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Measurements of t-channel single top quark production in pp collisions

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A summmary of the measurements of the t-channel single top quark production cross section and properties in proton-proton collisions at the LHC with the CMS detector is presented. Inclusive cross section measurements at centre-of-mass energies of 7 and 8 TeV are exploited to extract constraints on the Cabibbo Kobayashi Maskawa matrix element V_{tb}. The charge ratio between t-channel top and antitop cross sections is presented, as well as the measurement of the W-boson helicity fractions in single-top events. All the measurements show good agreement with the standard model predictions.

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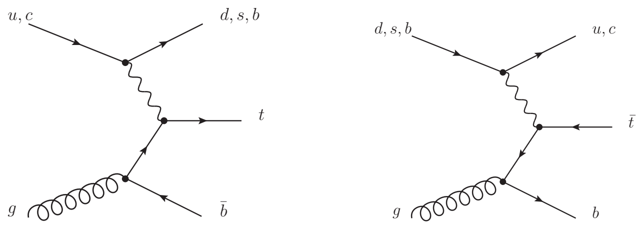
1. Introduction

Top quarks can be singly produced in proton-proton (pp) collisions via charged-current electroweak interactions. Three mechanisms contribute to single top-quarks production in the standard model (SM), referred to as the *t*, *s* and W-associated, or tW, channels. In proton-proton collisions at the Large Hadron Collider the *t*-channel mode is by far the most abundant of the three. The study of single top quark production provides a unique possibility to investigate many aspects of top-quark physics that cannot be easily probed in $t\bar{t}$ production: one can investigate the tWb vertex structure looking for anomalous couplings [1] and flavour-changing neutral current (FCNC) contributions [2] in the production. Moreover, all single-top channels' cross sections are are directly related to the modulus squared of the Cabibbo Kobayashi Maskawa matrix element V_{tb}. An additional feature of the *t* and *s* channels in pp collisions is the difference in the production cross section of top quarks with respect to antitops due to the different parton distribution functions (PDFs) of the quarks in the initial state, as the top quark inherits the sign of the charge from the light quark (u, d, s) involved in the hard scattering. The Feynman diagram for the *t*-channel is shown in Fig. 1.



(a) (b)

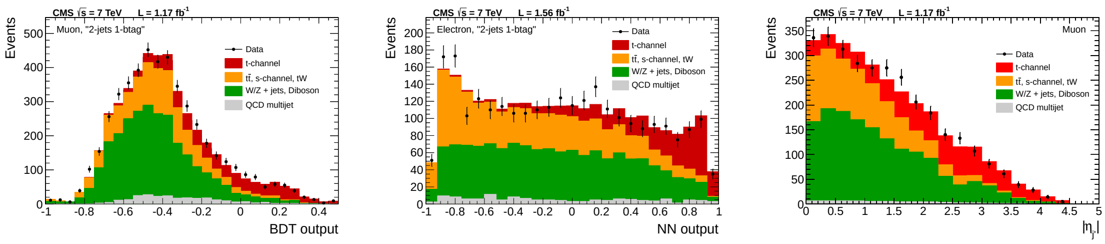
Figure 1: Leading order Feynman diagram for single-top (a) and anti-top (b) production in the *t*-channel.

Standard model predictions based on approximate next-to-next-to-leading-order (NNLO) from next-to-next-to-leading-logarithm (NNLL) calculations yield an expected total inclusive cross section of $\sigma^{\mathrm{th}}_{t\text{-ch.},\,7\,\mathrm{TeV}} = 64.6^{+2.1}_{-0.7}\,(\mathrm{scale})^{+1.5}_{-1.7}\,(\mathrm{pdf})\,\mathrm{pb}$ at 7 TeV [3], and $\sigma^{\mathrm{th}}_{t\text{-ch.},\,8\,\mathrm{TeV}} = 87.2^{+2.8}_{-1.0}\,(\mathrm{scale})^{+2.0}_{-2.2}$ (PDF) pb at 8 TeV [4] where the two contributions to the uncertainty are due to the variation of factorization and renormalization scale and to PDFs. The same calculations predicts at 8 TeV the following cross sections for top and antitop, separately $\sigma^{\mathrm{th}}_{t\text{-ch.},\,8\,\mathrm{TeV}}(\mathrm{t}) = 56.4^{+2.1}_{-0.3}\,(\mathrm{scale})^{+1.1}_{-1.1}\,(\mathrm{PDF})$ pb, and $\sigma^{\mathrm{th}}_{t\text{-ch.}\,8\,TeV}(\bar{\mathrm{t}}) = 30.7^{+0.7}_{-0.7}\,(\mathrm{scale})^{+0.9}_{-1.1}\,(\mathrm{PDF})$ pb for 8 TeV. We report here the measurements of the *t*-channel cross section performed by the Compact Muon Solenoid [5](CMS) experiment at 7 and 8 TeV, as well as the measurements of top charge ratio and W-boson polarisation in *t*-channel enriched events.

