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D and D_s Spectroscopy

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Introduction

Open Charm States

In the following overview the properties and nature of all discovered candidates for the open charm D and D_s states are discussed.

Figures 1(a) and 1(b) show the respective mass spectra for D and D_s states. The circles represent the observed candidate states assigned to the spectra [1], while the predicted mass values from the potential models of Godfrey and Isgur [2] and from DiPierro and Eichten [3] are also plotted. Until 2003, only four states had been detected in the D system and only four states were known in the D_s system. The parameters of these resonances were measured with good precision. The values for masses and decay widths were consistent with model predictions. After 2003 up to now, a total of two new D candidates and four new D_s candidates were discovered. Two of the new D_s states are narrow and have measured masses far from the theoretical values, which fueled new interest in the spectroscopy of open charm mesons. Concerning the nature of these states, these could be ordinary mesonic states, with improved theorical calculations explaining their low mass. Other interpretations are based on an exotic four-quark configuration, *e.g.* tetraquark states or a molecular combination of two quark-antiquark pairs [4, 5].

Experimental observables needed to establish the nature of D and D_s states include the mass, total and partial decay widths, spin-parity, isospin and mixing angles. Their measurements will be discussed in detail in the following sections, while their interpretation is left to the theoretical contributions.

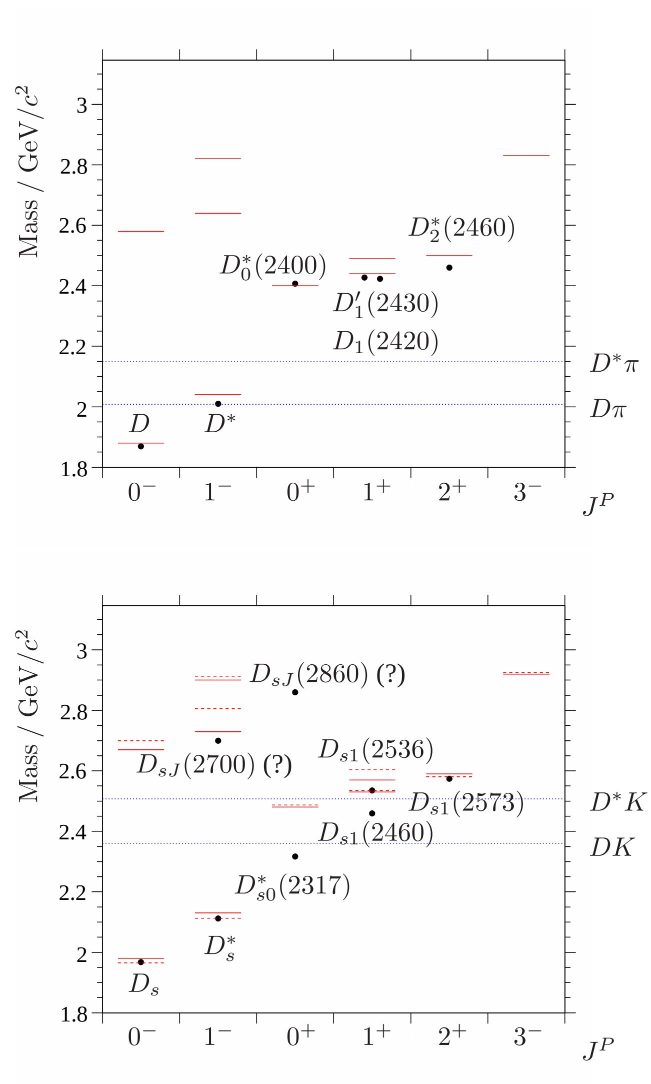

Figure 1: Spectra for open charm D mesons (a); D_s mesons (b). Plotted are resonance masses versus spin-parity J^{PC}. The circles show the experimental results, the solid lines predictions from the potential model by Godfrey and Isgur [2], the dashed lines predictions from DiPierro and Eichten [3]. The dotted lines show the $D^0\pi$ and $D^*\pi$ thresholds for the D system and the DK and D^*K thresholds for the D_s system.

Charm Production at B-Factories

The recently found open charm states were all observed at large e^+e^- colliders. One was discovered by the CLEO collaboration [6], the other five new states by the B-factories *BABAR* [7] and Belle [8]. Belle is still operating, while *BABAR* ceased data-taking in 2008. The combined data sample of these two experiments corresponds to a total integrated luminosity of more than $1\ \mathrm{ab}^{-1}$. Both B-factories were designed to run at a center-of-mass (CMS) energy of $10.58\ \mathrm{GeV}$ for resonant production of the $\Upsilon(4S)$ bottomium state. For some time, the CMS energy was changed, yielding resonant formation of the $b\bar{b}$ states $\Upsilon(2S)$, $\Upsilon(3S)$ (*BABAR*) and $\Upsilon(5S)$ (Belle) and non-resonant production at lower energies for background studies.

The high integrated lumininosity of these experiments in combination with a large cross-section for non-resonant $c\bar{c}$ production ($1.3\ \mathrm{nb}$) at the CMS energy of $10.58\ \mathrm{GeV}$ yielded more than 690×10^6 $c\bar{c}$ pairs in the case of *BABAR*. Also, with a cross section of $1.05\ \mathrm{nb}$, more than 558×10^6 $b\bar{b}$ pairs were produced. Since a b-quark favoritely decays into cW^-, the decays are also a rich source for particles

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with open or hidden charm. Together with detector components capable of very good PID, vertexing and tracking, the *BABAR* and Belle experiments provide thus excellent opportunities for precise, high-statistic studies in the field of charm physics.

