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Remarks concerning DVCS, TCS and WACS

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1 DVCS

It has been shown [1, 2] that in the generalized Bjorken regime of large Q^2 and large W but fixed x-Bjorken and $-t \ll Q^2$, DVCS factorizes in a hard partonic subprocess and in soft hadronic matrix elements which are parametrized in terms of generalized parton distributions (GPDs). DVCS has been extensively been studied phenomenologically. There are attempts to extract the so-called Compton form factors which are reduced scattering amplitudes, from experiment [3, 4] providing constraints on the GPDs. Also parametrizations of GPDs have been used to evaluate DVCS observables. For instance, in [5] GPDs extracted from hard exclusive meson electroproduction [6] and nucleon form factors [7] have been exploited for that purpose. In general good agreement with experiment have been found. Only for the JLab6 data the agreement is not good. Perhaps kinematic twist-3 corrections are needed in that region [8]. Precise DVCS data, polarized and unpolarized ones, at Q^2 and W larger than typical JLab6 values, would allow to improve the parametrizations of the GPDs. Data on DVCS observables, obtained with a neutron target, would be a valuable constraint on the GPDs.

Particular interesting is the comparison with the HERMES data [9] on asymmetries, A_{UT}, measured with a transversely polarized target. The $\sin(\phi - \phi_s)$ modulation of this observables, see Fig. 1 below, but also the $\sin(\phi - \phi_s)\cos\phi$ one, provide some information on the GPD E for sea quarks: its convolution with the relevant subprocess amplitude is negative. Admittedly this is not much but has already important consequences - with the

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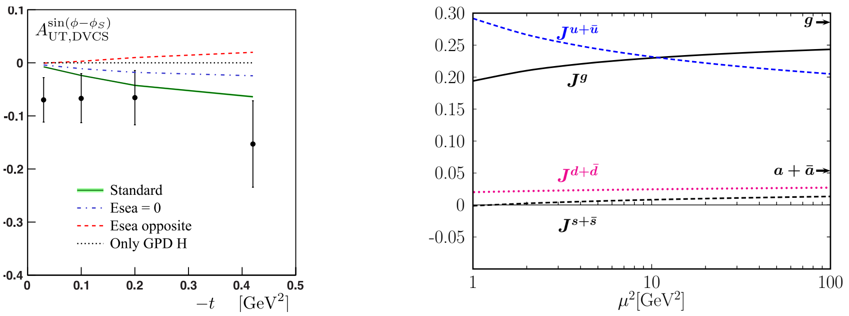

Figure 1: Left: The $\sin(\phi - \phi_s$ modulation of A_{UT} for DVCS. Data are taken from [9], theoretical results from [5]. Right: Parton angular momenta in dependence on the scale [11].

help of a positivity bound for E^s and a sum rule for the second moments, e_{20}, of E at $t = 0$ [10]

$$\sum_a e^a_{20} + e^g_{20} \;=\; 0 \tag{1}$$

this information suffices for a first evaluation of the angular momenta carried by the partons inside the proton in dependence on the scale [11]:

$$J^a \;=\; \frac{1}{2}(q^a_{20} + e^a_{20})\,, \qquad J^g \;=\; \frac{1}{2}(g_{20} + e^g_{20})\,. \tag{2}$$

Thereby a flavor symmetric sea is assumed and the usual unpolarized parton densities, $q^a(x), g(x0$ are used for the contribution from the GPD H. The results are also shown in Fig. 1. More precise data on A_{UT} would be extremely helpful for improving the results on the angular momenta. Reducing for instance the errors of the A_{UT} data from HERMES by, say, a factor of two would likely make unnecessary the use of the positivity bound.

2 TCS

Time-like Compton scattering is $s - u$ crossed DVCS. At large time-like Q^2 and large W TCS is expected to factorize as DVCS. There are no data on TCS yet. Thus, any data for this process is welcome. There are a few theoretical studies of that process, for instance [12, 13]. Predictions for TCS with linearly polarized photons are also given [14]. In my opinion, detailed predictions for TCS and their comparison with experiment are needed. The verification of factorization and universality for TCS is a non-trivial issue because the physics in the time-like region is complicated and often not understood. Thus, for instance, there is no theoretical explanation of the electromagnetic form factors of hadrons in the time-like region [15]. Another example is the semi-inclusive Drell-Yan process. It took a long-time before the huge discrepancy between the theoretical predictions and experiment, known as the K-factor, has been understood [16].

