Reconstruction and Calibration of SNO+ Water

Jie Hu

A Dissertation

Presented to the Faculty

of University of Alberta

in Candidacy for the Degree

of Doctor of Philosophy

Recommended for Acceptance

by the Department of

Department of Physics

January, 2019

Abstract

0.1 Abstract

A neutrino is one of the elementary particles we currently know and is included in the Standard Model (SM). However, some properties of neutrinos can not be described by the SM, which shows clues of the new physics beyond the Standard Model.

SNO+ experiment is planned to explore one of the unknown properties of neutrinos: whether the neutrinos are Majorana particles or Dirac particles.

Acknowledgements

Contents

Abstract **iii**

0.1 Abstract iii

Acknowledgements **iv**

Contents **v**

List of Figures **vii**

List of Tables **viii**

1 Introduction **1**

1.1 Neutrino Oscillation 1

1.2 Majorana Neutrino 1

2 The SNO+ Experiment **2**

2.1 A Description of SNO+ Detector 2

2.1.1 Overview 2

2.1.2 Trigger System 4

2.1.3 Liquid scintillator 4

3 Water Phase Analysis **5**

4 Partial-filled Scintillator Phase **6**

A Appendix Name **7**

References **8**

List of Figures

List of Tables

Chapter 1

Introduction

Yesterday's rose stands only in name,

we hold only empty names.

— Umberto Eco, *The Name of Rose*

A neutrino is one of the elementary particles we currently know and is included in the Standard Model (SM). However, some properties of neutrinos can not be described by the SM, which shows clues of the new physics beyond the Standard Model.

SNO+ experiment is planned to explore one of the unknown properties of neutrinos: whether the neutrinos are Majorana particles or Dirac particles.

Massive neutrinos are discussed ...

1.1 Neutrino Oscillation

solar neutrino oscillations

1.2 Majorana Neutrino

Dirac equation $(i\gamma^\mu\partial_\mu - m)\psi = 0$, get coupled equations

Chapter 2

The SNO+ Experiment

There is an art in the contemplation of water. It is necessary to look at it as foaming in waves.

— Mencius,
translated by James Legge

2.1 A Description of SNO+ Detector

2.1.1 Overview

The SNO+ experiment is located at SNOLAB in Vale's Creighton mine in Sudbury, Ontario, Canada. Deep underground, the SNOLAB provides a 2092 ± 6 m flat overburden of rock, which is 5890 ± 94 water equivalent meter (w.e.m). This rock overburden ensures an extremely low rate of cosmic muons passing through the detector. The rate is 0.27 $muons/m^2/day$, compared to an average flux of about 10^4 $muons/m^2/minute$ at sea level[1].

The detector has been running since December 2016[**?**],

The SNO+ detector is the successor of the SNO experiment, which makes use of the SNO detector structure.

detector consists of an acrylic vessel (AV) sphere of 12 m in diameter and

5.5 cm in thickness. The AV sphere is concentric within a stainless steel photomultiplier(PMT) support structure (PSUP), with an average radius of 8.4 m. The Hamamatsu 8-inch R1408 PMTs are mounted on the PSUP. 9394 PMTs are looking inward to the AV, giving a 50% effective coverage, while 90 PMTs are looking outward, serving as muon vetos. These two structures are housed in a rock cavity filled with 7000 tonnes of ultrapure water (UPW) to provide both buoyancy for the vessel and radiation shielding.

The SNO+ detector is designed for multi-purpose measurements of neutrino physics. The experiment will go through three phases[**?**]:

1. Water phase

The AV was filled with about 900 tonnes of ultra pure water (UPW). The detector has been collecting physics data since May 2017.

The main physics goal in this phase is to search for the invisible nucleon decay, which violates baryon number and is a prediction of Grand Unified Theory (GUT). In this decay mode, ^{16}O decays into ^{15}O* or ^{15}O*, which de-excites and produces a γ ray of about 6 MeV.

During the water phase, different types of calibration runs have been taken. The detector responses, systematics and backgrounds are studied. Multiple physics analyses of solar neutrinos, reactor antineutrinos and nucleon decay are going on. The external backgrounds are also measured, which will be the same as the following two phases.

2. Scintillator phase

The AV will be filled with 780 tonnes of liquid scintillator, which is a mixture of linear alkylbenzene (LAB) as a solvent and 2 g/L of 2,5-diphenyloxazole (PPO) as a fluor.

In this phase, the main physics goal is to measure low energy solar neutrinos: the CNO, pep and low energy ^{8}B neutrinos. The pep neutrinos are mono-energetic, with E_ν=1.442 MeV and their flux is well predicted by the Standard Solar Model. A measurement of the pep neutrinos will give more information of the matter effects in neutrino oscillations[**?**].

The solar metallicity is the abundance of elements heavier than ^{4}He (called "metal" elements in the context of astronomy). It is poorly constrained and the predictions from different solar models disagree with each other. A measurement of the CNO neutrinos can give the abundance of ^{12}C, ^{13}N and ^{15}O and can thus resolve the metallicity problem[**?**].

Geoneutrino, reactor antineutrino and supernova neutrino detections are additional goals.

A six-month period of scintillator filling and six to twelve months of data-taking are expected for this phase. During the filling, it is planned to operate the partially filled detector at a water level about 4.4 m for about two weeks. This partial filled transition phase is mainly aimed to understand the in-situ backgrounds of scintillator.

3. Tellurium loading phase

In this final phase, 0.5% natural Tellurium by mass will be loaded into the scintillator. Higher loading concentrations would be possible for a further loading plan[2]. The ^{130}Te is a double beta decay isotope. The main purpose in this phase is searching for $0\nu\beta\beta$ in ^{130}Te.

2.1.2 Trigger System

Calibration source

The ^{16}N source $^{3}\mathrm{H}(p,\gamma)^{4}$He reaction.

2.1.3 Liquid scintillator

Linear Alkyl Benzene (LAB)

The advantages of LAB are:

- It has a high light yield
- It has different timing spectrum for α and β events, which enables an $\alpha - \beta$ discrimination.
- It is chemically compatible with AV.
- It is cheap, for

water-based wavelength shifter

Chapter 3

Water Phase Analysis

There are two possible outcomes: If the result confirms the hypothesis, then you've made a measurement. If the result is contrary to the hypothesis, then you've made a discovery.

— Enrico Fermi

Chapter 4

Partial-filled Scintillator Phase

There are two possible outcomes: If the result confirms the hypothesis, then you've made a measurement. If the result is contrary to the hypothesis, then you've made a discovery.

— Enrico Fermi

Appendix A

Appendix Name

References

[1] Muons. https://cosmic.lbl.gov/SKliewer/Cosmic_Rays/Muons.htm, 2001. [Online; accessed 19-July-2019].

[2] J. Paton. Neutrinoless Double Beta Decay in the SNO+ Experiment. In *Prospects in Neutrino Physics (NuPhys2018) London, United Kingdom, December 19-21, 2018*, 2019.