νN: DETERMINATION OF STRUCTURE FUNCTIONS

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Since the 1980 conferences a large number of results on structure functions have been reported from neutrino experiments.

New data are available from ν and $\bar{\nu}$ scattering on protons and neutrons. Measurements of the cross section ratios $\sigma^{\nu n}/\sigma^{\nu p}$ as function of energy and scaling variables x and y allow the extraction of differences between the u- and d-quark momentum distributions.

Final results on structure functions from ν experiments on isoscalar targets exhibit clearly scaling violations. QCD fits to the data yield values of the scale breaking parameter $\Lambda = 0.1 - 0.2$ GeV. From a new measurement of the Q^2 evolution of the antiquarks together with F_2 data the gluon x distribution has been extracted.

The discrepancies in the measurement of the total cross section are still unresolved.

1. Recent results from ν and $\bar{\nu}$ scattering on protons and neutrons

The study of proton and neutron structure functions is still a domain of bubble chamber experiments. Within the last year, new data have been reported by the 7' BNL νNe experiment in the low energy range (1-10 GeV) and by various high energy experiments at FNAL and CERN, see Table 1. Typical event rates in these experiments are 1000-5000 events recorded in wide band beam exposures.

Table 1

	E(GeV)	Target	Events	Collaboration
νNe	1- 10	7' BNL	4000	Rutgers-Stevens-Columbia[1]
νD_2	>10	15' FNAL	4000	Illinois-Maryland-Stony Brook-Tohoku-Tufts[2]
νH_2 νNe	~30	BEBC-TST	600 1200	Bari-Birmingham-Brussels-Ecole Polytechnique-Saclay-U.C. London[3]
νp	>20	BEBC	3400	Aachen-Bonn-CERN-Munich-Oxford[4]
$\bar{\nu}NeH_2$	10-200	15' FNAL	4750	FNAL-Moscow-Serpukhov-Michigan[5]
$\bar{\nu}D_2$ νD_2	>10	BEBC	5600 1400	Amsterdam-Bologna-Padova-Pisa-Saclay-Torino[6]

1.1 Cross sections on neutrons and protons

All experiments in Table 1 except the BEBC νp experiment[4] have measured the cross section ratios for ν and/or $\bar{\nu}$ scattering on neutrons and protons.

The Quark-Parton-Model (QPM) relates these ratios to the quark densities u(x), d(x), s(x), ..., as:

$$R = \frac{\sigma^{\nu n}}{\sigma^{\nu p}} = \frac{u + (1-y)^2(\bar{d}+\bar{s})}{d + (1-y)^2(\bar{u}+\bar{s})} \simeq 1.90 - 1.95$$

$$\bar{R} = \frac{\sigma^{\bar{\nu} n}}{\sigma^{\bar{\nu} p}} = \frac{d(1-y)^2 + \bar{u} + \bar{s}}{u(1-y)^2 + \bar{d} + \bar{s}} \simeq 0.50 - 0.55$$

where $u = xu(x)$, $d = xd(x)$, ..., are the quark densities of the proton. Depending on the relative importance of the sea quarks and antiquarks the values of R and $\bar{R}$ are expected to be slightly below 2 and above 0.5 respectively.

This year's results on the cross section ratios together with some older measurements are summarized in Table 2.

		E(GeV)	R	$\bar{R}$	Year
ν H-C-L	GGM[7]	1- 10	2.08 ± 0.15		1978
νD_2	ANL[8]	<10	1.95 ± 0.21		1979
νNeH_2	7' BNL	1- 10	1.80 ± 0.19		1981
$\bar{\nu} NeH_2$	15'[9]	>20?		0.45 ± 0.08	1979
"	"	10-200		0.57 ± 0.05	1981
νD_2	15'	>10	2.03 ± 0.28	0.51 ± 0.16	1981
$\bar{\nu} D_2$	BEBC	>10	2.22 ± 0.28	0.51 ± 0.03	1981
$\nu H_2 Ne$	BEBC-TST	∿30	1.98 ± 0.19		1981

Table 2

All experiments find good agreement with the simple QPM predictions. Unfortunately, statistical and systematical uncertainties are still too large to let these experiments become a decisive test of the quark parton picture.

