IL NUOVO CIMENTO Vol. 35 C, N. 3 Maggio-Giugno 2012
DOI 10.1393/ncc/i2012-11217-6

Colloquia: TOP2011

Measurement of $t\bar{t}$ cross-section in single leptonand fully hadronic channels at the LHC

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ricevuto l' 1 Marzo 2012
pubblicato online il 28 Maggio 2012

Summary. — The most precise measurements of top quark pairs ($t\bar{t}$) production cross-section in proton-proton collisions at a centre-of-mass energy $\sqrt{s} = 7\,\text{TeV}$ at the LHC are described for the single lepton and fully hadronic decay channels.

PACS 14.65.Ha – Top quarks.

1. – Introduction

The top quark discovery completes the third quark family of the Standard Model (SM). Only two particle accelerators generate beams of sufficient energy to produce them. The Tevatron (Fermilab) where the top quark was discovered in 1995 and the LHC (CERN) where the most precise measurements are being carried out. Being the heaviest particle found so far, with a mass of $m_{\text{top}} \sim 173\,\text{GeV}$, the top quark is expected to play an important role in the electroweak symmetry breaking due to its Yukawa coupling being close to unity. The measurement of $t\bar{t}$ production cross-section ($\sigma_{t\bar{t}}$) is of particular interest as it represents a unique test of perturbative QCD. A very precise evaluation of the top quark cross-section can provide constraints on physics beyond the SM. Furthermore, $t\bar{t}$ final states represent one of the main backgrounds in searches for new physics such as supersymmetry.

2. – Cross-section measurements

The $t\bar{t}$ pair final state contains in all cases two b-quarks, since the top decays to a W boson and a b-quark almost 100% of the time. In this paper we describe the measurements in two final states. The single lepton channel, which accounts for $\sim 45\%$ of the decays, is characterised by four high-p_{T} jets (two b-quark jets from the top decays and two jets from the hadronic decay of the W boson), one isolated lepton (only electrons and muons are considered, including a $\sim 5\%$ contribution from leptonically decaying taus) and missing transverse energy associated to the neutrino. Measurements in the fully

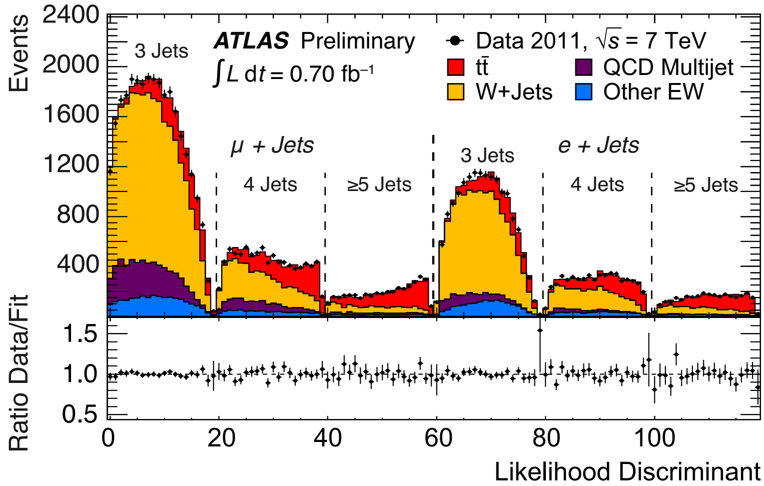

Fig. 1. – Likelihood discriminant for a multivariate analysis in ATLAS for the single-lepton channel with $700\,\text{pb}^{-1}$.

hadronic channel, with a total branching ratio similar to the single lepton channel, is also presented. This channel has more background from multi-jet processes since both W bosons are decaying hadronically.

2·1. *Measurement of $\sigma_{t\bar{t}}$ in the lepton plus jets untagged final state.* – Not using b-tagging avoids the impact of the large related systematic uncertainties, however at the cost of a worse signal-to-background ratio.

The ATLAS analysis [2] exploits the kinematical differences between the top signal and other backgrounds, mainly the W boson production associated with jets. It uses a maximum likelihood fit to a discriminant variable built from kinematical variables in the 3-jet exclusive, 4-jet exclusive and 5-jet inclusive final states shown in fig. 1. The variables are chosen for their separation power between signal and background, as well as

Table I. – *Summary of $\sigma_{t\bar{t}}$ for single lepton and fully hadronic final states for the ATLAS and CMS Collaboration.*

Analysis	Cross-section	Luminosity
ATLAS		
l+jets untagged	$\sigma_{t\bar{t}} = 179 \pm 3.9(\text{stat.}) \pm 9(\text{syst.}) \pm 7(\text{lumi.})$ pb	$0.7\,\text{fb}^{-1}$
l+jets tagged	$\sigma_{t\bar{t}} = 189 \pm 11(\text{stat.})^{+15}_{-14}(\text{syst.}) \pm 6(\text{lumi.})$ pb	$35\,\text{pb}^{-1}$
Full hadronic	$\sigma_{t\bar{t}} = 167 \pm 18(\text{stat.}) \pm 75(\text{syst.}) \pm 6(\text{lumi.})$ pb	$1.0\,\text{fb}^{-1}$
CMS		
l+jets untagged	$\sigma_{t\bar{t}} = 173 \pm 14(\text{stat.}) \pm 34(\text{syst.}) \pm 7(\text{lumi.})$ pb	$36\,\text{pb}^{-1}$
l+jets tagged	$\sigma_{t\bar{t}} = 164 \pm 3(\text{stat.}) \pm 12(\text{syst.}) \pm 7(\text{lumi.})$ pb	$1.0\,\text{fb}^{-1}$
Full hadronic	$\sigma_{t\bar{t}} = 136 \pm 20(\text{stat.}) \pm 40(\text{syst.}) \pm 8(\text{lumi.})$ pb	$1.0\,\text{fb}^{-1}$

