A preliminary investigation into determining CC0π cross-section sensitivities in SBND and performing a GENIE global fit to neutrino scattering data

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1[st] year PhD report

Abstract

Random stuff

1. Introduction

Neutrino physics is at the core of current high energy research. One of the profound discoveries made in recent years was the observation of neutrino flavour oscillations by the Super-Kamiokande (Super-K) experiment, which was the first confiramtion that physics existed beyond the standard model of particle physics. In brief, neutrinos described by the standard model would be massless particles, but since the flavours are made up of superpositions of mass states, the oscillation of the flavour states implies that the relative mass states are different, and therefore non-zero [1].

Future, long-baseline, neutrino experiments such as the Deep Underground Neutrino Experiment (DUNE) and Hyper-Kamiokande (Hyper-K) are hoping to investigate some of the most fundamental questions we are still asking: Why does the universe constist of matter, and not anti-matter? What is the neutrino mass heirarchy? Neutrino research is an extremely active field. Optimising the current and future detectors to maximise the accuracy of all interaction anaylses is a crucial step towards obtaining concrete answers to these questions.

A brief introduction to the topics covered in this report is as follows, more detail on each will be given in later sections.

1.1. Neutrino interactions

Due to the elusive nature of the neutrino, directly observing one in a detector isn't possible. It is therefore necessary to infer their existence from particles produced when they interact. Since this process relies upon the reconstruction capability of the experiment, purpose-built detectors will attempt to maximise the efficiency of this.

Another property of the neutrino which poses a significant difficulty within detectors is their interaction probability, or cross-section. A typical neutrino cross-section is on the order of 10^{-44} cm^2 which corresponds to $\sim$1 interaction every 10 light years in steel, for neutrinos with only a few MeV energy [2]. This fact introduces the need for the interacting neutrinos to have high energies in these dedicated experiments, if we are to sufficiently reduce their mean free path. More detail on this topic will be discussed in section 3.

1.2. Cross-sections

In order to correctly model neutrino events within a specific detector geometry and material, certain parameters have to be known. In particular, the probability of an interaction taking place - its cross-section - is required for each possible interaction the neutrino could undergo. Cross-section measurements are therefore a necessity for the generators, and consequently the future detector studies mentioned earlier.

The extent of our current knowledge of charged current neutrino cross sections is shown in Figure 1. The plot contains cross-section information from multiple types of neutrino experiment, differing in both target material and detector machinery. A feature of this plot which is of the most interest to a Short Baseline Near Detector (SBND) cross-section study in particular is the lack of precision in the measurements made towards the lower energy region [3]. SBND will not only be operational at this energy range, but it will also have substantial enough statistics to potentially make a significant contribution to improving the current knowledge in this region.

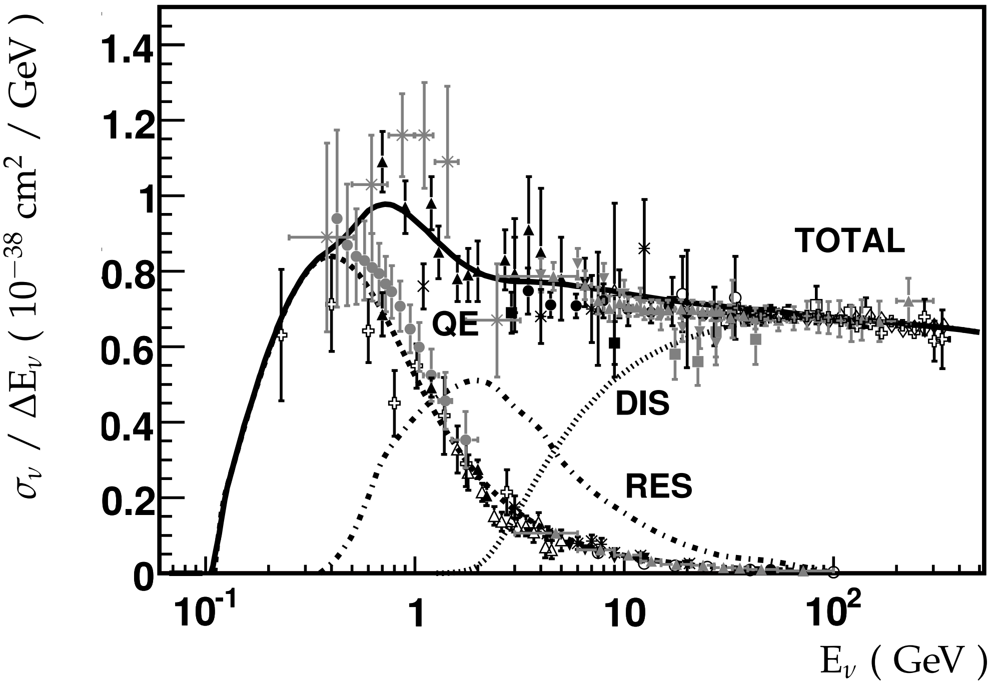

Figure 1: *A compilation of the total cross-section data across the ~1 MeV to ~100 GeV energy range. Including a breakdown in terms of the quasi-elastic, QE, resonant, RES and deep inelastic scattering, DIS, topologies [3].*

The scale of contribution SBND could make to this area of physics would in turn improve the predictions made by event generators for the next generation of neutrino experiments. Cross-sections will be discussed further in section 4.

