Vol. 29 (1998) *ACTA PHYSICA POLONICA B* No 11

CONSEQUENCES OF NONPERTURBATIVE NUCLEON STRUCTURE AT HIGH ENERGIES*

Antoni Szczurek

H. Niewodniczański Institute of Nuclear Physics
Radzikowskiego 152, 31-342 Kraków, Poland

(Received July 9, 1998)

I briefly review some consequences of the meson cloud in the nucleon for high-energy nucleon-nucleon and nucleon-antinucleon scattering. The discussion includes the analysis of the production of W and Z bosons and dijets in proton-antiproton collisions. A consistent analysis of deep-inelastic data and the gauge boson production data shows that the concept of virtual mesons in the nucleon is very useful in understanding the charged lepton asymmetry measured by the CDF collaboration at Fermilab. I discuss a possibility to test the $\bar{d}$–$\bar{u}$ asymmetry in the nucleon by the analysis of some asymmetries possible to measure in principle at RHIC. I discuss some selected effects which may potentially be responsible for an enhancement of the large-E_T inclusive jet production observed by the CDF collaboration at Fermilab. It is shown that target mass corrections in lepton DIS and effect of the pion cloud in the nucleon may be very important for a proper understanding of the experimental jet data.

PACS numbers: 12.38.Lg

1. Introduction

With the advent of high precision data on deep inelastic scattering, understanding of the nonperturbative flavour structure of the nucleon is becoming one of the pressing issues where the interests of particle and nuclear physics converge. It has been customarily assumed that the nucleon sea is flavor symmetric ($\overline{d}_p(x) = \overline{u}_p(x)$). There is no general principle that forces one to this hypothesis other than the fact that it appears as a natural consequence of a perturbative approach to the nucleon's parton distributions. At large Q^2 the perturbative QCD evolution is flavour independent and, to leading order in $\log Q^2$, generates equal number of $\bar{u}$ and $\bar{d}$ sea quarks.

* Presented at the MESON '98 and Conference on the Structure of Meson, Baryon and Nuclei, Cracow, Poland, May 26–June 2, 1998.

Perturbative QCD describes only the Q^2-evolution of deep inelastic structure functions, starting with certain nonperturbative input. There are no *a priori* reasons to expect a $\bar{u}$–$\bar{d}$ symmetric nonperturbative sea. Specifically, the observed [1] violation of the Gottfried Sum Rule (GSR) [2] provides experimental evidence that the nucleon sea is not flavour symmetric.

Furthermore, the strong correlations between quarks and antiquarks of the nonperturbative sea, exemplified by the pionic field in physical nucleons, leads to such an asymmetry [3–8]. The meson cloud model provides a natural explanation for the excess of $\overline{d}$ over $\overline{u}$ quarks already in its simplest form in which the proton contains components of a bare proton and π^0 and a bare neutron and π^+.

Recently [9] the CDF collaboration has reported a new evaluation of the measurement of the differential cross section for inclusive central jet production at the Fermilab $p\bar{p}$ Tevatron at $\sqrt{s}$ = 1.8 TeV. The results have been presented for jet transverse energies, E_T, in the range 15 to 440 GeV. It has been noticed long ago [10] that at the high E_T values such measurements probe the substructure of the (anti)proton in a previously unexplored kinematical region $\mathrm{Q}^2 \sim 10^5$ GeV^2, equivalent to distance scales of $\sim 10^{-2}$ fm, which is only a small fraction of the nucleon size. Thus, such measurements have a possibility to address the problem of the quark substructure provided the parton distributions in the nucleon are known sufficiently precise. Intriguingly, the CDF experimental result shows an evidence of possible deviations above that obtained from next-to-leading order (NLO) calculation based on the current phenomenological knowledge of parton distributions obtained from global analyses [11, 12] of a wide range of hard processes.

In this presentation I shall comment on possible consequences of the meson cloud for the W and Z weak gauge boson production in the nucleon-(anti)nucleon collisions and confront the predictions with the existing CERN and FNAL experimental data. In addition I shall discuss how the W/Z production in proton-proton and proton-deuteron collisions could shed some new light on the $\bar{d}$–$\bar{u}$ asymmetry in the nucleon and in the consequence on the nucleon structure. Finally I shall discuss how the meson cloud effects influence the inclusive E_T spectra of jets in proton-antiproton collisions.

2. Meson cloud and parton distributions in the nucleon

In our model (for a recent version see for instance [15]) the nucleon is viewed as a quark core, termed a bare nucleon, 'surrounded' by the mesonic cloud. The nucleon wave function can be schematically written as a superposition of a few principle Fock components (only πN and $\pi\Delta$ are shown explicitly)

$$
\begin{aligned}
|p\rangle_{\rm phys} = \sqrt{Z}\Bigg[& |p\rangle_{\rm core} \\
& + \int dy\, d^2\vec{k}_\perp \phi_{N\pi}(y,\vec{k}_\perp)\left(\sqrt{\frac{1}{3}}|p\pi^0;y,\vec{k}_\perp\rangle + \sqrt{\frac{2}{3}}|n\pi^+;y,\vec{k}_\perp\rangle\right) \\
& + \int dy\, d^2\vec{k}_\perp \phi_{\Delta\pi}(y,\vec{k}_\perp)\left(\sqrt{\frac{1}{2}}|\Delta^{++}\pi^-;y,\vec{k}_\perp\rangle - \sqrt{\frac{1}{3}}|\Delta^{+}\pi^0;y,\vec{k}_\perp\rangle \right. \\
& \left. + \sqrt{\frac{1}{6}}|\Delta^{0}\pi^+;y,\vec{k}_\perp\rangle\right) + \dots \Bigg] ,
\end{aligned}
\tag{1}
$$

with Z being the wave function renormalization constant which can be calculated by imposing the normalization condition $\langle p|p\rangle = 1$. The $\phi(y,\vec{k}_\perp)'s$ are the light cone wave functions of the πN, $\pi\Delta$, *etc.* Fock states, y is the longitudinal momentum fraction of the π (meson) and $\vec{k}_\perp$ its transverse momentum.

