RICCARDO 80
AUGURI !!!!

Tetraquarks: Successes & Mysteries

Luciano Maiani, CERN

starring:

- BABAR, BELLE, LHCb, BES II/III
- theorists (not many) aficionados to hadron spectroscopy

RICCARDO 70

The Muon Anomalous Magnetic Moment in Broken Supersymmetric Theories
Riccardo Barbieri (Pisa, Scuola Normale Superiore & INFN, Pisa), L. Maiani (Rome U. & INFN, Rome). Jul 1982. 16 pp.
Published in **Phys.Lett. B117 (1982) 203**
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DOI: 10.1016/0370-2693(82)90547-0
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service; Science Direct
Detailed record - Cited by 120 records 100+

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- no surprise we found ourselves writing about Supersymmetry after Higgs discovery, even if in slightly different frameworks, MSSM and NMSSM

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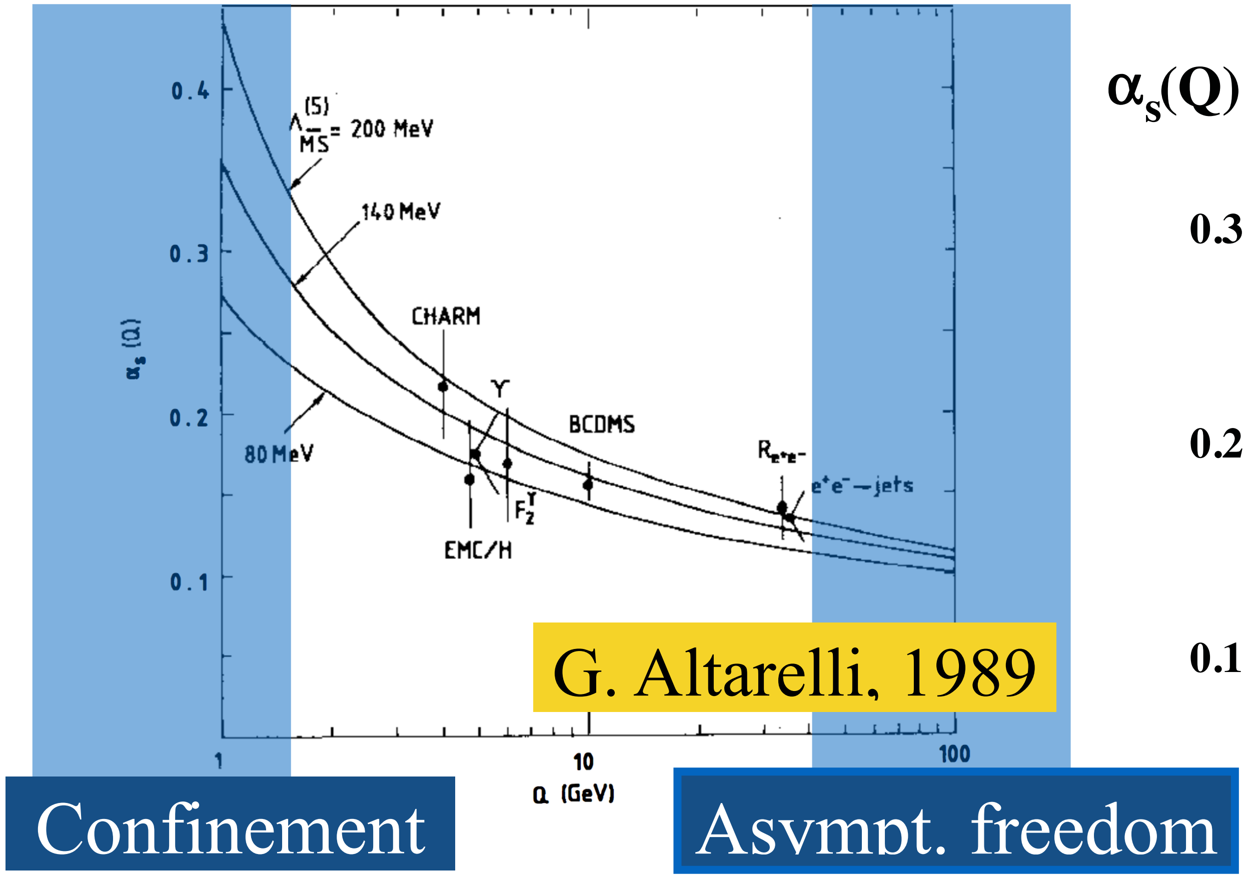
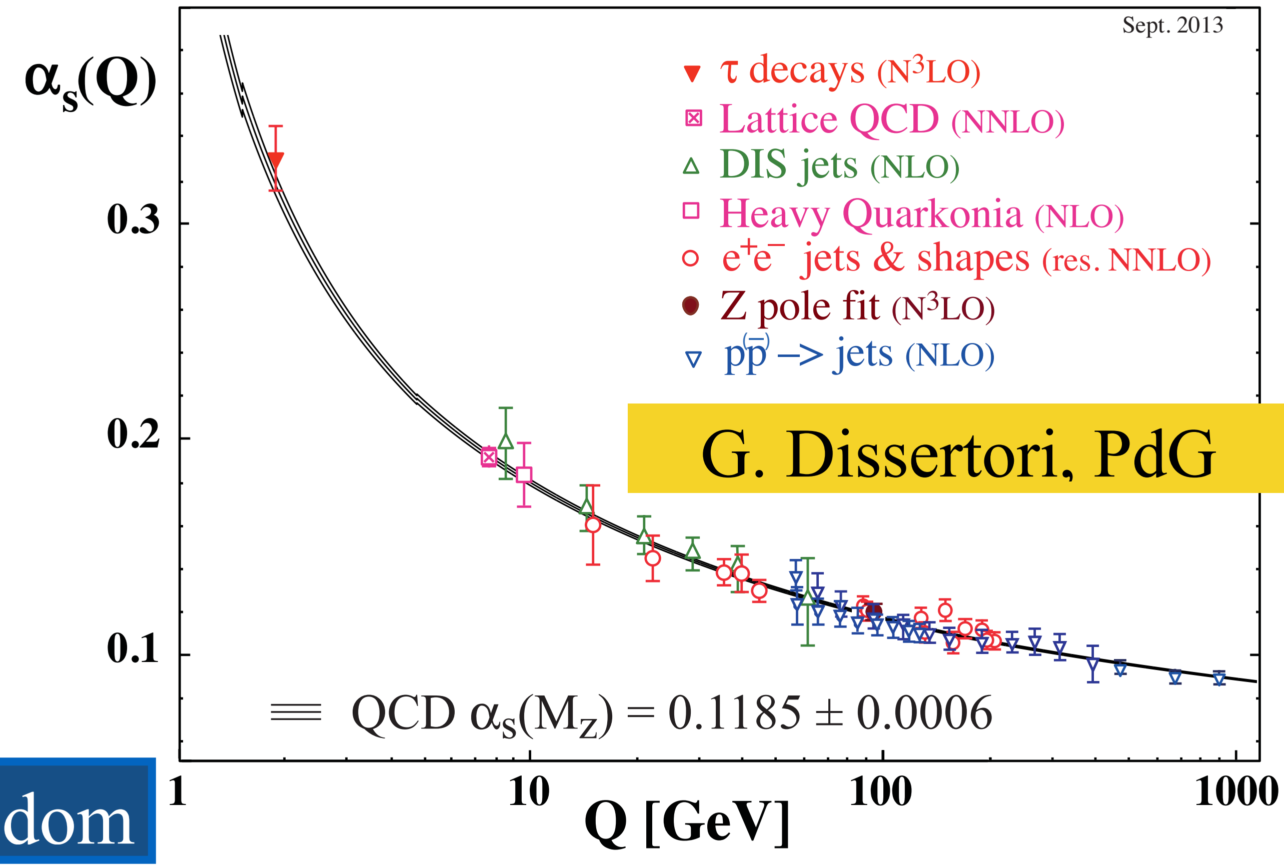
Conclusion Dec. 2013: → Look everywhere, no time to give up

1. QCD is the answer to (almost) any Strong Interaction question





- QCD is asymptotically free
- quarks carry **color symmetry**, **SU(3)**$_{\mathbf{col}}$, and are confined inside **color singlet hadrons**,
- $\Delta^{(++)} = \epsilon^{\alpha\beta\gamma} u^{\uparrow}_{\alpha} u^{\uparrow}_{\beta} u^{\uparrow}_{\gamma}$: Fermi statistics is obeyed

Constituent Quarks

- increasing q^2, quarks radiate gluons (the Altarelli-Parisi picture of scaling violations)
- at large q^2, we see quarks and neutral gluons as almost free partons.

QCD Partons

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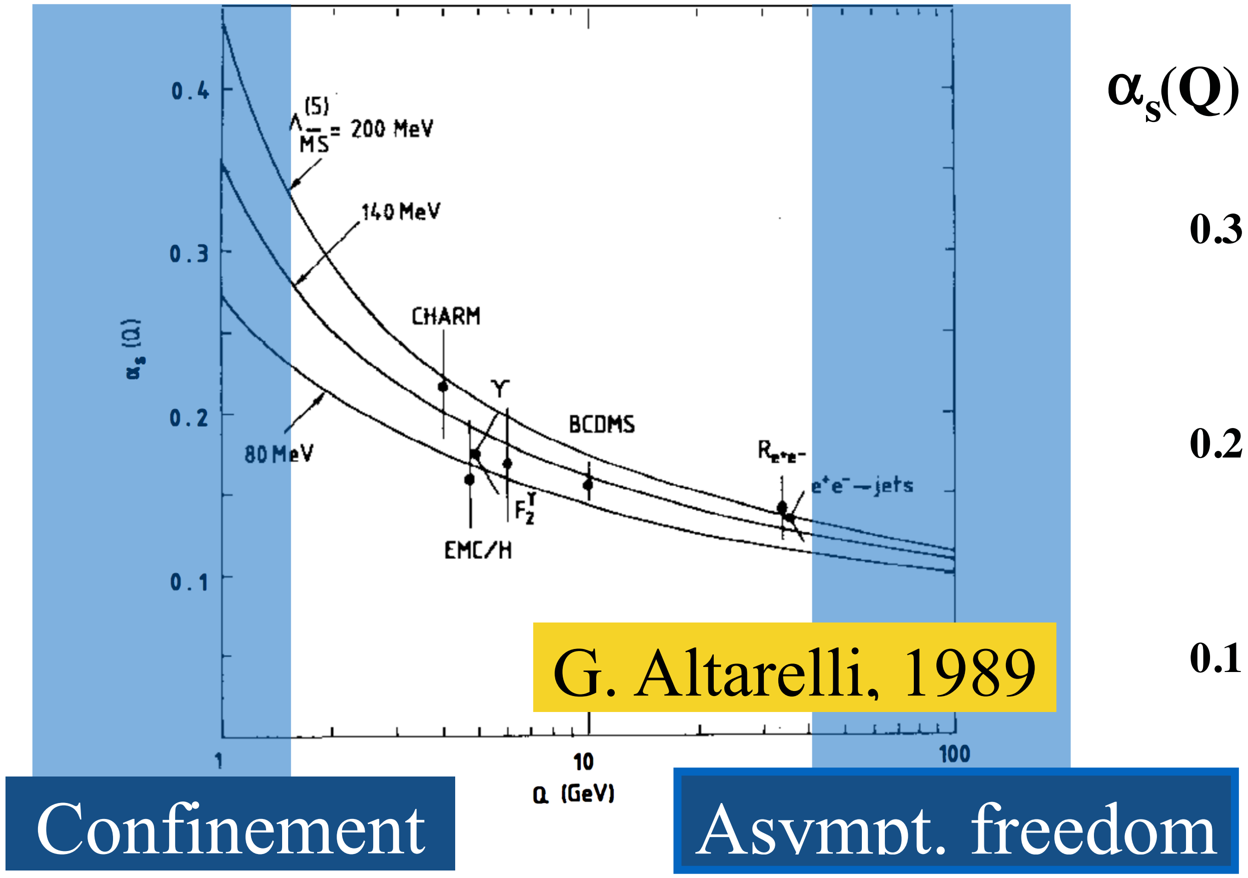

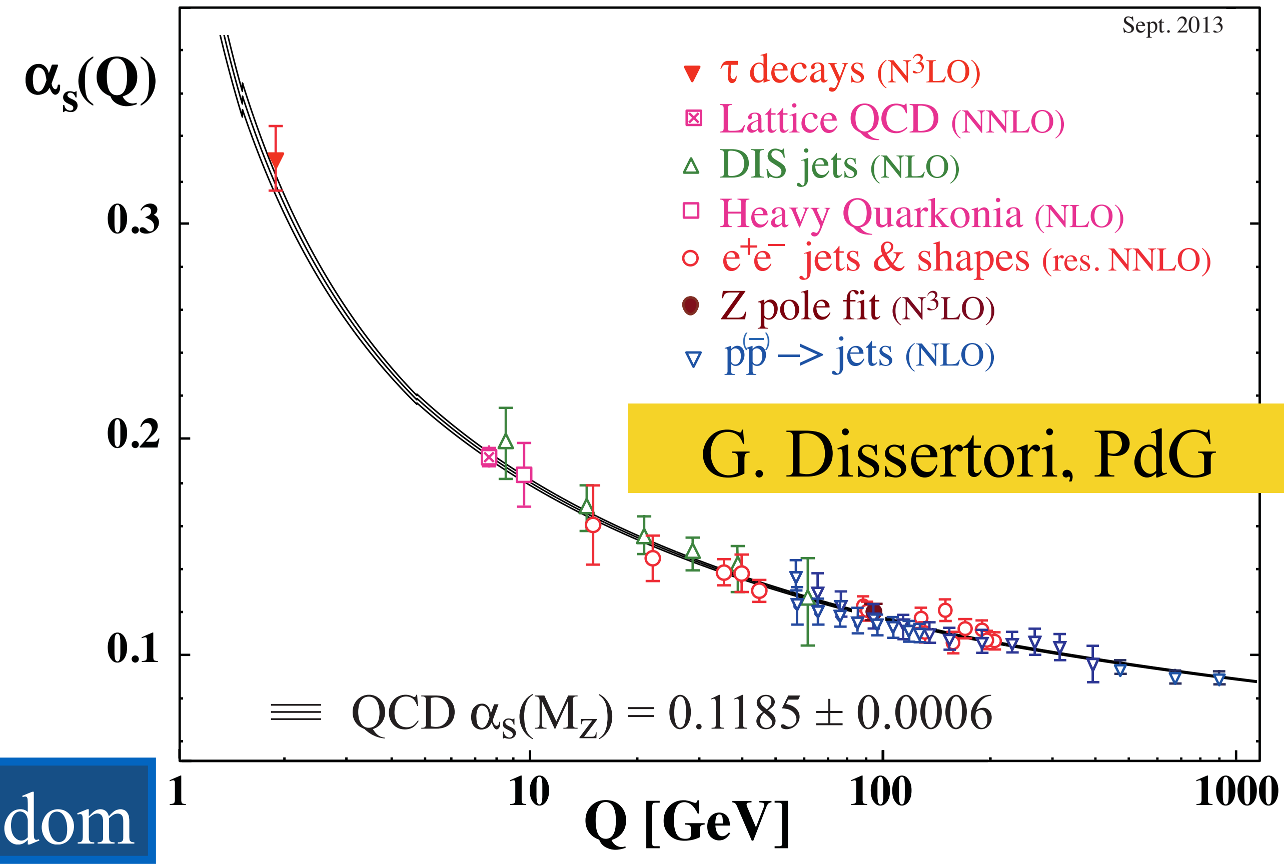

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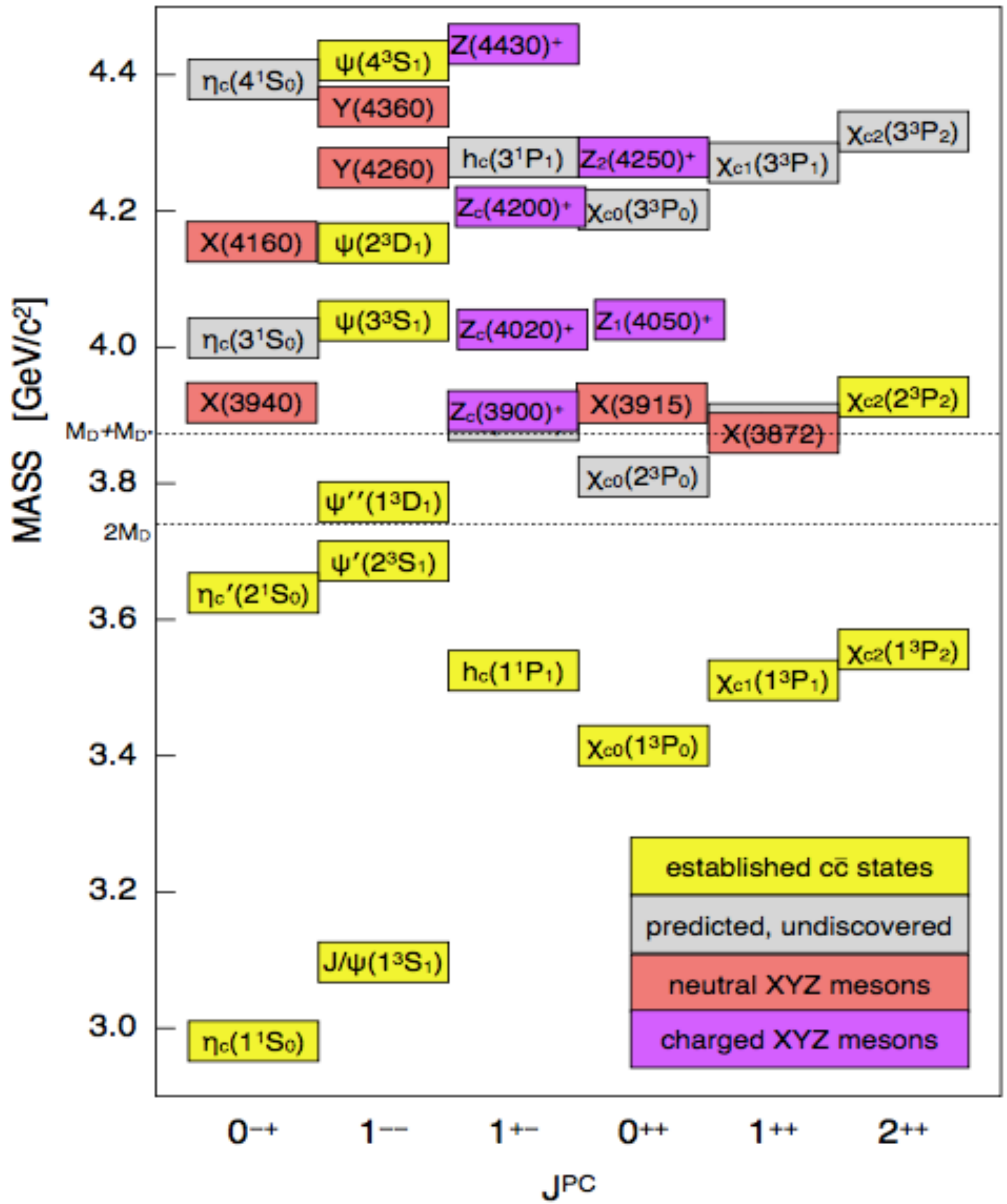
QCD Partons

Heavy quarks ($m_Q >> \Lambda_{QCD}$ ***)***:

- inclusive decays are calculable like deep inelastic processes;
- $c\bar{c}$ or $b\bar{b}$ bound states involve short distance forces: a calculable spectrum of charmonia/bottomonia;
- inside hadrons, $c\bar{c}$ or $b\bar{b}$ pairs are not easily created or destroyed:
- a hadron decaying into J/Ψ or $\Upsilon + \ldots$ indicates a valence $c\bar{c}$ or $b\bar{b}$ pair
- ***heavy-quark counting is possible***.

