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Expectations for observation of top-quark pair production in the dileptonic final state in early CMS data at $\sqrt{s} = 10\,\text{TeV}$

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Summary. — The dileptonic decay channel of the top-quark pair production at LHC is the best candidate for an early observation of a process involving top-quark. Due to its clean signature (two isolated and high-p_T leptons with opposite charge, two b-jets and missing transverse energy) and its large cross-section, the expected background events can be sufficiently reduced to allow a rediscovery after few inverse picobarns of integrated luminosity. This presentation describes the result of a Monte Carlo study done at $\sqrt{s} = 10\,\text{TeV}$ under the assumption $10\,\text{pb}^{-1}$ of integrated luminosity in the CMS experiment. It presents the expected precision on the cross-section measurement and covers the description of the simulation and the backgrounds, the event selection, the data-driven background estimation methods, the systematic uncertainties and two alternative analyses (tracker-based and b-quark content).

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1. – Introduction

The top-quark pair production ($t\bar{t}$) at the LHC can be studied to validate the Standard Model at unprecedented energy scale and could reveal new physics phenomena. In this framework, its dileptonic decay, thanks to its clean and distinctive signature, is the first candidate for an early observation. This paper presents a Monte Carlo study using realistic simulated conditions at $\sqrt{s} = 10\,\text{TeV}$, in the CMS experiment [1], for ee, $\mu\mu$ and $e\mu$ final states [2].

This study is designed to extract the cross-section from a simple counting experiment approach with $10\,\text{pb}^{-1}$ of CMS data. In these conditions, several precautions have been taken: data-driven methods to control the background have been developed; loose missing transverse energy (MET) cuts and no b-tag have been applied for early results. The estimation of the systematic uncertainties before their evaluation with first data has been chosen conservatively.

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TABLE I. – *Expected number of events passing the full event selection with $N_{\text{jets}} \geq 2$ in $10\,\text{pb}^{-1}$ reported with statistical uncertainties corresponding to the size of the simulated samples.*

	Main selection			Track-jet selection		
Data sample	ee	$\mu\mu$	$e\mu$	ee	$\mu\mu$	$e\mu$
$t\bar{t} \to \ell\ell$	11.6 ± 0.2	13.2 ± 0.2	35.6 ± 0.4	10.4 ± 0.2	11.3 ± 0.2	26.7 ± 0.4
Single top	0.46 ± 0.03	0.56 ± 0.03	1.40 ± 0.06	0.32 ± 0.03	0.35 ± 0.03	0.85 ± 0.04
DY $\to \ell\ell + jets$	4.4 ± 0.4	5.6 ± 0.4	0.8 ± 0.2	6.2 ± 0.5	6.9 ± 0.6	0.41 ± 0.11
Others	0.67 ± 0.11	0.37 ± 0.03	1.5 ± 0.1	0.75 ± 0.11	0.25 ± 0.03	1.0 ± 0.11
Total backgrounds	5.5 ± 0.4	6.6 ± 0.4	3.7 ± 0.2	6.9 ± 0.5	6.9 ± 0.6	1.6 ± 0.2
Data-driven fakes	1.1 ± 0.6	0.8 ± 0.4	2.5 ± 1.2	1.3 ± 0.6	0.5 ± 0.2	1.9 ± 1.0
Data-driven DY	4.0 ± 1.3	5.1 ± 1.6		6.6 ± 2.2	7.2 ± 2.4	

In addition to the baseline analysis, two other scenarios have been studied. The first one is a track-based scenario at $10\,\text{pb}^{-1}$, minimizing the use of the calorimeters. The second one is a first analysis on the b-quark content of jets at $100\,\text{pb}^{-1}$.

2. – Main backgrounds and event selection

The main backgrounds can be divided in three classes according to their leptonic final state. The diboson (WW, WZ, ZZ), Drell-Yan and single-top (tW) processes have two real isolated leptons. The $W + jets$ and semi-leptonic $t\bar{t}$ processes have one real isolated lepton. And the QCD multi-jets process can contribute due to its large cross-section even if the probability to contain two candidate leptons passing isolation cuts is small.

The events are required to pass single leptonic triggers. Two opposite-sign leptons with $p_T > 20\,\text{GeV}/c$ are required. A Z^0 veto is applied in the ee and the $\mu\mu$ channels on the invariant dileptonic mass. The event should also have two jets with $p_T > 30\,\text{GeV}/c$. Finally, according to the scenario, a MET cut is applied: $> 30\,\text{GeV}$ (respectively, > 20) for $ee/\mu\mu$ ($e\mu$) channels in the baseline scenario, $> 50\,\text{GeV}$ (respectively, > 30) in the b-tag study; no MET cut is applied in the tracker-based analysis.

