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Measurement of the Diffractive Cross Section in Charged Current Interactions at HERA

H1 Collaboration

Abstract

A first differential measurement of charged current diffractive interactions is presented using data taken by the H1 experiment amounting to an integrated luminosity of 63 pb^{-1}. The process $ep \to \nu XY$ is studied, where the Y system is a proton or proton remnant with M_Y <1.6 GeV and $|t|$ <1.0 GeV^2. It is separated from the X system by a large gap in pseudorapidity. Total and differential cross-sections are extracted in the kinematic range $Q^2 >$ 200 GeV^2, $y < 0.9$ and $x_{I\!P} <$ 0.05 and compared to predictions from a model of diffractive DIS in which the exchanged W boson scatters from diffractive parton densities extracted from fits to neutral current data at lower Q^2. The ratio of the diffractive charged current cross-section to the inclusive charged current cross-section is also measured.

1 Introduction

Neutral Current Diffractive Deep-Inelastic Scattering (DDIS) has been used to investigate the parton dynamics of diffractive exchanges throughout the accessible kinematic range at HERA [2–4]. A LO QCD fit [5] based on the hard scattering factorisation theorem for diffraction [6] has been made to a subset of these data allowing the extraction of diffractive parton densities. In this fit it was necessary to make the assumption of “Regge factorisation”, whereby the diffractive parton densities do not change in shape as $x_{I\!P}$ and t vary and their change in normalisation is given by a parameterisation based on Reggeon flux factors. Both a leading ‘pomeron’ contribution and a sub-leading ‘reggeon’ component are included in the fit, with different flux factors and separately evolving parton densities.

A new measurement is presented here using W bosons to probe the structure of the diffractive exchange and to test the assumed parton dynamics. The process $ep \rightarrow \nu XY$ is studied, where the presence of the diffractive exchange implies a large gap in rapidity between the two hadronic final state systems. Figure 1 shows the diagram for the charged current DDIS process.

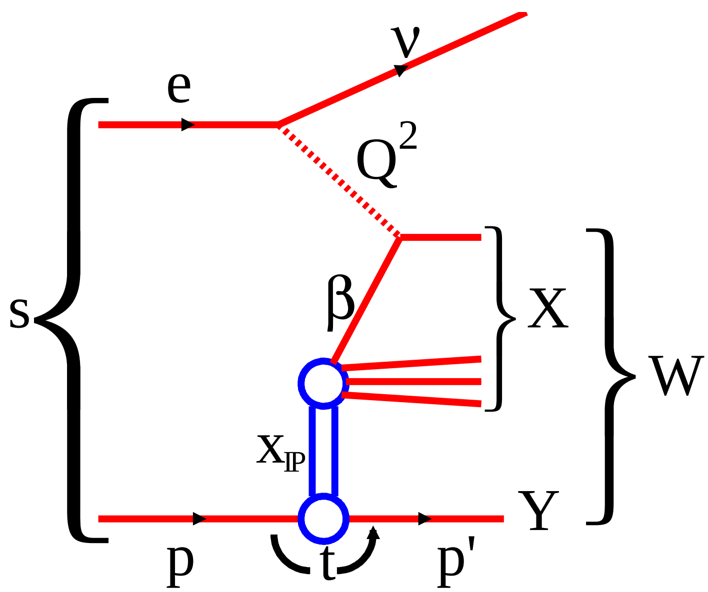

Figure 1: A schematic illustration of the charged current DDIS process at HERA, $ep \rightarrow \nu XY$. The positron couples to a virtual W boson of virtuality Q^2 which interacts with the proton via a colour-singlet exchange, producing two distinct final state systems, X and Y. These two systems are separated by a large gap in rapidity if their masses are small compared with that of the full hadronic final state (W).

Here, the standard charged current DIS variable definitions are used, namely

$$Q^2 = -q^2 \; ; \qquad y = \frac{P.q}{P.k} \; ; \qquad x = \frac{-q^2}{2P.q} \; , \tag{1}$$

determined by the four-momenta of the W boson (q), the proton (P) and the incoming positron (k). The additional diffractive variables are defined as

$$x_{I\!P} = \frac{q.(P - p_Y)}{q.P} \; ; \qquad \beta = \frac{-q^2}{2q.(P - p_Y)} \; ; \qquad t = (P - p_Y)^2 \; , \tag{2}$$

where p_Y is the four-momentum of the Y system. Here, $x_{I\!P}$ corresponds to the fraction of the proton beam energy transferred to the longitudinal momentum of the diffractive exchange, β is the fraction of the exchanged longitudinal momentum carried by the quark coupling to the virtual W boson and t is the squared 4-momentum transferred at the proton vertex.

