

85-9-194

DEUTSCHES ELEKTRONEN-SYNCHROTRON **DESY**

DESY 85-048
June 1985

DIRECT EVIDENCE FOR W EXCHANGE IN CHARMED MESON DECAY

by

ARGUS Collaboration

ISSN 0418-9833

NOTKESTRASSE 85 · 2 HAMBURG 52

DESY behält sich alle Rechte für den Fall der Schutzrechtserteilung und für die wirtschaftliche Verwertung der in diesem Bericht enthaltenen Informationen vor.

DESY reserves all rights for commercial use of information included in this report, especially in case of filing application for or grant of patents.

To be sure that your preprints are promptly included in the
HIGH ENERGY PHYSICS INDEX,
send them to the following address (if possible by air mail) :

DESY
Bibliothek
Notkestrasse 85
2 Hamburg 52
Germany

Using the ARGUS detector at DORIS II, we have observed a signal of 36.7 ± 8.0 events in the decay channel $D^0 \rightarrow K_S^0 \pi^+ \pi^-$. In the same data sample, we have observed the well established decay $D^0 \rightarrow K_S^0 \pi^+ \pi^-$, and find the ratio, $Br(D^0 \rightarrow K_S^0 \phi) / Br(D^0 \rightarrow K_S^0 \pi^+ \pi^-)$, 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 $D^0 \rightarrow \bar{K}^0 \phi$ gives direct evidence that W exchange contributes to D^0 decay.

DIRECT EVIDENCE FOR W EXCHANGE IN CHARMED MESON DECAY.

THE ARGUS COLLABORATION

H. ALBRECHT, U. BINDER, G. HARDER, A. PHILIPP,
W. SCHMIDT-PARZFALL, H. SCHRÖDER, H. D. SCHULZ, R. WURTH
DESY, HAMBURG, GERMANY

A. DRESCHER, B. GRÄWE, U. MATTHESEN,
H. SOECK, J. SPENGLER, D. WEGENER
INSTITUT FÜR PHYSIK,
UNIVERSITÄT DORTMUND¹, GERMANY

K. R. SCHUBERT, J. STIEWE, R. WALDI, S. WESELER
INSTITUT FÜR HOCHENERGIEPHYSIK,
UNIVERSITÄT HEIDELBERG¹, GERMANY

N. N. BROWN², K. W. EDWARDS³, W. R. FRISEN⁴,
CH. FUKUNAGA⁴, D. J. GILKINSON⁵, D. M. GINGRICH⁵, M. GODDARD⁴, P. C. H. KIM⁶,
R. KUTSCHKÉ⁶, D. B. MACFARLANE⁶, J. A. MCKENNA⁶, K. W. MCLEAN⁷,
A. W. NELSSON⁸, R. S. ORR⁶, P. PADLEY⁶, P. M. PATEL², J. D. PRENTICE⁶,
H. G. J. SKYWERD⁶, B. J. STACEY⁶, T.-S. YOON⁶, J. C. YUN⁶
INSTITUTE OF PARTICLE PHYSICS⁶, CANADA

R. AMMAR, D. COPPAGE, R. DAVIS, S. KANEKAL, N. KWAK
UNIVERSITY OF KANSAS⁷, LAWRENCE, KANSAS, USA

G. KERNEL, M. PLEŠKO
J. STEFAN INSTITUTE AND DEPARTMENT OF PHYSICS,
UNIVERSITY OF LJUBLJANA⁸, YUGOSLAVIA

L. JÖNSSON, Y. OKU
INSTITUTE OF PHYSICS, UNIVERSITY OF LUND⁹, SWEDEN

A. BABAËY, M. DANILOV, A. GOLUTVIN, V. LUBIMOV, V. MATVEEV,
V. NAGOVITSIN, V. RYTSOV, A. SEMENOV, V. SHEVCHENKO,
V. SOLOSHENKO, V. SOPOV, I. TICHOMIROV, YU. ZAITSEY
INSTITUTE OF THEORETICAL AND EXPERIMENTAL PHYSICS, MOSCOW, USSR

R. CHILDERS, G. W. DARDEN, AND H. GENNOW¹⁰
UNIVERSITY OF SOUTH CAROLINA¹¹, COLUMBIA, S.C., USA

¹Supported by the Bundesministerium für Forschung und Technologie, Federal Republic of Germany.