1.3. GENIE and the GENIE-Professor global fits

GENIE is the world leading Monte Carlo neutrino interaction generator. Generators are a crucial machinery in all high energy physics analyses as they use theoretical models to produce predictions of how and where neutrino interactions will occur in specific detector geometries [4]. With this information, comparisons between experimental data and theoretical predictions can be drawn, the models can be updated and potential new physics can be explored.

Generators such as GENIE bridge the gap between theory and experiment, whilst also providing opportunities to prepare simulations and perform sensitivity studies for the next generation of neutrino experiments.

Alongside building state-of-the art detectors and making high precision cross-section measurements to improve current and future neutrino physics analyses, the predictions made by the generators can be improved by taking existing neutrino data and performing a fit of the models to them.

An effort to do this is currently being carried out by GENIE, using the Professor software framework, which was written with this purpose for experiments at the LHC [5]. The ultimate goal of this exercise is to perfom a global fit to all neutrino scattering data and consequently produce comprehensive model configurations to further optimise the predictions made for the next generation of neutrino experiments. This work will and GENIE's role in current and future neutrino experiments will be discussed further in section 5.

2. Liquid Argon Time Projection Chambers and SBND

2.1. *Booster neutrino beam, BNB*

A Booster Neutrino Beam fires neutrinos directly into the time projection chamber of an experiment at such speeds that the particles can always be assumed to be forward-going. This technicality allows for a reasonably straightforward removal of backgrounds such as cosmogenic neutrinos, which would enter the time projection chamber (TPC) from all angles [6].

The beam is formed by firing protons at a beryllium target which produces a hadronic beam consisting mainly of pions. The pions in this beam are then focussed and polarised in order for them to go on to decay to mostly the dominant channel μ^+ and ν_μ [6], since the branching ratio of pions decaying to electrons over muons is on the order of $\sim 10^4$ times smaller due to the relation given in equation (1) [7].

$$R_\pi = \left(\frac{m_e}{m_\mu}\right)^2 \left(\frac{m_\pi^2 - m_e^2}{m_\pi^2 - m_\mu^2}\right)^2 \sim 10^{-4} \tag{1}$$

2.2. *Liquid argon time projection chambers, LArTPC*

In current and future neutrino experiments such as DUNE and the short baseline neutrino (SBN) program (SBND, MicroBooNE and ICARUS), liquid argon is the target material of the detector. Argon in this form is used due to its stability and purity as a noble gas, its high denisty and its low cost. These properties lead to resolution capabilities on the order of the Bubble Chamber experiments, which allows for high certainty in distinguishing between interactions and ultimately optimises the resolving power of the experiment [8].

- LArTPC general functionality
- LArTPC resolution benefits Bubb-chamb
- Comparison with other detector materials

An example event display on liquid argon is shown in Figure 3 [9]

