

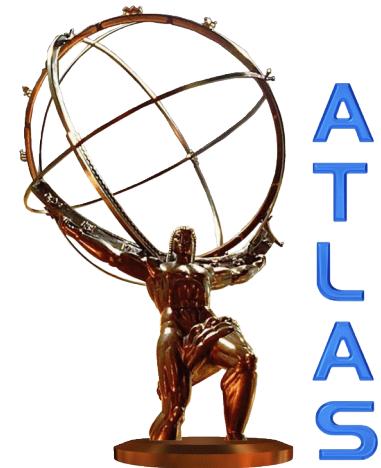
Top quark pair-production cross-section measurements with the ATLAS detector



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On behalf of the ATLAS collaboration



DIS 2018, Kobe

Motivation

measurement of $\sigma_{t\bar{t}}$

- provides a **stringent test of QCD calculations** with heavy quarks
- allows a **determination of the top-quark mass** in a well-defined renormalization scheme
 - see [M. Pinamonti's talk](#) on Thursday
- **sensitive to potential new physics**

Differential measurements

- important background for processes with Higgs boson
- **p_T of t quark, mass of $t\bar{t}$ system** – sensitive to the modeling of higher order corrections in QCD
- **rapidity of t quark and $t\bar{t}$ system** – sensitive to the parton distribution functions (PDF)
- **p_T of $t\bar{t}$ system** – sensitive to the amount of gluon radiation in the event, usefull for the tuning of Monte Carlo generators
- **opening azimuthal angle between top quarks** – sensitive to additional radiation in the main scattering process => sensitive to effects beyond LO in the matrix elements

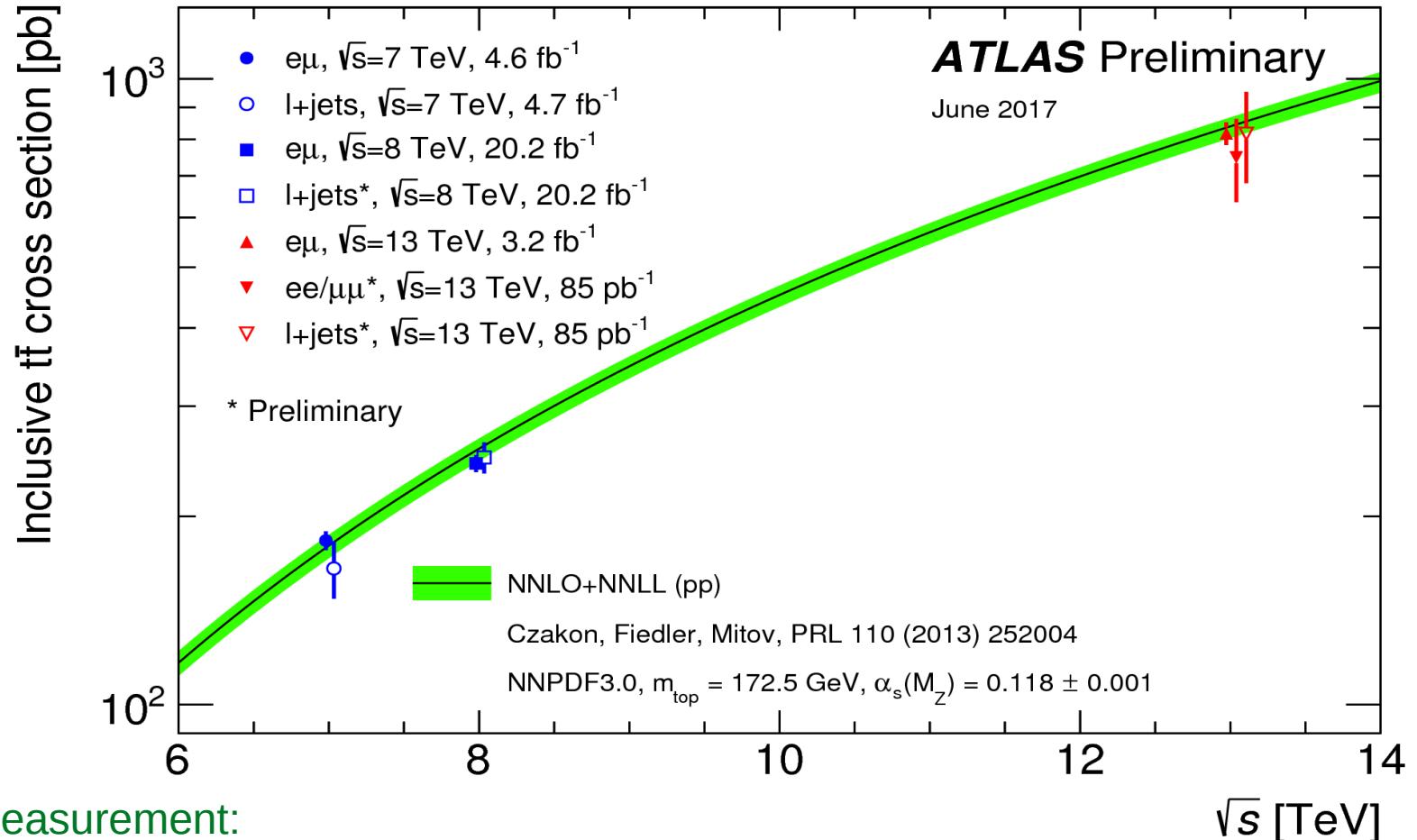
Measurement of lepton variable in di-lepton events → see [J. E. Garcia Navarro's talk](#)

(variables defined by leptons only – no need to reconstruct $t\bar{t}$ system):

- lepton pseudorapidity, dilepton rapidity – sensitive to PDFs
- azimuthal angle between leptons – sensitive to spin correlations
- single lepton p_T ; dilepton variables (p_T , inv. mass, ...) – sensitive to the top quark mass

Inclusive $t\bar{t}$ cross-section

$t\bar{t}$ cross section measurements compared to the NNLO QCD calculation complemented with NNLL resummation (top++2.0)



The most precise measurement:

$e\mu$ channel ($\sqrt{s} = 13$ TeV, $L = 3.2 \text{ fb}^{-1}$): Phys. Lett. B761 (2016) 136

$$\sigma_{t\bar{t}} = 818 \pm 8 \text{ (stat.)} \pm 27 \text{ (syst.)} \pm 19 \text{ (lumi)} \pm 12 \text{ (beam)} \text{ pb}$$

→ precision (4.4%) better than theoretical one (5.5%)

- some of the results were improved (with higher statistics)
- some of the new results not included in the plot

Inclusive $t\bar{t}$ cross-section @ 8 TeV (lepton+jets)

arXiv:1712.06857 [hep-ex]

→ supersedes results from PRD 91 (2015) 112013

Selection:

- one e or μ ; ≥ 4 small-R jets; E_T^{miss}
- ≥ 1 b-tagged jet

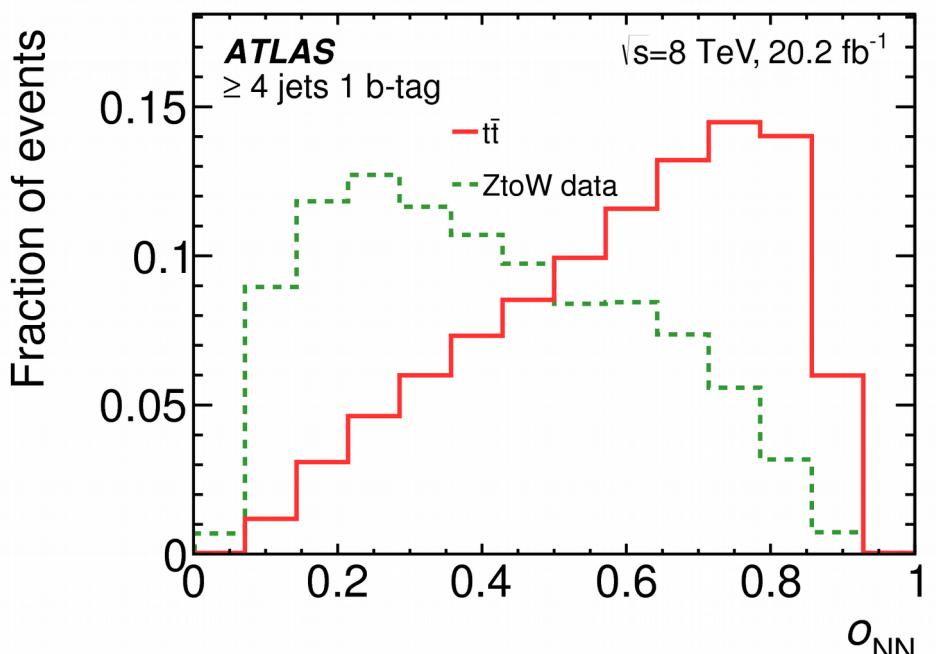
Measurement:

- sample divided into 3 signal regions (SR)
 - SR1:** ≥ 4 jets, 1 b-tagged jet
 - SR2:** = 4 jets, 2 b-tagged jet
 - SR3:** ≥ 4 jets, ≥ 2 b-tagged jet (excluding SR2)
- each SR has its own discriminating variable
 - SR1 and SR3: NN outputs**
 - SR2** invariant mass of two light jets $m(jj)$

Results:

- **binned maximum-likelihood fit** performed simultaneously in three signal regions
- fiducial cross-section (**uncer. 4.5%**):
 $\sigma_{t\bar{t}}^{fid} = 48.8 \pm 0.1 \text{ (stat.)} \pm 2.0 \text{ (syst.)} \pm 0.9 \text{ (lumi)} \text{ pb}$
- inclusive cross-section (**uncer. 5.7%**)
 $\sigma_{t\bar{t}}^{inc} = 248.3 \pm 0.7 \text{ (stat.)} \pm 13.4 \text{ (syst.)} \pm 4.7 \text{ (lumi)} \text{ pb}$
- the **largest systematics** from **signal Monte Carlo modeling and PDFs**
- **theory prediction (NNLO+NNLL):** $\sigma_{t\bar{t}} = 253^{+13}_{-15} \text{ pb}, m_{top} = 172.5 \text{ GeV}$

discriminating variable SR1:



Inclusive $t\bar{t}$ cross-section @ 8 TeV (τ +jets)

Phys. Rev. D 95, 072003 (2017)

Decay $t \rightarrow \tau \nu_\tau b$ – one can investigate coupling of the 3rd generation fermions in single process

→ deviation in BR($t \rightarrow \tau \nu_\tau b$) => indication of non-SM

Selection:

- one τ (hadronically decaying);
- ≥ 2 small-R jets; E_T^{miss}
- ≥ 2 b-tagged jets

Measurement:

- sample divided into 2 sub-samples
- $\tau_{1\text{-prong}}$: $\tau \rightarrow$ single charged particle
- $\tau_{3\text{-prong}}$: $\tau \rightarrow$ three charged particle ($\sum Q_i = 1$)
- for both sub-samples $\geq 0 \pi^0$ can be present
- BDT used to distinguish τ -jets from q - or g -jets

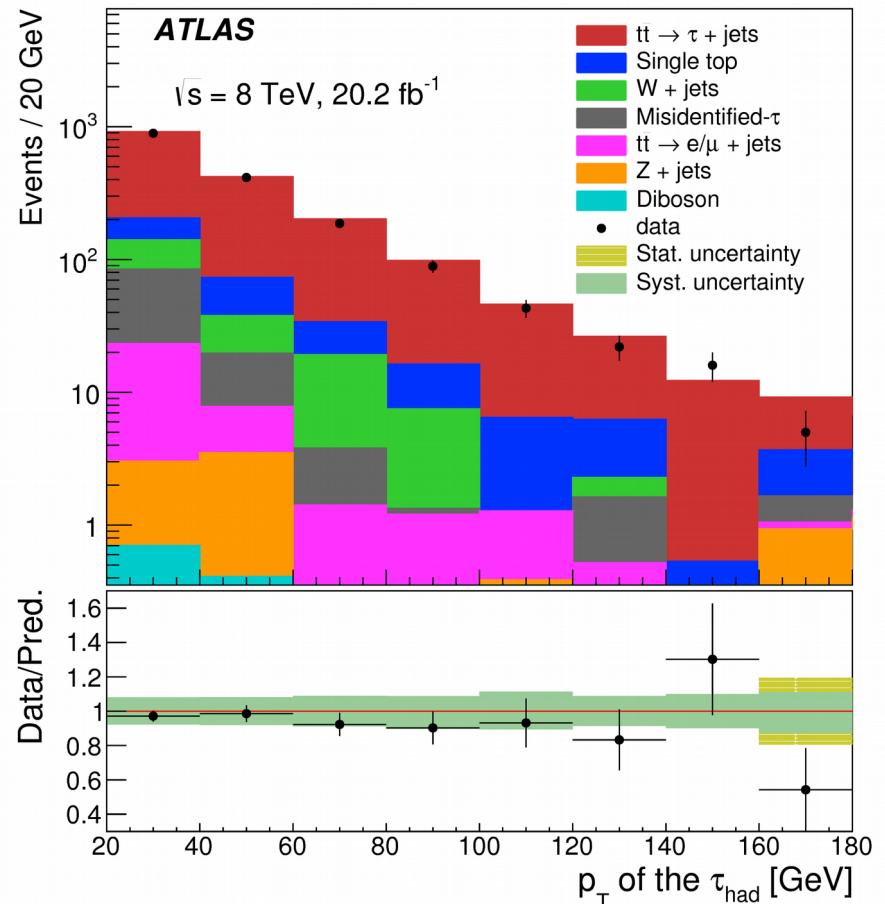
Results:

