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Measurement of low-p_T charm-meson production cross-section at CDF

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I present a measurement of the production cross-section of D^+ mesons in proton-antiproton collisions at 1.96 TeV center-of-mass energy, using the full data set collected by the CDF experiment at the Tevatron collider in Run II. For this initial state, the measurement probes a yet unexplored low transverse-momentum range, down to 1.5 GeV/c, using events selected with criteria that bias minimally the features of the collision. For initial state and collision energy, this remains a unique measurement of quantities that are important for QCD studies and for tuning Monte Carlo simulations.

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1. Introduction

The current perturbative-QCD theory cannot properly predict the behavior of the strong interactions in the low-transferred-four-momentum region (low Q^2) because in these kinematic conditions the strong coupling constant, α_s, is of the order of the unity. Measurements of cross sections for the production of hadrons containing bottom or charm quarks (heavy-flavors) in hadron collisions play an important role offering essential information to test and refine phenomenological models of the strong interaction at small transferred-four-momentum, a regime in which perturbative expansions are challenging.
The channel of interest is $D^+ \to K^-\pi^+\pi^+$ (and its charge-conjugate decay, $D^- \to K^+\pi^-\pi^-$).
The D^+ produced directly at the point where the primary $p\bar{p}$-interaction occured is the signal we are measuring, the primary component. Some D^+ can originate from decays of B mesons. They constitute a secondary component, a background which is caracterized by a wider impact-parameter distribution than the primary component. Three unrelated tracks with an effective mass near the D^+ peak value in the invariant mass distribution form a combinatoric background.
In 2003 the CDF Collaboration performed this measurement down to a minimum p_T of the D^+ of 6.0 GeV/c [1], due to a threshold in the on-line event selection used for that data set. To extend the previous measurement down to a $p_T(D^+)$ as low as 1.5 GeV/c, we use data samples selected online with the minimum-bias and zero-bias triggers which are designed to collect events while introducing minimum, if any, bias in the properties of the particles produced in the collision.
Because of its relatively large mass, the c quark production cross section is several orders of magnitude smaller than that for lighter quarks (u, d, and s). One of the main contributions of the present work is the optimization of the candidate selection in order to reduce the light-meson background, initially 10^4 times larger than the signal.
A pure data-driven optimization is introduced in a way that leads to unbiased sample selection. The optimization strategy of the selection is performed *independently* in each $p_T(D^+)$ bin. The statistics available is enough to probe the $p_T(D^+)$ range [1.5; 14.5] GeV/c in bins of variable size.
A two-dimensional simultaneous fit of the $K^-\pi^+\pi^+$-mass and D^+ transverse impact-parameter distributions allows determining a signal of 2950 D^+ decays produced directly in the hard scattering.
We factorize the efficiency correction in two contributions, online event-selection and reconstruction efficiencies. Each primary yield is combined with corresponding reconstruction and selection efficiencies, derived using simulation, to determine the cross section,

$$\sigma_i = \frac{N_i/2}{\int \mathscr{L} dt \cdot \varepsilon_i \cdot \mathscr{B}}, \tag{1.1}$$

where N_i is the observed number of primary D^+ and D^- mesons in each p_T bin. The factor $1/2$ is included because both D^+ and D^- mesons contribute to N_i and we report results solely for D^+, assuming flavor-symmetric production of charm quarks in the strong $p\bar{p}$ interaction. The quantity $\int \mathscr{L} dt$ is the integrated luminosity and ε_i is the global reconstruction and selection efficiency. The branching fraction of the $D^+ \to K^-\pi^+\pi^+$ decay used is $\mathscr{B} = (9.46 \pm 0.24)\%$ [2].

2. Yield extraction as a function of $p_T(D^+)$

In each event, the D^+ candidates are reconstructed offline by combining all the possible triplets of tracks in kinematic fits. If a fit returns a possible common origin for the three tracks, a D^+ candidate is defined. Tracks are selected only in the pseudorapidity range $|\eta| < 1$ where the reconstruction of the tracking system is highly efficient.
The event number is used as a random criterion to divide the sample into two statistically independent subsamples with approximately the same size, even-numbered and odd-numbered events. Selection requirements for each subsample are then optimized independently. The final sample is obtained applying to the even subsample the requirements optimized in odd subsample and viceversa.

