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SCALAR MESON SPECTROSCOPY FROM THREE CHANNEL MODEL ANALYSIS OF MESON–MESON SCATTERING*

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New isoscalar S-wave $\pi\pi$ phase shift solutions have been analysed. Separable potential model of three coupled channels $\pi\pi$, $K\bar{K}$ and an effective $2\pi 2\pi$ has been used. Spectrum of scalar resonances up to 1600 MeV has been evaluated.

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In this analysis we use results of PWA performed by the CERN–Cracow–Munich collaboration for reaction $\pi^- p_\uparrow \to \pi^+\pi^- n$ on polarized target at 17.2 GeV/c [1]. The data cover the $\pi\pi$effective mass range from 600 MeV to 1600 MeV and the t–momentum transfer range from -0.2 (GeV/c)^2 to -0.005 (GeV/c)^2. Combination of results of experiments on polarized and nonpolarized target yields a number of observables sufficient for performing a quasi–complete and energy independent PWA without any model assumptions. This removed ambiguities appearing in earlier studies, except for the old "up–down" ambiguity [2]. This ambiguity has not been resolved and all the studies of the *full* (*i.e.*, including polarized-target) data are consistent with both the "up" and "down" solutions.

Let us denote by f_0 a system of two pions in a relative S–wave isospin 0 state. Transition amplitude for the f_0 production process $\pi^- p \to f_0\, n$ can be written as the sum of two components A and B corresponding to pseudoscalar and pseudovector exchanges respectively. In our analysis we use two transversity amplitudes g and h, adequate for describing f_0 production on a transversely polarized target: $g \equiv \langle n \downarrow |T| p \uparrow\rangle$ and $h \equiv \langle n \uparrow |T| p \downarrow\rangle$. Separation of the amplitudes g and h into two components ($g = g_A + g_B$

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and $h = h_A + h_B$) proportional to the invariant amplitudes A and B has been described in [1].

In addition to the "up–down" ambiguity in the moduli of the g and h transversity amplitudes, there is also a phase ambiguity in each $m_{\pi\pi}$ bin. This ambiguity comes from the mathematical structure of the PWA equations from which only cosines of the relative phases of the partial waves can be obtained. In our analysis we present two arbitrary choices of the S-wave phases. In the first set, called "steep", S-wave phases grow faster than P-wave phases. In the other set, called "flat", increase in S-wave phases is slower than that for P-waves. Thus two sets of possible phases ("flat" or "steep") combined with two branches of moduli ("up" and "down") lead us to four solutions. Two of them, called "down–flat" and "up–flat" fully satisfy unitarity constraints. The "down–flat" solution is in good agreement with the former solution of Ref. [3] below 1400 MeV. In Ref. [4] the scalar meson spectrum was studied in terms of a relativistic $\pi\pi$and $K\overline{K}$coupled channel model from the $\pi\pi$ threshold up to 1400 MeV. Strong four-pion production, observed in different experiments [5, 6], provides a compelling argument to take into account the 4π channel. In this report we extend the isoscalar S-wave 2-channel model of Ref. [4] by adding to its $\pi\pi$ and $K\bar{K}$ channels an effective third coupled channel, here called $\sigma\sigma$.

We consider the S-wave scattering and transition reactions between three coupled channels of meson pairs labelled 1, 2 and 3. Reaction amplitudes T satisfy a system of coupled channel Lippmann–Schwinger equations [4] with a separable form of the interaction:

$$\langle \boldsymbol{p}|V_{\alpha\gamma}|\boldsymbol{q}\rangle = \sum_{j=1}^{n} \lambda_{\alpha\gamma,\,j}\ g_{\alpha,\,j}(\boldsymbol{p})\ g_{\gamma,\,j}(\boldsymbol{q}), \quad \alpha,\gamma = 1,2,3, \tag{1}$$

where $\lambda_{\alpha\gamma,\,j}$ are coupling constants and $g_{\alpha,\,j}(\boldsymbol{p}) = (4\pi/m_j)^{1/2}/(\boldsymbol{p}^2 + \beta^2_{\alpha,\,j})$ are form factors which depend on the relative centre of mass meson momenta $\boldsymbol{p}$ in the final channel or $\boldsymbol{q}$ in the initial channel. In the $\pi\pi$channel ($\alpha,\gamma = 1$) we choose a rank-2 separable potential ($n = 2$) and in the other channels, *i.e.*, $K\overline{K}$ ($\alpha,\gamma = 2$) and $\sigma\sigma$ ($\alpha,\gamma = 3$), a rank-1 potential ($n = 1$).

