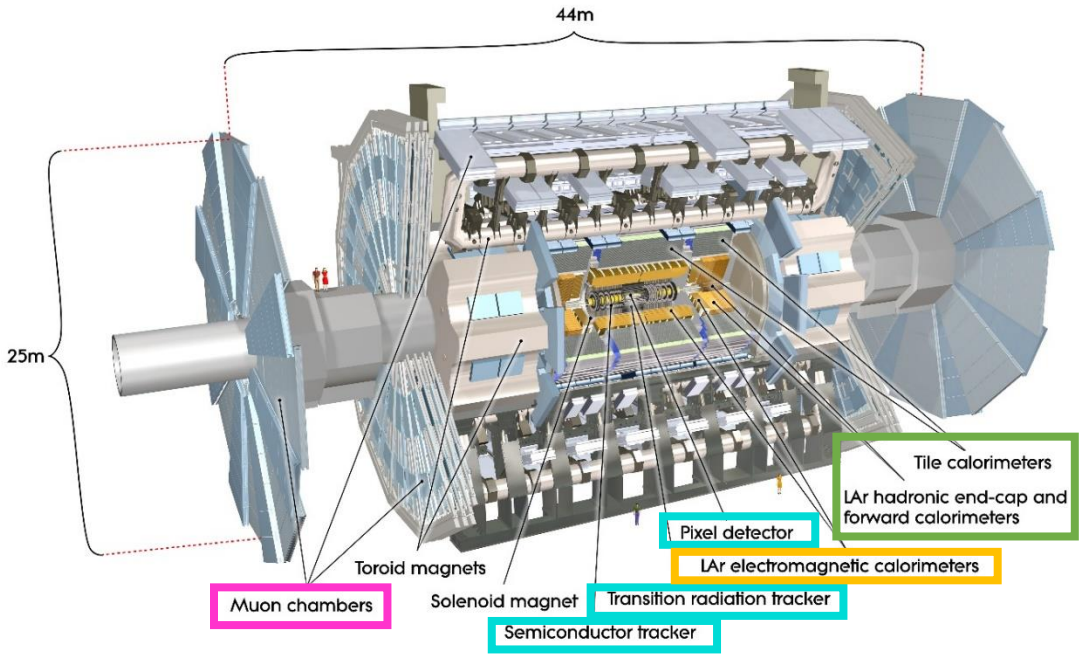
Backup

Direct detection experiments

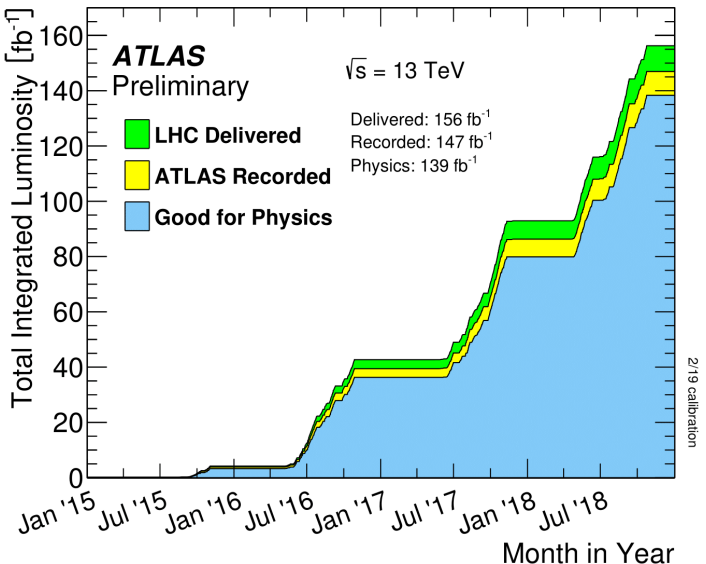


ATLAS Run 2 dataset

- **Solenoid Magnet**: 2T
- **Toroid Magnets**: 0.5-1T



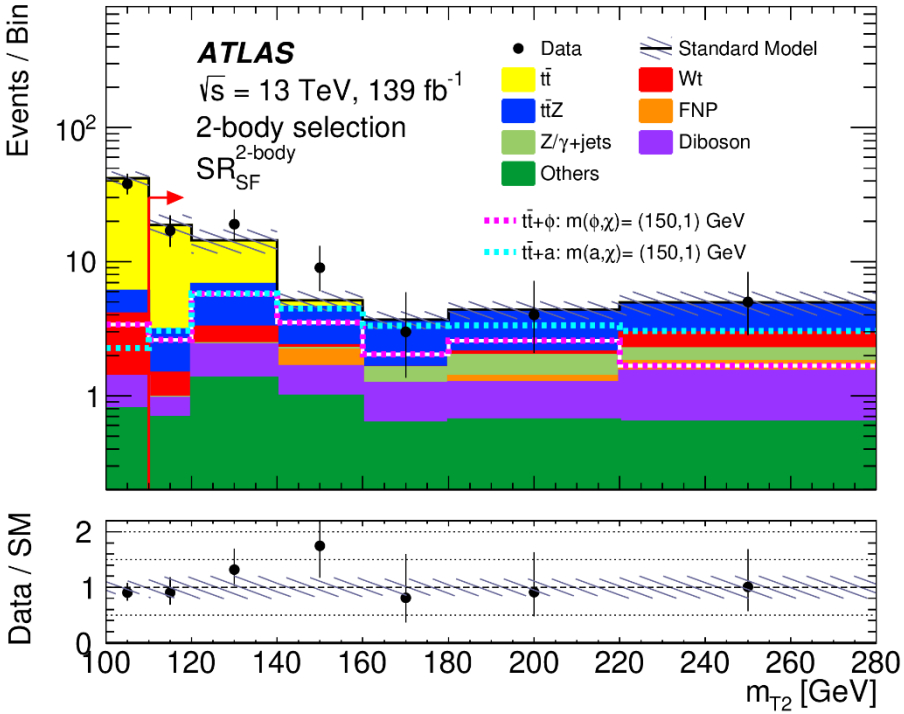
- **Inner detector** (|η|<2.5): Precise tracking and vertexing, e/π separation.