The model includes all the mesons and baryons required in the description of the low energy nucleon-nucleon and hyperon-nucleon scattering, *i.e.* π, K, ρ, ω, K^* and N, Λ, Σ, Δ and Σ^*. The main ingredients of the model are the vertex coupling constants, the parton distribution functions for the virtual mesons and baryons and the vertex form factors which account for the extended nature of the hadrons. The coupling constants are assumed to be related via SU(3) symmetry which seems to be well established from low-energy hyperon-nucleon scattering.

We have used the light cone meson-baryon vertex form factor [13]. By construction, such form factors assure the momentum sum rule [6, 13]. The parameters $\Lambda_{\rm MB}$ have been determined from an analysis of the $p \to n, \Delta, \Lambda$ fragmentation spectra [13].

The contributions from the virtual mesons can be written as a convolution of the meson (baryon) structure functions and its longitudinal momentum distribution in the nucleon [14]

$$
\delta^{(M)} F_2(x) = \int_x^1 dy f_M(y) F_2^M(\frac{x}{y}). \tag{2}
$$

Eq. (2) can be written in an equivalent form in terms of the quark distribution functions

$$\delta^{(M)} q_f(x) = \int_x^1 f_M(y)\, q_f^M(\frac{x}{y})\, \frac{dy}{y}. \tag{3}$$

The longitudinal momentum distributions (splitting functions, flux factors) of virtual mesons (or baryons) can be calculated assuming a model of the vertex. Further details can be found in Refs. [13].

The parton distributions "measured" in pion-nucleus Drell–Yan processes [16] are used for the mesons. The deep-inelastic structure functions of the bare baryons, $F_{2,\mathrm{core}}^N(x,Q^2)$, $F_{2,\mathrm{core}}^B(x,Q^2)$ are in principle unknown.

In the following we shall deal both with small and large x at relatively small Q^2, where the target mass corrections may play important role. To include the target mass corrections we follow Ref. [17] and replace the measured Bjorken-x by the target mass variable ξ [18]. In order to fix the parameters of the bare nucleon we have used the following sets of DIS data:

(a) $F_2^d(x,Q^2)$ [19],

(b) $F_2^p(x,Q^2) - F_2^n(x,Q^2)$ [19],

(c) $F_2^n(x,Q^2)/F_2^p(x,Q^2)$ [19],

(d) $F_3^{\nu N}(x,Q^2)$ [20].

The following simple parameterization has been used for the quark distributions in the bare proton at the initial scale $Q_0^2 = 4$ (GeV/c)^2.

$$\begin{aligned} xu_{v,\mathrm{core}}(x) &= A_u x^{\alpha_u}(1-x)^{\beta_u}(1+\gamma_u x)\;, && (4)\\ xd_{v,\mathrm{core}}(x) &= A_d x^{\alpha_d}(1-x)^{\beta_d}(1+\gamma_d x)\;, && (5)\\ xS_{\mathrm{core}}(x) &= A_S(1-x)^{\eta_S}(1+\gamma_S x)\;, && (6)\\ xg_{\mathrm{core}}(x) &= A_g(1-x)^{5.3}\;. && (7)\end{aligned}$$

Note, that we have used SU(2) symmetric sea quark distribution for the bare baryons and suppressed the strange sea by a factor 2, *i.e.*

$$S_{\mathrm{core}} = u_{s,\mathrm{core}} = \overline{u}_{s,\mathrm{core}} = d_{s,\mathrm{core}} = \overline{d}_{s,\mathrm{core}} = 2s_{s,\mathrm{core}} = 2\overline{s}_{s,\mathrm{core}}. \tag{8}$$

A typical fit to the data is shown in Fig. 1. The solid line corresponds to the fit, hereafter called "Model 1" for brevity, which explicitly includes the meson cloud corrections. For comparison by the dashed line we show also a result without meson cloud correction called "Model 2".

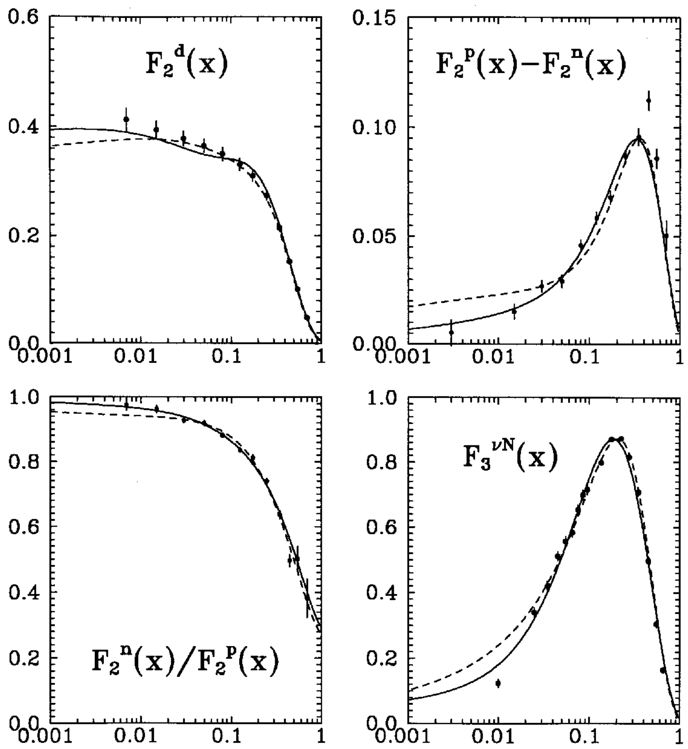

Fig. 1. The deep-inelastic scattering data. The solid line corresponds to the fit which explicitly includes the meson cloud corrections. For comparison we show result without meson cloud corrections (dashed line). (a) $F_2^d(x)$, (b) $F_2^p(x)-F_2^n(x)$, (c) $F_2^n(x)/F_2^p(x)$, (d) $F_3^{\nu N}(x)$.

