OPPORTUNITIES FOR A MASTER'S THESIS IN NEUTRINO PHYSICS!

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Thesis subjects

Coherent scattering of supernova neutrinos

Supervision : Natalie Jachowicz, Nils Van Dessel

In **coherent processes**, low-energy neutrinos are scattered off **the nucleus as a whole**, without resolving the individual nucleons. The lack of detectable reaction products hampers experimental studies of the process as these have to rely on measurements of the (small) recoil energies of the target nuclei. On the other hand, the coherent reaction mechanism has the advantage that **the cross section is relatively large**, and dominates the 'standard' inelastic neutrino-nucleus scattering processes for incoming energies up to a few tens of MeVs. This makes the coherent process **important for astrophysical neutrinos** where the large cross sections make it an important instrument for the transfer of energy from the neutrino to the surrounding material.

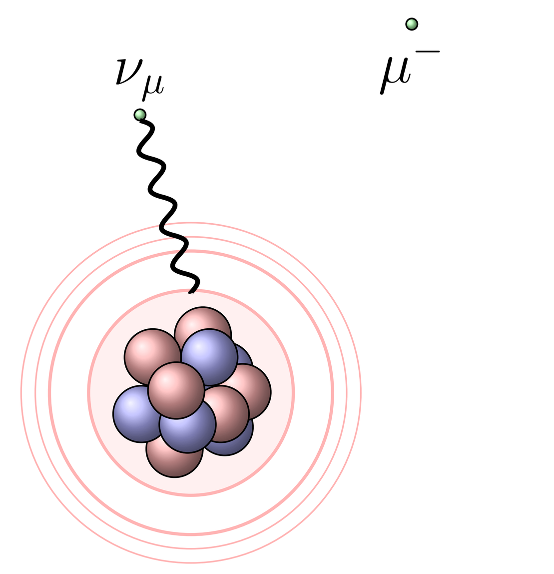

Figure 1: *Coherent scattering: low-energy neutrinos are scattered off the nucleus as a whole.*

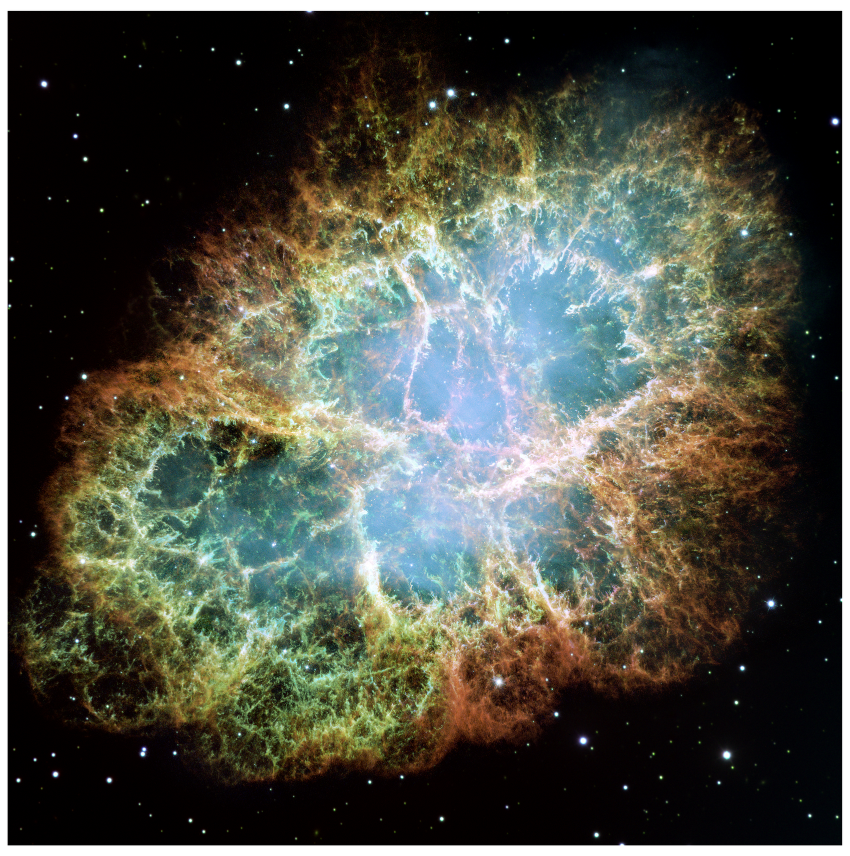

Figure 2: *The Crab Nebula. Supernovas are an important astrophysical source of neutrinos.*

