Open Problems in Hadron Spectroscopy

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Landau Memorial Meeting, Moscow, June 19-20, 2008

Hommage to Lev Landau

...scussione. Il fisico Lev Landau (a destra) con Werner Heis...

24 ORE

Data 20-01-2008
Pagina 40
Foglio 1 / 2

Protagonisti della fisica

Landau, genio contro Stalin

Pagò col carcere la propria indipendenza. Lo salvarono le ricerche sull'elio superfluido che gli valsero il Nobel. Leggendaria la sua autostima: «Resto solo io», disse quando morì Fermi

di **Luciano Maiani**

Quando un mio giovane collaboratore ha visto la foto sulla copertina del libro che mi era stato mandato per la recensione, ha spalancato gli occhi e ha ...

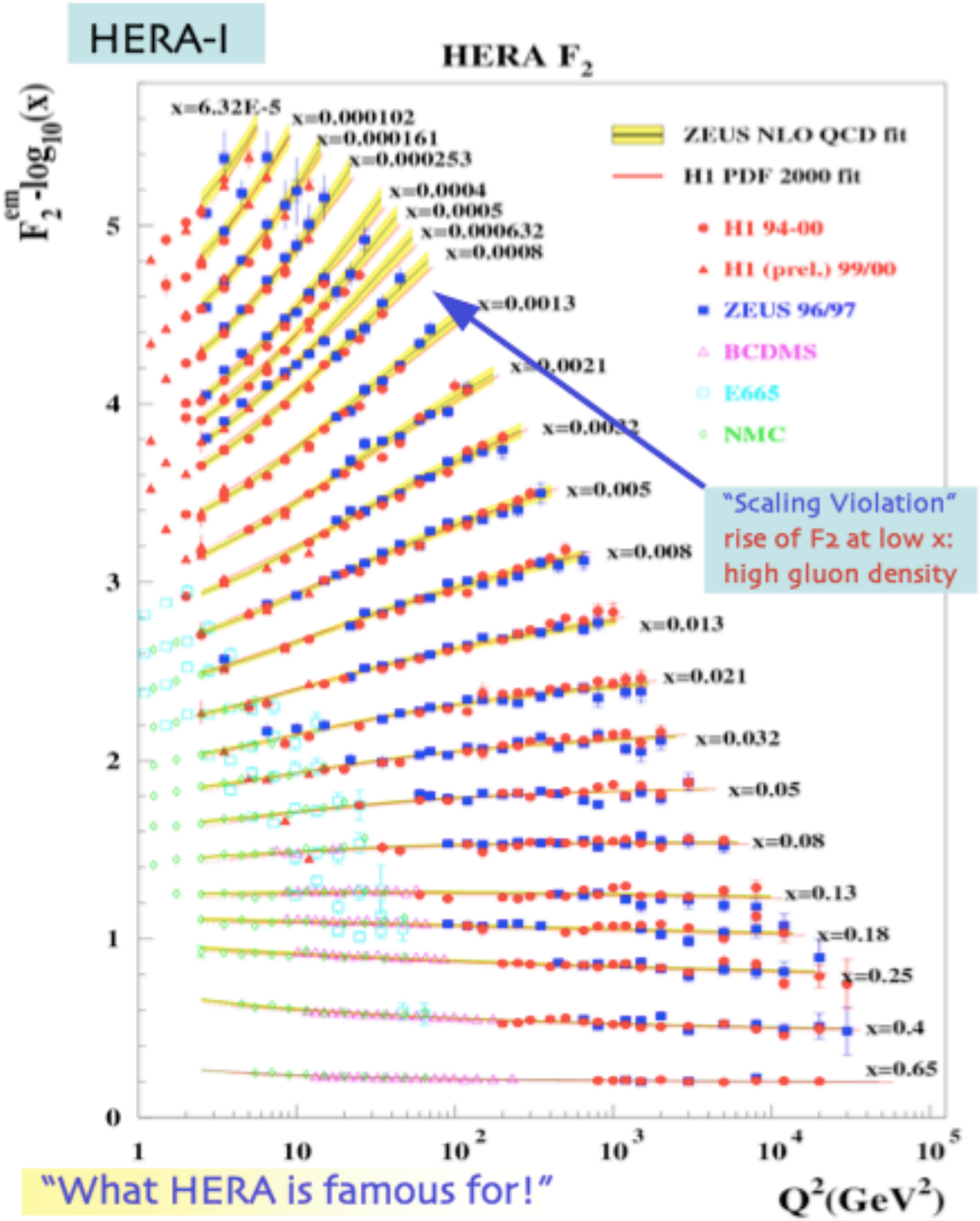
... di battaglia intellettuale esaltante.

A Leningrado, Landau e due suoi amici, Ivanenko e Gamov (che poi fuggirà negli Stati Uniti, vincerà il Nobel e diventerà il principale teorico del Big Bang), formeranno un terzetto di fisici di punta chiamato «I tre moschettieri», sempre oscillanti tra grande in-...

Nonostante questa fobia, Landau si rivelerà un grande maestro. Presuntuoso, certo. Come testimonia la sua personale graduatoria, articolata su un sistema di cinque punti, con la quale classificava i fisici teorici di tutto il mondo. Anche Fermi ne aveva una e la cosa curiosa è che le due graduato-...

Summary

1. Introduction
2. Light scalar mesons resolved
3. QCD strings
4. New Charmonium states
5. Thresholds, cusps and new states
6. Two X states ?
7. A charged charmonium ?
8. Outlook



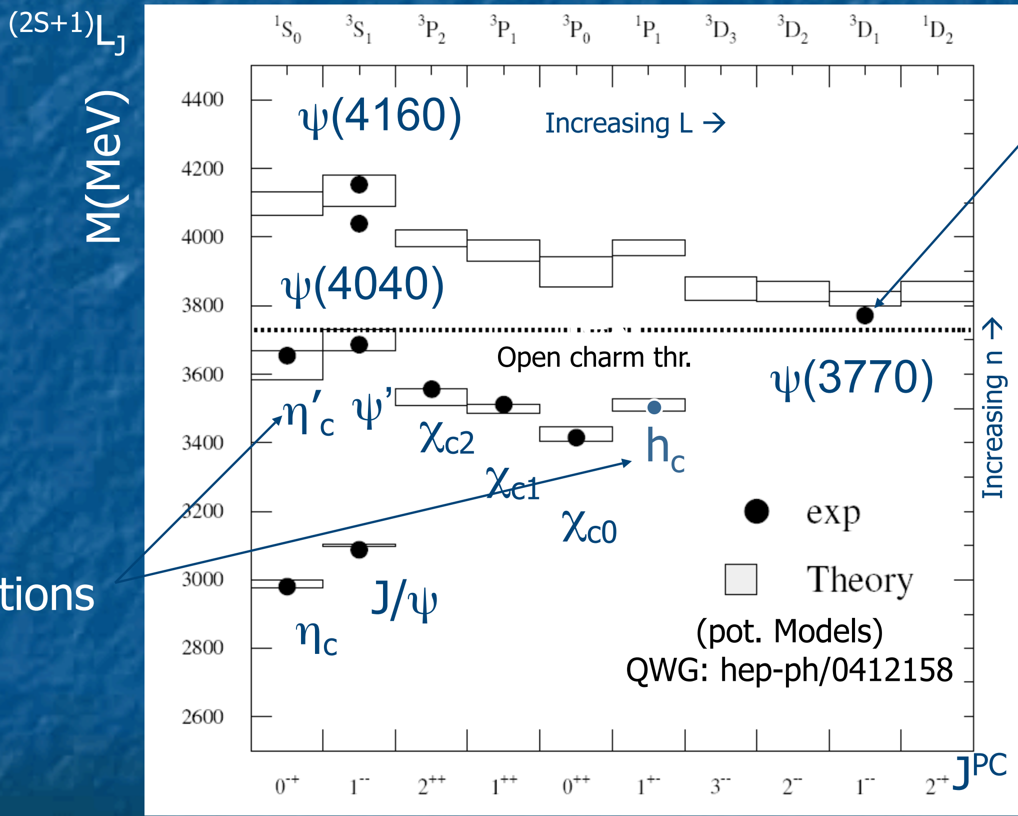
1. Introduction

- Thirty years after its discovery, we still do not fully control QCD.
- Only in few cases, we can produce reliable theoretical predictions. Even in these cases we need to rely upon phenomenological parameters. Ab initio calculations (lattice) still have many limitations.
- Scaling violations in DIS, input: the structure function at some Q_0^2

Large quark mass makes it possible to use potential theory for c-cbar states. Input: the parameters of the potential. Remarkable accuracy has been achieved

slide from R. Faccini, LP07

Charmonium: state of the art



same J^{PC} as J/ψ but mostly D wave !

