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Recent $t\bar{t}$ and single top inclusive cross section results in CMS

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With the delivered luminosity of around 150 fb^{-1} at a center-of-mass energy of 13 TeV during Run 2, almost 200 million top quarks were produced at the LHC. As top quarks can be produced through either strong or electroweak interaction, they are a suitable tool to probe the strong and electroweak sector of the Standard Model. In particular, precision measurements of the top quark pair ($t\bar{t}$) and of single top quark production cross section deliver constraints on the top quark mass, the strong coupling α_S, the parton distribution functions, and the CKM matrix element $|V_{tb}|$. In this contribution, recent measurements of the inclusive $t\bar{t}$ and single top quark cross sections performed by the CMS experiment, as well as the ATLAS and CMS combination of the Run 1 single top quark results, are presented.

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1. Inclusive $t\bar{t}$ cross section measurements

Precision measurements of the inclusive top quark pair ($t\bar{t}$) production cross section are crucial to constrain free parameters of the Standard Model (SM) such as the top quark mass and the strong coupling α_S. As $t\bar{t}$ production is the dominant background of many analyses beyond the SM, this process needs to be well understood. At $\sqrt{s} = 13\,\text{TeV}$, the predicted $t\bar{t}$ cross section is $832^{+20}_{-29}\,(\text{scale}) \pm 35\,(\text{PDF} + \alpha_S)$ (NNLO+NNLL) [1]. In this contribution, two recent $t\bar{t}$ analyses with dileptonic final states are presented, both using the 2016 data set recorded by the CMS experiment [2].

1.1 The ee, $\mu\mu$ and eμ final states

In this analysis [3], $t\bar{t}$ events containing two leptons (muons and/or electrons) are selected and categorized according to the number of jets with a transverse momentum of $p_T > 30\,\text{GeV}$ and according to the multiplicity of b-tagged jets. By performing a profile likelihood ratio fit in the fiducial region and extrapolating to the full phase space, the inclusive cross section is extracted. The fit is performed on the p_T distribution of the additional untagged jet of each event category, shown in Fig. 1. The measured cross section is

$$\sigma_{t\bar{t}} = 803 \pm 2\,(\text{stat}) \pm 25\,(\text{syst}) \pm 20\,(\text{lumi})\,\text{pb}, \tag{1}$$

assuming a top quark mass of $m_t^{MC} = 172.5\,\text{GeV}$. With a total uncertainty of 4.0%, the precision of this measurement is beyond the one of the theory prediction (5.2%). An additional fit is performed to simultaneously extract $\sigma_{t\bar{t}}$ and m_t^{MC} in the eμ final state by using the minimum invariant mass $m_{\ell b}$ as shown in Fig. 1:

$$\sigma_{t\bar{t}} = 815 \pm 2\,(\text{stat}) \pm 29\,(\text{syst}) \pm 20\,(\text{lumi})\,\text{pb}, \tag{2}$$

$$m_t^{MC} = 172.33 \pm 0.14\,(\text{stat})^{+0.66}_{-0.72}\,(\text{syst})\,\text{GeV}. \tag{3}$$

These results are compatible with the predicted cross section and with previous m_t^{MC} measurements, respectively. Using the result in Eq. (2), the top quark mass and the strong coupling $\alpha_s(m_Z)$ are determined in the $\overline{\text{MS}}$ scheme for different PDF sets. Details on this measurement are given in Ref. [3].

1.2 e/μ + τ_h final state

Events with either one muon or one electron, and one hadronically decaying tau lepton of opposite sign are selected in this analysis [4]. Furthermore, at least two jets with $p_T > 30\,\text{GeV}$, and at least one b-tagged jet are required. The signal and background categories are defined by calculating jet triplets for each combination of one b-tagged and two untagged jets. These jet triplets are then used to calculate the distance parameter $D_{jjb} = \sqrt{(m_W - m_{jj})^2 + (m_t - m_{jjb})^2}$. The distribution of D_{jjb} is shown in Fig. 2. Events are categorized as signal if $D_{jjb} > 60\,\text{GeV}$ or if there is only one untagged jet. The cross section is extracted by performing a profile likelihood ratio fit to the transverse mass $m_T(\ell, p_T^{miss}) = \sqrt{2|\vec{p}_T^{\,\ell}||\vec{p}_T^{\,miss}|(1 - \cos\Delta\phi)}$ in the signal- and background-like categories of the eτ_h and $\mu\tau_h$ final states. In Fig. 2, the $m_T(\ell, p_T^{miss})$ distribution is shown. The

