Total cross section in top production

Measurements by ATLAS and CMS

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Outline

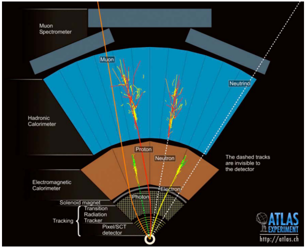
Analyses covered

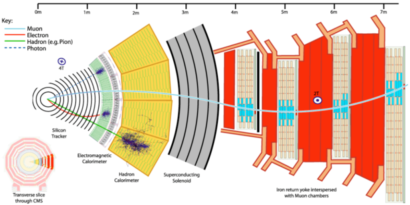
- $t\bar{t}$ dilepton measurements (13 TeV) by ATLAS and by CMS
- $t\bar{t}$ lepton+jets measurement (13 TeV) by ATLAS
- $t\bar{t}$ at 13 TeV with hadronically decaying τs by CMS
- t-channel measurement 13 TeV by CMS
- tW measurement at 8 TeV by ATLAS
- Combination of single top measurements ATLAS+CMS (7 and 8 TeV)
- tW measurement at 13 TeV CMS

Some differences between ATLAS and CMS

- A higher magnetic field is applied over the inner tracking detector in CMS (4T) than in ATLAS (2T).
- Scintillators with Liquid Argon as active material are used by ATLAS for EM calorimetry, while $\mathrm{PbWO_4}$ crystals are used by CMS. Higher energy resolution in EM calorimeter by CMS.
- 10λ hadronic calorimeter in ATLAS with higher energy resolution than in CMS, which covers 7λ.
- In general higher resolution for muons in CMS than in ATLAS.

Presentation by K. Jakobs





$t\bar{t}$ dilepton, ATLAS ($36.1\ \mathrm{fb}^{-1}$, 13 TeV)

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- **Inclusive**, fiducial and differential measurement and top pole mass extraction.
- Dilepton channel, targets $t\bar{t} \to W^+ b W^- \bar{b} \to e^\pm \mu^\mp \nu \bar{\nu} b \bar{b}$.
  - An $e^\pm \mu^\mp$ pair+jets are required of which 1 or 2 are b-tagged.
  - b-tagging with the MV2c10 algorithm (70% working point).
- Data collected in 2015-2016 is used.
- Most precise measurement of $t\bar{t}$ at 13 TeV to date.
- By taking the ratio to the measurements at 7 and at 8 TeV their precision is improved.
- Ratios to Z production and double ratios are computed.

See talk by Matteo Defranchis for top pole mass extraction and use of ratios to constrain PDFs.

$t\bar{t}$ dilepton, ATLAS (36.1 fb^{-1}, 13 TeV)

Events split into 2 regions by b-jet multiplicity (1 or 2 b-jets):

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

$N_{1,2}$ number of observed $e^{\pm}\mu^{\mp}$ events with 1, 2 b-tagged jet(s)

L integrated luminosity

$\epsilon_{e\mu}$ efficiency to pass the $e^{\pm}\mu^{\mp}$ selection $\sim$ 0.9 from MC

- 10% lower for 2016 (pileup, lepton triggers).

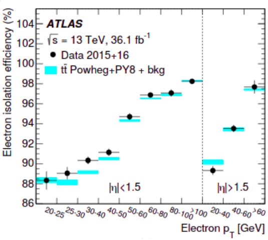
C_b tagging correlation coefficient, $\epsilon_{bb}/\epsilon_b^2$.

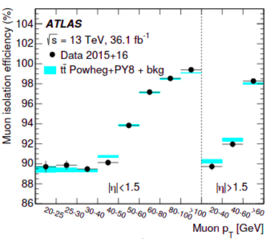
- Determined from MC as $C_b = \frac{N_{e\mu}^{t\bar{t}}N_2^{t\bar{t}}}{(N_1^{t\bar{t}}+2N_2^{t\bar{t}})^2}$

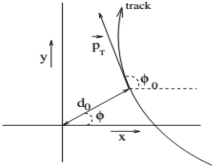
$N_{1,2}^{bkg}$ background prediction, evaluated with a combination of simulation and data control samples

ϵ_b b-tagging efficiency including acceptance, determined along with $\sigma_{t\bar{t}}$ by solving the above equations.

$t\bar{t}$ dilepton, ATLAS (36.1 fb^{-1}, 13 TeV)







Lepton isolation efficiencies

- The fraction of events where one of the leptons does not pass the isolation requirement is measured in $e\mu+b$-jet samples.
- Samples with leptons that fail the isolation requirements are contaminated by QCD multijet events.
  - The multijet contribution is estimated in data with an inverted cut on the transverse impact parameter significance $|d_0|/\sigma_{d_0}$ for one lepton.
  - Corrections for the multijet yield are applied to $t\bar{t}$ and tW.
- Derived corrections: up to 1% on $\epsilon_e^{isol.}$, 0.4% on $\epsilon_{e\mu}$.
- The choice of cut on $|d_0|/\sigma_{d_0}$ drives the uncertainty on $\epsilon^{isol.}$.

$t\bar{t}$ dilepton, ATLAS ($36.1\ \mathrm{fb}^{-1}$, 13 TeV)

- The BLUE method is used to combine the 2015 and 2016 results, weights of 0.49, 0.51 give the smallest uncertainty.
  - The total uncertainty is reduced by 9% compared to treating all data as one dataset.

