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DIRECT EVIDENCE FOR W EXCHANGE IN CHARMED MESON DECAY

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ARGUS Collaboration

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ABSTRACT

Using the ARGUS detector at DORIS II, we have observed a signal of 36.7±8.0 events in the decay channel $D^0 \to K_s^0 \phi$. In the same data sample, we have observed the well established decay $D^0 \to K_s^0 \pi^+ \pi^-$, and find the ratio, $Br(D^0 \to K_s^0 \phi)/Br(D^0 \to K_s^0 \pi^+ \pi^-)$, to be 0.186 ± 0.052. The substantial value of $(0.99 \pm 0.32 \pm 0.17)\%$ then derived for the branching ratio for $D^0 \to \overline{K}^0 \phi$ gives direct evidence that W exchange contributes to D^0 decay.

The difference in the lifetimes of neutral and charged D mesons[1,2] is not yet fully understood. In the light quark spectator model equal lifetimes and equal semi-leptonic branching ratios for D^0 and D^+ are predicted[3]. The inclusion of perturbative QCD effects[4], finite mass corrections[5] and radiative corrections does not change this picture substantially[6]. Two possible mechanisms have been advanced in order to explain this lifetime puzzle in charmed decays: quark interference in the final state[7], which should suppress the non-leptonic D^+ decays, and flavour annihilation by W exchange [8,9], which enhances the non-leptonic D^0 decays. In calculations based on valence quarks in a QCD potential, such exchange processes are helicity and colour suppressed. Other models predict that this suppression is removed or reduced by non-perturbative aspects of QCD. A crucial test for these ideas would be the observation of the decay $D^0 \to K_s^0 \phi$, which should occur predominantly through W exchange (fig. 1). The spectator mechanism will contribute to this decay only through an OZI forbidden process, which has been calculated to have a branching ratio below 10^{-5} [9]. W exchange enhanced models predict that this ratio for $D^0 \to \overline{K}^0 \phi$ could be as large as $\simeq 1.0\%$ [9,10]. Experimental results on this decay have so far yielded only an upper limit of 1.7% at the 95% C.L. for the branching ratio of $D^0 \to \overline{K}^0 \phi$ [11].

In this letter we report the observation of the $D^0 \to K_s^0 \phi$ decay and present a measurement of the branching ratio to this channel. The data sample used for this analysis was collected using the ARGUS detector, operating in the e^+e^- storage ring DORIS II at DESY. It comprises in total a luminosity of 82.2 pb^{-1} of which 21.6 pb^{-1}, 36.2 pb^{-1}, 11.4 pb^{-1} and 13.0 pb^{-1} were taken on the $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(4S)$, and in the continuum or during scanning, respectively. The detector is a 4π spectrometer, described in more detail elsewhere[12,13]. Charged particle momenta and mean dE/dx loss were reconstructed using the the ARGUS drift chamber. Particles were identified on the basis of both the dE/dx measurement and time-of-flight. For a given track, all mass hypotheses were accepted for which the likelihood ratio[12] constructed from these measurements exceeded 5%. The efficiency for the particle identification has been checked by investigating the dependence on identification of the number of reconstructed K_s^0's, ϕ's and Λ's in $\pi^+\pi^-$, K^+K^- and π^-p invariant mass distributions.

For the purposes of the analysis presented here, a K_s^0 is defined as a $\pi^+\pi^-$ pair which forms a secondary vertex, where at least one of the two pions is separated from the main vertex by more than 7σ. The invariant mass spectrum for such $\pi^+\pi^-$ pairs shows a clear K_s^0 signal with 54683±600 entries (fig.2a), while a ϕ signal with 5940±80 entries is evident in the invariant K^+K^- mass spectrum (fig.2b).

