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Measurement of top quark pair production cross-section in the lepton+jets channel at $\sqrt{(s)} = 7\,\text{TeV}$ at the LHC with the ATLAS experiment

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Summary. — Top quark pair production cross-section in pp collisions has been measured at a center-of-mass energy of 7 TeV using $35.5\,\text{pb}^{-1}$ of data recorded in 2010 by the ATLAS experiment at the LHC. A cut-based analysis was applied to select events containing exactly one energetic charged lepton, large missing transverse energy (compatible with the presence of an undetected neutrino) and four jets of which at least one tagged as originated from a b quark. The main backgrounds, due to QCD and W+jets processes, have been evaluated directly by data, while other sources of background and the signal are described by a Monte Carlo simulation. The final result is obtained combining the electron and muon channels using a technique based on Bayes' theorem that takes into account both correlated and uncorrelated systematics.

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PACS 13.38.Be – Decays of W bosons.
PACS 13.85.Hd – Inelastic scattering: many-particle final states.

1. – Introduction

Events in which top-quark pairs are produced are extremely important at the LHC, as they provide a unique environment to test the predictions of the Standard Model and of its possible extensions [1]. A first measurement of the $t\bar{t}$ cross-section by the ATLAS experiment [2] has been performed with the first $2.9\,\text{pb}^{-1}$ [3]. The measured cross-section of $\sigma_{t\bar{t}} = 145 \pm 31(\text{stat})^{+42}_{-27}(\text{syst})\,\text{pb}$ is in agreement with the theoretical prediction of $164.6^{+11.4}_{-15.7}\,\text{pb}$ as calculated at approximate next-to-next-to leading order (NNLO) [4], assuming a top mass of $m_t = 172.5\,\text{GeV}$. In this proceeding, an update of the analysis that makes use of $35.5\,\text{pb}^{-1}$ of data acquired in 2010 will be shown.

2. – Event topologies and experimental challenges

Analyses involving top quarks require an outstanding knowledge of the detector and an overall high performance of all the links of the analysis chain. Final states in $t\bar{t}$ events are classified into three categories, according to the W decay mode produced in the transition $t \to bW$. They usually contain charged leptons, hadronic jets (two of them originated by a bottom quark) and neutrinos that escape the experimental apparatus undetected and are associated to missing energy in the event.

From an experimental perspective, the lepton+jets (semileptonic) final state $l\nu b\ qqb$ is the favoured one in the first stage of data taking, since it is easy to trigger thanks to the charged lepton. Its background, mostly due to interactions producing a W boson in association with jets, is relatively low.

Thus, it is important to reconstruct efficiently charged tracks in the inner detector and in the muon spectrometer, and to measure with a high degree of accuracy the energy released in the calorimeters.

3. – Data samples

During 2010, the LHC delivered an integrated luminosity of $48.1\,\mathrm{pb}^{-1}$, of which $45\,\mathrm{pb}^{-1}$ was recorded by ATLAS with an efficiency of 93.6%. The peak of the instantaneous luminosity reached by the LHC was $2 \times 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. Considering only events in which the full ATLAS detector was ready, a total of $35.5\,\mathrm{pb}^{-1}$ remained available for top quark analyses. The uncertainty on the luminosity was estimated to be 3.4% [5], the average number of pile-up interactions being 3.

4. – Object and event selection

The reconstruction of $t\bar{t}$ events makes use of electrons, muons, jets, and of missing transverse energy.

Electrons are defined as clusters consistent with the energy deposition of an electron in the calorimeters and with an associated track in the inner detector satisfying quality criteria. Only candidates with transverse energy $E_T > 20\,\mathrm{GeV}$, $|\eta| < 2.5$ and sufficient isolation enter the analysis.

Muons are reconstructed from tracks in the muon spectrometer. Track segments are combined with a procedure that takes material effects and information from the inner detector into account. The final candidates are refitted using the complete track information, and are required to have a transverse momentum $p_T > 20\,\mathrm{GeV}$, $|\eta| < 2.5$ and sufficient isolation.

