# Measurement of electroweak parameters from $\nu_\mu - e^-$ scattering

## The CHARM II Collaboration

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## Abstract

A determination of the electroweak parameters performed by the CHARM II experiment from the study of neutrino–electron elastic cross-section is reported. Analysed data refer to detector exposure to the CERN wide band neutrino beam in the years from 1987 to 1990. The observation of about 2100 $\nu e^-$ and 2200 $\bar\nu e^-$ scattering events, together with a precise measurement of the neutrino fluxes, enable us to measure the effective vector and axial–vector coupling constants of the electron to the weak neutral current. They are determined to be $g_V^e = -0.025 \pm 0.019$ and $g_A^e = -0.503 \pm 0.018$.

The importance of the electroweak parameters measurement in purely leptonic processes is well described in modern literature [1]. The comparison between results coming from LEP ($Q^2 \approx M_Z^2$) and fixed target experiments ($Q^2 \approx 0$) is also of great interest for the evaluation of the high order corrections to the Standard Model predictions.

The CHARM II detector, built for the study of neutrino–electron elastic scattering, is well suited for such a comparison being that this process is nearly equivalent in terms of coupling constants to the electron–positron annihilation into lepton pairs.

The analysis here reported is based on a measurement of the differential $\nu e^-$ and $\bar{\nu} e^-$ cross-sections for the determination of $g_V^e$ and $g_A^e$, the effective vector and axial–vector coupling constants of the electron to the weak neutral current [2].

## The CHARM II detector

Due to the extremely low cross-section of neutrinos off electrons ($\sigma \approx 10^{-42} cm^2/GeV$) the detector consists of a 796 tons mass target–calorimeter whose dimensions are of 40 meters in length with a transverse detection area of $3.7 \times 3.7 \ m^2$. To detect neutrino interactions and to measure the energy ($E_e$) and the direction ($\theta_e$) of the showers induced by scattered electrons, the calorimeter is instrumented (sandwich like) with streamer tubes with digital (from anode wires) and analog (from cathode pick–up strips) read–out. The experimental resolutions for electron induced electromagnetic showers are

$$\sigma_\theta^{proj} \simeq \frac{17 \ mrad}{\sqrt{E(GeV)}} \qquad \frac{\sigma_E}{E} = 11\% + \frac{9\%}{\sqrt{E(GeV)}}$$

in the range from 2 to 40 GeV. A muon spectrometer follows the calorimeter on the beam line to perform $\nu$–flux measurements using charge–current neutrino induced events. A complete description of the detector and its performance can be found in refs.[3, 4].

## Data taking and events selection

The data presented here are selected from the whole sample recorded over four years (1987–1990) of detector exposure to the neutrino and antineutrino wide band beams (WBB) at CERN. This represents about 80% of the final statistics that will be avalaible with the data collected in 1991.

In total $2.1 \times 10^{19}$ protons of 450 GeV from the SPS were delivered on the primary target. High accuracy measurements of the absolute neutrino fluxes were obtained from monitor reactions of known cross-sections. The total fluxes of $\nu_\mu$ in $\nu$ beam and $\bar{\nu}_\mu$ in $\bar{\nu}$ beam were found to be $(7.09 \pm 0.33) \times 10^{16}$ and $(8.80 \pm 0.46) \times 10^{16}$ respectively, with a total uncertainty of about 5%. The mean energy of muon-neutrinos in both beams was about 20 GeV. Using Monte–Carlo techniques the electron neutrino component was estimated to be 1%, with a mean energy of 35 GeV.

