Searches for Top-associated DM Production at the LHC

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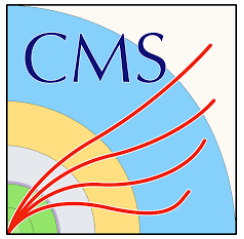
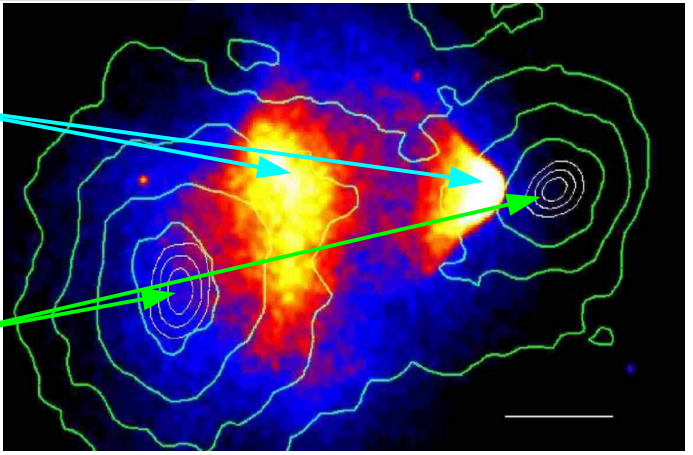
on behalf of the ATLAS and CMS collaborations

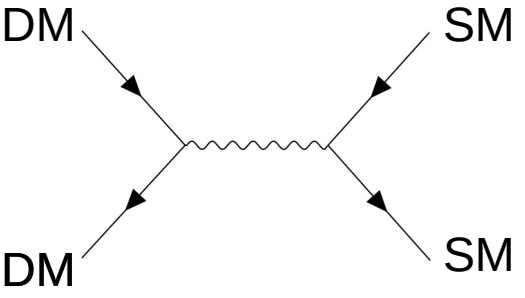
24.09.2024
17th Workshop on Top Quark Physics
St. Malo, France

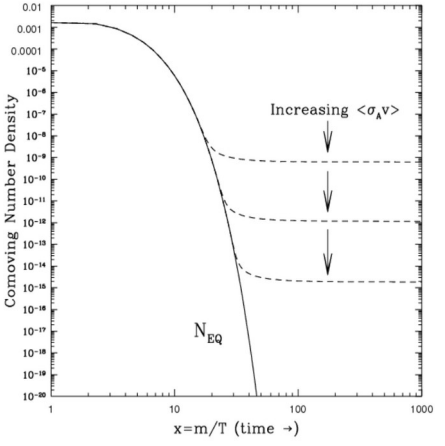


Evidence for Dark Matter

- Large amount of evidence from Astronomy and Cosmology for the existence of Dark Matter (DM)
- Density of DM today can be explained if some high energy interaction linked to SM in early universe
- If this is a mediator with order 1 couplings, would have mass around 100 GeV - 1 TeV => “WIMP miracle”

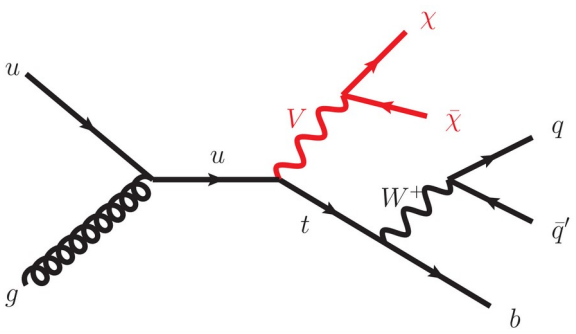


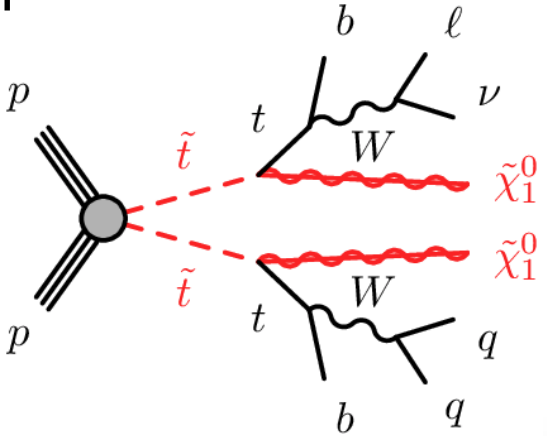


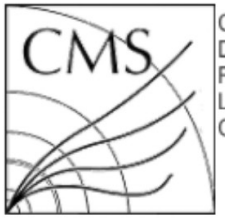


Dark Matter at the LHC

- DM might be produced at the LHC – could be detected as p_T^{miss}
- Many DM models also link to other new weak scale physics
- Often leads to DM produced together with top quarks







CMS Experiment at LHC, CERN
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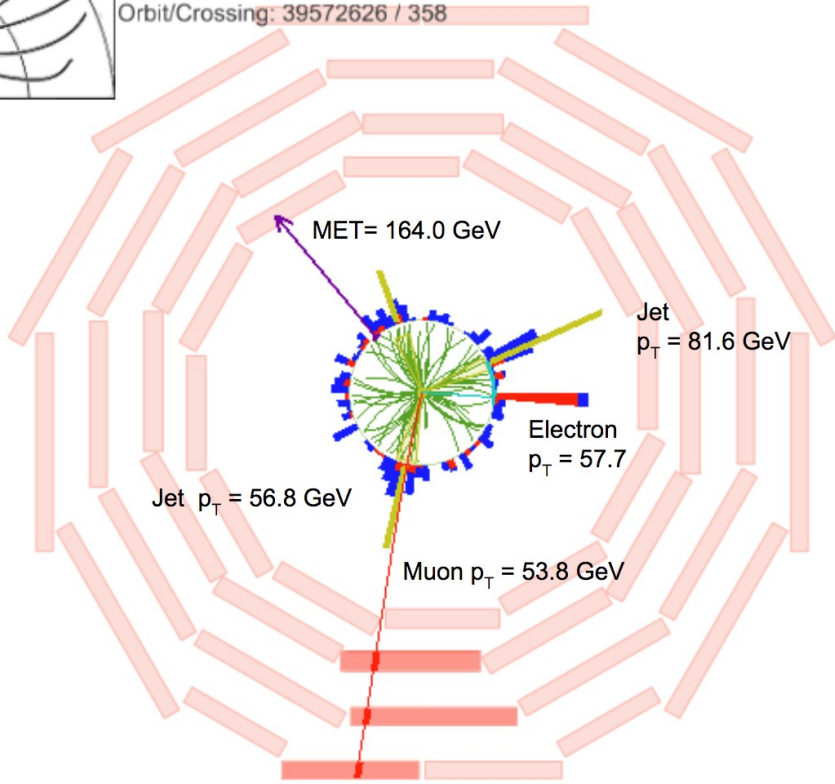
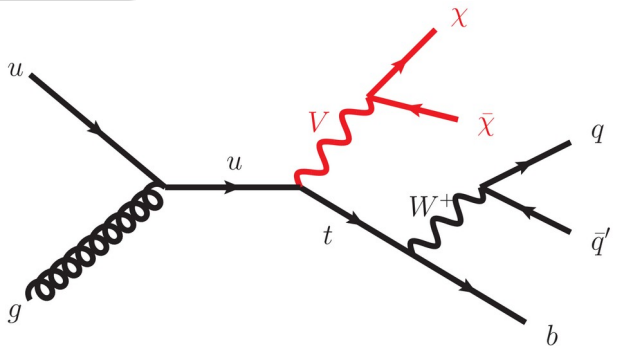
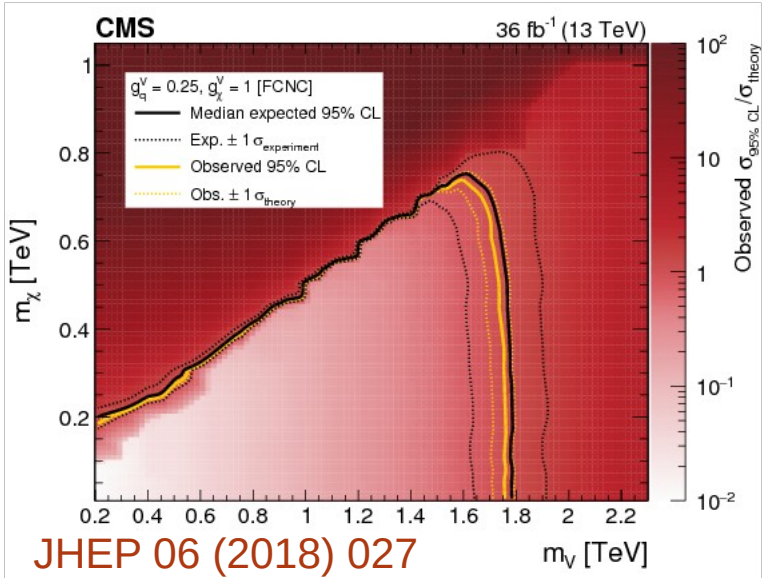
Run/Event: 251244 / 83494441
Lumi section: 151
Orbit/Crossing: 39572626 / 358



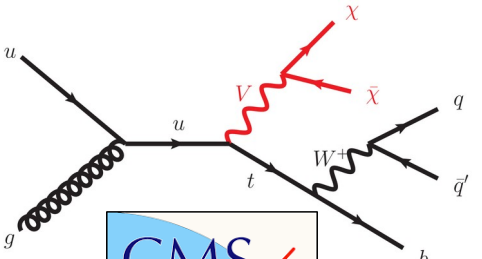
Mono-top - Existing Results

- Some models contain FCNC mediators
- Can produce a single boosted top quark recoiling against p_T^{miss}
- Hadronic top most sensitive
- Data-driven background estimation
- 13TeV analyses with 2016 data





Search strategies



ATLAS EXPERIMENT

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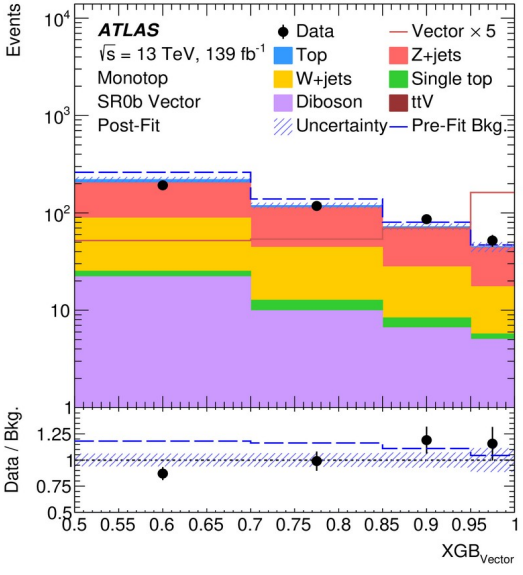
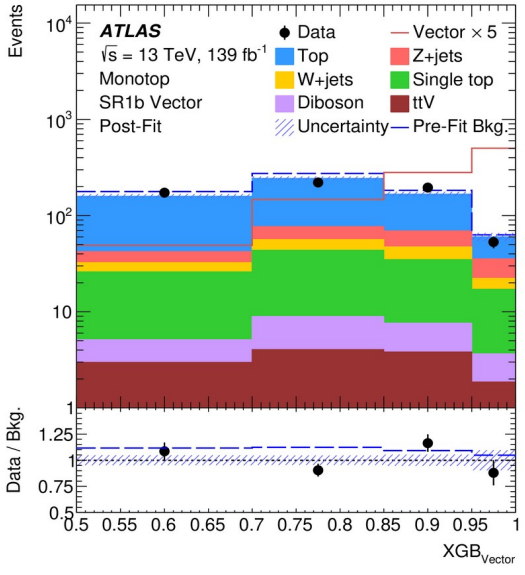
- New full Run 2 analyses
- Both use DNN top taggers on large-R jets
  - ΔR=1.0(1.5) for ATLAS (CMS)
- ATLAS categorises on number of b-jets (including inside large-R jet), CMS categorises in top tags

