SEMI-INCLUSIVE PRODUCTION OF PIONS IN DIS AND $\bar{d}-\bar{u}$ ASYMMETRY *

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We discuss the role of some nonpartonic effects which lead to $N_p^{\pi^+} \neq N_n^{\pi^+}$ and $N_p^{\pi^-} \neq N_n^{\pi^-}$ and may therefore modify the conclusion on the $\bar{d}-\bar{u}$ asymmetry extracted from semi-inclusive production of pions in DIS. Quantitative estimations for resolved photon and exclusive ρ^0 are given as examples. The results are discussed in the context of recent HERMES data.

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1. Introduction

In order to understand the nature of the Gottfried Sum Rule violation [1] two different Drell–Yan experiments were performed [2, 3]. The integrated result for the asymmetry from a more complete Fermilab experiment [3] is $\int_0^1 [\bar{d}-\bar{u}]\, dx = 0.09 \pm 0.02$, to be compared with the NMC result: $\int_0^1 [\bar{d}-\bar{u}]\, dx = 0.148 \pm 0.039$. The NMC integral asymmetry apears slightly bigger. It was suggested recently [4] that the difference can be partly due to large higher-twist effects for $F_2^p - F_2^n$. Recently the HERMES collaboration [5] used semi-inclusive unpolarized production of pions to extract the asymmetry.

We discuss briefly a disturbing role of some nonpartonic processes which cloud the extraction of the asymmetry from semi-inclusive DIS.

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2. Quark-parton model approach

In the quark-parton model (see Fig. 1(a)) the generalized semi-inclusive structure function can be written as

$$\mathcal{F}_2^{N\to\pi}(x,Q^2,z) = \sum_f e_f^2 x q_f(x,Q^2) D_{f\to\pi}(z) \; , \tag{1}$$

where the sum runs over the quark/antiquark flavours $f = u, d, s$, q_f are quark distribution functions and $D_{f\to\pi}(z)$ are so-called fragmentation functions.

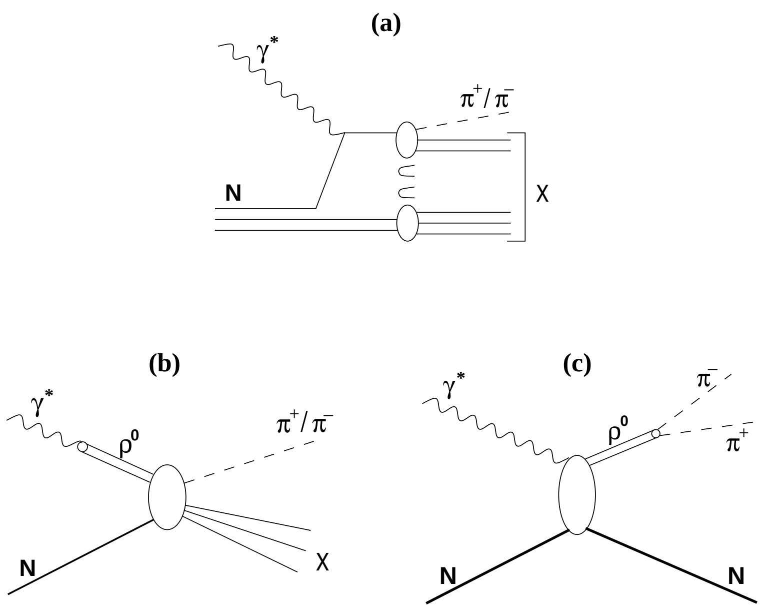

Fig. 1. Different possible mechanisms of the pion production: (a) quark fragmentation, (b) VDM contribution, (c) elastic production of the ρ^0 meson and its decay.

The isospin and charge conjugation symmetries allow to reduce the number of fragmentation functions to two: favoured $D_+(z)$ and unfavoured $D_-(z)$ [1].

