

Top quark pair production cross section using the ATLAS detector at the LHC

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on behalf of the ATLAS collaboration

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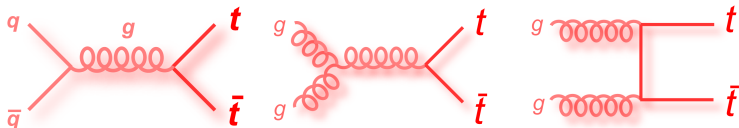
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Introduction

Motivations for $\sigma_{t\bar{t}}$ measurements :

- $pp \rightarrow t\bar{t}$ is main production mode of the heaviest known particle
- $\sigma_{t\bar{t}}$ is an input for many analyses
- Experimental test of NNLO SM predictions
- Probe for new physics



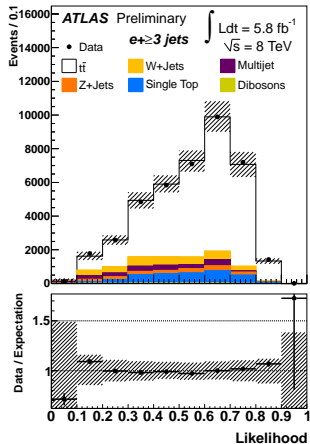
Latest available ATLAS results :

	\sqrt{s} [TeV]	L [fb^{-1}]	Reference
Inclusive, l+jets	8	5.8	ATLAS-CONF-2012-149
Inclusive, dilepton	7	4.6	arXiv :1406.5375 New!
	8	20.3	
Differential, l+jets	7	4.6	arXiv :1407.0371 New!

Inclusive cross-section in l+jets channel ATLAS-CONF-2012-149

Event selection and measurement method

- Using $L = 5.8 \text{ fb}^{-1}$ of 2012 $\sqrt{s} = 8 \text{ TeV}$ data
- Event selection :
 - Single isolated lepton trigger
 - 1 e or μ , $p_T > 40 \text{ GeV}$ and $|\eta| < 2.5$
 - ≥ 3 jets, $p_T > 25 \text{ GeV}$ and $|\eta| < 2.5$
 - ≥ 1 b-tagged jet, MVA tagger with 70% efficiency
 - e+jets : $E_T^{\text{miss}} > 30 \text{ GeV}$ and $m_T(W) > 30 \text{ GeV}$
 - μ +jets : $E_T^{\text{miss}} > 20 \text{ GeV}$ and $E_T^{\text{miss}} + m_T(W) > 60 \text{ GeV}$
- Measurement method :
 - Likelihood based on event aplanarity and lepton η
 - Fit of likelihood distribution to extract $N_{t\bar{t}}$
 - $$\sigma_{t\bar{t}} = \frac{N_{t\bar{t}}}{\int \mathcal{L} dt \times BR \times \epsilon_{\text{sig}}}$$



Inclusive cross-section in l+jets channel ATLAS-CONF-2012-149

Results

- Number of fitted $t\bar{t}$ events and corresponding cross-sections :

Channel	$N_{t\bar{t}}$ (stat)	$\sigma_{t\bar{t}}$ [pb] (stat)
e+jets	31050 ± 350	239 ± 3
μ +jets	45000 ± 400	242 ± 2
combined	76000 ± 500	241 ± 2

- Summary of relative systematic uncertainties on $\sigma_{t\bar{t}}$:

Source	e+jets	μ +jets	combined
Jet/MET reconstruction, calibration	+6.7 -6.3	+5.4 -4.6	+5.9 -5.2
Lepton trigger, identification 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	± 11
Total	± 14	± 13	± 13

- Result (assuming $m_t = 172.5$ GeV) :

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

- NNLO+NNLL prediction :

$$\sigma_{t\bar{t}} = 252.9 \pm 11.7(\text{PDF})_{8.6}^{6.4}(\text{QCD scale})\text{pb}$$