Recent acquisitions

Basically all states below the open charm threshold are observed and explained

The (unexplained) success of the constituent quark model

- A. Sakharov, Zeldovich
- H. Lipkin
- A. De Rujula, H. Georgi and S. Glashow

- Quark constituent masses and spin-spin interaction:

$$H = \sum_i m_i + \sum_{i<j} \kappa_{ij} \, (\sigma_i \cdot \sigma_j) \, \delta^3(\vec{r}_{ij})$$

$$\kappa_{ij} \simeq \frac{v}{m_i m_j}$$

- Hyperfine interaction explains, among other things, the Λ-Σ^0 mass difference (they have the same flavor composition) as due to the hyperfine interaction
- Baryons with one heavy and two light quarks can be described by a light diquark+the heavy quark

contribution of the hyperfine interaction energies is removed. For the two cases of spin-zero [8] $S=0$ and spin-one $S=1$ diquarks,

$$\begin{array}{ccccccc} M(N) - \tilde{M}(\rho) & = & M(\Lambda) - \tilde{M}(K^*) & = & M(\Lambda_c) - \tilde{M}(D^*) & = & M(\Lambda_b) - \tilde{M}(B^*) \\ 323 \text{ MeV} & \approx & 321 \text{ MeV} & \approx & 312 \text{ MeV} & \approx & 310 \text{ MeV} \end{array}$$

$$\begin{array}{ccccccc} \tilde{M}(\Delta) - \tilde{M}(\rho) & = & \tilde{M}(\Sigma) - \tilde{M}(K^*) & = & \tilde{M}(\Sigma_c) - \tilde{M}(D^*) & = & \tilde{M}(\Sigma_b) - \tilde{M}(B^*) \\ 517.56 \text{ MeV} & \approx & 526.43 \text{ MeV} & \approx & 523.95 \text{ MeV} & \approx & 512.45 \text{ MeV} \end{array}$$

- M. Karliner, H. Lipkin, hep-ph/0611306v3

Tilde= spin average= eliminates spin- spin interaction between the diquark and the “valence quark”

2. Light Scalar Mesons Resolved

Mass and width of the lowest resonance in QCD

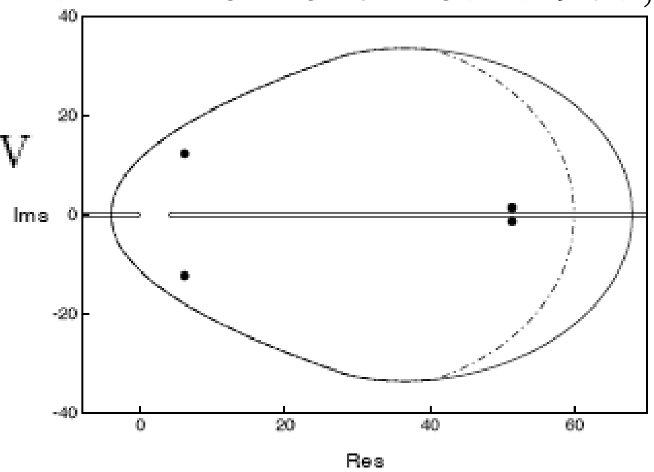
I. Caprini
National Institute of Physics and Nuclear Engineering, Bucharest, R-077125 Romania

G. Colangelo and H. Leutwyler
Institute for Theoretical Physics, University of Bern, Sidlerstr. 5, CH-3012 Bern, Switzerland

arXiv:hep-ph/0512364v2, 7 Apr 2006

Dispersion equation analysis of π π scattering in S-wave indicate a broad resonance around 500 MeV, σ, and a narrow one around 980, f_0.

$$m_0 = (441 \pm 4) - i\,(272 \pm 6)\ \mathrm{MeV}$$

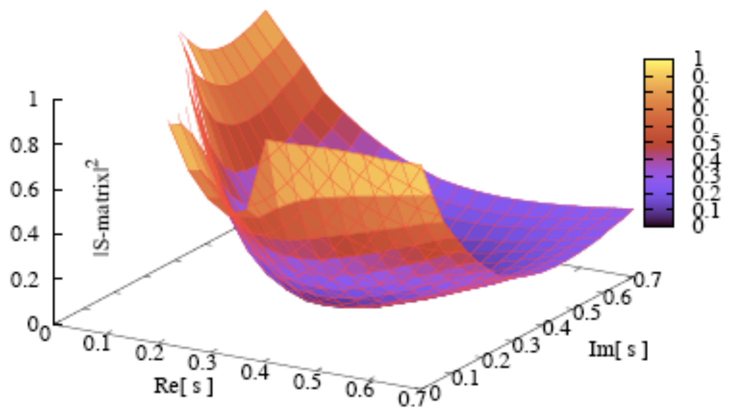


Re s and Im s are in units of m_π^2

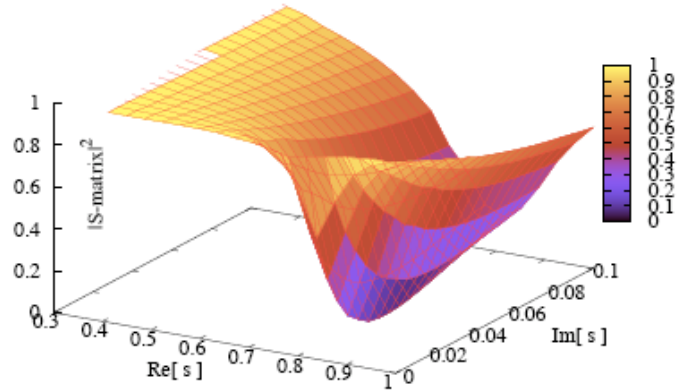
FIG. 2: Domain of validity of the Roy equations.

a similar analysis proves the existence of kappa

S-wave



P-wave



The $K_0^*(800)$ scalar resonance from Roy-Steiner representations of πK scattering

arXiv:hep-ph/0607133v2 25 Aug 2006

S. Descotes-Genon[a] and B. Moussallam[b]

$$M_\kappa = 658 \pm 13 \text{ MeV}, \quad \Gamma_\kappa = 557 \pm 24 \text{ MeV}$$

		M_κ (MeV)	Γ_κ (MeV)
	This work	658 ± 13	557 ± 24
	Zhou, Zheng [16]	694 ± 53	606 ± 89
	Jamin et al. [18]	708	610
E791	Aitala et al. [7]	$721 \pm 19 \pm 43$	$584 \pm 43 \pm 87$
	Pelaez [19]	750 ± 18	452 ± 22
	Bugg [9]	750^{+30}_{-55}	684 ± 120
BES II	Ablikim et al. [20]	$841 \pm 23^{+64}_{-55}$	$618 \pm 52^{+55}_{-87}$
	Ishida et al. [14]	877^{+65}_{-30}	668^{+235}_{-110}

