Single Top quark production cross section measurements using the ATLAS detector

Muhammad Alhroob

On Behalf of the ATLAS Collaboration

EPS Conference on High Energy Physics

05.07.2017 - 12.07.2017

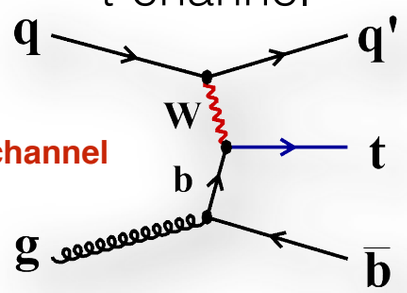
Venice/Italy

Outline

- Introduction
- t-channel results at 8 TeV using 20.3 fb^{-1}:
  - fiducial and total cross section
  - $R_t \equiv \sigma(tq)/\sigma(\bar{t}q)$
  - differential cross section
- t-channel results at 13 TeV using 3.2 fb^{-1}:
  - total cross section
  - $R_t \equiv \sigma(tq)/\sigma(\bar{t}q)$
- Total tW cross section at 8 TeV using 20.3 fb^{-1}
- Total tW cross section at 13 TeV using 3.2 fb^{-1}
- tZq results at 13 TeV using 36.1 fb^{-1}
- Summary

Introduction

t-channel

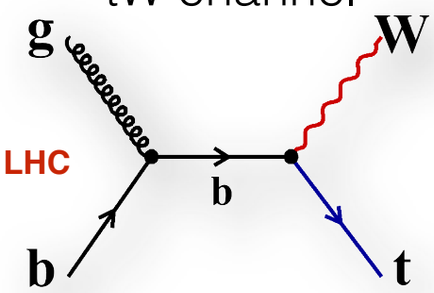


Golden channel

$\sigma(8\ \mathrm{TeV}) = 87.7^{+3.4}_{-1.9}\mathrm{pb}$

$\sigma(13\ \mathrm{TeV}) = 217.0^{+9.1}_{-7.7}\mathrm{pb}$

tW channel

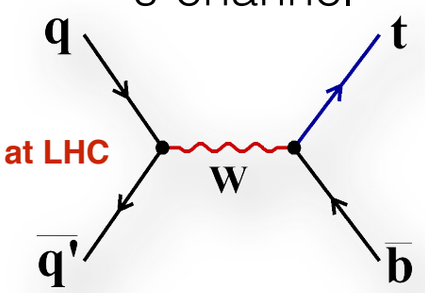


Observed at LHC

$\sigma(8\ \mathrm{TeV}) = 22.4 \pm 1.5\mathrm{pb}$

$\sigma(13\ \mathrm{TeV}) = 71.7 \pm 3.8\mathrm{pb}$

s-channel



Challenging at LHC

$\sigma(8\ \mathrm{TeV}) = 5.6 \pm 0.2\mathrm{pb}$

$\sigma(13\ \mathrm{TeV}) = 10.3 \pm 0.4\mathrm{pb}$

- Tests of SM prediction:
  - cross section $\propto |V_{tb}|^2$
  - test CKM matrix unitarity
  - can constrain PDFs
- Probing new physics
  - charged heavy W', H^+
  - access anomalous coupling
- Help tuning MC generators (unfolded distributions)

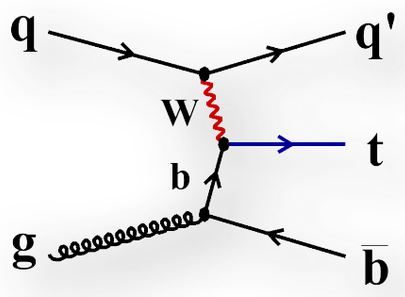
- Top is the heaviest particle known
- Life time ~ 10^{-25} s:
  - no hadronisation, study the bare quark
- Decays exclusively to Wb

- Golden t-channel:
  - has the largest cross section
  - has the largest S/B

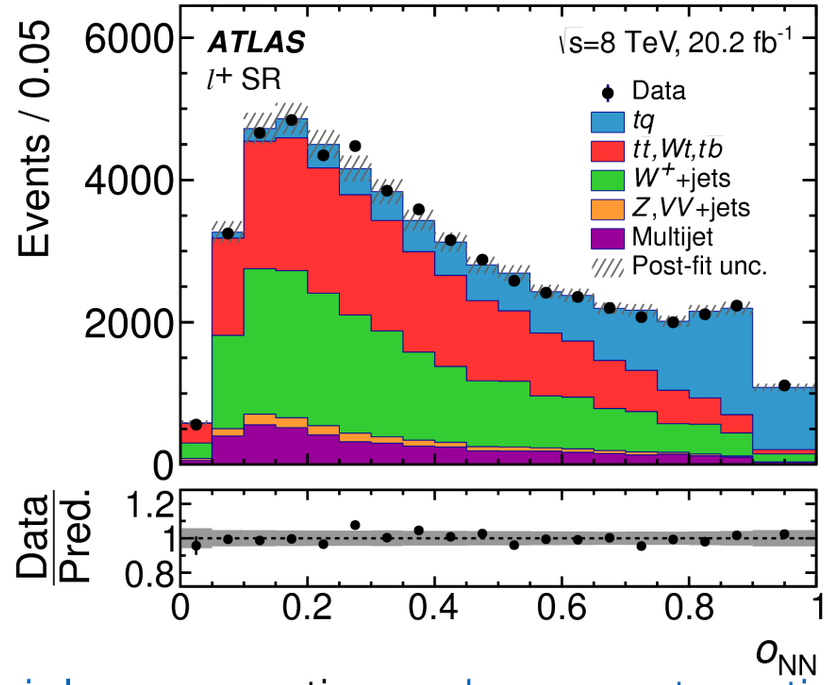
  - discovered at Tevatron 2009
  - observed at LHC 2011

