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Low p_T Charm Meson Production at CDF II

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Abstract. I report on the differential production cross-section measurements of D mesons (D^0 and $D^\pm$) extended to low transverse momentum; I also show the first D^0 signal ever observed in the sample collected at $\sqrt{s} = 900$ GeV. This measurement probes a region where perturbative QCD (pQCD) models are not able to describe the heavy-quark production because of the running of the strong coupling constant, α_S. The data samples collected at two different center of mass energies, 1.96 TeV and 900 GeV, also give the opportunity to assess the energy dependence of the production cross section. The CDF II experiment can still give us distinguishing results, complementary to B-factories and LHC, thanks to the uniqueness of the combination of energies and collision initial state ($p\bar{p}$), that are likely to remain the only ones of this kind for several years.

1 Introduction

The behavior of the strong interaction in the low Q^2 (four-momentum transferred in an interaction) region is neither describable nor predictable by theory because in these kinematic conditions the strong coupling constant α_s is of the order of the unity (see Figure 1). It's not, therefore,

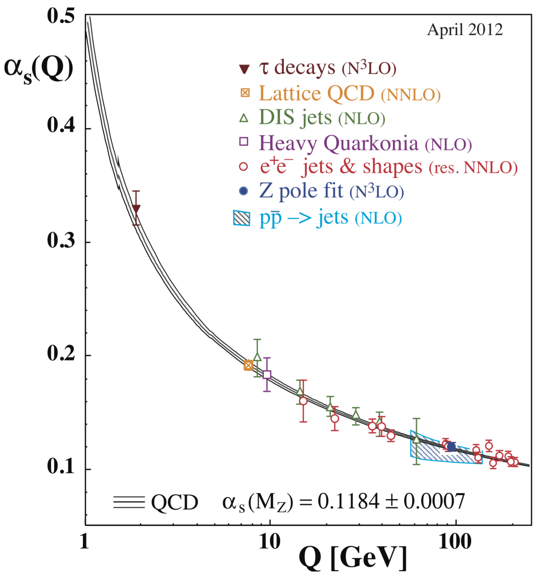

Figure 1. The running of the strong coupling constant as a function of the energy scale.

possible for low transferred momentum interactions to obtain QCD features through theories based on perturbative expansions. In that situation a global investigation of the physical quantities involved in the interactions becomes necessary in order to develop new models that overcome this mathematical limitation. The previous CDF measurement of the prompt charm production cross section [1] had a significant impact in the QCD community. It was the first measurement of charm production in hadron-hadron collisions in a scenario where large discrepancies were observed between measured heavy-flavor cross sections and NLO predictions. However, the kinematic regime probed by that measurement was limited, since the cross section, differential in the D-meson transverse momenta, probed a minimum p_T of 5.5 GeV/c, due to the biases introduced by the trigger selection. Extending the measurement to lower transverse momenta would provide to theory additional experimental lever arm to refine the calculations in a regime where c quark production is in non-perturbative conditions [2]. The huge amount of data collected during CDF Run II gives the chance to perform this kind of studies in the minimum-bias (MB) sample; indeed, by construction, the MB trigger has minimal and very generic requirements in order to reduce any kind of biases to the physics of the collected data but, of course, it carries the penalty of a very small quantity of heavy-flavor events in the huge light-quark background. The data samples collected at two different center of mass energies, 1.96 TeV and 900 GeV, also give the opportunity to assess the energy dependence of the production cross section (see Figure 2 [3]).

Here I report the attempt of reconstructing a charm signal in the MB sample in the channels $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$. In what follows C-conjugate decays are implied and branching fractions are CP averages.

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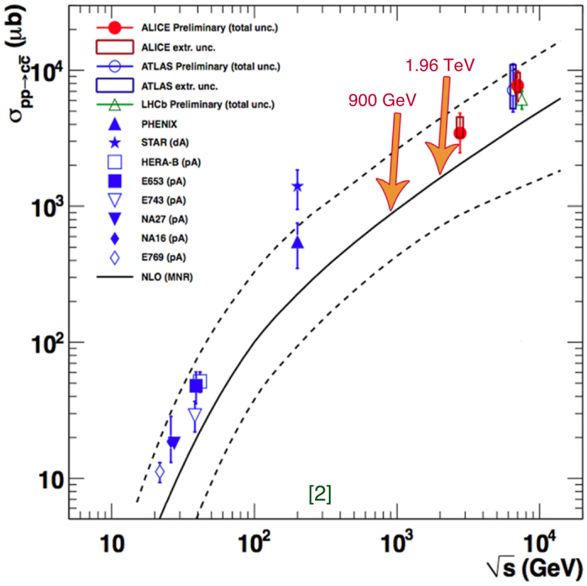

Figure 2. $pp \to c\bar{c}$ cross section as a function of $\sqrt{s}$.

