

ABSTRACT

SOMETHING ABOUT VECTOR BOSON SCATTERING

Mark Mekosh, M.S.
Department of Physics
Northern Illinois University, 2021
Michael Eads, Director

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

NORTHERN ILLINOIS UNIVERSITY
DE KALB, ILLINOIS

DECEMBER 2021

SOMETHING ABOUT VECTOR BOSON SCATTERING

BY

MARK MEKOSH
© 2021 Mark Mekosh

A THESIS SUBMITTED TO THE GRADUATE SCHOOL
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE
MASTER OF SCIENCE

DEPARTMENT OF PHYSICS

Thesis Director:
Michael Eads

ACKNOWLEDGEMENTS

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.

DEDICATION

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod
tempor incididunt ut labore et dolore magna aliqua.

TABLE OF CONTENTS

	Page
List of Tables	vi
List of Figures.	vii
List of Appendices.	viii
Chapter	
1 Introduction.	1
1.1 The Standard Model	1
1.1.1 Fermions	2
1.1.2 Bosons.	3
1.1.3 Electroweak Interactions	3
1.1.4 Quantum Chromodynamics	3
2 Vector Boson Scattering	4
3 The CMS Experiment	5
3.1 The Large Hadron Collider	5
3.2 The CMS Detector	5
4 Event Simulation and Reconstruction	6
5 Signal and Control Regions	7
5.1 Backgrounds.	7
5.1.1 Top Background	7
5.1.2 W+jets Background	7
5.2 Signal Discrimination	7

Chapter	Page
6 Uncertainties	8
7 Results	9
8 Conclusions	10
Appendices	12

LIST OF TABLES

Table	Page
2.1 Example VBS processes	4

LIST OF FIGURES

Figure	Page
2.1 Simple VBS diagram	4

LIST OF APPENDICES

Appendix	Page
A Statistical Learning Techniques	12
A.1 BDT	13
B Additional Plots	14

CHAPTER 1

INTRODUCTION

1.1 The Standard Model

The study of physics is fundamentally the study of how the universe and everything inside of it works. Naturally then, as physicists, we want to be able to explain everything we study in the most amount of detail we can, and to this end we develop models of the universe with as much explanatory power as possible. One of these such models for describing the fundamental interactions of our universe is named the Standard Model. This model attempts to understand the universe by understanding the interactions between elementary particles that the universe is comprised of.

The Standard Model was developed throughout the 1900's by many scientists contributing many different discoveries and theories. In the early part of the century after J. J. Thomson's 1897 discovery of the electron, Rutherford's 1918 discovery of the proton, and Chadwick's 1932 discovery of the neutron, the fundamental building blocks of matter seemed to have all been found [3]. We could explain the universe as being made up of atoms which were made up of the three smallest and most fundamental particles, the proton, neutron, and electron. It wasn't long though, before this simple model of the elementary particles was upended.

The 1930's through the 1950's saw a rapid expansion in the number of elementary particles proposed, predicted, and discovered. By 1960 the term "particle zoo" was used to describe the unwieldy amount of unique and seemingly fundamental particles. Much like Mendeleev organized the known elements into the periodic table, the particle zoo was in

need of organization. In 1961 Gell-Mann proposed the Eightfold Way, a way to organize the particles of the zoo based on their properties. In 1964 Gell-Mann and Zweig independently proposed the Quark Model to explain the substructure of the zoo's inhabitants, and 10 years later in 1974, when the J/ψ particle was discovered, the quark model won out as the best explanation for these particles [1].

In 1968 Glashow, Weinberg, and Salam combined the electromagnetic and weak interactions into a single electroweak theory, and in 1975 Pais and Treiman dubbed the electroweak theory with four quarks the “standard” model [2]. This model describes three of the four fundamental forces and how they govern the elementary particles that make up all matter. As the model and its predictions grew so too did the number of particles included in the standard model.

At present, the model contains 6 quarks and their anti-quark counterparts, 6 leptons and their antiparticles, as well as 6 bosons¹. As it currently stands the Standard Model is our best framework for understanding the fundamental building blocks of our universe and their interactions.

