# Top-quark physics results from CMS

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Recent results on top-quark physics from the CMS collaboration are presented. Among the many measurements performed by CMS, some of the most significant, related to the $t\bar{t}$ and single top production, top-quark mass and top properties measurements, are shown.

## 1 Introduction

The top quark is the heaviest particle observed. In many aspects, it is of a major interest in particle physics. It decays before it hadronizes, which allows for precise measurement of the top-quark properties. It also has the largest couplings to the Higgs boson, due to its large mass, and thus could play an special role in the electroweak symmetry breaking. While top-quark physic is crucial for our understanding of the Standard Model (SM), it is providing a very important window to potential new physics. Indeed, top-quark events have signatures comparable to many new physics prediction (BSM), and a good understanding of the top-quark background is mandatory for validating the detector performance and the simulation, but also for improving theoretical calculations and Monte-Carlo generation. Furthermore, precise measurements related to the top-quark can be used to indirectly probe new physics when searching for deviations with respect to the SM predictions.

While many major contributions to the top-quark physics were performed by the CMS collaboration [1], only some of the most significant results are presented in this proceeding. In the following, the top-quark pair and single-top-quark production cross section measurements will be first discussed. After discussing top-quark mass measurements, the top-quark properties, as well as the corresponding search for new physics, are discussed.

## 2 Top-quark production

The measurement of top-quark production cross sections are performed in both the $t\bar{t}$ and in single top channels, either inclusive [2], differential [3], or in association with additional particles [4, 5].

The most precise top-quark pair cross section measurement at 8 TeV is obtained in the dileptonic $e\mu$ channel, as it suffers from a very low background contamination, mainly the residual $Z/\gamma^* \to \tau\tau$ events with the $\tau$ decaying leptonically, and single-top-quark events in the $tW$ channel. The event selection requires two isolated high $p_T$ leptons with opposite signs, at least two high $p_T$ jets with at least one b-tagged jet. The jet and b-tagged jet multiplicities after the event selection is presented in Fig.1.

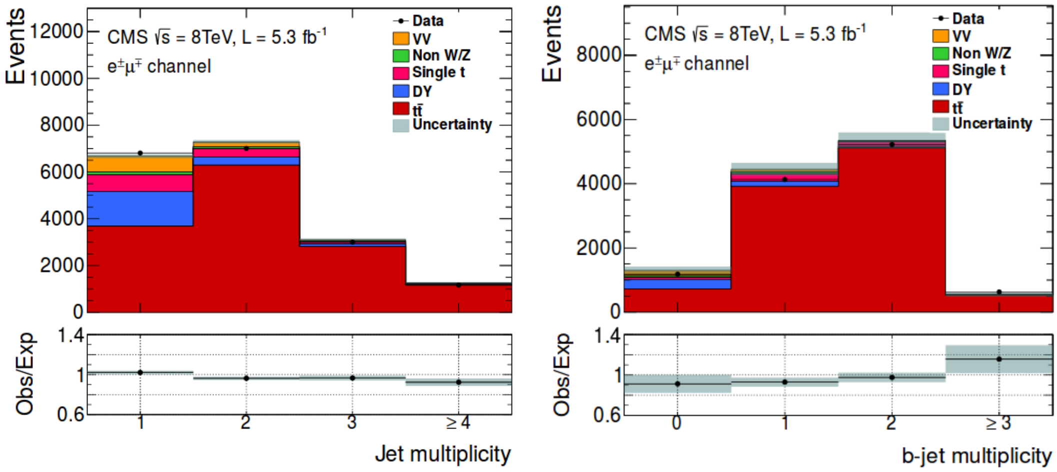


Figure 1: Jet and b-tagged jet multiplicities after the dilepton $e\mu$ event selection.