Expected and Unexpected Charmonia in 2015

figure by:
S. L. Olsen (2015)
arXiv:1511.01589



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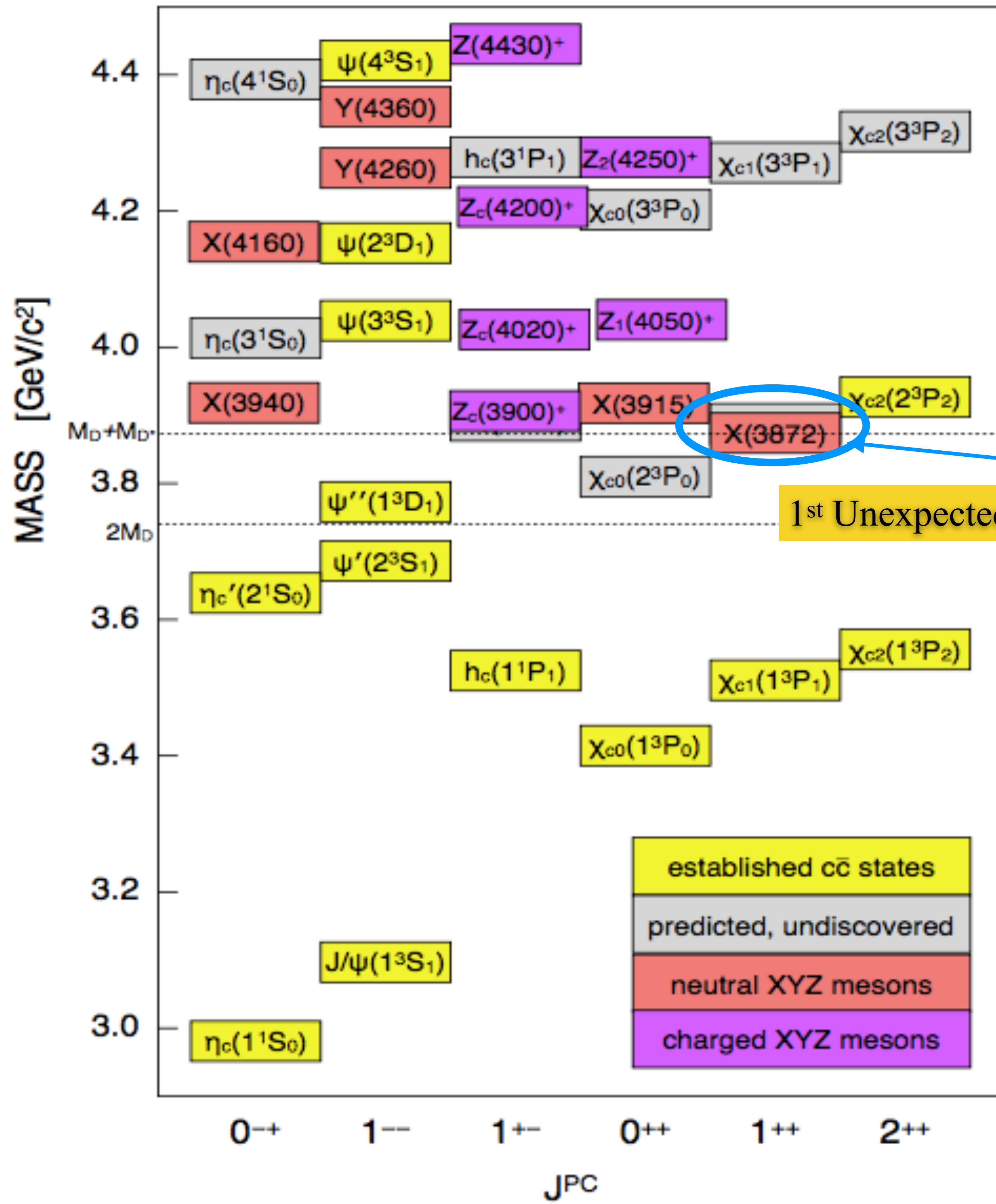

1st Unexpected (BELLE, BaBar, 2003)

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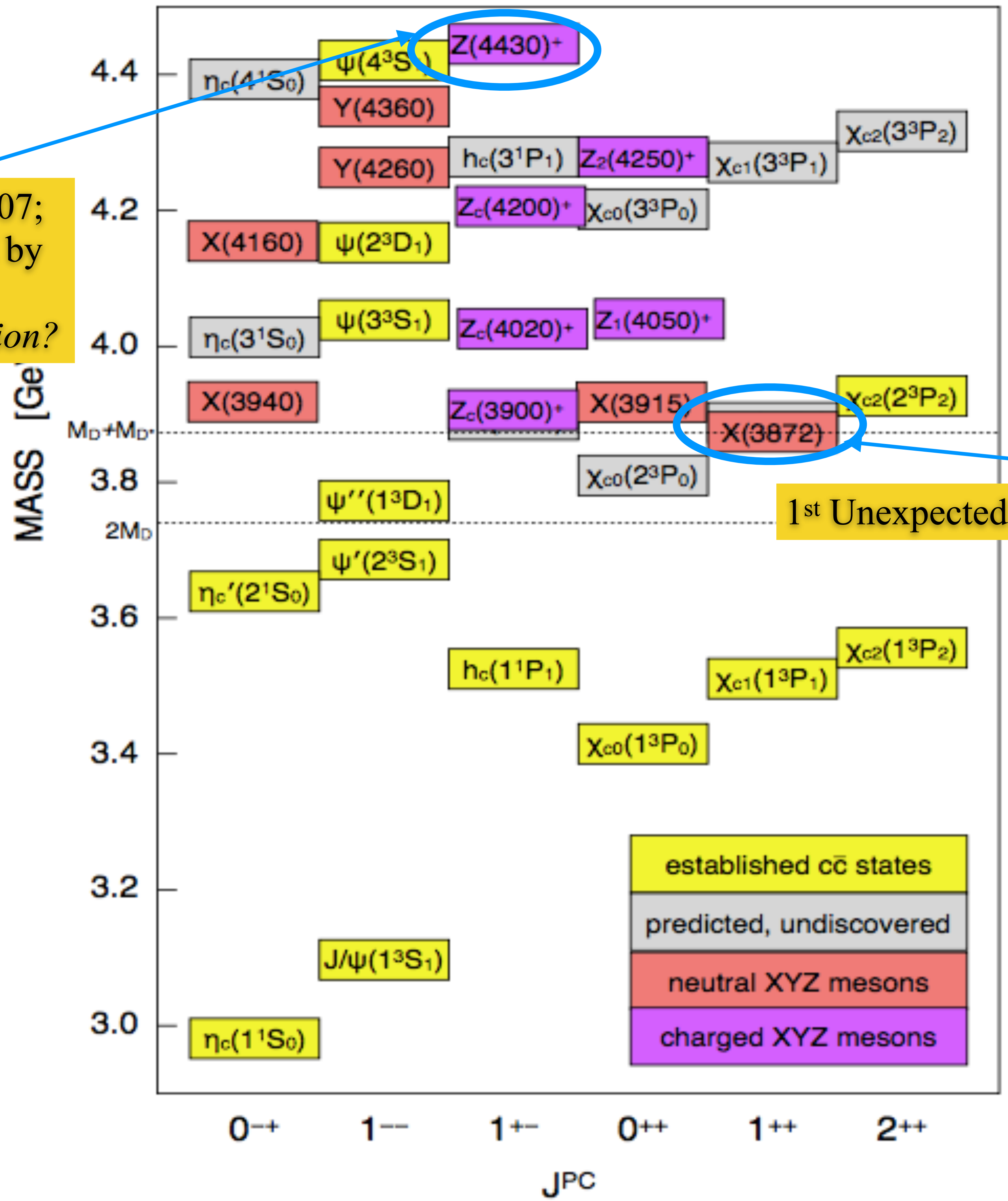
first charged, a radial excitation?



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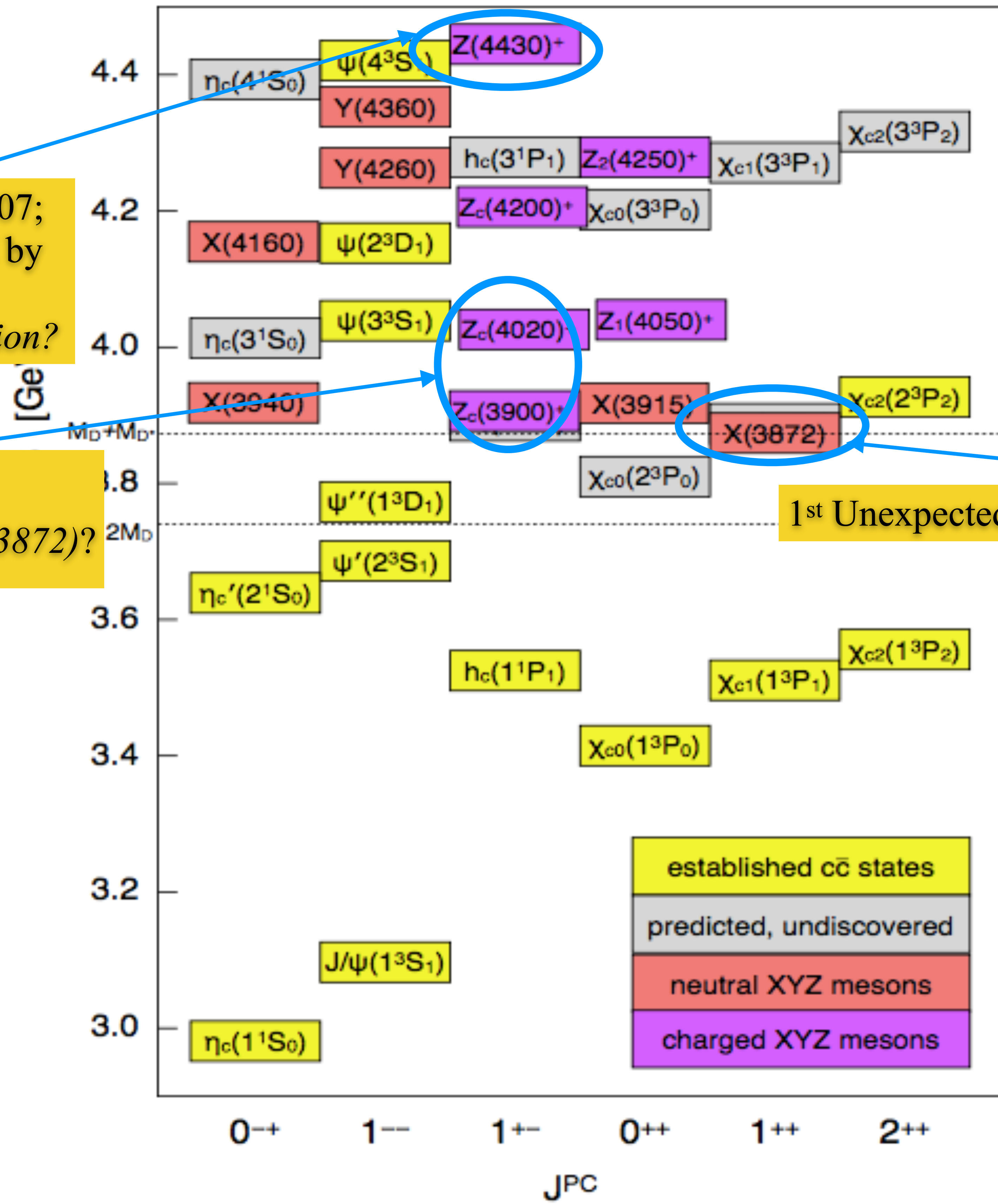

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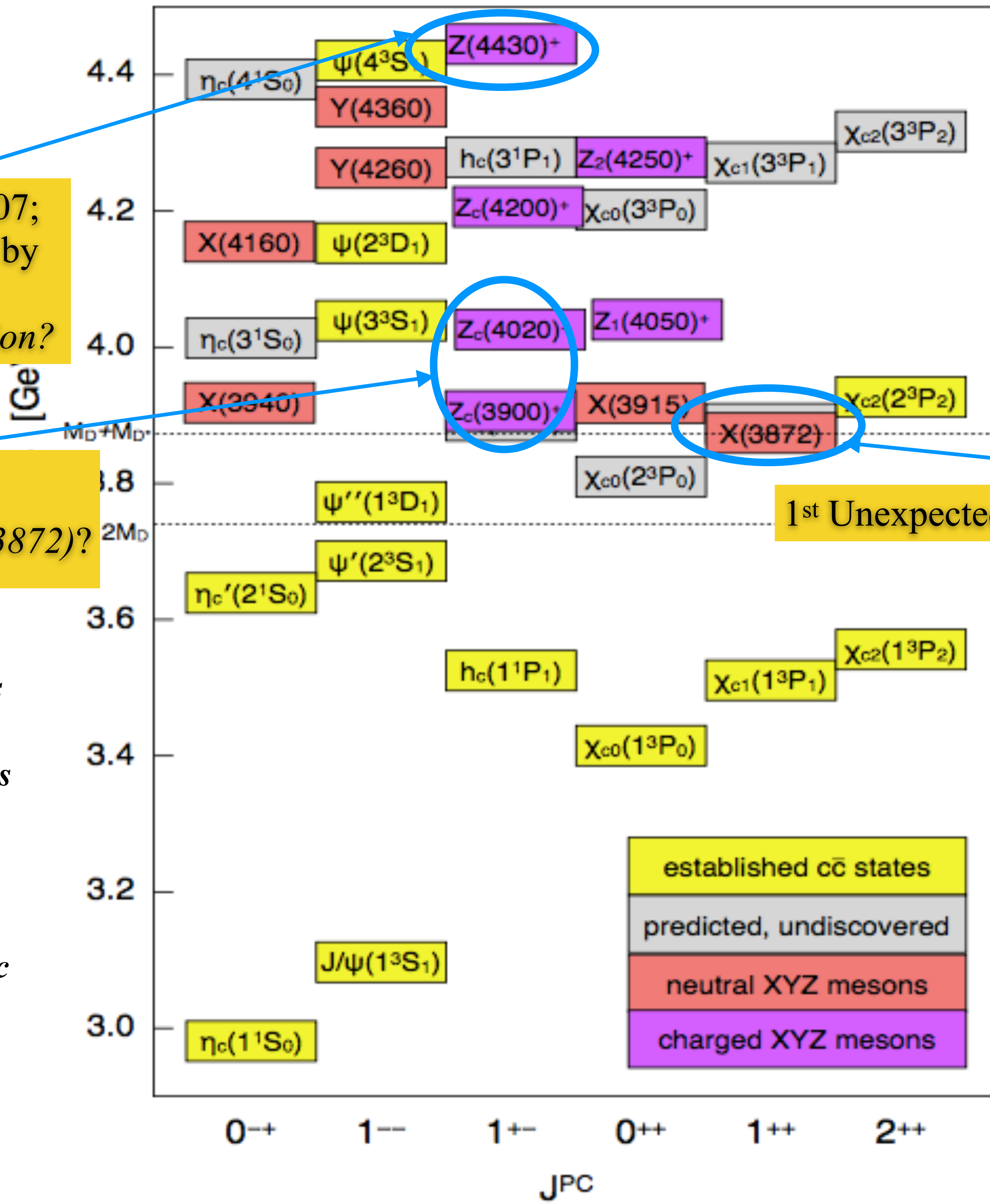

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BESII, Phys. Rev. Lett. **110** (2013) 252001

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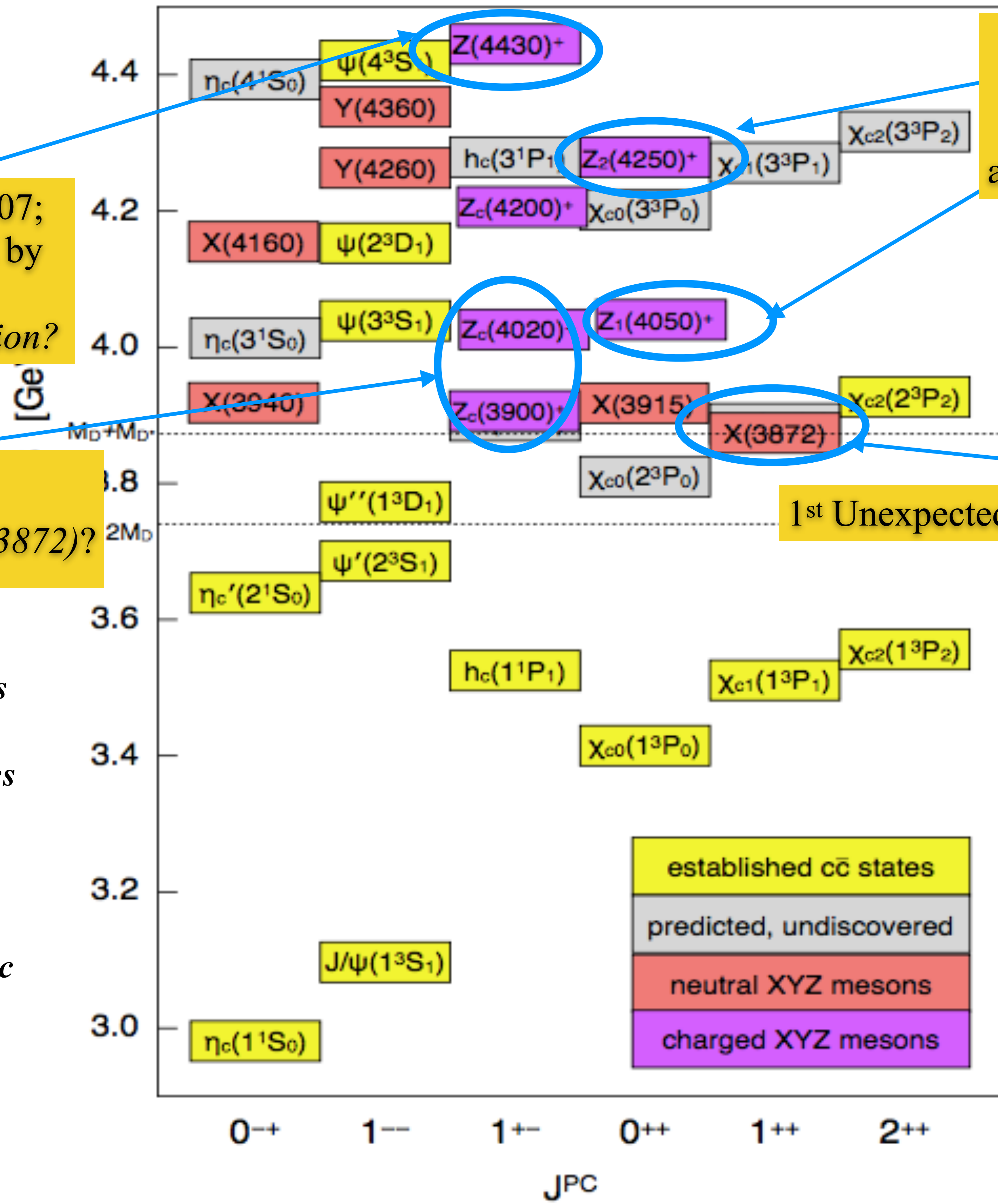

recent additions:
more than coincidence?
or
an almost filled multiplet?

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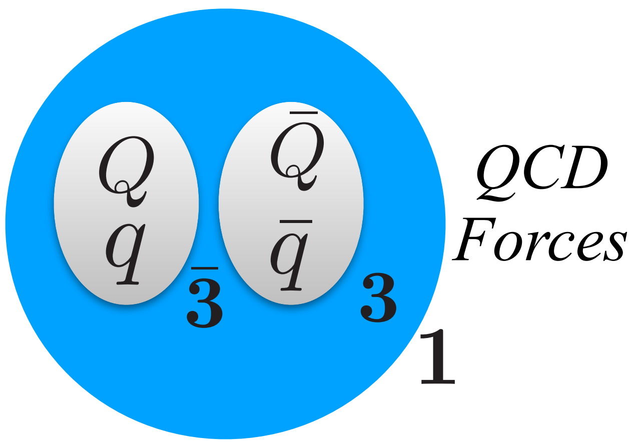
No consensus, yet

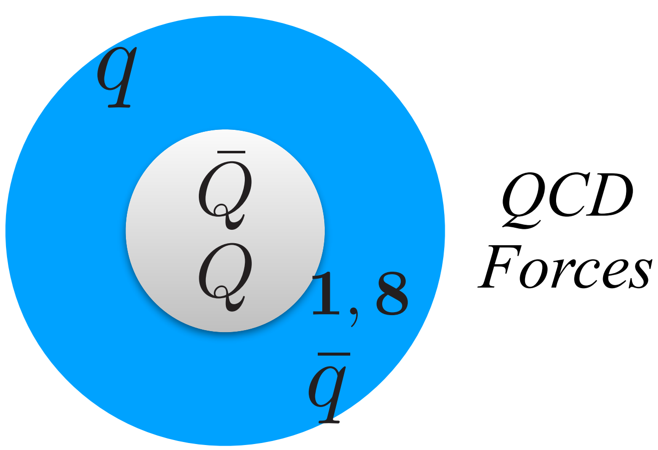
Hadron Molecule

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

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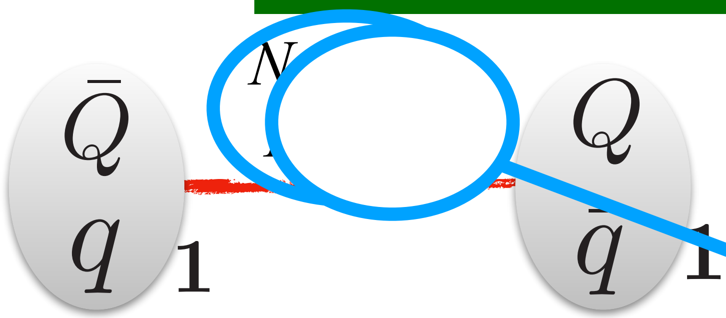

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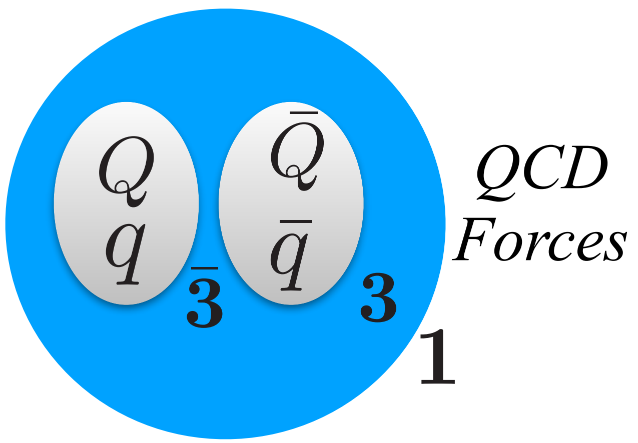
Contact interactions in Chiral Perturbation Theory

Z. H. Zhang *et al.*, JHEP **08** (2024) 130 see later



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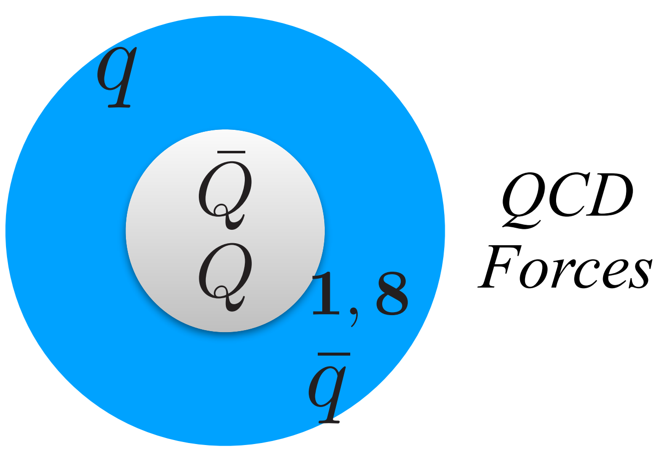

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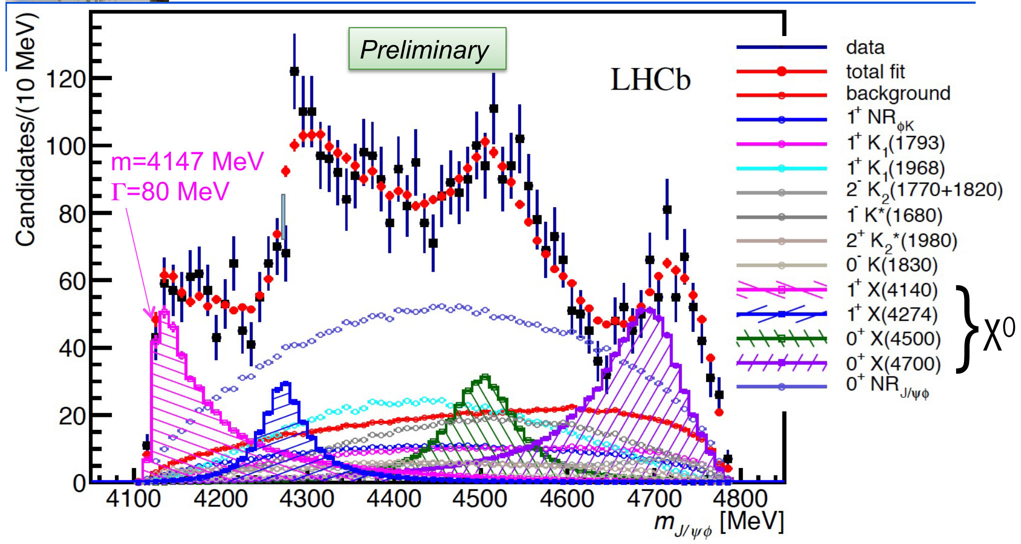
2. Exotics: More flavours

- 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 $Z_{cs}(4003)$
- No pion exchange forces could bind them as hadron molecules made by color singlet mesons
- molecular models applied to the new hadrons have to stand on the existence of "phenomenological forces" with undetermined parameters
- The New Exotics arise very naturally as $([cq]^{\bar{3}}[\bar{c}\bar{q}']_{3})_{1}$ bound in color singlet.

