



SMR.1751 - 45

Fifth International Conference on
PERSPECTIVES IN HADRONIC PHYSICS
Particle-Nucleus and Nucleus-Nucleus Scattering at Relativistic Energies

22 - 26 May 2006

New Hadrons as four-quark states

Fulvio PICCININI
Universita' di Pavia & INFN
Dipartimento di Fisica Nucleare-Teorica
Via Bassi 6
27100 Pavia
ITALY

These are preliminary lecture notes, intended only for distribution to participants

Fulvio Piccinini

INFN Sezione di Pavia and

Dip. di Fisica Nucleare e Teorica, Univ. di Pavia

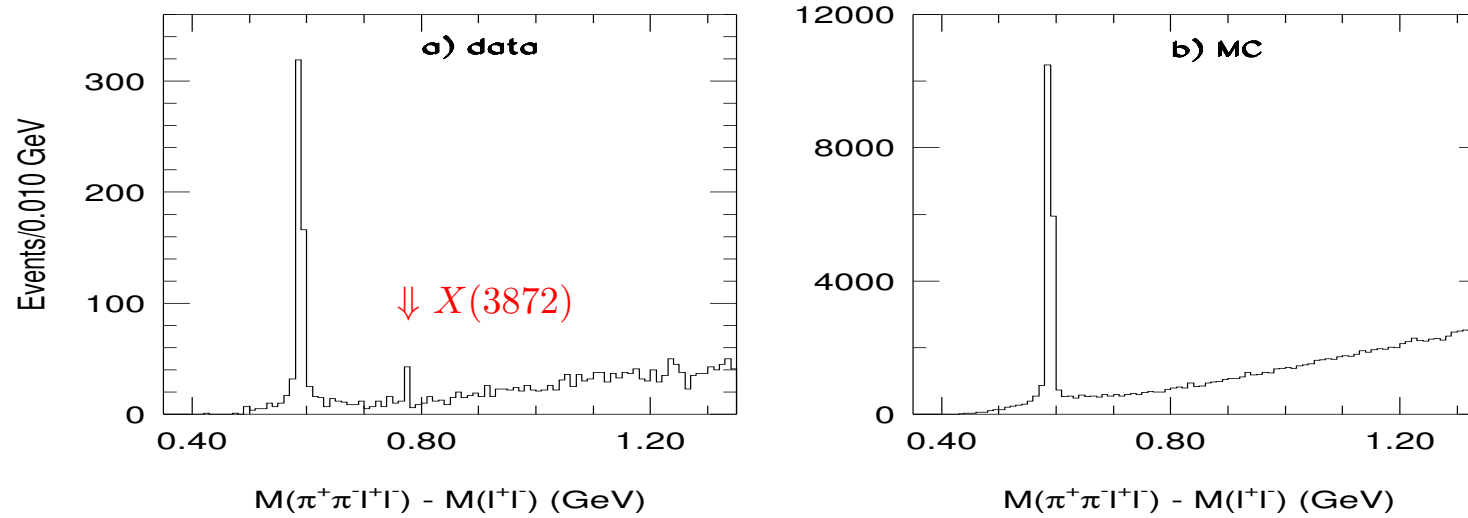
New Hadrons as four-quark states

in collaboration with L. Maiani, A.D. Polosa and V. Riquer

- Experimental data at energies around 4 GeV
- Possible interpretations of new states:
 1. Charmonium
 2. Hadronic molecules
 3. Hybrids
 4. Multiquarks
- Down to $m < 1$ GeV: the problem of scalar mesons
- 4q states as diquark-antidiquark bound states
- A model

Experimental facts

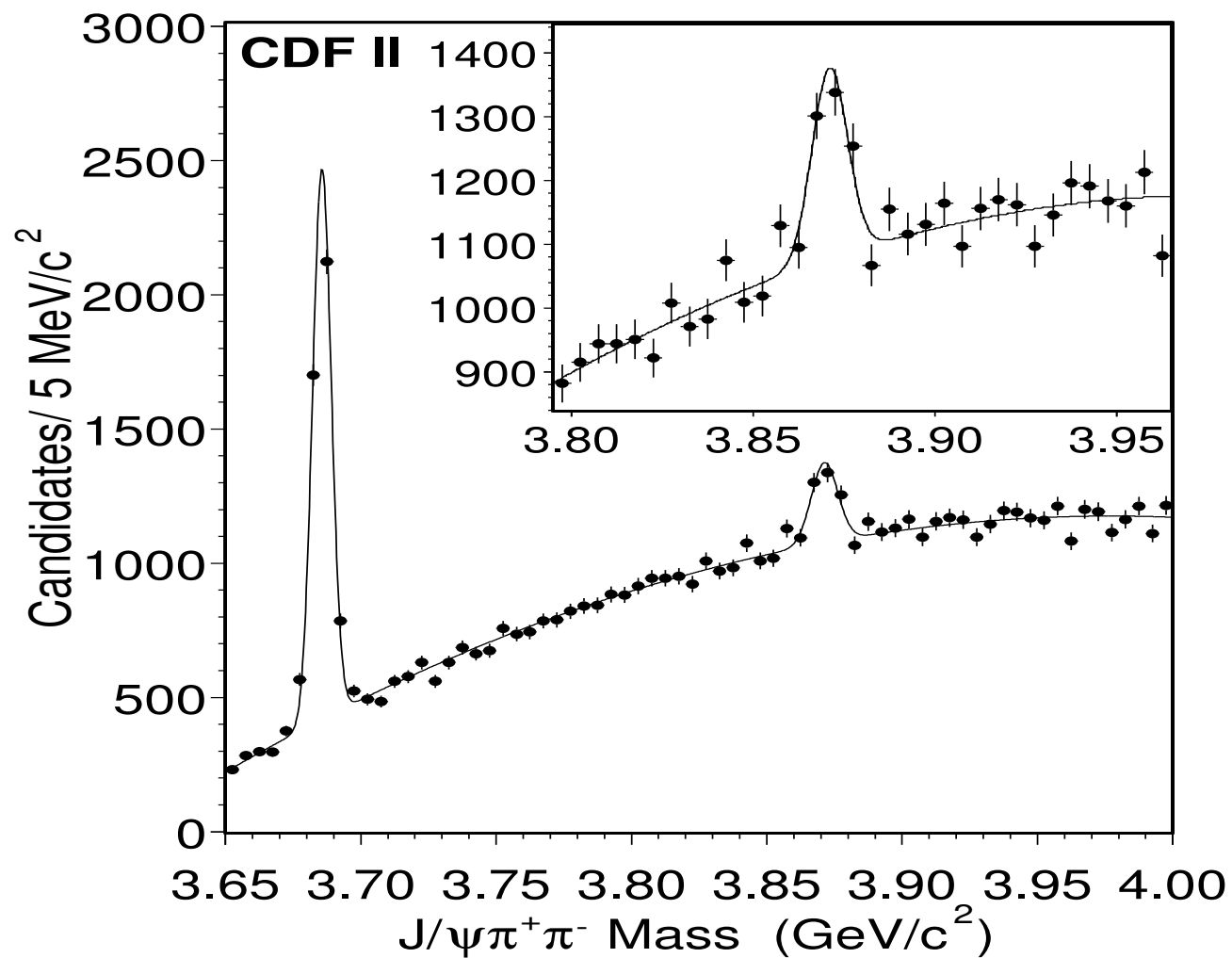
Discovery at Belle of a new state in $B^+ \rightarrow K^+ X \rightarrow K^+ \pi^+ \pi^- J/\Psi$



S.-K. Choi et al., (Belle Coll.), Phys. Rev. Lett. **91** (2003) 262001

mass (MeV)	width	production/decay mode	events	signif.	exp.
$3872.0 \pm 0.6 \pm 0.5$	< 2.3 90% C.L.	$B^\pm \rightarrow K^\pm X \rightarrow K^\pm \pi^+ \pi^- J/\psi$	25.6 ± 6.8	10σ	Belle
$3871.3 \pm 0.7 \pm 0.4$	resolution	$p\bar{p} \rightarrow X \rightarrow \pi^+ \pi^- J/\psi$	730 ± 90	11.6σ	CDFII
$M(J/\psi) + 774.9 \pm 3.1 \pm 3.0$	resolution	$p\bar{p} \rightarrow X \rightarrow \pi^+ \pi^- J/\psi$	522 ± 100	5.2σ	DØ
3873.4 ± 1.4	—	$B^- \rightarrow K^- X \rightarrow K^- \pi^+ \pi^- J/\psi$	25.4 ± 8.7	3.5σ	BaBar

