

LIMIT ON THE DECAY $D^0 \rightarrow e^\pm \mu^\mp$ †

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ABSTRACT

We have searched for the lepton flavor violating decay $D^0 \rightarrow e^\pm \mu^\mp$ in 204 pb⁻¹ of e^+e^- annihilation data at $E_{cm} = 29$ GeV from the Mark II detector. No candidates were found; we estimate an upper limit on the cross section times branching ratio of $\sigma(e^+e^- \rightarrow D^0, \bar{D}^0; \text{inclusive}) \times \text{BR}(D^0 \rightarrow e^\pm \mu^\mp) < 0.35$ pb at the 90% confidence level. Simple assumptions yield the rough limit $\text{BR}(D^0 \rightarrow e^\pm \mu^\mp) < 2.1 \times 10^{-3}$.

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Recent theoretical ideas¹⁻³ suggest it may be possible to observe the flavor changing reaction $D^0 \rightarrow e^\pm \mu^\mp$ despite current limits on $K^0 \rightarrow e^\pm \mu^\mp$ and $B^0 \rightarrow e^\pm \mu^\mp$. Typical schemes involve an isoscalar pair of scalar leptoquarks with charge $\pm \frac{1}{3}$, G and G_c , which couple charge $\frac{2}{3}$ quarks to charged leptons and charge $\frac{1}{3}$ quarks to neutral leptons. The decay $D^0 \rightarrow e^\pm \mu^\mp$ is allowed (see fig. 1) without introducing diquark couplings that are inconsistent with lower limits on the proton lifetime⁴. Since the leptoquark couplings are Yukawa couplings, strong flavor dependence is expected,² favoring the observation of heavy quark processes like $D^0 \rightarrow e^\pm \mu^\mp$.

We have searched for $D^0 \rightarrow e^\pm \mu^\mp$ (throughout this paper the charge conjugate reaction is also implied) in 204 pb^{-1} of data taken with the Mark II detector at PEP ($E_{cm} = 29 \text{ GeV}$). A detailed description of the Mark II can be found in ref. 5. A brief description of those elements important to this analysis is given here. Two cylindrical drift chambers concentric with the beam line provide charged particle tracking in a 2.35 kG solenoidal magnetic field. The inner vertex chamber contains seven axial sense wire layers; the outer chamber has ten stereo and six axial layers. Together they yield a momentum resolution $\delta p/p = [(.025)^2 + (.01p)^2]^{1/2}$ (p in GeV/c) in the plane transverse to the beam direction.

Immediately surrounding the magnetic coil are eight lead-liquid argon calorimeter modules which cover 64% of the solid angle and have an energy resolution for photons of $\delta E/E \approx .14/\sqrt{E}$ (E in GeV). Surrounding the calorimeter are four layers of steel and proportional tubes, providing in this analysis good muon identification over 45% of the solid angle for tracks with $p > 2 \text{ GeV}/c$.

Hadronic events were selected to have 5 or more charged tracks and a total visible energy (charged and neutral) greater than $\frac{1}{4} E_{cm}$. These charged tracks were required to have a measured momentum less than $16 \text{ GeV}/c$ and a momentum transverse to the beam direction greater than $100 \text{ MeV}/c$. In addition, they were required to pass within 8 cm of the interaction point along the beam direction and within 4 cm in the transverse plane. These criteria were satisfied by 82,000 events.

A further requirement was that the thrust axis, as calculated from the charged tracks, make an angle greater than 45° with respect to the beam direction.

The electron and muon selection criteria have been described previously.⁶ Briefly, an electron candidate is a charged track with $p > 1 \text{ GeV}/c$ that has an associated energy deposition in the liquid argon calorimeter consistent with the track momentum as measured by the drift chamber. For electrons in the fiducial acceptance of the calorimeter, the selection efficiency is 80% at $p \approx 1 \text{ GeV}/c$ and rises to 91% for $p > 2 \text{ GeV}/c$. The probability that a hadron is misidentified as an electron varies from 0.3% to 2.3%, depending on its momentum and proximity to other tracks. Higher momentum or isolated hadrons are less likely to be misidentified as electrons. Contamination due to electrons from photon conversions in the detector and from π^0 Dalitz decays is reduced with a pair-finding algorithm.

Muon candidates are those charged tracks with $p > 2 \text{ GeV}/c$ and one or more associated signals in each of the four layers of proportional tubes. Associated signals are those lying within 2σ of the track as projected from the drift chamber measurement, where σ is the rms extrapolation error due to multiple scattering and drift chamber tracking error. For muons in the fiducial acceptance of the proportional tubes the selection efficiency varies from 78% for $p \approx 2 \text{ GeV}/c$ to 92% for $p > 6 \text{ GeV}/c$. The probability that a hadron will punch through the steel and be misidentified as a muon varies from 0.2% for low momentum isolated tracks to 0.4% for higher momentum tracks in the center of a multitrack jet. In addition to the punchthrough background, a comparable background comes from pion and kaon decays occurring within the detector.

