Determination of $B(D_s^+ \to \phi\pi^+)$ via Observation of $D_s^+ \to \phi l^+ \nu$

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Using the CLEO detector at the Cornell Electron Storage Ring (CESR), we have determined the ratio $\Gamma(D_s^+ \to \phi l^+ \nu)/\Gamma(D_s^+ \to \phi\pi^+) = 0.49 \pm 0.10^{+0.10}_{-0.14}$. We use this measurement to derive $B(D_s^+ \to \phi\pi^+)$.

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Although the D_s meson has been observed in several decay modes, there are no direct measurements of an absolute branching fraction to any channel. Theoretical models of semileptonic D decay predict almost equal widths[1] for $D_s^+ \to \phi l^+ \nu$ and $D^+ \to \bar{K}^{*0} l^+ \nu$, with small corrections (~20%) due to phase-space and form-factor differences. Since

$$\Gamma(D^+ \to \bar{K}^{*0} l^+ \nu) = B(D^+ \to \bar{K}^{*0} l^+ \nu)/\tau_{D^+}$$

has been measured,[2]

$$B(D_s^+ \to \phi l^+ \nu) = \Gamma(D_s^+ \to \phi l^+ \nu)\tau_{D_s}$$

can be calculated. By measuring the ratio of branching ratios $B(D_s^+ \to \phi\pi^+)/B(D_s^+ \to \phi l^+ \nu)$ one can measure the absolute branching ratio of $D_s^+ \to \phi\pi^+$. Previous estimates of this branching ratio are 2% to 4% derived from a guess of the relative production rates for the D_s and the sum of the D_s, D^0, and D^+ in continuum e^+e^- annihilations,[3] and (2 ± 1)% derived by assuming that the charm production cross section is 37% of the total cross section in continuum e^+e^- annihilations.[4] There is also an upper limit of 4.1% from Mark III,[5] and a lower limit of 3.4% from E691 which did not observe a signal for $D_s^+ \to \phi l^+ \nu$.[6]

We use data taken with the CLEO detector at the Cornell Electron Storage Ring (CESR). The luminosities used consist of 212 pb^{-1} accumulated at the $\Upsilon(4S)$ resonance, 102 pb^{-1} taken at a center-of-mass energy 60 MeV below the $\Upsilon(4S)$, and 116 pb^{-1} taken at the $\Upsilon(5S)$ resonance. The sample consists of approximately 1 100 000 continuum events, 240 000 $\Upsilon(4S)$ decays, and 35 000 $\Upsilon(5S)$ decays. The CLEO detector is described in detail elsewhere.[7]

The event sample is defined by using standard CLEO hadronic-event-selection criteria.[8] In order to suppress $\Upsilon(4S)$ and $\Upsilon(5S)$ resonance decays, we require that the ratio of Fox-Wolfram event-shape parameters,[9] H_2/H_0, be greater than 0.25. This cut has a 90% efficiency for the continuum charm events we are interested in, while rejecting 74% of the resonant background. Candidate muons must have momentum above 1.4 GeV/*c* and penetrate all the detector iron. Electrons above 1.4 GeV/*c* are identified either by dE/dx in the drift chamber or a combination of this criterion with outer dE/dx information and shower-counter information. For the momentum interval 1.0–1.4 GeV/*c* we require that shower-counter information be present. We have 4400 muons and 10400 electrons in our sample.

Positive identification of the $D_s^+ \to \phi l^+ \nu$ decay is difficult because of the missing ν. To examine the signatures of such decays we simulate $\phi l^+ \nu$ decays using the model of Isgur *et al.*[1] The parent D_s momentum distribution is generated according to our measurements using the $\phi\pi^+$ mode. We require that the ϕl^+ momenta be greater than 2 GeV/*c*. In continuum e^+e^- annihilations this cut maximizes the signal relative to the background. In approximately 90% of the retained Monte Carlo events the ϕ has a momentum greater than 1 GeV/*c*. In addition, we find that 99% of the decays have ϕl^+ mass below 1.9 GeV.

