Radiating top quarks
Gosselink, M.

Citation for published version (APA):
Introduction

The Large Hadron Collider (LHC) at CERN in Geneva, Switzerland, will provide the research field of high-energy physics with an overwhelming amount of new data on the structure of matter. The accelerator supersedes earlier accelerators in all kinds of properties. The machine and its experiments owe their existence largely to the successful results obtained with their predecessors. Results from previous collider experiments have firmly established many aspects of the Standard Model, but have not managed to complete the puzzle entirely.

One of the main goals set for the LHC and its experiments is the completion of the search for the Higgs boson. The Higgs boson was already postulated in 1964 [1, 2, 3, 4, 5], but is experimentally still an awkwardly missing particle. Its existence would confirm the spontaneously broken symmetry of the electroweak interactions, leading to massive $W^+$, $W^-$, and $Z$ bosons [6, 7, 8]. Those gauge bosons were predicted in 1968, when the rôle of the Higgs boson was fully recognised, and first observed by the UA1 and UA2 experiments at the Sp$ar{p}$S in 1983 [9, 10]. Another key player in the Standard Model is the top quark, which is the sixth quark and has an abnormal large mass compared to the other quarks. Due to this large mass, the top quark was not discovered before 1995 [11, 12]. The quark was already postulated together with its counter part, the bottom quark, back in 1973 [13]. Both the $W^\pm$ boson mass and the top quark mass give hints on the mass of the Higgs boson. However, so far, the Tevatron has not been able to identify any sign from the Higgs boson. At the LHC the phase space for the production of known (and unknown) particles is orders of magnitude larger. This opens up the possibility to study those particles and their interactions in far greater detail than before. That gives confidence in the LHC potential for interesting ‘new’ physics.

Goals

The work of this thesis was initially driven by a search for the Higgs boson in association with a top quark pair, $t\bar{t}H$. In that perspective, a measurement of particular interest is the determination of extra jets in conjunction with a top quark pair: radiating top quarks.
Introduction

This type of events is a major background to $t\bar{t}H$ and thus needs to be understood in detail. The measurement is also interesting by itself, because it provides a test of QCD at the top quark mass scale. Therefore a part of this thesis is devoted to study this topic using simulated data, notably Chapter 4 and 6. The former concentrates on separating signal from background. The latter concentrates on the uncertainties in jet multiplicity predictions for $t\bar{t}$ events.

A goal on its own, but closely related to the previous subject, is the preparation of a $t\bar{t}$ cross section measurement in Chapter 5. The measurement is designed for early collision data with ATLAS at a centre-of-mass energy of 14 TeV. The work, based on simulated data, investigates what limits the accuracy during initial running. In this measurement, the predicted number of additional jets in $t\bar{t}$ events is an important uncertainty too.

The delay in the LHC start-up has prevented shifting the attention to collision data. Instead, available Monte Carlo techniques for the prediction of multi-jet events have been studied in more depth. This has resulted in a comparison between event generators for $W^{\pm}$ boson, $Z$ boson, and jet spectra in $W +$ jets and $Z +$ jets events (Chapter 7). The cross sections of $W +$ jets and $Z +$ jets production are relatively large compared to $t\bar{t}$ production. Therefore, these processes will rapidly provide a wealth of information which can be used to compare and tune various event generators at an early stage. This is useful, since $W +$ jets and $Z +$ jets are both prominent backgrounds in $t\bar{t}$ (and $t\bar{t}H$) studies.

Summarising, in the context of top quark physics, the work in this thesis converges backward in time. It starts with a glance on $t\bar{t}H$ production – potentially a few years of data-taking away from now, and one of the most challenging channels to search for the Higgs boson. Then it moves on to a nearby in time $t\bar{t}$ cross section measurement – at the doorstep of unexplored territory. And it ends with a study on the production of $W^{\pm}$ and $Z$ bosons – well-known ‘candles’ in particle physics to date, and recently observed in ATLAS [14].

Outline

Chapter 1 starts with an overview of top quark physics at the LHC. After a brief introduction to the LHC, the production of top quarks and its properties are discussed. This is followed by a few outstanding issues which are expected to be uncovered at the LHC.

Chapter 2 is an extensive review of Monte Carlo generators. A good understanding of the strengths and weaknesses of these tools is essential. This is the case especially in searches for ‘new’ physics in multi-jet events.

The ATLAS detector is outlined in Chapter 3. The design and performance of the detector are treated with emphasis on jet reconstruction, the key ingredient for top quark studies.

The first analysis chapter is Chapter 4. It starts with the investigation of $W +$ jets, $t\bar{t}$, and $t\bar{t}H$ production in proton-proton collisions. Characteristic differences in observables between the production processes can be used to enhance the separation of signal and background in the experiment. The study has a mainly instructive character. It bridges
the gap between phenomenology and its experimental observables.

In Chapter 5 an early $t\bar{t}$ cross section measurement scenario is presented. The measurement aims at a ‘re-establishment’ of the top quark. Since the measurement needs full detector capabilities, it can also be used in the commissioning phase as a benchmark for the performance of the ATLAS detector.

Predictions for the jet multiplicity in $t\bar{t}$ events are made in Chapter 6. For the first time, these predictions are compared between various state of the art event generators, specifically for the ATLAS experiment. The comparison includes an evaluation of the impact of the uncertainty in the jet multiplicity on the $t\bar{t}$ cross section measurement.

The last analysis chapter, Chapter 7, focusses on $W^\pm$ and $Z$ boson production with additional jets. In this chapter a comparison is made between event generator predictions for $W^+ + \text{jets}$ and $Z + \text{jets}$. An alternative approach for the prediction of these kind of multi-jet events, based on dipole radiation, is thereby introduced in the ATLAS environment. Distinctive features, which should be observable relatively early in ATLAS, are pointed out. Furthermore, the uncertainty in the predicted amount of background for a $t\bar{t}$ cross section measurement is discussed.

In March 2010 the LHC started operation at $\sqrt{s} = 7$ TeV. In Chapter 8 the first $W^\pm$ and $Z$ bosons recorded by ATLAS are shown. These events mark the beginning of the physics programme for the ATLAS experiment.