Measurement of the differential single top-quark tW production cross section with the ATLAS experiment

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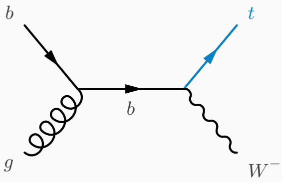
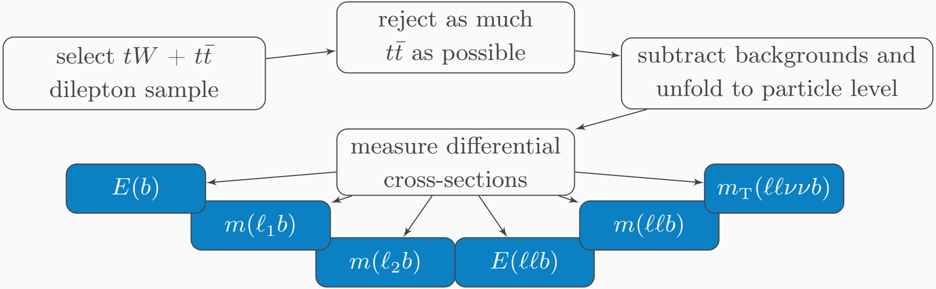
on behalf of the ATLAS Collaboration

Top2018, Bad Neuenahr: 16–21 September, 2018

Introduction

- tW production provides unique opportunities to study the SM
- Analysis goal: provide tW differential distributions as modelling input
- Complements existing total tW cross-section measurements in run 2 JHEP01(2018)063





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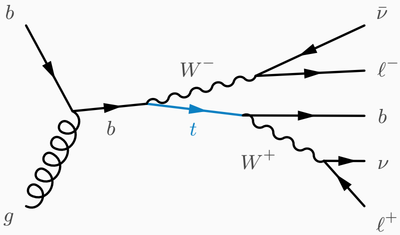
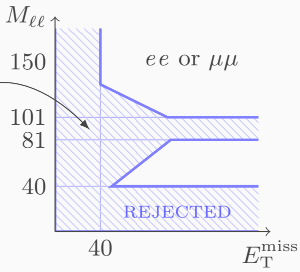
Selection of events

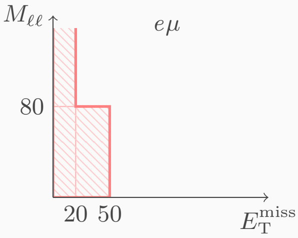
$36.1\,\mathrm{fb}^{-1}$ of 13 TeV pp collisions (2015+2016)



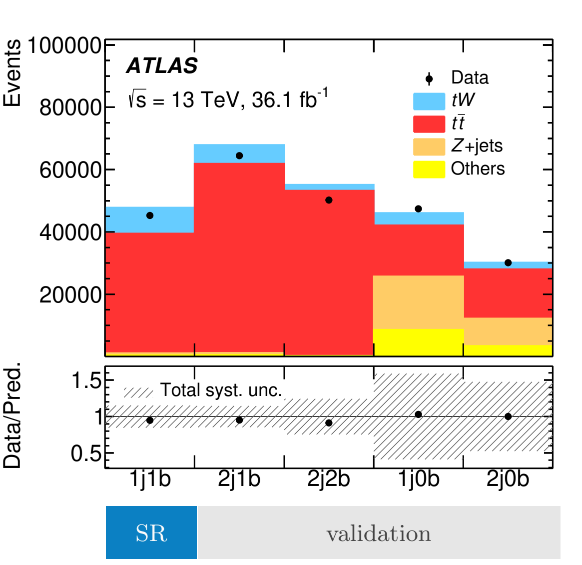
- single ℓ trigger — high-p_{T}, isolated
- at least 1 anti-k_t jet — $p_{\mathrm{T}} > 25$ GeV, $|\eta| < 2.5$, $R = 0.4$
- exactly 2 OS ℓ — $p_{\mathrm{T}} > 20$ GeV, $|\eta| < 2.5$
- at least 1 high-p_{T} ℓ — $p_{\mathrm{T}} > 27$ GeV