The model has 14 parameters: 9 coupling constants $\lambda_{\alpha\gamma,\,j}$, 4 range parameters $\beta_{\alpha,\,j}$ and the σ mass m_3. We can solve the system of Lippmann–Schwinger equations following the formalism developed in Refs. [4, 7]. The S-matrix elements $S_{\alpha\beta}$ ($\alpha,\beta = 1,2,3$) can be written in terms of the Jost function of different arguments (see [7]). The model satisfies the unitarity condition $S^{+}S = 1$. Some of the S-matrix poles in the complex energy plane can be interpreted as resonances. The diagonal matrix elements are parametrized as $S_{\alpha\alpha} = \eta_\alpha e^{2i\delta_\alpha}$, where η_α and δ_α are the channel α inelasticities and phase shifts, respectively. We fit the new experimental results [1] on the $\pi\pi$ S-wave isoscalar phase shifts and inelasticities together with the $K\bar{K}$ phase shifts from [8].

We have performed fits with both two ($\pi\pi$ and $K\overline{K}$) and three ($\pi\pi$, $K\overline{K}$, $\sigma\sigma$) channels. For 3-channel fits we have obtained two solutions for both down (solutions A and B) and up (solutions C and D) data sets. The main difference between the 2- and 3-channel fits lies in η above 1400 MeV, where the opening of the $\sigma\sigma$ channel leads to a fast decrease of inelasticity parameters (see [7]). Let us also note an improvement in $\varphi_{\pi K}$ over the 1000 to 1200 MeV range. The corresponding parameters for these best fits are given in Table I of [7].

Fits of similarly good quality were obtained with very different physical parameters in the $K\overline{K}$and $\sigma\sigma$channels. For example, in the 2-channel fits and in fit A the $K\overline{K}$interaction is attractive while in the case B it is repulsive. Similarly, interchannel couplings are very different in both cases. In fit A we see rather strong $\pi\pi$to $\sigma\sigma$and $K\overline{K}$to $\sigma\sigma$couplings, while in the case B the $\pi\pi$— $K\overline{K}$coupling, $\Lambda_{12,2}$, is particularly strong.

We have studied positions of the S-matrix poles in the complex energy plane ($E_{\text{pole}} = M - i\Gamma/2$). For the 3-channel model there are 8 different sheets which correspond to different signs of imaginary parts of the channel momenta (Im p_1, Im p_2, Im p_3). Resonance parameters predicted by the 3-channel model are summarized in Table I. At low energy we find a very broad $f_0(500)$ resonance (also called σ meson). The $f_0(980)$resonance is seen in the vicinity of the $K\overline{K}$threshold with a width of about 60 to 70 MeV. Mass of a relatively narrow state $f_0(1400)$ varies from about 1400 MeV to 1460 MeV. For the "down–flat" fits this resonance is narrower ($\Gamma \approx 100$ MeV) on sheet $(--+)$ than on sheet $(---)$. The parameters of this resonance are close to those of the $f_0(1500)$ resonance — a hypothetical glueball state — found by the Crystal Barrel Group [5, 6] in $p\overline{p}$ annihilation.

TABLE I

Masses and widths of resonances found for the 2- and 3-channel fits to the "down–flat" data.

pole	sheet	A		B	
		M (MeV)	Γ (MeV)	M (MeV)	Γ (MeV)
$f_0(500)$ (σ)	$-++$	518.1	521.4	511.8	532.6
$f_0(980)$	$-++$	989.0	62.0	992.4	68.2
$f_0(1400)$:	$---$	1405.1	147.8	1411.5	169.3
	$--+$	1456.4	93.3	1402.7	108.2

REFERENCES

[1] R. Kamiński, L. Leśniak, K. Rybicki, *Z. Phys.* **C74**, 79 (1997).

[2] B.R. Martin, D. Morgan, G. Shaw, in *Pion–Pion Interactions in Particle Physics*, Academic Press, London 1976.

[3] G. Grayer *et al.*, *Nucl. Phys.* **B75**, 189 (1974).

[4] R. Kamiński, L. Leśniak, J.-P. Maillet, *Phys. Rev.* **D50**, 3145 (1994).

[5] A. Abele *et al.*, *Phys. Lett.* **B385**, 425 (1996).

[6] A. Abele *et al.*, *Phys. Lett.* **B380**, 453 (1996).

[7] R. Kamiński, L. Leśniak, B. Loiseau, *Phys. Lett.* **B413**, 130 (1997).

[8] D. Cohen *et al.*, *Phys. Rev.* **D22**, 2595 (1980).