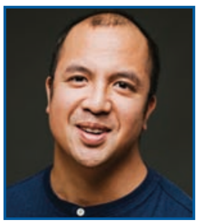
In 2015, the Division of Particle Physics (PPD) created a PhD Thesis Prize competition for best thesis in Subatomic Physics by any student receiving their PhD degree from a Canadian University in the current or prior calendar year. The PPD is pleased to announce that the recipient of the 2016 PPD Thesis Prize is Patrick de Perio. A summary of Dr. de Perio's thesis work appears below.

NEUTRINOS: PROBES TO THE INNER WORKINGS OF OUR EXISTENCE

BY PATRICK DE PERIO



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SUMMARY

We attempt to build an understanding of nature by precisely measuring neutrino oscillations with the T2K long-baseline neutrino experiment.

The understanding of how we came to exist is one of the greatest endeavors of humanity. This involves developing theories that can describe our current state and the entire chain of events from the Big Bang. One question towards this goal is the matter anti-matter asymmetry in the universe. It is very plausible that they were created in equal parts at the Big Bang, and thus should have completely annihilated. However, our existence posits there is some asymmetry in nature that affected the evolution of the early universe.

One candidate theory is leptogenesis, which presumes the existence of heavy neutrinos that violate charge-parity (CP) symmetry, and thus decay to leptons or anti-leptons with different rates. However, such theories must be verified by experimental and observational data. Despite the fact those heavy neutrinos in the early universe are not the light neutrinos we are familiar with today, we must take small steps to understand what is immediately in front of us before we can hope to make the connection to these grand theories.

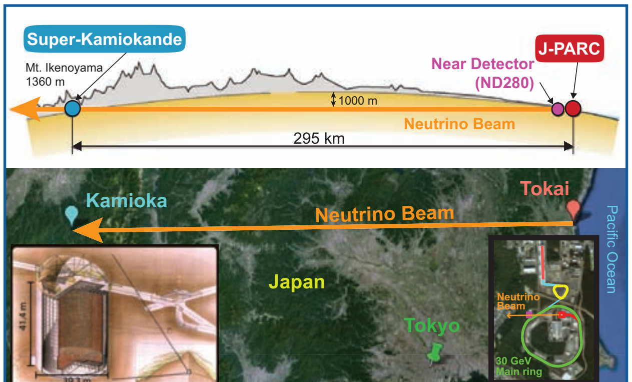

Fig. 1 Overview of the T2K experiment. A neutrino beam is produced at J-PARC (right inset), first measured at a near detector 280 m downstream, then propagates across Japan towards the Super-Kamiokande far detector (left inset) 295 km away.

THE T2K EXPERIMENT

The T2K (Tokai to Kamioka) long baseline neutrino experiment [1] aims to measure the CP phase parameter in the Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix describing neutrino oscillation, a quantum mechanical phenomenon where the three flavours of light neutrinos, electron (ν_e), muon (ν_μ), and tau (ν_τ), appear to trade flavours as they propagate. A high intensity ν_μ beam is produced from the Japan Proton Accelerator Research Complex (J-PARC), shown in Fig. 1. The beam is directed, first through the Canadian-led near detector for characterizing it, towards the far detector, Super-Kamiokande (SK), the world's largest pure water Cherenkov detector. The neutrinos interact in these detectors producing observable signals as shown in Fig. 2, which we use to infer the flavours of the incident neutrinos and any oscillation.

In order to accurately and precisely measure the parameters in the PMNS matrix, we must understand every aspect of the experiment. My thesis details my contributions to the understanding of the neutrino beam, neutrino interactions, and the SK detector event reconstruction and efficiency. Furthermore, a framework was developed to propagate all of this knowledge, including uncertainties, to a measurement of oscillation parameters.

MEASURING PROTONS FOR NEUTRINOS

Constraining the neutrino beam direction is necessary to minimize the uncertainty in the oscillation parameters. To this end, an optical transition radiation (OTR) monitor [2], which characterizes the proton beam just prior to collision

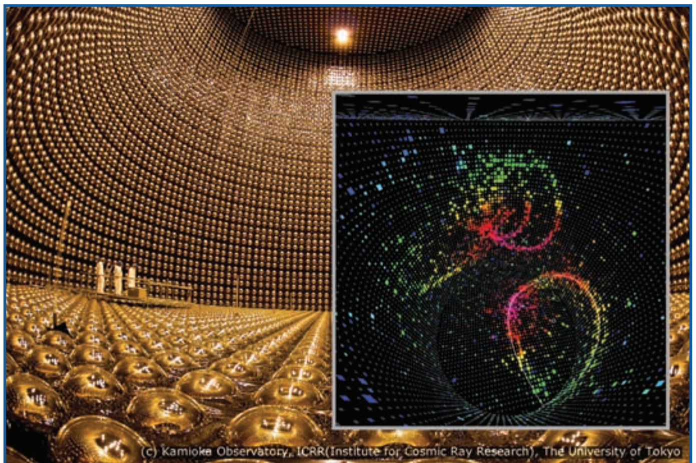

Fig. 2 Inside the Super-Kamiokande detector. During science data taking, the lights are turned off and the tank is filled with 50 kilotonne of ultra-pure water. The >11,000 orb-like objects are photo-multiplier tubes (PMTs) that act as our eyes peering into the center, taking snapshots of Cherenkov light (inset) produced by particles from neutrino interactions (Fig. 3).

with the target for producing the neutrinos, was implemented. The OTR measurements, combined with other beamline monitors, provide the strongest constraint on the prediction of the neutrino beam direction. This is a novel detector with many potential applications for particle beam monitoring in high radiation environments even outside of neutrino physics.

