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A model for final state interactions in $D^+ \to K^-\pi^+\pi^+$

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In a recent publication Magalhães *et al.* examined the importance of final-state interactions in $D^+ \to K^-\pi^+\pi^+$, stressing the consistency between two- and three-body channels. The calculation was based on an isospin-1/2 s-wave $K\pi$ amplitude motivated by unitarized chiral perturbation theory and with parameters determined from a fit to data from LASS. The resulting amplitude for s-wave $K^-\pi^+$ production in D^+ decay was compared with the one determined by the FOCUS collaboration. This work investigates further aspects of $D^+ \to K^-\pi^+\pi^+$ decay in an extension of that model. In particular, we consider the contribution of the isospin-3/2 s-wave $K\pi$ channel to the three-body rescattering. In this channel we take Pennington's parametrization of the phase shift from older LASS data. We include both single and double rescattering in the final state. Projecting onto the $K^-\pi^+\pi^+$ channel we are able to compare our results with the s-wave $K^-\pi^+$ production amplitude from FOCUS and E791.

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The decays of charm mesons are far from being well understood from either experimental or theoretical points of view (see for example Ref. [1]). New data from LHCb at CERN may help on the experimental side but on the theoretical side there are two main issues to be explored: the weak vertex (WV) and final state interactions (FSI). For the weak vertex, the problem is the lack of a directly applicable theory to describe charm decays. For example, one suggestion is to use factorization to construct an effective weak Hamiltonian [2], but it is still not clear if this approximation is valid for charm sector. The FSI in three-particle decays are often described using a single two-body scattering in each channel, with the third particle just a spectator. Recently, however, the $D^+ \to K^-\pi^+\pi^+$ decay amplitude was calculated using a three-body FSI model based on two-body rescattering processes to second order [3]. That work showed the need for a three-body FSI treatment and found agreement with $D^+ \to K^-\pi^+\pi^+$ data [4] with one of their models for the weak vertex.

In this work, we investigate further aspects of the FSI that go beyond the version of the model used in [3]. Particularly, we examine the role of interference between the isospin-1/2 and 3/2 $K\pi$ channels. Here we present only the main results and conclusions. For details of the motivation, theoretical context and FSI model we refer the reader to the previous Magalhaes *et al.* [3]; details of the new calculations in this work will be given in [5].

Without a reliable approach to the WV, we considered a simple schematic model based on structureless contact interactions. This is similar to the model used in [3], and shown in fig. 1 and has three parameters to be fixed by data. Rather than relating them to any model for the underlying physics, we take them to correspond to direct couplings to the two $K\pi$ isospin channels, and a isospin-1/2 resonance. Diagrams in fig. 1 are driving terms in our treatment of the three-

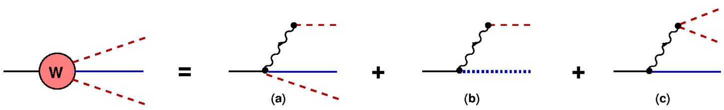

Figure 1: three different structureless weak vertex. Diagram from [3].

body system based on an integral equation in a Faddeev like formalism [6], which implements a convolution between the WV and the FSI, as shown in fig. 2.

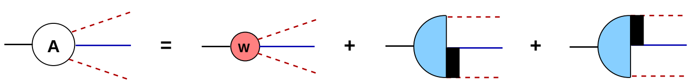

Figure 2: Faddeev like decomposition for $D^+ \to K^-\pi^+\pi^+$.

Making a perturbative expansion of the three-body equation to second order in $K\pi$ interactions, and neglecting $\pi^+\pi^+$ interaction, our FSI model is defined in fig. 3, where T is the two-body $K\pi$ scattering amplitude in either isospin-1/2 or 3/2 channel. Note that in reference [3] they considered only the dominant contribution of the isospin-1/2 s-wave $K\pi$ channel. The model for $T_{1/2}$ was based on unitarized chiral perturbation theory, with parameters determined from a fit to LASS data [7].

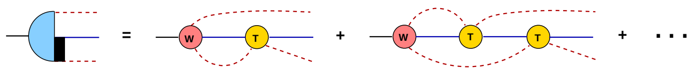

Figure 3: FSI series.

1. Isospin interference

The amplitude for S-wave $K^-\pi^+$ production in $D^+ \to K^-\pi^+\pi^+$, determined in experiments such as FOCUS [4], is a mixture of isospin-1/2 and 3/2 components. The total amplitude constructed using the relevant Clebsch-Gordan coefficients [8] is

$$A_{K^-\pi^+} = \sqrt{\frac{2}{3}} A_{1/2}\, |1/2;1/2\rangle + \sqrt{\frac{1}{3}} A_{3/2}\, |3/2;1/2\rangle\,; \tag{1.1}$$

Therefore the role of interference between these channels needs to be explored and understood. For this we require the isospin-3/2 $K\pi$ scattering amplitude. From older LASS data [9] we know that this amplitude is repulsive and small in the s-wave sector at low energies. Nonetheless, its phase shift grows to about 20° at around 1.0 GeV and so we include it in our rescattering calculation.

