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# Top-Quark Studies at CMS

**Tim Christiansen**[*] [†]
*CERN*
*E-mail:* tim.christiansen@cern.ch

We present the first results of a selection of top-quark pair production events in the dilepton channel, where both W bosons from the top quarks decay leptonically into either an electron or a muon, plus a neutrino. We use LHC collision data at 7 TeV centre-of-mass energy collected with the CMS experiment during the period of April to July 2010. Events with two isolated, prompt leptons with high energy, at least two jets with high transverse momentum, and significant missing transverse energy are selected. Several background contributions from other standard model processes, most importantly Drell-Yan and W+jets, are estimated in a data-driven way. Results obtained from data are compared with the simulation, indicating the status of the analysis towards a first cross section measurement in this channel at $\sqrt{s} = 7\,\text{TeV}$. Similarly, first results are reported for the lepton+jets channel, where one W boson from the top decays leptonically into a muon (or electron) and a neutrino, while the other one decays into a quark-antiquark pair. Finally, after applying dedicated identification of hadron jets originating from bottom quarks, the results from both channels in the first $0.25 \pm 0.03\,\text{pb}^{-1}$ of data already indicate a clear excess that could be explained by the presence of top-quark signal.

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[*]Speaker.
[†]On behalf of the CMS Collaboration

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The top quark, first observed in $p\bar{p}$ collisions at the Tevatron in 1995 [1], is a fundamental building block of the standard model. Due to the large cross section, top-antitop pairs will be copiously produced in high energy proton-proton collisions at the Large Hadron Collider (LHC). The top quark is the most massive of the known standard model particles at $m_t = 173.1 \pm 0.6^{(\text{stat})} \pm 1.1^{(\text{syst})}\,\text{GeV}/\text{c}^2$ [2]. The top quark decays rapidly, long before it can form a bound-state hadron. Therefore, the study of top-quark daughters allows a direct glimpse at the properties of the parent quark itself, thus allowing measurements of its mass, spin, charge and other properties in a way that is inaccessible for any of the other known quarks. Furthermore, because of its large mass, it is hypothesized that the top quark may play a special role in electroweak symmetry breaking and the generation of particle masses in alternatives to the Higgs mechanism. Finally, several signatures of new physics accessible at the LHC either suffer from top-quark production as a significant background or contain top quarks themselves.

At the LHC, the top quark is expected to be produced primarily via the strong interaction in top-antitop quark pairs ($t\bar{t}$). Next-to-leading order calculations predict a $t\bar{t}$ production cross section of approximately 158 pb [3]. A detailed description of the CMS experiment can be found at [4].

The event selection for the lepton+jets channel is targeted at the event signature of the semileptonic $t\bar{t}$ events, in which the decay products of one of the W bosons from the top-quark are a highly energetic lepton (electrons or muons are considered) and a neutrino, while the other W boson decays hadronically giving rise to two jets from the hadronization of the quarks. It is assumed that the top quark decays to 100 % into a b quark and a W boson. Two additional jets are expected from the hadronization of the bottom quarks. Events with one prompt, isolated electron (muon) with a transverse momentum $p_T$ exceeding 30 (20) GeV/c are selected. At this stage, the event sample is dominated by $W+X$ as well as QCD multi-jet events. The purity in $t\bar{t}$ events increases when requiring a minimum number of reconstructed jets with corrected transverse momentum exceeding $30\,\text{GeV}/\text{c}$. While the initial dataset of $78 \pm 9\,\text{nb}^{-1}$ does not yet show, as expected, any significant traces of top-quark signals, kinematic distributions, such as the lepton momentum and direction, the missing transverse energy $\not{E}_T$, the W transverse mass (reconstructed from the lepton momentum and $\not{E}_T$), and the jet spectra, are well reproduced by the full simulation. [5]

For higher jet multiplicities, where the $t\bar{t}$ signal eventually becomes more prominent, it is nearly impossible to provide an accurate prediction of QCD multi-jet events. Therefore, various methods of determining the QCD contribution from the data themselves have successfully been tested in the lower jet-multiplicity bins. These methods make use of background-enriched control samples, e.g. by inverting the isolation requirement or requiring small $\not{E}_T$.

