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A four quark-parton model analysis of recent high energy neutrino-nucleon scattering data

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Abstract. The data on neutrino (antineutrino), neutral and charged current cross-sections and their y-distributions are analysed within the framework of the Weinberg-Salam theory and the quark-parton model incorporating charm. Other existing models are also compared. Interpretation of data appears easy in the case of models with charm whereas it is not so if charm is absent. Under some reasonable assumptions, the numerical values of the first moments of parton distribution functions are obtained. The $\sin^2 \theta_W$ and other useful parameters are also determined for the various models.

Keywords. Charm; quark-parton model; parton distribution function; parametrisation.

1. Introduction

Various groups (HPWF, CITF, CDHS*, BEBC, etc.) have published data (Peccei 1979) on high energy neutrino (antineutrino) neutral current and charged current cross-sections in the energy range 30—200 GeV. Significantly these data indicate that $R(=\sigma^{\nu}_{nc}/\sigma^{\nu}_{cc})$ and $\bar{R}(=\sigma^{\bar{\nu}}_{nc}/\sigma^{\bar{\nu}}_{cc})$ are almost independent of incident neutrino and antineutrino energy and there is no high Y anomaly (Holder *et al* 1977 a, b). These suggest that the Bjorken scaling is valid for the range of energies used in these experiments. The scaling violations are rather small especially in the integrated quantities (such as $d_q = \int_0^1 xq(x)\, dx$, where q denotes the quark flavour) which are our main interest. Thus the parton model can easily be used to analyse these data. The general analysis uses a quark parton model (QPM) and a theory for the weak interactions such as the Weinberg-Salam theory to analyse the data.

It has been shown that the inclusion of the quark-sea in addition to the valence quarks is necessary to explain the data on neutral and charged current interactions. The quantitative description of the contribution from the quark sea is however far from satisfactory. Various authors (Albright 1974; McElhaney and Tuan 1973;

*The data on y-distribution ratio of neutral to charge currents at $y=0$ and $y=1$ was reported by CDHS group along with data on R and $\bar{R}$ (Paar 1977) in a preprint. But later only data on R, $\bar{R}$ was published (Holder *et al* 1978).

Barger and Phillips 1974; Field and Feynman 1977; Ross and Sachrajda 1979; Tsukerman 1979; Buras and Gaemers 1978) have used different parametrisations to quantitatively estimate the contribution of the sea and it appears that while the inclusion of sea is necessary, a proper description is lacking. Most of these authors have used a quark-parton model with two and/or three flavours and have tried to calculate the contributions of antiquarks and strange quarks from the sea. Some of them have discussed the difference between the antiquark contributions from the upquark and downquark, *i.e.* taking a non-SU(2) symmetric core. Possibilities of a charge-asymmetric core have also been discussed (Ross and Sachrajda 1979; Sarma and Godbole 1980). These authors have however not considered the effect of charm whose presence in the core at these high energies (2000 GeV) cannot be ignored. In this paper we have considered the effect of charm and have analysed the available data in a quark-parton model with four flavours (i.e. u, d, s and c) assuming the Weinberg-Salam theory. We find that the inclusion of charm greatly improves the interpretation of the present data.

An accurate determination of the quark sea in the nucleon is desirable because recent studies on the scattering of π, P and $\bar{p}$ beams from the nuclei (Kaplan *et al* 1978; Anderson *et al* 1979; Lefranequis 1980) indicate a large contribution from the nuclear sea (Kienzle 1979; Pilcher 1980). An understanding of the nuclear sea contributions requires a knowledge of the nucleon sea (*i.e.* quark sea in the nucleon). At the energies, where such experiments are done, it is likely that the charm will make its presence felt.

In § 2, we derive the general expression for R, $\bar{R}$ and Y distributions for the charged and the neutral current data. Under some general assumptions about the core, the first moments of the parton distribution and the Weinberg-angle are determined. In § 3, we briefly review the results of other analyses and compare them with our results. The conclusions reached from our analysis are summarised in § 4.