- inclusive cross-section (uncer. 12%)

$$\sigma_{t\bar{t}}^{\text{inc}} = 239 \pm 4 \text{ (stat.)} \pm 28 \text{ (syst.)} \pm 5 \text{ (lumi)} \text{ pb}$$

- the largest systematics from radiation, JES, and b-tag efficiency

p_T of τ having the largest p_T in the event



Upper limit for any non-SM process:

Observed (expected): $22(22^{+2}_{-1} \text{ fb})$

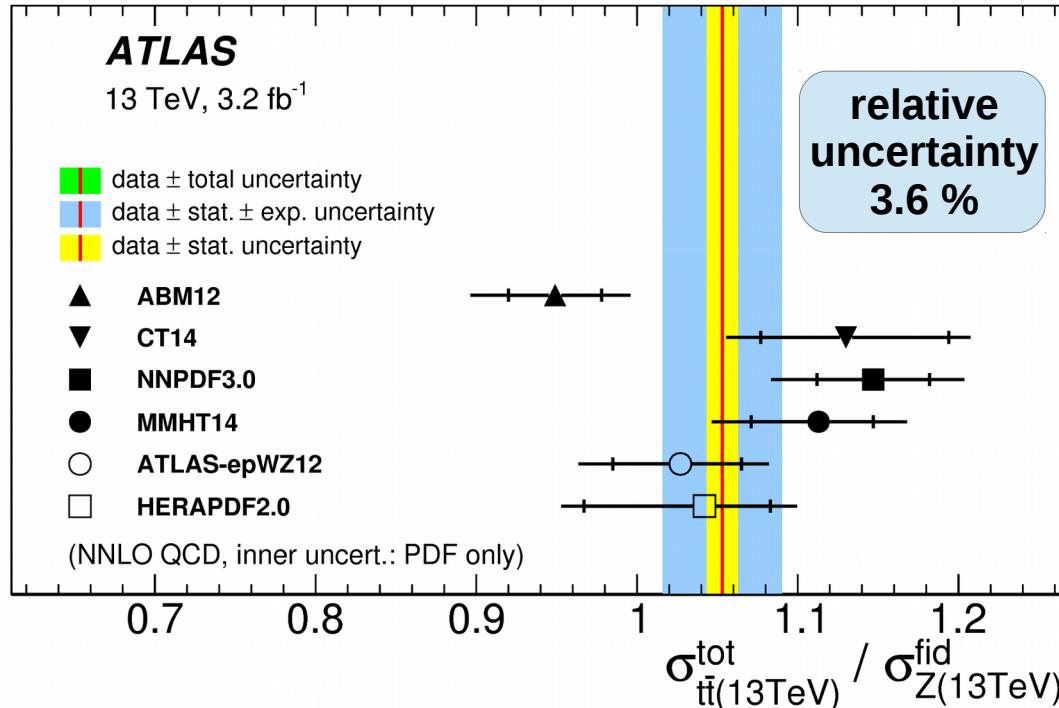
$t\bar{t}$ to Z-boson cross-section ratios (@ 7, 8, 13 TeV)

JHEP 02 (2017) 117

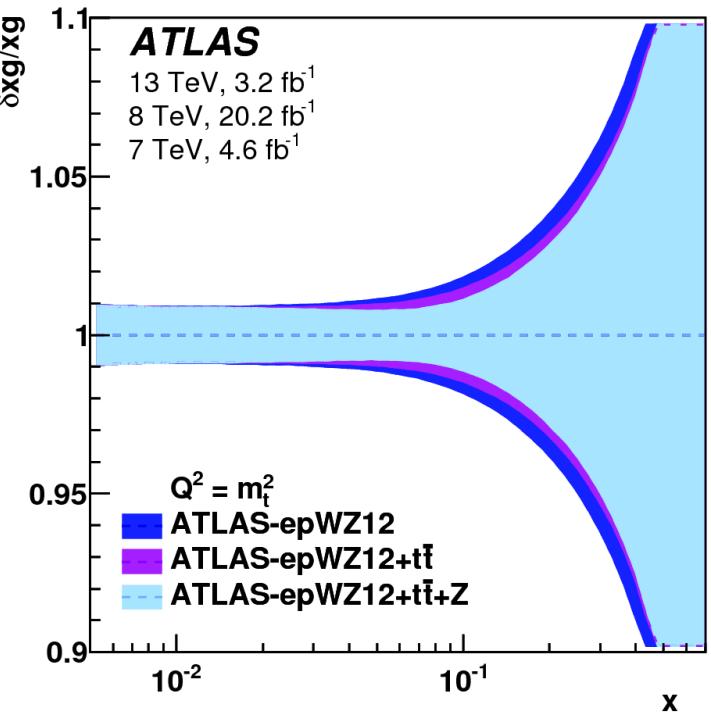
- ratios like $\sigma_{t\bar{t}}^{tot}/\sigma_Z^{fid}$ lead to **cancellation of luminosity** and some experimental **uncertainties**
- theoretical results: $\sigma_{t\bar{t}}$ @ NNLO + NNLL; and σ_Z @ NNLO QCD + NLO EW accuracies
- **the ratio** has a significant **sensitivity to the gluon-to-quark PDF ratio**
- results obtained from previously measured cross-sections except $Z \rightarrow l^+l^-$ @ 13 TeV (new):
 - **fiducial space for Z production:** $p_T^{lep} > 25$ GeV, $|\eta^{lep}| < 2.5$; $66 \text{ GeV} < m_{\parallel} < 116 \text{ GeV}$

Results from 13 TeV measurements:

- theory uncertainties dominated by PDFs uncertainties
- **data agree best with ATLAS-epWZ12 PDF set**
disfavor ABM12 PDF set



Data have power to constrain gluon distribution function at Bjorken-x ~ 0.1



Differential $t\bar{t}$ cross-section measurements @ 13 TeV

Lepton + jets channel

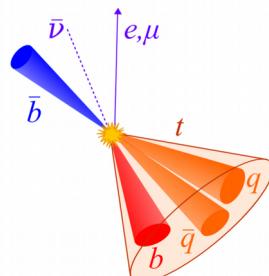
JHEP 11 (2017) 191

→ one **e or μ**

Resolved topology:

→ **≥ 4 small-R jets (≥ 1 b-jet)**

Boosted topology:



→ **≥ 1 small-R jets (≥ 1 b-jet)**

→ **≥ 1 (top-tagged) large-R jet**
(80% eff. point)

Observables:

$p_T^{t,had}$, $|y^{t,had}|$ (both topologies)
 $|y^{t\bar{t}}|$, $p_T^{t\bar{t}}$, $m^{t\bar{t}}$ (resolved only)

→ iterative Bayesian unfolding used to correct for detector effect

Di-lepton channel

Eur. Phys. J. C77 (2017) 299

→ one **e and μ (opposite charge)**

→ **≥ 2 small-R jets (≥ 1 b-jet)**

Observables:

p_T^t , $|y^t|$ (include t and \bar{t})
 $|y^{t\bar{t}}|$, $p_T^{t\bar{t}}$, $m^{t\bar{t}}$

All-hadronic channel

arXiv:1801.02052

Di-Boosted topology:

→ **≥ 2 large-R jets (top-tagged)**

→ small-R (b-tagged) jets “inside”
large R-jets

Observables:

$p_T^{t,1}$, $p_T^{t,2}$, $y^{t,1}$, $y^{t,2}$, $|y^{t\bar{t}}|$, $p_T^{t\bar{t}}$, $m^{t\bar{t}}$

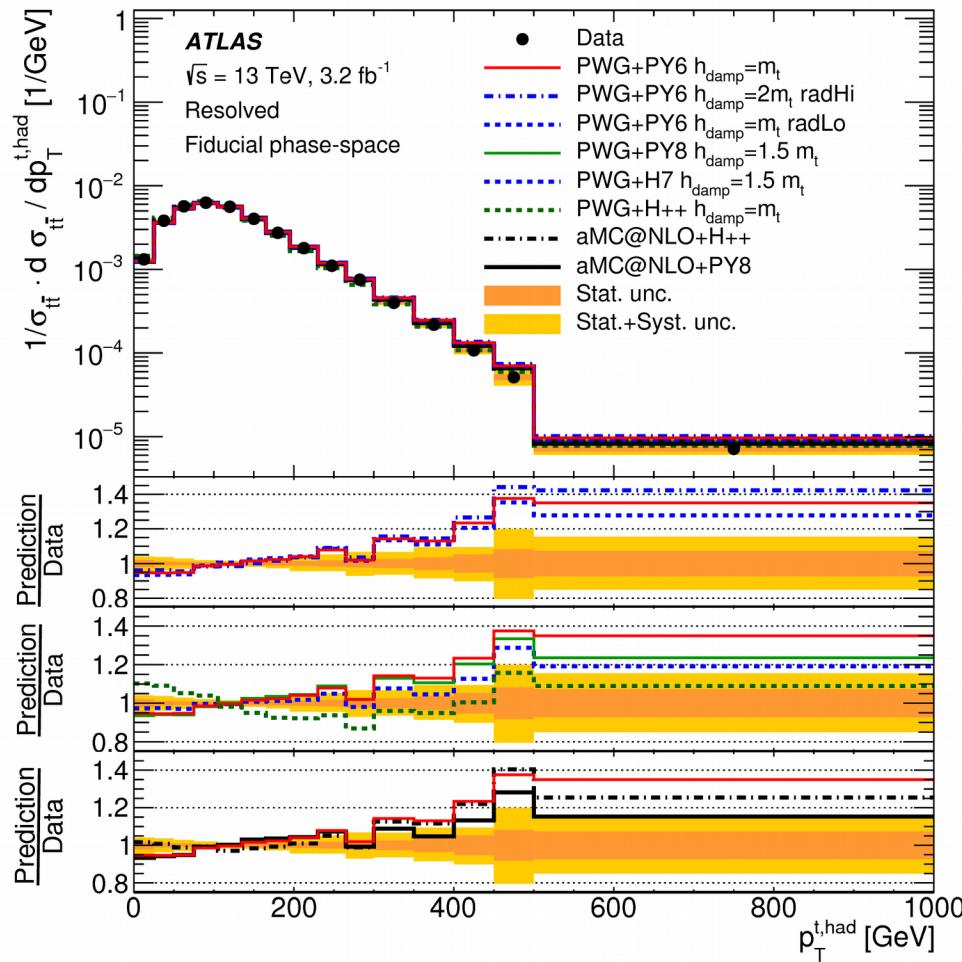
$t\bar{t}$ system longitudinal motion
in laboratory frame:

$y_B^{t\bar{t}}$ - sensitive to PDFs

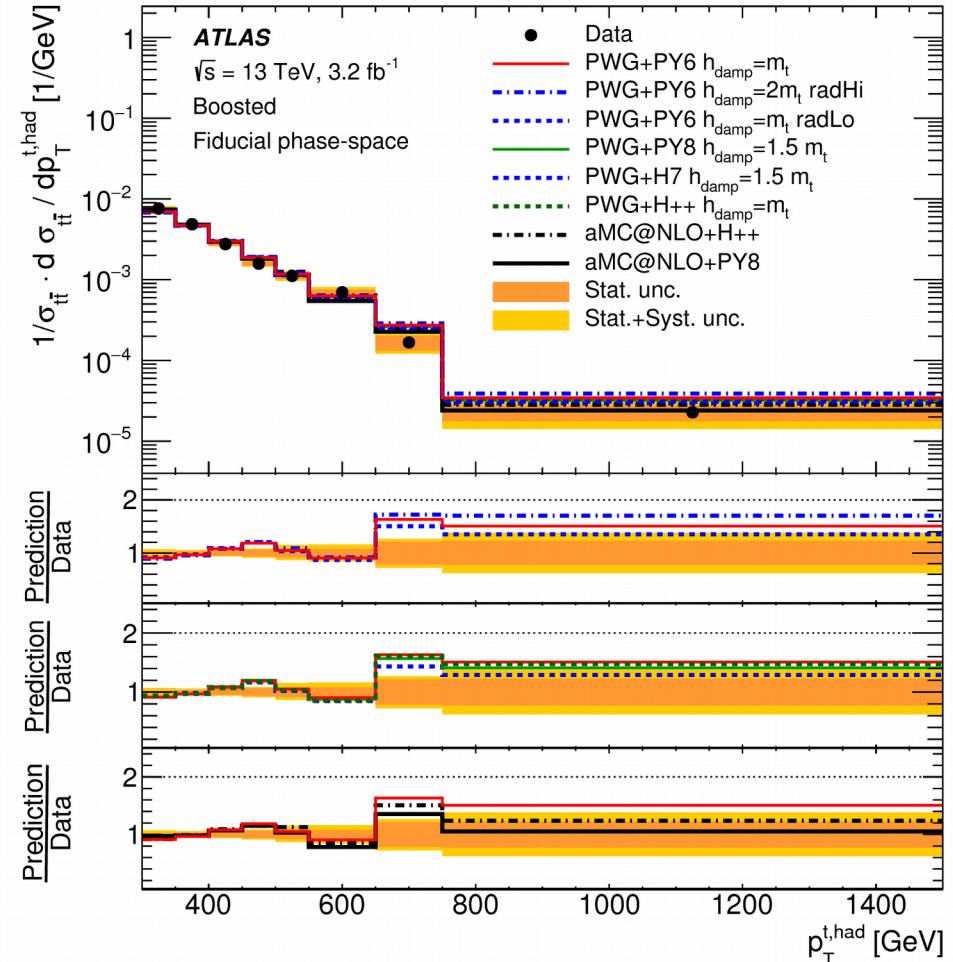
$\Delta \phi^{t\bar{t}}$ - sensitive to radiation
in the main scattering process
... (many other observables)

Top-quark transverse momenta (I)

L+jets – Resolved topology



L+jets – Boosted topology

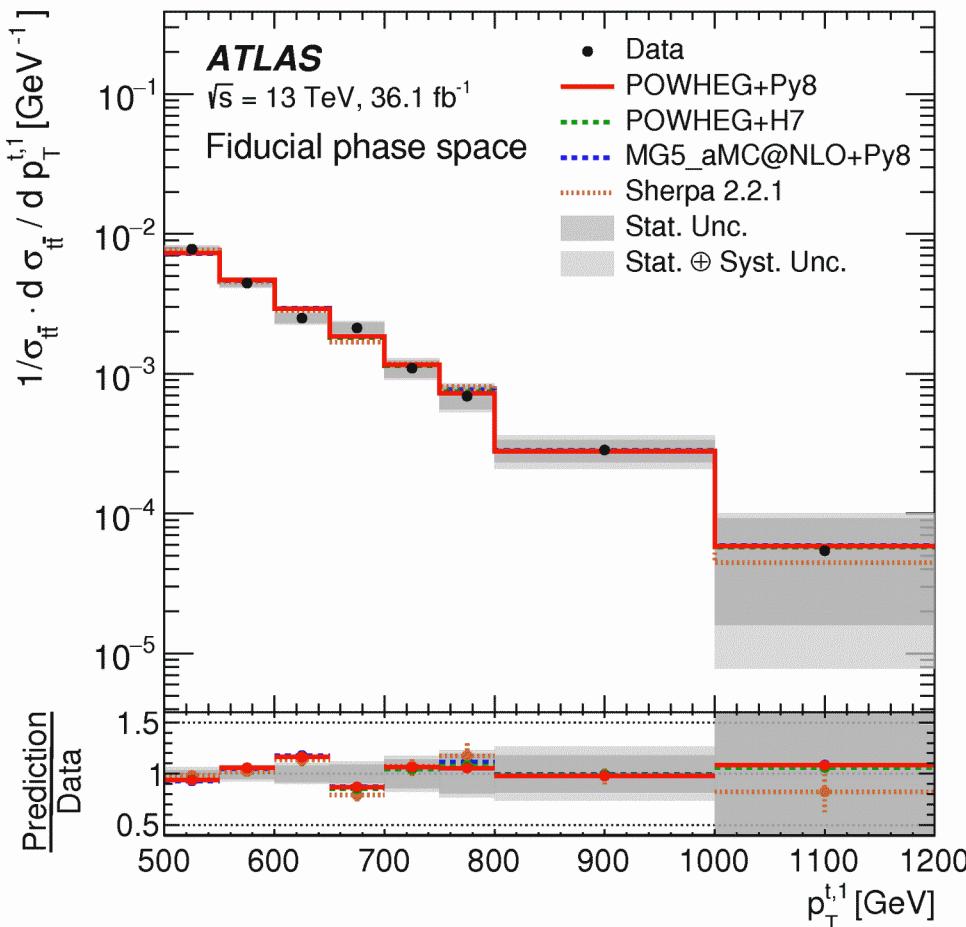


- tension between data and most predictions (resolved, higher uncer. in boosted)
- No electroweak (EW) correction used in predictions – effect is not large enough to remove discrepancy for $p_T \sim 1 \text{ TeV}$
- Powheg+Herwig7 gives the best p-values

Dependence on number of additional jets studied
arXiv:1802.06572
(A. Hasib's talk)

Top-quark transverse momenta (II)

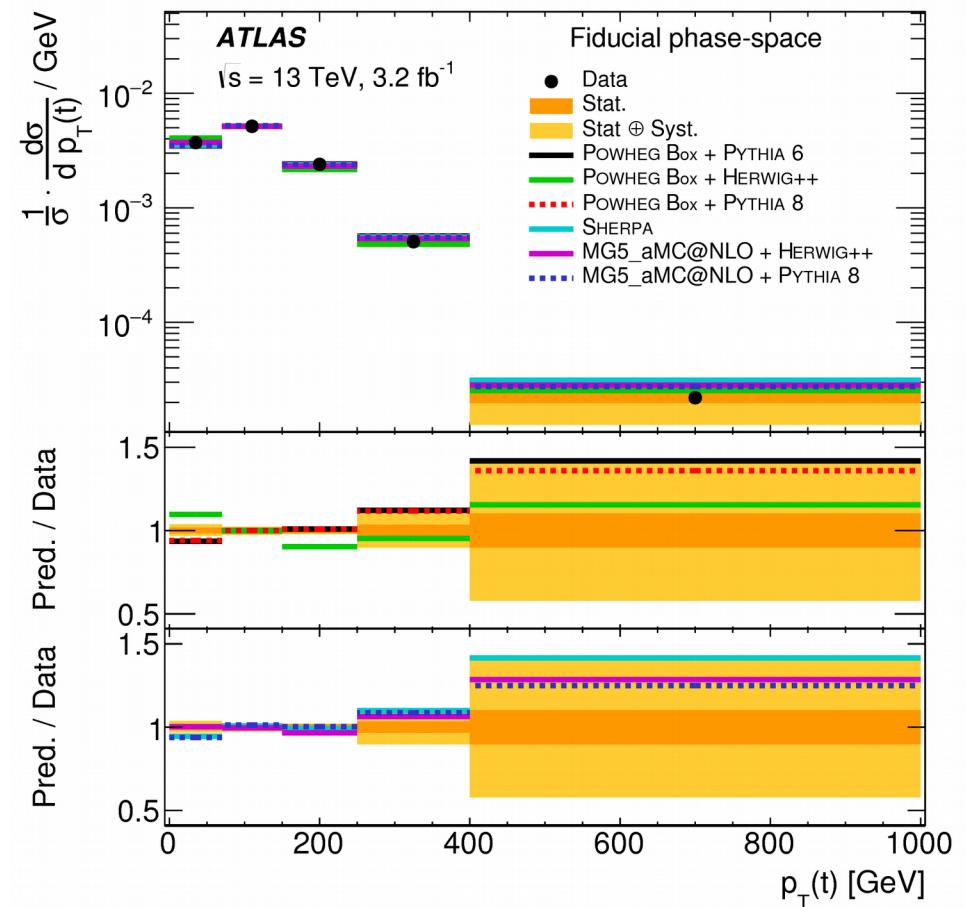
All-hadronic channel
Leading p_T top quark



All-hadronic channel

- Data in agreement with predictions
- no comparison w.r.t. Herwig++

Di-lepton channel

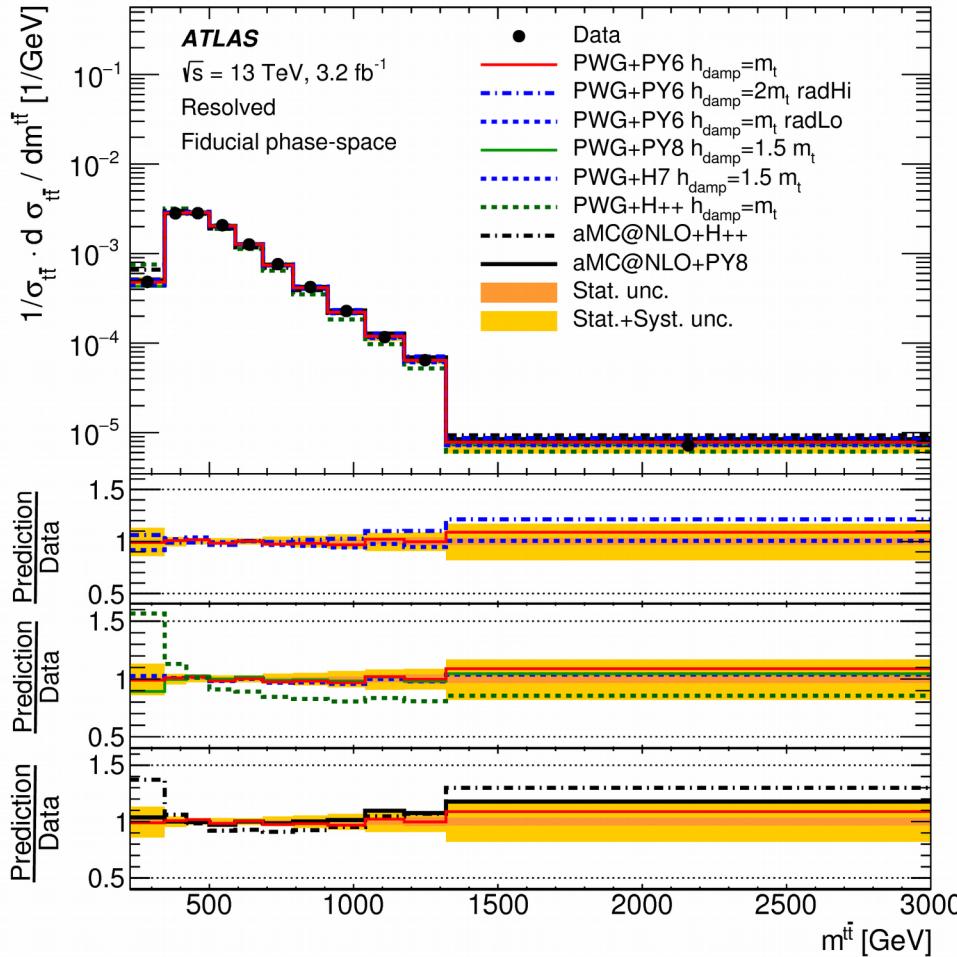


Dilepton channel

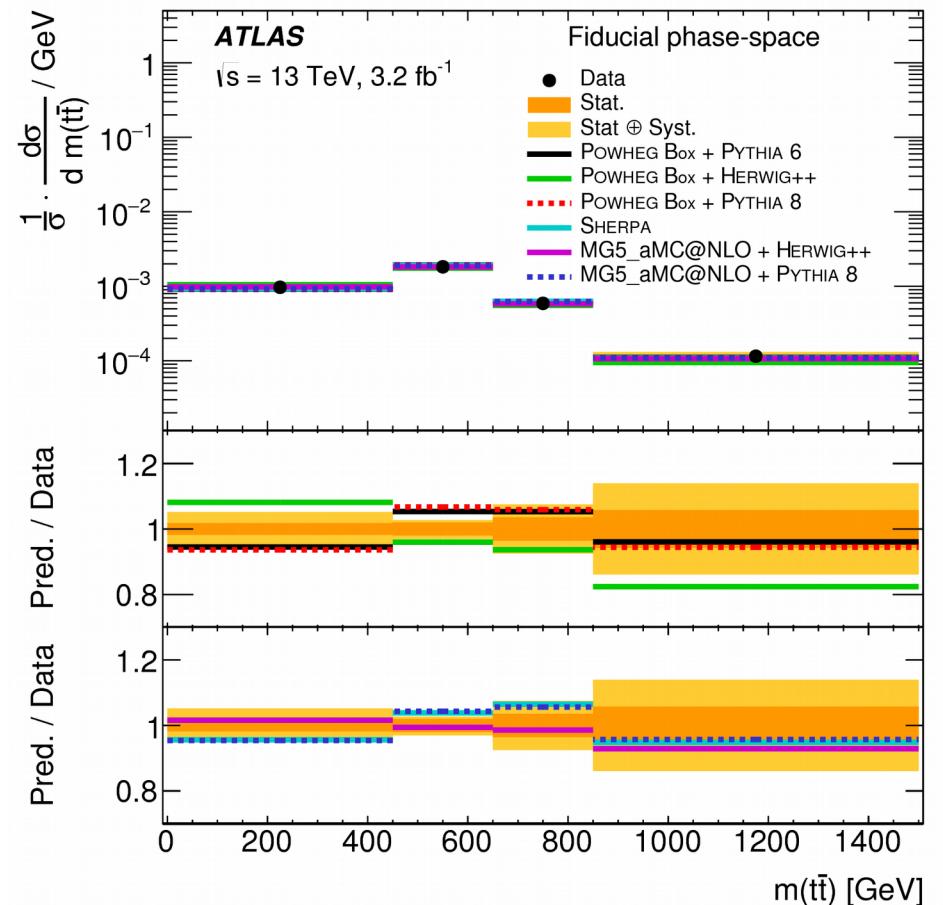
Powheg-Box + Herwig++
deviates from the data