a complete nonet

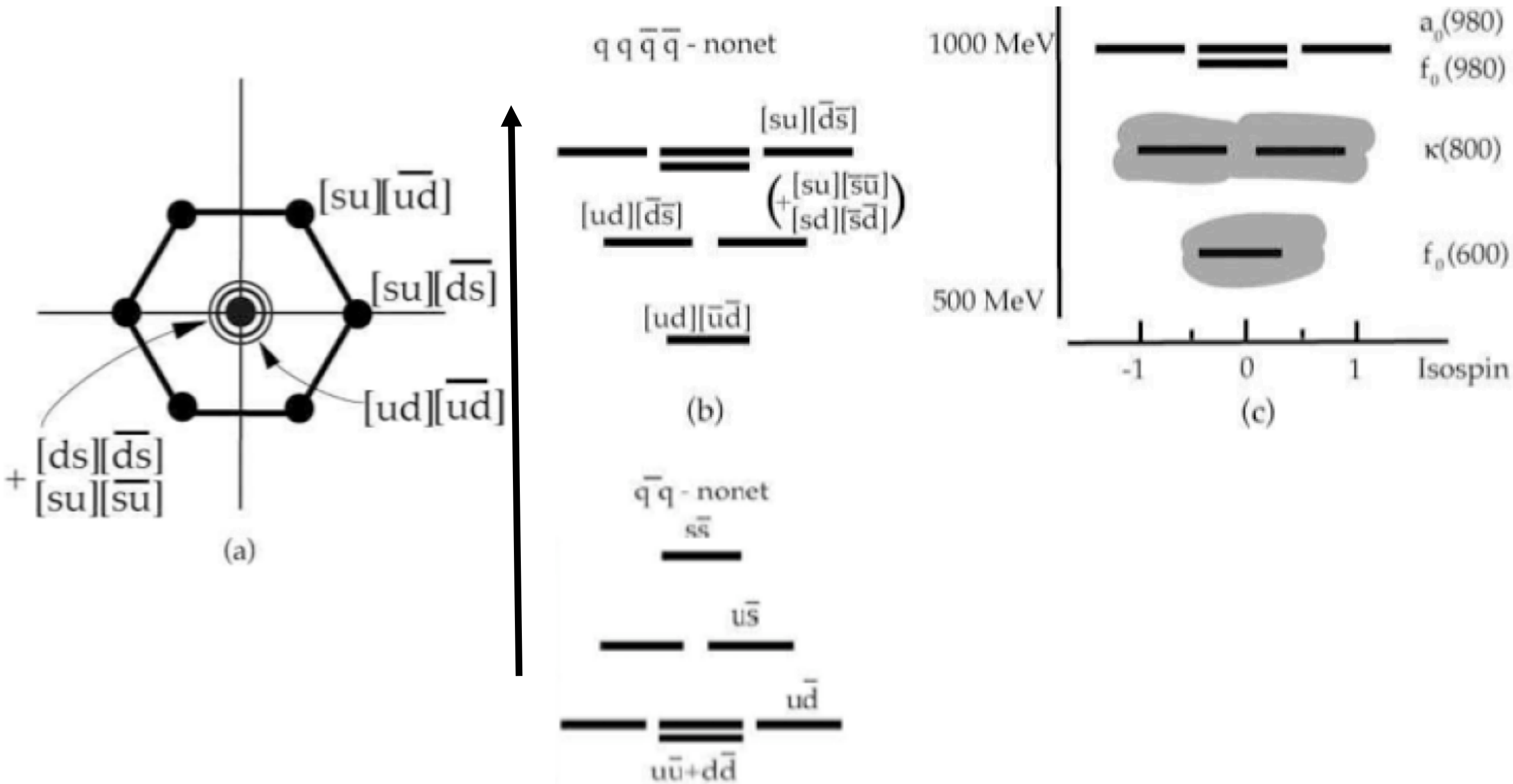
- σ(450, I=0), ϰ(660, I=1/2), f_0(980, I=0) and a_0(980, I=1)) fill neatly an entire nonet, but masses are in reverse order with respect to a q-qbar nonet
- pattern at complete variance with the very successful constituent quark model
- Candidate for a Cryptoexotic multiplet diquarks(antidiquarks) are antisymmetric in:
  - color (diquark = $\bar{\mathbf{3}}_{color}$, antidiquark = $\mathbf{3}_{color}$)
  - spin (diquark and antidiquark have spin = 0)
  - flavor (diquark is $\bar{\mathbf{3}}_{flavor}$, antidiquark is $\mathbf{3}_{flavor}$)
- earlier proposal by R. Jaffe (1977) and by R. Jaffe &F. Wilczeck, more recently reconsidered by our group.

L.Maiani, F. Piccinini, A. Polosa, V. Riquer, PRL **93**(2004) 212002

$$\begin{aligned} \kappa &= [su][\bar{u}\bar{d}],\ [sd][\bar{u}\bar{d}] \\ \sigma &= [ud][\bar{u}\bar{d}] \end{aligned}$$

$$f_0/(a_0)^0 = \frac{[su][\bar{s}\bar{u}] \pm [sd][\bar{s}\bar{d}]}{\sqrt{2}}$$

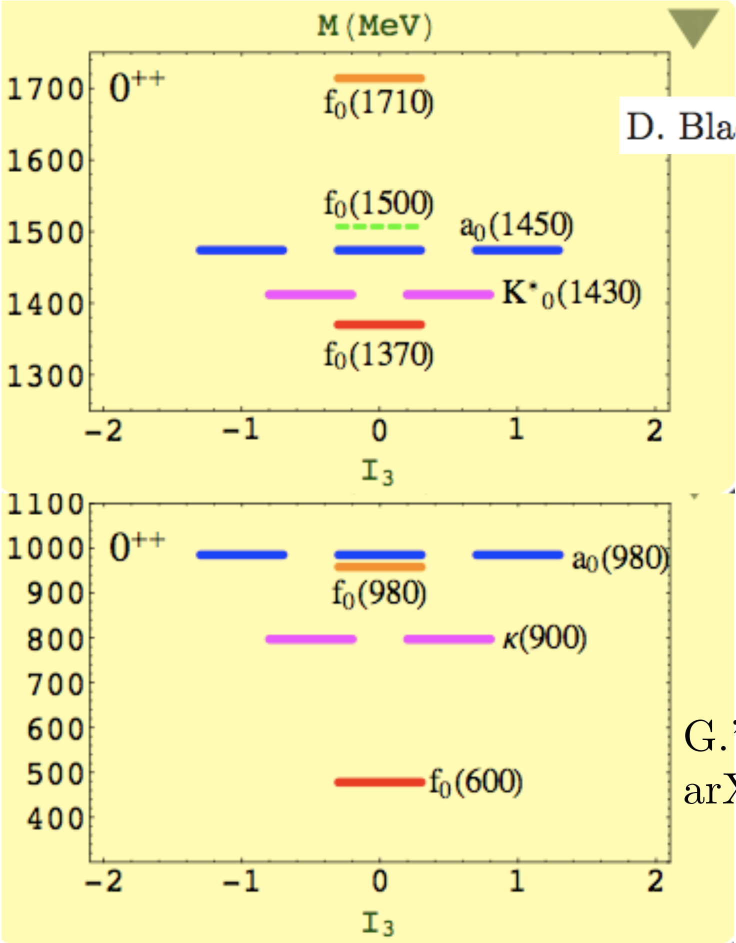
Quantum numbers and mass spectrum



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

The fully antisymmetric (anti) diquark structure agrees with the absence of truly exotic states, i.e. I=2, ππ resonances.

P-wave q-qbar scalar mesons: where are they?



- Identified with the decimet of $a_0(1450)$

D. Black, A. Fariborz, J. Schechter, Phys. Rev. **D** 61, 074001 (2000)

- with a possible glueball:

C. Amsler and F. Close, Phys. Rev. **D** 53, 295 (1996)

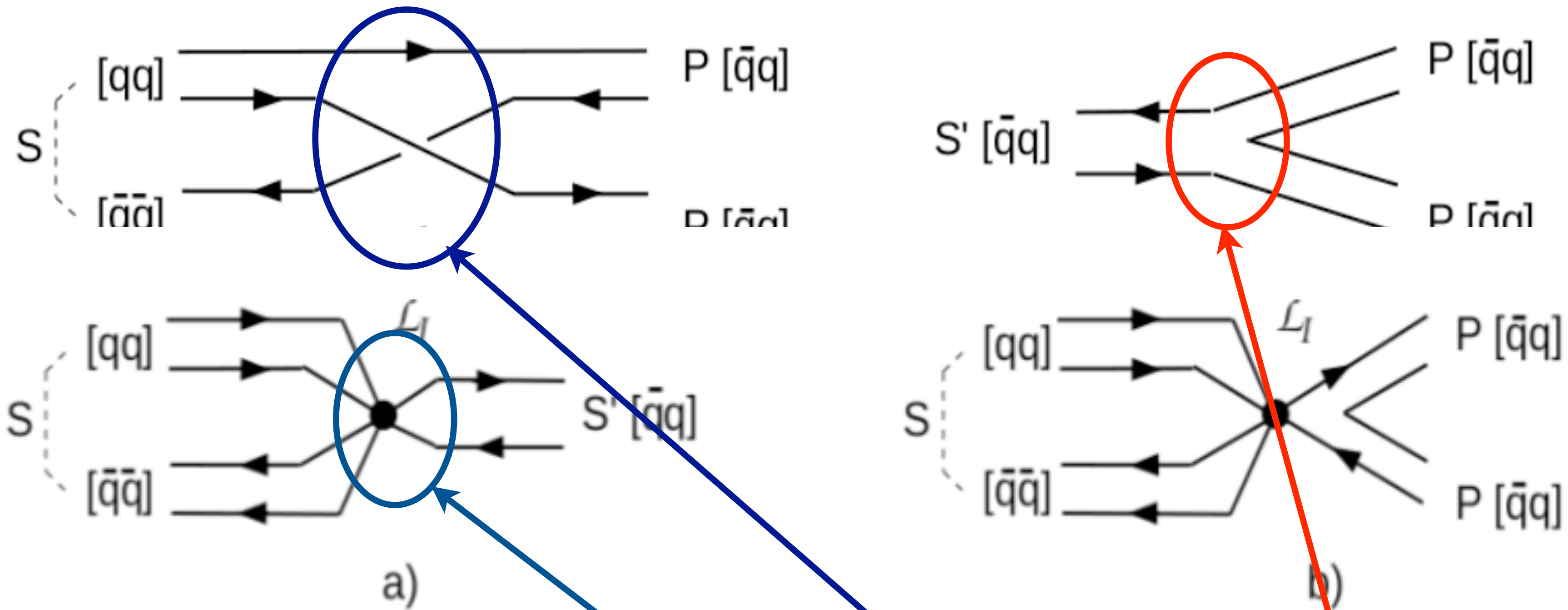
- peculiar features:
  - distorted spectrum, attributed by Black *et al*. to a (large) mixing with the lowest tetraquark multiplet
  - decay pattern rather fuzzy, with tetraquark features