2. Analysis

Using the neutrino-nucleon scattering data (Peccei 1979; Paar 1977) and the electroproduction data (Perkins 1977), different sets of values for the first moments of parton distribution functions and $\sin^2\theta_W$ are obtained. The predictions of similar models (Albright 1974; McElhaney and Tuan 1973; Barger and Phillips 1974; Field and Feynman 1977) reported in literature and which do not include charm are compared with our data. It is found that these models which do not include charm have serious difficulties in explaining the data whereas it is not so with our proposed parametrisation of the charm model.

2.1 *Formulae*

The weak and electromagnetic interactions of nucleons including charm are described in the Weinberg-Salam model by the Lagrangian (Rizvi 1975),

$$\mathscr{L}_I^{(q)(UB)} = e\, J_\mu^{\text{em}} \cdot A_\mu + \frac{g}{2\sqrt{2}} (J_\mu^W\, W_\mu^\dagger + \text{h.c.}) + \frac{1}{2} (g^2 + g'^2)^{\frac{1}{2}}\, J_\mu^z \cdot Z_\mu \tag{1}$$

with

$$e = g'g/(g^2 + g'^2)^{\frac{1}{2}}$$

$$J_\mu^{em} = \bar{q}\, \gamma_\mu\, Q_q,$$

$$J_\mu^W = \bar{q}\, \gamma_\mu\, (1 - \gamma_5)\, Wq,$$

$$J_\mu^z = \tfrac{1}{2}[\bar{q}\, \gamma_\mu\, (1 - \gamma_5) W^0 q - 4 \sin^2\theta_W J_\mu^{em}], \tag{2}$$

where $q = \begin{pmatrix} c \\ u \\ d \\ s \end{pmatrix}$ and θ_W is the Weinberg angle. Q_q; W and W^0 are the 4×4 matrix given by Rizvi (1975). The ratios of the cross-sections for neutral and charged current reactions defined by

$$R \equiv \sigma_{nc}^{\nu} \,/\, \sigma_{cc}^{\nu},$$

$$\bar{R} \equiv \sigma_{nc}^{\bar{\nu}} \,/\, \sigma_{cc}^{\bar{\nu}}$$

are derived, in the four-quark-parton model, to be

$$R = \{\tfrac{1}{3}(d_{\bar{u}} + d_{\bar{d}} + 2d_{\bar{c}}) + (d_u + d_d + 2d_s)\}^{-1} \cdot$$
$$\{\tfrac{1}{2}(1 - 2W)\,[(d_u + d_d) + \tfrac{1}{3}(d_{\bar{u}} + d_{\bar{d}})] + \tfrac{1}{2}(1 - 8W/3)\,(d_c + \tfrac{1}{3} d_{\bar{c}})$$
$$+ \tfrac{1}{2}(1 - 4W/3)\,(d_s + \tfrac{1}{3} d_{\bar{s}}) + 4W^2/27\,[5(d_u + d_d + d_{\bar{u}} + d_{\bar{d}})$$
$$+ 8(d_c + d_{\bar{c}}) + 2(d_s + d_{\bar{s}})]\}, \tag{3}$$

$$\bar{R} = R(d_q \longleftrightarrow d_{\bar{q}}), \tag{4}$$

where d_q and $d_{\bar{q}}$ are the first moments of the parton distribution and are defined by,

$$d_q = \int_0^1 x\, q(x)\, dx$$

x, y are the Bjorken scaling variables given as,

$$X = \frac{-q^2}{2M\,(E - E')},\quad Y = \frac{E - E'}{E}$$

E is the incident neutrino energy, E' is the energy of the outgoing lepton. The various Y-distributions are derived to be,

