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EVIDENCE FOR $D_s^+ \to e^+X$ †

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Abstract

We have searched for the inclusive reaction $D_s^\pm \to e^\pm X$ using a tagged sample of 73 $D_s^\pm$ produced in the reaction $e^+e^- \to D_s^\pm D_s^{*\mp}$. The data were collected by the Mark III experiment at SPEAR at a center-of-mass energy of 4.14 GeV. The tagged sample consists of the decays $D_s^+ \to \phi\pi^+$, $D_s^+ \to \overline{K^*}{}^0 K^+$ and $D_s^+ \to K_s^0 K^+$. We determine $B(D_s^+ \to e^+X) = 0.09^{+0.09}_{-0.07} \pm 0.02$.

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INTRODUCTION

Though the existence of the charmed-strange D_s^+ meson (formerly the F^+)[1] has been known for close to a decade, fewer than 30% of its decay modes have been observed. In fact, only the branching fractions of the various modes (which number a half-dozen or so) relative to the decay $D_s^+ \to \phi\pi^+$ have been well-measured.[2–5] Absolute branching ratios are obtained only through an estimate of the ratio of D_s^+ to total charm production. Furthermore, no observation of the leptonic decay of the D_s^+ has been made to date.

The Mark III experiment recently took data at SPEAR at a center-of-mass energy of 4.14 GeV. At this energy, the D_s^+ is produced in association with its vector meson partner, the D_s^{*-}; the production rate of $D_s^+D_s^-$ appears to be suppressed[4] at this center-of-mass energy. Several hadronic modes have already been studied. This analysis now addresses the subject of the semileptonic decays and in particular, the inclusive semi-electronic branching ratio, $D_s^+ \to e^+X$.

While the spectator decay mechanism is considered too naive a picture of hadronic charm decay, which may be affected by final state interactions, the same does not apply for the semileptonic decay. In fact, the measured partial widths $\Gamma(D^0 \to e^+X)$ and $\Gamma(D^+ \to e^+X)$ are approximately equal.[6] The semileptonic spectator decays of the D_s^+, D^0, and D^+ are shown in Fig. 1. Assuming that the partial electronic width of the D_s^+ is approximately equal to that of the D^0 or D^+, the inclusive electronic branching fraction $B(D_s^+ \to e^+X)$ can then be estimated:[7] it is $\approx 8\%$.

THE TAGGED SAMPLE

Three channels were used to tag the $D_s^+D_s^{*-}$ sample: $D_s^+ \to \phi\pi^+$, $K_s^0K^+$, and $\overline{K^{*0}}K^+$. The Mark III detector has been described in detail elsewhere.[8] Particle identification techniques, briefly summarized below, are similar for the three decay modes. Invariant mass calculations and kinematic fits have been used to extract the tagged signals, depending upon the background contamination in a given mode. Throughout the analysis, the goal has been to maximize the signal-to-noise without losing too much of the data.

Kaons are identified primarily using the TOF system, which resolves kaons and pions at 3 σ for $p < 1$ GeV/c. For momenta less than 650 MeV/c, dE/dx information from the drift chamber can be used when TOF data is lacking. Electrons are identified primarily using a lead-proportional chamber gas sampling calorimeter. Charged tracks are also required to pass reasonably close to the reconstructed vertex, within 0.015 m for pions and within 0.030 m for kaons. (This requirement is lifted in the case of detached vertices such as K_s^0.)

$D_s^+ \to \phi\pi^+$

Invariant mass combinations of K^+K^- pairs are formed and those which fall within ± 10 MeV/c^2 of the nominal ϕ mass are retained. Mass combinations of the ϕ with all $\pi^\pm$ in the event are then calculated. Figure 2 shows $M_{\phi\pi}$ vs. the recoil mass calculated using the constraint on the total event energy (4.14 GeV). Events which satisfy $1.92 < M_{\phi\pi} < 2.02$ GeV/c^2 and $2.04 < M_{recoil} < 2.18$ GeV/c^2 are selected for the tagged sample. There are 42 such events. The estimated number of signal tagged events is 36 ± 3.

