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LIMITS ON RARE D–MESON DECAYS*

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ABSTRACT

The latest results from a number of experiments on searches for rare decays of the charmed D-mesons are summarized. This talk reports on upper limits on flavour changing weak neutral current reactions and on processes that do not conserve the lepton family number.

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1. Introduction

The Standard model (SM) is a very remarkable theory with up to now no experimental results contradicting its predictions. Extensive experimental tests of the SM and its extensions include the search for new processes and unknown particles at high energies, precision measurements of key quantities at low energies, and sensitive searches for non-standard processes. Of particular interest are weak neutral currents that change hadronic flavours (hereafter referred to as FCWNC),[1] e.g. $D^0 \to \mu^+\mu^-$, and reactions that do not conserve the lepton-, or lepton family number (LFNVR hereafter),[2] like $D^0 \to \mu^\pm e^\mp$. The SM does not allow any first order transitions between $c \leftrightarrow u$ or $s \leftrightarrow d$ quarks, and thus does not allow FCWNC. However the same final states may occur through an interplay of electromagnetic and higher order weak interactions. Recall for example, that the decay $K_S^0 \to \mu^+\mu^-$ has actually been measured[3] with a branching ratio of $(9.1 \pm 1.9) \cdot 10^{-9}$. On the other hand, the occurrence of LFNVR are completely forbidden in the SM (with zero neutrino masses) and cannot be faked by other allowed processes.

Most extensions of the SM (e.g. models with heavy Higgs, with Technicolour or Leptoquarks; Supersymmetry ; composite models; superstring inspired models etc.) require these processes to occur at a presently unknown level. The detection of either FCWNC or LFNVR would indicate the presence of "new physics", and sensitive limits on branching ratios can be used to put stringent constraints on the parameters of particular theories.

Apart from purely leptonic processes, the efforts up to now have concentrated on looking for such processes among systems containing strange and bottom quarks (i.e. K- and B-decays). Recent theoretical suggestions,[4] such as the possibility of flavour dependent couplings which in particular cases could suppress s- and b-changing currents and even enhance c-changing currents, have motivated numerous experiments to search their data sets for such rare processes (FCWNC, LFNVR). The reactions under consideration here are the *exclusive* decays[5] $D^0 \rightarrow l\bar{l}'$, $D^+ \rightarrow \pi^+ l\bar{l}'$ and the *inclusive* reactions $c \rightarrow Xl\bar{l}$, where l, l' are electrons or muons.

2. The Experiments

All reported analyses deal with exclusive decay channels, with the exception of two inclusive studies performed by the CLEO group. The analysis procedures to isolate rare decay modes of the D are very similar in all experiments discussed here.[6] Therefore I shall first outline common concepts, then point out the differences between the experiments and finally summarize the results. A typical analysis consists of the following steps (illustrated for the decay $D^0 \rightarrow \mu e$):

a) Reconstruct all possible tracks, identify the leptons (i.e. μ, e) and apply kinematical constraints to the lepton candidates;

b) Scan for lepton ($\mu - e$) combinations to form the hypothetical parent meson (D) by studying the distribution of a key quantity like the invariant mass;

c) Estimate background contributions either by Monte Carlo simulation or by comparison with other data sets (e.g. identical sign lepton combinations

$e^{\pm}\mu^{\pm}$); Background events mainly arise from either misidentification of π or K as e or μ, or from real leptons originating from semileptonic D-decays or from non-charm sources (e.g. τ -decays);

d) Obtain a signal or an upper limit on the number of signal events, N_{90}, by either counting events in the relevant mass region around the D- meson mass (done by the ACCMOR, ARGUS and MARKIII groups), or by fitting the distribution to the decay hypothesis, assuming a Gaussian shaped signal and typically a polynomial or exponential distribution for the background (done by all other experiments);

e) Calculate the detection efficiency ϵ, e.g. from Monte Carlo simulations;

f) Obtain the branching ratio by normalizing N_{90} to the efficiency ϵ and to the total number of produced D-mesons N_D, which can be obtained in two ways. One way is to directly observe events (N_i) of an allowed decay channel i with well known branching ratio (B_i). Together with their detection efficiency ϵ_i these numbers determine N_D. This has been done by the ACCMOR, the ARGUS, the CLEO, the E691 and the MARKIII collaboration, using decays like $D^0 \rightarrow K^-\pi^+$ and $D^+ \rightarrow K^-\pi^+\pi^+$. The second method requires knowledge of the D production cross section σ_D, which can be calculated with reasonable assumptions on the D-production mechanism and/or on the fragmentation models. By multiplying with the total measured luminosity one then obtains N_D. This method was applied by the E615 and the MARKII collaboration, and by the CLEO group in their inclusive analysis.

