THE PARTON STRUCTURE OF THE PROTON AND THE CHARGE DISTRIBUTION IN MULTIPARTICLE PRODUCTION

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We assume that the charge distribution in non-diffractive multiparticle production (in the Feynman variable x) is the same as that of valence quarks in the proton. Combining the consequences of this assumption with information from deep inelastic electron-proton, electron-deuteron and neutrino-nucleus data one can separately estimate the parton distribution functions in the proton. The functions obtained in this way (by using charge distribution data including the diffractive component) are, within rather large errors, reminiscent of the usual models of parton distribution functions.

1. Introduction

The simple quark-parton model [1] successfully describes deep inelastic lepton-nucleon cross sections in terms of six independent probability distributions. However, these parton distribution functions cannot be separately calculated from deep inelastic electron-proton, electron-neutron and neutrino-nucleus data. The maximum information provided by these data (in the Bjorken scaling limit) is summarized in the following four equations

$$f_1^{ep}(x) = \tfrac{4}{9}\,[u(x)+\bar{u}(x)]+\tfrac{1}{9}\,[d(x)+\bar{d}(x)]+\tfrac{1}{9}\,[s(x)+\bar{s}(x)], \tag{1}$$

$$f_1^{en}(x) = \tfrac{1}{9}\,[u(x)+\bar{u}(x)]+\tfrac{4}{9}\,[d(x)+\bar{d}(x)]+\tfrac{1}{9}\,[s(x+\bar{s}(x)], \tag{2}$$

$$\frac{f_2^{\nu A}(x)}{x} = u(x)+d(x)+\bar{u}(x)+\bar{d}(x), \tag{3}$$

$$f_3^{\nu A}(x) = u(x)+d(x)-\bar{u}(x)-\bar{d}(x), \tag{4}$$

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where x is the Bjorken variable, $f_1^{ep}, f_1^{en}, f_2^{\nu A}, f_3^{\nu A}$ are standard structure functions, and $u(x)$, $d(x)$, $s(x)$, $\bar{u}(x)$, $\bar{d}(x)$, $\bar{s}(x)$ are parton probability distribution functions in the proton. The fifth equation follows from the assumption that the strangeness is locally compensated at the parton level

$$s(x) = \bar{s}(x) \tag{5}$$

but Eqs (1)–(5) are still not sufficient for calculating parton distribution functions.

2. *Partons and the charge distribution in multiparticle production*

In this section we shall make use of simple parton model ideas in studying some features of multiparticle production. Particularly, we shall assume that

the charge distribution $\varrho(x)$ in non-diffractive multiparticle production in pp collisions is the same as the charge distribution of partons in colliding protons.

The assumption, written down explicitly, says that (assuming the validity of Eq. (5))

$$\varrho(x) = \tfrac{2}{3}\,[u(x)-\bar{u}(x)]-\tfrac{1}{3}\,[d(x)-\bar{d}(x)]. \tag{6}$$

The restriction to non-diffractive processes seems to be essential to us, since parton distribution functions are related to reactions when partons act incoherently and in multiparticle production the coherence is destroyed only in non-diffractive events.

Furthermore, if a sizable part of stable hadrons observed in the final state comes from resonance decays, it seems most natural to apply our assumption to the charge distribution of the parents. We shall, however, forget about this complication in what follows.

Our extension of Feynman's hypothesis [2] on the retention of quark quantum numbers lacks at present any detailed motivation by a particular dynamical scheme of multiparticle production.

On the other hand, the available information on the charge distribution in multiparticle production indicates that with increasing energy $\varrho(x)$ is approaching a limiting distribution (see e. g. the compilation in [3]). It is quite natural to believe that this limiting distribution is related to the parton structure of the proton[1]. A specific form of this relationship is a much more debatable point. Our assumption corresponds to a situation when each of the partons brings in (on the average) its quantum numbers irrespectively of other partons present[2]. Such a point of view immediately leads to similar assumptions about distributions of other quantum numbers. For instance, the baryonic charge would be distributed as

$$\varrho_B(x) = \tfrac{1}{3}\,[u(x)-\bar{u}(x)]+\tfrac{1}{3}\,[d(x)-\bar{d}(x)] \tag{7}$$

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[1] From an alternative point of view, not necessarily related to parton model ideas, one can interpret the behaviour of the charge distribution as a consequence of the limiting fragmentation [4].

[2] This assumption requires the existence of an infinite "sea" of quark-antiquark pairs. A simple and naive model of this process, which leads to Eq. (6), is described in the Appendix.

