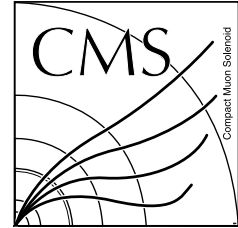




TOPLHC NOTE

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Combination of cross-section measurements for associated production of a single top-quark and a W boson at $\sqrt{s} = 8$ TeV with the ATLAS and CMS experiments

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Abstract

A combination of cross-section measurements for the associated production of a top quark and a W boson in proton-proton collisions at $\sqrt{s} = 8$ TeV by the ATLAS and CMS experiments is presented. The two measurements are based on integrated luminosities of 20.3 fb^{-1} and 12.2 fb^{-1} , respectively. The combined production cross section of a single top quark and a W boson is determined as $\sigma_{tW} = 25.0 \pm 1.4$ (stat.) ± 4.4 (syst.) ± 0.7 (lumi.) pb = 25.0 ± 4.7 pb, in agreement with the NLO+NNLL expectation. A 95% C.L. lower limit on the magnitude of the CKM matrix element V_{tb} of $|V_{tb}| > 0.79$ is extracted from the cross-section measurement.

¹ Work within the Top Physics LHC (TOP-LHC-WG) working group.

More information at <http://twiki.cern.ch/twiki/bin/view/LHCPhysics/TopLHCWG>.

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1 Introduction

Single top-quark production at hadron colliders proceeds, according to the Standard Model (SM) predictions, via three mechanisms that can be defined at leading order (LO): the t -channel, the s -channel and the production of a single top quark in association with a W boson (tW channel). The tW channel studied here is the second most abundant single top-quark production mechanism at the LHC, after t -channel production. The study of single top-quark processes not only provides a stringent test of SM predictions, but allows new physics beyond the SM (BSM) to be probed. In particular, each of the three single top-quark channels is sensitive to different new physics mechanisms [1–4]. This motivates the measurements of the individual cross sections in order to probe different possible manifestations of physics BSM. In the tW channel both the top quark and the W boson are present in the final state, and a measurement of the tW production cross section is sensitive to BSM physics which modifies the Wtb interaction, but insensitive to flavor-changing neutral currents (FCNCs) or the production of new particles such as W' , t' and techni-pions [5]. The measurement of single top-quark production cross sections allows the determination of the magnitude of the CKM matrix element V_{tb} assuming that the production and top-quark decay through vertices involving the matrix elements V_{ts} and V_{td} are small. In the tW channel, no assumption about the number of quark generations or unitarity of the CKM matrix is required [5–7], thus the determination of $|V_{tb}|$ in the tW channel provides complementary information with respect to the analogous measurement in the t -channel. The tW final state is also sensitive to singly produced new particles such as a vector-like quark B [3] or an excited quark b^* [4]. The tW process itself is also a background to Supersymmetry [8, 9] and Higgs [10, 11] searches.

The tW process is accessible at the LHC and has been measured by ATLAS and CMS at $\sqrt{s} = 7$ TeV [12, 13] and at $\sqrt{s} = 8$ TeV [14, 15]. Due to its low cross section at $\sqrt{s} = 1.96$ TeV, this process has not been observed at the Tevatron. The two LHC measurements at $\sqrt{s} = 8$ TeV are the most precise and are the subject of the combination described in this analysis.

The theoretical prediction for the tW production cross section in pp collisions at $\sqrt{s} = 8$ TeV at next-to-leading order (NLO) [16–18] in QCD, including resummation of next-to-next-to-leading soft gluon terms (NNLL) is [19, 20]:

$$\sigma_{tW}^{\text{th.}} = 22.2 \pm 0.6 \pm 1.4 \text{ pb.} \quad (1)$$

The first uncertainty term is the renormalisation scale uncertainty and the second term is the parton distribution function (PDF) uncertainty, evaluated using the MSTW2008_{NLO} [21, 22] PDFs. The theoretical prediction is computed at a top-quark mass of 172.5 GeV, which is the top-quark mass value used in ATLAS and CMS simulations and is used to perform this combination. This value, though being somewhat lower than the present top-quark-mass world average [23], is close to the latest most precise LHC results by CMS [24, 25].