The D Mesons

Overview

The D mesons are composed of a heavy charm quark c and a light anti-up or anti-down quark $\bar{q}$ (charge conjugation is implied throughout the text). The nomenclature used for this system is $n^{2S+1}L_J$, where n is the radial quantum number, L corresponds to the relative angular momentum between the $\bar{q}$- and the c-quark and S is the combined spin $S_c + S_{\bar{q}}$. In Heavy Quark Effective Theory (HQET) [10], the spin S_c decouples and $j_{\bar{q}} = L + S_{\bar{q}}$ is a good quantum number. Mesons with $L = 1$ form two doublets with $j_{\bar{q}} = \frac{1}{2}$ and $j_{\bar{q}} = \frac{3}{2}$, respectively, in this model. The total spin J of a D meson is given as $j_{\bar{q}} + S_c$.
For an angular momentum of $L = 0$, $j_{\bar{q}} = \frac{1}{2}$ results, since $S_{\bar{q}} = \frac{1}{2}$. With $S_c = \frac{1}{2}$, the total spin J couples either to 0 or 1. The D^0 meson with spin-parity $J^P = 0^-$ is identified as the 1^1S_0 ground state, while the 1^3S_1 state is the D^*. In the case of an angular momentum of $L = 1$, $j_{\bar{q}}$ can couple either to $\frac{1}{2}$ or $\frac{3}{2}$. For the total spin J, values of $J = 0$ and $J = 1$ are possible in the former, and $J = 1$ and $J = 2$ in the latter case. For all four P-wave states, candidates have been discovered ($D_0^*(2400)$, $D_1'(2430)$, $D_1(2420)$ and $D_2^*(2460)$, respectively).
The $j_q = \frac{1}{2}$ states $D_0^*(2400)$ and $D_1'(2430)$ must decay via $\pi - S$ wave, while the $j_q = \frac{3}{2}$ states $D_1(2420)$ and $D_2^*(2460)$ have to decay via $\pi - D$ wave in order to conserve parity and angular momentum. Therefore, small decay widths for the members of the $j_{\bar{q}} = \frac{3}{2}$ doublet and large widths for the $j_{\bar{q}} = \frac{1}{2}$ states are expected [9, 10]. This is consistent with the observed properties of the D states which are documented in more detail in the following sections.

D^0, D^+

The D^0 and D^+ mesons are identified as the neutral and charged version of the 1^1S_0 D ground state with spin-parity $J^P = 0^-$. This particle was already discovered in 1975 by the Mark I experiment in $c\bar{c}$ continuum events [11] and is well studied. The current value for the mass reported by the Particle Data Group (PDG, [1]) is (1864.84 ± 0.17) $\mathrm{MeV/c^2}$ for D^0 and (1869.62 ± 0.20) $\mathrm{MeV/c^2}$ for D^+. The decay lengths are $c\tau = (122.9 \pm 0.4)$ μm and (311.8 ± 2.1) μm, respectively. Over 200 decay channels have been studied so far, giving insight into weak decays and yielding the first discovery of $D^0 - \bar{D}^0$ mixing by the *BABAR* Collaboration [12].

D^{*0}, D^{*+}

The $D^*(2007)^0$ and $D^*(2010)^+$ were observed for the first time in continuum events by the Mark I experiment in 1977 [13]. The spin-parity is consistent with 1^-, so these resonances are assigned to the 1^3S_1 state. The masses are reported as (2006.97 ± 0.19) $\mathrm{MeV/c^2}$ (D^{*0}) and (2010.27 ± 0.17) $\mathrm{MeV/c^2}$ (D^{*+}). For the total decay width of the D^{*0}, an upper limit of 2.1 MeV was obtained. For the D^{*+}, the decay width is relatively low at (96 ± 22) keV [1], since the resonance mass lies just below the $D^+\pi^-$ threshold.

$D_0^*(2400)^0, D_0^*(2400)^+$

This state was recently discovered in 2004 in $B^- \rightarrow (D^+\pi^-)\pi^-$ (Fig. 2a) by the Belle Collaboration, using 62 fb^{-1} of data [14]. The mass of the resonance (charged version) was measured to be $(2308 \pm 17 \pm 22)$ MeV/c^2 and a width of $(276 \pm 21 \pm 63)$ MeV was derived.
The decay pattern has been used for an indirect estimation of J^P. Taking only two-body decays with open-charm final states into account, a $J^P = 0^+$ state can decay due to conservation laws only into $D\pi$ and a 1^+ state only into $D^*\pi$, whereas a 2^+ state can decay into either of these two final states. The $D_0^*(2400)$ is seen only in $D\pi$, from which $J^P = 0^+$ is favored. The large width is consistent with this finding; since the narrow $j_{\bar{q}} = \frac{3}{2}$ states are already occupied, this resonance is assigned to the 1^1P_0 state.
The Focus collaboration has seen a similar resonance in γA collisions [15] with decay widths of $(240 \pm 14 \pm 35)$ MeV and $(283 \pm 24 \pm 34)$ MeV for the neutral and charged states, respectively. The mass values $(2407 \pm 21 \pm 35)$ MeV/c^2 and $(2403 \pm 14 \pm 35)$ MeV/c^2, respectively, differ by about 100 MeV/c^2 from the Belle result, so it is not completely clear if these two states are indeed the same.

