A Search for $\nu_\mu \rightsquigarrow \nu_e$ Oscillations in the NOMAD Experiment

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Abstract

The NOMAD experiment is a neutrino oscillation experiment, capable of identifying ν_μ, $\overline{\nu}_\mu$, ν_e, $\overline{\nu}_e$ and ν_τ for use in oscillation analyses. A search for $\nu_\mu \rightsquigarrow \nu_e$ oscillations is conducted, emphasising the development of two separate beam simulators, to provide the background, (no oscillation), ν_e signal.

Both beam descriptions include fits to the results of the SPY experiment that measured hadron production from a 450 GeV proton beam on beryllium target. An independent analysis of the raw SPY data to produce the particle yield is reported.

A series of criteria are described for the selection and classification of neutrino events. These produce the data samples necessary for both tuning the beam simulation and determining the oscillation signal.

The development of a GEANT and FLUKA based Monte Carlo beam simulator is presented, providing good agreement to the measured neutrino beam. This simulation method has sizeable variations depending on the beamline geometry, which is not known precisely. This causes large systematic errors.

An empirical parametrisation is proposed and used for the first time in a NOMAD oscillation search. It uses the measured neutrino spectra at NOMAD, except the ν_e, to infer the meson production at the target, and then predict the ν_e spectrum. This method has good agreement with the data and is also insensitive to alterations of the beamline geometry, resulting in much smaller systematic errors.

The reduction of the systematic errors allows the $\nu_\mu \rightsquigarrow \nu_e$ oscillations search to be performed with much greater precision. Comparisons of the ν_e/ν_μ ratio between the empirical parametrisation and data yields no evidence for $\nu_\mu \rightsquigarrow \nu_e$ oscillations, setting a limit on the mixing parameter, $sin^2(2\theta) < 1.9 \times 10^{-3}$(90% CL) at high Δm^2. The present sensitivity of the analysis on the mixing parameter is 0.0017.

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There are many people at CERN who I would also like to thank. Dr Emmanuel Tsesmelis took the role of my supervisor during my first excursion to CERN in 1997. I owe a great deal to him for supporting my work in SPY and the neutrino beam studies, whilst also for presenting my work at CERN when I was in Sydney. When my focus shifted to the empirical parametrisation and the oscillation search I received great help from Dr Antonella de Santo, with whom I worked on the event selection and the empirical fitting programmes. Dr Fred Weber was also involved in these projects. Dr Sanjib Mishra provided deeper insights into the oscillation search, its requirements, goals and pitfalls. I am grateful to him for his help. Of course I was greatly helped by Dr Paul Soler who frequented both CERN and Falkiner in my time. Paul took interest in my projects, presented my work, reliably kept me up to date with the happenings at CERN and provided any extra aid I needed.

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To everyone mentioned, and those I forgot, thank you very much!

Author's Contribution

This work includes contributions from other members of the NOMAD collaboration. These contributions are acknowledged below on a chapter by chapter basis. Also note that the introduction is merely the author's summary of readily available neutrino theory and experimental results, given to provide a background for the project.

The description of the NOMAD experiment arises from the author's working knowledge of the systems, as well as published papers and internal papers, duly acknowledged. This is also true for the description of the SPY experimental setup.

The study of the SPY data is the author's work. The analysis of G.M. Collazuol and A. Guglielmi was used as a springboard, and was subsequently ratified during the author's investigation.

The neutrino event classification comprises work conducted by the author and A. DeSanto. The Calisto selection programme was written and maintained by the author, whilst Readall was developed by A. DeSanto until December 1999, and then by the author. The selection criteria are based on the studies of the NOMAD Phase II group, further refined by A. DeSanto, S.R. Mishra and the author.