2 The ATLAS and CMS tW cross-section measurements at 8 TeV

The ATLAS and CMS tW analyses use similar approaches to measure the tW production cross section. Both experiments select dilepton tW events containing one or two jets, both use a boosted decision tree [26] (BDT) to separate the signal from the background, and both determine the cross section in a likelihood fit to the data. Both experiments simulate the signal using the POWHEG generator [27] with the diagram removal (DR) [28] scheme to take account of the interference with $t\bar{t}$, and measure the cross section assuming a top-quark mass of 172.5 GeV. POWHEG is based on a NLO matrix element interfaced with parton showers and an underlying event model using PYTHIA [29] with the Perugia 2011 tune [30]. ATLAS uses the CT10 PDF set [31], while CMS uses the CTEQ6.6M PDF set [32].

ATLAS measured the tW production cross section at 8 TeV [14] in the electron-muon final state using a data sample corresponding to an integrated luminosity of 20.3 fb⁻¹. Events containing exactly

one electron and one muon candidate with opposite charge and either one or two jets are selected. At least one of those jets must be identified as containing a b quark. The electron candidate must have transverse energy $E_T > 25$ GeV and a pseudorapidity $|\eta| < 2.47$ (excluding the region $1.37 < |\eta| < 1.52$), and the muon candidate must have transverse momentum $p_T > 25$ GeV and $|\eta| < 2.5$. Isolation requirements are applied to the two lepton candidates. Jets are reconstructed using the anti- k_t algorithm [33, 34] with a distance parameter $R = 0.4$. The selected jets must have $p_T > 35$ GeV and $|\eta| < 2.5$. Events are separated by jet multiplicity to distinguish the signal region from the $t\bar{t}$ background-dominated region. The signal sample contains events with exactly one jet, and the $t\bar{t}$ background-dominated sample contains exactly two jets. Both samples are used in the signal extraction. In total, about 20,000 events are selected in data, with 1900 expected signal events. The tW signal is separated from the dominant top-quark pair production background and smaller backgrounds from diboson, Z +jets and fake leptons using a BDT discriminator, trained separately for events with one or two jets. No explicit requirement on missing transverse momentum (E_T^{miss}) is applied, but this variable is used as input to the BDT discriminator. The cross section is determined in a frequentist analysis in which several systematic uncertainties are also constrained to data (profiled): the background normalisation, b -tag modeling, and individual components of the jet energy scale and missing transverse momentum modeling uncertainties. The measured cross section is

$$\sigma_{tW} = 27.2 \pm 5.8 \text{ pb.} \quad (2)$$

The significance is evaluated from pseudo-datasets in a log-likelihood-ratio test. The observed signal corresponds to a significance of 4.2 standard deviations, with an expected significance (assuming the signal cross section from Eq. 1) of 4.0 standard deviations. From the cross-section measurement, a lower limit on the magnitude of the CKM matrix element V_{tb} of $|V_{tb}| > 0.72$ is obtained at the 95% confidence level.

CMS measured the tW production cross section at 8 TeV [15] in the dilepton (ee , $e\mu$, $\mu\mu$) final state using a data sample corresponding to 12.2 fb^{-1} . Events containing exactly two oppositely-charged isolated lepton candidates and one or two jets, at least one of which is b -tagged, are selected. Lepton candidates must have $p_T > 20$ GeV and electrons (muons) are required to have $|\eta| < 2.5$ (2.4). Events coming from the decays $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$ are vetoed in the ee and $\mu\mu$ channels by removing events with a dilepton invariant mass between 81 and 101 GeV. Jets are reconstructed using the anti- k_t algorithm with a distance parameter $R = 0.5$, and selected jets are required to have $p_T > 30$ GeV, $|\eta| < 2.4$. The missing transverse energy should be greater than 50 GeV. Events are separated into a signal-enhanced sample with exactly one jet which is b -tagged and two background-enriched two-jet control samples: one where one of the two jets is b -tagged and the other where both are b -tagged. The two control samples are mainly used to constrain the dominant $t\bar{t}$ background from data. In total, about 30,000 events are selected in data, with 2500 expected signal events. The tW signal is separated from the dominant top-quark pair production background and smaller backgrounds from diboson, Z +jets and fake leptons with a BDT discriminator. The cross section is determined in a simultaneous fit to the BDT distributions in the signal and control samples. The nuisance parameters associated with the main systematic uncertainty contributions affecting the rate and shape of the BDT distribution of the signal and background processes are constrained from data. Nuisance parameters associated to luminosity and theory uncertainties are not constrained from data. A profile-likelihood method is used to determine the signal cross section and its uncertainty. The measured cross section is

$$\sigma_{tW} = 23.4 \pm 5.4 \text{ pb.} \quad (3)$$

The significance is evaluated from pseudo-datasets using a test statistic that is asymptotically equivalent to the log-likelihood-ratio used by ATLAS. The significance of this measurement is 6.1 standard deviations, with an expected significance of 5.4 standard deviations. From the cross-section measurement,

a lower limit on the magnitude of the CKM matrix element V_{tb} of $|V_{tb}| > 0.78$ is obtained at the 95% confidence level.

