QCD Analysis of the Combined H1 and ZEUS $F_2^{c\bar{c}}$ Data and the Impact on the Z, W Cross Section Predictions at the LHC

Ringailė Plačakytė
on behalf of the H1 and ZEUS collaborations

Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany

Abstract. A next-to-leading order QCD analysis is performed to the preliminary combined H1 and ZEUS $F_2^{c\bar{c}}$ measurement together with the published HERA inclusive neutral and charged current cross sections. Several models in variable flavour number scheme were used for the treatment of the $F_2^{c\bar{c}}$ data in the fits and the optimal value of the charm quark mass parameter m_c^{model} was estimated for each of the given models. The parton distribution functions determined with the $F_2^{c\bar{c}}$ data and the optimal charm mass parameter m_c^{model} of the particular model are further used to predict the $W^{\pm}$ and Z production cross sections at the LHC. Good agreement between these predictions for the $W^{\pm}$ and Z cross sections is observed which allows to reduce the prediction uncertainty due to the heavy flavour treatment to below 1.0%.

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INTRODUCTION

In DIS heavy quarks are produced dominantly via boson-gluon fusion. The charm contribution to the total DIS cross section at HERA is significant and reaches about 30% at large values of Q^2 (the beauty contribution is an order of magnitude smaller). In the preliminary combination of the H1 and ZEUS $F_2^{c\bar{c}}$ measurements [1] the charm contribution $F_2^{c\bar{c}}$ to the proton structure function F_2 is determined with high precision $(5-10\%)$ in the covered kinematic range from 2 to 1000 GeV^2 in the four-momentum transfer squared Q^2. The high accuracy of the data allows to reduce the ambiguity in the separation of the heavy and light quark densities in parton distribution functions (PDFs) and to test various implementations of the variable flavour number schemes (VFNS). A QCD analysis is therefore performed including the charm data together with inclusive DIS cross sections measured at HERA [2].

At NLO VFNSs have a significant ambiguity in describing the onset of the heavy quark densities at scales Q comparable with the heavy quark pole masses for the charm and bottom quarks, m_c and m_b, respectively. Different approaches for the interpolation function and counting of orders in α_S lead to a number of VFNSs, several of which are considered here. In all schemes, the onset of the heavy quarks is controlled by the parameter $m_{b,c}^{\text{model}}$. In this analysis the optimal m_c^{model} value for each of the VFNS is determined and is used later in the calculation of the predictions for the $W^{\pm}$ and Z cross sections at the LHC.

QCD ANALYSIS OF THE CHARM DATA

QCD Fit Settings

For the QCD analysis of the HERA charm data the same analysis settings as in HERAPDF1.0 [2] were used. The PDFs are evolved using the DGLAP evolution equations at NLO in the $\overline{\text{MS}}$ scheme with the renormalisation and factorisation scales set to Q^2 and the strong coupling set to $\alpha_s(M_Z) = 0.1176$. The QCD predictions for the structure functions are obtained by a convolution of the PDFs with the NLO coefficient functions calculated using different implementations of the general mass variable favour number scheme: ACOT full [3] as used for the CTEQHQ releases of PDFs, S-ACOT-χ [4] as used for the latest CTEQ releases of PDFs, the RT standard scheme [5, 6] as used for the MRST and MSTW releases of PDFs, as well as an optimised RT scheme providing a smoother behaviour across thresholds [6]. The ZMVFNS as implemented by the NNPDF(2.0) group [7] is also considered in the analysis.

In additional to the standard parametrisation used in [2], a flexible parameterisation is used in this study which, compared to standard one, has additional parameters for the gluon in order to have more flexible shapes of the gluon PDF and the low starting scale. These modifications are necessary for the variation of the charm mass parameter down to $m_c^{\text{model}} = 1.2$ GeV where the starting scale must be chosen below $(m_c^{\text{model}})^2$. Other variants of the PDF parameterisations which proved to have an effect on HERAPDF1.0 have been considered and included in the evaluation of the systematic uncertainties for m_c^{model}.

