

Tetraquarks, pentaquarks and dibaryons

Laboratori Nazionali di Frascati, INFN, Nov. 16 , 2015
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The discovery of two pentaquarks by LHCb has reinforced the case of “exotic’ hadrons, which have diquarks and antidiquarks as basic units. I review the cases studied until now, the so called XYZ states, the theoretical basis for this concept and the implications for the existence of further states, with baryon number equal to two.

1. New States appear

constructed from quarks by using the combinations $(q\bar{q}q)$, $(q\bar{q}q\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(q\bar{q}\bar{q}\bar{q})$, etc.

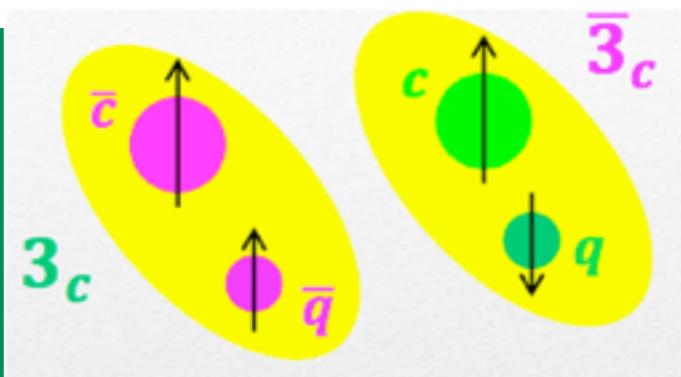
M. Gell-Mann, A Schematic Model of Baryons and Mesons, PL 8, 214, 1964

- For long, we lived with the simplest paradigm:

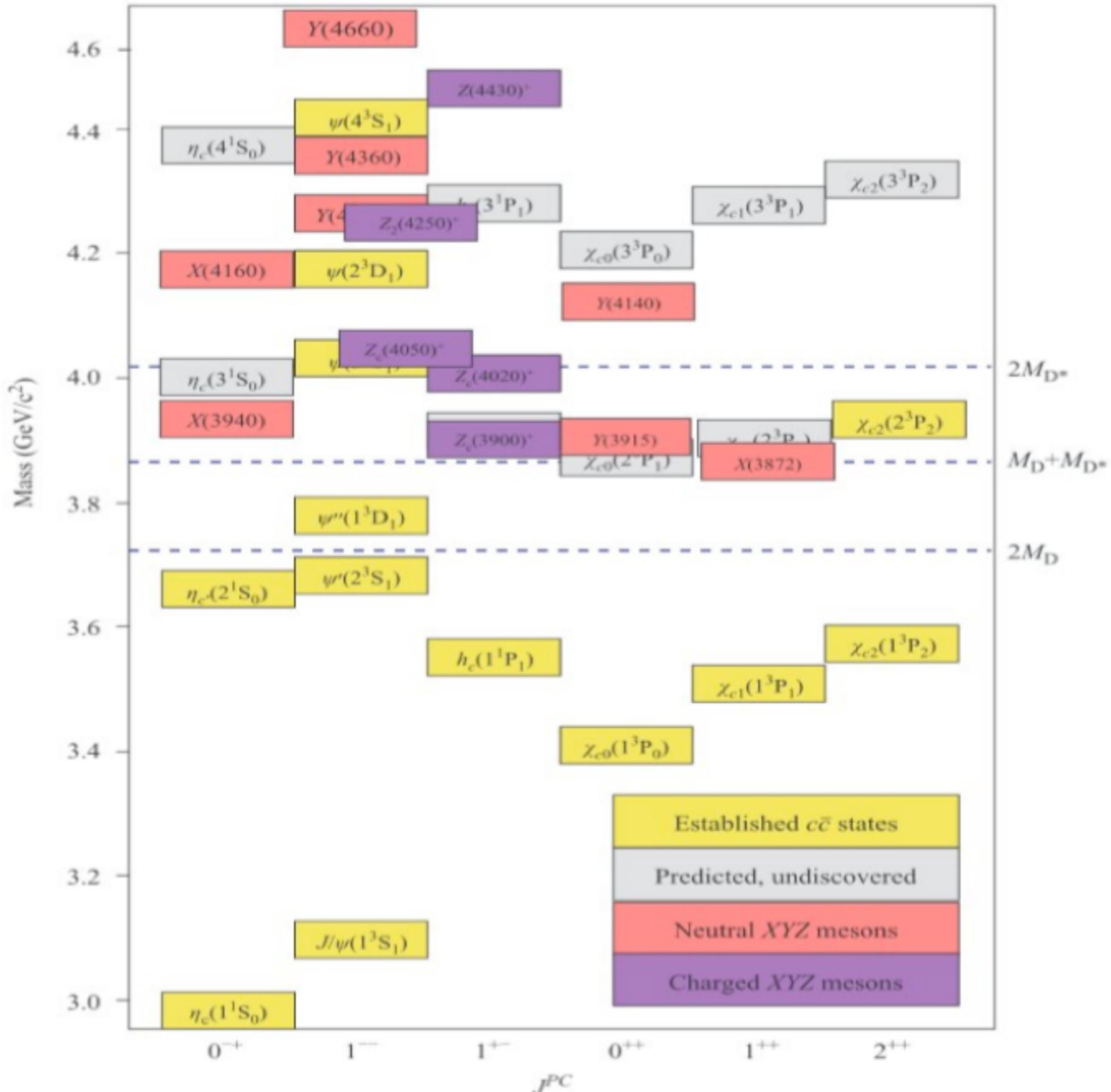
$$\text{mesons} = q\bar{q}, \quad \text{baryons} = qqq$$

- Paradigm rested on the absence of $I=2$, $\pi\pi$ resonances and of $S>0$ baryons.
- The case had to be revisited, because the lowest lying, octet of scalar mesons- $f_0(980)$, $a_0(980)$, $\kappa(800)$ and $\sigma(600)$ - does not fit in the picture.
- The $X(3872)$, narrow width, with decays into $J/\Psi + 2\pi/3\pi$, discovered by Belle in 2003, does not fit into the “charmonium” states,
- since then, Belle, BaBar, BES and LHCb have reported many other states that do not fit the charmonium picture, called $X(1^{++})$ and $Y(1^{-})$ states: molecules? hybrids? tetraquarks?
- In 2007, Belle observed a charged “charmonium”, $Z^+(4430) \rightarrow \psi(2S) + \pi$, that could not be interpreted as molecule, but later Babar suggested it was simply a reflection of K^* states
- LHCb has confirmed the $Z^+(4430)$ while other similar states, $Z^+(3900)$ and $Z^+(4020)$, have been established.

I shall follow the idea that X, Y, and Z states belong to a new spectroscopy of mesons, made by diquark-antidiquark pairs. For Beauty see also A. Ali, Belle II TIP, Krakow (slides available).

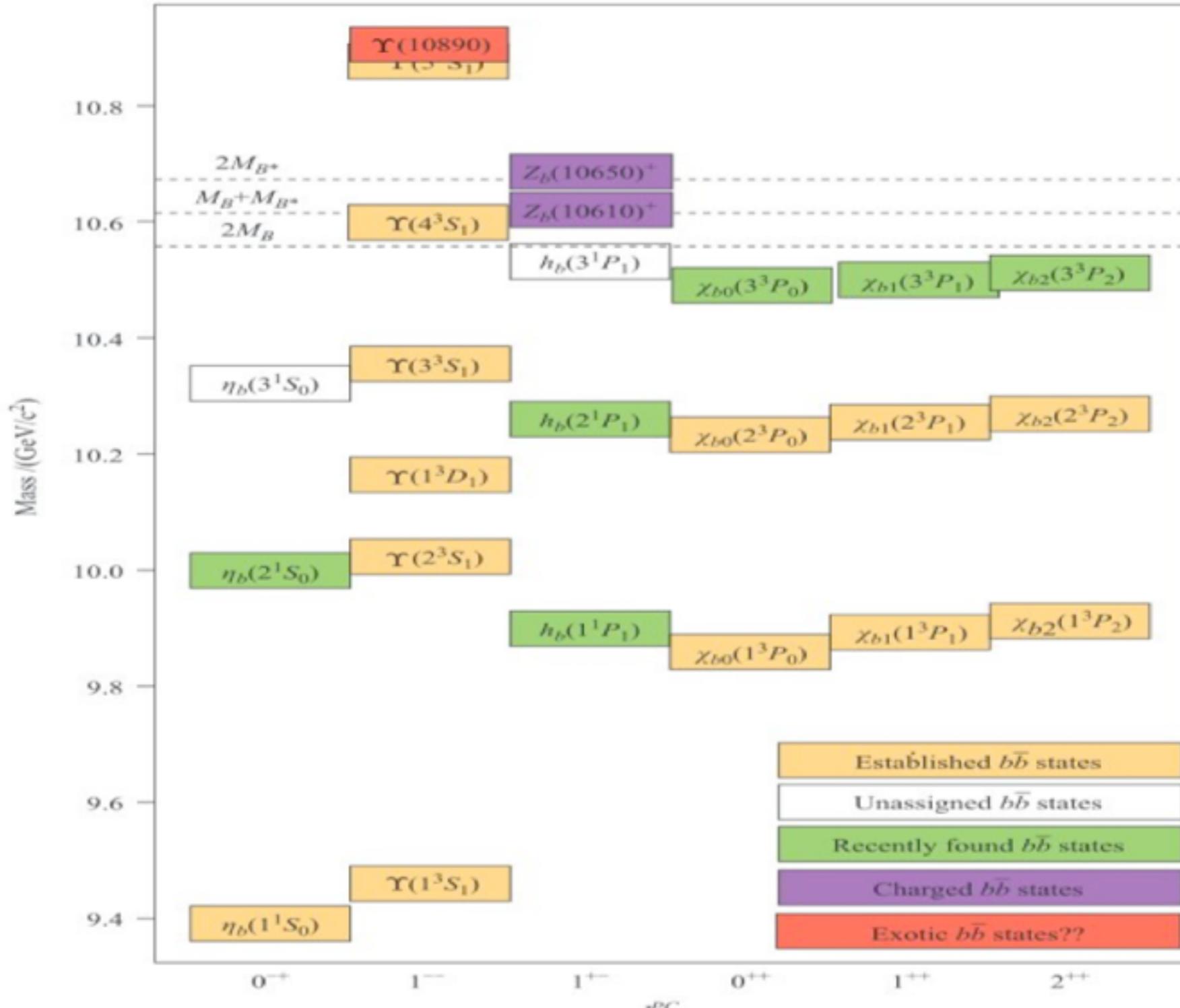


Charmonia and Charmonium-like Hadrons (Olsen, arxiv:1411.7738)



Exotic states in b-b bar

Bottomonia and Bottomonium-like Hadrons (Olsen, arxiv:1411.7738)



Ahmed Ali (DESY, Hamburg)

A. Ali, C. Hambrock, I. Ahmed and M. J. Aslam, Phys. Lett. B 684, 28 (2010);

A. Ali, C. Hambrock and M. J. Aslam, Phys. Rev. Lett. 104, 162001 (2010) [Erratum-ibid. 107, 049903 (2011)];

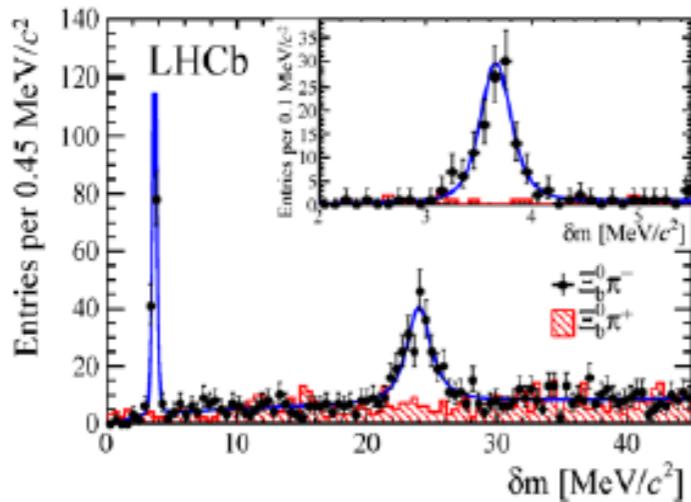
A. Ali, BELLE II ITIP, Krakow, 2015

terminology of unanticipated charmonia

- X, e.g. X(3872): neutral, typically seen in J/Psi +pions, positive parity, $J^{PC}=0^{++}, 1^{++}, 2^{++}$
- Y, e.g. Y(4260): neutral, seen in e^+e^- annihilation with Initial State Radiation, therefore $J^{PC}=1^{--}$
- Z, eg. Z(4430): charged/neutral, typically positive parity, mostly seen in J/Psi+pion and some in $h_c(1P)$ +pion

Exotic spectroscopy

LHCb has made several important discoveries in spectroscopy which fit into the ‘vanilla’ quark model...