ATLAS and CMS have similar event yields for signal and background. However, the discriminant distributions in the signal-dominated one-jet region differ. CMS has more expected signal events in the high-discriminant region, and more bins in that region than ATLAS.

3 Combination methodology

The combination is performed using the best linear unbiased estimator (BLUE) method [35,36]. Following the same approach as for the previous ATLAS and CMS combination of single top-quark production cross section in the t -channel [37], the BLUE method is applied iteratively in order to reduce a possible bias arising from the systematic uncertainty dependence of the cross-section central value [38]. This approach was also adopted in Ref. [39] where an iterative procedure was proposed for the combination of B lifetime measurements and in Ref. [40] for the combination of CMS measurements of single top-quark production cross section in the t -channel performed with three different analyses techniques.

The cross-section combination is performed at a top-quark mass of 172.5 GeV, as discussed in the previous section, and the same top-quark mass assumption has been used for the prediction used as theory reference value. A top-quark mass uncertainty is included in the $|V_{tb}|$ extraction, see Section 7.

4 Uncertainty categories

The 2012 LHC run allowed the collection of a dataset containing many thousands of tW events. In this regime the measurement precision is limited by the understanding of the several sources of systematic uncertainties involved in this measurement.

The list of uncertainty sources and their assumed correlation is presented in Table 1. The contribution from each individual systematic uncertainty is evaluated by ATLAS as the difference in quadrature of the uncertainties obtained using two ensembles of pseudodatasets, one including and the other not including that uncertainty. Each contribution is evaluated by CMS by comparing the uncertainty in the nominal profile-likelihood fit to the uncertainty in the fit when fixing this nuisance parameter to its central value. We consider the following sources of uncertainties:

Statistics: uncertainty due to the limited size of the data sample. This uncertainty is considered uncorrelated between ATLAS and CMS.

Simulation statistics: uncertainty due to the limited size of the simulation samples. This uncertainty is considered uncorrelated between ATLAS and CMS.

Luminosity: uncertainty on the measured integrated luminosity as determined by the individual experiments [41, 42]. This affects both the background normalisation and the extraction of the signal cross section. The correlated and uncorrelated components of the luminosity uncertainties are 2.5% and 1.1% for ATLAS and 1.5% and 2.1% for CMS. From these, a correlation of 0.31 is obtained.

Theory modeling: the uncertainty in the modeling of signal and the top-pair background. This includes parton-shower (PS) and PDF uncertainties and the uncertainty due to the tW top-quark pair interference treatment [43] as discussed below.

- The uncertainty on initial- and final-state radiation (ISR/FSR) for ATLAS is considered to be correlated with the renormalisation/factorisation scale for CMS. The ATLAS uncertainty due to ISR and FSR is derived from a study of additional jet activity in $t\bar{t}$ events at $\sqrt{s} = 7$ TeV [44, 45] and is applied to both signal and top-quark pair background samples. The renormalisation and factorisation scale uncertainty in CMS also accounts for uncertainties in the signal generator. It is estimated by varying the two scales consistently in the tW and $t\bar{t}$ samples to half or double of the nominal

Table 1: Categories of uncertainty, their magnitude (relative to the individual measurements) and correlation (ρ) between the ATLAS and CMS measurements. Uncertainties in the same row can be compared between experiments even if they have different names in the two analyses. The names here are the same as those in the original documents.

