Measurements of top quark production cross-sections with the ATLAS detector

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ATLAS EXPERIMENT

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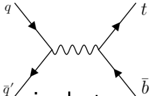
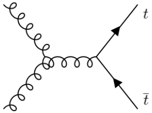
Introduction

In pp collisions, top quarks are produced predominantly in pairs via QCD or singly via EW interactions.



single-top

The large top-production cross section at the LHC results in high-statistics samples that enable unique tests of the SM and searches for new phenomena.



$t\bar{t}$

Motivation

Single-top production is a powerful probe of the top-quark electroweak couplings.

Measurements of the $t\bar{t}$-production cross section allow tests of QCD at the highest accessible energy scales:

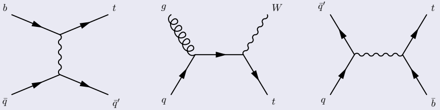
- predictions are available at NNLO QCD, including resummation of NNLL soft-gluon terms.
- $t\bar{t}$ measurements have been used to constrain the proton PDFs.

$t\bar{t}$-production: sensitive to new physics and dominant background in BSM searches.

Introduction

Single-top production and $t\bar{t}$ decay channels and their background processes:

single-top production channels

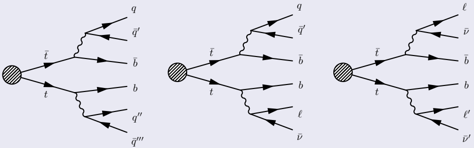


t-channel

Wt-channel

s-channel

top-pair decay channels



all-hadronic

semileptonic

dileptonic

single-top backgrounds

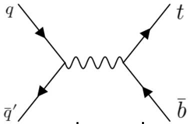
- $t\bar{t}$
- other single-top (t-channel, Wt)
- W+jets
- Z+jets
- diboson
- multijets

top-pair backgrounds

- single-top
- $t\bar{t}V$ and $t\bar{t}H$
- W+jets
- Z+jets
- diboson
- multijets

Measurement of single top-quark production in the s-channel in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector [arXiv: 2209.08990]

The dominant Feynman diagram for s-channel single top-quark production is $q\bar{q}' \to t\bar{b} \to Wb\bar{b}$.



s-channel

Observation of s-channel production by CMS at $\sqrt{s} = 7$ and 8 TeV with 2.5σ significance and by ATLAS at $\sqrt{s} = 8$ TeV with 3.2σ significance.

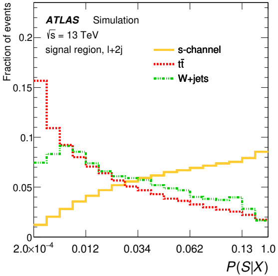
In the new ATLAS analysis using $\mathcal{L} = 139$ fb^{-1} at $\sqrt{s} = 13$ TeV, measurement of single-top production in leptonic channel:

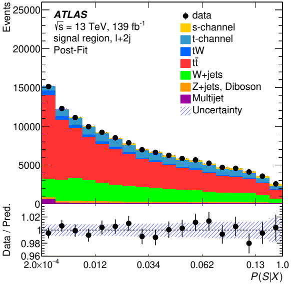
- experimental signature: isolated e or μ, large missing transverse momentum (due to undetected ν from W decay) and two b-tagged jets.

Measurement of single top-quark production in the s-channel in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector [arXiv: 2209.08990]

Signal extraction: discriminant based on simulations to separate signal from background.

The production cross section is measured using a binned profile maximum-likelihood fit of the discriminant in the signal region.





Cross-section:

Measurement: $\sigma = 8.2^{+3.5}_{-2.9}$ pb $\rightarrow$ 3.3σ (observed)

NLO Prediction: $\sigma_{NLO} = 10.32^{+0.40}_{-0.36}$ pb $\rightarrow$ 3.9σ (predicted)

Significance:

Measurements of inclusive $t\bar{t}$ cross sections

$\sqrt{s} = 5.02$ TeV, $\mathcal{L} = 257$ pb^{-1} [arXiv: 2207.01354]:

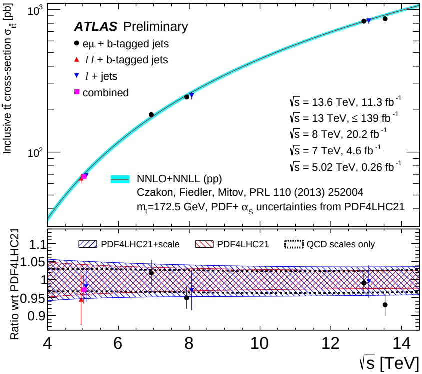
- Signal: dilepton (event counts) and single-lepton (BDT) final states decay channels measured separately and then combined.