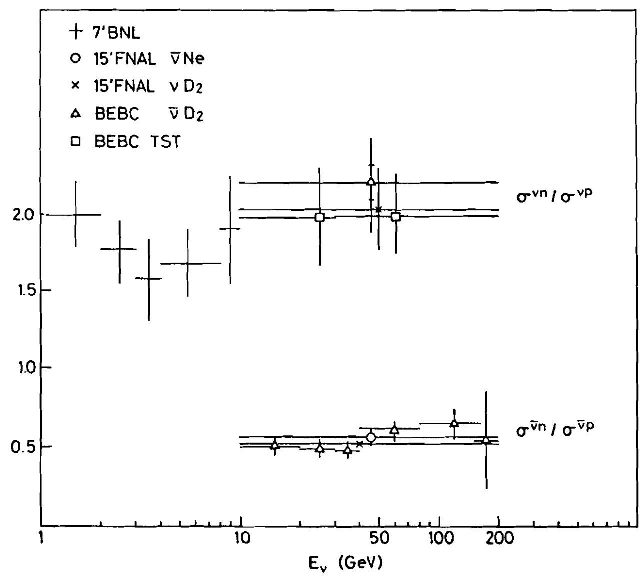

FIG. 1
Cross section ratios $\sigma^{\nu n}/\sigma^{\nu p}$ and $\sigma^{\bar{\nu} n}/\sigma^{\bar{\nu} p}$ as function of energy E_ν.

Figure 1 shows the energy dependence of R and $\bar{R}$. Again there is agreement between the different data sets and any gross energy dependence of the cross section ratios seems to be excluded.

1.2 x-dependence of u- and d-quarks

The QPM predicts a strong deviation of $\sigma^{\nu n}/\sigma^{\nu p}$ from the simple ratio of u- and d-valence quarks for small values of x where contributions from sea quarks are important and a constant ratio for $x \gtrsim 0.25$ where the sea quark content of the nucleon is negligible.

While the experiments observe the expected rise at small x, the large x behaviour does not agree with the QPM predictions. Figure 2 shows the structure function $F_2(x)$ as measured by the BEBC νp experiment normalized to F_2 as determined in e[10] and μ[11] scattering experiments (full circles). In the QPM this ratio is:

$$\frac{F_2^{\nu p}}{F_2^{e,\mu p}} = \frac{2x(d+s+\bar{u}+\bar{c})}{\frac{4}{9}\,x(u+c+\bar{u}+\bar{c}) + \frac{1}{9}\,x(d+s+\bar{d}+\bar{s})}$$

For $x \gtrsim 0.25$ where sea quarks can be neglected this ratio relates directly u and d quarks in the nucleon (right-hand scale in Figure 2)

$$\frac{F_2^{\nu p}}{F_2^{e,\mu p}} = \frac{2d}{\frac{4}{9}u + \frac{1}{9}d} = \frac{18\,\frac{d}{u}}{4 + \frac{d}{u}} \,.$$

Also shown are results obtained by some of the above quoted experiments transformed to express the same ratio of d/u for x > 0.25. There is good agreement in all experiments that the ratio rises above d/u = 0.5 for small x and falls - in contradiction to the naive QPM expectation - below 0.5 for $x \gtrsim 0.25$.

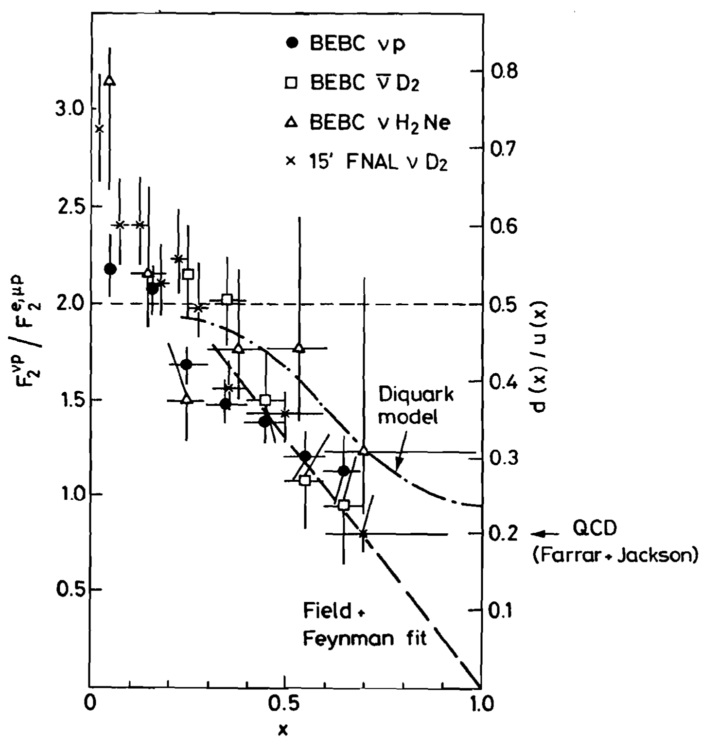

FIG. 2
The ratio $F_2^{\nu p}/F_2^{e,\mu p}$ and the corresponding quark density ratio d/u as function of the scaling variable x. Some model predictions as explained in the text are overlayed.

