Highlights of top quark cross-section measurements at ATLAS

Rafał Bielski

on behalf of the ATLAS Collaboration

ATLAS EXPERIMENT

MANCHESTER 1824
The University of Manchester

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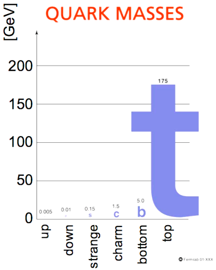
Introduction

Why top quark?

- The heaviest elementary particle → highest coupling to the Higgs boson and to possible new heavy particles
- Decays before hadronisation → allows to study bare quark properties
- Precision SM measurements → verification of the state-of-the-art theoretical calculations



What's new?

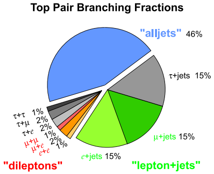
- LHC Run II → new energy, more and more data ($\sqrt{s}$ = 13 TeV, $\int \mathcal{L}\mathrm{dt}$ = 36 fb^{-1})
- I will summarise final and preliminary results published since LLWI2016

Biggest challenges in measuring top cross sections:

- Signal modelling – some of the new results already used to improve ATLAS MC tunes
- Jet energy scale and resolution, jet flavour tagging
- Background modelling – other top processes, QCD multi-jet production, V+jets, VV

Overview of the new results

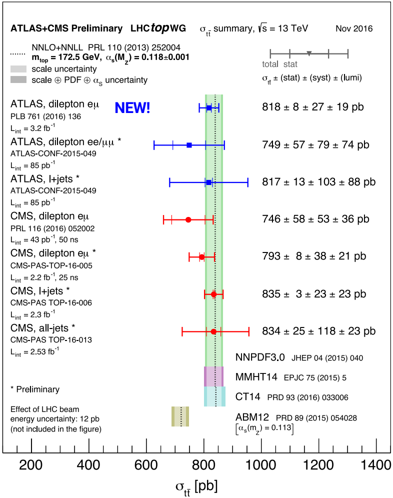
- Top quark decays nearly always into Wb, where the W can decay either leptonically or hadronically, defining different final states
- All new results (since LLWI2016) sorted by process and decay channel are listed in the table below (for links see the final slide)
- I will present the highlighted measurements in more detail

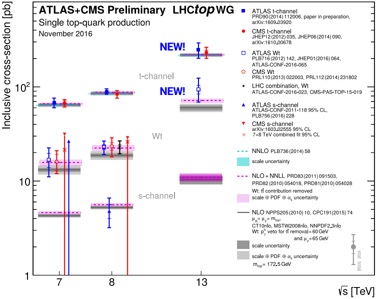


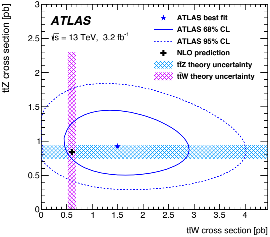
top cross section						
single top		top-antitop pair				ttW/ttZ
Wt	t-channel					
dilepton	lepton+jets	dilepton		lepton+jets	all-hadronic	2/3/4 lepton
		eμ	ee/μμ			
13 TeV inclusive	13 TeV inclusive	13 TeV inclusive	7,8 TeV differential	**13 TeV differential**	**13 TeV differential**	13 TeV inclusive
		13 TeV differential		8 TeV differential		
		13 TeV extra jets				
		8 TeV extra jets				
		7,8,13 TeV tt/Z ratio				

Inclusive cross section measurements

All measurements agree with the latest predictions

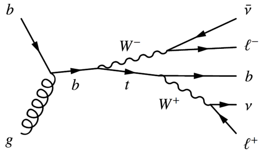






Wt inclusive cross section

arXiv:1612.07231



Motivation

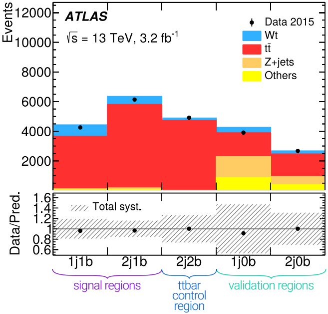
- Testing the fundamental SM structure (sensitive to V_{tb})
- Senstive to new physics that can affect the Wtb vertex
- Process first observed in 8 TeV LHC data (inaccessible at the Tevatron due to the low cross section)

