

Searches for Dark Matter with the ATLAS detector.

Blois 2022:

33rd Rencontres de Blois

"Exploring the Dark Universe"

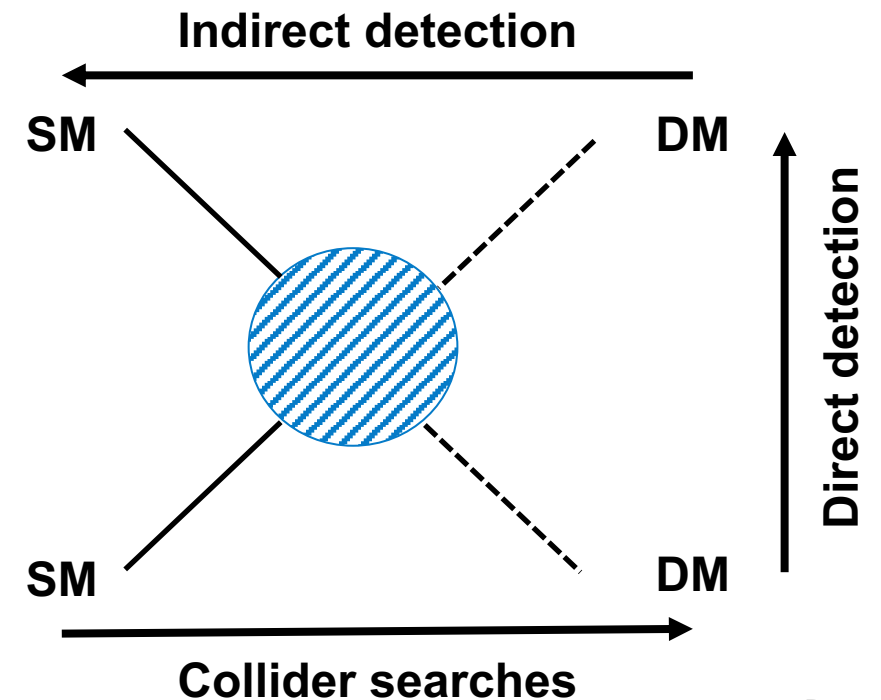
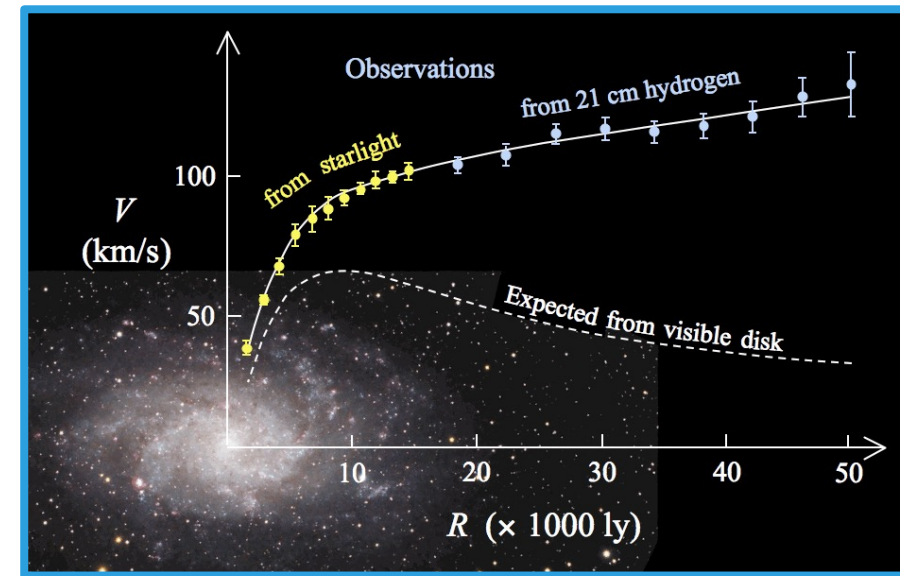
Marco Rimoldi on behalf of the ATLAS Collaboration
25th May 2022

HELMHOLTZ



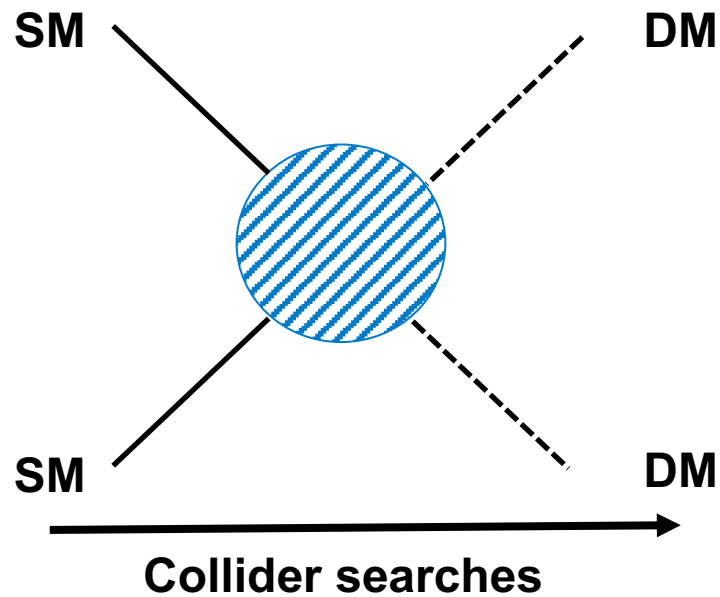
Dark Matter puzzle

- Longstanding evidence for **Dark Matter (DM)** from astronomical observations and gravitational effects.
- One of the proposed and most interesting DM candidates is a **Weakly Interactive Massive Particle (WIMP)**
- Why Dark Matter searches at colliders?
 - Directly probe production mechanism
 - Complementary to direct and indirect detection searches

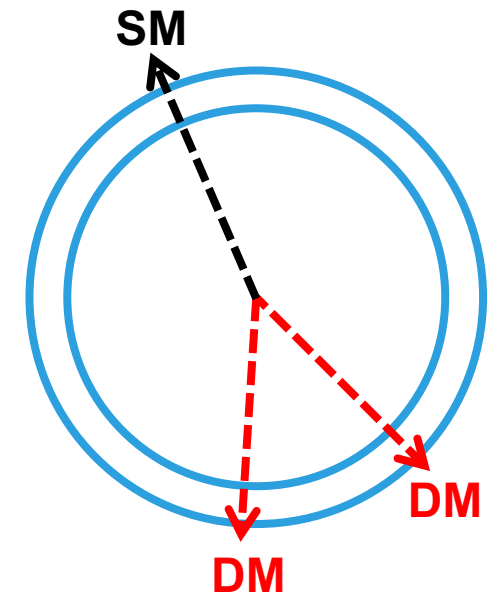
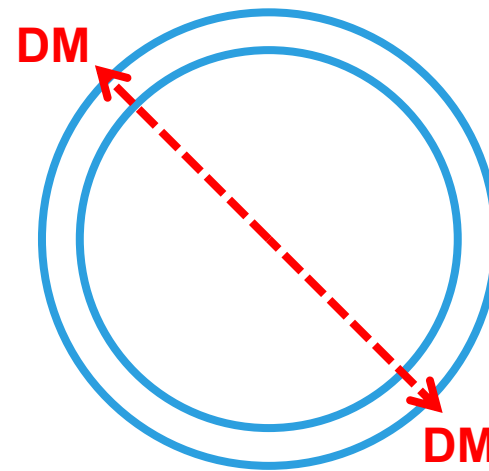


Dark Matter Collider Searches

Introduction



- DM doesn't interact with our apparatus \Rightarrow detectable as **Missing transverse energy (E_T^{miss})** due to p_T imbalance
- Search for a signature of $X + E_T^{miss}$, where "X" represents some visible SM particle(s).