1.1.1 Fermions

Fermions

¹Presently there is no experimental evidence for a 7th boson, the graviton, and its associated standard model explanation for the 4th fundamental force of gravity

1.1.2 Bosons

1.1.3 Electroweak Interactions

1.1.4 Quantum Chromodynamics

CHAPTER 2

VECTOR BOSON SCATTERING

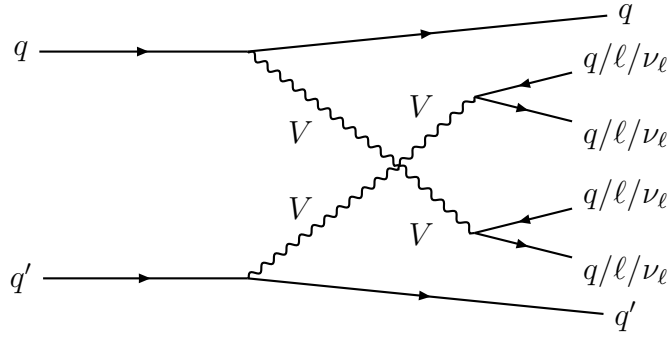


Figure 2.1: A basic quartic gauge coupling VBS process with the vector bosons decaying either hadronically, leptonically, or semi-leptonically

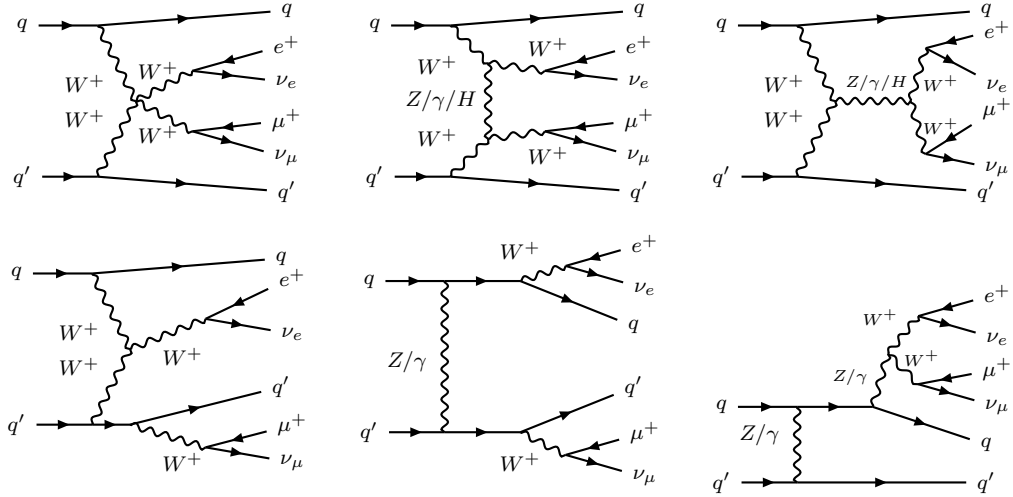


Table 2.1: Representative Feynman diagrams for VBS $pp \rightarrow e^+\nu_e\mu^+\nu_\mu jj$ and $pp \rightarrow e^+\nu_e\mu^-\bar{\nu}_\mu jj$ processes.

CHAPTER 3

THE CMS EXPERIMENT

3.1 The Large Hadron Collider

3.2 The CMS Detector

CHAPTER 4

EVENT SIMULATION AND RECONSTRUCTION

CHAPTER 5

SIGNAL AND CONTROL REGIONS

5.1 Backgrounds

5.1.1 Top Background

5.1.2 W+jets Background

5.2 Signal Discrimination

CHAPTER 6
UNCERTAINTIES

CHAPTER 7

RESULTS

CHAPTER 8

CONCLUSIONS

BIBLIOGRAPHY

- [1] David Griffiths. *Introduction to Elementary Particles*. Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2010. ISBN: 9783527406012.
- [2] A. Pais and S. B. Treiman. “How Many Charm Quantum Numbers are There?” In: *Phys. Rev. Lett.* 35 (23 Dec. 1975), pp. 1556–1559. DOI: 10.1103/PhysRevLett.35.1556. URL: <https://link.aps.org/doi/10.1103/PhysRevLett.35.1556>.
- [3] James Trefil. *From Atoms to Quarks*. New York: Charles Scriber’s Sons, 1980. ISBN: 0684164841.

APPENDIX A

STATISTICAL LEARNING TECHNIQUES

A.1 BDT

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

APPENDIX B
ADDITIONAL PLOTS