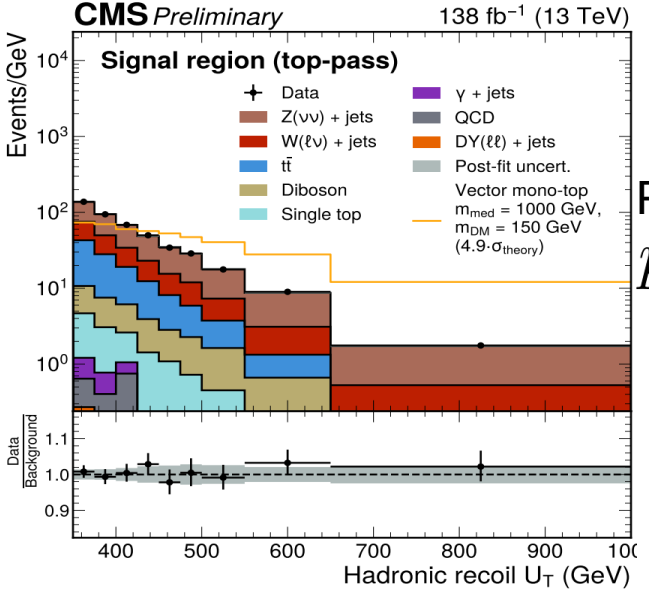
CMS

CMS-PAS-SUS-23-004

Fit on BDT score

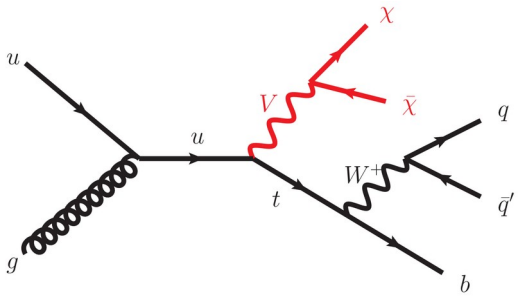




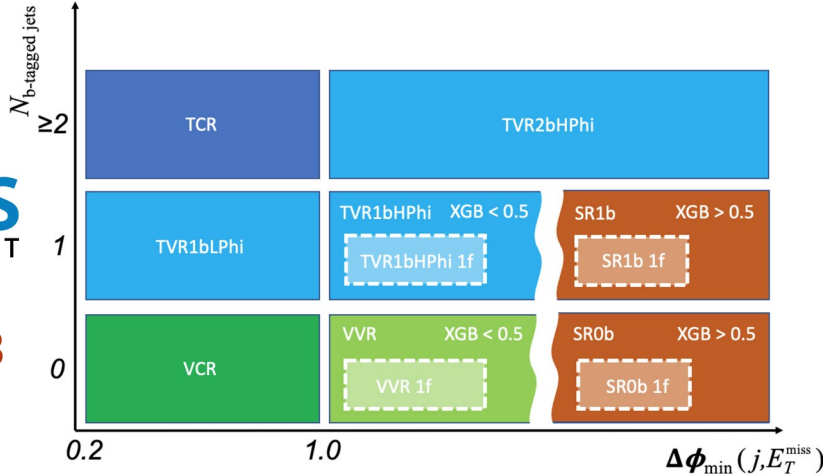


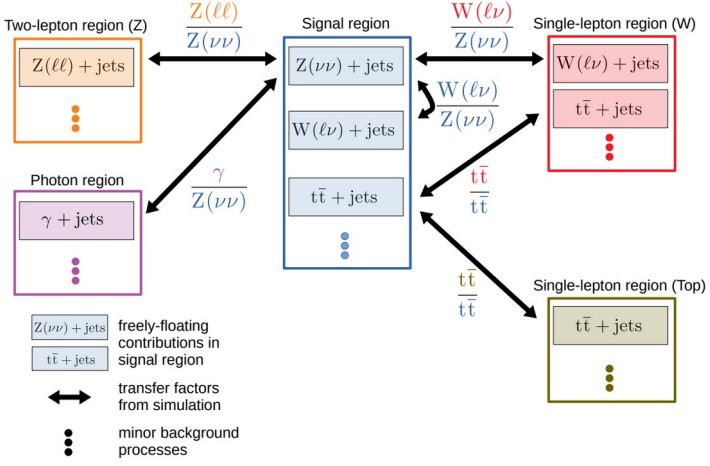
Fit on p_T^{miss}

Background estimation



- ATLAS estimate overall $t\bar{t}$ and V+jets rate using control regions differing in $\Delta\phi_{min}(j, E_T^{\text{miss}})$
  - Numerous dedicated VRs
- CMS use per-bin transfer factors from CRs differing in number of leptons





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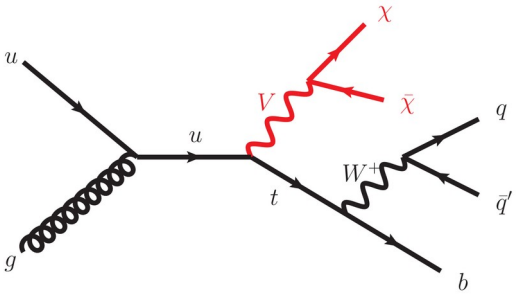
CMS
CMS-PAS-SUS-23-004

Mono-top results



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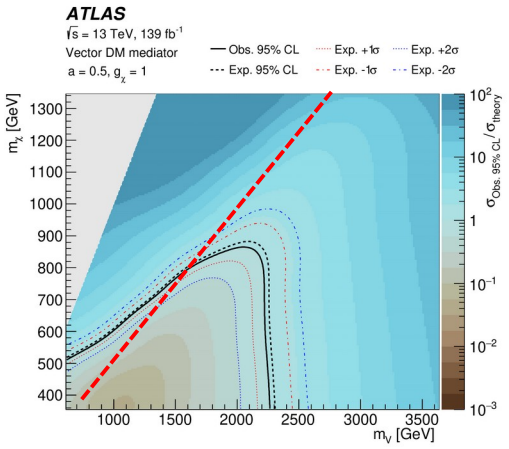
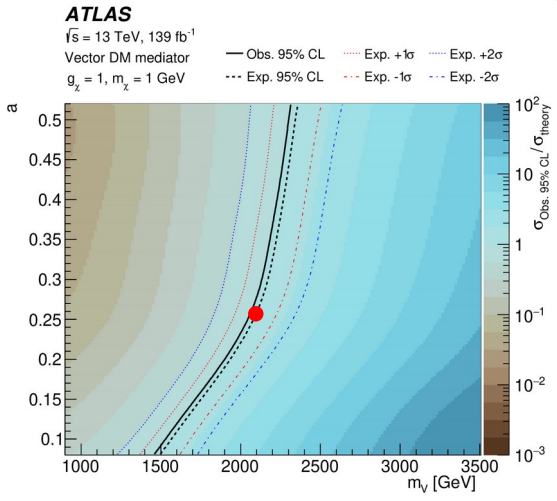
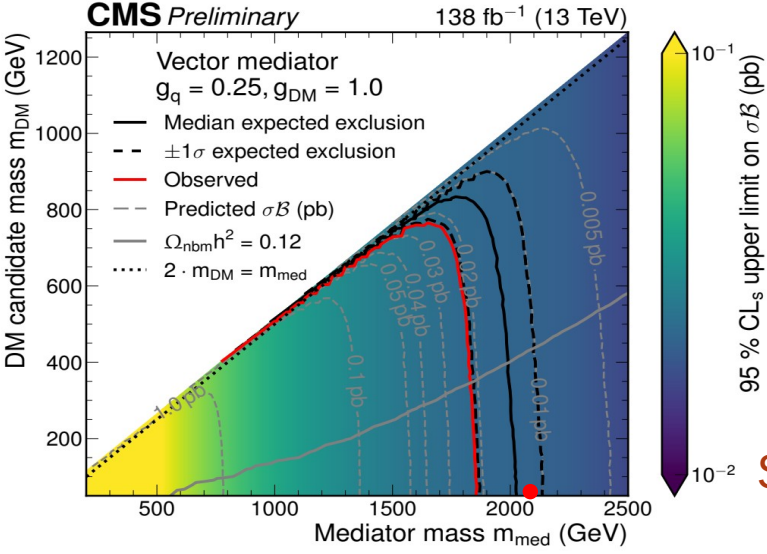
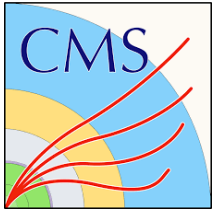




- Interpreted in different combinations of model parameters
- ATLAS ~80 GeV higher reach in m_V for low m_{DM}
- CMS slightly more sensitive for $m_{med} \approx m_{DM}$

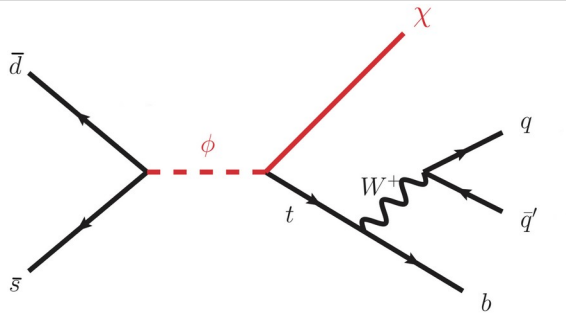


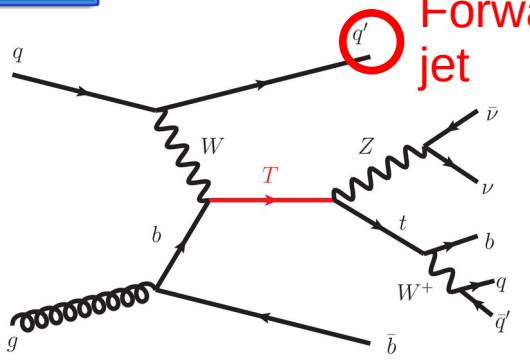


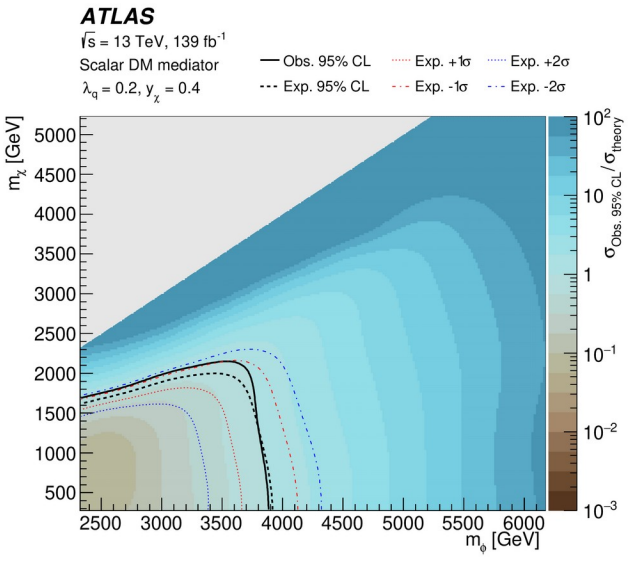
CMS-PAS-SUS-23-004

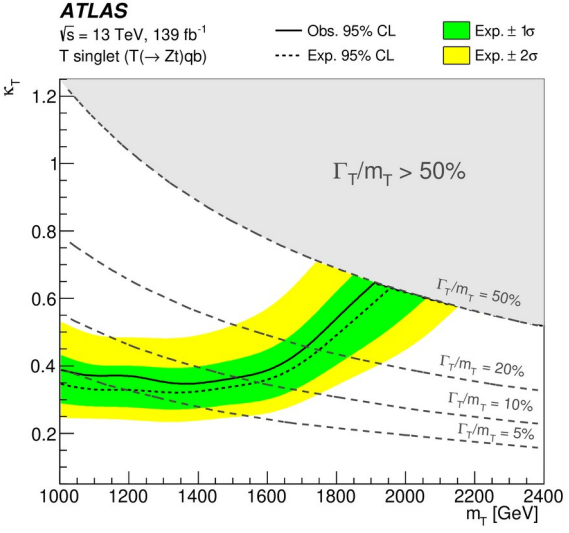
Further interpretations

- ATLAS analysis also optimised for resonant scalar mediator and vector-like-quark
- Separate BDT trainings for each model
- Dedicated forward jet category for VLQs









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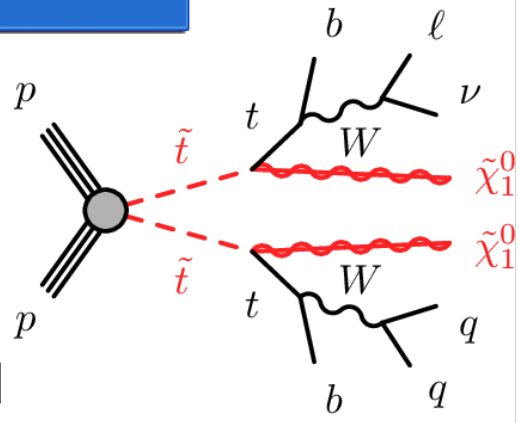
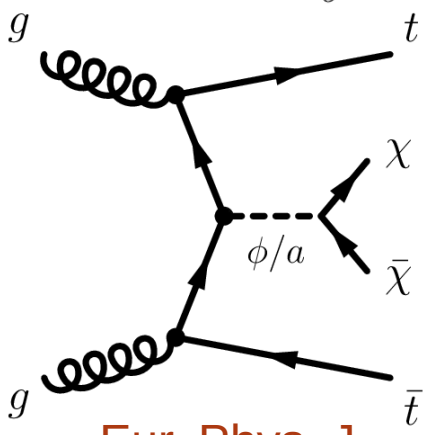
DM in $t\bar{t}$ events - Existing Results