3. Production of the W and Z bosons in nucleon-(anti)nucleon collisions

In the leading order (LO) approximation in the framework of improved parton model [21] the total B($=W^{\pm}$, Z^0) boson cross section is the convolution of elementary cross section $\hat{\sigma}(q\bar{q}' \to B)$ with the quark densities

$$\sigma(h_1 h_2 \to BX) = \frac{K}{3} \int_0^1 dx_1 dx_2 \sum_{q,q'} \times \Big[q(x_1, M_B^2)\, \bar{q}'(x_2, M_B^2)\, \hat{\sigma}(q\bar{q}' \to B) + \bar{q}'(x_1, M_B^2)\, q(x_2, M_B^2)\, \hat{\sigma}(\bar{q}' q \to B) \Big]. \tag{9}$$

In analogy to the Drell–Yan processes the so-called K-factor in Eq. (9) includes first order QCD corrections [21]). The elementary cross sections in

(9) can be easily calculated within Standard Model [21]. Then the rapidity distribution of $W^{\pm}$ boson produced in the $h_1 + h_2$ collision is

$$\begin{aligned}
&\frac{d\sigma}{dy_W}(h_1 h_2 \to W^{\pm} X) \\
&= K\, \frac{2\pi G_F}{3\sqrt{2}}\, x_1 x_2 \sum_{q,q'} |V_{qq'}|^2 \\
&\times \Big[q(x_1, M_W^2)\, \bar{q}'(x_2, M_W^2) + \bar{q}'(x_1, M_W^2)\, q(x_2, M_W^2) \Big] . \qquad (10)
\end{aligned}$$

In analogy the rapidity distribution for Z^0 boson is

$$\begin{aligned}
&\frac{d\sigma}{dy_Z}(h_1 h_2 \to Z^0 X) \\
&= K\, \frac{8\pi G_F}{3\sqrt{2}}\, x_1 x_2 \sum_{q} [(g_V^q)^2 + (g_A^q)^2] \\
&\times \Big[q(x_1, M_Z^2)\, \bar{q}(x_2, M_Z^2) + \bar{q}(x_1, M_Z^2)\, q(x_2, M_Z^2) \Big] . \qquad (11)
\end{aligned}$$

In Eq. (10) and (11) the quark distributions must be evaluated at $x_{1/2} = \frac{M_B}{\sqrt{s}} e^{\pm y_B}$, where $B = W$ or Z.

The formulae for the differential cross sections for the production of charged leptons from $W^{\pm}$ and Z decays are somewhat cumbersome and are presented in detail in Ref. [15].

The calculation of the cross sections for the gauge boson production (Eq. (10) and (11)) or the cross section for the lepton from the gauge boson decay requires parton distributions at $Q^2 = M_W^2 (M_Z^2)$. For this purpose the parton distributions as discussed in Section 2 have been evolved by the Gribov–Lipatov–Altarelli–Parisi (GLAP) evolution equations [22].

Naively one would expect that the total cross section for the production of gauge W bosons should be smaller in the proton-proton collisions than in the proton-antiproton collisions, because in the latter case the antiproton is an efficient donor of antiquarks. This was used in the past as a strong argument for the construction of proton-antiproton colliders such as those at CERN and Fermilab. Since at that time it was strongly believed that the nucleon sea is symmetric with respect to the light flavours, no $\bar{d} \neq \bar{u}$ scenario has been considered. At present there are fairly convincing arguments [23,29] for the $\bar{d}$–$\bar{u}$ asymmetry. Can the $\bar{d}$–$\bar{u}$ asymmetry induced by the meson cloud in the nucleon modify this simple expectation? In Fig. 2 we compare the proton-proton and proton-antiproton cross sections for the "asymmetric" (panel a) and "symmetric" (panel b) cases. The corresponding cross sections are denoted as: $\sigma_{\rm tot}(p\bar{p} \to W^+) = \sigma_{\rm tot}(p\bar{p} \to W^-)$ (solid), $\sigma_{\rm tot}(pp \to W^+)$

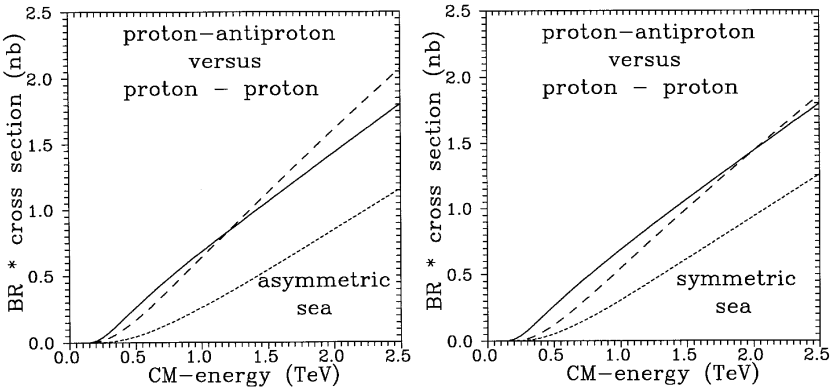

Fig. 2. A comparison of the total cross sections for the production of W-boson in the proton–proton (solid) and proton-antiproton (dashed) collisions. In panel (a) we show the results for the asymmetric sea induced by the meson cloud and in panel (b) the results for the symmetric sea quark parameterization.

