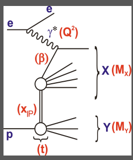
Combined Measurement of the Inclusive Diffractive Cross Section at HERA

H1 and ZEUS Collaborations

INCLUSIVE DIFFRACTION AT HERA

In the single diffractive dissociation process in hadron-hadron scattering, at least one of the beam hadrons emerges intact from the collision, having lost only a small fraction of its energy and gained only a small transverse momentum. In the analogous process involving virtual photons, $\gamma^* p \rightarrow Xp$, an exchanged photon of virtuality Q^2 dissociates through its interaction with the proton at a centre-of-mass energy W and squared four momentum transfer t to produce a hadronic system X with mass M_X. The fractional longitudinal momentum loss of the proton during the interaction is denoted x_{IP}, while the fraction of this momentum carried by the struck quark is denoted β. These variables are related to Bjorken x by $x = \beta x_{IP}$. The two groups of final state particles X and Y are well separated in phase space and have a large gap in rapidity between them. Events where also the proton dissociates into a state Y with low mass M_Y (a resonance or a continuum state) are termed double dissociative and constitute a background to the single dissociation.

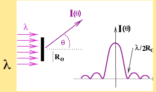


Similarly to inclusive DIS, cross section measurements for the reaction $ep \rightarrow eXp$ are conventionally expressed in terms of the diffractive reduced cross section, $\sigma_r^{D(3)}$, which is related to the measured cross section and to the diffractive structure function $F_2^{D(3)}$ and $F_L^{D(3)}$, by

$$\frac{d^3\sigma^{ep\rightarrow e'Xp'}}{d\beta dQ^2 dx_{IP}} = \frac{2\pi\alpha^2}{\beta Q^4} Y_+ [F_2^{D(3)}(\beta,Q^2,x_{IP}) - \frac{y^2}{Y_+} F_L^{D(3)}(\beta,Q^2,x_{IP})]$$

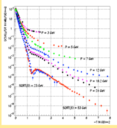
$$\sigma_r^{D(3)}(\beta,Q^2,x_{IP})$$

Why diffraction?

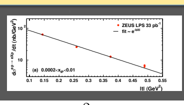


Light of wavelenght λ impinging on a black disk of radius R_0 produces on a distant screen a diffraction pattern characterized by a large forward peak for scattering angles $\theta=0$ (the "diffraction peak") and a series of symmetric minima and maxima.

The differential cross section $d\sigma/dt$ for elastic proton-proton scattering remarkably recalls such diffraction pattern.



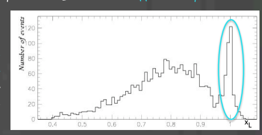
The large values of $|t|$ are exponentially suppressed, a feature which is well manifest in the HERA data.



Because of the variety of the selection methods, the complementary features of the data and the statistical limitations of some samples, COMBINING THE H1 and ZEUS DIFFRACTIVE DATA can provide the most accurate measurements of diffractive cross-sections in deep inelastic scattering, which can eventually be used to extract HERA diffractive parton distribution functions. A first step is taken towards such long term perspective by combining the H1 FPS [1] and the ZEUS LPS [4] proton-tagged data, for which both experiments published their final results. Though the H1 data taken with the VFPS are still under analysis, they cover a different kinematic region and are therefore expected to have little influence in the range of the combined FPS+LPS measurement.

METHODS TO SELECT DIFFRACTION AT HERA

Experimentally, diffractive ep scattering is characterized by the presence of a leading proton in the final state, carrying a large fraction, x_L, of the incoming proton momentum, and by a lack of hadronic activity in the forward (outgoing proton) direction. Diffractive events thus appear as a peak at $x_L \sim 1$, the diffractive peak, which at HERA approximately covers the region $0.98 < x_L < 1$.



The proton remains in the beam-pipe and can only be measured with detectors located inside the beam-pipe. The system X is cleanly separated and M_X can be measured in the central detector components.

These signatures have been widely exploited at HERA to select diffractive events by tagging the outgoing proton in the H1 Forward Proton Spectrometer (FPS) [1-3], in the H1 Very Forward Proton Spectrometer (VFPS) [4] and in the ZEUS Leading Proton Spectrometer (LPS) [5-8] or by requiring a large gap in the rapidity distribution of particles in the forward region [5, 9-11]. In a third approach [12,13] the inclusive DIS sample is decomposed into diffractive and non-diffractive contributions based on their characteristic dependences on M_X.

The methods differ in the kinematic coverage and in their dominant sources of systematic uncertainty. The LRG and M_X methods are limited to relatively low x_{IP} by the need to contain the system X in the central detector components. The largest uncertainty arise from proton dissociative events, which cannot always be distinguished from events in which the proton is scattered elastically. LPS and FPS data extend to $x_{IP} \sim 0.1$ and have little or no proton dissociation background, but are subject to large uncertainties in the proton tagging efficiency, which is strongly dependent on the proton-beam optics. Comparing the results from the three different methods is a powerful test of the control over the systematics of the measurements. At low x_{IP} the ratio of cross sections obtained with the LRG and M_X methods to those measured with the proton taggers can be used to quantify the residual proton dissociation background in the former samples.

COMBINATION METHOD

THE COMBINATION WAS PERFORMED WITH A METHOD INTRODUCED IN [14] AND EXTENDED IN [15] . THE SAME METHOD WAS ALREADY USED FOR OTHER HERA COMBINED RESULTS [16]. THE ONLY THEORETICAL INPUT OF SUCH AVERAGING PROCEDURE IS THE ASSUMPTION THAT THE H1 AND ZEUS EXPERIMENTS ARE MEASURING THE SAME CROSS SECTION AT THE SAME KINEMATIC POINTS. THE CORRELATED SYSTEMATIC UNCERTAINTIES ARE FLOATED COHERENTLY SUCH THAT EACH EXPERIMENT CALIBRATES THE OTHER ONE. THIS ALLOWS A MODEL INDEPENDENT CHECK OF THE DATA CONSISTENCY AND A SIGNIFICANT REDUCTION OF THE CORRELATED SYSTEMATIC UNCERTAINTY.

