Rare D Meson Decays at HERA

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Abstract: A status report on the prospects of measuring rare decays of charmed mesons at HERA is given. Based on actual experience with measuring charm at HERA, the sensitivity on limits of rare decays is estimated.

1 Why should we study rare charm decays?

At HERA recent measurements of the charm production cross section in ep collisions at an energy $\sqrt{s_{ep}} \approx 300$ GeV yielded a value of about 1μb [1]. For an integrated luminosity of 250 pb^{-1}, one expects therefore about $25 \cdot 10^7$ produced $c\bar{c}$ pairs, mainly through the boson-gluon fusion process. This corresponds to a total of about $30 \cdot 10^7$ neutral D^o, $10 \cdot 10^7$ charged $D^{\pm}$, some $5 \cdot 10^7$ D_S, and about $5 \cdot 10^7$ charmed baryons. A sizable fraction of this large number of D's is accessible via decays within a HERA detector, and thus should be used to improve substantially our knowledge on charmed particles.

There are several physics issues of great interest. This report will cover however only aspects related to the decay of charmed mesons in rare decay channels, and in this sense provides an update of the discussion presented in an earlier workshop on HERA physics [2]. In the following we shall discuss these aspects, and point out the theoretical expectations. Based on experiences made at HERA with charm studies, we shall present an estimate on the sensitivity for the detailed case study of the search for the rare decay $D^0 \rightarrow \mu^+\mu^-$. Other challenging aspects such as the production mechanism and detailed comparisons with QCD calculations, or the use of charmed particles in the extraction of proton and photon parton densities, will not be covered here.

Possibly the most competitive future source of D-mesons is the proposed tau-charm factory. The continuing efforts at Fermilab (photoproduction and hadroproduction experiments), at CERN (LEP) and at Cornell(CESR), which are presently providing the highest sensitivities, are compared with the situation at HERA. In addition, all these different approaches provide useful and complementary information on various properties in the charm system.

2 Decay processes of interest

2.1 Leading decays

The charm quark is the only heavy quark besides the b quark and can be used to test the heavy quark symmetry [3] by measuring form factors or decay constants. Hence, the D-meson containing a charmed quark is heavy as well and disintegrates through a large number of decay channels. The leading decays $c \to s + q\bar{q}$ or $c \to s + \bar{l}\nu$ occur with branching ratios of order a few % and allow studies of QCD mechanisms in a transition range between high and very low energies.

Although experimentally very challenging, the search for the purely leptonic decays $D^{\pm} \to \mu^{\pm}\nu$ and an improved measurement of $D_S^{\pm} \to \mu^{\pm}\nu$ should be eagerly pursued further, since these decays offer direct access to the meson decay constants f_D and f_{D_S}, quantities that can possibly be calculated accurately by lattice gauge theory methods [4],[5].

2.2 Singly Cabibbo suppressed decays (SCSD)

Decays suppressed by a factor $\sin\theta_C$, the socalled singly Cabibbo suppressed decays (SCSD), are of the form $c \to du\bar{d}$ or $c \to s\bar{s}u$. Examples of SCSD, such as $D \to \pi\pi$ or $K\bar{K}$ have been observed at a level of 10^{-3} branching ratio (1.5 and 4.3 $\cdot 10^{-3}$, respectively) [6]. They provide information about the CKM-matrix, and also are background processes to be worried about in the search for rare decays.

2.3 Doubly Cabibbo suppressed decays and $D^0 \longleftrightarrow \bar{D}^0$ mixing

Doubly Cabibbo suppressed decays (DCSD) of the form $c \to d\bar{s}u$ have not been observed up to now[6], with the exception of the mode $BR(D^0 \to K^+\pi^-)$ that has a branching ratio of $(2.9 \pm 1.4) \cdot 10^{-4}$. The existing upper bounds are at the level of a few 10^{-4}, with branching ratios expected at the level of 10^{-5}. These DCSD are particularly interesting from the QCD-point of view, and quite a few predictions have been made[7]. DCSD also act as one of the main background processes to the $D^0 \leftrightarrow \bar{D}^0$ mixing and therefore must be well understood, before the problem of mixing itself can be successfully attacked.

As in the neutral Kaon and B-meson system, mixing between the D^0 and the $\bar{D}^0$ is expected to occur (with $\Delta C = 2$). The main contribution is expected due to long distance effects, estimated to be as large as about $r_D \sim 5 \cdot 10^{-3}$ [8], while the standard box diagram yields $r_D \sim 10^{-5}$ [9]. Here r_D is the mixing parameter $r_D \simeq (1/2) \cdot (\Delta M/\Gamma)^2$, with contributions by the DCSD neglected. Recall that the DCSD poses a serious background source in case only the time-integrated spectra are studied. The two sources can however be better separated, if the decay time dependence of the events is recorded separately (see e.g. [10]). More details on the prospect of measuring mixing at HERA are given in [11].

