Preliminary Report **November 10, 2008**
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Combination of $F_2^{c\bar{c}}$ from $D^{*\pm}$ Measurement in DIS and inclusive measurement of displaced tracks at H1

H1 Collaboration

Abstract

The charm contribution to the proton structure, $F_2^c\left(x,Q^2\right)$, is determined using the cross sections of $D^{*\pm}(2010)$ meson production in deep-inelastic scattering and via measurements of the significance of the track displacement using the Central Silicon Tracker. The data are collected with the H1 experiment in the HERA-II running period corresponding to the integrated luminosity of 347 pb^{-1} for D^* analysis. For the displaced track analysis the HERA-II data of 2006 and 2007 are used corresponding to the integrated luminosity of 53.4 pb^{-1} (electron running) and 135.2 pb^{-1} (positron running). The measurements are interpolated to the common x, Q^2 grid using the massive Next-to-leading Order calculation in the fixed flavour number scheme. The results are combined using the averaging procedure developed for the inclusive F_2 taking into account the correlations between the systematic uncertainties of the single measurements and the cross correlations between both the measurement methods.

1 Introduction

Most recent results on the extraction of charm contribution to the proton structure function, F_2^c, at HERA have been published by the H1 collaboration [1],[2]. These data have shown clear evidence that the dynamics of charm production in ep scattering is dominated by the photon gluon fusion process. In this framework the process $e^+p \rightarrow e^+D^{*\pm}X$ is sensitive to the gluon density in the proton [3] and allows its universality to be tested. The current analysis uses data from the full HERA-II running period, yielding a integrated luminosity of 340 pb^{-1} for D^* analysis and 189 pb^{-1} for the displaced track measurements. H1 Preliminary results [4, 5] on the visible D^* inclusive cross sections at medium and high Q^2 as well as H1 Preliminary results on the measurement of the charm and beauty using the CST[2] are used.

The averaged $F_2^c\,(x, Q^2)$ obtained combining the D^* measurement and the results of the displaced track analysis provides yet the most precise $F_2^c\,(x, Q^2)$ measurement at HERA. Hence, more precise tests of perturbative QCD (pQCD) become possible.

2 Predictions for the charm contribution to the proton structure function

2.1 NLO Calculations in Fixed Flavour Number Scheme

The description of open heavy flavour production in electron proton collisions is based on perturbative QCD. In leading order (LO), the photon gluon fusion process ($\gamma g \rightarrow Q\overline{Q}$) is the dominant contribution. This treatment has been extended to next-to-leading order (NLO) for which calculations in several schemes are available [6, 7, 8, 9, 10]. All approaches assume the scale to be hard enough to apply pQCD and to guarantee the validity of the factorization theorem.

Here, the "massive approach" is adopted, i.e. a fixed order calculation with massive quarks assuming three active flavours in the proton. The momentum densities of the three light quarks and the gluon in the proton are evolved by the DGLAP equation [11]. The heavy quarks are assumed to be produced only at the perturbative level [6] via photon gluon fusion. These calculations are considered reliable in the regime $Q^2 \approx m_Q^2$. However, they are assumed to break down at some scale $Q^2 \gg m_Q^2$ due to large logarithms $\sim \ln(Q^2/m_Q^2)$.

Based on the NLO calculations of order α_s^2 in the coefficient functions[6] programs for different applications were developed in the fixed-flavour-number-scheme (FFNS). The Riemersma program [7] allows the calculation of inclusive quantities of heavy quark production, like $F_2^c(x, Q^2)$, while the HVQDIS program [8, 12] allows the calculation of exclusive quantities by providing the four-momenta of the outgoing partons. Both programs are based on the same calculation and use same input like PDFs, charm mass and factorization and renormalization scales.

The massive FFNS NLO calculation [7] was used to convert the reduced cross section measured with the lifetime tag technique[2] to the F_2^c values and to interpolate the values of the $F_2^c(x, Q^2)$ of both measurements to the common (x, Q^2)-grid. The MRST2004FF3NLO parton density was used, evaluated at m_c =1.43 GeV. The renormalization and factorization scales are set to $\mu_r = \mu_f = \sqrt{(}Q^2 + m_c^2)$. Additional asymmetric uncertainty due to variation of the scales $0.5\mu < \mu_r = \mu_f < 2\mu$ is added in quadrature to the total uncertainty of the averaged result. The CTEQ5F3 parton densities have been also used for the sake of comparison.

