OBSERVATION OF A NARROW MESON IN THE $D_s^+\pi^0$ FINAL STATE AT BABAR

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Abstract

The *BABAR* experiment has discovered a narrow state, denoted as $D_{sJ}^*(2317)^+$, near 2.32 GeV/c^2 in the $D_s^+\pi^0$ invariant mass distribution from inclusive e^+e^- interactions at center-of-mass energies near 10.6 GeV. This narrow resonance is characterized by a mass significantly lower than predicted by potential models and enough to close off the most natural decay modes, thus forcing isospin-violating transitions.

1 Observation of the $D_{sJ}^*(2317)^+$

BABAR has investigated the inclusively-produced $D_s^+\pi^0$ mass spectrum by combining charged particles corresponding to the decays $D_s^+ \to K^+K^-\pi^+$ with π^0 candidates that are reconstructed from a pair of photons and formed by performing a one-constraint fit to the π^0 mass. The inclusion of charge-conjugate configurations is implied throughout this paper. Reconstruction method, selection criteria and background reduction are described in detail elsewhere [1].

The upper histogram in Fig.1(a)-Left Set shows the $K^+K^-\pi^+$ invariant mass distribution for all candidates characterized by the peaks associated to D^+ and D_s^+ mesons signal. Further background rejection, providing the lower histogram of Fig.1(a), is achieved by selecting the quasi-two body decay modes into $\phi\pi^+$ and $\overline{K}^{*0}K^+$ final states. Fig.1(b) shows the mass distribution for all two-photon combinations

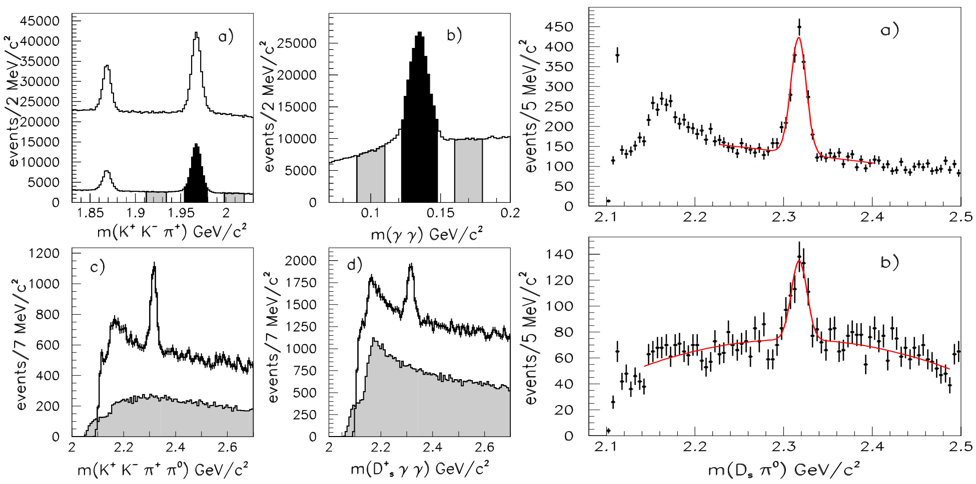

Figure 1: **Left Set: a)** The $K^+K^-\pi^+$ mass distribution for the selected candidates where the D_s^+ signal and sideband regions are shaded; **b)** the mass distribution of two-photon combinations in the selected events where the π^0 signal and sideband regions are shaded; **c)** the $K^+K^-\pi^+\pi^0$ mass distribution for candidates in the D_s^+ signal/sideband regions of (a) (top/shaded histogram respectively) where the π^0 candidates are mass-constrained; **d)** the $D_s^+\gamma\gamma$ mass distribution for candidates in the D_s^+ signal region of (a) coupled with photon pairs from the π^0 signal/sideband regions of (b) (top/shaded histogram respectively); both top and shaded histograms present a broad peak due to random combinations $D_s^{*+}\gamma$ where $D_s^{*+}\rightarrow D_s^+\gamma$. **Right Set:** The $D_s^+\pi^0$ mass distribution for **a)** the decay $D_s^+\rightarrow K^+K^-\pi^+$ and **b)** the decay $D_s^+\rightarrow K^+K^-\pi^+\pi^0$. The very narrow peak near threshold is associated to the isospin-violating $D_s^{*+}\rightarrow D_s^+\pi^0$ decay.

associated with the selected events. Candidates in the D_s^+ signal region of Fig.1(a) are combined with the mass-constrained π^0 candidates to provide the top histogram of Fig.1(c). The shaded histogram in Fig.1(c) represents combinations of candidates from the D_s^+ sideband regions with the same π^0 candidates. In Fig.1(d) the mass distributions result from the combination of candidates from the D_s^+ signal with the photon pairs from the π^0 signal and sideband regions of Fig.1(b); the mass resolution is poorer than in Fig.1(c) because there is no mass constraint for the photon pairs. To improve the resolution the nominal D_s^+ mass has been used to calculate the D_s^+ energy.

The top histograms of Fig.1(c) and Fig.1(d) are characterized by a clear narrow signal at a mass close to 2.32 GeV/c^2. In the corresponding shaded histograms this signal is absent. These facts indicate unambigously that the peak is associated with the $D_s^+\pi^0$ system. The signal is observed in both the quasi-two body D_s^+ decay modes. Moreover it has been checked, by Monte Carlo studies, that the $D_{sJ}^*(2317)^+$ signal is not due to a reflection from other known charmed states.

