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Study of the decay $D_s^+ \rightarrow \eta'\pi^+$

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We report a limit of the branching ratio of $D_s^\pm \rightarrow \eta'\pi^\pm$ from Fermilab charm photoproduction experiment E691. The η' decay channels used are $\eta' \rightarrow \eta\pi^+\pi^-$, $\eta \rightarrow \pi^+\pi^-\pi^0$; and $\eta' \rightarrow \rho\gamma$, $\rho \rightarrow \pi^+\pi^-$. We find $\Gamma(D_s^\pm \rightarrow \eta'\pi^\pm)/\Gamma(D_s^\pm \rightarrow \phi\pi^\pm) \leq 1.3$ at the 90% confidence level.

Although the major decay modes of the D^0 and $D^\pm$ are almost completely accounted for,[1] the hadronic decays of the $D_s^\pm$ are much less certain. It has been suggested that there is a deficit in two-body hadronic decays of the $D_s^\pm$, compared with the corresponding modes for the D^0 and $D^\pm$.[2] This comparison, however, is quite uncertain because the absolute scale of the $D_s^\pm$ branching ratios is not well known.[1] Recently, two experiments[3,4] have measured a branching ratio for the mode $D_s^\pm \rightarrow \eta'\pi^\pm$ which is much larger than expected from theoretical models,[5,6] and would represent by far the largest $D_s^\pm$ decay mode yet seen. In this paper we present a sensitive measurement of $D_s^\pm \rightarrow \eta'\pi^\pm$ relative to the mode $D_s^\pm \rightarrow \phi\pi^\pm$. (Throughout the rest of this paper charge-conjugate states are implicitly included.)

The data used for this measurement was taken from the full sample of 10^8 events recorded during the run of Fermilab photoproduction experiment E691. This experiment collected data using the Tagged Photon Spectrometer, a large-acceptance two-magnet spectrometer which is described in detail elsewhere.[7] Photons of average energy 145 GeV interacted in a beryllium target to produce the charmed particles. Separation of the charm decay vertex from the primary event vertex was achieved using silicon microstrip detectors.

We first present a measurement of the decay $D_s^+ \rightarrow \eta'\pi^+$, $\eta' \rightarrow \eta\pi^+\pi^-$, $\eta \rightarrow \pi^+\pi^-\pi^0$.[8] The kinematics of this decay chain allow us to search for a signature of the $D_s^+ \rightarrow \eta'\pi^+$ decay without reconstructing the π^0. The $\pi^+\pi^-\pi^+\pi^-$ mass from the η' must be between 0.56 and 0.82 GeV, and the $\pi^+\pi^-\pi^+\pi^-\pi^+$ mass spectrum from $D_s^+ \rightarrow \eta'\pi^+$ events is peaked near the upper limit of 1.83

GeV. [Hereafter we will use $(4\pi)^0$ to denote the $\pi^+\pi^-\pi^+\pi^-$ from candidate η' decays, and $(5\pi)^+$ to denote the $\pi^+\pi^-\pi^+\pi^-\pi^+$.] The background suppression from these constraints and from the requirement of an isolated five-particle vertex is enough to produce a very small background level.

In this search we applied analysis techniques used for several other decay modes with charged tracks.[9] The five charged tracks must form a good vertex, and must pass a minimum requirement on the product of Cherenkov probabilities for particle identification. We also require the line of flight of the reconstructed D_s^+ candidate to pass within 80 μm of a reconstructed primary vertex candidate. (We are able to cut this tightly because the π^0 from the D_s^+ decay is produced with very low-momentum transverse to the D_s^+ direction.) Candidates which decay at least a distance $16\sigma_z$ downstream of the primary vertex are selected as charm candidates, where σ_z is the error on the distance between the primary and secondary vertices, in the direction parallel to the photon beam. We also demand that each of the five charged tracks pass closer to the secondary vertex than the primary, and that no additional tracks pass within 80 μm of the secondary vertex. Finally, we demand that four of the five tracks pass through both analysis magnets, and that the remaining track pass through at least the most upstream magnet.