The reconstruction of D^0 mesons decaying into $\overline{K}^0\phi$ was investigated by first studying the $K_s^0K^+K^-$ channel. The invariant $\pi^+\pi^-$ mass of the K_s^0 candidates was required to lie within ±50 MeV/c^2 of the nominal K_s^0 mass, with the χ^2 of this mass hypothesis less than 36. Fig. 3 shows a scatter plot of the $K_s^0K^+K^-$ invariant mass versus the mass of the K^+K^- system for these events, where a cut on $x_p = p/p_{max}$ of the $K_s^0K^+K^-$ system of $x_p > 0.3$ has been applied. This enhances the population of heavy over light hadronic states in the sample, since charmed mesons are produced with a hard momentum distribution [12]. An accumulation of events is clearly evident at $m(K_s^0K^+K^-) = m(D^0)$, with the K^+K^- mass at the ϕ mass, along with some enhancement at the K^+K^- threshold.

With no requirement on $m(K^+K^-)$, one observes a D^0 signal with 69 ± 18 entries at a mass of 1866.0±2.0 MeV/c^2, based on a fit using a gaussian with width fixed to 7.5 MeV/c^2, as expected from Monte Carlo, above a polynomial background. The observed width of 8.1±2.0 MeV/c^2 is in agreement with the predicted value. If the mass of the K^+K^- pair is restricted to the ϕ band, with a cut of $1.01 < m(K^+K^-) < 1.03$ GeV/c^2, the invariant $K_s^0K^+K^-$ mass spectrum shows a pronounced D^0 signal of 37.7±8.0 entries with little background (fig. 4a). When the K^+K^- invariant mass lies below the ϕ mass, that is with $m(K^+K^-) < 1.01$ GeV/c^2, a small D^0 signal of 14.2±4.6 events is observed. The $K_s^0K^+K^-$ invariant mass spectrum, with invariant K^+K^- mass larger than 1.03 GeV/c^2 is shown in figure 4b. Little evidence for a D^0 signal can be seen, with a fitted value of 10±16 events at the D^0 mass. From this last observation, we conclude that non-resonant K^+K^- background contributes only 1±2 event in the ϕ region, based on an extrapolation assuming a flat phase space distribution in $m^2(K^+K^-)$. After subtracting this contribution, we find 36.7 ± 8.0 events in the decay $D^0 \to K_s^0\phi$.

Further evidence in support of this conclusion is provided by the angular distribution of the K^+ from the ϕ decay. The number of events as a function of $\cos\theta$ of the K^+ in the center of mass of the ϕ with respect to the K_s^0 momentum vector is shown in figure 5. The angular distribution of the kaons from the decay of the ϕ (spin= 1), which in turn results from the decay of the D^0 (spin= 0), is expected to exhibit the $\cos^2\theta$ behaviour observed. In contrast, the background events under the D^0 signal evidently are consistent with a uniform distribution.

In order to determine branching ratios for the observed D^0 decays, we have compared the results described above with the decay $D^0 \to K_s^0\pi^+\pi^-$ observed in the same data sample. This channel is well established, with a branching ratio recently determined[11] to be $(5.3 \pm 0.9 \pm 0.9)\%$. The virtue of such a procedure is that the two channels have similar detector acceptance. Common uncertainties, such as K_s^0 secondary vertex reconstruction efficiency, largely cancel. Combining K_s^0's with an additional $\pi^+\pi^-$ pair, and requiring x_p of the $K_s^0\pi^+\pi^-$ system to be larger than 0.5, we observe a clear D^0 signal of 345 ± 54 events in the invariant $K_s^0\pi^+\pi^-$ mass spectrum (fig. 6) at a mass of 1863.9±3.3 MeV/c².