$D_1(2420)^0, D_1(2420)^+$

The Argus collaboration observed this state in 1986 in continuum events $e^+e^- \rightarrow (D^*\pi)X, D^* \rightarrow D\pi$ [16]. Belle has seen it in $B^- \rightarrow (D^{*+}\pi^-)\pi^-$ (Fig. 2b) [14], using 62 fb^{-1} of data, and in $B \rightarrow (D\pi^+\pi^-)\pi^-$ (Fig. 3) with 145 fb^{-1} of data [17].
No decay into $D\pi$ is observed, so the decay pattern rules out 0^+ and 2^+. An angular analysis yields a spin-parity of $J^P = 1^+$ [18]. The resonance is assigned to the 1^3P_1 state.
The $D_1(2420)$ is not observed in color-suppressed decays like $\bar{B}^0 \rightarrow (D^{*+}\pi^-)\omega$ [19].
The mass values are (2422.3 ± 1.3) MeV/c^2 (neutral) and (2423.4 ± 3.1) MeV/c^2 (charged), while for the width values of (20.4 ± 1.7) MeV and (25 ± 6) MeV are found [1].
Since there are two 1^+ states in the D system, mixing with the $D_1'(2430)$ is possible. From Dalitz-plot studies, a mixing angle of $\theta = (-0.10 \pm 0.03 \pm 0.02 \pm 0.02)$ rad is obtained [14].

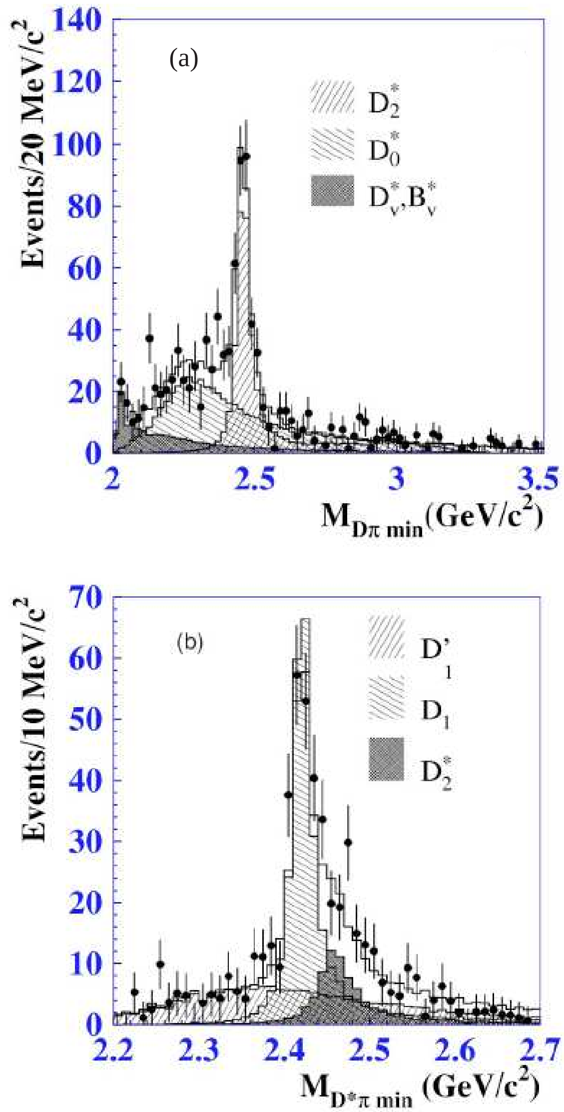

Figure 2: Belle analysis of $B \to D^{(*)}\pi\pi$. (a) The invariant $D\pi$ mass shows a large signal of $D_2^*(2460)$ and the first evidence of $D_0^*(2400)$. (b) The invariant $D^*\pi$ mass shows first evidence of $D_1'(2430)$. Also, a large signal of $D_1(2420)$ and a smaller contribution of $D_2^*(2460)$ are visible.

$D_1'(2430)^0, D_1'(2430)^+$

Evidence for this state was found by Belle in the decay $B^- \to (D^{*+}\pi^-)\pi^-$ (Fig. 2b), using 62 fb^{-1} of data [14]. The mass of the neutral state is $(2427 \pm 26 \pm 25)\ \mathrm{MeV}/c^2$ and the width $(384 \pm 107 \pm 74)$ MeV [1]. It is also observed in the color suppressed decay $\bar{B}^0 \to (D^{*+}\pi^-)\omega$, which yields $(2477 \pm 28)\ \mathrm{MeV}/c^2$ for the mass and (266 ± 97) MeV for the width [19]. The decay pattern is consistent with a $J^P = 1^+$ state. In combination with the large width, this leads to the assignment as the 1^1P_1 partner state of the $D_1(2420)$.

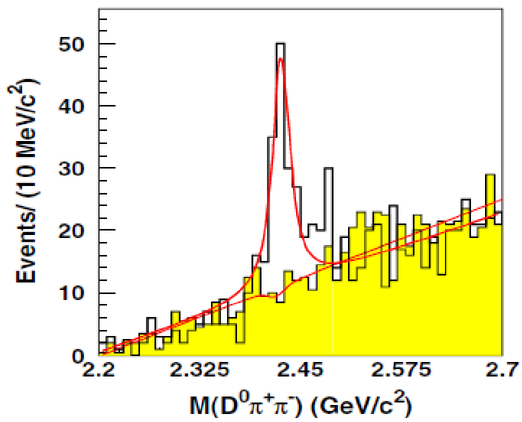

Figure 3: Belle analysis of $B \to D\pi\pi\pi$. The invariant $D^0\pi\pi$ mass shows a large signal of $D_1(2420)$, but no contribution of $D_2^*(2460)$.