In order to find the D^+ yield, a two-dimensional unbinned likelihood fit to the invariant $K^-\pi^+\pi^+$ mass and to the candidate-impact parameter distribution is performed.
It is assumed that in the signal region there are only three components: primary, secondary and combinatorics. In each bin, the distributions in mass and impact parameter are uncorrelated. The free parameters in each fit are only the prompt and secondary fractions. Using only the information from the invariant mass distribution, it is not possible to distinguish between primary and secondary D^+. The impact-parameter distribution can be used to separate these two components.

The results for the two-dimensional unbinned likelihood fit for one $p_T(D^+)$ bin are shown in Fig.1.

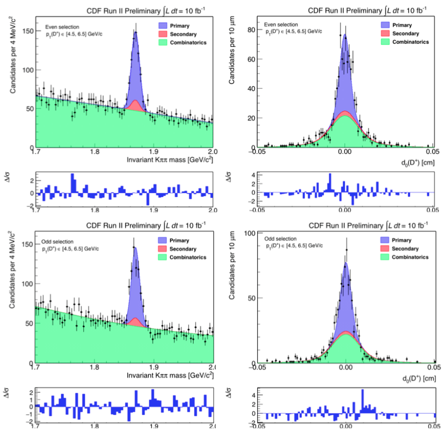

Figure 1: Two-dimensional unbinned likelihood fit for $p_T(D^+)$ in the range [4.5; 6.5] GeV/c for the even subsample (top) and odd subsample (bottom). On the left the results of the fit to the invariant mass distribution are shown, on the right the projection on the impact-parameter axis of the fit function in the signal region.

3. Efficiency and systematic uncertainties

We factorize the detection and reconstruction efficiency ε_i in each p_T-bin i as the product of trigger efficiency, offline efficiency for reconstructing three tracks that meet the quality and fiducial requirements in the drift chamber, offline efficiency for associating the information from the silicon

detector to these tracks, and the efficiency of the offline selection requirements.
All offline efficiencies are reproduced accurately by the simulation [3]. In order to evaluate a systematic uncertainty related to the reconstruction efficiencies, we perform some MC/data tests on two control samples. We derive a 11.5% uncertainty in all D^+ transverse momentum bins. Systematic uncertainties associated with the selected shape for the three components are evaluated by varying the shape modeling in both invariant-mass and impact-parameter distributions.

4. Cross-section

The measured differential cross sections, averaged over each p_T bin and integrated in the rapidity range $|y| < 1$, are displayed in Fig. 2. The total cross section, obtained by summing over all p_T bins, is $71.9 \pm 6.8 \pm 9.3$ μb, where the first contribution to the uncertainty is statistical and the second systematic. Although observed cross sections are compatible with those predicted in recent calculations [4] and with those determined in early Run II using an independent data set [1], some differences in the shape between theory and our measurements suggest that the theory can benefit from further input tuning.

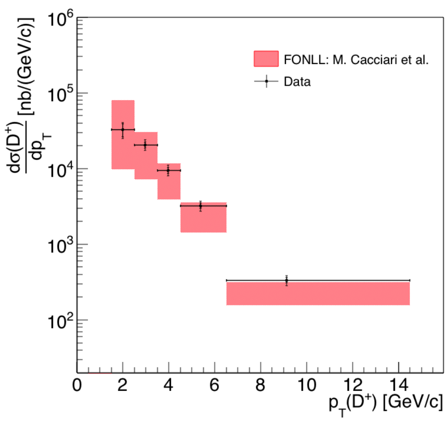

Figure 2: Differential cross section as a function of p_T for primary D^+ mesons with $p_T > 1.5$ GeV/c, compared with predictions from Ref. [4].

References

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