Top quark pair production cross section at LHC in ATLAS

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On behalf of the ATLAS collaboration

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ATLAS

FSP 101 ATLAS

PHYSICS AT THE TERA SCALE
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Motivation

- Precise pQCD tests for top quark production;
  Calculations available up to NNLO+NNLL with $m_t = 172.5\,\text{GeV}$:
  $\sigma_{t\bar{t}}(\sqrt{s} = 7\,\text{TeV}) = 177.3^{+10.1}_{-10.8}\,\text{pb}, \sigma_{t\bar{t}}(\sqrt{s} = 8\,\text{TeV}) = 252.9^{+13.3}_{-14.5}\,\text{pb}$
- Indirect sensitivity to new physics
- Important background for various analyses/searches such as $H \to b\bar{b}$ measurement
- Provides constraints to modeling like PDF and ISR/FSR

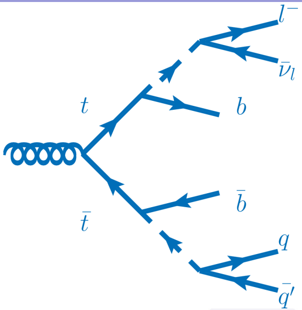
Six measurements from the ATLAS collaboration are presented:

- Inclusive top quark cross section
  - Single lepton channel @ 8 TeV [*ATLAS-CONF-2012-149*]
  - Dilepton channel @ 8 TeV [*ATLAS-CONF-2013-097*]
  - τ+lepton channel @ 7 TeV [*Phys.Lett.B717(2012)89-108*]
- Differential top quark cross section
  - $\sigma_{t\bar{t}}(p_t(t)), \sigma_{t\bar{t}}(m_{t\bar{t}})$ @ 7 TeV [*ATLAS-CONF-2013-099*]
  - $\sigma_{t\bar{t}}(n_{\text{jets}})$ @ 7 TeV [*ATLAS-CONF-2012-155*]
  - Gap fraction @ 7 TeV [*Eur.Phys.J.C72(2012)2043*]

TYPICAL EVENT SELECTION

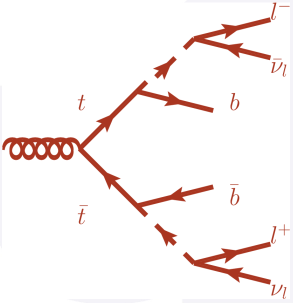
Single lepton $t\bar{t}$ selection

- Exactly one isolated, high-p_T lepton:
  electron with $p_T > 25$ GeV
  muon with $p_T > 20$ GeV
- At least three/four jets with $p_T > 25$ GeV,
  of which at least one jet is b-tagged
- High missing transverse energy: $E_T^{miss} > 30$ GeV (e+jets) or $E_T^{miss} > 20$ GeV (μ+jets)
- Transverse mass of leptonically decayed W boson: $m_T^W > 30$ GeV (e+jets) or $m_T^W + E_T^{miss} > 60$ GeV (μ+jets)



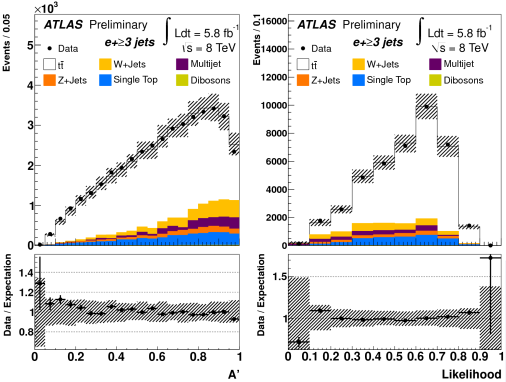
Dilepton $t\bar{t}$ selection

- Exactly two isolated, high-p_T leptons with $p_T > 20 - 25$ GeV and opposite electric charge
- At least two jets with $p_T > 25$ GeV
- $E_T^{miss} > 60$ GeV (ee, $\mu\mu$) or $H_T > 130$ GeV ($e\mu$)
- $m_{ll} > 15$ GeV and $|m_{ll} - m_Z| > 10$ GeV