$B^+ \to K^+ + X(4140) \to K^+ + \phi\ \Psi$, etc .

Results of fit: m(J/ψϕ)



- 4 visible structures fit with BW amplitudes

LHCb (2016): $\Psi\ \phi$ resonances (2016)

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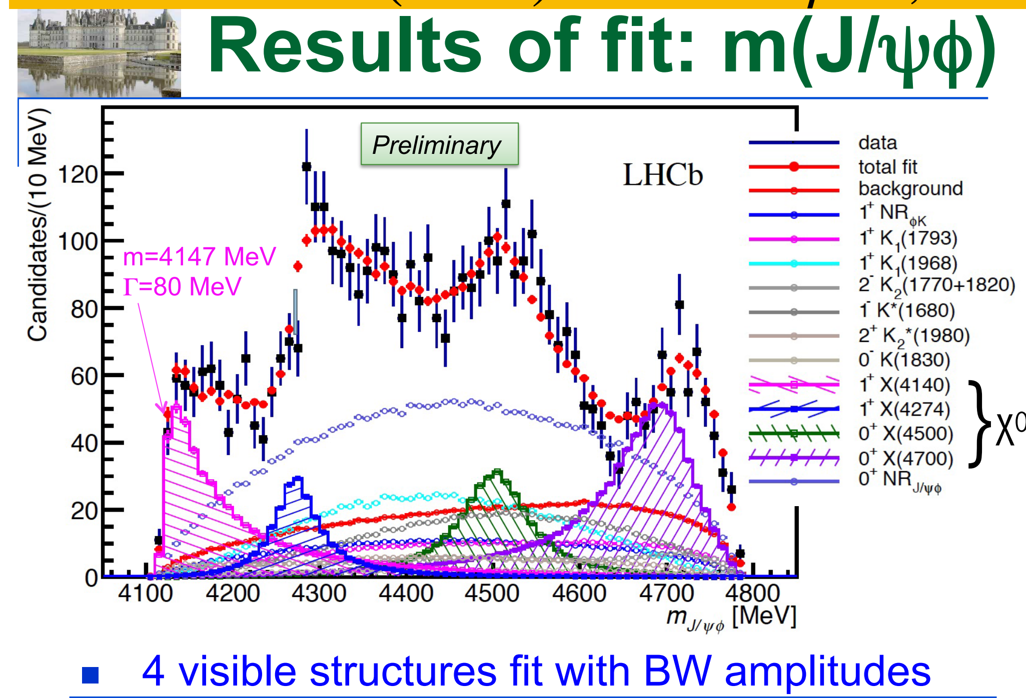
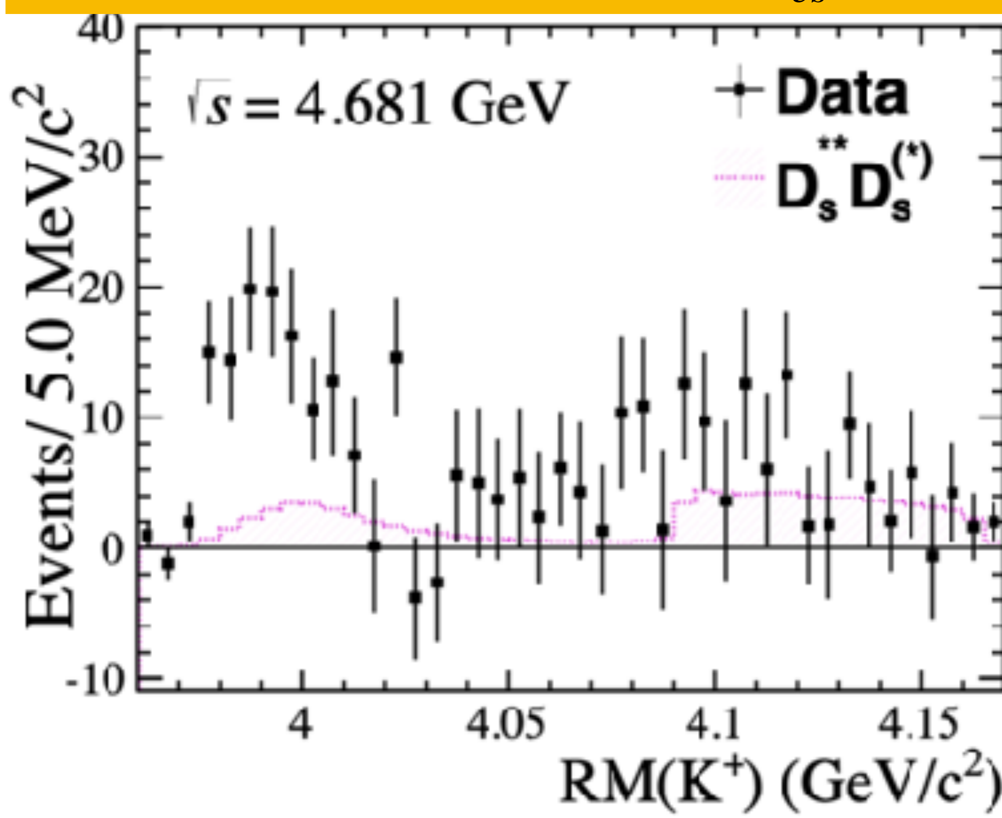
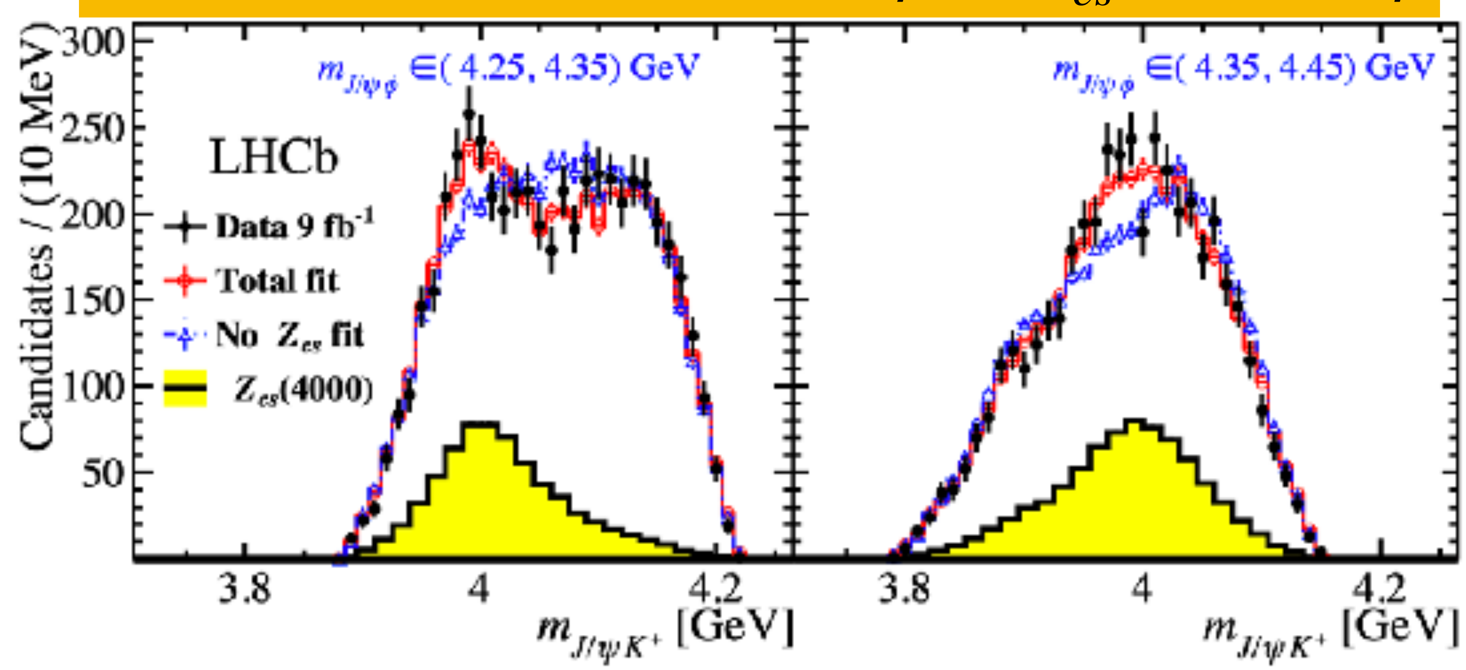


LHCb (2016): $\Psi\ \phi$ resonances (2016)

BES III(2021): $e^+e^- \to K^+ + Z^-_{cs}(3985) \to K^+(D^*_s D^0 + D^-_s D^{*0})$



LHCb (2021): $B \to \Psi + K^+ + \phi \to Z_{cs}(4003) + \phi$



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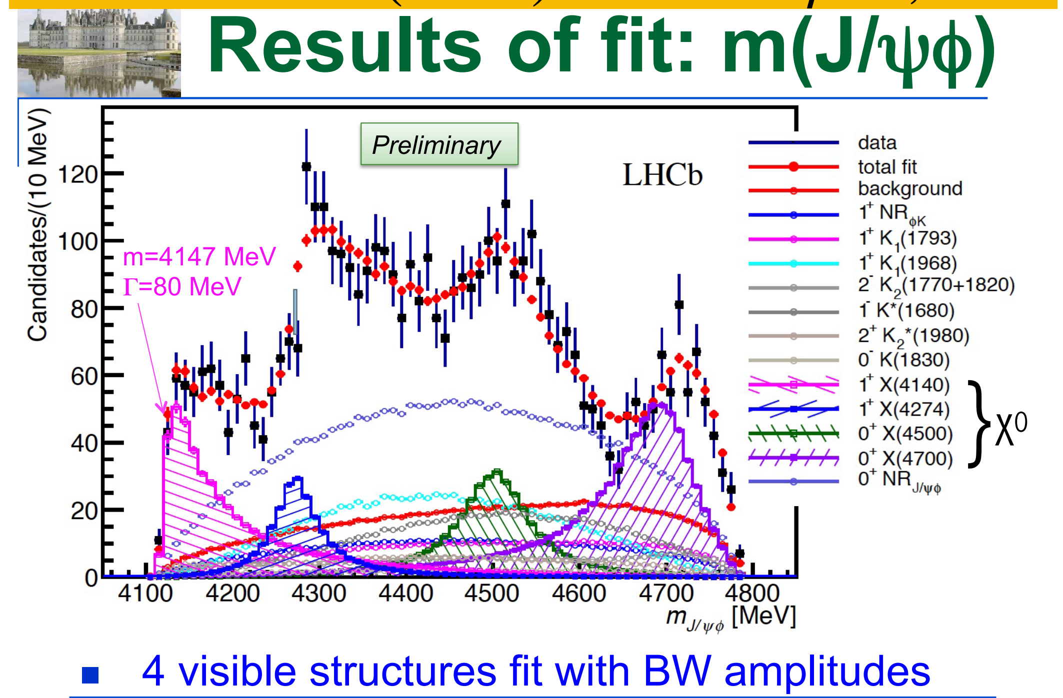

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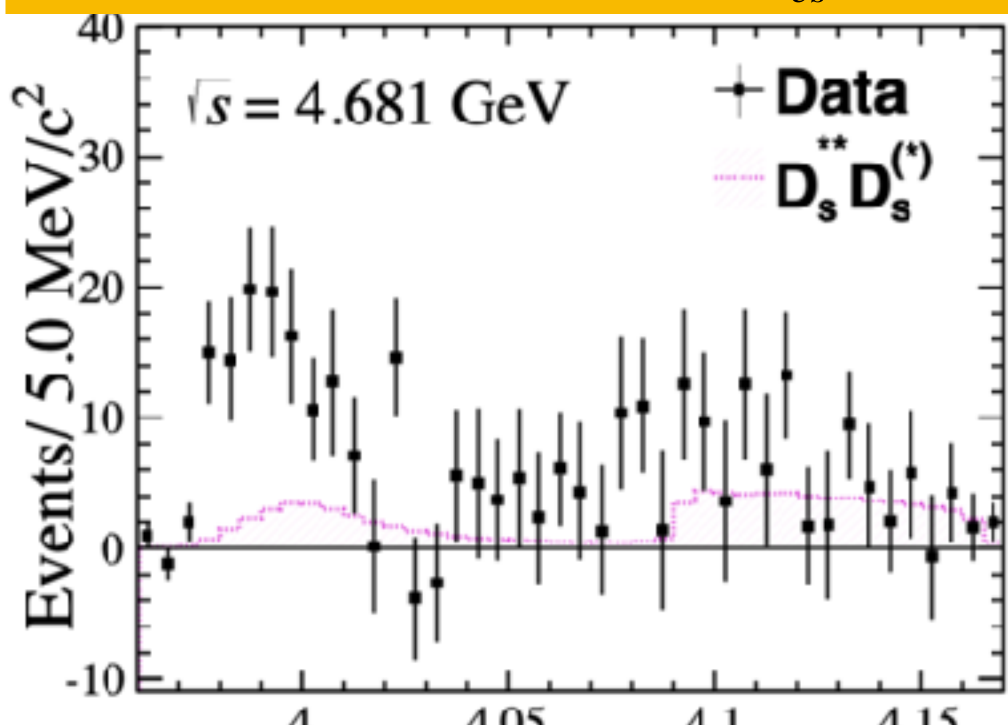

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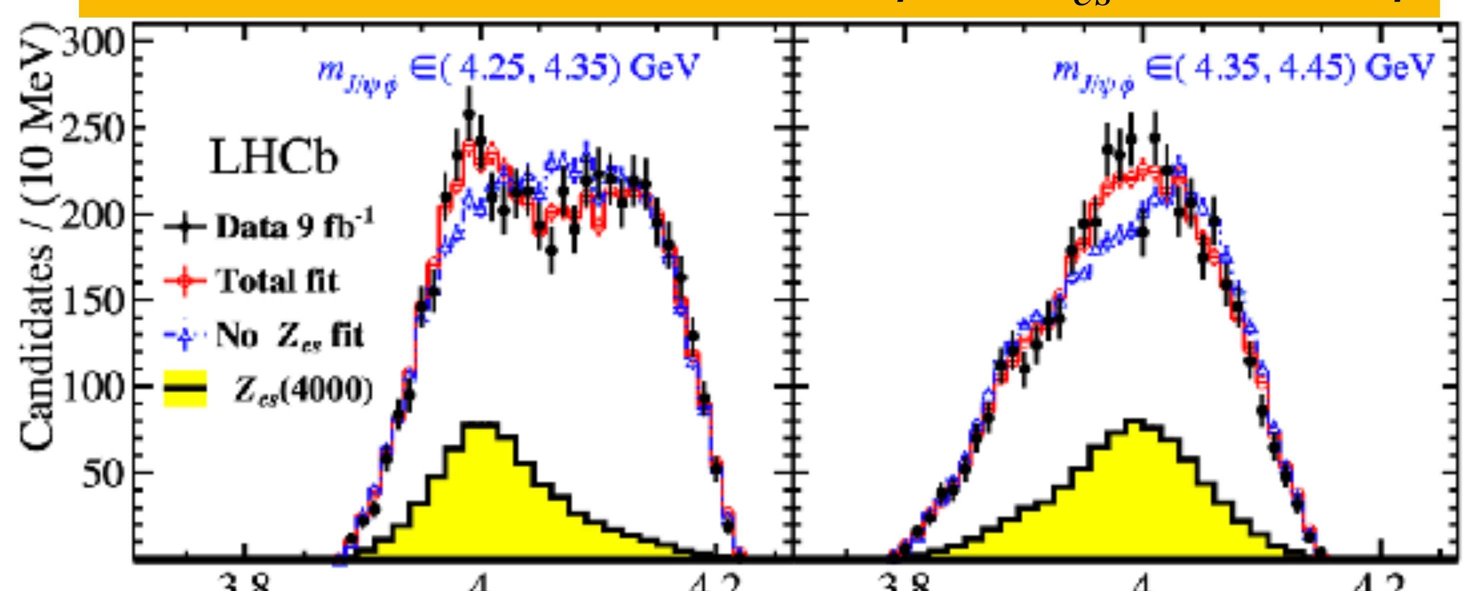

PdG: The incompatible values for the widths reported by AAIJ 2021E and ABLIKIM 2021G could either indicate the existence of two separate states or possibly be explained in a coupled channel model.

The most important message: The Flavour Symmetry of Compact Tetraquarks

- QCD interactions are approximately symmetric under flavour SU(3)
- diquark-antidiquark states ***must fall in complete SU(3) flavour multiplets,*** with mass differences determined by the quark mass difference

$$m_s - m_{u,d}$$

We have identified particles that can be assigned to 3 different multiplets:

- Hidden Charm $(\bar{c}cq_1q_2q_3)$, $SU(3)_f$: $\mathbf{8} \oplus \mathbf{1}$
- Single Charm $[(\bar{c}\bar{q}_1)_{S=0}(q_2q_3)_{S=0}]$, $J^P = 0^+$, $SU(3)_f$: $\mathbf{3} \oplus \bar{\mathbf{6}}$
- Double Charm (Beauty) $[(cc)_{S=1}(\bar{q}_2\bar{q}_3)_{S=0}]$, $J^P = 1^+$, $SU(3)_f$: $\mathbf{3}$

With Z_{cs}(3082), Z_{cs}(4003), Z_{cs}(4220) we can almost fill three tetraquark nonets with the expected scale of mass differences

The same happens with the three states of Scalar , Single Charm Tetraquarks recently discovered by LHCb

We may produce estimates of mass and decay modes of the missing partners

3. Hidden Charm Tetraquarks form nonets of flavor SU(3) with mass differences determined by the quark mass difference $m_s - m_{u,d}$

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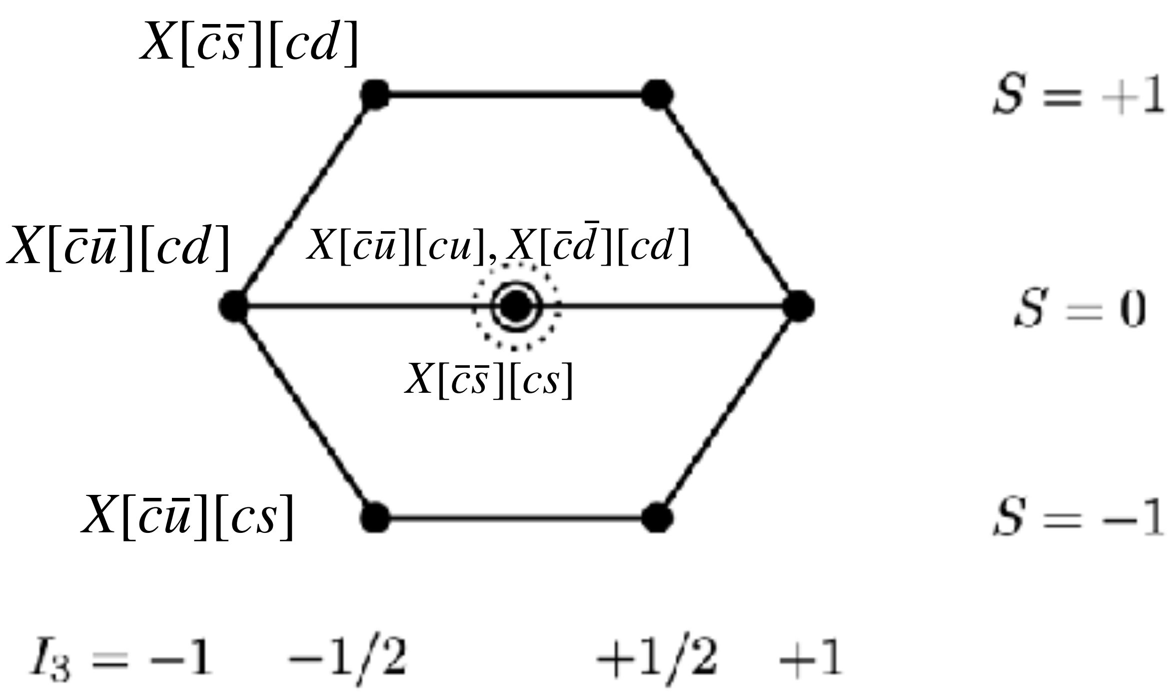

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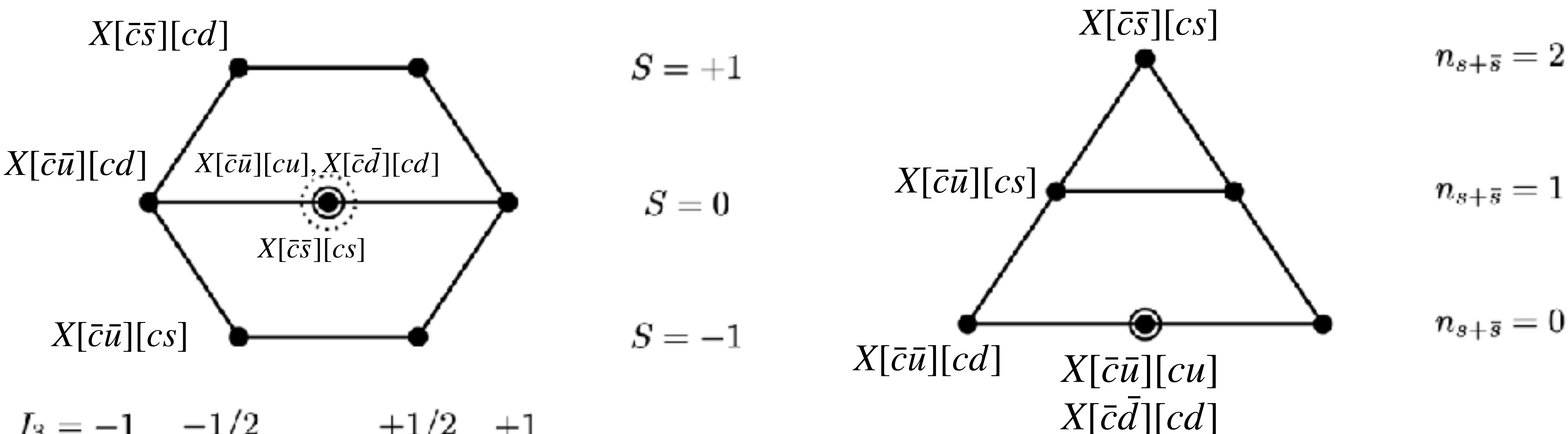


- Octet particles can be also represented in function of the total number of s or $\bar{s}$ quarks;
- octet breaking implies ***the equal spacing rule*** of the masses in the ladder.

