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Upper Limit on the Absolute Branching Fraction for $D_s^+ \to \phi\pi^+$*

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Abstract

We report a study of the hadronic branching fractions of the D_s^+ meson, which is used to extract an upper limit on the absolute branching fraction for $D_s^+ \to \phi\pi^+$. A search is made for fully reconstructed events from the reaction $e^+e^- \to D_s^{*\pm} D_s^{\mp}$, $D_s^{*\pm} \to \gamma D_s^{\pm}$, using a data sample of $6.30 \pm 0.46\,\mathrm{pb}^{-1}$, collected at $\sqrt{s} = 4.14\,\mathrm{GeV}$ with the Mark III detector at SPEAR. No candidate events are observed in twenty-eight exclusive $\gamma D_s^+ D_s^-$ final states. The measured relative D_s^+ branching fractions and $\sigma B(D_s^+ \to \phi\pi^+)$ are used to establish the limit $B(D_s^+ \to \phi\pi^+) < 4.1\%$ at 90% confidence level.

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Relative decay rates for a number of D_s^+ decay modes[1] have been measured. Determination of the absolute branching fractions from measurements of σB has been more difficult because knowledge of the D_s^+ production cross section is required. The branching fractions may, however, be determined independently of σ in e^+e^- annihilation in the charm resonance region, with a technique based on full reconstruction of D_s pairs ("double-tags"). The absolute branching fraction for $D_s^+ \to \phi\pi^+$ is used in the interpretation of measurements of B meson decays to D_s; estimates of $B_{\phi\pi^+} \equiv B(D_s^+ \to \phi\pi^+) = 2$–$3\%$ have been obtained from e^+e^- experiments at higher energies.[2-4] These estimates are based on assumptions about the charm production cross section, the probability that a D_s^+ is formed from a charm quark, and the D_s^+ momentum spectrum. The double-tag method does not rely on these assumptions.

We report herein the results of a search[5] for fully reconstructed $D_s^{*\pm}D_s^{\mp}$ events at $\sqrt{s} = 4.14\,\mathrm{GeV}$, using the following D_s^+ modes: $\phi\pi^+$, $\bar{K}^0K^+$, $f_0(975)\pi^+$, $\bar{K}^*(892)^0K^+$, $\bar{K}^{*0}K^{*+}$, $\phi\pi^+\pi^+\pi^-$, and $\phi\pi^+\pi^0$. The twenty-eight possible double-tag final states are considered. In e^+e^- collisions at this energy, D_s^+ production is dominated by the reaction $e^+e^- \to D_s^{*\pm}D_s^{\mp} \to \gamma D_s^+D_s^-$.[6] The number of produced events with $D_s^+ \to$ *mode i* and $D_s^- \to$ *mode j* is proportional to $\sigma B_{\phi\pi^+}^2 b_i b_j$, where $\sigma \equiv \sigma(e^+e^- \to D_s^{*\pm}D_s^{\mp})$ and $b_i \equiv B(D_s^+ \to \mathit{mode}\ i)/B(D_s^+ \to \phi\pi^+)$. The absolute branching fraction $B_{\phi\pi^+}$ may then be determined from the double-tag event rate and the measured $\sigma B_{\phi\pi^+}$ and b_i. We have used this technique to place a model-independent upper limit on $B_{\phi\pi^+}$.

The data sample of $6.30 \pm 0.46\,\mathrm{pb}^{-1}$ was collected with the Mark III detector[7] at the SLAC e^+e^- storage ring SPEAR. In this analysis, data from the main drift chamber, the time-of-flight system, and the electromagnetic calorimeter are used. For a particular $\gamma D_s^+ D_s^-$ final state, all events which contain the correct number of charged tracks and at least the correct number of photons are selected. All showers in the calorimeter not associated with charged tracks are considered to be photon candidates. No restriction is placed on the number of extra photons because spurious showers may be created by $K^\pm$ decay products, hadronic interactions, and electronic noise. Time-of-flight information is used to identify charged π and K candidates.[8] All combinations of photons and particle identification hypotheses consistent with the final state under study are formed. For each combination a kinematic fit which imposes total event energy and momentum conservation conditions (four constraints) is performed; combinations with $\chi^2 < 50$ are retained for further consideration. The fitted photon energies are required to be greater than 50 MeV; the detection efficiency is well modeled above this energy.

