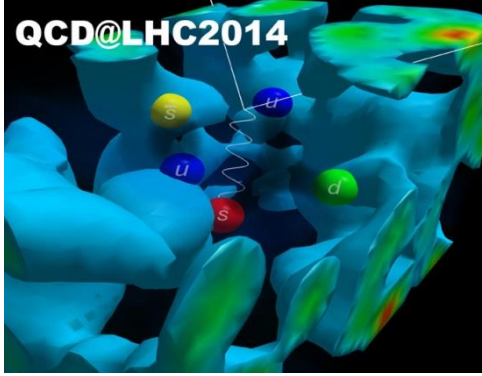
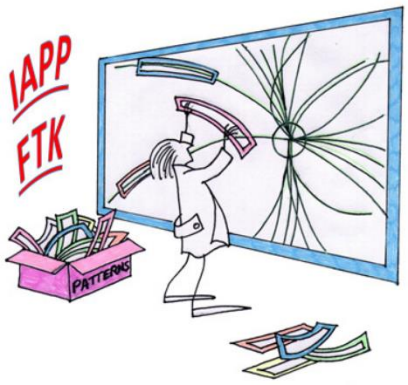


Top quark pair production cross section using the ATLAS detector at the LHC

Naoki Kimura (Aristotle University of Thessaloniki)

On behalf of the ATLAS Collaboration



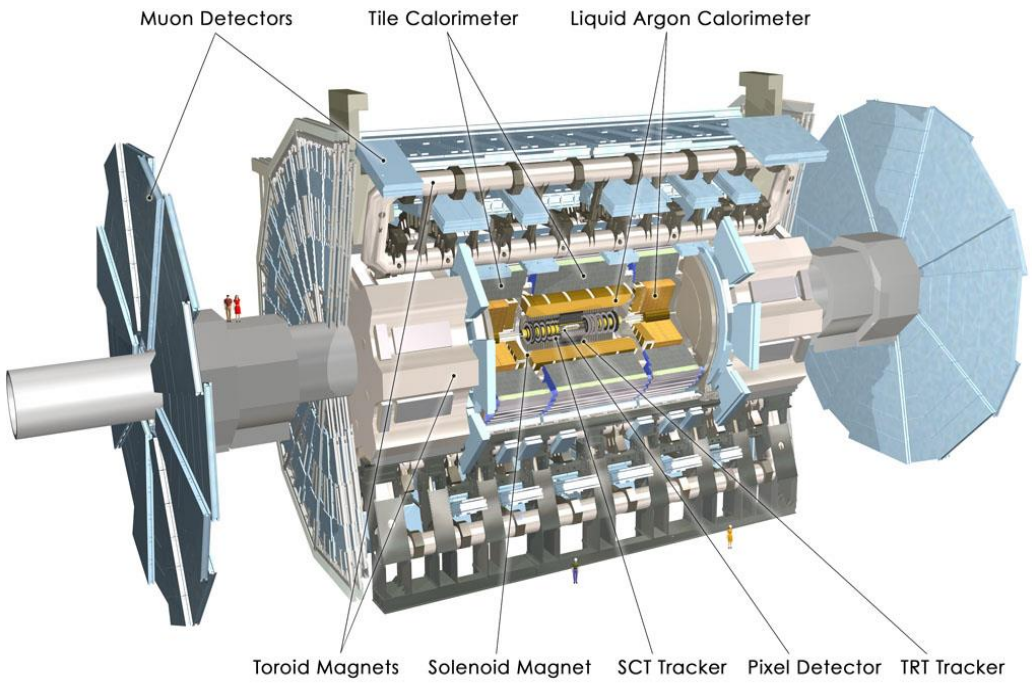
SEVENTH FRAMEWORK PROGRAMME

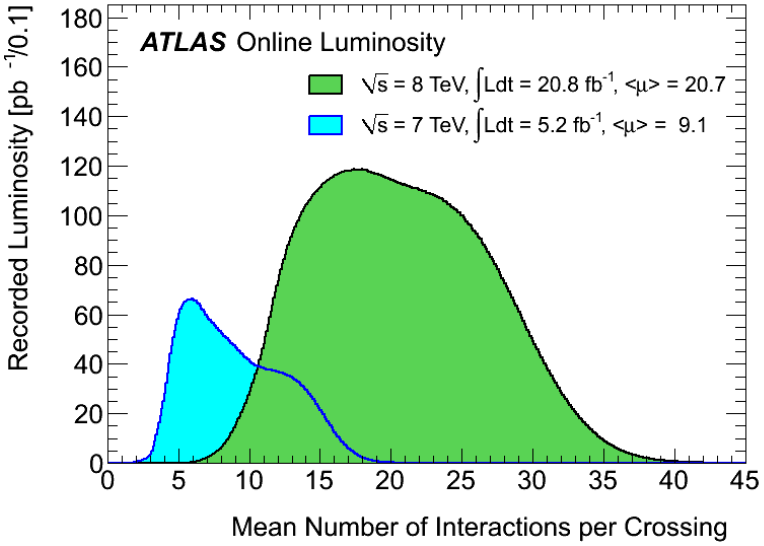
QCD@LHC2014
August 25-29, 2014, Suzdal, Russia

ATLAS Experiment

Proton-proton collision at $\sqrt{s}$ = 7 and 8 TeV

Integrated luminosity
2011 (7 TeV): 5 fb^{-1}
2012 (8 TeV): 21 fb^{-1}





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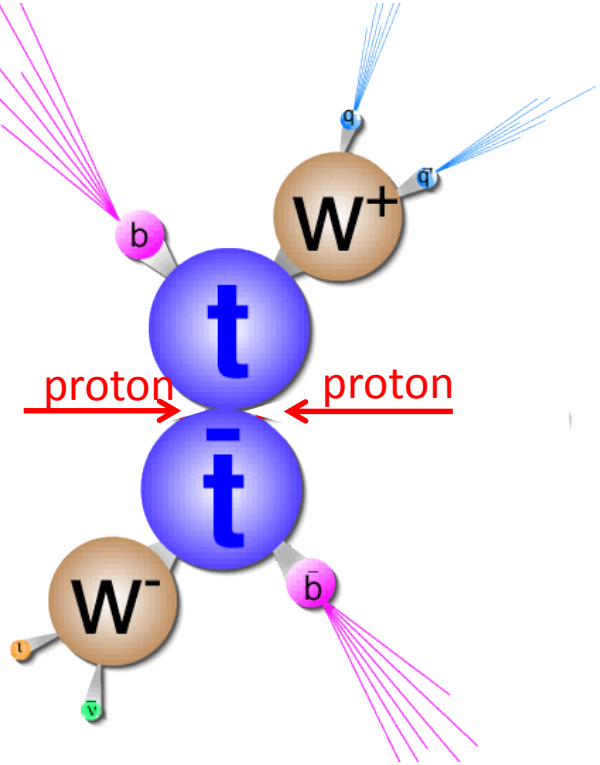
- **Inclusive top quark pair production cross section measurement**
- **Simultaneous measurements of $t\bar{t}$, W^+W^-, and $Z/\gamma^* \rightarrow \tau\tau$ cross section**
- **Different cross section measurement**
- **Top mass measurement**
- **Summary**

Inclusive top quark pair production cross section measurement

Physics motivation

- **Precision test of the perturbative QCD**
- **Top quark events contain a variety of physics processes**
- **Important background to Higgs and BSM processes**
- **Sensitive to new physics**



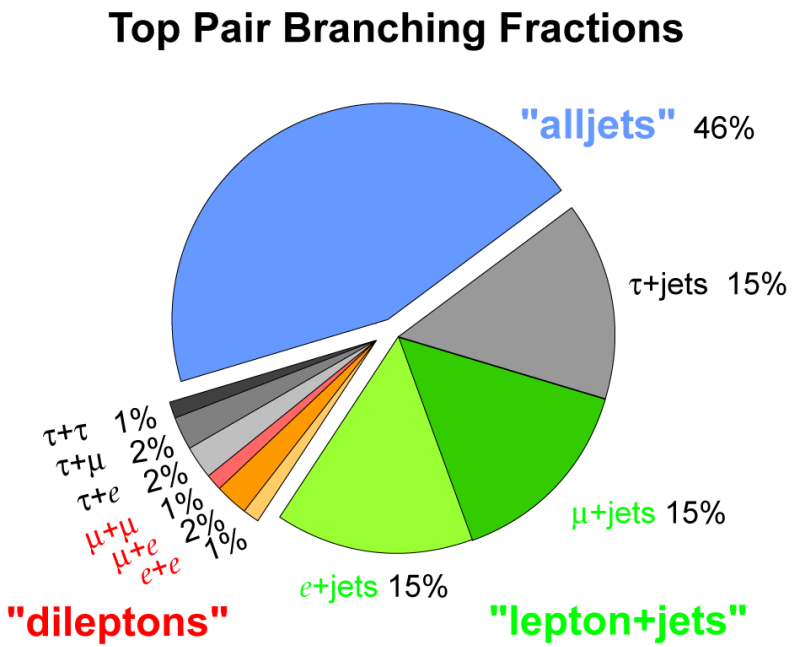
Top quark production

- ✓ Gluon-gluon fusion dominant at the LHC

- ✓ Theoretical prediction on the Cross-Section

NNLO+NNLL PRL.110(2013)252004

Collider	σ_{tot} [pb]	scales [pb]	pdf [pb]
Tevatron	7.164	$^{+0.110(1.5\%)}_{-0.200(2.8\%)}$	$^{+0.169(2.4\%)}_{-0.122(1.7\%)}$
LHC 7 TeV	172.0	$^{+4.4(2.6\%)}_{-5.8(3.4\%)}$	$^{+4.7(2.7\%)}_{-4.8(2.8\%)}$
LHC 8 TeV	245.8	$^{+6.2(2.5\%)}_{-8.4(3.4\%)}$	$^{+6.2(2.5\%)}_{-6.4(2.6\%)}$
LHC 14 TeV	953.6	$^{+22.7(2.4\%)}_{-33.9(3.6\%)}$	$^{+16.2(1.7\%)}_{-17.8(1.9\%)}$



- ✓ Top Quark Decay

  decay nearly 100% to Wb

Top quark pair production cross-section

Dilepton Channel (7 TeV 4.6 fb^{-1} and 8 TeV 20.3 fb^{-1}) (arXiv:1406.5375)

Very clean signal, small decay branching ratio 2%, 2lepton 2 neutrino 2b-jet

Event Selection:

- Exact 2 high P_T opposite sign of e μ
- Exact 1 b-tagged jet or 2 b-tagged jet event.

