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μ-e Universality in Charged Current Neutrino Interactions in A Neon-H_2 Mixture

H. C. BALLAGH, H. H. BINGHAM, P. BOSETTI, W. B. FRETTER, D. GEE, J.-F. GRIVAZ, G. LYNCH, J. P. MARRINER, J. ORTHEL, F. C. PORTER, M. D. SOKOLOFF, M. L. STEVENSON and G. P. YOST
University of California and Lawrence Berkeley Laboratory
Berkeley, CA. 94720

R. J. CENCE, F. A. HARRIS, M. D. JONES, S. I. PARKER, V. Z. PETERSON, M. W. PETERS and V. J. STENGER
University of Hawaii
Honolulu, HI. 96822

T. H. BURNETT, S. CSORNA, D. HOLMGREN, H. J. LUBATTI, K. MORIYASU, H. RUDNICKA†, G. M. SWIDER and B. S. YULDASHEV††
Visual Techniques Laboratory, University of Washington
Seattle, WA. 98105

ABSTRACT

From an exposure of the Fermilab 15-ft Neon (64 atomic %)-H_2 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.

†Visitor from the Inst. of Nuclear Physics and Tech. of the Academy of Mining and Metallurgy, Cracow, Poland.

††Present address: Physical Technical Inst., Tashkent, USSR.

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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 $\bar{\nu}_\mu$ charge current (CC) interactions under the same experimental conditions for energies between 10 and 150 GeV, the first such study above 10 GeV.[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. The experimental conditions[2] resulted in comparable numbers of ν_μ and $\bar{\nu}_\mu$-induced reactions. 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 have 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.[3] 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, ΣP_L ($\cong E_{visible}$) > 10 GeV, where the summation is over all measured charged and neutral particles; 2) p_ℓ > 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] $\mathcal{L} > 5$. 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.

In what follows, the ν_μ ($\bar{\nu}_\mu$) samples are normalized to the ν_e ($\bar{\nu}_e$) signal. 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.

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 ± 10% and approximately independent of momentum and angle in the accepted momentum range.

Each $e^\pm$ event has been carefully studied by a physicist. 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. 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.

The $e^\pm$ momenta are corrected for bremsstrahlung by a modified Behr-Mittner method.[5] 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, resolution-smearing in the lepton momentum can change the apparent shape of the distribution. To simulate the effects of resolution, we vary the momentum of muon tracks randomly according to a Gaussian[6] 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. The resultant distribution is shown where appropriate.

Within a certain fiducial volume, neutral strange-particle decays and electron pairs not identified as arising from the Bremsstrahlung of a primary $e^\pm$ are included in the hadronic energy. The interactions of neutrals emitted from the event are omitted. The resultant average neutral hadronic energy to the average charged hadronic energy (Σp_L) ratios are comparable: for ν_e we obtain 0.19 ± 0.06, compared with 0.22 ± .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 admixture of hadronic γ-rays falsely identified as $e^\pm$ Bremsstrahlung may have reduced the ν_e ($\bar{\nu}_e$) ratios by as much as ~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 ν_e and ν_μ and also between $\bar{\nu}_e$ and $\bar{\nu}_\mu$ distributions. We are insensitive to detailed agreement, because we restrict our study to variables which approximate scaling variables.

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}. However, when the muon spectrum is convoluted with the $e^\pm$ resolution function described above, we obtain the solid curves[7] (drawn smoothly through the points). Clearly, excellent agreement is observed when the resolution is taken into account.

Fig. 3 compares the $y_{vis} = 1 - E_\ell/\Sigma p_L$ distributions. We see no discrepancies. The effects of poorer energy resolution for electrons and positrons than for muons are not serious in this variable.

The variable $u_{vis} = \Sigma p_L^{had} \sin^2\theta_{had}/2\, M_p \simeq x(1-y)$ ("had" refers to "hadronic") does not depend upon the lepton energy. No significant disagreement is observed in the comparison for this variable (Fig. 4).