G.'t-Hooft, G. Isidori, L. Maiani, A. Polosa, V. Riquer, arXiv:0801.228 and Phys. Letters B, 2008.

- both features can be attributed to instanton effects, which also produce a better picture of the lowest scalar meson decays.

Instanton induced decays and mixing

Leading quark diagrams for the decays into two pseudoscalar mesons:
(a) tetraquark, (b) $q\bar{q}$ scalar mesons



The two main effects of the instanton lagrangian in the scalar sector
(a) the tetraquark-$q\bar{q}$ mixing;
(b) the Zweig-rule violating $S \to PP$ amplitude

$$\mathcal{L}_{\mathrm{eff,all}} = \mathrm{Tr}\left(S\mathcal{M}_S^2 S\right) + \mathrm{Tr}\left(S'\mathcal{M}_{S'}^2 S'\right) + \gamma\, \mathrm{Tr}\left(SS'\right) + c_f O_f(S) + c_f O_1(S')$$

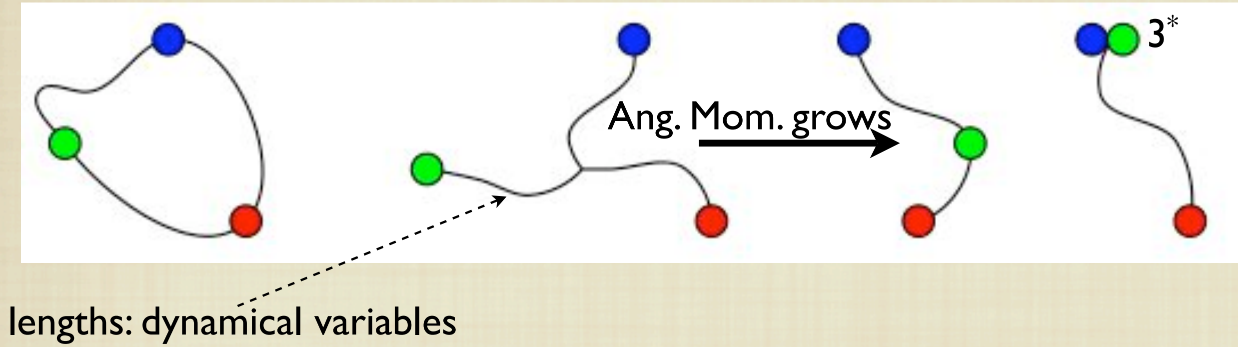
Two parameter fit to lightest scalar meson decays

G.'t-Hooft, G. Isidori, L. Maiani, A. Polosa, V. Riquer,
arXiv:0801.228 and Phys. Letters B, 2008.

Processes	$\mathcal{A}_{\rm expt}$	$\mathcal{A}_{\rm th}([qq][\bar{q}\bar{q}])$	$\mathcal{A}_{\rm th}(q\bar{q})$	
		best fit	with inst.	no inst.
$\sigma \to \pi^+\pi^-$	3.22 ± 0.04	1.6	input	input
$\kappa^+ \to K^0\pi^+$	5.2 ± 0.1	3.3	6.0	5.5
$f_0 \to \pi^+\pi^-$	1.4 ± 0.6	1.6	input	[0–1.6]
$f_0 \to K^+K^-$	3.8 ± 1.1	3.5	6.4	6.4
$a_0 \to \pi^0\eta$	2.8 ± 0.1	2.7	12.4	11.8
$a_0 \to K^+K^-$	2.16 ± 0.04	2.2	4.1	3.7

3. Strings & hadrons

G. `t Hooft hep-th/0408148



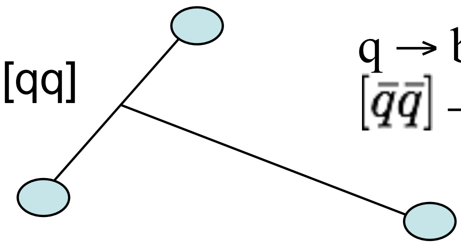
The Regge Trajectories for mesons and baryons seem to have the same slope.

The classically stable config. has a single open string with two quarks at the end points and one bouncing between them.

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

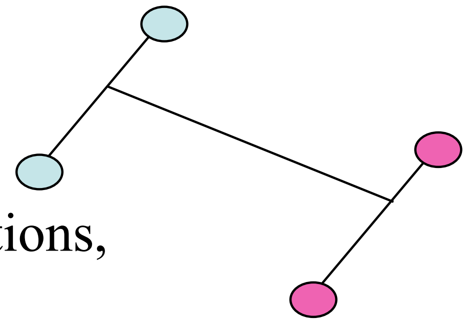
Diquark needs to combine with other colored objects

[qq]



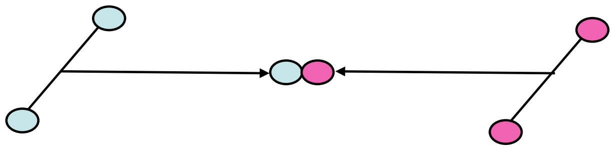
q → baryon (e.g. Λ), Y-shape

$[\bar{q}\bar{q}]$ → scalar meson, H-shape

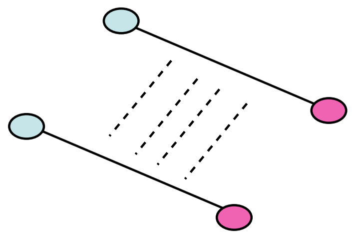


radial and orbital excitations, many states

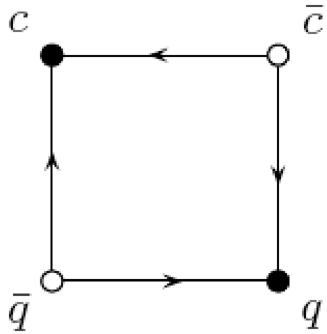
string topology is related to Baryon-antiBaryon: if you stretch the string, $[qq][\bar{q}\bar{q}] \to B\bar{B}$



Meson-meson molecules have a different string topology:
- are they bound?
- very few states

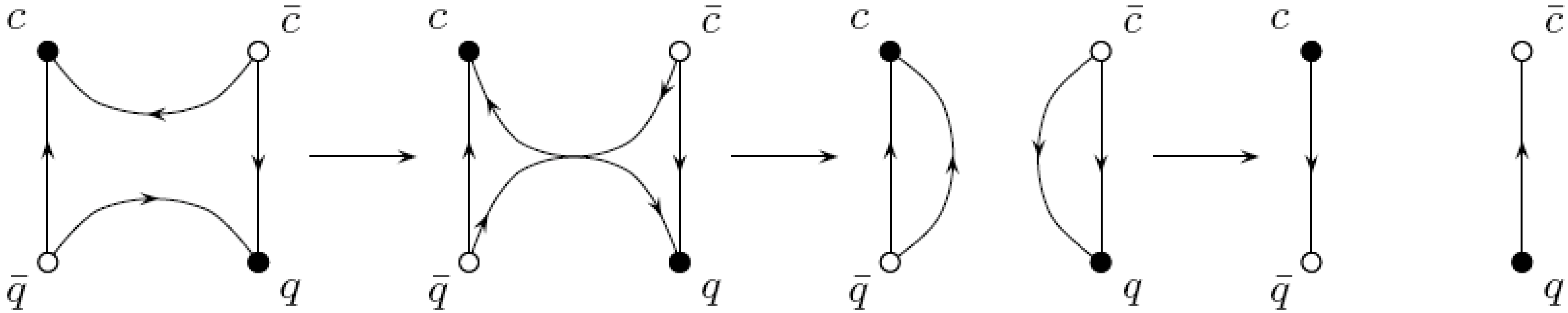


H-shaped diquarks are not the only possibility: □ tetraquarks proposed (S. S. Gershtein, A.K. Likhoded and G.P. Pronko) to explain 4-quark charmonia