In the analysis presented here, neither t, nor the mass M_Y are well measured as the Y system is not detected. The measured cross-section is corrected to the region

$$M_Y < 1.6 \text{ GeV} \; ; \qquad |\text{t}| < 1.0 \text{ GeV}^2 \; . \tag{3}$$

The preliminary results presented here are based on high Q^2 data collected with the H1 detector [1] in e^+p interactions at $\sqrt{s} = (k + P) = 319$ GeV at HERA in 1999 and 2000. The data correspond to an integrated luminosity of 63 pb^{-1}. Together with the neutral current analyses [2–4] they complete the H1 coverage of DDIS measurements for the first running period of the HERA machine. These charged current data provide a test of the factorisation schemes and other assumptions which have worked so well for the neutral current data. In particular, the charged current data are sensitive to particular quark flavours from the diffractive parton densities extracted from the analysis of the neutral current DDIS data and thus have the potential to test the flavour decomposition of the pomeron and the reggeon.

2 Experimental Method

2.1 Selection Criteria and Kinematic Reconstruction

The data used for the analysis are a subset of the high Q^2 inclusive charged current DIS sample studied in [7]. Charged current events are selected by requiring a missing transverse momentum $P_T^{miss} > 12$ GeV. The diffractive selection requires a large gap in the pseudorapidity distribution of the final state hadrons in the outgoing proton direction, signalling a colour singlet exchange between the W boson and the proton to produce two well separated systems X (contained in the main detector) and Y (escaping unobserved into the beampipe). The selection is based on an absence of activity in the components of the H1 detector which are sensitive to energy flow in the proton fragmentation region [2].

The reconstruction of the final state system X uses an algorithm which optimally combines tracking and calorimetric information without double counting [9]. The mass of the X system is reconstructed as

$$M_X^2 = (E^2 - p_x^2 - p_y^2 - p_z^2)_h \; . \tag{4}$$

Here, $(E, p_x, p_y, p_z)_h$ is the 4-vector of the overall hadronic final state observed in the detector. The inclusive DIS kinematic variables are obtained from

$$y = \frac{E_h - p_{z,h}}{2E_e} \; ; \qquad Q^2 = \frac{P_{T,h}^2}{1-y} \; ; \qquad x = \frac{Q^2}{sy} \; , \tag{5}$$

where $E_h - p_{z,h}$ is the difference between the energy and the longitudinal momentum of the X system, E_e is the positron beam energy and $P_{T,h}$ is the transverse momentum of the X system.

The diffractive kinematic variables are then reconstructed as

$$\beta = \frac{Q^2}{Q^2 + M_X^2} \; ; \qquad x_{I\!P} = \frac{x}{\beta} \; . \tag{6}$$

2.2 Corrections to the Data

The RAPGAP [10] Monte Carlo generator is used to describe the DDIS process $ep \rightarrow \nu X p$. It is used to correct the data for the effects of the detector acceptance and kinematic migrations due to the finite detector resolution and imperfections in the reconstruction. RAPGAP uses diffractive parton densities extracted from a leading order QCD fit, similar to that described in section 1, but performed on earlier H1 data [8]. The parton densities are convoluted with QCD matrix elements up to order α_s. Further QCD radiation is simulated via an interface to the ARIADNE [11] program, which is an implementation of the Colour Dipole Model [11, 12]. As required by the data [8], a sub-leading exchange is also included, with parton densities obtained from a parameterisation for the π-meson [13]. QED radiation is simulated via an interface to the HERACLES [14] program.

