PROCEEDINGS OF SCIENCE

Measurements of the top quark pair production cross section in pp collisions with the CMS Experiment

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Precision measurements are presented of the top-quark pair inclusive production cross section in proton-proton collisions at the LHC at center-of-mass energies of 7 TeV and 8 TeV. The data were collected with the CMS experiment during the years 2011 and 2012. The analyses include all top quark pair final states with the exception of events with two tau-leptons in the final state. In most analyses b-jet identification is used to increase the purity of the selection. The results are compared with theory predictions and found to be consistent. Indirect constraints on both the top quark mass and α_s are obtained through their relation to the inclusive cross section. Furthermore, $\mathrm{t\bar{t}}$ production in association with $\mathrm{b\bar{b}}$ or $\mathrm{t\bar{t}}$ is also discussed.

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1. Introduction

The top quark is the most massive known fundamental particle and unlike any other quark, it decays before hadronisation. This facilitates direct measurements of its properties and precise knowledge of them, including the production mechanisms, is crucial for the overall testing of the Standard model (SM). Within the SM, top quarks in pp collisions at the LHC are mainly produced in pairs via gluon-gluon fusion (80%). The total production cross section has been accurately predicted by quantum chromodynamics (QCD) calculations at next-to-next-to-leading order (NNLO). Deviations from these predictions are thus (potentially) very sensitive to physics beyond the standard model (BSM).

Additionally a measurement of $\sigma_{t\bar{t}}$ can provide useful constraints on the parton distribution functions (PDF) of the proton, which are an essential ingredient for the QCD calculation.

Lastly, the high center-of-mass energy that is achieved by LHC, leads to large samples of top quark events, enabling production measurements at a few percent precision level, to be confronted with the predictions.

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 $\sqrt{s} = 8$ TeV is $252.9 \pm^{6.4}_{8.6} (scales) \pm 11.7 (pdf) \pm^{7.6}_{7.3} (mass)$ pb [2]. The corresponding cross section at 13 TeV is expected to be 3.3 times larger.

According to SM, top quarks decay weakly in almost 100% of the cases into a W boson and a b quark. The subsequent decay of the W boson defines the final state of the process. Thus $t\bar{t}$ decays are classified as dileptonic, if both W bosons decay into leptons and neutrinos (which are measured as missing energy in the plane transverse to the beam axis), semi-leptonic if one decays into a lepton and neutrino, and the other into quarks, and finally as full hadronic, if both decay into quarks. In the following, selected measurements of $t\bar{t}$ production cross sections are presented at 8 TeV.

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 m_t and determine the value of α_s.

2. Top quark pair Inclusive Cross Section measurements

2.1 $\sigma_{t\bar{t}}$ at 8 TeV in the dilepton channel

The dilepton analysis at 8 TeV with 5.3 fb^{-1} data collected with the CMS detector, is performed using a cut-and-count method [4]. Figure 1 (left) shows the b-tagged jet multiplicity for the eμ channel which has the smallest background contamination. The measured cross section for the combined channel, for events with at least one b-tagged jet, by using the Best Linear Unbiased Estimate (BLUE) method [3] is: $\sigma_{t\bar{t}}^{e\mu}$ = 239.0 ± 2.1 (stat.) ± 11.3 (syst.) ± 6.2 (lum.) pb, with dominant systematics coming from JES and background modelling.

2.2 $\sigma_{t\bar{t}}$ at 8 TeV in the τ+lepton channel

The CMS collaboration has also measured the production cross section of $t\bar{t}$ pairs by considering dileptonic decays where one of the W bosons decays into taus. This decay channel is of particular interest because it is a natural background process to the search for a charged Higgs boson with a mass smaller than that of the top quark. The identification of the τ lepton is performed by means of its hadronic decay products and the $t\bar{t}$ cross section is extracted with a cut-and-count method using 19.6 fb^{-1} at $\sqrt{s}$ = 8 TeV. The main challenge of this analysis is the suppression of τ fakes originating from multi-jets and W, estimated from data. These uncertainties, together with b-tag uncertainties, dominate the systematics. Figure 1 (right) shows the reconstructed top-quark mass for the eτ and $\mu\tau$ channels and the corresponding measured cross section for the combined channel as determined with the BLUE method is: $\sigma_{t\bar{t}}$ = 257 $\pm$ 3 (stat.) $\pm$ 24 (syst.) $\pm$ 7 (lum.) pb [5].

