Top Physics at ATLAS*

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We describe the prospects for top physics with early data from the ATLAS experiment, focusing on the measurement of the top pair production cross-section in the single lepton and dilepton channels.

1. Introduction

Since early 2010, the ATLAS detector has been recording data from proton-proton collisions taking place at the Large Hadron Collider (LHC) at an unprecedented centre of mass energy of 7 TeV. With a relatively large cross-section at such energies, top quarks will be abundantly produced at the LHC, providing a valuable means of testing the predictions of the Standard Model. Top physics is also a useful window into possible signatures of physics beyond the Standard Model. Generic models of new physics designed to resolve the hierarchy problem contain particles which are partners of top quarks† and which have a large production cross-section.

In this note, we describe the top physics program with early data of the ATLAS experiment, focusing on the measurement of the top pair production cross-section.

The top pair production cross-section is known to next to leading order (NLO) with a 6% uncertainty, dominated by renormalisation and factorisation scale uncertainties, and the parton distribution function (PDF) uncertainty [1]. The values of the top pair production cross-section at different centre of mass energies are given in Table 1. With 1 fb^{-1} of data at a 7 TeV centre of mass energy, around 160,000 top quark pair events are expected, hence justifying the name 'top factory' for the LHC.

As well as in pairs, single top quarks can be produced at the LHC in electroweak processes. The cross-sections for these processes are smaller than those for top pair production by roughly a factor of three and are given in Table 2.

In the Standard Model, a top quark decays to a b-quark and W-boson with a branching ratio which is close to unity (see [2] and references therein). This results in a three-fold classification of possible final states of top pair decays:

- *single lepton* $t\bar{t} \to b\bar{b}q\bar{q}l\nu$ - with a branching ratio (BR) of 44% . Such events can be triggered on due to the presence of a lepton, and the hadronic top can be reconstructed.
- *dilepton* $t\bar{t} \to b\bar{b}ll'\nu_1\nu_2$ - BR$\sim$10%. This channel suffers from limited statistics, but the events are easy to trigger on and have small backgrounds. The top quarks cannot be reconstructed due to the presence of two neutrinos in the final state.
- *all-hadronic* $t\bar{t} \to b\bar{b}qqqq$ - BR $\sim$46% - Such events contain a lot of jets and are difficult to trigger on. The top quarks are difficult to reconstruct due to the large number of possible three jet combinations.

2. Measurements with early data

Measurements involving top quarks generically involve leptons, jets (originating both from light and heavy flavour quarks), and missing energy, and therefore require understanding of most detector components and their performance. The

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†Such as the top squark in supersymmetric extensions of the Standard Model.

Table 1
Theoretical cross-sections for top quark pair production at the LHC for different centre of mass energies (CME). The uncertainty in the cross-section prediction is around 6% [1].

CME (TeV)	σ_{tot} (pb)
14	886
10	403
7	161

Table 2
Theoretical cross-sections for single top production at the LHC, calculated using MCFM [3]. The theoretical uncertainty on the cross-section each single top process is about 5% [4].

	7 TeV	14 TeV
t-channel (a)	59 pb	247 pb
s-channel (c)	3.9 pb	11 pb
Wt-channel (b)	13 pb	66 pb

first top candidates from $p{-}p$ collisions at a centre of mass energy of 7 TeV have now been observed by ATLAS [5]. Subsequently, the first measurements of the top pair production cross-section may be expected in both the single lepton and dilepton channels with a few inverse picobarns of integrated luminosity. With a few hundred pb^{-1}, a rich top physics programme is possible, including the top mass measurement with a precision of a few GeV, and the more challenging single top production cross-section measurement.

3. Top pair cross-section measurement

The cross-section for top pair production will be measured in the single lepton and dilepton channels. The analyses are designed to use a simple event selection, applied to discriminate between signal ($t\bar{t}$) and background events. They do not rely on b-tagging, but b-tagging may be straightforwardly incorporated, yielding an improved sensitivity. The results shown in the rest of this note are for selections which do not use b-tagging.

Data driven methods will be used for determining the backgrounds suffering from a large theoretical uncertainty, such as W+jets, and the multijets background with fake leptons or leptons coming from heavy hadron decays in the single lepton channel. The Drell-Yan background in the dilepton channel can also be evaluated from data. For more details on data-driven background determination methods that will be applied with early data, see [6,7]. Similarly, data-driven strategies relying on Z+jets events may be used for measuring the lepton trigger and reconstruction efficiencies.

In the next few subsections, the event selections, methods and expectations for the top pair production cross-section measurement are described.

Following [6] and [7], the results quoted are for 200 pb^{-1} and a 10 TeV centre of mass energy.

3.1. Event selection

In the single lepton channel, the following selection cuts are applied:

- lepton trigger fired
- one isolated electron or muon with $P_T > 20\,\text{GeV}$
- $\not\!\!E_T > 20\,\text{GeV}$
- three jets with $P_T > 40\,\text{GeV}$ and one with $P_T > 20\,\text{GeV}$
- At least one b-tagged jet, for the b-tagging variant of the analysis

In the dilepton channel, the selection cuts are as follows:

- lepton trigger fired

- two isolated leptons (e or μ), $P_T > 20\,\text{GeV}$
- $\not{E}_T > 20\,\text{GeV}$ (in the $e\mu$ channel), $\not{E}_T > 35\,\text{GeV}$ (in the ee and $\mu\mu$ channels)
- two jets with $P_T > 20\,\text{GeV}$
- in the ee and $\mu\mu$ channels, the invariant dilepton mass is required to be inconsistent with the Z mass, $|m_Z - m_{l^+l^-}| > 5\,\text{GeV}$

3.2. Method

Two main methods will be used used in ATLAS for the top pair cross-section determination: a cut and count method, and a fitting method. The cut and count method is based on the simple formula

$$\sigma_{t\bar{t}} = \frac{\mathcal{D} - N_B}{\epsilon \times \mathcal{L}}, \tag{1}$$

where $\mathcal{D}$ is the number of events in the data passing the selection cuts, N_B the expected number of background events, ϵ the efficiency for signal events to pass the selection cuts, and $\mathcal{L}$ is the integrated luminosity.

