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**TOTAL CROSS SECTIONS OF CHARGED-CURRENT NEUTRINO AND
ANTI-NEUTRINO INTERACTIONS ON ISOSCALAR NUCLEI**

The CHARM Collaboration

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ABSTRACT

New measurements of the total cross-sections of charged-current interactions of muon-neutrinos and antineutrinos on isoscalar nuclei have been performed. Data were recorded in an exposure of the CHARM detector in an 160 GeV narrow-band beam. The antineutrino flux was determined from the measurements of the pion and kaon flux, and independently from the muon flux measured in the shield; the two methods are found to agree. The neutrino flux was determined from the muon flux ratio for ν_μ and $\bar{\nu}_\mu$ runs which was normalized to the antineutrino flux. The cross-section slopes thus determined are

$$\sigma_T^{\bar{\nu}}/E = (0.335 \pm 0.004(\text{stat}) \pm 0.010(\text{syst})) \cdot 10^{-38} \text{cm}^2/(\text{GeV} \cdot \text{nucleon})$$

$$\sigma_T^{\nu}/E = (0.686 \pm 0.002(\text{stat}) \pm 0.020(\text{syst})) \cdot 10^{-38} \text{cm}^2/(\text{GeV} \cdot \text{nucleon})$$

The momentum sum of the quarks in the nucleon and the ratio of sea quark to total quark momentum are derived from the measurements.

1. INTRODUCTION

In the study of semi-leptonic neutrino scattering on nuclei, precise knowledge of the total cross sections is a prerequisite for determining the structure functions of the nucleon. Previous measurements [1 - 12] show discrepancies at the level of 15% (see Table 1).

We report here a new measurement of the absolute total cross-sections of charged-current interactions of muon-neutrinos and antineutrinos on isoscalar nuclei which are more precise than our previous measurements [6]. The results are based on the analysis of data recorded in 1984 in 160 GeV neutrino and antineutrino narrow-band beams. The neutrino energy range from 10 to 160 GeV is thus covered in a single exposure. The ratios of cross-sections of deep inelastic neutral-current and charged-current semi-leptonic interactions of neutrinos and antineutrinos were determined in the same exposure and have already been reported; they were used for a precise determination of the electroweak mixing angle $\sin^2\theta_w$ and of the ratio of the strengths of the neutral-current and charged-current coupling [13]. The absolute cross-section measurement requires special care in the neutrino and antineutrino flux determination. The spectra are calculated from the hadron beam optics, the decay kinematics and the detector geometry. For this new measurement we adopted the following strategy. The absolute antineutrino flux was determined from the negative pion and kaon flux which we measured with a beam current transformer, and the absolute neutrino flux from the muon flux ratio measured in the iron shield and normalized to the absolute antineutrino flux. The absolute antineutrino flux can also be determined by using the absolute muon flux, thus allowing a cross-check.

2. THE NARROW BAND NEUTRINO BEAM

A schematic layout of the beam line is shown in Figure 1. Protons were extracted from the CERN SPS at 450 GeV and focused onto a 50 cm long carbon target with 3 cm diameter. Positive and negative hadron beams of 160 GeV/c were sign-selected and focused in a beam transport system of 120 m length; the beam then travelled through a 292 m-long decay tunnel which was evacuated to a pressure of 0.15 Torr. The beam transport system used was tuned [14] to increase

the flux with respect to the flux provided by the previously used optics [6]; as a consequence the momentum bite was increased to $\pm 9\%$ (rms) and the angular divergence to ± 0.40 mrad (horizontal) and ± 0.50 mrad (vertical). Pions and kaons of positive or negative charge produce a pure neutrino or antineutrino beam with a well-determined energy spectrum. The neutrino energy spectrum in the fiducial volume of the detector for events satisfying the selection criteria (see Chapter 4) is shown in Figure 2. A small background, predominantly of low energy is created from decays of hadrons which do not pass through the charge and momentum selection of the beam line. This so-called wide-band background (WBB) was determined experimentally by closing the beam line by a movable 1.5 m-long iron dump, just upstream of the decay tunnel. At the end of the decay tunnel all surviving hadrons are absorbed in the first few metres of a 185 m-long iron shield and muons are ranged out by a combination of the iron shield and a 220 m-long earth shielding.