$D_2^*(2460)^0, D_2^*(2460)^+$

The heaviest resonance assigned to the D spectrum was observed in $\gamma N \to (D\pi)X$ by the Tagged Photon Spectrometer Collaboration in 1989 [20]. It was also seen by Argus in $e^+e^- \to (D\pi)X$ continuum events ([21]) and in B decays to $(D^{*+}\pi^-)\pi^-$ and $(D^+\pi^-)\pi^-$ by Belle [14] (Fig. 2a,b), but so far not in the color-suppressed decay $\bar{B}^0 \to (D^{*+}\pi^-)\omega$ which shows the $D_1'(2430)$ [19].
The decay pattern and the results of a angular analysis are consistent with a spin-parity $J^P = 2^+$ [21]. The mass values are $(2461.1 \pm 1.6)\ \mathrm{MeV}/c^2$ for the neutral and $(2460.1 \pm 3.0)\ \mathrm{MeV}/c^2$ for the charged partner. For the widths, values of (43 ± 4) MeV and (37 ± 6) MeV, respectively, were obtained.
HQET predicts a polarization/alignment of the $j_{\bar{q}} = \frac{3}{2}$ states in continuum production. This was checked by Argus [21] and an upper limit for $W_{3/2}$ - describing the helicity population of the light degrees of freedom - was given ($W_{3/2} < 0.24$), in agreement with theoretical predictions.

In this overview, we have concentrated on results obtained in continuum production and hadronic B-decays. All these states have also been examined in semileptonic B-decays [22, 23], but with smaller statistics.

The D_s Mesons

Overview

The D_s mesons contain a heavy charm quark and a lighter anti-strange quark. The nomenclature $n^{2S+1}L_J$ is the same as discussed above for the D system. The strange quark couples with the angular momentum L to $j_{\bar{s}} = L + S_{\bar{s}}$, and the total spin is $J = j_{\bar{s}} + S_c$.
The 1^1S_0 ground state is the D_s state, while D_s^* is identified as the 1^3S_1 state. Also known since ten years are the

resonances $D_{s1}(2536)^+$ and $D_{s2}(2573)^+$, assigned to the two $j_{\bar{s}} = \frac{3}{2}$ states. As for the D system, decay widths for these states should be small.
The $D^*_{s0}(2317)^+$ and $D_{s1}(2460)^+$, candidates for the two missing $j_{\bar{s}} = \frac{1}{2}$ states, were detected in 2003. The measured mass values are far lower than predicted from potential models [2, 3]. The states lie below the DK (D^*K) thresholds. This probably explains their observed narrow widths, which are in contrast to theoretical expectations for these states.
More recently, two additional new states in the higher mass regions were detected which could so far not be assigned to a certain J^P value.

D_s^+

The D_s^+ is the 1^1S_0 ground state of the D_s system. The state was first observed by CLEO in 1983 [24] in $e^+e^- \rightarrow (\phi\pi)X$ continuum reactions. The high luminosity experiments of today provide large data samples for precise mass and lifetime measurements and Dalitz plot analyses; in total about 100 D_s decay modes have been studied so far. The current mass is stated as $m = (1968.49 \pm 0.34)\ \mathrm{MeV}/c^2$, with a decay length of $c\tau = (149.9 \pm 2.1)\ \mu m$ [1]. The spin assignment of $J^P = 0^-$ follows from angular analyses of the $\phi\pi$ and $K\bar{K}^*$ final states.

D_s^{*+}

First seen 1984 by the PEP-4 TPC detector in $e^+e^- \rightarrow (D_s\gamma)X, D_s \rightarrow KK\pi$ [25], the D_s^{*+} is identified as the 1^3S_1 state. Observed decay modes are consistent with spin-parity of 1^-. The mass is measured as $(2112.3 \pm 0.5)\ \mathrm{MeV}/c^2$ and an upper limit of $1.9\ \mathrm{MeV}$ is given for the width [1].

$D^*_{s0}(2317)^+$

The detection of the $D^*_{s0}(2317)^+$ is the first of the recent new discoveries which triggered a lot of new interest and activity in the field of open charm spectroscopy. The first observation was in 2003 by the *BABAR* Collaboration in $e^+e^- \rightarrow (D_s\pi^0)X$ continuum events [26] (Fig. 4(a)); shortly afterwards the Belle Collaboration observed this state for the first time in B-decays ($B \rightarrow (D_s\pi^0)D$ and $B \rightarrow (D_s\pi^0)K$).
The mass is $(2317.8 \pm 0.6)\ \mathrm{MeV}/c^2$ and an upper limit for the decay width of $3.8\ \mathrm{MeV}$ is given [1]. The experimentally obtained and validated mass value is too low compared with old potential models (for example Refs. [2, 3]), which were successful in describing the older known states. Several new models work better in predicting the mass. The low mass places this state below the DK threshold, so that only isospin-violating and electromagnetic decays are possible, resulting in a small decay width.
The decay pattern of observed and non-observed decay modes favors a spin-parity of $J^P = 0^+$. A study of the angular distribution in $B \rightarrow (D_s\gamma)D$ decays confirms spin 0 (Fig. 4(b)) [27]. The $D^*_{s0}(2317)^+$ is thus assigned to the 1^3P_0 state.
The spin assignment is thus settled, but the composition of this state is still under debate. As an alternative to a mesonic $c\bar{s}$ nature, a molecular interpretation is considered. In the process of determining the isopin of the $D^*_{s0}(2317)^+$, no evidences for neutral and doubly-charged isospin partner states were found by *BABAR* in $D_s^+\pi^-$ and $D_s^+\pi^-$ final states [28]. An isospin of 0 is inferred, which is compatible with a $c\bar{s}$ quark content.
As far as the nature of the states is concerned ($c\bar{s}$-states or multiquark states), the measurement of production rates and their comparison with theoretical predictions might be helpful. The decay ratio

