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COMPARISON OF ELECTRON AND MUON CHARGED CURRENT NEUTRINO AND
ANTINEUTRINO INTERACTIONS IN A NEON-H₂ MIXTURE

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ABSTRACT

From an exposure of the Fermilab 15-ft Neon (64 atomic %)-H₂ filled bubble chamber to a single-horn-focussed $\bar{\nu}$ beam, we have found 60 e⁻X and 35 e⁺X events, which we compare with 227 μ^- X and 202 μ^+ X events. No statistically significant departures from μ -e universality are seen in the shapes of various differential cross sections.

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Currently available high-energy neutrino beams present a unique opportunity for a study of μ -e universality over a wide range of energies. We report on a comparison of ν_e with ν_μ and $\bar{\nu}_e$ with $\bar{\nu}_\mu$ charged current (CC) interactions under the same experimental conditions for energies between 10 and 150 GeV, in the Q^2 range up to approximately 30 GeV^2 . No previous study has used data above 10 GeV, or Q^2 above approximately 10 GeV^2 [1].

The data were taken with the Fermilab 15-ft bubble chamber filled with a heavy mixture of Ne and H_2 and exposed to a broad-band neutrino and anti-neutrino beam. Muon neutrinos and anti-neutrinos are produced predominantly in the decays of $\pi^\pm$ and $K^\pm$ mesons; the ν_e and $\bar{\nu}_e$ flux comes from $K^\pm, 0$ decays with additional components resulting from $\mu^\mp$, Λ^0 , etc., decays. In spite of these differences, the meson focussing system produced beams of ν_μ and ν_e ($\bar{\nu}_\mu$ and $\bar{\nu}_e$) with comparable energy distributions, as we shall show, and resulted in comparable numbers of ν_μ and $\bar{\nu}_\mu$ -induced reactions [2]. Important for the present study is the short radiation length (39 cm), which provides good $e^\pm$ identification efficiency and γ -ray materialization probability, and the presence of a single-plane External Muon Identifier (EMI) behind the chamber.

In 45,000 pictures with EMI information, we found, after applying the acceptance criteria described below, 35 events with a single primary e^+ among the outgoing tracks and 60 with a single primary e^- ,

which we attribute to $\bar{\nu}_e$ and ν_e CC production, respectively.* We compare these with a sample of 202 $\bar{\nu}_\mu$ and 227 ν_μ -induced CC events from 6,000 pictures. All events satisfy the criteria: 1) the sum of longitudinal momenta, $\Sigma P_L (\cong E_{\text{visible}}) > 10$ GeV, where the summation is over all measured charged and neutral particles; 2) $p_\ell > 4$ GeV (ℓ refers to the outgoing lepton throughout); 3) visible potential length of forward-going tracks > 90 cm; and 4) ≥ 1 charged hadron at the primary vertex. Muon tracks were required to be identified as such by the EMI, with likelihood [4] $\mathcal{L} > 5$. We estimate that $< 1\%$ of our ν_μ ($\bar{\nu}_\mu$) samples are neutral current events with a hadron falsely identified in the EMI as a muon. Electrons and positrons were identified with any two of the signatures described in ref. [2]. We have removed six events interpreted as $\mu^- e^+$ and four as $\mu^+ e^-$ [2].

We reject $e^\pm$ events from the ν_e ($\bar{\nu}_e$) sample if any primary track for which an electron mass cannot be ruled out is consistent with being the partner of the $e^\pm$ in a Dalitz pair and we reject e^- events if the e^- is consistent with being a δ -ray on some track. Applying these criteria to the ν_μ ($\bar{\nu}_\mu$) sample (treating the muon as an electron) is found to result in negligible losses.

Because of uncertainties in the flux calculations, we do not compare absolute cross sections. In order to compare the shapes of distributions, the ν_μ ($\bar{\nu}_\mu$) samples are normalized to the ν_e ($\bar{\nu}_e$) signal.

*We estimate that $\lesssim 10\%$ of our ν_e ($\bar{\nu}_e$) candidate events could be due to the possibly anomalous source of prompt neutrinos of unknown identity reported in ref. [3].

