Prospects for the First Top-Quark Pair-Production Cross-Section Measurement in the Semileptonic Channel at CMS

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The advent of the LHC opens up a new era in top-quark physics. Given the large $t\bar{t}$ production cross-section and the high luminosity envisaged, the LHC can be considered a top-quark factory. We report on studies of early top-quark pair-production cross-section measurements with the CMS detector at a center-of-mass energy of 10 TeV. Of particular interest is the semileptonic channel in which the W boson from one top-quark decays into a charged lepton (electron/muon) and a neutrino, while the other decays into a quark and an anti-quark.

Introduction

More than one decade after its first observation in 1995 [1, 2], the top quark is to be rediscovered soon at the Large Hadron Collider. At a center-of-mass energy of $\sqrt{s} = 10$ TeV the $t\bar{t}$ production cross-section has been estimated to $\sigma(t\bar{t}) = 414 \pm 40(\text{scale}) \pm 20(\text{PDF})$pb [3].

This analysis addresses the potential of the CMS detector [4] to establish a top-quark signal within the first 20 pb^{-1} of LHC data. The experimental signature of the semileptonic $t\bar{t}$ decay is one high-energetic charged lepton (electron/muon), at least four jets and missing transverse energy. A more detailed review of the analyses can be found in [5, 6], where the μ+jets and the e+jets channel are treated separately.

Selection of $t\bar{t}$ Event Candidates

Striving for an early top-quark rediscovery, this analysis uses a simple and robust method able to identify top-quark pairs. Events are selected which contain exactly one high-energetic isolated lepton and at least four jets. The specific requirements on the muon are $p_{\text{T}} > 20$ GeV/c and $|\eta| < 2.1$, while for the electron $E_{\text{T}} > 30$ GeV and $|\eta| < 2.5$ are required. The momentum threshold for each jets is $p_{\text{T}} > 30$ GeV/c in the range $|\eta| < 2.4$.

The event selection yields about 320 $t\bar{t}$ signal and about 171 background events in the μ+jets channel. For the e+jets channel stricter requirements have to be applied in order to have comparable contributions of QCD events. Consequently, the statistics are reduced to 172 $t\bar{t}$ signal and 108 background events. The background in both channels is dominated by contributions originating from W+jets production. Figure 1 illustrates the expected event yield

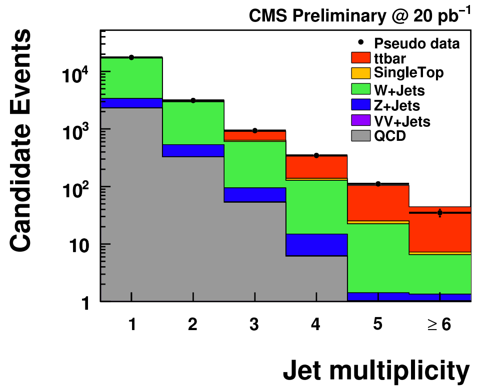

Figure 1: Expected event yield as a function of the jet multiplicity for the μ+jets channel. The *pseudo data* distribution is obtained by applying a bin-by-bin smearing based on Poisson statistics.

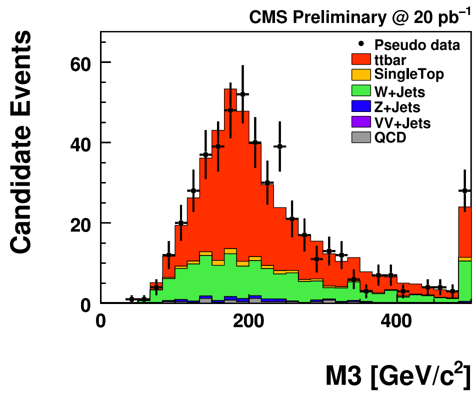

Figure 2: Invariant mass of the three jets with the highest vectorially summed transverse momentum for the μ+jets channel. The *pseudo data* distribution is obtained as in Figure 1.

as a function of the jet multiplicity for the μ+jets channel with the full event selection applied except the requirement on the number of jets.

Data-Driven Estimation of Background Contributions

We plan to employ data-driven techniques in order to reduce the dependence on the Monte Carlo modelling of background contributions. The estimation of QCD multi-jet contributions is investigated in both channels while in the μ+jets channels an additional method for the estimation of the W+jets contribution is studied.

