Early Top Physics with ATLAS

J. Schieck
Max-Planck-Institut für Physik,
Föhringer Ring 6
80805 München, Germany.
On behalf of the ATLAS Collaboration

Abstract

The ATLAS detector is one of the two multi-purpose experiments located at the Large Hadron Collider (LHC) at CERN and is expected to collect first collision data in summer 2009. Due to the large top-quark production cross-section the LHC will function as a top-quark factory allowing to measure top-quark properties even at initial luminosities. We present some recently-performed studies, focussing on measurements of the top pair and single top production cross-sections with the first fb$^{-1}$ of data. The potential for the measurement of other top-quark properties like the mass will be also briefly discussed.

Introduction

The top-quark was discovered at Fermilab in 1995 and its discovery completed the experimental verification of the three generation structure of the Standard Model. The top-quark decays rapidly without forming a hadron and almost exclusively into a W-boson and a b-quark. In about 1/3 of all cases the W-boson decays in a highly-energetic lepton and the corresponding neutrino, leading to a clear experimental signature in the detector.

The center-of-mass energy (CME) for initial data-taking is currently under discussion, but will be most likely below 14 TeV. All results presented here are based on simulated events using the ATLAS detector at a CME of 14 TeV. During the first year, one can expect to collect $\approx 100$pb$^{-1}$ with initial luminosity of $\approx 10^{31}$cm$^{-2}$s$^{-1}$. As the luminosity increases, one may reach 1 fb$^{-1}$ of data. A more detailed discussion of the results presented in this paper can be found in [1].

Top Quark Pair Production Cross-Section

At the LHC the production of top-quark pair events is dominated by gluon fusion processes and only about 10% of all top-quark pairs are produced via quark-antiquark annihilation. The expected top-quark pair production cross-section $\sigma_{\text{pair}}$ at a CME of 14 TeV is about 900 pb and is about a
factor two smaller at a CME of 10 TeV. The “golden channel” to identify the production of top-quark pair events is through the identification of the decay of one W-boson into a lepton and a neutrino, with the lepton being an electron or a muon, while the other W-boson decays hadronically. In this final state one top-quark decays in a three jet final state and the other decays into a jet and a high \( p_T \) lepton. The main background are events with a W-boson and several jets. First measurements of the top-quark pair production cross-section will be performed without identifying the b-quark from the top-quark decay, leading to an increased contribution from background processes but decreased systematic uncertainties from the b-quark identification. Events are identified by requiring a high \( p_T \) lepton, at least four high \( p_T \) jets and missing energy. Using these cuts about 20% of the \( t\bar{t} \)-events with one W-boson decaying hadronically and the other one decaying in a lepton and a neutrino are selected. The combination of the three out of four jets with the largest transverse momentum is identified as the hadronically decaying top-quark candidate. Figure 1 (a) shows the three-jet invariant mass distribution for the muon channel after the standard selection. The signal is indicated with the white area, while the dark shaded area shows the combinatorial background, where the wrong jet combination has been selected, and the light shaded area represents the background contribution from events with a W-boson and several jets. To further decrease the number of events originating from background events we require that at least one di-jet pair combination of the hadronically decaying top quark is within 10 GeV of the mass of the W-boson. This additional cut reduces the selection efficiency to about 10%.

To determine \( \sigma_{\text{pair}} \) two methods are investigated. In a first method a likelihood fit is applied to the three-jet invariant mass distribution to

Figure 1: (a) Expected distribution of the three-jet invariant mass after the standard selection. (b) Fit to the three-jet invariant mass top-signal. Contributions from background events are suppressed by applying an additional W-boson constraint. The background obtained from a Chebychev polynomial fit is indicated by a dotted line. The gaussian fit to the signal events is indicated by the full line.
estimate the number of selected $t\bar{t}$-events, while the second is a cut-and-count method. Figure 1 (b) shows the result of the likelihood fit to the three-jet invariant mass in the muon decay channel. With 100 pb$^{-1}$ of data and using the likelihood fit method we expect to reach $\Delta\sigma_{\text{pair}}/\sigma_{\text{pair}} = (7(\text{stat.}) \pm 15(\text{sys}) \pm 3(\text{pdf}) \pm 5(\text{lumi}))\%$. For the counting method $\Delta\sigma_{\text{pair}}/\sigma_{\text{pair}} = (3(\text{stat.}) \pm 16(\text{sys}) \pm 3(\text{pdf}) \pm 5(\text{lumi}))\%$ is expected. Due to the high production cross-section the accuracy of the analysis will be limited by systematic uncertainties. The systematic uncertainties are dominated by the evaluation of the W+jets background and the jet-energy scale in the case of the counting method and by the shape of the fit function in the likelihood method.

