Search for new physics in final states with heavy-flavour quarks using the ATLAS detector

Hector de la Torre, On behalf of the ATLAS Collaboration

Michigan State University

ATLAS EXPERIMENT

MICHIGAN STATE UNIVERSITY

Searches with heavy flavour quarks in the final state

Final states with bottom and top quarks are a large part of the searches program in ATLAS and the LHC in general

Supersymmetry

Thursday BSM parallel

Generic resonance "bump" searches (Vector, Scalar, Pseudoscalar)

Yesterday BSM parallel

Leptoquarks

Tomorrow BSM parallel

Searches through top quark properties

Today Top and EW parallel

Vector-like quarks (VLQ)

Dark matter searches

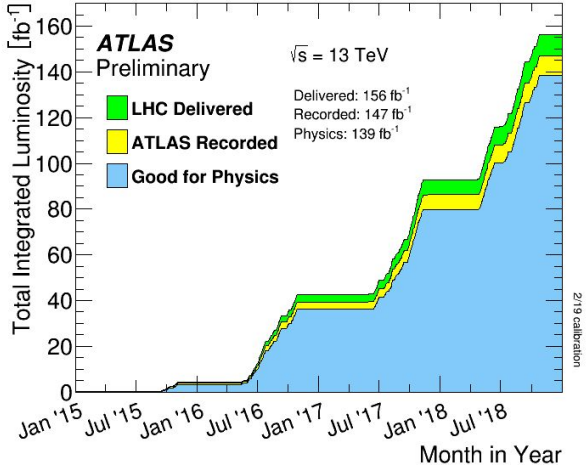
Yesterday DM parallel

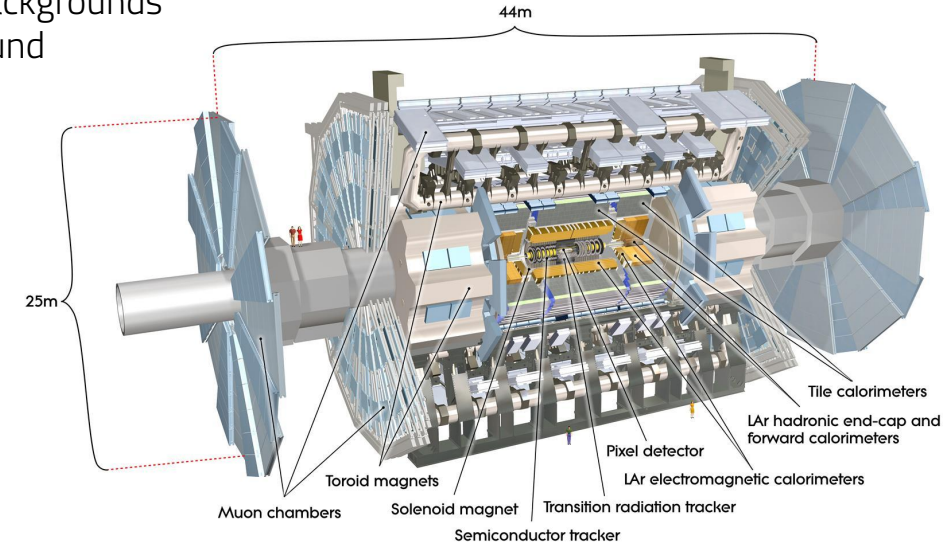
This talk focuses on two recent searches by the ATLAS collaboration:

- ***Search for $t\bar{t}$ resonances in fully hadronic final states***
- ***Search for dark matter associated with a single top quark***

Full Run 2 searches

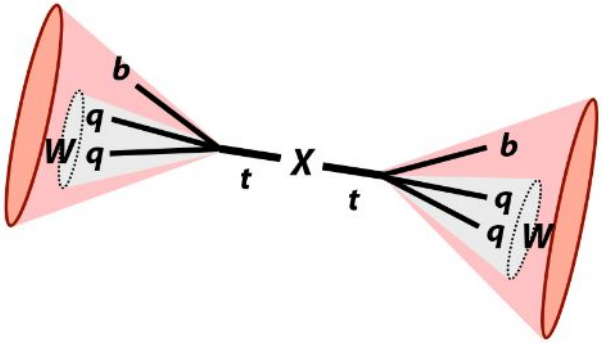
- Both searches shown today use the full Run 2 dataset (2015-2018), with a total of **139 fb^{-1}** of "good for physics" **ATLAS** data at **13 TeV.**
- Beyond the **increase in integrated luminosity**, they take advantage of the full range of improvements developed during and after Run 2
  - Better bottom and top-tagging performance
  - Better Monte-Carlo simulations for critical backgrounds
  - Data driven approaches to estimate background
  - Machine learning based analysis techniques





arXiv:2005.05138

Search for $t\bar{t}$ resonances in fully hadronic final states



- Search on the invariant mass of two large-R jets (Anti-Kt Calorimeter jets, R=1)
  - Both jets Top-tagged and associated to b-tagged jets
- **Bump-hunt** focused on high mass
  - Functional form to estimate background
- Interpretations
  - Top color assisted Technicolor Z' with three different widths
  - Vector axial mediator Z' for Dark matter models

- *Top-tagging: Deep Neural Network (DNN) with substructure variables as inputs*
- *b-tagging : DNN with impact parameters and topological properties as inputs.*
  - *On Variable R jets: Anti-kt Inner detector tracks with Effective radius R = ρ/P_T (ρ= 30 GeV)*