(dashed) and $\sigma_{\rm tot}(pp \to W^-)$ (dotted). As expected, without meson cloud, with symmetric sea quark distributions, the cross section for the production of W^+ is smaller in the proton-proton case than in the proton-antiproton case. In contrast, much larger cross sections are obtained if the meson cloud effects are included (see panel a). As seen from the figure, in the broad range of energy $\sigma_{\rm tot}(pp \to W^+) > \sigma_{\rm tot}(p\bar{p} \to W^+) = \sigma_{\rm tot}(p\bar{p} \to W^-)$. A huge enhancement of the cross section due to the meson cloud effects close to the threshold can be observed in the proton-proton collision case. In principle this effect could be studied in the future at the heavy-ion collider RHIC. There is practically no such enhancement in the proton-antiproton collision case [15], except very close to the threshold, where the corresponding cross section is negligibly small.

A very interesting quantity is the asymmetry of charged leptons from $W^\pm \to l^\pm(\nu,\overline{\nu})$ decays defined as

$$A_{p\bar{p}}^{l^+l^-}(y_l) = \frac{\frac{d\sigma}{dy_l}(p\bar{p} \to W^+X \to l^+\tilde{X}) - \frac{d\sigma}{dy_l}(p\bar{p} \to W^-X \to l^-\tilde{X})}{\frac{d\sigma}{dy_l}(p\bar{p} \to W^+X \to l^+\tilde{X}) + \frac{d\sigma}{dy_l}(p\bar{p} \to W^-X \to l^-\tilde{X})} \,. \tag{12}$$

The quantity has been measured recently by the CDF collaboration at the Fermilab $p\bar{p}$ Tevatron collider [24, 25]. In Fig. 3 I show the experimental result together with results of different calculations. The experimental data have been folded across $y_l = 0$ [25] based on the CP invariance. In this calculation experimental cut [25] $p_{T,\rm min}^l = 25$ GeV has been applied. We show both asymmetries obtained in our Model 1 (solid line) and Model 2 (dashed line). As clearly seen from the figure the presence of the meson cloud consid-

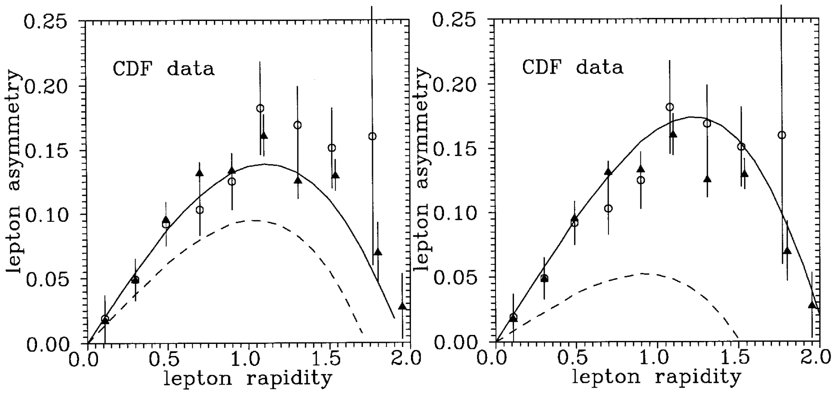

Fig. 3. Predictions for the asymmetry $A_{p\bar{p}}^{e^+e^-}$ of the rapidity distributions of the charged leptons from the $W^{\pm} \to l^{\pm}\nu$ decays in the proton–antiproton collisions. The results of Model 1 (solid) and Model 2 (dashed) are shown in panel (a). For comparison in panel (b) we show lepton asymmetries calculated with the GRV95(LO) [28] (solid) and Owens [30] (dashed) parameterizations of quark distributions. The published CDF experimental data [25] are shown by the open circles and the new preliminary CDF data [26] by the full triangles.

erably improves the agreement with the experimental asymmetry. A similar quality agreement with the CDF asymmetry has been achieved recently in Ref. [27] where the quark distributions from Ref. [28] have been used. While in Ref. [28] the $\bar{d}$–$\bar{u}$ asymmetry was introduced purely phenomenologically, in the present paper the $\bar{d}$–$\bar{u}$ asymmetry is ascribed to the effects caused by the meson cloud in the nucleon.

Having shown that our parton distributions lead to good description of DIS data at relatively low Q^2 and describe the gauge bosons production data in the proton-antiproton collisions fairly well, we shall try to make some interesting predictions for the W/Z production in nucleon-nucleon collisions, which will be measured at the future collider RHIC originally designed to study the quark-gluon plasma in heavy ion — heavy ion collisions. In the following we shall fix the energy $s^{1/2}$ to 500 GeV which is roughly adequate for the proton-proton collisions at RHIC. In Fig. 4 I present $A_{pp}^{W^+W^-}$ (panel a) and in analogy to the proton-antiproton case $A_{pp}^{e^+e^-}$ (panel b). Let us demonstrate that the $A_{pp}^{W^+W^-}$ is a quantity sensitive to the $\bar{u}$–$\bar{d}$ asymmetry. For this purpose let us write

$$\bar{u}(x,Q^2) = S(x,Q^2) - \frac{\Delta(x,Q^2)}{2} \quad , \quad \bar{d}(x,Q^2) = S(x,Q^2) + \frac{\Delta(x,Q^2)}{2} \; . \quad (13)$$

