Stati di Mesoni Pseudoesotici

Luciano Maiani
Dipartimento di Fisica, Universita' di Roma "La Sapienza" and INFN, Roma, Italy.

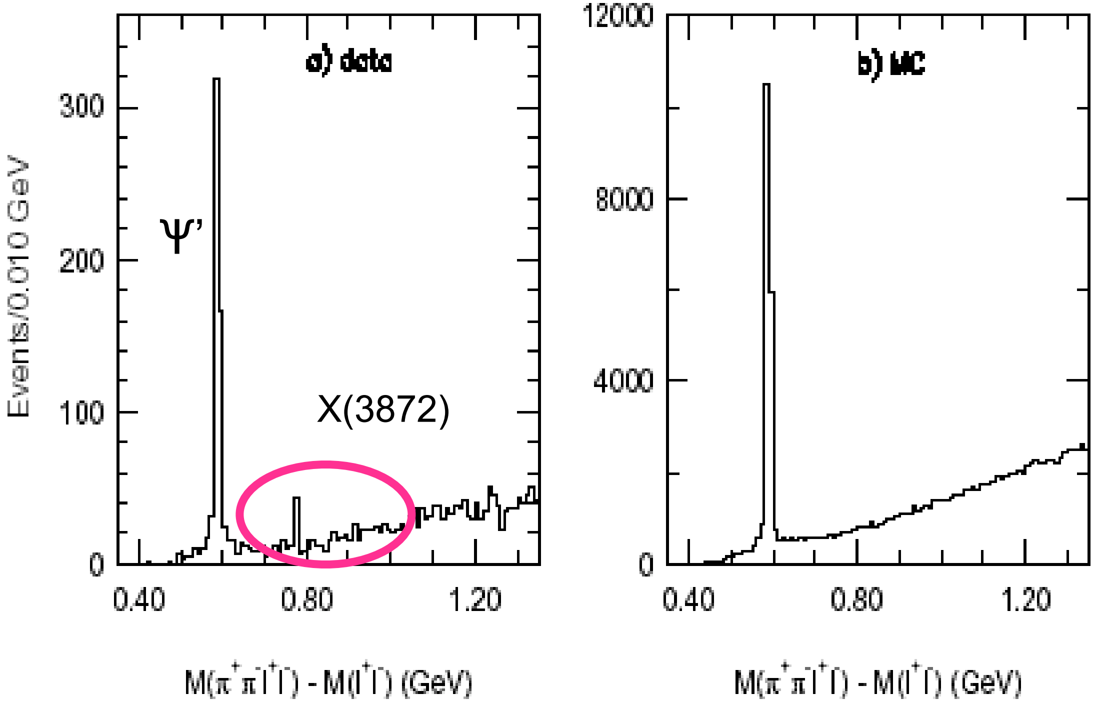
Abstract
La persistenza di indicazioni sperimentali dei mesoni sigma(500) e kappa (800) ha riaperto la questione dell' esistenza di stati diquark-antidiquark.
Il nostro gruppo (L. M., F. Piccinini, A. Polosa, V. Riquer) ha proposto una simile interpretazione per i nuovi stati osservati da BELLE a BaBar che, pur decadendo in J/Psi+mesoni leggeri, non sembrano rientrare nello schema degli stati c-cbar.
Nel seminario, presentero' una rassegna aggiornata della situazione attuale e delle prospettive future.

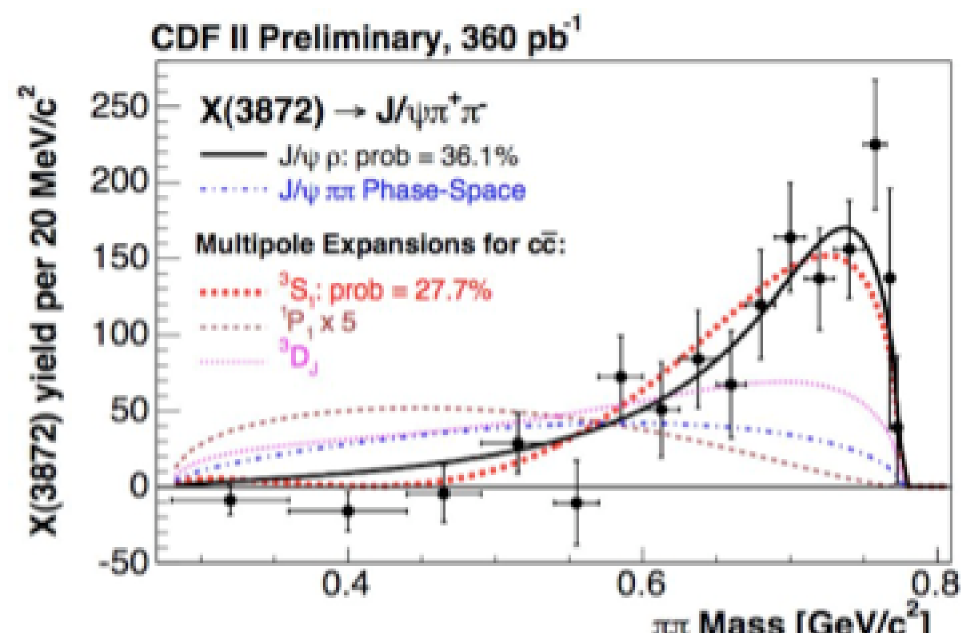
1. Hidden charm mesons are being found by BELLE and BaBar, which do not fit the Charmonium picture

Observation of a narrow charmonium-like state in exclusive $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$ decays

BELLE Collaboration

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





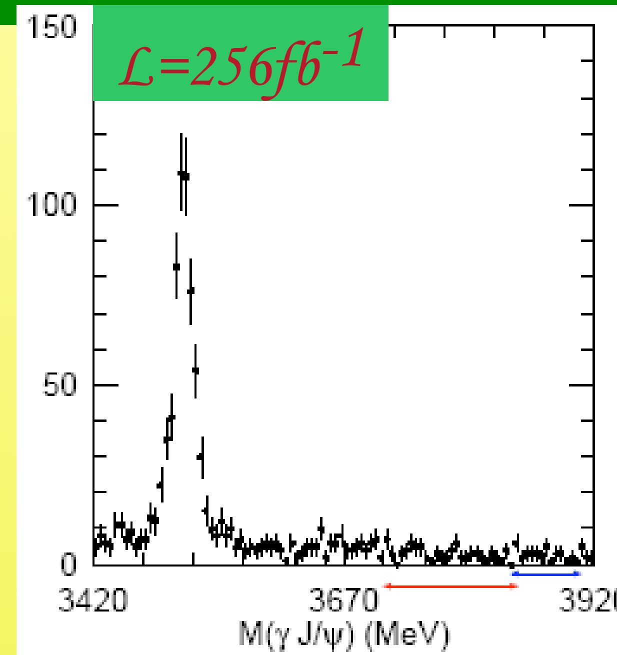
$p\bar{p} \to X \to \pi^{+}\pi^{-}J/\psi$

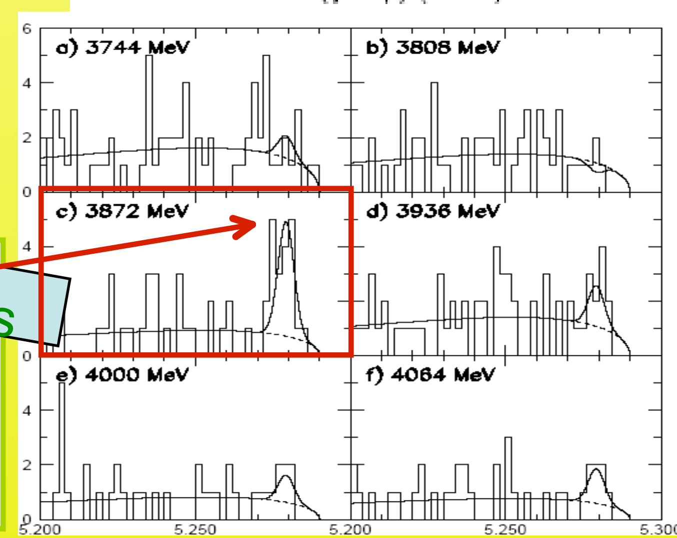
$$\frac{\Gamma(X \to J/\psi\omega)}{\Gamma(X \to J/\psi\pi^{+}\pi^{-})} = 0.8 \pm 0.3 \pm 0.1$$

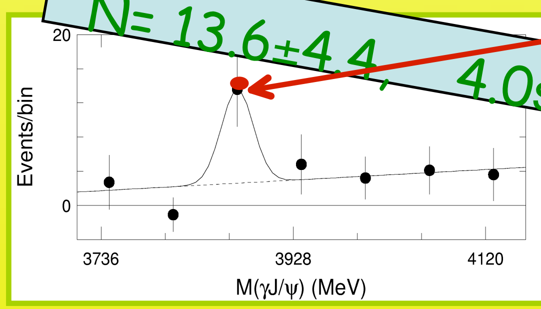
No D-Dbar decay seen: unnatural spin-parity?
$X \to \psi\gamma$ decay seen: C=+1