Inclusive cross-section in $e\mu$ channel arXiv :1406.5375 **New!**

Event selection and measurement method

- Two measurements, same method

- Using $L = 4.6 \text{ fb}^{-1}$ of 2011 $\sqrt{s} = 7 \text{ TeV}$ data
- Using $L = 20.3 \text{ fb}^{-1}$ of 2012 $\sqrt{s} = 8 \text{ TeV}$ data
(update of ATLAS-CONF-2013-097)

- Event selection :

- Single isolated lepton trigger
- 1 e and 1 μ , OS, $p_T > 25 \text{ GeV}$ and $|\eta| < 2.5$
- ≥ 1 jets, $p_T > 25 \text{ GeV}$ and $|\eta| < 2.5$
- ≥ 1 b-tagged jets, MVA tagger with 70% efficiency

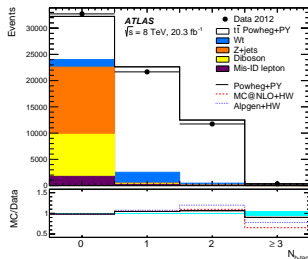
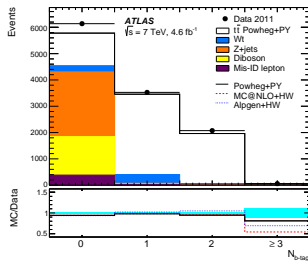
- Measurement method :

- Count events with 1 or 2 b-tagged jets

$$N_{1tag} = L\sigma_{t\bar{t}}\epsilon_{e\mu}2\epsilon_b(1 - C_b\epsilon_b) + N_{1tag}^{bkg}$$

$$N_{2tag} = L\sigma_{t\bar{t}}\epsilon_{e\mu}C_b\epsilon_b^2 + N_{2tag}^{bkg}$$

- Solve equations to obtain $\sigma_{t\bar{t}}$ and ϵ_b
- ϵ_b : reconstruction and b-tagging of jets from top decays
- Correlation C_b between b-tagged jets measured on MC
- Signal pre-selection efficiency $\epsilon_{e\mu}$ measured on MC



Inclusive cross-section in $e\mu$ channel [arXiv :1406.5375](https://arxiv.org/abs/1406.5375) **New !**

Systematic uncertainties

- Uncertainties on C_b , $\epsilon_{e\mu}$ and $N_{1,2tag}^{bkg}$ propagated to $\sigma_{t\bar{t}}$
- Summary of relative uncertainties on $\sigma_{t\bar{t}}$ (in %) :

Source	$\sqrt{s} = 7 \text{ TeV}$	$\sqrt{s} = 8 \text{ TeV}$
$t\bar{t}$ modelling and QCD scale	± 1.46	± 1.26
PDF	± 1.04	± 1.13
Background modelling	± 0.83	± 0.83
Lepton efficiencies	± 0.87	± 0.88
Jets and b-tag	± 0.58	± 0.82
Misidentified leptons	± 0.41	± 0.34
Total of above sources	± 2.27	± 2.26
Data statistics	± 1.69	± 0.71
Luminosity	± 1.98	± 3.10
Beam energy	± 1.79	± 1.72
Total	± 3.89	± 4.27

Inclusive cross-section in $e\mu$ channel arXiv :1406.5375 **New!**

Results

- Number of observed events and of expected background events :

Number of events	$\sqrt{s} = 7 \text{ TeV}$		$\sqrt{s} = 8 \text{ TeV}$	
	N_{1tag}	N_{2tag}	N_{1tag}	N_{2tag}
Data	3527	2073	21666	11739
Total background	400 ± 70	70 ± 16	2590 ± 230	460 ± 130

- Result (assuming $m_t = 172.5 \text{ GeV}$) :

$$\sigma_{t\bar{t}}(7 \text{ TeV}) = 182.9 \pm 3.1(\text{stat.}) \pm 4.2(\text{syst.}) \pm 3.6(\text{lumi.}) \pm 3.3(\text{beam en.})\text{pb}$$

$$\sigma_{t\bar{t}}(8 \text{ TeV}) = 242.4 \pm 1.7(\text{stat.}) \pm 5.5(\text{syst.}) \pm 7.5(\text{lumi.}) \pm 4.2(\text{beam en.})\text{pb}$$

