Euroflavour 08

Annual meeting and Mid-term review

Momentum dependence of $a_0(980)$ and $f_0(980)$ meson interactions in $\mathrm{R}\chi\mathrm{T}$ face the KLOE data

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Outline

Focus on

- light scalar mesons (S):

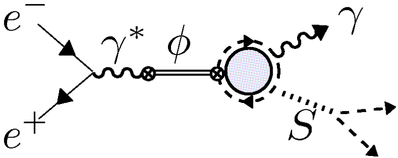
  $a_0(980)$ ($I^G(J^{PC}) = 1^-(0^{++})$) and $f_0(980)$ ($0^+(0^{++})$)

Employ

- Resonance chiral perturbation theory ($\mathrm{R}\chi\mathrm{T}$)

Study

- $\frac{\mathrm{d}B_{\phi\to\gamma\pi^0\pi^0}}{\mathrm{d}m_{\pi^0\pi^0}}$ and $\frac{\mathrm{d}B_{\phi\to\gamma\pi^0\eta}}{\mathrm{d}m_{\pi^0\eta}}$
- important influence from pseudoscalar meson dynamics



$$\frac{\mathrm{d}B}{\mathrm{d}m} = \frac{\mathrm{d}\sigma}{\mathrm{d}m} \, \frac{m_\phi^2}{12\pi} \, \frac{\Gamma_{\phi,\, tot}}{\Gamma_{\phi \to e^+ e^-}}$$

$$\Downarrow$$

$$\frac{\mathrm{d}B_{\phi \to \gamma \pi^0 \pi^0}}{\mathrm{d}m_{\pi^0 \pi^0}}, \quad \frac{\mathrm{d}B_{\phi \to \gamma \pi^0 \eta}}{\mathrm{d}m_{\pi^0 \eta}}$$

THE MODEL

Resonance Chiral Theory (RχT)

- non-linear realization of spontaneous chiral symmetry breaking
- not assuming any given internal structure

RχT features

- ChPT + V, A, S resonances $\leftrightarrow$ QCD
- reliable below and even near 1 GeV
- momentum-dependent vertices, decoupling in the chiral limit

Resonance chiral perturbation theory Lagrangian

$$L_{scalar,pseudoscalar} = c_d \left\langle S^{oct} u_\mu u^\mu \right\rangle + c_m \left\langle S^{oct} \chi_+ \right\rangle + \tilde{c}_d S^{sing} \langle u_\mu u^\mu \rangle + \tilde{c}_m S^{sing} \langle \chi_+ \rangle ,$$

$$L_{vector,pseudoscalar} = \frac{F_V}{2\sqrt{2}} \left\langle V_{\mu\nu} f_+^{\mu\nu} \right\rangle + \frac{iG_V}{\sqrt{2}} \left\langle V_{\mu\nu} u^\mu u^\nu \right\rangle$$

"$\langle \cdots \rangle$" – trace in the flavor space
$u_\mu = \imath u^+ D_\mu u^+$
$u = \exp(i\sqrt{2}\Phi / F_\pi)$ – non-linear parametrization of the pseudoscalar fields
D_μ – chiral covariant derivative
F_π – the pion decay constant
S^{oct}, S^{sing}, $V_{\mu\nu}$ – scalar and vector resonances
$c_{d,m}$, $\tilde{c}_{d,m}$, F_V, G_V – effective couplings
$f_+^{\mu\nu} = eF^{\mu\nu}(uQu^+ + u^+Qu)$, $Q \equiv \mathrm{diag}(\frac{2}{3}, -\frac{1}{3}, -\frac{1}{3})$
$\chi_+ = u^+\chi u^+ + u\chi u$,
$\chi = 2B_0\ \mathrm{diag}(m_u, m_d, m_s) \approx \chi = \mathrm{diag}(m_\pi^2,\ m_\pi^2,\ 2m_K^2 - m_\pi^2)$,

Ecker et al. NP B **321**, 311 (1989)

Resonance chiral perturbation theory Lagrangian

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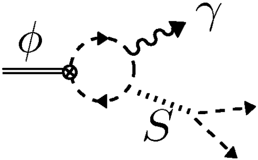
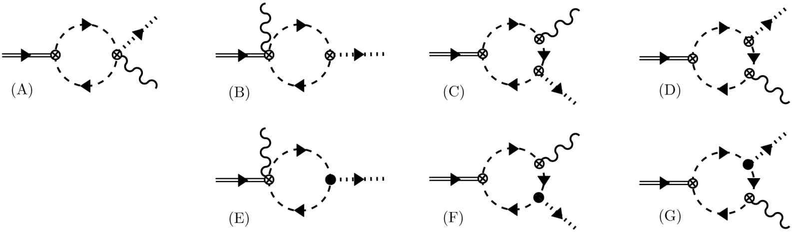
$F_V = 2\,G_V$	consistency with QCD asymptotic behavior
$c_d = c_m = f_\pi/2 = 46.2$ MeV	short-distance constraints
$\tilde{c}_m = c_m/\sqrt{3}$, $\tilde{c}_d = c_d/\sqrt{3}$	large-N_c limit