Category	ATLAS		CMS		ρ
Data statistics	Data statistics	7.1%	Fit statistics	8.1%	0.0
Category subtotal		7.1%		8.1%	0.0
Simulation statistics	Sim. statistics	2.8%	Sim. statistics	2.4%	0.0
Category subtotal		2.8%		2.4%	0.0
Luminosity		3.7%		3.0%	—
Category subtotal		3.7%		3.0%	0.31
Theory modeling	ISR/FSR	5.9%	Ren./fact. scale	12.4%	1.0
	tW gen. and PS	11.0%			—
	$t\bar{t}$ gen. and PS	7.5%	ME/PS match. thr.	14.1%	1.0
	PDF	2.5%	PDF	1.7%	1.0
	$tW/t\bar{t}$ overlap	1.4%	DR/DS scheme	2.1%	1.0
			Top p_T reweight.	0.4%	—
Category subtotal		14.8%		19.0%	0.66
Background normalization	bkg. mod.	3.6%	$t\bar{t}$ cross section	1.7%	0.0
			Z+jets	2.6%	—
Category subtotal		3.6%		3.1%	0.0
Jets	JES common	10.0%	JES	3.8%	0.0
	JES flavour	5.0%			—
	Jet id	0.2%			—
	Jet res.	0.7%	Jet resolution	0.9%	0.0
Category subtotal		11.2%		3.9%	0.0
Detector modeling	Lepton modeling	2.4%	Lepton modeling	1.8%	0.0
	MET scale	4.1%	MET modeling	0.4%	0.0
	MET resolution	4.5%			—
	b -tagging	8.4%	b tagging	0.9%	0.5
Category subtotal		10.6%	Pileup	0.4%	—
Total		23.3%		21.7%	0.38

value. This uncertainty is larger than the sum in quadrature of the two individual contributions due to tW and $t\bar{t}$, determined by varying the scales for the two processes independently. Thus the combined uncertainty has been chosen in order to avoid any possible underestimate. The CMS scale uncertainty is larger than the ATLAS ISR/FSR uncertainty due to the inclusion of lower- p_T -jets. It was verified in a previous study that though the methods are different, they mostly address the same uncertainty, hence this uncertainty is considered correlated [37].

- ATLAS includes an uncertainty for the tW generator and parton-shower modeling. This is evaluated by comparing the POWHEG and MC@NLO [46] generators interfaced with Herwig [47] (with JIMMY [48] for underlying event modeling) and PYTHIA. This uncertainty is not explicitly considered in the CMS analysis, where the DR/DS scheme uncertainty is assumed to be the dominant generator uncertainty, which has been evaluated in a specific study (see below). The effect of dropping this uncertainty from the ATLAS measurement on the combination is evaluated in Section 6.
- ATLAS includes a separate uncertainty for the top-quark-pair generator and parton-shower modeling, evaluated by comparing the POWHEG and MC@NLO generators interfaced with PYTHIA and HERWIG, respectively. For the top-quark pair background in the CMS analysis, this is covered by the matrix element/parton shower (ME/PS) matching threshold uncertainty. This CMS uncertainty is estimated from simulated samples with the values of the ME/PS matching thresholds and renormalisation/factorisation scale doubled and halved from their respective initial values of 20 GeV and $m_t^2 + \sum p_T^2$ (where the sum is over all additional final state partons). This uncertainty is larger for CMS due to the inclusion of lower- p_T -jets. This uncertainty is considered correlated.
- The PDF uncertainty is evaluated following the PDF4LHC procedure [49] and is considered correlated between ATLAS and CMS.
- Associated tW production interferes with top-quark pair production at NLO [28, 50, 51]. This is dealt with in both ATLAS and CMS by comparing two simulation approaches: diagram subtraction [6, 28] (DS), and diagram removal [28] (DR). In the DS approach, the diagrams with two on-shell top quarks are subtracted in the amplitude evaluation. In this way interference terms are not included in the simulation. In the DR approach, diagrams with two on-shell top quarks are removed from the amplitudes. This approach accounts for the interference term, but is not gauge-invariant. The DR approach is the default, and the DS approach is used to evaluate this systematic uncertainty. This uncertainty is considered correlated between the two experiments.
- For CMS, the small uncertainty on the modeling of the top-quark transverse momentum is also included. This is evaluated based on a model of the difference between the top-quark transverse momentum in $t\bar{t}$ events between data and simulation [52, 53]. For ATLAS, there is no such difference and this uncertainty is not included [54].

Note that in Ref. [15] CMS also reports an uncertainty due to m_t which propagates into an uncertainty on the measured tW cross section of 9.4%, corresponding to an assumed m_t uncertainty of 2 GeV. This contribution was dropped in the combination, consistent with the treatment in the $t\bar{t}$ cross-section combination [55]. The measured cross-section value is quoted at a nominal m_t value of 172.5 GeV. The top-quark mass uncertainty is included in the extraction of the CKM matrix element $|V_{tb}|$. An uncertainty contribution due to the spin correlation uncertainty in $t\bar{t}$ of 0.1% is also reported in CMS measurement [15]. This has been dropped from the combination since spin correlation has been observed at the level expected in the SM within uncertainties [56, 57].