$$\left(\frac{d\sigma}{dY}\right)_{cc}^{\nu N} = \sigma_0[(1 - Y)^2\,(d_{\bar{u}} + d_{\bar{d}} + 2d_{\bar{c}}) + (d_u + d_d + 2d_s)], \tag{5}$$

$$\left(\frac{d\sigma}{dY}\right)_{cc}^{\bar{\nu}N} = \left(\frac{d\sigma}{dY}\right)_{cc}^{\nu N} (d_q \longleftrightarrow d_{\bar{q}}) \tag{6}$$

$$\left(\frac{d\sigma}{dY}\right)_{nc}^{\nu N} = \sigma_0 \{\tfrac{1}{2}(1-2W)[(d_{\bar{u}}+d_{\bar{d}})(1-Y)^2+(d_u+d_d)]$$

$$+\tfrac{1}{2}(1-8W/3)$$

$$[(1-Y)^2 d_{\bar{c}} + d_c] + \tfrac{1}{2}(1-4W/3)[(1-Y)^2 d_{\bar{s}} + d_s]$$

$$+\frac{W^2}{9}[1+(1-Y)^2][5(d_u+d_d+d_{\bar{u}}+d_{\bar{d}})+8(d_c+d_{\bar{c}})$$

$$+2(d_s+d_{\bar{s}})]\}, \tag{7}$$

$$\left(\frac{d\sigma}{dY}\right)_{nc}^{\bar{\nu}N} = \left(\frac{d\sigma}{dY}\right)_{nc}^{\nu N} (d_q \longleftrightarrow d_{\bar{q}}) \tag{8}$$

where $\sigma_0 = G^2ME/\pi$, E in GeV and $W \equiv \sin^2\theta_W$. The various form factors occurring in the electron-nucleon and the neutrino-nucleon scattering are given by

$$F_2^{ep}(x) = \{x[4/9\,(u(x)+\bar{u}(x)+c(x)+\bar{c}(x))$$

$$+1/9\,(d(x)+\bar{d}(x)+s(x)+\bar{s}(x))]\}, \tag{9}$$

$$F_2^{en}(x) = x\{4/9\,[d(x)+\bar{d}(x)+c(x)+\bar{c}(x)]$$

$$+1/9[u(x)+\bar{u}(x)+s(x)+\bar{s}(x)]\}, \tag{10}$$

$$[xF_3^{\nu N}(x)]_{cc} = 2x\{\bar{c}(x)-s(x)+\tfrac{1}{2}[\bar{u}(x)+\bar{d}(x)-u(x)-d(x)]\}, \tag{11}$$

$$[F_2^{\nu N}(x)]_{cc} = 2x\{s(x)+\bar{c}(x)+\tfrac{1}{2}[u(x)+\bar{u}(x)+d(x)+\bar{d}(x)]\}, \tag{12}$$

$$[XF_3^{\nu N}(x)]_{nc} = X\{(2c_v c_A)[\bar{c}(x)-c(x)+\tfrac{1}{2}(\bar{u}(x)-u(x)+\bar{d}(x)-d(x))]$$

$$+2(c_{v'}c_{A'})[\bar{s}(x)-s(x)+\tfrac{1}{2}(\bar{u}(x)-u(x)+\bar{d}(x)-d(x))]\}, \tag{13}$$

$$[F_2^{\nu N}(x)]_{nc} = X\{(c_v^2+c_A^2)[c(x)+\bar{c}(x)+\tfrac{1}{2}(u(x)+\bar{u}(x)+d(x)+\bar{d}(x))]$$

$$+(c_{v'}^2+c_{A'}^2)[s(x)+\bar{s}(x)+\tfrac{1}{2}(u(x)+\bar{u}(x)+d(x)+\bar{d}(x))]\}, \tag{14}$$

where c_v, c_A, etc. are the coupling strengths of the vector and axial vector currents. In the Weinberg-Salam model they are given by

$$c_v = (\tfrac{1}{2}-\tfrac{4}{3}\sin^2\theta_W),\ c_{V'} = (\tfrac{1}{2}-\tfrac{2}{3}\sin^2\theta_W),\ c_A = c_{A'} = \tfrac{1}{2}. \tag{15}$$

