First Top results at 13 TeV — ATLAS

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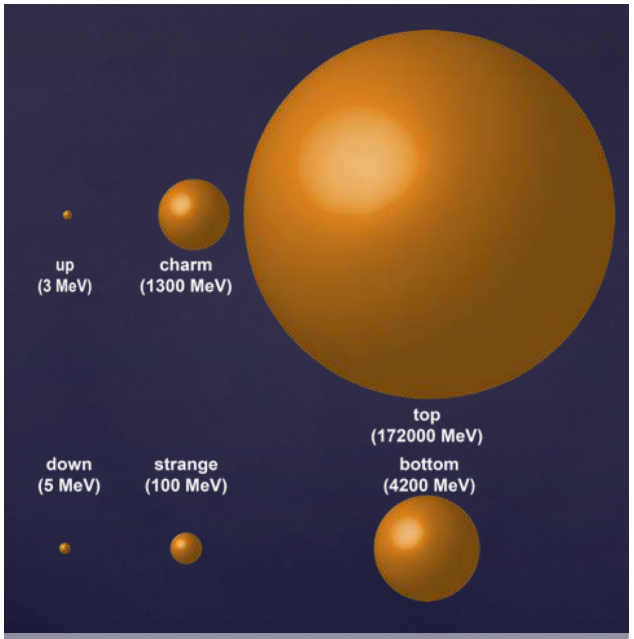
Brookhaven Forum 2015, BNL 2015-10-07

On behalf of the ATLAS Collaboration

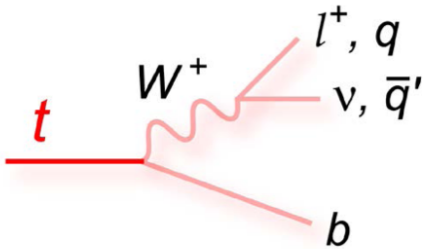
Why do we still care about top

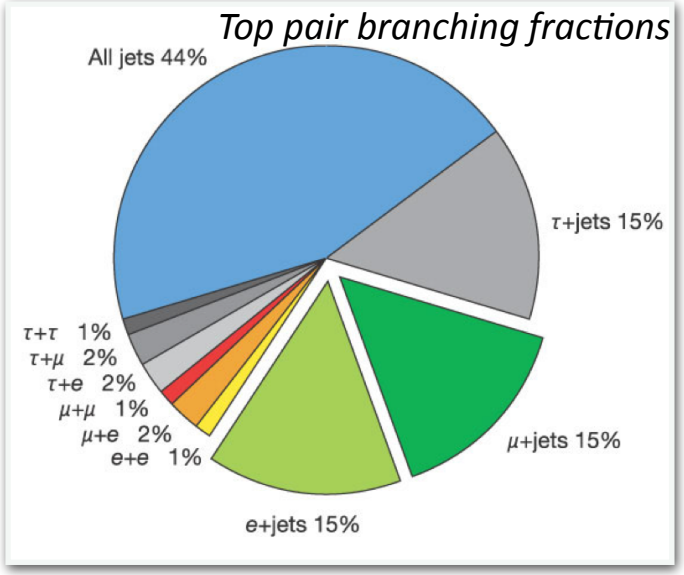
- **Many top properties experimentally confirmed** (m_T, charge, spin, …..)
  - LHC is a "top factory"
- **Cross-section increased by factor ~3.5**
  - 8->13 TeV
- **Top pair cross section measurements are**
  - Excellent precision tests of Standard Model
    - Only place to study the properties of a bare quark (Lifetime<hadronisation)
    - Sensitive to QCD effects, PDF, top quark mass, …
  - Probe for new physics
    - First place a new particle could be observed
    - Particularly if new particle couples to mass
    - Top is a background to many other searches



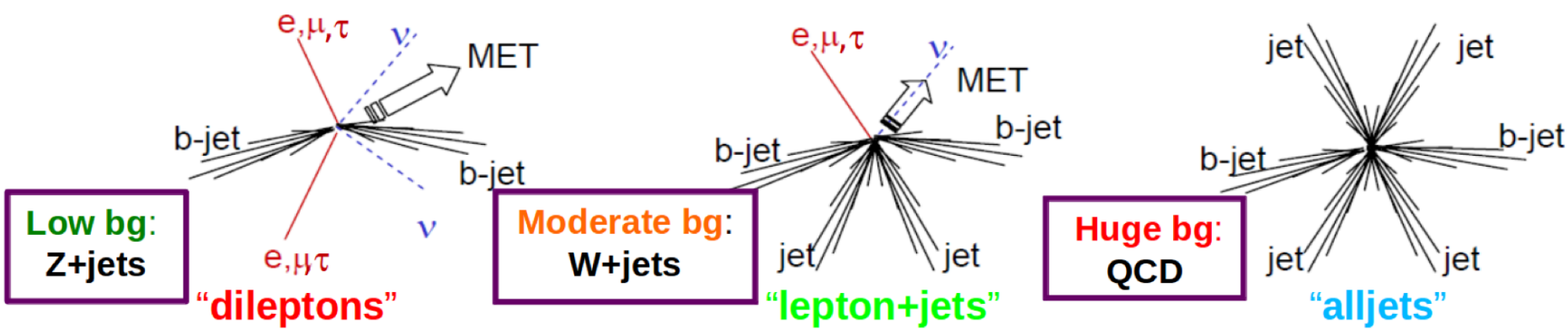
Top quark production — decay

- Pair production in *gg* fusion (87%) and qq interaction (13%)
- Top pair decays almost exclusively to Wb
- Final state topology depends on W decay:
  - Dilepton (e/μ) ~5%
  - L+jets (e/μ) ~30%
  - All jets, τ-lepton channels





