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New Hadrons as four-quark states

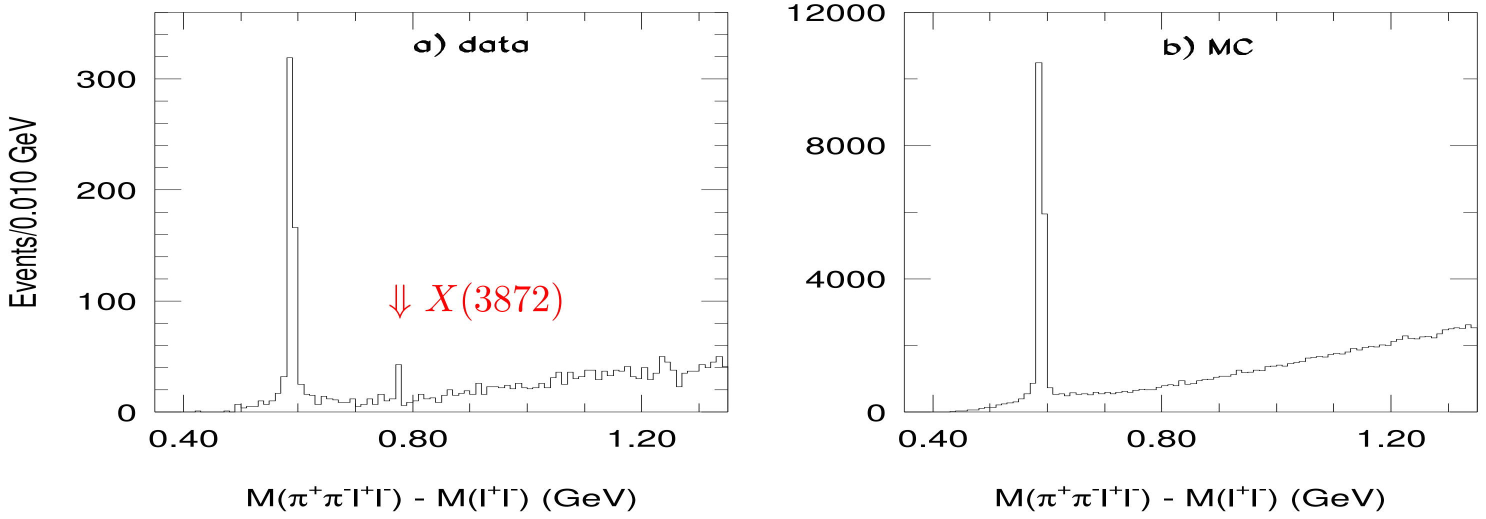
in collaboration with L. Maiani, A.D. Polosa and V. Riquer

- 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

Perspectives in Hadronic Physics, 25 May 2006, ICTP - Trieste

Experimental facts

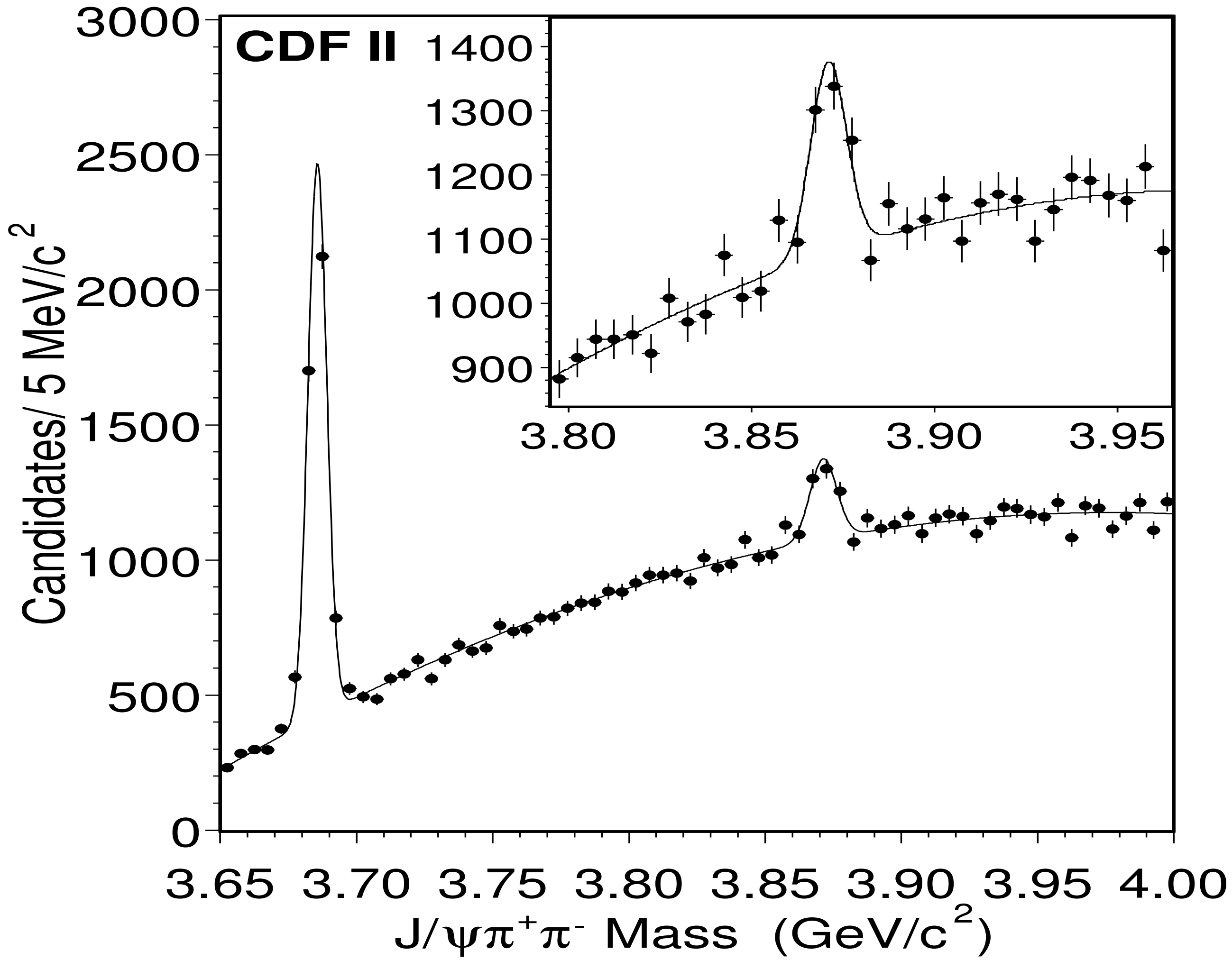
Discovery at Belle of a new state in $B^+ \to K^+ X \to K^+ \pi^+ \pi^- J/\Psi$