$$\frac{\mathcal{B}(B^0 \rightarrow D^- D^*_{s0}(2317)^+)}{\mathcal{B}(B^0 \rightarrow D^- D_s^+)} \quad (1)$$

was determined as ≈ 0.1 [29], in contrast to HQET theory [30], which expects a value of 1.
A strange process, where both initial quarks undergo a weak decay, is the reaction $B^0 \rightarrow D^*_{s0}(2317)^- K^+$. Possible diagrams describing the process include PQCD factorization W exchange or, alternatively final state interactions. Also an exotic tetraquark formation is possible. The ratio

$$\frac{\mathcal{B}(B^0 \rightarrow D^*_{s0}(2317)^- K^+)}{\mathcal{B}(B^0 \rightarrow D_s^- K^+)} \quad (2)$$

was determined to be ≈ 1, which surprises, given the larger phasespace for the decay into D_s^+. It is different from Eq. 1 and does not correspond to the arguments given in Ref. [31].
The conclusion at this point is that a $c\bar{s}$ $D^*_{s0}(2317)^+$ is probable, but other explanations are not excluded.

$D_{s1}(2460)^+$

This state was discovered by CLEO in $e^+e^- \rightarrow (D_s\pi^0)X$ [32] (Fig. 5(a)). Later, the Belle Collaboration observed this state for the first time in B-decays ($B \rightarrow D_{s1}(2460)K$).
The mass is determined given as $(2459.6 \pm 0.6)\ \mathrm{MeV}/c^2$ and the upper limit for the decay width is $3.5\ \mathrm{MeV}$ [1]. The mass thus lies below the D^*K threshold. As in the case of the $D^*_{s0}(2317)$, the measured mass is very low compared with old predictions, while new models work better.
The decay pattern favors spin-parity $J^P = 1^+$. A number of the allowed decays have not yet been observed, requiring larger data samples in these cases. An angular distribution study by Belle (Fig. 5(b)) favors spin 1 [27], and a similar study by *BABAR* based on continuum events favors natural spin-parity [28]. Thus this resonance is assigned to the 1^3P_1 state.
The ratio

$$\frac{\mathcal{B}(B^0 \rightarrow D^*_{s1}(2460)^+ D^-)}{\mathcal{B}(B^0 \rightarrow D_s^{*+} D^-)} \quad (3)$$

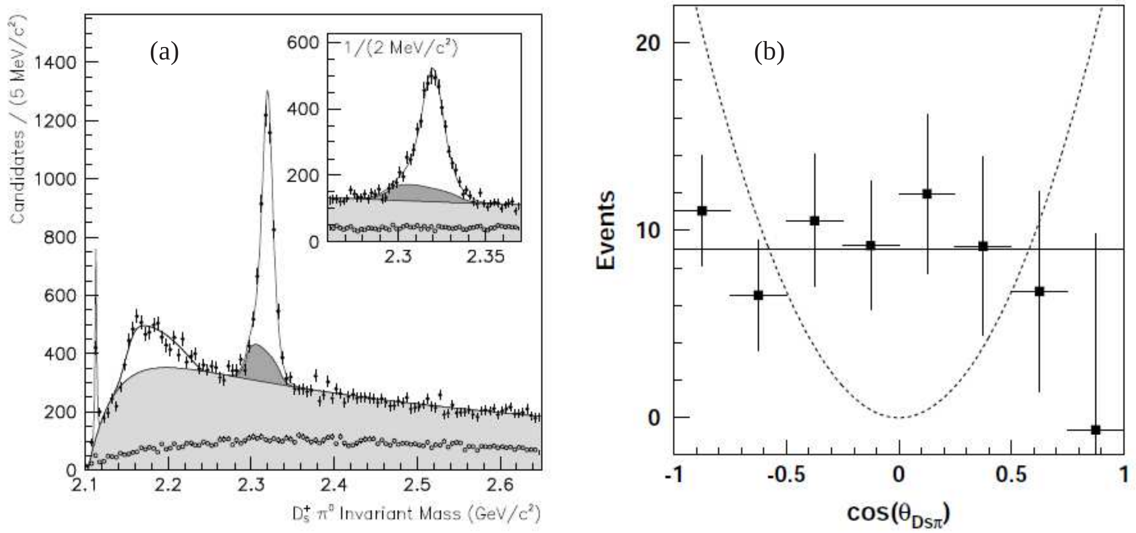

Figure 4: (a) *BABAR* analysis of $e^+e^- \to D_s^+\pi^0 X$. The invariant $D_s^+\pi^0$ mass shows a large signal of $D_{s0}^*(2317)^+$. A reflection from $D_{s1}(2460)^+ \to D_s^{*+}\pi^0$ peaks directly under the $D_{s0}^*(2317)^+$ signal. Other reflections are visible in the lower mass region. (b) Angular analysis of $B \to D_{s0}^*(2317)^+ D$. The solid line shows the expected lineshape for $J = 0$, the dotted line that for $J = 1$.

was determined to be $\approx 1/3$, in disagreement with theoretical considerations [30].