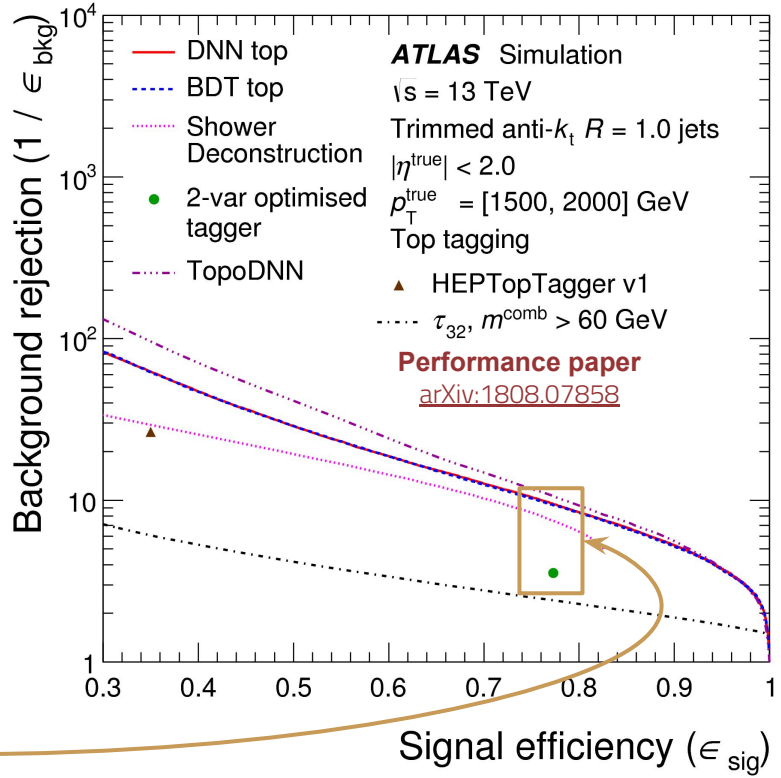
Improvements from partial run 2 analysis with 36.1 fb $^{-1}$

arXiv:1902.10077

arXiv:2005.05138

Search for $t\bar{t}$ resonances in fully hadronic final states

- First analysis using the new high level DNN top-tagger in ATLAS
  - Several jet-moment observables related to substructure as input to a DNN algorithm:
    - P_T, m^{comb}, $\sqrt{d_{12}}$, $\sqrt{d_{23}}$, τ_{21}, τ_{32} ...
- Large improvement over previous algorithms used by ATLAS
  - Better background rejection. Especially at **high mass**!



4 times better background rejection

arXiv:2005.05138

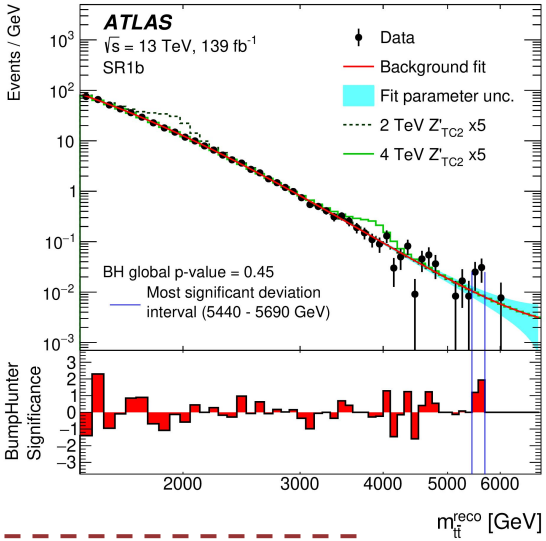
Search for $t\bar{t}$ resonances in fully hadronic final states

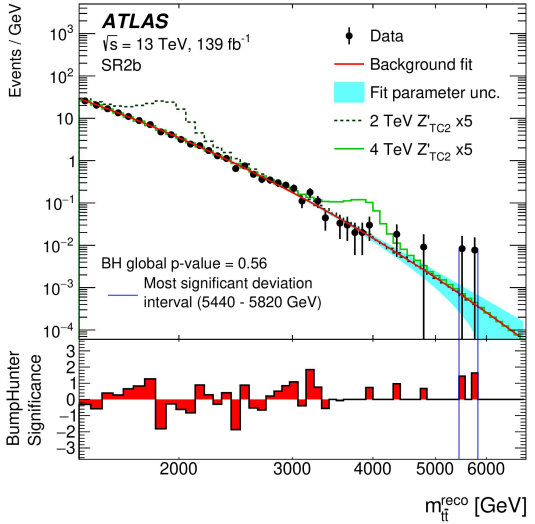
- Fully Data driven background. Global function fitted directly in the SRs
  - Functional form and uncertainties estimated using a template built using MC and Data driven mixture (ABCD Multijet + MC ttbar and Multijet).

$$F(x) = p_0(1-x)^{p_1}\, x^{p_2+p_3\log(x)+p_4\log(x)^2},$$

Event selection

- Large-R jet trigger
- 2 large-R jets with P_T > 350 GeV
  - J_1 with P_T > 500 GeV
- Lepton veto
- $\Delta\varphi(J_1,J_2)$ >1.6, $\Delta\eta(J_1,J_2)$ < 1.8
- Left plot: 1 Top candidate has associated b-tagged jet
- Right plot: 2 Top candidates have associated b-tagged jet