Main Background :

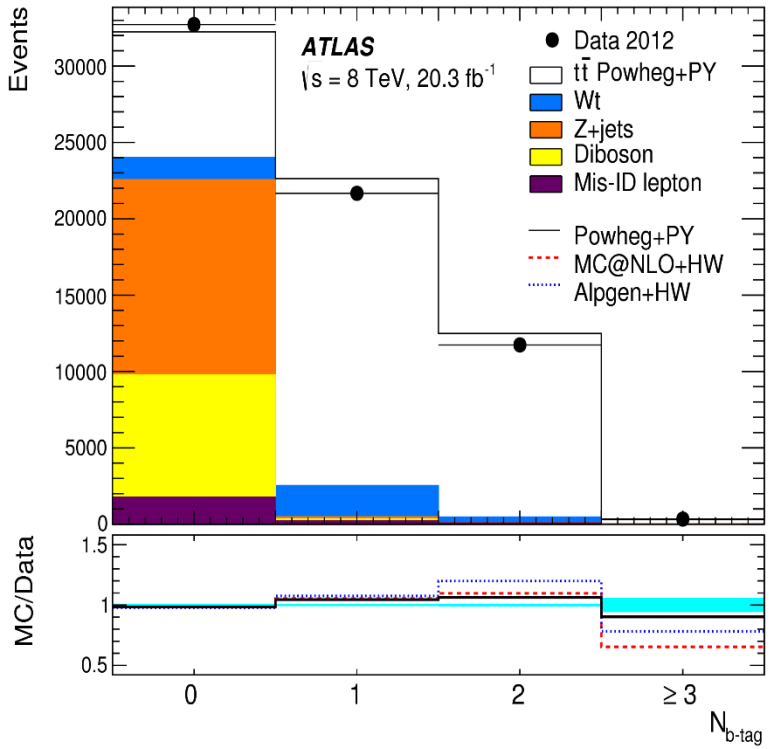
Wt Single top

Analysis Method :

Simultaneous estimation of cross section and the efficiency of reconstruct and b-tag jets to reduced jet and b-tag uncertainties.

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

$$N_2 = L\sigma_{t\bar{t}}\ \epsilon_{e\mu} C_b {\epsilon_b}^2 + N_2^{\mathrm{bkg}}$$



Top quark pair production cross-section

(arXiv:1406.5375)

Dilepton Channel (7 TeV 4.6 fb^{-1} and 8 TeV 20.3 fb^{-1})

Uncertainty	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)	
$\sqrt{s}$	7 TeV	8 TeV
Data statistics	1.69	0.71
$t\bar{t}$ modelling and QCD scale	1.46	1.26
Parton distribution functions	1.04	1.13
Background modelling	0.83	0.83
Lepton efficiencies	0.87	0.88
Jets and b-tagging	0.58	0.82
Misidentified leptons	0.41	0.34
Analysis systematics ($\sigma_{t\bar{t}}$)	2.27	2.26
Integrated luminosity	1.98	3.10
LHC beam energy	1.79	1.72
Total uncertainty	3.89	4.27

Most precise measurement

Measured Cross-Section

$$\sigma_{t\bar{t}} = 182.9 \pm 3.1 \pm 4.2 \pm 3.6 \pm 3.3\,\text{pb}\ (\sqrt{s} = 7\,\text{TeV})$$

$$\sigma_{t\bar{t}} = 242.4 \pm 1.7 \pm 5.5 \pm 7.5 \pm 4.2\,\text{pb}\ (\sqrt{s} = 8\,\text{TeV})$$

Stat. Syst. Lum. Beam energy.

Theoretical prediction

$$\sigma_{t\bar{t}} = 172.0^{+\,4.4\ +4.7}_{-\,5.8\ -4.8}$$

$$\sigma_{t\bar{t}} = 245.8^{+\,6.2\ +6.2}_{-\,8.4\ -6.4}$$

Good agreement with prediction.

Top quark pair production cross-section

Lepton + jets Channel at 8 TeV

(ATLAS-CONF-2012-149) **8 TeV**

(5.8 fb^{-1})

Good statistics, Good sensitivity, BR = 34.4%,

Event Selection:

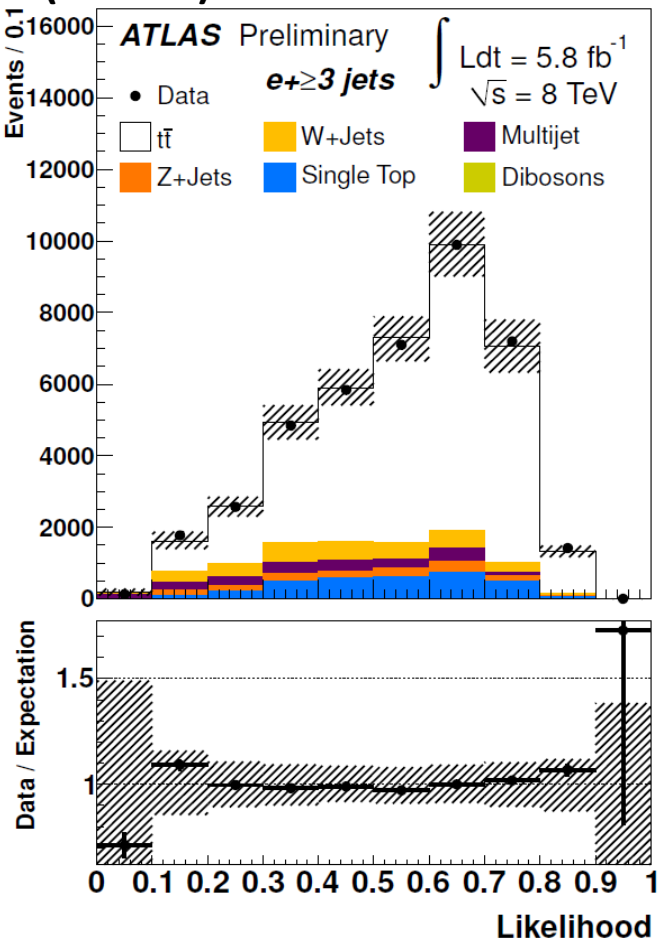
- One high P_T lepton
  P_T > 40 GeV electron, P_T > 40 GeV muon
- At least 3 good jets (P_T >25 GeV)
- At least 1 b-tagged jet
- Missing E_T > 35 (e), 25 (mu)

Main Background

W + jets

Analysis Method :

Cross section is determined from a fit to a distribution of the multivariate likelihood distribution. (aplanarity and lepton eta)



Measured Cross-Section

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

Systematic :

MC modeling, Jet/MET uncertainty

Theoretical prediction

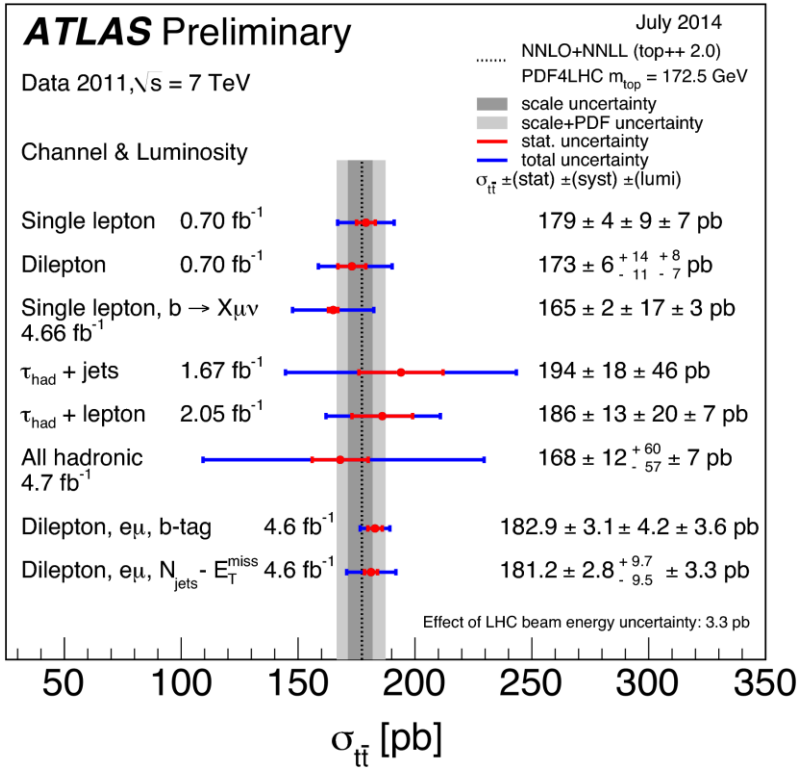
$$\sigma_{t\bar{t}} = 245.8\ ^{+\ 6.2}_{-\ 8.4}\ ^{+6.2}_{-6.4}$$

