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D^0 mixing at the BaBar experiment

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Summary. — After a brief introduction on the mixing of neutral charmed mesons, we discuss the time-dependent Dalitz plot analysis of $D^0 \to K^0_S h^+ h^-$ ($h = \pi, K$) with the BaBar data sample. This measurement is directly sensitive to x_D and y_D, the mixing parameters that describe, respectively, mass and width differences between the mass eigenstates of the neutral D system.

PACS 13.25.Ft – Decays of charmed mesons.
PACS 14.40.Lb – Charmed mesons ($|C| > 0, B = 0$).

1. – The mixing of neutral charmed mesons

Mixing is a well established phenomenon which occurs in systems of neutral mesons in which the flavour eigenstates are not eigenstates of the Hamiltonian. In such systems the flavour eigenstates mix one into the other during the time evolution. Mixing has been observed and measured in each of the four systems predicted by the Standard Model (SM): K^0-$\overline{K}^0$, D^0-$\overline{D}^0$, B^0-$\overline{B}^0$ and B_s-$\overline{B}_s$.

Mixing in the charm sector is described by two parameters x_D and y_D:

$$x_\mathrm{D} = \frac{m_1 - m_2}{\Gamma}, \qquad y_\mathrm{D} = \frac{\Gamma_1 - \Gamma_2}{2\Gamma}, \tag{1}$$

where $m_{1,2}$ and $\Gamma_{1,2}$ are the masses and widths of the eigenstates of the Hamiltonian $|D_{1,2}\rangle = p\,|D^0\rangle \pm q\,|\overline{D}^0\rangle$ and $\Gamma = (\Gamma_1 + \Gamma_2)/2$. Despite the large uncertainties in the SM predictions [1] due to the estimation of the dominant long-distance contributions, this measurement plays an important role within the SM. Not only it completes the picture of mixing in the SM, it also brings new information on mixing since the D system is the only one in which the virtual quark in the loops are down-type. Moreover this

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measurement puts constraints in the space of parameters of NP models which must be able to reproduce the results.

From the experimental point of view the direct measurement of x_D and y_D is very challenging since the predictions are of the order of 10^{-3} or less for both the parameters. The sensitivity to the mixing parameters comes from the proper time distribution of the D^0. When the neutral D meson is reconstructed in a hadronic final state f, there are two possible ways to reach f: the D meson can decay directly into the final state, otherwise it can mix into a $\overline{D}$ and then decay to the final state. Therefore the presence of mixing modifies the usual exponential law for the decay rate, the probability for a D^0 to decay into a final state f at time t can be shown to be:

$$\text{(2)} \qquad \mathrm{Prob}(D^0 \to f, t) \propto e^{-\Gamma t}|A_f|^2 \Bigg[\frac{1+|\lambda_f|^2}{2}\cosh(y_\mathrm{D}\Gamma t) + \frac{1-|\lambda_f|^2}{2}\cos(x_\mathrm{D}\Gamma t) - \mathrm{Re}\,\lambda_f \sinh(y_\mathrm{D}\Gamma t) + \mathrm{Im}\,\lambda_f \sin(x_\mathrm{D}\Gamma t) \Bigg],$$

where λ_f is [2]

$$\text{(3)} \qquad \lambda_f \equiv \frac{q}{p}\frac{\bar{A}_f}{A_f} = -\left|\frac{q}{p}\right| \left|\frac{\bar{A}_f}{A_f}\right| e^{i(\phi_f + \Delta_f)},$$

and A_f ($\bar{A}_f$) is the amplitude of the process $D^0(\overline{D}^0) \to f$, ϕ_f is the *CP*-violating weak phase and Δ_f is the *CP*-conserving strong phase.

2. – D^0 mixing at the BaBar experiment

The BaBar detector [3] has been running at the B-Factory PEP II, the e^+e^- asymmetric collider located at the SLAC National Accelerator Laboratory. The data taking started in 1999 and ended in April 2008, resulting in a total integrated luminosity of $530\,\mathrm{fb}^{-1}$. The collider operated mostly at a center-of-mass energy of 10.58 GeV, corresponding to the mass of the $\Upsilon(4S)$ resonance. During the last period of data taking it also operated at lower energies, corresponding to the masses of the $\Upsilon(3S)$ and $\Upsilon(2S)$. The asymmetry in the beam energies led to a boost $\beta\gamma = 0.56$. The internal part of the detector consists of the Silicon Vertex Tracker (SVT), the drift chamber (DCH), the Cherenkov light detector (DIRC) and the electromagnetic calorimeter (EMC). Outside there is the instrumented flux return (IFR) and a superconductive solenoid which produces a uniform magnetic field of 1.5 T parallel to the direction of the electron beam. The B-Factory produced around 690 millions of $e^+e^- \to c\bar{c}$ events, working also as a Charm Factory.