The main differences between the various experiments lie in the D-production mechanisms, the amount of data collected, the background treatment, and the way the normalization is performed.

A data sample of 255 pb^{-1} at the $\Upsilon(1s)$, the $\Upsilon(2s)$ and in the continuum was collected by the ARGUS collaboration in e^+e^--annihilation. ARGUS employs the $D^* - D^0$-tagging method to find the correct particle correlations. Having not observed any candidate events for non-standard modes, it obtains the upper limits by normalizing directly to a total of 1290 observed $D^0 \to K^-\pi^+$ decays.

The E615 collaboration uses its prescaled trigger sample, which constitutes 122630 μ-pairs, produced in πp, with $p_\pi = 255$ GeV/c. As they do not observe open charm, they normalize to the decay $J/\psi \to \mu^+\mu^-$. To deduce their limit on $D^0 \to \mu^+\mu^-$, they take the average σ_D from other experiments with $\sigma_{D^0} = \sigma_{D^+}$, and assume the following dependence of the D-production distribution on Feynman x_F and p_T: $(d\sigma^2/dx_F dp_T^2) \sim (1 - x_F)^3 \cdot exp(-p_T^2)$.

The MARKII group uses a total integrated luminosity of 204 pb^{-1}, collected at $E_{CM} = 29$ GeV in e^+e^--annihilation. They find an upper limit of 63 candidates at the 90% confidence level (c.l.) for the decay $D^0 \to \mu^\pm e^\mp$, at an expected contribution of 29 background events.

The conversion into a limit on B is based on the following assumptions: 1) standard model production of c-quarks with a 1^{st} order QCD correction; 2) (c-meson/c-quark)-production = 0.8 for primary c-quarks; 3) relative abundances of D's and D^*'s,($D^0 : D^+ : D_s = 1 : 1 : 0.3$; $D^* : D = 3 : 1$; $D^{*0} : D^{*+} = 1 : 1$); 4) D^* branching ratios : $B(D^{*0} \to D^0 X) = 1$; $B(D^{*+} \to D^0 X) = 0.49$; 5)

b-quark production is 0.25 that of primary charm with 100% $b \to c$; 6) analogous ratios for bottom meson and baryon abundances.

The ACCMOR spectrometer, used to accumulate data from a 200 GeV/c π-beam interacting in a Be-target, does not have the capability to distinguish between pions and muons, and therefore all π's are treated as μ-candidates. Three $D^0 \to \mu^{\pm}e^{\mp}$candidate events are observed within $\pm$ 45 MeV of m_D. A background of 3 events is extracted from a comparison with likesign particle combinations. The calculation of the acceptance is based on the same dependence of $\sigma(x_F, p_t^2)$ as given above for E615. The normalization is done with 74 decays of the type $D^+ \to \bar{K}^{0*}e^+\nu_e$ with $\bar{K}^{0*} \to K\pi$, and with their own measured $\sigma_{D^0}/\sigma_{D^+}$ ratio of 1.5.

The MARKIII collaboration's data sample is based on 9.3 pb^{-1} gathered at the ψ'', produced in e^+e^-, corresponding to 27700 $D^0\bar{D}^0$. With an expected background contribution of 0.18 events through particle misidentification in Cabibbo suppressed D-decays, they do not see any signal candidates within $\pm$5.5 MeV of m_D. The number of totally produced D's is extracted from the absolute branching ratio analysis and employed to obtain a limit on $D^0 \to \mu^{\pm}e^{\mp}$.

The CLEO group has collected 77 pb^{-1} at the $\Upsilon(4s)$, 33 pb^{-1} at the $\Upsilon(3s)$ and 36 pb^{-1} in the e^+e^- continuum between the 4s and 3s. For the analyses of exclusive decay channels they combine all well identified leptons with any other tracks and search for an excess of combinations in the mass spectrum. The $\sim$ 2000 observed $D^0 \to K^-\pi^+$- and $D^+ \to K^-\pi^+\pi^+$-decays are used for normalization.