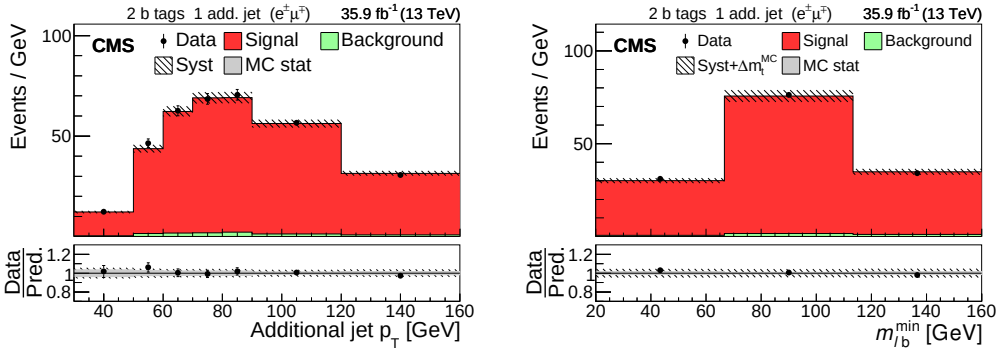

Figure 1: The distribution of the additional jet p_T (left) and of the invariant mass $m_{\ell b}$ (right) are shown for the 2 b tags 1 add. jet category of the eμ final state. Taken from Ref. [3].

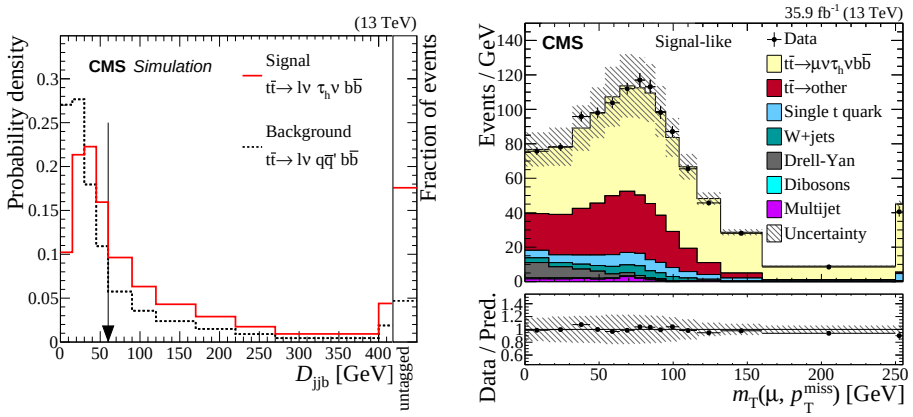

Figure 2: The distribution of the distance parameter D_{jjb} (left) is shown for the signal and main background process. Good agreement between data and prediction is observed in the $m_T(\mu, p_T^{miss})$ distribution (right) of the signal-like category. Taken from Ref. [4].

measured cross section precision is dominated by the τ_h misidentification uncertainty and is given by

$$\sigma_{t\bar{t}} = 781 \pm 7\,(\text{stat}) \pm 62\,(\text{syst}) \pm 20\,(\text{lumi})\,\text{pb}, \tag{4}$$

which is in agreement with the theory prediction. Using the result in Eq. (1), the cross section ratio is calculated:

$$R_{\ell\tau_h/\ell\ell} = 0.973 \pm 0.009\,(\text{stat}) \pm 0.066\,(\text{syst}). \tag{5}$$

As this result is compatible with unity, no sign of lepton universality violation is found.

