The Charm–Strange Contribution to Charged–Current DIS Structure Functions

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Abstract: We review the present theoretical knowledge of the charm–strange contribution to charged–current DIS structure functions. In particular, the uncertainties arising from the choice of the factorization scale, of the massive QCD scheme, and of the parton fit are discussed.

1 Cross Sections

Charm production in charged–current (CC) deep inelastic scattering (DIS) is the best way to obtain information on the strange sea density [1], which is at present the most poorly known among the light–quark distributions. The strange distribution can also be obtained by properly combining fully inclusive CC cross sections. CC reactions are thus necessary in order to determine the strange sector and, in general, to reconstruct the whole flavor systematics.

The relevant subprocesses for charm excitation in CC DIS are (we consider only Cabibbo unsuppressed diagrams):

i) the $\mathcal{O}(\alpha_s^0)$ direct transition $W^+ s \to c$;

ii) the $\mathcal{O}(\alpha_s^1)$ W-gluon and W-quark fusion processes $W^+ g \to \bar{s} c\,,\ \ W^+ s \to gc$.

The CC DIS cross section reads

$$\frac{\mathrm{d}^2\sigma^{\pm}}{\mathrm{d}x\mathrm{d}y} = \frac{G^2 s}{4\pi(1+\frac{Q^2}{M_W^2})^2}\left[xy^2 F_1 + (1-y-\frac{m_N^2 xy}{s})F_2 \mp (y-\frac{y^2}{2})xF_3\right] , \tag{1}$$

where the subscript + (−) denotes the reaction $e^+ N \to \bar{\nu} X$ ($e^- N \to \nu X$). If we restrict ourselves to charm excitation we get at order α_s^0 (for electron scattering)

$$\frac{\mathrm{d}^2\sigma_{cs}}{\mathrm{d}\xi\mathrm{d}y} = \frac{G^2 s}{4\pi(1+\frac{Q^2}{M_W^2})^2}\, 2\xi\, \bar{s}(\xi,Q^2)|V_{cs}|^2\,[(1-y)^2 + \frac{m_c^2}{s\xi}\,(1-y)] , \tag{2}$$

where the slow rescaling variable $\xi = x\,(1+m_c^2/Q^2)$ accounts for the finite mass of the charmed quark in the $Ws \to c$ transition. The cross section for positron scattering is obtained by the replacement $\bar{s} \to s$. The cross section (2) provides a direct measure of the strange sea density.

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However, at order α_s (often referred to, somehow improperly, as the next–to–leading order) formula (2) does not hold any longer because of the more complicated relation between structure functions and parton densities. The most important $\mathcal{O}(\alpha_s)$ contribution comes from the vector-boson–gluon fusion term which incorporates important dynamical effects (quark–mass threshold effects and large longitudinal contributions due to the non conservation of weak currents [2]).

2 Theoretical Uncertainties

The QCD analysis of the charm–strange structure function at order α_s is affected by theoretical uncertainties which have two sources: *i)* the choice of the massive QCD scheme; *ii)* the arbitrariness of the factorization scale. Besides these, there is a further uncertainty coming from the choice of the parton fit among those available on the market.

The most commonly used $\mathcal{O}(\alpha_s)$ schemes for massive quarks are the Fixed Flavor Scheme (FFS) [3] and the Variable Flavor Scheme (VFS) [4].

In the FFS, charm is treated as a heavy quark, in an absolute sense. There is no charm excitation term in the structure functions and the number of active flavors is $N_f = 3$. The collinear divergence $\log(Q^2/m_s^2)$ in the gluon fusion term is regularized at a scale μ^2. For the cs contribution to the F_2 structure function one explicitly has

$$\text{FFS}: \quad F_2^{cs}(x,Q^2) = 2\,\xi\, s(\xi,\mu^2) + \frac{\alpha_s(\mu^2)}{2\pi}\int_\xi^1 \frac{\mathrm{d}z}{z}\, 2\xi\left[C_2^g(z,\mu^2)\, g(\xi/z,\mu^2) + C_2^q(z,\mu^2)\, s(\xi/z,\mu^2)\right], \tag{3}$$

where the Wilson coefficients C_2^g and C_2^q can be found in the literature [5].

In the VFS, charm is a "heavy" flavor for $\mu^2 < m_c^2$, and a partonic constituent of the nucleon for $\mu^2 > m_c^2$. Both the strange and the charm excitation terms appear and hence there are two subtractions in the Wilson coefficient, corresponding to the two singularities in the limits $m_s \to 0$ and $m_c^2/Q^2 \to 0$. The explicit expression is

$$\begin{aligned} \text{VFS}: \quad F_2^{cs}(x,Q^2) &= 2\,\xi\left[s(\xi,\mu^2) + c(x,\mu^2)\right] \\ &+ \frac{\alpha_s(\mu^2)}{2\pi}\int_\xi^1 \frac{\mathrm{d}z}{z}\, 2\xi\left[\hat{C}_2^g(z,\mu^2)\, g(\xi/z,\mu^2) + \hat{C}_2^q(z,\mu^2)\, s(\xi/z,\mu^2)\right], \end{aligned} \tag{4}$$

where $\hat{C}_2^{g,q}$ denotes the doubly subtracted massive Wilson coefficients.