²McGill University, Montreal.

³Carleton University, Ottawa.

⁴York University, Downsview.

⁵University of Toronto, Toronto.

⁶Supported by the Natural Sciences and Engineering Research Council, Canada.

⁷Supported by the U.S. National Science Foundation and a University of Kansas Faculty Improvement award.

⁸Supported in part by the Internationales Büro KfA, Jülich and DESY Hamburg.

⁹Supported by the Swedish Research Council.

¹⁰On leave of absence from the University of Stockholm, Sweden.

¹¹Supported by the U.S. Department of Energy, under contract DE-AS09-80ER10690.

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 $D^0 \rightarrow K_s^0 \phi$, 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 $D^0 \rightarrow \bar{K}^0 \phi$ could be as large as $\approx 1.0\%$ ^(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 $D^0 \rightarrow \bar{K}^0 \phi$ ⁽¹¹⁾.

In this letter we report the observation of the $D^0 \rightarrow K_s^0 \phi$ 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 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 $\pi^-\pi^+$ 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 $\bar{K}^0 \phi$ was investigated by first studying the $K_s^0 K^+ K^-$ channel. The invariant $\pi^+\pi^-$ mass of the K_s^0 candidates was required to lie within $\pm 50 \text{ MeV}/c^2$ 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 $K_s^0 K^+ K^-$ invariant mass versus the mass of the $K^+ K^-$ system for these events, where a cut on $x_p = p/p_{\text{max}}$ of the $K_s^0 K^+ K^-$ 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⁽¹⁹⁾. An accumulation of events is clearly evident at $m(K_s^0 K^+ K^-) = m(D^0)$, 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 $1866.0 \pm 2.0 \text{ MeV}/c^2$, based on a fit using a gaussian with width fixed to $7.5 \text{ MeV}/c^2$, as expected from Monte Carlo, above a polynomial background. The observed width of $8.1 \pm 2.0 \text{ MeV}/c^2$ 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 $1.01 < m(K^+ K^-) < 1.03 \text{ GeV}/c^2$, the invariant $K_s^0 K^+ K^-$ 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 $m(K^+ K^-) < 1.01 \text{ GeV}/c^2$, a small D^0 signal of 14.2 ± 4.6 events is observed. The $K_s^0 K^+ K^-$ invariant mass spectrum, with invariant $K^+ K^-$ mass larger than $1.03 \text{ GeV}/c^2$ 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 $D^0 \rightarrow K_s^0 \phi$.

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 $D^0 \rightarrow K_s^0 \pi^+ \pi^-$ observed in the same data sam-

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 $D^0 \rightarrow \bar{K}^0 \phi$ 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 $D^0 \rightarrow \bar{K}^0 \phi$, 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.

ple. 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/ c^2 .

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

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

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 $K_s^0 K^+ K^-$ system, we find 51.9 ± 12.6 events for the decay $D^0 \rightarrow K_s^0 K^+ K^-$, 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:

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

and

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

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

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

and

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

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 $D^0 \rightarrow \bar{K}^0 K^+ K^-$ 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 $D^0 \rightarrow \bar{K}^0 \phi$ is well within their quoted limit of 1.7% at the 95% confidence level.

ACKNOWLEDGEMENTS

It is a pleasure to thank E. Michel, W. Reinsch, K. Rauschnabel and Mrs. U. Djuanda for their competent technical help in running the experiment and processing the data. We thank Drs. H. Neemann, K. Wille and the DORIS group for the good operation of the storage ring. The visiting groups wish to thank the DESY directorate for the support and kind hospitality extended to them.

