

## HERAPDF fits including $F_2(\text{charm})$ data

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PDF fits in the HERAPDF1.0 formalism have been made to the combined HERA-I inclusive data and the combined  $F_2(\text{charm})$  data from the H1 and ZEUS experiments. The charm data are found to be sensitive to the value of the charm mass and the choice of the heavy quark scheme. This has consequences for the predictions of  $W$  and  $Z$  cross-sections at the LHC.

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## 1. Introduction

The HERAPDF1.0 set of parton density functions was extracted from a fit to the combined inclusive deep-inelastic scattering data from the H1 and ZEUS experiments [1]. The predictions of these PDFs give a good description of the newly combined HERA  $F_2(\text{charm})$  data, for  $Q^2 > 4 \text{ GeV}^2$ . This PDF analysis used a central value for the charm quark mass  $m_c = 1.4 \text{ GeV}$  following previous PDF analyses [2]. However a model uncertainty,  $1.35 < m_c < 1.65 \text{ GeV}$ , was also evaluated. The newly combined charm data are sensitive to the choice of charm mass, thus a reduction in model uncertainty should be possible. However, the HERAPDF1.0 used a specific heavy quark mass scheme - the general-mass variable-flavour-number scheme of Thorne and Roberts (RT-VFN) [3]. The present contribution describes fits made in the HERAPDF formalism, including the combined HERA  $F_2(\text{charm})$  data, using various different heavy quark mass schemes and various values of the charm quark mass. Full details are given in the original talk [4].

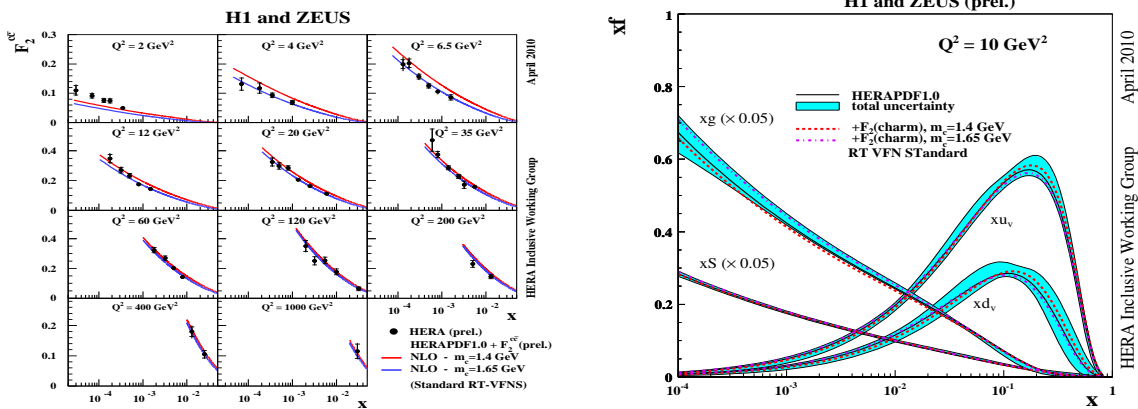
## 2. HERAPDF Fits including $F_2(\text{charm})$ data

Firstly the HERA combined  $F_2(\text{charm})$  data are included in the fit using the standard version of the RT-VFN scheme as used for MSTW08 PDFs. The usual cut,  $Q^2 > 3.5 \text{ GeV}^2$ , is applied to these fits such that there are 41 charm data points in addition to the 592 data points from combined HERA-I inclusive data on Neutral Current (NC) and Charged Current (CC)  $e^+p$  and  $e^-p$  scattering. Charm mass values,  $m_c = 1.4 \text{ GeV}$ , and the pole-mass,  $m_c = 1.65 \text{ GeV}$ , are investigated. The charm data prefer the higher value, see Table 1. These fits and the PDFs which correspond to them are shown in Fig. 1. The larger charm mass suppresses charm production and the gluon PDF which corresponds to it is enhanced at low  $x$ .