(if the validity of Eq. (5) is assumed) and similar equations can easily be written for isotopic spin and strangeness (identical to zero).

In other models quarks do not act independently of each other and the connection among parton distribution functions and distribution functions for various quantum numbers take on different forms. E. g. the model of Van Hove and collaborators [5] in which valence partons form after the collision a proton (or a baryonic resonance) predicts, in our opinion, that the electric and the baryonic charge distributions should be very similar or equal, in contradistinction to our Eqs (6) and (7). In this type of models the charge and baryonic charge distributions are not given by inclusive distributions of individual partons, but by a joint probability distribution [5] for valence quarks.

Even if one is rather uncertain at present about the precise form of the connection between the general features of the multiparticle production and the parton structure of hadrons we share the opinion of many others (e. g. [5–8]) that such a connection does exist and that it is essential for understanding the multiparticle production from the parton model point of view.

3. *Extraction of parton distribution functions from the data*

After an excursion into rather general questions we shall come back to our particular assumption contained in Eq. (6) and study one of its implications.

Noting that Eqs (1)–(6) are sufficient for extracting the parton distribution functions in the proton we invert them and find that

$$\begin{bmatrix} u(x) \\ \bar{u}(x) \\ d(x) \\ \bar{d}(x) \\ s(x) \end{bmatrix} = \begin{bmatrix} 3/4 & -3/4 & 1/4 & 1/6 & 1/2 \\ 3/4 & -3/4 & 1/4 & -1/6 & -1/2 \\ -3/4 & 3/4 & 1/4 & 1/3 & -1/2 \\ -3/4 & 3/4 & 1/4 & -1/3 & 1/2 \\ 9/4 & 9/4 & -5/4 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} f_1^{ep} \\ f_1^{en} \\ f_2^{\nu A}/x \\ f_3^{\nu A} \\ \varrho \end{bmatrix} \tag{8}$$

and $s(x) = \bar{s}(x)$.

The data on multiparticle production in pp collisions published up to now do not contain the charge distribution without the diffractive component. In order to show — at least roughly — what Eqs (8) may lead to we shall use in the following the data on $\varrho(x)$ which contain both diffractive and non-diffractive components.

Experimental values of $f_1^{ep}(x), f_1^{en}(x), f_2^{\nu A}(x), f_3^{\nu A}(x)$ and $\varrho(x)$ which we have used come from:

1) measurement of the differential cross sections for deep inelastic electron-proton and electron-deuteron scattering at the SLAC [9];

2) results on the neutrino-nucleon differential cross sections (Gargamelle collaboration) [10];

