ITEP-9-94

Fermilab Library
0 1160 0034470 0

INSTITUTE OF THEORETICAL
AND EXPERIMENTAL PHYSICS

ITEP 9-94

E.P. Shabalin

FAMILAB
APR 8 1994
LIBRARY

CHIRAL THEORY OF SCALAR MESONS

MOSCOW 1994

UDK 530.1 M-16

CHIRAL THEORY OF SCALAR MESONS[1]. Preprint ITEP 9-94/

E.P. Shabalin - M., 1994 - 12p.

The existing scalar resonances are considered as the elements of a Chiral Theory. Such an approach allows:

1) to understand the nature of the properties of the scalar resonances,

2) to obtain very good and clear description of many low-energy phenomena both the weak and the strong ones.

References- 19.

© Институт теоретической и экспериментальной физики, 1994

[1]Report at the Workshop on Scalar Mesons, St. Petersburg, Russia, December 1-6, 1993.

1 The reasons to incorporate the scalar mesons into Chiral Theory. The effective chiral lagrangian.

There are at least two reasons to have a theory with the scalars:

1) Scalar resonances exist and we need the theoretical description and understanding of their properties.

2) Like the vector mesons defining the momentum behaviour of the form factors in the channels with $J = 1$, the scalar mesons can define the momentum behaviour in the $J = 0$ channels of the low–energy mesonic processes.

Then, the momentum dependence of the mesonic amplitudes, both the strong one and the weak one, will be determined by the momentum dependence originated by S, V and A meson exchange.

As the modern theory of strong interaction – Quantum Chromodynamics (QCD) is not applicable to description of the low–energy processes, one is enforced to use for this aim the Effective Chiral Lagrangians (EChL) taken in one or another form. Such lagrangians allow to reproduce in a simple way all results following from the algebra of currents and soft–pion technics for the processes with the pseudoscalar mesons. These results are independent of the properties of the scalar mesons. Therefore, the last ones must be incorporated in such a way that do not spoil the relationships arising in the leading approximation in momentum expansion for the amplitudes with the pseudoscalar mesons. One of the ways to do this consists in introduction of the scalar mesons as the elements of the Chiral Theory itself. Such a possibility is in accordance actually with the properties of the underlying QCD. To be convinced of this let's turn to the QCD lagrangian.

The main part of the QCD lagrangian

$$L_0^{QCD} = -\frac{1}{4}G^a_{\mu\nu}G^a_{\mu\nu} + \bar{q}\gamma_\mu(\partial_\mu - igA^a_\mu)q \tag{1}$$

possesses the left–right global symmetry, which means, in particular, that before a breakdown of the symmetry, the degenerated states of opposite parity and the same spin must exist.

At the EChL level this phenomenon can be taken into account for the spin 0 particles representing the lagrangian in terms of the matrix

$$U = \hat{\sigma}' + i\hat{\pi} = (\sigma'_B + i\pi_B)t_B\ ,\ B = 0, 1, ...8 \tag{2}$$

where σ'_B and π_B are the nonets of scalar and pseudoscalar mesons respectively, $t_0 = \frac{1}{\sqrt{3}}I$ and $t_{1,...8} = \frac{1}{\sqrt{2}}\lambda_{1,...8}$.

Then, the left–right symmetric part of EChL corresponding to L_0^{QCD} can be written in the form

$$L_0 = \frac{1}{2}Tr\{\partial_\mu U \partial_\mu U^+\} - cTr\{UU^+UU^+\} - c\xi(Tr\{UU^+\})^2 \tag{3}$$

which is invariant under the transformation

$$U \to exp(i\frac{\hat{\varepsilon}_V - \hat{\varepsilon}_A}{\sqrt{2}})Uexp(-i\frac{\hat{\varepsilon}_V + \hat{\varepsilon}_A}{\sqrt{2}}) \tag{4}$$

corresponding to the independent transformations of the left–handed and right–handed quark fields

$$q_L \to exp(\frac{i\hat{\varepsilon}_L}{\sqrt{2}})q_L \; ; \; q_R \to exp(\frac{i\hat{\varepsilon}_R}{\sqrt{2}})q_R \tag{5}$$

