

Quasi elastic scattering of $\bar{\nu}_\mu$ off ^{12}C

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Introduction

Neutrinos are elementary particles with no electric charge, no magnetic moment, half integral spin and a small but non-zero mass. Being electrically neutral, neutrinos rarely interact with matter via weak force. There are many neutrino scattering processes such as quasi elastic scattering (QES) [1], resonance pion production (RES) [2] and deep inelastic scattering (DIS) [3], at various neutrino energies. In charged current quasi elastic scattering, an (anti)neutrino interacts with a (proton)neutron producing a corresponding lepton and the (proton)neutron changes to (neutron)proton.

$$\nu_l + n \rightarrow l^- + p. \quad (1)$$

$$\bar{\nu}_l + p \rightarrow l^+ + n. \quad (2)$$

In this work, we study charged current anti-neutrino - nucleus (^{12}C) QES. To describe CCQES, we use the Llewellyn Smith (LS) model [4]. For incorporating the nuclear effects, we use the Fermi gas model along with Pauli suppression condition. We calculate $\bar{\nu}_\mu$ - ^{12}C CCQES differential and total cross sections for different values of axial mass M_A and compare the results with experimental data, with the goal of finding the most appropriate M_A value.

Formalism for Quasi Elastic $\bar{\nu} - A$ Scattering

The differential cross section per proton for anti-neutrino - nucleus quasi elastic scattering

is defined as:

$$\frac{d\sigma^A(E_{\bar{\nu}}, Q^2)}{dQ^2} = \frac{2V}{Z(2\pi)^3} \int_0^\infty 2\pi k_p^2 dk_p d(\cos\theta) f(\vec{k}_p) S(\nu - \nu_{min}) \frac{d\sigma^N(E_{\bar{\nu}}^{eff}(E_{\bar{\nu}}, \vec{k}_p), Q^2)}{dQ^2}, \quad (3)$$

where the factor 2 accounts for the spin of the proton, V is the volume of the nucleus, k_p is the momentum of the proton, $\frac{d\sigma^N}{dQ^2}$ is the differential cross section of the anti-neutrino quasi elastic scattering off free proton and $E_{\bar{\nu}}^{eff}$ is the effective anti-neutrino energy in the presence of Fermi motion of nucleons defined as:

$$E_{\bar{\nu}}^{eff} = \frac{(s^{eff} - M_p^2)}{2M_p}. \quad (4)$$

Here, M_p is the proton mass and s^{eff} is defined as:

$$s^{eff} = M_p^2 + 2E_{\bar{\nu}} \left(E_p - k_p \cos\theta \right). \quad (5)$$

Here, E_p is the proton energy.

The Fermi distribution function $f(\vec{k}_p)$ is defined as:

$$f(\vec{k}_p) = \frac{1}{1 + \exp\left(\frac{k_p - k_F}{a}\right)}, \quad (6)$$

where $a = kT$ ($= 0.020$ GeV) is the diffuseness parameter. The Fermi momentum k_F for carbon nucleus is 0.221 GeV.

The Pauli suppression factor $S(\nu - \nu_{min})$ is defined as:

$$S(\nu - \nu_{min}) = \frac{1}{1 + \exp\left(-\frac{(\nu - \nu_{min})}{a}\right)}, \quad (7)$$

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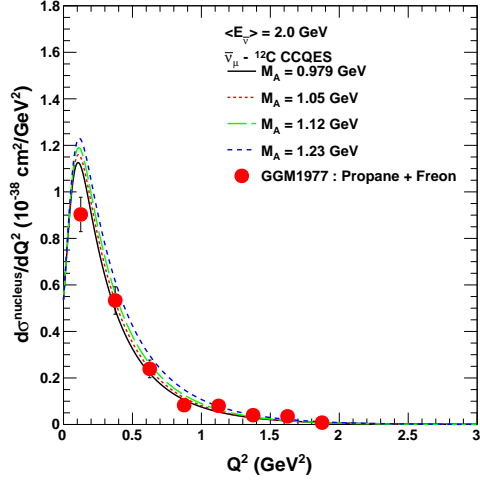


FIG. 1: $\frac{d\sigma}{dQ^2}$ per proton for $\bar{\nu}_\mu-^{12}\text{C}$ CCQES as a function of Q^2 , for different values of axial mass M_A and for $\langle E_{\bar{\nu}} \rangle = 2$ GeV compared with GGM data.

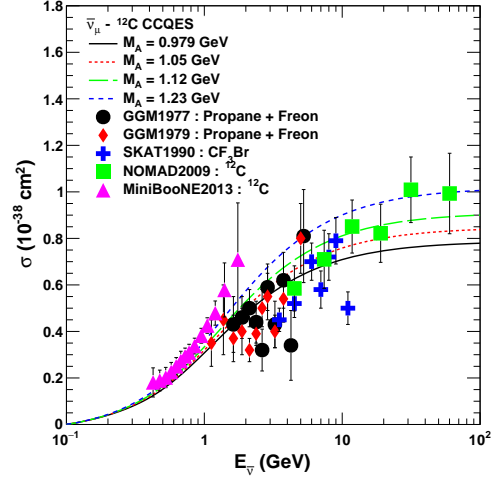


FIG. 2: σ per proton for $\bar{\nu}_\mu-^{12}\text{C}$ CCQES as a function of $E_{\bar{\nu}}$, for different values of axial mass M_A compared with GGM(1977), GGM(1979), SKAT, NOMAD and MiniBooNE data.

where ν is the energy transfer in the interaction and ν_{min} is defined as:

$$\nu_{min} = \sqrt{k_F^2 + M_n^2} - \sqrt{k_p^2 + M_p^2} + E_B. \quad (8)$$

Here, M_n is the final state neutron mass and E_B is the binding energy. Complete formalism and references can be found in Ref. [1].

Results and Discussions

Fig. 1 shows $\frac{d\sigma}{dQ^2}$ per proton for $\bar{\nu}_\mu-^{12}\text{C}$ CCQES as a function of Q^2 , for different values of axial mass ($M_A = 0.979, 1.05, 1.12$ and 1.23 GeV) and for $\langle E_{\bar{\nu}} \rangle = 2$ GeV. The results obtained are compared with data from Gargamelle (GGM), studying quasi elastic reactions of neutrinos and antineutrinos on propane plus freon target. The calculations with axial mass $M_A = 0.979$ and 1.05 GeV are compatible with data.

Fig. 2 shows σ per proton for $\bar{\nu}_\mu-^{12}\text{C}$ CCQES as a function of $E_{\bar{\nu}}$, for different values of axial mass ($M_A = 0.979, 1.05, 1.12$ and 1.23 GeV). The results obtained are compared with data from GGM(1977), GGM(1979),

SKAT, NOMAD and MiniBooNE experiments. The calculations with axial mass $M_A = 0.979$ and 1.05 GeV are compatible with GGM(1977), GGM(1979) and SKAT data, though the calculations overestimate the data at low anti-neutrino energies. The calculation with axial mass $M_A = 1.05$ GeV is compatible with NOMAD data and the calculation with axial mass $M_A = 1.23$ GeV is compatible with MiniBooNE data.

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