Scalar meson phenomenology in the extended linear sigma model at zero temperature

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Excited QCD 2013, February 3 - 9, Bjelasnica Mountain, Sarajevo

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- Motivation, scalar mesons
- QCDs chiral symmetry, effective models
- Axial(vector) meson extended linear σ-model
- Technical difficulty: particle mixing
- Tree-level masses, Decay widths
- Parametrization
- Particle identification
- Conclusions

Scalar mesons

	Mass (MeV)	width (MeV)	decays
$a_0(980)$	(980 ± 20)	$50 - 100$	$\pi\pi$ dominant
$a_0(1450)$	(1474 ± 19)	(265 ± 13)	$\pi\eta$, $\pi\eta'$, $K\bar{K}$
$K_0^\star(800) = \kappa$	(676 ± 40)	(548 ± 24)	$K\pi$
$K_0^\star(1430)$	(1425 ± 50)	(270 ± 80)	$K\pi$ dominant
$f_0(500) = \sigma$	$400 - 1200$	$600 - 1000$	$\pi\pi$ dominant
$f_0(980)$	(980 ± 10)	$40 - 100$	$\pi\pi$ dominant
$f_0(1370)$	$1200 - 1500$	$200 - 500$	$\pi\pi \approx 250$, $K\bar{K} \approx 150$
$f_0(1500)$	(1505 ± 6)	(109 ± 7)	$\pi\pi \approx 38$, $K\bar{K} \approx 9.4$
$f_0(1710)$	(1720 ± 6)	(135 ± 8)	$\pi\pi \approx 30$, $K\bar{K} \approx 71$

scalar nonet: a_0, K_0, $2\ f_0 \rightarrow$ pseudoscalar nonet: π, K, η, η'
Possible scalar states: $\bar{q}q$, $\bar{q}q\bar{q}q$, meson-meson molecules, glueballs
multiquark states: $f_0(980)$, $a_0(980)$, $f_0(500)$, $K_0^\star(800)$???
meson-meson bound state $(K\bar{K})$: $f_0(980)$???
glueballs: $f_0(1500)$, $f_0(1710)$???

Chiral symmetry

If the quark masses are zero (chiral limit) $\Longrightarrow$ QCD invariant under the following global transformation (chiral symmetry):

$$U(3)_L \times U(3)_R \simeq U(3)_V \times U(3)_A = SU(3)_V \times SU(3)_A \times U(1)_V \times U(1)_A$$

$U(1)_V$ term $\longrightarrow$ barion number conservation

$U(1)_A$ term $\longrightarrow$ broken through axial anomaly

$SU(3)_A$ term $\longrightarrow$ broken down by any quark mass

$SU(3)_V$ term $\longrightarrow$ broken down to $SU(2)_V$ if $m_u = m_d \neq m_s$ (isospin symmetry)
$\longrightarrow$ totally broken if $m_u \neq m_d \neq m_s$ (realized in nature)

Since QCD is very hard to solve $\longrightarrow$ low energy effective models can be set up $\longrightarrow$ reflecting the global symmetries of QCD $\longrightarrow$ degrees of freedom: observable particles instead of quarks and gluons

Linear realization of the symmetry $\longrightarrow$ linear sigma model
(nonlinear representation $\longrightarrow$ chiral perturbation theory (ChPT))

Vector meson extended linear sigma model

(based on: chiral symmetry + dilatation symmetry)