An existence of the non-zero vacuum values $< G^a_{\mu\nu}G^a_{\mu\nu} >_0$ and $< \bar{q}q >_0$ in QCD may be taken into account writing the potential part of eq. (3) in the form

$$V = -cTr\{UU^+ - a^2t_0^2\}^2 - c\xi(Tr\{UU^+ - a^2t_0^2\})^2 \tag{6}$$

meaning that the field σ_0 acquires the v.e.v.

$$< \sigma_0' >= a \tag{7}$$

As a consequence, all scalar fields become the massive ones:

$$m^2_{\sigma_0} = \frac{8}{3}a^2(1+3\xi) \; , \; m^2_{\sigma_{1,\dots 8}} = \frac{8}{3}a^2 \tag{8}$$

The pseudoscalar fields remain massless at this step. They acquire the masses due to explicit breakdown of the rest symmetry due to non-zero masses of quarks. In QCD this effect is produced by the term

$$L_m^{QCD} = -\bar{q}Mq$$

where

$$M = \begin{pmatrix} m_u & & \\ & m_d & \\ & & m_s \end{pmatrix} \tag{9}$$

In a chiral theory the corresponding term of EChL is

$$\frac{1}{2}b^2Tr\{M(U+U^+)\} =$$

$$= b^2(\frac{m_u + m_d + m_s}{\sqrt{3}}\sigma_0' + \frac{m_u + m_d - 2m_s}{\sqrt{6}}\sigma_8' + \frac{m_u - m_d}{\sqrt{2}}\sigma_3') \tag{10}$$

It does not produce the masses of pseudoscalar mesons directly, but it shows that there are the transitions of the fields σ_8 and σ_3 to vacuum proportional to $m_u + m_d - 2m_s$ and $m_u - m_d$ respectively. In other words, the fields σ_8 and σ_3 acquire the non-zero v.e.v. proportional to corresponding mass difference. The v.e.v. $< \sigma_0 >$ now is not equal to a, but contains the additional part proportional to $m_u + m_d + m_s$. The masses of the pseudoscalar mesons appear from the potential part of L_0 after a minimization of this part with

$$\sigma'_A t_A = < \sigma_0 > t_0 + < \sigma_8 > t_8 + < \sigma_3 > t_3 + \sigma_A t_A \tag{11}$$

The theory described by the lagrangian containing the terms (3), (6) and (10) has one disadvantage. The η' meson turns out to be too light in it. In QCD, there is one mechanism allowing to get $m_{\eta'}$ different of the masses of the rest members of the pseudoscalar nonet. Namely, it is a mix of the isosinglet π_0 meson with the gluonic state $G^a_{\mu\nu}\tilde{G}^a_{\mu\nu}$ occuring through the triangle quark diagram.

The explicit form of the term solving this so-called $U(1)$ problem in the sector of pseudoscalar mesons is not important for our present purposes. As for the scalar mesons, one can conclude from the relations (8) that the $U(1)$ problem for the scalars receives a resolution if the parameter ξ is different from zero. Of course, such a splitting between m_{σ_0} and $m_{\sigma_{1,\dots 8}}$ has the same origin in QCD as for the pseudoscalar mesons: it occurs due to mixing between σ_0 and gluonic state $G^a_{\mu\nu}G^a_{\mu\nu}$.

The potential part of L_0 can be presented in the form:

$$\begin{aligned} V &= -cTr\{UU^+ - a^2t_0^2\}^2 - c\xi(Tr\{UU^+ - a^2t_0^2\})^2 = \\ &= -\frac{c}{3}(1+3\xi)(\sigma'^2_A + \pi^2_A - a^2)^2 - \\ &- c\{\frac{1}{2}[d_{jkl}(\sigma'_j\sigma'_k + \pi_j\pi_k) + \frac{4}{\sqrt{6}}(\sigma'_0\sigma'_l + \pi_0\pi_l)]^2 + 2[f_{jkl}\sigma'_j\pi_k]^2\} \end{aligned} \tag{12}$$

