SEARCH FOR THE DECAY $D_s \to \rho^0 \pi$ AS EVIDENCE FOR QUARK ANNIHILATION

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We have searched for the decay $D_s^+ \to \rho^0\pi^+$ which can only occur via annihilation of the constituent quarks, and compared it to the decay $D_s^+ \to \phi\pi^+$ where the charm quark may decay independently of the light quark. An upper limit on the ratio $BR(D_s^+ \to \rho^0\pi^+)/BR(D_s^+ \to \phi\pi^+)$ of 0.22 at the 90% confidence level is obtained. This result constrains models which enhance the weak annihilation contribution to heavy meson decays by final-state interactions, a mechanism used for explaining the large branching ratio observed for $D^0 \to \phi \bar{K}^0$.

According to the valence quark model in QCD, decays of heavy mesons are dominated by the spectator mechanism (fig. 1a), whereas the contribution of quark annihilation (fig. 1b) turns out to be very small [1] [#1]. Nevertheless, recently published measurements [3] of the branching ratio for the decay

$$D^0 \to \phi\bar{K}^0 \quad (1)$$

point to unexpectedly large contributions of flavor annihilation to heavy meson decays [4]. This result stimulated a number of publications on models which are able to describe the observed branching ratio for (1) [5–7]. These models, however, differ widely in their prediction for the yet unobserved decay

$$D_s^+ \to \rho^0\pi^+ , \quad (2)$$

which can occur only via annihilation of the constituent quarks (fig. 1b). A measurement of the branching ratio for this decay mode, or an upper limit, is very helpful in clarifying the role of annihilation in two-body decays of heavy mesons.

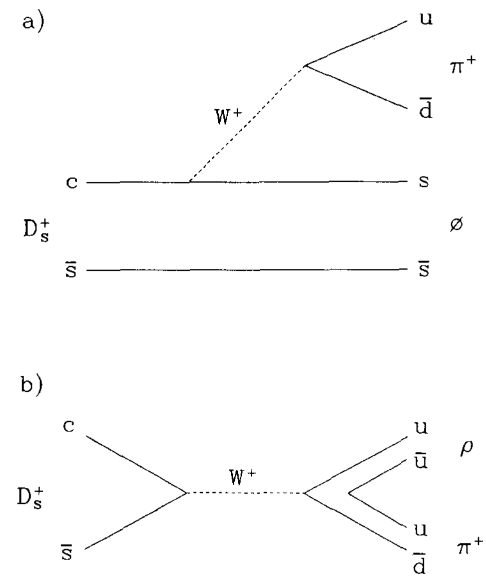

Fig. 1 (a) Spectator diagram, illustrated for the decay $D_s^+ \to \phi\pi^+$. (b) Annihilation diagram, illustrated for the decay $D_s^+ \to \rho^0\pi^+$.

In this letter we report on the search for the decay $D_s^+ \to \rho^0\pi^+$ [#2] and present an upper limit for the ratio $BR(D_s^+ \to \rho\pi^+)/BR(D_s^+ \to \phi\pi^+)$. The data sample used for this analysis was collected with the ARGUS detector, operating at the e^+e^- storage ring DORIS II at DESY. The data taken at center-of-mass energies around 10 GeV correspond to a total luminosity of 255 pb^{-1}, of which 46.5 pb^{-1}, 38.7 pb^{-1}, 106.5 pb^{-1} and 62 pb^{-1} were obtained on the $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(4S)$, and in the nearby continuum, respectively. The detector is a 4π spectrometer described in more detail elsewhere [8]. Charged particle momenta and mean dE/dx losses were determined using the central drift chamber. Particles were identified on the

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[#1] For a complete list of references see ref. [2].

[#2] References in this paper to a specific charged state also imply the charge conjugate state.

basis of measurements of both dE/dx and time of flight. For a given track all mass hypotheses were accepted for which the likelihood [9] constructed from these measurements exceeded 5%.

Multihadron final states were selected by requiring $\geqslant 3$ tracks reconstructed in the drift chamber and associated with the primary interaction point. All identified $\pi^+\pi^-$ pairs with invariant masses within ± 90 MeV/c^2 of the nominal ρ mass were taken as ρ^0 candidates and combined with an additional $\pi^\pm$ to form a $\rho^0\pi$ combination.

