SLAC-PUB-4809
November 1988
(T/E)

Rare Decays of Charmed D Mesons*

Christoph Grab[+]

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94309

Abstract

We summarize the results of searches for rare decays of the charmed D mesons, based on a data sample of 9.3 pb^{-1}, collected with the MarkIII detector at $\sqrt{s}$ = 3.77 GeV at the e^+e^- storage ring SPEAR. We searched for flavour-changing weak neutral currents and for lepton family number violation in the D°-decay modes $D^\circ \to \mu e$, $D^\circ \to e^+e^-$ and $D^\circ \to K^\circ e^+e^-$. No candidates were observed at a sensitivity to the branching ratios at the 10^{-4} level. Since couplings of many new intermediate particles in models beyond the Standard Model are expected to be flavour-dependent, these searches in the charmed sector are complementary to the ones performed with leptons and with K- or B-mesons.

1. Introduction

The Standard Model (SM) is a remarkable theory with up to now no experimental results contradicting its predictions. Extensive experimental tests of the SM and its extensions include searches for non-standard processes and possible manifestations of new particles. Of particular interest are flavour-changing weak neutral currents (hereafter referred to as FCNC). The SM does not allow any first order transitions between $c \leftrightarrow s$ or $s \leftrightarrow d$ quarks, and thus does not permit FCNC. Processes of this type can either be lepton family number conserving (LFNC such as $D^\circ \to e^+e^-$) or lepton family number violating (LFNV e.g. $D^\circ \to \mu e$). However, final states identical to the ones occurring through LFNC processes may also be produced within the SM through an interplay of higher order electromagnetic and weak interactions, whereas the occurrence of LFNV-processes are completely forbidden in the SM (with zero neutrino masses) and can-

*Work supported in part by the National Science Foundation and by the Department of Energy contracts DE-AC03-76SF00515,DE-AC02-76ER01195,DE-AC03-81ER40050 and DE-AM03-76SF00034.

+ Representing the MarkIII collaboration.

Invited talk presented at the Rare Decay Symposium
Vancouver, Canada, November 30 - December 3, 1988

not be faked by other processes.

Most extensions of the SM (e.g. models with heavy Higgs, with Technicolour, with Leptoquarks[1] or Superstring-inspired phenomenological models[2]) require both types of FCNC to occur at a substantial, but model-dependent level. Detection of FCNC's at a level in excess of that due to second-order standard processes would provide evidence for "new physics", while already highly sensitive limits on branching ratios can be used to constrain parameters of particular theories.

While sensitivities in the K-meson decays have reached the 10^{-8} level, limits on charm-changing neutral currents are much less stringent. However, since many models predict flavour-dependent couplings of new intermediate particles, searches in the charm sector are complementary to the work done with leptons and with K- or B-mesons. In particular cases[1], s- and b-changing currents could be suppressed or even forbidden, relativ to c-changing currents.

The FCNC reactions under consideration here are the exclusive decays of the D°-meson in the LFNV decay $D^\circ \rightarrow \mu e$, and the LFNC decays $D^\circ \rightarrow e^+e^-$ and $D^\circ \rightarrow K^\circ e^+e^-$. The two-body decay $D^\circ \rightarrow e^+e^-$ is expected to be helicity suppressed within certain models. The addition of a third particle (in this case a K) removes this suppression and hereby may result in detectable decay rates. Apart from their sensitivity to more exotic models, these decays provide a direct test of the SM itself.

