Neutrino-induced coherent pion production off nuclei reexamined

Tina Leitner, Ulrich Mosel, and Stefan Winkelmann

Institut für Theoretische Physik, Universität Giessen, Germany

Abstract

- So far all theoretical estimates of coherent pion production off nuclei induced by neutrinos rely on the 'local approximation' for the Delta propagator.
- The validity of this approximation is studied.
- The local approximation overestimates the coherent neutrino-induced pion production on nuclei significantly, at least before pion final state interactions [1].

Introduction

- previous theoretical approaches
  - PCAC models (e.g. Rein-Sehgal):
    relate coherent pion production to forward scattering amplitude via PCAC assuming that specific nuclear effects play no role, besides providing nuclear size information
  - nuclear structure models (e.g. Amaro et al.):
    start from theoretical description of nuclear structure and sum pion production amplitude coherently over all target nucleon states
- both rely on local approximation: factorizes pion production amplitude into a part that contains pion production amplitude and one that contains nuclear size information
- How good is the local approximation for neutrino-induced processes?

Full calculation vs. local approximation

- assumption: pions are dominantly created via the $\Delta(1232)$ resonance
- hadronic current:

$$J^{\mu}_{\text{nucleon}}(p,q) \sim \bar{u}(\vec{p}\,')k^{\alpha}_{\pi}G_{\alpha\beta}(p_{\Delta})\Gamma^{\beta\mu}(p,q)u(\vec{p}) \qquad (1)$$

pion momentum k_π
nucleon final and initial momenta p' and p
$\Rightarrow q = p' - p$ and Δ momentum $p_\Delta = p + q$
$G_{\alpha\beta}$: full Rarita-Schwinger propagator
$\Gamma^{\beta\mu}$: electroweak vertex structure

- single particle current (1) has to be summed over all occupied states of the target nucleus (**full calculation**):

$$J^{\mu}_{\text{nucleus}}(q) = \sum_i \int d^3p\, J^{\mu}_i(p,q)$$
$$\sim \sum_i \int d^3p\, \bar{\psi}_i(\vec{p}\,')k^{\alpha}_{\pi}G_{\alpha\beta}(p_{\Delta})\Gamma^{\beta\mu}(p,q)\psi_i(\vec{p}) \qquad (2)$$

with bound-state-spinors $\psi_i(\vec{p})$ obtained in Walecka-type mean field model replacing the free-particle-spinors $u(\vec{p})$ in (1).
Note: momentum integration extends also over Δ propagator since $p_\Delta = p + q$.

- 'local approximation':
  fixing momentum of the initial nucleon state in the product $G_{\alpha\beta}(p_\Delta)\Gamma^{\beta\mu}(p,q)$ to some value, here:

$$\vec{p}^{\,0} = -(\vec{q} - \vec{k}_\pi)/2 \quad \Rightarrow \quad \vec{p}^{\,0}_{\Delta} = (\vec{q} + \vec{k}_\pi)/2 \qquad (3)$$

- consequences:
  $\Rightarrow$ momentum of Δ resonance is determined
  $\Rightarrow$ Δ propagator can be moved out of the integral, even out of the sum
  $\Rightarrow$ $W, Z + N \to \pi + N$ vertex becomes local
- current in **local approximation**:

$$J^{\mu}_{\text{nucleus, local}}(q) \sim k^{\alpha}_{\pi}\int d^3r\, e^{i(\vec{q}-\vec{k}_\pi)\cdot\vec{r}}\,\text{tr}\left(\rho(\vec{r},\vec{r})G_{\alpha\beta}(p^0_{\Delta})\Gamma^{\beta\mu}(p^0,q)\right) \qquad (4)$$

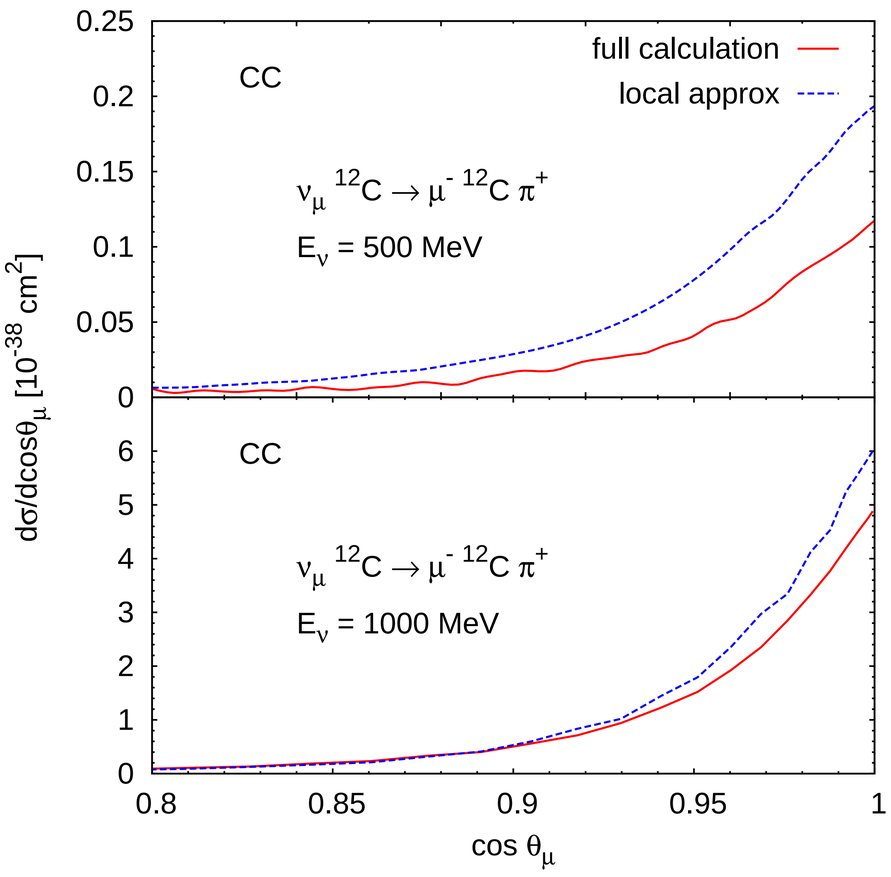
$\rho(\vec{r},\vec{r})$: diagonal element of the one-body density matrix