t-channel at 8 TeV: fiducial

- Signatures:
  - 1 isolated lepton
  - E_T^{miss} from the neutrino
  - 1 high P_T forward jet $|\eta|<4.5$
  - 1 high P_T b-tagged jet $|\eta|<2.5$
- Dominant backgrounds
  - $t\bar{t}$, W+jets and multi-jets
- Neural network to enhance S/B
- Separate cross section determined for l^+ and l^- events
- Binned maximum likelihood fit to extract cross section



arXiv:1702.02859v2



- Fiducial cross section reduces systematic uncertainties of MC generators
- Fiducial volume define using stable particles selected with cuts very close to the final selection

$$\sigma_{\text{fid}} = \frac{N_{\text{fid}}}{N_{\text{sel}}} \cdot \frac{\hat{\nu}}{L_{\text{int}}}$$

← **Measured number of signal events**

$$\sigma_{\text{fid.}}(tq) = 9.78 \pm 0.57 \text{ pb}$$

$$\sigma_{\text{fid.}}(\bar{t}q) = 5.77 \pm 0.45 \text{ pb}$$

- **Uncertainties**: systematically dominated: jet energy scale, NLO matching choice and lepton reconstruction

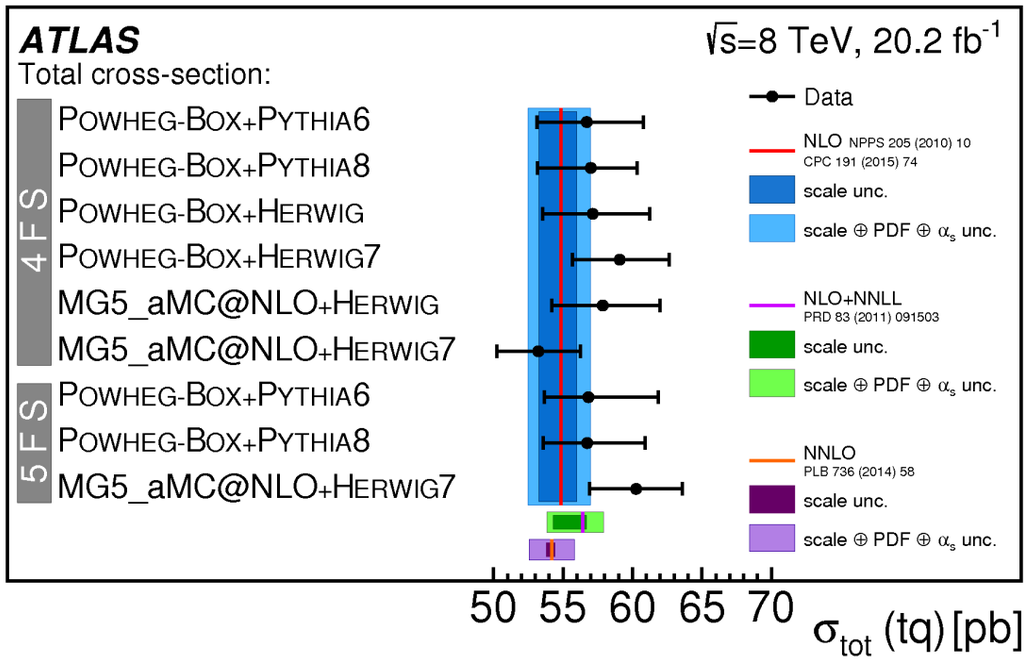
t-channel at 8 TeV: total

arXiv:1702.02859v2

Fiducial cross section extrapolated into full phase space to measure the full cross section

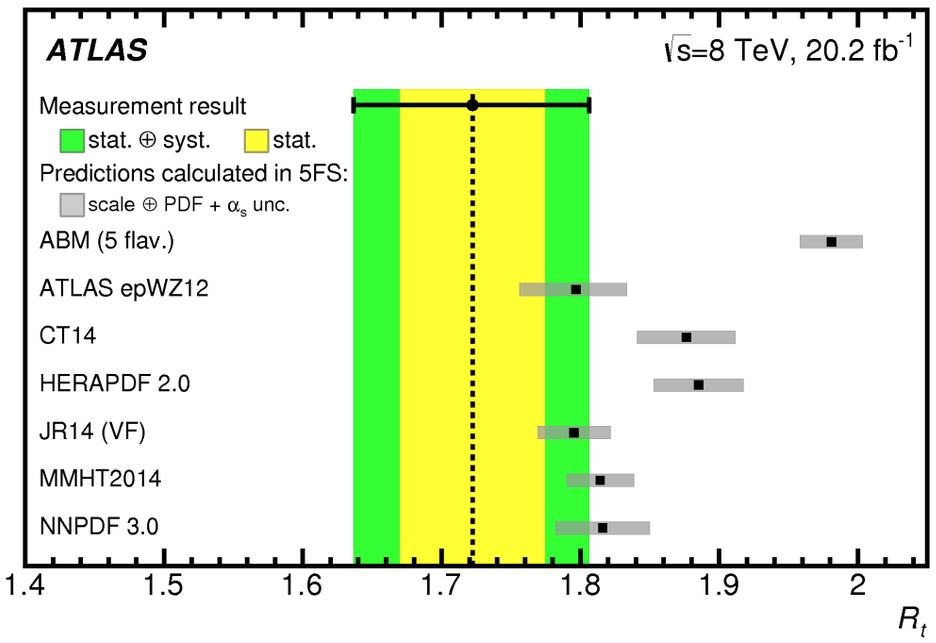
$$\sigma_{\text{tot}} = \frac{N_{\text{tot}}}{N_{\text{fid}}} . \sigma_{\text{fid}}$$