Final state objects:



Top quark production — decay

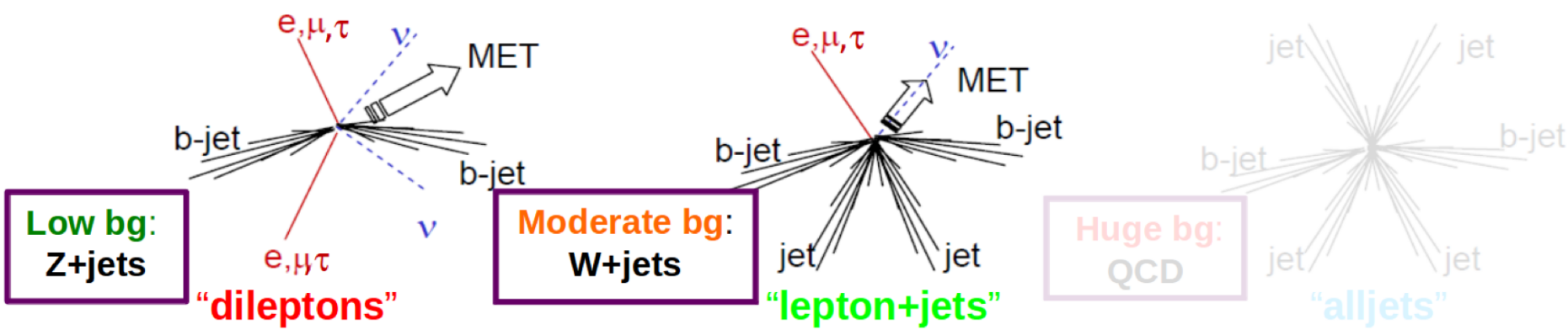
First inclusive top pair production measurements at 13 TeV in ATLAS:

- Dilepton eμ-channel
  - Ratio of $t\bar{t}/Z$ cross-sections
- Dilepton ee/μμ-channels
- L+jets (e/μ)-channel

ATLAS-CONF-2015-033

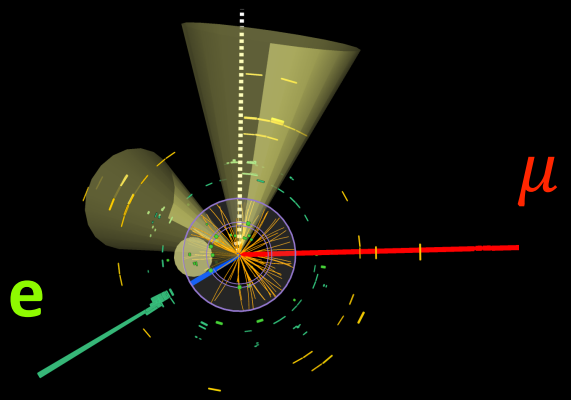
ATLAS-CONF-2015-049

Final state objects:

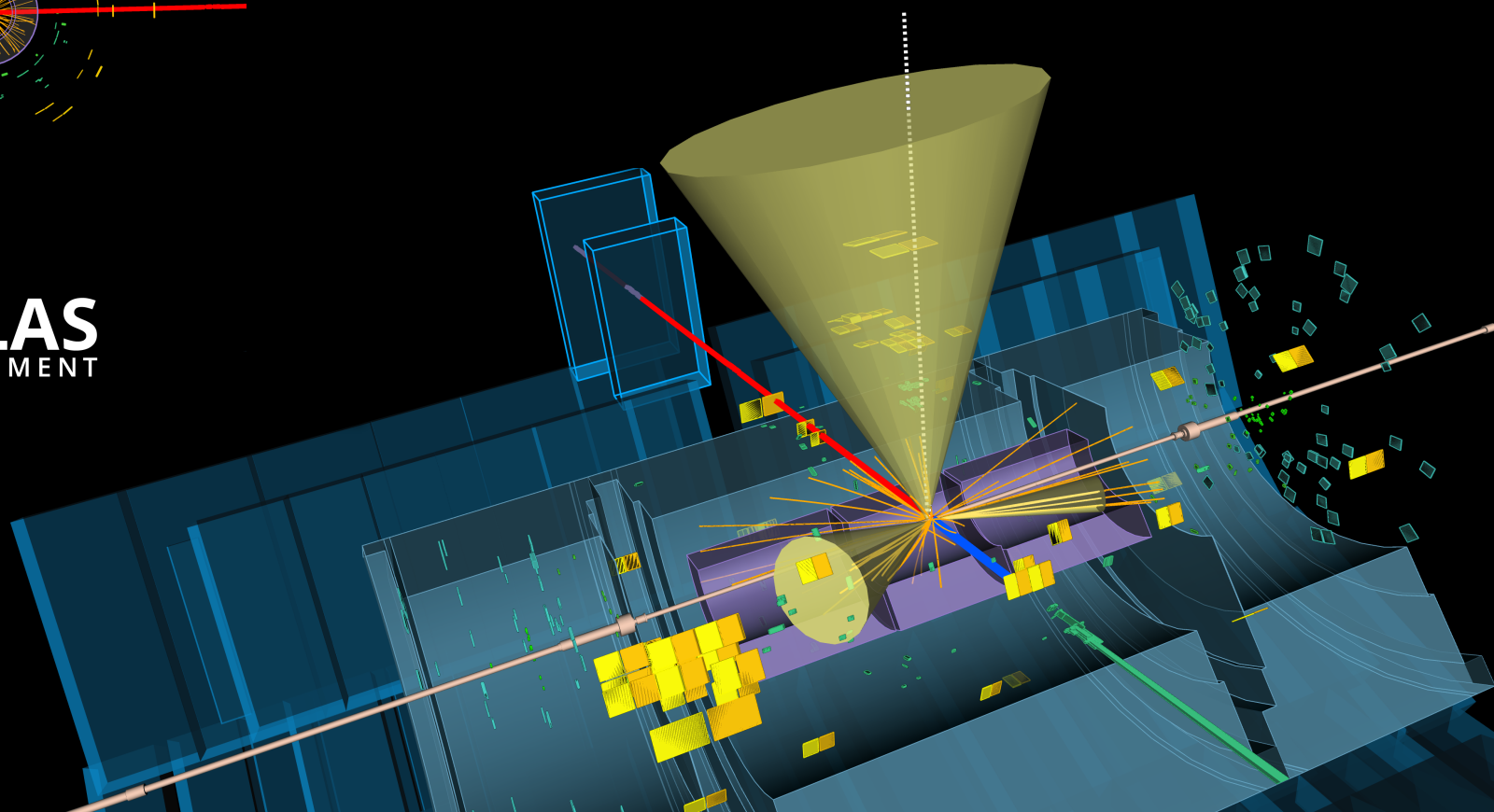


Motivation — new data

3 jets (2 b-jets)
30 to 80 GeV



13 TeV $t\bar{t}$+jets candidate event
(Dilepton channel)



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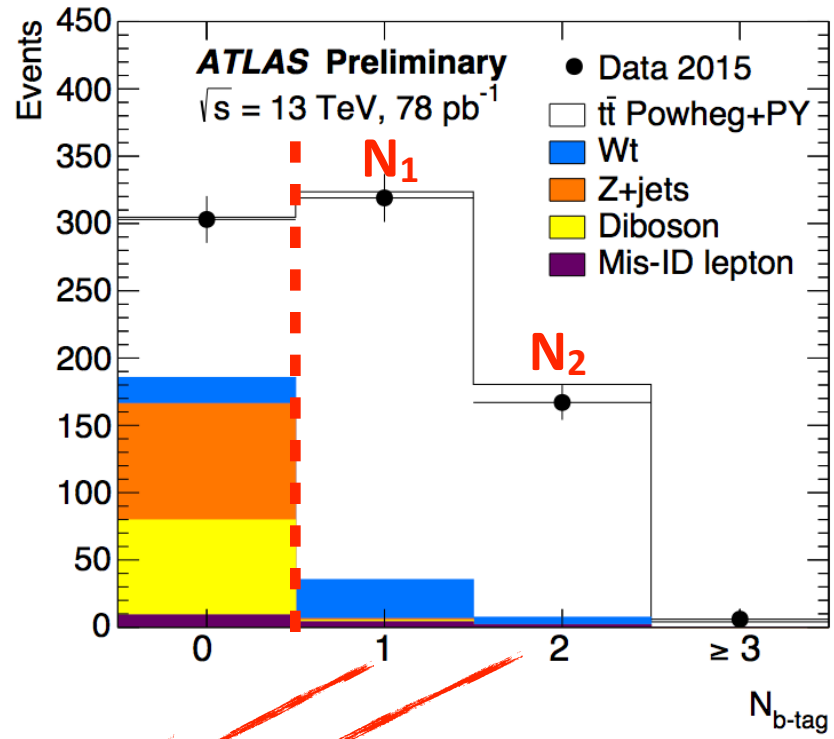
eμ+b-jets @13TeV — method

Analysis method:

