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ABSTRACT

We have searched for candidates for the weak neutral leptonic current reaction $\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$ in the Fermilab 15-ft. bubble chamber filled with a heavy neon-hydrogen mix. Based on zero observed events of this type we find the 90% confidence level upper limit for the rate for this reaction relative to the total antineutrino charged current rate to be 3.9×10^{-4} and, in the Weinberg-Salam model, $\sin^2\theta_W \leq 0.37$.

The elastic scattering reactions

$$\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^- \quad (1)$$

and

$$\nu_\mu + e^- \rightarrow \nu_\mu + e^- \quad (2)$$

provide sensitive tests of weak interaction theories because these reactions can proceed only via the weak neutral leptonic current and interpretation of the data is not complicated by hadronic structure effects. Virtually all neutrino-hadron neutral current data reported to date are consistent with the gauge model of Weinberg[1] and Salam[2] (W-S), which contains a single free parameter, θ_W, that has been determined experimentally as $\sin^2\theta_W \simeq 1/4$.[3] Data for Reactions (1) and (2) obtained at neutrino and antineutrino energies of a few GeV in the Gargamelle bubble chamber[4] and in a counter experiment[5] are in agreement with this model. However, recently another measurement in Gargamelle of the rate for Reaction (2) at higher neutrino energies has been reported[6] which is significantly in excess of the rate predicted by the W-S model with $\sin^2\theta_W = 1/4$. Subsequently an experiment performed in the Fermilab 15-ft bubble chamber also at higher neutrino energies has measured a rate for Reaction (2)[7] which agrees with this model with $\sin^2\theta_W \simeq 1/4$. We report here the first search at higher energies for examples of Reaction (1) and a resulting upper limit for its rate relative to all charged current events.

The data come from an exposure of 85,000 pictures in the Fermilab 15-ft bubble chamber to the horn focused, broad band antineutrino beam with 2 mr absorptive plug. The bubble chamber was filled with a mixture of 64% neon and 36% hydrogen by atoms resulting in a radiation length of 39 cm. The primary proton beam was 400 GeV/c. Flux calculations indicate that the approximate rates of charged current events due to the four kinds of neutrinos in the beam are expected to be in the ratios $\bar{\nu}_\mu$: ν_μ: $\bar{\nu}_e$: ν_e: : 100: 9: 0.6: 0.6.

The film was scanned for neutral induced events with special emphasis for events containing electrons or positrons at the primary interaction. Candidates for Reaction (1), which are events consisting of a single electron not pointing to another event, were included in the scan, but obvious Compton electrons were not recorded. Electrons and positrons were recognized using as a track signature spiralization to a point, a sudden change of curvature, bremsstrahlung conversion, trident formation or large delta rays. A partial rescan indicated the recognition efficiency for electron and positron candidate tracks was 85 ± 5%. The sample was purified by requiring the electron or positron candidate to have momentum P_e > 0.8 GeV/c and to show two signatures, at least one of which was a bremsstrahlung conversion. Application of this selection procedure to known electrons and positrons from gamma conversions showed its efficiency was 83 ± 5%.

No candidate for Reaction (1) was found. We considered whether the detection efficiency for electrons determined above as an average over all topologies is appropriate for the specific topology of Reaction (1): A dedicated rescan for one and two prong events containing an electron or positron was conducted for nearly one half of the film. In the first scan nine events consisting of either a single positron or an electron or positron and a short stub (less than 2 cm long) were found. These events, whose lepton momenta range from 2 GeV/c to $\geq$ 30 GeV/c, have the same general appearance to the scanner as the sought after candidates for Reaction (1), and the recognition efficiency for these events should be the same as for events from Reaction 1. One of these nine events is $\nu_e + n \rightarrow e^- + p$, where we observe the proton; and eight are either $\bar{\nu}_e + p \rightarrow e^+ + n$ or $\bar{\nu}_e + p \rightarrow e^+ + n +$ (undetected π^o), where we observe in five events a stub which is a fragment of the struck neon nucleus. The film selected for the dedicated rescan contained all nine of these events; all nine were found again in the rescan as well as an additional $\bar{\nu}_e + p \rightarrow e^+ + n + (\pi^o)$ candidate.