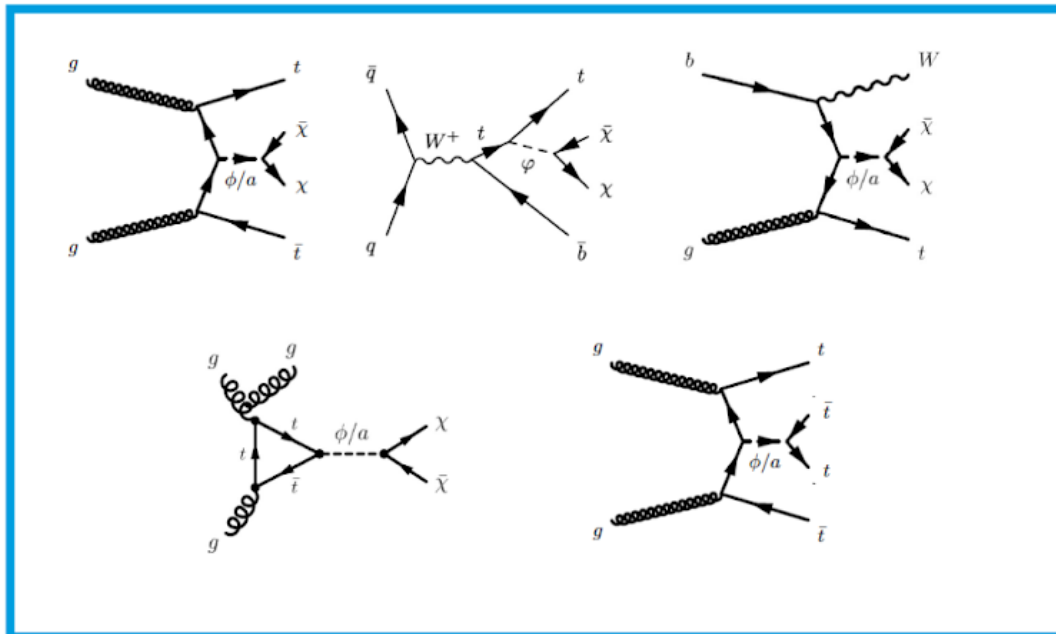
Model considered

- **Two classes of DM** models will be considered in this talk:

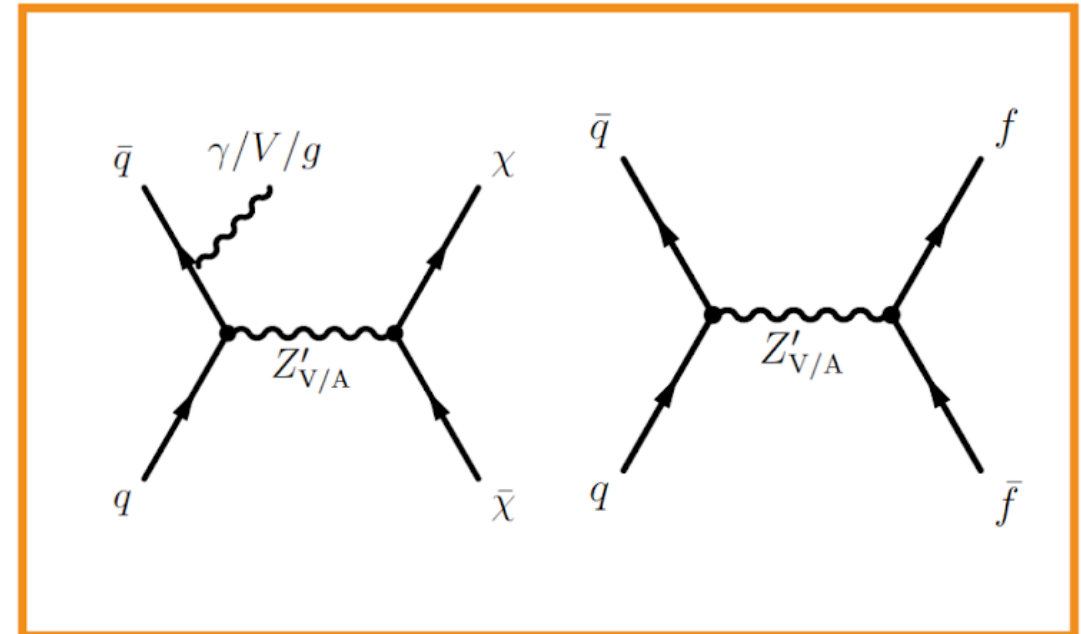
1. Simplified models:

- Signature-driven first-order description of new physics.
- Mediator couples SM with DM sector.
- Limits depend on the mediator mass and coupling strengths ($m_\chi, m_{a/\phi}, g_q, g_\chi, \dots$)

Spin 0 mediator model
Scalar/Pseudoscalar mediator



Spin 1 mediator model
Vector/Axial Vector mediator

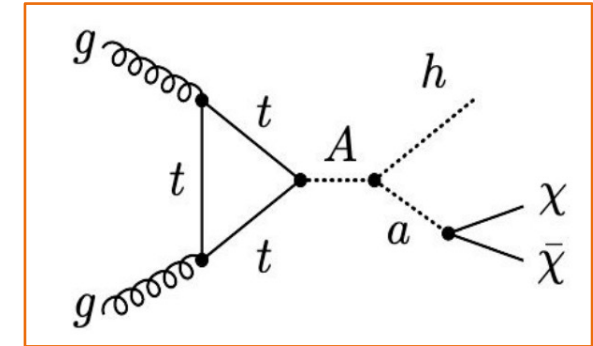


Model considered

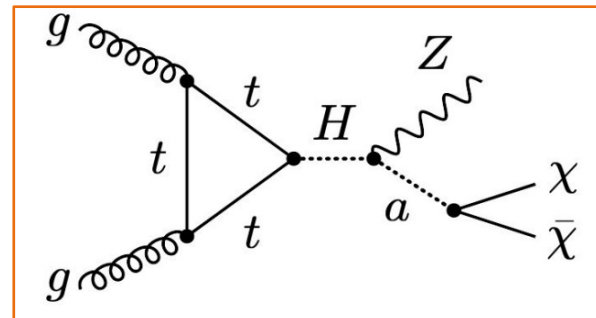
- **Two classes of DM** models will be considered in this talk:

2. 2HDM+a Model:

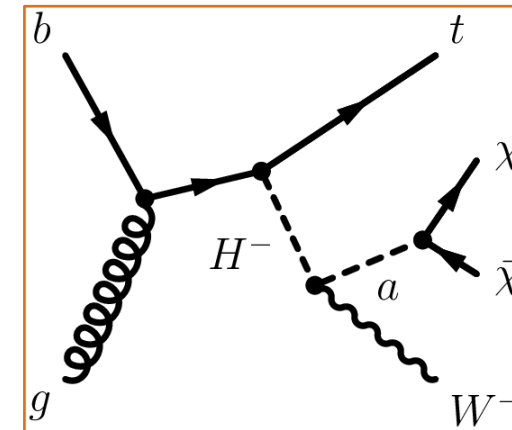
- Extend the Standard Model:
 - **Two** Higgs doublets (h (SM Higgs), H^0 , H^\pm , A)
 - **New pseudoscalar DM mediator "a"**
- Several free parameters:
 - Different masses $m_A, m_{H^\pm}, m_{H^0}, m_a$
 - $\tan\beta$: ratio of the v_{ev} of the Two Higgs doublet
 - $\sin\theta$: Mixing angle between the pseudoscalar mediator (a and A)



