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Results on D and D_s Decays from Mark III[†]

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Abstract

The decays $D^0 \to \pi^- e^+ \nu_e$ and $D^0 \to K^- e^+ \nu_e$ are observed in a sample of $e^+e^- \to \psi(3770)$ events collected with the Mark III detector at SPEAR. The branching fractions $B(D^0 \to \pi^- e^+ \nu_e) = (0.39\,^{+0.23}_{-0.11} \pm 0.04)\%$ and $B(D^0 \to K^- e^+ \nu_e) = (3.4 \pm 0.5 \pm 0.4)\%$ are measured. The ratio of Kobayashi-Maskawa matrix elements $|V_{cd}/V_{cs}|^2 = (0.057\,^{+0.038}_{-0.015} \pm 0.005)$ is obtained under the assumption that the form factors $f_+^K(0)$ and $f_+^\pi(0)$ are equal. A study of the absolute D_s^+ hadronic branching fractions is made by searching for fully reconstructed $e^+e^- \to D_s^{*\pm} D_s^{\mp}$ events at $\sqrt{s} = 4.14\,\mathrm{GeV}$. The 90% confidence level limit $B(D_s^+ \to \phi\pi^+) < 5.9\%$ is established.

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I discuss two topics related to charmed meson decays: (1) a determination of the ratio of the Kobayashi-Maskawa matrix elements $|V_{cd}/V_{cs}|^2$ from our measurements of the branching fractions for the exclusive semileptonic decays $D^0 \to \pi^- e^+ \nu_e$ and $D^0 \to K^- e^+ \nu_e$, and (2) a study of the absolute hadronic branching fractions of the D_s^+.

1. Semileptonic D^0 Decays and $|V_{cd}/V_{cs}|^2$

The determination of $|V_{cd}/V_{cs}|^2$ is briefly described in this paper; further details are available in Reference 1. A sample of 27 700 produced $e^+e^- \to \psi(3770) \to D^0\bar{D}^0$ events is used for the analysis. Candidate events are selected which contain a $\bar{D}^0$ decay* which is observed in one of the following tag modes: $\bar{D}^0 \to K^+\pi^-$, $K^+\pi^-\pi^-\pi^+$, $K_S^0\pi^+\pi^-$, or $K^+\pi^-\pi^0$. A search is then made for the decays $D^0 \to \pi^- e^+ \nu_e$ and $D^0 \to K^- e^+ \nu_e$ in the recoiling system from each tag candidate. The momentum and energy of the D^0 is completely determined from the measurements of the reconstructed $\bar{D}^0$ tag. Electrons are identified using information from the time of flight (TOF) system and the barrel shower counter. Charged pions and kaons are identified by TOF. In addition, the π or K assignment must be consistent with the hypothesis that the missing energy and momentum are carried away by a single massless particle. No extra charged tracks or isolated photons may be present in the recoiling system. Seven $\pi^- e^+ \nu_e$ and 56 $K^- e^+ \nu_e$ candidates are found, with expected backgrounds of 0.5 and 1.5 events, respectively. The corresponding branching fractions are $B(D^0 \to \pi^- e^+ \nu_e) = (0.39\,^{+0.23}_{-0.11} \pm 0.04)\%$ and $B(D^0 \to K^- e^+ \nu_e) = (3.4 \pm 0.5 \pm 0.4)\%$.

The ratio $|V_{cd}/V_{cs}|^2$ is determined under the assumption that the t dependence of the vector form factor is described by a single pole.[2] We obtain

$$\left|\frac{V_{cd}}{V_{cs}}\right|^2 = (0.057\,^{+0.038}_{-0.015} \pm 0.005) \times \left[\frac{f_+^K(0)}{f_+^\pi(0)}\right]^2 .$$

The ratio $f_+^K(0)/f_+^\pi(0)$ is expected to deviate from unity by $\sim 10\%$.[3]

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* Throughout this paper, reference to a charge state also implies reference to its charge conjugate.