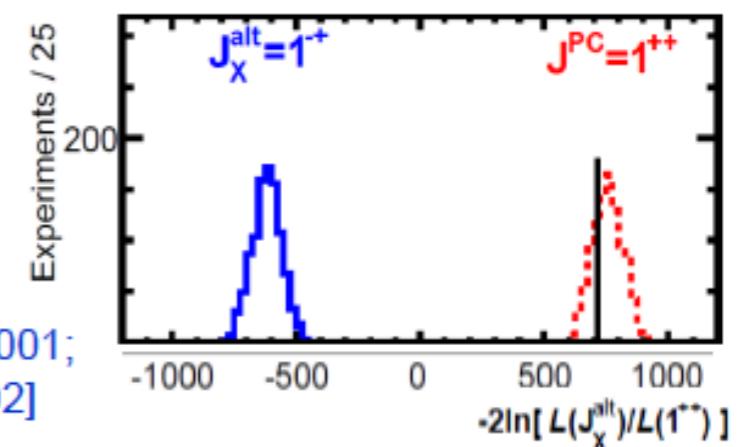


...and has made important contributions to the elucidation of exotic states

e.g. the discovery of the Ξ_b^- and Ξ_b^{*-}
[PRL 114 (2015) 062004]

e.g. quantum numbers of the X(3872)
[PRL 110 (2013) 222001; PRD 92 (2015) 01102]

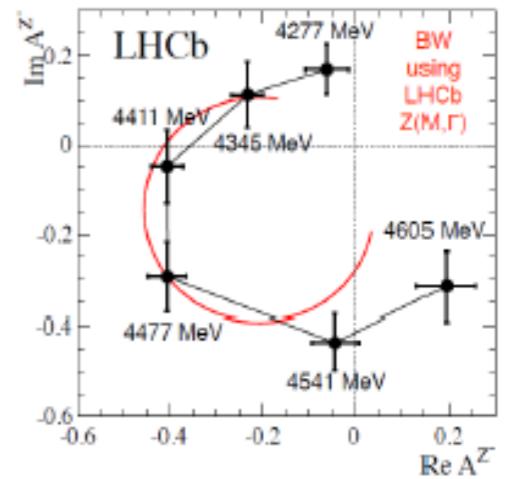
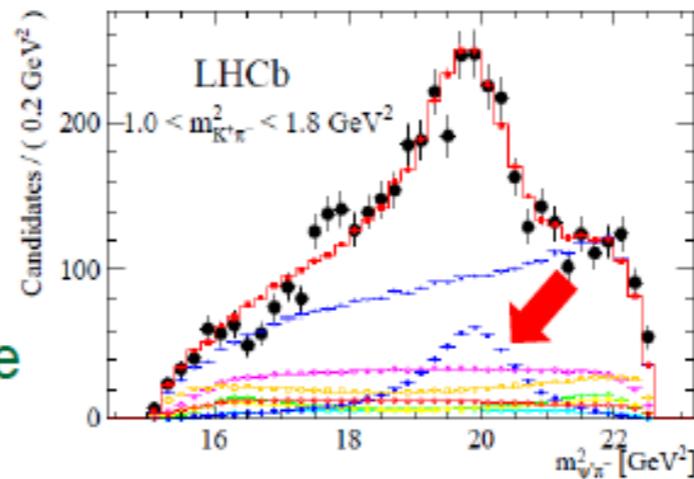
LHCb results
Sergio Bertolucci
Bologna, 6/11/2015



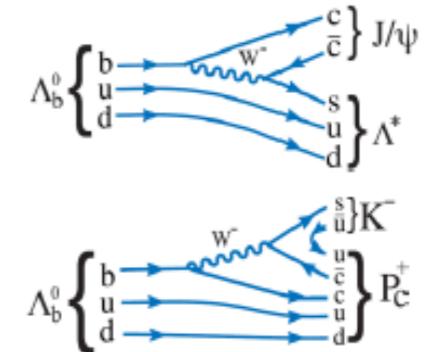
Until recently, the most important was to provide first unambiguous evidence of a four-quark state, the Z(4430).

1. Confirm Belle’s observation of ‘bump’
2. Can NOT be built from standard states
3. Textbook phase variation of a resonance

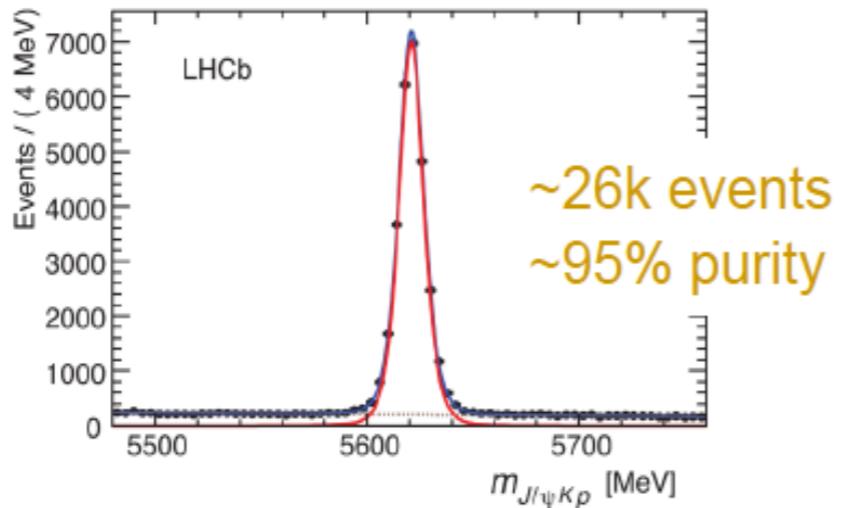
[PRL 112 (2014) 222002]



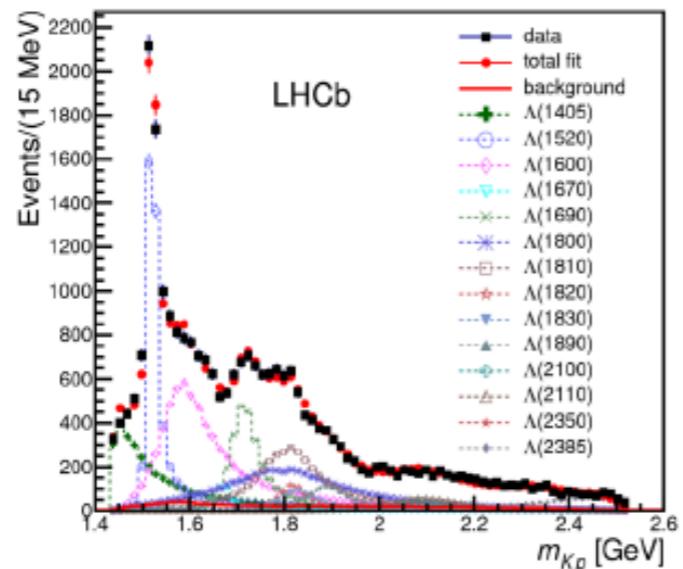
$J/\Psi p$ resonances consistent with pentaquark states



Large & pure sample of $\Lambda_b \rightarrow J/\Psi p K$ decays

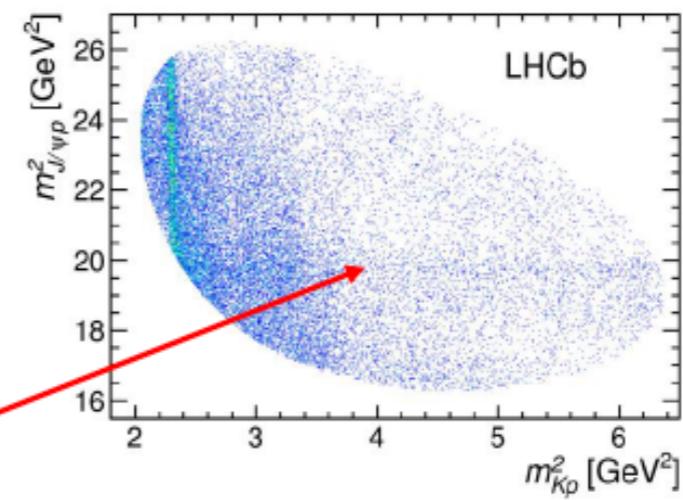


Amplitude model of conventional states can reproduce Kp spectrum well enough...



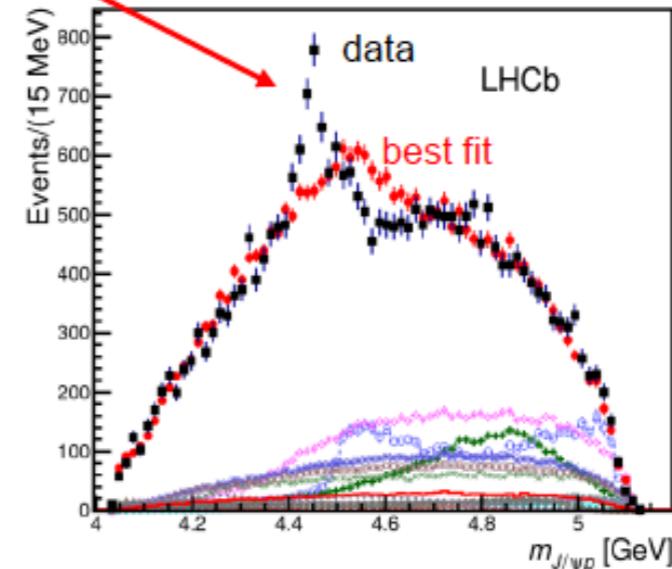
14/09/15

Distinctive structure in $J/\Psi p$ spectrum



?

...but cannot describe the J/Ψ projection at all.



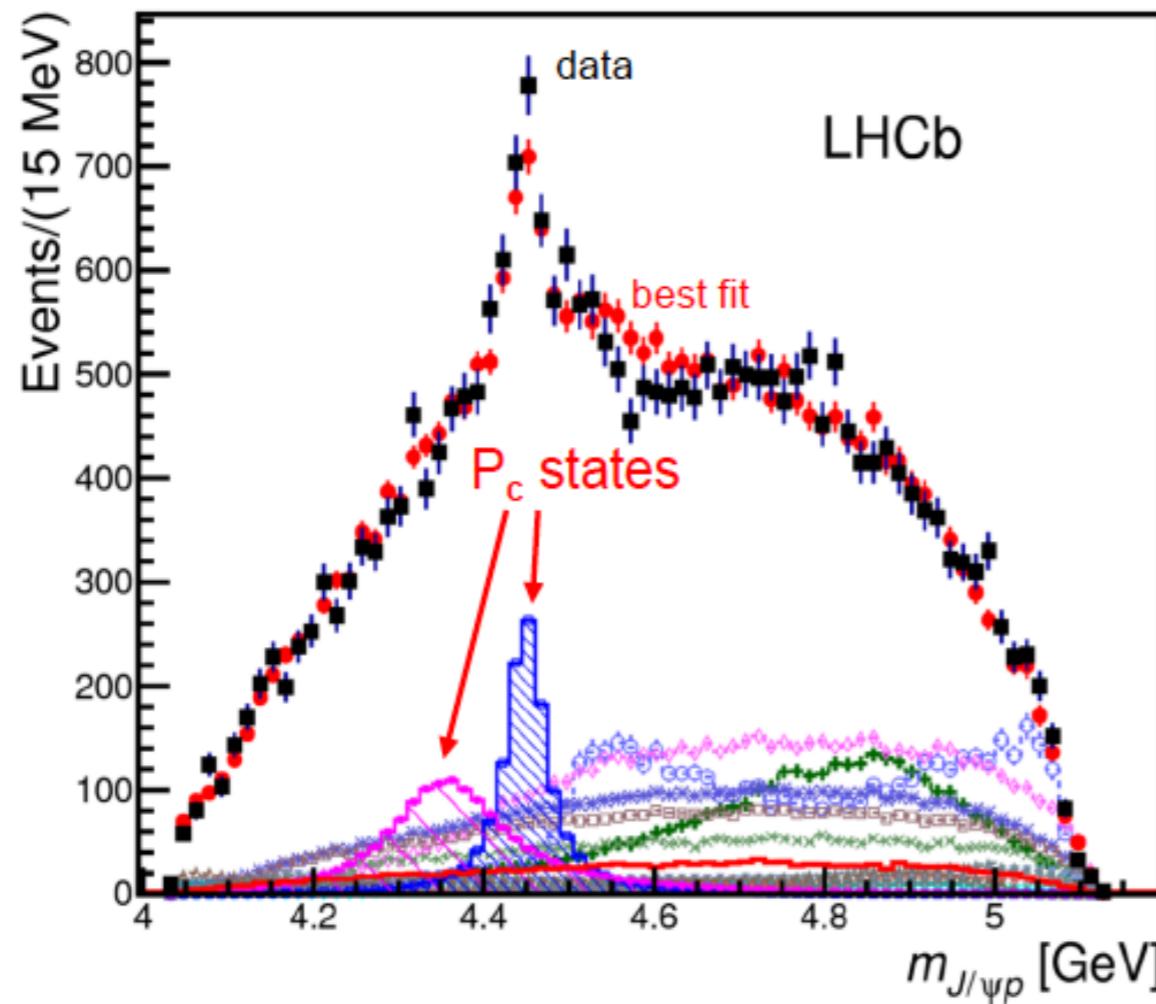
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LHCb - SPC, September 2015

$J/\Psi p$ resonances consistent with pentaquark states

[PRL 115
(2015) 072001]

Need to add two states with content $uud\bar{c}\bar{c}\bar{b}$.
Best fit has $J=3/2$ and $5/2$ with opposite parities.



