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A complete model for $D^+ \to K^- \pi^+ \pi^+$ s-wave

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The $D^+ \to K^- \pi^+ \pi^+$ decay have been observed in LHCb collaboration with thousands of events per second from $K\pi$ threshold. The theoretical treatment of this decay includes a rich dynamic behaviour that mix weak and strong interactions in a non trivial way.

In the present work we show recently progress on $D^+ \to K^- \pi^+ \pi^+$ decay within a effective hadronic formalism. The weak sector followed a similar formalism from heavy meson ChPT[1], where quark c is an external object of SU(3) Goldstone bosons sector and FSI description is based in three-body model from[2]. The results concerning the vector weak transition revealed a very interesting new scenario in s-wave phase-shift: agrees well with data in the elastic region, and it starts from -60 degrees. Up to now the reason way the experimental phase starts at negative degrees(≈ -138) was a mystery. However, we show that this behaviour is a consequence of interference between a correct weak vertex dynamic, dominated by ρ meson propagator, and a rescattering model to the final state interaction. Therefore, this work represent a progress in the understanding of $D^+ \to K^- \pi^+ \pi^+$ and could be applied to other decays.

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1 Introduction

The S-wave $K^-\pi^+$ sub-amplitude in the decay $D^+ \to K^-\pi^+\pi^+$, denoted by $[K^-\pi^+]_{D+}$ has been extracted from data by the E791[3] and FOCUS[4] collaborations. A remarkable feature of the results is a significant phase shift deviation between $[K^-\pi^+]_{D+}$ and elastic $K^-\pi^+$ LASS data [5], which was considered to be a puzzle until recently. However, this is a clearly indication that the dynamical relationship between both types of processes is not simple and has motivated an effort by our group aimed at understanding the origins of this problem. A schematic calculation was presented in [2] and recent progress can be found in [6]. Here we briefly summarize the main issues and progress. The programme is implemented by means of effective lagrangians, which incorporate the symmetries of QCD, where weak and electromagnetic interactions are included as external sources. The inclusion of heavy mesons can be performed by suitable adaptations of the light sector [1].

2 Dynamics

The reaction $D^+ \to K^-\pi^+\pi^+$ involves two distinct structures: weak vertex and final state interactions (FSI). The first one concerns the primary quark transition $c \to s\, W^+$, which occurs in the presence of the light quark condensate of the QCD vacuum and is dressed into hadrons. The second class of processes corresponds to three-body FSI, associated with the strong propagation of the state produced in the weak vertex to the detector. These ideas are summarized in Fig.1.
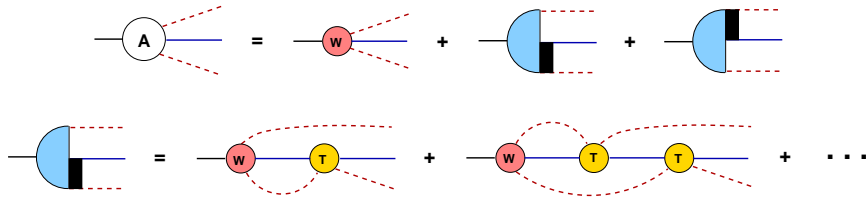

Figure 1: Diagrammatic representation of the heavy meson decay into $K\pi\pi$, starting from the weak amplitude (red) and including hadronic final state interactions.

weak vertex

For description of the weak vertex in $D^+ \to K^-\pi^+\pi^+$, we concentrate on the colour allowed class of diagrams proposed by Chau[7], which gives rise to the hadronic amplitudes shown in Fig.2. Processes on the top involve an *axial* weak current, whereas the bottom diagram is based on a *vector* current. The blob in the diagrams summarizes several hadronic processes which contribute to form factors. In the absence of
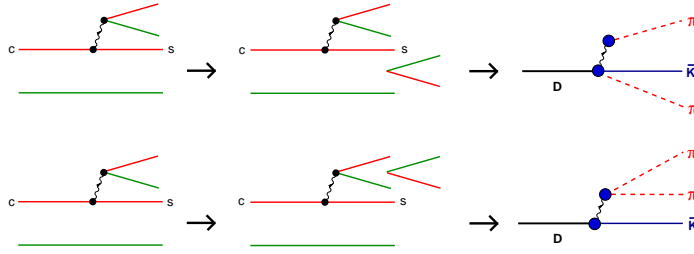
Figure 2: Mechanisms for hadronization; quarks u and d are not specified.