A factor 1.08 ± 0.10 is required to correct the data to the measured range $M_{\rm Y} < 1.6$ GeV and $|t| < 1$ GeV^2. This factor was evaluated using the DIFFVM [15] generator, which simulates diffractive events both with intact final state protons and with proton dissociation. Migrations into the measured range from very large $x_{I\!P} > 0.15$ or large $M_{\rm Y} > 5$ GeV values are estimated using the DJANGO [16] generator of non-diffractive charged current DIS. This program is an interface between the HERACLES ep event generator and the ARIADNE program.

Corrections are made for several small background contributions to the data. The contamination from hard diffractive photoproduction processes, in which mismeasurements lead to large fake missing transverse momentum, is estimated using the RAPGAP program. High Q^2 neutral current background, entering the sample due to similar mismeasurements, is estimated using DJANGO. EPVEC [17] is used to simulate background from real heavy gauge boson ($W^{\pm}, Z^0$) production. Comparisons of the full simulation with the uncorrected data for several kinematic distributions can be seen in figure 2. The simulation gives a good description of the data for all variables.

2.3 Extraction of the Cross-Section

The cross-section is corrected for the effects of background processes and detector acceptance and migrations. The effects of QED radiation are ignored, which is reasonable given the statistical precision of the data. The acceptance, purity and stability[1] for each quoted bin is required to be greater than 20 % and is on average greater than 50 %.

A full analysis of the systematic uncertainties of the measurement was performed. The sources of systematic uncertainty associated with the reconstruction of the final state hadrons are discussed in [7]. Those uncertainties particular to the diffractive measurement are described in [2]. The dominant systematic uncertainties arise from the corrections for smearing about the M_Y boundary of the measurement and the correction for smearing into the sample from very large $x_{I\!P}$ as described using the DJANGO model. The systematic error on the final cross-sections is approximately 20% on average and is small in comparison to the average statistical error of approximately 45%.

3 Results

3.1 The Total Cross-Section and Ratio to the Inclusive

The total charged current DDIS cross-section, measured for $Q^2 > 200\ \mathrm{GeV}^2, y < 0.9$ and $x_{I\!P} < 0.05$, is

$$\sigma_{CC}^{diff} = 0.42 \pm 0.13\ (stat.) \pm 0.09\ (sys.)\ \mathrm{pb} \tag{7}$$

This measurement agrees very well with the prediction based on the “H1 2002 fit” to neutral current DDIS data as implemented in RAPGAP of $\sigma_{CC}^{diff} = 0.43 \pm 0.01\ (stat.)\ \mathrm{pb}$.

The ratio of the diffractive charged current cross-section, measured in the kinematic range above, to the inclusive charged current cross-section σ_{CC}^{inc}, measured in the corresponding kinematic range $Q^2 > 200\ \mathrm{GeV}^2, y < 0.9$ and $x_{Bj} < 0.05$, is

$$\frac{\sigma_{CC}^{diff}}{\sigma_{CC}^{inc}} = 2.5 \pm 0.8\ (stat.) \pm 0.6\ (sys.)\ \% \tag{8}$$

[1]The purity (stability) of a bin is defined as the fraction of events reconstructed (generated) in a bin that were also generated (reconstructed) in that bin, according to the simulation.

3.2 The Differential Diffractive Charged Current Cross-Section

In figure 3, the diffractive charged current cross-section is shown differentially in $x_{I\!P}$. It is compared to the LO prediction from the "H1 2002 fit" to neutral current DDIS data [5]. The sub-leading reggeon or "meson" contribution is also shown as a dashed line and is large, as expected, in the highest $x_{I\!P}$ bin. Within the the current limited statistical precision, the predictions are consistent with the data

Figures 4 and 5 show the diffractive charged current cross-section differentially in Q^2 and β, respectively. The prediciton of the fit is shown again with the contribution from the meson. Both differential cross-sections are described well by the prediction.

4 Conclusions

A new measurement of charged current DDIS has been presented in the kinematic range $Q^2 > 200\ \mathrm{GeV}^2, y < 0.9$ and $x_{I\!P} < 0.05$. The results have been compared with predictions from a fit to lower Q^2 neutral current DDIS data in which the partons are evolved to higher Q^2 using the DGLAP equations. Both the total diffractive charged current cross-section and the $x_{I\!P}$, Q^2 and β dependencies are well described by the predictions.

