Measurement of low p_T D^+ meson production cross section at CDF

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Summary. — We report a measurement of the number of low-p_T D^+ mesons produced 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 during Run II. The measurement is performed in a yet unexplored low transverse momentum range, down to 1.5 GeV/c. The actual QCD theory cannot predict the behavior of the strong interactions in the low transferred-four-momentum region because in these kinematic conditions the strong coupling constant is of the order of the unity. Thus, a perturbative expansion is not useful At present, several phenomenological models have been proposed, but they are able to describe only a few aspects of the observed physical quantities and not the full complexity. Experimental results in these conditions are then crucial to test new QCD models. The measurement of the differential cross section at low p_T plays an important role in this context allowing refinement of current knowledge.

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1. – Introduction

This work is part of a specific effort by the CDF Collaboration to measure the differential cross section of prompt charmed mesons at low transverse momentum (p_T).
The channel of interest is $D^+ \to K^-\pi^+\pi^+$ (and its charge-conjugate decay, $D^- \to K^+\pi^-\pi^-$).
Two background sources are present: secondary and combinatoric components. The D^+ produced directly at the point where the primary $p\bar{p}$-interaction occured is the signal we are measuring, the prompt component. Some D^+ can originate from decays of B mesons. They constitute a secondary component which is caracterized by a wider impact parameter distribution than the prompt component. Three unrelated tracks with an effective mass near the D^+ peak value in the invariant mass distribution form a combinatoric backgorund.
A previous published analysis by the CDF Collaboration in 2003 [1] performed this measurement down to a minimum p_T of the D^+ of 6.0 GeV/c, 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 2.5 GeV/c, we use data samples selected online with the minimum-bias and zero-bias triggers.
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, intially 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 [2.5; 14.5] GeV/c in bins of variable size.

2. – Data selection

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.

Let $\mathcal{M}$ be the data sample on which the selection is optimized.

1. The event number is used as a random criterion to divide the sample $\mathcal{M}$ into two statistically independent subsamples with approximately the same size, even-numbered and odd-numbered events.

2. A configuration space is built considering three optimization variables: $p_T(TRK)$, the transverse momenta of the decay tracks, the χ^2 returned by the kinematic fit of the decay, and the decay length projected onto the transverse plane, L_{xy}. We consider ten possible different values of the cut applied to each variable. The *i-th* element of the configuration space is a possible different combination of the cuts applied to the three variables.

3. Considering the *i-th* configuration, signal ($\mathcal{S}_i$) and background ($\mathcal{B}_i$) are obtained through a binned likelihood fit on the invariant $K^-\pi^+\pi^+$ mass plot, within 2σ around the D^+ peak (*Signal Region*). The figure of merit is defined as:

$$f(\mathcal{S}_i, \mathcal{B}_i) = \mathcal{S}_i/\sqrt{\mathcal{S}_i + \mathcal{B}_i}. \tag{1}$$

   It is used to minimize the statistical uncertainty on the measured signal.

4. Considering the even subsample E, the configuration space is scanned in order to find the parameters that maximize our figure of merit, $f(\mathcal{S}^E, \mathcal{B}^E)$. The selection corresponding to the maximum of f optimizes $f(\mathcal{S}^E, \mathcal{B}^E)$.

5. The last two steps are repeated using the odd sample O to obtain the set of cuts which optimize the sample O. Due to statistical fluctuations, they are in general different from the ones obtained in sample E.

6. The final sample is obtained applying to the subsample E the requirements optimized in subsample O and viceversa.

Splitting the sample $\mathcal{M}$ as described avoids a bias in the selection and, at the same time, uses all the available statistics.

3. – Yields as a function of $p_T(D^+)$

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: prompt, secondary and combinatoric. For each component, the distributions in mass and impact parameter are uncorrelated. Thus the likelihood function to be maximized is the following:

$$\mathcal{L} = f_P \cdot F_{SP}(m) \cdot F_P(d_0) + f_S \cdot F_{SP}(m) \cdot F_S(d_0) + (1 - f_P - f_S) \cdot F_C(m) \cdot F_C(d_0) \quad (2)$$

where $F_{SP}(m)$ is the common shape in the invariant $K^-\pi^+\pi^+$ mass distribution for the primary and secondary components; $F_P(d_0)$, $F_S(d_0)$ and $F_C(d_0)$ are the shapes in the D^+-impact parameter distribution for the primary, secondary, and combinatoric components, respectively. $F_C(m)$ is the shape in the invariant-mass distribution for the combinatoric component. The free parameters are only the prompt and secondary fractions, f_P and f_S.
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 the two components. The shapes for the prompt and secondary impact-parameter distributions are determined using the Monte Carlo simulations, while the combinatoric-background shape is determined using data. From the invariant-mass distribution, we define the side-band (SB) regions as $[1.7; 1.8]$ GeV/c^2 and $[1.9; 2.0]$ GeV/c^2. The combinatoric-background shape comes from the impact-parameter distribution in the side-band regions of the D^+ invariant mass plot. The D^+ mass shapes are modeled from a single fit to the invariant $K^-\pi^+\pi^+$ mass distribution.

