$D^0 - \bar{D}^0$ mixing at the ep-collider HERA

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Abstract: The sensitivity to $D^0 - \bar{D}^0$ mixing at the ep-collider HERA is evaluated. It is found that with an integrated luminosity of about 600 pb^{-1}, a limit for the $D^0 - \bar{D}^0$ mixing which is more than a factor 5 better than the existing limits can be reached. Furthermore, it can establish a more accurate measurement of the Doubly Cabbibo Suppressed Decays.

1 Introduction

It is known in particle physics that mixing between a neutral P^0 meson and its CP-conjugate state $\bar{P}^0$ can occur. Up to now mixing has been observed only in the kaon and B-meson system and is expected to be present at the D-meson system as well.

One can characterize $D^0\bar{D}^0$ mixing in terms of two dimensionless variables: $x = \delta m/\Gamma_+$ and $y = \Gamma_-/\Gamma_+$, where the quantities $\Gamma_\pm$ and δm are defined by $\Gamma_\pm = (\Gamma_1 \pm \Gamma_2)/2$ and $\delta m = m_2 - m_1$ with m_i, Γ_i $(i = 1, 2)$ being the masses and decay rates of the two CP eigenstates. One usually defines the parameter r as

$$r \equiv \frac{\int_0^\infty \mathcal{P}(D^0 \to \bar{D}^0; t)dt}{\int_0^\infty \mathcal{P}(D^0 \to D^0; t)dt} = \frac{N_{mixed\ evts}}{N_{unmixed\ evts}}$$

with $\int_0^\infty \mathcal{P}(\mathcal{X}; t)dt$ being the probability that the process $\mathcal{X}$ occurs. Assuming a small mixing, i.e. $\delta m, \Gamma_- \ll \Gamma_+$ we have $r = (x^2 + y^2)/2$. Mixing can be caused either by $x \neq 0$ (meaning that the mixing is genuinly caused by the $D^0 - \bar{D}^0$ transition) or by $y \neq 0$ (meaning that the mixing is caused by the fact that the fast decaying component quickly disappears, leaving the slow decaying component which is a mixture of D^0 and $\bar{D}^0$).

There are big uncertainties on the theoretical estimates of r. The predicted rate of the $D^0\bar{D}^0$ mixing in the Standard Model is $r < 10^{-7}$ [1]. However, long distance effects expect r to be of the order of 10^{-4}[2]. r can be measured experimentally by measuring the ratio

$$r = \frac{N(D^0 \to \bar{D}^0 \to X)}{N(D^0 \to X)}.$$

At HERA, the charm production cross section in ep collisions at an energy of $\sqrt{s} \sim 300 GeV$, was found to be about 1 μb [3]. This corresponds to about 10^8 $c\bar{c}$ pairs produced per 100 pb^{-1} collected luminosity. A more detailed report on the production and the expected number of events for the different decay channels can be found in the article of R. Eichler and S. Frixione in these proceedings.

In this report an attempt is made to evaluate the sensitivity to measure $D^0\bar{D}^0$ mixing at a high luminosity HERA run. A Monte Carlo simulation of the H1 detector [4] equipped with a silicon vertex detector [5] was used. The events were generated with AROMA 2.1 [6] and the study corresponds to an integrated luminosity of about 600 pb^{-1}.

2 $D^0 - \bar{D}^0$ Mixing Studies with H1

The possibility of a mixing signal is studied by looking at the decay chain[1] $D^{*+} \to D^0\pi_s^+$. The charge of the charm quark in the D^0 at production is tagged through the slow pion, π_s, of the decay $D^{*+} \to D^0\pi_s^+$. Two ways of tagging the charge of the charm quark in the D^0 at the time of its decay are used. In the first, the decay $D^0 \to K^+\mu^-\nu$ is used, where the charge of the lepton is identified and in the second the decay $D^0 \to K^+\pi^-$ where the charge of the kaon is taken. The first decay mode is free of Double Cabibbo Suppressed Decays (DCSD). One would measure the ratio

$$r = \frac{D^{*+} \to D^0\pi_s^+ \to \bar{D}^0\pi_s^+ \to (K^+\ell^-\nu)\pi_s^+}{D^{*+} \to D^0\pi_s^+ \to (K^-\ell^+\nu)\pi_s^+}.$$

