Inclusive top pair production at 7, 8 and 13 TeV in ATLAS

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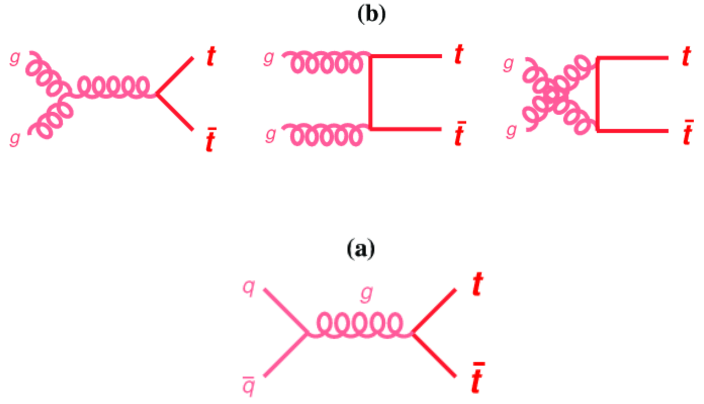
on behalf of the
ATLAS Collaboration

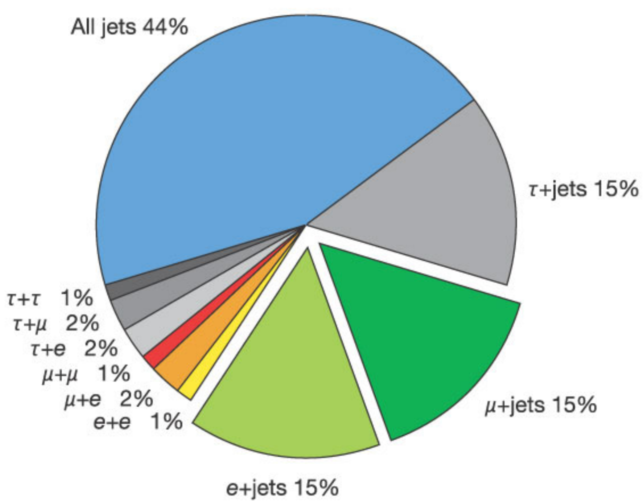
Top 2015
8th International Workshop on Top Quark Physics

Introduction

The top quark

- Heaviest quark
- Pair produced in gluon-gluon fusion (87%) and quark-quark interaction (13%)
- Top pair decay channels
  - Dilepton (e/μ) ~5%
  - l+jets (e/μ) ~30%
  - All jets, τ-lepton channels



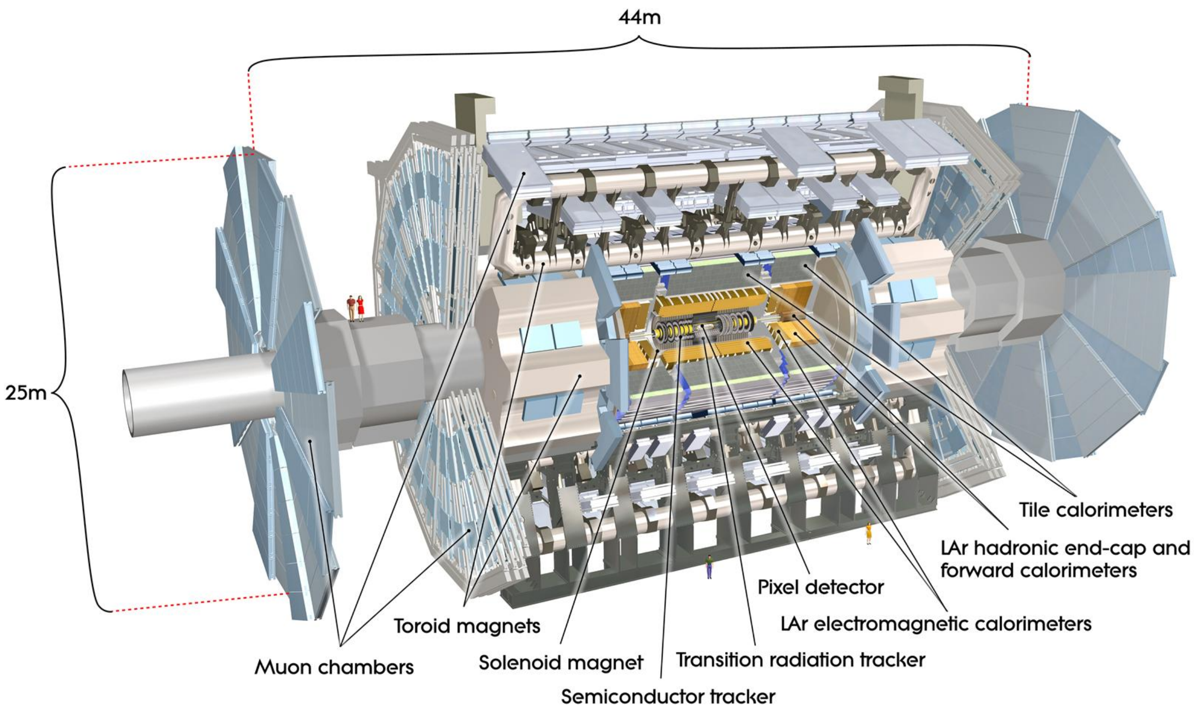


$t\bar{t}$ production at the LHC

- LHC is a top factory
- Cross-section increased by almost factor 3.5 (8-13 TeV)

Top quark pair cross section measurements are
→ Excellent precision tests of Standard Model
→ Sensitive to QCD effects, PDF, top quark mass, ...
→ Probe for new physics

The ATLAS Experiment



Multi-purpose detector using tracking system, calorimeters and a muon spectrometer

Electrons
$|\eta|<2.47$

Muons
$|\eta|<2.5$

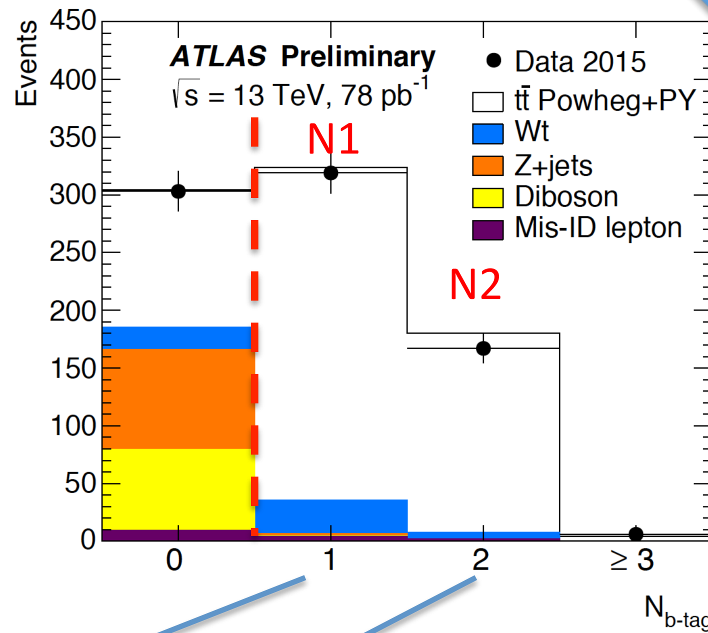
τ_{had} candidates
$|\eta|<2.5$

Jets
Anti-k_t R=0.4,
3D topological clusters

eμ + b-jets @ 13 TeV: Method

78/pb

- Select opposite-sign eμ pair
- b-tagging using multivariate discriminator (MV2c20)
  - 70% efficiency
  - rejection 440 (light), 8 (c)
- High b-tagging uncertainties → Determine efficiency from data