With the very large luminosity delivered by the LHC, the uncertainty is largely dominated by the systematics, with the largest contributions coming from the Jet Energy Scale (JES), the modelling of the $t\bar{t}$ signal and the luminosity. A simple counting experiment is already able to reach a very high level of precision, as demonstrated in [2]. The inclusive $t\bar{t}$ cross section is measured, with an overall precision of 5.8% , to be :

$$\sigma_{t\bar{t}} = 239.0 \pm 2.1(stat.) \pm 11.3(syst.) \pm 6.2(lumi.). \tag{1}$$

The top-quark production can also be studied through the single-top modes : the $s$-channel, the $t$-channel and the $tW$-channel, the two latest being observed at CMS [6]. The $t$-channel cross section is measured in the leptonic channel, after selecting events with one high $p_T$ isolated lepton, at least one jet, a large missing transverse energy and a large transverse mass of the $W$ candidates. The cross sections is extracted from the $|\eta|$ distribution of the recoiling jet in various signal and control regions, defined by different jet and b-tagged jet multiplicities, and by different reconstructed top-quark mass requirements. The measured cross section at 8 TeV is :

$$\sigma_{t-chan.} = 83.6 \pm 2.3(stat.) \pm 7.4(syst.). \tag{2}$$

The mains systematic uncertainties are related to the signal modelling, the jet selection and the b-tagging. Several other interesting measurements can also be performed using the same event selection and similar techniques, such as the top/anti-top cross sections ratio $\sigma_{t-chan.}(t)/\sigma_{t-chan.}(\bar{t})$ $(= 83.6 \pm 2.3(stat.) \pm 7.4(syst.).)$ which is sensitive to PDF, or the measurement of $|V_{tb}| > 0.92$, at 95% confidence level.

The first observation of the $tW$-channel was also performed for the first time by the CMS collaboration [7]. The measurement is performed in the dilepton channel, using an event selection similar to the $t\bar{t}$ inclusive cross section analysis. A boosted decision tree is used to discriminates signal against backgrounds, and fitted in various signal and background regions (using categorization in jet and b-tagged jet multiplicities). The $tW$ cross section is measured to be $23.4 \pm 5.4$, with a significance of $6.1\sigma$.

# 3 Top-quark mass measurement

The top-quark mass is measured by the CMS collaboration through different channels and techniques. The most precise measurement is performed with the 8 TeV dataset with $t\bar{t}$ lepton+jets events [8] using the ideogram technique. The event selection ask for one isolated leptons with a high $p_T$ (either a muon or an electron), at least 4 high $p_T$ jets with two b-tagged jets. A high purity of events can be reached, and a kinematic fit is used to improve the rate of correct jet-to-parton assignments by cutting on the goodness of the kinematic fit.

The correction factor the the Jet Energy Scale (JSF) is fitted simultaneously with the top-quark mass using a likelihood fit technique. The measured mass and JSF are found to be :

$$m_t = 172.04 \pm 0.19(stat. + JSF) \pm 0.75(syst.)GeV, JES = 1.007 \pm 0.002(stat.) \pm 0.012(syst.). \quad (3)$$

This result constitutes the most precise single measurement of the top-quark mass. The main systematic uncertainties are related to the JSF, the Jet Energy Resolution, the pile-up and the signal modelling. The different mass measurements performed within CMS are also combined[9] and improve slightly the overall precision.

# 4 Top-quark properties and search for new physics

As the top-quark decays before it hadronizes, the decay product of the top-quarks can be used to probe the top-quark properties. In particular, the $t\bar{t}$ spin correlation can be used to probe the $t\bar{t}g$ couplings and to search for new physics [10]. The signatures that carries most of the spin information is the $t\bar{t}$ in the dileptonic channel. Spin correlation, and the corresponding asymmetry, can be measured from the azimuthal angle $\Delta\phi(ll)$ between the two charged leptons in the $t\bar{t}$ rest frame. The differential $t\bar{t}$ cross section as a function of $\Delta\phi(ll)$, unfolded at parton level, can be seen in Fig.2 (left plot).

The differential cross section can also be used to probe new physics, by searching for chromo-magnetic dipole-moment $\hat{\mu}_t$. By comparing the unfolded distribution to theoretical predictions, the real part of $\hat{\mu}_t$ was found to be within the range $-0.043 < Re(\hat{\mu}_t) < 0.0117$ at 95% confidence level.