The fluxes of the primary protons hitting the target, of the secondary hadrons and of the decay muons were monitored for each accelerator cycle. The intensity of the primary proton beam was measured with a beam current transformer (BCT), and the beam width and impact point on the target was carefully monitored by segmented secondary emission chambers mounted in front of the target. Another secondary emission chamber, mounted on the downstream end of the target, monitored the yield of secondary hadrons produced. The intensity of the secondary hadron beam was measured with two identical BCTs mounted around the beam pipe in front of the decay tunnel. Eight ionization chambers were installed around the beam pipe upstream of the BCTs to monitor the beam halo.

The composition of the beam (π, K, p) was determined in special runs using a helium-filled differential Cherenkov counter which could be moved into the beam line, between the two BCTs.

The flux of muons originating from pion and kaon decays was measured at different depths and beam radii using a system of solid-state detectors (SSD) inserted into narrow gaps of the iron shield. These counters also monitored the beam position and profile. The spill-time structure of the muon flux intensity was measured by scintillation counters located in the same gaps of the iron shield and was folded with the busy signals of the neutrino detector to determine the loss of neutrino events due to dead-time.

3. NEUTRINO FLUX DETERMINATION

The neutrino flux was determined by two independent methods. One is based on the measurement of the total secondary hadron flux by the BCTs and of its composition by the Cherenkov counter. The other method is based on the measurement of the muon flux with the SSDs and on the measurement of the K/π ratio of the hadron beam using the Cherenkov counter. Both methods make use of a Monte-Carlo simulation to calculate the neutrino flux in the fiducial volume of the neutrino detector, taking into account the hadron beam optics, the π and K decay kinematics and the tracking of the muons in the iron shield [15], the aperture of the neutrino detector and the event selection criteria were simulated.

3.1 BEAM COMPOSITION

The composition of the hadron beam was determined with the help of a differential Cherenkov counter [16]. Figure 3 shows a typical pressure (P) curve in the positive beam. The peaks in the regions $0 < P < 110$ matm, $135 < P < 210$ matm and $450 < P < 750$ matm correspond to pion, kaon and proton signals. The flux ratios (Table 2) were obtained by integrating the area underneath the peaks and subtracting a linearly varying background which was determined by interpolation from the regions outside the peaks.

Corrections have been applied for electrons ($e/\pi \sim 0.5\%$ in the positive beam and $e/\pi \sim 1\%$ in the negative beam) and for trapped muons from hadron decays before the BCT or Cherenkov counter, contributing 2.1% in the positive beam and 1.7% in the negative beam.

3.2 HADRON FLUX MEASUREMENT

The total hadron beam flux was measured using two BCTs surrounding the beam pipe. These consist of a toroid made of high-permeability steel foils, a pick-up coil and a calibration coil [17]. After every beam spill the current induced in the pick-up coil is amplified, integrated and digitized. The backgrounds determined by repeating the readout with a second time-gate outside the spill, was subtracted. The number of particles passing through the BCT is obtained by comparing the signal induced by the beam with an internal calibration signal.

We have investigated the linearity and stability of the response of one of the beam current transformers BCT1 against the observed rate of neutrino and antineutrino induced charged current events in the detector. Figure 4 shows the ratio $N(CC)/BCT1$ as a function of the BCT1 rate and Figure 5 as a function of time, for the neutrino beam (a) and the antineutrino beam (b), respectively. The neutrino event rates have been corrected for the loss of events due to dead-time. The deviations from stability or linearity are smaller than 1%.