$$
\begin{aligned}
\mathcal{L}_{\text{vec}} = {} & \text{Tr}[(D_\mu\Phi)^\dagger(D_\mu\Phi)] - m_0^2\,\text{Tr}(\Phi^\dagger\Phi) - \lambda_1[\text{Tr}(\Phi^\dagger\Phi)]^2 - \lambda_2\,\text{Tr}(\Phi^\dagger\Phi)^2 \\
& - \frac{1}{4}\text{Tr}(L_{\mu\nu}^2 + R_{\mu\nu}^2) + \text{Tr}\left[\left(\frac{m_1^2}{2} + \Delta\right)(L_\mu^2 + R_\mu^2)\right] + \text{Tr}[\hat{\epsilon}(\Phi + \Phi^\dagger)] \\
& + c_1(\det\Phi - \det\Phi^\dagger)^2 + i\frac{g_2}{2}(\text{Tr}\{L_{\mu\nu}[L^\mu, L^\nu]\} + \text{Tr}\{R_{\mu\nu}[R^\mu, R^\nu]\}) \\
& + \frac{h_1}{2}\text{Tr}(\Phi^\dagger\Phi)\,\text{Tr}(L_\mu^2 + R_\mu^2) + h_2\,\text{Tr}[(L_\mu\Phi)^2 + (\Phi R_\mu)^2] + 2h_3\,\text{Tr}(L_\mu\Phi R^\mu\Phi^\dagger). \\
& + g_3[\text{Tr}(L_\mu L_\nu L^\mu L^\nu) + \text{Tr}(R_\mu R_\nu R^\mu R^\nu)] + g_4[\text{Tr}\,(L_\mu L^\mu L_\nu L^\nu) + \text{Tr}\,(R_\mu R^\mu R_\nu R^\nu)] \\
& + g_5\,\text{Tr}\,(L_\mu L^\mu)\ \text{Tr}\,(R_\nu R^\nu) + g_6[\text{Tr}(L_\mu L^\mu)\,\text{Tr}(L_\nu L^\nu) + \text{Tr}(R_\mu R^\mu)\,\text{Tr}(R_\nu R^\nu)],
\end{aligned}
$$

where

$$D^\mu\Phi = \partial^\mu\Phi - ig_1(L^\mu\Phi - \Phi R^\mu) - ieA^\mu[T_3, \Phi]$$

$$\Phi = \sum_{i=0}^{8} (\sigma_i + i\pi_i) T_i$$

$$R^\mu = \sum_{i=0}^{8} (\rho_i^\mu - b_i^\mu) T_i$$

$$L^\mu = \sum_{i=0}^{8} (\rho_i^\mu + b_i^\mu) T_i$$

$$L^{\mu\nu} = \partial^\mu L^\nu - ieA^\mu [T_3, L^\nu] - \{\partial^\nu L^\mu - ieA^\nu [T_3, L^\mu]\}$$

$$R^{\mu\nu} = \partial^\mu R^\nu - ieA^\mu [T_3, R^\nu] - \{\partial^\nu R^\mu - ieA^\nu [T_3, R^\mu]\}$$

$$\hat{\epsilon} = \sum_{i=0}^{8} \varepsilon_i T_i$$

$U(3)$ generators: $T_0 := \frac{1}{\sqrt{6}}\mathbf{1}$, $T_i = \frac{\lambda_i}{2}$ $i = 1 \dots 8$

determinant breaks $U_A(1)$ symmetry

explicit symmetry breaking: external fields $\varepsilon_0, \varepsilon_8 \neq 0 \Longleftrightarrow m_u = m_d \neq 0, m_s \neq 0$ or $\varepsilon_0, \varepsilon_3, \varepsilon_8 \neq 0 \Longleftrightarrow m_u \neq m_d \neq 0, m_s \neq 0$

non strange – strange base:

$$\varphi_N = \sqrt{2/3}\,\varphi_0 + \sqrt{1/3}\,\varphi_8,$$

$$\varphi_S = \sqrt{1/3}\,\varphi_0 - \sqrt{2/3}\,\varphi_8, \qquad \varphi \in (\sigma, \pi, \varepsilon)$$

broken symmetry: non-zero condensates $\langle\sigma_N\rangle, \langle\sigma_S\rangle \longleftrightarrow \phi_N, \phi_S$