Of special interest is the high x behaviour of the d/u ratio for which precise model predictions exist. In principle νp scattering - in the absence of Fermi motion and nuclear effects - is the ideal tool to investigate this region.

Unfortunately data at $x \simeq 1$ are still too sparse to allow discrimination between the different predictions which are also indicated in Figure 2:

- Field and Feynman[12] predict a 1-x behaviour with $d/u = 0$ at $x = 1$.
- Farrar and Jackson[13] predict $d/u = 0.2$ within the framework of QCD.
- diquark models (Close and Roberts[14], Donnachie and Landshoff[15]) expect $d/u = 1/2 \times 3/7$ for $x = 1$.

1.3 The amount of $\bar{u} + \bar{s}$ and $\bar{d} + \bar{s}$ in the nucleon

The most sensitive tool to extract information about the relative amount of the different antiquark flavours in the proton is antineutrino scattering on neutrons and protons.

The BEBC $\bar{\nu}D_2$ experiment and the 15' FNAL $\bar{\nu}NeH_2$ experiment have determined these contributions from fits to the y dependence of the cross sections (see Chapter 1.1) as listed in Table 3.

Table 3

	BEBC $\bar{\nu}D_2$	15' $\bar{\nu}NeH_2$
$\int xu(x)dx$	0.285 ± 0.012	0.235 ± 0.016
$\int xd(x)dx$	0.129 ± 0.010	0.111 ± 0.016
$\int x(\bar{u}+\bar{s})dx$	0.021 ± 0.003	0.032 ± 0.006
$\int x(\bar{d}+\bar{s})dx$	0.034 ± 0.003	0.042 ± 0.006
$\frac{\int(\bar{u}+\bar{s})dx}{\int(\bar{d}+\bar{s})dx}$	0.62 ± 0.19	0.75 ± 0.17

Apparent problems in the absolute normalization as in the 15' experiment will cancel if only ratios are regarded. For the first time the relative amount of $\bar{u} + \bar{s}$ quarks compared to $\bar{d} + \bar{s}$ quarks has been measured. Both experiments find values of $\sim$0.7 about 1.5-2 standard deviations below the naively expected value of 1.

2. Recent results from ν and $\bar{\nu}$ scattering on nuclear targets

Final results on total cross sections and structure functions from ν and $\bar{\nu}$ scattering on isoscalar targets have been reported by the experiments listed in Table 4.

Many of these experiments are second generation experiments not only with improved statistics but also the analysis of the data has largely improved compared to the 1976-1978 publications.

Table 4

	Target	E(GeV)	Beam	ν	$\bar{\nu}$	Collaboration
BEBC[16]	Ne	20-200	NB			Aachen-Bonn-CERN-Demokritos-I.C. London-Oxford-Saclay
CDHS[17]	Fe	30-200 70-300 20-100	NB NB WB	62.000 32.000 35.000	26.000 155.000	CERN-Dortmund-Heidelberg-Saclay
CFRR[18]	Fe	50-250	NB	130.000	23.000	Caltech-Fermilab-Rochester-Rockefeller
CHARM[19]	Marble	20-200	NB	6.300	4.300	CERN-Hamburg-Amsterdam-Rome-Moscow
GGM[20]	Pro-pane	10-150	WB	3.000	3.800	Aachen-Bergen-Brussels-CERN-Milano-Orsay-Strasbourg-U.C. London
HPWFOR[21]	H-C-Fe	20-325	QT, SSBT	21.600	7.400	Harvard-Pennsylvania-Wiscon sin-Fermilab-Ohio-Rutgers
15' FNAL[22]	Ne	10-200	WB		6.500	FNAL-Moscow-Serpukhov-Michigan
15' FNAL[23]	D_2	10-170	WB	17.000		Tohoku-Illinois-Maryland-Stony Brook-Tufts

2.1 The total cross section

Concerning the measurement of the absolute total cross section the situation in 1981 is much more confused than it was a couple of years ago when all experiments agreed on cross section slopes of $\sim$0.60 and 0.30 $\times$ 10^{-38} cm^2/GeV/nucleon for ν and $\bar{\nu}$ scattering. These "standards" were set by the high statistics experiments of CITFR (1977)[24] and CDHS (1978)[25], see Table 5.

