Top quark pair production cross section at LHC in ATLAS

John Morris
Queen Mary University of London
3^{rd} June 2014

On behalf of the ATLAS collaboration

Selected cross section results

Motivation for measuring $\sigma_{t\bar{t}}$

- Top is the heaviest quark, all observables are of interest
- $\sigma_{t\bar{t}}$ provides a test of the Standard Model
- Differential $\sigma_{t\bar{t}}$ probes BSM physics

Talk outline

1. Differential cross section in ℓ+jets at $\sqrt{s} = 7$ TeV
   - $p_{\mathrm{T}}^{\mathrm{t}}$, $m_{\mathrm{t\bar{t}}}$, $p_{\mathrm{T}}^{\mathrm{t\bar{t}}}$ & $\mathrm{y_{t\bar{t}}}$
   - Comparison to different generators, theories and PDF sets
2. Production cross section in $e\mu$ at $\sqrt{s} = 8$ TeV
   - Highest precision ATLAS 8 TeV result
3. Production cross section in ℓ+jets at $\sqrt{s} = 8$ TeV
4. Summary of all ATLAS top pair cross section results and global comparisons

ATLAS-CONF-2013-099

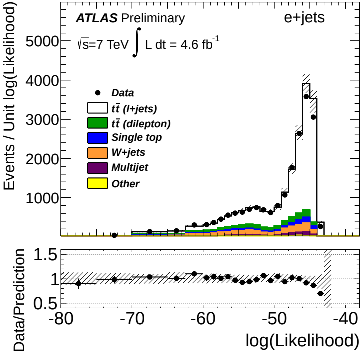
Differential cross-sections in ℓ+jets at $\sqrt{s} = 7$ TeV

- Different kinematic variables provide stringent test of SM
- Unfolded data compared to MC, NLO QCD and PDF sets
  - p_{T}^{t} - Transverse momentum of a single top quark
    - Higher order corrections and NP signals in high p_{T} tail
  - $m_{t\bar{t}}$ - Mass of $t\bar{t}$ system
    - Possible deviation from SM due to exotic resonances $\rightarrow t\bar{t}$
  - $p_{\mathrm{T}}^{t\bar{t}}$ - Transverse momentum of $t\bar{t}$ system
    - Sensitive to extra radiation, it is identically null at leading order
  - $y_{t\bar{t}}$ - Rapidity of $t\bar{t}$ system
    - Important constraint to PDFs, especially at high-x

Event selection

Trigger	Single lepton
Exactly one isolated lepton	Muons: $p_{\mathrm{T}} > 25$ GeV, $\lvert\eta\rvert < 2.5$
	Electrons: $p_{\mathrm{T}} > 25$ GeV
	$\lvert\eta\rvert < 2.47$, excluding $1.37 < \lvert\eta\rvert < 1.52$
Anti-k_t $(\mathrm{R} = 0.4)$ jets	≥ 4 jets with $p_{\mathrm{T}} > 25$ GeV, $\lvert\eta\rvert < 2.5$
b-tagging	≥ 1 b-tagged jet at $\epsilon_b = 70\%$ working point
$E_{\mathrm{T}}^{\mathrm{miss}}$	$E_{\mathrm{T}}^{\mathrm{miss}} > 30$ GeV
$m_{\mathrm{T}}^{\mathrm{W}}$	$m_{\mathrm{T}}^{\mathrm{W}} > 35$ GeV
Kinematic fitter	$\log \mathcal{L} > -50$

