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Measurement of the top-quark pair production cross section in pp collisions at $\sqrt{s} = 7\,\text{TeV}$ in $\mu + \tau$ final states with ATLAS

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Summary. — A measurement of the cross section of top quark pair production in proton-proton collisions at a center-of-mass of 7 TeV at the LHC using events with an isolated μ and a τ lepton decaying hadronically is reported. In addition to a μ and a τ lepton, large missing transverse energy and two or more jets are required. At least one of the jets must be identified as originating from a b quark. To identify τ leptons, the analysis uses a multivariate technique based on boosted decision trees. A data sample collected by ATLAS corresponding to an integrated luminosity of $1.08\,\text{fb}^{-1}$ yields $\sigma_{t\bar{t}} = 142 \pm 21(\text{stat.}) \pm^{20}_{16} (\text{syst.}) \pm 5$ (lumi.) pb.

PACS 14.65.Ha – Top quarks.
PACS 14.60.Fg – Taus.

1. – Introduction

Measuring the top-quark pair ($t\bar{t}$) production cross section ($\sigma_{t\bar{t}}$) using a channel with tau leptons (τ) is of great interest because it can open a window to physics beyond the Standard Model (SM). In the SM, the top-quark decays nearly 100% of the time into a W-boson and a b-quark, and $t\bar{t}$ pairs are identified by either the hadronic decays ($W \to q\bar{q}'$) or leptonic decays ($W \to \ell\nu$) of the W-bosons and the presence of additional jets.

The $W \to \tau\nu$ branching ratio has been measured with high precision, and it is in very good agreement with the SM expectations. However, the best previous measurement of $\sigma(t\bar{t}) \times \text{BR}(t \to \tau\nu + b)$ has an uncertainty of 25% [1]. If a charged Higgs boson ($H^{\pm}$) exists, as required by the minimal supersymmetric standard model (MSSM) [2], and its mass is lower than the top-quark mass minus the b-quark mass, the top quark can have a substantial branching ratio to $H^{\pm} + b$. For large values of the MSSM parameter $\tan\beta$ the charged Higgs decays mainly to $\tau\nu$ and can increase significantly the top quark branching ratio to final states with τs. The much larger cross section for $t\bar{t}$ production at the LHC provides an opportunity to measure the $\text{BR}(t \to \tau\nu b)$ with higher precision, and thus increases the sensitivity to $H^{\pm}$ or other processes that could enhance this branching ratio [3,4]. CMS has recently measured this cross section at the LHC with an uncertainty of 24% using a $\mu+\tau$ data sample of 1.09 fb^{-1} integrated luminosity [5]. These proceedings summarize the measurement presented in ATLAS-CONF-2011-119 [6].

After application of kinematic preselection criteria described in sect. **2** and identification of a jet as a b-quark jet (b-tagging), the dominant background to the $t\bar{t} \to \mu + \tau$ channel with the τ decaying hadronically is the $t\bar{t} \to \mu+$ jets channel in which a jet fakes a hadronic tau decay. Therefore, the most powerful remaining discriminator between signal and background is τ identification (TauID). The TauID employed in this analysis is a multivariate discriminator built using a boosted decision tree (BDT) algorithm [7]. The number of τs in a sample is extracted by fitting the shape of the BDT discriminant using background and signal templates.

The method relies on a background model for jets misidentified as τ's derived from data and a signal model derived from Monte Carlo (MC). This analysis uses 1.08 fb^{-1} of data recorded between April and June 2011.

2. – Event selection

The $\mu + \tau$ analysis starts by requiring events selected online by a single-muon trigger with a p_T threshold of 18 GeV. The event selection was optimized using Monte Carlo and requires: 1) an event to have a primary vertex with at least five tracks, 2) events are discarded if any jet with $p_\mathrm{T} > 20$ GeV fails jet-quality selections, 3) one and only one isolated muon and no identified electrons, 4) at least one loose τ candidate (defined in [6]), 5) at least two jets reconstructed with the anti-k_t algorithm [8] (with distance parameter $R = 0.4$) having $p_\mathrm{T} > 25$ GeV not overlapping with a τ candidate, 6) $E_\mathrm{T}^\mathrm{miss} > 30$ GeV, 7) $H_\mathrm{T} = \sum |E_\mathrm{T}| > 200$ GeV, and 8) at least one jet identified as a b-jet (≥ 1 b-tag). The data are split into two categories: τ_1 for one track candidates, and τ_3 for candidates with two or three tracks. This selection when applied to a 1.08 fb^{-1} data sample yields 1593 τ_1 events and 4086 τ_3 events. These samples are further divided by the charge of the τ and μ into events with opposite-sign charges (OS) and events with same-sign charges (SS).