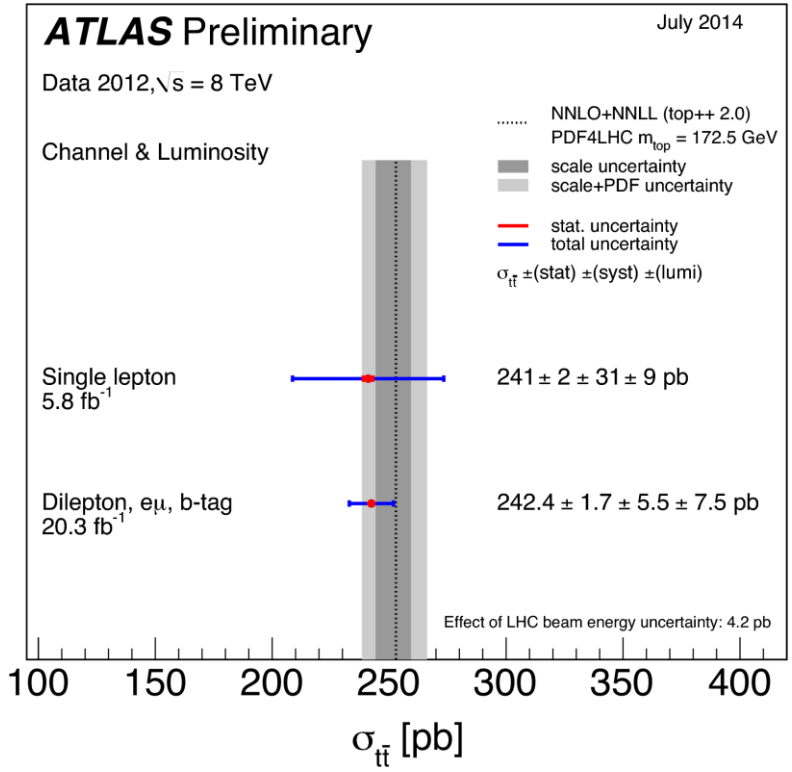
Good agreement with prediction.

Top pair production Cross Section Summary at 7 TeV and 8 TeV

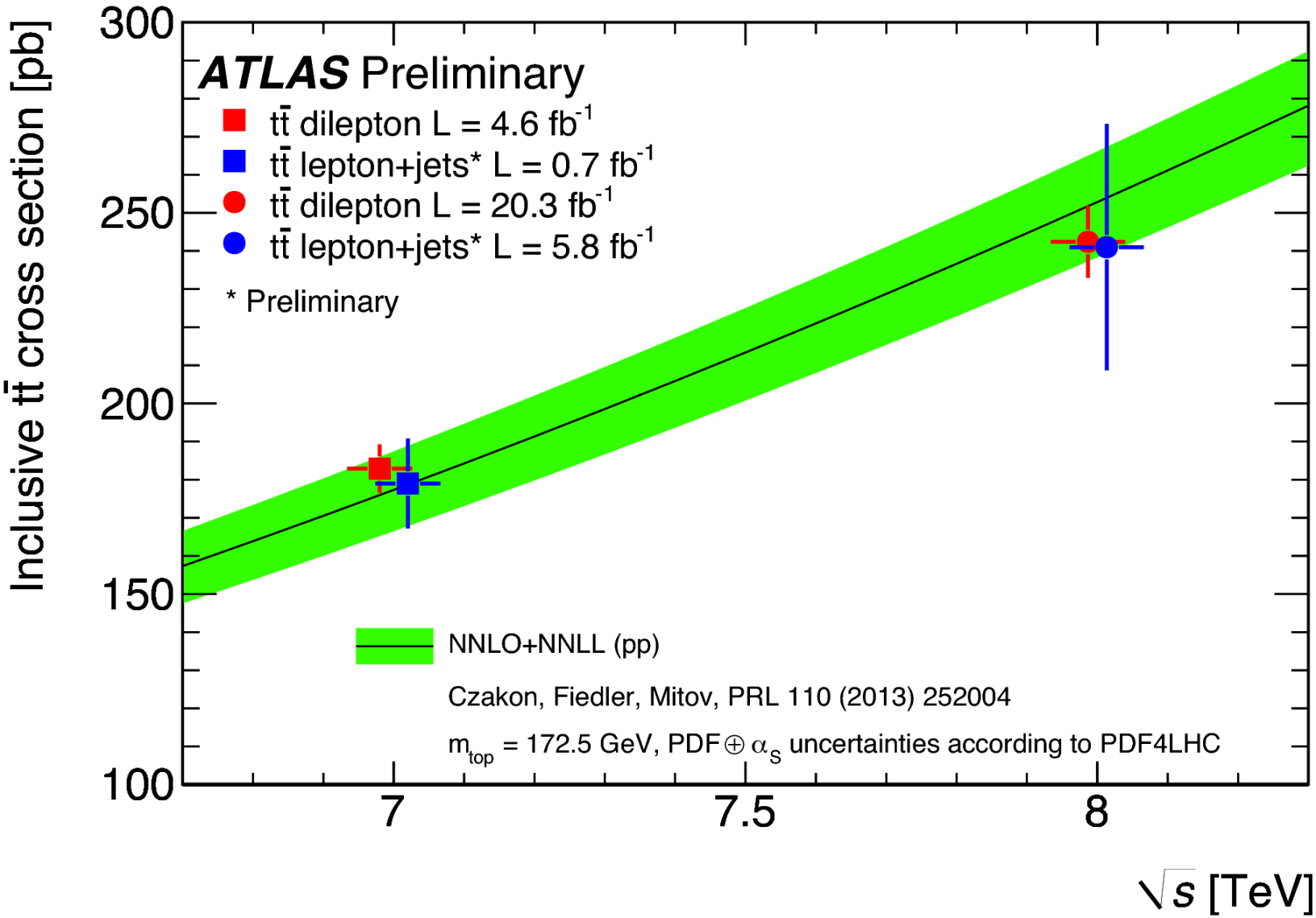
Good agreement with the NNLO+NNLL calculation in All channels.
The analyses are limited by systematics.

Precision of ~ 4%.





Summary of ttbar cross section



Simultaneous measurements of $t\bar{t}$, W^+W^-, and $Z/\gamma^* \rightarrow \tau\tau$ cross section

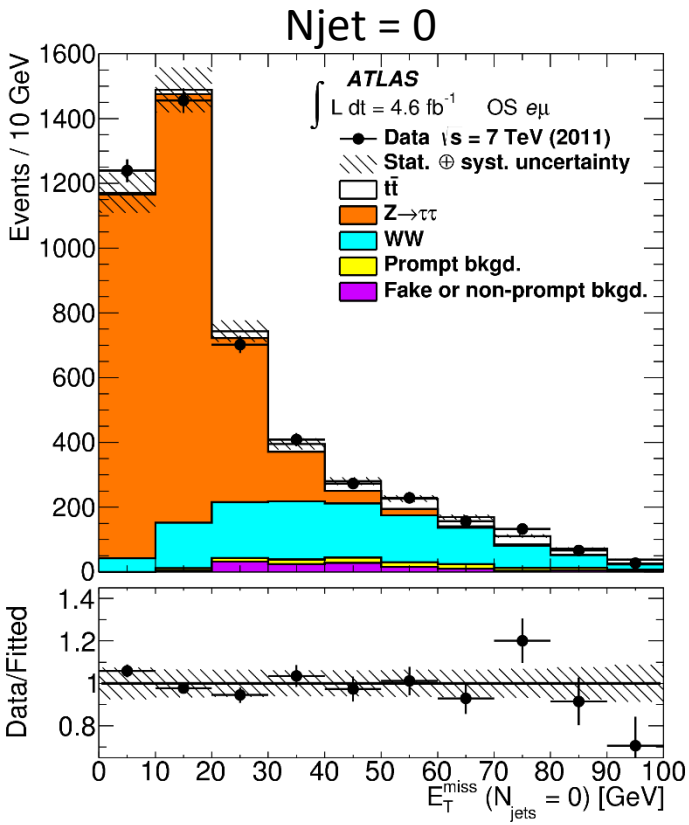
Simultaneous measurements of tt^-, W^+W^-, and $Z/\gamma^* \rightarrow \tau\tau$ cross section

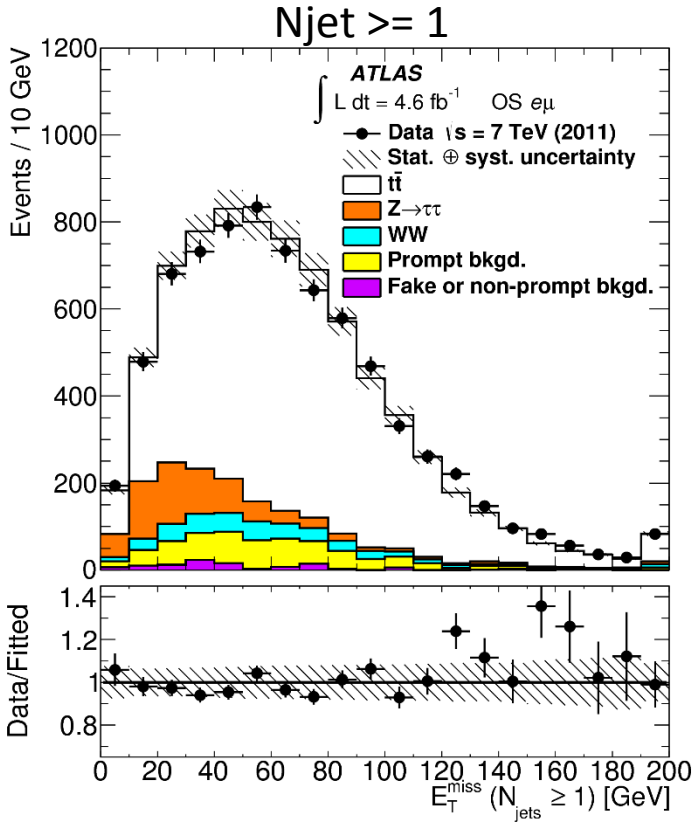
7 TeV

(ArXiv:1407.0573)

The first simultaneous measurement of the tt, W^+W^- and Z/Υ^*

- Opposite high p_T e μ events.
- Missing ET and Jet multiplicity distinguish tt, W^+W^- and Z/Υ^* process





Simultaneous measurements of tt^{-}, $W^{+}W^{-}$, and $Z/\gamma^{*}\rightarrow\tau\tau$ cross section

Measured cross sections are consistent with the dedicated ATLAS cross section measurement.