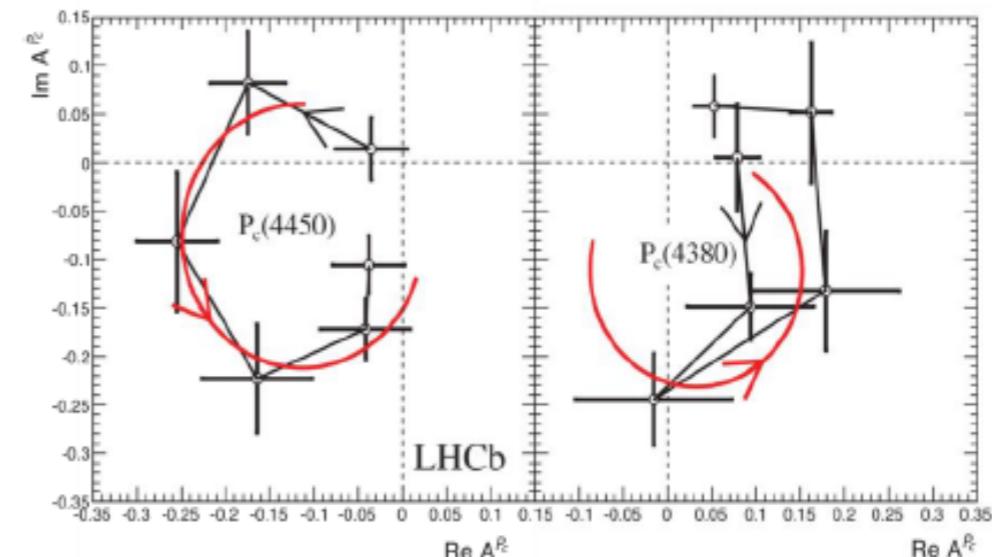
$P_c(4380)$:

$$M = 4380 \pm 8 \pm 29 \text{ MeV},$$
$$\Gamma = 205 \pm 18 \pm 86 \text{ MeV}$$

$P_c(4450)$:

$$M = 4449.8 \pm 1.7 \pm 2.5 \text{ MeV}$$
$$\Gamma = 39 \pm 5 \pm 19 \text{ MeV}$$

Clear resonant behaviour for narrow state,
Need more statistics to elucidate other state.



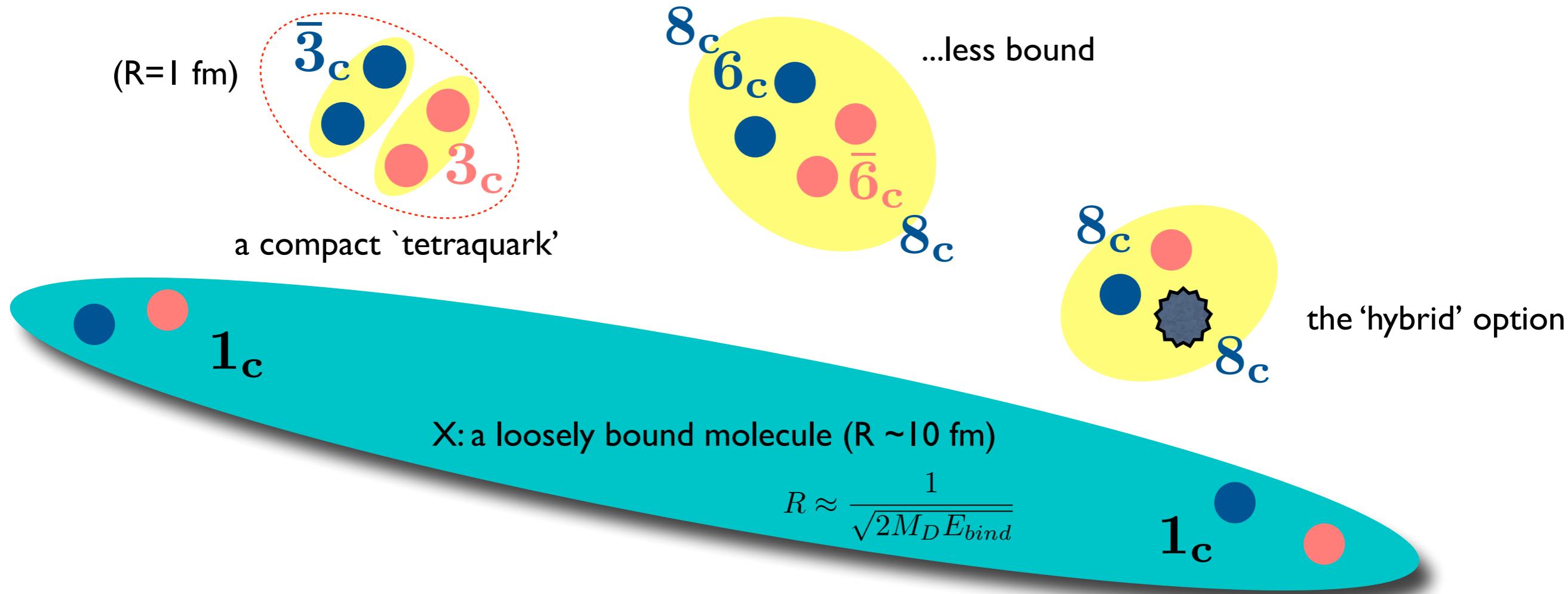
preferred fit

$$P(4450)=5/2^+, P(4380)=3/2^-$$

14/09/15

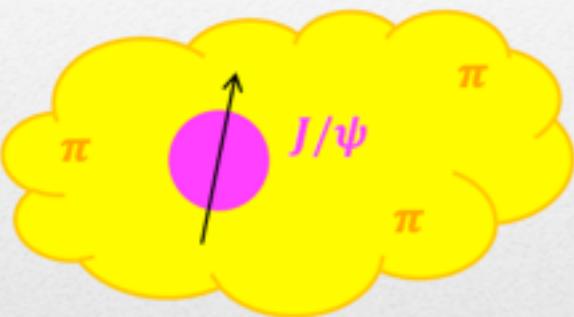
LHCb - SPC, September 2015

Models for X Y Z mesons



Hadro-charmonium

Voloshin arXiv:1304.0380

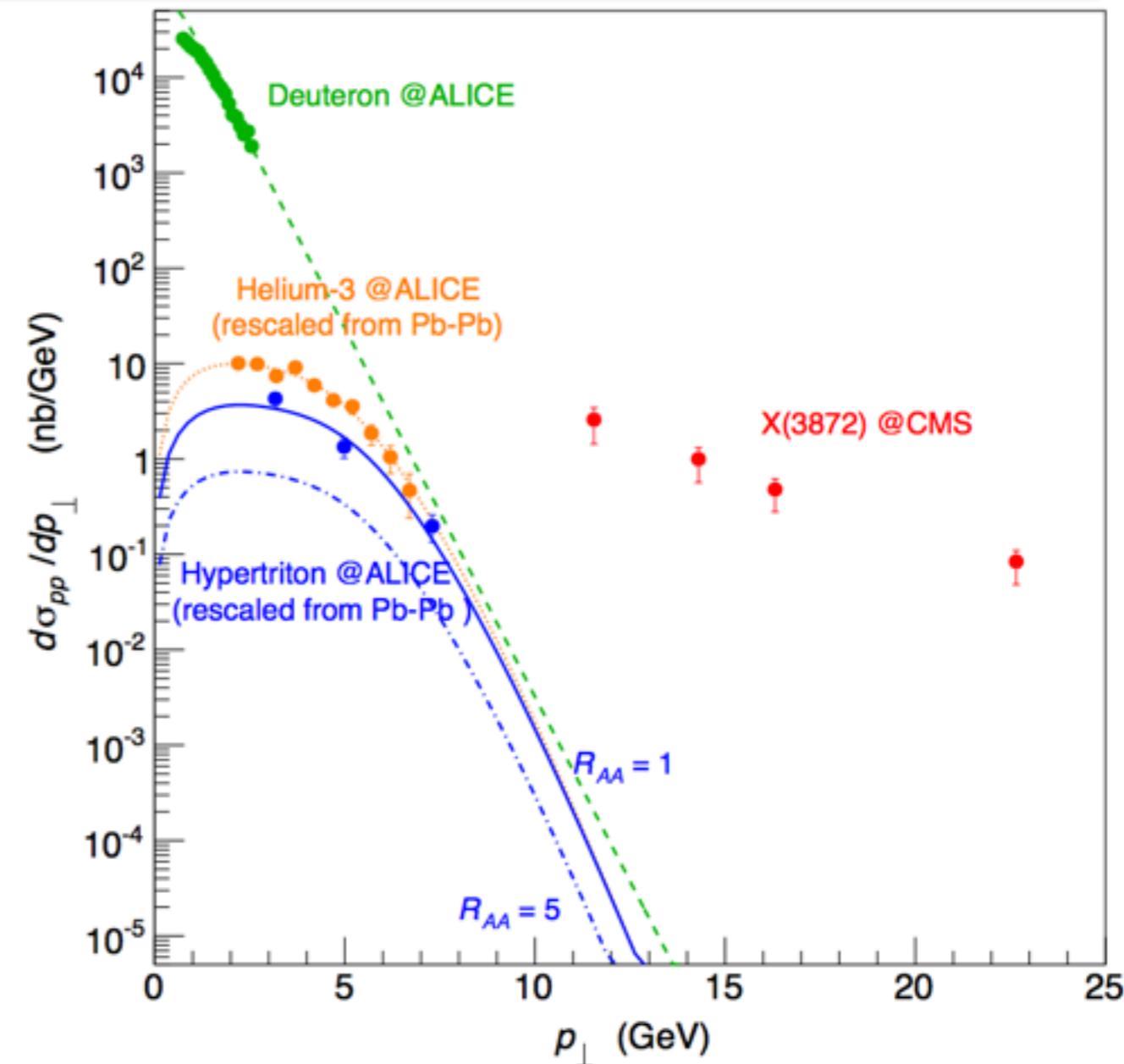
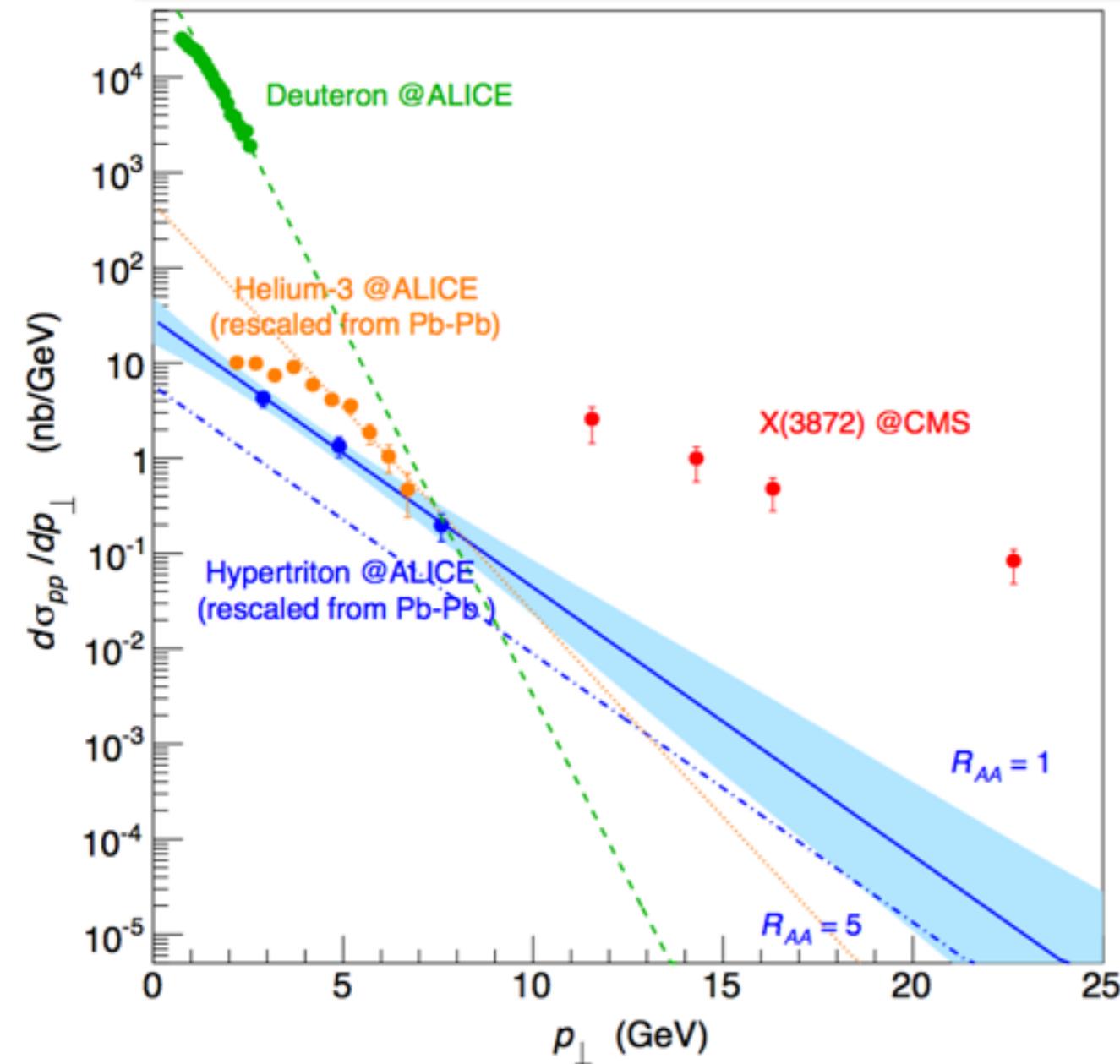


