The new exotics Z_{cs}(3085), Z_{cs}(4003), Y(4230) decays and Flavour SU(3)

Luciano Maiani
Università di Roma La Sapienza. Roma. Italy

X,Y, Z Workshop
April 14, 2021

1. Hidden charm and beauty hadrons reveal *tetraquarks* and *pentaquarks*

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

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

•Heavy quark pairs are difficult to be created or destroyed by QCD forces inside hadrons.

• Hadrons electrically charged ***and*** featuring a $c\bar{c}$ or $b\bar{b}$ pair ***must*** contain additional light quarks, ***realising the hypothesis advanced by Gell-Mann in the Sixties***

•These are the exotic X, Y, Z mesons and the pentaquarks discovered over the last decade

There are, indeed, new valence quark configurations !!

- First hypothesis of tetraquarks by R. Jaffe, as a model of the lightest scalar mesons
- Tetraquarks are more easy to identify at the increase of quark mass
- Hidden heavy flavors have been the first,
- hidden charm and open strangeness ***discovered now !!***
- The first, *unexpected charmonium* was the still controversial X(3872)
- Nearness to heavy pair threshold is to be expected, but the X(3872) is exceptionally close, we do not know yet if it is above or below the $D^0\bar{D}^{*0}$ threshold, within some 80 keV.

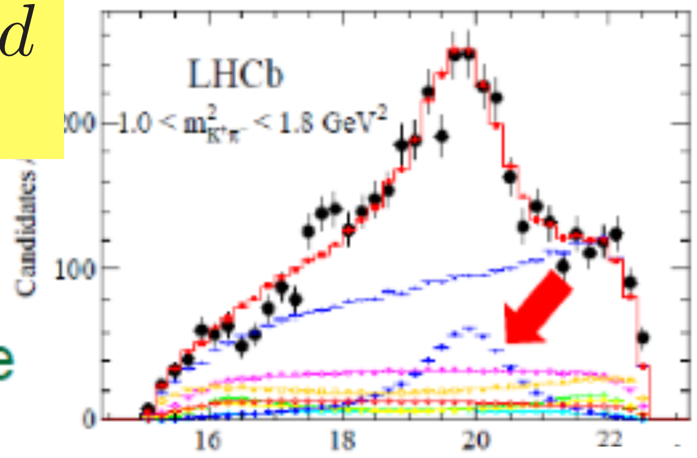
Explicit Tetraquarks

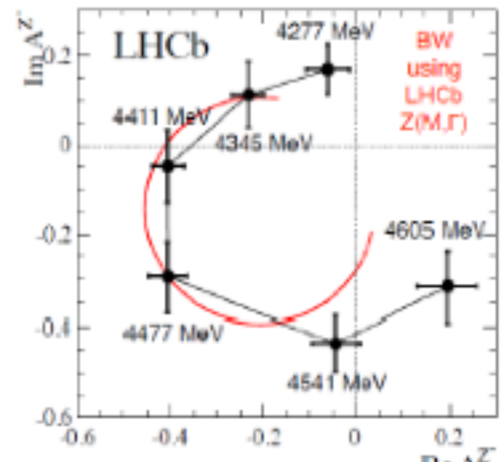
$Z_c(4430)^{\pm} \rightarrow J/\Psi + \pi$

valence quark composition: $c\bar{c}u\bar{d}$

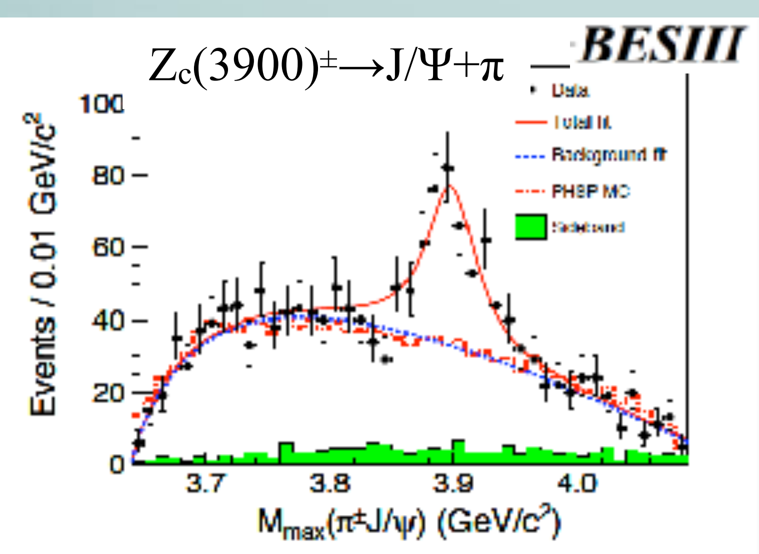
1. Confirm Belle's observation of 'bump'
2. Can NOT be built from standard states
3. Textbook phase variation of a resonance

[PRL 112 (2014) 222002]

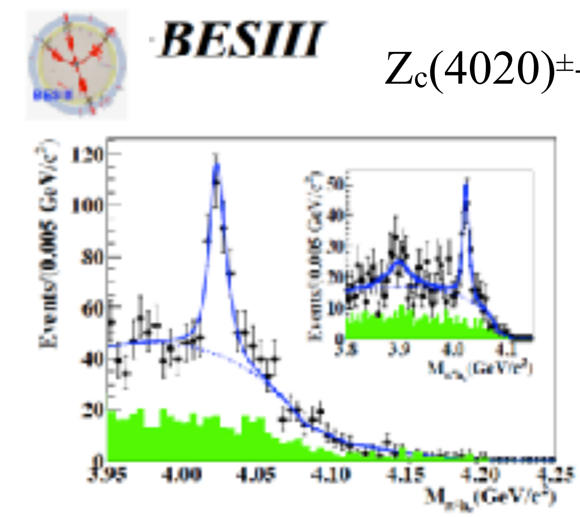




$Z_c(3900)^{\pm} \rightarrow J/\Psi + \pi$



$Z_c(4020)^{\pm} \rightarrow h_c + \pi$



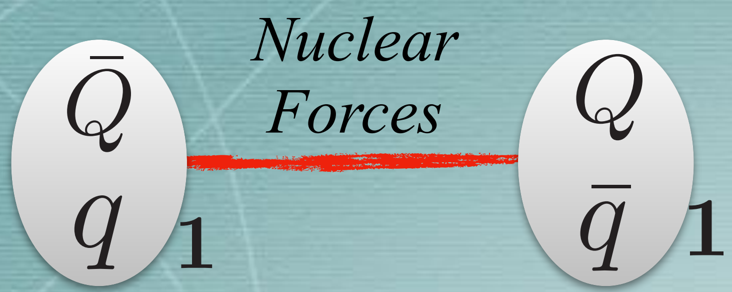
BESIII: PRL111, 242001

Simultaneous fit to 4.23/4.26/4.36 GeV data, 16 η_c decay modes. 8.9σ

$M(Z_c(4020)) = 4022.9 \pm 0.8 \pm 2.7$ MeV;

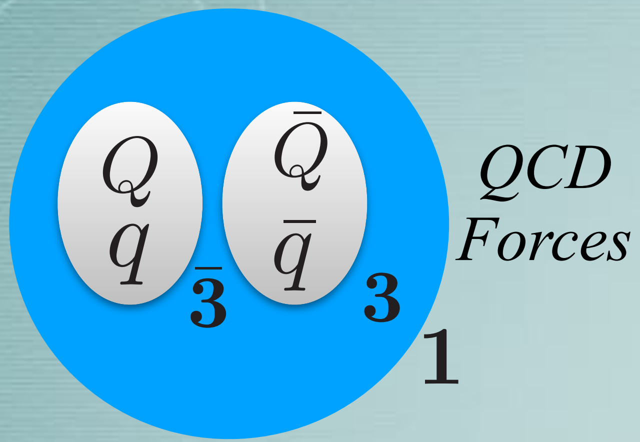
$\Gamma(Z_c(4020)) = 7.9 \pm 2.7 \pm 2.6$ MeV

No consensus, yet



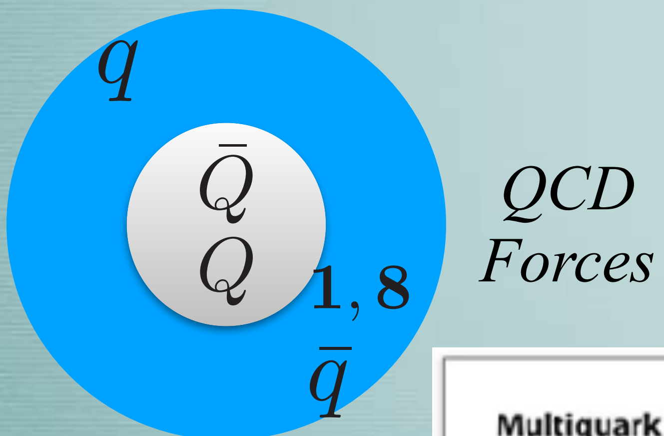
Hadron Molecule

F-K. Guo, C. Hanhart, U-G Meißner, Q. Wang, Q. Zhao, and B-S Zou, arXiv 1705.00141 (2017)