$\sqrt{s} = 7$ TeV, $\mathcal{L} = 4.6$ fb^{-1} [arXiv: 2212.00571]:

- Signal: ℓ+jets.
- Method: support vector machines.

$\sqrt{s}$ [TeV]	Measurement $\sigma_{t\bar{t}}$ [pb]	NNLO+NNLL $\sigma_{t\bar{t}}$ [pb]
5.02	67.5 ± 2.7	$68.2^{+5.2}_{-5.3}$
7	$168.5^{+7.1}_{-6.7}$	177^{+10}_{-11}
13.6	859 ± 29	924^{+32}_{-40}

ATLAS measurements for different $\sqrt{s}$:



[ATLAS-CONF-2023-006]

$\sqrt{s} = 13.6$ TeV, $\mathcal{L} = 11.3$ fb^{-1} [ATLAS-CONF-2023-006]:

- Signal: decays with an opposite-charge eμ pair in the final state.

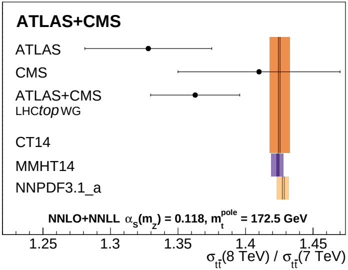
Measurements of inclusive $t\bar{t}$ cross sections

$\sqrt{s}$ = 7 and 8 TeV, $\mathcal{L}$ = 5 and 20 fb^{-1} from ATLAS and CMS [arXiv: 2205.13830]:

- Combination of measurements of the inclusive $t\bar{t}$ production cross section performed by ATLAS and CMS.
- Signal: decays with an opposite-charge $e\mu$ pair in the final state.

	Measurement	NNLO+NNLL
$\sigma_{t\bar{t}}$ (7 TeV)	178.5 ± 4.7 pb	177^{+10}_{-11} pb
$\sigma_{t\bar{t}}$ (8 TeV)	$243.3^{+6.0}_{-5.9}$ pb	$255.3^{+10.6}_{-12.2}$ pb
$R_{8/7}$	1.363 ± 0.032	$1.428^{+0.005}_{-0.004}$

ATLAS, CMS and ATLAS+CMS measurements:



[arXiv: 2205.13830]

Fits to the combined measurements using NNLO+NNLL QCD predictions were performed to extract:

- $m_t^{pole} = 173.4^{+1.8}_{-2.0}$ GeV (with $\alpha_s(m_Z)$ fixed to 0.118 ± 0.001)
- $\alpha_s(m_Z) = 0.1170^{+0.0021}_{-0.0018}$ (with m_t^{pole} fixed to 172.5 ± 1.0 GeV)

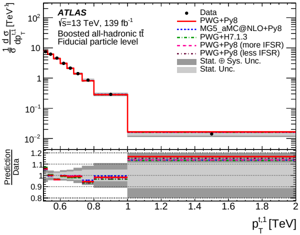
Differential $t\bar{t}$ cross-section measurements using boosted top quarks in the all-hadronic final state with 139 fb^{-1} [arXiv: 2205.02817]

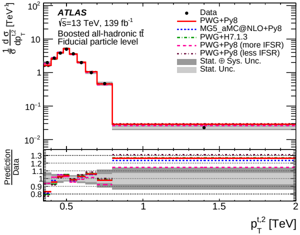
Highly boosted tops probing QCD at TeV scale: large prediction uncertainties and sensivity to BSM.

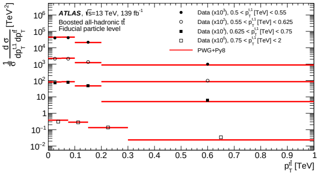
Signal extraction using DNN for top-quark-tagging and b-tagging.

Selection: $p_T^{t,1} > 500$ GeV and the second-leading top-quark jet has $p_T^{t,2} > 350$ GeV.

Measurements of normalised differential cross sections at particle level:



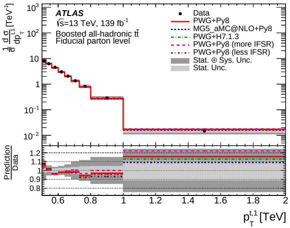


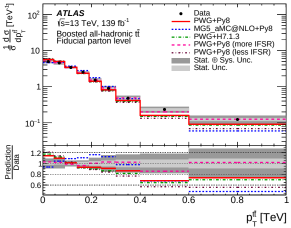


Disagreement between data and theory (NLO) observed in some regions of phase space.