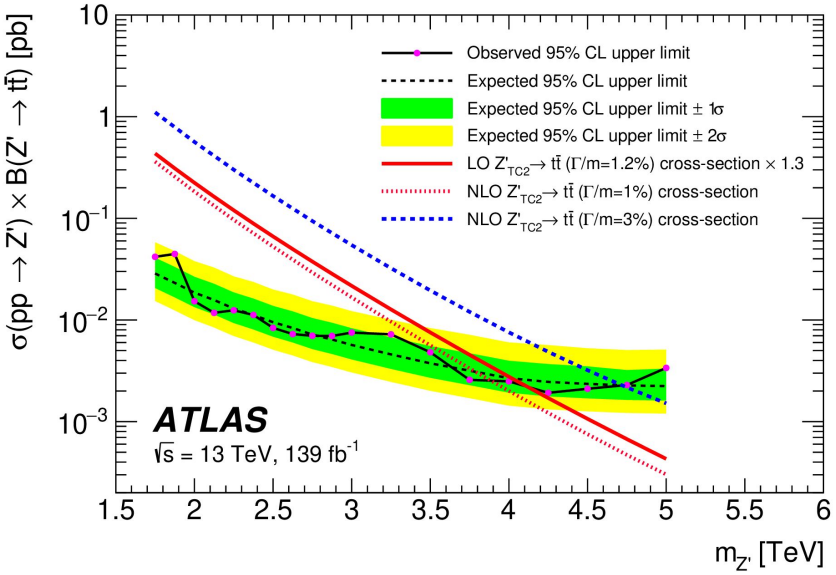




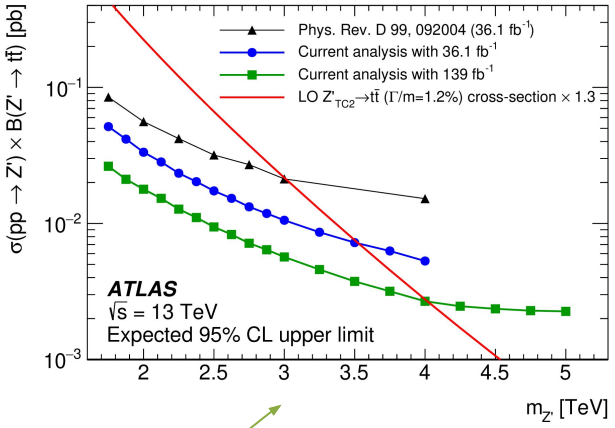
No significant deviation from the Standard Model

arXiv:2005.05138

Search for $t\bar{t}$ resonances in fully hadronic final states



exclusion of masses up to 3.9 TeV and 4.7 TeV for decay widths of 1% and 3%,respectively

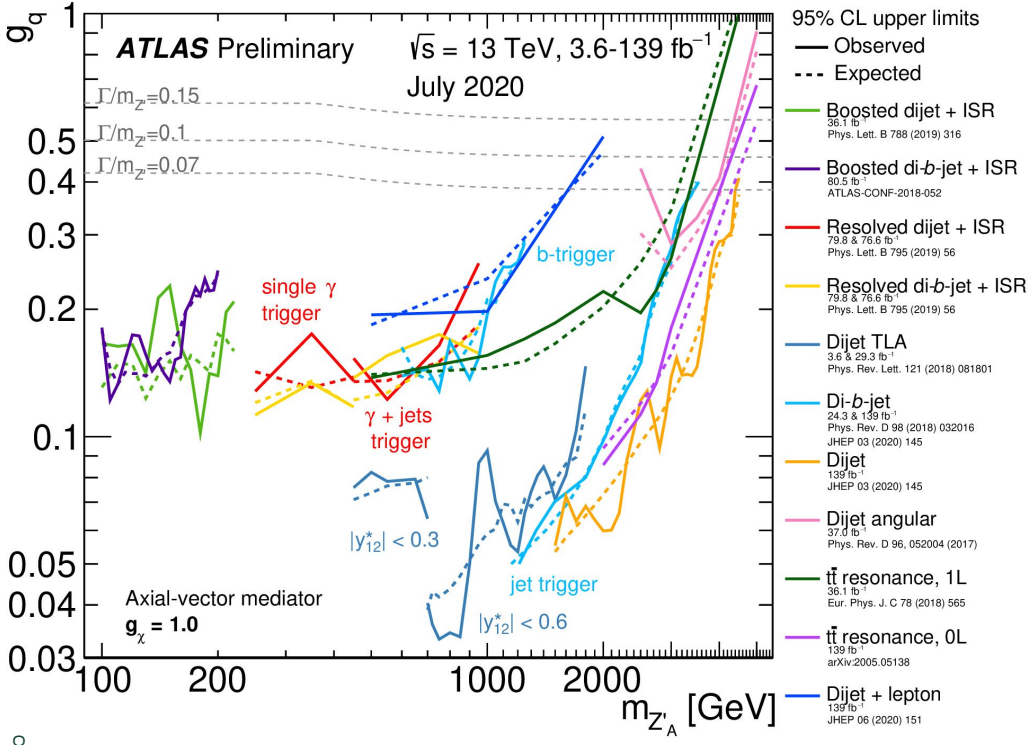


65% improvement in the expected cross-section limit at 4 TeV!

arXiv:2005.05138

Search for $t\bar{t}$ resonances in fully hadronic final states

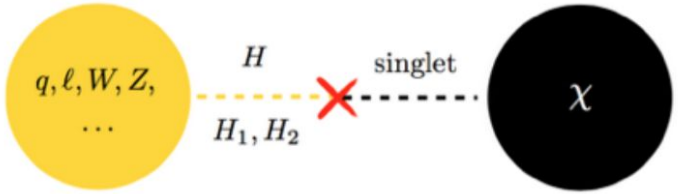
ATL-PHYS-PUB-2020-021



Leptophobic Z'_A axial-vector mediator model

Much more about dark matter ATLAS results in talk by Ben Carlson yesterday

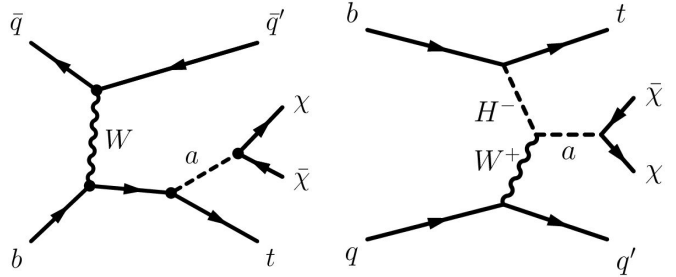
Search for dark matter associated with a single top quark



- **Search focused on studying 2HDM+a model**
  - CP-even bosons: h and H
  - CP-odd bosons: A,a
  - Charged bosons: H+,H-
  - Dirac DM candidate
  - Other major signatures: **mono-H** and **mono-Z**

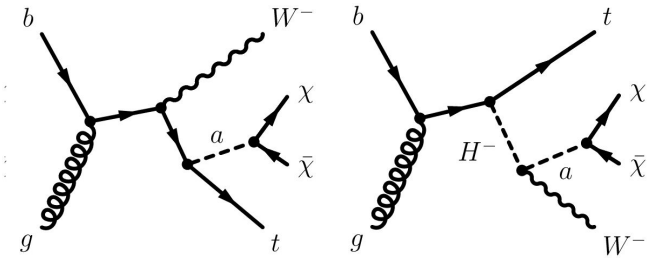
First time exploring this final state in ATLAS

