Angular correlations in $D\bar{D} \to (VV)(VV)$ coherent decays

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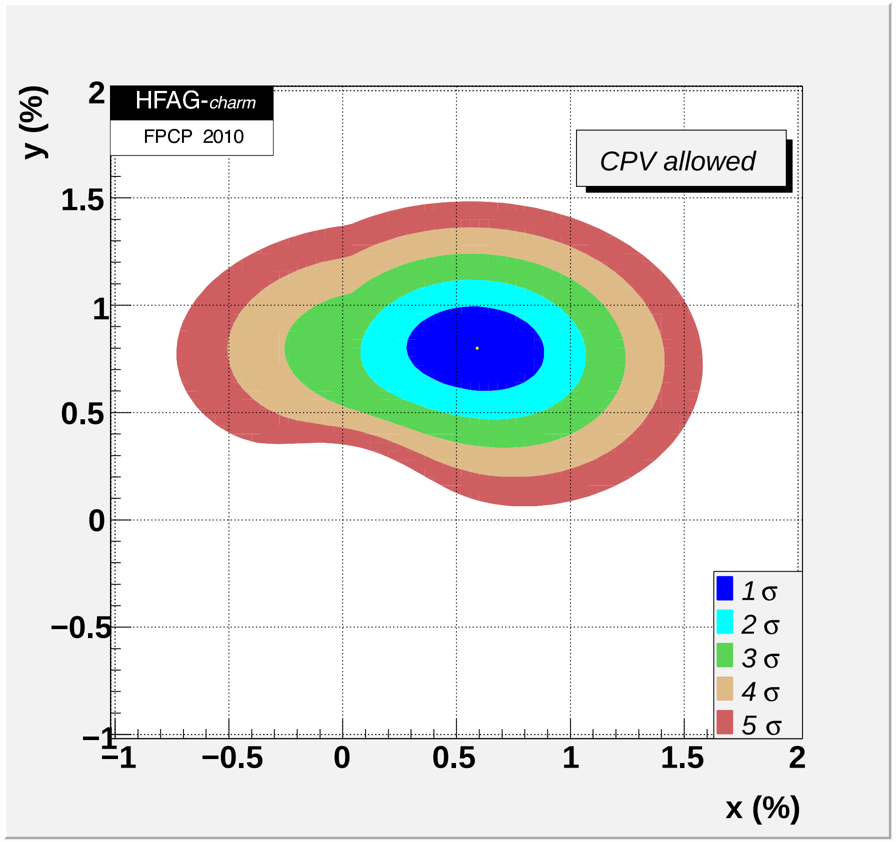
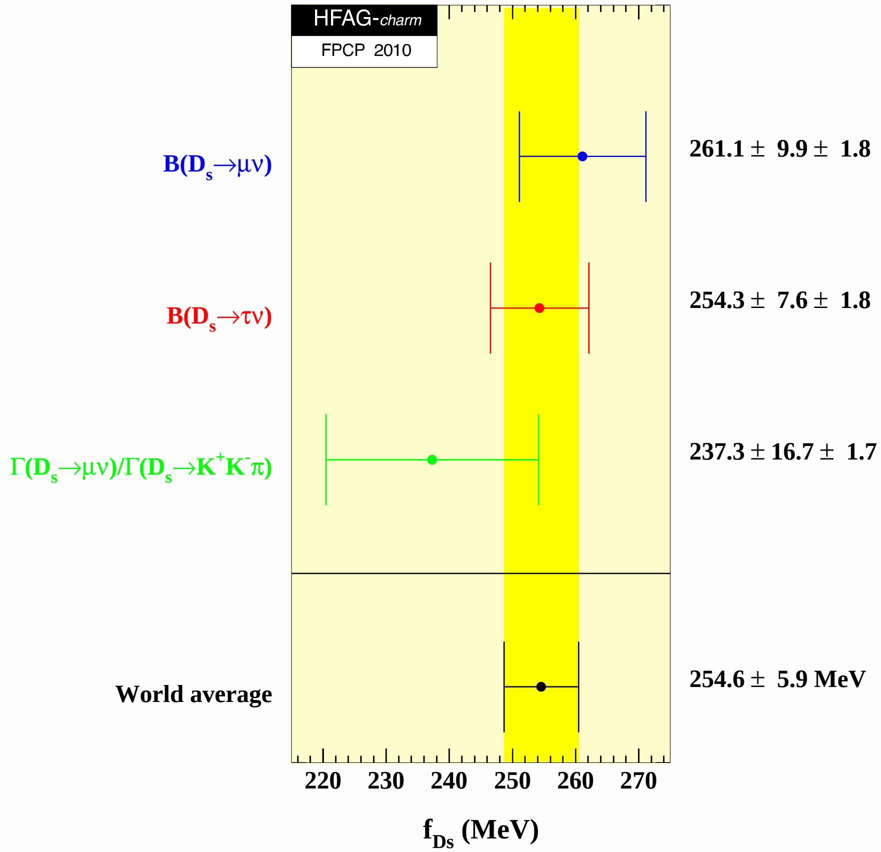
in the last few years the impact of mixing and decay observables of the D mesons on the understanding of the CKM mechanism and CP violation has increased significantly (B-factories, CDF&D0, CLEO-c, BESIII...)