Compact Diquark-Antidiquark

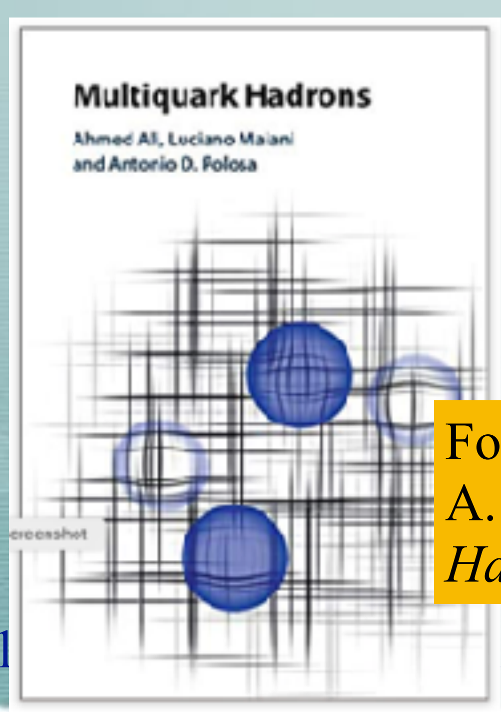
L. Maiani, F. Piccinini, A. D. Polosa and V. Riquer, Phys. Rev. D 71 (2005) 014028; **D 89** (2014) 114010.



HadroCharmonium (1)
Quarkonium Adjoint Meson (8)

S. Dubynskiy, S. and M. B.Voloshin, Phys. Lett. **B 666**,(2008) 344.

E. Braaten, C. Langmack and D. H. Smith, Phys. Rev. **D 90** (2014) 01404



For a review, see:
A. Ali, L. Maiani and A.D. Polosa, *Multiquark Hadrons*, Cambridge University Press (2019)

One-pion exchange vs X(3872), Z_c(3900) and Z_c(4020)

N.~A.~Tornqvist, Phys. Lett. B **590** (2004), 209-215
M. Karliner and J. L. Rosner, Phys. Rev. Lett. **115** (2015) 122001
Ali et al. Cambridge University Press (2019)

- The $DD^*\pi$ lagrangian is

$$\mathscr{L}_{\pi D^* D} = \frac{g}{f_\pi}\left[(D^*_\mu)^\dagger \mathbf{t}\cdot(\partial^\mu \pi)D + \bar{D}^\dagger \mathbf{t}\cdot(\partial^\mu\pi)\bar{D}^*_\mu\right] + \text{ h.c.}$$

- It produces a potential that can possibly make molecular bound states in S wave. Interaction: $H \propto I^a \oplus I^a$. Lowest energy states
- $D - \bar{D}^*$, $D^* - \bar{D}$, $J=1^+$, (C=+1, I=0) and (C=-1, I=1) (X(3872), Zc(3900) ?)
- $D^* - \bar{D}^*$, $J=1^+$, (C=-1, I=0) yet to be seen? Zc(4020) ?
- what exchange could bind a meson-meson molecular $X_{s\bar{s}}$(4140)? or Z_c
- η, ϕ…J/Ψ…? ???

2. Exotic mesons: the ***New Wave***

- Starting from 2016, new kinds of exotic hadrons have been discovered:

$J/\Psi\ \phi$ resonances, $di - J/\Psi$ resonances, open strangeness Exotics: $Z_{cs}(3082)$ and $Z_{cs}(4003)$

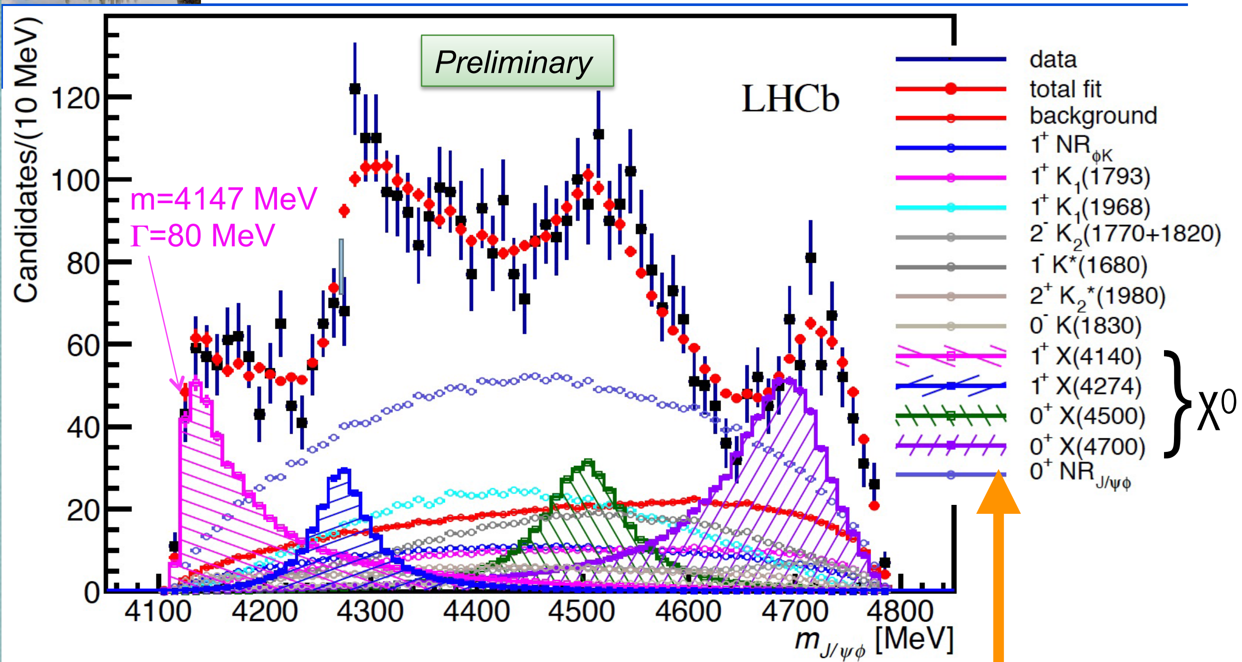
- Pion exchange forces cannot bind them as hadron molecules made by color singlet mesons: molecular models have to stand on the existence of "phenomenological forces" with undetermined parameters
- Not necessarily "just on threshold", no cusp behaviour..
- The New Exotics arise very naturally as $([cq]^{\bar{\mathbf{3}}}[\bar{c}\bar{q}']^{\mathbf{3}})_{\mathbf{1}}$ bound by QCD in color singlets
- A firm prediction: ***hidden charm tetraquarks must form complete multiplets of flavor SU(3)***
- with mass differences determined by:

$$m_s - m_u = 120 - 150 \text{ MeV}.$$

- ***with $Z_{cs}(3082)$ and $Z_{cs}(4003)$ we can almost fill two tetraquark nonets with the expected scale of mass differences.***

The New Wave started with the discovery of $J/\Psi\ \phi$ resonances, LHCb 2016

Results of fit: m(J/ψφ)



- 4 visible structures fit with BW amplitudes

28 Recontres de Blois, June 2, 2016

Results of fit

- J^P also measured all with >4σ significances

Particle	J^P	Significance	Mass (MeV)	Γ (MeV)	Fit Fraction (%)
X(4140)	1^+	8.4 σ	$4146.5\pm4.5^{+4.6}_{-2.8}$	$83\pm21^{+21}_{-14}$	$13.0\pm3.2^{+4.8}_{-2.0}$
X(4274)	1^+	6.0 σ	$4273.3\pm8.3^{+17.2}_{-3.6}$	$56\pm11^{+8}_{-11}$	$7.1\pm2.5^{+3.5}_{-2.4}$
X(4500)	0^+	6.1 σ	$4506\pm11^{+12}_{-15}$	$92\pm21^{+21}_{-20}$	$6.6\pm2.4^{+3.5}_{-2.3}$
X(4700)	0^+	5.6 σ	$4704\pm10^{+14}_{-24}$	$120\pm31^{+42}_{-33}$	$12\pm5^{+9}_{-5}$
NR	0^+	6.4 σ			$46\pm11^{+11}_{-21}$