The response of the BCTs can be affected by beam halo particles. We have investigated this effect by comparing the response of BCT1 and the muon flux measured by SSDs in the positive and in the negative beam. We found a halo correction of $+(3 \pm 1.8)\%$ and $-(3.5 \pm 1.8)\%$ for positive and negative beam, respectively. The error is dominated by the uncertainties of the measured beam composition (see Table 2). Corrections have also been applied for electrons, protons and trapped muons.

We determined the following integrated fluxes of pions and kaons from the measurements of the BCT1 response

$$N(\pi^-) + N(K^-) = (0.176 \pm 0.004) \cdot 10^{16}$$

$$N(\pi^+) + N(K^+) = (0.147 \pm 0.005) \cdot 10^{17}$$

The uncertainties affecting the energy-weighted neutrino and antineutrino fluxes derived from these measurements are summarized in Tables 3 and 4.

3.3 MUON FLUX MEASUREMENT

The muon flux was measured with a system of solid state detectors inserted in gaps of the iron shield after ~ 20 m and ~ 40 m of iron [18]. In each gap the SSD's were arranged on a circle around the beam axis at a radius of 15 cm and 30 cm; one additional detector was located on the axis. The measurements from three sets of counters were combined for the muon flux measurements: the average of eight detectors at 15 cm radius in gap 2 (20 m iron), and the average of four detectors at 15 cm radius and at 30 cm radius in gap 3 (40 m iron).

The absolute response of one SSD in each gap was calibrated by counting tracks in nuclear emulsions exposed to a few beam pulses [19]. Tracks due to muons and delta rays were separated by their distinctly different angular distributions. The other detectors were calibrated relative to that one with the help of movable detectors. The linearity and the stability with time of the SSD response was investigated relative to that of BCT1. Figure 6 shows the ratio SSD/BCT1 in gap 2 as a function of the BCT1 rate and Figure 7 as a function of time. The response was found to be stable to within 1%.

The modification of the SSD response induced by delta rays, determined by the nuclear emulsion exposures, is symmetric for the positive and the negative beam. Two other corrections depend on the beam polarity. One is due to a weak dependence of the SSD response on the muon energy [20]. Owing to the different K/π ratio, the mean muon energy in gap 2 is 64 GeV for the positive beam and 62 GeV for the negative beam, inducing a $(1 \pm 1)\%$ difference in the SSD response. Trapped muons have to be subtracted from the total measured muon flux to relate the neutrino flux at the detector to hadron decays in the tunnel. These muons come from pion and kaon decays in front of the decay tunnel, the corresponding neutrinos are the so-called wide-band background (WBB). We measured the flux of trapped muons at the same time as the WBB by moving the 1.5 m-long iron dump into the hadron beam. The muon flux distributions in the gaps of the iron shield were folded with the multiple scattering and energy loss in the 1.5 m-long iron dump by Monte Carlo simulation. The correction for trapped muons, as for instance measured in gap 2 at a radius of 15 cm, affects the muon flux by $-(16 \pm 2)\%$ and by $-(14 \pm 2.5)\%$ in neutrino and antineutrino beam exposures respectively. The systematic uncertainties affecting the energy-weighted neutrino flux determined from the muon flux measurements are summarized in Table 5. In the ratio of neutrino and antineutrino fluxes most of the uncertainties cancel, and the remaining total uncertainty is 1.7%. Averaging the three corrected muon flux measurements we determined the corresponding fluxes of pions and kaons (see Table 5).

$$N(\pi^-) + N(K^-) = (0.173 \pm 0.005) \cdot 10^{16}$$

$$N(\pi^+) + N(K^+) = (0.144 \pm 0.004) \cdot 10^{17},$$

in excellent agreement with those determined from BCT1 and beam composition measurements.

4. NEUTRINO DETECTION

Neutrino interactions were recorded in the CHARM detector [21]. It is composed of a fine-grain calorimeter and of a muon spectrometer. The target calorimeter consists of 78 marble plates of 8 cm thickness and $3 \times 3 \text{ m}^2$ cross-section which are interlaced between layers of scintillation detectors (3 cm thick, 15 cm wide and 300 cm long), proportional drift-tubes ($3 \times 3 \times 400 \text{ cm}^3$) and streamer tubes (1 cm wire distance, 265 cm long). The proportional tubes extend into the 45 cm wide magnetized iron frames surrounding the marble plates.

