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Theoretical Description of Heavy Quark Production in DIS*

J. Amundson[a], F. Olness[b,c]†, C. Schmidt[a], W. K. Tung[a], X. Wang[a]
[a] *Michigan State University*
[b] *Southern Methodist University*
[c] *Fermi National Accelerator Laboratory*

We present results from a new event-generator Monte Carlo program for semi-inclusive DIS heavy quark production computed in a composite 3-flavor/4-flavor scheme, which is applicable over a wider range of energy scales than existing calculations. We compare the semi-inclusive distributions in p_t, Q^2 and W at $\mathcal{O}(\alpha_s^1)$ with recent HERA results. We also compare the inclusive F_2^{charm} with the data and the existing $\mathcal{O}(\alpha_s^2)$ 3-flavor scheme calculation. Both calculations agree will with current HERA data, but the resummed $\mathcal{O}(\alpha_s^1)$ composite scheme calculation is simpler and more efficient by an order of magnitude.

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Several experimental groups[1] have studied the semi-inclusive deeply inelastic scattering (DIS) process for heavy-quark production $\ell_1 + N \to \ell_2 + Q + X$. New data from HERA investigates the DIS process in a very different kinematic range from that available at fixed-target experiments. This perception has changed the way that we compute the semi-inclusive DIS heavy quark production. Traditionally, the heavy quark mass was treated as a large scale and the number of active parton flavors was fixed to be the number of quarks lighter than the heavy quark. In this scheme, the perturbation expansion begins with the $\mathcal{O}(\alpha_s^1)$ heavy quark creation fusion process $\gamma + g \to c + \bar{c}$, (*cf.*, Fig. 1b). We refer to this approach as the 3-flavor scheme since the number of flavors coming from parton distributions is fixed at three for charm production.

More recently, a new composite scheme (ACOT[2]) has been proposed which includes the heavy quark as an active parton flavor and involves matching between 3-flavor scheme and a 4-flavor scheme with non-zero heavy quark mass. In this case, the perturbation expansion begins with the $\mathcal{O}(\alpha_s^0)$ heavy quark excitation process $\gamma + c \to c$, (*cf.*, Fig. 1a). The key advantages of this scheme are:

1. By incorporating the heavy quark into the parton framework, the composite scheme yields a result which is valid from threshold to asymptotic energies; in contrast, the 3-flavor scheme contains unsubtracted mass singularities which will vitiate the perturbation expansion in the $m \to 0$ or $E \to \infty$ limit.

2. Because the composite scheme resums the large logarithms appearing in the 3-flavor scheme into the parton distribution functions, it includes the numerically most important terms of the $\mathcal{O}(\alpha_s^2)$ 3-flavor scheme calculation in a $\mathcal{O}(\alpha_s^1)$ calculation.

In effect, the composite scheme subsumes the 3-flavor scheme. We now present the preliminary results of a new event-generator Monte Carlo program to compute semi-inclusive DIS heavy quark production.[3] For a full explanation of the composite scheme and complete numerical results see Ref. 3.

Some sample distributions are displayed in Fig. 2 for the composite scheme calculation.[†] Since this process is implemented in a event generator Monte Carlo, we have the flexibility to produce arbitrary differential distributions, impose full experimental cuts, and easily incorporate fragmentation of charm quarks into mesons. We find good agreement between the NLO composite calculation and the HERA data.

[†]As a shorthand we shall denote the first order $\mathcal{O}(\alpha_s^1)$ 3-flavor calculation as "LO 3-flavor," second order $\mathcal{O}(\alpha_s^2)$ 3-flavor calculation as "NLO 3-flavor," and the second order $\mathcal{O}(\alpha_s^1)$ composite calculation as "NLO composite"

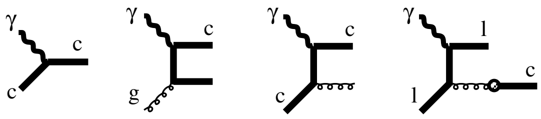

Figure 1: Basic processes for DIS heavy quark production. a) $\mathcal{O}(\alpha_s^0)$ flavor excitation: $\gamma + c \to c$; b) $\mathcal{O}(\alpha_s^1)$ flavor creation: $\gamma + g \to c + \bar{c}$; c) $\mathcal{O}(\alpha_s^1)$ flavor excitation: $\gamma + c \to c + g$; d) $\mathcal{O}(\alpha_s^1)$ light-quark (l) fragmentation: $(\gamma + l \to l + g) \otimes g \to c$.

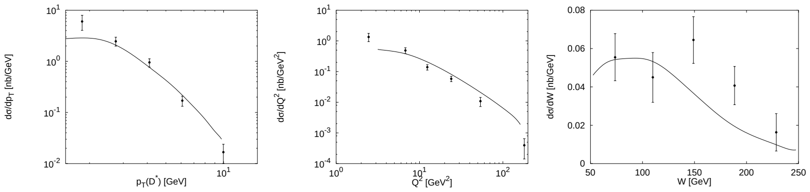

Figure 2: Selected distributions for DIS production. The points are ZEUS '95 data.

