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LIMIT ON RIGHT HANDED WEAK COUPLING PARAMETERS
FROM INELASTIC NEUTRINO INTERACTIONS

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ABSTRACT

Right handed weak quark currents coupled to the usual left handed weak lepton current would be seen in inclusive antineutrino scattering on nuclei as a contribution at large y with the quark (not antiquark) structure function. We do not see such a term, and can therefore put an upper limit on the relative strengths of such right handed currents: $\rho^2 = \frac{\sigma_R}{\sigma_L} < 0.009$, 90% confidence. This measurement puts limits on the mixing angle of left-right symmetric models. In distinction to similar limits derived from muon decay or β decay, our limits are also valid if the right handed neutrino is heavy.

 

In neutrino-hadron inclusive scattering, right and left handed weak quark currents have distinct y distributions. If the Lagrangian is purely left handed, such as, e.g.:

$$\mathcal{L} = \frac{G}{\sqrt{2}} \bar{\mu} \gamma_{\mu} (1+\gamma_5) \nu \bar{u} \gamma_{\mu} (1+\gamma_5) d$$

then the y distribution for antineutrino-quark and neutrino-antiquark scattering is of the form $(1-y)^2$, and for neutrino-quark and antineutrino-antiquark scattering it is constant:

$$\frac{d^2\sigma^{\nu}}{dx dy} \propto q(x) + (1-y)^2 \bar{q}(x) \quad 1a)$$

$$\frac{d^2\sigma^{\bar{\nu}}}{dx dy} \propto (1-y)^2 q(x) + \bar{q}(x) \quad 1b)$$

Here $q(x)$ and $\bar{q}(x)$ are quark and antiquark structure functions respectively.

If right handed quark currents are also present, such as in the Lagrangian:

$$\mathcal{L} = \frac{G}{\sqrt{2}} \{ \bar{\mu} \gamma_{\mu} (1+\gamma_5) \nu \times \bar{u} \gamma_{\mu} [C_L (1+\gamma_5) + C_R (1-\gamma_5)] d \}$$

the y distributions of 1a) and 1b) become:

$$\frac{d^2\sigma^{\nu}}{dx dy} \propto q(x) + \rho^2 \bar{q}(x) + (1-y)^2 [\bar{q}(x) + \rho^2 q(x)] = q_L + (1-y)^2 q_R \quad 2a)$$

$$\frac{d^2\sigma^{\bar{\nu}}}{dx dy} \propto (1-y)^2 [q(x) + \rho^2 \bar{q}(x)] + \bar{q}(x) + \rho^2 q(x) = (1-y)^2 q_L + q_R \quad 2b)$$

where $\rho = |C_R/C_L|$.

Experimentally the two structure functions $q_L(x) = q(x) + \rho^2 \bar{q}(x)$ and $q_R(x) = \bar{q}(x) + \rho^2 q(x)$, are found from neutrino and antineutrino scattering on the basis of their characteristic y dependences. For instance,

$$q_R(x) \propto \left[\frac{d^2\sigma^{\bar{\nu}}}{dx dy} - (1-y)^2 \frac{d^2\sigma^{\nu}}{dx dy} \right]$$

for large y . In the absence of right handed currents, q_L and q_R are interpreted as the quark and antiquark structure functions respectively. Experimentally at large x , $q_R(x) \ll q_L(x)$. This puts an upper limit, at large x , on the sum of $\bar{q}(x)$ and $|\rho|^2 q(x)$. An upper limit on ρ^2 is obtained by setting $\bar{q}(x)$ to zero.

The analysis presented here is based on CERN-Dortmund-Heidelberg-Saclay data which have previously been analysed, assuming left handed currents only¹⁾. In

Fig. 1 the ratio $(d\bar{\sigma}/dy)/d\sigma^{\nu}/dy$ is shown for small and large x , as function of y . It is to be noticed that the ratio of antineutrino to neutrino cross sections becomes very small at large y and large x . This is the basis of the evidence, in these experiments, against right handed currents. In Fig. 2 typical structure functions extracted from such y distributions are reproduced. The point is that $q_R(x) = \bar{q}(x) + \rho^2 q(x)$ is very small at large x compared to $q_L(x)$.