The results for the two-dimensional unbinned likelihood fit for the $p_T(D^+)$ bins are shown from fig.1 to fig.4 . All the results are summarized in Table I and fig.5.

4. – Conclusions

The extraction of the CDF D^+ yields has been presented. The results show the status of the analysis as of March 2015. In order to measure the D^+ meson production cross section, the efficiency correction is required and is in progress.

REFERENCES

[1] The CDF Collaboration, D.Acosta, *et al.*, *Measurement of Prompt Charm Meson Production Cross Section in p anti-p Collisions at s**(1/2) = 1.96 TeV*, *Phys. Rev. Lett.*, **91:241804** (2003) .

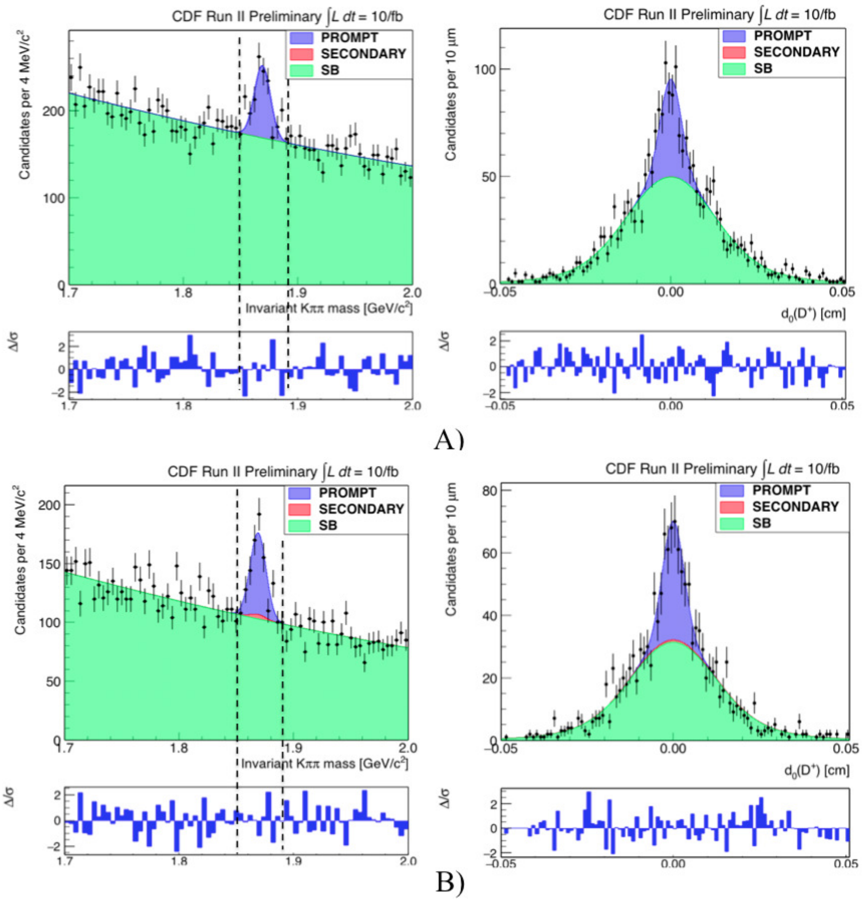

Fig. 1. – Two-dimensional unbinned likelihood fit for $p_T(D^+)$ in the range [2.5; 3.5] GeV/c for the even subsample A) and odd subsample B). On the left the results of the fit to the invariant mass distribution are shown, on the right the projection on the impact-parameter axis of the fit function in the signal region.

TABLE I. – D^+ *yields as a function of* p_T.