Inclusive top quark pair cross section measurements

- First ATLAS measurement of $\sigma_{t\bar{t}}$ at 8 TeV [*ATLAS-CONF-2012-149*]
- Tighter lepton selection with $p_T > 40$ GeV to further reduce multjet background
- Inclusive cross section measured using a likelihood discriminant template fit
- Discriminants: $\eta_{e,\mu}$, aplanarity A'



- Dominant uncertainties due to signal modeling (11%) and jet uncertainties (5-6%)

$$\sigma_{t\bar{t}} = 241 \pm 2\,(\text{stat.}) \pm 31\,(\text{syst.}) \pm 9\,(\text{lumi})\,\text{pb}$$

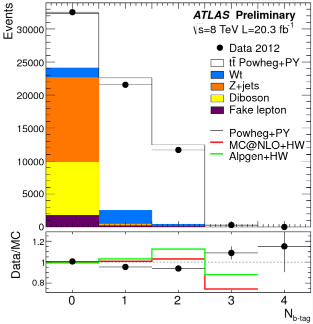
- Consistent with SM expectation $\sigma_{t\bar{t}}^{\text{NNLO+NNLL}} = 252.9^{+13.3}_{-14.5}$ pb

DILEPTON CHANNEL, $\sqrt{s} = 8\,\text{TeV}$, $L_{\text{int}} = 20.3\,\text{fb}^{-1}$

- Measurement in $e\mu$-channel with exactly one (N_1) or two b-tagged jets (N_2) [*ATLAS-CONF-2013-097*]
- Highly pure signal selection, only 11% background events in sample with one b-tagged jet, 4% background in sample with two b-tagged jets
- Simultaneous determination of $\sigma_{t\bar{t}}$ and the efficiency to reconstruct & b-tag jets

$$N_1 = L\sigma_{t\bar{t}}\epsilon_{e\mu}2\epsilon_b(1 - C_b\epsilon_b) + N_1^{\text{bkg}},$$
$$N_2 = L\sigma_{t\bar{t}}\epsilon_{e\mu}\epsilon_b^2 C_b + N_2^{\text{bkg}},$$

with $N_{1,2}$: Number of selected events,
L: Integrated luminosity
$\sigma_{t\bar{t}}$: $t\bar{t}$ cross section
$\epsilon_{e\mu}$: Efficiency to pass $e\mu$ preselection,
ϵ_b: Combined probability for a jet from $t \to Wq$ to be within acceptance, reconstructed as jet and b-tagged,
C_b: Correlations between two b-tagged jets,
with $N_{1,2}^{\text{bkg}}$: Number of background events

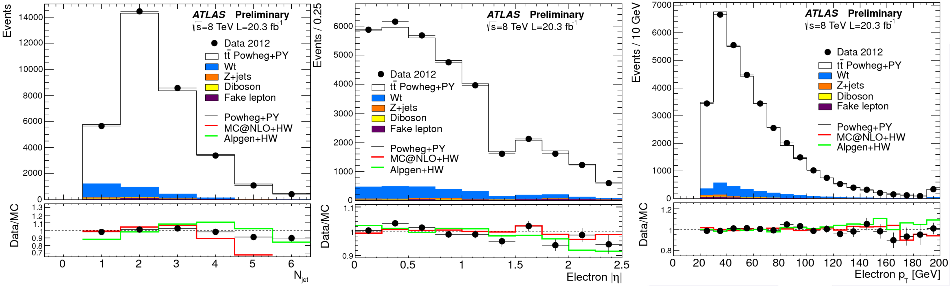


⇒ **Approach reduces jet-related systematic uncertainties**

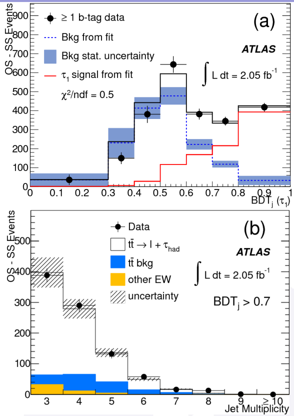
- Dominant uncertainties due to luminosity (3.1%) and beam energy measurement (1.7%); leading systematic uncertainties from signal modeling (1.5%) and electron-ID (1.4%)