Background normalisation: the uncertainty in the modeling of the background normalisation. This includes for both experiments the uncertainty on the cross-section predictions for top-quark pair production. For ATLAS the uncertainties on diboson and Z+jets backgrounds and the data-driven fake lepton

background normalisation uncertainty are included as well. For CMS the data-driven Z+jets background normalisation uncertainty is also included. These uncertainties are considered uncorrelated because they are either data-driven or constrained in the fit to data by both experiments.

Jets: uncertainty in the modeling of the jet identification, jet energy scale (JES) and jet energy resolution. For ATLAS, the JES uncertainty is split into components representing the systematic uncertainties of the in-situ techniques [58]. They are categorised as modeling and detector components, statistical components, pile-up dependence and flavor dependence. The detector modeling component is profiled in the fit to data. For CMS, the JES uncertainty is not separated into components in the analysis [59] and it is constrained to data in the profile likelihood fit, hence this uncertainty is smaller. Given that this uncertainty is constrained to data, it is considered uncorrelated between ATLAS and CMS, and the result is stable against variations of this correlation as documented in Section 6.

Detector modeling: the uncertainty in the modeling of leptons, missing transverse energy and b tagging. It includes the sources described below.

- The lepton modeling uncertainty is considered uncorrelated between ATLAS and CMS since it is determined from data.
- ATLAS includes separate uncertainties for the scale and resolution uncertainty components of E_T^{miss} . The scale uncertainty is profiled in the ATLAS fit to data [60]. CMS includes a E_T^{miss} modeling uncertainty. This uncertainty is smaller for CMS due to the use of low- p_T -jets, which allow this uncertainty to be constrained in the fit to data. This uncertainty is considered uncorrelated between ATLAS and CMS.
- For ATLAS, the b -tag modeling uncertainty is separated into b -quark, c -quark and light quark components [61–63], and the b -quark component is profiled in the fit to data. For CMS, the average b -tagging efficiency is constrained from control samples in data within the same fit procedure used to perform the signal extraction. The quoted b -tagging uncertainty estimates the uncertainty due to the possible extra mismodeling in simulation of the b -tagging efficiency dependency on the jet p_T and η that is not constrained from data. Since it is mainly constrained from data, the b -tagging uncertainty is significantly smaller in CMS than in ATLAS, and due to possible theory dependence in the simulation modeling of b -tagging uncertainty, correlations between ATLAS and CMS b -tagging uncertainties are possible. It is difficult to provide a precise estimate of this correlation, due to the very different treatment of this uncertainty in the two analyses. A 50% correlation is considered and it has been checked that the combination is stable against possible variations of this assumption (see Section 6).
- For CMS an uncertainty due to pile-up modeling is included here. For ATLAS, pile-up is included in the JES uncertainty.

The total uncertainty in the last row of Table 1 is simply given by the sum in quadrature of the individual components. This differs slightly from the total uncertainty in Eqs. 2 and 3 due to correlations of uncertainties. Also, in this note m_t and spin correlation uncertainties for CMS have been dropped, as discussed above.

5 Result

The combined result is:

$$\sigma_{tW} = 25.0 \pm 1.4 \text{ (stat.)} \pm 4.4 \text{ (syst.)} \pm 0.7 \text{ (lumi.) pb} = 25.0 \pm 4.7 \text{ pb.} \quad (4)$$

The overall correlation of the ATLAS and CMS measurements is $\rho = 0.38$. The weights of the ATLAS and CMS measurements in the combination are 0.43 and 0.57, respectively. The χ^2/ndof of the combination is 0.37, corresponding to a p -value of 0.54. The pull of the ATLAS and CMS measurements with respect to the combination are 0.61 and -0.61 , respectively. The contribution of each uncertainty category to the combined cross-section uncertainty is shown in Table 2. The theory uncertainty gives the dominant contribution to the total uncertainty.

This result has a relative precision of 19%, and improves the precision of the individual ATLAS and CMS measurements of 21% and 23% respectively. The method converges to a relative difference between combined cross sections in two subsequent iterations of better than 0.01%.

Table 2: Contribution of each uncertainty category to the combined cross-section uncertainty.

