PROCEEDINGS OF SCIENCE

Experimental studies of low energy charged current neutrino interactions

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Over the last year, new results on few-GeV charged current neutrino interactions have been presented. The MiniBooNE experiment, running since 2002, has published results on charged current quasi-elastic neutrino interactions on Carbon. Also, experiments which have already completed data-taking such as K2K, with a running period 1999-2004, have recently published results on charged current interactions producing single π^+. Otherwise, the SciBooNE experiment, an extraordinary short term experiment (2007-2008), has presented preliminary results on charged current coherent pion production on Carbon, as well as their progress on charged current quasi-elastic and resonance production. An overview with all these new results, including comparisons with previous ones, is presented here.

10th International Workshop on Neutrino Factories, Super beams and Beta beams
June 30 - July 5 2008
Valencia, Spain

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PoS(NuFact08)062

1. Introduction

In the last year, new results on few-GeV charged current neutrino interactions have been presented. These results are reported mainly from neutrino oscillation experiments like K2K and MiniBooNE, but also from a new dedicated neutrino scattering experiment, SciBooNE. These results are characterized by high statistics data samples, allowing for a better understanding of low energy neutrino interactions, essential for neutrino oscillation experiments.

2. Charged current quasi-elastic interactions

The differential cross section $d\sigma/dQ^2$ for free nucleon charged current quasi-elastic (CCQE) interactions ($\nu_l + N \to l + N'$) is described by the Llewellyn Smith formalism[1][1]. In such a context, the $d\sigma/dQ^2$ can be expressed in terms of vector and axial form factors. The vector form factors are obtained from electron scattering experiments and the axial form factor is usually assumed to have a dipole form approximation, $F_A(0)/(1+Q^2/M_A^2)^2$, where F(0) is extracted from beta decay experiments. The axial mass M_A is therefore the only free parameter in the $d\sigma/dQ^2$ equation. Two procedures determine the M_A value in neutrino scattering experiments, either fitting the shape of the Q^2 distribution or calculating the total cross section[2]. Since the latter one requires the knowledge of the absolute neutrino flux, which represents an important source of systematic uncertainties, the first procedure is usually adopted.

The K2K collaboration has published two independent values of M_A[3][4], corresponding to the data extracted from neutrino-oxygen and neutrino-carbon interactions produced respectively on SciFi and SciBar detectors. Both analyses fit the shape of the Q^2 distribution excluding the region of $Q^2 < 0.2\ GeV^2$, where the uncertainties due to the nuclear model effects are larger (with a data deficit observed). The M_A values obtained on both cases are compatible to each other but higher than the world average (see table 1).

Experiment	**flux averaged energy (GeV)**	**Main nuclear target**	Q^2**fitted region (**GeV^2**)**	M_A **value (**GeV**)**
K2K-SciFi	1.2	oxygen	>0.2	1.20 ± 0.12
K2K-SciBar	1.2	carbon	>0.2	1.14 ± 0.13
MiniBooNE	0.8	carbon	>0.25	1.25 ± 0.12
MiniBooNE(*)	0.8	carbon	>0.	1.23 ± 0.20
				$(\kappa = 1.019 \pm 0.011)$
World-Average	>1.0	deuterium,argon	-	1.026 ± 0.021

Table 1: M_A values obtained on few-GeV neutrino energy experiments compared with the world average[5].(*) MiniBooNE M_A fitted value with an additional free parameter (see text).

[1]In CCQE scattering with Carbon and other heavy targets, the prediction model is modified to include the nuclear effects, using the Smith-Moniz Fermi gas model[2].

[2]It is convenient to remark that both procedures could obtain different values of M_A because different assumptions are taken in the two cases.

The MiniBooNE collaboration has published recently (2008) their results on CCQE neutrino scattering on carbon[6]. Two M_A values are reported in that paper, one extracted by fitting Q^2 above 0.25 GeV^2 and the other using the entire Q^2 range (see table 1). For the latter case, another free parameter (κ) is added to the fit. This κ parameterizes the Pauli blocking suppression in the relativistic Fermi gas model (RFG), used in MiniBooNE Monte Carlo simulation. This tuning on the RFG allows a better description of the data at low Q^2, where a data deficit was observed.

The SciBooNE collaboration expects to publish their first CCQE physics results in 2009. On that channel, two independent analyses are being developed, covering in that way a wide range of neutrino energies. In one analysis, the CCQE candidate is selected from events completely contained in the SciBar detector[3], using Michel electron information for tagging the muon tracks. Meanwhile, the other analysis requires that the muon-like track, produced by a neutrino interaction in the SciBar detector, reaches the MRD detector and stops inside it. The dE/dx information is used in both analyses in order to distinguish protons from pions. Preliminary results on the latter analysis shows the shape of the reconstructed Q^2 distribution, essential for final M_A fits (see fig. 1).

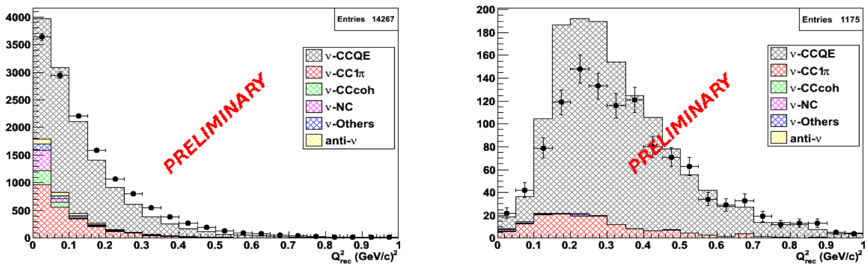

Figure 1: Preliminary results on reconstructed Q^2 distributions for SciBooNE CCQE analysis. The left and right plots correspond to 1 and 2 track sample selection. In each plot a comparison between data (points), with only statistical errors, and Monte Carlo (filled histogram) is shown, with the Monte Carlo prediction based on NEUT with M_A set to 1.1 GeV.

