PROCEEDINGS OF SCIENCE

Single top quark production measurements in CMS

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Single top quark can be produced via the electroweak interaction of the protons at the CMS experiment. There are 3 production mechanisms, known as t, tW and s channels. Studying the production of the single-top quark production in all these channels helps in better understanding of the electroweak interaction for heavy quarks. Recent results on the cross section measurements in proton-proton collisions by the CMS collaboration at center-of-mass energies of 7,8 and 13 TeV are reviewed in this report.

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1. Introduction

In proton-proton (pp) collisions, the top quark can be produced via the electroweak interaction in 3 different channels : t-channel, W-associated (tW) channel and s-channel. The feynman diagram of all of these channels are presented in Fig.1. In opposite to the pure QCD production which always leads to a pair of top-quarks, in all of the production modes that the electroweak interaction is involved, just a single-top quark is produced. The production of top quark in the single mode was first discovered at the Tevatron [1, 2]. At the Large Hadron Collider (LHC) the dominant process is the t-channel mode, which amounts to almost 80% of the total single top quark production cross section. The other two production mechanisms, tW production and production via the s-channel have smaller contribution. [3].

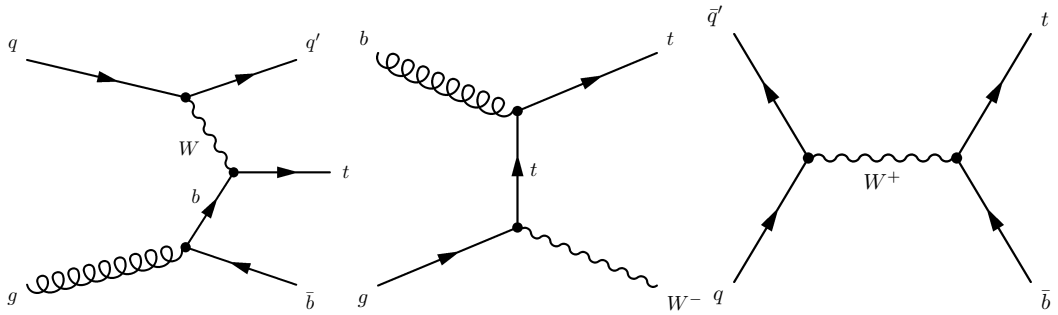

Figure 1: The leading order feynman diagrams of the single-top quark production in t-channel (left), tW-channel (middle) and s-channel (right).

Studying the cross section of these processes helps in understanding the electroweak interaction of the heavy quarks and provides a model independent probe of the CKM matrix element (V_{tb}). The CMS [4] collaboration has analyzed the 7 [5, 6],8 [7, 8] and 13 TeV datasets and has measured the cross section of different production modes. In this report, the most recent results are summarized.

2. Cross section measurements of t-channel single-top-quark production at 13 TeV

The 2015 dataset of pp collisions which corresponds to 2.3 fb^{-1} has been analyzed by the CMS collaboration to measure the inclusive [9] and differential [10] cross section of the single top production via a t-channel mode at the center of mass energy of 13 TeV. In the analysis solely single muon final states are considered. Events with exactly one isolated muon with the transverse momentum of $p_T > 22$ GeV are selected. As it is shown in Fig.1(left), the presence of a light quark recoiling against the top quark which is within detector acceptance is one of the most distinct features of the t-channel production mode. In order to benefit from this forward jet in the selection, all the reconstructed jets with $p_T > 40$ GeV and $|\eta| < 4.7$ are selected. Events with exactly two chosen jets from which one is tagged as b-jet, are selected as the signal region, which is entitled to "2J1T". To control the $t\bar{t}$ background, a control region with 3 selected jets among which one or two are tagged as b-jet is defined (3J1T, 3J2T).

Multijet background events are discarded by applying a cut on the transverse mass of the W boson (m_T). These events are expected to accumulate in the low m_T region, as shown in Fig. 2. It