A positive definiteness of energy in the theory with such V requires:

$$c > 0\ ;\ (1+3\xi) > 0 \tag{13}$$

Minimization of V with σ'_A defined by eq.(11) and $m_u = m_d$ gives:

$$m^2_\pi = X + Y\ ;\ m^2_K = X - Y \cdot \frac{1-5\varepsilon}{2-\varepsilon} \tag{14}$$

$$m^2_{\sigma_\pi} = X + Y + \Lambda^2$$

$$m^2_{\sigma_K} = X - \frac{1}{2}Y + \Lambda^2\frac{(1-\varepsilon/2)^2}{(1+\varepsilon)^2}$$

$$m^2_{\sigma_8} = X - Y + \Lambda^2(1+\varepsilon)^{-2}[(1-\varepsilon)^2 + 2\varepsilon^2(1+3\xi)] \tag{15}$$

$$m^2_{\sigma_0} = X + \Lambda^2(1+\varepsilon)^{-2}[1+3\xi+2\varepsilon^2]$$

$$m^2_{\sigma_0\sigma_8} = 6\sqrt{2}(Y + \Lambda^2(1+\varepsilon)^{-2}\varepsilon\xi)$$

where

$$X = \frac{4}{3}c(1+3\xi)[<\sigma_0>^2(1+2\varepsilon^2) - a^2] \tag{16}$$

$$Y = \frac{8}{3}c<\sigma_0>^2\varepsilon(1-\varepsilon/2) = \varepsilon(1-\varepsilon/2)(1+\varepsilon)^{-2}\Lambda^2 \tag{17}$$

$$\varepsilon = <\sigma_8>/(\sqrt{2}<\sigma_0>) \tag{18}$$

As it follows from eqs. (14), (15) and (17), m_{σ_π} and m_{σ_K} are expressed through m_π, m_K and parameter ε. The last one can be found using the general expression for the axial current:

$$A^{(i)}_\mu = \frac{1}{\sqrt{2}}Tr\{\partial_\mu\hat{\pi}(t_i\hat{\sigma}' + \hat{\sigma}'t_i) - \partial_\mu\hat{\sigma}(t_i\hat{\pi} + \hat{\pi}t_i)\} \tag{19}$$

Then

$$<0 \mid A^{1-3}_\mu \mid \pi> = \sqrt{2}\frac{<\sigma_0>}{\sqrt{3}}(1+\varepsilon)\partial_\mu\pi^{1-3} \equiv F_\pi\partial_\mu\pi^{1-3} \tag{20}$$

$$<0 \mid A^{4,5}_\mu \mid K> = \sqrt{2}\frac{<\sigma_0>}{\sqrt{3}}(1-\frac{\varepsilon}{2})\partial_\mu K^{4,5} \equiv F_K\partial_\mu K^{4,5} \tag{21}$$

Therefore

$$\frac{1-\frac{\varepsilon}{2}}{1+\varepsilon} = \frac{F_K}{F_\pi} \equiv R \tag{22}$$

In terms of the parameter R

$$m^2_{\sigma\pi} - m^2_\pi = (m^2_K - m^2_\pi)(R-1)^{-1}(2R-1)^{-1} \tag{23}$$

$$m^2_{\sigma K} - m^2_K = (m^2_K - m^2_\pi)(R-1)^{-1} \tag{24}$$

Using the experimental value of R we could find $m_{\sigma\pi}$ and $m_{\sigma K}$. But there is some uncertainty in determination of R because of the value of R following from the data on β–decay turns out to be smaller than one following from π_{l_3} and K_{l_3} decay. For this reason it seems to be more convenient to determine

a magnitude of R using eq.(23) and identifying σ_π meson with the isovector resonance $a_0(980)$. Then

$$R = 1.176^2 \tag{25}$$

$$m_{\sigma_K} = 1.23GeV \tag{26}$$

To find the masses of the isosinglet scalar mesons we need to know a magnitude of the parameter ξ. It can be determined using the data on K_{l_4} decay, as it will be shown a little later. But the general expressions for the masses of the diagonal states

$$\begin{aligned} \sigma_{\eta'} &= \sigma_0 \cos\theta_S + \sigma_8 \sin\theta_S \\ \sigma_\eta &= -\sigma_0 \sin\theta_S + \sigma_8 \cos\theta_S \end{aligned} \tag{27}$$

we can write down here.