- c-cbar are in color octet (favoured in B decay?)
- radial and orbital excitations are possible

Mechanism for strong decay of □- mesons
is very different from that of H mesons



4. New particles in the charmonium region: X&Y

- Mesons with hidden charm are being found by BELLE (at KEK) and BaBar (SLAC), which do not fit the Charmonium picture
- main processes are:
  - B non leptonic decays:

$$B^{\pm} \to K^{\pm} + X^0; \quad B^0 \to K^0 + X^0$$
$$X^0 \to \psi(nS) + \pi' s, \text{ or } D^{(*)} D^{(*)}$$

seen

$$B^{\pm} \to K^0 + X^{\pm}; \quad B^0 \to K^{\pm} + X^{\mp}$$
$$X^+ \to \psi(nS) + \pi^+ + \pi^0, \text{ or } D^{(*)} D^{(*)}$$

not seen (yet?)

  - Initial State Radiation:

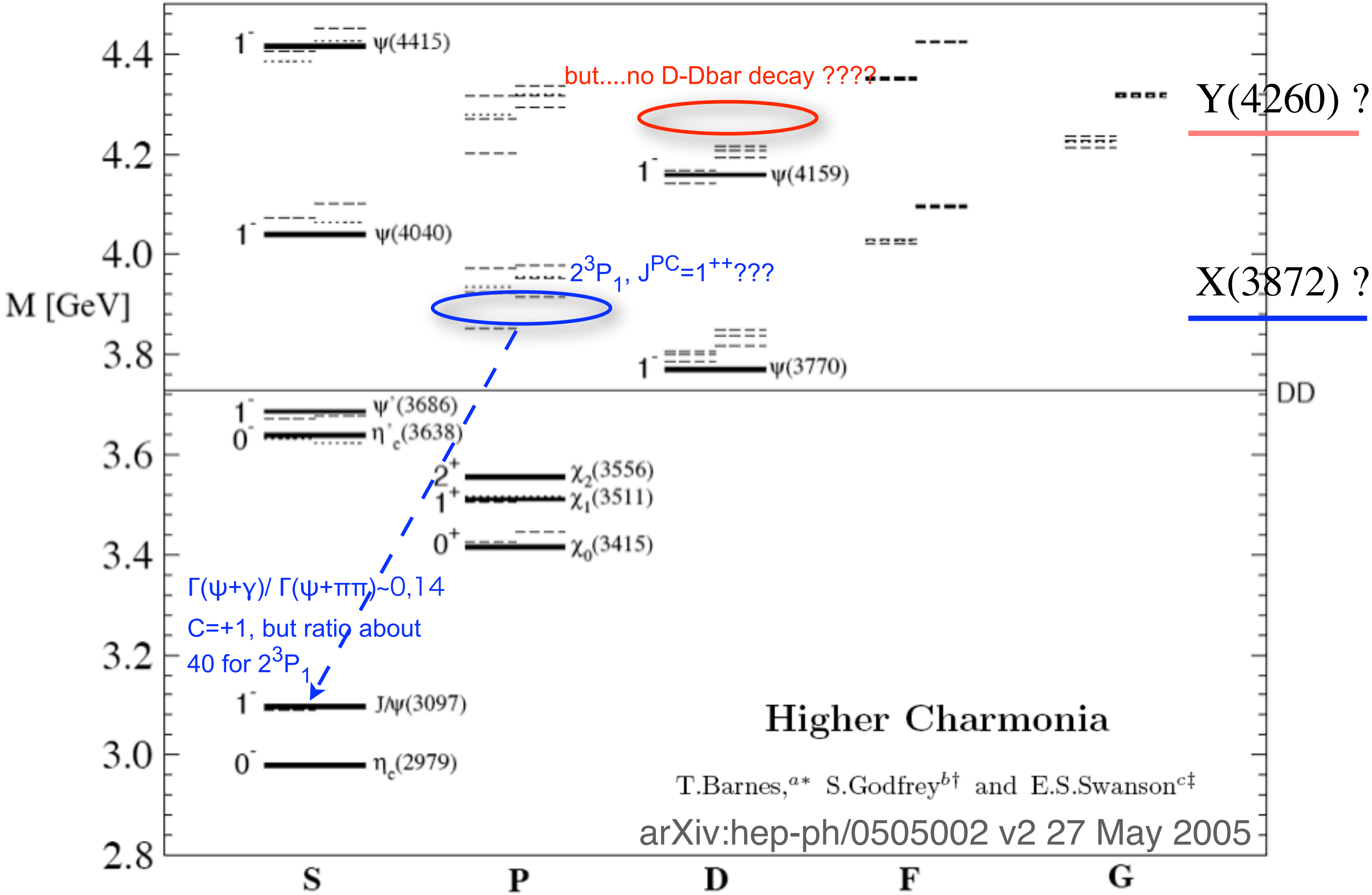
$$e^+e^- \to \gamma(\text{initial state}) + Y$$
$$Y \to \psi(nS) + \pi' s, \text{ or } D^{(*)} D^{(*)}$$

seen

since Y originates from a virtual photon, it has $J^{PC}=1^{--}$.

  - $e^+e^- \to \psi(1S) + (D^{(*)} D^{(*)})_M$ (only C=+1 are produced)

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



Proposed interpretations

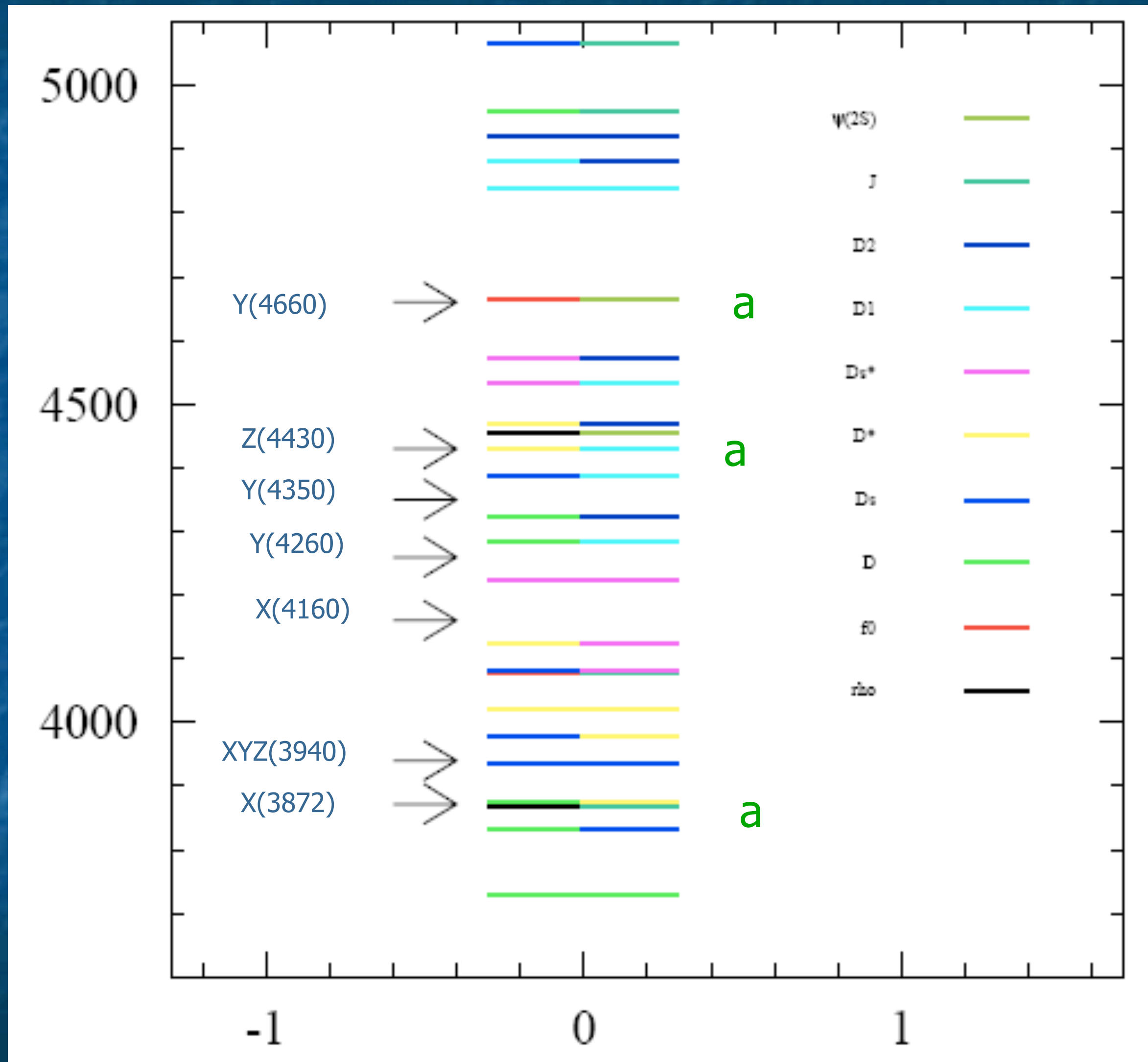
- X(3872) =
  - D-D* molecule:
    $M(X) - M(D^{*0}\bar{D}^0) = +0.6 \text{ MeV}$
    - •Close and Page PL B 578 (2004) 119;
    - • Tornqvist PLB 590 (2004) 209;
    - • Swanson, PL B588 (2004) 189.
  - diquark-antidiquark bound state: $[(cq)\,(\bar{c}\bar{q})]_{S-wave},\ J^{PC} = 1^{++};\ \ (q = u,\, d)$
    - •Maiani, Piccinini, Polosa and Riquer, PR D 71 (2005) 014028
- Y(4260) =
  - Hybrid state: $(c\,\bar{c}\,g)$
    - •Close and Page, PL B 628 (2005) 215;
    - • Kou and Pene, PL B 631, 164 (2005)
  - diquark-antidiquark bound state: $[(cs)\,(\bar{c}\bar{s})]_{P-wave},\ J^{PC} = 1^{--}.$
    - •Maiani, Piccinini, Polosa and Riquer, PR D 72 (2005) 031502
  - molecular state ($\chi_c + \omega$)
    - • Yuan, Wang and Mo, PL B 634 (2006) 399
  - baryonium: $\Lambda_c^+\text{-}\Lambda_c^-$
    - • Qiao, PL B 639 (2006) 263