2. Inclusive single top cross section measurements

As single top quarks are produced through the electroweak interaction, the CKM matrix element $|V_{tb}|$ can be directly extracted from the measurement of the inclusive cross section. Furthermore, the cross section ratio between top quark and top antiquark production constrains different sets of parton distribution functions (PDFs). Two recent measurements are presented in this talk, both analyzing the 2016 data set of the CMS experiment.

2.1 Production via the t-channel

With a predicted cross section of 217^{+7}_{-5} (scale) ± 6 (PDF + α_S) pb (NLO, HATHOR 2.1) [5, 6], the t-channel process is the most dominant single top production mode at the LHC. In the presented analysis [7], the inclusive t-channel cross section, as well as the cross section ratio between top quarks and top antiquarks, as well as $|V_{tb}|$, are determined with events containing one electron or muon. According to the number of jets (j) and b-tagged jets (t) with $p_T > 40$ GeV, three different event categories are defined: the 2j1t signal category and the 3j1t and 3j2t $t\bar{t}$ control categories. A boosted decision tree (BDT) is trained in the 2j1t category to separate the signal process from all background contributions. The distribution of the BDT output values is shown in Fig. 3. The t-channel top quark and top antiquark cross sections as well as their ratio $R_{t\text{-ch.}}$ are simultaneously extracted by a maximum likelihood fit on the BDT output distribution in all event categories. A total cross section of

$$\sigma_{t\text{-ch.}} = 207 \pm 1\,(\text{stat}) \pm 31\,(\text{syst})\,\text{pb} \tag{6}$$

is obtained and the result for $R_{t\text{-ch.}}$ is shown, in comparison with predictions of different PDF sets, in Fig. 3. The total t-channel cross section in Eq. 6 is used to extract $|V_{tb}|$:

$$|f_{LV}V_{tb}| = \sqrt{\sigma_{t\text{-ch.}}/\sigma^{\text{theo.}}_{t\text{-ch.}}} = 0.98 \pm 0.02\,(\text{exp}) \pm 0.07\,(\text{theo}), \tag{7}$$

with the anomalous form factor for left-handed vector couplings f_{LV} (unity for SM). All results agree well with the SM predictions.

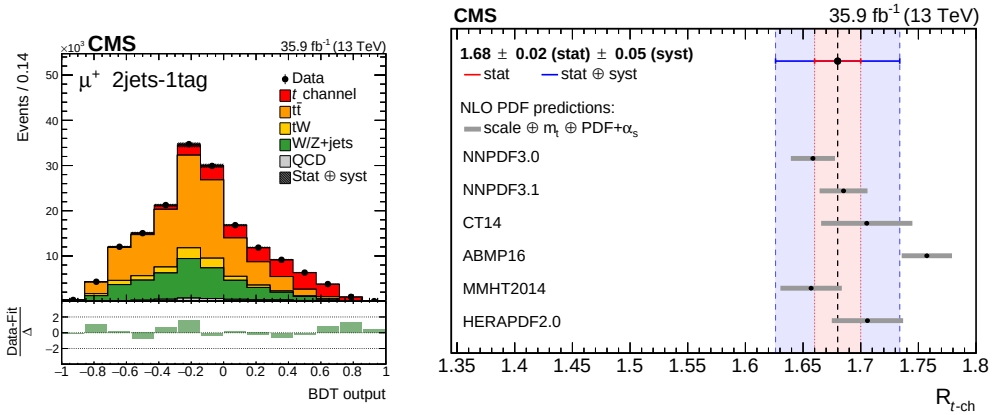

Figure 3: The distribution of the BDT output values in the 2j1t category (left) and the measured cross section ratio $R_{t\text{-ch.}}$ in comparison with different PDF predictions (right) are shown. Taken from Ref. [7].

