Production of excited charmed mesons at LEP

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Abstract

Studies of the production of orbitally excited charmed and charmed strange mesons in e^+e^-collisions, performed by the LEP collaborations are reviewed. Measurements of the production rates of orbitally excited charmed mesons in semileptonic b decays are presented. Searches for charmed meson radial excitations are also briefly discussed.

1. Introduction

In the hadronization of charm quarks into charmed mesons, states with angular momentum $L = 1$ can be produced, generically indicated with $D^{\star\star}_{(s)}$, where the subscript applies to charmed strange mesons.

Four such states of the $c\bar{q}$ system are predicted ($q = u, d, s$), one of total spin 0 (usually indicated as $D^\star_0$, $J^P = 0^+$), two of spin 1 (D_1, $J^P = 1^+$) and one of spin 2 ($D^\star_2$, $J^P = 2^+$). These excited states decay via strong interactions to D or $D^\star$ accompanied by a pion (a kaon in the case of the $D^{\star\star}_s$ states). Spin–parity conservation implies that the $D^\star_0$ decays to $D\pi$ only, the D_1 to $D^\star\pi$ only, while the $D^\star_2$ can access both final states.

In the framework of HQET, for $m_Q \to \infty$, the light quark degrees of freedom decouple from the heavy quark, and new symmetries arise. In this limit the $D^\star_0$ and one of the two D_1 mesons are expected to decay in S wave only, and to be broad (Γ around 100 MeV), the other D_1 and the $D^\star_2$ in D wave only, with narrow widths. No clear evidence for the broad states has been found so far, while the two narrow states have been measured for all of the three systems $D^{\star\star 0}$, $D^{\star\star +}$, $D^{\star\star}_s$ [1]. At LEP $D^{\star\star}$ states can be produced in the fragmentation of charm quarks from Z decays, or in the decay of bottom hadrons.

The production rate of orbitally excited charmed mesons in semileptonic decays of bottom mesons is a major b–physics issue. The exclusive decay rates into $D\ell\nu$ and $D^\star\ell\nu$ only account for 70–80% of the total inclusive semileptonic rate. The remaining part should be ascribed to narrow or wide $D^{\star\star}$, or non resonant four–body decays. The rates and the nature of final states other than $D\ell\nu$ and $D^\star\ell\nu$ is one of the major sources of systematic uncertainty for many b–physics measurements which make use of semileptonic final states such as $\tau_{B^0_d}$, Δm_d or V_{cb}. Theoretical predictions exist on the ratio of $D^\star_2$ to D_1 expected in semileptonic b decays.

Radially excited charmed mesons are also predicted to exist, in two states, the D' ($J^P = 0^-$), and the $D^{\star\prime}$ ($J^P = 1^-$), with dominant decay modes $D\pi\pi$ and $D^\star\pi\pi$, respectively. While the first state is too difficult to reconstruct in present experiments, the $D^{\star\prime}$ has been searched for at LEP, with contradictory results.

2. Production of $D^{??}$ mesons in Z decays

2.1. The channels

The cleanest channel to reconstruct $D^{\star\star}$ states is the $D^{\star +}\pi^-$ final state, which takes advantage of the clear experimental signature of the small mass difference between the $D^{\star +}$ and the D^0 in the $D^{\star +} \to D^0\pi^+$ decay. This channel has been used by ALEPH [2], DELPHI [3] and OPAL [4], where OPAL reconstructs the D^0 via $D^0 \to K^-\pi^+$ decays, DELPHI uses also $D^0 \to K^-\pi^+\pi^-\pi^+$ and ALEPH the previous two plus $D^0 \to K^-\pi^+\pi^0$. The $D^{\star +}\pi^-$ final state is accessible for both the D^0_1 and the $D^{\star 0}_2$ mesons, and therefore the reconstructed candidates can be either of the two states.

ALEPH has also studied the $D^+\pi^-$ final state, which has a larger background but is accessible only by the $D^{\star 0}_2$ meson. In this case the tighter kinematic cuts applied make the analysis sensitive to the charm contribution only ($D^{\star\star}$ from charm fragmentation have on average higher momentum than those from b decays).

Table 1. Results on $D^{\star\star}$ production probabilities in Z hadronic decays.