Pseudoscalar and Scalar Meson nonets

$$\Phi_{PS} \quad = \quad \sum_{i=0}^{8} \pi_i T_i = \frac{1}{\sqrt{2}} \begin{pmatrix} \frac{\eta_N+\pi^0}{\sqrt{2}} & \pi^+ & K^+ \\ \pi^- & \frac{\eta_N-\pi^0}{\sqrt{2}} & K^0 \\ K^- & \bar{K}^0 & \eta_S \end{pmatrix} \; (\sim \bar{q}_i \gamma_5 q_j)$$

$$\Phi_S \quad = \quad \sum_{i=0}^{8} \sigma_i T_i = \frac{1}{\sqrt{2}} \begin{pmatrix} \frac{\sigma_N+a_0^0}{\sqrt{2}} & a_0^+ & K_S^+ \\ a_0^- & \frac{\sigma_N-a_0^0}{\sqrt{2}} & K_S^0 \\ K_S^- & \bar{K}_S^0 & \sigma_S \end{pmatrix} \; (\sim \bar{q}_i q_j)$$

Particle contents:
Pseudoscalars: $\pi(138), K(495), \eta(548), \eta'(958)$
Scalars: $a_0(980 \text{ or } 1450), K_0^\star(800 \text{ or } 1430)$,
$(\sigma_N, \sigma_S) : 2 \text{ of } f_0(500, 980, 1370, 1500, 1710)$

Vector Meson nonets

$$V^{\mu} = \sum_{i=0}^{8} \rho_i^{\mu} T_i = \frac{1}{\sqrt{2}} \begin{pmatrix} \frac{\omega_N+\rho^0}{\sqrt{2}} & \rho^+ & K^{\star +} \\ \rho^- & \frac{\omega_N-\rho^0}{\sqrt{2}} & K^{\star 0} \\ K^{\star -} & \bar{K}^{\star 0} & \omega_S \end{pmatrix}^{\mu}$$

$$A_V^{\mu} = \sum_{i=0}^{8} b_i^{\mu} T_i = \frac{1}{\sqrt{2}} \begin{pmatrix} \frac{f_{1N}+a_1^0}{\sqrt{2}} & a_1^+ & K_1^+ \\ a_1^- & \frac{f_{1N}-a_1^0}{\sqrt{2}} & K_1^0 \\ K_1^- & \bar{K}_1^0 & f_{1S} \end{pmatrix}^{\mu}$$

Particle contents:

Vector mesons: $\rho(770), K^{\star}(894), \omega_N = \omega(782), \omega_S = \phi(1020)$

Axial vectors: $a_1(1230), K_1(1270), f_{1N}(1280), f_{1S}(1426)$

Characteristics of the model

Parameters of the Lagrangian at $T = 0$:

$$m_0, \lambda_1, \lambda_2, c_1, m_1, g_1, g_2, h_1, h_2, h_3, \delta_N, \delta_S, \Phi_N, \Phi_S$$

$\longrightarrow$ choose $\delta_N = 0 \longrightarrow 13$ unknown parameters

particles (mesons up to ~ 2 GeV):

- pseudoscalars: $\pi(138)$, $K(495)$, $\eta(548)$, $\eta'(958)$
- vectormesons: $\rho(770)$, $K^\star(894)$, $\omega(782)$, $\Phi(1020)$
- axialvector-mesons: $a_1(1230)$, $K_1(1270)$, $f_1(1280)$, $f_1(1426)$
- scalars: more physical states than we can describe:
  $2\ a_0$'s $(a_0(980), a_0(1450))$, $2\ K_S$'s $(K_0^\star(800), K_0^\star(1430))$,
  $5\ f_0$'s $(f_0(500), f_0(980), f_0(1370), f_0(1500), f_0(1710))$

technical difficulty: mixing in the $N - S$ sector

Spontaneous symmetry breaking and particle mixing

SSB ⟶ through Higgs mechanism generates particle masses ⟶ since vacuum has zero quantum numbers ⟶ only $\sigma_0, \sigma_8, \sigma_3$ (equivalently $\sigma_N, \sigma_S, \sigma_3$) can have non-zero vev (σ_3 ⟶ isospin violation ⟶ neglected)

note: pion/kaon condensates ⟶ even other σ's have non-zero expectation values (⟶ parity, charge violation)

shifting with vev in the Lagrangian: $\sigma_i \to \sigma_i + \phi_i$ (⟶ mass generation)