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.	$B^\pm \to K^\pm X \to K^\pm \pi^+ \pi^- J/\psi$	25.6 ± 6.8	10σ	Belle
$3871.3 \pm 0.7 \pm 0.4$	resolution	$p\bar{p} \to X \to \pi^+ \pi^- J/\psi$	730 ± 90	11.6σ	CDFII
$M(J/\psi) + 774.9 \pm 3.1 \pm 3.0$	resolution	$p\bar{p} \to X \to \pi^+ \pi^- J/\psi$	522 ± 100	5.2σ	DØ
3873.4 ± 1.4	–	$B^- \to K^- X \to K^- \pi^+ \pi^- J/\psi$	25.4 ± 8.7	3.5σ	BaBar

$X(3872)$ at CDF



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

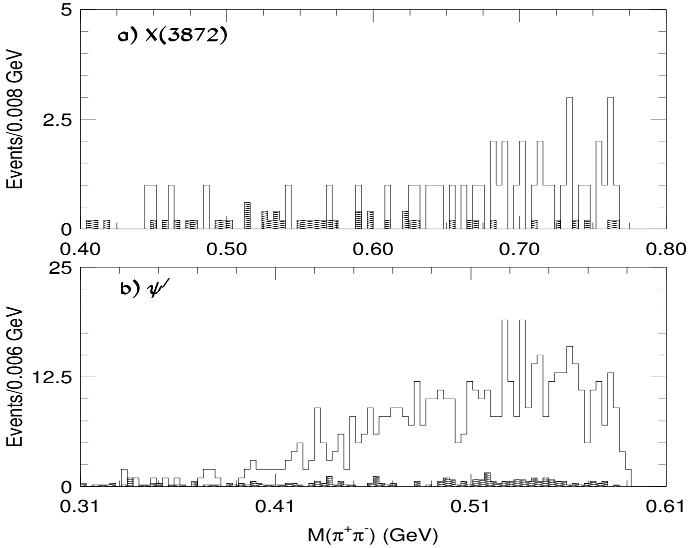
$X(3872)$ properties

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

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

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

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



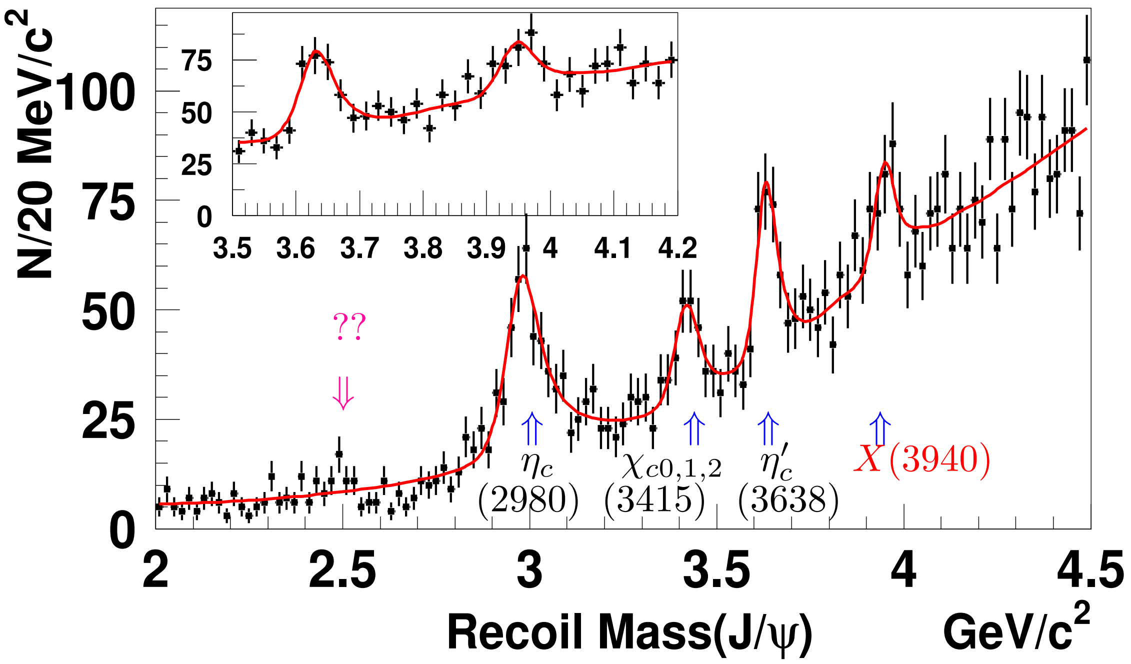
Not seen in direct production

at BES and BABAR (radiative return)

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

$X(3940)$ at Belle

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



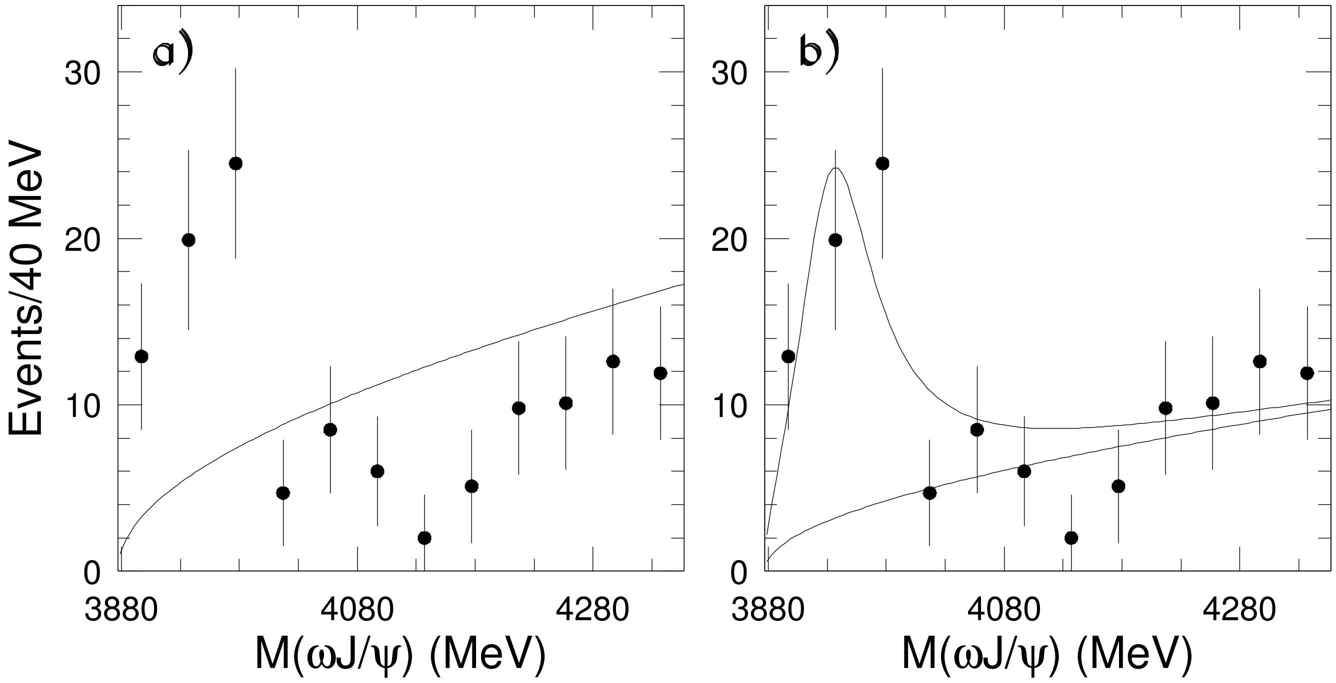
K. Abe et al. (Belle Coll.), hep-ex/0507019

