

Generalized parton distributions of the nucleon in constituent quark models

S. Boffi^a, B. Pasquini^{a, b}, M. Traini^{b, c}

^aDipartimento di Fisica Nucleare e Teorica, Università degli Studi di Pavia and INFN, Sezione di Pavia, Pavia, Italy

^bECT*, Villazzano (Trento), Italy

^cDipartimento di Fisica, Università degli Studi di Trento, Povo (Trento), and INFN, Gruppo Collegato di Trento, Trento, Italy

Generalized parton distributions (GPDs) are studied at the hadronic (nonperturbative) scale within different assumptions based on a relativistic constituent quark model. In particular, by means of a meson-cloud model we investigate the role of nonperturbative antiquark degrees of freedom and the valence quark contribution. A QCD evolution of the obtained GPDs is used to add perturbative effects and to investigate the GPDs' sensitivity to the nonperturbative ingredients of the calculation at larger (experimental) scale.

1. Modeling GPDs with double distributions

We will concentrate our attention on the chiral even (helicity conserving) distribution $H^q(\bar{x}, \xi, Q^2, t)$ for partons of flavor q at the hadronic scale where the models we are going to discuss are assumed to be valid to evaluate the twist-two amplitude. The invariant momentum square is $t = \Delta^2 = (P'^\mu - P^\mu)^2$, \bar{x} is the quark light-cone momentum fraction with respect to the average nucleon momentum $\bar{P}^\mu = \frac{1}{2}(P^\mu + P'^\mu)$, and the skewedness ξ describes the longitudinal change of the nucleon momentum, $2\xi = -\Delta^+/\bar{P}^+$. In the following the dependence on the scale Q^2 is understood.

We also introduce non-singlet (valence) and singlet quark distributions,

$$H^{NS}(\bar{x}, \xi, t) \equiv \sum_q [H^q(\bar{x}, \xi, t) + H^q(-\bar{x}, \xi, t)] = H^{NS}(-\bar{x}, \xi, t), \quad (1)$$

$$H^S(\bar{x}, \xi, t) \equiv \sum_q [H^q(\bar{x}, \xi, t) - H^q(-\bar{x}, \xi, t)] = -H^S(-\bar{x}, \xi, t), \quad (2)$$

respectively. Besides being symmetric or antisymmetric in \bar{x} , they are also symmetric under $\xi \rightarrow -\xi$ due to the polynomiality property [2]. The analogous GPD for gluons is symmetric in \bar{x} , i.e. $H^g(\bar{x}, \xi, t) = H^g(-\bar{x}, \xi, t)$, and reduces to the gluon density $g(x)$ in the forward limit ($\bar{x} \rightarrow x$, $H^g(x, 0, 0) = x g(x)$, $x > 0$).

Following ref. [1] we will assume a factorized t dependence determined by some form factor, and parametrize the t -dependent part in terms of double distributions (DDs) involving a given profile function and the forward parton distribution $q(x)$ derived in some

model. At the hadronic scale Q_0^2 , where the short range (perturbative) part of the interaction is negligible and, therefore, the glue and sea are suppressed, the long range (confining) part of the interaction produces a proton composed by (three) valence quarks, mainly [3]. Therefore quark models are suitable to construct the parton distribution at the scale Q_0^2 [4].

According to the method discussed in two recent papers [5, 6] along the lines of ref. [7], we evaluate the valence contribution $q^{bare}(x)$ to the parton distribution within relativistic light-front constituent quark models (CQMs) at the scale Q_0^2 . This distribution automatically fulfills the support condition and satisfies the (particle) baryon number and momentum sum rules. Results presented here are obtained for the hypercentral CQM [8].

2. Parton distributions and the meson-cloud model

The meson-cloud model introduces the sea by incorporating $q\bar{q}$ contributions into the valence-quark model of the parton distribution discussed in the previous section. The basic hypothesis of the meson-cloud model is that the physical nucleon state can be expanded (in the infinite momentum frame (IMF) and in the one-meson approximation) in a series involving bare nucleons and two-particle, meson-baryon states [9]. We will consider fluctuations of the proton including both pion-nucleon and pion-Delta states. The partonic content of the Δ and the pion will be consistently evaluated within the same scheme assuming light-front dynamics and valence contributions only.