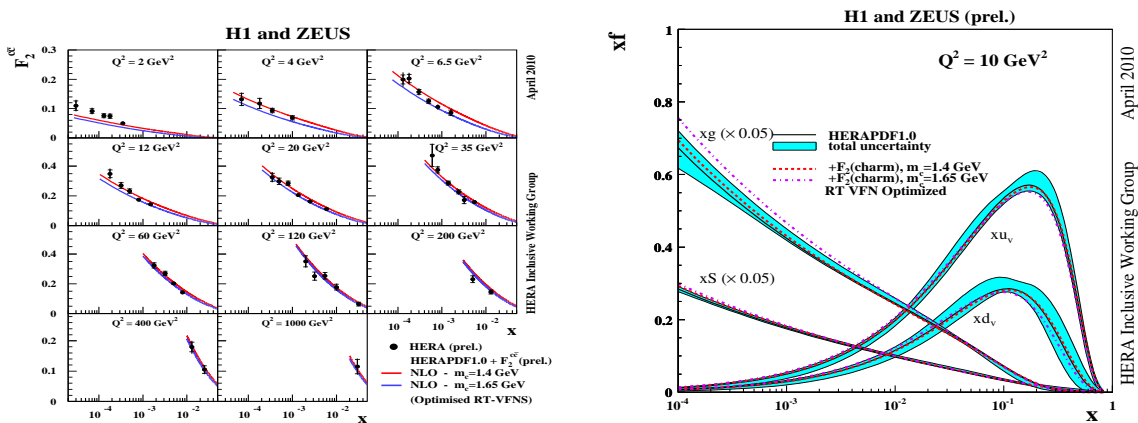
Scheme	total $\chi^2/\text{ndp}$	$F_2(\text{charm}) \chi^2/\text{ndp}$
RTVFN Standard ( $m_c = 1.4$ )	730.7/633	134.5/41
RTVFN Standard ( $m_c = 1.65$ )	627.5/633	43.5/41
RTVFN Optimized ( $m_c = 1.4$ )	644.6/633	64.8/41
RTVFN Optimized ( $m_c = 1.65$ )	695.4/633	100.1/41
ACOT ( $m_c = 1.4$ )	644.6/633	89.5/41
ACOT ( $m_c = 1.65$ )	605.7/633	41.4/41
FFN ( $m_c = 1.4$ )	567.0/565	51.7/41
FFN ( $m_c = 1.65$ )	852.0/565	248.9/41
NNLO ( $\alpha_s = 0.1176$ , $m_c = 1.4$ )	703.1/633	60.3/41
NNLO ( $\alpha_s = 0.1176$ , $m_c = 1.65$ )	832.9/633	185.7/41
NNLO ( $\alpha_s = 0.1145$ , $m_c = 1.4$ )	681.1/633	54.5/41
NNLO ( $\alpha_s = 0.1145$ , $m_c = 1.65$ )	862.3/633	198.0/41

**Table 1:**  $\chi^2$  per data point for HERAPDF fits to HERA-I data and combined  $F_2(\text{charm})$  data for various values of the charm mass and various heavy quark schemes. Fits are made at NLO unless otherwise stated.

Thorne has suggested possible modifications of the heavy quark scheme [5]. An optimized scheme has been selected for study because of its smooth threshold behaviour. In this scheme the



**Figure 1:** Left: comparison of  $F_2(\text{charm})$  data to a PDF fit which includes these data for  $m_c = 1.4$  and  $1.65$  GeV, using the standard RT-VFN scheme. Right: the PDFs which correspond to these two fits.

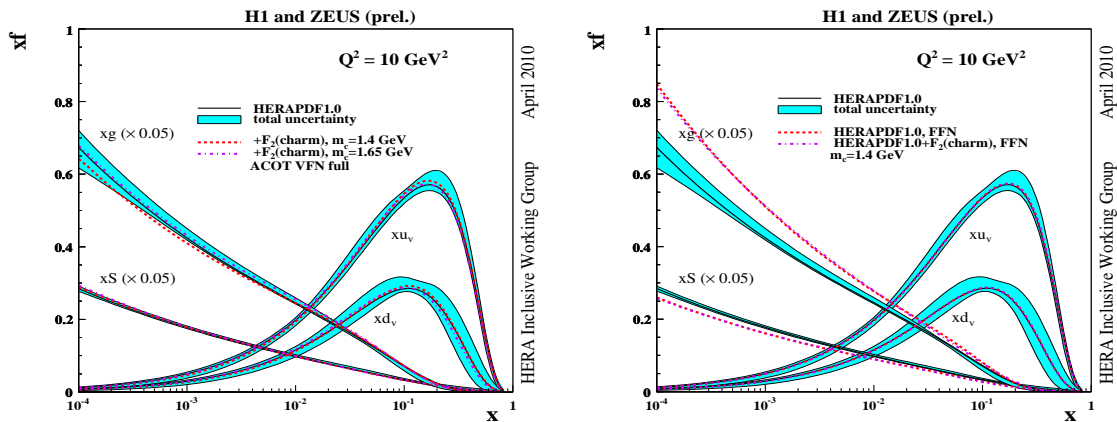


**Figure 2:** Left: comparison of  $F_2(\text{charm})$  data to a PDF fit which includes these data for  $m_c = 1.4$  and  $1.65$  GeV, using the optimized RT-VFN scheme. Right: the PDFs which correspond to these two fits.

charm data prefer mass charm,  $m_c = 1.4$  GeV, see Table 1. The fits to the data and the resulting PDFs are shown in Fig. 2. The smoother threshold behaviour of this scheme can be clearly seen. Charm production at threshold is somewhat suppressed in this scheme relative to the standard scheme so that a large charm mass is not needed for a good fit to data. The gluon PDF is somewhat enhanced at low  $x$  in the optimal scheme as compared to the standard scheme.