$X(3872)$ at CDF



D. Acosta et al., CDF II Coll., Phys. Rev. Lett. **93** (2004) 072001

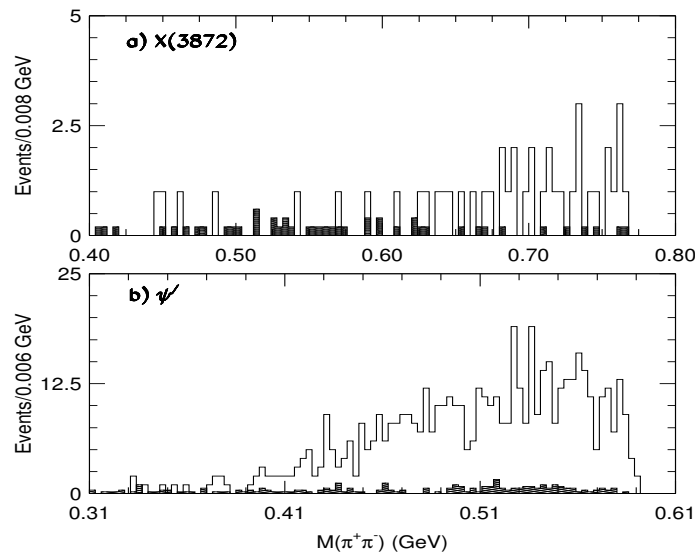
$X(3872)$ properties

$$Br(B^+ \rightarrow XK^+)Br(X \rightarrow \pi\pi J/\psi) = (1.01 \pm 0.25 \pm 0.10) \cdot 10^{-5}$$

$$\frac{\Gamma(X \rightarrow \pi^+\pi^-\pi^0 J/\psi)}{\Gamma(X \rightarrow \pi^+\pi^- J/\psi)} = 1.0 \pm 0.4 \pm 0.3 \Rightarrow \text{Isospin breaking}$$

$$\frac{\Gamma(X \rightarrow \gamma J/\psi)}{\Gamma(X \rightarrow \pi^+\pi^- J/\psi)} = 0.14 \pm 0.05 \quad \text{radiative decay suppressed}$$

$$\Gamma(X \rightarrow D^0 \bar{D}^0 \pi^0) \geq 10\Gamma(X \rightarrow J/\psi \pi \pi)$$



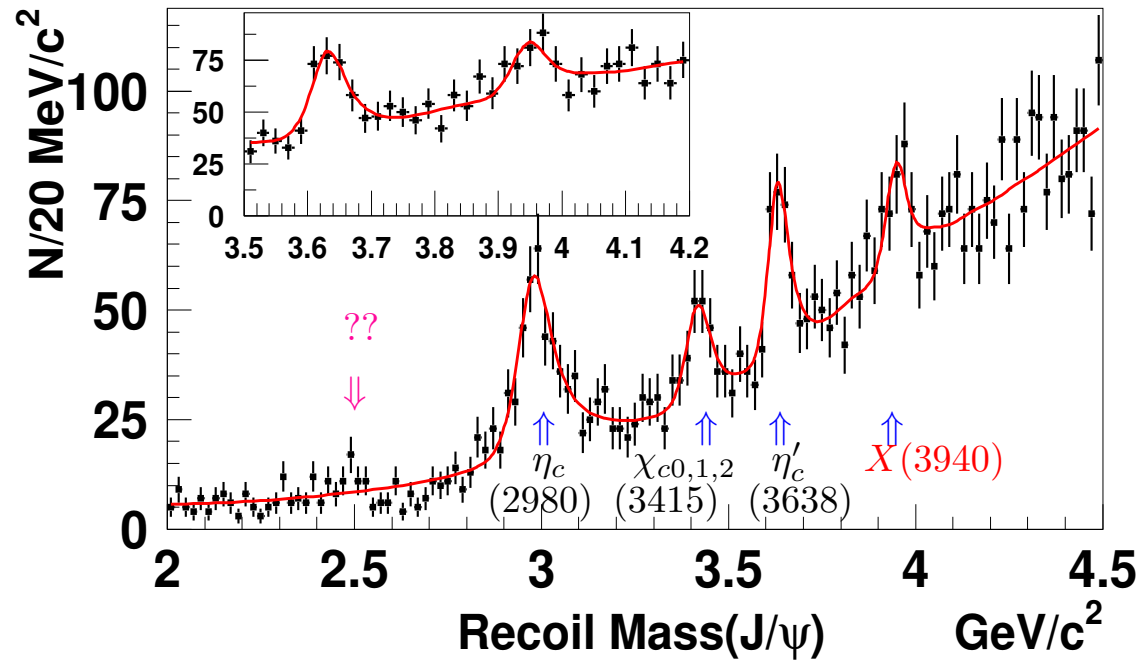
Not seen in direct production

at BES and BABAR (radiative return)

$$\Gamma(X \rightarrow e^+e^-) \cdot Br(X \rightarrow J/\psi \pi^+ \pi^-) < 6.2 \text{ eV}$$

$X(3940)$ at Belle

$$e^+e^- \rightarrow J/\Psi + X$$



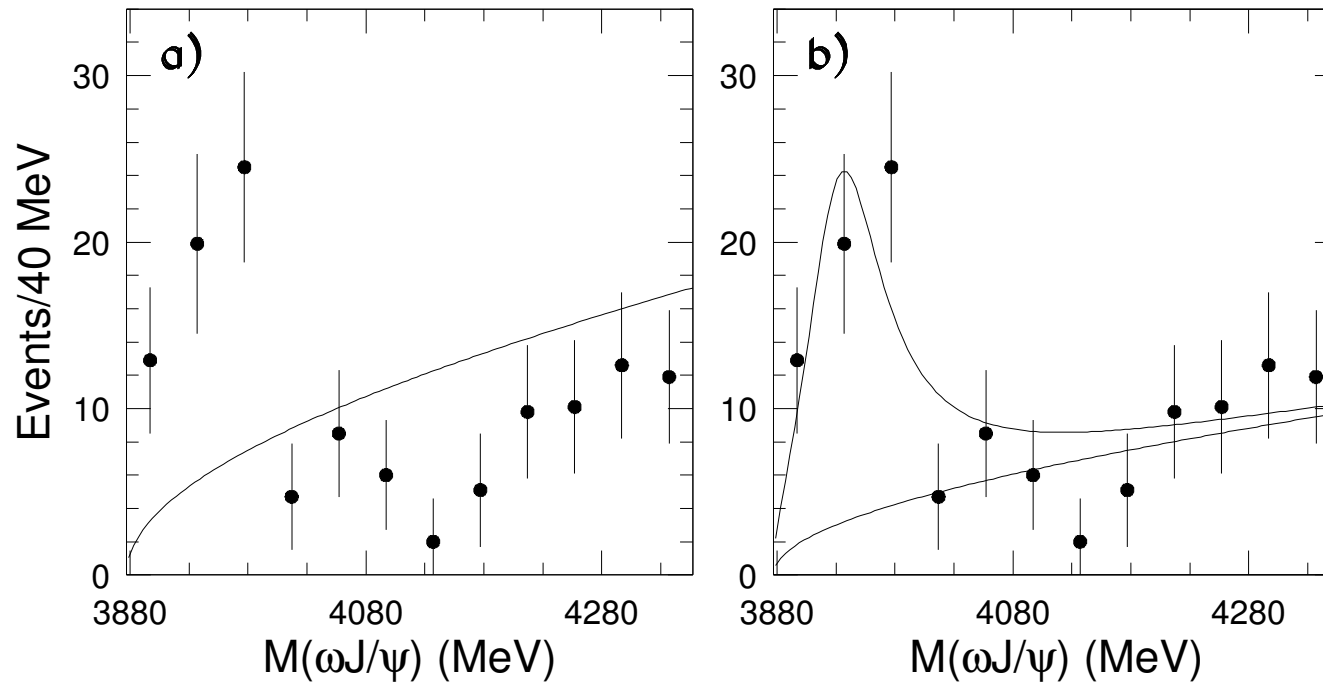
K. Abe et al. (Belle Coll.), hep-ex/0507019

$$M_X = 3943 \pm 6 \pm 6 \text{ MeV}, \quad \Gamma_X < 52 \text{ MeV at } 90\% \text{ c.l.}$$

$$X \rightarrow D\bar{D}^* \text{ and not } X \rightarrow D\bar{D}, \quad X \rightarrow J/\psi\omega$$