FIGURE CAPTIONS

- Figure 1 Diagram for W exchange mechanism in the decay $D^0 \rightarrow \bar{K}^0 \phi$.
- 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 ($\Gamma = 4.1 \text{ MeV}/c^2$) folded with a gaussian resolution function ($\sigma = 2.8 \text{ MeV}/c^2$), plus a polynomial times a square root threshold factor to describe the background.
- Figure 3 Scatter plot $m(K_s^0 K^+ K^-)$ versus $m(K^+ K^-)$ for events containing a $K_s^0 K^+ K^-$ system with $x_p > 0.3$.
- Figure 4a $K_s^0 K^+ K^-$ mass spectrum with $x_p > 0.3$ and $1.01 < m(K^+ K^-) < 1.03$.
- Figure 4b $K_s^0 K^+ K^-$ 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_s^0 direction for the decay $D^0 \rightarrow K_s^0 \phi$. 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 $K_s^0 \pi^+ \pi^-$ mass spectrum with $x_p > 0.5$.

REFERENCES

- (1) N.Ushida et al., Phys.Rev.Lett. **45** (1980), 1049 and **45** (1980), 1053;
 N.W.Reay, Proceedings of the 1983 International Lepton/Photon Symposium, Cornell (1983), 244;
 N.Ushida et al., Phys.Rev.Lett. **51** (1983), 2362;
 K.Abe et al., Phys.Rev. **D30** (1984), 1;
 M.I.Adamovich et al., Phys.Lett. **140B** (1984), 119 and **140B** (1984), 123;
 M.Aguilar-Benitez et al., Phys.Lett. **146B** (1984), 266;
 J.M.Yelton et al. (MARK II collaboration), Phys.Rev.Lett. **52** (1984), 2019.
- (2) W.Bacino et al. (DELCO collaboration), Phys.Rev.Lett. **45** (1980), 329.
 R.H.Schindler et al. (MARK II collaboration) Phys.Rev. **D24** (1981), 78.
 R.M.Baltrusaitis et al. (MARK III collaboration), Phys.Rev.Lett. **54** (1985), 1976.
- (3) M.K.Gaillard, B.W.Lee and J.L.Rosner, Rev.Mod.Phys. **47** (1975) 277;
 J.Ellis, M.K.Gaillard and D.V.Nanopoulos, Nucl.Phys. **B100** (1975) 313;
 A.Pais and S.B.Treiman, Phys.Rev. **D15** (1977) 2529.
- (4) M.K.Gaillard and B.W.Lee, Phys.Rev.Lett. **33** (1974) 108;
 G.Altarelli and L.Maiani, Phys.Lett. **52B** (1974) 351;
 R.Kingsley, S.Treiman, F.Wilczek and A.Zee, Phys.Rev. **D11** (1975) 1919;
 J.F.Donoghue and B.R.Holstein, Phys.Rev. **D13** (1975) 1454;
 M.B.Einhorn and C.Quigg, Phys.Rev. **D13** (1975) 2015;
 G.Altarelli, N.Cabibbo and L.Maiani, Nucl.Phys. **B88** (1975) 285;
 G.Altarelli et al., Phys.Lett. **99B** (1981) 141 and Nucl.Phys. **B187** (1981) 461.
- (5) G.Altarelli et al., Nucl.Phys. **B208** (1982) 365;
 U.Baur and H.Fritzsch, Phys.Lett. **109B** (1982) 402;
 J.L.Cortes, X.Y.Pham and A.Tounsi, Phys.Rev. **D25** (1982) 188.
- (6) N.Cabibbo and L.Maiani, Phys.Lett. **79B** (1978) 109;
 M.Suzuki, Nucl.Phys. **B145** (1978) 420;
 N.Cabibbo, G.Corbo and L.Maiani, Nucl.Phys. **B155** (1979) 93;
 A.Ali and E.Pietarinen, Nucl.Phys. **B154** (1979) 519;
 G.Corbo, Phys.Lett. **116B** (1982) 238 and Nucl.Phys. **B122** (1983) 99.
- (7) B.Guberina, S.Nussinov, R.D.Peccei and R.Rückl, Phys.Lett. **89B** (1979) 111;
- (8) Y.Koide, Phys.Rev. **D20** (1979) 1739;
 K.Jagannathan and V.S.Mathur, Phys.Rev. **D21** (1980) 3165;
 T.Kobayashi and N.Yamazaki, Progr.Theor.Phys. **65** (1981) 775;
 G.Altarelli and L.Maiani, Phys.Lett. **118B** (1982) 414;
 H.Sawayanagi et al., Phys.Rev. **D27** (1983) 2107;
 V.A.Khoze and M.A.Shifman, Uspekhi.Fiz.Nauk. **10** (1983) 2 and DESY 83-105;
 M.A.Shifman and M.B.Voloshin, ITEP 84-62.
- (9) W.Bernreuther, O.Nachtmann and B.Stech, Z.Phys. **C4** (1980) 257;
 I.Bigi, Z.Phys. **C5** (1980) 313;
 H.Fritzsch and P.Minkowski, Phys.Lett. **90B** (1980) 455;
 V.Barger et al., Phys.Rev. **D22** (1980) 693;
 S.P.Rosen, Phys.Rev.Lett. **44** (1980) 4;
 M.Bander, D.Silverman and A.Soni, Phys.Rev.Lett. **44** (1980) 7,
 and Erratum Phys.Rev.Lett. **44** (1980) 962.
- (10) I.Bigi and M.Fukugita, Phys.Lett. **91B** (1980) 121.
 A.N.Kamal, SLAC preprint SLAC-PUB-3443, Sept.1984, submitted to Phys.Rev. **D**.
- (11) R.H.Schindler, Proceedings of the XXIIIrd International Conference on High Energy Physics, Leipzig (1984), Volume 1, 171.
- (12) H.Albrecht et al. (ARGUS collaboration), Phys.Lett. **150B** (1985) 235.
- (13) H.Albrecht et al. (ARGUS collaboration), Phys.Lett. **134B** (1984) 137.
- (14) S.Nussinov, Phys.Rev.Lett. **35** (1975) 1672;
 G.J.Feldman et al., Phys.Rev.Lett. **38** (1977) 1313.

