PROCEEDINGS OF SCIENCE

Inclusive top-quark pair cross section in CMS with cut-and-count method

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The inclusive cross section for top-quark pair production is measured in proton-proton collisions at center-of-mass energies of 7, 8 and 13 TeV with the CMS experiment at the LHC using the full data samples collected in 2011 and 2012 and the first data collected in 2015. The measurement is performed with events containing an opposite charge electron muon pair. Background estimates are obtained using data driven techniques and a cut and count method is used for the final measurement.

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1. Introduction and motivation

The measurement of $t\bar{t}$ production cross section is a fundamental test for the standard model (SM), particulary for the theory of quantum chromodynamics. This cross section is dominated at LHC by gluon-gluon fussion (85%) and increases with the energy in pp collisions. This measurement has a great discovery potential for physics beyond the SM because new phenomena could significantly enhance the $t\bar{t}$ cross section. Furthermore, the $t\bar{t}$ process is an important source of background in many searches for physics beyond the SM.

The cut-and-count analysis provides a simple and robust method to extract the cross section by counting the number of signal events above the background expectation. This method is used as a cross-check for the measurement, using the total CMS integrated luminosity at $\sqrt{s} = 7$ and 8 TeV [1]. This method is also applied for obtaining a first measurement of the $t\bar{t}$ cross section at $\sqrt{s} = 13\ TeV$ using an integrated luminosity of 42 pb^{-1}, collected by the CMS collaboration [2].

2. Event selection

In the SM, top quarks are predominantly pruduced in $t\bar{t}$ pairs and each top quark decays almost exclusively to a W boson and a b quark. For these studies, events containing an electron and a muon of opposite sign with at least two jets are selected. In the measurements at $\sqrt{s} = 7$ and 8 TeV b-tagging techniques are used [3] and signal events are required to contain at least one b-tagged jet.

In Figure 1 the distributions of jet multiplicity at $\sqrt{s} = 13\ TeV$ (left) and b-jet multiplicity at $\sqrt{s} = 8\ TeV$ are shown as examples, supporting the chosen event selection.

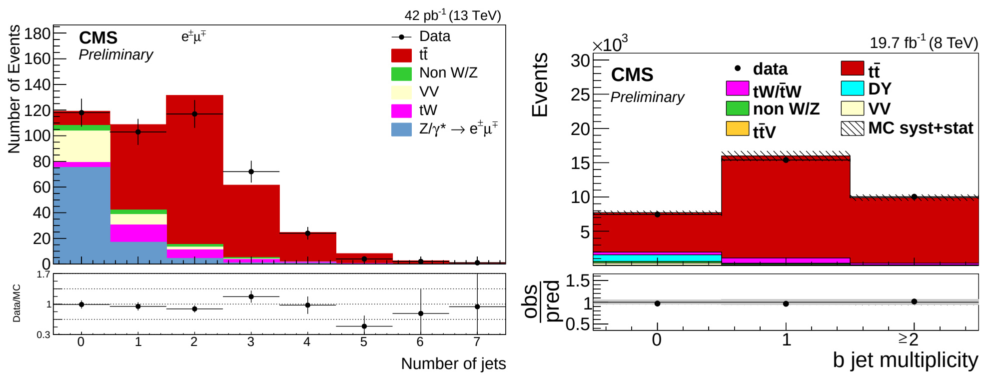

Figure 1: Distribution of the jet multiplicity after the $e\mu$ selection for 13 TeV (left) and distribution of the b-jet multiplicity after selecting events with at least two jets for 8 TeV (right).

3. Background estimation

There are some other processes in the SM leading to events that satisfy the selection. The most relevant background process is the single top quark production (tW) when b-tagging is applied and is estimated from MC simulations. Drell-Yan events constitute another source of background, as relevant as tW when b-tagging is not applied, and is estimated from data using the $R_{in/out}$ method. In this method the shapes of kinematic distribution for DY events are taken from MC but nomalised by a factor calculated from data using the Z peak as a control region.

Other background sources such as *W+jets* events in which at least one jet is incorrectly identified as a lepton or $t\bar{t}$ in the *lepton+jets channel* semileptonic decay where a lepton from the decay of a bottom is taken, are grouped in the *non-W/Z* category and estimated with data-driven techniques, using a dilepton same-sign control region.

There are some other less important backgrounds, classified into diboson (WW, WZ, ZZ) and *rare* ($t\bar{t}W$, $t\bar{t}Z$) categories. The $t\bar{t}$ signal is simulated as well, assuming a top mass of 172.5 GeV. In Table 1 the total number of events observed in data and the expectation for signal and background are shown.

Source	Number of $e^{\pm}\mu^{\mp}$ events		
	7 TeV	8 TeV	13 TeV
DY	$22.1 \pm 3.1 \pm 3.3$	$173.3 \pm 25.1 \pm 26.0$	6.4 ± 1.2
Non-W/Z	$51.0 \pm 0.7 \pm 15.3$	$145.9 \pm 14.8 \pm 43.8$	8.5 ± 4.3
Single top quark (tW)	$204.0 \pm 3.1 \pm 61.2$	$1033.6 \pm 2.9 \pm 313.8$	10.6 ± 3.4
VV	$6.9 \pm 0.6 \pm 2.1$	$35.4 \pm 1.9 \pm 11.1$	2.6 ± 0.9
Rare ($t\bar{t}V$)	$--$	$83.6 \pm 1.3 \pm 25.5$	$--$
Total background	$284.0 \pm 16.0 \pm 63.2$	$1471.7 \pm 46.7 \pm 319.1$	28.1 ± 5.7
t$\bar{\text{t}}$ dilepton signal	$5008.2 \pm 15.4 \pm 188.0$	$24439.6 \pm 43.6 \pm 956.4$	207 ± 16
Data	4970	25441	220

Table 1: Number of $e\mu$ events after the selection for the 7, 8 and 13 TeV datasets. The uncertainties include the statistical and systematic components.

