SLAC-PUB-10708

Observation of a Narrow Resonance in the $D_s^+\pi^0$ System at 2.32 GeV$/c^2$ with BABAR

Presented at the QCD, Spectroscopy, Structure, and Dynamics parallel session of the Conference on the Intersections of Particle and Nuclear Physics, New York City, 19–24 May 2003

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Abstract. A new state with invariant mass near 2.32 GeV$/c^2$ has been observed by the BABAR Collaboration in the inclusive $D_s^+\pi^0$ mass distribution using 91 fb^{-1} of e^+e^- annihilation data taken at the PEP-II asymmetric-energy storage ring at energies near 10.6 GeV. The new state is narrow, with an observed width that is consistent with the experimental resolution. This narrow width combined with the quantum numbers of the final state imply that the decay is isospin-violating. The state has natural spin-parity, and its low mass suggests a $J^P = 0^+$ assignment.

INTRODUCTION

Quark potential models have been successfully used to describe the properties of charm-strange mesons for some time. Two examples are the models of Godfrey, Isgur, & Kokoski [1, 2] and Di Pierro & Eichten [3]. Four of the states predicted by these models have been observed experimentally: the D_s^+ [1], the $D_s^*(2112)^+$, the $D_{s1}(2536)^+$, and the $D_{s2}(2573)^+$ [4]. Two predicted but as yet unobserved states are expected to have masses in the 2.4–2.6 GeV$/c^2$ range. Expected to decay to $D^{(*)}K$, these states should be very broad, with widths on the order of a few hundred MeV, making them difficult to observe. However, if their masses should be below $D^{(*)}K$ threshold, they could be much narrower.

A new state, shown in Figure 1, decaying to $D_s^+\pi^0$ with mass near 2317 MeV$/c^2$ and experimental width $\Gamma \approx 10$ MeV, was first noted by Antimo Palano, of the BABAR Collaboration, in early 2003 [5].

THE DATA SET, EVENT SELECTION, AND ANALYSIS

The BABAR detector is a general purpose, solenoidal, magnetic spectrometer, and is described in detail elsewhere [6]. A data set of 91.5 fb^{-1} of e^+e^- data taken near

[1] Charge-conjugate states are implied throughout.

Work Supported in part by the Department of Energy Contract DE-AC02-76SF00515
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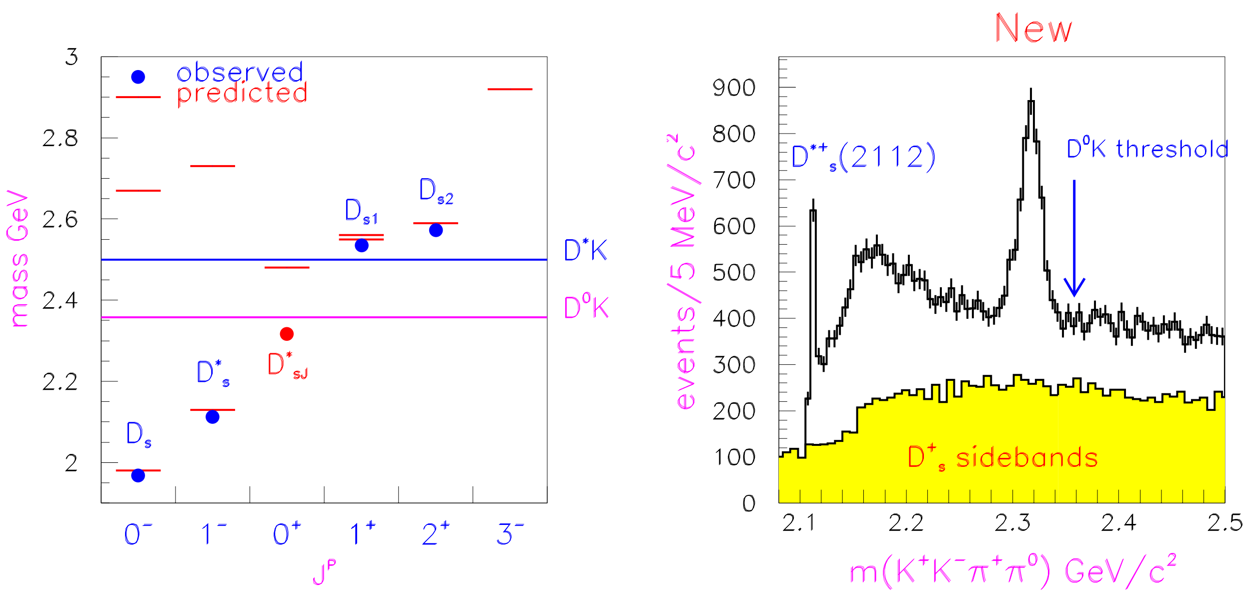