2. Absolute D_s^+ Hadronic Branching Fractions

Relative branching fractions for many D_s^+ decay modes have been measured, but the absolute scale is unknown. Estimates of absolute branching fractions can been made by measuring σB in e^+e^- annihilation far above charm threshold, and making some assumptions about the D_s cross section. A value of $B(D_s^+ \to \phi\pi^+) =$ 2–3% is indicated by the existing measurements of σB.[4–12]

In e^+e^- collisions at $\sqrt{s} = 4.14\,\mathrm{GeV}$, D_s production is found to be dominated by the reactions $e^+e^- \to D_s^{*\pm}D_s^{\mp}$, $D_s^{*\pm} \to \gamma D_s^{\pm}$.[13] A study of the absolute hadronic D_s^+ branching fractions is made by searching for fully reconstructed $e^+e^- \to D_s^{*\pm}D_s^{\mp} \to \gamma D_s^+ D_s^-$ events. A "double tag" mode is specified by the two D_s decay channels it contains. The expected number of events with $D_s^+ \to \mathit{Mode}\ i$ and $D_s^- \to \mathit{Mode}\ j$ is proportional to $\sigma B_i B_j$, where $\sigma \equiv \sigma(D_s^{*\pm}D_s^{\mp})$ and $B_i \equiv B(D_s^+ \to \mathit{Mode}\ i)$. It is therefore possible (in principle) to use double tag events, along with the measured relative D_s^+ branching fractions and $\sigma B_{\phi\pi^+}$, to determine the B_i.

The following D_s^+ decay modes have been included in this study: $\phi\pi^+$, $\bar{K}^0K^+$, $f_0(975)\pi^+$, $\bar{K}^{*0}K^+$, $\phi\pi^+\pi^+\pi^-$, and $\phi\pi^+\pi^0$. All final states *Mode i vs. Mode j* are considered, except for $\{\phi\pi^+\pi^+\pi^-$ or $\phi\pi^+\pi^0\}$ *vs.* $\{\phi\pi^-\pi^-\pi^+$ or $\phi\pi^-\pi^0\}$; these double tag modes are excluded because Monte Carlo simulation shows that the signals would be overwhelmed by multiple entries from each event.

For a particular final state, all consistent combinations of photons and particle identification assignments are formed. Loose TOF criteria are used to select charged π and K candidates.† No restriction is imposed on extra photons because spurious showers may be created by $K^\pm$ decay products, electronics noise, and hadronic shower "split-offs." For each combination a kinematic fit is performed which imposes total event energy and momentum conservation conditions (four constraints). Candidate events are selected with fit χ^2 confidence level CL > 5%.

† A more stringent requirement is imposed on the kaons in the final states $\bar{K}^{*0}K^+$ *vs.* $\phi\pi^-\pi^0$ and charge conjugate, in order to reduce combinatoric background.

Since the detection efficiency for low energy photons is difficult to determine, the fitted photon energies are required to be greater than 50 MeV.

Within each track combination, candidates for $D_s^+ \rightarrow$ *Mode i* and $D_s^- \rightarrow$ *Mode j* decays are formed from all permutations of identical particles in the combination. The number of permutations is dramatically reduced by cuts on the resonant substructure of the D_s decay modes. The following mass intervals are selected: $\phi \rightarrow K^+K^-$, $\pm 20\,\mathrm{MeV}/c^2$; $K_S^0 \rightarrow \pi^+\pi^-$, $\pm 25\,\mathrm{MeV}/c^2$; $f_0(975) \rightarrow \pi^+\pi^-$, $\pm 25\,\mathrm{MeV}/c^2$; $\bar{K}^{*0} \rightarrow K^-\pi^+$, $\pm 80\,\mathrm{MeV}/c^2$. A scatter plot is then made of the masses of the D_s^+ and D_s^- candidates. Signal events would contribute to the plot near $M_+ = M_- = M(D_s)$. In the scatter plot for each double tag mode a rectangular region is selected which contains 95% of the Monte Carlo signal events, and the number of distinct events in the data which populate this region is determined. The plots are shown in Fig. 1; charge conjugate modes have been combined together. No candidate events are observed in any of the signal regions.

