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Gluon and Charm Measurements in DIS at HERA

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On behalf of the H1 and ZEUS Collaborations

Abstract

A short overview of gluon and charm measurements from deep inelastic scattering data at HERA is presented.

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315:Gluon and Charm Measurements in DIS at HERA

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Abstract. A short overview of gluon and charm measurements from deep inelastic scattering data at HERA is presented.

1 Introduction

During the last five years HERA has provided the H1 and ZEUS Collaborations with high statistics deep inelastic scattering (DIS) data. Measurements of the proton structure function F_2 are presently extended over five orders of magnitude in Q^2 and Bjorken x, allowing for the first time an overlap with measurements from fixed target experiments at $Q^2 < 100$ GeV^2 and $x > 10^{-2}$. For the definitions of the DIS kinematic variables and a discussion of the latest measurements we refer to [1].

When plotted versus Q^2 at various values of x, F_2 exhibits strong scaling violations with decreasing x. In leading order (LO) Quantum Chromodynamics (QCD) these scaling violations are due to the presence of gluon radiation from the initial or the final quark line or gluon splitting into a $q\bar{q}$ pair. Whereas F_2 measures directly the quark content of the proton, the gluon is indirectly extracted by fits to the measured F_2 data assuming the Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) model for the QCD evolution.

A large part of the DIS cross section, typically of $\sim 20\%$, in the low-x HERA regime is due to charm production. In LO perturbative QCD charm is produced in $c\bar{c}$ pairs *via* boson-gluon fusion (BGF). Recent next-to-leading order (NLO) theoretical calculations indicate that charm can be predicted, given the gluon and light flavour densities, and there is no need to be put in as an arbitrary density in the F_2 fits. Therefore, a measurement of the charm contribution $F_2^{c\bar{c}}$ to the inclusive proton structure function F_2 gives an excellent consistency check of the whole picture.

2 Gluon from NLO F_2 fits

F_2 was split into two parts, one coming from the light flavours and one coming from the charm

$$F_2 = F_2^{uds} + F_2^c \ . \tag{1}$$

The b quark contribution, heavily suppressed to typical values of $\sim 1\%$ by mass and charge effects, was neglected.

The three light flavours (or the valence and total sea) were parametrized at a low starting scale of $Q_0^2 = 1$ GeV^2 (H1) / 7 GeV^2 (ZEUS) as functions of x, e.g. (H1)

$$\begin{aligned} xg(x) &= A_g x^{B_g}(1-x)^{C_g} \\ xu_v(x) &= A_u x^{B_u}(1-x)^{C_u}(1+D_u x + E_u\sqrt{x}) \\ xd_v(x) &= A_d x^{B_d}(1-x)^{C_d}(1+D_d x + E_d\sqrt{x}) \\ xS(x) &= A_S x^{B_S}(1-x)^{C_S}(1+D_S x + E_S\sqrt{x}) \end{aligned} \tag{2}$$

where A_i are normalisation factors, and the x^{B_i} and $(1-x)^{C_i}$ terms give the singular and the valence-type behaviour of the partons densities respectively. The s quark was assumed to be 20-25% of the total sea at this initial

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scale. The normalisations for the quarks were determined by the quark counting rules and for the gluon by the momentum sum rule. The total normalisation was left free. The value of $\alpha_s(M_Z^2) = 0.118(0.113)$ for H1(ZEUS) was given as an input to the fit.

The three light flavours were evolved to a higher scale using the next-to-leading order (NLO) splitting and coefficient functions in the $\overline{MS}$ factorisation and renormalisation scheme to give the F_2^{uds} part of eq. 1. F_2^c was calculated analytically at NLO using the procedure of [2], added to the light flavours and the resulting F_2 was fitted to the experimental data. H1 used their nominal vertex data from the 1994, 1995 and 1996 running periods and that part of the 1995 run where the interaction point was shifted allowing to access smaller scattering angles of the final state positron and, thus, smaller $Q^2 \simeq 1.5\text{GeV}^2$. ZEUS used their 1994 nominal and shifted vertex data as well as events where the initial positron has radiated a hard photon before interacting with the proton, allowing for a smaller c.m. energy and thus accessing $Q^2 \simeq 1.5\text{GeV}^2$. In addition to their own data, H1 and ZEUS used proton and deuteron F_2 data from NMC and BCDMS, to pin down the high x region.

The result of the H1 fit can be found in [1] where F_2 is plotted versus x in various bins of Q^2. The NLO fit gives an excellent description of the data. The ZEUS fit is shown in Fig. 1 where now F_2 is plotted versus $\log_{10} Q^2$ in various bins of x allowing to observe the transition from the region of approximate scaling at $x \sim 0.1$ to the region of strong scaling violations at $x \sim 0.0001$. The solid fit line, representing the result for eq. 1, gives again an excellent description of the data. The F_2^{uds} part is shown as a dashed line. It is clear that the charm contribution is very significant, especially at small x.