The mixing of $D_{s1}(2460)^+$ with $D_{s1}(2536)^+$ has been investigated in comparing its decays into $D_s^*\gamma$ and $D_s^+\gamma$. The former decay is possible only for the $^3P_1$ component of D_{s1}^+, the latter only for the $^1P_1$ component. The ratio

$$\frac{\Gamma(D_{s1}^+ \to D_s^{*+}\gamma)}{\Gamma(D_s^+\gamma)} \tag{4}$$

was determined to be ≈ 0.3 [33], showing a sizeable mixing of the states.

$D_{s1}(2536)^+$

This state was discovered in 1989 by the ARGUS collaboration in $e^+e^- \to (D^*K)X$ [34]. The first observation in $B \to \bar{D}^{(*)}D^{*0}K^+$ decays was achieved by the *BABAR* collaboration in 2003. The mass is given as $2535.35 \pm 0.34 \pm 0.5$ MeV$/c^2$ and an upper limit of 2.3 MeV has been obtained for the width [1].

An angular analysis, based on 347 fb^{-1} of data, is consistent with spin 1 [35], while the non-observation of the decay into DK implies an unnatural spin-parity. The mass lies near the prediction for the 1^1P_1 state, so that $J^P = 1^+$ is assigned for this state.

Both in B decays and in continuum reactions, large signals are observed (Fig. 6), making precise measurements of the mass and width possible. Preliminary results from an analysis of $e^+e^- \to (D^{*+}K_S^0)$ at *BABAR* using 232 fb^{-1} of data include an improvement for the mass difference $m(D_{s1}(2536)^+) - m(D^{*+})$ by an order of magnitude and also a first direct measurement of the decay width [36].

The $D_{s1}(2536)^+$ can mix with the other 1^+ state $D_{s1}(2460)$. This mixing was investigated in analyzing the angular distribution of the decay $D_{s1}(2536)^+ \to D^{*+}K_S^0$ [37]. As in the case of $D_2^*(2460)^+$, the D_{s1}^+-resonance is produced from the continuum with a (small) polarization/alignment. A fit to the 3-dimensional angular distribution allows the extraction of $W_{3/2}$ and the ratio of D-wave to S-wave amplitudes. The ratio D/S was found to be $(0.63 \pm 0.07 \pm 0.02) \times \exp(\pm i(0.76 \pm 0.03 \pm 0.01))$, demonstrating a clear mixing between the D_{s1}^+ states. The S-wave dominates in its contribution to the total width $\Gamma_S/\Gamma_{total} = 0.72 \pm 0.05 \pm 0.02$, which is also influenced by the small energy release in the $D_{s1}^+ \to D^{*+}K_S^0$ decay. This value is in contrast to HQET predictions.

$D_{s2}(2573)^+$

Not much is known about the $D_{s2}(2573)$ which was first seen by CLEO in 1994 in $e^+e^- \to (DK)X$ continuum reactions [38]. No angular distribution was studied, but the only observed decay into DK is consistent with natural spin parity and the measured mass is consitent with the prediction for the 1^3P_2 state, thus $J^P = 2^+$ is inferred.

A large $D_{s2}(2573)^+$ sample from the reaction $e^+e^- \to (DK)X$ was collected by *BABAR* based on 240 fb^{-1} of data (Fig. 7), yielding an improved measurement of the mass ($(2572.2 \pm 0.3 \pm 1.0)$ MeV$/c^2$) and the decay width ($(27.1 \pm 0.6 \pm 5.6)$ MeV) [39].