New physics in top events can also be performed by searching for flavour changing neutral current (FCNC) interactions, which are highly suppressed by the GIM mechanism in the SM. Top-quark FCNC are searched for in top decays in $t\bar{t}$ events [11], when a top-quark decays into a $c$ or an $u$ quark and a $Z$ boson. The search is performed in the three-lepton signature by asking for three isolated leptons (electrons or muons) with high $p_T$, and a pair of opposite-sign and same-flavour leptons compatible with the Z boson mass. At least two jets, with at least one b-tagged jet, is also required. No excess over the data is observed. Exclusion limits are calculated from the observed number of events with reconstructed top-quark masses compatible

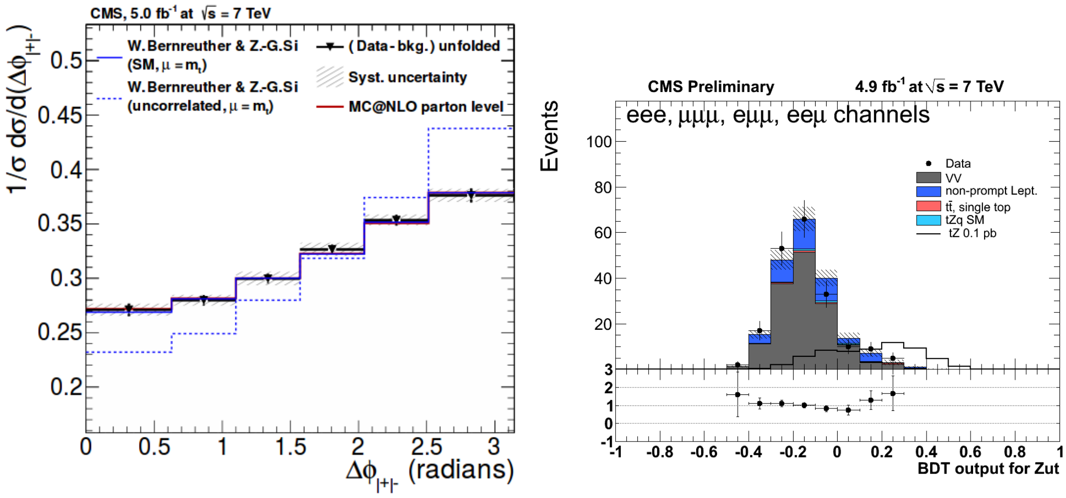


Figure 2: Left, $\Delta\phi(ll)$ differential cross section in $t\bar{t}$ events. Right : BDT distribution after the tZ selection.

with the known top-quark mass. Limit on the decay branching fraction of top quark into $Zq$ is found to be $Br(t \to Zq) < 0.05\%$ at 95% confidence level.

Similar searches can be performed in the single top signature, as the search for a top-quark produced in association with a $Z$ boson [12]. This channel has the advantage of being sensitive to the flavour of the quark $q$ entering into the FCNC vertex $tZq$. The event selection is similar to [11], but with a looser jet selection. The analysis uses a BDT to extract the signal from the backgrounds, and to calculate exclusion limits. The BDT distribution in data and simulation can be found on Fig.2, right plot. Exclusion limits on the branching ratios are found to be $Br(t \to Zu) < 0.056$ and $Br(t \to Zc) < 7.12\%$. Similarly, on can probe $t\gamma q$ FCNC interactions by searching for a top quark produced in association with a real photon [13]. The corresponding limits on the top-quark branching fractions are $Br(t \to \gamma u) < 0.0279$ and $Br(t \to \gamma c) < 0.0161\%$.

# 5 Conclusion

The CMS collaboration covers a wide range of top-related topics and only a tiny fraction of the performed measurements is presented in this document. While these measurements correspond to a big step forward in our understanding of top-quark physics, there are still many open questions that need to be answered. Future runs of the LHC can provide the amount of data needed to perform those important investigations.

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