- Stop squarks can decay to tops + lightest supersymmetric partner (DM)
- Tops may or may not be boosted
- Extended Higgs sectors could include a spin-0 DM mediator with a yukawa coupling
- Generally lower mediator masses and less boosted tops
- Full Run 2 analyses published, but room for improvement

Eur. Phys. J. C81 (2021) 970





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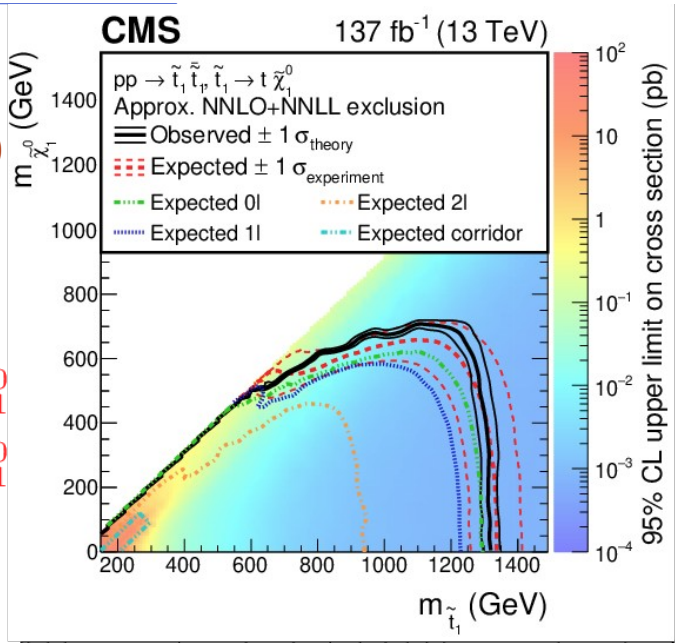
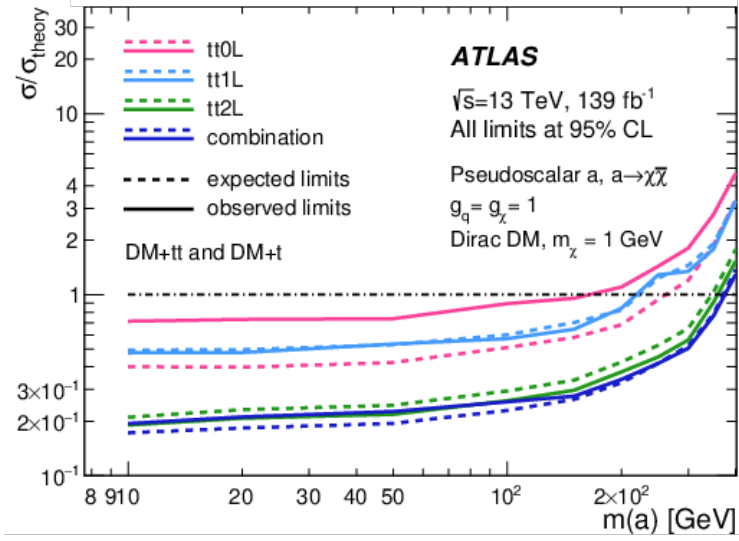
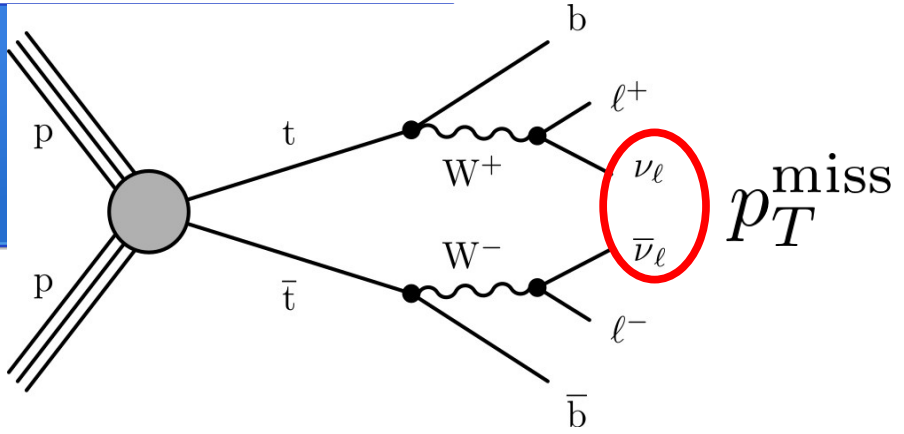
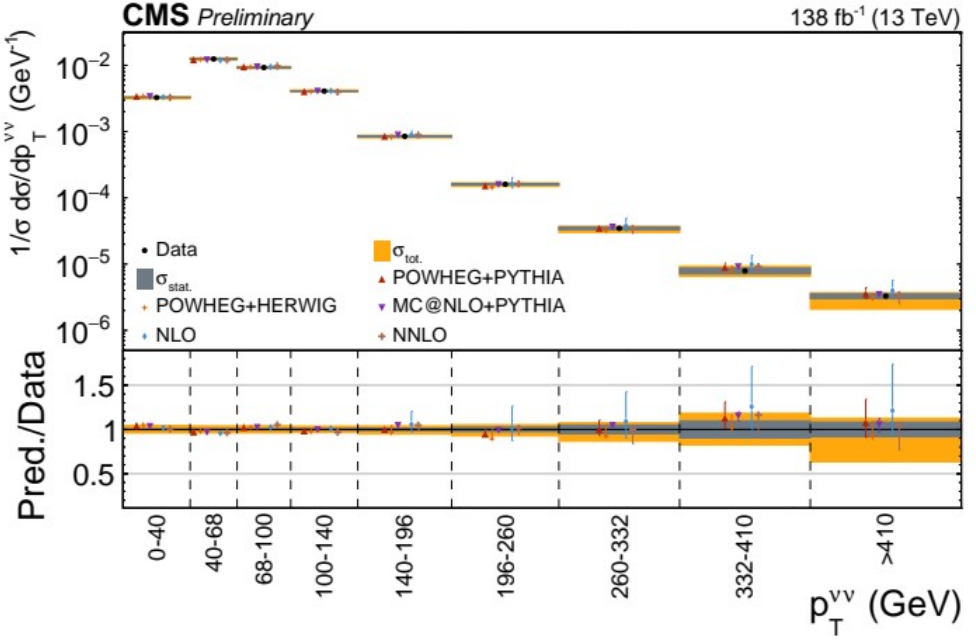




Measurement of SM $t\bar{t}$ neutrino kinematics

- Dileptonic SM $t\bar{t}$ has two neutrinos
  - Major background in both 2 and 1 lepton channels (miss-reconstructed leptons)
- First measurement of $\nu\bar{\nu}$ kinematics in top pair production
- See Sandra's talk on Friday

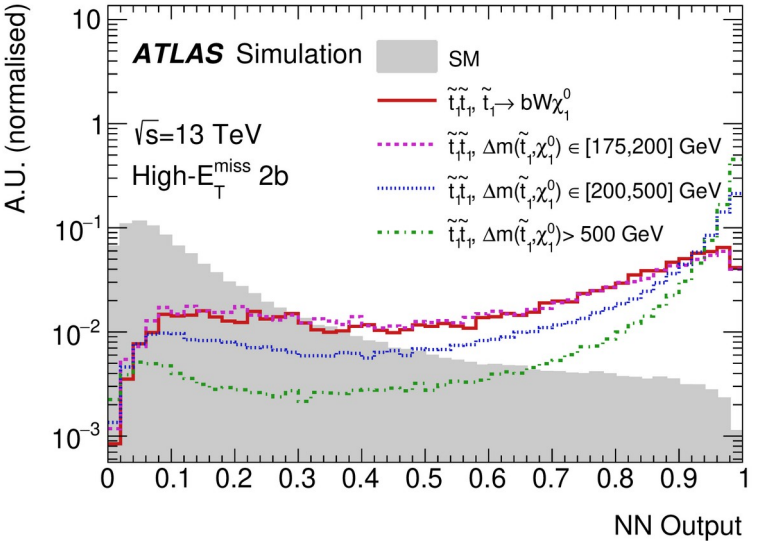


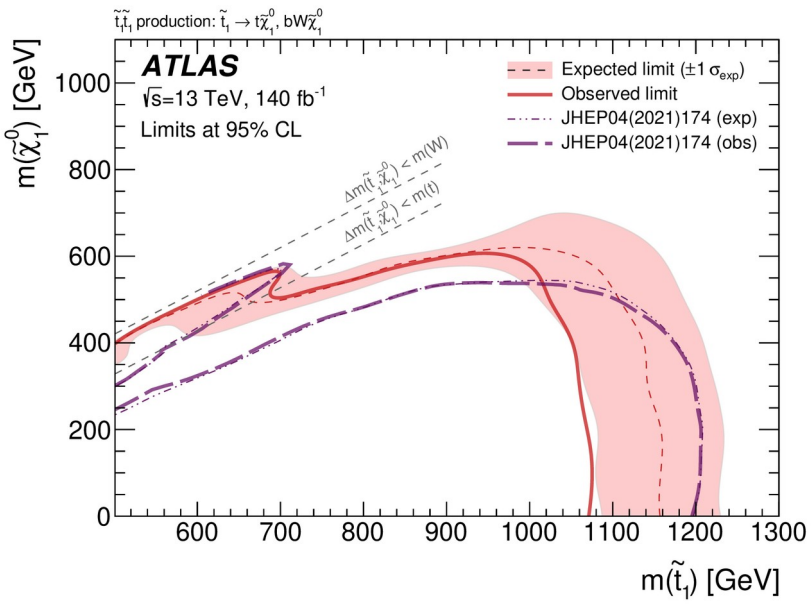


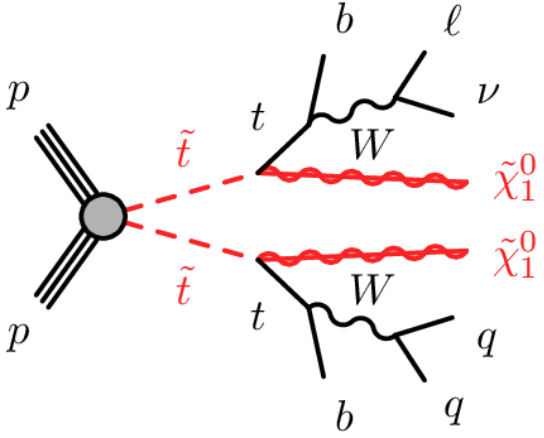
CMS-PAS-TOP-24-001

Single lepton stop search

- Re-analysis of single lepton channel
- MVA-based resolved (new) and boosted top taggers
- Neural networks (NN) in different categories
- Low (intermediate) NN values used as CRs (VRs) for rates of W boson, single top and 1- and 2- lepton tt backgrounds
- Significant improvement for intermediate mass-gap







