DEPARTMENT OF PHYSICS
UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

Search for tWZ production in the Full Run 2 ATLAS dataset using events with four leptons

Jake Reich
Student Number: RCHJAK001
Supervisor: Dr. James Keaveney
Co-Supervisor: Dr. Sahal Yacoob

October 2021

Abstract

Declaration

I certify that this assignment/report is my own work, based on my personal study and/or research and that I have acknowledged all material and sources used in its preparation, whether they be books, articles, reports, lecture notes, and any other kind of document, electronic or personal communication. I also certify that this assignment/report has not previously been submitted for assessment in any other unit, except where specific permission has been granted from all unit coordinators involved, or at any other time in this unit, and that I have not copied in part or whole or otherwise plagiarised the work of other students and/or persons.

Acknowledgements

Contents

Chapter 1

Introduction

Write similar to what is in nrf application.

Talk about previous paper's (tWZ3-lep) findings - http://cds.cern.ch/record/2625170

Explain that SM aims to describe fundamental physics, but fails in certain cases (DM, gravity etc.)

Possibly talk about EFT? Finding tWZcross section -¿ global fit. FOR REFERENCE:
The production of a single top quark in association with a W and Z boson (tWZ) is sensitive to both the neutral and charged electroweak couplings of the top quark as the process involves the simultaneous production of a W boson and a Z boson in association with the top quark. Due to the very large coupling of the top quark to the Higgs boson, the electroweak couplings of the top quark are a theoretically well-motivated area to expect the first signs of new physics. The recent lack of signs of new physics from LHC data tells us that new physics is either very heavy, or is very weakly coupled to Standard Model particles, therefore we might only observe signs of new physics in anomalous rates of well-chosen processes. A prime example of such a process is tWZ. This has an extremely low production cross section (0.7 fb), meaning that it is an extremely rare process to observe and subsequently, it has never been observed by any particle physics experiment. However, the latest datasets recorded by ATLAS are sufficiently large to allow a potential observation of this rare, novel process.

We aim to use the Full Run 2 dataset recorded by the ATLAS experiment at CERN to search for the production of a top quark together with a W and Z boson for the channel with four leptons (two originating from the decay of the Z boson, one from the associated W boson and one from the W boson which decays from the top quark (together with a b quark)). The Standard Model of particle physics has been confirmed to an extraordinary degree of precision, however we know there are stark deficiencies therein. These include its incompatibility with the theory of gravity and an explanation of the matter-antimatter asymmetry in the universe. Especially relevant is the Standard Model's lack of an explanation for the vast differences in the strengths of the fundamental forces (The Hierarchy Problem), constraining the electroweak couplings of the top quark squarely addresses this fundamental scientific question.

Chapter 2

Theory

2.1 Standard Model of Particle Physics

What is SM (renormalisable qft), come from symmetry, brief description of group structure? Explain structure/properties (fermions, bosons, etc.), coupling constants. 'Particles carry color/electric charge, some particles can interact with others/themselves, some can't' Where does it how? How well does it work? Where doesn't it work?

2.1.1 Electroweak Theory

2.1.2 Top Quark

Properties. History (when/how was it discovered/theorised). Why interesting (large mass). Hierarchy problem. Decay channels. Extremely short lifetime (makes b's so important for top ID).

2.2 tWZ

2.2.1 Tetra-lepton Channel

Provide feynman diagram. Cross section.

2.2.2 Comparison to Tri-lepton Channel

Less backgrounds to deal with (in tetralepton). However lower stats (in tetra). Give cross sections (and feynman diagram). Maybe talk a bit about analysis related challenges (trilepton has a hadronically decaying W, does this make the analysis easier or more difficult?).

2.3 Effective Field Theory (EFT)

2.4 Machine Learning in the Context of Particle Physics Analyses

2.5 Statistical Techniques

2.5.1 Maximum Likelihood Fitting

2.5.2 Significance

2.5.3 Limit Setting

Chapter 3

The ATLAS Detector

3.1 Coordinate System and Kinematics

3.2 Tracking Detectors

3.3 Calorimeter System

3.3.1 Electromagnetic Calorimeter

3.3.2 Hadronic Calorimeter

3.4 Muon Spectrometer

3.5 Trigger and Data Acquisition System

Chapter 4

Analysis Setup and Strategy

4.1 Data and Monte Carlo Simulation

4.1.1 Data Samples

4.1.2 Monte Carlo Samples

4.2 Object Reconstruction

4.2.1 Leptons

4.2.2 Jets

4.2.3 b-tagging

4.3 Regions and Event Selection

4.4 Machine Learning Techniques

4.5 Fake Lepton Estimation

4.6 Analysis Framework: TRExFitter

Chapter 5

Search for tWZ Production

5.1 Backgrounds

5.1.1 $t\bar{t}Z$

5.1.2 ZZ

5.1.3 other

5.2 Control Plots

5.3 Post-Fit Plots

5.4 Results

Chapter 6

Conclusion and Outlook

Appendix A

Appendix