Single Pion production in Neutrino-Nucleon Reactions

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Abstract
This work represents an extension of the single pion production model proposed by Rein [1]. The Rein’s original model consists of resonant and nonresonant-background contributions in the helicity basis, where the latter is described with three Born diagrams. The new work includes lepton mass effects, and the nonresonant background is described by five diagrams as it is proposed in [4].

Introduction

• Neutrino-induced single pion production has significant contribution in quasi-elastic (QE) interactions at low energy.
• These pions can be produced either by decay of excited resonance, or directly by nonresonant interaction.

Resonant and Non-Resonant Interactions

• Each Nucleon in initial and final states has two helicity states. In case of massive charged lepton, vector boson can have 4 polarizations. Altogether there are 2 x 2 x 4 = 16 helicity amplitudes for each vector and axial currents.
• Resonant interactions are described by the Rein-Sehgal model [2] which is based on helicity amplitudes in Adler or resonance rest frame.

Adler (πN center of mass) system
This is the most suitable coordinate system for discussing the resonance production contributions. The amplitudes of nonresonant-background are also calculated in this system. The z-axis is defined as the direction of the momentum transfer, k.

• Neutral background is defined by a set of Feynman diagrams determined by the relativistic model.

The output of the model is dσ/dQπ dΦπ, and describes pion kinematics and very easy to be implemented in neutrino generators.

Result

• The full model consists of the RS model based on Berger-Sehgal paper for the resonance contribution, and the five diagrams based on the non-linear σ model for non-resonant contributions.
• The proposed form-factors in [3] with only M4 axial parameter are replaced with updated form-factors proposed by [6] for RS model (with M4 and C2 free axial parameters) and Galster vector form-factor (proposed in [4]) for non-resonance big. Both sets of form-factors agree very well with ANL data after fitting.

• The following plots show the differences between the full model (Red), resonances w/o background and only Δ contribution (NEUT predictions) in pion polar angle differential cross-section averaged over T2K flux. Background contribution and interference terms between resonances as well as resonance-background are not negligible, and they change the pion directions.

ANL [9] and BNL [10] distribution of events in the pion azimuthal angle in πN rest frame with W < 1.4 GeV for π⁺ π⁻ final state are shown below. Curves are flux-averaged, area-normalized prediction of the model. According to [8], φ angle is a good observable to extract form-factors. φ distribution is almost unaffected by nuclear effects. The bubble chamber data is not precise enough to distinguish different models. Hopefully data from current experiments might shed light on φ observable.

References