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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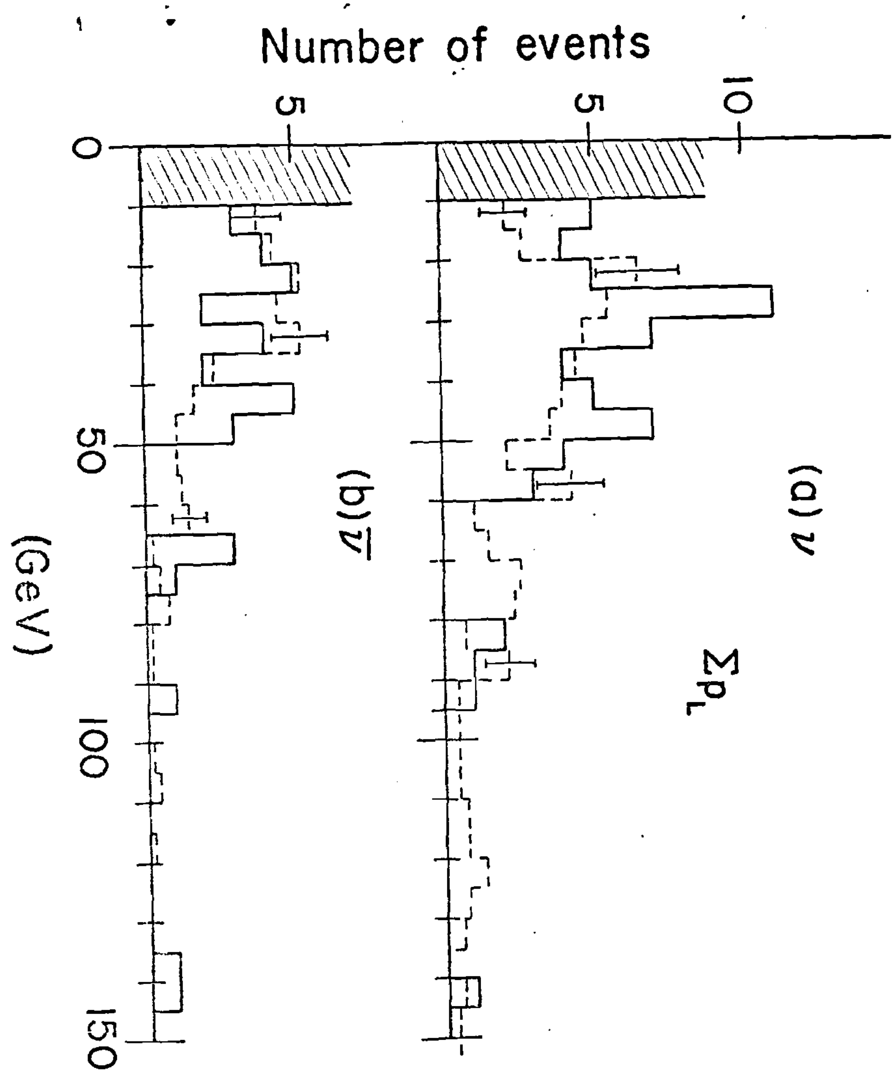
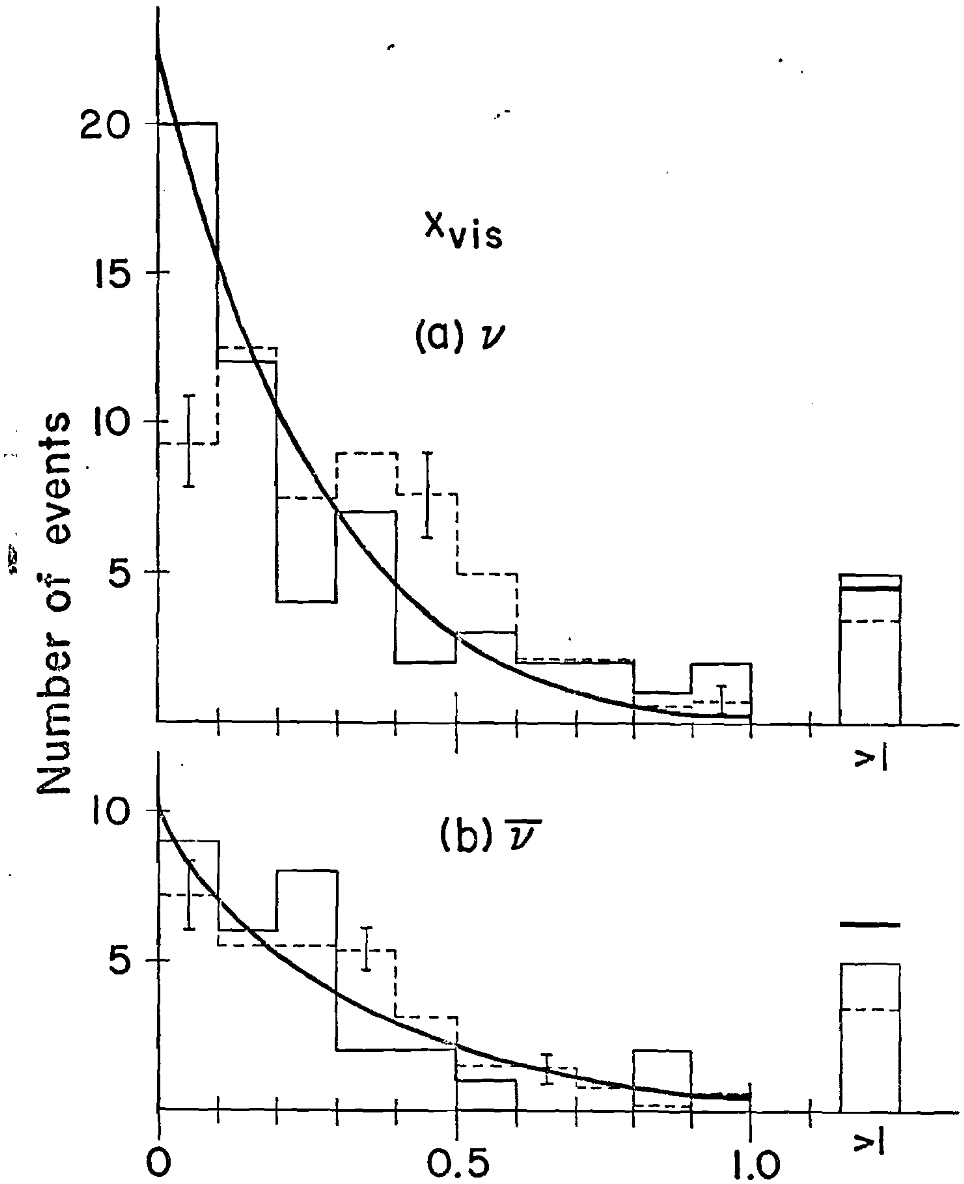
REFERENCES