Reconstruction & unfolding

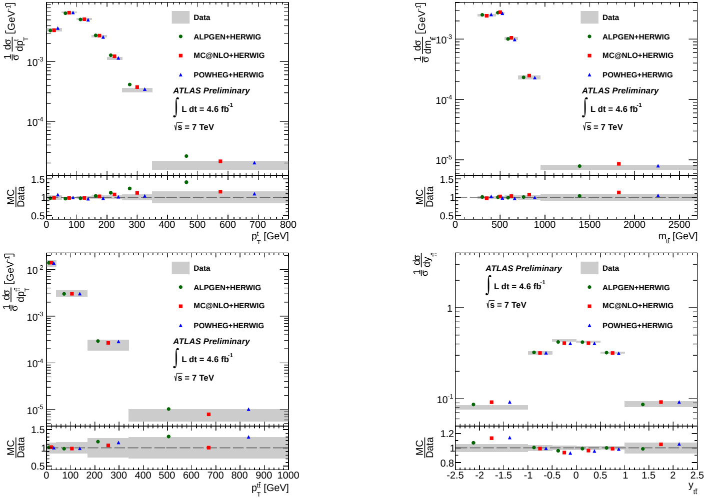


- Kinematic likelihood fitter fully reconstructs the $t\bar{t}$ system
- Relates reconstructed objects to leading-order representation of $t\bar{t}$
- Event likelihood $L > -50$
- Data unfolded via regularized SVD method
- e+jets and μ+jets channels combined with BLUE method

Dominant systematic uncertainties

- Dominant systematics are MC generator, ISR/FSR, jet energy scale, b-tagging efficiency and lepton reconstruction
- Systematics vary bin-by-bin for each unfolded distribution:
  - e.g. JES$\sim$ 2% at low $p_t^{t\bar{t}}$, JES$\sim$ 7% at high $p_t^{t\bar{t}}$
  - e.g. MC generator varies from $3-7\%$, depending on bin

Unfolded data Vs MC generator

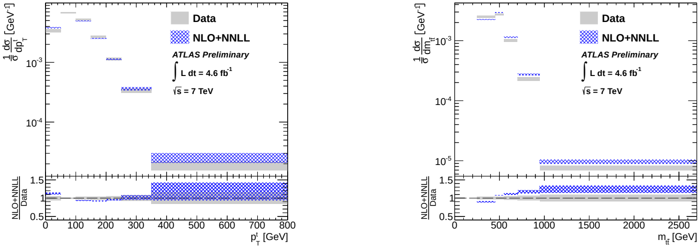


- Largest deviation from data observed for Alpgen in p_{T}^{t} for large values of p_{T}^{t}
- Measured p_{T}^{t} is softer than any prediction above 200 GeV

Unfolded data Vs NLO+NNLL

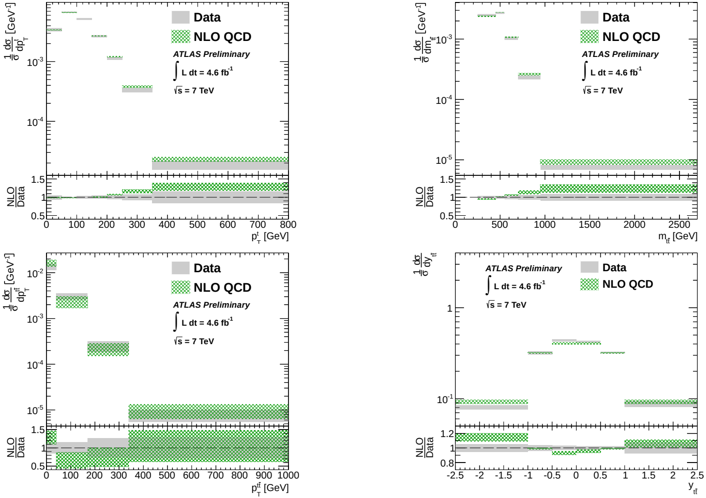
Unfolded data Vs QCD predictions

- Unfolded data compared to NLO+NNLL and NLO QCD
- NLO+NNLL uncertainties:
  - Factorization and renormalization scale $\mu = m_t = 172.5\,\text{GeV}$
  - Uncertainty from scale variation ↑↓ from $m_t/2$ to $2m_t$
  - Uncertainty from alternative dynamic scale $\mu = \sqrt{m_t^2 + {p_{\mathrm{T}}^t}^2}$
- NLO QCD (MCFM) uncertainties:
  - PDF evaluated at 68% CL using CT10 error-PDF set