$Y(3940)$ at Belle

$$B \rightarrow KY \rightarrow K\pi\pi\pi J/\Psi$$



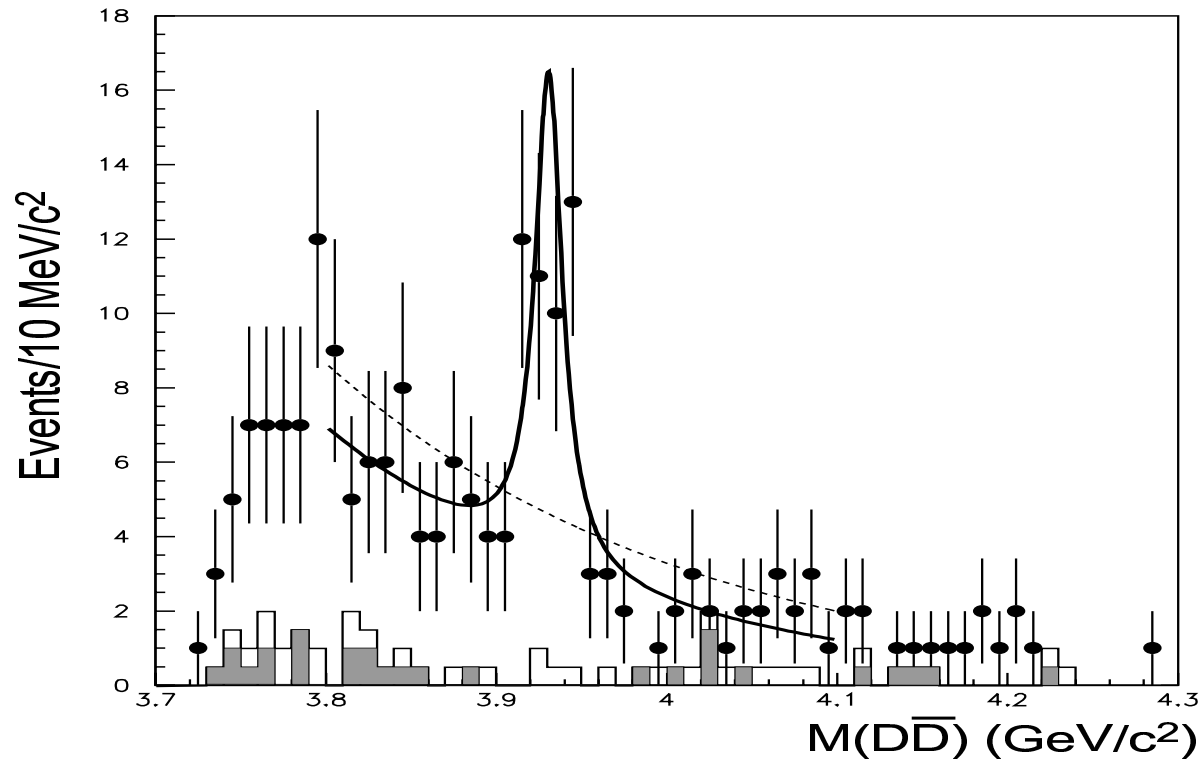
S.K. Choi et al. (Belle Coll.), Phys. Rev. Lett. **94** (2005) 182002

$$M_Y = 3943 \pm 11 \pm 13 \text{ MeV}, \quad \Gamma_Y = 87 \pm 22 \pm 26 \text{ MeV} \quad 58 \pm 11 \text{ evts}, 8\sigma$$

not $Y \rightarrow D\bar{D}^*$ and not $X \rightarrow D\bar{D}$

$Z(3930)$ at Belle

$$\gamma\gamma \rightarrow D\bar{D}$$

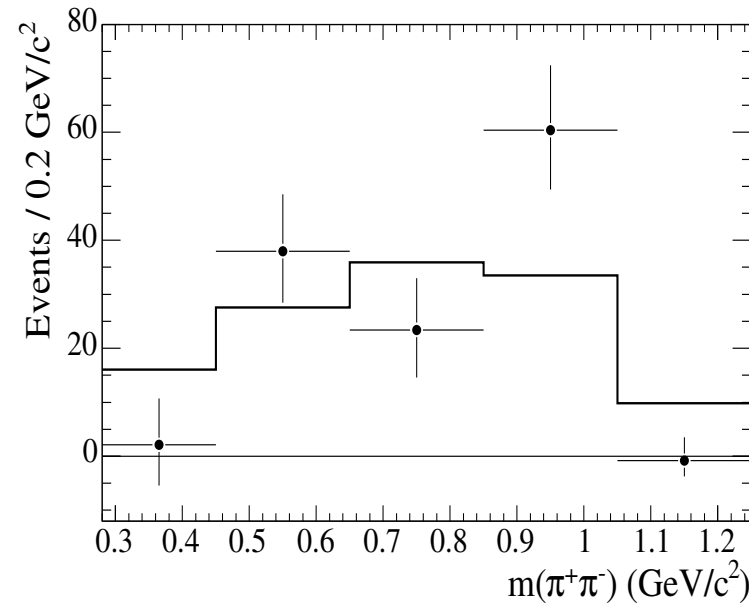
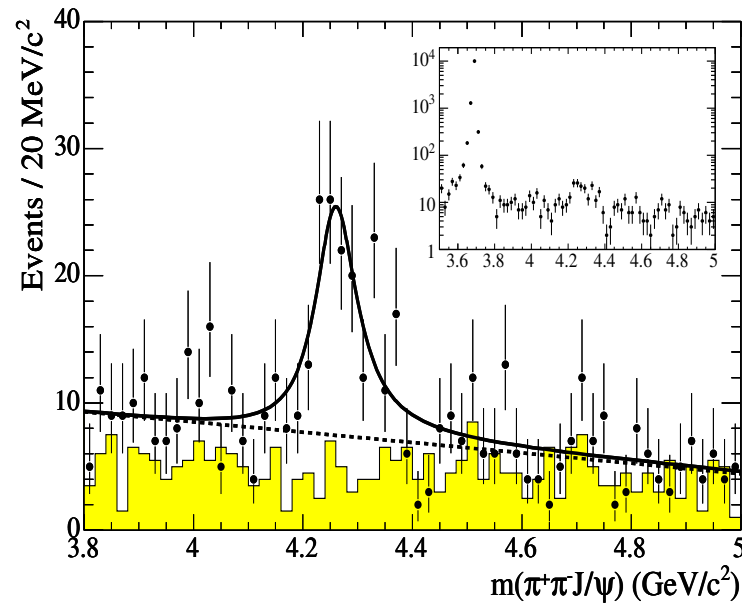


K. Abe et al. (Belle Coll.), hep-ex/0507033; S. Uehara et al. (Belle Coll.), hep-ex/0512035

$$M_Z = 3931 \pm 4 \pm 2 \text{ MeV}, \quad \Gamma_Z = 20 \pm 8 \pm 3 \text{ MeV} \quad 5.5\sigma$$

$Y(4260)$ at BaBar

$$e^+e^- \rightarrow \gamma_{\text{ISR}} Y \rightarrow \gamma_{\text{ISR}} J/\psi \pi\pi$$

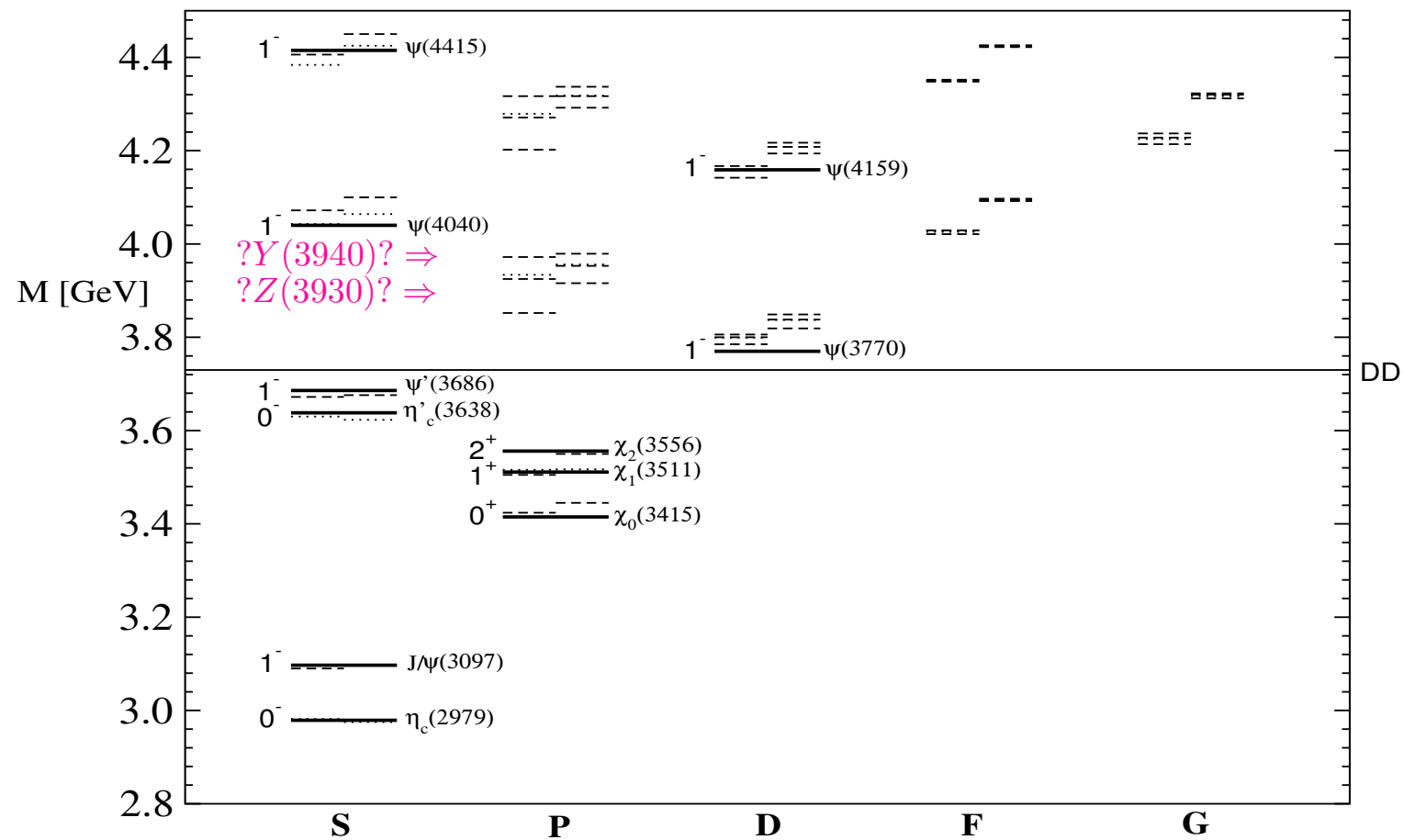


B. Aubert et al. (BaBar Coll.), Phys. Rev. Lett. **95** (2005) 142001

$$M_Z = 4259 \pm 8 \pm 4 \text{ MeV}, \quad \Gamma_Z = 88 \pm 23 \pm 5 \text{ MeV} \quad 125 \pm 23 \text{ evts}, 5.5\sigma$$

$$\Gamma(Y \rightarrow e^+e^-)\text{Br}(Y \rightarrow J/\psi\pi\pi) = 5.5 \pm 1.0^{+0.8}_{-0.7} \text{ eV}$$

Minimal hypothesis: are these states charmonium excitations?



