Single Pion production in Neutrino-Nucleon Reactions

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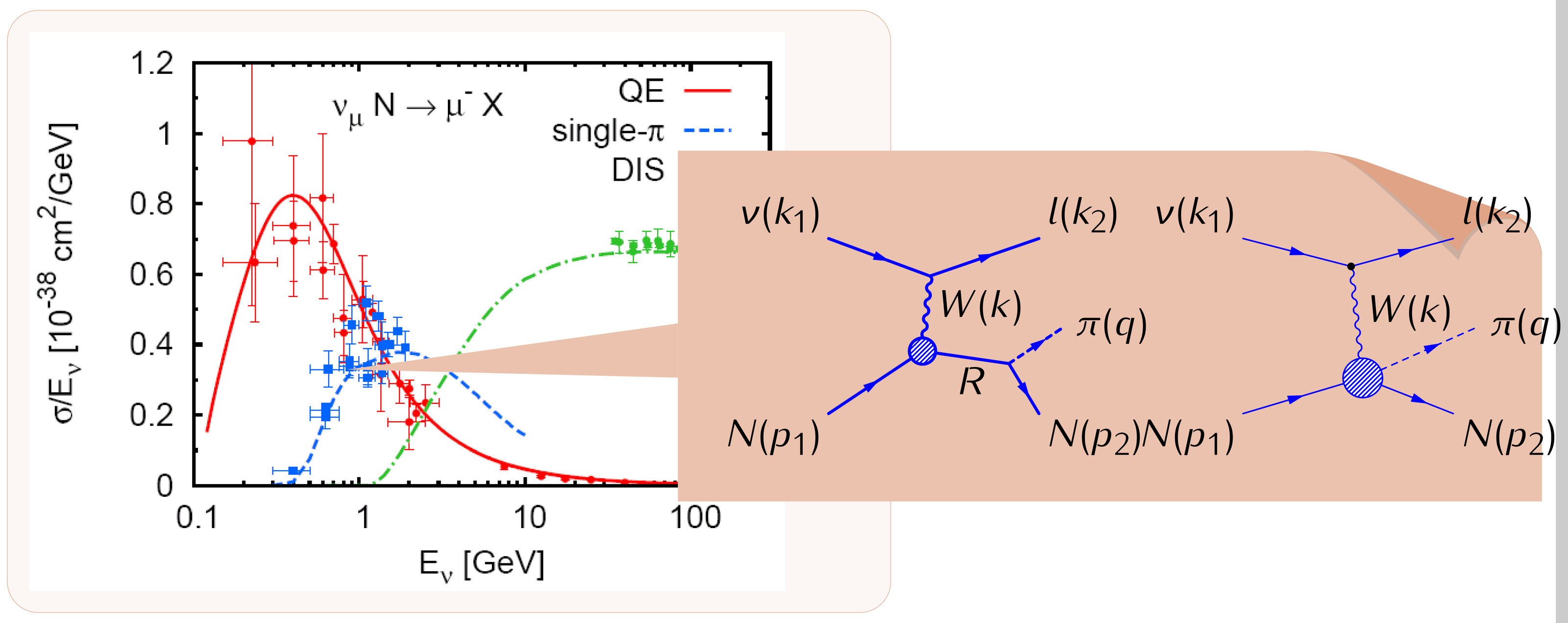
Abstract

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]