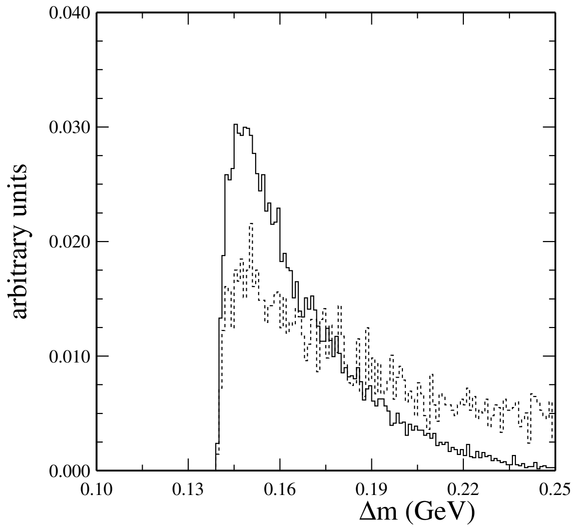

Figure 1: Monte Carlo simulation of mass difference $M(K\mu\pi_s) - M(K\mu)$ for the correct π_s assignment (full histogram) and the π_s from the wrong D^* decay (dashed histogram). The two histograms are normalized to the same number of events.

The Monte Carlo simulation has shown that an irreducible background of order 5% comes from events with two D*-mesons produced in the same event. The slow pion π_s^+ from the D^{*+} decay

[1]Henceforth, charge conjugate states are always implicitly included.

can be combined with a $\bar{D}^0$ from the D^{*-} decay. This is illustrated in Figure 1, where the mass difference $\Delta M = M(K\mu\pi_s) - M(K\mu)$ is ploted for the correct π_s assignment (full histogram) and the π_s from the wrong D^* decay (dashed histogram). Both histograms are normalized to the same number of events. The background clearly peaks at the same place as the signal and we consider this background as very difficult to subtract on a statistical basis. This background is absent in pion-production of charm on a nucleon, where single charmed mesons are produced [7]. An attempt was made to get information about the charge of the second charm in the event by requiring an additional lepton in the event. This way one could use the charge of the two leptons to tag a possible mixed event. The tag of the second lepton reduces the statistics considerably and the range of R_{mix} that can be reached is not competitive.

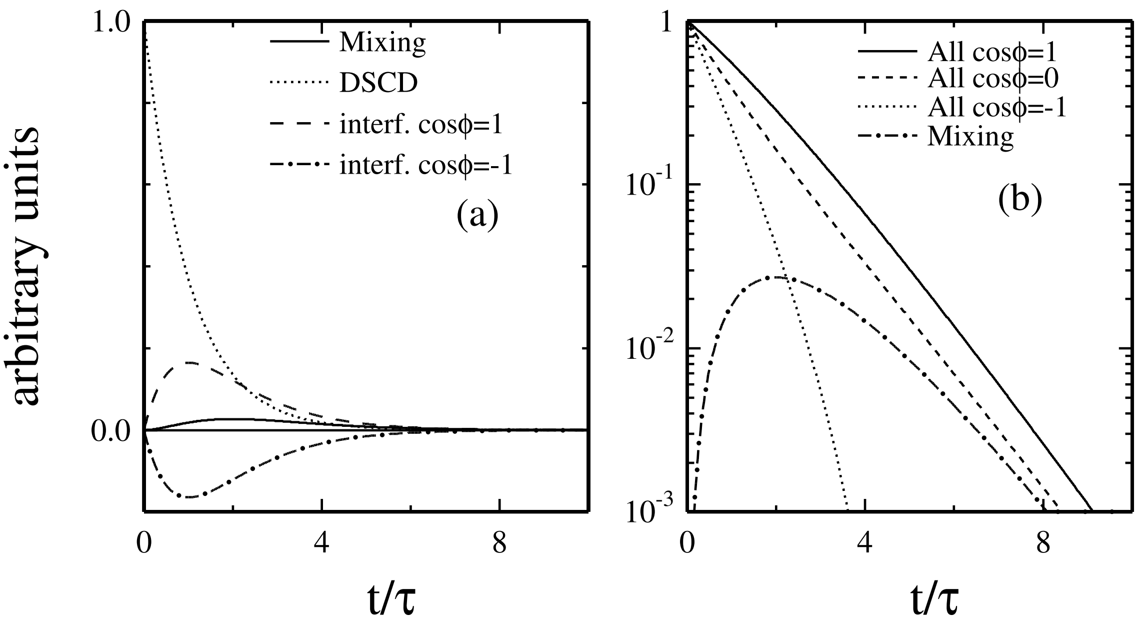

Figure 2: (a) The expected distributions for the DSCD term, the mixing term and the interference term for $\cos\phi = -1, 1$ contributing to $R(t)$ assuming $R_{DCSD} = 1$ and $R_{mix} = 0.1 \cdot R_{DCSD}$. (b) The expected distributions for $R(t)$ for $\cos\phi = -1, 0, 1$ assuming $R_{DCSD} = 1$ and $R_{mix} = 0.1 \cdot R_{DCSD}$.