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

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

$Y(3940)$ at Belle

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



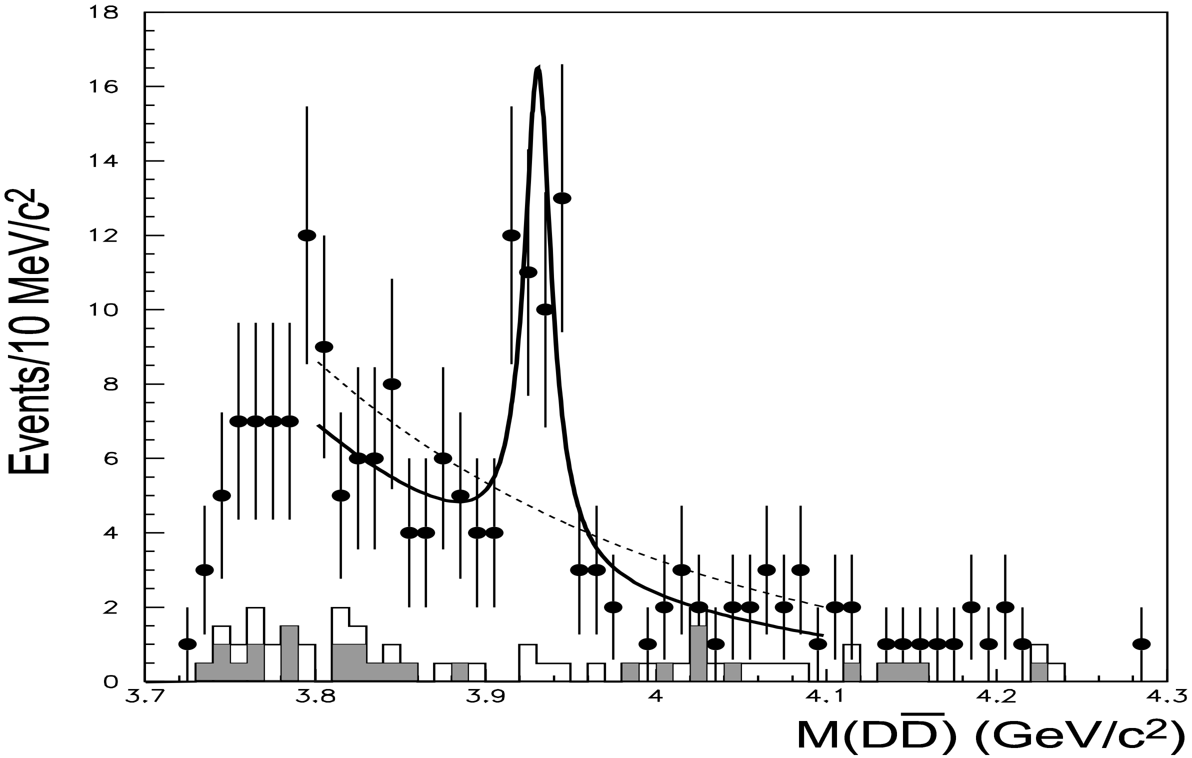
S.K. Choi et al. (Belle Coll.), Phys. Rev. Lett. **94** (2005) 182002