A key signature of $t\bar{t}$ events that allows one to further reject non-$t\bar{t}$ background is the presence of jets from bottom-quark decays, so-called *b*-jets. The significantly boosted B hadron travels a macroscopic distance in the lab frame before decaying. The daughters in that decay will produce charged-particle tracks inconsistent with originating from the primary pp interaction point. One *b*-jet identification algorithm in place at CMS exploits the signed impact parameter significance ($\text{IP}_{\text{sig}} = \text{IP}/\sigma_{\text{IP}}$ ) of a subset of the high quality tracks in each jet. Tracks are ordered in decreasing $\text{IP}_{\text{sig}}$ and the $\text{IP}_{\text{sig}}$ value of the second track is taken as the discriminant for this algorithm. A cut is placed on this discriminant, corresponding to approximately 81 % efficiency for tagging b jets, as measured in simulated top-quark decays, at the expense of a 10 % false positive rate, as estimated in non-*b* jets from simulated QCD multi-jet events. Figure 1 (left) shows the result of applying



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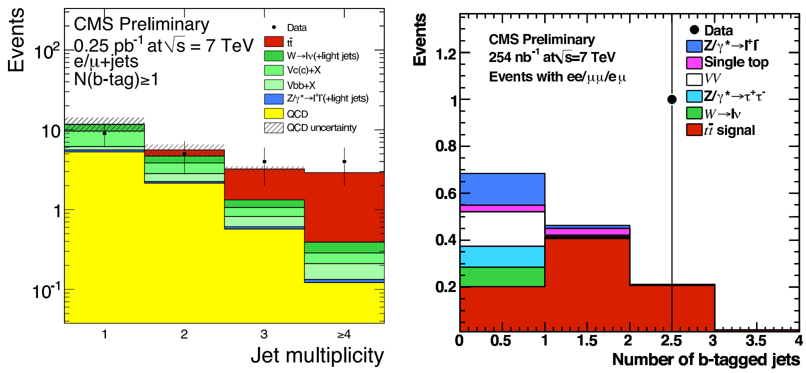


**Figure 1:** Jet multiplicity of event with one or more identified bottom-quark jet in the lepton+jets channel (left) and the $b$-tag multiplicity in the dilepton channel (right). The colored histograms show the prediction from simulation normalized to $0.25\,\mathrm{pb}^{-1}$ using NLO predictions (LO for QCD multi-jets).

this requirement to $0.25 \pm 0.03\,\mathrm{pb}^{-1}$ of data: the jet multiplicity for events with at least one jet identified as a $b$-jet for both channels, electron+jets and muon+jets, combined. Already with this relatively small dataset, a clear indication of the presence of top-quark signal is visible for events with three or more jets.

A complementary channel, with lower branching fraction but also less background compared to the semi-leptonic $t\bar{t}$ channel, is the channel, in which both W bosons decay to a lepton and a neutrino. Events with two prompt, isolated leptons (electron or muon) of opposite charge ($e^+e^-$, $\mu^+\mu^-$, and $e^\pm\mu^\mp$) are considered. The signal is expected to contain two additional jets from the bottom quarks (corrected $p_T(\mathrm{jet}) > 30\,\mathrm{GeV/c}$) and significant missing transverse energy $\not\!\!E_T > 30$ (20) GeV for $e^+e^-$ and $\mu^+\mu^-$ ($e^\pm\mu^\mp$). The dominant background in the same-flavor channels is Drell-Yan/Z production (DY/Z). This background is reduced by vetoing events with a dilepton mass in the vicinity of the known Z-boson mass (Z-veto).

Similar to the lepton+jets channel, various data-driven methods have been explored on a relaxed selection applied to $78 \pm 9\,\mathrm{nb}^{-1}$ of data in order to demonstrate the ability to estimate the contribution from dominant background sources from the data. The DY/Z background in the same-flavor channels is estimated from the events in the Z-veto region, corrected for non-DY/Z contributions using $e^\pm\mu^\mp$ events and scaled by the predicted ratio of DY/Z events outside to inside the Z-veto region. It has also been demonstrated that background from events with one (e.g. W+jets) or two (e.g. QCD multi-jets) reconstructed leptons that “falsely” appear as prompt and isolated, can be measured from the data themselves. Kinematic distributions, like distributions of jet multiplicity, $\not\!\!E_T$ and the sum of lepton transverse momenta, as well as the background estimates from the data are well reproduced by the full simulation. [5]

One event from a dataset of $0.25 \pm 0.03\,\mathrm{pb}^{-1}$ passes the whole selection including the requirement of one $b$-tagged jet. This $t\bar{t}$ candidate event is shown in Fig. 2. The right distribution in Fig. 1 shows this event compared to the predicted $b$-tag multiplicity for events with one or more jets identified as $b$-jets, illustrating the excellent purity expected for events with two or more jets.