- Also providing fiducial cross-section measurements

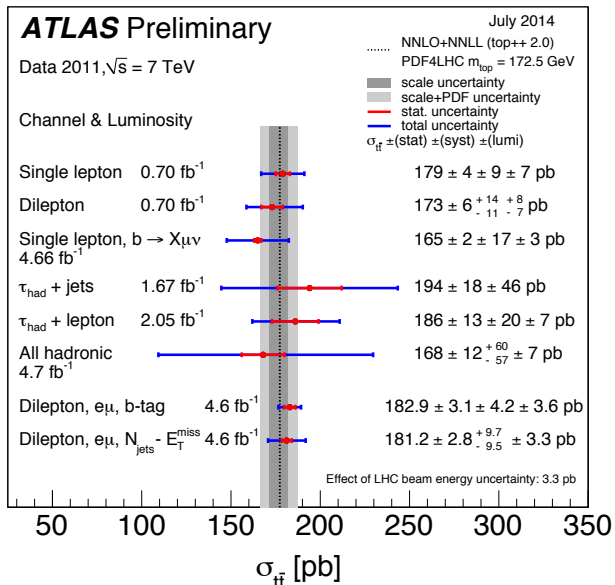
→ Reduction of systematic uncertainties (PDF, QCD scale)

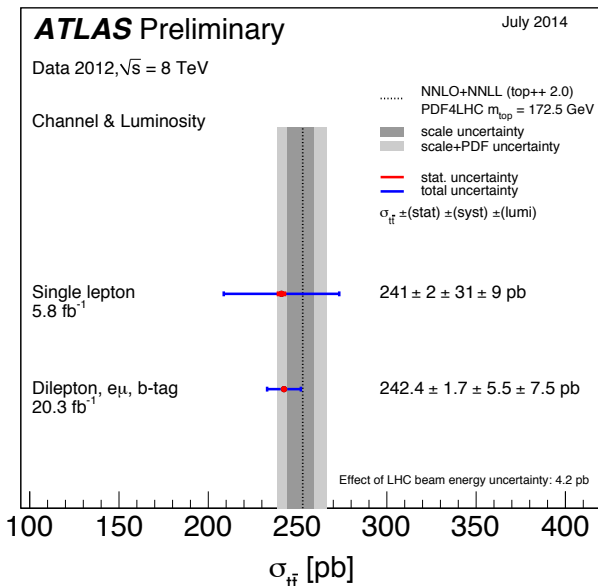
- Ratio $R_{t\bar{t}} = \sigma_{t\bar{t}}(8 \text{ TeV})/\sigma_{t\bar{t}}(7 \text{ TeV})$:

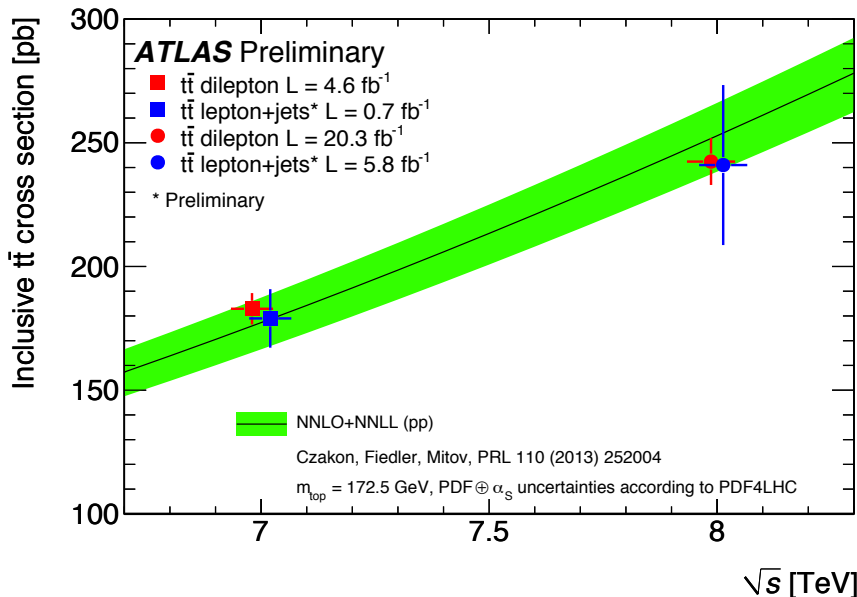
$$\text{measured} : 1.326 \pm 0.024(\text{stat.}) \pm 0.015(\text{syst.}) \pm 0.049(\text{lumi.}) \pm 0.001(\text{beam en.})$$