$h + E_T^{miss}$ Signature



$Z + E_T^{miss}$ Signature

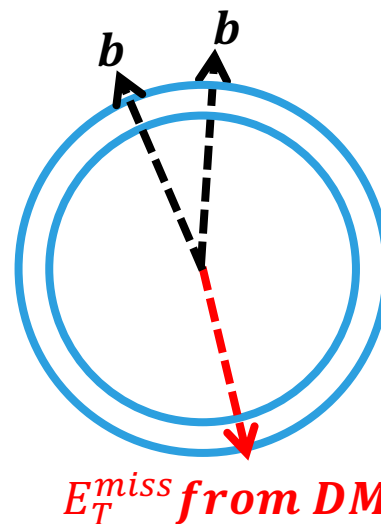


$tW + E_T^{miss}$ Signature

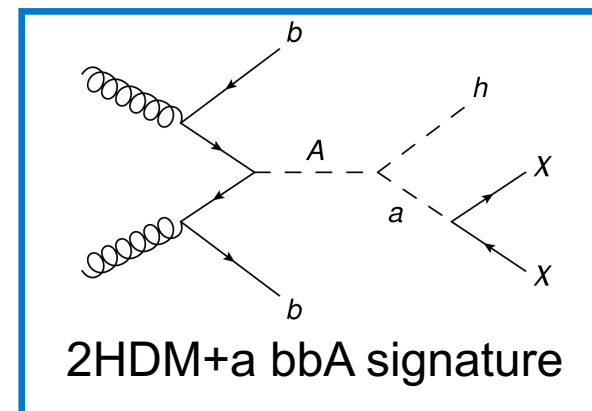
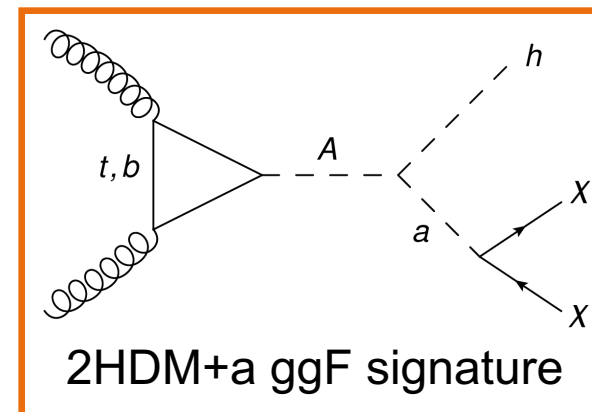
This model is the simplest gauge-invariant and renormalizable extension of the simplified pseudoscalar DM mediator model characterized by a wide range of signature. Visible SM particle(s) produced by hard scattering rather than ISR

Search for $h(bb) + E_T^{\text{miss}}$

Description



- This analysis probe 2HDM+a model with $h + E_T^{\text{miss}}$ final state.
- $h \rightarrow bb$ decay mode.
- At least 2 b-tagged jets recoiling against E_T^{miss} with no leptons
- 2 b-tagged jets:
targets gluon-gluon fusion (**ggF**) signature
- ≥ 3 b-tagged jets:
targets b-associated production (**bbA**) signature

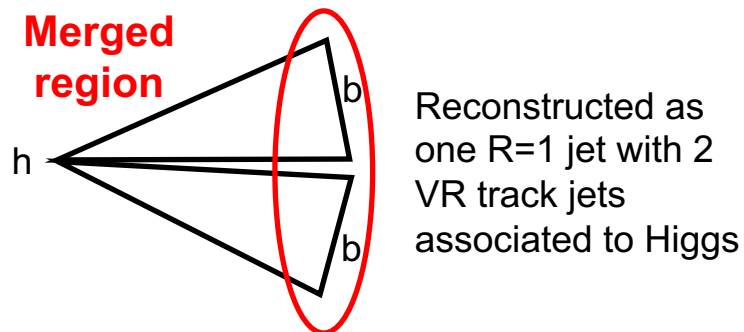
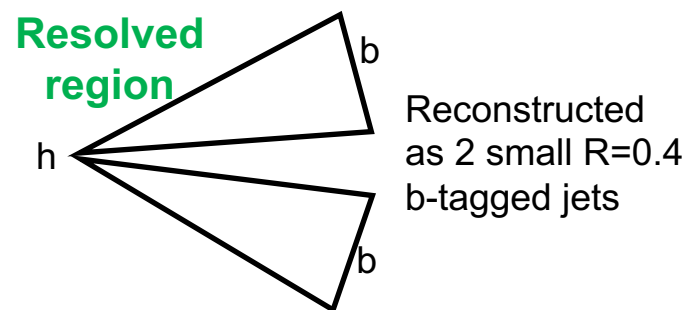


Complementary sensitivity with $h \rightarrow \gamma\gamma$ ([JHEP 10 \(2021\) 013](#)).

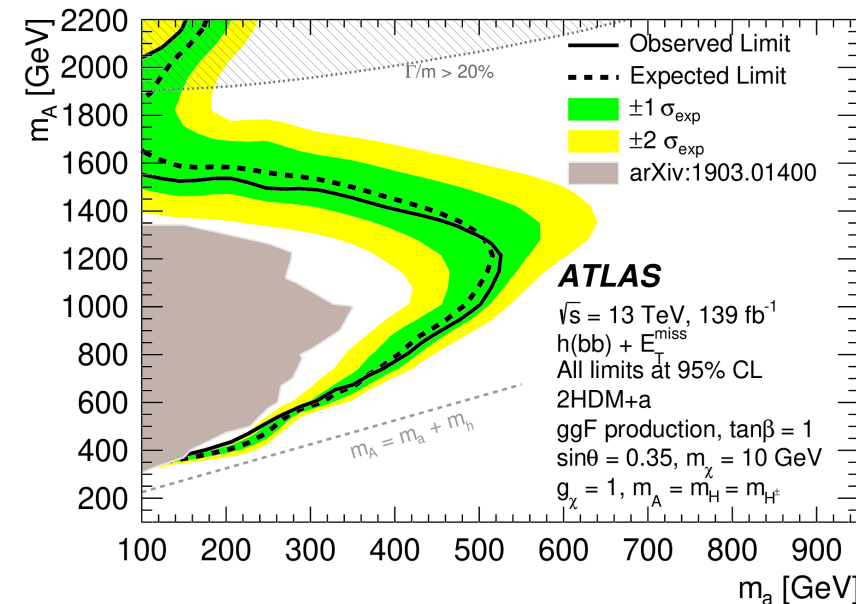
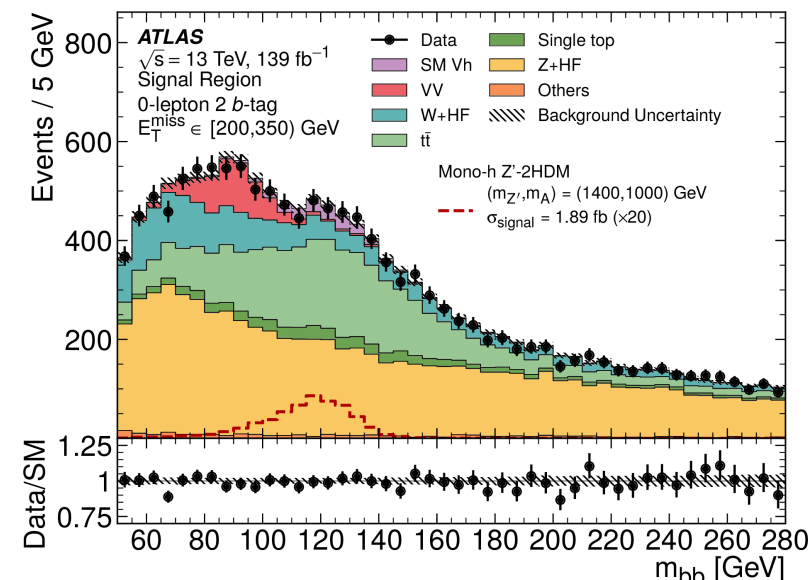
Search for $h(bb) + E_T^{miss}$

Results

- Further divide into resolved and merged regions depending on final-state topology.



