Combination of the Inclusive Diffractive Cross Sections at HERA

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A combination of the inclusive diffractive cross section measurements made by the H1 and ZEUS Collaborations at HERA is presented. The analysis uses samples of diffractive deep-inelastic ep scattering data at $\sqrt{s} = 318$ GeV where leading protons are detected by special spectrometers. Correlations of systematic uncertainties are taken into account by the combination method, resulting in improved precision.

1 Inclusive Diffraction at HERA

Diffractive processes have been studied extensively in deep-inelastic ep scattering (DIS) at the HERA collider. Such interactions, $ep \to eXp$, are characterised by the presence of a leading proton in the final state carrying most of the initial energy and by the presence of a large gap in rapidity between the proton and the rest of the hadronic system, X. The kinematic variables used to describe diffractive DIS are the four-momentum squared of the exchanged photon, Q^2, the squared four-momentum transfer at the proton vertex, t, the longitudinal momentum fraction of the proton carried by the diffractive exchange, $x_{I\!P}$, and the longitudinal momentum fraction of the struck parton with respect to the diffractive exchange, β. The latter two are related to the Bjorken scaling variable, x, by $x = x_{I\!P}\beta$.

The experimental signatures of diffractive interactions have been widely exploited at HERA to select diffractive events by tagging the outgoing proton in the H1 Forward Proton Spectrometer (FPS) [1, 2], in the H1 Very Forward Proton Spectrometer (VFPS) [3] and in the ZEUS Leading Proton Spectrometer (LPS) [4, 5] or by requiring the presence of a Large Rapidity Gap (LRG) [5, 6, 7] between the proton and the system X. The methods differ in the kinematic coverage and in their dominant sources of systematic uncertainty. The LRG method is limited to relatively low $x_{I\!P}$ by the need to contain the system X in the central detector components. The largest uncertainty arise from proton dissociative events, i.e. events where the proton dissociates into a low mass state that escapes entirely undetected into the beam-pipe. These events affect the global normalization of the measured LRG cross section. On the other hand, LPS and FPS data extend to $x_{I\!P} \sim 0.1$. They have little or no proton dissociation background, but are subject to small acceptance and large uncertainties in the proton tagging efficiency, which is strongly dependent on the proton-beam optics.

Combining the H1 and ZEUS diffractive data leads to the most accurate measurements of diffractive cross sections in deep inelastic scattering. These data provide high precision input for the extraction of diffractive parton distribution functions (DPDFs). A first step, presented here [8], is taken towards such long term perspective by combining the H1 FPS [2] and the ZEUS LPS [5] proton-tagged data, for which both experiments published their final results.

2 Combination of the H1 and ZEUS Diffractive Cross Sections

2.1 Combined Data Sets

The H1 FPS data [2] correspond to an integrated luminosity of 156.6 pb^{-1} and were collected in the years from 2005 to 2007, after the HERA luminosity upgrade. The ZEUS LPS sample [5] was collected in the years 1999 and 2000 and corresponds to an integrated luminosity of 32.6 pb^{-1}. Since the H1 and ZEUS measurements were made with different binning, the ZEUS points are swum to the H1 bin centers by using the NLO QCD fit ZEUS SJ [9].

In the original analyses [2, 5] the reduced cross sections $\sigma_r^{D(3)}$ are directly measured in the t range visible to the proton taggers ($0.09 < |t| < 0.55$ GeV^2 for ZEUS and $0.1 < |t| < 0.7$ GeV^2 for H1) and extrapolated to the full range $0 < |t| < 1$ GeV^2. For the extrapolations an exponential t dependence is assumed with a slope parameter b between 5 and 6 GeV^{-2} depending on $x_{I\!P}$ for H1 and $b = 7.0 \pm 0.3$ GeV^{-2} for ZEUS as extracted from the diffractive cross sections in the visible ranges of the analyses. These extrapolations introduce extra uncertainties of the cross sections. In order to minimize such systematic effect the H1 and ZEUS cross sections are combined in the ZEUS visible t range $0.09 < |t| < 0.55$ GeV^2, common to both acceptances. In this range the normalization uncertainties are smaller and the ratio of the H1 FPS to ZEUS LPS data averaged over the measured kinematic range is $0.91 \pm 0.01(stat) \pm 0.03(sys) \pm 0.08(norm)$, consistent with unity. The resulting kinematic range of the combined data is $0.09 < |t| < 0.55$ GeV^2, $2.5 < Q^2 < 200$ GeV^2, $0.0018 < \beta < 0.56$ and $0.0009 < x_{I\!P} < 0.09$.

2.2 Combination Method

The combination is based on the χ^2 minimization method described in [10] and already used for previous combined HERA results [11]. The averaging procedure is based on the assumption that at a given kinematic point the H1 and ZEUS experiments are measuring the same cross section. The correlated systematic uncertainties are treated as free parameters and thereby enable a cross-calibration of the two experiments. It allows a model independent check of the data consistency and leads to a significant reduction of the correlated uncertainty. For an individual data set, the χ^2 function is defined as:

$$\chi^2_{exp}(\mathbf{m}, \mathbf{b}) = \sum_i \frac{[m^i - \sum_j \gamma^i_j m^i b_j - \mu^i]^2}{\delta^2_{i,stat}\mu^i (m^i - \sum_j \gamma^i_j m^i b_j) + (\delta_{i,uncor} m^i)^2} + \sum_j b_j^2. \qquad (1)$$

Here μ^i is the measured value at a point i and γ^i_j, $\delta_{i,stat}$ and $\delta_{i,uncor}$ are relative correlated systematic, relative statistical and relative uncorrelated systematic uncertainties, respectively. The function χ^2_{exp} depends on the true values m^i of the measurements and the shift b_j of the correlated systematic error sources. The total χ^2 function, χ^2_{tot}, is built from the sum of the χ^2_{exp} functions for each data set.