Main systematics

- The main uncertainty on the $\sigma_{t\bar{t}}$ comes from the integrated luminosity (1.9 % impact on $\sigma_{t\bar{t}}$).
- The analysis systematics have an impact of 1.39 %, with the main contributions coming from the normalisation of single top (5.3 % for tW) and modelling uncertainties for $t\bar{t}$.
  - Since the lepton isolation efficiencies have been measured *in situ*, the predictions for lepton isolation from different generators do not enter the modelling uncertainties, thus reducing their impact.

$t\bar{t}$ dilepton, ATLAS ($36.1\ \mathrm{fb}^{-1}$, 13 TeV)

Results

- $\sigma_{t\bar{t}}^{\mathrm{fid}}$=14.07±0.06(stat.)±0.18(syst.)±0.27(lumi.)±0.03(beam)pb.
- $\sigma_{t\bar{t}}$=826.4±3.6(stat.)±11.5(syst.)±15.7(lumi.)±1.9(beam)pb.
- $\sigma_{t\bar{t}}^{theo.}$=832±35(pdf+$\alpha_s$)$^{+20}_{-29}$(scale)pb,(NNLO+NNLL, Top++).
- $\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}} = 2.4\%$, most precise inclusive measurement of $t\bar{t}$.

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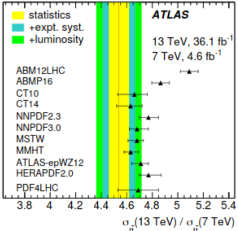
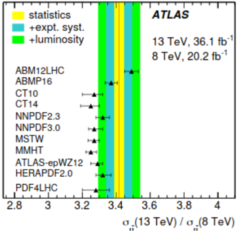
Ratios

- PDF uncertainties reduce in $\sigma^{t\bar{t}}_{13\ \mathrm{TeV}}/\sigma^{t\bar{t}}_{7\ (8)\ \mathrm{TeV}}$.
- Improvement for 7 (8) TeV: 4.9 → 3.9% (4.7 → 3.6%).



(a)



(b)

Gluon PDFs at high Bjoerken-x are constrained.

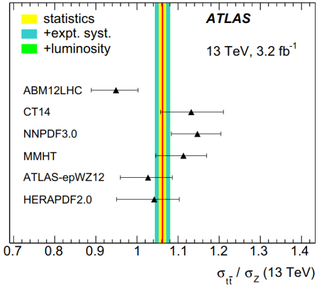
$t\bar{t}$ dilepton, ATLAS (36.1 fb^{-1}, 13 TeV)

Ratios to Z production

The luminosity uncertainty almost cancels in ratios to $Z \to \ell\ell$ production in the same dataset:

$$R^{t\bar{t}/Z} = \frac{\sigma_{t\bar{t}}}{0.5(\sigma_{Z\to ee} + \sigma_{Z\to\mu\mu})}$$

- Measured to 1.7% precision.

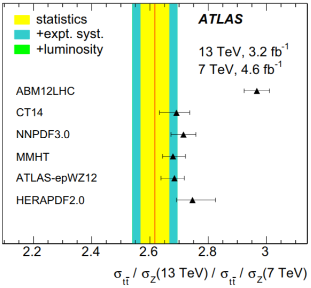


Double ratios

Cancellations for beam energies and production processes occur in:

$$R^{t\bar{t}/Z}_{i/j} = \frac{R^{t\bar{t}/Z}(i)}{R^{t\bar{t}/Z}(j)}$$

- Precision: 3.0% (2.5%) for $R_{13/7}$ ($R_{13/8}$). Main systematics: signal modelling.



$t\bar{t}$ dilepton, CMS ($35.9\ \mathrm{fb}^{-1}$, 13 TeV)

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- Measurement in the opposite sign dilepton channel.

Selection and regions

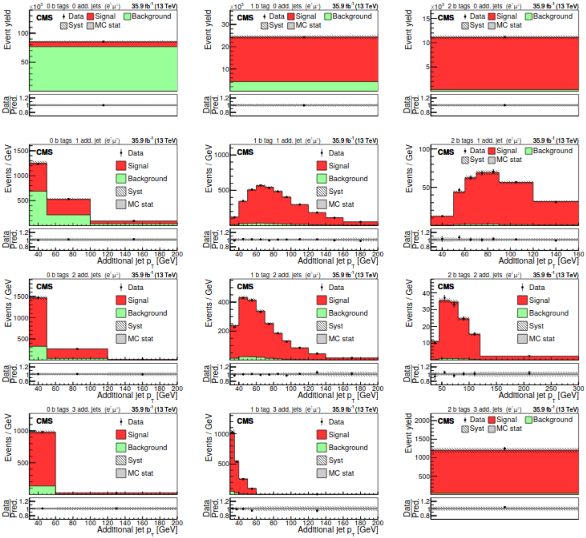
- Split by lepton channels (ee, $e\mu$, $\mu\mu$).
  - The same-flavour channels help constrain the lepton identification efficiencies.
- Removing the Z-mass peak in the same-flavor channel.
- Divided into regions by b-jet multiplicity (0,1,2) and additional jets (0,1,2).
  - The b-tagging efficiency is 44%.
  - The 0 b-jet category is only used for $e\mu$ events.
  - There are 28 regions in total ($12 + 8 \cdot 2$).

- A template fit is made.

Fitting variable

- Leading additional jet p_T (if present).
- Otherwise: event yield.

- The input distributions in the $e\mu$ channel are shown here.