Event selection

- exactly two leptons ($ee/\mu\mu/e\mu$)
- at least one jet
- a set of simple kinematic cuts in ($m_{\ell\ell}$, $E_{\mathrm{T}}^{\mathrm{miss}}$)-plane minimising the Z+jets background contribution

Analysis strategy:

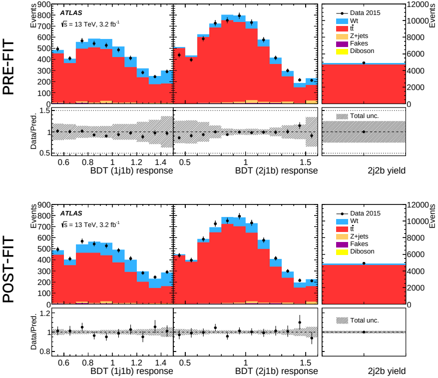
- Separate events into regions of jet and b-jet multiplicity
- BDT trained to discriminate between $t\bar{t}$ and Wt in signal and control regions
- profile-likelihood fit using MC templates for signal and background
- fitting binned BDT score in **1j1b**, **2j1b** and a single bin in **2j2b**, extracting the signal strength μ_{Wt}

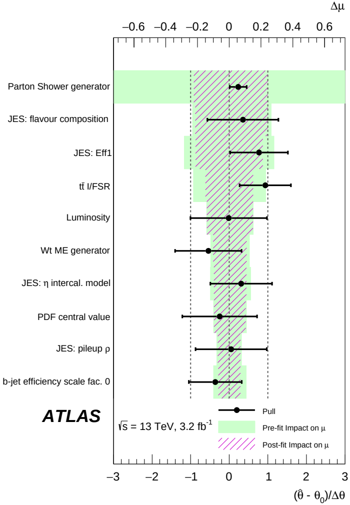


Wt inclusive cross section

arXiv:1612.07231

The profile-likelihood fit constrains some of the systematic uncertainties, particularly the ones related to parton shower generator and $t\bar{t}$ I/FSR



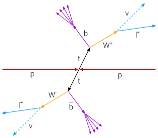


Result: $\sigma_{Wt} = 94 \pm 10(\text{stat.})\ ^{+28}_{-22}(\text{syst.}) \pm 2(\text{lumi})$ pb

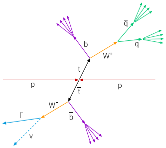
Prediction: $\sigma_{\text{theory}} = 71.7 \pm 1.8(\text{scale}) \pm 3.4(\text{PDF})$ pb

$t\bar{t}$ differential cross section

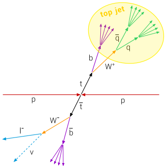
arXiv:1612.05220
ATLAS-CONF-2016-040
ATLAS-CONF-2016-100



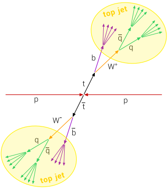
dileptonic
resolved



lepton+jets
resolved



lepton+jets
boosted



all-hadronic
boosted

- lowest BR → low statistics
- low background → very clean
- difficulty in full event reconstruction due to two neutrinos
- use of the Neutrino Weighting algorithm

Event selection:
2 leptons ($e^{\pm}\mu^{\mp}$), ≥2 jets (≥1 b-tagged)

- middle-ground between the two other channels
- medium statistics, medium background level
- relatively easy full event reconstruction using final-state objects in the resolved selection
- the top-tagged large-R jet used directly as a top quark proxy in boosted

Event selection:
1 lepton, ≥4 jets (≥2 b-tagged) or
1 lepton, ≥1 top-tagged large-R jet, ≥1 b-jet

- highest BR → large statistics
- high QCD multijet background
- top-tagged jets can be used directly as top-quark proxies
- boosted topologies allow to reach higher in top p_{T}
- more precise $t\bar{t}$ reconstruction thanks to the lack of neutrinos

Event selection:
0 leptons, ≥2 top-tagged large-R jets, each containing a b-jet

$t\bar{t}$ differential cross section

arXiv:1612.05220
ATLAS-CONF-2016-040
ATLAS-CONF-2016-100

Analysis strategy:

- Background estimates – a mixture of data-driven techniques and simulated samples
- Correct for the **detector** effects (*"unfolding"*)
  - Acceptance and efficiency corrections
  - Use migration matrices – iterative Bayesian unfolding
  - Unfold to **particle level** – use only objects constructed from stable final-state particles, avoiding extrapolation to parton level (i.e. correcting for parton showering)
- Present either absolute or relative results (divided by total fiducial cross section)