- For (pseudo)scalars this shifting results in particle mixing in the $N-S$ sector ⟶ $\sigma_N/\pi_N, \sigma_S/\pi_S$ fields are not mass eigenstates ⟶ orthogonal transformations needed to resolve
- For (axial)vectors ⟶ mixing between different nonets ⟶ resolved by certain field shiftings

Mixing in the extended model

Making the $\sigma_{N/S} \to \sigma_{N/S} + \Phi_{N/S}$ transformation in $\mathcal{L}_{\text{vec}}$

Quadratic terms after shifting:

$$\begin{aligned}
\mathcal{L}^{quad} = & -\frac{1}{2}\sigma_a(\partial^2\delta_{ab} + (m_\sigma^2)_{ab})\sigma_b - \frac{1}{2}\pi_a(\partial^2\delta_{ab} + (m_\pi^2)_{ab})\pi_b \\
& - \frac{1}{2}\rho_a^\mu \left[(-g_{\mu\nu}\partial^2 + \partial_\mu\partial_\nu)\delta_{ab} - g_{\mu\nu}(m_\rho^2)_{ab}\right]\rho_b^\nu \\
& - \frac{1}{2}b_a^\mu \left[(-g_{\mu\nu}\partial^2 + \partial_\mu\partial_\nu)\delta_{ab} - g_{\mu\nu}(m_b^2)_{ab}\right]b_b^\nu \\
& -\frac{1}{2}\rho_a^\mu(g_1 f_{abc} v_c \partial_\mu)\sigma_b - \frac{1}{2}\sigma_a(g_1 f_{abc} v_c \partial_\mu)\rho_b^\mu \\
& -\frac{1}{2}b_a^\mu(g_1 d_{abc} v_c \partial_\mu)\pi_b + \frac{1}{2}\pi_a(g_1 d_{abc} v_c \partial_\mu)b_b^\mu
\end{aligned}$$

Mixing in the $N - S$ sector for σ and π $\longrightarrow$ $(m_\sigma^2)_{NS} \neq 0$, $(m_\pi^2)_{NS} \neq 0$

resolved by simple 2 dim. orthogonal transformations

Mixing between nonets $\longrightarrow$ $\rho_a^\mu \leftrightarrow \sigma$ and $b_a^\mu \leftrightarrow \pi$

take a closer look ⟶

Explicit form of nonet mixing crossterms:

$$\begin{aligned}
&- g_1\phi_N(f_{1N}^{\mu}\partial_\mu\eta_N + \vec{a}_1^{\mu}\cdot\partial_\mu\vec{\pi}) - \sqrt{2}g_1\phi_S f_{1S}^{\mu}\partial_\mu\eta_S - \Big(\frac{g_1}{\sqrt{2}}\phi_S + \frac{g_1}{2}\phi_N\Big)\Big(K_1^{\mu 0}\partial_\mu\bar{K}^0 \\
&+ K_1^{\mu +}\partial_\mu K^- + \text{h.c.}\Big) + \Big(i\frac{g_1}{\sqrt{2}}\phi_S - i\frac{g_1}{2}\phi_N\Big)\Big(\bar{K}^{\star\mu 0}\partial_\mu K_S^0 + K^{\star\mu -}\partial_\mu K_S^+\Big) \\
&+ \Big(-i\frac{g_1}{\sqrt{2}}\phi_S + i\frac{g_1}{2}\phi_N\Big)\Big(K^{\star\mu 0}\partial_\mu\bar{K}_S^0 + K^{\star\mu +}\partial_\mu K_S^-\Big)
\end{aligned}$$

Resolved by the following field shifts:

$$\begin{aligned}
f_{1N/S}^{\mu} &\longrightarrow f_{1N/S}^{\mu} + w_{f_{1N/S}}\partial^\mu\eta_{N/S}, \\
a_1^{\mu +,0} &\longrightarrow a_1^{\mu +,0} + w_{a_1}\partial^\mu\pi^{+,0}, (+\text{h.c.}) \\
K_1^{\mu +,0} &\longrightarrow K_1^{\mu +,0} + w_{K_1}\partial^\mu K^{+,0}, (+\text{h.c.}) \\
K^{\star\mu +,0} &\longrightarrow K^{\star\mu +,0} + w_{K^\star}\partial^\mu K_S^{+,0}(+\text{h.c.})
\end{aligned}$$

