Preface

The Standard Model of particle physics has been tested by many experiments and has been shown to accurately describe high energy particle interactions. The existence of a scalar particle, known as the Higgs boson, is central to the theory. The Higgs boson breaks electro-weak symmetry and provides mass to the elementary particles in a consistent way. The Higgs boson was the only fundamental particle in the Standard Model that had not been observed prior to the turn-on of the Large Hadron Collider. The ultimate motivation of the work in this thesis is the Higgs; the goal of this work was to discover or exclude the presence of the Standard Model Higgs boson.

The mass of the Higgs boson is not predicted by the Standard Model. Experiments at LEP have excluded Higgs boson masses below 115 GeV. Fits to precision electro-weak data disfavor a Higgs mass above 200 GeV. Between these masses, the search for the $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ decay is one of the most sensitive channels. This decay occurs with a relatively high rate, and can be efficiently observed experimentally. The work presented in this thesis builds to a search for $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$, performed with the ATLAS detector at the LHC.

The $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ analysis suffers from many sources of background, the most important being: continuum Standard Model $WW \rightarrow l\nu l\nu$ production and events in which a W boson is produced in association with a particle that is misidentified as a lepton, referred to as W+jet background. To understand these backgrounds, in preparation for the $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ analysis, a measurement of the Standard Model WW cross section has been performed. This measurement allowed for the development of analysis techniques carried over directly to the Higgs search. The most important example is the development of a data-driven procedure for measuring W+jet background arising from particle misidentification.

Searches for $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ using $\sqrt{s} = 7$ TeV data collected in 2011, and using $\sqrt{s} = 8$ TeV data collected in 2012, have been performed. An excess of events over the expected background, consistent with the production of the Standard Model Higgs boson, is observed. These analyses are combined with other ATLAS Higgs searches, resulting in the observation of a new neutral boson with mass of 126 GeV and a production cross section consistent the Standard Model Higgs boson.

I have worked on ATLAS since joining the University of Pennsylvania in the summer of 2006, and have been a member of the collaboration since the summer of 2008. After finishing 2-year graduate course work, I moved to CERN and was based at the lab for three and half years. I began working on ATLAS during a period of transition from detector installation and calibration, to physics commissioning and analysis. Being involved throughout this unique period has allowed me to learn how experiments are brought together, and how analysis techniques are developed. It has provided me with the opportunity to play key roles in a broad range of topics described briefly below.

Accurately reconstructing charged particles is a basic ingredient of any collider experiment. ATLAS includes an inner tracking system with the precise position resolution needed to measure the momentum and direction of high p_{T} charged particles. For the tracking system to be effective, the position and orientation of the active elements need to be determined to an accuracy of tens of microns, far better than can be achieved during installation. To reach the required accuracy, an algorithm using the properties of reconstructed particles is used to determine the alignment of the ~350 k detector elements, the majority of which occur in the Transition Radiation Tracker (TRT).

I have been actively involved in the ATLAS inner detector alignment since the summer of 2007. I was responsible for the alignment of the TRT and was a member of a group responsible of accessing the overall quality of the alignment. With the collision data collected in 2010, I led a group that extended the alignment procedure to include each individual channel of the TRT, corresponding to the determination of over 700 k degrees of freedom. This alignment corrected effects of distorted detector modules and improved the TRT position resolution beyond that of the design [1, 2].

Identifying high p_{T} leptons is a critical aspect of doing physics at a hadron collider. High p_{T} leptons are the primary means by which events are selected online by the trigger, they are used to calibrate the detector, and form the basis of many physics analyses, including those presented in this thesis. Electron identification is particularly challenging at the LHC due to the large level of background from charged hadrons and photon conversions.

With data collected in the fall of 2010, I led a team that optimized the electron identification in ATLAS. This optimization was needed to cope with the high LHC luminosity data taking. It serves as the default electron identification algorithm used in ATLAS [3].

Measuring known Standard Model processes is a crucial first step in commissioning the ATLAS physics program. Expected Standard Model signals can be used to understand the detector and refine analysis techniques in preparation for the unexpected.

I have been involved in Standard Model measurements with high p_{T} leptons beginning with the first 7 TeV collision data taken in 2010. I participated in the first measurements of the $W \rightarrow l\nu$ and $Z \rightarrow ll$ production cross sections [4]. In the fall of 2010, I began working on measuring the Standard Model *WW* di-boson production.

This process is an important test of the Standard Model and is the dominant background to a Higgs boson search in the $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ channel. I worked on Standard Model WW production cross section measurements in 2010 with 35 pb^{-1} [5] and in 2011 using 1 fb^{-1} [6], for which I developed data-driven techniques for measuring W+jet background.