For the estimation of the QCD contribution we studied two different methods which both yield a 50% systematic uncertainty. In the μ+jets channel, the ABCD method is investigated. Therein the phase space of two uncorrelated variables is divided into four regions (A, B, C and D). Among these three are highly enriched in QCD events while the fourth represents the signal region. Using the relation $N_{\mathrm{A}}/N_{\mathrm{B}} = N_{\mathrm{C}}/N_{\mathrm{D}}$ one can estimate the number of QCD multi-jet events N_{A} in the signal region A from measuring the number of events N_i in the three background enriched regions i. In the second method, which was studied in both lepton+jets channels, one single variable is investigated. This variable must exhibit a side-band region which is enriched in QCD multi-jet events, e.g. an isolation variable. After performing a fit to this variable in the side-band region and the subsequent extrapolation of the fitted function into the signal region, the number of QCD multi-jet events in the selected dataset can be estimated.

The estimation of the W+jets contribution utilizes the inverse of the charge asymmetry $R_{\pm} = \frac{N_{W^+}+N_{W^-}}{N_{W^+}-N_{W^-}}$, which will be calculated from predictions based on Monte Carlo simulations. Using this quantity we are able to estimate the number of charge asymmetric events—dominated by W+jets events—from the selected dataset via the number-difference of leptons (N^-) to anti-leptons (N^+): $(N^+ + N^-)_{\mathrm{data}} = \mathrm{R}_{\pm} \cdot (N^+ - N^-)_{\mathrm{data}}$. For an integrated luminosity of 100 pb^{-1} this method yields a 30% uncertainty on the prediction of W+jets events among the selected event candidates dominated by the statistical uncertainty.

Extraction of the Cross Section

The extraction of the cross section is performed via a template fit to a discriminating variable using a binned likelihood procedure. Exemplarily the distribution of the M3 variable is shown in Figure 2 which is used as one possible discriminating variable for the fit. It represents the invariant mass of the three jets with the highest vectorially summed transverse momentum in the event. We employ ensemble tests (sets of 5k pseudo experiments) in order to estimate the sensitivity and the systematic uncertainties of the method. For the muon+jets channel we expect a statistical uncertainty of 12–18% and a systematic uncertainty of 19–25% depending on the discriminating variable investigated. Due to the smaller statistics, the electron+jets channel exhibits an increased statistical uncertainty of 23%, while the systematic uncertainty of 20% is comparable to the one estimated in the μ+jets channel. The dominating source for the systematic uncertainty of the method originates from the uncertainty on the jet energy scale. Additionally, for both channels the uncertainty arising from the uncertainty of the luminosity is estimated to be 10% and treated separately.

Conclusion

We demonstrated the early measurability of the $t\bar{t}$ cross-section within 20 pb^{-1} of LHC data at a center-of-mass energy of 10 TeV. The two feasibility studies presented investigate the μ+jets and the e+jets channel which both utilize data-driven techniques to estimate background contributions. For the measurement of the cross section a template fit is used leading to statistical as well as systematic uncertainties in the order of 20%. The dominating systematic uncertainty arises from the jet energy scale uncertainty.

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References

[1] F. Abe et al. Observation of Top Quark Production in $p\bar{p}$ Collisions with the Collider Detector at Fermilab. *Phys. Rev. Lett.*, 74(14):2626–2631, Apr 1995.

[2] S. Abachi et al. Observation of the Top Quark. *Phys. Rev. Lett.*, 74(14):2632–2637, Apr 1995.

[3] Matteo Cacciari, Stefano Frixione, Michelangelo L. Mangano, Paolo Nason, and Giovanni Ridolfi. Updated predictions for the total production cross sections of top and of heavier quark pairs at the Tevatron and at the LHC. *JHEP*, 09:127, 2008.

[4] CMS Collaboration, R. Adolphi, et al. The CMS experiment at the CERN LHC. *JINST*, 0803:S08004, 2008.

[5] CMS Collaboration. Prospects for the first Measurement of the $t\bar{t}$ Cross Section in the Muon-plus-Jets Channel at $\sqrt{s} = 10$ TeV with the CMS Detector. *CMS Physics Analysis Summary*, CMS PAS TOP-09-003, 2009.

[6] CMS Collaboration. Plans for an early measurement of the $t\bar{t}$ cross section in the electron+jets channel at $\sqrt{s} = 10$ TeV. *CMS Physics Analysis Summary*, CMS PAS TOP-09-004, 2009.