A $c\bar{c}$ state surrounded by light matter

Decay into $\eta_c \rho$ forbidden by HQSS

- quark (heavy or light)
- antiquark
- gluon

Rescaling from Pb-Pb ALICE cross sections to p-p CMS cross section is done with:
 Glauber model (**left panel**) and blast-wave function (**right panel**) (R_{AA} or $R_{CP} = 1$)



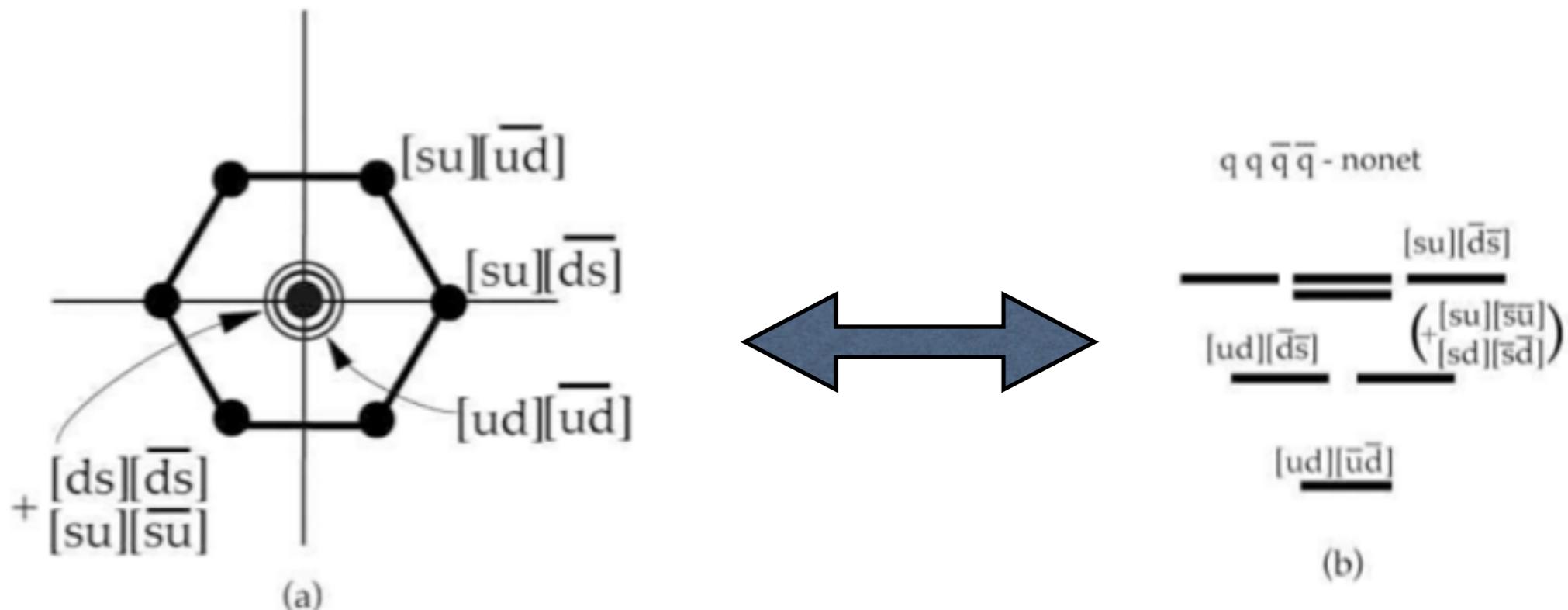
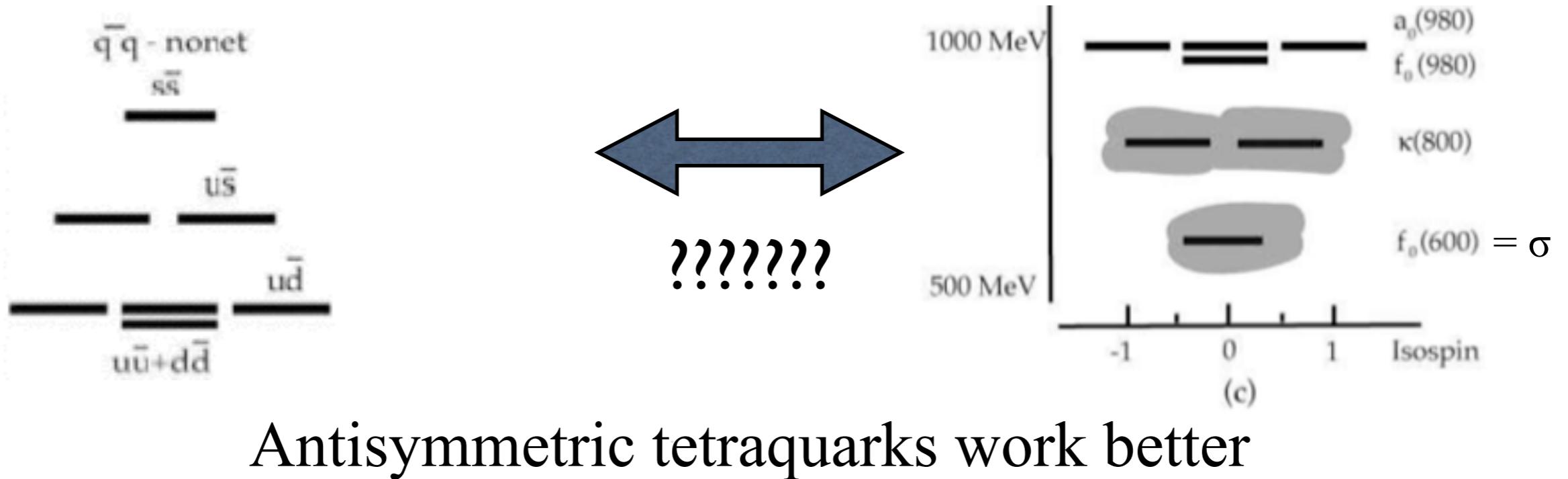
Collective effects in Pb-Pb (e.g. quark-gluon plasma) enhance nuclear cross sections and therefore reduce the cross section rescaled to p-p.

Few think X, Y, Z are only kinematic effects due to the opening of new channels. For one, see:

E. S. Swanson, Cusps and Exotic Charmonia, arXiv:1504.07952 [hep-ph]
I think it takes a lot of unconventional dynamics to produce the X(3872)
as a “cusp”

Also, the phase of Z(4430) goes at 90^0 at the peak, like a well-behaved Breit-Wigner resonance.

2. The octet of light scalar mesons and diquarks



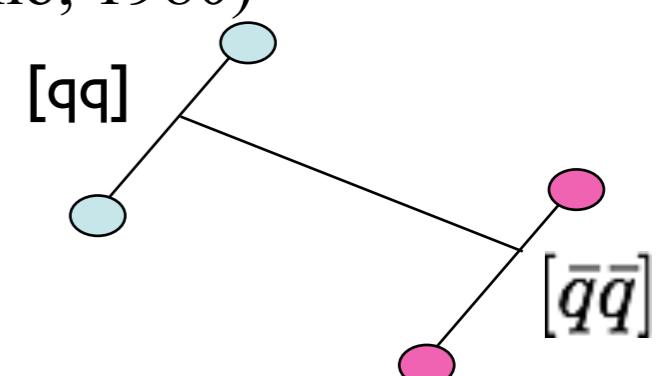
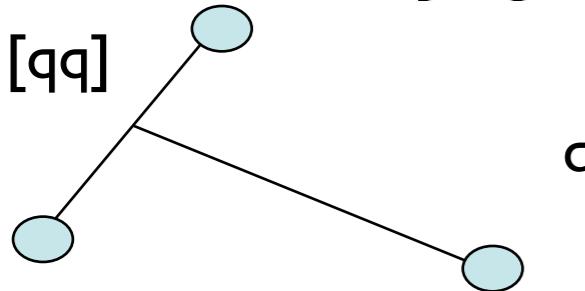
Diquarks vs molecules

QCD forces are attractive (in 1 gluon approx.) for diquark $[qq']$: color = 3bar, SU(3) flavour = 3bar, spin=0, spin-spin force also attractive: *good diquark* (Jaffe, 1977)
 -makes a simple unit to form color singlets (Jaffe & Wilczek, 2003)
 - $[cq]$ may make a stable configuration even for spin 1, *bad diquark*, since spin-spin interactions, repulsive in spin 1, decrease with mass)

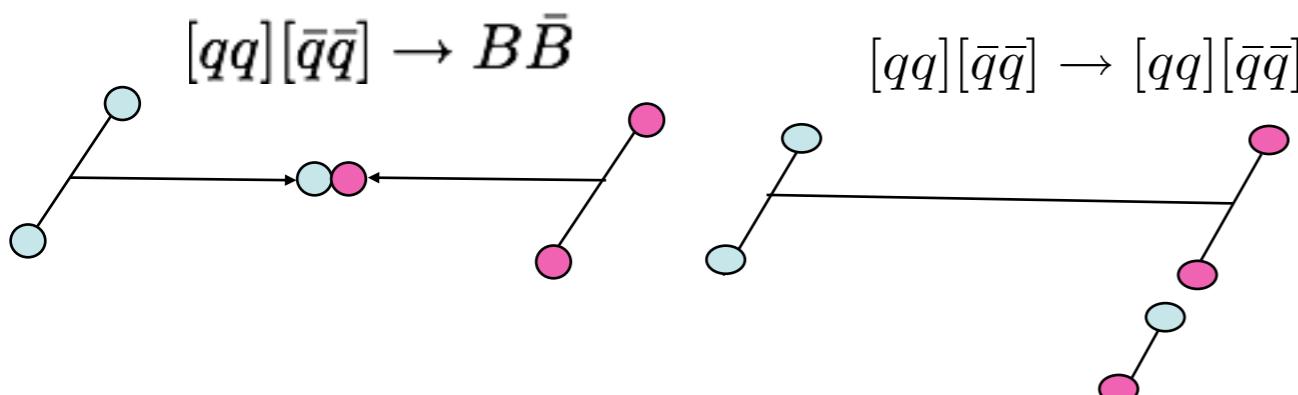
Diquark needs to combine with other colored objects:

with $q \rightarrow$ baryon (e.g. Λ), Y-shape

with $[\bar{q}\bar{q}] \rightarrow$ scalar meson, H-shape (Rossi & Veneziano, 1980)