The ratio of branching ratios for the two observed D^0 decays is given by

$$\frac{Br(D^0 \rightarrow K_s^0K^+K^-)}{Br(D^0 \rightarrow K_s^0\pi^+\pi^-)} = \epsilon \times \frac{N(D^0 \rightarrow K_s^0K^+K^-)}{N(D^0 \rightarrow K_s^0\pi^+\pi^-)}$$

where ϵ is the ratio of efficiencies for the two processes, and N the number of events obtained using the same cuts. The efficiency ratio ϵ has been determined from Monte Carlo calculations to be 1.23 ± 0.08, the difference due largely to the finite probability for kaons to decay in flight before detection. Applying the same cut of $x_p > 0.5$ on the $K_s^0K^+K^-$ system, we find 51.9±12.6 events for the decay $D^0 \rightarrow K_s^0K^+K^-$, 25.7±5.8 for the decay $D^0 \rightarrow K_s^0\phi$ and 6±3 for the case where the K^+K^- mass lies below the ϕ mass. Using the known branching ratio for $\phi \rightarrow K^+K^-$ of $49.3 \pm 1.0\%$, this yields:

$$\frac{Br(D^0 \rightarrow K_s^0\phi)}{Br(D^0 \rightarrow K_s^0\pi^+\pi^-)} = 0.186 \pm 0.052$$

and

$$\frac{Br(D^0 \rightarrow K_s^0K^+K^-)}{Br(D^0 \rightarrow K_s^0\pi^+\pi^-)} = 0.185 \pm 0.055$$

where the second ratio includes the contribution from $K_s^0\phi$. Finally, using the measured branching ratio for $D^0 \rightarrow \overline{K}^0\pi^+\pi^-$ from MARK III[11], we obtain:

$$Br(D^0 \rightarrow \overline{K}^0\phi) = (0.99 \pm 0.32)\%$$

and

$$Br(D^0 \rightarrow \overline{K}^0K^+K^-) = (0.98 \pm 0.34)\%$$

An additional 17% uncertainty in these branching ratios results from the systematic scale error on the branching ratio for $D^0 \rightarrow K_s^0\pi^+\pi^-$. The result for the branching ratio for $D^0 \rightarrow \overline{K}^0K^+K^-$ is in good agreement with that derived from preliminary MARK III[11] results, which give $(1.13 \pm 0.37 \pm 0.26)\%$, while the observed signal for $D^0 \rightarrow \overline{K}^0\phi$ is well within their quoted limit of 1.7% at the 95% confidence level.

For consistency we have checked our results by using tagged D^0's from the decay $D^{*+} \rightarrow D^0\pi^+$. It is well known[14] that the low Q value for this decay results in excellent resolution for the mass difference, $\Delta M = M(D^0\pi^+) - M(D^0)$. By means of a cut on ΔM, background contributions can be substantially reduced. We observe 11±4 tagged events in the decay $D^0 \rightarrow K_s^0\phi$ and 192±35 events in the decay $D^0 \rightarrow K_s^0\pi^+\pi^-$, where x_p for the D^{*+} system was required to be greater than 0.3. These numbers are consistent with the those from the untagged D^0 sample, but with considerably larger errors.

In summary, we conclude that the substantial rate measured for the decay $D^0 \rightarrow \overline{K}^0\phi$ is 3 orders of magnitude above that predicted by the spectator model[9], where only an OZI violating process can contribute. The only way that this process can proceed in a simple quark picture is via a W exchange diagram. Therefore, the detection of the decay $D^0 \rightarrow \overline{K}^0\phi$, with a branching ratio of $(0.99 \pm 0.32 \pm 0.17)\%$, represents the first direct evidence for W exchange in heavy quark decays.

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FIGURE CAPTIONS

Figure 1 Diagram for W exchange mechanism in the decay $D^0 \to \overline{K}^0 \phi$.

Figure 2a $\pi^+\pi^-$ mass spectrum for pions from a secondary vertex.

Figure 2b K^+K^- mass spectrum. The fitted curve is a Breit-Wigner ($\Gamma = 4.1$ MeV/c^2) folded with a gaussian resolution function ($\sigma = 2.8$ MeV/c^2), plus a polynomial times a square root threshold factor to describe the background.

Figure 3 Scatter plot $m(K^0_sK^+K^-)$ versus $m(K^+K^-)$ for events containing a $K^0_sK^+K^-$ system with $x_p > 0.3$.

