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Search for Wrong Sign D^0 Decays with the HRS Detector

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ABSTRACT

Using a data sample corresponding to an integrated luminosity of $300pb^{-1}$ obtained at PEP with the HRS detector we have searched for the wrong sign decay of D^0 mesons in the decays $D^* \rightarrow D^0\pi$. We obtain a 90% confidence level limit of 4.0% on the ratio of the wrong sign to the right sign decay rate in the $K\pi$ mode. This is the best model independent limit on mixing currently available and constrains the nature of the wrong sign signal recently reported by the MARK III group.

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Using the HRS detector [1] we have searched for wrong sign decays of D^0 mesons tagged by the decay $D^{*+} \rightarrow D^0\pi^+$ using $D^0 \rightarrow K^-\pi^+$ for right sign decay and $D^0 \rightarrow K^+\pi^-$ for wrong sign decay. The corresponding charge conjugate states are also used. The data sample consist of an integrated luminosity of $300pb^{-1}$ collected with the HRS detector at PEP. The superior momentum resolution of the HRS is crucial in improving on the 8% limit obtained by the DELCO collaboration in the same channel [2]. The MARK III experiment sees a signal of 3 wrong sign D^0 decays in a sample of 162 fully reconstructed $\psi'' \rightarrow D^0\overline{D}^0$ events [3] with an estimated background of 0.4 ± 0.2 events. This corresponds to a wrong to right sign ratio of $\approx 0.8\%$. A ratio of $tan^4\theta_c \approx 0.3\%$ is expected for doubly Cabbibo suppressed decays, however these decays are strongly suppressed by Bose statistics in the P-wave $D^0\overline{D}^0$ state produced by ψ'' decay [4]. In the standard model mixing is only expected to contribute at the 10^{-3} level [5]. Limits from other experiments are well above the MARK III result or suffer from extreme model dependence [2,6,7]. Our limit of 4% does not exclude the MARK III result. However, since D mesons from D^* decays are not affected by the Bose suppression which operates on the $D^0\overline{D}^0$ system, our result does constrain the nature of the wrong sign decay mechanism.

Our analysis uses the decays $D^* \rightarrow D^0\pi^+$ where $D^0 \rightarrow K^-\pi^+$ for the right sign decay and $D^0 \rightarrow K^+\pi^-$ for the wrong sign decay. Particle identification is not used. Both the kaon and pion mass hypotheses is tried for each track. D^* production is isolated in the standard way using $M_{K\pi}$ and $\delta = M_{K\pi\pi} - M_{K\pi}$. In order to reduce the background in the wrong sign channel due to reflections from the right sign channel, as well as the combinatorial background, we apply the following cuts:

$$0.2 < (P_K - P_\pi)/(P_K + P_\pi) < 0.9,$$

$$Z_{D^*} > 0.45.$$

The lower bound on the momentum asymmetry excludes combinations where the two possible $K\pi$ mass hypotheses are ambiguous in $K\pi$ mass. The upper bound removes a large portion of the combinatorial background which is strongly peaked near ± 1 in the momentum asymmetry. Taking only positive asymmetries eliminates the background from low $K\pi$ masses which are pulled up to the D mass by taking the wrong sign mass hypothesis. There are a large number of such $K\pi$ pairs, which give nearly the right value of $\delta = M_{K\pi\pi} - M_{K\pi}$, arising from higher multiplicity decays of D's produced by the $D^* \rightarrow D\pi$ mechanism. The Z_{D^*} cut eliminates more than five times as much background as signal since the D^* momentum spectrum is much harder than the combinatorial background.

To determine the background level in the wrong sign channel and the number of D's from the right sign channel we fit the distributions in $M_{K\pi}$ and δ to a flat background plus the product of two independent guassians for the M_D and δ distributions due to D mesons. The assumption of independence is valid, since the distribution of $M_{K\pi}$ depends only the momenta of the K and the fast π and the δ distribution depends to first order only on the slow π's momentum.