$$\sigma_{tq}^{\text{tot}} = 56.7^{+4.3}_{-3.8}\ \text{pb}$$
$$\sigma_{\bar{t}q}^{\text{tot}} = 32.9^{+3.0}_{-2.7}\ \text{pb}$$



Total cross section using different MC generators

$$R_t = \frac{\sigma_{tq}}{\sigma_{\bar{t}q}} = 1.72 \pm 0.09$$



- Without unitarity assumption

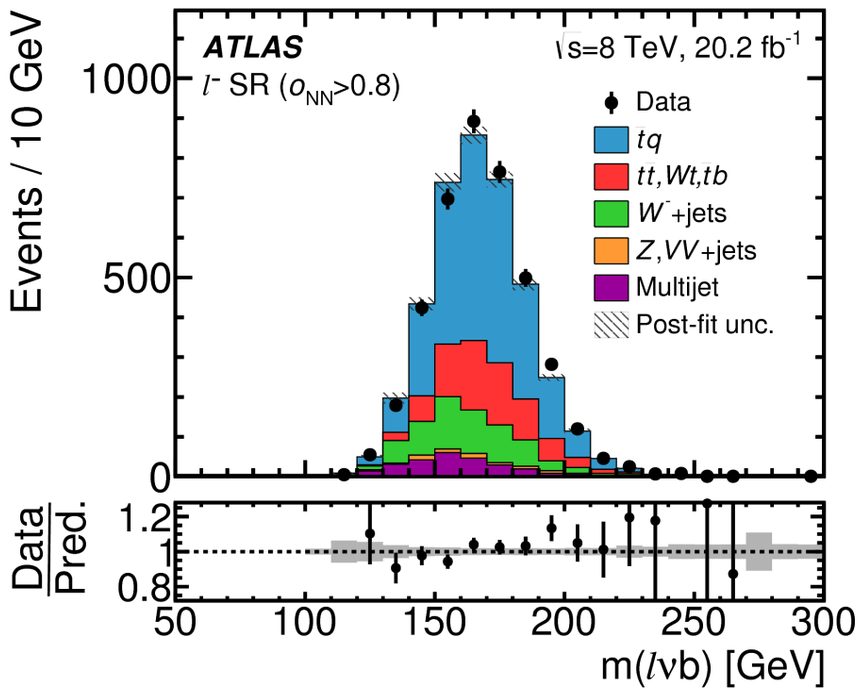
$$|f_{LV}.V_{tb}|^2 = \frac{\sigma(tq+\bar{t}q)_{\text{meas.}}}{\sigma(tq+\bar{t}q)_{\text{pred.}}} = 1.09 \pm 0.048$$