The scatter plot of $(4\pi)^0$ vs $(5\pi)^+$ masses from events satisfying all the above criteria is shown in Fig. 1(a). The corresponding scatter plot from a Monte Carlo simulation of this decay chain is shown in Fig. 1(b). Note the small fraction of total phase space which is populated by the events from D_s^+ decays. To extract a possible $D_s^+ \to \eta'\pi^+$ signal, a two-dimensional fit was performed on the events shown in Fig. 1(a). The fit allowed for four components: $D_s^+ \to \eta'\pi^+$ decays, $D^+ \to \eta'\pi^+$ decays, background, and feedthrough from $D^+ \to K^-\pi^+\pi^+\pi^-\pi^+$ where the kaon is misidentified as a pion. Feedthroughs from other charm decay modes are negligible. The number of events due to the latter component was fixed; the numbers of events from the other three components were allowed to vary in the fit. The background was parametrized using candidate events which decayed farther upstream than the events used in this analysis. The D_s^+ and D^+ signal terms were parametrized based on the Monte Carlo distribution shown in Fig. 1(b), with the D^+ term shifted downward 0.1 GeV in $(5\pi)^+$ mass relative to the D_s^+ term. The feedthrough term was also parametrized based on a Monte Carlo simulation, and the branching fraction $B(D^+ \to K^-\pi^+\pi^+\pi^-\pi^+) = 0.8\%$.[10]

The fit yielded $5.8 \pm 3.9 D_s^+$ events, $7.0 \pm 4.5 D^+$ events, and 161 ± 13 background events. The projection of data and fit onto the $(5\pi)^+$ invariant-mass axis is shown in Fig. 2, for events with $(4\pi)^0$ invariant mass less than 0.82 GeV. The reconstruction efficiency for $D_s^+ \to \eta'\pi^+$ in this decay chain is $(0.83 \pm 0.06)\%$. The systematic error is dominated by the case where the number of $D^+ \to \eta'\pi^+$ events is fixed to zero in the fit. Systematic errors due to varying the background shape were found to be negligible. Normalizing to $D_s^+ \to \phi\pi^+$, and correcting for the product of branching fractions

$$B(\eta' \to \eta\pi^+\pi^-)B(\eta \to \pi^+\pi^-\pi^0) = 0.10 ,$$

we find

$$\Gamma(D_s^+ \to \eta'\pi^+)/\Gamma(D_s^+ \to \phi\pi^+) = 0.7 \pm 0.5 \pm 0.4 .$$

We also searched for the decay $D_s^+ \to \eta'\pi^+$, $\eta' \to \rho\gamma$, $\rho \to \pi^+\pi^-$. The analysis cuts used for this mode are

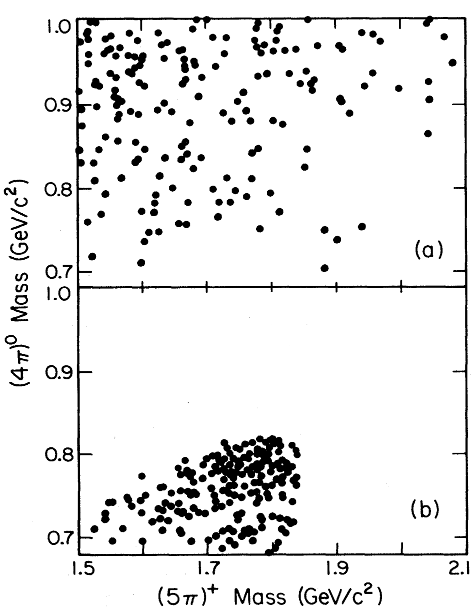

FIG. 1. (a) The $(4\pi)^0$ mass vs $(5\pi)^+$ mass scatter plot for events from E691 data sample. (b) The corresponding scatter plot from a Monte Carlo simulation of the decay $D_s^+ \to \eta'\pi^+$, $\eta' \to \eta\pi^+\pi^-$, $\eta \to \pi^+\pi^-\pi^0$.