$M_Y = 3943 \pm 11 \pm 13$ MeV, $\Gamma_Y = 87 \pm 22 \pm 26$ MeV 58±11 evts, 8σ

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

$Z(3930)$ at Belle

$\gamma\gamma \to D\bar{D}$

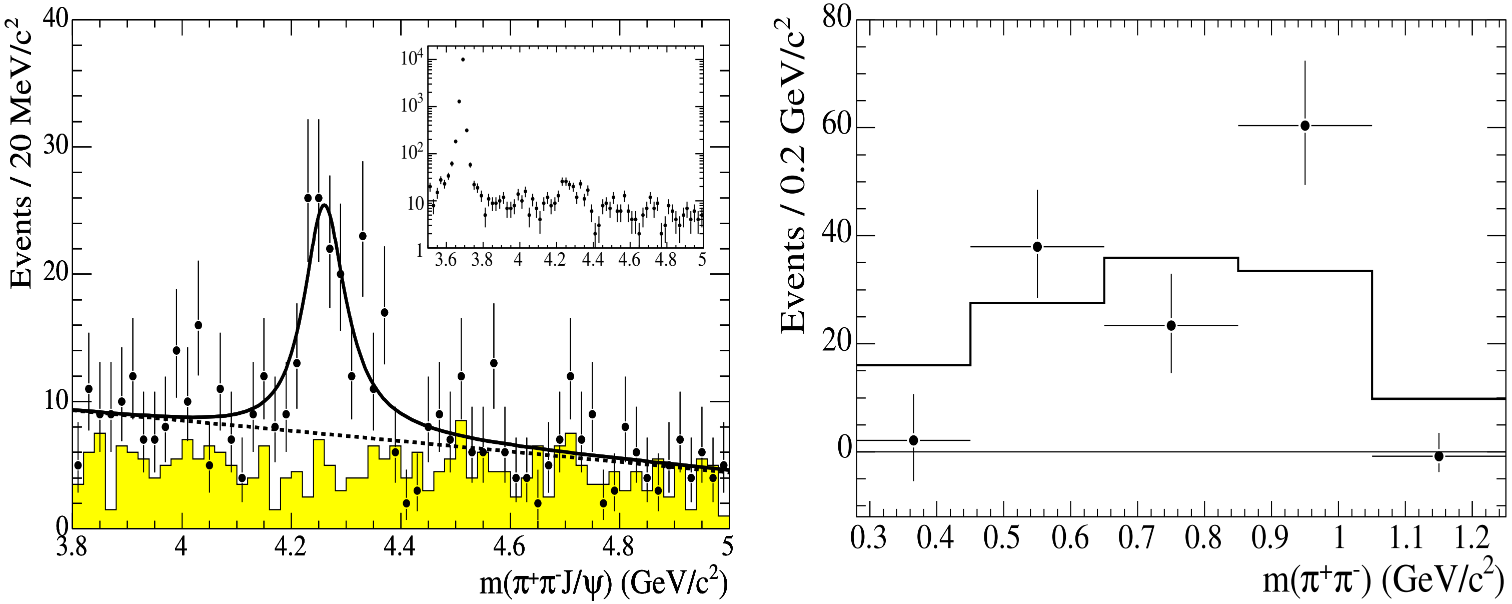


K. Abe et al. (Belle Coll.), hep-ex/0507033; S. Uehara et al. (Belle Coll.), hep-ex/0512035

$M_Z = 3931 \pm 4 \pm 2$ MeV, $\Gamma_Z = 20 \pm 8 \pm 3$ MeV 5.5σ

$Y(4260)$ at BaBar

$$e^+e^- \to \gamma_{\mathrm{ISR}} Y \to \gamma_{\mathrm{ISR}} J/\psi\pi\pi$$

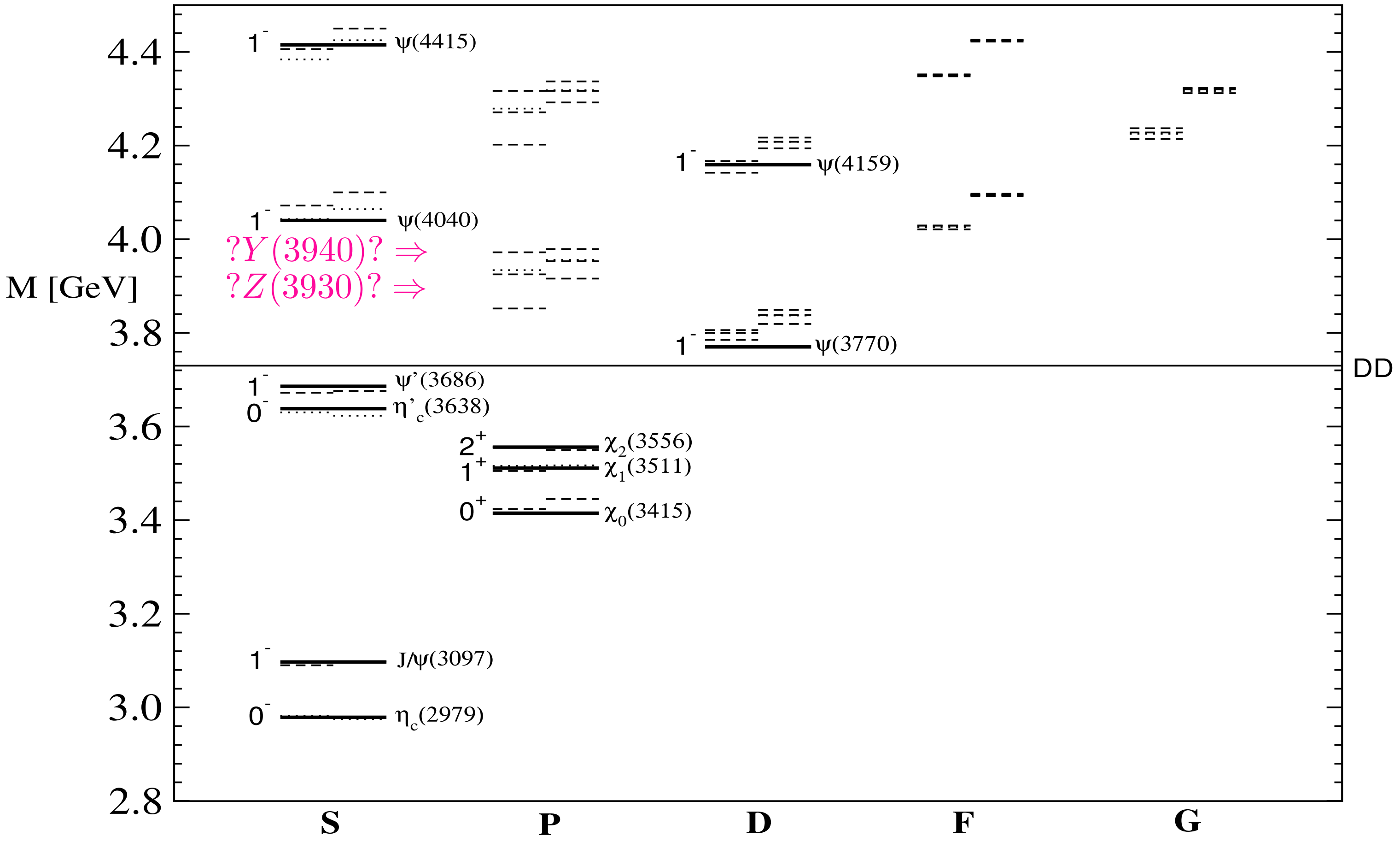


B. Aubert et al. (BaBar Coll.), Phys. Rev. Lett. **95** (2005) 142001

$M_Z = 4259 \pm 8 \pm 4$ MeV, $\Gamma_Z = 88 \pm 23 \pm 5$ MeV 125±23 evts, 5.5σ

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

Minimal hypothesis: are these states charmonium excitations?