Evidence for X(3872)→J/ψγ

- Look for B → XK; X → J/yg   K=K^+, K_S
- Use c_{c1}→J/ψγ for calibration
- Fit M_{bc} in bins of J/ψγ invariant mass with 64 MeV/c^2 bin (° ±2.5s_M): The only bin with significant B signal is around X mass.
- Strong evidence for X → J/ψγ decay: G(X→J/ψγ)/G(X→J/ψππ)=0.14±0.05
- Theory expects this ratio ~40 for X=$c_{c1}(2^3P_1)$







hep-ex/0505037

arXiv:hep-ex/0506081 v1 30 Jun 2005

Observation of a Broad Structure in the $\pi^+\pi^-$ J/ Mass Spectrum around 4.26GeV/c^2, B. Aubert et al. BaBar Collaboration

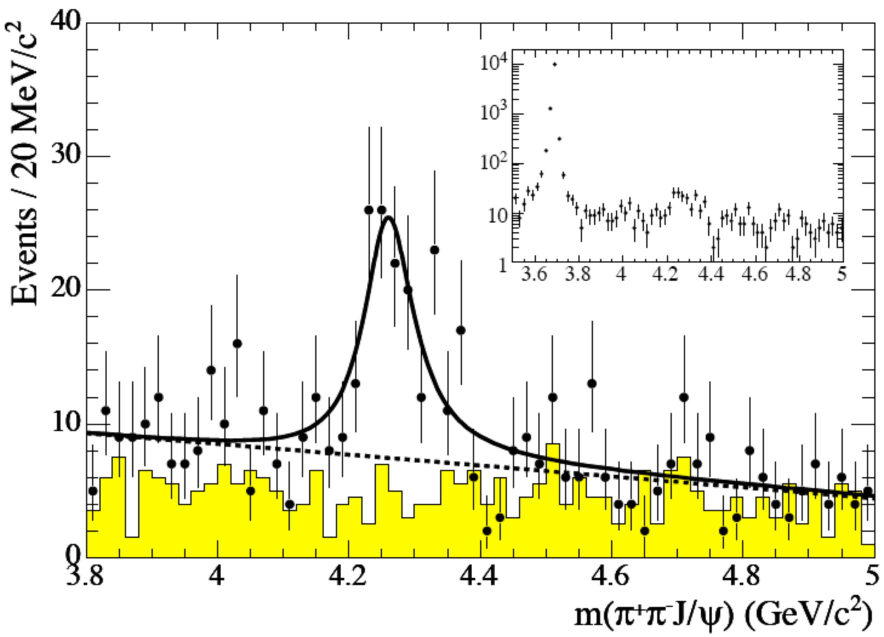
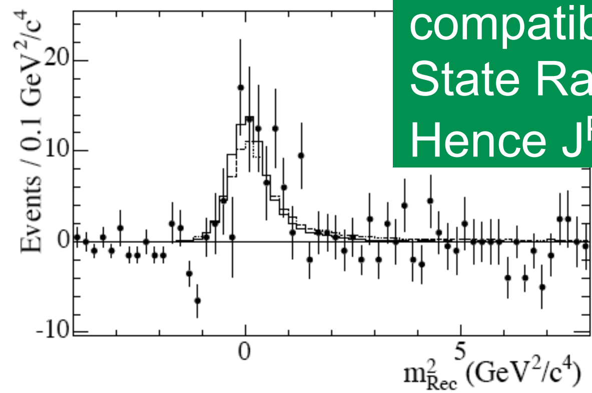
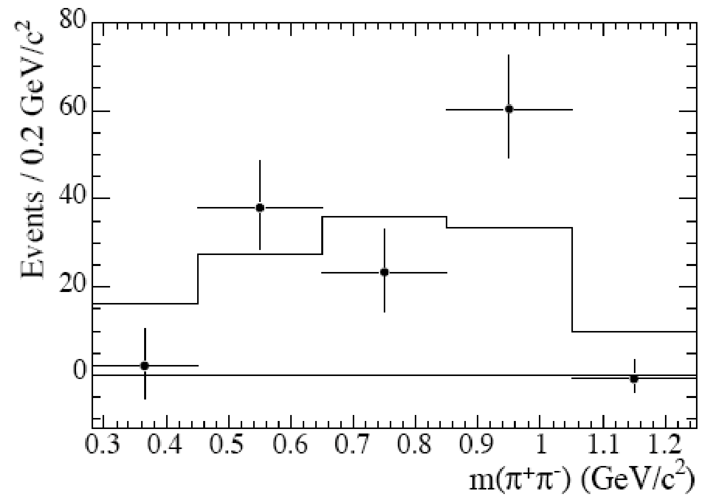


FIG. 1: The $\pi^+\pi^- J/\psi$ invariant mass spectrum in the range 3.8–5.0 GeV/c^2 and (inset) over a wider range

Recoil mass distribution compatible with Initial State Radiation process. Hence $J^{PC}=1^{--}$



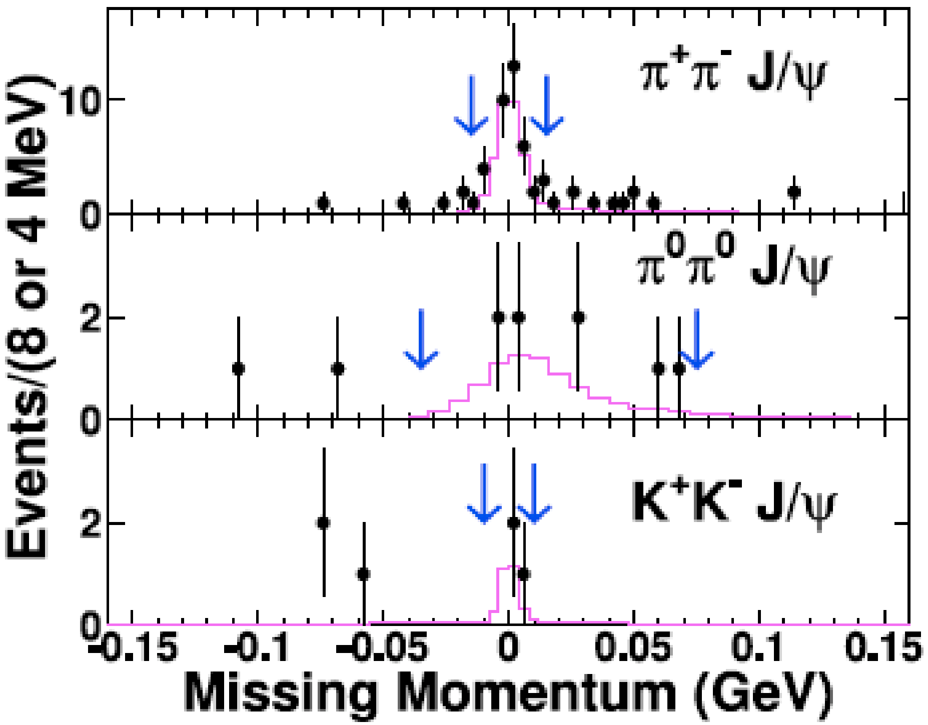


$f_0(980)$??

FIG. 3: The dipion mass distribution for $Y(4260) \to \pi^+\pi^- J/\psi$ data is shown as points with error bars. The histogram shows the distribution for Monte Carlo events where $Y(4260) \to \pi^+\pi^- J/\psi$ is generated according to an S-wave phase space model.

Charmonium Decays of Y (4260), ψ(4160), and ψ(4040)
(CLEO Collaboration)

arXiv:hep-ex/0602034 v1 20 Feb 2006



IG. 2: The missing momentum (k) distribution for $\pi^+\pi^-J/\psi$ (top), $\pi^0\pi^0J/\psi$ (middle), and K^+K^-J/ψ (bottom) in the data at $\sqrt{s} = 4.26$ GeV (circles), and the signal shape as predicted by MC simulation (solid line histogram) scaled to the net signal size.

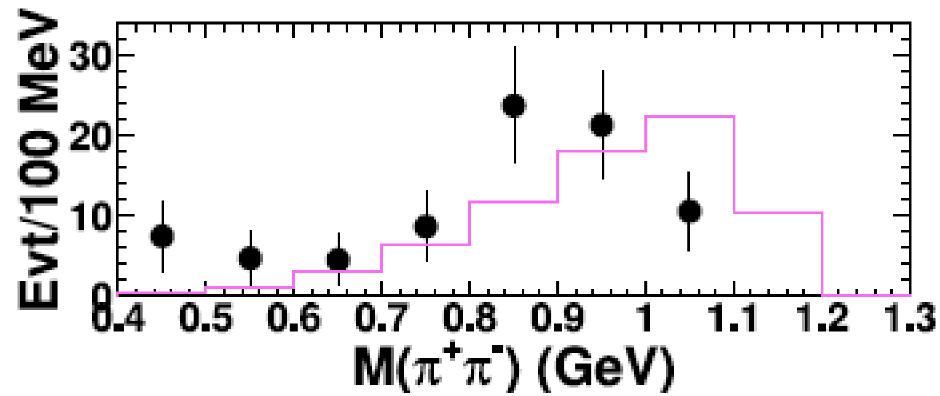


FIG. 3: The efficiency-corrected dipion invariant mass distribution for the $\pi^+\pi^-J/\psi$ final state in the signal region at $\sqrt{s} = 4.26$ GeV for the data (circles) and the signal shape (solid line histogram) as predicted by $\psi(2S)$-like MC simulation scaled to the net signal size.