$t\bar{t}$ dilepton, CMS (35.9 fb^{-1}, 13 TeV)

- A multitude of regions with different compositions is used to constrain systematics.
  - A priori, the uncertainty of the electron identification efficiency is higher than for muons. Fitting the different lepton channels simultaneously constrains $\Delta\epsilon_e$ to $\Delta\epsilon_\mu$.
  - This in turn reduces the total measurement uncertainty.

Results

- $\sigma_{t\bar{t}} = 803 \pm 2$ (stat.) ± 25 (syst.) ± 20 (lumi) pb, in agreement with the SM prediction.
  - The main uncertainties relate to the integrated luminosity (2.5%) and lepton identification and isolation (2.0%).

See talk by Matteo Defranchis for the extraction of the top quark pole mass and α_s.
Valentina Vecchio discusses the uncertainties further.

2006.13076 [hep-ex], submitted to PLB

- The full Run 2 dataset at $\sqrt{s} = 13$ TeV is used.

Selection

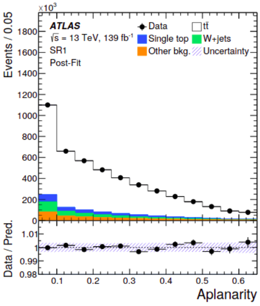
- Exactly one lepton (e or μ) is required and at least 4 jets.
- Requirements on $E_T^{\mathrm{miss}}$and m_T^Wsuppress backgrounds.
- Split by jet, b-jet multiplicity (with the 60% working point).
  - Different sentitivities to backgrounds & modelling in SR1, SR2.
  - Sensitivity to extra radiation in SR3.

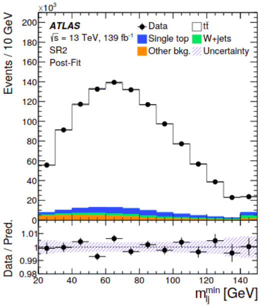
Signal region	**# jets**	**# b-jets**	**Dominant background**
SR1	≥ 4	$= 1$	W+jets
SR2	$= 4$	$= 2$	Single-top
SR3	≥ 5	$= 2$	Single-top

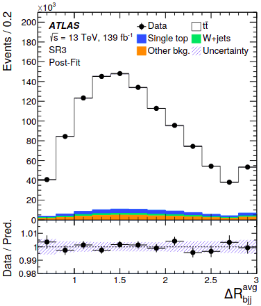
- Scale factors for the reconstruction, identification and trigger performance for leptons are determined in $Z \to \ell^+\ell^-$ events.

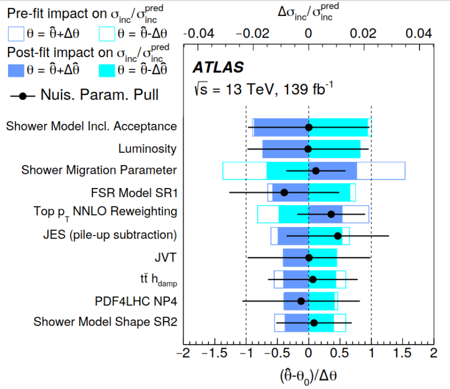
Analysis strategy

- SR1: aplanarity $A = \frac{2}{3}\lambda_3$, λ_3: smallest eigenvalue of $\frac{\sum_i p_i^\alpha p_i^\beta}{\sum_i |p_i|^2}$.
- SR2: m_{lj}^{min}, minimum invariant mass over all lepton-jet pairs.
- SR3: ΔR_{bjj}^{avg}, average distance between the three jets.
  - Constructs a system similar to a hadronially decaying top.
  - The jets are selected to give the highest p_{T} for the system.









- Shower: Powheg+Pythia8 vs Powheg+Herwig7.
- Luminosity uncertainty (1.7%): determined with LUCID-2, correction factors from data+associated uncertainties are applied.
- Final state radiation: variation by factors 2.0, 0.5 of μ_{FSR}.
- 85 eigenvectors are used for the *b*-tagging uncertainties.

Results

- $\sigma_{fid} = 110.7 \pm 0.05$ (stat.) $^{+4.5}_{-4.3}$(syst.) ± 1.9 (lumi.) pb, 4.1%.
- $\sigma_{inc} = 830 \pm 0.4$ (stat.) ± 36 (syst.) ± 14 (lumi.) pb, 4.6%.
- Most precise inclusive $t\bar{t}$ measurement in this channel.
- The result is consistent with the theoretical prediction.

$t\bar{t}$ with a hadronic τ, CMS ($35.9\ \mathrm{fb}^{-1}$, 13 TeV)

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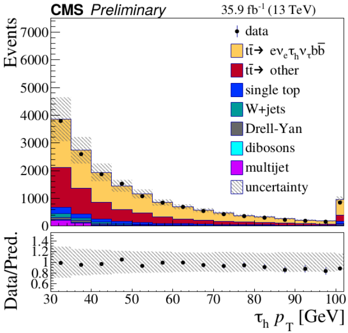
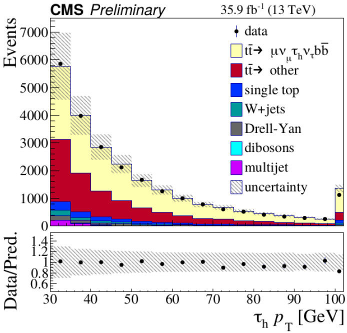
- $t\bar{t}$ with a hadronically decaying τ: $t\bar{t} \to (l\nu)(\tau_h \nu_\tau)bb$.
  - This channel covers $\sim$5% of $t\bar{t}$ final states.
  - A test of lepton universality.
  - $\mathrm{Br}(\tau \to \mathrm{hadrons}) = 65\%$.
- Selection: one electron or muon, one hadronic τ candidate of opposite charge and two jets of which at least one is b-tagged.

