SEARCH FOR D^0 DECAYS INTO LEPTON PAIRS

ARGUS Collaboration

H. ALBRECHT, P. BÖCKMANN, R. GLÄSER, G. HARDER, A. KRÜGER, A. NIPPE, M. SCHÄFER, W. SCHMIDT-PARZEFALL, H. SCHRÖDER, H.D. SCHULZ, F. SEFKOW, J. SPENGLER, R. WURTH, A. YAGIL

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R.D. APPUHN, A. DRESCHER, D. KAMP, H. KOLANOSKI, U. MATTHIESEN, H. SCHECK, G. SCHWEDA, B. SPAAN, A. WALTHER, D WEGENER

Institut für Physik, Universität Dortmund [1], D-4600 Dortmund, Fed. Rep. Germany

J.C. GABRIEL, T. RUF, K.R. SCHUBERT, J. STIEWE, K. STRAHL, R. WALDI, S. WERNER

Institut für Hochenergiephysik, Universität Heidelberg [2], D-6900 Heidelberg, Fed. Rep. Germany

K.W. EDWARDS [3], W.R. FRISKEN [4], D.J. GILKINSON [5], D.M. GINGRICH [5], H. KAPITZA [3], R. KUTSCHKE [5], D.B. MACFARLANE [6], K.W. McLEAN [6], A.W. NILSSON [6], R.S. ORR [5], J.A. PARSONS [5], P.M. PATEL [6], J.D. PRENTICE [5], J.D. SWAIN[5], G. TSIPOLITIS [6], T.-S. YOON [5]

Institute of Particle Physics [7], Canada

R. AMMAR, S. BALL, D. COPPAGE, R. DAVIS, S. KANEKAL, N. KWAK

University of Kansas [8], Lawrence, KS 66045, USA

B. BOŠTJANČIČ, G. KERNEL, P. KRIŽAN, E. KRIŽNIČ

Institut J. Stefan and Oddelek za fiziko, Univerza v Ljubljania [9], 61111 Ljubljana, Yugoslavia

L. JÖNSSON

Institute of Physics, University of Lund [10], S-223 62 Lund, Sweden

A. BABAEV, M. DANILOV, B. FOMINYKH, A. GOLUTVIN, I. GORELOV, V. LUBIMOV, V. MATVEEV, A. SEMENOV, S. SEMENOV, V. SHEVCHENKO, V. SOLOSHENKO, V. TCHISTILIN, I. TICHOMIROV, Yu. ZAITSEV

Institute of Theoretical and Experimental Physics, 117 259 Moscow, USSR

R. CHILDERS, C.W. DARDEN and R.C. FERNHOLZ

University of South Carolina [11], Columbia, SC 29208, USA

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We have searched for the lepton flavour-violating decay $D^0 \to \mu^\pm e^\mp$ and for the rare decays $D^0 \to \mu^+\mu^-$, e^+e^-, using the ARGUS detector at the e^+e^- storage ring DORIS II. No candidates were found, leading to the upper limits $BR(D^0 \to \mu^+\mu^-) < 7 \times 10^{-5}$, $BR(D^0 \to e^+e^-) < 1.7 \times 10^{-4}$, and $BR(D^0 \to \mu^\pm e^\mp) < 1.0 \times 10^{-4}$ at 90% confidence level.

The standard model of electroweak and strong interactions is, up to now, able to describe all known phenomena in particle physics. Nevertheless, it is unsatisfying in the sense that the strong and weak interactions are not unified into a simple symmetry group and hence nature cannot be described with one interaction. One prediction of many unified extensions to the standard model is the existence of a new particle, which couples to quarks and leptons called the leptoquark [1–3]. In a SU(5) theory the scalar fields G and G_c, which are colour triplets, complete the Higgs doublets of the standard model to obtain SU(5) representations [2]. The G and G_c leptoquarks couple up-type quarks to charged leptons and down-type quarks to neutrinos. This is in contrast to the Pati–Salam SU(4) type leptoquarks [3]. Hence G and G_c do not contribute to the lepton flavour-violating decay $K^0 \to \mu^\pm e^\mp$, but do contribute to the decay $D^0 \to \mu^\pm e^\mp$ (fig. 1a). The exchange of the leptoquarks G and G_c induces a chirality changing operator which leads to pseudoscalar meson decays without helicity suppression. Besides the known upper limits for rare K meson decays, it is essential to derive new limits for D meson decays. The branching ratios of the decays $D^0 \to \mu^+\mu^-$, e^+e^-, in the frame of the standard model (fig. 1b), are expected to be lower than 10^{-10}. Besides the search for leptoquarks, these decays also allow setting bounds on the existence of flavour-changing neutral currents, which are absent in the standard model.