The second method measures the time dependence of the ratio

$$R(t) = \frac{D^{*+} \to D^0\pi_s^+ \to (K^+\pi^-)\pi_s^+}{D^{*+} \to D^0\pi_s^+ \to (K^-\pi^+)\pi_s^+},$$

where $D^{*+} \to D^0\pi_s^+ \to (K^-\pi^+)\pi_s^+$ is the Cabbibo allowed decay and $D^{*+} \to D^0\pi_s^+ \to (K^+\pi^-)\pi_s^+$ is the sum of the decays with $D^0\bar{D}^0$ mixing and the DCS decays. One also expects interference between the DCSD and the decays through $D^0\bar{D}^0$ mixing. Therefore $R(t)$ can be written as :

$$R(t/\tau) \propto (R_{DCSD}(1 + \sqrt{2\alpha}\frac{t}{\tau}\cos\phi + \frac{1}{2}R_{mix}(\frac{t}{\tau})^2)e^{-\frac{t}{\tau}})$$

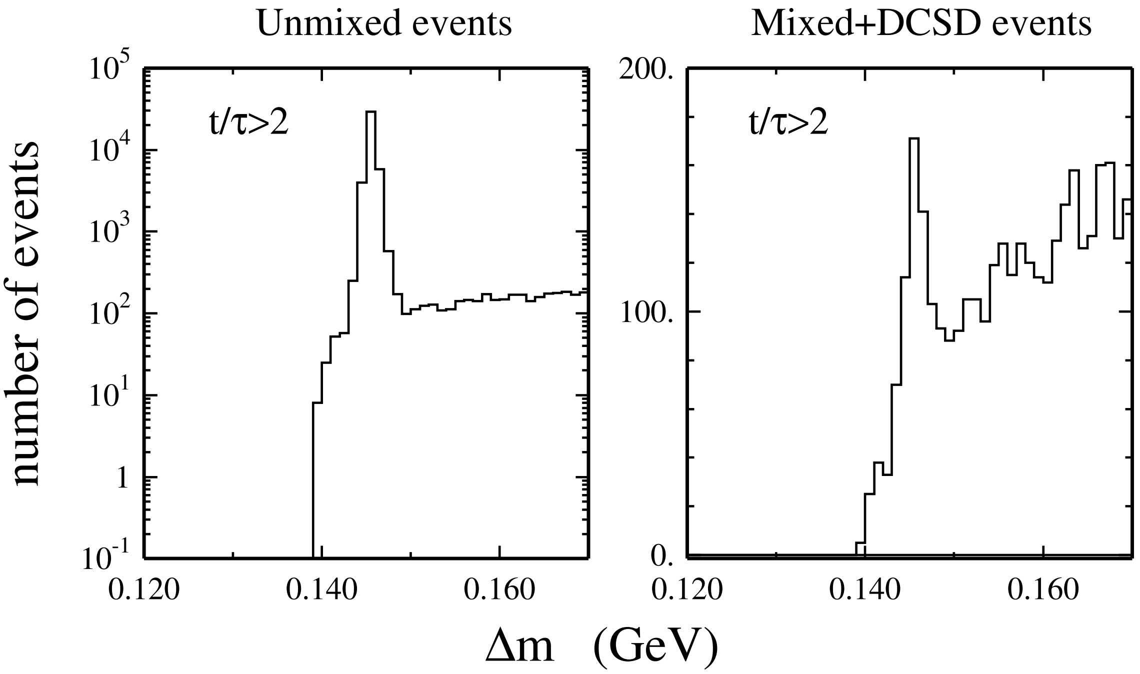

Figure 3: Monte Carlo simulation of mass difference $\Delta m = M(K\pi\pi_s) - M(K\pi)$ for 600 pb^{-1} and $t/\tau > 2$. Left plot: unmixed events; right plot: a rate of DCSD of $5 \cdot 10^{-3}$ and a mixing of $r = 10^{-3}$ without interference was assumed.

where $R_i = (D^0 \to K^+\pi^-)_i/(D^0 \to K^-\pi^+)$ with $(i = mix, DCSD)$, $\alpha = R_{mix}/R_{DCSD}$ and ϕ is the interference angle.