In the data we search for ϕ's only in the K^+K^- decay mode. We then consider all $K^+K^-l^\pm$ combinations which have invariant mass below 1.9 GeV and momentum above 2.0 GeV/*c*. In addition, we require that the K^+K^- momentum be above 1.0 GeV/*c*. The resulting K^+K^- invariant-mass distribution is shown in Fig. 1, separately for electrons and muons. We fit these distributions with a Gaussian centered at the ϕ mass and fixed width determined by investigating all ϕ's in our data sample having momenta between 1 and 2 GeV/*c*. We have 48.5 ± 9.0 and 26.3 ± 6.4 ϕ's in the electron and muon samples, respectively. The numbers of events and detection efficiencies are shown in Table I.[10] Because we will be interested in comparing with the $\phi\pi^+$ rate above 2.5 GeV/*c*, the detection efficiencies shown in Table I correspond to the number of detected events normalized to the number of the D_s produced in the momentum range above 2.5 GeV/*c*.

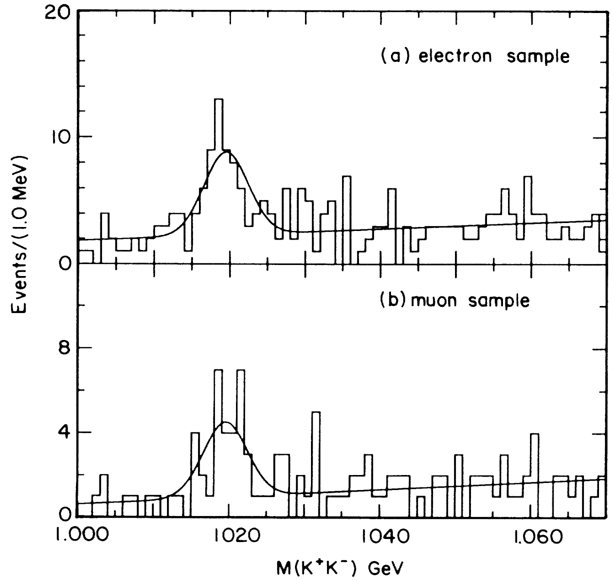

FIG. 1. Invariant K^+K^- mass (a) for electron events and (b) for muon events selected by the kinematic cuts described in the text. The curves show the fits to the background and signal.

Background sources include fake leptons and random combinations of real ϕ's and real leptons which happen to fall in the signal region. The latter contain contributions from continuum charm events, the only known source of real leptons in the continuum, and $\Upsilon(4S)$ and $\Upsilon(5S)$ resonant decays which have been suppressed by the shape cut mentioned above.

In order to determine the number of fake leptons we count the number of charged tracks in events with real ϕ's, as a function of momentum, that satisfy the kinetic cuts discussed above. (To get the number associated with only the ϕ signal we do a sideband subtraction in the K^+K^- mass plot.) We then assume that the mixture of the particle species of this track sample is the same as the nominal continuum. We determine a fake rate per track from the fake rates measured separately for $\pi^\pm$, $K^\pm$, p, and $\bar{p}$ multiplied by the assumed particle fractions.[11] We find a total of 8.6 ± 2.0 electron fakes and 8.0 ± 1.5 muon fakes, where the errors reflect the uncertainty in the fake rates and particle fractions. We have also investigated the contribution of converted γ's in our electron sample. It is found to be negligible.

In continuum events real leptons can only come from charm decays. To determine the level of uncorrelated ϕ-$l^\pm$ combinations from this source, we use a sample of fully reconstructed charmed mesons to find the yield of the ϕ associated with a charmed particle. We sum D^0's in the decay modes $K^-\pi^+$ and $K_S\pi^+\pi^-$, and D^0's from $D^{*+} \to \pi^+ D^0$ with D^0 decaying into $K^-\pi^+\pi^+\pi^-$. We have 12200 events above 2.5 GeV/*c* in the D^0 mass peak. The ϕ's we are interested in have momenta above 1 GeV/*c*. The ϕ's within 90° of the D^0 direction (same hemisphere) are quite likely to end up in the signal region ($M_{\phi l} < 1.9$ GeV) while ϕ's in the opposite hemisphere make large invariant masses and do not affect the

TABLE I. Summary of event numbers.