We now define the following quantities,

$$B^{\nu} \equiv - \int_0^1 x F_3^{\nu N}(x)\, dx \Bigg/ \int_0^1 F_2^{\nu N}(x)\, dx \tag{16}$$

$$\langle Y \rangle \equiv \int_0^1 Y \left(\frac{d\sigma}{dY}\right) dy \Bigg| \int_0^1 \left(\frac{d\sigma}{dY}\right) dY. \tag{17}$$

Then the average energy carried by the neutrino,

$$\langle E'/E \rangle = 1 - \langle Y \rangle. \tag{18}$$

Some of the corresponding relations in three quark-parton model, that we need for our analysis are given as (Rizvi 1975)

$$\left(\frac{d\sigma}{dY}\right)_{cc}^{\nu N} = \sigma_0 \left[(1 - Y)^2 (d_{\bar{u}} + d_{\bar{d}}) + (d_u + d_d) \cos^2\theta_c + 2d_s \sin^2\theta_c\right] \tag{19}$$

$$\left(\frac{d\sigma}{dY}\right)_{nc}^{\nu N} = \sigma_0 \{1/2\,(1 - 2W)\,[(d_{\bar{u}} + d_{\bar{d}})(1 - Y)^2 + (d_u + d_d)]$$

$$+ 1/2\,(1 - 4W/3)\,[(1 - Y)^2 d_{\bar{s}} + d_s] + W^2/9\,[1 + (1 - Y)^2]$$

$$[5\,(d_u + d_a + d_{\bar{u}} + d_{\bar{d}}) + 2\,(d_s + d_{\bar{s}})]\} \tag{20}$$

θ_c : Cabibbo angle.

2.2 *First moments of parton distribution functions*

In order to extract the first moments of parton distribution functions (d_q) from the data, we make some reasonable assumptions about the core. We define

$$d_q = d_q^{\text{valence}} + d_q^{\text{sea}},$$

i.e. $d_u = d_u^{\text{valence}} + d_u^{\text{sea}}$, $d_d = d_d^{\text{valence}} + d_d^{\text{sea}}$

and $\quad d^{\text{sea}} = d_u^{\text{sea}} + d_d^{\text{sea}} + d_{\bar{u}} + d_{\bar{d}} + d_s + d_{\bar{s}} + d_c + d_{\bar{c}},$

and make the following assumptions:

(i) $d_u^{\text{valence}} = 2d_d^{\text{valence}}$,

(ii) Assume the sea to be charged symmetric**

i.e. $d_q = d_{\bar{q}}$.

**If the Pauli exclusion principle operates as effectively as was emphasised by Ross and Sachrajda (1979) and Barrois (1977) then the contribution of the core part of the quark having non-zero valence part will be different from the contribution of its antiquark in the sea and the charge symmetry will not hold.

(iii) Assume the sea to be either (a) SU(4) symmetric or (b) SU(3) symmetric.

i.e. (iiia) $d_u^{\text{sea}} = d_d^{\text{sea}} = d_s = d_c$,

(iiib) $d_u^{\text{sea}} = d_d^{\text{sea}} = d_s$.

Using these assumptions and the various sets of data, different sets of parameters (*ds*) could be obtained. We find four such parametrisations which are given in table 1. While extracting *ds*, we have also calculated $\sin^2\theta_W$ in all these cases and these are also given in table 1.

3. Comparison with earlier work

In this section we first derive some constraints on the first moments of the parton distribution function which are implied by the following data (Paar 1977):

$$\left(\frac{d\sigma^{\nu}}{dY}\right)^{nc}_{y=0} \Bigg/ \left(\frac{d\sigma^{\nu}}{dY}\right)^{cc}_{y=0} = 0{\cdot}29. \tag{21}$$

Table 1. First moments of parton distribution functions and $\sin^2\theta_W$ in charm parametrisations.