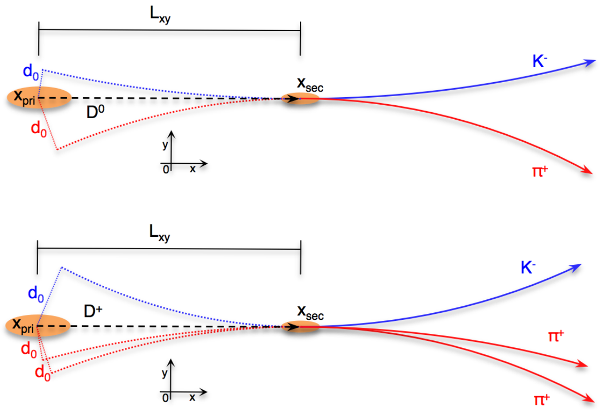

Figure 3. Scheme of the topologies of the D^0 and D^+ decay channels in the transverse plane.

2 Analysis overview

The $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$ channels are the simplest topologies that can be studied at CDF to detect these two charmed mesons, because they have a relatively high branching ratio (about 3.9 % for the D^0 and about 9.1% for the D^+) and they can be fully detected by the tracking system. The relatively large mean lifetime of the D mesons results in a travelled path, away from the $p\bar{p}$ collision where they are produced, of the order of few hundreds μm which can be measured thanks to the resolution of the CDF silicon tracker. To unfold the D^0 (D^+) signal from the background the track helices are fitted looking for an intersection point displaced from the production point (primary vertex). If the fit returns a possible common origin for the two (three) tracks, a D^0 (D^+) "candidate" is found. Studying the decay topologies is fundamental to choose the selection variables in order to optimize the signal significance. Figure 3 shows the topologies of the two D mesons and some of the fundamental quantities used in this analysis for both the channels studied:

- $\vec{p}_T$, the *transverse momentum*, is the projection of the momentum vector to the plane transverse to the beam line.
- L_{xy}, the *transverse decay length*, is the signed distance between the primary and the secondary vertices projected to the transverse plane. It is defined as follows:

$$L_{xy} = \frac{(\vec{x}_{sec} - \vec{x}_{pri}) \cdot \vec{p}_T}{p_T} \quad (1)$$

  where $\vec{x}_{pri}$ is the projected position of the $p\bar{p}$ collision and $\vec{x}_{sec}$ is the projected position of the decay vertex.
- d_0, the *impact parameter*, is the signed distance between the primary vertex and the track helix at their point of closest approach.

The selection cuts are optimized directly on data maximizing the figure of merit in Equation 2

$$F(S;B) = \frac{S}{\sqrt{S+B}} \quad (2)$$

where S and B are the fitted signal and background yields in the region of the D^0 peak (1.864 GeV/c^2 $\pm\, 2\sigma_{m_{D^0}}$). To get the (unbiased) optimized invariant mass plots shown in the following sections, the following procedure is used:

- The sample is divided into two random subsamples (e.g., even and odd events).
- The selection is optimized separately for each of the subsamples maximizing the figure of merit in Equation 2.
- The two subsamples are resummed applying the optimized selection of the former to the latter and viceversa.

This procedure is performed separately for each of the five p_T bin in the range [1.5; 14.5] GeV/c.

3 Yields measurement

3.1 D^0

Candidates are identified fitting any possible combination of two reconstructed tracks with opposite charge in each event, assuming that the negative one is due to a K^- and the positive one to a π^+. The candidate's invariant mass is plotted and used to fit the signal yield. For this p_T range the particle ID is not available, so the signal is composed of both D^0 and $\bar{D}^0$ candidates. Figure 4 shows the invariant $K^-\pi^+$ mass distribution at both $\sqrt{s}$ = 1.96 TeV and $\sqrt{s}$ = 900 GeV of all the candidates with $p_T \geq 1.5$ GeV/c. A binned maximum likelihood fit of the invariant $K^-\pi^+$ mass is performed. The fit function accounts for both D^0 and $\bar{D}^0$ and the shapes of the two components are obtained through a complete Monte Carlo simulation of the decays and of the detector. The D^0 signal is represented by the narrow peak centered at a mass of 1.864 GeV/c^2 while the $\bar{D}^0$ candidates are described by a wider distribution (in

