FERMILAB-CONF-04-424-E

Measurement of Orbitally Excited D-Mesons at CDF II

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Abstract

Results of the first measurement of ^3P orbitally excited neutral D-meson states, D_2^{*0} and D_1^0, produced in hadron collisions at the Tevatron are presented. Using data from the displaced track trigger, CDF II collects a large sample of these states in decay modes D^{*+} π^-, D^+ π^-. Masses and widths of both states have been measured with precision better than or comparable to that of the world average.

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1 Introduction

The mesons containing one heavy quark are a useful laboratory to test QCD models. In the limit of heavy quark mass $m_Q \to \infty$, heavy mesons' properties are governed by the dynamics of the light quark. As such, these states become "hydrogen atoms" of hadron physics. In this Heavy Quark Symmetry approach (see References [1, 2, 3, 4, 5]) the quantum numbers of the heavy and light quarks are separately conserved by the strong interaction. For the charmed D-mesons the heavy charmed quark spin, $\mathbf{s_Q}$, couples with the light quark momentum $\mathbf{j_q} = \mathbf{s_q} + \mathbf{L}$, where $\mathbf{s_q}$ is the spin of the light quark and $\mathbf{L}$ is its angular momentum. Hence for P-wave ($L = 1$) mesons we obtain two $j_q = 3/2^+$ states, the $J^P = 2^+, 1^+$ states, and two $j_q = 1/2^+$ states, the $J^P = 0^+, 1^+$ states. In the Heavy Quark Symmetry limit, conservation of parity and $\mathbf{j_q}$ requires that the strong decays $D_J(j_q = 3/2^+) \to D^{(*)}(j_q = 1/2^-)\,\pi(J^P = 0^-)$ proceed via D-wave while $D_J(j_q = 1/2^+) \to D^{(*)}(j_q = 1/2^-)\,\pi(J^P = 0^-)$ proceed via S-wave. Therefore

*talk given on behalf of the CDF Collaboration at the First Meeting of the APS Topical Group on Hadronic Physics, GHP 2004, Oct 24-26, 2004, Fermilab, Batavia, Illinois.

$D_2^*(J^P = 2^+, j_q = 3/2^+)$ decays both to $D^*(J^P = 1^-)\pi(J^P = 0^-)$ and to $D(J^P = 0^-)\pi(J^P = 0^-)$ in D-wave, in contrast to $D_1(J^P = 1^+, j_q = 3/2^+)$ which decays only into $D^*(J^P = 1^-)\pi(J^P = 0^-)$ and again via D-wave. $D'_1(J^P = 1^+, j_q = 1/2^+)$ converts only into $D^*(J^P = 1^-)$ emitting a pseudoscalar π in S-wave, while $D_0^*(J^P = 0^+, j_q = 1/2^+)$ decays only to $D(J^P = 0^-)\pi(J^P = 0^-)$ and only in S-wave. States decaying via S-wave are expected to be broad while those decaying via D-wave are expected to be narrow.
The first observation of excited charmed mesons was made by the ARGUS Collaboration (see References [6, 7, 8, 9, 10]) and immediately confirmed by CLEO [11] and the Tagged Photon Spectrometer (FNAL) [12] Collaborations. The states have also been studied at LEP [13, 14, 15]. A high statistics analysis has been done with the CLEO-II detector [16, 17]. The most recent measurements by the CLEO-II [18], BELLE [19], and FOCUS [20, 21] experiments have improved the previous ones and extracted the contributions of broad D'_1 and D_0^* states.
Recently the CDF Collaboration has analyzed the signals of orbital D_J-meson states using 210 pb^{-1} of data taken with the CDF II Detector. We present here the measurements of the ^3P orbitally excited neutral D_2^{*0} and D_1^0 charmed mesons.