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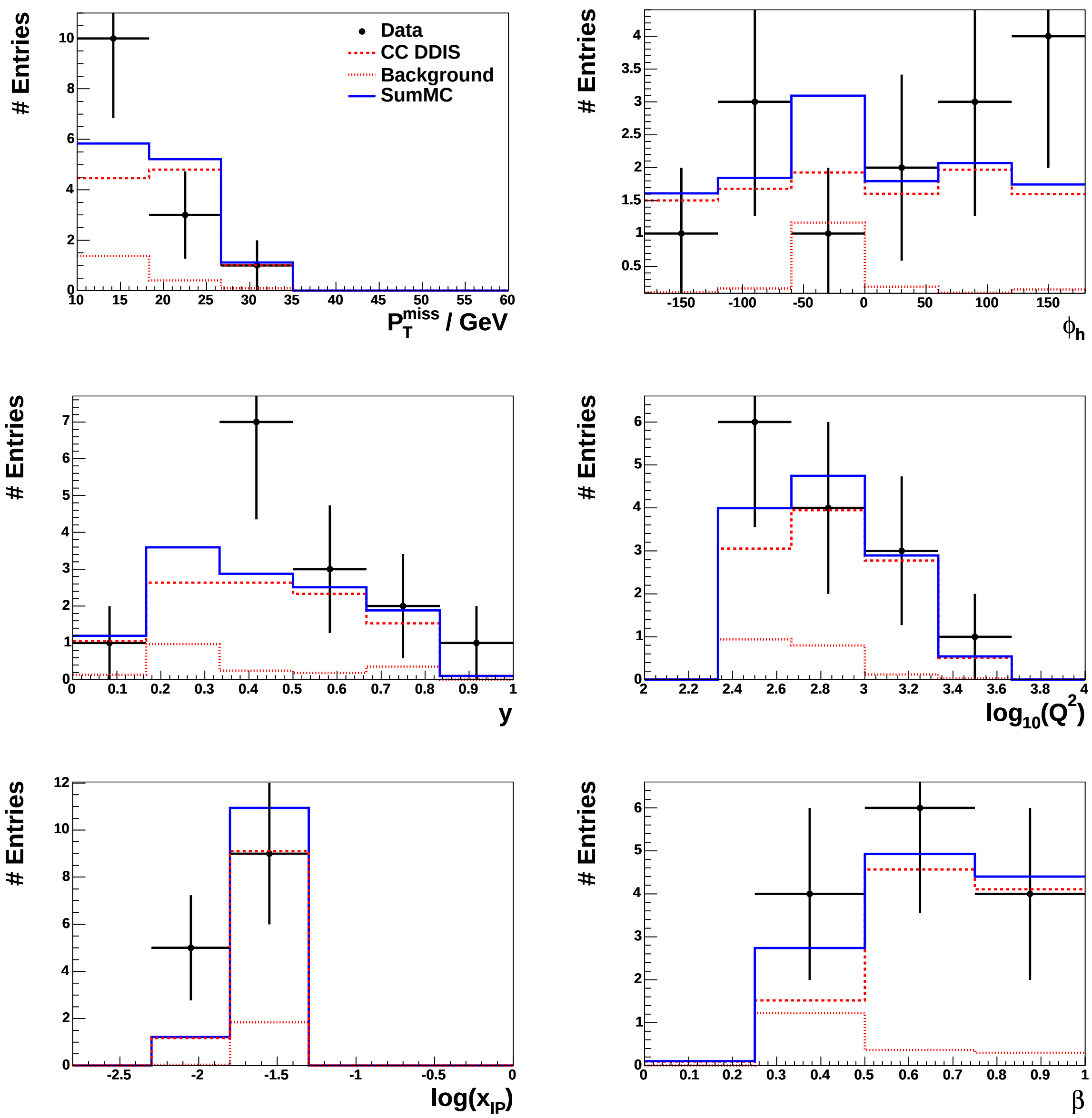

Figure 2: Distributions of the uncorrected data are compared with the predictions of the RAPGAP CC DDIS simulation (dashed line), the total background simulation (dotted line) and the sum of both (solid line).