Invariant mass of $t\bar{t}$ system

L+jets – Resolved topology



Di-lepton channel



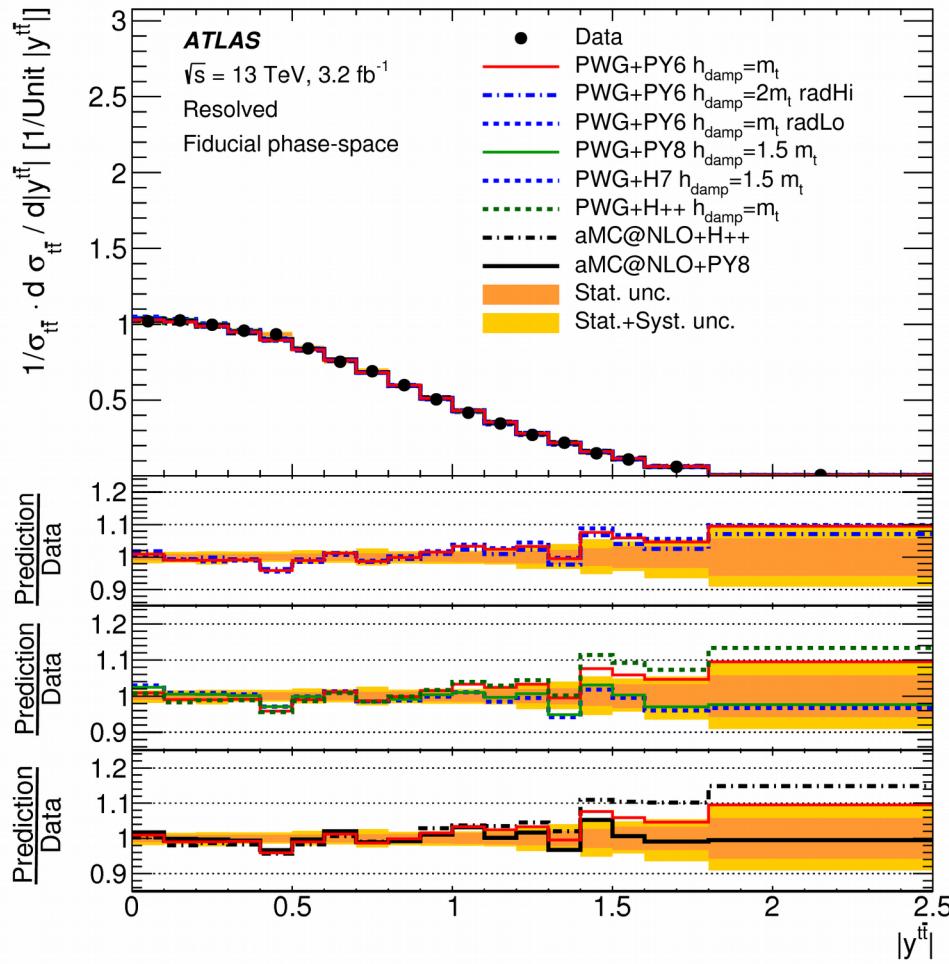
L+jets and di-lepton channel

→ data reasonably agree with predictions except Hervig++ samples

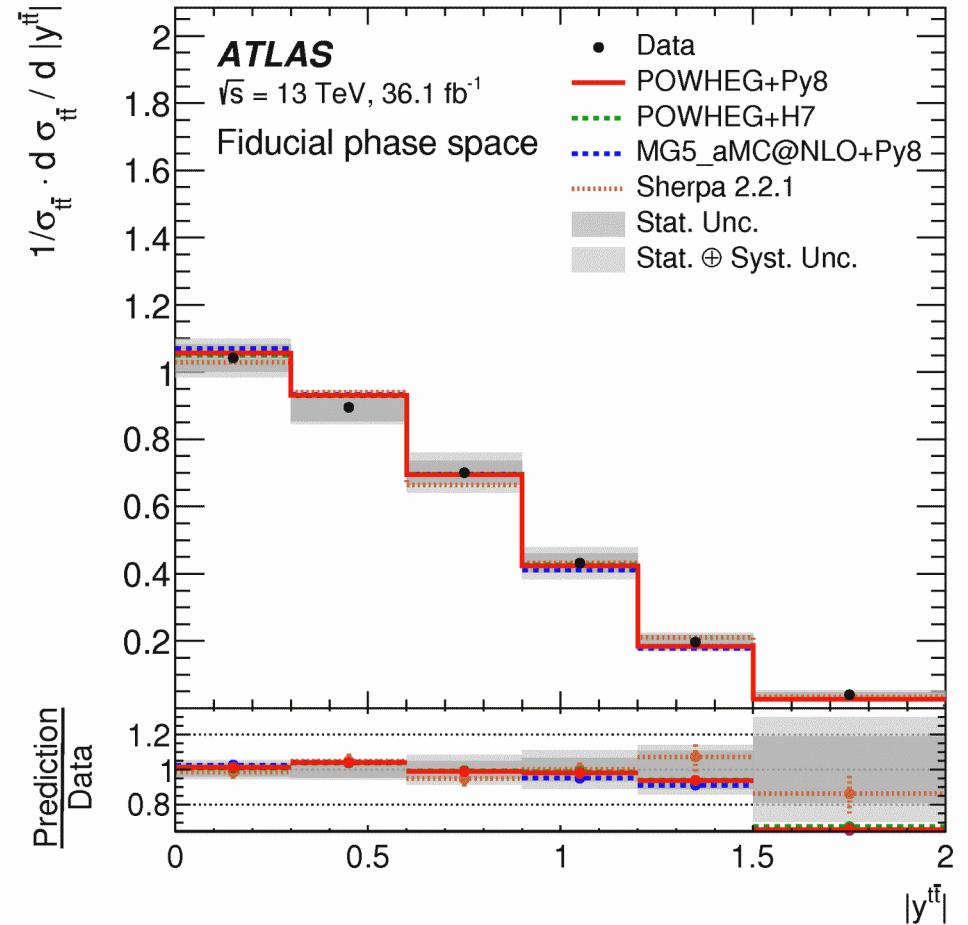
All hadronic channel (good agreement achieved)

Rapidity of $t\bar{t}$ system

L+jets – Resolved topology



All-hadronic channel



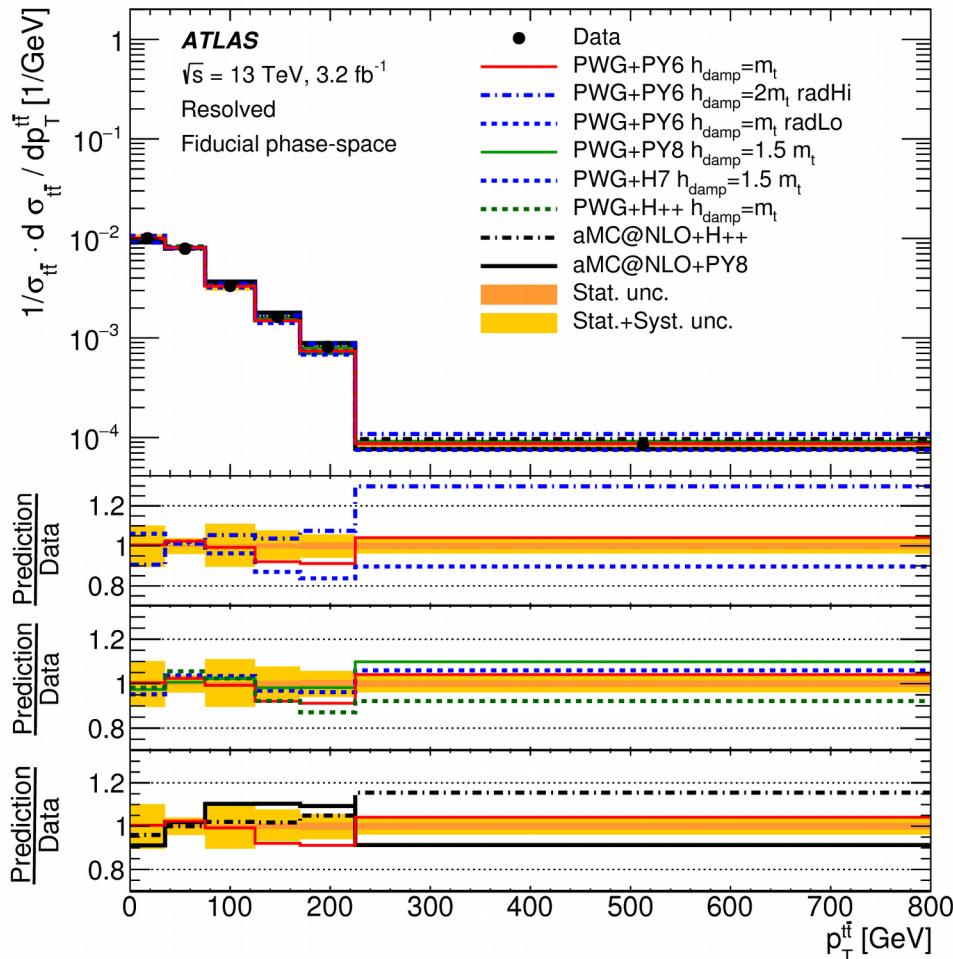
L+jets and di-lepton channel

→ high value of rapidity of $t\bar{t}$ system not adequately described by Herwig++

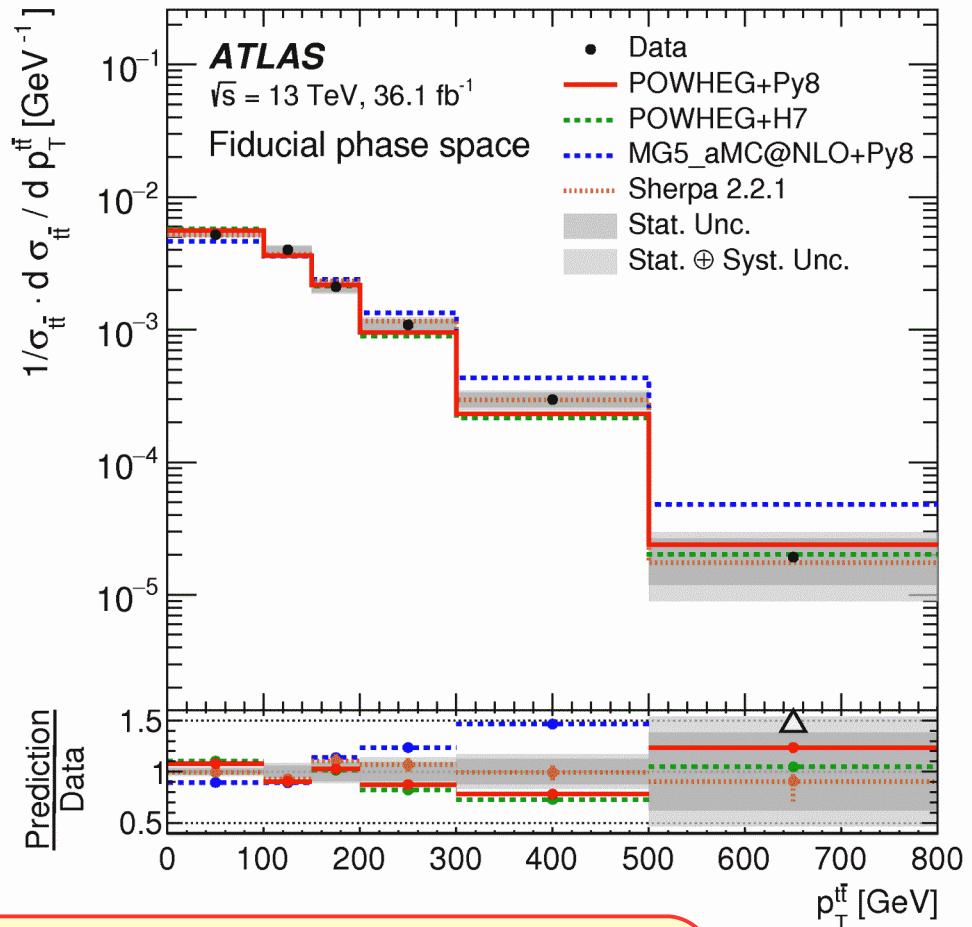
All hadronic channel (data a bit broader than predictions)

