Eur. Phys. J. A **18**, 359–361 (2003)
DOI 10.1140/epja/i2002-10235-1

THE EUROPEAN PHYSICAL JOURNAL A

Aspects of a_0^0-f_0 mixing in the reaction $pn \to dX$

C. Hanhart[a]

Institut für Kernphysik, Forschungszentrum Jülich, D-52425 Jülich

Received: 30 September 2002 /
Published online: 22 October 2003 –

Abstract. Possibilities to study the a_0^0-f_0 mixing amplitude in meson production reactions in nucleon-nucleon collisions are discussed. It is argued that, even without knowing the production operator, it is possible to gain valuable insights from these reactions.

PACS. 13.60.Le Meson production – 13.75.-n Hadron-induced low- and intermediate-energy reactions and scattering (energy $\leq$ 10 GeV) – 14.40.Cs Other mesons with $S = C = 0$, mass < 2.5 GeV

The structure as well as the properties of the lightest scalar mesons is not yet understood. It is believed that the a_0^0-f_0 mixing amplitude will give some hint on the nature of these resonances. In this paper the experimental signal from the reaction $pn \to d(\pi\eta)_{(s\text{-wave})}$ induced by a_0^0-f_0 mixing is discussed in a model-independent way. It was observed recently that this reaction is an ideal system to study the mixing, for the deuteron in the final state acts as an isospin filter that kinematically enhances the signal of the mixing [1]. We will come back to this point later.

Naturally there are two ingredients that contribute to any observable of the reaction $pn \to d(\pi\eta)_{(s\text{-wave})}$, namely the primary production of the two-meson system and its propagation. It is the latter that we are interested in, however, we first need to understand the former to draw definite conclusions. In the close-to-threshold regime it should be sufficient to include the lowest partial waves possible only. However, even this simplification is still insufficient to allow us to construct the production operator directly. But it limits the number of partial waves allowed sufficiently that it is still possible to make definite statements. The energy dependence of the initial-state interaction as well as the one of the production operator should scale with the initial momentum. The interactions in the outgoing system, however, should scale with the typical momentum in the final-state $k \simeq \sqrt{2M_N Q}$, where $Q = \sqrt{s} - \sqrt{s_{\rm thr}} = \sqrt{s} - \sqrt{2M_N + m}$. Note, since we study the production of an unstable meson or more exactly a two-meson system, one has to generalize the definition of the excess energy: the mass m in the above equation denotes the invariant mass of this system. Following the same philosophy as that of effective field theories, we simply construct the most general structure of the amplitude consistent with the symmetries of the underlying theory. The coefficients appearing can be assumed constant (up to corrections of the order $(|\boldsymbol{k}|/|\boldsymbol{p}|)^2$). Thus, based on rather general arguments it should be possible to study the final state even without knowing anything about the actual mechanism of production.

The goal of the present investigation is to study the a_0^0-f_0 mixing that demands the presence of charge symmetry breaking. However, the resonance parameters of f_0 and a_0 are very close to each other. Therefore, as long as we stay close to the resonance mass, the mixing in the propagating meson system should be far more important than any possible mechanism of charge symmetry breaking in the primary production amplitude. This is the central assumption of this investigation.

As was stated in the beginning, in this presentation we consider the mesons to be in a relative s-wave. This largely simplifies the construction of the transition operator, for under this assumption only $\boldsymbol{k}$ (the center-of-mass momentum of the deuteron), $\boldsymbol{S}$ (the spin of the initial NN system), $\boldsymbol{p}$ (the beam momentum) and ϵ (the deuteron polarization) can appear explicitly in the transition operator. In addition, conservation of angular momentum, isospin and parity demands that an isospin-one scalar state is to be produced in a p-wave with respect to the deuteron. Therefore, only the following four transitions are possible: ${}^3P_J \to ({}^3S_1 - {}^3D_1)p$ and ${}^3F_2 \to ({}^3S_1 - {}^3D_1)p$, where $J = 0, 1, 2$. Having said this it is a straightforward task to express all observables for the isospin-one system in terms of the partial-waves amplitudes. However, there is a more transparent way to come to the same result, that at the same time allows for a more straightforward interpretation of the observables in terms of the spin structure of the production operator. For that one just has to construct

