AC

KFA IKP TH 93-35
SW 9426

Institut für Kernphysik

PIONS IN THE
LIGHT-CONE NUCLEON AND
ELECTROMAGNETIC
FORM FACTORS

N.N. Nikolaev¹, A. Szczurek², J. Speth
and V.R. Zoller³

IKP (Theorie), KFA Jülich, 5170 Jülich, Germany

¹also: Landau Inst. for Theor. Physics, Moscow, Russia

²Inst. of Nuclear Physics, Krakow, Poland

³also: Inst. for Theor. and Exper. Physics, Moscow, Russia

KFA-IKP(TH)-1993 - 35

CERN LIBRARIES, GENEVA

P00024099

Pions in the Light-cone Nucleon and Electromagnetic Form Factors

N.N.Nikolaev^{1,2)}, A.Szczurek^{1,3)}, J.Speth¹⁾, and V.R.Zoller⁴⁾

¹⁾*IKP(Theorie), Forschungszentrum Juelich GmbH,
52425 Jülich, Germany*

²⁾*L.D.Landau Institute for Theoretical Physics,
GSP-1, 117940, ul.Kosygina 2, 117334 Moscow, Russia*

³⁾*Institute of Nuclear Physics, PL-31-342 Krakow, Poland*

⁴⁾*Institute for Theoretical and Experimental Physics,
ul.B.Cheremushkinskaya 25, 117259 Moscow, Russia*

A b s t r a c t

The light-cone Fock-state decomposition of the nucleon involves pion - quark core ($\pi'N'$ and $\pi'\Delta'$) components. The size of the quark core is at present of special importance for the analysis of the onset of colour transparency in the $A(e, e'p)$ reactions. With the light-cone $N\pi'N'$ and $N\pi'\Delta'$ vertex functions deduced from experimental data on high-energy proton fragmentation into nucleons and isobars, we evaluate the effect of the pionic cloud on the electromagnetic form factors of nucleons. We find the quark core radius to be about 10% smaller than the nucleon's radius. Analysis of the renormalization of the total nucleon-nucleon cross section for the presence of the pionic cloud suggests a similar core radius.

1 Introduction

The Gottfried Sum Rule violation observed by NMC [1] strongly suggests the flavour asymmetry of the sea of light quarks which can be naturally accounted for by the presence of the meson-quark core ($\pi'N'$, $\pi'\Delta'$,...) components in the light-cone nucleon [2, 3, 4, 5, 6, 7, 8]. The radius of the quark core emerges as an important parameter in the discussion of the onset of color transparency in the $A(e, e'p)$ scattering. Simplifying somewhat the discussion, at large Q^2 the hard $(e, e'p)$ scattering selects the quark core stripped of the mesonic cloud. Such an object is expected to have a smaller interaction cross section and therefore a weaker intranuclear final state interaction than the physical proton [9]. The size of the core can be estimated from an analysis of the electromagnetic form factors of nucleons viewed as a quark core surrounded by a mesonic cloud. This is the subject of the present communication.

The discussion of mesonic corrections to the electromagnetic properties of nucleons dates back to the fifties[10]. However, a consistent light-cone treatment of the problem is still missing. The objective of the present paper is a light-cone description of the effects of the πN and $\pi\Delta$ Fock states on electromagnetic form factors of the nucleon. In order to obtain quantitative results the light-cone wave function technique must be supplemented with experimental information on the $N\pi N$ and $N\pi\Delta$ vertex functions. We use vertex functions consistently deduced in the light-cone framework from the analysis of high-energy $p \rightarrow n$ and $p \rightarrow \Delta$ fragmentation [6, 11]. (For early work on the pion-exchange contribution to the fragmentation processes see [12]). Evidently, the πN and $\pi\Delta$ Fock states have a radius larger than the bare quark-core, and at large Q^2 the electromagnetic form factors should be dominated by the bare-core contribution. Our primary concern is the onset of this bare-core dominance, and the light-cone approach is best suited at large Q^2 . Although there has been much work on mesonic effects for the electromagnetic properties of nucleons within the framework of the cloudy bag model [13], it is relevant only in the domain of very small Q^2 .

