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A Search for the Decay $D^0 \rightarrow e^+e^-$ †

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Abstract

We report a search for the decay $D^0 \rightarrow e^+e^-$ based on a data sample of 9.6 pb^{-1} collected at the $\psi(3770)$ resonance with the MARK III detector at SPEAR. We find no evidence for this flavor-changing weak neutral current decay and set an upper limit on the branching ratio of $B(D^0 \rightarrow e^+e^-) < 1.3 \times 10^{-4}$ at the 90% confidence level. This limit constrains various extensions of the Standard Model.

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Searches for non-standard processes and new particles at high energies provide sensitive tests of the Standard Model and its extensions. Of particular interest are flavor-changing weak neutral currents (FCNC),[1,2] forbidden in first order in the Standard Model, which allow decays such as $D^0 \rightarrow e^+e^-$ [3] and $D^0 \rightarrow \mu^+\mu^-$ to occur. While decays such as $K_L^0 \rightarrow \mu^+\mu^-$ [4] have been observed at a level of 10^{-8}, limits on charm-changing weak neutral currents are much less stringent.[5] Most extensions of the Standard Model[6] require these processes to occur at a substantial, but model dependent, level. Detection of FCNC at a level in excess of that due to second order processes would provide evidence for "new physics", while highly sensitive limits on branching ratios can be used to constrain parameters of particular theories. We present herein an upper limit on the decay branching ratio of $D^0 \rightarrow e^+e^-$.

The data, collected at the peak of the $\psi(3770)$ resonance with the MARK III detector at the e^+e^- storage ring SPEAR, represent an integrated luminosity of (9.6 ± 0.5) pb^{-1}.[7] The apparatus has been described in detail elsewhere.[8] The D^0 production cross section at this energy is $\sigma_{D^0} = 5.8 \pm 0.5 \pm 0.6$ nb.[9] Since the $\psi(3770)$ lies 40 MeV above $\bar{D}D$ threshold, but below D^* threshold, all D's are produced monochromatically (with momentum $p_{D^0} = 0.27$ GeV/c) in the laboratory frame. In the decay $D^0 \rightarrow e^+e^-$, the electron momentum in the D^0 rest frame is 0.93 GeV/c, which results in a flat momentum distribution between 0.76 and 1.10 GeV/c in the laboratory frame.

The data are searched for electron-positron pair candidates originating from a D^0 by the following steps: the leptons are identified, cuts are applied on their kinematic properties and on the event multiplicity, and then the invariant mass distribution of the e^+e^- pair candidates is studied. This procedure closely follows that used in our previous analysis of the decay $D^0 \rightarrow \mu^\pm e^\mp$.[10]

Information from the drift chamber, from the time-of-flight (TOF) scintillation counters and from the shower counter is used for particle identification. The separation of electrons from pions is achieved by use of a recursive partitioning algorithm, which utilizes the shape of the shower in the finely segmented barrel shower counter and the TOF measurements.[11] Within the geometrical acceptance, this procedure rejects 96% of pions with $p > 0.75\,\text{GeV}/c$, while retaining 89% of electrons.

The data sample is reduced by restricting the momenta of the individual electrons to $0.5 < p < 1.3\,\text{GeV}/c$, the total pair momentum to $0.1 < p_{e^+e^-} < 0.45\,\text{GeV}/c$ and the laboratory opening angle of the pair to $cos(\alpha) < -0.91$. Particle identification and these kinematical criteria reduce the data sample by three orders of magnitude, leaving 502 candidate events, while losing less than 4% of a $D^0 \rightarrow e^+e^-$ signal, as determined by Monte Carlo simulations.

The principal sources of background to the decay $D^0 \rightarrow e^+e^-$ are: (1) Bhabha-scattering with additional photons arising either from final state radiation or from bremsstrahlung in the detector; (2) charged hadronic two-body D^0 decays, in which hadrons are misidentified; and (3) τ pair production with electrons from leptonic τ-decays or pion "punchthrough" from the $\pi\nu$ and $\rho\nu$ decay chains. Higher multiplicity D^0 decays with electrons or misidentified hadrons constitute a negligible fraction of the background, as do two-photon processes.