- **EM calorimeter** (|η|<3.2): e/γ trigger, identification and measurement.
- **Hadronic calorimeter** (|η|<4.9): Trigger and measurement of jets and E_T^{miss}.
- **Muon Spectrometer** (|η|<2.7): Muon trigger and tracking.

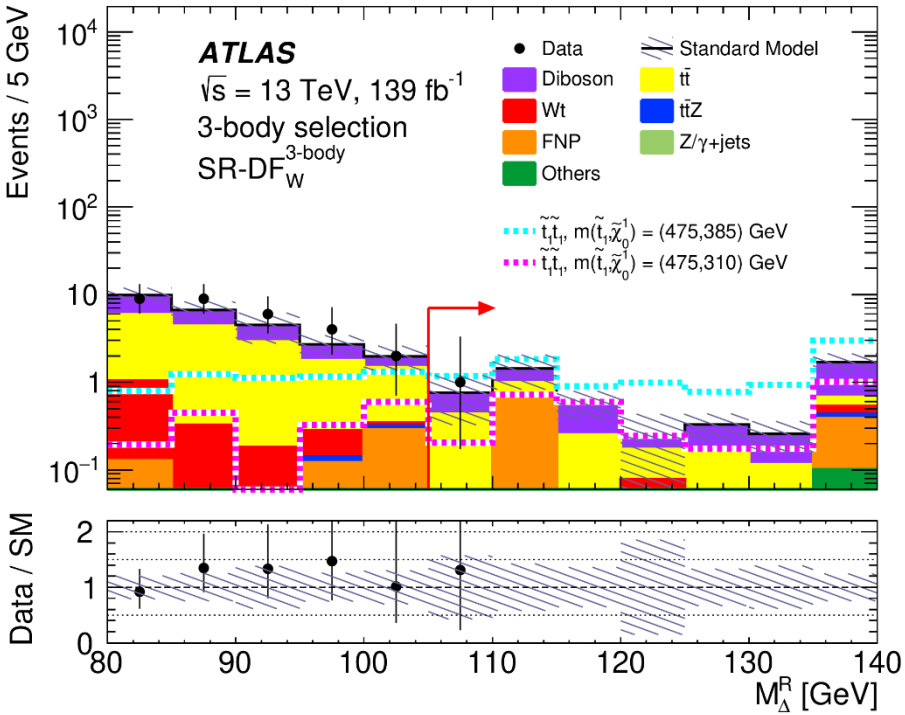


Large dataset collected by ATLAS in Run 2 (2015-2018) with 139 fb^{-1} integrated luminosity