Within each track combination, candidates for the decays $D_s^+ \rightarrow mode\ i$ and $D_s^- \rightarrow mode\ j$ are formed from all permutations of identical particles in the combination. The number of permutations is considerably reduced by requirements on the resonant substructure of the D_s decay modes.[9]

Further background rejection is achieved by imposing additional kinematic constraints on the candidate events. Kinematic fits to the hypotheses $e^+e^- \rightarrow D_s^{*+} D_s^-$ and $D_s^{*-} D_s^+$ are attempted for each track permutation, requiring $M(\gamma D_s^\pm) = M(D_s^*) = 2.109\,\mathrm{GeV}/c^2$.[6] The D_s candidates in the event are constrained to have equal but unspecified mass $M(X)$; this quantity is determined in the fit. The fit with the smaller χ^2 is retained, with the confidence level requirement $\mathrm{CL}(\chi^2) > 5\%$. Double-tag events would produce a signal at the D_s^+ mass in the resulting $M(X)$

distribution.

For each final state, a signal region in the $M(X)$ distribution is selected which contains 95% of a Monte Carlo-generated signal. The half-widths of the signal regions range from 8 to $30\,\mathrm{MeV}/c^2$. Figure 1 shows the combined $M(X)$ distribution for the twenty-eight double-tag final states. No signal events are observed.

An upper limit on $B_{\phi\pi^+}$ is found by computing the likelihood of observing zero candidate events as a function of $B_{\phi\pi^+}$. The expected number of reconstructed double-tag events is $[\sigma L B_{\phi\pi^+}] B_{\phi\pi^+} \sum b_i b_j \epsilon_{ij}$, where L is the integrated luminosity and ϵ_{ij} is the detection efficiency for double-tag final state i *vs.* j. The measured quantities used as inputs are[10]: $\sigma L B_{\phi\pi^+} = 156 \pm 38$,[11] $b_{\bar{K}^0 K^+} = 0.92 \pm 0.38$,[12] $b_{f_0\pi^+} = 0.28 \pm 0.10$,[13] $b_{\bar{K}^{*0} K^+} = 0.93 \pm 0.12$,[14-17] $b_{\bar{K}^{*0} K^{*+}} = 2.3 \pm 1.4$,[16] $b_{\phi\pi^+\pi^+\pi^-} = 0.41 \pm 0.10$,[3,15,16] and $b_{\phi\pi^+\pi^0} = 2.4 \pm 1.1$.[18] The detection efficiencies are determined with a Monte Carlo simulation. The likelihood function $\mathcal{L}(B_{\phi\pi^+}, \sigma L B_{\phi\pi^+}, b_i)$ is constructed with Poisson statistics for the number of observed events and Gaussian errors for the measured quantities. Correlations between the measurements of $\sigma L B_{\phi\pi^+}$, $b_{\bar{K}^0 K^+}$, and $b_{\bar{K}^{*0} K^+}$ are taken into account. The marginal likelihood[19] $\mathcal{L}(B_{\phi\pi^+})$ [Fig. 2] is computed by integrating $\mathcal{L}(B_{\phi\pi^+}, \sigma L B_{\phi\pi^+}, b_i)$ with respect to the seven measured quantities $\sigma L B_{\phi\pi^+}$ and the b_i.[20] The upper limit of a 90% likelihood interval is $B_{\phi\pi^+} = 3.8\%$.[21] The number of signal events expected for $B_{\phi\pi^+} = 3.8\%$ is 2.8, using the measured central values of $\sigma L B_{\phi\pi^+}$ and b_i. The uncertainty on the number of signal events includes contributions from the charged and neutral track reconstruction efficiency (7%), Monte Carlo statistics (2%), and the efficiency of the resonance and signal region requirements (2%). These contributions are added in quadrature to give a total of 8%. This uncertainty is included by increasing the limit by $1/(1-0.08)$, which yields

$$B(D_s^+ \to \phi\pi^+) < 4.1\%$$

at 90% CL.

In summary, we have obtained the first model-independent limit on the absolute branching fraction for $D_s^+ \to \phi\pi^+$. Theoretical predictions for $B_{\phi\pi^+}$ are approximately 3%,[22-24] consistent with the upper limit presented, and with previous estimates. The experimental results imply that a large fraction of D_s^+ decays have not yet been observed.