Vanishing of the crossterms ⟶ determination of the w_i's

After these shifts, π, η_N, η_S, K, and K_S are not canonically normalized ⟶ field renormalization ⟶ renormalization factors: Z_π, Z_{η_N}, Z_{η_S}, Z_K, Z_{K_S}

Tree-level masses

Pseudoscalar mass squares:

$$
\begin{aligned}
m_\pi^2 &= Z_\pi^2 \left[m_0^2 + \Lambda_N \Phi_N^2 + \lambda_1 \Phi_S^2\right] \\
m_K^2 &= Z_K^2 \left[m_0^2 + \Lambda_N \Phi_N^2 - \frac{\lambda_2}{\sqrt{2}} \Phi_N \Phi_S + \Lambda_S \Phi_S^2\right] \\
m_{\eta_N}^2 &= Z_\pi^2 \left[m_0^2 + \Lambda_N \Phi_N^2 + \lambda_1 \Phi_S^2 + c_1\, \Phi_N^2 \Phi_S^2\right] \\
m_{\eta_S}^2 &= Z_{\eta_S}^2 \left[m_0^2 + \lambda_1 \Phi_N^2 + \Lambda_s \Phi_S^2 + \frac{c_1}{4} \Phi_N^4\right] \\
m_{\eta_{NS}}^2 &= Z_\pi Z_{\pi_S} \frac{c_1}{2} \Phi_N^3 \Phi_S
\end{aligned}
$$

Scalar mass squares:

$$
\begin{aligned}
m_{a_0}^2 &= m_0^2 + \Lambda_N' \Phi_N^2 + \lambda_1 \Phi_S^2 \\
m_{K_S}^2 &= Z_{K_S}^2 \left[m_0^2 + \Lambda_N \Phi_N^2 + \frac{\lambda_2}{\sqrt{2}} \Phi_N \Phi_S + \Lambda_S \Phi_S^2\right] \\
m_{\sigma_N}^2 &= m_0^2 + 3\Lambda_N \Phi_N^2 + \lambda_1 \Phi_S^2 \\
m_{\sigma_S}^2 &= m_0^2 + \lambda_1 \Phi_N^2 + 3\Lambda_s \Phi_S^2 \\
m_{\sigma_{NS}}^2 &= 2\lambda_1 \Phi_N \Phi_S
\end{aligned}
$$

Mass square eigenvalues for σ and π in the $N-S$ sector

$$m^2_{f_0^H/f_0^L} = \frac{1}{2}\left[m^2_{\sigma_N} + m^2_{\sigma_S} \pm \sqrt{(m^2_{\sigma_N} - m^2_{\sigma_S})^2 + 4m^2_{\sigma_{NS}}}\right]$$

$$m^2_{\eta'/\eta} = \frac{1}{2}\left[m^2_{\eta_N} + m^2_{\eta_S} \pm \sqrt{(m^2_{\eta_N} - m^2_{\eta_S})^2 + 4m^2_{\eta_{NS}}}\right]$$

Vector mass squares:

$$m^2_\rho = m^2_1 + \frac{1}{2}(h_1 + h_2 + h_3)\Phi^2_N + \frac{h_1}{2}\Phi^2_S + 2\delta_N$$

$$m^2_{K^\star} = m^2_1 + H_N\Phi^2_N + \frac{1}{\sqrt{2}}\Phi_N\Phi_S(h_3 - g^2_1) + H_S\Phi^2_S + \delta_N + \delta_S$$

$$m^2_{\omega_N} = m^2_\rho$$

$$m^2_{\omega_S} = m^2_1 + \frac{h_1}{2}\Phi^2_N + \left(\frac{h_1}{2} + h_2 + h_3\right)\Phi^2_S + 2\delta_S$$

