FLAVOR DEPENDENCE OF THE SPIN-INDEPENDENT AND SPIN-DEPENDENT PARTS OF GPDs(x,t,ξ = 0)

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Abstract

The different sets of PDF with the new form of t-dependence of generalized parton distributions (GPDs) were examined in the descriptions of the electromagnetic form factors of the proton and neutron. One of the purposes was to minimize the number of fitting parameters. We found that main flavor difference related to the spin-dependent of PDF incoming as part in GPDs. Hence, contrary to some other work, our result shows a little flavor dependence of the t-dependence of the GPDs(x,t,ξ = 0).

The parton picture of the hadron is in most part represented by the parton distribution functions (PDFs). They are determined in the deep inelastic processes. The next step in the development of the picture of the hadron was made by introducing the non-forward structure functions - general parton distributions - GPDs [1] with spin-independent the \(H(x,ξ,t)\) and the spin-dependent \(E(x,ξ,t)\) parts. Generally, GPDs depend on the momentum transfer \(t\), the average momentum fraction \(x = 0.5(x_i + x_f)\) of the active quark, and the skewness parameter \(2ξ = x_f − x_i\) that measures the longitudinal momentum transfer. Some of the advantages of GPDs were presented by the sum rules [1]

\[
F_1^q(t) = \int_0^1 dx \, H^q(x,ξ = 0,t), \quad F_2^q(t) = \int_0^1 dx \, E^q(x,ξ = 0,t).
\]

(1)

Now we cannot obtain the \(t\)-dependence of GPDs from the first principles, but it can be obtained from the phenomenological description by GPDs of the nucleon electromagnetic form factors. Many different forms of the \(t\)-dependence of GPDs were proposed. In the quark diquark model [2][3] the form of GPDs consist of three parts - PDFs, function distribution and Regge-like.

\[
F_q(x,t) = N_q \, G^{H,E}_{Mq,t}(x,t) \, R^{q\alpha q\alpha'}_{pq}(x,t)
\]

(2)

The parameters have the flower dependence for the all three parts. As a result, they came to the conclusion: ”The data show, in particular, a suppression of \(d\) quarks with respect to \(u\) quarks at large momentum transfer”. In other works (see e.g. [4]) the description of the \(t\)-dependence of GPDs was developed in a more complicated picture using the polynomial forms with respect to \(x\). Note that in [5] it was shown that at large \(x \rightarrow 1\) and momentum transfer the behavior of GPDs requires a larger power of \((1−x)^n\) in the \(t\)-dependent exponent:

\[
\mathcal{H}^q(x,t) \sim exp[a \, (1−x)^n \, t] \, q(x).
\]

(3)
Figure 1: The model description of the electromagnetic form factors for the proton (left) $\mu G_E^p/G_M^p$ and the neutron (right) $G_m^n/\mu Gd$ with the different PDFs.

with $n \geq 2$. It was noted that $n = 2$ naturally leads to the Drell-Yan-West duality between parton distributions at large $x$ and the form factors.

Let us modify the original Gaussian ansatz and choose the $t$-dependence of GPDs in the simple form

$$H^q(x, t) = q(x) \exp[a_+ (1 - x)^2/x^m t].$$

The value of the parameter $m = 0.4$ is fixed by the low $t$ experimental data while the free parameters $a_\pm$ ($a_+$ for $H$ and $a_-$ for $E$) were chosen to reproduce the experimental data in the whole $t$ region. The isotopic invariance can be used to relate the proton and neutron GPDs. Hence, we do not change any parameter and keep the same $t$-dependence of GPDs as in the case of proton.

In our first work [6] the function $q(x)$ is based on the MRST02 global fit [7]. In all calculations we restrict ourselves to the contributions of only valence $u$ and $d$ quarks. Following the standard representation we have for the Pauli form factor $F_2$

$$E^q(x, t) = E^q(x) \exp[a_− (1 − x)^2/x^{0.4} t];$$

where $\kappa_1 = 1.53$ and $\kappa_2 = 0.31$ [8]. According to the normalization of the Sachs form factors, we have $k_u = 1.673$, $k_d = -2.033$, $N_u = 1.53$, $N_d = 0.946$.

