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Generalized parton distributions from neutrino experiments: twist-three effects

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Abstract. We study the twist-3 corrections to the neutrino induced deeply virtual meson production due to the chiral odd transversity Generalized Parton Distribution (GPD). We found that in contrast to pion *electro*production, in neutrino-induced processes these corrections are small. This occurs due to large contribution of unpolarized GPDs H, E to the twist-2 amplitude in neutrinoproduction. Our results are important for analyses of the pion and kaon production in the MINERVA experiment at FERMILAB.

1. Introduction

The generalized parton distributions (GPDs) are important phenomenological objects parametrizing the nonperturbative structure of the target. In the Bjorken kinematics, in which the collinear factorization is applicable [1, 2], the cross-sections for a wide class of processes can be expressed in terms of GPDs. Nowadays all available information on GPDs is provided by the electron-proton and positron-proton experiments at Jefferson Lab and HERA, particularly by measurements of deeply virtual Compton scattering (DVCS) and deeply virtual meson production (DVMP) [1–11]. The future constraints on GPD parametrizations will come from upgraded CLAS12 at JLAB [12] and muon-induced DVCS and DVMP measurements at COMPASS [13, 14]. In a more distant future, EIC [15] and LHeC [16] machines could also contribute to a better understanding of the GPDs.

In addition to the virtual photon-mediated processes, extra constraints on GPD parametrizations can be inferred from deeply virtual neutrinoproduction of the pseudo-Goldstone mesons (π, K, η), as we recently suggested in [17]. The νDVMP process is complementary to the eDVMP. Due to the $V-A$ structure of the charged current, in νDVMP one can access simultaneously the unpolarized GPDs, H, E, and the helicity flip GPDs, $\tilde{H}$ and $\tilde{E}$. The produced Goldstone mesons due to chiral symmetry have very close characteristics and in this way act as natural probes for the flavor content, enabling us to extract the full flavour structure of the GPDs. Experimentally neutrino-induced DVMP could be studied with the high-intensity NuMI beam at Fermilab, which recently switched to the middle-energy (ME) regime with

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the mean neutrino energy of about 6 GeV. Potentially the energy can reach 20 GeV without essential loss of luminosity.

It is worth reminding that the cross-sections were evaluated in [17] in the leading twist approximation, and for a correct extraction of the GPDs at the energies of MINERvA in ME regime, an estimate of the higher twist effects is required. The first twist-3 correction arises due to contribution of the transversely polarized intermediate virtual bosons and is controlled by convolution of the poorly known transversity GPDs H_T, E_T, $\tilde{H}_T$, $\tilde{E}_T$ and twist-3 DAs of pion. While this correction vanishes at asymptotically large Q^2, in *electro*production at moderate Q^2 it gives a sizable contribution, as was confirmed by CLAS collaboration [12]. In the case of neutrino-production the situation is different because there is an additional and numerically dominant contribution of the unpolarized GPDs H, E to the leading twist amplitude due to the $V - A$ structure of the weak currents. In what follows we analyze the relative magnitude of the twist-3 contributions to the neutrino-production of pions and demonstrate that they are indeed small. In this respect we are different from [18], where the contribution of the chiral odd GPDs was assumed to be numerically dominant.

2. Cross-section of the νDVMP process

The cross-section of the Goldstone mesons production in neutrino-hadron collisions has the form

$$\frac{d\sigma}{dt\,dx_B dQ^2 d\phi} = \epsilon\frac{d\sigma_L}{dt\,dx_B dQ^2 d\phi} + \frac{d\sigma_T}{dt\,dx_B dQ^2 d\phi} + \sqrt{\epsilon(1+\epsilon)}\cos\phi\frac{d\sigma_{LT}}{dt\,dx_B dQ^2 d\phi} \tag{1}$$
$$+\epsilon\cos 2\phi\frac{d\sigma_{TT}}{dt\,dx_B dQ^2 d\phi} + \sqrt{\epsilon(1+\epsilon)}\sin\phi\frac{d\sigma_{L'T}}{dt\,dx_B dQ^2 d\phi} + \epsilon\sin 2\phi\frac{d\sigma_{T'T}}{dt\,dx_B dQ^2 d\phi},$$

where $t = (p_2 - p_1)^2$ is the momentum transfer to baryon, $Q^2 = -q^2$ is the virtuality of the charged boson, $x_B = Q^2/(2p \cdot q)$ is Bjorken x, ϕ is the angle between the lepton and meson production scattering planes, and we introduced shorthand notations

$$\epsilon = \frac{1 - y - \frac{\gamma^2 y^2}{4}}{1 - y + \frac{y^2}{2} + \frac{\gamma^2 y^2}{4}}, \quad \gamma = \frac{2m_N x_B}{Q}, \quad y = \frac{Q^2}{s x_B}.$$