Parametrisation/data used	Assumptions made	d_u	d_d	$d_{\bar u}$	d_c	$\sin^2\theta_W$
†$\int F_2^{ep}(x)dx = (0{\cdot}16 \pm 0{\cdot}005)$, †$\int F_2^{en}(x)dx = 0{\cdot}12 \pm 0{\cdot}008$ ††$R = (0{\cdot}29 \pm 0{\cdot}01)$	(i), (ii), (iiia)	0·258 ±0·088	0·138 ±0·01	0·018 ±0·01	0·018 ±0·01	0·27 ±0·04
$\int F_2^{ep}(x)dx = 0{\cdot}16 \pm 0{\cdot}005$, $\int F_2^{en}(x)dx = 0{\cdot}12 \pm 0{\cdot}008$ $R = 0{\cdot}29 \pm 0{\cdot}01$††, $\bar R = 0{\cdot}35 \pm 0{\cdot}03$	(i), (ii), (iiib)	0·255 ±0·088	0·135 ±0·01	0·015 ±0·01	0·022 ±0·01	0·26 ±0·04
$\int F_2^{ep}(x)dx = 0{\cdot}16 \pm 0{\cdot}005$, $\int F_2^{en}(x)dx = 0{\cdot}12 \pm 0{\cdot}008$ †††$\left(\frac{d\sigma^{\bar\nu}}{dy}\right)^{nc}_{y=1} \Big/ \left(\frac{d\sigma^{\bar\nu}}{dy}\right)^{cc}_{y=1} = 0{\cdot}5 \pm 0{\cdot}05$	(i), (ii), (iiia)	0·258 ±0·088	0·138 ±0·01	0·018 ±0·01	0·018 ±0·01	0·26 ±0·04
$\int F_2^{ep}(x)dx = 0{\cdot}16 \pm 0{\cdot}005$, $\int F_2^{en}(x)dx = 0{\cdot}12 \pm 0{\cdot}008$ $\left(\frac{d\sigma^{\bar\nu}}{dy}\right)^{nc}_{y=1} \Big/ \left(\frac{d\sigma^{\bar\nu}}{dy}\right)^{cc}_{y=1} = 0{\cdot}5 \pm 0{\cdot}05$ †††$\left(\frac{d\sigma^{\bar\nu}}{dy}\right)^{nc}_{y=0} \Big/ \left(\frac{d\sigma^{\bar\nu}}{dy}\right)^{cc}_{y=0} = 0{\cdot}3 \pm 0{\cdot}03$	(i), (ii), (iiib)	0·258 ±0·088	0·138 ±0·01	0·108 ±0·01	0·017 ±0·01	0·25 ±0·04

†(Perkins 1977), ††(Peccei 1997), †††(Paar 1977).

In the quark-parton model with four flavours, using (5), (7) and (21), we get

$$\begin{aligned}\{2W^2/9\ &[5\,(d_u + d_{\bar{u}} + d_d + d_{\bar{d}}) + 8\,(d_c + d_{\bar{c}}) + 2\,(d_s + d_{\bar{s}})]\\ &- W\,[(d_u + d_d + d_{\bar{u}} + d_{\bar{d}}) + \tfrac{4}{3}\,(d_c + d_{\bar{c}}) + \tfrac{2}{3}\,(d_s + d_{\bar{s}})]\\ &+ \tfrac{1}{2}\,[d_u + d_d + d_{\bar{u}} + d_{\bar{d}} + d_c + d_{\bar{c}} + d_s + d_{\bar{s}}]\\ &- 0{\cdot}29\,[(d_{\bar{u}} + d_{\bar{d}} + 2d_{\bar{c}}) + (d_u + d_d + 2d_s)]\} = 0 \end{aligned} \tag{22}$$