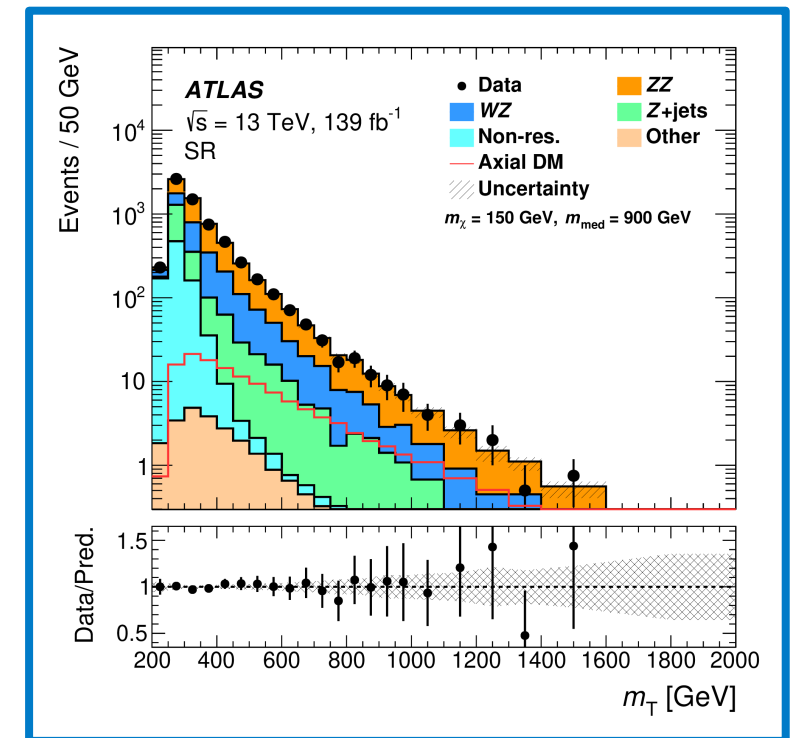
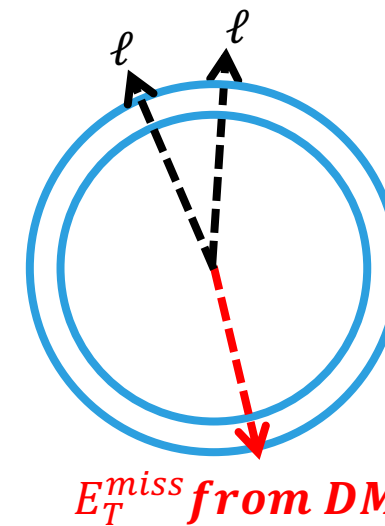
- Bin all SRs and CRs in E_T^{miss} (same binning across all regions) improve sensitivity at high m_A .
- Additional binning for SR in m_{bb} in each E_T^{miss} bin.



Searches for $Z(\ell\ell) + E_T^{\text{miss}}$

Description

- Search for Z decay to $\ell^+\ell^-$ target 2HDM+a Models
- $E_T^{\text{miss}} > 90$ GeV to select events in the SR consistent with invisible particles recoiling against the Z boson.
- Complementary and similar sensitivity on 2HDM+a model; also sensitive to Higgs portal, **(axial) vector** mediator signals.
- Main backgrounds:
 - ZZ, ZW; Z+jets with fake E_T^{miss} .
 - Data-driven constraints from CRs with 2 (DF), 3, 4 leptons.



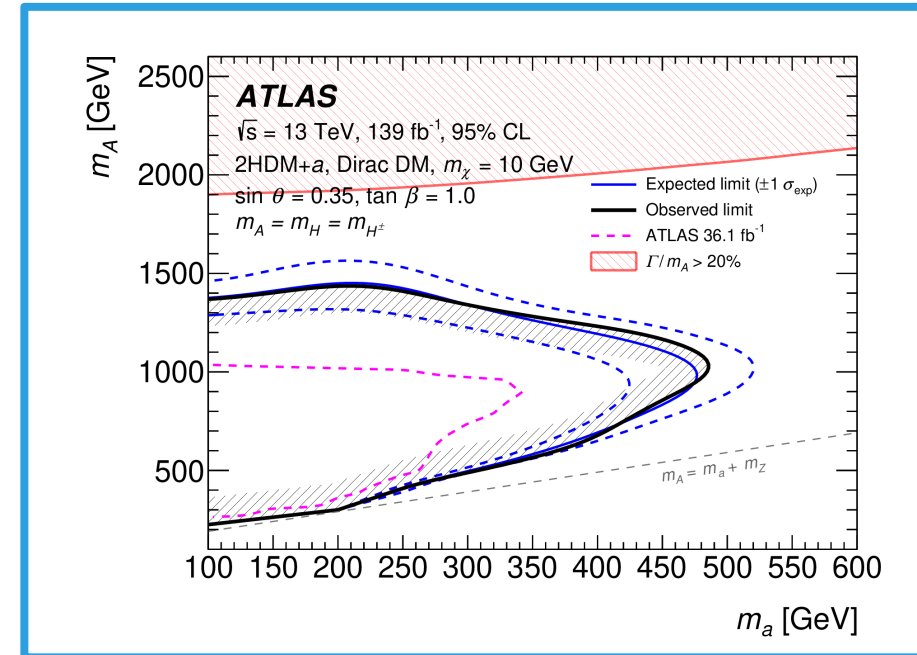
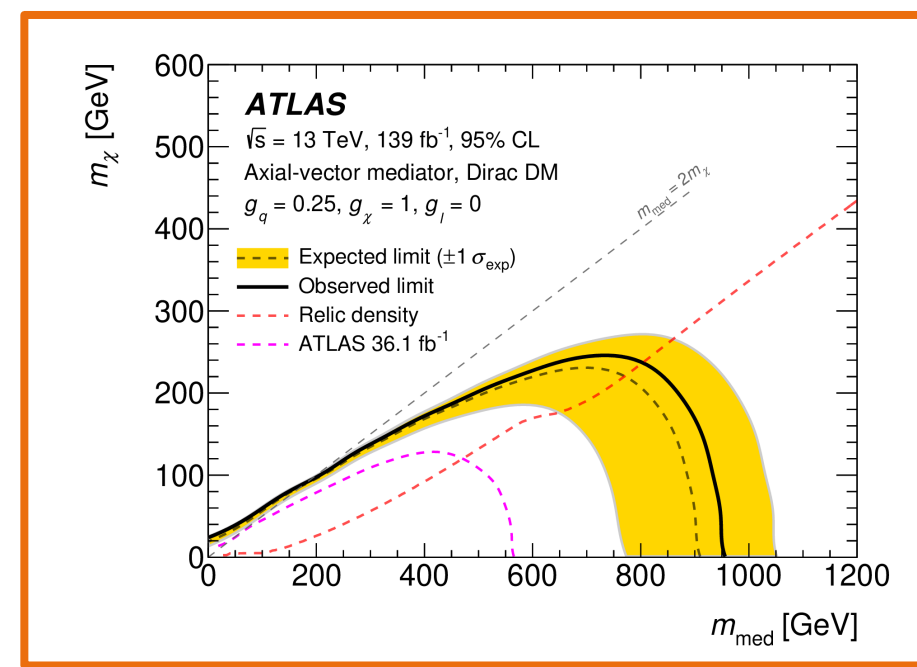
Searches for $Z(\ell\ell) + E_T^{\text{miss}}$

