Wrocław neutrino event generator

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Abstract

A neutrino event generator developed by the Wrocław Neutrino Group is described. The physical models included in the generator are discussed and illustrated with the results of simulations. The considered processes are quasi-elastic scattering and pion production modelled by combining the \( \Delta \) resonance excitation and deep inelastic scattering.

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(Some figures in this article are in colour only in the electronic version.)

1. Introduction

Many of the neutrino experiments now operating or in preparation are those with artificial neutrino beams. The beam energy ranges from 0.5 to about 30 GeV (MINOS, CNGS, T2K). The uniform theoretical description of neutrino interaction within this region is problematic, because three different dynamics: quasielastic (QE), resonance excitation (RES), and deep inelastic scattering (DIS) must be taken into account. Especially in the region of about 1 GeV, they contribute with comparable strength and the problem of the overlap between the DIS formalism and the resonances production model appears.

Up to now most of the Monte Carlo codes use the Rein–Sehgal model of the resonances production. However, another approach has been proposed [1] which makes use of the postulated quark–hadron duality in neutrino reactions. One can assume that the contributions from higher resonances are averaged by the deep inelastic scattering structure functions and only the dominant \( \Delta \) resonance has to be treated separately. In this approach the exclusive inelastic final states must be obtained from the DIS formalism even in the resonance region \( W \in (M+m_\pi, 2 \text{ GeV}) \), where the most important contribution comes from pion production channels.

2. Generator description

Dynamical models included in the generator are described below. For the quasielastic scattering the usual Llewellyn Smith [2] model is used with BBBA05 form factors [3]. For elastic scattering new strange form factors are taken into account [4]. For antineutrino CC interaction there are three additional channels with hyperons \( \Lambda, \Sigma^+, \Sigma^0 \) production (\( |\Delta Y| = 1 \)). The \( \Delta \) resonance is described by the form factors as in [5], and for DIS we use parton distribution functions GRV94 [6] with modification proposed by [7]. In order to get the final state from the inclusive DIS cross-section, we use a model of fragmentation based on the LUND model, implemented in the PYTHIA6 generator. It is assumed that the interaction occurs on a separate constituent of the nucleon. The fragmentation procedure was described in [8]. In order to get good agreement with experimentally measured charged particle multiplicity [9], we have changed a few PYTHIA6 parameters. The final values, fine-tuned for the specific procedure of choosing the interacting parton inside the nucleon, are: \( \text{PARJ}(32) = 0.1 \text{ GeV}, \text{PARJ}(33) = 0.5 \text{ GeV}, \text{PARJ}(34) = 1 \text{ GeV}, \text{PARJ}(36) = 0.3 \text{ GeV}, \text{MSTJ}(17) = 3 \). The definitions and default values of the parameters one can find in PYTHIA manual [10].

We use a procedure which gives exclusive cross-sections for each single pion production (SPP) channel:

\[
\frac{d\sigma^{SPP}}{dW} = \frac{d\sigma^\Delta}{dW} (1 - \alpha(W)) + \frac{d\sigma^{DIS}}{dW} F^{SPP}(W)\alpha(W),
\]

where \( F^{SPP} \) is the percentage of the given SPP channel within the overall DIS cross-section. The function \( \alpha(W) \) defines transition between two SPP models: mediated by the \( \Delta \) resonance and the inelastic one, and accounts for the non-resonant background.

3. Results

Many of the results from the Wrocław Neutrino Generator have already been presented [8]. The basic results for
CC neutrino and antineutrino scattering of nucleons are shown in figures 1 and 2. The cross-section for the SPP channel induced by an antineutrino is shown in figure 3. In figures 1–3 only SPP events with $W < 2$ GeV are taken into account. The cross-sections for two channels with two final pions, for which experimental data exist, are presented in figures 4 and 5, and the sum of the cross-sections for three pion production is given in figure 6. The simulation results agree with the experimental data for single and double pion production, but some discrepancy occurs for triple pion production.
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