$$\begin{aligned} m^2_{\sigma_{\eta'}} - m^2_\pi = (m^2_{\sigma\pi} - m^2_\pi) \cdot \{1 + 2R(R-1)(\cos\theta_S - \sqrt{2}\sin\theta_S)^2 + \\ + \frac{1}{3}\xi[(2R+1)\cos\theta_S - 2\sqrt{2}(R-1)\sin\theta_S]^2\} \ , \end{aligned} \tag{28}$$

$$\begin{aligned} m^2_{\sigma\eta} - m^2_\pi = (m^2_{\sigma\pi} - m^2_\pi) \cdot \{1 + 2R(R-1)(\sqrt{2}\cos\theta_S + \sin\theta_S)^2 + \\ + \frac{1}{3}\xi[(2R+1)\sin\theta_S + 2\sqrt{2}(R-1)\cos\theta_S]^2\} \ , \end{aligned} \tag{29}$$

where

$$\theta_S = \frac{1}{2}\arctan\{2\sqrt{2}\frac{1 + \xi(2R+1)(3R)^{-1}}{1 - \xi(2R+1)^2[6R(R-1)]^{-1}[1 - 8(R-1)^2(2R+1)^{-2}]}\}$$

The coupling constants of the scalar mesons to the pseudoscalar ones are determined by the expression (12) and the part $\Delta L^{U(1)}_{PS}$ solving the $U(1)$ problem for the pseudoscalar mesons.

At

$$\Delta L^{U(1)}_{PS} = -\frac{\mu^4}{2}[-\frac{i}{2}Tr(\ln\frac{U}{U^+})]^2 \quad ,[3,4] \tag{30}$$

[2]Using the standard relations

$$R = (0.275 \pm 0.002)\,|\frac{V_{ud}}{V_{us}}|,$$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 \ ,$$

and putting into them $|V_{ud}| = 0.9735 \pm 0.0015$ [1] and $|V_{ub}| < 0.007$[2] one comes to the result $R = 1.171 \pm 0.045$.

we obtain, for example

$$g_{\sigma_\pi^- \pi^+ \eta} = -\frac{m_{\sigma_\pi}^2 - m_\pi^2}{\sqrt{3}F_\pi}(\cos\theta_P - \sqrt{2}\sin\theta_P) + \frac{m_0^2(1-2\varepsilon)}{\sqrt{3/2}F_\pi}[-(1-\varepsilon)\sin\theta_P - -\sqrt{2}\varepsilon\cos\theta_P] \;;$$

$$g_{\sigma_\pi^- K^+ \bar{K}^0} = -\frac{(m_{\sigma_\pi}^2 - m_\pi^2)(1+4\varepsilon)}{\sqrt{2}F_\pi(1+\varepsilon)} \;, \quad m_0^2 = 0.634 GeV^2 \quad (31)$$

where θ_P is the mixing angle between π_0 and π_8:

$$\eta = -\pi_0 \sin\theta_P + \pi_8 \cos\theta_P$$
$$\eta' = \pi_0 \cos\theta_P + \pi_8 \sin\theta_P \quad (32)$$

A width of the isovector resonance σ_π calculated with the above coupling constants turns out to be $\approx 300 MeV$ [5]. But as it was noticed long time ago [6], the observed width may be considerably smaller due to different effects including an opening of the channel K^+K^0 at the resonance energy. The situation is illustrated by fig. 2 in ref. [5]. Of course, the theoretical curve in this figure corresponds to observed width of order of 70-90 MeV instead of the experimental value $\Gamma_{a_0(980)} = 54 \pm 7 MeV$, but there is very important, but unresolved question how to extrapolate the expressions for the vertices $\sigma_j \pi_K \pi_l$ given by EChL to the region of energy of order $1 GeV$. It is not excluded a considerable renormalization of these vertices diminishing the effective coupling constant. A naive calculation [5] of the width of the strange σ_K meson led to $\Gamma_{\sigma_K} \approx 570 MeV$ which has to be compared with the experimental results

$$\Gamma = 485 \pm 80 MeV \quad \text{for} \quad m_\kappa = 1245 \pm 30 MeV \quad [7]$$

and

$$\Gamma = 477 \pm 51 MeV \quad \text{for} \quad m_\kappa = 1240 \pm 22 MeV \quad [8]$$

Though the Particle Data Group gives the different value of $m_\kappa \sim 1350 MeV$ [9] and sometimes $m_\kappa \sim 1500 MeV$ [5] with $\Gamma_\kappa \sim 250 \div 300 MeV$, the experimental data on $(p_{K^0} + p_\pi)^2$ distribution show a position of this resonance at $m_\kappa \approx 1240 MeV$ [7,8].