T. Barnes, S. Godfrey and E.S. Swanson, hep-ph/0505002

Molecular interpretation

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

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

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

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

while

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

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 $I = 0$

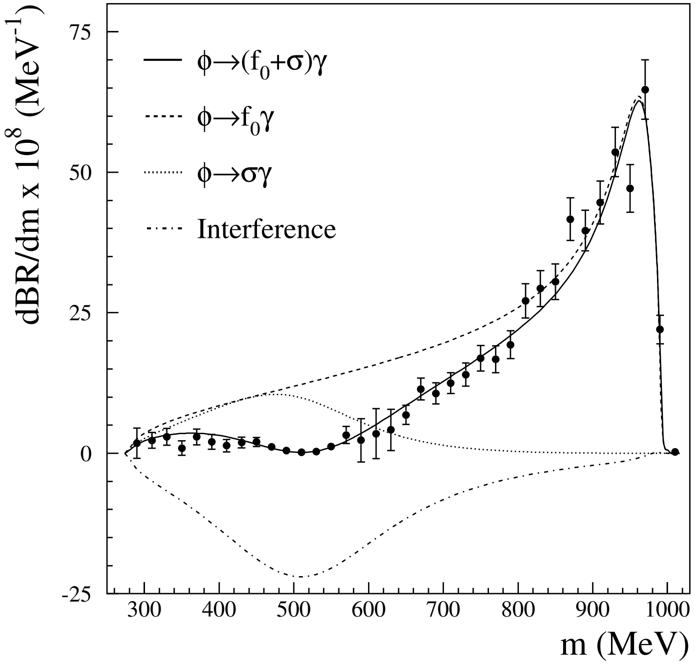
Multi-quark states: a look down to 1 GeV

- $f(980)$, $(I=0)$
- $a(980)$, $(I=1)$ (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

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

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

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 $\Rightarrow \mathbf{3}_c \otimes \bar{\mathbf{3}}_c \otimes \mathbf{3}_c \otimes \bar{\mathbf{3}}_c = 81$ particles ...

Where are they?

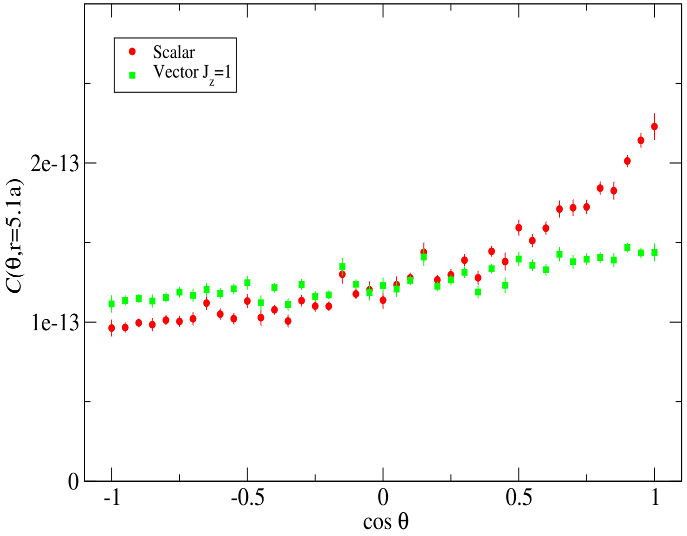
The problem is evaded if we have binding configurations of the type qq and $\bar{q}\bar{q}$: diquarks, coloured objects, which don't leave freely

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

$\mathbf{3}_\mathrm{c} \otimes \mathbf{3}_\mathrm{c} = \bar{\mathbf{3}}_\mathrm{c} \oplus \mathbf{6}_\mathrm{c}$, $\bar{\mathbf{3}}_\mathrm{c}$ attractive, $\mathbf{6}_\mathrm{c}$ 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 $[qq]_{\bar{\mathbf{3}}_\mathbf{c}\mathbf{1}_\mathbf{s}\bar{\mathbf{3}}_\mathbf{f}}$

But $\bar{\mathbf{3}}_\mathbf{f}$ (and $\mathbf{3}_\mathbf{f}$ 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

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

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

most binding configuration →

Flavor	Spin	Color	ΔE
$\bar{3}(A)$	$1(A)$	$\bar{3}(A)$	-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

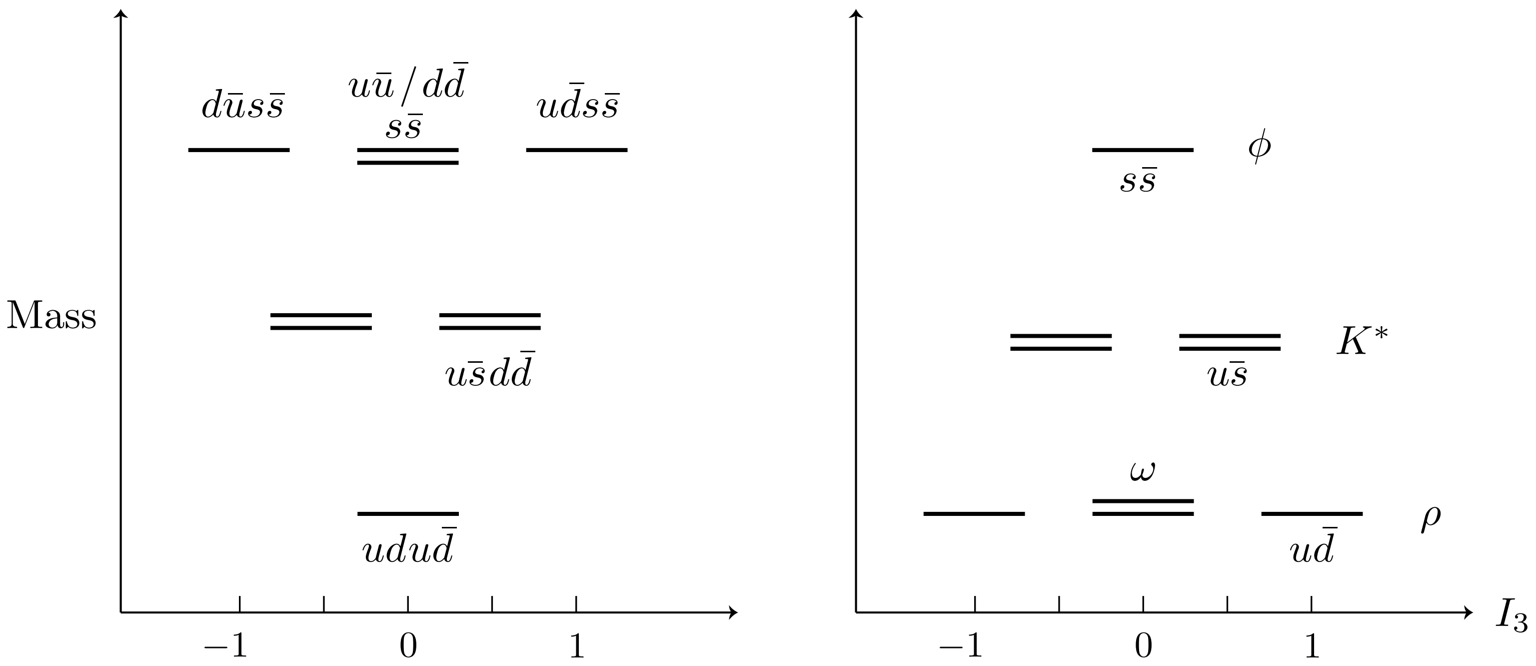
$[q_1 q_2]$: fully antisymmetric diquark