Kaon loop for ϕ decay from RχT

S.I. and A.Korchin, Eur. Phys. J. C **54** (2008) 89
arXiv: 0707.2700 (hep-ph)





(momentum-dependent ⊗ and momentum-independent ● vertices for interactions with scalar meson)

Summarizing benefits from RχT

- **Loop integrals are universal**:

  $\Rightarrow$ known analytical expressions $I(a, b)$

  e.g. Lucio, Pestieau, PR D **42**, 3253 (1990), *erratum ibid.* **43**, 2447

- no counter-terms needed, provided $F_V = 2\,G_V$

  (Ecker et al. PL, B **223**, 425)

- momentum-dependent vertex functions enter the game

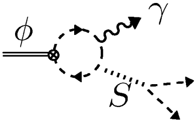
- No contact $V\gamma S$ and $\gamma\gamma S$ coupling

  $\Rightarrow$ leading-order diagrams are one-loop

THE MODEL WORKS

Invariant mass distributions

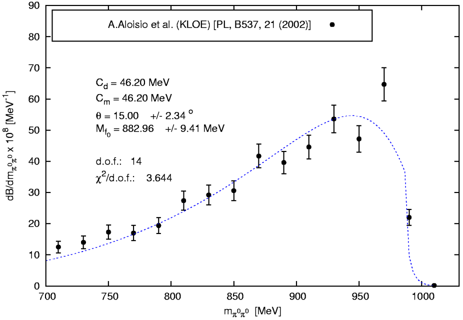
$$\frac{dB_{\phi\to\gamma\pi^0\pi^0}}{dm_{\pi^0\pi^0}}$$

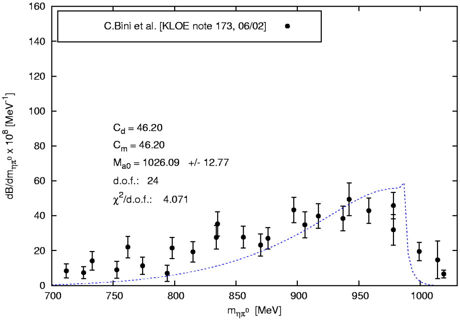


$$\frac{dB_{\phi\to\gamma\pi^0\eta}}{dm_{\pi^0\eta}}$$

2 parameters: M_{f_0}, θ

1 parameter: M_{a_0}





Mid-term summary

- fit results depend crucially on the **scalar meson propagator** form
  - relativ. BW
  - Flatté - like
  - model - dependent self-energy inclusion
  - mixtures
  - etc.
- to calculate a scalar meson propagator in RχT — still a challenge

B E H I N D T H E C U R T A I N :

momentum dependence of effective couplings

Invariant mass distributions: formulae

$$\frac{\mathrm{d}B}{\mathrm{d}m_{\pi^0\pi^0}} = \frac{\Gamma_{\phi\to\gamma f_0\to\pi^0\pi^0}}{\Gamma_{\phi,\,tot}}, \qquad m_{\pi^0\pi^0} \equiv \sqrt{p^2}$$

$$\frac{\mathrm{d}B}{\mathrm{d}m_{\pi^0\pi^0}} = \frac{1}{2}\,\frac{1}{\Gamma_{\phi,\,tot}}\,\frac{\alpha\sqrt{p^2}\,\sqrt{1-4m_\pi^2/p^2}}{4\times 48\pi^4 m_K^4} \times \left|\frac{I(a,b)}{D_{f_0}(p^2)}\right|^2 \left(\frac{M_\phi^2-p^2}{M_\phi}\right)^3 \times \frac{G^2_{f_0\pi\pi}(p^2)}{4\pi}\,\frac{G^2_{f_0KK}(p^2)}{4\pi}\left(\frac{\sqrt{2}G_V M_\phi}{f_\pi^2}\right)^2$$

$a = M_\phi^2/m_K^2$, $b = p^2/m_K^2$, $\alpha \approx 1/137$. $1/2$ — for identity of the π^0s.

$\pi^0\eta$ case is analogous.