ATLAS EXPERIMENT

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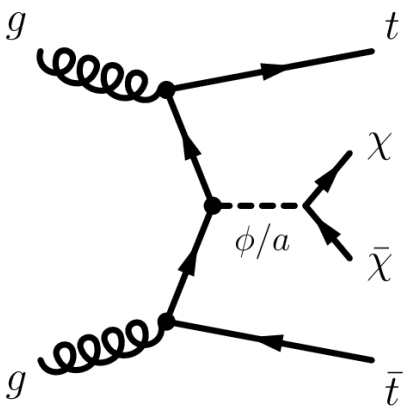
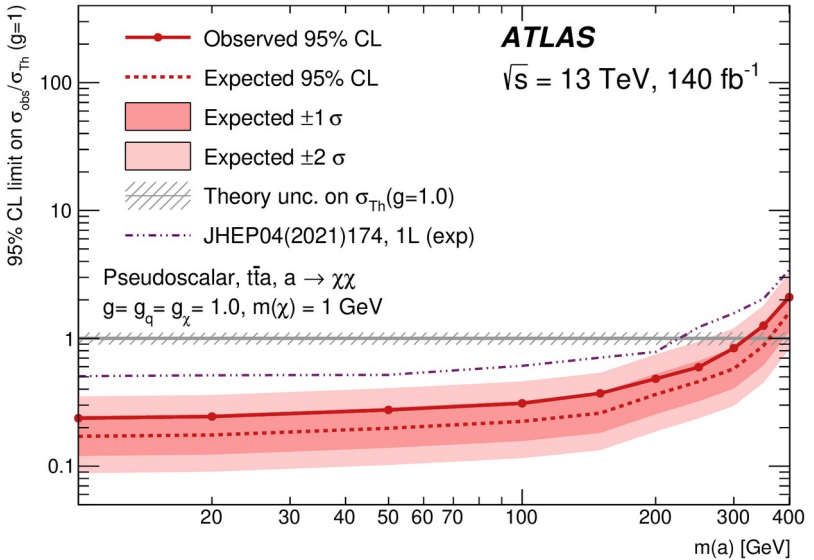
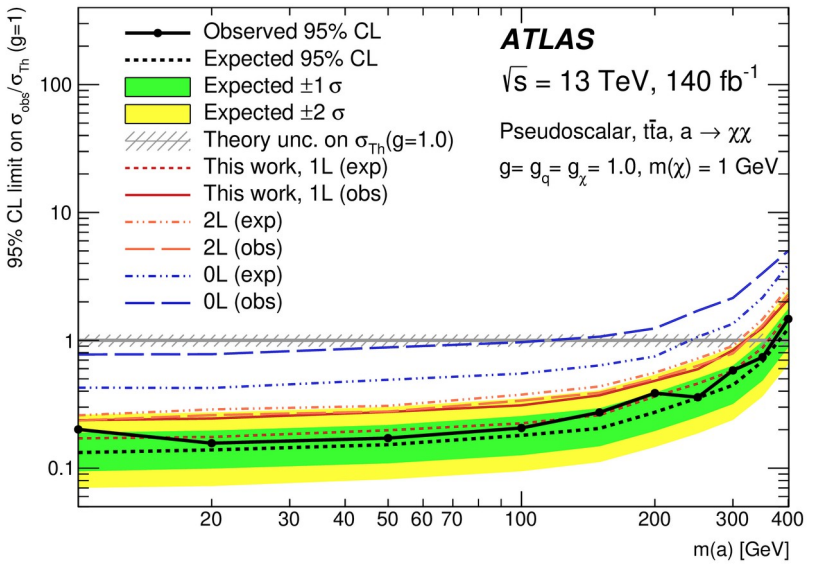
Single lepton $t\bar{t}$+DM search

- Also optimised to search for $t\bar{t}$+DM
  - Dedicated neural network
- Significant improvement from resolved top-tagger
- Combined with previous 0 and 2 lepton searches







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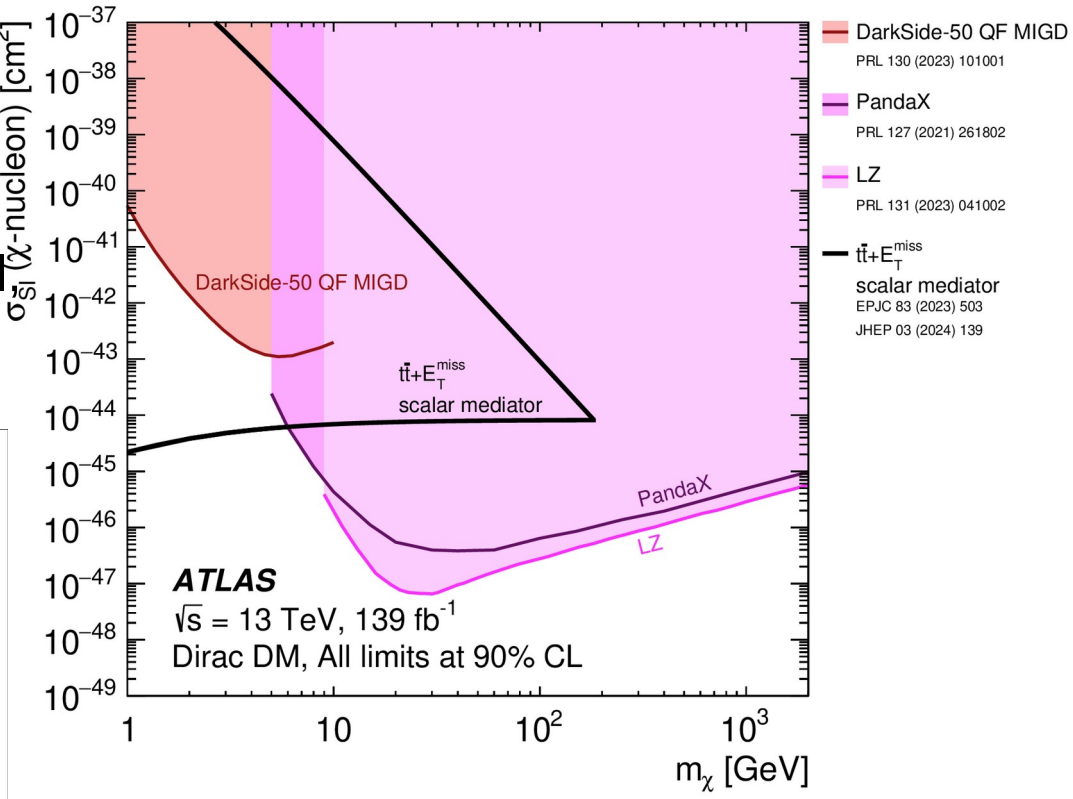
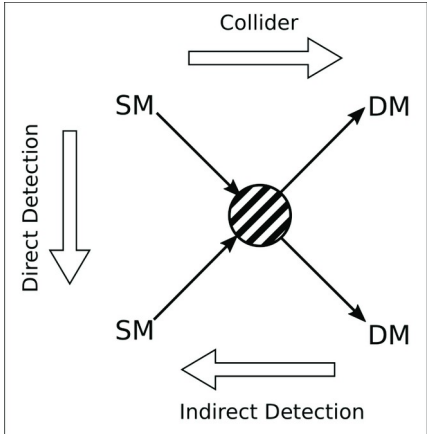
Wider context

- Many limits on DM from direct detection experiments
- Can compare limits for specific models
- For simplified Scalar mediator model LHC can improve exclusion at lower DM masses



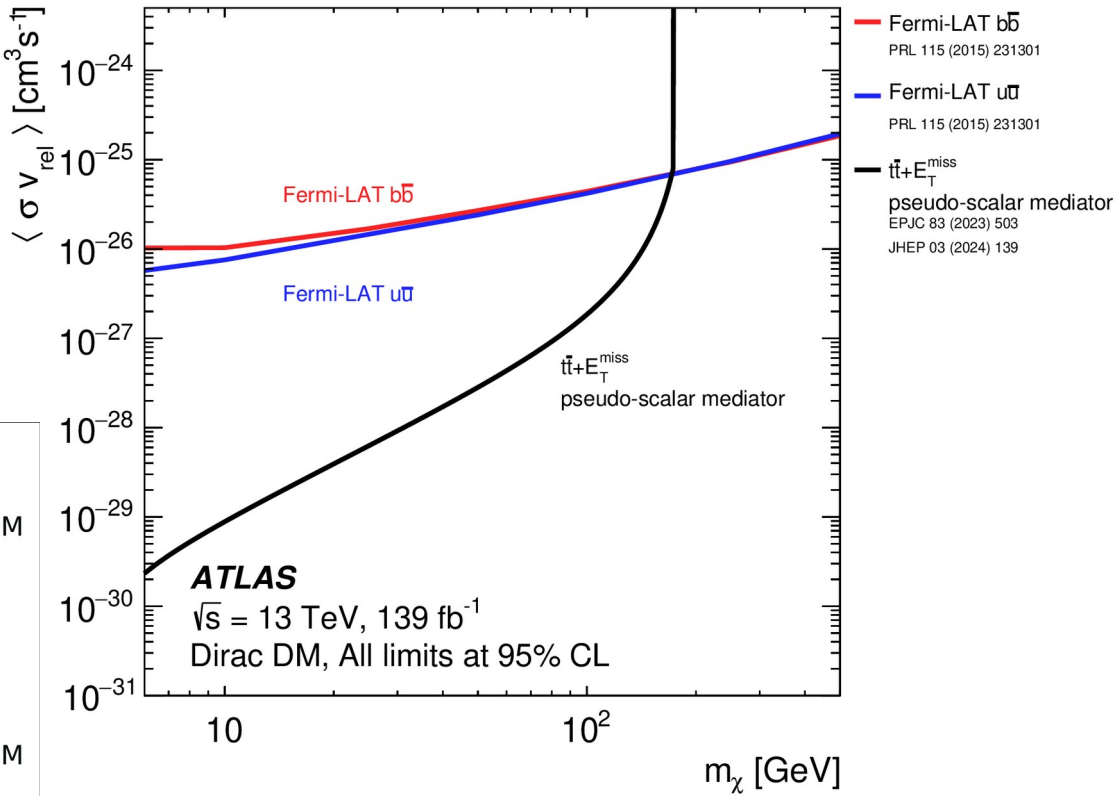


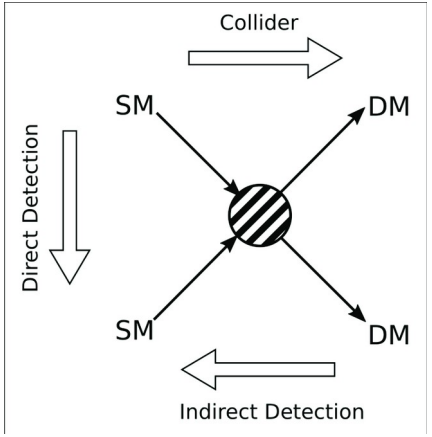
ATLAS EXPERIMENT

CERN-EP-2024-102

Wider context

- Direct detection less sensitive to pseudoscalar mediators
- LHC provides best limits within its mass reach
- Above this mass best limits from indirect detection