$$\sigma_{t\bar{t}} = 237.7 \pm 1.7\,(\text{stat.}) \pm 7.4\,(\text{syst.}) \pm 7.4\,(\text{lumi}) \pm 4.0\,(\text{beam energy})\,\text{pb}$$

- Consistent with SM expectation $\sigma_{t\bar{t}}^{\text{NNLO+NNLL}} = 252.9^{+13.3}_{-14.5}$ pb



- Cross section measurement with hadronically decaying τ in final state [*Phys.Lett.B717(2012)89-108*]
- Search for $t \to bH^+$ decay with $H^+ \to \tau^+ \nu_\tau$
- τ-reconstruction: 1-3 associated tracks with $p_T > 1$ GeV, 20 GeV $< E_T <$ 100 GeV, $|\eta| < 2.3$
- τ-ID: Boosted decision trees (BDT) from calorimeter- & track-based variables to discriminate between τ leptons and misidentified electrons (BDT$_e$) or jets (BDT$_j$)
- Separate BDT$_j$ for τ candidates with exactly one track (τ_1) and ≥ 1 track (τ_3)



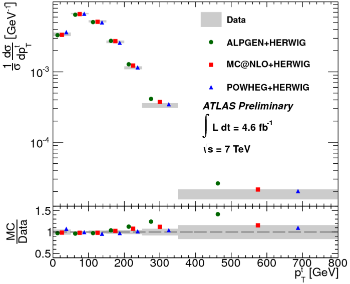
- χ^2-fits to BDT$_j$ distributions of events with for ≥ 1 *b*-jet
- Signal templates from MC, background from events with no *b*-jet
- Main systematic uncertainties from *b*-tagging, τ-ID and ISR/FSR modeling

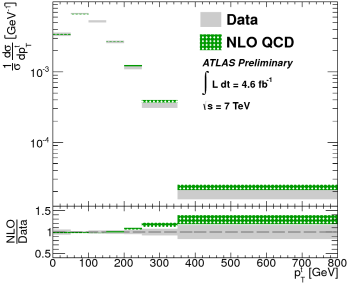
$$\sigma_{t\bar{t}} = 186 \pm 13\,(\text{stat.}) \pm 20\,(\text{syst.}) \pm 7\,(\text{lumi})\,\text{pb}$$

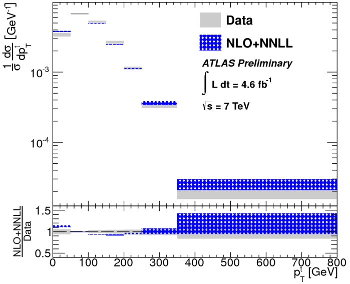
- Consistent with SM expectation $\sigma_{t\bar{t}}^{\text{NNLO+NNLL}} = 177.3^{+10.1}_{-10.8}$ pb

Differential top quark pair cross section measurements

Comparison to SM simulations/calculations [*ATLAS-CONF-2013-099*]