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[3] Carleton University, Ottawa, Ontario, Canada K1S 5B6.
[4] York University, Downsview, Ontario, Canada M3J 1P3.
[5] University of Toronto, Toronto, Ontario, Canada M5S 1A7.
[6] McGill University, Montreal, Quebec, Canada H3A 2T8.
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The analysis presented here is based on a data sample corresponding to an integrated luminosity of 189 events/pb. The data used were collected using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY operating at center-of-mass energies around 10 GeV. Details about the ARGUS detector can be found in ref. [4]. Hadronic events were selected by requiring at least three reconstructed charged particles coming from the interaction region with transverse momentum larger than 80 MeV/c and $|\cos\theta| < 0.9$.

All selected events were searched for e^+e^-, $\mu^+\mu^-$ and $\mu^\pm e^\mp$ pairs. The lepton identification procedure calculates the likelihood function for the lepton hypothesis using four detector measurements, the specific ionization in the drift chamber, the time of flight, the energy deposition and shower shape in the electromagnetic calorimeter, and hits in the muon chamber [5,6]. The lepton momentum was required to be greater than 0.9 GeV/c in order to have a sufficient lepton/hadron separation.

The invariant mass distributions of e^+e^-, $\mu^+\mu^-$, and $\mu^\pm e^\mp$ pairs are shown in figs. 2a–2c. Only combinations with $x_p > 0.55$ have been considered. The quantity x_p is defined by $p(D^0)/p(D^0)_{max}$, where $p(D^0)_{max} = \sqrt{E^2_{beam} - M^2_{D^0}}$. This requirement makes use of the known hard fragmentation function of the

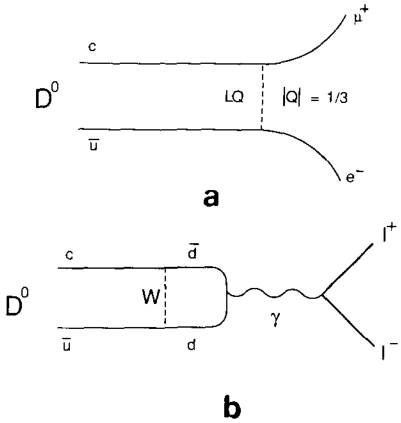

Fig. 1. (a) Quark diagram for the decay $D^0 \to \ell^+\ell^-$ via leptoquark exchange. (b) Quark diagram for the decay $D^0 \to \ell^+\ell^-$ in the standard model.