1 lepton t-channel (tj1L)



1 lepton tW channel (tW1L)

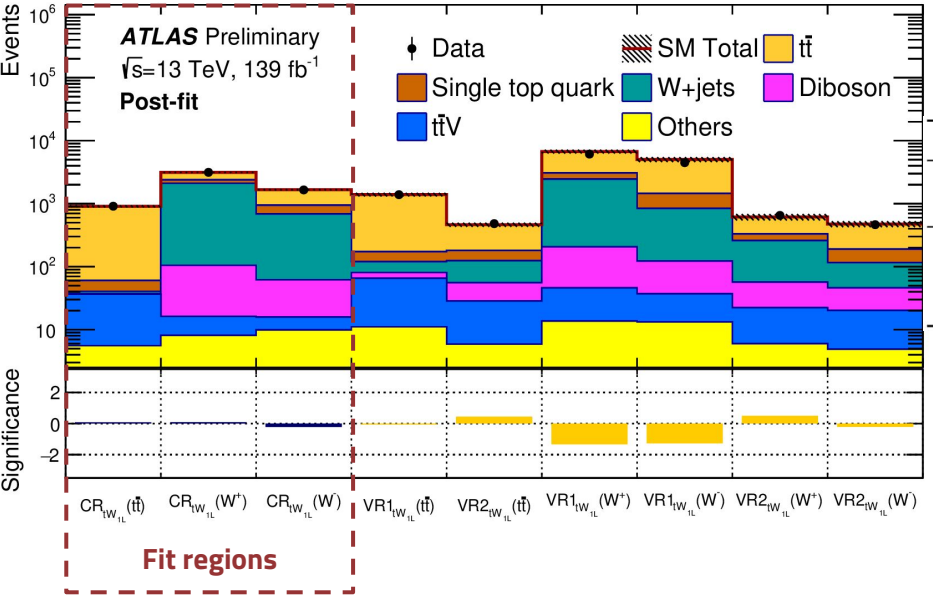
2 lepton tW channel (tW2L)



ATLAS-CONF-2020-034

Search for dark matter associated with a single top quark

- 1 lepton tW channel
  - E_T^{miss} trigger and 1 lepton + jets selection
  - Transverse quantities to improve sensitivity
    - Constructed with P_T^{miss} and other objects
  - Single bin control regions and validation regions for ttbar and W+jets estimation



- Preselection
  - One Isolated lepton
  - At least three jets
  - At least one b-jet
  - $E_T^{miss} > 200$ GeV
  - $M_t^{lep} > 30$ GeV

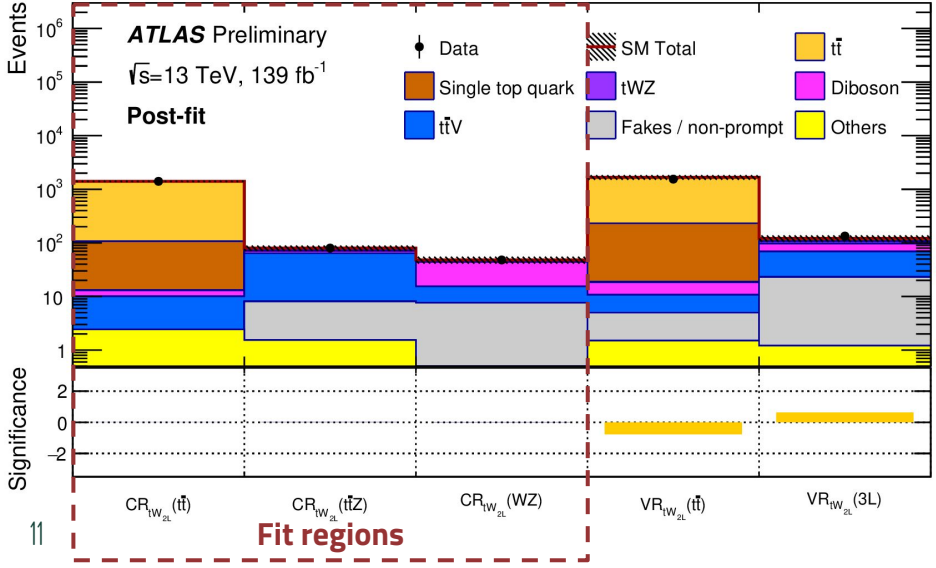
Variable [Unit]	SR	CR($t\bar{t}$)	CR(W)	VR1($t\bar{t}$)	VR2($t\bar{t}$)	VR1(W)	VR2(W)
$N_{b\text{-jet}}$	$= 1$	≥ 2	$= 1$	$= 1$	$= 1$	$= 1$	$= 1$
$p_T(b_2)$ [GeV]	< 50	> 50	< 50	< 50	< 50	< 50	< 50
$m_W^{reclustered}$ [GeV]	> 60	incl.	< 60	incl.	< 60	> 60	< 60
m_T^{lep} [GeV]	> 200	> 200	$\in [40, 100]$	> 200	> 200	$\in [40, 100]$	> 100
am_{T2} [GeV]	> 220	< 220	> 220	< 220	> 220	> 220	> 220

$M_W^{reclustered}$: Iterative reclustering of jets to find the hadronic W candidate with $R=m_W/P_T$(First step R=3.0)

ATLAS-CONF-2020-034

Search for dark matter associated with a single top quark

- 2 lepton tW channel
  - Di-lepton trigger and Opposite sign lepton + jets selection
  - Transverse and angular quantities to improve sensitivity
  - Single bin control regions and validation regions for tt, ttZ and WZ estimation



