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QCD factorization of exclusive processes beyond leading twist: $\gamma_T^* \to \rho_T$ impact factor with twist three accuracy

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Abstract

We describe a consistent approach to factorization of scattering amplitudes for exclusive processes beyond the leading twist approximation. The method involves the Taylor expansion of the scattering amplitude in the momentum space around the dominant light-cone direction and thus naturally introduces an appropriate set of non-perturbative correlators which encode effects not only of the lowest but also of the higher Fock states of the produced particle. The reduction of original set of correlators to a set of independent ones is achieved with the help of equations of motion and invariance of the scattering amplitude under rotation on the light cone. We compare the proposed method with the covariant method formulated in the coordinate space, based on the operator product expansion. We prove the equivalence of two proposed parametrizations of the ρ_T distribution amplitudes. As a concrete application, we compute the expressions of the impact factor for the transition of virtual photon to transversally polarised ρ-meson up to the twist 3 accuracy within these two quite different methods and show that they are identical.

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1. Introduction

The study of exclusive reactions in the generalized Bjorken regime has been the scene of significant progresses in the recent years, thanks to the factorization properties of the leading twist amplitudes [1] for deeply virtual Compton scattering and deep exclusive meson production. It however turned out that transversally polarized ρ-meson production did not enter the leading twist controllable case [2] but only the twist 3 more intricate part of the amplitude [3–5]. This is due to the fact that the leading twist distribution amplitude (DA) of a transversally polarized vector meson is chiral-odd, and hence decouples from hard amplitudes at the twist two level, even when another chiral-odd quantity is involved [2] unless in reactions with more than two final hadrons [6]. An understanding of the quark–gluon structure of a transversally polarized vector meson is however an important task of hadronic physics if one cares about studying confinement dynamics. This quark–gluon structure may be described by distribution amplitudes which have been discussed in great detail [7,8]. On the experimental side, a continuous effort has been devoted to the exploration of ρ-meson photo and electro-production, from moderate to very large energy [9,10]. The kinematical analysis of the final π-meson pair allows then to separate the different helicity amplitudes, hence to measure the transversally polarized ρ-meson production amplitude. Although non-dominant for deep electroproduction, this amplitude is by no means negligible at moderately large Q^2 and needs to be understood in terms of QCD. Up to now, experimental information comes from electroproduction on a proton or nucleus. Future progress may come from real or virtual photon–photon collisions, which may be accessible either at electron–positron colliders or in ultraperipheral collisions at hadronic colliders, as recently discussed [11,12].

In the literature there are two approaches to the factorization of the scattering amplitudes in exclusive processes at leading and higher twists. The first approach [4,13], being the generalization of the Ellis–Furmanski–Petronzio (EFP) method [14] to the exclusive processes, deals with the factorization in the momentum space around the dominant light-cone direction. We shall call it the Light-Cone Collinear Factorization (LCCF). On the other hand, there exists a covariant approach in coordinate space successfully applied in [7] for a systematic description of distribution amplitudes of hadrons carrying different twists. This approach will be called the Covariant Collinear Factorization approach (CCF). Although being quite different and using different distribution amplitudes, both approaches can be applied to the description of the same processes. This fact calls for verification whether these two descriptions are equivalent and lead to the same physical consequences. This can be clarified by establishing a precise vocabulary between objects appearing in the two approaches and by comparing physical results obtained with the help of the two methods.

The first aim of our paper is to prove that LCCF and CCF are equivalent methods for the description of exclusive processes. For that we derive the dictionary between DAs appearing in the LCCF method and in the CCF one. We perform our analysis within LCCF method in momentum space and use the invariance of the scattering amplitude under rotation of the light-cone vector n^μ, which we call n-independence condition. This method leads to a definitions of relevant soft correlators which are generally not independent ones. The reduction of their number to a minimal set of independent correlators is obtained with the use of equation of motions and of the n-independence condition. We obtain the same number of independent correlators in both LCCF and in CCF approaches and establish explicit relations between them.

As a concrete application, the second aim of our paper is to calculate within both methods the impact factor $\gamma^* \to \rho_T$, which is the building block of the description of the $\gamma^* p \to \rho p$