Nuclear correlation effects in neutrino-nucleus interactions

J. Marteau[a]

[a]Institut de Physique Nucléaire de Lyon,
IN2P3-CNRS and Université Claude Bernard,
43 Bd du 11 Novembre 1918,
F-69622 Villeurbanne cedex, France

We present the results of the $^{16}O(\nu_\mu,\mu^-)$ cross-sections calculations within a model of neutrino-nucleus interactions taking into account the effects of resudiual interactions, Delta resonance excitation with a medium modified decay width and (*np-nh*) excitations (n=2,3) relevant in the region between the quasi-elastic peak and the Delta peak.

1. Introduction

We present the results obtained with a nuclear model detailed in Ref.[1,2], which provides an unified description of the nuclear processes relevant for the neutrino-nucleus interactions in the GeV region. These processes include the quasi-elastic and the resonant reactions but also the resonant and non resonant *np-nh* excitations relevant in the "dip" region. The model also takes into account the short range correlations by the means of the ring approximation of the RPA. The main features of this description are described in Ref.[1].

2. Presentation of the results

The results are organized as follows. First we show the double differential cross-section :

$$\frac{\partial^2\sigma}{4\pi\partial\cos\theta_\mu\partial E_\mu}$$

for a scattering angle $\theta_\mu = 30^o$, for incident neutrino energies $E_\nu = 0.5$ GeV and $E_\nu = 1.0$ GeV as a function of $E_\nu - E_\mu$ from 0 to 0.5 GeV. Then we present the integrated cross-sections :

$$\frac{\partial\sigma}{\partial E_\mu}$$

for incident neutrino energies $E_\nu = 0.5$ GeV and $E_\nu = 1.0$ GeV as a function of E_μ from 0 to 1.0 GeV;

$$\frac{\partial\sigma}{4\pi\partial\cos\theta_\mu}$$

for incident neutrino energies $E_\nu = 0.5$ GeV and $E_\nu = 1.0$ GeV as a function of $\cos\theta_\mu$ from -1 to +1.

2.1. Results for $\partial^2\sigma/4\pi\partial\cos\theta_\mu\partial E_\mu$

The cross-sections are expressed in units of $10^{-38}\mathrm{cm}^2\mathrm{GeV}^{-1}\mathrm{sr}^{-1}$. The basic features of the nuclear effects are :

- a hardening and a decrease of the cross-sections (clearly visible in the quasi-elastic peak, see Fig.3) which are characteristic of the transverse response functions behaviour. As pointed out in Ref.[1], the longitudinal channel is largely suppressed in the quasi-elastic peak which therefore is almost entirely dominated by the transverse channel. In this channel the residual interaction remains repulsive over a wide range of momenta and then hardens and decreases the response functions. The Delta peak is less affected by this effect because the longitudinal channel (in which the *pionic branch* plays a role) is less suppressed;
- a large contribution of the *np-nh* excitations which provide a large amount of strength in the "dip" region between the quasi-elastic and the Delta peaks (see Fig.1, Fig.2, Fig.4,

Fig.5). These excitations should be accounted for in simulations because they have the same experimental signature than the quasi-elastic events in water Čerenkov detectors such as Super-Kamiokande;

- a modified contribution of the Delta resonance due to a large broadening of the resonance in the medium (we denote Delta resonance the so-called "quasi-elastic" channel of decay : $\Delta \longrightarrow \pi N$, modified in the medium by the pion distorsion and the Pauli blocking of the nucleon [3]);
- at higher neutrino energies the effects of the residual interaction become negligible (see Fig.6).

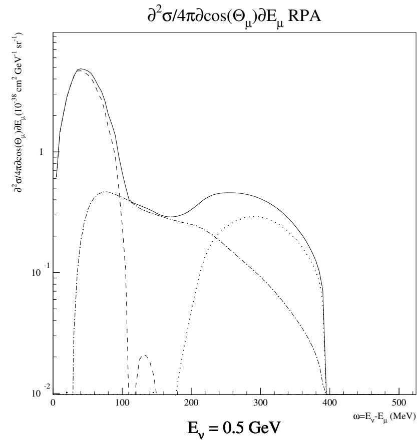

Figure 2. Same plot as in Fig.1 with RPA response functions.