Molecular interpretation

e.g. E.S. Swanson, Phys. Lett. **B588** (2004) 189

Average $X(3872)$ mass: 3872.0 ± 1.8 MeV

$$M(D^0) + M(\bar{D}^{0*}) = 3871.2 \pm 1.0 \text{ MeV}$$

$X(3872)$ as a loosely bound state $D^0\bar{D}^{0*}$ (S -wave) held together by π exchange and also quark exchange

good prediction:

$$\frac{BR(X \rightarrow J/\psi\rho)}{BR(X \rightarrow J/\psi\omega)} \simeq 1$$

while

$$\frac{BR(X \rightarrow D^0\bar{D}^0\pi^0)}{BR(X \rightarrow D^0\bar{D}^0\gamma)} \simeq \frac{62}{38}$$

Hybrids

Also bound configurations of the kind $q\bar{q}g$ are allowed in QCD

For $c\bar{c}g$ lattice QCD predicts lowest mass in the range 4200-4400 MeV, thus leaving only $Y(4260)$ as a candidate

X. Liao, T. Manke, hep-lat/0210030

F. Close, P.R. Page, hep-ph/0507199

states of definite isospin $I = 0$

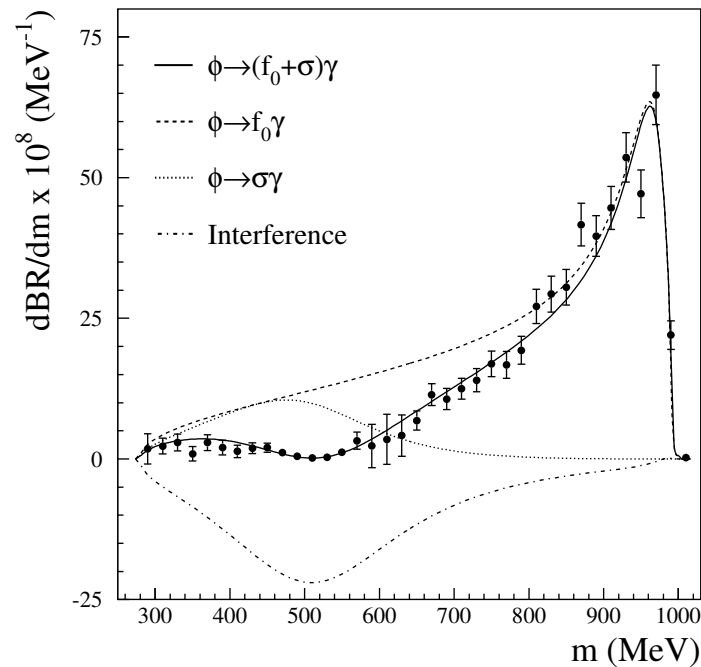
Multi-quark states: a look down to 1 GeV

- $f(980)$, ($I = 0$)
- $a(980)$, ($I = 1$) (also named δ)
- four $K\pi$ states, $\kappa(800)$ or $K_0^*(800)$, ($I = 1/2$) nature of these resonances still controversial
- $\sigma(450)$ (also $f_0(600)$) ($I = 0$)
 $\pi\pi$ s -wave resonance

$$M_\sigma = 478_{-17}^{+24} \pm 17 \text{ MeV}$$

$$\Gamma_\sigma = 324_{-40}^{+42} \pm 21 \text{ MeV}$$

KLOE Coll., Phys. Lett. **B537** (2002) 21



Are light scalar mesons hints of exotic states?

Are qqq and $q\bar{q}$ the only binding configurations according to QCD?

“Baryons can now be constructed from quarks by using the combinations (qqq) , $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. It is assuming that the lowest baryon configuration (qqq) gives just the representations **1**, **8**, and **10** that have been observed, while the lowest meson configuration $(q\bar{q})$ similarly gives just **1** and **8**.”

M. Gell-Mann, Phys. Lett. **8**(1964) 214

1977 first attempt to interpret scalar mesons as tetraquark $(qq\bar{q}\bar{q})$
bound states

R.L. Jaffe, Phys. Rev. **D15** (1977) 281

but: colour neutrality $\Rightarrow \mathbf{3}_c \otimes \bar{\mathbf{3}}_c \otimes \mathbf{3}_c \otimes \bar{\mathbf{3}}_c = \mathbf{81}$ particles ...

Where are they?

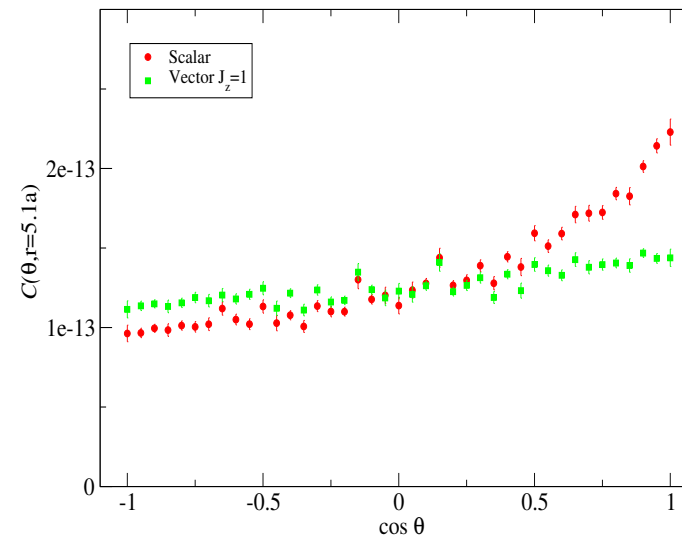
The problem is evaded if we have binding configurations of the type qq and $\bar{q}\bar{q}$: **diquarks**, coloured objects, which don't leave freely

R.L. Jaffe and F. Wilczek, Phys. Rev. Lett. **91** (2003) 232003

The colour correlation between two quarks in the diquark should limit the number of possible states

$$\mathbf{3}_c \otimes \mathbf{3}_c = \bar{\mathbf{3}}_c \oplus \mathbf{6}_c, \bar{\mathbf{3}}_c \text{ attractive}, \mathbf{6}_c \text{ repulsive}$$

From **Lattice QCD** studies spin **0** configuration energetically preferred



C. Alexandrou, P. DeForcrand and B. Lucini, hep-lat/0509113

Fermi-Dirac statistics imposes, for a common spatial configuration, antisymmetric flavour wave-function

The most energetically favoured configuration is $[qq]\bar{\mathbf{3}}_c\mathbf{1}_s\bar{\mathbf{3}}_f$

But $\bar{\mathbf{3}}_f$ (and $\mathbf{3}_f$ for $[\bar{q}\bar{q}]$) gives rise to $\mathbf{1} \oplus \mathbf{8} \Rightarrow 9$ scalar states...