2 Analysis and Tracking Calibration.

Our analysis is based on a data sample collected by a trigger which selected events with at least two displaced tracks of opposite charge, each having an impact parameter measured by the CDF silicon detector to be larger than $100\,\mu$m and a momentum above $2.0\,\mathrm{GeV}/c$. The total momentum of the track pair was required to be larger than $5.5\,\mathrm{GeV}/c$. This "impact parameter two track trigger" sample is enriched by events with heavy quarks decaying via hadronic modes. For example the reconstructed signal of the D^{*+} contains $\sim 0.5 \times 10^6$ events in the peak.
The ^3P-wave neutral charmed mesons D_J^0 were analyzed in their decay modes to $D^{*+}\pi^-$ and to $D^+\pi^-$[1].
Both D_1^0 and D_2^{*0} contribute to the mode $D^{*+}\pi^-$. Here a D^{*+} was reconstructed from the final state of $D^0\pi^+_{soft}$, with $D^0 \rightarrow K^-\pi^+$ combined with a π^+_{soft} soft track ($p_T > 400\,\mathrm{MeV}/c$) where events were triggered by the two hardest tracks of four, and the trigger information was matched with tracks offline. The four-track combination was subjected to the two-dimensional vertex fit without mass constraints and the resulting decay length L_{xy} was required to be longer than $500\,\mu$m. The candidates for D^0 were required to have mass within $\pm 3\sigma$ of the $M(D^0)$ signal. Next, the candidates for D^{*+} were extracted from the mass difference δM spectrum of $M(D^0\pi^+_{soft}) - M(D^0)$ and again from within $\pm 3\sigma$ of δM around the narrow ($\sigma(\delta M) \sim 0.6\,\mathrm{MeV}/c^2$) D^{*+} peak.
The mode $D_J^0 \rightarrow D^+\pi^-$, $D^+ \rightarrow K^-\pi^+\pi^+$ has only one narrow D_2^{*0} that contributes directly. As the D^+ signal has a higher combinatorial background, harder cuts were applied. The fitted secondary decay vertex was required to be separated from the primary one by applying a $L_{xy} > 1000\,\mu$m cut. The candidates for D^+ were selected from the $\pm 3\sigma$ window around the $M(D^+)$ peak. To further suppress the background, a cut on momentum $p_T(\pi^-) > 800\,\mathrm{MeV}/c$ was applied as well.
Finally the signals of D_1^0 and D_2^{*0} were extracted from mass difference spectra

$$\Delta M = M((D^{*+}\ or\ D^+)\pi^-) - M(D^{*+}\ or\ D^+).$$

[1] Unless otherwise stated all references to the specific charge combination imply the charge conjugate combination as well.

A precise measurement of mass requires good calibration of the tracking system. The mass scale was calibrated using large samples of $J/\psi \to \mu^+\mu^-$ and $K_S^0 \to \pi^+\pi^-$ events as reference signals. The quality of the calibration was validated by checking the variations in mass of the final states, D^0 (see Figure 1), D^{*+} (see Figure 2) and D^+ (see Figure 3) against their transverse momentum. The variations were found to lie within $\pm 1\sigma$ of the corresponding world averaged measurements assigned by the Particle Data Group (PDG) [22].

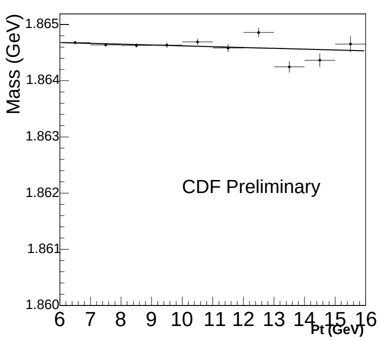

Figure 1: $M(D^0)_{meas}$ variation versus its momentum p_T, $M(D^0)_{meas} \in M(D^0)_{PDG} \pm 1\sigma_{PDG}$.

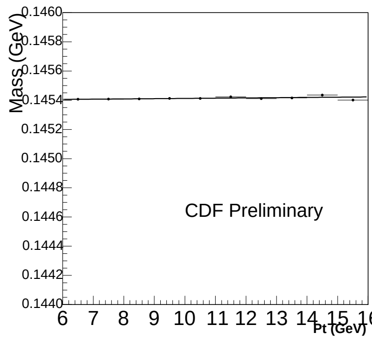

Figure 2: $\delta M(D^{*+})_{meas}$ variation versus its momentum p_T, $\delta M(D^{*+})_{meas} \in \delta M(D^{*+})_{PDG} \pm 1\sigma_{PDG}$.

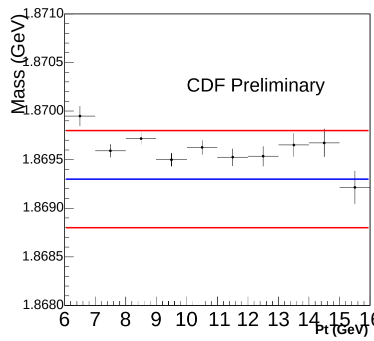

Figure 3: $M(D^+)_{meas}$ variation versus its momentum p_T, $M(D^+)_{meas} \in M(D^+)_{PDG} \pm 1\sigma_{PDG}$.