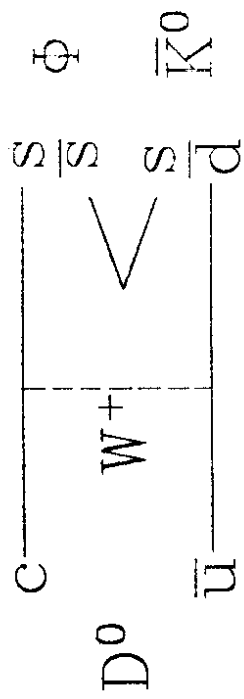


Fig. 1

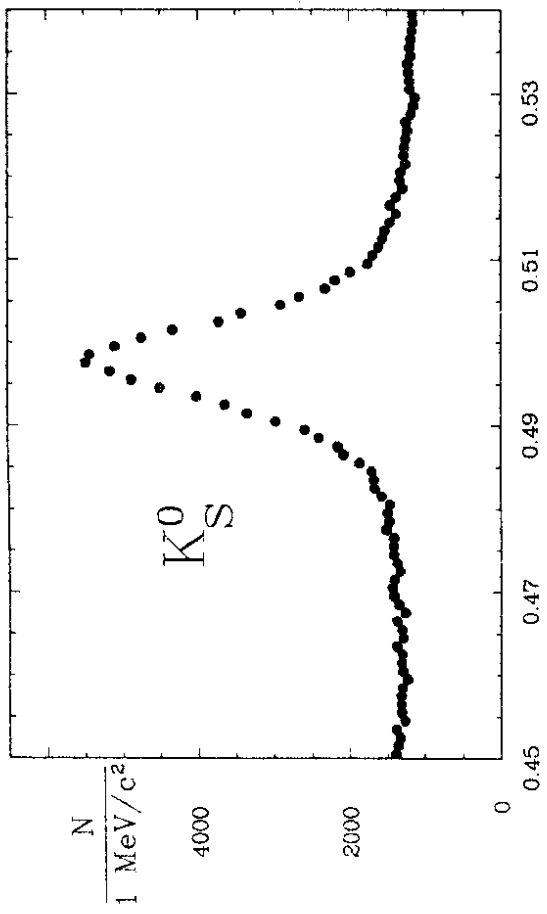


Fig. 2a