The result for the gluon density is shown in Fig. 2. At the scale of $Q^2 = 20$ GeV^2 the results of the two experiments, darker band for ZEUS and lighter for H1, are in good agreement. The bands represent the error estimations including contributions from the experimental statistical and systematic errors and the uncertainties on α_s and the charm mass. The hatched band at higher x is the result from NMC. On the same plot two results of global fits to DIS and related data (e.g. prompt photon data) from the MRS [3] and CTEQ [4] collaborations are shown (solid and dashed line respectively). The GRV [5] prediction (dotted line) overshoots the ZEUS and H1 fits, but it should be noted that this can be partially explained by the lower value of α_s used for this prediction which is compensated by a higher gluon density especially at low x. Generally, the gluon is known with a total error of $\sim$10% at $x \sim 10^{-4}$.

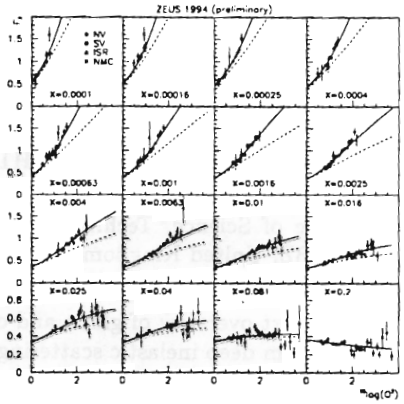

Fig. 1. The ZEUS NLO fit

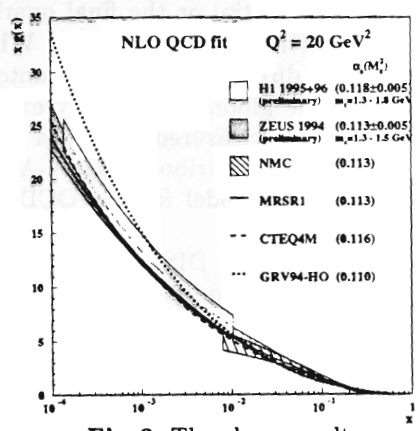

Fig. 2. The gluon result

3 Charm in DIS

In LO perturbative QCD charm is produced via the BGF process of Fig. 3. In its NLO

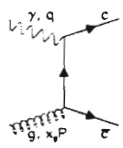

Fig. 3. The boson-gluon fusion process

extension, this approach was followed in the GRV analyses including the latest massive charm calculations [2] which actually predict a charm quark density given the gluon and light flavour densities. However, the inclusive F_2 behaviour can be equally well described by an arbitrary charm density $c(x, Q^2) = 0$ for $Q^2 \leq \mu_c^2$, evolved as a massless parton like the light flavours for $Q^2 > \mu_c^2$. The μ_c scale was chosen to fit the EMC data. It is however clear that the latter approach is not strictly correct. In the low x HERA regime BGF charm production is kinematically allowed even at very low Q^2 if the partonic centre of mass energy $\hat{s} = Q^2(1-z)/z \geq (2m_c)^2$, where $z = x/x_g$, x_g being the fraction of the proton momentum carried by the interacting gluon and m_c the charm mass. On the other hand, far from this energy threshold the charm is expected to behave like a massless parton. It is therefore very interesting to investigate both the onset of such a process and the transition between a heavy quark and a massless parton behaviour.

ZEUS and H1 have studied charm in DIS using D mesons in the final state. Current measurements are restricted in the region $1\,\text{GeV}^2 \leq Q^2 \leq 600\,\text{GeV}^2$ and $0.01 \leq y \leq 0.7$. The channels under investigation are $D^{*+} \to D^0\pi_s^+ \to (K^-\pi^+)\pi_s^+$ (+c.c.) and $D^0\pi_s^+ \to K^-\pi^+$ (+c.c.). It should be noted that the tracking detector acceptances limit the measurements in the region where $p_T(D) > 1.5$ GeV and $|\eta(D)| < 1.5$, where p_T is the transverse momentum with respect to the beam axis and $\eta = -\ln(\tan\frac{\theta}{2})$, the pseudorapidity of the D (θ being the polar angle w.r.t. the proton beam direction).

