Summary. — I briefly introduce the status of charm physics and I discuss the case of the meson with open charm \( D_{sJ}(2700) \).

1. – Introduction

This period can be considered a sort of “Renaissance” for charm physics. Recently, a great number of new states have been discovered in both the open and the hidden charm sector. Among these there are \( D^{*}_{sJ}(2317) \), \( D_{sJ}(2460) \), \( D_{sJ}(2700) \), \( D_{sJ}(2860) \), \( D^{0}(2308) \), \( D^{*}_{1}(2440) \), \( h_{c} \), \( \eta_{c} \), \( X(3872) \), \( X(3940) \), \( Y(3940) \), \( Z(3930) \), \( Y(4260) \), the mysterious \( Z(4430) \). Part of the renewed interest growing around this branch of particle physics is due to the fact that some of the above states fail to fit into standard classification. This fact has lead people to propose many interpretations, like molecular charmonium, hybrids, orbital and radial excitations, tetraquarks, and so on. In this paper I discuss the case of the \( c\bar{s} \) meson \( D_{sJ}(2700) \), giving hints on how to classify it. For a more comprehensive discussion on charm physics the reader can refer to [1].

2. – \( D_{sJ}(2700) \)

\( D_{sJ}(2700) \) has been observed by Belle Collaboration in the Dalitz plot analyses of the process \( B^{+} \rightarrow K^{+} D^{0} \bar{D}^{0} \) as accumulation of events at \( M^{2}(D^{0}K^{+}) = 7–8 \) GeV\(^2\) in the invariant mass distribution \( M^{2}(D^{0}K^{+}) \) [2]. The branching fractions \( \mathcal{B}(B^{+} \rightarrow D^{0} D^{0} K^{+}) = (22.2 \pm 2.2|_{\text{stat}} \pm 2.2|_{\text{sys}}) \times 10^{-4} \) and \( \mathcal{B}(B^{+} \rightarrow D_{sJ}(2700)D^{0}) \times \mathcal{B}(D_{sJ}(2700) \rightarrow D^{0} K^{+}) = (11.3 \pm 2.2|_{\text{stat}} \pm 1.4|_{\text{sys}}) \times 10^{-4} \) have been measured. Measured mass and width are respectively \( M = 2708 \pm 9|_{-10}^{+11}\) MeV, \( \Gamma = 108 \pm 23|_{-31}^{+36}\) MeV. Moreover, from the distribution in the helicity angle \( \theta \), the angle between the \( D^{0} \) momentum and the opposite of the kaon momentum in the \( D^{0} \bar{D}^{0} \) rest frame, it was possible to assign spin-parity \( J^{P} = 1^{-} \) to \( D_{sJ}(2700) \).

The classification of the \( c\bar{s} \) states is easier in the heavy-quark limit \( m_{c} \rightarrow \infty \). In this limit the spin \( s_{Q} \) of the heavy quark and the total angular momentum \( s_{\ell} \) of the meson light degrees of freedom: \( s_{\ell} = s_{q} + \ell \) (\( s_{q} \) light antiquark spin, \( \ell \) orbital angular
momentum of the light degrees of freedom relative to the heavy quark) are decoupled, and the spin-parity \( s_\ell^P \) is conserved in processes involving strong interactions [3]. This allows to classify mesons into doublets labeled by \( s_\ell^P \), each containing a pair of mesons with \( J^P = (s_\ell^P - 1/2, s_\ell^P + 1/2) \) and degenerate in mass. The standard classification of known \( c\bar{s} \) states in this scheme is given in Table I [4]. The states labeled by \( D_{s}^* \), \( D_{s2}^* \),

| \( s_\ell^P \) | \( J^P \)     |
|----------------|----------------|
| \( s_\ell^P = s_\ell^P - 3/2 \) | \( D_s(1965) \) (0−) |
| \( s_\ell^P = s_\ell^P + 3/2 \) | \( D_s^*(2317) \) (0+) |
| \( s_\ell^P = s_\ell^P - 1/2 \) | \( D_{s1}(2536) \) (1+) |
| \( s_\ell^P = s_\ell^P + 1/2 \) | \( D_{s2}(2573) \) (2+) |

Table I. – \( c\bar{s} \) states organized according to \( s_\ell^P \) and \( J^P \). The mass of known mesons is indicated.