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

$\varepsilon_{e\mu}$: eμ preselection efficiency
ε_b: b-jet acceptance and tagging efficiency
C_b: 1/2-btag correlation (=1.005)

eμ + b-jets: Event Yields

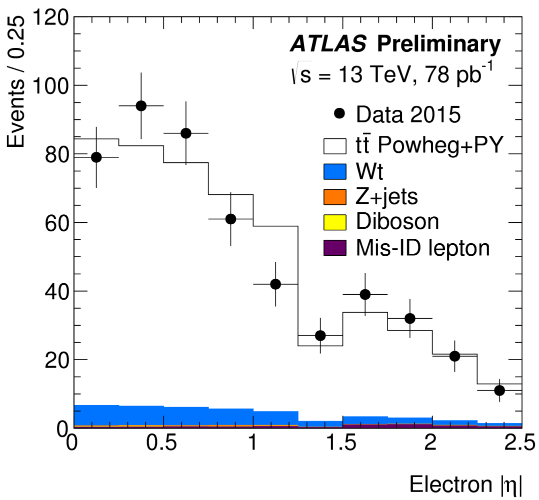
78/pb

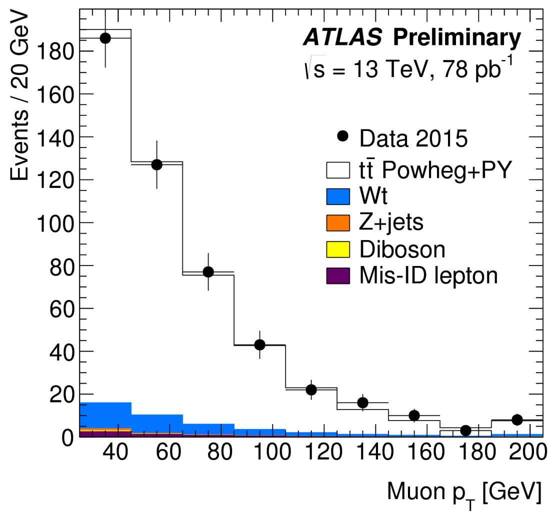
Background measured from simulation

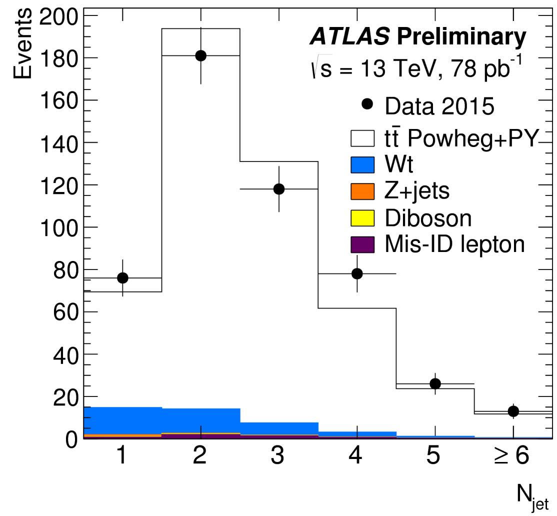
- Single top Wt
- Z+jets
- Diboson

Event counts	N_1	N_2
Data	319	167
Wt single top	29.0 ± 3.8	5.6 ± 2.0
Dibosons	1.1 ± 0.2	0.0 ± 0.0
$Z(\to \tau\tau \to e\mu)$+jets	1.3 ± 0.7	0.1 ± 0.1
Misidentified leptons	6.0 ± 3.9	2.8 ± 2.9
Total background	37.3 ± 5.5	8.5 ± 3.5

Misidentified lepton events (Mis-ID) data-driven from same-sign events







e/μ + b-jets @ 13 TeV

78/pb

Uncertainties

Luminosity	10.0%
Statistical	6.0%
Hadronisation	4.5%
Electron ID	3.2%
NLO modelling	2.2%
Total	**13.5%**

Luminosity: Preliminary measurement

Hadronisation: Comparison of Powheg+Herwig++ and Powheg+Pythia

NLO modelling: Comparison of Powheg+Herwig++ and aMC@NLO+Herwig++

(Total uncertainty 4% for 7 and 8 TeV measurement)

Result

$$\sigma_{t\bar{t}} = 829 \pm 50\ (\text{stat})\ \pm 56\ (\text{syst})\ \pm 83\ (\text{lumi})\ \text{pb}$$

Theory NNLO+NNLL 832^{+40}_{-46} pb at $m_t = 172.5$ GeV

Czakon, Fiedler, Mitov PRL 110 252004

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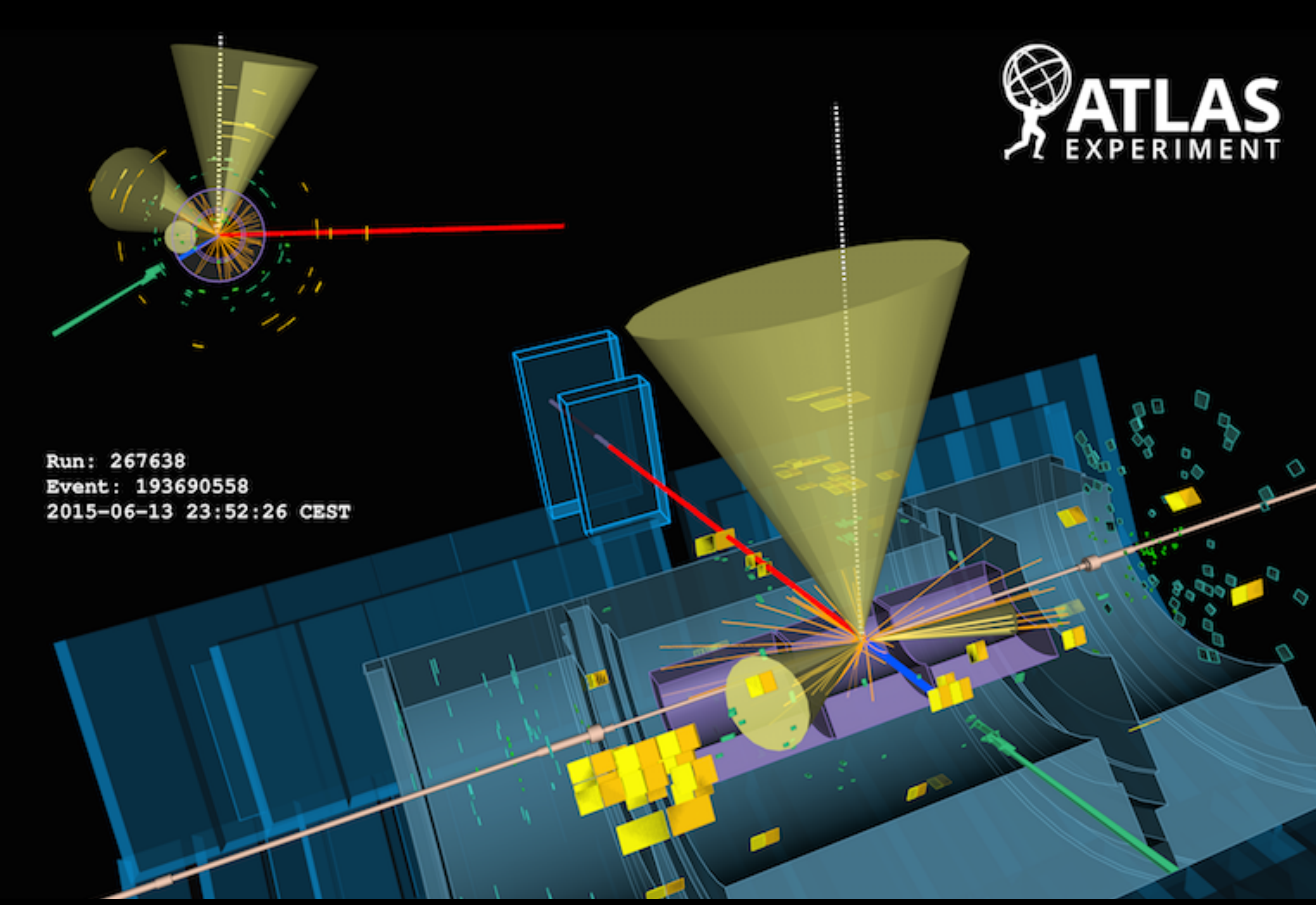
ATLAS
EXPERIMENT
Run: 267638
Event: 193690558
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Ratio of $t\bar{t}$ and Z cross-sections

$$R_{t\bar{t}/Z} = \frac{\sigma_{t\bar{t}}}{0.5\left(\sigma_{Z\to ee} + \sigma_{Z\to\mu\mu}\right)}$$

Highest uncertainty from luminosity will cancel!