In the QPM one can combine semi-inclusive cross sections for the production of π^+ and π^- on proton and neutron targets to isolate a quantity sensitive to the flavour asymmetry [5]

$$\frac{\bar{d}(x) - \bar{u}(x)}{u(x) - d(x)} = \frac{J(z)[1 - r(x,z)] - [1 + r(x,z)]}{J(z)[1 - r(x,z)] + [1 + r(x,z)]} \; , \tag{2}$$

[1] A third type of fragmentation functions $D_s(z)$ for strange quarks does not enter the quantity analyzed here (2).

where $J(z) = \frac{3}{5}\frac{1+D_-(z)/D_+(z)}{1-D_-(z)/D_+(z)}$ and $r(x,z) = \frac{N_p^{\pi^-}(x,z)-N_n^{\pi^-}(x,z)}{N_p^{\pi^+}(x,z)-N_n^{\pi^+}(x,z)}$. In the absence of other mechanisms the equation can be used to extract the x-dependence of the difference $\bar{d}-\bar{u}$.

In order to demonstrate the effect of nonpartonic components on the extraction of $\bar{d}-\bar{u}$ asymmetry we need to fix the effective fragmentation functions which the main partonic term will be calculated with. Most of the model fragmentation functions were constructed in the context of e^+e^- pion production data, where amount of π^+ and π^- produced is equal, and do not manage to describe separately multiplicity distributions of positive and negative pions in DIS [6]. Besides separate yields of π^+ and π^- the QPM formula (2) directly depends also on the ratio of unfavoured and favoured fragmentation functions.

Surprisingly only a rather old Field–Feynman parametrization [7] provides a good representation of the available *ep* pion production data in the HERMES kinematical region [6]. This parametrization will be used in the following analysis.

3. Nonpartonic components

For small Q^2, as in the case of the HERMES experiment , some mechanisms of nonpartonic origin may become important too. For instance the virtual photon can interact with the nucleon via its intermediate hadronic state. Such a mechanism can be described within the vector dominance model (VDM). The photon could also fluctuate into a pair of pions, where both or one of them interact with the nucleon. Some exclusive processes can produce pions directly or as decay products of heavier mesons.

To our best knowledge none of such processes has been investigated in the literature. Their influence on the extracted $\bar{d}-\bar{u}$ asymmetry also remains unknown. Here for illustration we discuss only two of them.

3.1. VDM contribution

Let us start from the VDM component (see Fig. 1(b)). It was shown recently that the inclusion of the VDM contribution and a related modification of the partonic component help to understand the behaviour of structure functions F_2^p and F_2^d at small Q^2 and broad range of Bjorken-x [8]. This model was confirmed by a recent analysis of the Q^2-dependence of the world data for $F_2^p - F_2^n$ [4]. The model for inclusive structure functions [8] can be generalized to semi-inclusive production of pions:

$$
\begin{aligned}
\mathcal{F}_2^{N\to\pi}(x,Q^2,z) \;&=\; \frac{Q^2}{Q^2+Q_0^2}\sum_f e_f^2 x q_f(x,Q^2) D^{\mathrm{eff}}_{f\to\pi}(z) \\
&+\; \frac{Q^2}{\pi}\sum_V \frac{1}{\gamma_V^2}\frac{\sigma_{VN\to\pi X}(s^{1/2})M_V^4}{(Q^2+M_V^2)^2}\,\Omega_V(x,Q^2). \qquad (3)
\end{aligned}
$$

The second sum above runs over vector mesons $V=\rho^0,\omega,\Phi$ and Ω_V decribes a correction factor due to finite fluctuation time of virtual photon into vector mesons for large x [8].

