Pion-Photon Transition Distribution Amplitudes

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Abstract. The newly introduced Transition Distribution Amplitudes (TDAs) are discussed for the \( \pi\gamma \) transitions. Relations between \( \pi\gamma \) and \( \gamma\pi \) TDAs for different cases are given. Numerical values for the \( \pi\gamma \) TDAs in different models are compared. GPD’s features are extended to TDAs and the role of PCAC highlighted. We give hints for the evaluation of cross sections for meson pair production in our approach.

Keywords: TDA, GPD, parton distributions, pion

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1. INTRODUCTION

One of the main open questions in particle physics is the understanding of the structure of hadrons in terms of quarks. An important tool for such a purpose is provided by hard processes. The large virtuality \( Q^2 \) involved in these processes allows the factorization of their amplitudes into hard and soft contributions. The hard contribution to the scattering amplitude is known from perturbative QCD but the interesting quantity unveiling the structure of hadrons is the soft or non-perturbative contribution. In Deep Inelastic Scattering (DIS) this nonperturbative quantity is expressed in terms of the parton distribution functions (PDF). PDFs can be expressed as the Fourier transform of a bilocal current between the same initial and final hadronic state. Generalized parton distributions (GPD) [1, 2, 3] extend this concept to off-diagonal matrix elements of the same currents. GPD govern exclusive processes with the same hadron in the initial and final state in the soft part of the process but with momentum transfer different from zero. Deeply virtual Compton scattering (DVCS) is a typical example of processes governed by GPDs. Recently a further “generalization” to transition distribution amplitudes (TDA) in which the initial and the final state in the soft part of the amplitude are different has been introduced. They have been defined for processes like hadron annihilation into two photons and backward VCS in the kinematical regime where the virtual photon is highly off-shell but with small momentum transfer \( t \) [4]

\[
H\bar{H} \rightarrow \gamma^*\gamma \rightarrow e^+e^-\gamma \quad \text{and} \quad \gamma^*H \rightarrow H\gamma ,
\]

(1)
with $H$ a hadron, or exclusive meson pair production in $\gamma^* \gamma$ scattering in the same kinematical regime [3]

$$\gamma^*_L \gamma \rightarrow M^\pm \pi^\mp ,$$

(2)

$M$ being either $\rho_L$ or $\pi$. Advocating [4] that the factorization theorems for exclusive processes can be extended to the processes under consideration, i.e. (1) and (2), the amplitude can be factorized as shown in Fig. 1 with the TDAs, describing the $\pi \rightarrow \gamma$ transition, being the Fourier transform of the matrix element of bilocal currents at a light-like distance.

The nonperturbative nature of the distribution functions imposes the use of effective theories, models or phenomenological parametrizations. In Ref. [6] the calculation of the $\pi-\gamma$ TDAs in a covariant Bethe-Salpeter approach has been defined. All the invariances of the problem are hence preserved, e.g. gauge and translational invariance. For the numerical evaluation, the Nambu - Jona-Lasinio (NJL) model for the description of the pion has been used. The Pauli-Villars regularization scheme has been chosen because it is Lorentz invariant.

Estimates for the $\pi-\gamma$ TDAs have been given in Ref. [7] and a calculation has been performed in the Spectral Quark Model (SQM) [8]. Both studies parametrize the TDAs by means of double distributions [1]. A detailed comparison of the SQM and the NJL models in the determination of the pion GPD can be found in Ref. [9]. Finally in Ref. [10] TDAs have been calculated in a non-local chiral quark model, confirming the results of the previous calculations.

In the following Section we introduce the vector and axial TDAs emphasizing their connection to the pion transition form factors, appearing in the radiative pion decay [11]. The presence of an additional contribution due to PCAC is explicitly shown. Numerical results and a comparison between the different models are presented in Section 3.

2. DEFINITION OF THE PION-PHOTON TDAS

General arguments, such as Lorentz invariance, lead to some important properties of GPDs. Taking their first Mellin moment, one can relate GPDs to the corre-
sponding form factors through the sum rules. Also their higher Mellin moments are polynomials in the skewness variable $\xi$ by Lorentz invariance.