Therefore, a naive approach to calculation of the widths of the isovector and strange scalar mesons gives the results close to the experimental observations.

A situation with the isosinglet mesons $\sigma_{\eta'}$ and σ_η is more complicated. At the value $\xi = -0.225$ following from the data on K_{l_4} decay

$$m_{\sigma_{\eta'}}(\text{at}\,\xi = -0.225) \cong 650 MeV \;,$$
$$\Gamma_{\sigma_{\eta'}} \cong 680 MeV \quad (33)$$

So, the $\sigma_{\eta'}$ meson can be identified with the old scalar resonance $\varepsilon(600 \div 800)$ (see, for example, ref. [10]). It does not included into PDG tables because of a very large width. However, the indications on existence of such a resonance continue to appear. In particular, the Omicron Collaboration [11] have confirmed an existence of the wide scalar resonance with $m \equiv 600MeV$ and $\Gamma \sim 600MeV$.

The last isosinglet scalar meson σ_η has the following characteristics

$$m_{\sigma_\eta}(\text{at}\xi = -0.2255) = 1365MeV$$
$$\Gamma_{\sigma_\eta} \equiv 720MeV \qquad [5] \tag{34}$$

But at such big mass it seems to be not convenient to believe the result of the naive calculation of the width. To identify σ_η meson with any of the scalar resonance laying at $m \sim 1300$ MeV one needs to elaborate a method of extrapolation of the chiral theory results to energy ≥ 1 GeV.

Let turn now to application of our theory of the scalar mesons.

2 Application.

2.1 Form factors of K_{l_4} decay.

The hadronic part of the matrix element of this decay is

$$< \pi^+\pi^- \mid A_\mu^{(\bar{K})} \mid K^+ >= f_1 \cdot (p_\pi + p_{\pi'})_\mu + f_2(p_\pi - p_{\pi'})_\mu + f_3(p_K - p_\pi - p'_\pi)_\mu \tag{35}$$

$$< \pi\pi' \mid V_\mu^{(K)} \mid K >= if_4\varepsilon_{\mu\nu\sigma\tau}(p_K)_\nu(p_\pi)_\sigma(p_{\pi'})_\tau \tag{36}$$

A contribution of the term proportional to f_3 to K_{e4} amplitude can be neglected because it is suppressed by factor m_e/m_K. In the soft-pion limit

$$f_1 = f_2 = \frac{1}{\sqrt{2}F_\pi} \ [12]\ , \quad f_4 = \frac{m_K^2}{2\pi(\sqrt{2}F_\pi)^3} \ [13] \tag{37}$$

At these values of f_i the theoretical magnitude of a probability of K_{e4} decay turns out to be by 2 times smaller than the experimental one. The second term in r..h.s. of eq. (37) gives only 1/5 of the probability at $f_1 = f_2$ and the term (38) gives only 0.13% of total probability. For this reason, to explain the experimental situation we need increasing the form factor f_1 by $\simeq 1.4$ times and, moreover, this increasing must occur in the non-physical region of the quantity $Q^2 \equiv (p_\pi + p'_\pi)^2$ because of the experimental data do not show any considerable alteration of f_1 in the physical region of Q^2.

To preserve the results of the soft-pion approach obtained at $Q^2 = m_\pi^2$, one is enforced to adopt that an increasing of f_1 happens due to considerable dependence of f_1 of Q^2 leading to the result

$$f_1(Q^2 = 4m_\pi^2) \simeq 1.4 f_1(Q^2 = m_\pi^2). \tag{38}$$

As the form factor f_1 describes a production of the pair $\pi^+\pi^-$ in S-wave state, the result (40) can be obtained if a mass of the intermediate scalar meson is small enough. The analysis [14] shows that the result (40) requires $m_{\sigma\eta'} \simeq 650$ MeV. According to eqs. (29) and (31) this value of $m_{\sigma\eta'}$ takes place at $\xi = -0.225$. The experimental observation that f_1 is constant practically at $Q^2 > 4m_\pi^2$ is explained by an appearence of a width of $\sigma_{\eta'}$ meson rapidly increasing with an increase of Q^2.