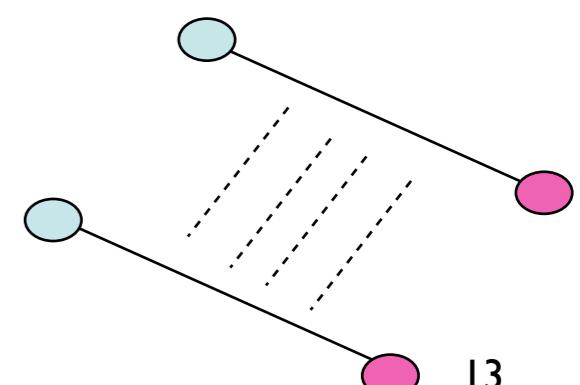


Many states: tetraquarks may have radial and orbital excitations
 string topology is more related to Baryon-antiBaryon:
 if you break the string,



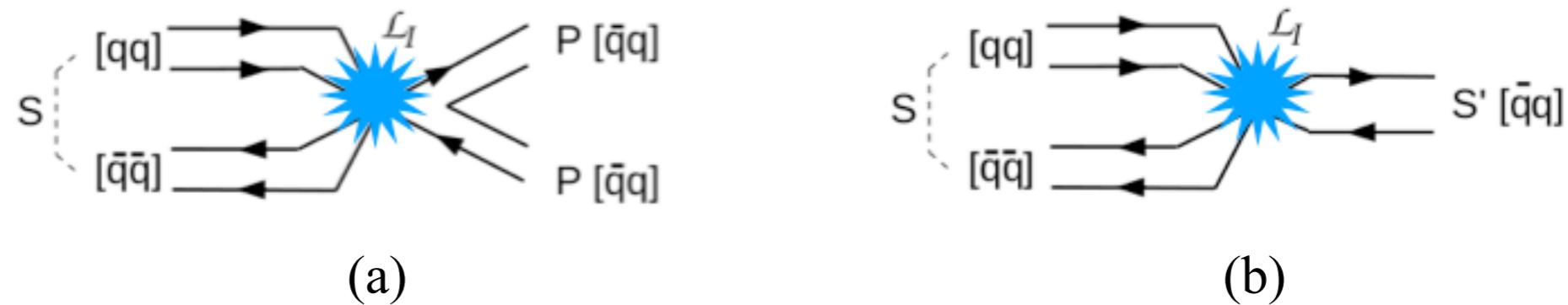
A. De Rujula, H. Georgi and S. L. Glashow,
 Phys. Rev. Lett. 38 (1977) 317.

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



Non-perturbative instantons: may explain two or three further puzzles

G. 't Hooft, G. Isidori, L. Maiani, A. D. Polosa and V. Riquer,
 PL **B662** (2008) 424.
 A. H. Fariborz, R. Jora and J. Schechter, PR **D77** (2008) 094004.



- (a) the decay $f_0(980) \rightarrow 2\pi$ ($f_0 = \frac{([su][\bar{s}\bar{u}] + u \rightarrow d)}{\sqrt{2}}$)
- (b) the mixing of light (tetraquark) scalar mesons with q-qbar mesons, the latter being made by $a_0(1474)$ ($I=1$), $K_0(1412)$, ($I=1/2$), and three isosinglets: $f_0(1370)$, $f_0(1507)$ and $f_0(1714)$ (one could be a glueball);
- (c)= (b) in the reverse:
 - with: $Y(4260) = \frac{([cu][\bar{c}\bar{u}] + u \rightarrow d)}{\sqrt{2}}$, the u-ubar or d-dbar pair in Y may give rise to the observed decay:
$$Y(4260) \rightarrow J/\Psi + f_0(q\bar{q})_{off-shell} \rightarrow J/\Psi + f_0([qq][\bar{q}\bar{q}])$$

Z(4430) as a radially excited tetraquark

- There *are* 4 quarks in Z(4430)
- in 2007 we classified the Z(4430) as a tetraquark, the radial excitation of the S-wave companion of X(3872)
- this was because of its decay into $\psi(2S) + \pi$ and its mass ~ 550 MeV larger than the X
- We noted then: *A crucial consequence of a Z(4430) charged particle is that a charged state decaying into $\psi(1S) \pi^\pm$ or $\eta_c \rho^\pm$ should be found around 3880 MeV* (i.e. almost degenerate with X(3872))
- The $Z_c(3900)$ has been seen later by BES III and Belle with the anticipated decay:
 - $Z^+(3900) \rightarrow \psi(1S) \pi^+$
- a neutral partner was suggested by CLEO,
- The further observation of Z(4020) by the BES III Collaboration reinforces the tetraquark picture, which looks more attractive and constrained as compared to some years ago
- The Z(4430) decay into $\psi(2S)$ as indication of a radially excited tetraquark has been confirmed by S. Brodski *et al.* (arXiv:1406.7281 [hep-ph])

3. Tetraquarks in the large N expansion

- Reputation of tetraquarks was somehow tarnished by a theorem of S. Coleman:
tetraquarks correlators for $N \rightarrow \infty$ reduce to disconnected meson-meson propagators
S. Coleman, Aspects of Symmetry (Cambridge University Press, Cambridge, England, (1985), pp. 377–378
- The argument was reexamined by S. Weinberg who argued that if the connected tetraquark correlator develops a pole, it will be irrelevant that it is of order $1/N$ with respect to the disconnected part: *at the pole the connected part will dominate anyhow*;
S. Weinberg, PRL 110, 261601 (2013)
- the real issue is the width of the tetraquark pole: it may increases for large N, to the point of making the state undetectable;
- Weinberg's conclusions is the the decay rate goes like $1/N$, making tetraquarks a respectable possibility.
- Weinberg's discussion has been enlarged by M. Knecht and S. Peris (arXiv:1307.1273) and further considered by T. Cohen and R. Lebed et al. (arXiv: 1401.1815, arXiv: 1403.8090).

What is not forbidden is NECESSARY

Decay amplitudes in 1/N expansion

- By Fierz rearrangements, tetraquark operators can be reduced to products of color singlet bilinears;
- interpolating field operators have to be multiplied by powers of N, such as to make the connected two-point correlators to be normalized to unity;
- one loop amplitude with insertions of quark color singlet operators gives a factor N.

$$Q = \frac{1}{\sqrt{N}} [cu][\bar{c}\bar{u}] \left\{ \begin{array}{l} \text{---} \\ \text{---} \\ \text{---} \\ \text{---} \end{array} \right\}$$

$\frac{1}{\sqrt{N}} (\bar{u}c) (D, D^*)$
 $\frac{1}{\sqrt{N}} (\bar{c}u) (\bar{D}, \bar{D}^*)$
 $+ (c \leftrightarrow u)$
 $\frac{1}{\sqrt{N}} (\bar{c}c) (\eta_c, J/\Psi, \chi_c, h_c, \dots)$
 $\frac{1}{\sqrt{N}} (\bar{u}u) (\pi, \eta, \rho, \omega, \dots)$

- two independent amplitudes

- The result is that *decay amplitudes into two mesons are of order*: $\frac{1}{N^{3/2}} N = \frac{1}{\sqrt{N}}$
- These two amplitudes were introduced long ago for tetraquark light scalar decay: reassuringly, they turn out both to be leading in 1/N.

L. Maiani, F. Piccinini, A. D. Polosa, V. Riquer, PRL **B93**, 212002 (2004)

further decay amplitudes

- tetraquark de-excitation amplitudes by meson emission, e.g. $Y(4260) \rightarrow Z_c(3900) + \pi$, are also of order $1/\sqrt{N}$

$$Y(4260) = \frac{1}{\sqrt{N}} [cu][\bar{c}\bar{u}] \quad \left\{ \begin{array}{c} \text{---} \\ \text{---} \\ \text{---} \\ \text{---} \end{array} \right. \quad \begin{array}{c} u \\ \bar{c}u \\ \bar{u}c \\ u \end{array} \quad \begin{array}{c} u \\ c \\ \bar{c}d \\ d \end{array} \quad \left. \begin{array}{c} u \\ \bar{u}c \\ \bar{c}d \\ \bar{d}u \end{array} \right\} \quad Z_c^-(3900) = \frac{1}{\sqrt{N}} [cd][\bar{c}\bar{u}]$$

$$\pi^+ = \frac{1}{\sqrt{N}} (ud)$$

- however, e.m. currents need no normalization factor, so that the de-excitation amplitudes via photon emission are of order $eQ \times 1$.

$$Y(4260) = \frac{1}{\sqrt{N}} [cu][\bar{c}\bar{u}] \quad \left\{ \begin{array}{c} \text{---} \\ \text{---} \\ \text{---} \\ \text{---} \end{array} \right. \quad \begin{array}{c} u \\ \bar{c}u \\ \bar{u}c \\ u \end{array} \quad \begin{array}{c} u \\ c \\ \bar{c}u \\ u \end{array} \quad \left. \begin{array}{c} u \\ \bar{u}c \\ \bar{c}u \\ eQ \end{array} \right\} \quad X(3872) = \frac{1}{\sqrt{N}} [cu][\bar{c}\bar{u}]$$

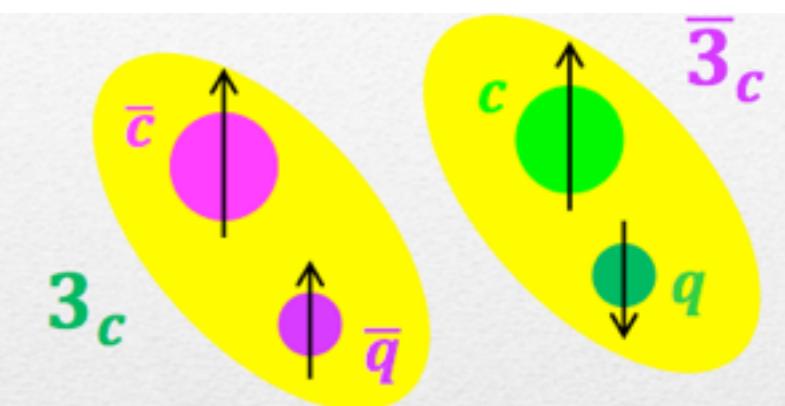
$$\gamma$$

4. Tetraquark picture of unexpected quarkonia

L.Maiani, F.Piccinini, A.D.Polosa and V.Riquer, Phys. Rev. D 71 (2005) 014028

$$[cq]_{s=0,1} [\bar{c}\bar{q}']_{\bar{s}=0,1}$$

- I=1, 0
- S-wave: positive parity
- total spin of each diquark, S=1, 0
- neutral states may be mixtures of isotriplet and isosinglet
- mass splitting due to spin-spin interactions (e.g. the non-relativistic constituent quark model)



$$H = 2M_{diquark} - 2 \sum_{i < j} \kappa_{ij} (\vec{s}_i \cdot \vec{s}_j) \frac{\lambda_i^A}{2} \frac{\lambda_j^A}{2}$$

The S-wave, J^P=1⁺ charmonium tetraquarks

- use the basis $|s, \bar{s}\rangle_J$

$$J^P = 0^+ \quad C = + \quad X_0 = |0, 0\rangle_0, \quad X'_0 = |1, 1\rangle_0$$

$$J^P = 1^+ \quad C = + \quad X_1 = \frac{1}{\sqrt{2}} (|1, 0\rangle_1 + |0, 1\rangle_1)$$

$$J^P = 1^+ \quad G = + \quad Z = \frac{1}{\sqrt{2}} (|1, 0\rangle_1 - |0, 1\rangle_1), \quad Z' = |1, 1\rangle_1$$

$$J^P = 2^+ \quad C = + \quad X_2 = |1, 1\rangle_2$$

X(3872)=X₁
Z(3900), Z(4020)=lin. combs. of
Z&Z' that diagonalize H
X(3940)=X₂ ??