The main features of this detector are the hadron energy measurement by calorimetry with a resolution of $\sigma/E_h = 0.49/\sqrt{E_h/\text{GeV}}$, vertex position measurement with a resolution of 3 cm at 50 GeV and muon energy determination from measurement of the deflection in the magnetic field with a resolution of 15%.

For this experiment the fiducial volume extended over 55 target plates, leaving 5 plates at the beginning of the detector to reject incoming tracks and 18 plates at the end to ensure good shower containment. The fiducial mass was 87.4 tons with a mean target density of 1.38 g/cm^3 and a corresponding number of nucleons per cm^2 of

$$N = 9.24 \cdot 10^{26} \text{ nucleons/cm}^2,$$

with an uncertainty of $\pm 1\%$.

A unique feature of the CHARM detector is the minimum bias trigger requiring an energy deposition of 1/5 of a minimum ionizing particle in at least four scintillation detectors. For charged-current induced events with muons of energy larger than 1 GeV the trigger efficiency was measured to be better than 99.99%. Events which followed each other within the conversion time of the electronics (1.2 μs) were rejected.

The loss of neutrino events due to dead time of the detector was determined by folding the busy signals with the spill-time structure of the beam intensity. The effective average dead-time was found to be $(19 \pm 1)\%$ in the neutrino exposure and $(15 \pm 1)\%$ in the antineutrino exposure.

Events were selected as charged-current interaction candidates if a muon with a total range exceeding 1 GeV was found, originating within 30 cm of the measured hadron vertex, inside a fiducial region of $240 \times 240 \text{ cm}^2$. No threshold in the shower energy was applied. Cosmic ray background for events with $E_h < 2 \text{ GeV}$ was reduced by a special filter program which required a muon angle with respect to the neutrino beam line in the vertical plane within the range

$$-0.4 \leq \tan\theta_\mu \leq 0.4.$$

This selection introduces an inefficiency ($\epsilon = 99.1\%$ for ν_μ , $\epsilon = 99.4\%$ for $\bar{\nu}_\mu$); the corresponding correction was therefore applied. The remaining cosmic background was measured during periods without beam and subtracted.

The so-called "wide-band background" from pions and kaons decaying before the decay tunnel was measured by moving a 1.5 m-long iron dump into the beam line. Approximately 28% of the neutrino beam exposure and 52% of the antineutrino beam exposure was used for this measurement.

In total 116'000 CC events were recorded in the neutrino beam and 6'000 CC events in the antineutrino beam. In Table 6 the corrections applied are summarized. Details were given in a previous publication [13].

5. CROSS-SECTION RESULTS

The total cross-section slope σ/E is obtained by dividing the observed event sample by the product of the energy-weighted neutrino flux and the number of nucleons/cm² of the detector.

The most precise results are obtained by determining the antineutrino flux from the hadron flux and the neutrino cross-section from the muon flux ratio normalized to the absolute antineutrino flux. The systematic uncertainties affecting the total cross-sections are given in Table 7. Assuming a linear rise in the cross-section, we find the following slopes:

$$\sigma_T^{\bar{\nu}}/E = (0.335 \pm 0.004 \text{ (stat)} \pm 0.010 \text{ (syst)}) 10^{-38} \text{ cm}^2/(\text{GeV} \cdot \text{nucleon})$$

$$\sigma_T^{\nu}/E = (0.686 \pm 0.002 \text{ (stat)} \pm 0.020 \text{ (syst)}) 10^{-38} \text{ cm}^2/(\text{GeV} \cdot \text{nucleon})$$

