Inclusive D-Meson Production at the LHC

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I present predictions for the inclusive production of D mesons at the CERN LHC in the general-mass variable-flavor-number scheme at next-to-leading order. Numerical results are compared to data where available, and uncertainties to scale variations, parton distribution functions and charm mass are discussed. I point out that measurements at large rapidity have the potential to pin down models of intrinsic charm.

D-meson production at the LHC was studied by the ALICE [1], ATLAS [2], and LHCb Collaborations [3]. Here I present predictions for the inclusive production of D mesons at the LHC within the general-mass variable-flavor-number scheme (GM-VFNS) [4]. More results and additional details of the calculation can be found in [5]. In a recent paper [6], we have also considered the inclusive production of B mesons, for which experimental results from the CMS Collaboration are available [7]. For an alternative approach, see Ref. [8].

Figure 1 shows a comparison of the GM-VFNS predictions for the transverse momentum distribution with data from ALICE. Here the renormalization (μ_R) and factorization scales for initial state (μ_I) and final state (μ_F) singularities are fixed by $\mu_i = \xi_i \sqrt{p_T^2 + m_c^2}$, where m_c is the charm quark mass, and the scale parameters ξ_i ($i = R, F, I$) are varied about the default values of 1 by factors of 2 up and down to obtain an estimate of a theory uncertainty band (dotted lines in the figure). The data are reasonably well described by theory at the larger values of p_T, where data are available, but theory starts to overshoot at $p_T < 5$ GeV. There, the fixed flavor number scheme (FFNS) [9] works better (see the dashed lines in Fig. 1). The GM-VFNS is preferred at large p_T since it includes resummed contributions from large logarithms by virtue of the DGLAP evolution equations for the parton distribution (PDFs) and fragmentation functions (FFs). The GM-VFNS also predicts smaller scale uncertainties than the FFNS. We have used CTEQ6.6 PDFs [15] and, in the case of the GM-VFNS, FFs of Ref. [10]. The FFNS calculation is performed without including a FF; the transition from the

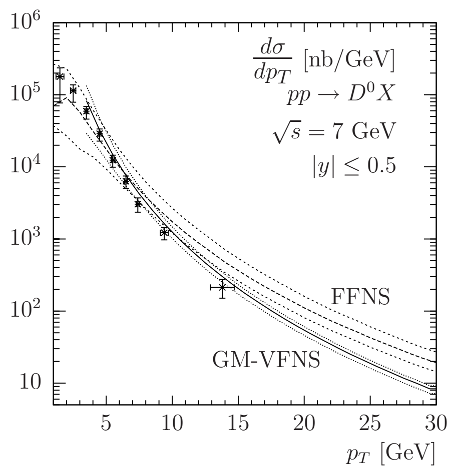

Figure 1: $\mathrm{d}\sigma/\mathrm{d}p_T$ for $p + p \to D^0 + X$ integrated over rapidity in the range $-0.5 \leq y \leq 0.5$ for $\sqrt{s} = 7$ TeV at NLO in the GM-VFNS (solid line) and the FFNS (dashed line). Dotted lines describe the corresponding error bands from scale variations. The ALICE data were taken from [1].