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

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

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

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



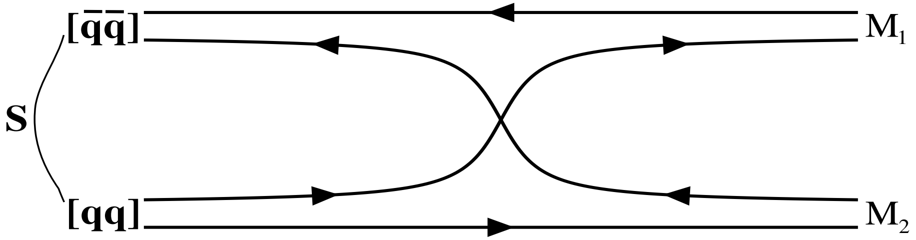
$I = 0$ state is the lightest one

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

Strong decays

Being diquarks $\bar{\mathbf{3}}_{\mathbf{c}}$, 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

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

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

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

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

Data taking started at the beginning of this year

Process to look for:

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

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

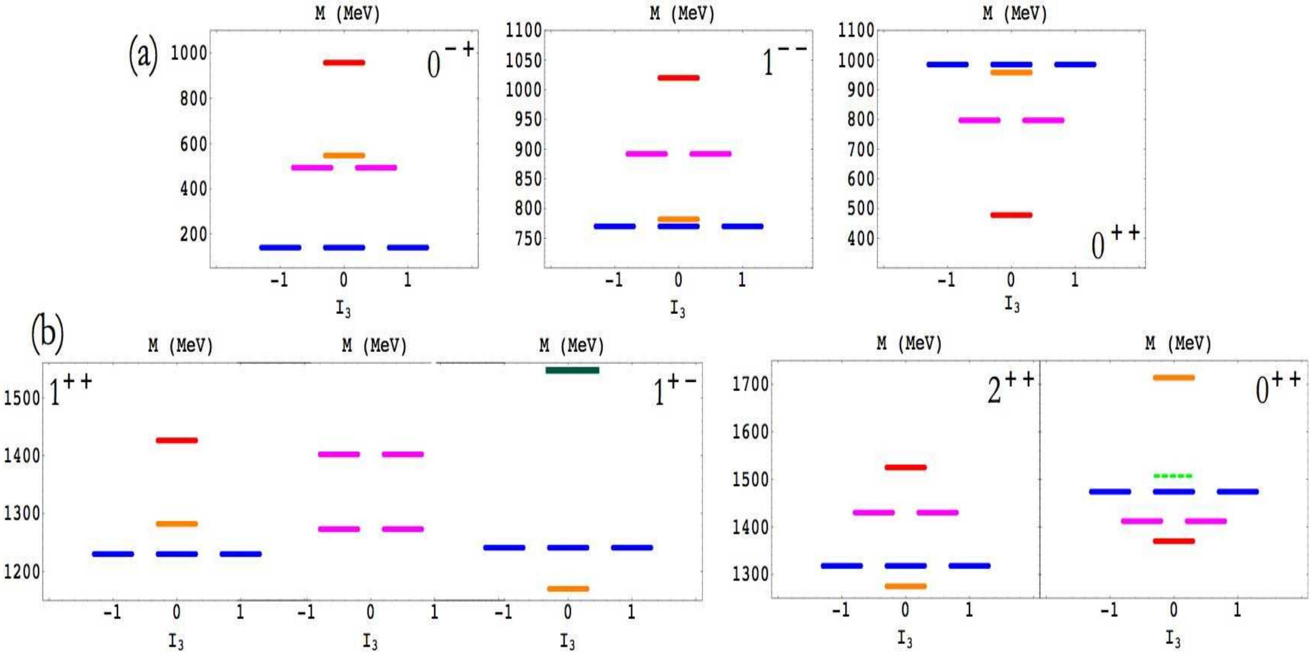
There is some hope to distinguish this signal from ChPT predictions for $\gamma\gamma \to \pi^0\pi^0$

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

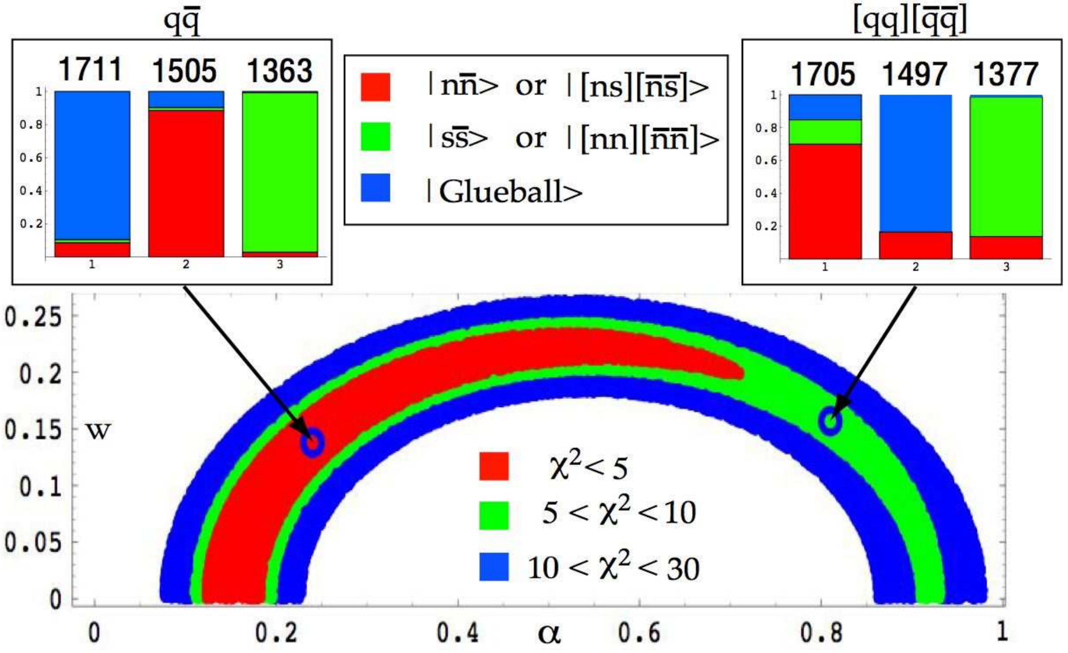


$a_1(1230)$ $b_1(1230)$ $a_2(1318)$

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
$[qq][\bar{q}\bar{q}]$	β =400 MeV	0.42	0.23	0.17
	β =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 $m_c \to \infty$) implies the presence of both spin zero and spin one diquarks.