Using the differential charm distributions, we can integrate to obtain the inclusive structure function F_2^{charm}; the results are displayed in Fig. 3. For comparison, we also display the LO and NLO 3-flavor results.[5] Again, the NLO composite calculation yields a good description of the HERA F_2^{charm} data. In particular, we find it interesting that we have good agreement to the data (comparable to the NLO 3-flavor calculation) even in the lowest Q^2 bin, ($7\ GeV^2$), implying that the 4-flavor scheme is reliable even near threshold.[‡]

Although the composite scheme, with much of the heavy quark effects resummed into the parton distribution functions and fragmentation functions, gives a good account of suitable inclusive cross-sections, it lacks some of the final state information in the $\mathcal{O}(\alpha_s^2)$ 3-flavor scheme calculation. To incorporate all of this information the composite scheme needs to be extended to $\mathcal{O}(\alpha_s^2)$. This work lays the groundwork for such a calculation[7], which will make use of existing 3-flavor results. The $\mathcal{O}(\alpha_s^2)$ composite scheme calculation will combine the best attributes of both calculations and will yield unprecedented accuracy in testing QCD and heavy quark production.

1. H1 Collaboration (C. Adloff *et al.*). Z. Phys. C72, 593 (1996).
   ZEUS Collaboration (J. Breitweg *et al.*). Talk given at International

[‡] We have taken $\mu = \sqrt{(Q^2 + m_c^2)/2}$, and used CTEQ4 distributions.[6] In this instance, $Q^2 = \mu^2 = 7\ GeV^2$, $m_Q = 1.6$, so $\mu/m_Q \sim 1.7$. The matching between the 3- and 4-flavor schemes is performed at $\mu = m_Q$.

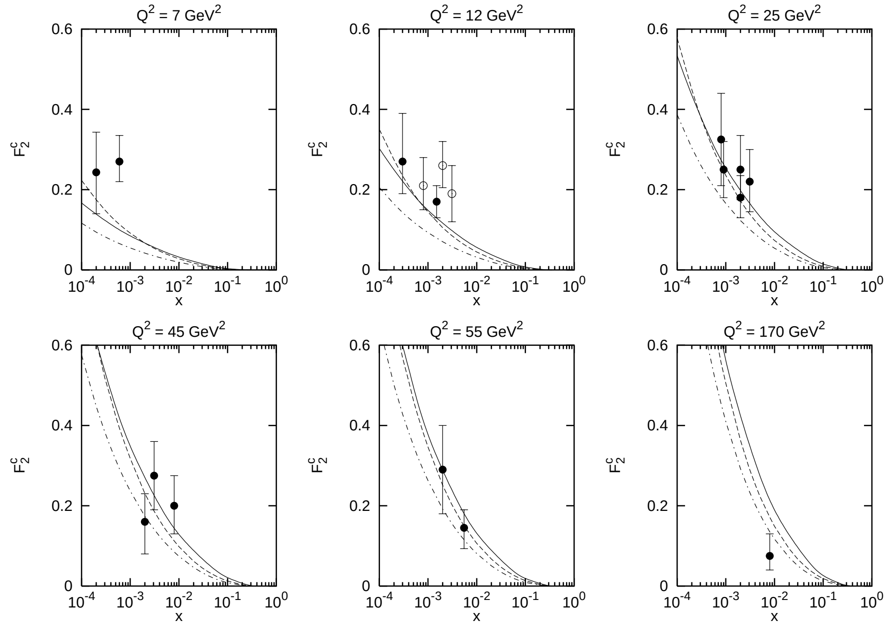

Figure 3: F_2^{charm} *vs.* x for select Q^2 bins. The solid curve is the NLO composite scheme. The dash-dotted and dashed curves are LO and NLO 3-flavor schemes, respectively. The solid points are ZEUS '95 data, and the open points are H1 '95.

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2. M.Aivazis, J.C.Collins, F.Olness, W.-K.Tung, *Phys.Rev.* **D50**, 3102 (1994); M.Aivazis, F.Olness, W.-K.Tung, *Phys.Rev.Lett.* **65**, 2339 (1990).
3. First results of this approach were presented by C. Schmidt, in a talk at the 5th International Workshop on Deep Inelastic Scattering and QCD (DIS 97), Chicago, IL, 14-18 Apr 1997, hep-ph/9706496.
4. J. Amundson, C. Schmidt, W. K. Tung, X. Wang, MSU preprint, in preparation.
5. E. Laenen, S. Riemersma, J. Smith, W.L. van Neerven, *Nucl. Phys.* B392, 162 (1993); *Nucl. Phys.* B392, 229 (1993).
6. H.L. Lai *et al.*, Phys. Rev. D55:1280, (1997).
7. P. Agrawal, F. Olness, S. Riemersma, W. K. Tung. Proceedings of 30th Rencontres de Moriond: QCD and High Energy Hadronic Interactions, Moriond 1995, p.353.