Similarly, as a consequence of Lorentz invariance, TDAs are constrained by sum rules and polynomial expansions. The first Mellin moments of $\pi-\gamma$ transition distribution functions are related to the vector and axial-vector transition form factors, $F_\nu$ and $F_A$, through the sum rules. The definition of these form factors is given from the vector and axial-vector currents [11]

\[
\langle \gamma(p')|\bar{q}(0)\gamma_\mu\gamma^- q(0)|\pi(p)\rangle = -ie\varepsilon^\nu \epsilon_{\mu\nu\rho\sigma} p'^\rho p^\sigma \frac{F_\nu(t)}{m_\pi} ,
\]

\[
\langle \gamma(p')|\bar{q}(0)\gamma_\mu\gamma_5\gamma^- q(0)|\pi(p)\rangle = e\varepsilon^\nu \left(p'_\mu p_\nu - g_{\mu\nu} p'.p\right) \frac{F_A(t)}{m_\pi} + e\varepsilon^\nu \left(p' - p\right)_\mu \frac{2\sqrt{2}f_\pi}{m_\pi^2} \left(\frac{2}{m_\pi^2} - t\right) - \sqrt{2}f_\pi g_{\mu\nu} ,
\]

with $f_\pi = 92.4$ MeV, $\varepsilon^{0123} = 1$ and $\gamma^- = (\tau_1 - i\tau_2)/2$. All the structure of the decaying pion is included in the form factors $F_\nu$ and $F_A$. The vector current only contains a Lorentz structure associated with the $F_\nu$ form factor. The axial form factor $F_A$ also gives the structure of the pion but contains additional terms required by electromagnetic gauge invariance. The second term on the right-hand side of Eq. (1), which corresponds to the axial current for a point-like pion, contains a pion pole coming from the pion inner bremsstrahlung: the incoming pion and outgoing photon couple with the axial current through a virtual pion (Fig. 2) as required by the Partial Conservation of the Axial Current (PCAC). The third term in Eq. (4) is a pion-photon-axial current contact term, proportional to $f_\pi g_{\mu\nu}$.

Going to the TDAs we introduce the light-cone coordinates $v^\pm = (v^0 \pm v^3)/\sqrt{2}$ and the transverse components $\vec{v}^\perp = (v^1, v^2)$ for any 4-vector $v^\mu$. We define $P = (p + p')/2$ and the momentum transfer, $\Delta = p' - p$, therefore $P^2 = m_\pi^2/2 - t/4$ and $t = \Delta^2$. The skewness variable describes the loss of momentum in the light front direction of the incident pion, i.e. $\xi = (p - p')^+ / 2P^+$. Its value ranges between $t/(2m_\pi^2 - t) < \xi < 1$. Negative values of the skewness variable can be allowed. Regarding the real photon polarization, $\varepsilon^\nu$, we have the transverse condition $\varepsilon^\nu p' = 0$ and an additional gauge fixing condition. We assume that this condition is such that $\varepsilon^+/P^+$ is kinematically higher twist. The standard gauge fixing conditions, $\varepsilon^0 = 0$ or $\varepsilon^+ = 0$, both satisfy the previous requirement. To leading twist, the TDAs
are therefore defined

\[
\int \frac{dz^-}{2\pi} e^{ixP_z} \gamma(p') |\bar{q}\left(-\frac{z}{2}\right)\gamma^+\tau^- q\left(\frac{z}{2}\right) \gamma^0 (p)| \bigg|_{z^+ = z^- = 0}
\]

\[
= i \epsilon \epsilon_\nu \epsilon^{\nu\rho\sigma} P_\rho \Delta_\sigma \frac{V^{\pi^+ \to \gamma} (z, \xi, t)}{\sqrt{2f_\pi}},
\]

\[
\int \frac{dz^-}{2\pi} e^{ixP_z} \gamma(p') |\bar{q}\left(-\frac{z}{2}\right)\gamma^+\gamma_5\tau^- q\left(\frac{z}{2}\right) \gamma^0 (p)| \bigg|_{z^+ = z^- = 0}
\]

\[
= e (\vec{\epsilon}_\perp \cdot \vec{\Delta}_\perp) \frac{A^{\pi^+ \to \gamma} (x, \xi, t)}{\sqrt{2f_\pi}} + e (\vec{\epsilon} \cdot \vec{\Delta}) \frac{2\sqrt{2f_\pi}}{m^2_\pi - t} \epsilon (\xi) \phi \left(\frac{x + \xi}{2\xi}\right),
\]

with \(\epsilon(\xi)\) equal to 1 for \(\xi > 0\), and equal to \(-1\) for \(\xi < 0\). Here \(V(x, \xi, t)\) and \(A(x, \xi, t)\) are respectively the vector and axial TDAs. Hence the axial matrix element contains the axial TDA and the pion pole contribution that has been isolated in a model independent way \[7, 6, 12\]. The latter term is parametrized by a point-like pion propagator multiplied by the distribution amplitude (DA) of an on-shell pion, \(\phi(x)\). Notice that the pion DA obeys the normalization condition \(\int_0^1 dx \phi(x) = 1\); the connection through the sum rules of Eq. \(5\) with Eqs. \(3\) and \(4\) is therefore obvious.