τ reconstruction with the hadron-plus-strips (HPS) algorithm

- In each jet, a charged hadron is combined with other nearby charged hadrons or photons to identify the decay modes.
- Clustering electrons and photons in strips along the bending direction enhances π^0 identification by taking into account early showering of photons.

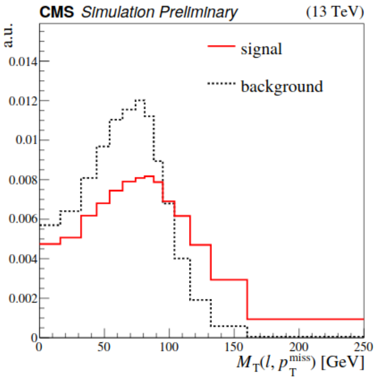
$t\bar{t}$ with a hadronic τ, CMS (35.9 fb^{-1}, 13 TeV)





- Main background: $t\bar{t}$ (lepton+jets) with a misidentified τ.
- A BDT is used to distinguish the τ candidates from QCD.
- Identification efficiency uncertainty of τ with $p_{\mathrm{T}} > 20$ GeV: 5%. This is the dominating uncertainty in the measurement.
  - Determined with tag-probe technique using $Z \to \tau_\ell \tau_h$ events.
  - Includes a charge mismeasuring probability of 1%.

- Fitting $M_T(\ell, E_T^{\mathrm{miss}})$ in a profile likelihood fit.
- For each combination of 1 b-tagged jet and 2 light jets, the distance parameter $D_{jjb} = \sqrt{(m_W - m_{jj})^2 + (m_t - m_{jjb})^2}$ is calculated. 2 categories:
  - Signal-like if $D_{jjb}^{\mathrm{min}} > 60\mathrm{GeV}$.
  - Background-like otherwise.



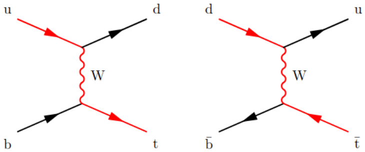
Results

- $\sigma_{t\bar{t}} = 781 \pm 7$ (stat.) ± 62 (syst.) ± 20 (lumi.) pb.
- $\Gamma(t \to \tau\nu_\tau b)/\Gamma(t \to \mathrm{all}) = 0.1050 \pm 0.0009(\mathrm{stat.}) \pm 0.0071(\mathrm{syst})$.
- Consistent with the SM prediction (0.1083 ± 0.0002 for width).
- The first measurement of $t\bar{t}$ production with a τ in the final state at 13 TeV has been performed.

t-channel, CMS (35.9 fb^{-1}, 13 TeV)

- Single top t-channel production is measured for top, anti-top and their ratio $R_t = \sigma_t / \sigma_{\bar{t}}$.
- Due to the valence quark content of the protons, more top than anti-top events are produced.

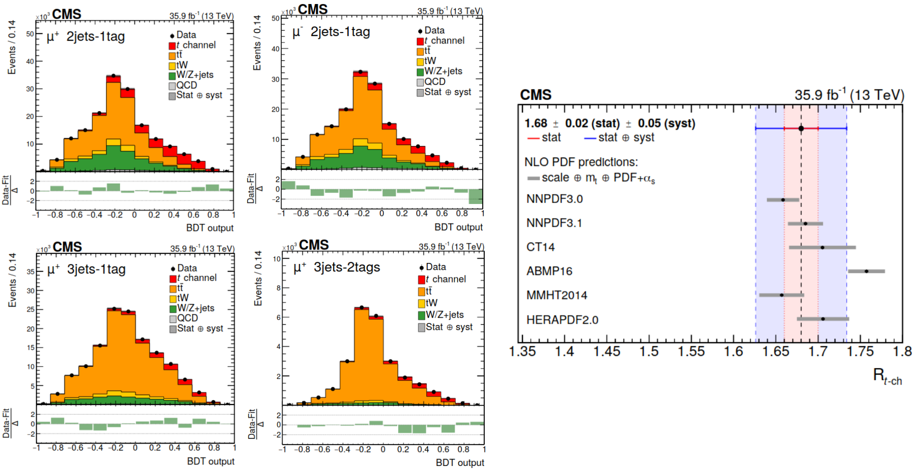
Phys.Lett.B 800 (2020) 135042



Signature and selection

- The e/μ+jets final states are analyzed with additional requirements related to E_T^{miss}.
- Categories split by lepton flavour and charge, jet and b-jet multiplicity:
  - 2 jets 1 b-tag: signal-enriched
  - 3 jets, 1 b-tag, 3 jets 2 b-tags: control regions dominated by $t\bar{t}$
- BDT algorithms enhance the separation of signal from large backgrounds.

t-channel, CMS (35.9 fb^{-1}, 13 TeV)



- A simultaneous fit to all categories, split by the lepton charge, is performed.
- R_t is extracted directly from the fit, together with $\sigma_{t\text{-}ch}$.

t-channel, CMS ($35.9\ \mathrm{fb}^{-1}$, 13 TeV)

To profile or not to profile...

Profiling

Allows for constraints.

- Experimental uncertainties
- Background rates
- Background modelling (shapes)

Not profiling

Avoids constraints.