We find that the hybrid quark core-pion model reproduces well the form factor of the nucleon if the radius of the core R_{3q} is smaller by $\approx 10\%$ than the radius R_p of the physical nucleon. A similar estimate follows from an analysis of the renormalization of the total nucleon-nucleon cross section due to the presence of the pionic cloud. The major reason that we find a

fairly large core radius is as follows. With the realistic vertex functions, as determined from the experimental data on the fragmentation of high-energy nucleons, one finds rather a small admixture of the $\pi N, \pi\Delta$ states in the nucleon. Since the πN and $\pi\Delta$ are expected to have larger size than the nucleon itself, the asymptotic (high Q^2) behavior of the proton form factor should be dominated by the form factor of the bare core multiplied by the probability to find the core in the nucleon. As a consequence, with $R_{3q} \ll R_p$ one would find too slow a decrease of the proton form factor, in contradiction with the experiment.

2 Electromagnetic form factor of the hybrid nucleon

In a somewhat symbolic form, the Fock state decomposition of the hybrid light-cone proton (neutron) reads

$$|p\rangle = \cos\theta|(3q)\rangle + \sin\theta \left[\sin\phi \left(\sqrt{2/3}|\pi^+n\rangle - \sqrt{1/3}|\pi^0p\rangle \right) + \cos\phi \left(\sqrt{1/2}|\pi^-\Delta^{++}\rangle - \sqrt{2/6}|\pi^0\Delta^+\rangle + \sqrt{1/6}|\pi^+\Delta^0\rangle \right) \right] , \quad (1)$$

$$|n\rangle = \cos\theta|(3q)\rangle + \sin\theta \left[\sin\phi \left(\sqrt{1/3}|\pi^0n\rangle - \sqrt{2/3}|\pi^-p\rangle \right) + \cos\phi \left(\sqrt{1/2}|\pi^+\Delta^-\rangle - \sqrt{2/6}|\pi^0\Delta^0\rangle + \sqrt{1/6}|\pi^-\Delta^+\rangle \right) \right] . \quad (2)$$

The two mixing angles are related to the number of pions ($n_\pi = n_{\pi N} + n_{\pi\Delta}$) in the pionic cloud

$$\begin{aligned} \sin^2\theta &= n_\pi / (1 + n_\pi) \\ \sin^2\phi &= n_{\pi N} / n_\pi . \end{aligned}$$

If $\sin^2\theta \ll 1$, then the effects of the multi-pion Fock states can be disregarded. In the present paper the contribution of $|\eta N\rangle$ and $|KY\rangle$ states are neglected. It has been shown, however, that the admixture of these states is rather small [7, 14, 11].

Both the πN and $\pi\Delta$ components, which are expected to be more extended objects than the proton itself, should contribute significantly to the charge radius of the proton. Therefore the quark core radius R_{3q} should be smaller than the radius of the proton itself. Therefore at large Q^2 the electromagnetic form factors of the proton should be dominated by the quark

core contribution. As a consequence the electron scattering at large Q^2 should select the nucleon with its mesonic cloud stripped off. Such a bare quark core should have a smaller interaction cross section, and a weaker intranuclear final state interaction, than the physical nucleon. It is important to understand the Q^2 dependence of the effect quantitatively.

To study the problem we will analyze the Dirac form factor of the proton:

$$F_1^p(Q) = \frac{\langle p', 1/2 | J_+^{em} | p, 1/2 \rangle}{(p_+ + p'_+)} \quad (3)$$

in the light-cone Breit frame where the virtual photon has purely transversal four-momentum $Q = (0, \vec{q}, 0)$ [15]. This choice of reference frame guarantees suppression of the so-called vacuum pair production processes [16]. In this frame of reference four-momenta of the initial and final proton can be written as

$$\begin{aligned} p &= (E, -\vec{q}/2, p_3) \\ p' &= (E, \vec{q}/2, p_3) \end{aligned} \quad (4)$$

Throughout this paper the conventional light-cone notations $J_{\pm} = (J_0 \pm J_3)/\sqrt{2}$ and $p_{\pm} = (p_0 \pm p_3)/\sqrt{2}$ are used.