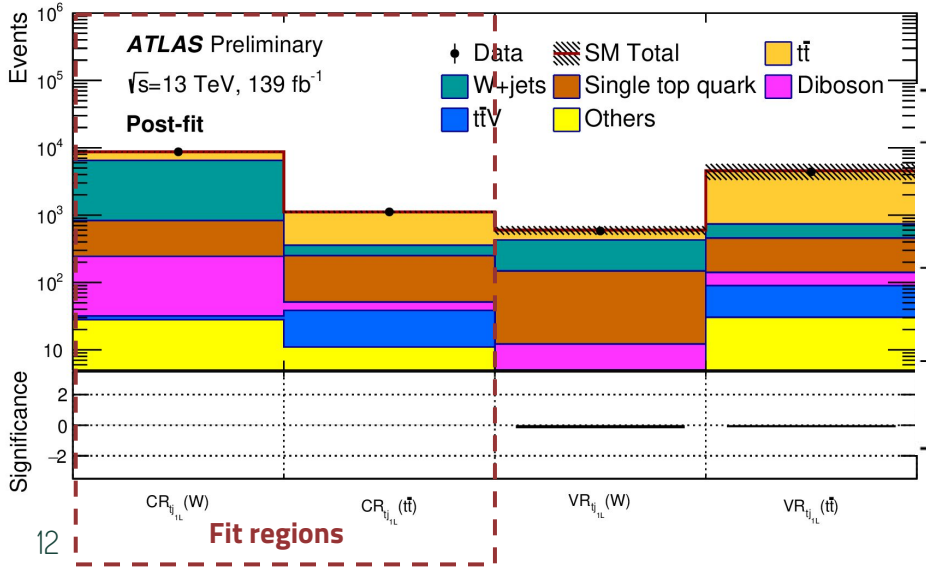
- Preselection
  - Two Isolated OS leptons
  - At least one b-jet
  - $E_T^{miss} > 250$ GeV
  - $M_t^{lep} > 30$ GeV
  - $m_{ll} > 40$ GeV, $m_{ll} \notin [71,111]$ if Same flavour

Variable [Unit]	SR	CR($t\bar{t}$)	CR($t\bar{t}Z$)	CR(WZ)	VR($t\bar{t}$)	VR(3ℓ)
N_ℓ^{signal}	$= 2$ (OS)	$= 2$ (OS)	$= 3$ (≥ 1 SFOS)	$= 3$ (≥ 1 SFOS)	$= 2$ (OS)	$= 3$ (≥ 1 SFOS)
$p_T(\ell_3)$ [GeV]	-	-	> 20	> 20	-	> 20
$m_{ee/\mu\mu}$ [GeV]	$\notin [71, 111]$	$\notin [71, 111]$	$\in [71, 111]$	$\in [71, 111]$	$\notin [71, 111]$	$\in [71, 111]$
N_{jet}	≥ 1	≥ 1	≥ 3	$\in [1, 3]$	≥ 1	≥ 1
$N_{b\text{-jet}}$	≥ 1	≥ 1	≥ 1 (≥ 2 if $N_{jet} = 3$)	$= 1$	≥ 1	≥ 1
$m_{b\ell}^{min}$ [GeV]	< 170	< 170	< 170	> 170	< 170	varies
$m_{b\ell}^{t}$ [GeV]	> 150	< 150	incl.	incl.	> 150	incl.
m_{T2} [GeV]	> 130	$\in [40, 80]$	> 90	> 90	$\in [40, 80]$	> 90
$\Delta\phi_{min}$ [rad]	> 1.1	> 1.1	incl.	incl.	> 1.1	incl.

ATLAS-CONF-2020-034

Search for dark matter associated with a single top quark

- 1 lepton t-channel
  - E_T^{miss} and lepton trigger combination, lepton + jet selection
  - **Boosted decision tree (BDT) with 9 variables**:
    - leading jet, transverse quantities and lepton-bjet system.
  - Single bin control regions and validation regions for ttbar and W+jets estimation

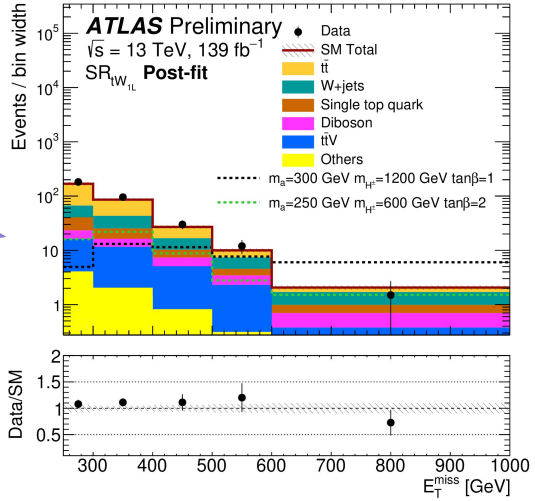


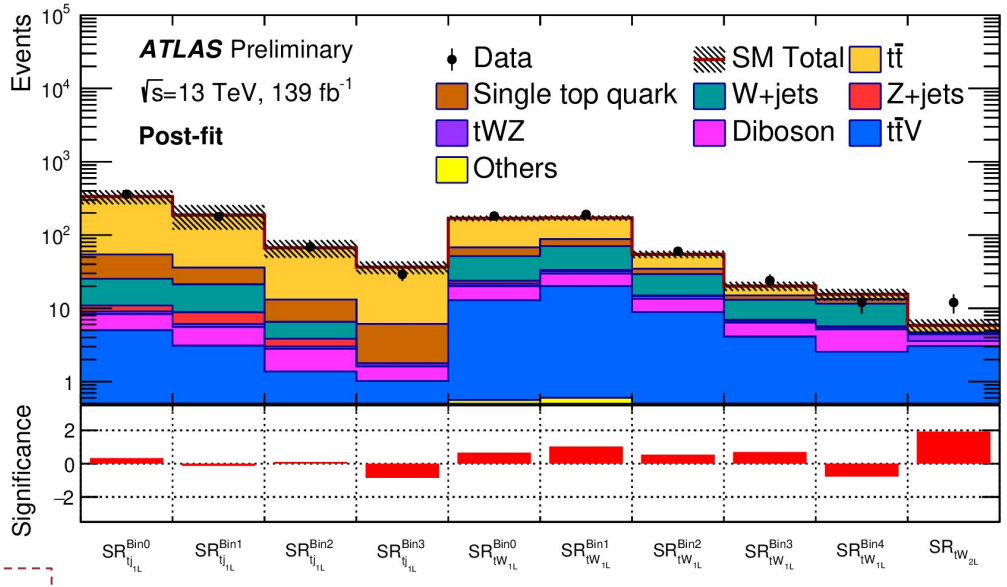
- Preselection
  - One Isolated lepton
  - Between one and four jets
  - Between one and 2 b-jets
  - $E_T^{miss} > 200$ GeV
  - $M_T^{lep} > 60$ GeV

