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Top quark cross-section measurements with early ATLAS data

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Summary. — We present a study of the prospects for measuring the $t\bar{t}$ production cross-section with the ATLAS detector at the CERN LHC. This paper describes the $t\bar{t}$ production cross-section measurement in the single lepton ($t\bar{t} \rightarrow e(\mu)$ + jets) and the dilepton final states. The early $t\bar{t}$ pair cross-section measurements at $\sqrt{s} = 10\,\text{TeV}$ using simulated data will be shown, with a particular emphasis on the understanding the backgrounds through data-driven methods. These techniques are intended to re-establish the top signal at the LHC with early data at $\sqrt{s} = 7\,\text{TeV}$.

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1. – Introduction

Top quark pair production will be the dominant process, after QCD, W and Z boson production, at the LHC. During the initial phase of LHC data taking we expect $1\,\text{fb}^{-1}$ of data at $\sqrt{s} = 7\,\text{TeV}$, which will be enough to produce ≈ 0.2 million $t\bar{t}$ pairs. The measurement of $t\bar{t}$ pair production cross-section in different sub-channels will be an important tool at the LHC, not only to test the Standard Model (SM) as the theoretical predictions are now at a level of around 10%, but physics beyond the SM. An abundant $t\bar{t}$ pair sample will be a useful calibration tool for reconstructed objects like jets and missing transverse energy ($\not{E}_T$). The $t\bar{t}$ pair production cross-section will be measured in the two decay channels characterized by the subsequent decay of the W bosons to leptons. Namely, the single lepton [1] and the di-lepton [2] channels, outlined in sects. **2** and **3**, respectively. The sensitivity of the analyses in these two channels with the ATLAS detector at $\sqrt{s} = 10\,\text{TeV}$ using simulated data is presented here.

2. – Single lepton channel

The single lepton channel has higher branching ratios (about 15% for each flavor) which leads to higher statistics for this channel. The identification requirement for this channel consists of a single lepton (electron or muon) with transverse momentum $p_T > 20\,\text{GeV}$, pseudo-rapidity $|\eta| < 2.5$, $\not{E}_T > 20\,\text{GeV}$ from an accompanying neutrino and at least 4 jets with $|\eta| < 2.5$, and $p_T > 20\,\text{GeV}$. In addition, we require 3 of the jets

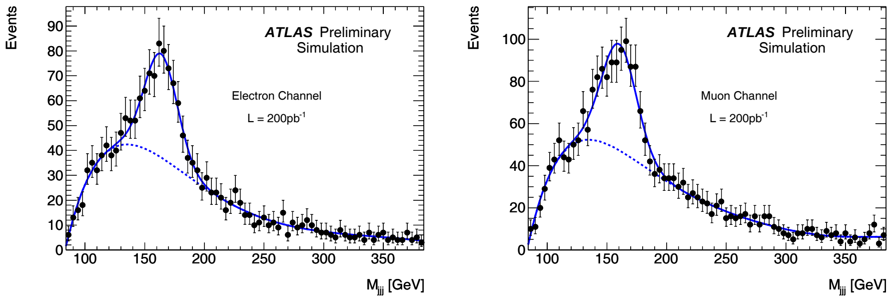

Fig. 1. – Fit to the top-quark candidate invariant mass distribution (m_{jjj}) for the e + jets channel (left) and the μ + jets channel (right).

to have $p_T > 40\,\text{GeV}$. A hadronic top quark candidate is reconstructed from the 3 jet combination with greatest total p_T.

Since complete understanding of the measurement of $\not{E}_T$ will require a good understanding of the detector response, we also plan to use the scalar sum of the p_T of the lepton and 2nd, 3rd and, 4th jet (HT2) instead of the $\not{E}_T$ requirement. This exploits the different energy sharing in jets between QCD multi-jet and $t\bar{t}$ events. The cuts on lepton p_T and η are also tightened for this variation of the analysis.

The most straightforward method to determine the cross-section is by counting the total number of events passing the basic section criteria and deriving the result from $\sigma = \frac{N_{\text{sig}}}{\mathcal{L}\times\epsilon} = \frac{N_{\text{obs}}-N_{\text{bkg}}}{\mathcal{L}\times\epsilon}$, where $\mathcal{L}$ is the integrated luminosity and ϵ is the signal efficiency. One of the main background processes of this analysis is W boson production in association with jets. The Monte Carlo (MC) uncertainty for the production of W + jets events is large, but the W to Z boson ratio uncertainty is smaller. Therefore, one can estimate the number of W + jets events contributing to the signal region by measuring this ratio in a control region with 0 or 1 jet and then extrapolating to the top signal region with 4 or more jets. Another method is to extract the cross-section by finding the number of events in the peak of the 3 jet invariant mass distribution after applying a M_W requirement (an invariant mass of one of the three 2 jet combinations within $\pm 10\,\text{GeV}$ of the W mass). A binned maximum likelihood fit is performed using a Gaussian to represent the signal region and a Chebychev polynomial for the background region, as shown in fig. 1.