Uncertainty	Z→ee	Z→μμ	$t\bar{t}$	Ratio
Data Stat.	0.5%	0.5%	6.0%	6.0%
Analysis Syst.	4.4%	2.3%	6.7%	6.3%
Luminosity	9.0%	9.0%	10.0%	1.0%
Total	**10.0%**	**9.3%**	**13.5%**	**8.8%**

Mostly due to cancellation of e/μ identification uncertainty

$$R_{t\bar{t}/Z} = 0.445 \pm 0.027\ (\text{stat}) \pm 0.028\ (\text{syst})$$

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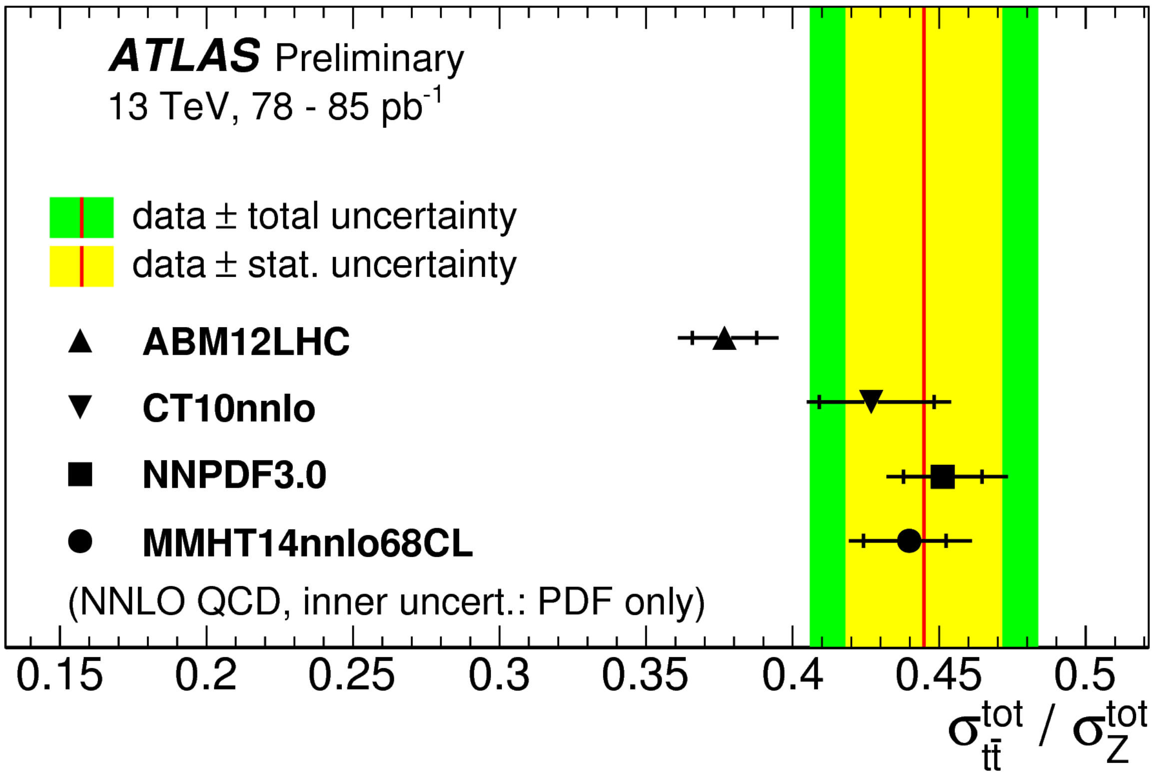
Ratio of $t\bar{t}$ and Z cross-sections



Result is compared to prediction from

- FEWZ for Z production [Gavin et al., Comput. Phys. Commun. 182 2388]
- top++ for top pair production [Czakon, Mitov, Comput. Phys. Commun. 185 2930]

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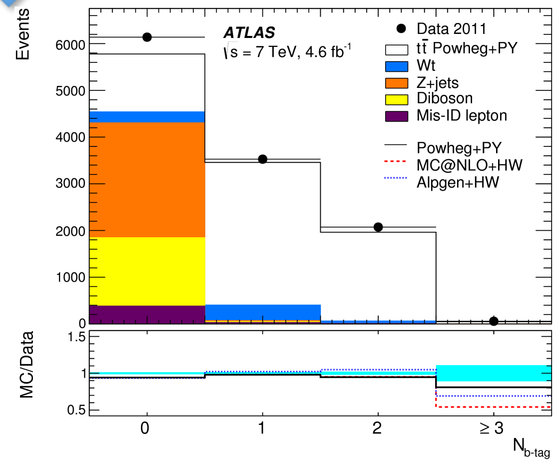
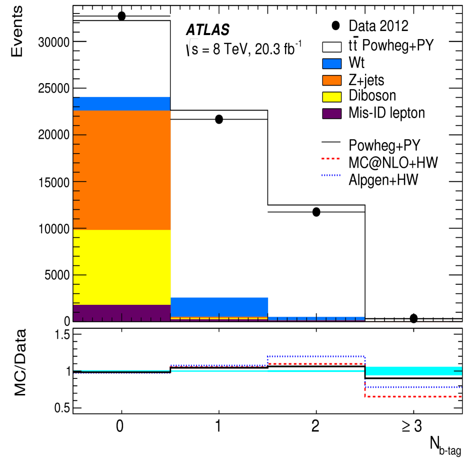
eμ + b-jets @ 7/8 TeV

4.6/fb

20.3/fb

Very similar selection and same method as with 13 TeV





Uncertainties

	7TeV/8TeV	13 TeV
Luminosity	2.0%/3.1%	10.0%
Data stat.	1.7%/0.7%	6.0%
Beam	1.8%/1.7%	-
tt modelling	1.4%/1.2%	5.2%
PDF	1.0%/1.1%	1.4%
Total	**3.9%/4.3%**	**13.7%**

Precision Measurement

stat syst lumi beam

$$\sigma_{t\bar{t}} = 182.9 \pm 3.1 \pm 4.2 \pm 3.6 \pm 3.3\,\mathrm{pb}\ (\sqrt{s} = 7\,\mathrm{TeV})$$ 3.9%

$$\sigma_{t\bar{t}} = 242.4 \pm 1.7 \pm 5.5 \pm 7.5 \pm 4.2\,\mathrm{pb}\ (\sqrt{s} = 8\,\mathrm{TeV})$$ 4.3%

2%/1% 2%/2% 2%/3% 2%/2%

Eur. Phys. J. C (2014) 74:3109

ee/μμ + b-jets @ 13 TeV

85/pb

Method

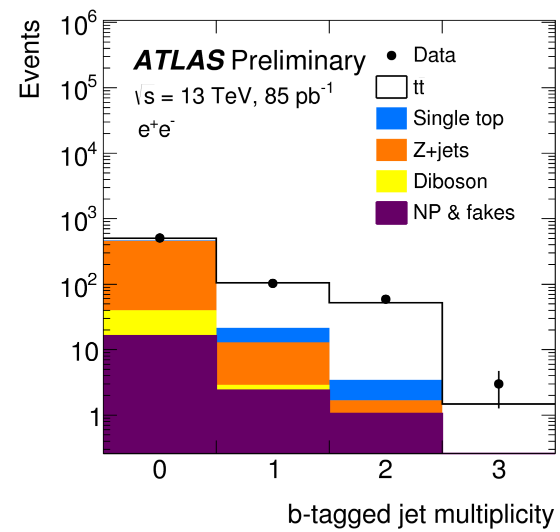
- Opposite-sign ee/μμ
- $60 < m_{ll} < 81$ GeV or $m_{ll} > 101$ GeV
- $E_T^{miss} > 30$ TeV
- b-tagging using multivariate discriminator (MV2c20) with 70% efficiency

$$
\begin{aligned}
N_1^{ee} &= L\sigma_{t\bar{t}}\,\epsilon_{\mathrm{presel}}^{ee} 2\epsilon_b^{ee}(1 - C_b^{ee}\epsilon_b^{ee}) + N_1^{\mathrm{bkg},ee} \\
N_2^{ee} &= L\sigma_{t\bar{t}}\,\epsilon_{\mathrm{presel}}^{ee} C_b^{ee}\epsilon_b^{ee}\epsilon_b^{ee} + N_2^{\mathrm{bkg},ee} \\
N_1^{\mu\mu} &= L\sigma_{t\bar{t}}\,\epsilon_{\mathrm{presel}}^{\mu\mu} 2\epsilon_b^{\mu\mu}(1 - C_b^{\mu\mu}\epsilon_b^{\mu\mu}) + N_1^{\mathrm{bkg},\mu\mu} \\
N_2^{\mu\mu} &= L\sigma_{t\bar{t}}\,\epsilon_{\mathrm{presel}}^{\mu\mu} C_b^{\mu\mu}\epsilon_b^{\mu\mu}\epsilon_b^{\mu\mu} + N_2^{\mathrm{bkg},\mu\mu}
\end{aligned}
$$

Obtain best $\sigma_{t\bar{t}}\ \epsilon_b^{ee}\ \epsilon_b^{\mu\mu}$ using maximum likelihood fit

Event Yield Estimation

- Z background scaled in control region
- MisID from MC (100% uncertainty)



