$\bar{u} - \bar{d}$ asymmetry - a few remarks.

A. Szczurek[a], V. Uleshchenko[a]

[a]H. Niewodniczanski Institute of Nuclear Physics, ul. Radzikowskiego 152, Kraków, Poland

We make a few remarks on possible sources of uncertainties of the $\bar{d}-\bar{u}$ asymmetry obtained by different methods and comment on its possible verification in the future. In addition we comment on its present understanding.

In the last year both the E866 collaboration at Fermilab (Drell-Yan production of dimuons) and HERMES collaboration at DESY (semi-inclusive production of charged pions) published their new results on $\bar{d} - \bar{u}$ asymmetry in the nucleon [1,2]. During the DIS99 conference both groups have presented their new results with somewhat better statistics [3,4]. The new results complement the older results obtained by the NMC on the Gottfried integral [5] and earlier Drell-Yan experiment NA51 from CERN [6].

The E866 collaboration measured the ratio of the cross sections: $\sigma_{pd}^{DY}/\sigma_{pp}^{DY}$. This ratio is extremely sensitive to the $\bar{d}/\bar{u}$ ratio. The $\bar{d}/\bar{u}$ ratio is extracted in an iterative procedure assuming leading order formulae and that valence quark distributions as well as $\bar{u}+\bar{d}$ are as given by PDF's [8]. Next the difference $\bar{d} - \bar{u}$ is obtained from

$$\bar{d} - \bar{u} = \frac{\bar{d}/\bar{u} - 1}{\bar{d}/\bar{u} + 1} \cdot [\bar{u} + \bar{d}] \; . \tag{1}$$

In practice the E866 collaboration uses $\bar{u}+\bar{d}$ from one of the global NLO fit to the world data. Here different global PDF fits [8] yield roughly similar result for $x > 0.05$. In this range of x the sum is strongly constrained from the (anti)neutrino experiments. At smaller values of x one should worry about the consistency of using NLO PDF's in LO formulae. At larger values of $x > 0.4$ our knowledge of $\bar{u} + \bar{d}$ is rather limited. This must be taken into account particularly seriously in the planned P906 experiment [7]. The average value of Q^2 in the E866 experiment is high enough not to expect any higher-twist effects.

In obtaining the $\bar{d}-\bar{u}$ asymmetry the HERMES collaboration assumes the factorization between the hard scattering process and the hadronization of the struck quark

$$N^{\pi^\pm}(x,z) \propto \sum_i e_i^2 [q_i(x) D_{q_i}^{\pi^\pm}(z) + \bar{q}_i(x) D_{q_i}^{\pi^\pm}(z)] \; , \tag{2}$$

i.e. assumes implicitly the validity of the parton model. The isospin symmetry (IS) between proton and neutron reduces the number of light-quark fragmentation functions to two, favoured and disfavored. Then [2]

$$\frac{1+r}{1-r} = \frac{u - d + \bar{u} - \bar{d}}{[u - \bar{u}] - [d - \bar{d}]} J(z) \; , \tag{3}$$

where $r(x,z) = \frac{N_p^{\pi^-}(x,z) - N_n^{\pi^-}(x,z)}{N_p^{\pi^+}(x,z) - N_n^{\pi^+}(x,z)}$ and $J(z) = \frac{3}{5}(\frac{1+D'(z)}{1-D'(z)})$, $D'(z) = D_u^{\pi^-}(z)/D_u^{\pi^+}(z)$.

The HERMES experiment is a fixed target experiment with the beam electron energy of about 30 GeV, i.e. the small x is associated with relatively small Q^2. In the lowest x bin the average Q^2 is only slightly larger than 1 GeV^2. It is an open problem how big are the higher-twist effects beyond the parton model at such small values of Q^2. A simple estimate of the VDM contribution to the structure function shows that it can be of the order of 20 %. Assuming IS for hadronic components we get for nucleon - virtual vector meson scattering: $\sigma(pV^0 \to \pi^+) = \sigma(nV^0 \to \pi^-) > \sigma(pV^0 \to \pi^-) = \sigma(nV^0 \to \pi^+)$. The inequality comes from the fact that presumably $u_p > d_p$ and $\bar{d}_p > \bar{u}_p$. Thus the presence of hadronic component would lead to a reduction of the experimentally extracted quantity $r(x,z)$. This means that the corresponding purely partonic quantity (exclusively theoretical quantity) would be bigger. This would result in a smaller $\bar{d} - \bar{u}$. No

quantitative estimate of the effect has been made up to now.

Assuming the validity of the parton model the HERMES collaboration extracts the quantity $(\bar{d}-\bar{u})/(u-d)$. The denominator is in our opinion not extremely well known. The measured region of x is sensitive to the meson cloud effects [10]. We wish to stress a poorly known fact that the meson cloud effects contribute both to the sea and valence quark distributions. Therefore it is not clear whether the PDF parametric forms used in global fits (even for valence quark distributions) are flexible enough to accomodate those effects.