3. Three nonets: 2 solutions

L. Maiani, A. D. Polosa and V. Riquer, Sci. Bull. **66** (2021), 1616, arXiv:2103.08331

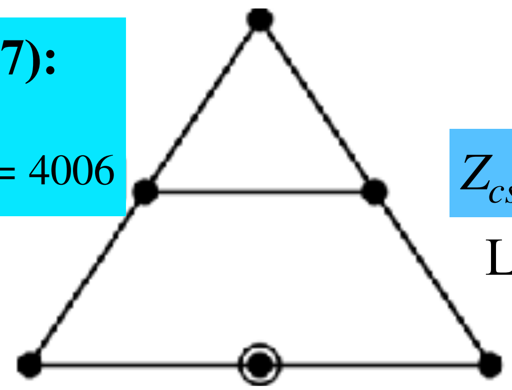
$J^{PC} = 1^{++}$ $\qquad$ $J^{PC} = 1^{+-}$

Solution 1

Predicted (2017):

$$\frac{X(4140) + X(3872)}{2} = 4006$$

$X(4140)$



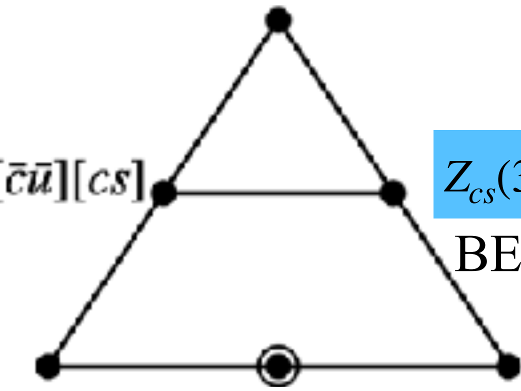
$Z_{cs}(4003)$

LHCb

$X(3872)$

$Z([\bar{c}\bar{s}][cs])$???

$X[\bar{c}\bar{u}][cs]$



$Z_{cs}(3982)$??

BES III

$Z(3900)$ BES II

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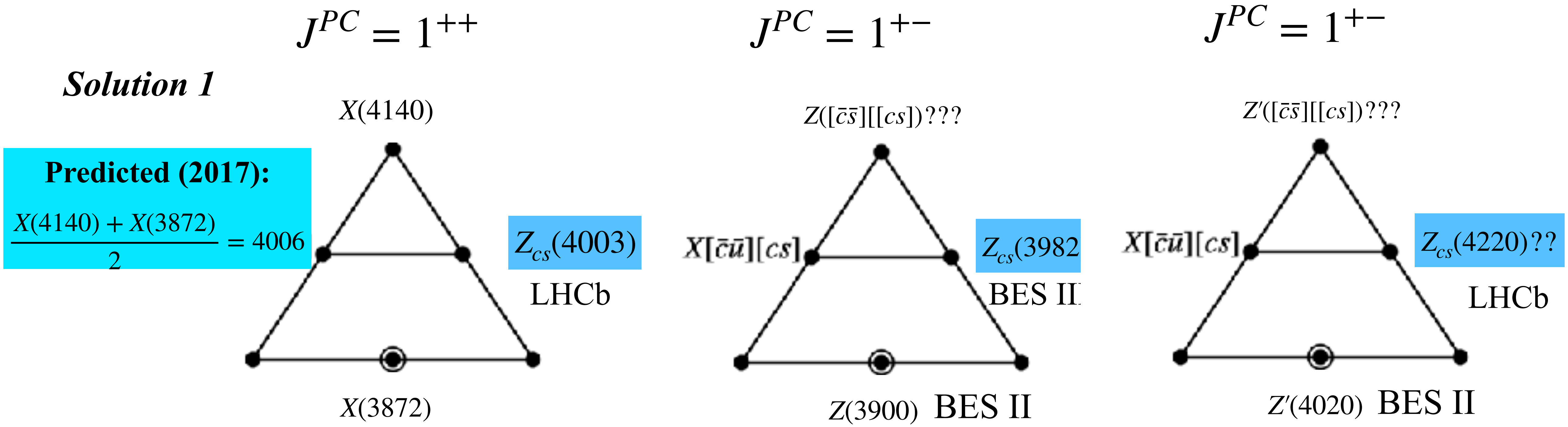

- There is a ***third nonet associated with*** $Z_c(4020)$, $J^{PC}=1^{+-}$: a third Z_{cs} is required, with Mass=4150 - 4170
- LHCb sees a $Z_{cs}(4220)$, $J^{P}=1^{+}$***: is it too heavy ?***
- A bold proposal: ***two nonets mixing***

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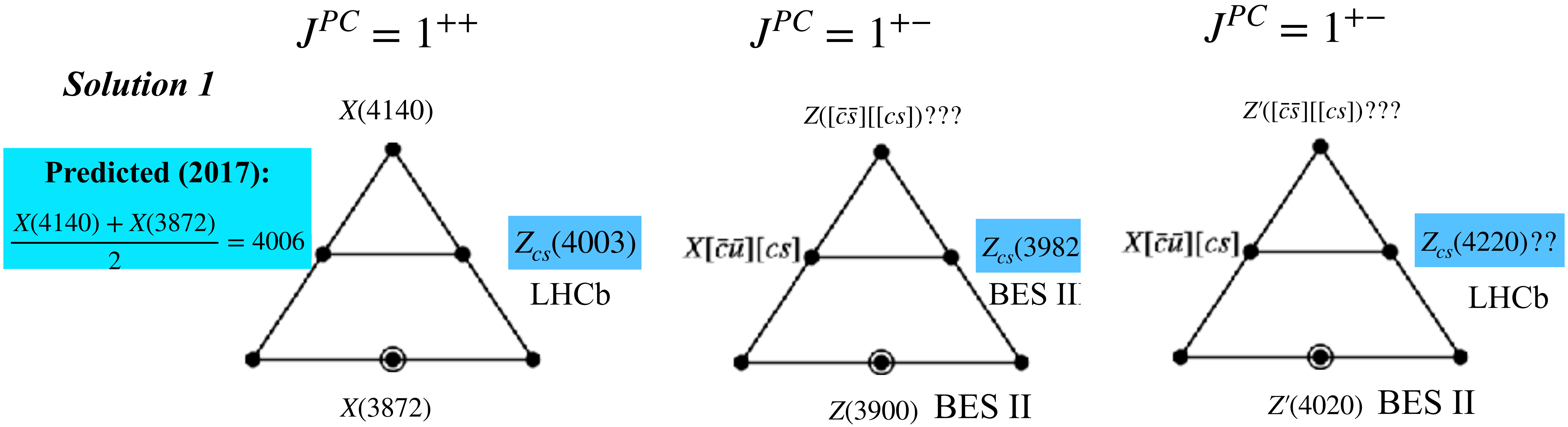

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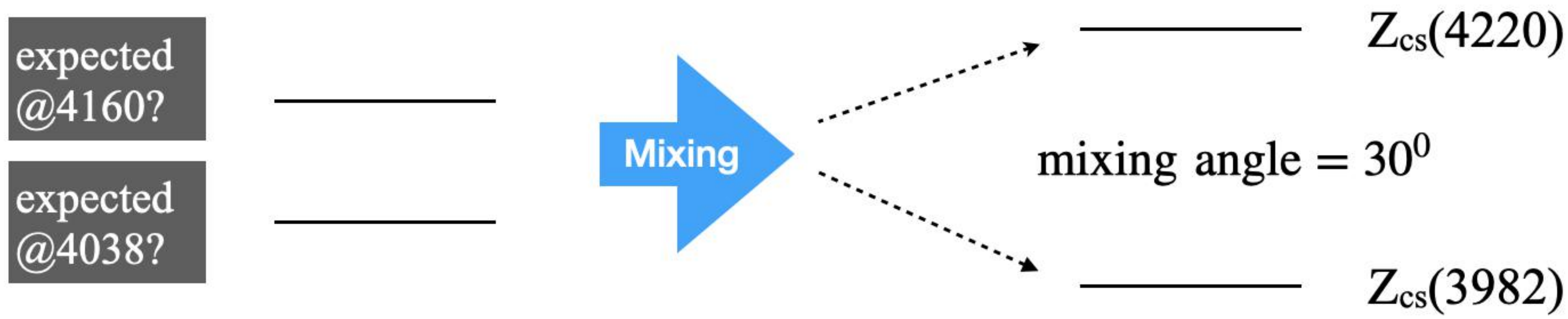

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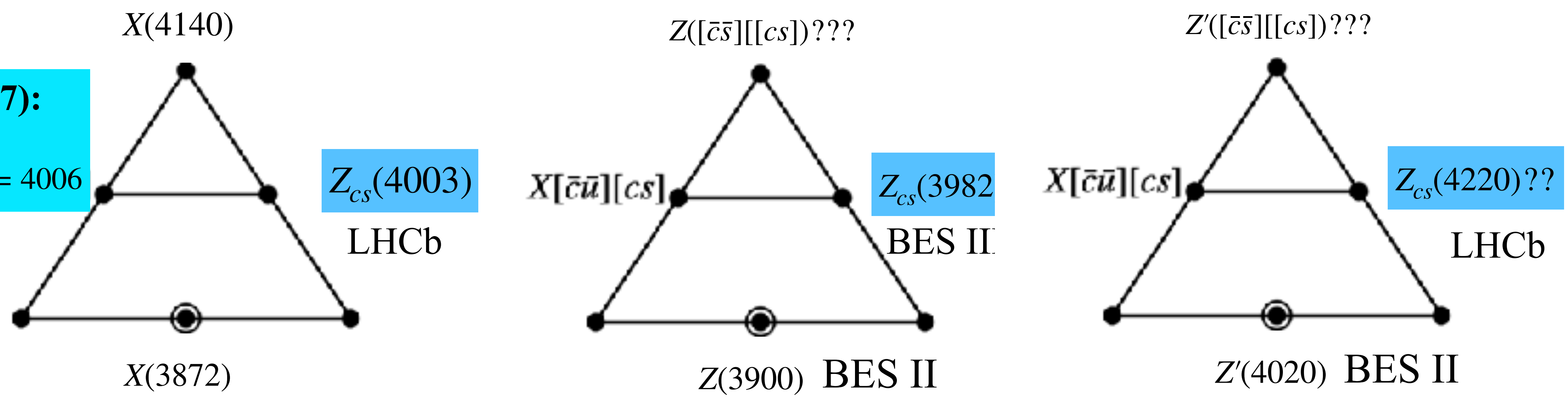
Predicted (2017):

$\frac{X(4140) + X(3872)}{2} = 4006$



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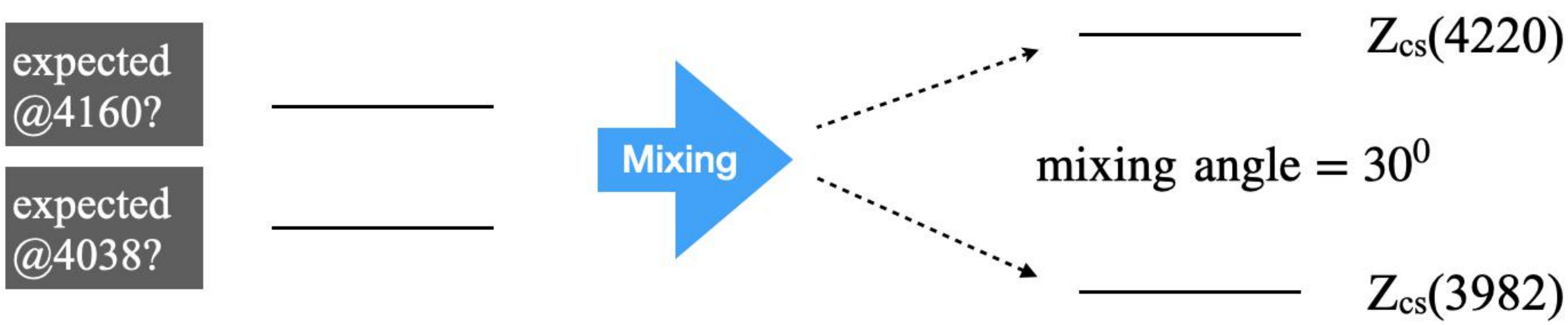

Only few particles are missing, in well defined mass regions and with identified decay modes.

4. Single charm tetraquarks, with three SU(3)-flavour light mesons: the case of $J^P = 0^+$

L.Maiani, A. Polosa, V.Riquer, Phys. Rev. D **110** (2024) 034014

- In a recent lattice QCD calculation the $SU(3)_{flavor}$ configurations of possible bound states in the $\bar{D}K, J^P = 0^+$, channel are studied;
- the allowed $SU(3)_{flavor}$ channels are those appearing as irreducible components of the tensor product

J. D. E.Yeo *et al.,* JHEP **07** (2024) 012

$$\bar{D}K = \mathbf{3} \otimes \mathbf{8} = \mathbf{3} \oplus \bar{\mathbf{6}} \oplus \mathbf{15}$$

- Yeo *et al.* find attraction in **3** and $\bar{\mathbf{6}}$ but not in **15**.

4. Single charm tetraquarks, with three SU(3)-flavour light mesons: the case of $J^P = 0^+$

L.Maiani, A. Polosa, V.Riquer, Phys. Rev. D **110** (2024) 034014

- In a recent lattice QCD calculation the $SU(3)_{flavor}$ configurations of possible bound states in the $\bar{D}K, J^P = 0^+$, channel are studied;
- the allowed $SU(3)_{flavor}$ channels are those appearing as irreducible components of the tensor product

J. D. E.Yeo *et al.*, JHEP **07** (2024) 012

$$\bar{D}K = \mathbf{3} \otimes \mathbf{8} = \mathbf{3} \oplus \bar{\mathbf{6}} \oplus \mathbf{15}$$

- Yeo *et al.* find attraction in **3** and $\bar{\mathbf{6}}$ but not in **15**.

- Consider now four-quark mesons in the simplest diquark-antidiquark model restricting to the case of all diquark spin = 0:

$$[\bar{c}\bar{q}]^{\mathbf{3}}_{S_{c3}}[q_1 q_2]^{\bar{\mathbf{3}}}_{S_{12}}, \qquad S_{c3} = S_{12} = 0;\; J^P = S_{c3} + S_{12} = 0^+$$

- The product $[q_1 q_2]^{\bar{\mathbf{3}}}_{S_{12}=0}$ is antisymmetric in spin (to get total spin 0) and color (to obtain a $\bar{\mathbf{3}}_c$).

- Fermi statistics: *quarks in the light diquark must be antisymmetric in flavour, i.e they must be in a* $\bar{\mathbf{3}}$ *of* $SU(3)_{flavor}$.
- combining with the light antiquark $\bar{q} \propto \bar{\mathbf{3}}$, the tetraquark must be in a $SU(3)_{flavor}$ multiplet:

$$\bar{\mathbf{3}} \otimes \bar{\mathbf{3}} = \mathbf{3} \oplus \bar{\mathbf{6}}\text{ , no } \mathbf{15}$$

in agreement with the lattice indication.

$J^P = 0^+$, Open Charm and Strangeness Tetraquarks: what do we know ?

- We restrict to particles with Charm C=-1(C=+1 particles obtained by CPT symmetry), i.e. with quark composition: $\bar{c}$+uncharmed quarks/antiquarks. PdG reports 4 entries with $J^P = 0^+$:
  - $D^*_{s0}(2317)^{\pm}$, observed decay: $D^*_{s0}(2317)^- \to D_s^- + \pi^0$: I=0 ?

  quark composition: $D^{*-}_{s0} = (\bar{c}sq\bar{q}),\ (q = u, d)$
- $X(2900)^0$, required by LHCB for the full amplitude analysis of $B^+ \to D^+D^-K^+$,

  quark composition $X(2900)^0 = (\bar{c}\bar{s}ud)$
- $T^*_{c\bar{s}0}(2900)^{--,0}$, $I = 1$, $(I_3 = -1, +1)$, *alias*, in LHCB notation,

  $D^{--}_{s0}(2900)$, $D^0_{s0}(2900)$

Decays: $D^{--}_{s0}(2900) \to D_s^-\pi^-$ $(\bar{c}s\bar{u}d)$, $D^0_{s0}(2900) = D_s^-\pi^+ -$ $(\bar{c}s\bar{d}u)$

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- The lightest particle $D^*_{s0}(2317)$ goes in the basic $\mathbf{3} \oplus \bar{\mathbf{6}}$ multiplet.
- However X and $T^*$are ***too heavy to be included in the same*** $\mathbf{3} \oplus \bar{\mathbf{6}}$ ***multiplet***:

$$M(2900) - M(2317) = 583 \text{ MeV}$$

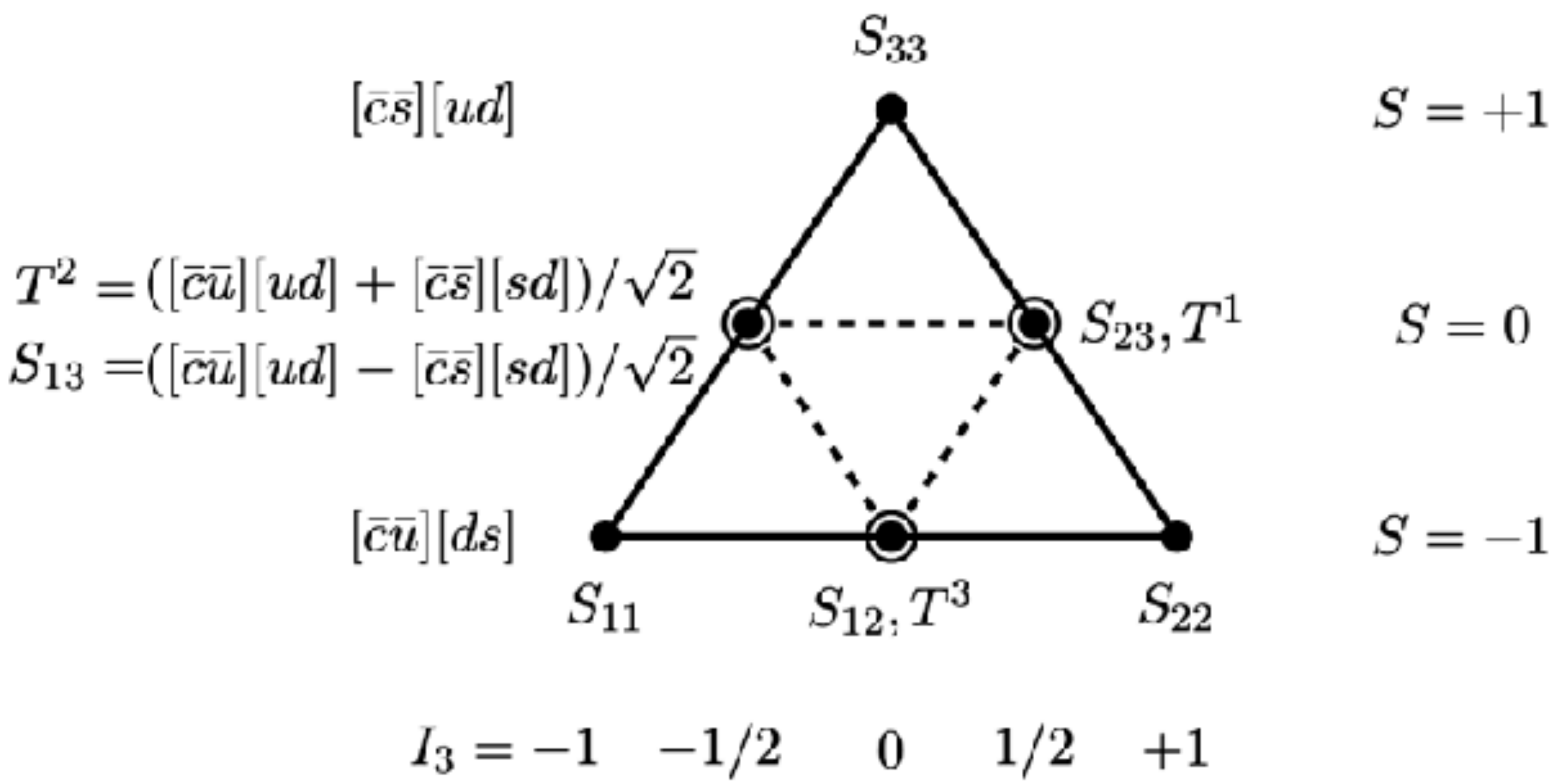
is similar to the mass gaps:

$$M(J/\Psi) - M(\psi') = 590 \text{ MeV}, \; M(X(3872) - M(Z(4430)) = 558 \text{ MeV}$$