$$\sigma_T^{\bar{\nu}}/\sigma_T^{\nu} = 0.488 \pm 0.006 \pm 0.012.$$

A small correction for non-isoscalarity of the target has been applied (+0.2% for σ^{ν} and -0.2% for $\sigma^{\bar{\nu}}$). The cross-section values reported here agree with recent results from the CCFRR experiment at FNAL [10], the CDHS experiment [11] and the revised results from the BEBC experiment at CERN [12]. They are higher (13.6% for σ_T^{ν} and 11.3% for $\sigma_T^{\bar{\nu}}$) than previous CHARM results [6]. The origin of this discrepancy is not understood in detail but can be traced back to errors in the hadron flux monitoring. The new measurement reported here is based on independent neutrino flux determinations from hadron flux and muon flux measurements which were found to agree well. We therefore feel confident that the new result is reliable.

The new cross-section values have already been taken into account in a recent parametrization of the structure functions determined by the CHARM Collaboration [22]. In an earlier publication on structure functions [23] a correction factor of 1.14 should be applied to $F_2(x)$ and $xF_3(x)$ to take into account the new results of σ_T .

The momentum sum-rule of the nucleon was evaluated using the inelastic cross-section values which were calculated by imposing the condition $E_h > 4$ GeV [13] and extrapolating to $y = 0$:

$$\int F_2(x) dx = 0.492 \pm 0.006 \text{ (stat)} \pm 0.019 \text{ (syst)}$$

implying that quarks carry only one-half of the momentum of the nucleon [24].

The ratio of deep inelastic antineutrino and neutrino cross-sections is

$$r^{\text{inel}} = 0.486 \pm 0.006 \text{ (stat)} \pm 0.012 \text{ (syst)}.$$

For the fraction of nucleon momentum carried by sea quarks (neglecting strange and charm quarks) compared to that carried by all quarks, we find

$$\bar{q}/(\bar{q} + q) = 1/2 (3r^{\text{inel}} - 1)/(1 + r^{\text{inel}}) = 0.154 \pm 0.005 \text{ (stat)} \pm 0.011 \text{ (syst)}.$$

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REFERENCES

1. T. Eichten et al., Phys. Lett. 46B (1973) 274.
2. B.C. Barish et al., Phys. Rev. Lett. 39 (1977) 1595.
3. J.G.H. de Groot et al., Z. Phys. C1 (1979) 143.
4. A.E. Asratyan et al., Phys. Lett. 76B (1978) 239.
5. D.C. Colley et al., Z. Phys. C2 (1979) 187.
6. M. Jonker et al., Phys. Lett. 99B (1981) 265 and Phys. Lett. 100B (1981) 520(E) .
7. P. Bosetti et al., Phys. Lett. 110B (1982) 167; updated in M. Aderholz et al., Phys. Lett. 173B (1986) 211.
8. N.J. Baker et al., Phys. Rev. Lett. 51 (1983) 735.
9. G.N. Taylor et al., Phys. Rev. Lett. 51 (1983) 739.
10. R. Blair et al., Phys. Rev. Lett. 51 (1983) 343.
11. P. Berge et al., Z. f. Physik C35 (1987) 443.
12. M. Aderholz et al., Phys. Lett. 173B (1986) 211.
13. J.V. Allaby et al., CHARM Collaboration, Phys. Lett. 177B (1986) 446.
14. A. Grant and J.M. Maugain, CERN/EF/BEAM 83-2 (internal report).
15. W. Lohmann, R. Kopp and R. Voss, CERN Yellow Report, CERN 85-03.
16. G. Stefanini, CERN-EP Division, private communication.
17. K. Unser, CERN-ISR-OP/81-14 (internal report).