Then taking $y_W \approx 0$ ($x_1 \approx x_2$) and neglecting small (Cabbibo suppressed)

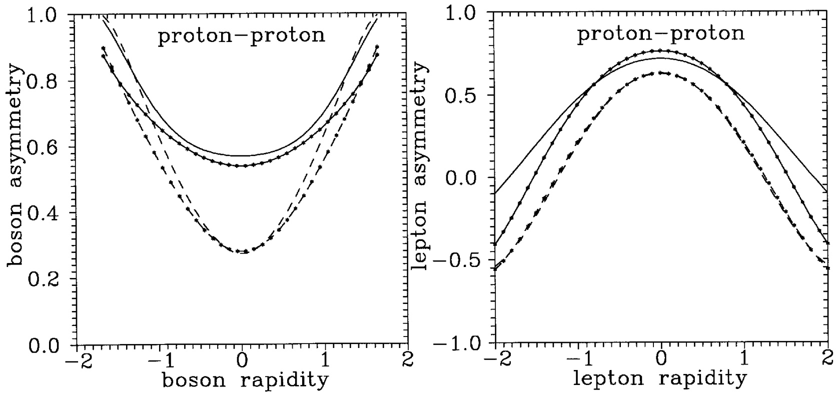

Fig. 4. $A_{pp}^{W^+W^-}$ (panel a) and corresponding $A_{pp}^{e^+e^-}$ (panel b). The asymmetries obtained in Model 1 (solid line) and Model 2 (dashed line) are compared with the results obtained with the GRV95(LO) parameterization [28] (solid line with dots) and the Owens parameterization [30] (dashed line with dots).

contributions from the strange quarks, the asymmetry $A_{pp}^{W^+W^-}$ can be written as

$$A_{pp}^{W^+W^-}(x) \approx \frac{R_v(x)\,S(x) + \frac{\Delta(x)}{2}}{S(x) + R_v(x)\,\frac{\Delta(x)}{2}}\,, \tag{14}$$

where we have introduced $R_v(x) \equiv \frac{u_v(x)-d_v(x)}{u_v(x)+d_v(x)}$ for brevity. Eq. (14) clearly demonstrates the sensitivity to the $\bar{u}$–$\bar{d}$ asymmetry which in our model is due to the meson cloud. The sensitivity to the $\bar{u}$–$\bar{d}$ difference can be better visualized in

$$R_{pp}^{W^+W^-} \equiv \frac{\sigma(pp \to W^+X)}{\sigma(pp \to W^-X)} \approx \frac{u(x,M_W^2)}{d(x,M_W^2)} \cdot \frac{\bar{d}(x,M_W^2)}{\bar{u}(x,M_W^2)}\,. \tag{15}$$

The first ratio is known fairly well from the CDF data (see for instance [11]). Therefore the measurement of $R_{pp}^{W^+W^-}(x = \frac{M_W}{\sqrt{s}})$ in p+p collision should give an accurate determination of the ratio $\frac{\bar{d}(x,M_W^2)}{\bar{u}(x,M_W^2)}$. For a typical RHIC energy $s^{1/2} = 500$ GeV, $x \approx 0.16$. This is a region of sizeable $\bar{u}$–$\bar{d}$ asymmetry. Analogous ratio has been determined recently at $Q^2 \approx 20$ GeV^2 from the measurement of Drell–Yan asymmetry in proton-proton and proton-deutron collisions by the NA51 experiment at CERN [23]. There, however, the $\frac{\bar{u}(x)}{\bar{d}(x)}$ is biased by the explicit assumption about proton-neutron isospin symmetry [29]. In contrast $R_{pp}^{W^+W^-}(x)$ is free of such an assumption.

In Ref. [15] we have studied different similar asymmetries possible to measured in the proton-proton and proton-deuteron collisions which would be of great help in studying the asymmetry of the sea quark distributions in the nucleon.

4. Jet production in proton-antiproton collisions

In the last year two groups [31, 32] have analyzed a possibility to modify the large-x gluon distribution in the nucleon in order to describe the inclusive CDF jet production data. Rather contradictory results have been obtained. While Glover, Martin, Roberts and Stirling [31] have found impossible to achieve a simultaneous description of both the CDF jet distribution for $E_T > 200$ GeV and the deep inelastic structure function data for $x > 0.3$, the CTEQ group has found [32] enough room for such modifications. Here we touch upon a problem of sufficient flexibility of the shapes of parton distributions. On the other hand, too large flexibility of parametric forms may allow for unwanted unphysical results. At present it is not clear what is the ultimate answer and whether the modifications made recently by the CTEQ group will find a physical confirmation. In addition it is not clear how much the conclusions are biased by functional parametric forms of the input parton distributions used.

For the sake of transparency in the present *intentionally simplified* analysis in order to make some points more explicit we shall use rather leading order (LO) formalism [33]. However, most of the results discussed here are independent of NLO corrections. In the LO approximation the cross section for dijet production in $h_1 + h_2$ collison reads

$$\frac{d^3\sigma}{dy_3 dy_4 dp_T^2} = \frac{1}{16\pi s^2} \sum_{i,j} \sum_{k,l} \frac{f_i(x_1, \mu_{\rm F})}{x_1} \frac{f_j(x_2, \mu_{\rm F})}{x_2} \overline{\sum} |M(ij \to kl)|^2 \frac{1}{1+\delta_{kl}} \, , \tag{16}$$

where f_i, f_j are parton (gluon, quark) distributions in hadron h_1 and h_2 respectively and $M(ij \to kl)$ are invariant amplitudes for the $i + j \to k + l$ partonic subprocesses. In the following we shall use LO quark distributions found in Ref. [15] and discussed in Section 2.