2.4 Flavour Changing Neutral Currents (FCNC)

An important feature of the standard model is that *flavour changing neutral currents (FCNC with $\Delta C = 1$)* only occur at the one loop level in the SM *i.e.* through short distance contributions, such as e.g. in penguin and box diagrams as shown in figs.1 and 2. These are transitions of the form $s \to d + N$ or $c \to u + N$, where N is a non-hadronic neutral state such as γ or $l\bar{l}$, and give rise to the decays $D \to \rho\gamma$, $D^0 \to \mu^+\mu^-$, $D^+ \to \pi^+\mu^+\mu^-$ etc. Although the relevant couplings are the same as those of leading decays, their rates are very small as they are suppressed by the GIM mechanism [12] and the unfavourable quark masses within the loops. The SM-prediction for the branching ratios are of order 10^{-9} for $D^0 \to Xl^+l^-$ and of $O(10^{-15})$ for $D^0 \to l^+l^-$, due to additional helicity suppression. A summary of the expected branching ratios obtained from calculations of the loop integrals ([13], [7], [2], [14]) using also the QCD-short distance corrections available [15] is given in table 1.

However, FCNC are sensitive to new, heavy particles in the loops, and above all, to new physics in general.

In addition to these short distance loop diagrams, there are contributions from long distance effects, which might be even larger by several orders of magnitude[14]. To mention are photon pole amplitudes (γ-pole) and vector meson dominance (VMD) induced processes. The γ-pole model (see fig.3) in essence is a W-exchange decay with a virtual photon radiating from one of the quark lines. The behaviour of the amplitude depends on the spin state of the final state particle (vector V or pseudoscalar P). The dilepton mass distribution for $D \to Vl^+l^-$ modes peaks at zero (small Q^2) since the photon prefers to be nearly real. On the other hand, the pole amplitude for $D \to Pl^+l^-$ decays vanishes for small dilepton masses because $D \to P\gamma$ is forbidden by angular momentum conservation. The VMD model (see fig.3b) proceeds through the decay $D \to XV^0 \to Xl^+l^-$. The intermediate vector meson V^0 (ρ, ω, ϕ) mixes with a virtual photon which then couples to the lepton pair. The dilepton mass spectrum therefore will exhibit poles at the corresponding vector meson masses due to real V^0 mesons decaying.

Observation of FCNC processes at rates that exceed the long distance contributions hence opens a window into physics beyond the standard model. Possible scenarios include leptoquarks or heavy neutral leptons with sizable couplings to e and μ.

A measurement of such long distance contributions in the charm sector is inherently of interest, as it can be used to estimate similar effects in the bottom sector [16], e.g. for the decay $b \to s\gamma$, which was seen at the level of $2.3 \cdot 10^{-4}$. A separation of short and long range contributions would allow e.g. a determination of $\mid V_{td}/V_{ts} \mid$ from the ratio $BR(B \to \rho\gamma)/BR(B \to K^*\gamma)$ and bears as such a very high potential.

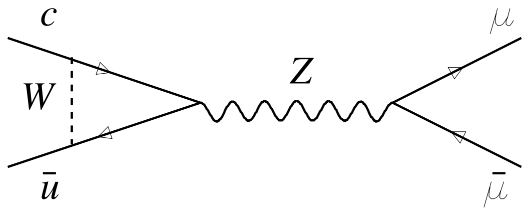


Figure 1: *Example of an FCNC process in the standard model at the loop level: $D^0 \to \mu^+\mu^-$.*

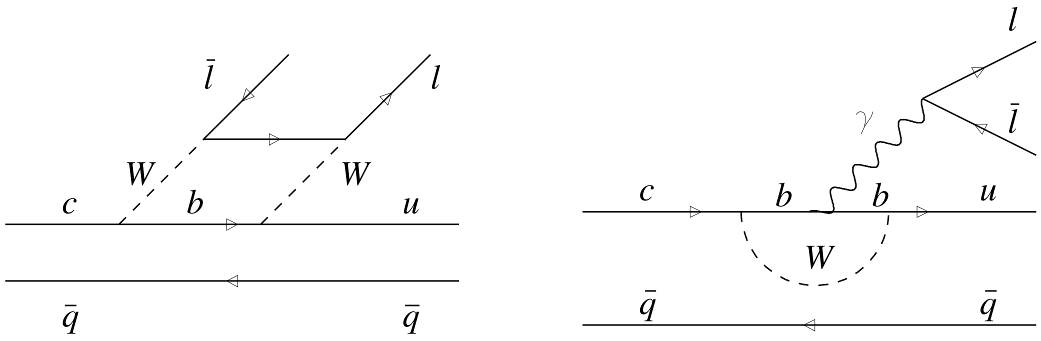


Figure 2: *FCNC processes: short range contributions due to box diagrams (a) or penguin diagrams (b).*