For the analysis the following selection criteria are imposed: 2 tracks with opposite charge and $p_t > 0.3$ GeV/c fitted to a common vertex with probability greater than 5%. For each of these track pairs both the $K\pi$ and πK hypothesis are assumed. The invariant mass of the two track system is required to be between 1.819 and 1.909 GeV/c^2. To suppress the double misidentification background if the $M_{K\pi}$ is in the range 1.819 and 1.909 the $M_{\pi K}$ is required to be outside this range and vice versa. In addition the angle θ^* between the K and the direction of flight of the D^0 candidate has to be $-0.6 < \cos\theta^* < 0.6$. Furthermore, an additional track with $p_t > 0.150$ GeV/c originating from the main vertex is required and is assumed to be the π_s of the D^* decay. The p_t of the $K\pi\pi_s$ system has to be greater than 1.5 GeV/c.

Without any information on the decay length only the integral of $R(t)$ can be measured. This has been already done by the CLEO collaboration and found to be $\int R(t)dt = (7.7{\pm}3.5){\cdot}10^{-3}$[8]. Taking this number one would expect a sample of 380 ± 175 events in the decay $D^{*+} \to D^0\pi_s^+ \to (K^+\pi^-)\pi_s^+$ with the above mentioned cuts and an integrated luminosity of about 600 pb^{-1}. Figure 2 shows the expected distributions for $R(t)$ as a function of t/τ for three different hypothesis for the interference angle as well as the individual contributions to the $R(t)$ of R_{DCSD}, R_{mix} and their interference term. With τ being the lifetime of the D^0 meson. It is clear that the mixing term peaks at $t/\tau \approx 2$. If one studies the evolution of the number of observed events as a function of t/τ the maximum information on the composition of the observed signal can be obtained.

In Figure 3 the result of a MC simulation is shown. The background shape can be accurately estimated by fitting simultaneously the $\Delta M = M(K\pi\pi_s) - M(K\pi)$ distributions for both the $K^-\pi^+$ and $K^+\pi^-$.

In Figure 4 the number of fitted events as a function of the decay time t/τ is shown. The open points give the total event number for an integrated luminosity of 600 pb^{-1} for three different phase angles of the interference term between DCSD and mixing.