28 Recontres de Blois, June 2, 2016

37

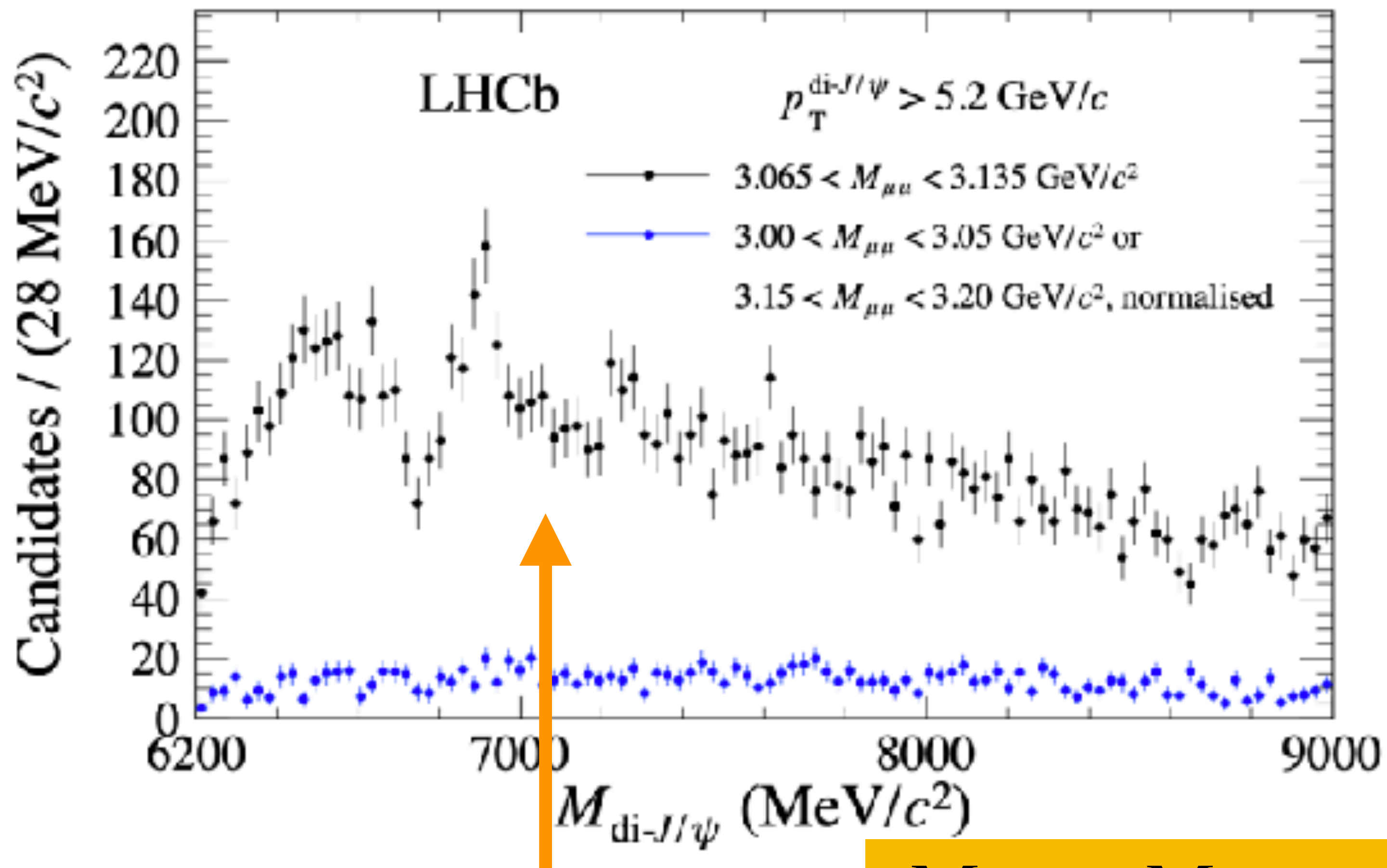
- Meson-Meson molecule: no way

- J/Ψ φ mass distribution: four structures
- positive parity, J=0 and 1, positive charge conjugation
- X(4140) seen previously by CMS and by BELLE
- interpreted as $[cs][\bar{c}\bar{s}]$ tetraquarks

- Baryon-antibaryon molecules? $\Xi_c^+ = [csu]$ $2M_{\Xi_c} \sim 4930$ MeV!!!

L. Maiani, A. Polosa, V. Riquer, Phys. Rev. D **94**, 054026 (2016)

di-J/\Psi resonances !!! LHCb November 2020



•Meson-Meson molecule: no way

Figure 2: Invariant mass spectrum of J/ψ-pair candidates passing the $p_T^{\text{di-}J/\psi} > 5.2\,\text{GeV}/c$ requirement with reconstructed J/ψ masses in the (black) signal and (blue) background regions, respectively.

•Baryon-antibaryon molecule? $\Xi_{cc} = [ccu]$

$2M_{\Xi_{cc}} \sim 7242$ MeV!!!

Open Strangeness

$e^+e^- \to K^+ Z_{cs}^-(3985) \to K^+(D_s^{*\,-} D^0 + D_s^- D^{*\,0})$

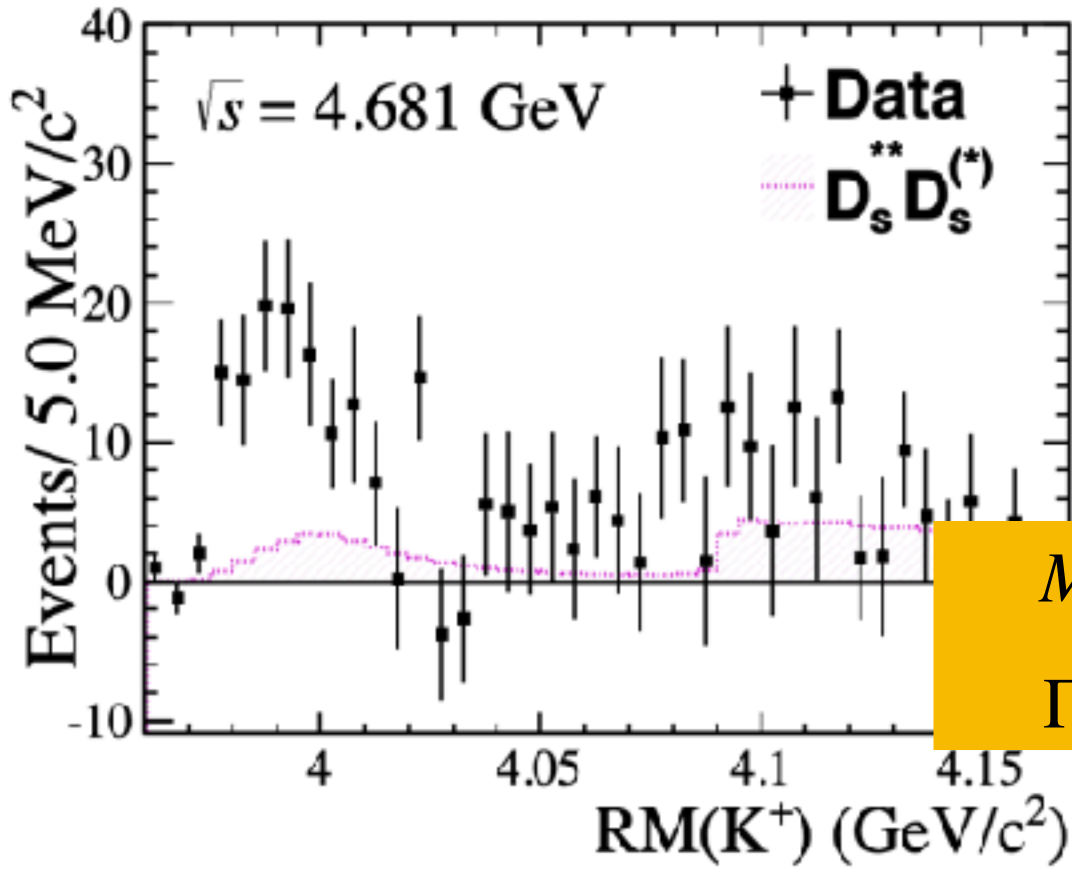


FIG. 4. The K^+ recoil-mass spectrum in data at $\sqrt{s}$ = 4.681 GeV after subtraction of the combinatorial backgrounds.

$M = (3982.5 + 1.8 \pm 2.1)\ MeV$

$\Gamma = (12.8 + 5.3 \pm 3.0)\ MeV$

- Meson-Meson molecule: no way

- Baryon-antibaryon molecule?

$\Xi_c^+ = [csu],\ \bar{\Sigma}_c^{--} = [\bar{c}\bar{u}\bar{u}]$

$M_{\Xi_c} + M_{\bar{\Sigma}_c} \sim 4923$ MeV!!!