Source	Uncertainty	
	(%)	(pb)
Data statistics	5.5%	1.4
Simulation statistics	1.8%	0.5
Luminosity	2.7%	0.7
Theory modeling	15.8%	4.0
Background normalization	2.3%	0.6
Jets	5.3%	1.3
Detector modeling	4.9%	1.2
Total systematics (excl. lumi)	17.5%	4.4
Total systematics (incl. lumi)	17.7%	4.4
Total uncertainty	18.6%	4.7

6 Stability tests

In order to test the stability of the cross-section combination with respect to the assumed correlations between ATLAS and CMS uncertainties the correlation coefficients have been varied for important uncertainty sources, namely for luminosity, theory modeling, b -tagging and JES uncertainties. Table 3 summarises the result of these tests for the assumed correlation which are varied in a very extreme range. In particular the theory modeling category has been varied from its default value to half and no correlation. The largest change in the central value is 0.1 pb, while the largest change in uncertainty is -0.6 pb corresponding to the case where theory uncertainties are assumed to be all uncorrelated.

As another test, the BLUE method has also been applied with fixed absolute uncertainties, i.e. without scaling the relative uncertainties from each experiment to the combined central value. The combined cross section decreases by 0.4 pb, consistent with the expected bias of the standard BLUE method of 0.4 pb, estimated using a dedicated Monte Carlo exercise [38].

As a test of the importance of the ATLAS tW generator uncertainty, the BLUE combination has been performed with that uncertainty removed. The resulting cross section is 0.4 pb higher than the nominal result from Eq. 4, with a corresponding larger ATLAS weight of 0.52, and the uncertainty is reduced by 0.1 pb. The changes are small and the behaviour as expected when removing one of the larger uncertainties.

All the performed tests show that the analysis is robust and does not depend critically on any of the correlation assumptions.

Table 3: Results of the stability tests performed on the correlation assumptions about the uncertainty categories. For each test the correlation factor ρ is varied from its default value to a test value and the corresponding shifts on the combined central value and on the measured uncertainty are reported.

Source	Default ρ	Test ρ	Shift: central value (pb)	Shift: uncertainty (pb)
Luminosity	0.3	0.0/0.5	0.0/0.0	0.0/0.0
$t\bar{t}$ PS	1.0	0.0/0.5	+0.1/0.0	-0.4/-0.2
Theory modeling	0.7	0.0/0.3	+0.1/+0.1	-0.6/-0.3
Background norm.	0.0	0.5/1.0	0.0/0.0	+0.1/+0.1
b -tagging	0.5	0.0/1.0	0.0/0.0	0.0/0.0
Jets	0.0	0.5/1.0	0.0/0.0	+0.1/+0.1

7 Extraction of $|V_{tb}|$

The tW cross section is proportional to the square of the magnitude of the CKM matrix element V_{tb} [64, 65]. A value for $|V_{tb}|^2$ is obtained by dividing the measured cross section by the theory prediction from Eq. 1 (which is obtained for $|V_{tb}|^2 = 1$). This does not assume three quark generations or unitarity of the CKM matrix. It is assumed that the tWb coupling is left-handed and that the production and decay of the top quark are dominated by V_{tb} and that the contributions from V_{ts} and V_{td} are negligible.

The BLUE combination is performed including the top-quark mass uncertainty in the determination of $|V_{tb}|^2$. For a shift of 1 GeV in the mass, the ATLAS cross section shifts by 0.5 pb, while the CMS cross section shifts by 1.1 pb. The ATLAS uncertainty is estimated from the impact of the top-quark mass shift on acceptances and normalisations and discriminating variable shapes. The theory cross-section uncertainty for the same mass shift is 0.4 pb. The uncertainty in the LHC beam energy [66] is also included in the $|V_{tb}|^2$ extraction. The uncertainty on the theory cross section due to the beam energy uncertainty is 0.38 pb. These additional uncertainties have a small impact on the BLUE $|V_{tb}|^2$ combination compared to the cross-section combination. When comparing a cross-section combination that includes these additional uncertainties with the default cross-section combination from Sec. 5, the central value, uncertainty, χ^2 and p -value all change by less than 2%. Similarly, the $|V_{tb}|^2$ result is unchanged whether the experimental and theoretical uncertainties due to the top-quark mass are considered correlated or not.