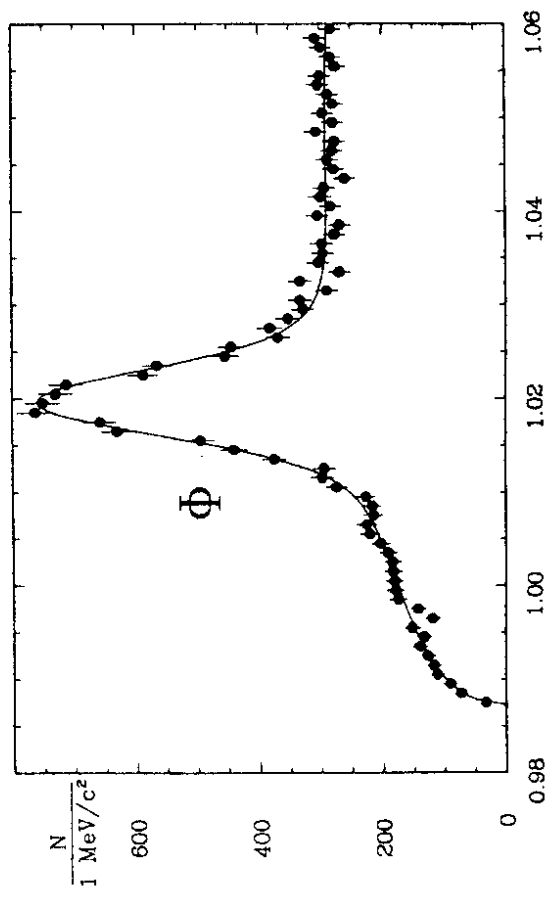


Fig. 2b

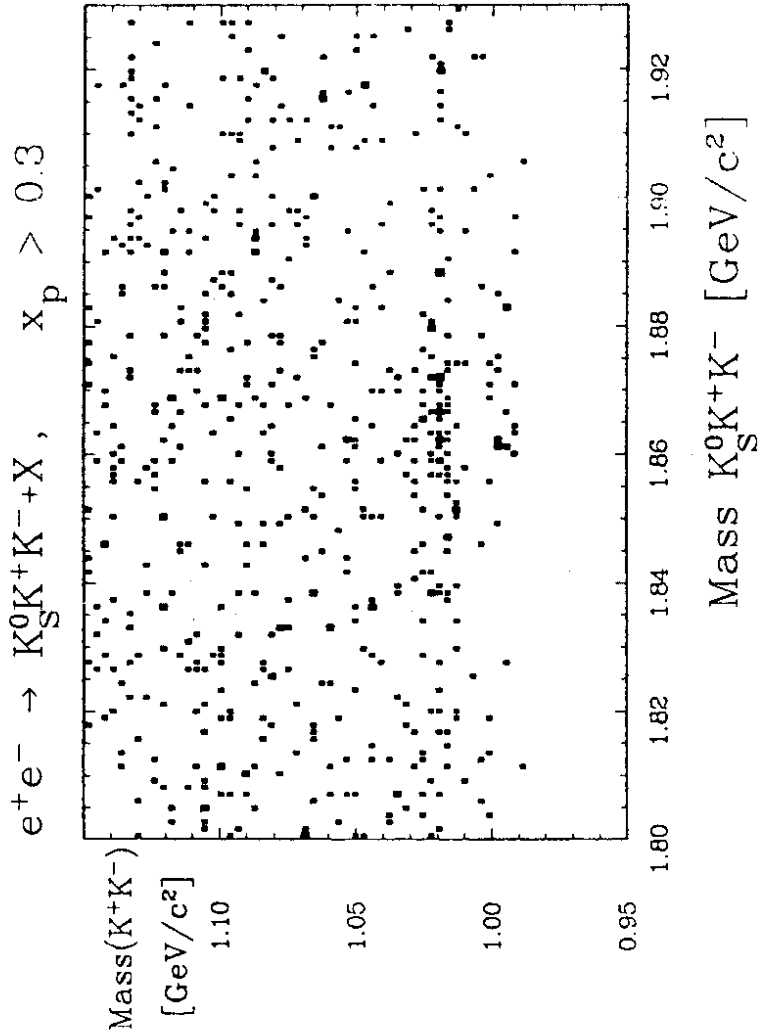


Fig. 3

