IL NUOVO CIMENTO Vol. 35 C, N. 3 Maggio-Giugno 2012
DOI 10.1393/ncc/i2012-11252-3

Colloquia: TOP2011

Combined measurement of the $t\bar{t}$ cross section and the b-tagging efficiency using μ+jet events

M. Maes on behalf of the CMS Collaboration

Vrije Universiteit Brussel, Inter-university Institute for High Energies - Brussels, Belgium

ricevuto l' 1 Marzo 2012
pubblicato online il 5 Giugno 2012

Summary. — The Large Hadron Collider, built at CERN, is the first collider in the world able to act as a top-quark factory. The large amounts of top-quark events produced allow us to study the properties of this heavy quark in great detail. We propose a combined measurement of the $t\bar{t}$ cross section and the b-tagging efficiency using the muon+jets event topology observed by the CMS experiment in the 7 TeV proton collisions of the LHC. The data collected in 2011 used for this measurement corresponds to an integrated luminosity of $1.1\,\text{fb}^{-1}$. The obtained $t\bar{t}$ cross section is 177.8 ± 11.2 (stat.) $\pm\, 50.6$ (syst.) $\pm\, 11.3$ (lumi) pb together with a measured b-tagging efficiency of 60.3 ± 3.2 (stat.) $\pm\, 33.1$ (syst.)%. A b-tag algorithm based on the second highest 2D impact parameter significance among all tracks in the jet is applied with a threshold corresponding to a light-flavor mistagging rate of 1%. The result of this crosscheck analysis is in agreement with the main CMS result of 164.4 ± 2.8 (stat.) $\pm\, 11.9$ (syst.) $\pm\, 7.4$ (lum.) pb obtained.

PACS 14.65.Ha – Top quarks.
PACS 14.65.Fy – Bottom quarks.

1. – Introduction

The measurement of the top-quark pair cross section at the LHC [1] is important for diverse reasons. The measurement on its own is a test of the Standard Model as well as a benchmark for the theoretical calculations. The result is also relevant for those searches beyond the Standard Model for which the top-quark pair processes are the dominant background. In the decay of top quarks bottom quarks are present as the CKM element V_{tb} is constrained to be close to unity. Therefore the top-quark pair signal, two b-quarks and two W-bosons in the final state, can be isolated from the background in the proton collisions at the LHC by use of b-quark identification algorithms or so-called b-tagging [2]. Although the application of b-tagging will purify the selected sample, it will also introduce important systematic uncertainties due to our understanding of the performance of these b-tagging algorithms. With a combined measurement of the top-quark pair cross section with the b-tagging efficiency we will be able to remove this additional uncertainty. We present the potential of performing this combined measurement in a maximally data-driven way at the CMS [4] experiment. The b-tagging efficiency will be estimated from a specific sample which is enhanced in b-quark jets. In a data-driven way the non–b-quark jets will be subtracted, and the measured distribution of the b-tag variable will be obtained for true b-quark jets. The b-tagging efficiency at different working points or thresholds can be determined from this distribution. Using the same event sample, but after applying a b-tag cut in the event selection, the top-quark pair cross section will be obtained from a template fit on a kinematic variable which differentiates between the top-quark process and the main background. This method is a crosscheck to the reference measurement extracting the cross section from a a profile likelihood method using a fit to the number of reconstructed jets, the number of b-tagged jets, and the secondary vertex mass distribution [3].

The measurement will be applied on the semi-muonic decaying top quark pairs, namely $t\bar{t} \to bWbW \to bqqb\mu\nu_\mu$ reflecting about 4/27 of the total branching ratio of top-quark pairs.

2. – Event selection and reconstruction

The results are obtained on a dataset of $1.1\,\text{fb}^{-1}$ of proton-proton collisions recorded at the CMS experiment at a center-of-mass energy of 7 TeV. A trigger is used requiring an isolated muon with a transverse momentum (p_T) exceeding $17\,\text{GeV}/c$. Then the events are reconstructed using the ParticleFlow algorithm [5] and required to contain an isolated muon with p_T exceeding $35\,\text{GeV}/c$ within a pseudorapidity of $|\eta| < 2.1$ that passes a series of tight muon identification criteria. Furthermore, we require at least four jets in the event with $p_T > 30\,\text{GeV}/c$ within the acceptance of $|\eta| < 2.4$. Finally events are rejected if they contain one or more looser electrons or muons. No missing transverse energy ($\not{E}_T$) is used.