A different general-mass VFN scheme is the ACOT scheme [6]. In fits using the ACOT scheme the charm mass,  $m_c = 1.65$  GeV, is preferred, see Table 1. The fits to the data are similar to the RTVFN standard scheme fits. The corresponding PDFs are shown in Fig. 3. The PDFs including the charm data for all these general-mass VFN schemes are not very different from the HERAPDF1.0 PDFs.

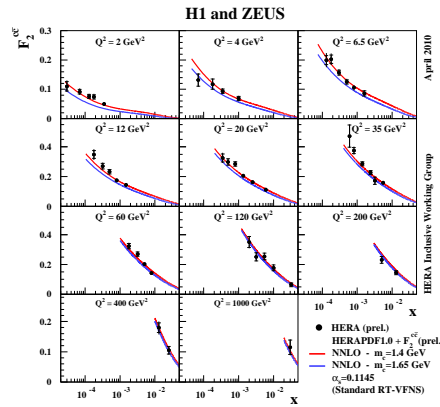
A Fixed Flavour Number (FFN) scheme can also be used [7]. However, the CC  $e^+$  and  $e^-$  scattering data cannot be used in such a scheme since there is no complete calculation of the appropriate NLO coefficient functions. In the HERAPDF1.0 analysis the CC data were used to



**Figure 3:** Left: PDFs corresponding to the ACOT scheme fit for  $m_c = 1.4$  and  $1.65$  GeV. Right: PDFs corresponding to the FFN scheme fit for  $m_c = 1.4$  and  $1.65$  GeV.

constrain the valence quark PDFs. Thus for the FFN fits the valence quark parameters are fixed at their HERAPDF1.0 values and only the sea and gluon parameters are varied while fitting to NC data (524 points) and the charm data. Two further modifications are made for the FFN fit: firstly the heavy quark factorisation scale is chosen to be  $Q^2 + 4m_c^2$  (instead of  $Q^2$  as for the RTVFN and ACOT schemes); secondly the running of  $\alpha_s(Q^2)$  with  $Q^2$  is calculated using only 3-flavours (instead of using 3-, 4- and 5-flavour evolution with matching prescription at flavour thresholds as for the general mass VFN schemes). This means that a low equivalent value of  $\alpha_s(M_Z) = 0.105$  must be used to ensure that  $\alpha_s$  is not too high to give a good description of low-scale data. For these FFN fits charm is suppressed at threshold relative to the RT-VFN fits and the value  $m_c = 1.4$  GeV is preferred by the data, see Table 1. The fits to the data are similar to those of the optimized TR-VFN scheme but the corresponding gluon PDF is strikingly different, see Fig. 3. The FFN gluon is very much enhanced compared to that of the GMVFN schemes (note the Sea only appears smaller because of the lack of a charmed parton). Variations of the FFN fit have also been tried:  $Q^2$  has been used as the heavy quark factorisation scale; a cut  $Q^2 < 3000$  GeV<sup>2</sup> has been applied since the FFN scheme does not resum  $\ln(Q^2/m_c^2)$  terms; alternative PDF parametrisations have been tried. None of these modifications change the resulting PDF shapes significantly, although the addition of an extra gluon parameter gives a modest improvement in  $\chi^2$ .

Finally NNLO fits in the RT-VFN scheme were tried. Although Thorne has suggested possible variations in the heavy quark scheme at NNLO the differences between these schemes are far less than at NLO. The Standard NNLO scheme was used. Fits were made for two different values of  $\alpha_s(M_Z)$ ; 0.1176 -the HERAPDF1.0 central value- and 0.1145. This is because PDF fits with  $\alpha_s(M_Z)$  free prefer the latter value at NNLO- albeit with a large error. By contrast, at NLO the preferred value, 0.1166, is much closer to the standard value. The NNLO fits prefer  $m_c = 1.4$  GeV, whichever value of  $\alpha_s(M_Z)$  is used, see Table 1. Fig. 4 shows the NNLO fits to data for  $\alpha_s(M_Z) = 0.1145$ . The shape of NNLO fit is somewhat different from the NLO fits and even though data at  $Q^2 = 2$  GeV<sup>2</sup> are not included in the fit they are well described.



**Figure 4:** Comparison of  $F_2(\text{charm})$  data to a PDF fit which includes these data for  $m_c = 1.4$  and  $1.65$  GeV, using the standard RT-VFN scheme at NNLO and  $\alpha_s = 0.1145$ .

### 3. Summary and Discussion

PDF fits have been made to the combined HERA-I inclusive NC and CC data and to the combined  $F_2$  charm data. The charm data are sensitive to the value of the charm mass and the choice of heavy quark mass scheme. This has consequences for predictions of the  $W$  and  $Z$  cross-sections at the LHC. A larger charm mass means suppressed charm at threshold and thus the lighter quarks are enhanced to compensate. This results in a 2.5% higher  $W, Z$  cross-section for  $m_c = 1.65$  GeV as compared to  $m_c = 1.40$  GeV [8]. Thus there is some uncertainty in these predictions resulting from the use of different heavy quark schemes and masses, which will be the subject of further study.

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