- Signal modelling (shapes): scales, NLO matching, parton shower, pdfs.
  - Avoids assuming the same constraints on signal modelling when extrapolating to full phase space.
- Integrated luminosity (rate): known to 2.5%.

Results

σ_t=130±1(stat)±19(syst)pb

$\sigma_{\bar{t}}$=77±1(stat)±12(syst)pb

R_t=1.68±0.02(stat)±0.05(syst)

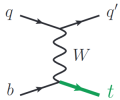
Theory, NLO with HATHOR

$\sigma_t^{theo}=136.0^{+4.1}_{-2.9}(\text{scale})\pm3.5(\text{pdf}+\alpha_S)\text{pb}$

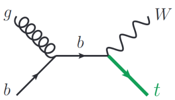
$\sigma_{\bar{t}}^{theo}=81.0^{+2.5}_{-1.7}(\text{scale})\pm3.2(\text{pdf}+\alpha_S)\text{pb}$

$R_t^{theo.} = 1.68$

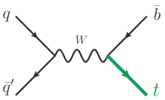
Single top combination ATLAS and CMS (7 and 8 TeV)



t-channel



tW-channel



s-channel

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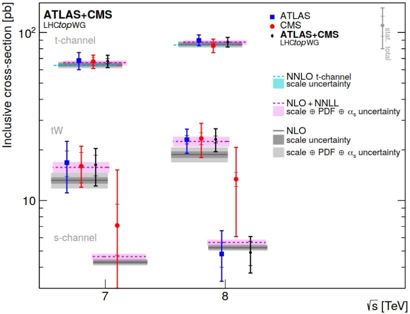
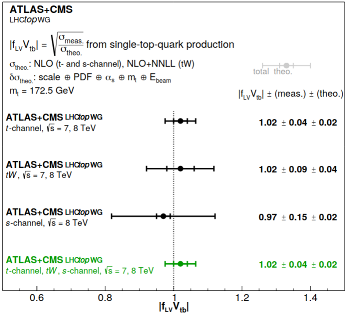
The BLUE method is used for the combination.





	7 TeV	8 TeV
t-channel xs [pb]	67.5 ± 5.7	87.7 ± 5.8
tW-channel xs [pb]	16.3 ± 4.1	23.1 ± 3.6
s-channel xs [pb]	-	4.9 ± 1.4

tW lepton+jets, ATLAS (20.2 fb^{-1}, 8 TeV)

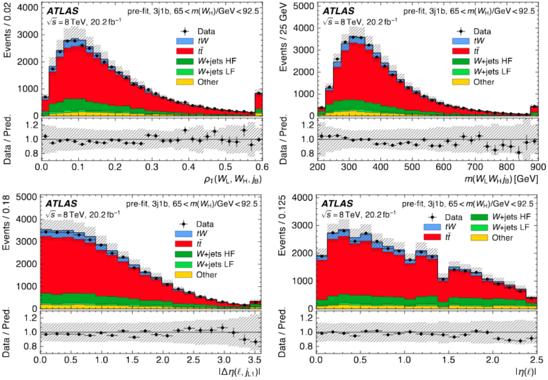
2007.01554, submitted to EPJC

- One isolated lepton and at least 3 jets are required, targeting one hadronically and one leptonically decaying W.
- A neural network is trained to separate the signal from the background, which is dominated by $t\bar{t}$.

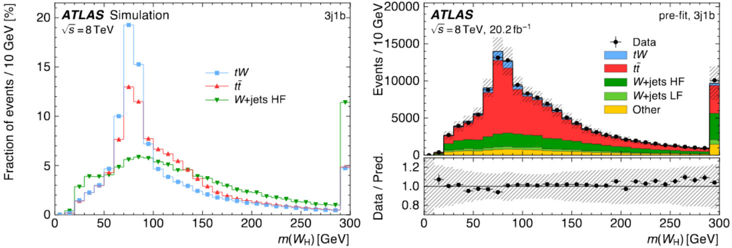
Neural network variables

1. $p_{\mathrm{T}}(W_H, W_L, j_B) = \dfrac{p_{\mathrm{T}}(W_H W_L j_B)}{p_{\mathrm{T}}(W_H)+p_{\mathrm{T}}(W_L)+p_{\mathrm{T}}(j_B)}$
2. $m(W_L W_H j_B)$
3. $|\Delta\eta(\ell, j_{L1})|$
4. $|\eta(\ell)|$

A 2D discriminant is constructed from the NN output and $m(W_H)$.



tW lepton+jets, ATLAS (20.2 fb^{-1}, 8 TeV)



- For $65 < m(W_H) < 92.5$ [GeV], a 2D discriminant is constructed from $m(W_H)$ and the NN response.
- Outside of this range, just $m(W_H)$ is used.

Results

- $\sigma_{tW} = 26 \pm 7$ pb (of which data statistics $\pm$ 4 pb).
- $\sigma_{tW}^{theo.} = 22.4 \pm 0.6(\text{scale}) \pm 1.4(\text{PDF})$ pb (NLO+NNLL).