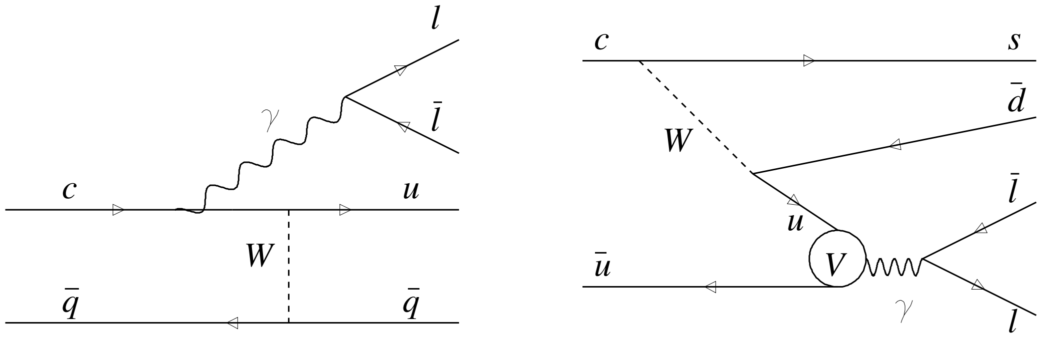


Figure 3: *FCNC processes : long range contributions due to γ-pole amplitude (a) and vector meson dominance (b).*

2.5 Forbidden decays

Decays which are not allowed to all orders in the standard model, the *forbidden* decays, are exciting signals of new physics. Without claim of completeness, we shall list here some of the more important ones:

- Lepton number (L) or lepton family (LF) number violation (LFNV) in decays such as $D^0 \to \mu e$, $D^0 \to \tau e$. It should be strongly emphasized that decays of D-mesons test couplings complementary to those effective in K- or B-meson decays. Furthermore, the

Decay mode	Expected branching ratio
$c \to u\gamma$	$10^{-15} - 10^{-14}$
$D \to \rho\gamma$	10^{-7}
$D \to \gamma\gamma$	10^{-10}
$c \to ul\bar{l}$	$5 \cdot 10^{-8}$
$D^+ \to \pi^+ e^+ e^-$	10^{-8}
$D^0 \to \mu^+ \mu^-$	10^{-19}

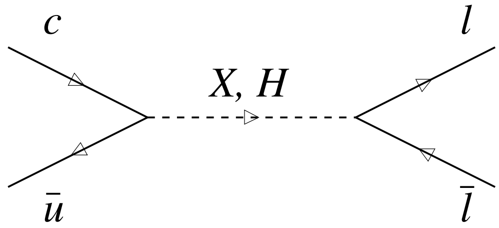
Table 1: Expectations for branching ratios of loop processes based on SM calculations, hereby assuming the BR of both $D \to \rho\rho$ and $D \to \rho\pi$ to be below 10^{-3}.

charmed quark is the only possible charge 2/3 quark which allows detailed investigations of unusual couplings. These are often predicted to occur in models with i) technicolour [17]; ii) compositeness [18]; iii) leptoquarks [19] [20]; (see e.g. fig.4a and b); this can include among others non-SU(5) symmetric flavour-dependent couplings (u to $l^{\pm}$, and d to ν), which would forbid decays of the sort $K_L \to \mu\mu,\ \mu e$, while still allowing for charm decays; iv) massive neutrinos (at the loop level) in an extended standard model; v) superstring inspired phenomenological models e.g. MSSM models with a Higgs doublet; vi) scalar exchange particles that would manifest themselves e.g. in decays of the form $D^0 \to \nu\bar{\nu}$.

- Further models feature *horizontal* interactions, mediated by particles connecting u and c or d and s quarks (see e.g. fig.4a). They appear with similar signatures as the doubly Cabibbo suppressed decays.

- Baryon number violating decays, such as $D^0 \to pe^-$ or $D^+ \to ne^-$. They are presumably very much suppressed, although they are not directly related to proton decay.

- The decay $D \to \pi\gamma$ is absolutely forbidden by gauge invariance and is listed here only for completeness.