The Fock state decomposition of the proton and neutron wave function given by Eqs.(1),(2) leads to the following simple decomposition (see Fig.1) for the Dirac form factor of the proton

$$\begin{aligned} F_1^p(Q) = & \cos^2 \theta G_{(3q)}(Q) + \sin^2 \theta \sin^2 \phi [G_{(3q)}(Q) F^{N\pi}(Q) + 2G_{\pi}(Q) F^{\pi N}(Q)] \\ & + \sin^2 \theta \cos^2 \phi [(8/3)G_{(3q)}(Q) F^{\Delta\pi}(Q) - (2/3)G_{\pi}(Q) F^{\pi\Delta}(Q)] \end{aligned} \quad (5)$$

Similarly for the neutron

$$\begin{aligned} F_1^n(Q) = & 2 \sin^2 \theta \sin^2 \phi [G_{(3q)}(Q) F^{N\pi}(Q) - G_{\pi}(Q) F^{\pi N}(Q)] \\ & + (2/3) \sin^2 \theta \cos^2 \phi [G_{\pi}(Q) F^{\pi\Delta}(Q) - G_{(3q)}(Q) F^{\Delta\pi}(Q)] \end{aligned} \quad (6)$$

(with standard normalization $F^{N\pi}(0) = 1$ etc.). The form factor of the core is not known a priori. For the purpose of the estimate of the core radius it seems sufficient to use the dipole parameterization for the core form factor

$$G_{(3q)}(Q) = \frac{1}{(1 + Q^2/\Lambda^2)^2}. \quad (7)$$

We assume the same radius of the bare nucleon ($S = 1/2$) and the bare delta ($S = 3/2$) core. For the pion we take the conventional monopole form factor

$G_\pi(Q) = 1/(1 + Q^2/m_\rho^2)$. For simplicity, the form factor of the zero-charge quark core (n, Δ^0) is assumed to vanish (the improvements for the $SU(6)$ symmetry breaking effects can easily be made, but go beyond the scope of the present communication). Recall that the form factor of the proton is well approximated by the dipole formula

$$G_D(Q) = \frac{1}{(1 + Q^2/\Lambda_D^2)^2} \quad (8)$$

with $\Lambda_D^2 = 0.71(\text{GeV}/c)^2$.

Our aim is to find the core radius at which the hybrid model will reproduce the phenomenological dipole form factor in a possibly wide range of Q^2 .

3 The body form factors of the light-cone nucleon

The body form factors can easily be evaluated using the light-cone technique. Let $y = k_+/p_+$ be a fraction of the nucleons light-cone momentum p_+ carried by the baryon (N, Δ) of the $\pi N, \pi \Delta$ Fock state. Let us start with the effects of the πN Fock component. We take the $N\pi N$ vertex of the form $g_{N\pi N} \bar{u}(k) \gamma_5 u(p) \varphi(p-k) \Gamma_{\pi N}$. The calculation of the diagram shown in Fig.1b within the light-cone perturbation theory gives the number of pions in the nucleon [6]

$$n_{\pi N} = \frac{g_{N\pi N}^2}{16\pi^2} \int_0^1 \frac{dy}{y(1-y)} \int_0^\infty dk_\perp^2 \frac{|\Gamma_{N\pi}(M^2)|^2}{(M^2 - m_N^2)^2} \frac{1}{y} \left[m_N^2(1-y)^2 + \vec{k}_\perp^2 \right]. \quad (9)$$

and the body form factor

$$F^{N\pi}(Q) = \frac{g_{N\pi N}^2}{16\pi^3 n_{\pi N}} \int_0^1 \frac{dy}{y(1-y)} \int d^2 \vec{k}_\perp \frac{\Gamma_{N\pi}(M_f^2)}{(M_f^2 - m_N^2)} \frac{\Gamma_{N\pi}(M_i^2)}{(M_i^2 - m_N^2)} \times \frac{1}{y} \left[m_N^2(1-y)^2 + \vec{k}_\perp^2 - (1-y)^2 \vec{q}^2/4 \right] \quad (10)$$

(the calculation within the time-ordered perturbation theory in the infinite-momentum frame [16] gives the same results). Here $\vec{k}_\perp$ is the transverse momentum of the pion. In the light-cone approach the vertex function $\Gamma_{N\pi}$ is a function of the invariant mass squared [17] of the πN state, $M^2 = M_{\pi N}^2(y, \vec{k}_\perp, 0)$, $M_i^2 = M_{\pi N}^2(y, \vec{k}_\perp, \vec{q})$, $M_f^2 = M_{\pi N}^2(y, \vec{k}_\perp, -\vec{q})$, where

$$M_{\pi N}^2(y, \vec{k}, \vec{q}) = \frac{m_N^2}{y} + \frac{m_\pi^2}{1-y} + \frac{[\vec{k} - (1-y)\vec{q}/2]^2}{y(1-y)} \quad (11)$$

