

The Ground Scalar Nonet in D Decays

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Based on hep-ph/0609062 (ICHEP06), Nucl. Phys. A790: 510, 2007,
Int. J. Mod. Phys. A22: 641, 2007

Motivation

- What is a light scalar meson?
 - Structure still controversial
 - $f_0(980)$, $a_0(980)$ mass degeneracy
 - Too many 0^{++} mesons below 2 GeV
 - ...

Our work: Make use of 3-body B and D decays to

- Test the quark structure of scalars
- Predict transition form factor Pseudo-scalar \rightarrow scalar
- Improve the Dalitz plot analysis

Outline

1

Scalar mesons

- $SU(3)$ nonet
- Experimental evidences
- Model

2

Results

- Application to the $f_0(980)$
- Generalization to the light scalars

3

Conclusion

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SU(3) nonet

From Particle Data Group...

$$\sigma : I^G(J^{PC}) = 0^+(0^{++})$$

$$(q\bar{q}) : 1/\sqrt{2}(u\bar{u} + d\bar{d})$$

mass 400 – 1200 MeV**width** 600 – 1000 MeV

$$\kappa : I(J^P) = \frac{1}{2}(0^+)$$

$$(q\bar{q}) : s\bar{u}, d\bar{s}, s\bar{d}, u\bar{s}$$

mass 672 ± 40 MeV**width** 550 ± 34 MeV

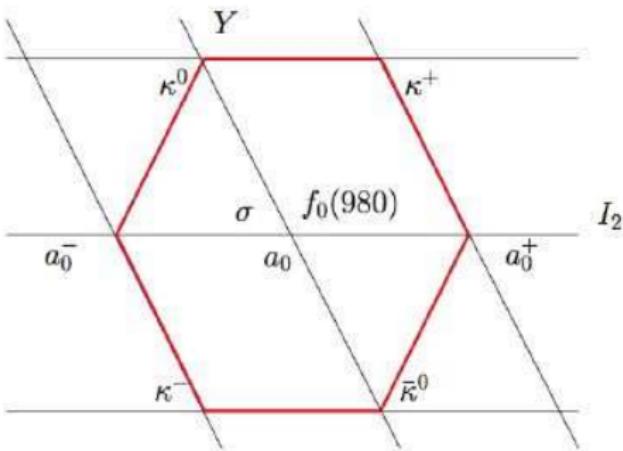
$$f_0 : I^G(J^{PC}) = 0^+(0^{++})$$

$$(q\bar{q}) : s\bar{s}$$

mass 980 ± 10 MeV**width** 40 – 100 MeV

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

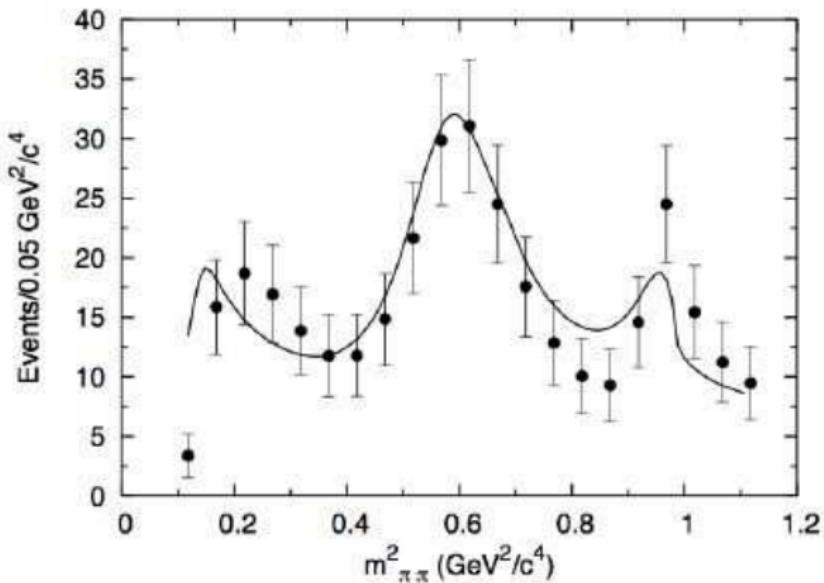
$$(q\bar{q}) : d\bar{u}, 1/\sqrt{2}(u\bar{u} - d\bar{d}), u\bar{d}$$