The contribution of a pion pole is not a new feature of large-distance distributions. TDAs like GPDs are low-energy quantities in QCD though their degrees of freedom are quarks and gluons. One thus expects chiral symmetry to manifest itself, what implies a matching between the degrees of freedom of parton distributions and the low-energy degrees of freedom such as pions. Actually, in the region \(x \in [-|\xi|, |\xi|]\), the emission of a \(q\bar{q}\) pair from the initial state can be assimilated to a meson distribution amplitude.

Here we have defined the TDAs in the particular case of a transition from a \(\pi^+\) to a photon, parametrizing the processes given by Eq. \(1\). Symmetries relate the latter distributions to TDAs involved in other processes. For instance, we could wish to study the \(\gamma-\pi^-\) TDAs entering the factorized amplitude of the process \(2\).

Unifying our notations with the notations of Ref. \[5\], we define the \(\gamma-\pi^\pm\) TDAs

\[
\int \frac{dz^-}{2\pi} e^{ixP_z} \gamma^\pm (p') |\bar{q}\left(-\frac{z}{2}\right)\gamma^+\tau^- q\left(\frac{z}{2}\right) \gamma^0 (p')\bigg| \bigg|_{z^+ = z^- = 0}
\]

\[
= i \epsilon \epsilon_\nu \epsilon^{\nu\rho\sigma} P_\rho (p - p') \frac{V^{\gamma-\pi^\pm} (x, -\xi, t)}{\sqrt{2f_\pi}},
\]

\[
\int \frac{dz^-}{2\pi} e^{ixP_z} \gamma^\pm (p') |\bar{q}\left(-\frac{z}{2}\right)\gamma^+\gamma_5\tau^\pm q\left(\frac{z}{2}\right) \gamma^0 (p')\bigg| \bigg|_{z^+ = z^- = 0}
\]

\[
= -e (\vec{\epsilon}_\perp \cdot (\vec{p}_\perp - \vec{p}_\perp')) \frac{A^{\gamma-\pi^\pm} (x, -\xi, t)}{\sqrt{2f_\pi}}
\]
\[ \pm e (\varepsilon \cdot (p - p')) \frac{2\sqrt{2} f_\pi}{m_\pi^2 - t} \epsilon(-\xi) \phi \left( \frac{x + \xi}{2\xi} \right), \quad (6) \]

where we have preserved the definition \( \xi = (p - p')^+/(p + p')^+ \) given before the Eq. (5).

Time reversal relates the \( \pi^+\gamma \) TDAs to \( \gamma\pi^+ \) TDAs in the following way

\[ D^{\pi^+\rightarrow\gamma}(x, \xi, t) = D^{\gamma\rightarrow\pi^+}(x, -\xi, t), \quad (7) \]

where \( D = V, A \). And CPT relates the presently calculated TDAs to their analog for a transition from a photon to a \( \pi^- \)

\[ V^{\pi^+\rightarrow\gamma}(x, \xi, t) = V^{\gamma\rightarrow\pi^-}(-x, -\xi, t), \]
\[ A^{\pi^+\rightarrow\gamma}(x, \xi, t) = -A^{\gamma\rightarrow\pi^-}(-x, -\xi, t). \quad (8) \]

3. DISCUSSION

Basic properties of GPDs and TDAs, like sum rules and polynomiality are related to Lorentz and gauge symmetries. Therefore, we need a method of calculation which preserves these properties. The main problem here is the description of hadrons, as bound states of quarks, preserving these symmetries. One solution is to use a field theroretical formalism, with a covariant Bethe-Salpeter approach for the description of the hadrons. In this formalism, GPDs and TDAs are integrals over the Bethe-Salpeter amplitudes. This method has been developed in Refs. [6, 13] for local lagrangians and in Refs. [14, 15] for non-local lagrangians. In the case of pions, the simplest realistic model which realizes these ideas is the NJL model within the Pauli-Villars regularization scheme. We will therefore use this model for the discussion of the calculation.

