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EXPERIMENTAL VERIFICATION OF THE UNIVERSALITY OF ELECTRON-NEUTRINO
AND MUON-NEUTRINO COUPLING TO THE NEUTRAL WEAK CURRENT

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ABSTRACT

We report on the ratio of the coupling strengths of electron- and muon neutrinos to the neutral weak current, derived from measurements of total semileptonic neutrino cross sections on an isoscalar target. Using an enriched electron-neutrino beam with equal fluxes of ν_e and $\bar{\nu}_e$ produced by dumping the 400 GeV proton beam of the CERN-SPS into thick copper targets (beam-dump) we measured $\sigma(\text{NC}(\nu_e^{(-)}))/\sigma(\text{CC}(\nu_e^{(-)})) = 0.406^{+0.145}_{-0.135}$. Combining this value with the result we obtained in an exposure to a narrow band neutrino beam, we derived the ratio of the coupling constants $g_{\nu_e \bar{\nu}}/g_{\nu_\mu \bar{\nu}_\mu} = 1.05^{+0.15}_{-0.18}$, in good agreement with universal coupling strength of the electron- and muon-neutrino to the neutral weak current.

The notion of universality of the coupling of the electron, the muon and the tau family to the charged and the neutral weak currents is mainly based on experimental data [1].

The most precise comparison at low values of Q^2 of the relative coupling strength of the electron and muon families to the charged weak current has been derived from precise measurements of the ratio of the corresponding pion decay rates [2]

$$\Gamma(\pi \rightarrow e \nu_e) / \Gamma(\pi \rightarrow \mu \nu_\mu) = (1.218 \pm 0.014) \cdot 10^{-4} \quad (1)$$

with the result

$$(g_{e\nu_e} / g_{\mu\nu_\mu}) = 0.9939 \pm 0.0057 \quad (2)$$

From measurements of muon-neutrino electron scattering [3] and of the forward-backward asymmetry in the $e^+e^- \rightarrow \mu^+\mu^-$ [4] the relative axial-vector coupling strengths of the electron and the muon to the neutral-current have been derived, with the result

$$g_{ee}/g_{\mu\mu} = 0.96 \pm 0.11 \quad (3)$$

No measurements of comparable accuracy have been reported on the ratio

$$g_{\nu_e \bar{\nu}_e} / g_{\nu_\mu \bar{\nu}_\mu} \quad (4)$$

of the coupling strengths of electron- and muon-neutrinos to the neutral weak current. This ratio can be derived from measurements of the ratios of total cross sections for semileptonic neutrino scattering

$$R^e = \sigma(\nu_e N \rightarrow \nu_e X) / \sigma(\nu_e N \rightarrow e X) \quad (5)$$

and

$$R^\mu = \sigma(\nu_\mu N \rightarrow \nu_\mu X) / \sigma(\nu_\mu N \rightarrow \mu X) \quad (6)$$

in high energy neutrino beams using eq.(2). Values of R^μ for high energy ν_μ and $\bar{\nu}_\mu$ beams have been reported elsewhere [5]. In a beam composed of equal fluxes of ν_μ and $\bar{\nu}_\mu$ we expect

$$R^{\mu} = 0.340 \pm 0.005 \quad , \quad (7)$$

for E_h , the energy of the hadronic shower, larger than 2 GeV. Precise values for R^e have not yet been reported, because of the difficulty of producing high energy electron-neutrino beams.

We report here a measurement of R^e using a neutrino beam produced by a high energy proton beam dump, which is enriched ($\phi_{\nu_e}/\phi_{\nu_{\mu}} \sim 1/6$) in electron-neutrinos. The 400 GeV proton beam was extracted from the CERN SPS in a single turn (23 μ sec) and dumped onto thick copper targets in the direction of the neutrino detector. The targets were installed at the downstream end of the decay tunnel used for normal neutrino beam operation. The distance to the centre of the fiducial volume of the detector was 487.3 m. Targets with full and one-third density were bombarded by $13.26 \cdot 10^{17}$ and $6.35 \cdot 10^{17}$ protons, respectively. Prompt muon-neutrinos from decays of short-lived parent particles (mainly charmed mesons) and conventional neutrinos from long-lived parents (pion and kaons) were found to contribute in a ratio of about 1 to 2.7 (density 1) and 1 to 8 (density $1/3$) to the beam [6]; for electron-neutrinos these ratios are about 1 to 0.2 (density 1) and 1 to 0.6 (density $1/3$). The flux of prompt neutrinos is composed of electron- and muon-neutrinos with approximately equal contributions of neutrinos and antineutrinos[6]. The flux of neutrinos of conventional origins is composed of electron neutrinos again with equal contributions of neutrinos and antineutrinos, mainly from neutral kaon decays, and of muon-neutrinos with neutrinos and antineutrinos in the ratio of 1.6 to 1, mainly from pion decays. The mean energy of electron-neutrino induced events is 54.3 GeV and that of muon-neutrinos is 25.2 GeV [10]. For the following analysis we summed up events from both densities.