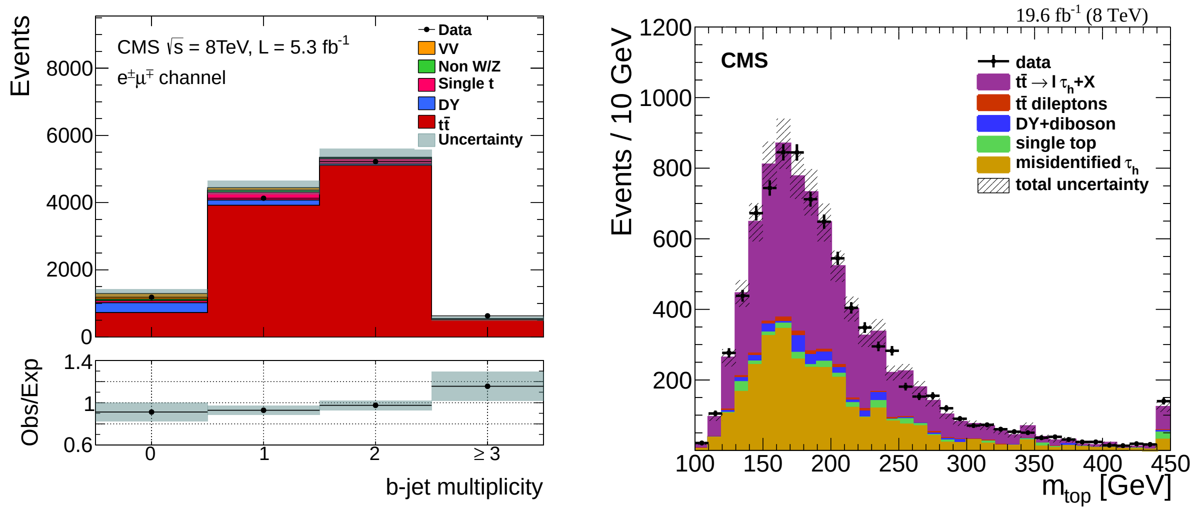

Figure 1: Left: b-jet multiplicity for the eμ channel [4]. Right: reconstructed top-quark mass for the eτ and $\mu\tau$ channels combined. The expected distributions for $t\bar{t}$ signal and background sources are shown in the histograms; data are shown by black dots [5].

2.3 $\sigma_{t\bar{t}}$ at 8 TeV in the lepton+jets channel

Inclusive cross section measurements of the top quark pairs are also performed in the lepton+jets channel. The analysis is done in the top quark pair decay channel with one isolated, high transverse momentum electron or muon, and at least four hadronic jets with at least one of them originating from a b-quark. A technique for extracting $\sigma_{t\bar{t}}$ from the candidate event sample is described in Ref.[6] and is done with two approaches; a) a binned log likelihood fit of signal and background to the distribution of a discriminant variable in data: the invariant mass of the b-jet and the lepton (M_{lb}), b) template fit of the mass of the three-jet combination with the highest transverse momentum in the event (M3 mass). The M3 variable (Fig.2, right) is a measure for the hadronic top quark mass, while M_{lb} is related to the leptonic top quark mass (Fig.2, left). Compatible results are obtained with both approaches, in particular the measured inclusive cross section with M_{lb} is: $\sigma_{t\bar{t}}$ = 228.4 $\pm$ 9.0 (stat.) $^{+29.0}_{-26.0}$ (syst.) $\pm$ 10.0 (lum.) pb.

2.4 Summary of $\sigma_{t\bar{t}}$ Inclusive Cross Sections

The inclusive cross section results for ATLAS and CMS show a very good agreement with each other and combined (in the eμ channel) they reach a precision of 3.5% challenging the current theoretical predictions at NNLO+NNLL [2].