	$D_s^\pm \to \phi e^\pm \nu$	$D_s^\pm \to \phi \mu^\pm \nu$	$D_s^\pm \to \phi\pi^\pm$
Number of events	48.5 ± 9.0	26.3 ± 6.4	400 ± 27
Lepton fakes	8.6 ± 2.0	8.0 ± 1.5	
$B\bar{B}$ background	3.0 ± 1.0	1.0 ± 0.5	
Fake subtracted	37.4 ± 9.0	17.0 ± 6.0	400 ± 27
Efficiency	3.2%	1.2%	16%
Corrected yield	1162 ± 281	1374 ± 485	2448 ± 166

result. We find 0.6 ± 8.8 ϕ's in the same hemisphere.[12] After normalizing to the total of 14800 lepton events in our sample we assign an asymmetric systematic error of $^{+0}_{-11}$ events.[13]

To calculate the level of uncorrelated real ϕ-$l^{\pm}$ combinations from resonant $\Upsilon(4S)$ and $\Upsilon(5S)$ decays, we take the measured momentum spectrum of ϕ's and leptons from B decays and use a Monte Carlo simulation to determine how many ϕ-$l^{\pm}$ pairs populate our signal region. The resulting numbers are also shown in Table I.

We have considered the possibility that our $\phi l^{\pm}$ sample is contaminated with events containing extra particles. Two candidate reactions are $D \to \phi K l \nu$ or $D_s \to \phi \pi l \nu$. The first case, even if such a final state existed, is excluded by our lepton and ϕ momentum cuts. If the second reaction existed, our kinematic cuts would not necessarily exclude it. However, we note that $\phi\pi^0$ production, from $s\bar{s}$ quark pair hadronization by simple $u\bar{u}$ or $d\bar{d}$ popping is Okubo-Zweig-Iizuka suppressed.[14,15] Furthermore, we note that our measurement of $K^* l \nu$ (see below) compares well with the previous measurement and thus gives evidence that our detection technique does not introduce large backgrounds.

Another way of displaying the signal and background components is to select a ϕ sample on the basis of K^+K^- mass and then plot the $\phi l^{\pm}$ mass for ϕ momentum greater than 1 GeV/c and $\phi l^{\pm}$ momentum greater than 2 GeV/c. In Fig. 2 we display the $\phi l^{\pm}$ mass spectrum after ϕ sideband subtraction. Also shown is the sum of background shapes from lepton fakes, uncorrelated ϕ-lepton production, and B decays. We see that the signal shape agrees reasonably with the Monte Carlo spectra for semileptonic decay.

We have previously reported signals for the channel $D_s^{\pm} \to \phi\pi^{\pm}$.[3,4] In this analysis we use a procedure as similar as possible to the one used in finding the $\phi l \nu$ rate. We first find $K^+K^-\pi^{\pm}$ candidates consistent with the D_s mass and having momentum greater than 2.5 GeV/c. Then we fit the K^+K^- mass spectrum with a Gaussian. We find 400 ± 27 D_s events.

After averaging the $\phi\mu\nu$ and $\phi e \nu$ samples we find

$$\frac{B(D_s^+ \to \phi l^+ \nu)}{B(D_s^+ \to \phi\pi^+)} = 0.49 \pm 0.10^{+0.10}_{-0.14},$$

where the first error is statistical and the second is systematic and includes the uncertainties in the background subtraction and efficiencies. This number is marginally consistent with an upper limit at 90% confidence level of 0.45 as reported by E691.[6]

We derive a $\phi l^+ \nu$ branching ratio from the following relation:

$$B(D_s^+ \to \phi l^+ \nu) = \frac{\Gamma(D_s^+ \to \phi l^+ \nu)}{\Gamma_{\text{tot}}} = \Gamma(D_s^+ \to \phi l^+ \nu)\tau_{D_s}$$

$$= (0.80 \pm 0.08) B(D^+ \to \bar{K}^{*0} l^+ \nu) \frac{\tau_{D_s}}{\tau_{D^+}}.$$