2. Cross section measurements

A precise measurement of the single-top *t*-channel cross section is important to spot eventual deviations from the standard model that modify the strength of the coupling at the tWb vertex. The single-top *t*-channel event topology features the top quark decay products, a jet stemming from the hadronisation of the light quark recoiling against the top, and a spectator b-quark. The top mostly decays to Wb. All the CMS analyses presented consider only the leptonic decay cascade of the top, producing a lepton and a neutrino in the final state. All single-top analyses at 7 and 8 TeV take advantage of this topology, selecting at least 2 jets with at least one of them being tagged as b-jet, one lepton and missing energy in the final state. The main standard model processes that constitute a background to this topology are $t\bar{t}$, W-bosons produced in association with jets, and *QCD* multijet.

At 7 TeV three different analyses are performed to extract the cross section [6]: two multivariate analyses using a boosted decision tree (BDT) discriminant and a neural network (NN) discriminant respectively, best exploiting the knowledge of the standard model single-top *t*-channel event topology to discriminate signal from the backgrounds; and an analysis based on a maximum likelihood fit on the pseudorapidity of the jet recoiling agains the top quark ($\eta_{j'}$). All analyses share a baseline selection requiring exactly one muon or electron in the final state, and a *QCD* rejection cuts on missing transverse energy in the detector ($\not{E}_{\mathrm{T}}$) for the electron channel, or the transverse mass constructed from of the lepton and missing energy (m_{T}) for the muon channel. The jet selection is different for the analyses, as the BDT and NN analyses select events with 2 to 4 jets and with 1 or 2 b-tags, while the $\eta_{j'}$ analysis selects events with exactly 2 jets, one of which b-tagged. To estimate the contribution of the *QCD* multijet background, all three analyses perform a fit to the $\not{E}_{\mathrm{T}}$ or m_{T} in the full range of the variable. The BDT and NN use a bayesian procedure for the signal extraction, treating most of the systematic uncertainties as nuisance parameters and marginalising them with the profile likelihood method. The W+jets background, is divided in the different components according to the flavour content of the jets and fitted separately. The $\eta_{j'}$ analysis makes a further requirement on the mass of the top quark reconstructed from the lepton, the neutrino, and the missing energy. The fit to $|\eta_{j'}|$ is then performed using for the W+jets component the distribution extracted from the region outside the cut. The three analyses are then combined with the BLUE method [7]. Figures in 2 shows the distributions of the discriminating variables



(a) (b) (c)

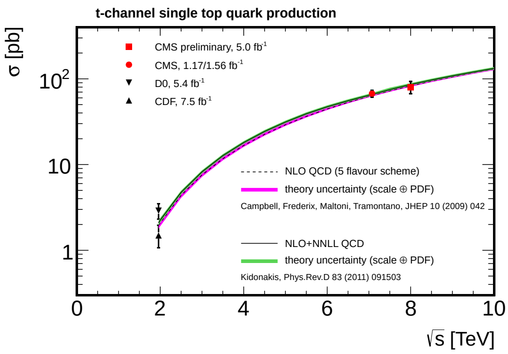
Figure 2: Discriminating variables in a sample with 2-jets, 1 of which b-tagged for the BDT analysis (a), the NN analysis(b), and the $\eta_{j'}$ analysis(c).