18. G. Cavallari et al., IEEE Trans. on Nucl. Sc., Vol. NS-25, 600 (1978); W. Venus and H. Wachsmuth, CERN-TCL-int. 73-2; E.H.M. Heijne, CERN Yellow Report, CERN 83-06.
19. H. Wachsmuth, CERN/EP/NBU 86-01. The calibration in each pit has an uncertainty of 2.8%.
20. I. Abt and R. Jongejans, Nucl. Instr. Methods A235 (1985) 85.
21. A.N. Diddens et al., CHARM Collaboration, Nucl. Instr. Methods 178 (1980) 27; C. Bosio et al., Nucl. Instr. Methods 157 (1979) 35; M. Jonker et al., CHARM Collaboration, Nucl. Instr. Methods 200 (1982) 183; F. Bergsma et al., CHARM Collaboration, Nucl. Instr. Methods. A253 (1987) 203.
22. J.V. Allaby et al., CHARM Collaboration, Phys. Lett. B 197B (1987) 281.
23. F. Bergsma et al., CHARM Collaboration, Phys. Lett. 123B (1983) 269.
24. For an earlier evaluation see e.g. J.G.H. de Groot et al, Z. f. Physik C1 (1979) 143.

TABLE 1

Previous total cross-section measurements. Where two errors are given, the first is statistical, the second systematic.

EXPERIMENT	E_ν (GeV)	σ^{ν}/E $10^{-38} \text{cm}^2/(\text{GeV} \cdot \text{nucleon})$	$\sigma^{\bar{\nu}}/E$ $10^{-38} \text{cm}^2/(\text{GeV} \cdot \text{nucleon})$	Ref.
GGM ^{*)}	1 - 10	$0.74 \pm 0.02 \pm 0.07$	$0.28 \pm 0.03 \pm 0.03$	[1]
CITFR	45 - 205	$0.609 \pm 0.030 \pm 0.025$	$0.290 \pm 0.015 \pm 0.012$	[2]
CDHS ^{*)}	30 - 190	0.62 ± 0.03	0.30 ± 0.02	[3]
ITEP-IHEP	3 - 30	0.72 ± 0.07	0.32 ± 0.03	[4]
BEBC	10 - 50	0.73 ± 0.08	0.32 ± 0.06	[5]
CHARM	20 - 200	0.604 ± 0.032	0.301 ± 0.018	[6]
BEBC	20 - 200	$0.657 \pm 0.012 \pm 0.027$	$0.309 \pm 0.009 \pm 0.013$	[7]
FNAL-15'	10 - 240	0.62 ± 0.05		[8]
FNAL-15'	5 - 250		$0.340 \pm 0.019 \pm 0.022$	[9]
CCFRR	30 - 240	$0.669 \pm 0.003 \pm 0.024$	$0.340 \pm 0.003 \pm 0.020$	[10]
CDHS	10 - 200	$0.686 \pm 0.002 \pm 0.019$	$0.339 \pm 0.003 \pm 0.009$	[11]
BEBC (rev.)	20 - 200	$0.723 \pm 0.013 \pm 0.036$	$0.351 \pm 0.010 \pm 0.016$	[12]

^{*)} Not corrected for non-isoscalarity

TABLE 2

Particle Composition

Positive Beam	$p/\pi = 1.628 \pm 0.070$ $K/\pi = 0.1282 \pm 0.0028$ $e/\pi = 0.005 \pm 0.003$
Negative Beam	$\bar{p}/\pi = 0.010 \pm 0.005$ $K/\pi = 0.0630 \pm 0.0032$ $e/\pi = 0.010 \pm 0.005$

TABLE 3

Systematic uncertainties affecting the energy-weighted flux factors

Source of uncertainty	Flux factor from BCT [*] %	Flux factor from SSD ^{**} %	$\bar{\nu}/\nu$ Flux factor ratio from SSD ^{***} %
MC statistics	0.4	0.7	1.0
K/ π ratio	1.2	1.0	0.9
Beam width	0.4	0.3	0.2
Beam steering	0.4	0.2	0.1
Fid. volume definition	0.2	0.2	0.1
Muon tracking	-	0.4	0.3
SSD position	-	0.5	0.3
Total	1.4	1.4	1.4

* The energy-weighted neutrino flux factor determined with the BCT, not including the errors in the absolute normalization of the BCT