Cryptoexotic states

The fully antisymmetric quantum numbers of diquarks come directly from the “colorspin” interaction of QCD

$$\mathcal{H}_{\text{eff}} \propto - \sum_{i \neq j} \lambda_i \cdot \lambda_j \vec{\sigma}_i \cdot \vec{\sigma}_j = 4P_{12}^F + \frac{4}{3}P_{12}^S + 2P_{12}^C - \frac{2}{3}$$

P_{12}^X are C , F , S exchange operator with eigenvalue $(-)+1$ for states (anti)symmetric under exchange

	Flavor	Spin	Color	ΔE
most binding configuration $\rightarrow$	$\bar{3}(A)$	$1(A)$	$\bar{3}(A)$	-8
	$\bar{3}(A)$	$3(S)$	$6(S)$	$-4/3$
	$6(S)$	$3(S)$	$\bar{3}(A)$	$8/3$
	$6(S)$	$1(A)$	$6(S)$	4

R.L. Jaffe, hep-ph/0001123

Another way is to consider the Casimir $\mathbf{T}^2$ of the product of representations: $4/3$ in $\bar{\mathbf{3}}$ and $10/3$ in $\mathbf{6}$

Quantum numbers assignment

L. Maiani, F.P., A.D. Polosa and V. Riquer, Phys. Rev. Lett. **93** (2004) 212002

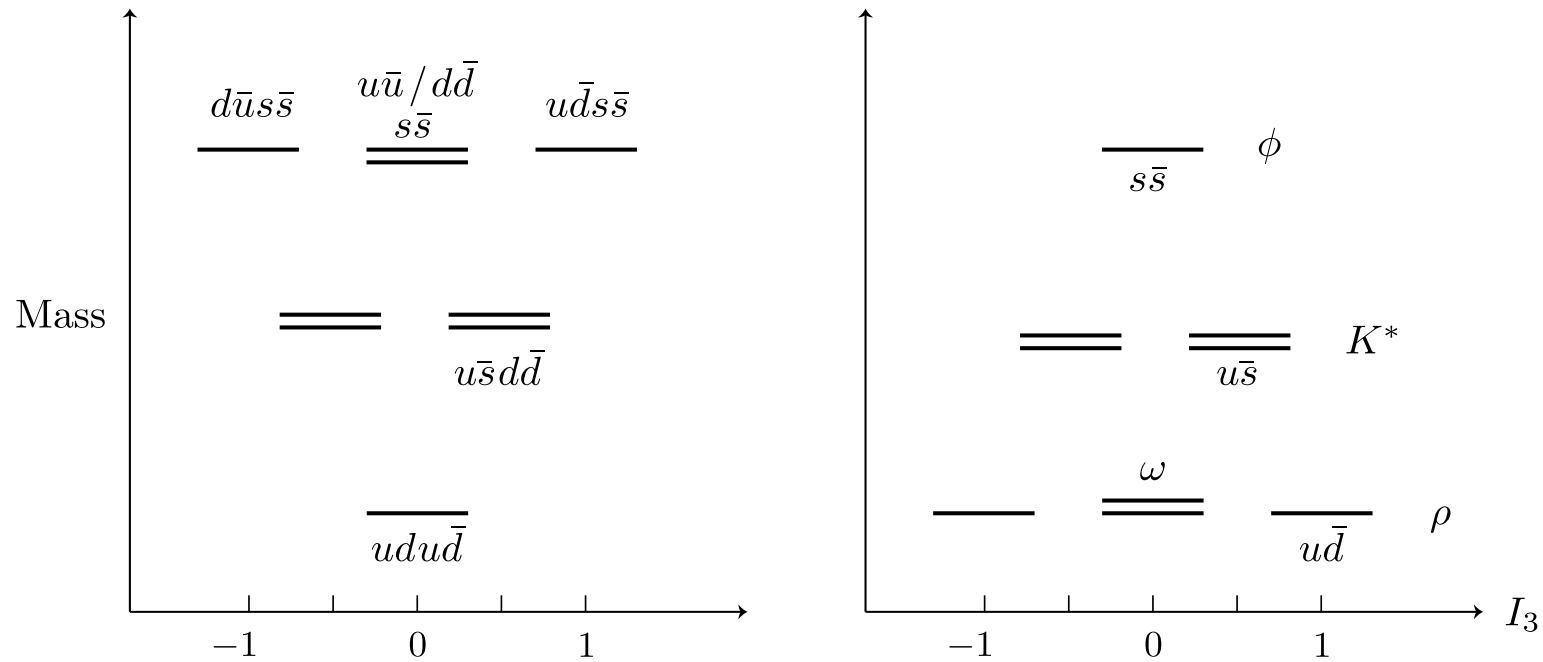
$[q_1 q_2]$: fully antisymmetric diquark

$$\begin{aligned}a^+(I = 1, I_3 = +1, S = 0) &= [su][\bar{s}\bar{d}] \\a^0(I = 1, I_3 = 0, S = 0) &= \frac{1}{\sqrt{2}} ([su][\bar{s}\bar{u}] - [sd][\bar{s}\bar{d}]) \\a^-(I = 1, I_3 = -1, S = 0) &= [sd][\bar{s}\bar{u}] \\f_\circ(I = 0, S = 0) &= \frac{1}{\sqrt{2}} ([su][\bar{s}\bar{u}] + [sd][\bar{s}\bar{d}]) \\\sigma_\circ(I = 0, S = 0) &= [ud][\bar{u}\bar{d}] \\\kappa(I = 1/2, I_3 = +1/2, S = +1) &= [ud][\bar{s}\bar{d}] \\\kappa(I = 1/2, I_3 = -1/2, S = +1) &= [ud][\bar{s}\bar{u}] \\\kappa(I = 1/2, I_3 = +1/2, S = -1) &= [us][\bar{d}\bar{u}] \\\kappa(I = 1/2, I_3 = -1/2, S = -1) &= [ds][\bar{d}\bar{u}]\end{aligned}$$

$f_\circ$ and $\sigma_\circ$ are states with definite composition in strange quark pairs

$$\begin{aligned}|f\rangle &= \cos \phi |f_\circ\rangle + \sin \phi |\sigma_\circ\rangle \\|\sigma\rangle &= -\sin \phi |f_\circ\rangle + \cos \phi |\sigma_\circ\rangle\end{aligned}$$

Inverted mass spectrum of a $(q)^2(\bar{q})^2$ nonet w.r.t. to a $q\bar{q}$ nonet



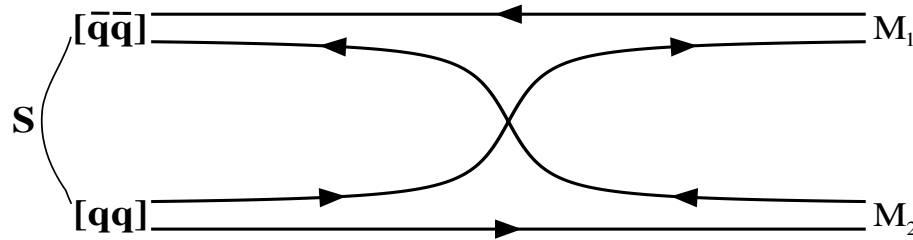
$I = 0$ state is the lightest one

a strong indication in favour of the four-quark nature of the scalar nonet

Strong decays

Being diquarks $\bar{\mathbf{3}}_c$, natural decays of scalar mesons would be dissociation into baryon-antibaryon pairs, but too high thresholds

Alternative mechanism: a quark-antiquark pair is switched between the members of the pair, to form a pair of colourless $q - \bar{q}$ states, which can indefinitely separate from each other. The lightest decay channel is a pair of pseudoscalar mesons. In the exact $SU(3)$ limit there is only one amplitude, $\mathcal{A}$, to describe this process



$\mathcal{A}$ (assumed flavour independent) describes the tunneling from the bound diquark pair to the unbound meson-meson pair

$$a^+ = [su]_{\bar{\mathbf{3}}_c} [\bar{s}d]_{\mathbf{3}_c} \rightarrow (s\bar{d})_{1_c} (\bar{s}u)_{1_c} - (s\bar{s})_{1_c} (\bar{d}u)_{1_c} = \bar{K}^0 K^+ - \pi^+ \eta_s$$

$$\text{Ampl.}(a^+ \rightarrow \bar{K}^0 K^+) = \mathcal{A};$$

$$\text{Ampl.}(a^+ \rightarrow \pi^+ \eta) = \left(-\sqrt{\frac{2}{3}} \cos \phi_{PS} + \sqrt{\frac{1}{3}} \sin \phi_{PS} \right) \mathcal{A} \simeq -0.69 \mathcal{A}$$

The model can be further tested at the 2006 run of DAΦNE at $\sqrt{s} = 1 \text{ GeV}$

Data taking started at the beginning of this year

Process to look for:

$e^+e^- \rightarrow e^+e^-\pi^0\pi^0$, which is mediated by two quasi-real photons:

$$\gamma\gamma \rightarrow \pi^0\pi^0$$

the initial state photons can interact (via VMD) with the σ and subsequently decay to $\pi^0\pi^0$.