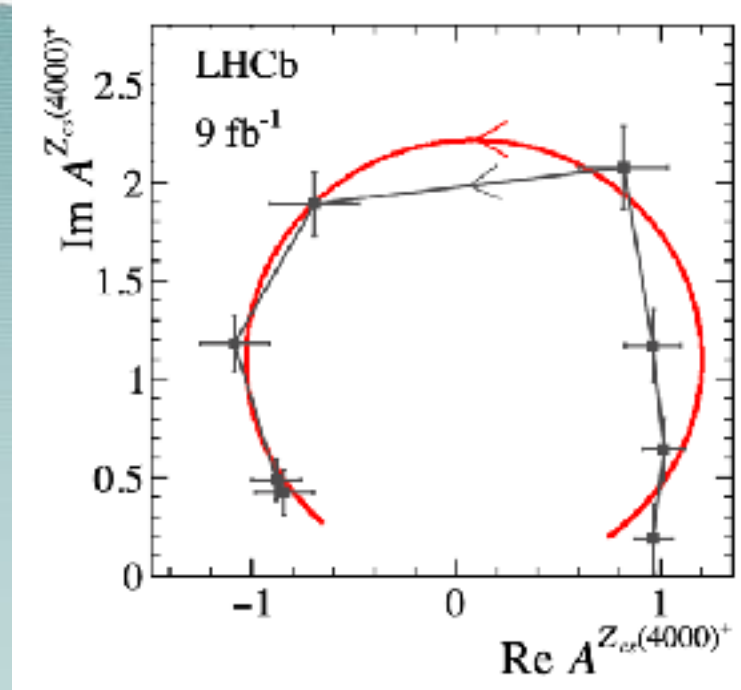
LHCb:

The decay: $B^+ \to J/\Psi\ \phi\ K^+$

displays exotic resonances in two channels:

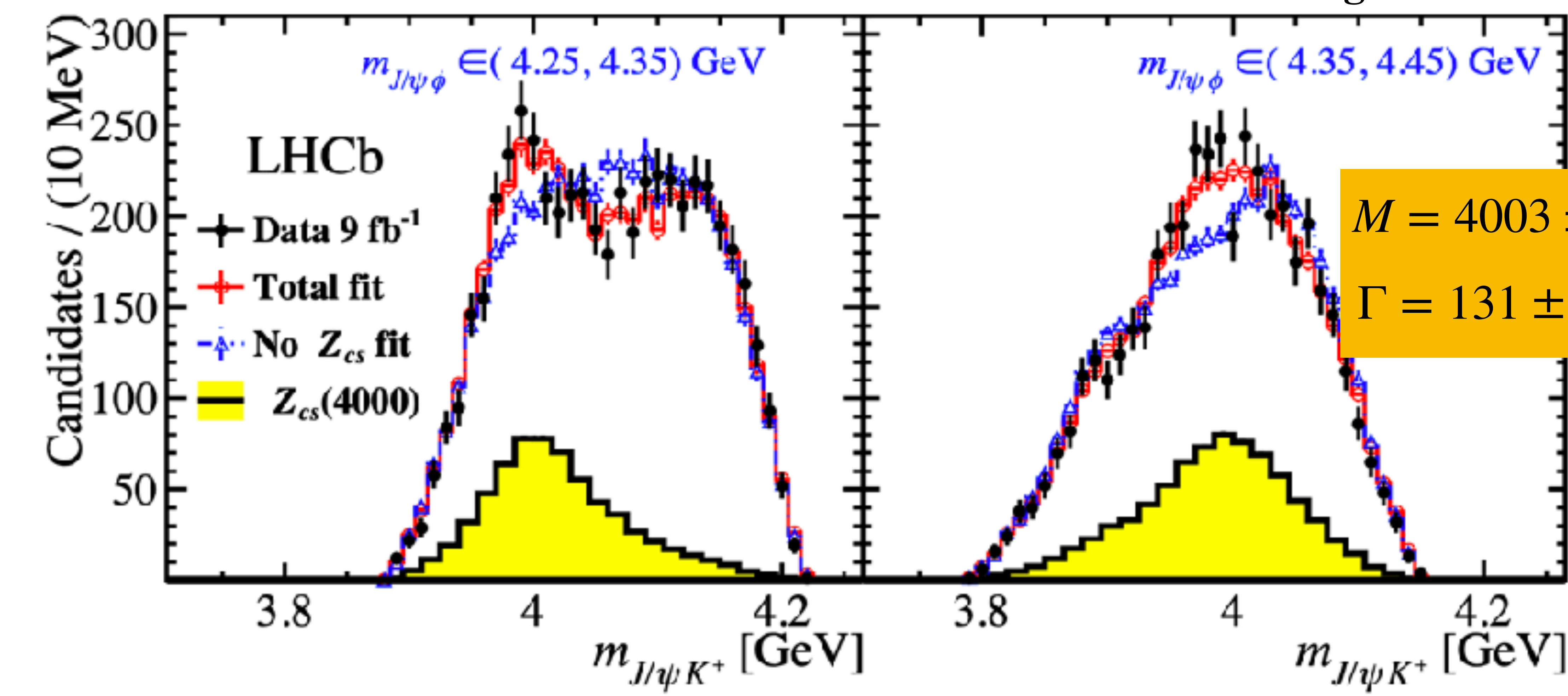
$J/\Psi\ \phi\ (X_{s\bar{s}} = [cs][\bar{c}\bar{s}])$ and

$J/\Psi\ K^+\ (Z^+_{cs} = [cu][\bar{c}\bar{s}])$



LHCb:
Argand's Plot of $Z^+_{cs}(4003)$

LHCb: $Z^+_{cs}(4003)$
March 2021



$M = 4003 \pm 6^{+4}_{-14}$ MeV

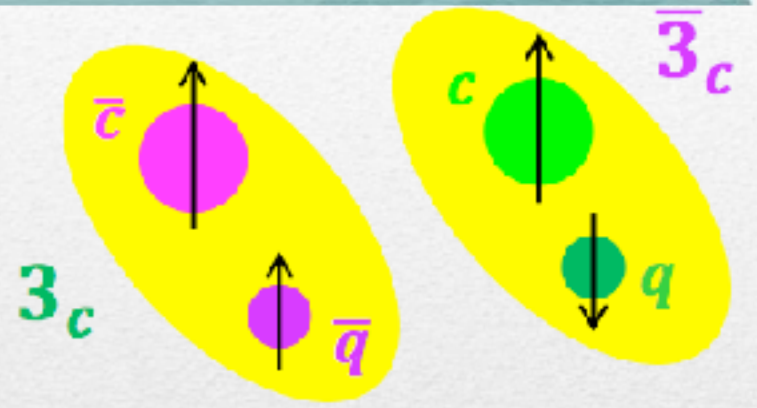
$\Gamma = 131 \pm 15 \pm 26$ MeV

LHCb and BES III see two DIFFERENT particles !!!

3. Tetraquark constituent picture of unexpected quarkonia

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

- [cq] in color $\bar{\mathbf{3}}$, $[cq]_{S=0,1}[\bar{c}\bar{q}']_{S=0,1}$ 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 costituent quark model

