AN IMPROVED DETERMINATION OF THE ELECTROWEAK MIXING ANGLE FROM MUON-NEUTRINO ELECTRON SCATTERING

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Abstract

We are reporting an improved determination of the electroweak mixing angle $\sin^2\theta_W$ from the ratio of $\nu_{\mu}e$ to $\bar{\nu}_{\mu}e$ scattering cross sections. The CHARM II detector was exposed to neutrino and antineutrino wide band beams at the 450 GeV CERN SPS. Including new data collected in 1989 we have obtained 1316 ± 56 $\nu_{\mu}e$ and 1453 ± 62 $\bar{\nu}_{\mu}e$ events. From the ratio of the visible cross sections we determined $\sin^2\theta^0 = 0.239 \pm 0.009(\text{stat}) \pm 0.007(\text{syst})$ without radiative corrections and $g_V^e/g_A^e = 0.047 \pm 0.046$. Combining this last result with recent results on g_A^e at LEP we obtain $g_V^e = -0.023 \pm 0.023$.

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1. Introduction

Measurements of neutral current processes at low energy can now be confronted with the precise results obtained in e^+e^- annihilations at the Z^0 pole. It is therefore of great interest to improve their precision. We have reported [1] on a determination of the electroweak mixing angle $\sin^2\Theta_W$ from the measurement of the ratio of the cross sections of $\nu_\mu e$ and $\bar{\nu}_\mu e$ scattering. Here we present a more precise determination of $\sin^2\Theta_W$ based on the same method. Improvements came from the inclusion of additional data, increasing the available statistics by 63%, and from a new and extensive calibration of the detector in electron and pion beams leading to better energy calibration and more precise direction determination for electromagnetic showers. A more careful consideration of background processes made it possible to reduce the systematic error in the separation of $(\bar{\nu}_\mu e)$ scattering from background.

In Born approximation, the cross section ratio depends on the value of $\sin^2\Theta_W$ through the relation

$$R = \frac{\sigma(\nu_\mu e)}{\sigma(\bar{\nu}_\mu e)} = 3 \frac{1 - 4 \sin^2\Theta_W + (16/3) \sin^4\Theta_W}{1 - 4 \sin^2\Theta_W + 16 \sin^4\Theta_W}$$

QED radiative corrections cancel to a large extent in this ratio [2] and can be neglected. Electroweak radiative corrections, however, change the value of $\sin^2\Theta_W$ by an amount which depends on the definition of the electroweak mixing angle, and in the framework of the Standard Model with three generations, on the unknown mass of the top quark m_t and of the Higgs boson m_H . In our previous publication [1] we have used the definition of $\sin^2\Theta_W$ by Marciano and Sirlin [3]. Here we consider also the on-shell scheme [4] because the result of our measurement, expressed in this definition of $\sin^2\Theta_W$, has a much weaker dependence on the unknown value of m_t .

The ratio of cross sections is determined from the ratio of neutrino electron scattering events $N(\nu e)$ and $N(\bar{\nu} e)$ obtained in the ν -beam or $\bar{\nu}$ -beam, respectively, with electron recoil energies in the range of 3 - 24 GeV. Since the cross sections are proportional to the neutrino energy we normalize the observed ratio of event numbers by the ratio F of energy weighted fluxes of the main components

$$F = \frac{\int \Phi_{\bar{\nu}_\mu}(E_{\bar{\nu}}) E_{\bar{\nu}} dE_{\bar{\nu}}}{\int \Phi_{\nu_\mu}(E_\nu) E_\nu dE_\nu}$$

and thus obtain an empirical ratio

$$R_{\text{vis}} = \frac{N(\nu e)}{N(\bar{\nu} e)} F$$

R_{vis} differs from the ideal ratio R because our analysis accepts recoil energies from 3 to 24 GeV only and because the selected events include a small number of indistinguishable events which are due to the minor components of the beam (i.e. $\bar{\nu}_\mu$, ν_e and $\bar{\nu}_e$ in

the neutrino beam, respectively ν_μ , ν_e and $\bar{\nu}_e$ in the antineutrino beam). The dependence of R_{vis} on $\sin^2\Theta_W$ is similar to that of R . The functions $R_{\text{vis}}(\sin^2\Theta_W)$ and $R(\sin^2\Theta_W)$ are shown in figure 1 of our previous publication [1].