2.2 Predictions from the NLO and NNLO global fit

The averaged $F_2^c(x, Q^2)$ is compared to the preliminary predictions from the NLO and NNLO global fit of the MSTW-Group[13]. The calculation is done in the Thorne-Roberts Variable-Flavour number scheme, the coefficient functions for heavy quarks are based on ones in the ACOT-χ [14].

3 Averaging procedure

3.1 Instrument

The developed averaging program for combination of the inclusive DIS cross sections was used taking into account the bin-to-bin correlations of systematic uncertainties of the single measurement as well as the cross-correlations of the systematic of different measurement methods. The details of the inclusive averaging procedure can be found in[15].

3.2 Systematic uncertainties of D^*-measurement

The details of the systematic studies in D^* analysis can be found in [4, 5]. Sources of totally correlated, uncorrelated and partially correlated experimental systematic uncertainties are distinguished:

- correlated: electron kinematics: E_e, θ_e, hadronic energy E_{had}, luminosity L, trigger efficiency, branching ratio for the decay channel $D^* \to KK\pi$, charm fragmentation fraction $c \to D^*$, photoproduction background, stability of the efficiency due to usage of RAPGAP or CASCADE Monte-Carlo Simulation.
- uncorrelated: Extraction of the D^* signal (fit shape), stability of the efficiencies due to the variation of the PDF in the Monte-Carlo, variation of the cut on the D^0 mass, contribution of reflections to the D^* signal, radiative corrections
- partially (50%): CJC tracking efficiency, reconstruction of the primary vertex.

As reported in[1] the extrapolation of the visible D^* cross section to the full phase space can be done using the models CASCADE or HVQDIS. Although the extrapolation factors of the two models differ only by few percent at low x, in the highest x bin at $5 < Q^2 < 100$ GeV^2 they differ by a factor of two. The origin of this difference is apparently neither the parton evolution nor the difference of the NLO and the parton shower model. It is assumed that the reason for such a difference in the extrapolation at low y is a color drag effect with is currently under investigation. For the combination, the average value of the F_2^c obtained using HVQDIS and CASCADE models is taken. The highest x points are excluded. The half-difference of the CASCADE and HVQDIS extrapolated F_2^c values are taken as a symmetric systematic uncertainty. This extrapolation uncertainty is treated 100% bin-to-bin correlated. The extrapolation uncertainties due to variation of the parameters of the charm fragmentation model are taken into account as 100% bin-to-bin correlated.

3.3 Systematic uncertainties of the displaced track measurement

The details of the systematic studies in displaced track analysis can be found in [2]. The correlated and uncorrelated uncertainty courses are:

- correlated: dca smearing, CJC track finding efficiency, CST track finding efficiency, D- and B- multiplicities, c- and b-fragmentation, QCD model uncertainty, hadronic energy E_{had}, ϕ_{had}, normalization uncertainty[1].
- uncorrelated: the light flavour background

Three systematic uncertainty sources are treated as cross-correlated between the D^* and the displaced track measurements: CJC track finding efficiency, hadron energy and the c-quark fragmentation.

3.4 Results

The common $(x, Q2)$-grid which is a compromise from the grids of both measurements is presented in Tab. 1. The $F_2^c(x, Q^2)$ is interpolated to the common grid using the NLO calculation.

Q^2	x			
6.5	0.000800	0.000500	0.000300	0.000160
12.0	0.001500	0.000900	0.000500	0.000320
20.0	0.002500	0.001350	0.000800	0.000500
35.0	0.003400	0.002400	0.001400	0.000800
60.0	0.008000	0.005000	0.003200	0.001800
120.0	0.003200	0.002000		
200.0	0.013000	0.005000		
400.0	0.025000	0.013000		

Table 1: Common grid for the F_2^ccombination

In Fig. 1 the interpolation factors for the point swimming to the common grid are shown.

As a result of the averaging procedure the correlated uncertainties of the single measurement decrease. The improvement of the systematic uncertainties due to the averaging is summarized in [17]. The combined values of $F_2^c(x, Q^2)$ are shown in Fig. 2.

Precision of the combined values of $F_2^c(x, Q^2)$ compared with the original measurements is shown in Fig. 3. The combined values of the $F_2^c(x, Q^2)$ are compared to the theoretical predictions in Fig. 4. The massive FFNS NLO calculation [7] using the CTEQ5F3 parton densities describes the data best. The prediction using the matched FFNS-VFNS NLO approach for the global fit by the MSTW group [13] is much above the data, while the NNLO prediction describes data best at medium Q^2 and overshoots the data at high Q^2.

