QCD Factorization in Diffraction

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Abstract. I present measurements of dijet and open charm cross-sections in diffractive DIS and photoproduction taken with the H1 and ZEUS detectors at the HERA accelerator. Diffractive events were identified by a rapidity gap selection. The resulting differential cross sections are compared to QCD calculations in NLO, based on parton densities extracted from inclusive diffraction. Additionally a fit of diffractive parton densities to the combined data sets of the inclusive $F_D^2$ measurement and the dijet data was performed. This leads to reduced uncertainties for the gluon density.

1. Introduction
Theoretically it is expected that the cross sections of diffractive deep-inelastic scattering (DIS) factorises into universal diffractive parton distributions and process dependent hard scattering coefficients [1]. Diffractive parton densities have been determined from DGLAP QCD fits to inclusive diffractive HERA data [2, 3] and have been found to be dominated by the gluon distribution. Diffractive dijet and open charm production are directly sensitive to the gluon component of the diffractive exchange and has been shown - for DIS [4–6] - to be in decent agreement with the QCD fits to the inclusive diffractive data. In this paper, a measurement of diffractive dijet and open charm cross sections in deep inelastic scattering are presented, based on data collected with the H1 and ZEUS detectors at HERA. A combined NLO QCD fit is performed to the differential dijet cross sections and the inclusive diffractive structure function $F_D^2$ in order to determine the diffractive quark and gluon distributions with higher accuracy.

However, applying this approach in LO QCD calculations to predict diffractive cross sections for dijet production in $p\bar{p}$ collisions at the Tevatron leads to an overestimation of the observed rate by approximately one order of magnitude [7]. This discrepancy has been attributed to the presence of the additional beam hadron remnant in $p\bar{p}$ collisions, which leads to secondary interactions and a breakdown of factorisation. The suppression, often characterised by a ‘rapidity gap survival probability’, cannot be calculated perturbatively and has been parameterised in various ways (see for example [8]).

The transition from deep-inelastic scattering to hadron-hadron scattering can be studied at HERA in a comparison of scattering processes in DIS and in photoproduction. Processes in which a real photon participates directly in the hard scattering are expected to be similar to the deep-inelastic scattering of highly virtual photons. By contrast, processes in which the photon is first resolved into partons which then initiate the hard scattering resemble (and thus may grant insight into) hadron-hadron scattering.
2. Rapidity Gap Survival

While dijetive dijet and open charm production in DIS shows reasonable agreement with NLO QCD calculations based on the factorisation approach [9, 10], the situation is much less clear for dijets in photoproduction. This disagreement is often interpreted as a ‘rapidity gap survival probability’ smaller than one due to secondary interactions of spectator partons and measured from the difference between the measured cross section and perturbative NLO QCD calculations. With this method, the uncertainty of the diffractive parton densities used for the prediction limits the accuracy of the measurement. Figure 1 shows a comparison of the data measured with the ZEUS experiment and a NLO calculation as function of $x_{\gamma}$ and the double ratio $\frac{\sigma_{\text{data}}}{\sigma_{\text{NLO}}}^{P_{HN}}$, in which the parton density uncertainties mostly cancel. This shows that diffractive dijet production in photoproduction is suppressed compared to perturbative calculations. Magnitude and significance of this suppression differ between the two experiments. Most surprisingly, the suppression shows no kinematic dependence. Diffractive open charm production does not show this suppression [10,11]. However, it should be noted that dijetive charm production is dominated by direct photon processes, so that the suppression is not expected.

Figure 1. On the left (a), the diffractive dijet cross section in photoproduction as measured by the ZEUS collaboration. The experimental data is shown as blue points, where error bars indicate experimental uncertainties. The red band indicates the jet energy scale uncertainty. The data are compared to NLO predictions based on different diffractive parton densities, the yellow band indicating the theoretical uncertainty. On the left (b) shows the ratio $\frac{\sigma_{\text{data}}}{\sigma_{\text{NLO}}}$. The black line and red hatched band show the expectation for a suppressed resolved contribution. At the bottom, the hadronisation corrections are given. On the right the double ratio $\frac{\sigma_{\text{data}}}{\sigma_{\text{NLO}}}^{P_{HN}}$ as measured by the H1 experiment. The error bars on the points represent the statistical uncertainty, while the inner error band shows the experimental systematic uncertainties and the outer band represents the uncertainties connected to the NLO calculation.
3. Parton Density Fit
In DIS the differential dijet cross section in $z_P$ is used in the fit in 4 bins of the scale variable $p_T^2 + Q^2$ to constrain the gluon density, where $p_T^*$ is the transverse momentum of the hardest jet. Additionally the inclusive data sample of a previous H1 analysis [3] is used to constrain the quark density and the gluon density at low momentum fraction.

The parton densities are parameterised as functions of momentum fraction $z$ at a starting scale $Q^2_0$ as $A \cdot z^B \cdot (1 - z)^C$ and evolved to higher scales by the DGLAP equations in NLO. Here, $A$, $B$ and $C$ are free parameters, determined in the fit. Additionally the Regge intercept $\alpha(0)$ of the pomeron flux factor and the normalisation of the sub-leading reggeon exchange enter the fit as free parameters. From these parton densities the reduced cross section for inclusive diffractive DIS is computed in NLO as well as the dijet cross section (using the nlojet++ program).

The fit has a high quality as shown by the overall value $\chi^2/df = 0.89$ which splits into $\chi^2/df = 27/36$ for the dijet cross sections and $\chi^2/df = 169/190$ for $F^D_2$. The resulting parton distributions are shown in Figure 2.

As the NLO QCD DGLAP evolution is able to describe both the shape and scaling violations of $F^D_2$ and the dijet cross sections consistently, we conclude that QCD factorisation in DIS is valid in our kinematic region. The data has allowed for the first time to determine both the diffractive gluon and the singlet quark distribution with good accuracy in the range $0.1 < z_P < 0.9$.

![Figure 2.](image)

**Figure 2.** The diffractive singlet density (left) and diffractive gluon density (right) for a value of the hard scale of 90 GeV$^2$. The blue line indicates the combined fit, surrounded by the experimental uncertainty band in light blue and the total uncertainty in dark blue. The two dashed lines show the two fit results from [3] for comparison.

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