Results

- Binned SR and e μ CR in ZZ in m_T to improve shape discrimination:

$$m_T = \sqrt{\left[\sqrt{m_Z^2 + (p_T^{\ell\ell})^2} + \sqrt{m_Z^2 + (E_T^{\text{miss}})^2} \right]^2 - \left[\vec{p}_T^{\ell\ell} + \vec{E}_T^{\text{miss}} \right]^2}$$

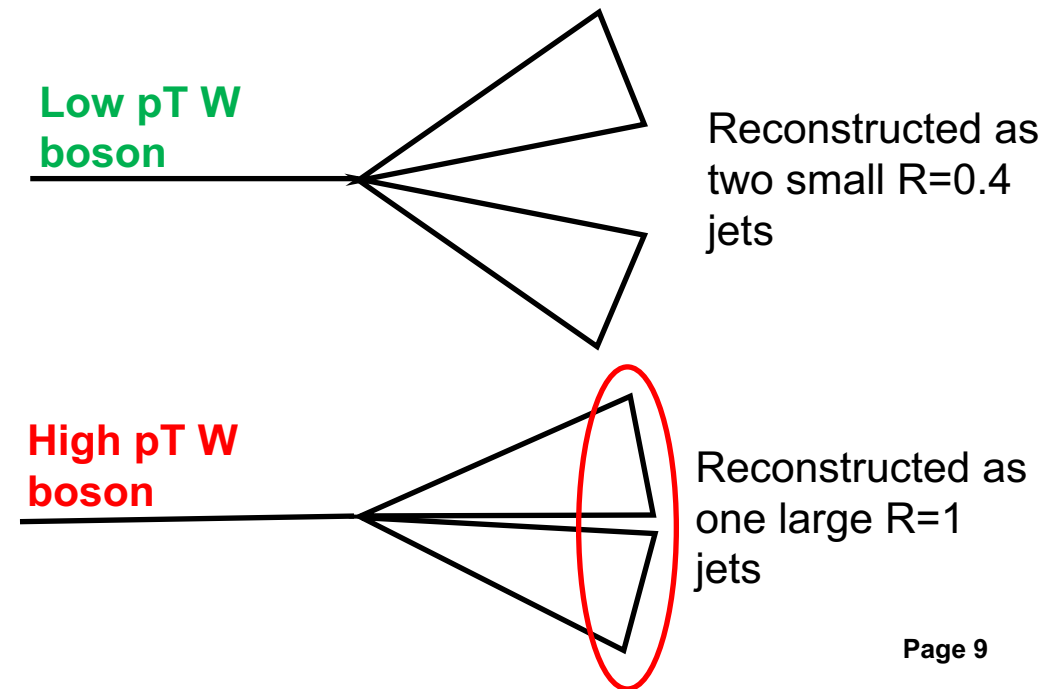
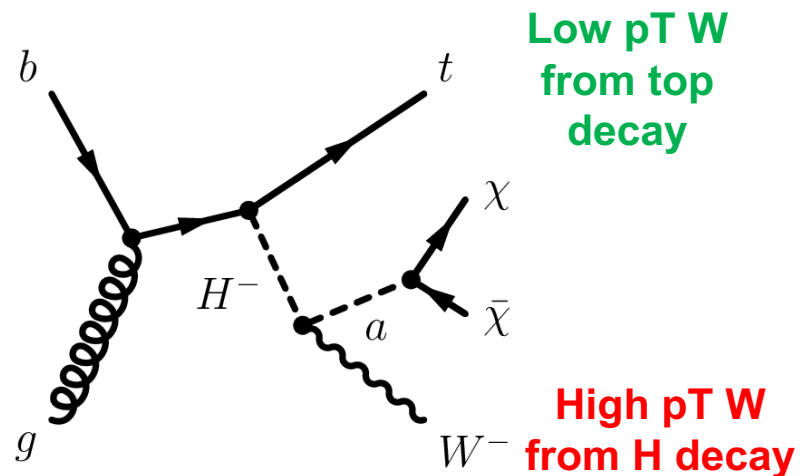
- Good agreement between data and SM background prediction.
- Analysis used to set limits set both on **Simplified spin-1 model** or **2HDM+a model**.