- hybrid X(3872) excluded by large isospin violation: decays in $\psi\rho$ and $\psi\omega$;

5. Thresholds, cusps and new states

Molecular models and threshold effects require vicinity to threshold

Is this the case?



Cusps effects

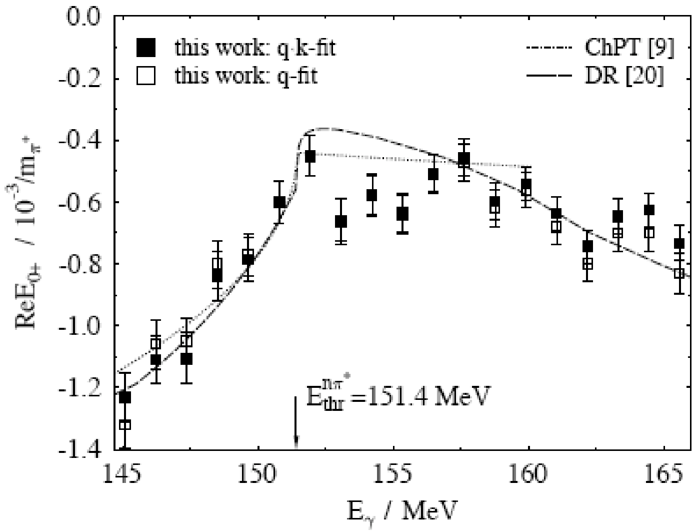
EFFECTS OF S-WAVE THRESHOLDS

Jonathan L. Rosner

Enrico Fermi Institute and Department of Physics, University of Chicago
5640 South Ellis Avenue, Chicago, IL 60637

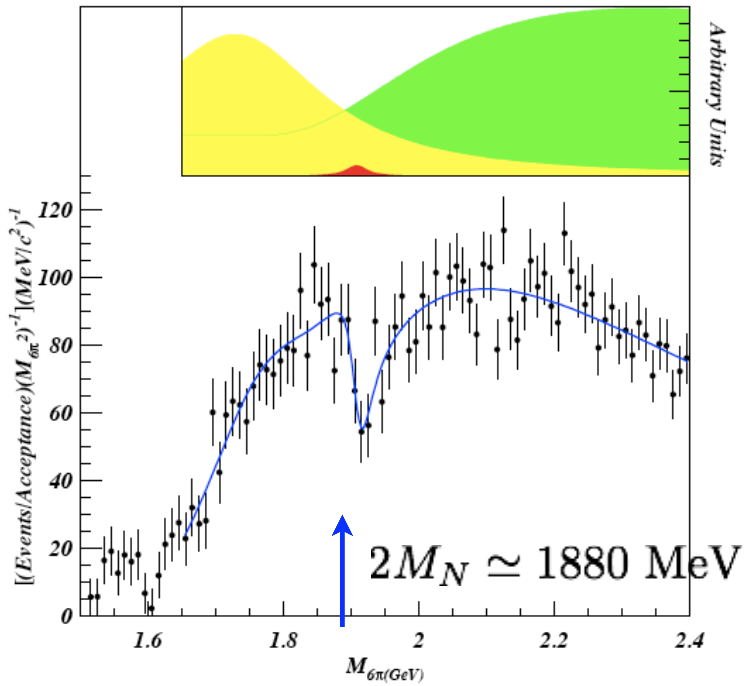
August 2006

- Dips are observed in various reactions as the effect of the opening of an S-wave threshold in another channel

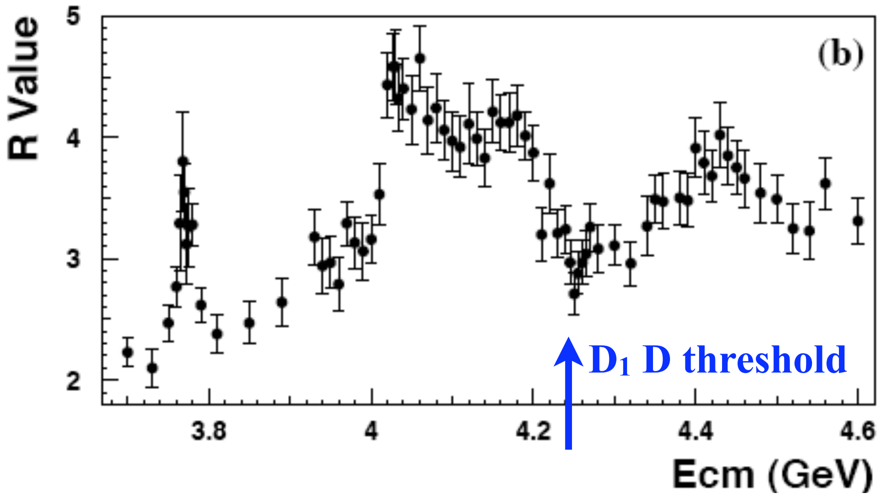


$\gamma p \to p\pi^0$ in the proximity of the $n\pi^+$ threshold
A. Schmidt et al., Phys. Rev. Lett. **87** (2001), 232501

Spectrum of diffractively produced $3\pi^+3\pi^-$, together with results of a fit with two resonances and continuum.
The inset shows the relative fraction of each amplitude without interference.