- Left-handed form factor
- In the SM it is exactly 1

t-channel at 8 TeV: differential

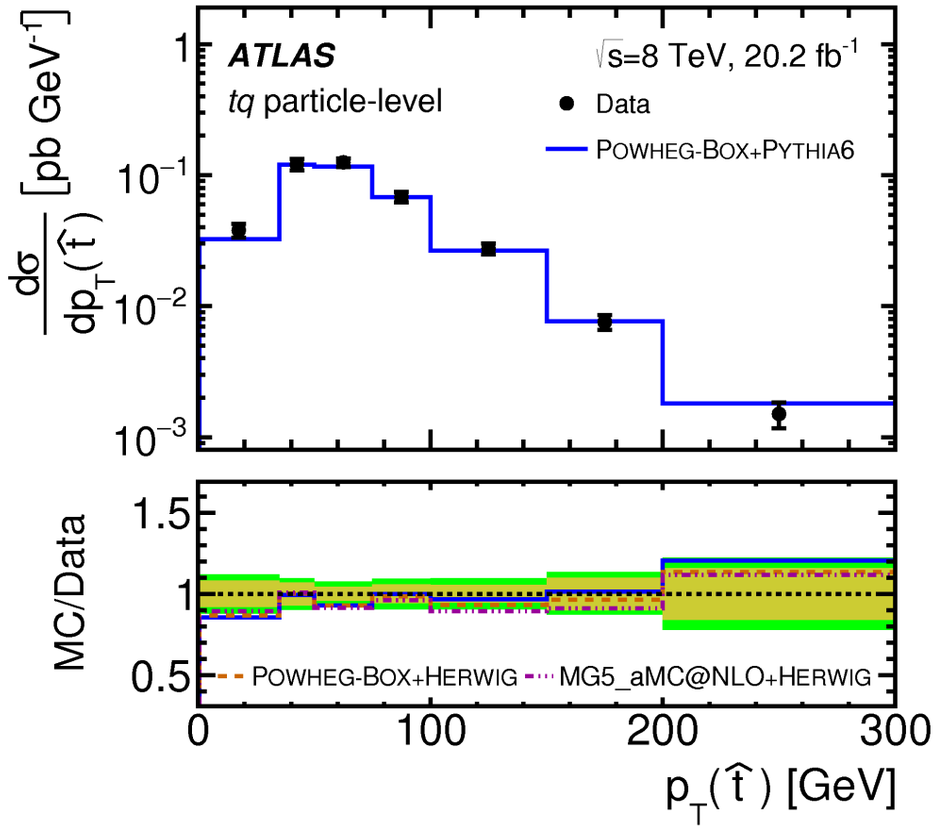
arXiv:1702.02859v2

- Select events with O_{NN} >0.8 to enhance signal purity



- Unfolded distributions:
  - $P_T(t)$ and y(t) for top and anti-top at parton level
  - $P_T(t)$, |y(t)|, $P_T(j)$, and |y(j)| for top and antitop at particle level

Particle level

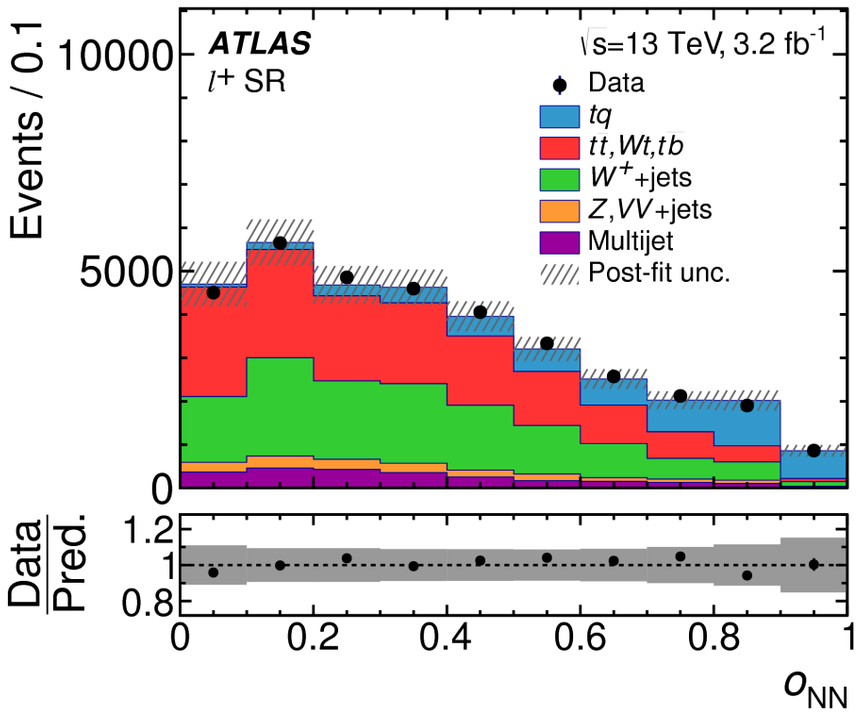


- Good agreement with the NLO predictions
- Main sources of systematic uncertainties similar to fiducial cross section measurement

t-channel at 13 TeV: total

arXiv:1609.03920

- Similar strategy to the 8 TeV analysis

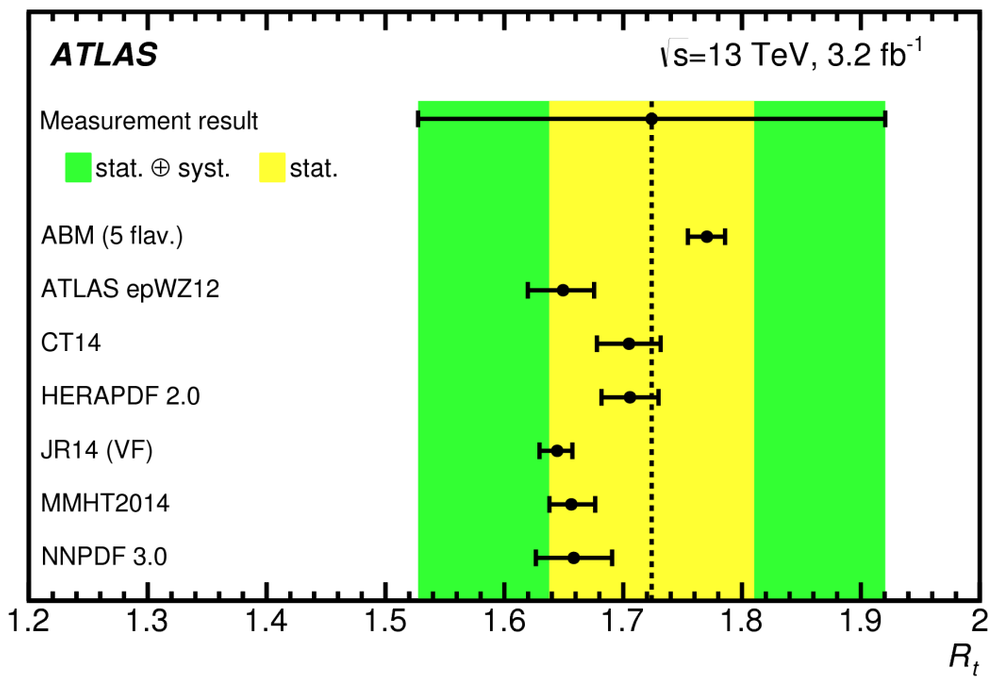


$$\sigma_{tq} = 156 \pm 5(\text{stat.}) \pm 27(\text{syst}) \pm 3(\text{lumi}) \text{ pb}$$