\( D_{s1}^* \) and \( D_{s2}^* \) are still to be discovered. There are hints of the fact that the \( D_{s3} \) state is the \( D_{sJ}(2860) \) meson [5, 6]. In this picture \( D_{sJ}(2700) \) could be the \( D_{s}^* \) state of the \( s_\ell^P = 3/2^- \) doublet or \( D_{s}^* \), the first radial excitation of \( D_s^*(2112) \). A way to select the right assignment between these two is to examine ratios of partial decay widths. Using an effective Lagrangian describing strong decays of heavy mesons to final states comprising a light pseudoscalar meson, and displaying heavy quark and chiral symmetries, the ratios \( R_1 = \frac{\Gamma(D_s^- \to D^0 K^-)}{\Gamma(D_s^- \to D^- K^0)} \), \( R_2 = \frac{\Gamma(D_s^- \to D^0 \eta)}{\Gamma(D_s^- \to D^- \eta)} \) and \( R_3 = \frac{\Gamma(D_s^- \to D^0 \eta')}{\Gamma(D_s^- \to D^- \eta')^2} \) have been calculated with results given in Table II [7]. The ratios \( R_1 \) and \( R_3 \) are very different if \( D_{sJ}(2700) \) is \( D_{s1}^* \) or \( D_{s2}^* \), so that the measurements of these ratios allow to properly identify the \( D_{sJ}(2700) \). In particular the decay mode to \( D^* K \) has very different branching ratios in the two possible assignments, so that a measurement of such a branching fraction would be useful to identify \( D_{sJ}(2700) \). Within the same framework, individual branching ratios have also been calculated and they are shown in Table III [7].

Since in the heavy quark limit the heavy mesons are collected in doublets with a definite value of \( s_\ell^P \), the state \( D_{sJ}(2700) \) has a partner from which it differs only for the value of the total spin.

The partner of \( D_{s}^* \) (\( s_\ell^P = 1/2^- \)) has \( J^P = 0^- \); it is denoted \( D_s' \), the first radial excitation of \( D_s \). On the other hand, the partner of \( D_{s1}^* \) (\( s_\ell^P = 3/2^- \)) has \( J^P = 2^- \) (\( D_{s2}^* \)). In both cases, the decay modes \( D_s' \), \( D_{s2}^* \to D^{*0} K^+ \), \( D^{*+} K^{*0} \), \( D_s^* \to \gamma \), are permitted. In the heavy quark limit, these partners are degenerate, hence, assigning them the same mass as \( D_{sJ}(2700) \) one finds:

\[
\Gamma(D_s') = (70 \pm 30) \text{ MeV} \\
\Gamma(D_{s2}^*) = (12 \pm 5) \text{ MeV}
\]
\begin{table}
\begin{tabular}{c|ccc}
& $B(D_{sJ} \rightarrow D^0 K^+)$ & $B(D_{sJ} \rightarrow D^+ K_S)$ & $B(D_{sJ} \rightarrow D_s \eta)$ \\
\hline
$D_s^+$ & $(24 \pm 14)\%$ & $(12 \pm 7.0)\%$ & $(7 \pm 4)\%$

$D_s'^1$ & $(44 \pm 25)\%$ & $(21 \pm 12)\%$ & $(11 \pm 6)\%$

$B(D_{sJ} \rightarrow D^{*0} K^+)$ & $B(D_{sJ} \rightarrow D^{*-} K_S)$ & $B(D_{sJ} \rightarrow D_s^* \eta)$ \\
\hline
$D_s^*$ & $(22 \pm 13)\%$ & $(10 \pm 6)\%$ & $(1.7 \pm 1.2)\%$

$D_s'^1$ & $(1.9 \pm 1.1)\%$ & $(0.9 \pm 0.5)\%$ & $(0.12 \pm 0.09)\%$
\end{tabular}
\end{table}

Table III. – $D_{sJ}(2700)$ branching fractions corresponding to the two assignments.

and the branching fractions in Table IV. Therefore, in the two assignments the spin partners differ for their decay width.

\begin{table}
\begin{tabular}{c|ccc}
& $B(D_s' (D_s'^2) \rightarrow D^{*0} K^+)$ & $B(D_s' (D_s'^2) \rightarrow D^{*-} K_S)$ & $B(D_s' (D_s'^2) \rightarrow D_s^* \eta)$ \\
\hline
$D_s'^1 (J^P = 0^-)$ & $(50.0 \pm 0.5)\%$ & $(23.7 \pm 0.2)\%$ & $(2.6 \pm 0.9)\%$

$D_s'^2 (J^P = 2^-)$ & $(49.8 \pm 0.6)\%$ & $(23.6 \pm 0.2)\%$ & $(3.1 \pm 1.0)\%$
\end{tabular}
\end{table}

Table IV. – Branching ratios of the spin partner of $D_{sJ}(2700)$ for the two quantum number assignments.

* * *

I thank P. Colangelo, F. De Fazio and F. Gianmuzzi for collaboration.

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