Hence, we do not correct for losses which contribute only to the relative normalization. We also do not correct for biases expected to affect the ν_e ($\bar{\nu}_e$) and ν_μ ($\bar{\nu}_\mu$) samples equally, such as those due to the loss of undetected neutral particles; we do not as yet attempt accurate estimates of scaling or other variable distributions. Differences in the radiative corrections to our distributions, which are expected to be small in comparison with our statistical errors, are neglected.

The ν_μ ($\bar{\nu}_\mu$) samples are weighted by an average of 1.02 for the momentum and angle-dependent part of the EMI acceptance. We estimate that the $e^\pm$ detection efficiency is $90 \pm 10\%$ and approximately independent of momentum and angle in the accepted momentum range.

Each $e^\pm$ event has been carefully studied by physicists. Following this, the probability of misidentification of a Compton electron or an $e^\pm$ from an asymmetric Dalitz pair or close γ conversion as a single primary $e^\pm$ is estimated to be such that less than 0.1 such events of either sign are included.

The $e^\pm$ momenta are corrected for bremsstrahlung by a modified Behr-Mittner method [6]. This has been supplemented by the addition of the momentum of catastrophic bremsstrahlung gammas, when detected. The method has been calibrated from the mass of reconstructed π^0 's. We obtain a peak mass of about 130 MeV, with FWHM of 40 MeV. However, uncertainties in this procedure are large, and increase with electron energy. The range of $e^\pm$ energies we observe extends above 50 GeV, with median values around 25 GeV. For some variables, in particular, the x distribution, resolution-smearing in the lepton momentum can change the

apparent shape of the distribution. To simulate the effects of resolution we begin with the ν_μ ($\bar{\nu}_\mu$) events and vary the momentum of the muon tracks randomly according to a Gaussian distribution, centered on the measured muon momentum, with FWHM chosen as a function of p_ℓ to duplicate the estimated momentum resolution of electron tracks. From each ν_μ ($\bar{\nu}_\mu$) event we generate at random five such "Monte Carlo" events. The resultant distribution is shown where appropriate.

Within a certain fiducial volume, neutral strange-particle decays and electron pairs identified as originating from the primary interaction, and not from secondary sources such as bremsstrahlung of a primary $e^\pm$, are included in the hadronic energy. The secondary interactions of neutrals emitted from the event are omitted. The ratios of the resultant average neutral hadronic energy to the average charged hadronic energy (Σp_L^{had}) are comparable: for ν_e we obtain 0.19 ± 0.06 , compared with $0.22 \pm .03$ for ν_μ ; for $\bar{\nu}_e$ we obtain 0.18 ± 0.06 , compared with 0.27 ± 0.04 for $\bar{\nu}_\mu$. From study of the ν_μ ($\bar{\nu}_\mu$) events, we find that a small fraction of the hadronic γ -rays might have been falsely identified as $e^\pm$ bremsstrahlung had the $\mu^\pm$ been an $e^\pm$. This effect may have reduced the ν_e ($\bar{\nu}_e$) ratios by as much as $\sim 10\%$; the effects on the inclusive distributions which we show are negligible.

The total visible Σp_L for the ν_e and $\bar{\nu}_e$ events is compared with that for the ν_μ and $\bar{\nu}_\mu$ events (normalized to the $e^\pm$ signal) in Fig. 1a,b. These distributions are sufficiently similar to permit meaningful comparison between inclusive ν_e and ν_μ and also between $\bar{\nu}_e$ and $\bar{\nu}_\mu$ distributions.

The first three variables we shall compare scale approximately. For these, we are insensitive to detailed agreement between the Σp_L distributions.

Fig. 2 shows the $x_{vis} = 2(\Sigma p_L) E_\ell \sin^2(\frac{\theta_\ell}{2}) / [M_p(\Sigma p_L - E_\ell)]$ distribution for ν_e and $\bar{\nu}_e$ events again compared with ν_μ and $\bar{\nu}_\mu$ normalized to the ν_e ($\bar{\nu}_e$) signal. An excess of events for electron neutrinos at roughly the three-standard deviation level is observed at low x_{vis} . When the muon spectrum is convoluted with the $e^\pm$ resolution function described above, we obtain the histograms drawn with black dots*, which agree to within better than two standard deviations with the ν_e ($\bar{\nu}_e$) data everywhere, when the indicated probable statistical and systematic errors in the smeared spectra are taken into account.