The CHARM neutrino detector was exposed to this dump neutrino beam in 1982. The detector [7] is composed of a fine-grain target calorimeter and of a muon spectrometer. The target calorimeter consists of 72 marble plates of 8 cm thickness (about one radiation length) and of 3 m x 3 m cross-section which are interlaced between layers of scintillation counters, (3 cm thick, 15 cm wide and 300 cm long), proportional drift-tubes, (3 cm x 3 cm x 400 cm), and digital wire chambers working in the limited streamer mode [8] with wires oriented at 90° with respect to those of the proportional drift tubes. The

proportional drift-tubes extend into the 45 cm wide magnetized iron frame that surrounds the calorimeter. The orientation of all detector elements alternates between horizontal and vertical in consecutive gaps. The total mass of the fiducial volume (59 planes, $2.4 \times 2.4 \text{ m}^2$) is 90.6 tons. The other parts of the calorimeter volume have only detector functions; the first two planes are used to veto incident muons, the lateral iron frames and the outer 30 cm of the calorimeter planes are used to veto cosmic rays and to perform shower measurements. The last 14 planes and the end calorimeter are used only for shower measurements and event classification. The response and resolution of the calorimeter to hadronic and electromagnetic showers has been measured in pion and electron beams in the energy range from 5 to 140 GeV [9].

Interactions in the CHARM detector were classified by an automatic pattern recognition program on an event-by-event basis. Events with an outgoing muon with more than 1 GeV energy were classified as charged-current muon-neutrino interactions (1μ), all others were called muonless. Muonless events are composed of neutral-current events initiated by muon- or electron-neutrinos and by charged-current electron-neutrino interactions $N(1e)$. The latter class of events was recognized directly by using the characteristic difference in lateral profile of electron and hadron induced showers [9].

We determined the quantity R^e eq.(5) from the observed rates of these events after proper corrections for background losses and event class mixing, averaging over ν_e and $\bar{\nu}_e$ fluxes which are nearly equal [10]:

$$R^e = \frac{N(0\mu, E_{sh} > 2 \text{ GeV}) - \bar{R}^\mu N(1\mu, E_{sh} > 2 \text{ GeV}) - N(1e, E_{sh} > 2 \text{ GeV})}{N'(1e, E_h > 2 \text{ GeV})} \quad (8)$$

$\bar{R}^\mu$ is obtained by taking into account the ratio of observed ν_μ and $\bar{\nu}_\mu$ induced CC events [5].

We now give some details on the analysis. A filter program rejected events with topologies typical for cosmic rays. The remaining cosmic ray background was found to be $(0.40 \pm 0.04)\%$ for muonless events and subtracted.

The classification efficiency of the automatic pattern recognition is very high. The program recognized and flagged event topologies for which the automatic procedure could fail. A visual inspection of these flagged events

and a double scan of 10% randomly selected events allowed us to correct errors introduced by the pattern recognition code. As a result of the scanning we increased the sample of muonless events $N(0\mu)$ by 2.1% and decreased the muonic sample $N(1\mu)$ by 5.0%; the uncertainty of classification was found to be $\sigma \cong \pm 0.3\%$.

A small fraction of NC events contains a track which fulfils the requirements of a primary muon of a CC event; these events are classified as CC events. This background is caused by decays of pions or kaons in the shower or by non-interacting hadrons, the so-called punch-through tracks. The correction is calculated as the fraction of charged-current events in which after removing the primary muon another track is found which satisfies the muon recognition criteria. We corrected for genuine dimuon events and for double tracks amounting to about 0.5% of the original 1μ events and found that the number of (0μ) events had to be increased by $(2.1 \pm 0.6)\%$.

