IL NUOVO CIMENTO Vol. 32 C, N. 3-4 Maggio-Agosto 2009
DOI 10.1393/ncc/i2009-10453-1

Colloquia: IFAE 2009

Charmed meson decays: Theoretical overview and experimental results

M. Pappagallo
Università di Bari and INFN, Sezione di Bari - Bari, Italy

(ricevuto il 19 Settembre 2009; pubblicato online il 13 Novembre 2009)

Summary. — The study of the charmed meson decays is getting a renewable interest because it provides a critical input to the CKM-γ measurements. In addition the discovery of new physics can be revealed in the search for the mixing and CP violation and the large coupling to the light mesons makes charm decays an important probe of light meson spectroscopy. The Dalitz plot technique and a selection of recent experimental results are briefly reviewed.

PACS 11.80.Et – Partial-wave analysis.
PACS 11.30.Er – Charge conjugation, parity, time reversal, and other discrete symmetries.
PACS 12.15.Hh – Determination of Kobayashi-Maskawa matrix elements.
PACS 13.25.Ft – Decays of charmed mesons.

1. – Introduction

The Dalitz plot analysis is an invaluable technique exploited to study the three-body decay. The decay amplitude can be written as the sum of partial waves labeled by the angular momentum quantum number: S-wave, P-wave, D-wave, ... Analyses typically use an isobar model formulation in which each wave is described by a coherent sum of a number of quasi–two-body (resonance + bachelor) amplitudes where the bachelor particle is one of the three final-state products, and the resonance decays to the remaining pair by a Breit-Wigner propagator. Sometimes such formalism is believed to be unsuitable for the S-wave and a K-matrix formalism is preferred. A Model Independent Partial Wave Analysis (MIPWA) [1] is an alternative formalism where the S-wave is defined as an interpolation between points in the complex plane. The magnitude and phase of each point are considered floated parameters of a fit.

2. – Measurement of CKM γ angle

Determinations of the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements provide important tests on the consistency of the standard model and ways to search for new

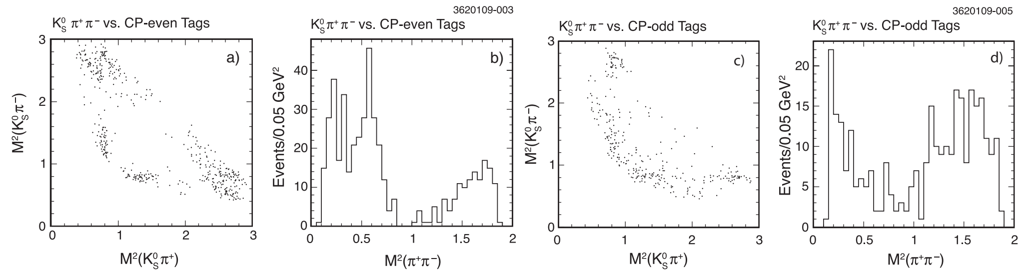

Fig. 1. – CP-even tagged $K^0_S\pi^+\pi^-$ Dalitz plot (a), and its $m^2(\pi^+\pi^-)$ projection (b). CP-odd tagged $K^0_S\pi^+\pi^-$ Dalitz plot (c), and its $m^2(\pi^+\pi^-)$ projection (d) (CLEO-c Collaboration).

physics. The angle γ is the less constrained and therefore it is object of accurate measurements. The most powerful manner in which to measure the angle γ is with $B^- \to \tilde{D}^0 K^-$ decays. Here, $\tilde{D}^0$ is either D^0 or $\bar{D}^0$, and both decay to the same final state, and so their amplitudes interfere. One of the most promising $\tilde{D}^0$ decays for measuring γ using this method is $\tilde{D}^0 \to K^0_S\pi^+\pi^-(\tilde{D}^0 \to K^0_S K^+K^-)$, because it is Cabibbo favored (CF) for both D^0 and $\bar{D}^0$ decays, thus providing large event yields.

The B-factory experiments have devoted a great deal of effort to modelling the $\tilde{D}^0 \to K^0_S\pi^+\pi^-$ decay for the purposes of the γ measurement [2,3]. A recent *BABAR* study has used a sample of 487 k flavour tagged $D^{*+} \to D^0(K^0_S\pi^+\pi^-)\pi^+$ events and a sample of 69 k flavour tagged $D^{*+} \to D^0(K^0_S K^+K^-)\pi^+$ events. The former sample is fitted by an isobar model involving ten resonances and a K-matrix and LASS parametrization to describe the $\pi^+\pi^-$ and the $K^0_S\pi$ contributions, respectively. The latter sample is fitted by a pure isobar model involving only eight resonances. The resulting measurements of γ angle suffer of a systematic uncertainties of 5° arising from how well the model represents reality. However this model systematic is uncomfortable for future very high statistics measurements (*e.g.*, LHCb, Super-B).

