Fully hadronic ttbar cross section measurement with ATLAS detector

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I. INTRODUCTION

The top quark, discovered at Fermilab in 1995, completed the three generation structure of the Standard Model, SM. The top quark is distinguished by its large mass, \(m \sim 172\) GeV. Precision measurements in the top quark sector will shed light on the electroweak symmetry breaking mechanism and indirectly on the Higgs mechanism of elementary particle mass generation. In particular, the measurement of the top quark pair production cross section is an important test of QCD perturbative calculations as well as an estimation of one of the major background sources for several new physics signatures. The full hadronic \(t\bar{t}\) is important background for several analyses beyond the Standard Model: production of new particle(s) de-caying to many hadronic jets in association with missing transverse momentum, predicted by SUSY; search for the Higgs boson in the all hadronic (4\(\ell\)+jets) final state, such as associated production with vector boson or top pair.

In proton-proton collisions, top-antitop pairs are created when a parton from each colliding proton interact through the strong force. The production mechanisms at the LHC are the gluon-gluon fusion (85\%) and \(q\bar{q}\) annihilation (15\%).

Within the SM, the top quark decays into a W boson and a \(b\)-quark almost 100\% of the time. The W boson subsequently decays into either a pair of quarks or a lepton-neutrino pair. In the \(t\bar{t}\) production in the fully hadronic final state both Ws decay hadronically.

The experimental signature of fully hadronic \(t\bar{t}\) is characterized by a nominal six-jet topology with \(b\)-jets. This channel has the advantage of a large BR, top pair decay in full hadronic signature in (44\%) of the case, although it suffers from a large QCD multijet background.

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2 b-tagged jets. The baseline tag rate function (TRF) to be used for the background modelling in the signal region are derived from the 5 jets control bin with 2 b-tags, as seen in Fig. 1. The tag rates are evaluated separately for 1 b- and 2 b-tag events, because the event topology in the 2 b-tag case is different due to gluon splitting process ($g \rightarrow bb$). The background tag rate for a jet (TR) is defined as:

$$TR_{n_{b_{\text{bin}}}, n_{j_{\text{bin}}}} = \frac{n_{j_{\text{tag}}}}{n_{j_{\text{all}}} \times n_{b_{\text{bin}}} \times n_{j_{\text{bin}}} C_{n_{b_{\text{bin}}}}}$$  \hspace{1cm} (1)$$

The $TR_{n_{b_{\text{bin}}}, n_{j_{\text{bin}}}}$ function is calculated in each jet and b-tag multiplicity bin separately. The variables $n_{j_{\text{all}}}$ and $n_{j_{\text{tag}}}$ are respectively the total number of jets and the number of b-tagged jets, the symbol $C$ stands for the binomial coefficient ($C_r = \frac{n!}{(n-r)!}$) for jets to be selected as b-tagged jets in the event.

The variables $n_{j_{\text{tag}}}/n_{b_{\text{bin}}}$ and $n_{j_{\text{all}}}/n_{j_{\text{bin}}}$ correspond to the number of tagged events in $n_{b_{\text{bin}}}$ and $n_{j_{\text{bin}}}$, and the number of pretag events in $n_{j_{\text{bin}}}$, respectively. The coefficient $C_r$ is a factor to make this probability on a per-jet basis. $TR_{n_{b_{\text{bin}}}, n_{j_{\text{bin}}}}$ is to be applied to a jet to obtain an event weight. The TRF is parametrized as a function of the jet $p_T$ and $\eta$ to take into account a possible dependence on those quantities. The weight for an event with 6 jet (2 b-tag) is obtained applying as follows the TRF:

$$w(6j, 2b) = \sum_{k=1}^{n_{j_{\text{bin}}}} TR_{n_{j_{\text{bin}}, 5j}} \times \frac{n_{j_{\text{bin}}} C_{n_{b_{\text{bin}}}}}{n_{j_{\text{bin}}}}$$  \hspace{1cm} (2)$$

After applying TRF kinematic distribution are compared in control region, 4 jet 2 b-tag events, see fig. 2

IV. FITTING PROCEDURE

The background normalization, for the cross section measurement, is extracted from a fit to the mass $\chi^2$ variable

$$\chi^2 = \sum_{i=1}^{2} \left( \frac{m_{jjb} - m_{\text{top}}}{\sigma_{\text{top}}} \right)^2 + \left( \frac{m_{jj} - m_W}{\sigma_W} \right)^2$$  \hspace{1cm} (3)$$

Only the leading 6 jets are considered in $\chi^2$ computation for $N_{j_{\text{jet}}} \geq 6$ events. In the case of 2 b-tag events (signal) there are 6 combination, and we select the combination with the minimum $\chi^2$ to build the final $\chi^2$ distribution.