$$\sigma_{\bar{t}q} = 91 \pm 4(\text{stat.}) \pm 18(\text{syst}) \pm 2(\text{lumi}) \text{ pb}$$

$$R_t = 1.72 \pm 0.09(\text{stat.}) \pm 0.18(\text{syst})$$

$$f_{LV}.|V_{tb}| = 1.07 \pm 0.09$$

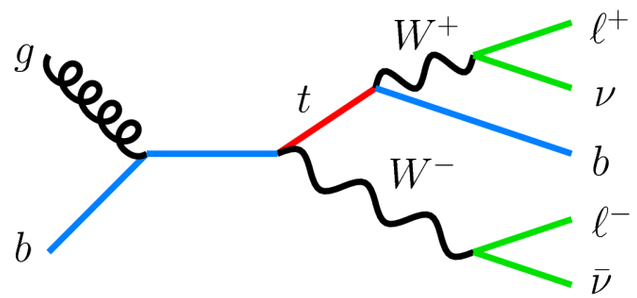


R_t agrees with PDFs

- Total uncertainty 18%(l^+),20%(l^-)
- Leading systematics:
  - parton shower (14%)
  - b-tagging efficiency (7%)

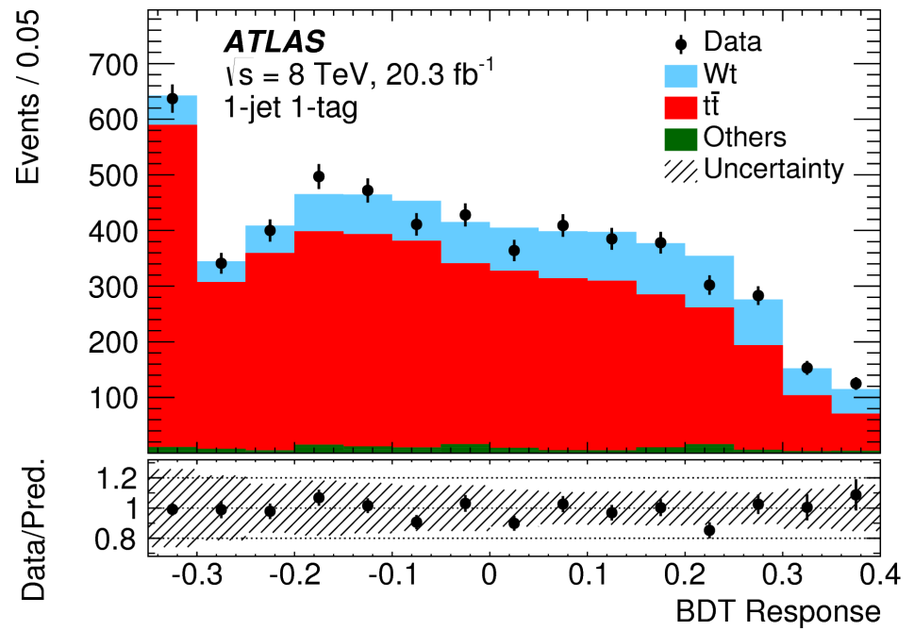
tW at 8 TeV: total

arXiv:1510.03752



Signatures:

- 2 opposite sign isolated leptons
- E_T^{miss} from 2 neutrinos
- 1 high P_T b-tagged jet



- Main background: $t\bar{t}$ and Z+jets
- Signal and control regions defined according to number of jets and b-tagged jets
- 3 Separate BDTs used to enhance S/B
- Binned maximum likelihood fit used to extract the cross section from 1 signal and 2 control regions

$$\sigma_{tW} = 23.0 \pm 1.3(\text{stat.})^{+3.2}_{-3.5}(\text{syst.}) \pm 1.1(\text{lumi})\text{pb}$$
$$|V_{tb}| = 1.01 \pm 0.10$$

Observed (expected) significance 7.7σ (6.9σ)