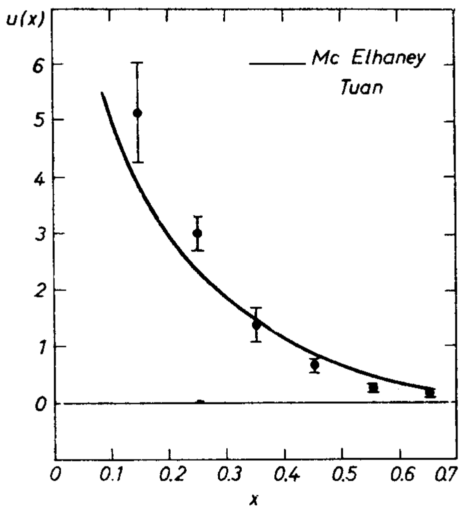

Fig. 1

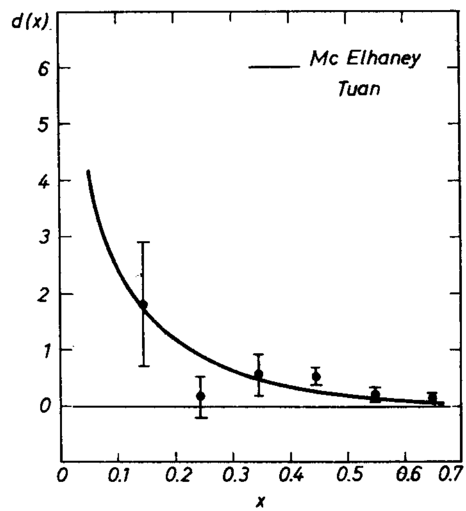

Fig. 2

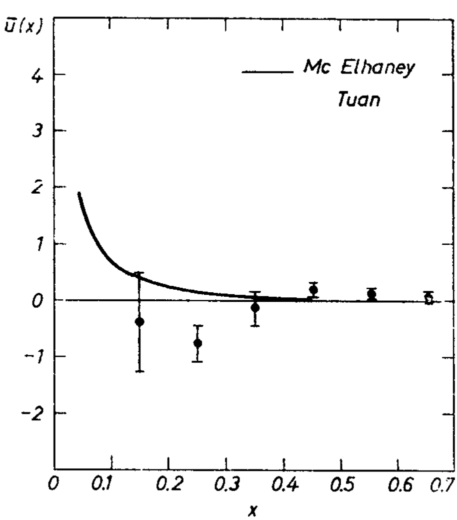

Fig. 3

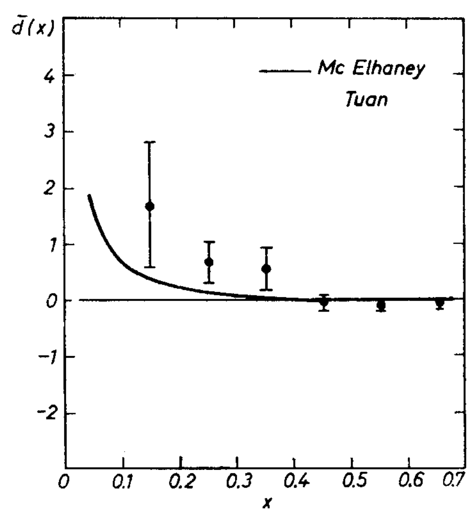

Fig. 4

3) charge distribution in pp collisions extracted by Sivers [11][3] from inclusive invariant cross sections measured at the CERN ISR (see also [12]).

Inserting these data into Eqs (8) we obtained the parton distribution functions presented in Figs 1–5. The curves show for comparison McElhaney and Tuan [13] distribution functions.

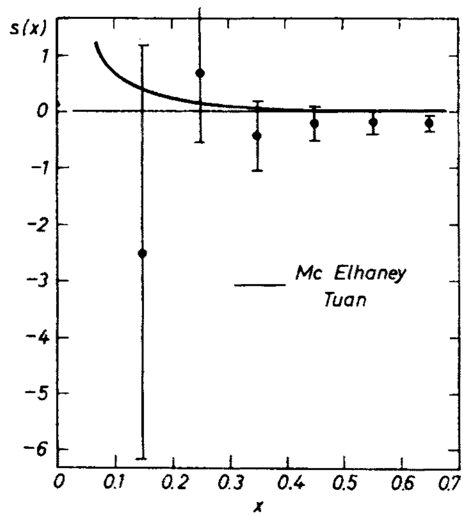

Fig. 5

Figs. 1–5. The parton distribution functions calculated using Eqs (8) and the data from [9–11]. The curves show McElhaney and Tuan [13] distribution functions

In Fig. 6 we have compared the data on $\varrho(y)$ which we have used with $\varrho(y)$ calculated from Eq. (6) with McElhaney and Tuan [13] and Kuti and Weisskopf [14] distribution functions. (Other probability distributions used at present lead to curves quite similar to that obtained by using McElhaney's and Tuan's set). The rapidity y is calculated from Feynman's x assuming that all particles contributing to $\varrho(y)$ have masses equal to the pion mass and $p_\perp = 0.4$ GeV/c.

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[3] In [11] the CERN ISR data at $p_\perp = 0.4$ GeV/c and $E = 53$ GeV were used. To compensate approximately for different $p_\perp$ distributions, the pion data were normalized to $\langle n_{\pi^+}\rangle - \langle n_{\pi^-}\rangle = 0.5$, the K-data to $\langle n_{K^+}\rangle - \langle n_{K^-}\rangle = 0.25$, and the baryon data to $\langle n_p\rangle - \langle n_{\bar{p}}\rangle = 1.25$. The charge distribution was expressed in [11] as a function of the rapidity y. Transforming it into the x-variable we used the formulae

$$x = \frac{m_T}{P_0} \sinh y, \quad m_T = (m^2 + p_\perp^2)^{1/2},$$

where P_0 is the momentum of a colliding proton ($P_0 = 26.7$ GeV/c), $p_\perp = 0.4$ GeV/c and m is the pion mass (since the majority of the produced particles are pions).