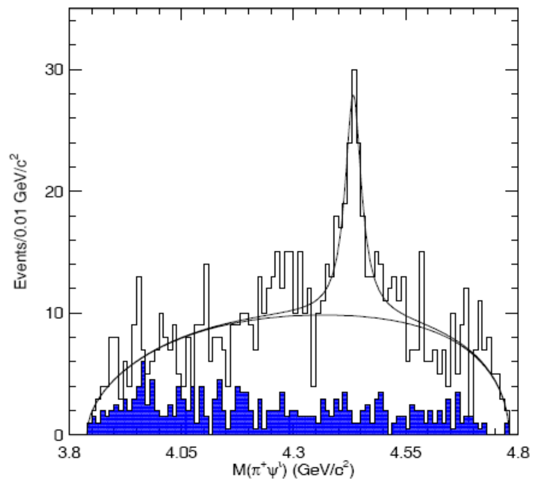


Cusp effects (cont'd)



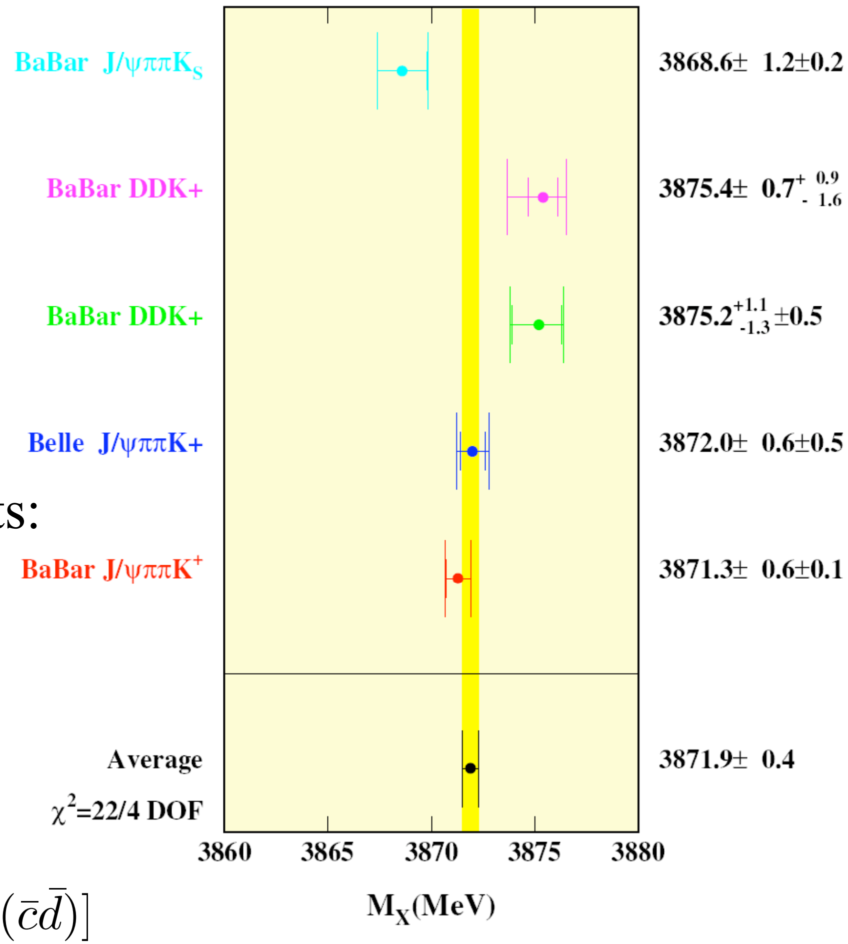
The lightest established candidate for D_1 has a mass of about 2.42 GeV/c^2, corresponding to a threshold of 4.285 GeV. It is this threshold that we associate with the dip in R between 4.19 and 4.25 GeV.

For comparison:
$Z^+(4430) \rightarrow \pi^+ \psi(2S)$



6. Two X states?

arXiv:0707.3354 [hep-ph] 23 Jul 2007



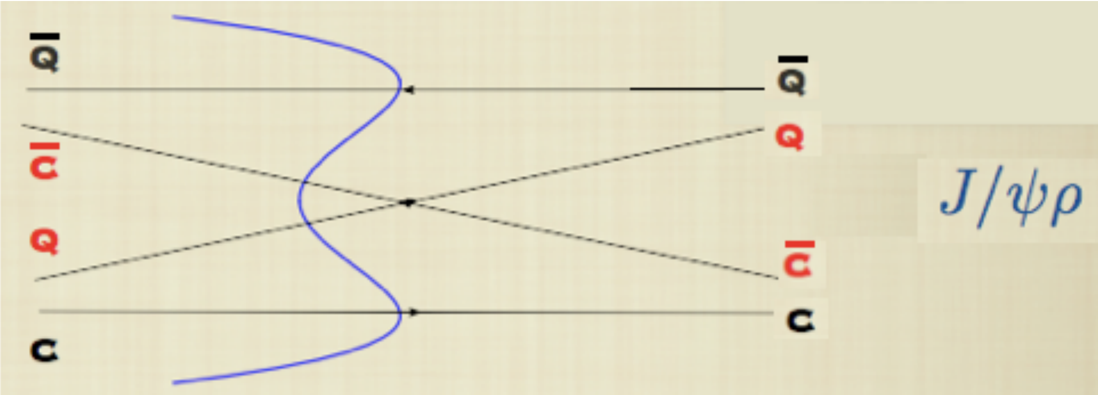
Poor agreement among mass measurements:

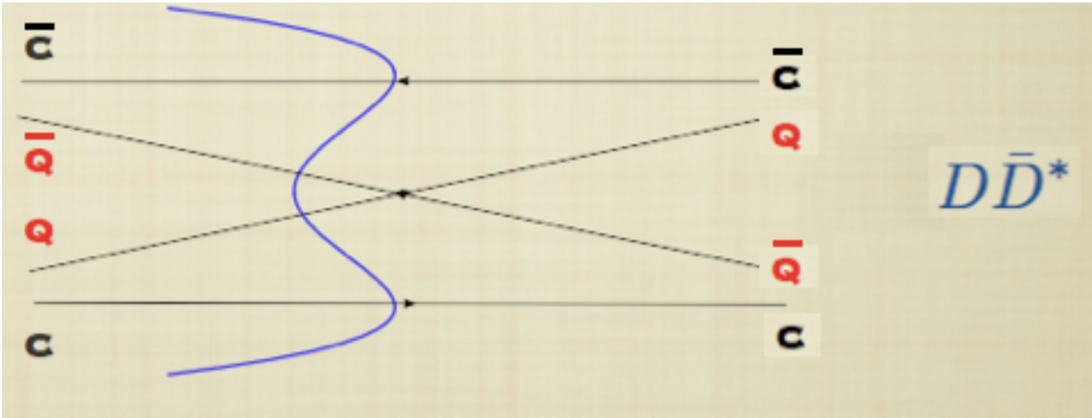
$X \to J/\psi\pi\pi$ and $X \to DD^{(*)}$ differ by ~4σ

two X states @ 3872 and 3876 ?

- simplest interpretation: $[(cu)(\bar{c}\bar{u})]$ and $[(cd)(\bar{c}\bar{d})]$
- molecule interpretation disfavored

Babar confirms two different masses with 4.5 σ are production and decay consistent? J/ψππ must be suppressed w.r.t. D*D





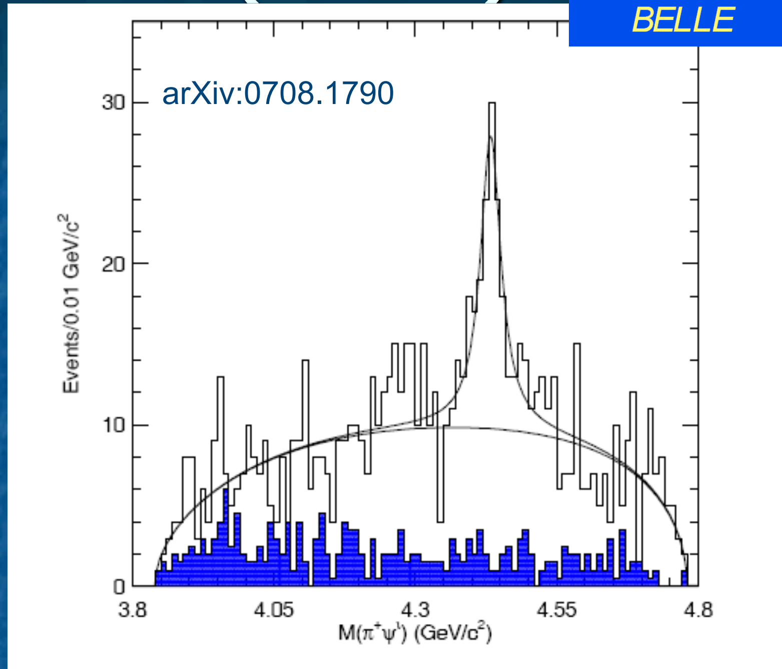
Tunneling of c quark to flip from one equilibrium position to the other could be much suppressed with respect to the tunneling of the light quark Q:

$$\Gamma(X_u \to D^0\bar{D}^0\pi^0) >> \Gamma(X_u \to J/\psi\pi^+\pi^-) \simeq$$
$$\simeq \Gamma(X_d \to J/\psi\pi^+\pi^-) >> \Gamma(X_d \to D^0\bar{D}^0\pi^0)$$

The first charged state: Z(4430)!