If the muon produced in a charged-current interaction had less than 1 GeV energy, or left the detector with a visible track length corresponding to less than 1 GeV energy loss, or had a track which did not emerge from the hadron shower, the muon would have escaped detection. These event losses were calculated using Monte Carlo methods. The correction increased the number of muonic events by $(7.6 \pm 0.5)\%$ and reduced the number of muonless events by $(11.0 \pm 0.7)\%$ [10].

In the case of electron-neutrino induced charged-current events the shower detected in the calorimeter consists of an electromagnetic component induced by the electron and a hadronic component induced by the recoiling hadron system. In most cases these two components are not separated in space. To recognize an electron shower and to determine its energy and that of the hadron shower separately, we exploited the narrow width (2.5 cm FWHM) and regular longitudinal development of electron showers, in contrast to the broader and irregular hadron showers (20 cm FWHM). We selected a road of scintillators (15 cm wide) starting at the shower vertex to estimate the energy of electron showers. The vertex and direction of this road was varied until the best consistency of four different estimators was reached. The energy response and resolution of the estimators was calibrated using data obtained in electron beams of 5 to 50 GeV energy [9]. Figure 1 shows the result of the method when applied to a mixed beam of 15 GeV electrons and

pions. The observed distribution of inelasticity, $y = (E_{\text{total}} - E_{\text{elm}})/E_{\text{total}}$, shows a clear separation of electron and pion showers. For electron-neutrino induced charged-current events the response of the electron energy estimators is shifted by the presence of the hadron shower. We evaluated this effect by artificially constructing such events from charged-current muonic events, by replacing the muon by an electron shower of the same energy and direction, which we generated by Monte Carlo simulation. In this way we avoided the more difficult task of simulating hadron showers.

We calculated the corrected inelasticity for all events of the muonless sample. Figure 2(a) shows the observed distribution (full line); it is composed of genuine electron-neutrino charged-current events and background due to neutral current events. We determined the shape of that background experimentally by evaluating the inelasticity distribution for muonless events obtained in horn focussed wide band neutrino and antineutrino beams. This beam contains only a small contamination of electron-neutrinos (about 2.2% [11]) which was taken into account in the analysis. The contributions of electron-neutrino charged-current events and of background were separated by a fit of their two known shapes to the observed distributions. Figure 2(a) shows the background component (dashed line) and figure 2(b) shows a comparison of the electron-neutrino distribution thus determined with the expected distribution, assuming equal fluxes of ν_e and $\bar{\nu}_e$; the agreement is good. We unfolded the effects of different electron and hadron energy response and resolution, of the muon energy resolution and of the event selection criteria from the observed distributions using an iterative Monte Carlo method.

We selected 0μ and 1μ events with $E_{\text{sh}} > 2$ GeV to evaluate the quantity R^e of eq. (8), and applied the corresponding selection of $E_{\text{sh}} = E_e + E_h > 2$ GeV for $1e$ events; in the denominator of eq.(8) we use, appropriately, $N'(1e, E_h > 2 \text{ GeV}) = \alpha \times N(1e, E_{\text{sh}} > 2 \text{ GeV})$ with $\alpha = 0.865 \pm 0.025$ [12].

The corrected event numbers are summarized in table 1. Taking into account correlations of the errors, we deduced from eq. (8) for equal fluxes of ν_e and $\bar{\nu}_e$

$$R^e = 0.406 \begin{matrix} + 0.145 \\ - 0.135 \end{matrix},$$

and combining with the value of R^μ from eq.(7) we derive, assuming $(g_{e\nu_e}/g_{\mu\nu_\mu}) = 1$, in agreement with eq. (2),

$$(g_{\nu_e \bar{\nu}_e} / g_{\nu_\mu \bar{\nu}_\mu}) = (R^e / R^\mu)^{1/2} = 1.09^{+0.18}_{-0.20} . \quad (9)$$

Combining eq. (9) with the value we obtained in the analysis of data from an exposure to a narrow band neutrino beam [13] we obtained the final result

$$g_{\nu_e \bar{\nu}_e} / g_{\nu_\mu \bar{\nu}_\mu} = 1.05^{+0.15}_{-0.18} , \quad (10)$$

in good agreement with unity as expected for universality of the coupling of the electron- and muon-neutrino to the neutral weak current.