Fig.1-Right Set shows the $D_s^+\pi^0$ mass distribution for (a) $D_s^+ \to K^+K^-\pi^+$ and the additional decay mode (b) $D_s^+ \to K^+K^-\pi^+\pi^0$. The fit function, including a single Gaussian for the signal and a polynomial function for the background distribution, yields for decay (a) [(b)] 1267 ± 53 [273 ± 33] candidates for a fitted mass of 2316.8 ± 0.4 [2317.6 ± 1.3] MeV/c^2 with a standard deviation of 8.6 ± 0.4 [8.8 ± 1.1] MeV/c^2 (statistical errors only). The systematic uncertainty in the mass is conservatively estimated to be less than 3 MeV/c^2 .

An estimate of the mass resolution for the $K^+K^-\pi^+\pi^0$ system can be provided directly from the data by fitting the mass distribution for $D_s^+ \to K^+K^-\pi^+\pi^0$ and the measured width is consistent with that of $D_{sJ}^*(2317)^+$ signal. A similar mass resolution can be obtained from the simulation of the $D_{sJ}^*(2317)^+$ decaying to $K^+K^-\pi^+\pi^0$ with a generated intrinsic width close to zero. Thus the observed width is consistent with the experimental resolution and the intrinsic width of the $D_{sJ}^*(2317)^+$ must be below 10 MeV.

A search for other $D_{sJ}^*(2317)^+$ decays has been performed [1]. No indication of a $D_{sJ}^*(2317)^+$ production has been found in the $D_s^+\gamma$ or the $D_s^+\gamma\gamma$ mass distributions. No signal is observed in the $D_s^+\pi^0\gamma$ mass distribution as well. This implies the absence of a $D_s^{*+}\gamma$ decay mode at the present level of statistics. However a peak is visible near a mass value of 2.46 GeV/c^2 and survives at the $D_s^{*+} \to D_s^+\gamma$ selection. It has been checked the possibility that this peak would kinematically feed-down the $D_{sJ}^*(2317)^+$ signal, provided that it could eventually be a new additional narrow state decaying to $D_s^{*+}\pi^0$. Such $D_s^+\pi^0$ reflected peak, however, would have a root-mean-square of about 15 MeV/c^2 , namely quite twice the width of the observed $D_{sJ}^*(2317)^+$ signal. The second crucial check is obtained by a Monte Carlo unfolding method: if the apparent signal at 2.46 GeV/c^2 were due to a state decaying entirely to $D_s^{*+}\pi^0$, it would produce only one-sixth of the observed signal at 2.32 GeV/c^2 . *BABAR* has been rather careful to state that the structure observed in the $D_s^+\pi^0\gamma$ mass spectrum is a new narrow state because the complexity of the overlapping kinematics between the $D_s^{*+} \to D_s^+\gamma$ and $D_{sJ}^*(2317)^+ \to D_s^+\pi^0$ signals has suggested a dedicated study to evaluate the feeding-up from the $D_{sJ}^*(2317)^+$ [1].

For a parity-conserving decay of $D_{sJ}^*(2317)^+$ to $D_s^+\pi^0$ only a natural spin-parity series is allowed, that is $J^P = \{0^+, 1^-, 2^+, ...\}$. $J^P = 0^+$ is suggested by considering at the same time that (1) the mass is low compared to that of the $D_{s1}(2536)^+$ and $D_{sJ}^*(2573)^+$ and (2) the efficiency corrected helicity distribution is consistent with being flat [1], as expected for a spin-zero particle or for a particle of higher spin that is produced unpolarized. The absence of the $D_s^+\gamma$ [1] decay mode makes a $J^P = 0^+$ assignment most likely.

2 Further developments: the $D^*_{sJ}(2458)^+$

The announcement of the $D^*_{sJ}(2317)^+$ discovery in April 2003 has led to a great effort on theoretical side too and several possible interpretations have appeared: since the $D^*_{sJ}(2317)^+$ contradicts the current models of charmed mesons spectroscopy [2] either these models need modification or the observed state might have a non-$q\overline{q}$ nature.

CLEO [3] and Belle [4] have confirmed the $D^*_{sJ}(2317)^+$ state seen by *BABAR* . They have also analyzed the $D_s^{*+}\pi^0$ mass spectrum finding evidence for the structure in the 2.46 GeV$/c^2$ region and claiming it is a new state, the $D^*_{sJ}(2458)^+$. Afterwards *BABAR* has confirmed the existence of the $D^*_{sJ}(2458)^+$ state [5]. These two new states have been observed for the first time by Belle also in B decays ($B \rightarrow \overline{D} D^*_{sJ}$) [6].

The masses of the new states appear surprisingly low for quark model spectroscopy; specifically $D^*_{sJ}(2317)^+$ is below DK threshold and $D^*_{sJ}(2458)^+$ falls below D^*K one. If they are interpreted as ordinary $c\overline{s}$ states, this fact forces them to decay mainly via isospin-violating transition making their widths quite narrow. A possible mechanism is the decay through a virtual η followed by $\eta - \pi^0$ mixing [7]. It should be pointed out that most of the properties of $D^*_{sJ}(2317)^+$ and $D^*_{sJ}(2458)^+$ can be explained if they are $c\overline{s}$ states and the most likely assignment for their spin-parity is 0^+ and 1^+ namely consistent with their identification with the $(0^+, 1^+)$ missing doublet [8]. Further experimental information coupled with theoretical ideas can definitively shed light on the nature of these new mesons.

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