As already emphasized [1], the determination of R_{vis} involves measurements of ratios and therefore does not require knowledge of absolute efficiencies and of the absolute neutrino fluxes. Systematic uncertainties are therefore expected to be small.

2. The Experimental Set-up

The CHARM II detector and the horn focussed wide band neutrino beam have been described in detail previously [1, 5]. The detector consists of a target-calorimeter of 796 tonnes mass and a muon spectrometer. The calorimeter is instrumented with streamer tubes to detect neutrino interactions and to measure the energy and direction of particle showers.

The direction of electron showers was previously [1] determined with a resolution for the projected angle Θ_e of $\sigma(\Theta_e) = 22 \text{ mrad}/\sqrt{E/\text{GeV}}$. Using the new calibration data obtained in electron beams of 2-30 GeV energy we developed a new direction algorithm. This algorithm uses simultaneously wire hit and cathode strip information for the measurement of the lateral profile along the shower and gives an improved resolution of $\sigma(\Theta_e) = (18 \pm 1) \text{ mrad}/\sqrt{E/\text{GeV}}$. This resolution has been achieved for the neutrino data sample after an accurate survey of the position of the detector elements using cosmic rays.

The new calibration data were also used to define the energy response of the calorimeter. We recall that the energy of electromagnetic showers is determined from the number of wire hits and independently by summing the charge on the cathode strips [5] inside the shower region. In this paper we use the energy as given by the wire hits. Using the scintillator system of the calorimeter as a reference [1, 5] we checked that the response is uniform over the entire calorimeter. Small variations of effective high voltage on the streamer tubes which were not compensated by the automatic feed-back system [5] were determined using cosmic ray data and corrected for. The remaining uncertainty in the energy scale is estimated at $\pm 5\%$. The energy resolution for electron showers is found to be 16% at 3 GeV and 11% at 24 GeV.

We summarize the average of the beam composition and the mean energies in Table 1. The ν_μ and $\bar{\nu}_\mu$ components and their mean energies were obtained by analyzing CC events without visible hadronic recoil with low momentum transfer ("quasielastic-like"). The ν_e and $\bar{\nu}_e$ components were calculated by Monte Carlo methods.

3. Data Taking

We are reporting here on data recorded over three years (1987-1989). The trigger-scheme has been described before [1, 5]. The number of protons on target for neutrino and antineutrino exposures are summarized in Table 2. We alternated between data runs in neutrino and antineutrino beams every 2-3 days. On average the sharing of protons between ν and $\bar{\nu}$ beams was in the ratio of $\nu/\bar{\nu} = 1/1.64$ to compensate for the difference

between neutrino and antineutrino fluxes per proton on target thus obtaining equal statistical errors on the event samples $N(\nu_e)$ and $N(\bar{\nu}_e)$.

4. Measurement of Neutrino Electron Scattering

The selection of the candidates of neutrino electron scattering proceeds as follows : in the first step we selected events with a topology of electromagnetic showers and in the second step we reconstructed the shower vertex and selected those events which have only one hit in the first streamer tube plane following the vertex. Events showing distinct tracks visible outside the shower core and originating from the vertex region were rejected. We selected events which have a large fraction of their energy deposited in a narrow road along the shower direction. The selection efficiency was measured in electron test beams with energies of 2-40 GeV and found to be 0.76 ± 0.03 , independent of energy.

The quantity $E\Theta^2$ is related to the inelasticity $y = E/E_\nu$ by the relation (for $E_\nu \gg m_e$)

$$E\Theta^2 = 2(1-y)m_e ,$$

where E , Θ and m_e are, respectively, the energy, the polar angle of the electron with respect to the neutrino direction and the mass of the recoil electron. Neutrino electron scattering is thus characterized by the kinematical bound $E\Theta^2 < 2m_e$.