- Main systematics: jet reconstruction, b-tagging and the modelling of $t\bar{t}$ and tW and their interference.

tW dilepton, CMS ($35.9\ \mathrm{fb}^{-1}$, 13 TeV)

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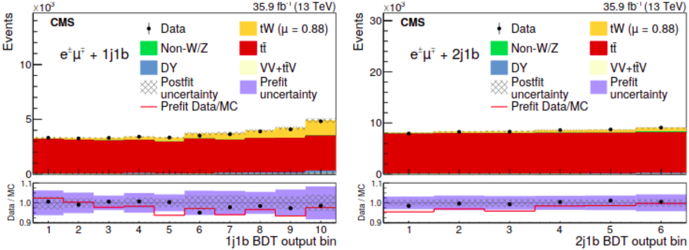
- A dilepton $e\mu$ selection with 1 or 2 jets is applied. Split into regions by jet and b-jet multiplicity (1j1b, 2j1b, 2j2b CR).
- Separate BDTs are trained for 1j1b and 2j1b.
- A likelihood fit to the signal strength is performed.
- Main systematics: pileup, jet energy scale, lepton efficiencies.



Results

$\sigma_{tW} = 63.1 \pm 1.8\ \text{(stat)} \pm 6.4\ \text{(syst)} \pm 2.1\ \text{(lumi)}$ pb, consistent with $\sigma_{tW}^{theo} = 71.7 \pm 1.8\ \text{(scale)} \pm 3.4\ \text{(PDF)}$.
The most precise measurement at 13 TeV to date.

Summary

- Some of the latest results for the total cross section in $t\bar{t}$ and single top production by ATLAS and CMS have been shown.
- Several results for obtained from a partial Run 2 dataset collected at $\sqrt{s} = 13$ TeV, have been published.
- The first results using the full Run 2 dataset are becoming public.
- We are pushing the limit in precision with novel treatments of experimental uncertainties.
- Combinations of results from ATLAS and CMS are performed.

Backup

$t\bar{t}$ dilepton, ATLAS (36.1 fb^{-1}, 13 TeV)

Table 1 Summary of the main object and event selection requirements

Object	Identification	Selection
Electrons	Tight likelihood	$E_{\mathrm{T}} > 20\,\mathrm{GeV}$, $\lvert\eta\rvert < 1.37$ or $1.52 < \lvert\eta\rvert < 2.47$, isolation
Muons	Medium	$p_{\mathrm{T}} > 20\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.5$, isolation
Jets	Anti-k_t $R = 0.4$	$p_{\mathrm{T}} > 25\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.5$, b-tagging with MV2c10 at 70% efficiency
Event		1 electron+1 muon with opposite sign, 1 or 2 b-tagged jets

- When solving Eqs. 1, 2 the number of b-tagged jets in tW and diboson backgrounds is predicted by simulation.
- The correlation coefficient C_b also has a weak dependence on the efficiencies for tagging heavy- and light-flavoured jets.
- The modelling of the b-tagging performance in simulation was then corrected using scale factors determined from:
  - Dilepton $t\bar{t}$ events for b-jets
  - Single-lepton $t\bar{t}$ events for charm jets
  - Dijet events for jets from light-quarks and gluons.
- The corresponding uncertainties were propagated to the background and correlation coefficient estimates.

$t\bar{t}$ dilepton, ATLAS

Signal modelling

Evaluated for $\epsilon_{e\mu}$, $G_{e\mu}$ and C_b and propagated to the cross section.

- NLO matching: Powheg+Pythia8 vs aMC@NLO+Pythia8.
- Hadronisation: Powheg+Pythia8 vs Powheg+Herwig7.
- ISR/FSR: varying μ_R, μ_F by factors of 2, 0.5.

Background modelling

- tW normalisation uncertainty: 5.3%. tW modelling: Diagram Removal vs Diagram Subtraction to remove overlaps with $t\bar{t}$.
- Scale factors for Z+jets are derived from data. The multijet background is measured in data.

Luminosity and beam energy

- Uncertainty on integrated luminosity: 2.0% for 2015, 2.1% for 2016, applied separately. Determined with LUCID-2.
- Beam energy: 0.1% precision, impact on $\sigma_{t\bar{t}}$: 0.23%.

	Uncertainty source	$\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%)	$\Delta G_{e\mu}/G_{e\mu}$ (%)	$\Delta C_b/C_b$ (%)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)	$\Delta\sigma^{\mathrm{fid}}_{t\bar{t}}/\sigma^{\mathrm{fid}}_{t\bar{t}}$ (%)
	Data statistics				0.44	0.44
$t\bar{t}$ mod.	$t\bar{t}$ generator	0.38	0.05	0.05	0.43	0.10
	$t\bar{t}$ hadronisation	0.24	0.42	0.25	0.49	0.67
	Initial/final-state radiation	0.30	0.26	0.16	0.45	0.41
	$t\bar{t}$ heavy-flavour production	0.01	0.01	0.26	0.26	0.26
	Parton distribution functions	0.44	0.05	-	0.45	0.07
	Simulation statistics	0.22	0.15	0.17	0.22	0.18
Lept.	Electron energy scale	0.06	0.06	-	0.06	0.06
	Electron energy resolution	0.01	0.01	-	0.01	0.01
	Electron identification	0.34	0.34	-	0.37	0.37
	Electron charge mis-id	0.09	0.09	-	0.10	0.10
	Electron isolation	0.22	0.22	-	0.24	0.24
	Muon momentum scale	0.03	0.03	-	0.03	0.03
	Muon momentum resolution	0.01	0.01	-	0.01	0.01
	Muon identification	0.28	0.28	-	0.30	0.30
	Muon isolation	0.16	0.16	-	0.18	0.18
	Lepton trigger	0.13	0.13	-	0.14	0.14
Jet/b	Jet energy scale	0.02	0.02	0.06	0.03	0.03
	Jet energy resolution	0.01	0.01	0.04	0.01	0.01
	Pileup jet veto	-	-	-	0.02	0.02
	b-tagging efficiency	-	-	0.04	0.20	0.20
	b-tag mistagging	-	-	0.06	0.06	0.06
Bkg.	Single-top cross-section	-	-	-	0.52	0.52
	Single-top/$t\bar{t}$ interference	-	-	-	0.15	0.15
	Single-top modelling	-	-	-	0.34	0.34
	Z+jets extrapolation	-	-	-	0.09	0.09
	Diboson cross-sections	-	-	-	0.02	0.02
	Diboson modelling	-	-	-	0.03	0.03
	Misidentified leptons	-	-	-	0.43	0.43
	Analysis systematics	0.91	0.75	0.44	1.39	1.31
L/E_b	Integrated luminosity	-	-	-	1.90	1.90
	Beam energy	-	-	-	0.23	0.23
	Total uncertainty	0.91	0.75	0.44	2.40	2.36