The fit method for measuring the cross-sections can be applied in the single lepton channel, where the hadronically decaying top is reconstructed by taking the highest P_T combination of three jets. The number of $t\bar{t}$ events can then be estimated by performing a binned maximum likelihood fit on the three-jet mass distribution (for more details see [6]). An example fit of the three jet invariant mass with the $t\bar{t}$ peak fitted with a Gaussian, on top a background modelled by a Chebyshev polynomial is shown in Figure 1.

To improve the signal over background ratio (S/B), an additional cut can be used, requiring two out of the three jets used to reconstruct the hadronic top to satisfy the W mass constraint $|m_{jj} - m_W| < 10\,\text{GeV}$, with m_W the the pole W mass. This also removes some of the combinatorial background.

3.3. Single lepton channel

The dominant background to $t\bar{t}$ signal in the single lepton channel are W+jets events with the W boson decaying to a lepton and a neutrino. Other important backgrounds are single top events, $Z \to l\bar{l}$+jets with a misreconstructed lepton, or one outside the fiducial kinematic region, and multijet QCD processes with fake leptons, or non-isolated leptons from heavy quark decays.

The expected numbers of events for 200 pb^{-1} at 10 TeV after applying the default cuts in the single lepton channel, requiring the reconstructed hadronic top to satisfy also the W mass constraint, are shown in Table 3. The S/B ratio can be further improved by a factor of roughly 3 if a b-tagged jet in the final state is required.

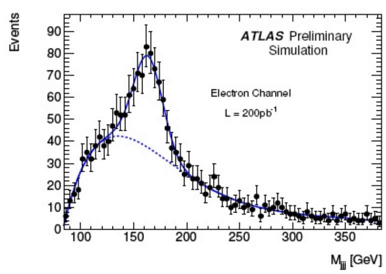

Figure 1. Likelihood fit of the three-jet invariant mass distribution in the electron channel.

With 200 pb^{-1} of integrated luminosity at 10 TeV, the cross-section can be measured with a total relative uncertainty of $(3.4(\text{stat})^{+18.2}_{-21.1}(\text{syst}) \pm 29.3(\text{lumi}))\%$ in the single lepton channel. The dominant sources of systematic uncertainty are the jet energy scale (JES) uncertainty, initial and final state radiation (ISR/FSR) modelling in Monte Carlo simulation, and the normalisation of the W+jets background.

With the fitting method, a total relative uncertainty $(14(\text{stat})^{+6}_{-15}(\text{syst}) \pm 20(\text{lumi}))\%$ can be achieved.

3.4. Dilepton channel

The dominant backgrounds in the dilepton channel are Z+jets, diboson (WW, WZ, ZZ), Wt-channel single top and W+jets with fake leptons or leptons arising in heavy hadron decays. Data-driven methods have been developed

Table 3
Expected numbers of events in the single lepton channel for 200 pb^{-1} at 10 TeV.

	e channel	μ channel
S	1286	1584
B	598	799
S/B	2.1	2.0

Table 4
Expected numbers of events in the dilepton channel for 200 pb^{-1} at 10 TeV.

Channel	S	B
$e\mu$	683	123
ee	209	54
$\mu\mu$	327	87

to evaluate the Z+jets background as well as the W+jets background.

The expected numbers of events in the dilepton channel for an integrated luminosity of 200 pb^{-1} at 10 TeV are shown in Table 4.

Combining the $ee, e\mu$ and $\mu\mu$ channels using a profile likelihood which takes into account correlations between systematics gives a combined uncertainty of $\Delta\sigma/\sigma = (3.1(\text{stat})^{+9.6}_{-8.7}(\text{syst})^{+26.2}_{-17.4}(\text{lumi}))\%$ for the cross-section measurement in the dilepton channel with 200 pb^{-1} at 10 TeV. The JES uncertainty and therefore also the total systematic uncertainty is significantly smaller than the JES uncertainty in the single lepton channel.

4. Conclusions

In this note we have reviewed the prospects for measuring the top pair production cross-section with the early data from the ATLAS detector in both the single lepton and dilepton channels. With a few hundred inverse picobarns of integrated luminosity at 7 TeV, the uncertainty in the measurement is expected to be dominated by the systematic uncertainties, most importantly the jet energy scale.

As well as the top pair production cross-section, the single top cross-section in the t-channel will also be measured. This is a rather challenging measurement, due to large backgrounds from $t\bar{t}$ and W+jets and uncertainties in the heavy flavour fraction in W+jets events. b-tagging must be used, and multivariate methods to separate signal from background yield substantial improvements of the sensitivity. The expected significance of the single top signal, assuming the Standard Model value for its cross-section, is 2.7σ with 200 pb^{-1} at 10 TeV.

The top mass can be also be measured with 100 pb^{-1} at 10 TeV with a precision of $(2(\text{stat}) \pm 3.8(\text{syst}))$ GeV. With 1fb^{-1} at 10 TeV, the uncertainty will go down to $(0.6(\text{stat}) \pm 2.0(\text{syst}))$ GeV [9].

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