On the New Puzzling Results from MiniBooNE

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We look into the recent puzzling results from MiniBooNE and contrast their results with that of NOMAD. A picture which provides a consistent description of both is discussed here. This also points to future directions in neutrino studies.

Recently MiniBooNE experiment has extracted the first measurement of the double differential cross section for CCQE scattering of muon neutrinos on carbon and from this they obtained the single differential cross section and the absolute cross section \[1\]. An effective axial mass of \(M^A_{\text{eff}} = 1.35 \pm 0.17 \text{ GeV}\), significantly higher than the historical world average value was extracted. Here we would like to offer an explanation of this unexpected result.

Depending upon the available energies, upon the nature of the various particles interacting with nuclei, and upon the physical quantities under study, the nucleus offers a rich spectrum right from the quark-gluon to the nucleonic and further to the cluster degrees of freedom. For example for \(A = 3\) nuclei, the wave function that works well is

\[
\Psi^{(3\text{He})} = a\psi(\text{ppn}) + b\phi(9q)
\]

where \(\psi(\text{ppn})\) is significant for approximate distances \(0.7 \leq r \leq 1.8 \text{ fm}\) (size of \(3\text{He}\)) and \(\phi(9q)\) for \(r \leq 0.7 \text{ fm}\) approximately where the three nucleons overlap strongly \[2\].

In an analogous manner we suggest that the degrees of freedom relevant for neutrino interacting with \(^{12}\text{C}\) is

\[
\Psi^{(12\text{C})} = a\psi(6p,6n) + b\phi(2t,2h)
\]

where triton \(t \equiv ^3\text{H}\) and helion \(h \equiv ^3\text{He}\). The first term represents the standard shell model structure of \(^{12}\text{C}\) as consisting of 6 protons and 6 neutrons. The second term \(\phi(2t,2h)\) represents the clusters of \(A = 3\) kind i.e. \(2t+2h\).

Now \(^{12}\text{C}\) has often been treated as made up of three alpha-clusters. However for neutrino charge changing interactions, it shall play no role here.

To start with, let us accept the wave function (2) and derive the consequences. Later we shall show why the above structure should be physically acceptable and thus provide a consistent and valid description of \(^{12}\text{C}\) for the neutrino experiments. Now given Eqn. (2) for \(\Psi^{(12\text{C})}\) two kind of simultaneous knockout processes may occur

\[
\nu_\mu + n \rightarrow p + \mu^- \quad (3)
\]

\[
\nu_\mu + t \rightarrow h + \mu^- \quad (4)
\]

The process (3) is represented by Fig.4 of ref. \[1\]. Here we draw another figure (Fig.1) representing the process occurring from the reaction (4).

![Schematic illustration of the CCQE interaction of reaction (4) in addition to Fig.4 of ref. \[1\].](image)

Now very often triton \(t \equiv ^3\text{H}\) and helion \(h \equiv ^3\text{He}\) have been used as elementary in Elementary Particle Model(EPM) in \(\nu_\mu/\mu\) interactions on these nuclei \[3\] to provide a fruitful description of experimental data. We suggest similar perspective of \(^{12}\text{C}\) described as made up of \(2t\) and \(2h\). Just as in Eq.(1) there are two kinds of independent fermi gasses—that of nucleons (ppn) and another one of quarks (9q), here in Eq.(2) there are two independent Fermi gas pictures relevant for \(^{12}\text{C}\): the standard one of the nucleons (6p,6n) and the other one of the \(A = 3\) entities (called musospin- see below).

Here as per our model the \(\nu_\mu\) beam knocks out an \(^3\text{He}\). As the MiniBooNE group is not observing the outgoing proton (or helion), what they are observing actually is the cumulative effects due to these two independent channels. As all the models discussed by them \[1\] correspond to \(\psi(6p,6n)\) term and modifications thereof, these models are actually completely missing the contribution arising from the \(\phi(2t,2h)\) state.

Hence we suggest that the excess \(\sim 30\%\) enhancement in cross section is due to the missing \(\phi(2t,2h)\) term in their analysis. Neutrino charged current terms are unique in that these are picking up the two special structures of...
may have h-t structure in the ground state. In fact there are strong experimental evidences supporting $^6\text{Li} \equiv t+h$ (with Mintz in [3]). Simultaneous existence of $^3\text{H}(^3\text{He},^\gamma)^6\text{Li}$ in the ground state and $^{12}\text{C}(^3\text{He},^\gamma\alpha)^{12}\text{C}$ in the ground state in the same experimental setup is indicative of a pre-existing $^3\text{H}$ structure in $^{12}\text{C}$ [4]. Also $(h,t)$ structure in $A=3$ transfer reactions is evident for $^{12}\text{C}$ and other neighboring nuclei [4]. As such we may take $^{12}\text{C}$ as made up of clusters $2t+2h$. In fact MiniBooNE and NOMAD data both simultaneously taken, be treated as a strong justification of the wave function given in Eq.(2).

One of the authors (SAA) has already written several papers where t(and h) appears to be playing fundamental role in various physical structures (see for example [8]). It may be remarked that the picture offered here may also be used for explaining the quenching of Gamow-Teller strength obtained in $(p,n)$ and $(^3\text{He},^\mu)^{12}\text{C}$ reactions in nuclei [8].

Also a new SU(2) symmetry named as 'nusospin' symmetry where $(h,t)$ form a fundamental representation has already been suggested [8]. Just as $(p,n)$ are nucleons in $SU(2)_I$ isospin, $(h,t)$ are called 'nusons' in $SU(2)_A$ nusospin group.

In conclusion, we suggest that miniBooNE group should try at identifying a knocked out proton in coincidence with a knocked out helium as per Eq.(3) and Eq.(4). This will enable them to extract the two strengths simultaneously. This also offers an advantage for antineutrino case where $\nu_\mu+p \rightarrow n+\mu^+$ and $\bar{\nu}_\mu+h \rightarrow t+\mu^-$. Whereas knocked out n is not easily detectable while the outgoing triton could be easily identified due to its charge.

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