** The energy-weighted neutrino flux factor determined with the SSD's, not including the errors in the absolute normalization of the SSD's

*** The ratio of the energy-weighted antineutrino and neutrino flux factors measured with the SSD's, not including the errors in the relative normalization of the SSD's

TABLE 4

Systematic uncertainties affecting the energy-weighted $\bar{\nu}$ and ν flux derived from hadron flux (BCT) measurements

Uncertainty	$\bar{\nu}$ (in %)	ν (in %)
Absolute BCT calibration	0.5	0.5
Correction for halo	1.8	1.8
Trapped muons	0.8	0.8
e/ π	0.8	0.8
p/ π	0.5	2.7
Energy-weighting factor*	1.4	1.4
Total	2.6	3.7

* See Table 3, first column

TABLE 5

Systematic uncertainties affecting the energy-weighted neutrino flux determined by the average of three muon flux (SSD) measurements

Uncertainty	$\bar{\nu}$ (%)	$\bar{\nu}/\nu$ (%)
SSD stability	1.0	0.7
Calibration	2.0	0.4
Trapped muons	2.0	0.5
Flux factor*	1.4	1.4
Total	3.3	1.7

*See Table 3, columns 2 and 3

TABLE 6

Event candidates recorded in ν and $\bar{\nu}$ exposures and corrections

BEAM	$\bar{\nu}$	ν
Uncorrected data sample	7187 $\pm$ 85	120708 $\pm$ 347
Veto inefficiency	6 $\pm$ 2	99 $\pm$ 10
Cosmic rays filter inefficiency	22 $\pm$ 5	546 $\pm$ 23
Scan correction	0 $\pm$ 0	60 $\pm$ 44
Corrected raw data sample	7215 $\pm$ 93	121413 $\pm$ 353
WBB correction	-1048 $\pm$ 88	- 6472 $\pm$ 193
Cosmic correction	- 23 $\pm$ 1	-18 $\pm$ 1
Clean NBB data	6144 $\pm$ 128	114923 $\pm$ 402
Lost muons	50 $\pm$ 6	3995 $\pm$ 116
π and K decay	- 117 $\pm$ 6	-2009 $\pm$ 53
K _{e3} correction	-5 $\pm$ 1	-148 $\pm$ 8
Corrected event numbers	6072 $\pm$ 129	116761 $\pm$ 422

TABLE 7

Systematic uncertainty of total cross-sections

Uncertainty	$\bar{\nu}$ (%)	ν (%)	$\bar{\nu}/\nu$ (%)
Absolute flux calibration (BCT, SSD combined)	2.0	2.0	-
Relative $\bar{\nu}/\nu$ flux	-	1.7	1.7
Dead-time	0.7	0.7	0.5
Target density	1.0	1.0	-
Event number systematic errors	1.7	0.2	1.7
Total systematic error	2.9	2.9	2.5

FIGURE CAPTIONS

- Fig. 1 Schematic layout of the narrow-band beam and of the beam observation instrumentation
- Fig. 2 Energy spectrum of the neutrino flux
- Fig. 3 Typical Cherenkov counter pressure curve in the neutrino beam
- Fig. 4 Ratio of the neutrino event rate and BCT recording as a function of the BCT rate, to investigate the linearity
a) for ν and b) for $\bar{\nu}$ beam
- Fig. 5 Ratio of neutrino events (N^{CC}) and beam current transformer (BCT) recording as a function of time, to investigate the stability a) for the ν and b) for the $\bar{\nu}$ beam
- Fig. 6 Ratio of solid state counter (SSD) and beam current transformer (BCT) recording as a function of the BCT rate, to investigate the linearity a) for the ν and b) for the $\bar{\nu}$ beam
- Fig. 7 Ratio of the solid state detector (SSD) and beam current transformer (BCT) recording as a function of time to study the stability, a) in the ν and b) in the $\bar{\nu}$ beam

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7