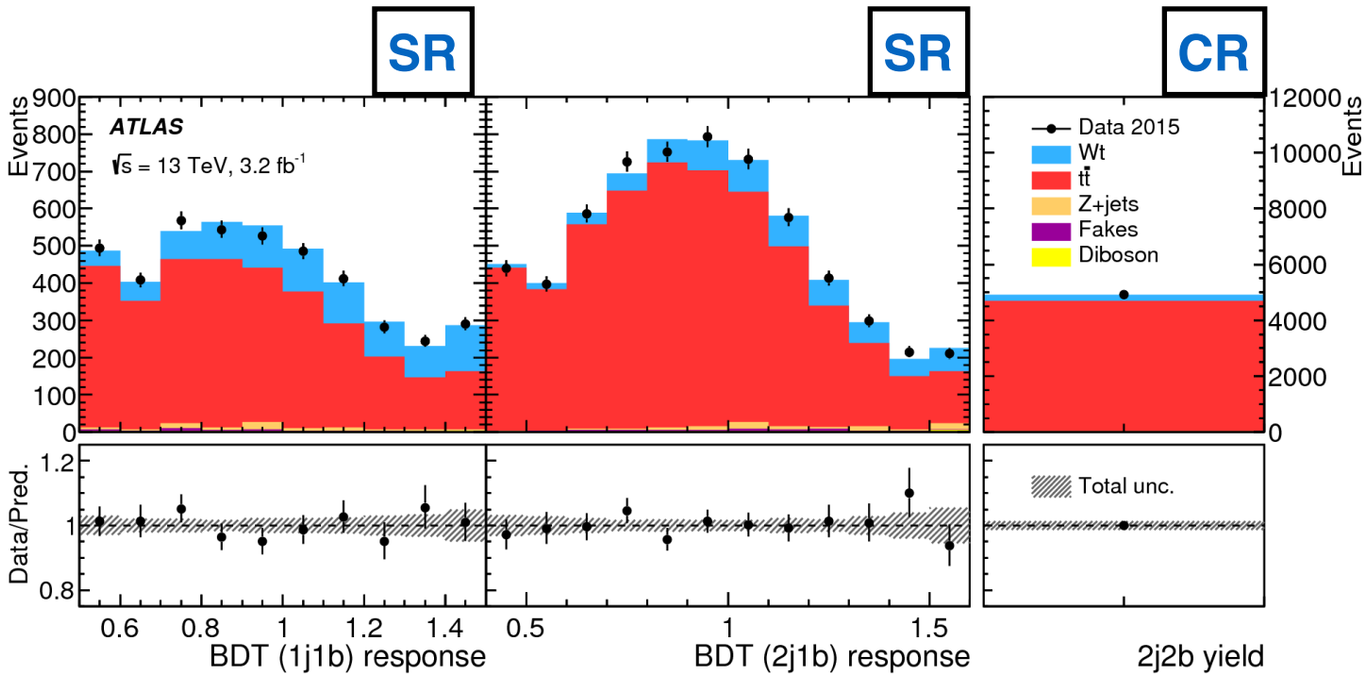
Leading systematics:

- $t\bar{t}$ normalisation
- jet reconstruction
- ISR/FSR

tW at 13 TeV: total

arXiv:1612.07231

- Similar to the 8 TeV analysis
- 2 separate BDTs trained in two signal regions (1j1b and 2j1b)



- Profile binned likelihood fit used to extract the cross section
- Leading systematics:
  - jet energy scale
  - NLO matrix element
  - jet energy resolution

$$\sigma_{tW} = 94 \pm 10(\text{stat.})^{+28}_{-22}(\text{syst.}) \pm 2(\text{lumi.})\text{pb}$$

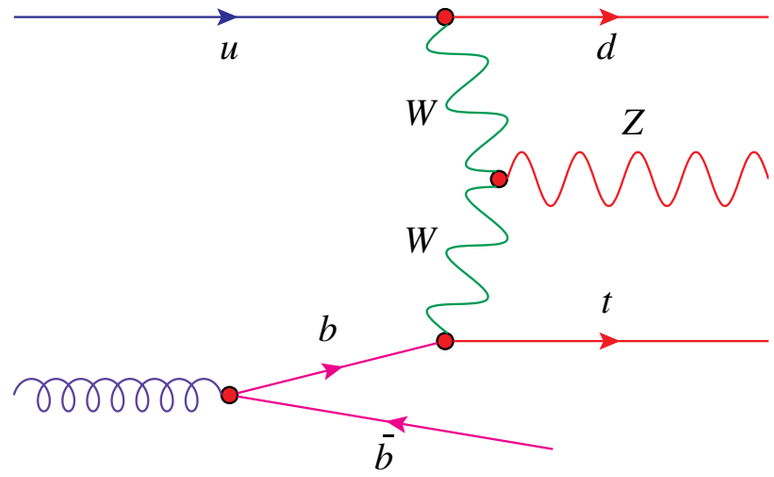
$$\text{significance} = 4.5(3.9)\sigma, \text{ observed (expected)}$$

tZq at 13 TeV

ATLAS-CONF-2017-052

New measurement

- **Motivation**:
  - Electroweak process not observed so far (800 fb at 13 TeV)
  - Sensitive to tZ and WWZ coupling
  - First step on the way to tH measurement
- Trilepton channel is most promising for first observation despite small BR (2.2%)



Event Selection

exactly 3 leptons with $|\eta| < 2.5$ and $p_T > 15$ GeV
$p_T(\ell_1) > 28$ GeV, $p_T(\ell_2) > 25$ GeV, $p_T(\ell_3) > 15$ GeV
p_T(jet) > 30 GeV
$m_T(\ell_W, \nu) > 20$ GeV