Table 5 Total cross sections on isoscalar targets $\sigma_{tot}/E_\nu \times 10^{-38}$ cm^2/GeV

	Beam E(GeV)	$\bar{\nu}$	ν	$\bar{\nu}/\nu$	Syst. uncert.
CITFR '77	NB 45-225	0.29 ± 0.015	0.61 ± 0.03		
CDHS '78	NB 30-200	0.30 ± 0.02	0.62 ± 0.05	0.48 ± 0.02	8%
CFRR '79	NB 60-260		0.70 ± 0.038		
BEBC '80/81	NB 20-200	0.305 ± 0.016	0.663 ± 0.032	0.463 ± 0.025	4%
CHARM	NB 20-200	0.301 ± 0.018	0.604 ± 0.032	0.498 ± 0.019	5%
CDHS	NB 30-300	E_ν dependence only			
CFRR	NB 40-220	0.371 ± 0.020	0.719 ± 0.037	0.516 ± 0.020	5%
GGM	WB 10-150	0.29 ± 0.04	0.62 ± 0.08	0.47 ± 0.09	10%
15' FNAL D_2	WB 10-170		0.68 ± 0.06		>10%(?)

2.1.1 New cross section data

The common agreement was first questioned in 1979 by the data of the CFRR experiment[26] at FNAL (using essentially the same detector as CITFR) which reported a slope of 0.70 ± 0.04 for the neutrino cross section. Since then the same group has performed a new series of runs. The newest even higher values of 0.719 ± 0.037 and 0.37 ± 0.02 for neutrinos and antineutrinos lie about 20% above their old measurements and are in statistically significant disagreement with the cross section reported by the other experiments.

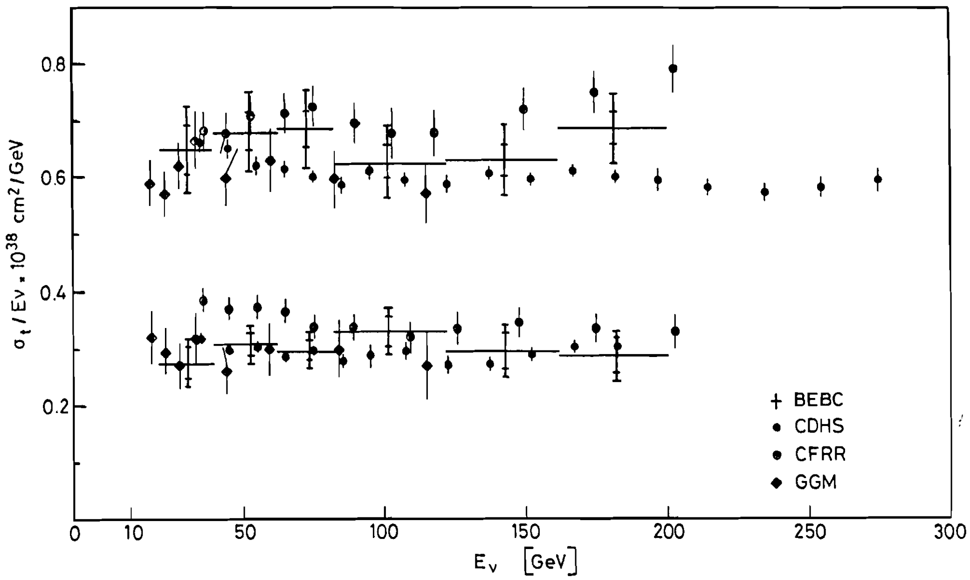

FIG. 3 The total neutrino and antineutrino cross section slopes as function of the neutrino energy E_ν. Data points from BEBC, CDHS, CRFF, and GGM are shown.

CHARM and GGM agree with the old standard slopes of ∿0.60 and ∿0.30. BEBC reports a new neutrino cross section of 0.663 ± 0.032 slightly higher than their old value, while their antineutrino cross section remains 0.30. Also above the previous world standard is a preliminary result from a νD_2 wide band beam exposure at the 15' chamber with σ = 0.68, however, with at least 10% flux uncertainty. The CDHS group reported new high statistics data on the energy dependence of the total cross sections from 200 and 300 GeV narrow band beam exposures without measuring the absolute neutrino flux, Figure 3. While there may be some energy dependence in the neutrino cross section below ∿70 GeV, no energy dependence has been observed between 70 and 300 GeV for both neutrino and antineutrino cross sections.