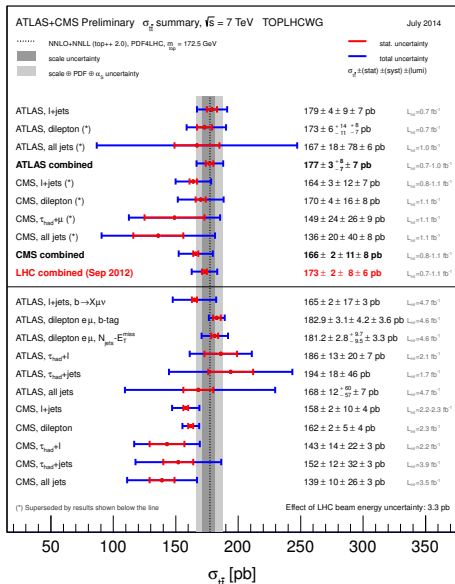
$$\text{NNLO} + \text{NNLL} : 1.430 \pm 0.013(\text{PDF} + \alpha_s) \pm 0.001(\text{QCD scale})$$

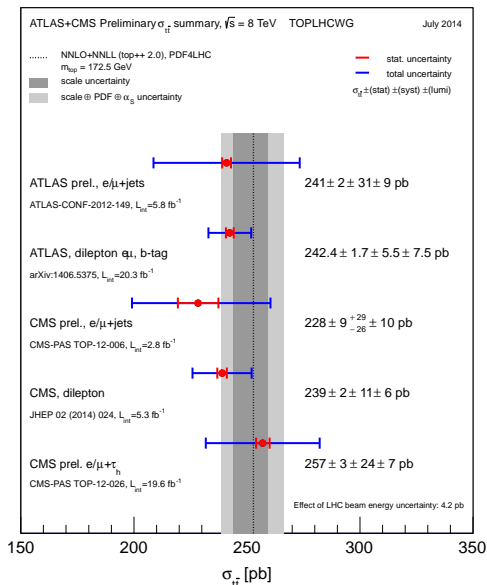
- Determination of top-quark mass combining 7 and 8 TeV : $m_t^{\text{pole}} = 172.9_{-2.6}^{+2.5} \text{ GeV}$
(see talk by K. Yau Wong)
- 95% CL exclusion of $m_t < m_{\tilde{t}} < 177 \text{ GeV}$ (assuming $BR(\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0) = 100\%$)
(see talk by J. Firmino da Costa)