This is in particular the case for **supernova neutrinos**, both for their interactions within the collapsing and exploding star core as for their detection on earth. The difficulties met by experiments measuring these coherent cross sections, make theoretical simulations all the more important. The theoretical description of the target nucleus is **non–trivial**. Each nucleus is constructed of protons and neutrons which are constantly interacting with each other through **nuclear forces**. This thesis project has following **goals**:

- Model the cross section for coherent neutrino-nucleus scattering.
- Examine its importance for astrophysical neutrinos.
- Investigate the influence of nuclear parameters (e.g. the strange-quark content of nucleons).

Energy reconstruction in neutrino-nucleus scattering and neutrino-oscillation studies

Supervision : Natalie Jachowicz, Nils Van Dessel

A central issue in current neutrino experiments is the **lack of a monochromatic neutrino beam**. This stands in stark contrast with experiments that use charged leptons as projectiles, where the incoming energy is well-known. However, since neutrinos are produced out of decaying pions, their energy is not known a priori.

This thesis topic focuses on a **central issue** in the synergy between theory and experiment in the understanding of neutrino-nucleus scattering : **the reconstruction of the incoming energy of the neutrino in an interaction.**

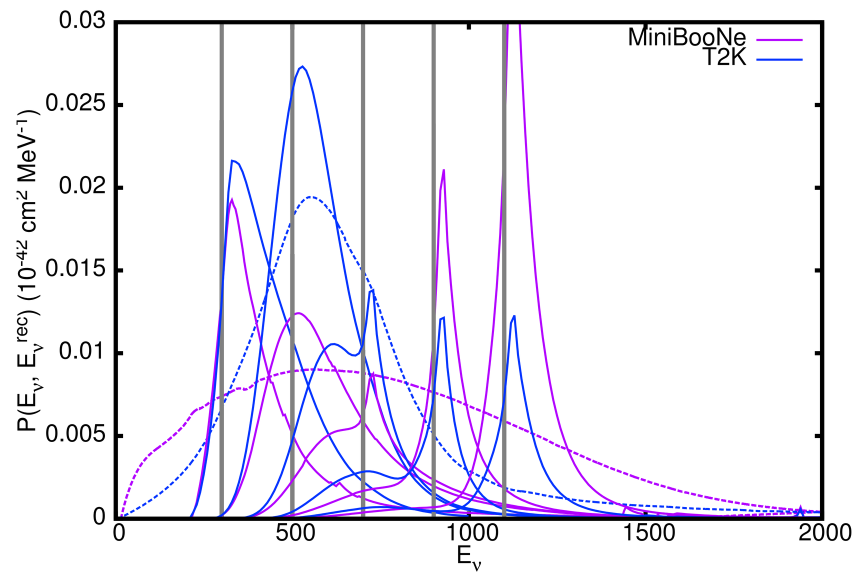

Figure 3: *Energy reconstruction for set incoming energies.*

This distribution of reconstructed energies is a **model-dependent quantity**. It is the goal of this thesis work to **examine the role of correlations between the nucleons in the nucleus on the reconstructed energy**. Work on this thesis involves a mix of **weak interaction physics**, **nuclear scattering theory** and **numerical work**.