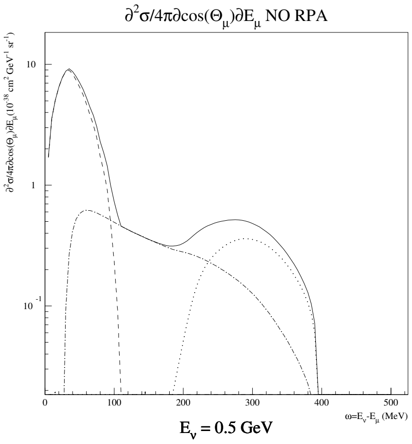

Figure 1. Double differential cross-section for $E_\nu =$ 0.5 GeV w.r.t. the transfer energy $\omega = E_\nu - E_\mu$. The continuous line represents the total cross-section, the dashed line gives the quasi-elastic contribution, the dashed line gives the Delta contribution and the dot-dashed line is the sum of all the *np-nh* contributions (both resonant and non-resonant). The response functions include no RPA. Note the log scale on the y axis.

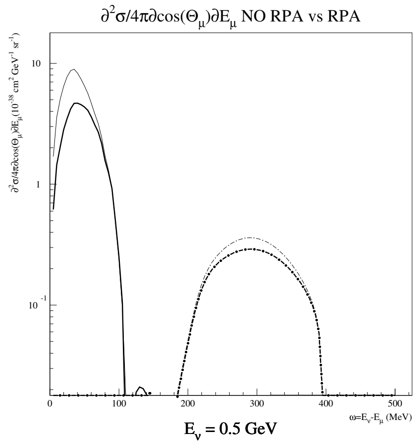

Figure 3. Double differential cross-section for $E_\nu =$ 0.5 GeV w.r.t. the transfer energy $\omega = E_\nu - E_\mu$: comparison of the no RPA (thin curves) and RPA (thick curves) cross-sections. The continuous lines represent the quasi-elastic contribution and the dashed lines give the Delta contribution.

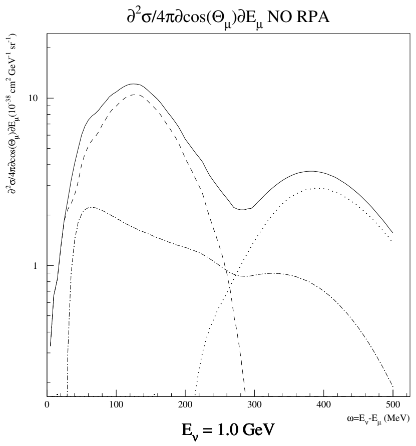

Figure 4. Same plot as in Fig.1 for $E_\nu = 1.0$ GeV.

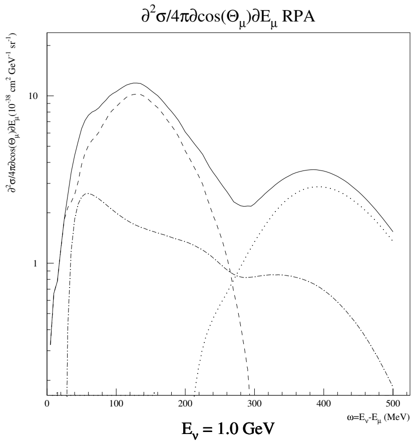

Figure 5. Same plot as in Fig.2 for $E_\nu = 1.0$ GeV.

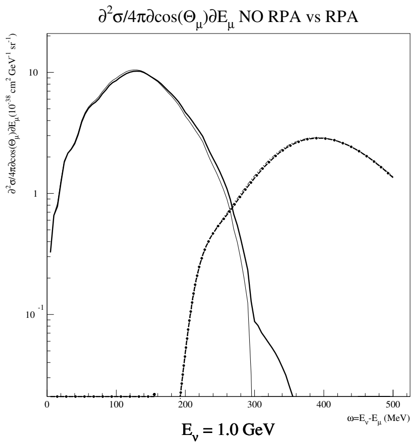

Figure 6. Same plot as in Fig.3 for $E_\nu = 1.0$ GeV.