2. The Experiment

The data, collected at the peak of the $\psi''(3770)$ resonance with the MarkIII detector[3] at the SLAC e^+e^- storage ring SPEAR, represent an integrated luminosity of 9.6 ± 0.5 pb^{-1}, which corresponds to about 55000 produced D° mesons. Since the ψ'' lies 40 MeV above $D\overline{D}$ threshold, but below $D\overline{D}^*$ threshold, it decays nearly exclusively into $D\overline{D}$. This provides several advantages for increasing the background rejection over experimental techniques employed by other experiments[4], e.g. CLEO[5] or ARGUS[6], which look at fast D's originating from $D^* \rightarrow \pi D$ decays. Since in the case of the ψ'' the D's are produced monochromatically nearly at rest, the momenta of the leptons in the two-body decays show a rather narrow flat spectrum. Exploiting the information from E_{cm}, a resolution of 2.25 MeV/c^2 is obtained for the beam-constrained invariant mass, as compared to 25 MeV/c^2 in the standard invariant mass variable. Thus even though other experiments reach similar sensitivities for branching ratios, they tend to suffer from much higher background.

Since the analysis methods are very similar for all three modes discussed here, I shall outline the common concept and point out the differences later. The following procedure leads to the isolation of candidate events :

(1) All possible charged tracks are reconstructed and tested for being leptons. In all three modes, the lepton identification is a very crucial point. Electrons are separated from pions by the use of a recursive partitioning algorithm, based on the TOF counter and the shower counter information. In the momentum range of 0.5 to 1.5 GeV/c this procedure retains about 90% of the electrons, while re-

jecting 96% of the pions with momenta above 0.75 GeV/c. Muon candidates must have a TOF within 1.4 ns of the predicted one. Muon candidate tracks must be uniquely identified by the muon system, providing >90% rejection of pions, kaons and punchthroughs. The muon detection efficiency exceeds 90% above 0.9 GeV/c. To increase the acceptance, tracks outside the muon-system range are also called muons, if they deposite less than 0.3 GeV in the shower counter.

(2) We identfy and estimate background contributions either by Monte Carlo simulation or by comparison with well-known measured decays in the same data set. The signal-to-background ratio then is improved by applying a series of kinematical requirements. One of the background sources feeding into both decay modes $D^\circ \to \mu e$ and $D^\circ \to e^+e^-$ through particle misidentification are hadronic charged two-body decays such as $D^\circ \to K^- \pi^+$ and $\pi^+ \pi^-$. These contributions are suppressed by kinematic requirements and can be identified as reflections to lower masses in the invariant mass distributions (see e.g. in fig. 2).

The direct production of $\tau^+\tau^-$ - pairs, which consequently decay to leptons (directly into $l\nu\bar{\nu}$ or through π or ρ intermediate states) can fake final states like the ones looked for. However, their total event charged particle multiplicity $N_{charged}$ is in average lower than in the charmed decay modes, where the opposite D-meson decays predominantly to charged tracks. In addition, the $\tau^+\tau^-$ events show a significantly higher missing energy in the total event, since there are always at least two neutrinos escaping undetected. The third important background source (particularly important in the $D^\circ \to e^+e^-$ case) originates from radiative Bhabha-scattering events. Events of this type are suppressed through a requirement on the minimal number of charged tracks in the events.

(3) We study a key quantity such as the invariant mass M_{inv} or the beam-constrained invariant mass M_{BC} of the candidate decay channel. A signal or an upper limit on the number of signal events is obtained from the relevant mass region, where relevant means within two sigma (of the resolution) of the nominal D°-mass.

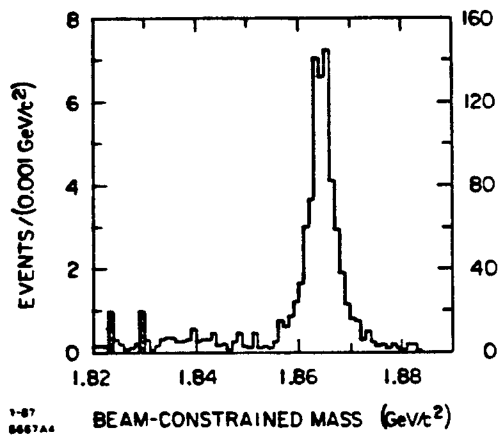

Fig. 1: M_{BC} distribution of $D^0 \to K^-\pi^+$ events. Superimposed (hashed) are the two closests $D^0 \to \mu e$ candidate events.

