PROCEEDINGS OF SCIENCE

Top Quark Cross Section Measurements with CMS

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Measurements of the inclusive top quark pair production cross section at 7 TeV and 8 TeV are presented, based on CMS data collected in 2011 and 2012. The total cross section is measured in the lepton+jets, dilepton and fully hadronic channels, including the tau-dilepton and tau+jets modes. Indirect constraints on both the top quark mass and α_s are obtained through their relation to the inclusive cross section. First measurements of top quark pair production with additional b-quarks in the final state are also presented. Differential cross sections are measured as functions of various kinematic observables, including the transverse momentum and rapidity of the (anti)top quark and the top-antitop system and the jets and leptons of the event final state. Multiplicity and kinematic distributions of the jets produced in addition to the top-quark pair are also investigated. The results are combined and confronted with precise theory calculations.

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1. Introduction

The top quark is the most massive known particle and unlike any other quark, it decays before hadronisation. This facilitates a direct measurement of the top quark properties. Due to its large mass, the top quark plays a crucial role in electroweak loop corrections, providing indirect constraints on the Higgs boson mass. The direct measurement of its Yukawa coupling, expected to be of the order 1, can also shed light on possible beyond-the-standard-model physics, for example through the possible coupling to new particles. Top-quark measurements also allow comparison to precision QCD calculations.

Top quarks at the LHC are mostly produced in pairs via the strong interaction. The gluon-gluon fusion is the dominant mechanism, corresponding to about 80% of the cases. For a mass of the top quark of 172.5 GeV, the total cross-section $\sigma_{t\bar{t}}$ at a center of mass energy $\sqrt{8}$ TeV is 252.89$\pm^{6.39}_{8.64}$ (scales) $\pm^{11.67}_{11.64}$ (pdf) $\pm^{7.58}_{7.33}$ (mass) pb [1, 2]. The cross section at 13 TeV will be about 3.3 times larger. The top quark decays in almost 100% of the cases into a W boson and a b quark. The decay of the W defines the final state of the process and thus $t\bar{t}$ decays are classified as dileptonic, if both W decay into leptons, as semi-leptonic if one of the W decays into a lepton and the other one into quarks, and finally as fully hadronic, if both W decay into quarks.

In the following, the main analyses of top-quark pair production performed at CMS are presented, focusing on results measured at 8 TeV, but also presenting some relevant results at 7 TeV. All public CMS results on top-quark physics can be found in [3].

2. Production

In the following, selected results for both inclusive and differential top-pair production cross sections will be presented.

2.1 Inclusive top-pair production cross section

The inclusive cross section results at 7 TeV include all decay channels except for $\tau\tau$, whereas at 8 TeV $t\bar{t}$ cross sections have been measured in the dilepton, semi-leptonic and τ-plus-lepton channels so far. All the results show a very good agreement with each other and with the theory predictions. The currently publicly available results at 7 and 8 TeV can be seen in figure 1.

The dilepton channel analysis at 8 TeV is performed using a cut-and-count approach, and the dominant systematics are JES and background modelling. The clean final state and small background of this process allow a precision up to 5% for the cross-section measurement [5].

The τ-plus-leptons channel cross section measurement at 8 TeV is difficult due to the correct τ identification, the fake τ being the main systematic uncertainty, leading to a precision of the cross section measurement of about 10% [6].

The most precise measured cross section so far is the LHC combination for ATLAS and CMS: $\sigma_{t\bar{t}} = 241.5 \pm 8.5$ pb [8].

Given the high-precision measurements available for $\sigma_{t\bar{t}}$, for a chosen set of parton distribution functions (PDF), it is possible to fix the value of the m_t and determine the value of α_s. The obtained values for different PDF sets agree with the official PDG value [7].