2.2. Results for $\partial\sigma/\partial E_\mu$

The cross-sections are expressed in units of $10^{-38}\mathrm{cm}^2\mathrm{GeV}^{-1}$. The main features of these plots have already been pointed out in the previous section. The hardening and smoothing of the quasi-elastic peak w.r.t. the standard Lindhard function is clear. The Delta is not very much affected by the RPA but is strongly affected by the existence in the medium of the *np-nh* absorption channels. These excited states (to which we add the non resonant *np-nh* states) populate the "dip" region.

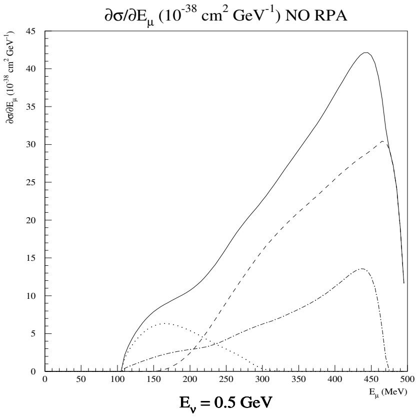

Figure 7. Differential cross-section for $E_\nu = 0.5$ GeV w.r.t. the muon energy E_μ. The continuous line represents the total cross-section, the dashed line gives the quasi-elastic contribution, the dashed line gives the Delta contribution and the dot-dashed line is the sum of all the *np-nh* contributions (both resonant and non-resonant). The response functions include no RPA. Note the log scale on the y axis.

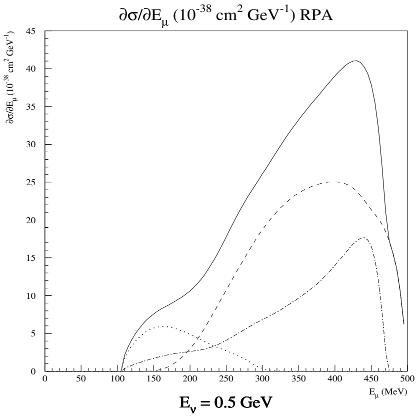

Figure 8. Same plot as in Fig.7 with RPA response functions.

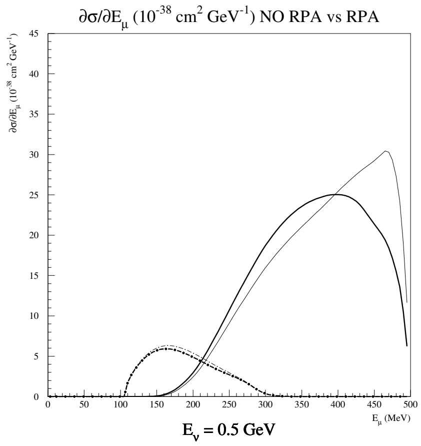

Figure 9. Differential cross-section for $E_\nu = 0.5$ GeV w.r.t. the muon energy E_μ : comparison of the no RPA (thin curves) and RPA (thick curves) cross-sections. The continuous lines represent the quasi-elastic contribution and the dashed lines give the Delta contribution.

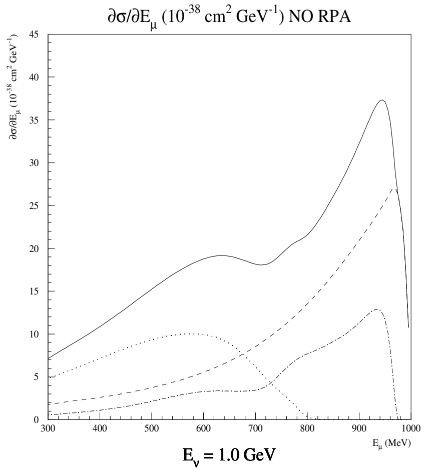

Figure 10. Same plot as in Fig.7 for $E_\nu = 1.0$ GeV.

