HIGHER-TWIST CONTRIBUTIONS IN EXCLUSIVE PROCESSES

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Using the renormalon technique, we estimate higher-twist contributions in deeply virtual Compton scattering and in hard exclusive $\pi^0$ leptoproduction.

1 Introduction

The present work deals with exclusive virtual-photon–nucleon processes such as deeply virtual Compton scattering $\gamma^* N \rightarrow \gamma N'$ (DVCS) and hard exclusive pion production $\gamma^* N \rightarrow \pi N'$. For kinematical reasons, exclusive processes always involve a finite longitudinal momentum transfer and therefore probe matrix elements of QCD operators between nucleon states of different momenta. At leading twist ($\tau = 2$) and in light-cone gauge, one parton is extracted from the initial nucleon and another returned to the final nucleon, carrying a different momentum fraction. These matrix elements can be expressed in terms of so-called skewed parton distributions (SPDs), which are functions of two momentum-fraction variables. SPDs are a generalization of the more familiar forward parton distribution functions and form factors.

The photon–nucleon scattering amplitude is a convolution of an SPD and a photon-parton amplitude. In the present work we have estimated higher-twist corrections, i.e. terms suppressed by $\Lambda^2/Q^2$ where $Q^2$ is the photon virtuality and $\Lambda$ is a hadronic mass scale, to DVCS and pion production. We used the renormalon technique to estimate power-suppressed contributions to the photon-parton amplitude, which is then convoluted with skewed quark distributions (unpolarized distributions in DVCS and polarized in pion production). Working in Radyushkin’s formalism of double distributions $F(x, y, \mu^2)$, we employed the model

$$ F_q(x, y, \mu^2) = h(x, y)(1 - x)^{-3}q(x, \mu^2), \quad (1) $$

where $q(x, \mu^2)$ is a forward quark distribution and $h(x, y) = 6y(1 - x - y)$ ("polynomial model") or $h(x, y) = \delta(y - (1 - x)/2)$ ("delta-function model").
2 The renormalon technique

It is well known that the perturbation expansion in gauge theories diverges for any nonzero coupling constant. Because the expansion is nevertheless successful in practice, it is believed to be an asymptotic expansion. For an observable $R(\alpha)$ having a perturbation series $\sum_n r_n \alpha^{n+1}$, the concepts of Borel transformation $B[R](t) = \sum r_n t^n / n!$ and Borel integral

$$\tilde{R}(\alpha) = \int_0^\infty dt \, e^{-t/\alpha} B[R](t)$$

(2)

provide a means of assigning a potentially finite number ("sum") $\tilde{R}(\alpha)$ to the divergent series. However, the Borel integral for QCD observables is not finite because $B[R]$ has singularities, known as (infrared) renormalon poles, on the contour of integration. Regularization by deformation of the contour introduces an ambiguity depending on whether the contour is chosen below or above the poles. In phenomenological applications of renormalons, this ambiguity, i.e. the residue of the pole, is used as an estimate of terms beyond the perturbation series which should be included in the recipe for calculating $R$. The residues are proportional to $\exp(-t_i/\alpha_s)$, where $t_i$ is the location of the $i$'th pole. In QCD, where $1/\alpha_s = \beta_0 \ln(Q^2/\Lambda^2)$, the new terms are thus suppressed by $(\Lambda^2/Q^2)^{\beta_0 t_i}$.

A particular source of the renormalon divergence is the all-order resummation of loop diagrams with chains of vacuum-polarization bubbles. In the following we shall calculate contributions to exclusive amplitudes from diagrams with bubble chains. After summing over the number of bubbles and Borel transforming, we evaluate the residue of the pole closest to $t = 0$, which will serve as an estimate of the next-to-leading-twist contribution to the amplitude. It turns out to be suppressed by $\Lambda^2/Q^2$, i.e. it is of $\tau = 4$.

3 Results

Bubble-chain diagrams giving renormalon contributions to DVCS and pion production are shown in fig. 1. The leading-twist diagrams for DVCS have no gluons, those for pion production have a single gluon instead of the bubble chain.

Evaluating the bubble-chain diagrams according to Feynman rules, taking the residue of the first pole and convoluting with model SPDs, we obtain an estimate of the next-to-leading-twist term in the amplitude $A$. We then calculate the ratio of the first correction in $|A|^2$ (i.e. the interference of $\tau = 2$ and $\tau = 4$ amplitudes) and the leading term (square of $\tau = 2$ amplitude),
Figure 1. Examples of bubble-chain diagrams contributing to DVCS (top row) and to hard exclusive meson production (bottom row).

which is plotted in fig. 2 for DVCS and pion production using the two models of SPDs introduced in section 1.

Figure 2. The ratio of estimated higher-twist correction and leading-twist contribution in DVCS and pion production at $Q^2 = 4$ GeV$^2$ for two models of SPDs, plotted as a function of Bjorken $x$. 

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The correction increases with $x_B$, similarly to renormalon contributions in inclusive deep inelastic scattering. The magnitude is rather large, especially in pion production, and in fact we chose $\Lambda^2 = (200 \text{ MeV})^2$, i.e. a factor 3 smaller than the value used in fits of inclusive processes. This is not a problem because theory does not require the normalization factor to be process-independent. In pion production there is a significant difference between the polynomial and delta-function models of SPDs, whereas in DVCS the two models give similar estimates.

In conclusion, we have found that higher-twist contributions to exclusive virtual-photon–nucleon processes can be significant at scales as high as $Q^2 \simeq 4 \text{ GeV}^2$. We note that at $x > 0.3$ a theoretical uncertainty arises from the $t$ dependence of the SPDs which we have not taken into account.

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