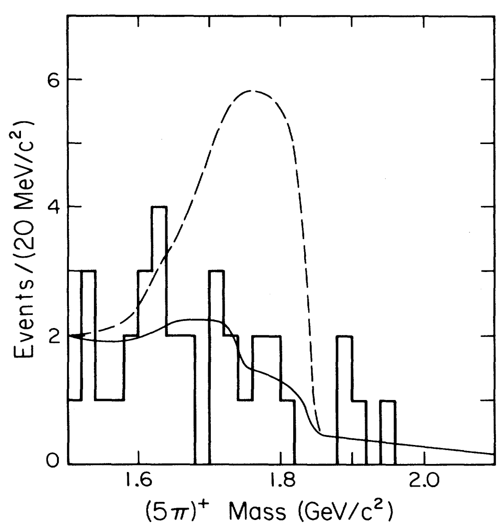

FIG. 2. The $(5\pi)^+$ mass spectrum for events with $(4\pi)^0$ mass less than 0.82 GeV. The lower curve represents the best fit to the entire scatter plot of 1(a). The upper curve corresponds to the decay rate $B(D_s^+ \to \eta'\pi^+) = 4B(D_s^+ \to \phi\pi^+)$, consistent with the results of Refs. 2 and 3.

similar to those described above; the minimum decay distance was required to be $10\sigma_z$ downstream of the primary vertex. Additional cuts were applied for the purpose of photon identification; these cuts are similar to those described elsewhere.[11] We also demanded that the photon candidates have energy greater than 4 GeV, and not be associated with any π^0. Then, each $\pi^+\pi^-\gamma$ combination was required to have invariant mass in the range 0.9–1.02 GeV; the $\pi^+\pi^-$ invariant mass from this combination was required to be between 0.68 and 0.86 GeV. A correction was then made to the photon candidate's energy such that this invariant mass of this $\pi^+\pi^-\gamma$ system be consistent with the mass of the η'. This correction was found to improve the $\pi^+\pi^-\pi^+\gamma$ mass resolution for D_s^+ decays from about 30 to 10 MeV. We also demanded that the absolute value of $\cos\theta$ be less than 0.8, where θ is the angle between the photon and either pion from the ρ decay, in the rest frame of the ρ. The latter cut was motivated by the fact that the differential decay rate $d\Gamma/d(\cos\theta)$ for $\eta' \to \rho\gamma$ is proportional to $\sin^2\theta$.

The spectrum of events satisfying the criteria listed above is shown in Fig. 3. We fit this spectrum to a sum of three components: a cubic polynomial, plus Gaussians of width 10 MeV for both D_s^+ and D^+ decays to $\eta'\pi^+$. The fit yielded 2.0 ± 3.4 D_s^+ events and 5.0 ± 4.5 D^+ events. The reconstruction efficiency for $D_s^+ \to \eta'\pi^+$ in this chain is $(0.17 \pm 0.09)\%$. The large error in this efficiency is due to the uncertainty in the single γ reconstruction efficiency. Normalizing to $D_s^+ \to \phi\pi^+$, and correcting for the branching fraction $B(D_s^+ \to \rho\gamma) = 0.30$, we find $\Gamma(D_s^+ \to \eta'\pi^+)/\Gamma(D_s^+ \to \phi\pi^+) = 0.4 \pm 0.7 \pm 0.2$, in agreement with the measurement quoted above.

We calculate an upper limit on $\Gamma(D_s^+ \to \eta'\pi^+)$ by taking a weighted average of the two independent measurements. We thus obtain, for our best measurement,

$$\Gamma(D_s^+ \to \eta'\pi^+)/\Gamma(D_s^+ \to \phi\pi^+) = 0.6 \pm 0.5\,,$$

from which we calculate the upper limit

$$\Gamma(D_s^+ \to \eta'\pi^+)/\Gamma(D_s^+ \to \phi\pi^+) \leq 1.3$$

at the 90%-confidence level. This measurement is consistent with theoretical predictions,[5,6] and with the measurement of the Mark III Collaboration.[12] It is mildly inconsistent with the result of the ARGUS Collaboration (2.5 standard deviations);[13] however, it is in sharp contrast to the Mark II and NA14′ results.[3,4]

Our measurement implies that the $\eta'\pi^+$ mode represents less than about 5% of all D_s^+ decays at the 90%-confidence level, assuming a branching ratio for D_s^+ to $\phi\pi^+$ of 4%. Thus the $\eta'\pi^+$ mode does not play a dominant role in the hadronic decays of the D_s^+.