Fig. 3 compares the $y_{vis} = 1 - E_\ell / \Sigma p_L$ distributions. We see no discrepancies. The average value of y_{vis} for ν_μ is 0.37 ± 0.02 , compared with 0.38 ± 0.04 for ν_e ; for $\bar{\nu}_\mu$ we find 0.26 ± 0.01 , compared with 0.26 ± 0.03 for $\bar{\nu}_e$. The effects of poorer energy resolution for electrons and positrons than for muons are not serious in this variable.

The variable $u_{vis} = \Sigma p_L^{had} \sin^2 \theta_{had} / (2 M_p) \cong x(1-y)$ ("had" refers to

*We have also tried "smearing" functions with non-Gaussian (but still unbiased) shapes, including one with asymmetries based on that expected for bremsstrahlung processes, with similar results. From these studies, we estimate systematic errors in the smeared distribution to be about $\pm 1/2$ event everywhere. The errors sketched include this contribution in quadrature. The accumulation of events at $x_{vis} < 0.1$ occurs in the smeared distribution because dx_{vis}/dE_ℓ , the Jacobean of the transformation from E_ℓ to x_{vis} , increases as x_{vis} increases.

"hadronic") does not depend upon the lepton energy. No significant disagreement is observed in the comparison for this variable (Fig. 4). We find $\langle u_{\text{vis}} \rangle$ to be 0.110 ± 0.006 for ν_μ , compared with 0.140 ± 0.014 for ν_e ; for $\bar{\nu}_\mu$ we obtain 0.116 ± 0.007 , compared with 0.126 ± 0.017 for $\bar{\nu}_e$.

In Fig. 5 we restrict our attention to $\sin^2(\theta_\ell/2)$, the angular part of x_{vis} . This variable, though dependent upon track curvature, is not sensitive to the ability to detect bremsstrahlung gammas emitted close to the beginning of the track, which is a major source of $e^\pm$ momentum uncertainty. The agreement is seen to be quite good.

Finally, in Fig. 6 we show the charged particle multiplicity distributions, for which we also observe good agreement.

We have compared these event samples also for a number of other variables, which vary in their dependence on lepton energy and on undetected neutral hadrons. We find no areas of disagreement within the available statistics.

We conclude that within our statistics there is no evidence for differences between the behavior of CC events produced by ν_e and ν_μ interactions, or between $\bar{\nu}_e$ and $\bar{\nu}_\mu$ interactions, consistent with μ -e universality.

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FIGURE CAPTIONS

1. E_{vis} , defined to be $\Sigma p_L (\cong E_\nu)$, (a) for ν_e -induced CC events, with ν_μ -induced results dashed, normalized to ν_e signal; (b) for $\bar{\nu}_e$ -induced CC events, $\bar{\nu}_\mu$ dashed.
2. (a) $x_{vis} = 2 (\Sigma p_L) E_\ell \sin^2(\frac{\theta_\ell}{2}) / [M_P (\Sigma p_L - E_\ell)]$ for ν_e events (unbroken histogram), with ν_μ events dashed; (b) x_{vis} for $\bar{\nu}_e$ events, $\bar{\nu}_\mu$ dashed. Black dots: ν_μ ($\bar{\nu}_\mu$) data with "smeared" muon energy determination (see text). $x_{vis} > 1$ events shown in a single overflow bin.
3. (a) $y_{vis} = 1 - E_\ell / \Sigma p_L$, for ν_e , ν_μ dashed; (b) y_{vis} for $\bar{\nu}_e$, $\bar{\nu}_\mu$ dashed.
4. (a) $u_{vis} = \Sigma p_L^{had} \sin^2 \theta_{had} / (2 M_P)$ for ν_e , ν_μ dashed; (b) u_{vis} for $\bar{\nu}_e$, $\bar{\nu}_\mu$ dashed.
5. (a) $\sin^2(\theta_\ell/2)$ for ν_e , ν_μ dashed; (b) $\sin^2(\theta_\ell/2)$ for $\bar{\nu}_e$, $\bar{\nu}_\mu$ dashed.
6. (a) Charged particle multiplicity distribution for ν_e , ν_μ dashed; (b) Same for $\bar{\nu}_e$, $\bar{\nu}_\mu$ dashed.

XBL 785-919

Figure 1

Figure 2

XBL 785 - 918

Figure 3

XBL 785-917

Figure 4

Figure 5

XBL 786 - 1182

Figure 6

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