Differential $t\bar{t}$ cross-section measurements using boosted top quarks in the all-hadronic final state with 139 fb^{-1} [arXiv: 2205.02817]

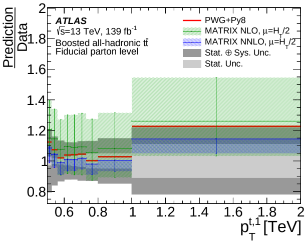
Measurements of normalised differential cross sections at parton level:

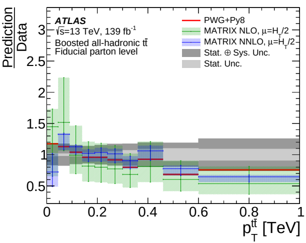




Also disagreements with NLO observed.

Comparison with NLO and NNLO QCD predictions:



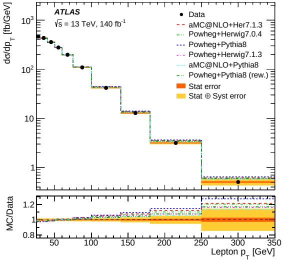


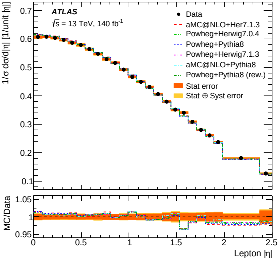
Improved description of data by NNLO predictions.

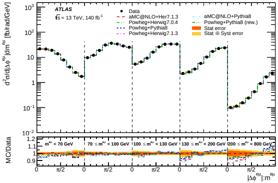
Inclusive and differential cross-sections for dilepton $t\bar{t}$ production measured in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector [arXiv: 2303.15340]

New ATLAS analysis with $\mathcal{L} = 140$ fb^{-1} at $\sqrt{s} = 13$ TeV, in opposite sign $e\mu$ channel and one or two b-tagged jets.

Very precise absolute and normalised single and double differential cross sections are measured.







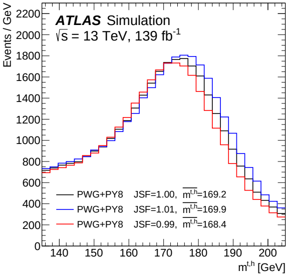
The precision of the measurements is 2% for the absolute cross sections and at 1% level for the normalised cross sections.

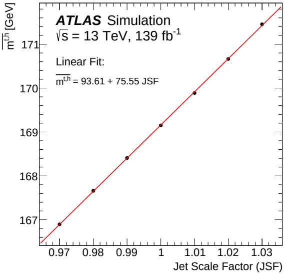
No single NLO QCD prediction can describe all measured observables simultaneously.

Measurement of differential cross-sections in top-quark pair events with a high transverse momentum top quark and limits beyond the Standard Model contributions to top-quark pair production with the ATLAS detector at $\sqrt{s} = 13$ TeV [JHEP 06 (2022) 063]

Measurements of $t\bar{t}$ production in the semileptonic channel with the hadronically decaying top reconstructed as a $R = 1.0$ jet with high p_T.

The analysis introduces a novel method which uses the reconstructed top-quark mass to reduce the impact of uncertainties from the jet energy scale by introducing an Scale Factor.





Uncertainties:

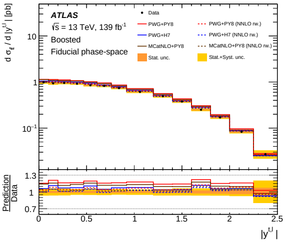
	Before		After
JES	$\pm 4.2\%$	$\rightarrow$	$\pm 0.7\%$
Total	$\pm 6\%$	$\rightarrow$	$\pm 4\%$

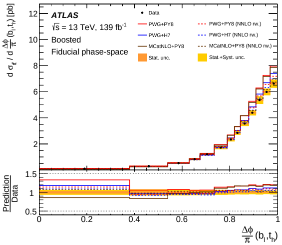
(b-tagging $\pm 2.4\%$)

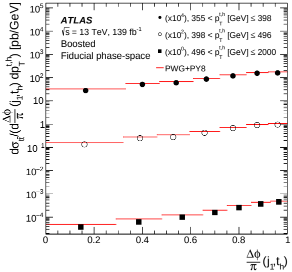
The use of this method improves significantly the precision of the measurements.

Measurement of differential cross-sections in top-quark pair events with a high transverse momentum top quark and limits beyond the Standard Model contributions to top-quark pair production with the ATLAS detector at $\sqrt{s} = 13$ TeV [JHEP 06 (2022) 063]

Differential cross-section measurements for the observables related to the kinematics of the top quarks compared with theoretical predictions.







