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PARAMETRIZATION OF PROTON STRUCTURE FUNCTIONS

The CHARM Collaboration

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ABSTRACT

We present a parametrization of the parton densities as derived from the data collected by the CHARM collaboration in the wide band beam neutrino and antineutrino weak charged current interactions. They are rescaled to the proton and calculated at a reference Q^2 value of 10 GeV^2 including the next to leading order corrections and imposing the Gross-Llewellyn Smith and the momentum sum rules.

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In the calculations of the hadronic cross sections required by present and future collider machines, a large piece of information arises from the parton densities as determined in deep inelastic scattering, mainly by neutrino experiments, having the unique feature to discriminate quarks from antiquarks. In this paper we try to give the best knowledge of these densities as determined by the CHARM Collaboration from deep inelastic semileptonic neutrino and antineutrino scattering[1], including in a coherent way the corrections up to the first non leading terms of the expansion in the strong coupling constant. These densities are presented in a parametrized form suitable to be used as a starting point for numerical QCD-evolution calculations.

We present here the densities for u_v , d_v (referred to the proton), $\bar{q}$ and the gluon at $Q_0^2 = 10 \text{ GeV}^2$. The experimental data come from the analysis of wide band beam neutrino and antineutrino charged current interactions, described in ref. [1] In order to fully exploit the available information and to reduce at the same time the statistical uncertainties associated with each set of points at a given Q^2 , we use as input for the parametrization the Furmanski-Petronzio[2] QCD fit to the whole set of data already presented in ref. 1, recalculated at a Q^2 value of 10 GeV^2 , where the largest x range is spanned by our experimental points. Besides, at this Q^2 value higher twist and finite mass effects are presumably negligible. The described procedure, mandatory for the gluon density, can be interpreted as a "theory weighted" average over Q^2 of all our experimental data.

The published data are rescaled to take into account the newly measured neutrino cross sections[3]. As there is an evidence[4, 5, 6] that quark structure functions measured in heavy nuclei are softer than the ones measured on proton, we also applied to our data measured in marble a linear correction in the region $0.275 < x < 0.65$, derived from ref. [4].

Before performing the final parametrization we have to include next to leading corrections to the relationships between the parton densities and the structure functions defined in terms of the measured ν and $\bar{\nu}$ cross sections. As it is well known, the definition of parton densities at the next to leading order is not unambiguous. Our choice is to resolve

the ambiguity by imposing the quark parton model relationship

$$F_2(x, Q^2) = q(x, Q^2) + \bar{q}(x, Q^2) \quad (1)$$

to be valid to all orders[7]. This choice implies:

$$\int_0^1 (q_f - \bar{q}_f) \frac{dx}{x} = v_f \quad (2)$$

where v_f is the number of valence quarks of a given flavour f , giving for the proton

$$\int_0^1 (u_v + d_v) \frac{dx}{x} = 3 \quad (3)$$

$$\int_0^1 u_v \frac{dx}{x} = 2. \quad (4)$$

Then, in the relationships for $x F_3^{exp}$ and $\bar{q}^{exp}$, terms of order α_s will appear as a correction, namely F_L and ΔF_3 :

$$x F_3^{exp}(x, Q^2) = u_v(x, Q^2) + d_v(x, Q^2) - x \Delta F_3(x, Q^2) \quad (5)$$

$$\bar{q}^{exp}(x, Q^2) = \bar{q}^{CG}(x, Q^2) - \frac{y^2}{2} F_L(x, Q^2) + \frac{1}{2} x \Delta F_3(x, Q^2) \quad (6)$$

where $\bar{q}^{CG} = \bar{u} + \bar{d} + 2(\bar{s} - \bar{c})$. The Gross-Llewellyn Smith sum rule will read as:

$$\int_0^1 F_3 dx = 3(1 - \frac{\alpha_s}{\pi}). \quad (7)$$

The contribution from F_L entering in equation (6) can be evaluated by assuming[8]

$$F_L(x, Q^2) = \frac{\alpha_s(Q^2)}{2\pi} x \int_x^1 \frac{dy}{y^2} \left(F_2(y, Q^2) C_{qq}^L\left(\frac{x}{y}\right) + 2N_f G(y, Q^2) C_{qG}^L\left(\frac{x}{y}\right) \right) \quad (8)$$

where

$$C_{qq}^L(z) = 8z/3$$

$$C_{qG}^L(z) = 2z(1 - z)$$

while

$$\Delta F_3(x, Q^2) = \frac{\alpha_s(Q^2)}{2\pi} x \int_x^1 \frac{dy}{y} \left(\Sigma^-(y, Q^2) C_{qq}^3\left(\frac{x}{y}\right) \right) \quad (9)$$

where

$$C_{qq}^3(z) = 4(1+z)/3$$

and

$$x\Sigma^-(x, Q^2) = q(x, Q^2) - \bar{q}(x, Q^2)$$

The value of $\Lambda_{\overline{MS}}$ used is 310 MeV as determined by CHARM collaboration in ref. 9.

