Measurement of the Inclusive ep Deep Inelastic Scattering Cross Section at Low Q^2 with the H1 Detector at HERA

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Abstract. The focus of this report are the recent measurements of the cross section and proton structure function F_2 in ep deep inelastic scattering (DIS) at low virtuality of the exchanged boson, Q^2 , with the H1 detector at the HERA accelerator in Hamburg. The region of low Q^2 and low Bjorken x allows precision tests of perturbative QCD at high gluon densities to be performed and also the transition from the perturbative to non-perturbative QCD domains to be explored. The recent H1 measurements of charm and beauty cross sections and structure functions, $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$, for photon virtuality $12 < Q^2 < 60 \text{ GeV}^2$ will also be discussed.

Keywords: Structure function F_2 , Neutral current, Deep inelastic scattering (DIS), HERA, H1, Perturbative Quantum Chromodynamics (pQCD), Initial state radiation (ISR), QED Compton (QEDC), Low Q^2 , Low x

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CROSS SECTION AND STRUCTURE FUNCTION $F_2(x, Q^2)$ AT LOW Q^2

Neutral Current DIS processes proceed via the exchange of neutral bosons, photon and Z^0 . The dominant contribution is photon exchange which is given in terms of the proton structure function $F_2(x, Q^2)$. This structure function provides information on the total quark content of the proton at given values of the Bjorken scale variable x and of the modulus of the squared four-momentum transfer, Q^2 , carried by the exchanged boson. Results obtained by the HERA experiments, H1 and ZEUS, have shown that the Q^2 evolution of the $F_2(x, Q^2)$ is well described by pQCD over a wide range of x and Q^2 . However, at $Q^2 \simeq 1 \text{ GeV}^2$ the transition to soft hadronic processes takes place, the strong coupling constant becomes large and pQCD is no longer applicable. In this "non-perturbative" domain data are described only by phenomenological models.

In order to access the transition region, the interaction vertex was shifted by about 70 cm along the proton beam direction during a dedicated time period in 2000. Data collected in 1999, with a special trigger set-up ("minimum bias run") are used for measurements in the region of high inelasticity, y , which is related to x and Q^2 via $y \simeq Q^2/(sx)$ with s being the squared centre of mass energy. The characteristics of low Q^2 DIS events is an electron ¹ scattered into the backward ² region the energy of

which is accurately measured in a lead fibre calorimeter (SpaCal). The Backward Silicon Tracker (BST) which is used to reconstruct the angle of the scattered electron, also significantly reduces background from neutral particles from photoproduction events. To further extend the available phase space at low Q^2 towards larger x , special event topologies, initial state radiation (ISR) [1] and inelastic QED Compton (QEDC) events [2], are used.

In ISR events a hard photon is emitted collinear with the incoming electron. Such event is treated as a usual ep interaction at a lower electron beam energy. This results in lower centre of mass energy such that larger values of x are reached at fixed Q^2 compared to non-radiative events. In this analysis detection of the radiated photon is not required and its existence is inferred from energy and longitudinal momentum conservation. The conservation law is also used to determine the photon energy.

In QEDC, emission of a photon from the electron line produces an experimental signature in which the outgoing electron and radiated photon are approximately back-to-back in the azimuthal plane in the main detector. In this configuration the transverse momenta of photon and electron nearly balance which characterises events with low virtuality Q^2 . The measured cross sections,

$$\sigma_r = \frac{Q^4 x}{2\pi\alpha^2 Y_+} \frac{d^2\sigma}{dx dQ^2} = F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2) \quad (1)$$

at lowest Q^2 values obtained with H1 are depicted in figure 1 as a function of x at fixed Q^2 . Here $Y_+ = 1 + (1-y)^2$ and F_L is the longitudinal structure function which gives sizable contributions at high y only. From figure 1 one can see that the results from

¹ In the text the expression "electron" is used to refer to both electrons and positrons.

² Backward is in H1 convention direction of lepton beam.

FIGURE 1. Reduced cross section measurements at lowest Q^2 from H1 compared with measurements from other experiments and theoretical model predictions (lines).

different analyses of the H1 data are consistent and are also in good agreement with measurements from ZEUS [3] and fixed target experiments. Also results of several model predictions are shown as lines.

High precision measurements from the region of medium Q^2 values have shown that the structure function F_2 can be parametrised as $F_2(x, Q^2) = c(Q^2) \cdot x^{-\lambda(Q^2)}$ for $x < 0.01$. The parameter λ is a measure of the rise of F_2 towards low x at fixed Q^2 . Results on the dependence of the parameter λ on Q^2 obtained from selected H1 data and their comparison to ZEUS data are shown on figure 2. At low Q^2 there is a change from a logarithmic dependence of λ on Q^2 to a weaker dependence approaching the value of 0.08 as $Q^2 \rightarrow 0$. Such a value is known to describe total hadron-hadron and photoproduction cross section. A distance scale which corresponds to this change is about 0.3 fm and can be interpreted as being related to a transition from partonic to hadronic degrees of freedom.

CHARM AND BEAUTY AT LOW Q^2

The H1 collaboration recently measured the charm (c) and beauty (b) contributions to the inclusive proton structure function F_2 in DIS in the range of low Q^2 , $12 \leq Q^2 \leq 60 \text{ GeV}^2$ and x , $0.0002 \leq x \leq 0.005$ [4]. This region is of particular interest because the large

FIGURE 2. Q^2 dependence of parameter λ (see the text) obtained from the fits to low x data from H1 compared to ZEUS measurements.

mass of the b quark suppresses the phase space available for production. Therefore, the measurement of beauty quarks at low Q^2 provides an important test of our understanding of QCD and the strong interaction in the threshold region. These heavy quarks are not ordinary constituents in the proton but are produced from the gluon density of the proton. Events containing heavy quarks are distinguished from those containing only light quarks by reconstructing the displacement of tracks from the primary vertex, using precise spatial information from the H1 vertex detector. The long lifetimes of c and b flavored hadron lead to larger displacements than for light quark events. The charm structure function $F_2^{c\bar{c}}$ and the beauty structure function $F_2^{b\bar{b}}$ are obtained from the measured c and b cross sections. The beauty data are the first measurement in this kinematic range. In this kinematic range the charm cross section contributes with about 24% of the inclusive ep cross section, and the beauty fraction increases from 0.4% at $Q^2 = 12 \text{ GeV}^2$ to 1.5% at $Q^2 = 60 \text{ GeV}^2$. The measurements are well described by predictions of perturbative QCD.

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