The quark distributions in a physical proton are then given by

$$q_p(x) = Zq_p^{bare}(x) + \delta q_p(x), \quad (3)$$

where $\delta q_p(x)$ is the contribution coming from the meson-baryon fluctuations, and Z is a suitable renormalization constant.

Matching the sea, valence and gluon distributions within the radiative parton model we start evolution with continuous functions all over the range $-1 \leq \bar{x} \leq 1$ and identify the matching scale $Q_0^2 = 0.27 \text{ GeV}^2$ consistent with QCD evolution equations [10, 11].

3. Results and discussion

Results are presented in this section according to the model based on DDs. The t dependence is dropped from the very beginning and could be reintroduced in the final results by an appropriate t -dependent factor. The D-term is omitted as well. The QCD evolution was numerically performed to NLO accuracy according to a modified version of the code of ref. [12] (see [13] for further details and results).

The singlet quark, non-singlet quark and gluon GPDs obtained in the model have been studied as a function of \bar{x} , ξ and Q^2 . With no initial gluons and an input parton distribution given by $q^{bare}(x)$ the model already gives a nonvanishing contribution to quark GPDs in the ERBL region $|\bar{x}| < \xi$ at the hadronic scale without introducing discontinuities at $\bar{x} = \xi$ and with a weak ξ dependence. In particular, the absence of the sea contribution gives $H^S = H^{NS}$ at $\bar{x} > \xi$. After evolution up to $Q^2 = 5 \text{ GeV}^2$ GPDs are almost confined into the ERBL region with a significant ξ dependence.