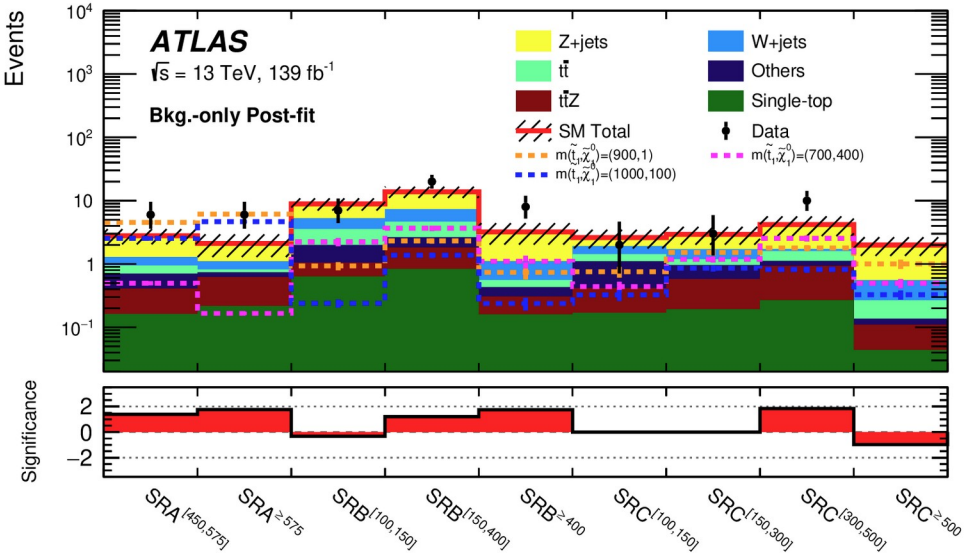


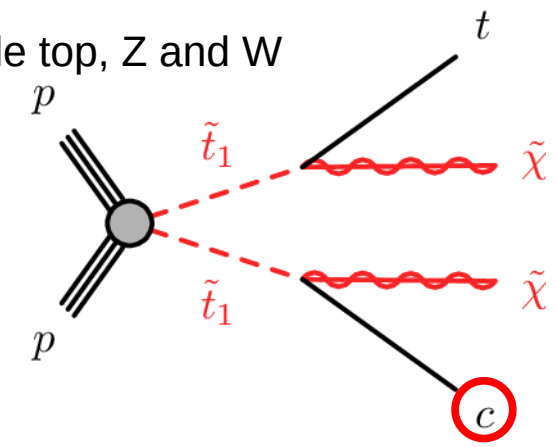
ATLAS EXPERIMENT

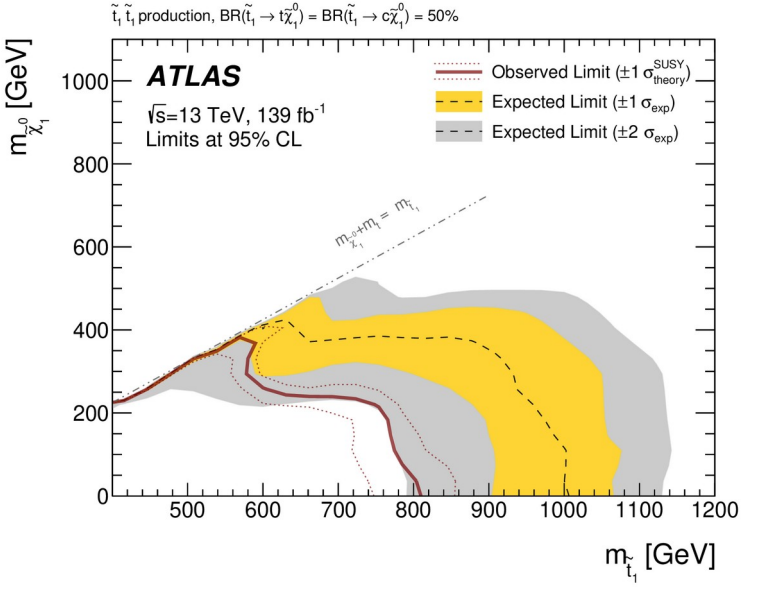
CERN-EP-2024-102

A charming alternative

- Flavour changing SUSY model => stops can decay to top or charm
- Search for 1 hadronic top (boosted or resolved) and 1 charm (dedicated tagger)
- Cuts on numerous kinematic variables
- SR categories targeting bulk, intermediate and compressed topologies
- CRs controlling rates of single top, Z and W boson and $t\bar{t}$ production







ATLAS EXPERIMENT

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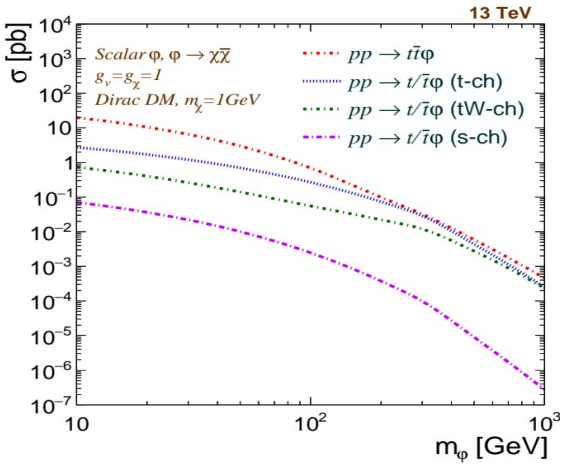
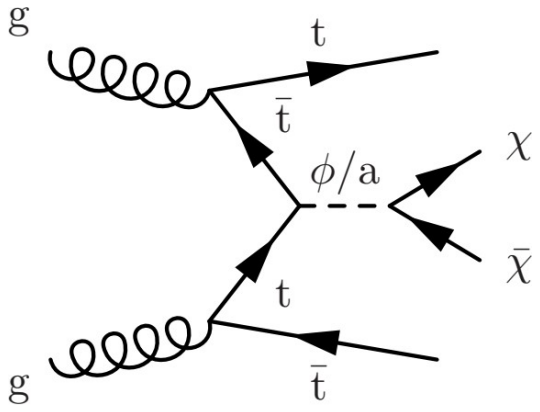
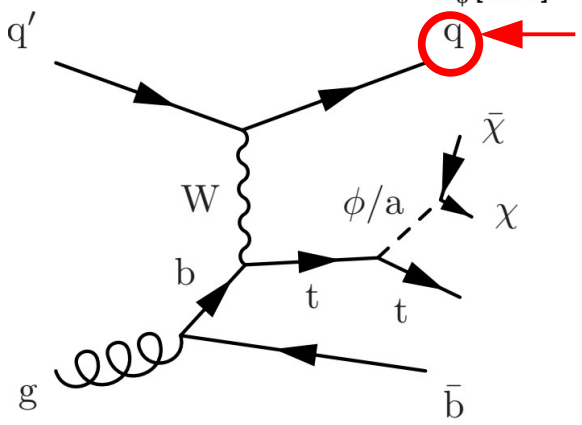
Putting it all together: t/$t\bar{t}$+DM

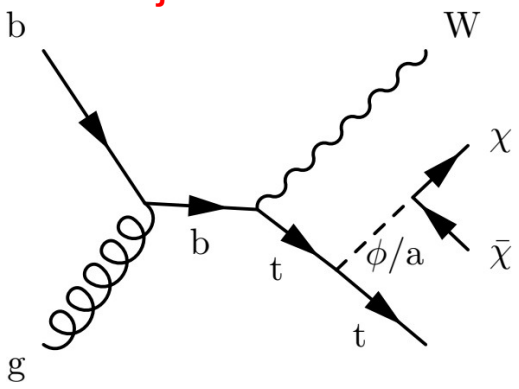
- Spin-0 DM models can produce both $t\bar{t}$+DM and single top + DM (t+DM)
- Particularly helpful for high mediator masses
- Much less boosted than mono-top
- Categorisation in number of b-jets and forward jets
- Combined search across all lepton channels

CMS-PAS-EXO-22-014





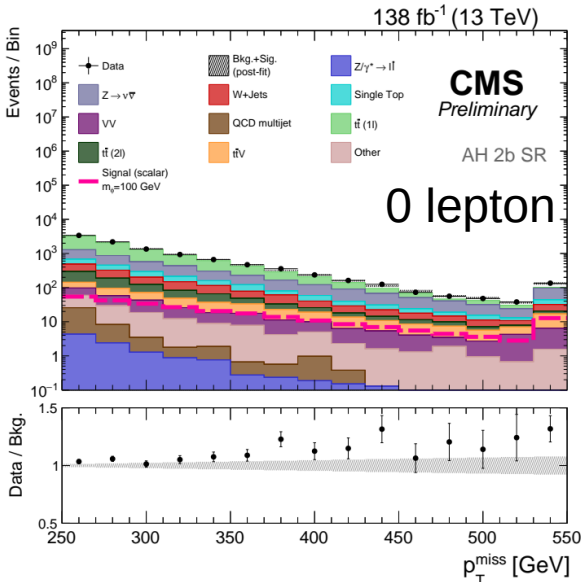


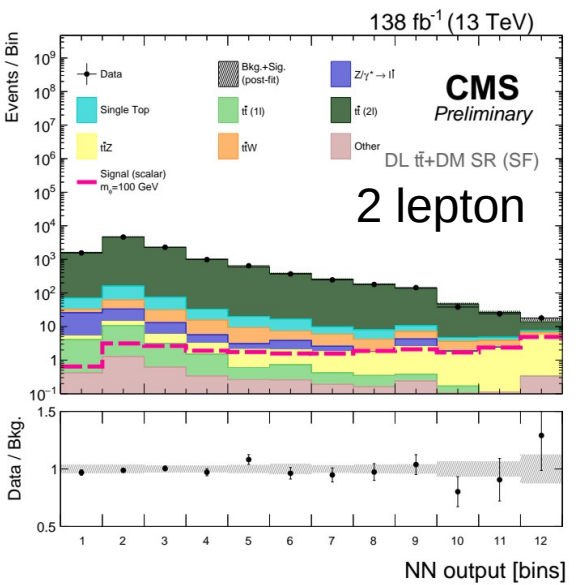


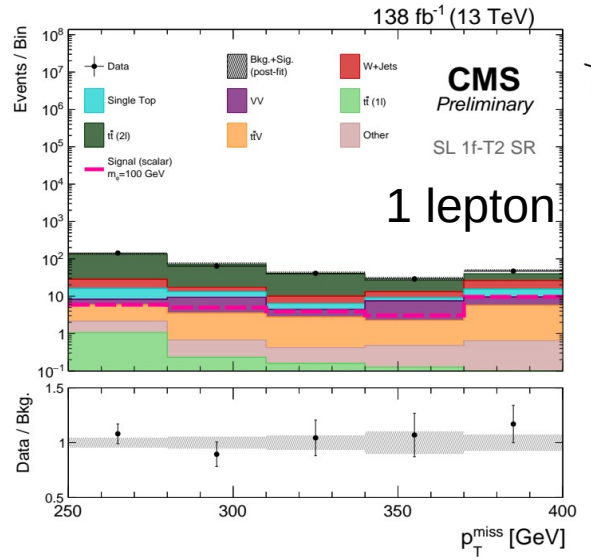
t/t̄t+DM

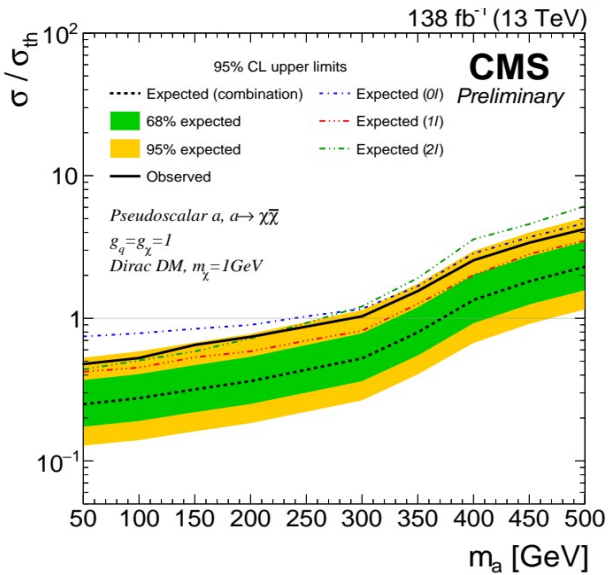
- 0 and 1 lepton channels use cuts on kinematic variables and fit on p_T^{miss}
  - Per-bin background estimation from CRs
  - Categorisation on “topness” variable in 1 channel
- p_T^{miss} less sensitive in 2 lepton channel due to two neutrinos in SM t̄t
  - Use NN to maximise sensitivity

CMS-PAS-EXO-22-014



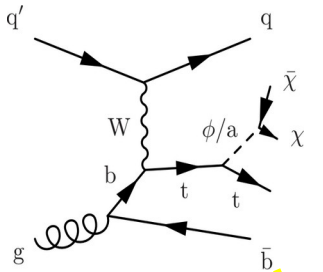


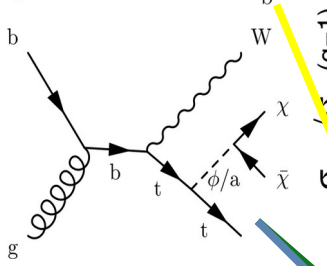


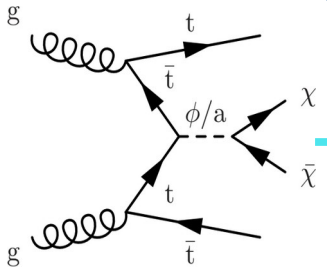


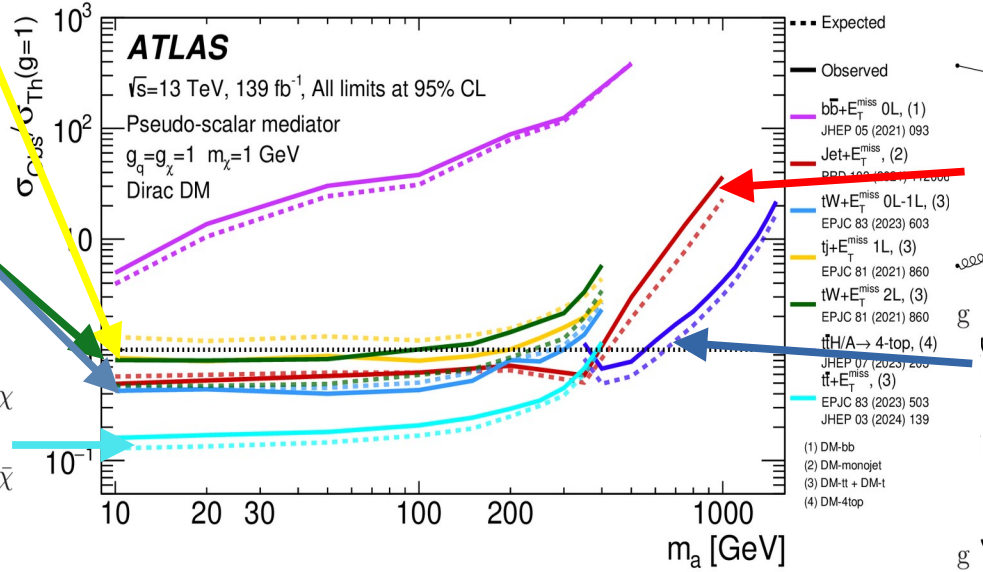
t/$\bar{t}$t+DM summary

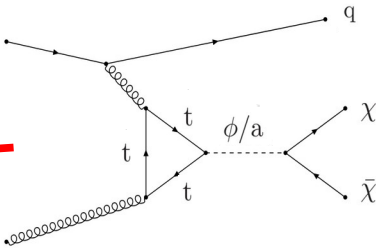
- Large amount of phase space explored
- However couplings < 1 also possible
- 4 top and $t\bar{t}$ resonance searches also sensitive (see last session)