discovery of $D\bar{D}$ mixing

experimental WA $f_{D_s} = 254.6 \pm 5.9$ MeV

LQCD average $f_{D_s} = 246.3 \pm 1.2 \pm 5.3 MeV$

a lot of improvement still to come from present and close future experiments in the following, we exploit the angular correlations in correlated $D\bar{D} \rightarrow (VV)(VV)$ decays to get two kinds of observables:

null-tests of the SM through CP-forbidden transitions

determination of the hadronic phase $\delta_{K\pi}$ to improve the extraction of γ in $B \rightarrow$ charm decays

CP-forbidden transitions

consider $\psi(3770) \to D^0\bar{D}^0 \to f_a f_b$; since $CP(D^0\bar{D}^0) = +1$ and $L(D^0\bar{D}^0) = L(\psi) = -1$, any correlated $D^0\bar{D}^0$ decay to a pair $f_a f_b$ of CP eigenstates of the same parity violates the CP symmetry (Bigi & Sanda, 1986)

neglecting $D^0\bar{D}^0$ mixing one has in this case

$$\mathcal{B}(D^0\bar{D}^0 \to f_a f_b) = 2\mathcal{B}_a\mathcal{B}_b|\rho_a - \rho_b|^2$$

with $\rho_f = A(\bar{D}^0 \to f)/A(D^0 \to f)$

thus to get CP violation one needs $\rho_a \neq \rho_b$ (in particular $a \neq b$)

simplest example is $D\bar{D} \to (\pi^+\pi^-)(K^+K^-)$ with branching ratio $\sim 10^-5 \times |\rho_{\pi\pi} - \rho_{KK}|^2$

in principle it is possible to have no CP violation in $D \to f$ ($|\rho_f| = 1$) but CP violation in $D\bar{D} \to f_a f_b$ ($\rho_a \neq \rho_b$)

in practice if both types of CP violation are of the same order, the total CP violating decay rate is expected to be very small because of present bounds: need as many modes as possible in order to get sensitivity to New Physics in addition to $D \to PP$ modes, $D \to PV, VV$ modes are worth the effort

also, interferences between helicity amplitudes in a $P \to VV$ transition are known to bring new, valuable observables (see, *e.g.* $B \to J/\psi K^*$, $B_s \to J/\psi\phi$)

what about correlated interferences in $D\bar{D} \to (VV)(VV)$?

basic idea: $P \to VV$ is described by three transversity amplitudes $0, \perp, \|$, that have CP-eigenvalues $+1, +1, -1$; thus, if CP is conserved, only the following combinations are allowed: $(0, \perp)$ and $(0, \|)$

a full angular analysis allows to extract the corresponding terms in the decay rate; alternatively one can construct angular moments from orthogonality relations

note that to have $a \neq b$, one can choose two different VV pairs, or same VV pair but different transversity modes