[1]To obtain the value of the F_2^c, the charm fraction extracted via the lifetime information is normalized to the published value of the inclusive F_2[16]. The normalization uncertainty therefore refers to the error of the luminosity measurement for the HERA-I data.

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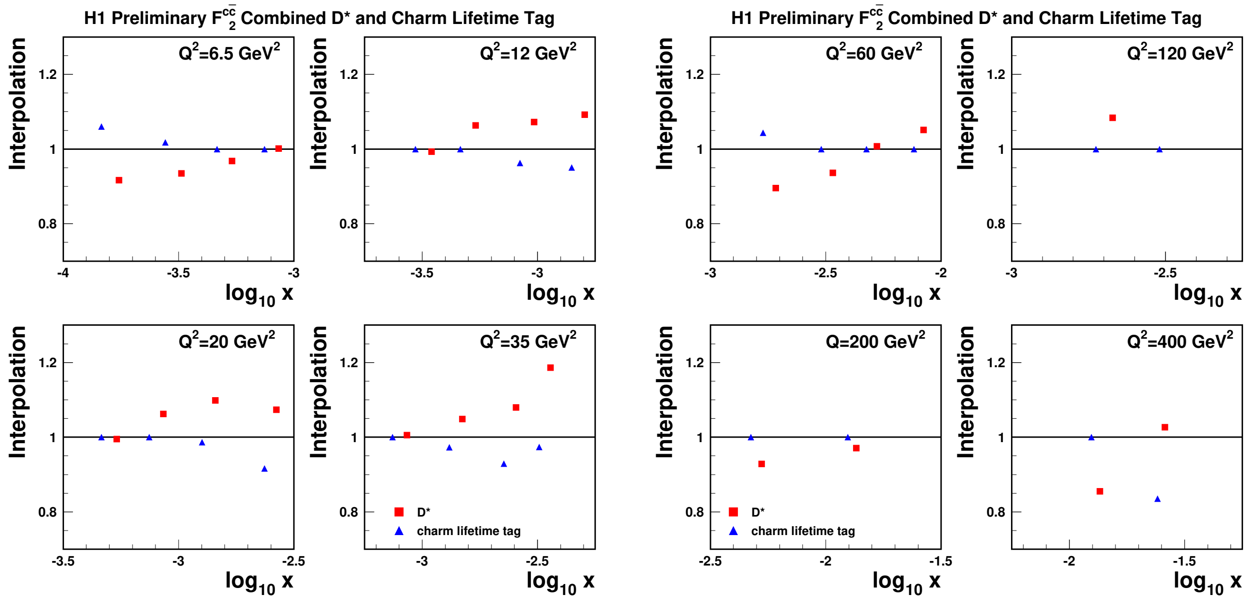

Figure 1: Interpolation factors for the point swimming to the common grid for D^*-measurement (red squares) and the displaced track measurement (blue triangles)