The inclusive cross section for pion production in vector meson (ρ^0,ω,ϕ) scattering off proton and neutron is not known experimentally. In analogy to the total cross section the pion production inclusive cross section $\rho^0 N \to \pi^{\pm} X$ can be estimated as:

$$
\begin{aligned}
\sigma(\rho^0 p\to\pi^{\pm}X) \;&\approx\; 1/2\left[\sigma(\pi^+ p\to\pi^{\pm}X)+\sigma(\pi^- p\to\pi^{\pm}X)\right], \\
\sigma(\rho^0 n\to\pi^{\pm}X) \;&\approx\; 1/2\left[\sigma(\pi^+ n\to\pi^{\pm}X)+\sigma(\pi^- n\to\pi^{\pm}X)\right]. \qquad (4)
\end{aligned}
$$

Experimental data from the ABBCCHW collaboration [9] at $p^{\pi}_{\mathrm{lab}}=8$, 16 GeV correspond approximately to the range of the HERMES experiment [5].

However, the experimental spectra for $\pi^{\pm}p\to\pi^{\pm}X$ contain components due to peripheral processes, which are specific, different for different beams. We wish to note that peripheral processes in the $\pi^+p\to\pi^+X$ and $\pi^-p\to\pi^-X$ reactions do not contribute to the $\rho^0p\to\pi^{\pm}X$ reaction and should be eliminated; only nondiffractive components for $\pi p\to\pi X$ reactions should be taken into account. This requires a physically motivated parametrization of the $\pi+N\to\pi+X$ data. Therefore we have parametrized the experimental differential cross sections for four different reactions $\pi^{\pm}p\to\pi^{\pm}X$ from [9] as a sum of central and peripheral components

$$
\frac{d\sigma}{dx_{\mathrm{F}}dp_{\perp}^2}=\frac{d\sigma^{\mathrm{cen}}}{dx_{\mathrm{F}}dp_{\perp}^2}+\frac{d\sigma^{\mathrm{per}}}{dx_{\mathrm{F}}dp_{\perp}^2}\,. \qquad (5)
$$

The details of the analysis will be given elsewhere [6]. Because the CM-energy of the ABBCCHW collaboration is very similar to that of the HERMES experiment, we believe that the parametrization is suitable in the limiting range of energy relevant for the HERMES experiment [5]. The cross sections on the neutron can be obtained from those on the proton by assuming isospin symmetry for the hadronic reactions.

The analysis of experimental data [9] combined with the assumption of isospin symmetry strongly indicate that for the *nondiffractive* components [6]

$$\sigma(\rho^0 p \to \pi^\pm X) \neq \sigma(\rho^0 n \to \pi^\pm X)\ . \tag{6}$$

This automatically means that the VDM contribution modifies the r.h.s. of Eq. (2).

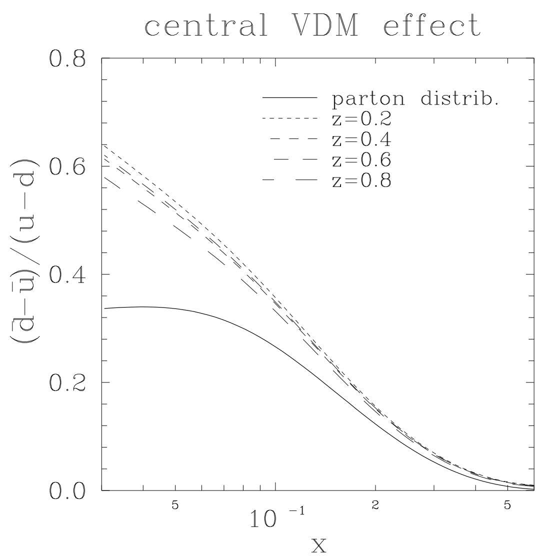

Fig. 2. The "true" (solid) and the modified by the central VDM contribution $\frac{\bar{d}-\bar{u}}{u-d}$ calculated according to l.h.s. and r.h.s. of Eq. (2), respectively, as a function of Bjorken-x for different values of z and $W = 5$ GeV.