Process	Source	σ_X^{tot} [pb]	Uncertainties Stat.	Syst.	Lumi.	Beam	Total	$\int \mathcal{L}\,dt$ [fb^{-1}]
$t\bar{t}$	Simultaneous	181	3	10	3	3	11	4.6
	Dedicated	183	3	4	4	3	7	4.6
	NNLO QCD	177					11	
WW	Simultaneous	53.3	2.7	7.7	1.0	0.5	8.5	4.6
	Dedicated	51.9	2.0	3.9	2.0		4.9	4.6
	NLO QCD	49.2					2.3	
$Z/\gamma^{*} \rightarrow \tau\tau$	Simultaneous	1174	24	80	21	9	87	4.6
	Dedicated ($e\mu$)	1170	150	90	40		170	0.036
	NNLO QCD	1070					54	

Simultaneous measurements of tt^-, W^+W^-, and $Z/\gamma^* \rightarrow \tau\tau$ cross section

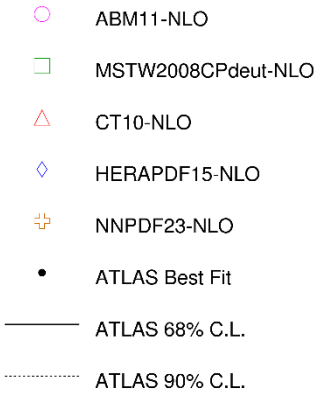
Fiducial cross section (MCFM NLO)

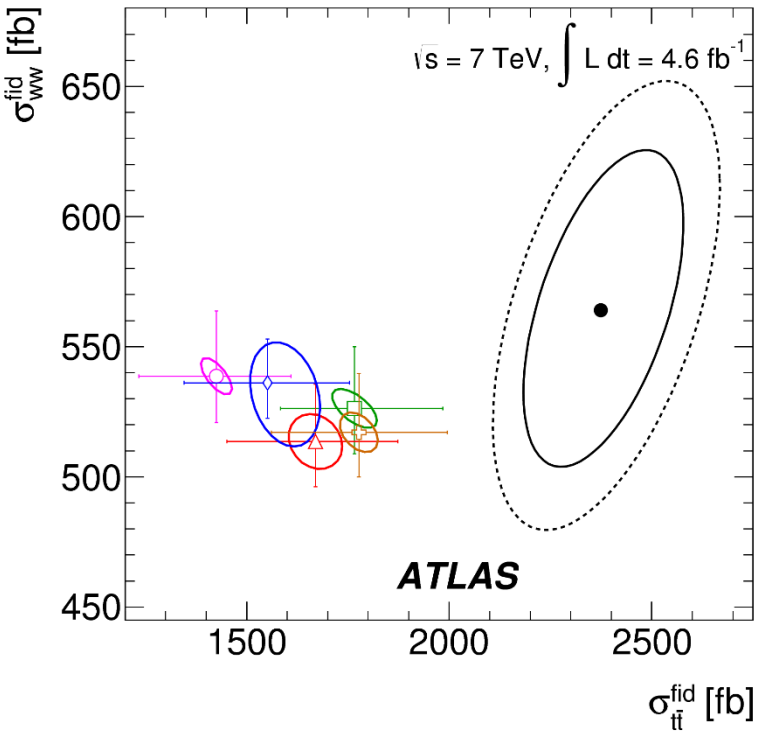
$$\sigma_X^{\text{fid}} = \frac{N_X^{\text{fid}}}{\mathcal{C} \cdot \mathcal{L}}$$

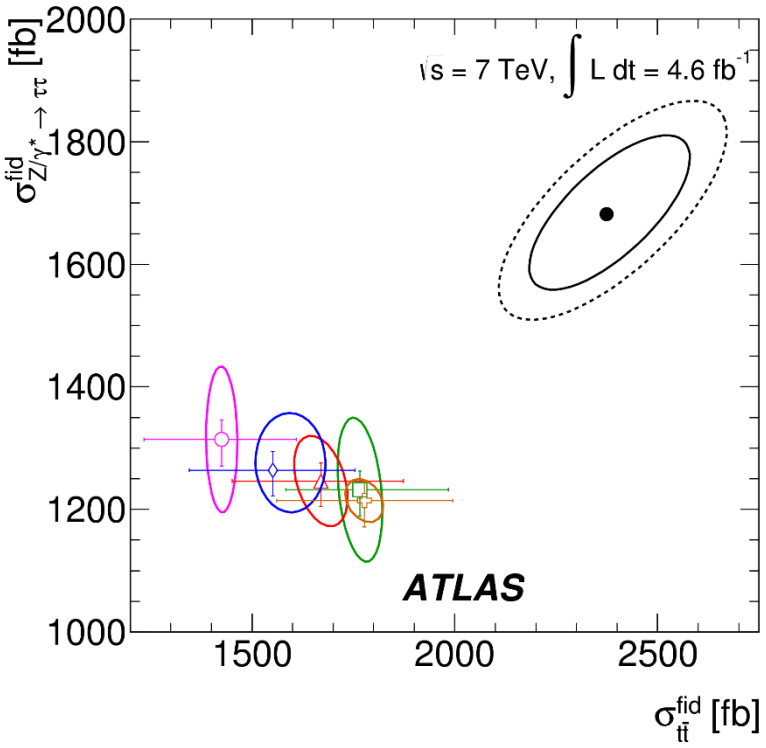
C: Ratio of event passing the event selection in the fiducial

L: Luminosity

- NLO predictions underestimate tt and Z/ϒ* irrespective of the PDF set







Simultaneous measurements of tt^-, W^+W^-, and $Z/\gamma^* \rightarrow \tau\tau$ cross section

Total cross section (NLO and NNLO)

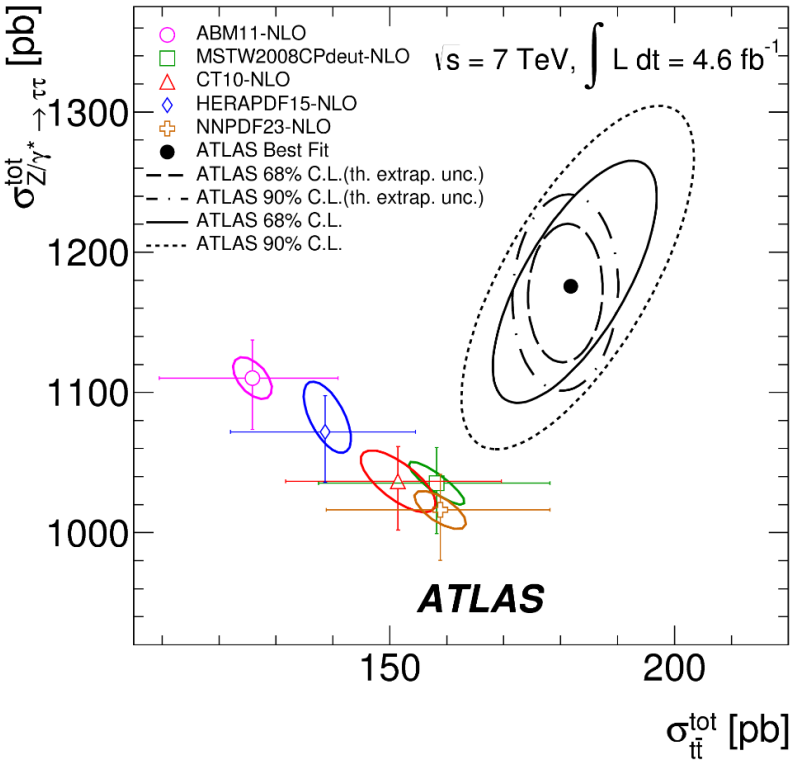
$$\sigma_X^{\text{tot}} = \frac{N_X^{\text{tot}}}{\mathcal{A} \cdot \mathcal{C} \cdot B(X \rightarrow e\mu + Y) \cdot \mathcal{L}}$$

A: Kinematic and geometric acceptance

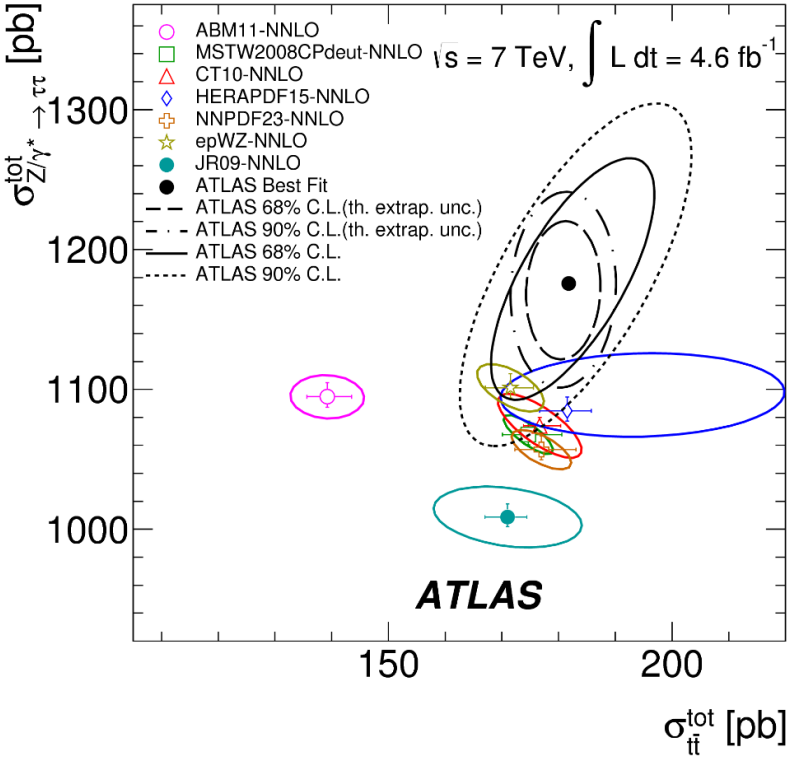
B: Branching fraction

- NNLO and corresponding PDF sets have good overlap.