2.2 Associated production with a W boson

Single top quark production in association with a W boson (tW) is predicted with a cross section of 72 ± 2 (scale) ± 3 (PDF + α_S) pb (approx. NNLO) [8, 9]. Events with one electron and one muon are selected in this analysis [10], and are categorized into three different event categories according to the number of jets (j) and b-tagged jets (b) with $p_T > 30$ GeV. To account for the interference between the NLO tW process with the $t\bar{t}$ background, the diagram removal scheme is applied. In the 1j1b signal and 2j1b control categories, a BDT is trained to discriminate the

signal process against the $t\bar{t}$ background. The BDT output distributions are shown in Fig. 4. By performing a maximum likelihood fit on these two distributions and on the p_T distribution of the subleading jet in the 2j2b control category, the tW cross section is measured as

$$\sigma_{tW} = 63.1 \pm 1.8\,(\text{stat}) \pm 6.4\,(\text{syst}) \pm 2.1\,(\text{lumi})\,\text{pb}, \tag{8}$$

which is in agreement with the SM prediction.

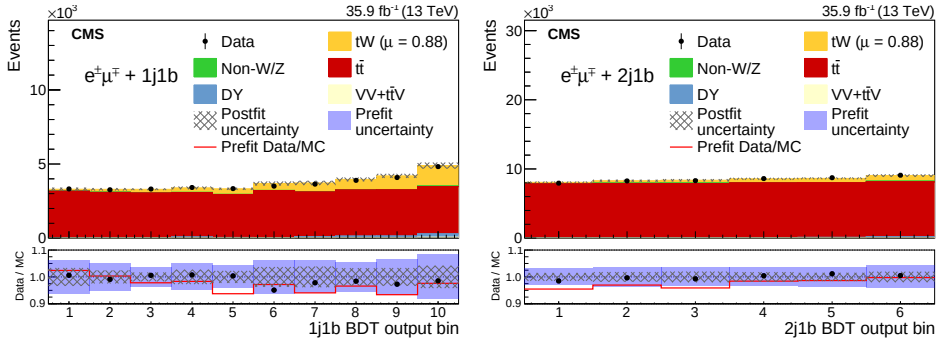

Figure 4: The post-fit distribution of the BDT output values in the 1j1b signal category (left) and in the 2j1b control category (right) are shown. Taken from Ref. [10].

3. LHC combination of Run-1 single top results

In a dedicated analysis [11], the 7 and 8 TeV single top quark cross section measurements of the ATLAS and CMS Collaborations are combined for all three main production modes: the t channel, tW, and the s channel. The results are shown in Fig. 5. The most precise result is obtained for the t-channel cross section measurement at 8 TeV. Using the combined cross section results, the CKM matrix element $|V_{tb}|$ is extracted, separately for each production mode and for all production processes combined. The results are presented in Fig. 5. In comparison with the measurement at the Tevatron [12], the most precise $|V_{tb}|$ measurement is obtained in this combination.

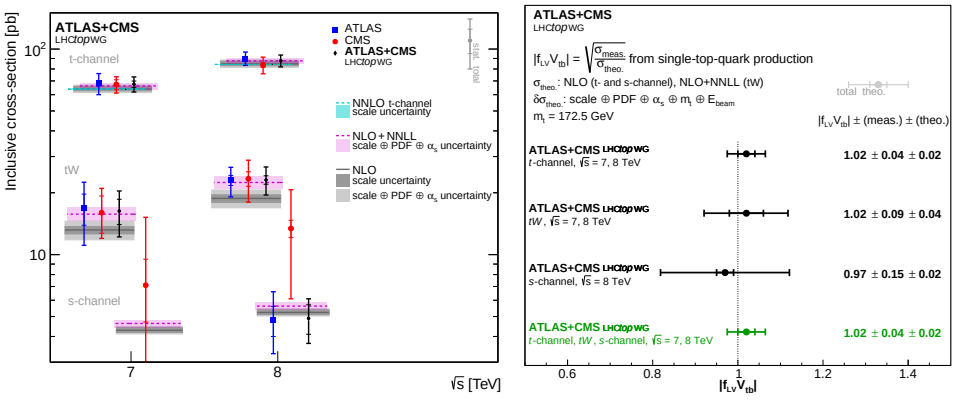

Figure 5: The results for the combined single top quark cross sections (left) and for $|V_{tb}|$ (right) are shown. Taken from Ref. [11].

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