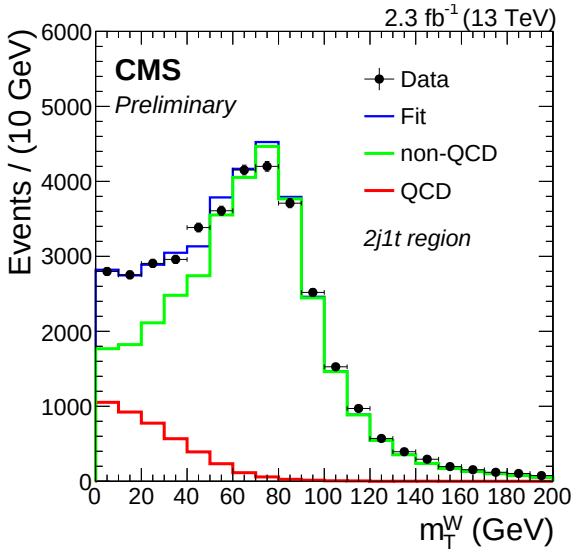

Figure 2: Fit to the m_{T} distributions in the 2-jets-1-tag sample. The QCD fit template is derived from a side band region in data. Only statistical uncertainties are taken into account in the fit.

has been found that discarding events with $m_{\mathrm{T}} < 50$ GeV helps in reducing this background. The shape of the distribution of m_{T} for multijet events is obtained in a similar region to the signal but with anti-isolated muons and is used to estimate the contamination of the QCD-multijet background in the signal region.

Multivariate techniques (MVA) are used to separate the signal from $\mathrm{t\bar{t}}$ and W+jets backgrounds. For the inclusive cross section measurement, a neural network (NN) is trained while for the differential measurement, the Boosted Tree Decision (BDT) is found more reliable. The output MVA distributions of both analysis are shown in Fig 3. The inclusive cross section is estimated using a simultaneous binned maximum-likelihood (ML) fit to the distribution of its discriminant in signal (2J1T) and $\mathrm{t\bar{t}}$ control regions (3J1T and 3J2T). The inclusive cross section is measured σ = 227.8 + 33.7 - 33.0 pb which agrees well with the next-to-leading order prediction of $\sigma^{\mathrm{th}}_{\mathrm{t-ch.}} = 216.99^{+6.62}_{-4.64}\,(\mathrm{scale}) \pm 6.16\,(\mathrm{PDF})$ pb [11]. Assuming that the other relevant matrix elements ($|\mathrm{V_{td}}|$ and $|\mathrm{V_{ts}}|$) are much smaller than$|\mathrm{V_{tb}}|$, the product of $|\mathrm{V_{tb}}|$ with a an anomalous left-handed form factor $|f_{LV}|$ can be estimated as :

$$|\mathrm{f_{LV}V_{tb}}| = \sqrt{\frac{\sigma_{\mathrm{t-ch.}}}{\sigma^{\mathrm{th}}_{\mathrm{t-ch.}}}} = 1.02 \pm 0.07(\mathrm{exp.}) \pm 0.02(\mathrm{theo.}),$$

The charge ratio is also measured using separate fits to the MVA distributions from top quark and antiquark events. A good agreement is observed with the measured ratio comparing to the predictions by various PDF sets.

To measure the differential cross section, simultaneous fits are performed to the distributions of m_{T} and the BDT output of the events within an interval of the p_{T} and rapidity of the top quark. The results are unfolded to parton level and compared to the predictions by various generator. The results are shown in Fig. 4

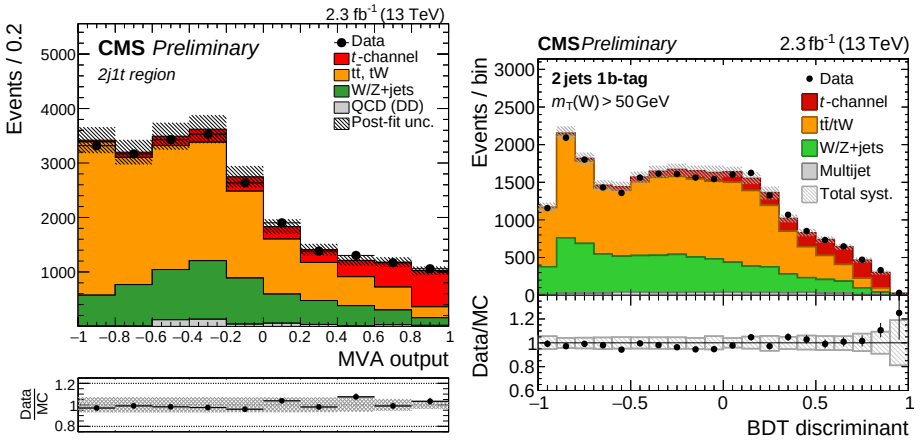

Figure 3: The distribution of the MVA output for the inclusive (left) and differential (right) measurements.

