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# SEARCH FOR DOUBLY CABIBBO-SUPPRESSED $D^+$ DECAYS†

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## ABSTRACT

Preliminary results of a search for the doubly Cabibbo-suppressed $D^+$ decays $D^+ \to K^+\pi^-\pi^+$ and $D^+ \to K^+\pi^0$, in the MarkIII detector at SPEAR are presented. Theoretical arguments suggest that these decays may be enhanced relative to Cabibbo-allowed $D^+$ decays. Use of hadronically tagged $D^+D^-$ events produced in the decay of the $\psi(3770)$, reduce backgrounds significantly, allowing the isolation of three candidate events in the $K^+\pi^+\pi^-$ final state and a limit on the relative decay rate of the $K^+\pi^0$ channel.

## INTRODUCTION

Double Cabibbo-suppressed decays (DCSD) of the $D^0$ and $D^+$ present a rich test of our understanding of weak hadronic decays.[1] The rate for DCSD relative to Cabibbo-allowed decays (CAD) goes naively like $\frac{|V_{cd}V_{us}^*|}{|V_{cs}V_{ud}^*|} \sim \tan^4\theta_c$. For $D^0$ decay, a mild deviation from this estimate is expected within the factorization hypothesis, arising from SU(3) and SU(6) breaking, and from form-factors.[2] Evidence for 3 $D^0D^0$ events at the $\psi(3770)$, was previously reported[3] when $0.4 \pm 0.2$ background events were expected. For small values of the mixing parameter ($r_D \leq 4\times10^{-3}$), the events can be interpreted as evidence for DCSD with $|\bar{\rho}_{K^-\pi^+\pi^0}|^2 \geq 1.9$ at 90% C.L.

Unlike the $D^0$, the $D^+$ DCSD are expected in many cases to have large enhancements over CAD resulting from the lack of interference amongst their amplitudes. Interference is believed responsible for $\Gamma(D^+) \ll \Gamma(D^0)$. Equivalently, the possibility of both I=1/2 and I=3/2 final states in $D^+$ DCSD would lead to an enhanced width. Estimates using factorization but not considering final state interactions (FSI)[2] for four candidate DCSD are :

$$|\bar{\rho}_{K^+\pi^0}|^2 = \frac{\Gamma(D^+ \to K^+\pi^0)}{\Gamma(D^+ \to \bar{K}^0\pi^+)} \cdot \frac{1}{\tan^4\theta_c} \approx 3$$

$$|\bar{\rho}_{K^*\pi^+}|^2 = \frac{\Gamma(D^+ \to K^{*0}\pi^+)}{\Gamma(D^+ \to \bar{K}^{*0}\pi^+)} \cdot \frac{1}{\tan^4\theta_c} \approx 5-11$$

$$|\bar{\rho}_{K^{*+}\pi^0}|^2 = \frac{\Gamma(D^+ \to K^{*+}\pi^0)}{\Gamma(D^+ \to \bar{K}^{*0}\pi^+)} \cdot \frac{1}{\tan^4\theta_c} \approx 12-25$$

$$|\bar{\rho}_{K^+\rho^0}|^2 = \frac{\Gamma(D^+ \to K^+\rho^0)}{\Gamma(D^+ \to \bar{K}^0\rho^+)} \cdot \frac{1}{\tan^4\theta_c} \approx 0.4$$

No prediction for non-resonant $D^+ \to K^+\pi^-\pi^+$ exists. A search for all except the $K^{*+}\pi^0$ final state is reported here.

## THE $K^+\pi^-\pi^+$ FINAL STATE

In the analysis, a sample of 2538 $D^\pm$ hadronic *tags* is selected. Events are required to contain three additional charged tracks satisfying total charge zero. The recoiling charged tracks are loosely assigned particle-ID by time-of-flight (TOF) and dE/dX. Combinations opposite a $D^\mp$ tag and consistent with a $K^\pm\pi^\mp\pi^\pm$ assignment are plotted in invariant versus beam constrained (BC) mass. The invariant mass is sensitive to particle miss-ID, reflecting $\pm120$ MeV for a single $\pi \rightleftharpoons K$ interchange. Double miss-ID however, reflects back to the same invariant mass. The BC-mass follows the candidate's momentum, which is monochromatic for pair-produced $D^\pm$ and remains unchanged by particle miss-ID. Figure 1(a) shows the data. The signal region is defined by $\sim 2.5\sigma$ vertical and horizontal bands (1.862-1.876 and 1.819-1.919 GeV/c$^2$, respectively). There are 19 events in the signal region, as well as higher and lower mass reflections of Cabibbo-suppressed decays with single miss-ID. Two background events from $K_s^0K^\pm$,