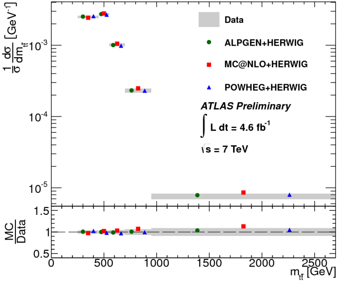


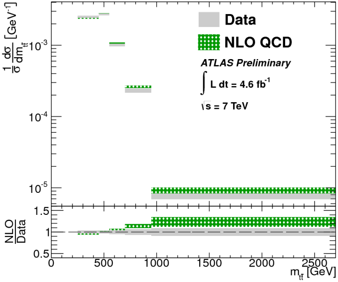


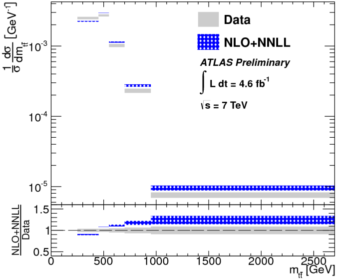
- Comparison to ALPGEN, MC@NLO, POWHEG, MCFM (QCD NLO) and NLO+NNLL
- All generators show harder p_T distribution than data
- Best data description by POWHEG+HERWIG

$\sigma_{t\bar{t}}(m_{t\bar{t}})$, $\sqrt{s} = 7$ TeV, $L_{\text{int}} = 4.6\ \text{fb}^{-1}$

Comparison to SM simulations/calculations [*ATLAS-CONF-2013-099*]

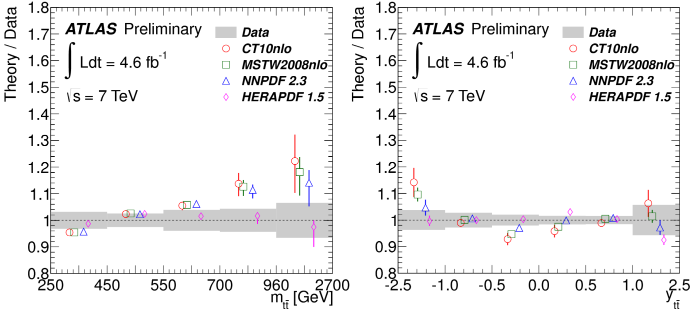






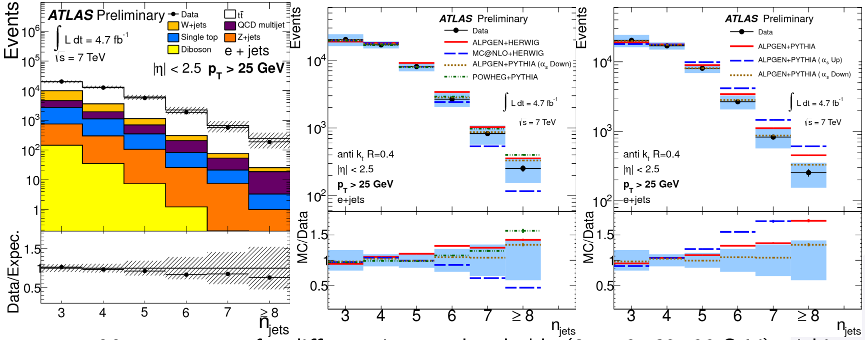
- Comparison to ALPGEN, MC@NLO, POWHEG, MCFM (QCD NLO) and NLO+NNLL
- Good agreement between data and MC simulations
- NLO calculation overestimates spectrum for $m_{t\bar{t}} > 500$ GeV
- NLO+NNLL calculation does not describe data well
- Further measurements for $y(t\bar{t})$ and $p_t(t\bar{t})$

Comparison to NLO calculation with different PDFs [*ATLAS-CONF-2013-099*]



- Comparison to CT10, MSTW2008, NNPDF and HERAPDF
- Best data description by HERAPDF, agrees with data within uncertainties
- Other PDFs: Increasing deviations from data for larger $m_{t\bar{t}}$, tension for $|y| < 0.5$ and $y < -1.0$
- Further measurements for $p_t(t)$ and $p_t(t\bar{t})$
- Besides PDF uncertainties, other modeling uncertainties need to be considered like the variation of the factorization and renormalization scale