tW+DM Signature

Description

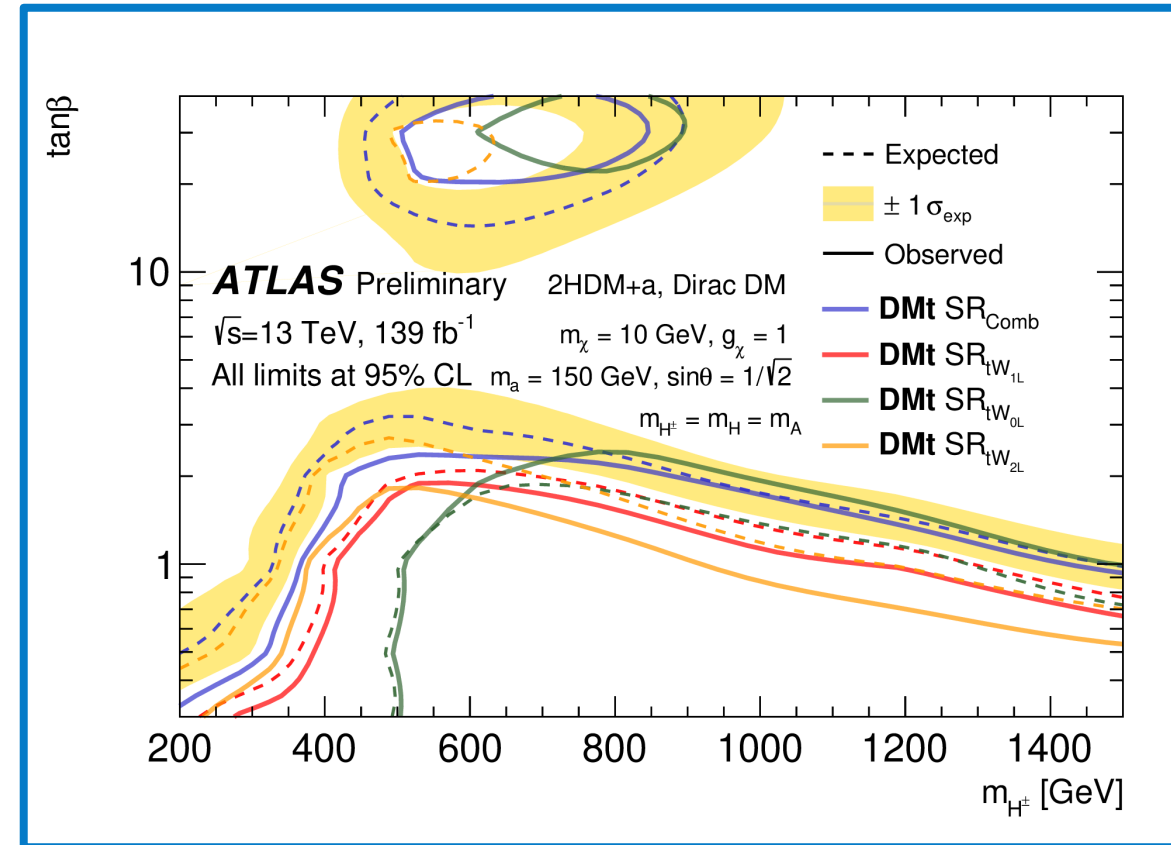
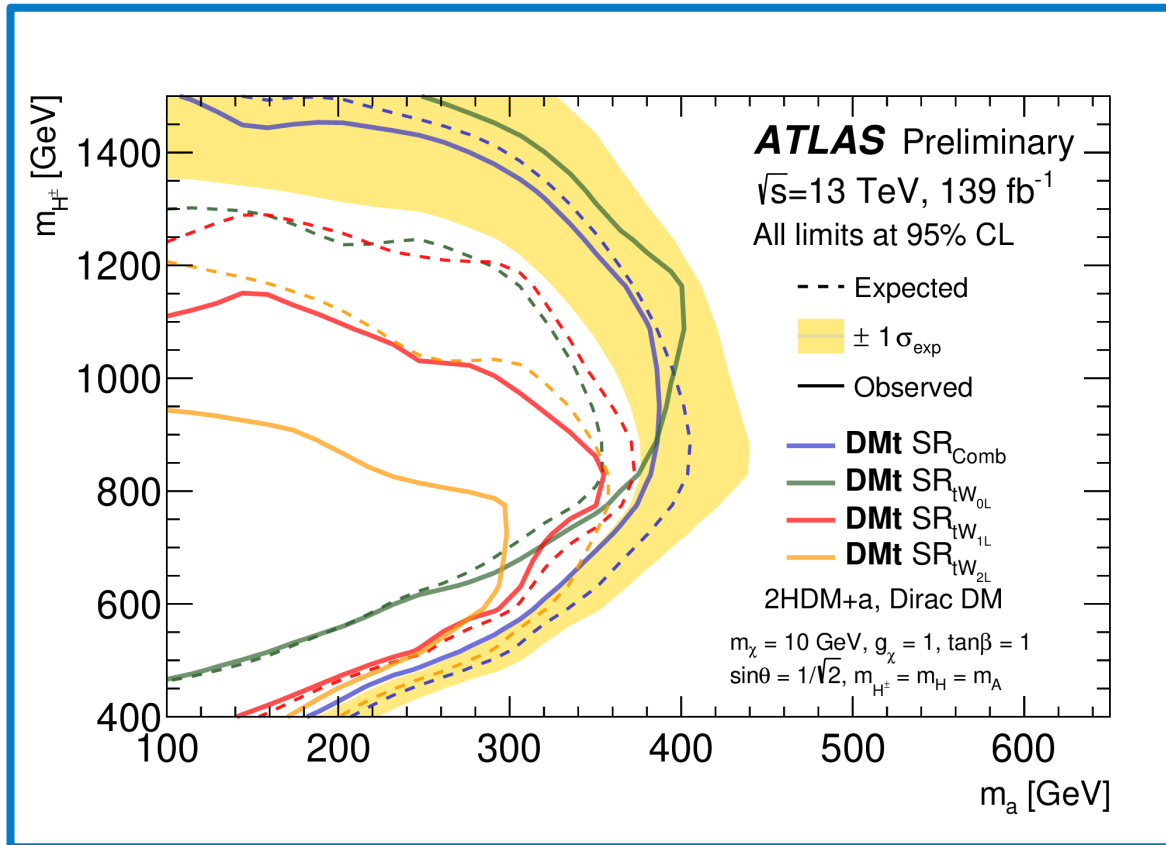
- Analysis targets events with **single top quark and an energetic W-boson**
- $E_T^{miss} \geq 250$ GeV, 0-2 e/ μ , ==1 b-jet
- Main backgrounds:
ttbar, Z/W+jets, ttZ \rightarrow constrained in CRs
- Reduce backgrounds by selection requirements on various transverse mass variables such as m_T , m_{Tb} , m_{T2} , am_{T2} , etc.
- In 0L/1L channel, if $m_{H^\pm} \gg m_W + m_a$, W from H^\pm has high p_T
 \rightarrow **Use W-tagging for S/B separation!**



