SCALAR MESONS IN VES EXPERIMENT

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Outlook

- Introductory remarks
- VES Experiment
- Scalars at VES – various topics
- Conclusions
NOTE ON SCALAR MESONS
by C. Amsler, T. Gutsche, S. Spanier and N.A.T. Törnqvist (in RPP 2011):

- quantum numbers of the vacuum ($J^{PC} = 0^{++}$)
- can condense into the vacuum and break a symmetry such as a global chiral $U(N_f)_L \times U(N_f)_R$
- *How they break?*
Numerous and various

- OPE scattering $\pi/K N \rightarrow N \pi/K \pi$, $N K/\pi K$
- Diffractive $\pi N \rightarrow N PPP$
- $p p^- \rightarrow PPP$ (at rest & in flight)
- $\gamma \gamma \rightarrow PP$
- $D(\ast)/B \rightarrow PPP$ Dalitz plot
- $J/\psi \rightarrow K^* K \pi$
- $\tau \rightarrow K \pi \nu$
- $\phi \rightarrow [a0(980) + f0(980)] \gamma$
- ..... 

- In general: mostly PP – S wave
VES setup

- secondary (mostly $\pi^-$) beam of U-70, $p \sim 25 - 45 \text{ GeV/c}$
- magnetic spectrometer $p_t = 0.5 - 0.7 \text{ GeV/c}$
- EM – calorimetry
- K/$\pi$ – identification (4-18 GeV/c)
- Fast DAQ (10$^4$/spill)
- Minimum bias trigger

1 - target; 2 - veto counters; 3 - multiplicity discriminator; 4 - magnet; 5 - Čh detector; 6 - Sci – hodoscope; 7 - Ecal
Experimental studies of scalars with VES

- Form-factor of the decay $\eta' \rightarrow \eta \pi \pi$
- The ($\omega \phi$) in Charge Exchange Reaction
- ISB decay $f_1(1285) \rightarrow 3 \pi$
- Search for ISB decay $\pi(1800) \rightarrow \eta \pi \pi$
Form-factors in the decays $\eta' \to \eta \pi \pi$

- The width and **spectral shape** of the $\eta' \to \eta \pi \pi$ are of interest for various aspects.

- General tool: ChPT (expansion in $p^2$, $m_{u,d,s}$, $1/N_c$ in $N_c \to \infty$ approach)
  - + FSI (heavy $\eta'$)
  - intermediate Resonances in play
    - encoded in LEC (at low $s$)
    - introduced “by hands” or dynamically
  - Mainly with $J^{PC} = 0^{++}$ (coupling to $1^-$ suppressed in $I=0$ $P \to PPP$ due to $G$-parity)
Measured in
- diffractive associative production $\eta' \pi^-$
- Charge exchange reaction

largest sample at the moment ($\sim 23$ k ev)

more general DP parameterization:

$$|M|^2 \propto 1 + a \times Y + b \times Y^2 + c \times X + d \times X^2 + \ldots$$  \hspace{1cm} (1)

Compared w. “linear” one ($\alpha$ complex)

$$|M|^2 \propto |1 + \alpha \times Y|^2 + c \times X + d \times X^2$$  \hspace{1cm} (2)

(1) & (2) equivalent \hspace{0.5cm} ONLY for $b > a^2/4 \geq 0$
Y - dependence of Dalitz plot distribution for 8 slices on X. Data (points) and fitting function (line)
The parameter $c$ compatible with zero as expected from $C$ - symmetry

The $b$ NEGATIVE $\rightarrow$

the “linear” parameterization not adequate

The large and NEGATIVE $d$ impacts models
PL B651 22 (2007) (VES)
PAN 72 231 (2009) (GAMS) (neutral mode; may differ)
PR D 83, 012003 (2011) (BESIII) - New (~44 k ev)

JHEP 1105:094,2011 Rafel Escribano, Pere Masjuan, Juan Jose Sanz-Cillero
Large-Nc ChPT vs. RChT
Scalars in $\eta' \rightarrow \eta \pi \pi$ DP

- $a_0(980)$ contribution dominant
- $\sigma$ is essential
- But … heavier tensor states are not negligible
- Accounting for other states required to study scalers
Scalar in (ωφ) system

in charge-exchange

(OPE compatible) reaction
X(1812): Earlier observation in $J/\psi \rightarrow (\gamma \omega \varphi)$