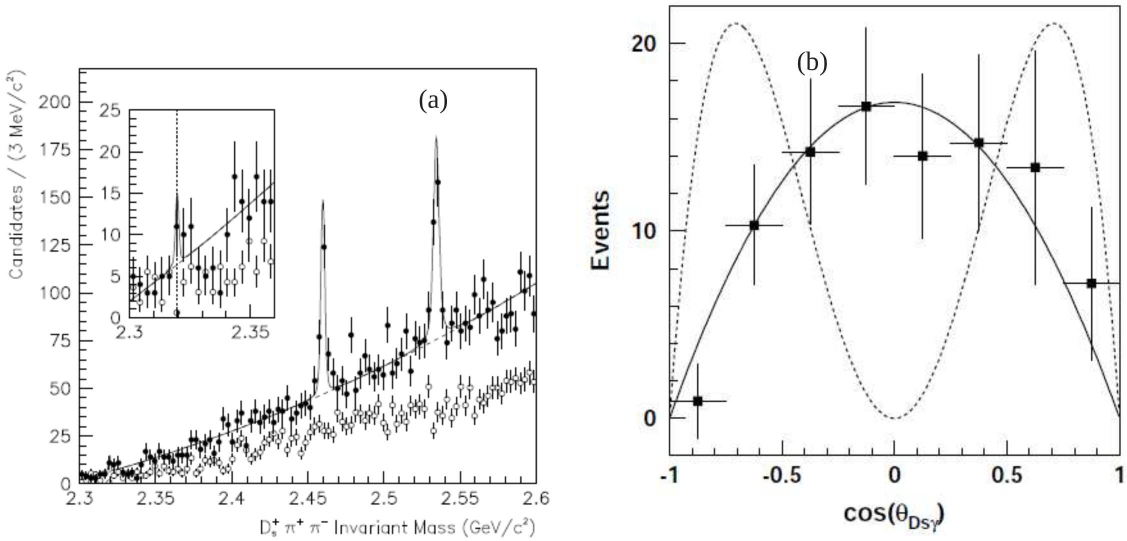

Figure 5: (a) *BABAR* analysis of $e^+e^- \to D_s\pi^+\pi^-X$. The invariant $D_s\pi^+\pi^-$ mass shows large signals of $D_{s1}(2460)$ and $D_{s1}(2536)$. (b) Angular analysis of $B \to D^*_{s0}(2460)^+D$. The solid line shows the expected lineshape for $J = 1$, the dotted line that for $J = 2$.

$D_{sJ}(2700)^+$

BABAR observed this state in $e^+e^- \to (DK)X$ (see Fig. 7), based on a data sample of $240\,\mathrm{fb}^{-1}$ [39]. A mass of $(2688 \pm 4 \pm 3)\,\mathrm{MeV}/c^2$ and width of $(112 \pm 7 \pm 36)\,\mathrm{MeV}$ was obtained. From the final state, a natural spin parity is inferred. Belle made a similar observation in $B^+ \to (D^0K^+)\bar{D}^0$ with a mass of $(2708 \pm 9 \pm 10)\,\mathrm{MeV}/c^2$ and width of $(108 \pm 23 \pm 33)\,\mathrm{MeV}$ [40] (see Fig. 8a). This analysis was based on a data sample corresponding to $414\,\mathrm{fb}^{-1}$. An angular distribution study based on this data sample favors spin 1 (Fig. 8b). These two analyses are likely observing the same state.
A possible interpretation of the $D_{sJ}(2700)^+$ is the 2^3S_1 radial excitation of the D^*_s which is predicted at $2720\,\mathrm{MeV}/c^2$ [2, 41]. The state might also be the 1^- chiral doublet state to the $D_{s1}(2536)$ 1^+ state, predicted at $2720\,\mathrm{MeV}/c^2$ [42]. More analyses are necessary to confirm or reject any of these models.

$D_{sJ}(2860)^+$

The last of the recently discovered states was only observed by *BABAR* in $e^+e^- \to (DK)X$ so far (see Fig. 7), using $240\,\mathrm{fb}^{-1}$ of data [39]. The measured mass and width are $(2856.6 \pm 1.5 \pm 5.0)\,\mathrm{MeV}/c^2$ and $(108 \pm 23 \pm 33)\,\mathrm{MeV}$, respectively. The final state observed implies a natural spin parity. The state was not seen in $B \to (D^0K^+)\bar{D}^0$ decays by Belle, analyzing a data sample of $414\ \mathrm{fb}^{-1}$ [40]. This could be due to a high total spin J of this resonance, which would result in a suppressed production in B decays.

Outlook

New observations made in the recent years yielded a number of open charm states which could be identified as the missing states of the D and D_s spectra. Still, a number of open questions are remaining.
To differentiate between the models explaining the particle parameters and composition, accurate measurements of the mass, partial and total width are mandatory, which are still not available in some cases, mainly due to limited statistics. Hadronic and radiative transitions from higher mass states into $D^*_{s0}(2317)^+$ and $D_{s1}(2460)^+$ have to be studied to provide more clues on the nature of these states. Also tests of the mixing scheme for the open charm 1^+ and 2^+ states are necessary.
The tools already available for these studies are ongoing data analyses at *BABAR* , Belle, Cleo, CDF and D0. High-luminosity B-factories, *e.g.* LHCB for B_s studies, will also provide large charm-containing data samples in the future. The same applies for direct charm production in $\bar{p}p$ collisions at PANDA/FAIR, enabling high precision measurements of decay widths not affected by the detector resolution [43].

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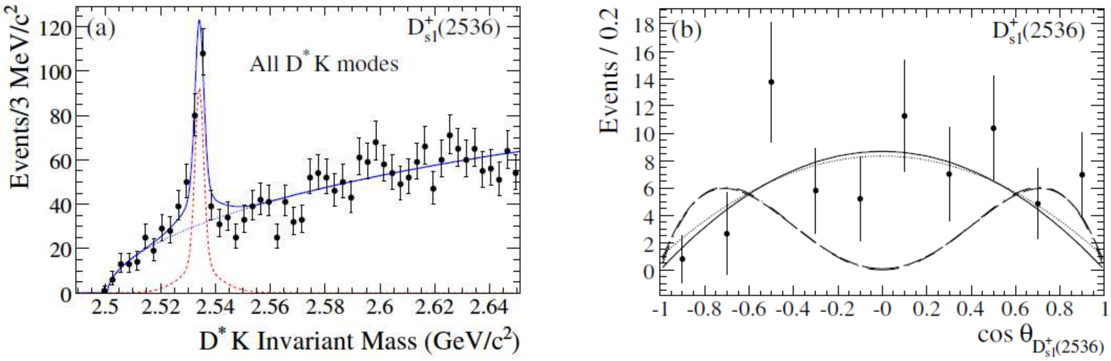

Figure 6: *BABAR* analysis of $B \to D^{(*)}D^{(*)}K$. (a) The invariant D^*K mass shows a large signal of $D_{s1}(2536)^+$. (b) Angular distribution analysis. The solid line shows the expected distribution for $J^P = 1^-$, the dotted line for $J^P = 1^+$ with $S-D$ wave admixture and the dashed line for $J^P = 0^+$.