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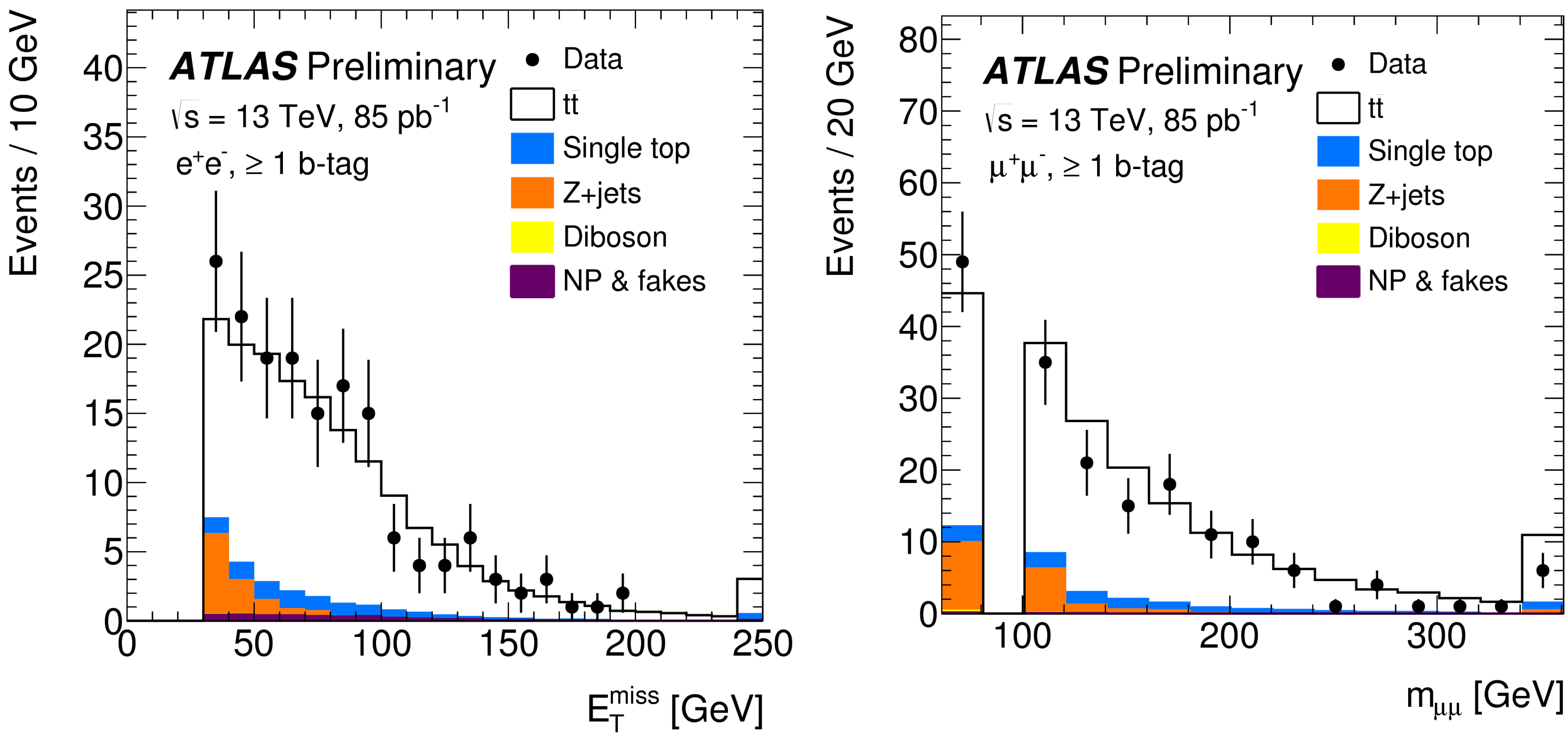
ee/μμ + b-jets @ 13 TeV



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ee/μμ + b-jets @ 13 TeV: Result

85/pb

Result

$\sigma_{t\bar{t}} = 749 \pm 57\ \text{(stat)}\ \pm 79\ \text{(syst)}\ \pm 74\ \text{(lumi) pb}$ 16%

8% 11% 10%

Theory NNLO+NNLL prediction

$832^{+40}_{-46}\ \text{pb}$ at $m_t = 172.5\ \text{GeV}$

For comparison: eμ + b-jets

$\sigma_{t\bar{t}} = 829 \pm 50\ \text{(stat)}\ \pm 56\ \text{(syst)}\ \pm 83\ \text{(lumi) pb}$ 14%

6% 7% 10%

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l+jets @ 13 TeV

85/pb

Event Selection

- One e/μ
- Four jets (1 b-tagged)
- E_T^{miss}>40 GeV, m_T^W>50 GeV (e)
- $E_T^{miss}+m_T^W$>60 GeV (μ)

Sample	e + jets	μ + jets
$t\bar{t}$	2800 ± 400	2620 ± 340
W+jets	340 ± 100	230 ± 60
Single top	192 ± 34	180 ± 30
Z+jets	71 ± 35	45 ± 22
Dibosons	10 ± 5	10 ± 5
Fakes	200 ± 70	130 ± 60
Total background	820 ± 130	600 ± 100
Total expected	3600 ± 500	3220 ± 350
Observed	3439	3314

~80% pure

Cross section obtained with

data

$$\sigma_{t\bar{t}} = \frac{(N - B)}{\epsilon_{\ell j} L}$$

background

Efficiency from simulation

Integrated luminosity

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l+jets @ 13 TeV W Estimation

85/pb

Exploit expected charge asymmetry to estimate W background

Define control region (e/μ+1jet, no b-jet). Extrapolate using simulation.

$$N_{\geq 1b}^{W,DD} = \frac{N_{0b}^{W,DD}}{N_{0b}^{W,MC}} \cdot N_{\geq 1b}^{W,MC}$$

Get difference between positive and negative charge events in CR.

$$N_{0b}^{W,DD} = \frac{\left(N_d^+ - N_b^+\right) - \left(N_d^- - N_b^-\right)}{A_W} \qquad A_W = \frac{\left(N_{\mathrm{MC}}^+ - N_{\mathrm{MC}}^-\right)}{\left(N_{\mathrm{MC}}^+ + N_{\mathrm{MC}}^-\right)}$$