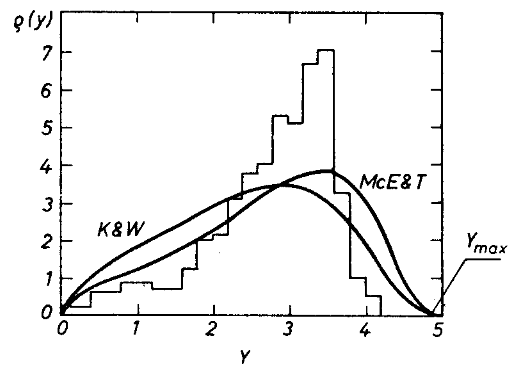

Fig. 6. The histogram [11] of the charge distribution $\varrho(y)$ in pp collisions at the CERN ISR (E = 53 GeV, $p_\perp$ = 0.4 GeV/c), compared with ϱ obtained from Eq. (6) using McElhaney and Tuan [13] and Kuti and Weisskopf [14] distribution functions and transformed into rapidity

4. Conclusions and comments

The conclusions from our calculations may be summarized as follows:

the data on the charge distribution with the non-diffractive component only (defined e. g. as $n > \langle n \rangle$) would be desirable;

the calculated parton distribution functions show features similar to those of commonly used models and phenomenological fits;

Fig. 5 indicates that in interpreting simultaneously both electro- and neutrino-production data at small x in terms of the parton model one arrives at some inconsistencies (quite independently of the behaviour of the charge distribution). This probably means that one should be rather cautious in applying the simple parton model at low x. An alternative but much less probable possibility is that the data are really inconsistent.

We believe that even in case the conjectured simple relation between $\varrho(x)$ and parton distribution functions turns out to be wrong any clarification of the connection between some features of the multiparticle production and the parton distribution functions would be very useful. For these purposes charge distributions are a very suitable starting point.

I am very grateful to J. Pišút, V. Černý, and P. Lichard for many helpful discussions.

APPENDIX

We shall briefly sketch here a simple and very naive model for materialization of quarks to hadrons in multiparticle production. The model contains quark quantum number retention and leads directly to Eqs (6) and (7) for the distribution of charge and baryonic charge. The model is not meant to be a serious dynamical scheme. It should only illustrate what might be the content of the assumption made in the text.

We assumed that quantum numbers of quarks are on the average locally conserved. It is most natural to picture that as a result of a statistical recombination of valence quarks with a "sea" of pairs which carry almost no momentum.

Since all quarks are supposed to act independently let us consider a single quark with the momentum given by Feynman's x (such a quark will be denoted as $u(x)$ and we shall consider for simplicity only one type of quarks). This quark has to be confined and can materialize to hadrons only by picking up companions from the sea. Let us therefore suppose that there appears a pair $u(0)\,\bar{u}(0)$ (zeros in parenthesis indicate that $x = 0$), which recombines with $u(x)$. We assume that in this step we obtain with equal probabilities combinations

$$[\bar{u}(0)u(x)]\,u(0) \text{ and } [u(0)u(x)]\bar{u}(0).$$

In the former case $[\bar{u}(0)u(x)]$ form a meson which leaves the interaction region and the remaining $u(0)$ will recombine later on with remnants of other quarks which are present. In the latter case we have a diquark $u(0)u(x)$ and a single antiquark $\bar{u}(0)$. Confinement prohibits both of them from leaving and another pair is picked out of the sea. We get with equal probabilities combinations

$$\{[u(0)u(0)u(x)]\,[\bar{u}(0)\bar{u}(0)]\} \text{ and } \{[u(0)\bar{u}(0)u(x)]\,[\bar{u}(0)u(0)]\}.$$

The former results in a baryon at x and a $[\bar{u}(0)\bar{u}(0)]$ pair (which recombines with the other sea quark), and the latter is equivalent to the situation with which we have started. Let the charge sitting at x after picking up n pairs be denoted as $Q^{(n)}(x)$ and let $Q(u)$ and $Q(uuu)$ denote charges of a single quark and a baryon formed from 3 quarks, respectively. Writing up explicitly probabilities mentioned above we obtain after two steps

$$Q^{(2)}(x) = \tfrac{1}{4}\,Q(uuu)+\tfrac{1}{4}\,Q^{(0)}(x).$$

Consequently $Q^{(2)}(x) = Q(u)$ (since $Q^{(0)}(x) = Q(u)$).

The same argument can be applied again giving

$$Q^{(n+2)}(x) = \tfrac{1}{4}\,Q(uuu)+\tfrac{1}{4}\,Q^{(n)}(x).$$

This shows that the mesons and baryons produced at a given x do have on the average the same charge as the original quark.

We stress again that the model was meant only as an illustration of the content of our assumption about the charge distribution. The model is oversimplified but it is difficult to imagine a mechanism leading to the same result which would not be based on the statistical and independent recombination of original partons with (at least potentially infinite) sea of very soft pairs.

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