Fig. 1 shows the $K\pi$ mass distribution and the δ distribution for right sign combinations. The curve is a result of the fit. The fit is used to determine the widths of the D and δ peaks as well as the number of D's in the sample. The widths(σ) found are 20 MeV for the D mass peak and 0.71 MeV for the mass difference peak. Masses are taken from the Particle Data Book [8]. Fig. 2 shows the same distributions for the wrong sign combinations. There is no hint of a signal. In the wrong sign case we fit only above a $K\pi$ mass of $1.84 GeV$, since below that there is a large contribution from D's that move down in mass when the $K\pi$ mass hypothesis is reversed. To determine the upper limit for wrong sign decays we use a D-region defined to be $1.84 < M_{K\pi} < 1.89 GeV$ and $0.144 < \delta < 0.148 GeV$. The fit to the wrong sign data yields an estimate of 1.25 background events inside the D-region and the right sign fit gives 68.7 signal events in the D-region.

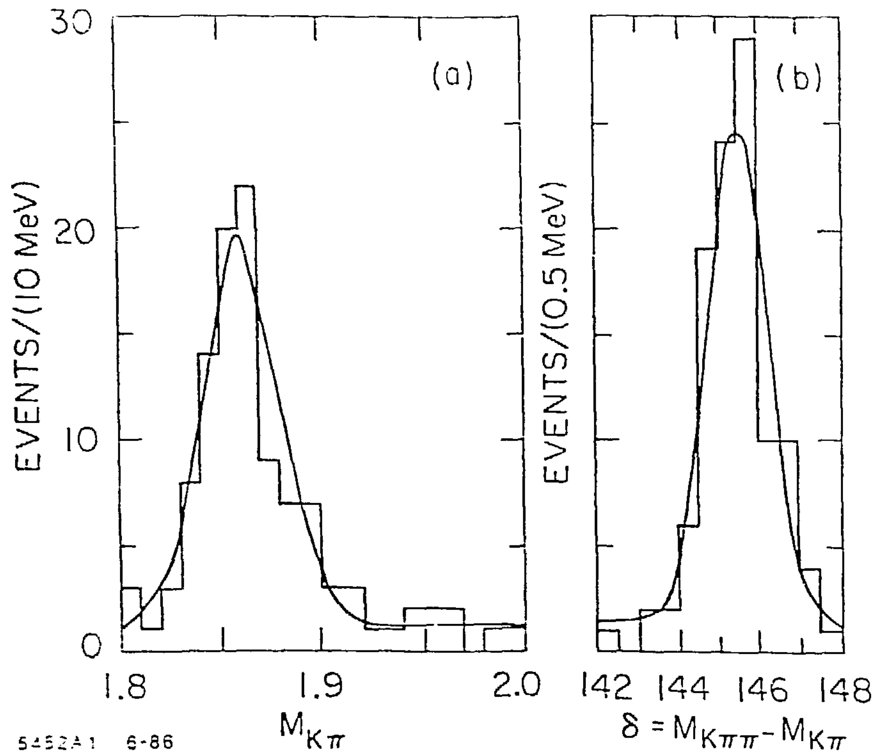

Figure 1. a) Mass of right sign $K\pi\pi$ pairs. Curve is result of fit. b) $K\pi\pi$, $K\pi$ mass difference for right sign $K\pi$ pairs.

Using the widths obtained from the fit to the right sign data we fit the wrong sign data with a fixed amount of D-signal but with the background still free. We increase the signal forced on the fit until the probability of seeing one or less events in the D region is 10%. The signal that can be accommodated is ≈ 3 events which yields a 4.0% limit at 90% confidence level. Acceptance and efficiency have canceled out in ratios of right sign and wrong sign results. We also find the limit obtained is insensitive to the widths of the D^0 and δ peaks used. We conclude that our limit is largely free of systematic error at the current level of statistics.

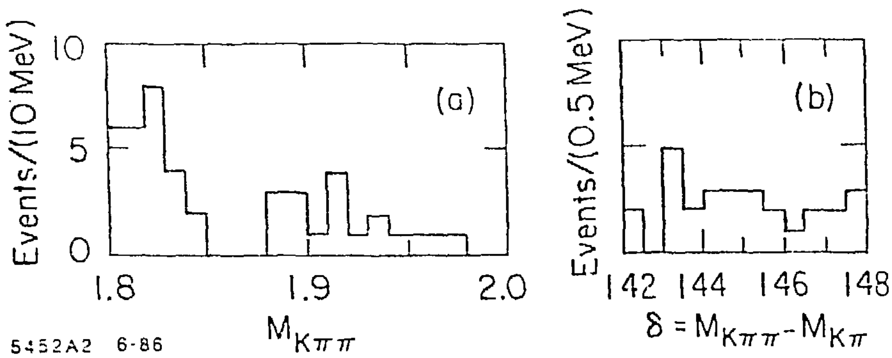

Figure 2. a) Mass of wrong sign $K\pi$ pairs. b) $K\pi\pi$, $K\pi$ mass difference for wrong sign pairs.