[a] e-mail: c.hanhart@fz-juelich.de

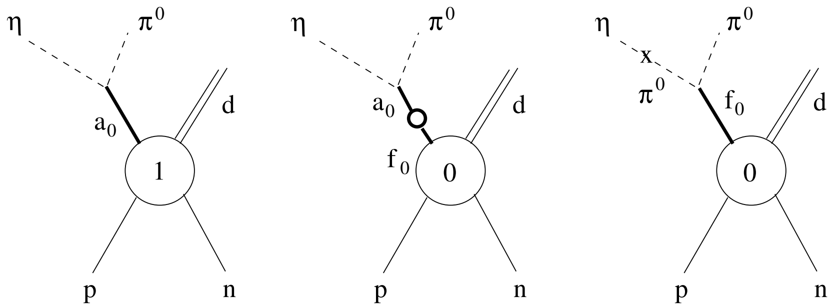

Fig. 1. Diagrammatic representation of the approach for the π-η final state. The large circles denote the primary production amplitudes, whereas the little circle indicates the a_0^0-f_0 transition amplitude. The thick solid lines denote the propagation of the resonances.

all possible scalars from the vectors available. We get

$$M_1 = a\,(\boldsymbol{p}\cdot\boldsymbol{S})\,(\boldsymbol{k}\cdot\boldsymbol{\epsilon}^*) + b\,(\boldsymbol{p}\cdot\boldsymbol{k})\,(\boldsymbol{S}\cdot\boldsymbol{\epsilon}^*) + c\,(\boldsymbol{k}\cdot\boldsymbol{S})\,(\boldsymbol{p}\cdot\boldsymbol{\epsilon}^*) + d\,(\boldsymbol{p}\cdot\boldsymbol{S})\,(\boldsymbol{p}\cdot\boldsymbol{\epsilon}^*)\,(\boldsymbol{k}\cdot\boldsymbol{p})\,. \quad (1)$$

This procedure was advocated in ref. [2] and applied more rigorously in ref. [3].

The isoscalar f_0, on the other hand, can be produced in an s-wave and we find

$$M_0 = f\,(\boldsymbol{S}\cdot\boldsymbol{\epsilon}^*) + g\,(\boldsymbol{p}\cdot\boldsymbol{S})\,(\boldsymbol{p}\cdot\boldsymbol{\epsilon}^*)\,. \quad (2)$$

It is obvious from eqs. (1) and (2) that $\mathcal{M}_1 \propto k$ and $\mathcal{M}_0 \propto$ const near the threshold. For the isospin-conserving case we therefore get

$$\frac{\mathrm{d}\sigma}{\mathrm{d}m^2}(pn \to da_0) \propto Q^{3/2} \text{ and } \frac{\mathrm{d}\sigma}{\mathrm{d}m^2}(pn \to df_0) \propto Q^{1/2}\,.$$

Thus, if we study a channel where the two-meson system is produced in an isovector state, namely $\pi^0\eta$, only the occurrence of charge symmetry breaking allows the contribution of s-wave production. This is the kinematical enhancement mentioned in the beginning. In addition, that the symmetry conserving piece starts with a p-wave has a large influence on any differential observable as we will discuss below.

Since the main focus of the paper is the $\pi\eta$ channel it is convenient to introduce a mixing parameter ξ by

$$\xi(m) = \varSigma_{01}(m)\,\tilde{G}_{f_0}(m^2), \quad (3)$$

where $\varSigma_{01}$ was defined in ref. [3] and is related to the a_0^0-f_0 transition amplitude. Let $\boldsymbol{p}\cdot\boldsymbol{k} = pk\cos\theta$ and $\boldsymbol{\zeta}\cdot[\boldsymbol{k}\times\boldsymbol{p}] = \zeta\,pk\sin\theta\,\sin\varphi$ $(\zeta = |\boldsymbol{\zeta}|)$. Using those expressions we get

$$\overline{|\mathcal{M}(\theta,\varphi)|^2} = C_0 + C_1\cos\theta + C_2\cos^2\theta + \zeta\,\sin\theta\,\sin\varphi\,(D_0 + D_1\cos\theta)\,, \quad (4)$$

where

$$C_0 = \frac{1}{2}\left(|a|^2+|c|^2\right)p^2k^2 + \left(|f|^2 + \frac{1}{2}|f+p^2g|^2\right)|\xi|^2\,,$$

$$C_1 = pk\,\mathrm{Re}\left(\left[(a+b+c+p^2d)^*(f+p^2g) + 2b^*f\right]\,\xi\right)\,,$$