Flatté-like form of the scalar-meson propagator

$$D_S(p^2) = \left[p^2 - m_S^2 + i\sqrt{p^2}\,\tilde{\Gamma}_{S,\,tot}(p^2)\right]^{-1}$$

$$\tilde{\Gamma}_{f_0,\,tot}(p^2) = \tilde{\Gamma}_{f_0\to\pi\pi}(p^2) + \tilde{\Gamma}_{f_0\to K\bar{K}}(p^2)$$
$$\tilde{\Gamma}_{a_0,\,tot}(p^2) = \tilde{\Gamma}_{a_0\to\pi^0\eta}(p^2) + \tilde{\Gamma}_{a_0\to K\bar{K}}(p^2)$$

$$\tilde{\Gamma}_{f_0\to\pi\pi}(p^2) = \frac{3}{2}\,\frac{1}{2p^2}\sqrt{\frac{p^2}{4} - m_\pi^2} \times \frac{G^2_{f_0\pi\pi}(p^2)}{4\pi}$$

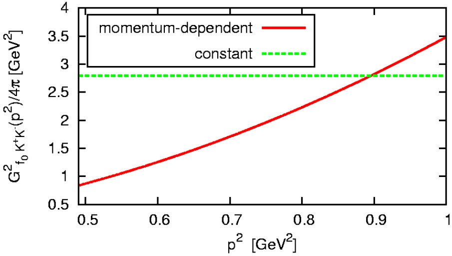
analytic function of p^2, defined **above** and **below the threshold** with $\sqrt{p^2/4 - m_\pi^2} = i\sqrt{|p^2/4 - m_\pi^2|}$.

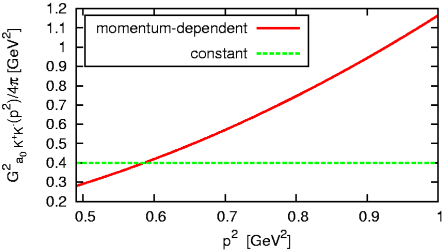
The analogous formulae hold for other decays.

Momentum dependence of effective couplings

$$\frac{G^2_{f_0 KK}(p^2)}{4\pi}$$

$$\frac{G^2_{a_0 KK}(p^2)}{4\pi}$$





Summary

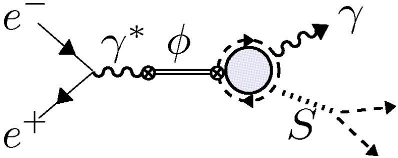
- There is a room for model improvement

  3 parameters – too few to fit $\frac{\mathrm{d}B_{\phi\to\gamma\pi^0\pi^0}}{\mathrm{d}m_{\pi^0\pi^0}}$, $\frac{\mathrm{d}B_{\phi\to\gamma\pi^0\eta}}{\mathrm{d}m_{\pi^0\eta}}$ with good χ^2
- momentum-dependent vertex functions enter the game
- mind the scalar resonance propagator.

Acknowledgements

- H. Czyż for discussion of prospects
- NASU grant for young researchers (contract 8.63/2008)
- Joint NASU-RFFR scientific project N 38/50-2008
- EU MRTN-CT-2006-035482 (FLAVIAnet)
- INTAS grant 05-1000008-8328.

SPARES



We study the dynamical properties of the decay mechanism exploiting the Chiral Dynamics!

(Energies are within the RχT applicability limits)

Assumptions

- in order to study $a_0 \to \pi\eta$, one cannot avoid the pseudoscalar octet-singlet mixing problem (η - η' mixing)

$$\begin{cases} \eta = & \eta_8 \cos\theta_8 - \eta_1 \sin\theta_1 , \\ \eta' = & \eta_8 \sin\theta_8 + \eta_1 \cos\theta_1 , \end{cases}$$

$$\theta_8 \ = \ -9.2^\circ, \ \theta_1 = -21.2^\circ$$

[Feldmann, Kroll and Stech, PR, D58, 114006]

- a scheme for multiplet decomposition

$$\begin{cases} a_0 = S_3^{oct}, \\ f_0 = S^{sing} \cos\theta - S_8^{oct} \sin\theta, \end{cases}$$

S_3, S_8 – octet S^{oct} components, θ – octet-singlet mixing angle.

- for octet and siglet ($\tilde{}$) chiral couplings we employ

$$\tilde{c}_m = \frac{c_m}{\sqrt{3}}, \qquad \tilde{c}_d = \frac{c_d}{\sqrt{3}},$$

(Can be derived from assumption of large number of quark colors ($N_c \to \infty$))

Disclaimer

- R ChPT contains the $U(1)$ axial anomaly

η - η' mixing is complicated

- a priori one does not know whether the light scalars fit into the scalar nonet of R ChPT (how to verify?),
  do isovector $a_0(980)$ and isoscalar $f_0(980)$ mix with each other?

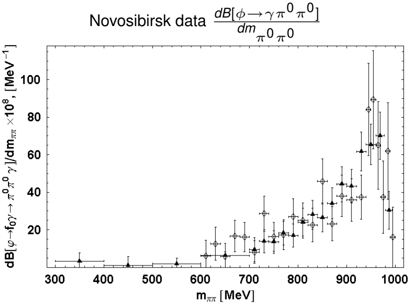
- see papers by J.R. Peláez for large-N_c analysis:

- ordinary resonances — become stable for $N_c \to \infty$: $\Gamma \to 0$
- extraordinary ones — **disappear** in $N_c \to \infty$: width grows!