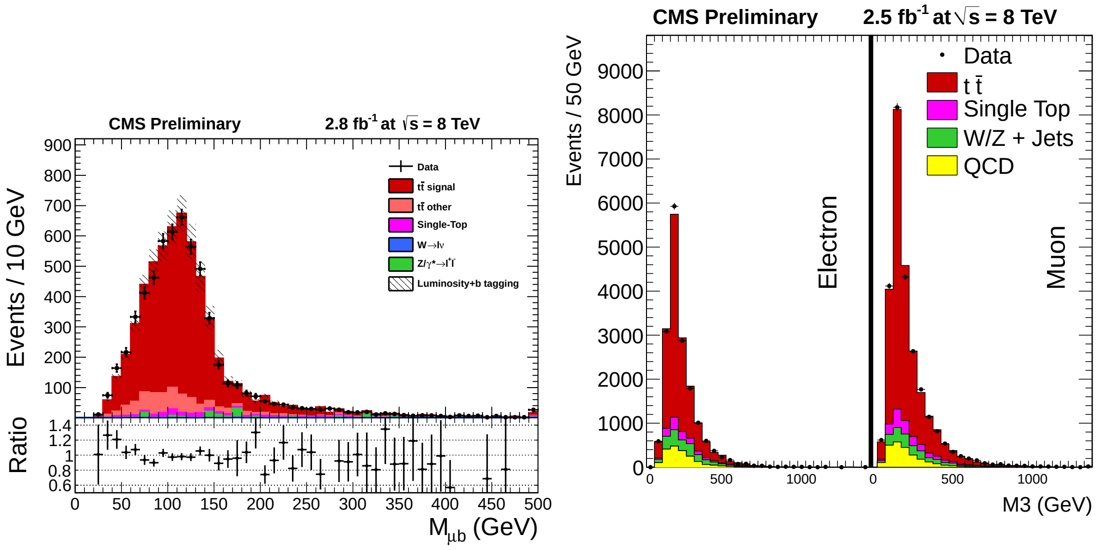

Figure 2: Left: Jet-lepton mass distribution for all relevant processes in the muon+jet channel. The uncertainty bands include the uncertainty on the luminosity measurement and the b-tagging systematic uncertainty. The ratio between data and simulation is shown in the lower panel. Right: M3 template likelihood fit to data for the two channels.

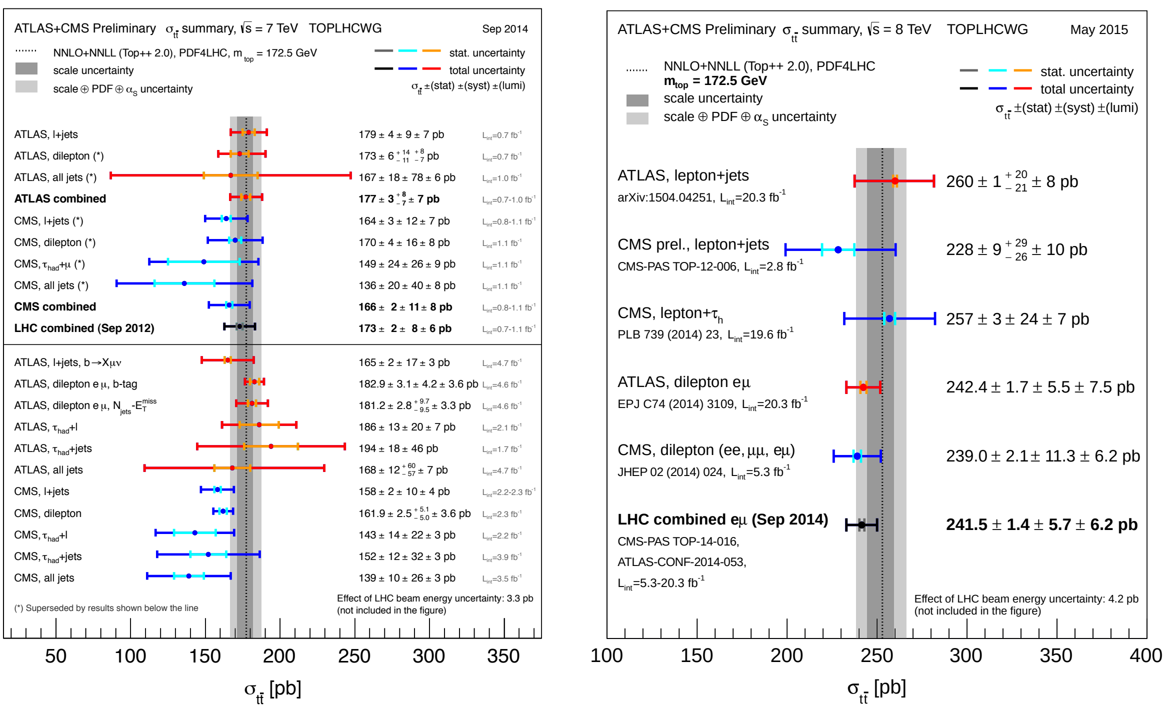

Figure 3: Summaries of inclusive tt̄ cross section measured with the CMS and ATLAS detectors at 7 and 8 TeV [8].

3. Cross section ratio $\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj}$

An especially interesting case of $t\bar{t}$ produced together with jets is the $t\bar{t}b\bar{b}$ production, given that it constitutes an irreducible background for the ttH(bb) process.

Both the $t\bar{t}b\bar{b}$ cross section and the ratio $\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj}$ are measured. In the ratio, those uncertainties that are common to both measurements cancel out.