Correct for single-top events and divide by charge asymmetry

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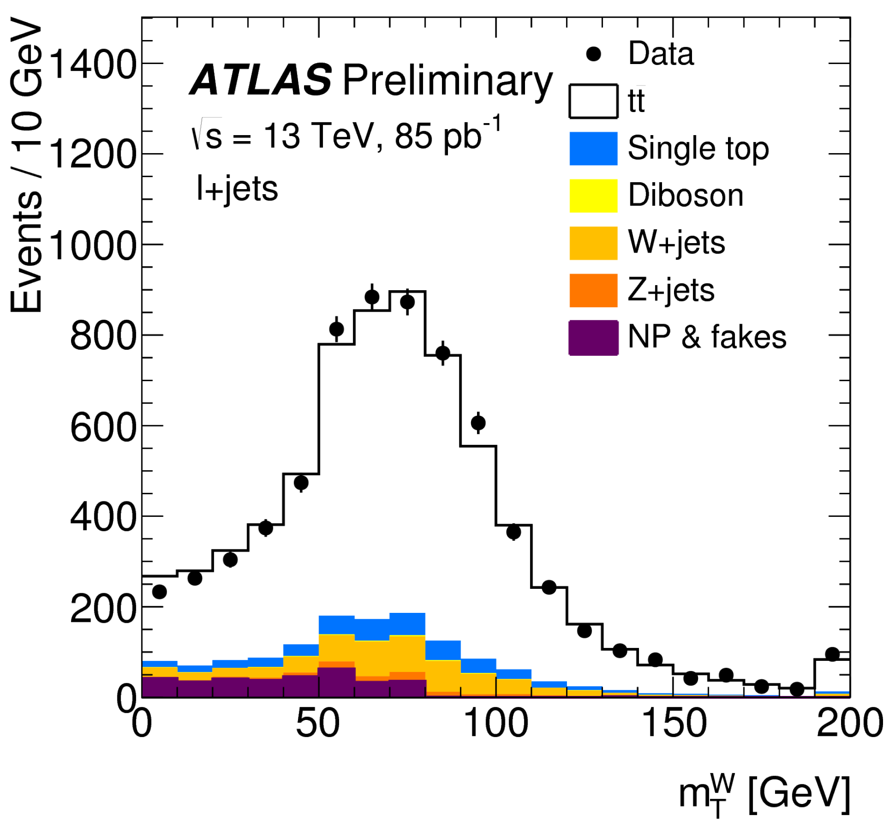
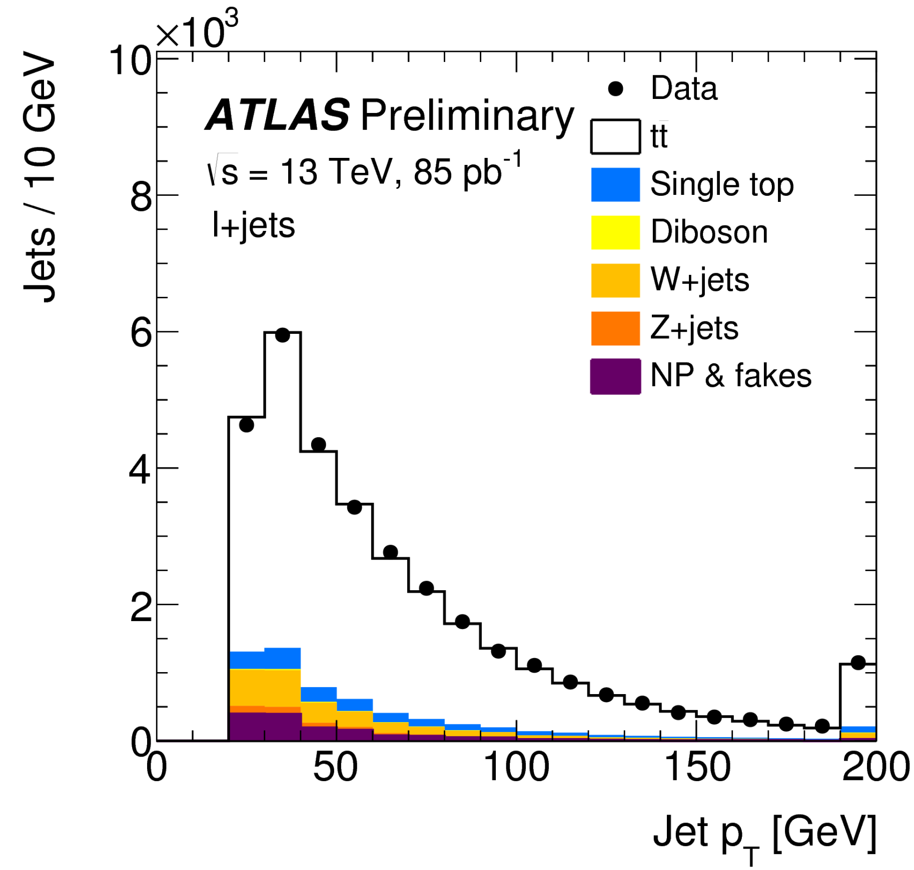
l+jets @ 13 TeV





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l+jets @ 13 TeV: Result

85/pb

Result

$$\sigma_{t\bar{t}} = 817 \pm 13\ (\mathrm{stat})\ \pm 103\ (\mathrm{syst})\ \pm 88\ (\mathrm{lumi})\ \mathrm{pb}$$

2% 13% 11% 17%

Theory NNLO+NNLL prediction

832^{+40}_{-46} pb at $m_t = 172.5$ GeV

For comparison: eμ + b-jets

$$\sigma_{t\bar{t}} = 829 \pm 50\ (\mathrm{stat})\ \pm 56\ (\mathrm{syst})\ \pm 83\ (\mathrm{lumi})\ \mathrm{pb}$$

6% 7% 10% 14%

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l+jets @ 8 TeV: Fit-based analysis

Base selection

e/μ + 3 jets
E_T^{miss}, $m_T(W)$ selection

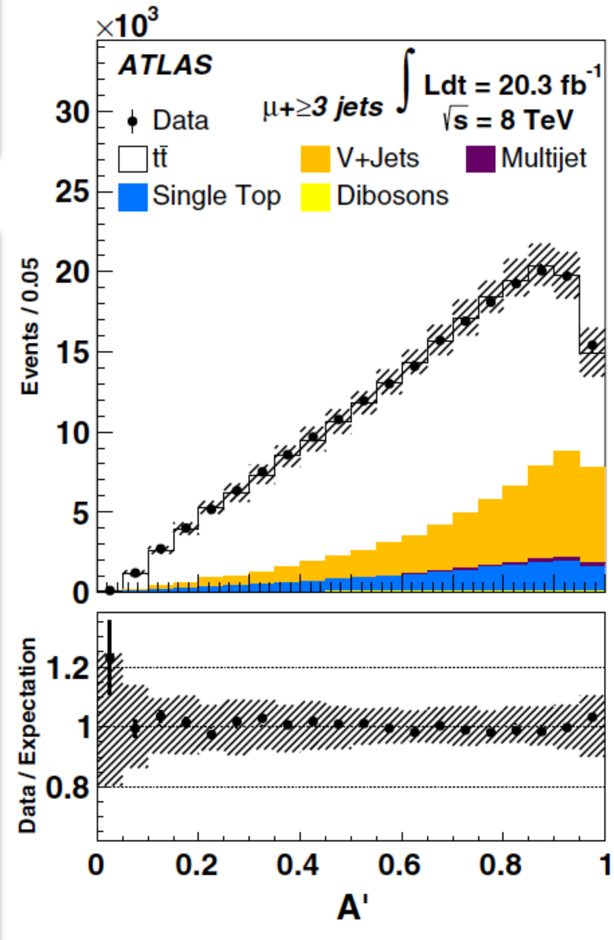
Fit to Likelihood Function

Template fit to LHD distribution

$$D_i = \frac{L_i^s}{L_i^s + L_i^b}$$

Signal likelihood
Signal + background likelihood

in e + jets / μ + jets
Likelihood functions are products of PDFs for kinematic variables
- Pseudorapidity of lepton
- Transformed Aplanarity = 3/2 smallest eigenvector of momentum tensor

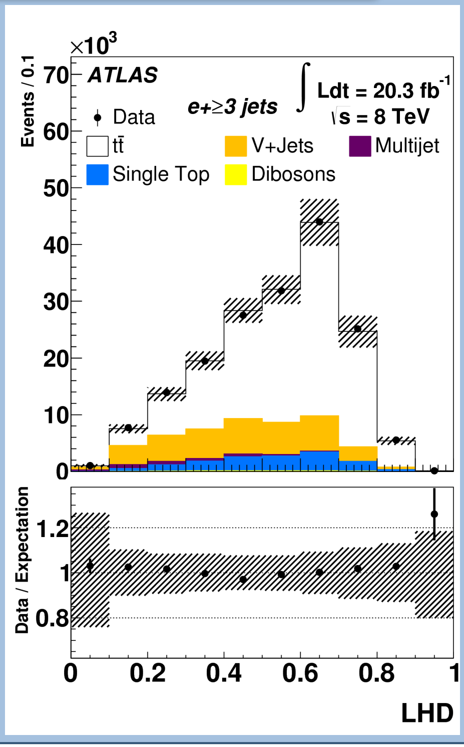


Phys. Rev. D 91, 112013 (2015)

l+jets @ 8 TeV

20.3/fb

LHD distribution



Uncertainties

Uncertainty	
PDF	5.9%
MC generator	3.3%
Jet/E_T^{miss}	3.2%
Luminosity	2.8%
Parton Shower	2.6%
Total	**8.7%**

For comparison eμ+b-jets 4.3%

Results

$$260 \pm 1(\text{stat})\,^{+22}_{-23}(\text{syst}) \pm 8(\text{lumi}) \pm 4(\text{beam})\,\text{pb}$$

Phys. Rev. D 91, 112013 (2015)