As a consequence a reach 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 $\bar{\mathbf{3}}_{\mathbf{c}}$

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
$(\kappa_{ij})_{\mathbf{0}} m_i m_j (\text{GeV})^3$	0.029	0.029		0.036	0.059	0.16

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

Hamiltonians to diagonalize

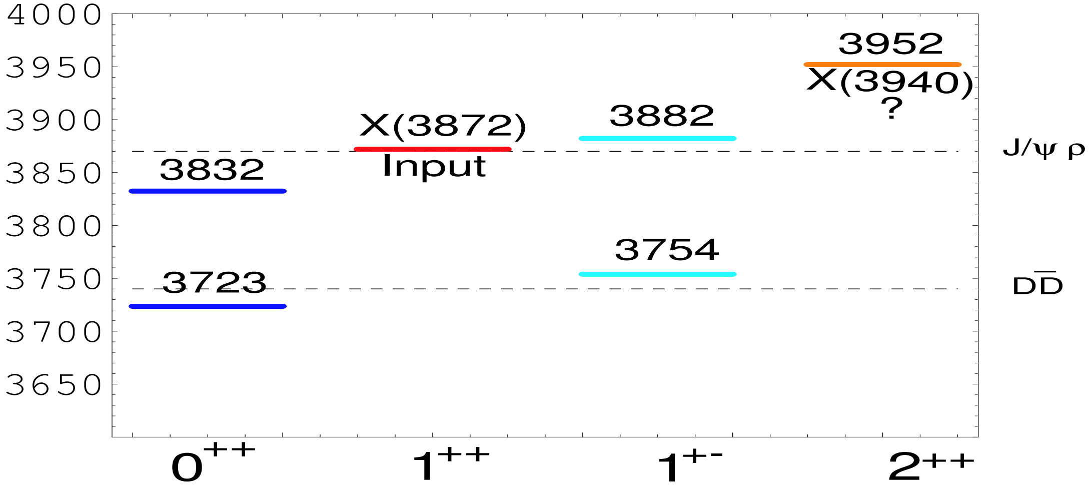
For $[cq][\bar{c}\bar{q}']$ diquarks

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

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 $B^{+,0} \to K^{+,0} X$

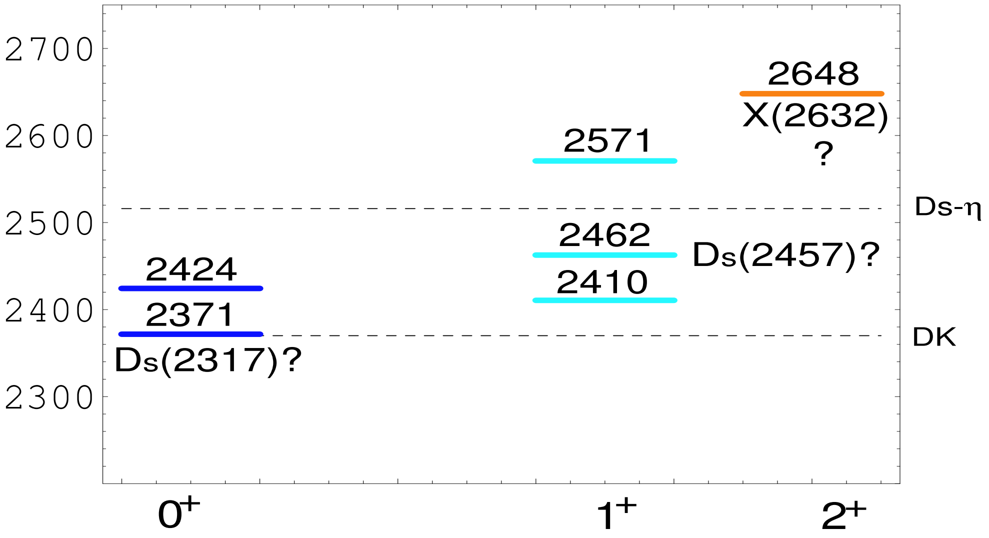
$(cq)_{S=1}[\bar{c}\bar{q}]_{S=0} + [cq]_{S=0}(\bar{c}\bar{q})_{S=1}$

- 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 $J/\Psi+$ 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)

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

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



Compatible with

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

Isospin breaking: the X fine structure

At the high mass scale of $c\bar{c}$ annihilation diagrams become small (asymptotic freedom) → 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

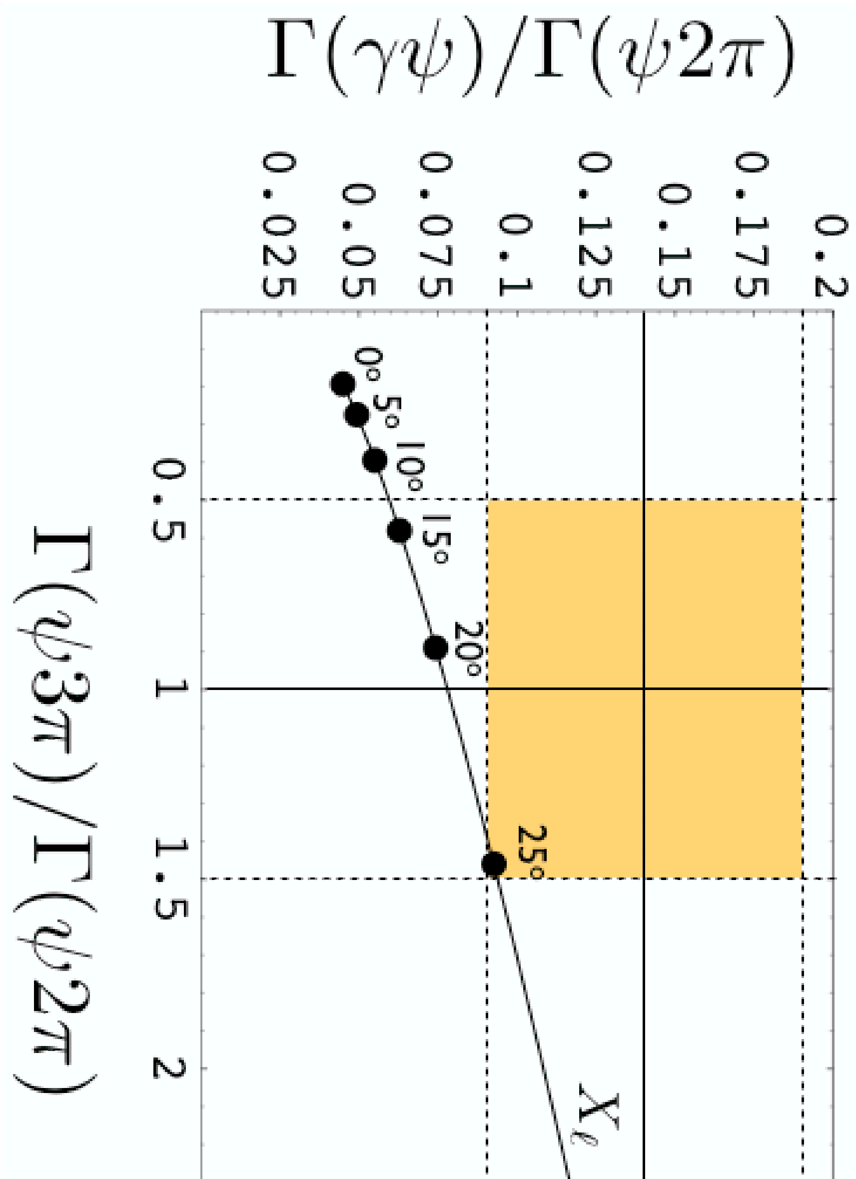
$$\begin{pmatrix} 2m_u + \delta & \delta \\ \delta & 2m_d + \delta \end{pmatrix}$$