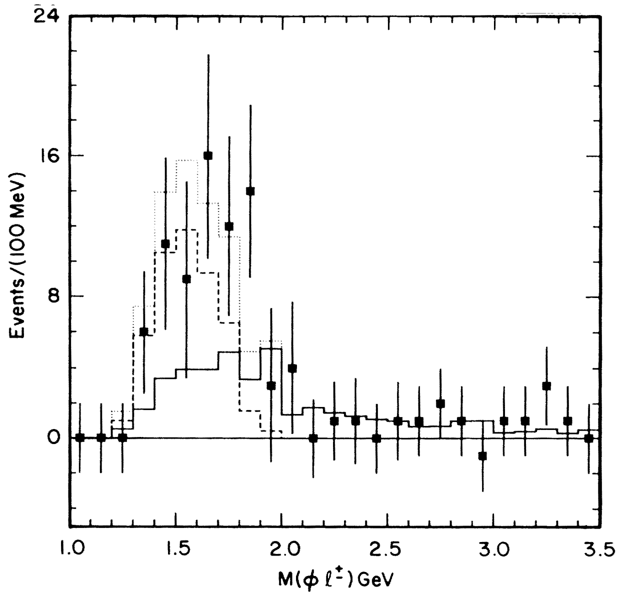

FIG. 2. Invariant $\phi l^{\pm}$ mass. The points are data. The solid histogram shows the sum of the expected backgrounds. The dashed histogram shows the ϕl mass for $D_s \to \phi l \nu$ decays from the model of Isgur *et al.* normalized to the background-subtracted sample and the dotted histogram shows the sum of the solid and dashed histograms.

The factor 0.8 is the average of two theoretical results,[1] and the error reflects a large range of possible differences in form factors. The measured branching ratio[2] for $D^+ \to \bar{K}^{*0} e^+ \nu$ is $(4.5 \pm 0.7 \pm 0.5)\%$ and the ratio of D_s/D^+ lifetimes[16] is 0.42 ± 0.03. The resulting estimate is $B(D_s^+ \to \phi l^+ \nu) = (1.50 \pm 0.31)\%$, where the error contains uncertainties on the D^+ branching ratio, the lifetime ratio, and theory. Then $B(D_s^+ \to \phi\pi^+) = (3.1 \pm 0.6^{+0.9}_{-0.6} \pm 0.6)\%$, where the first error is statistical, the second systematic, and the third is also systematic and arises from the uncertainty on the predicted value of $B(D_s \to \phi l \nu)$.

As a check on this analysis we have repeated the procedure on the reaction $D^0 \to K^{*-} l^+ \nu$. Here the signal region is defined by having the $K_S\pi^{\pm}l^+$ invariant mass between 0.9 and 1.8 GeV, the $K_S\pi^{\pm}l^+$ momentum above 2 GeV/c, and the $K_S\pi^{\pm}$ momentum above 1 GeV/c. The $K_S\pi^{\pm}$ invariant-mass spectrum is shown in Fig. 3 for the sum of electron and muon events. Fits to a polynomial background and Breit-Wigner shapes fixed at the known $K^{*\pm}$ mass and width give 82 ± 24 electrons and 55 ± 14 muon events. To find the branching ratio we normalize to the decay $D^0 \to K_S\pi^+\pi^-$. Following the same procedure as above we have

$$\frac{B(D^0 \to K^{*-} l^+ \nu)}{B(D^0 \to \bar{K}^0 \pi^+ \pi^-)} = 0.24 \pm 0.07 \pm 0.06,$$

where the first error is statistical and the second is systematic. This translates into a branching ratio for

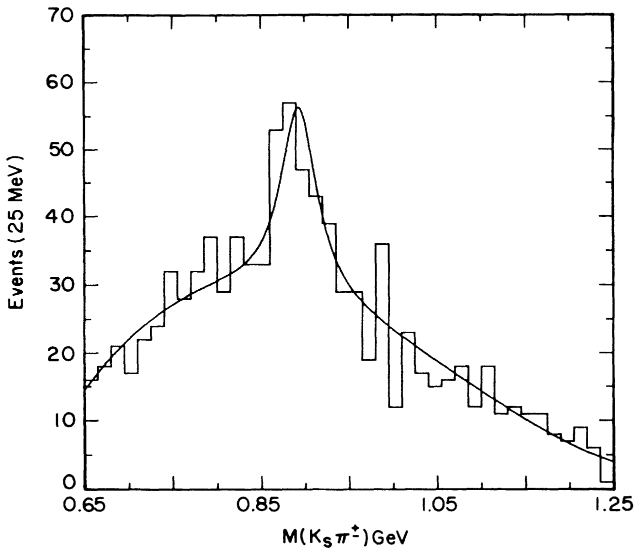

FIG. 3. Invariant $K_S\pi^{\pm}$ mass for the sum of electron and muon events selected by the kinematic cuts described in the text. The curve shows the fit to the background and signal.