NLO



NNLO



Differential Cross-Section measurement

Differential cross-section

Lepton + jets Channel (4.7 fb^{-1}) (arXiv:1407.0371)

7 TeV

The large dataset allows for differential cross-section measurement in various variables.

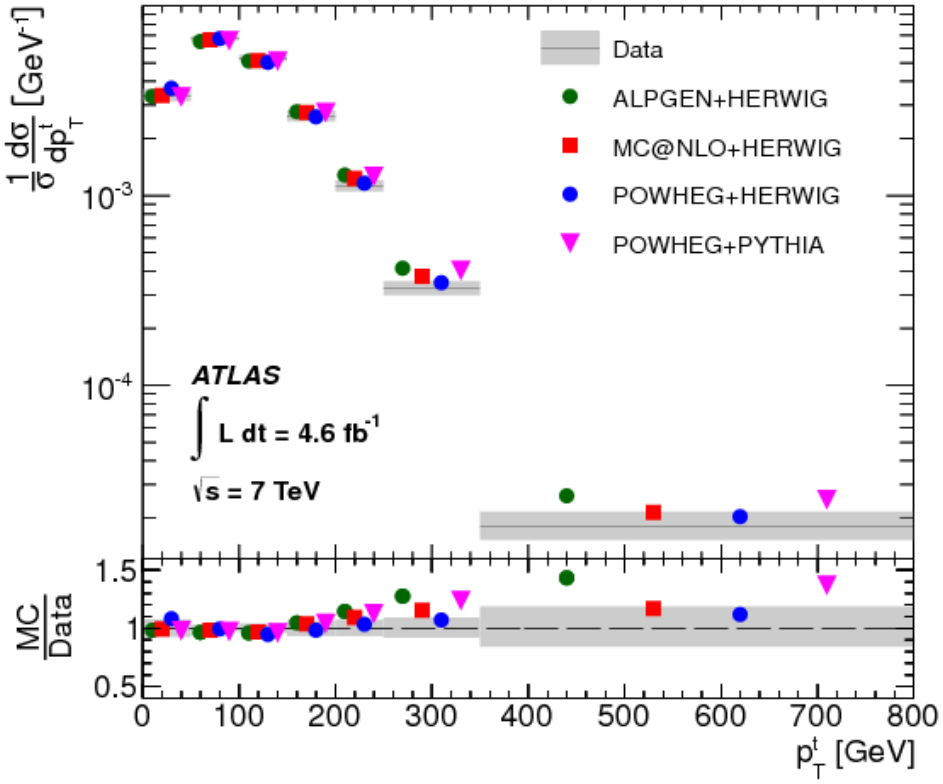
- Unfolded data compared to MC, NLO QCD and PDF sets
  - ➢ $p_{\mathrm{T}}^{\mathrm{t}}$ Transverse momentum of top quark
    - ✓ Higher order corrections and NP signal in high PT tail
  - ➢ $m_{\mathrm{t\bar{t}}}$ Mass of ttbar system
    - ✓ Exotic resonance
  - ➢ $p_{\mathrm{T}}^{\mathrm{t\bar{t}}}$ Transverse momentum of ttbar system
    - ✓ Extra radiation
  - ➢ $\mathrm{y}_{\mathrm{t\bar{t}}}$ Rapidity of ttbar system
    - ✓ PDF
- Standard lepton + jets final state selection
- Data is unfolded by inverting migration matrix from MC.
- Dominant systematics are MC generator, ISR/FSR, JES, b-tag efficiency
- Absolute cross section agree with the theoretical calculation.
- Generally good agreement

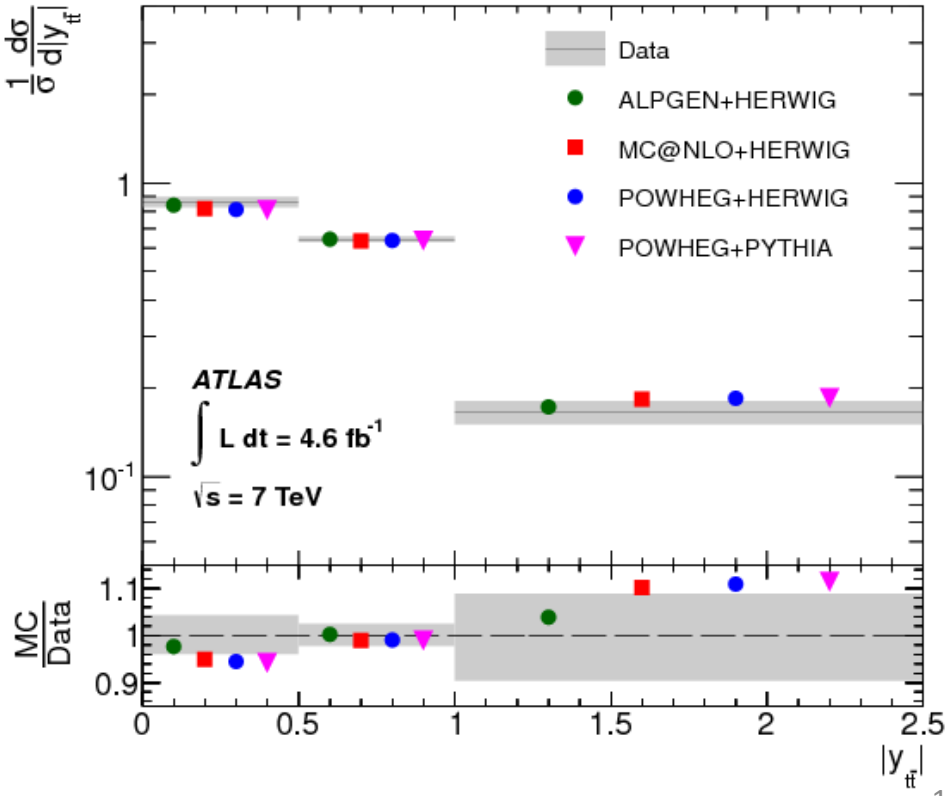
Differential cross-section

Lepton + jets Channel (4.7 fb^{-1}) (arXiv:1407.0371)

7 TeV

- Observed softer top p_T spectrum than prediction.
- More central observed than most predictions.
- Some of the prediction agree with uncertainties withdata.