In summary, the early results from a selection of $t\bar{t}$ events in the dilepton and lepton plus jets channels already indicate the presence of top-quark signal in the early CMS data of $0.25\,\mathrm{pb}^{-1}$ only.



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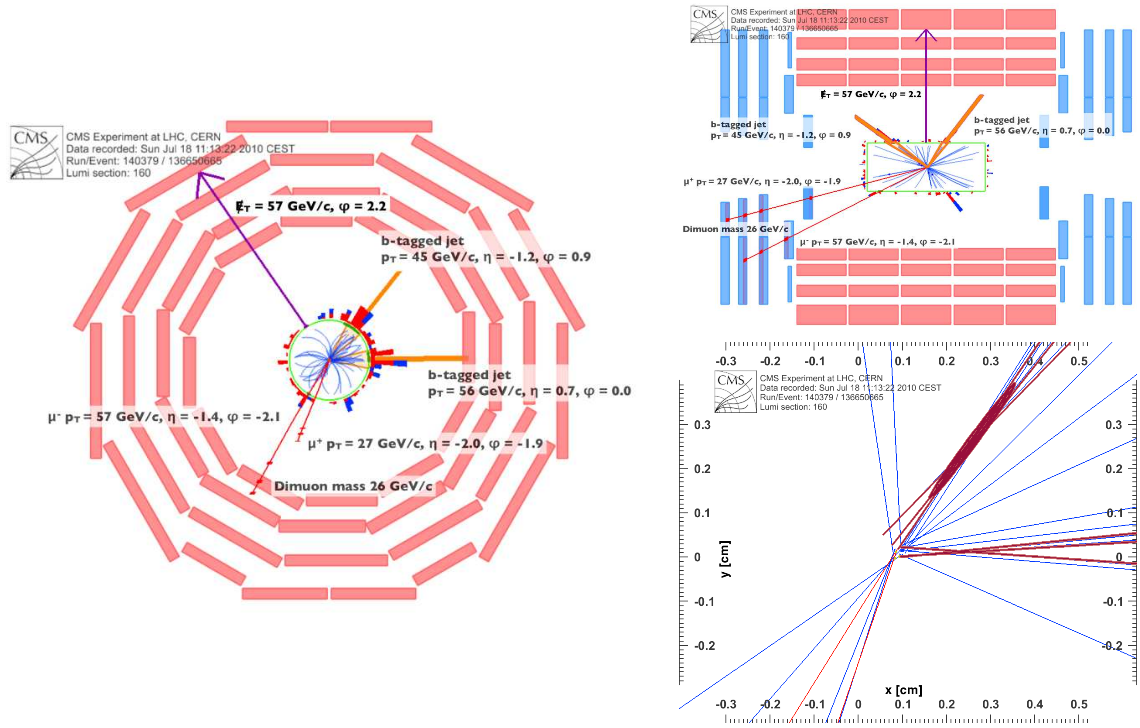


**Figure 2:** Event display of the first $t\bar{t}$ candidate event recorded in the $\mu\mu+X$ channel, as seen from the beam axis (left) and from the side (top right). The bent curves in the center show reconstructed tracks from charged particles in the Si tracker; The red and blue histograms represent signals in the electromagnetic and hadron calorimeters. Further outside is the layered muon system of CMS. The zoomed view into the interaction region as seen from the beam axis is shown in the bottom right. The purple ellipses, reconstructed from the purple tracks with significant impact parameter, denote the $6\sigma$ contour of the reconstructed secondary vertices, which are clearly separated from the primary interaction point in the center.

Kinematic comparisons demonstrate the good agreement between simulation and current data, and various methods to estimate the background contribution from the data are successfully introduced, putting the prospect of the measurement of the top-quark pair-production cross section on firm ground. It should be noted, that this has recently been confirmed by the first measurement of the $t\bar{t}$ production cross section in $pp$ collisions at $\sqrt{s} = 7\,\text{TeV}$ performed by the CMS Collaboration [6].

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