$D_s^+ \to K^{*0}K^+$

For this channel, particle identification is done using only TOF. A 1–C fit is performed with the recoil mass constrained to equal the value of the D_s^* mass. Additional criteria are applied: that the 1–C fit probability be ≥ 0.10; that the $K\pi$ mass be within 60 MeV/c^2 of the nominal K^* mass; and that the angle of the K in the K^* rest frame, $|\cos\theta_{K^*}| \geq 0.3$.

Figure 3 shows the K^*K mass after the constrained fit and the above criteria are applied. This channel is particularly plagued with D-related backgrounds. To maximize the signal-to-noise ratio, those events which satisfy $1.96 \leq M_{K^*K} \leq 1.98$ GeV/c^2 are selected for the tagged sample. This yields 24 events, of which 18 ± 3 are estimated to be signal.

$D_s^+ \to K^0K^+$

A 2–C fit is performed using the K^0 mass and the recoil D_s^* mass as constraints. For the tagged sample, events with a fit probability ≥ 0.10 and $1.92 \leq M_{K^0K} \leq 2.02$ Gev/c^2 are retained. The reconstructed decay length of the K^0 is required to be greater than zero. Figure 4 shows M_{K^0K} after these selection criteria are applied. There are 27 events which satisfy this criteria; the estimated number of signal events is 19 ± 3.

THE RECOIL SYSTEM

Tracks which pass within 0.015 m of the vertex and which have not been used in the "tag" are examined for possible electron identification. For tracks with momenta less than 300 MeV/c, the identification is made using TOF. For tracks with momenta greater than 300 MeV/c, a recursive partitioning algorithm[9] is employed, which makes use of information from the TOF and the electromagnetic calorimeter. Kaons identified using TOF are first excluded. In addition, to eliminate electrons due to photon conversions, tracks which have an opening angle $\leq 14°$ with any other oppositely-charged track are also excluded. The remaining recoil tracks are then assigned one of three identifications: electron, pion or ambiguous identification.

The numbers of electrons and pions found for each of the tagged channels are shown in Table 1. The probability for misidentification of tracks is momentum-dependent. For the purposes of the branching ratio calculation, we have used seven momentum bins. Table 2 shows the numbers of electrons and pions found in each momentum bin.

Table 1. The tagged D_s channels and the total numbers of right- and wrong-sign electrons and pions found in the recoil, where, for example, n_e^R denotes the number of right-sign electrons.

Channel	Tagged Events	Signal Events	n_e^R	n_e^W	n_π^R	n_π^W
$\phi\pi$	42	36 ± 4	4	1	32	14
K^0K	27	19 ± 3	2	1	32	16
K^*K	24	18 ± 3	3	1	18	6
Totals	93	73 ± 10	9	3	82	36

Table 2. Momentum distribution of observed electrons and pions in the recoil against a D_s tag.

	< 0.3 GeV/c	0.3-0.4 GeV/c	0.4-0.5 GeV/c	0.5-0.6 GeV/c	0.6-0.8 GeV/c	0.8-1.0 GeV/c	> 1.0 GeV/c
n_e^R	5	2	1	1	0	0	0
n_e^W	1	1	0	0	1	0	0
n_π^R	30	11	14	8	12	4	3
n_π^W	15	6	8	4	3	0	0

The numbers of right- and wrong-sign electrons were also tabulated for mass sideband regions. The sideband for each channel was the mass range 1.72 – 1.92 GeV/c^2. The region above the D_s mass contains insufficient numbers of events to be of use. The masses for those events, both in the signal and sideband regions, which contain an electron in the recoil are shown in Fig. 5.