3 WACS

Wide-angle Compton scattering is complementary to DVCS in so far as the the large $-t$ GPDs control the first process whereas the small $-t$ behavior of the GPDs is probed by DVCS. The familiar handbag graph controls both the processes. As derived in [17, 18], for large Mandelstam variables, $s, -t, -u$, the WACS amplitudes are given by products of hard, perturbatively calculable subprocess amplitudes and form factors, specific to WACS, which represent $1/x$-moments of zero-skewness GPDs. From the GPD analysis of the nucleon form factors [7] the GPDs H and E for valence quarks are known as well a rough estimate of $\widetilde{H}$. This knowledge allows to work out the Compton form factors

$$R_i^a(t) \,=\, \int \frac{dx}{x} K_i^a(x,t)\,, \qquad R_i(t) \,=\, \sum_a e_a^2 R_i^a(t) \tag{3}$$

(a: u or d valence quarks, $i = V, T, A$ corresponding to the GPDs $K_i = H, E, \widetilde{H}$). The wide-angle Compton cross section is then given by the familiar Klein-Nishina cross section multiplied by a structure factor parametrized in terms of the three form factors. The GPD $\tilde{E}$ does not contribute. The results for the WACS cross section is in fair agreement with the data from the JLab E99-114 experiment [19] for $-t, -u > 2.5$ GeV. Measurement of this cross section at large values of s would be helpful in testing the handbag approach further.

The helicity correlation between the initial state photon and proton, A_{LL}, and the analogous correlation between the photon and the outgoing proton, K_{LL}, are very interesting observables. The handbag approach predicts

$$A_{LL} \,=\, K_{LL} \tag{4}$$

and, approximatively, these observables are given by the Klein-Nishina helicity correlation diluted by the form factor ratio R_A/R_V. Thus, data on A_{LL} and/or K_{LL} would allow a better determination of R_A and, subsequently, of $\widetilde{H}$ at large $-t$ [20]. Apart from data on the axial form factor, for which no large $-t$ data are available at present, this seems to be the only way to access $\widetilde{H}$ at large $-t$. Knowledge of this GPD would allow to study the impact-parameter distribution of valence quarks with definite helicity, defined as

$$q^a_{\pm}(x,b) \,=\, \frac{1}{2}\Big[q^a(x,b) \pm \Delta q^a(x,b)\Big] \tag{5}$$

where $q^a_{\pm}$ is the distribution of valence quarks of flavor a with helicity parallel (+) or antiparallel (-) to the proton's helicity, q^a and Δq^a are the Fourier transforms (the momentum transfer $\Delta_\perp$ is canonically conjugated to the impact parametrer b, $t = -\Delta^2_\perp$) of the zero-skewness GPDs H and $\widetilde{H}$, respectively. The helicity distributions, evaluated from the present GPDs [7, 20], are shown in Fig. 2. While at low x there are broad distributions for all quarks with about the same magnitude there is a rather narrow distribution at large x. For such values of x u-quarks with the same helicity as the proton dominate. This is expected from perturbative QCD [21]. On the other hand, the behavior of the d-quark distribution does not match the perturbative QCD prediction at the current experimentally accessible range of x. Data on A_{LL} and/or K_{LL} at large values of s will allow to verify the properties of $q^a_{\pm}(x,b)$.

Last not least, data on WACS of a neutron target would also be very interesting.

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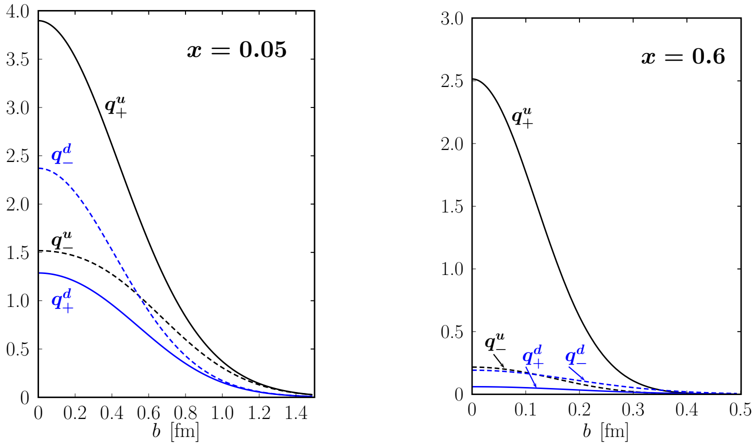

Figure 2: The helicity distribution for u abd d valence quarks at $x = 0.05$ (left) and $x = 0.6$ (right) at the scale 2 GeV. Figures are taken from [20].

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