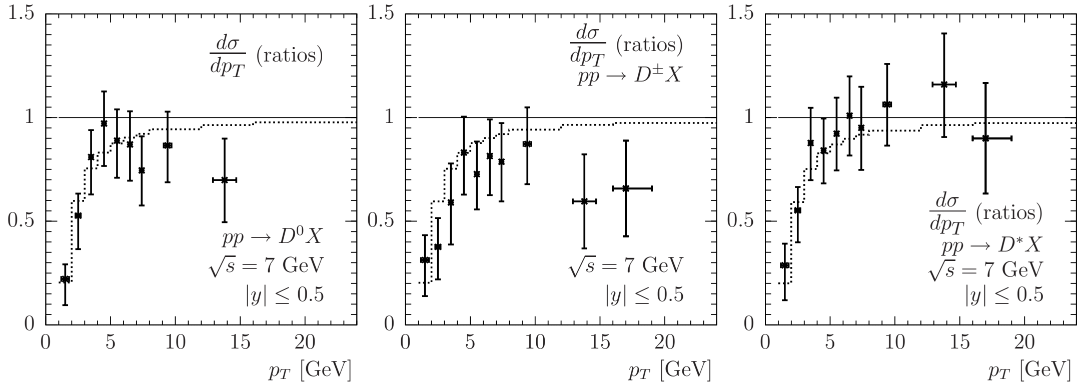

Figure 2: Ratios of $d\sigma/dp_T$ for D-meson production at ALICE at $\sqrt{s} = 7$ TeV using $\xi_I = \xi_F = 0.8$ and $\xi_R = 1$. All cross sections and the data from Ref. [1] are normalized to the GM-VFNS prediction with $\xi_i = 1$. The PDFs are taken from MSTW08-NLO [13] and the charm quark mass is $m_c = 1.5$ GeV.

charm quark to the charmed meson is taken into account by multiplying the parton level result with the branching ratio $BR(c \to D^0) = 0.628$.

The uncertainties due to variations of the factorization scales are dominant. It is interesting to see that the scale parameters can be chosen to bring the GM-VFNS predictions into agreement with the data also at low values of p_T. This is shown in Fig. 2 for MSTW08-NLO PDFs [13] and using $m_c = 1.5$ GeV for the charm quark mass. The differential cross sections $d\sigma/dp_T$ are shown here for $\xi_I = \xi_F = 0.8$, $\xi_R = 1$ in p_T bins and compared with data points from the ALICE collaboration [1]. All results are normalized to the GM-VFNS prediction with $\xi_i = 1$. One can see that a proper choice of the factorization scales can help to ensure that the

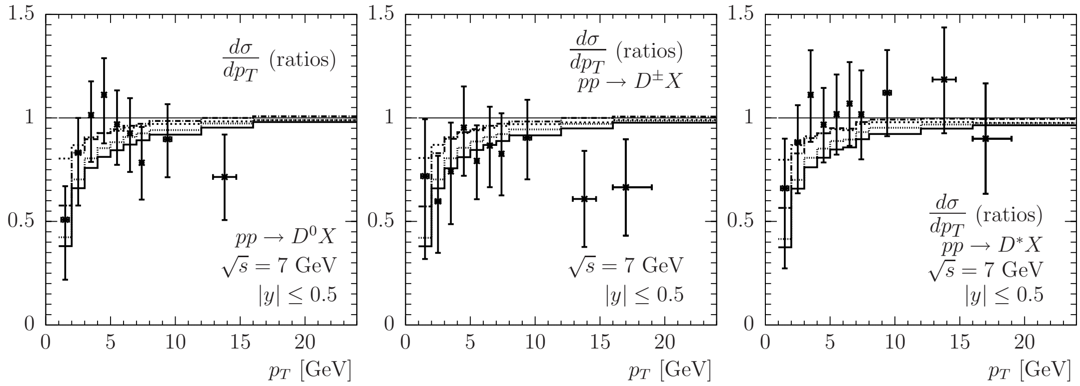

Figure 3: $d\sigma/dp_T$ for D-meson production at ALICE at $\sqrt{s} = 7$ TeV for different PDFs. All cross sections are calculated with $\xi_I = \xi_F = 0.7$, $\xi_R = 1$ and normalized to the GM-VFNS prediction with CTEQ6.6 PDFs. The histograms from top down correspond to CT10 [11], HERAPDF 1.5 (NLO) [12], MSTW08-NLO [13] and NNPDF 2.1 [14].

resummed contributions due to incoming heavy quarks, and those due to light-parton fragmentation, fade out in a controlled manner as $p_T/m \to 0$, i.e. in the kinematic region where the FFNS should be appropriate.

In Figure 3 an attempt is made to show the uncertainties coming from using different PDF input. The results for most of the bins lie within the error bars of the experimental data and do not prefer one PDF set over another. Actually, due to the different values of m_c used in the PDF fits, there is some residual m_c dependence of the predicted cross sections at low values of p_T. The value $m_c = 1.5$ GeV used in our calculation agrees with the one in the fragmentation functions of Ref. [10], but not with the one in the parton distribution functions used here. While the CTEQ6.6 and CT10 sets use $m_c = 1.3$ GeV, in the MSTW08-NLO, NNPDF 2.1, and HERAPDF 1.5 (NLO) sets $m_c = 1.4$ GeV was chosen. A consistent calculation would require the same value of m_c in all components of the cross section formula. However, separate fits of the fragmentation functions for different values of m_c are not available. The dependence on the heavy quark mass is, however, not very strong and non-negligible only in the low p_T range, see Fig. 4.