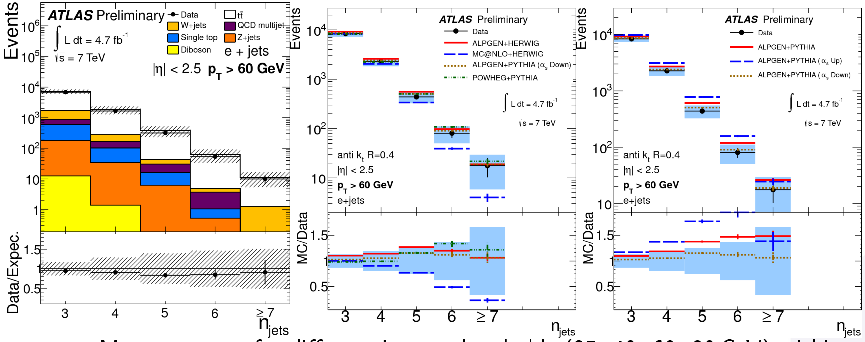
Comparison to MC modeling with additional jets [*ATLAS-CONF-2012-155*]



- Measurements for different jet-p_T thresholds (25, 40, 60, 80 GeV) within a fiducial volume that is closely matched to the detector acceptance
- Comparison to ALPGEN+HERWIG, MC@NLO+HERWIG, ALPGEN+PYTHIA and POWHEG+PYTHIA
- MC@NLO+HERWIG predicts too few jets in high multiplicity bins
- Other generators show similar distribution shapes
- Measurement sensitive to scale settings of α_s
- ALPGEN+PYTHIA with α_s down (ktfac=2) shows best data description

$\sigma_{t\bar{t}}(n_{\text{jets}})$, $\sqrt{s} = 7\,\text{TeV}$, $L_{\text{int}} = 4.7\,\text{fb}^{-1}$

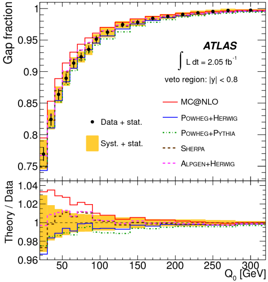
Comparison to MC modeling with additional jets [*ATLAS-CONF-2012-155*]

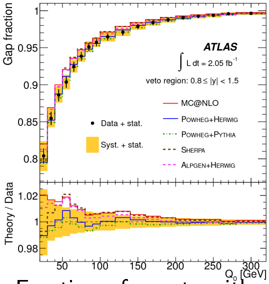


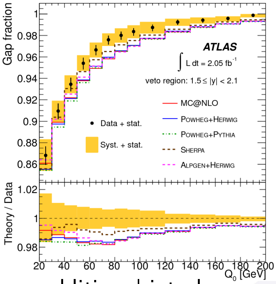
- Measurements for different jet-p_T thresholds (25, 40, 60, 80 GeV) within a fiducial volume that is closely matched to the detector acceptance
- Comparison to ALPGEN+HERWIG, MC@NLO+HERWIG, ALPGEN+PYTHIA and POWHEG+PYTHIA
- MC@NLO+HERWIG predicts too few jets in high multiplicity bins
- Other generators show similar distribution shapes
- Measurement sensitive to scale settings of α_s
- ALPGEN+PYTHIA with α_s down (ktfac=2) shows best data description

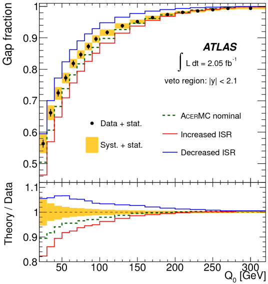
Gap fraction, $\sqrt{s} = 7\,\text{TeV}$, $L_{\text{int}} = 2.1\,\text{fb}^{-1}$

Comparison to jet activity modeling in $t\bar{t}$ events [*Eur.Phys.J.C72(2012)2043*]