The CLEO-c Collaboration employs an alternative and model-independent approach by exploiting the quantum coherence of D^0-$\bar{D}^0$ pairs at the $\Psi(3770)$ [4]. Because of this quantum correlation, $K^0_S\pi^+\pi^-$ decays recoiling against flavor tags, CP-tags, and $D^0 \to K^0_S\pi^+\pi^-$ tags, taken together provide direct sensitivity to the strong phase difference. Figure 1 shows the $K^0_S\pi^+\pi^-$ Dalitz plots and the corresponding projections made with the CLEO-c data for CP-even and CP-odd tags. The difference in structure is apparent, for example the absence of the $K^0_S\rho^0$ peak in the events containing a CP-odd tag. This measurement will result in a substantial reduction in the systematic uncertainty associated with the interference effects between $B^- \to D^0(K^0_S\pi^+\pi^-)K^-$ and $B^- \to \bar{D}^0(K^0_S\pi^+\pi^-)K^-$. Such systematic is estimated 1.7°. It is not related to any model and it depends only on the statistic of the CLEO-c data sample.

3. – Search for CP violation

Within the Standard Model, the CP-violating effects are predicted to be negligibly small in D decays ($O(10^{-5}$–$10^{-4})$). Observation of a larger CP violation will constitute an unambiguous signal of new physics.

The *BABAR* Collaboration searches for time-integrated CP violation in the three-body singly Cabibbo suppressed (SCS) decays $D^0 \to \pi^+\pi^-\pi^0$ and $D^0 \to K^+K^-\pi^0$ [5]. These decays proceed via CP eigenstates (*e.g.*, $\rho\pi^0$, $\phi\pi^0$) and also via flavor states (*e.g.*, $\rho^\pm\pi^\mp$,

$K^{*\pm}K^{\mp}$), thus making it possible to probe CP violation in both types of amplitudes and in the interference between them. Four approaches are adopted, three of which are model independent. No evidence of CP violation has been found and any CP violation in the SCS charm decays occurs at a rate which is not larger than a few percent.

Assuming the validity of the CPT theorem, an alternative approach to test the presence of CP violation is to search for T violation. A T violation effect can come out by measuring a non-zero value of $A_{T_{\rm viol}} \equiv \frac{1}{2}(A_T - \bar{A}_T)$, where A_T is the T-odd asymmetry. The FOCUS Collaboration measures such asymmetry in the singly Cabibbo suppressed decay $D^0 \to K^+K^-\pi^+\pi^-$ [6]. A sample of 828 ± 46 events shows no evidence of T-violation ($A_{T_{\rm viol}}(D^0) = 0.010 \pm 0.057(\text{stat}) \pm 0.037(\text{syst})$). A precision of $4 \cdot 10^{-3}$ could be achieved with the BABAR dataset.

4. – Scalar meson spectroscopy

Some puzzles still remain in light meson spectroscopy. The scalar resonances $J^{PC} = 0^{++}$ are too numerous to fit in a single $SU(3)$ octet. This makes still opened the discussion of the existence of broad states close to threshold such as $k(800)$ and $f_0(600)$ and of the possibility that states such as the $a_0(980)$ or $f_0(980)$ may be 4-quark states, due to their proximity to the $K\bar{K}$ threshold.

4·1. $k(800)$ *and the* $D^+ \to K^-\pi^+\pi^+$ *decay.* – The $D^+ \to K^-\pi^+\pi^+$ decay was once thought to require very large, constant NR amplitudes. Using larger sample, the Fermilab E791 Collaboration found that a satisfactory description of these decays requires more structure. By including S-wave isobar $k(800) \to K^-\pi^+$, a much-improved modelling of the Dalitz plot was achieved, and the need for a constant NR term was much reduced. Later the E791 Collaboration has redone the Dalitz plot analysis implementing a model independent partial wave analyis for the $K^-\pi^+$ S-wave [1]. A significant phase variation is observed over the full range of invariant mass, with the strongest variation near the $K_0^*(1430)$ resonance. The magnitude is largest just above threshold, peaking at about $0.725\,\text{GeV}/c^2$, above which it falls. A shoulder is seen at the mass of the $K_0^*(1430)$, after which the magnitude falls sharply to its minimum value just above $1.5\,\text{GeV}/c^2$. Finally E791 states that, at the statistical level, differences between the MIPWA and the isobar model result are not found to be significant, and both provide good descriptions of the data.

The CLEO-c Collaboration found the E791 results are not suitable to describe the Dalitz plot of its high statistic sample of $D^+ \to K^-\pi^+\pi^+$ (140 k events) [7]. Both isobar and MIPWA approach are performed by adding a $I = 2$ $\pi^+\pi^+$ contribution whose parametrization is taken from the scattering experiments. The addition of the $I = 2$ $\pi^+\pi^+$ S-wave to either the isobar model or the MIPWA approach results the key piece that gives good agreement with data in both cases. The magnitude plot does not show any peak just above the threshold and the $K^-\pi^+$ S-wave has a almost flat behavior but in the $K_0^*(1430)$ region.