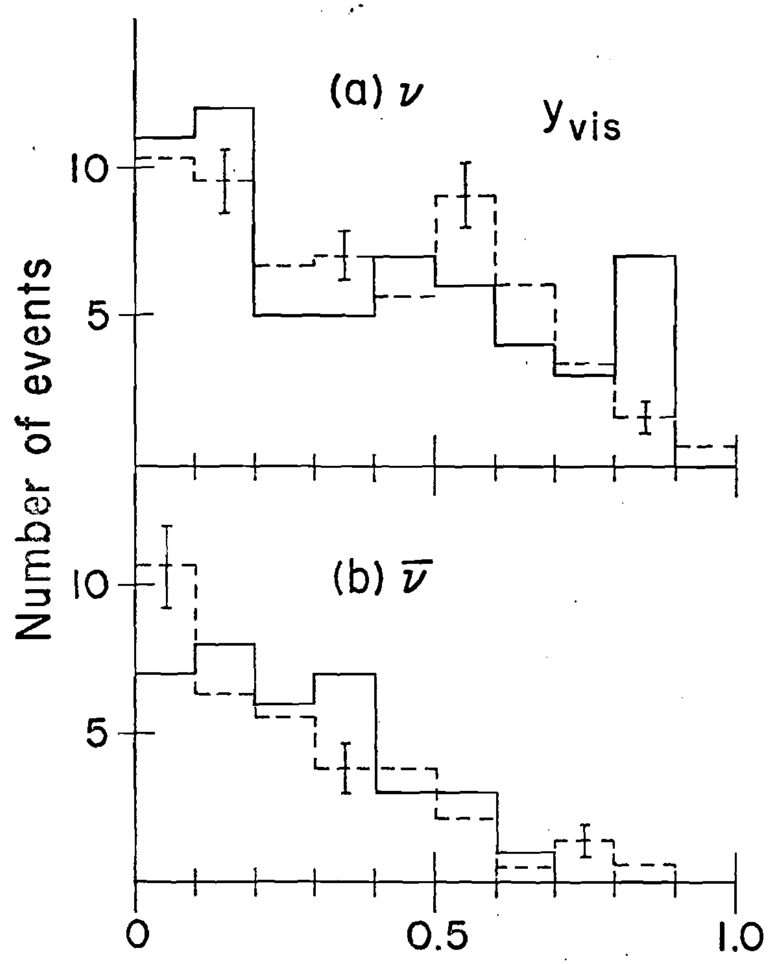
1. J. Blietschau et al., CERN/EP/PHYS 77-47 (1977); T. Eichten et al., Phys. Lett. 46B, 281 (1973).
2. H. C. Ballagh et al., Phys. Rev. Letts. 39, 1650 (1977).
3. The source of ν_e ($\bar{\nu}_e$) candidate events from prompt neutrinos of unknown identity [P. Alibran et al., Phys. Letts. 74B, 134 (1978); T. Hansl et al., ibid, p.139; P. C. Bosetti et al., ibid, p.143], which may contribute $\lesssim$ 10% of our events, is assumed not to affect our comparisons.
4. R. J. Cence et al., Nucl. Inst. and Meth. 138, 245 (1976). G. Lynch, LBL Physics Notes No. 808, Sept. 24, 1975. C. Ballagh, University of California Internal Report UCB-CB, June 4, 1977.
5. L. Behr and P. Mittner, Nucl. Inst. and Meth. 20, 446 (1963).
6. We have also tried smearing functions with asymmetries based on those expected for Bremsstrahlung processes, with similar results.
7. 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}, is a decreasing function of x_{vis}.