Axialvector meson mass squares:

$$m^2_{a_1} = m^2_1 + \frac{1}{2}(2g^2_1 + h_1 + h_2 - h_3)\Phi^2_N + \frac{h_1}{2}\Phi^2_S + 2\delta_N$$

$$m^2_{K_1} = m^2_1 + H_N\Phi^2_N - \frac{1}{\sqrt{2}}\Phi_N\Phi_S(h_3 - g^2_1) + H_S\Phi^2_S + \delta_N + \delta_S$$

$$m^2_{f_{1N}} = m^2_{a_1}$$

$$m^2_{f_{1S}} = m^2_1 + \frac{h_1}{2}\Phi^2_N + \left(2g^2_1 + \frac{h_1}{2} + h_2 - h_3\right)\Phi^2_S + 2\delta_S$$

Decay widths

For a $A \to BC$ decay process the decay with is:

$$\Gamma_{A\to BC} = \frac{k}{8\pi m_A^2} \left|\mathcal{M}_{A\to BC}\right|^2$$

$k \longrightarrow$ three momentum of the produced particles in the restframe of A
$\mathcal{M}_{A\to BC} \longrightarrow$ transition matrix element

If A is a vector particle and $C = B^\dagger \Longrightarrow$

$$\left|\mathcal{M}_{A\to BB^\dagger}\right|^2 = \frac{4}{3} k^2 V_\mu V^{\mu\star}$$

$V_\mu \longrightarrow$ vertex function directly followed from the three-coupling terms of $\mathcal{L}$

If A is a vector particle, B scalar and $C = \gamma$ a photon $\Longrightarrow$

$$\left|\mathcal{M}_{A\to B\gamma}\right|^2 = \frac{1}{3}\left(g^{\alpha\beta} - \frac{k_A^\alpha k_A^\beta}{m_A^2}\right) V_{\alpha\alpha'} V_\beta^{\star\alpha'}$$

Some decay widths in the extended model

The $\rho \to \pi\pi$ decay width:

$$\Gamma_{\rho\to\pi\pi} = \frac{m_\rho^5}{48\pi m_{a_1}^4}\left[1-\left(\frac{2m_\pi}{m_\rho}\right)^2\right]^{3/2}\left[g_1 Z_\pi^2 - \frac{g_2}{2}\left(Z_\pi^2-1\right)\right]^2$$

The experimental value from the PDG: $\Gamma_{\rho\to\pi\pi}^{\text{(exp)}} = (149.1 \pm 0.8)$ MeV

The $a_1 \to \pi\gamma$ decay width:

$$\Gamma_{a_1\to\pi\gamma} = \frac{e^2 g_1^2 \Phi_N^2}{96\pi m_{a_1}} Z_\pi^2 \left[1-\left(\frac{m_\pi}{m_{a_1}}\right)^2\right]^3$$

The experimental value: $\Gamma_{a_1\to\pi\gamma}^{\text{(exp)}} = (0.640 \pm 0.246)$ MeV

Parametrization: general considerations

In order to make predictions ⟶ unknown constants of the model must be determined

⟹ choose a set of (well known) physical quantities/conditions for fitting procedure

For instance:

- PartiallyConservedAxialCurrent ⟶ fix the condensates (2 parameter)
- Particle masses (which can be compared with PDG (K. Nakamura et al., J. Phys. G **37**, 075021 (2010)))
- Decay widths (which can be compared with PDG)

Finding a good parameter set ⟶ non-trivial task (usually there are lots of solutions, but non of them is perfect)