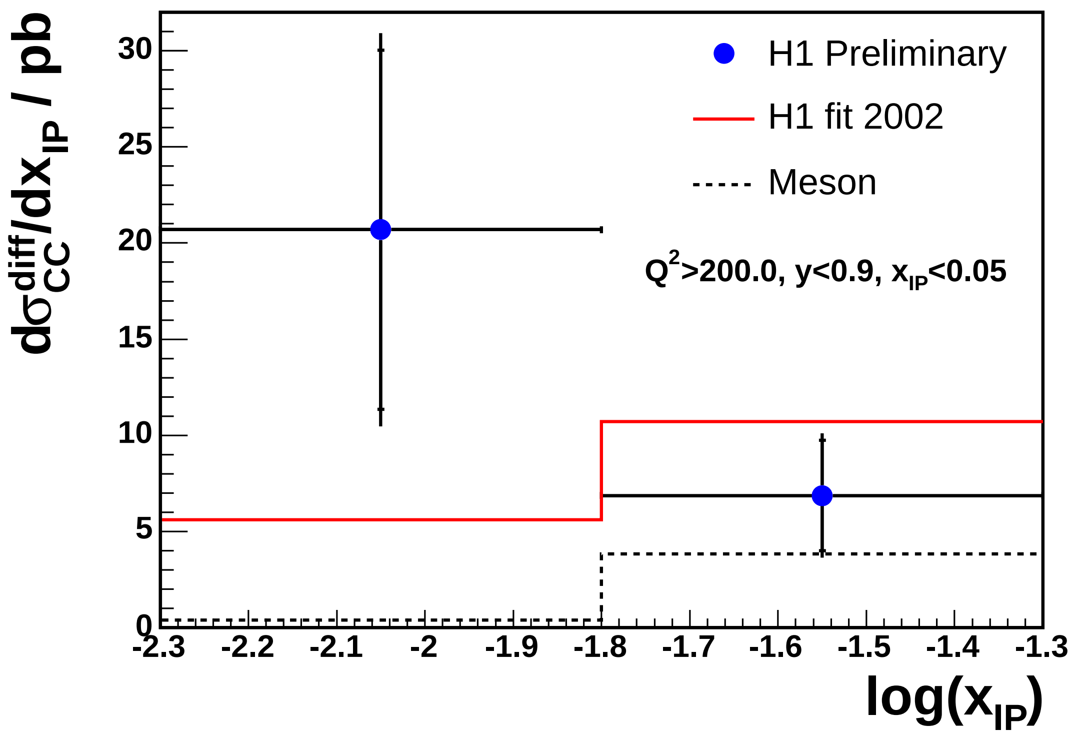

Figure 3: The diffractive charged current cross-section differential in $x_{I\!P}$ plotted as a function of $\log(x_{I\!P})$, compared with the prediction from the "H1 2002 fi t" to neutral current DDIS data. Also shown is the sub-leading reggeon or "meson" contribution (dashed line).