- 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



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

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

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

78/fb eμ+b-jets @13TeV — event yields

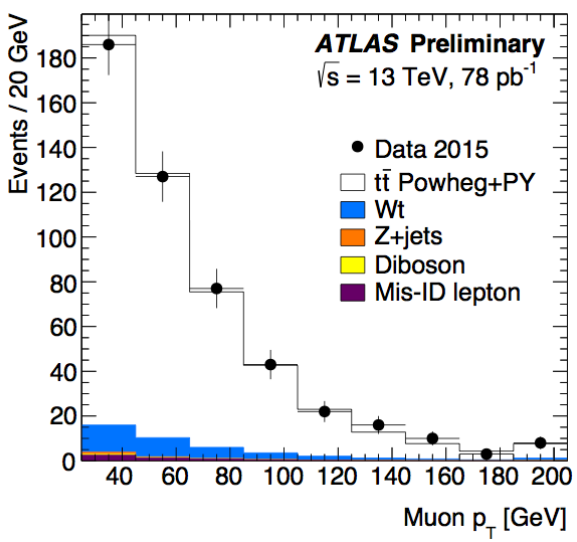
Background measured from simulation:

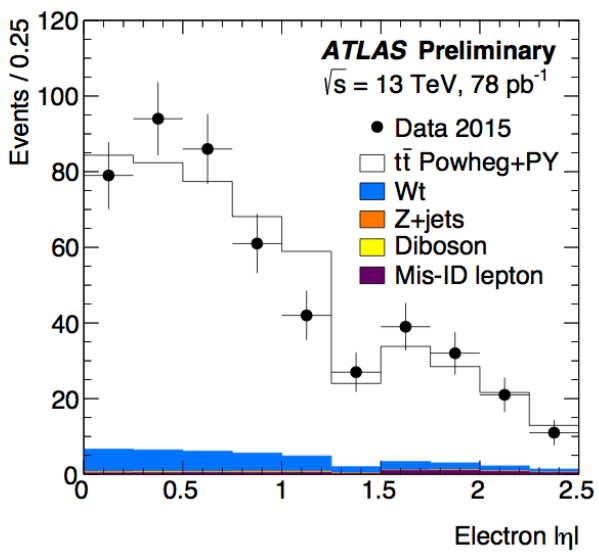
- Single top Wt
- Z+jets
- Diboson

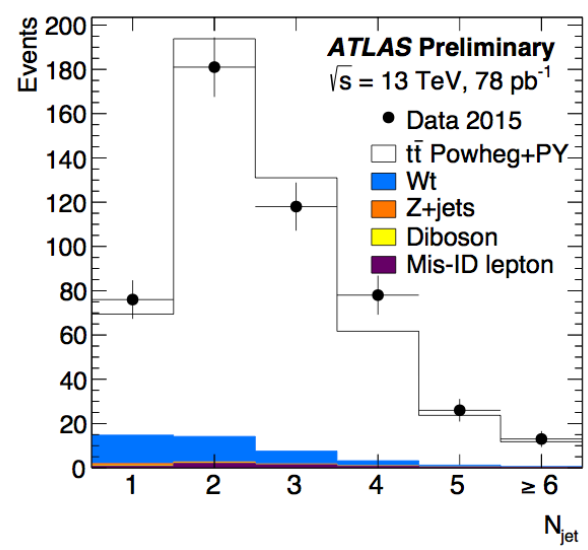
Event counts	N_1	N_2
Data	319	167
Wt single top	29.0 ± 3.8	5.6 ± 2.0
Dibosons	1.1 ± 0.2	0.0 ± 0.0
$Z(\rightarrow \tau\tau \rightarrow e\mu)$+jets	1.3 ± 0.7	0.1 ± 0.1
Misidentified leptons	6.0 ± 3.9	2.8 ± 2.9
Total background	37.3 ± 5.5	8.5 ± 3.5

Misidentified lepton events (MisID)

- data-driven from same-sign events







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eμ+b-jets @13TeV — results

Uncertainties

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

Preliminary measurement

Comparison of Powheg+Herwig++ and Powheg+Pythia

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

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

Results

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

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

Czakon, Fiedler, Mitov PRL 110 252004

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Ratio of tt and Z cross-sections

Highest uncertainty from luminosity cancels!

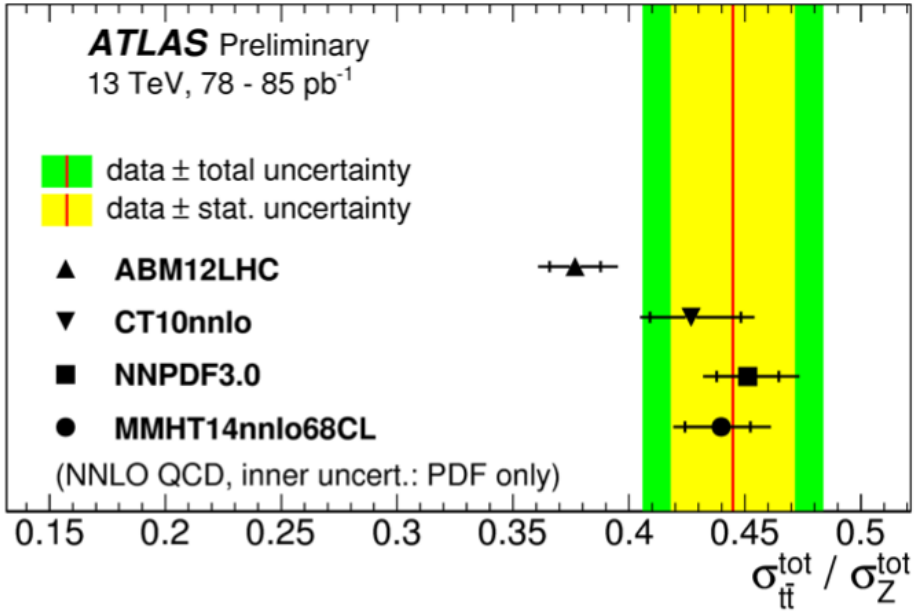
Uncertainty	Z→ee	Z→μμ	$t\bar{t}$	Ratio
Data Stat.	0.5%	0.5%	6.0%	6.0%
Analysis Syst.	4.4%	2.3%	6.7%	6.3%
Luminosity	9.0%	9.0%	10.0%	1.0%
Total	**10.0%**	**9.3%**	**13.5%**	**8.8%**

