The top and beyond: missing energy and little Higgs in ATLAS
Rijpstra, M.

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Summary

In this thesis, two types of events have been studied: The ‘top’ (semileptonic $t\bar{t}$ events) and ‘beyond’ ($W' \rightarrow tb$ events).

The topology of semileptonic $t\bar{t}$ events contains a large variety of final state objects: a charged lepton, missing energy and at least four jets, two of which originate from $b$ quarks. The complex final state is expected to resemble signatures of physics beyond the Standard Model. The kinematics are however well understood, which makes it a good place to study and understand reconstruction algorithms before setting out to search for signals of new physics. The procedure to select semileptonic $t\bar{t}$ events was outlined in Chapter 5.

Of all final state objects, the missing transverse energy is the most challenging to reconstruct as it is built up of all other reconstructed objects in the event. In Chapter 6, the expected reconstruction performance was studied in simulated $t\bar{t}$ events. A method was introduced to estimate the performance of the reconstruction in data. It makes use of the distribution of the transverse $W$ boson mass; a Jacobian peak which is sensitive both to the magnitude and the angle of the reconstructed missing energy in the transverse plane. By comparing this $m_W^T$ distribution to templates from simulated events, the method aims to reveal any deviations from the expected resolution and scale of the missing transverse energy. Apart from semileptonic $t\bar{t}$ events, the sample of selected events contained a large contribution from $W + \text{jets}$ events. It was demonstrated that these events can be regarded as part of the signal when studying the $m_W^T$ distribution. In order to test the template fit method, several possible scenarios were considered by distorting the missing transverse energy by hand. It followed that both an overall scale and an additional resolution up to 8 GeV on the missing energy can indeed be retrieved by means of a template fit of the $m_W^T$ distribution. In addition, an estimate of the poorly predicted contribution from QCD multi-jet events to the selected sample of events was demonstrated to follow from the method.

In chapter 8, the proposed template fit was ultimately carried out on the very first data recorded by ATLAS up to September 2010, corresponding to an integrated luminosity of 2.9 pb$^{-1}$. The event selection was relaxed with respect to Chapter 5 in order to increase the size of the sample, albeit thereby dominated by $W + \text{jets}$ events. The template fit resulted in the following values of the scale $\alpha$ and the additional resolution $r$:  

- **Muon channel:** $(\alpha, r)^{\text{fit}} = (1.08^{+0.13}_{-0.07}, 0.0^{+10.2}_{-0.5})$ GeV 
- **Electron channel:** $(\alpha, r)^{\text{fit}} = (1.08^{+0.05}_{-0.22}, 0.0^{+13.9}_{-1.0})$ GeV 

The statistical uncertainties were large due to the limited size of the data sample and will decrease rapidly in the near future.
The $W'$ boson is introduced in several proposed extensions of the Standard Model. One particular class, the Little Higgs models, were briefly discussed in Chapter 1. In these models, a handful of heavy new particles follow from a symmetry breaking mechanism, which is inspired by the desire to solve the little hierarchy problem. The $W'$ boson thus introduced accomplishes the cancellation of the divergent contribution to the Higgs mass from the Standard Model $W$ boson loop. The discovery potential of its decay channel $W' \rightarrow tb$ with ATLAS was investigated in Chapter 7. The main background is formed by semileptonic $t\bar{t}$ events, which underlines the importance of a thorough understanding of ‘top’ events.

Two particular realizations of Little Higgs models were considered as benchmarks to illustrate the procedure. Two different possible values of $m_{W'}$ were used for each model, motivated by the lower limit set by previous experiments. It was demonstrated that by means of a multivariate selection technique the signal can be isolated from the Standard Model backgrounds. The mass of the $W'$ boson was reconstructed by summing up the four-momenta of all final state objects and the number of events in the signal peak was estimated by means of a likelihood fit. It was shown that a signal significance of $5\sigma$ can be achieved as soon as 400 pb$^{-1}$ of data is accumulated in case of the Littlest Higgs model and when $m_{W'} = 750$ GeV. In the scenario of the left-right Twin Higgs model, the signal cross section is smaller and in particular for $m_{W'} = 1$ TeV the amount of data needed for discovery turned out to be 10 fb$^{-1}$. The discovery or exclusion of a peak in the $W'$ mass spectrum lies within reach for ATLAS and will contribute to our understanding of what physics lies beyond the Standard Model.

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5The study was performed on simulated collisions at $\sqrt{s} = 10$ TeV.