If the MARK III wrong sign events are the result of mixing, they will have been suppressed by about a factor of 2 by Bose statistics [4] . This means that the $\approx 0.8\%$ rate observed corresponds to a 1.6% rate in D^* decays - well below our limit.

On the other hand, if doubly Cabbibo suppressed decays (DCSD) are responsible for the signal, the effect of Bose suppression is complex. Decays where both the D^0 and the $\overline{D}^0$ decay to the same two body final state are not allowed. For example the decay chain $\psi'' \to D^0\overline{D}^0 \to (K^+\pi^-)(K^+\pi^-)$ is forbidden. Bigi and Sanda [4] find wrong sign to right sign ratios for P-wave states to be

$$R_{wr} = |\rho_k - \rho_j|^2 tan^4\theta_c$$

where ρ_i is the factor by which the wrong sign decay to state i differs from the quark level result ($tan^4\theta_c$). Only final states in which the ρ values of the two D decay states differ a lot can make a significant contribution. These effects must be taken into account when making a comparison of ψ'' decay and D^* decay results.

MARK III sees wrong sign events in two channels: $K^+\pi^-$ vs $K^+\pi^-\pi^0$ and $K^+\pi^-\pi^0$ vs $K^+\pi^-\pi^0$. In D decays the $K^+\pi^-\pi^0$ final state is essentially saturated by the two body modes $K^+\rho^-$, $K^{*+}\pi^-$, and $K^{*0}\pi^0$ [8] . Only the states $K^{*0}\pi^-$ vs $K^+\rho^-$, $K^{*0}\pi^0$ vs $K^+\pi^-$, and $K^{*0}\pi^-$ vs $K^{*0}\pi^0$ can contribute to the $K\pi\pi$ vs $K\pi\pi$ channel if DCSD is the wrong sign production mechanism. In the factorization model employed by Bigi and Sanda [4, 9] the $K^+\pi^-$, and the $K^{*+}\pi^-$ modes are enhanced relative to the quark level rate, the $K^+\rho^-$ mode is suppressed, and the $K^{*0}\pi^0$ is almost unaffected, so significant contributions from all three allowed pairs of $K\pi\pi$ final states as well as from the $K^+\pi^-$ vs $K^+\rho^-$ and $K^+\pi^-$ vs $K^{*0}\pi^0$ components of $K^+\pi^-$ vs $K^+\pi^-\pi^0$ can be expected.

If we exclude from the denominator identical two body states, and count each remaining event only once to account for the minimal effect of Bose suppression on non-identical final states, we find the wrong sign rate is $\approx 4.5\%$ of the right sign rate for two body decays. With such a high rate we would expect 3 wrong sign decays in our sample (4 including background). This makes the DCSD interpretation of MARK III events seem implausible, but can not strictly rule it out. A priori mixing seems a much more unlikely explanation, but by the same token a very interesting one. It would be the first crack in the standard model.

Comparison of wrong sign rates in $D^0\overline{D}^0$ events and D^* decays is powerful tool for distinguishing the effects of DCSD from the effects of mixing. Large samples, in as many different D decay channels as possible are needed. Modes involving π^0's are important. We set a 4% limit at 90% confidence level on the $K^+\pi^-$ channel. Much better limits are possible. Nothing but statistics prevents it from being reduced to the 1% level. DCSD decays should be accessible, and mixing and DCSD can be distinguished if they are observed in both $\psi'' \rightarrow D^0\overline{D}^0$ events and D^* decays. Plans to collect large samples of D^* decays should be vigorously pursued [10].

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10. Eg. FNAL experiment 619, CLEO II, or the PEP luminosity upgrade

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