D meson decays to VV CP-eigenstates

VV	$\mathcal{B}$ (%)	ϵ^2
$\rho^0\rho^0$	0.18	0.24
$K^{*0}_{CP}\rho^0$	0.27	0.12
$\rho^0\phi$	0.14	0.07
$K^{*0}_{CP}\omega$	0.33	0.09
$\rho^+\rho^-$	[$\sim$ 0.6]	0.18
$\rho^0\omega$	[$\sim$ 0]	0.18
$K^{*+}K^{*-}$	[0.08]	0.07
$K^{*0}_{CP}\bar{K}^{*0}_{CP}$	0.003	0.09

efficiencies correspond to double tag

numbers in brackets are predictions for yet unseen channels

A glimpse at the formulae

(0, 0) term

$$\int d\Gamma_{4V} \frac{1}{128}(5\cos^2\theta_1 - 1)(5\cos^2\theta_2 - 1)(5\cos^2\theta_3 - 1)(5\cos^2\theta_4 - 1) \sim$$

$$\sim |A(D^0 -> V_1 V_2|^2 |A(D^0 -> V_3 V_4|^2 \times |\rho^0_{V_1 V_2} - \rho^0_{V_3 V_4}|^2$$

(0, ||) term

$$\int d\Gamma_{4V} \prod_{i=1}^{4}(5\cos^2\theta_i - 1)(5\cos^2\theta_i - 3)(4\cos^2\Phi_{12} - 1)(4\cos^2\Phi_{34} - 1) \sim$$

$$\sim |A(D^0 -> V_1 V_2|^2 |A(D^0 -> V_1 V_2|^2 \times |\rho^0_{V_1 V_2} - \rho^{||}_{V_1 V_2}|^2$$

Numerics

parametrize ρ_f as

$$\rho_f = \eta_f (1 + \delta_f) e^{i\alpha_f}$$

where δ_f represents CP-violation in decay, and α_f is a CP-odd phase. Then, if $\delta_f = 0$ (no CP in decay)

$$|\rho_a - \rho_b|^2 = 4 \sin^2 \frac{\alpha_a - \alpha_b}{2}$$

at BES-III at 20 fb^{-1} one would get from the non observation of the $(\rho^0 \rho^0)(K^{*0}_{CP} \rho^0)$ channel the upper limit

$$|\alpha_{\rho\rho} - \alpha_{K^*\rho}| < 4^\circ$$

this is the purely statistical error; in practice, among other systematics, one has to take into account the resonance finite width effects, which prevent VV to be a pure CP-eigenstate

The case $D^0\bar{D}^0 \to (K\pi)(V_1V_2)$ and the extraction of δ

selecting one single amplitude on one side one gets the expression for $D\bar{D} \to (PP)(VV)$ as a subcase of $D\bar{D} \to (VV)(VV)$

one shows that the differential decay rate only depends on

$$M_{0,||} = A_{0,||}(1 + re^{i\delta}), \;\; M_\perp = A_\perp(1 - re^{i\delta}) \quad \text{with} \quad re^{i\delta} = \frac{A(\bar{D}^0 \to K^+\pi^-)}{A(D^0 \to K^+\pi^-)}$$

r and δ are important inputs to the extraction of γ in $B \to D$ decays (see talks by Descotes-Genon and Asner)

present determination of δ from correlated $D\bar{D}$ decays do not use VV modes yet

if rate and polarization of single $D \to VV$ decay are measured independently, one gets from the double tag decay r, cos δ and $|\sin\delta|$

since δ is small $\sim 26°$, the sensitivity to $|\sin\delta|$ is welcome; with other methods it can only be accessed through $D\bar{D}$ mixing terms

a naive estimate of the error on δ with this method at BES-III is about $\sigma(\delta) \sim 4°$, neglecting all systematics

Conclusion

we have shown that correlated $D\bar{D}$ decays to final states with VV pairs provide new observables and information thanks to the interference between the transversity amplitudes

CP-forbidden transitions are a nice test of the Standard Model, in a different manifestation of CP-violation

in $D^0\bar{D}^0 \to (K\pi)(V_1V_2)$ one can extract simultaneously the hadronic parameters r, $\cos\delta$ and $|\sin\delta|$, that are valuable input to B meson decays relevant for the determination of the CKM angle γ

from the pure statistics point of view prospects at BES-III are promising, with uncertainties on the phases of a few degrees

more work is needed to assess the impact of systematics, in particular by how much the description of the hadronic resonance decay introduces model-dependence

it is worth trying !