The testing of NUBEAM involved a great deal of the author's time. Whilst most developments where implemented into the NUBEAM code by D. Daniels, F.J.P. Soler, V. Valuev and T. Weiße, tests and comparisons were carried out by the author, amongst others. A. Ferrari was responsible for the development of FLUKA, and G.M. Collazuol and A. Guglielmi for the SPY weighting, and again testing was undertaken by the author. The comparison of simulations to the muon pit data was conducted by the author alone, within NOMAD. The FCAL analysis was entirely the author's work, along with the comparison of NUBEAM to the drift chamber data. The systematic error study reported is that of V. Valuev.

The concept of the empirical parametrisation in NOMAD is S.R. Mishra's. The description given is of the author's implementation of the concept, to obtain a parametrisation independently to S.R. Mishra. The initial fitting programme was set up by F. Weber. The author made the extensions and adaptations necessary to include the simplex fitting mechanism, $\overline{\nu}_\mu$ and $\overline{\nu}_e$ fitting, the fit to SPY data and the production of the ν_e estimate. The independent prediction of the ν_e flux formed a major part of the work for this thesis.

The last chapter is the author's analysis, with the inclusion of S.R. Mishra's beam prediction and small contributions noted therein.

Preface

This thesis is a report on work carried out for the degree of Doctor of Philosophy in the Falkiner High Energy Physics Department at the University of Sydney. The work was undertaken as part of the NOMAD Collaboration at CERN. This thesis describes the NOMAD experiment and the analysis of its data for indications of muon neutrino to electron neutrino oscillations, featuring the prediction of the neutrino beam by the empirical parametrisation, in a blind analysis. Additional studies, relevant to the oscillation search, are also presented.

The first chapter introduces the theory of neutrinos. A history is given as to their importance in particle physics and cosmology. The concept and relevance of a massive neutrino is introduced, and neutrino oscillations are examined as an avenue for determining neutrino mass.

Chapter 2 describes the NOMAD experiment. The neutrino oscillation search technique is summarised, which indicates the necessary requirements of NOMAD. The neutrino beam is briefly discussed, followed by a rundown on the subdectors that comprise NOMAD. The NOMAD triggering, slow control and data taking are detailed, along with a description of event reconstruction and simulation in NOMAD.

The stand-alone experiment, SPY, is described in chapter 3. This experiment measured meson production relevant to the NOMAD neutrino beam. The layout of the SPY experiment is described, and then an analysis of its data is presented, including particle identification and yield computations. The results of this analysis and an indication of the future uses of the SPY data in neutrino beam simulation and parametrisation are given.

The fourth chapter deals with the classification of neutrino interactions within NOMAD. It presents the selection criteria for accepting and classifying neutrino triggers and also tabulates the efficiency of the selection process, which is later used in data to simulation comparisons. The event samples produced by these criteria are used throughout this thesis. The determination of the number of electron and muon neutrinos in this chapter, along with the beam predictions of the two following chapters, form the two parts of the oscillation search.

Chapter 5 summarises the traditional effort to simulate the neutrino beam with the programmes NUBEAM and FLUKA, and with fits to the SPY data. The chapter explains why the neutrino beam is so critical to the oscillation search and the available means for testing its simulation, including the muon pit data and quasielastic-like events in the FCAL. The three beam focusings used are described, and then the results of their simulation are compared with the NOMAD data.

The empirical parametrisation is proposed in chapter 5 as a new and novel beam flux prediction method. The theory, practice and merits of the method are described. A parametrisation is then fully determined from fits to SPY and NOMAD data. This parametrisation is cross checked with the parametrisation of S.R. Mishra in the next chapter.

The work of chapters 4, 5 and 6 are combined in chapter 7 to determine the oscillation signal. A study of systematic errors and a discussion of why the empirical parametrisation is better suited to the oscillation search than NUBEAM alone are included. The principles of a blind analysis are highlighted, before the oscillation signal is searched for by the comparison of the expected ν_e/ν_μ energy spectrum with that from data. The results are then quoted and discussed, before being reiterated in the conclusion.

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