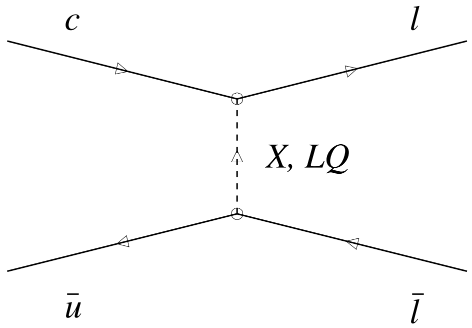


Figure 4: *FCNC processes or LFNV decays, mediated by the exchange of a scalar particle X or a particle H mediating "horizontal interactions", or a leptoquark LQ.*

The clean leptonic decays make it possible to search for leptoquarks. If they do not couple also to quark-(anti)quark pairs, they cannot cause proton decay but yield decays such as $K \to \bar{l_1} l_2$ or $D \to \bar{l_1} l_2$. In the case of scalar leptoquarks there is no helicity suppression and consequently the experimental sensitivity to such decays is enhanced. Let us emphasize here again, that decays of D-mesons are complementary to those of Kaons, since they probe different leptoquark types. To estimate the sensitivity we write the effective four-fermion coupling as (g_{eff}^2/M_{LQ}^2), and obtain

$$\frac{(M_{LQ}\ /\ 1.8\ TeV)}{g_{eff}} \geq \sqrt[4]{\frac{10^{-5}}{BR(D^0 \to \mu^+\mu^-)}}. \tag{1}$$

Here g_{eff} is an effective coupling and includes possible mixing effects. Similarly, the decays $D^+ \to e^+\nu$, $D^+ \to \pi^+ e^+ e^-$ can be used to set bounds on M_{LQ}. With the expected sensitivity, one can probe heavy exchange particles with masses in the 1 (TeV/g_{eff}) range.

Any theory attempting to explain the hadron-lepton symmetry or the "generation" aspects of the standard model will give rise to new phenomena connected to the issues mentioned here. Background problems make it quite difficult to search for signs of them at high energies; therefore precision experiments at low energies (like the highly successful μ-, π- or K-decay experiments) are very suitable to probe for any non-standard phenomena.

3 Sensitivity estimate for HERA

In this section we present an estimate on the sensitivity to detect the decay mode $D^0 \rightarrow \mu^+\mu^-$. As was pointed out earlier, this is among the cleanest manifestation of FCNC or LFNV processes [13]. We base the numbers on our experience gained in the analysis of the 1994 data, published in [1]. There the D-meson decay is measured in the decay mode $D^{*+} \rightarrow D^0\pi_s^+$; $D^0 \rightarrow K^-\pi^+$, exploiting the well established $D^{*+}(2010)$ tagging technique[21]. In analogy, we assume for the decay chain $D^{*+} \rightarrow D^0\pi_s^+; D^0 \rightarrow \mu^+\mu^-$, a similar resolution of $\sigma \approx 1.1$ MeV in the mass difference $\Delta M = M(\mu^+\mu^-\pi_s^+) - M(\mu^+\mu^-)$ as in [1]. In order to calculate a sensitivity for the $D^0 \rightarrow \mu^+\mu^-$decay branching fraction we make the following assumptions:

i) luminosity $L = 250\ pb^{-1}$; ii) cross section $\sigma(ep \rightarrow c\bar{c}X) \mid_{\sqrt{s_{ep}}\approx 300; Q^2<0.01} = 940\ nb$; iii) reconstruction efficiency $\epsilon_{reconstruction} = 0.5$; iv) trigger efficiency $\epsilon_{trigger} = 0.6$; this is based on electron-tagged events, and hence applies to photoproduction processes only. v) The geometrical acceptance A has been properly calculated by means of Monte Carlo simulation for both decay modes $D^0 \rightarrow K^-\pi^+$ and $D^0 \rightarrow \mu^+\mu^-$ for a rapidity interval of $\mid \eta \mid < 1.5$. For the parton density functions the GRV parametrizations were employed, and the charm quark mass was assumed to be $m_c = 1.5$. We obtained
$A = 6\%$ for $p_T(D^*) > 2.5$ (for $K^-\pi^+$)
$A = 18\%$ for $p_T(D^*) > 1.5$ (for $K^-\pi^+$)
$A = 21\%$ for $p_T(D^*) > 1.5$ (for $\mu^+\mu^-$)

A direct comparison with the measured decays $N_{K\pi}$ into $K^-\pi^+$ [1] then yields the expected number of events $N_{\mu\mu}$ and determines the branching ratio to

$$BR(D^0 \rightarrow \mu^+\mu^-) = BR(D^0 \rightarrow K^-\pi^+) \cdot \frac{N_{\mu\mu}}{L_{\mu\mu}} \cdot \frac{L_{K\pi}}{N_{K\pi}} \cdot \frac{A(p_T > 2.5)}{A(p_T > 1.5)}$$

Taking the numbers from [1] $N_{K\pi} = 119$ corresponding to an integrated luminosity of $L_{K\pi} = 2.77\ pb^{-1}$, one obtains

$$\boxed{BR(D^0 \rightarrow \mu^+\mu^-) = 1.1 \cdot 10^{-6} \cdot N_{\mu\mu}}$$

In the case of *NO* events observed, an upper limit on the branching ratio calculated by means of Poisson statistics ($N_{\mu\mu} = 2.3$), yields a value of $BR(D^0 \rightarrow \mu^+\mu^-) < 2.5 \cdot 10^{-6}$ at 90% c.l.

