Studies of $D^{(*)}_{sJ}$ production in B decays and $e^+e^- \rightarrow c\bar{c}$ events

V. Poireau

To cite this version:
V. Poireau. Studies of $D^{(*)}_{sJ}$ production in B decays and $e^+e^- \rightarrow c\bar{c}$ events. 11th International Conference on Hadron Spectroscopy, HADRON 05, Aug 2005, Rio de Janeiro, Brazil. pp.498-502, 10.1063/1.2176531. in2p3-00025040

HAL Id: in2p3-00025040
http://hal.in2p3.fr/in2p3-00025040
Submitted on 14 Nov 2005

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
Studies of $D^{(*)}_{sJ}$ production in $B$ decays and
\[ e^+e^- \rightarrow c\bar{c} \] events

V. Poireau
for the BABAR Collaboration

LAPP-IN2P3-CNRS
BP. 110, F-74941 Annecy-le-Vieux Cedex

Presented at HADRON 2005
11th International Conference on Hadron Spectroscopy, HADRON 05
Rio de Janeiro (Brazil), August 21-26, 2005
Studies of $D_{sJ}^{(*)}$ Production in $B$ Decays and $e^+e^- \rightarrow c\bar{c}$ Events

V. Poireau (on behalf of the BaBar Collaboration)

Laboratoire de Physique des Particules, F-74941 Annecy-le-Vieux, France

Abstract. We report a study of $D_{sJ}^*(2317)^+$ and $D_{sJ}(2460)^+$ meson production in $B$ decays. We observe and measure branching fractions for the decays $B^+ \rightarrow D_{sJ}^+(2317)^+\bar{D}_{sJ}^-\bar{D}_{sJ}^{(*)0}$ and $B^0 \rightarrow D_{sJ}^0\bar{D}_{sJ}^{(*)-}$ with the subsequent decays $D_{sJ}^*(2317)^+ \rightarrow D_s^+\pi^0$, $D_{sJ}(2460)^+ \rightarrow D_s^+\pi^0$, and $D_{sJ}(2460)^+ \rightarrow D_s^+\gamma$. In addition, we perform an angular analysis of $D_{sJ}(2460)^+ \rightarrow D_s^+\gamma$ decays to test the different $D_{sJ}(2460)^+$ spin hypotheses.

From a dataset of $e^+e^- \rightarrow c\bar{c}$ events we measure the masses of the $D_{sJ}^*(2317)^+$ and $D_{sJ}(2460)^+$ mesons and the $D_{sJ}(2460)^+ \rightarrow D_s^+\gamma$ and $D_{sJ}(2460)^+ \rightarrow D_s^+\pi^+\pi^-$ branching fractions. A search is performed for neutral and doubly-charged partners.

We have also searched for the $D_{sJ}(2632)^+$ reported by the SELEX collaboration at FNAL. The resulting $D_s^+\eta$ and $D^0K^+$ mass spectra show no evidence for the $D_{sJ}^*(2632)^+$ state. In addition, no signal is observed in the $D^+K_s$ mass spectrum.

All the above studies are performed on data samples collected with the BaBar detector at the SLAC PEP-II $B$ factory.

Keywords: Spectroscopy, Hadron, New Resonance

PACS: 14.40.Lb

INTRODUCTION

The unexpected observation of a narrow $D_s^+\pi^0$ resonance with a mass of 2317 MeV/$c^2$ was recently reported by the BaBar collaboration [1] and confirmed by the CLEO experiment [2]. CLEO observed a second $D_s^{*+}\pi^0$ resonance with a mass close to 2460 MeV/$c^2$ [2], previously suggested [1] and later confirmed [3] by BaBar. The Belle collaboration confirmed both resonances and found two additional decay modes for the higher-mass state [4], $D_s^+\gamma$ and $D_s^+\pi^+\pi^-$. These resonances are usually interpreted as $P$-wave $c\bar{s}$ quark states [5, 6, 7, 8, 9], although other interpretations [10, 11, 12, 13, 14] cannot be ruled out, and will be referred to in the following as $D_{sJ}^*(2317)^+$ and $D_{sJ}(2460)^+$ mesons.