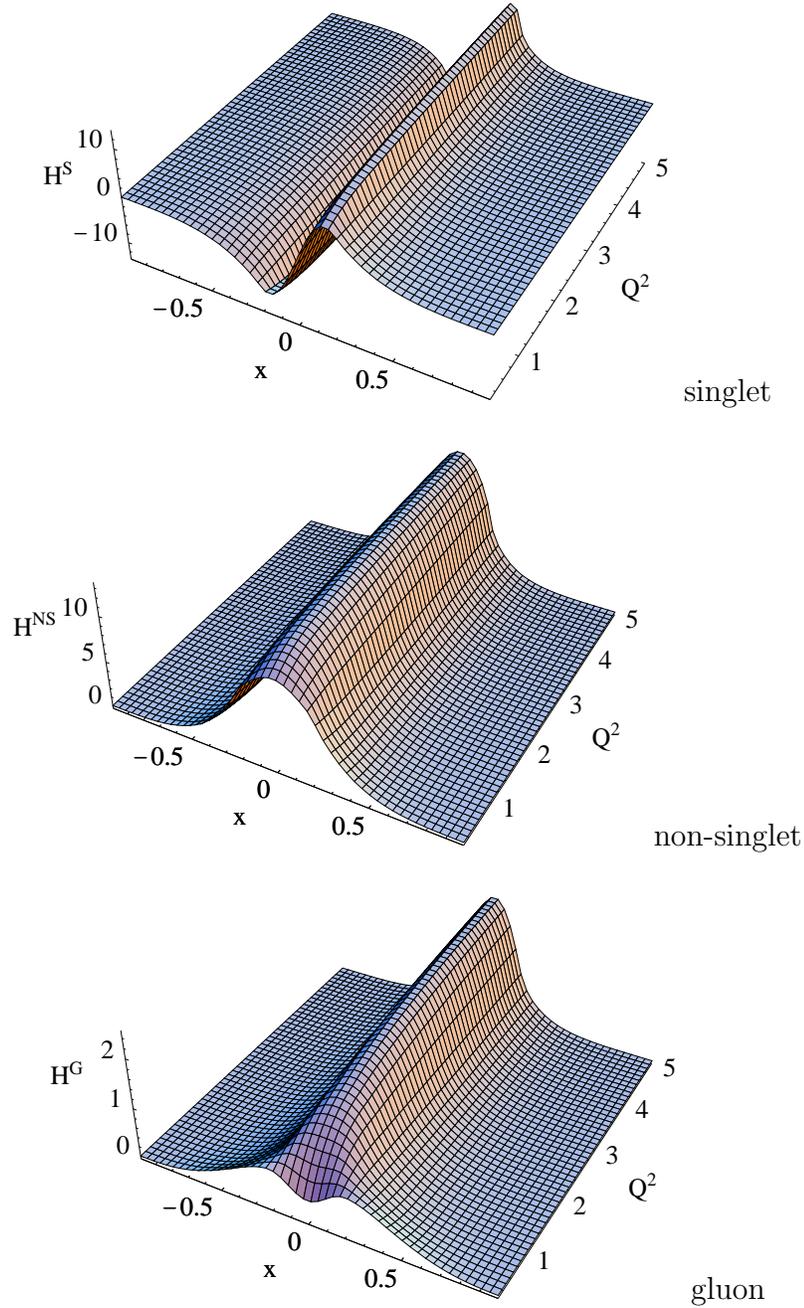


Figure 1. Singlet and non-singlet quark and gluon GPDs at $\xi = 0.2$ obtained from NLO evolution within the double-distribution model using parton distributions of the hypercentral CQM with the sea contribution at the initial scale $Q_0^2 = 0.27 \text{ GeV}^2$.

In fig. 1 results are shown for QCD evolution up to $Q^2 = 5 \text{ GeV}^2$ of the singlet quark, non-singlet quark and gluon GPDs obtained with the parton distributions of the hypercentral CQM and including the sea contribution at the initial scale $Q_0^2 = 0.27 \text{ GeV}^2$. The distributions are plotted at $\xi = 0.2$ as a function of Q^2 . In fact, the largest effects of evolution modify the input GPDs within the first few GeV^2 in the Q^2 evolution, $Q^2 = 5 \text{ GeV}^2$ being a value where GPDs have already reached a stable configuration with respect to their asymptotic shape.

The model already gives a nonvanishing gluon contribution at the hadronic scale. Under evolution as the resolution scale increases the distributions are again swept from the DGLAP domain to lie almost fully within the ERBL region. This is a consequence of the fact that functions with support entirely in the time-like ERBL region are never pushed out of the ERBL domain. In fact, the evolution in the ERBL region depends on the DGLAP region, whereas the DGLAP evolution is independent of the ERBL region. The qualitative result after evolution is similar to the case without the sea [13] in spite of a more pronounced ξ dependence of H^S at the input hadronic scale and a shape of H^{NS} sensitive to the input at $\bar{x} = 0$.

The present results focus on the ERBL region as the most interesting one to look at the nonperturbative effects surviving evolution. This is suggesting that one has to investigate suitable processes under appropriate kinematic conditions to study such effects.

This research is part of the EU Integrated Infrastructure Initiative Hadronphysics Project under contract number RII3-CT-2004-506078 and was partially supported by the Italian MIUR through the PRIN Theoretical Physics of the Nucleus and the Many-Body Systems.

REFERENCES

1. A.V. Radyushkin, Phys. Rev. D 59, 014030 (1999).
2. Xiangdong Ji, J. Phys. G 24 (1998) 1181.
3. G. Parisi and R. Petronzio, Phys. Lett. B 62 (1976) 331.
4. R.L. Jaffe and G.C. Ross, Phys. Lett. B 93 (1980) 313.
5. S. Boffi, B. Pasquini and M. Traini, Nucl. Phys. B 649, 243 (2003).
6. S. Boffi, B. Pasquini and M. Traini, Nucl. Phys. B 680, 147 (2004).
7. M. Diehl, Th. Feldmann, R. Jakob and P. Kroll, Nucl. Phys. B 596, 33 (2001).
8. P. Faccioli, M. Traini and V. Vento, Nucl. Phys. A 656, 400 (1999).
9. W. Melnitchouk, J. Speth and A.W. Thomas, Phys. Rev. D 59, 014033 (1999); S. Kumano, Phys. Rep. 303, 183 (1998); A.W. Thomas, W. Melnitchouk and F.M. Steffens, Phys. Rev. Lett. 85, 2892 (2000).
10. M. Glück, E. Reya and A. Vogt, Z. Phys. C 53, 127 (1992); M. Glück, E. Reya and A. Vogt, Z. Phys. C 67, 433 (1995).
11. M. Traini, V. Vento, A. Mair and A. Zambarda, Nucl. Phys. A 614, 472 (1997); A. Mair and M. Traini, Nucl. Phys. A 628, 296 (1998).
12. A. Freund and M. McDermott, Phys. Rev. D 65, 056012 (2002); (E) 66, 079903 (2002) and <http://durpdg.dur.ac.uk/hepdata/dvcs.html>.
13. B. Pasquini, M. Traini and S. Boffi, hep-ph/0407228.