This gives the constraints for physically acceptable (real and positive) values of $\sin^2\theta_W$ as,

$$\epsilon_c - \epsilon_s < 14{\cdot}4 \qquad \text{(positivity constraint)}, \tag{23}$$

$$0{\cdot}313\,\epsilon_s + 1{\cdot}287\,\epsilon_c < 1 \qquad \text{(reality constraint)}, \tag{23a}$$

where $$\epsilon = \frac{d_{\bar{u}} + d_{\bar{d}}}{d_u + d_d},\quad \epsilon_s = \frac{2d_s}{d_u + d_d} = \frac{2d_{\bar{s}}}{d_u + d_d},\quad \epsilon_c = \frac{2d_c}{d_u + d_d} = \frac{2d_{\bar{c}}}{d_u + d_d} \tag{24}$$

We derive a similar inequality in the case of quark-parton models with three flavours, so that we can compare various earlier results which do not take into account the effect of charm. Using (19), (20) and (21) we get,

$$\begin{aligned}\{2W^2/9\ &[5\,(d_u + d_{\bar{u}} + d_d + d_{\bar{d}}) + 2\,(d_s + d_{\bar{s}})]\\ &- W\,[(d_{\bar{u}} + d_{\bar{d}} + d_u + d_d) + \tfrac{2}{3}\,(d_s + d_{\bar{s}})]\\ &+ \tfrac{1}{2}\,[(d_u + d_d + d_{\bar{u}} + d_{\bar{d}} + d_s + d_{\bar{s}}]\\ &- 0{\cdot}29\,[d_{\bar{u}} + d_{\bar{d}} + (d_u + d_d)\cos^2\theta_c + 2d_s\sin^2\theta_c]\} = 0 \end{aligned} \tag{25}$$

which gives

$$\epsilon > 4{\cdot}76\,\epsilon_s - 0{\cdot}376\ (\epsilon,\ \epsilon_s \text{ are as defined in (24)}), \tag{26}$$

as the constraint for having physically acceptable values of $\sin^2\theta_W$.

The constraints (23, 23a) are likely to be satisfied in all 4—QPM parametrisations as ϵ_c, ϵ_s are small quantities (of the order of 10^{-1}—10^{-2}) and are obviously satisfied in our parametrisations listed in table 1. But the corresponding constraint in 3-QPM *i.e.* (equation (26)) is not satisfied in the parametrisations of Albright Mc-Elhaney and Tuan. However the Barger-Phillips and the Field-Feynman parametrisations do satisfy it, but the physically acceptable values of $\sin^2\theta_W$ obtained from (25) for these parametrisations are 0·40 and 0·35 respectively. These values are much higher than the present world average. The $\sin^2\theta_W$ values obtained in different parametrisations and given in table 2 rule out the Albright parametrisation and the McElhaney Tuan parametrisation as they yield complex values. We therefore leave these two from our discussion.

After obtaining the *ds* and $\sin^2\theta_W$, we have also calculated other physically interesting parameters like

$$\int F_2^{ep}(x)\,dx,\ \int F_2^{en}(x)\,dx,\ R,\ \bar{R},\ \left(\frac{d\sigma}{dY}\right)_{nc}^{\nu,\bar{\nu}} \Bigg/ \left(\frac{d\sigma}{dY}\right)_{cc}^{\nu,\bar{\nu}}$$

at $Y=0$ and 1, B_{cc}, B_{nc}, $\langle Y\rangle$ in the various model parametrisations. The significance of the parameters B_{cc} and B_{nc} is evident. They provide a clue to the structure of charged current and neutral current respectively. In this connection, the value of B_{nc} is of special interest. Also $\langle Y\rangle$ is a measure of the average energy loss suffered by the incident lepton. Table 3 compares our parametrisations (table 1) with the

Table 2. $\sin^2\theta_W$ for different parametrisations extracted from the data:

Parametrisation	Albright (1974)	Mc-Elhaney and Tuan (1973)	Barger-Phillips (1974)	Field-Feynman (1977)	Charm parametrisation
$\sin^2\theta_W$	Complex	Complex	0·40	0·35	0·26 ± 0·04

Table 3. Experimental and calculated values of some parameters (defined in the text in different parametrisations).