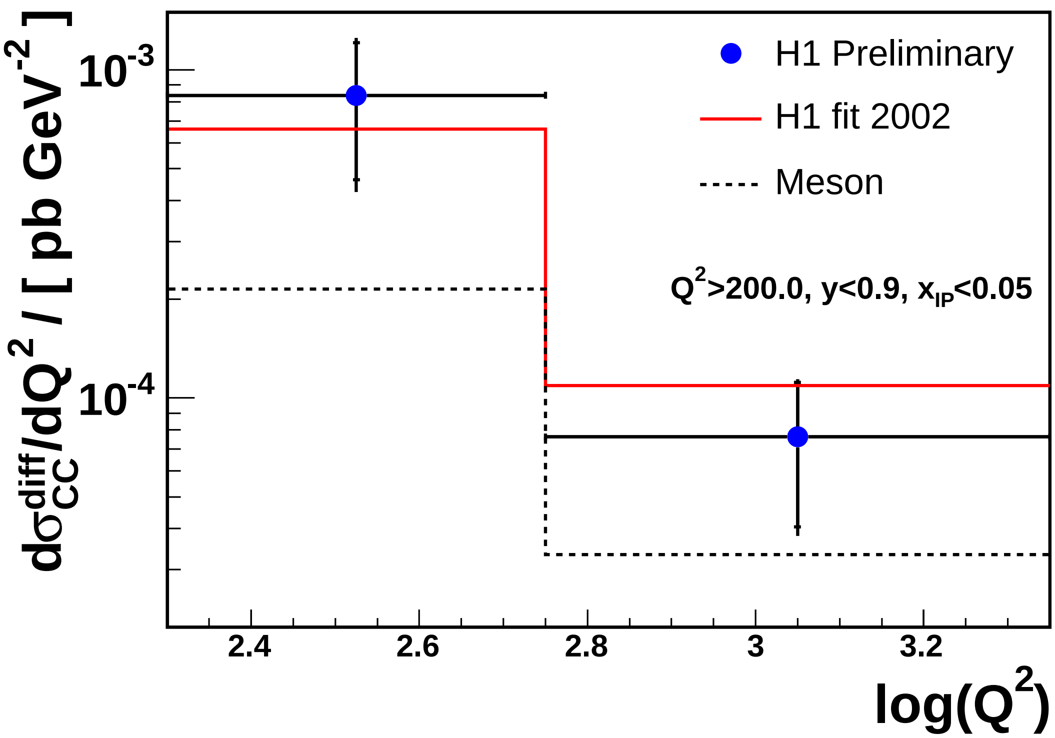

Figure 4: The diffractive charged current cross-section differential in Q^2 plotted as a function of $\log(Q^2)$, compared with the prediction from the "H1 2002 fit" to neutral current DDIS data. Also shown is the sub-leading reggeon or "meson" contribution (dashed line).

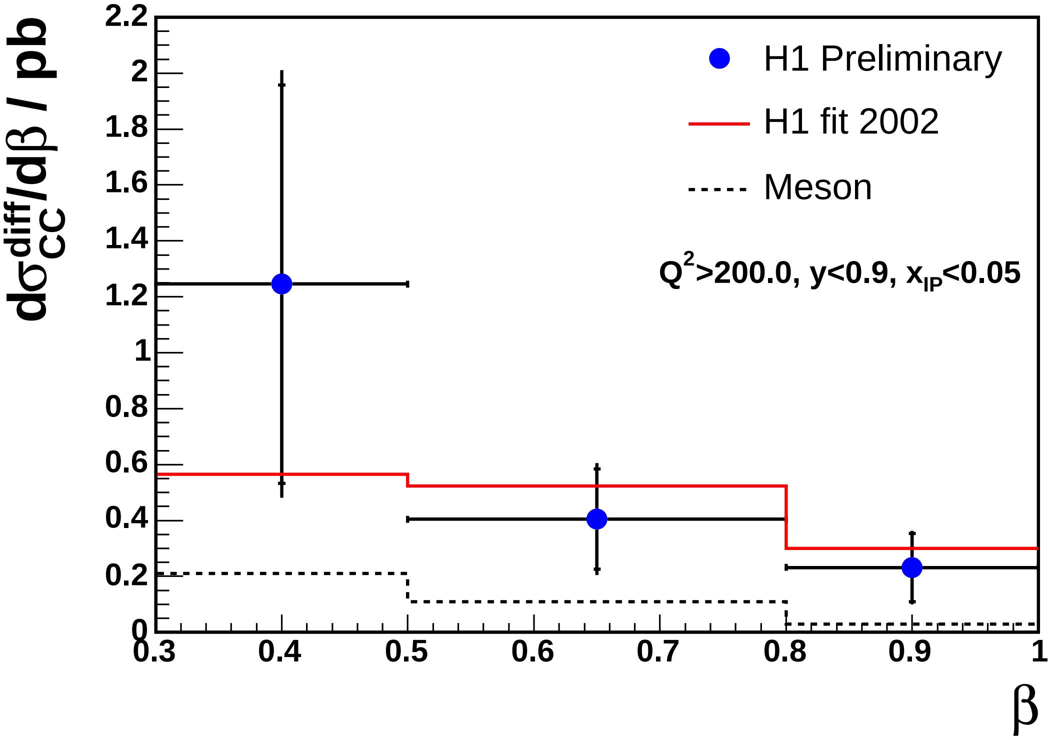

Figure 5: The diffractive charged current cross-section differential in β plotted as a function of β, compared with the prediction from the "H1 2002 fit" to neutral current DDIS data. Also shown is the sub-leading reggeon or "meson" contribution (dashed line).