In the framework of the heavy quark effective theory, an analogy is made between the $c\bar{s}$ system and a hydrogen atom. The approximation consists to consider a light quark (s quark) spinning around a heavy quark (c quark), such as the heavy quark is regarded as fixed. In this case, the quantum number of the s quark, $j = s_L + L$, where $s_L$ is the spin of the s quark and $L$ the orbital quantum number, is considered as good quantum number. The total quantum number of the $c\bar{s}$ system is defined as $J = j + s_c$, where $s_c$ is the spin of the c quark. In this context, 2 $S$-wave states are predicted, identified as the $D_s(1686)^+$ and the $D_s^*(2112)^+$ mesons, and 4 $P$-wave states are predicted, where the states with $j = 3/2$ are identified with the $D_{s1}(2536)^+$ and $D_{s2}^*(2573)^+$ mesons. The agreement
between the mass prediction of this model [15] and the real masses of the resonances is good. The 2 \( P \)-wave states with \( j = 1/2 \) (with \( J^P = 0^+ \), \( 1^+ \)) are predicted with a mass between 2400 and 2600 MeV/c\(^2\), and with a very large width (with a decay to \( D^{(*)} K \)).

This contradicts with the smaller masses and the narrow widths of the \( D_{sJ}^{(*)}(2317)^+ \) and \( D_{sJ}^{(*)}(2460)^+ \) mesons. It is then very important to measure further the properties of these 2 new resonances, and in particular to try to measure their quantum number.

The analyses presented below were performed using a 113 fb\(^{-1}\) and a 125 fb\(^{-1}\) data sample (depending if off-resonance data were used) collected on or near the \( \Upsilon(4S) \) resonance with the BaBar detector at the PEP-II asymmetric-energy \( e^+ e^- \) storage ring. The BaBar detector, a general-purpose, solenoidal, magnetic spectrometer, is described in detail elsewhere [16].

**STUDY OF B \( \rightarrow D_{sJ}^{(*)} \bar{D}^{(*)} \)** DECAYS

The new states were first observed in \( e^+ e^- \rightarrow c \bar{c} \) collisions. Their observation in exclusive \( B \rightarrow D_{sJ}^{(*)} \bar{D}^{(*)} \) decays allows additional properties of the \( D_{sJ}^{(*)} \) state to be studied: the helicity angle distribution in \( B \) decays can be used to obtain information on the spin \( J \), and the measurement of the different branching fractions can help clarify the nature of these states. This analysis [17] considers the production modes \( B^+ \rightarrow D_{sJ}^{(*)} + \bar{D}^{(*)} 0 \) and \( B^0 \rightarrow D_{sJ}^{(*)} + \bar{D}^{(*)} \) with the subsequent decays \( D_{sJ}^{(*)}(2317)^+ \rightarrow D_s^+ \pi^0 \), \( D_{sJ}^{(*)}(2460)^+ \rightarrow D_s^{(*)} \pi^0 \), and \( D_{sJ}^{(*)}(2460)^+ \rightarrow D_s^{(*)} \gamma \). After reconstruction of the \( \bar{D}^{(*)} \) and \( D_{sJ}^{(*)} \) mesons, these candidates are combined with a photon or a \( \pi^0 \) to form \( B \) candidates. A \( B \) signal region is defined in terms of the beam energy substituted mass, \( m_{ES} \equiv \sqrt{s/4 - p_B^2} \), and the difference between the reconstructed energy of the \( B \) candidate and the beam energy, \( \Delta E \equiv E_B^* - \sqrt{s}/2 \), where \( \sqrt{s} \) is the total energy in the \( \Upsilon(4S) \) center-of-mass frame and \( E_B^* \) (\( p_B^* \)) is the energy (momentum) of the \( B \) candidate in the same frame. Different cuts are defined on these variables depending on the final state, and only one \( B \) candidate is selected per event. Signals are observed in the 3 decay modes: 88 \( \pm \) 17 events with a mass of 2317.2 \( \pm \) 1.3 MeV/c\(^2\) for the \( D_{sJ}^{(*)}(2317)^+ \bar{D}^{(*)} [D_s^{(*)} \pi^0] \) decay mode, 112 \( \pm \) 14 events with a mass of 2458.9 \( \pm \) 1.5 MeV/c\(^2\) for the \( D_{sJ}^{(*)}(2460)^+ \bar{D}^{(*)} [D_s^{(*)} \pi^0] \) decay mode and 139 \( \pm \) 17 events with a mass of 2461.1 \( \pm \) 1.6 MeV/c\(^2\) for the \( D_{sJ}^{(*)}(2460)^+ \bar{D}^{(*)} [D_s^{(*)} \gamma] \) decay mode. Signals are also observed for each of the twelve \( D_s^{(*)} + \bar{D}^{(*)} \pi^0 / \gamma \) final states. A significance larger than 4 is observed for 10 of the 12 modes. From the \( D_{sJ}^{(*)} \) event yields in the data, the cross-feed-corrected branching fractions are computed, using the signal efficiency and the relative contributions from cross-feed between the different \( D_{sJ}^{(*)} \) decay modes as obtained from simulated signal events.