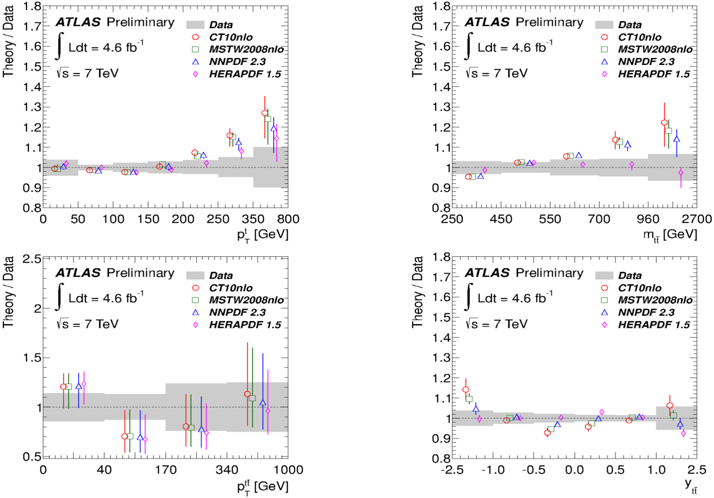
- Unfolded data is softer than theory for large p_{T}^t and $m_{t\bar{t}}$

Unfolded data Vs NLO QCD



- NLO QCD based on MCFM with CT10 PDF
- Unfolded data is softer than theory for large p_{T}^{t} and $m_{t\bar{t}}$
- $p_{\mathrm{T}}^{t\bar{t}}$ is sensitive to parton showering, not included in prediction

Unfolded data Vs PDF set



- 4 different PDF sets evaluated using MCFM
- Tension between data and all PDFs observed for for large p_T^t
- HERAPDF1.5 provides best description of $m_{t\bar{t}}$ and $y_{t\bar{t}}$

ATLAS-CONF-2013-097

$t\bar{t}$ production cross section in $e\mu$ at $\sqrt{s} = 8$ TeV

- Most precise ATLAS $t\bar{t}$ cross section measurement
- Count number of opposite-sign $e\mu$ events with:

$$1\,b\text{–tagged jet} : N_1 = \mathcal{L}\sigma_{t\bar{t}}\epsilon_{e\mu}2\epsilon_b(1 - C_b\epsilon_b) + N_1^{bkg}$$

$$2\,b\text{–tagged jets} : N_2 = \mathcal{L}\sigma_{t\bar{t}}\epsilon_{e\mu}C_b\epsilon_b^2 + N_2^{bkg}$$

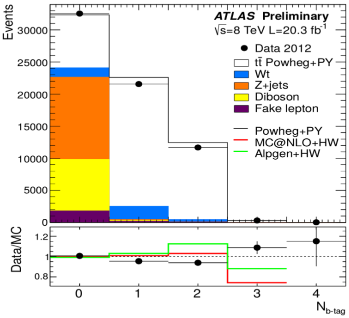
$\mathcal{L}$	: Integrated luminosity of sample
$\epsilon_{e\mu}$	: Event selection efficiency
ϵ_b	: Jet reconstruction & b-tagging efficiency
C_b	: Tagging correlation $C_b = \epsilon_{bb}/\epsilon_b^2 = 1.007 \pm 0.002$
$N_{1,2}^{bkg}$	: Observed background events

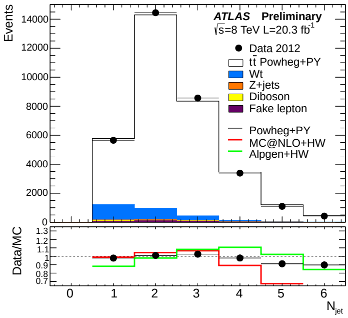
- Solve equations for ϵ_b and $\sigma_{t\bar{t}}$
- Benefit from reduction in systematic uncertainties
- Measurement uses $\mathcal{L} = 20.3\text{fb}^{-1}$ of $\sqrt{s} = 8$ TeV data

Di-lepton event selection

Event selection

Trigger	Single lepton
Exactly one isolated lepton	Muons: $p_T > 25$ GeV, $\lvert\eta\rvert < 2.5$
	Electrons: $p_T > 25$ GeV
	$\lvert\eta\rvert < 2.47$, excluding $1.37 < \lvert\eta\rvert < 1.52$
Anti-k_t (R = 0.4) jets	≥ 1 jet with $p_T > 25$ GeV, $\lvert\eta\rvert < 2.5$
b-tagging	≥ 1 b-tagged jet at $\epsilon_b = 70\%$ working point