mass 985.1 ± 2.7 MeV**width** 50 – 100 MeV

Scalar mesons below 2 GeV

- They exist, experimentally
 - 2 isovectors : $a_0(980)$, $a_0(1450)$
 - 5 isoscalars :
 $f_0(600)/\sigma$, $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$
 - 3 isodoublets : $K_0^*(1430)$, $K_0^*(1950)$, $K_0^*(800)/\kappa$
- Too many !, theoretically
 - 1st nonet from 500 MeV to 1 GeV:
 $f_0(600)/\sigma$, $a_0(980)$, $K_0^*(800)/\kappa$, $f_0(980)$
 - 2nd nonet from 1 GeV to 2 GeV:
the others ...
- Properties
 - Light mass, broad width
 - Quark structure is a mixing of $q\bar{q}$, $(qq)(\bar{q}\bar{q})$, glueball states

Experimental evidences in D decay



- From $D^+ \rightarrow \pi^+\pi^-\pi^+$ decay: $f_0(600)/\sigma$ and $f_0(980)$

Experimental evidences

- **$s\bar{s}$ component in the $f_0(980)$ structure**

PDG: $Br(J/\Psi \rightarrow f_0(980)\phi) = (3.2 \pm 0.9) \times 10^{-4}$

DM2: $Br(J/\Psi \rightarrow f_0(980)\omega) = (1.4 \pm 0.5) \times 10^{-4}$

- **$(q\bar{q})$ or $(qq)(\bar{q}\bar{q})$ structure**

DAPΦNE: $Br(\phi \rightarrow \gamma f_0(980)) = (2.4 \pm 0.1) \times 10^{-4}$

DAPΦNE: $Br(\phi \rightarrow \gamma a_0) = (0.60 \pm 0.05) \times 10^{-4}$

- **$f_0(600)/\sigma$ existence**

E791: $D \rightarrow \sigma\pi \rightarrow 3\pi$

BES: $J/\psi \rightarrow \sigma\omega \rightarrow \pi\pi\omega$

CLEO: τ decay

- **$K^*(800)/\kappa$ existence**

E791: $D^+ \rightarrow K^-\pi^+\pi^+$

LASS: Elastic $K\pi$ scattering

Various theoretical models

- **($q\bar{q}$) state:** ($q\bar{q}$) L=0 nonet built on the ($q\bar{q}$) L=1 nonet
Nucl. Phys. A790: 510-513, 2007
- **($q\bar{q}$) state + glueball:** Lattice simulations
Phys. Rev. D72: 094006, 2005
- **$qq(\bar{q}\bar{q})$ state:** Two configurations in color space
Phys. Rev. D59: 074026, 1999
- **Chiralon model:** S-wave ($q\bar{q}$) bound states with $J^{PC} = 0^{++}$
AIP. Conf. Proc. 717: 717-725, 2004
- **Mesonic molecules:** A compact four quark state
J. Phys. G28: R249-R267, 2002

Our model

- Theoretical assumption: $(q\bar{q})$ state

$$\begin{aligned}|f_0(980)\rangle &= \frac{1}{\sqrt{2}}|u\bar{u} + d\bar{d}\rangle \sin \theta_m + |s\bar{s}\rangle \cos \theta_m \\ |q\bar{q}\rangle &\propto \alpha_q \exp[-\beta_q k^2]\end{aligned}$$

- Theoretical framework:
Weak Effective hamiltonian, QCD Factorization, FF $P \rightarrow S$ in CLFD
- Constraints:
 - Normalization
 - D branching ratios :
($u\bar{u}$) component: $D^+ \rightarrow f_0\pi^+$; $D^+ \rightarrow f_0K^+$; $D^0 \rightarrow \bar{K}^0$; $D^0 \rightarrow f_0\pi^0$
($s\bar{s}$) component: $D_S^+ \rightarrow f_0\pi^+$; $D_S^+ \rightarrow f_0K^+$
- Uncertainties:
 - Constituent quark model
 - From BES:

$$Br(f_0 \rightarrow \pi^+\pi^-) = 0.50 \pm 0.08 ; Br(f_0 \rightarrow K^+K^-) = 0.125 \pm 0.060$$