Variable [Units]	SR	CR($t\bar{t}$)	CR(W)	VR($t\bar{t}$)	VR(W)
N_{jet}	$\in [1,4]$	$\in [1,4]$	$\in [1,2]$	$\in [1,4]$	$\in [1,2]$
$N_{b\text{-jet}}$	$\in [1,2]$	$= 2$	$= 1$	$\in [1,2]$	$= 1$
$N_{jet}^{forward}$	> 0	incl.	incl.	incl.	incl.
E_T^{miss} [GeV]	> 225	> 225	> 225	> 225	> 225
m_T^{lep} [GeV]	> 100	> 100	$\in [60,100]$	> 100	$\in [60,100]$
$\Delta\phi(\ell_1, b_1)$ [rad]	< 1.2	> 1.5	> 1.5	< 1.5	< 1.5
BDT score	> 0.6	incl.	incl.	< 0.5	incl.

Search for dark matter associated with a single top quark

- A total of ten signal regions. Background estimation from CR-only fit.
  - tj1L: 4 bins in BDT output (>0.6)
  - tW1L: 5 bins in E_T^{miss}
  - tW2L: Single bin SR



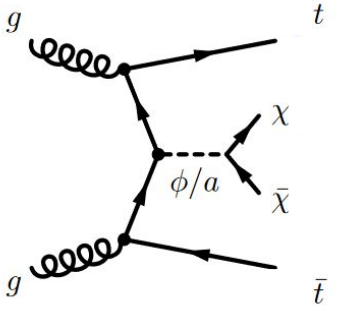


Good agreement with the SM background prediction

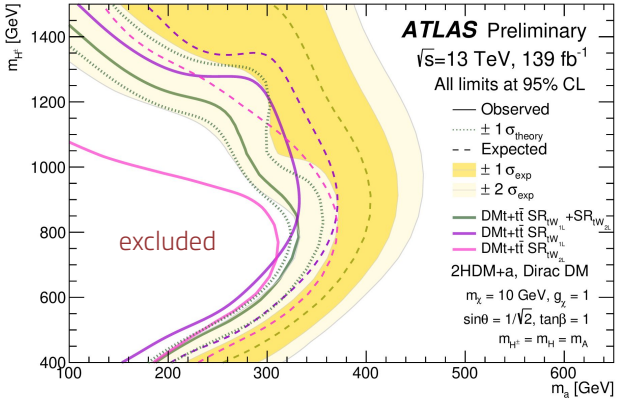
ATLAS-CONF-2020-034

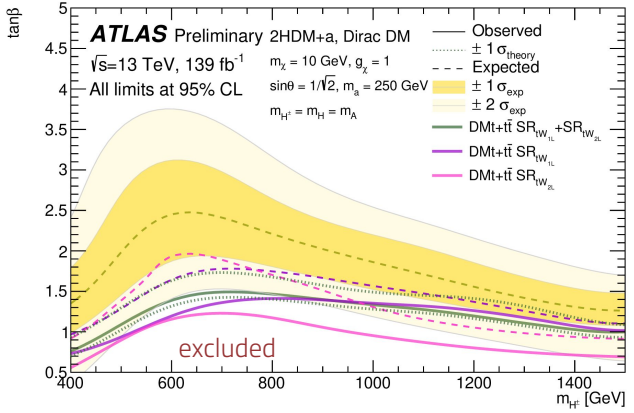
Search for dark matter associated with a single top quark

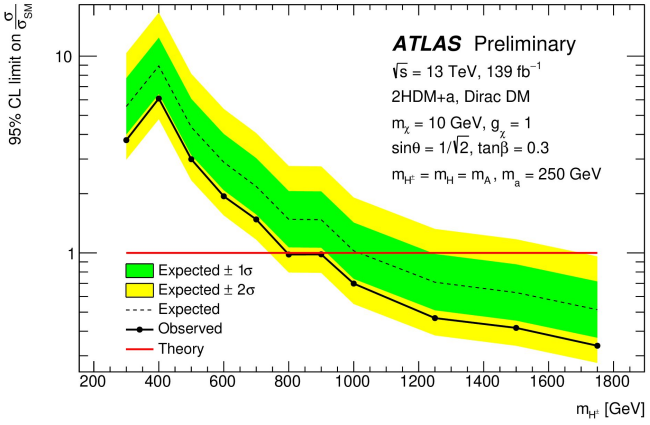
Statistical combination between tw1L and tw2L channels

