EPJ Web of Conferences **49**, 18007 (2013)
DOI: 10.1051/epjconf/20134918007

Measurement of Jet Multiplicity Distributions in Top Quark Pair Events with Two Leptons in the Final State at a center of mass energy of 7 TeV.

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Abstract. The jet activity in top-antitop quark pair events is measured in pp collisions at $\sqrt{s}$ =7 TeV with the CMS detector using a dataset recorded in 2011 corresponding to an integrated luminosity of 5.0 fb^{-1}. The measurement is performed in the dileptonic decay channels (where the two W bosons decay to leptons) of the top-antitop quark pairs, with at least two isolated leptons and at least one b-jet in the final state. The differential top anti-top quark cross section is measured as a function of the jet multiplicity. Furthermore, the distribution of the fraction of events without additional jets above a momentum threshold is measured. Several QCD calculations are compared with the data.

1 Introduction

Measurements of top-antitop quark pair production cross sections and properties are being performed at unprecedented precision, providing crucial information for testing the expectations of the Standard Model. At LHC energies, the fraction of $t\bar{t}$ events with additional hard jets in the final state is about half of the total number of events. The jet activity in top-antitop quark pair events is studied with the CMS detector [1] using the dataset recorded in 2011 in the dileptonic decay channels [2]. The understanding of these processes is crucial to constrain ISR/FSR and provides a test of QCD at the LHC energy regime. Also new physics can potentially manifest in top final states, so $t\bar{t}$+jets is a background for many searches.

2 Event Selection

Events are selected if there are at least two isolated leptons (electrons or muons) of opposite charge and two jets of which at least one is identified as b-jet. The leptons are required to have a transverse momentum $p_T > 20$ GeV within a pseudo-rapidity region $|\eta| < 2.4$. Jets are selected in the pseudo-rapidity interval $|\eta| < 2.4$ and with a transverse momentum of at least 30 GeV. Jets originating from bottom quarks are identified from combined secondary vertex and track-based lifetime information.These events are triggered using combinations of two leptons fulfilling transverse momentum thresholds and isolation cuts. Events with a lepton pair invariant mass smaller than 12 GeV are removed in order to suppress events from heavy flavour resonance decays. In the $\mu\mu$ and ee channels, the dilepton invariant mass is required to be outside a Z-boson mass window of 91 ± 15 GeV and E_T^{miss} is required to be larger than 30 GeV.

A kinematic reconstruction method is used to determine the top-quark pair kinematic properties and to identify the two b-jets originating from the decays of the two top quarks. In the kinematic reconstruction the following constraints are imposed: the balance of the transverse momentum of the two neutrinos; the W-boson invariant mass of 80.4 GeV; and the equality of the top and antitop quark masses. The remaining ambiguities are resolved by prioritising those event solutions with two or one b-tagged jets over solutions using jets without b-tag. The top mass can be experimentally reconstructed in a broad range due to resolution effects. To take this into account, the assumed top quark mass for each lepton-jet combination is varied between 100 GeV and 300 GeV in steps of 1 GeV. Finally, among the physical solutions, the solution of highest priority and most probable neutrino energies according to a simulated spectrum of the neutrino energy is chosen. Fig. 1 shows the distribution of the jet multiplicity and the transverse momentum and pseudorapidity of the first leading additional reconstructed jet, compared to signal and background simulated samples. The main background contributions stem from Z/γ+jets, single top quark (tW-channel), W+jets.

3 Differential Cross Section as Function of Jet Multiplicity

The differential cross section as a function of jet multiplicity is measured from the number of signal events after background subtraction, scaled to the integrated luminosity, and corrected for detector efficiencies and acceptances in each bin of the measurement. The normalised differential cross section is then derived by dividing the result by the total cross section measured in the same analysis. Due to the normalization, those systematic uncertainties

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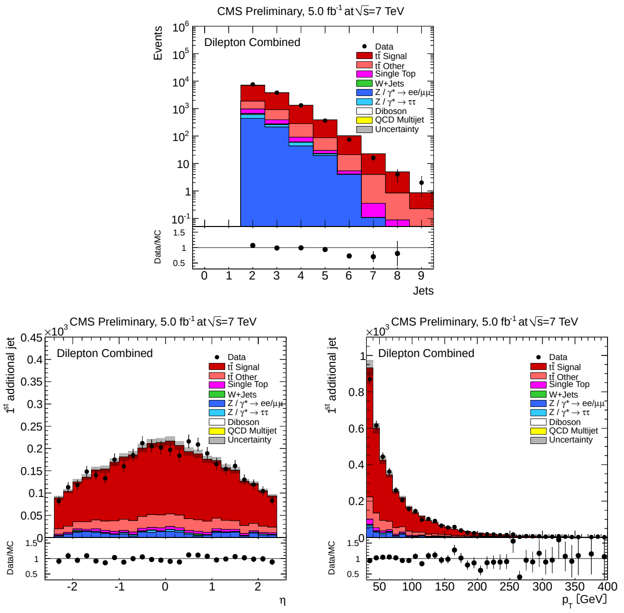

Figure 1. Top: jet multiplicity in the event. Bottom: pseudo-rapidity (left) and the transverse momentum (right) of the first leading additional reconstructed jet. The hatched area represents the uncertainty on the predicted $t\bar{t}$ cross section (scale and PDF) and the luminosity.