The body form factor $F^{\pi N}(Q)$ for the case in which the photon is coupled to the pion is obtained by the substitution $\vec{q} \rightarrow y\vec{q}/(1-y)$ in the integrand of Eq. (10), which can easily be understood in the so-called mixed $(y, \vec{\rho})$ -representation, where the vector $\vec{\rho}$ is the transverse separation of pion and nucleon ($\vec{\rho}$ is a variable conjugated to the transverse momentum $\vec{k}_\perp$). The body form factors take transparent quantum mechanical form in terms of the wave function in the mixed representation $\tilde{\Psi}_{\pi N}(y, \vec{\rho})$

$$F^{N\pi}(Q) = \int dy \int d^2\vec{\rho} \exp[i\vec{q}\vec{\rho}(1-y)] |\tilde{\Psi}_{\pi N}(y, \vec{\rho})|^2 \quad (12)$$

and

$$F^{\pi N}(Q) = \int dy \int d^2\vec{\rho} \exp[i\vec{q}\vec{\rho}y] |\tilde{\Psi}_{\pi N}(y, \vec{\rho})|^2 \quad (13)$$

and differ by the relative distance $y\vec{\rho}$ and $(1-y)\vec{\rho}$ to the 'center of mass' of the system. The density distribution $|\tilde{\Psi}_{\pi N}(y, \vec{\rho})|^2$ can easily be derived taking the Fourier-Bessel transform in Eqs. (9)

$$|\tilde{\Psi}_{\pi N}(y, \vec{\rho})|^2 = \frac{g_{N\pi N}^2}{4\pi n_{\pi N}} \frac{1}{y^2(1-y)} [m_N^2(1-y)^2 |\Phi_{\pi N}(y, \vec{\rho})|^2 + |\partial_{\vec{\rho}} \Phi_{\pi N}(y, \vec{\rho})|^2], \quad (14)$$

where

$$\Phi_{\pi N}(y, \vec{\rho}) = \int \frac{d^2\vec{k}_\perp}{(2\pi)^2} \frac{\Gamma_{\pi N}(M^2)}{M^2 - m_N^2} \exp(i\vec{k}_\perp \vec{\rho}). \quad (15)$$

Then the body form factors $F^{N\pi}(Q)$ and $F^{\pi N}(Q)$ can be obtained from equations (12,13).

Extension to the $\pi\Delta$ Fock components is straightforward. We take the $\pi N\Delta$ vertex in the form $g_{N\pi\Delta} \bar{u}_\mu(k) u(p) p_\mu \Gamma_{\pi\Delta}$. The number of Δ 's in the nucleon is given [6] by

$$n_{\pi\Delta} = \frac{g_{N\pi\Delta}^2}{16\pi^2} \int_0^1 \frac{dy}{y(1-y)} \int_0^\infty dk_\perp^2 \frac{|\Gamma_{\pi\Delta}(M^2)|^2}{(M^2 - m_N^2)^2} \times \frac{1}{6m_\Delta^2 y^3} [(m_\Delta + ym_N)^2 + \vec{k}_\perp^2]^2 [(m_\Delta - ym_N)^2 + \vec{k}_\perp^2] \quad (16)$$

and the body form factor $F^{\Delta\pi}(Q)$ takes the form

$$F^{\Delta\pi}(Q) = \frac{g_{N\pi\Delta}^2}{16\pi^3 n_{\pi\Delta}} \int d^2\vec{k}_\perp \frac{dy}{y(1-y)} \frac{\Gamma_{\Delta\pi}(M_f^2)}{(M_f^2 - m_N^2)} \frac{\Gamma_{\Delta\pi}(M_i^2)}{(M_i^2 - m_N^2)}$$

$$\begin{aligned}
& \times \frac{1}{6m_{\Delta}^2 y^3} \left[(m_{\Delta} + ym_N)^2 + (\vec{k}_{\perp} + (1-y)\vec{q}/2)^2 \right] \\
& \times \left[(m_{\Delta} + ym_N)^2 + (\vec{k}_{\perp} - (1-y)\vec{q}/2)^2 \right] \\
& \times \left[(m_{\Delta} - ym_N)^2 + \vec{k}_{\perp}^2 - (1-y)^2 \vec{q}^2/4 \right] . \quad (17)
\end{aligned}$$