Parametrization in the extended model

13 unknown parameters $\longrightarrow$ Determined by the minimalization of the χ^2:

$$\chi^2(x_1,\ldots,x_N)=\sum_{i=1}^{M}\left[\frac{Q_i(x_1,\ldots,x_N)-Q_i^{\text{exp}}}{\delta Q_i}\right]^2,$$

where $(x_1,\ldots,x_N)=(m_0,\lambda_1,\lambda_2,\ldots)$, $Q_i(x_1,\ldots,x_N)$ calculated from the model, while $Q_i^{\text{exp}}\pm\delta Q_i$ taken from the PDG

multiparametric minimalization $\longrightarrow$ MINUIT

- PCAC $\rightarrow$ 2 physical quantities: f_π, f_K
- Tree-level masses $\rightarrow$ 14 physical quantities:
  $m_\pi, m_\eta, m_{\eta'}, m_K, m_\rho, m_\Phi, m_{K^\star}, m_{a_1}, m_{f_1^H}, m_{K_1}, m_{a_0}, m_{K_s}, m_{f_0^L}, m_{f_0^H}$
- Decay widths $\rightarrow$ 12 physical quantities:
  $\Gamma_{\rho\to\pi\pi}, \Gamma_{\Phi\to KK}, \Gamma_{K^\star\to K\pi}, \Gamma_{a_1\to\pi\gamma}, \Gamma_{a_1\to\rho\pi}, \Gamma_{f_1\to KK^\star}, \Gamma_{a_0}, \Gamma_{K_S\to K\pi}$,
  $\Gamma_{f_0^L\to\pi\pi}, \Gamma_{f_0^L\to KK}, \Gamma_{f_0^H\to\pi\pi}, \Gamma_{f_0^H\to KK}$

The question: which a_0, $K_0^\star$ and f_0s belong to the scalar nonet?

Particle identification, results

In the first step f_0 mesons were left out → their properties are very uncertain (Different analyses give different results)

First run → which pairs of $a_0, K_0^\star$ give acceptable fits

Then we continue by studying which pair of f_0's can be described better

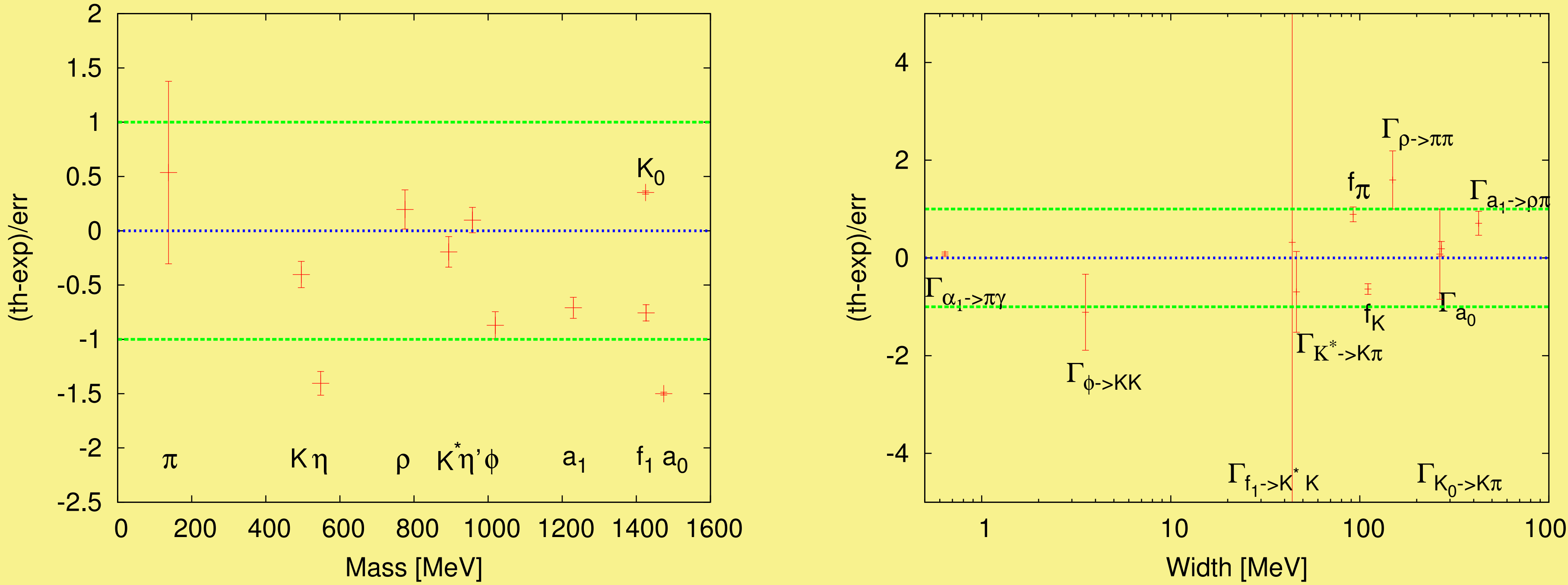
13 parameters to fit 28 measured quantities