BRANCHING RATIO

The number of observed electrons has two components: electrons which have been correctly identified and pions which have been misidentified. The probabilities for identification and misidentification are momentum-dependent. There are four identification/misidentification probabilities for a given momentum bin. These we call: $P_{e\to e}$, $P_{e\to\pi}$, $P_{\pi\to\pi}$, and $P_{\pi\to e}$, where for example, $P_{e\to\pi}$ is the probability that an electron is called a pion. Thus for each momentum bin, where we have *observed* pions and electrons (n_π and n_e), we have the *true* (or produced) numbers of pions and electrons ($\tilde{n}_\pi$ and $\tilde{n}_e$):

$$\begin{aligned}
n_e^R &= P_{e\to e}\,\tilde{n}_e^R + P_{\pi\to e}\,\tilde{n}_\pi^R \quad ,\\
n_e^W &= P_{e\to e}\,\tilde{n}_e^W + P_{\pi\to e}\,\tilde{n}_\pi^W \quad ,\\
n_\pi^R &= P_{\pi\to\pi}\,\tilde{n}_\pi^R + P_{e\to\pi}\,\tilde{n}_e^R \quad ,\\
n_\pi^W &= P_{\pi\to\pi}\,\tilde{n}_\pi^W + P_{e\to\pi}\,\tilde{n}_e^W \quad ,
\end{aligned}$$

where the superscripts denote right- and wrong-sign. The total number of right-sign electrons is assumed to be due to semileptonic D_s decay and to charge-symmetric background, such as photon conversions. The number of wrong-sign electrons is assumed to be due solely to charge-symmetric background. The effects of D semileptonic background have been ignored. We estimate the number of semileptonic decays due to misidentified D decays to be at most one (right-sign) event. Of the three tagged channels, only the $\overline{K^*}{}^0K^\pm$ channel suffers substantial background contamination: hence the more stringent requirement on the invariant tagged mass. The branching ratio is:

$$B(D_s \to eX) = \frac{\sum(\tilde{n}_e^R - \tilde{n}_e^W)/\epsilon}{n_{tags}} \quad .$$

where ϵ, the momentum-dependent efficiency, is a product of the geometric acceptance (0.80 ± 0.05) and the ability to classify a track as a pion or electron. The numerator is summed over the seven momentum bins.

The probability to correctly classify an electron ranges from 0.78 to 0.90. The probability to misclassify a pion as an electron varies between 0.03 and 0.06.

Using the numbers of right- and wrong-sign electrons and pions given in Table 2, and the momentum-dependent identification probabilities, we obtain $B(D_s^+ \to e^+X) = 0.09$.

ERROR CALCULATIONS

In general, the numbers of produced electrons and pions arise from parent distributions:

$$\tilde{N}_e^R \ , \ \tilde{N}_e^W \ , \ \tilde{N}_\pi^R \ , \ \text{and} \ \tilde{N}_\pi^W \ .$$

Likewise, the number of tags can be considered to arise from a parent distribution, N_{tags}. We then construct a probability function using Poisson statistics for the numbers of electrons and Gaussian statistics for the numbers of pions. (Again, n_e^R is the number of observed right-sign electrons.) We have averaged over the momentum bins. The number of tags is treated like a Gaussian, with σ being equal to the error on the number of tags, which is due to background fluctuation. We have:

$$
\begin{aligned}
P_1 &= \frac{e^{-(P_{e\to e}\,\tilde{N}_e^R + P_{\pi\to e}\,\tilde{N}_\pi^R)} \cdot (P_{e\to e}\,\tilde{N}_e^R + P_{\pi\to e}\,\tilde{N}_\pi^R)^{n_e^R}}{n_e^R!} \\
P_2 &= \frac{e^{-(P_{e\to e}\,\tilde{N}_e^W + P_{\pi\to e}\,\tilde{N}_\pi^W)} \cdot (P_{e\to e}\,\tilde{N}_e^W + P_{\pi\to e}\,\tilde{N}_\pi^W)^{n_e^W}}{n_e^W!} \\
G_1 &= \frac{1}{\sqrt{2\pi n_\pi^R}} e^{-((P_{\pi\to\pi}\,\tilde{N}_\pi^R + P_{e\to\pi}\,\tilde{N}_e^R) - n_\pi^R)^2/2n_\pi^R} \\
G_2 &= \frac{1}{\sqrt{2\pi n_\pi^W}} e^{-((P_{\pi\to\pi}\,\tilde{N}_\pi^W + P_{e\to\pi}\,\tilde{N}_e^W) - n_\pi^W)^2/2n_\pi^W} \\
G_3 &= \frac{1}{\sqrt{2\pi}\Delta n_{tags}} e^{-(N_{tags} - n_{tags})^2/2n_{tags}}
\end{aligned}
$$