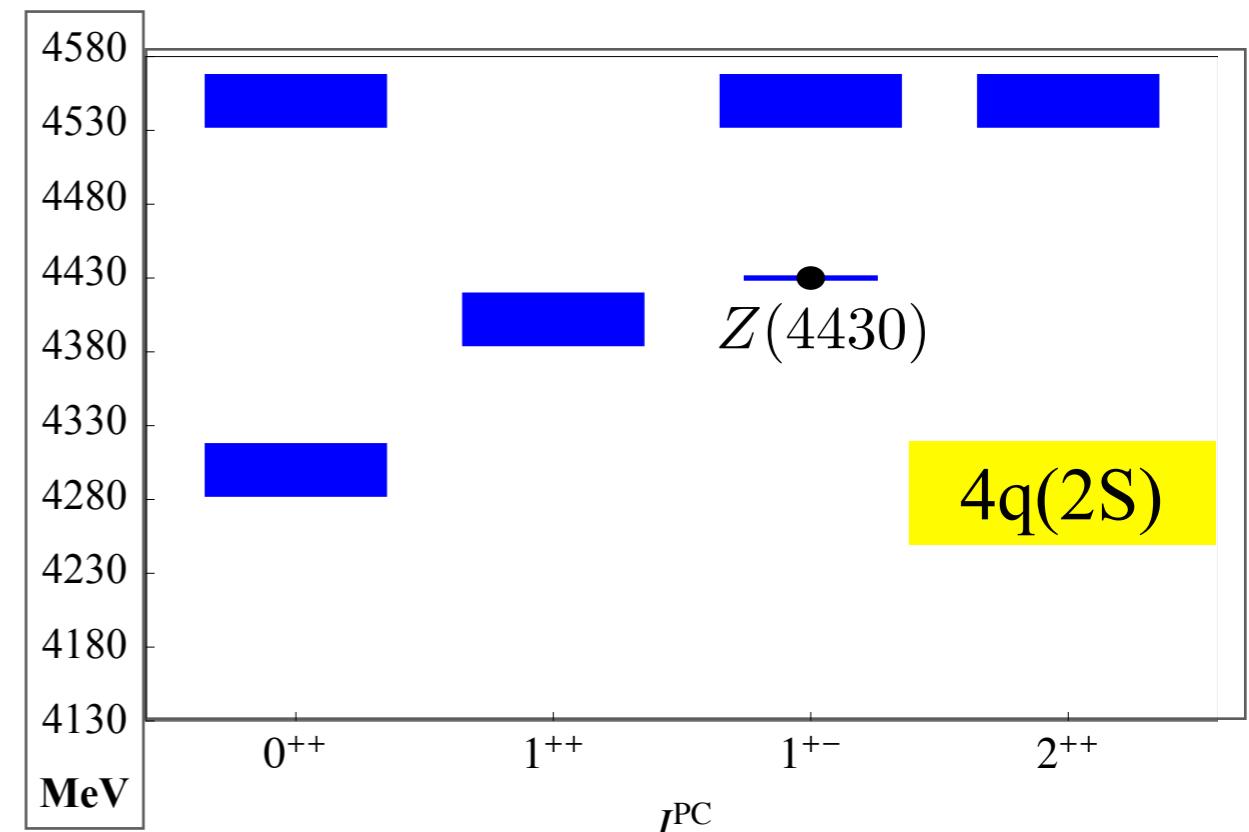
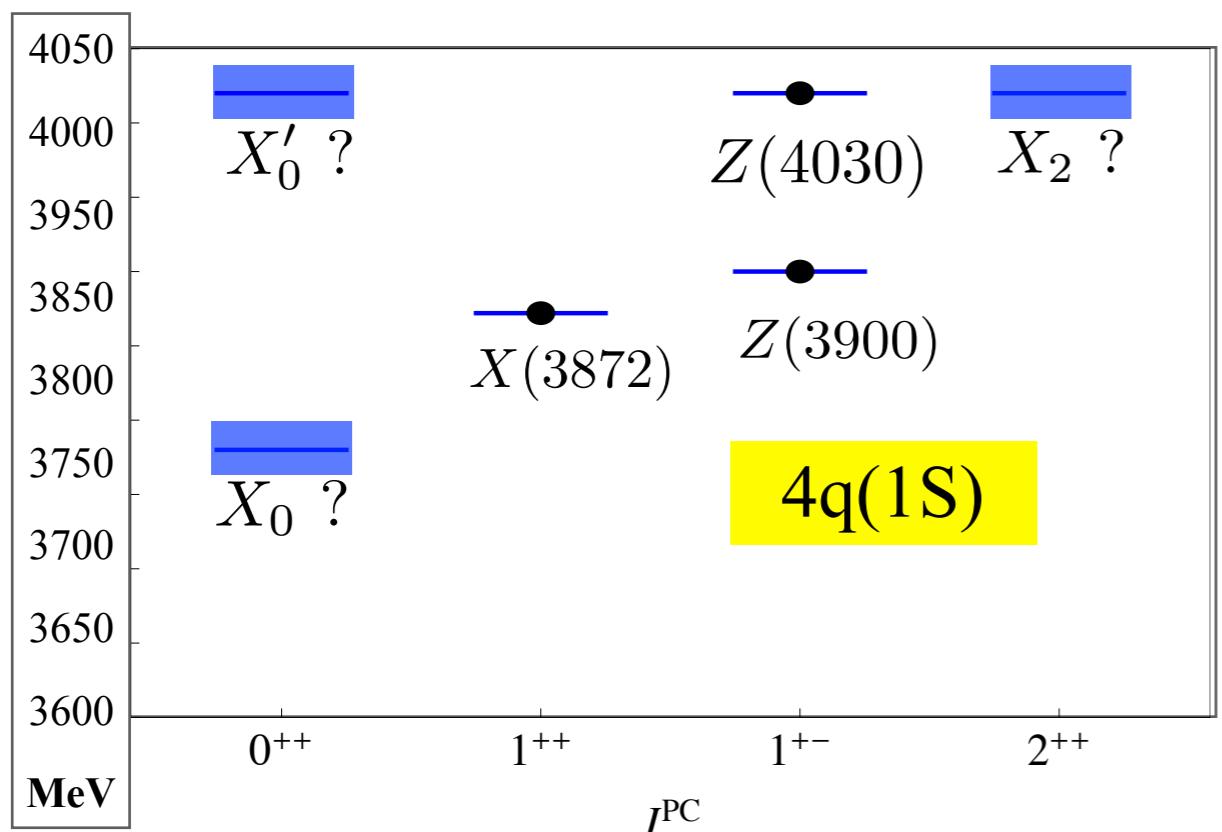
Mass spectrum: the new paradigm

A. Polosa, V. Riquer, F. Piccinini, PRD **89**, 114010 (2014)

- A tentative mass spectrum for the S-wave tetraquarks was derived in the 2005 paper, based on an extrapolation of the spin-spin interactions in conventional S-wave mesons and baryons.
- Does NOT agree with the observed level ordering of X(3872), Z(3900) and Z(4020)
- A new, simple paradigm accounts for the observed pattern: dominant interactions are those ***between quarks in the same (tightly bound?) diquark*** (or antiquarks in the same antidiquark):

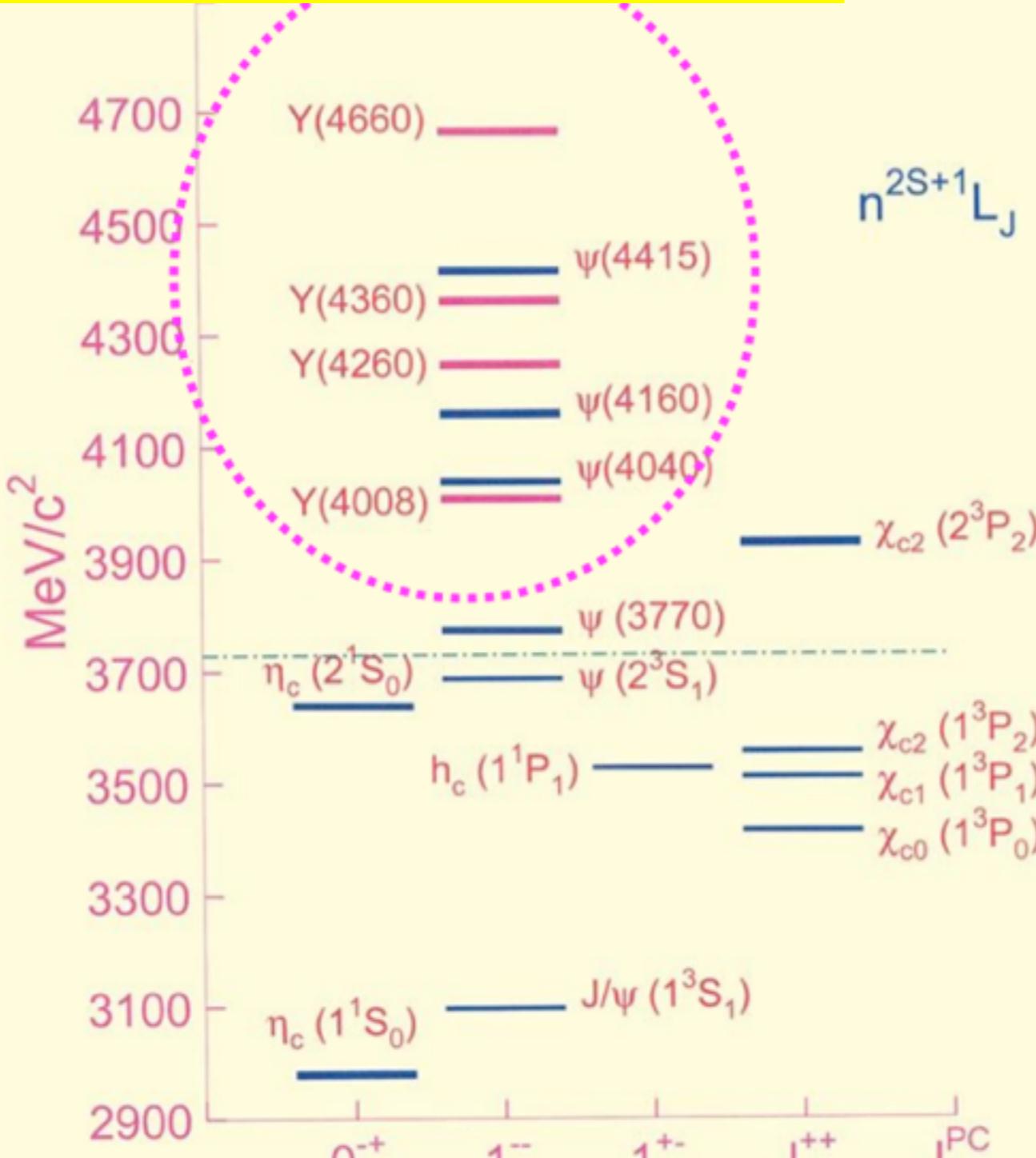
$$H \approx 2\kappa_{qc} (s_q \cdot s_c + s_{\bar{q}} \cdot s_{\bar{c}}) = \kappa_{qc} [s(s+1) + \bar{s}(\bar{s}+1) - 3]$$

- H is diagonal in the basis of diquark total spin and counts the number of spin=1 diquarks
- one Z is degenerate with X(3872), the other is heavier;
- $\kappa_{qc} \sim 60$ MeV from fit (larger than κ_{qc} in baryons).