An upper limit on $B_{\phi\pi^+}$ is established by computing the relative likelihood of observing zero candidate events as a function of $B_{\phi\pi^+}$. The expected number of reconstructed double tag events is $\nu_s = [\sigma\mathcal{L}B_{\phi\pi^+}]B_{\phi\pi^+}\sum b_i b_j \epsilon_{ij}$, where $\mathcal{L}$ is the integrated luminosity ($6.30 \pm 0.46\,\mathrm{pb}^{-1}$), $b_i = B_i/B_{\phi\pi^+}$, and ϵ_{ij} is the detection efficiency for *Mode i vs. Mode j*. The ϵ_{ij} are obtained from Monte Carlo samples of the double tag modes. At most one entry per simulated event is counted in the efficiency determination.

The measured quantities are: $\sigma\mathcal{L}B_{\phi\pi^+} = 162 \pm 47$,[13] $b_{\bar{K}^0K^+} = 0.92 \pm 0.35$,[14] $b_{f_0\pi^+} = 0.28 \pm 0.10$,[15] $b_{\bar{K}^{*0}K^+} = 0.93 \pm 0.11$,[14,16-19] $b_{\phi\pi^+\pi^+\pi^-} = 0.41 \pm 0.10$,[10,17,18] and $b_{\phi\pi^+\pi^0} = 2.4 \pm 1.1$.[20] The likelihood function $\ell(B_{\phi\pi^+}, \sigma\mathcal{L}B_{\phi\pi^+}, b_i)$ is constructed by assuming Gaussian errors for these measured quantities, and Poisson statistics for the number of observed events. The relative likelihood $\ell(B_{\phi\pi^+})$ is computed by maximizing $\ell(B_{\phi\pi^+}, \sigma\mathcal{L}B_{\phi\pi^+}, b_i)$ with respect to $\sigma\mathcal{L}B_{\phi\pi^+}$ and the b_i. The likelihood is set to zero if $B_{\phi\pi^+}\Sigma b_i > 100\%$. The 90% CL upper limit B_{90} on the value of