We then construct the negative log-likelihood function:

$$
-\ln \mathcal{L} = -\ln(P_1 \cdot P_2 \cdot G_1 \cdot G_2 \cdot G_3) \quad .
$$

The five parameters, N_e^R, N_e^W, N_π^R, N_π^W, and N_{tags}, are varied. Using MINUIT, the minimum of $-\ln \mathcal{L}$ was found for each value of the branching ratio. This is plotted in Fig. 6.

The 1 σ errors on the branching ratio are obtained by moving along the vertical axis by 0.5 units. This gives:

$$
B(D_s^+ \to e^+ X) = 0.09^{+0.09}_{-0.07} \quad .
$$

The systematic error, ± 0.02, arises from the error on the geometric acceptance and the errors on the classification probabilities. The latter are determined from a study of electrons from radiative Bhabha events and charged pions from K^0 decays.

DISCUSSION

We have obtained the first evidence of semileptonic decay of the D_s^+ meson, using a sample of 73 tagged hadronic events. Though the result is not statistically compelling, it also represents the first measurement of an absolute branching ratio of the D_s^+, whose hadronic decays have previously been measured in terms of relative branching ratios. The value of $B(D_s^+ \to e^+X)$ agrees with that predicted assuming equal semileptonic partial decay widths for the D^0, D^+, and D_s^+. This may lend support to the theory that interference effects play a significant role in hadronic charm decay, leading to the differing charm lifetimes, rather than to suggestions of the importance of annihilation/exchange diagrams.

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FIGURE CAPTIONS

Figure 1: The spectator picture of semileptonic decay of the D^0, D^+, and D_s^+ showing the expected (right-sign) charge of the electron relative to the charm of the parent particle.

Figure 2: (a) The calculated M_{recoil} vs. $M_{\phi\pi}$, and (b) $M_{\phi\pi}$ when M_{recoil} is required to lie in the range $2.04 - 2.18$ GeV/c^2.

Figure 3: M_{K^*K} following a 1–C fit and the selection criteria described in the text.

Figure 4: M_{K^0K} following a 2–C fit and the selection criteria described in the text.

Figure 5: The masses for tagged events, both in the D_s^+ signal and sideband regions, which contain an electron of either right or wrong sign in the recoil.

Figure 6: The likelihood function $\mathcal{L}$ shown vs. the branching ratio, $B(D^+ \to e^+X)$.

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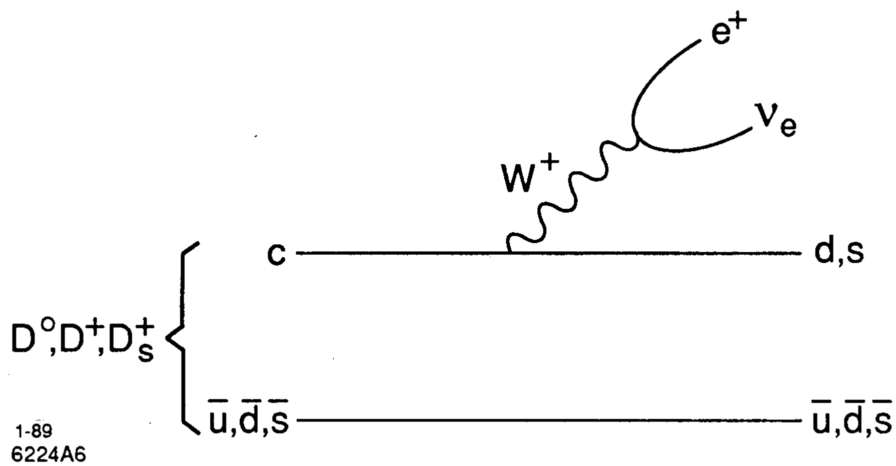