(3.7σ). We measure e^+e^- cross-sections at $\sqrt{s} = 4.26\,\text{GeV}$ as $\sigma(\pi^+\pi^-J/\psi)=58^{+12}_{-10}\pm4\,\text{pb}$, $\sigma(\pi^0\pi^0J/\psi)=23^{+12}_{-8}\pm1\,\text{pb}$, and $\sigma(K^+K^-J/\psi)=9^{+9}_{-5}\pm1\,\text{pb}$, in which the uncertainties are statis-

$$\frac{\sigma(\pi\pi)}{\sigma(\pi\pi)+\sigma(K\bar{K})} = \frac{81}{81+18} \simeq 0.89$$

Data support f_0 hypothesis

$$\frac{\Gamma(\pi\pi)}{\Gamma(\pi\pi)+\Gamma(K\bar{K})}\Bigg|_{f_0} \simeq 0.8$$

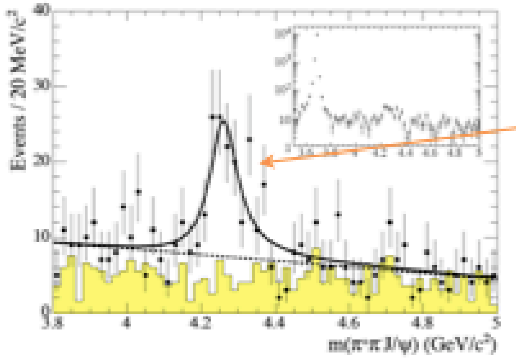
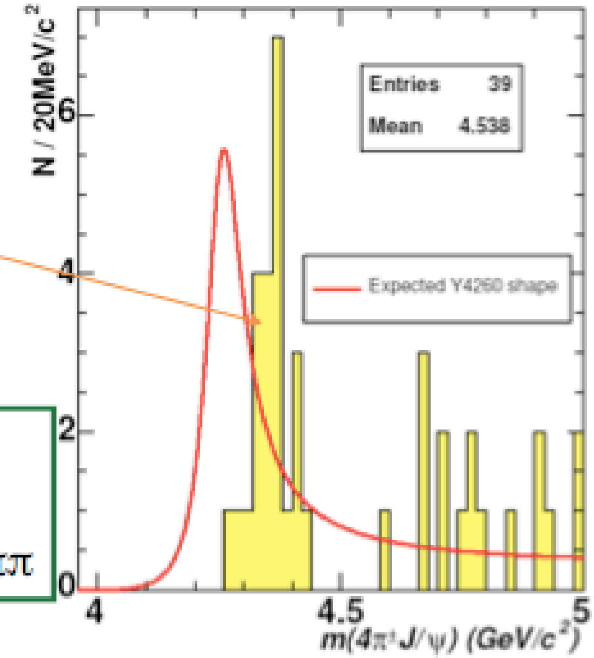


FIG. 1: The $\pi^+\pi^- J/\psi$ invariant mass spectrum in the range 3.8–5.0 GeV/c^2 and (inset) over a wider range that includes

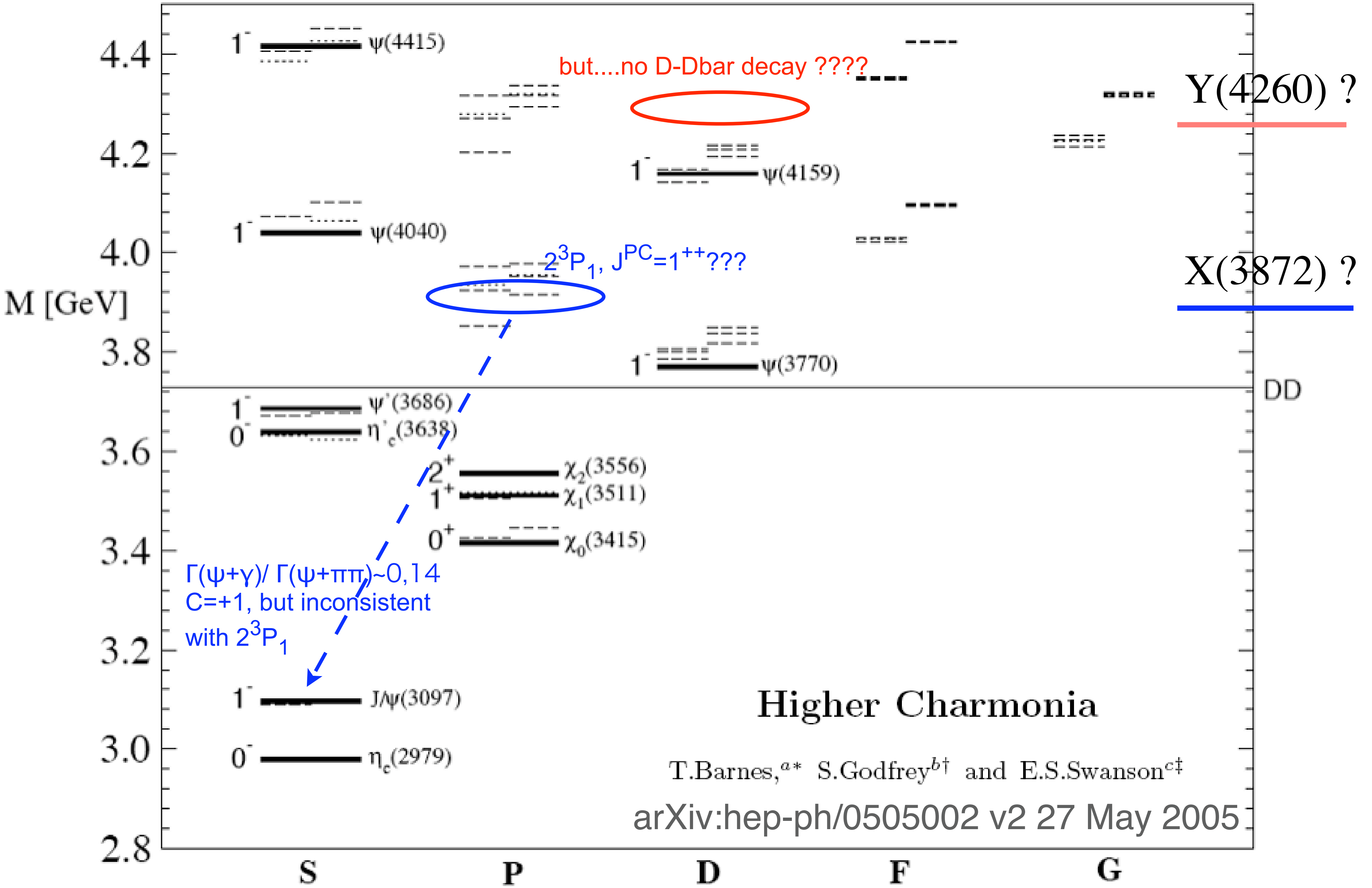
<u>A narrow satellite line?</u>

Search for e+e-→Y(4260)γ_{ISR}
Y→Ψ(2S)ππ
Ψ(2S)→J/Ψππ



- There may be a narrow satellite line at M ~ 4330 MeV.
- Such a mass difference is of the order of the spin-spin interaction.
- If one calls into play *bad diquark states with S = 1* there are several additional 1^{--} states with the same quark composition, (cs)(cbar sbar).
- Among them, the state with *both diquark and antidiquark with S=1, combined to give S_{tot} = 2.*
- This state projects only on spin one cbar s and sbar c states.
- In the limit where the spin of the s quark is a good quantum number, such state could decay only into $D^*_s(D^*_s)$bar, with substantial reduction of its decay width.

X(3872) and Y(4260) are not charmonium states



Proposed interpretations

- X(3872) =
  - D-D* molecule: $M(X)-M(D^{*0}D^0)=0.6\pm1$ MeV F.E. Close, and P.R. Page (2003); N.A. Tornqvist (2003), E. Swanson (2004)
  - diquark-antidiquark bound state: $[(cq)\ (\bar{c}\bar{q})]_{S-wave},\ J^{PC}=1^{++};\ \ (q=u,\ d)$

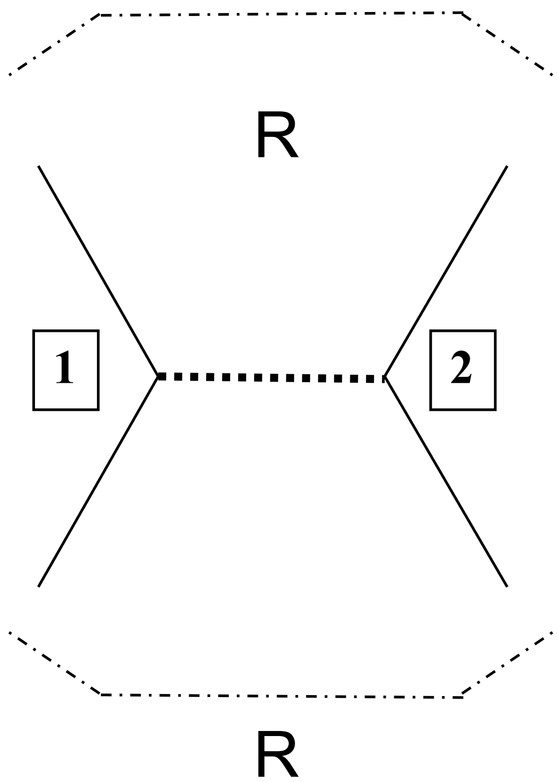
    L. Maiani, F. Piccinini, A. Polosa, V. Riquer (2004)
- Y(4260) =
  - Hybrid state: $(c\ \bar{c}\ g)$ F.E. Close, and P.R. Page (2005); E. Kou, O. Pene (2005)
  - diquark-antidiquark bound state: $[(cs)\ (\bar{c}\bar{s})]_{P-wave},\ J^{PC}=1^{--}.$

    L. Maiani, F. Piccinini, A. Polosa, V. Riquer (2005)

- hybrid classification for X(3872) excluded by the large isospin violation seen in ψρ and ψω decays;
- Y(4260) is some 33 MeV above D*-D* threshold; parity calls for P-wave: molecule unfavoured ??