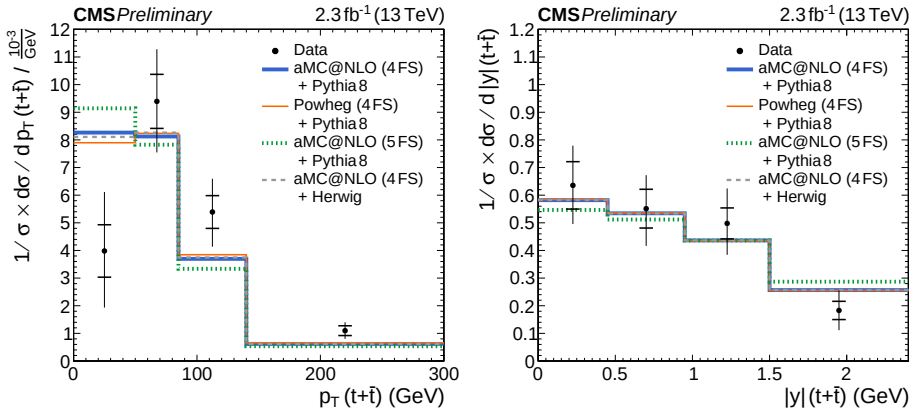

Figure 4: The differential cross section of the single top production in the t-channel mode vs p_{T} (left) and rapidity (right) of the top quark.

3. Search for s-channel single top quark production at 7 and 8 TeV

The production of the single top via the s-channel at LHC has the lowest cross section among all channels. Its value has been calculated up to the Next-to-leading order (NLO) and next-to-next-to-leading-logarithm (NNLL) level [12] and is found to be $\sigma^{7\ \mathrm{TeV}}_{s-ch.} = 4.6 \pm 0.2$ pb and $\sigma^{8\ \mathrm{TeV}}_{s-ch.} = 5.6 \pm 0.2$ pb.

The CMS collaboration has analyzed the full dataset of 7 and 8 TeV to search for this very rare standard model process [13]. Leptonic (e or μ) decays of the top quark are combined to increase the sensitivity. All the events with exactly one isolated lepton with p_{T} thresholds ranging from 20 GeV to 30 GeV (corresponding to the trigger level threshold) are selected. After requesting for 2 b-tagged jets with $p_{\mathrm{T}} > 40$ GeV, the main overwhelming background is $\mathrm{t\bar{t}}$. To separate the signal from background, different BDTs are trained for ℓ and μ per center-of-mass energy. The distribution of the BDT outputs in the 8 TeV dataset are shown in Fig. 5

The individual cross sections are extracted using the ML fit and obtained as $\sigma^{7\ \mathrm{TeV}}_{s-ch.} = 7.1 \pm 8.1$ pb and $\sigma^{8\ \mathrm{TeV}}_{s-ch.} = 13.4 \pm 7.3$ pb. The combined fit to the 7 and 8 TeV data, results to the signal strength of $\beta = 2.0 \pm 0.9$ where $\beta = \sigma^{meas.}/\sigma^{theo.}$ with the observed(expected) significance of

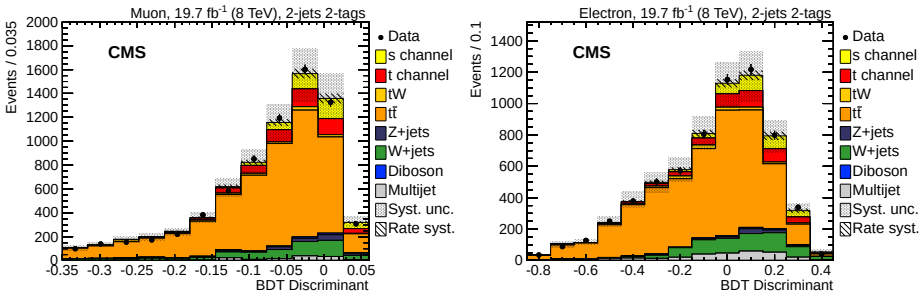

Figure 5: The comparison of the BDT output for the s-channel analysis, optimized for the 8 TeV analysis for muon (left) and electron (right) channels.

$2.5(1.1)\sigma$.

4. Summary

The results of the measurement of the inclusive and differential cross section of the t-channel production of the single top using the full 2015 pp dataset were presented. In addition, the results of the search for the s-channel which has the lowest production rate were reviewed. All the CMS measurements, including the measurement of the tW-channel cross section [14] at 8 TeV are shown together in the Fig. 6.