By BESII Collab. (Ablikim et al.),
PWA of (ωφ) system

(Hadron-2009, Proceedings of XIII International Conference)
PWA of (ωω) system
$N(\omega \phi)/N(\omega \omega)$ ratio for $J^P=0^+$
OZI rule in 0+ & 2+

\[ \frac{N_{0+}(\omega \phi)}{N_{0+}(\omega \omega)} = 0.65 \pm 0.10 \quad (1.82 \text{ GeV} < M < 2.0 \text{ GeV}) \]

- Compare with 2+

\[ \frac{N_{2+}(\omega \phi)}{N_{2+}(\omega \omega)} = 0.045 \pm 0.010 \]

- The violation of the OZI rule in decays of scalar resonances is expected in many models

"On the origin of the OZI rule in QCD", Nathan Isgur, H.B. Thacker
Phys.Rev. D64 094507, 2001
ISB Decay $f_1(1285) \rightarrow \pi^+\pi^-\pi^0$

- $I^GJ^{PC} = 0^{+}1^{++}$, $M = 1282$ MeV, $\Gamma = 24$ MeV
- Dominant channels: $KK\pi$, $\eta\pi\pi$ (incl. $a_0(980)\pi$), $4\pi$
- Decay to $3\pi$ violates Isospin Symmetry

Possible mechanisms
- $f_1(1285) \leftrightarrow a_1(1260)$ mixing (à la $\omega \leftrightarrow \rho$, $\eta \leftrightarrow \pi$, $\Delta \leftrightarrow N$, $\Sigma \leftrightarrow \Lambda$)
- «contact» $f_1 \rightarrow 3\pi$
- Intermediate scalars mixing: $f_1 \rightarrow \pi a_0 \rightarrow \pi f_0 \rightarrow 3\pi$

(possibly) enhanced through KK-loops (Achasov, Devyanin, Shestakov PL B88, 1979)
Experimental findings

• 1-st report @Meson-2008 (Cracow)
• Final publication EPJ A (2011) 47: 68
• Associative $f_1\pi^-$ production

\[ \pi^- A \rightarrow A f_1\pi^- \]

$M(\pi^+\pi^-)$ for $M(3\pi)$ within $f_1(1285)$ mass region

Effect of angular weighting

$1^+ \rightarrow (0^+ 0^-) P$ on $M(\pi^+\pi^-)$
Experimental result

\[
\frac{BR(f_1 \rightarrow f_0(980)\,\pi^0 \rightarrow \pi^+ \pi^- \pi^0)}{BR(f_1 \rightarrow \eta \pi^+ \pi^-)} = (0.86 \pm 0.16(\text{stat}) \pm 0.20(\text{syst.}))% 
\]

\[
BR(a_0(980) \rightarrow f_0(980) \rightarrow \pi^+ \pi^-) = (2.0 \pm 0.6 \pm 0.4)% 
\]

Estimates within "Achasov' model" varying \(a_0/f_0\) parameters

\[
\frac{BR(f_1 \rightarrow \pi^+ \pi^- \pi^0)}{BR(f_1 \rightarrow \eta \pi^+ \pi^-)} \sim 0.05 - 0.5 \%
\]

VES result exceeds maximal (with extreme \(f_0(980)-KK\) coupling)

\[
\frac{BR(f_1 \rightarrow \pi^+ \pi^- \pi^0)}{BR(f_1 \rightarrow \eta \pi^+ \pi^-)} = (0.86 \pm 0.16(\text{stat})^{+0.70}_{-0.20})% 
\]

More: accounting for lower 2\(\pi\)-mass tail
\[ \xi_{af} = \frac{\text{Br}(f_1 \to a_0^0 \pi^0 \to f_0(980) \pi^0 \to \pi^+ \pi^- \pi^0)}{\text{Br}(f_1 \to a_0^0 \pi^0 \to \eta \pi^0 \pi^0)} = (2.5 \pm 0.5 \pm 0.6)\% \quad \text{VES} \]

\[ \xi_{af} = \frac{\text{Br}(\psi' \to \gamma \chi_{c1} \to \gamma a_0^0 \pi^0 \to \gamma f_0(980) \pi^0 \to \gamma \pi^+ \pi^- \pi^0)}{\text{Br}(\psi' \to \gamma \chi_{c1} \to \gamma a_0^0 \pi^0 \to \gamma \eta \pi^0 \pi^0)} = (0.3 \pm 0.2 \pm 0.1)\% \quad \text{BES-III} \]
- FSI (re-scattering) expected
  -- small @ BES as $a_0(f_0)$ and $\pi$ well separated
  -- large @ VES as all products “confined”
- An example: Triangle Singularity (TS)
  ISB $\eta(1405/1475) \rightarrow f_0 \pi$ arXiv:1108.3772v1 Jia-Jun Wu et al.

