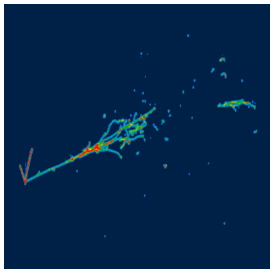
DEPARTMENT OF PHYSICS

2016 – 2020

SEARCH FOR ELECTRON NEUTRINO ANOMALIES WITH THE MICROBOONE DETECTOR



Wouter Van De Pontseele

Jesus College, University of Oxford

Supervisors: Prof Roxanne Guenette
Prof Alfons Weber

A thesis submitted for the degree of
Doctor of Philosophy

Statement of Originality

This thesis and the work presented in it are my own and were produced by me as a result of my own original research. Results and figures from published works by others have been clearly attributed and the assistance received in preparing this thesis has been acknowledged. Furthermore, this work has not been submitted for another qualification at this or any other university.

Chapter 1 contains a brief introduction, Chapter 2 gives some background information about the theory motivating the work presented in this thesis, and Chapter 3 describes the MicroBooNE experiment whose data was analysed in this work. These chapters represent my summary of the work of others, and all relevant papers and documents have been cited. Chapter 4 describes the reconstruction techniques used to allow a high-level analysis of the data. The different components of this thesis are described in Chapters 5, 6, 7, 8 and 9, and, where not specified otherwise, is entirely my own work.

Acknowledgements

It is not an understatement to say that without my supervisor, Roxanne, this journey – let alone this thesis – would never have been completed. I owe you an enormous thank you for enabling and supporting me to pursue the research I could not have imagined to be part of before commencing my DPhil. Your guidance and ideas are present everywhere in this document, not at least through the thousands of comments you supplied me with. Thank you even more for the moose burger BBQ and Christmas parties you hosted, back in the days that corona was not a thing yet.

I want to thank all the scientists involved in the design, construction and commissioning of MicroBooNE; enabling me to act as if neutrino data grows on the trees. A big thank you to all organisations that financially and logistically supported my DPhil: the University of Oxford, Harvard University, Jesus College, Oxford University Press and Fermilab. Thank you, Sue and Kim, for the complicated arrangements I often needed your help with.

Santiago, thank for your introduction in authentic Latin-American fiesta music and your imitation of the pelican. Peter, thank you for visiting me in Boston on my birthday without realising by surprise. And Priyav, thank you for always going on trips and adventures, even when it involves landing a glider without reading the safety instructions. Luca, thank you for attending the most obscure Clarendon events. Miha, thank you for smuggling me into Vincent's Club, and even lending me your tie. Ben, thank you for joining the expeditions to Zuzu's kitchen. All other Belgians in Boston, thank you for convincing me that there is always the option for a second beer. Supraja, Avinay, Krishan and Raquel, thanks for making my time at Fermilab wonderful and joining me on haunted wine walks at the local hairdresser. Andy S. & Lorena, you were amazingly helpful whenever pandora problems occurred, thank you for that. Lars, thank you for making sure there was never shortage of free food supplies at Harvard, even non-pizza lunches. Roberto, thank you for sledging down a mountain with me. I hope the Korean girl is okay by now. Nicolò, thanks for all our conversations, but especially the ones while eating frozen thanksgiving lunch in the snow in the middle of nowhere. And, of course, Marco, thank you for being my inflatable boat companion during fireworks on the river.

A huge thank you to my family: mam, dad and Lisa, for always coping with me and making Belgium still feel like my home. Finally, Aurélie, I dedicate this thesis to you, in the hope you will feel a little obliged to read something slightly scientific when you grow older.

Abstract

The Micro Booster Neutrino Experiment (MicroBooNE) is a Liquid Argon Time Projection Chamber (LArTPC) located in the Booster Neutrino Beam at Fermi National Accelerator Laboratory. The experiment was devised to investigate a series of observed anomalies concerning short-baseline neutrino oscillation physics. The LArTPC technology enables the experiment to study neutrino-argon scattering with an unprecedented detail.

This thesis presents a cosmic-ray characterisation and rate measurement. The understanding of cosmic activity in the detector – MicroBooNE's dominant background – is then used to develop cosmic rejection tools. A flavour-agnostic neutrino selection is constructed, which forms the cornerstone of this and further analyses. Inclusive muon and electron charged-current neutrino interaction selections with unprecedented purity and efficiency are presented.

The first fully-automated characterisation of electron neutrinos in a muon neutrino beam with the LArTPC detector technology is performed. The Booster Neutrino Beam has an energy peaking around 1 GeV and an intrinsic electron content of approximately 0.5%. The analysis investigates electrons produced in charged-current electron neutrino interactions. The kinematics of the electrons are measured along with comparisons to simulation. Most of the systematic uncertainties are constrained using a data-driven sample of charged-current muon neutrino events. The measurement of electron neutrinos originating from the Booster Neutrino Beam is a crucial component towards understanding the nature of the observed excess of low-energy electromagnetic-like events at its predecessor, MiniBooNE.