for each analysis normalised to the result of the signal extraction. The resulting cross section for 7 TeV is:

$$\sigma_{\text{t-ch., 7 TeV}} = 67.2 \pm 3.7\,(\text{stat.}) \pm 4.6(\text{syst.}) \pm 1.5(\text{lumi.}) \qquad (\text{ 7 TeV}). \tag{2.1}$$

At 8 TeV, the $\eta_{j'}$ analysis is ported with few optimisations to cope with the increased centre-of-mass energy and the different pileup scenario [8]. The resulting cross section is:

$$\sigma_{\text{t-ch., 8 TeV}} = 80.1 \pm 5.7\,(\text{stat.}) \pm 11.0(\text{syst.}) \pm 4.0(\text{lumi.}) \qquad (\text{ 8 TeV}). \tag{2.2}$$



(a)

Figure 3: Summary of the single-top t-channel cross section measurements as function of the centre-of-mass energy.

2.1 Extraction of $|V_{tb}|$

Another important consequence of including the tWb vertex in the produciton is that the cross section measurements can provide a direct measurement of $|V_{tb}|$ that does not rely on the assumptions on the number of generations of quarks. If one considers $|V_{td}|, |V_{ts}| << |V_{tb}|$, it yields $|V_{tb}| = \sqrt{\sigma_{meas.}/\sigma_{theory}}$. The results for 7 and 8 TeV are thus:

$$|V_{tb}| = 1.026 \pm 0.046\,(\text{meas.}) \pm 0.017(\text{th.}) \qquad (\text{ 7 TeV}). \tag{2.3}$$

$$|V_{tb}| = 0.96 \pm 0.08\,(\text{meas.}) \pm 0.016(\text{th.}) \qquad (\text{ 8 TeV}). \tag{2.4}$$

Under the assumption that $|V_{tb}| < 1$ one thus can retrieve a lower limit on $|V_{tb}|$ using the Feldman Cousins [9] approach:

$$0.92 < |V_{tb}| < 1 \,@\, 95\%\,\text{confidence level} \qquad (\text{ 7 TeV}). \tag{2.5}$$

$$0.81 < |V_{tb}| < 1 \,@\, 95\%\,\text{confidence level} \qquad (\text{ 8 TeV}). \tag{2.6}$$

3. Single top properties measurement

3.1 Top charge ratio

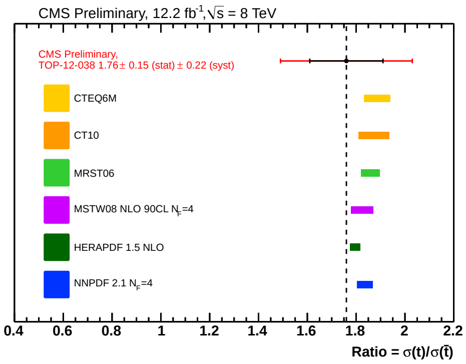
A measure of the ratio between the production cross sections for single top and antitop in the t-channel, R_{charge}, therefore, may provides a constraint on PDF modeling. R_{charge} is also directly sensitive to physics beyond SM manifested as anomalous couplings in the tWb vertex, or to possible contributions from Flavour Changing Neutral Current processes. The analysis $\eta_{j'}$ at 8 TeV has been repeated for events with positively and negatively charged leptons [10], obtaining the following result for the cross sections for top and antitop production and the respective ratio R_{charge}:

$$\sigma_{\text{t-ch., top, 8 TeV}} = 49.9 \pm 1.9\,(\text{stat.}) \pm 8.9(\text{syst.} + \text{lumi})\,\text{pb}. \tag{3.1}$$

$$\sigma_{\text{t-ch., antitop, 8 TeV}} = 28.8 \pm 2.4\,(\text{stat.}) \pm 4.9(\text{syst.} + \text{lumi})\,\text{pb} \tag{3.2}$$

$$R_{\text{charge}} = 1.76 \pm 0.15\,(\text{stat.}) \pm 0.022(\text{syst.}). \tag{3.3}$$

Figure 4 shows the charge ratio compared to the predictions of several parton distribution functions.