The factorization scale μ^2 is arbitrary and only an educated guess can be made on it. It is clear that a knowledge of the CC structure functions at order α_s^2, still lacking at present, would allow testing the perturbative stability of the various choices.

3 Results

We estimate now the theoretical uncertainties on F_2^{cs} and on the cs contribution to the DIS cross section.

In Fig. 1 we show the results of the calculation of F_2^{cs} and of

$$\tilde{\sigma}^{cs} \equiv K\,\frac{d\sigma^{cs}}{dx\,dy}\,, \qquad K^{-1} = \frac{G^2 s}{2\pi\,(1+Q^2/M_W^2)^2}\,|V_{cs}|^2\left[(1-y)^2 + \frac{m_c^2}{s\xi}\,(1-y)\right], \tag{5}$$

at $Q^2 = 100$ GeV^2, for various NLO parton fits: MRS(A) [6], MRS(R$_1$) [7], CTEQ(4M) [8], GRV [9]. The scheme used is the FFS and the factorization scale is taken to be $\mu^2 = Q^2$. In the box on the right we also display $\xi s(\xi, Q^2)$, that is what $\tilde{\sigma}^{cs}$ reduces to at order α_s^0. Note that the CTEQ(4M) and MRS(R$_1$) curves nearly coincide whereas there is a non negligible difference between the two MRS fits and a larger discrepancy between MRS(R$_1$) and GRV. The global uncertainty due to the choice of the fit amounts to $\sim 30\%$ both for F_2^{cs} and for $\tilde{\sigma}^{cs}$.

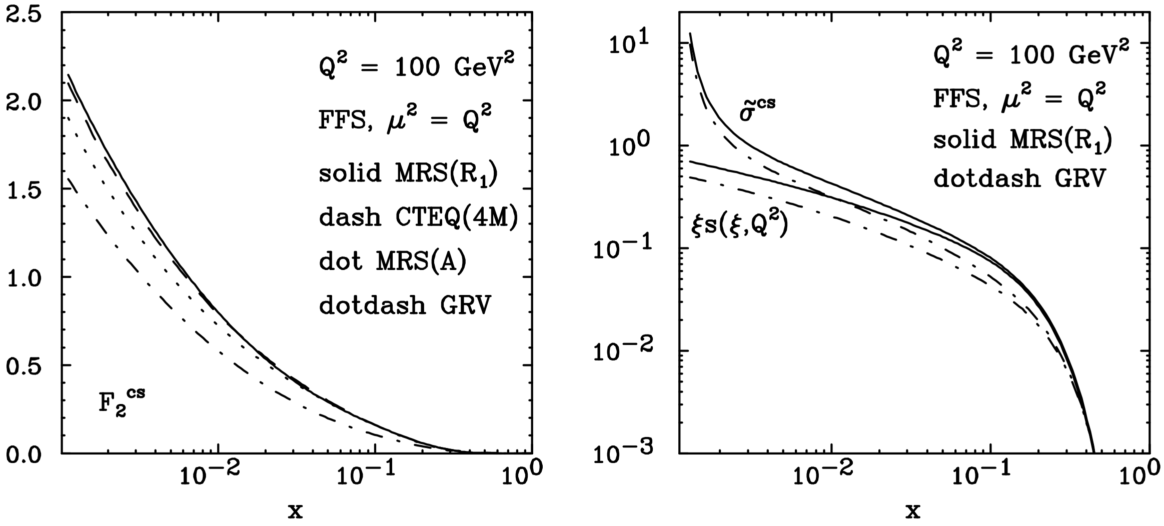

Figure 1: *F_2^{cs} and $\tilde{\sigma}^{cs}$ in the FFS for various parton fits.*