$B^{\pm} \rightarrow Z^{\pm} K_s$ or $B^0 \rightarrow Z^i K^{\pm}$

$Z^{\pm} \rightarrow \psi(2S)\pi^{\pm}$



Total significance: 7.3s

M = (4433±4) MeV

$\Gamma = (44^{+17}_{-13})$ MeV

Too narrow to be a reflection

$BF(B \rightarrow KZ) \times BF(Z \rightarrow \psi(2S)\pi) = (4.1 \pm 1.0 \pm 1.3)\ 10^{-5}$

Subset	Signal events	Mass (GeV)	Width (GeV)	signif. (σ)	constr. yield ($\Gamma = 0.044$GeV)
$\psi' \to \pi^+\pi^- J/\psi$	52.9 ± 15.1	4.435 ± 0.004	$0.026^{+0.013}_{-0.008}$	5.5	67.3 ± 14.9
$\psi' \to \ell^+\ell^-$	104.8 ± 34.5	4.435 ± 0.010	$0.097^{+0.041}_{-0.031}$	5.6	60.1 ± 13.8
$J/\psi(\psi') \to e^+e^-$	45.4 ± 16.6	4.430 ± 0.010	$0.052^{+0.026}_{-0.020}$	4.1	40.9 ± 11.9
$J/\psi(\psi') \to \mu^+\mu^-$	79.4 ± 24.6	4.434 ± 0.004	$0.039^{+0.022}_{-0.013}$	6.1	84.8 ± 17.0
$K^{\pm}\pi^{\mp}\psi'$	106.5 ± 26.6	4.434 ± 0.005	$0.046^{+0.017}_{-0.013}$	6.6	104.7 ± 18.6
$K_S\pi^{\mp}\psi'$	21.0 ± 8.3	4.430 ± 0.009	0.046-fixed	3.0	20.6 ± 8.2
vary K^* veto	238.1 ± 64.2	4.436 ± 0.005	$0.068^{+0.031}_{-0.019}$	7.9	178.4 ± 26.4

Xcheck: separate in subsamples

BF and mass consistent between $B^{\pm}$ and B0 within large errors [in $B^{\pm}$ decays M=(4430±9) MeV ; BF_/ BF_0=1.0±0

Prior search with no evidence: $B \rightarrow X^+K$ with $X^+ \rightarrow J/\psi\ \pi\pi^0$

PRD 71, 031501 (2005)

R.Faccini, LeptonPhoton Conference 2007

Proposed interpretations

- $Z^+(4433)$, BELLE Collaboration

  arXiv:0708.1790v1 [hep-ex] 14 Aug 2007

  – charged tetraquark: $[cu][\bar{c}\bar{d}]$

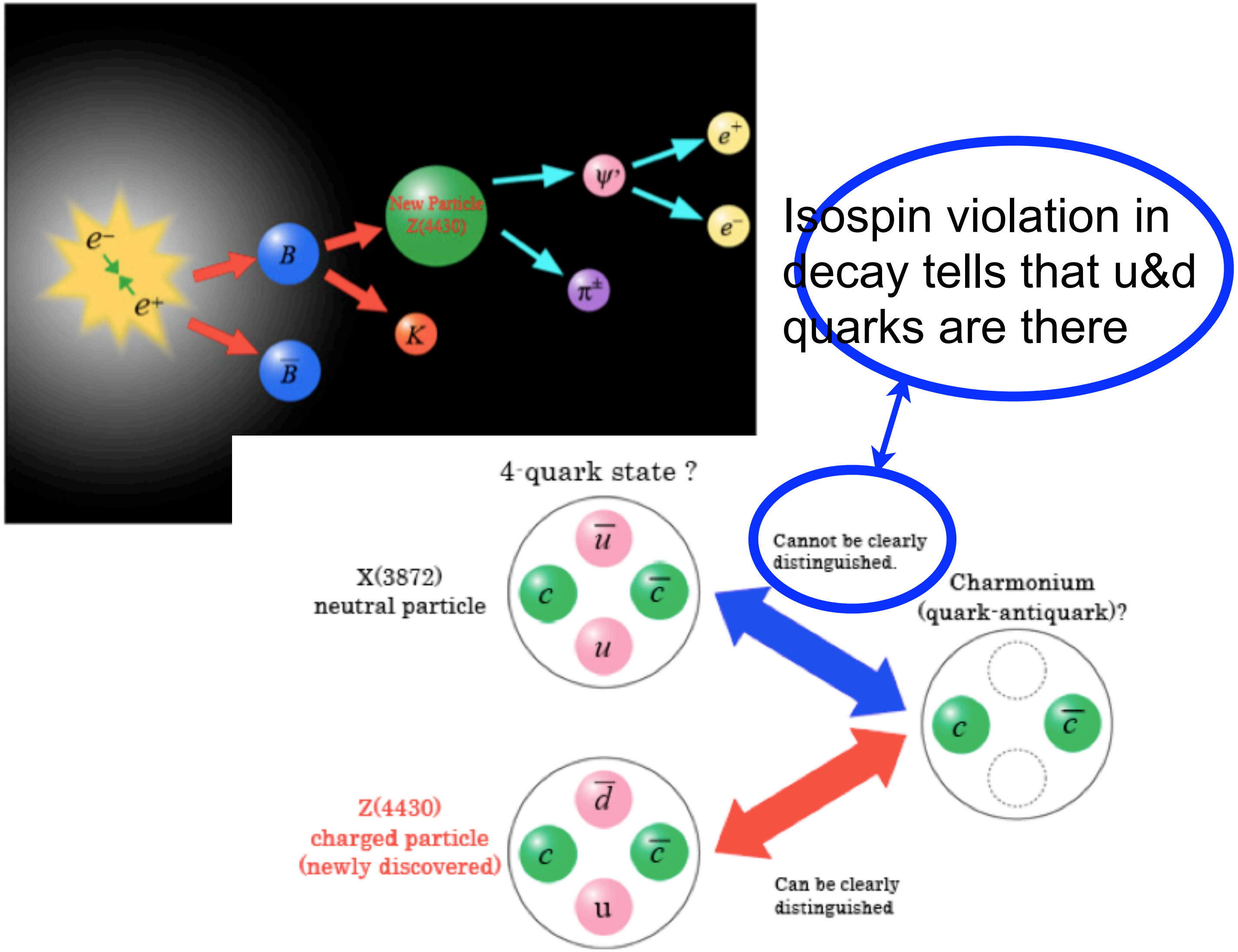
  •L. Maiani, A.D. Polosa and V. Riquer, hep-ph: 0708.3997;
  • S. S. Gershtein, A.K. Likhoded and G.P. Pronko, hep-ph 0709.2058
  • K.m. Cheung, W.Y. Keung and T. C. Yuan,hep-ph:0709.1312 [hep-ph] (propose similar states with b quark)

  – Threshold enhancement in D_1-D*

  • J.L. Rosner, hep-ph:0708.3496;
  • C. Meng and K.T. Chao, hep-ph:0708.4222;
  • D.V. Bugg, hep=ph :0709.1254;

  – Baryonium: $\Lambda_c^+ \; \bar{\Sigma}_c^0$

  • C.~F.~Qiao, hep-ph :0709.4066


e−
e+
B
B
K
New Particle
Z(4430)
ψ'
π±
e+
e−
Isospin violation in decay tells that u&d quarks are there
4-quark state ?
X(3872)
neutral particle
Cannot be clearly distinguished.
Charmonium
(quark-antiquark)?
Z(4430)
charged particle
(newly discovered)
Can be clearly distinguished

8. Outlook

- A new spectroscopy is being discovered with the new "charmonia";
- this is made possible by the fact that the Standard Charmonium model is so precise: years of efforts to compute precisely the c-cbar spectroscopy produce now their reward;
- The observation of two X states and of the charged charmonium, Z, has given more credibility to the tetraquark interpretation;
- In this case, there must exist neutral states close to Z as well as the Z(1S) around 3890 MeV, with $Z(1S) \rightarrow \pi + \psi(1S)$.
- X and Z states should fall in complete nonets, with masses calculable within the constituent quark model, that works so well for S-wave hadrons;
- Confirmation of Z(4430) is essential!!
- alternative schemes still exist and more data are (badly) needed.

A new generation of machines and detectors are called for
Super-B factory ideal. Meanwhile, can FAIR take the challenge? Can Lattice QCD calculations play a role ?