Mostly due to cancellation of e/μ identification uncertainty

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

$$= 0.445 \pm 0.027\ (\text{stat}) \pm 0.028\ (\text{syst})$$

- Ratio provides constraints on the gluon to sea-quark distributions ratio
- PDF uncertainties are anti-correlated for the two observables.
  - $pp \to \gamma^*/Z + X$ sensitive to *qq*-PDF
  - $pp \to t\bar{t} + X$ sensitive to *g*-PDF



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ee/μμ+b-jets @13TeV

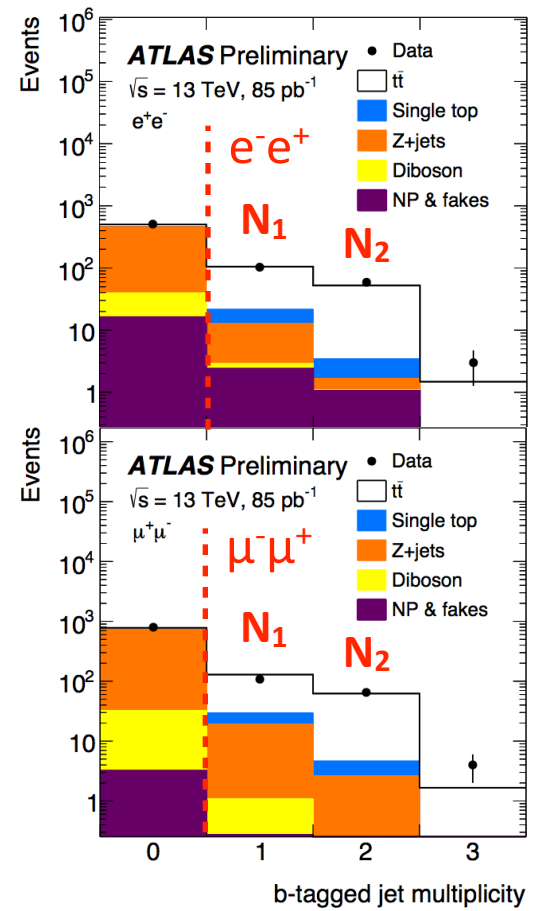
Analysis method:

- Select opposite-sign ee/μμ
- $60 < m_{ll} < 81$ GeV or $m_{ll} > 101$ GeV
- $E_T^{miss} > 30$ GeV
- b-tagging using multivariate discriminator (MV2c20) with 70% efficiency
- Obtain best $\sigma_{t\bar{t}}$, ϵ_b^{ee} and $\epsilon_b^{\mu\mu}$ using maximum likelihood fit

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

Event yield estimation:

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



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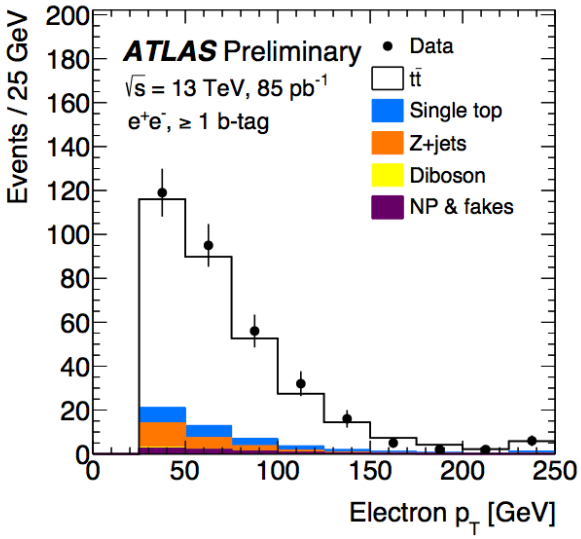
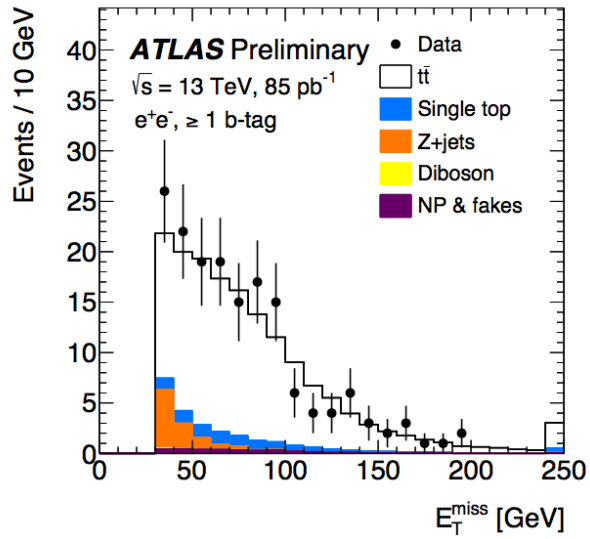
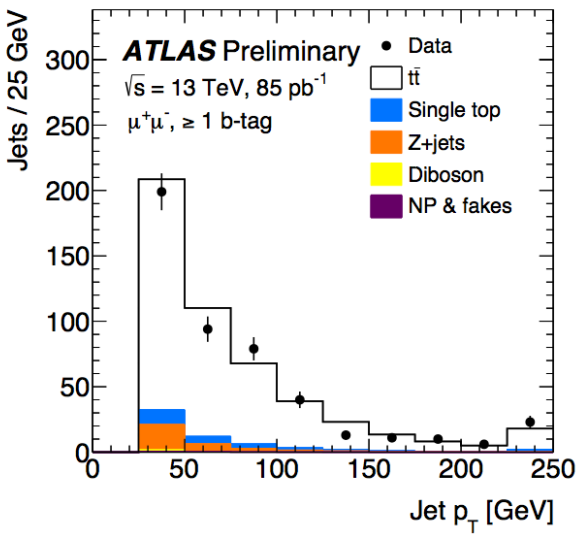
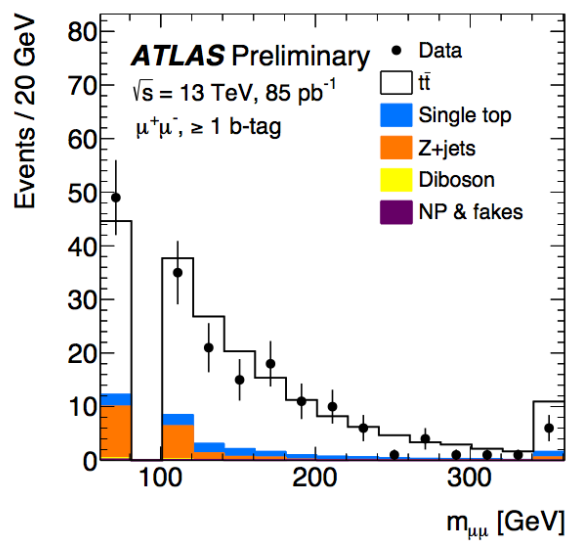
ee/μμ+b-jets @13TeV









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ee/μμ+b-jets @13TeV — Results

Result

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

8% 11% 10%

Theory NNLO+NNLL prediction

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

For comparison: eμ + b-jets

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

6% 7% 10%

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L+jets @13TeV

Event selection:

- Select events with single lepton 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 sample

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 @13TeV — W-bg estimation

- W background normalisation only: (shape is taken from MC)

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.