A. $t\bar{t}$ cross section measurement analysis with 2010 data

The final mass $\chi^2$ distribution is fitted with signal and background template. Figure 3 shows the fit result of the minimum mass $\chi^2$ distribution. The cross section $\sigma_{t\bar{t}}$ is obtained by

$$\sigma_{t\bar{t}} = \frac{N_{\text{obs}} \times f_S}{\epsilon \times \int L dt}$$  \hspace{1cm} (4)$$

where $f_s$ is the signal fraction of 6.4% from the fit; the factor $\epsilon$ of 1.8% includes signal acceptance and branching fraction.
TABLE I: Fit results for events with at least 6-jets and 2 $b$-tags

| Source         | Number of events |
|----------------|------------------|
| Background     | 1097.0           |
| $t\bar{t}$     | $75.0 \pm 46.5$ (stat.) |
| Data ($N_{obs}$)| 1172             |

The fitted cross section with 36 pb$^{-1}$ is

$$\sigma_{pp \rightarrow t\bar{t}} = 118 \pm 73\text{(stat.)} \pm 48\text{(syst.)} \pm 4\text{(lumi.)pb}. $$

The significance of the fitted value is 1.6 $\sigma$ whereas the expected sensitivity was 2.2 $\sigma$. The observed one-sided upper limit at 95% confidence level is $\sigma_{t\bar{t}} < 261\text{pb}$. The total systematic uncertainty on the $t\bar{t}$ cross-section is 41%. The most important systematic sources considered are Jet energy scale uncertainty (JES), Trigger efficiency, b-tagging, Background modeling, Initial & Final State Radiation (ISR & FSR). Table II shows a summary of the most important individual contributions.

TABLE II: Summary of the most important individual contributions on the systematic uncertainties on the fitted cross-section value

| Source                     | $\Delta \sigma/\sigma$ |
|----------------------------|------------------------|
| JES                        | 17%                    |
| Trigger                    | 10%                    |
| b-tagging                  | 29%                    |
| Background modeling        | 7%                     |
| ISR/FSR                    | 16%                    |

V. OUTLOOK: b-JET TRIGGER

The ATLAS trigger and data acquisition system is based on three levels. Trigger levels must provide a rejection to reduce the 40 MHz bunch-crossing rate to an output of about few hundred Hz. The level 1 is hardware based, uses the calorimeter and muon spectrometer with coarse granularity; the level 2 is software-based, exploits regions of interest identified by the level 1 and accesses data from all sub detectors with full granularity; the Event Filter (EF) runs offline-quality software-based algorithms.

A. Online b-tagging

The identification of jets stemming from the hadronization of $b$-quarks is made possible by the relatively long lifetime of hadrons containing $b$-quarks (lifetime of the order of 1.5 ps corresponding to $c\tau \approx 450\mu m$). This allows the identification of $b$-jets from the one containing only lighter quarks. Given the high instantaneous luminosity the LHC will deliver in the next year, $b$-tagging at HLT is a possibility for collecting $t\bar{t}$ in the full hadronic final state with an acceptable data taking rate.

B. Future analysis

At the high instantaneous luminosity foreseen for LHC data taking, most multi-jet trigger will be prescaled unless their threshold and jet multiplicity are constantly increased to keep the trigger rate under control. For this reason ATLAS has put in place a combination of multijet and $b$-jet trigger to efficiency select events with final states containing several $b$-jets. The $b$-jet trigger for hadronic top requires four EF-jets with $E_T > 30$ GeV at electromagnetic scale and 1 $b$-jet with $E_T > 10$ GeV at EM scale and tight instance for the $b$-tagging criteria, as seen in Fig. 4. The signal efficiency is $\sim 40\%$.

FIG. 4: Trigger rate for 1b/4j topology. LVL1, LVL2 and EF rate of a b-jet trigger requiring at least four jets in the event and at least one $b$-tagged jet [3].

VI. CONCLUSIONS

The analysis is performed using 36 pb$^{-1}$ of pp collisions produced at the LHC with a center-of-mass energy of $\sqrt{s} = 7$ TeV and recorded with the ATLAS detector. A 95% confidence level limit is set at 261 pb, compatible with the expected Standard Model cross-section of $165^{+11}_{-16}$ pb.

[1] The ATLAS Collaboration, G. Aad et al., JINST3, 08003 (2008), The ATLAS Experiment at the CERN Large Hadron Collider
[2] ATLAS-CONF-2011-066, Search for tt\bar{b} production in the all-hadronic channel in ATLAS with $\sqrt{s} = 7$ TeV data (http://cdsweb.cern.ch/record/1346693).

[3] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BJetTriggerPublicResults

[4] In the right-handed ATLAS coordinate systems, the pseudorapidity $\eta$ is defined as $\eta = -\ln[\tan(\theta/2)]$, where the polar angle $\theta$ is measured with respect to the LHC beamline. Transverse energy is defined $E_T = E \sin \theta$. 