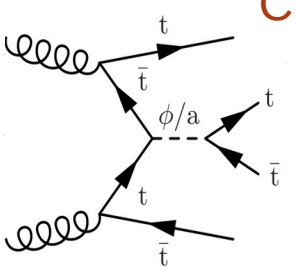


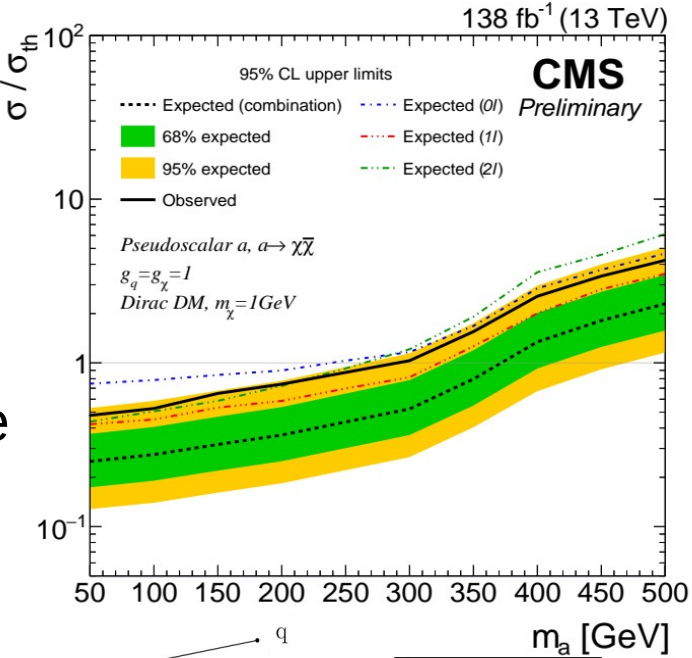


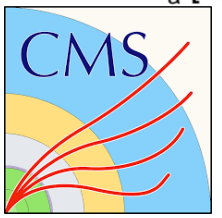












CMS-PAS-EXO-22-014

ATLAS EXPERIMENT

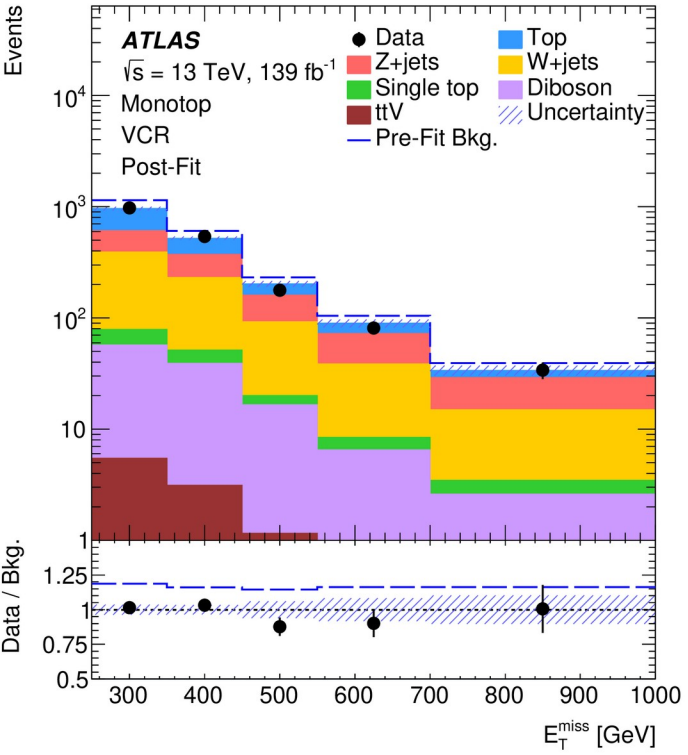
ATL-PHYS-PUB-2024-010

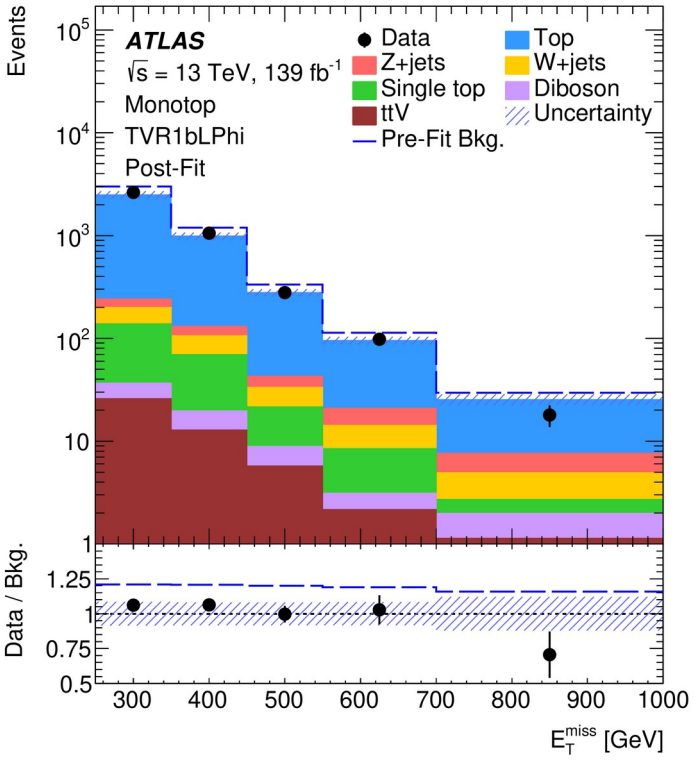
Conclusion and Outlook

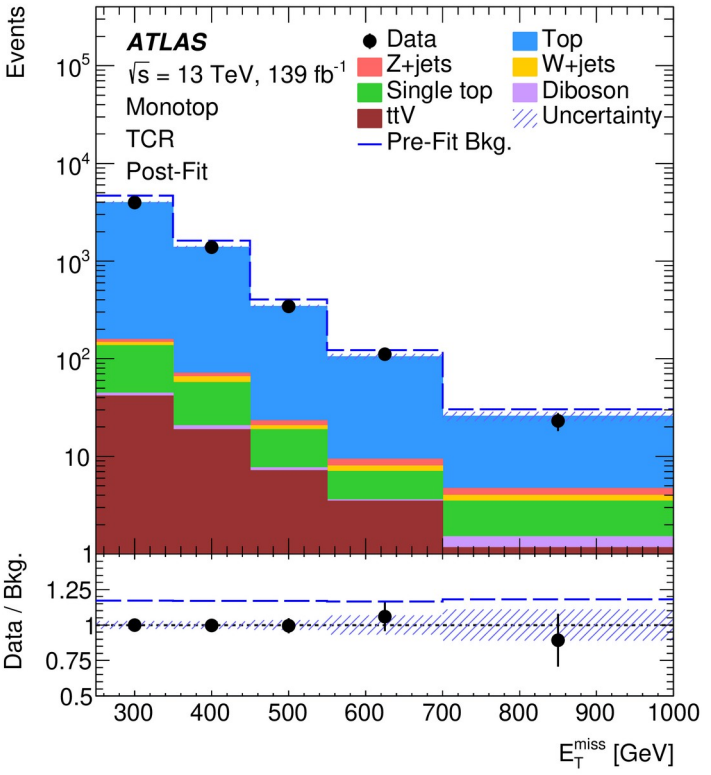
- Many models predict dark matter could appear in final states with top quarks
- Full Run 2 searches optimised with machine learning and advanced background estimation techniques
- Still phase space to be explored in Run 3 and beyond:
  - Many analyses still statistically limited
  - Cross sections for high mediator masses increase significantly with collider energy