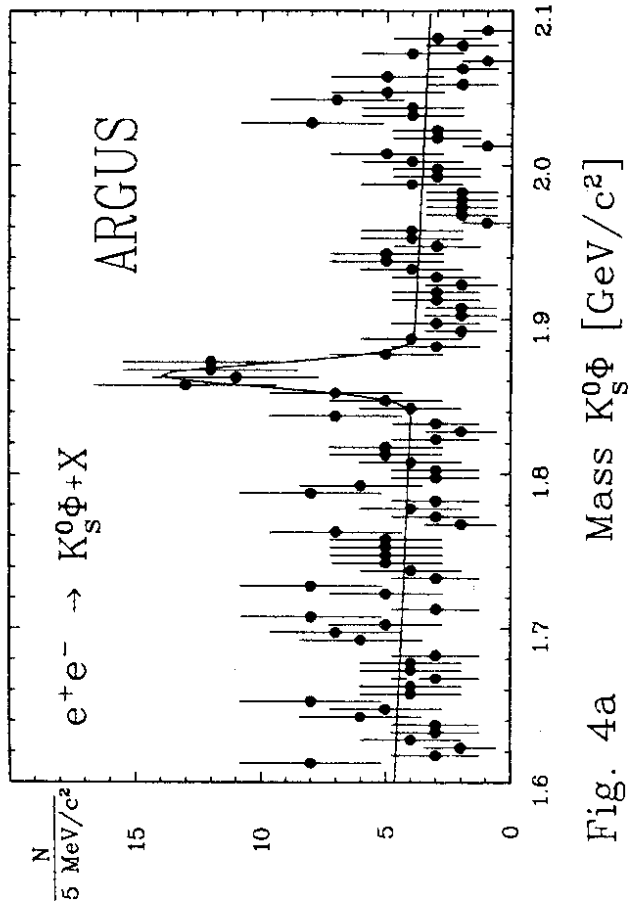


Fig. 4a

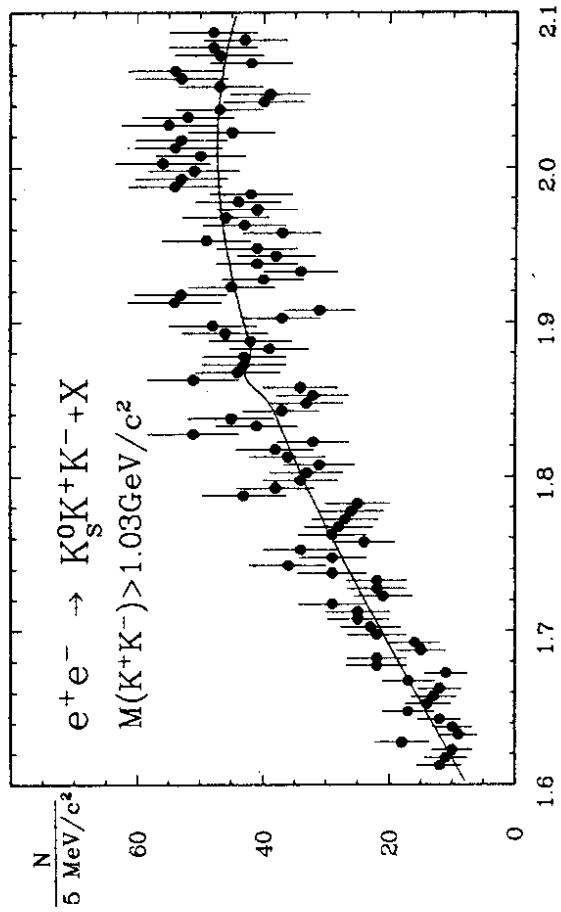


Fig. 4b