In the asymptotic Bjorken limit the cross-section is dominated by the first angular independent term $\epsilon\, d\sigma_L/dt\,dx_B dQ^2 d\phi$ which was studied in our previous paper [17] and is a straightforward extension of the electroproduction of pions studied in [19–25]. As we will see below the twist-3 corrections are small, for this reason it is convenient to normalize all the cross-sections in (1) to this term,

$$\frac{d\sigma}{dt\,dx_B dQ^2 d\phi} = \epsilon\frac{d\sigma_L}{dt\,dx_B dQ^2 d\phi}\sum_n (c_n\cos n\phi + s_n \sin n\phi) \tag{2}$$

and discuss the higher-twist effects in terms of harmonics c_n, s_n. Here we omit the details of evaluation and refer the reader to [26]. The most important harmonics is c_0, because its deviation from unity affects the extraction of GPDs in the leading twist approximation, which requires an experimentally challenging Rosenbluth separation with varying energy neutrino beam. All the other harmonics generate nontrivial angular dependence and can be easily separated from the leading-twist contribution. For example, the angle-integrated cross-section $d\sigma/d\ln x_B dt\, dQ^2$ is not sensitive to those harmonics at all.

For numerical estimates we used the Kroll-Goloskokov parametrization of GPDs [21–23, 27].

In Fig. 1 we show the harmonics c_n, s_n for some processes. At $x_B \lesssim 0.5$, where the cross-section is the largest, the harmonics are small and do not exceed few per cent. The largest twist-3 contribution is due to the c_1 harmonics, which can reach up to twenty percents. This is different from the electroproduction experiments, where c_1 ($\sim\sigma_{LT}$) is very small: due to parity nonconservation in weak interactions we have for the interference term $\sigma_{0+} \neq \sigma_{0-}$. A positive value of c_1 for most processes

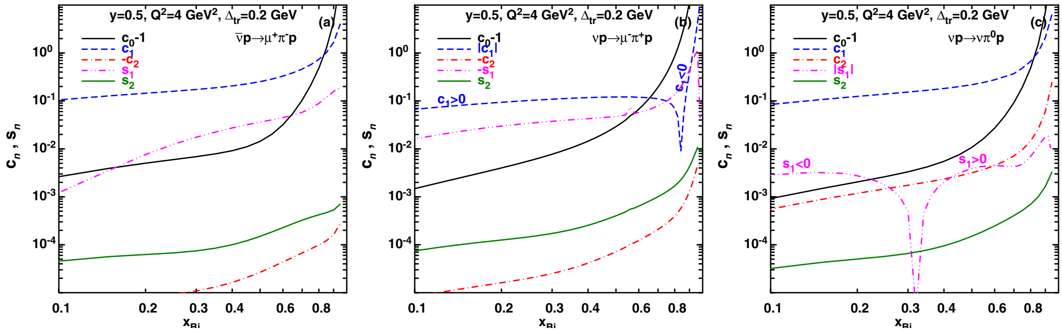

Figure 1. Pion production on nucleons. See (2) for definition of harmonics c_n, s_n.

implies that pion production correlates with the direction of the produced muon (scattered neutrino) in the case of CC (NC) mediated processes. The interference term also yields a relatively large harmonics s_1 which appears due to the interference of the vector and axial vector contributions.

In the region of $x \gtrsim 0.5$ all the harmonics increase, but the cross-sections for both the leading twist and subleading twist results are suppressed there due to increase of $|t_{min}|$ and are hardly accessible with ongoing and forthcoming experiments.

Similar results can be obtained for the processes with change of the baryon state and for processes with strangeness production.

Notice that similar angular harmonics can be generated by interference of the leading twist result with the electromagnetic corrections [28]. At moderate virtualities of the order a few GeV^2 this mechanism also gives small harmonics (of the order few per cent), however those corrections grow rapidly as a function of Q^2, and already at $Q^2 \sim 100\,\mathrm{GeV}^2$ electromagnetic mechanism becomes dominant.

To summarize, we conclude that deeply virtual production of pions and kaons on protons and neutrons by neutrinos with typical values of Q^2 of the order few GeV^2 provide a theoretically clean probe for the GPDs, with various corrections of the order of few per cent. Our results are relevant for analysis of the pion and kaon production in the MINERVA experiment at FERMILAB as well as for the planned Muon Collider/Neutrino Factory [29–31]. An optimal target for study of the GPDs could be hydrogen or deuterium. For other targets there is an additional uncertainty due to the nuclear effects which will be addressed elsewhere.

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