FIGURE 1. (Left) Spectroscopy of charm-strange mesons, showing known states (blue dots), potential model predictions (red lines), and the new $D_{sJ}(2317)^+$ state (red dot). (Right) $D_s^+\pi^0$ invariant mass distribution (white) for D_s^+ decay mode $D_s^+ \to K^+K^-\pi^+$, showing the known $D_s^*(2112)^+$ and the new state. The distribution for candidates in the D_s^+ sidebands is also shown (shaded).

10.58 GeV, on and off the $\Upsilon(4S)$ resonance, was used. Events from continuum $c\bar{c}$ production were selected and inclusive production of $D_s^+\pi^0$ studied, where $D_s^+ \to K^+K^-\pi^+(\pi^0)$. Combinations of three charged tracks were required to fit a common vertex consistent with production at the interaction region. Pairs of photons forming π^0 candidates were found and constrained to originate from the intersection of the $K^+K^-\pi^+$ candidate flight direction and the beam envelope.

Backgrounds were reduced by removing two-body D^0 decays, by selecting quasi two-body $\phi\pi^+$ and $\bar{K}^{*0}K^+$ decays of the D_s^+, and by helicity angle cuts on the ϕ and $\bar{K}^{*0}$ sub-decays, producing the distribution shown in Figure 1(right) with some 2200 events near 2.32 GeV. Additional checks showed that the signal was associated with both the D_s^+ and the π^0. The mass resolution was improved by use of a nominal mass [4] constraint $E_{D_s^+} = \sqrt{\mathbf{p}^2_{K^+K^-\pi^+} + m^2_{D_s^+}(PDG)}$

The $D_s^+\pi^0$ mass distribution was studied in intervals of center-of-mass (CMS) momentum p^* from 2.5 GeV/c to 5 GeV/c. The signal was present in all intervals; events with $p^* > 3.5$ GeV/c were retained, further improving the signal-to-background and mass resolution. The $D_s^+\pi^0$ signal was also seen in another D_s^+ decay mode, $D_s^+ \to K^+K^-\pi^+\pi^0$, where the π^0 was required to originate from the $K^+K^-\pi^+$ vertex.

Fitting the mass spectrum yields a value for the mass of $m = 2316.8 \pm 0.4$ MeV/c^2 and a width of $\sigma = 8.6 \pm 0.4$ MeV/c^2 (errors are statistical). We call this state the $D_{sJ}(2317)^+$. Studies of detector response to a state at 2317 MeV/c^2 show that this width

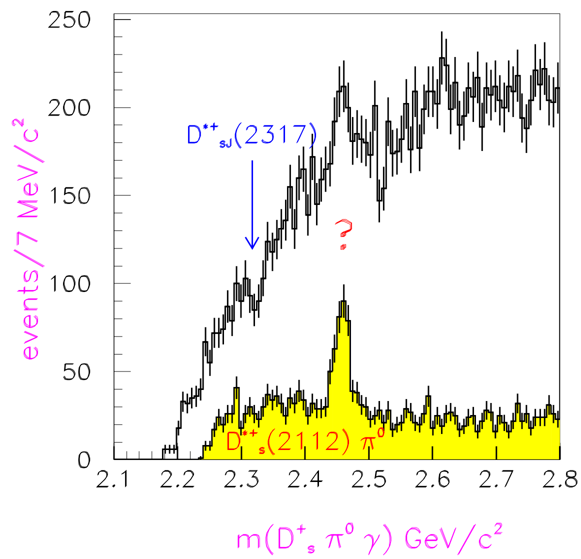

FIGURE 2. $D_s^+\pi^0\gamma$ invariant mass distribution (white) showing no obvious $D_{sJ}(2317)^+$ signal, but does show some structure near 2.46 GeV/c^2 is visible. The same distribution additionally requiring the sub-decay $D_s^*(2112)^+ \to D_s^+\gamma$ shows an enhanced peak near 2.46 GeV/c^2 (shaded).

is consistent with the experimental resolution.