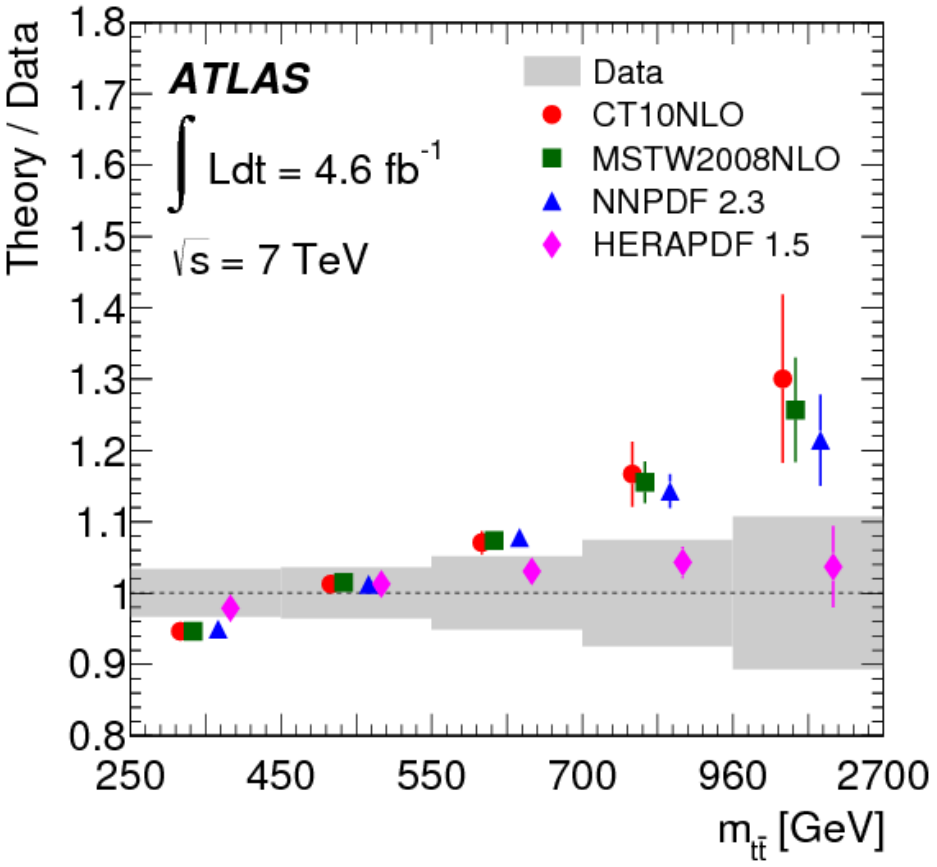


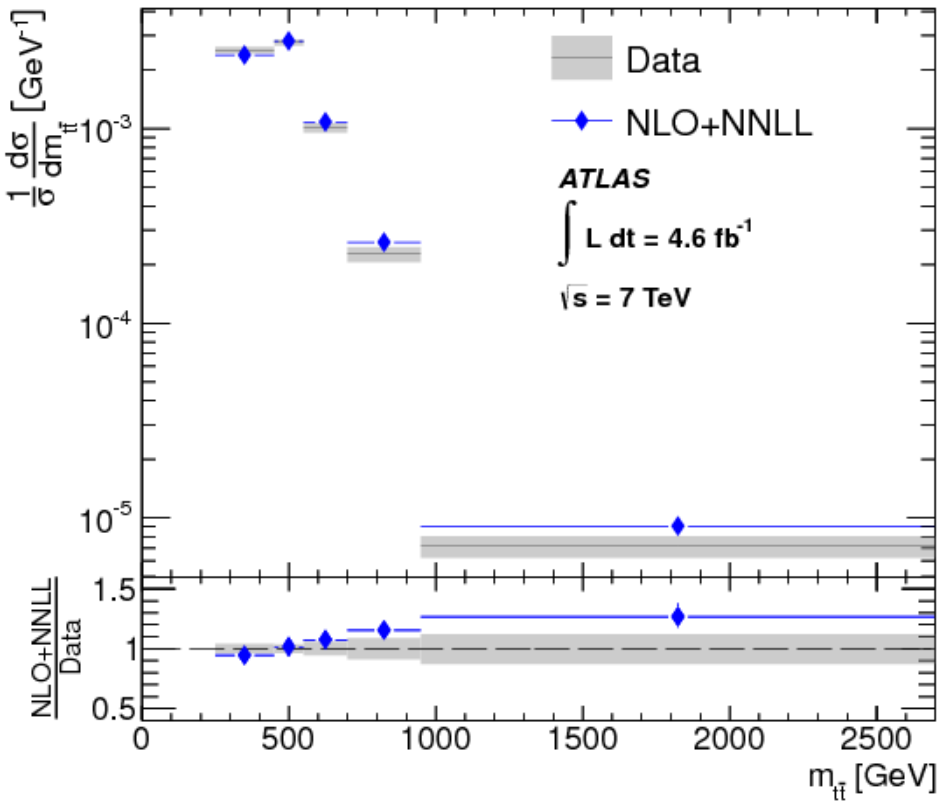
Differential cross-section

Lepton + jets Channel (4.7 fb^{-1}) (arXiv:1407.0371)

7 TeV

- m_{tt} is systematically softer then NLO+NLL



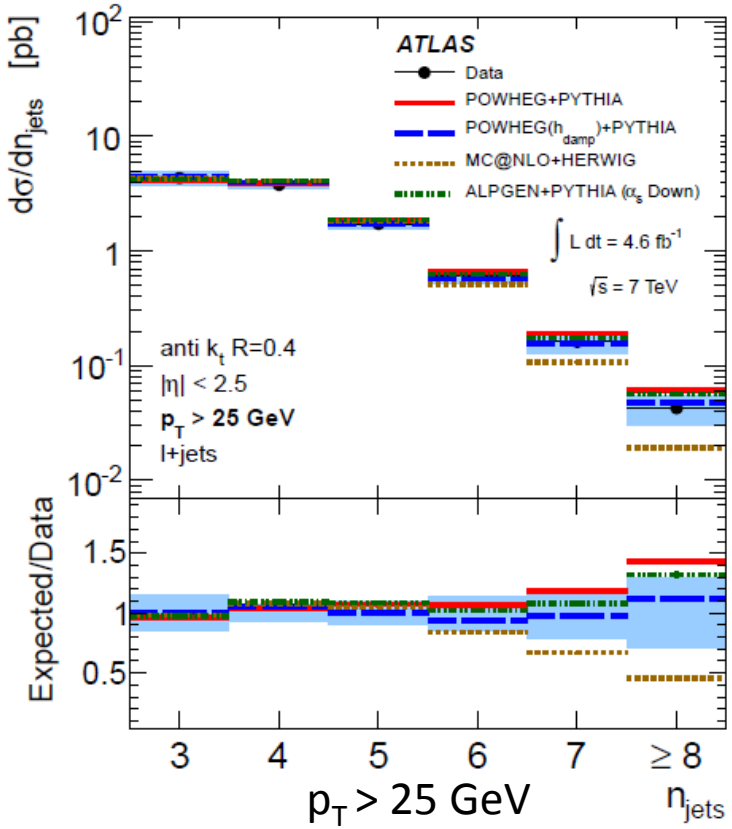


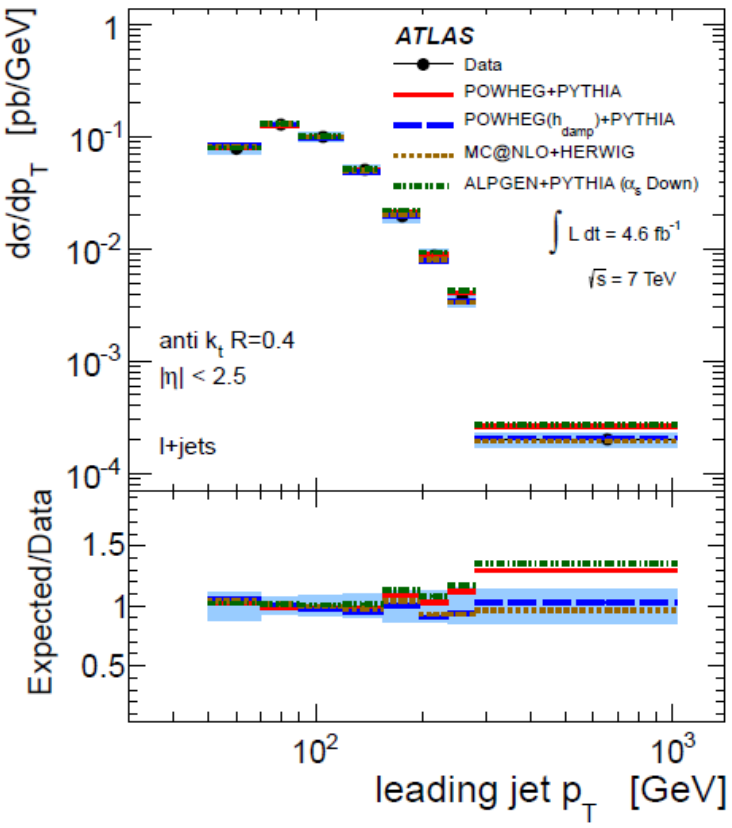
Cross-section as a function of jet multiplicity and jet transverse momentum

Lepton + jets Channel (4.7 fb^{-1}) (arXiv:1407.0891) 7 TeV

Spectrum was corrected to particle level within optimized fiducial.

- The MC@NLO+HERWIG MC is found to predict too few events at higher jet multiplicities.
- The POWHEG with hdamp setting describes the data quite well.





Top quark Mass Measurement

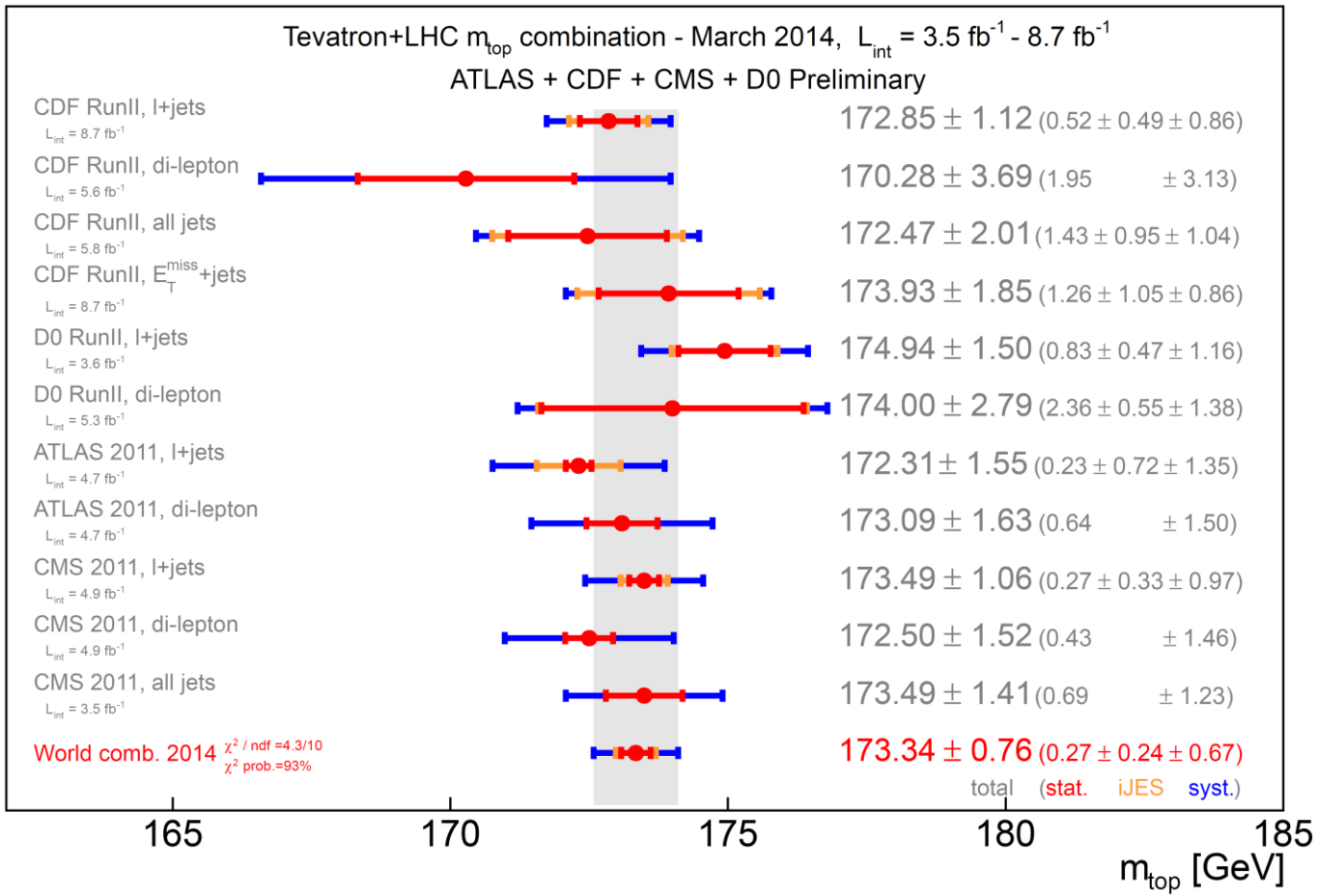
Top quark Mass Measurement

Physics motivation

- **Top quark mass is one of the SM parameters**
- **Good test of the SM**
- **Sensitive to new physics**