3 Mass Spectra and Fits

Figure 4 shows the distribution of $\Delta M \equiv M(D^{*+}\pi^-) - M(D^{*+})$. A double peaked structure is seen with a peak at $\sim 410\,\text{MeV}/c^2$ attributed to the $D_1^0(2420)$ and another at $\sim 450\,\text{MeV}/c^2$ corresponding to the $D_2^{*0}(2460)$.
Figure 5 shows the mass difference spectrum of $\Delta M \equiv M(D^+\pi^-) - M(D^+)$. The pronounced peak at $\Delta M \sim 600\,\text{MeV}/c^2$ is a signal for the $D_2^{*0}(2460)$ state while the structure below at $\Delta M \sim 400\,\text{MeV}/c^2$ is created by feed-down from the $D_1^0(2420)$ and $D_2^{*0}(2460)$ states decaying via the $D^{*+}\,\pi^-$ mode, with $D^{*+} \to D^+\pi^0(\gamma)$ with a branching ratio of $\sim 32.3\%$ [22].
The signals are observed on top of a large combinatorial background. The broad states contributions, D'^0_1 in Figure 4 and D_0^{*0} in Figure 5 are shown as well.
Both ΔM histograms were fitted simultaneously. The likelihood function used has independent background and broad state $\Delta M(D'^0_1\, or\, D_0^{*0})$ terms, while the same values for masses ΔM and widths Γ of D_1^0 or D_2^{*0} were kept in the fit. The broad and narrow resonances as well as feed-down enhancements are described by a non-relativistic Breit-Wigner form convoluted with a Gaussian resolution function $\mathcal{BW} \otimes Gauss$. The resolutions σ for Gaussian functions were obtained from extensive Monte-Carlo studies and fixed in the fit. The broad states masses and widths were fixed to the PDG ones for D'^0_1 [22] or to the most recent measurements for D_0^{*0} [19]. The fit was tested with a Monte-Carlo sample a factor of 2 larger in size than the data, and no selection biases were observed. The corresponding statistical uncertainty on fits of Monte-Carlo samples contributes to the total systematic error.

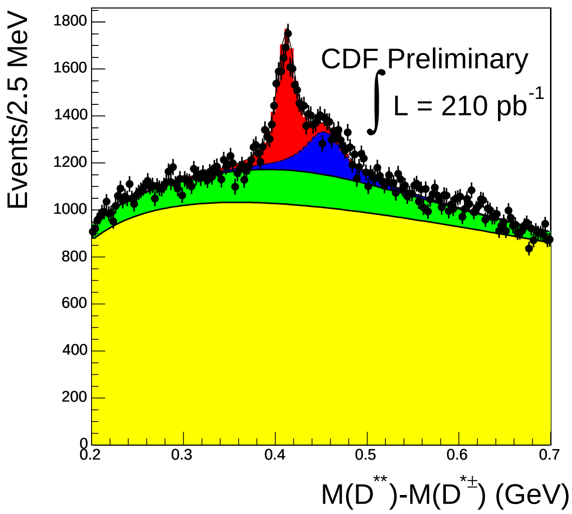

Figure 4: Two peaks corresponding to narrow resonances: $\Delta M(D_1^0(2420)) \sim 410\,\mathrm{MeV}/c^2$, $\Delta M(D_2^{*0}(2460)) \sim 450\,\mathrm{MeV}/c^2$.