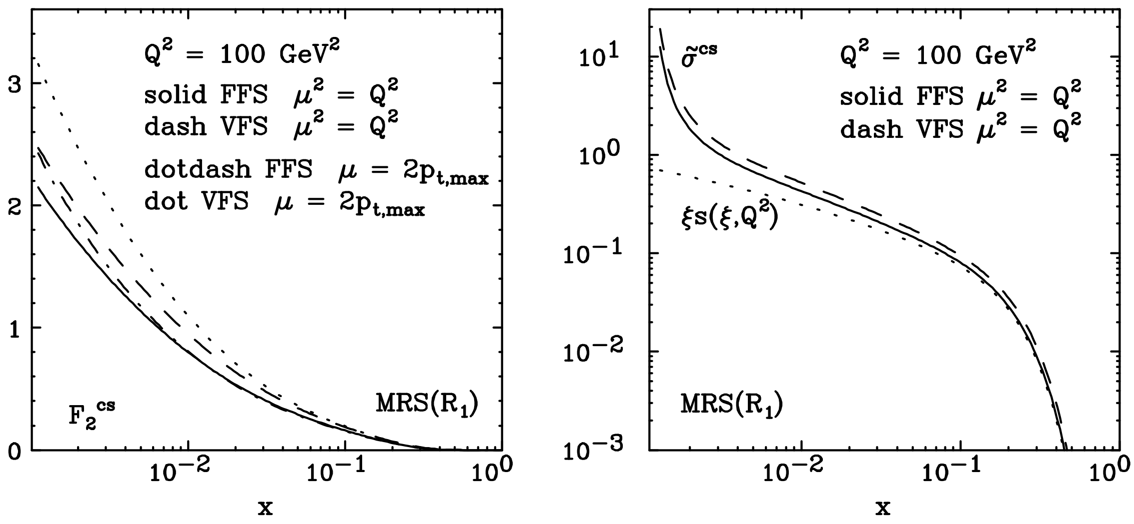

Figure 2: *F_2^{cs} and $\tilde{\sigma}^{cs}$ in the two schemes (FFS and VFS) and with two choices of the factorization scale.*

In Fig. 2, considering now only the MRS(R$_1$) parametrization, we illustrate the scheme dependence for two different factorization scales: $\mu^2 = Q^2$ and $\mu = 2p_{t,max}$, where p_t is the transverse momentum of the produced charmed quark. The difference between the FFS and the VFS results at $Q^2 = 100$ GeV^2 is again up to $\sim 30 - 40\%$ (attaining the largest value for $\mu = 2p_{t,max}$).

In Fig. 3 we show the situation at a higher physical scale, $Q^2 = 1000$ GeV^2. Notice that the difference between the two schemes is still relatively large whereas the choice $\mu = 2p_{t,max}$ gives curves (not displayed) which are indistinguishable from those corresponding to $\mu^2 = Q^2$.

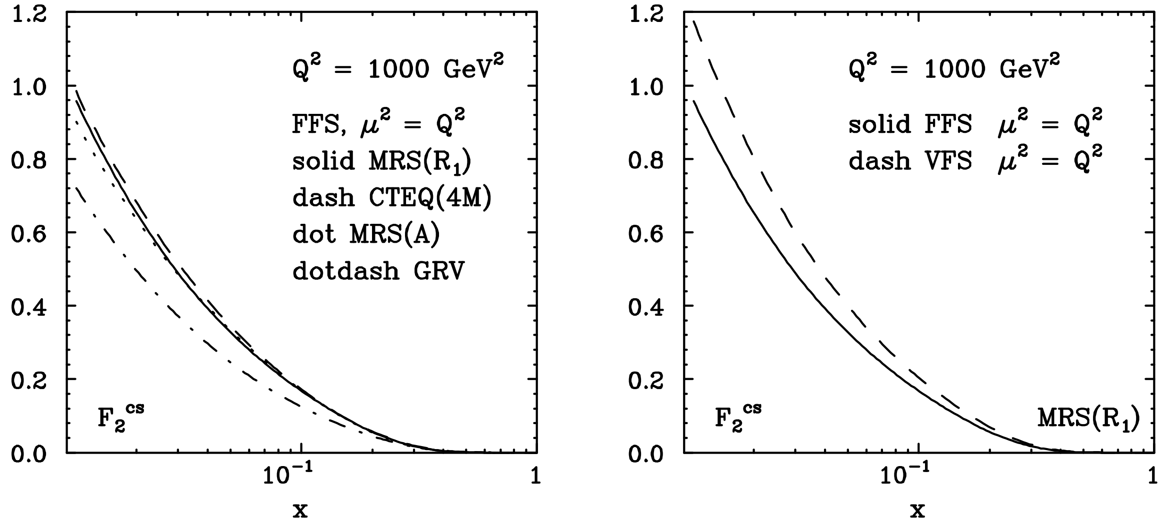

Figure 3: *Fit and scheme dependence of* F_2^{cs} *at* $Q^2 = 1000\ GeV^2$.