2. Attractive & repulsive channels in QCD

Interaction of two colored objects:



$$\text{Energy} \propto \; g^2 < \vec{T}_1 \cdot \vec{T}_2 >_R = \frac{g^2}{2}[C^{(2)}(R) - 2\,C^{(2)}(1)]$$

$$q\bar{q} = \begin{cases} \text{octet} = +1/3 & \text{repulsion} \\ \text{singlet} = -8/3 & \text{attraction} \end{cases}$$

$$qq = \begin{cases} \text{“3bar”} = -4/3 & \text{attraction} \\ \text{“6 “} = +2/3 & \text{repulsion} \end{cases}$$

Spin-spin interaction

$$\propto -g^2 < \sigma_1 \vec{T}_1 \cdot \sigma_2 \vec{T}_2 >_R \propto -g^2 [C^{(2)}{}_{eff}(R)][J(J+1) - 3/2]$$

$$< q\bar{q} >_1 \; and \; < qq >_{\bar{3}} = \begin{cases} \text{spin } 1 = +1/2 & \text{repulsion} \\ \text{spin } 0 = -3/2 & \text{attraction} \end{cases}$$

Baryons in the octet:

Λ=([ud] $_{J=0}$ s); Σ^0 =({ud}$_{J=1}$s)→ Λ is lighter than Σ

Lattice: C. Alexandrou, P. de Forcrand, B. Lucini

hep-lat/0509113

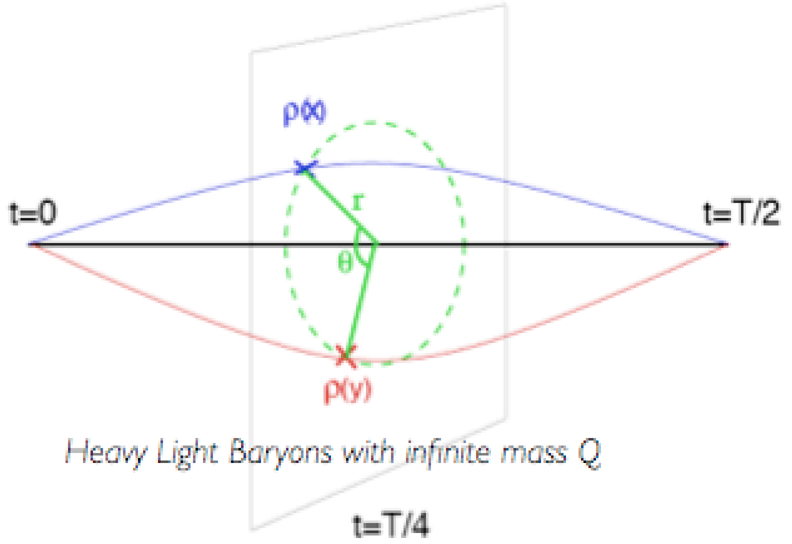
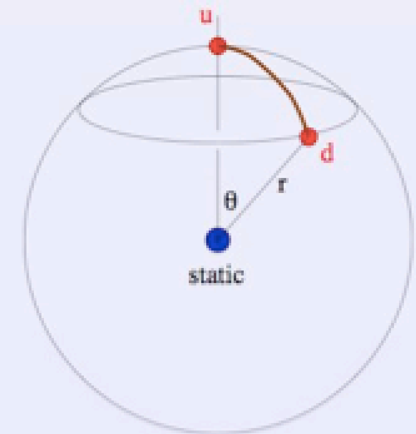
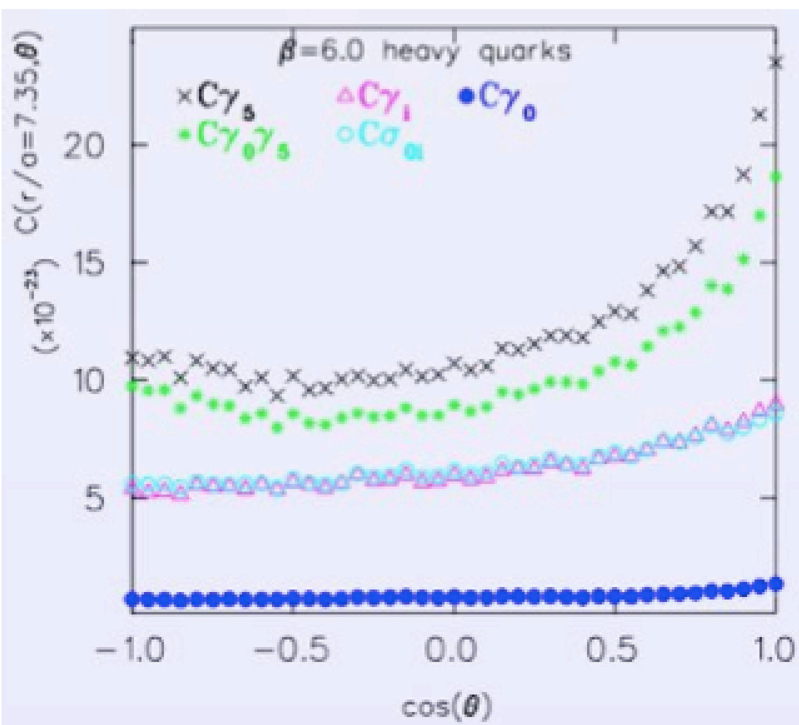


Figure 1: Setup for the computation of the density-density correlators.



$$C_{tot}(r) = \int \langle N|\rho^u \rho^d|N\rangle \sin\theta d\theta d\phi \equiv \int d(\cos\theta) C(\theta, r), \quad \rho^q =: \bar{q}\gamma_0 q:$$

No correlation ⇔ flat in cos θ



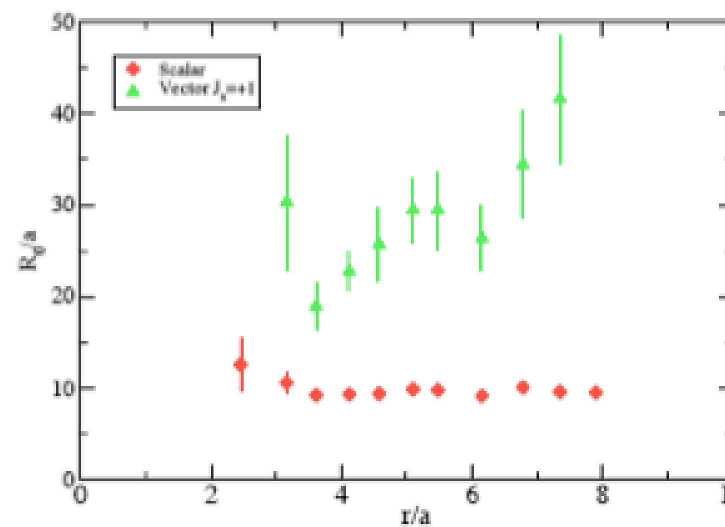
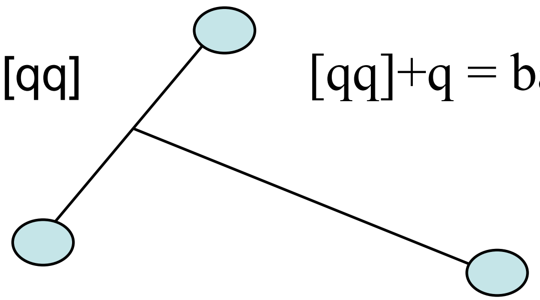


Figure 4: Fitted diquark size R_0 (in units of a) as a function of the distance r/a of the diquark from the static quark.