	ALEPH (preliminary)	DELPHI (preliminary)	OPAL (published)
$f(c \to D_1)$	0.032 ± 0.009	0.019 ± 0.004	0.021 ± 0.008
$f(c \to D_2^\star)$	0.094 ± 0.019	0.047 ± 0.013	0.052 ± 0.026
$f(b \to D_1)$	0.046 ± 0.014	0.020 ± 0.006	0.050 ± 0.015
$f(b \to D_2^\star)$	< 0.039 @ 95% CL	0.048 ± 0.020	0.047 ± 0.027

Finally ALEPH has also studied the channel $D^0\pi^+$, which is a final state for $D_2^{\star+}$ decays. the D^0 is reconstructed in the channels $D^0 \to K^-\pi^+$ and $D^0 \to K^-\pi^+\pi^-\pi^+$, and in this second, again, kinematic cuts imposed to reduce the background damp the contribution of b events.

2.2. Fitting methods and results

Samples enriched in b and c events are prepared, by applying lifetime b–tagging in the hemisphere opposite to the reconstructed candidate, combined with the information of the measured decay length (longer for b events) and the momentum (larger for c events) of the reconstructed candidate.

ALEPH performs a simple fit to the $D^{\star\star} - D^\star$ or $D^{\star\star} - D$ mass difference, using a double Breit–Wigner when both the D_1 and the $D_2^\star$ are expected to contribute.

DELPHI and OPAL, that did not study the channels where only the $D_2^\star$ contributes, use the helicity angle to help disentangling the two states. This is defined in the $D^\star$ rest frame as the angle Θ_H between the π from the $D^\star$ decay and the π from the $D^{\star\star}$ decay. It is expected to be distributed, in the HQET limit, as $1 + 3\cos^2\Theta_H$ in the case of D_1 decays and as $\sin^2\Theta_H$ in the case of $D_2^\star$ decays.

The fit yields the probability of observing the selected final state in a hadronic Z decay. Folding Z partial widths, decay branching ratios and selection efficiencies, the probability of producing a $D^{\star\star}$ state from the fragmentation of a charm quark or the decay of a bottom hadron can be derived, obtaining the results reported in Table 1.

Although no compelling discrepancy can be claimed, several differencies, at the level of twice the estimated errors, are observed. In particular ALEPH reports a significantly higher rate of $D_2^\star$ from c hadronization than the two other experiments, DELPHI has a lower D_1 rate from b decays, and ALEPH finds no $D_2^\star$ production in b decays while the other collaborations find a signal of about 2σ significance. ALEPH and DELPHI results are still preliminary.

3. $D^{??}$ mesons in semileptonic b decays

Two strategies have been adopted to study $D^{\star\star}$ production and generic four–body final states in semileptonic b decays. In both cases the first step is to select $(D^+\ell^-)$, $(D^0\ell^-)$, $(D^{\star+}\ell^-)$ pairs. Then one possibility is to look for a charged pion that forms a heavier resonance with the $D^{(\star)}$ candidate, and extract the individual $B \to D_J^{(\star)}$ rates. The other strategy is to search for pions incompatible with the primary vertex and compatible with the reconstructed b vertex, using inclusive discriminants. This yields an estimate of the total four–body decay rate, including narrow resonant, wide resonant and non resonant final state hadronic systems.

The most recent results from ALEPH [5] and DELPHI [6] are reported in Table 2.

The inclusive four–body decay rate observed by DELPHI would account for the difference between the total semileptonic rate and the sum of D and $D^\star$ rates. The corresponding ALEPH results is lower by 1.8σ. No significant production of $D_2^\star$ is observed, in contrast with what is given by all available theoretical predictions.

4. Production of $D_s^{??}$ mesons in Z decays

$D_s^{\star\star}$ mesons are reconstructed in the channels $D^\star K$ and DK. The $D_{s1}^{\star+}$ is searched for in the $D^{\star0}K^+$ and $D^{\star+}K_S^0$ final states. The second has a cleaner experimental signature but lower efficiency due to the K_S^0 reconstruction, and lower branching ratio both due to phase space (the Q–value of the decay is very small) and to the factor 1/2 because of the K_S^0. The $D^{\star+}$ is reconstructed in the $D^0\pi^+$ final state, with $D^0 \to K^-\pi^+$ in the case of OPAL [4], while ALEPH [7] uses also $D^0 \to K^-\pi^+\pi^-\pi^+$ and $D^0 \to K^-\pi^+\pi^0$. For the $D^{\star0}K^+$ final state, the $D^{\star0}$ decays to $D^0\pi^0$ or $D^0\gamma$, where the photon or the pion are not detected. The D^0 is reconstructed in the channel $D^0 \to K^-\pi^+$, and the resolution in the $D_{s1}^{\star+} - D^0$ mass difference only marginally