SR	Diboson VR / CR	$t\bar{t}$ VR
≥ 1 OSSF Pair	≥ 1 OSSF Pair	≥ 1 OSSF Pair
$\lvert m_{\ell\ell} - m_Z \rvert < 10$ GeV	$\lvert m_{\ell\ell} - m_Z \rvert < 10$ GeV	$\lvert m_{\ell\ell} - m_Z \rvert > 10$ GeV
$= 2$ jets, $\lvert\eta\rvert < 4.5$	$= 1$ jet, $\lvert\eta\rvert < 4.5$	$= 2$ jets, $\lvert\eta\rvert < 4.5$
$= 1$ b-jet, $\lvert\eta\rvert < 2.5$	—	$= 1$ b-jet, $\lvert\eta\rvert < 2.5$
—	CR: $m_T(\ell_W, \nu) > 60$ GeV	—

Background estimation

- Diboson normalisation calculated using validation region
- $t\bar{t}$ normalisation calculated using data-driven technique
- $t\bar{t}$+(W/Z): completely estimated by MC
- Z+jets (fakes): totally estimated using data-driven technique

tZq at 13 TeV

ATLAS-CONF-2017-052

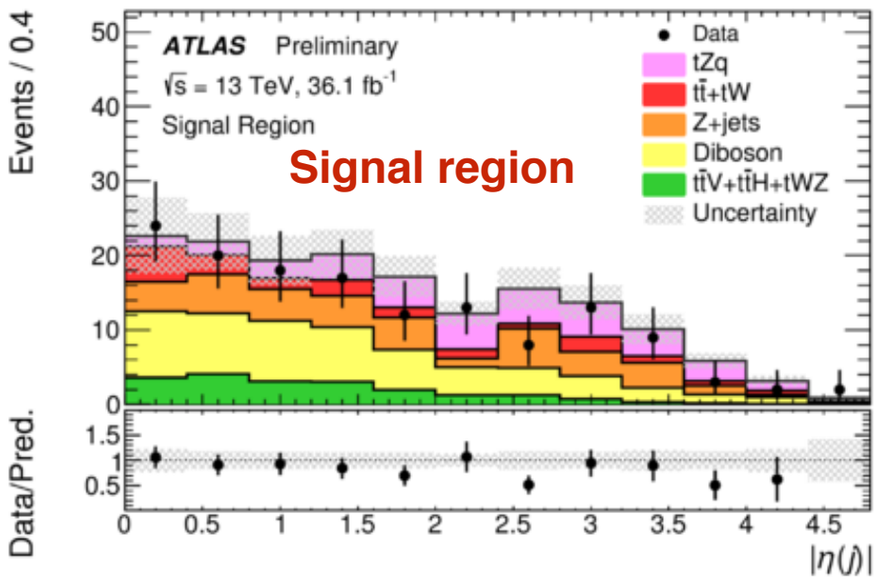
New measurement

- Neural network is used to enhance S/B
- 10 variables used as input e.g. η(j), $P_T(j)$, m(t), $P_T(l^W)$

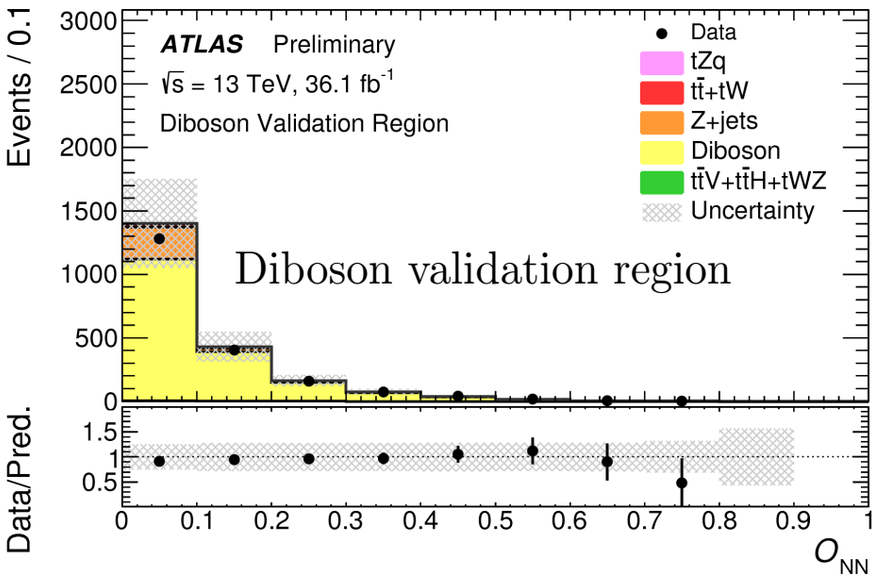
Data collected in 2015 & 2016: 3.2 fb^{-1}+33 fb^{-1}