In Fig. 2 we show a modification of the measured HERMES quantity $\frac{\bar{d}-\bar{u}}{u-d}$ due to the VDM component. In the present calculation the photon-proton CM energy was fixed at the average HERMES value $W = 5.0$ GeV^2 and the quark fragmentation component was rescalled by a factor $\frac{Q^2}{Q^2+Q_0^2}$ (see Eq. (3)). The solid line represents $\frac{\bar{d}-\bar{u}}{u-d}$ obtained directly from the parton distributions [12]. As can be seen from the figure the r.h.s. of Eq. (2) clearly deviates from the partonic result. Thus, if not canceled by other effects, the quark flavour asymmetry extracted from semi-inclusive experiments in the simple QPM approach seems to be highly overestimated.

3.2. Exclusive ρ meson production

The exclusive meson production $\gamma^* N \to MN'$ is not included in the fragmentation formalism and may also modify the extraction of $\bar{d}-\bar{u}$ asymmetry. The pion exclusive channels ($M = \pi$) contribute at $z \approx 1$, *i.e.* outside of the range of the HERMES kinematics and will be ignored here. The pions from decays of light vector mesons can be important in the context of the $\bar{d}-\bar{u}$ asymmetry. The production of ρ mesons ($M=\rho$) seems to be of particular importance. First of all the $\rho^0 N$ channel is know to be the dominant exclusive channel in the $\gamma^* N$ scattering. Secondly, because ρ^0 decays predominantly into two pions it will produce pions with $\langle z\rangle \sim \frac{1}{2}$. A detailed calculation [6] shows that the dispersion of the decay-pion z-distribution is large and therefore this effect could be observed at large z where hadronization rate is rather small. Below as an example we shall consider the ρ^0 elastic production only.

The elastic ρ^0-production contribution (diagram (c) in Fig. 1) to semi-inclusive structure function can be written formally as

$$\mathcal{F}_2^{\mathrm{el},\rho^0}(x,Q^2,z) = \frac{Q^2}{4\pi^2\alpha}\sigma_{\gamma^* N\to\rho^0 N}(W,Q^2) f_{\mathrm{decay}}(z)\ . \tag{7}$$

The cross section for proton and neutron target and their difference can be estimated within the Regge approach as well as in a QCD inspired quark-exchange model. It is not clear *a priori* what is the applicability range of these models. In this short note we shall try to understand the elastic ρ^0 meson production only within the Regge phenomenology. This requires an analysis of relevant experimental data for the proton and deuteron targets simultaneously. While for the proton target there are data in quite a broad kinematical range of x and Q^2 [11] (although slightly different from the HERMES kinematics), there is almost no data for the deuteron target.

We have parametrized the existing experimental data for exclusive ρ^0 production by means of the following simple Regge-inspired reaction amplitude

$$\begin{aligned} A^{\lambda_V\leftarrow\lambda_\gamma}_{\lambda_{N'}\leftarrow\lambda_N}(\gamma^* N\to\rho^0 N;t) = \Bigg(& i\, C_{\mathrm{IP}}(t)\left(\frac{s}{s_0}\right)^{\varepsilon} + \left[\frac{-1+i}{\sqrt{2}}\right] C_{\mathrm{IS}}(t)\left(\frac{s}{s_0}\right)^{-1/2} \\ & \pm \left[\frac{-1+i}{\sqrt{2}}\right] C_{\mathrm{IV}}(t)\left(\frac{s}{s_0}\right)^{-1/2}\Bigg) \\ & \times \left[\frac{m_\rho^2}{m_\rho^2+Q^2}\right]\delta_{\lambda_{N'}\lambda_N}\delta_{\lambda_V\lambda_\gamma} \end{aligned} \tag{8}$$

with "+" for proton and "−" for neutron, respectively. In practical application we shall assume the same t-dependence of C_{IP}, C_{IS} and C_{IV} and take $\Lambda = m_\rho$.