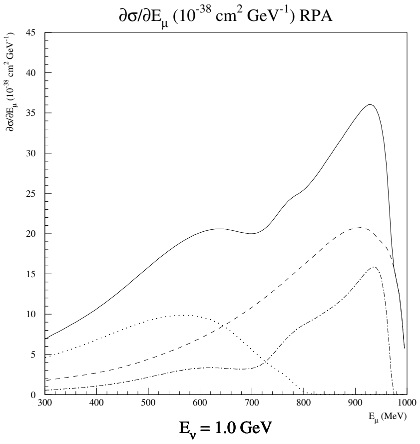

Figure 11. Same plot as in Fig.8 for $E_\nu = 1.0$ GeV.

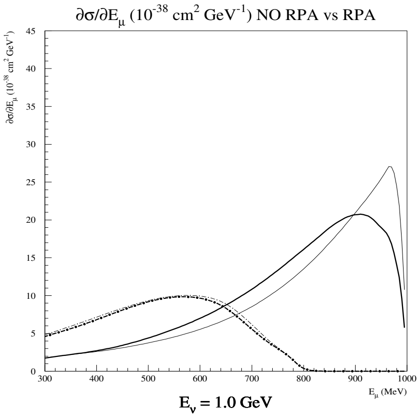

Figure 12. Same plot as in Fig.9 for $E_\nu = 1.0$ GeV.

2.3. Results for $\partial\sigma/4\pi\partial\cos\theta_\mu$

The cross-sections are expressed in units of $10^{-38}\mathrm{cm}^2\mathrm{sr}^{-1}$. The curves are peaked at the high values of $\cos\theta_\mu$ (corresponding to the low values of the transferred momentum). The conclusions drawn in the previous sections are still valid for these distributions.

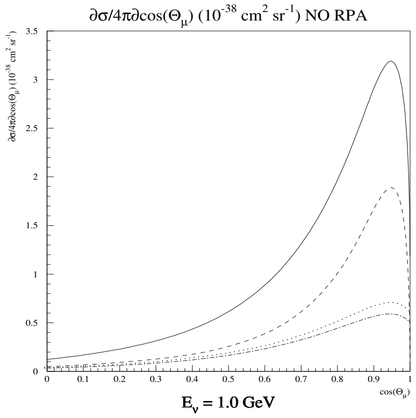

Figure 13. Differential cross-section for $E_\nu = 1.0$ GeV vs $\cos\theta_\mu$. The continuous line represents the total cross-section, the dashed line gives the quasi-elastic contribution, the dashed line gives the Delta contribution and the dot-dashed line is the sum of all the *np-nh* contributions (both resonant and non-resonant). The response functions include no RPA.

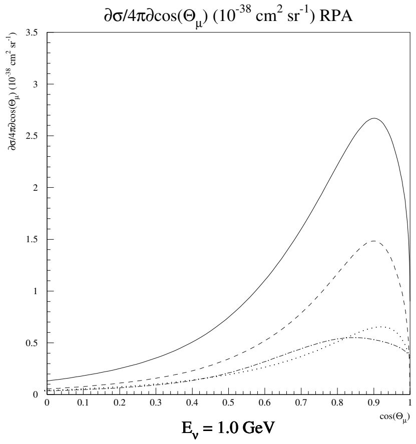

Figure 14. Same plot as in Fig.13 with RPA response functions.

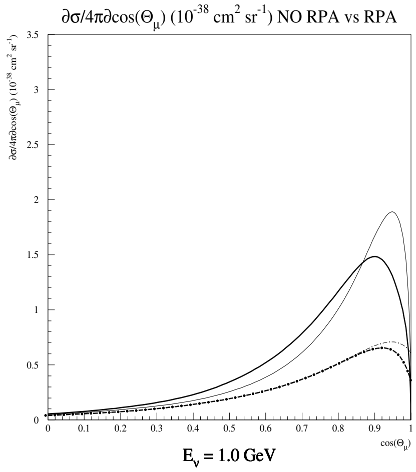

Figure 15. Differential cross-section for $E_\nu = 1.0$ GeV vs $\cos\theta_\mu$: comparison of the no RPA (thin curves) and RPA (thick curves) cross-sections. The continuous lines represent the quasi-elastic contribution and the dashed lines give the Delta contribution.