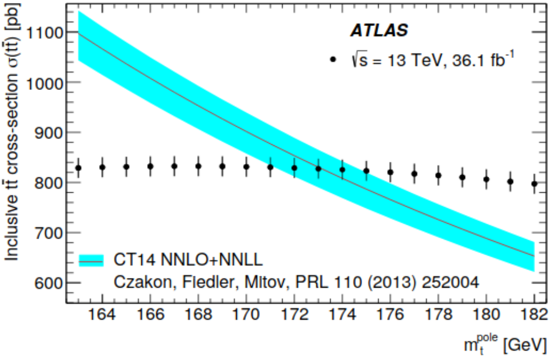
- Uncertainties for efficiencies, correlations and the total and fiducial cross section are evaluated.
- Main uncertainty: integrated luminosity.
- Main analysis systematics: normalisation of the single top cross section, $t\bar{t}$ modelling uncertainties.

$t\bar{t}$ dilepton, ATLAS, background details

- The main background tW is evaluated with simulation, as well as diboson production.
- Z+b-jets has large theoretical uncertainties: simulated with SHERPA, incusive xs normalised to FEWZ prediction and further scaled by 1.10 ± 0.12 (1 b-tag) and 1.20 ± 0.12 (2 b-tags), derived in data in an OS same flavour selection. In addition 5% and 23% uncertainties were assigned from a re-evaluation for the SFs using MG5_aMC@NLO+PYTHIA8.
- The contribution of events with one misidentified lepton was estimated in a same sign $e\mu$ selection for j b-tags (1,2):

$$N_j^{\mathrm{mis-id}} = R_j(N_j^{\mathrm{data,SS}} - N_j^{\mathrm{sim,prompt,SS}}) \quad (1)$$

$$R_j = \frac{N_j^{\mathrm{sim,mis-id,OS}}}{N_j^{\mathrm{sim,mis-id,SS}}} \quad (2)$$



- The predicted cross-section also depends strongly on m_t, decreasing by 2.7% for a 1 GeV increase in the top mass.
- A 0.1 % variation inscorresponds to a 0.23% variation $\sigma_{t\bar{t}}$.

$t\bar{t}$ production, lepton+jets inclusive (ATLAS)

Category	$\frac{\Delta\sigma_{\text{fid}}}{\sigma_{\text{fid}}}$ [%]	$\frac{\Delta\sigma_{\text{inc}}}{\sigma_{\text{inc}}}$ [%]
Signal modelling		
$t\bar{t}$ shower/hadronisation	±2.8	±2.9
$t\bar{t}$ scale variations	±2.2	±2.7
h_{damp}	±1.5	±1.1
Background modelling		
MC background modelling	±1.8	±2.0
Multijet background	±0.8	±0.6
Detector modelling		
Jet reconstruction	±2.5	±2.6
Luminosity	±1.7	±1.7
Flavour tagging	±1.2	±1.3
$E_{\text{T}}^{\text{miss}}$ + pile-up	±0.3	±0.3
Muon reconstruction	±0.6	±0.5
Electron reconstruction	±0.7	±0.6
Simulation stat. uncertainty	±0.6	±0.7
Total systematic uncertainty	±4.3	±4.6
Data statistical uncertainty	±0.05	±0.05
Total uncertainty	±4.3	±4.6

$t\bar{t}$ with a hadronic τ, CMS ($35.9\ \mathrm{fb}^{-1}$, 13 TeV)

- Selection: one electron (muon) with p_{T} >30 (26) GeV, one hadronic τ candidate of opposite charge, $p_{\mathrm{T}} > 30$ GeV and two jets of which at least one is b-tagged (66% efficiency).
- A BDT is used to distinguish the τ candidates from QCD. Input: multiplicity and the p_{T} of e, γ candidates near the τ, kinematics of hadrons and strips, info about τ lifetime.
- Fitting $M_T(\ell, E_T^{\mathrm{miss}}) = \sqrt{2 p_{\mathrm{T}}^{\ell} E_T^{\mathrm{miss}} \cdot (1 - \cos\Delta\phi)}$ in a profile likelihood fit.

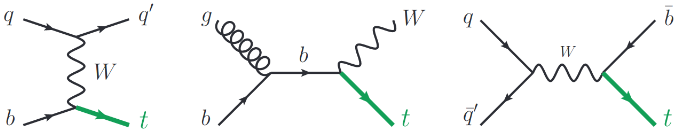
t-channel, CMS (35.9 fb^{-1}, 13 TeV)

Selection: an electron $p_{\mathrm{T}} > 24$ GeV or muon $p_{\mathrm{T}} > 32$ GeV + jets.