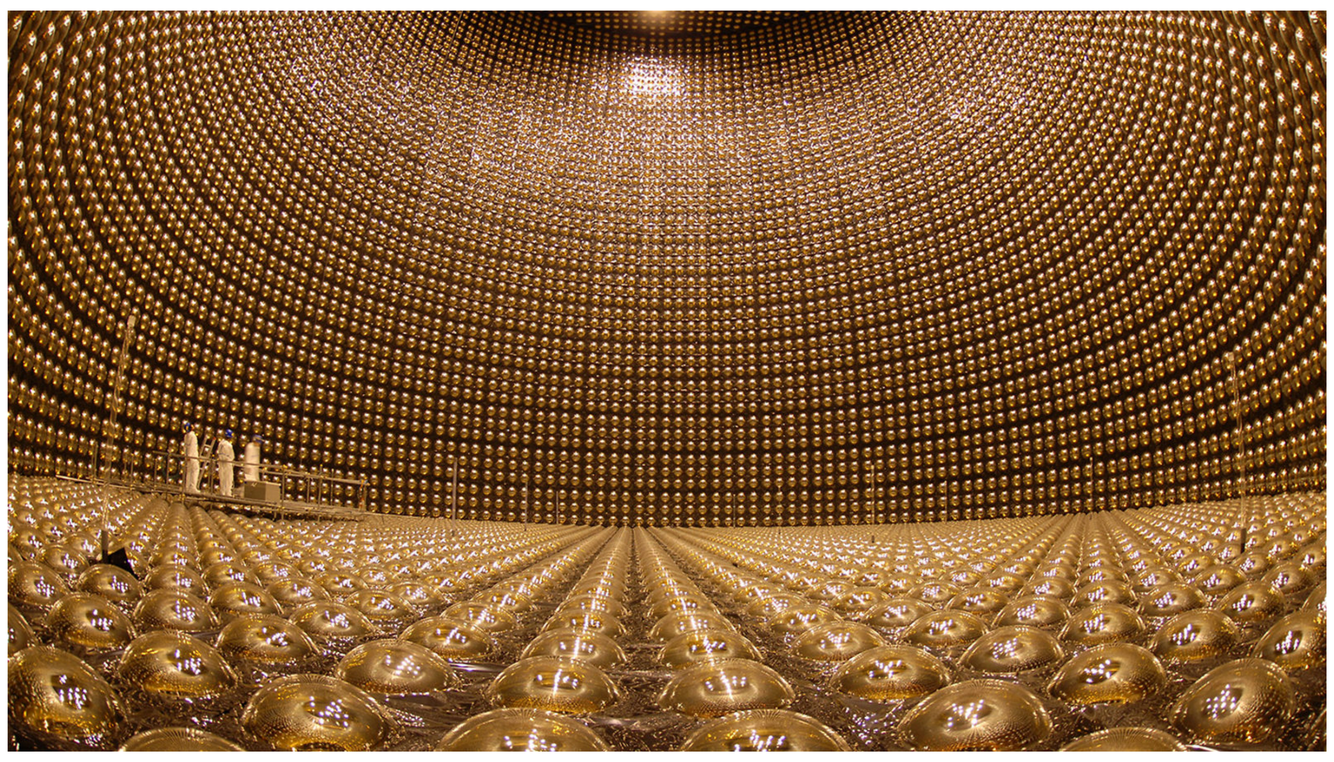

Figure 4: *The Super–Kamiokande detector used in the T2K experiment.*

Parity–violating asymmetry for electron-nucleon scattering in the pion-production region

Supervision : Raul González-Jiménez, Natalie Jachowicz

To make any progress in the determination of neutrino-oscillation parameters, it is essential to have a good **knowledge of the weak properties of the nucleon**. Unfortunately, the **weak interaction** is approximately 5 orders of magnitude weaker than electromagnetic interactions, which makes it truly **challenging to demonstrate its effects**. For this, one needs observables whose presence is unequivocally due to the weak interaction. In this project the student will study one of these observables: the "**parity–violating asymmetry**" for electron-nucleon scattering in the pion-production region. When taking into account the weak neutral current interaction the scattering probability of negative/postive helicity electrons is not the same, demonstrating **parity violation**.

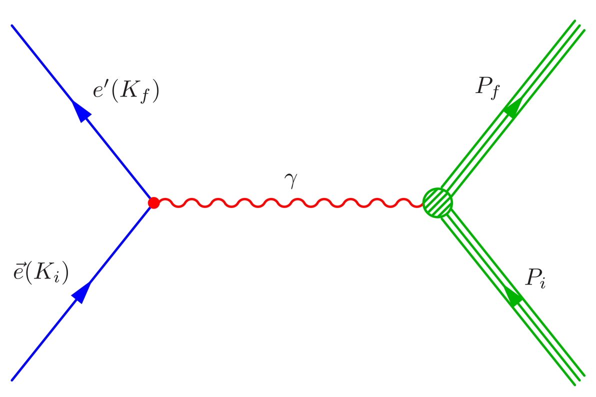

Figure 5: *The electromagnetic interaction conserves parity, making reactions independent of the helicity of the incoming electron.*