The $E\Theta^2$ distributions of the selected events in the energy range 3-24 GeV are shown in figure 1a for the neutrino beam and in figure 1b for the antineutrino beam exposure. The pronounced peak for $E\Theta^2 < 3$ MeV is attributed to neutrino electron scattering, the broad background is mainly due to coherent and diffractive π^0 production by neutral current interactions [6, 7] and quasielastic-like ν_e and $\bar{\nu}_e$ events. We extracted the neutrino electron signal from a fit of the two dimensional E - $E\Theta^2$ distribution in the kinematic range $E\Theta^2 < 72$ MeV and $3 \text{ GeV} < E < 24 \text{ GeV}$. The shapes of the E - $E\Theta^2$ distributions are quite different for the signal and the background components and have been taken from a model. Their relative contributions are treated as free parameters of the fit.

The principles of the modelling of the background distribution are described in our previous paper [1]. It has been improved on several points. Pauli suppression at low Q^2 for diffractively produced π^0 has been introduced. A small component of inclusive π^0 events is now also considered and was estimated using the Lund Monte Carlo simulation program [8].

The statistics of ν_μ and $\bar{\nu}_\mu$ induced quasielastic-like events used as input for the simulation of ν_e and $\bar{\nu}_e$ events has been increased by a factor of five and the description of the Pauli suppression at low Q^2 , of the VA interference term and of the inverse muon decay contribution to the ν_μ sample have been improved.

The results of the best fit to the 2-dimensional (E , $E\Theta^2$) distributions are shown in figure 1. The quality of the fits is good : the fit with 841 degrees of freedom gives for the neutrino events $\chi^2 = 797$ and for the antineutrino events $\chi^2 = 814$. The relative contributions of the background reactions determined by the fit are given in Table 3

which also gives the results of an independent determination using the energy loss distribution in the scintillation counters immediately following the vertex plane [1, 5], from which the ratio of events with π^0 's and electrons can be deduced.

From the fit we determined for the kinematic region $3 \text{ GeV} < E < 24 \text{ GeV}$ and $0 < E\Theta^2 < 3 \text{ MeV}$ the following event numbers :

$$N(\nu_e) = 1316 \pm 56 \text{ (stat)}$$

$$N(\bar{\nu}_e) = 1453 \pm 62 \text{ (stat)}$$

The background subtracted $E\Theta^2$ distributions of these events are shown in figure 2a and b; they agree well with a Monte Carlo simulation using the experimental resolutions and the flux spectra.

Several systematic uncertainties affect the background subtraction. They are summarized in Table 4. Quadratically combined, they introduce a systematic error on $\sin^2\Theta_W$ of $\Delta\sin^2\Theta_W = \pm 0.006$, to be compared to ± 0.007 in our previous publication [1].

5. Flux Normalization

The value of the empirical ratio R_{vis} is the product of the ratio of ν_e and $\bar{\nu}_e$ events and the ratio F of the energy weighted $\bar{\nu}_\mu$ and ν_μ fluxes. We determined the flux ratio F in four independent ways: from the number of events recorded in the neutrino and antineutrino beams induced by *inclusive* NC and CC processes on nucleons and the known cross section ratio [11], from the number of NC produced π^0 events recorded in the range $5 \text{ MeV} < E\Theta^2 < 72 \text{ MeV}$, from the number of *quasielastic-like* CC processes observed in the range $0.10 \text{ GeV}^2 < Q^2 < 0.50 \text{ GeV}^2$ and from the integrated *muon flux* recorded in the muon shield of the beam line. Improvements since our previous publication [1] have allowed us to reduce some of the systematic errors. The results are summarized in Table 5.