Transverse momenta of $t\bar{t}$ system

L+jets – Resolved topology



All-hadronic channel



L+jets channel

→ most of the predictions disagree with data at high values $p_T(t\bar{t})$

All-hadronic channel

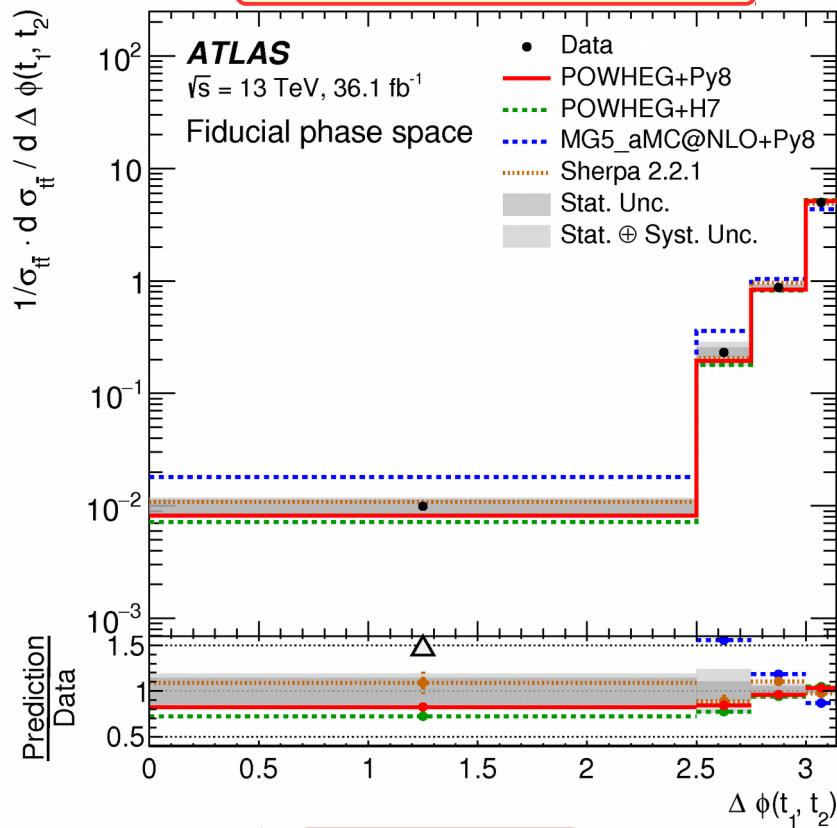
→ Powheg +Pythia8 (Herwig7) softer; MG5_aMC@NLO harder spectrum

Differential $t\bar{t}$ cross-section @ 13 TeV (all hadronic)

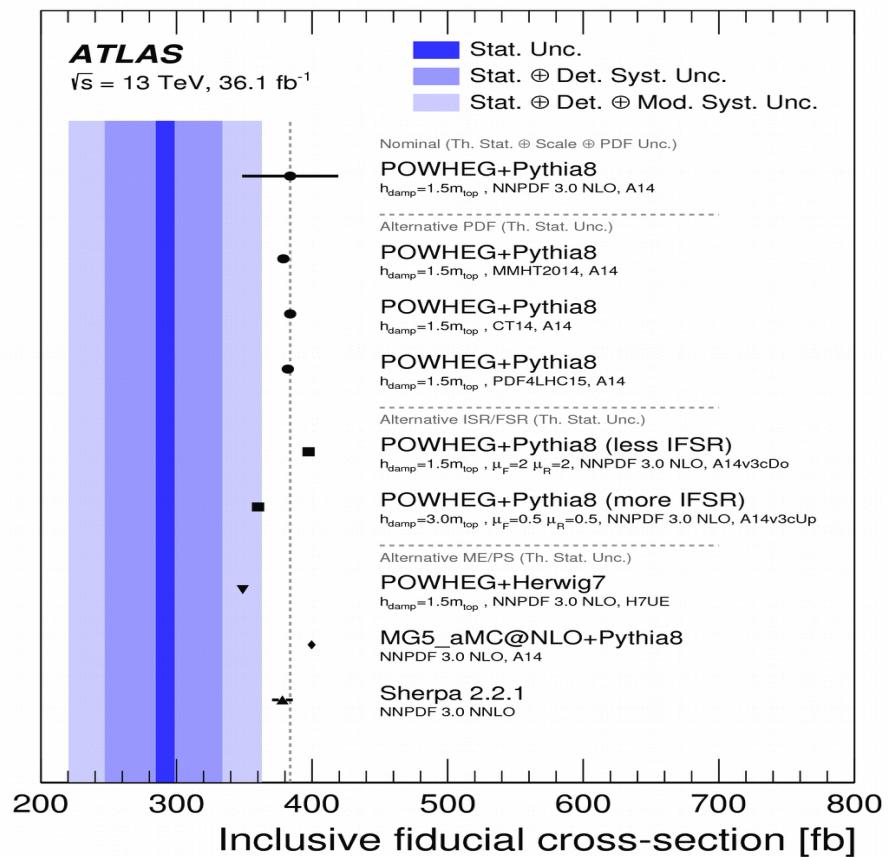
Boosted topology

arXiv:1801.02052

azimuthal opening angle



Most significant
disagreement
with
MG5_aMC@NLO



Fiducial cross section ($p_T^{t,1} > 500 \text{ GeV}, p_T^{t,2} > 350 \text{ GeV}$)
at particle level

$$\sigma_{t\bar{t}}^{fid} = 292 \pm 7 \text{ (stat.)} \pm 76 \text{ (syst.) fb}$$

→ To be compared
with Powheg+Pythia8 (NNLO+NNLL): $384 \pm 36 \text{ fb}$

Conclusions

Inclusive cross-section measurements

- precision at the level of theory or better
- significant constraining power to gluon PDFs at high Bjorken-x ($x \sim 0.1$)

Several differential measurements

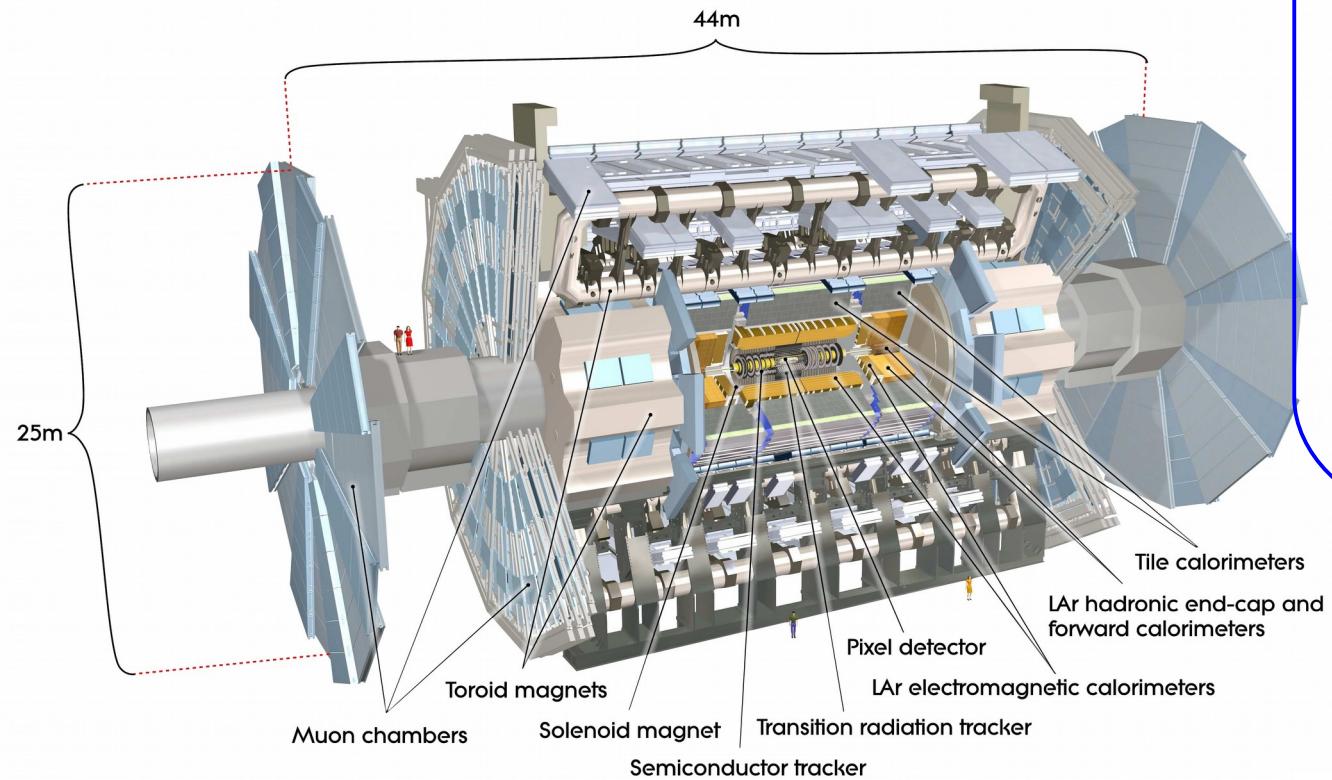
- exploring large phase space
- sensitive to QCD modeling and MC generator tuning
- data comparable with theory predictions within uncertainties
- some tension between measurement and NLO predictions for some quantities (e.g. top p_T)

For more information see: [Top Quark Physics - public results](#)

THANK YOU!

Back up slides

Atlas detector



- **Inner Detectors (ID)**
 - silicon pixel & strip tracker + transition radiation tracker
 - coverage $|\eta| < 2.5$
 - $\sigma / p_T \approx 0.05\% p_T + 1.5\%$
 - impact parameter resolution $\approx 10 \mu\text{m}$
 - inside 2T magnetic field

- **Calorimetry**
 - high-granularity LAr EM calorimeter – $|\eta| < 2.5$
 - iron-scintillator tile calorimeter – $|\eta| < 4.9$

Muon Spectrometers (MS)

- tracking chambers + detectors for triggering
- inside toroidal magnetic field; **coverage: $|\eta| < 2.7$; $\sigma / p_T \approx 2 - 7 \%$**

Inclusive $t\bar{t}$ cross-section @ 8 TeV ($\ell + \text{jets}$)

→ Results from PRD 91 (2015) 112013

$$\sigma_{t\bar{t}} = 258 \pm 1 \text{ (stat.)} {}^{+22}_{-23} \text{ (syst.)} \pm 8 \text{ (lumi)} \pm 4 \text{ (beam) pb}$$

→ Results from arXiv:1712.06857 [hep-ex]

$$\sigma_{inc}^{t\bar{t}} = 248.3 \pm 0.7 \text{ (stat.)} \pm 13.4 \text{ (syst.)} \pm 4.7 \text{ (lumi) pb}$$

| Source | $\frac{\Delta\sigma_{inc}}{\sigma_{inc}} [\%]$ | $\frac{\Delta\sigma_{fid}}{\sigma_{fid}} [\%]$ |
|---------------------------------|--|--|
| Statistical uncertainty | 0.3 | 0.3 |
| Physics object modelling | | |
| Jet energy scale | 1.1 | 1.1 |
| Jet energy resolution | 0.1 | 0.1 |
| Jet reconstruction efficiency | <0.1 | <0.1 |
| E_T^{miss} scale | 0.1 | 0.1 |
| E_T^{miss} resolution | <0.1 | <0.1 |
| Muon momentum scale | <0.1 | <0.1 |
| Muon momentum resolution | <0.1 | <0.1 |
| Electron energy scale | 0.1 | 0.1 |
| Electron energy resolution | <0.1 | <0.1 |
| Lepton identification | 1.4 | 1.4 |
| Lepton reconstruction | 0.3 | 0.3 |
| Lepton trigger | 1.3 | 1.3 |
| b -tagging efficiency | 0.3 | 0.3 |
| c -tagging efficiency | 0.5 | 0.5 |
| Mistag rate | 0.3 | 0.3 |

| Source | $\frac{\Delta\sigma_{inc}}{\sigma_{inc}} [\%]$ | $\frac{\Delta\sigma_{fid}}{\sigma_{fid}} [\%]$ |
|---|--|--|
| Signal Monte Carlo modelling and parton distribution functions | | |
| NLO matching | 1.1 | 0.9 |
| Scale variations | 2.2 | 1.0 |
| Parton shower | 1.3 | 0.9 |
| PDF | 3.0 | 0.1 |
| Background normalisation for non-fitted backgrounds | | |
| Single top | 0.3 | 0.3 |
| Z+jets | 0.2 | 0.2 |
| Diboson | 0.1 | 0.1 |
| Background modelling | | |
| ZtoW modelling | 1.1 | 1.1 |
| Multijet | 0.6 | 0.6 |
| Luminosity | | |
| Total (syst.) | 5.7 | 4.5 |
| Total (syst.+stat.) | 5.7 | 4.5 |