form factors, the weak vertex entering Fig. 1 is given by the diagrams shown in Fig. 3, where processes a and b involve the axial current and c contains a vector current. The inclusion of form factors can be made either by using phenomenological input or
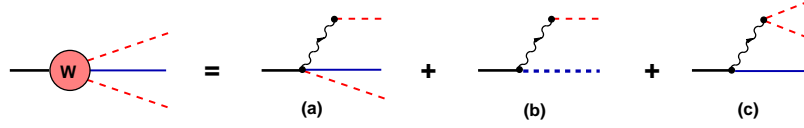

Figure 3: Topologies for the weak vertex: the dotted line is a scalar resonance and the wavy line is a W^+, which is contracted to a point in calculations.

by allowing the intermediate propagation of $(c\bar{s})$ states, as shown in Fig. 4.
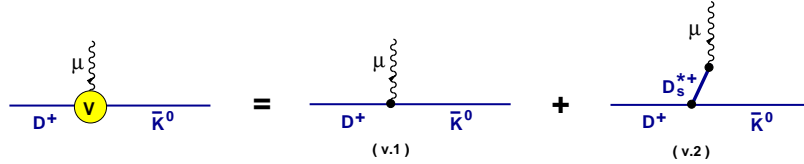

Figure 4: Vector form factor.

final state interactions

When final state interactions are added to the processes, one finds three families of color-allowed amplitudes denoted respectively by A_a, A_b, and A_c. The class of FSIs considered is based on a succession of elastic two-body interactions, which bring the $K\pi$ phase into the problem. The $K\pi$ amplitude is derived by means of chiral effective lagrangians, based on leading order contact terms [8] and supplemented by resonances [9], which allow for a wider energy range.

3 First results

In a previous publication [2], we evaluated the contributions of the three topologies (Fig. 3) up to second order in a perturbative series to the S-wave $[K^-\pi^+]_{D^+}$. With the purpose of taming the calculation we made some simplifying assumptions: the weak amplitudes of Fig. 3 were taken to be constants, isospin 3/2 and P waves were not included in the $K\pi$ amplitude and couplings to either vector mesons or inelastic channels were neglected. Results for the phase are displayed in Fig. 5. Leading order
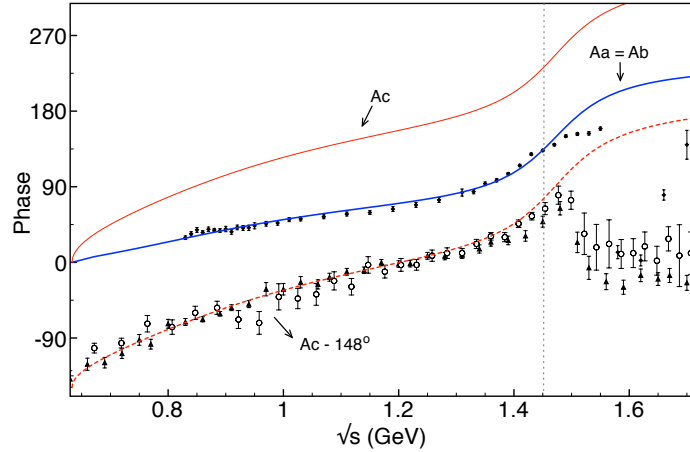

Figure 5: Phase for A_a, A_b, A_c at leading order and A_c shifted by -148^0 compared with FOCUS [4](triangle) and E791[3](circle) data, together with elastic $K\pi$ results from LASS[5](diamond).

contributions from the axial weak current, represented by A_a and A_b, obey Watson's theorem and fall on top of elastic $K\pi$ data. The curve for the vector A_c amplitude has a different shape and, if shifted by -148^0, can describe well FOCUS data[4], up to the region of the peak.