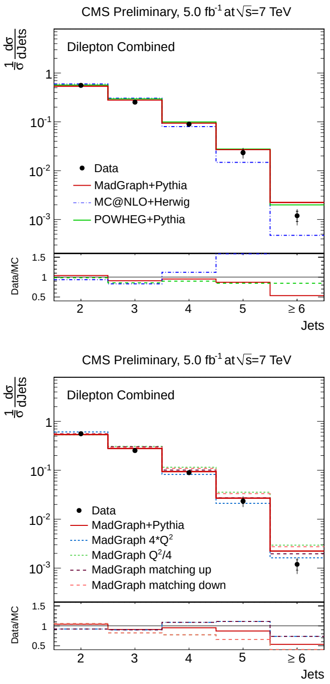

Figure 2. Normalised differential cross section as a function of jet multiplicity for jets with $p_T > 30$ GeV. Top: the data are compared with predictions from MADGRAPH and POWHEG interfaced with PYTHIA and MC@NLO interfaced with HERWIG. Bottom: comparison with predictions from MADGRAPH with varied Q^2 and matching scales. The errors on the data points indicate the statistical and the total uncertainty.

that are correlated across all bins of the measurement, e.g. the one for the integrated luminosity as well as all other normalisation uncertainties, cancel out.

Effects from trigger and detector efficiencies and resolutions, leading to migrations of events across bin boundaries and statistical correlations among neighbouring bins, are corrected using a regularised unfolding method.

The differential cross section is reported for a kinematic phase space at particle level in which the generated pseudo-rapidities and transverse momenta of the leptons are $|\eta^{ll}| < 2.4$ and $p_T^{ll} > 20$ GeV and the generated b-jets from the top quark decays both lie within the range $|\eta^{b}| < 2.4$ and $p_T^{b} > 30$ GeV. A jet is defined at particle level by applying the anti-k_T clustering algorithm with size parameter $R = 0.5$ to all stable particles (including neutrinos). A jet is defined as b-jet if it contains the decay products of a B hadron.

The results are compared at particle level to theory predictions obtained with three different generators: MADGRAPH, MC@NLO and POWHEG. Additionally, dedicated MADGRAPH samples were generated using different choices for the renormalization/factorization Q^2 and jet-parton matching scales. These are used both to determine the systematic errors of the measurement due to model uncertainties, as well as for comparisons with the measured distributions. The nominal Q^2-scale is defined as $M_t^2 + \sum p_t^2(jet)$ and the Q^2-varied samples use scales of $4 \cdot Q^2$ and $1/4 \cdot Q^2$, respectively.

Systematic uncertainties of the measurement arise from detector effects as well as theoretical uncertainties. The dominant ones arise from the uncertainty of the jet energy scale, as well as from model uncertainties, such as Q^2 scale, matching scales and hadronisation uncertainties. The total systematic uncertainty is about 3% at low jet multiplicities increasing to about 20% in the bin with at least five jets.

In Fig. 2 the normalised differential cross section is shown. The results are presented for a nominal top quark mass of 172.5 GeV. In general the MADGRAPH and POWHEG generators interfaced with PYTHIA are found to provide a reasonable description of the data. In contrast MC@NLO interfaced with HERWIG does not generate sufficiently large jet multiplicities. The sensitivity of MADGRAPH to scale variations is investigated through comparison of different Q^2 and matching scales with respect to the nominal MADGRAPH simulation. The choice of larger scales leads to an improved description of the data for jet multiplicities above three jets.