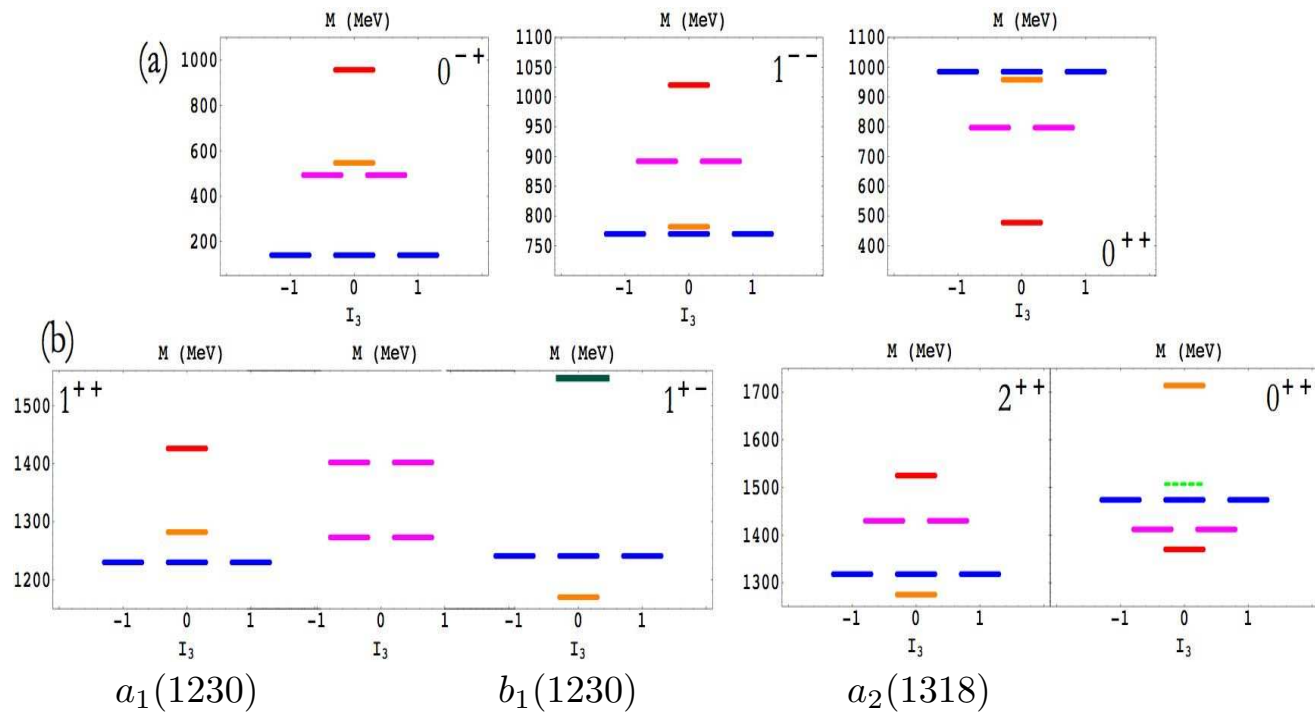
There is some hope to distinguish this signal from ChPT predictions for $\gamma\gamma \rightarrow \pi^0\pi^0$

in collaboration with F. Nguyen and A.D. Polosa

Very high resolution on γ 's from π_0 's and possibly small angle detectors for forward electron tagging would be very useful

Positive parity scalar states between 1 and 2 GeV

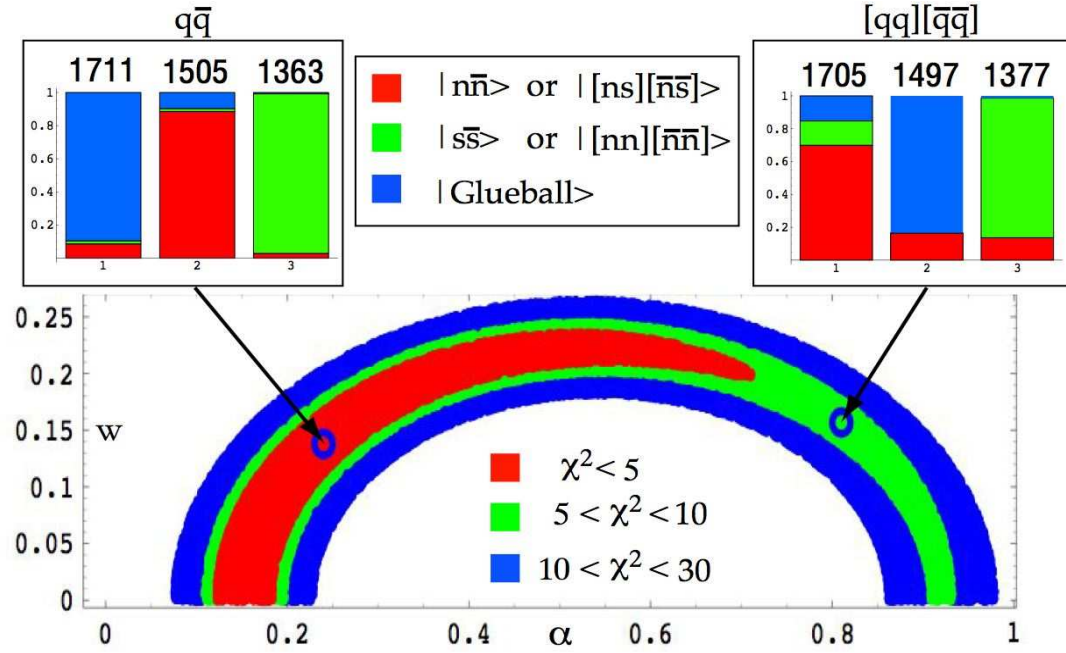
decuplet: $f_0(1370)$, $f_0(1500)$, $f_0(1710)$, $K_0(1412)$, $a_0(1474)$



L. Maiani, F.P., A.D. Polosa and V. Riquer, hep-ph/0604018

Problems with 0^{++} assignment as P -wave $q\bar{q}$ nonet (+ glueball):

- spin-orbit couplings $\Rightarrow m(2^{++}) \geq m(1^{++}) \geq m(0^{++})$
- inverted mass spectrum



		$\mathcal{B}_{\pi\pi}/\mathcal{B}_{KK}[f_0(1710)]$	$\mathcal{B}_{KK}/\mathcal{B}_{\pi\pi}[f_0(1500)]$	$\mathcal{B}_{KK}/\mathcal{B}_{\pi\pi}[f_0(1370)]$
	no form factor	0.5	0.18	0.14
$[qq][\bar{q}\bar{q}]$	$\beta = 400$ MeV	0.42	0.23	0.17
	$\beta = 240$ MeV	0.31	0.32	0.23
$q\bar{q}$	no form factor	0.24	0.42	22
Expt.		$< 0.11^a, 0.24^b \pm 0.024 \pm 0.036$	0.246 ± 0.026	$0.1^c - 0.9^d$

A natural extension of the model is the inclusion of diquarks involving one or more heavy constituents

$([cq][\bar{c}\bar{q}'])$ and $([cq][\bar{s}\bar{q}'])$, with $q, q' = u, d$

assuming $[cq]$ is binding

L. Maiani, F.P., A.D. Polosa and V. Riquer, Phys. Rev. **D70** (2004) 054009; **D71** (2005) 014028

For $[cq][\bar{c}\bar{q}]$ the near spin independence of heavy quark interactions (exact in the limit $m_c \rightarrow \infty$) implies the presence of both spin zero and spin one diquarks.

As a consequence a rich spectrum is implied, with states with $J = 0, 1, 2$ and both natural and unnatural J^{PC}

We describe the mass spectrum in terms of

1. constituent diquark masses
2. spin-spin interactions, whose strength is derived from known meson and baryon masses when possible or from educated guesses from one-gluon exchange otherwise

In the **constituent quark model** the hadron masses depend on

- quark composition
- constituent quark masses
- spin-spin interactions

$$H = \sum_i m_i + \sum_{i < j} 2\kappa_{ij}(S_i \cdot S_j)$$

A. De Rujula, H. Georgi and S.L. Glashow, Phys. Rev. Lett. **38** (1977) 317

Phys. Rev. **D12** (1975) 147

κ_{ij} depend on the flavour of constituents and on the colour state of the pair

For instance, for the $L = 0$ mesons K and K^*

$$M = m_q + m_s + \kappa_{s\bar{q}} \left[J(J+1) - \frac{3}{2} \right]$$

Baryon masses allow to obtain q-q spin interaction in $\bar{\mathbf{3}}_c$

We find for the diquark masses:

$$\begin{aligned}
m_{[ud]} &= 395\text{MeV} \\
m_{[sq]} &= 590\text{MeV} \\
m_{[cq]} &= 1933\text{MeV}
\end{aligned}$$

and for the couplings

	$q\bar{q}$	$s\bar{q}$	$s\bar{s}$	$c\bar{q}$	$c\bar{s}$	$c\bar{c}$
$(\kappa_{ij})_{\mathbf{0}}$ (MeV)	315	195	121*	70	72	59
$(\kappa_{ij})_{\mathbf{0}}m_im_j(\text{GeV})^3$	0.029	0.029		0.036	0.059	0.16

	qq	sq	cq	cs
$(\kappa_{ij})_{\mathbf{\bar{3}}}$ (MeV)	103	64	22	25
$(\kappa_{ij})_{\mathbf{\bar{3}}}m_im_j(\text{GeV})^3$	0.014	0.013	0.014	0.024