The larger E_T the larger Bjorken-x becomes important. In general the region of sensitivity to Bjorken-x is shifted towards larger x than it may be expected from the simple estimation $x \sim \frac{2p_T}{\sqrt{s}}$. At $E_T \sim 400$ GeV relevant for the recent CDF result [9] the cross section is sensitive to x $\in$ (0.4,0.8). The large-x region is connected through the QCD evolution to even slightly larger-x region at low Q^2. This is really a large-x region where both gluon and sea quark distributions are poorly known. In addition in this range of Bjorken-x in low-Q^2 DIS (SLAC, NMC, CCFR) the target mass corrections become extremely important [15, 34]. On the other hand in both MSR [11] and CTEQ [12] QCD analyses of the low-Q^2 DIS the effect of the target mass corrections were not included.

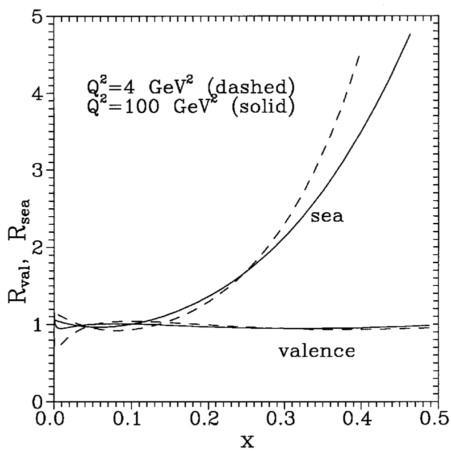

Fig. 5. The ratio of "mc" (meson cloud included) to "0" (no meson cloud effects) sea and valence quark distributions at $Q^2 = 4$ GeV^2 (dashed line) and $Q^2 = 10000$ GeV^2 (solid line).

In the following we shall concentrate on the dominant *quark* − *quark* component and on a special role of the meson cloud. In Fig. 5 we compare the quark distributions obtained from the fit to DIS data by displaying the following ratios

$$\begin{aligned} R_{\mathrm{val}}(x,Q^2) &= \frac{u_{\mathrm{val}}^{\mathrm{mc}}(x,Q^2)+d_{\mathrm{val}}^{\mathrm{mc}}(x,Q^2)}{u_{\mathrm{val}}^{0}(x,Q^2)+d_{\mathrm{val}}^{0}(x,Q^2)}\,, \\ R_{\mathrm{sea}}(x,Q^2) &= \frac{u_{\mathrm{sea}}^{\mathrm{mc}}(x,Q^2)+d_{\mathrm{sea}}^{\mathrm{mc}}(x,Q^2)+s_{\mathrm{sea}}^{\mathrm{mc}}(x,Q^2)}{u_{\mathrm{val}}^{0}(x,Q^2)+d_{\mathrm{val}}^{0}(x,Q^2)+s_{\mathrm{sea}}^{0}(x,Q^2)}\,, \end{aligned} \tag{17}$$

at $Q^2 = 4$ GeV^2 (dashed line) and $Q^2 = 10000$ GeV^2 (solid line) relevant for the inclusive jet production at large-E_T. In the formulae above "mc" denotes the set of parton distributions with meson cloud corrections and "0" their counterparts without meson cloud effects. While the explicit inclusion of the mesonic corrections leads to a small modification of the valence quarks only, the modification of the sea at $x > 0.2$ is substantial. This is the region of the Bjorken-x where the magnitude of the sea quark distributions is small and rather poorly known. As shown in Ref. [15] such an enhancement is allowed both by the muon and (anti)neutrino DIS data. Can this large-x effect cause a visible effect on the E_T distribution of the inclusive jet cross section at $E_T \sim 300$–400 GeV? In the meson cloud model a considerable part of the nucleon sea comes from the valence quarks in a pion, ρ meson *etc.* This is the mechanism which generates large-x sea in the nucleon. At x of about 0.5 the ρ meson, as carrying large amount of the proton light-cone momentum, is the dominant mechanism.

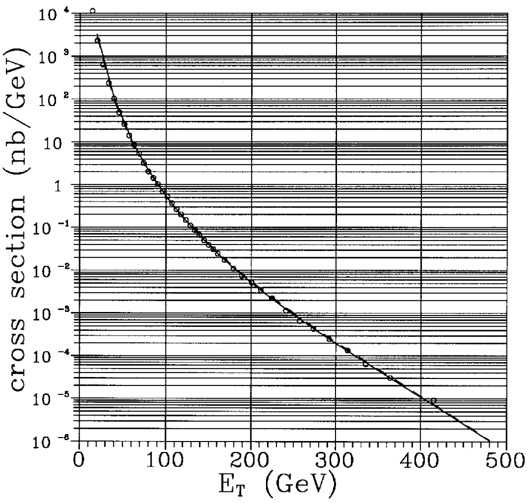

Fig. 6. $\frac{d\sigma}{dE_T}(E_T)$ calculated with parton distributions which include meson cloud effects compared to the recent CDF data [9]. The solid line corresponds to the set of parton distributions with glue adopted from [30] and the dashed line with glue from [36].