The following value is obtained for $|V_{tb}|^2$:

$$|V_{tb}|^2 = 1.12 \pm 0.23. \quad (5)$$

Requiring $|V_{tb}| \leq 1$, the lower limit on $|V_{tb}|$ is obtained in a Bayesian approach, assuming a Gaussian probability distribution for $|V_{tb}|^2$ and a flat prior in $|V_{tb}|^2$: $|V_{tb}| > 0.79$ at 95% CL.

8 Summary

The ATLAS and CMS measurements of the production cross section of a top quark in association with a W boson are combined using the best linear unbiased estimator (BLUE) method. The combined cross section is $\sigma_{tW} = 25.0 \pm 1.4$ (stat.) ± 4.4 (syst.) ± 0.7 (lumi.) pb = 25.0 ± 4.7 pb, in agreement with the NLO+NNLL prediction. The result of the combination of ATLAS and CMS measurements is shown together with the individual ATLAS and CMS measurements and compared to the prediction in Fig. 1.

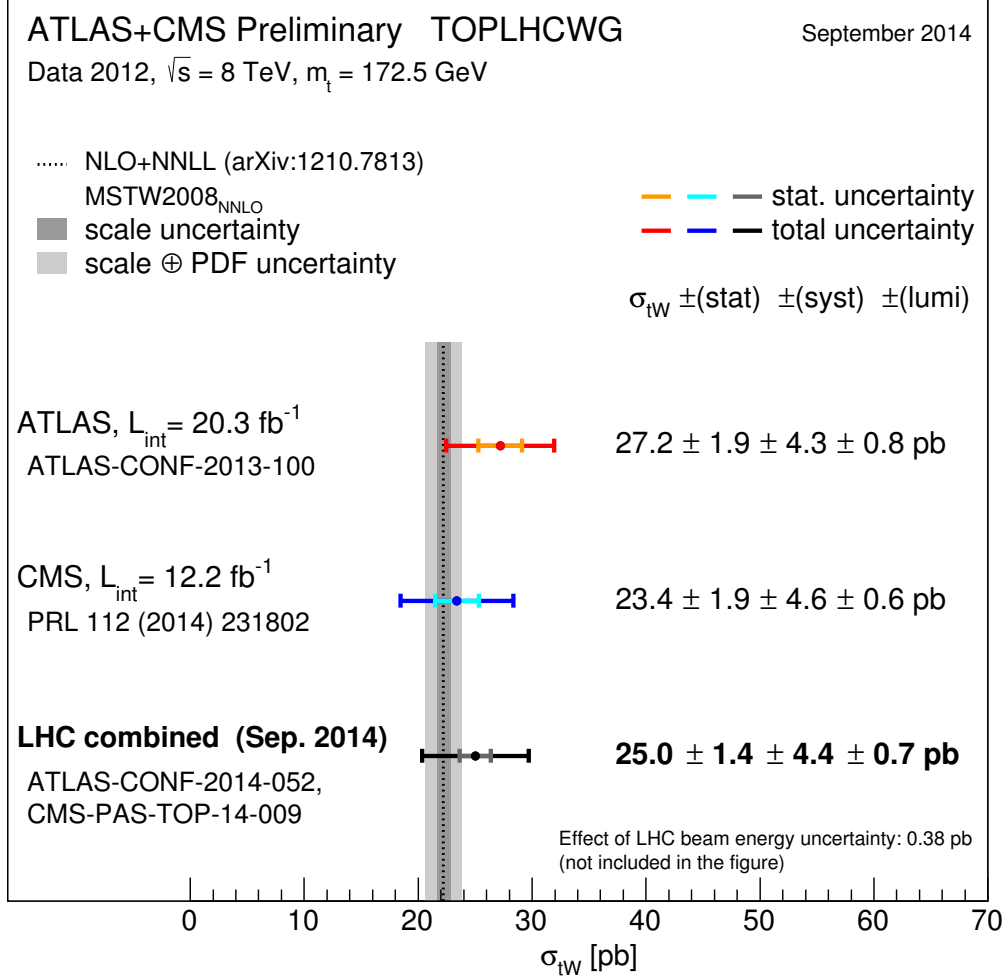


Figure 1: Cross-section measurements for the associated production of a top quark and a W boson performed by ATLAS and CMS, and combined result compared with the NLO+NNLL prediction [20] (gray bands). Statistical and total uncertainties are represented by red and blue error bars, respectively. The uncertainties in the theoretical prediction are represented by dark and light gray bands for renormalisation/factorisation scale and PDF (evaluated using MSTW2008 [22]), respectively.

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