Measured observables:

	$p_T(t)$	$y(t)$	$p_T(t\bar{t})$	$y(t\bar{t})$	$m(t\bar{t})$	$\lvert\cos\theta^*\rvert$	$H_T(t\bar{t})$	$y_B(t\bar{t})$	$\Delta\phi(t_1,t_2)$	$\chi(t\bar{t})$	$\lvert p_{out}(t\bar{t})\rvert$
$e\mu$	✓	✓	✓	✓	✓						
ℓ+jets resolved	✓*	✓*	✓	✓	✓						
ℓ+jets boosted	✓*	✓*									
all-had	✓†	✓†	✓	✓	✓	✓	✓	✓	✓	✓	✓

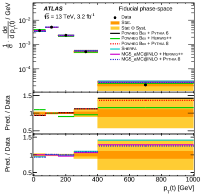
* hadronically-decaying top only

† separately for the leading and sub-leading top-jet

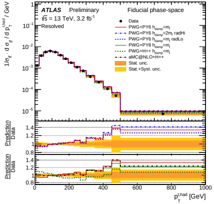
$t\bar{t}$ differential cross section – results

arXiv:1612.05220
ATLAS-CONF-2016-040
ATLAS-CONF-2016-100

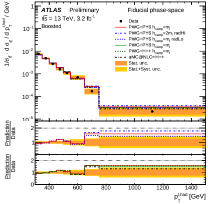
top quark p_T *(keep in mind the different definitions)*



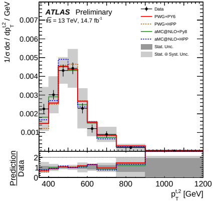
dilepton



lepton+jets
resolved



lepton+jets
boosted

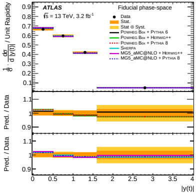


all-hadronic

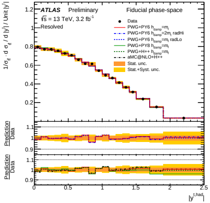
- Softer top p_T distribution wrt the prediction consistently seen in all channels
- Similar observations made also at 7 and 8 TeV (larger discrepancy with LO generators)
- Studies to improve the generator setup and tuning are ongoing, see ATL-PHYS-PUB-2016-020
- The all-hadronic measurement is so far the only one including 2016 data

$t\bar{t}$ differential cross section – results

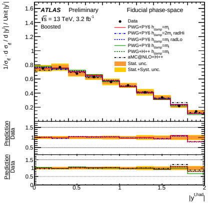
top quark rapidity *(keep in mind the different definitions)*



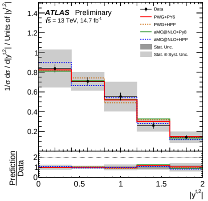
dilepton



lepton+jets
resolved



lepton+jets
boosted



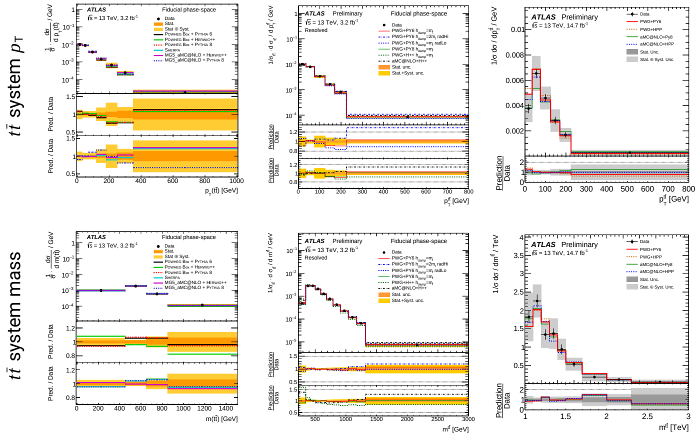
all-hadronic

- No deviations seen in top rapidity
- All generators provide consistent predictions
- Observable sensitive to PDF

$t\bar{t}$ differential cross section – results

arXiv:1612.05220
ATLAS-CONF-2016-040
ATLAS-CONF-2016-100

dilepton | lepton+jets resolved | all-hadronic



All generators provide good agreement in wide kinematic range, but each one shows local disagreements in different parts of the phase-space. Work is needed in order to further improve the generators and the tuning.