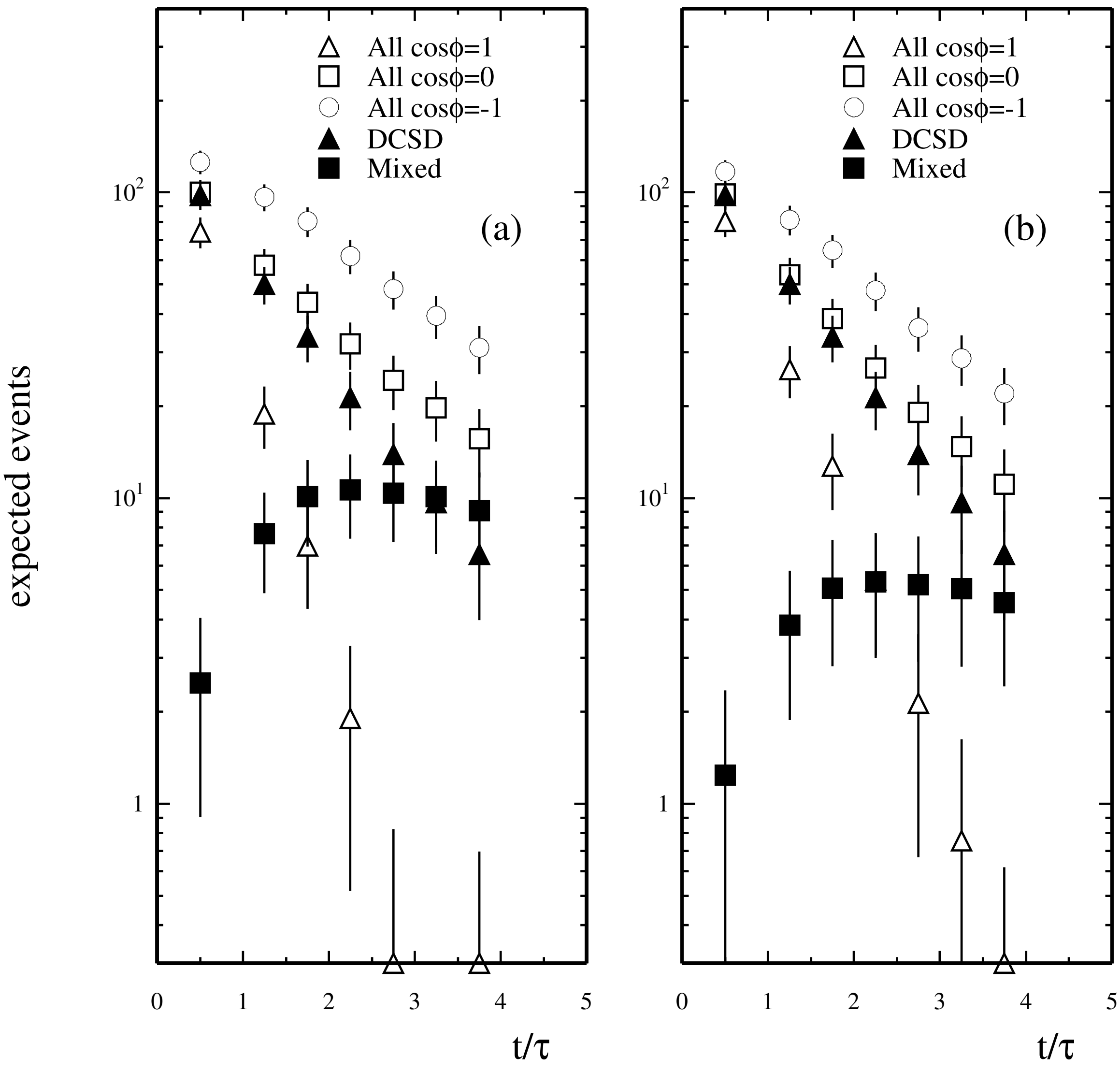

Figure 4: Simulated number of expected events for 600 pb^{-1}. A rate of DCSD of $5 \cdot 10^{-3}$ and a mixing of $r = 10^{-3}$ (a) and $r = 5 \cdot 10^{-4}$ (b) was assumed.

From this figure, it is concluded that a mixing ratio, R_{mix}, less than 10^{-3} can be achieved with HERA, which is more than a factor 5 better than the existing limit of $5{\cdot}10^{-3}$ [7, 9]. Furthermore, the DCSD can be studied with high accuracy.

References

[1] See, for example, A. Datta and D. Kumbhakar, *Z. Phys.* **C27**(1985)515; J.F. Donoghue *et al.*, *Phys. Rev.* **D33**(1986)179;T.Ohl, G.Ricciardi and E.H. Simmons, *Nucl. Phys.* **B403**(1993)605.

[2] See, for example, K.S.Babu *et al.*, pl B20588540; L.Hall and S.Weinberg, *Phys. Rev.* **D48**(1993)979; E.Ma, Mod. Phys. Lett. **A3**(1988)319; A.Datta, *Phys. Lett.* **B154**(1985)287.

[3] H1-Collaboration, S. Aid *et al.*,*Nucl. Phys.* **B472**(1996)32.

[4] H1-Collaboration, S. Aid *et al.*, DESY 96-01, accepted by *Nucl. Instr. & Meth.* (1996).

[5] W. Erdmann *et al.*, *Nucl. Instr. & Meth.* **A372**(1996)188.

[6] G.Ingelman, J.Rathsman and G.A.Schuler, DESY 96-058

[7] E791 Collaboration, E.M. Aitala *et al.*, Fermilab-PUB-96/109E, and hep-ex/9606016.

[8] CLEO Collaboration, D. Cinabro *et al.*, *Phys. Rev. Lett.* **72**(1994)1406.

[9] E615 Collaboration, J.C. Anjos *et al.*, *Phys. Rev. Lett.* **60**(1988)1239; W.C. Louis et al., *Phys. Rev. Lett.* **56**(1986)1027;
E791 Collaboration, E.M.Aitala *et al.*, hep-ex/9608018.