NON UNIVERSALITY OF STRUCTURE FUNCTIONS
AND MEASUREMENT OF THE STRANGE SEA
DENSITY

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Abstract

We show that there is no real conflict between the two determinations of the strange sea density from the opposite–sign dimuon production and from the difference of the $F_2$ structure functions measured in neutrino and muon deep inelastic scattering. Once non universal sea parton densities are introduced, which take into account the effects of different mass thresholds and different longitudinal contributions, the discrepancy is shown to disappear and both sets of data are simultaneously well reproduced. No need for a large strange sea content of the nucleon emerges.
In a series of previous papers [1, 2, 3] we pointed out that the sea parton densities measured in deep inelastic scattering (DIS) are not universal: neutrinos and muons do not probe the same strange and charm distributions. This is the consequence of two effects which have their origin in the dynamical mechanism of excitation of the sea.

First of all, in the $W$–gluon fusion process (Fig. 1c,d).

$$W^+ g \rightarrow c\bar{s} ,$$

involved in charged current neutrino DIS the excitation of strangeness is inseparable from the simultaneous production of charm. Notice also that (1) describes two processes: excitation of $c$ on $s$ and excitation of $\bar{s}$ on $\bar{c}$. Therefore in $\nu$ DIS we should not expect $c(x) \ll s(x)$ since we are rather probing a charm–strange density $cs(x)$ not coinciding with the strange density measured in $\mu$ DIS. The mass threshold of the reaction (1) is different from that of the photon–gluon fusion process $\gamma^* g \rightarrow c\bar{c}, s\bar{s}$ (Fig. 1a,b).

By definition, the Bjorken variable is related to $Q^2$ and to the mass $m_X$ of the hadronic final state through

$$x = \frac{Q^2}{Q^2 + \mathcal{M}^2 - m_N^2} ,$$

and one can immediately see that having $\mathcal{M}^2 \sim (m_s + m_c)^2$ instead of $\mathcal{M}^2 \sim 4m_s^2$ makes a non negligible difference up to moderate $Q^2$ [1] (for a recent related discussion see also [4]).

The second source of non universality comes from the non conservation of the vector and axial $c\bar{s}, s\bar{c}$ currents. This leads to a large value of $R = \sigma_L/\sigma_T \sim 4m_c^2/Q^2$ in the neutrino excitation of charm and strangeness at low and moderately large $Q^2$ [3].

The mass threshold effect and the large $R$ effect point to opposite directions: the former depletes the transverse part of $cs(x)$ with respect to $s(x)$ while the latter produces a relevant longitudinal contribution to $cs(x)$. The purpose of this letter is to show that the residual difference between $cs(x)$ and $s(x)$ can easily explain the discrepancy which presently seems to exist between two different experimental determinations of the strange density.

To start with, let us summarize the current status of knowledge about the strange distribution.

According to the conventional parton decomposition of the DIS structure functions [5], in principle one can extract $s(x)$ from the difference between $F_2^\nu$ (measured in $\nu$ DIS) and $F_2^\mu$ (measured in $\mu$ DIS) for an isoscalar target

$$\frac{5}{6}F_2^\nu(x) - 3F_2^\mu(x) \simeq xs(x) ,$$

(3)
where we have made the customary assumption $s'(x) = s''(x) = s(x)$ and $c'(x) = c''(x) = c(x)$, and used $c(x) \ll s(x)$.

On the other hand, one can extract directly $s(x)$ from the data on the opposite–sign dimuon production in $\nu N$ interaction [6]. In the conventional parton model, the cross section for this process reads

$$\frac{d^2 \sigma(\nu N \rightarrow \mu^+ \mu^- X)}{dxdy} \sim 2x s(x)|V_{cs}|^2 + x [u(x) + d(x)]|V_{cd}|^2.$$ (4)

and has been recently measured to a good accuracy by the CCFR collaboration [7].

Although the available information on the difference (3), coming from the CCFR measurement [8] of $F_2^{\nu}$ and from the NMC measurement [9] of $F_2^\mu$, is rather poor due to large errors, and somehow unsafe since one has to subtract data from two different experiments, it seems clear that the strange distribution obtained from (3) is considerably larger than the one extracted from (4) (see Figs. 2,3).

All the available global fits to the deep inelastic data are unable to solve this puzzle. For instance, the CTEQ1M parametrization [10] reproduces the $\nu - \mu$ difference at the price of a very large strange sea content $\kappa = 2S/(\bar{U} + \bar{D}) = 0.9$ ($S = \int dx s(x)$, etc.) and its strange distribution considerably overshoots the dimuon data. Martin, Roberts and Stirling [11, 12] constrain $\kappa$ to 0.5 and are forced to content themselves with a fit which represents only a reasonable compromise between the two sets of data, still largely overshooting the dimuon results.