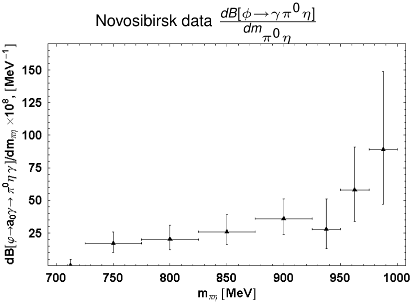
Novosibirsk data

the $e^+e^- \to \phi(1020) \to \pi^0\pi^0\gamma, \pi^0\eta\gamma$ events are convenient

The final photon may come only from the final state radiation (ϕ meson decay)



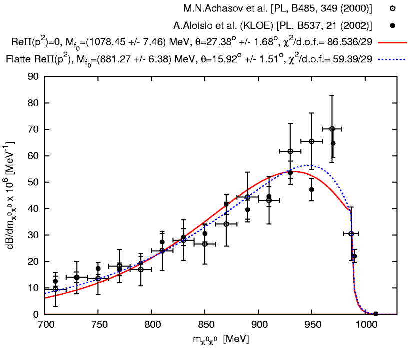
PL,B 440 (1998) 442; PL, B 485 (2000) 349



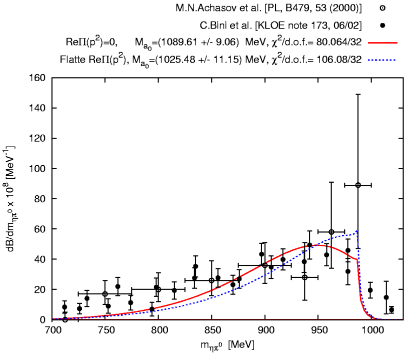
PL,B 479 (2000) 53

The analyses favor the kaon-loop mechanism for the ϕ decay

Our previous fit



data: [PL,B 440 (1998) 442; PL, B 485 (2000) 349]



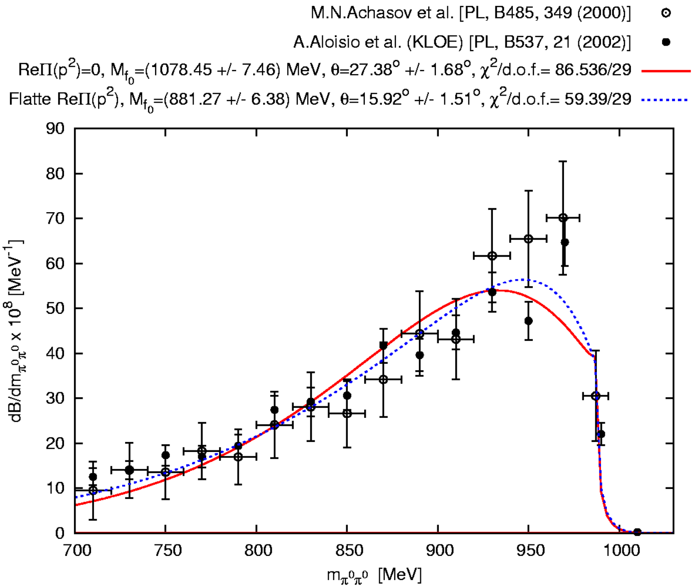
data: [PL,B 479 (2000) 53]

$$c_d = c_m = f_\pi/2 = 46.2 \text{ MeV}$$

to appear in Nucl. Phys. Proc. Suppl.

see also AIP Conf. Proc. **1030** (2008) 123; arXiv:0805.4088

$\pi^0\pi^0$ distribution: zoom



$\pi^0\pi^0$ and $\pi^0\eta$ distributions vs widths: summary

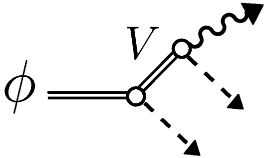
Pros of the distributions **+**

- much more sensitive to parameters of the model
- sensitive to momentum dependence of the vertices
- more reliable
  (widths depend on the model used in the data analysis)

Cons of the distributions **-**

- often available only as plots

Background is complicated!



Background channels

- $\phi \to \rho^0\pi^0 \to \pi^0\pi^0\gamma$,
- $\phi \to \omega\eta \to \eta\pi^0\gamma$,
- $\phi \to \rho^0\pi^0 \to \eta\pi^0\gamma$,
- other contributions . . .

A good option to fix model parameters and to test a model –
to put the model into MC generator for Dalitz plots and distributions analysis.