Since both the radiative Bhabha-scattering events and the decays from τ-

pair production have a lower total charged particle event multiplicity (N_{ch}) than $D^0\bar{D}^0$ decays, the requirement $N_{ch} > 3$ eliminates most of these backgrounds (see Figure 1). Eight events remain.

The remaining major background source is hadronic charged two-body D^0 decays. Background from misidentified $D^0 \to K^-\pi^+$ decays appears as $D^0 \to e^+e^-$ at lower invariant mass, whereas the Cabibbo-suppressed decays $D^0 \to \pi^+\pi^-$ lie at mass values very close to the D^0 mass (see Figure 2). Candidate pairs are rejected if their invariant mass differs from the nominal D^0 mass by more than 0.05 GeV$/c^2$, which corresponds to $\pm 2\sigma$ in the mass resolution.[12] This rejects the misidentified $K^-\pi^+$ events but not the $\pi^+\pi^-$ events, which persist as a background with an estimated contribution of 0.03 ± 0.01 events. As can be seen in Figure 2, no $D^0 \to e^+e^-$ candidate events fall within ± 0.05 GeV$/c^2$ of the D^0 mass, leading to an upper limit on the $D^0 \to e^+e^-$ branching ratio.

The detection efficiencies for the $D^0 \to e^+e^-$ decay mode and for the background channels are determined by a Monte Carlo simulation of the detector and by an analysis of observed $D^0 \to K^-\pi^+$ decays in the same data sample. The probability of observing more than 3 charged particles per event, $(83.6 \pm 1.3 \pm 0.5)\%$, is determined from a study of the N_{ch} distribution of the data with a $D^0 \to K^-\pi^+$ tag (see Figure 1). The resulting total efficiency for detection of the $D^0 \to e^+e^-$ mode is $(37.9 \pm 0.6 \pm 1.5)\%$.

Radiative corrections have a negligible effect on the efficiency. The contribution of initial state radiation is expected to be the same (to lowest order) for the e^+e^- and $K^-\pi^+$ final states. Energy loss due to bremsstrahlung of the electron in the detector is taken into account in the Monte Carlo simulation. Final state radiation results in a relative loss of efficiency of less than 1.5%,[13] which has been included in the systematic error on the efficiency.

The main contribution to the systematic error is the uncertainty of 9.4 % in the total number of produced $D^0\bar{D}^0$ events. Additional systematic uncertainties arise from tracking and particle identification efficiency (2% per electron track).

After all analysis requirements have been imposed, no significant background contributions remain. The observation of zero events of the type $D^0 \rightarrow e^+e^-$ yields a 90% confidence level (C.L.) upper limit of 2.3 on the total number of signal and background events. The total statistical error (8.8%) and all separate systematic errors are added linearly to obtain the total relative error. This procedure increases the upper limit from 2.30 to 2.81 events. Employing the total number of $27700 \pm 2400 \pm 2600$ produced $D^0\bar{D}^0$ events[9], an upper limit on $\mathrm{B}(D^0 \rightarrow e^+e^-)$ of 1.3×10^{-4} at the 90% C.L. is obtained.

This upper limit may be used to constrain parameters of various extensions of the Standard Model. In a particular model where $D^0 \rightarrow e^+e^-$ is mediated by scalar leptoquarks,[6] a lower bound on their mass is calculated to be approximately 1 TeV for a D decay constant of $f_D = 0.2$ GeV, assuming a constant matrix element and a constant coupling (both set to unity).

In a low-energy dynamical model inspired by superstrings,[6] we can derive bounds on the Yukawa superpotential couplings. If the decay $D^0 \rightarrow e^+e^-$ proceeded through the exchange of scalar Higgs particles, then we would obtain an upper limit of $(\lambda_1 \cdot \lambda_2)^{1/2} < 0.06$ for the Higgs couplings λ_i, assuming $f_D = 0.2$ GeV and a Higgs mass of $\mathrm{m}_H = 100\ \mathrm{GeV}/c^2$.