$p_T(D^+)$ [GeV/c]	SUBSAMPLE	N_{D^+}
2.5 - 3.5	EVEN	365 ± 27
2.5 - 3.5	ODD	304 ± 34
3.5 - 4.5	EVEN	304 ± 28
3.5 - 4.5	ODD	301 ± 28
4.5 - 6.5	EVEN	381 ± 29
4.5 - 6.5	ODD	386 ± 29
6.5 - 14.5	EVEN	282 ± 24
6.5 - 14.5	ODD	328 ± 27

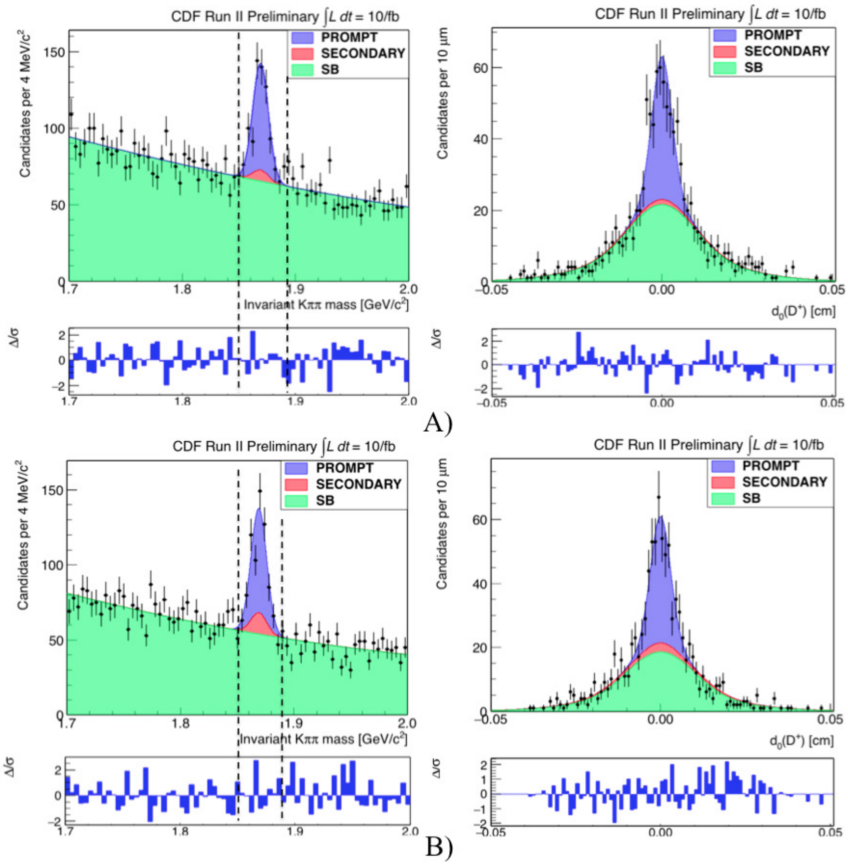

Fig. 2. – Two-dimensional unbinned likelihood fit for $p_T(D^+)$ in the range [3.5; 4.5] GeV/c for the even subsample A) and odd subsample B). On the left the results of the fit to the invariant mass distribution are shown, on the right the projection on the impact-parameter axis of the fit function in the signal region.

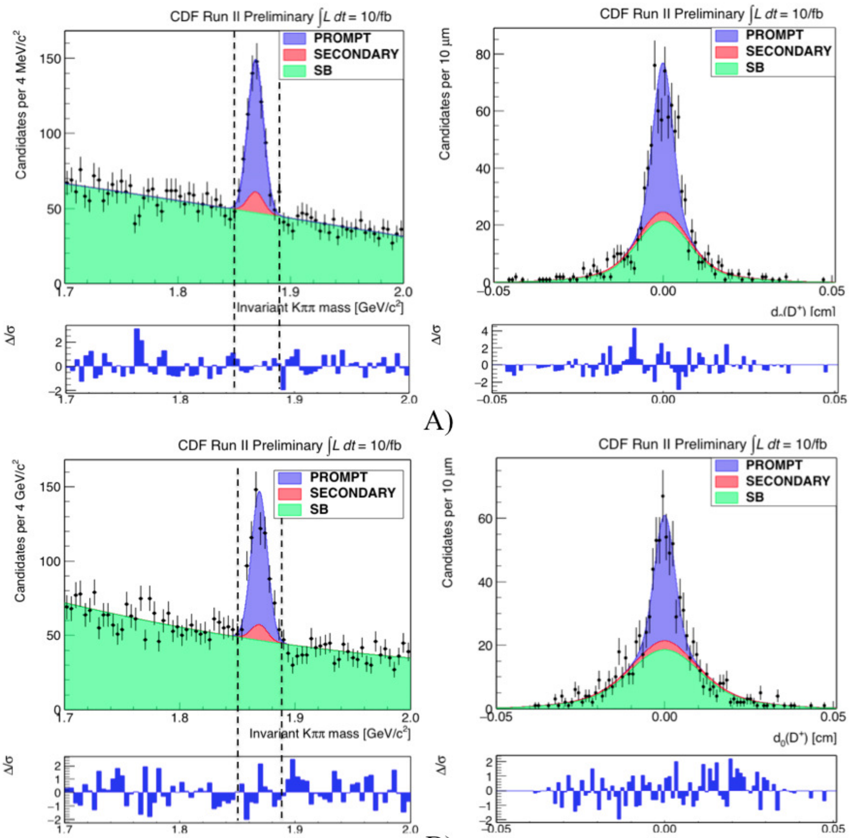

Fig. 3. – Two-dimensional unbinned likelihood fit for $p_T(D^+)$ in the range [4.5; 6.5] GeV/c for the even subsample A) and odd subsample B). On the left the results of the fit to the invariant mass distribution are shown, on the right the projection on the impact-parameter axis of the fit function in the signal region.