In the case of an observation of a handful events e.g. of $O(N_{\mu\mu} \approx 10)$, one obtains $BR(D^0 \rightarrow \mu^+\mu^-) \approx 10^{-5}$. This can be turned into an estimate for the mass of a potential leptoquark mediating this decay according to eqn.1, and yields a value of $M_{LQ}/g_{eff} \approx 1.8$ TeV.

4 Background considerations

4.1 Background sources and rejection methods

The most prominent sources of background originate from i) genuine leptons from semileptonic B- and D-decays, and decay muons from K, π decaying in the detector; ii) misidentified hadrons, *i.e.* π, K, from other decays, notably leading decays and SCSD; and iii) combinatorial background from light quark processes.

The background can be considerably suppressed by applying various combinations of the following techniques:

Mode	BR (90% C.L.)	Interest	Reference
$r=\frac{(\bar{D}^0\to\mu^+ X)}{(\bar{D}^0\to\mu^- X)}$	$1.2 * 10^{-2}$	$\Delta C = 2$, Mix	BCDMS 85
	$5.6 * 10^{-3}$	$\Delta C = 2$, Mix	E615 86
$\frac{(D^0\to\bar{D}^0\to K^+\pi^-)}{(D^0\to K^+\pi^- + K^-\pi^+)}$	$4 * 10^{-2}$	$\Delta C = 2$, Mix	HRS 86
	$= 0.01^*$	$\Delta C = 2$, Mix	MarkIII 86
	$1.4 * 10^{-2}$	$\Delta C = 2$, Mix	ARGUS 87
	$3.7 * 10^{-3}$	$\Delta C = 2$, Mix	E691 88
$D^0 \to \mu^+\mu^-$	$7.0 * 10^{-5}$	FCNC	ARGUS 88
$D^0 \to \mu^+\mu^-$	$3.4 * 10^{-5}$	FCNC	CLEO 96
$D^0 \to \mu^+\mu^-$	$1.1 * 10^{-5}$	FCNC	E615 86
$D^0 \to e^+e^-$	$1.3 * 10^{-4}$	FCNC	MarkIII 88
$D^0 \to e^+e^-$	$1.3 * 10^{-5}$	FCNC	CLEO 96
$D^0 \to \mu^\pm e^\mp$	$1.2 * 10^{-4}$	FCNC, LF	MarkIII 87
$D^0 \to \mu^\pm e^\mp$	$1.0 * 10^{-4}$	FCNC, LF	ARGUS 88
$D^0 \to \mu^\pm e^\mp$	$(1.9 * 10^{-5})$	FCNC, LF	CLEO 96
$D^0 \to \bar{K}^0 e^+e^-$	$1.7 * 10^{-3}$		MarkIII 88
$D^0 \to \bar{K}^0 e^+e^-/\mu^+\mu^-/\mu^\pm e^\mp$	$1.1/6.7/1. * 10^{-4}$	FCNC, LF	CLEO 96
$D^0 \to \bar{K}^{*0} e^+e^-/\mu^+\mu^-/\mu^\pm e^\mp$	$1.4/11.8/1. * 10^{-4}$	FCNC, LF	CLEO 96
$D^0 \to \pi^0 e^+e^-/\mu^+\mu^-/\mu^\pm e^\mp$	$0.5/5.4/.9 * 10^{-4}$	FCNC, LF	CLEO 96
$D^0 \to \eta e^+e^-/\mu^+\mu^-/\mu^\pm e^\mp$	$1.1/5.3/1. * 10^{-4}$	FCNC, LF	CLEO 96
$D^0 \to \rho^0 e^+e^-/\mu^+\mu^-/\mu^\pm e^\mp$	$1./4.9/0.5 * 10^{-4}$	FCNC, LF	CLEO 96
$D^0 \to \omega e^+e^-/\mu^+\mu^-/\mu^\pm e^\mp$	$1.8/8.3/1.2 * 10^{-4}$	FCNC, LF	CLEO 96
$D^0 \to \phi e^+e^-/\mu^+\mu^-/\mu^\pm e^\mp$	$5.2/4.1/0.4 * 10^{-4}$	FCNC, LF	CLEO 96
$D^0 \to K^+\pi^-\pi^+\pi^-$	< 0.0015	DC	CLEO 94
$D^0 \to K^+\pi^-\pi^+\pi^-$	< 0.0015	DC	E691 88
$D^0 \to K^+\pi^-$	$= 0.00029$	DC	CLEO 94
$D^0 \to K^+\pi^-$	< 0.0006	DC	E691 88

Table 2: Experimental limits at 90% c.l. on rare D^0-meson decays (except where indicated by =). Here L, LF, FCNC, DC and Mix denote lepton number and lepton family number violation, flavour changing neutral currents, doubly Cabibbo suppressed decays and mixing, respectively.