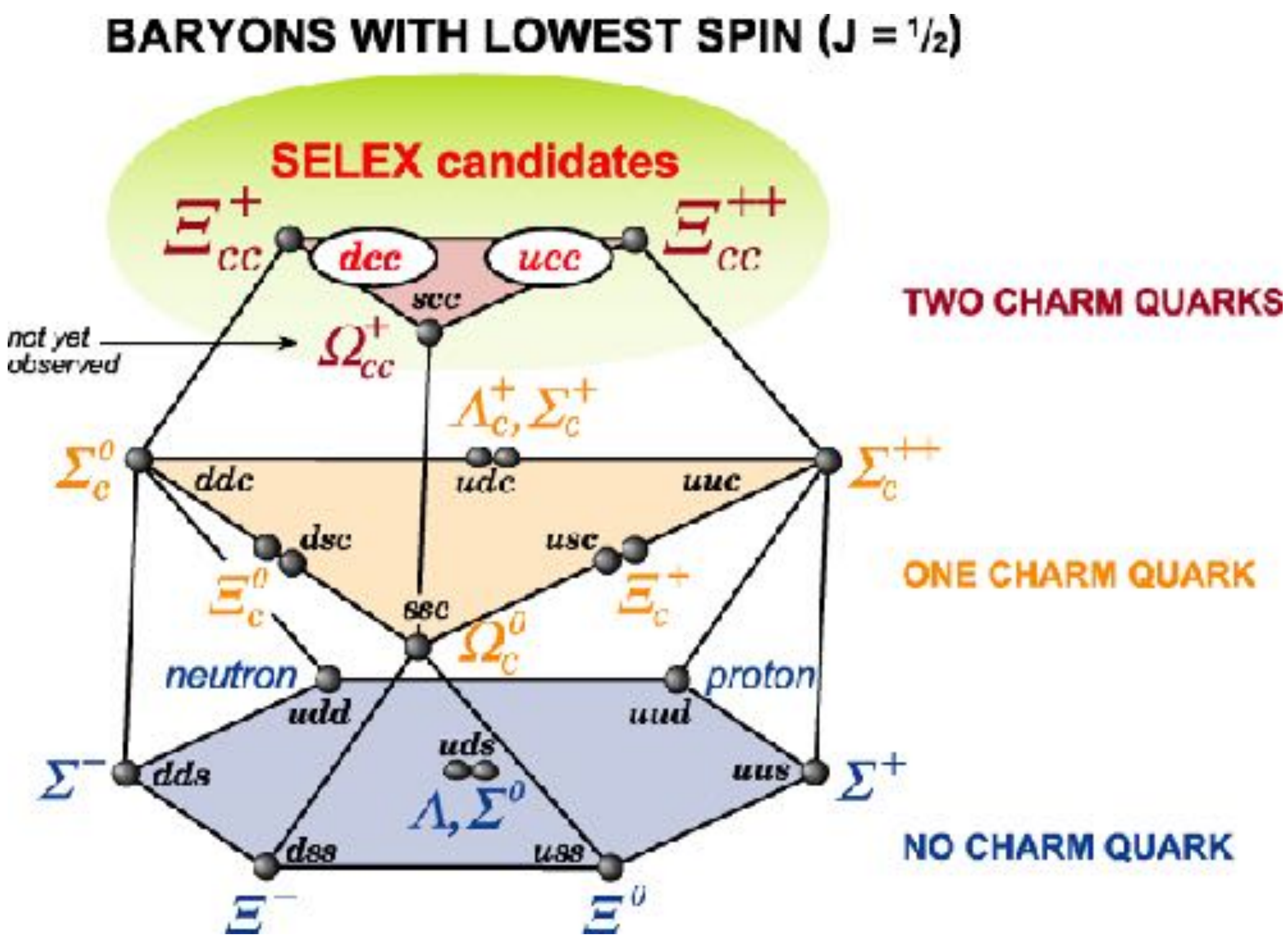
- We interpret the LHCb resonances as the ***first radial excitations*** of the basic $D^*_{s0}(2317)$ multiplet, to be allocated in a different $\mathbf{3} \oplus \bar{\mathbf{6}}$ $(n = 2)$ multiplet.

5. Quantum numbers and Mass Formulae for $[\bar{c}\bar{q}]^{\mathbf{3}}_{S_{c3}=0}[q_1 q_2]^{\bar{\mathbf{3}}}_{S_{12}=0}$

The $\mathbf{3} \oplus \bar{\mathbf{6}}$ representation in the $I_3 - S$ plane:



$6 \oplus \bar{3}$ & Fermi Statistics appear in Single Charm Baryons



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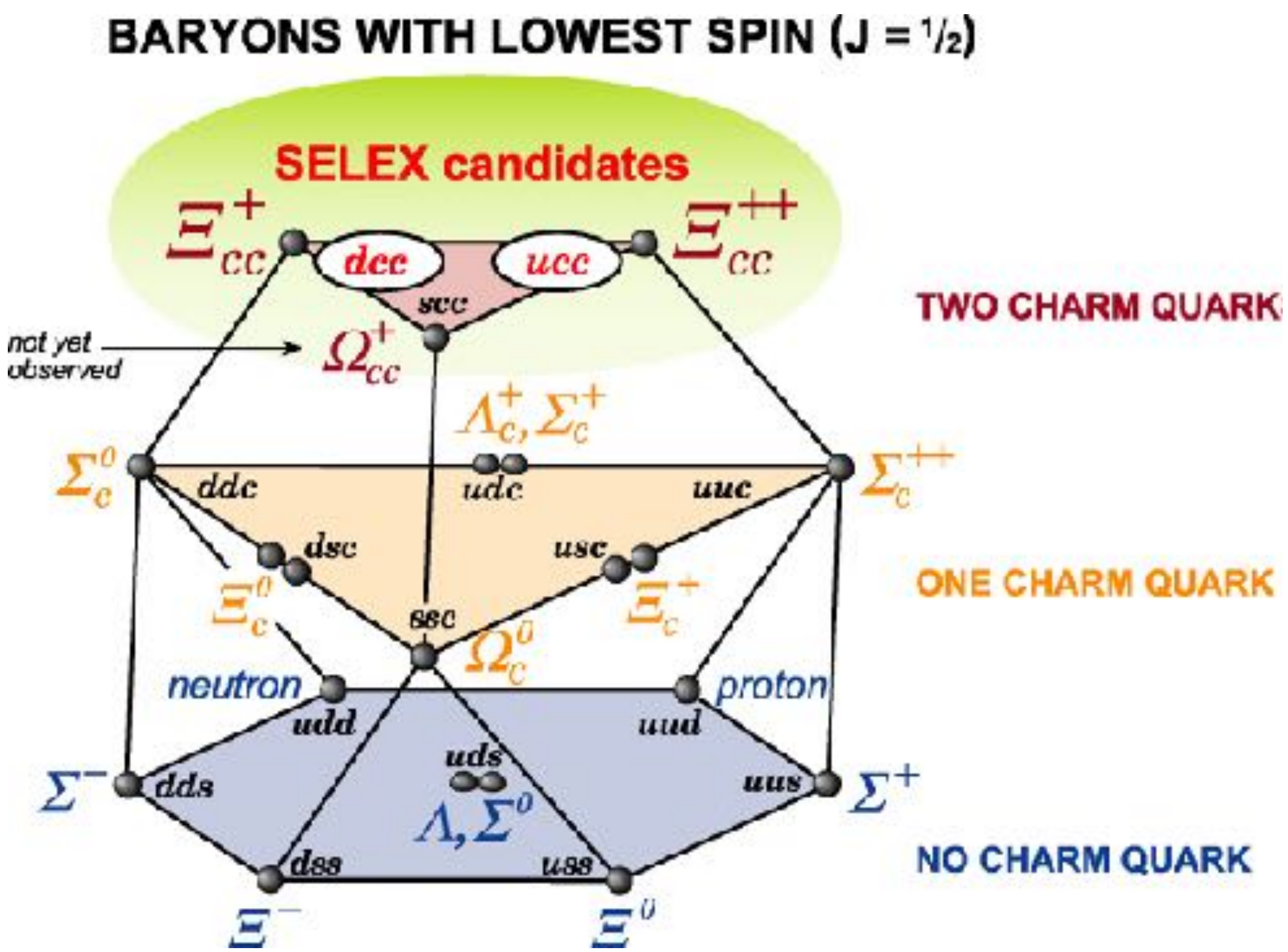


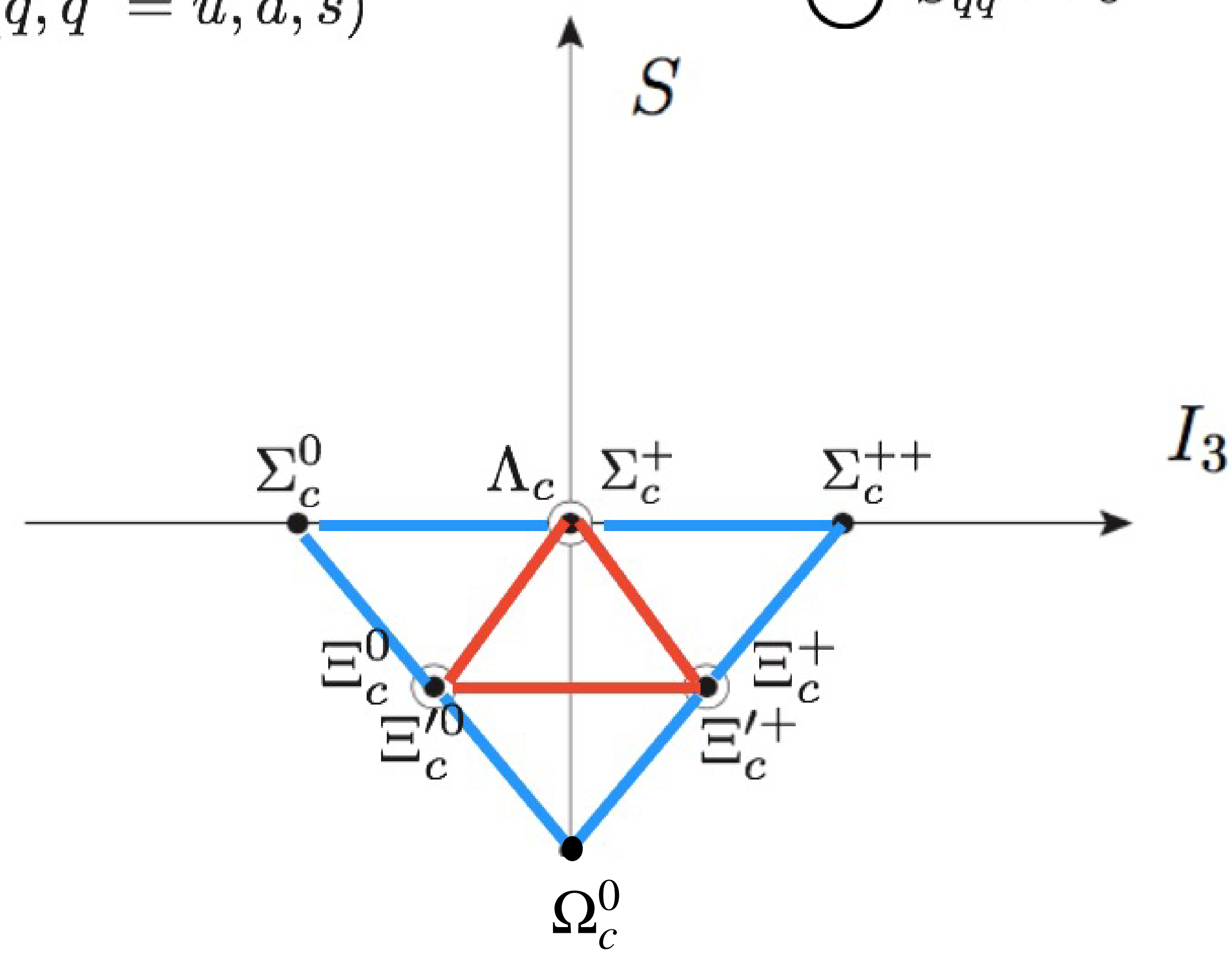
$q,\ q'$: color $= \mathbf{3} \otimes \mathbf{3} \to \bar{\mathbf{3}}$

$\mathbf{J} = 1/2: \ \mathbf{6} \oplus \bar{\mathbf{3}}$

$(q, q' = u, d, s)$

$\bullet \ S_{qq'} = 1$

$\bigcirc \ S_{qq'} = 0$



$$I = 1 \ \leftrightarrow \ spin = 1, \ (\Sigma_c^{0,+,++})$$

$$I = 0 \ \leftrightarrow \ spin = 0 \ \ (\Lambda_c^+)$$

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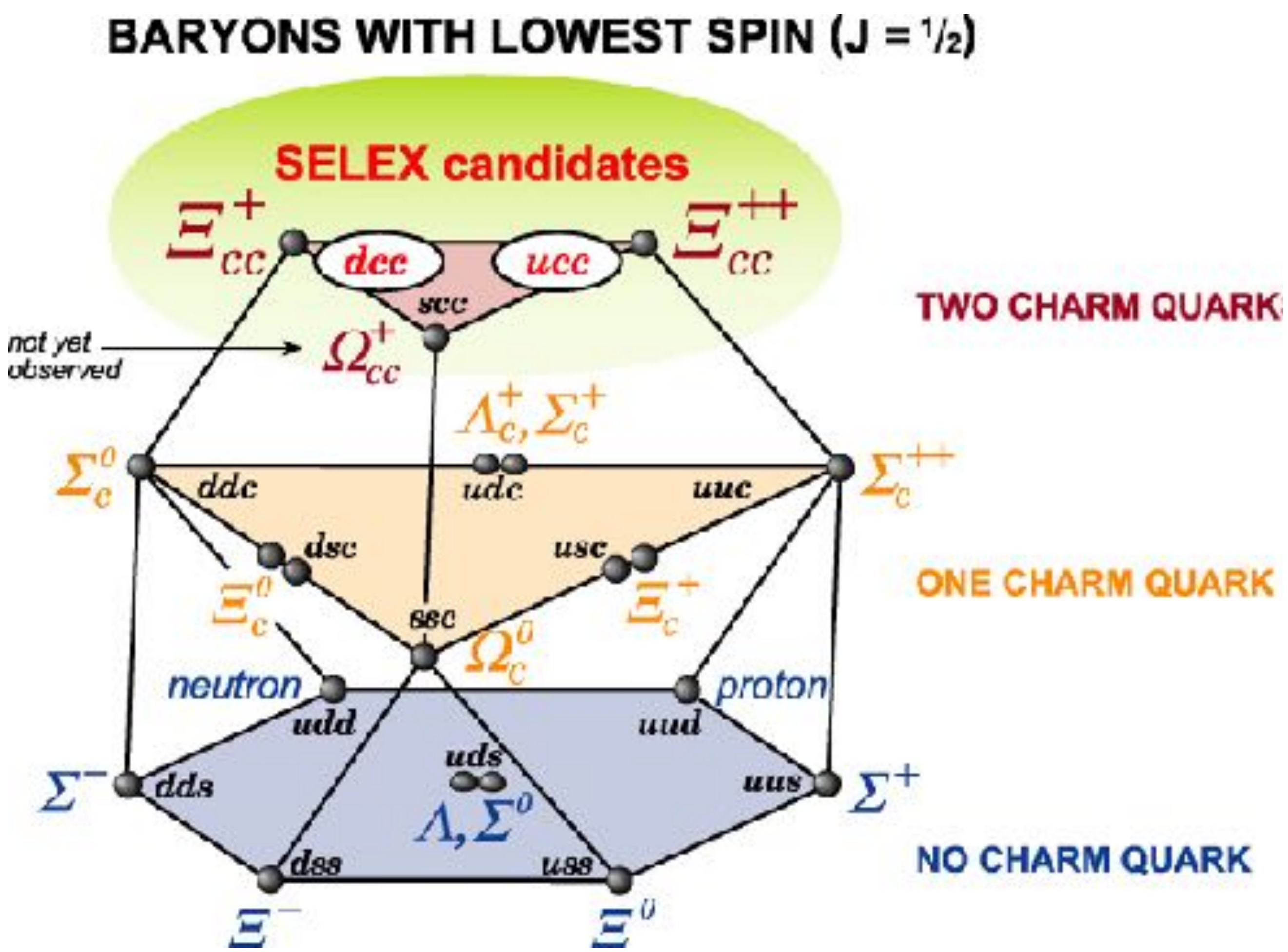

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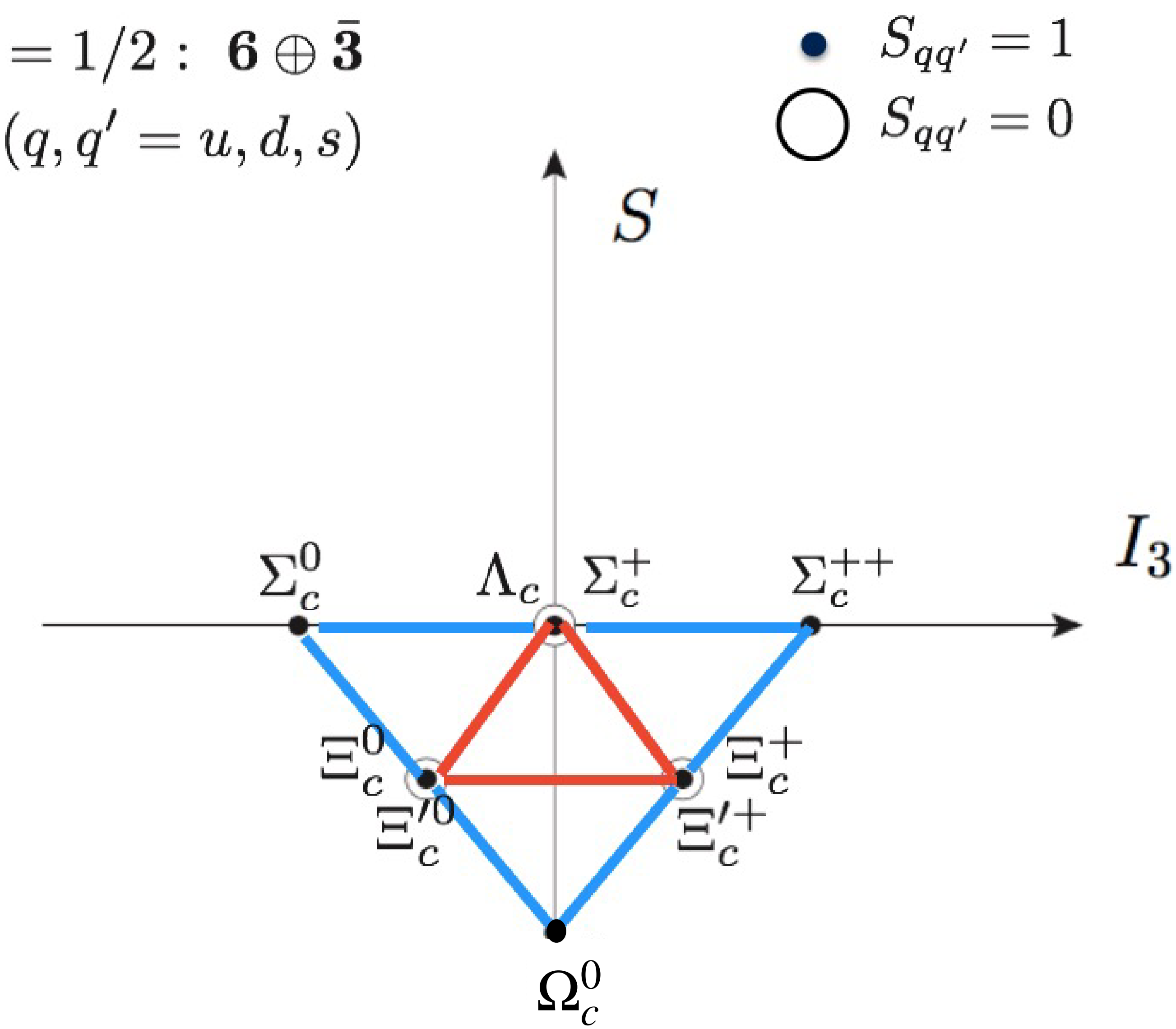


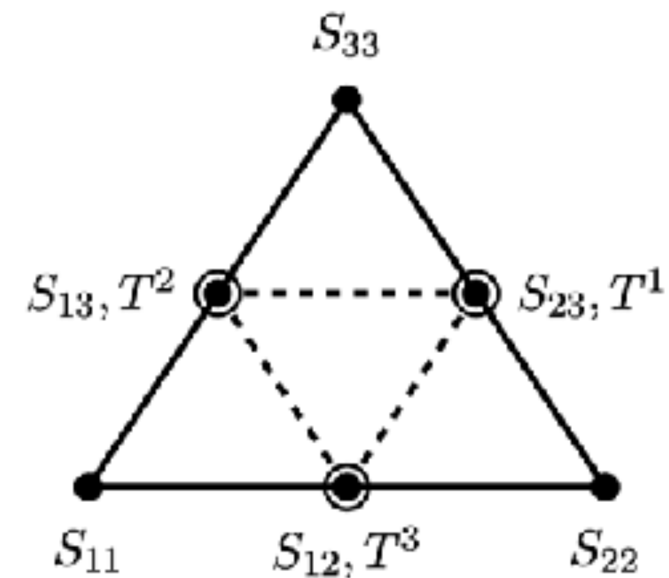
The masses of spin 1 diquarks in the **6** increase linearly with Strangeness, i.e. with the number of strange quarks: $M(\Omega_c) - M(\Sigma_c) \simeq 270$ MeV

$$I = 1 \ \leftrightarrow \ spin = 1, \ (\Sigma_c^{0,+,++})$$

$$I = 0 \ \leftrightarrow \ spin = 0 \ \ (\Lambda_c^+)$$

A remarkable regularity

- Like the masses of single charm mesons, the masses of single charm tetraquarks are equally spaced in Strangeness, with a slope given by a parameter α.
- However, ***unlike charmed baryons,*** the lower indices in S_{11} correspond to the quark-diquark antisymmetric configuration $\bar{u} \otimes [ds]_A$, while the lower indices in S_{33} correspond to $\bar{s} \otimes [ud]_A$,



which have obviously the same content in quark masses, two light and one heavy.

- Exact equality $M(S_{33}) = M(S_{11})$ corresponds to $\alpha = 0$: same masses at the upper vertex and lower corners of the triangle in the figure.
- In this case, symmetry breaking is restricted to the mass difference between the two $S = 0$, $I = 1/2$ multiplets induced by the $\mathbf{3} - \bar{\mathbf{6}}$ mixing and of order $\delta \sim 2(m_s - m_q)$, with all other masses degenerate at M.
- A small, non vanishing value of α may arise from differences in the hyperfine interactions, which are between different pairs in the two cases.