Neutrino–electron scattering events appear in the detector as electromagnetic showers kinematically constrained to have values smaller than 1 MeV in the $E_e \theta_e^2$ variable. The algorithms to select these events have been well described previously [5]. Using electron test-beam data the total efficiency of the selection chain was found to be 84%±3%, almost independent on the shower energy.
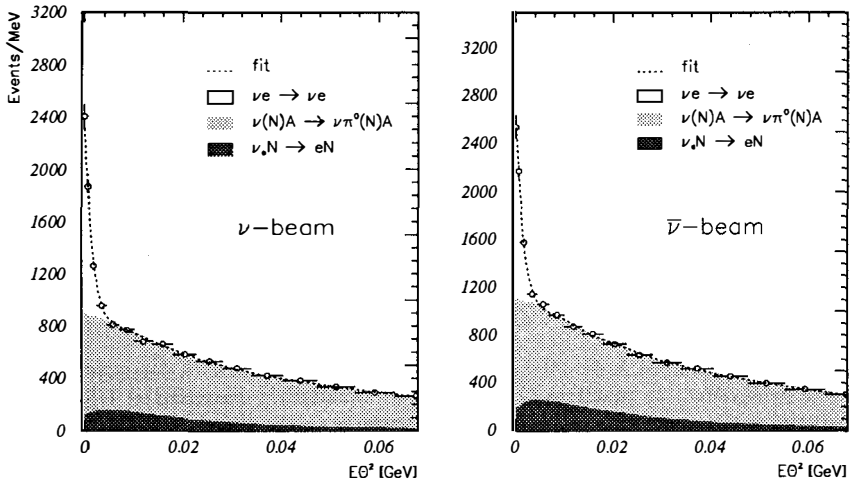
Figure 1: $E_e\theta_e^2$ distributions of the experimental data for neutrino and antineutrino exposures. Contributions of different processes are shown accordingly to the fit results.

As shown in figure 1, the main contribution to the background comes from large cross section ($\sigma \approx 10^{-38}cm^2$) neutrino reactions producing a predominately electromagnetic final state. A significant contribution comes from coherent and diffractive $\pi^o$ production in neutrino neutral current interactions [6]. Electromagnetic showers are also produced in quasi–elastic neutrino–nucleon reactions of electron–neutrinos. A small fraction of the background is due to inclusive neutrino reactions with a large electromagnetic component in the final state. All these background components are fully reproduced by Monte–Carlo simulations, as described in a previous paper [5].

## Analysis method

The procedure to determine the electroweak coupling constants of the electron to the neutral current makes use of the neutrino–electron scattering differential cross-sections

$$\left(\frac{d\sigma}{dy}\right)_i = \frac{G_F^2 m_e}{2\pi}E_\nu \cdot \left[A_1^i(g_V^e + g_A^e)^2 + A_2^i(g_V^e - g_A^e)^2 + A_3^i(2 + g_V^e + g_A^e)^2\right] \qquad (1)$$

where the index $i$ runs over the four possible reactions, as shown in table 1; also crucial is the knowledge of the absolute amount of the four neutrino species in $\nu$ and $\bar\nu$ beams together with their energy spectrum. The differential distributions of the expected amount of signal events in both beams are then written as a function of $g_V^e$ and $g_A^e$

$$\frac{d^2 n^{\nu e}}{dE_e d(E_e \theta_e^2)} = f^{\nu e}(g_V^e, g_A^e) \qquad (2)$$

where $f^{\nu e}$ contain all information about the target density, the neutrino fluxes and energy spectra, the cross section expressions $A_i$ and the experimental resolutions and acceptances.

Table 1: *Terms of the differential cross-section for different processes.*

| Process | $A_1$ | $A_2$ | $A_3$ |
|---------|-------|-------|-------|
| $\nu_\mu e \rightarrow \nu_\mu e$ | 1 | $(1-y)^2$ | 0 |
| $\bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e$ | $(1-y)^2$ | 1 | 0 |
| $\nu_e e \rightarrow \nu_e e$ | 0 | $(1-y)^2$ | 1 |
| $\bar{\nu}_e e \rightarrow \bar{\nu}_e e$ | 0 | 1 | $(1-y)^2$ |

Similarly, theoretical predictions give for the expected amount of background

$$\frac{d^2 n^{BG}}{dE_e d(E_e \theta_e^2)} = \sum_{i=1}^{4} b_i f_i^{BG} \tag{3}$$

where the coefficients $b_i$ determine the absolute contribution of each component to the total background. In equations (2) and (3) the variable $E_e \theta_e^2$ discriminates between signal and background while $E_e$ makes the fit sensitive to the energy spectra of different background sources.