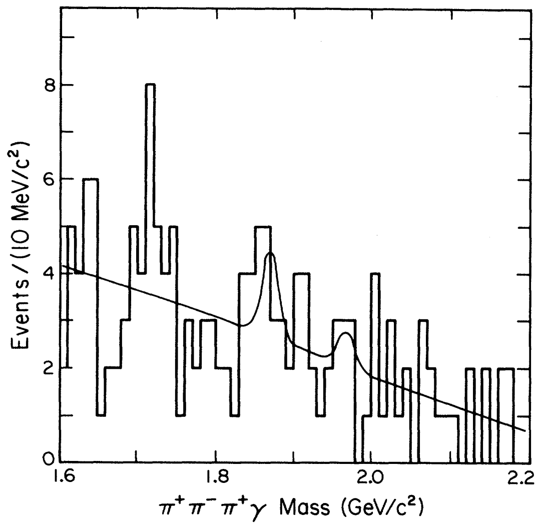

FIG. 3. The $\pi^+\pi^-\pi^+\gamma$ mass spectrum used in the search for $D_s^+ \to \eta'\pi^+$, $\eta' \to \rho\gamma$, $\rho \to \pi^+\pi^-$.

We are also able to set an upper limit on the Cabibbo-suppressed decay $D^+ \to \eta'\pi^+$. The efficiency is $(1.5 \pm 0.2)\%$ for the $\eta' \to \eta\pi^+\pi^-$, $\eta \to \pi^+\pi^-\pi^0$ mode, and $(0.28 \pm 0.09)\%$ for the $\eta' \to \rho\gamma$, $\rho \to \pi^+\pi^-$ mode. To calculate the $D^+ \to \eta'\pi^+$ upper limit we use the same calculational procedure as for $D_s^+ \to \eta'\pi^+$. The weighted average for D^+ is dominated by the measurement in the $\eta' \to \eta\pi^+\pi^-$, $\eta \to \pi^+\pi^-\pi^0$ channel. The decay rate relative to $D^+ \to K^-\pi^+\pi^+$ is

$$\Gamma(D^+ \to \eta'\pi^+)/\Gamma(D^+ \to K^-\pi^+\pi^+) = 0.06 \pm 0.04\,.$$

We combine this with the Mark III measurement[14] of the absolute branching ratio $B(D^+ \to K^-\pi^+\pi^+) = (9.1 \pm 1.3 \pm 0.4)\%$ to get the 90%-confidence upper limit $B(D^+ \to \eta'\pi^+) \leq 1.2\%$. This mode is expected to be much less than 1%, however.[5]

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$\rightarrow D_s^+)B(D_s^+ \rightarrow \eta'\pi^+) = 8.4 \pm 3.7$ pb, from which they estimate $B(D_s^+ \rightarrow \eta'\pi^+)$ is about 19%.

[4]G. Wormser, in *Heavy Quark Physics,* Proceedings of the International Symposium, Ithaca, New York, 1989, edited by P. S. Drell and D. L. Rubin, AIP Conf. Proc. No. 196 (AIP, New York, 1990). The NA14' Collaboration has reported $\Gamma(D_s^+ \rightarrow \eta'\pi^+)/\Gamma(D_s^+ \rightarrow \phi\pi^+) = 5.0 \pm 1.8 \pm 1.2$.

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[8]We also searched for $D_s^+ \rightarrow \eta'\pi^+$, $\eta' \rightarrow \eta\pi^+\pi^-$, $\eta \rightarrow \gamma\gamma$. Our sensitivity in this mode is several times worse than in the two modes for which the results are presented herein. No signal was observed.

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[13]H. Albrecht *et al.*, Phys. Lett. B **245**, 315 (1990); the ARGUS Collaboration has reported $\Gamma(D_s^+ \rightarrow \eta'\pi^+)/\Gamma(D_s^+ \rightarrow \phi\pi^+) = 2.5 \pm 0.5 \pm 0.3$.

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