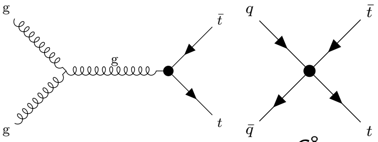
No single prediction describes all the measured observables simultaneously. Applying parton-level reweighting to match NNLO QCD predictions improves the description

- the NNLO corrections are important given the precision of the measurements.

BSM searches were performed on the analyses presented based on the EFT approach, using this Lagrangian:

$$\mathcal{L}_{EFT} = \mathcal{L}_{SM} + \sum_{i,D} \frac{C_i^D}{\Lambda^{D-4}} O_i^D$$

Only D=6 operators were added to the SM Lagrangian in these analyses.



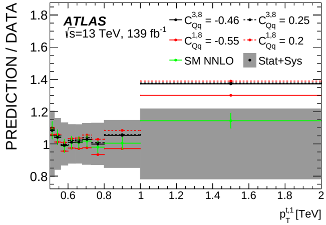
C_{tG} C_{tq}^8

All-hadronic channel

[arXiv: 2205.02817]

Using dim6top & EFT*fitter*

$C_{Qq}^{3,8}$, $C_{Qq}^{1,8}$, C_{Qu}^8, C_{Qd}^8, C_{tq}^8, C_{tu}^8 and C_{td}^8

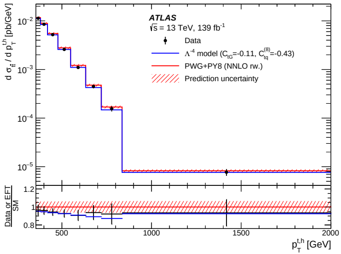


Semileptonic channel

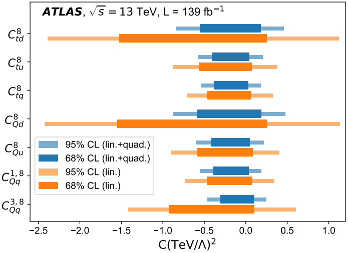
[JHEP 06 (2022) 063]

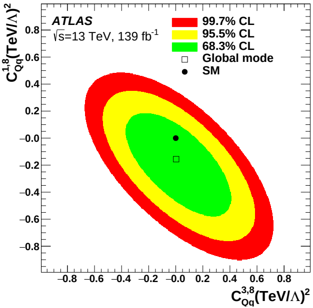
Using SMEFT@NLO & EFT*fitter*

C_{tG} and C_{tq}^8



All-hadronic channel [arXiv: 2205.02817]

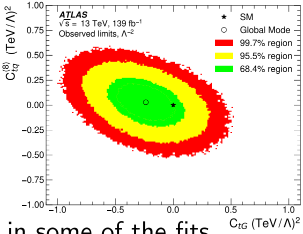




The inclusion of the quadratic terms leads to tighter bounds for all Wilson coefficients.

Semileptonic channel [JHEP 06 (2022) 063]

Model	C_i $(\Lambda/\text{TeV})^2$	Marginalised 95% intervals Expected	Marginalised 95% intervals Observed	Individual 95% intervals Expected	Individual 95% intervals Observed	Global fit 95% limits
Λ^{-4}	C_{tG}	[−0.44, 0.35]	[−0.53, 0.21]	[−0.44, 0.28]	[−0.52, 0.15]	[0.006, 0.107]
	$C^{(8)}_{tq}$	[−0.57, 0.17]	[−0.60, 0.13]	[−0.57, 0.18]	[−0.64, 0.12]	[−0.48, 0.39]
Λ^{-2}	C_{tG}	[−0.44, 0.44]	[−0.68, 0.21]	[−0.41, 0.42]	[−0.63, 0.20]	[0.007, 0.111]
	$C^{(8)}_{tq}$	[−0.35, 0.35]	[−0.30, 0.36]	[−0.35, 0.36]	[−0.34, 0.27]	[−0.40, 0.61]



Better bounds than the global fit are achieved for C^8_{tq} in some of the fits performed.

Conclusions

Several new measurements of single-top and $t\bar{t}$ production at different centre-of-mass energies and in different decay channels were presented, including a combination with CMS data.

The precision of the measurements in leptonic channels is higher.

Novel methods to reduce the jet energy scale uncertainty were developed.

No single NLO+PS model describes all the measurements simultaneously.

- Clearly, higher-order corrections are needed to improve the description of the data.
- This is supported by applying parton-level reweighting to match NNLO QCD predictions, which shows that NNLO corrections are important.

Searches of physics BSM were performed by using an EFT interpretation.

- No evidence of new physics is seen.
- Tighter bounds on some Wilson coefficients were obtained.