We consider that the process is dominated by the handbag diagram. Each TDA has two related contributions \[6], depending on which quark (u or d) of the pion is scattered off by the deep virtual photon. The leading contributions to the handbag diagram are depicted in Fig. 3 for an active u-quark, with the diagram on the
right corresponding to a coupling of the bilocal current to a quark-antiquark pair. The vector TDA receives contribution only from the first type of diagram, i.e. the diagram on the left of Fig. 3. In the case of the axial TDA, a contribution in the $-|\xi| < x < |\xi|$ region arises from the second diagram of Fig. 3. This second contribution comes from the re-scattering of a $q\bar{q}$ pair in the pion channel. It contains the pion pole which, according to Eq. (5), must be subtracted in order to obtain the axial TDA.

We can express both, $V(x, \xi, t)$ and $A(x, \xi, t)$, TDAs as the sum of the active $u$-quark and the active $\bar{d}$-quark distributions. The first contribution will be proportional to the $d$'s charge, $Q_d$, and the second contribution to the $u$'s charge, $Q_u$. Therefore, we can write

$$D^{\pi^+}(x, \xi, t) = Q_d d^{\pi^+}_{u\rightarrow d}(x, \xi, t) + Q_u d^{\pi^+}_{d\rightarrow \bar{u}}(x, \xi, t) \quad ,$$

with $D = V, A$ and $d = v, a$. Isospin relates these two contributions. For the vector TDA, we obtain $v^{\pi^+}_{d\rightarrow \bar{u}}(x, \xi, t) = v^{\pi^+}_{u\rightarrow d}(-x, -\xi, t)$. For the axial TDA we have $a^{\pi^+}_{d\rightarrow \bar{u}}(x, \xi, t) = -a^{\pi^+}_{u\rightarrow d}(-x, -\xi, t)$ where the minus sign is originated in the change in helicity produced by the $\gamma_5$ operator. The $d^{\pi^+}_{d\rightarrow \bar{u}}(x, \xi, t)$ contribution is non-vanishing in the region $-|\xi| < x < 1$ while $d^{\pi^+}_{d\rightarrow \bar{u}}(x, \xi, t)$ in the region $-1 < x < |\xi|$. Given the relation (9), the support of the whole TDA, $V^{\pi^+}(x, \xi, t)$ or $A^{\pi^+}(x, \xi, t)$, is therefore $x \in [-1, 1]$, as required.

In Fig. 4 we show the vector and axial TDA calculated in the NJL model for different values of the momentum transfer $t$. The mass of the pion, being either $m_\pi = 0$ MeV in the chiral limit or $m_\pi = 140$ MeV, does not significantly influence the result. A $\xi$-symmetry is observed for $V(x, \xi, t)$ in the chiral limit: the vector TDA is an even function of the skewness variable so that we show the results for positive $\xi$ only. At the contrary, the shape of the axial TDA depends on the sign of the skewness variable. The two distinct behaviours are shown in Fig. 4. For positive $\xi$, the contribution coming from the second diagram of Fig. 4 is dominant and produces the maxima around $x = 0$. For negative values of the skewness variable, the contribution of both diagrams have opposite signs, as shown in Fig. 5. Given Eq. (9), we can say that isospin relates the value of the vector and axial TDAs in the $|\xi| < x < 1$ and $-1 < x < -|\xi|$ regions,

$$V(x, \xi, t) = -\frac{1}{2} V(-x, -\xi, t) \quad \& \quad A(x, \xi, t) = \frac{1}{2} A(-x, -\xi, t), \quad |\xi| < x < 1 \quad .$$

The factor $1/2$ corresponds to the ratio between the charge of the $u$ and $d$ quarks. We observe in Fig. 4 that our TDAs satisfy these relations. It must be realized that the relation (10) cannot be changed by evolution.

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1 For numerical predictions, the standard values of the parameters given in Ref. [16] are used.
The obtained TDAs should obey the sum rules, as already mentioned. For the form factors given in the NJL model (see Appendix of Ref. [6]), the sum rules

\[ \int_{-1}^{1} dx \ D^{\pi^+}(x, \xi, t) = \frac{\sqrt{2} f_\pi}{m_\pi} F_D(t) , \]  

(11)

with \( D = V, A \), are recovered. In particular we obtain the value \( F_V^{\pi^+}(0) = 0.0242 \) for the vector form factor at \( t = 0 \), which is in agreement with the experimental value \( F_V(0) = 0.017 \pm 0.008 \) given in [17]. We also obtain \( F_A^{\pi^+}(0) = 0.0239 \) for the axial form factor at \( t = 0 \), which is about twice the value \( F_A^{\pi^+}(0) = 0.0115 \pm 0.0005 \) given by the PDG [17].