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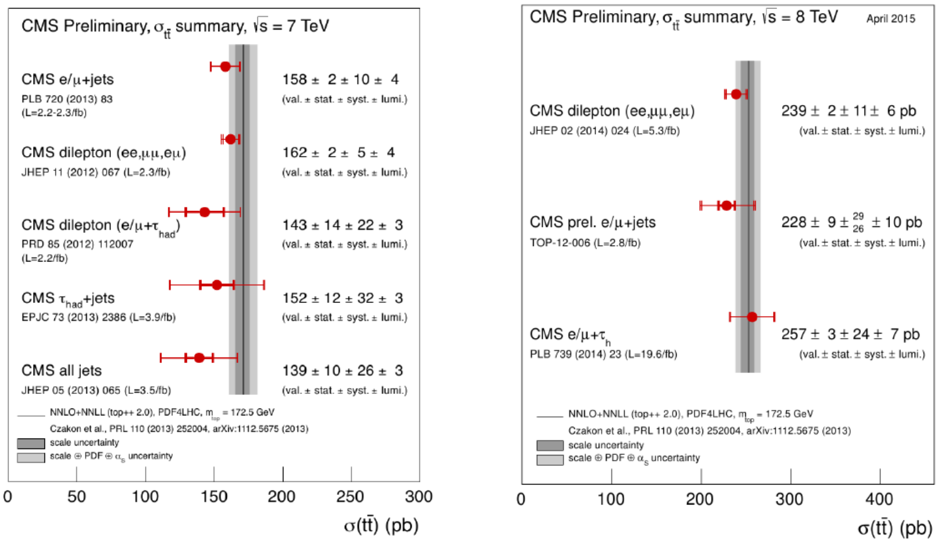

Figure 1: Summaries of inclusive $t\bar{t}$ cross section measured with the CMS detector at 7 and 8 TeV respectively, from [4]

2.2 Differential top-pair production cross section

Differential cross sections provide precise tests of perturbative QCD in different kinematic regions of the phase space, for the tuning of MC generators and for theory predictions, as well as the setting of constraints on BSM effects.

Several measurements of differential top-pair quark cross sections were performed by the CMS Collaboration, not only as a function of top quark final state, such as leptons and jets, but also as a function of the top quark kinematics [9, 10]. Also, exclusive measurements of $t\bar{t}$ pairs produced in association with other objects, like jets [11, 12] or global event variables [13] have been performed.

The measurements are corrected for detector effects and a regularised unfolding procedure is used to determine the cross section at parton or particle-level, for direct comparison with theory calculations. At particle level, detector effects such as efficiencies and resolution effects are removed. At parton level, hadronisation effects are corrected. All the cross sections are normalised to the in-situ measured total cross section in order to cancel in the ratio the systematic uncertainties correlated between all bins.

In general good agreement between data and the different theory models is observed. No deviation from the SM is seen (see figures 2 and 3). Both p_T^{top} and $m_{t\bar{t}}$ show a softer spectrum in data. ATLAS and CMS collaborations see the same behaviour, especially towards high values of p_T^{top}.

2.3 Cross section measurements with additional particles in the final state

Differential cross section measurements, have also been performed with additional gluons or quarks in the final state.

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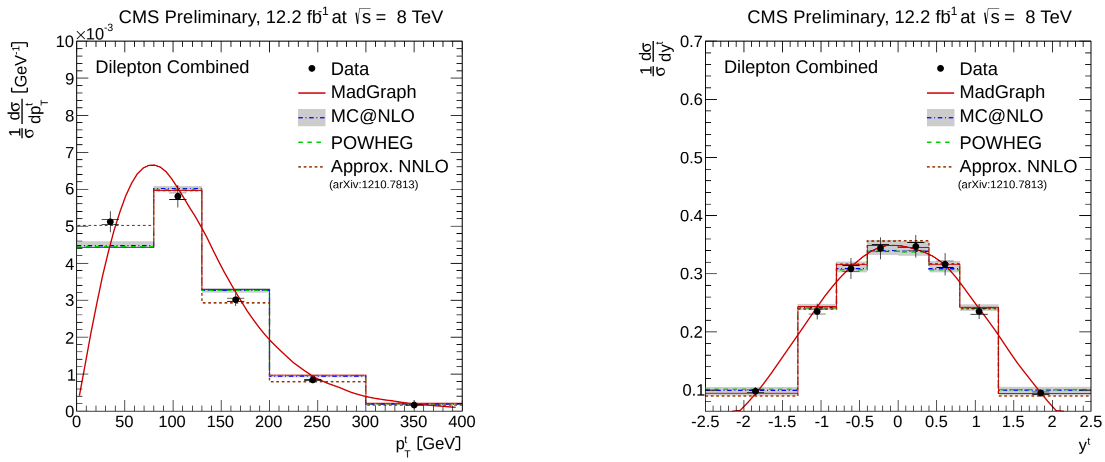