The indicated statistical single scan recognition efficiency for this small sample of events is therefore 90 ± 10%. We conclude that our recognition efficiency for events from Reaction (1) should be approximately the same as the 85 ± 10% recognition efficiency determined for our entire sample of events containing primary electrons or positrons.

In order to assess the possibility of a systematic loss of $\bar{\nu}_e + p \rightarrow e^+ + n + (\pi^o)$ events, which would indicate a similar loss of events from Reaction (1), we have used the calculated $\bar{\nu}_e$ content of the beam and theoretical estimates of the cross-sections[8] to predict $4\,^{+4}_{-2}$ events of the type $\bar{\nu}_e + p \rightarrow e^+ + n + (\pi^0)$. The nine observed events show that systematic losses are not significant.

The dominant background for Reaction (1) is expected to be events of type $\nu_e + n \rightarrow e^- + p + (\pi^0)$ where the proton is not observed. Additional sources of background include Compton electrons and asymmetric gamma conversions where the positron is not seen. The ν_μ contamination in the beam is expected to produce a negligible number of events corresponding to Reaction (2), which are indistiniguishable from events from Reaction (1). We estimate that all sources of background combine to give 0.2 ± 0.2 events in this experiment.

The size of the $\bar{\nu}_\mu$ induced charged current "normalization" sample was determined as follows: the External Muon Identifier (EMI) was used to identify 5270 events having muon momentum P_μ greater than 4.0 GeV/c, total energy $E_{\bar{\nu}}$ greater than 10 GeV, and hadron energy ν greater than 2.0 GeV. This number was corrected for EMI geometric acceptance, EMI instrumental efficiency, and the P_μ and ν cuts.[9] The number of events with $E_{\bar{\nu}} < 10$ GeV was estimated from calculations of the $\bar{\nu}_\mu$ energy spectrum. We estimate the total $\bar{\nu}_\mu$ induced charged current sample was 8400 events with an uncertainty of 6% due to the correction procedure.

Using for our overall electron efficiency the product of our 85% electron candidate recognition efficiency and our 83% signature efficiency, we find based on zero observed events a 90% confidence level upper limit ratio

$$\frac{\text{Rate}(\bar{\nu}_\mu + e^- \to \bar{\nu}_\mu + e^-,\ P_e > 0.8\ \text{GeV/c})}{\text{Rate}(\bar{\nu}_\mu + \text{Ne} \to \mu^+ + X)} \leq 3.9 \times 10^{-4}.$$

We use the $\bar{\nu}_\mu$ total cross section $\sigma_{total} = 0.29\ E_{\bar{\nu}} \times 10^{-38}$ cm^2/GeV-nucleon[10] and take the electron to nucleon ratio in the bubble chamber mixture as 0.51, to obtain the 90% confidence level upper limit cross section

$$\sigma(\bar{\nu}_\mu + e^- \to \bar{\nu}_\mu + e^-,\ P_e > 0.8\ \text{GeV/c}) \leq 2.1 \times 10^{-42}\ E_{\bar{\nu}}$$

cm^2/GeV-electron.

Within the context of the W-S model our result implies $\sin^2\theta_W < 0.37$.[11] On the other hand, if $\sin^2\theta_W = 0.25$, we would expect to observe 1.5 events in this experiment. Reference 5 notes that their result would be consistent with the W-S model with $\sin^2\theta_W > 0.74$. Such a situation would predict > 10 events observed in this experiment, which is clearly incompatible with our data.

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[9]The statistical single scan efficiency for events in general was measured using a partial rescan to be 88 ± 2%. The size of the normalization sample is not corrected for this efficiency, for it effects the signal as well.

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[11]Within the context of W-S theory with $\sin^2\theta_W = 0.37$ the $P_e > 0.8$ GeV/c cut would result in the loss of 6% of events.