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

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

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

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

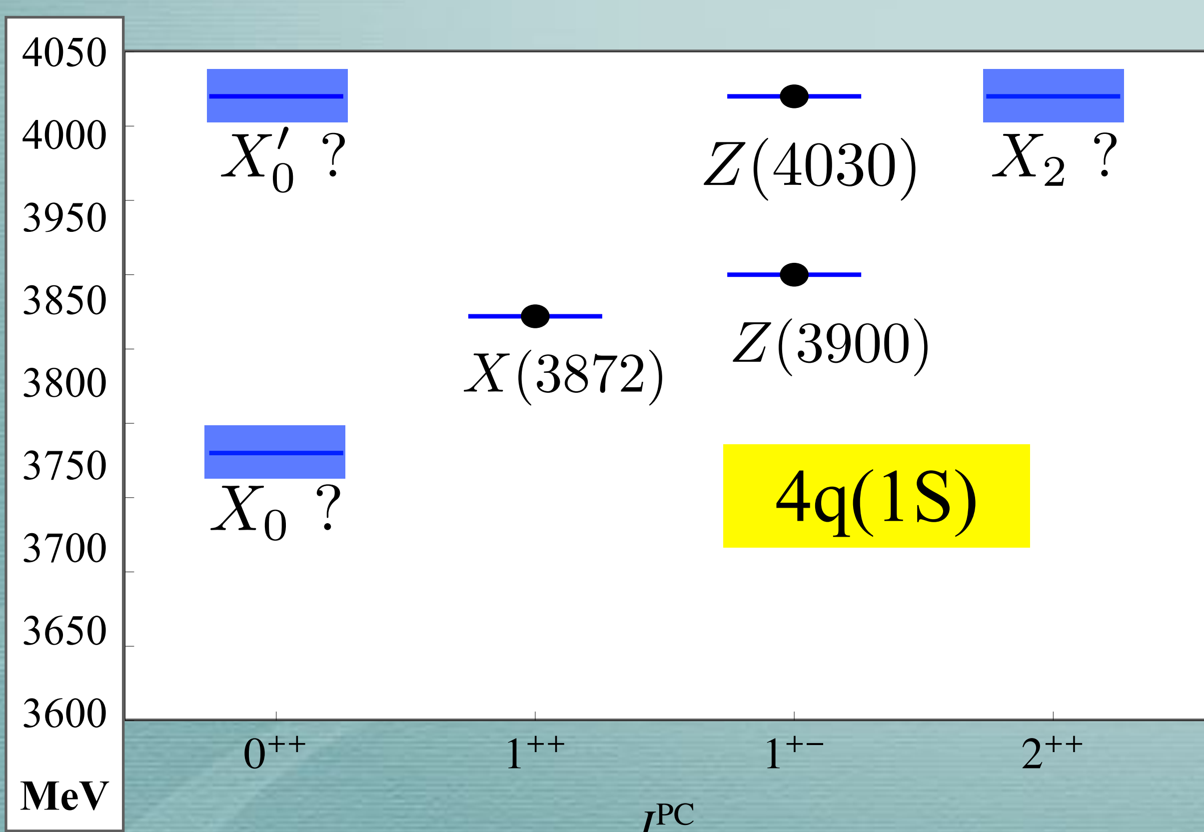
$$J^P=1^+ \quad G=+ \quad Z=\frac{1}{\sqrt{2}}\left(|1,0\rangle_1-|0,1\rangle_1\right),\ Z'=|1,1\rangle_1$$

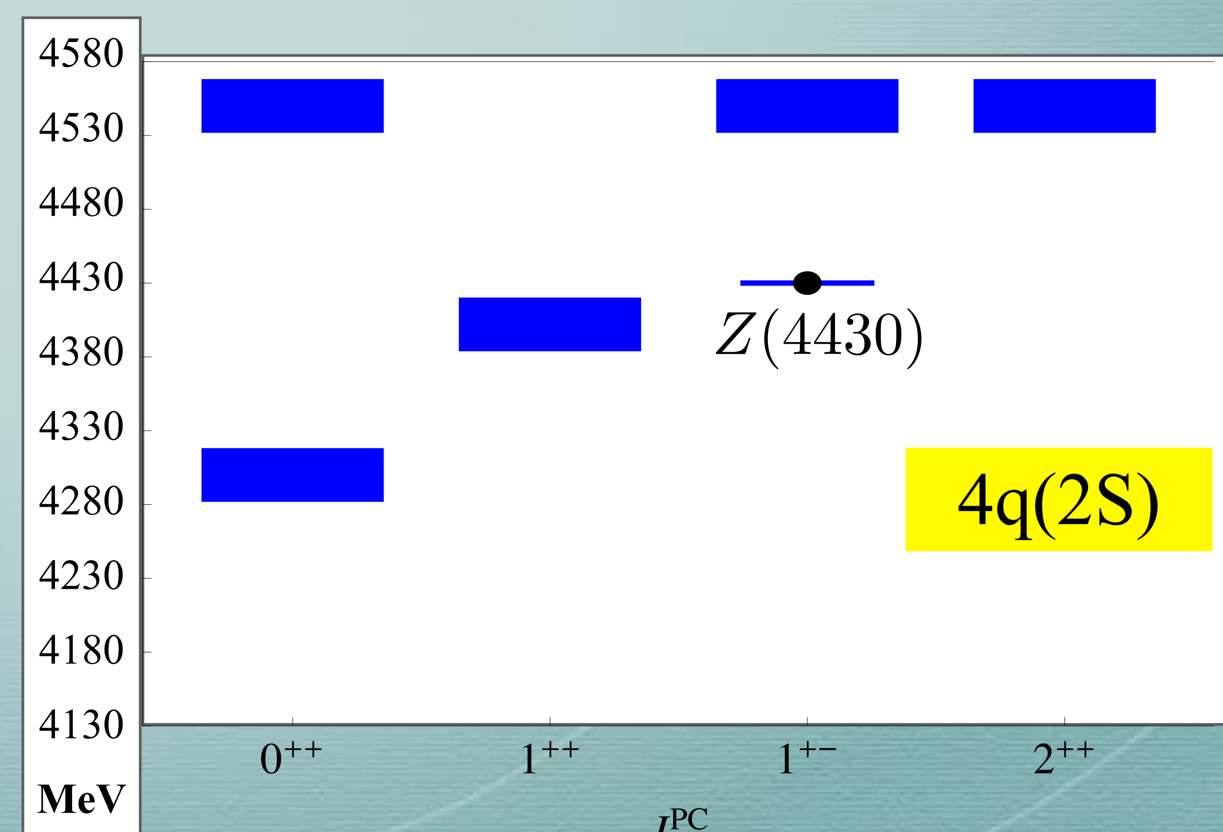
$$J^P=2^+ \quad C=+ \quad X_2=|1,1\rangle_2$$

X(3872)=X_1
$Z_c(3900)$, $Z_c(4020)$=lin. combs. of Z&Z'

Z(4340) as Radial excitation

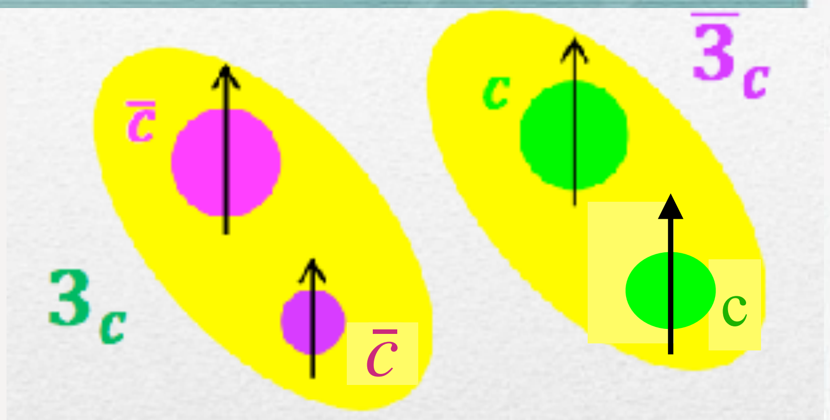
- in 2007 we classified the Z(4430) as a tetraquark, the radial excitation of the S-wave companion of X(3872)
- this was because its mass ~530 MeV larger than the X and its preference to decay into $\psi(2S) + \pi$
- *a crucial consequence of a Z(4430) charged particle is that another charged state decaying into Ψ(1S) $\pi^{\pm}$ or $\eta_c\ \rho^{\pm}$ should be found around 3880 MeV*
- The Z_c(3900) has been seen by BES III and confirmed by Belle and CLEOc, with the anticipated decay:
  - Z^{+} (3900)→ $\psi(1S)\ \pi^{+}$
- can one find the other 1S and 2S X s and Z s ??…





Tetraquark constituent picture of di-J/Ψ resonances

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



- [cc] in color $\bar{\mathbf{3}}$

$$[cc]_{S=1}[\bar{c}\bar{c}]_{S=1}$$

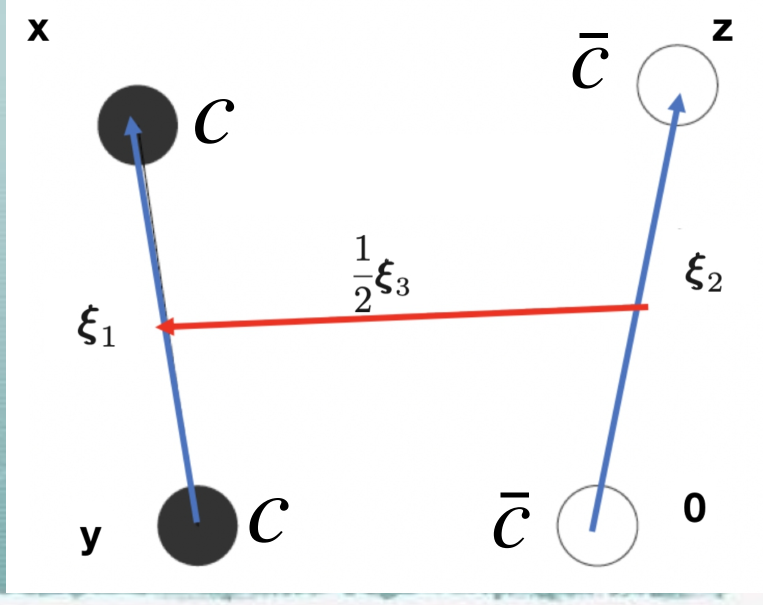
- total spin of each diquark, S=1 (color antisymmetry and Fermi statistics)
- S-wave: positive parity