These cuts yield 5587 electron and 1252 muon candidate tracks. Only 93 events survive in which both an electron and a muon candidate appear. The further requirement that the leptons have opposite charges and lie in the same thrust hemisphere leaves 25 $e \mu$ pairs. Figure 2 shows their invariant mass spectrum.

There are no apparent D^0 candidates. To verify this quantitatively, Monte Carlo events (Lund model⁷) were generated in which all produced D^0 's decayed into electron muon pairs, allowing a measure of the detector's resolution function. (Previous measurements have verified the accuracy of invariant mass resolutions derived from the detector simulation.) This function was fit to a gaussian component with $\sigma = 85$ MeV added to an asymmetric component(14%) coming from electron energy loss due to bremsstrahlung in the detector. Total efficiency for detecting $D^0 \rightarrow e^\pm \mu^\mp$ was measured to be $7.8 \pm 0.5\%$.

Backgrounds were estimated from hadronic Monte Carlo event samples generated according to Lund⁷ and Ali⁸ fragmentation schemes. Previous measurements have verified reasonable agreement between the two Monte Carlo programs and the Mark II data. Especially important to this analysis is the good agreement in the electron and muon candidate productions and spectra. Hadrons misidentified as electrons dominate low pair masses (<1.5 GeV/c²) while cascade events (semileptonic decay of b followed by semileptonic decay of c) dominate higher masses. Figure 3 shows a fit to the distribution; the equivalent integrated luminosity is about twice that in the data. From this background estimate, 29 $e \mu$ pairs are expected in the data.

The shape of the data was then fit to a sum of the signal resolution function and the Monte Carlo background shape. A maximum likelihood technique was used in which only the relative contribution from the signal function was allowed to vary. The fitted signal was 13 pairs. Finding the value of the contribution that yielded a log likelihood value .82 units below the maximum value placed a 90% confidence level(C.L.) upper limit of 63 $D^0 \rightarrow e^\pm \mu^\mp$ pairs produced in the detector (after correction for efficiency). Figure 2 shows the fitted sum of background and signal along with the sum associated with the 90% C.L. upper limit.

The upper limit on signal contribution leads to a limit of .31 pb for the neutral D production cross section times $BR(D^0 \rightarrow e^\pm \mu^\mp)$. Systematic and statistical errors arise in determining efficiency, resolution and the total integrated luminosity.

The dominant uncertainty comes from the systematic error on the resolution function. Together, these errors raise the limit by 15%, giving the limit

$$\sigma(e^+e^- \rightarrow D^0, \bar{D}^0; \text{inclusive}) \times \text{BR}(D^0 \rightarrow e^\pm \mu^\mp) < 0.35 \text{ pb} \quad (90\% \text{ C.L.}).$$

The conversion of .35 pb into a branching ratio limit requires knowledge of the total number of D^0 's in the data. This number can be estimated with some reasonable assumptions:

1) Standard model production of c quarks with a 1st order QCD correction: $\sigma(e^+e^- \rightarrow c\bar{c}[g]) = (1 + \alpha_s/\pi) \times N_{color} \times (Q_{charm})^2 \times \sigma(e^+e^- \rightarrow \mu^+\mu^-)$. We use $\alpha_s = .14$.

2) Charmed meson / charm quark production = .80 for primary c quarks (based on Mark II / SPEAR measurement⁹ at $E_{cm} = 5.2 \text{ GeV}$).

3) Relative abundances of primary $D^0 : D^+ : D_s = 1 : 1 : 0.3$ (based on the usual sea quark extraction probabilities).

4) Relative abundances of primary $D^* : D = 3 : 1$ (based on simple spin counting). Relative abundances of $D^{*0} : D^{*+} = 1 : 1$. Higher excited states of the D are not considered; their effect would be to increase the $D^* : D$ ratio.

$$5) \text{BR}(D^{*0} \rightarrow D^0 X) = 1.00; \text{BR}(D^{*+} \rightarrow D^0 X) = .49.^{10}$$

6) Bottom quark production is $\frac{1}{4}$ that of primary charm with 100% $b \rightarrow c$ and assumptions analogous to 2) and 3) for bottom meson and baryon abundances. (Bottom quark decays into two charmed quarks are ignored.)