Here $M^2 = M_{\Delta\pi}^2(y, \vec{k}_{\perp}, 0)$, $M_i^2 = M_{\Delta\pi}^2(y, \vec{k}_{\perp}, \vec{q})$ and $M_f^2 = M_{\Delta\pi}^2(y, \vec{k}_{\perp}, -\vec{q})$, where

$$M_{\Delta\pi}^2(y, \vec{k}_{\perp}, \vec{q}) = \frac{m_{\Delta}^2}{y} + \frac{m_{\pi}^2}{1-y} + \frac{[\vec{k}_{\perp} - (1-y)\vec{q}/2]^2}{y(1-y)} . \quad (18)$$

The corresponding density distribution in the mixed representation $|\tilde{\Psi}_{\pi\Delta}(y, \vec{\rho})|^2$ can easily be derived taking the Fourier-Bessel transform in Eqs. (16)

$$\begin{aligned}
|\tilde{\Psi}_{\pi\Delta}(y, \vec{\rho})|^2 &= \frac{g_{N\pi\Delta}^2}{4\pi n_{\pi\Delta}} \frac{1}{6m_{\Delta}^2 y^4 (1-y)} \\
& \left[(m_{\Delta} - ym_N)^2 |\Phi_{\pi\Delta}(y, \vec{\rho})|^2 + |\partial_{\vec{\rho}} \Phi_{\pi\Delta}(y, \vec{\rho})|^2 \right] , \quad (19)
\end{aligned}$$

where

$$\Phi_{\pi\Delta}(y, \vec{\rho}) = \int \frac{d^2 \vec{k}_{\perp}}{(2\pi)^2} \frac{\Gamma_{\pi\Delta}(M^2) [(m_{\Delta} + ym_N)^2 + \vec{k}_{\perp}^2]}{M^2 - m_N^2} \exp(i\vec{k}_{\perp} \vec{\rho}) . \quad (20)$$

Then the body form factors $F^{\Delta\pi}(Q)$ and $F^{\pi\Delta}(Q)$ can be calculated from equations analogous to (12,13).

4 Results and discussion

In order to perform a practical calculation one has to fix parameters of the vertex functions $\Gamma_{BM}(y, \vec{k}_{\perp})$. In the present paper we use the parameters recently obtained [6, 11] from the analysis of the experimental data on the fragmentation of high-energy protons into nucleons and isobars - the processes being dominated by the stripping off of the mesons from the meson-baryon Fock component in the nucleon [6]. In Refs. [6, 11] the vertex form factors has been parametrized by the exponential function of the invariant mass M of the intermediate BM system

$$\Gamma(M^2) = \exp \left[-\frac{1}{2} R^2 (M^2 - m_N^2) \right] , \quad (21)$$

with R being a free parameter. The $N\pi N$ and $N\pi\Delta$ vertex parameters, $R_{\pi N}^2$ and $R_{\pi\Delta}^2$, are determined by fitting to the data for $p \rightarrow n$ and $p \rightarrow \Delta^{++}$ fragmentation processes [6, 11].

As far as the $N\pi N$ vertex can be fairly well determined from the fragmentation data, the extraction of the $N\pi\Delta$ vertex is more ambiguous due to the background subtraction, and depends slightly on the set of experimental data chosen. In Ref.[6] the one-pion-exchange model has been employed while in Ref.[11] the ρ -meson exchange has been taken into account additionally. In the present paper we include only πN and $\pi\Delta$ Fock components.