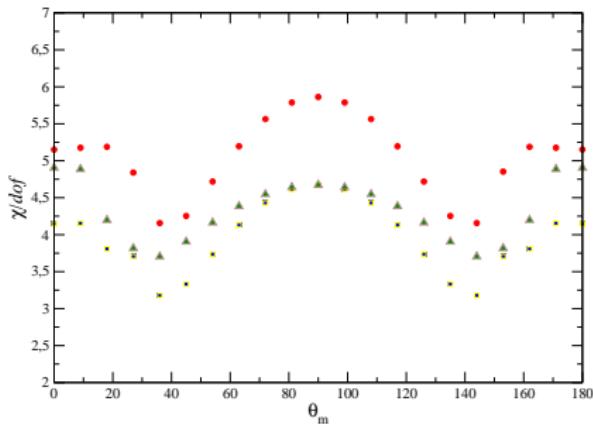
Application to the $f_0(980)$

Within the $q\bar{q}$ state approximation ...

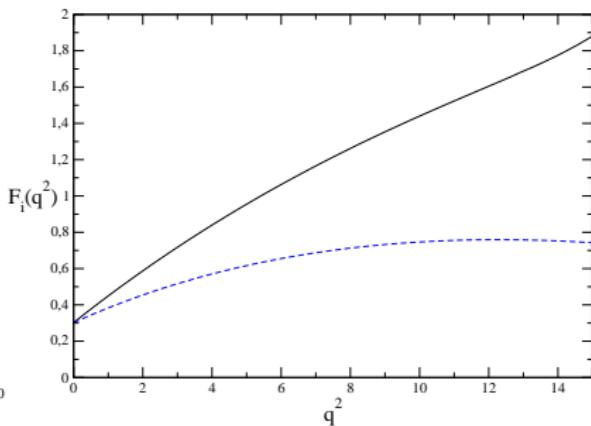
Channel	\mathcal{BR} Experiment	\mathcal{BR} Theory	χ^2
$D^+ \rightarrow f_0 \pi^+$	$(2.37 \pm 1.05) \times 10^{-4}$ (E791)	1.80×10^{-4}	0.28
$D^0 \rightarrow f_0 \bar{K}^0$	$(4.05 \pm 1.83) \times 10^{-3}$ (ARGUS)	3.24×10^{-5}	4.72
	$(3.12 \pm 1.42) \times 10^{-3}$ (CLEO)	3.24×10^{-5}	4.71
	$(1.09 \pm 1.02) \times 10^{-2}$ (BABAR)	3.24×10^{-5}	1.14
$D^+ \rightarrow f_0 K^+$	$(3.49 \pm 1.47) \times 10^{-4}$ (FOCUS)	5.63×10^{-6}	5.46
	$(7.65 \pm 5.90) \times 10^{-5}$ (FOCUS)	5.63×10^{-6}	1.44
$D_s^+ \rightarrow f_0 \pi^+$	$(4.45 \pm 2.90) \times 10^{-2}$ (E687)	6.05×10^{-3}	1.76
	$(7.13 \pm 3.37) \times 10^{-3}$ (E791)	6.05×10^{-3}	0.01
	$(6.36 \pm 2.88) \times 10^{-2}$ (FOCUS)	6.05×10^{-3}	3.99
	$(1.19 \pm 0.56) \times 10^{-2}$ (FOCUS)	6.05×10^{-3}	1.08
$D_s^+ \rightarrow f_0 K^+$	$(2.55 \pm 1.64) \times 10^{-3}$ (FOCUS)	1.00×10^{-3}	0.88
$D^0 \rightarrow f_0 \pi^0$	$(1.10 \pm 1.28) \times 10^{-6}$ (CLEO)	1.49×10^{-6}	0.09