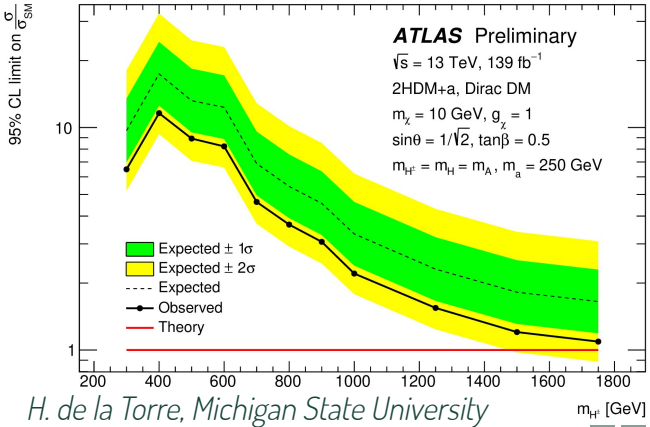


Sensitivity of tj1L smaller due to small t-channel cross section









H. de la Torre, Michigan State University

ATLAS-CONF-2020-034

Search for dark matter associated with a single top quark

Inclusive discovery regions

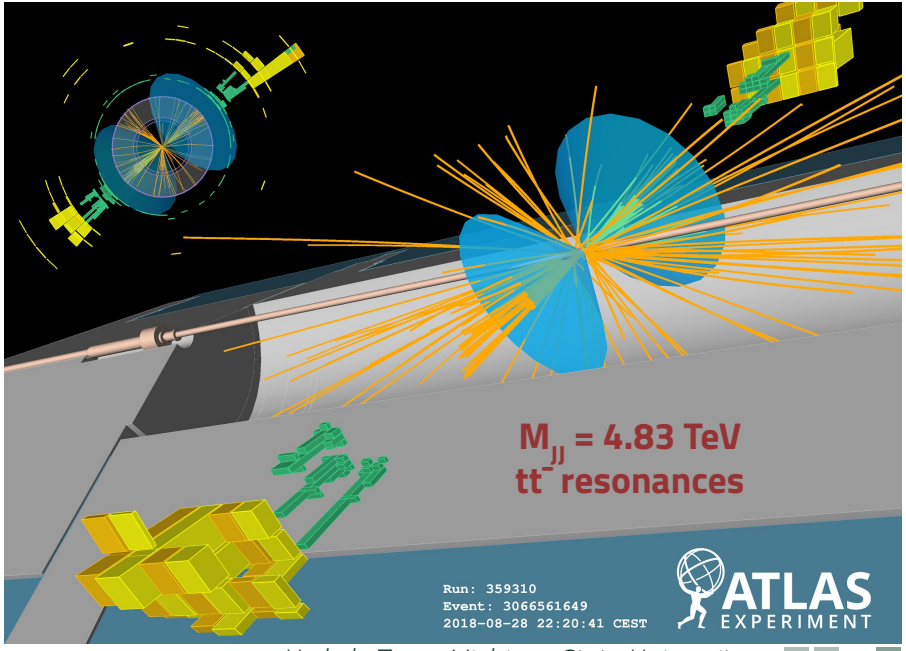
- **tw1L: Events above 5 E_T^{miss} thresholds**
- **tw2L: Same signal region**
- **tj1L: BDT > 0.9**

Signal channel	Limit on visible cross section $\langle\epsilon\sigma\rangle^{95}_{obs}$[fb]	Limit on number of signal events S^{95}_{obs}	Limit on number of signal events given the expected number of background events S^{95}_{exp}	Confidence level for B-only hypothesis CL_B	Probability of the standard model to fluctuate to the observed number of events $p(s=0)$ (Z)
$SR^{250}_{tW_{1L}}$	0.72	100.6	$66.7^{+32.7}_{-16.4}$	0.85	0.12 (1.16)
$SR^{300}_{tW_{1L}}$	0.51	70.8	$54.1^{+16.0}_{-15.9}$	0.85	0.15 (1.02)
$SR^{400}_{tW_{1L}}$	0.24	32.9	$29.4^{+10.1}_{-6.4}$	0.64	0.30 (0.52)
$SR^{500}_{tW_{1L}}$	0.14	18.9	$18.7^{+7.6}_{-4.9}$	0.52	0.45 (0.13)
$SR^{600}_{tW_{1L}}$	0.08	10.6	$12.0^{+2.7}_{-3.6}$	0.24	0.50 (0.00)
$SR_{tW_{2L}}$	0.10	13.8	$7.3^{+2.9}_{-1.1}$	0.97	0.02 (2.07)
$SR_{tj_{1L}}$ (BDT>0.9)	0.10	14.4	$18.7^{+5.9}_{-4.6}$	0.24	0.50 (0.00)

Summary

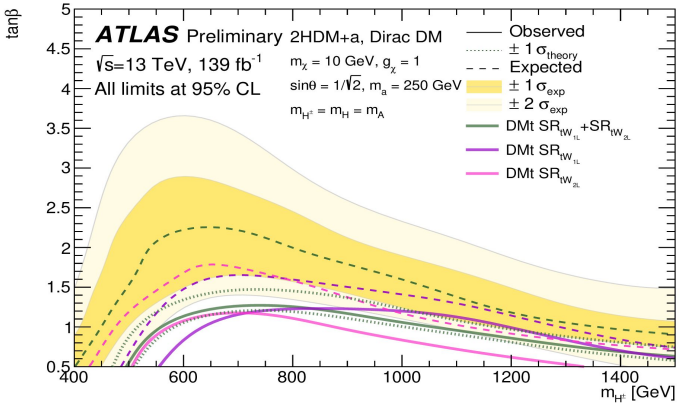
- Presented two latest searches from the extensive field of searches with 3rd generation quarks in the final state
  - Search for $t\bar{t}$ resonances in fully hadronic final states
  - Search for dark matter associated with a single top quark

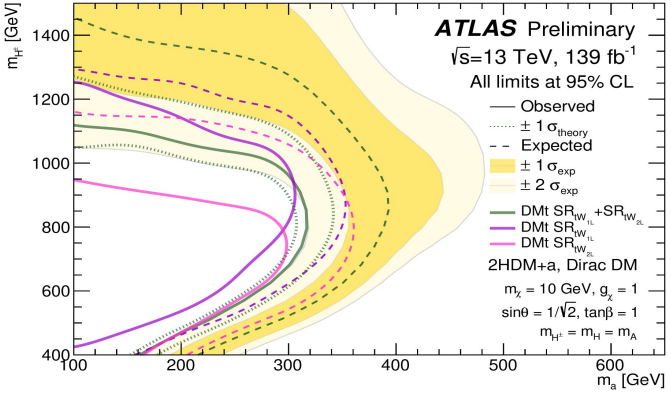
- Both 13 TeV searches take advantage of the latest advances in experimental techniques and the full Run 2 dataset
- New top-tagging and b-tagging provide large improvements for the ttbar 0L search
  - 65% improvement in the expected cross-section limit at 4 TeV!
- A new search with focus on 2HDM+a model explores new process with pseudo-scalar production together with a single top quark
  - Three different channels, model independent results and 2HDM+a limits!