Figure 4a $K^0_sK^+K^-$ mass spectrum with $x_p > 0.3$ and $1.01 < m(K^+K^-) < 1.03$.

Figure 4b $K^0_sK^+K^-$ mass spectrum with $x_p > 0.3$ and $m(K^+K^-) > 1.03$.

Figure 5 Angular distribution of the K^+ in the ϕ rest frame with respect to the K^0_s direction for the decay $D^0 \to K^0_s\phi$. The solid curve is a $\cos^2\theta$ fit to this distribution. The open squares show the corresponding points for the background under the D^0 signal.

Figure 6 $K^0_s\pi^+\pi^-$ mass spectrum with $x_p > 0.5$.

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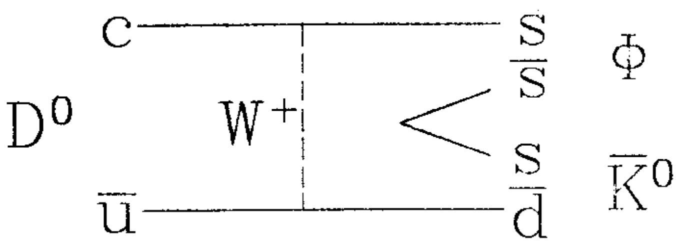


Fig. 1

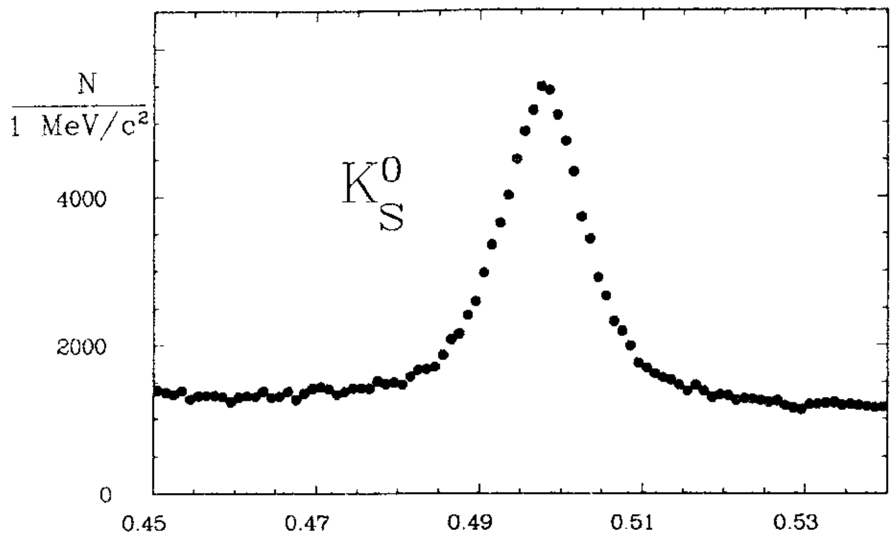


Fig. 2a Mass $\pi^+\pi^-$[GeV/c²]