(4) An upper limit on the branching ratio is determined by normalizing the upper limit on the number of signal events to the efficiency and the total number of produced D°-mesons. The detection efficiency is calculated from Monte Carlo simulation for the kinematical requirements. For the efficiency of the $N_{charged}$ -cut the multiplicity distributions of well-known decay channels (e.g. $K\pi$ or $K\pi\pi\pi$) within the same data sample are studied. In the

numbers quoted below, both the statistical and systematical errors have been folded linearly into the upper limit on the number of events in a conservative way. The largest contribution to the error comes from the uncertainty in the number of D°-mesons.

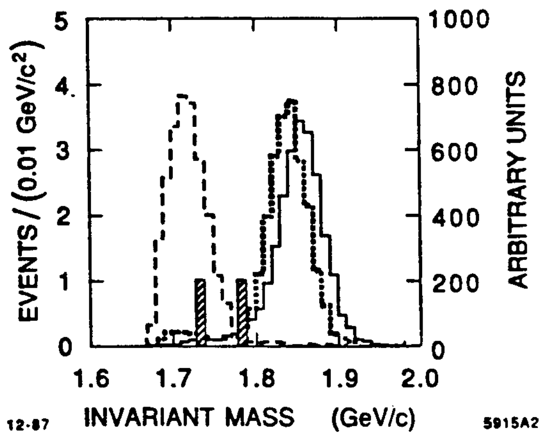

Fig. 2: M_{inv} distribution of Monte Carlo generated $D^\circ \to e^+e^-$ (solid), $K^-\pi^+$ (dashed), and $\pi^+\pi^-$ (dotted) events. The hashed bins represent the two closests $D^\circ \to e^+e^-$ candidates.

3. Results

The beam-constrained mass distribution in the search for the decay mode $D^\circ \to \mu e$ does not yield any candidate events within 2σ of the nominal D-mass (see fig. 1). after applying cuts on the invariant mass ($\pm 2\sigma$) and on the missing energy (< 1GeV *for two-prong events only*). The background sources are expected to be negligible (below the 0.1 event level). With a detection efficiency of 43%, this yields an upper limit on the decay branching ratio of $B(D^\circ \to \mu e) < 1.2{*}10^{-4}$ at 90% C.L.[7]

In the case of the $D^\circ \to e^+e^-$ decay channel, the restriction ($N_{charged} > 3$) on the particle multiplicity with an efficiency of 84%, and kinematical cuts are sufficient to reduce the background to below the 0.1 event level. Having not observed a single candidate in the prospective mass range (fig.2), and based on an efficiency of 38%, we obtain an upper limit of $B(D^\circ \to e^+e^-) < 1.3{*}10^{-4}$ at 90% C.L.[8]

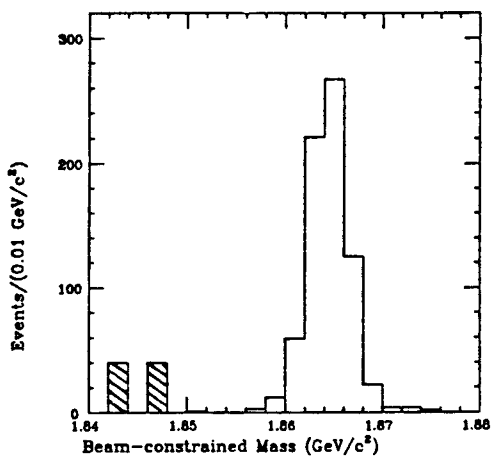

Fig.3: M_{BC} distribution of Monte Carlo generated $D^\circ \to K^\circ e^+e^-$ events. The two closests candidate events are indicated by the hashed bins.