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References

1. Throughout this paper, reference to a charge state also implies reference to its charge conjugate.
2. A. Chen *et al.*, Phys. Rev. Lett. **51**, 634 (1983); G. Moneti, in *Proceedings of the XXIII International Conference on High Energy Physics,* Berkeley, 1986, edited by S. Loken (World Publishing, Singapore, 1987); M. Althoff *et al.*, Phys. Lett. B **136**, 130 (1984); W. Braunschweig *et al.*, Z. Phys. C **35**, 317 (1987); H. Albrecht *et al.*, Phys. Lett. B **146**, 111 (1984); **187**, 425 (1987); M. Derrick *et al.*, Phys. Rev. Lett. **54**, 2568 (1985); S. Abachi *et al.*, Argonne National Laboratory preprint ANL-HEP-CP–86-71, 1986 (unpublished).
3. J.A. McKenna, Ph.D. thesis, University of Toronto, 1987.
4. The Particle Data Group's estimate is $B_{\phi\pi^+} = 8 \pm 5\%$. G.P. Yost *et al.* (Particle Data Group), Phys. Lett. B **204**, 1 (1988).
5. S.R. Wasserbaech, Ph.D. thesis, Stanford University, 1989, SLAC-Report-345.
6. J. Adler *et al.*, Phys. Rev. Lett. **58**, 2171 (1987). We assume $B(D_s^{*+} \to \gamma D_s^+) = 100\%$.
7. D. Bernstein *et al.*, Nucl. Instrum. Methods **226**, 301 (1984).
8. A charged track is used as a π or K unless the measured time of flight is more than 5σ from the predicted time for that hypothesis. In order to reduce combinatoric background, a more stringent requirement is imposed on the kaons in the final state $\phi\pi^+\pi^0$ *vs.* $\phi\pi^-\pi^0$.

9. The half-widths of the accepted mass intervals are $\phi \to K^+K^-$, 20 MeV/c^2; $K^0_S \to \pi^+\pi^-$, 25 MeV/c^2; $f_0(975) \to \pi^+\pi^-$, 40 MeV/c^2 (centered at 965 MeV/c^2); $\bar{K}^{*0} \to K^-\pi^+$, 80 MeV/$c^2$ (for $\bar{K}^{*0}K^+$) or 100 MeV/c^2 (for $\bar{K}^{*0}K^{*+}$); $K^{*+} \to K^0_S\pi^+$, 100 MeV/c^2; $\pi^0 \to \gamma\gamma$, 30 MeV/c^2 (for $\phi\pi^+\pi^0$ *vs.* $\{K^{*0}K^{*-}$ or $\phi\pi^-\pi^-\pi^+\}$) or 35 MeV/c^2 (for $\phi\pi^+\pi^0$ *vs.* all others).

10. Weighted averages of the measurements are computed after adding the statistical and systematic uncertainties in quadrature.

11. The Mark III measurement of $\sigma B(D_s^+ \to \bar{K}^{*0}K^+)$ and the world average value of $b_{\bar{K}^{*0}K^+}$ are used to obtain $\sigma LB_{\phi\pi^+} = 146 \pm 57$. Combining this with the direct Mark III measurement of 162 ± 51 (Reference 12) and accounting for common systematic errors yields $\sigma LB_{\phi\pi^+} = 156 \pm 38$. The uncertainty on the integrated luminosity cancels entirely in this analysis.

12. J. Adler *et al.*, SLAC preprint SLAC-PUB-4952, 1989, Phys. Rev. Lett. (to be published).

13. J.C. Anjos *et al.*, Phys. Rev. Lett. **62**, 125 (1989).

14. H. Albrecht *et al.*, Phys. Lett. B **179**, 398 (1986).

15. J.C. Anjos *et al.*, Phys. Rev. Lett. **60**, 897 (1988).

16. S. Barlag *et al.*, CERN preprint CERN-EP/88-103, 1988 (unpublished).

17. M.P. Alvarez *et al.*, CERN preprint CERN-EP/88-148, 1988 (unpublished).

18. J.C. Anjos *et al.*, Phys. Lett. **223**, 267 (1989).

19. A.G. Frodesen, O. Skjeggestad, and H. Tøfte, *Probability and Statistics in Particle Physics* (Universitetsforlaget, Bergen, 1979).

20. For each value of $B_{\phi\pi^+}$, the seven-dimensional integral is evaluated numerically using Gaussian quadrature with fourteen nodes in each dimension.

21. This quantity is the value of $B_{\phi\pi^+}$ below which 90% of the integral of $\mathcal{L}(B_{\phi\pi^+})$ is found.

22. The D_s^+ lifetime, $4.36\,^{+0.38}_{-0.32} \times 10^{-13}$ s, is taken from Reference 4.

23. M. Bauer, B. Stech and M. Wirbel, Z. Phys. C **34**, 103 (1987). Revised values of $a_1 = 1.2$ and $a_2 = -0.5$ are taken from B. Stech, Heidelberg report HD-THEP-87-18, 1987 (unpublished).