Dominant systematics and result

Dominant systematic uncertainties

Uncertainty	$\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%)	$\Delta C_b/C_b$ (%)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)	$\Delta\sigma_{t\bar{t}}$ (pb)	$\Delta\epsilon_b/\epsilon_b$ (%)
Data statistics	-	-	0.72	1.7	0.57
$t\bar{t}$ modelling	0.91	-0.61	1.52	3.6	0.61
ISR/FSR	-0.76	0.26	1.23	2.9	0.37
PDF	1.08	-	1.09	2.6	0.06
Single-top Wt cross section	-	-	0.70	1.7	0.24
Electron ID/isolation	1.28	0.00	1.42	3.4	0.05
Muon ID/isolation	0.50	0.00	0.52	1.2	0.01
Jet energy scale	0.46	0.07	0.49	1.2	0.11
Jet energy resolution	-0.44	0.04	0.59	1.4	0.08
Total systematic	2.29	0.69	3.12	7.4	1.02
Integrated luminosity	-	-	3.11	7.4	0.11
LHC beam energy	-	-	1.70	4.0	0.00
Total Uncertainty	2.29	0.69	4.77	11.3	1.17

- Only showing systematics with $\Delta\sigma_{t\bar{t}} > 1.0\text{pb}$

Measured cross section

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

ATLAS-CONF-2012-149

$t\bar{t}$ production cross section in ℓ+jets at $\sqrt{s} = 8$ TeV

Trigger	Single lepton
Exactly one isolated lepton	Muons: $p_T > 40$ GeV, $\|\eta\| < 2.5$ Electrons: $p_T > 40$ GeV $\|\eta\| < 2.47$, excluding $1.37 < \|\eta\| < 1.52$
Anti-k_t $(R = 0.4)$ jets	≥ 3 jets with $p_T > 25$ GeV, $\|\eta\| < 2.5$
b-tagging	≥ 1 b-tagged jet at $\epsilon_b = 70\%$ working point
e+jets	$E_T^{miss} > 30$ GeV, $m_T^W > 35$ GeV
μ+jets	$E_T^{miss} > 20$ GeV, $E_T^{miss} + m_T^W > 60$ GeV

- Uses a likelihood to discriminate between $t\bar{t}$ and background
  - Based on transformed aplanarity and lepton pseudo-rapidity
- Measurement uses $\mathcal{L} = 5.8\text{fb}^{-1}$ of $\sqrt{s} = 8$ TeV data

Dominant systematics and result

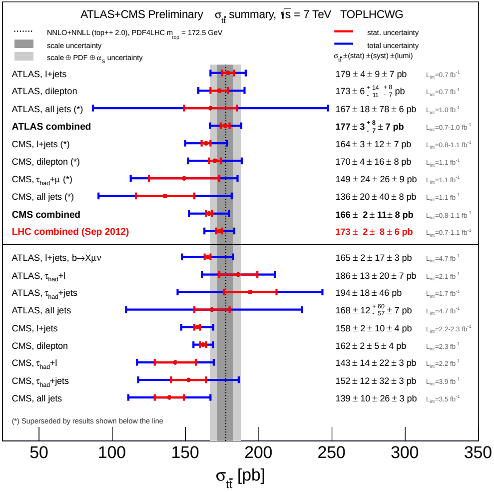
Dominant systematic uncertainties

Source	$e+\geq 3$ jets	$\mu+\geq 3$ jets	combined
Jet/MET reconstruction, calibration	6.7,-6.3	5.4,-4.6	5.9,-5.2
Lepton trigger, ID and reconstruction	2.4,-2.7	4.7,-4.2	2.7,-2.8
Background normalization and composition	1.9,-2.2	1.6,-1.5	1.8,-1.9
b-tagging efficiency	1.7,-1.3	1.9,-1.1	1.8,-1.2
MC modelling of the signal	± 12	± 11	± 13
Total	± 14	± 13	± 13