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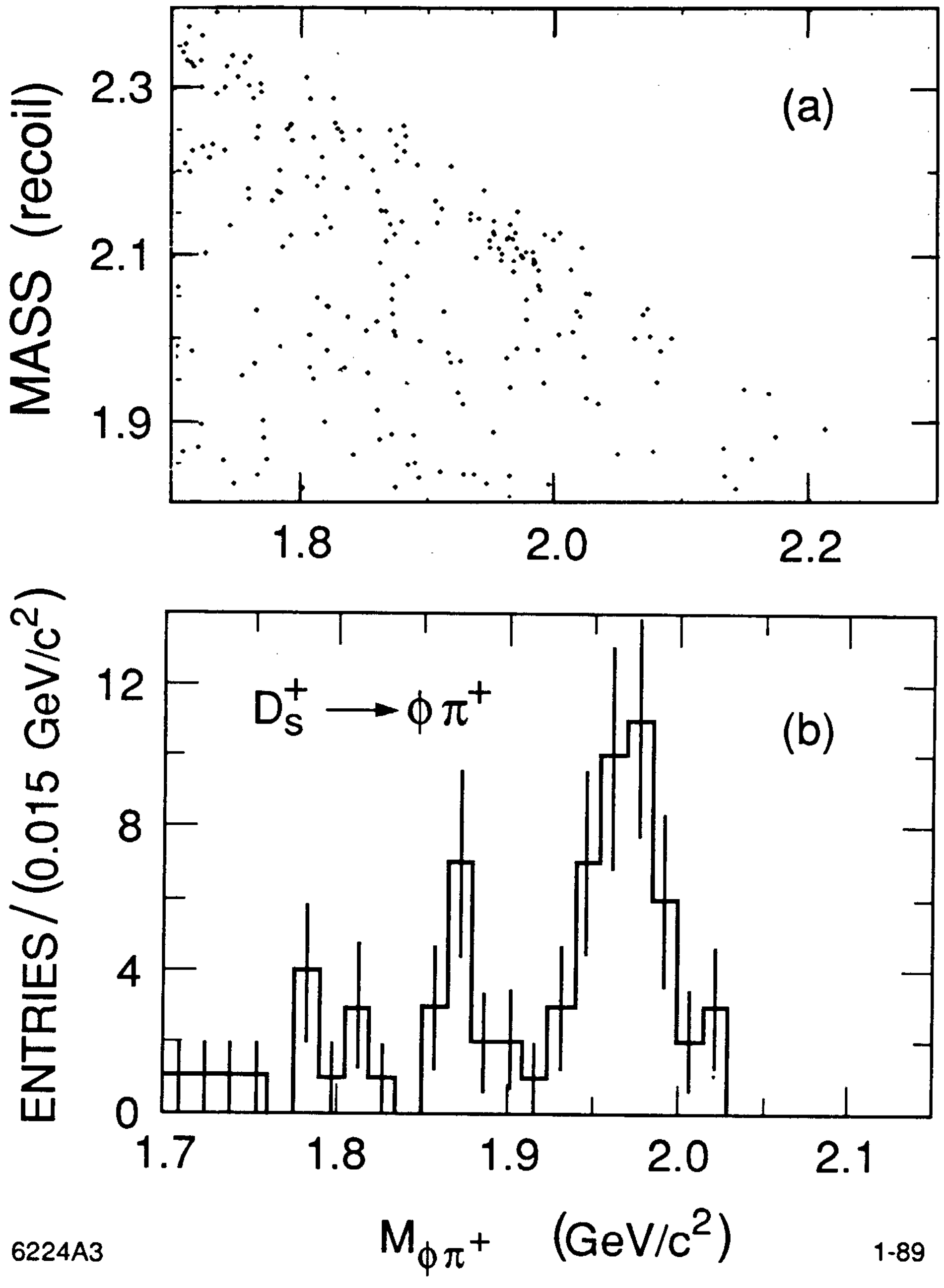