In the case of $D^\circ \to K^\circ e^+e^-$, the K° is detected through the decay mode $K_s \to \pi\pi$. For this purpose, all charged tracks are treated as pions. All 2-π combinations are kinematically fitted to the $K \to \pi\pi$ hypothesis. Combinations with a $P(\chi^2) > 1\%$ and a detached vertex are retained as K° candidates. Events with a $|\cos(p_k, p_e)| > 0.95$ are removed. In this decay mode, another backgound source becomes important. The decay $D^\circ \to K^\circ\pi\pi$, where both pions are misidentified as electrons, is found to contribute to 0.25 events. After a cut on the invariant mass M_{inv} ($m_D \pm 2\sigma$) and on the event multiplicity ($N_{charged} > 5$), there are no candidates within 2σ of the D-mass in the beam-constrained mass distribution (see fig.3). Folding in the K_s production rate and its decay branching ratio, we obtain an upper limit of $B(D^\circ \to K^\circ e^+e^-) < 1.7*10^{-3}$ at 90% C.L.[9]

4. Implications

By choosing a particular theoretical model, the above limits on the branching ratios may be translated into constraints on masses of intermedidate particles, assuming values for their couplings to quarks or leptons or vice versa. In the following we assume a constant matrix element and use $f_D = 200$ MeV for the D-decay constant. For unity coupling, the mass of scalar leptoquarks[1], mediating the decays $D^\circ \to \mu e$ and $D^\circ \to ee$, is bound to lie above 1 TeV/c^2.

In the superstring-inspired phenomenological model of ref. [2], where $D^\circ \to \mu e$ and $D^\circ \to ee$ proceed through the exchange of scalar Higgs particles $(H,\overline{H})$, we determine an upper limit of $(\lambda_1\lambda_2)^{1/2} < 0.06$ for the Higgsboson couplings λ_i, assuming $m_H = 100$ GeV/c^2. If on the other had, within the same model, the process $D^\circ \to K^\circ e^+e^-$ proceeds through the exchange of massive colour triplets $\underline{D}$ and $\underline{D}^c$, with masses of say also 100 GeV/c^2, we obtain information on their Yukawa superpotential coupling strength λ_8 and λ_9. For a $B(D^\circ \to K^\circ \mu\nu) = 7\%$, we find λ_8 and $\lambda_9 < 0.5$, respectively. By comparison, the decay $K^\circ \to \mu\mu$ ($B \approx 10^{-8}$) results in a similar limit on λ_9, namely $\lambda_9 < 0.6$ (it does not give any information on λ_8). B°-$\overline{B^\circ}$ mixing and the decay $\mu \to e\gamma$ both result in limits for λ_9 around 0.1.

5. Conclusions

The MarkIII collaboration has, among other experiments, searched for flavour-changing neutral currents in the decay of D-mesons. No signal events have been observed sofar, yielding upper limits on the branching ratios of the order of 10^{-4}, which is similar to the sensitivity reached in B-decays, but still far below the one in μ-decay or K-decay experiments. Since our sensitivity is presently limited by statistics only, one may expect to reach a level of 10^{-5} to 10^{-6} in the future.

Since the couplings involved in such decays are unknown and probably flavour-dependent, separate searches in the different flavour sectors remain complementary tools to challenge the SM and and explore the regions beyond.

References

[1] W.Buchmuller and D. Wyler, Phys. Lett. **B**177, 377 (1986).

[2] B.A. Campbell *et al.*, Int. J. Mod. Phys. **A2**, 831 (1987).

[3] D.Bernstein *et al.*, Nucl. Instrum. Methods 226, 301 (1984).

[4] For a comparison see e.g. C.Grab, in Proceed. of Int. EPS-conf. Uppsala, V1, 349 (1988).

[5] P.Haas *et al.*, Phys.Rev.Lett. 60,1616 (1988).

[6] H.Albrecht *et al.*, Phys.Lett. **B**209, 380 (1988).

[7] J.J.Becker *et al.*, Phys. Lett. **B** 193, 147 (1987); J.Adler *et al.*, Phys. Lett. **B**198, 590 (1987).

[8] J.Adler *etal.*, Phys. Rev. **D**37, 2023 (1988).

[9] J.Adler *et al.*, SLAC Pub. 4671, (1988).