Both the E866 and HERMES collaborations tried to estimate the integral $\int_0^1 [\bar{d} - \bar{u}]\ dx$. It appears that the number obtained by the E866 collaboration is slightly lower than those obtained by the NMC and HERMES collaborations. Is it a random statistical fluctuation or there is a physical reason behind it? Recently we have shown [13] that a two component model which includes the VDM contribution (modified for large x for finite fluctuation times of the hadronic component of the photon) and a modified partonic component (vanishing at small Q^2 [1]) can describe both the proton and deuteron structure functions in the broad range of x and Q^2; considerably better than the pure QCD-improved parton model. The model from [13] has interesting predictions for $F_2^p - F_2^n$. Here the VDM contribution cancels and one is left with a modified partonic component which tends to zero at $Q^2 \to 0$. Already at Q^2 as large as 4 GeV^2 (typical for NMC data) we find [13] a non-negligible reduction of the parton model result. This prediction for a strong Q^2 dependence of the $F_2^p - F_2^n$ seems to be confirmed by the world data for F_2^p and F_2^d. The $F_2^p - F_2^n$ as a relatively small quantity is very sensitive to statistical uncertainties and cannot be obtained by a simple subtraction of $F_2^p - (F_2^d - F_2^p)$. Here one can use the method proposed by the NMC [5]. The QCD improved parton model seems to fail for the extracted $F_2^p - F_2^n$ already at Q^2 as large as 7 GeV^2 [14]. In the language of the higher-twist expansion this means that the twist-4 contribution is rather large and negative. This phenomenological observation is consistent with a recent QCD lattice result [15]. The substantial higher-twist effects strongly modify our present understanding of the applicability of the QCD-improved parton model. The strong Q^2 dependence of the $F_2^p - F_2^n$ can potentially explain the difference between the E866 (large Q^2) and NMC (small Q^2) results.

Despite the not fully resolved problems, mentioned above, the new experiments provided valuable information on $\bar{d} - \bar{u}$ asymmetry in the nucleon and constitute a useful input which can be used to constrain PDF's. The LO Altarelli-Parisi evolution equations generate an equal number of $\bar{u} - u$ and $\bar{d} - d$ pairs. The two-loop evolution gives a rather negligible effect [9]. Because perturbative QCD is not able to explain the large asymmetry and the Gottfried Sum Rule violation it is clear that the relevant physics must be of nonperturbative origin.

The chiral symmetry and chiral symmetry breaking lead to the presence of the pion cloud in the nucleon. This concept provides the most natural and economic explanation of the asymmetry (see for instance [10]). There exists two technical formulations of such a model. In the traditional nuclear physics formulation the physical nucleon is expanded in terms of the meson-baryon Fock states as

$$|N>=|N_0>+|\pi N'>+|\pi\Delta>+etc. \qquad (4)$$

The most complete version of the model has been presented in [10]. If the coupling constants are fixed from low-energy hadronic physics and the vertex form factors from high-energy production of barions, the model leads to (a) $\pi^+ > \pi^0 > \pi^-$, (b) the number of pions in the nucleon $N(\pi) = 0.2$ - 0.3, and (c) the pion distribution $P(x_\pi)$ which peaks at $x_\pi \sim 0.2$ - 0.3. The latter means that the momentum fraction of the neutron associated with the pion would be about 0.7 - 0.8. This is fully consistent with the spectra of leading neutrons at HERA [16].

Parallel to the traditional approach, the effective chiral quark theory provides an alternative explanation. Here the relevant degrees of freedom are constituent quarks and Goldstone bosons. The most extended analysis of the light-antiquark asymmetry in this type of models can

[1] the traditional parton model do not posses this property

be found in [11]. If the constituent quark - pion vertex form factor is fixed to the size of the Gottfried Sum Rule violation then: (a) $\pi^+ : \pi^0 : \pi^-$ = 2:3/2:1, (b) $N(\pi)$ = 0.6 - 0.7 and (c) $P(x_\pi)$ which peaks at $x_\pi \sim 0.1$.

The recent E866 experiment at Fermilab has reported a first high-precision mapping of the x-dependence of the $\bar{u} - \bar{d}$ asymmetry with the finding that the difference of $\bar{d} - \bar{u}$ seems to vanish at large $x \geq 0.3$. This surprising observation was not predicted by models which used only limitations on leading baryons. It was shown in [12] that if the information on leading pions in hadronic reactions is used in addition, to limit the hadronic vertex form factors, than the new E866 data on $\bar{d} - \bar{u}$ can be described automatically.

In all the present experimental analyses: muon deep inelastic scattering [5], E866 Drell-Yan experiment [1] and HERMES semi-inclusive pion production [2] both the proton and neutron (deuteron) targets are used. In order to obtain the information on the $\bar{u} - \bar{d}$ asymmetry one assumes IS of quark (antiquark) distributions in the proton and neutron i.e.

$$u_n(x) = d_p(x), \quad d_n(x) = u_p(x),$$
$$\bar{u}_n(x) = \bar{d}_p(x), \quad \bar{d}_n(x) = \bar{u}_p(x) \; . \qquad (5)$$

Such a symmetry for PDF was never tested experimentally. Recently a simple analysis of the muon and neutrino structure function led to the conclusion of substantial isospin violation in PDF's [17]. Ascribing all the observed effect to isospin violation is rather an extreme view [18]. Even if the true violation of IS is much smaller than suggested in [17] it remains essentially unknown experimentally. Therefore all the present analyses are to some extent biased by the explicit assumption of IS. In [19] we have suggested how to test the $\bar{u} - \bar{d}$ asymmetry avoiding the assumption of IS. We suggested to measure at RHIC the asymmetry

$$A(pp \to W^\pm) = \frac{\sigma(pp \to W^+) - \sigma(pp \to W^-)}{\sigma(pp \to W^+) + \sigma(pp \to W^-)} \qquad (6)$$

as a function of W-boson rapidity or similar asymmetry for charged leptons from the decay of W bosons. The x-dependence of the asymmetry could be obtained by varying the beam energy at RHIC.

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