Wide Angle Compton Scattering

Rainer Jakob

Fachbereich Physik, Universität Wuppertal, D-42097 Wuppertal, Germany

Abstract. We present the handbag contribution to Wide Angle Compton Scattering (WACS) at moderately large momentum transfer obtained with a proton distribution amplitude close to the asymptotic form. In comparison it is found to be significantly larger than results from the hard scattering (pQCD) approach.

INTRODUCTION

Compton scattering off nucleons provides us with valuable information on the nucleon structure. In general, the Compton process involves the relativistic propagation of an excited, composite system, a bound state, which is extremely difficult to describe. Fortunately, in special kinematic situations the description of the process becomes much simpler. In this contribution we focus on Compton scattering off protons with large momentum transfer and small (or zero) photon virtuality, i.e. Compton scattering at wide angles (WACS). Here the process receives its main contribution from the lowest Fock state of the nucleon, i.e. a three quark configuration. The propagation of hard gluons and quarks is described perturbatively. We argue that in the region of large, but not yet asymptotically large, momentum transfer the process is dominated by the handbag contribution involving new Compton form factors defined from skewed parton distributions. We compare the handbag contribution calculated from the overlap of soft wave functions [1,2] with the results obtained in the hard scattering approach [3].

HARD VS. SOFT SCATTERING MECHANISM

It is generally accepted that the hard scattering mechanism in the context of perturbative QCD [4] provides the correct description for processes at asymptotically large momentum transfer. In this picture a hard scattering amplitude describes the redistribution of the transferred momentum among partons via hard gluon exchange, and the non-perturbative part is given as distribution amplitudes (DAs), i.e. light-cone wave functions (LCWFs) integrated over transverse momenta. There is a minimal number of hard gluons required to connect all parton lines, the lowest Fock state gives the dominant contribution. In Fig. 1 the diagrams c and d (and
WACS IN THE HARD SCATTERING APPROACH

For a comparison we will quote the results from a recent leading order calculation of real WACS off protons in the hard scattering approach [3] superseding (and partly correcting) earlier calculations [5,6].

The unpolarised cross section, scaled by $s^6$, obtained with different DAs is shown in Fig. 2 in comparison to the data. To minimize the influence of choices for the $\alpha_s(\mu)$ argument, the same quantity normalized to the factor $(Q^4 F_p^D(Q^2))^2$, where $F_p^D$ is the Dirac form factor of the proton, is also shown. Uncertainties are expected to cancel from this ratio to a large extent.

Clearly, the results of the hard scattering (pQCD) contributions to the unpolarised cross sections fall short to describe the available data, which are admittedly at rather lowish momentum transfers. From the ratio shown on the RHS the authors of [3] conclude that ‘...it seems unlikely that the elastic proton form factor and the Compton scattering amplitudes are both described by pQCD at presently accessible energies’.

These results suggest, that hard scattering is not the dominant reaction mechanism at the intermediate large momentum transfer, a situation very similar to the elastic nucleon (and pion) form factors.
FIGURE 2. Left: The hard scattering contribution to the unpolarised differential cross section for WACS obtained with different DAs compared to the data [7]. Right: The same quantity scaled by the pQCD result for $(Q^4 F^p_1(Q^2))^2$. Figures reproduced from [3] with one additional curve (BK) provided by the same authors.

WACS IN THE SOFT PHYSICS APPROACH

The contribution from the Feynman mechanism to WACS is described by a handbag diagram [8]. The diagram factorises in a hard photon-parton amplitude and a non-perturbative part [1], the latter described by a skewed parton distribution at vanishing 'skewedness', which can be calculated from the overlap of LCWFs, as indicated by diagram a in Fig. 1. The cat-ears diagram b was shown to be power suppressed relativ to the handbag diagram [1]. The (unpolarised) differential cross section can be written

$$\frac{d\sigma}{dt} = \frac{2\pi\alpha^2_{em}}{s^2} \left[ -\frac{u}{s} - \frac{s}{u} \right] \left\{ \frac{1}{2} \left( R_V^2(t) + R_A^2(t) \right) - \frac{us}{s^2 + u^2} \left( R_V^2(t) - R_A^2(t) \right) \right\}$$

(1)

with new form factors [8] specific to Compton scattering depending on $-t$ only

$$\sum_a e_a^2 \int_0^1 \frac{dx}{x} p^+ \int \frac{dz}{2\pi} e^{i x p^+ z^-} \left( \langle p' | \bar{\psi}_a(0) \gamma^+ \psi_a(z^-) - \bar{\psi}_a(z^-) \gamma^+ \psi_a(0) | p \rangle \right) = R_V(t) \bar{u}(p') \gamma^+ u(p) + R_T(t) \frac{i}{2m} \bar{u}(p') \sigma^{\nu \mu} \Delta_{\nu \mu} u(p).$$

(2)

$R_T$ being related to nucleon helicity flips is neglected in Eq. (1). An analogous definition holds for $R_A$ involving the axialvector nucleon matrix element.

Assuming a Gaussian model for transverse parton momenta the form factors factorise in ordinary parton distribution functions (PDFs) and a $(t, x)$ dependent exponential for each $N$ parton Fock state separately

$$R_V^{(N)}(t) = \int_0^1 \frac{dx}{x} \exp \left[ a_N^2 \frac{t}{2} \frac{1 - x}{x} \right]$$

$$\times \left\{ e_u^2 \left[ u_v^{(N)}(x) + 2 \Pi^{(N)}(x) \right] + e_d^2 \left[ d_v^{(N)}(x) + 2 \Pi^{(N)}(x) \right] + e_s^2 2 \bar{\Sigma}^{(N)}(x) \right\},$$

(3)
and analogously for $R_V \rightarrow R_A$, $q(x) \rightarrow \Delta q(x)$. With a phenomenologically based model for the $x$-dependence of the LCWF, the BK distribution amplitude [9] for the lowest Fock state, the form factors $R_V$ and $R_A$ can be calculated. The results are shown in Fig. 3 together with estimates for the additional contributions from the next higher Fock states (N=4,5), and an estimate for the the effect of all Fock states based on parametrizations for PDFs [10]. For details see Ref. [1]. Inserting the form factors into Eq. (1) the cross section of WACS are obtained as displayed in Fig. 4. A comparison shows that the predictions for cross sections from the handbag diagram are much higher then the corresponding ones obtained in the hard scattering picture and can fairly well describe the present data. Note that for a direct comparison a curve was added in Fig. 2 (left) obtained within the hard scattering approach in exactly the same way (same value for the parameter $f_N$) as the other curves in Fig. 2, but with the BK distribution amplitude as input.
Of particular interest is the initial state helicity correlation

$$A_{LL} \frac{d\sigma}{dt} = \frac{1}{2} \left( \frac{d\sigma(\mu = +1, \nu = +1/2)}{dt} - \frac{d\sigma(\mu = +1, \nu = -1/2)}{dt} \right)$$

(4)

where $\mu, \nu$ are the helicities of the incoming photon and proton, respectively. The prediction for this quantity from the handbag diagram is distinctively different from predictions obtained in the hard scattering approach, or the diquark model [11].

**FIGURE 5.** Initial state helicity correlation. Left: Predictions of the handbag contribution for different energies. Right: Comparison of different predictions at $E = 4\text{ GeV}$ (taken from [3]).

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