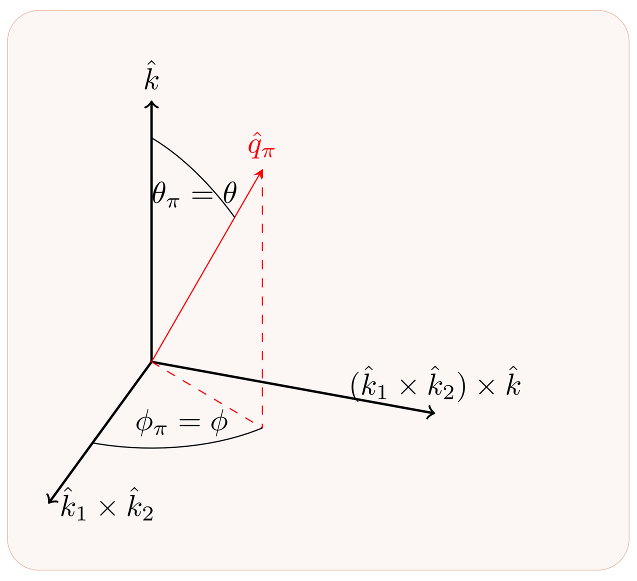
Introduction

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



- To add the resonant and the non-resonant contributions coherently a consistent model description, using the same frame is needed.

Resonant and Non-Resonant Interactions



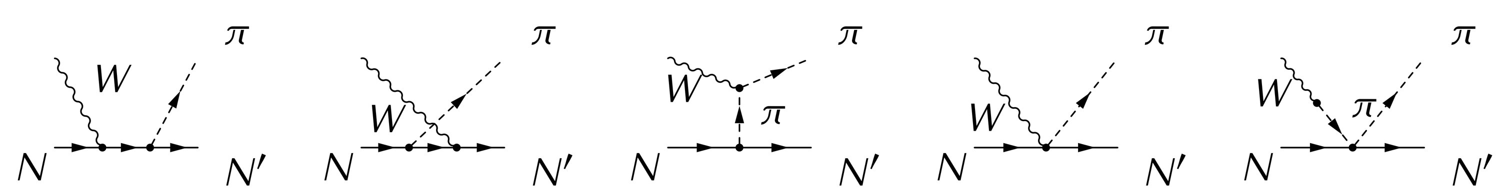
Adler (πN center of mass) system

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

- 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 $2 \times 2 \times 4 = 16$ 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.

→ It is a default model in NEUT[5] and GENIE neutrino generators for single pion production.
→ The output of the model is $d\sigma/dWdQ^2$ and the pion angular distributions is calculated separately by the definition of density matrices, that has very complicated form for more than two resonances. Therefore NEUT has only the dominant Δ implementation for the angular distribution.
→ The pion angular distributions has been revised based on [7], in order to have convenient model for neutrino generators .
→ The original RS model neglects the charged lepton's mass, but extended model in this work takes into account the mass using the methods Berger-Sehgal [3].

- **non-resonant background** is defined by a set of Feynman diagrams determined by HNV model based on nonlinear σ model.