3. – Dilepton channel

Although the branching ratio for these channels is approximately 5%, the di-lepton channel has a very clean signature and very high trigger efficiency. Events are selected by requiring opposite sign (OS) leptons (electrons or muons) with $p_T > 20\,\text{GeV}$ and $|\eta| < 2.5$, $\not{E}_T > 35\,\text{GeV}$ for ee and $\mu\mu$ events and $\not{E}_T > 20\,\text{GeV}$ for $e\mu$ events, and at least 2 jets with $p_T > 20\,\text{GeV}$ and $|\eta| < 2.5$. For the ee and $\mu\mu$ channels, exclusion of the events with a di-lepton invariant mass within $\pm 5\,\text{GeV}$ of the Z boson mass window and large $\not{E}_T$ requirement reduces the Drell-Yan (DY) background significantly. Figure 2 shows the jet multiplicity and $\not{E}_T$ distributions for the different contributions after all cuts except on the number of jets. Due to difficulties in modeling the background distributions in the tail regions of the $\not{E}_T$ distribution by mis-measurements, methods for background estimation using data-driven techniques have been developed. The largest contributions

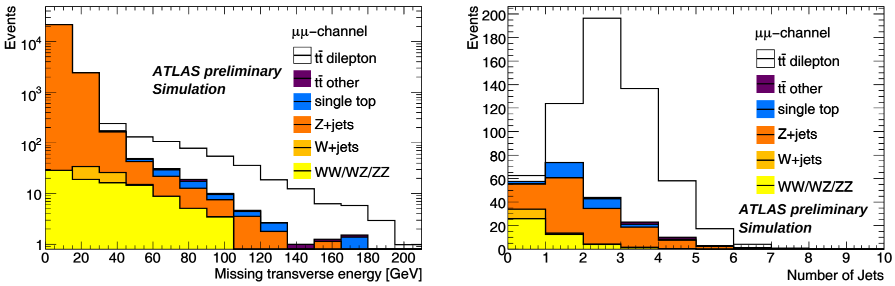

Fig. 2. – Missing transverse energy distribution (left) after requiring two opposite-sign leptons and jet multiplicity distribution (right) after all requirements (except the two-jet requirement) for $\mu\mu$ signal and MC-based background estimations after all cuts. The samples are normalized to $200\,\text{pb}^{-1}$ of data.

are expected to be the DY background as well as fakes coming from QCD and W + jets events. As outlined above, two main selections are used to suppress the DY events: one on $\not\!\!E_T$ and one on the invariant masses of the two same flavor leptons. The DY background is estimated by scaling the MC prediction in the tail regions of $\not\!\!E_T$ and away from Z mass window (where DY still dominates) to match the observed number of events in the above corresponding tail regions of data and then extrapolating to the signal region.

To estimate the background coming from fakes, we first measure the efficiency ϵ (using the tag and probe method on $Z \to \ell\ell$ events) and the fake rate f (using a data sample dominated by fakes) of our lepton selections. Loose and tight lepton selections are defined and 3 different types of reconstructed events are considered: events with two tight leptons, events with the highest (lowest) p_T lepton called tight (loose), and vice versa. At MC truth level, events again come in 3 types: events with two real leptons, events with the highest (lowest) p_T lepton called real (fake), and vice versa. The truth level events are related to the reconstruction level events through a matrix equation using the measured fake rates and efficiencies. With this technique, an estimate for the number of events coming from fakes can be determined.

4. – Results and conclusions

Several studies to measure the $t\bar{t}$ cross-section in $200\,\text{pb}^{-1}$ of data using $\sqrt{s} = 10\,\text{TeV}$ simulated pp collisions in ATLAS are summarized in table I. The different methods are sensitive to different sources of systematic uncertainties which will allow an optimal

Table I. – *Expected number of signal events, S/B ratio, and uncertainties with* $200\,\text{pb}^{-1}$ *of* $10\,\text{TeV}$ *data are shown in this table. The single lepton channels show results using the cut-and-count method.*

Channel	S	S/B	$\frac{\Delta(\text{stat})}{\sigma}$	$\frac{\Delta(\text{syst})}{\sigma}$	$\frac{\Delta(\text{lumi})}{\sigma}$
ee	209	3.9	$+7.8 - 7.5$	$+13.9 - 12.7$	$+26.3 - 17.3$
$\mu\mu$	327	3.8	$+6.2 - 6.0$	$+10.2 - 8.9$	$+26.2 - 17.4$
$e\mu$	683	5.6	$+4.1 - 4.0$	$+13.9 - 12.7$	$+26.3 - 17.3$
e + jets	1286	2.1	± 3.4	$+14.4 - 15.2$	± 22.3
μ + jets	1584	2.0	± 3.1	$+11.9 - 14.7$	± 22.2

choice once the conditions of the ATLAS detector during the early data-taking period are understood. Under assumed detector conditions, these methods lead to a systematic uncertainty of less than 20%, plus the luminosity uncertainty.

REFERENCES

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