Deeply virtual Compton scattering and
generalized parton distributions

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Abstract. We present a comparison of a recently proposed model, which describes the Deeply
Virtual Compton Scattering amplitude, to the HERA data.

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Exclusive production of a real photon, a vector meson or lepton pairs via deeply
virtual scattering, \( ep \rightarrow eVp \), where \( V \) stands generically for produced particles, is an
interesting tool to investigate the diffractive properties of the Pomeron.

The linear Regge-trajectory of the Pomeron is,

\[
\alpha_P(t, Q^2) = \alpha_0(Q^2) + \alpha'(Q^2)t,
\]

where \( t \) is the squared four-momentum transferred at the proton vertex and \( Q^2 \) is the
virtuality of the exchanged photon. The standard Regge pole parametrization of the
scattering amplitude is

\[
A(s, t, Q^2) = A_0 e^{B(t, Q^2)} \left( \frac{s}{s_0} \right) ^{\alpha_P(t, Q^2)},
\]

where \( s = W^2 \) is the squared \( \gamma'p \) centre-of-mass energy, \( s_0 = 1 \text{ GeV}^2 \) and \( B(t, Q^2) \) is
related to the radius associated with the proton vertex.

Models based on the Regge phenomenology have been proposed to describe the
Deeply Virtual Compton Scattering (DVCS) amplitude \[1, 2, 3, 4\]. DVCS measurements
are an important source in extracting information about General Parton Distributions
(GPDs). These distributions can offer a holographic picture of the nucleon.

The DVCS data collected at the lepton-proton collider HERA can help to understand
the properties of the Pomeron trajectory. There are many papers discussing in details the
form and the values of the parameters of the Pomeron trajectory as well as their possible
\( Q^2 \) dependence (for a recent review, see, e.g. \[5\]).

In the present paper we compare the model described in Ref. \[1\] and applied in
Ref. \[6\] to the high-energy data on DVCS collected by the H1 and ZEUS detectors
at HERA \[7, 8, 9\]. The model makes use of a logarithmic Pomeron Trajectory. The
scattering amplitude has the form \[1, 6\]
A(s, t, Q^2)_{\gamma p \rightarrow \gamma p} = -A_0 e^{b \alpha(t)} e^{b \beta(z)} (-i s/s_0)^{\alpha(t)} \gamma(\gamma + bL) \alpha(t) + b \beta(z),
(3)

where $L \equiv \ln(-is/s_0)$, the trajectory at the proton vertex is
\begin{equation}
\alpha(t) = \alpha_0 - \alpha_1 \ln(1 - \alpha_2 t),
(4)
\end{equation}

whereas the trajectory at the photon vertex is
\begin{equation}
\beta(z) = \alpha_0 - \alpha_1 \ln(1 - \alpha_2 z),
(5)
\end{equation}
z = t - Q^2 being a new variable introduced in Ref. [1].

For not too large $Q^2$ the contribution from longitudinal photons to DVCS is small (it vanishes for $Q^2 = 0$). Moreover, at the high energies typical of the HERA collider, the amplitude is dominated by the exchange a Pomeron conserving the helicity and, since the final photon is real and transverse, the initial one is also transverse and the helicity is conserved. Consider, instead, that electroproduction of vector mesons requires to take into account both longitudinal and transverse cross sections.

The cross section is given by
\begin{equation}
\frac{d \sigma}{dt}(s, t, Q^2) = \pi s^2 |A(s, t, Q^2)|^2.
(6)
\end{equation}

and the slope of the forward cone is
\begin{equation}
B = \frac{d}{dt} \ln(|A(s, t, Q^2)|^2).
(7)
\end{equation}

The parameters $s_0$, $\alpha_1$ and $\alpha_2$ can be fixed by theoretical constraints, as explained in Ref. [1]. The free parameters are the intercept $\alpha_0$, the slope $\alpha$ and the normalization factor $A_0$. Fit to the DVCS data collected at HERA [7, 8, 9] was performed and the results are shown in Fig. [1]. The comparison of the model with data for the cross section as a function of $Q^2$ and $W$ is shown in plot[a] and plot[b], respectively, while the comparison with the H1 data for the differential cross section is shown in plot[c]. The fit suggests that the Pomeron in the DVCS has the intercept $\alpha_0 \approx 1.2$, greater than that in hadronic reactions, and has the slope $\alpha' \approx 0.25$, value typical of hadronic scattering. Then the Pomeron trajectory, according to this fit, seems to be not so flat as it was observed in the diffractive electroproduction of vector mesons in hard regime.

The fit of $d\sigma/dt$ was performed with all the parameters fixed except for the normalization factor. One can see from plot[c] that the model does not agree with the H1 measurements (for a relevant discussion see Ref. [6]).

The slope $B$ (see Eq. [7]) is predicted to slightly rise with $W$, but to be almost independent of $Q^2$. Fig. [2] shows the slope dependence for different values of $W$ and $t$ as $t$ increases. In particular, the $t$ dependence is shown in plot[a] at $Q^2 = 4 \text{ GeV}^2$ for three different values of $W$. The shrinkage of the slope for several values of $t$ as a function of $Q^2$ at $W = 60 \text{ GeV}$ is shown in plot[b] and as a function of $W$ at $Q^2 = 4 \text{ GeV}^2$ in Fig. [2c].

One of the main goals in studying DVCS is the possible extraction of the GPDs. In view of the difficulties encountered in performing the convolution procedure (see,
FIGURE 1. Comparison of the model of Ref. [1] with the DVCS data [7, 8, 9]. The cross section as a function of $Q^2$ (a) and $W$ (b), and the differential cross section (c) are shown.

e.g., Ref. [3, 4]), the construction of any explicit model that satisfies the theoretical requirement, and fits the data, is important, since the amplitudes of such a model, in the first approximation, can be identified with the GPDs [10]. The model considered in the present paper is valid in the limit of high energies. At low energies, where direct channel resonances dominate, a similar model was constructed in Ref. [11]. Experimentally, DVCS was and is studied in different kinematical regions, from low energies (at JLab), through intermediate energies (by COMPASS) to high energies (at HERA). The unification of the asymptotic solutions is an ambitious goal of the theory, and duality may play here an important role, as shown in the “Road map” of Ref. [12] and in Fig. 3. In this figure, the present model is described in the upper right corner (small $x$ and large $Q^2$, the third variable, $t$, being “compactified”). There is a link between low and high energies along the horizontal axes, at the bottom of the figure, corresponding to the low-$Q^2$, or the on-mass-shell connection between the resonance region and the high-energy smoothly asymptotic region. This connection was established by means of the dual models. A similar one, between low and high $x$ values, should exist also for the off-mass-shell scattering or the structure function (upper part of Fig. 3).
FIGURE 2. Slope behaviour, as calculated from Eq. (7), for several values of $W$, $Q^2$ and $t$.

FIGURE 3. A Road map linking different asymptotic regimes of the scattering amplitude $A(s,t,Q^2)$ [12] is shown.
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