Note: *In charmed baryons, two light quarks in spin one are in a* **6** *representation. In this case, indices 1 or 3 correspond univocally to u or s quarks:*

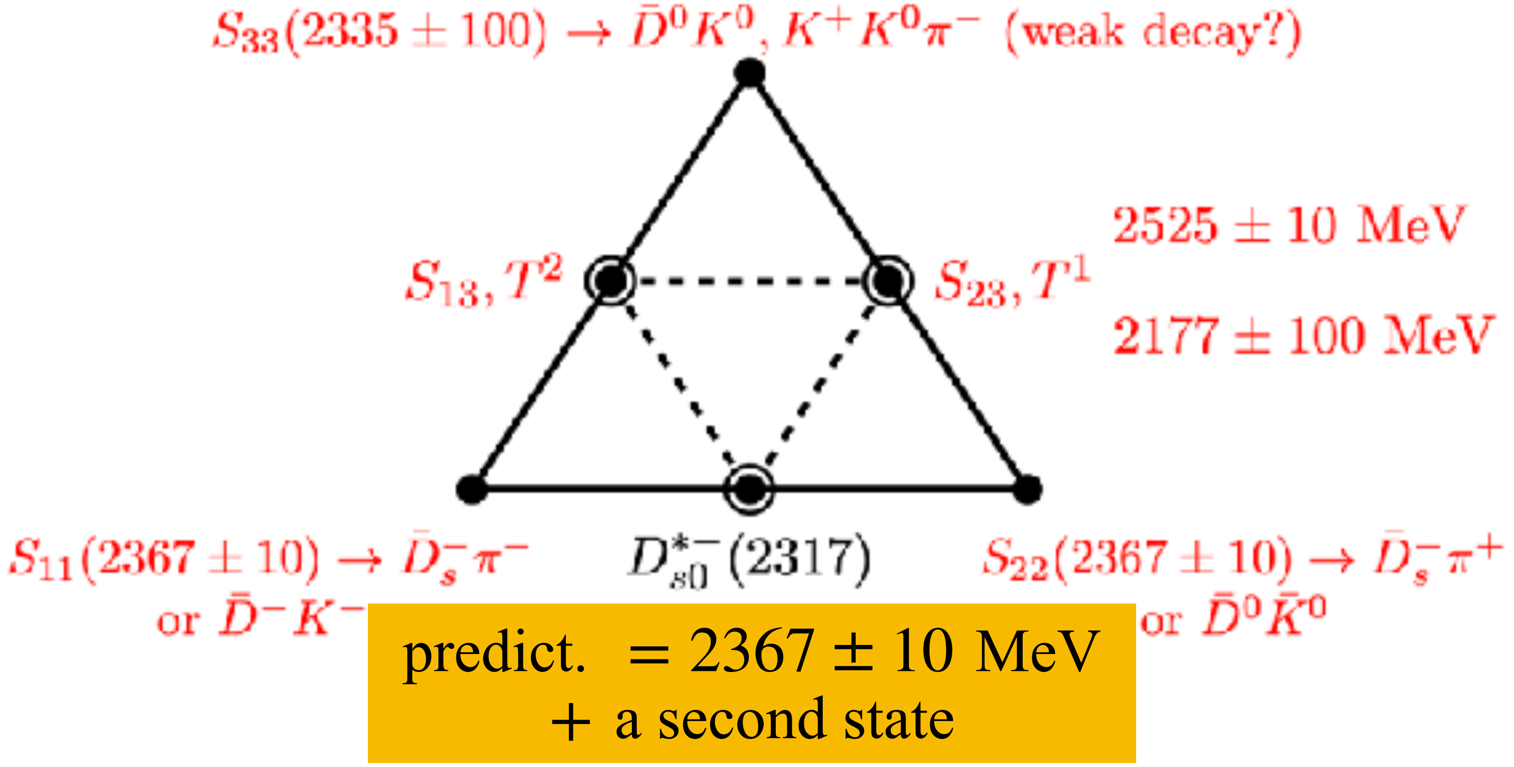
- *Group theory disentangles efficiently the ambiguity in these two* **6** *representations* ***making use of the parameter*** α required by the Wigner-Eckart theorem.

5. The missing partners of the lightest charm-strange tetrquark yet observed : $D^*_{cs0}(2317) \to \bar{D}^-_s \pi^0$

In red the missing S=0 states and their estimated masses. Expected decay modes:

$$[\bar{c}\bar{s}][su](2525 \pm 10) \to \bar{D}^-_s K^0, \bar{D}^0\eta$$

$$[\bar{c}\bar{d}][ud](2177 \pm 100) \to \bar{D}\pi$$



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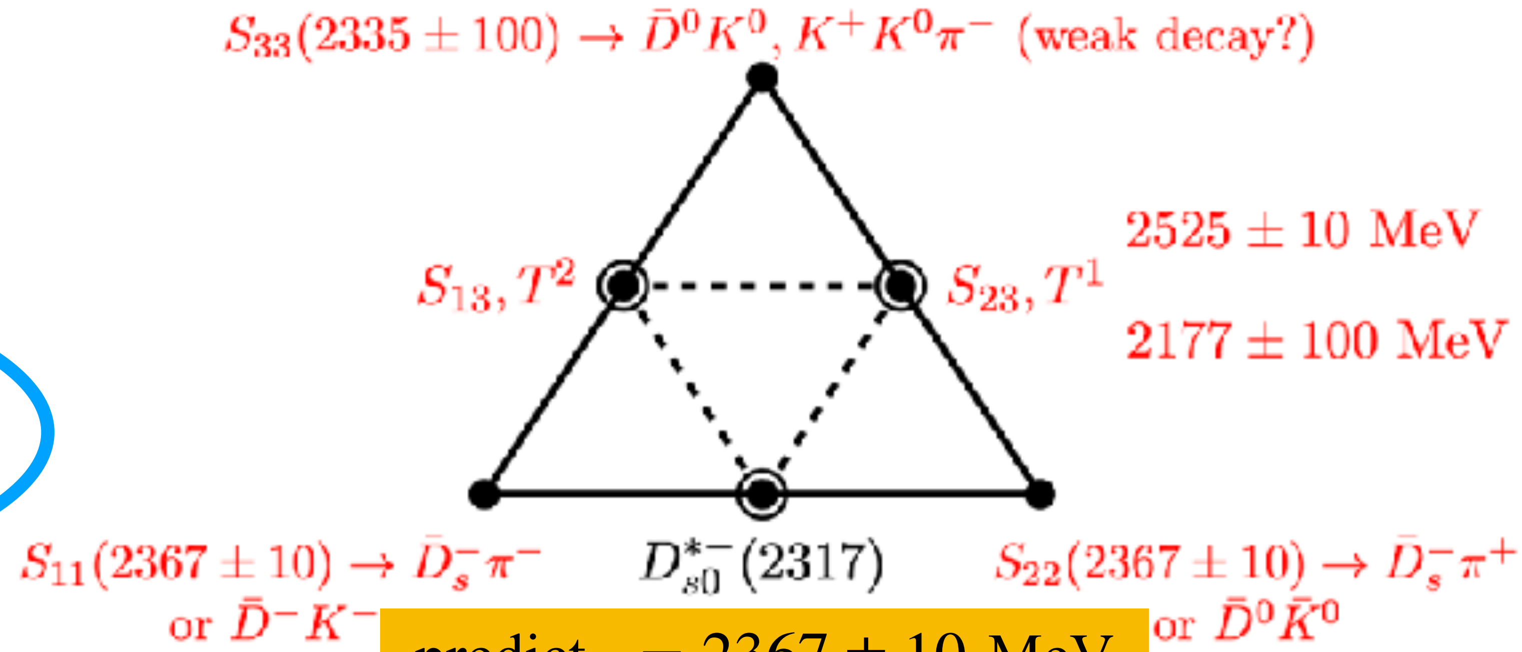

predict. $= 2367 \pm 10$ MeV
+ a second state

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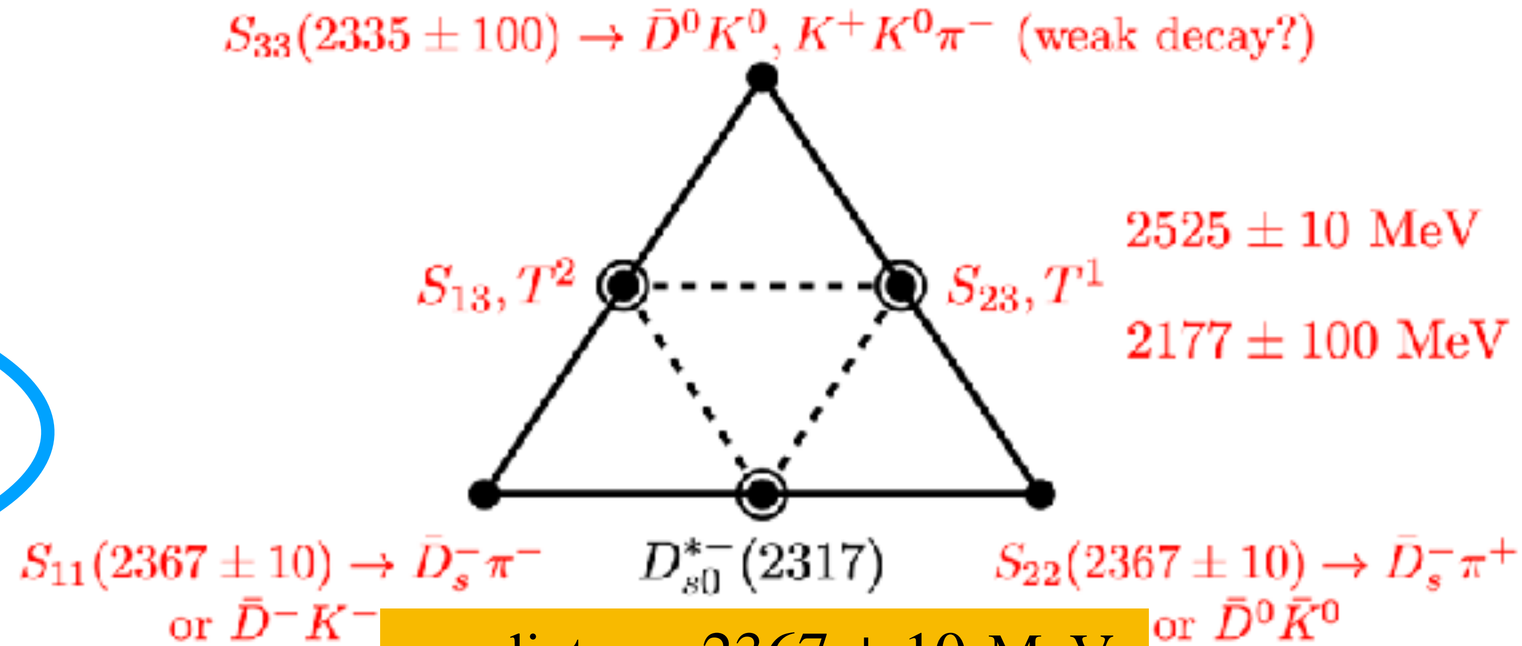

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- $D^{*-}_{s0}(2317)$ has I=0 (PdG) and it should decay into $\bar{D}_s^- \eta$, which however is forbidden by phase space.
- There are two independent mechanisms for the observed $\bar{D}_s^- \pi^0$decay, both related to the $m_d - m_u \sim 5$ MeV mass difference: mixing $T^3 - S_{12}$, or $\eta - \pi^0$mixing.
- ***Interesting*** to observe the decay $D^*_{s0} \to \bar{D}_s \gamma\gamma$, quoted in PdG with the upper bound $B(\gamma\gamma) < 0.18$, to compare with $D^*_{s0}(2317) \to D_s^- \eta^* \to D_s^- \gamma\gamma$ via a virtual η.

6. The $\mathbf{3} \oplus \bar{\mathbf{6}}$ (n=2) radially excited multiplet

- $X_0(2900)$ and $D_{s0}^0(2900)$, $D_{s0}^{++}(2900)$ observed by LHCb

$X_0(2900)$ R. Aaij et al. [LHCb], Phys. Rev. D 102 (2020), 112003

$D_{s0}^{0,++}(2900)$ R. Aaij et al. [LHCb], Phys. Rev. Lett. 131 (2023) 0419

- We interpret the LHCb resonances as the ***first radial excitations*** ($n = 2$) of the basic $D_{s0}^*(2317)$ multiplet.

The n=2 multiplet:

(i) in black the resonances observed by LHCb;

(ii) in red the missing S=0 states and their estimated masses (indicative only) .

(iii) expected decay modes:

$$[\bar{c}\bar{s}][sd]_{(n=2)}(3050) \to \bar{D}^-\eta,\ \bar{D}_s^-K^0,\ \bar{D}^{*-}\phi,$$

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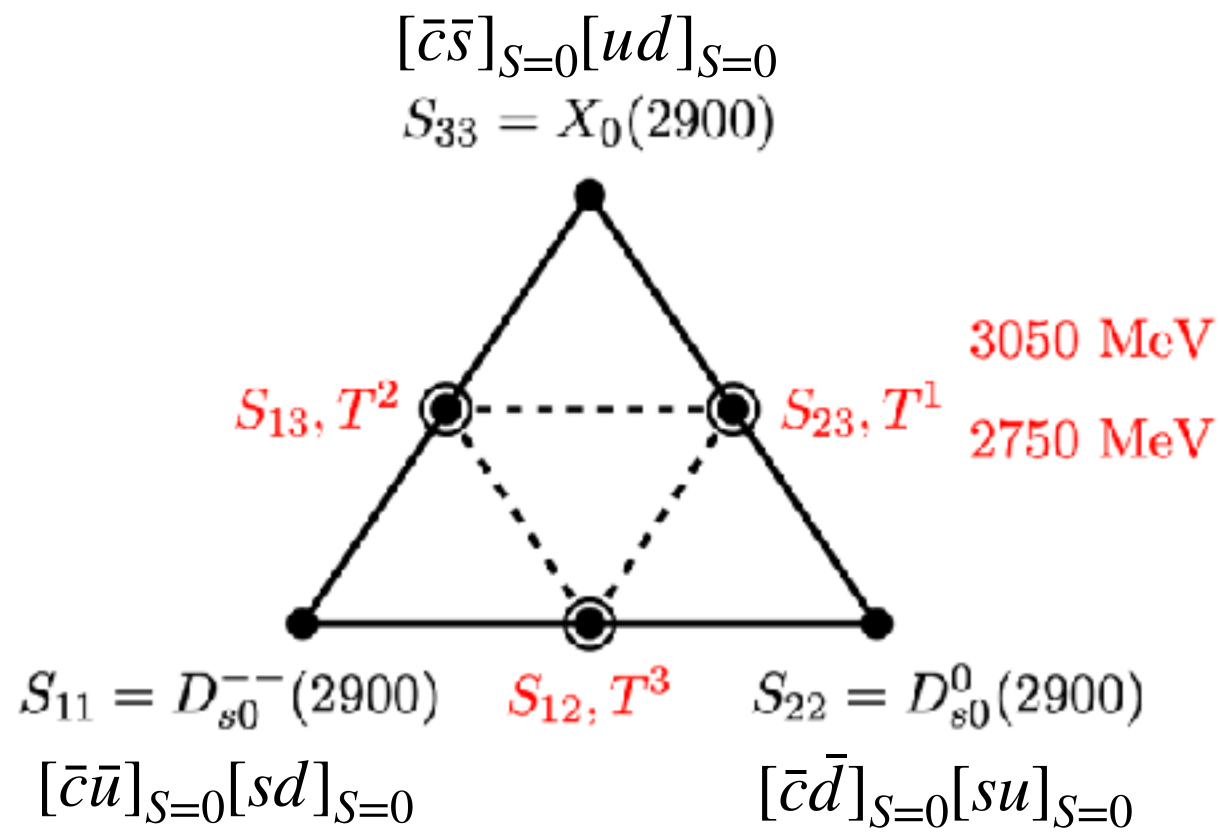

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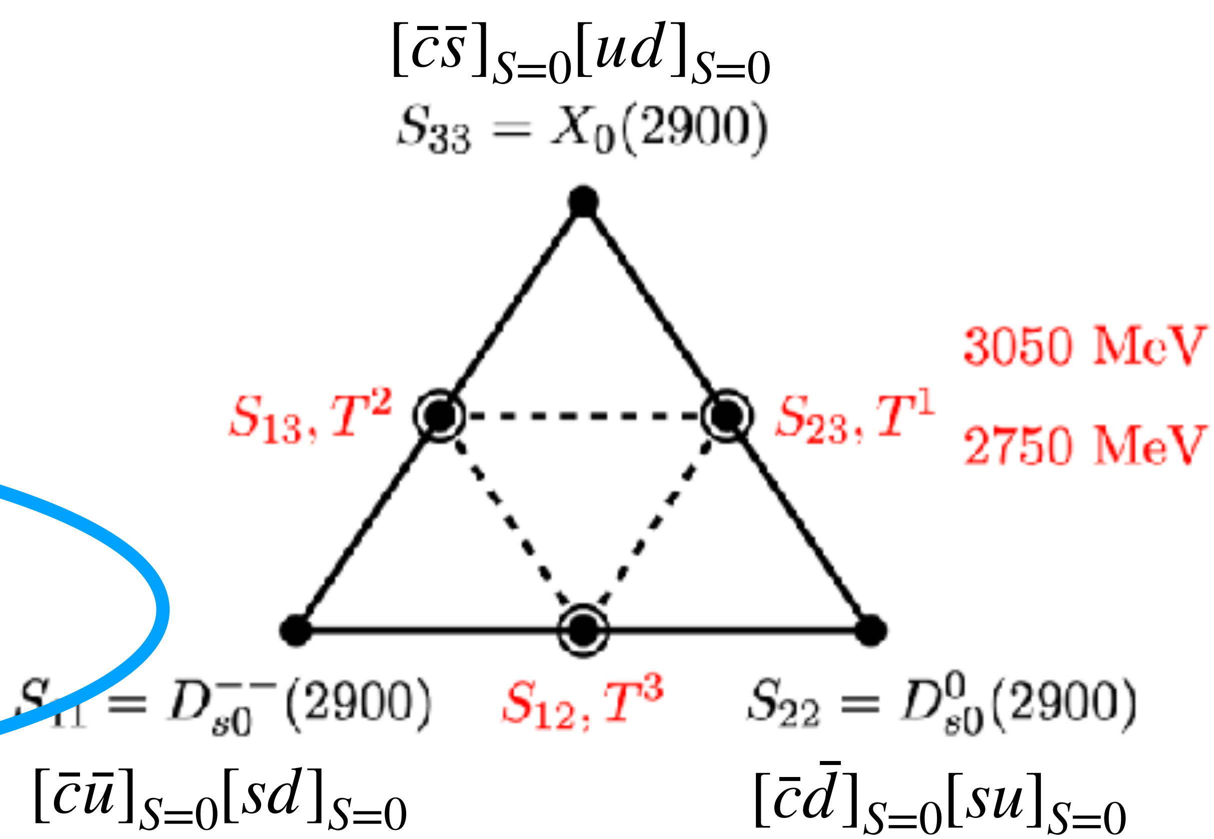

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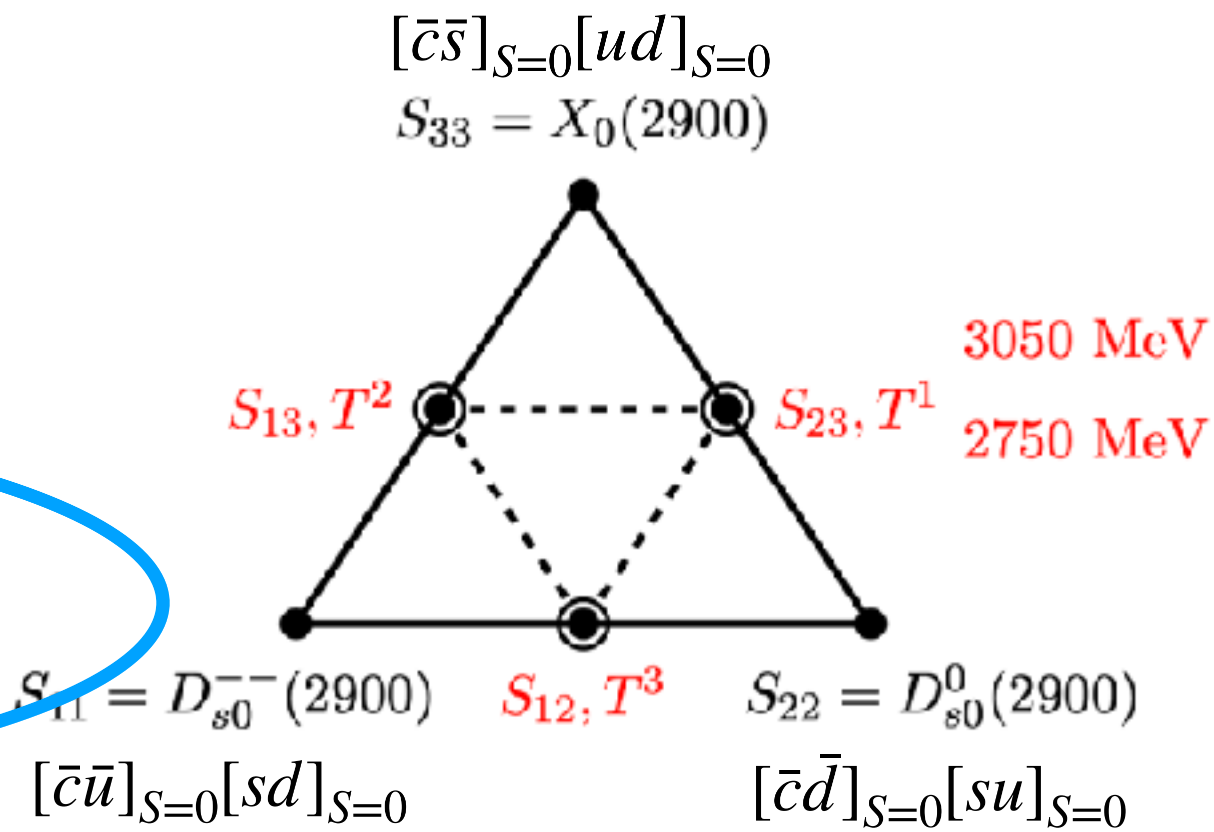

- ***Mass degeneracy between*** $\mathbf{X_0(2900)}$ ***(S=+1) and*** $\mathbf{D^{--,0}_{s0}(2900)}$ ***(S=-1) is the footprint of the tetraquark compositions:***

$$[\bar{c}\bar{s}]_0[ud]_0 \text{ and } [\bar{c}\bar{u}]_0[sd]_0$$

7. Heavy particle spin conservation and Fermi Statistics of light quark pairs: QCD tetraquarks vs hadron molecules

- For molecular tetraquarks *treated in Chiral Perturbation Theory*, the light quark total spin is a separatly conserved quantity in the limit of very massive charm quark (this is the *light quark spin symmetry in the static quark approximation* introduced by Isgur and Wise).
- For hidden charm molecules $(\bar{c}q)(\bar{q}'c)$, flavour symmetry, e.g. Isospin, is also an independent (commuting) conserved quantity. The possible combinations of light and heavy spin generate six states with definite Isospin, total angular momentum and charge conjugation:

Z. H. Zhang *et al.*, JHEP **08** (2024) 130

$$J_I^{PC} = 0_I^{++},\ 1_I^{+-},\ 1_I^{'+-},\ 1_I^{++},\ 0_I^{'++},\ 2_I^{++}$$

- These are the same J_I^{PC} states predicted for diquark-antidiquark tetraquarks of the form $[cq]^{\bar{\mathbf{3}}}[\bar{c}\bar{q}']^{\mathbf{3}}$. Noticeably, they include the I=1 partner of $X(3872)$, i.e. X^+

L. Maiani et al., Phys. Rev. D 89 (2014), 114010; Phys. Rev. D 94 (2016) , 054026

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- Concerning Fermi Statistics, the situation for the molecular structure $(\bar{c}q_1)(\bar{s}q_2)$ is different with respect to diquark-antidiquark situation.
- q_1 and q_2, sit in different color singlets and the color of the pair $q_1 \otimes q_2$ is not determined (in fact it is a superposition of $\bar{\mathbf{3}}_c$ and $\mathbf{6}_c$). There is no definite restriction to their behaviour under flavor exchange and no forbidden **15**.