Top Quark Mass world average:

(ATLAS-CONF-2014-008, CDF-NOTE-11071, CMS-PAS-TOP-13-014, D0-NOTE-6416)



Top mass: Lepton + jets channel

7 TeV 4.7 fb^{-1} data

(ATLAS-CONF-2013-046)

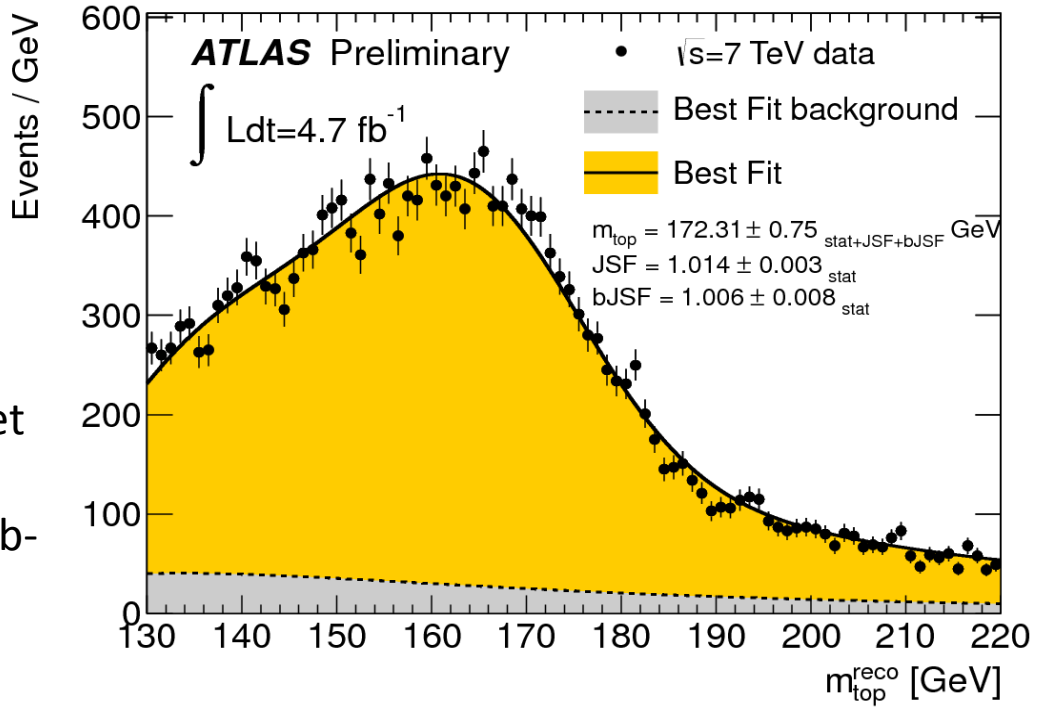
- Analysis :

3-D template mtheod (m_t, m_w, R_{lb})

$$R_{\mathrm{lb}}^{\mathrm{reco,2b}} = \frac{p_{\mathrm{T}}^{b_{\mathrm{had}}} + p_{\mathrm{T}}^{b_{\mathrm{lep}}}}{p_{\mathrm{T}}^{W_{\mathrm{jet}_1}} + p_{\mathrm{T}}^{W_{\mathrm{jet}_2}}},$$

$$R_{\mathrm{lb}}^{\mathrm{reco,1b}} = \frac{p_{\mathrm{T}}^{b_{\mathrm{tag}}}}{(p_{\mathrm{T}}^{W_{\mathrm{jet}_1}} + p_{\mathrm{T}}^{W_{\mathrm{jet}_2}})/2}$$

- ✓ M_w used to constrain the global jet scale factor (JSF).
- ✓ R_{lb} used to constrain the relative b-jet to light-jet energy scale factor (bJSF).



- Systematic uncertainties:

  JES, ISR/FSR, b-tag efficiency and mistag rate

$$m_{\mathrm{top}} = 172.31 \pm 0.75\,(\mathrm{stat} + \mathrm{JSF} + \mathrm{bJSF}) \pm 1.35\,(\mathrm{syst})\ \mathrm{GeV}$$

Top mass: Di-lepton channel

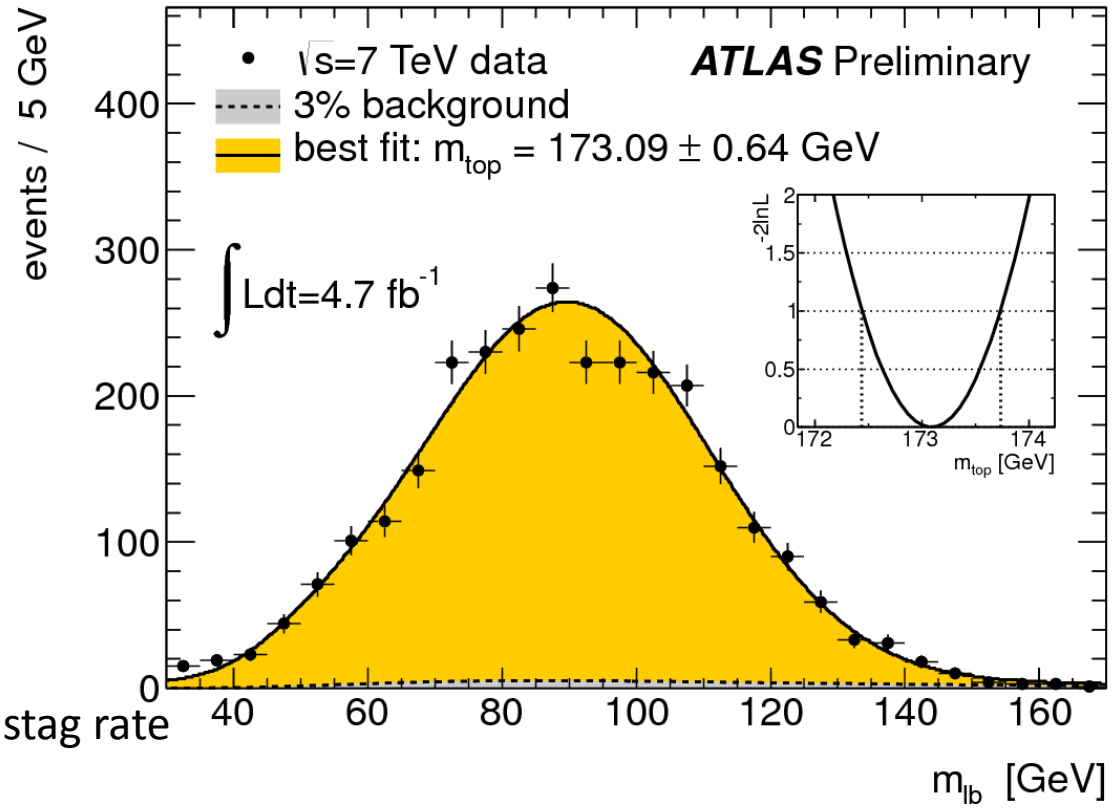
7 TeV 4.7 fb^{-1} data

(ATLAS-CONF-2013-077)

- Event selection:
  2 b-tagged jets
  less than 3 % background
  (single top)

- Analysis :
  1-D template method
  (m_{lb} as estimator for m_t).
  mlb : average invariant mass of
  b-jet lepton systems

- Systematic uncertainties:
  JES, bJES, b-tag efficiency and mistag rate



$$m_{\text{top}} = 173.09 \pm 0.64\,(\text{stat}) \pm 1.50\,(\text{syst})\ \text{GeV}$$

Summary

ATLAS has performed a complete set of top quark production cross section analysis

- **Observed production cross sections are consistent with the theoretical predictions in all channels.**
- **Uncertainty of cross section is limited by systematic uncertainties.**

First simultaneous extraction of the cross-sections for the tt, W^+W^- and Z/Υ^*

- **Measurements are consistent with the dedicated ATLAS cross section measurements.**
- **NNLO and corresponding PDF sets describe the data well.**
- **The measurement can be useful to constrain PDFs and uncertainty.**

Differential cross-section was measured at 7 TeV data.