The most recent analysis is performed by selecting single lepton events. The contributions of $t\bar{t}jj$ and $t\bar{t}b\bar{b}$ with at least two additional jets of any flavor or b jets to the inclusive $t\bar{t}+$jets production are extracted with a simultaneous template fit of b-tag discriminants. The measured cross section ratio $\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj}$ = 0.0117 ± 0.0040 (stat.) ± 0.0003 (syst.) corresponds to the phase space of additional jets (aj) defined at generator-level as: p_{Taj} >40 GeV, $|\eta_{aj}|$ <2.5, ΔR_{ajj} >0.5 [10]. The flavor of generated jets is defined by the flavor of the leading quark in the jet. The obtained results are in good agreement with NLO calculations and with a previous CMS measurement in the dilepton channel when the same jet definition is used [11].

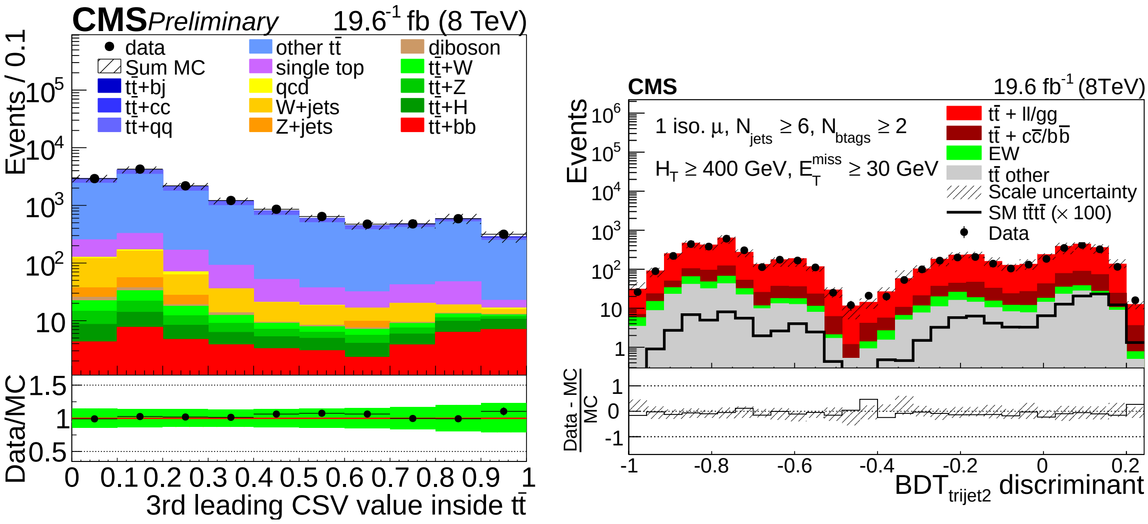

Figure 4: Left: Pre-fit distribution of the CSV b-tag discriminant for the jet categories of 4 jets and 0 b-tags of additional jets, in the muon channel. The errors include the statistical and systematic uncertainties [10]. Right: Distribution in the BDT$_{trijet2}$ discriminant for the μ+jets channel. The ratio at the bottom reflects the relative difference between data and MC events. The hatched areas show the changes in the calculated predictions produced by variations of factors of two and one half of the factorisation and renormalisation scales in the $t\bar{t}$ simulation [12].

4. $t\bar{t}+t\bar{t}$ production

A rare process that has become possible to study with the large center-of-mass energies of the LHC is the production of four top quarks. The cross section in the SM is expected to be around 1 fb. This measurement was performed in the lepton+jets channel. The main background in this channel is $t\bar{t}$+jets production with a 5 orders of magnitude larger cross section value than that of the signal. The technique used to distinguish the signal from background is by a combination of kinematic reconstruction and multivariate techniques. The data are consistent with expectations of

SM, and an upper limit of 32 fb is set at 95% confidence level on the cross section for producing four top quarks in the SM [12], where a limit of 32±17 fb is expected.

5. Conclusions

Top quark measurements provide crucial information about QCD production processes, as well as sensitivity to BSM physics. The large samples of $t\bar{t}$ data collected from LHC Run1, contributed to the very precise inclusive $t\bar{t}$ cross section measurements that have been achieved with about 3.5% precision for the ATLAS and CMS combination results [7]. Additionally, measurements of $\sigma_{\mathrm{t\bar{t}b\bar{b}}}$ and $\sigma_{\mathrm{t\bar{t}b\bar{b}}}/\sigma_{\mathrm{t\bar{t}jj}}$ have been performed; the later is of great importance for the $\mathrm{t\bar{t}}H(bb)$ search since $\mathrm{t\bar{t}b\bar{b}}$ represents an irreducible background. Lastly, studies of four-top quark production have been carried out. These studies will be of particular interest in LHC Run2 since cross sections for all top quark related processes are expected to increase. Furthermore, since larger samples are expected the statistical uncertainties will be reduced. All results so far are consistent with the expectations of the SM.

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