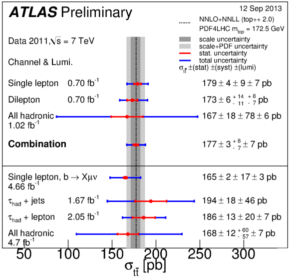


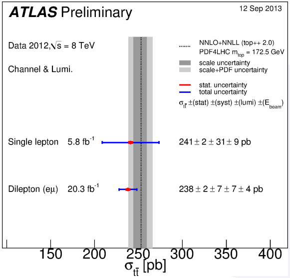




- Fraction of events without an additional jet above a certain p_T in a central rapidity region, measured in dileptonic decay channel
- Comparison to MC@NLO+HERWIG, POWHEG+HERWIG, POWHEG+PYTHIA, SHERPA and ALPGEN+HERWIG
- MC@NLO predicts too little jet activity in very central region, all MC generators simulate too much forward jet activity
- Contraint on ISR/FSR emission

- Broad range of inclusive and differential top quark pair production cross section measurements with ATLAS
- All decay channels covered @ 7 TeV
- First cross section measurements @ 8 TeV in single lepton and dileptonic channel
- 5% precision achieved @ 8 TeV in dileptonic channel
- All inclusive cross section results in agreement with SM expectation
- Differential cross section measurements largely consistent with SM expectation
- Essential results to gain sensivity to SM modeling differences



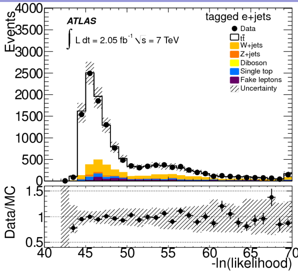


Backup

Analysis strategy:

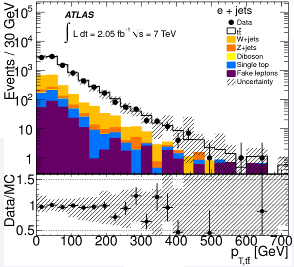
1. Event selection
2. $t\bar{t}$ kinematic reconstruction
3. Bin-wise cross section measurement

$\Rightarrow$ **Differential $t\bar{t}$ cross section**

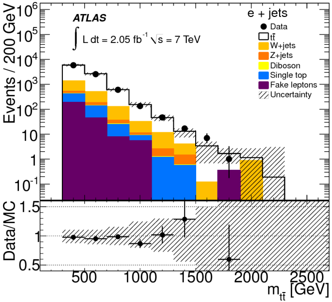


$t\bar{t}$ kinematic reconstruction

- Maximum likelihood fit to measured objects
- Inputs:
  - Energies and directions of selected jets
  - Energy and direction of selected lepton
  - Missing transverse energy
  - b-tagging information



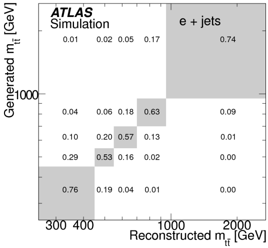
$$L = \left(\prod_{i=1}^{4} W\left(\tilde{E}_i, E_i\right)\right) \cdot \left(\prod_{i=1}^{4} W\left(\tilde{\Omega}_i, \Omega_i\right)\right) \cdot W\left(\tilde{E}_l, E_l\right) \cdot W\left(\not{E}_T | p_y^{\nu}\right) \cdot$$
$$BW\left(m_{jj}|M_W\right) \cdot BW\left(m_{l\nu}|M_W\right) \cdot BW\left(m_{jjj}|M_t\right) \cdot BW\left(m_{l\nu j}|M_t\right)$$