Inclusive $t\bar{t}$ cross-section @ 8 TeV (τ +jets)

$\tau + \text{jets}$ channel ($\sqrt{s} = 8 \text{ TeV}$, $L = 20.2 \text{ fb}^{-1}$)

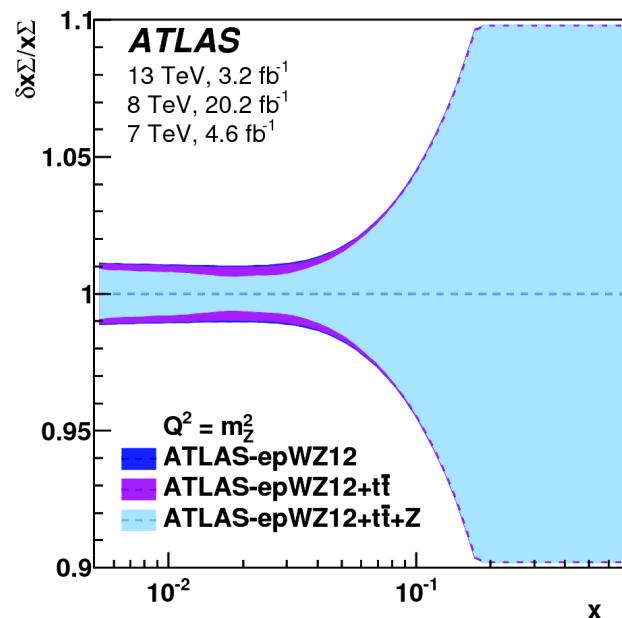
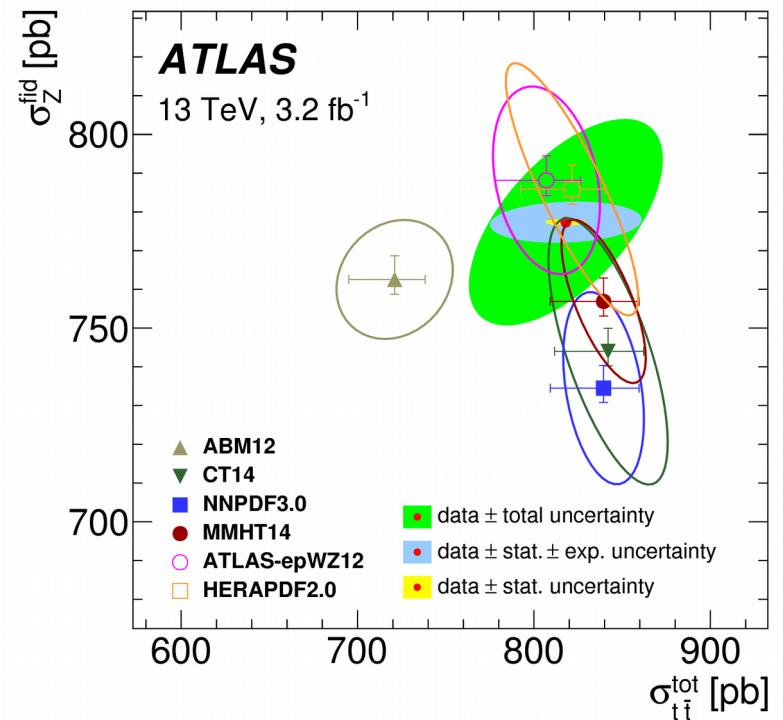
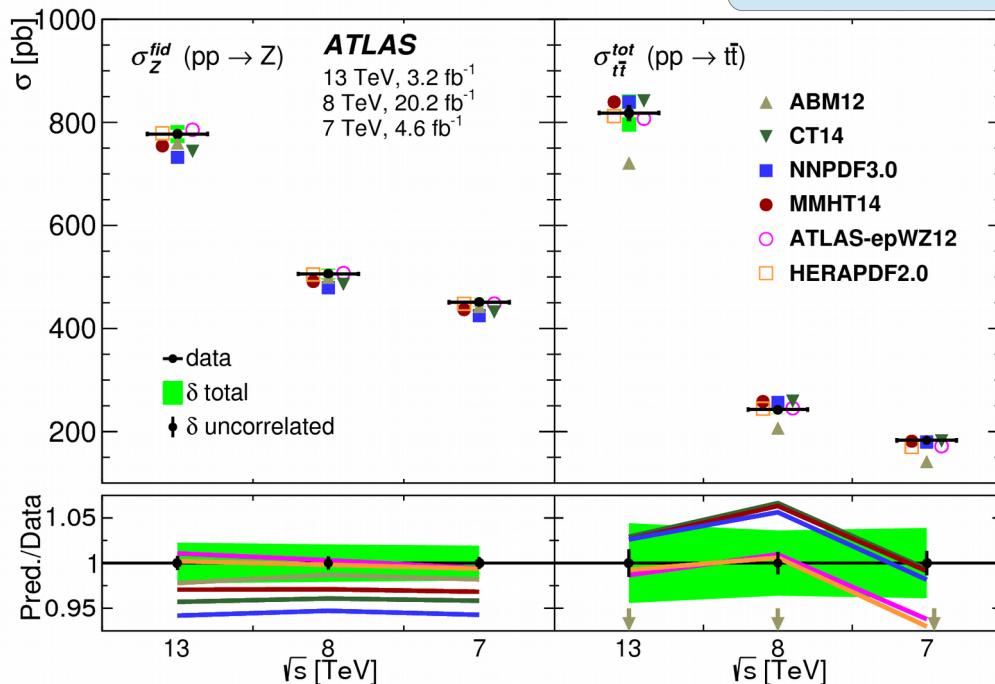
Phys. Rev. D 95, 072003 (2017)

$$\sigma_{t\bar{t}} = 239 \pm 4 \text{ (stat.)} \pm 28 \text{ (syst.)} \pm 5 \text{ (lumi) pb}$$

| Uncertainty | $\tau_{1\text{-prong}}$ | $\tau_{3\text{-prong}}$ | τ_{had} |
|---|-------------------------|-------------------------|---------------------|
| Systematic | - 11 /+ 11 | - 16 /+ 14 | - 12 /+ 12 |
| Jet energy scale | - 4.0 /+ 4.2 | - 8.4 /+ 5.7 | - 5.0 /+ 4.5 |
| b -tag efficiency | - 4.7 /+ 5.0 | - 4.8 /+ 5.0 | - 4.7 /+ 5.0 |
| c -mistag efficiency | - 1.6 /+ 1.6 | - 1.5 /+ 1.5 | - 1.6 /+ 1.6 |
| Light-jet mistag efficiency | - 0.3 /+ 0.3 | - 0.5 /+ 0.5 | - 0.4 /+ 0.4 |
| E_T^{miss} | - 0.3 /+ 0.5 | - 1.7 /+ 0.5 | - 0.6 /+ 0.4 |
| τ_{had} identification | - 3.5 /+ 3.4 | - 6.0 /+ 5.6 | - 4.1 /+ 3.9 |
| τ_{had} energy scale | - 2.1 /+ 2.0 | - 1.2 /+ 1.4 | - 1.9 /+ 1.9 |
| Jet vertex fraction | - 0.1 /+ 0.3 | - 0.3 /+ 0.3 | - 0.2 /+ 0.3 |
| Jet energy resolution | - 1.4 /+ 1.4 | - 0.2 /+ 0.2 | - 1.1 /+ 1.1 |
| Generator | - 1.5 /+ 1.5 | - 2.5 /+ 2.5 | - 2.1 /+ 2.1 |
| Parton Shower | - 2.0 /+ 2.0 | - 2.6 /+ 2.6 | - 2.1 /+ 2.1 |
| ISR/FSR | - 6.2 /+ 6.2 | - 8.5 /+ 8.5 | - 6.7 /+ 6.7 |
| Misidentified- τ_{had} background | - 1.3 /+ 1.4 | - 2.0 /+ 2.2 | - 1.6 /+ 1.6 |
| $W + \text{jets}$ background | - 2.9 /+ 2.9 | - 3.6 /+ 3.6 | - 3.0 /+ 3.0 |
| Statistics | - 2.2 /+ 2.2 | - 5.6 /+ 5.6 | - 1.7 /+ 1.7 |
| Luminosity | - 2.3 /+ 2.3 | - 2.3 /+ 2.3 | - 2.3 /+ 2.3 |

$t\bar{t}$ to Z-boson cross-section ratios (@ 7, 8, 13 TeV)

JHEP 02 (2017) 117



| | $\sigma_{t\bar{t}}^{tot} / \sigma_{t\bar{t}}^{fid}$ |
|--|---|
| Value \pm stat \pm syst \pm lumi | |
| $t\bar{t}/Z(13)$ | $1.053 \pm 0.010 (0.9\%) \pm 0.036 (3.4\%) \pm 0.002 (0.2\%)$ |
| $t\bar{t}/Z(8)$ | $0.480 \pm 0.003 (0.7\%) \pm 0.012 (2.6\%) \pm 0.001 (0.2\%)$ |
| $t\bar{t}/Z(7)$ | $0.406 \pm 0.007 (1.7\%) \pm 0.011 (2.6\%) \pm 0.001 (0.2\%)$ |

Relative uncertainty $\sim 2.5 - 3.5 \%$

Differential $t\bar{t}$ cross-section @ 13 TeV ($\ell + \text{jets}$)

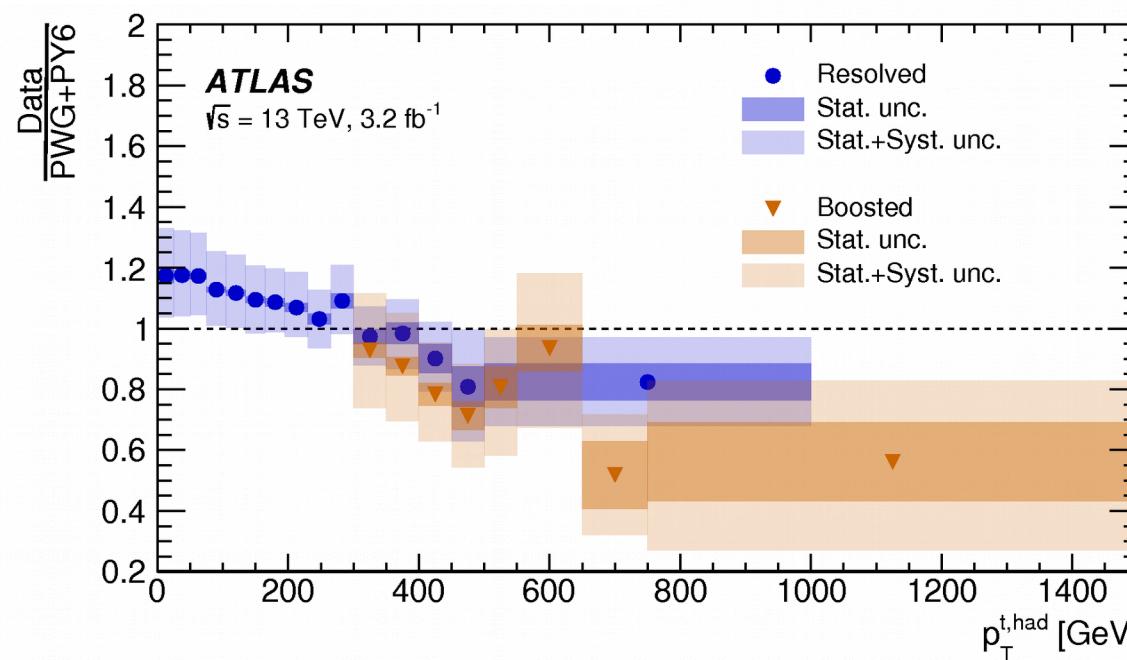
JHEP 11 (2017) 191

| Level | Detector | | Particle |
|----------------------------|--|---|--|
| Topology | Resolved | Boosted | |
| Leptons | $ d_0 /\sigma(d_0) < 5$ and $ z_0 \sin \theta < 0.5 \text{ mm}$ Track and calorimeter isolation $ \eta < 1.37$ or $1.52 < \eta < 2.47$ (e), $ \eta < 2.5$ (μ) $E_T(e)$, $p_T(\mu) > 25 \text{ GeV}$ | | $ \eta < 2.5$ $p_T > 25 \text{ GeV}$ |
| Small- R jets | $ \eta < 2.5$ $p_T > 25 \text{ GeV}$ JVT cut (if $p_T < 60 \text{ GeV}$ and $ \eta < 2.4$) | | $ \eta < 2.5$ $p_T > 25 \text{ GeV}$ |
| Num. of small- R jets | ≥ 4 jets | ≥ 1 jet | Same as detector level |
| E_T^{miss}, m_T^W | | $E_T^{\text{miss}} > 20 \text{ GeV}$, $E_T^{\text{miss}} + m_T^W > 60 \text{ GeV}$ | Same as detector level |
| Leptonic top | Kinematic top-quark reconstruction for detector and particle level | At least one small- R jet with $\Delta R(\ell, \text{small-}R \text{ jet}) < 2.0$ | |
| Hadronic top | Kinematic top-quark reconstruction for detector and particle level | The leading- p_T trimmed large- R jet has: $ \eta < 2.0$, $300 \text{ GeV} < p_T < 1500 \text{ GeV}$, $m > 50 \text{ GeV}$, Top-tagging at 80% efficiency $\Delta R(\text{large-}R \text{ jet}, \text{small-}R \text{ jet associated with lepton}) > 1.5$, $\Delta\phi(\ell, \text{large-}R \text{ jet}) > 1.0$ | Boosted: $ \eta < 2.0$ $300 < p_T < 1500 \text{ GeV}$ Top-tagging: $m > 100 \text{ GeV}$, $\tau_{32} < 0.75$ |
| b -tagging | At least 2 b -tagged jets | At least one of: 1) the leading- p_T small- R jet with $\Delta R(\ell, \text{small-}R \text{ jet}) < 2.0$ is b -tagged 2) at least one small- R jet with $\Delta R(\text{large-}R \text{ jet}, \text{small-}R \text{ jet}) < 1.0$ is b -tagged | Ghost-matched b -hadron |