(a)

Figure 4: Charge ratio of single-top and antitop t-channel production at 8 TeV compared with predictions from different sets of parton distribution functions.

3.2 W helicity in t-channel

Due to electroweak nature of the top-quark decay, the fraction of left (F_L), right (F_L), and longitudinally polarised (F_0) W-bosons is predicted by the standard model.A precise measurement of such fractions allows to spot eventual deviaitons due to anomalous couplings in the tWb vertex which would modify the $V-A$ nature of the standard model coupling. The variable $\cos(\theta^*_l)$ is defined in the top-quark rest frame as the angle between the lepton 3-momentum in the W-boson rest-frame and the 3-momentum of W-boson, and its distribution is a function of the polarisation fractions. A measurement the W-helicity fractions is performed by CMS on 7 and 8 TeV data [11]. After applying the same selection as for the cross section measurements in Sec. 2, a fit to $\cos(\theta^*_l)$ is performed on both 7 and 8 TeV data. Figure 5(a) shows the distribution of $\cos(\theta^*_l)$ after the fit on 8 TeV data, and the extracted values of F_R and F_0 are compared with the standard model expectation in Fig. 5(b). The resulting values obtained from the combination of the 7+8 TeV fit are $F_L = 0.293 \pm 0.069\,(\text{stat.}) \pm 0.030\,(\text{syst.})$, $F_R = -0.06 \pm 0.057\,(\text{stat.}) \pm 0.027\,(\text{syst.})$, and $F_0 = 0.713 \pm 0.114\,(\text{stat.}) \pm 0.023\,(\text{syst.})$. This measurement can be used to extract direct limits on anomalous tensor terms in the couplings at the tWb vertex, shown in Figure 5(c).

4. Conclusions

A summary of the measurements of the single-top t-channel cross section and properties has been shown. The cross sections reported are $\sigma_{\text{t-ch., 7 TeV}} = 67.2 \pm 3.7$ (stat.) ± 4.6(syst.) ± 1.5