2.1.2 Neutrino oscillations?

The striking discrepancy between the old CITFR results and the 1979/81 CFRR measurements has triggered some discussion*) about possible flux variations due to neutrino oscillations[27]. The reason is that both the CITFR and the CDHS detectors were placed at about 600 m distance from the neutrino source, while the CFRR detector is at roughly twice the distance (∿1100 m).

*) and not only discussion: the CFRR group is setting up a neutrino oscillation experiment using two detectors at 600 m and 1100 m target-detector distance.

In fact a) ν_μ could oscillate into ν_x at 600 m and reappear at 1100 m distance, or b) still undetected ν_x could oscillate into ν_μ with a long oscillation length. Either possibility seems to be very unlikely. The oscillation probability can be approximated by

$$P(\nu_i \rightarrow \nu_j) \propto \sin^2 2\alpha \times \sin^2(1.27 \times \frac{L}{E} \times \Delta m^2)$$

where 2α determines the maximum mixing amplitude, L is the distance detector - ν source in (m), E is the ν energy in (MeV), and Δm^2 is $|m_{\nu_i}{}^2 - m_{\nu_j}{}^2|$. Thus ν oscillations are equally determined by the distance L and the energy 1/E which means that any oscillation due to doubling L should be reproducible by reducing E by a factor 2 or vice versa. The cross section slopes of CITFR and CDHS at 100 GeV should therefore agree with the CFRR measurement at 200 GeV if there were strong ν oscillations. The same argument should lead to a strong energy dependence of the cross section which has not been seen in the new high statistics CDHS data, see Figure 3.

Given the difficulties in the determination of the absolute ν flux it seems to be more plausible that not well enough understood problems in the absolute flux measurements are the explanation of the cross section discrepancies.

2.2 Structure functions and their Q2 dependence

Final results have been reported by BEBC, CDHS, CHARM, GGM and HPWFRO on the singlet structure function

$$F_2 \simeq \frac{\sigma^{\nu} + \sigma^{\bar{\nu}}}{1 + (1-y)^2} + \text{corr.} \simeq q + \bar{q}$$

and the non-singlet structure function

$$xF_3 \simeq \frac{\sigma^{\nu} + \sigma^{\bar{\nu}}}{1 - (1-y)^2} + \text{corr.} \simeq q - \bar{q} = q_{valence}$$

which in the QPM correspond to the structure functions of all quarks and of valence quarks only.

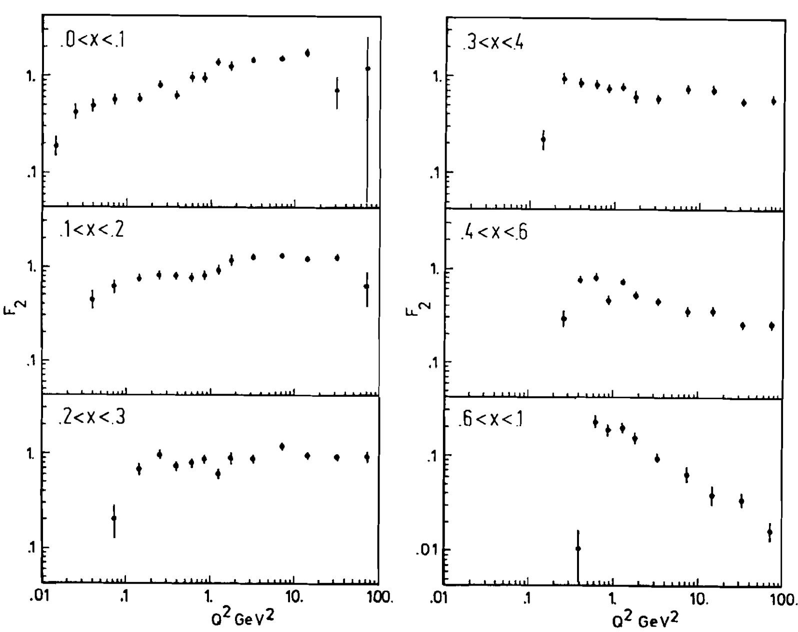

FIG. 4

As an example of the Q^2-evolution of the structure function F_2 for different x-intervals the combined data points from GGM (PS) and BEBC are shown.

The corrections are different for the different experiments and will not be discussed in detail. They usually include corrections for non-isoscalar targets, Fermi-motion, strange sea, gluon radiation, and non-zero longitudinal cross sections (Callan-Gross violation).

There is general agreement in the observation of scale breaking. The structure functions F_2 and xF_3 are rising with Q^2 for small x values while they are falling at large values of x. As an example the Q^2-dependence of $F_2(x)$ as determined from the BEBC high energy and the GGM low energy (PS) data is shown in Fig. 4.