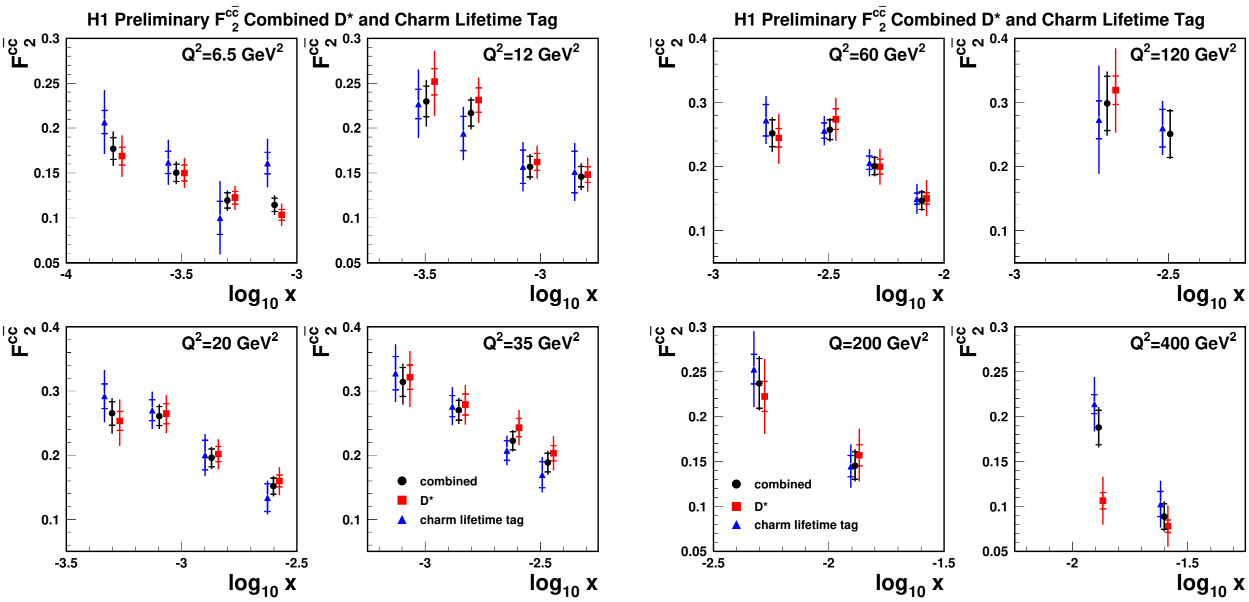

Figure 2: Charm contribution to the proton structure function, F_c^2, as a function of x in bins of Q^2 as combined (black circles) from the D^*-measurement (red squares) and the displaced track measurement (blue triangles). The measured values with total uncertainties are shown. Interpolation is taken into account. The x-values of the D^* and the displaced track measurements are shifted left and right from the central x-values for the presentation purpose.