Determination of the Optimal m_c^{model}

In this analysis first the HERAPDF1.0 data sets, i.e. the H1 and ZEUS combined inclusive NC and CC cross sections from HERA I [2] are fitted not including the charm $F_2^{c\bar{c}}$ data, then fits are repeated including the charm $F_2^{c\bar{c}}$ data. The procedure is repeated for all considered heavy flavour schemes.
In each heavy flavour scheme PDF fits were performed by varying m_c^{model} from 1.2 GeV to 1.8 GeV. For each fit the χ^2 value is calculated and the optimal value $m_c^{\text{model}}(\text{opt})$ is subsequently determined from a parabolic fit to the χ^2 data of a form

$$\chi^2(m_c^{\text{model}}) = \chi^2_{\min} + \left(\frac{m_c^{\text{model}} - m_c^{\text{model}}(\text{opt})}{\Delta_{m_c^{\text{model}}(\text{opt})}} \right)^2 , \quad (1)$$

where $\chi^2_{\min}$ is the χ^2 value at the minimum and $\Delta_{m_c^{\text{model}}(\text{opt})}$ is the experimental uncertainty on $m_c^{\text{model}}(\text{opt})$.
In the case when the fits are performed without charm data (Figure 1 left), χ^2 varies only little with m_c^{model} in the range 1.2 GeV to 1.8 GeV. When the charm data are included, χ^2 is much more sensitive to m_c^{model} (Figure 1 right). Fits using the standard and flexible gluon parameterisation show very similar behaviour as can be seen from Figure 1.

Figure 2 (left) summarises the study by showing the m_c^{model} scanning results for all schemes together. It is interesting to observe that the $\chi^2_{\min}$ values are comparable for all

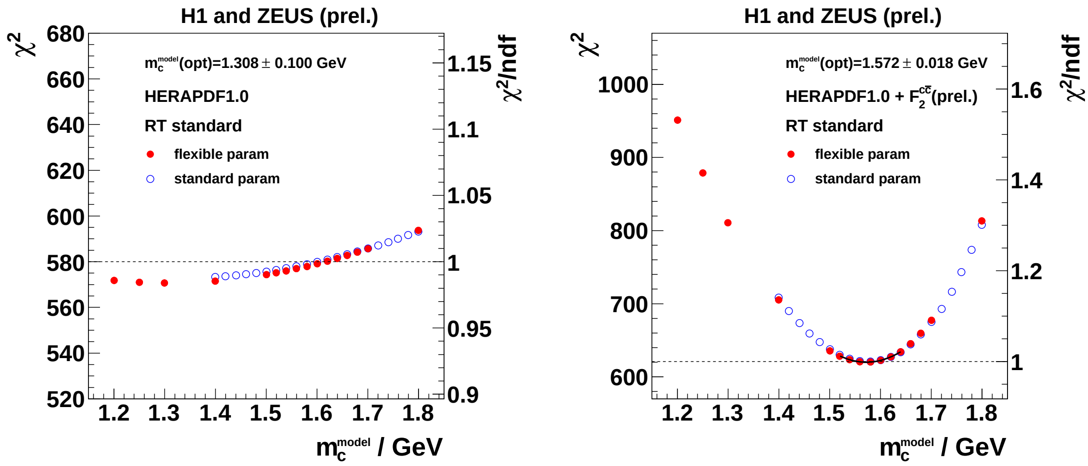

FIGURE 1. *χ^2 of the HERA I data fit (HERAPDF1.0) (left) and HERA I+$F_2^{c\bar{c}}$ fit (right) in the standard RT scheme as a function of m_c^{model} . Open and closed symbols represent flexible and standard gluon parametrisation, respectively (see text for the explanation).*

schemes despite different values of m_c^{model}(opt): The values of χ^2_{min} are almost identical for the standard RT, optimised RT and ACOT full schemes, and are worse by ~ 20 units for the S-ACOT χ scheme and by ~ 50 units for the ZMVFN scheme.

Impact to $W^{\pm}$ and Z Cross Section Predictions at the LHC

PDFs obtained from fits to the HERA data by the m_c^{model} scanning procedure are used to calculate predictions for $W^{\pm}$ and Z production cross sections at the LHC for $\sqrt{s} = 7$ TeV. These predictions are calculated for $1.2 \leq m_c^{model} \leq 1.8$ GeV in 0.1 GeV steps for each of the VFN schemes using the MCFM program, version 5.7, with the same conditions as for the PDF4LHC benchmarking [8]. As an example, the W^+ cross section as a function of m_c^{model} for the different schemes is shown in Figure 2 (right).

