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The Single Top T-Channel Fiducial Cross Section at 8 TeV Measured with the ATLAS Detector

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Summary

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This thesis describes my research work performed from 2010 to 2015 using 8 TeV proton-proton collision data collected with the ATLAS detector.

The ATLAS detector is one of the four major experiments of the LHC collider at CERN. It is a general-purpose detector, designed to record proton-proton collisions. Through the use of various types of subdetectors, the trajectories and energy deposits of particles created in the interaction are recorded. The raw data is processed and then sent to the Grid for further reconstruction and analysis.
The Grid is a distributed computing network, which connects many computing clusters located in various institutes worldwide. This gives the ATLAS collaboration the massive data-processing power that it needs in order to process the recorded data of the detector and simulated events. For this thesis, I heavily relied on the Nikhef Tier 1 Grid-site to analyse 50TB of data, using over a hundred CPU-years.

The ATLAS scientific programme focuses on measurements in a new energy and luminosity domain to understand the generation of mass of elementary particles. Meanwhile, the long elusive Higgs boson has been discovered which confirms the Standard Model prediction. The Standard Model is however considered as incomplete and new physics may be around the corner. Known processes may show subtle deviations between prediction and actual measurements.
The test-case which is pursuit in this thesis is the production of top-quarks. The top-quarks have a mass of about the electroweak scale and decay before the hadronization can start. Hence, the top-quark process offers a possibility to study a bare heavy quark for which accurate predictions exist which are confronted with data in this thesis.

In this thesis, a single top t-channel cross section measurement at 8 TeV is performed using the 2012 ATLAS data, corresponding to an integrated lumi of 20.3 fb. This cross section

measurement is a direct probe of the V_{tb} CKM-matrix element, and the couplings that play a role for the *Wtb*-vertex.
To compare the data against the predictions of theory in the perturbative regime is not easy. First, events are generated using Monte Carlo (MC) techniques, which incorporate all non-perturbative effects by employing parton showering methods. In addition to that, the ATLAS detector response has to be simulated.

Besides the signal events, also all background events have to be generated. One of the main backgrounds is the *W*+jets process, which is generated in this thesis with the Alpgen software package. A study into the generator uncertainties of the Alpgen generator is performed. For the normalization of this background a data-driven extrapolation technique is used. The extrapolation uses the MC prediction for *W*+jets events with *b*- or *c*-jets in the final state. The use of MC information introduces uncertainties in the prediction.
The study of these extrapolation uncertainties required the generation of almost 2.5 billion events with different settings, occupying over 10TB of disk-space. Previously, this uncertainty was estimated to be 25%, dominated mostly by the limited amount of event statistics in the sample. The study in this thesis leads to the relatively small uncertainty of 10%, which is now dominated by the actual theoretical uncertainty instead of statistical fluctuations.

Fitting procedure
Both the recorded data and the simulated Monte Carlo events are processed on the Grid to reconstruct physical objects like electrons, muons, and jets. By applying selection cuts on these objects, a region of phase space is selected where the single top t-channel signal is enhanced. Further event reconstruction leads to a distribution of the top-quark mass, which is used in a fitting procedure. The fit is able to separate the signal from the backgrounds, resulting in the measurement of the single top t-channel cross section:

$$\sigma_{t-channel}\,(8\text{ TeV, data}) = 83.4 \pm 2.1\ (\text{stat.})^{+9.8}_{-9.6}\ (\text{syst.})\text{ pb}\,.$$

The total cross section as predicted by NNLO theory is:

$$\sigma_{t-channel}\,(8\text{ TeV, pred.}) = 87.2^{+2.8}_{-1.0}\ (\text{scale var.})^{+2.0}_{-2.2}\ (\text{PDF})\text{ pb}\,.$$

The measurement is compatible with this prediction.

The cross section measurement above uses a rather large correction to extrapolate from the phase space of the detected events to the total phase space using the MC prediction. In fact, this correction includes a large part of phase space that remains undetected by ATLAS and has large uncertainties. To reduce these uncertainties and to facilitate the comparisons of (new) predictions with the actual measurement a so-called fiducial cross

section measurement is also performed.
To define the fiducial sample, the selection is mimicked on truth particle level to provide an unambigious definition of the fiducial region that can be reproduced independently of the MC generator used.

The uncertainty associated with the choice of signal MC generator is studied by using the differences between three generators: `Powheg`, `aMC@NLO`, and `AcerMC`. Their event predictions are compared at truth particle level, and the difference in their cross section measurements is used as the uncertainty on the signal MC choice. This results in a 8 TeV inclusive fiducial single top t-channel cross section measurement with a significant reduction of the systematic uncertainties:

$$\sigma_{t-channel,fid}\,(8\ \mathrm{TeV}) = 4.07 \pm 0.09\ (\mathrm{stat.})^{+0.37}_{-0.34}\ (\mathrm{syst.})\ \mathrm{pb}\ \cdot$$

The corresponding predictions for `Powheg`, `aMC@NLO`, and `AcerMC` are 1.43 pb, 1.49 pb, and 1.24 pb respectively. The predictions are thus consistent with the observation, and there are no indications of new physics. However, the `LHC` has increased the proton-proton collision energies to 13 TeV, and more data than previously will be recorded, which allows to use more aggressive requirements to remove background. This may lead to the discovery of new physics through the top-quark sector.