Our calculation with meson cloud effects included are compared to experimental data $\frac{1}{\Delta\eta}\int d^2\sigma/(dE_T d\eta)\, d\eta$ integrated over central pseudorapidity region $0.1 \leq |\eta| \leq 0.7$ in Fig. 6 based on a data sample of 19.5 pb^{-1} collected in 1992-1993 for two sets of parton distributions with gluon distribution adopted from [30] (solid) and [36] (dashed). In order to account for the experimental normalization uncertainty, a possible mismatch between theoretical and experimental definition of jets or/and higher order corrections, not included here, we allow for a free parameter $K_{\rm eff}$ to be adjusted to the CDF experimental data. We find $K_{\rm eff} \approx 1.1$ for renormalization ($\mu_{\rm R}$) and factorization ($\mu_{\rm F}$) scales fixed for $\mu_{\rm R} = \mu_{\rm F} = E_T/2$ which is in full agreement with the value found recently by a comparison of LO and NLO calculations [31] for the same choice of the factorization and renormalization scales. To a very good approximation a change of $\mu_{\rm R}$ and $\mu_{\rm F}$ causes only a modification of $K_{\rm eff}$. For instance for $\mu_{\rm R}^2 = \mu_{\rm F}^2 = E_T^2/2$ we find $K_{\rm eff} \approx 1.3$ in agreement with the K-factor found in Ref. [39]. Having in view a simplicity of our analysis we obtain a rather good agreement with the measured cross section over 9 orders of magnitude! In order to facilitate a detailed comparison of our numerical results with experimental data we display also in Fig. 7 the ratio "experiment/theory". The agreement found in the simple analysis here is comparable or better than that found in [9] with NLO parton distributions. A small disagreement for small E_T may be easily repaired by a small modification of the gluon distribution at $x \sim 0.05$–0.1 which enters here rather quadratically. In the case of the D0 collaboration data (two lower panels) we have presented also their estimated band of systematical uncertainties. Having in view these rather large systematical uncertainties, the agreement of our calculation with the data is fairly good. In our opinion the success of our calculation is based upon inclusion of target mass corrections and/or meson cloud effect.

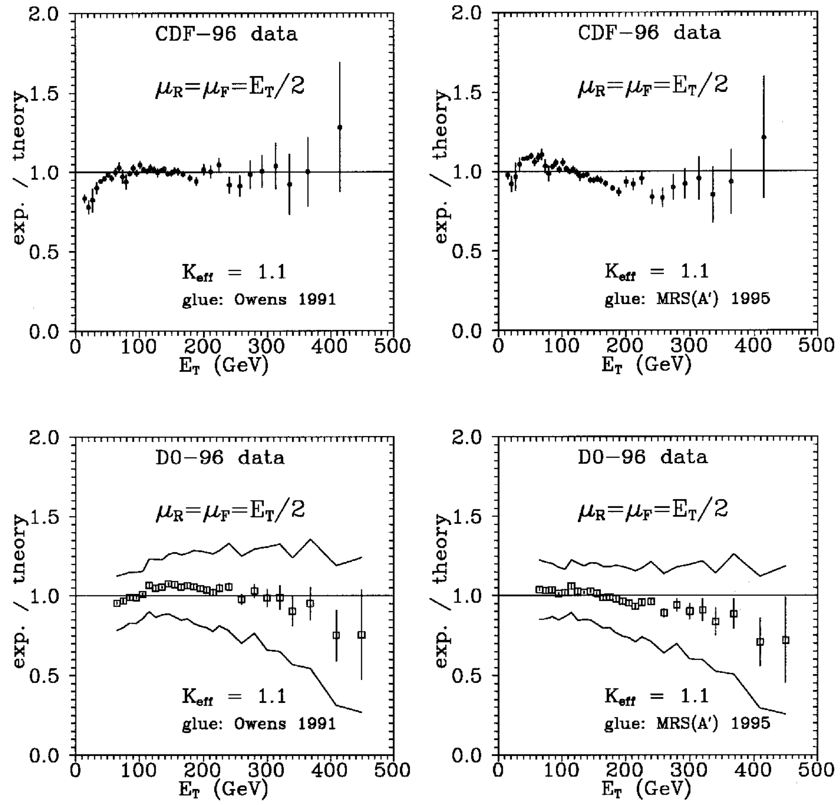

Fig. 7. The "experiment-to-theory" ratio for the parton distributions which include meson cloud effects.

5. Conclusions

The concept of a pion cloud in the nucleon was recently found to be very useful in understanding the Gottfried sum rule violation observed by the New Muon Collaboration [1] and the Drell–Yan asymmetry measured recently in the NA51 Drell–Yan experiment at CERN [23].

Here I have discussed also possible effects of the meson cloud in the nucleon on the production of weak gauge bosons in proton-antiproton, proton-proton and proton-deuteron collisions. A reasonable agreement of the total cross sections with those measured at CERN by the UA1, UA2 collaborations and at Fermilab by the CDF collaboration has been obtained [15]. If the meson cloud effects are included in the broad range of energy $\sigma_{\rm tot}(pp \to W^-) > \sigma_{\rm tot}(p\bar{p} \to W^+) = \sigma_{\rm tot}(p\bar{p} \to W^-)$, in contrast to naive expectations. In contrast to parton distributions with SU(2) symmetric sea we find a good description of the charged lepton asymmetry measured recently by the CDF collaboration [25] which may be treated as an indirect evidence of the meson cloud in the nucleon.

We have analysed some asymmetries of the cross sections for the production of W/Z bosons in the proton-proton and proton-deuteron collisions. We find that such observables can be very useful to shed new light on the problem of the $\bar{d}$–$\bar{u}$ asymmetry in the nucleon. These quantities could in principle be studied in the future at the heavy ion collider RHIC. Whether such an analysis will be possible in practice will require, however, new studies of several experimental aspects.