A helicity analysis of the \( D_{sJ}^{(*)}(2460)^+ \) state has been performed, using the decays \( B \rightarrow D_{sJ}^{(*)}(2460)^+ D \) with \( D_{sJ}^{(*)}(2460)^+ \rightarrow D_s^{(*)} \gamma \). The helicity angle \( \theta_h \) is defined as the angle between the \( D^{(*)} \) momentum in the \( B \) meson rest frame and the \( D_s \) momentum in the \( D_{sJ}^{(*)} \) rest frame. A fit of the \( D_s \gamma \) invariant mass is performed for five different \( \cos(\theta_h) \) regions. A good agreement is found with the \( J = 1 \) hypothesis.
STUDY OF $D^*_S(2317)^+$ AND $D^*_{sJ}(2460)^+$ IN CONTINUUM PRODUCTION

The properties of the $D^*_S(2317)^+$ and $D^*_{sJ}(2460)^+$ mesons are studied using $e^+e^- \rightarrow c\bar{c}$ events [18]. Searches are performed for the decay to the $D^+_s$ meson along with one or more $\pi^0$, $\pi^+$, or $\gamma$ particles. A search is also performed for neutral and doubly-charged partners.

In this analysis, each $D^+_s$ candidate is constructed by combining a $K^+K^-$ candidate pair with a $\pi^+$ candidate in a geometrical fit to a common vertex. Once a $D^+_s$ candidate is obtained, a search is performed for all accompanying $\pi^0$, $\gamma$ and $\pi^\pm$ particles. Each final state is restricted to the same minimum center-of-mass momentum ($p^*$) value of 3.2 GeV/c$^2$.

The kinematic is complex, and leads to competing contributions and mutual cross-feeds between different modes.

$D^+_s\pi^0$ final states: to form $D^+_s\pi^0$ combinations, each $D^+_s$ candidate is combined with one $\pi^0$ candidate (the $\pi^0$ momentum is required to be greater than 400 MeV/c). A clear peak signal is seen at the mass of the $D^*_S(2317)^+$ resonance. Three types of background are present: the combinatorial background, background coming from the contribution of $D^*_S(2112)^+ \rightarrow D^+_s\gamma$ (where an unassociated $\gamma$ forms a fake $\pi^0$ candidate), and background coming from the contribution of $D^*_{sJ}(2460)^+ \rightarrow D^*_S(2112)^+\pi^0$. These background contributions must be accurately determined from the simulation in order to extract the properties of the $D^*_S(2317)^+$. After taking into account these contributions, the results give a $D^*_S(2317)^+$ mass of 2318.9 \pm 0.3 MeV/c$^2$, and $D^*_S(2317)^+$ and $D^*_{sJ}(2460)^+$ yields of 1275 \pm 45 and 3 \pm 26 mesons (statistical errors only).