The example of K_{l4} decay shows, that a theory with scalar mesons allows to understand the underlying physics of such an unusual phenomenon as very considerable change of the form factor in non-physical region of a variable.

2.2 Form factors of K_{l_3} decay.

The hadronic part of the matrix element is

$$< \pi(p_\pi) \mid V_\mu^{(K)} \mid K(p_K) >= f_+(q^2)(p_K + p_\pi)_\mu + f_-(q^2)(p_K - p_\pi)_\mu \tag{39}$$

where $q^2 = (p_K - p_\pi)^2$.

The combination

$$f_0(q^2) = f_+(q^2) + \frac{q^2}{m_K^2 - m_\pi^2} f_-(q^2) \tag{40}$$

describes the S wave state in the $K\pi$ system.

Usually $f_0(q^2)$ is represented in the form

$$f_0(q^2) = f_0(0)[1 + \lambda_0 q^2/m_\pi^2] \tag{41}$$

In our theory

$$f_+(0) = 1 \ , \ f_-(q^2) = \frac{m_K^2 - m_\pi^2}{m_{\sigma_K}^2 - q^2} \quad [15] \tag{42}$$

Consequently

$$\lambda_0 = m_\pi^2/m_{\sigma_K}^2 \tag{43}$$

or

$$\lambda_0 \cong 0.013 \ \text{ at } \ m_{\sigma_K} = 1235 MeV \tag{44}$$

To verify this prediction, more accurate measurement of the K_{l_3} form factors is necessary.

2.3 $K_S \to 2\pi$ decay.

As it was noticed in ref.[16], a half of a value of the $\Delta I = 1/2$ ppart of $K_S \to 2\pi$ amplitude is originated by an exchange of the isosinglet scalar meson. The authors of ref. [16] considered the mass of σ field as a free parameter. In our chiral theory their expression

$$A(K_S \to \pi^+\pi^-)\,|_{O_{5,6}} \sim [R - 1 + R\frac{P_K^2 - m_\pi^2}{m_\sigma^2}]$$

is replaced (at $\xi = 0$) by the expression

$$A(K_S \to \pi^+\pi^-)\,|_{O_{5,6}} \sim [R - 1 + \frac{R-1}{1-2(R-1)}] \;, \quad [17] \tag{45}$$

showing a considerable increasing of $A\,|_{O_{5,6}}$ due to corrections of next orders in $(R-1)$. This effect first mentioned in ref. [17] was confirmed later by the authors of ref. [18].

An additional enlargement of $A\,|_{O_{5,6}}$ arises due to mix of σ_0 state with the gluonic state $(G^a_{\mu\mu})^2$. As it was shown in ref. [17], this effect proportional to ξ leads to the magnitude of $A\,|_{O_{5,6}}$ sufficient for an explanation of the $\Delta I = 1/2$ rule for $K \to 2\pi$ decays.

2.4 $K \to 3\pi$ decays.

In the leading p^2 approximation, the chiral theory with the scalar mesons give the usual expressions for the matrix elements of different modes of $K \to 3\pi$ decay.

At the convenient values of the coefficients $\bar{c}_i$ in the operator expansion of the $\Delta S = 1$ part of weak non-leptonic lagrangian, the probability of $K^+ \to \pi^+\pi^+\pi^-$ decay and slope parameter g turn out to be smaller then the experimental ones. Namely, at $\xi = 0$ (which case corresponds to $m_{\sigma_{\eta'}} = m_{\sigma_\pi} = 981 MeV$)

$$\Gamma^{th}(K^+ \to \pi^+\pi^+\pi^-) = 0.73\Gamma^{exp}(K^+ \to \pi^+\pi^+\pi^-)$$

$$g^{th} = 0.78 g^{exp}$$

When the effects of the corrections of next orders in p^2 expansion and effect of mixing between σ_0 and $(G^a_\mu)^2$ are taken into account the theoretical values of Γ and g turn out to be coinsiding with the experimental ones [19].

It should be mentioned that these two parameters are not connected in considerable way one to another, because of the part of the amplitude proportional to g in the general expression.

$$| M(K^+ \to \pi^+\pi^+\pi^-) |^2 \sim 1 + g\frac{S_3 - S_0}{m_\pi^2} + \dots ,$$

where $S_3 = (p_K - p_{\pi'}$ and $S_0 = m_K^2/3 + m_\pi^2$, gives a very small contribution to Γ.