In this work we truncate the rescattering series at up to second order in the two-body amplitudes. For the isospin-1/2 channel we use the same amplitude as in [3] whereas for isospin-3/2 channel we take the parametrization proposed by Pennington [10] of the phase shift determined from older LASS data [9].

Projecting our final state with eq.(1.1) we are able to compare our results with the s-wave $K^-\pi^+$ amplitude from FOCUS [4] and E971 [11] data as shown in fig. 4. This shows that without

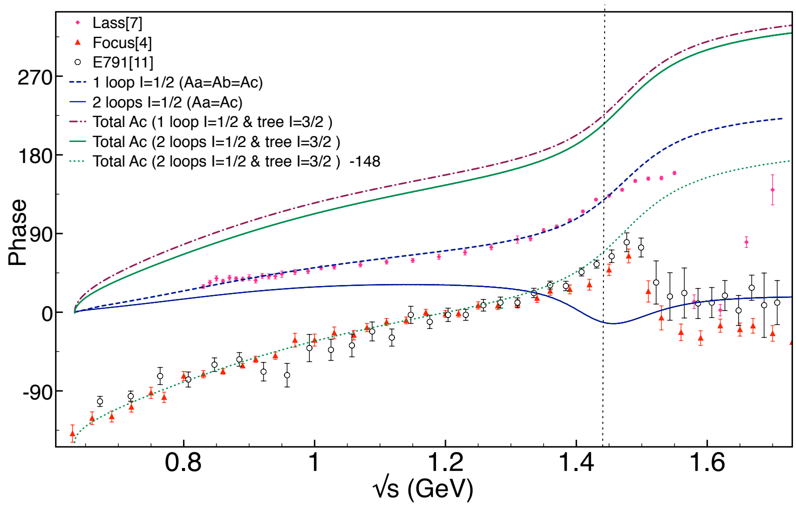

Figure 4: Phase of the s-wave $K^-\pi^+$ amplitude from $D^+ \to K^-\pi^+\pi^+$ including isospin-1/2 rescattering up to second order and isospin-3/2 just to first order. The phases are compared with experimental data on $K\pi$ scattering [7] and $D^+ \to K^-\pi^+\pi^+$ [4, 11].

the isospin-3/2 channel the phase up to single isospin-1/2 rescattering matches the two-body one from $K\pi$ scattering, as expected from Watson's Theorem [12]. However, when we include either a second rescattering or second loop or the isospin-3/2 contribution at tree level (that is, with no scattering), the theorem no longer holds. On the other hand, even the simple case of adding the isospin-3/2 channel at tree level allows us to describe experimental phase from $D^+ \to K^-\pi^+\pi^+$ decay (after a global shift of $-148°$). This form were obtained before in [3] from a particular model of the WV, and now we can understand it as a consequence of interference between the isospin channels.

The importance of the interference effect even at tree level in isospin-3/2 motivates us to explore higher orders. Our model for the amplitude is

$$A_{K\pi\pi} = p(A_{1/2} + W_b A_b) + z_2 A_{3/2}\,. \tag{1.2}$$

This has three parameters: p and z_2 describing the strengths of the weak vertex in the two isospin channels, and W_b a direct coupling to a resonance in the isospin-1/2 channel. The last is needed because in our model the two-body amplitude is generated from a kernel that contains a bare pole [3].

In order to explore how well we can describe both the phase and modulus of the amplitude from FOCUS[4], it is convenient to present them on an Argand diagram, as in fig. 5. We have not

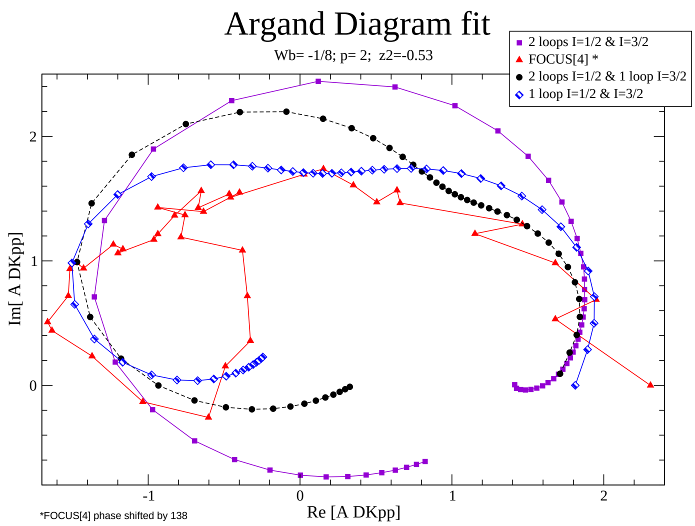

Figure 5: Argand diagram for $A_{K\pi\pi}$ with different combinations of rescattering in the two isospin channels.

attempted any detailed fits but, including single rescattering in both channels, we can describe the data quite well with the parameter set: $W_b = -0.125$, $p = 2$ and $z_2 = -0.53$.

