Extracting the Weinberg angle at intermediate energies

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Abstract

A recent experiment by the NuTeV collaboration resulted in a surprisingly high value for the weak mixing angle $\sin^2\theta_W$. The Paschos-Wolfenstein relation, relating neutrino cross sections to the Weinberg angle, is of pivotal importance in the NuTeV analysis. In this work, we investigate the sensitivity of the Paschos-Wolfenstein relation to nuclear structure aspects at neutrino energies in the few GeV range. Neutrino-nucleus cross sections are calculated for ^{16}O and ^{56}Fe target nuclei within a relativistic quasi-elastic nucleon-knockout model.

Neutrinos have astounded physicists on many occasions, in a fascinating process that resulted in the present knowledge about these particles and the weak interaction. Recently, the NuTeV collaboration extracted an anomalously high value for the Weinberg angle $\sin^2\theta_W$ [1], using ν_μ and $\overline{\nu}_\mu$ deep inelastic scattering (DIS) reactions on an iron target. The resulting $\sin^2\theta_W = 0.22773 \pm 0.00135(\text{stat}) \pm 0.00093(\text{syst})$ was obtained in an analysis based on the Paschos-Wolfenstein (PW) relation [2] for an isoscalar target of u and d quarks

$$\frac{\sigma(\nu,NC)-\sigma(\overline{\nu},NC)}{\sigma(\nu,CC)-\sigma(\overline{\nu},CC)} = \left(\frac{1}{\cos^2\theta_c}\right)\left(\frac{1}{2}-\sin^2\theta_W\right). \tag{1}$$

Three standard deviations above the common $\sin^2\theta_W$ value of 0.2227 ± 0.0004, the NuTeV anomaly predicts a weaker coupling of the neutrino to the Z^0-boson. Whether this result points to new physics or can be explained through a reexamination of the initial analysis, remains a controversial issue [3]. Accordingly, the NuTeV outcome called for a thorough investigation of the PW relation (1). Although the bulk of proposed explanations addresses QCD uncertainties, considerable attention has been paid to the role played by nuclear effects, e.g. in [4], where the neutron excess correction to the Paschos-Wolfenstein relation is claimed to be larger than the one used in the NuTeV analysis.

Here, we present a study of the Paschos-Wolfenstein relation for neutrino energies of a few GeV. Instead of considering (1) as a combination of DIS (anti)neutrino-nucleon cross sections, quasi-elastic (QE) (anti)neutrino-nucleus cross sections will be employed. As a consequence our PW relation is not longer based on quark couplings, but is determined by form factor values. To calculate the QE cross sections, a fully relativistic nucleon-knockout model [5] is adopted. Final-state interactions (FSI) can be included by means of a relativistic Glauber approach, a multiple-scattering extension of the eikonal approximation based on nucleon-nucleon scattering data [5, 6].

In figure 1, we show relativistic plane-wave impulse approximation (RPWIA) results for the Paschos-Wolfenstein relation. The left panel presents total cross sections for the isoscalar $^{16}_{8}$O nucleus. The effects of FSI are found to be very small. At very low incoming energies, binding effects cause relatively large deviations from the standard PW value (1). For slightly higher incoming energies, the calculated

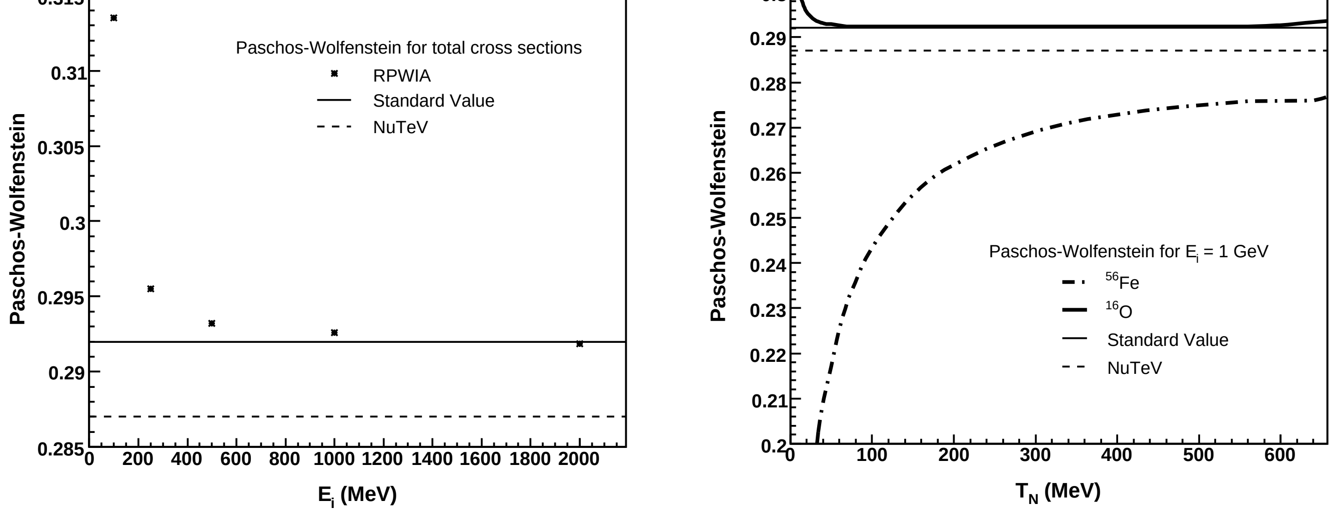

Figure 1: Comparison between RPWIA results, and the standard and NuTeV values for the Paschos-Wolfenstein relation. Left, total ^{16}O cross sections for incoming energies ranging from 100 MeV to 2 GeV. The right panel illustrates the dependence of the Paschos-Wolfenstein relation on the ejectile energy T_N for an incoming neutrino energy of $E_i = 1$ GeV for both ^{16}O and ^{56}Fe target nuclei.

RPWIA results can hardly be distinguished from the standard value, reaching perfect agreement at $E_i = 2$ GeV. Indeed, the $\sin^2\theta_W$ dependence of the Paschos-Wolfenstein relation, calculated here in a totally different energy regime, is in very good agreement with the standard value ($\sim 0.5\%$ at $E_i = 500$ MeV).

Considering the differential cross sections as a function of the outgoing nucleon's kinetic energy T_N, the Paschos-Wolfenstein relation behaves as shown in the right panel of the figure. The results for ^{16}O again emphasize the consistency between our calculation and the standard $\sin^2\theta_W$ value. The ^{56}Fe target on the other hand, yields a different $\sin^2\theta_W$ dependence. This can be attributed to the neutron excess in the $^{56}_{26}$Fe nucleus, which strongly enhances the $\sigma(\nu, CC)$ contribution, thereby lowering the PW values quite drastically. As a consequence, a large neutron-excess correction occurs. Several other aspects of the Paschos-Wolfenstein relation are currently under study [7], including the influence of the nucleon's strangeness content.

References

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