Additional cuts to remove smaller contaminations (Z + jets, diboson, fake and non-prompt)





Signal region and backgrounds

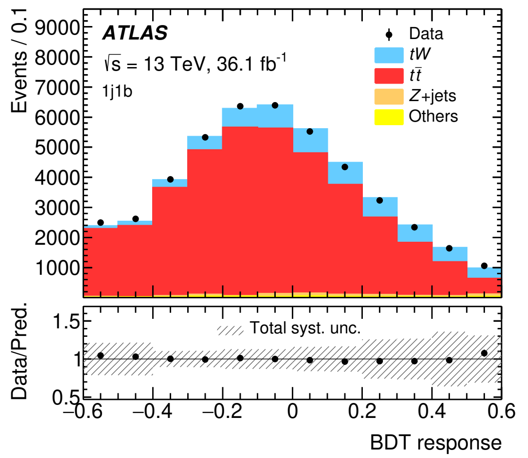


- Signal region: exactly one b-jet
- Mostly tW and $t\bar{t}$ remaining
- SR choice also reduces the tW-$t\bar{t}$ interference effects

- Other backgrounds including fake and non-prompt are estimated from MC simulation
- Modelling of background processes is checked in regions with no b-jets (`1j0b` and `2j0b`)

NB: njmb means n jets of which m are b-tagged

Separating tW from $t\bar{t}$



A BDT is trained to separate tW from $t\bar{t}$

BDT inputs:

MOST IMPORTANT

$p_{\mathrm{T}}(\ell_1 \ell_2 E_{\mathrm{T}}^{\mathrm{miss}} b)$

$\Delta p_{\mathrm{T}}(\ell_1 \ell_2 b, E_{\mathrm{T}}^{\mathrm{miss}})$

$\sum E_{\mathrm{T}}$

$\eta(\ell_1 \ell_2 E_{\mathrm{T}}^{\mathrm{miss}} b)$

$\Delta p_{\mathrm{T}}(\ell_1 \ell_2, E_{\mathrm{T}}^{\mathrm{miss}})$

$p_{\mathrm{T}}(\ell_1 \ell_2 b)$

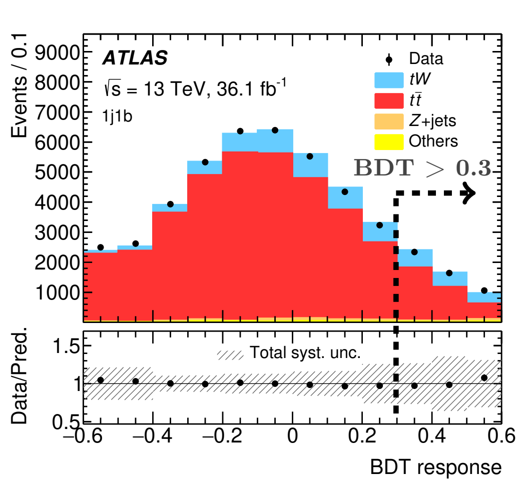
$C(\ell_1 \ell_2)$

$m(\ell_2, b)$

$m(\ell_1, b)$

LEAST IMPORTANT

Separating tW from $t\bar{t}$



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BDT inputs:

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$\Delta p_{\mathrm{T}}(\ell_1\ell_2 b, E_{\mathrm{T}}^{\mathrm{miss}})$
$\sum E_{\mathrm{T}}$
$\eta(\ell_1\ell_2 E_{\mathrm{T}}^{\mathrm{miss}} b)$
$\Delta p_{\mathrm{T}}(\ell_1\ell_2, E_{\mathrm{T}}^{\mathrm{miss}})$
$p_{\mathrm{T}}(\ell_1\ell_2 b)$
$C(\ell_1\ell_2)$
$m(\ell_2, b)$
$m(\ell_1, b)$
LEAST IMPORTANT