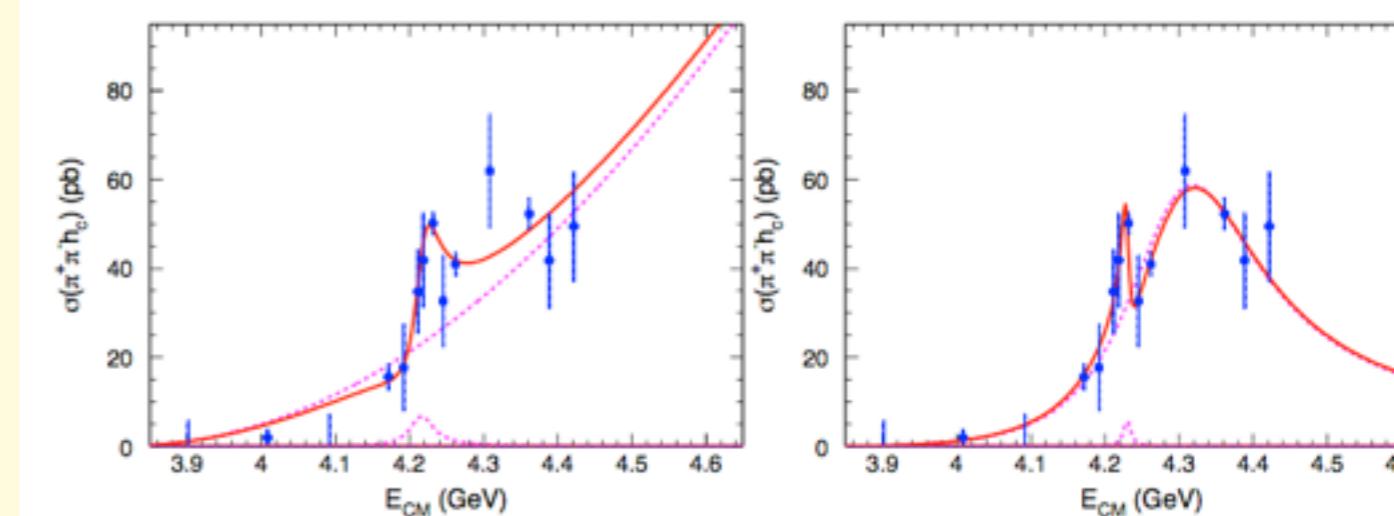


5. What are the Y states?

Changzheng YUAN, IHEP Beijing, 2014



later BES III has observed another one: $Y(4230)$ which decays in $h_c \pi \pi$



or maybe two? (narrow and wide)

Our survey:

- $Y(4660)$ and $Y(4360)$, decaying into $\psi(2S)\pi$
- $Y(4630)$ decaying into $\Lambda_c \bar{\Lambda}_c$
- $Y(4220)$, narrow (and $Y(4290)$, wide ???) in $h_c(1P) + \pi$, BES III
- $Y(4260)$ and $Y(4008)$ decaying into $J/\psi + \pi$,

Y- tetraquarks

- Tetraquark states with $J^{PC}=1^{--}$ can be obtained with odd values of the orbital angular momentum $L=1, 3$ and diquark and antidiquark spins s, \bar{s} $s_{\bar{s}}=0,1$.
- use the notation: $|s, s \bar{s}; S, L\rangle_{J=1}$, and charge conjugation invariance we

| | spin composition: $ s, \bar{s}, S, L\rangle_J$ | $P(s_{c\bar{c}} = 1)$ | $P(s_{c\bar{c}} = 0)$ | assign. |
|-------|---|-----------------------|-----------------------|-----------|
| Y_1 | $ 0, 0; 0, 1\rangle_1$ | 0.75 | 0.25 | $Y(4008)$ |
| Y_2 | $\frac{1}{\sqrt{2}}(1, 0; 1, 1\rangle_1 + 0, 1; 1, 1\rangle_1)$ | 1 | 0 | $Y(4260)$ |
| Y_3 | $ 1, 1; 0, 1\rangle_1$ | 0.25 | 0.75 | $Y(4230)$ |
| Y_4 | $ 1, 1; 2, 1\rangle_1$ | 1 | 0 | $Y(4630)$ |

Interpretation of Y states:

- leave aside the $L = 3$ state (too heavy);
- $Y(4360)$ and $Y(4660) =$ radial excitations of $Y(4008)$ and $Y(4260)$ (decay into $\psi(2S)$, $\Delta M \sim 350, 400$ MeV in the range of ΔM of $L = 1$ charmonia and bottomonia);
- the 4 states Y_{1-4} identified with $Y(4008)$, $Y(4260)$, $Y(4220)$ (the narrow structure in the h_c channel) and $Y(4630)$.

6. Selection rules

- Conservation of the heavy quark spin is well established in QCD: decays indicate the value of c-cbar spin in the initial wave function:
 - X(3872): $S(c\bar{c})=1 \rightarrow J/\Psi$ yes, but no η_c
 - Y(4230): both χ_c ($S(c\bar{c})=1$) and h_c ($S(c\bar{c})=0$)
- conservation of light quark spin is not reliable:
 - initial spin composition not necessarily reflected in $K K^*$ vs K^*K^* decay modes
- observed X, Y, Z in the new paradigm of spin-spin coupling respect these rules, as far as we can see !
- more precise measurements of different decay channel will be of the outmost importance.

Radiative decays

- The identical spin structure implied in the model for Y(4260) and X(3872) suggests the decay

$$Y(4260) \rightarrow X(3872) + \gamma$$

M.Ablikim et al. [BESIII Collaboration], arXiv:1310.4101 [hep-ex]

to be an ***unsuppressed E₁ transition***, with $\Delta L=1$ and $\Delta \text{Spin}=0$, similar to the observed transitions of charmonium χ states.

- The decay rate could provide a first estimate of the radius of the tetraquark.
- A comparison of the spin structures in Y and X states provides selection rules for E₁ transitions that should provide a better identification of the levels.
- The assignments we have made produce the table:

$$Y_4 = Y(4630) \rightarrow \gamma + X_2 \quad (J^{PC} = 2^{++}) = \gamma + X(3940), ??$$

$$Y_3 = Y(4220) \rightarrow \gamma + X'_0 \quad (J^{PC} = 0^{++}) = \gamma + X(3916), ??$$

$$Y_2 = Y(4260) \rightarrow \gamma + X_1 \quad (J^{PC} = 1^{++}) = \gamma + X(3872), \text{ seen}$$

$$Y_1 = Y(4008) \rightarrow \gamma + X_0 \quad (J^{PC} = 0^{++}) = \gamma + X(3770 ??), ??$$

ED1 transition in *diquarkonium*

*Hua-Xing Chen, Luciano Maiani, Antonio Polosa, V. Riquer,
arXiv:1510.03626*

$$Y(4260) \rightarrow \gamma + X(3872)$$

ED1 transition from a Y tetraquark, P-wave, to a X tetraquark, S-wave, with the same spin structure.
can be computed in the approximation where diquarks are treated as pointlike objects of electric charge Q:

$$\Gamma = \frac{4}{9} \alpha \omega^3 \sum_{mki} |\langle X, m | Qx^i | Y, k \rangle|^2$$

pointlike approx. introduced by: A. Ali, C. Hambrock and S. Mishima, Phys. Rev. Lett. **106** (2011) 092002

- our estimate: $\Gamma(Y(4260) \rightarrow \gamma X(3872)) = \begin{cases} 496 \text{ keV } (I : 0 \rightarrow 0) \\ 179 \text{ keV } (I : 1 \rightarrow 0) \end{cases}$
- Basic formula: $\sigma_{peak}(e^+ + e^- \rightarrow V \rightarrow f) = \frac{12\pi}{M^2} B(V \rightarrow e^+ e^-) B(V \rightarrow f)$

- BES III measures: $5 \cdot 10^{-3} = \frac{\sigma(e^+ e^- \rightarrow \gamma + [J/\Psi \pi\pi]_X)}{\sigma(e^+ e^- \rightarrow J/\Psi \pi\pi)} \approx \frac{B(Y \rightarrow \gamma X) B(X \rightarrow J/\Psi \pi\pi)}{B(Y \rightarrow J/\Psi \pi\pi)}$

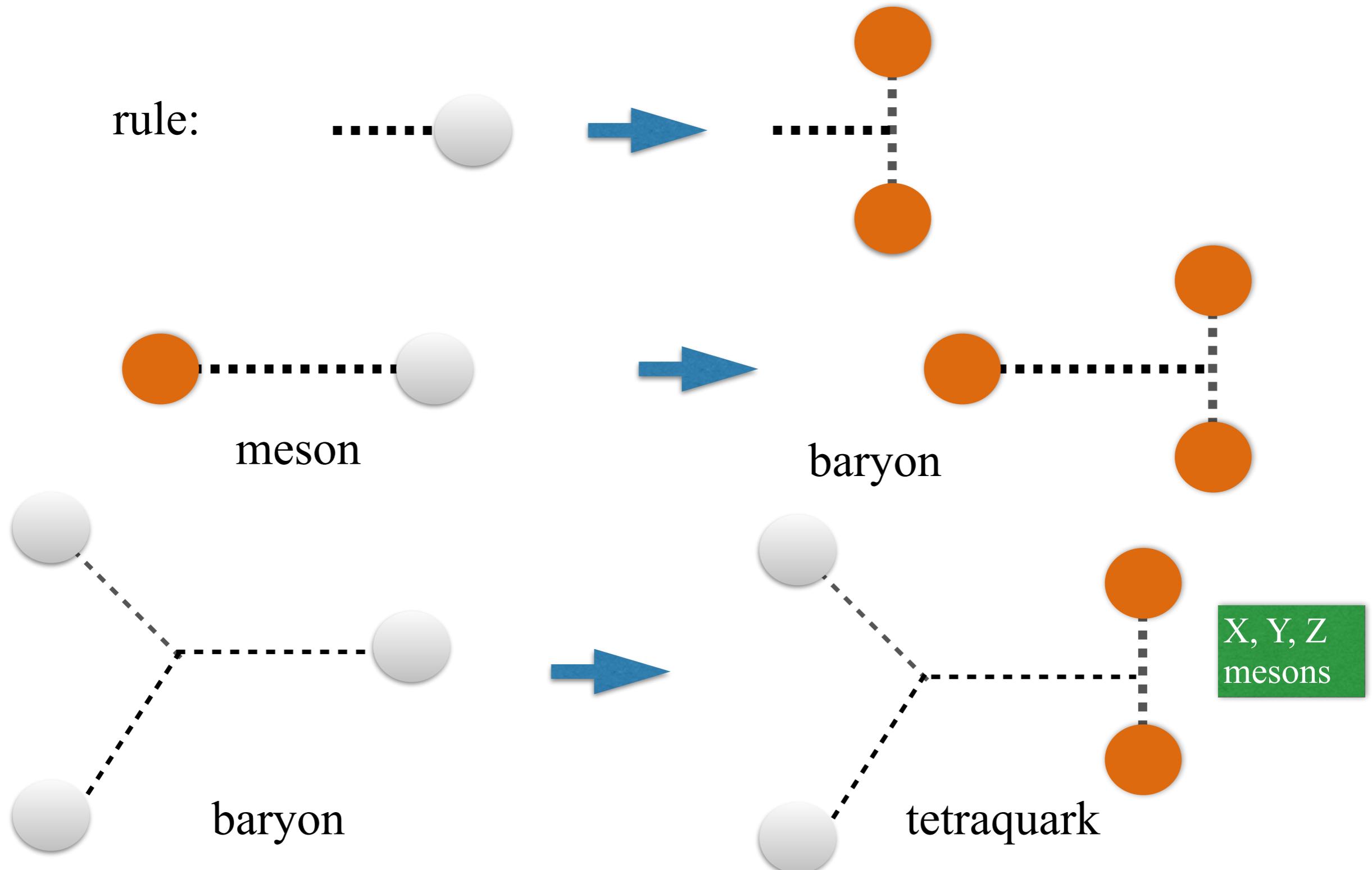
With $\Gamma(X \rightarrow J/\Psi \pi \pi) > 2.5\%$
our result implies:

$$B(Y \rightarrow J/\Psi \pi\pi) > \begin{cases} 2.1 \cdot 10^{-2} & (I : 0 \rightarrow 0) \\ 0.78 \cdot 10^{-2} & (I : 1 \rightarrow 0) \end{cases}$$

$$\Gamma(Y \rightarrow e^- e^+) \lesssim \frac{226}{(\Gamma(Y \rightarrow X\gamma)/\text{keV})} \text{ keV} = \begin{cases} 0.45 & \text{keV} \\ 1.26 & \text{keV} \end{cases}$$