FIGURE CAPTIONS

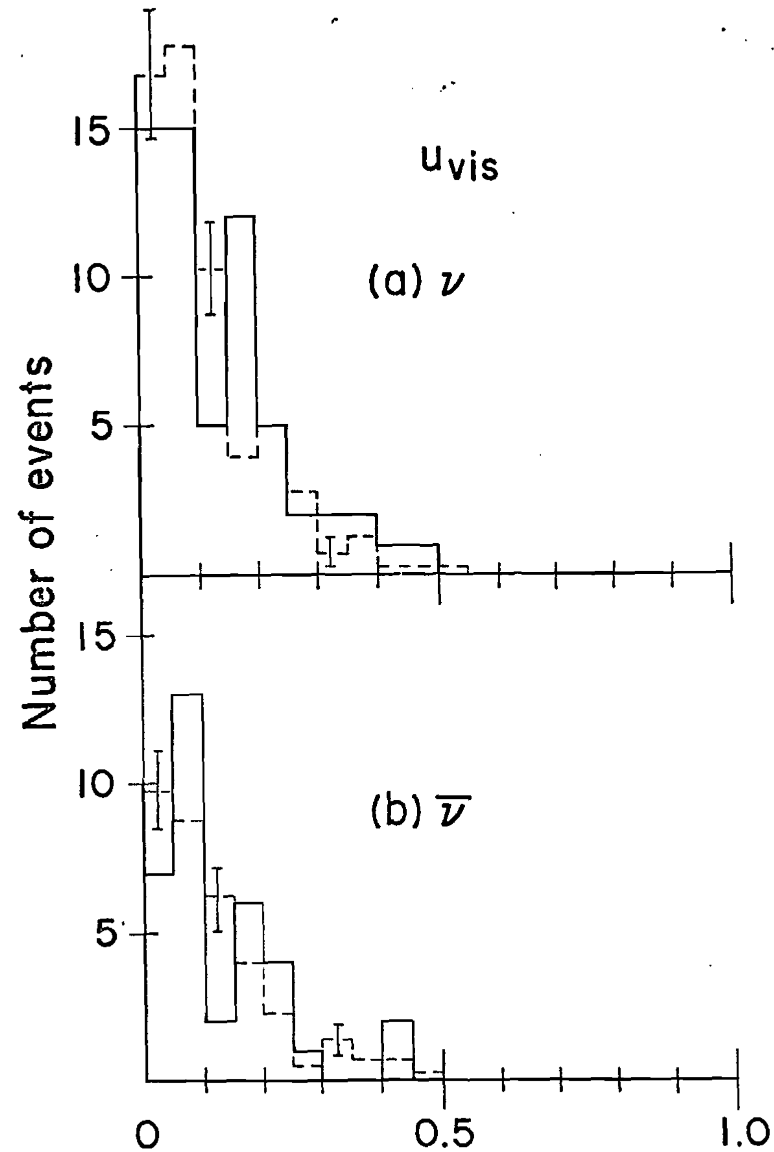
1. E_{vis}, defined to be Σp_L ($\cong E_\nu$), (a) for ν_e-induced CC events, with ν_μ-induced results dashed, normalized to ν_e signal; (b) for $\bar{\nu}_e$-induced CC events, $\bar{\nu}_\mu$ dashed.
2. (a) $x_{vis} = 2\,(\Sigma p_L)\,E_\ell \sin^2(\frac{\theta_\ell}{2})/M_p(\Sigma p_L - E_\ell)$ for ν_e events (unbroken histogram), with ν_μ events dashed; (b) x_{vis} for $\bar{\nu}_e$ events, $\bar{\nu}_\mu$ dashed. Solid curves: 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.


Number of events
(a) ν
(b) $\overline{\nu}$
Σp_L
(GeV)


Number of events
x_{vis}
(a) ν
(b) $\overline{\nu}$
>1


(a) ν
y_{vis}
(b) $\bar{\nu}$
Number of events
10
5
10
5
0
0.5
1.0

XBL 785-918


u_{vis}
(a) ν
(b) $\bar{\nu}$
Number of events
15
10
5
15
10
5
0
0.5
1.0