Summary

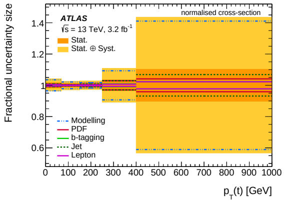
- The LHC is very capable of providing many millions of top-quark events
- Top quark cross section measurements provide precise test of the SM and can probe new physics
- No ATLAS results yet exploit the full 2015+2016 dataset (>10x larger than just 2015), so stay tuned for **new measurements coming out soon!**
- Given the available $t\bar{t}$ statistics, differential measurements are the baseline now – double-differential will soon provide even higher sensitivity

Measurement	$\sqrt{s}$ [TeV]	$\int\mathcal{L}\mathrm{d}t$ [fb^{-1}]	ATLAS code	Link
Wt inclusive	13	3.2	TOPQ-2015-16	arXiv:1612.07231
t-channel single top inclusive	13	3.2	TOPQ-2015-15	arXiv:1609.03920
ttbar(emu) inclusive	13	3.2	TOPQ-2015-09	Phys. Lett. B761 (2016) 136
ttbar(emu) differential	13	3.2	TOPQ-2016-04	arXiv:1612.05220
ttbar(emu) + extra jets	13	3.2	TOPQ-2015-17	arXiv:1610.09978
ttbar(emu) + extra jets	8	20.2	TOPQ-2015-04	JHEP 09 (2016) 074
ttbar(emu) to Z(ee/mumu) ratio	7 / 8 / 13	4.6 / 20.2 / 3.2	STDM-2016-02	arXiv:1612.03636
ttbar(ee/mumu) differential	7 / 8	4.6 / 20.2	TOPQ-2015-07	Phys. Rev. D 94, 092003 (2016)
ttbar(l+jets) differential	13	3.2	CONF-2016-040	ATLAS-CONF-2016-040
ttbar(l+jets) differential	8	20.2	TOPQ-2015-06	Eur. Phys. J. C76 (2016) 538
ttbar(allhad) differential	13	14.7	CONF-2016-100	ATLAS-CONF-2016-100
ttW and ttZ inclusive	13	3.2	TOPQ-2015-22	Eur. Phys. J. C (2017) 77:40

backup slides

Uncertainties in $t\bar{t}$ cross section

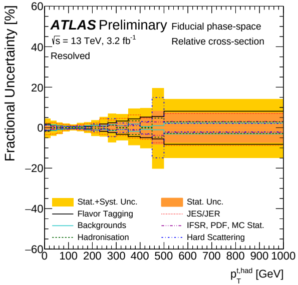
dilepton



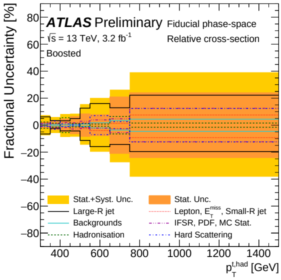
all-hadronic (inclusive uncertainty)

Large-R jets	+18 / -15
Monte Carlo signal modelling	$\pm$17
b-tagging	+13 / -12
Pileup	$\pm$2.9
Luminosity	$\pm$2.9
Small-R jets	$\pm$1.0
Total Systematic Uncertainty	+29 / -24

ℓ+jets (resolved)



ℓ+jets (boosted)



$t\bar{t}$ modelling studies

A public note released in September on tuning $t\bar{t}$ generator setups: ATL-PHYS-PUB-2016-020

Aims:

- Describe the optimisation of new ATLAS setups with **Powheg+Pythia8** and **Powheg+Herwig7** and compare different matrix element generators
- Parameters studied: h_{damp} (Powheg), `pTdef` and `pThard` (Pythia8 `main31`), scale variations, `KinematicsReconstructor:ReconstructionOption` (Herwig7)
- Using differential cross section measurements at 7, 8 and 13 TeV

Conclusions:

- Decided on the optimal choice of the studied parameters
- All relevant distributions in agreement within experimental uncertainties for Powheg+Pythia8
- Powheg+Herwig7 shows very good top kinematics modelling (particularly top p_{T}), however fails to describe the additional radiation – more studies needed
- See a few plots in the next slide

$t\bar{t}$ modelling studies