With these assumptions one finds $\sigma(e^+e^- \rightarrow D^0, \bar{D}^0; \text{inclusive}) = 0.17 \text{ nb}$ and obtains the limit

$$\text{BR}(D^0 \rightarrow e^\pm \mu^\mp) < 2.1 \times 10^{-3}.$$

The neutral D production cross section assumed here is consistent with a previous measurement, $\sigma(e^+e^- \rightarrow D^0, \bar{D}^0; \text{inclusive}) = 0.19 \pm 0.05 \text{ nb}$, by the HRS experiment at PEP.¹¹ That measurement assumed the branching ratio value $\text{BR}(D^0 \rightarrow K^- \pi^+) = 3.0\%$. A more recent measurement by the Mark III experiment at SPEAR, however, found $\text{BR}(D^0 \rightarrow K^- \pi^+) = 5.6 \pm 0.4 \pm 0.3\%$. This would have

reduced the HRS cross section to 0.10 nb, which would change the above limit to $\text{BR}(D^0 \rightarrow e^\pm \mu^\mp) < 3.5 \times 10^{-3}$. A more general discussion of the apparent discrepancy between expected and measured charm production rates in e^+e^- annihilation can be found in ref. 12.

In conclusion, we have placed an upper limit on the production of D^0 's that decay according to the lepton flavor violating mode $D^0 \rightarrow e^\pm \mu^\mp$: $\sigma(e^+e^- \rightarrow D^0, \bar{D}^0; \text{inclusive}) \times \text{BR}(D^0 \rightarrow e^\pm \mu^\mp) < 0.35 \text{ pb}$ (90% C.L.). With simple assumptions concerning D^0 production rates, we have estimated an upper limit on the decay branching ratio. This measurement should place constraints on theoretical models that propose charge $\pm \frac{1}{3}$ leptoquarks with strongly flavor-dependent couplings.

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FIGURE CAPTIONS

- Fig. 1. A possible mechanism for $D^0 \rightarrow e^+ \mu^-$ involving an isoscalar charge $-\frac{1}{3}$ scalar leptoquark G .
- Fig. 2. Mass spectrum of $e \mu$ pairs from the data with fitted background and signal contributions (dotted curve) and with contributions corresponding to the 90% C.L. upper limit quoted in the text (solid curve).
- Fig. 3. Distribution of background $e \mu$ pairs predicted from Monte Carlo simulation. Shown here are nearly equal contributions from Ali and Lund model event generators. The equivalent integrated luminosity is 440 pb^{-1} . The maximum likelihood fit shown is used to fix the shape of the background.

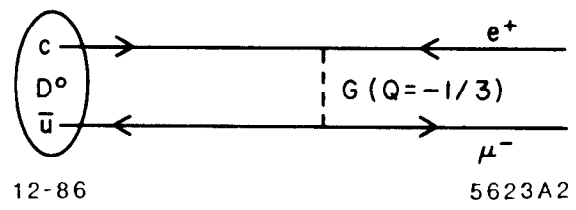
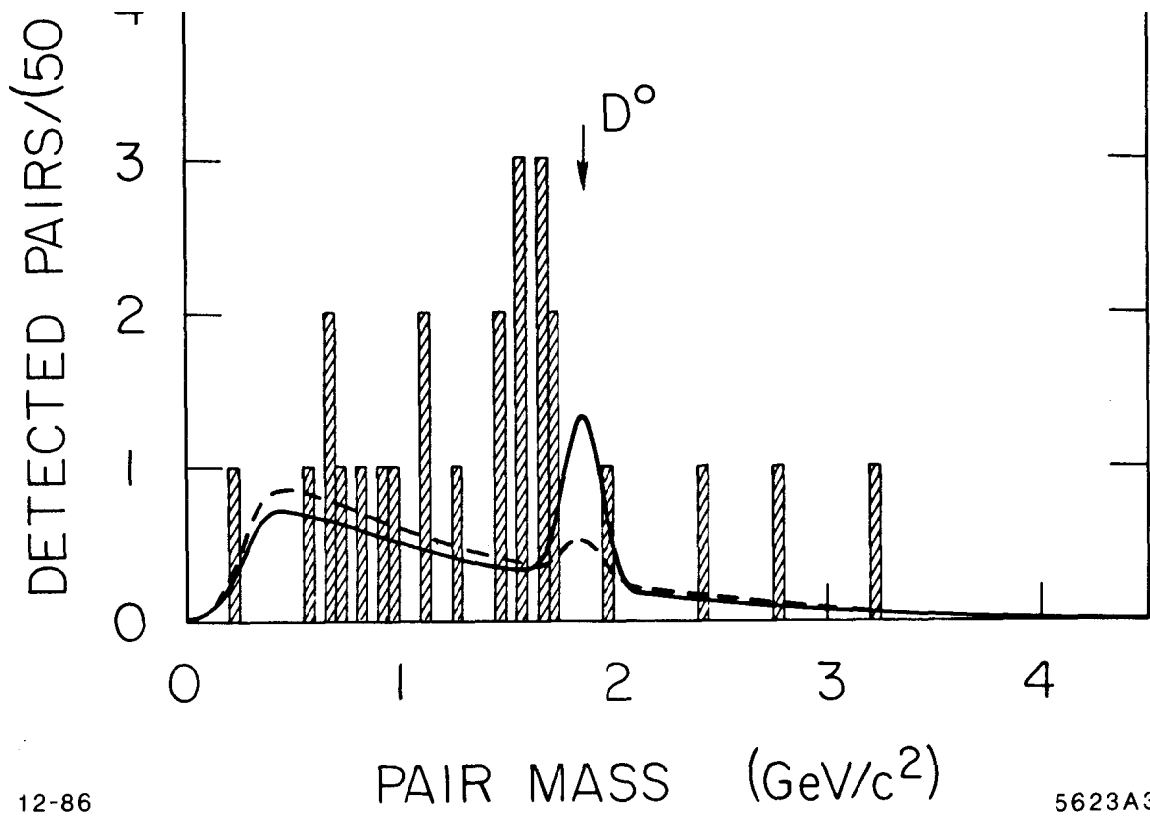