Non-negligible gluon annihilation diagrams mix X_u ad X_d

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

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

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



$\Gamma(\gamma\psi)/\Gamma(\psi 2\pi)$
0.025
0.05
0.075
0.1
0.125
0.15
0.175
0.2
$\Gamma(\psi 3\pi)/\Gamma(\psi 2\pi)$
0.5
1
1.5
2
2.5
0°
5°
10°
15°
20°
25°
30°
X_ℓ

Distinguishing X_u and X_d

A way of distinguish X_u and X_d would be the observation of the leptonic decay $X(3872) \to J/\Psi e^+e^-$, 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

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

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

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

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

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

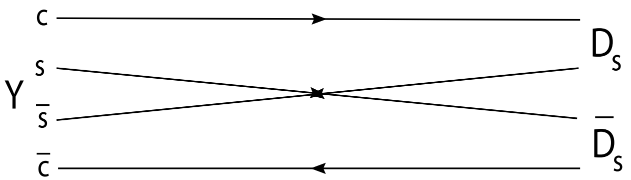
$$M_Y = 2m_{[cq]} + 2(m_s - m_q) - 3\kappa_{cs} + B_c\left(\frac{L(L+1)}{2}\right)$$

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

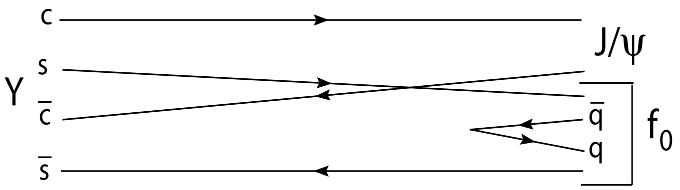
Y(4260) decays

Given its quark composition, a striking prediction is

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



(a)



(b)

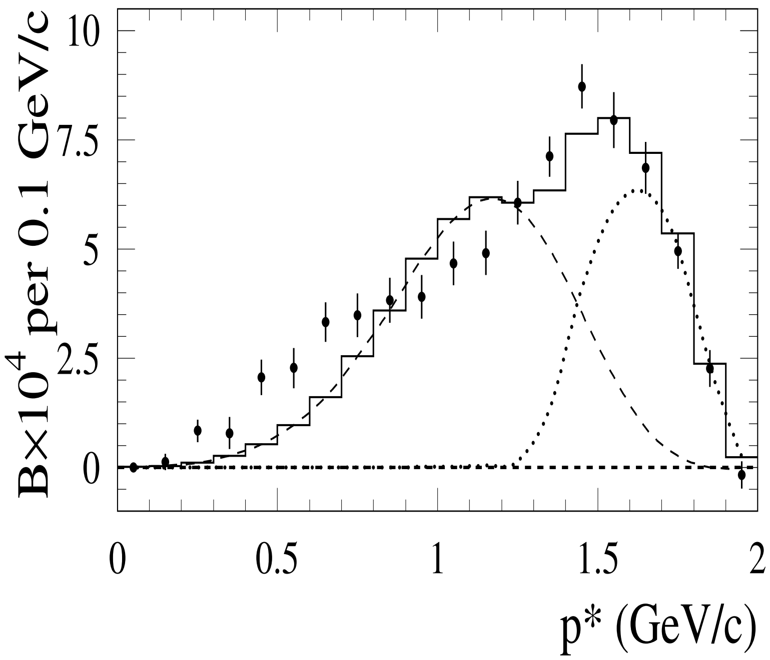
Assuming a partial width similar to the total width of $X(3872)$, $\mathcal{O}$(few MeV) → $\mathcal{BR}(J/\Psi f_0(980)) \sim 10^{-1} \div 10^{-2}$ implying a leptonic width of $50 \div 500$ eV

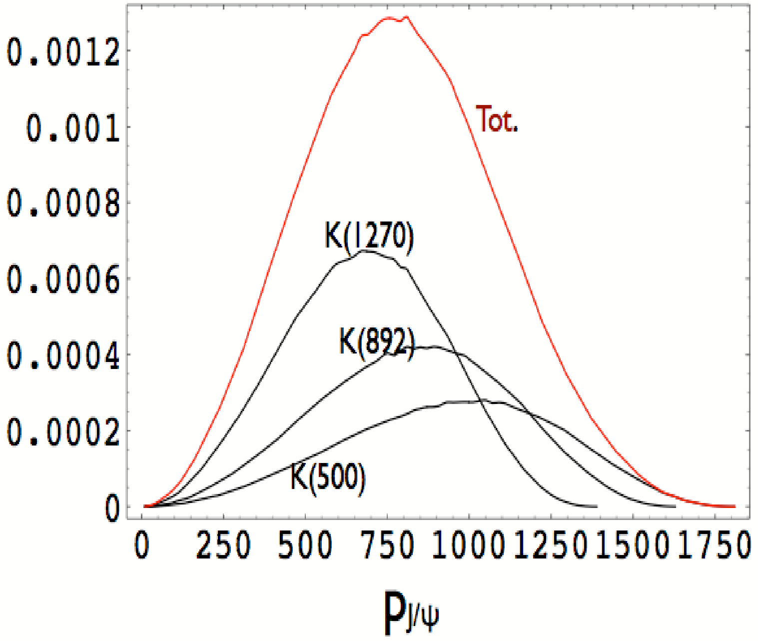
Other hints of multiquark mesons?

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 dont'fall in the classification of stantard $q\bar{q}$
- 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 accomodate 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??