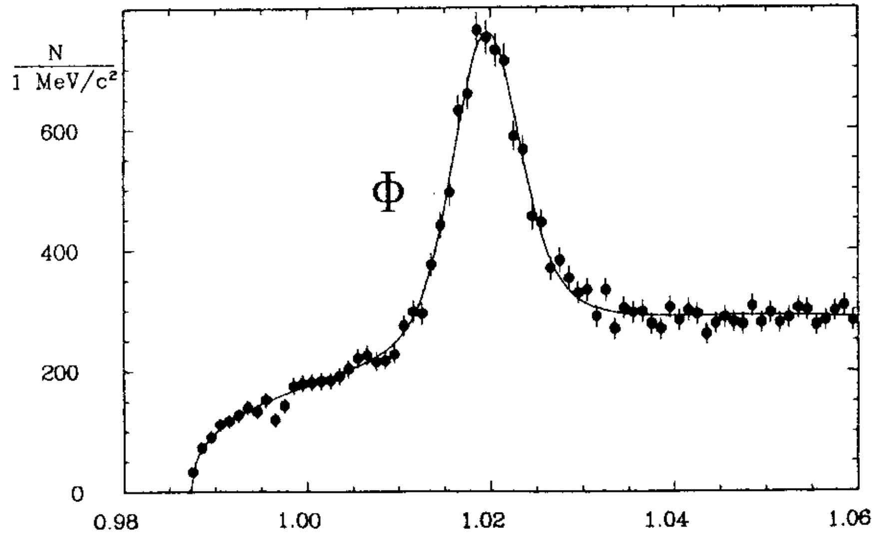


Fig. 2b Mass K^+K^- [GeV/c²]