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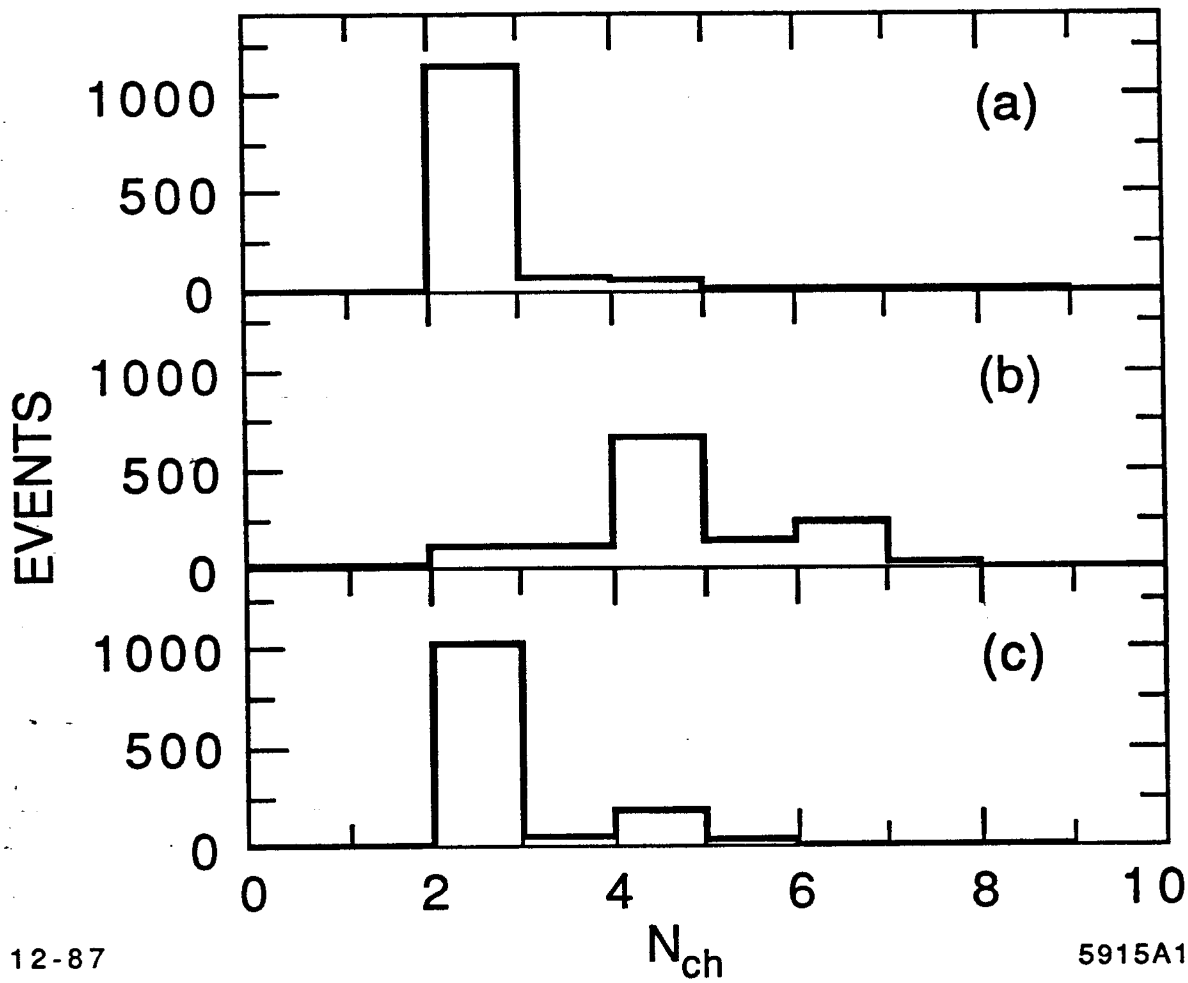
FIGURE CAPTIONS

1. Distribution of the total number of charged particles in the event, N_{ch}, for (a) e^+e^- candidate events, (b) reconstructed $K^-\pi^+$ events (representing the expected e^+e^- distribution) and (c) Monte Carlo simulated $\tau^+\tau^-$ events. No kinematical constraints have been applied.

