Thesis Title

A DISSERTATION
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA
BY

Vladimir Bychkov

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Gregory Pawloski

..., 2018

Acknowledgements

There are many people that have earned my gratitude for their contribution to my time in graduate school.

Dedication

To those who held me up over the years

Abstract

Contents

Acknowledgements i

Dedication ii

Abstract iii

List of Tables vi

List of Figures vii

1 Introduction 1

2 Physics of Neutrinos 3

3 The NOvA Experiment 4

4 Simulation 5

5 Event Reconstruction 6

6 Data Analysis Strategy 7

7 ν_μ CC Selection 8

8 Analysis 9

8.1 Analysis Procedure 9

8.2 Analysis Result 9

9 Systematics **10**

10 Conclusion and Discussion **11**

References **12**

Appendix A. Glossary and Acronyms **13**

A.1 Glossary 13

A.2 Acronyms 13

List of Tables

A.1 Acronyms 13

List of Figures

Chapter 1

Introduction

The goal of this work is to study and understand properties of one of the most mysterious elementry particles in the universe - neutrinos. Neutrino is chargeless and has mass which is less by many orders of magnitude than masses of others fundamental particles. It is known that neutrinos could interact only through weak and gravitational forces which leads to a several light years of mean free path in the matter. Despite their tiny mass and weak interaction with the matter, they are very interesting not only to elementary particle physics community but also to cosmologists and astrophysicists. Neutrinos carry away almost all energy of supernova explosion and can tell a lot about a dying star's internal structure and the last seconds of its life. Neutrino telescopes may open a new window for Universe observation and give a unique look into phenomena which could not be seen by conventional telescopes. These light, electrically neutral particles also can show physicists a possible direction towards new physics. The list of examples why neutrinos are important continues to grow, and it gives a sense that neutrino physics is a very rich and interesting subject to study.

In addition, neutrinos take part in one more fascinating phenomenon called neutrino oscillations. While produced in one flavour after travel some distance neutrino is changing its flavour to another one in an oscillatory way. The NOvA - NuMI[1] Off-axis Neutrino Appearnace - experiment was designed to study properties of these oscillations.

[1] Neutrino at the Main Injector

There are several parameters which fully describe neutrino oscillations and analysis presented in this work is focused on measuring $\sin^2\theta_{23}$ and $|\Delta m^2_{32}|$. The measurements come from studying a specific mode of the oscillations - $\nu_\mu \to \nu_\mu$.

- Chapter 2 briefly presents the history of, and science behind, the subjects presented in this thesis.
- In Chapter 3 the experiment is outlined.
- Chapter 4 describes the simulation process used in the analysis.
- Chapter 5 follows the chain of reconstruction software used to obtain meaningful results from data.
- Chapter 6 hashes out the strategy for analysis and presents the data and simulated sets that will be used in the analysis.
- Chapter 7 demonstrates the implementation of the event selection processes.
- In Chapter 8 those events selected in Chapter 7 are analyzed.
- Chapter 9 presents a final discussion of the analyses presented in the thesis.

Chapter 2

Physics of Neutrinos

Hello!!!!!!!! QQQQQQQQQQQQQ

qwqwqwqw

Chapter 3

The NOvA Experiment

Chapter 4

Simulation

Chapter 5

Event Reconstruction

Chapter 6

Data Analysis Strategy

Chapter 7

ν_μ CC Selection

Chapter 8

Analysis

8.1 Analysis Procedure

8.2 Analysis Result

Chapter 9

Systematics

Chapter 10

Conclusion and Discussion

In this chapter we will briefly summarize our results! Or maybe not! Or maybe yes! QQWQWWQQQW

References

Appendix A

Glossary and Acronyms

Care has been taken in this thesis to minimize the use of jargon and acronyms, but this cannot always be achieved. This appendix defines jargon terms in a glossary, and contains a table of acronyms and their meaning.

A.1 Glossary

- **Cosmic-Ray Muon** (**CR** μ) – A muon coming from the abundant energetic particles originating outside of the Earth's atmosphere.

A.2 Acronyms

Table A.1: Acronyms

Acronym	Meaning
CRμ	Cosmic-Ray Muon