38656

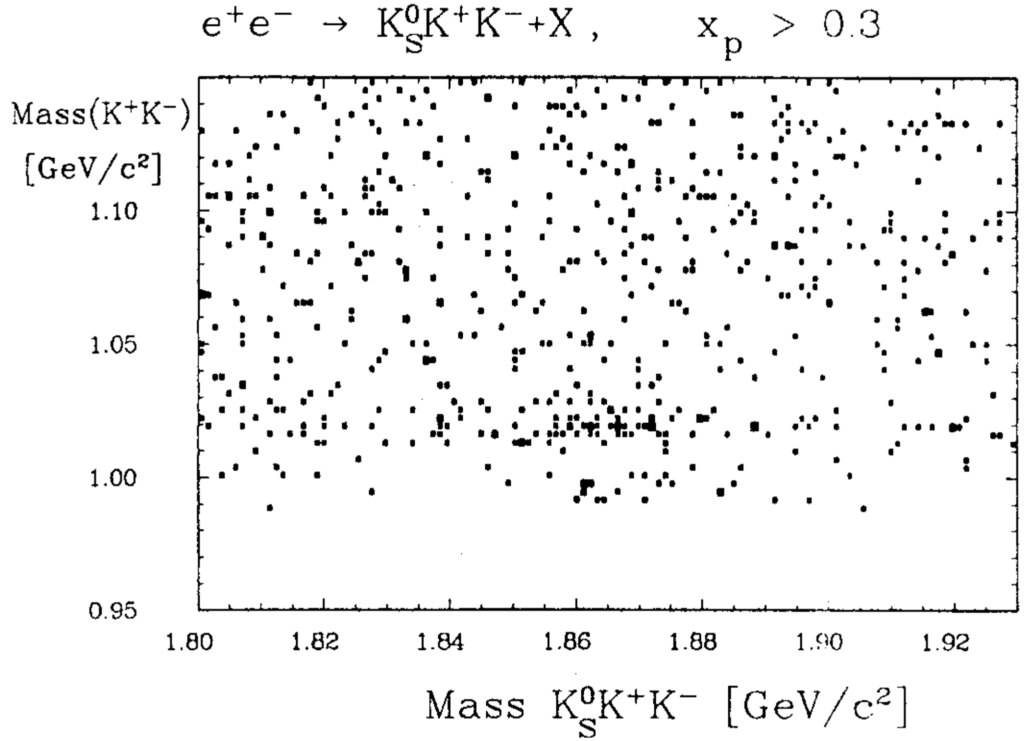


Fig. 3

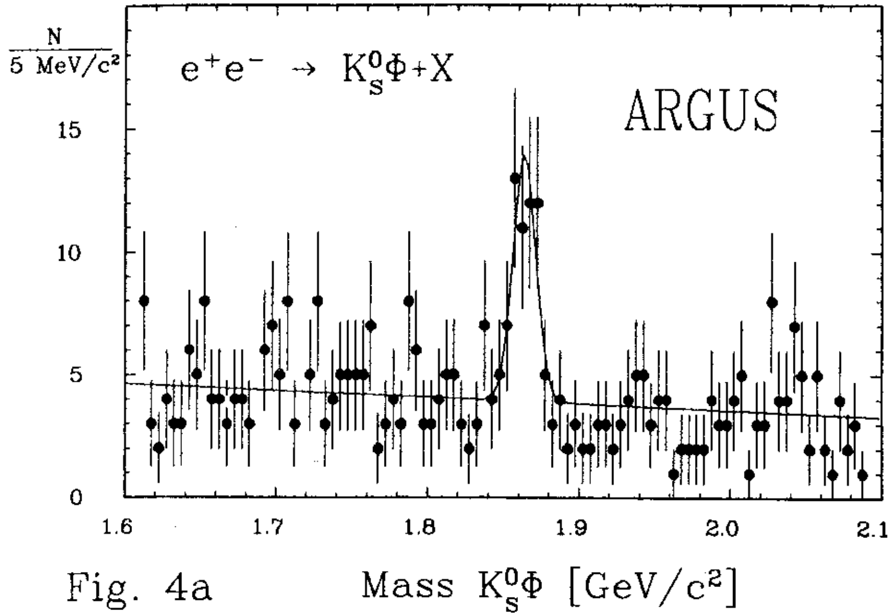


Fig. 4a

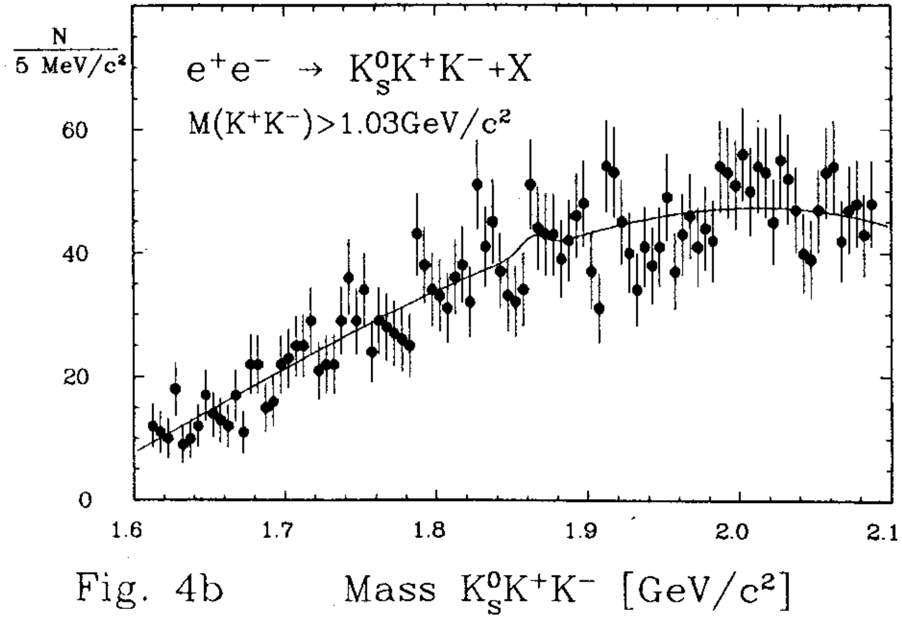
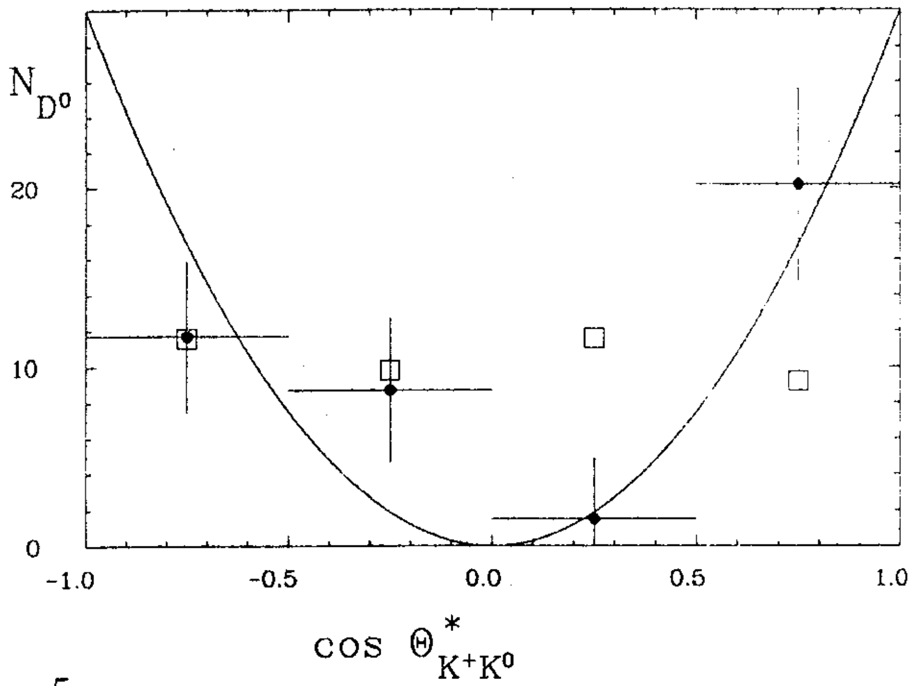