Preliminary results from the ZEUS analysis of the 1995 data on the cross sections for the production of D^* as functions of their p_T, η and the event Q^2 and hadronic invariant mass W for events in the forementioned $Q^2, y, p_T(D^*), \eta(D^*)$ region are shown in Fig. 4. The cross sections are compared with the prediction of [2] (shaded band) as

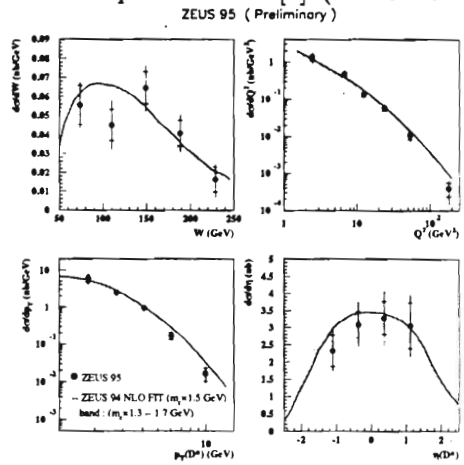

Fig. 4. Cross sections for D^* production

implemented in a 'Monte Carlo-like' program which allows charm to fragment to D^*. The Peterson fragmentation model with $\epsilon = 0.035$ was used. The input to this prediction is the gluon density and light flavours extracted from the ZEUS NLO fit to F_2 discussed in the previous section. The band width corresponds to the uncertainty on the charm mass. With the present experimental errors (quadratic sum of statistical and systematic) the theoretical predictions are in good agreement with the data in both shape and total normalisation.

By extrapolating the measured cross section to the whole $p_T(D^*), \eta(D^*)$ phase space and correcting for charm to D^* branching ratios the contribution $F_2^{c\bar{c}}$ of charm to the inclusive proton structure function F_2 is extracted. The

result is shown in Fig. 5 where $F_2^{c\bar{c}}$ is plotted

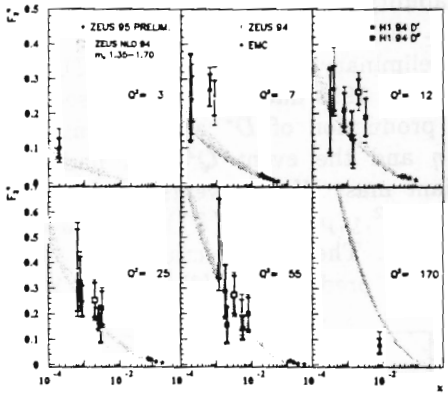

Fig. 5. $F_2^{c\bar{c}}$

as a function of x in various bins of Q^2. Data are shown from the 1994 analyses of H1 and ZEUS and the preliminary 1995 ZEUS analysis extending the Q^2 range to lower and higher Q^2. On the same plot data from the EMC collaboration are shown at higher x. The structure function at HERA rises by an order of magnitude compared to the EMC data. The shaded band is the prediction of [2] including the uncertainty on the charm mass. In general this prediction is in good agreement with the data of H1 and ZEUS.

In LO BGF the fraction of the proton momentum carried by the gluon, x_g, can be reconstructed from the virtual photon and one of the final state charm quarks, the momenta of which can be estimated from the scattered positron and the tagged D meson respectively. Although in higher orders the picture is not that simple, an estimator, x_g^{obs}, of the true x_g can always be reconstructed. A cross section for D production can then be measured in the restricted $p_T(D), \eta(D)$ region as a function of the x_g^{obs} observable quantity. Finally, using the Monte Carlo-like program of [2] to estimate the correlation between the observed and true x_g in NLO, the gluon momentum density $xg(x)$ can be extracted. The preliminary result of H1 from the 1995 data is shown in Fig. 6 as dots, compared to the H1 result

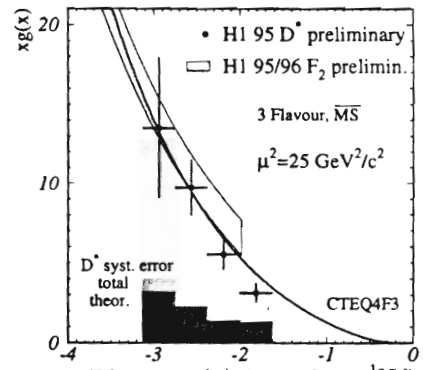

Fig. 6. $xg(x)$ from charm

for the gluon from their F_2 NLO fit discussed in the previous section, at an average scale of 25 GeV^2. The two results are in good agreement.

4 Summary and Conclusions

From NLO F_2 fits to the HERA data the gluon is constrained with an uncertainty of $\sim 10\%$ at $x \sim 10^{-4}$. In these fits the charm part of the structure functions is calculated analytically from BGF in NLO QCD. These calculations are consistent with direct measurements of the charm contribution from c-tagged events responsible for up to 25% of the proton structure function in the HERA regime. Future higher statistics measurements will allow the HERA experiments to make precise investigations of the charm production mechanism in the threshold region.

References

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