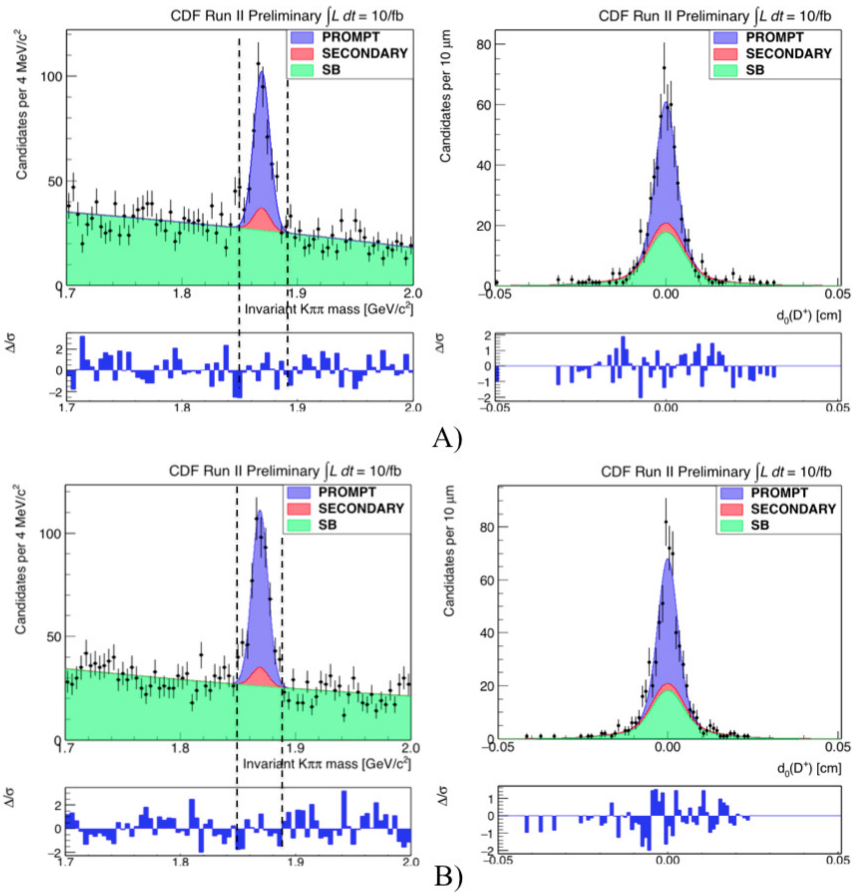

Fig. 4. – Two-dimensional unbinned likelihood fit for $p_T(D^+)$ in the range [6.5; 14.5] GeV/c for the even subsample A) and odd subsample B). On the left the results of the fit to the invariant mass distribution are shown, on the right the projection on the impact-parameter axis of the fit function in the signal region.

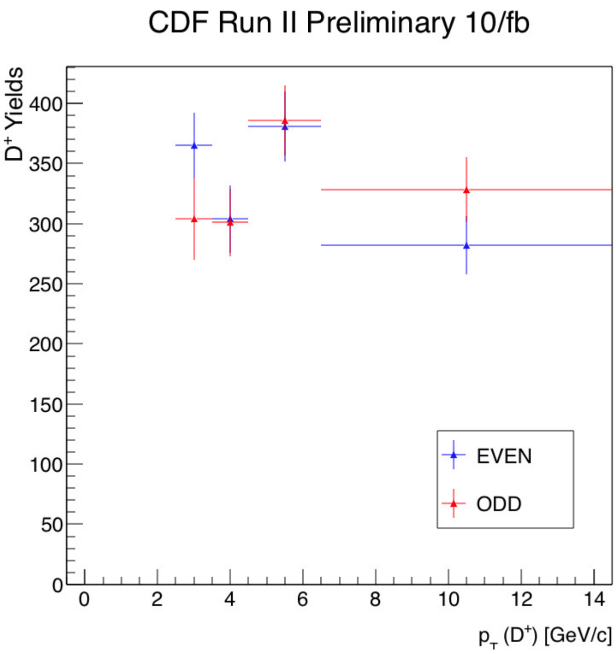

Fig. 5. – D^+ yields as a function of p_T.