Composition after cut:

tW	35 %
$t\bar{t}$	60 %
Z + jets	3 %
Diboson	1.5 %
Fakes	<1 %

S/B: 0.21 → 0.58

Fiducial region defined in terms of stable particles chosen to match detector-level selection:

exactly 2 OS ℓ — $p_{\mathrm{T}} > 20\,\mathrm{GeV}$, $|\eta| < 2.5$

↓

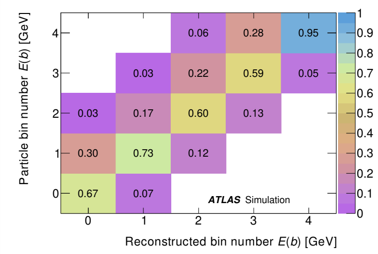
at least 1 high-p_{T} ℓ — $p_{\mathrm{T}} > 27\,\mathrm{GeV}$

↓

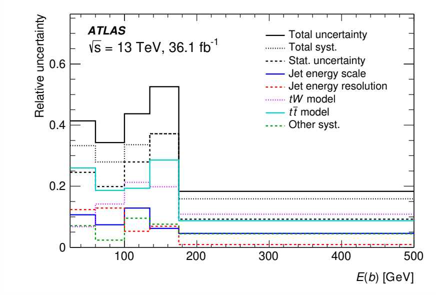
exactly 1 anti-k_t b-jet — $p_{\mathrm{T}} > 25\,\mathrm{GeV}$, $|\eta| < 2.5$, $R = 0.4$

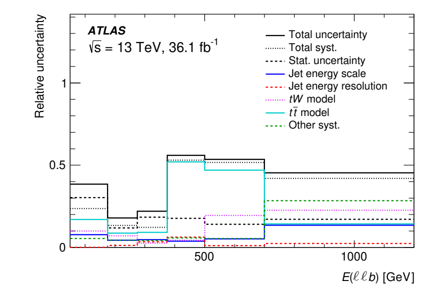
- No requirements on $E_{\mathrm{T}}^{\mathrm{miss}}$ or $M_{\ell\ell}$
- b-jets defined by ghost-matching B hadrons

- Iterative Bayesian unfolding to particle level
- 5–15 iterations depending on observable
- Variable binning optimised for stability



Uncertainties



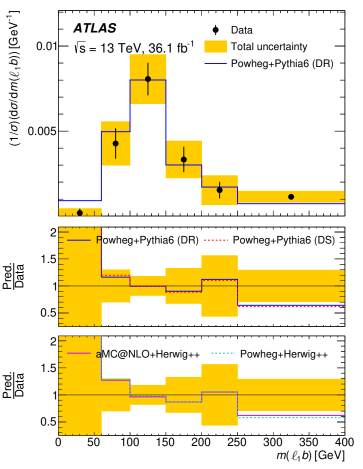


- The importance of sources of uncertainty varies between bins
- tW and $t\bar{t}$ modelling are generally important
- Data statistics are also important

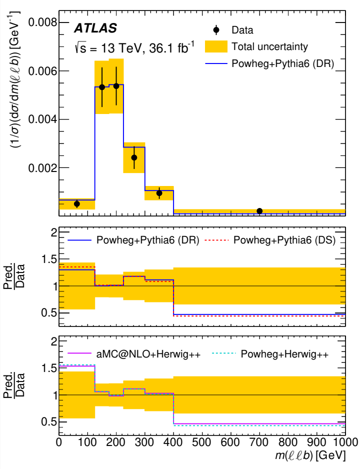
- The cross-sections are normalised
- Many uncertainties cancel nicely as a result
- In particular $t\bar{t}$ parton shower (which was important in the total cross-section)

Differential tW particle level cross-sections

$m(\ell_1 b)$



$m(\ell\ell b)$



- Cross-sections are compared to different predictions
- Agreement is good (p-values in backup)
- In most cases there is a small negative slope (excess of events with high-momentum objects)
- No significant discrimination between predictions