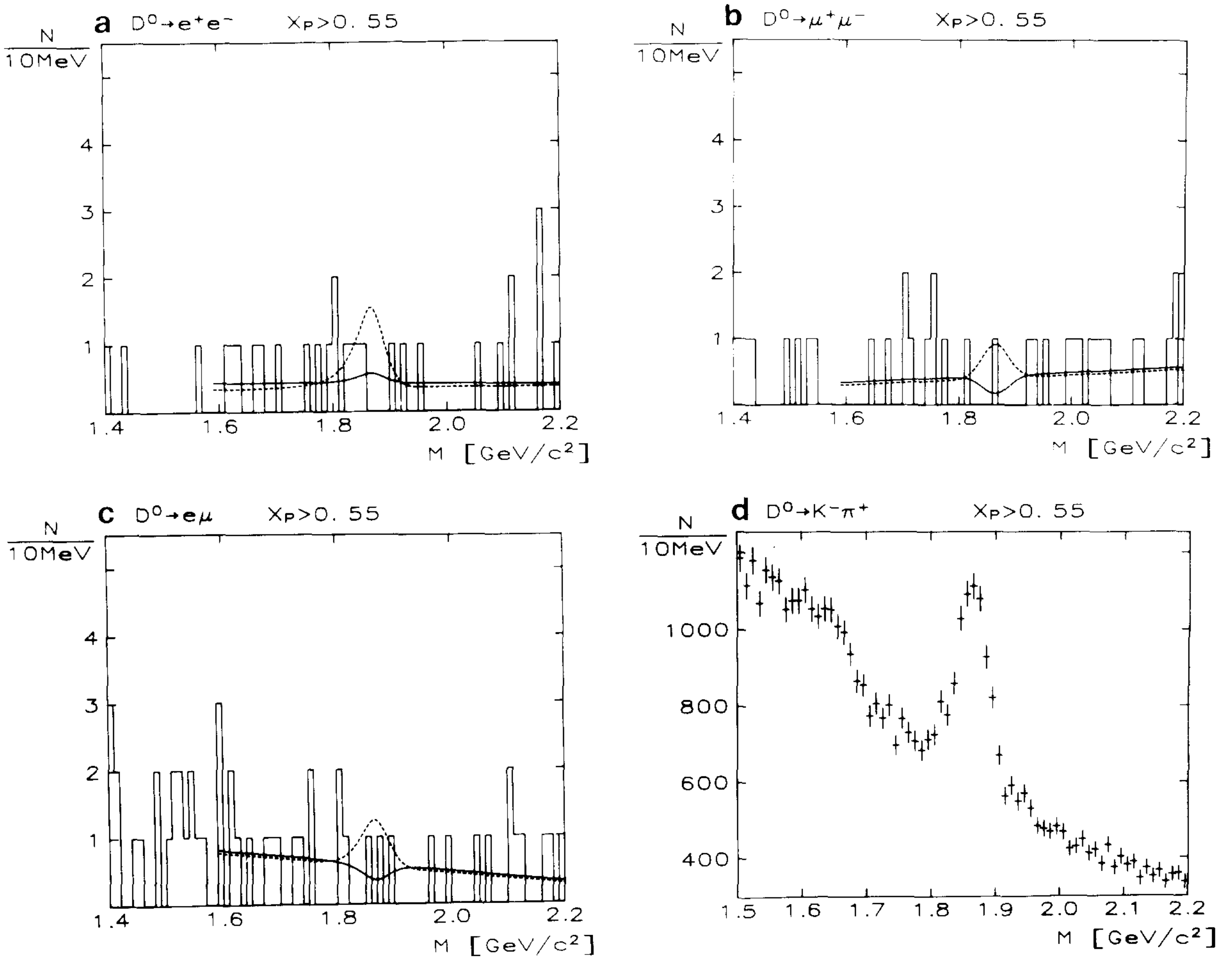

Fig. 2. Invariant mass distributions of lepton pair candidates with $p_\ell > 0.9$ GeV/c and $x_p(\ell\ell) > 0.55$; the solid curves are the results of a fit and the dashed curves represent the 90% confidence level upper limit. (a) e^+e^-, (b) $\mu^+\mu^-$, (c) $e^\pm\mu^\mp$, (d) $D^0 \to K^-\pi^+$ for comparison.

D^0 meson in e^+e^- annihilations [7]. From our Monte Carlo simulation of these decays and from the width of the D^0 signal in $K^-\pi^+$ decays we expect an invariant mass resolution σ of 24 MeV/c^2. No D^0 signal is observed in any of the decay channels. To verify this quantitatively, we fitted the invariant mass spectra of the lepton pairs with a second-order polynomial to describe the background and a modified gaussian of fixed width and mass to describe a possible signal. A small asymmetrical term was added to the gaussian to take into account the energy loss of electrons due to bremsstrahlung as calculated in a Monte Carlo simulation. The efficiency for detecting each of the three decay modes is (34 ± 4)%. A maximum likelihood fit gives the solid curves shown in figs. 2a–2c and the dashed curves represent the 90% confidence level upper limit. The corresponding numbers are listed in table 1.

To obtain the efficiency for observing the above

Table 1

Decay channel	Upper limit at 90% CL	
	number of events	branching ratio
$D^0 \to e^+e^-$	7.1	1.7×10^{-4}
$D^0 \to \mu^+\mu^-$	3.1	7×10^{-5}
$D^0 \to e^\pm\mu^\mp$	4.2	1.0×10^{-4}

decays, we generated D^0 mesons using the Peterson fragmentation function with an ϵ parameter of 0.24. The total number of D^0 mesons in our event sample, with $x_p > 0.55$, was calculated using the decay $D^0 \to K^- \pi^+$. The D^0 signal in this channel is shown in fig.2d. With the measured number of $D^0 \to K^- \pi^+$ decays (3323 ± 188), the efficiency η for this decay channel obtained from a detector simulation ($\eta = 0.66 \pm 0.02$) and a branching ratio for $D^0 \to K^- \pi^+$ of ($4.2 \pm 0.4 \pm 0.4$)% [8], we obtain the total number of produced D^0 mesons with $x_p > 0.55$ of