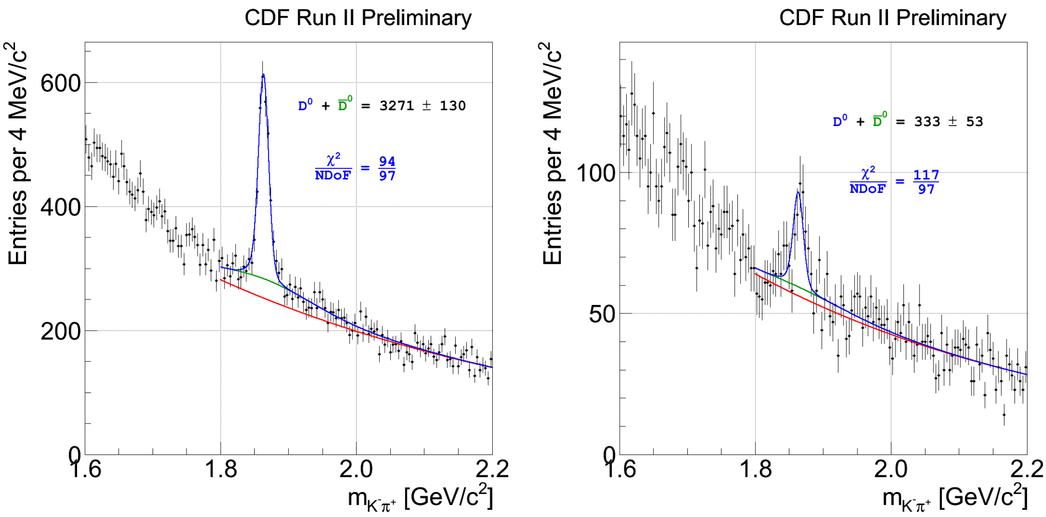

Figure 4. Invariant $K^-\pi^+$ mass distribution at $\sqrt{s}$ = 1.96 TeV (left) and $\sqrt{s}$ = 900 GeV (right) of all the candidates with $p_T \geq 1.5$ GeV/c. In the fit region, stacked curves show the exponential background and broad $\bar{D}^0$ signal under the narrower D^0 signal resulting from the fit to the data.

green in Figure 4 but still centered at its nominal mass (this behaviour is due do the misassignment of the masses of the two daughters). Both the signals are parametrized by the sum of two Gaussians and an exponential function is used for the combinatorial background. The fit range is restricted to [1.8 ÷ 2.4] GeV/c^2 in order to reduce the (negligible) background due to other decay channels.

3.2 D^+

Candidates are identified fitting any possible combination of three reconstructed tracks in each event; the sum of their charges must be ± 1. Because $D^\pm \to K^\pm\pi^\mp\pi^\mp$, the assume that the two tracks with the same charge are due to pions and the other one to a kaon is used. The candidate's invariant mass is plotted and used to fit the signal yield. Figure 5 shows the invariant $K^\pm\pi^\mp\pi^\mp$ mass distribution at $\sqrt{s}$ = 1.96 TeV of all the candidates with $p_T \geq 2.5$ GeV/c. A binned maximum likelihood fit of the invariant $K^\pm\pi^\mp\pi^\mp$ mass is performed. The fit function accounts for both the D^+ and D^- candidates. The signal is parametrized by a single Gaussian and an exponential function is used for the combinatorial background. The fit range is restricted to [1.7 ÷ 2.0] GeV/c^2. The fit range and the signal shape are fixed using a Monte Carlo simulation.

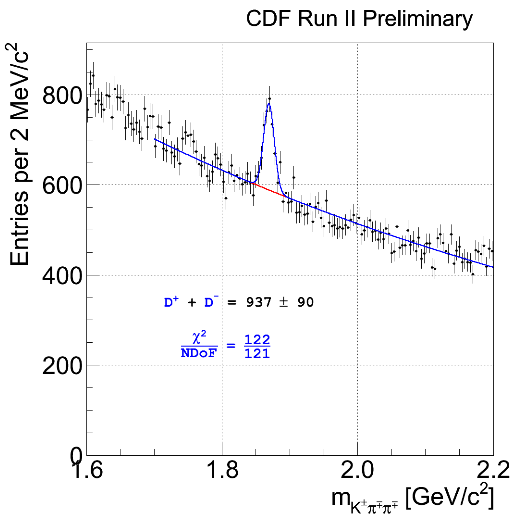

Figure 5. Invariant $K^\pm\pi^\mp\pi^\mp$ mass distribution at $\sqrt{s}$ = 1.96 TeV of all the candidates with $p_T \geq 2.5$ GeV/c. In the fit region, stacked curves show the exponential background and the D^+ signal resulting from the fit to the data.