$D^+_s\gamma$ final states: to form $D^+_s\gamma$ combinations, each $D^+_s$ candidate is combined with a $\gamma$ candidate with energy greater than 500 MeV/c. A clear peak is seen in the invariant mass distribution for the $D^*_{sJ}(2460)^+$. There is also a lower mass structure composed of $D^*_S(2317)^+ \rightarrow D^+_s\pi^0$ and of $D^*_{sJ}(2460)^+ \rightarrow D^+_s\pi^0\gamma$, which could be described by the simulation. A $D^*_{sJ}(2460)^+$ mass of 2457.2 \pm 1.6 MeV/c$^2$ and yield of 509 \pm 46 mesons is obtained (statistical errors only). The fit, which allows the signal yield to fluctuate to negative values, obtains -107 \pm 84 $D^*_S(2317)^+$ decays.

$D^+_s\pi^0\gamma$ final states: $D^+_s$, $\pi^0$ and $\gamma$ particles are combined together, with the requirement that the minimum $\pi^0$ momentum is 400 MeV/c and that the minimum $\gamma$ energy is 135 MeV. The $D^*_{sJ}(2460)^+$ signal can be better isolated by requiring the $D^+_s\gamma$ invariant mass to reside within 2 MeV/c$^2$ of the $D^*_S(2112)^+$ mass. This procedure isolates clearly the $D^*_{sJ}(2460)^+$ signal, but also introduces some peaking background in the invariant mass distribution ($D^*_S(2112)^+ \rightarrow D^+_s\gamma$ and $D^*_{sJ}(2317)^+ \rightarrow D^+_s\pi^0\gamma$). A fit is then performed on this distribution, taking into account all contributions: the fit obtains a $D^*_{sJ}(2460)^+$ mass of 2459.1 \pm 1.3 MeV/c$^2$ and yield of 292 \pm 29 mesons (statistical errors only). It has also been shown that the decay $D^*_{sJ}(2460)^+ \rightarrow D^*_S\pi^0\gamma$ can be successfully described as proceeding entirely through the channel $D^*_S(2112)^+\pi^0$.

$D^+_s\pi^+\pi^-$ final states: to form $D^+_s\pi^+\pi^-$ candidates, each $D^+_s$ is combined with a $\pi^+$ and $\pi^-$ candidates with momentum above 230 MeV/c. The resulting invariant mass distribution has two distinct, narrow peaks, which correspond to the decays of the...
$D_{sJ}^{*}(2460)^+$ and $D_{sJ}^{*}(2536)^+$ mesons. The result of the fit of the invariant mass is a $D_{sJ}^{*}(2317)^+$ yield of 0.6 ± 1.8 decays; a $D_{sJ}^{*}(2460)^+$ mass and yield of 2460.1 ± 0.3 MeV/c² and 67 ± 11 decays.

$D_s^\pm\pi^\pm$ final states: there has been some conjecture [14, 10] that the $D_{sJ}^{*}(2317)^+$ may be a four-quark hybrid state. It might be expected, if it was true, that neutral and doubly-charged partners should exist with a similar mass. The $D_s^\pm\pi^\pm$ system can be used to test this possibility. To form $D_s^+\pi^\pm$, each $D_s^+$ candidate is combined with $\pi^\pm$ candidates with momentum greater than 300 MeV/c. No resonant structure is observed in the resulting mass distribution.

After taking into account the systematic errors, and combining the different results of this analysis, the $D_{sJ}^{*}(2317)^+$ and $D_{sJ}^{*}(2460)^+$ masses are measured to be 2318.9 ± 0.3 (stat.) ± 0.9 (syst.) MeV/c² and 2459.4 ± 0.3 (stat.) ± 1.0 (syst.) MeV/c², respectively.