8. $X(3872)$ radiative decays into Charmonium states

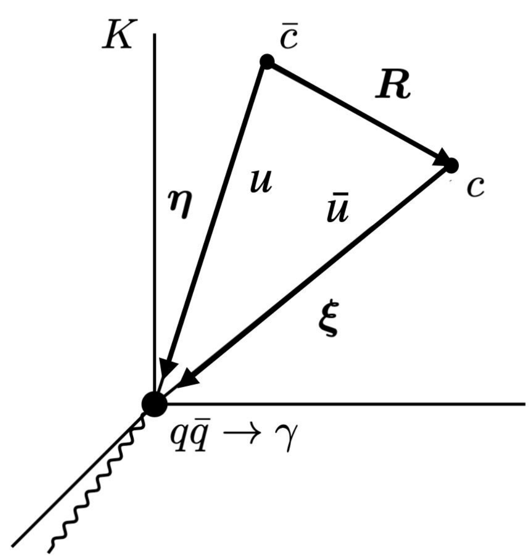
B.Grinstein, L. M. and A. Polosa, arXiv:2401.11623

- The decays: $X(3872) \to \psi(3092) + \gamma$ and $X(3872) \to \psi(3690) + \gamma$ have both observed, with a ratio of rates (see PdG)

$$\mathcal{R} = \frac{\Gamma(X \to \psi'\gamma)}{\Gamma(X \to \psi\gamma)} = 2.6 \pm 0.6;\ \text{(phase space ratio=0.26 !!!)}$$

- the result is somewhat surprising, since the Q-values of the two decays favour by far ψ over ψ' decay ($Q \sim 780,\ 180\ \text{GeV}$)

- Decays are due to the annihilation in a single point of the light quark pair, coming either from the $D^0\bar{D}^{*0}$ molecule or from the diquark-antidiqark in the compact tetraquark. The annihilation transforms the X into a pure charmonium state, $\psi_{1S}(|\mathbf{r}_c - \mathbf{r}_{\bar{c}}|)$ or $\psi_{2S}(|\mathbf{r}_c - \mathbf{r}_{\bar{c}}|)$



- Recently, LHCb at CERN, has performed new measurement, to discriminate between molecule and compact tetraquark.

X decay: molecule (cont'd)

B.Grinstein *et al.* arXiv:2401.11623

- Numerical results:

Molecule:

- we find: $\mathscr{R} = \dfrac{\mathscr{B}(X \to \psi'\gamma)}{\mathscr{B}(X \to \psi\gamma)} = 0.036$; the ratio

grows for larger values of the meson radius, it gets above 1 only for D/D^* radius >1 fm (fit to mass spectra give rather radius=0.83 fm).

Compact tetraquark:

- we find: $\mathscr{R}_{\text{min}} = \dfrac{\mathscr{B}(X \to \psi'\gamma)}{\mathscr{B}(X \to \psi\gamma)} = 0.95^{+0.01}_{-0.07}$

the error corresponds to the uncertainty on the starting point of the string confining the diquark orbitals.

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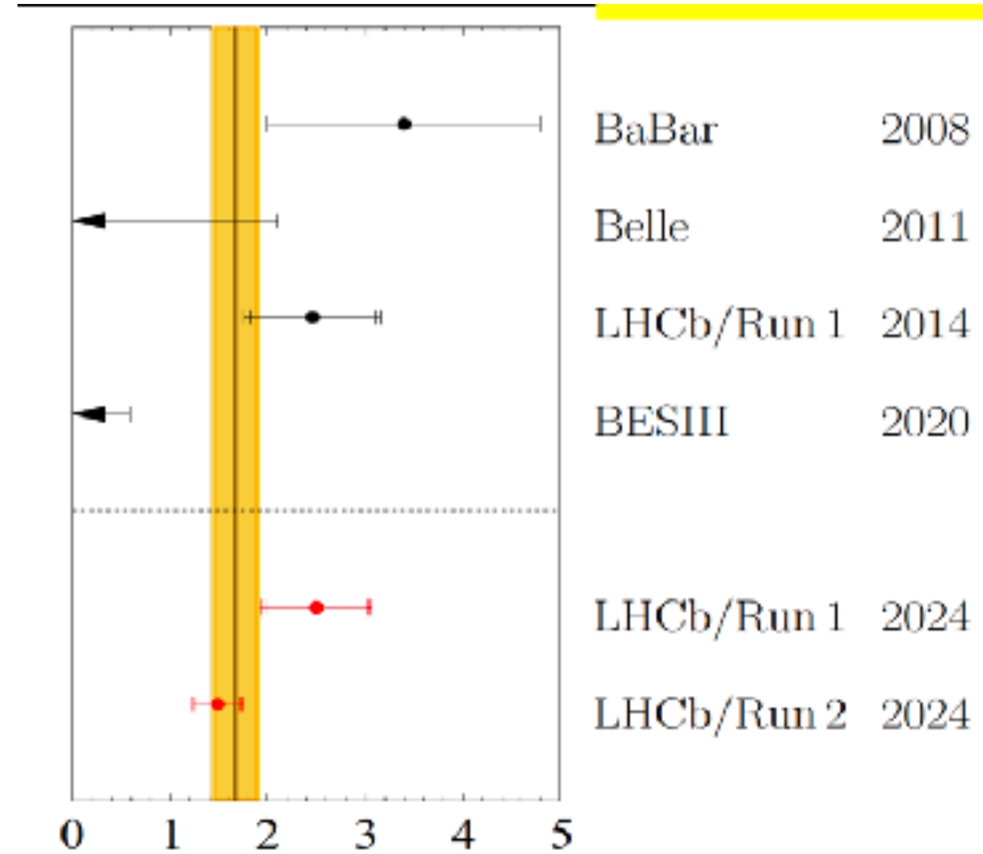

$$\mathscr{R}_{\psi\gamma} = \frac{\Gamma_{\chi_{c1}(3872)\to\psi(2S)\gamma}}{\Gamma_{\chi_{c1}(3872)\to J/\psi\gamma}}$$

$$\mathscr{R}_{\psi\gamma} = 1.67 \pm 0.21 \pm 0.12 \pm 0.04 .$$

Vanya Belyaev "Probing X(3872) nature"

arXiv:2406.17006

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Conclusions

LHCb

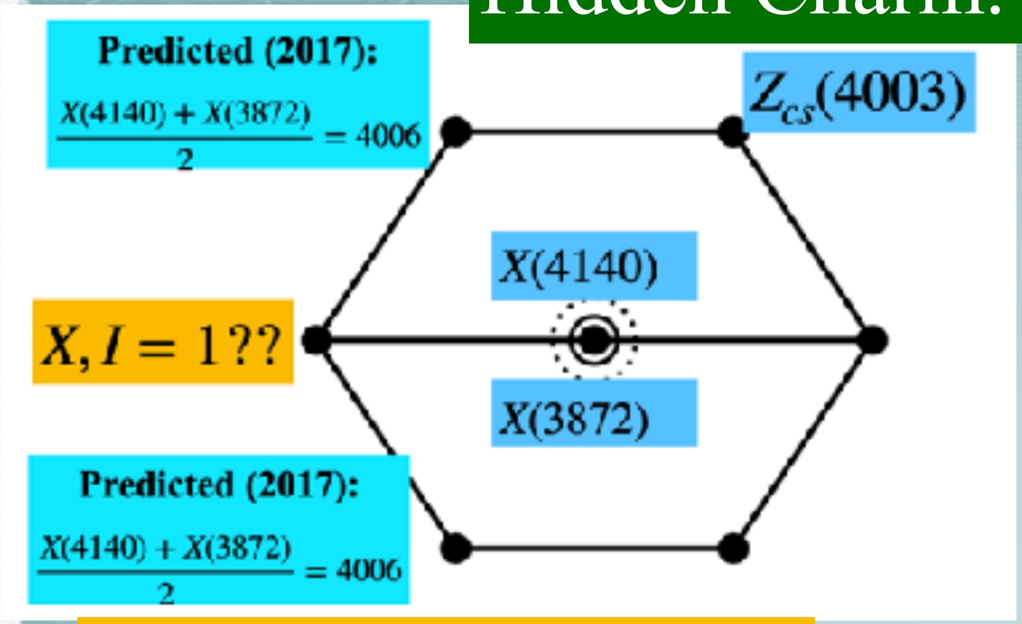
- The first observation of $X(3972) \rightarrow \psi'\gamma$ decay
- New measurement of $\mathscr{R}_{\psi\gamma}$ ratio
  - Good agreement with previous Run 1 LHCb-2014 measurement
  - Large tension with BESIII
  - Ratio is not compatible with simple molecular models
  - Ratio is well compatible with charmonium, tetraquark and mixture models

What are conclusion about X(3872) nature?

9. Summing up

Hidden Charm. : **8 ⊕ 1**

$Z([\bar{c}\bar{s}][cs])$

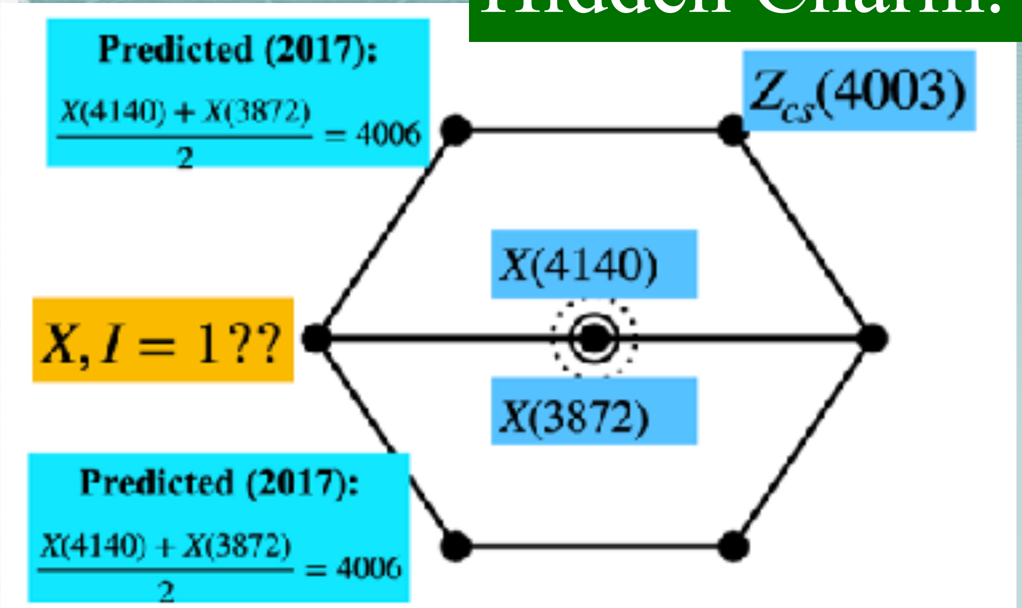


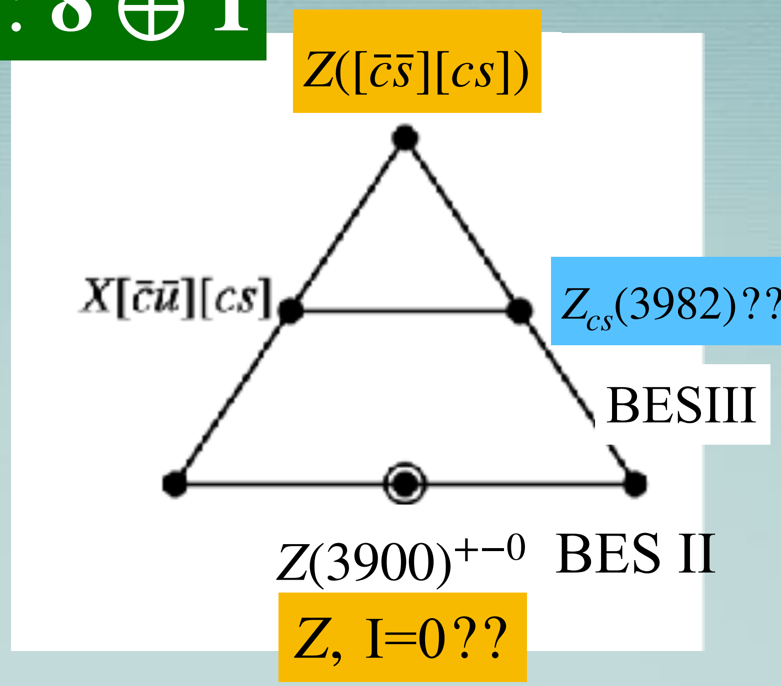
$$X^+ \to J/\psi\ \rho^\pm \to J/\psi\ \pi^+\pi^0$$

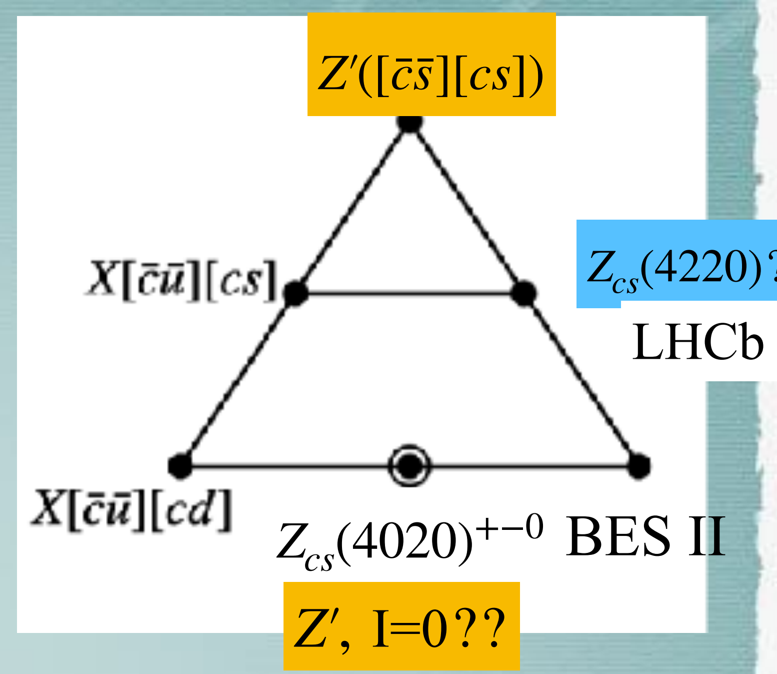
$$0.057 < R_{2\pi}^{(0+,00)} = \frac{\Gamma(B^0 \to K^+X^- \to K^+\psi\ \pi^0\pi^-)}{\Gamma(B^0 \to K^0X(3872) \to K^0\psi\ \pi^+\pi^-)} < 0.50$$

9. Summing up

Hidden Charm. : $\mathbf{8} \oplus \mathbf{1}$







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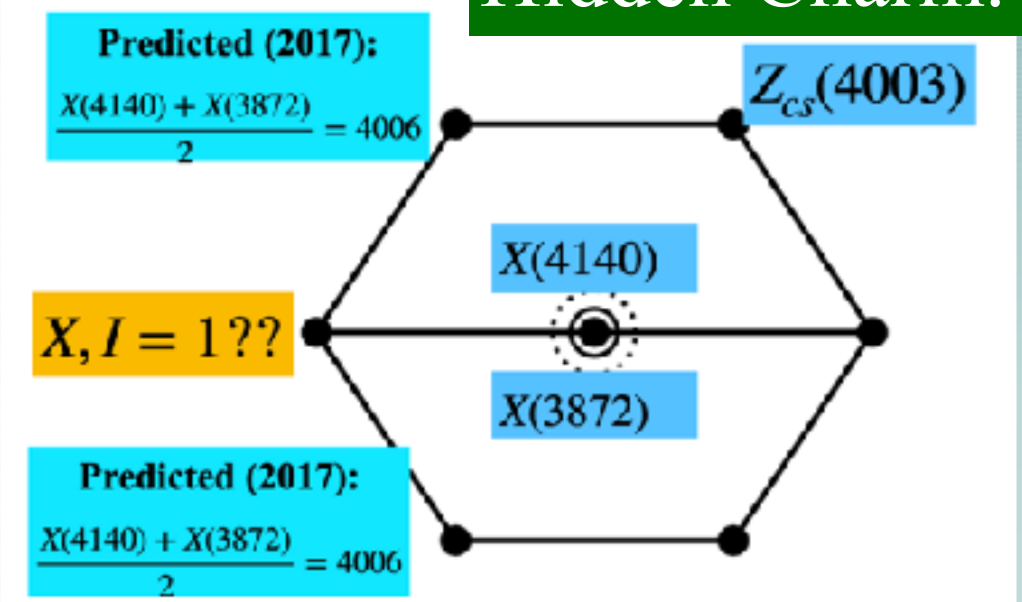
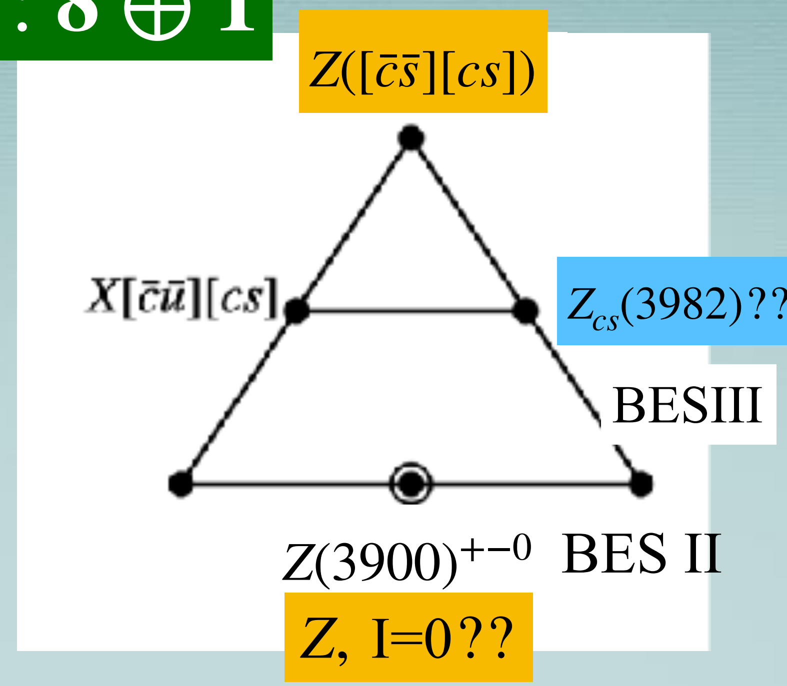
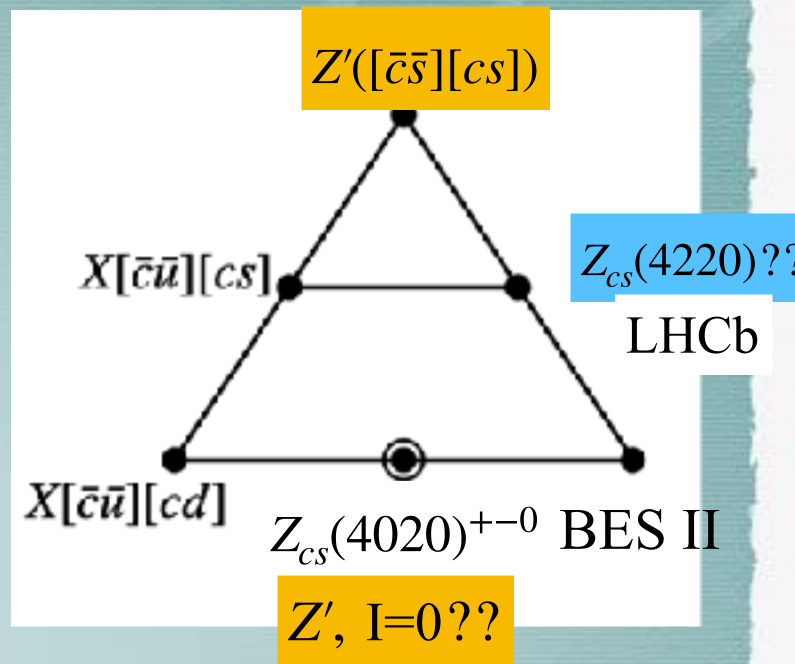
$$0.057 < R_{2\pi}^{(0+,00)} = \frac{\Gamma(B^0 \to K^+X^- \to K^+\psi\ \pi^0\pi^-)}{\Gamma(B^0 \to K^0X(3872) \to K^0\psi\ \pi^+\pi^-)} < 0.50$$