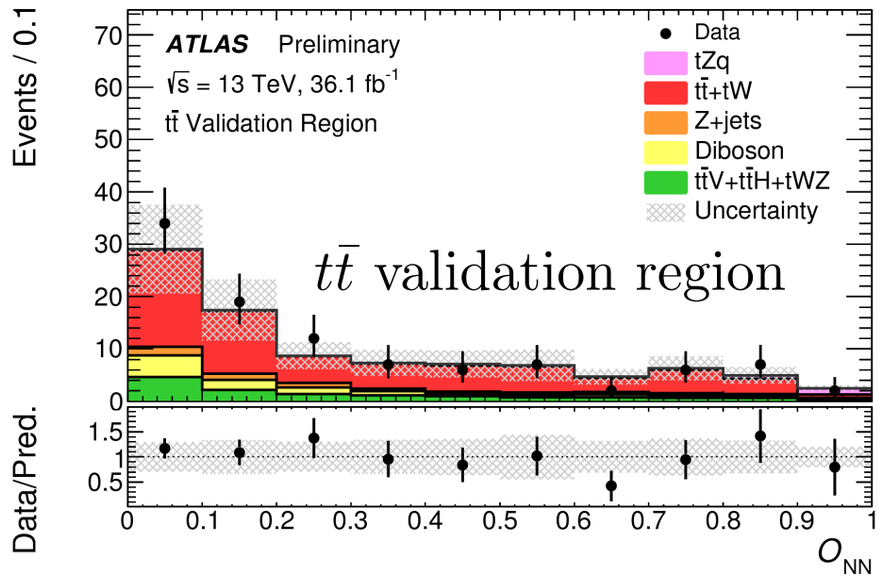
Channel	Number of events	
	Asimov dataset	Real data
tZq	35 ± 9	26 ± 8
$t\bar{t} + tW$	18 ± 7	17 ± 7
Z + jets	37 ± 11	34 ± 11
Diboson	53 ± 13	48 ± 12
$t\bar{t}V + t\bar{t}H + tWZ$	20 ± 3	19 ± 3
Total	163 ± 12	143 ± 11

S/B=0.3



Input variables are well modelled in the signal and validation regions





tZq at 13 TeV

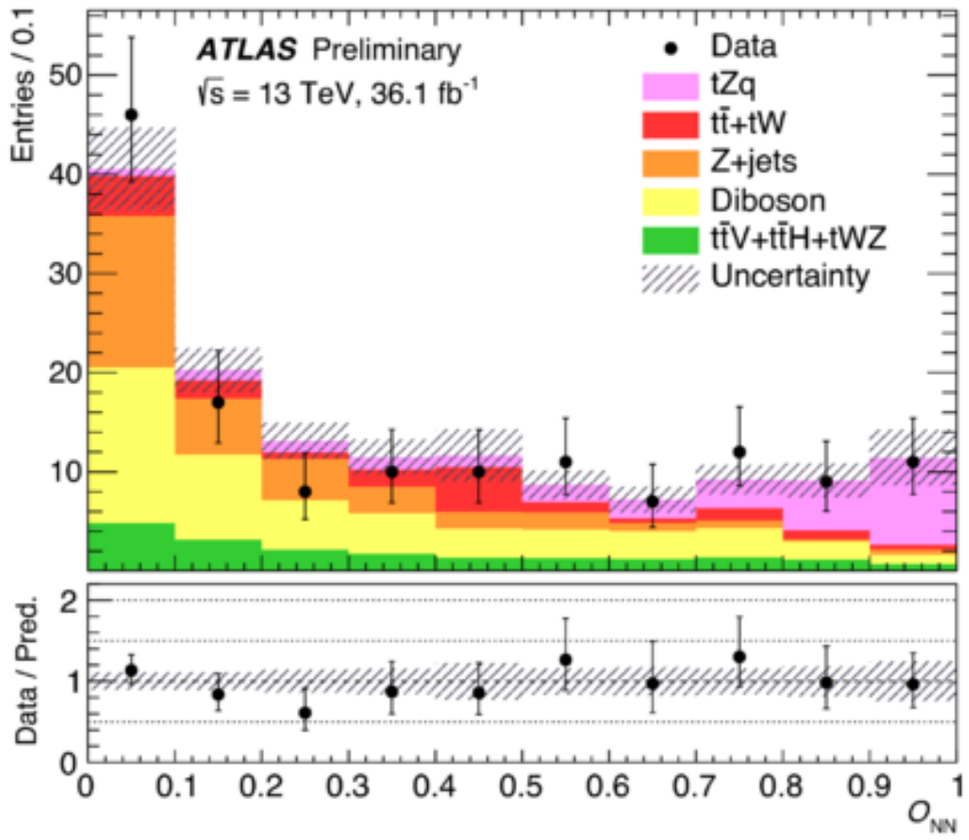
ATLAS-CONF-2017-052

New measurement

- Binned maximum likelihood fit used to extract the cross section
- Full NN distribution is used in the fit
- The observed (expected) significance is 4.2σ (5.4σ)

$$\sigma_{tZq} = 600 \pm 170(\text{stat.}) \pm 140(\text{syst.})\text{fb}$$

Source	Uncertainty [%]
tZq radiation	±10.8
Jets	±4.6
Luminosity	±3.2
b-tagging	±2.9
MC statistics	±2.8
Leptons	±2.1
tZq PDF	±1.2
$E_{\text{T}}^{\text{miss}}$	±0.3



Summary

- Single top quark production processes are measured at different CME by ATLAS Collaboration
  - comprehensive measurements at 8 TeV
  - good agreement with SM
  - will be used to tune MC generators and PDFs

- ATLAS has clear evidence for the single top quark associated to the Z boson at 13 TeV;
  - The observed (expected) significance is 4.2σ (5.4σ)
  - $\sigma_{tZ_q} = 600 \pm 170(\mathrm{stat.}) \pm 140(\mathrm{syst.})\mathrm{fb}$
  - good agreement with the SM
  - with the incoming data, the cross section measured will improve