Parameter	Experimental Value	Calculated values for		
		Charm parametrisation*	Barger-Phillips parametrisation	Field-Feynman parametrisation
$\int F_2^{ep}(x)dx$	0·16 ± 0·016	0·16	0·16	0·16
$\int F_2^{en}(x)dx$	0·12 ± 0·012	0·12	0·11	0·12
R	0·293 ± 0·01	0·29	0·245	0·27
$\bar{R}$	0·35 ± 0·03	0·35	0·4	0·37
$\left(\frac{d\sigma^{\bar{\nu}}}{dY}\right)_0^{nc} \Big/ \left(\frac{d\sigma^{\bar{\nu}}}{dY}\right)_0^{cc}$	0·30 ± 0·03	0·31	0·30	0·30
$\left(\frac{d\sigma^{\bar{\nu}}}{dY}\right)_1^{nc} \Big/ \left(\frac{d\sigma^{\bar{\nu}}}{dY}\right)_1^{cc}$	0·50 ± 0·05	0·52	1·71	1·1
$\left(\frac{d\sigma^{\nu}}{dY}\right)_1^{nc} \Big/ \left(\frac{d\sigma^{\nu}}{dY}\right)_1^{cc}$	0·284	0·28	0·21	0·25
$\sigma_{cc}^{\bar{\nu}} \big/ \sigma_{cc}^{\nu}$	0·45	0·46	0·40	0·47
$\sin^2\theta_W$	0·25	0·26	0·40	0·35
B_{cc}^{ν}	0·78	0·59	0·87	0·80
B_{nc}^{ν}	0·68	0·56	0·48	0·44
$(a-b)$	0·25	0·22	0·09	0·15
$1-\langle Y\rangle_{cc}^{\nu N}$		0·52	0·506	0·52
$1-\langle Y\rangle_{cc}^{\bar{\nu} N}$		0·62	0·709	0·70
$1-\langle Y\rangle_{nc}^{\nu N}$		0·53	0·535	0·53
$1-\langle Y\rangle_{nc}^{\bar{\nu} N}$		0·62	0·595	0·57

*[$d_u=0{\cdot}257$, $d_d=0{\cdot}137$, $d_{\bar{u}}=d_{\bar{d}}=d_s=d_{\bar{s}}=0{\cdot}017$, $d_c=d_{\bar{c}}=0{\cdot}019$ $\sin^2\theta_W=0{\cdot}26$]

experimental results as well as with those of the Barger-Phillips and the Field-Feynman model.

We find that the agreement between the calculated and the experimental values of the different parameters for example

$$\left[R,\ \bar{R},\ \sin^2\theta_W,\ \left(\frac{d\sigma^{\nu,\bar{\nu}}}{dY}\right)^{nc}_{y=0,\,1} \Big/ \left(\frac{d\sigma^{\nu,\bar{\nu}}}{dY}\right)^{cc}_{y=0,\,1}\right]$$

in the models of Barger-Phillips and Field-Feynman is very poor, while it is quite good for our parametrisations. It is noteworthy that our charm parametrisations give a good agreement with all the data except for B_{cc} and B_{nc}, where it is 25% off. Even in this case, it gives better results than all other parametrisations.