Summary

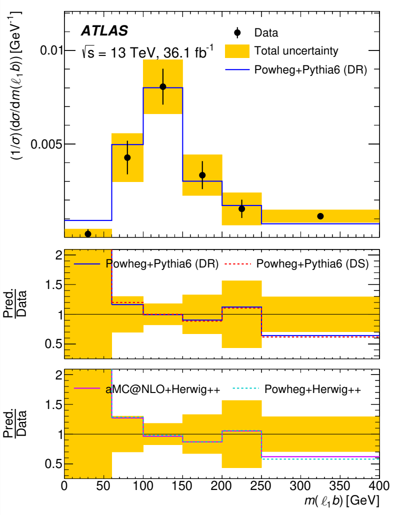
- Differential cross-sections of tW production with $36.1\,\text{fb}^{-1}$ of $13\,\text{TeV}$ pp collisions
- Unfolded to particle level to correct for detector effects
- Major uncertainties: tW and $t\bar{t}$ modelling, data statistics
- Good agreement with predictions from several MC event generators

$E(b)$ | $m(\ell_1 b)$ | $m(\ell_2 b)$ | $E(\ell\ell b)$ | $m(\ell\ell b)$ | $m_{\mathrm{T}}(\ell\ell\nu\nu b)$

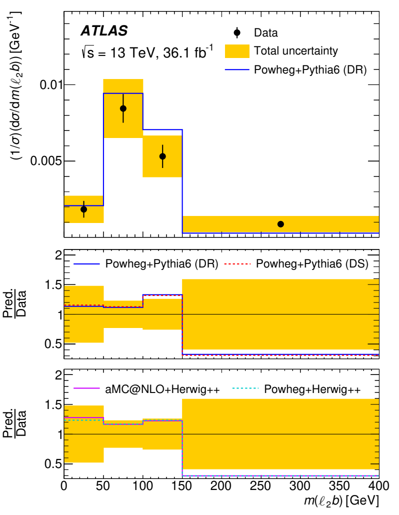
Backup

Differential tW particle level cross-sections [1/2]

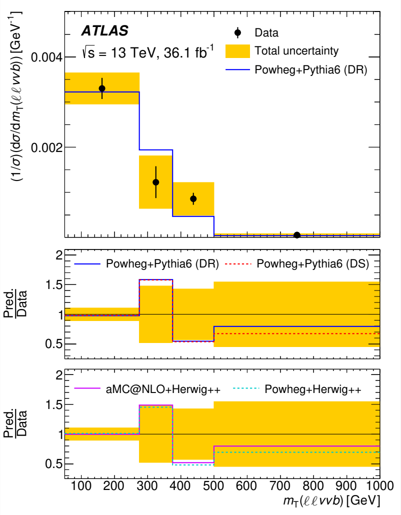
$m(\ell_1 b)$



$m(\ell_2 b)$

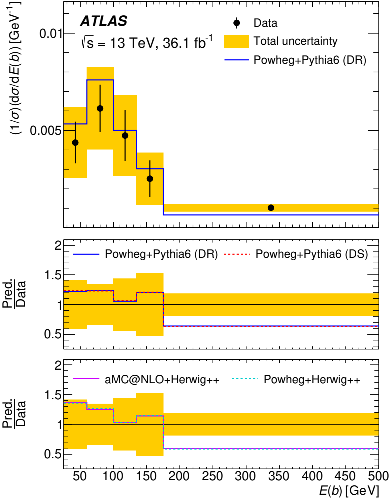


$m_{\mathrm{T}}(\ell\ell\nu\nu b)$

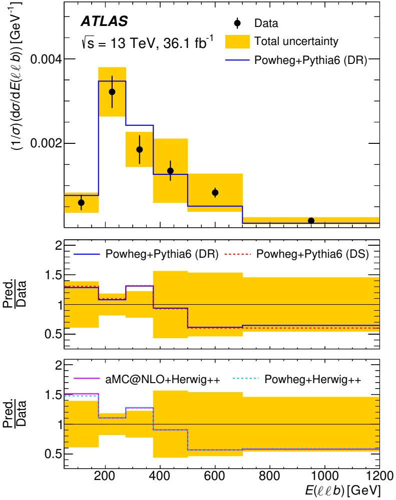


Differential tW particle level cross-sections [2/2]