$t\bar{t}$ branching ratios @ 7TeV

4.6/fb

Method

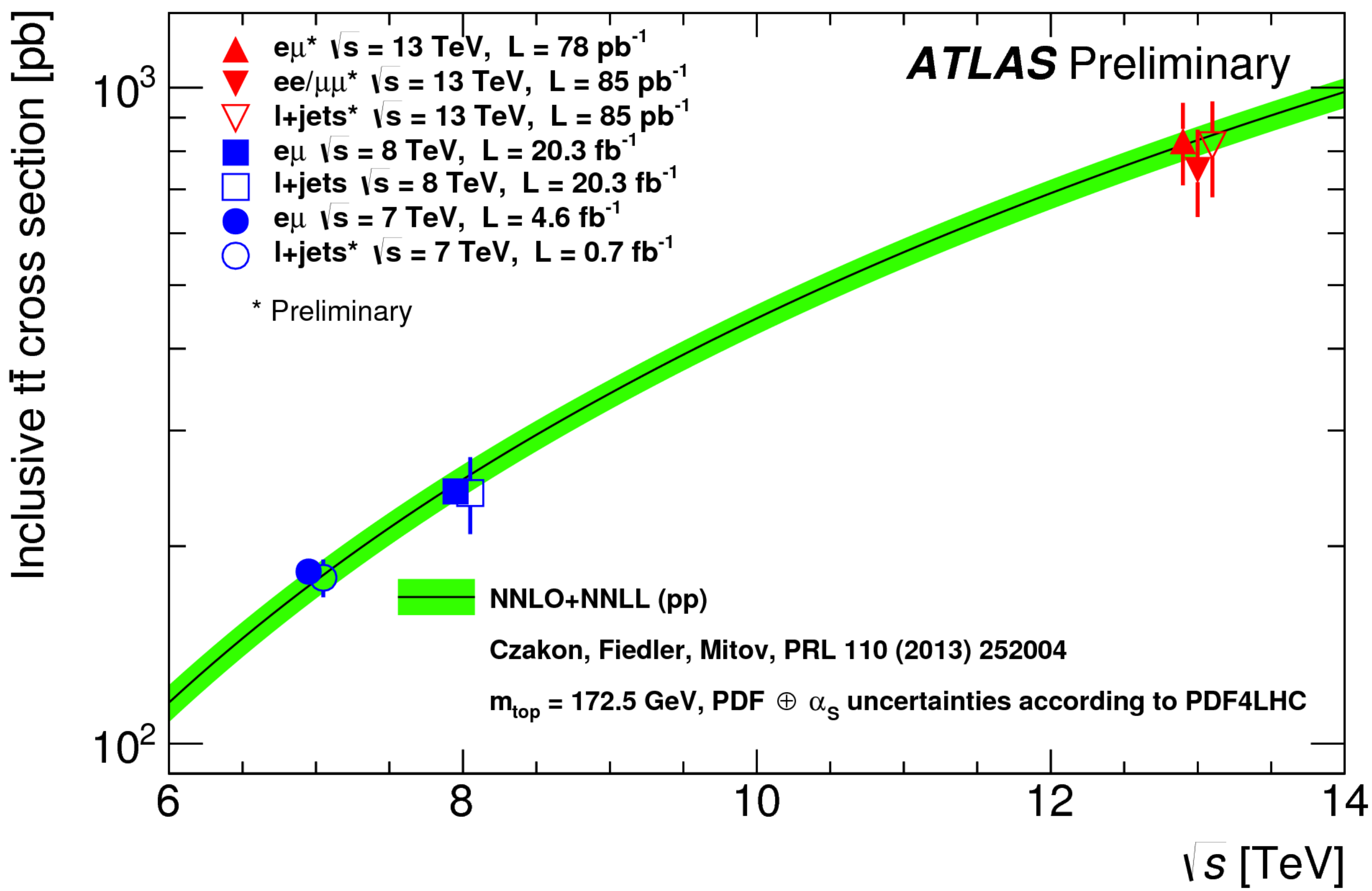
1. Measure number of events for dilepton (ee, eμ, μμ), l+jets (e+jets, μ+jets) and lτ channels and correct full phase space
2. σ, B_j, B_l and B_τ obtained from combined dilepton, l+jets and lτ measurement
3. B_e and B_μ obtained with χ^2 method using ee, μμ, e+jets, μ+jets results

Result

	Measured (top quark)	SM	LEP (W)
$\sigma_{t\bar{t}}$	178 ± 3 (stat.) ± 16 (syst.) ± 3 (lumi.) pb	$177.3 \pm 9.0^{+4.6}_{-6.0}$ pb	
B_j	66.5 ± 0.4 (stat.) ± 1.3 (syst.)	67.51±0.07	67.48±0.28
B_e	13.3 ± 0.4 (stat.) ± 0.5 (syst.)	12.72±0.01	12.70±0.20
B_μ	13.4 ± 0.3 (stat.) ± 0.5 (syst.)	12.72±0.01	12.60±0.18
B_τ	7.0 ± 0.3 (stat.) ± 0.5 (syst.)	7.05±0.01	7.20±0.13

arXiv: 1506.05074

Top pair cross section @ 7, 8 and 13 TeV



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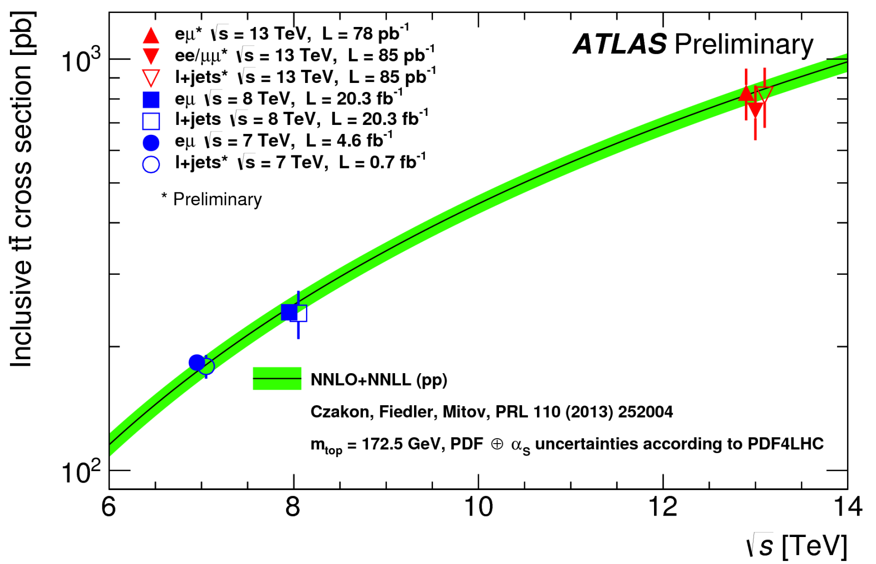
Summary

ATLAS performed inclusive cross-section measurements of $t\bar{t}$ production at 7, 8 and 13 TeV and in a wide variety of measurement channels

With 3.9% the experimental accuracy has reached the precision of the theoretical calculations

Measurements at 7, 8 and 13 TeV are in agreement with NNLO +NNLL calculations

LHC run 2 promises many more interesting results from ATLAS



BACKUP

eμ + b-jets @ 13 TeV: Systematic Uncertainties

Uncertainty	$\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%)	$\Delta C_b/C_b$ (%)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics			6.0
$t\bar{t}$ NLO modelling	1.9	-0.3	2.2
$t\bar{t}$ hadronisation	-4.0	0.5	4.5
Initial/final state radiation	-1.1	0.1	1.2
Parton distribution functions	1.3	-	1.4
Single-top generator*	-	-	0.5
Single-top/$t\bar{t}$ interference*	-	-	0.1
Single-top Wt cross-section	-	-	0.5
Diboson modelling*	-	-	0.1
Diboson cross-sections	-	-	0.0
Z+jets extrapolation	-	-	0.2
Electron energy scale/resolution	0.2	0.0	0.2
Electron identification	3.6	0.0	4.0
Electron isolation	1.0	-	1.1
Muon momentum scale/resolution	0.0	0.0	0.1
Muon identification	1.1	0.0	1.2
Muon isolation	1.0	-	1.1
Lepton trigger	1.3	0.0	1.3
Jet energy scale	-0.3	0.0	0.3
Jet energy resolution	-0.1	0.0	0.1
b-tagging	-	0.1	0.3
Misidentified leptons	-	-	1.3
Analysis systematics	6.4	0.6	7.3
Integrated luminosity	-	-	10.0
Total uncertainty	6.4	0.6	13.7