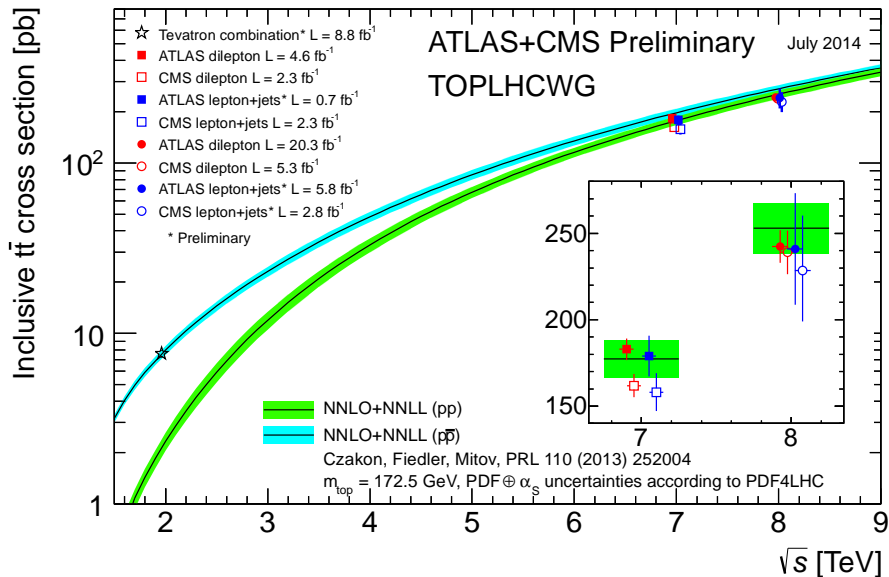
Summary of ATLAS results @7 TeV for $\sigma_{t\bar{t}}$ 

Summary of ATLAS results @8 TeV for $\sigma_{t\bar{t}}$ 

Summary of ATLAS results vs. \sqrt{s} for $\sigma_{t\bar{t}}$ 

Summary of ATLAS and CMS results @7 TeV for $\sigma_{t\bar{t}}$ 

Summary of ATLAS and CMS results @8 TeV for $\sigma_{t\bar{t}}$ 

Summary of ATLAS and CMS results vs. \sqrt{s} for $\sigma_{t\bar{t}}$ 

Differential cross-section in l+jets channel [arXiv :1407.0371](https://arxiv.org/abs/1407.0371) **New!**

Event selection and measurement method

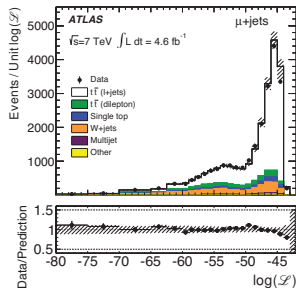
- Using $L = 4.6 \text{ fb}^{-1}$ of 2011 $\sqrt{s} = 7 \text{ TeV}$ data
(update of ATLAS-CONF-2013-09)
- $\sigma_{t\bar{t}}$ vs. kinematic variables : test of the SM
 - p_T^t : sensitive to higher order corrections at high values
 - $m_{t\bar{t}}$: sensitive to new $t\bar{t}$ resonances
 - $p_T^{t\bar{t}}$: sensitive to extra radiation
 - $y_{t\bar{t}}$: test of PDF sets

- Event selection :

- Single isolated lepton trigger
- 1 e or μ , $p_T > 25 \text{ GeV}$ and $|\eta| < 2.5$
- ≥ 4 jets, $p_T > 25 \text{ GeV}$ and $|\eta| < 2.5$
- ≥ 1 b-tagged jet, MVA tagger with 70% efficiency
- $E_T^{\text{miss}} > 30 \text{ GeV}$ and $m_T(W) > 35 \text{ GeV}$

- Measurement method :

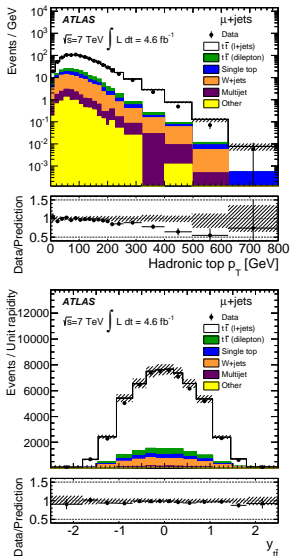
- Likelihood fitter to reconstruct $t\bar{t}$ kinematics
- Kinematic variables are then unfolded to derive differential cross-sections



Differential cross-section in l +jets channel [arXiv :1407.0371](https://arxiv.org/abs/1407.0371) **New !**