The fit in Ref.[6] gives the cut-off parameters $R_{\pi N}^2 = 0.7 \text{ (GeV/c)}^{-2}$, $R_{\pi\Delta}^2 = 1.4 \text{ (GeV/c)}^{-2}$ and as a consequence leads to $n_{\pi N} \approx 0.42$ and $n_{\pi\Delta} \approx 0.22$. The corresponding fit in Ref.[11] gives $R_{\pi N}^2 = 0.83 \text{ (GeV/c)}^{-2}$, $R_{\pi\Delta}^2 = 1.04 \text{ (GeV/c)}^{-2}$ and as a consequence leads to $n_{\pi N} \approx 0.32$ and $n_{\pi\Delta} \approx 0.11$ (also the corresponding coupling constants differ slightly). This leads to the mixing angle $\sin^2 \theta = \frac{n_{\pi N} + n_{\pi\Delta}}{1 + n_{\pi N} + n_{\pi\Delta}} = 0.39$ [6], 0.30 [11] (similar estimate comes from the cloudy bag model [13]),

In Fig.2 the Q^2 -dependence of the $F^{N\pi}$, $F^{\pi N}$, $F^{\Delta\pi}$ and $F^{\pi\Delta}$ body form factors is shown. The slopes of $F^{N\pi}$ and $F^{\pi N}$, $F^{\Delta\pi}$ and $F^{\pi\Delta}$ at small Q^2 differ substantially. This can easily be understood from Eqs. (12),(13) which show that the slopes of $F^{N\pi}(Q)$ and $F^{\pi N}(Q)$ are proportional to $\langle(1-y)^2\rangle$ and $\langle y^2\rangle$, respectively.

Indeed, the integrands of Eqs. (12,13) decrease rapidly with the increase of M_i^2, M_f^2 . At small $\vec{q}$, the invariant masses have a minimum at

$$y^* = \frac{\sqrt{m_N^2 + k_\perp^2}}{\sqrt{m_N^2 + k_\perp^2} + \sqrt{m_\pi^2 + k_\perp^2}}. \quad (22)$$

and because of the large difference of the nucleon and pion masses, $1 - y^* \ll y^*$. A similar consideration holds for the $\pi\Delta$ state.

The term $\propto (1-y)^2 \vec{q}^2/4$ in the square brackets in the integrand of Eq.(10) may cause $F^{N\pi}$ to change sign at large Q^2 . The position of the cross-over is subject to a detailed form of the vertex function $\Gamma_{N\pi}$. With the Gaussian parameterization (21) we encounter such a (model dependent) dip of $F^{N\pi}$ at $Q^2 \gtrsim 10(\text{GeV/c})^2$.

As already discussed, only the core contribution to the form factor survives at large Q^2 . Our aim is to determine the core radius which gives the proton form factor reproducing the standard dipole parametrization (8) for

as broad a range of Q^2 as possible. According to the expansion (5), in the core dominance region we have

$$\frac{F_1^p(Q)}{G_D(Q)} \approx \cos^2 \theta \frac{G_{(3q)}^p(Q)}{G_D(Q)} \approx \cos^2 \theta \frac{\Lambda^4}{\Lambda_D^4} \quad (23)$$

so that a reasonable choice of cut-off parameter in Eq.(7) is

$$\frac{\Lambda_D^2}{\Lambda^2} \approx 1 - 2 \sin^2 \frac{\theta}{2} \approx 1 - \frac{1}{2} \frac{n_\pi}{1 + n_\pi} \quad (24)$$

If the vertex functions of Ref.[6] are used, then we find $R_{3q}/R_p = \Lambda_D/\Lambda = 0.88$, and $R_{3q}/R_p = \Lambda_D/\Lambda = 0.91$ for the vertex functions of Ref.[11]. This leads to core radius approximately 10% smaller than the proton radius. Extending the simple parametrization (7) over the whole range of Q^2 is a very strong assumption, but we find that it works remarkably well at moderately large $Q^2 < 10 \text{ GeV}^2$, where the experimental data are available (see solid lines in Fig.3). In Fig.3 we show the ratio of the Dirac form factor $F_1^p(Q)$ (Eq.(5)) to the conventional dipole parametrization $G_D(Q)$ (Eq.(8)) with vertex parameters from Ref.[11] (lhs) and from Ref.[6] (rhs).

As expected, the contributions from the πN (dashed lines) and $\pi\Delta$ (dotted lines) components of the nucleon vanish at large Q^2 compared to the core contribution. The two sets of vertex functions considered here [6, 11] differ in the absolute normalization of the quark core-pion components, but give similar rate of decrease of the quark core-pion contribution to the form factor. From the point of view of the application to the color transparency problem, simplifying somewhat, we may say that at $Q^2 \gtrsim 5 \text{ GeV}^2$ what emerges from the hard ep scattering is the nucleon stripped of its pionic cloud.