CLEO's study of the inclusive decay modes uses only the continuum data, corresponding to ≈ 47100 charm events, to avoid contamination from Υ-resonance related lepton-production. Here only well identified leptons are included in the search for an excess of dilepton events.

The calculation of background contributions - mainly from semileptonic decays and hadron misidentification - to the dilepton yields $(\mu^+\mu^-, e^+e^-)$ is checked by a comparison of the expected (3.8) to the observed (4) $(\mu^\pm e^\mp)$-yield, with the a priori assumption that the μe-channel is completely absent. Only about 3 to 5 dilepton events exceed the background contributions. To derive an upper limit on the inclusive decays they assume $\sigma_{charm} = 0.4 \cdot \sigma_{tot}^{cont}$ and use the spectator model to calculate the efficiency.

The results presented by the Tagged Photon Spectrometer collaboration (E691) are based on about 50% of their total data sample of 10^8 triggers. The D-mesons are produced with a γ-beam at $< E_\gamma >= 145$ GeV, and the overall normalization is done relative to the decay $D^0 \to K^-\pi^+$. In the preliminary fit to the mass distributions, the central value of a possible signal was constrained to positive values, after a vertex separation cut, individually chosen for each decay channel according to the expected background contributions of about 1 to 2 events/5 MeV.

The various results, summarized in table I, are upper limits at the 90% confidence level (C.L.) on the relative branching ratio of the decay channel in question to all possible decay modes. All numbers shown in the table are based on the latest absolute branching ratios,[7] determined by the MARKIII collaboration.

4. Conclusions

Within roughly half a year, the sensitivity for LFNVR and FCWNC in the decay of D-mesons was increased to the 10^{-4}-level and thus has reached about the same sensitivity as in the rare B-decays. Experiments with kaons do some 10^4 times better, but still lie above the limits on rare muon decays, which are at the 10^{-12}-level. Within the next few years, experiments are most likely to increase the sensitivity to rare D-decays to the 10^{-6}-level, limited only by statistics, since background contributions are predictable and are not anticipated to impose a big problem.

No hints for any non-standard behaviour have been observed, leaving the quest for flavour changing weak neutral currents and lepton family number violation open to experimental adventure and to theoretical speculation.

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Upper Limits on D-meson decays		
Mode$^\diamond$	B (90% C.L.)	Reference
$D^0 \to \mu^+\mu^-$	$2.0 * 10^{-4}$	CLEO 87
$D^0 \to \mu^+\mu^-$	$1.0 * 10^{-4}$	E691 87
$D^0 \to \mu^+\mu^-$	$8.0 * 10^{-5}$	ARGUS 87
$D^0 \to \mu^+\mu^-$	$1.1 * 10^{-5}$	E615 86†
$D^0 \to e^+e^-$	$2.4 * 10^{-4}$	CLEO 87
$D^0 \to e^+e^-$	$1.3 * 10^{-4}$	ARGUS 87
$D^0 \to e^+e^-$	$0.8 * 10^{-4}$	E691 87
$D^0 \to \mu^\pm e^\mp$	$2.6 * 10^{-3}$	MARKII 87†
$D^0 \to \mu^\pm e^\mp$	$1.0 * 10^{-3}$	ACCMOR 87†
$D^0 \to \mu^\pm e^\mp$	$1.2 * 10^{-4}$	MARKIII 87†
$D^0 \to \mu^\pm e^\mp$	$0.9 * 10^{-4}$	ARGUS 87
$D^0 \to \mu^\pm e^\mp$	$0.8 * 10^{-4}$	E691 87
$D^+ \to \pi^+e^+e^-$	$1.2 * 10^{-3}$	CLEO 87
$D^+ \to \pi^+\mu^+\mu^-$	$8.6 * 10^{-4}$	CLEO 87
$D^+ \to \pi^+\mu^\pm e^\mp$	$2.0 * 10^{-4}$	E691 87
$c \to X\mu^+\mu^-$	$3.5 * 10^{-2}$	CLEO 87
$c \to Xe^+e^-$	$6.4 * 10^{-3}$	CLEO 87

Table I : Upper limits (90% c.l.) on the branching ratio of rare D-meson decays. All numbers include the latest MARKIII absolute branching ratios.
$\diamond$: Reference to a mode includes its charge-conjugate mode.
$\dagger$: Published, all other numbers are of preliminary nature.