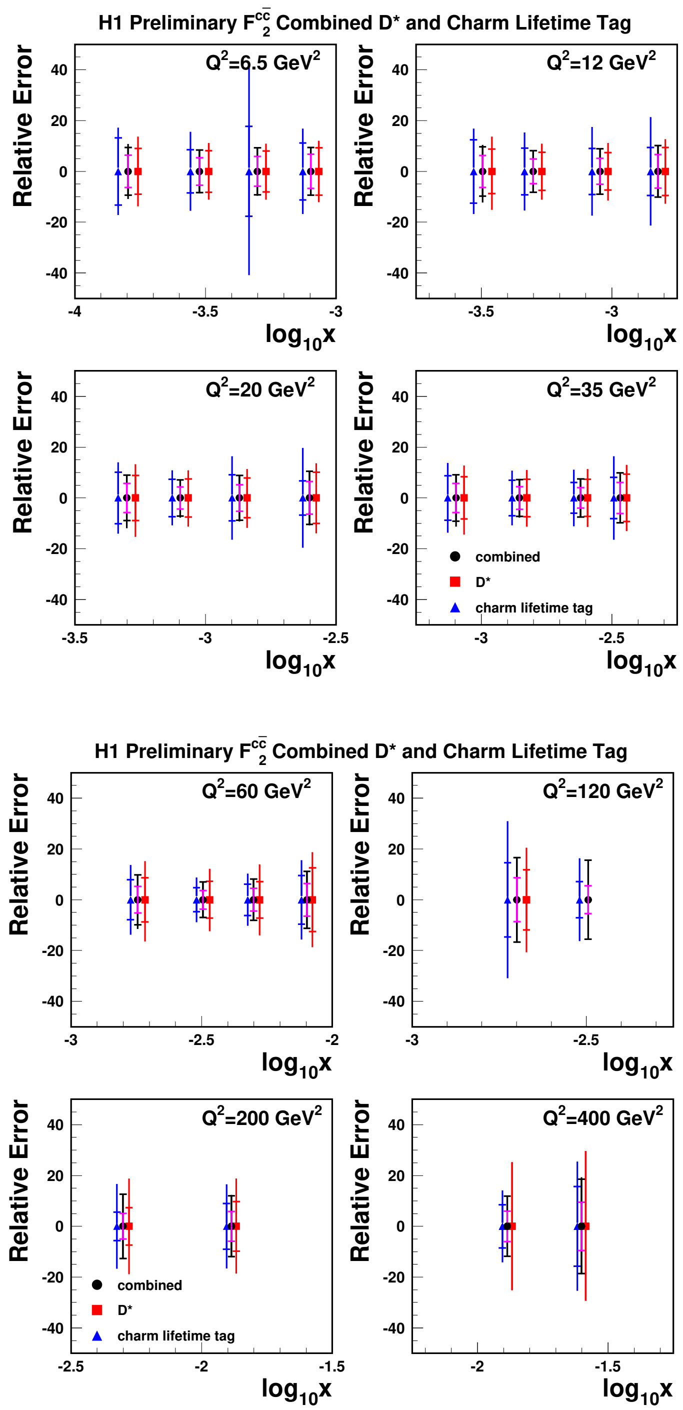

Figure 3: Relative uncertainties (percent) of the combined F_c^2(black circles) are compared with the D^*-measurement (red squares) and the displaced track measurement (blue triangles). The inner (full) error bars represent the uncorrelated (total) uncertainty of the D^* and displaced track measurement. The uncorrelated uncertainty of the combined measurement is shown in magenta. The total uncertainty as obtained from the averaging procedure is represented by the outer error bar. The scale variation uncertainty added in quadrature to the total uncertainty (full error bar).

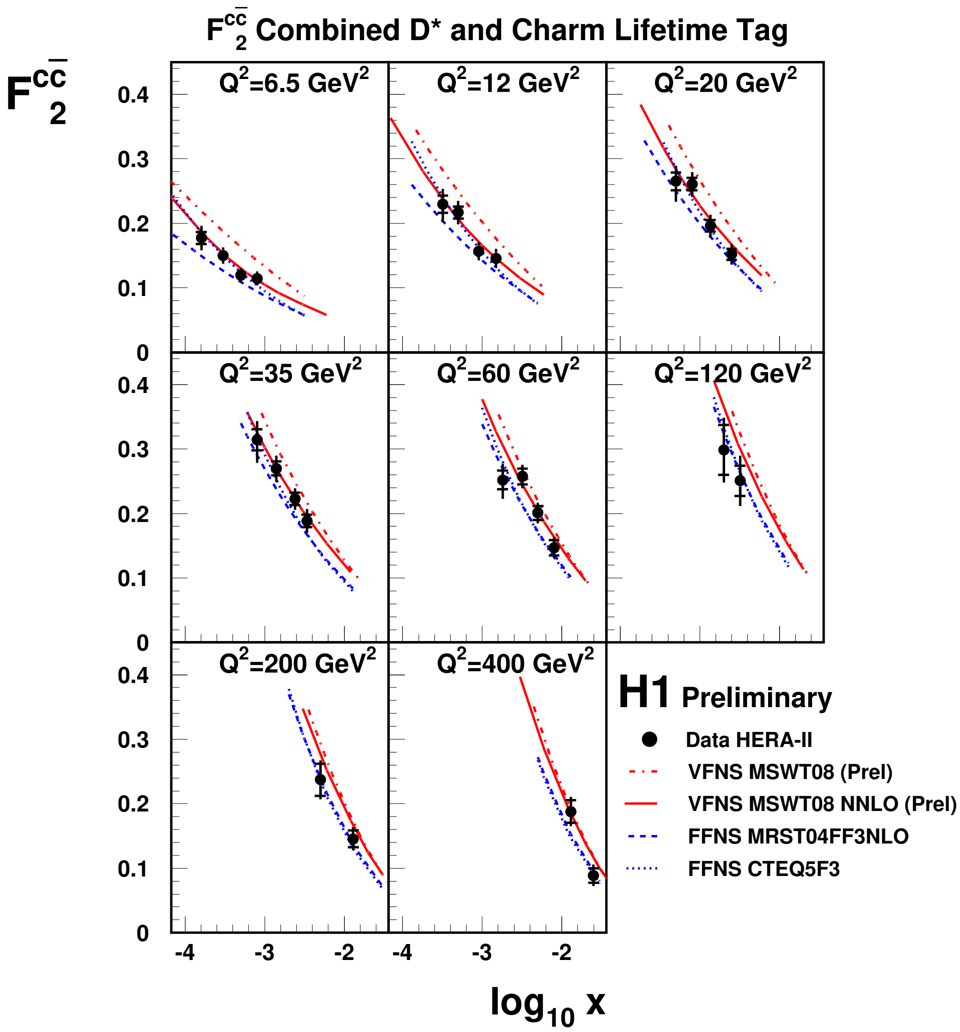

Figure 4: The combined F_2^c (black symbols) compared to the theory curves: RT-matched VFNs with MSTW08 PDF in NLO (red dash-dotted line), and NNLO(red solid line); massive FFNS calculation using MRST04nlo PDFs(blue dashed line) and CTEQ5F3 (blue dotted line). The inner error bars represent the statistic uncertainty, the full error bar show the total uncertainty.