2·1. *A time-dependent analysis on the Dalitz plot.* – A direct measurement of the mixing parameters is possible through a full time-dependent analysis of the Dalitz plot (DP) for the three-body final states $K^0_S h^+ h^-$ ($h = \pi, K$) with the K^0_S recostructed in the $\pi^+\pi^-$ final state. In order to use eq. (2) one should measure the flavour of the D at production, this is done by tagging the D with the charge of the pion emitted in the decays $D^{*+} \to D^0\pi^+$ and $D^{*-} \to \overline{D}^0\pi^-$. Furthermore the relative strong phase Δ_f between the processes $D \to f$ and $\overline{D} \to f$ is not measurable at B-Factories and this lack of knowledge could bring to a redefinition of x_D and y_D by a rotation of this phase.

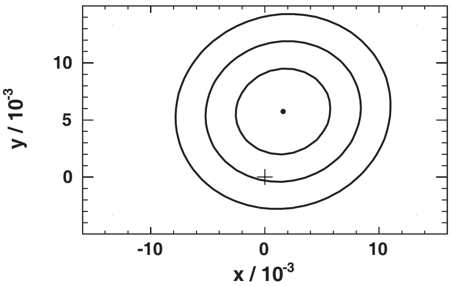

Fig. 1. – Fit results for $K_S^0\pi^+\pi^-$-$K_S^0K^+K^-$ combined fit with the confidence-level (CL) contours for $1 - \text{CL} = 0.317$ (1σ), 4.55×10^{-2} (2σ) and 2.70×10^{-3} (3σ). Systematic uncertainties are included. The no-mixing point is shown as a plus sign (+).

A time-dependent amplitude analysis of the $K_S^0h^+h^-$ decays allows, indeed, to extract both A_f and the mixing parameters x_{D} and y_{D} without strong phase uncertainties. The peculiarity of the $K_S^0h^+h^-$ decays is that the final states $|f\rangle$ and $|\bar{f}\rangle = CP|f\rangle$ belong to the same DP. By assuming *CP* conservation in the decay, this allows to parameterize the decay rate probability using only one amplitude among A_f and $\bar{A}_f$ since $\bar{A}_f = A_{\bar{f}}$.

The three-body D^0 decay is assumed to proceed through two-body intemediate states where one is a resonance, and it is described by two independent Dalitz variables, m_+^2 and m_-^2 which are the reconstructed invariant mass squared of $K_S^0h^+$ and $K_S^0h^-$. In the following we assume CP conservation in the decay, *i.e.* $A(m_-^2, m_+^2) = \bar{A}(m_+^2, m_-^2)$. The total amplitude $A(m_-^2, m_+^2)$ can be written as the superimposition of the amplitudes of each resonance (r) plus a non-resonant (NR) term:

$$A(m_-^2, m_+^2) = \sum_r a_r e^{i\phi_r} A_r(m_-^2, m_+^2) + a_{NR} r^{i\phi_{NR}}, \tag{4}$$

where a_r and ϕ_r are the modulus and the phase of the amplitudes and $A_r(m_-^2, m_+^2)$ reproduces the dependance on the Dalitz variables. According to [4] the modulus and the phases are extracted from the data while we assume a phenomenological model for each $A_r(m_-^2, m_+^2)$. This assumption is a source of a systematic error which we will refer to as "model error". After selecting a sample of D^0 of purity greater than 98% for both the D^0 decay modes, we discriminate signal from background events fitting the distribution in the ($\Delta m = m_{D^*} - m_{D^0}, m_{D^0}$) plane for the signal and background categories. An extended maximum-likelihood fit is then performed on the combined samples of $D^0 \to K_S^0\pi^+\pi^-$ and $D^0 \to K_S^0K^+K^-$ decays in order to extract the Dalitz model and the resolution function parameters, yielding [5]

$$\begin{aligned} x_{\text{D}} &= [1.6 \pm 2.3(\text{stat}) \pm 1.2(\text{syst}) \pm 0.8(\text{model})] \times 10^{-3}, \\ y_{\text{D}} &= [5.7 \pm 2.0(\text{stat}) \pm 1.3(\text{syst}) \pm 0.7(\text{model})] \times 10^{-3}. \end{aligned} \tag{5}$$

This measurement, done on $485\,\text{fb}^{-1}$, is the most precise direct measurement of x_{D} and y_{D}. In fig. 1 is reported the contour plot for the 1 to 3 standard deviations regions.

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