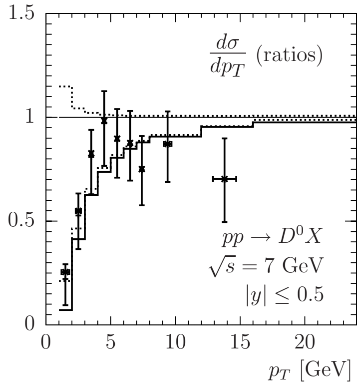

Figure 4: $d\sigma/dp_T$ for D^0-meson production at ALICE [1] with MSTW08-NLO PDFs [13] normalized to the GM-VFNS prediction with $\xi_{I,F,R} = 1$ and $m_c = 1.5$ GeV. The lower two histograms are obtained using $\xi_{I,F} = 0.7$ and $\xi_R = 1$ and the two dashed histograms are for $m_c = 1.4$ GeV.

Non-perturbative contributions to the charm quark content of the proton may lead to enhanced charm parton distributions $c(x, \mu_F)$ at $x > 0.1$. This can become visible in the cross section for D meson production at large rapidities. Parametrizations of this so-called intrinsic charm are available from the CTEQ collaboration, based on various models and compatible with the global data samples. In Ref. [17], we have studied the impact of these models on possible measurements at the Tevatron and at BNL RHIC. Here, I present results of a calculation using the parametrization CTEQ6.6 [15] to obtain an estimate of the expected relative enhancements of the p_T distributions in bins of rapidity. Figure 5 shows typical results for D^0 production; for other D mesons, the results are very similar. Two models have been selected among the possible options in CTEQ6.6 (see Ref. [16] for details): Fig. 5a shows the calculation using the BHPS model with a 3.5 % $(c + \bar{c})$ content in the proton (at the scale $\mu_F = 1.3$ GeV), Fig. 5b refers to the model of a high strength sea-like charm component. In both cases, one observes large enhancements, increasing with rapidity, and in the first model also with p_T. Thus one can expect that forthcoming data from the LHCb experiment should be able to exclude or narrow down models for intrinsic charm.

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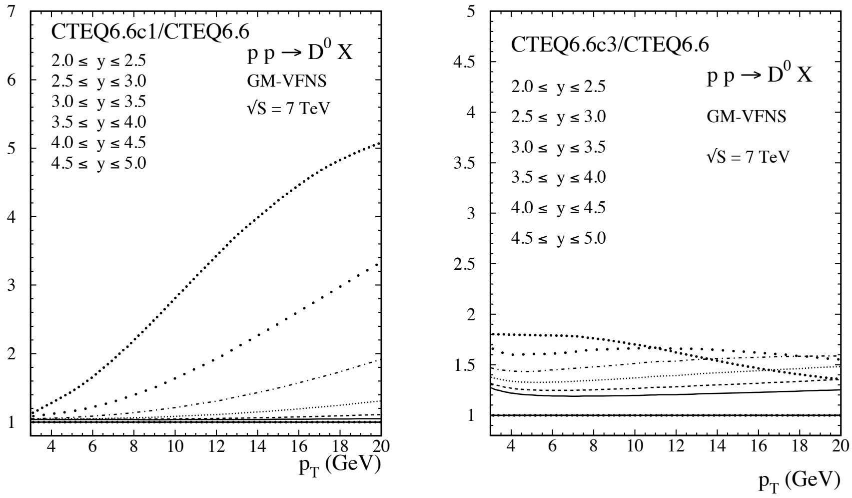

Figure 5: Ratio of the p_T distributions $\mathrm{d}\sigma/\mathrm{d}p_T$ for $p + p \to D^0 + X$ at NLO in the GM-VFNS at $\sqrt{s} = 7$ TeV, using two different models of intrinsic charm: (a) BHPS model with 3.5 % $(c + \bar{c})$ content (at $\mu_F = 1.3$ GeV), (b) model with a high strength sea-like charm component. The FFs are taken from Ref. [10]. The various lines represent the default predictions for $\xi_R = \xi_I = \xi_F = 1$, integrated over the rapidity regions indicated in the figures (larger rapidities correspond to larger cross section ratios everywhere in (a) and at small p_T in (b)).

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