$D^0 \to K^{*-} l^+ \nu$ of $(1.5 \pm 0.4 \pm 0.4)\%$.[17] By scaling the E691 measurement[2] of $B(D^+ \to \bar{K}^{*0} l^+ \nu)$ by the ratio of D^+ to D^0 lifetimes,[16] we extract a branching ratio of $(1.8 \pm 0.3)\%$. Thus our measurement is consistent with the E691 data.

In conclusion, we have presented the first positive evidence of a signal for $D_s \to \phi l \nu$. Using the expected near equality of semileptonic widths for pseudoscalar to vector transitions of charm mesons we infer $B(D_s^+ \to \phi\pi^+) = (3.1 \pm 0.6 {}^{+0.9}_{-0.6} \pm 0.6)\%$. This fits into the range of previous indirect estimates.

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[1] N. Isgur *et al.*, Phys. Rev. D **39**, 799 (1989) (private communication). These authors predict 0.78 for the ratio $\Gamma(D_s^+ \to \phi l^+ \nu)/\Gamma(D \to \bar{K}^* l^+ \nu)$, while M. Wirbel (private communication) predicts 0.83; see M. Wirbel *et al.*, Z. Phys. C **29**, 269 (1985).

[2] J. C. Anjos *et al.*, Phys. Rev. Lett. **62**, 722 (1989).

[3] S. Stone, in *Weak Decays of Heavy Quarks*, Proceedings of the International Symposium on Lepton Photon Interactions, edited by D. G. Cassel and D. L. Kreinick (Cornell University, Ithaca, NY, 1983); R. H. Schindler, in *Proceedings of the Twelfth International Workshop on Weak Interactions and Neutrinos, Ginosar, Israel 1989*, edited by P. Singer and G. Eilam [Nucl. Phys. B (Proc. Suppl.) **13** (1990)].

[4] W.-Y. Chen *et al.*, Phys. Lett. B **226**, 192 (1989).

[5] J. Adler *et al.*, Phys. Rev. Lett. **64**, 169 (1990).

[6] J. C. Anjos *et al.*, Phys. Rev. Lett. **64**, 2885 (1990).

[7] D. Andrews *et al.*, Nucl. Instrum. Methods Phys. Res. **211**, 47 (1983); D. G. Cassel *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **252**, 325 (1986).

[8] S. Behrends *et al.*, Phys. Rev. D **31**, 2161 (1985).

[9] G. C. Fox and S. Wolfram, Phys. Rev. Lett. **41**, 1581 (1978).

[10] We use the ratio of Γ_L/Γ_T measured in Ref. 2. Our efficiency varies only 5% between longitudinal and transversely polarized ϕ's.

[11] R. Kowalewski, Ph.D. dissertation, Cornell University, 1988 (unpublished).

[12] We find 45 ± 22 ϕ's in the hemisphere opposite to the D^0 direction.

[13] The background from semileptonic D decays with momenta below 2.5 GeV/c combined with real ϕ's is much reduced in our signal region because these D's produce leptons with sufficiently small momentum that they generally do not satisfy our lepton momentum cut or our ϕl momentum cut.

[14] Also, although it is possible that the D_s decays to an excited $s\bar{s}$ state, no such state has been found which decays into ϕ's.

[15] Another possible background could come from $D^+ \to \phi l^+ \nu$. However, this reaction is Cabbibo suppressed at the quark level and the $d\bar{d}$ system must form a ϕ, which is unlikely.

[16] Particle Data Group, J. J. Hernández *et al.*, Phys. Lett. B **239** (1990).

[17] Our measurement allows extra π^0's in the final state. E691 can limit this from the small size of the non-K^* signal in their $K\pi$ mass distribution. We use this comparison to justify that there are no other additional sources of background.