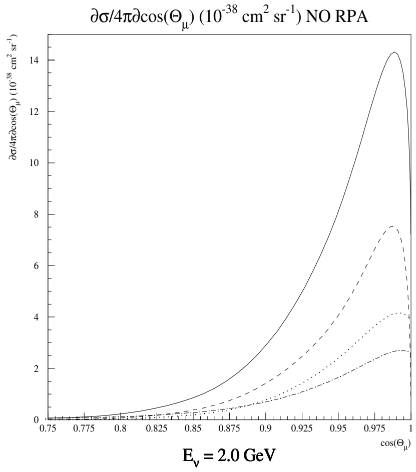

Figure 16. Same plot as in Fig.13 for $E_\nu = 2.0$ GeV.

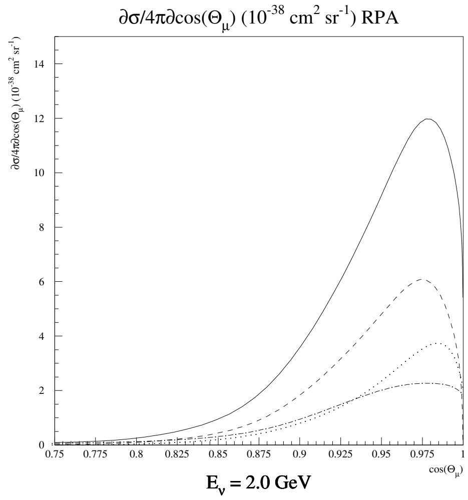

Figure 17. Same plot as in Fig.14 for $E_\nu = 2.0$ GeV.

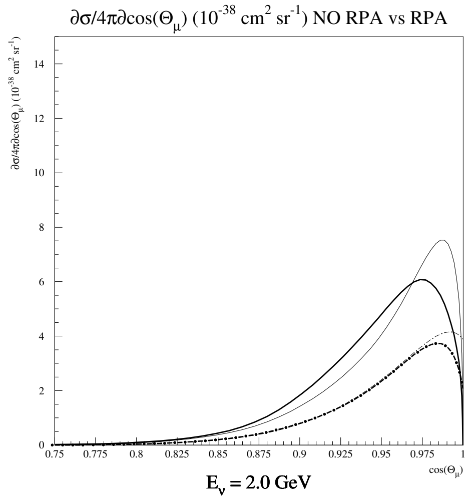

Figure 18. Same plot as in Fig.15 for $E_\nu = 2.0$ GeV.

3. Conclusion

In this work we presented the effects on the neutrino-oxygen cross-sections of some low energy nuclear physics processes such as residual interaction (short range correlations accounted for with the ring approximation of the RPA), Delta resonance excitation in the medium, *np-nh* states. We emphasize the role of these multi-particles which have the same experimental signature than the quasi-elastic events in a water Čerenkov detector. The role of the residual interaction (mainly hardening and decrease of the quasi-elastic peak) becomes small for neutrino energies higher than 1 GeV. It should however affect the events yields of atmospheric neutrinos which spectra decrease sharply with energy. The modification of the Delta resonance in the medium is also important since it affects the pion emission rates. The model presented here offers a detailed treatment of these modifications. All these nuclear effects should be compared to the standard Monte-Carlo calculations based on the Fermi gas model. This implementation is under investigation.

REFERENCES

1. J. Marteau, Eur. Jour. J. A**5**, 183-190(1999).
2. J. Marteau, *Nuclear correlation effects in neutrino-nucleus interactions*, these proceedings.
3. E.Oset, L.L.Salcedo, D.Strottman, Phys. Lett. **165**B, 13(1985).