3. – Analysis based on fits of BDT_j distributions

The final background normalization and signal measurements are established through fitting templates to data distributions of the BDT_j for the τ candidates. The background templates are built from data using both OS and SS $W \to \mu\nu$+jets samples. The signal BDT_j template is derived from real τs in $t\bar{t}$ and $Z \to \tau\tau$ Monte Carlo simulations. Because the contribution from electrons cannot be distinguished by BDT_j, it is treated as part of the signal. The contribution from electrons in $t\bar{t} \to \mu e+$ jets is also derived from the Monte Carlo simulation and added to the signal BDT_j template. A χ^2 fit to the opposite-sign minus same-sign (OS − SS) distribution is made with three free parameters to set the normalization of each template

$$(a \cdot \mathrm{OS} - b \cdot \mathrm{SS}) + c \cdot \mathrm{signal}, \tag{1}$$

where OS, SS and signal are the templates of W+jets (OS), W+jets (SS) and signal events, and a, b and c are the number of W+jets (OS), W+jets (SS) and signal events. The fits are performed separately for τ_1 and τ_3 candidates (fig. 1).

Figure 2 shows the OS − SS distribution of the number of jets for b-tagged events satisfying $BDT_j < 0.7$, which is expected to be dominated by $t\bar{t} \to \mu+$ jets, and $BDT_j > 0.7$, which is expected to have a large contribution from $t\bar{t} \to \mu + \tau$. As expected, the

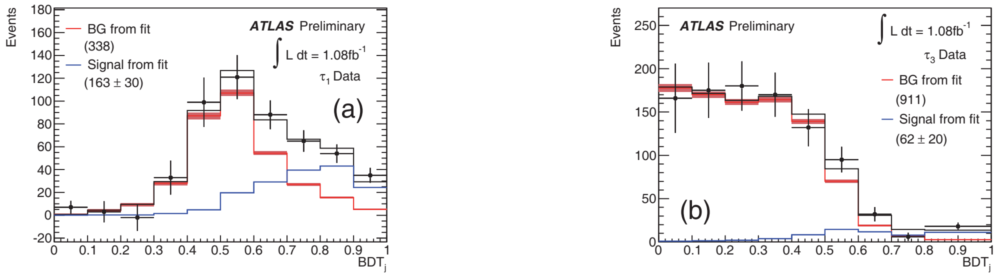

Fig. 1. – The OS−SS BDT_j distributions for (a) τ_1, (b) τ_3 candidates. The normalization of each template is derived from a fit to the data and are shown as the blue (signal), red (background) and black (total) lines. Red hatched bands are the statistical uncertainties of the background template.

multiplicity of jets peaks at four when $BDT_j < 0.7$ and three when $BDT_j > 0.7$ (the τ is counted as a jet).

4. – Results and conclusions

After subtracting the small contributions from channels other than $t\bar{t} \to \mu + \tau$, the cross section is determined using measured luminosity and acceptance calculated from MC, including systematics described in [6]. The cross section is measured to be

$$\sigma_{t\bar{t}} = 142 \pm 21\,(\text{stat.}) \pm^{20}_{16}\ (\text{syst.}) \pm 5\ (\text{lumi.})\,\text{pb},$$

in good agreement with the Standard Model prediction ($164\pm^{11}_{16}$ pb) [9].

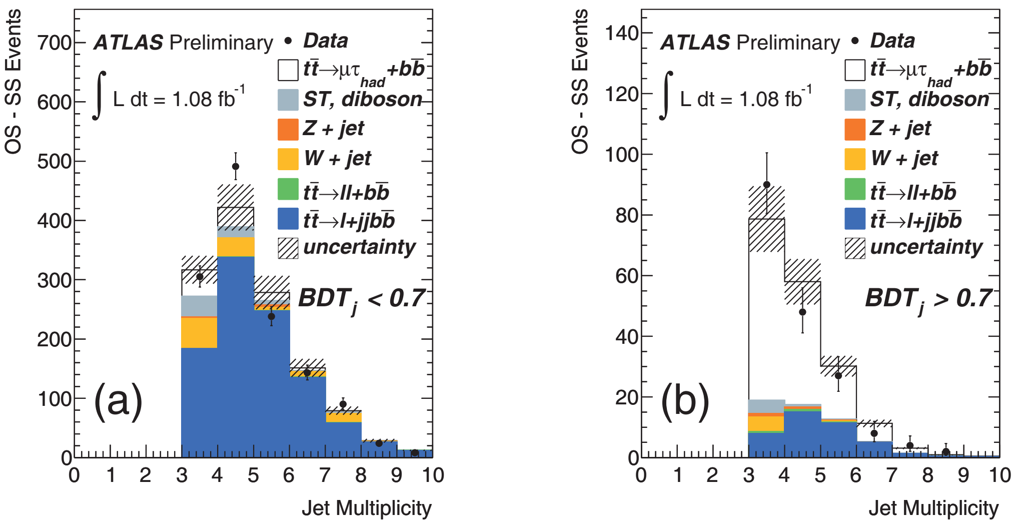

Fig. 2. – Number of jets distributions for OS − SS events after the b-tagging selection. The solid circles indicate data and the histograms indicate the expected signal and backgrounds from MC. The normalization of the expected signal and the backgrounds are based on the fit result. The fraction of each background is estimated from MC. (a) $BDT_j < 0.7$, (b) $BDT_j > 0.7$.

The production cross section for $t\bar{t}$ production in pp collisions at 7 TeV has been measured in the $\mu + \tau$ channel in which the τ decays hadronically. A boosted decision tree multivariate technique is used to obtain the number of signal events by fitting the opposite sign minus same sign BDT_j distributions with signal and background templates. The measured cross section is in good agreement with the SM predictions and other measurements.

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