A $\chi^2$ minimization is then performed to fit the experimental data to the predicted distributions leaving $g_V^e$ $g_A^e$ and $b_i$ as free parameters. The results of the fit ($\chi^2 = 703$ for 695 d.o.f.) are illustrated in figure 2 and summarized in table 2 for both beam polarities. The fourfold ambiguity in the determination of $g_V^e$ and $g_A^e$ which is expected from the quadratic dependence of the cross-sections on the couplings, is reduced to a twofold one by the contribution of $\nu_e e^-$ and $\bar{\nu}_e e^-$ elastic scattering events to the signal (about 10%). Results from LEP experiments resolve the remaining ambiguity [7].
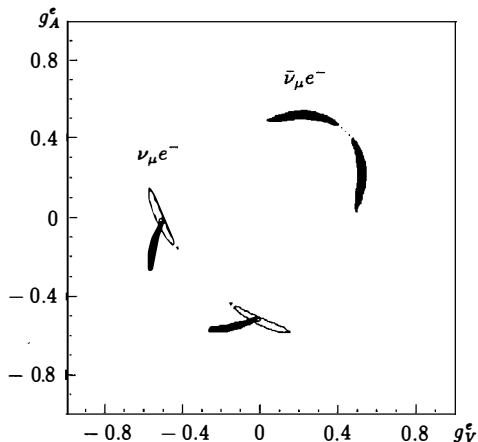


Figure 2: *Figure shows the $1\sigma$ contour region of the $\chi^2$ function in the $g_V^e$ - $g_A^e$ plane. Electroweak parameters are given by the intersections of the black area with the white one.*

Table 2: *Results of the fit to neutrino and antineutrino data. The errors are statistical only. The coefficients $b_i$ are the number of background events in the full fit range. Also shown is the number of neutrino–electron scattering events.*

| fit parameter | $\nu$–reaction | $\nu$-beam | $\bar{\nu}$-beam |
|---|---|---|---|
| $g_V^e$ | | $-0.0254 \pm 0.0138$ | |
| $g_A^e$ | | $-0.5027 \pm 0.0069$ | |
| | $\nu - e$ scattering | $2105 \pm 69$ | $2215 \pm 76$ |
| $b_1$ | $\pi^o$ coherent | $22238 \pm 1335$ | $25723 \pm 1542$ |
| $b_2/b_1$ | $\pi^o$ diffractive/coherent | $0.34 \pm 0.06$ | |
| $b_3$ | $\nu_e$ quasielastic | $4234 \pm 233$ | $7413 \pm 269$ |
| $b_4$ | inclusive | $681 \pm^{194}_{358}$ | $381 \pm^{224}_{380}$ |

The systematic errors are dominated by uncertainties on the background determination, on the absolute neutrino flux measurements and on the selection efficiency [2].

## Results and comparison with other experiments

The effective electroweak vector and axial–vector coupling constants of the electron to neutral current are found to be

$$g_V^e = -0.025 \pm 0.019 \qquad g_A^e = -0.503 \pm 0.018$$

where statistical and systematic errors have been added in quadrature.

The precision reached by the CHARM II experiment in the measurement of the electroweak coupling constants from neutrino–electron scattering, in comparison with previous neutrino experiments [8, 9], is shown in figure 3.
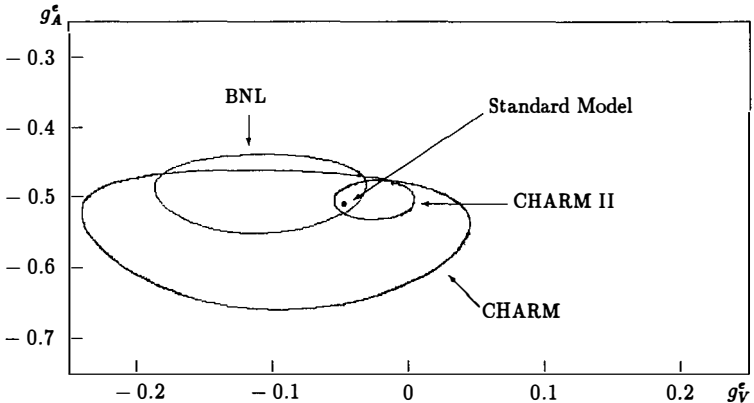