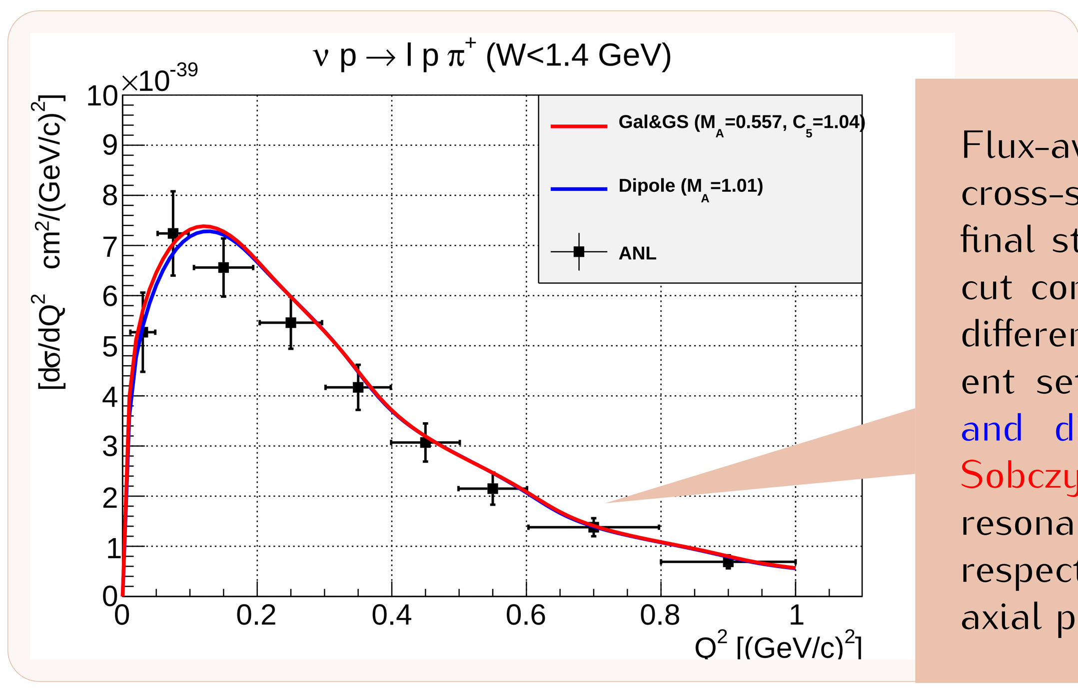


→ The Rein model consists of the first 3 of the above diagrams (Born graphs) which are described by linear σ model.
→ The lepton mass is now also included in the non-resonant pion production channels, which too was neglected in the Rein model.
→ The amplitudes of above diagrams are calculated from Feynman rules.
→ The helicity of particles and helicity amplitudes of above diagrams are related to the defined framework. They are calculated in Adler frame.

- The resonance and the non-resonance contributions can combined by summing their helicity amplitudes coherently.
- The output of the model is $d\sigma/dWdQ^2d\Omega_\pi$ and describes pion full kinematics and very easy to be implemented in neutrino generators.

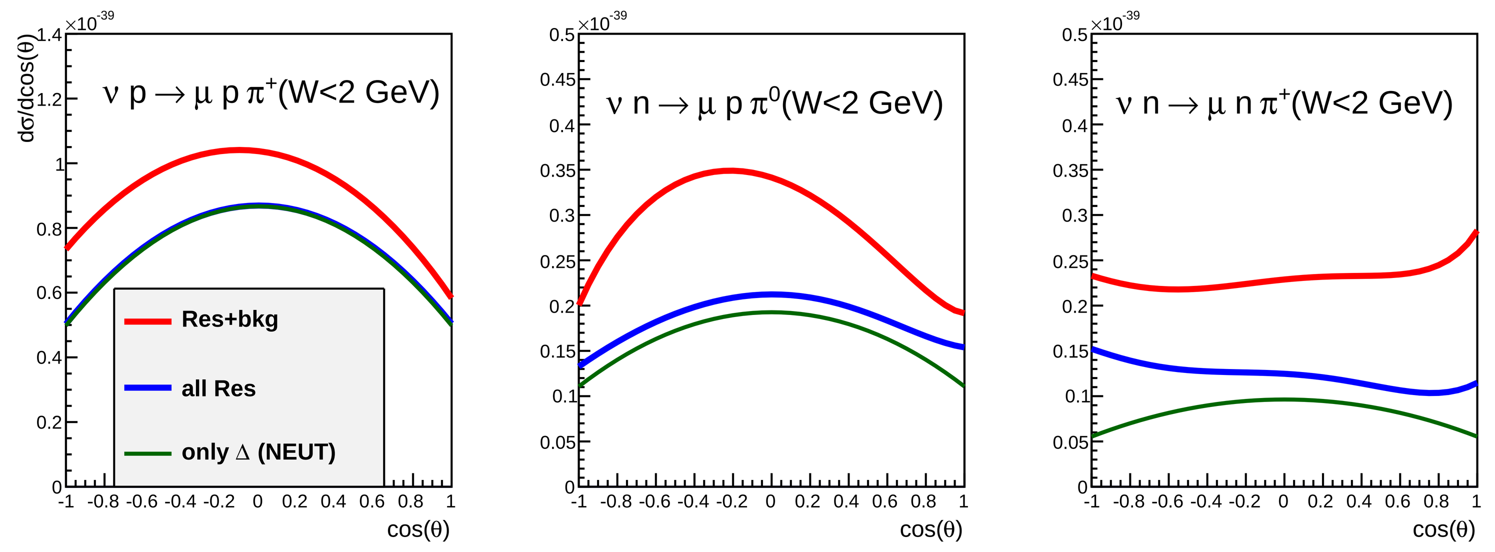
Result

- 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-resonance contributions.
- The proposed form-factors in [1] (with only M_A axial parameter) are replaced with updated form-factors proposed by [6] for RS model (with M_A and C_A^5 free axial parameters) and Galster vector form-factor (proposed in [4]) for non-resonance bkg. Both sets of form-factors agree very well with ANL data after fitting.