Let us consider the core radius from another point of view. Within our hybrid model of the nucleon, the total nucleon-nucleon cross section can be estimated as

$$\sigma_{NN}^{tot} = \cos^2 \theta \sigma_{(3q)N}^{tot} + \sin^2 \theta [\sigma_{(3q)N}^{tot} + \sigma_{\pi N}^{tot}] \approx \sigma_{(3q)N}^{tot} + \sin^2 \theta \sigma_{\pi N}^{tot}. \quad (25)$$

Here we have neglected the Glauber shadowing in the $3q - \pi$ system, so that

$$\sigma_{(3q)N}^{tot} = \sigma_{NN}^{tot} - \sigma_{\pi N}^{tot} \sin^2 \theta, \quad (26)$$

which gives rather a lower bound for $\sigma_{(3q)N}^{tot}$. Making use of the approximate high-energy scattering rule $\sigma_{\pi N}^{tot} \approx \frac{2}{3}\sigma_{NN}^{tot}$, we find

$$\frac{R_{3q}^2}{R_p^2} \approx \frac{\sigma_{(3q)N}^{tot}}{\sigma_{NN}^{tot}} \gtrsim 1 - \frac{2}{3}\sin^2 \theta \quad (27)$$

in agreement with the estimate from the form factor analysis (see Eq.(24); the difference between the coefficients $\frac{1}{2}$ and $\frac{2}{3}$ in Eq.(24) and Eq.(27) must be neglected, as subject to a specific choice of the form factor parameterization and approximations made. The analysis shows that (bare nucleon)-nucleon cross section is smaller by $\approx 20\%$ than the nucleon-nucleon cross section.

The neutron form factor $F_1^n(Q)$ (Eq.(6)), shown in Fig.4, peaks at $Q^2 \approx 0.2(GeV/c)^2$ and steeply falls at higher momentum transfers. In this calculation we have made a strong assumption that the form factor of the zero-charge n, Δ^0 core is identically zero. Therefore, what is shown in Fig.4 should be regarded as the quark core-pion state contribution to the neutron form factor. The significant difference in the slope of $F^{N\pi}$ and $F^{\pi N}$, and $F^{\pi\Delta}$ and $F^{\Delta\pi}$ leads to the positive charge of the core located at smaller distances, surrounded by the negatively charged pionic cloud. On the other hand the intrinsic electromagnetic form factor of the pion, given by the monopole formula, decreases slowly with Q^2 compared to the dipole form factor of the core (Eq.(7)). This leads to very strong cancellations of the $\pi(N)$ and $N(\pi)$ contributions to F_1^n and similar cancellations for the $\pi(\Delta)$ and $\Delta(\pi)$ components. In addition the total πN (dashed line) and the total $\pi\Delta$ (dotted line) contributions are of opposite sign.

For comparison, we also show in Fig.4 the phenomenological parametrization from Ref.[18] (dash-dotted line). The cancellations discussed above means that the neutron form factor is extremely sensitive to the choice of the vertex function and may depend slightly on the functional form of the core form factor. It is well known from deep inelastic scattering experiments that the x -distributions of the valence "up" and "down" quarks in the nucleon are different, which suggests a nonvanishing form factor of the charge-zero quark core. This may explain the departure of F_1^n from the Gari-Krümpelmann parameterization. Therefore our results should be regarded rather as an indication of the importance of the mesonic-baryonic degrees of freedom for the neutron form factor. Corrections from the admixture of other Fock components, like $N\rho$ for example, may also play some

role in this context [11].

5 Conclusions

We have presented estimates of the radius of the quark core of the nucleon based on the analysis of the electromagnetic form factor of the proton and of the nucleon-nucleon cross sections. Both approaches give consistent results that the core radius is smaller by $\approx 10\%$ than the proton radius. These estimates are based on the independent determination of the vertex parameters [6, 11] from high-energy $p \rightarrow n$ and $p \rightarrow \Delta^{++}$ fragmentation processes. The same set of parameters was used to explain the departure from the Gottfried Sum Rule yielding 0.249 [6] and 0.224 [11]. The relatively small admixture (30 – 40%) of the quark core-pion states in the nucleon excludes the possibility of a very small radius of the quark core. The core contribution to the proton form factor dominates at $Q^2 \gtrsim 10 \text{ GeV}^2$, where the proton can be regarded as stripped of its pionic cloud. This is an important effect for the signal of color transparency in the $A(e, e'p)$ reactions [9] but the discussion of this effect goes beyond the the scope of the present paper.