S-wave, fully charm tetraquarks

- C=+1 states: $J^{PC} = 0^{++},\ 2^{++}$, decay in:2 J/ψ, 2 η_c, 2 $\chi_{c0}(1P)$, 2 $\chi_{c1,2}(1P)$, $D\bar{D}$
- C= -1 states: $J^{PC} = 1^{+-}$, decays in $J/\psi + \eta_c$, $D\bar{D}$

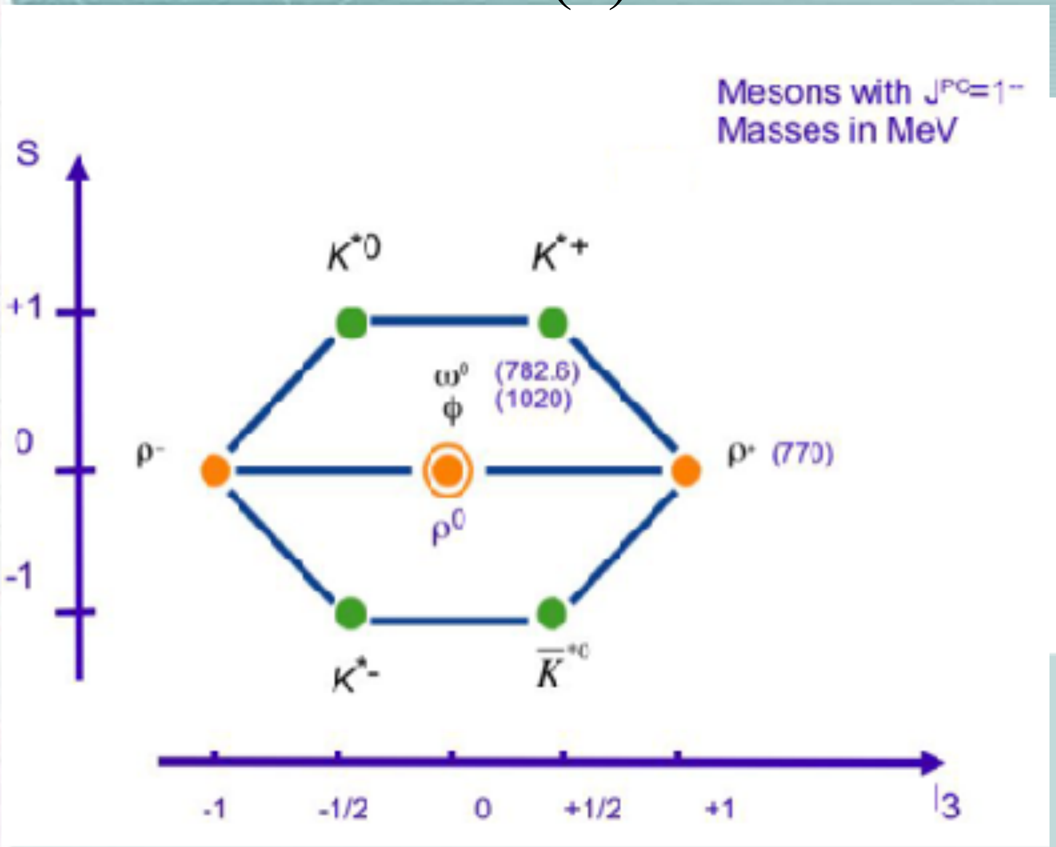
- mass spectrum can be computed (see e.g. M.A.Bedolla, J.Ferretti, C.D.Roberts and E.Santopinto, arXiv:1911.00960 [hep-ph]:
  - QCD inspired potential (Coulomb+linear potential), gaussian wave functions in the three Jacobi coordinates, ξ_1, ξ_2, ξ_3
- Urgent: measure Spin-Parity of the resonances in the spectrum

Jacobi coordinates in the tetraquark

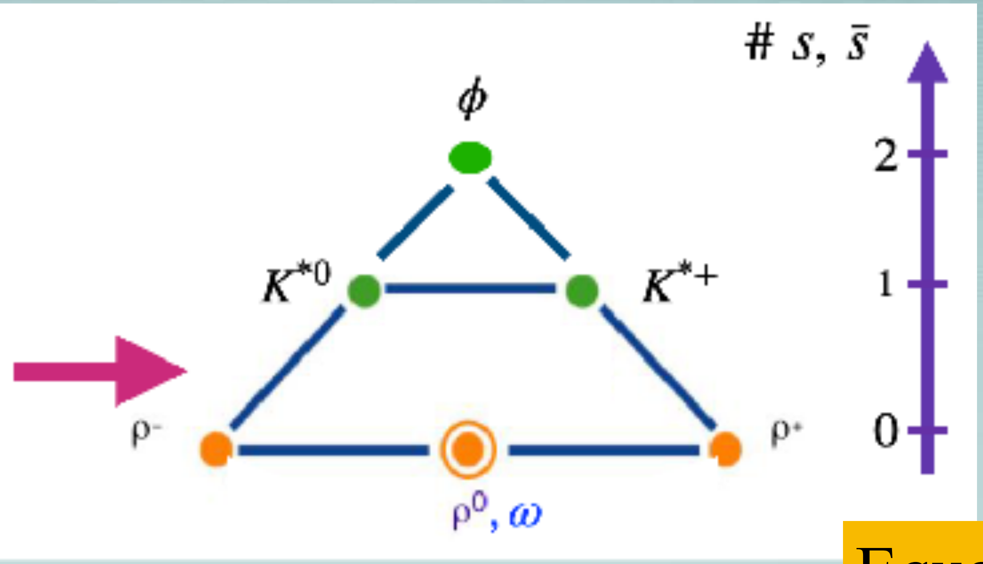


4. Hidden charm tetraquarks make Flavour SU(3) nonets

classical SU(3) nonet



can be plotted v.s. number of strange quarks



Nonet Mixing: mass differences $\propto (n_s + n_{\bar{s}})(m_s - m_u)$

Equal Spacing rule, e.g.:

$$\frac{\rho(775) + \phi(1020)}{2} - K^*(892) \sim 6 \text{ MeV}$$

$$\phi(1020) - \rho(775) \sim 244 \text{ MeV}$$

The lightest $J^P = 1^+$ tetraquarks fall into two different nonets

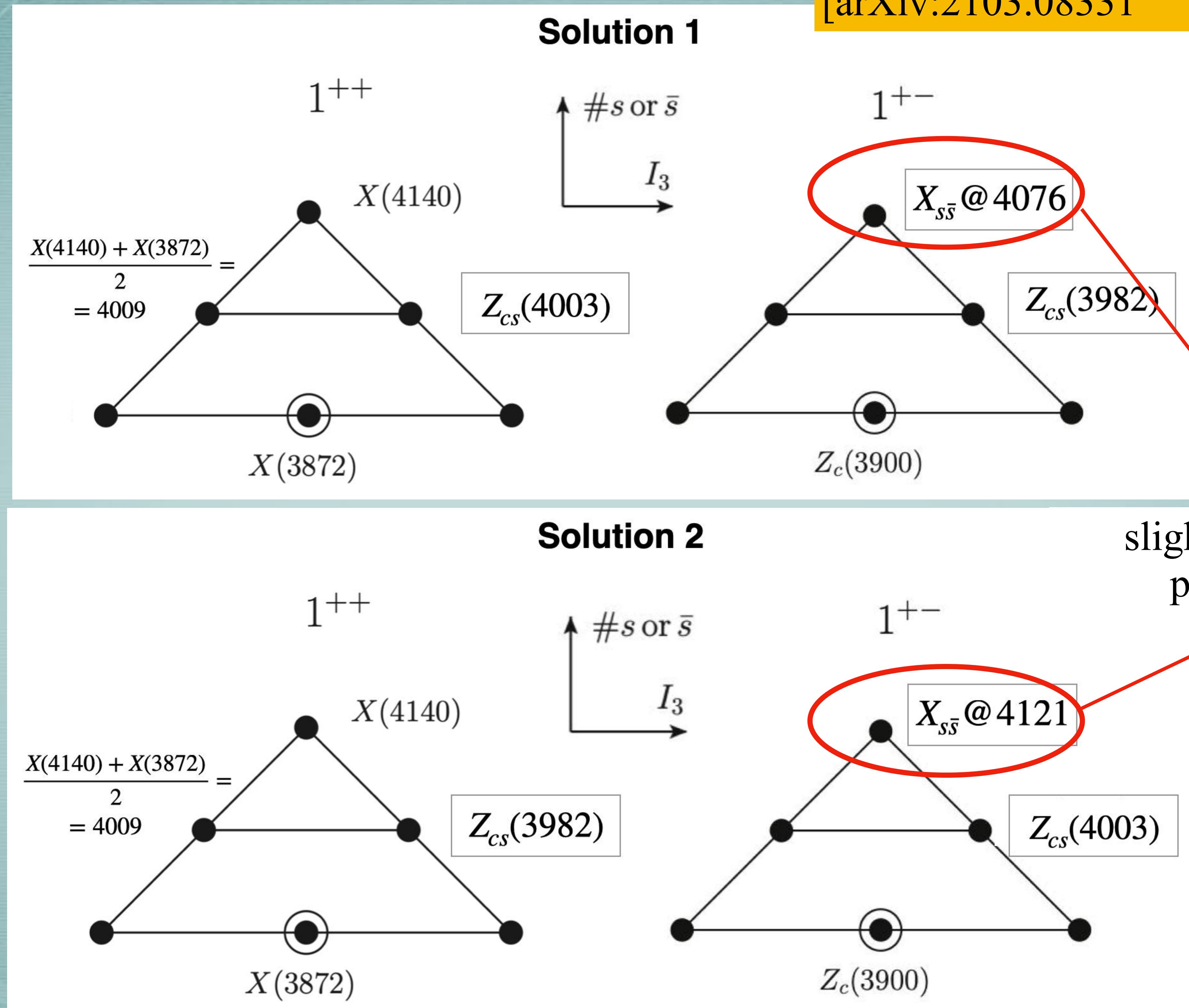
- X(3872) & X(4140) (the lowest $J/\Psi \; \phi$ resonance) belong to one ($J^{PC} = 1^{++}$) nonet, as indicated by the mass difference:

$$Z_c(4140) - X(3872) = 275 \text{ MeV}$$

- $Z_c(3900)$ needs a second ($J^{PC} = 1^{+-}$) nonet
- $Z_{cs}(3985)$ and $Z_{cs}(4003)$ almost completely fill them…

Two solutions

L. Maiani, A. D. Polosa and V. Riquer, [arXiv:2103.08331



slightly different predictions

Solution 1 is favoured. The scale of the mass differences is in line for both

a well identified shopping list

- $X_{s\bar{s}}$, $M = 4076$ or 4121, decays: $\eta_c\ \phi$, $D_s^*\bar{D}_s$:
- the I=1 partners of X(3872), decaying into $J/\Psi + \rho^{\pm}$ (see later)
- the I=0 partners of $Z_c(3900)$ and $Z_c(4020)$, possibly decaying into $J/\Psi + f_0(500)$(aka $\sigma(500)$)
- The nonet of $Z_c(4020)$, $J^{PC} = 1^{+-}$, requires a third Z_{cs} at 4150-4170 MeV;
- LHCb indeed sees a $Z_{cs}(4220)$, $J^P = 1^+$or 1^-, which however may be a bit too heavy.

5. Radiative and Pionic Decays of Y(4230)

L. Maiani, A. D. Polosa and V. Riquer, arXiv:2103.14356

- Have been studied by BESIII in e^+e^- annhilation:

$$e^+e^- \to Y(4230) \to \pi + Z_c(3900)/Z_c(4020) \text{ or } \gamma + X(3872)$$

Ref.	Z(Mass)	$\sqrt{s}$ (GeV)	$e+e \to Y(4230) \to \dots$	Q-value	σ (pb)
PRL 115[20]	$Z_c(3885)$	4.226	$\pi^0 Z_c^0 \to \pi^0 (D\bar{D}^* + c.c.)^0$	197	77 ± 21
PRD 92[21]	$Z_c(3885)$	4.23	$[\pi^+ Z_c^- + c.c.] \to [\pi^+(D\bar{D}^*)^- + c.c.]$	197	141 ± 14
PRL 112 [22]	$Z_c(4020)$	4.26	$[\pi^+ Z_c^- + c.c.] \to [\pi^+(D^*\bar{D}^*)^- + c.c.]$	65	$(0.65 \pm 0.11)\cdot$ $\cdot(137 \pm 17) =$ $= 89 \pm 19$
PRL 115 [23]	$Z_c(4020)$	4.23	$\pi^0 Z_c^0 \to \pi^0 (D^*\bar{D}^*)^0$	65	62 ± 12
PRL 115[24]	$X(3872)$	4.226	$\gamma X \to \gamma \pi^+\pi^- J/\psi$	−−	$0.27 \pm 0.09 \pm 0.12$
PRD100[25]			γX	354	$5.5^{+2.8}_{-3.6}$
2011.07855[2]	$Z_{cs}(3982)$	4.681	$K^+ Z_{cs}^- \to K^+(D_s^{*-} D^0 + D_s^- D^{*0})$	199	4.4 ± 0.9

TABLE I: e^+e^- annhilation cross sections into exotic hadrons, determined by BES III in the $Y(4230)$ region.

- the cross section at the peak is

$$\sigma_{\text{peak}}(e^+e^- \to Y(4230) \to f) = \frac{12\pi}{M_Y^2} \frac{\Gamma_e \Gamma_f}{\Gamma^2} \qquad \Gamma(Y(4230)) = (56.0 \pm 3.6 \pm 6.9)\ \text{MeV}$$

- Assume Y has a valence quark composition $[cu][\bar{c}\bar{u}]$ or $[cd][\bar{c}\bar{d}]$ with diquarks in P-wave. Then:

- the photon is emitted from the light quark or antiquark: $q \to q + \gamma$, same for q̄,

coupling $= e\, Q_{u,d}$, $\frac{e^2}{4\pi} = \frac{1}{137}$

- pionic decay arises from the elementary transitions
- $u \to d\ \pi^+$ or $\bar{d} \to \bar{u}\ \pi^+$ (and similar for π^- and π^0)
- the pion couples to the axial current:

where M is the meson SU(3) matrix

$$\mathcal{H}_I^\pi = \frac{g}{f_\pi} \bar{q}\gamma\gamma_5(\nabla \mathbf{M})q,\ f_\pi = 132 \text{ MeV}$$

- The same transitions are operative in

$$D^* \to \gamma/\pi + D\ \ (\Delta L = 0)$$

and $D_1 \to \pi\ D^*\ (\Delta L = 1)$

R. Casalbuoni, A. Deandrea, N. Di Bartolomeo,
R. Gatto, F. Feruglio and G.Nardulli,
Phys. Rept. **281**, 145(1997).

Is quark dynamics the same in mesons and tetraquarks ?

- the ratio $R_\Gamma = \dfrac{\Gamma(Y4230) \to \pi^0 Z_c(3900))}{\Gamma(Y(4230) \to \gamma X(3872))}$ depends only on g (the dependence upon wave functions cancel out)

- setting:

$$R_\Gamma = R_\sigma = \frac{\sigma(e^+e^- \to \pi^0 Z_c(3900)^0 \to \pi^0(D\bar{D}^* + c\,.\,c.)^0)}{\sigma(e^+e^- \to \gamma X(3872))} \sim 14$$

we find:

$$Y \to \pi Z/\gamma X : g = 1.0\,^{+0.6}_{0.3}$$

compared to

- $D^* \to D\pi : g \sim 0.56$
- $D_1 \to D^*\pi : g = 0.61 \pm 0.8$

Not so different !

Charge conjugation for SU(3) nonets

- A charge conjugation quantum number can be given to each self conjugate SU(3) multiplet according to

$$\mathscr{C} T \mathscr{C} = \eta_T \tilde{T},\ \tilde{T} = \text{transpose matrix},\ \eta_T = \pm 1$$

- η is the sign taken by neutral members, but it can be attributed to all members of the multiplet.
- η =-1 is given to the electromagnetic current while $\eta_Y = -1,\ \eta_{K,\pi} = +1$
- Trilinear couplings for nonets A, B, C (η_A, η_B, η_C)
  - SU(3) invariant couplings: $\mathrm{Tr}(ABC), \mathrm{Tr}(ACB)$
  - $\mathscr{C}$: $\mathrm{Tr}(ABC) \to \eta_A \eta_B \eta_C \mathrm{Tr}(ACB)$
  - invariants with definite C:

$$D = \mathrm{Tr}\Big(A\{B,C\}\Big),\ \text{for } \eta_A\eta_B\eta_C = +1,\ F = \mathrm{Tr}\Big(A[B,C]\Big),\ \text{for } \eta_A\eta_B\eta_C = -1$$

- Y Decay:

$$\mathscr{H}_I \propto \mathrm{Tr}[Y[M,X]]\ (\eta_X = +1),\ \ \mathscr{H}_I \propto \mathrm{Tr}[Y\{M,Z\}]\quad (\eta_Z = -1)$$