The main problem in the search for $D_s^+ \to \rho^0\pi^+$ is the enormous combinatorial background, a consequence of the width of the ρ and the large number of pions per event. Three cuts have been applied to the $\rho^0\pi$ combinations to reduce this background:

- Only combinations with scaled momenta $x_p \geqslant 0.6$ were used, where $x_p = p/p_{max}$ and $p_{max} = (E^2_{beam} - M^2_{D_s^+})^{1/2}$. This cut efficiently enhances the signal-to-background ratio, since in the fragmentation process D_s^+ mesons are produced with a hard momentum distribution [10].
- A cut, $|\cos\theta_0| \leqslant 0.8$, on the decay angle θ_0 between the ρ and the D_s^+ direction in the D_s^+, rest frame removes regions of high background in the forward and backward directions, a consequence of the jet-like topology of events. This cut reduces the background by a factor of 4, whereas the loss in signal is only 20%.
- We demand that the helicity angle θ_h, the angle of the π^+ from the decay of the ρ^0 with respect to the bachelor $\pi^\pm$ in the ρ^0 rest frame, satisfy the condition $|\cos\theta_h| \geqslant 0.5$. In the decay $D_s^+ \to \rho^0\pi^+$, this angular distribution should be of the form $\cos^2\theta_h$, since the ρ^0 must have helicity zero in the D_s^+ rest frame. This cut removes 50% of the uniformly distributed combinatorial background, while retaining 87.5% of the D_s^+ signal.

In parallel to the search for $D_s^+ \to \rho^0\pi^+$ we observed the well established decay $D_s^+ \to \phi\pi^+$ [10]. To study the $D_s^+ \to \phi\pi^+$ signal, identified K^+K^- pairs with invariant masses within ± 10 MeV/c^2 of the nominal φ mass were taken as φ candidates. The same cuts as in the $\rho^0\pi$ analysis were made on the scaled momenta and decay and helicity angles of the $\phi\pi$ combinations.

Figs. 2 and 3 show the invariant mass distributions for $\phi\pi$ and $\rho^0\pi$ combinations, respectively. There is a clear D_s^+ peak in the $\phi\pi$ mass distribution, but no indication of a signal at the D_s^+ mass can be seen in the $\rho^0\pi$ mass distribution. We present the limit on the ratio of the branching ratios for the $D_s^+ \to \rho^0\pi^+$ and $D_s^+ \to \phi\pi^+$ channels. The virtue of this procedure is that the two channels have similar acceptances, and thus, common uncertainties cancel. The ratio of branching ratios is given by

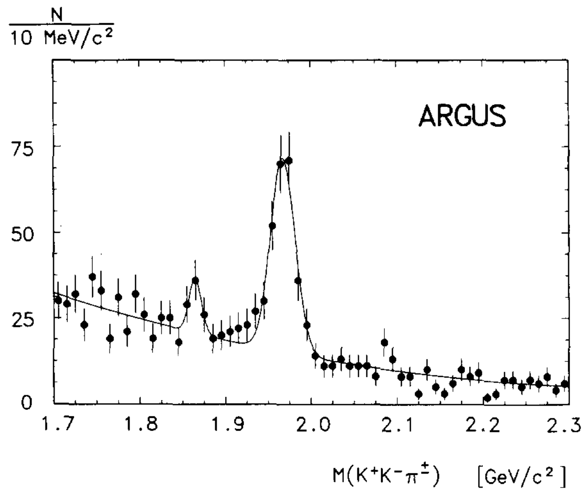

Fig. 2. $(K^+K^-\pi^\pm)$ invariant mass distribution with $M(K^+K^-)$ in the φ region, $x_p(K^+K^-\pi^\pm) \geqslant 0.6$, $|\cos\theta_0| \leqslant 0.8$ and $|\cos\theta_h| \geqslant 0.5$. The fit includes the contribution from $D^+ \to \phi\pi^+$.

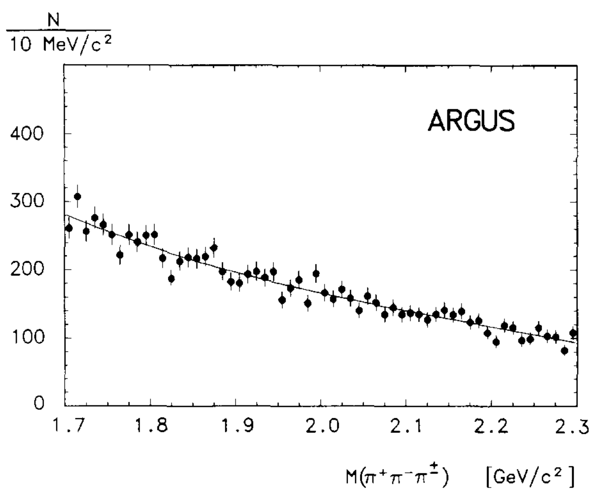

Fig. 3. $(\pi^+\pi^-\pi^\pm)$ invariant mass distribution with $M(\pi^+\pi^-)$ in the ρ region, $x_p(\pi^+\pi^-\pi^\pm) \geqslant 0.6$, $|\cos\theta_0| \leqslant 0.8$ and $|\cos\theta_h| \geqslant 0.5$.