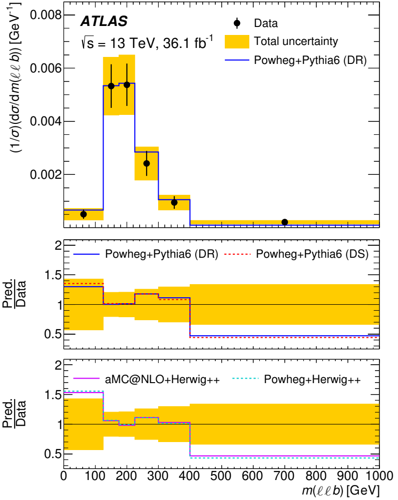
$E(b)$



$E(\ell\ell b)$



$m(\ell\ell b)$

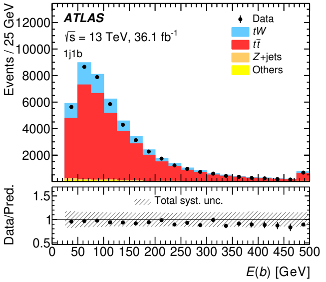


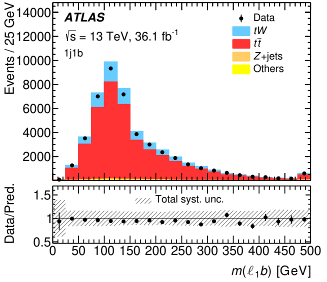
BDT

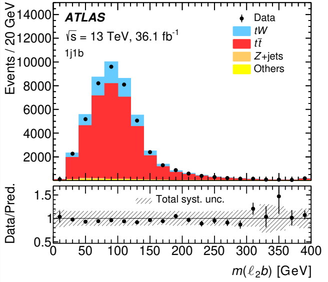
Variable	S $[10^{-2}]$
$p_{\mathrm{T}}(\ell_1\ell_2E_{\mathrm{T}}^{\mathrm{miss}}b)$	4.1
$\Delta p_{\mathrm{T}}(\ell_1\ell_2b, E_{\mathrm{T}}^{\mathrm{miss}})$	2.5
$\sum E_{\mathrm{T}}$	2.3
$\eta(\ell_1\ell_2E_{\mathrm{T}}^{\mathrm{miss}}b)$	1.3
$\Delta p_{\mathrm{T}}(\ell_1\ell_2, E_{\mathrm{T}}^{\mathrm{miss}})$	1.1
$p_{\mathrm{T}}(\ell_1\ell_2b)$	1.0
$C(\ell_1\ell_2)$	0.9
$m(\ell_2, b)$	0.2
$m(\ell_1, b)$	0.1
BDT response	8.1

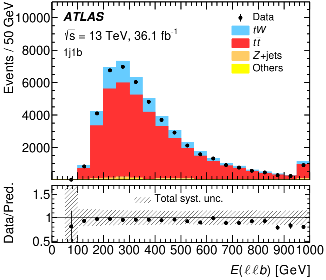
Process	Events	Events BDT response > 0.3
tW	$8\,300 \pm 1\,400$	$1\,970 \pm 560$
$t\bar{t}$	$38\,400 \pm 6\,600$	$3\,400 \pm 1\,300$
$Z+$jets	620 ± 310	159 ± 80
Diboson	230 ± 58	81 ± 20
Fakes	220 ± 220	19 ± 19
Predicted	$47\,800 \pm 7\,300$	$5\,600 \pm 1\,700$
Observed	$45\,273$	$5\,043$

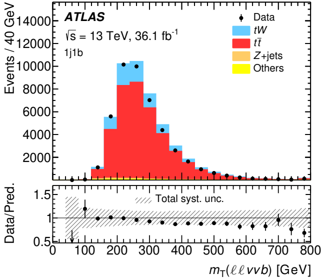
Distributions before BDT cut

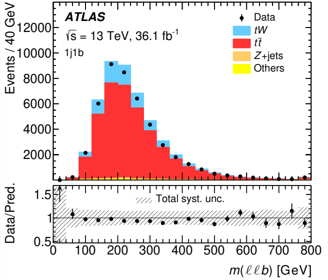








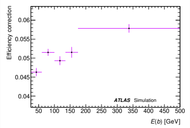


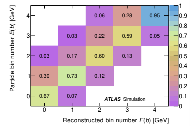


Unfolding details

Efficiency of reconstructing a fiducial event

$$\frac{1}{C_i^{\mathrm{eff}}} = \frac{N^{\mathrm{fid}}}{N^{\mathrm{fid\&reco}}}$$