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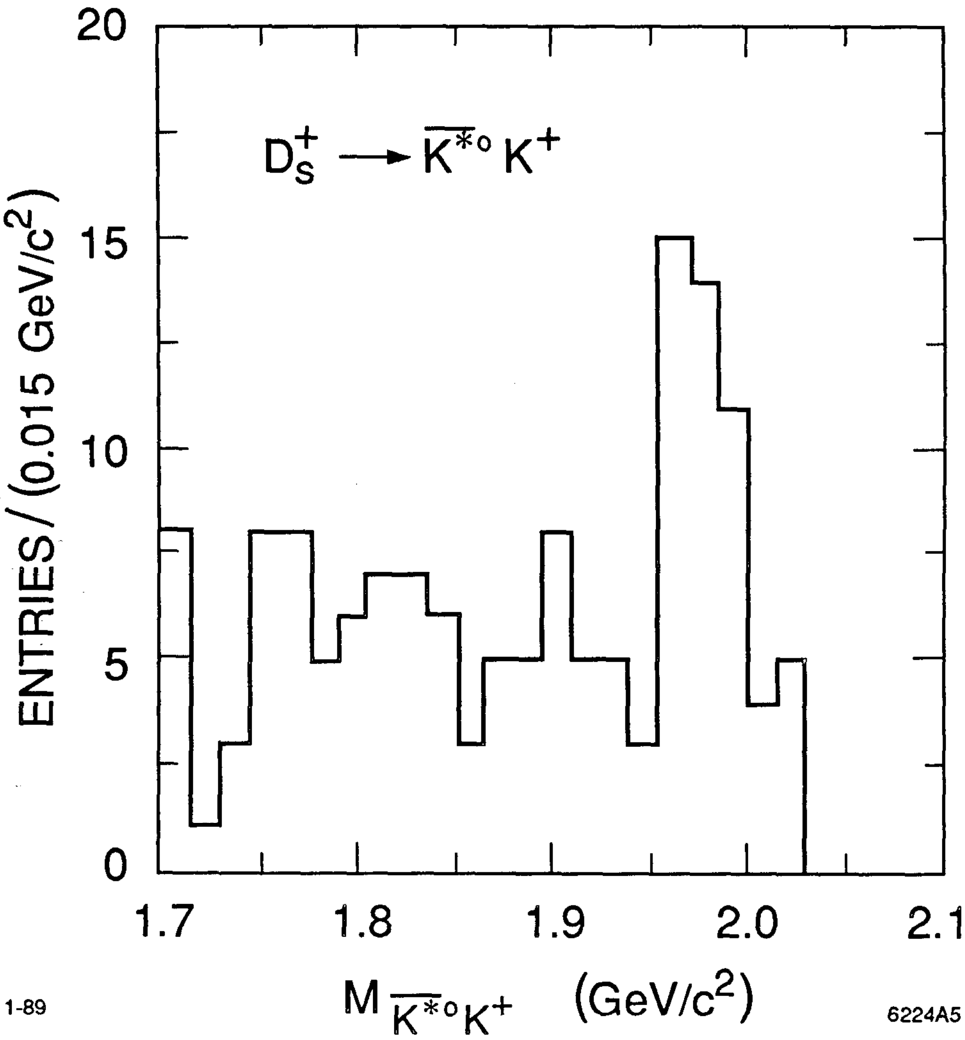