It has been found that the meson cloud in the nucleon produces a sizable enhancement of the large-E_T inclusive jet cross section. This enhancement is caused by a substantial enhancement over standard parameterizations of the nucleon sea quark distributions at intermediate and large values of Bjorken-x and/or a special structure of valence quark distributions due to the meson cloud. Before any speculation about the substructure of the quark from the analysis of the inclusive jet E_T distributions can be made, one must study carefully:

- consistent inclusion of the target mass corrections in lepton DIS at large Bjorken-x,
- the role of the meson cloud effects in various high and low energy phenomena.

I wish to thank A. Budzanowski, H. Holtmann, J. Speth, V. Uleshchenko for collaboration on issues presented here.

REFERENCES

[1] P. Amaudruz *et al.*, *Phys. Rev. Lett.* **66**, 2712 (1991).

[2] K. Gottfried, *Phys. Rev. Lett.* **18**, 1174 (1967).

[3] E.M. Henley, G.A. Miller, *Phys. Lett.* **B251**, 453 (1990).

[4] A. Signal, A.W. Schreiber, A.W. Thomas, *Mod. Phys. Lett.* **A6**, 271 (1991).

[5] W-Y.P. Hwang, J. Speth, G.E. Brown, *Z. Phys.* **A339**, 383 (1991).

[6] V.R. Zoller, *Z. Phys.* **C53**, 443 (1992).

[7] A. Szczurek, J. Speth, *Nucl. Phys.* **A555**, 249 (1993).

[8] A. Szczurek, H. Holtmann, *Acta Phys. Pol.* **B24**, 1833 (1993).

[9] F. Abe *et al.* (CDF), *Phys. Rev. Lett.* **77**, 438 (1996).

[10] E.J. Eichten, K.D. Lane, M.E. Peskin, *Phys. Rev. Lett.* **50**, 811 (1983).

[11] A.D. Martin, W.J. Stirling, R.G. Roberts, *Phys. Rev.* **D50**, 6734 (1994).

[12] H.L. Lai, J. Botts, J. Huston, J.G. Morfin, J.F. Owens, J.W. Qiu, W.K. Tung, H. Weerts, *Phys. Rev.* **51**, 4763 (1995).

[13] H. Holtmann, A. Szczurek, J. Speth, *Nucl. Phys.* **A596**, 631 (1996).

[14] J.D. Sullivan, *Phys. Rev.* **D5**, 1732 (1972).

[15] A. Szczurek, V. Uleshchenko, H. Holtmann, J. Speth, *Nucl. Phys.* **A624**, 495 (1997).

[16] P.J. Sutton, A.D. Martin, R.G. Roberts, W.J. Stirling, *Phys. Rev.* **D45**, 2349 (1992).

[17] A.D. Martin, W.J. Stirling, R.G. Roberts, *Phys. Rev.* **D51**, 4756 (1995).

[18] A.de Rujula, H. Georgi, H.D. Politzer, *Ann. Phys. (N.Y.)* **109**, 315 (1977).

[19] M. Arneodo *et al.*, *Phys. Rev.* **D50**, R1 (1994).

[20] W.C. Leung, *Phys. Lett.* **B317**, 655 (1993).

[21] V.D. Barger, R.J.N. Philips, Collider Physics, Addison-Wesley Pub. Com., Redwood City 1987.

[22] G. Altarelli, G. Parisi, *Nucl. Phys.* **B126**, 298 (1977).

[23] A. Baldit *et al.*, (NA51), *Phys. Lett.* **B332**, 244 (1994).

[24] F. Abe *et al.*, (CDF Collaboration), *Phys. Rev. Lett.* **68**, 1459 (1992).

[25] F. Abe et al. (CDF Collaboration), *Phys. Rev. Lett.* **74**, 850 (1995).

[26] A. Bodek, a talk given at the third Int. Symp. on Radiative Corrections, Cracow, Poland, August 1-5, 1996.

[27] S. Kretzer, E. Reya, M. Stratmann, *Phys. Lett.* **B348**, 628 (1995).

[28] M. Glück, E. Reya, A. Vogt, *Z. Phys.* **C67**, 433 (1995).

[29] A. Szczurek, M. Ericson, H. Holtmann, J. Speth, *Nucl.Phys.* **A596**, 397 (1996).

[30] J.F. Owens, *Phys. Lett.* **B266**, 126 (1991).

[31] E.W. Glover, A.D. Martin, R.G. Roberts, W.J. Stirling, technical report RAL-TR-96-019.

[32] J. Huston, E. Kovacs, S. Kuhlmann, H.L. Lai, J.F. Owens, D. Soper, W.K. Tung, *Phys. Rev. Lett.* **77**, 444 (1996).

[33] B.L. Combridge, J. Kripfganz, J. Ranft, *Phys. Lett.* **B70**, 234 (1977).

[34] A.D. Martin, W.J. Stirling, R.G. Roberts, *Phys. Rev.* **D51**, 4756 (1995).

[35] M. Bonesini et al.(WA70), *Z. Phys.* **C38**, 371 (1988).

[36] A.D. Martin, W.J. Stirling, R.G. Roberts, *Phys. Lett.* **B354**, 155 (1995).

[37] D0 Collaboration, private communication.

[38] G.C. Blazey (for D0 collaboration), Proceedings of the XXXI-st Recontres de Moriond, Les Arcs, Savoie, France, March 23-30, 1996;
G.C. Blazey (for D0 collaboration), Fermilab preprint CONF-96-132-E, 1996.

[39] W.T. Giele, E.W.N. Glover, FERMILAB-Conf-95/169-T; DTP/95/72.