- **Generally observed and prediction have good agreement.**
- **Observed softer than prediction slightly in high top p_T and ttbar mass region.**
- **The information from these analyses is used to constrain PDFs and modeling uncertainties on ttbar production.**

Top mass measurement were performed

- **Top mass was measured at better than 1% uncertainty.**
- **Physics beyond the SM is not observed.**

All detail and other analysis :
https://twiki.cern.ch/twiki/bin/view/AtlasPublic

backup

Top quark pair production cross-section

Lepton + jets Channel (0.70 fb^{-1}) (ATLAS-CONF-2011-121)

7 TeV

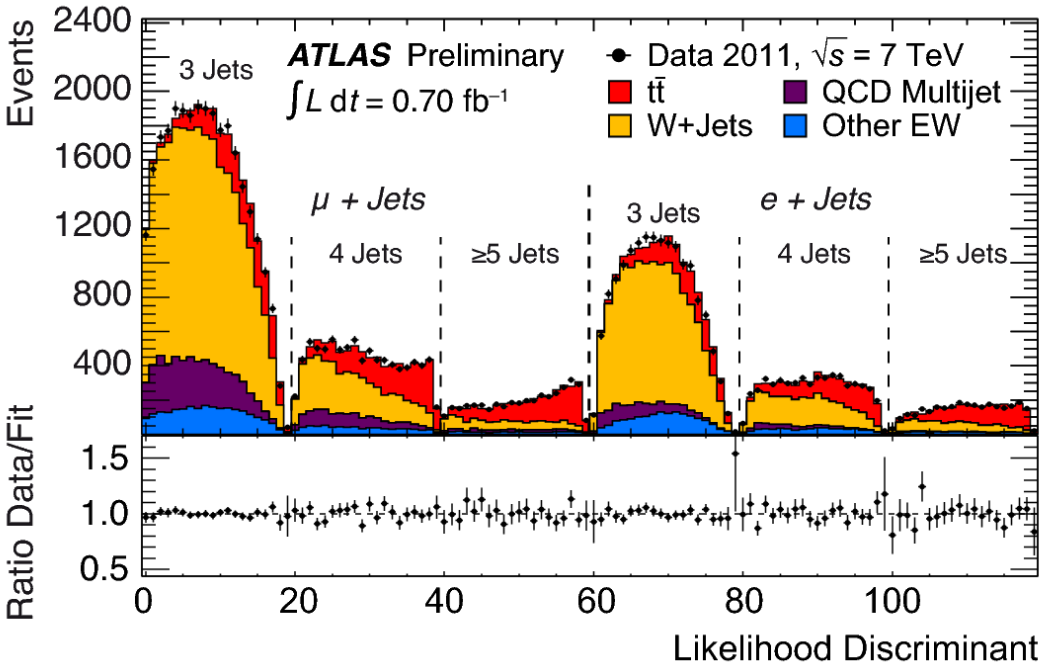
Good statistics, Good sensitivity, BR = 34.4%, 1lepton 1neutrino 2b-jet 2jet

Event Selection:

- One high P_T lepton

P_T >25 GeV electron, P_T >20 GeV muon

- At least 3 good jets (P_T >25 GeV)
- Missing E_T > 35 (e), 25 (mu)



Main Background :

W + Jets

Analysis Method :

Extract cross section from maximum likelihood fit of discriminant

Systematic :

Signal MC Generator, JES, ISR/FSR

Measured Cross-Section

$$\sigma_{t\bar{t}} = 179.0 \pm 3.9\,(\text{stat}) \pm 9.0\,(\text{syst}) \pm 6.6\,(\text{lumi})\ \text{pb}$$

Theoretical prediction

$$\sigma_{t\bar{t}} = 172.0^{+\,4.4\ +4.7}_{-\,5.8\ -4.8}$$

Good agreement with prediction. Uncertainty is dominated by systematic uncertainty.

Top quark pair production cross-section

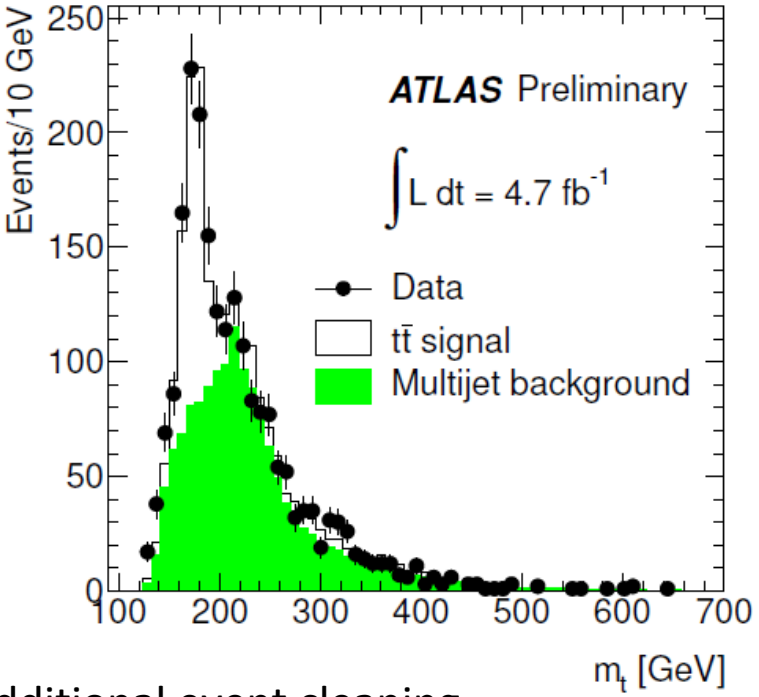
All-Hadronic Channel (4.7 fb^{-1}) (ATLAS-CONF-2012-031)

7 TeV

Highest BR = 44%, Huge QCD background, 2b-jet 4jet

Event Selection:

- No isolated good lepton
- At least 6 good jets
  5th Jet P_T >55 GeV, 6th jet Jet P_T >30 GeV
- At least 2 b-tagged P_T >55 GeV jets
- Low Missing E_T Significance



Main Background :

QCD

Analysis Method :

Unbinned likelihood fit to top Mass distribution after additional event cleaning.

Systematic :

JES, B-tagging efficiency, ISR/FSR

Measured Cross-Section

$$\sigma(pp \to t\bar{t}) = 168 \pm 12\ (\text{stat.})\ ^{+60}_{-57}\ (\text{syst.})\ \pm 7\ (\text{lum.})\ \text{pb}$$

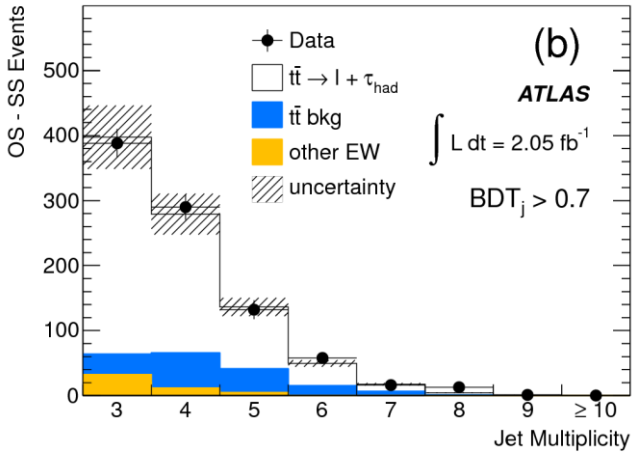
Theoretical prediction

$$\sigma_{t\bar{t}} = 172.0^{+\ 4.4\ +4.7}_{-\ 5.8\ -4.8}$$

Good agreement with prediction. Uncertainty is dominated by systematic uncertainty.

Top quark pair production cross-section

Hadronic τ + Lepton Channel (2.05 fb^{-1}) (arXiv:1205.2067v1) 7 TeV



Event Selection : One good high P_T lepton and hadronic tau candidate, At lease 2 good jets, missing ET, btagged-jet

Main Background : other top event

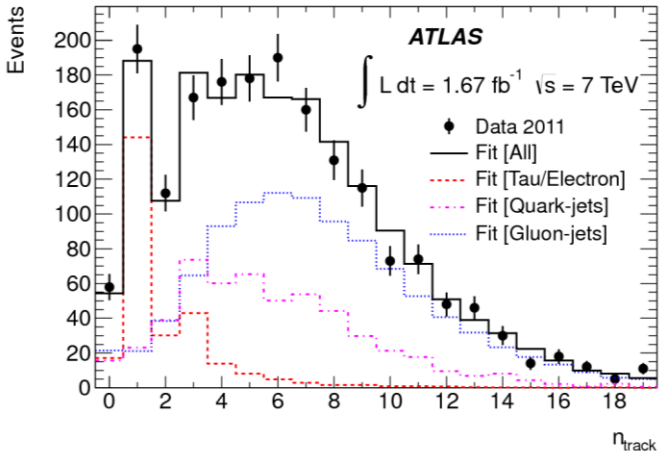
Analysis Method : Extract cross section from BDT discriminant.

Systematic : b-tag efficiency, tau ID

Measured Cross-Section

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

Hadronic τ + Jet Channel (1.67 fb-1)(Eur.Phys.J. C, 73 3 (2013) 2328)



Event Selection : No good high P_T lepton, At lease 5 high-P_T jets with at least 2-btagged jets and one hadronic tau candidate. High Missing E_T significance

Main Background : Multi Jet event

Analysis Method : 1D fit to the distribution of the number of track associated to hadronic tau candidate.

Systematic : Modeling (ISR/FSR, generator), b-tag efficiency

Measured Cross-Section

$$\sigma_{t\bar{t}} = 194 \pm 18\ (\text{stat.}) \pm 46\ (\text{syst.})\ \text{pb}$$

Theoretical prediction

$$\sigma_{t\bar{t}} = 172.0^{+\ 4.4\ +4.7}_{-\ 5.8\ -4.8}$$

Good agreement with prediction. Uncertainty is dominated by systematic uncertainty.