Nomenclature

AC Alternating Circuit

APA Anode Plane Assemblies

ArgoNeuT Argon Neutrino Teststand

BDT Boosted Decision Tree

BNB Booster Neutrino Beam

BSM Beyond Standard Model

C.L. Confidence Level

CC Charged Current

CE Cold Electronics

CERN European Organisation for Nuclear Research

CPA Cathode Plane Assembly

CPT Charge Parity Time symmetries

CRT Cosmic Ray Tagger

CRUMBS Cosmic Rejection Using a Multi-system Boosted decision tree Score

DAQ Data AcQuisition

DCA Distance of Closest Approach

DUNE Deep Underground Neutrino Experiment

ETRIG Event TRIGger

FD Fine Delay

FEB Front End Board

FMC Field programmable gate arrays Mezzanine Card

FTRIG Flash TRIGger

HNL Heavy Neutral Lepton

ICARUS Imaging Cosmic And Rare Underground Signals

KDAR Kaon Decay At Rest

KEK High Energy Accelerator Research Organization (Kō Enerugī Kasokuki Kenkyū Kikō)

LArTPC Liquid Argon Time Projection Chamber

LSND Liquid Scintillator Neutrino Detector

MC Monte Carlo

MCS Multiple Coulomb Scattering

MicroBooNE Micro Booster Neutrino Experiment

MiniBooNe Mini Booster Neutrino Experiment

MIP Minimum Ionising Particle

MTC/A Master Trigger Card Analog

NC Neutral Current

NTB Nevis Trigger Board

NTP Network Time Protocol

NuMI Neutrinos at the Main Injector beam

NuTeV Neutrino at the Tevatron

PDF Probability Density Function

PDS Photon Detection System

PE PhotoElectron

PID Particle IDentification

PIENU **Pi**on → **E**lectron + **Neu**trino

PMNS Pontecorvo-Maki-Nakagawa-Sakata

PMT PhotonMultiplier Tube

POT Protons On Target

PPS Pulse Per Second

PTB Penn Trigger Board

QE Quantum Efficiency

RWM Resistor Wall Monitor

s.d. standard deviation

SBN Short-Baseline Neutrino

SBND Short-Baseline Near Detector

SCE Space Charge Effect

SER Single Electron Response

SIN Swiss Institute for Nuclear Research

SiPM Silicon PhotoMultiplier

SM Standard Model

SPEC Simple PCIe FMC Carrier

SVEC Simple VME FMC Carrier

T2K Tokai to Kamioka

TAI Coordinated Universal Time

TDC Time to Digital Converter

TPB TertraPhenyl Butadiene

TPC Time Projection Chamber

UTC International Atomic Time

VUV Vacuum Ultraviolet

WIB Warm Interface Board

WR White Rabbit

Chapter 1

Introduction

Neutrino oscillation implies that neutrinos have mass, which cannot be currently explained by the Standard Model (SM) due to an absence of right-handed partners to the left-handed neutrinos. Chapter 2 begins with the motivation of a right-handed heavy neutrino state, also referred to as *Heavy Neutral Leptons* (HNLs), that allows for the construction of neutrino mass. An overview of the theoretical models of HNLs is additionally given, covering their productions and decays. The focus is on kinematically-allowed channels that can be produced from the Booster Neutrino Beam (BNB) and subsequently decay inside the Short-Baseline Near Detector (SBND).

In following, a description of Liquid Argon Time Projection Chamber (LArTPC) is provided in Chapter 3, which is the main detector technology of SBND. The operating principles of a LArTPC is presented, identifying key physical processes of the two main detection signals, ionisation electrons and scintillation photons, that underpin the performance of a LArTPC.

Chapter 4 then provides an overview of the SBND and the BNB. The chapter begins with the physics program of SBND, followed by the detector design, describing each subsystem that comprise the detector. The BNB is discussed next, detailing the beam design and presenting the secondary meson fluxes and neutrino fluxes arriving at SBND.

The simulation framework at SBND is outlined in Chapter 5, to produce Monte Carlo (MC) samples ideally representing data. A description on different generators to simulate SM neutrinos, cosmic muons and HNLs is first provided. The HNL generator is presented in details to illustrate the physics behind the lateness of HNLs compared to SM neutrinos produced from the BNB, that the thesis work presented in later chapters rely upon. Finally, the simulation of the particle propagation and the detection response is summarised.

Following that, the reconstruction framework is provided in Chapter 6, covering the reconstruction for each detection subsystem: (1) TPC, (2) Photon Detection System (PDS) and (3) Cosmic Ray Tagger (CRT). Specifically in the TPC reconstruction workflow, an update to an algorithm separating track-like and shower-like reconstructed object is detailed. An overview of some high-level analysis tools, combining complementary signals from all subsystems, is discussed next.

Chapter 7 outlines the timing performance of the Data AcQuision (DAQ) at SBND. The chapter begins with a description of the White Rabbit timing system setup to maintain timing synchronisation across different DAQ subsystems. The timing precision of the readout electronics of the CRT and PDS are then accessed, which are the two detection subsystems with signals $\mathcal{O}(1\text{ ns})$.

Some studies within the scope of charge calibration are discussed in Chapter 8. The first study is on the measurement of electron lifetime, performed on MC samples of anode-to-cathode crossing cosmic muon tracks that fully traverse the detector volume. The second study is to assess the impacts of delta ray fluctuations on recombination, via simulation studies varying delta ray thresholds.

A selection procedure has been developed to select HNLs and reject backgrounds from SM neutrinos and cosmic muons, which will be presented in Chapter 9. Firstly, a signal and background definition is provided, followed by a description of MC samples used to perform the selection. Dedicated cuts for cosmic background and SM neutrinos rejection and HNL showers selection are detailed subsequently. The result of the selection is analysed next, identifying the most impactful cuts of the selection. Finally, a *truth*-based study is presented, proposing a hypothetical scenario if the resolution of the timing reconstruction is improved.

Finally, the capabilities of SBND to search of HNLs is assessed in Chapter 10. The systematic uncertainties in the analysis is discussed, covering their sources and treatments. The procedure used to set an upper limits at the 90% confidence level is detailed next. The result of the limit setting is then presented, covering three result projections that can be achieved at SBND. A discussion of the results is finally given, including suggestions for future developments.