We expect the TDAs to respect the polynomiality condition. However no constraint from time reversal enforces the polynomials to be even functions of the skewness variable, i.e. the polynomials include all powers of \( \xi \)

\[ \int_{-1}^{1} dx \ x^{n-1} D(x, \xi, t) = \sum_{i=0}^{n-1} C_{n,i}^D(t) \xi^i , \]  

(12)

where \( C_{n,i}^D(t) \) are the generalized form factors. The relation (12) has been numerically verified. In the chiral limit, we have numerically found that the odd powers in \( \xi \) go to zero for the polynomial expansion of the vector TDA.

Other studies of pion-photon TDAs have already been done [7, 8, 10]. In Refs. [7, 8], double distributions have been used. Therefore polynomiality is implemented by definition and cannot be considered a result. The aim of the author of Ref. [7] is to provide some estimates of the vector and axial TDAs on the basis of the positivity bounds. In this way we must compare only the order of magnitude of the obtained amplitudes, which is similar to ours.

The vector and axial TDAs calculated in the SQM [8], NJL model [6] and non-local chiral quark model [10] are compared in Fig. 6. The authors of the first reference use the so-called asymmetric notation. The comparison is here awkward.
FIGURE 5. Contributions to the axial TDA for both positive ($\xi = 0.25$, solid line) and negative ($\xi = -0.5$, dashed line) values of the skewness variable. In each case, and in the $x \in [-|\xi|, |\xi|]$ region, the contribution coming from the first diagram of Fig. 3 is represented by the dashed-dotted lines and the non-resonant part of the second diagram of Fig. 3 is represented by the dotted lines.

since the authors define, after their Eq. (3), $\zeta = (p_\gamma - p_\pi)^+ / p_\pi^+$ while, after their Eq. (4), the definition $-\zeta = (p_\gamma - p_\pi).n$ is given. We nevertheless decide to use the standard relation between their asymmetric notations and our symmetric ones. Their functions $V_{\text{SQM}}$ and $A_{\text{SQM}}$ corresponds to our $d^{\pi^+ \rightarrow \gamma}$ given in Eq. (9). The normalization condition is different from the one used here and the results quoted by these authors must be corrected, for the vector TDA, by a factor $48\pi^2 \sqrt{2} f_{\pi} F_V(0)/m_\pi \sim 10$ before comparison. From Fig. 6 we conclude that there is a qualitative and quantitative agreement, for the vector TDA, between the results of Ref. [8] and those obtained in the NJL model. Regarding the axial TDA we observe, in addition to the normalization factor $48\pi^2 \sqrt{2} f_{\pi} F_A(0)/m_\pi \sim 10$, a change in the global sign due to different definitions. In the first version of [8] the axial TDA for positive values of $\xi$ is given. It coincides with the results in the NJL model, as observed in Fig. 6. Surprisingly, the result presented in Ref. [8] coincides with our result for negative $\xi$ (perhaps due to the change in the definition of $\xi$ mentioned above).

In Ref. [10] the TDAs are calculated in three different models. The first one is a local model which pole structure has some similarity with the one of the NJL model. The two other models, i.e. semi-local and full non-local, follow the results of the local one. The most prominent difference between the results obtained in

\footnote{There is a typographic error in Eq. (23) of the first version of this reference, where a factor $M_\xi^2/6$ must be dropped.}
the non-local and the NJL models is the appearance of important odd powers in $\xi$ in the polynomial expansion of the vector TDA. We know from Ref. [14] that, for non-local models, there are additional contributions to those calculated in Ref. [10]. In the case of PDFs, disregarding these contributions can produce small isospin violations [15]. It can therefore be considered that, on that point, the results of Ref. [10] must be confirmed. For numerical comparison, the results obtained in [10] must be corrected by a factor $2\pi^2\sqrt{2f_\pi F_V(0)/m_\pi} \sim 0.45$ due to the use of a different normalization condition. For the axial TDA, there is a change in the definition of the skewness variable between the caption of Figs. 3, 5 and Fig. 9 of Ref. [10]. We observe, see Fig. 6, that our results in the NJL model coincide with the results of the latter reference if the convention of the caption of their Fig. 9 is chosen.