**Single Top Quark Production Cross-Section**

The production cross-section for single-top events is significantly smaller than the top-quark pair production cross-section. There are three possible production channels which can lead to a single top-quark in the final state: the t-channel with an expected cross-section of about 240 pb, the tW-channel with an expected cross-section of about 60 pb and the s-channel with an expected cross-section of about 10 pb, all at 14 TeV. Measurements of the single-top cross-section are sensitive to the production of new particles and flavour changing neutral currents (FCNC) and allows the determination of the CKM-matrix element $V_{tb}$. The background contribution is higher than for the top-quark pair production and originates predominantly from top-quark pair events, QCD and W+jet events.

For the event selection only top-quark decays with the W-boson decaying into an electron or a muon are considered. Events with at least one highly-energetic isolated lepton, two high $p_T$ jets, where one jet is identified as a b-quark jet, and missing transverse energy in the transverse plane are considered. With a purely cut based analysis it is very difficult to reduce the background sufficiently to allow a measurement of the cross-section. For this reason multivariate analysis methods, like the boosted decision tree (BDT) method, are used to determine the production cross-section. Figure 2 shows the BDT-output variable for the selection of t-channel events, separated for signal and background events. For a luminosity of 1 fb$^{-1}$ about 500 signal events are selected using a BDT-cut of 0.6 with a signal to background ratio of 1.3. The measurement of the single top-quark production in the Wt- and the s-channel is considerably more difficult, with signal to background ratios of less than one. In order to firmly establish the signal at least 1-10 fb$^{-1}$ of data are required. The expected statistical and systematic uncertainties on the measurements for the three different single top-quark production cross-sections are shown in Figure 2.

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1Pdf stands for the uncertainty originating from the parton density function and lumi for the uncertainty from the total integrated luminosity.
Figure 2: The Figure shows the BDT output for single-top events produced in the t-channel. The different signal and background contributions are indicated. Events with a BDT-value larger than 0.6 are used for the measurement of the cross-section. The table on the right summarizes the expected statistical and systematical uncertainty for the three single-top cross-section measurements evaluated for an integrated luminosity of 1 \( \text{fb}^{-1} \) of data. The first line corresponds to a cut and count method, while the three others correspond to a BDT method.

### Further Top Analysis

With a data sample of 1 \( \text{fb}^{-1} \) it is also possible to determine precisely the mass of the top-quark. As for the measurement of the pair production cross-section, a very pure sample of reconstructed top hadronic decays is obtained in a sample of \( tt \)-pairs where the other top decays leptonically. Due to the large production cross-section the statistical uncertainty is negligible and the overall uncertainty is dominated by the knowledge of the jet energy scale, leading to an uncertainty on the mass of 1 to 3.5 GeV assuming a jet energy scale uncertainty of 1 to 5%. A precision of the order of 30–50% on the parameters describing spin correlation is expected with 1 \( \text{fb}^{-1} \). The limit on the branching fraction is \( \approx 10^{-2} \) for the \( t \rightarrow qg \) decay and \( 10^{-3} \) for \( t \rightarrow q\gamma/Z \) decays.

### Conclusion and Outlook

The ATLAS experiment is expected to collect in the course of next year the first data from proton-proton collisions. Due to the large number of produced top-quark pairs the top-quark pair production cross-section \( \sigma_{\text{pair}} \) can be already measured with an accuracy of \( \Delta \sigma_{\text{pair}}/\sigma_{\text{pair}} \approx 18\% \) using 100 \( \text{pb}^{-1} \). A precise determination of single top quark cross-sections can be achieved with a few \( \text{fb}^{-1} \) in the t-channel and Wt-channel, while for the s-channel higher statistics will be required.
References

[1] ATLAS Collaboration, "Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics", CERN-OPEN-2008-020, Geneva, 2008.