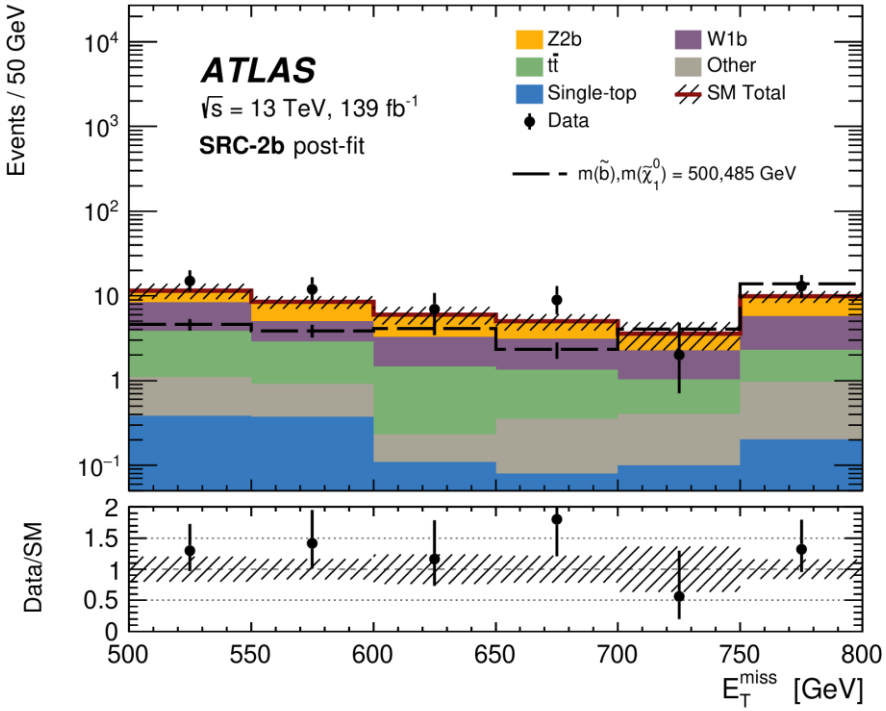
ATLAS public results

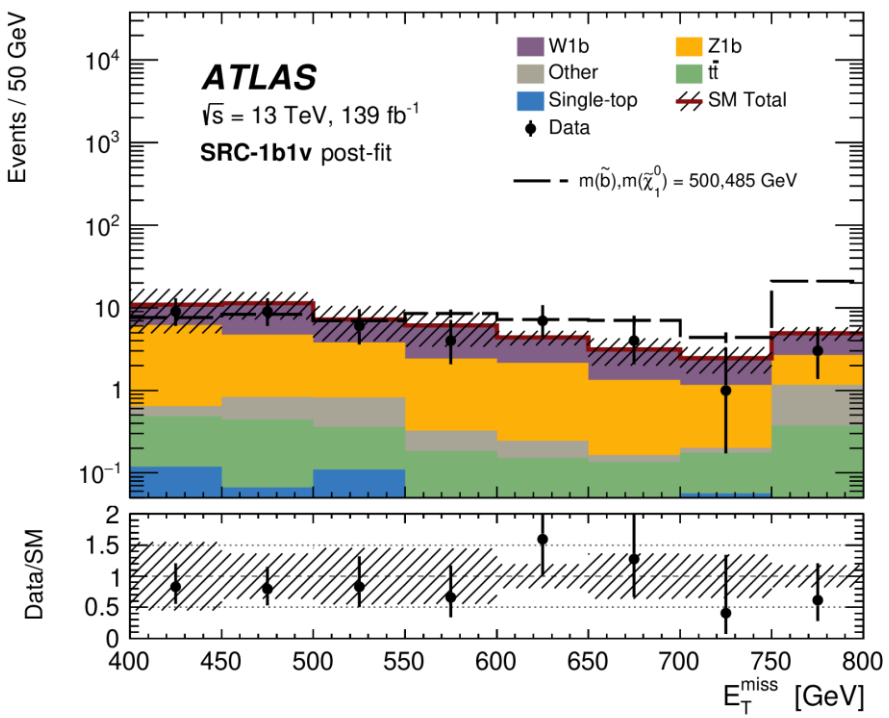
tt+MET 2L SR distributions





bb+MET SR distributions





Mono-H(γγ) selection/ compare to mono-H(bb)

- Trigger selection: diphoton trigger with p_T thresholds of 35 and 25 GeV
- $p_T/m_{\gamma\gamma} > 0.35$ and 0.25 for leading and subleading photon
- Lepton veto
- $MET > 90$ GeV
- $m_{\gamma\gamma} \in (105,160)$ GeV
- $\Delta MET < 30$ GeV
  $(MET_{diphoton} - MET_{hardestVertex})$