4 B feed-down

Both D^0 and D^+ samples are also affected by a physics background due to B-meson decays (e.g. $B^+ \to D^0X$ and $B^0 \to D^+X$). To assess the direct fraction of candidates promptly produced in the $p\bar{p}$ collisions, a procedure that exploits the difference in the mesons impact parameter distribution between direct and secondary D components was developed. Because of the longer B lifetime and the longer reconstructed path for the secondary mesons (it includes the path travelled by the B meson), the d_0 distribution has a larger width with respect to the one related to the particles generated in the primary interaction. The invariant mass of the candidates is fitted as a function of the d_0. We can then assess the direct fraction from the yields as a function of the d_0 plot using a Monte Carlo simulation to fix the impact parameter distributions for the direct and secondary mesons. Figure 6 shows an example of the whole procedure for the D^0 case using a Monte Carlo sample. The fit range is the same used to assess the total yield.

- The first plot (at the top) shows the impact parameter d_0 vs $K^-\pi^+$ invariant mass.

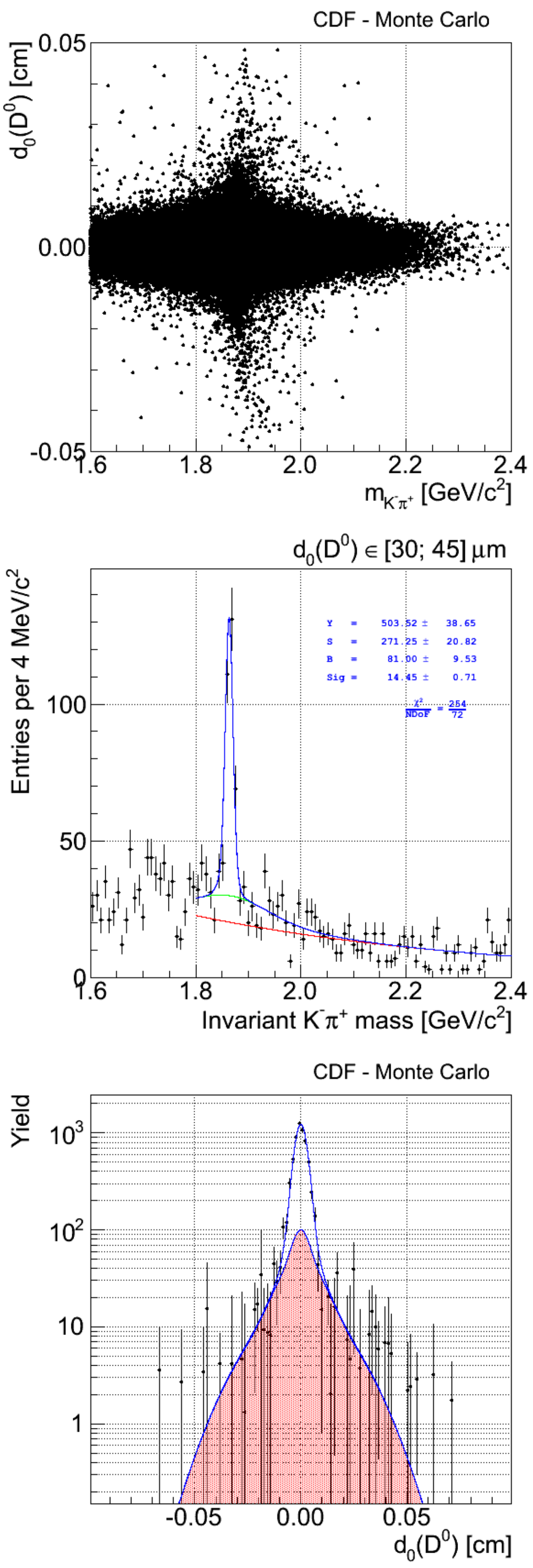

Figure 6. Impact parameter d_0 vs $K^-\pi^+$ invariant mass of a D^0 Monte Carlo simulation sample (top); example of the invariant mass fit of a d_0-slice of the scatter plot (center); yields as a function of the d_0 and direct fraction fit (bottom).

- The second plot shows an example of the invariant mass fit of a d_0-slice of the scatter plot (at the top); this slice is obtained with all the candidates with an impact parameter between 30 and 45 μm.
- The last plot shows the yields as a function of the d_0 obtained scanning the whole d_0 range as described in the previous bullet. The fit of the direct fraction is also shown; the distribution in red represents the component due to secondary D^0.

5 Conclusion

The reconstruction of the charm signal at CDF II in the minimum-bias samples collected at two different center of mass energies (1.96 TeV and 900 GeV) is reported. The channels studied are $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$. The total yields obtained fitting the signals of the reconstructed candidates with $p_T \geq 1.5$ GeV/c are shown. The technique developed to assess the B feed-down correction to the differential cross section is also shown.

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