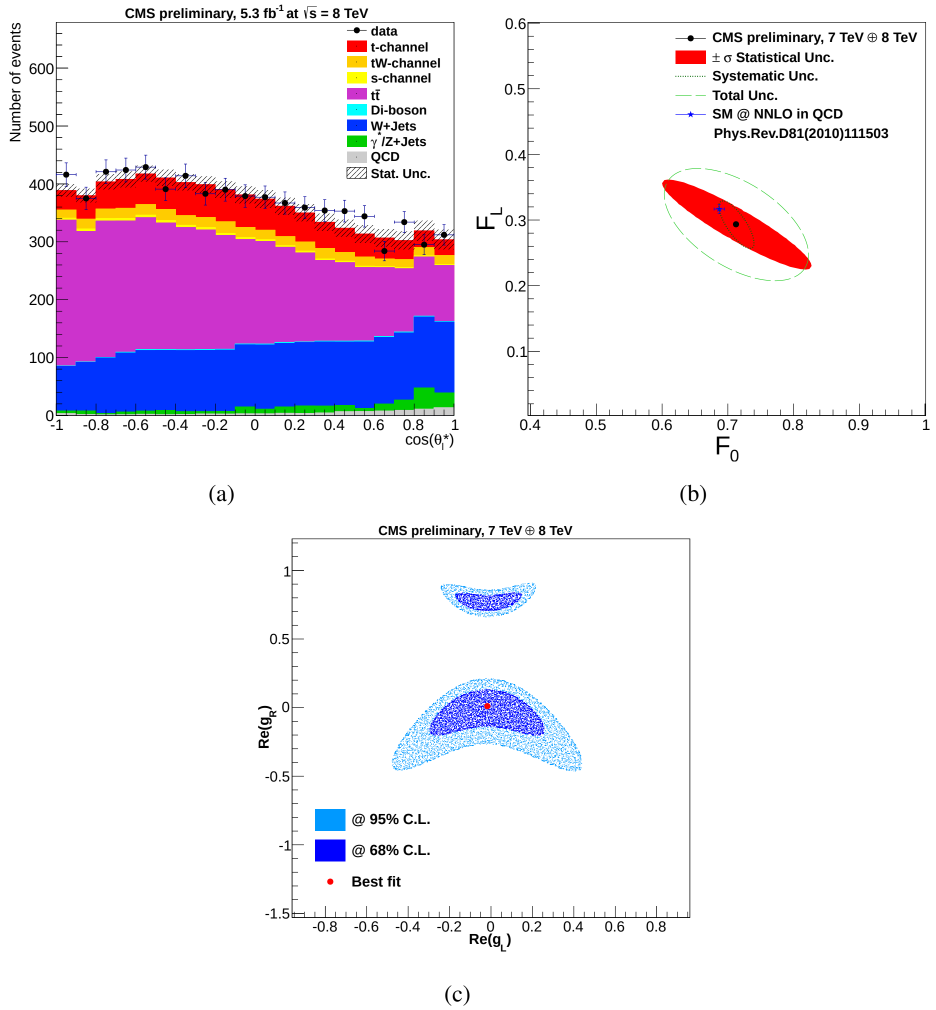


Figure 5: Distribution of $\cos(\theta_l^*)$ obtained from the fit (a), results of the fit plus in the $F_R - F_0$ plane versus the standard model prediction (b), and limit on left and right tensor coupling extracted from the W-helicity fractions measurement (c).

(lumi.) pb, and $\sigma_{\text{t-ch.}, 8\,\text{TeV}} = 80.1 \pm 5.7$ (stat.) ± 11.0 (syst.) ± 4.0 (lumi.) pb, in agreement with the standard model predictions. The $|V_{tb}|$ measurement extracted from the 7 TeV measurement, the most precise, is $|V_{tb}| = 1.026 \pm 0.046(\text{meas.}) \pm 0.017(\text{th.})$, and in the assumption of unitarity, one finds $0.92 < |V_{tb}| < 1$ @ 95%CL. The charge ratio was measured at 8 TeV, resulting in $R_{\text{charge}} = 1.76 \pm 0.14$ stat ± 0.10 (syst.). The W-helicity fractions in single-top events are measured to be $F_L = 0.293 \pm 0.069$ (stat.) ± 0.030 (syst.), $F_R = -0.06 \pm 0.057$ (stat.) ± 0.027 (syst.), and $F_0 = 0.713 \pm 0.114$ (stat.) ± 0.023 (syst.), allowing also to extract limits on the anomalous tensor terms in the couplings. All the measurements show good agreement with the standard model predictions.

References

[1] Single top quark production at LHC with anomalous Wtb couplings, Aguilar-Saavedra, J.,Nucl. Phys. B 804 (2008) 160-192

[2] Search for anomalous top quark production at the early LHC, Gao, J. et al., Phys. Rev. Lett. 107 (2011) 092002.

[3] Next-to-next-to-leading-order collinear and soft gluon corrections for t-channel single top quark production, N. Kidonakis, Phys. Rev. D 83, 091503(R)

[4] Differential and total cross sections for top pair and single top production, N. Kidonakis, arXiv:1205.3453

[5] CMS Collaboration, "The CMS experiment at the CERN LHC", JINST 03 (2008) S08004.

[6] Measurement of the single-top-quark t-channel cross section in pp collisions at $\sqrt{s} = 7$ TeV , The CMS Collaboration, JHEP12(2012)035

[7] How to combine correlated estimates of a single physical quantity, Lyons, L. et al, Nucl. Instr. and Meth. A 270 (1988) 110.

[8] Measurement of the single top t-channel cross section in pp collisions at $\sqrt{s} = 8$ TeV , The CMS Collaboration, CMS PAS TOP-12-011

[9] A unified approach to the classical statistical analysis of small signals, Feldman, Gary J. and Cousins, Robert D., Phys. Rev. D 57 (1998) 3873, doi:10.1103/PhysRevD.57.3873, arXiv:physics/9711021.

[10] Measurement of the single-top t-channel charge ratio at 8 TeV, The CMS Collaboration, CMS PAS TOP-12-038

[11] W-helicity measurement in single top events topology, The CMS Collaboration, CMS PAS TOP-12-020

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