2.2.1 Scale breaking parameter Λ

The most straightforward approach to extract the Quantum Chromo Dynamics (QCD) parameter Λ is an analysis of the Q^2 dependence of the non-singlet structure function xF_3. No knowledge of the gluon structure function $G(x,Q^2)$, the strange sea $\bar{q}(x,Q^2)$ and the Callan-Gross term $R = \sigma_L/\sigma_T$ is needed. Usually xF_3 and the F_2 data points for $x > 0.4$ where the sea quarks have vanished are used in the analysis.

The following methods to describe the Q^2 evolution of the non-singlet structure function have been applied by the different experiments:

a) parametrization *à la* Buras and Gaemers[28],

b) numerical integration of the Altarelli-Parisi equations[29] *à la* Abbott and Barnett[30] and Gonzalez, Lopez and Yndurain[31],

c) fits to moments including 2nd order effects following the $\overline{MS}$ scheme of Bardeen and Buras[32].

Table 6 contains a summary of the results on Λ obtained by the different groups. There is some agreement that Λ should have a value of 0.1-0.2 GeV, however, depending to some extent on the specific cuts and the experimental conditions. Including second order effects in the QCD analysis changes the Λ value only by a small amount.

Table 6

	Q^2 (GeV^2)	$\Lambda_{L.O.}$ (GeV)	$\Lambda_{\overline{MS}}$ (GeV)	Method
BEBC + GGM	>1.0	0.460 ± 0.100		Moments
	>1.5	$0.245 \pm^{0.130}_{0.145}$	$0.185 \pm^{0.085}_{0.105}$	Moments
	>2.0	0.210 ± 0.095	$0.145 \pm^{0.095}_{0.035}$	A.-P. + target mass corr.
CHARM	>3.0	0.29±0.12±0.10		B.-G. + Fermi motion corr.
		0.18 ± 0.10		B.-G.
GGM	>2.0	$0.19 \pm^{0.16}_{0.12}$	$0.15 \pm^{0.15}_{0.11}$	A.-P.
		$0.02 \pm^{0.09}_{0.02}$		A.-P. + target mass corr.
CDHS	>2.0	$0.19 \pm^{0.08}_{0.07}$	$0.21 \pm^{0.08}_{0.07}$	$W^2 > 11$ GeV^2 A.-P. + target mass corr. W- propagator term
	>10.0	0.14 ± 0.06		

A.-P. = Altarelli and Parisi
B.-G. = Buras and Gaemers

In spite of the rough overall consistency of the results, some peculiarities are worth while mentioning:

- The BEBC group reports on a significant increase of Λ from 0.2 to 0.46 when data with Q^2 as low as 1 GeV^2 are included in the analysis.
- In the GGM data - suffering, however, from statistical limitations - almost all Q^2 dependence can be absorbed by target mass corrections lowering the value of Λ from 0.2 to 0.02.
- The CDHS results have been obtained by including target mass corrections and W-mass propagator effects as well as excluding at the same time the kinematical region (W^2 < 11 GeV^2) where data might be affected by higher twist contributions[33], see Figure 5.

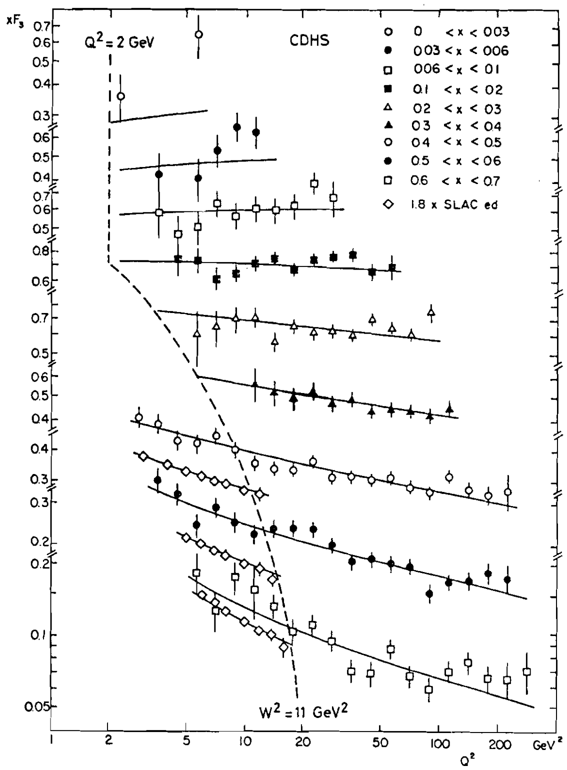

FIG. 5

$xF_3(x,Q^2)$ as determined by the CDHS experiment; indicated is the kinematical region on the right side of the dashed line where data are used to fit the QCD parameter Λ.