It can eventually be concluded that there is no disagreement between the different studies concerning the $\pi\gamma$ TDAs besides the ambiguity in the definition of the skewness variable. Calculations of Refs. [8, 10] are performed in the chiral limit, where $\xi$ runs from $-1$ to 1. The symmetric nature of this interval makes difficult to check the sign of $\xi$. On the other hand, the NJL calculation [6] is given for physical pion mass. In this case, the kinematics of the process imposes $t/(2m_\pi^2-t) < \xi < 1$. From Eqs. (22) and (23) of Ref. [6] we observe that there is a pole in the axial TDA for the limit value $\xi = t/(2m_\pi^2-t)$, preventing us from going through unphysical values of $\xi$. Moreover, the sum rule Eq. (11) for both the vector and axial TDAs are here satisfied for physical values of $\xi$, and broken in the unphysical regions $\xi < t/(2m_\pi^2-t)$ and $\xi > 1$. We therefore conclude that the choice of sign in Ref. [6] is consistent and gives a guideline for comparing with other models.

The $\pi\gamma$ vector and axial Transition Distribution Amplitudes have been defined. The results in different models have been discussed. In particular, the numerical results of Ref. [8, 6, 10] have been compared. The use of a fully covariant and gauge invariant approach guarantees that all the fundamental properties of the TDAs will be recovered, in particular, the right support, i.e. $x \in [-1,1]$, the sum rules and the polynomiality expansions. Hence, in the NJL model, these three properties are not inputs, but rather results of the calculation.

Recently, cross section estimates for the process (2) have been proposed in Ref. [3] using, for the non-perturbative part, $t$-independent double distributions, in a first approach, and, in a second, the $t$-dependent results of Ref. [7]. In the line of sight of this reference, similar estimates for the meson pair production in hard $\gamma^*\gamma$ scattering using the results for the TDAs cited above could be given [18]. In particular, it would be worth investigating the model independence of the structure independent terms [12] and then estimating the pion pole contribution to the cross section [18].

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FIGURE 6. Comparison of the $\pi^+ \rightarrow \gamma$ TDAs for $t = -0.1$ GeV$^2$ of Refs. [8, 10] for $m_\pi = 0$ MeV and Ref. [6] for $m_\pi = 140$ MeV. On the left, we have: the vector TDA for $\xi = \pm 0.5$ as a single (solid) curve for the results of both the NJL model and SQM (these four curves are indistinguishable); the result of the non-local $\chi$QM calculation for $\xi = 0.5$ (dotted line) and for $\xi = -0.5$ (dashed-dotted line). On the right, we have the results of the axial TDA with the choice for the sign of $\xi$ as discussed in the text.

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REFERENCES

1. A. V. Radyushkin, Phys. Lett. B 380 (1996) 417, Phys. Lett. B 385 (1996) 333.
2. X. D. Ji, Phys. Rev. Lett. 78 (1997) 610, Phys. Rev. D 55 (1997) 7114.
3. M. Diehl, Phys. Rept. 388 (2003) 41.
4. B. Pire and L. Szymanowski, Phys. Rev. D 71 (2005) 111501.
5. J. P. Lansberg, B. Pire and L. Szymanowski, Phys. Rev. D 73 (2006) 074014.
6. A. Courtoy and S. Noguera, Phys. Rev. D 76, 094026 (2007).
7. B. C. Tiburzi, Phys. Rev. D 72 (2005) 094001.
8. W. Broniowski and E. R. Arriola, Phys. Lett. B 649 (2007) 49. The expression of the axial TDA for the positive values of the skewness variable is given in arXiv:hep-ph/0701243v1.
9. W. Broniowski, E. R. Arriola and K. Golec-Biernat, Phys. Rev. D 77 (2008) 034023.
10. P. Kotko and M. Praszalowicz, arXiv:0803.2847 [hep-ph].
11. M. Moreno, Phys. Rev. D 16 (1977) 720, D. A. Bryman, P. Depommier and C. Leroy, Phys. Rept. 88 (1982) 151.
12. B. Pire and L. Szymanowski, arXiv:0709.1193 [hep-ph].
13. S. Noguera, L. Theussl and V. Vento, Eur. Phys. J. A 20 (2004) 483.
14. S. Noguera, Int. J. Mod. Phys. E 16 (2007) 97.
15. S. Noguera and V. Vento, Eur. Phys. J. A 28 (2006) 227.
16. S. P. Klevansky, Rev. Mod. Phys. 64 (1992) 649.
17. W. M. Yao et al. [Particle Data Group], J. Phys. G 33 (2006) 1.
18. A. Courtoy and S. Noguera (in preparation)
19. D. Binosi and L. Theussl, Comput. Phys. Commun. 161 (2004) 76.