Figure 2: $t\bar{t}$ differential cross section as a function of the top quark p_T^{top} and y^{top} respectively at 8 TeV, from [10]

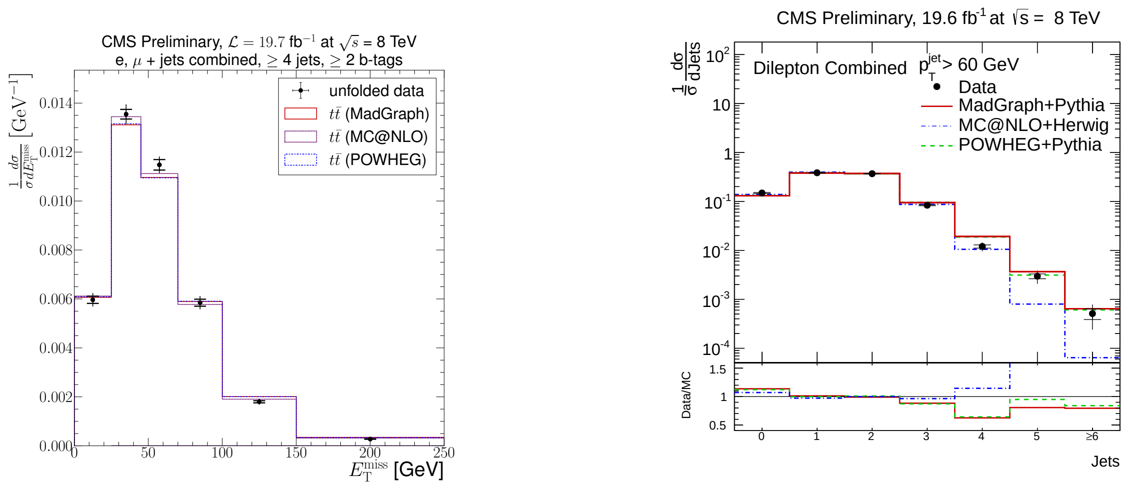

Figure 3: $t\bar{t}$ differential cross section as a function of the global variable MET, and as a function of different jet multiplicities ($p_T^{Jet} > 60$ GeV) respectively at 8 TeV, from [13] and [12] respectively

2.3.1 Gap fraction

The jet activity arising from quark and gluon radiation produced with the $t\bar{t}$ system is quantified by the so-called gap-fraction, i.e. the determination of the fraction of events that do not contain additional jets above a given threshold (see figure 4 for H_T threshold observable). The gap fraction is useful for the understanding of extra radiation in $t\bar{t}$ events and MC tuning. Good agreement is observed with SM predictions [12]

2.3.2 $t\bar{t}+b\bar{b}$ production

The $t\bar{t}+b\bar{b}$ process is an irreducible background for $t\bar{t}H$, where the Higgs boson decays into a pair of b quarks. A precise measurement thus has the potential to reduce the background and increase the sensitivity of the measurement. CMS has measured the cross section ratio $\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj}$