For the *inclusive processes* an important contribution to the systematic error of F was due to the uncertainty of the correction for the energy threshold ($\sim 2\%$). The calibration of the energy response of the detector in pion and electron beams of 2 to 40 GeV and a simulation of the difference of the effective thresholds in NC and CC processes using a version of the Lund program adapted to neutrino scattering [8] allowed us to reduce this uncertainty to less than 1%. The overall systematic error (now 4.6%) is dominated by the uncertainty in the ratio of total ν and $\bar{\nu}$ cross sections below $E_\nu = 30 \text{ GeV}$, and the uncertainty of the beam composition.

Quasielastic-like events were selected with a cut on the hadronic energy $E_{\text{had}} < 1.5 \text{ GeV}$. The cross section for these events in the limit $Q^2 \rightarrow 0$ is equal for ν_μ and $\bar{\nu}_\mu$ for our isoscalar target. With increasing Q^2 one expects a slight difference due to the VA interference term which is approximately proportional to Q^2/E_ν . To determine F we extrapolate with a linear fit the ratio of quasielastic-like $\bar{\nu}_\mu$ to ν_μ events as a function of Q^2 from the interval $0.1 \text{ GeV}^2 < Q^2 < 0.5 \text{ GeV}^2$ to $Q^2 = 0$. The kinematic domain $Q^2 <$

0.1 GeV² is excluded in the fit because of the presence of inverse muon decay events amongst the ν_μ events and because of Pauli suppression. Corrections are applied for the small differences of the geometrical acceptance and the effect of the cut on the hadronic energy for ν_μ and $\bar{\nu}_\mu$ events. The error (3.8%) is essentially of systematic origin. It contains the uncertainty of the corrections and the uncertainty due to slight changes of F with the Q^2 interval of the fit.

Neutral-current induced coherent and diffractive π^0 production on nuclei proceed by axial-vector interaction and hence have equal cross sections for neutrinos and anti-neutrinos. Contributions from the resonance region are effectively excluded by the energy threshold of 3 GeV. We used the number of events recorded in the $E\Theta^2$ range from 5 to 72 MeV as a flux monitor. The systematic uncertainty is mainly due to the subtraction of the $(\bar{\nu}_e)N \rightarrow e^\pm N'$ contribution and of an inclusive π^0 contribution. We improved the description of the $(\bar{\nu}_e)N$ contribution as explained before and thereby reduced the systematic uncertainty, compared to our previous work [1], to $\Delta F/F (\pi^0) = \pm 4\%$.

The *flux of muons* produced by the decay of pions and kaons in the beam was measured as before [1] with a system of solid state detectors inserted into gaps in the shield behind 10 m and 30 m of iron [9] following the decay tunnel. The relation between the neutrino-antineutrino flux ratio and the corresponding muon flux ratio is only weakly dependent on the production spectra of pions and kaons produced in the target and has been recalculated by Monte Carlo simulation with high statistics; the systematic uncertainty is $\pm 3\%$. The remaining errors arise from uncertainties in the beam composition and the lateral beam profile. The total error is estimated as $\Delta F/F (\mu) = \pm 4\%$.

Corrections for dead time effects and for double events due to random overlays were applied where necessary.

The four normalization factors agree within their errors, their weighted mean value $F = 1.030 \pm 0.022$ was used in determining R_{vis} .

Determination of $\sin^2\theta_w$

Multiplying the ratio of the number of the neutrino-electron and antineutrino-electron scattering events with the flux ratio F , we obtained

$$R_{\text{vis}} = 0.933 \pm 0.057 \text{ (stat)} \pm 0.043 \text{ (syst)}$$

and determined

$$\sin^2\theta^0 = 0.239 \pm 0.009(\text{stat}) \pm 0.007(\text{syst}),$$

without radiative corrections.

The systematic error on $\sin^2\theta^0$ contains contributions from uncertainties of the flux normalization (± 0.002), of the abundancy of wrong-helicity muon neutrinos (± 0.001) and of electron-neutrinos (± 0.002), of the mean energies of the different beam components (± 0.002), from the background subtraction (± 0.006) and from the energy calibration of the detector (± 0.001); they were combined quadratically.