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with $\pi^+\pi^-$ pairs having the $K^0$ mass are rejected. The 17 remaining events are reduced to six, (Figure 1(b)) by tightening particle-ID requirements. This reduces the single miss-ID reflections, and eliminates most double miss-ID in the signal region. Residual background comes from $D^+D^-$ and $\bar{D}^0D^0$, where the tag has a $K^0_S$, and particle interchange *across* the event has occurred. In those events, easily swapped $\pi$'s determine the charge and hence the charm. An example is $\bar{K}^0\pi^+\pi^-$ *vs* $K^+\pi^-\pi^+\pi^-$ identified as $\bar{K}^0\pi^+\pi^-\pi^-$ *vs* $K^+\pi^-\pi^+$. By testing all such combinations, these events are entirely eliminated. Fake events also occur from lost $\pi^0$ accompanied by single $\pi \rightleftharpoons K$ miss-ID. Vetoing events with extra photons eliminates this background.

Figure 1(c) shows five surviving events, three belonging to the signal region. Residual background from double miss-ID is estimated to be $0.8\pm0.3\pm0.3$ events. The detection efficiency for $K\pi\pi$ final states is $\sim 0.35$. Using the number of tags, the detection efficiency and the CAD branching ratios, 0.2-0.5 $K^\pm\rho^0$ and 0.1 $K^{*0}\pi^+$ events are expected under the factorization hypothesis, while instead, two events consistent with $K^\pm\rho^0$, and one event consistent with $K^{*0}\pi^+$ are observed.

Non-resonant decays cannot be distinguished from resonant ones. If $|\bar{\rho}|^2 = 1$ for non-resonant decays, 0.2 events would be detected. After background subtraction a value $|\bar{\rho}_{K\pi\pi}|^2 \approx 11$ is extracted, assuming all events are non-resonant.

## The $K^+\pi^0$ Final State

For this analysis the tag sample is reduced to 2255 by removing those tags containing a $\pi^0$. This improves the missing energy resolution subsequently used in the analysis. To improve efficiency, $\pi^0$ reconstruction is explicitly avoided. The search proceeds by identifying tags with one and only one correct-charge track (assigned the kaon mass) in the recoil, and $\geq$ one photon within $|\cos\theta| \geq 0.84$ of the $P_{MISS}$ ($\pi^0$) direction. Figure 2(a) shows the data plotted in the variable $U = \Sigma(P_{EVENT} - P_{TAG})^\nu \cdot (P_K)_\nu$. A real $K^+\pi^0$ signal will be 97% contained for $1.8 \leq U \leq 1.92$ (GeV/$c^2$)$^2$. Thirty candidate signal events are observed. The backgrounds from $D^+ \to \pi^+\pi^0$ and $\bar{K}^0K^+$ where either $\pi^+ \rightleftharpoons K^+$ or $\bar{K}^0 \to (K^0_S \to \pi^0\pi^0)$ or $\to K^0_L$, are shifted to higher and lower U values, and rejected.

The principle CAD background $D^+ \to \bar{K}^0\pi^+$ manifests itself by $\pi^+ \rightleftharpoons K^+$ and $K^0 \to \pi^0\pi^0$ or $K^0_L$, where the $\pi^0$'s are asymmetric, or the $K_L$ interacts faking a photon. Misidentified $\bar{K}^0\pi^+$ peak at the same U value where a $K^+\pi^0$ signal would peak. A $K^+\pi^0$ signal has at least one photon of energy $\geq$0.4 GeV/c$^2$ within a tighter cone $|\cos\beta| \geq 0.98$ around the expected $\pi^0$ direction There are no additional photons of energy $\geq$ 0.3 GeV/c$^2$ outside the cone. Figure 2(b) results from these energy and veto cuts. Five events remain. The sum of photon directions ($\Sigma_{cone}P_\gamma$) within the initial cone, relative to $P_{MISS}$ is peaked sharply for the signal, but has a large dispersion when originating from $K^0_L$ interactions or multi-$\pi^0$'s from $K^0_S \to \pi^o\pi^0$. Figure 2(c) shows the result after a tight direction cut; one signal event and one event on the cut boundary remains, with an expectation of 2.8 events from Monte Carlo. Requiring positive kaon-ID eliminates four events including the one signal candidate (Figure 2(d)). Less than 0.2 background events in the signal region, less than one $\bar{K}^0K^+$ event below and less than 0.5 $\pi^+\pi^0$ events above the signal region are expected. A visual scan of these remaining events confirms their origin.