The decay angular distribution of the π^0 angle in the $D_s^+\pi^0$ rest frame with respect to the $D_s^+\pi^0$ flight direction in the CMS was consistent with being flat (43% probability). This would be expected for a spin-0 state or a higher-spin state produced unaligned.

Tests were performed to find reflections from known charm states and for particle identification problems by exchanging kaon and pion particle hypotheses. No significant signals near 2.32 GeV/c^2 were seen.

Searches for other decay modes of the $D_{sJ}(2317)^+$ were made: $D_s^+\gamma$, $D_s^+\gamma\gamma$, $D_s^*(2112)^+\gamma$, $D_s^+\pi^0\pi^0$, and $D_s^+\pi^0\gamma$. No significant signals were seen for the first four modes. However, a small peak was observed in $m(D_s^+\pi^0\gamma)$, where the $D_s^*(2112)^+ \to D_s^+\gamma$ and $D_{sJ}(2317)^+ \to D_s^+\pi^0$ decays overlap. See Figure 2. A narrow state near 2.46 GeV/c^2 would produce a peak in $D_s^+\pi^0$ near 2.32 GeV/c^2. However, simulations showed that the number of events in the small peak in the data could only explain $\approx 1/6$ of the observed $D_{sJ}(2317)^+$ signal, and therefore could not be its only source. The presence of the peak near 2.46 GeV/c^2 requires further study.

SUMMARY & CONCLUSIONS

BABAR has observed a narrow signal in the inclusive $D_s^+\pi^0$ mass distribution with $m = 2316.8 \pm 0.4$ MeV/c^2 and has assigned a conservative systematic error on the mass of 3 MeV/c^2. The mass distribution has a gaussian width of $\sigma = 8.6 \pm 0.4$ MeV/c^2 which is consistent with the experimental resolution, implying a small intrinsic width $\Gamma <$ 10 MeV. Angular distribution studies show consistency with a spin-parity assignment $J^P = 0^+$, but other natural spin-parity possibilities are not excluded. A small peak in the $D_s^+\pi^0\gamma$ invariant mass distribution near 2.46 GeV/c^2 has also been observed and requires additional study[2].

If the $D_{sJ}(2317)^+$ is a $c\bar{s}$ state, it does not fit well into existing potential models, being too low in mass and, in particular, below DK threshold. The small intrinsic width is likely due to an isospin-violating decay (if $c\bar{s}$). Alternatively it could be a four-quark scalar state as proposed earlier by R.L. Jaffe [12, 13] and N. Isgur & H.J. Lipkin [14, 15, 16].

We expect interesting times ahead for experimentalists and theorists alike.

ACKNOWLEDGMENTS

We are grateful for the excellent luminosity and machine conditions provided by our PEP-II colleagues, 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. This work is supported by DOE and NSF (USA), NSERC (Canada), IHEP (China), CEA and CNRS-IN2P3 (France), BMBF and DFG (Germany), INFN (Italy), FOM (The Netherlands), NFR (Norway), MIST (Russia), and PPARC (United Kingdom). Individuals have received support from the A. P. Sloan Foundation, Research Corporation, and Alexander von Humboldt Foundation.

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[2] Much more has been learned since the time of this talk [7]. The observation of the $D_{sJ}(2317)^+$ has been confirmed by CLEO [8] and BELLE [9, 10], and the existence of a $D_{sJ}(2460)^+$ state established [8, 9, 11]. The latter has also been observed in B decays and via another decay mode $D_{sJ}(2460)^+ \to D_s^+\gamma$.