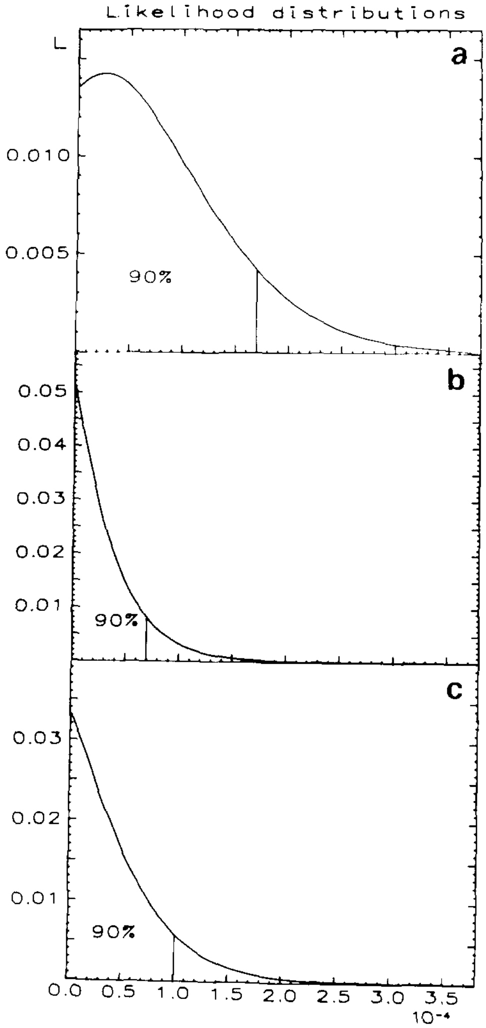

Fig. 3. Likelihood distributions for the D^0 branching ratios: (a) $D^0 \to e^+e^-$, (b) $D^0 \to \mu^+\mu^-$, (c) $D^0 \to e^\pm \mu^\mp$.

Table 2

Decay channel	Experiment	Upper limit at 90% CL
$D^0 \to e^+e^-$	CLEO [9]	2.4×10^{-4}
	E691 [10]	8×10^{-5}
	this analysis	1.7×10^{-4}
$D^0 \to \mu^+\mu^-$	CLEO [9]	2.0×10^{-4}
	E691 [10]	1.0×10^{-4}
	E615 [11]	1.1×10^{-5}
	this analysis	7×10^{-5}
$D^0 \to e^\pm \mu^\mp$	MARK-II [12]	2.1×10^{-3}
	ACCMOR [13]	9×10^{-4}
	MARK-III [14]	1.2×10^{-4}
	E691 [10]	8×10^{-5}
	this analysis	1.0×10^{-4}

$120\,000 \pm 18\,000$ adding the statistical and systematical error in quadrature.

In fig. 3 we show the likelihood functions for the three branching ratios which contain the maximum information available from our experiment. This allows in principle to combine our results with those of other experiments in a consistent way. Using the bayesian approach they lead to the 90% CL upper limits given in table 1. These measurements confirm the existing limits found by other experiments (table 2).

Using a special model of leptoquarks [2] one finds for the D^0 partial decay width into two leptons

$$\Gamma(D^0 \to \ell_1 \ell_2) = \frac{f_D^2 M_D^2}{32\pi} \left(\frac{M_D}{m_u + m_c}\right)^2 \left|\frac{1}{2M_{LQ}^2} \bar{\lambda}_{pq} \lambda_{rs}\right|^2 ,$$

where the coefficients $\bar{\lambda}$ and λ are coupling strengths of a leptoquark to a quark–lepton pair, M_D and f_D are the mass and decay constant of the D^0, respectively. We assume one generation of leptoquarks, i.e. $\zeta = 1$ in ref. [2]. Using our results one derives the following bounds on the mass and coupling of a SU(5)-type scalar leptoquark:

$$M_{LQ} > 0.9\ \mathrm{TeV}\, |\bar{\lambda}_{ue} \lambda_{ce}|^{1/2} \left(\frac{f_D}{100\ \mathrm{MeV}}\right)^{1/2} ,$$

$$M_{LQ} > 1.1\ \mathrm{TeV}\, |\bar{\lambda}_{u\mu} \lambda_{c\mu}|^{1/2} \left(\frac{f_D}{100\ \mathrm{MeV}}\right)^{1/2} ,$$

$$M_{LQ} > 1.0\ \mathrm{TeV}\,(\,|\bar{\lambda}_{u\mu}\lambda_{ce}|^2 + |\bar{\lambda}_{ue}\lambda_{c\mu}|^2\,)^{1/4} \times\left(\frac{f_D}{100\ \mathrm{MeV}}\right)^{1/2} .$$

In conclusion we present upper limits on *flavour-changing neutral currents* and *lepton flavour-violation* in D^0 decays. These results place bounds on the mass and coupling of a new type of particle, the leptoquark, which is predicted in unified theories.

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