Therefore, the above mentioned corrections to the leading terms in $M(K^+ \to \pi^+\pi^+\pi^-)$, calculated in the framework of the theory with scalar mesons, improve the results for two practically independent quantities.

2.5 Concluding remarks.

The chiral theory incorporating the scalar mesons as the elements of this theory has an evident advantage consisting in a clear understanding of a nature of one or another momentum dependence of different amplitudes. Such a theory allows to understand, in particular, why the momentum dependence of the amplitudes with the S-wave 2π states is considerably stronger than the dependence in other states. It happens because of for the S-wave state, the momentum expansion is the expansion in $p^2/m^2_{\sigma\eta'}$ and $m^2_{\sigma\eta'}$ is considerably smaller than $m^2_{\sigma_{\eta'},\sigma_\pi,\sigma_K}$.

One more advantage of the considered theory is a possibility to estimate the role of higher order corrections in p^2, in particular the corrections of order p^6 and higher. Such a possibility is absent really in usual Chiral Perturbation Theory.

At last, the properties of the resonances $\varepsilon(600-800)$, $a_0(980)$ and the strange scalar resonance obtain the theoretical foundation. But for an overall quanttitative description of the widths of these resonances one needs an elaboration of the selfconsistent procedure of extrapolation of the vertex functions $\sigma\pi\pi$ from the energy region of order m_π to the region of order 1GeV.

References

[1] Bourguin M. et al, Z.Phys. C-Particles and Fields 1982, v.12, p. 307; 1983, v.21, pp. 1,17,27.

[2] Particle Data Group, Phys.Rev. 1992, v.45, No.11, Part II.

[3] Rosenzweig C., Schechter J., Trahern G., Phys.Rev. 1980, v. D21, p. 3388.

[4] Di Vecchia P., Veneziano C., Nucl.Phys. 1980, v. B171, p. 253.

[5] Shabalin E.P. Yad.Fiz., 1985, v.42, p. 260 [Sov.J.Nucl.Phys. 1985, v.42, p. 164].

[6] Flatte S.M., Phys.Lett. 1976, v. 63B, p. 224.

[7] Lausher P. et al, Nucl.Phys., 1975, v. B86, p. 189.

[8] Engelen J.J. et al, Nucl.Phys. 1978, v. B134, p. 14.

[9] Particle Data Group, Phys.Lett. 1986, v. 170B (April 1986).

[10] Hill C.T., RToss G.G., Phys.Lett. 1980, v. 94B, p. 234.

[11] Kernel G. et al, Preprint CERN-PPE/90-152. The report at the 1990 IUCF Topical Conference "Particle Production near Threshold" 1990, Nashville, USA.

[12] Weinberg S., Phys.Rev.Lett. 1966, v.17, p.336; (E) 1967, v.18, p. 1178.

[13] Terent'ev M.V., Yad.Fiz. 1972, v. 16, p. 153.

[14] Shabalin E.P., Yad.Fiz. 1989, v. 49, p. 588 [Sov.J.Nucl. Phys. 1989, v.49, p.365].

[15] Shabalin E.P., Yad.Fiz. 1990, v.51, p.464 [Sov.J.Nucl.Phys. 1990, v.51, p. 296].

[16] Vainshtein A.I., Zakharov V.I., Shifman M.A., Zh.Eksp.i Teor.Fiz. (JETP) 1977, v. 72, p. 1275.

[17] Shabalin E.P., Yad.Fiz. 1988, v.48, p. 272 [Sov.J.Nucl.Phys. 1988, v.48, p. 164].

[18] Morozumi et al, Phys.Rev.Lett. 1990, v. 65, p. 404.

[19] Shabalin E.P., Ppreprint IC/93/51, Miramare-Trieste, 1993 (to be published in Nucl.Phys. B).

Е.П.Шабалин
Киральная теория склярных мезонов.

Подписано к печати II.0I.94 Формат 60x90 I/I6 Офсетн.печ.
Усл-печ.л.0,75. Уч.-изд.л.0,5 Тираж I03 экз. Заказ 9.
Индекс 3649

Отпечатано в ИТЭФ, II7259, Москва, Б.Черемушкинская,25