Taking the factorization estimate, the detection efficiency of 0.37 and the Br($\bar{K}^0\pi^+$) one predicts that 0.2 events would be seen. No events are observed (with an expected background $\leq$0.2), leading to a preliminary limit of $|\bar{\rho}_{K^+\pi^0}|^2 \leq 30$ at 90% CL.

## Conclusions

In a preliminary analysis of $D^+$ DCSD, three events are observed in the $K^\pm\pi^+\pi^-$ final state, with $0.8\pm0.3\pm0.3$ expected background events. The excess events are consistent with a value of $|\bar{\rho}|^2 \gg 1$, divided between the different final states, as anticipated for $D^+$ DCSD and similar to that observed for the $D^0$ DCSD. No events are seen for $D^+ \to K^+\pi^0$ and a weak limit on $|\bar{\rho}|^2$ is derived, consistent with factorization. FSI have not been considered in the predictions, and may play an important role in the presence of potentially large channels like $K^{*+}\pi^0$.[4]

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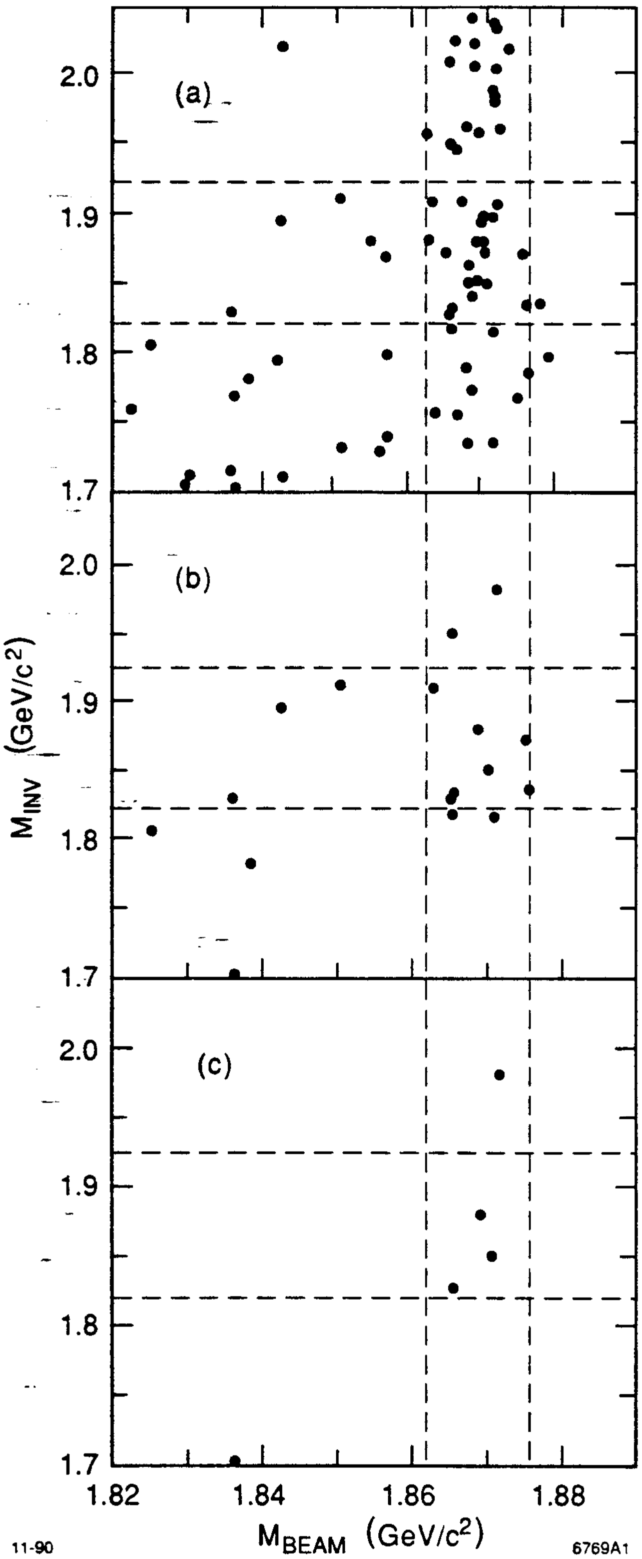
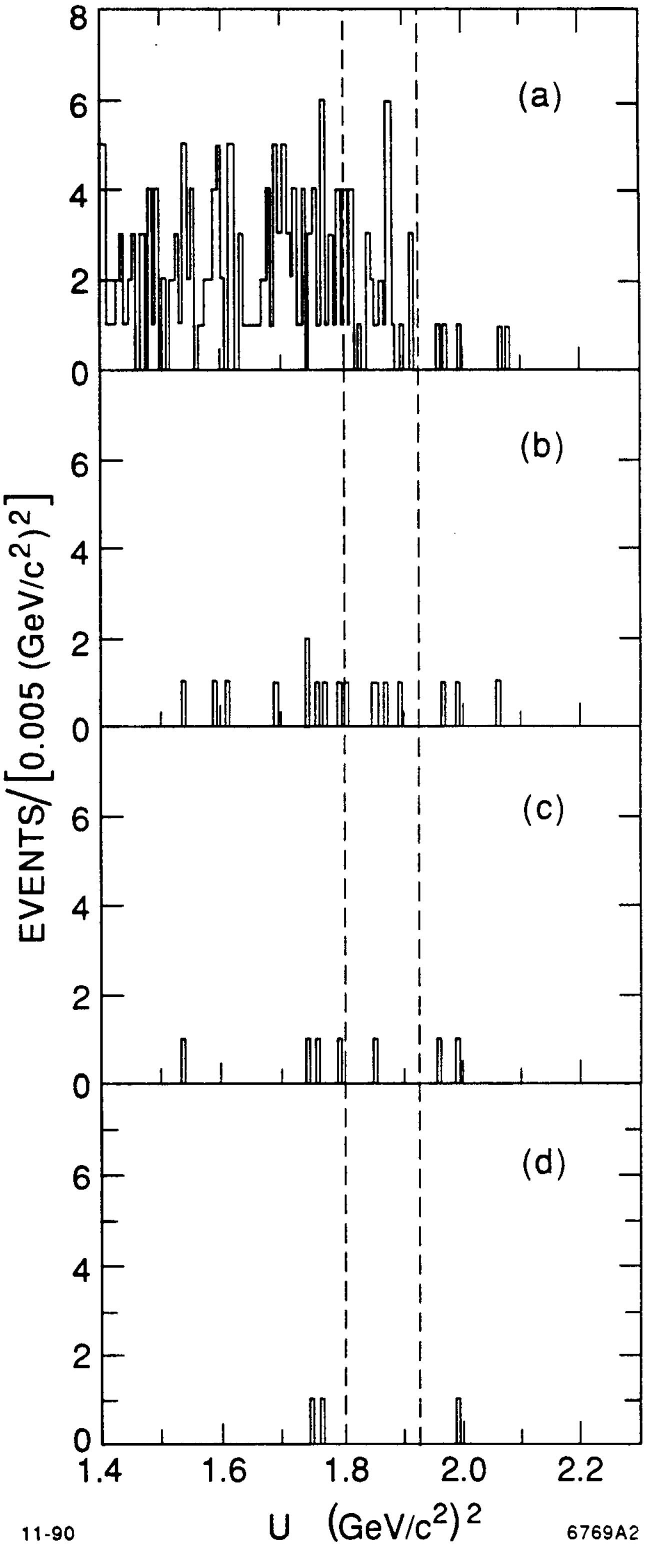



1) (a)Invariant vs. beam constrained mass, loose cuts. Dashed lines indicate the signal region. (b)After anti-$K^0$ and tighter particle-ID cuts. (c)After final cuts to reduce $D^+D^-$ and $\bar{D}^0D^0$ feedown.




2) (a) U for events before cuts, (b) U after photon energy and veto cuts, (c) U after photon direction cuts, (d) U after demanding K identification.