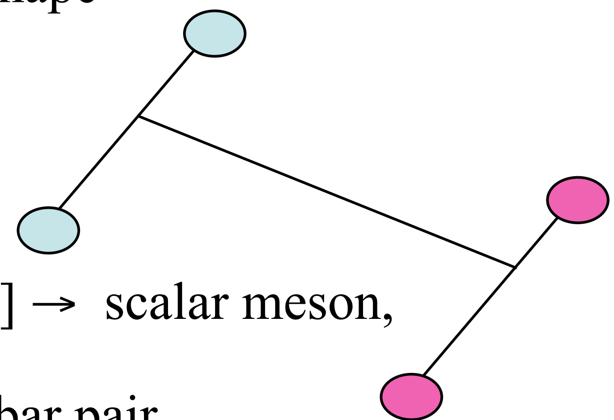
"Good diquarks": [qq] in color = 3bar, spin=0, SU3 flavour = 3bar make a simple unit to form color singlets (Jaffe..more recently Jaffe&Wilcezck, Karliner & Lipkin for penta-quark)

A diquark needs to combine with other colored objects

[qq]

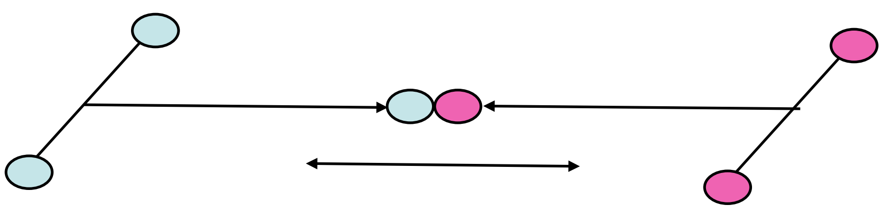


[qq]+q = baryon (e.g. Λ), Y-shape



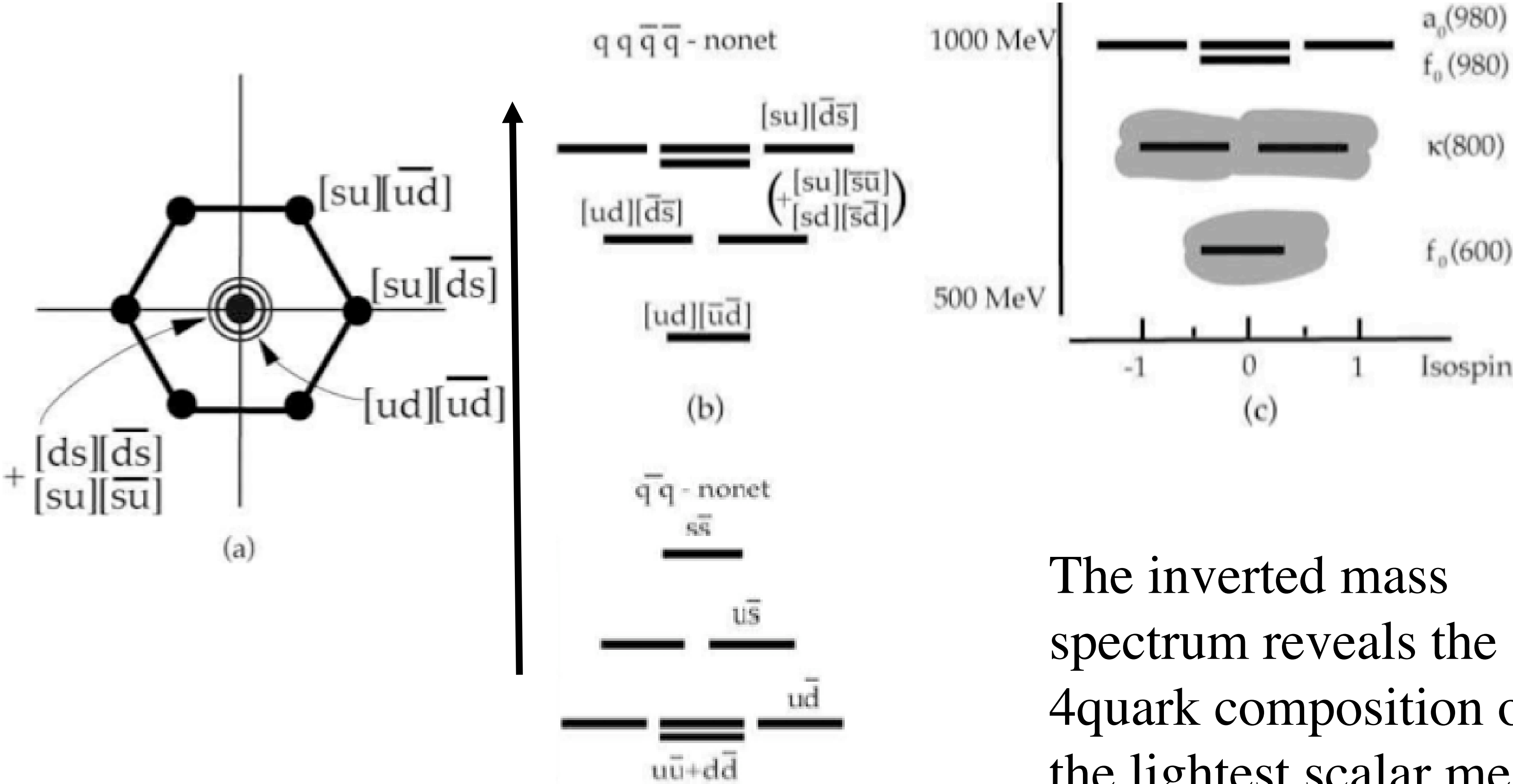
[qq]+ [qbar qbar] → scalar meson,

if you stretch the string, [qq][qbar qbar]→ B Bbar pair
a new topology, related to B-B bar.

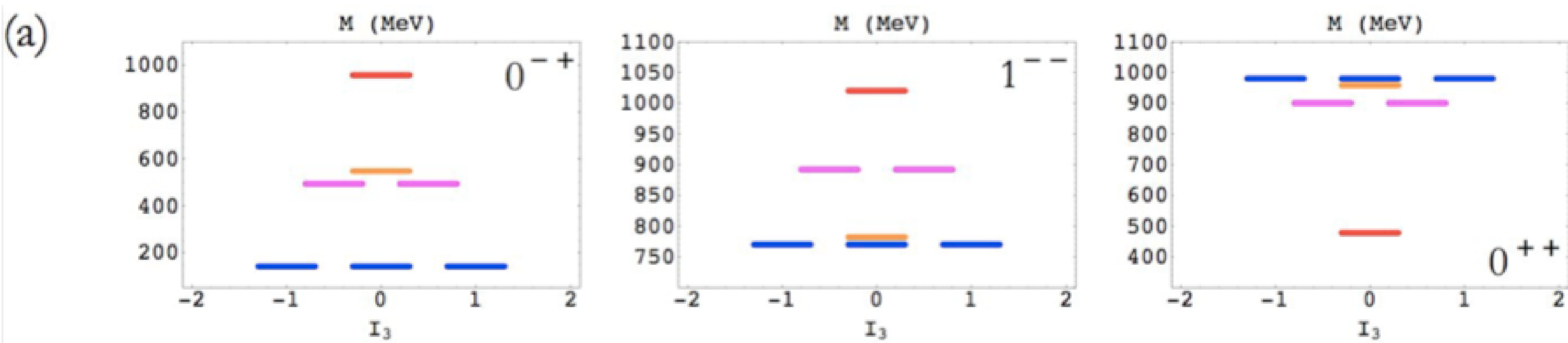


meson-meson molecules are in different color configuration.
But: do "residual" forces bind?