Bin migration matrix

Number of detector level events

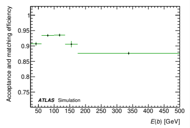
Background subtraction

$$N_i^{\mathrm{ufd}} = \frac{1}{C_i^{\mathrm{eff}}} \sum_j M_{ij}^{-1} C_j^{\mathrm{oof}} (N_j^{\mathrm{data}} - B_j)$$

Number of particle level events

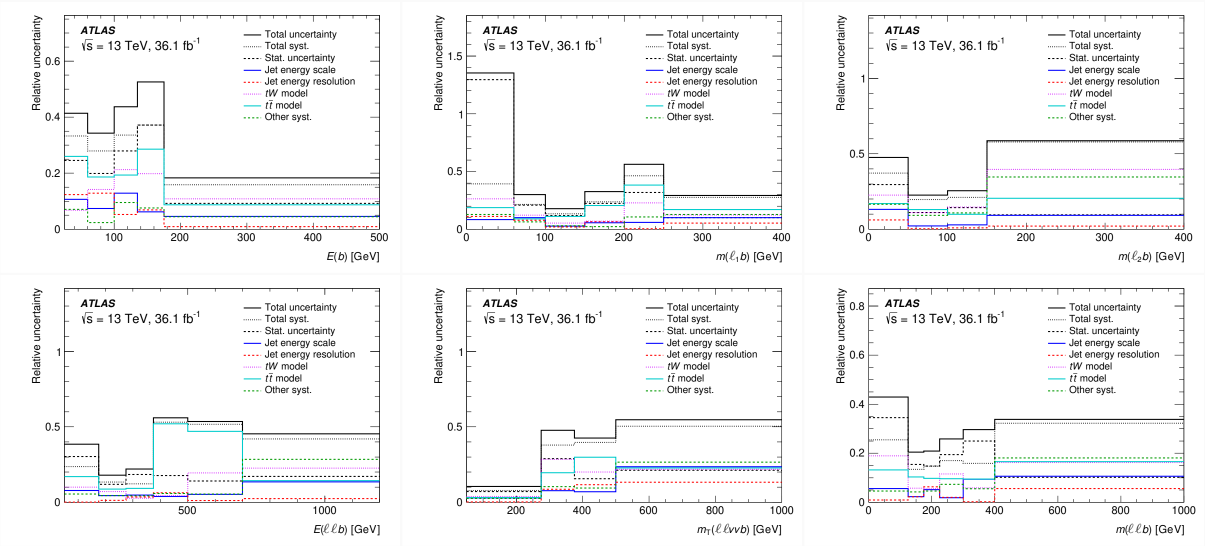
$$C_j^{\mathrm{oof}} = \frac{N^{\mathrm{fid\&reco}}}{N^{\mathrm{reco}}}$$

Reconstructed but not accepted (out-of-fiducial)



Observable	Number of iterations
$E(b)$	15
$m(\ell_1 b)$	7
$m(\ell_2 b)$	5
$E(\ell\ell b)$	5
$m_{\mathrm{T}}(\ell\ell\nu\nu b)$	7
$m(\ell\ell b)$	5