The main lesson to be drawn from our first approach to this problem is that, for some yet unknown reason, the amplitude which begins with a vector weak current, represented by diagram (c) of Fig. 3, seems to be favoured by data. This amplitude receives no contribution at tree level, since the W^+ emitted by the charmed quark decays into a $\pi^+\pi^0$ pair. Therefore, the leading term in this kind of process necessarily involves loops and the corresponding imaginary components.

4 Vector vertex

A limitation of our first study [2] was that all weak vertices were described by momentum independent functions. Those results are now improved by considering the proper P-wave structure of the weak vertex, corrections associated with form factors and contributions from intermediate ρ mesons. The ρ is introduced by means of stan-
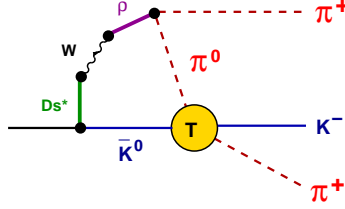

Figure 6: Leading vector contribution.

dard vector meson dominance, using the formalism given in Ref.[9]. The $D \to W\overline{K}$ vertex may contain $(\overline{s}c)$ intermediate states and can be obtained either by means of heavy-meson effective lagrangians [1] and the diagrams of Fig. 4, or by using phenomenological information parametrized in terms of nearest pole dominance [10]. Our basic interaction for this process became the diagram in Fig. 6. New predictions for
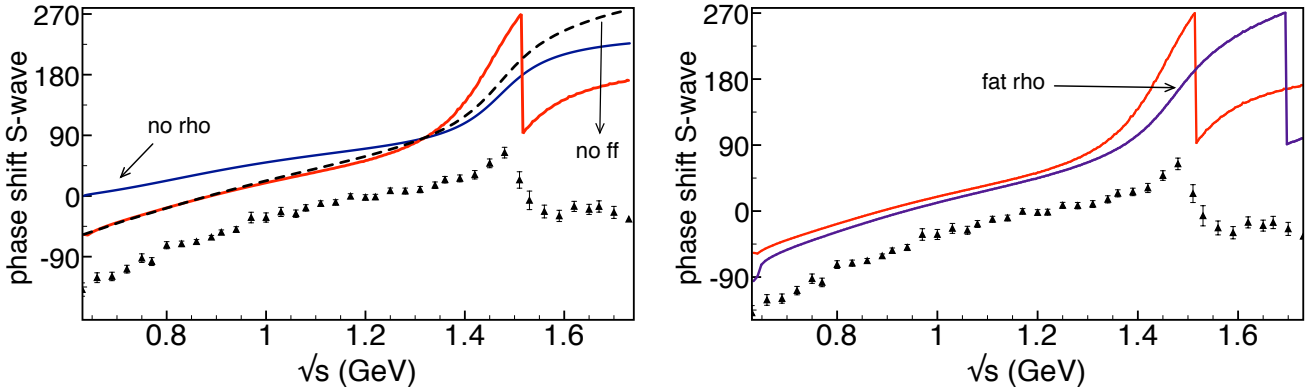

Figure 7: Predictions for the phase, compared with FOCUS results[4].

the phase are shown in the red curve of Fig. 7. Form factors, as expected, become more important at higher energies, as indicated by "no form factors" curve. The "no rho" is obtained by taking the limit $m_\rho \to \infty$ in the calculation and tends to that labelled A_c in Fig. 5. The most prominent feature of the full phase is that it now has a negative value at threshold, showing that contributions from light intermediate resonances are important. So far, the rho has just been treated as a point-like particle,

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however its width, associated with two-pion intermediate states, is a new source of complex amplitudes and was included in Fig. 7(right) with the label "fat rho", which compared with the point-like ρ show the relevance of including off-shell effects in this vertex.

5 Final remarks

We have presented results for the decay $D^+ \to K^- \pi^+ \pi^+$ and shown that final state interactions are visible in data. It is already clear that hadronic processes occurring between the primary weak decay and asymptotic propagation to the detector do play a key role in shaping experimental results. Although derived from a single instance, the patterns of hadronic interpolation are quite general and it is fair to assume that this conclusion can be extended to other processes.

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