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Table 1

Number of events selected according to the definitions,
used to evaluate the ratio $R^e = \frac{NC}{CC} (\nu_e + \bar{\nu}_e)$ from eq.(8).

A value of $R^\mu = 0.3334 \pm 0.0042$ is used [5]

Event definition	Number of selected events
$N(l\mu, E_h > 2 \text{ GeV})$	$5004.6 \pm 68.8(\text{stat.}) \pm 46.5(\text{syst.})$
$N(O\mu, E_{sh} > 2 \text{ GeV})$	$2847.8 \pm 56.2(\text{stat.}) \pm 43.4(\text{syst.})$
$N(le, E_{sh} > 2 \text{ GeV})$	$872.3 \pm 60.2(\text{stat.}) \pm 65.5(\text{syst.})$
$N'(le, E_h > 2 \text{ GeV})$	$754.5 \pm 52.1(\text{stat.}) \pm 56.7(\text{syst.})$

REFERENCES

1. J.D. Borken and S. Weinberg, Phys. Rev. Letters 38 (1977) 622.
2. E. Di Capua et al., P.R. 133B (1964) 1333, see also D.A. Bryman et al., P.R. D11 (1975) 1337, and D.A. Bryman et al., Phys. Rev. Letters 50 (1983) 7.
3. F. Bergsma et al., CHARM Collaboration, Phys. Letters 147B (1984) 481.
L.A. Ahrens et al., Phys. Rev. Letters 55 (1985) 1814.
4. See e.g. B. Naroska, Proc. Int. Symp. Lepton Photon Interactions at High Energies, Ithaca 1983, eds.
D.G. Cassel and L. Kreinick (Cornell Univ., Ithaca, N.Y. 1983).
5. The value of $\bar{R}^\mu$ used in eq.(8) is $\bar{R}^\mu = 0.3334 \pm 0.0042$ taking into account the observed flux ratio $\phi(\nu_\mu)/\phi(\bar{\nu}_\mu)$.
F. Bergsma et al., CHARM Collaboration, Phys. Letters 99B (1981) 265 and Phys. Letters B (to be published) have measured for $E_h > 2$ GeV
 $R^\nu = 0.3132 \pm 0.0031$
 $R^{\bar{\nu}} = 0.395 \pm 0.014$.
6. P. Fritze et al., ABCLOS Coll., Phys. Letters 96B (1980) 427.
M. Jonker et al., CHARM Coll., Phys. Letters 96B (1980) 435.
H. Abramowicz et al., CDHS Coll., Z. f. Phys. 13C (1982) 17.
7. A.N. Diddens et al., CHARM Coll., Nucl. Instr. Methods 178 (1980) 27,
8. M. Jonker et al., CHARM Coll., Nucl. Instr. Methods 215 (1983) 361
9. M. Jonker et al., CHARM Coll., Nucl. Instr. Methods 200 (1982) 183
F. Bergsma et al., CHARM Coll. (to be published)
10. A full account of these corrections will be published in Z.Phys.C. The near equality of ν_e and $\bar{\nu}_e$ fluxes follows from a Monte Carlo simulation of charged and neutral kaons, Λ and Ξ for conventional origins and from the assumption of $D\bar{D}$ dominance for prompt origins.

11. M. Jonker, Ph.D. thesis, University Amsterdam 1983.
12. The ratio $\alpha = N'(1e, E_h > 2 \text{ GeV})/N(1e, E_{sh} > 2 \text{ GeV}) = 0.865 \pm 0.025$ has been determined by Monte Carlo simulation.
13. J.V. Allaby et al., CHARM Collaboration, "Test of the universality of electron-neutrino and muon-neutrino coupling to the charged weak current", Phys. Letters B (submitted).

FIGURE CAPTIONS

Figure 1 Result of the electron search algorithm applied to 15 GeV electron events and to 15 GeV pion events. The quantity evaluated is $y = (E_{\text{total}} - E_{\text{elm}}) / E_{\text{total}}$.

Figure 2 Distribution of the corrected inelasticity y for all events with $40 < E_{\text{total}} < 60$ GeV of the muonless sample.

(a) observed distribution (full line) and background from neutral current events (dashed line)

(b) inelasticity of the resulting electron-neutrino CC y -distribution with the expected distribution assuming equal ν_e and $\bar{\nu}_e$ fluxes.

Fig. 1

Fig. 2