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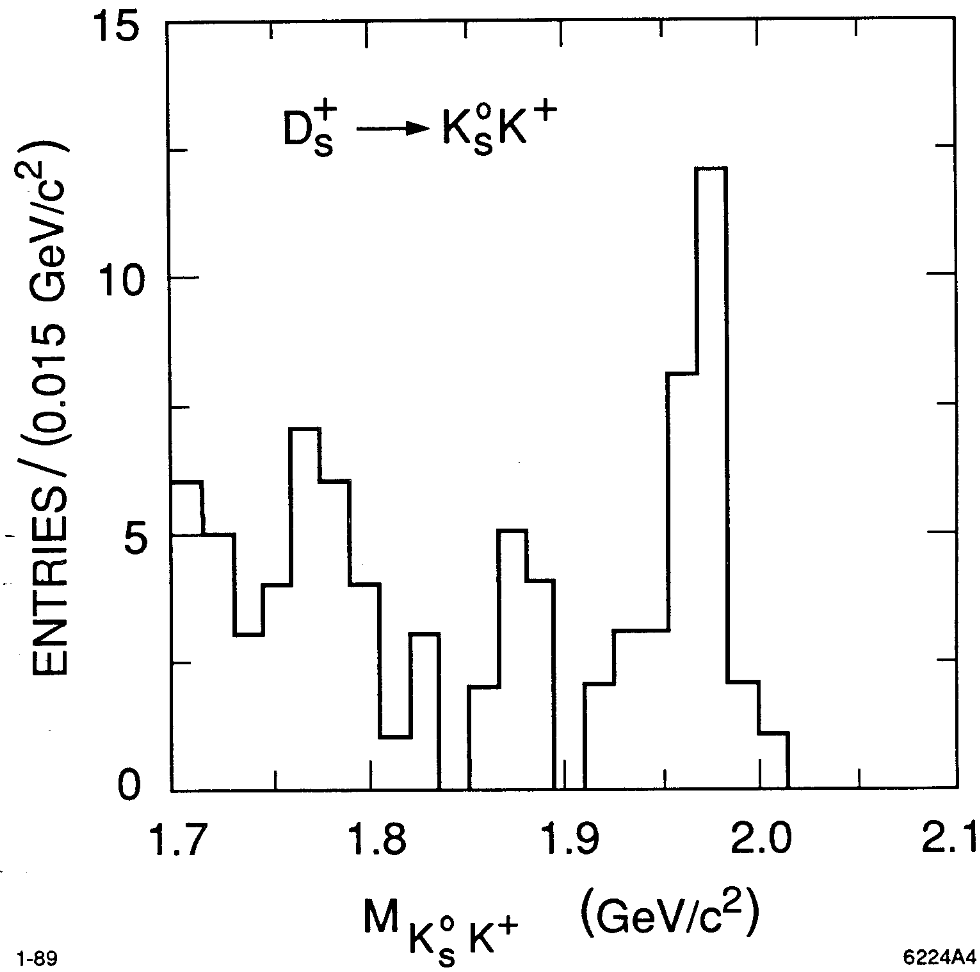
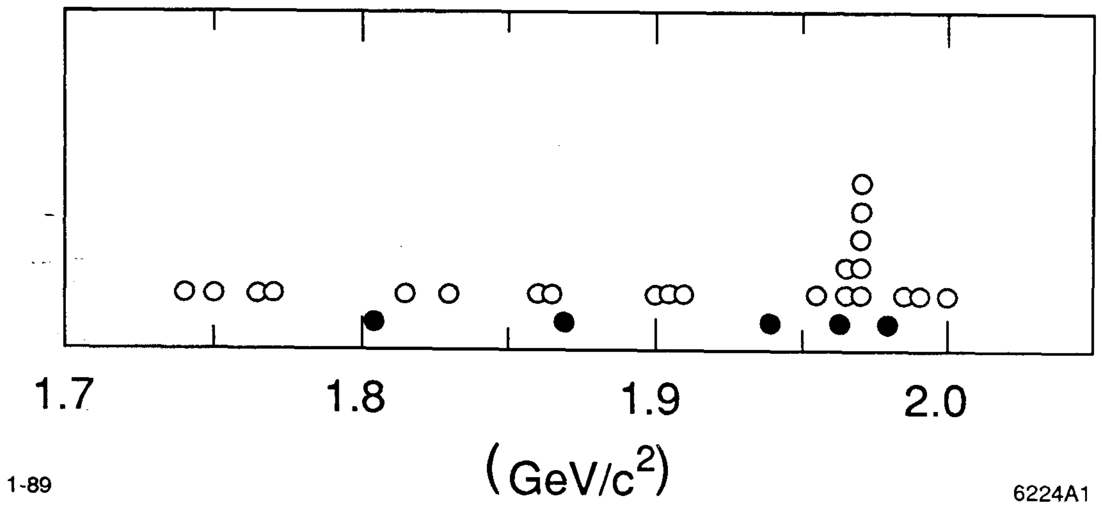