The relative abundances of the different beam components and their mean energies (Table 1) do not only enter into the flux normalization but also in the determination of $\sin^2\theta^0$ from R_{vis} ; we have taken this correlation into account.

To compare $\sin^2\theta^0$ with the weak mixing angle $\sin^2\theta_W$ as defined in the Marciano-Sirlin scheme [3] we apply radiative corrections with $m_t = 100 \text{ GeV}$ and $m_H = 100 \text{ GeV}$ and find

$$\sin^2\theta_W = 0.237 \pm 0.009(\text{stat}) \pm 0.007(\text{syst}).$$

The value of $\sin^2\theta^0$ coincides to within 0.001 with the effective on-shell mixing angle $\sin^2\bar{\theta}_W$ at the Z^0 mass [4] and with the mixing angle defined in the minimal subtraction scheme [10]. The difference $\sin^2\theta^0 - \sin^2\bar{\theta}_W$ depends much less on the unknown value of the m_t than the difference $\sin^2\theta^0 - \sin^2\theta_W$. The comparison of $\sin^2\theta^0$ with $\sin^2\bar{\theta}_W$ is therefore more suitable to test the validity of the Standard Model.

The new result, presented in this paper, is compared in Table 6 with those derived from the measurements of the Z^0 boson mass [12] and from the decay width $\Gamma_{Z^0}(\ell^+\ell^-)$ [12], using the formulas quoted by ALEPH [13], as well as with those obtained from deep inelastic neutrino scattering [11] and from the ratio of W and Z^0 boson masses [14].

We note excellent agreement with the other determinations. The agreement with the value derived from $\Gamma_{Z^0}(\ell^+\ell^-)$ is of particular interest as both measurements involve leptons only.

The comparison of $\sin^2\theta^0$ derived from neutrino-electron scattering before radiative corrections are applied and from the new precise measurement of the Z^0 mass shows good agreement with the prediction of the Standard Model. To make the comparison we evaluated the relation [15]

$$\delta_Z = 1 - \left(\frac{A_0}{\sin\theta^0 \cos\theta^0 m_{Z^0}} \right)^2$$

where $A_0 = 37.281 \text{ GeV}$. For m_{Z^0} we used the average of the measurements at LEP [12] $m_{Z^0} = 91.177 \pm 0.031 \text{ GeV}$ and obtained

$$\delta_Z(\text{exp}) = 0.080 \pm 0.030.$$

The value of δ_Z can be calculated from the radiative corrections relating muon decay,

neutrino electron scattering and m_{Z^0} ,

$$\delta_Z = \Delta r - \frac{\Delta \sin^2 \Theta}{\sin^2 \Theta^0} (1 - \Delta r) (1 - \tan^2 \Theta^0 - \Delta \sin^2 \Theta / \cos^2 \Theta^0),$$

where Δr and $\Delta \sin^2 \Theta$ are given in ref. [16]; $\Delta \sin^2 \Theta$ is the radiative correction of $\sin^2 \Theta^0$ for neutrino electron scattering in the conditions of this experiment [1, 2]. This expression depends only weakly on m_t and m_H [16]. If we choose $m_t = m_H = 100$ GeV, we obtain

$$\delta_Z (\text{theor}) = 0.0592 \pm 0.0013,$$

which is in agreement with $\delta_Z (\text{exp})$ above.

From the ratio of cross sections of neutrino-electron scattering we have derived the ratio $g_V^e / g_A^e = 0.047 \pm 0.036(\text{stat}) \pm 0.028(\text{syst})$ for the NC coupling constants g_V^e and g_A^e of the electron. The error includes a contribution from the uncertainties of ρ and of WZ interference to which we are sensitive because of the presence of a few $(\bar{\nu}_e)e$ scattering events in our signal. Another solution, $g_V^e / g_A^e = 1/0.048$ which *a priori* is also possible, as well as a positive value for g_A^e are excluded by results derived from $e^+e^- \rightarrow e^+e^-$ experiments [17] and from $(\bar{\nu}_e)e$ elastic scattering [18, 19]. Measurements of $d\sigma/d\cos\theta$ in the reaction $e^+e^- \rightarrow e^+e^-$ at the Z^0 mass determine g_A^e and g_V^e . The results are compared in figure 3.