In 2011, my focus turned to the Higgs search. I was part of an analysis that made exclusions in the $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ channel using 4.7 fb^{-1} of $\sqrt{s} = 7$ TeV data in 2011 [7], and observed an excess of over three standard deviations using 5.8 fb^{-1} of $\sqrt{s} = 8$ TeV data in 2012 [8]. I lead a team responsible for measuring the W+jet background and optimizing lepton identification criteria. This work reduced the W +jet background in the 2012 analysis by a factor two, substantially improving the sensitivity for Higgs masses around 125 GeV. These analyses, combined with $H \rightarrow ZZ^{(*)} \rightarrow llll$ and $H \rightarrow \gamma\gamma$ searches, lead to the discovery of the Higgs boson [9].

This thesis is written in a way that follows my path as a graduate student on ATLAS. The first three chapters give a brief introduction to the Higgs, the LHC, and the ATLAS detector.

Chapter 4 describes the basic particle reconstruction and identification used throughout the thesis. The types of commissioning activities required to understand the detector and the performance of the particle reconstruction algorithms are introduced.

Chapter 5 introduces detector alignment. Track-based alignment, a procedure for performing the detector alignment using the reconstructed trajectories of charged particles, or tracks, is described. The alignment of the ATLAS Inner Detector (ID) is presented. The ID alignment involves measuring the positions of over 300,000 detector elements, spanning meters in space, to an accuracy of tens of microns.

Chapter 6 documents the alignment of the TRT in detail. The TRT alignment began with the first recorded cosmic-ray data and continued through to the 7 TeV collision data, used to perform the wire-level alignment. The various stages of the alignment procedure are documented, and the results are presented.

Chapter 7 describes the reconstruction and identification of electrons in ATLAS. Efficient electron identification, with large background rejection, is achieved through the precision tracking and transition radiation detection in the Inner Detector, and the fine segmentation of the electromagnetic calorimeter. The optimization of the electron identification is documented. This optimization had to cope with mis-modeling in simulation, high instantaneous luminosities, and the simultaneous occurence of multiple pp collisions.

Chapter 8 provides a general introduction to WW physics. The motivation for using the WW final state is outlined, and the basics of the signature and event selection are presented. The primary backgrounds to WW events are discussed, and the methods used to estimate them are introduced. This chapter serves as a basic introduction to the more detailed presentations of the WW cross section measurement and the search for $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$.

Chapter 9 describes the "fake factor" method, a procedure for estimating background arising from misidentification. Misidentification is an important source of background for physics analyses using particle-level identification criteria. For the analyses presented in this thesis, misidentification leads to *W*+jet background, when a jet is misidentified as a lepton. It is important to measure this background from data as the rate of misidentification may not be accurately modeled in the simulation. The fake factor method is a data-driven procedure for modeling background from particle misidentification. This procedure is used both in the *WW* cross section measurement presented in Chap. 10 and in the search presented in Chap. 11.

Chapter 10 presents a measurement of the *WW* production cross section in *pp* collisions with $\sqrt{s} = 7$ TeV. The measurement is performed using data corresponding to an integrated luminosity of 1.02 fb^{-1}. The total measured cross section is $\sigma(pp \to WW) = 54.4 \pm 4.0$ (stat.) ± 3.9 (syst.) ± 2.0 (lumi.) pb, consistent with the Standard Model prediction of $\sigma(pp \to WW) = 44.4 \pm 2.8$ pb. A precise measurement of the *WW* cross section provides an important test of the Standard Model and is an important step in the search for the Higgs.

Chapter 11 presents the search for the Standard Model Higgs boson using the $H \to WW^{(*)} \to l\nu l\nu$ decay mode. The analysis has been performed using 4.7 fb^{-1} of $\sqrt{s} = 7$ TeV data collected in 2011, and 5.8 fb^{-1} of $\sqrt{s} = 8$ TeV data collected in the first half of 2012. In the 2011 analysis, no significant excess of events over the expected background was observed, and the Standard Model Higgs boson with mass in the range between 133 and 261 GeV has been excluded at 95 % confidence level. In the 2012 analysis, an excess of events over the expected background is observed, corresponding to a local significance of 3.2 standard deviations. The 2011 and 2012 results are combined and the observed excess corresponds to a local significance of 2.8 standard deviations.

Chapter 12 presents the combined ATLAS search for the Standard Model Higgs boson. The analysis has been performed using 4.7 fb^{-1} of $\sqrt{s} = 7$ TeV data collected in 2011, and 5.8 fb^{-1} of $\sqrt{s} = 8$ TeV data collected in the first half of 2012. The results of the $H \to WW^{(*)} \to l\nu l\nu$ analyses presented in Chap. 11 are combined with searches in the $H \to ZZ^{(*)} \to llll$ and $H \to \gamma\gamma$ channels, using both the 7 and 8 TeV datasets, and with several other Higgs searches using the 7 TeV dataset. Clear evidence for the production of a neutral boson with a mass of around 126 GeV is found. This observation has a significance of 5.9 standard deviations and is compatible with the production and decay of the Standard Model Higgs boson.

Not all of the chapters are intended for the same audience. A guide has been included to orient the reader.

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