9. Summing up

Hidden Charm. : $\mathbf{8 \oplus 1}$







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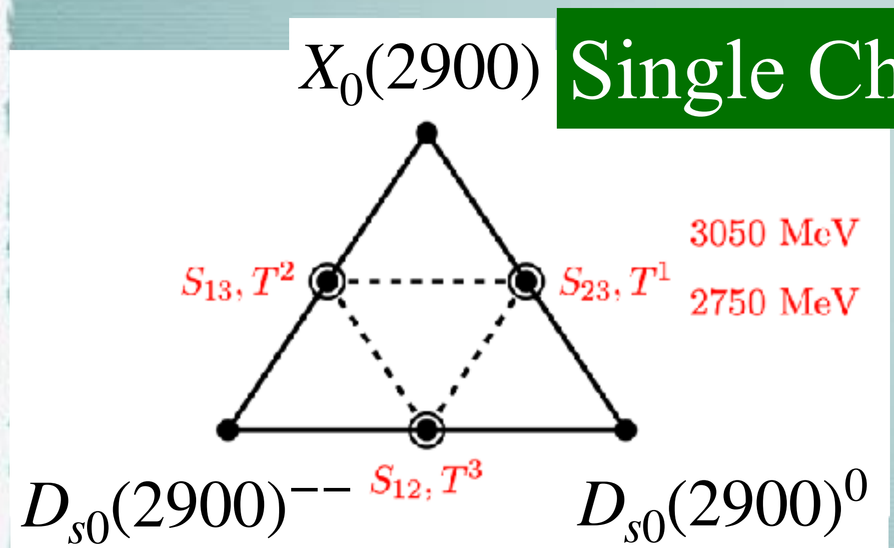

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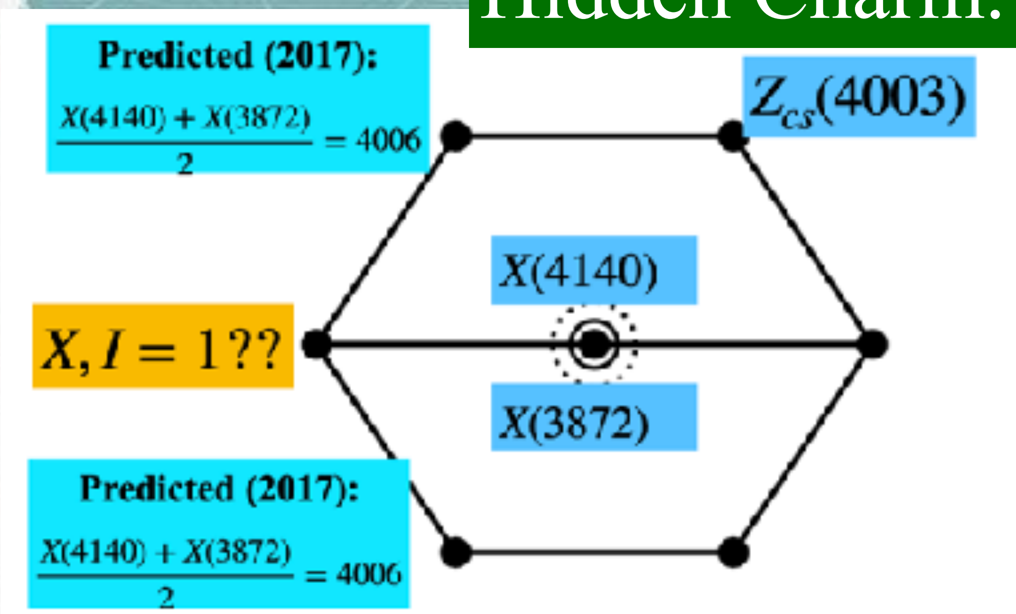

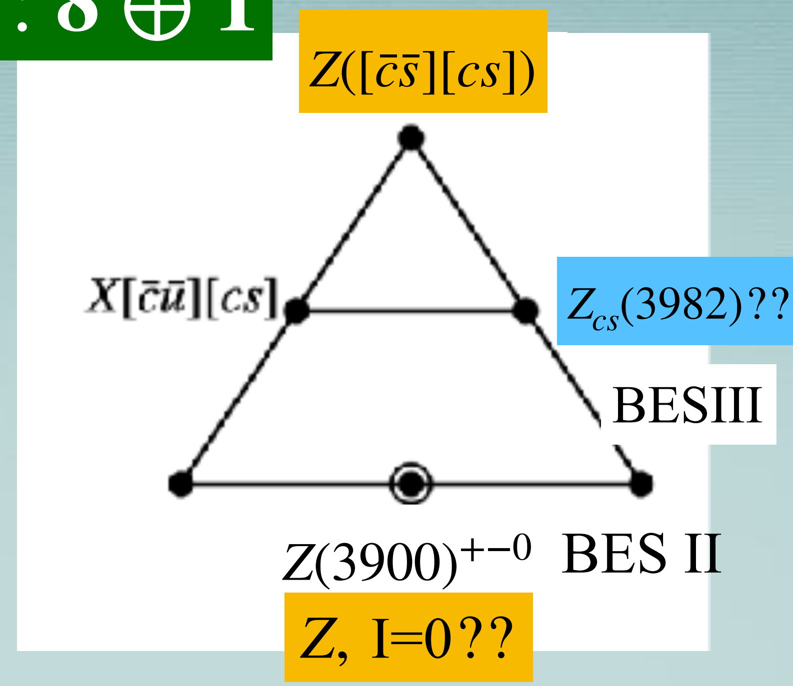

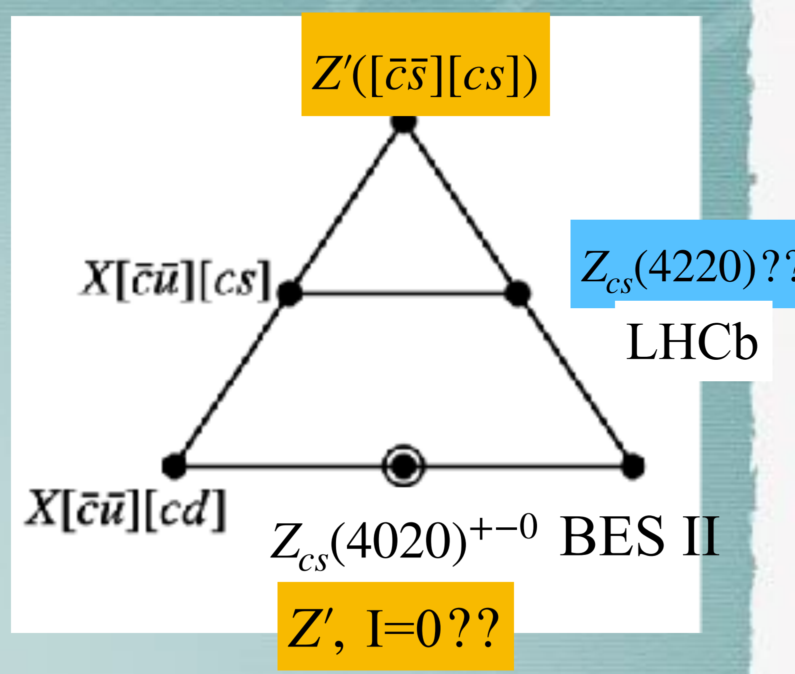

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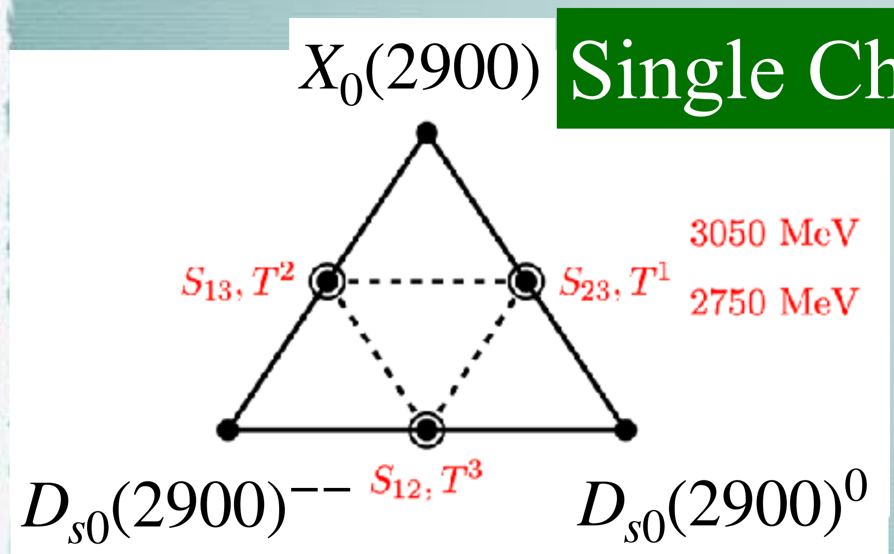
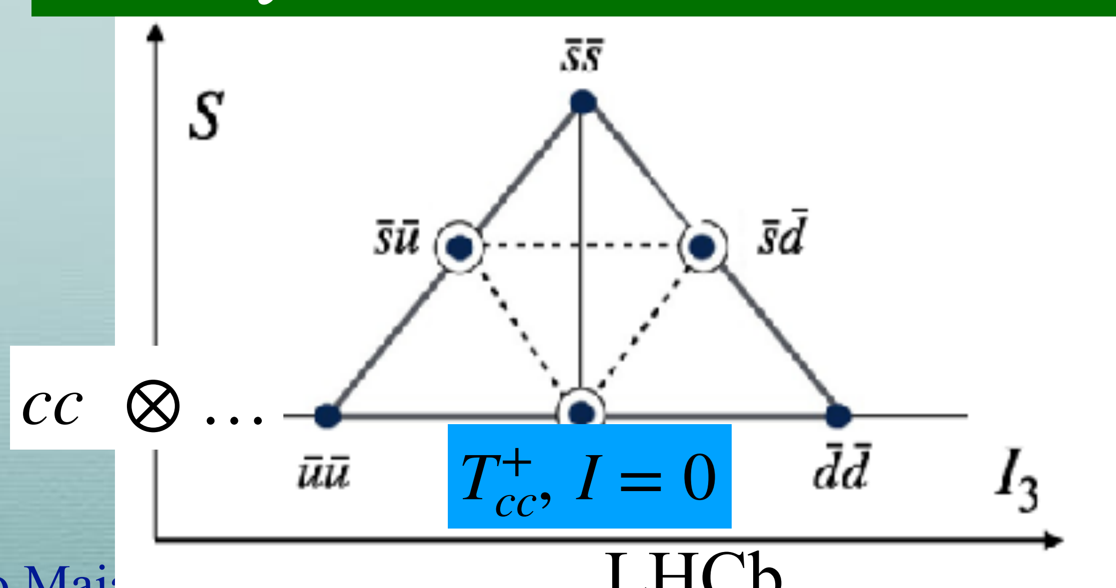


Doubly Charmed: $J = 1^+ : \mathbf{3}$, $J = 0^+ : \bar{\mathbf{6}}$



Final questions (to LHCb and BESIII)

- Are $Z_{cs}(3986)$ and $Z(4003)$ two different states? is there a third $Z_{cs}(4220)$?
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Hidden charm: complete nonets ?

- Can we find the missing partners of the $\bar{\mathbf{6}} \oplus \mathbf{3}$, (n=2) multiplet:

$[\bar{c}\bar{s}][sd]_{(n=2)}(3050) \to \bar{D}^- \eta,\ \bar{D}_s^- K^0,\ \bar{D}^{*-}\phi, \ldots$

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Open charm and strangeness: Complete $\bar{\mathbf{6}} \oplus \mathbf{3}$?

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- ***Tough orders***: more luminosity, better energy definition, detectors with exceptional qualities… a lot of work…
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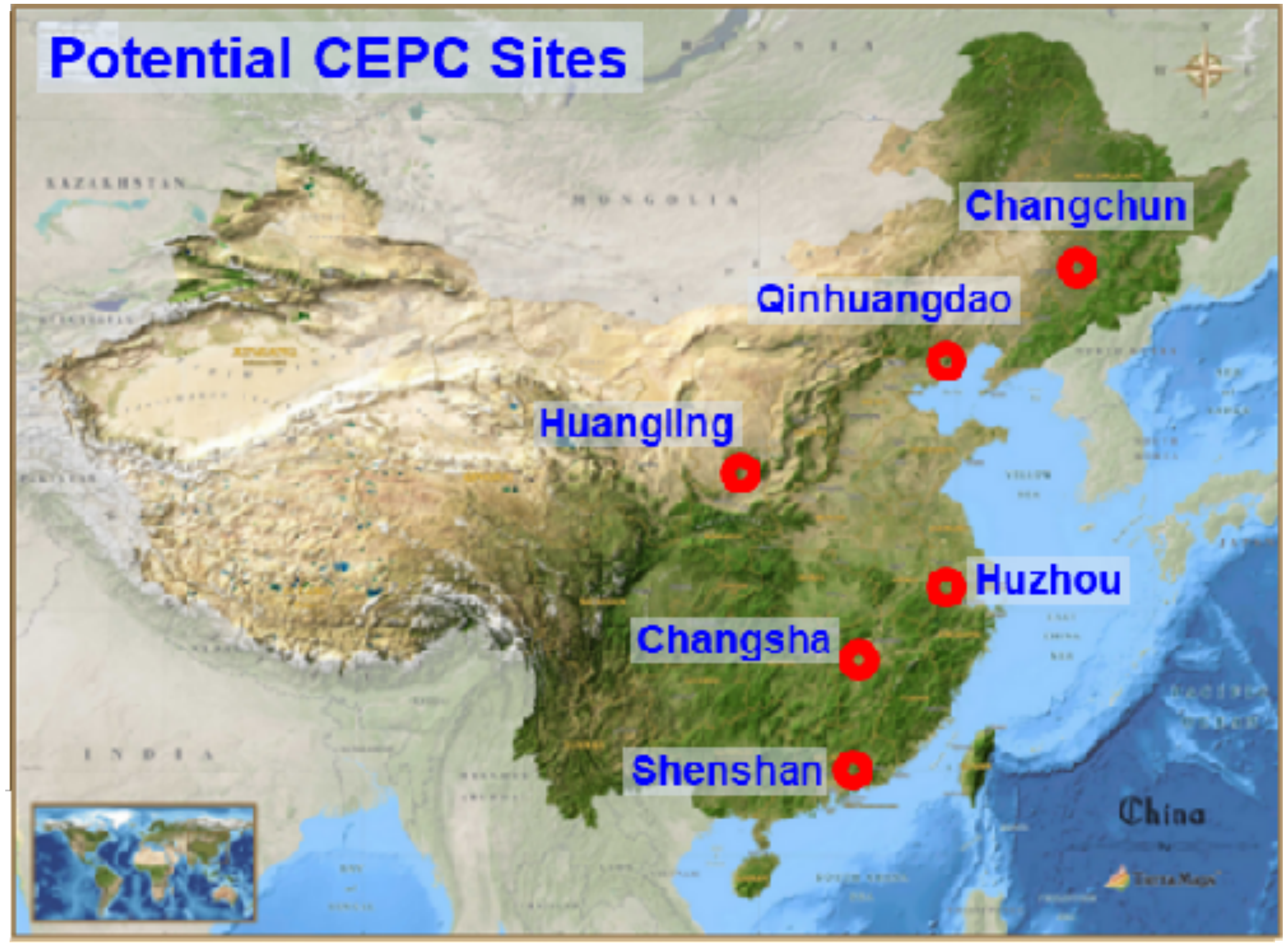
So much accomplished, and so much more left to do (Winston Churchill)

Physics Beyond the Standard Model: the High Energy Way

The large European Project:
Future Circular Collider
at CERN

Kick-off Meeting of the
Future Circular Collider Design Study
University of Geneva, 2014

CEPC site investigation and facility study

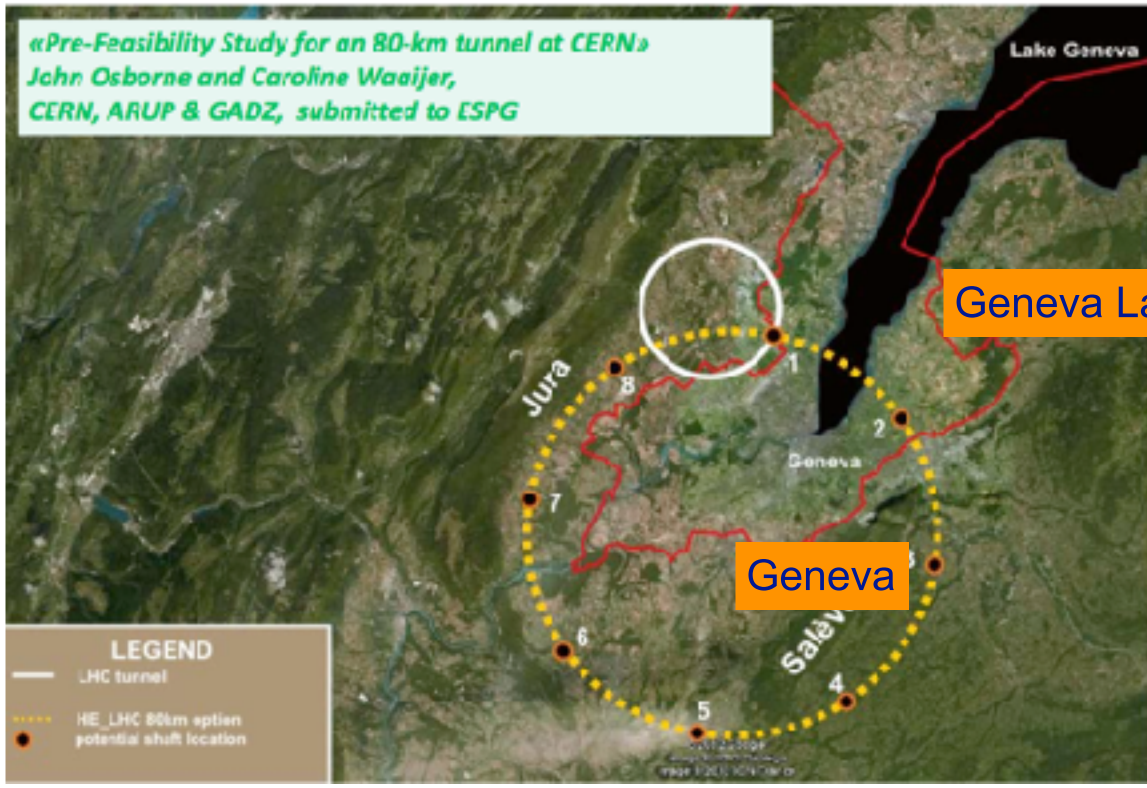


- Site selection based on geology, electricity supply, transportation, environment for foreigners, local support & economy,…
- North are better for running cost savings
- CDR study is based on Qing-Huang-Dao, 300 km towards the east of Beijing

- More invitations from local governments: Changsha, Changchun, …
- Recent visit to Shangsha: best for geology & transportation(20 km from a large city & an international airport)

Dreams about the future??

TLEP tunnel in the Geneva area – "best" option



A good example is Qinghungdao (秦皇岛)

- 100 TeV proton Collider is a fantastic challenge
- new innovative technologies: material science, low temperatures, electronics, computing, big data
- an attraction for new physics ideas and young talents to solve the hardest scientific problem which we have been confronted over the last 100 years.

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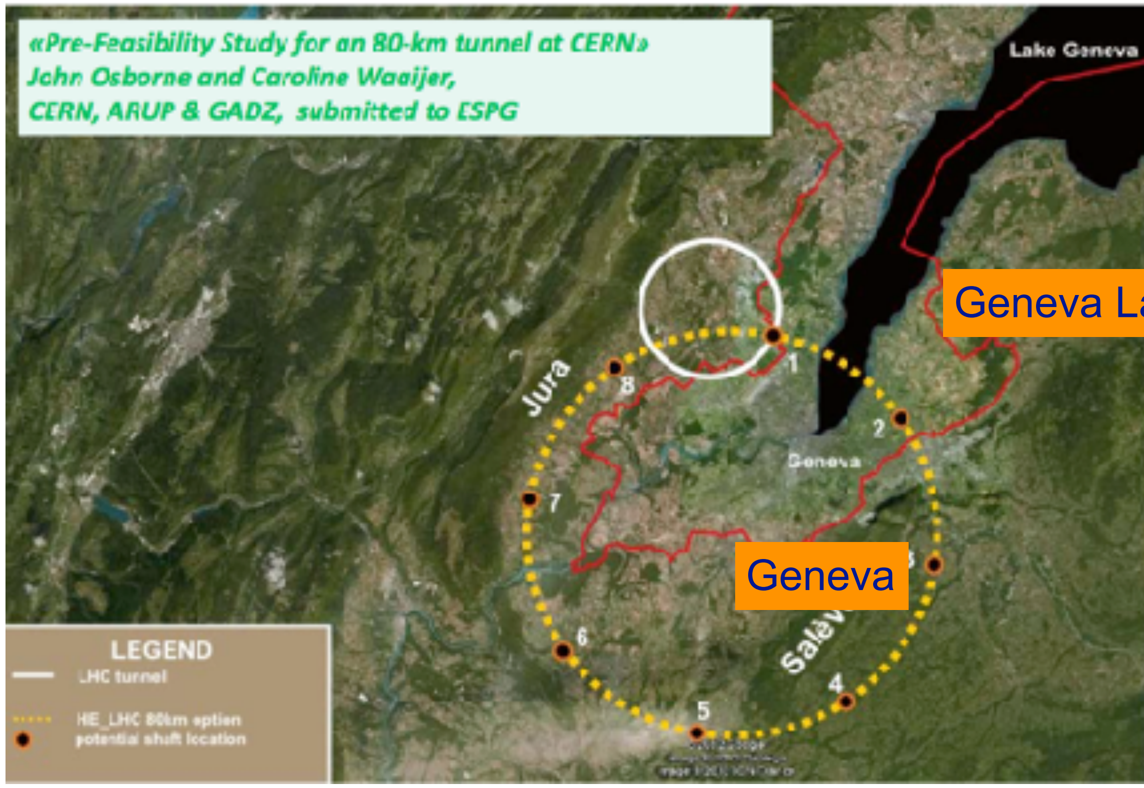

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Feb. 24, 2014

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1950's: National Laboratories in IT, FR, UK, DE... united forces to make CERN-Europa
2030's: Regional Laboratories in Europe, America, Asia … will they unite in a Global Accelerator Network - The World ??