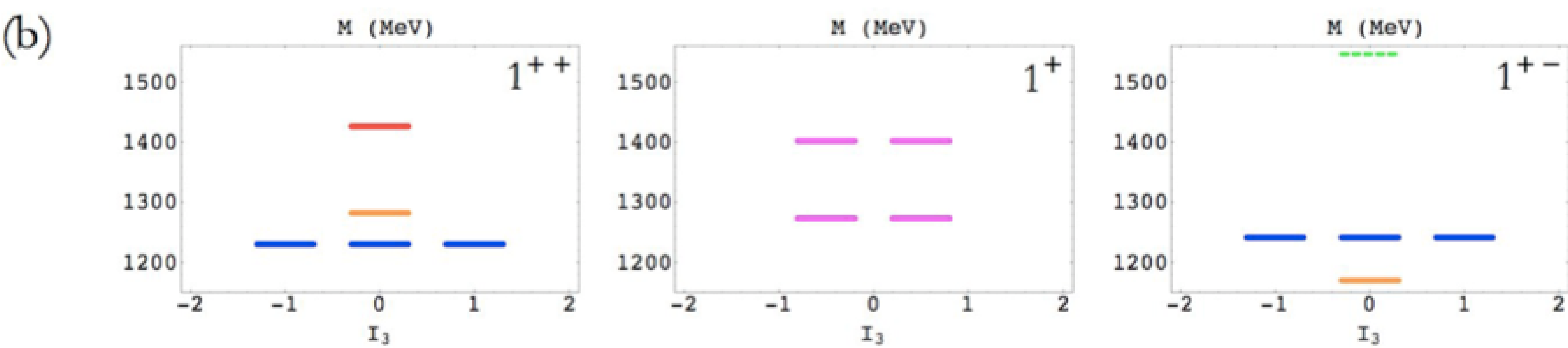
Quantum numbers and mass spectrum



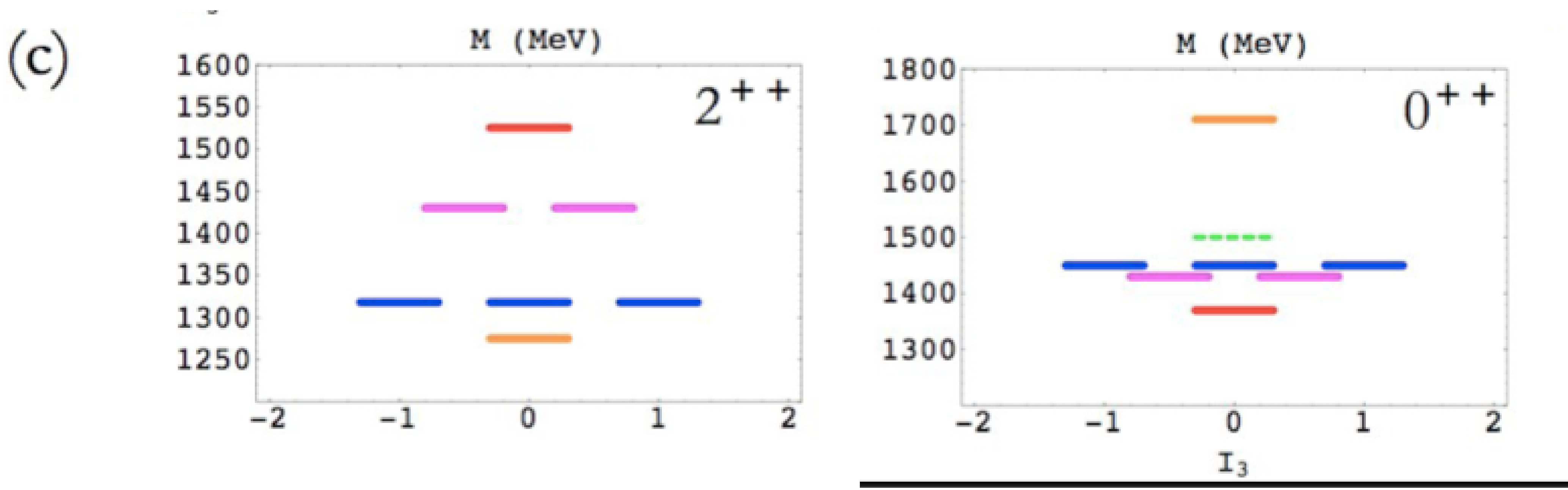
The inverted mass spectrum reveals the 4quark composition of the lightest scalar mesons



q-qbar, P-waves,
Borchi & Gatto 1965 !!



Compare normal (2^{++}) with 0^{++}



- In q-qbar scheme impossible (??) to explain inversion of order
- there are 10, 0++, states: 1 4q nonet + 1 glueball??

Positive parity scalar mesons in the 1–2 GeV mass range

(Maiani–Piccinini–Polosa–Riquer)

Back to the decuplet formed by:

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

$$\mathbf{\Pi} = \begin{pmatrix} \frac{X_1}{\sqrt{2}} + \frac{a_0}{\sqrt{2}} & a^+ & k^+ \\ a^- & \frac{X_1}{\sqrt{2}} - \frac{a_0}{\sqrt{2}} & k^0 \\ k^- & \bar{k}^0 & X_2 \end{pmatrix}$$

$X_1 = |n\bar{n}\rangle;\ X_2 = |s\bar{s}\rangle$

$X_1 = |[ns][\bar{n}\bar{s}]\rangle;\ X_2 = |[nn][\bar{n}\bar{n}]\rangle$

$$\mathcal{L}_{\rm mass} = \frac{1}{2}m(a){\rm Sp}(\mathbf{\Pi}\cdot\mathbf{\Pi}) + {\rm Sp}\left(\mathbf{\Delta}\cdot\mathbf{\Pi^2}\right) + \frac{c}{2}[{\rm Sp}(\mathbf{\Pi})]^2$$

c: annihilation of quark pairs into pure glue states

$$\mathbf{\Delta} = \begin{pmatrix} 0 & & \\ & 0 & \\ & & \delta \end{pmatrix}$$

$$\mathcal{L}_{\rm mass} = \frac{1}{2}m_a a^2 + \frac{1}{2}(m_a + 2c)X_1^2 + \frac{1}{2}(m_a + c + 2\delta)X_2^2 + \sqrt{2}cX_1X_2 \ldots$$

In a X_1,X_2,G mixing scheme:

$$\mathbf{M} = m(a) + \begin{pmatrix} 2c & \sqrt{2}c & \sqrt{2}w \\ \sqrt{2}c & c+2\delta & w \\ \sqrt{2}w & w & \Delta m_G \end{pmatrix}$$

annihilation

$$3c + \Delta m_G + 2\delta = \sum_i f_0^i - 3a \quad (\delta < 0!!!)$$

$$\Sigma = 3c + \Delta m_G$$

$$\Delta m_G = \Sigma(1-\alpha)$$

$$\mathbf{M} = m(a) + \begin{pmatrix} \frac{2}{3}\Sigma\alpha & \frac{\sqrt{2}}{3}\alpha & \sqrt{2}w \\ \frac{\sqrt{2}}{3}\alpha & \frac{1}{3}\Sigma\alpha + 2\delta & w \\ \sqrt{2}w & w & \Sigma(1-\alpha) \end{pmatrix}$$

which can be treated numerically

Strong Decays of X(3872): 4quarks

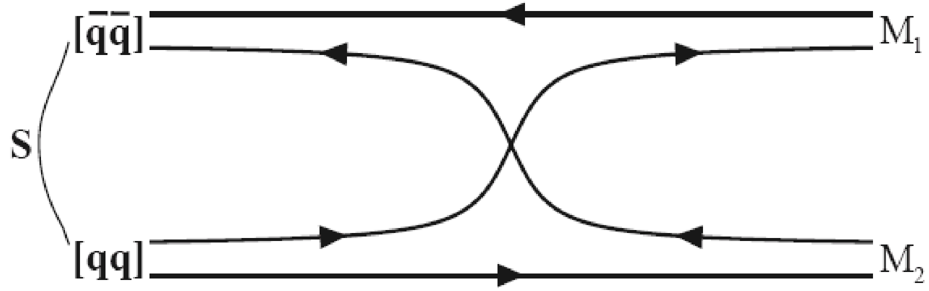


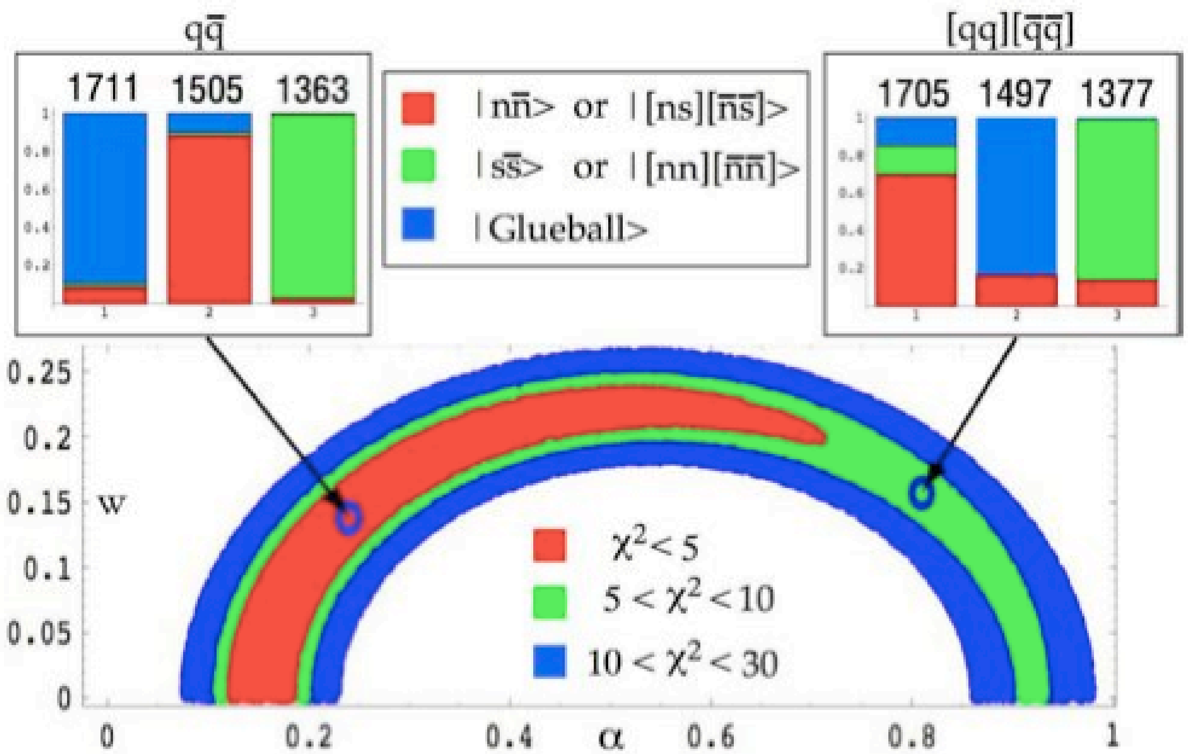
FIG. 1: The decay of a scalar meson S made up of a diquark-antidiquark pair in two mesons $M_1 M_2$ made up of standard $(q\bar{q})$ pairs.

Tunneling from colored to uncolored pairs, free to move away from each other

$$\Gamma(s \to i) = \frac{A^2}{8\pi} \frac{p}{M^2} x_{s\to i}$$

p is the decay momentum,
M the mass of the decaying particle,
$x_{s\to i}$ a numerical coefficient (quark overlap to final mesons),
A a scale factor with dimension of mass.