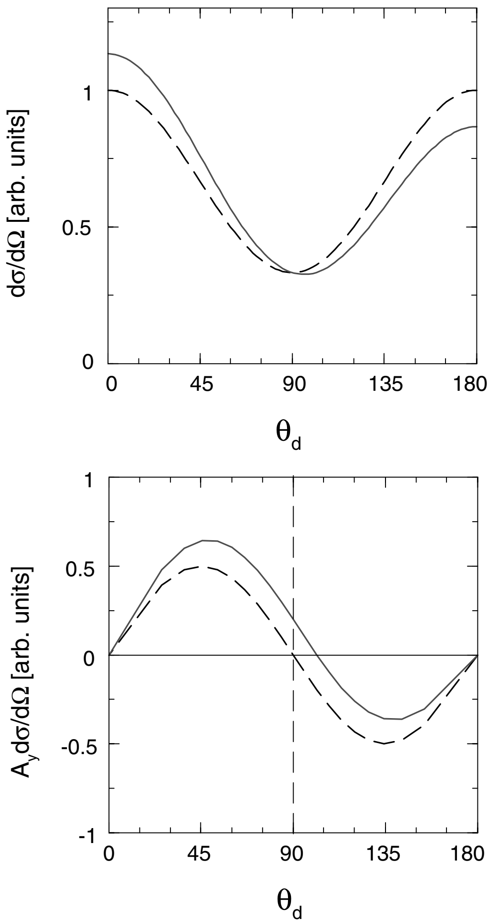

Fig. 2. Sketch of the possible signal for both the differential cross-section as well as the analyzing power in the reaction $pn \to \pi\eta d$. The dashed line corresponds to the observables without isospin breaking, whereas the solid line shows the expected signal in the presence of isospin violation.

$$C_2 = p^2k^2\left[|b|^2 + \frac{1}{2}|b+p^2d|^2 + \mathrm{Re}\left(a^*c + (a+c)^*(b+p^2d)\right)\right],$$

$$D_0 = pk\,\mathrm{Im}\left(\left[a^*f - c^*(f+p^2g)\right]\xi\right)\,,$$

$$D_1 = p^2k^2\,\mathrm{Im}(a^*b + a^*c + b^*c + p^2d^*c)\,.$$

Here, also the role of the deuteron as isospin filter becomes clear: since it is an isoscalar, the isospin of the two-meson system determines the isospin of the initial two-nucleon system, as long as isospin is conserved. Therefore, in the absence of isospin breaking the differential cross-section is necessarily forward-backward symmetric. Therefore any forward-backward asymmetry is a direct measure of isospin violation. This is indicated in the upper panel of fig. 2. Please note that the curves are not based on a calculation but are meant as a sketch for illustration.

Another interesting observable is the analyzing power. As one can read directly of eq. (4), in the absence of isospin violation the analyzing power vanishes at 90°. Thus, any deviation from zero at 90° directly measures the isospin violation. This is true not only if only the lowest partial waves are included, but also in the presence of higher partial waves, as long as we restrict ourselves to a relative s-wave in the two-meson system. However, it should be stressed that a relative p-wave in the two-meson system can also lead to a shift of the zero in the analyzing power, even in the absence of any isospin breaking. This effect can be studied in the reaction $\boldsymbol{pp} \to d\pi^+\eta$, since a charged two-meson state does not mix with an isospin-zero state.

In ref. [4] it was argued recently that especially in the $K\bar{K}$ channel not only the resonances in the two-meson system, but also a meson-baryon resonance, namely the $\Lambda(1405)$, should play a significant role in the reaction under consideration. The authors predicted a significant change in the invariant-mass distributions of the final particles. Since this resonance favors an s-wave of the $\bar{K}$ and the deuteron, it is this additional final-state interaction that should strongly enhance the p-waves in the meson-meson system. Again, also this point can already be studied in the reaction $pp \to d\pi^+\eta$. It should be stressed, that preliminary data from the ANKE Collaboration at COSY indicate, that there is indeed a sizable amount of p-wave strength in the $K\bar{K}$ system.

To summarize, in this paper recent studies were presented, that demonstrate, that the production of scalar mesons in nucleon-nucleon collisions might be the ideal reaction to investigate the properties of scalar mesons, especially their mixing. It is the latter attribute that is believed to be the key to an understanding of the nature of scalar mesons.

References

1. A.E. Kudryavtsev, V.E. Tarasov, JETP Lett. **72**, 401 (2000), nucl-th/0102053.
2. V.Yu. Grishina, L.A. Kondratyuk, M. Büscher, W. Cassing, H. Ströher, Phys. Lett. B **521**, 217 (2001).
3. A.E. Kudryavtsev, V.E. Tarasov, J. Haidenbauer, C. Hanhart, J. Speth, Phys. Rev. C **66**, 015207 (2002).
4. E. Oset, J.A. Oller, Ulf-G. Meißner, Eur. Phys. J. A **12**, 435 (2001).