Acknowledgements. We are indebted to P.J.Sutton for careful reading the manuscript. This work was supported in part by the Polish KBN grant 2 2409 9102.

References

- [1] P.Amaudruz et al., Phys.Rev.Lett.66 (1991) 2712
- [2] E.M.Henley and G.A.Miller, Phys.Lett.B251 (1990) 453
- [3] S.Kumano, Phys.Rev. D43 (1991) 59
- [4] A.Signal, A.W.Schreiber and A.W.Thomas, Mod.Phys.Lett.A6 (1991) 271
- [5] W-Y.P.Hwang, J.Speth and G.E.Brown, Z.Phys.A339 (1991) 383
- [6] V.R.Zoller, Z.Phys. C53 (1992) 443
- [7] A.Szczurek and J.Speth, Nucl.Phys. A555 (1993) 249
- [8] A.Szczurek, J.Speth and G.T.Garvey, Jülich preprint KFA-IKP(TH)-13 (1993), to be published in Nucl.Phys.A
- [9] N.N.Nikolaev, A.Szczurek, J.Speth, J.Wambach, B.G.Zakharov and V.R.Zoller, paper in preparation
- [10] H.Umezawa, Y.Takahashi and S.Kamefuchi, Phys. Rev. 85 (1952) 505;
R.G.Sachs, Phys. Rev. 87 (1952) 1100;
B.D.Fried, Phys. Rev. 88 (1952) 1142;
M.H.Friedman, Phys. Rev. 97 (1955) 1123;
H.Miyazawa, Phys. Rev. 101 (1956) 1564
- [11] H.Holtmann, A.Szczurek and J.Speth, paper in preparation
- [12] K.G.Boreskov and G.G.Arakelyan, Sov. J. Nucl. Phys. 31 (1980) 1578;
G.G.Arakelyan and A.A.Grigoryan, Sov.J.Nucl.Phys.34 (1981) 745
- [13] A.W.Thomas, S.Théberge and G.A.Miller, Phys. Rev. D24 (1981) 216;
S.Théberge, G.A.Miller and A.W.Thomas, Can. J. Phys. 60 (1982) 59
- [14] V.R.Zoller, Z.Phys. C60 (1993) 141
- [15] S.D.Drell and T-M.Yan, Phys.Rev.Lett.24 (1970) 181
- [16] S.D.Drell, D.J.Levy and T-M.Yan, Phys.Rev.D1 (1970) 1035

- [17] M.V.Terent'ev, Sov.J.Nucl.Phys. 24 (1976) 106; V.B.Berestetskii and M.V.Terent'ev, ibid. 24 (1976) 547; 25 (1977) 347.
- [18] M.Gari and W.Krümpelmann, Z.Phys. A322 (1985) 689

Figure Captions

Fig.1 The diagrams contributing to the nucleon form factors.

Fig.2 The Q^2 -dependence of the $N\pi$ (dashed), πN (dashed), $\Delta\pi$ (dotted) and $\pi\Delta$ (dotted) body form factors. The results obtained with parameters from Ref.[11] are shown on the lhs whereas those obtained with parameters from Ref.[6] on the rhs.

Fig.3 The ratio of the form factor $F_1^p(Q^2)$ obtained in our hybrid model to the conventional dipole parameterization $G_D(Q^2)$ (solid curve). The contributions from different components are shown separately with the notation consistent with Fig.2. As in Fig.2 we show results obtained with parameters from Ref.[11] (lhs) and Ref.[6] (rhs).

Fig.4 The Q^2 -dependence of the neutron form factor (solid line). We also show separately contribution from the πN (dashed line) and $\pi\Delta$ (dotted line) Fock states. As in Fig.2 we show results obtained with parameters from Ref.[11] (lhs) and Ref.[6]. For comparison we present also often used parametrization by Gari-Krümpelmann [18].

Fig. 1

Fig. 2

Fig. 3

Fig. 4