tW+DM Signature

Results

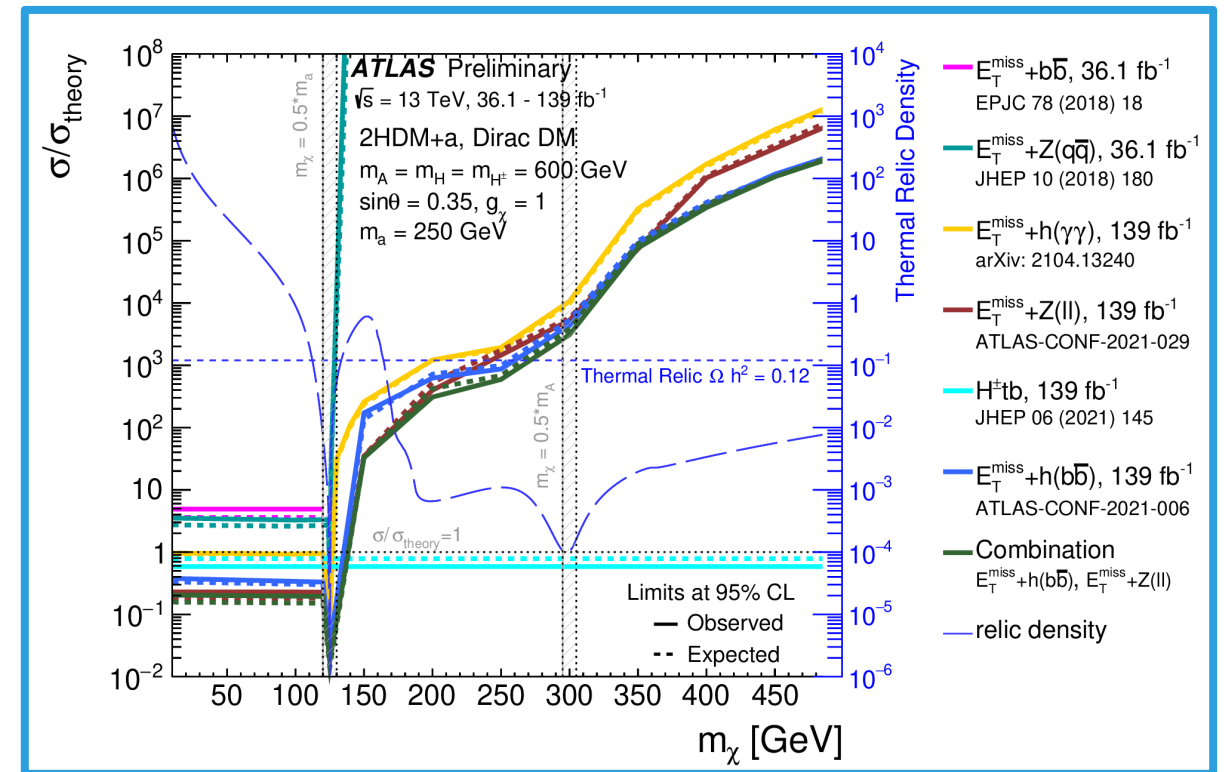
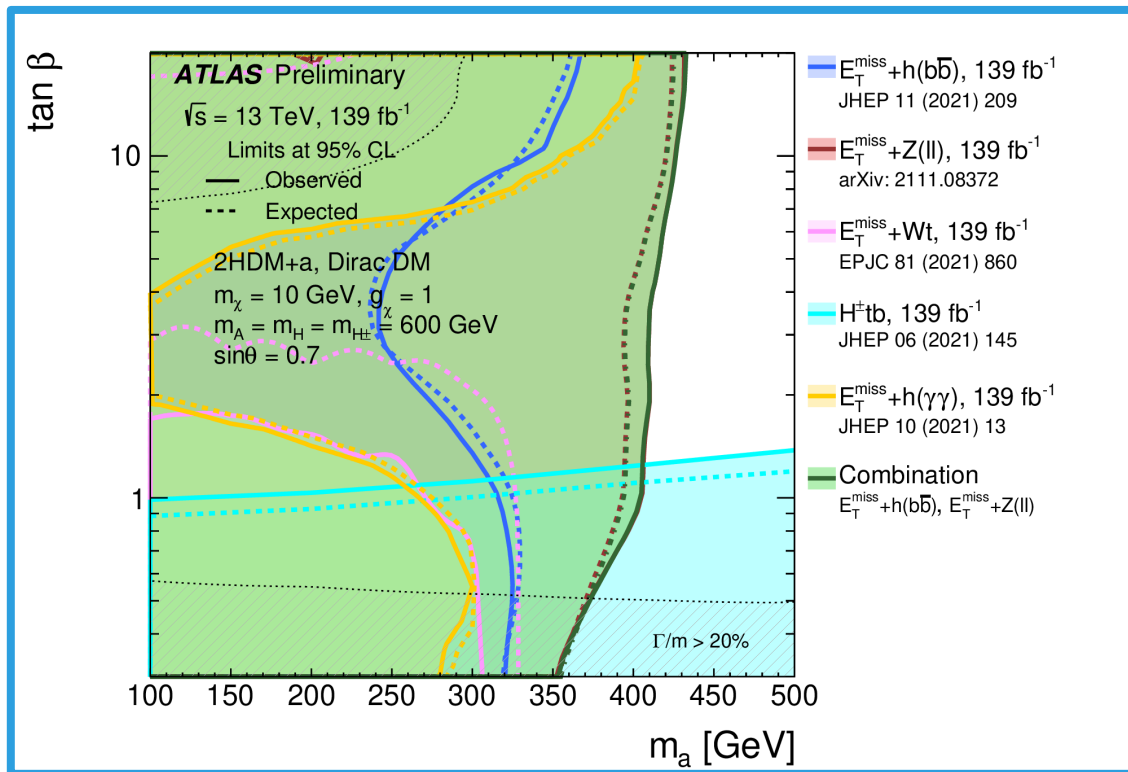
- 0L/1L channel with strongest exclusion for $m_{H^{\pm}} > 700$ GeV
- 2L dominant for $m_{H^{\pm}} < 700$ GeV
- Model excluded between $m_a=100-400$ GeV and $m_{H^{\pm}} = 400-1500$ GeV



Combined Limits on 2HDM+a Model

Combination Results

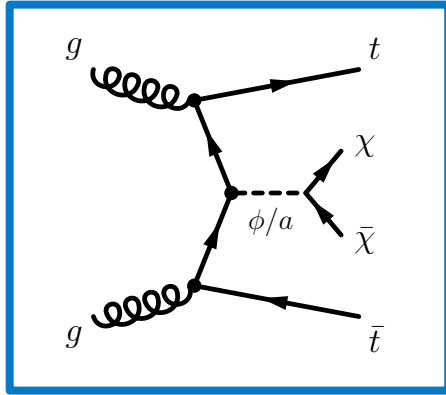
- Statistical combination performed of most sensitive channels $\mathbf{Z}(\ell\ell) + E_T^{miss}$, $\mathbf{H}(\mathbf{bb}) + E_T^{miss}$
- Large area of phase space excluded by different analysis targeting 2HDM+a
- Limits presented as various parameter scans, including 1D scan over DM mass m_χ .



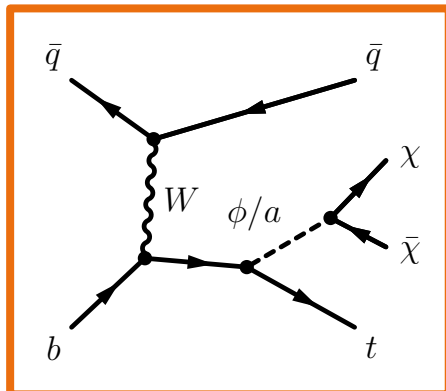
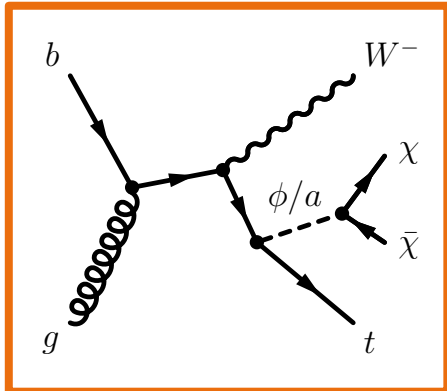
tt+MET analysis

Description

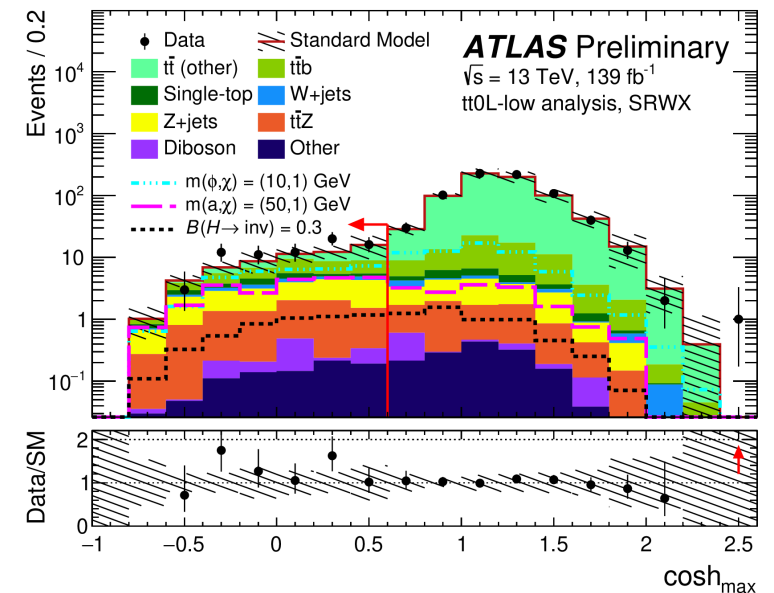
- DM produced in association with **two top quark (DM+tt)**