- Z_{cs}, X_{cs} decay:

$$\mathscr{H}_I = \lambda\mu\ \psi\ (\mathrm{Tr}\{Z,M\})\ ([\mu] = \text{mass}),\ = \lambda\ \mu\ [Z^-_{cs}\ (\psi K^+) + c.c.]$$

$$\mathscr{H}_I = \lambda\ i\psi\ \mathrm{Tr}([\epsilon_8[X,M]) \sim \lambda\ (m_s - m_u)\ i[X^-_{cs}\ (\psi K^+) - c.c.]$$

Isospin and Flavour SU(3) Selection Rules

Isospin:

- $Y(I=0) \nrightarrow \pi^{\pm,0} X^{\mp,0}$;
- $Y(I=1) \to \pi^+ X^- - \pi^- X^+$;
- $Y(I=0) \to \pi^+ Z_c^- + \pi^- Z_c^+ + \pi^0 Z_c^0$, same for Z_c';

SU(3)

- $Y(I=0,1)$ or $Y([cs][\bar{c}\bar{s}]) \to (K^+ X_{cs}^- - c.c.)$ and $(K^+ Z_{cs}^- + c.c.)$;
- in the exact SU(3) limit $Z_{cs} \to J/\psi K$ is allowed for $(J^{PC} = 1^{+-})$;
- $\mathscr{M} = \lambda\ \mu\ \psi \mathrm{Tr}\Big([Z, M]\Big) = 0$, $(J^{PC} = 1^{++})$ exact SU(3)
- $\mathscr{M} = \lambda\ i\psi \mathrm{Tr}(\epsilon_8 [X, M]) \sim \lambda\ (m_s - m_u)\ i\psi (Z_{cs}^+ K^- - \ c.c.)$, $(J^{PC} = 1^{++})$ first order in SU(3) symmetry breaking

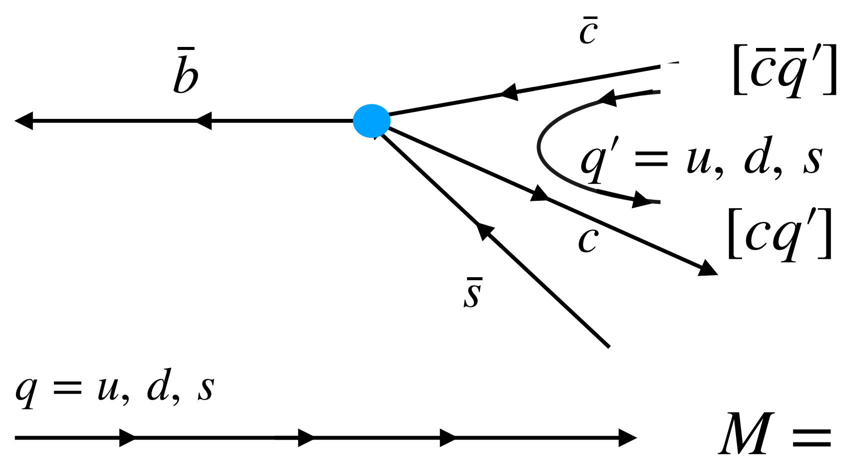
If produced from Y state BES III should see in his spectrum two more Z_{cs} : $Z_{cs}(4003)$ and the Z_{cs} associated to the nonet of $Z_c(4020)$

The LHCb way

- The main process: $B^+ \to K^+ \, \phi \, J/\Psi$

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

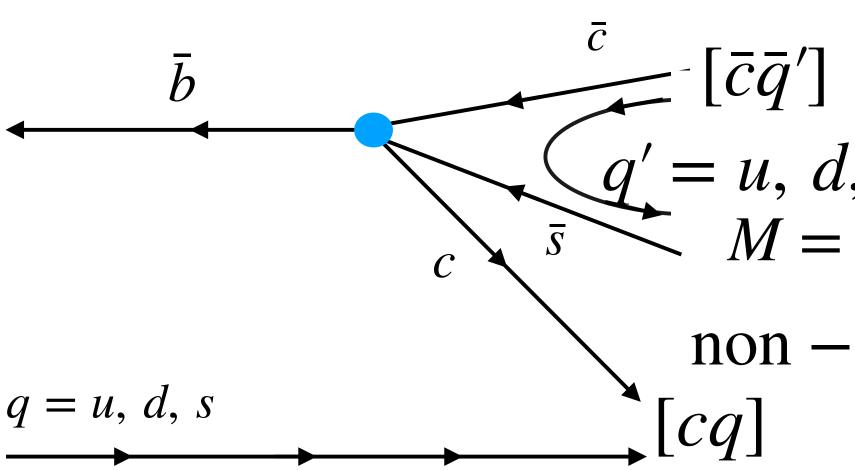
- B decays into meson + tetraquark are described by two quark diagrams:



$\text{diagonal Tetraq. only} = X_{u,\,d,\,s}$

$M = (\bar{s}q) = K^+, K^0, \phi$

(a)



$M = (\bar{s}q') = K^+, K^0, \phi$

$\text{non-diagonal Tetraq. possible} = X_{u\bar{d},u\bar{s},\ldots}$

(b)

e.g.

$B^+ \to K^+ + X_u/X_d/X_s$

$B^+ \to \phi + X_{us}$

Originate from the weak decay

$$\bar{b} \to \bar{c} + (c + \bar{s})$$

The strange antiquark may form a meson with
(a) the spectator quark
(b) a quark from the sea

- diagonal tetraqs. are formed with K^+
- strange tetraqs. with ϕ

X has been abundantly observed.
Is there a selection rule discriminating Z nonet vs X's ?: no

The $X^{\pm}$ puzzle

- $X^+([cu][\bar{c}\bar{u}])$ and X^- must exist, not far from 3872 MeV !
- expected decays: $X^+ \to D^0\bar{D}^{*+} + c.c.,\ J/\Psi + \pi^+\pi^0$
- the first channel may be below thresold, the second must exist
- There is only a very old limit by BABAR:

$$R^-_{2\pi} = \frac{Br(B^0 \to K^+X(3872)^- \to K^+J/\psi\ \pi^0\pi^-)}{Br(B^0 \to K^0X(3872) \to K^0J/\psi\ \pi^+\pi^-)} < 1$$

- From more recent data on B^+, B^0 and B^0_s decays, we derive the bounds

L. Maiani, A. D. Polosa and V. Riquer, Phys. Rev. **D 102** (2020), 034017

$$0.05 < R^-_{2\pi} = \frac{Br(B^0 \to K^+X(3872)^- \to K^+J/\psi\ \pi^0\pi^-)}{Br(B^0 \to K^0X(3872) \to K^0J/\psi\ \pi^+\pi^-)} < 0.57$$

- Can we afford a new search?

The *not so bright* side…

- $\Gamma \propto q^5$: the decay $Y(4230) \to \pi Z_c(4020)$ is strongly suppressed
- rate would be OK if the signal comes from the next line, Y(4320): is it possible?
- the $J/\Psi\ \phi$ resonance X(4274) is classified by LHCb as $J^P = 1^+$, but for color 3 diquarks, there may be only one $J^P = 1^+$, which is X(4140). Could there be also color 6 ***diquarks quarks*** as suggested in

J. Wu, et al., Phys. Rev. **D 94**, 094031(2016)

(but no evidence color of color 6 diquarks from lattice calculations)

- Can we exclude that the X(4274) signal consists of two almost degerate lines with $J^+ = 0^+$, $J^P = 2^+$?

In conclusion….

- The existence of exotic SU(3) flavour multiplets, with a characteristic scale of symmetry breaking is a distinctive prediction of compact tetraquarks.
- The newly found strange exotics are close in mass, like X(3872) and $Z_c(3900)$, and fit into their nonets: a clear score in favour.
- Decays: $Y(4230) \to \gamma\, X(3872)$ and $\pi\, Z_c(3900)$ are consistent with D* and D1 decays
- $Y \to \pi\, Z_c(4020)$???? needs clarification
- Much remains to be done, to produce more precise data and to search for still missing particles, some with well defined mass and decay modes
- it is a ***tough order***: more luminosity, better energy definition, detectors with exceptional qualities… a lot of work…
- a much closer exchange between theory and experiment is needed.

The exchange that took place in the sixties and seventies led to the quark picture of mesons and baryons

Starting in 1957, a new generation of film Directors, in France and Italy, proposed a completely new way of making movies…
the were called
La Nouvelle Vague
(The New Wave).

Similarly, we assist now to the discovery of a completely New Wave of Exotic Hadrons…

Like La Nouvelle Vague of film directors

Let us take the message from the New Wave of Exotic Hadrons and face the challenges !!