For all VFN schemes a similar monotonic dependence of the $W^{\pm}$ and Z boson production cross sections is observed. There is, however, a sizable offset between the predictions if they are considered for a fixed value of m_c^{model}: if the ZMVFN scheme is excluded (included) the difference reaches 4.5% (7%). Similarly, for each scheme the change of the prediction varies by about 7% for m_c^{model} rising from 1.2 to 1.8 GeV. However, when using m_c^{model}(opt) the spread of the predictions is reduced to 0.7% (2.3%) when excluding (including) the ZMVFNS. The ZMVFN scheme describes the data worst and differs significantly from the other schemes in the $W^{\pm}$ and Z cross section predictions.

CONCLUSIONS

Using preliminary $F_2^{c\bar{c}}$ data together with the published HERA I combined data, a NLO QCD analysis was performed based on different implementations of the variable

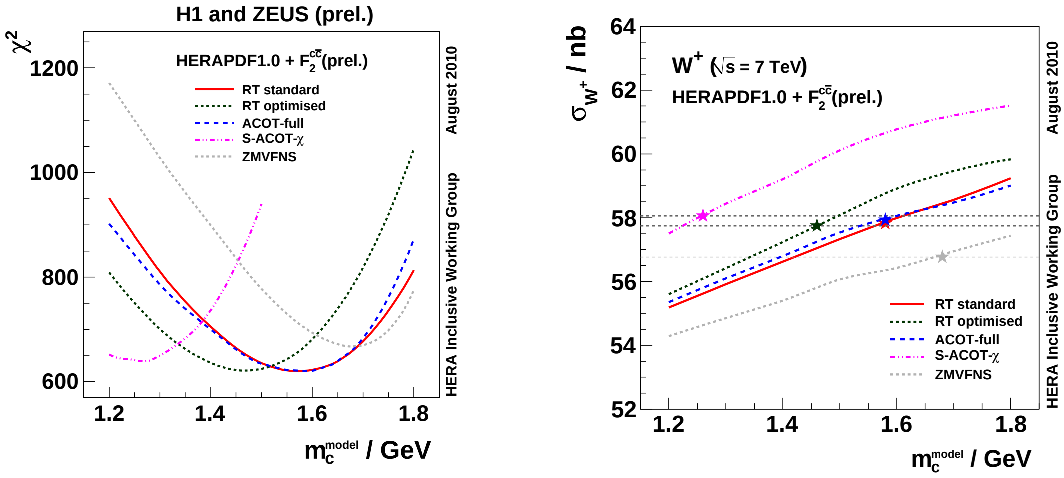

FIGURE 2. *Comparison of the χ^2 of the HERA I + $F_2^{c\bar{c}}$ fits using different heavy flavour schemes represented as lines of different styles (left). W^+ production cross section σ_{W^+} at the LHC for $\sqrt{s} = 7$ TeV as a function of m_c^{model}. The lines show predictions for different VFN schemes as indicated by the legend (right). The stars show the position of the corresponding $m_c^{model}(\mathrm{opt})$ values. The thick dashed horizontal lines indicate the range of σ_{W^+}, determined for $m_c^{model} = m_c^{model}(\mathrm{opt})$, if only the massive VFN schemes are considered. The thin dashed horizontal line corresponds to the prediction using the ZMVFN scheme for $m_c^{model} = m_c^{model}(\mathrm{opt})$.*

flavour number scheme. For each implementation, an optimal value of the charm mass parameter m_c^{model} was determined. The values of optimal m_c^{model} show a sizable spread, ranging between 1.26 GeV and 1.68 GeV. Apart from the ZMVFN scheme, all schemes were found to describe the data well, with comparable χ^2/dof, as long as m_c^{model} was taken at corresponding optimal values.

PDFs obtained from fits with different m_c^{model} were used to predict $W^{\pm}$ and Z production cross sections at the LHC. A sizable spread in the predictions was observed for each model when m_c^{model} was varied between 1.2 and 1.8 GeV, as well as when considering different schemes at a fixed value of m_c^{model}. This spread is significantly reduced when the optimal value of m_c^{model} is used in each VFNS model.

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