Top-quark transverse momenta (I)

| L+jets – Resolved topology | $p_T^{t,\text{had}}$ | | $ y^{t,\text{had}} $ | | $m_{t\bar{t}}$ | | $p_T^{t\bar{t}}$ | | $ y^{t\bar{t}} $ | |
|----------------------------|----------------------|----------------|----------------------|----------------|---------------------|----------------|---------------------|----------------|---------------------|----------------|
| | χ^2/NDF | $p\text{-val}$ | χ^2/NDF | $p\text{-val}$ | χ^2/NDF | $p\text{-val}$ | χ^2/NDF | $p\text{-val}$ | χ^2/NDF | $p\text{-val}$ |
| POWHEG+PYTHIA6 | 19.0/15 | 0.22 | 7.8/18 | 0.98 | 9.8/11 | 0.55 | 14.9/6 | 0.02 | 20.0/18 | 0.33 |
| POWHEG+PYTHIA6 (radHi) | 20.9/15 | 0.14 | 8.5/18 | 0.97 | 8.7/11 | 0.65 | 56.1/6 | <0.01 | 17.3/18 | 0.51 |
| POWHEG+PYTHIA6 (radLo) | 20.8/15 | 0.14 | 7.4/18 | 0.99 | 12.7/11 | 0.32 | 22.1/6 | <0.01 | 25.5/18 | 0.11 |
| MADGRAPH5_aMC@NLO+HERWIG++ | 23.5/15 | 0.07 | 10.7/18 | 0.91 | 32.4/11 | <0.01 | 16.4/6 | 0.01 | 28.1/18 | 0.06 |
| POWHEG+HERWIG++ | 30.3/15 | 0.01 | 7.9/18 | 0.98 | 34.8/11 | <0.01 | 28.0/6 | <0.01 | 30.4/18 | 0.03 |
| MADGRAPH5_aMC@NLO+PYTHIA8 | 19.1/15 | 0.21 | 8.4/18 | 0.97 | 7.6/11 | 0.75 | 19.0/6 | <0.01 | 16.1/18 | 0.59 |
| POWHEG+PYTHIA8 | 18.4/15 | 0.24 | 10.5/18 | 0.92 | 7.7/11 | 0.74 | 11.7/6 | 0.07 | 12.3/18 | 0.83 |
| POWHEG+HERWIG7 | 13.8/15 | 0.54 | 10.9/18 | 0.90 | 7.0/11 | 0.80 | 11.6/6 | 0.07 | 12.8/18 | 0.80 |

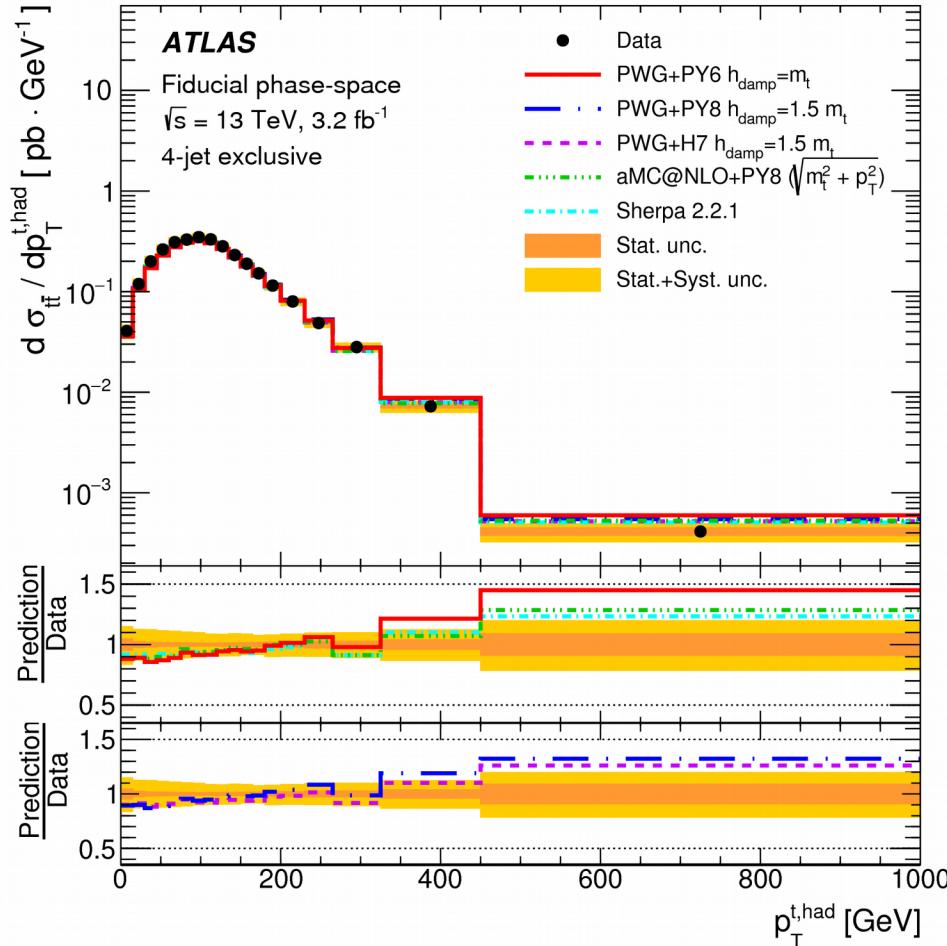
| L+jets – Boosted topology | $p_T^{t,\text{had}}$ | | $ y^{t,\text{had}} $ | |
|----------------------------|----------------------|----------------|----------------------|----------------|
| | χ^2/NDF | $p\text{-val}$ | χ^2/NDF | $p\text{-val}$ |
| POWHEG+PYTHIA6 | 14.7/8 | 0.06 | 11.0/10 | 0.36 |
| POWHEG+PYTHIA6 (radHi) | 19.5/8 | 0.01 | 12.3/10 | 0.27 |
| POWHEG+PYTHIA6 (radLo) | 15.0/8 | 0.06 | 10.0/10 | 0.44 |
| MADGRAPH5_aMC@NLO+HERWIG++ | 17.9/8 | 0.02 | 12.8/10 | 0.24 |
| POWHEG+HERWIG++ | 14.1/8 | 0.08 | 8.0/10 | 0.63 |
| MADGRAPH5_aMC@NLO+PYTHIA8 | 12.8/8 | 0.12 | 20.4/10 | 0.03 |
| POWHEG+PYTHIA8 | 16.7/8 | 0.03 | 18.4/10 | 0.05 |
| POWHEG+HERWIG7 | 11.9/8 | 0.15 | 11.7/10 | 0.30 |



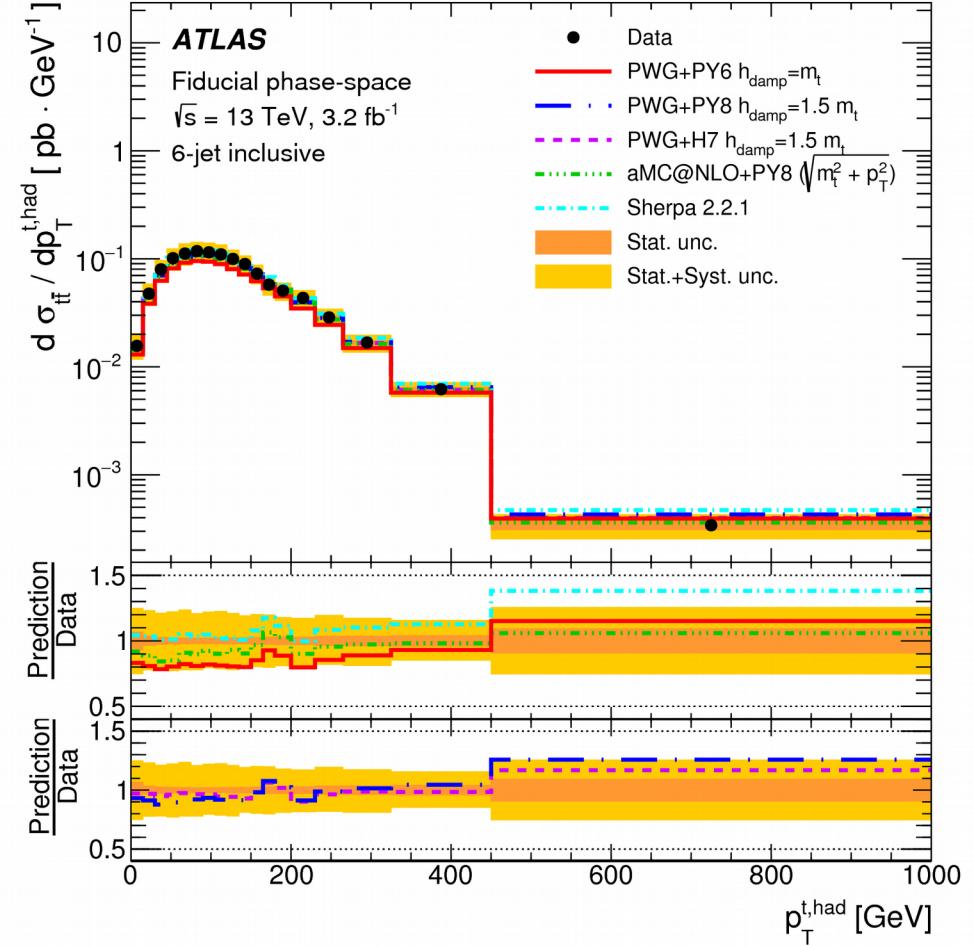
Top-quark transverse momenta (II)

Dependence on number of additional jets studied
arXiv:1802.06572 (A. Hasib's talk)