- D^*-tagging technique [21]:
  A tight window on the mass difference ΔM is the most powerful criterium.

- Tight kinematical constraints ([22],[2]):
  Misidentification of hadronic D^0 2-body decays such as $D^0 \to K^-\pi^+$(3.8% BR), $D^0 \to \pi^+\pi^-$(0.1% BR) and $D^0 \to K^+K^-$(0.5% BR) are suppressed by more than an order of magnitude by a combination of tight windows on both ΔM and M_D^{inv}. Final states containing Kaons can be very efficiently discriminated, because the reflected M^{inv} is sufficiently separated from the true signal peak. However, this is not true for a pion-muon or pion-electron misidentification. The separation is slightly better between $D^0 \to e^+e^-$ and $D^0 \to \pi^+\pi^-$.

- Vertex separation requirements for secondary vertices:

Background from light quark production, and of muons from K- and π- decays within the detector are further rejected by exploiting the information of secondary vertices (e.g. decay length separation, pointing back to primary vertex etc.).

- Lepton identification (example H1) :
  Electron identification is possible by using dE/dx measurements in the drift chambers, the shower shape analysis in the calorimeter (and possibly the transition radiators information). Muons are identified with the instrumented iron equipped with limited streamer tubes, with the forward muon system, and in combination with the calorimeter information. The momentum has to be above ~ 1.5 to 2 GeV/c to allow the μ to reach the instrumented iron. Thus, the decay $D^0 \to \mu^+\mu^-$ suffers from background contributions by the SCSD mode $D^0 \to \pi^+\pi^-$, albeit with a known $BR = 1.6 \cdot 10^{-3}$; here μ-identification helps extremely well. An example of background suppression using the particle ID has been shown in ref.[2], where a suppression factor of order $O(100)$ has been achieved.

- Particle ordering methods exploit the fact that the decay products of the charmed mesons tend to be the *leading* particles in the event (see e.g. [23]). In the case of observed jets, the charmed mesons are expected to carry a large fraction of the jet energy.

- Event variables such as e.g. the total transverse energy $E_{transverse}$ tend to reflect the difference in event topology between heavy and light quark production processes, and hence lend themselves for suppression of light quark background.

4.2 Additional experimental considerations

- Further possibilities to enhance overall statistics are the usage of inclusive decays (no tagging), where the gain in statistics is expected to be about $\frac{N(allD^0)}{N(D^0 fromD^*)} = 0.61/0.21 \approx 3$, however on the the cost of higher background contributions.

- In the decays $D^0 \to ee$ or $D^0 \to \mu e$ one expects factors of 2 to 5 times better background rejection efficiency.

- Trigger : A point to mention separately is the trigger. To be able to measure a BR at the level of 10^{-5}, the event filtering process has to start at earliest possible stage. This should happen preferably at the first level of the hardware trigger, because it will not be feasible to store some 10^{+7} events on permanent storage to dig out the few rare decay candidates. This point, however, has up to now not yet been thoroughly studied, let alone been implemented at the hardware trigger level.

5 Status of sensitivity in rare charm decays

Some of the current experimental upper limits at 90% c.l. on the branching ratios of rare D decays are summarised in tables 2 and 3 according to [6].

Taking the two-body decay $D^0 \to \mu^+\mu^-$ to be the sample case, a comparison of the achievable sensitivity on the upper limit on branching fraction $B_{D^0\to\mu^+\mu^-}$ at 90% c.l. is summarized in table 4 for different experiments, assuming that NO signal events are being detected (see