Jets are reconstructed with the anti-kt algorithm [6] with parameter $R = 0.4$. The input to the jet finder are topological clusters of energy deposits in the calorimeters, calibrated to the hadronic energy scale. Jets with an angular distance $\Delta R < 0.2\,\mathrm{rad}$ from an electron are removed to avoid double-counting of electrons as jets.

In order to tag jets originated by the decay of a B hadron, a dedicated algorithm is deployed [7]. It hinges on the information about the secondary vertex formed by the decay products of the bottom hadron. The discriminating variable is the decay length significance, measured in 3D and signed with respect to the jet direction. The operating point provides a 50% tagging efficiency for b-jets and a mistagging efficiency for light jets less than 0.4% in simulated $t\bar{t}$ events.

5. – Measurement of the production cross-section

5˙1. *Event selection.* – $t\bar{t}$ events contain in their final state a charged lepton, at least 4 particle jets and a missing transverse energy compatible with the signature of an undetected neutrino. Events are first skimmed using a high-p_T lepton trigger. After the trigger, events are required to satisfy the following preselection cuts:

1. Single charged lepton matching the trigger;

2. Missing transverse energy and transverse mass compatible with the presence of a W boson decayed into a charged lepton plus neutrino;

3. At least one jet with $p_T > 25\,\text{GeV}$.

Events are then classified according to the number of jets and their flavor tagging.

5˙2. *Baseline multivariate analyses.* – Baseline analyses are based on multivariate techniques that combine a small number of features extracted on an event-by-event basis in order to estimate the production cross-section.

The simplest analysis [8] does not deploy b-tagging information and makes use of only 3 kinematic quantities: the pseudorapidity of the lepton, the charge of the lepton and the aplanarity of the event. These are used to build a likelihood discriminant. A projective likelihood approach is applied as implemented in the TMVA package [9]. A binned maximum likelihood fit is performed at the same time to four orthogonal samples (e/μ + 3,4 jets) and the fitted cross-section is:

$$\sigma_{t\bar{t}} = 171 \pm 17(\text{stat})^{+20}_{-17}(\text{syst}) \pm 6(\text{lumi})\ \text{pb}. \tag{1}$$

The overall uncertainty is $\sim 15\%$. This measurement is in good agreement with the Standard Model prediction.

A more precise measurement has been performed exploiting b-tagging information [4]. This time 4 quantities have been deployed: the pseudorapidity of the lepton, the aplanarity of the event, the average of the two lowest light-jet tag probabilities and the variable $H_{T,3p} = \sum_{i=3}^{N_{jets}} p^2_{T,i} / \sum_{j=1}^{N_{obj}} |p_{z,j}|$, where N_{jets} is the number of jets and N_{obj} is the number of final state objects, including the reconstructed neutrino. The fit is performed simultaneously to six samples (e/μ + 3,4, $\geq$ 5-jets). Most of the signal is expected to contribute in the 4- and $\geq$ 5-jet bins, while the 3-jet bin helps constraining the $W + jets$ background contribution. The cross-section is then extracted from a binned likelihood fit to the discriminant distribution. Systematics entering the fit are scaled by nuisance parameters in a profile likelihood. The maximum likelihood fit including statistical and all systematic uncertainties yields a cross-section of:

$$\sigma_{t\bar{t}} = 186 \pm 10(\text{stat})^{+21}_{-20}(\text{syst}) \pm 6(\text{lumi})\ \text{pb}, \tag{2}$$

again in agreement with the Standard Model expectation. The overall uncertainty is 12%, comparable with the theoretical uncertainty.