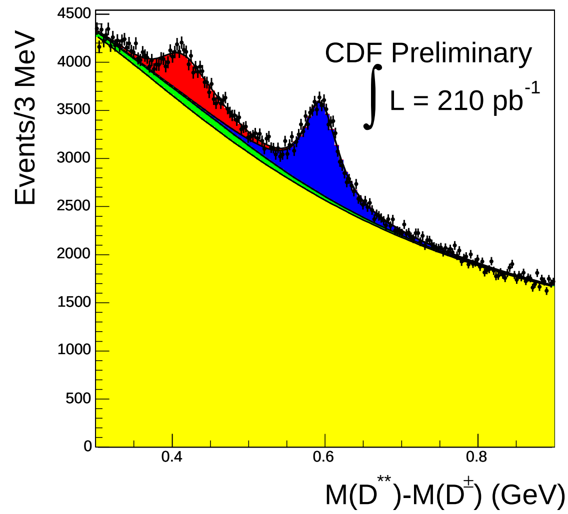

Figure 5: Two visible bumps can be attributed to: $\Delta M(D_2^{*0}(2460)) \sim 600\,\mathrm{MeV}/c^2$ and structure at $\Delta M \sim 400\,\mathrm{MeV}/c^2$ created by the feed-down from $D^{*+}\ \pi^-$ states when $D^{*+} \to D^+\pi^0(\gamma)$ with BR $\sim$ 32% and $\pi^0(\gamma)$ goes undetected.

4 Results

The fits of our spectra yielded the numbers shown in Table 1. Results by other high-statistics experiments are shown as well. Our mass difference measurements are also presented.
The systematic uncertainty on the mass and width measurements comprises the uncertainty due to the size of the Monte-Carlo sample used to determine the systematic error on the fits, the uncertainty of the masses and the natural widths of broad state contributions which were fixed in the fits, the uncertainty on the CDF II tracker calibration and the systematic uncertainty on the magnetic field in the CDF II detector. The error assigned by the PDG to the masses of the D^+ and D^{*+} does contribute to the uncertainty on the absolute mass measurements.
The CDF II mass measurements of the D_2^{*0} and D_1^0 charmed mesons are in good agreement with world data. While the width $\Gamma(D_1^0)$ is in good agreement with world data, $\Gamma(D_2^{*0})$ lies within 1σ of the most recent results from BELLE [19] and FOCUS [21], but does differ from the PDG 2004 [22] average value.

5 Conclusions

The CDF Collaboration presents here the first mass and width measurements of neutral ^3P-wave D_1^0 and D_2^{*0} charmed mesons produced at the Tevatron hadron collider. Thanks to the excellent CDF II tracking, the measurements have the lowest statistical and systematical uncertainties among current data. The mass measurements are in good agreement with the most recent experimental data.

Table 1: CDF II measurements of D^0_J-meson masses and widths, shown in **bold style**, compared with other experiments' measurements.

Group	**State**	**Mode**	**Mass,** MeV/c^2	$\mathbf{\Gamma}$, MeV/c^2
CLEO [16]	D_2^{*0}	$D^+\ \pi^-$	2465±3±3	$28^{+8}_{-7}\pm 6$
BELLE [19]	D_2^{*0}	$D^+\ \pi^-$	2461.6±2.1±3.3	45.6±4.4±6.7
FOCUS [21]	D_2^{*0}	$D^+\ \pi^-$	2464.5±1.1±1.9	38.7±5.3±2.9
PDG [22]	D_2^{*0}	$D^{*+}\ \pi^-$, $D^+\ \pi^-$	2458.9±2.0	23± 5
CDF II, this study	$\mathbf{D_2^{*0}}$	$\mathbf{D^+\pi^-}$	**2463.3±0.6±0.8** $\mathbf{M(D_2^{*0}) - M(D^+)}$ **594.0±0.6±0.5**	**49.2±2.1±1.2**
CLEO [16]	D_1^0	$D^{*+}\ \pi^-$	$2421^{+1}_{-2}\pm 2$	$20^{+6}_{-5}\pm 3$
BELLE [19]	D_1^0	$D^{*+}\ \pi^-$	2421.4±1.5±0.9	23.7±2.7±4.0
PDG [22]	D_1^0	$D^{*+}\ \pi^-$	2422.2± 1.8	$18.9^{+4.6}_{-3.5}$
CDF II, this study	$\mathbf{D_1^0}$	$\mathbf{D^{*+}\pi^-}$	**2421.7±0.7±0.6** $\mathbf{M(D_1^0) - M(D^{*+})}$ **411.7±0.7±0.4**	**20.0±1.7±1.3**

Acknowledgments

The author is grateful to his colleagues from the CDF B-Physics Working Group, especially to Dr. E. Gerchtein for useful suggestions and comments made during preparation of this talk. The author would like to thank Prof. Sally C. Seidel for support of this work, fruitful discussions, and comments. The author thanks Dr. M. Hoeferkamp for useful comments.

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