The free parameters in Eq. (8) *i.e.* ε, C_{IP} and $C_{\mathrm{IS}}+C_{\mathrm{IV}}$ have been fitted to the existing experimental data for t-integrated differential cross section for ρ^0 production on hydrogen [11]. In this fit we have limited to the experimental data with $W > 3$ GeV (to avoid resonances) and $Q^2 < 10$ GeV^2 (above genuine hard QCD processes should reveal) and fixed the slope parameter $B = 6$ GeV^{-2} in exponential t-distribution which is known experimentally. All other details of the analysis will be discussed in [6].

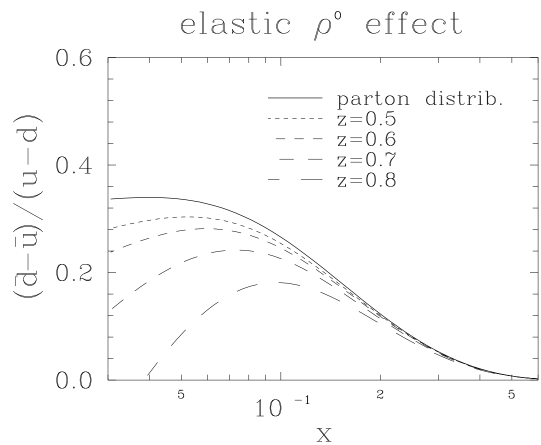

Fig. 3. The "true" (solid) and the modified by the exclusive ρ^0 production $(\bar{d}-\bar{u})/(u-d)$ as a function of Bjorken-x for different z and $W = 5$ GeV.

From the fit to the proton data we have obtained only a sum of the coefficients $C_{\rm IS} + C_{\rm IV}$. The separation into the isoscalar and isovector contributions cannot be done in a model independent way. The size of the isovector a_2-exchange contribution was estimated long ago for total photoproduction cross section (see for instance [10]). Our Regge model can be applied to both real and virtual photoproduction and exclusive as well as inclusive case [6]. We have used the data for real photoproduction total cross section and the data for exclusive ω photoproduction to estimate the size of the isovector amplitude [6] *i.e.* the strength of a_2-reggeon exchange.

Although the difference of the cross sections for exclusive ρ^0 photoproduction on the neutron/proton targets calculated with resulting amplitudes is small, its effect on the $\frac{\bar{d}-\bar{u}}{u-d}$ ratio extracted by the HERMES collaboration, shown in Fig. 3, is not negligible at all. We show in the figure the "measured" HERMES quantity as a function of Bjorken-x for a few values of z for a fixed $W = 5$ GeV. As in the case of the VDM contribution the QPM term was modified by the factor $\frac{Q^2}{Q^2+Q_0^2}$ according to our prescription for inclusive structure functions [8].

4. Conclusions

The semi-inclusive production of pions was recently used to determine the $\bar{u}-\bar{d}$ asymmetry in the nucleon sea. In the present analysis we have investigated a few effects beyond the quark-parton model which may influence the so-extracted asymmetry.

According to our estimation the interaction of the resolved hadron-like component of the photon with the nucleon leads to an artificial enhancement of the measured $\bar{d}-\bar{u}$ asymmetry in the region of small x. This enhancement depends on z very weakly.

The elastic production of ρ^0 meson is equally important. This effect, however, modifies the measured $\bar{d}-\bar{u}$ asymmetry in the opposite direction from the resolved photon component, but the two effects cancel only within a narrow interval of z. The elastic ρ^0 production makes the r.h.s. of Eq. (2) z-dependent invalidating somewhat averaging done in [5].

Here we have only shortly discussed two effects. A more detailed analysis of these two and other effects will be presented elsewhere [6]. Finally we wish to conclude that nonperturbative effects beyond QPM may substantially disturb the extraction of the $\bar{d}-\bar{u}$ asymmetry from semi-inclusive production of pions in DIS. Such an extraction requires a carefull combined analysis including many nonpartonic effects together with main partonic term.

In addition we would like to point out that some of the effects discussed in the present paper may also influence the extraction of the polarized quark distributions from semi-inclusive production of pions in DIS.

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