4. Summary and conclusions

We summarize below the main conclusions which can be drawn from our analysis:

(i) The first moments of parton distributions for charm parametrisations are listed in table 2. The central values for the parameters could be taken as

$$d_u = 0{\cdot}257,\ \ d_d = 0{\cdot}137,\ \ d_{\bar{u}} = d_{\bar{d}} = d_s = d_{\bar{s}} = 0{\cdot}017,\ \ d_c = d_{\bar{c}} = 0{\cdot}019.$$

If we exclude charm and do a similar type of exercise to determine the first moments of parton distribution functions from the data on electroproduction (Perkins 1977) and Y-distribution (Paar 1977), we get, $d_u = 0{\cdot}27$, $d_d = 0{\cdot}15$, $d_{\bar{u}} = d_{\bar{d}} = d_s = d_{\bar{s}} = 0{\cdot}03$, $W = 0{\cdot}28$. This value of $\sin^2\theta_W$ is very much higher than the present world average and subsequently it gives $R = 0{\cdot}6$ and $\bar{R} = 0{\cdot}7$ which are nowhere near the data. Thus it lends support to our choice of including charm.

(ii) In our set of parameters, a measure of sea contribution, the ratio

$$\bar{Q}/(Q+\bar{Q})\ (Q^{(-)}) = d_{u^{(-)}} + d_{d^{(-)}} + d_{s^{(-)}} + d_{c^{(-)}}$$

is found to be 0·12, which agrees with other experimental results (Banerjee 1977) given below:

Experiment	$\bar{Q}/(Q+\bar{Q})$,
CDHS	$0{\cdot}12 \pm 0{\cdot}02$,
BEBC	$0{\cdot}11 \pm 0{\cdot}03$,
HPW	$0{\cdot}14 \pm 0{\cdot}03$,
World average	$0{\cdot}13 \pm 0{\cdot}02$.

(iii) The constraints imposed by the Y-distribution data (Paar 1977) on reality and positivity of $\sin^2\theta_W$ in 4-QPM (equationt (23) and (23a)) are satisfied quite well in all of our parametrisations (table 1).

The corresponding constraints in the 3-QPM are not satisfied in some of the models discussed in literature. The models of Barger-Phillips and Field-Feynman satisfy this constraint, but the values obtained for $\sin^2\theta_W$ in these parametrisations are 0·35 and 0·40 respectively (table 2). These are much higher than the present world average and therefore result in their subsequent disagreement with the data (table 3).

(iv) The average energy loss suffered by the leptons in the neutrino-induced charged as well as neutral current reactions is less than that in $\bar{\nu}$-induced reactions. In our parametrisation, the loss in ν case is about 50% and for $\bar{\nu}$ induced reactions it is about 60%. The other two models considered also give the same value for the energy loss suffered by the lepton in ν-induced reactions but give different results in $\bar{\nu}$ induced reactions. This shows that the effect of presence of charm will be more accessible in $\bar{\nu}$-induced reactions than in ν-induced reactions.

(v) The sets of parameters obtained in our analysis work exceedingly well with all the data except for B_{cc} and B_{nc}, where it is 25% off. Probably we need more refinement in the data to determine the parameters more successfully and having better agreement with the data on parameters like B_{nc}. This will help establish the character of the neutral current. The need for refinement in the data is also evident from the large error bars found in our analysis for the parameters (table 1).

This analysis has shown that models without charm cannot explain this data whereas our parametrisations with charm are successful in explaining the data.

We have found $d_c = d_{\bar{c}} = 0{\cdot}02 \pm 0{\cdot}01$, which is quite small and at a first glance, it appears that the exclusion of charm will not matter. But it is not so, when we put $d_c = d_{\bar{c}} = 0$ where we have to take recourse to the 3-QPM formulae. In the neutral current sector, one can go from 4-QPM to 3-QPM by just neglecting charm. But in charge current reactions it is not so simple. In 3-QPM, we have Cabibbo suppressing terms. Many authors arbitrarily put $\theta_c = 0$, without any justification whereas in 4-QPM, they are automatically eliminated by the GIM Scheme. The desirable procedure is therefore to use 4-QPM, which does not require any assumption about the Cabibbo angle and consider the effect of charm. The analysis presented here emphasizes the need to analyse the high energy neutral current and charged current data in the models which include charm.

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