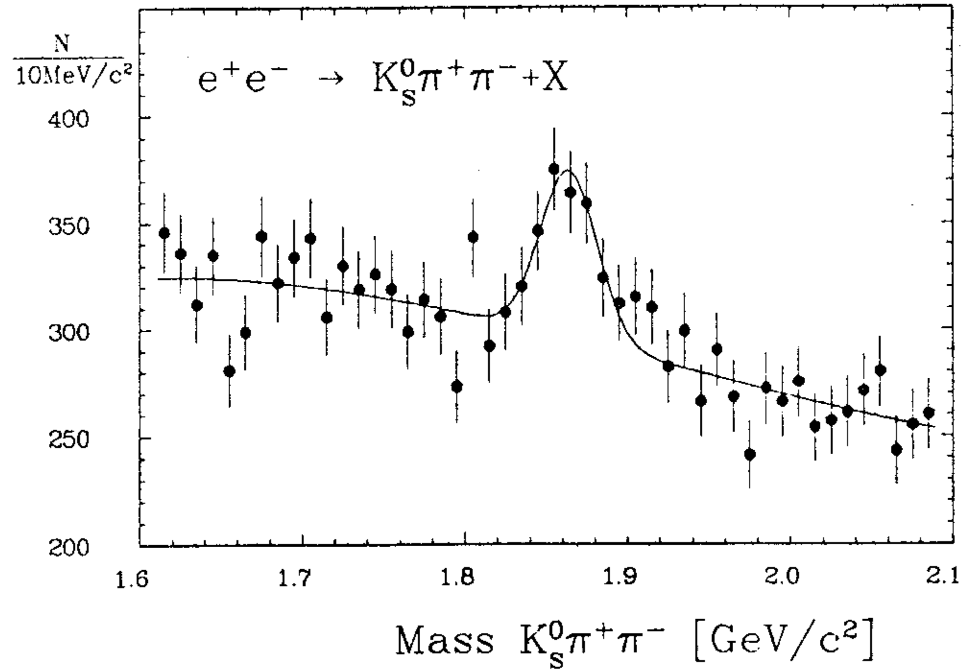
Fig. 4b

38655



N_{D^0}
20
10
0
-1.0
-0.5
0.0
0.5
1.0
$\cos \Theta^*_{K^+K^0}$

Fig. 5



$\frac{N}{10MeV/c^2}$
$e^+e^- \rightarrow K_s^0\pi^+\pi^-+X$
400
350
300
250
200
1.6
1.7
1.8
1.9
2.0
2.1
Mass $K_s^0\pi^+\pi^-$ [GeV/c²]

Fig. 6