Measured cross section

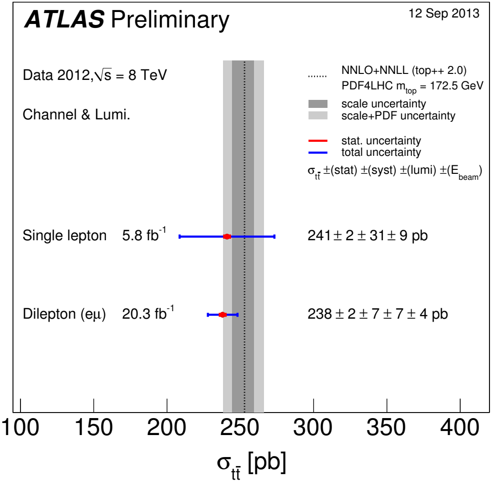
$$\sigma_{t\bar{t}} = 241 \pm 2(\mathrm{stat}) \pm 31(\mathrm{syst}) \pm 9(\mathrm{lumi})$$

$\sqrt{s} = 7$ TeV cross section summary



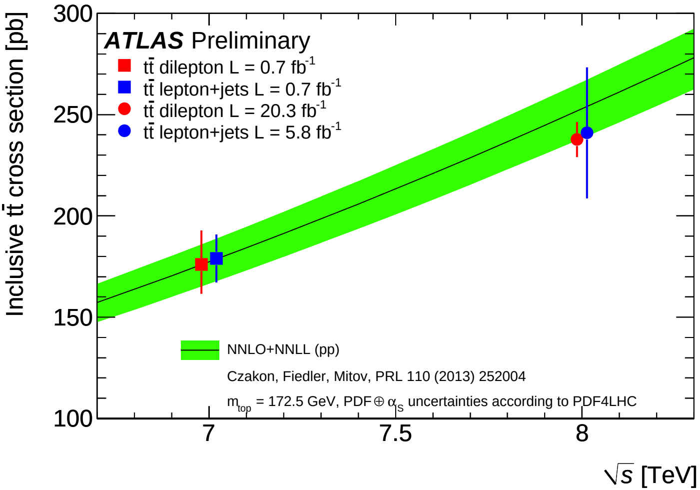
- Summary of LHC $\sqrt{s} = 7$ TeV $t\bar{t}$ cross sections

$\sqrt{s} = 8$ TeV cross section summary



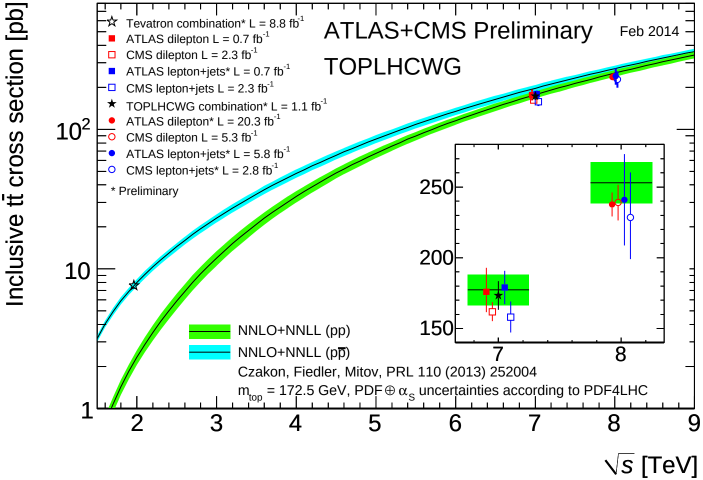
- Summary of ATLAS $\sqrt{s} = 8$ TeV $t\bar{t}$ cross sections

ATLAS $t\bar{t}$ cross section summary



- ATLAS $t\bar{t}$ cross sections Vs $\sqrt{s}$
- Prediction in agreement with observed data

Global $t\bar{t}$ cross section summary



- Global $t\bar{t}$ cross sections Vs $\sqrt{s}$
- Prediction in agreement with observed data

Conclusions

Summary of ATLAS $t\bar{t}$ cross section measurements

- Differential cross sections at $\sqrt{s} = 7$ TeV
  - Unfolded data compared to MC, NLO QCD and PDF sets
  - Predictions agree with data in a wide kinematic region
  - Data is softer than any prediction for large p_{T}^{t}
- Inclusive cross sections at $\sqrt{s} = 8$ TeV
  - Di-lepton $e\mu$ measurement using 1 and 2 b-tagged events gives highest precision
  - ℓ+jets measurement in broad agreement
- Theoretical prediction accurately describes data from multiple experiments across large $\sqrt{s}$ range