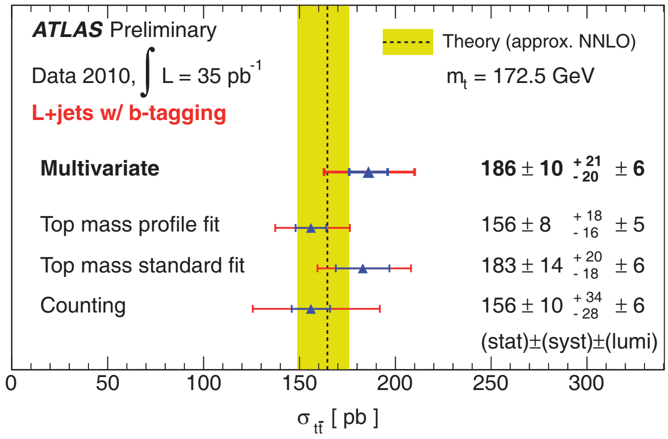

Fig. 1. – Comparison of $t\bar{t}$ cross-section measurements.

5·3. *Cut-and-count analysis.* – A simpler method based on the cut-and-count technique has been used as a cross-check [4]. Previously used as the baseline analysis for the first 2.9 pb^{-1} [3], this method still represents a simple and effective way to measure the cross-section and provides a common ground for future analyses that needs a top-enriched sample.

An admixture of data-driven and Monte Carlo-based techniques have been adopted to evaluate the background to $t\bar{t}$ events.

QCD Multi-jet events due to QCD interactions with fake/non-prompt isolated charged leptons plus mis-reconstructed E_T^{miss} in their final state are evaluated using data driven estimations. In the electron channel, lepton candidates that fail particle identification (but not kinematic) cuts are used to estimate the properties of the background. The normalization is extracted by fitting to the data-background E_T^{miss} distribution. Instead, in the muon channel the so-called matrix method has been adopted [3]. To each event a weight is assigned representing the likelihood of the background-hypothesis.

W+jets events are an irreducible background and represent the largest fraction of the background after event selection. The Monte Carlo simulation predict correctly the W+jet kinematical distributions, but not the relative normalizations of the different jet multiplicities. These normalization factors are extracted from data by measuring the ratio of the cross-sections of W/Z+jets processes. A Monte Carlo-driven correction factor that accounts for different heavy flavor composition in pre-tag and tagged samples is applied.

Other Single top, $Z + jets$ and $WW/WZ/ZZ$ backgrounds contribute much less and have been evaluated using NLO Monte Carlo simulations.

5˙4. *Calculation of the cross-section and combination of the results.* – In the cut-and-count method the calculation of the cross-section is:

$$\sigma = \frac{N_{obs} - N_{bkg}}{\int L\mathrm{d}t \times \mathcal{B} \times \epsilon}, \tag{3}$$

where N_{obs} is the number of observed events, N_{bkg} is the number of expected background events, $\int L\mathrm{d}t$ is the integrated luminosity, $\mathcal{B}$ is the branching ratio and ϵ is the selection efficiency. The results from the $e+jets$ and $\mu+jets$ channels have been combined using a method based on Bayes' theorem. The joint posterior is calculated from the likelihood of each channel, times the prior. Systematics are treated as nuisance parameters in the likelihood. The combined cross-section is:

$$\sigma_{t\bar{t}} = 156 \pm 10(\mathrm{stat})^{+34}_{-28}(\mathrm{syst}) \pm 6(\mathrm{lumi})\ \mathrm{pb}. \tag{4}$$

This result proved to be in agreement with a calculation performed using a frequentist approach. The total uncertainty, of the order of 20%, is larger than in the one obtained with the multivariate analyses (fig. 1).

6. – Conclusions

With 35.5 pb^{-1} of data acquired in 2010, the ATLAS experiment measured the $t\bar{t}$ production cross-section in the lepton+jets channel. The resulting cross-section with the smallest uncertainty is

$$\sigma_{t\bar{t}} = 186 \pm 10(\mathrm{stat})^{+21}_{-20}(\mathrm{syst}) \pm 6(\mathrm{lumi}),$$

in good agreement with the theoretical Standard Model prediction as calculated at the approximate NNLO. The total uncertainty of 12% is comparable with the theoretical one. With the data that will be acquired in 2011, the top quark physics will finally enter the precision era.

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