Hamiltonians to diagonalize

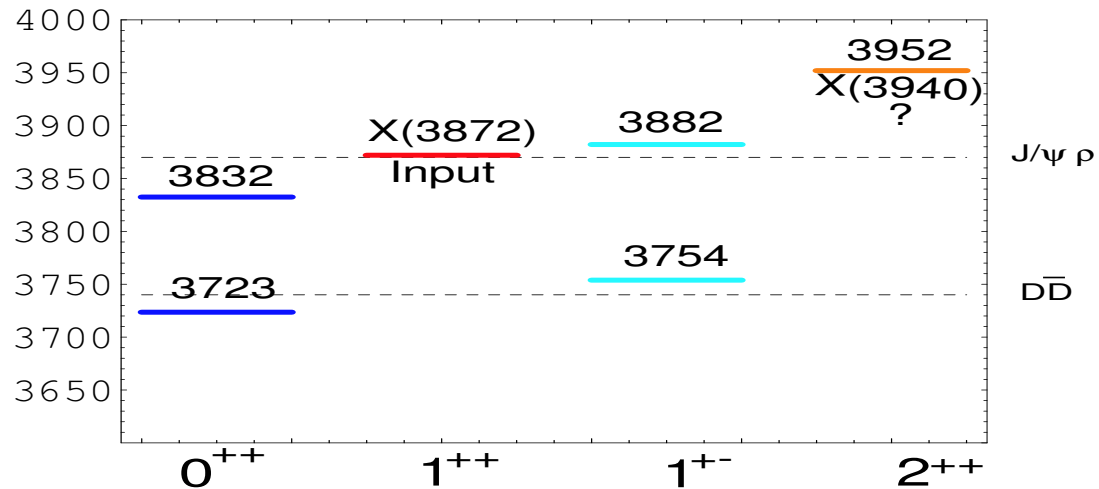
For $[cq][\bar{c}\bar{q}']$ diquarks

$$\begin{aligned} H = 2m_{[cq]} &+ 2(\kappa_{cq})\bar{\mathbf{3}}[(S_c \cdot S_q) + (S_{\bar{c}} \cdot S_{\bar{q}']) \\ &+ 2\kappa_{q\bar{q}}(S_q \cdot S_{\bar{q}']) \\ &+ 2\kappa_{c\bar{q}}[(S_c \cdot S_{\bar{q}']) + (S_{\bar{c}} \cdot S_q)] \\ &+ 2\kappa_{c\bar{c}}(S_c \cdot S_{\bar{c}}) \end{aligned}$$

For $[cq][\bar{s}\bar{q}']$ diquarks

$$\begin{aligned} H = 2m_{[cs]} &+ 2(\kappa_{sq})\bar{\mathbf{3}}[(S_s \cdot S_q) + (S_{\bar{s}} \cdot S_{\bar{q}']) \\ &+ 2\kappa_{q\bar{q}}(S_q \cdot S_{\bar{q}']) \\ &+ 2\kappa_{s\bar{q}}[(S_s \cdot S_{\bar{q}']) + (S_{\bar{s}} \cdot S_q)] \\ &+ 2\kappa_{s\bar{s}}(S_s \cdot S_{\bar{s}}) \end{aligned}$$

Full spectrum for X particles



1^{++} good candidate to be identified with the $X(3872)$ of $B^{+,0} \rightarrow K^{+,0} X$

$(cq)_{S=1}[\bar{c}\bar{q}]_{S=0} + [cq]_{S=0}(\bar{c}\bar{q})_{S=1}$

- expected to be narrow, below the baryon-antibaryon threshold
- unnatural spin-parity forbids the decay in $D\bar{D}$ (not observed)
- consistent with observed decays in J/Ψ + light vector mesons
- Due to isospin breaking it decays in both ρ and ω

$X(2^{++})$ could be the $X(3940)$: decay to $J/\Psi\omega$ (seen by Belle) and also $D\bar{D}$ in D -wave (not yet seen)

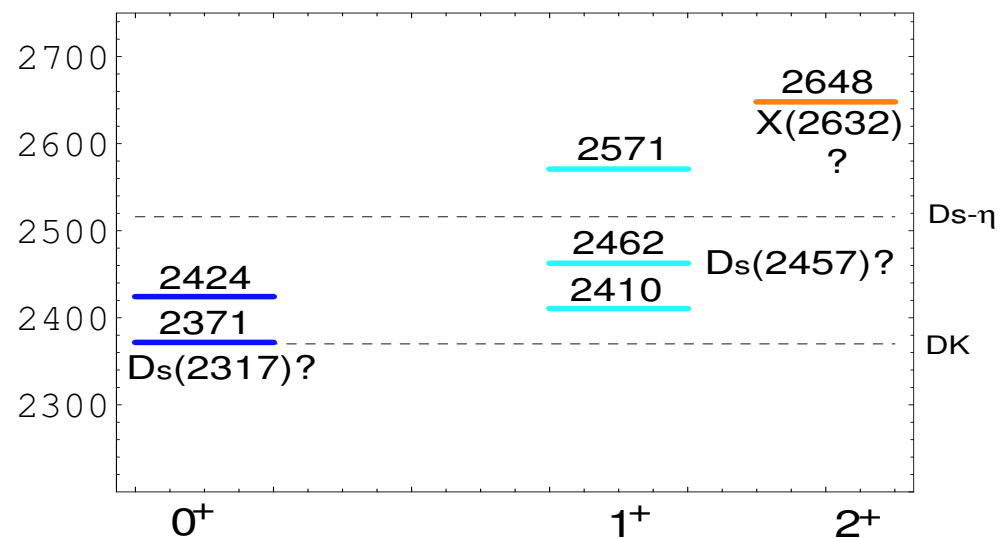
$X(0^{++})_{3832} \rightarrow D\bar{D}$; $X(0^{++})_{3723} \rightarrow \eta_c\pi, \eta_c\eta$, or multihadron; $X(1^{+-}) \rightarrow J/\Psi + \pi(\eta), \eta_c + \rho(\omega)$

missing

missing

missing

Predicted spectrum for open charm particles $[cq][\bar{s}\bar{q}']$



Compatible with

$$D_s(2317) \rightarrow D_s \pi^0; \quad D_s(2457) \rightarrow D_s \gamma \pi^0; \quad (D_s^*) \pi^0$$

Isospin breaking: the X fine structure

At the high mass scale of $c\bar{c}$ annihilation diagrams become small (asymptotic freedom) $\rightarrow$ particle masses should be approximately diagonal with quark masses, even for u and d quarks

G.C. Rossi and G. Veneziano, Phys. Lett. **70B** (1977) 255; **B597** (2004) 338
L. Maiani, F.P., A.D. Polosa and V. Riquer, Phys. Rev. **D70** (2004) 054009

In the large m_c limit we have the (neutral) states

$$X_u = [cu][\bar{c}\bar{u}]; \quad X_d = [cd][\bar{c}\bar{d}]$$

Physical states could fall in isospin multiplets with $I = 0, 1$

$$f_{c\bar{c}} = (X_u + X_d)/\sqrt{2}; \quad a_{c\bar{c}} = (X_u - X_d)/\sqrt{2}$$

Being δ the contribution of annihilation diagrams, the mass matrix is given by

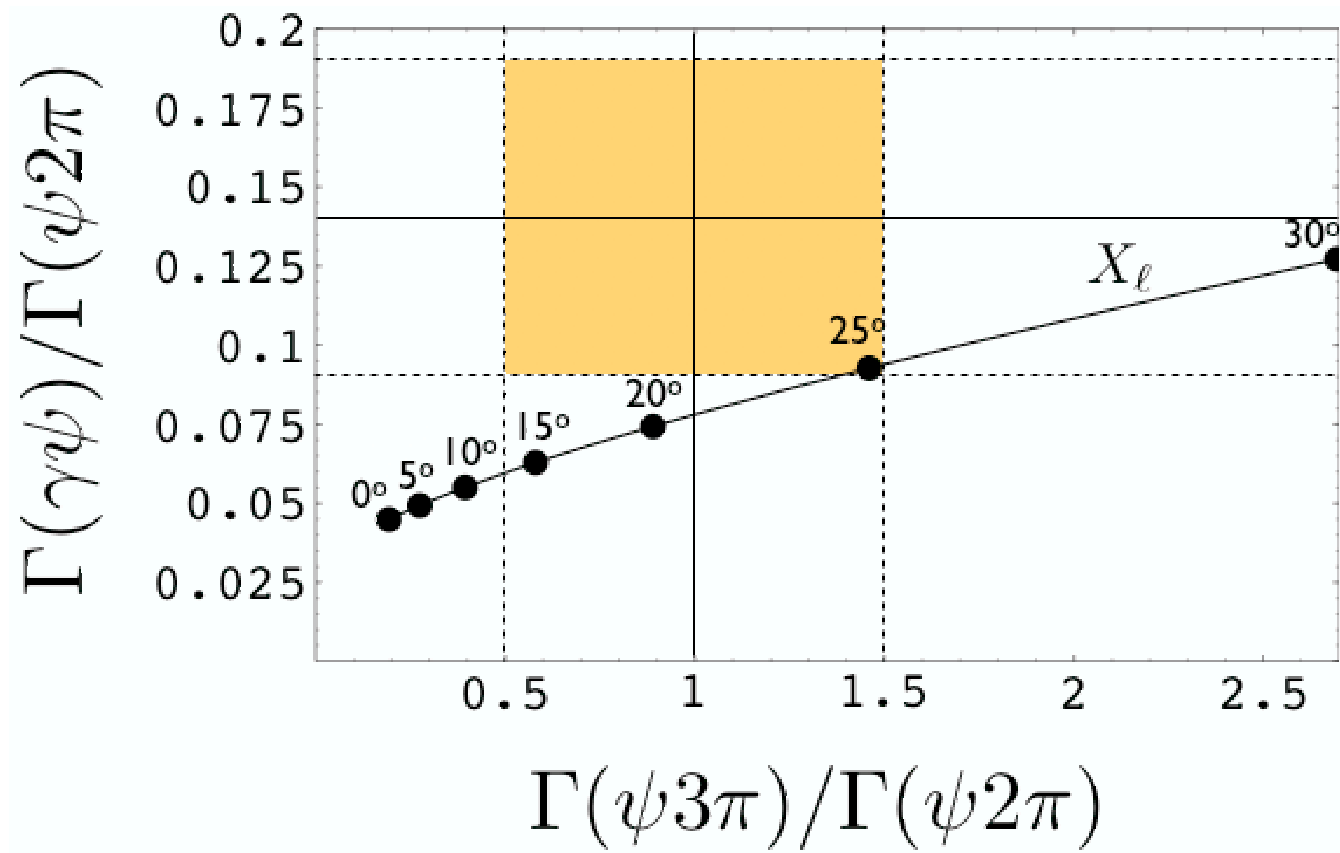
$$\begin{pmatrix} 2m_u + \delta & \delta \\ \delta & 2m_d + \delta \end{pmatrix}$$