Pair	χ^2	χ^2_{red}
$a_0(1450)/K_0^\star(1430)$	12.33	1.23
$a_0(980)/K_0^\star(800)$	129.36	11.76
$a_0(980)/K_0^\star(1430)$	22.00	2.00
$a_0(1450)/K_0^\star(800)$	242.27	24.23

The best χ^2 is given by the pair: $a_0(1450), K_0^\star(1430)$

Observable	Fit [MeV]	Experiment [MeV]
f_π	96.3 ± 0.7	92.2 ± 4.6
f_K	106.9 ± 0.6	110.4 ± 5.5
m_π	141.0 ± 5.8	137.3 ± 6.9
m_K	485.6 ± 3.0	495.6 ± 24.8
m_η	509.4 ± 3.0	547.9 ± 27.4
$m_{\eta'}$	962.5 ± 5.6	957.8 ± 47.9
m_ρ	783.1 ± 7.0	775.5 ± 38.8
$m_{K^\star}$	885.1 ± 6.3	893.8 ± 44.7
m_ϕ	975.1 ± 6.4	1019.5 ± 51.0
m_{a_1}	1186 ± 6	1230 ± 62
$m_{f_1(1420)}$	1372.5 ± 5.3	1426.4 ± 71.3
m_{a_0}	1363 ± 1	1474 ± 74
$m_{K_0^\star}$	1450 ± 1	1425 ± 71
$\Gamma_{\rho\to\pi\pi}$	160.9 ± 4.4	149.1 ± 7.4
$\Gamma_{K^\star\to K\pi}$	44.6 ± 1.9	46.2 ± 2.3
$\Gamma_{\phi\to\bar{K}K}$	3.34 ± 0.14	3.54 ± 0.18
$\Gamma_{a_1\to\rho\pi}$	549 ± 43	425 ± 175
$\Gamma_{a_1\to\pi\gamma}$	0.66 ± 0.01	0.64 ± 0.25
$\Gamma_{f_1(1420)\to K^\star K}$	44.6 ± 39.9	43.9 ± 2.2
Γ_{a_0}	266 ± 12	265 ± 13
$\Gamma_{K_0^\star\to K\pi}$	285 ± 12	270 ± 80

Comparison of theory and experiment for observables



After the fit above $\longrightarrow$ f_0 particles can be investigated
Detailed analysis $\longrightarrow$ $(f_0(1370), f_0(1710))$ are favored

More detail in $\longrightarrow$ Phys. Rev. D **87**, 014011 (2013), [arXiv:1208.0585 [hep-ph]]

$(f_0(1370), f_0(1500), f_0(1710))$: mixing of glueball and the 2 states above
$(f_0(500), f_0(980))$: ? molecular states, tetraquark

Conclusions and outlook

- With multiparametric χ^2 minimalization, the meson assignment to a $q\bar{q}$ state can be constrained
- According to the model the $a_0(q\bar{q})$ must be assigned to $a_0(1450)$, while the $K_S(q\bar{q})$ to $K_0^\star(1430)$
- It seems that most probably the two f_0's are both above 1 GeV, namely they should be assigned to $f_0(1370)$ and $f_0(1710)$
- $f_0(1370), f_0(1500), f_0(1710)$ mixing of glueball and the 2 scalar-isoscalar states
- $f_0(500), f_0(980)$ can be either molecular states, or tetraquarks
- Outlook: It is possible to add barions to the described model $\longrightarrow$ barion nonet, barion decouplet (e.g. $\longrightarrow$ investigation of Δ decays)

Phys. Rev. D **87**, 014011 (2013), [arXiv:1208.0585 [hep-ph]]