Ratio of $t\bar{t}$ and Z cross-sections: Systematic Uncertainties

Uncertainty (%)	$\sigma_{Z\to ee}$	$\sigma_{Z\to\mu\mu}$	$\sigma_{t\bar{t}}$	$R_{t\bar{t}/Z}$
Data statistics	0.5	0.5	6.0	6.0
$t\bar{t}$ NLO modelling	-	-	2.2	2.2
$t\bar{t}$ hadronisation	-	-	4.5	4.5
Initial/final state radiation	-	-	1.2	1.2
Parton distribution functions ($t\bar{t}$, Wt)	-	-	1.4	1.4
Single-top modelling	-	-	0.5	0.5
Single-top/$t\bar{t}$ interference	-	-	0.1	0.1
Single-top Wt cross-section	-	-	0.5	0.5
Diboson modelling	-	-	0.1	0.1
Diboson cross-sections	-	-	0.0	0.0
Z+jets extrapolation	-	-	0.2	0.2
Electron energy scale/resolution	0.2	-	0.2	0.1
Electron identification	3.8	-	3.2	1.3
Electron charge identification	0.8	-	-	0.4
Electron isolation	1.0	-	1.1	1.2
Muon momentum scale/resolution	-	0.1	0.1	0.0
Muon identification	-	0.9	0.5	0.1
Muon isolation	-	0.5	1.1	1.1
Lepton trigger	0.5	1.1	0.8	0.7
Jet energy scale	-	-	0.3	0.3
Jet energy resolution	-	-	0.1	0.1
b-tagging	-	-	0.3	0.3
Misidentified leptons	-	-	1.4	1.4
Pileup modelling	0.9	0.9	-	0.9
Z acceptance	1.5	1.5	-	1.5
Z backgrounds	0.1	0.1	-	0.1
Analysis systematics	4.4	2.3	6.7	6.3
Integrated luminosity	9.0	9.0	10.0	1.0
Total uncertainty	10.0	9.3	13.5	8.8

eμ + b-jets @ 7/8 TeV: Systematic Uncertainties

$\sqrt{s}$ Uncertainty (inclusive $\sigma_{t\bar{t}}$)	7 TeV $\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%)	7 TeV $\Delta C_b/C_b$ (%)	7 TeV $\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)	8 TeV $\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%)	8 TeV $\Delta C_b/C_b$ (%)	8 TeV $\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics			1.69			0.71
$t\bar{t}$ modelling	0.71	−0.72	1.43	0.65	−0.57	1.22
Parton distribution functions	1.03	-	1.04	1.12	-	1.13
QCD scale choice	0.30	-	0.30	0.30	-	0.30
Single-top modelling	-	-	0.34	-	-	0.42
Single-top/$t\bar{t}$ interference	-	-	0.22	-	-	0.15
Single-top Wt cross-section	-	-	0.72	-	-	0.69
Diboson modelling	-	-	0.12	-	-	0.13
Diboson cross-sections	-	-	0.03	-	-	0.03
Z+jets extrapolation	-	-	0.05	-	-	0.02
Electron energy scale/resolution	0.19	−0.00	0.22	0.46	0.02	0.51
Electron identification	0.12	0.00	0.13	0.36	0.00	0.41
Muon momentum scale/resolution	0.12	0.00	0.14	0.01	0.01	0.02
Muon identification	0.27	0.00	0.30	0.38	0.00	0.42
Lepton isolation	0.74	-	0.74	0.37	-	0.37
Lepton trigger	0.15	−0.02	0.19	0.15	0.00	0.16
Jet energy scale	0.22	0.06	0.27	0.47	0.07	0.52
Jet energy resolution	−0.16	0.08	0.30	−0.36	0.05	0.51
Jet reconstruction/vertex fraction	0.00	0.00	0.06	0.01	0.01	0.03
b-tagging	-	0.18	0.41	-	0.14	0.40
Misidentified leptons	-	-	0.41	-	-	0.34
Analysis systematics ($\sigma_{t\bar{t}}$)	1.56	0.75	2.27	1.66	0.59	2.26
Integrated luminosity	-	-	1.98	-	-	3.10
LHC beam energy	-	-	1.79	-	-	1.72
Total uncertainty ($\sigma_{t\bar{t}}$)	1.56	0.75	3.89	1.66	0.59	4.27

Uncertainty (fiducial $\sigma_{t\bar{t}}^{\text{fid}}$)	$\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%)	$\Delta C_b/C_b$ (%)	$\Delta\sigma_{t\bar{t}}^{\text{fid}}/\sigma_{t\bar{t}}^{\text{fid}}$ (%)	$\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%)	$\Delta C_b/C_b$ (%)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
$t\bar{t}$ modelling	0.84	−0.72	1.56	0.74	−0.57	1.31
Parton distribution functions	0.35	-	0.38	0.23	-	0.28
QCD scale choice	0.00	-	0.00	0.00	-	0.00
Other uncertainties (as above)	0.88	0.21	1.40	1.00	0.17	1.50
Analysis systematics ($\sigma_{t\bar{t}}^{\text{fid}}$)	1.27	0.75	2.13	1.27	0.59	2.01
Total uncertainty ($\sigma_{t\bar{t}}^{\text{fid}}$)	1.27	0.75	3.81	1.27	0.59	4.14

ee/μμ + b-jets @ 13 TeV: Systematic Uncertainties

Uncertainty	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics	7.6
$t\bar{t}$ NLO modelling	2.6
$t\bar{t}$ hadronisation	7.9
Initial/final state radiation	1.5
PDF	3.7
Single-top Wt cross-section	0.6
Single-top interference	<0.05
Diboson cross-section	0.4
Z+jets → $ee/\mu\mu$ modelling	1.5
Z+jets → $\tau\tau$ modelling	0.1
Electron energy scale	0.3
Electron energy resolution	0.2
Electron identification	3.6
Electron trigger	0.2
Electron isolation	1.0
Muon momentum scale	0.1
Muon momentum resolution	1.1
Muon identification	0.8
Muon trigger	0.6
Muon isolation	1.0
Jet energy scale	1.2
Jet energy resolution	0.2
b-tagging efficiency	0.8
Missing transverse momentum	0.3
NP & fakes	1.5
Analysis systematic	11
Integrated luminosity	10
Total uncertainty	16

l+jets @ 13 TeV: Systematic Uncertainties

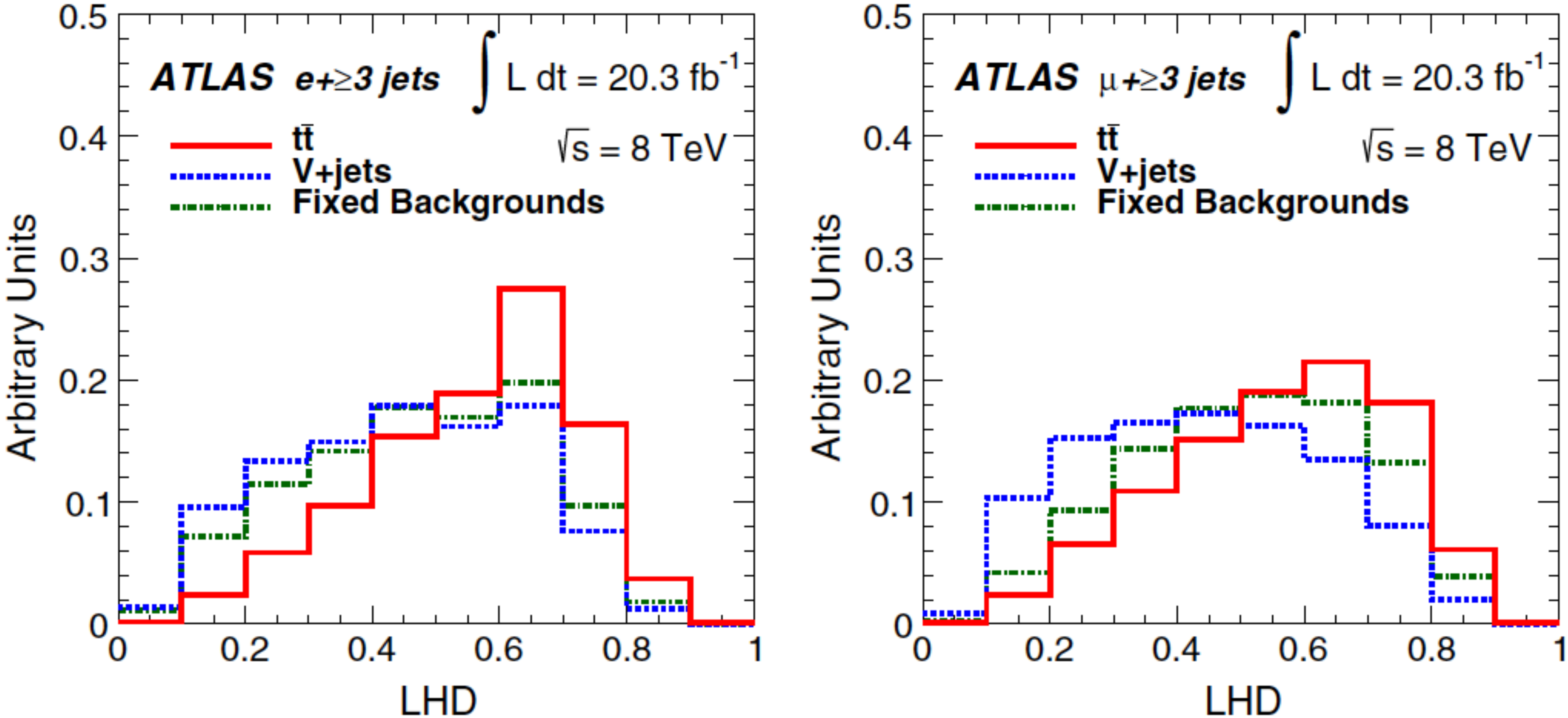
Uncertainty	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics	1.5
$t\bar{t}$ NLO modelling	0.6
$t\bar{t}$ hadronisation	4.1
Initial/final state radiation	1.9
PDF	0.7
Single top cross-section	0.3
Diboson cross-sections	0.2
Z+jets cross-section	1.0
W+jets method statistics	1.7
W+jets modelling	1.0
Electron energy scale/resolution	0.1
Electron identification	2.1
Electron isolation	0.4
Electron trigger	2.8
Muon momentum scale/resolution	0.1
Muon identification	0.2
Muon isolation	0.3
Muon trigger	1.2
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale/resolution	0.4
Jet energy scale	${}^{+10}_{-8}$
Jet energy resolution	0.6
b-tagging	4.1
NP & fakes	1.8
Analysis systematics	${}^{+13}_{-11}$
Integrated luminosity	${}^{+11}_{-9}$
Total uncertainty	${}^{+17}_{-14}$