Mode	BR (90% C.L.)	Interest	Reference
$D^+ \to \pi^+ e^+ e^-$	$6.6 * 10^{-5}$	FCNC	E791 96
$D^+ \to \pi^+ \mu^+ \mu^-$	$1.8 * 10^{-5}$	FCNC	E791 96
$D^+ \to \pi^+ \mu^+ e^-$	$3.3 * 10^{-3}$	LF	MarkII 90
$D^+ \to \pi^+ \mu^- e^+$	$3.3 * 10^{-3}$	LF	MarkII 90
$D^+ \to \pi^- e^+ e^+$	$4.8 * 10^{-3}$	L	MarkII 90
$D^+ \to \pi^- \mu^+ \mu^+$	$2.2 * 10^{-4}$	L	E653 95
$D^+ \to \pi^- \mu^+ e^+$	$3.7 * 10^{-3}$	L+LF	MarkII 90
$D^+ \to Kll$	similar	L+LF	MarkII 90
$c \to X \mu^+ \mu^-$	$1.8 * 10^{-2}$	FCNC	CLEO 88
$c \to X e^+ e^-$	$2.2 * 10^{-3}$	FCNC	CLEO 88
$c \to X \mu^+ e^-$	$3.7 * 10^{-3}$	FCNC	CLEO 88
$D^+ \to \phi K^+$	$1.3 * 10^{-4}$	DC	E687 95
$D^+ \to K^+ \pi^+ \pi^-$	$= 6.5 * 10^{-4}$	DC	E687 95
$D^+ \to K^+ K^+ K^-$	$1.5 * 10^{-4}$	DC	E687 95
$D^+ \to \mu^+ \nu_\mu$	$7.2 * 10^{-4}$	f_D	MarkIII 88
$D_S \to \pi^- \mu^+ \mu^+$	$4.3 * 10^{-4}$	L	E653 95
$D_S \to K^- \mu^+ \mu^+$	$5.9 * 10^{-4}$	L	E653 95
$D_S \to \mu^+ \nu_\mu$	$= 9 * 10^{-4}$	$f_{D_S} = 430$	BES 95

Table 3: Selection of experimental limits at 90% c.l. on rare D^+- and D_s-meson decays[6] (except where indicated by =).

[24] and [6]). Note that the sensitivity reachable at HERA is compatible with the other facilities, provided the above assumed luminosity is actually delivered. This does not hold for a proposed τ-charm factory, which - if ever built and performing as designed - would exceed all other facilities by at least two orders of magnitude ([25]).

The status of competing experiments at other facilities is the following :

- SLAC : e^+e^- experiments : Mark-III, MARK-II, DELCO : stopped.
- CERN : fixed target experiments : ACCMOR, E615, BCDMS, CCFRC : stopped.
  LEP-experiments : previously ran at the Z^0-peak; now they continue with increased $\sqrt{s}$, but at a *reduced* σ for such processes;
- Fermilab (FNAL) : the photoproduction experiments E691/TPS and hadroproduction experiments E791 and E653 are stopped, with some analyses being finished based on about $O(10^5)$ reconstructed events. In the near future highly competitive results are to be expected from the γp experiments E687 and its successor E831 (FOCUS), based on an statistics of about $O(10^5)$ and an estimated 10^6 reconstructed charm events, respectively. But also the hadroproduction experiment E781 (SELEX) is anticipated to reconstruct some 10^6 charm events within a few years.
- DESY : ARGUS e^+e^- : stopped, final papers emerging now.
  HERA-B : With a very high cross section of $\sigma(pN \to c\bar{c}) \approx 30\mu$b at $\sqrt{s} = 39$ GeV and an extremely high luminosity, a total of up to 10^{12} $c\bar{c}$-events may be produced. Although

	SPEAR	BEPC	E691	LEP	$\tau - cF$	CLEO	HERA
σ_{cc} (nb)	5.8	8.6	500	4.5	5.8	1.3	$\sigma_{ep} = 940$
$L(pb^{-1})$	9.6	30	0.5	150	10^4	3850	250
N_D	$6 * 10^4$	$3 * 10^5$	$2.5 * 10^5$	10^6	$6 * 10^7$	$5 * 10^6$	$2.4 * 10^8$
$\epsilon \cdot A$	0.4	0.5	0.25	0.05	0.5	0.1	0.06
N_{BGND}	O(0)	O(1)	O(10)	O(10)	O(1)	O(1)	S/N≈1
$\frac{\sigma_{charm}}{\sigma_{total}}$	1	0.4	0.01	0.1	1	0.1	0.1
$B_{D^0 \to \mu^+\mu^-}$	$1.2 * 10^{-4}$	$2 * 10^{-5}$	$4 * 10^{-5}$	$5 * 10^{-5}$	$5 * 10^{-8}$	$3.4 * 10^{-5}$	$2.5 * 10^{-6}$

Table 4: Comparison of estimated sensitivity to the sample decay mode $D^0 \to \mu^+\mu^-$ for different facilities or experiments.

no detailed studies exist so far, a sensitivity of order 10^{-5} to 10^{-7} might be expected, depending on the background rates.