- $J^P = 1^+$ vs. $0^-$ → other TS character
- $f_1(1285)$ light → loop particles off-shell
Assuming $a_0(980) \leftrightarrow f_0(980)$ mixing

major $J^P=0^- \pi(1800) \to f_0(980)\pi \to a_0\pi \to \eta\pi\pi$

Rich source: diffractive $\pi^-N \to N\pi^-(1800)$ with $\pi^-(1800) \to (\eta\pi^0)\pi^-$

3-particles final state compared w. $f_1\pi$ case

but: broad ($>120$ MeV) $\pi(1800)$ compared w. narrow ($\sim25$ MeV) $f_1(1285)$

Specific feature (PWA needed):
$0^-(1800) \to 0^+(\eta\pi)\pi$ $M(0^+)\sim0.98$ GeV neutral only
\[ \pi^- N \rightarrow N \eta \pi^0 \pi^- \quad \text{with} \quad \eta \rightarrow \pi^+\pi^-\pi^0 \]

for \( \pi(1800) \) region \( 1.72 < M(\eta \pi^0 \pi^-) < 1.92 \text{ GeV} \)

\[ M(\eta \pi^0) \quad \text{- left} \quad \text{M}(\eta \pi^-) \quad \text{- right} \]

Signal compatible w. \( a_0(980) \):

\[ N(a_0^0) \approx 600 \pm 60 \quad \text{N}(a_0^-) \approx 130 \pm 60 \]
η → π⁺π⁻π⁰ with final experimental width

Very large (combinatorial) background

5-particles PWA (includes ω(782) → π⁺π⁻π⁰ and bckg.)

Many isobars ρ(770), a₂(1320), a₁(1260), b₁(1235), a₀(980)

24 waves (J^{PC}=0^-, 0^+, 1^-, 1^+, 2^+, 2^+, ...)

Different production mechanisms (exchanges) (OPE, ω, diffraction) → t - dependencies

Separate waves w. (not symmetric) a₀⁰ and a₀⁻

Model dependent a₀ (980) ↔ f₀ (980) “mixing” signal

J^P = 0⁻ for π(1800) → “a₀⁰” π⁻
Some (large) waves (preliminary)

$2^{++}$ $\omega \rho$

$0^{-} \rightarrow "a_{0}^{0}" \pi^{-}$

$0^{-} a_{1} \rho$
Preliminary result

\[
\frac{BR(\pi(1800) \rightarrow a_0(980) \pi \rightarrow (\eta \pi^0) \pi)}{BR(\pi(1800) \rightarrow f_0(980) \pi \rightarrow (\pi^+ \pi^-) \pi)} < 1.9 \% \quad @ \, 90\% \, CL
\]

N.B.: $\pi(1800) \rightarrow K^*K$ => no TS-like enhancement

- Analyses $\pi^- N \rightarrow N \pi^-(1800) \rightarrow (\eta \pi^0) \pi^- \rightarrow (\gamma \gamma) (\gamma \gamma) \pi^-$ desired
- much less bckg $\rightarrow$ lower noise; less states; (relatively) larger signal
- pilot VES run (2010) with 1-track final state: promising
- full run planned for November 2011
Conclusions

- Specific shape of Dalitz plot for $\eta' \to \eta \pi^+ \pi^-$ adopted with RChT; **scalars AND tensors contribute**

- **Scalar** near threshold in $\omega(782) \varphi(1020)$ compatible w. $X(1812)$ by BESII strongly violates OZI rule

- ISB–decay $f_1(1285) \to \pi^+ \pi^- \pi^0$ incompatible with “KK-loop mixing” of $a_0(980) \leftrightarrow f_0(980)$ alone: too intensive and structured