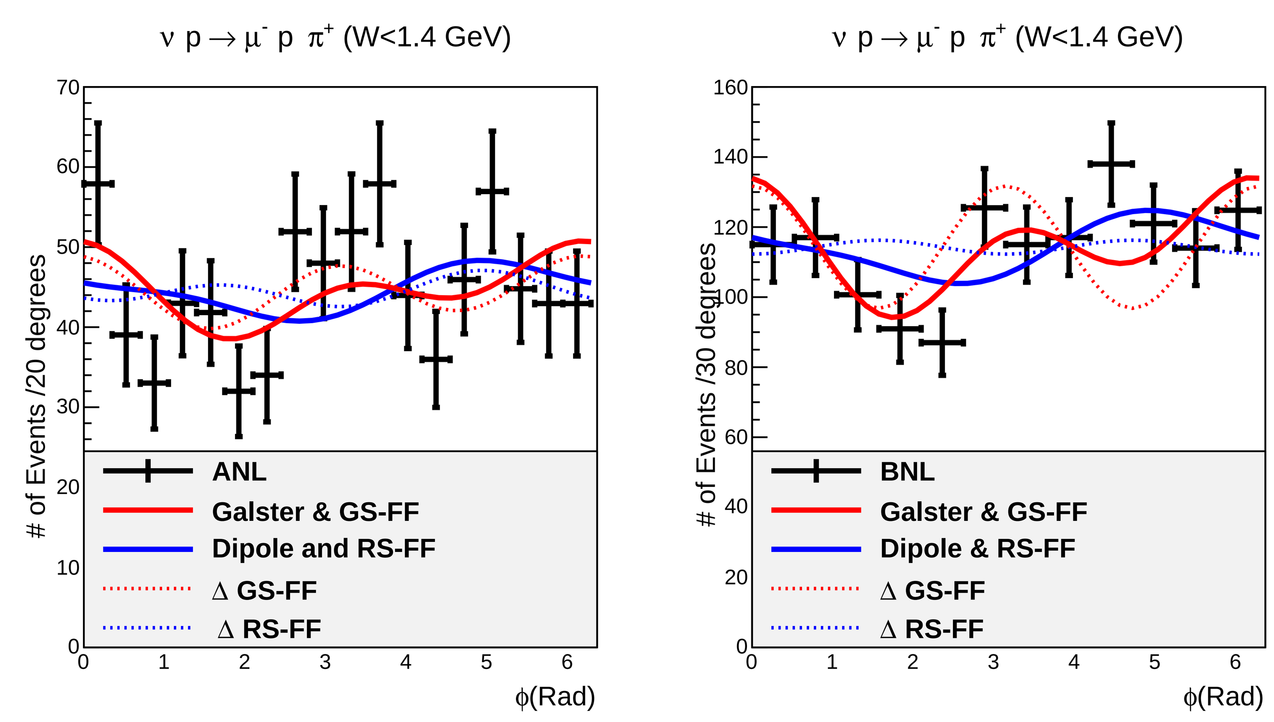


Flux-averaged differential cross-section $d\sigma/dQ^2$ for $p\pi^+$ final state with $W < 1.4GeV$ cut compared with ANL data. different curves show different sets of form-factors. RS and dipole versus Graczyk-Sobczyk and Galster for resonance and bkg models respectively after fitting the axial parameters

- The following plots show the differences between the full model (Red), resonances w/o bkg 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 $W < 1.4GeV$ for $\mu^- p \pi^+$ 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 obsevable!



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