3. – Measuring the $t\bar{t}$ cross section

The $t\bar{t}$ production cross section is measured using a template fit on a the invariant mass of the muon and leptonic b-jet candidate ($m_{\mu j}$), shown in fig. 1. To reconstruct $m_{\mu j}$ distribution, the b-quark jet in the $t \to b\mu\nu_\mu$ decay should be identified among all selected jets. A χ^2 sorting algorithm is applied using as input the top-quark and W-boson masses and widths from simulation to points out the b-jet candidate in each event. Since the $m_{\mu j}$ variable is sternly dependent on the $t\bar{t}$ decay kinematics it has proven to have good discriminate between $t\bar{t}$ events and the various backgrounds. The templates for $t\bar{t}$ and background distributions are obtained from simulation, after applying the event selection outlined in the previous section together with a requirement of medium b-tag on the jet associated to the leptonically decaying top quark, and are fitted on the distribution from data. A b-tag algorithm based on the second highest 2D impact parameter significance among all tracks in the jet [2] is applied with a cut which provides a light-flavor mistagging rate of 1%. The template fit results in a number of observed $t\bar{t}$ events. From this number, using eq. (1), the event selection efficiency and b-tagging efficiency, the cross section is obtained. The b-tagging efficiency entering the cross section

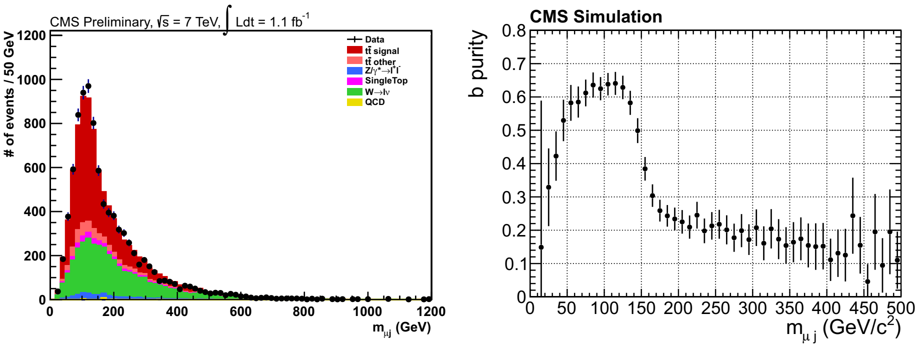

Fig. 1. – Left: Invariant mass distribution of the b-jet candidate and the muon system and (right) b-jet purity as a function of the invariant mass distribution of the b-jet candidate and the muon system

calculation is measured simultaneously with the $t\bar{t}$ cross section

$$\sigma_{t\bar{t}} = \frac{N_{t\bar{t}}}{L} = \frac{N_{t\bar{t}^{obs}}}{L} \times \frac{1}{\epsilon_{sel}\epsilon_{\chi^2_{cut}}\epsilon_{\text{b-tag}}}. \tag{1}$$

The efficiencies ϵ_{sel} and $\epsilon_{\chi^2_{cut}}$ used in eq. (1) are determined on simulation and a scale factor is applied to account for differences with respect to data. The b-tagging efficiency is determined by reconstructing the b-tag discriminant distribution for true b-jets ($\hat{\Delta}_b$) in a fully data-driven way.

Before applying the b-tagging criteria on the b-jet associated to the leptonically decaying top quark in the events, these candidates for b-flavored jets are used to define a b-candidate jet sample. This jet sample is divided into a b-flavor enriched and b-flavor depleted subsample. As shown in fig. 1 (right) the subdivision is performed according to the $m_{\mu j}$ variable of the event, which yields the b-enriched region as $80\,\text{GeV}/c^2 < m_{\mu j} <$

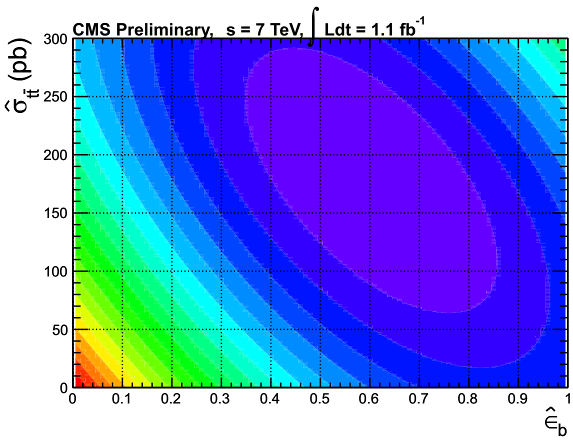

Fig. 2. – $\Delta\chi^2$ distribution in the $(\hat{\epsilon}_b, \hat{\sigma}_{t\bar{t}})$-plane.