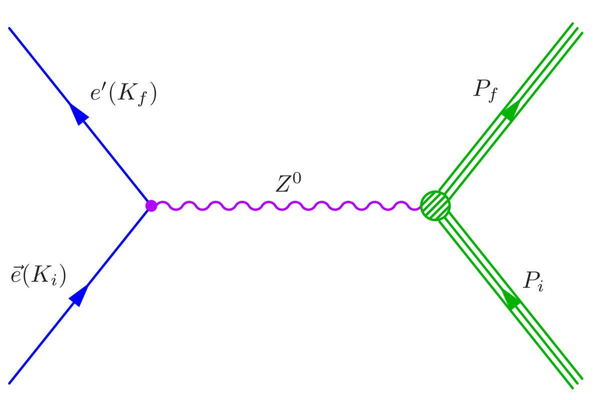

Figure 6: *Interference from the weak interaction violates this symmetry.*

This asymmetry can be used to reveal **information about the axial structure** of the matter. In particular, this project focuses on the kinematic region around the pion production threshold. This will allow one to study the **axial form factors of the Delta resonance** which are essential input for any theoretical model which aims at predicting neutrino nucleon (neutrino-nucleus) cross sections at intermediate energies. This thesis will involve the following goals:

- A **literature study** of the electron-induced pion production **formalism** and **current experimental and theoretical work** on the subject.
- A **numerical implementation** of this framework to compare theory with experiment.

Monte Carlo study of neutrino scattering off atomic nuclei at intermediate energies

Supervision : Nils Van Dessel, Natalie Jachowicz, Raul González-Jiménez

A thorough understanding of the **interaction between neutrinos and nuclei** is essential in the interpretation of **oscillation experiments**. In our research group **theoretical models** are developed to explain experimental results, but in the scientific process, besides experiment and theory, there's a third aspect: **computational simulations**. These simulations form a bridge between theoretical models and experimental results. **GENIE** (Generates Events for Neutrino Interaction Experiments) and **NuWro** are two state-of-the-art **neutrino event generators** that are freely available. These are used by several experimental collaborations such as MiniBooNE, Minerνa and T2K to assess the feasability of the proposed experiments, to design the detectors and to determine the efficiency of these detectors.

Figure 7: *GENIE is one of two freely available generators for neutrino events.*

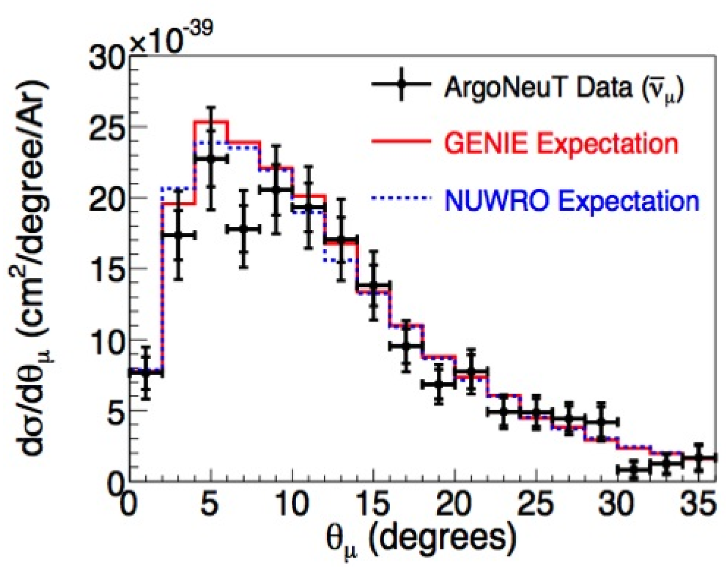

Figure 8: *A comparison of the angular distribution of the outgoing muon in the charged-current interaction, between ARGONEUT Data and generator (GENIE and NuWro) results.*

The **goal** of this thesis subject is to start **a comparative study** between these Monte Carlo simulations and the models developed in our own group. Afterwards attention will be given to experiments such as ArgoNeuT and MicroBooNE. Contrary to experiments from the previous generation these ones also measure, besides the muon, the knocked-out nucleons. Are the Monte Carlo simulations also suitable to predict these **semi-exclusive measurements**? Experimental results aren't yet available, but **our own models are suitable for a comparison**.

This thesis subject offers **the opportunity to spend a research stay** in the neutrino research group of **Wroclaw University**, originators of the NuWro generator.

References

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[4] T. Van Cuyck, N. Jachowicz, R. González-Jiménez, *et al.*, (2016, in preparation)