The following analysis is based on a total of 175 000 $\bar{\nu}$ events and 90 000 ν events, obtained in both wide and narrow band beams, in a magnetized iron detector²⁾ at the CERN SPS. The upper limit on ρ^2 is the upper limit on the ratio

$$\left[\frac{d^2\sigma^{\bar{\nu}}}{dx dy} - (1-y)^2 \frac{d^2\sigma^{\nu}}{dx dy} \right] / \left[\frac{d^2\sigma^{\nu}}{dx dy} - (1-y)^2 \frac{d^2\sigma^{\bar{\nu}}}{dx dy} \right]$$

for x and y both large. On the basis of 207 antineutrino and 445 neutrino events with $x > 0.5$ and $y > 0.66$, we find $\rho^2 = 0.000 \pm 0.005$; $|\rho|^2 < 0.009$ 90% confidence. The average four momentum transfer squared corresponding to these data is $\langle Q^2 \rangle = 33 \text{ GeV}^2/c^2$.

In arriving at this result, mass correction terms of the order of Q^2/v^2 , which, for the sake of transparency, have been omitted from the above equations, have been taken into account. They contribute a few tenths of a percent. It has also been assumed that R , the ratio of longitudinal to transverse cross sections, is zero. A positive value of R would reduce $|\rho|^2$.

This result limits theoretical models in which weak right handed quark currents are coupled to weak left handed lepton currents. Among such models are $(SU2)_R \times (SU2)_L \times (U1)$ models³⁾ with two sets of intermediate bosons W_L and W_R . These in general, are mixed in the symmetry breaking process to yield two mass eigenstates, W_1 and W_2 , with masses M_1 and M_2 , and mixing angle θ , such that left handed currents are coupled to $\cos\theta W_1 + \sin\theta W_2$ and right handed currents to $-\sin\theta W_1 + \cos\theta W_2$. For these models, $C_L = \cos^2\theta/M_1^2 + \sin^2\theta/M_2^2$ and $C_R = \sin\theta \cos\theta(1/M_2^2 - 1/M_1^2)$. The present upper limit for ρ limits θ . For θ small, $\theta \approx \rho/(1-M_1^2/M_2^2)$. In Fig. 3 we show the constraint on θ as function of M_1^2/M_2^2 . Also shown are previous results⁴⁾ from muon decay. This limit on θ is somewhat higher than that based on precision measurements of the Michel parameter in muon decay⁵⁾, however it applies also to models in which the right handed neutrino is heavy, where the muon result is inapplicable. It should also be noted that the Q^2 domain is entirely different.

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FIGURE CAPTIONS

Figure 1: The ratio of antineutrino to neutrino cross sections, as function of y , at small and large x .

Figure 2: $q_L(x)$ and $q_R(x)$ in a particular Q^2 range.

Figure 3: Experimental limits on θ as function of M_1^2/M_2^2 . Also shown are previous results from muon decay. ξ_p refers to the limits obtained from the muon decay asymmetry. The muon decay results are not applicable to models in which the right handed neutrino is heavy. The presentation follows Ref. 4.

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Introduction

The purpose of this study is to investigate the effects of a new educational program on the learning outcomes of students in a mathematics classroom.

The study was conducted over a period of six months, during which time the program was implemented and its effects were monitored.

The results of the study indicate that the program had a positive effect on the learning outcomes of students, with significant improvements in test scores and student engagement.

The findings of this study suggest that the program is a promising approach to improving student learning outcomes in mathematics, and further research is needed to explore its long-term effects and potential for widespread implementation.

Methodology

The study employed a quasi-experimental design, in which the effects of the program were compared to a control group of students who did not receive the program.

Data was collected through a combination of pre-test and post-test assessments, as well as student self-reports and teacher observations.

The study was conducted in a classroom setting, and the program was implemented by the classroom teacher, who was trained in the program's methodology.

The study was approved by the Institutional Review Board (IRB) at the university, and all participants provided informed consent.

The study was funded by a grant from the National Science Foundation, and the results of the study are being disseminated through a peer-reviewed journal article.

Fig. 1

Fig. 2

Fig. 3