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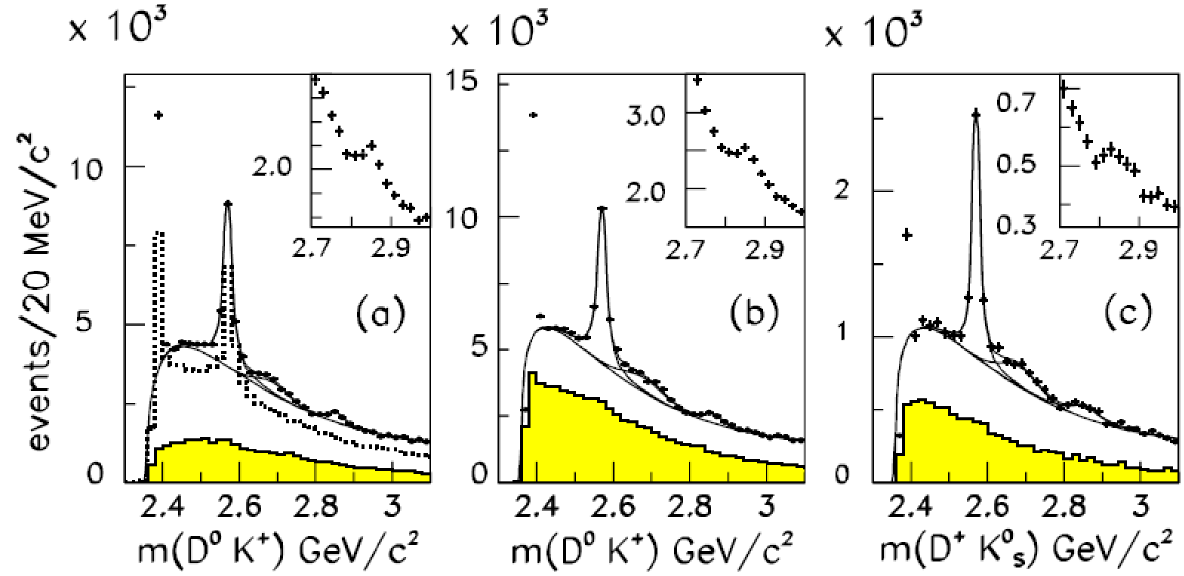

Figure 7: Invariant DK mass from the analysis of $e^+e^- \to (DK)X$ by *BABAR* . a) $D^0K^+, D^0 \to K^-\pi^+$; b) $D^0K^+, D^0 \to K^-\pi^+\pi^+\pi^+$, c) $D^+K^0_S$. The spectra show a large $D_{s2}(2573)^+$ signal. The structure at the DK threshold is a reflection from $D_{s1}(2536) \to D^*K$. In the higher mass region, signals from $D_{sJ}(2700)^+$ and $D_{sJ}(2860)^+$ are visible. The inserts show the signal region of the latter resonance in close-up view, while the yellow histograms show the DK mass using candidates from D sidebands. In the first plot, the dotted line represents the distribution obtained from Monte Carlo simulation data.

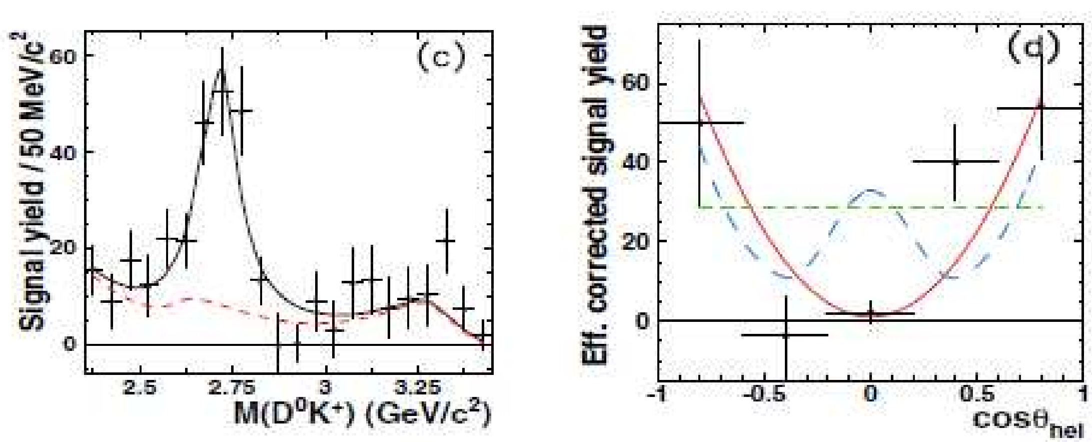

Figure 8: a) Invariant DK mass from the $B^+ \to (D^0K^+)\bar{D}^0$ analysis by Belle, showing a large signal of $D_{sJ}(2700)^+$. No $D_{sJ}(2860)^+$ is visible. b) Angular distribution for $D_{sJ}(2700)^+$. The solid line is for spin 1, the dashed lines for spin 0 (flat) and 2.