On the Argand diagram, we also show results with double rescattering in the s-wave channels. We find that contributions of second order in the isopin-1/2 amplitude and of mixed rescattering (one isospin-1/2 and one 3/2) are both significant. The total amplitude to this order has the wrong shape compared to the data and adjusting the paramters does not improve matters. This means that we are not able to describe simultaneously both the phase and modulus, as shown explicitly in the graphs of fig. 6.

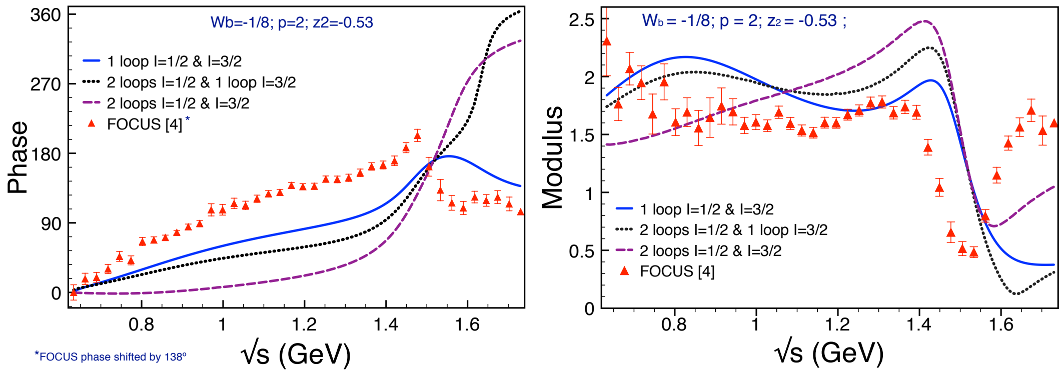

Figure 6: Phase and modulus of $A_{K\pi\pi}$ with different combinations of rescattering in the two isospin channels.

2. Conclusion

The single rescattering amplitudes satisfy Watson's theorem in the individual isospin channels. However, we find that the interference between the isospin-1/2 and 3/2 channels is important for the $K^-\pi^+$ production amplitude in $D^+ \to K^-\pi^+\pi^+$, and can explain some of the features found in [3]. The double-rescattering contributions mean that Watson's theorem no longer holds. At this level, the isospin-1/2 channel provides the most important contribution, although the mixed rescattering terms are also significant.

Within this improved framework, we can understand some of the results obtained using the model in [3]. In particular, the good agreement with the FOCUS phase shift is found to arise largely from the interference between the two isospin channels. We also find that double-rescattering effects in the three-body system are significant. However, we are not able to describe simultaneously both the phase and the modulus of the FOCUS data [4]. This is an indication that we are still missing important physics. Two possible sources of this should be investigated. One is the weak-vertex, where a better model including possible energy dependence is needed. The other is a more complete treatment of the three-body final state, such as a full solution of the Faddeev equation.

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References

[1] B. Bhattacharya and J. L. Rosner, arXiv:1104.4962.

[2] D. Boito, R. Escribano, Phys.Rev.D80, 054007 (2009).

[3] P. C. Magalhaes *et al.*, Phys. Rev. **D84**, 094001 (2011).

[4] J. M. Link *et al.* (FOCUS), Phys. Lett. **B681**, 14 (2009).

[5] P. C. Magãlhaes and M. C. Birse, in preparation.

[6] K.S.F.F. Guimaraes, T. Frederico, I. Bediaga, A. Delfino and A.C. dos Reis, Nucl.Phys.Proc.Suppl. **199** 341 (2010).

[7] D. Aston *et al.*, Nucl. Phys. **B296**, 493 (1988).

[8] K. Nakamura *et al.* (PDG), J. Phys. **G37**, 075021 (2010).

[9] P. Estabrooks *et al.* , Nucl. Phys. ,**B133** , 490 (1978).

[10] J. M. Link *et al.* (FOCUS), Phys. Lett. **B653**, 1 (2007).

[11] E. M. Aitala et al. (E791), Phys. Rev. Lett. **89**, 121801 (2002), hep-ex/0204018.

[12] K. M. Watson, Phys. Rev. **88**, 1163 (1952).