Non-negligible gluon annihilation diagrams mix X_u and X_d

$$X_{\text{low}} = \cos\theta X_u + \sin\theta X_d, \quad X_{\text{high}} = -\sin\theta X_u + \cos\theta X_d$$

$$M(X_h) - M(X_l) = 2(m_d - m_u)/\cos(2\theta) = (7 \pm 2)/\cos(2\theta) \text{ MeV} \quad \theta \sim \pm 20^\circ \text{ from } \Gamma(3\pi)/\Gamma(2\pi)$$

measured by BaBar: $\Delta M(X) = 2.7 \pm 1.3 \pm 0.2 \text{ MeV}$



Distinguishing X_u and X_d

A way of distinguish X_u and X_d would be the observation of the leptonic decay $X(3872) \rightarrow J/\Psi e^+ e^-$, since the leptons originate from the coherent superposition of ρ and ω . Assuming the quark-model ratio for the leptonic amplitudes of ρ and ω , with $\theta = 0$, we find

$$\mathcal{B}(X_u \rightarrow J/\Psi + e^+ e^-) = 0.8 \cdot 10^{-4}$$

$$\mathcal{B}(X_d \rightarrow J/\Psi + e^+ e^-) = 0.3 \cdot 10^{-4}$$

From X to $Y(4260)$

L.Maiani, F.P., A.D. Polosa and V. Riquer, Phys. Rev. **D72** (2005) 031502

Coloured objects in a rising confining potential, such as diquarks, should exhibit orbital angular excitations

Within this framework, the $Y(4260)$ seen by BaBar decaying in $J/\Psi\pi^+\pi^-$ (consistently with $J/\Psi f_0(980)$), $J^{PC} = 1^{--}$ can be interpreted as

$$Y(4260) = ([cs]_{S=0}[\bar{c}\bar{s}]_{S=0})_{\text{P-wave}}$$

As for the X particles, the mass formula, adding an angular momentum term, can be written as

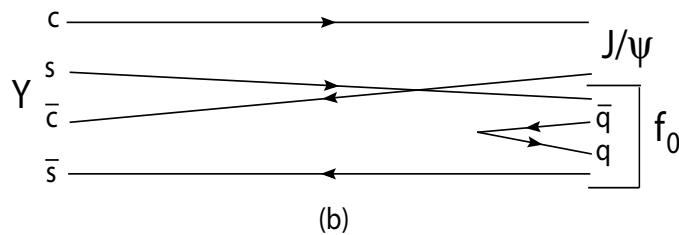
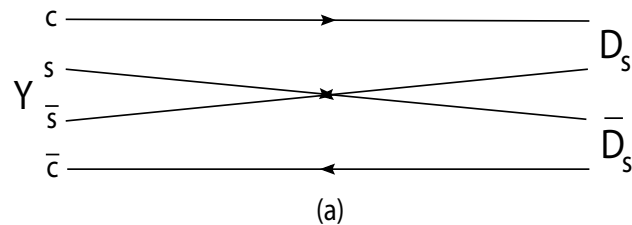
$$M_Y = 2m_{[cq]} + 2(m_s - m_q) - 3\kappa_{cs} + B_c \left(\frac{L(L+1)}{2} \right)$$

$$M_Y^{\text{th}} = 4330 \pm 70 \text{ MeV}$$

Y(4260) decays

Given its quark composition, a striking prediction is

$$\Gamma_Y(D_s \bar{D}_s) \gg \Gamma_Y(D \bar{D})$$



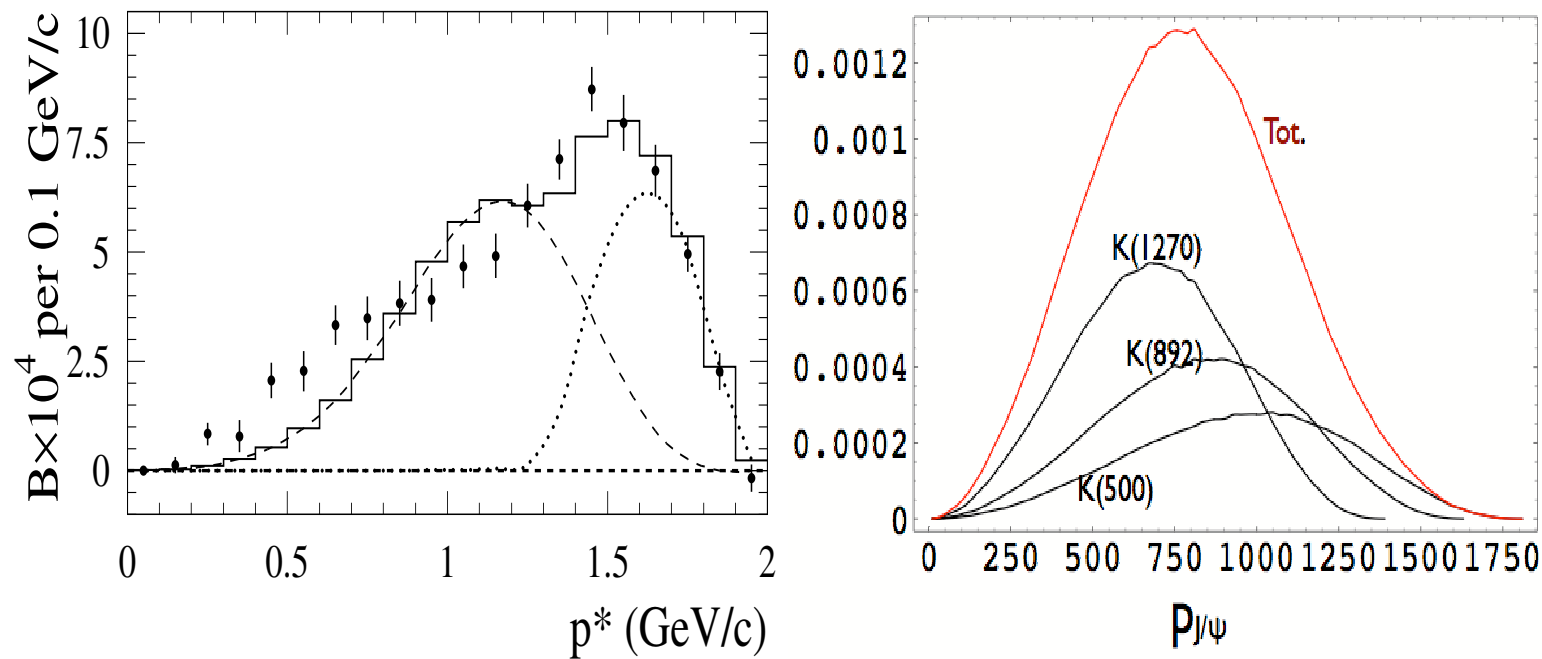
Assuming a partial width similar to the total width of $X(3872)$, $\mathcal{O}(\text{few MeV}) \rightarrow \mathcal{BR}(J/\psi f_0(980)) \sim 10^{-1} \div 10^{-2}$ implying a leptonic width of $50 \div 500$ eV

Other hints of multiquark mesons?

Excess in low momentum J/ψ at BaBar and CLEO

R. Balest et al., Phys. Rev. **D52** (1995) 2661

B. Aubert et al., Phys. Rev. **D67** (2003) 032002



I. Bigi, L. Maiani, F.P., A.D. Polosa and V. Riquer, Phys. Rev. **D72** (2005) 114016

Summary

- Exciting new mesonic states have been discovered around 4 GeV very recently, thanks to the very high statistics of BaBar and Belle
- Some of the new states don't fall in the classification of standard $q\bar{q}$
- Exotic theoretical interpretations can be divided in three main streams:
 1. molecular states, still viable for $X(3872)$ but not for $Y(4260)$ (too far away from thresholds and difficult to have a bound state in P -wave)
 2. hybrid states, viable for $Y(4260)$ but not for $X(3872)$ because of isospin symmetry breaking (and also low mass)
 3. diquark-antidiquark states can accommodate many features of the new particles. The model introduced provides stringent test able to confirm or disprove it
- New experimental results are needed to clarify the situation!
- Shall we introduce these new states in the hadronization models for LHC??