13 TeV Measurements

Channel	Cross-section measurement
ee	824 ± 88 (stat) ± 91 (syst) ± 82 (lumi) pb
$\mu\mu$	683 ± 74 (stat) ± 76 (syst) ± 68 (lumi) pb
ee and $\mu\mu$ combined	749 ± 57 (stat) ± 79 (syst) ± 74 (lumi) pb
e+jets	775 ± 17 (stat) ± 123 (syst) ± 85 (lumi) pb
μ+jets	862 ± 18 (stat) ± 93 (syst) ± 94 (lumi) pb
e+jets and μ+jets combined	817 ± 13 (stat) ± 103 (syst) ± 88 (lumi) pb

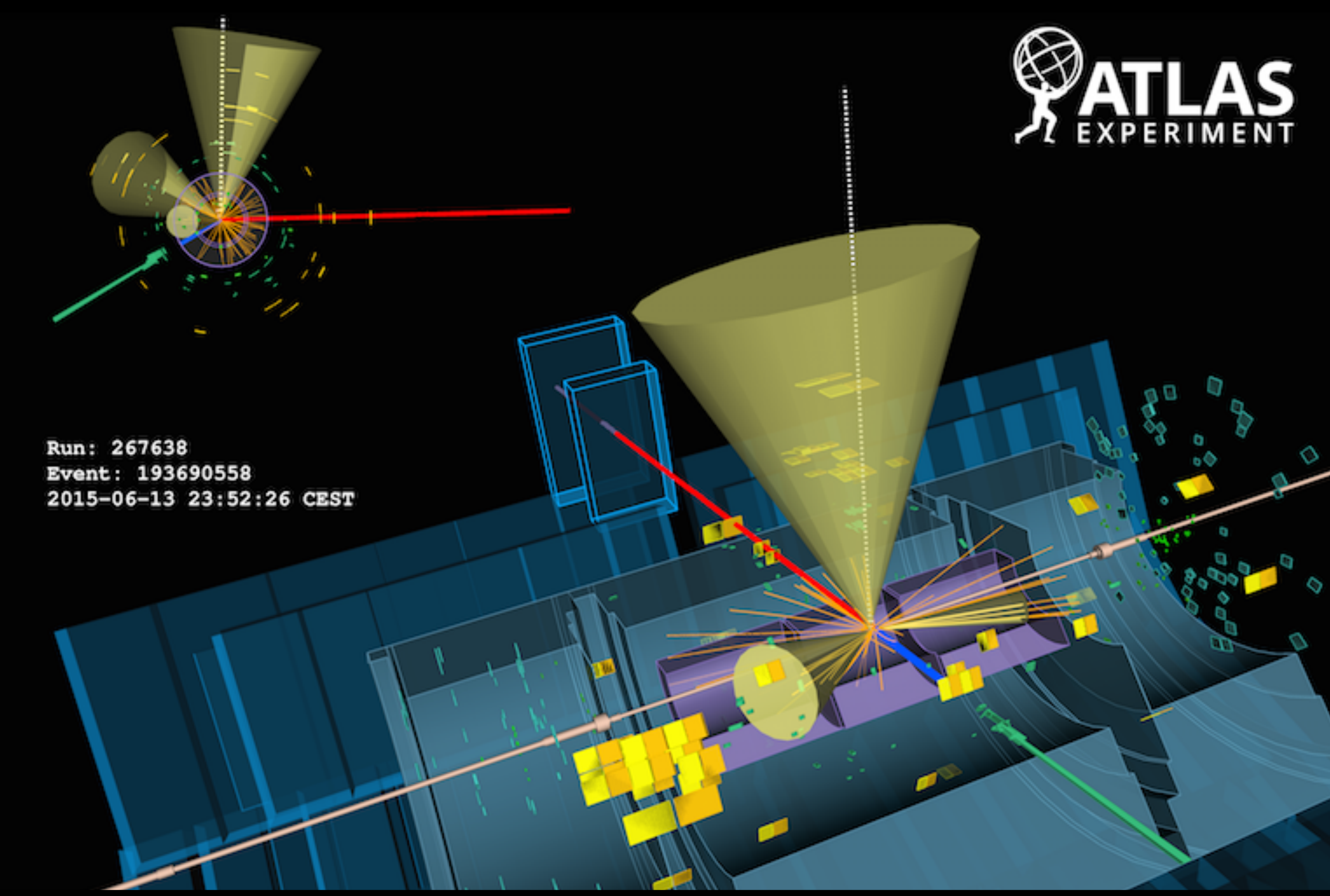
eμ: $\boxed{\sigma_{t\bar{t}} = 829 \pm 50\ (\text{stat})\ \pm 56\ (\text{syst})\ \pm 83\ (\text{lumi})\ \text{pb}}$

l+jets @ 8 TeV: Template Shapes



l+jets @ 8 TeV: Systematic Uncertainties

Uncertainty on inclusive $\sigma_{t\bar{t}}$	e + jets	μ + jets	ℓ + jets
Lepton reconstruction	+2.7 −2.6	+2.1 −1.9	+1.7 −1.6
Jet reconstruction and $E_{\mathrm{T}}^{\mathrm{miss}}$	+3.3 −3.9	+2.6 −3.2	+2.8 −3.4
b tagging	+2.1 −1.9	+2.2 −1.9	+2.1 −1.9
Backgrounds	+2.8 −3.0	+1.8 −2.1	+1.7 −2.1
Monte Carlo generator	−2.2 +2.2	−3.3 +3.3	−2.7 +2.7
Parton shower and fragmentation	+2.0 −2.0	+2.6 −2.6	+2.3 −2.3
Initial- and final-state radiation	−4.1 +4.1	−1.8 +1.8	−3.0 +3.0
Parton distribution functions	+6.2 −6.0	+5.6 −5.9	+5.9 −5.9
Total	+9.7 −9.8	+8.4 −8.7	+8.6 −8.9
Uncertainty on fiducial $\sigma_{t\bar{t}}$	e + jets	μ + jets	ℓ + jets
Monte Carlo generator	−2.1 +2.1	−3.5 +3.5	−2.8 −2.8
Parton shower and fragmentation	−2.6 +2.6	−3.1 +3.1	−2.9 +2.9
Initial- and final-state radiation	+0.4 −0.4	+0.2 −0.2	+0.3 −0.3
Total	+8.9 −9.0	+8.5 −8.8	+8.3 −8.6


ATLAS
EXPERIMENT
Run: 267638
Event: 193690558
2015-06-13 23:52:26 CEST

Display of a ttbar candidate event from proton-proton collisions recorded by ATLAS with LHC stable beams at a collision energy of 13 TeV. The red line shows the path of a muon with transverse momentum around 140 GeV through the detector. The green line shows the path of an electron with transverse momentum around 170 GeV through the detector. The green and yellow bars indicate energy deposits in the liquid argon and scintillating-tile calorimeters, from these deposits 3 jets are identified with transverse momenta between 30 and 80 GeV. Two of the jets are identified as having originated from b-quarks. Tracks reconstructed from hits in the inner tracking detector are shown as arcs curving in the solenoidal magnetic field.