2.3 Procedural Uncertainties

A series of uncertainties that may affect the combined measurement due to the combination procedure are studied. All the following effects are considered and treated as correlated procedural errors and for each data point their value is estimated and summed in quadrature to the total uncertainty.

The χ^2 function given by Eq. 1 treats all systematic uncertainties as multiplicative, i.e. proportional to the expected central values. To study the sensitivity of the average result to this error treatment, an alternative averaging is performed, for which only normalization uncertainties are taken as multiplicative while all other uncertainties are treated as additive. The difference between this average and the nominal average result is of the order of 4%.

The H1 and ZEUS experiments use similar methods for detector calibration, apply similar reweighting to the Monte Carlo for the acceptance corrections and employ similar Monte Carlo simulation models for radiative corrections, for the hadronic final state simulation and for the proton dissociation backgound subtraction. Such similarities may lead to correlations between the H1 and ZEUS measurements. To investigate the effect of correlations, 4 sources of similar systematic uncertainties of the two experiments are identified. These are related to the electromagnetic energy scale of the caloriemter of the main detector, the proton dissociation backgound and the $x_{I\!P}$ and t reweighting. Averages are formed for each of the 2^4 possible assumptions on whether these systematics are correlated or uncorrelated between the experiments and are compared with the nominal average for which all sources are assumed to be uncorrelated. The maximum difference between the nominal and the alternative averages is taken as an additional uncertainty.

In the nominal average the systematic error sources of the H1 FPS measurement [2] are all considered as point-to-point correlated. An alternative average is performed considering the hadronic energy scale, the event vertex reconstruction, the bin centre corrections and the background subtraction as uncorrelated errors. The difference with the nominal case is on average below 1%, increasing up to 10% for the lowest $x_{I\!P}$ bin.

The bias introduced by extrapolating the ZEUS data to the H1 binning scheme has been studied. An alternative average was performed once the ZEUS cross sections are swum according to an altrernative NLO QCD fit, the H1 'Fit B' [6]. The estimated overall effect is of the order of 1%.

3 Results

In the minimization procedure 227 data points were combined to 169 cross section measurements. The data show good consistency with $\chi^2/ndof = 52/58$. In Fig. 1 the combined data are compared to the input H1 FPS and ZEUS LPS data. The combination is driven by the H1 results, which are statistically more powerful. The combined measurement shows though an average improvement in precision of about 20% with respect to the original H1 data.

A total of 20 sources of correlated systematic uncertainties are considered, which shift by up to 1σ of the nominal value in the averaging procedure, with the exception of the H1 hadronic energy scale which shifts by 1.6σ. Several correlated systematic uncertainties are reduced significantly by the averaging procedure; notably, the contribution of the H1 uncertainty in the leading proton energy is reduced by a factor of 2.

These combined data are very valuable in the scenario of inclusive diffraction at HERA and beyond. They can provide the absolute normalization of the diffractive reduced cross section in

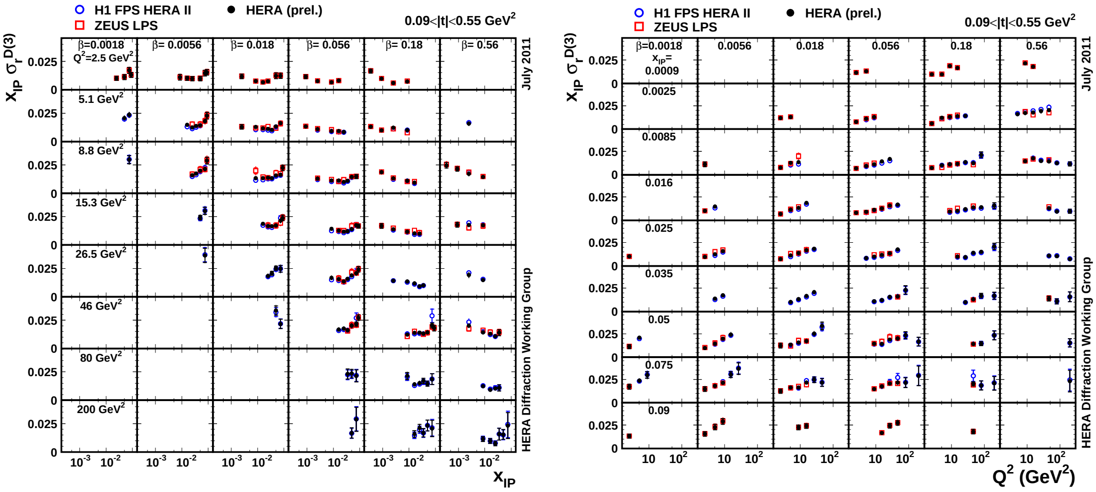

Figure 1: HERA diffractive reduced cross section as a function of $x_{I\!P}$ for different β and Q^2 (left) and as a function of Q^2 for different β and $x_{I\!P}$, compared to the H1 FPS and ZEUS LPS measurements.

deep inelastic scattering and they can help to quantify the proton dissociation contributions in the samples selected with the LRG method.

4 Conclusions

The H1 and ZEUS diffractive cross sections based on proton-tagged data are combined for the first time, resulting in a unique HERA diffractive DIS data set with improved precision. This result fixes the absolute normalization of the DIS diffractive reduced cross section and can be used as input for a QCD analysis to extract a unique set of HERA DPDFs.

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