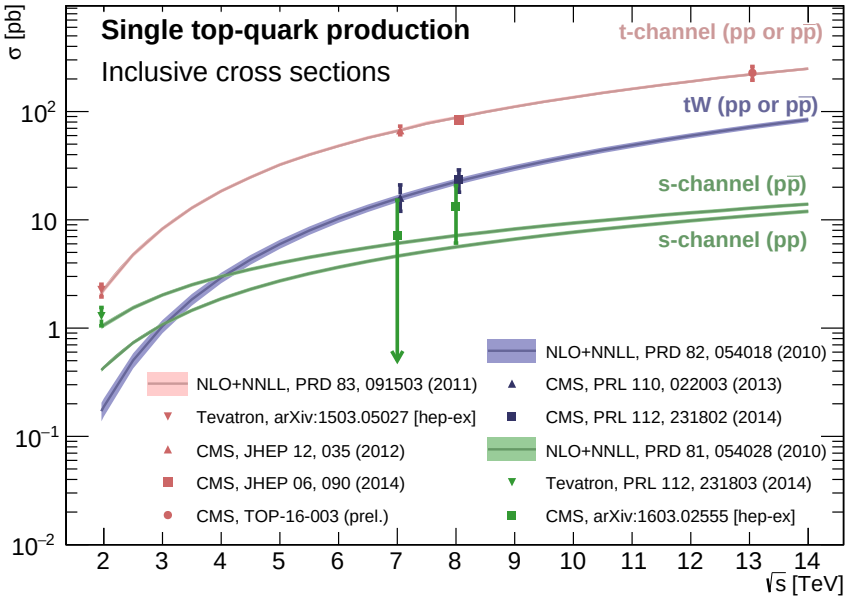

Figure 6: The summary of all the measured single top cross sections by the CMS experiments at different center-of-mass energies.

References

[1] T. Aaltonen et al. First Observation of Electroweak Single Top Quark Production. *Phys. Rev. Lett.*, 103:092002, 2009.

[2] V. M. Abazov et al. Observation of Single Top-Quark Production. *Phys. Rev. Lett.*, 103:092001, 2009.

[3] Nikolaos Kidonakis. Differential and total cross sections for top pair and single top production. page 831, 2012.

[4] S. Chatrchyan et al. The CMS experiment at the CERN LHC. *JINST*, 3:S08004, 2008.

[5] Serguei Chatrchyan et al. Measurement of the single-top-quark t-channel cross section in pp collisions at $\sqrt{s} = 7$ TeV. *JHEP*, 12:035, 2012.

[6] Serguei Chatrchyan et al. Evidence for associated production of a single top quark and W boson in pp collisions at $\sqrt{s}$ = 7 TeV. *Phys. Rev. Lett.*, 110:022003, 2013.

[7] Vardan Khachatryan et al. Measurement of the t-channel single-top-quark production cross section and of the $| V_{tb} |$ CKM matrix element in pp collisions at $\sqrt{s}$= 8 TeV. *JHEP*, 06:090, 2014.

[8] Single top t-channel differential cross section at 8 TeV. Technical Report CMS-PAS-TOP-14-004, CERN, Geneva, 2014.

[9] Vardan Khachatryan et al. Measurement of the top quark pair production cross section in proton-proton collisions at $\sqrt{(s)} = 13$ TeV. *Phys. Rev. Lett.*, 116(5):052002, 2016.

[10] Measurement of the differential cross section for t-channel single-top-quark production at $\sqrt{s} = 13$ TeV. Technical Report CMS-PAS-TOP-16-004, CERN, Geneva, 2016.

[11] M. Aliev, H. Lacker, U. Langenfeld, S. Moch, P. Uwer, and M. Wiedermann. HATHOR: HAdronic Top and Heavy quarks crOss section calculatoR. *Comput. Phys. Commun.*, 182:1034–1046, 2011.

[12] Nikolaos Kidonakis. NNLL threshold resummation for top-pair and single-top production. *Phys. Part. Nucl.*, 45(4):714–722, 2014.

[13] Vardan Khachatryan et al. Search for s channel single top quark production in pp collisions at $\sqrt{s} = 7$ and 8 TeV. *JHEP*, 09:027, 2016.

[14] Serguei Chatrchyan et al. Observation of the associated production of a single top quark and a W boson in pp collisions at $\sqrt{s}$ =8 TeV. *Phys. Rev. Lett.*, 112(23):231802, 2014.