Figure 3: *Comparison of the electroweak coupling constants as measured in neutrino experiments. The regions in the $g_V^e$ - $g_A^e$ plane refers to 68% C.L. contours. The dot represents the Standard Model prediction assuming $m_t = [0, 300]$ GeV and $m_H = 100$ GeV.*
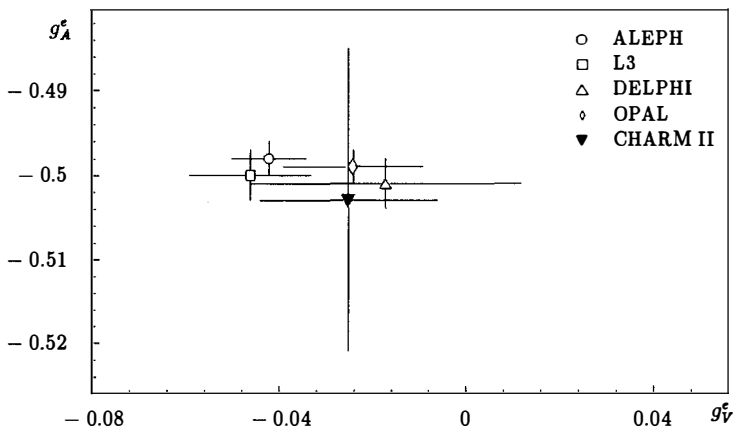
Figure 4: *Comparison of CHARM II results with LEP ones. In $e^+e^-$ annihilation $g^e_V$ and $g^e_A$ are measured from lepton partial widths and forward-backward asymmetries assuming leptonic universality [7].*

Since neutrino–electron scattering is related by crossing symmetry to electron–positron annihilation at the $Z^o$ pole, CHARM II results can be also compared directly with the measurements coming from LEP. Moreover, in the change of the energy scale from $Q^2 \approx 0.01\ GeV^2$ to $Q^2 \approx M_Z^2$, radiative corrections that are expected to arise from the running of the fine structure constant $\alpha$ and from the effect of the neutrino charge radius almost completely cancel [2, 10]. The comparison with the four LEP experiment results is illustrated in figure 4.

Using the Standard Model relations between the coupling constants and the electroweak mixing angle

$$g^e_V = \rho(-\frac{1}{2} + 2\sin^2\theta_W) \qquad g^e_A = -\frac{1}{2}\rho$$

it is also possible to perform a fit to the data considering $\sin^2\theta_W$ and $\rho$ as free parameters. In the $\overline{MS}$ renormalization scheme [1, 10] at $Q^2 = M_Z^2$ this yields to

$\sin^2\theta_W = 0.237 \pm 0.010(exp.) \pm 0.002(theor.) \qquad \rho = 1.001 \pm 0.038(exp.) \pm 0.004(theor.).$

The theoretical uncertainties account for $m_t = [80,180]GeV$ and $m_H = [50,1000]\ GeV$. This result can be compared directly to the predictions of the Minimal Standard Model using as input parameters $\alpha$, $G_F$ and the mass measurement of the $Z^o$ boson performed in LEP experiments [11]

$$\sin^2\theta_W = 0.233 \pm 0.002(theor.) \qquad \rho = 1.001 \pm 0.004(theor.)$$

where the theoretical errors arise from the same sources as above. The experimental errors from the uncertainty on the $Z^o$ mass measurement are comparably negligible.

In conclusion, electroweak parameters determined from the differential cross-section of neutrino-electron scattering are in very good agreement with the measurements from LEP experiments. The observed agreement, in spite of the wide range in $Q^2$ spanned by the experiments (about $10^6$), is a remarkable confirmation of the Standard Model predictions. In the next future more data will be included in the analysis, which will also be further improved.

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