2. Distribution of the invariant mass of Monte Carlo simulated D^0 decays of the type e^+e^- (solid line), $K^-\pi^+$ (dashed line) and $\pi^+\pi^-$ (dotted line). Kinematical constraints and the multiplicity cut have been applied. In the $K^-\pi^+$ and $\pi^+\pi^-$ cases all tracks are assumed to be electrons. Each histogram contains the same number of events. The two $D^0 \rightarrow e^+e^-$ candidate events that fall within the mass range of the figure are indicated by the hashed bins. The other six candidate events lie outside.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500
0
(a)
1000
500
0
(b)
EVENTS
1000
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0
(c)
0
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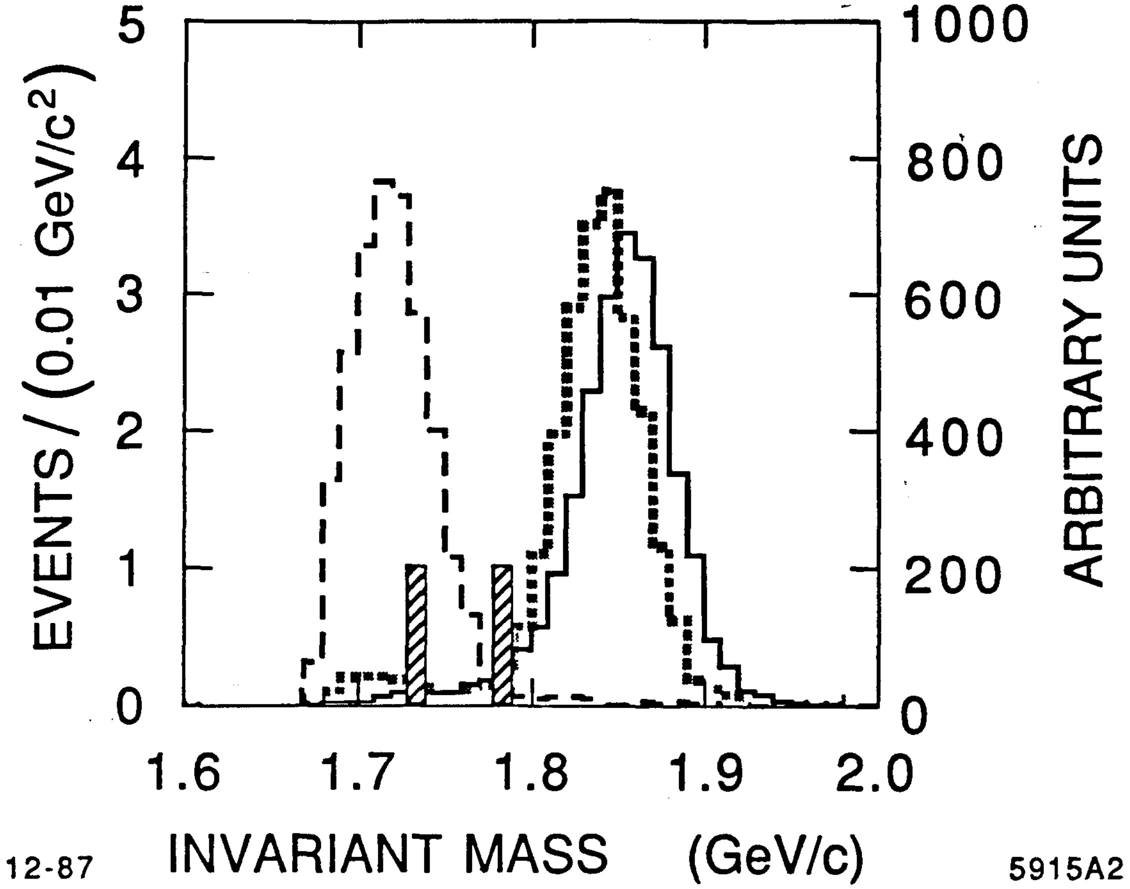
4
6
8
10
12-87
N_{ch}
5915A1

Fig. 1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4
3
2
1
0
1000
800
600
400
200
0
EVENTS / (0.01 GeV/c^2)
ARBITRARY UNITS
1.6
1.7
1.8
1.9
2.0
12-87
INVARIANT MASS (GeV/c)
5915A2

Fig. 2