4 Gap fraction

An alternative way to investigate the jet activity arising from quark and gluon radiation is to determine the fraction of events that do not contain an additional jet above a given threshold, referred to as gap fraction:

$$f(p_T) = \frac{N(p_T)}{N_{total}}, \qquad (1)$$

where N_{total} is the number of selected events and $N(p_T)$ is the number of events that do not contain an additional

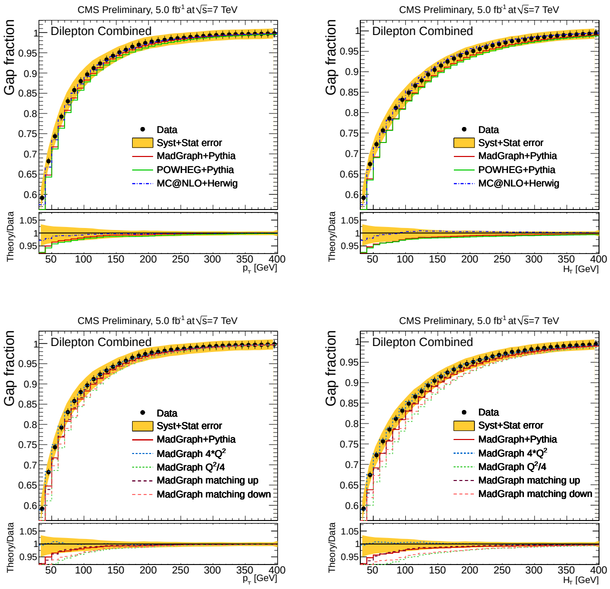

Figure 3. Measured gap fraction as a function of the additional jet p$_T$ (left) and of H_T (right). Data are compared to predictions from MADGRAPH, POWHEG interfaced with PYTHIA and MC@NLO interfaced with HERWIG (top row) and to MADGRAPH with varied Q^2 and jet-parton matching scales (bottom row). The errors on the data points indicate the statistical uncertainty. The shaded band corresponds to the total uncertainty.

jet (apart from the two jets from the solution hypothesis) above a p$_T$ threshold in the whole rapidity range used in the analysis ($|\eta|$ <2.4). The veto can be extended beyond the additional leading jet criteria by defining the gap fraction as

$$f(H_T) = \frac{N(H_T)}{N_{total}}, \qquad (2)$$

where $N(H_T)$ is the number of events in which the sum of the scalar transverse momentum of the additional jets is less than a certain threshold (H_T). Detector effects are unfolded with the MADGRAPH simulation to obtain the results at particle level. The additional jets at generator level are defined as all jets within the kinematic acceptance except the two highest p$_T$ b-jets originated from different B hadrons. For each value of p_T and H_T thresholds the gap fraction at generator level is evaluated along with the equivalent distributions after the detector simulation and analysis cuts. The ratio of the true, at particle level, to the simulated distributions provides the correction factor which is then applied to the data.

The measured gap fraction distribution is compared to predictions from MADGRAPH and POWHEG interfaced with PYTHIA, MC@NLO interfaced with HERWIG, and to the predictions from the Q^2 and matching threshold varied MADGRAPH samples. In Fig. 3 the gap fraction is measured as a function of the transverse momentum of the first leading additional jet and as a function of the scalar sum of transverse momenta of all jets. The gap fraction is better described by MC@NLO interfaced with HERWIG. Increasing the Q^2-scale in the MADGRAPH sample improves the agreement between data and simulation.

The total systematic uncertainty is about 3.5% for values of the threshold (p_T or H_T) below 40 GeV and decreases to 0.2% for values of the thresholds above 200 GeV. Dominant systematics arise from the uncertainty of the jet energy scale and the background contamination. Other sources with a smaller impact on the total uncertainty are the b-tagging efficiency, jet energy resolution, pile-up and the procedure used to correct the data to particle level.

The measurement of the normalised top quark pair production cross section using 5.0 fb^{-1} at 7 TeV in the dilepton decay channel is presented as function of number of jets in the event. The comparison of the data with several QCD calculations shows reasonable agreement. MADGRAPH and POWHEG interfaced with PYTHIA describe well the data up to high jet multiplicities; while MC@NLO interfaced with HERWIG generates lower multiplicities than observed.

The gap fraction is measured as a function of the p$_T$ of the leading additional jet and the scalar sum of the transverse momentum of the additional jets. The gap fraction is lower as a function of H_T showing the measurement is probing quark and gluon emission beyond the first emission. In general, all these generators are found to give a reasonable description of the data. MC@NLO interfaced with HERWIG seems to describe more accurately the gap fraction for all values of the threshold. This result is compatible with the observation described above, because the gap fraction requires the jets to have a certain p$_T$ above the threshold, which does not imply necessarily large jet multiplicities. The difference between MC@NLO interfaced with HERWIG and POWHEG or MADGRAPH interfaced with PYTHIA, is similar to the precision of the measurement. Increasing the Q^2 scale improves the agreement of MADGRAPH with data, while varying the matching threshold increases difference between data and simulation.

References

[1] CMS Collaboration, *The CMS experiment at the CERN LHC*, JINST 03 (2008) S08004

[2] CMS Collaboration, *Measurement of Jet Multiplicity Distributions in Top Quark Pair Events with Two Leptons in the Final State at a center of mass energy of 7 TeV*, CMS PAS TOP-12-023 (2012)