24. B.Yu. Blok and M.A. Shifman, Yad. Fiz. **45**, 841 (1987) [Sov. J. Nucl. Phys. **45**, 522 (1987)].

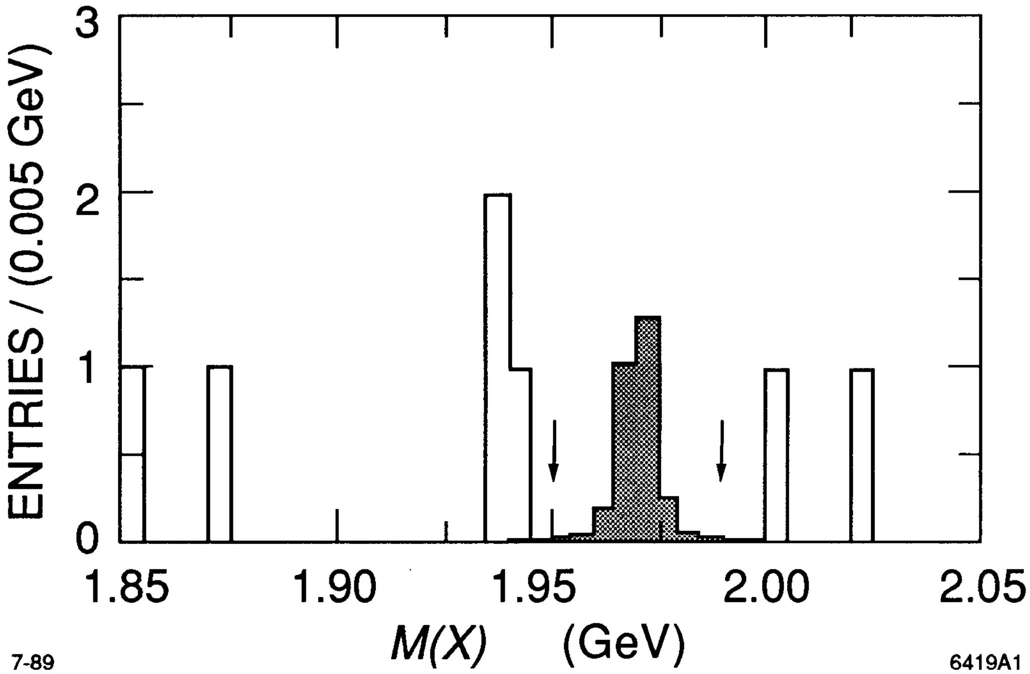

Figure 1 Combined $M(X)$ distribution (unshaded histogram). The arrows indicate the widest signal region ($\pm 20\,\mathrm{MeV}/c^2$) among the double-tag final states which yield entries between 1.85 and $2.05\,\mathrm{GeV}/c^2$. The shaded histogram shows the expected signal for $B_{\phi\pi^+} = 4.1\%$.

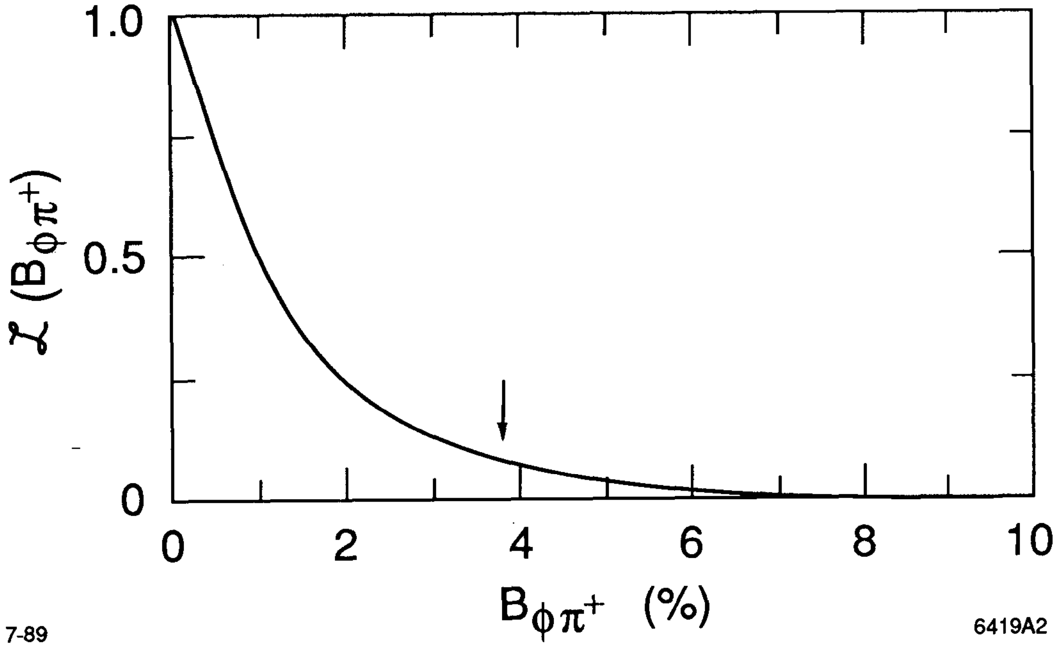

Figure 2 Marginal likelihood $\mathcal{L}(B_{\phi\pi^+})$. The value $B_{\phi\pi^+} = 3.8\%$ is indicated by the arrow. The vertical scale is arbitrary.