Flavour Universality of Neutrino Couplings with the Z

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Abstract

We are reporting the first experimental result of the coupling of the muon neutrino with the Z. This result is in good agreement with the average value of the coupling of the three neutrino families as derived from the invisible decay width of the Z. We also determined $g^{V\tau}$ assuming $N_V = 3$.

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The couplings of the charged leptons and of the quarks of different flavours with the Z have been studied in high precision experiments of e^+e^- annihilation at the Z pole [1]. Much less is known about the couplings of the neutrinos.

We are reporting the first experimental result of the coupling of the muon neutrino with the Z. It is obtained by combining the result of the CHARM II experiment on muon-neutrino electron scattering [2] with the results of the four LEP experiments on coupling of the electron with the Z. Novikov, Okun and Vysotsky [3] have stressed that the unique importance of the CHARM II results is determined by the fact that their interpretation does not imply neutrino flavour universality. We compare the CHARM II result with the average value of neutrino Z coupling derived from the invisible decay width of the Z for three neutrino flavours. Next we also use previous results on the coupling of the electron-neutrino to the Z reported by the CHARM Collaboration and by an experiment at LAMPF and determine the coupling of ν_τ to the Z from Γ_{inv} and the assumption of three neutrino flavours. These two results are consistent with neutrino flavour universality of the Z coupling.

In deriving from Γ_{inv} the number of light neutrino flavours N_ν , universality of their coupling to the Z has to be assumed. This can now be done, for the first time, with an experimental justification. The other assumption^{a)} which has been made, $2g^V = 1$, is no longer required as the experimental result for ν_μ coupling to the Z from this experiment can be used. Finally, we give a new evaluation of N_ν using the experimental result for g^V .

From the CHARM II experiment on muon-neutrino electron scattering the following values of coupling constants have been determined [2] without assumption about neutrino flavour universality of the Z coupling,

$$g_A^{e\nu\mu}(\text{CHARM II}) = -0.503 \pm 0.006(\text{stat}) \pm 0.016(\text{syst}) \quad (1)$$

$$g_V^{e\nu\mu}(\text{CHARM II}) = -0.035 \pm 0.012(\text{stat}) \pm 0.012(\text{syst}) \quad (2)$$

The authors of reference [3] have shown that these coupling constants determined from $\nu_\mu e$ scattering can be expressed by the products of g_A^e or g_V^e and $g^{\nu\mu}$. In brackets we give the q^2 domains of the experiments from which they are determined.

$$g_A^{e\nu\mu}(0.01 \text{ GeV}^2) = 2g^{\nu\mu}(m_Z^2) g_A^e(m_Z^2) \quad (3)$$

$$g_V^{e\nu\mu}(0.01 \text{ GeV}^2) = 2g^{\nu\mu}(m_Z^2) g_V^e(m_Z^2) \quad (4)$$

Hence, the ν_μ coupling with the Z can be determined using the LEP results for g_A^e and g_V^e from $Z \rightarrow e^+e^-$ [1]. The relations (3) and (4) are valid because large contributions from γ -Z mixing and from the neutrino charge radius in $\nu_\mu e$ scattering nearly cancel each other and can be safely neglected compared with the experimental uncertainties of the CHARM II results, and because the couplings of the Z boson do not run unless $|q^2| \gg m_Z^2$ [3].

a) For clarity, we neglect here a small radiative correction of $\sim 3.5 \cdot 10^{-3}$ which has been applied in the LEP analysis.

From the LEP experiments one obtains [1] the following values for the electron axial vector and vector couplings

$$g_A^e (\text{LEP}) = -0.50084 \pm 0.00095 \quad (5)$$

$$g_V^e (\text{LEP}) = -0.0382 \pm 0.0032 \quad (6)$$

From eqs (1) - (6) we determined

$$2g^{V\mu} = 1.004 \pm 0.033 \quad (7)$$

to be compared with the LEP result on the average value of neutrino Z coupling derived from the invisible decay width of the Z [1], Γ_{inv} ,

$$2g^V = 0.9999 \pm 0.0043 \quad (8)$$

for three neutrino flavours. In the LEP analysis [1] this result is obtained from the relation $(2g^V)^2 = \Gamma_{\text{inv}}/N_\nu \cdot 2\Gamma_0$ with $\Gamma_0 = \sqrt{2}G_F m_Z^3/48\pi$. The agreement of eqs (7) and (8) is the first direct evidence for neutrino flavour universality in NC coupling.

Using a previous measurement of the ratio

$$g^{Ve}/g^{V\mu} = 1.05^{+0.15}_{-0.18} \quad (9)$$

by the CHARM Collaboration [4] we determine using eq. (7) a value of

$$2g^{Ve} = 1.054 \pm 0.165 \quad (10)$$

Another result can be derived in a way similar to $g^{V\mu}$ from the $\nu_e e$ scattering experiment at LAMPF [5] and from LEP results

$$2g^{Ve} (\text{LAMPF}) = 0.92 \pm 0.28 \quad (11)$$

The combined result is

$$2g^{Ve} = 1.019 \pm 0.142 \quad (12)$$

Now we can determine $g^{V\tau}$ from Γ_{inv} assuming $N_\nu = 3$ and inserting (7) and (12). The result,

$$2g^{V\tau} = 0.98 \pm 0.15 \quad (13)$$

is in good agreement with $2g^V$ from eq (8) and thus reduces the possibility that the agreement between $g^{V\mu}$ and g^V is fortuitous.

At this point it is important to verify that the small component ($\sim 1\%$) of ν_e of the neutrino beam used in the CHARM II experiment [6] does not spoil the argument. Taking

into account the uncertainty of g^{Ve} in the analysis of the CHARM II experiment we find an additional error of

$$\Delta g^{V\mu} = \pm 0.003$$

negligible in comparison with the present experimental error on $g^{V\mu}$ of ± 0.033 .

Finally, we re-evaluated the number of light neutrino flavours from Γ_{inv} [1], assuming, based on the results presented above, that neutrino coupling with the Z is flavour universal and using the coupling strength of ν_μ from the present analysis

$$2g^{V\tau} = 2g^{Ve} = 2g^{V\mu} = 1.004 \pm 0.033 ,$$

with the result

$$N_V = 2.98 \pm 0.20 , \tag{14}$$

in good agreement with the result [1] obtained from Γ_{inv}

$$N_V = 2.980 \pm 0.027 \tag{15}$$

obtained assuming both neutrino flavour universality and standard model coupling ($2g^V = 1$) but with much larger error. It also agrees with $N_V = 2.80 \pm 0.14$ obtained [1] from the reaction $e^+e^- \rightarrow \gamma(Z \rightarrow \nu\bar{\nu})$; here again the same assumptions have been made. However, the errors in eq (14) are reflecting the status of our present knowledge.

In conclusion, because the CHARM II results on neutrino electron scattering have been obtained without assumption about neutrino flavour universality, the coupling $g^{V\mu}$ can be determined from this experiment. Earlier experiments had established the equality of g^{Ve} and $g^{V\mu}$ at the 15% level. Combining these results with LEP data neutrino flavour universality in NC coupling is demonstrated for the first time and $g^{V\tau}$ is calculated assuming $N_V = 3$. The assumption $2g^V = 1$ (standard model) is not required any more for evaluating the number of neutrino flavours. The result is in good agreement with the previous result on the number of neutrino flavours, however the error is about seven times larger.

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