The effect of ΔF_3 correction on the valence distribution is shown in fig. 1 where the fit to xF_3^{exp} is plotted as a continuous line and $(u_v + d_v)$ as a dashed line. The u and d flavours are separated by imposing $\bar{u} = \bar{d}$ and

$$\frac{d_v}{u_v} = r(1-x)$$

as suggested by experimental results[10]. Recent results from BEBC Collaboration[11] indicate that this relationship is practically Q^2 independent in the range from 1 to 100 GeV^2 .

As for $\bar{q}$, to subtract from the experimentally measured antiquark distribution the $[\bar{s}(x, Q^2) - \bar{c}(x, Q^2)]$ contribution we assume:

$$\bar{s} = 0.2 \cdot (\bar{u} + \bar{d}) = 0.4 \cdot \bar{u} \quad (10)$$

as suggested by neutrino produced dimuon events[12], and

$$c(x, Q_0^2) \sim 0. \quad (11)$$

The resulting curve is shown as a continuous line in fig. 2. The global effect of the order α_s corrections, shown by a dashed line in the same figure, is nearly zero owing to the almost complete cancellation of the two single contributions to (6), which are both at the 10% level.

The gluon density has been constrained by imposing the momentum sum rule

$$\int_0^1 (q + \bar{q} + G) dx = 1 \quad (12)$$

up to and including terms of order α_s and it is shown in fig. 3.

In order to determine a satisfactory parametrization of the resulting densities, corrective terms have to be applied to the usual $x^\alpha(1-x)^\beta$ form. The best agreement is obtained by introducing a polynomial factor in powers of $(1-x)$ for the valence distribution and a polynomial factor in powers of x for the sea distribution. The gluon fit requires an x dependent power law of the term $(1-x)$ to represent in a satisfactory way the data.

The densities are then represented by:

$$u_v(x, Q_0^2) = 2.85x^{0.70}(1-x)^{2.4}(1 - 1.007(1-x) + 0.756(1-x)^2 + 0.863(1-x)^3) \quad (13)$$

$$d_v(x, Q_0^2) = 0.58(1-x)u_v(x, Q_0^2) \quad (14)$$

$$\bar{q}(x, Q_0^2) = 0.80(1-x)^{8.5}(1 - 4.18x + 20.3x^2 - 15.3x^3) \quad (15)$$

$$G(x, Q_0^2) = 0.24x^{-0.64}(1-x)^{\beta(x)} \quad (16)$$

where $\beta(x) = 7.5 + 5.5 \ln\{\ln[1/(1-x)]\}$.

We note that the uncertainties of the valence quark densities are strongly reduced with respect to the original experimental errors by imposing the sum rules (3) and (4) related to the conservation of the number of valence quarks in the nucleon. We feel justified in doing so by the good agreement of the Gross-Llewellyn Smith sum rule evaluated from our data[1] at $Q^2=10 \text{ GeV}^2$:

$$\int_{0.0075}^1 F_3(x) dx = 2.56 \pm 0.41(\text{stat.}) \pm 0.10(\text{syst.})$$

and the value predicted by QCD, $3(1 - \alpha_s/\pi) \simeq 2.8$. In fig. 4a we compare the curve corresponding to the given parametrization of the valence quark density with the constrained parametrization of the upper and lower limits (dotted and dashed line) of the experimental uncertainty band. Possible systematic uncertainties are represented in fig. 4b where the constrained fit is applied to the data scaled by $\pm 1\sigma$ of the average neutrino cross sections[3] (dotted and dashed line) and to the data not corrected for nuclear effects (dashed-dotted line).

The dominant uncertainty on the sea and the gluon densities appears as a correlated variation in their normalization constants in (15) and (16), resulting from statistical and systematical experimental errors and from the uncertainty on the strange sea contribution (10) and on the measurements of neutrino and antineutrino total cross sections[3]. It can be quantified to be $\pm 15\%$ for the sea and $\mp 3\%$ for the gluon distribution, and is shown as a confidence band in figs. 2 and 3.

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FIGURE CAPTION

- Fig. 1 Valence quark density at $Q_0^2 = 10 \text{ GeV}^2$: the continuous line represents $x F_3^{exp}$ as determined from the fit to the data while the dashed line is $(u_v + d_v)$ including next to leading corrections.
- Fig. 2 Antiquark density at $Q_0^2 = 10 \text{ GeV}^2$, before (continuous line) and after next to leading corrections (dashed line); dotted lines delimit 1σ confidence band.
- Fig. 3 Gluon density at $Q_0^2 = 10 \text{ GeV}^2$; dotted lines delimit 1σ confidence band.
- Fig. 4 Valence quark density (continuous line) compared with: (a) constrained fit to the upper (dotted line) and lower (dashed line) limits of the 1σ statistical uncertainty band; (b) constrained fit to the valence quark density scaled for $\pm 1\sigma$ of the average neutrino cross section (dotted lines) and to the data from marble, not corrected for nuclear effects (dashed line).

Fig. 1

Fig. 2

Fig. 3

Fig. 4a

Fig. 4b