- An indication to ISB–decay $\pi(1800) \to \eta \pi \pi$ through “$a_0(980)$” needs more analyses

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results from VES Collaboration [9]. (3) The negative value of the coefficient $b$ indicates that the two kinds of parametrizations are not equivalent. This conclusion is consistent with that from GAMS-4$\pi$ Collaboration [10]; however, it is different from the conclusion by the VES Collaboration [9], where the fit with the linear parametrization yields an unsatisfactory $\chi^2/NDF = 170.5/114$ ratio. (4) The
In conclusion, the large-$N_C$ ChPT framework seems to be suitable for describing $\eta' \rightarrow \eta\pi\pi$ decays even though higher next-to-next-to-leading chiral orders turn out to be relevant. The RChT approach tries to cure this problem since part of the higher order local terms in ChPT are now resummed through the exchange of heavy resonances. We have seen that the $a_0(980)$ contribution is dominant but, at the same time, the $\sigma$ contribution is also essential to agree with experiment. However, we find that heavier states, which are not present in the original RChT framework, are not negligible. In particular, the lowest lying tensor resonances produce a noticeable effect in the RChT estimates. Therefore, although RChT resums higher chiral orders, at this level of precision, it requires a much more detailed knowledge of the resonance content and properties. On the other hand, in the large-$N_C$ ChPT approach, the effect of any possible heavy state is encoded in the low-energy constants and hence the resonance spectrum does not need to be known in detail. For these reasons, we consider both frameworks, large-$N_C$ ChPT and RChT, to be complementary, where each one has its own advantages and disadvantages. We hope
Backup slides
waves for PWA of $(\omega\omega)$

- 1 - (0++)0- JLS=000
- 2 - (2++)0- JLS=202
- 3 - (2++)0- JLS=220
- 4 - (2++)0- JLS=222
- 5 - (2++)1- JLS=202
- 6 - (4++)0- JLS=422
- 7 - (4++)0- JLS=440
- 8 - (4++)0- JLS=442
- 9 - (4++)0- JLS=422
- 10 - (6++)0- JLS=642

- 11 - (0-+)0+ JLS=011
- 12 - (2-+)0+ JLS=211
- 13 - (1++)0+ JLS=122
- 14 - (3++)0- JLS=322
- 15 - (2++)1+ JLS=202
- 16 - (4++)1+ JLS=422
- 17 - FLAT
Dynamical coupled-channel study of $K^*\bar{K}^*$ and $\omega\phi$ states in a chiral quark model

W.L. Wang$^{1,2}$ and Z.Y. Zhang$^{1,2}$

previous work [35] and the present work show that there is no $\omega\phi$ bound state or resonance state, but there is an isospin $I = 0$ and spin $S = 0$ $K^*\bar{K}^*$ bound state with the energy of about $1720 - 1727$ MeV, which couples relatively strong to $\omega\phi$. This provides some sort of support for the $X(1812)$ observed in $\omega\phi$ channel being from the effects of the tail of $f_0(1710)$ through $K^*\bar{K}^*$ re-scattering.
X(1812) search @ BELLE in B+ → K+ (ωφ)
- no signal  (arXiv:0902.4757v2)
\[ \eta(1405) \rightarrow f_0(980)\pi^0 \] @ BESIII

Helicity analysis indicates that peak at 1400MeV is from \[ \eta(1405) \rightarrow f_0(980)\pi^0 \] not from \[ f_1(1420) \].

First observation of \[ \eta(1405) \rightarrow f_0(980)\pi^0 \] (isospin violated decays) and \[ J/\psi \rightarrow \gamma f_0(980)\pi^0 \].

**Preliminary results:**

\[
Br(J/\psi \rightarrow \gamma \eta(1405) \rightarrow \gamma f_0\pi^0 \rightarrow \gamma \pi^0\pi^+\pi^-) = (1.48 \pm 0.13(stat.) \pm 0.17(sys.)) \times 10^{-5}
\]

\[
Br(J/\psi \rightarrow \gamma \eta(1405) \rightarrow \gamma f_0\pi^0 \rightarrow \gamma \pi^0\pi^0\pi^0) = (6.99 \pm 0.93(stat.) \pm 0.95(sys.)) \times 10^{-6}
\]
Backup slides
$M(\pi^+ \pi^-)$ in $\eta(1440) \to \eta\pi\pi$ w. TS