**SEARCH FOR THE $D_{sJ}^{*}(2632)^+$**

The SELEX collaboration at FNAL has recently reported the existence of a narrow state at a mass of 2632 MeV/c² decaying to $D_s^+\eta$ [20]. Evidence for the same state in the corresponding $D^0K^+$ mass spectrum was also presented. In the present analysis [19], inclusive production of the $D_s^+\eta$, $D^0K^+$ and $D^{*+}K_s$ systems in $e^+e^-\rightarrow c\bar{c}$ collisions is investigated in a search for the $D_{sJ}^{*}(2632)^+$ state.

**Search for $D_{sJ}^{*}(2632)^+\rightarrow D_s^+\eta$:** each $D_s^+$ candidate is constructed by combining a $K^+K^-$ candidate pair with a $\pi^+$ candidate. For events containing a $D_s^+$ candidate, $\eta$ candidates are selected in the $\gamma\gamma$ decay mode. The precise cuts for this reconstruction are defined in the original paper [19]. The center-of-mass momentum $p^+(D_s^+\eta)$ of the $D_s^+\eta$ system is required to be at least 2.5 GeV/c to suppress background. In order to establish the presence of an excess of events in the correlated $D_s^+$ and $\eta$ production, a two-dimensional subtraction is performed in the $D_s^+\eta$ invariant mass plane. After this subtraction is done, and looking at the invariant mass of the $D_s^+\eta$ system, no evidence of a signal has been found.

**Search for $D_{sJ}^{*}(2632)^+\rightarrow D^0K^+$:** a $D^0$ candidate is constructed by combining a $\pi^+-K^-$ pair in a geometric fit to a common vertex. A good $D^0$ candidate is combined with a well-identified $K^+$ track in a fit to a common vertex. The $D^0K^+$ mass spectrum is obtained after requiring $p^+(D^0K^+)>4.0$ GeV/c. There is no evidence for structure in the 2.632 GeV/c² mass region.

**Search for $D_{sJ}^{*}(2632)^+\rightarrow D^{*+}K_s$:** a $D^0$ candidate with mass within 25 MeV/c² of the central mass value is combined with a well-identified $\pi^+$ track in a fit to a common vertex. A candidate $K_s$ track is reconstructed by vertexing a well-identified $\pi^+\pi^-$ pair. The center-of-mass momentum of the $D^{*+}K_s$ system is required to be greater than 4 GeV/c. There is no evidence for production of the $D_{sJ}^{*}(2632)^+$ state in the data.

**CONCLUSION**

Given the previous results, it is possible to make some assumptions on the spin of the $D_{sJ}^{*}(2317)^+$ and $D_{sJ}^{*}(2460)^+$ resonances. The $J^P$ quantum numbers of the $D_{sJ}^{*}(2317)^+$...
resonance is probably $0^+$ since it does not decay to $D_s^+\pi^0$, to $D_s\gamma$ and to $D_s^+\pi^+\pi^-$, as expected for a $0^+$ state. The $D_{sJ}(2460)^+$ is probably a $1^+$ state since it decays to $D_s\gamma$ and $D_s^+\pi^+\pi^-$, and does not decay to $D_s\pi^0$ and $DK$. In addition, the helicity measurement in the exclusive analysis confirms this hypothesis.

Thus, on the experimental point of view, one natural possibility would be to identify the $D_{sJ}(2317)^+$ and $D_{sJ}(2460)^+$ with the two missing states $0^+$ and $1^+$ of the $c\bar{s}$ system.

In summary, the properties of the resonances $D_{sJ}^+(2317)$ and $D_{sJ}(2460)^+$ were studied. Masses, spin assignments, decay modes and branching fractions were determined using the data collected by the BaBar detector. In addition, no evidence for the $D_{sJ}^+(2632)^+$ state was found.

ACKNOWLEDGMENTS

The author is grateful for the excellent luminosity and machine conditions provided by our PEP-II colleague, and for the substantial dedicated effort from the computing organizations that support BaBar. The collaborating institutions wish to thank SLAC for its support and kind hospitality.

The author would like also to thank the organizers for this excellent conference on hadron spectroscopy.

REFERENCES

18. B. Aubert et al., hep-ex/0408067.
19. B. Aubert et al., hep-ex/0408087.