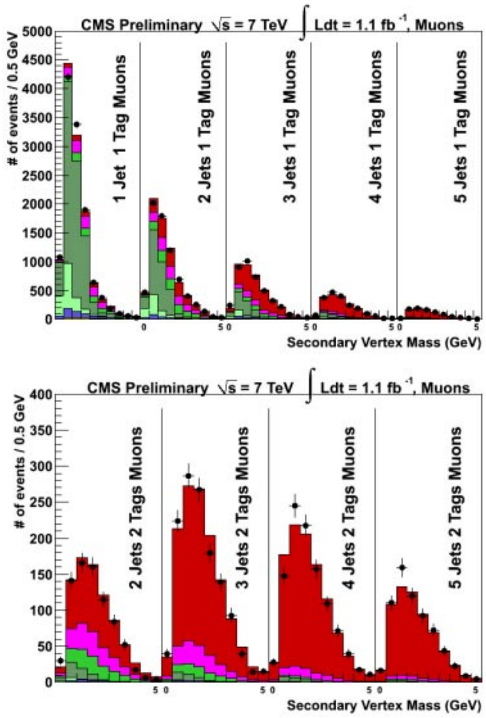

Fig. 2. – Secondary vertex distribution for muons with $1.1\,\mathrm{fb}^{-1}$.

their sensitivity to the dominant systematic uncertainties. These variables are the lepton pseudorapidity, $\exp(-4\times H_{T,3p})$ (related to the transverse energy of all jets except the two leading ones), $\exp(-8\times \mathrm{Aplanarity})$ and the leading jet p_{T}. The latter is very sensitive to the jet energy scale (JES). An important contribution to the systematic uncertainty comes from $t\bar{t}$ modelling (ISR/FSR and generator uncertainty).

The result, shown in table I, represents the most precise measurement of $\sigma_{t\bar{t}}$ with a relative error of 6.6%, challenging the NNLO calculation [1] with an error of about 10% dominated by PDF uncertainty.

The CMS Collaboration also reports an untagged analysis with $36\,\mathrm{pb}^{-1}$ [3] consisting in a simultaneous binned likelihood fit to the invariant mass of the candidate hadronic top decay and $E_{\mathrm{T}}^{\mathrm{miss}}$ distributions. In the 3-jet bin, $E_{\mathrm{T}}^{\mathrm{miss}}$ can differentiate in a powerful way multi-jet background and Z boson production from W+jets and top events, while the hadronic top mass separates efficiently top from W+jets events in the 4-jet inclusive bin. Systematic uncertainties are dominated by JES (20%) and generator factorization and shower matching threshold (10%). The total error is 23%.

2˙2. *Measurement of $\sigma_{t\bar{t}}$ in the lepton plus jets tagged final state.* – b-tagging algorithms are useful to select rather pure samples of $t\bar{t}$ events, with the drawback of the systematic uncertainties associated to b-tagging efficiencies and heavy-flavour fractions in background processes.

ATLAS uses $35\,\mathrm{pb}^{-1}$ of data to measure $\sigma_{t\bar{t}}$ using b-tagging information [4]. The analysis is similar to the untagged measurement but using jets with lowest light-quark jets probabilities instead of leading jet p_T. The largest systematic uncertainties come from W+jets heavy flavour content, b-tagging calibration, followed by JES, jet reconstruction efficiency and ISR/FSR modelling.

CMS updated their analysis using $0.8\,\text{fb}^{-1}$ of data for the electron channel and $1.1\,\text{fb}^{-1}$ for the muon channel [5]. The technique used is a maximum likelihood fit to the number of reconstructed jets from the 1-jet exclusive to the 5-jet inclusive bins, to the number of b-tagged jets and to the secondary vertex mass distribution shown in fig. 2.

The combined statistic and systematic uncertainty for this analysis give an error of 8.7%. The main systematic uncertainties are the PDF, JES, jet energy resolution and b-tagging efficiency.

2˙3. *Measurement of* $\sigma_{t\bar{t}}$ *in the fully hadronic final state*. – Both ATLAS and CMS use $1\,\text{fb}^{-1}$ of data [6] and [7], respectively. The signature for this decay mode is six high-p_{T} jets with two of them tagged as b-jets. Since there are no leptons nor $E_{\text{T}}^{\text{miss}}$, multi-jet processes constitute the main background.

ATLAS developed an *Event Mixing* technique that uses a sample with a lower number of jets (exclusive) to model a sample with a larger multiplicity. The jets produced in the decay of the top quarks and the W boson are selected by minimizing a χ^2 testing the reconstructed masses. The $t\bar{t}$ fraction is extracted from a likelihood fit to the mass chisquare distribution. A conservative evaluation of the systematic errors, with largest contributions from JES, b-tagging and ISR/FSR, gives a total error of 48%. CMS estimates the multi-jet background by re-weighting the sample of events containing no b-tagged jets, with less than 1% signal content, with a p_{T} and η dependent jet tagging probability.

The cross-section is determined from an unbinned maximum likelihood fit to the reconstructed top quark mass. The total systematic uncertainty is 33%, smaller than the ATLAS result. The largest contributions come from b-tagging, JES and background modeling.

3. – Summary

In table I we have summarized all results presented in the Top 2011 workshop. All results presented are in good agreement with theoretical predictions within the Standard Model [1].

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