4·2. $f_0(980)$ *and* D_s^+ *decays.* – In Cabibbo favored decays of D_s^+ mesons the primary c quark converts into an s quark under emission of an external W^+ while the $\bar{s}$ quark acts as a spectator particle. The most likely decay of the W^+ produces a π^+ and the remaining $s\bar{s}$ system hadronizes into resonances, such as $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_2(1270)$, ... Studying the $D_s^+ \to \pi^+\pi^-\pi^+$ and $D_s^+ \to K^+K^-\pi^+$ decays can explore the property of these mesons decaying to the $\pi^+\pi^-$ and K^+K^- systems.

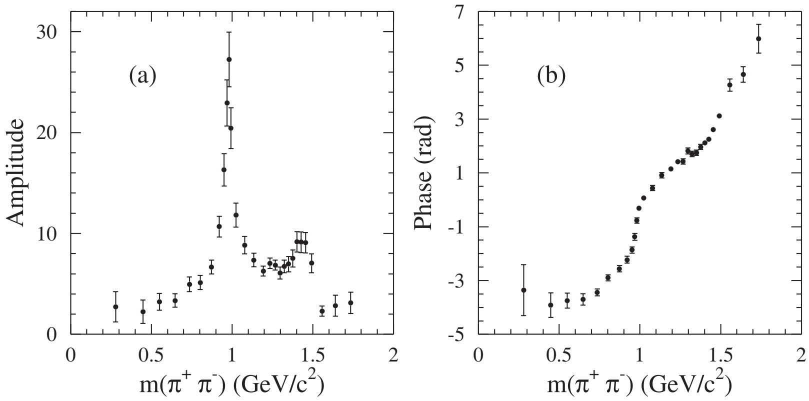

Fig. 2. – Magnitude (a) and phase (b) of the $\pi^+\pi^-$ S-wave (*BABAR* Collaboration).

The *BABAR* Collaboration reports in a recent paper the Dalitz plot analysis of $D_s^+ \to \pi^+\pi^-\pi^+$ where a MIPWA approach is used for the $\pi^+\pi^-$ S-wave [8]. The decay is dominated by the $\pi^+\pi^-$ S-wave and there is also an important contribution from $f_2(1270)$. The S-wave shows, in both magnitude and phase (fig. 2), the expected behavior for the $f_0(980)$ resonance. The S-wave shows further activity in the regions of the $f_0(1370)$ and $f_0(1500)$ resonances. The S-wave is small in the $f_0(600)$ region, indicating that this resonance has a small coupling to $s\bar{s}$.

The $D_s^+ \to K^+K^-\pi^+$ decay has been studied by the *BABAR* [9] and CLEO-c [10] Collaborations as well. The decay is dominated by P-waves: $D_s^+ \to \phi\pi^+$ and $D_s^+ \to \bar{K}^*(892)^0K^+$. The $f_0(980)$ contribution is large but affected by big systematic uncertainties due to the interference with the $f_0(1370)$ whose parameters are not well measured. The $D_s^+ \to K^+K^-\pi^+$ decay is also suitable to explore the $K\pi$ S-wave. The $\langle Y_1^0\rangle$ spherical moments in the $K^-\pi^+$ system hints a very small $S-P$ interference in low $K^-\pi^+$ mass region and therefore the absence of a $k(800)$ contribution. The fit results confirm the $K\pi$ S-wave is well described by a $K_0^*(1430)$ contribution only.

REFERENCES

[1] Aitala E. M. *et al.* (E791 Collaboration), *Phys. Rev. D*, **73** (2006) 032004.
[2] Aubert B. *et al.* (*BABAR* Collaboration), *Phys. Rev. D*, **78** (2008) 034023.
[3] Abe K. *et al.* (Belle Collaboration), [arXiv:0803.3375].
[4] Briereit R. A. *et al.* (CLEO Collaboration), *Phys. Rev. D*, **80** (2009) 032002.
[5] Aubert B. *et al.* (*BABAR* Collaboration), *Phys. Rev. D*, **78** (2008) 051102.
[6] Link J. M. *et al.* (FOCUS Collaboration), *Phys. Lett. B*, **622** (2005) 239.
[7] Bonvicini G. *et al.* (CLEO Collaboration), *Phys. Rev. D*, **78** (2008) 052001.
[8] Aubert B. *et al.* (*BABAR* Collaboration), *Phys. Rev. D*, **79** (2009) 032003.
[9] Pappagallo M. (*BABAR* Collaboration), [arXiv:0711.4769].
[10] Mitchell R. E. *et al.* (CLEO Collaboration), *Phys. Rev. D*, **79** (2009) 072008.