Uncertainty



Results: p-values

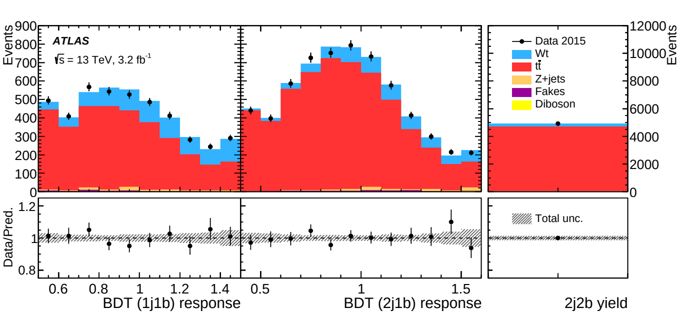
Observable	$E(b)$		$m(\ell_1 b)$		$m(\ell_2 b)$		$E(\ell\ell b)$		$m_{\mathrm{T}}(\ell\ell\nu\nu b)$		$m(\ell\ell b)$	
Degrees of freedom	4		5		3		5		3		5	
Prediction	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p
POWHEG+PYTHIA 6 (DR)	4.8	0.31	5.7	0.34	2.6	0.45	8.1	0.15	2.0	0.56	4.0	0.55
POWHEG+PYTHIA 6 (DS)	5.0	0.29	6.1	0.30	2.6	0.46	9.1	0.11	2.4	0.49	4.4	0.50
aMC@NLO+Herwig++	5.6	0.23	5.4	0.37	2.4	0.49	8.7	0.12	1.8	0.61	3.6	0.61
POWHEG+Herwig++	6.2	0.18	8.1	0.15	2.3	0.52	11.0	0.05	2.0	0.57	5.2	0.40
POWHEG+PYTHIA 6 radHi	4.8	0.30	5.3	0.38	2.5	0.48	7.9	0.16	1.9	0.60	3.7	0.60
POWHEG+PYTHIA 6 radLo	5.0	0.29	5.8	0.33	2.6	0.45	8.4	0.14	2.1	0.56	4.0	0.55

Calculated as $v^{\mathrm{T}} C^{-1} v$ where v is the vector of differences between measured and predicted cross-sections, and C is the covariance matrix (computed to include all sources of systematic uncertainty).

ATLAS tW 13 TeV total cross-section ($3.2\,\text{fb}^{-1}$) arXiv:1612.07231

- Separate BDTs trained for the two signal regions `1j1b` and `2j1b`
- Most significant BDT inputs:
  - $p_{\mathrm{T}}^{\mathrm{sys}}(\ell_1 \ell_2 E_{\mathrm{T}}^{\mathrm{miss}} j_1)$ and
  - $p_{\mathrm{T}}^{\mathrm{sys}}(\ell_1 \ell_2)$

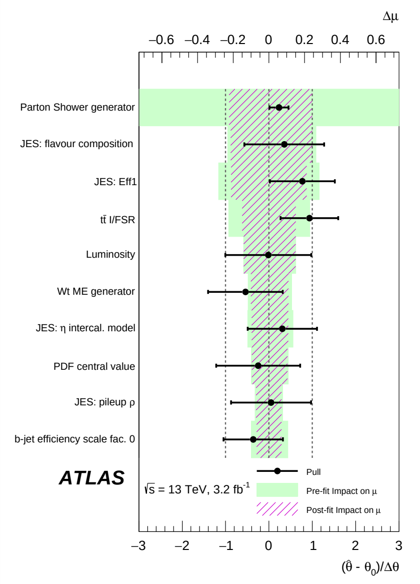
  respectively
- Leading systematics:
  - jet energy scale (21 %)
  - NLO matrix element (18 %)
- Systematics are expected to reduce with more data and improved predictions



$$\sigma_{tW} = 94 \pm 10\ (\text{stat.})\ {}^{+28}_{-22}\ (\text{syst.}) \pm 2\ (\text{lumi.})\ \text{pb}\ (31\,\%)$$

$p_{\mathrm{T}}^{\mathrm{sys}}$: magnitude of the vectorial p_{T} sum

Systematics: ATLAS tW 13 TeV total cross-section ($3.2\,\mathrm{fb}^{-1}$)



Source	$\Delta\sigma_{Wt}/\sigma_{Wt}[\%]$
Jet energy scale	21
Jet energy resolution	8.6
$E_{\mathrm{T}}^{\mathrm{miss}}$ soft terms	5.3
b-tagging	4.3
Luminosity	2.3
Lepton efficiency, energy scale and resolution	1.3
NLO matrix element generator	18
Parton shower and hadronisation	7.1
Initial-/final-state radiation	6.4
Diagram removal/subtraction	5.3
Parton distribution function	2.7
Non-$t\bar{t}$ background normalisation	3.7
Total systematic uncertainty	30
Data statistics	10
Total uncertainty	31