Now many PPDs, proposed by different Collaborations, were examined to compare the descriptions of the electromagnetic form factors of the proton and neutron. We take 464 experimental data and take into account only statistical errors. As a result, we find that the different PDF sets, which well describe the deep inelastic processes, gave the large difference in the description of the form factors [9]. The whole sets of the results will be published. Now we note that a better description of the form factors was given by PDFs of [10, 11] and [12]. The obtained description of the electromagnetic form factors is shown on Fig. 1 (left) for the proton and Fig.1(right) for the neutron. Note that at small momentum transfer practically all PDFs gave the same descriptions. However, at large $t$ we obtain the different description for the different PDFs.

Now let us examine separate contributions of the $u$ and $d$ quarks to the electromagnetic form factors in our model of the $t$-dependence of GPDs. We take PDFs of [10] which give the one of the best descriptions of the electromagnetic form factors. We analyze the two cases: first - the base variant of GPDs with only 4 free variation parameters, second -
Figure 2: The $u$ and $d$ quarks contributions to the $t^2 F_1(t)$: - the fit with 4 free parameters (left) and with 10 free parameters (right). The data take from [13].

Figure 3: The same as in Fig.2 for the $k^{-2} t^2 F_2(t)$. with the maximum number of free variation parameters - 10.

$$H^u(x,t) = q(x)u \exp[\alpha(x_5 x(1-x) + (1-x)^a_1/(\epsilon + x)^a_2 t)]$$

$$E^u(x,t) = q(x)(1-x)k_1 \exp[\alpha(x_5 x(1-x) + (1-x)^a_1/(\epsilon + x)^a_2 t)]$$

Here the parameters $a_3, a_4, a_5, a_6$ represent the flavor dependence of the Regge part of GPDs and the parameters $k_1, k_2$ are responsible for the flavor dependence of the spin-dependent part of PDFs. If we take the PDFs sets from [10] we obtain the small difference in $\sum \chi^2$ in the descriptions of the electromagnetic form factors in these two cases, only 25%. However, the number of free parameters differs essentially: 4 and 10. Further increase in the number of free parameters leads to a very small decrease in $\sum \chi^2$.

The $u$ and $d$ quark contributions to $F_1(t)$ multiplied by $t^2$ is shown in Fig.2. We compare the fits with 4 free parameters (left) and 10 free parameters (right). It is clear that the difference is very small. Only the $d$ quark contribution is slightly less in the last case. However, the $t$-dependence in both the cases is practically the same. In Fig.2, we present the same calculations for $F_2(t)$. Again, the contribution of the $d$ quark decreases in the case of a large number of free parameters. Despite the large number of the free parameters, our calculations better coincide with extractions of the $u$ and $d$ quark contributions up to $-t = 2$ GeV² [13]. The $u$ and $d$ quark contributions to $F_1(t)$ (left) and $F_2(t)$ (right) at large momentum transfer are shown in Fig.3. It is clear that at large $t$ the behavior of the $u$ and $d$ quark contributions is the same.
Our analysis of PDFs sets of the different Collaborations show a large difference in the descriptions of the electromagnetic form factors of the proton and neutron. The best result can be obtained with PDFs sets of [10] and [11]. These sets lead to minimum of \( \sum \chi^2 \). They also show the small dependence of the GPDs on the increasing different free parameters. The obtained \( t \) dependence of GPDs has a simple form and a small number of the free parameters.

The flavor dependence in these cases in most part comes from the spin dependent part of PDFs. We obtained the good descriptions of the electric and magnetic form factors of the proton and neutron simultaneously. We found that different PDFs gave almost the same descriptions of the proton form factors at small momentum transfer. The difference appear only at large \( t \). Our calculations of the \( u \) and \( d \) quark contributions show the same \( t \) dependence at large \( t \).

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