4. Systematic uncertainties

The measurement of the $t\bar{t}$ production cross section is affected by several systematic uncertainties that originate from detector effects and theoretical assumptions. A great effort has been done to accurately estimate these uncertainties affecting the measurements. Each source of systematic uncertainty is assessed individually by suitable variations of the MC simulations or varying parameter values within their estimated uncertainties.

One important experimental uncertainty comes from trigger and lepton identification efficiencies, which are estimated from varying data-to-simulation scale factors (SFs) by their uncertainties. The effect on the measurement for 7 and 8 TeV is arround 1.2%. The lepton energy scale uncertainties (LES) are evaluated by varying the scale by 0.3% and 0.15% for muons or electrons, respectively, and 2.5% to 5% for jets (JER).

The effect of the pile-up events is evaluated by changing the pp total cross section and produce a systematic uncertainty in the measurement at 7 and 8 TeV of about 0.8%.

The uncertainty due to the limited knowledge of the jet energy scale (JES) is determined by changes implemented in jet energy in bins of transverse momentum p_T and absolute value of pseudorapidity $|\eta|$ and has an effect on the measurement uncertainty for 7 and 8 TeV of about 2%. The b-tagging efficiency affects the measurement only at 7 and 8 TeV producing an uncertanty of about 1.4%. All background sources (except DY) have a conservative 30% uncertainty asociated.

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The uncertainty on the measurement is only significantly affected by the one of the tW background, resulting in a 1.3% uncertainty for 7 and 8 TeV.

On the other hand, among the most relevant modelling uncertainties are the QCD renormalization and factorization scales, varied coherently by a factor 2 up and down. The uncertanty due to the choice of the scale that separates jet production from matrix element/parton shower is studied by changing its reference value of 20 GeV to 40 and 10 GeV. The knowledge in the PDF is determined by reweighting the sample of simulated $t\bar{t}$ events according to the 52 CT10 error PDF sets for 7 and 8 TeV. These three uncertainties affect the measurement with an error of about 1.2%, 1% and 1.1% respectively, for 7 and 8 TeV.

The value of the systematic uncertainties at 13 TeV are, in general, higher than for the other energies. In particular, the uncertainty on luminosity is dominant in this measurement.

5. Results

The measured cross section at the three different center-of-mass energies are:

$$\sigma_{t\bar{t}}^{7TeV} = 174.5 \pm 2.1(\text{stat.}) \pm^{4.5}_{4.0}(\text{syst.}) \pm 3.8(\text{lumi.})\text{pb} \quad \text{at } \sqrt{s} = 7 \text{ (TeV)}$$

$$\sigma_{t\bar{t}}^{8TeV} = 245.6 \pm 1.3(\text{stat.}) \pm^{6.6}_{5.5}(\text{syst.}) \pm 6.5(\text{lumi.})\text{pb} \quad \text{at } \sqrt{s} = 8 \text{ (TeV)}$$

$$\sigma_{t\bar{t}}^{13TeV} = 772 \pm 60(\text{stat.}) \pm 62(\text{syst.}) \pm 93(\text{lumi.})\text{pb} \quad \text{at } \sqrt{s} = 13 \text{ (TeV)}$$

These results are plotted in Figure 2 along with other $t\bar{t}$ cross section measurements.

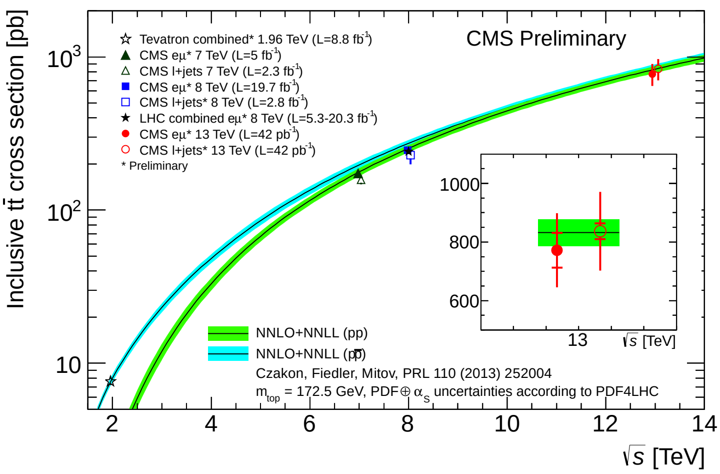

Figure 2: $t\bar{t}$ production cross section in pp and $p\bar{p}$ collisions as a function of the certer-of-mass energy.

References

[1] CMS Collaboration, *Measurement of the top quark pair cross section in the eμ final state with* $19.7 fb^{-1}$ *collected at* $\sqrt{s} = 8$ *TeV and* $5.0 fb^{-1}$ *at* $\sqrt{s} = 7$ *TeV, CMS-PAS-TOP-13-004*

[2] CMS Collaboration, *Measurement of the top quark pair production cross section in proton-proton collisions at* $\sqrt{s} = 13$ *TeV, Phys. Rev. Lett. 116(2016) 052002.* [hep-ex/1510.05302]

[3] CMS Collaboration, *Identification of b-quark jets with the CMS experiment, JINST 0 (2013) 04013* [hep-ex/1211.4462]