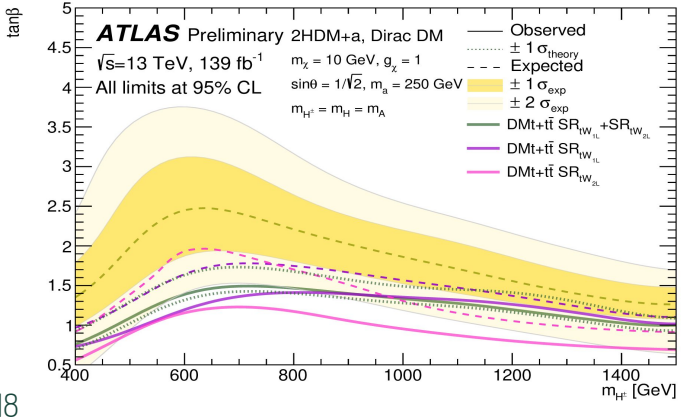


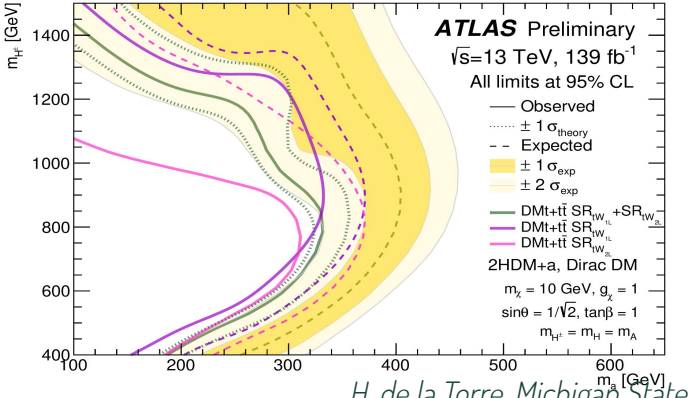
BACKUP

Monotop limit plots with only DMt





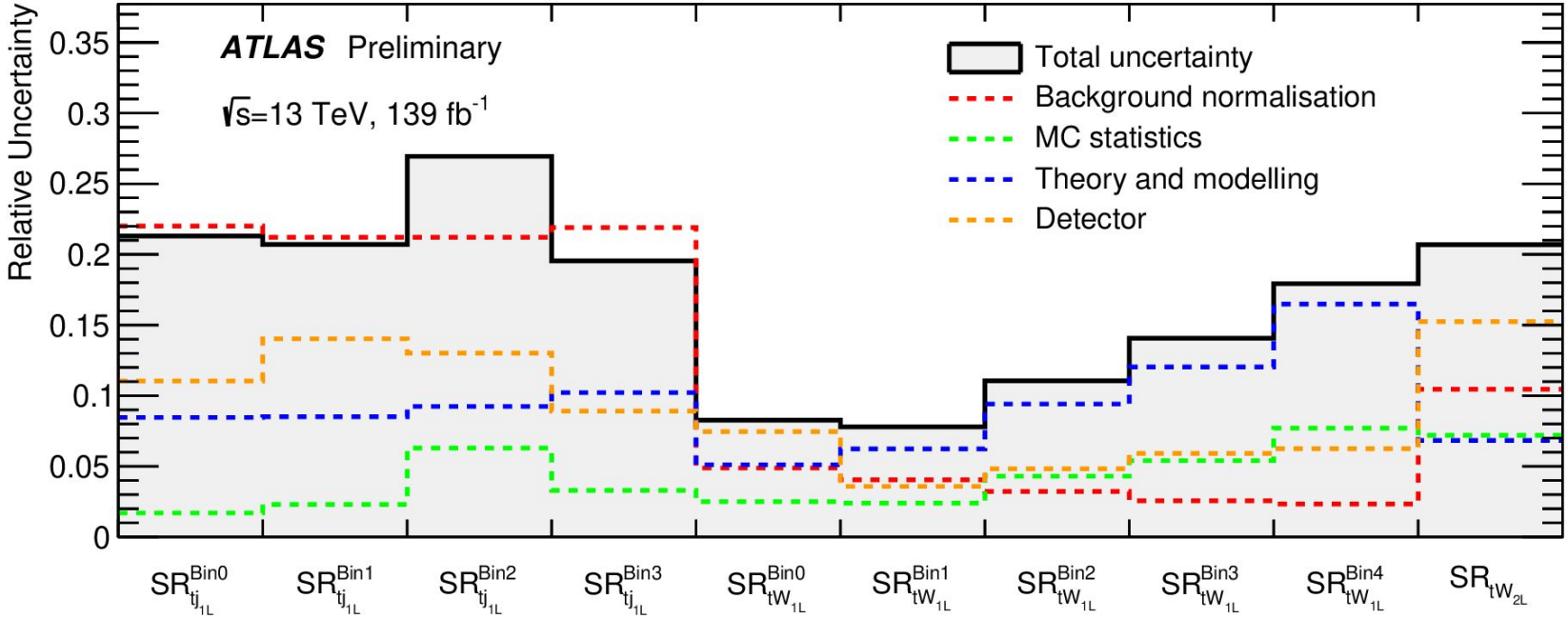




Preselection table for monotop analysis

Variable	tW_{1L}	tW_{2L}	tj_{1L}
Trigger	E_T^{miss}	di-lepton	E_T^{miss} OR one-lepton
N_ℓ^{signal}	$= 1$	$= 2$ (OS)	$= 1$
$p_T(\ell_1)$ $[GeV]$	> 30	> 25	> 30
$p_T(\ell_2)$ $[GeV]$	-	> 20	-
N_{jet}	≥ 3	≥ 1	$\in [1, 4]$
p_T(jet) [GeV]	> 30	> 30	> 30
$N_{b\text{-jet}}$	≥ 1	≥ 1	$\in [1, 2]$
$p_T(b_1)$ [GeV]	> 50	> 50	> 50
E_T^{miss} $[GeV]$	> 250	> 200	> 200
m_T^{lep} $[GeV]$	> 30	-	> 60
$m_{\ell\ell}$ $[GeV]$	-	≥ 40	-
	-	$\notin [71, 111]$ $(ee/\mu\mu)$	-
$\Delta\phi_{min}$ [rad]	> 0.5	-	> 0.5

Uncertainty breakdown for monotop analysis



Acceptance x efficiency for tt resonances