$X \to \psi\rho(\to\pi^+\pi^-)$, $X \to \psi\omega(\to\pi^+\pi^-\pi^0)$, $X \to D^{*0}$ $Dbar^0$ $+Dbar^{*0}$ D^0
all come from quark rearrangement diagrams,
similar couplings, rates determined by phase space and BW shape



$$\mathcal{L}_{\rm decay} = c_1[\mathrm{Sp}(\mathbf{X_1}\cdot\mathbf{P^2}) - x\mathrm{Sp}(\mathbf{X_1})\mathrm{Sp}(\mathbf{P^2})] + c_2[\mathrm{Sp}(\mathbf{X_2}\cdot\mathbf{P^2}) - x\mathrm{Sp}(\mathbf{X_2})\mathrm{Sp}(\mathbf{P^2})] + c_3\gamma\mathrm{Sp}(\mathbf{P^2})$$

x=0 2q; x=1/2 4q

γ: GPP coupling

$c_i=c_i(w,\alpha)$

		$\mathcal{B}_{\pi\pi}/\mathcal{B}_{KK}[f_0(1710)]$	$\mathcal{B}_{KK}/\mathcal{B}_{\pi\pi}[f_0(1500)]$	$\mathcal{B}_{KK}/\mathcal{B}_{\pi\pi}[f_0(1370)]$
	no form factor	0.5	0.18	0.14
$[qq][\bar{q}\bar{q}]$	β =400 MeV [4]	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	$0.1^c - 0.9^d$

ϕf_0 form factor as a probe for the $f_0(980)$ structure

Power-law behaviour & helicity rule

The cross section for $e^+e^- \to a\,b$ is

$$\sigma_{ab}(s) = \underbrace{\sigma_{ab}^{QED}(s)}_{\text{point-like}}\,|F_{ab}(s)|^2$$

Asymptotic behaviour as $s \to \infty$

$$F_{ab}(s) \propto s^{-[n_h+|\lambda_a+\lambda_b|-1]}$$

n_h = number of flavor fields

$\lambda_{a,b}$ = helicity of $h_{a,b}$

Quark hadron duality

Analyticity gives the "low-energy sum rule" $\int_{s_0}^{s_{max}} |F_{ab}(s)|^2 ds \approx \int_{s_0}^{s_{max}} |F_{asy}(s)|^2 ds$

Low energy VMD resonant contributions average out to the asymptotic behaviour extrapolated at low s

$$\overline{F^2_{ab,j}} = \frac{1}{\Delta s}\int_{s_j}^{s_{j+1}} |F_{ab}(s)|^2 ds \qquad s_j = s_0 + j\cdot\Delta s$$

$j = 0, 1, \ldots, N_{int}$ and $\Delta s = (4GeV)^2/N_{int}$

$\Delta E \Delta t \geq \hbar$

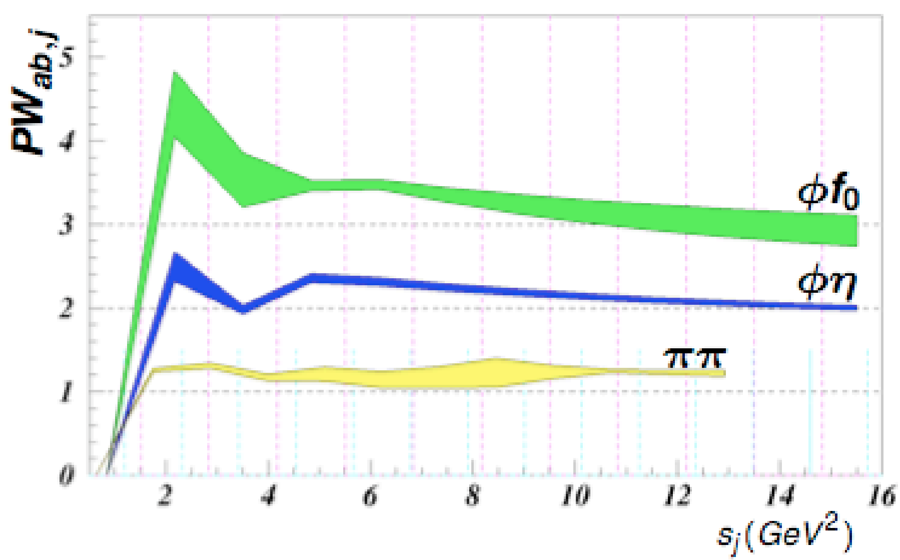
By integrating over a large ΔE we are investigating small Δt before the quark hadronization

Three cases: $ab = \phi\eta, \phi f_0, \pi\pi$

The asymptotic power is

$$PW_{ab,j} = -\frac{\ln\left(\overline{F^2_{ab,j}}/\overline{F^2_{ab,1}}\right)}{2\ln[(s_j+s_{j+1})/(s_0+s_1)]}$$

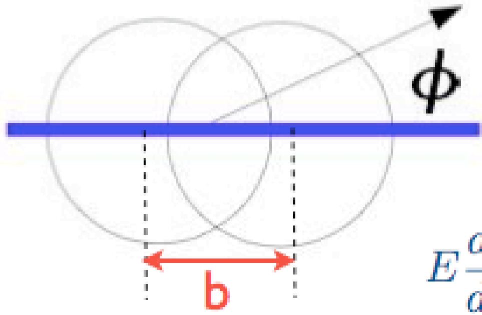
$$PW_{ab,j} \underset{j>1}{\approx} \begin{cases} n_h & ab = \phi\eta, \phi f_0 \quad |\lambda_a+\lambda_b| = 1 \\ n_h - 1 & ab = \pi\pi \quad |\lambda_a+\lambda_b| = 0 \end{cases}$$