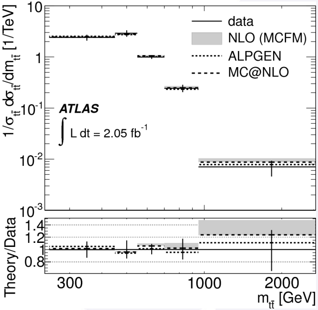


Bin-wise cross section measurement

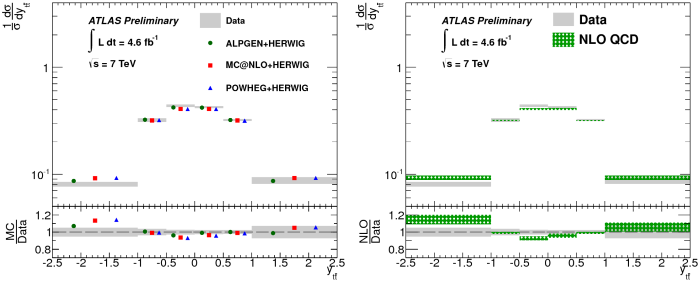
- Unfolding of signal distributions after background subtraction
- Correction for detector effects and acceptance with
  migration matrix M_{ji} derived from simulated events

$$\frac{d\sigma}{dX_j} = \frac{1}{\Delta X_j} \cdot \frac{\sum_i M_{ji}^{-1} [D_i - B_i]}{\mathrm{BR} \cdot \mathcal{L} \cdot \epsilon_j}$$



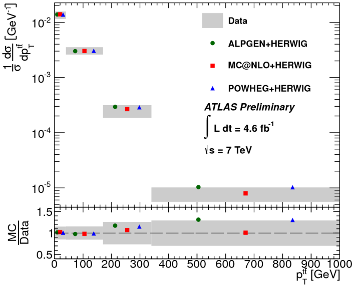


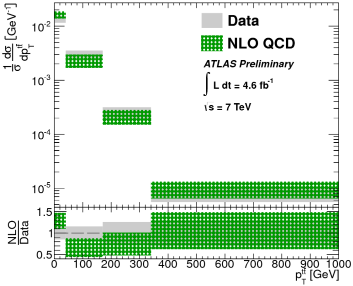
Comparison to SM simulations/calculations [*ATLAS-CONF-2013-099*]



- Comparison to ALPGEN, MC@NLO, POWHEG and MCFM (QCD NLO)
- Best data description by ALPGEN
- Similar behavior by MC@NLO, POWHEG and QCD NLO, overestimating data for $y < -1$ and underestimating data for $|y| < 0.5$
- Comparison to NLO calculation with different PDFs: Best description by HERAPDF

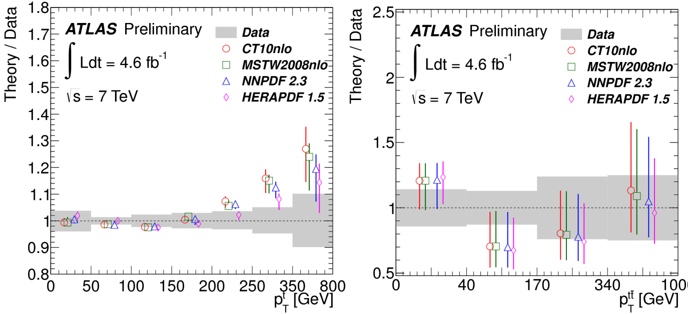
Comparison to SM simulations/calculations [*ATLAS-CONF-2013-099*]





- Comparison to ALPGEN, MC@NLO, POWHEG and MCFM (QCD NLO)
- Comparison to NLO calculation with different PDFs
- Still large uncertainties in data and theory predictions

Comparison to NLO calculation with different PDFs [*ATLAS-CONF-2013-099*]



- Comparison to CT10, MSTW2008, NNPDF and HERAPDF
- PDF dependence of $p_T(t)$ above 200 GeV with best data description by HERAPDF
- Still large uncertainties in data and theory predictions for $p_t(t\bar{t})$
- Besides PDF uncertainties, other modeling uncertainties need to be considered like the variation of the factorization and renormalization scale