3. – Results

3˙1. *Baseline analysis*. – This analysis allows a measurement of the $t\bar{t}$ cross-section after $10\,\text{pb}^{-1}$ of integrated luminosity with ± 15 (stat.) $\pm$ 10 (syst.) $\pm$ 10 (lumi.)% of uncertainty. The baseline analysis gives a signal-over-background ratio of 3.8 in all channels and 9.6 in the clearer channel which is $e\mu$. The expected number of events at $10\,\text{pb}^{-1}$ is shown in table I. The jet multiplicity distributions for the three channels are shown in fig. 1. The use of the track-corrected MET has also been studied, and it confirms that this method allows a better rejection of the backgrounds.

3˙2. *Track-based analysis*. – This analysis aims at minimizing the dependence on calorimeters and uses charged jets reconstructed from tracks instead of standard jets reconstructed in the calorimeters. It can be used as a complementary study or as a cross-check of the baseline study. The signal-over-background ratio is 3.0 (respectively, 16.7) for all channels ($e\mu$ channel). The expected number of events is shown in table I.

3˙3. *B-tagging study*. – A study of the flavour content of the selected sample after $100\,\text{pb}^{-1}$ of integrated luminosity can be performed with a simple and robust b-tag

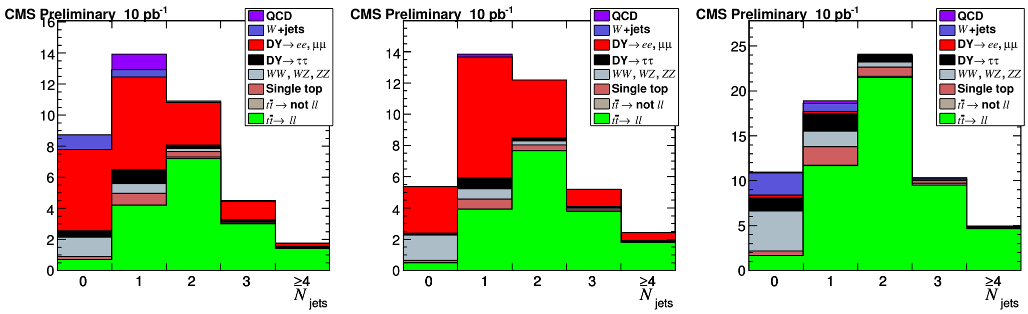

Fig. 1. – The expected number of dilepton events as a function of jet multiplicity based on Monte Carlo simulation only and normalized to $10\,\text{pb}^{-1}$ in ee (left), $\mu\mu$ (center), $e\mu$ (right).

algorithm based on counting tracks associated to the jet and displaced from the primary collision vertex. If at least one b-tagged jet is requested, the signal-over-background ratio is 9.3 (respectively, 11.1) for all channels ($e\mu$ channel). If two b-tagged jets are requested, the signal-over-background ratio is 15.9 (respectively, 15.7) for all channels ($e\mu$ channel).

4. – Data-driven estimate

4˙1. *Drell-Yan + jets estimate*. – To predict the DY contribution in the ee and $\mu\mu$ channels, where this backgrounds is dominant, a pure DY sample is obtained by selecting events where the dileptonic mass is close to the Z^0 mass, without any MET and jets requirement. Knowing the ratio with the complementary region in MC simulation, the number of expected events in the signal sample can be evaluated from data.

4˙2. *Fake leptons estimate*. – In order to evaluate reliably the fake leptons contribution without need to rely on simulation, a looser isolation cut selection is then defined and the ratio, called tight-to-lepton ratio, between the standard selected leptons and the loose selected leptons can be determined in QCD multi-jets data triggered on jets. Assuming that this ratio is similar in other backgrounds and knowing that QCD multi-jets does not contain prompt leptons, the contamination due to non-prompt leptons in the selected events can be estimated.

5. – Uncertainties

The final uncertainties are based on the luminosity uncertainty at $10\,\text{pb}^{-1}$, which is 10%, the statistical uncertainty expected at $10\,\text{pb}^{-1}$, which is 25% for the same flavour channel and 18% for the $e\mu$ channel, and systematic uncertainties based on detector and reconstruction performances (lepton identification and isolation, jet energy scale), background data-driven methods and theoretical uncertainty (based on a comparison between different MC generators).

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