Simone Pacetti LNF-INFN

Quark Counting in Heavy Ion Collisions

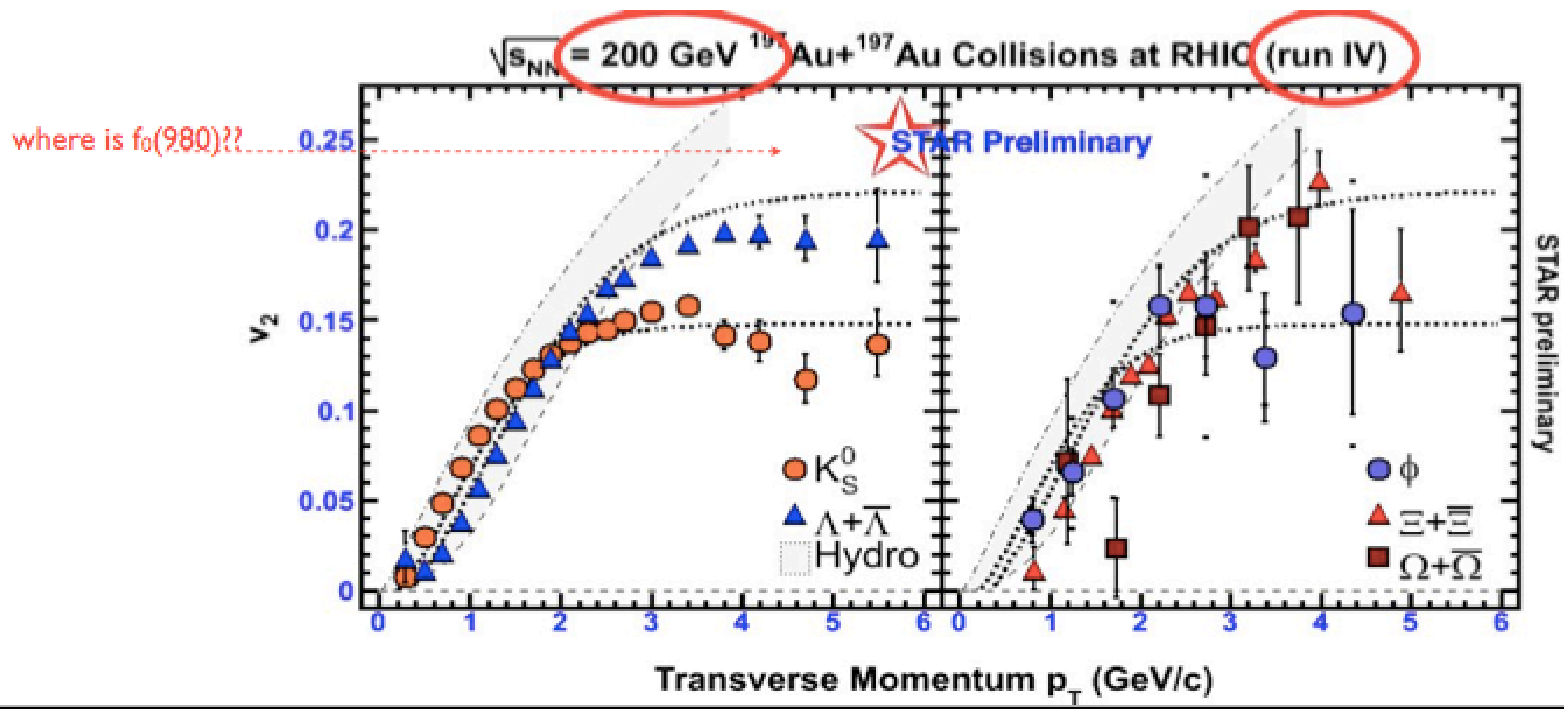
The elliptic-flow counting



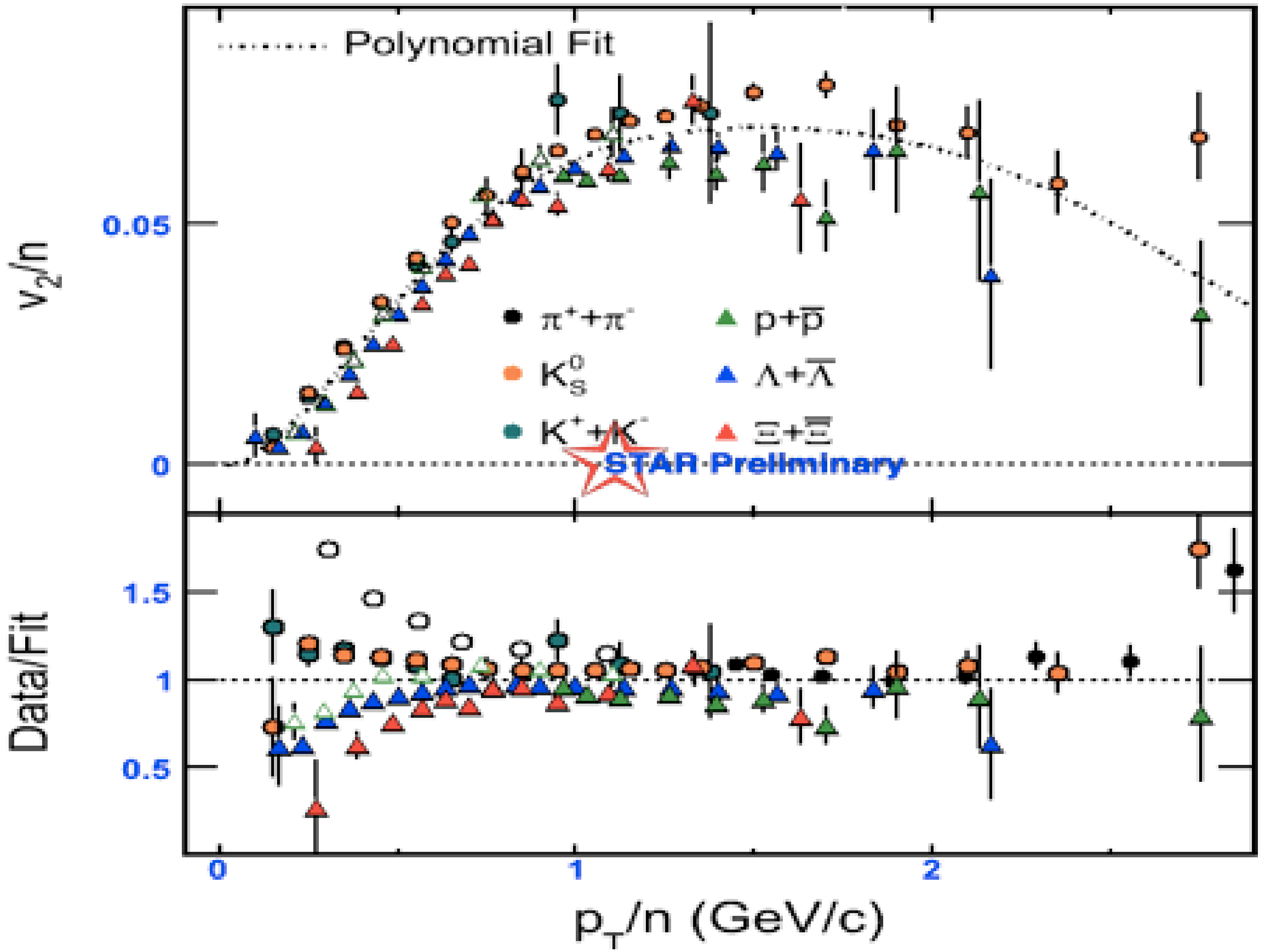
The collision plane is undetermined

$$E\frac{dN}{d^3p} = \frac{1}{2\pi}\frac{dN}{p_\perp dp_\perp d\eta}[1 + 2v_2(p_\perp)\cos(2(\phi - \psi_{\rm plane})) + ...]$$

$v_2 \sim 0.2 \Leftrightarrow$ 40% more particles emitted in the reaction plane

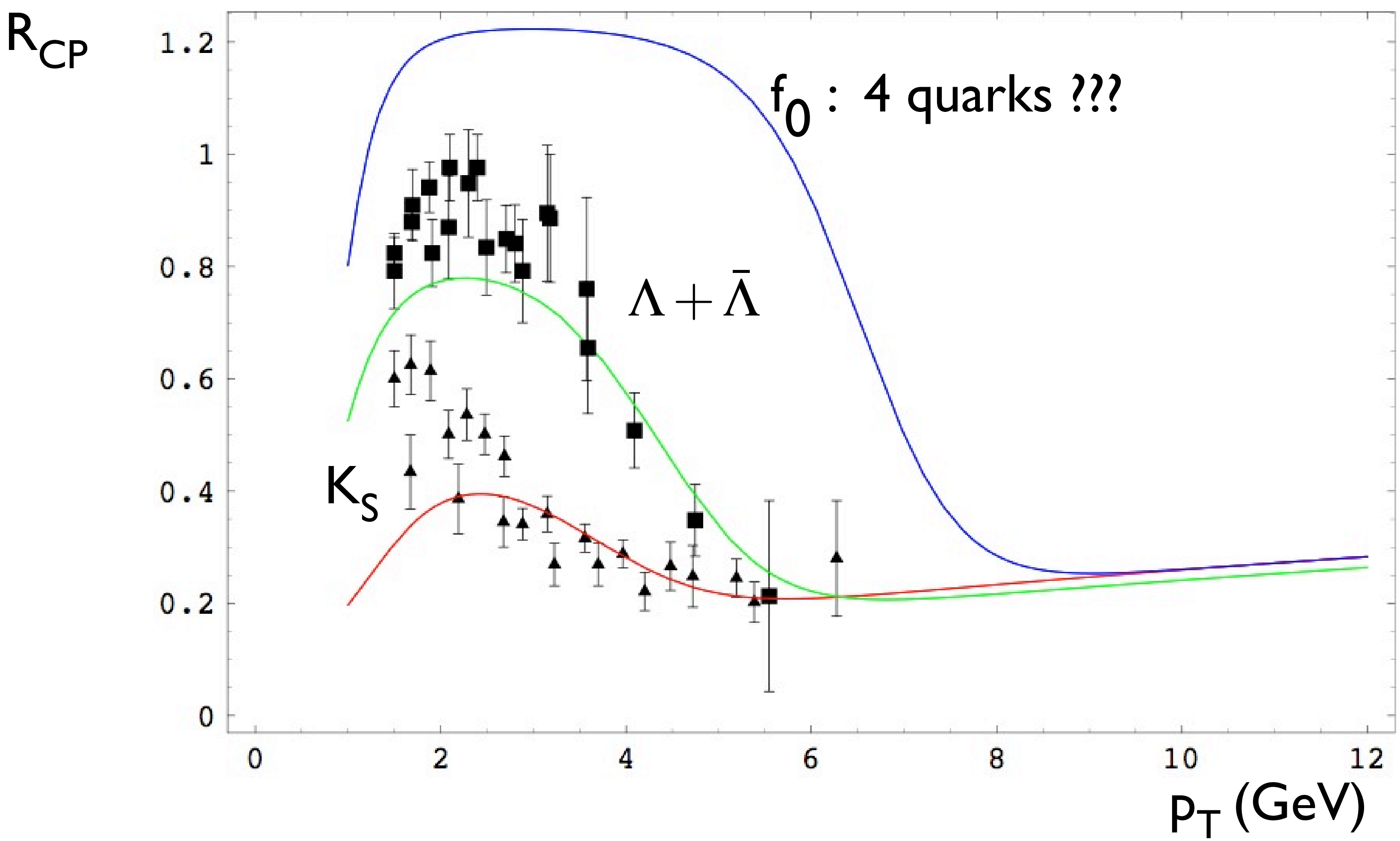


Quark Counting



Ratio: Central to peripheral (Au-Au)

(L. M., A. Polosa, V. Riquer, C. Salgado in preparation)



8. Conclusions

- From the heaven of charmonium ...we are now in quest of a ***new paradigm;***
- Basic QCD does not help much (for now), theoretical research is DATA DRIVEN;
- a variety of J^{PC} quantum numbers have been observed, several particles decay in J/Ψ +pions: X(3872), X(3940) and Y(4260);
- The observation of $J^{PC}=1^{--}$ state Y(4260) is very interesting: orbital excitations are typical of colored objects in confining potential;
- hybrid (constituent gluon) interpretation of Y(4260) also possible and actively pursued.

Conclusions (cont'd)

- Low-energy spectroscopy is also very interesting
- A second nonet displays anomalous spectrum
- is there a glueball at 1500??
- meson production in heavy ion Collisions can be an exceptional tool to count quarks!!
- What is the number of constituents of a glueball???

Hadron spectroscopy is alive and well!!