Event reconstruction and unfolding

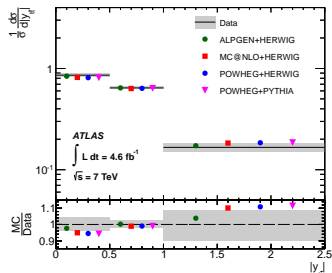
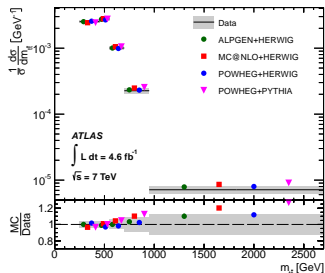
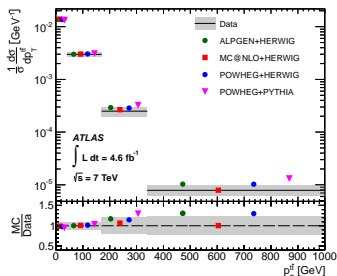
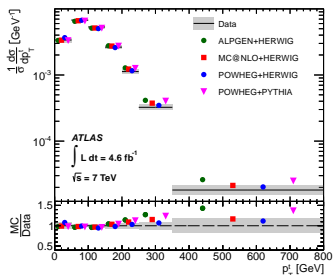
- Likelihood fitter :
 - Associates reconstructed object kinematics to $t\bar{t}$ system
 - Using LO representation of the $t\bar{t}$ decay
 - Maximization of likelihood by testing all permutations
 - $\log\mathcal{L} > -50$ to remove poorly fitted solutions
- Data is unfold to derive parton-level kinematics
 - Regularized SVD method
 - Migration matrices from LO simulated $t\bar{t}$ sample
- Computation of $1/\sigma d\sigma_{t\bar{t}}/dX$ where $X = p_T^t, m_{t\bar{t}}, p_T^{t\bar{t}}, y_{t\bar{t}}$
 - e and μ channels combined with BLUE method
- Main systematic uncertainties :
 - Signal MC generator (2-7%), JES (1-7%), b-tag (1-4%)



Differential cross-section in l +jets channel [arXiv :1407.0371](https://arxiv.org/abs/1407.0371) **New!**

Comparison of unfolded data and generators

- Softer p_T^t on unfolded data above 200 GeV
- $p_T^{\bar{t}\bar{t}}$ and $m_{\bar{t}\bar{t}}$ well described
- Alpgen gives best description of $y_{\bar{t}\bar{t}}$



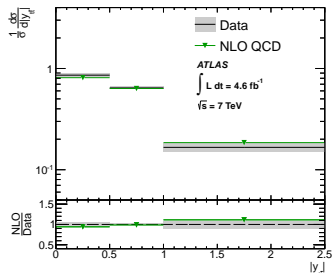
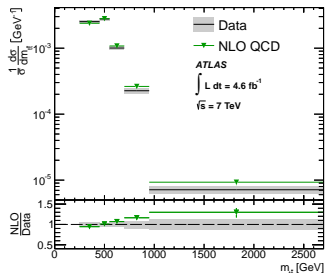
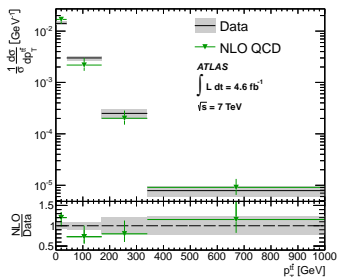
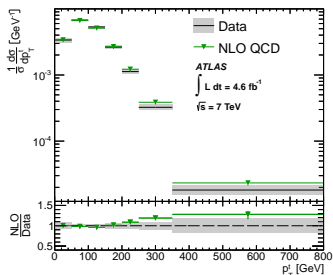
Differential cross-section in l+jets channel [arXiv :1407.0371](https://arxiv.org/abs/1407.0371) **New!**

Comparison of unfolded data and NLO QCD calculations

- NLO QCD predictions with MCFM, using CT10

- Scale : 172.5 GeV - uncertainty from 2-1/2 up-down variation
- PDF uncertainty from error-PDF set