2.3. *SBND*

- SBND specifics
  - Dimensions
  - Beamline
  - Flux
  - Statistics

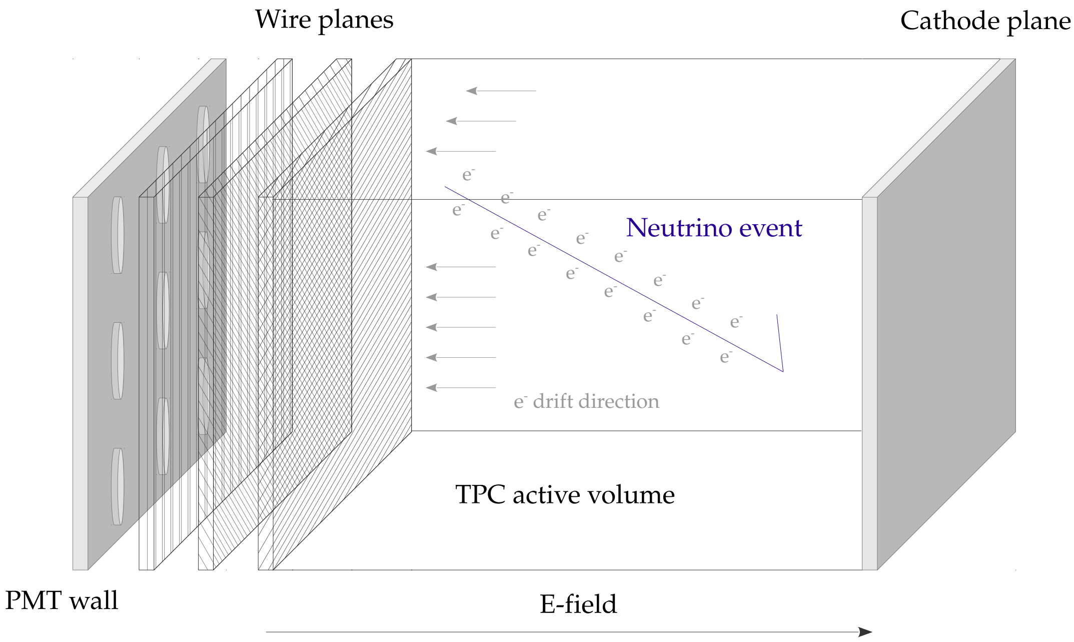

Figure 2: *LArTPC*

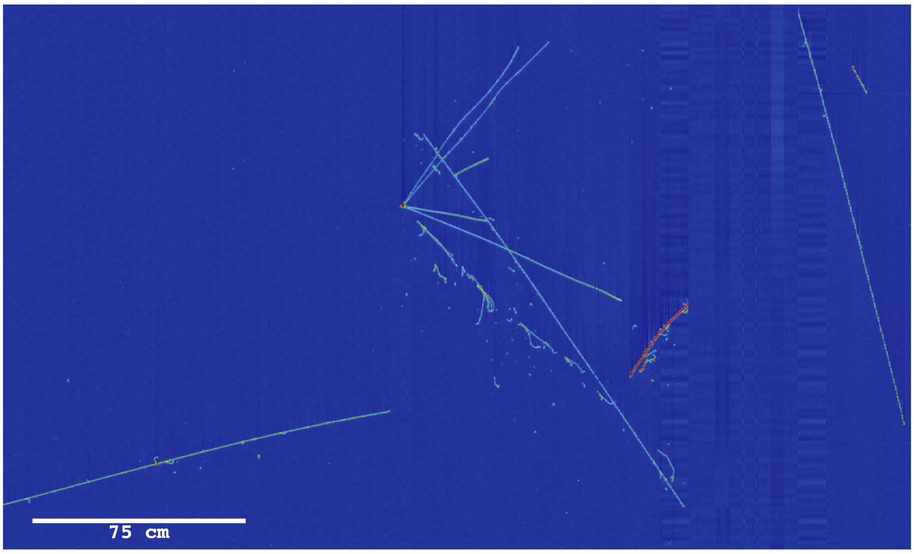

Figure 3: *MicroBooNE*

  - Physics goals

- Cross-section precision capabilites

Process		**No. Events**
	ν_μ Events	
CC 0 π	$\nu_\mu N \rightarrow \mu + Np$	**3,551,830**
CC 1 $\pi^\pm$	$\nu_\mu N \rightarrow \mu + nucleons + 1\pi^\pm$	**1,161,610**
CC $\geq 2\pi^\pm$	$\nu_\mu N \rightarrow \mu + nucleons + \geq 2\pi^\pm$	97,929
CC $\geq 1\pi^0$	$\nu_\mu N \rightarrow \mu + nucleons + \geq 1\pi^0$	497,963
NC 0 π	$\nu_\mu N \rightarrow nucleons$	1,371,070
NC 1 $\pi^\pm$	$\nu_\mu N \rightarrow nucleons + 1\pi^\pm$	260,924
NC $\geq 2\pi^\pm$	$\nu_\mu N \rightarrow nucleons + \geq 2\pi^\pm$	31,940
NC $\geq 1\pi^0$	$\nu_\mu N \rightarrow nucleons + \geq 1\pi^0$	358,443
Total ν_μ & ν_e events		**7,251,948**

3. Neutrino Interaction Phenomenology in the few-GeV Energy Range

3.1. Dominant topologies

3.2. Golden channel

3.3. Signal

3.4. Potential backgrounds

*3.5. **Maybe some results here?***

4. Theory and Recent Measurements of CC0π Cross-Section

4.1. *Cross-sections*

- Why?
  - Simulation
  - GENIE
- Historical
- Current knowledge
- Needs for future
  - LArTPCs
  - Statistics

Inc. equations

4.2. *Method*

4.3. *Unfolding*

4.4. *Results*

Plots and cross-section values

5. A Global Fit of CC0π Data

5.1. Experiments involved

5.2. Process

5.3. Results

6. Prospects for a CC0π Measurement at SBND and Sensitivity Esimates

6.1. SBND sensitivity

6.2. Future

7. Discussion

References

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