- nuclear form factor has been factorized out; all the other nonlocal densities present in the full expression no longer appear

- to isolate the effects of the local approximation we do not include in-medium changes of the Δ spectral function and final state interactions

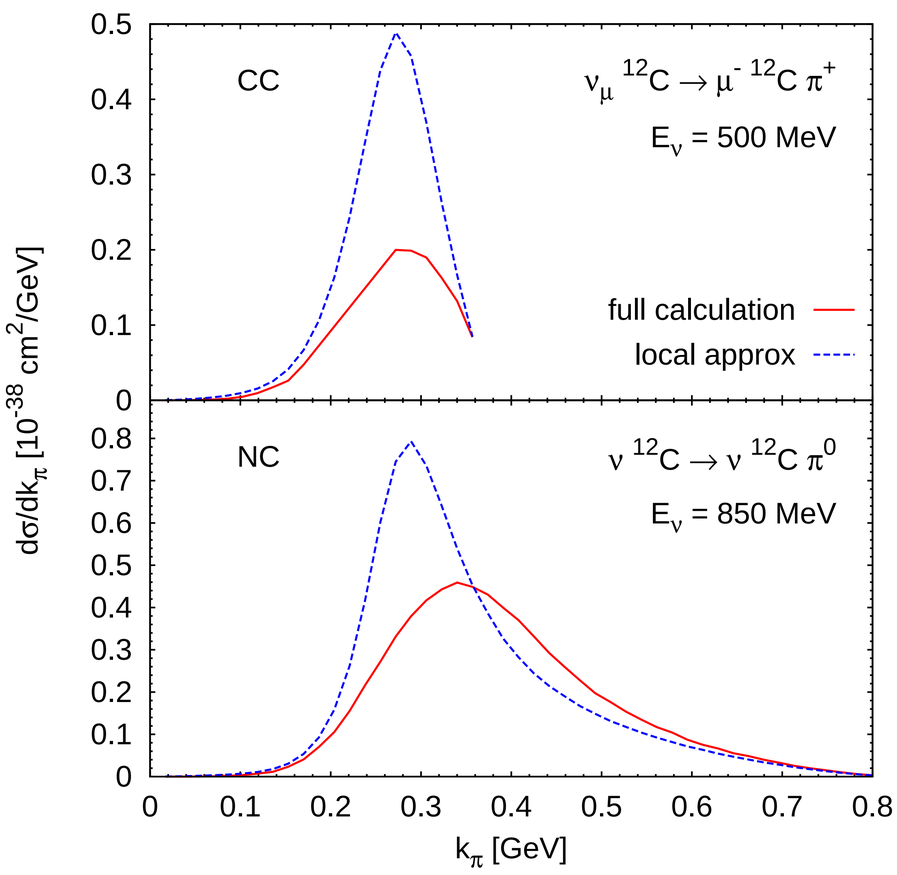
CC induced pion angular distributions of pions

- discrepancy at forward angles
- difference between full and approximate calculation is larger at lower energy: order of 100% at 0.5 GeV and of 20% at 1 GeV neutrino energy



CC and NC induced momentum distributions of pions

- local approximation overestimates full result by about 70% at the peak
- qualitatively similar results for NC induced coherent pion production
- quantitativ agreement with recent results of the Ghent group [2]



Conclusions

- **use of local approximation overestimates the coherent neutrino-induced pion production and thus involves errors which can reach up to 100%**
- discrepancy decreases with the neutrino energy
- outlook: calculations including pion final state interactions and Δ medium modifications needed for comparison with experiment

References

- [1] T. Leitner, U. Mosel, S. Winkelmann, PRC in press, arXiv:0901.2837
- [2] C. Praet, PhD thesis, Universiteit Gent, 2009

http://theorie.physik.uni-giessen.de/ leitner@theo.physik.uni-giessen.de, mosel@theo.physik.uni-giessen.de