Combining our result with the recent result $g_A^e = -0.499 \pm 0.006$ from a measurement at LEP [22] we obtain, in the case where one considers only purely leptonic reactions and does not make the assumption of universality for charged leptons, the most precise determination of the NC vector coupling constant of the electron

$$g_V^e = -0.023 \pm 0.018(\text{stat}) \pm 0.014(\text{syst})$$

in good agreement with the prediction of the Standard Model for $\sin^2 \bar{\Theta}_W = 0.231 \pm 0.003$, which we derived from $\Gamma_{Z^0}(e^+e^-) = 83.6 \pm 1.0 \text{ MeV}$ [12].

$$g_V^e = -\frac{1}{2} + 2 \sin^2 \bar{\Theta}_W = -0.037 \pm 0.007.$$

The processes of Z^0 decay into lepton pairs and of neutrino scattering on electrons may also differ, e.g. by the exchange of an additional neutral boson ($Z^{0'}$) in the scattering process. A lower limit on the mass of the $Z^{0'}$ may be derived [23], assuming, for simplicity, equal coupling strengths of Z^0 and $Z^{0'}$ to leptons and no mixing, by combining g_V^e obtained from neutrino electron scattering and from $\Gamma_{Z^0}(e^+e^-)$. We obtain

$$\left(\frac{m_{Z^0}}{m_{Z^{0'}}}\right)^2 < 0.088 \quad (90\% \text{ c.l.}).$$

and

$$m_{Z^{0'}} > 307 \text{ GeV} \quad (90\% \text{ c.l.}).$$

In conclusion, the improved result of $\sin^2\theta^0$ derived from neutrino-electron scattering presented here provides a new and significant test of the Standard Model when compared to deep inelastic neutrino scattering and the recent precise measurements of m_{Z^0} and $\Gamma_{Z^0}(e^+e^-)$. It gives a precise determination of g_V^e/g_A^e and an improved lower limit on the mass of an additional neutral boson, $m_{Z^0} > 307$ GeV (90% c.l.).

More data have been collected and the analysis is being further refined.

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Table 1

The relative abundances and mean energies of the neutrino beam components

beam	component	relative abundance	$\langle E_\nu \rangle$ (GeV)
ν	ν_μ	1.0	23.8 ± 0.5
	$\bar{\nu}_\mu$	0.072 ± 0.004	20.6 ± 1.0
	ν_e	0.0087 ± 0.0013	44.0 ± 2.2
	$\bar{\nu}_e$	0.0017 ± 0.0003	33.8 ± 1.7
$\bar{\nu}$	$\bar{\nu}_\mu$	1.0	19.3 ± 0.4
	ν_μ	0.136 ± 0.007	30.1 ± 1.5
	$\bar{\nu}_e$	0.0071 ± 0.0011	36.5 ± 1.8
	ν_e	0.0043 ± 0.0006	37.0 ± 1.9

Table 2

Summary of proton exposures
for data runs in ν and $\bar{\nu}$ beams

year	protons on target	
	ν	$\bar{\nu}$
1987	$1.09 \cdot 10^{18}$	$1.96 \cdot 10^{18}$
1988	$2.10 \cdot 10^{18}$	$4.07 \cdot 10^{18}$
1989	$2.50 \cdot 10^{18}$	$3.32 \cdot 10^{18}$
total	$5.69 \cdot 10^{18}$	$9.35 \cdot 10^{18}$

Table 3

Ratio of $\nu_e N \rightarrow e N$ to total background ($3 \text{ GeV} < E < 24 \text{ GeV}$) determined from the fit of the $E\theta^2 - E$ distributions and from the energy loss in the scintillators following the vertex.