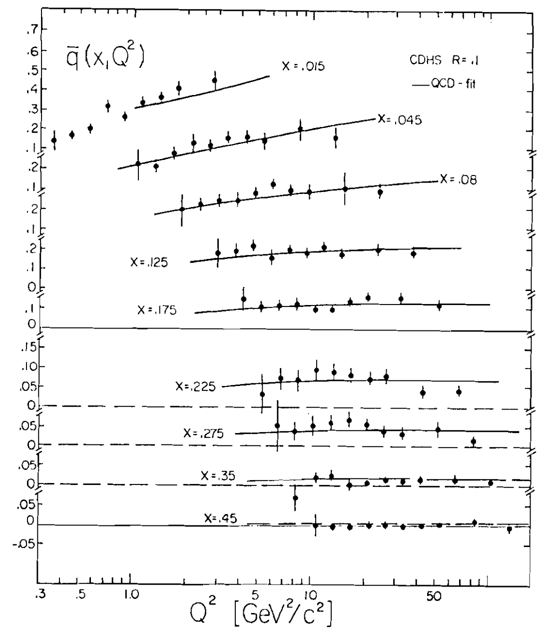

FIG. 6

$\bar{q}(x,Q^2)$ as determined by the CDHS experiment from the analysis of 155.000 $\bar{\nu}$; the curves represent a QCD fit which describes the data well.

2.2.2 The antiquark structure function $\bar{q}(x,Q^2)$

A novel result comes from the CDHS experiment which for the first time has measured the Q^2 evolution of the antiquark structure function. Data were collected in a wide band beam exposure with neutrino energies between 20 and 100 GeV. 155,000 $\bar{\nu}$ and 35,000 ν events have been analyzed to extract the antiquark distributions from $\bar{\nu}$ events with inelasticity y > 0.5 which are almost entirely due to $\bar{\nu}$ scattering on antiquarks. The neutrino sample serves to subtract the remaining small background from $\bar{\nu}$q scattering. Figure 6 shows the resulting Q^2 development of $\bar{q}$ for different x values overlayed with a QCD fit which describes the data well. Especially at small x the rise of $\bar{q}$ is clearly visible. At x > 0.4 sea quarks have vanished.

2.2.3 The gluon structure function $G(x,Q^2)$

Within the framework of QCD the Q^2 evolution of $F_2(x)$ and $\bar{q}(x)$ is described by the Altarelli-Parisi equations

$$\frac{dF_2}{d\ln Q^2} = \frac{\alpha_s}{2\pi} \int_x^1 \frac{xdy}{y^2} \left[P_{qq}\left(\frac{x}{y}\right) F_2(y,Q^2) + 2nf \times P_{gq}\left(\frac{x}{y}\right) G(y,Q^2) \right]$$

$$\frac{d\bar{q}}{d\ln Q^2} = \frac{\alpha_s}{2\pi} \int_x^1 \frac{xdy}{y^2} \left[P_{qq}\left(\frac{x}{y}\right) \bar{q}(y,Q^2) + nf \times P_{gq}\left(\frac{x}{y}\right) G(y,Q^2) \right]$$

The gluons are responsible for $q\bar{q}$ pair production as illustrated in Figure 7. From a fit to the slopes of $F_2(x,Q^2)$ and $\bar{q}(x,Q^2)$ the gluon x distribution can then be extracted for fixed values of Q^2. Figures 7a and 7b show the slopes of F_2 and $\bar{q}$ as measured by the CDHS experiment together with best fits to the data for Q^2 = 4.5 GeV^2. Also shown are the contributions from $q\bar{q}$ pairs production and gluon radiation to the slopes.