THE METHOD USES AN ITERATIVE χ^2 MINIMIZATION PROCEDURE. THE PROBABILITY DISTRIBUTION OF A MEASURED QUANTITY M FOR A SINGLE DATA SET CAN BE REPRESENTED AS A χ^2 FUNCTION

$$\chi^2_{exp}(M^{i,true},\Delta\alpha_j) = \sum_i \frac{[M^{i,true} - (M^i + \sum_j \frac{\partial M^i}{\partial \alpha_j}\frac{M^{i,true}}{M^i}\Delta\alpha_j)]^2}{(\sigma_i \frac{M^{i,true}}{M^i})^2} + \sum_j \frac{(\Delta\alpha_j)^2}{\sigma^2_{\alpha_j}}$$

M^i measured central values

$M^{i,true}$ fitted combined H1 – ZEUS values

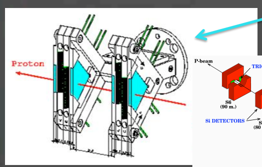
σ_i statistical and uncorrelated systematic uncertainties

σ_{α_j} correlated systematic uncertainties

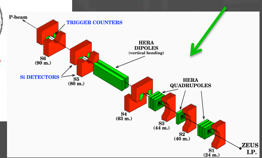
i = measured data point
j = correlated systematic error source

A χ^2_{TOT} IS BUILT FROM THE SUM OF THE χ^2 OF EACH DATA SET. THE χ^2_{TOT} IS MINIMIZED WITH RESPECT TO $M^{i,\,true}$ AND α_J.

H1 FPS



ZEUS LPS



DATA SAMPLES

The H1 FPS data [1] correspond to an integrated luminosity of 156 pb^{-1} and were collected in the years from 2005 to 2007 after the HERA luminosity upgrade. The ZEUS LPS sample [4] was collected in the years 1999 and 2000 and corresponds to an integrated luminosity of 32.6 pb^{-1}.

The binning was originally very different between the H1 and ZEUS measurements (fixed M_X for ZEUS, fixed β for H1). The ZEUS points were swum to the H1 bin centers by using the NLO QCD fit ZEUS SJ [17].

In the analyses [1] and [4] the reduced cross sections $\sigma_r^{D(3)}$ are directly measured in the t range visible to the proton taggers ($0.09 < |t| < 0.55$ GeV² for ZEUS and $0.1 < |t| < 0.7$ GeV² for H1) and extrapolated to the range $0 < |t| < 1$ GeV². Such extrapolation, which depends on the exponential slope of the t distribution and on its uncertainty, introduces an extra uncertainty in the normalization of the cross section. To avoid such systematic effect the H1 and ZEUS cross sections were combined in the restricted t range $0.09 < |t| < 0.55$ GeV², common to both acceptances. In such range the normalization uncertainties are smaller and the average normalizations closer than in the full t range.

t range	Norm. unc. ZEUS	Norm. unc. H1	Ratio H1/ZEUS
$[t_{min}$-1] GeV²	+11% -7%	± 6%	H1/ZEUS = 0.85 ± 0.01 (stat) ± 0.03 (syst) + 0.09 / - 0.12 (norm)
[0.09-0.55] GeV²	± 7%	± 4.5%	H1 / ZEUS = 0.91 ± 0.01 (stat) ± 0.03 (syst) ± 0.08 (norm)

In the combination procedure, each sample enters with its original normalization and the corresponding uncertainty which is treated as a correlated systematic uncertainty.

RESULTS

In total 227 data points were combined to 169 cross section measurements.

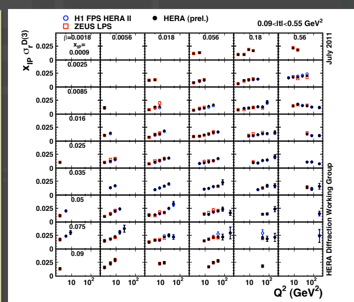
The data show good consistency with $\chi^2/n_{dof} = 52/58$.

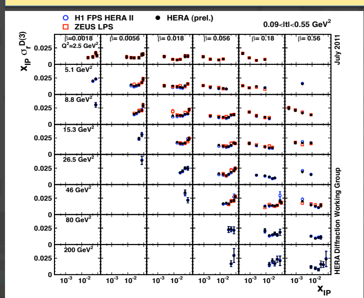
The combination is driven by the H1 results which are statistically more powerful. The combined measurement shows though an average improvement in precision of ~20% with respect to the original H1 data.

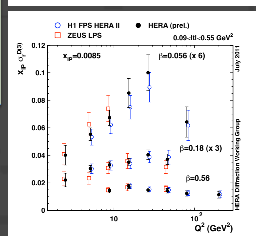
A total of 20 sources of correlated systematic uncertainties were considered which shift by up to one σ of the nominal value in the averaging procedure, with the exception of the H1 hadronic energy scale which shifts by 1.6σ.

The influence of several correlated systematic uncertainties is reduced significantly for the averaged result.

These combined data are very valuable in the scenario of inclusive diffraction at HERA and beyond. They can quantify the proton dissociation contributions in the samples Selected with the LRG and M_X methods and can provide the absolute normalization of $F_2^{D(3)}$.







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