Application to the $f_0(980)$

- θ_m mixing angle: $35^0 \pm 3^0$

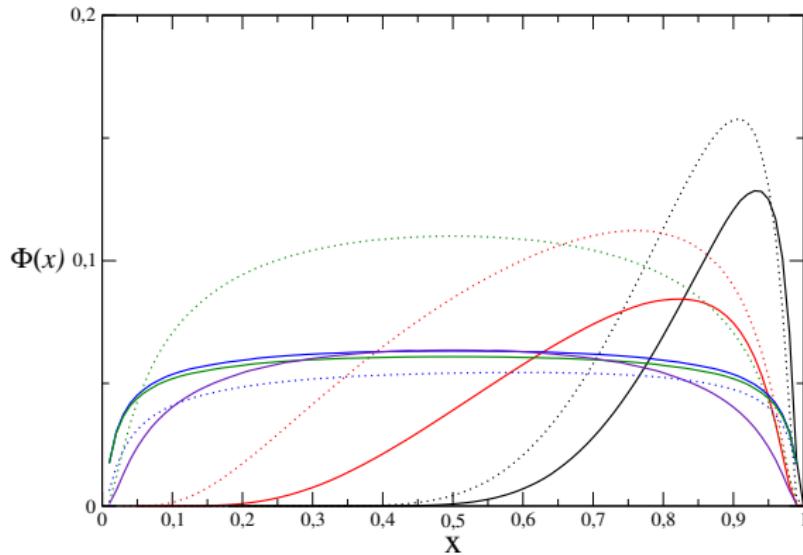


- Transition form factor
 $B \rightarrow f_0(980)$



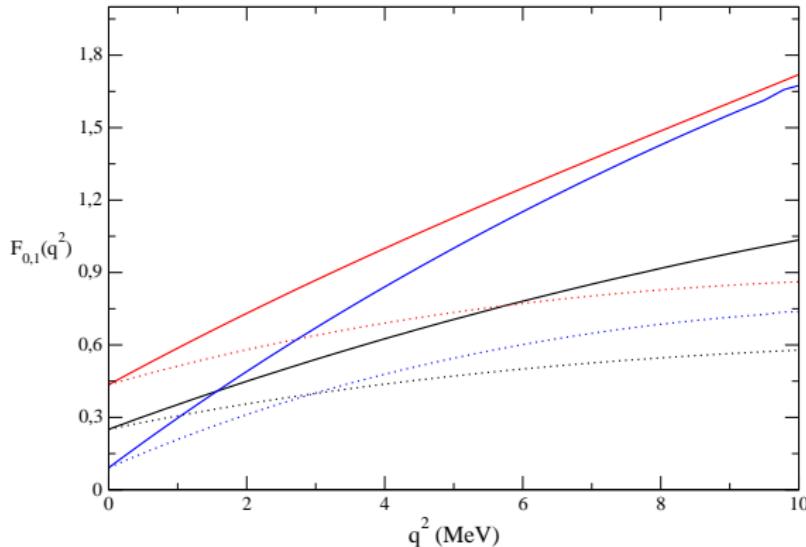
Naïve quark structure

- Wave function distributions for scalar mesons within the $(q\bar{q})$ state approximation...



Transition form factors

- Transition form factors $B \rightarrow S$, $S = \{\sigma, a_0^0, a_0^+\}$



Comments/Conclusion

- Assuming correct the ($q\bar{q}$) state description for scalar mesons:
 - Prediction to the transition form factors $B \rightarrow S$, $S = \{\sigma, \kappa, a_0, f_0\}$
 - Mixing angle between the ($u\bar{u}$) and ($s\bar{s}$) components for $\{\sigma, f_0\}$
 - Difficulties in reproducing the experimental D -branching ratios
- But scalar particles are
 - Not as simple as for the $L = 1$ nonet
 - A mixing of ($q\bar{q}$) and (qq)($\bar{q}\bar{q}$) states
- Better experimental D-data are expected to check the various theoretical models “on the market”

Scalar meson effects on direct CPV in B -decays

- **LHCb** Monte-carlo simulations of direct CP violation in $B^- \rightarrow \pi^+ \pi^- K^-$: huge contribution of scalar mesons...