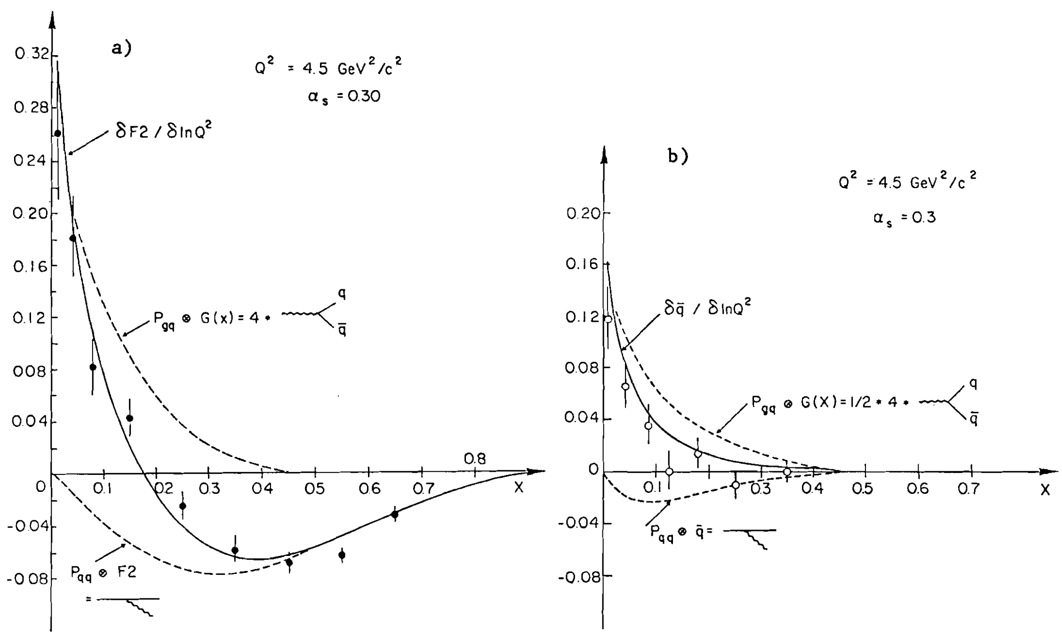

FIG. 7 QCD slopes a) $dF_2/d\ln Q^2$ and b) $d\bar{q}/\ln Q^2$ as a function of x. The dashed curves represent the contribution from $q\bar{q}$ pair production off gluons and from gluon radiation.

From leading order fits to F_2 and $\bar{q}$ the following parameters have been obtained at Q^2 = 4.5 GeV^2

$$G(x) \simeq (1-x)^{5.9\pm0.5} \left[1 + (3.5\pm1.0)x\right]$$

$\int F_2 dx = 0.45 \pm 0.22$ $\langle x\rangle_{F_2} = 0.25 \pm 0.01$

$\int G\, dx = 0.55 \pm 0.11$ $\langle x\rangle_G = 0.156 \pm 0.012$

$\int \bar{q}\, dx = 0.055 \pm 0.002$ $\langle x\rangle_{\bar{q}} = 0.095 \pm 0.002$

3. CONCLUSIONS

In ν and $\bar{\nu}$ scattering experiments with proton and neutron targets cross section ratios of $\sigma^{\nu n}/\sigma^{\nu p} \simeq 2$ and $\sigma^{\bar{\nu} n}/\sigma^{\bar{\nu} p} \simeq 0.5$ consistent with the naive QPM expectations have been found. Unfortunately, the statistical weight of these measurements is still too poor to test more subtle models than the simple QPM. The x distribution of the up quark in the protons is wider than that of the corresponding down quark.

Two antineutrino experiments have measured the relative amount of $\bar{u}(x) + \bar{s}(x)/\bar{d}(x) + \bar{s}(x)$ to be smaller than 1, an interesting result to be confirmed by other experiments with improved statistics and systematics.

In the measurement of the total cross section a discrepancy of 15-20% is still not understood and probably due to flux determination problems.

A large number of final results on structure functions have been reported within the past year. All experiments observe scaling violations in qualitative agreement with QCD. The non-singlet structure function xF_3 has been analyzed to extract values for the scale breaking parameter Λ in leading and next to leading order. Values $\Lambda = 0.1$-0.2 GeV were obtained and very little dependence on the inclusion of second order effects has been observed.

Finally a new measurement of the Q^2 dependence of the antiquark structure has been presented. From this measurement together with the data of F_2 the gluon structure function has been extracted.

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(33) A detailed discussion of higher twist effects can be found in the talk of J. Drees in this conference and has therefore been omitted here. Also, no comparison is made with structure function results from μ experiments. For a comparison of ν and μ data see the talks of J. Drees and G. Smadja in these proceedings.

Discussion

G. Barbiellini, CERN: Concerning the total cross section νN disagreement between FERMILAB and CERN data, I am not sure that all the problem is on the neutrino flux measurement and it will be very important to have the x distribution from the CFRR group that have the larger total cross section.

J. Ludwig, Caltech: I think that if the cross sections differ you also have to expect that the structure functions will differ. We are not so far in the moment to say exactly how they will differ, but you have to expect a difference.