$$\frac{BR(D_s^+ \to \rho^0\pi^+)}{BR(D_s^+ \to \phi\pi^+)} = \eta \frac{N(D_s^+ \to \rho^0\pi^+)}{N(D_s^+ \to \phi\pi^+)} ,$$

where η is the ratio of the detection efficiencies for the two processes, and N is the number of events obtained in the two channels. η has been determined from a Monte Carlo simulation to be 1.09 ± 0.12 multiplied by the known branching ratio for $\phi \to K^+K^-$ which is $(49.5 \pm 1.5)\%$ [11].

Fitting a gaussian plus a third order polynomial to the $\phi\pi$ mass distribution in fig. 2, we find a signal of $N(D_s^+ \to \phi\pi^+) = 203 \pm 19$ with mass of $(1967 \pm 2 \pm 3)$ MeV/c^2 and RMS width of (14 ± 1) MeV/c^2. A similar fit to the $\rho^0\pi$ mass distribution with fixed D_s^+ mass taken from the $D_s^+ \to \phi\pi^+$ signal, and RMS width of 24 MeV/c^2 taken from Monte Carlo calculations, yields $N(D_s^+ \to \rho^0\pi^+) = 1 \pm 48$. For the ratio of branching ratios we obtain the upper limit

$$\frac{BR(D_s^+ \to \rho^0\pi^+)}{BR(D_s^+ \to \phi\pi^+)} < 0.22 \quad (90\%\ \mathrm{CL}) .$$

The absolute branching ratio for $D_s^+ \to \phi\pi^+$ has not yet been directly measured. An estimate can be obtained from the known value for the production cross section times branching ratio [10], based on the following assumptions: (1) the fraction of the hadronic events containing a pair of charmed quarks is 40%, and (2) the probability to produce an $s\bar{s}$ pair from the vacuum is 15%, based on the observed ratio of K to π production in continuum e^+e^- annihilation. Using an average hadronic cross section of 3.5 nb, we estimate the cross section for D_s^+ production to be 0.42 nb. From our previously reported value for the cross section times branching ratio [10], we calculate $BR(D_s^+ \to \phi\pi^+) = 3\%$ which leads to an upper limit for $BR(D_s^+ \to \rho^0\pi^+) < 0.7\%$.

This limit is relevant for the theoretical interpretation of heavy meson decays. The branching ratio for the decay $D^0 \to \phi\bar{K}^0$ which should also be dominated by weak flavor annihilation has been determined to be 1%. This value is much larger than expected from valence quark model calculations in QCD [4]. It seems to indicate that flavor annihilation does indeed make a strong contribution to heavy meson decays. However, is has long been known [12,5] that final state interactions may strongly enhance or simulate annihilation processes if nearby resonances contribute. Models which take this into account fall into two classes:

(I) The weak annihilation amplitude is *enhanced* by resonance scattering in the final state to the amount observed in the decay $D^0 \to \phi\bar{K}^0$ [5,6,13]. A similar enhancement then applies to the decay $D_s^+ \to \rho^0\pi^+$ resulting in a predicted branching ratio $BR(D_s^+ \to \rho^0\pi^+) \approx 10\%$.

(II) The weak annihilation process is *simulated* by a spectator type diagram plus quark annihilation in a resonance scattering process after the weak decay of the heavy quark [7]. In this case, the annihilation occurs at the strong vertex. Using the measured value for the decay $D^0 \to \phi\bar{K}^0$ as input, the model predicts a branching ratio $BR(D_s^+ \to \rho^0\pi^+) \approx 0.5\%$.

Our upper limit on $BR(D_s^+ \to \rho^0\pi^+)$ clearly rules out model (I), but is compatible with model (II), as well as with the QCD sum rule prediction [14].

In summary we have obtained an upper limit on the ratio of branching ratios $BR(D_s^+ \to \rho^0\pi)/BR(D_s^+ \to \phi\pi)$ of 0.22 at the 90% confidence level. This result represents a new input for estimates of the annihilation contribution to heavy meson decay.

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