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

Correct for single-top events and divide by charge asymmetry

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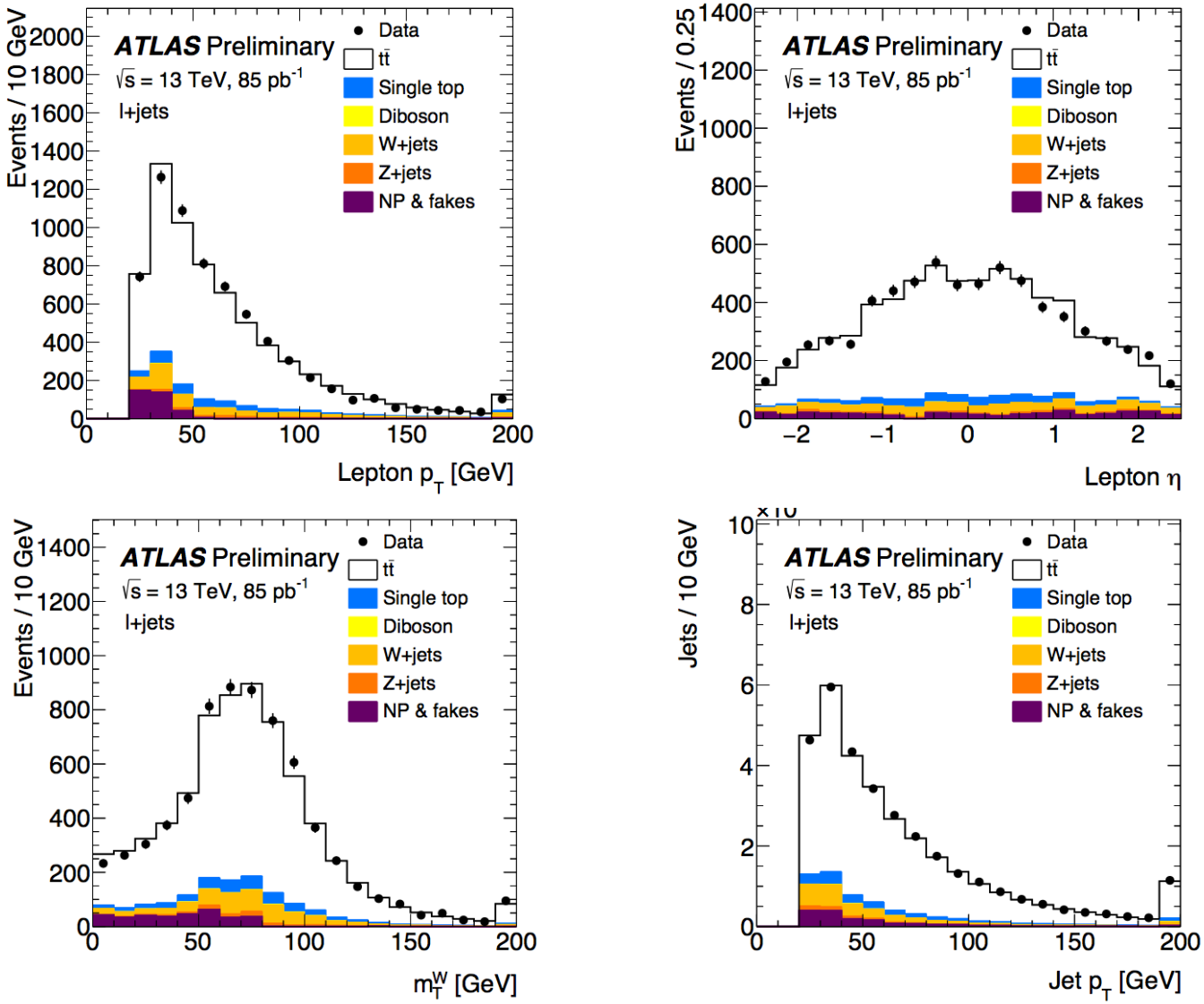
L+jets @13TeV