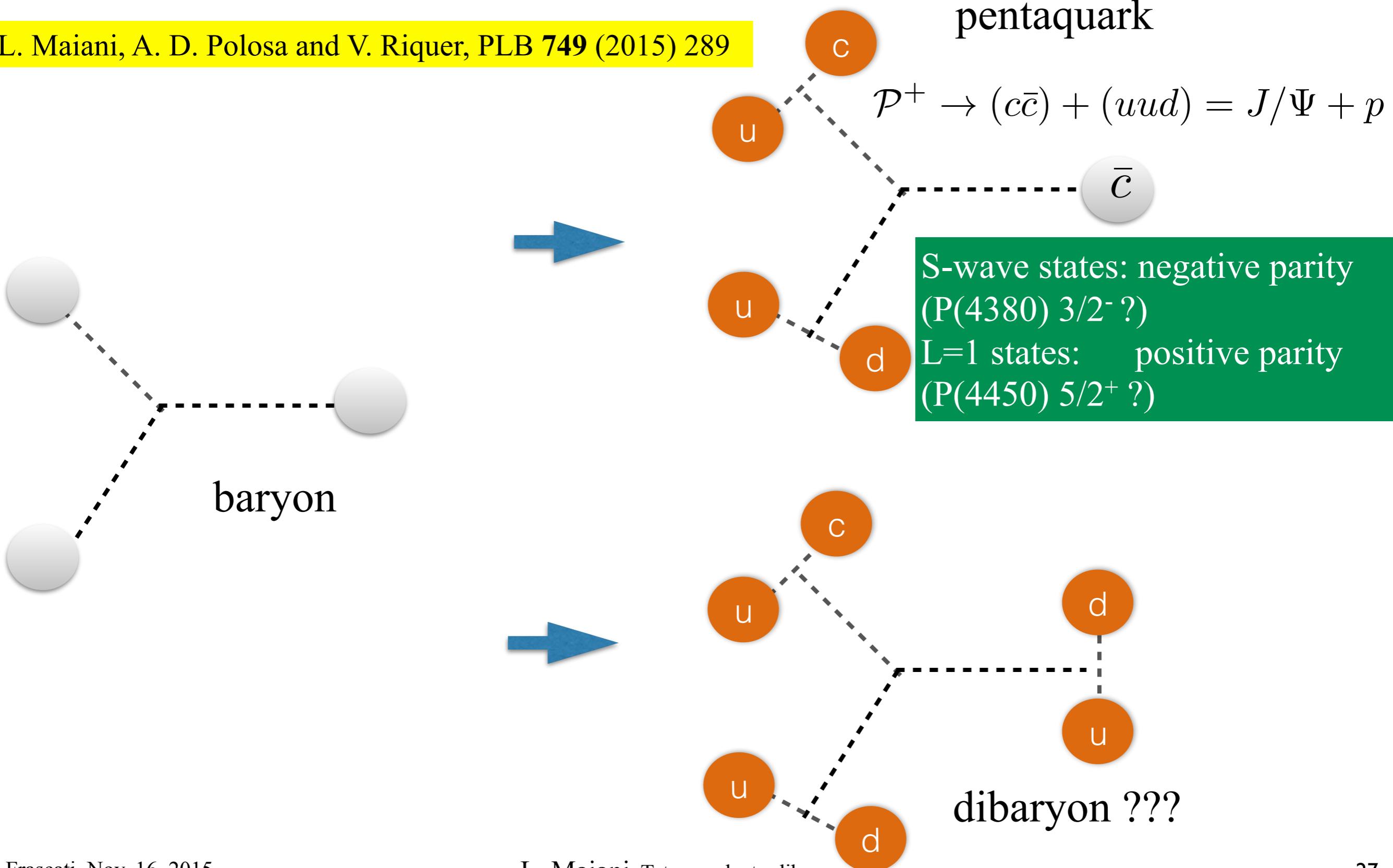
$$\sigma(e^+ e^- \rightarrow \mu^+ \mu^-)_Y \lesssim \frac{2871}{(\Gamma(Y \rightarrow X\gamma)/\text{keV})^2} \text{ pb} = \begin{cases} 0.01 & \text{pb} \\ 0.09 & \text{pb} \end{cases}$$

7. Replacing one antiquark with a diquark makes new objects



more spectacular results for 2 and 3 substitutions in baryons

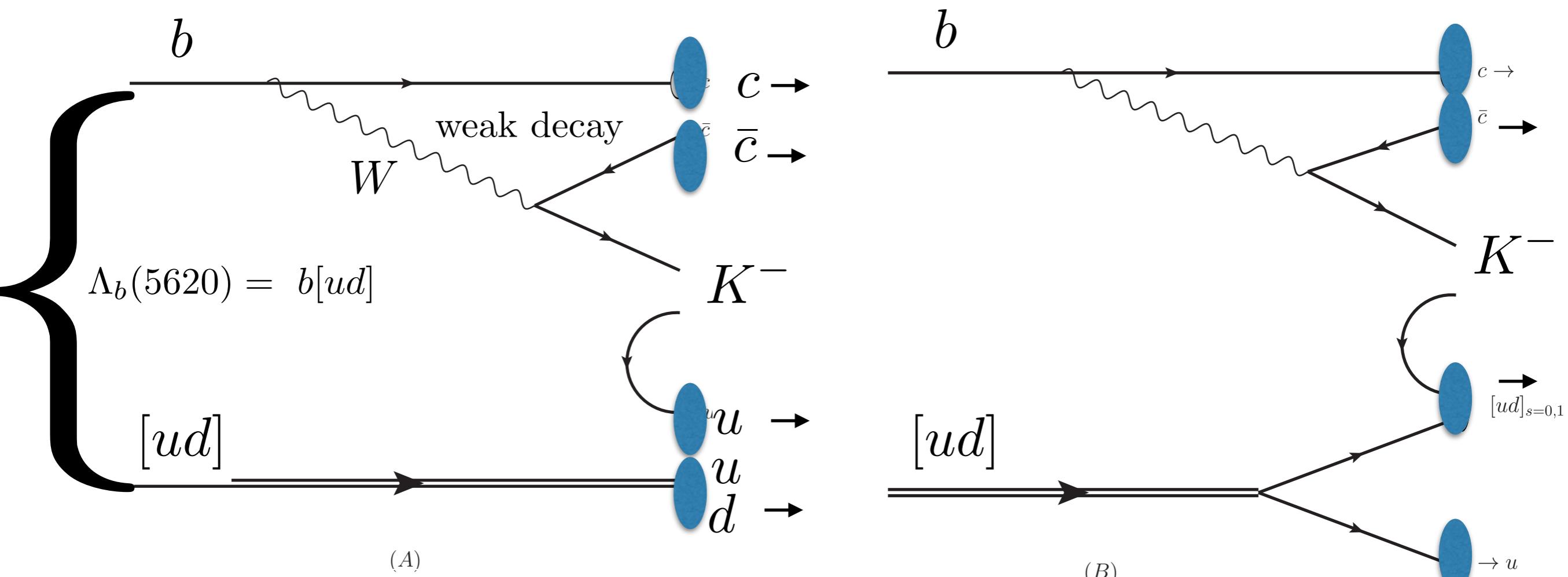
L. Maiani, A. D. Polosa and V. Riquer, PLB **749** (2015) 289



Two amplitudes for Pentaquark production in the decay of $\Lambda_b(5620)$

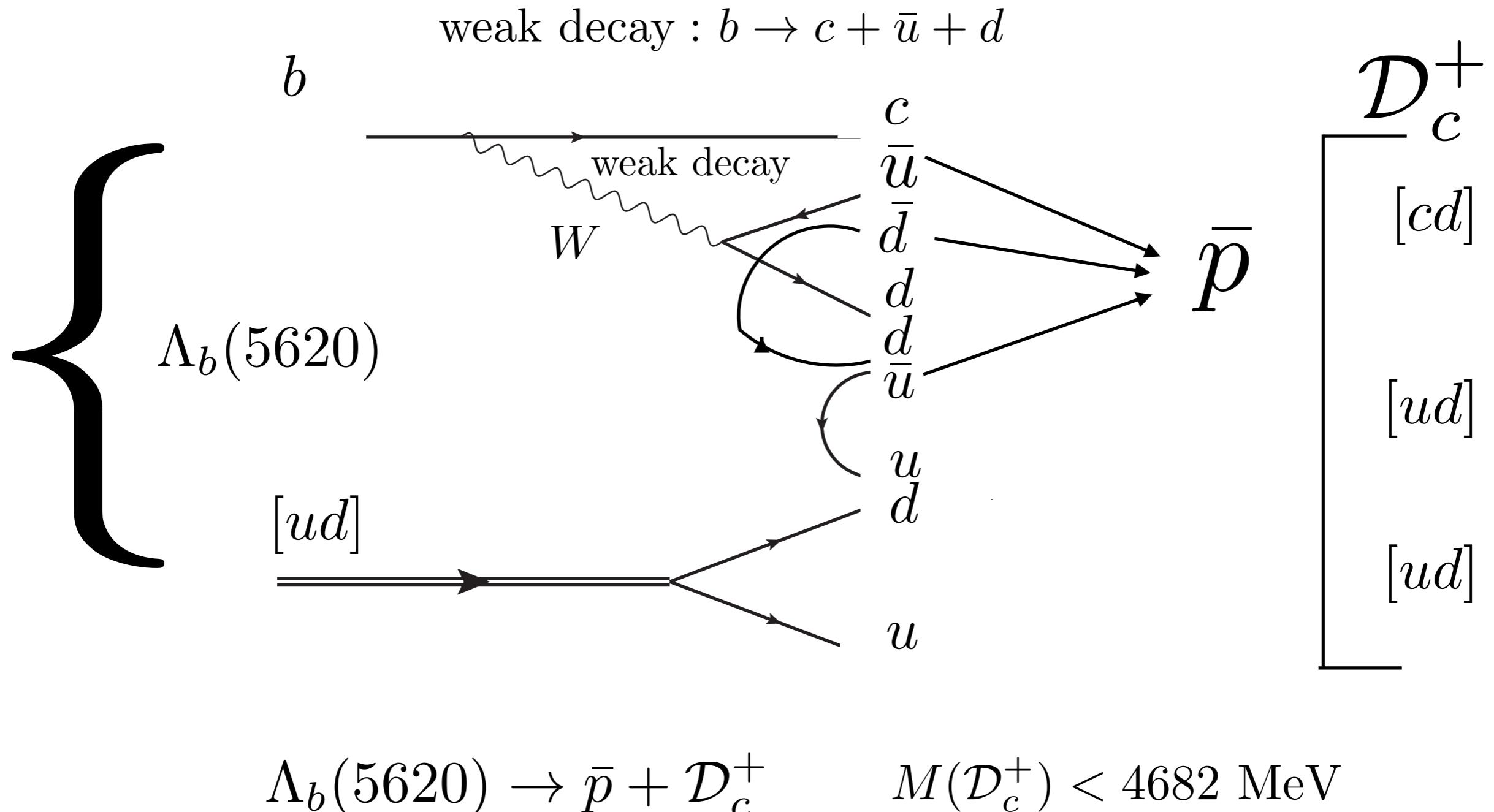
L. Maiani, A. D. Polosa and V. Riquer, *The New Pentaquarks in the Diquark Model*, Phys. Lett. **B 750**, 37 (2015)

weak decay : $b \rightarrow c + \bar{c} + s$



$\longrightarrow \mathcal{P}^+$ constituents = $\bar{c}[cu][ud]$

Production of hypothetical charmed Dibaryonium in $\Lambda_b(5620)$ decay



Dibaryon decays

L. Maiani, A. D. Polosa and V. Riquer, in preparation

- A dibaryon could decay in several different ways

- By string breaking, into baryon+pentaquark, e.g.:

$$\mathcal{D}_c^+ = [cd][ud][ud] \rightarrow p + \mathcal{P}_c^0 = p + \bar{u}[cd][ud] \rightarrow p + (D^0 + n, \text{ or } \pi^- + \Lambda_c);$$
$$M(\mathcal{D}_c^+) > 3740 \text{ MeV}$$

- By quark rearrangement, into two baryons, e.g.:

$$\mathcal{D}_c^+ \rightarrow p + \Sigma_c^0 \rightarrow p + \Lambda_c^+ + \pi^-$$
$$M(\mathcal{D}_c^+) > 3390 \text{ MeV}$$

- By beta decay of the c quark ($c \rightarrow s(d) + e^+ + \nu_e$), lifetime $\approx 10^{-12} \text{ s}$:

$$\mathcal{D}_c^+ \rightarrow e^+ \nu_e + \Sigma^- + p, \quad M(\mathcal{D}_c^+) > 2135$$

$$\mathcal{D}_c^+ \rightarrow e^+ \nu_e + \Delta^- + p, \quad M(\mathcal{D}_c^+) > 2170$$

8. Conclusions

- Diquarks seem to be a useful organising principle, to classify the structure of exotic mesons, pentaquark and yet to be discovered dibaryons;
- dibaryons can be searched for in Λ_b decays for a wide range of masses (from 4680 down to 2135 MeV;
- if found, dibaryons we could complete a second layer of hadron spectroscopy, following the Gell-Mann Zweig layer and completing the saturation possibilities of one and three QCD strings;
- until now, exotics seen contain heavy quark flavours: an experimental reexamination of the lack of existence of light exotic mesons and positive strangeness baryons is in order.
- much remains to be done, in theory and experiments,
- we look forward to exciting times