Figure 4: M_{K^oK} following a 2–C fit and the selection criteria described in the text.



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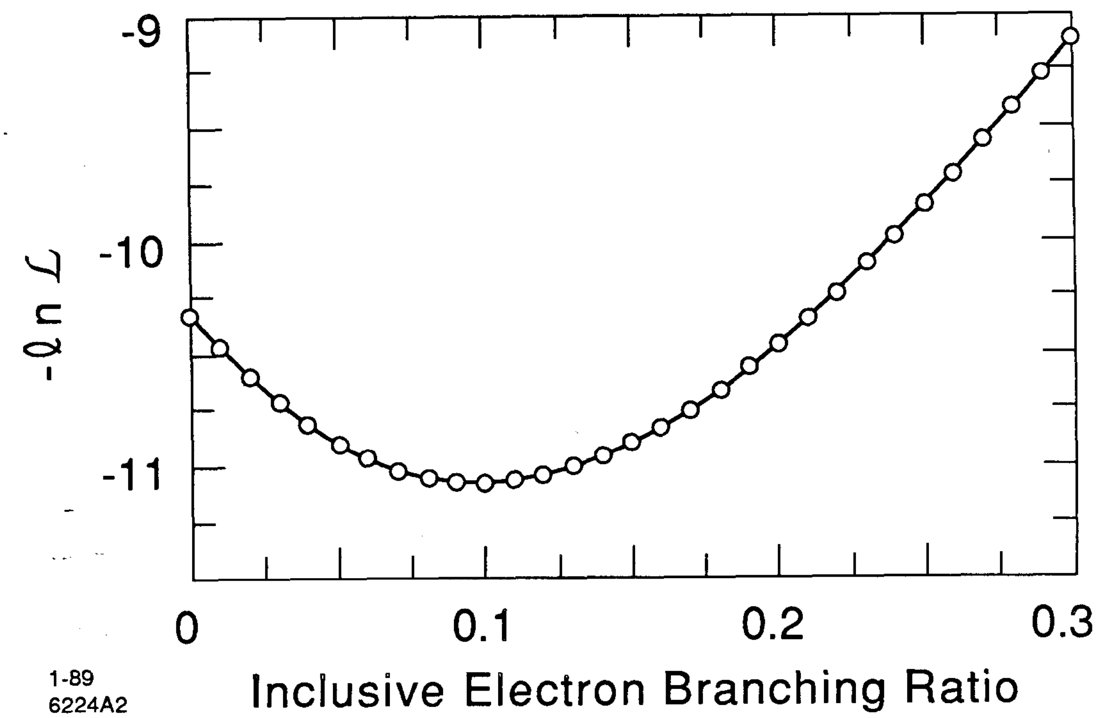

Figure 6: The likelihood function $\mathcal{L}$ shown vs. the branching ratio, $B(D^+ \rightarrow e^+X)$.