3. Charged current resonance production

The neutrinos can interact with the nucleons producing resonance states which subsequently decay, $\nu + N \rightarrow \mu + N^* \rightarrow \mu + N' + \pi$. The Rein and Sehgal model[8] is generally used to simulate the pion production via baryon resonances. The K2K-SciBar has recently (2008) presented the result of the cross section for single π^+ production in the resonance region (W< 2 GeV) relative to the CCQE cross section at few-GeV neutrino energies [9]. The ratio $\sigma_{cc1\pi}/\sigma_{ccqe}$=$0.734^{+0.140}_{-0.153}$ is consistent with previous experiments and compatible with the model prediction (Rein and Seghal model with M_A^π set to 1.1 GeV). For detailed anlysis description see L. Whitehead on these proceedings[10].

Inclusive charged current analysis producing π^0 in final states was also reported by K2K-SciBar[11]. The CCπ^0 candidate selection requires 3 tracks, one μ and two γ-like tracks which

[3]The SciBooNE experiment is composed of three detectors: the SciBar detector (acting as target), an electromagnetic calorimeter (EC) and a muon range detector (MRD)[7].

point to the interaction vertex. The ratio $\sigma_{cc\pi^0}/\sigma_{ccqe}$ obtained is 0.306±0.023(stat)±0.025(syst)[11], higher than the model prediction. SciBooNE analyses in those channels (CCπ^0,CCπ^+) are being developed, with first preliminary results expected for 2009.

4. Charged current coherent pion production

The neutrinos can also produce pions interacting with the whole nucleus, instead of with the nucleon ($\nu + A \rightarrow \mu + A + \pi$, being A the nucleus). On that channel, K2K-SciBar published in 2005 the first results at few-GeV neutrino energies[12]. The CC pion coherent candidate was selected by requiring two tracks, one μ and one π-like tracks, low vertex activity and low momentum transfer (Q^2 < 0.1 GeV^2). The final data selection was compared with the Rein and Sehgal model for CC coherent pion production[8], assuming an $M_A = 1.1$ GeV for QE and CC1π interactions. In such a context, no evidence of coherent pion production was observed, reporting therefore an upper limit of 0.60 x 10^{-2} for the ratio σ(CCcoh)/σ(CC-inclusive) at 90% confidence level.

The SciBooNE collaboration is currently working in a paper to publish the results on CC coherent pion production. The preliminary results show fewer CC coherent events than the Monte Carlo prediction, which is made using the updated Rein and Sehgal model[14] for CC coherent and resonant production and setting M_A to 1.2 GeV for QE and 1π (see fig. 2).

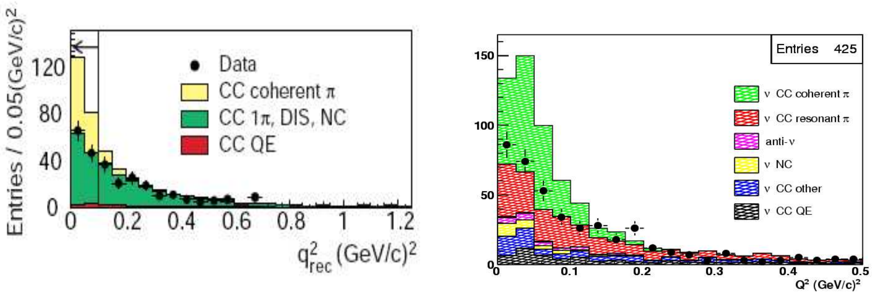

Figure 2: Distributions of the reconstructed Q^2 for the final CC coherent sample for K2K-SciBar (left) and SciBooNE (right) experiments.

5. Systematic errors

The accuracy of moderm high-statistics measurements of neutrino interactions is typically limited by systematic uncertainties. In particular:

1. The models of nuclear effects on neutrino-nucleus interactions produce the main source of systematic uncertainties. These effects can be broken up into three categories[1][13]: (1) the Fermi motion of nucleons, affecting the kinematics, (2) the Pauli suppression phase space, modifying the Q^2 shape, essential for M_A^{ccqe} fits and (3) the final state interactions inside nucleus, changing the composition of the hadronic part of the final states.

2. The absolute neutrino flux has large uncertainties due to difficulties in the absolute estimation of the primary proton beam intensity, the proton targeting efficiency and the hadron production cross sections.

3. The detector response models (e.g. crosstalk simulation for SciBar detector, or light production and propagation on mineral oil for MiniBooNE detector) are affected by systematic uncertainties too.

6. Conclusions

The latest results on charged current neutrino interactions in the few-GeV neutrino energy range have been presented. These results make use of high statistics data samples, and their accuracy is therefore limited by systematic uncertaintes. Such uncertainties are, in many analyses[9][12], dominated by the nuclear effects which are not so well reproduced in the nuclear models commonly used. That is the case of the relativistic Fermi gas model (RFG), unable to explain the data deficit observed in the low Q^2 region in the CCQE channel, unless that modifications to this were included. Nuclear model defficiencies are observed studing other neutrino interaction channels too. This is the case of the no-evidence of CC coherent pion production observed in the K2K analysis[9].

Therefore, efforts to achieve a better understanding of nuclear effects must be pursued, using new high statistics data sample. Fortunately, several experiments will report results in the upcoming years. That is the case for SciBooNE, with new results expected in 2009, as well as for MINERvA and T2K, which are scheduled to start data-taking the same year.

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