4 jets, exclusive



6 jets inclusive



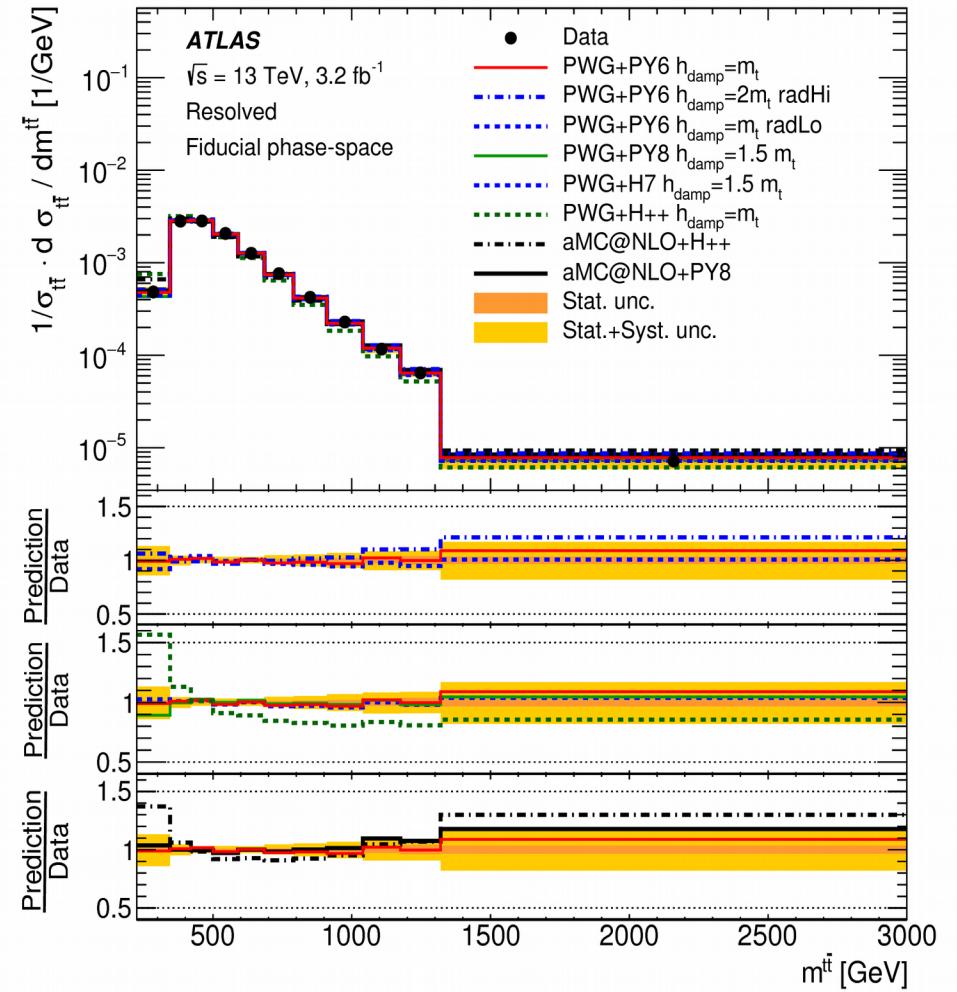
Differential $t\bar{t}$ cross-section @ 13 TeV ($\ell+jets$)

Resolved topology

JHEP 11 (2017) 191

mass of $t\bar{t}$ system

→ all predictions agree with data
except Herwig++



Differential $t\bar{t}$ cross-section @ 13 TeV (dilepton)

Resolved topology

Eur. Phys. J. C77 (2017) 299

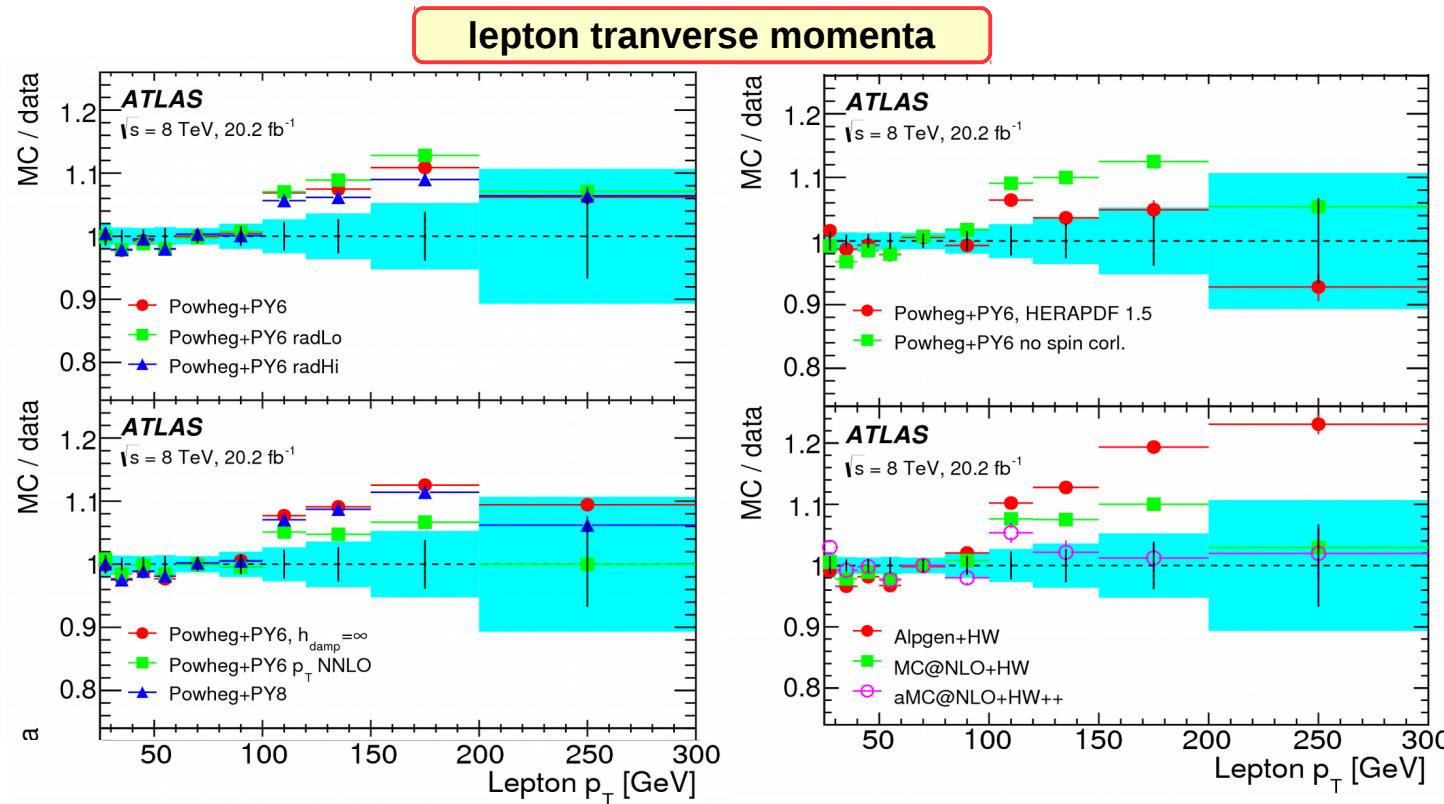
top-quark transverse momenta

| $p_T(t)$ | 0 – 70 GeV | 70 – 150 GeV | 150 – 250 GeV | 250 – 400 GeV | 400 – 1000 GeV |
|---------------------|----------------------------|--------------|---------------|---------------|----------------|
| Source | Systematic uncertainty (%) | | | | |
| Radiation scale | +2.1 – 0.3 | +0.0 – 1.1 | +0.4 – 0.3 | +0.0 – 1.2 | +2.1 – 0.0 |
| MC generator | ±0.2 | ±0.2 | ±0.4 | ±2.7 | ±5.4 |
| PDF extrapolation | ±0.5 | ±0.4 | ±0.4 | ±2.4 | ±0.8 |
| PDF4LHC 100 | ±0.6 | ±0.3 | ±0.5 | ±1.7 | ±4.0 |
| Parton shower | ±2.8 | ±2.1 | ±1.6 | ±8.9 | ±41 |
| Background | +0.1 – 0.2 | +0.0 – 0.1 | +0.3 – 0.0 | +0.3 – 0.1 | +0.1 – 1.2 |
| Pile-up | +0.4 – 0.8 | ±0.0 | +0.3 – 0.2 | +0.8 – 0.7 | +5.1 – 0.0 |
| Lepton | +0.4 – 0.3 | +0.1 – 0.3 | +0.3 – 0.1 | ±0.7 | +2.3 – 1.9 |
| b -tagging | ±0.2 | ±0.2 | ±0.2 | ±0.9 | +2.3 – 2.4 |
| Jet | +0.9 – 0.8 | +0.4 – 1.0 | +0.8 – 0.6 | +3.0 – 2.4 | +6.9 – 7.3 |
| E_T^{miss} | +0.2 – 0.1 | +0.0 – 0.1 | +0.2 – 0.1 | +0.3 – 0.5 | +1.0 – 0.4 |
| Luminosity | ±0.0 | ±0.0 | ±0.0 | ±0.0 | ±0.0 |
| MC stat. unc. | ±0.0 | ±0.2 | ±0.0 | ±0.4 | ±2.6 |
| Total syst. unc. | +3.8 – 3.2 | +2.2 – 2.7 | +2.1 – 2.0 | +10 – 10 | +42 – 42 |
| Data statistics | ±1.8 | ±1.3 | ±1.8 | ±3.4 | ±10 |
| Total uncertainty | +4.2 – 3.6 | +2.6 – 2.9 | +2.8 – 2.7 | +11 – 11 | +44 – 43 |

Differential cross-section of leptons in $t\bar{t}$ di-lepton events @ 8 TeV

Eur. Phys. J. C 77 (2017) 804

- opposite charge leptons - one e and one μ ($p_T > 25$ GeV, $|\eta| < 2.5$)
- **≥ 2 small-R anti-k_T jets**: ($p_T > 25$ GeV, $|\eta| < 2.5$), **≥ 1 b-tagged jet** (70% efficient point)
- results corrected to detector effects => at particle level
- 8 distributions considered: p_T^l , $|\eta^l|$; $|y^{e\mu}|$, $p_T^{e\mu}$, $m^{e\mu}$, $\Delta\phi^{e\mu}$, $p_T^e + p_T^\mu$, $E^e + E^\mu$



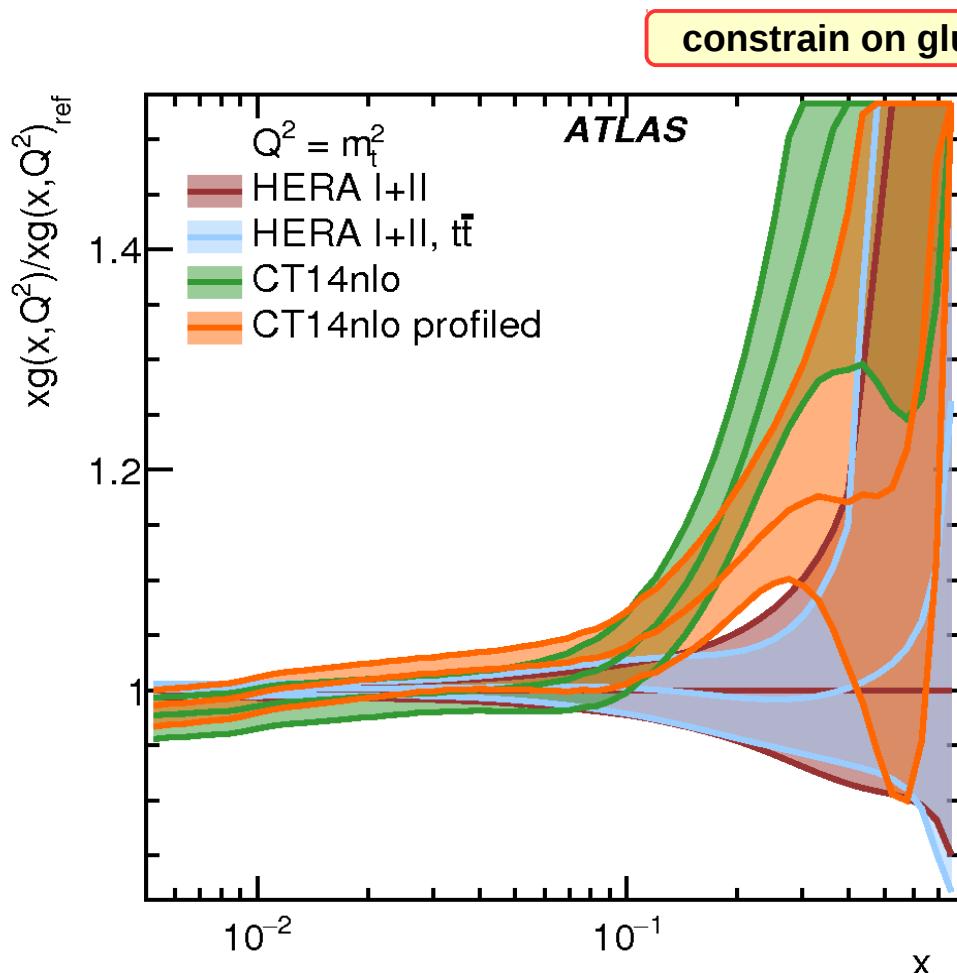
More dependences in
J. E. Garcia's talk

- data are softer than the predictions from Powheg (CT10 PDFs), interfaced to Pythia (6 or 8)
- Powheg predictions do not depend strongly on parton shower, hadronisation, or radiation modeling
- agreement with data - improved for HERAPDF 1.5 or reweighting to the NNLO prediction

Differential cross-section of leptons in $t\bar{t}$ di-lepton events @ 8 TeV

Eur. Phys. J. C 77 (2017) 804

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Ability to constrain the gluon PDF

- fit performed to DIS data from HERA I+II
- additional constrain from $|\eta^l|$, $|y^{e\mu}|$, $E^e + E^\mu$ measurements
- inclusion of $t\bar{t}$ data reduces the uncertainty by 10-25 % over the relevant x range
- profiling of CT14 (NNPDF 3.0) → shifts gluon distribution to the lower values