Fig. 1



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Fig. 2

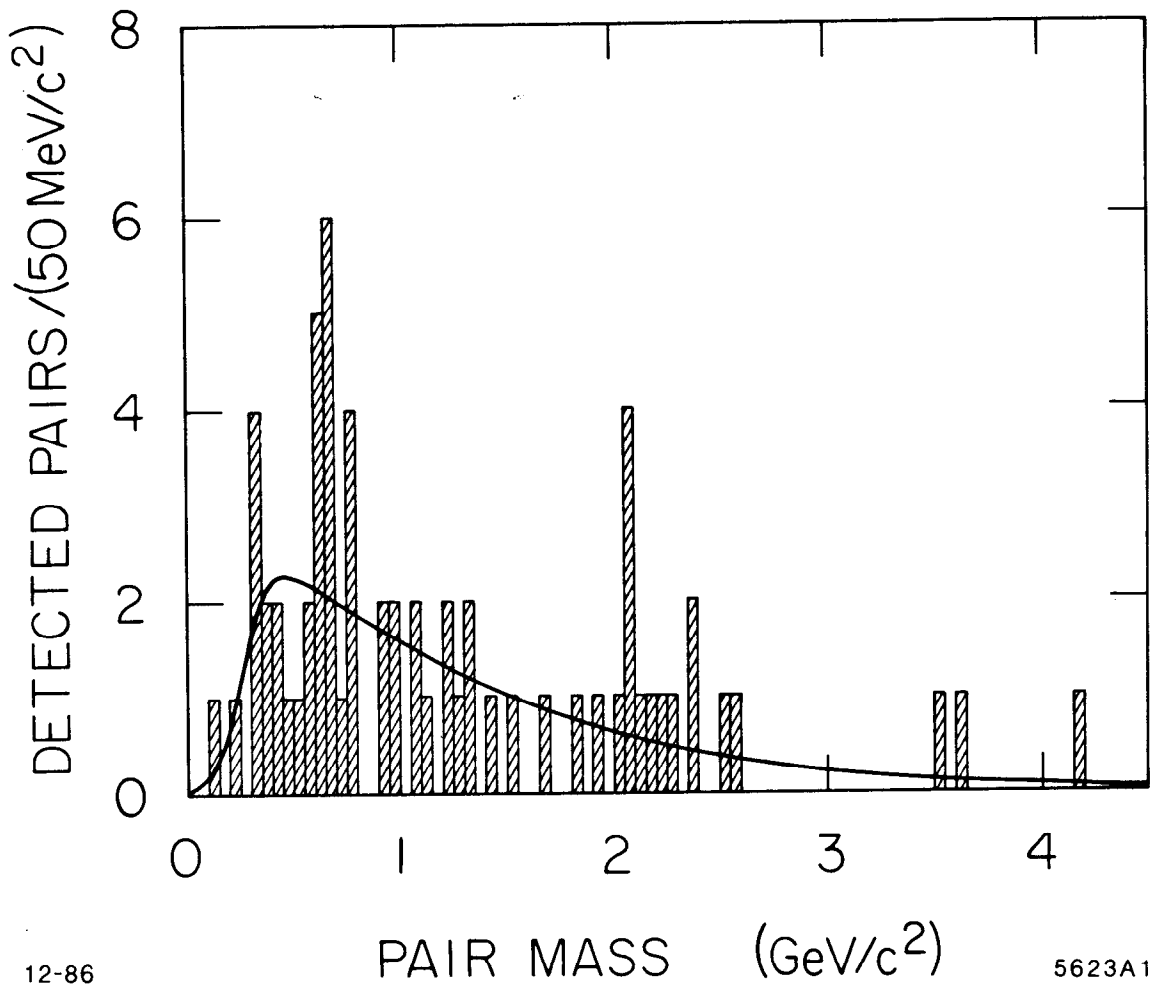


Fig. 3