- DM produced in association with **single top quark (DM+t)**

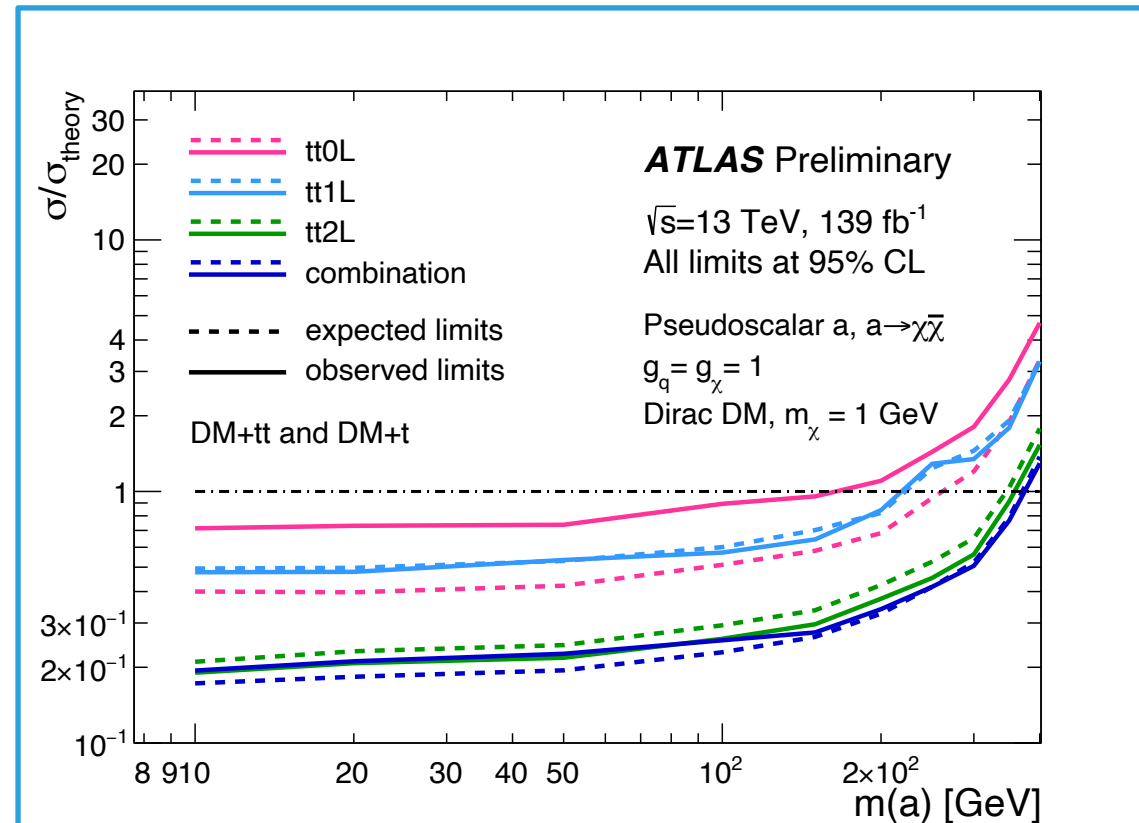
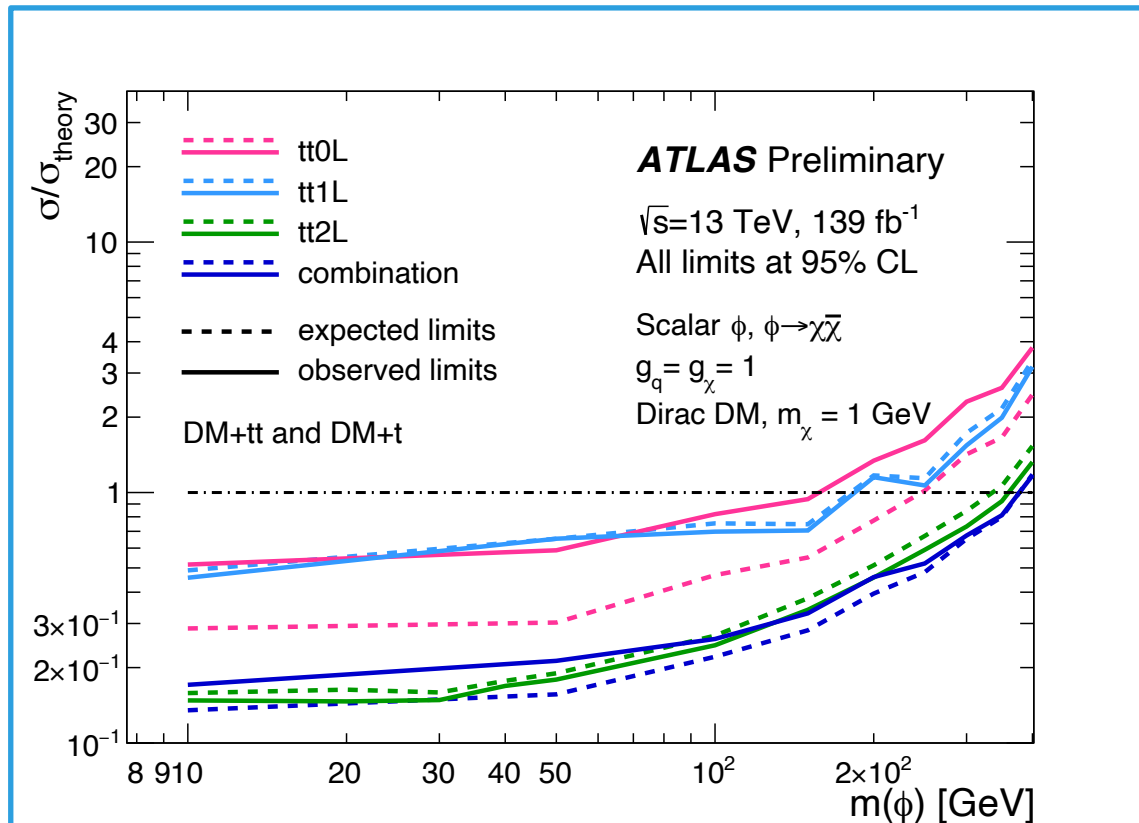


- Different analysis have been developed considering different decay of the top quark.
 - tt0L-high analysis**: Full Hadronic top pair decay [EPJC 80 \(2020\) 737](#)
 - tt1L analysis**: Semi-leptonic top pair decay [JHEP 04 \(2021\) 174](#)
 - tt2L analysis**: Di-leptonic top pair decay [JHEP 04 \(2021\) 165](#)
- In addition, a **NEW** extended and improved selection with 0 lepton final state have been considered (**tt0L-low analysis**).
- b-jets trigger to improved the sensitivity for events **with lower** E_T^{miss}
- New variables to suppress $t\bar{t}$ with fake E_T^{miss}
- Dominant backgrounds: $t\bar{t}$, W+jets, Z+jets, $t\bar{t} + Z \rightarrow$ constrained in CRs



tt+MET analysis

Results



- For scalar (pseudoscalar) DM models, the combination extends the excluded mass range by 100 (30) GeV
- Excluding mediator masses up to 370 GeV.
- Improves the expected cross section limit by 14% (24%), for low mass scalar (pseudoscalar) DM mediators.

Conclusion

- Presented latest ATLAS results in several searches for dark matter.
- Presented new limits on multiple DM models:
 - Simplified model
 - 2HDM+a
- Wide programme across many interesting and complementarity signatures, lots of results, many still to come.
- Stay tuned!!
- Thank you for your attention!

Contact

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