- Softer unfolded distributions at high p_T^t and $m_{t\bar{t}}$



Differential cross-section in l+jets channel [arXiv :1407.0371](https://arxiv.org/abs/1407.0371) **New !**

Comparison of unfolded data and NLO+NNLL QCD calculations

- NLO+NNLL QCD predictions using MSTW2008NNLO

→ Scales set at $m_{l\bar{l}}$

- Uncertainties :

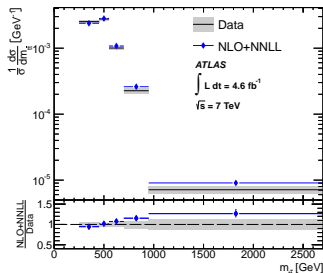
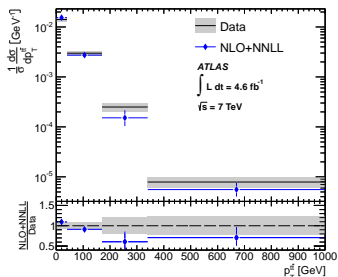
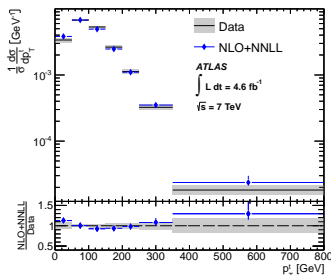
→ PDF uncertainty from error-PDF set except for p_T^t

→ Scale uncertainty from 2-1/2 up-down variation

→ For p_T^t : also contribution of dynamic scale uncertainty

$$\mu = \sqrt{m_t^2 + p_T^t{}^2}$$

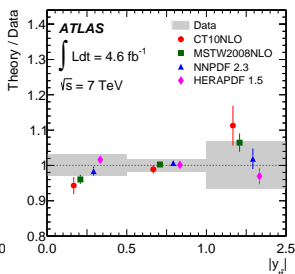
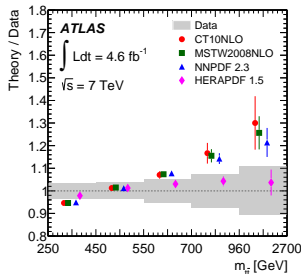
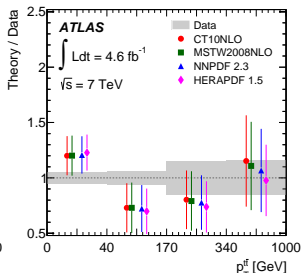
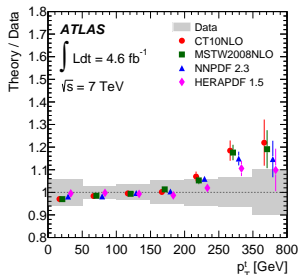
- Softer distributions at high p_T^t , $m_{l\bar{l}}$



Differential cross-section in l+jets channel [arXiv :1407.0371](https://arxiv.org/abs/1407.0371) **New!**

Comparison of unfolded data and PDF sets

- MCFM predictions using 4 PDF sets
- Tension at high p_T^t for all PDF sets
- HERAPDF1.5 gives best description of $m_{t\bar{t}}$
- HERAPDF1.5 and NNPDF2.3 give best description of $y_{t\bar{t}}$



Conclusions

- Measurements in good agreement with SM theory predictions
- Preliminary result for inclusive cross-section in l +jets at 8 TeV
 - Using 5.8 fb⁻¹ of 2012 data
 - Result dominated by systematic uncertainties
- New result for inclusive cross-section in $e\mu$ channel at 7 and 8 TeV
 - Using the full run-I dataset
 - Most precise measurement so far (4.3% @8 TeV)
 - Also providing fiducial cross-sections, pole-mass, limit on $m_{\tilde{t}}$
- New result for differential cross-section in l +jets at 7 TeV
 - Using the full 2011 dataset
 - Comparison with MC generators, PDF sets, NLO (+NNLL) QCD computation
 - Data softer than predictions at high p_{T}^l values
- Not yet the end of run-I measurements !