How the above mentioned non universality effects solve this seemingly contradictory situation?

Introducing the charm–strange distribution $cs(x)$ probed in neutrino DIS (from now on $c(x)$ and $s(x)$ will refer to muon DIS), we obtain for the $\nu - \mu$ difference the following decomposition

$$\frac{5}{6} F_2^{\nu}(x) - 3 F_2^\mu(x) = \frac{10}{3} x cs(x) - \frac{2}{3} x s(x) - \frac{8}{3} x c(x) ,$$ (5)

which replaces Eq. (3). The main difference between (3) and (3) is that the charm–strange distribution $cs(x)$, as defined in terms of the underlying QCD subprocess (4), simultaneously describes the $sc$ and the $c\bar{s}$ excitation processes.

The ratio

$$r(x) = \frac{2 cs(x)}{c(x) + s(x)}$$ (6)

is an $x$–dependent quantity, different in general from the naive assumption 1, which would correspond to the conventional parton model and to Eq. (4).

In the model of Ref. [1, 3] we found that at $Q^2 = 10 GeV^2/c^2$ the ratio $r(x)$ varies from $r(x) \simeq 1.5$ at $x = 10^{-3}$ to $r(x) \simeq 0.8$ at $x = 10^{-1}$ and is empirically expressible in the form

$$r(x) = 0.72 x^{-0.13} (1 - x)^{0.35} .$$ (7)
This ratio has been obtained with the choice $\mathcal{M}^2 = (m_c + m_s)^2 = 4 \text{GeV}^2/c^2$ and can be taken as a realistic quantitative estimate of the non universality of the strange sea density.

In terms of $r(x)$ Eq. (5) can be rewritten as

$$\frac{5}{6} F'_2(x) - 3 F'_1(x) \approx \frac{1}{3} x s(x) \left[ 5 r(x) - 2 \right], \quad (8)$$

and in the small-$x$ region, $x \lesssim (0.5 - 1) \cdot 10^{-1}$, where $r(x) \gtrsim 1$, the $\nu - \mu$ difference turns out to be larger than the corresponding quantity calculated with an universal $s(x)$ distribution. This is precisely what emerges from the comparison of the data with the MRS($D'_0$) parametrization [12].

Turning to the dimuon production, the Cabibbo unsuppressed contribution to the cross section now reads

$$d^2\sigma(\nu N \to \mu^+ \mu^- X) \, dr \, dy \sim 2 x c s(x) |V_{cs}|^2 \sim x r(x) s(x), \quad (9)$$

and for $x \lesssim 10^{-1}$ is more than a factor 2 smaller than the quantity predicted with $r(x) = 1$. Again, this is exactly the discrepancy existing between the standard fits and the data.

By means of Eqs. (5–9) one can now easily reproduce the experimental determinations. To this purpose, we used for $s(x)$ and $c(x)$ the distributions computed within our model [1, 3, 13]. The results are presented in Figs. 2,3 and show that a very satisfactory agreement with both sets of data has been achieved. For completeness, in Fig. 3 we present also our predictions for the transverse contribution to $x c s(x)$ and for the strange distribution probed by muons.

Our complete set of parton distributions gives for the strange sea fraction at $Q^2 = 10 \text{GeV}^2/c^2$ the following values

$$\kappa^\mu = \frac{2 S}{U + D} = 0.45, \quad \kappa^\nu = \frac{2 C S}{U + D} = 0.30. \quad (10)$$

In particular $\kappa^\nu$ is found to be rather stable in the range $10 \text{GeV}^2/c^2 \leq Q^2 \leq 30 \text{GeV}^2/c^2$, a feature confirmed by the CCFR experiments, whose finding is $\kappa^{\nu}_{\exp}(Q^2 = 22.2 \text{GeV}^2/c^2) = 0.373^{+0.048}_{-0.041} \pm 0.018$ with no appreciable $Q^2$ variation. The reason for such a $Q^2$ independence is that the rise with $Q^2$ of the transverse component of $c s(x)$ is totally compensated by the simultaneous decrease of the longitudinal contribution.

Another relevant quantity is the strange sea content $\eta = 2 C S / (U + D)$ for which we found $\eta = 0.07$ to be compared to the CCFR result $\eta_{\exp} = 0.064^{+0.008}_{-0.007} \pm 0.002$.