HOW NEUTRINOS INTERACT

As the neutrinos pass through our detectors they interact with nuclei, producing the lepton and hadron particles that we can measure. Modelling of these interactions is an important and potentially precision-limiting factor in neutrino oscillation experiments. The hadrons are subject to complicated nuclear effects as they traverse the nuclear medium until they escape, as depicted in Fig. 3, after which they can undergo secondary interactions (Sis). Both processes can significantly alter the observable final state and obscure the physics of the initial neutrino interaction, again affecting the oscillation parameter estimation. A single hadron propagation model was implemented in both the neutrino interaction and detector Monte Carlo (MC) simulations, allowing a unified treatment of hadron interactions within the neutrino target nucleus and SIs. Furthermore, a new MC statistical reweighting framework was developed to fit the model to the world's pion-nucleus scattering data, pion photo-production data, and past neutrino experiments, in order to tune and constrain the model parameters, which are propagated to the oscillation analysis.

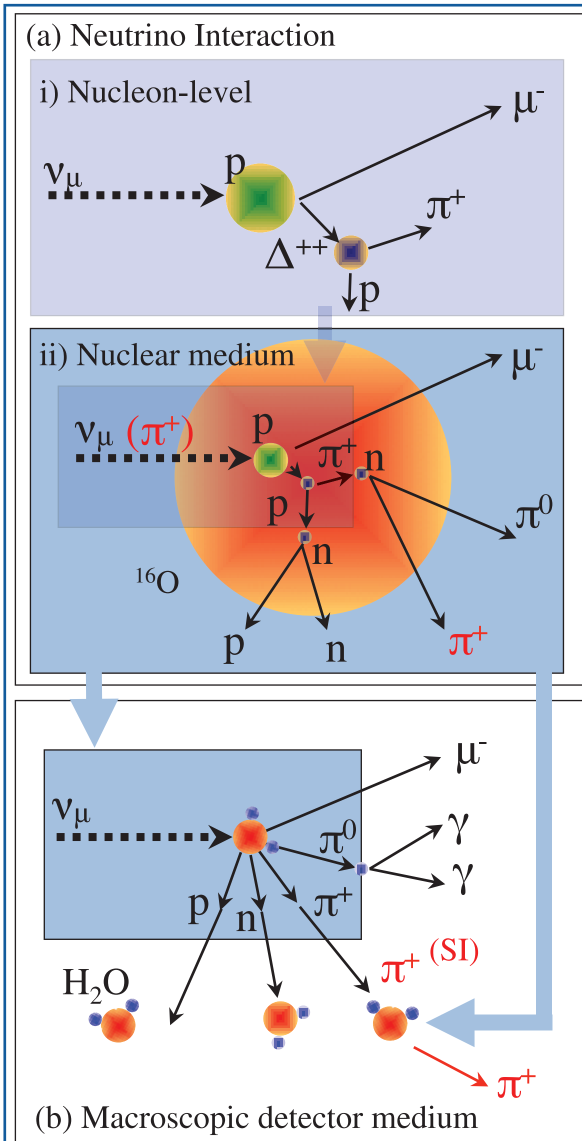

Fig. 3 Cartoon of a neutrino interacting with a proton (a.i) producing a lepton and hadrons that re-interact within the parent nuclear medium (a.ii) prior to escape. The child particles that finally escape the nucleus (b) are what we aim to observe with the detector as in Fig. 2. Furthermore, as particles traverse the detector medium, they may experience secondary interactions (SI) with other nuclei, altering their kinematics or even disappearing completely, which affects the observed light patterns.

NEUTRINO OSCILLATION ANALYSIS

The SK detector can distinguish ν_μ and ν_e flavours, and we combine both samples to maximize the information for the oscillation parameter measurements. A new Markov Chain MC statistical analysis of the SK atmospheric neutrino data was developed to estimate the detector efficiency systematic errors, correlated between the two samples. The T2K oscillation analysis combines multiple neutrino oscillation channels while fully treating the correlations in every systematic error source, including the neutrino beam, neutrino and hadron interactions, and detector efficiencies. This spirit of explicitly and precisely propagating all our knowledge resulted in one of the first hints of non-zero CP violation [3] in the lepton sector of particle physics, bringing us one small step closer to a grander understanding of the universe.

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