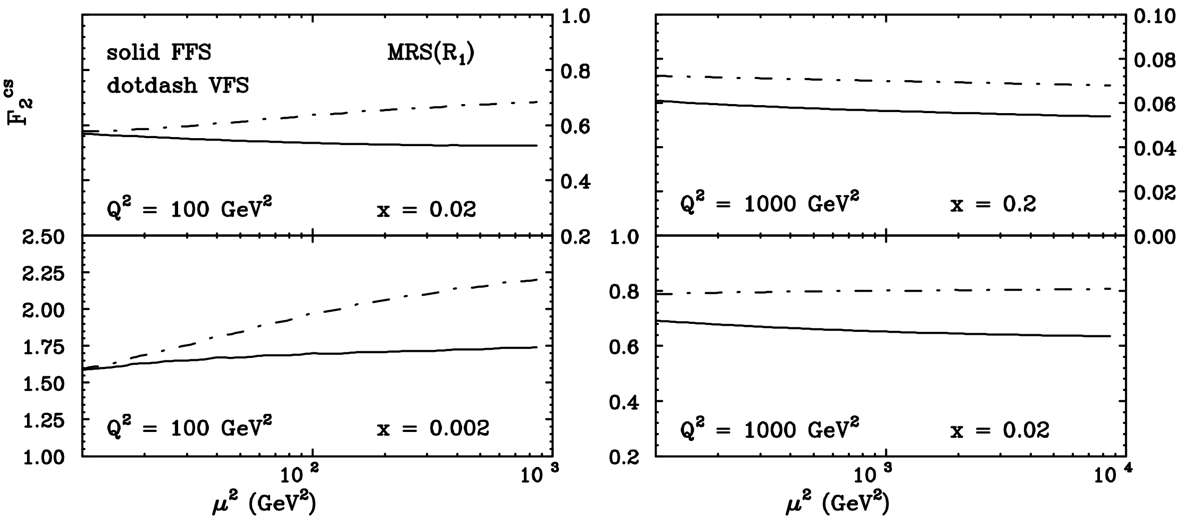

Figure 4: *Dependence of* F_2^{cs} *on the factorization scale in the two massive QCD schemes.*

In Fig. 4 we illustrate the dependence on the factorization scale. The parton fit used is the MRS(R$_1$) and the results of both schemes are presented for some kinematically accessible (x, Q^2) bins. It is clearly seen that when Q^2 is not very large the VFS is more unstable than the FFS. At very high Q^2 both the VFS and the FFS are not very sensitive to the factorization scale.

It is important for HERA to know also the expected uncertainties on the charm–strange contribution to the total cross section. These are presented in Table 1. It is interesting to notice that the main difference (~ 40 %) arises from the choice of the scheme.

σ^{cs}_{tot} (pb)	FFS/MRS(R_1)	FFS/GRV	VFS/MRS(R_1)
$\mu^2 = Q^2$	4.66	4.02	6.79
$\mu = 2p_{t,max}$	4.20	3.57	6.80

Table 1: *Total charm-strange cross-section for different parton fits, factorization scales and schemes in the kinematic region* $Q^2 > 200$ GeV^2 *and* $x > 0.006$ ($\sqrt{s} \simeq 300$ GeV).

4 Conclusions

The overall theoretical uncertainty on the charm–strange contribution to the charged–current structure functions is relatively large, being at least of order of 30 % in the typically accessible (x, Q^2) region. At not very high Q^2 the Fixed Flavor Scheme turns out to be preferable due to its greater stability. An order α_s^2 calculation is necessary to settle the problem of the scheme and factorization scale dependence. For the sake of consistency and for a safer analysis it would be important to use massive QCD evolution in the heavy–quark sector of the global fits. Possible HERA data on the charm–strange structure functions at large Q^2 would certainly be of the greatest utility.

References

[1] V. Barone *et al.*, Phys. Lett. B 317 (1993) 433; Phys. Lett. B 328 (1994) 143; Z. Phys. C 70 (1996) 83. V. Barone, U. D'Alesio and M. Genovese, Phys. Lett. B 357 (1995) 435. V. Barone and M. Genovese, Phys. Lett. B 379 (1996) 233.

[2] V. Barone *et al.*, Phys. Lett. B 268 (1991) 279; Phys. Lett. B 304 (1993) 176.

[3] M. Glück, E. Hoffmann and E. Reya, Z. Phys. **C13** (1982) 119; M. Glück, R.M. Godbole and E. Reya, Z. Phys. **C38** (1988) 441; M. Glück, E. Reya and M. Stratmann, Nucl. Phys. **B422** (1994) 37.

[4] M.A.G. Aivazis, J.C. Collins, F.I. Olness and W.-K. Tung, Phys. Rev. D 50 (1994) 3102. F.I. Olness and S.T. Riemersma, Phys. Rev. D 51 (1995) 4746.

[5] T. Gottschalk, Phys. Rev. D 23 (1981) 56.

[6] A.D. Martin, R.G. Roberts and W.J. Stirling, Phys. Rev. D 50 (1994) 6734.

[7] A.D. Martin, R.G. Roberts and W.J. Stirling, hep-ph/9606345.

[8] H.L. Lai *et al.* (CTEQ), hep-ph/9606399.

[9] M. Glück, E. Reya and A. Vogt, Z. Phys. C 67 (1995) 433.