BDT input variables

1. Light-quark jet $|\eta|$
2. Invariant mass of top
3. Dijet mass of the of (b,j) from the top decay.
4. $\Delta R(\ell, b)$
5. $\cos\theta^*$
6. p_{T} sum for jets from top
7. m_T^W
8. E_T^{miss}
9. $\Delta R(j, b)$ (jets from top)
10. $|\eta(\ell)|$
11. $|\eta(W)|$
12. Invariant mass of light jet

Single top combination ATLAS and CMS (7 and 8 TeV)



t-channel tW-channel s-channel

Combining with BLUE

The BLUE method is applied iteratively to combine the single top results from ATLAS and CMS.

- BLUE minimises the global χ^2 by adjusting the weight of each input measurement.
- Convergence criterion: the change in χ^2 is less than 0.01% from the previous iteration.
- Systematic uncertainties are scaled with the cross section in each iteration (relative uncertainties).
- Data and MC statistics are not scaled.

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Decorrelated uncertainties

- Data statistical, simulation statistical.
- Background normalisation.
- Jet energy scale, jet energy resolution
- Lepton modelling
- E_T^{miss} calculation
- b-tagging
- Pileup modelling

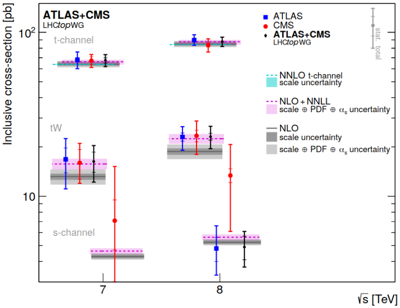
Partially correlated uncertainties

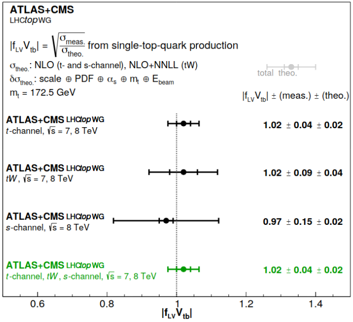
- Integrated luminosity (0.3)

Fully correlated uncertainties

- Signal modelling and dependence on top quark mass.
- Some uncertainties in theoretical cross-section predictions: μ_R and μ_F for tW.

Single top combination ATLAS and CMS (7 and 8 TeV)



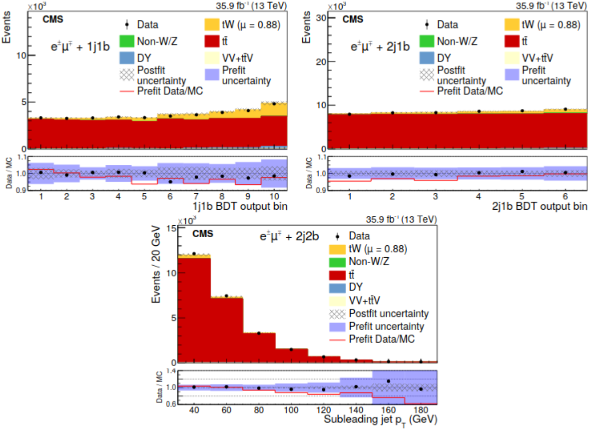


	7 TeV	8 TeV
Integrated luminosity [fb^{-1}]	1.17 - 5.1	12.2 - 20.3
t-channel xs [pb]	67.5 ± 5.7	87.7 ± 5.8
tW-channel xs [pb]	16.3 ± 4.1	23.1 ± 3.6
s-channel xs [pb]	-	4.9 ± 1.4

The coupling at the tWb vertex:

$$|f_{LV}V_{tb}| = \sqrt{\frac{\sigma_{meas.}}{\sigma_{theo.}(V_{tb}=1)}} = 1.02 \pm 0.04(\mathrm{meas.}) \pm 0.02(\mathrm{theo.})$$

tW 13 TeV (CMS)


CMS
35.9 fb⁻¹ (13 TeV)
e±μ∓ + 1j1b
Data
tW (μ = 0.88)
Non-W/Z
tt̄
DY
VV+tt̄V
Postfit uncertainty
Prefit uncertainty
Prefit Data/MC
Events
Data / MC
1j1b BDT output bin
e±μ∓ + 2j1b
2j1b BDT output bin
e±μ∓ + 2j2b
Events / 20 GeV
Subleading jet p_T (GeV)

tW 13 TeV CMS

Source	Uncertainty (%)
Experimental	
Trigger efficiencies	2.7
Electron efficiencies	3.2
Muon efficiencies	3.1
JES	3.2
Jet energy resolution	1.8
b tagging efficiency	1.4
Mistag rate	0.2
Pileup	3.3
Modeling	
$t\bar{t}$ μ_R and μ_F scales	2.5
tW μ_R and μ_F scales	0.9
Underlying event	0.4
Matrix element/PS matching	1.8
Initial-state radiation	0.8
Final-state radiation	0.8
Color reconnection	2.0
B fragmentation	1.9
Semileptonic B decay	1.5
PDFs	1.5
DR-DS	1.3
Background normalization	
$t\bar{t}$	2.8
VV	0.4
Drell–Yan	1.1
Non-W/Z leptons	1.6
$t\bar{t}V$	0.1
MC finite sample size	1.6
Full phase space extrapolation	2.9
Total systematic (excluding integrated luminosity)	10.1
Integrated luminosity	3.3
Statistical	2.8
Total	11.1