Let us now make some comments about the slow–rescaling procedure [14]. This is based on the assumption that in the $W^+ + s \rightarrow c$ transition the $s$ quark, which carries momentum $\xi p_N$, is on shell and massless, whereas the mass of the $c$ quark is retained. Then $(\xi p_N + q)^2 = k_c^2 = m_c^2$ implies $\xi = x(1 + m_c^2/Q^2)$. The parton distributions
are rewritten as functions of $\xi$ and the Callan–Gross relation is assumed to hold in terms of $\xi$, so that an extra kinematical factor $(1 - y + xy/\xi)$ appears in the cross sections. However, putting both quarks on mass shell and taking $k_s^2 = 0$ does not find any justification in the dynamical mechanism for the excitation of the sea, which is produced in the $W^+-$gluon fusion process. The approach we presented in [1, 13], based on the concept of Fock states of the virtual photon and of the $W, Z$ bosons, takes correctly into account the mass effects arising from the presence of heavy quarks and cannot be simply reduced to the slow rescaling. In a subsequent paper we shall present our prediction for the energy dependence of the opposite-sign dimuon rate, which is usually regarded to be a successful validity test of the slow–rescaling procedure.

In conclusion, we outline our results. There is no puzzling conflict between the $\nu - \mu$ and the dimuon data. Simply, they represent different quantities whose parton content is given by Eqs. (5) and (9). Both data sets are simultaneously reproduced by relying on non universal sea parton densities. The strange sea probed by neutrinos is smaller than the one probed by muons. Their ratio $r(x)$ could be used as a further input in the global parametrizations of the deep inelastic structure functions and we expect, for instance, that allowing for $r(x) \neq 1$ would considerably improve the agreement of the MRS($D_0$) fit with the data. Finally, there is no need for a large intrinsic strange sea content of the nucleon. The data seem to favour the values $\kappa^\mu = 0.4 - 0.5$ and $\kappa^\nu = 0.3 - 0.4$ at $Q^2 \simeq 20 GeV^2/c^2$.

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References

[1] V. Barone, M. Genovese, N.N. Nikolaev, E. Predazzi and B.G. Zakharov, Phys. Lett. B268 (1991) 279.

[2] V. Barone, M. Genovese, N.N. Nikolaev, E. Predazzi and B.G. Zakharov, Phys. Lett. B292 (1992) 181.

[3] V. Barone, M. Genovese, N.N. Nikolaev, E. Predazzi and B.G. Zakharov, Phys. Lett. B304 (1993) 176.

[4] A. Donnachie and P.V. Landshoff, Cambridge preprint DAMTP 93-23 (May 1993, revised version).

[5] See for instance, E. Leader and E. Predazzi, An Introduction to Gauge Theories and the New Physics, Cambridge University Press, 1982. R.G. Roberts, The Structure of the Proton, Cambridge University Press, 1990.

[6] R. Brock, Phys. Rev. Lett. 44 (1980) 1027.

[7] S.A. Rabinowitz et al. (CCFR), Phys. Rev. Lett. 70 (1993) 134.

[8] S.R. Mishra et al. (CCFR), Nevis preprints 1459 and 1465 (1992); A. Bazarko, private communication.

[9] P. Amaudruz et al., NMC, Phys. Lett. B295 (1992) 159.

[10] J. Botts et al. (CTEQ), Phys. Lett. B304 (1993) 159.

[11] A.D. Martin, W.J. Stirling and R.G. Roberts, Phys. Lett. B306 (1993) 145.

[12] A.D. Martin, W.J. Stirling and R.G. Roberts, Rutherford preprint RAL-93-027, J. Phys. G, in press.

[13] V. Barone, M. Genovese, N.N. Nikolaev, E. Predazzi and B.G. Zakharov, Z. Phys. C58 (1993) 541. Int. J. Mod. Phys. A8 (1993) 2779.

[14] H. Georgi and H.D. Politzer, Phys. Rev. D14 (1976) 1829. R.M. Barnett, Phys. Rev. D14 (1976) 70.
Figure captions

Fig. 1 Photon–gluon fusion (a,b) and W–gluon fusion (c,d) processes producing strange and charmed sea.

Fig. 2 Our prediction for the difference $5/6 F_2^\nu - 3 F_2^\mu$ at $Q^2 = 10 GeV^2/c^2$ compared to the data (CCFR for $F_2^\nu N$ and NMC for $F_2^\mu D$).

Fig. 3 The CCFR data on the strange sea density extracted from opposite–sign dimuon production compared to our result for $x cs(x)$ at $Q^2 = 10 GeV^2/c^2$ (solid line). Also shown are our predictions for the transverse component of $x cs(x)$ (dotted line) and for $x s(x)$ (dashed line).