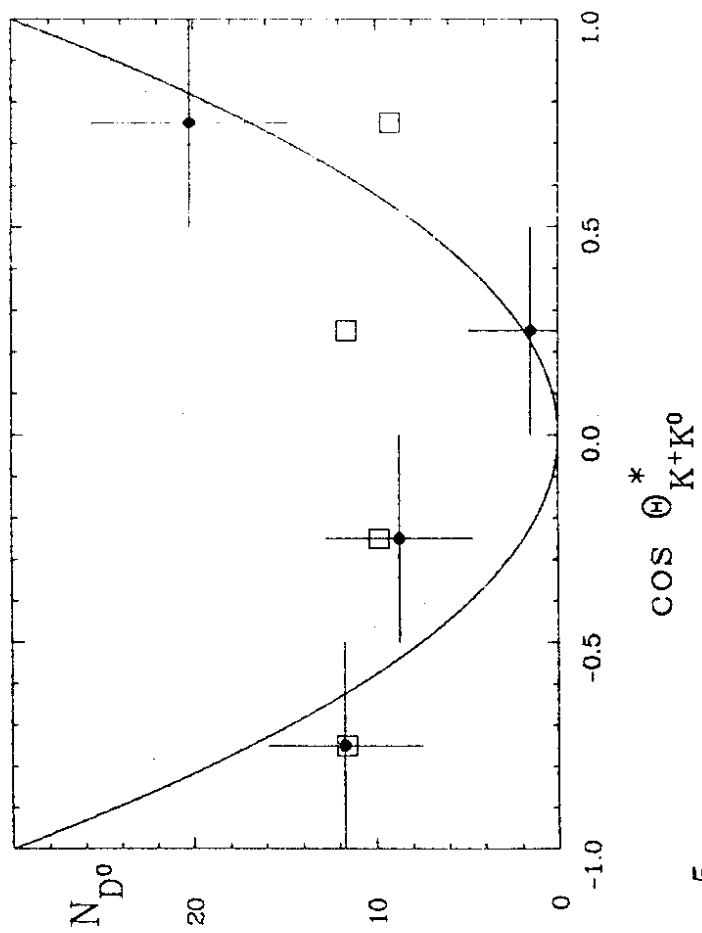


Fig. 5

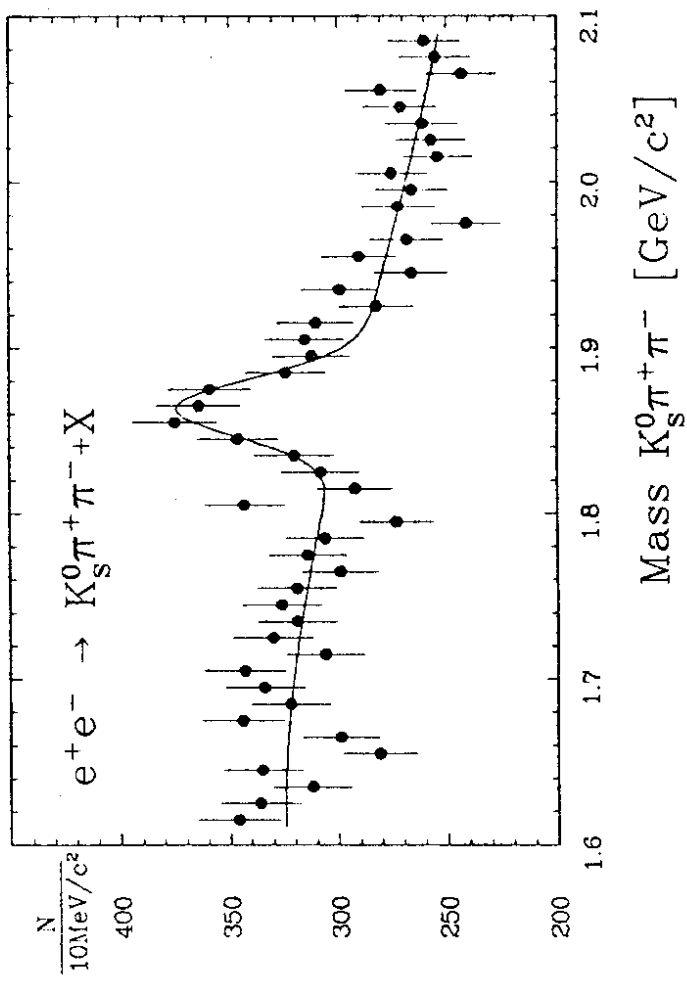


Fig. 6