beam	ν_e/total (energy loss)	ν_e/total ($E\theta^2 - E$ distr.)
ν beam	$(11.4 \pm 1.9)\%$	$[12.0 \pm 0.7(\text{stat}) \pm 1.6(\text{syst})]\%$
$\bar{\nu}$ beam	$(14.8 \pm 1.6)\%$	$[16.4 \pm 0.7(\text{stat}) \pm 1.8(\text{syst})]\%$

Table 4

Summary of systematic uncertainties affecting the background subtraction expressed in $\Delta \sin^2 \theta^\circ$

source of uncertainty	$\Delta \sin^2 \theta^\circ$
Beam spectra and composition	0.0016
Detector calibration and resolution	0.0036
Electron-neutrino background model	0.0008
Coherent π^0 production model	0.0032
Diffraction and inclusive π^0 production model	0.0031
Combined error	0.006

Table 5

Summary of the energy-weighted $\bar{\nu}_\mu$ and ν_μ flux ratio $F = \int \Phi_{\bar{\nu}_\mu}(E_\nu) E_\nu dE_\nu / \int \Phi_{\nu_\mu}(E_\nu) E_\nu dE_\nu$ determined by four independent methods. The error includes the correlations

method	$F \pm \text{syst. error}$
inclusive	1.021 ± 0.047
quasielastic	1.051 ± 0.040
$(\bar{\nu})N \rightarrow (\bar{\nu})\pi^0 N$	1.013 ± 0.044
muon flux	1.036 ± 0.041
mean value	1.030 ± 0.022

Table 6

Summary of recent determinations of $\sin^2 \Theta_W$ (Marciano-Sirlin scheme) and $\sin^2 \bar{\Theta}_W$ (on-shell at m_{Z^0}) for $m_H = 25 - 1000$ GeV and $m_t = 60 - 220$ GeV. Central values are for $m_t = m_H = 100$ GeV.

method	group	$\sin^2 \bar{\Theta}_W$	$\sin^2 \Theta_W$
$\sigma(\nu_\mu e) / \sigma(\bar{\nu}_\mu e)$	CHARM II (this experiment)	$0.239 \pm 0.009(\text{stat}) \pm 0.007(\text{syst})$	$0.237 \pm 0.009(\text{stat}) \pm 0.007(\text{syst})$
$\sigma^{\text{NC}}(\nu) / \sigma^{\text{CC}}(\nu)$	CHARM and CDHS [11]		$0.230 \pm 0.004(\text{exp}) \pm 0.005(\text{theor})$
$m_{Z^0} = 91.177 \pm 0.031$ GeV	LEP [12]	0.233 ± 0.002	
$\Gamma_{Z^0}(e^+e^-) = 83.7 \pm 0.7$ MeV	LEP [12]	0.231 ± 0.002	
m_W / m_{Z^0}	UA2 and CDF [14]		0.2273 ± 0.0059

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Figures

- Figure 1** Distribution of selected events as a function of $E\theta^2$, (a) in the neutrino, (b) in the antineutrino beam. The background reactions $\nu_e N \rightarrow e N'$ and $\nu N \rightarrow \nu \pi^0 N$ are shown separately.
- Figure 2** Distribution of neutrino-electron scattering events as a function of $E\theta^2$, (a) in the neutrino, (b) in the antineutrino beam, after subtraction of the background. The points represent the expected distributions.
- Figure 3** Contours with 68% c.l. of g_A^e and g_V^e obtained from neutrino experiments and $e^+e^- \rightarrow e^+e^-$ at LEP. Area A is determined by the CHARM Collaboration [20] and area B is the BNL result [21], both derived from $\sigma(\nu_\mu e)$ and $\sigma(\bar{\nu}_\mu e)$. Area C is the $\bar{\nu}_e e$ result of Reines et al. [18] and area D is the $\nu_e e$ result of Allen et al. [19]. The black area E is derived from the measurement of $d\sigma(e^+e^- \rightarrow e^+e^-)/d\cos \vartheta$ at the Z^0 mass, assuming no correlation of the errors of g_V^e and g_A^e [22]. The shaded area represents the results of this experiment.

Fig. 1

Fig. 2

Fig. 3