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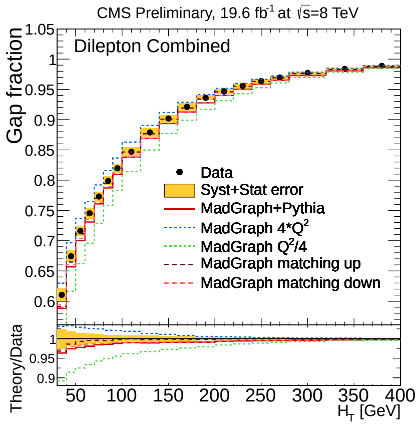

Figure 4: H_T (scalar p_T sum of all additional jets) gap fraction measurements for different MadGraph varied scales at 8 TeV, from [12]

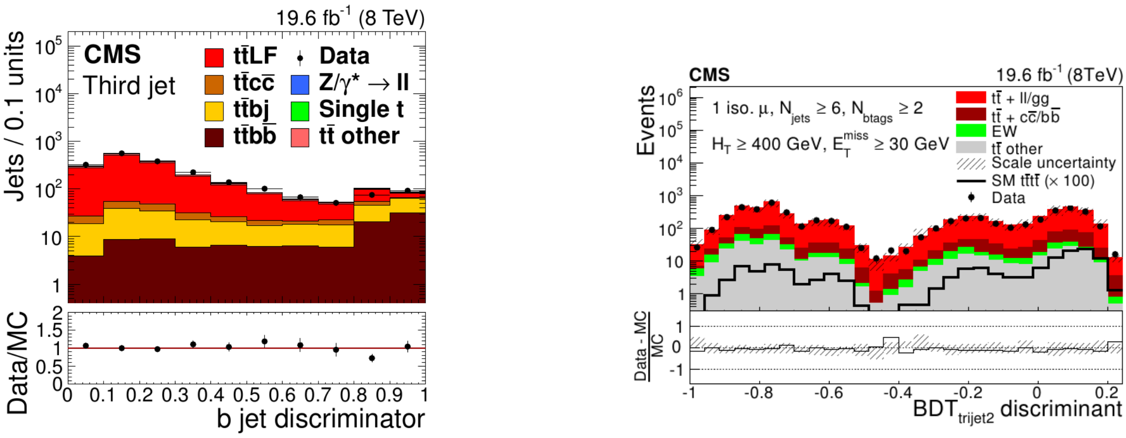

Figure 5: b jet discriminator distribution for the third leading jet in the $t\bar{t}b\bar{b}$ and BDT discriminant for $t\bar{t}+t\bar{t}$ processes at 8TeV, from [14] and [15] respectively

for events with two leptons and four reconstructed jets. The relative contribution from $t\bar{t}+b\bar{b}$ is determined from a fit to the measured b-tagging algorithm discriminators of the leading additional jets in the event (see figure 5, left), where jets are p_T ordered. The results are 0.023 ± 0.003(stat.)± 0.005(sys.), for jets with $p_T > 20$ GeV and 0.022 ± 0.004(stat.)± 0.005(sys.), for jets with $p_T > 40$ GeV [14].

2.3.3 $t\bar{t}+t\bar{t}$ production

This process has a very low cross section predicted by the SM (1 fb), with the main background being tt+jets with a 5 orders of magnitude larger cross section value. In order to identify the four-top events, boosted decision tree for event classification is used (see figure 5, right). An upper limit on the cross section was determined to be: $\sigma_{t\bar{t}t\bar{t}} = 32 \pm 17$ fb (exp.) and 32 fb (obs.) [15]

2.4 Conclusions

Top quark measurements provide crucial information about QCD production processes, as

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well as sensitivity to BSM physics. Thanks to the large amount of top quarks produced at the LHC, large statistics have been collected, and very precise inclusive (about 3.5% precision for the ATLAS and CMS combination results [8]) and differential $t\bar{t}$ cross section measurements (precision of $5-10\%$) have been achieved. The main goal for the upcoming LHC runs will be to try to reduce the systematic uncertainties further, and to achieve results at even higher precision. All results so far are consistent with the expectations of the SM.

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