- CESR : CLEO is continuing steadily to collect data, and above all is the present leader in sensitivity for many processes (see table 2).
- BEPC : BES has collected data at $\sqrt{s} = 4.03$ GeV (and 4.14 GeV), and is continuing to do so; BES will become competitive as soon as enough statistics is available, because the background conditions are very favourable.
- τ-charm factory : The prospects for a facility being built in China (Beijing) are uncertain. If realized, this is going to be the most sensitive place to search for rare charm decays. Both, kinematical constraints (e.g. running at the $\psi''(3700)$) and the missing background from non-charm induced processes will enhance its capabilities.

6 Summary

D-meson decays offer a rich spectrum of interesting physics; their rare decays may provide information on new physics, which is complementary to the knowledge stemming from K-meson and B-decays. With the prospect of order a few times 10^8 produced charmed mesons per year, HERA has the potential to contribute substantially to this field. Further competitive results can be anticipated from the fixed target experiments at Fermilab or from a possible τ-charm factory.

For the rare decay $D^0 \to \mu^+\mu^-$investigated here we expect at least an order of magnitude improvement in sensitivity over current results (see table given above) for a total integrated luminosity of $\int Ldt = 250$ pb^{-1}, the limitation here being statistical. An extrapolation to even higher luminosity is rather difficult without a very detailed numerical simulation, because at some (yet unknown) level the background processes will become the main limiting factor for the sensitivity, rendering sheer statistics useless. For this, a good tracking resolution, excellent particle identification (e, μ, π, K, p) and a high resolution for secondary vertices is required to keep the systematics under control, and either to unambigously identify a signal of new physics, or to reach the ultimate limit in sensitivity.

References

[1] S. Aid *et al.,* H1 collab., DESY 96-055, submitted to Nucl. Phys. 1996; M. Derrick *et al.,* ZEUS collab., Phys. Lett. B349, (1995), 225.

[2] Proc. 'Physics at HERA', Eds. W. Buchmüller, G. Ingelman, DESY 1992, p. 770.

[3] N. Isgur and M. Wise, Phys.Lett. **B**232, (1989) 113; ibid **B**237, (1990) 527; M. Wise Nucl.Phys. **A**527, (1991) 209; M. Neubert, V. Rieckert, B. Stech and A. Xu, Heidelberg Uni. preprint HD-THEP-91-28, 1991.

[4] C. Alexandrou *et al.,* Phys.Lett. **B**256, (1991) 60;
and G. Martinelli in Proc. of LP-HEP conf. Geneva, 1991.

[5] H. Wittig, Preprint DESY 96-110, 1996.

[6] Review of Particle Properties; Phys. Rev. **D**54, (1996) 1.

[7] I. Bigi, F. Gabbiani and A. Masiero, Z. Phys. **A**48, (1990) 633; I. I. Bigi in SLAC report 343, 1989; ibid UND-HEP-88-01, (1988); UND-HEP-89-01, (1989).

[8] L. Wolfenstein, Phys. Lett. **B**164, (1985) 170.

[9] L. L. Chau, Phys. Rep. 95, (1983) 1.

[10] J. C. Anjos *et al.,* Phys. Rev. Lett. 60, (1988) 1239.

[11] G. Tsipolitis, these proceedings.

[12] S. Glashow, J. Iliopoulos and L. Maiani, Phys. Rev. D**2**, (1970) 1285.

[13] R. S. Willey in Proc. of τ-charm factory workshop, SLAC report. 343, 1989, p.196.

[14] A. J. Schwartz, Mod. Phys. Lett. A8, (1993) 967; J. L. Hewett, SLAC-PUB-95-6821.

[15] see e.g. G. Cella *et al.,* Phys. Lett. **B**258, (1991) 212.
and B. Grinstein *et al.,* Phys. Lett. **B**202, (1988) 138.

[16] E. Golowich and S. Pakvasa, Phys. Rev. D**51**, (1995) 1215.

[17] A. Masiero *et al.,* Phys. Lett. **B**115, (1982) 229.

[18] W. Buchmüller, Proc. of Schladming School 1985, p.517.

[19] W. Buchmüller, D. Wyler, Phys. Lett. **B**177, (1986) 377.

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

[21] G. J. Feldman *et al.,* Phys. Rev. Lett. 38, (1977) 1313.

[22] C. Grab in Proc. of Rare Decay Symposium, Vancouver, Dec. 1988; World Scient. 1989.

[23] S. Aid *et al.,* H1 collab., DESY 96-138, submitted to Z. f. Phys.

[24] C. Grab in Proc. of Int. Europhys. conf. on HEP, EPS Vol.1, p.349, 1987.

[25] R. H. Schindler in Proc. of τ-charm factory workshop, Stanford, SLAC report. 343, 1989.