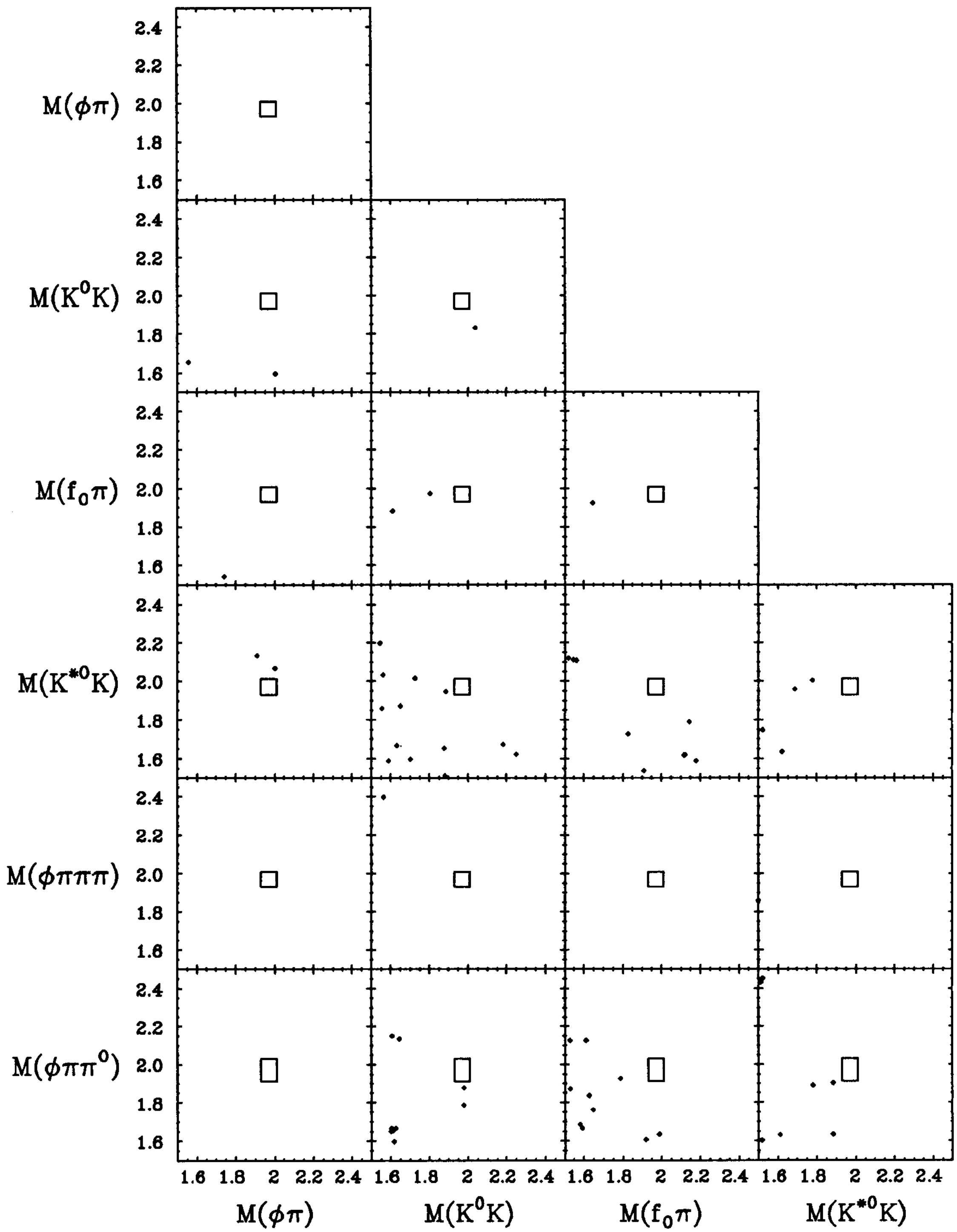

Figure 1 *M(Mode i) vs. M(Mode j)*. All masses are in GeV/c^2. The signal regions are indicated by the small rectangles.

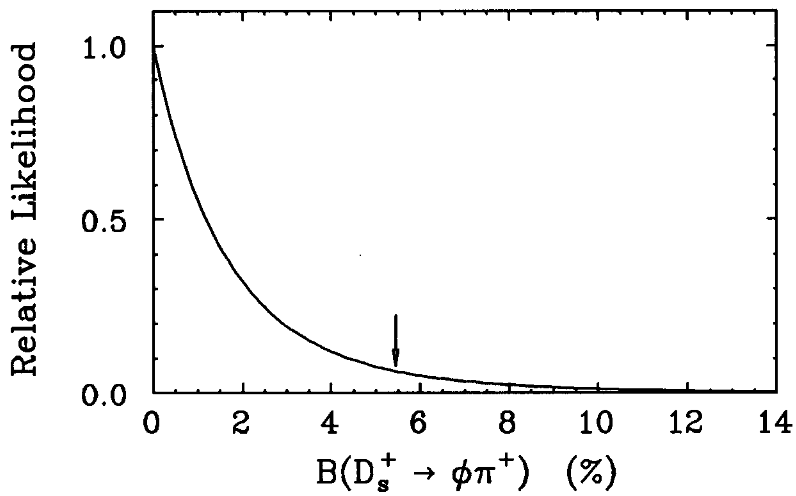

Figure 2 Relative likelihood $\ell(B_{\phi\pi^+})$. The 90% point is indicated by the arrow.

$B_{\phi\pi^+}$ is obtained numerically from

$$\frac{\int_0^{B_{90}} \ell(B)\,dB}{\int_0^1 \ell(B)\,dB} = 0.90\,.$$

The likelihood function $\ell(B_{\phi\pi^+})$ is shown in Fig. 2, with $B_{90} = 5.4\%$. The total uncertainty on the efficiency is 8.4%, including contributions from charged and neutral track reconstruction (6.4%), the kinematic fit χ^2 cut (5.0%), Monte Carlo statistics (2.0%), and particle identification (0.5%) (added in quadrature). These uncertainties are accounted for in the limit on $B_{\phi\pi^+}$ by multiplying B_{90} by 1.084, which yields

$$B(D_s^+ \to \phi\pi^+) < 5.9\% \qquad (90\%\ \mathrm{CL}).$$

The branching fraction for $D_s^+ \to \phi\pi^+$ is predicted to be approximately 3.5% or smaller.[21–23] The upper limit on $B(D_s^+ \to \phi\pi^+)$ is consistent with the values of 2–3% which are typically used in the interpretation of $B \to D_s$ measurements.

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