Backup

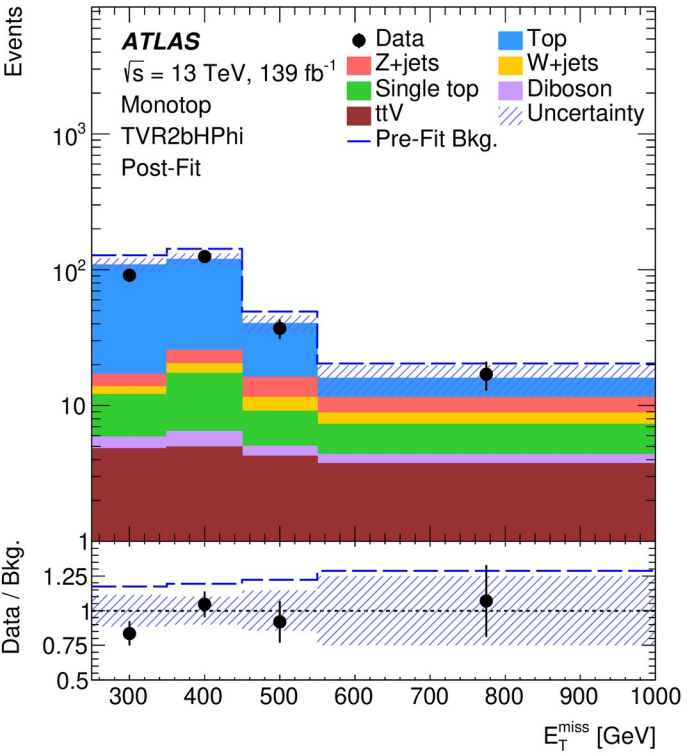
ATLAS Monotop CRs and VRs

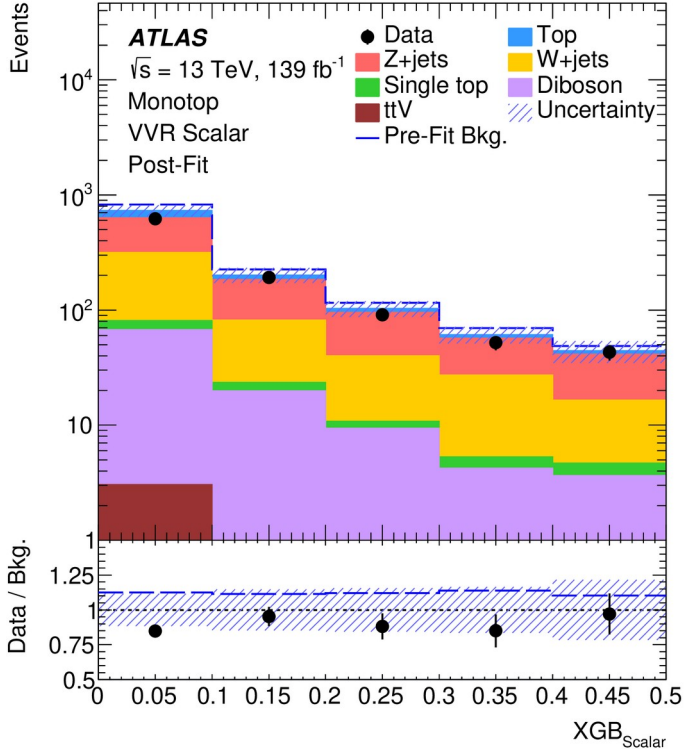


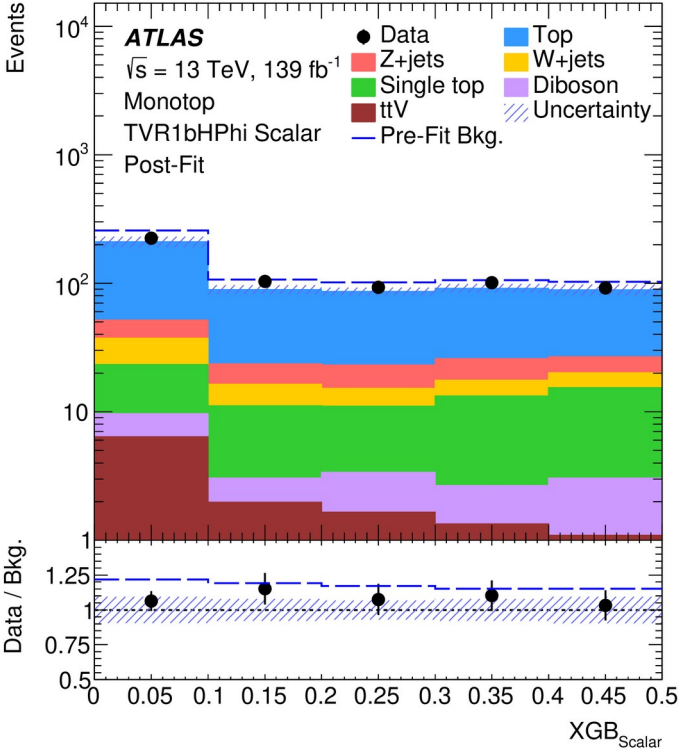




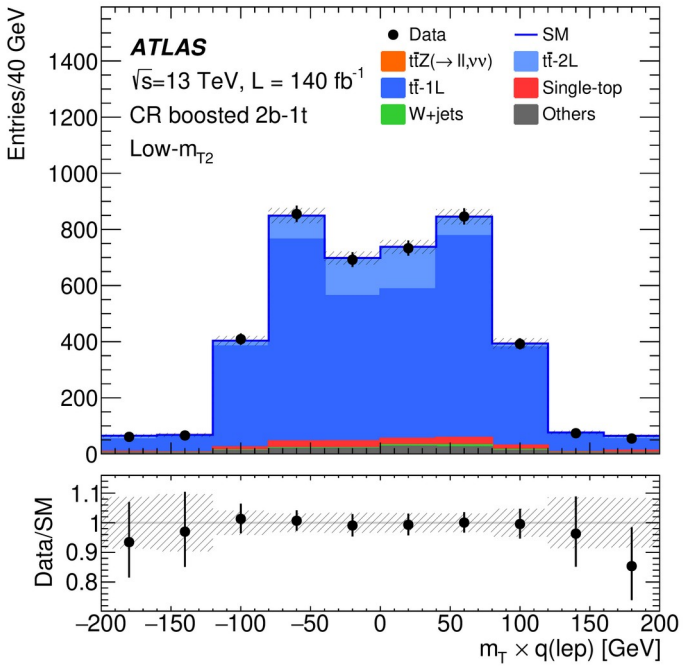
ATLAS Monotop CRs and VRs

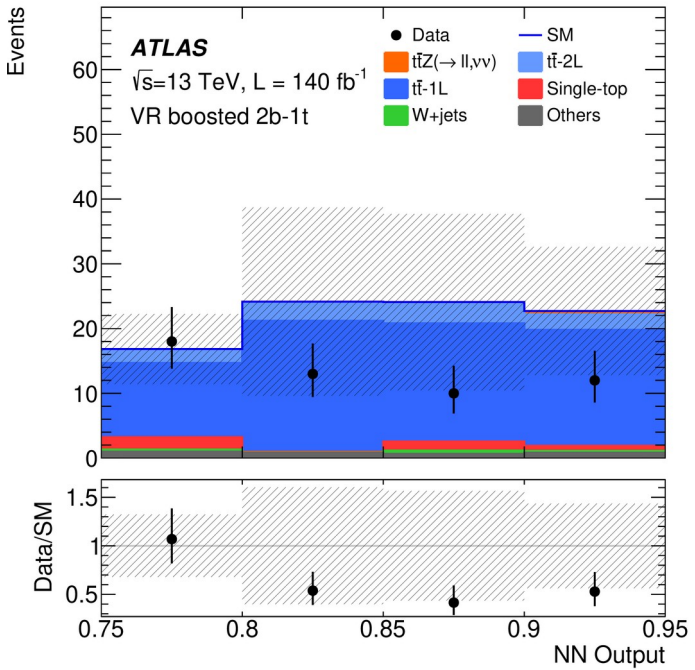


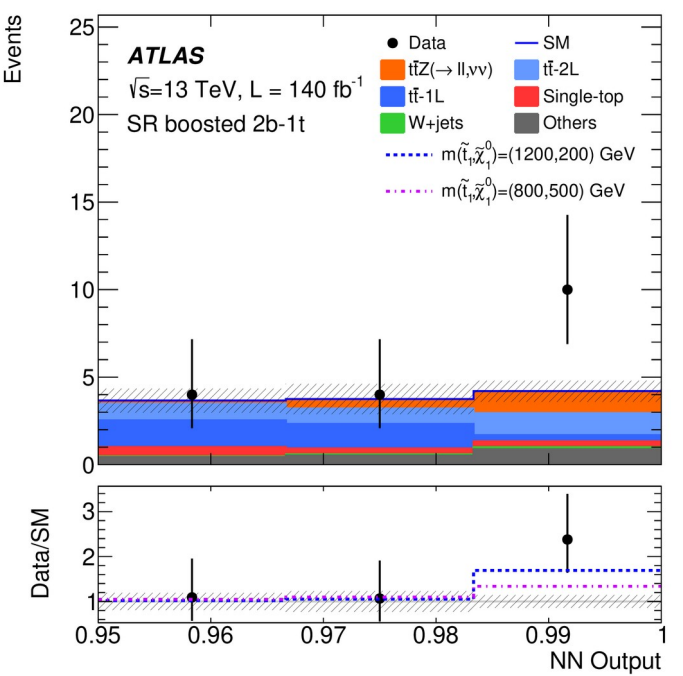




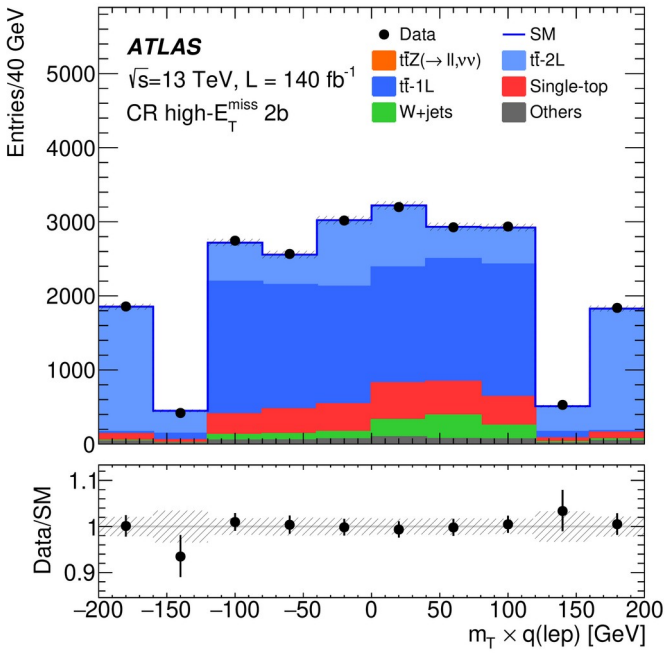
ATLAS 1l stop boosted 2b-1t regions

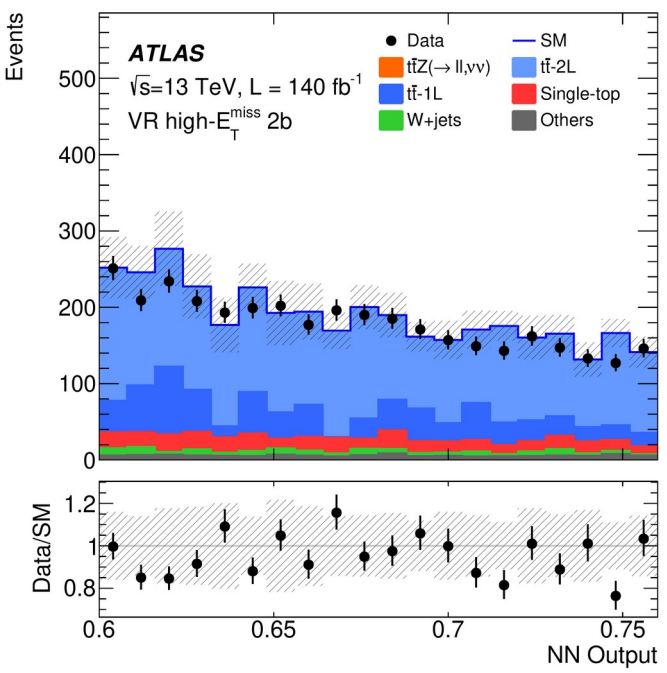


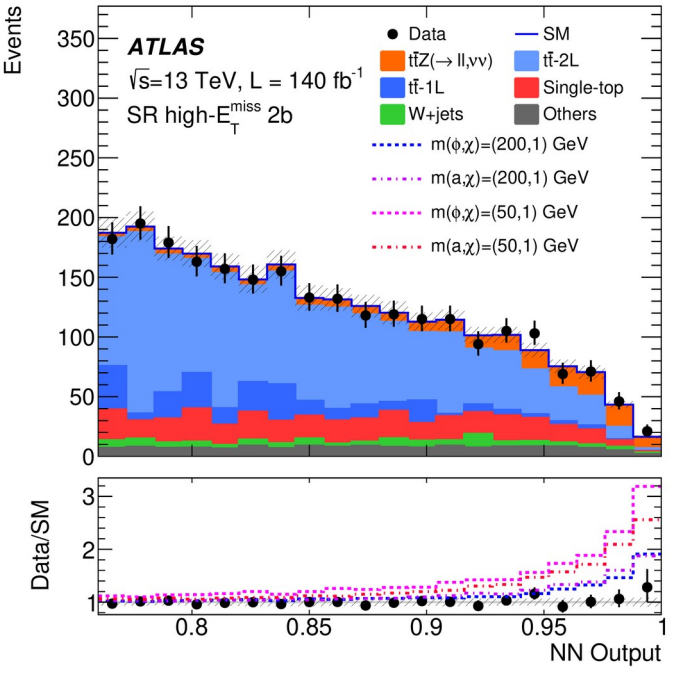




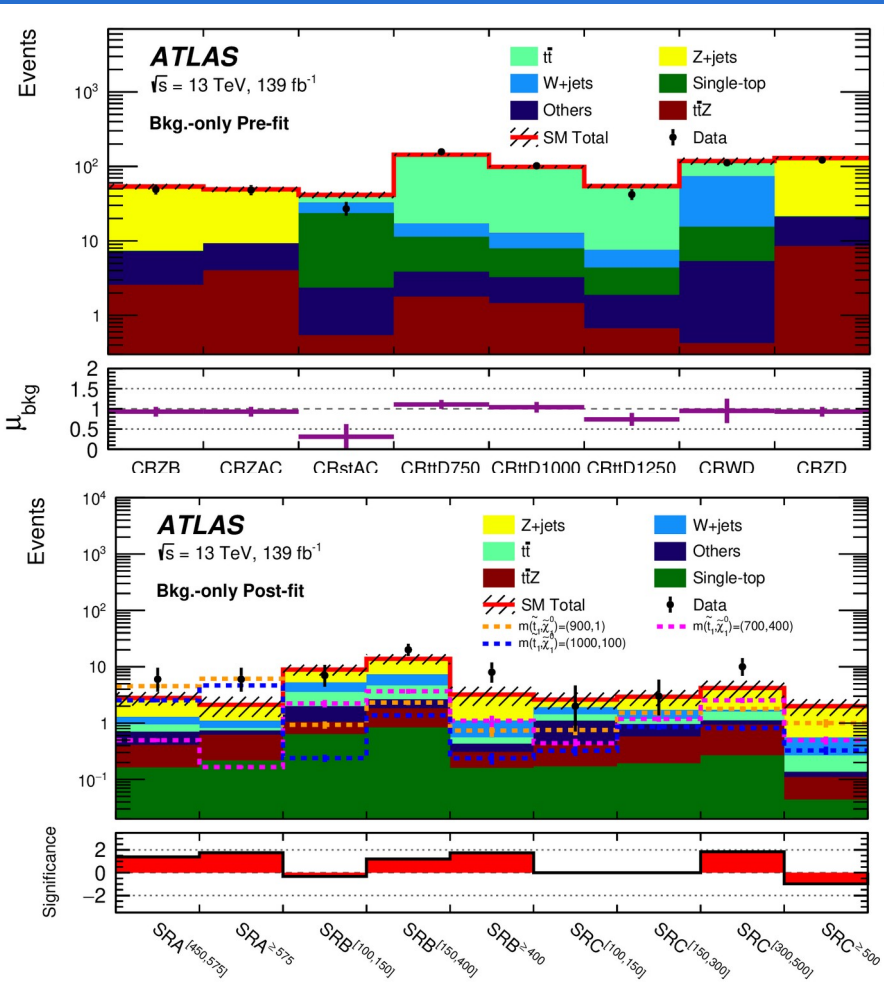
ATLAS 1l tt+DM 2b High E_T^{miss} regions