$150\,\mathrm{GeV}/c^2$ and the b depleted region as $150\,\mathrm{GeV}/c^2 < m_{\mu j} < 250\,\mathrm{GeV}/c^2$. The subdivision is defined such that the $m_{\mu j}$ variable remains uncorrelated with the b-tagging discriminators in the selected enriched and depleted regions.

To obtain the true b-jet discriminator ($\hat{\Delta}_b$), the non–b-jet contamination in the b-flavor enriched subsample is removed by subtracting the b-tag discriminant distribution of the b-flavor depleted subsample (Δ_b^{depl}) from the b-flavor enriched subsample (Δ_b^{enr})

$$\hat{\Delta}_b = \Delta_b^{enr} - F \times \Delta_b^{depl}. \tag{2}$$

The factor F in eq. (2) represents the ratio between the number of non–b-jets in the b-flavor enriched and b-flavor depleted subsamples which therefore rescales the number of non–b-jets in the depleted region to the number of non–b-jets in the enriched subsample. This factor F is obtained by constructing a control sample with a high purity in non–b-jets. The control sample of jets is defined as those jets in the events which are associated with the hadronically decaying W-boson. Additionally these jets in the control sample are requested to be anti–b-tagged to further reduce the b-jet contamination. In the control sample, the same subsamples are defined as within the signal b-candidate jet sample by use of the $m_{\mu j}$ variable which allows direct access to the factor F from data. The kinematics of the jets in the control sample are matched to those in the signal b-candidate sample using reweighing techniques based on the observed data itself. Also in the data driven determination of F and in the application of eq. (2) the participating jets in the b-flavor depleted region are reweighed to match the kinematics of the jets in the b-flavor enriched region. From the estimated b-tag discriminator distribution, $\hat{\Delta}_b$, the b-tagging efficiency for diverse working points is estimated.

4. – Results

On a dataset of $1.1\,\mathrm{fb}^{-1}$ of proton-proton collisions at $\sqrt{s} = 7\,\mathrm{TeV}$ recorded by the CMS experiment at the Large Hardron Collider during 2011, a $t\bar{t}$ cross section of 177.8 ± 11.2 (stat.) ± 50.6 (syst.) ± 11.3 (lumi.) pb is measured for a measured b-tagging efficiency of 60.3 ± 3.2 (stat.) ± 33.1 (syst.)% for the tagger and working point defined above, a. This result is in agreement with the CMS reference result of 164.4 ± 2.8 (stat.) ± 11.9 (syst.) $\pm$ 7.4 (lum.) pb [3]. Figure 2 shows the correlation between the b-tagging efficiency and the cross section from data which arrises from the combined measurement of the two properties. The dominating systematic uncertainty in the measurements of the $t\bar{t}$ cross section arises from the uncertainty in the determination of the jet energy scale.

REFERENCES

[1] Kidonakis N. and Vogt R., *The theoretical top quark cross section at the Tevatron and the LHC*, arXiv:0805.3844 [hep-ph] (2008).

[2] CMS Collaboration, *Performance of b-jet identification in CMS, CMS Physics Analysis Summary*, CMS-PAS-BTV-11-001 (2011).

[3] CMS Collaboration, *Measurement of the $t\bar{t}$ Pair Production Cross Section at $\sqrt{s} = 7$ TeV using b-quark Jet Identification Techniques in Lepton + Jet Events, CMS Physics Analysis Summary*, CMS-PAS-TOP-11-003 (2011).

[4] CMS Collaboration, *JINST*, **3** (2008) S08004, doi=10.1088/1748-0221/3/08/S08004.

[5] CMS Collaboration, *Commissioning of the Particle-Flow reconstruction in Minimum-Bias and Jet Events from pp collisions at $\sqrt{s} = 7$ TeV, CMS Physics Analysis Summary*, CMS-PAS-PFT-10-002 (2010).