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L+jets @13TeV — Results

Result

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

2% 13% 11% 17%

Theory NNLO+NNLL prediction

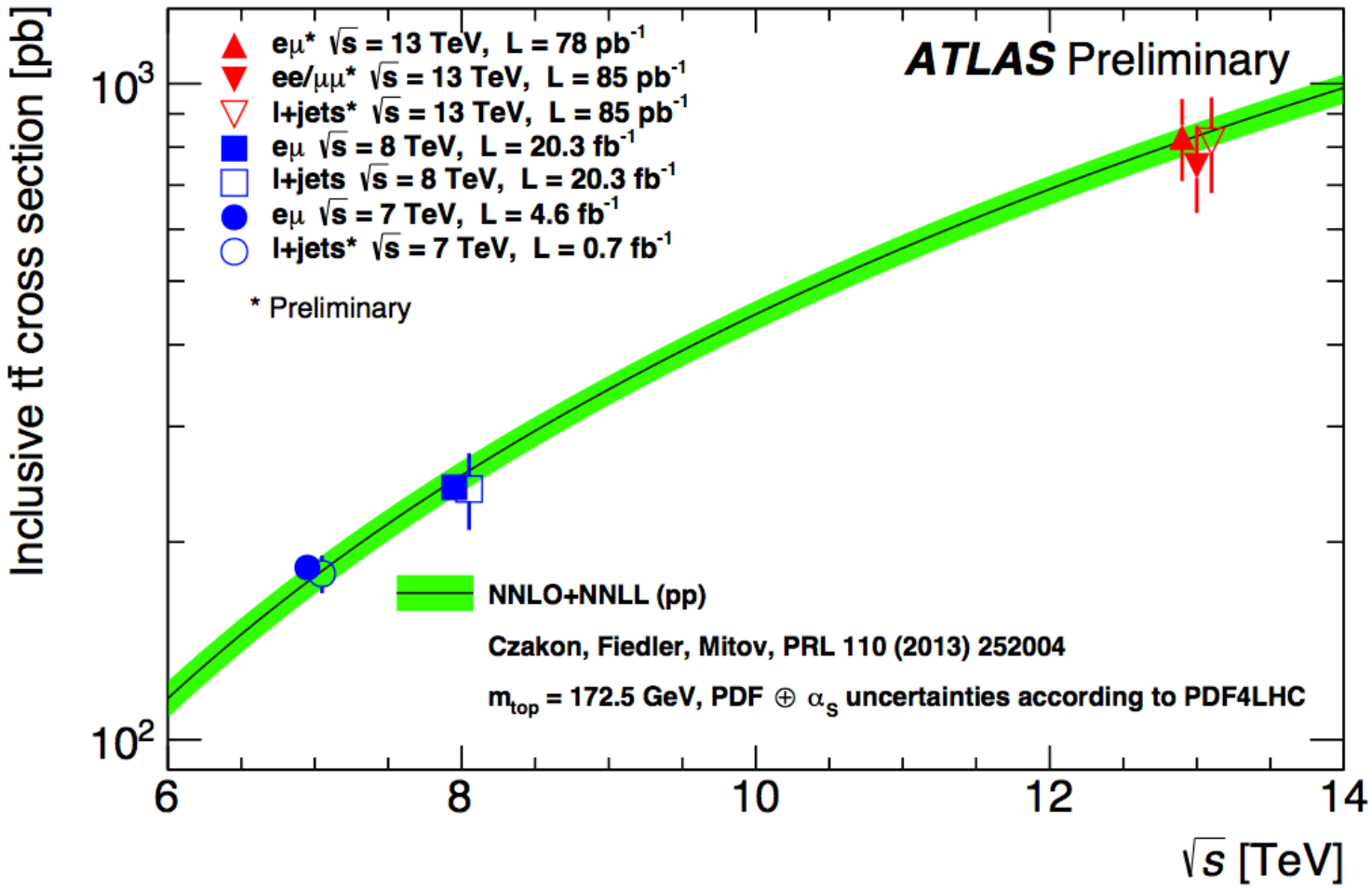
832^{+40}_{-46} pb at $m_t = 172.5$ GeV

For comparison: eμ + b-jets

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

6% 7% 10% 14%

Top pair cross-section @ (7,8) 13TeV



Summary

- ATLAS performed inclusive cross-section measurements of tt production at 13 TeV in the dilepton and l+jets channels
- First preliminary 13TeV results use 78-85fb^{-1}
  - Total uncertainty is between 15-20%
  - Not yet at same impressive precision achieved in Run1 (3.9%)
    - At the level of the theoretical calculations
- Measurements are in agreement with NNLO+NNLL calculations
- This was just a first glimpse into Run2 data …..

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

Additional material

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

eμ+b-jets @13TeV — 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

ee/μμ+b-jets & L+jets @13TeV — systematic uncertainties

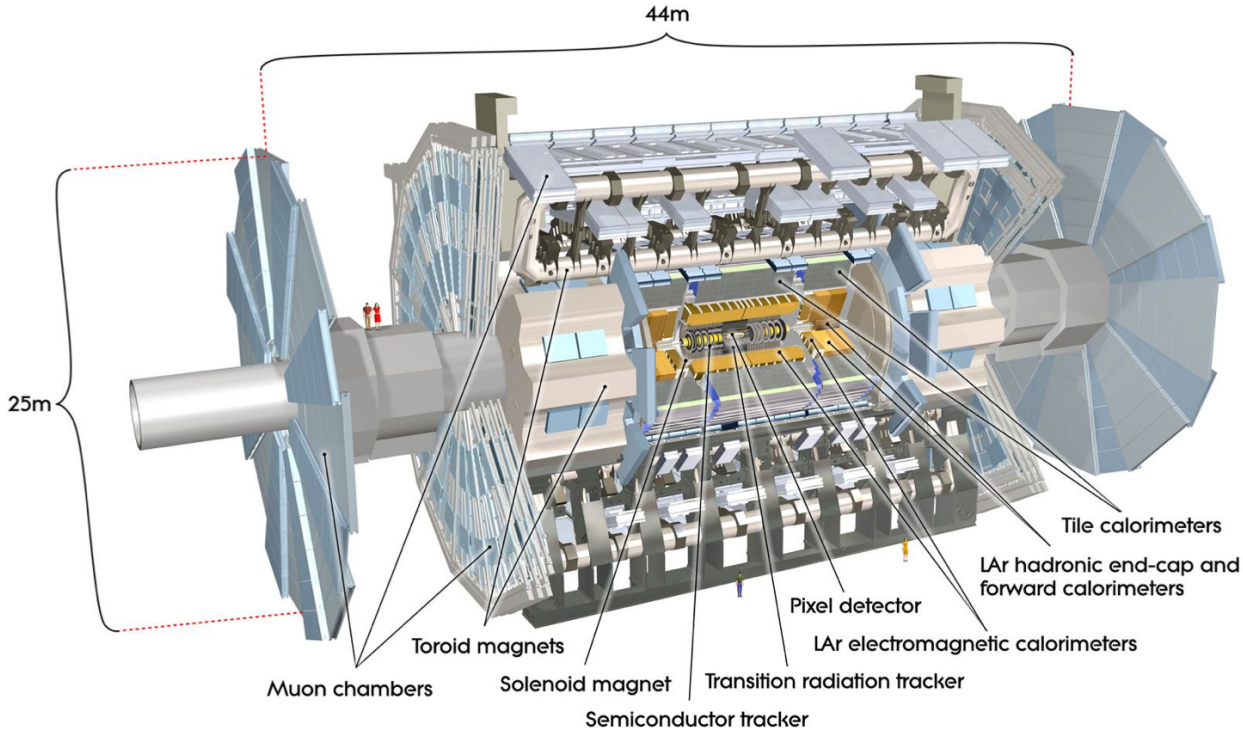
ee/μμ+b-jets

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 $\rightarrow ee/\mu\mu$ modelling	1.5
Z+jets $\rightarrow \tau\tau$ 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 systematics	11
Integrated luminosity	10
Total uncertainty	16

L+jets

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	$^{+17}_{-14}$

The ATLAS detector



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