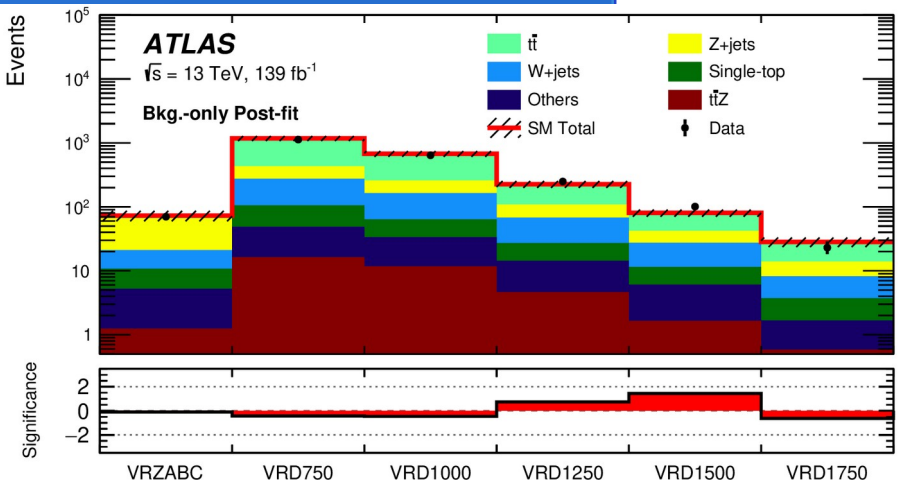


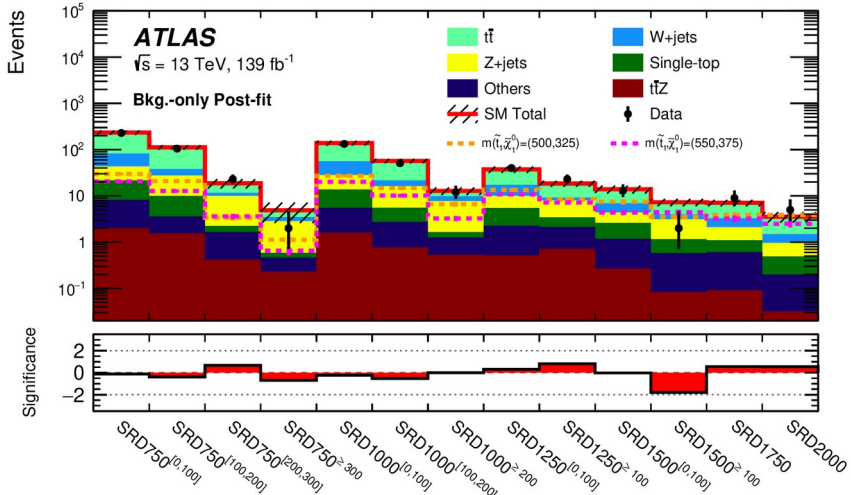




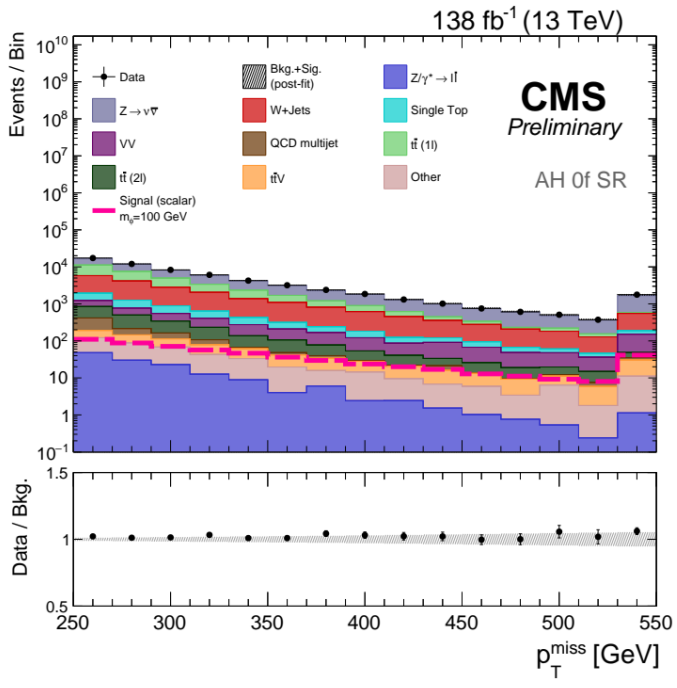
Stop → top+charm regions

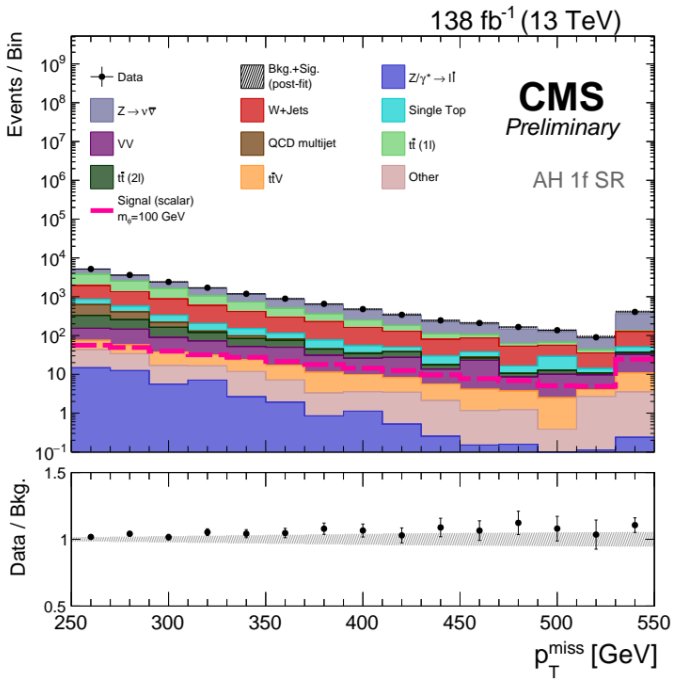


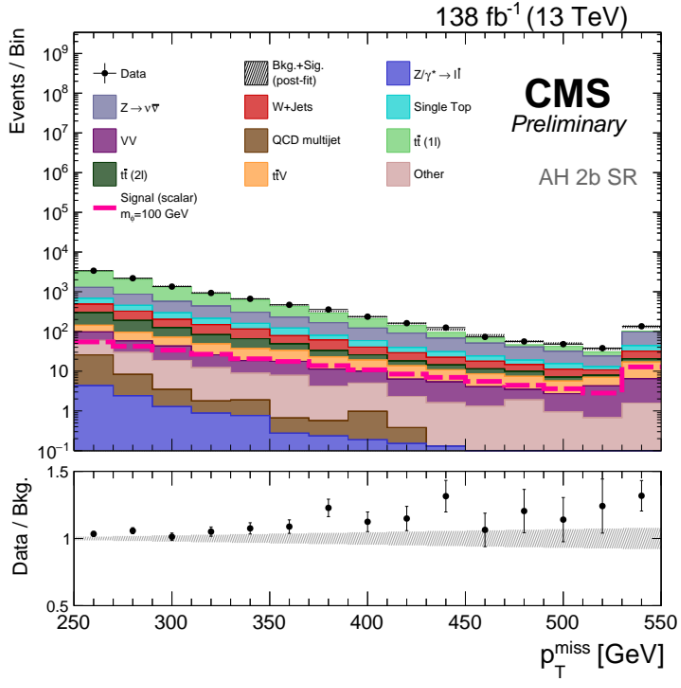




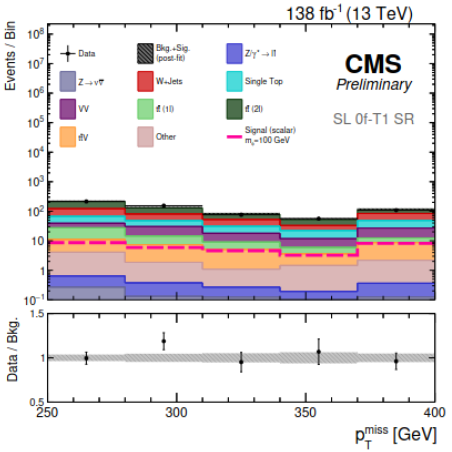
CMS t/t̄+DM 0 lepton SRs

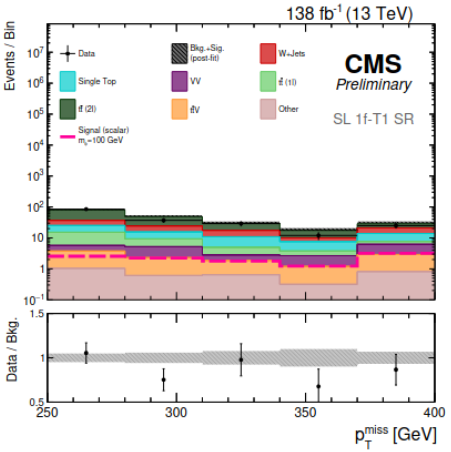


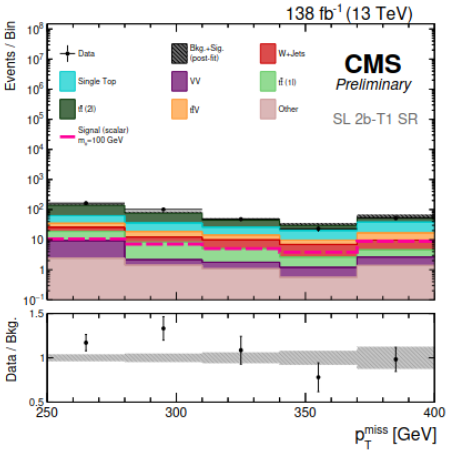


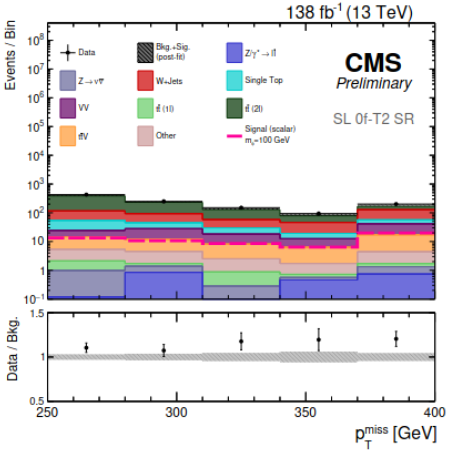


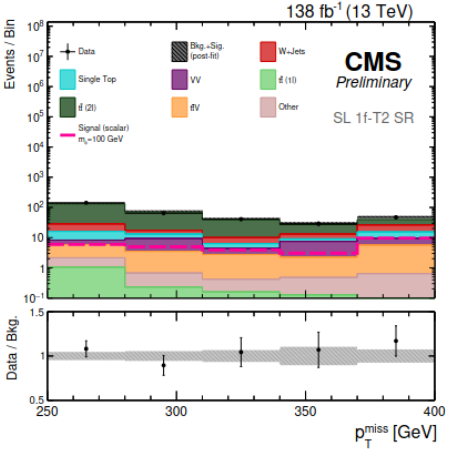
CMS t/$t\bar{t}$+DM 1 lepton SRs

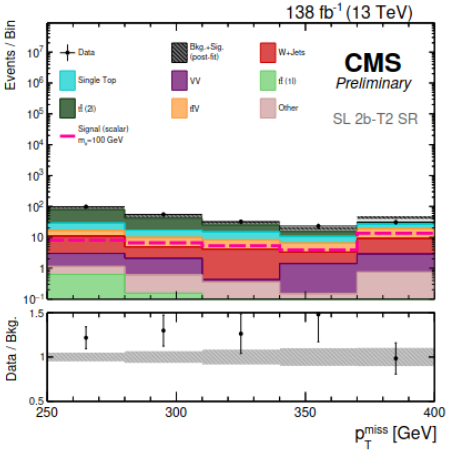












CMS t/t̄t+DM 2 lepton SRs