XYZ Particles

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Multiquark states have been discussed since the 1st page of the quark model

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

If we assume that the strong interactions of baryons and mesons are correctly described in terms of the broken "eightfold way" [1-3], we are tempted to look for some fundamental explanation of the situation. A highly promised approach is the purely dynamical "bootstrap" model for all the strongly interacting particles within which one may try to derive isotopic spin and strangeness conservation and broken eightfold symmetry from self-consistency alone [4]. Of course, with only strong interactions, the orientation of the asymmetry in the unitary space cannot be specified; one hopes that in some way the selection of specific components of the F-spin by electromagnetism and the weak interactions determines the choice of isotopic spin and hypercharge directions.

Even if we consider the scattering amplitudes of strongly interacting particles on the mass shell only and treat the matrix elements of the weak, electromagnetic, and gravitational interactions by means

ber $n_t - n_{\bar{t}}$ would be zero for all known baryons and mesons. The most interesting example of such a model is one in which the triplet has spin $\frac{1}{2}$ and $z = -1$, so that the four particles d^-, s^-, u^0 and b^0 exhibit a parallel with the leptons.

A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" [6] q and the members of the anti-triplet as anti-quarks $\bar{q}$. 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. It is assuming that the lowest baryon configuration $(q\,q\,q)$ gives just the representations **1**, **8**, and **10** that have been observed, while the lowest meson configuration $(q\,\bar{q})$ similarly gives just **1** and **8**.

Multiquark states have been discussed since the 1st page of the quark model

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Where are they??

If we assume that the strong interactions of baryons and mesons are correctly described in terms of the broken "eightfold way" [1-3], we are tempted to look for some fundamental explanation of the situation. A highly promised approach is the purely dynamical "bootstrap" model for all the strongly interacting particles within which one may try to derive isotopic spin and strangeness conservation and broken eightfold symmetry from self-consistency alone [4]. Of course, with only strong interactions, the orientation of the asymmetry in the unitary space cannot be specified; one hopes that in some way the selection of specific components of the F-spin by electromagnetism and the weak interactions determines the choice of isotopic spin and hypercharge directions.

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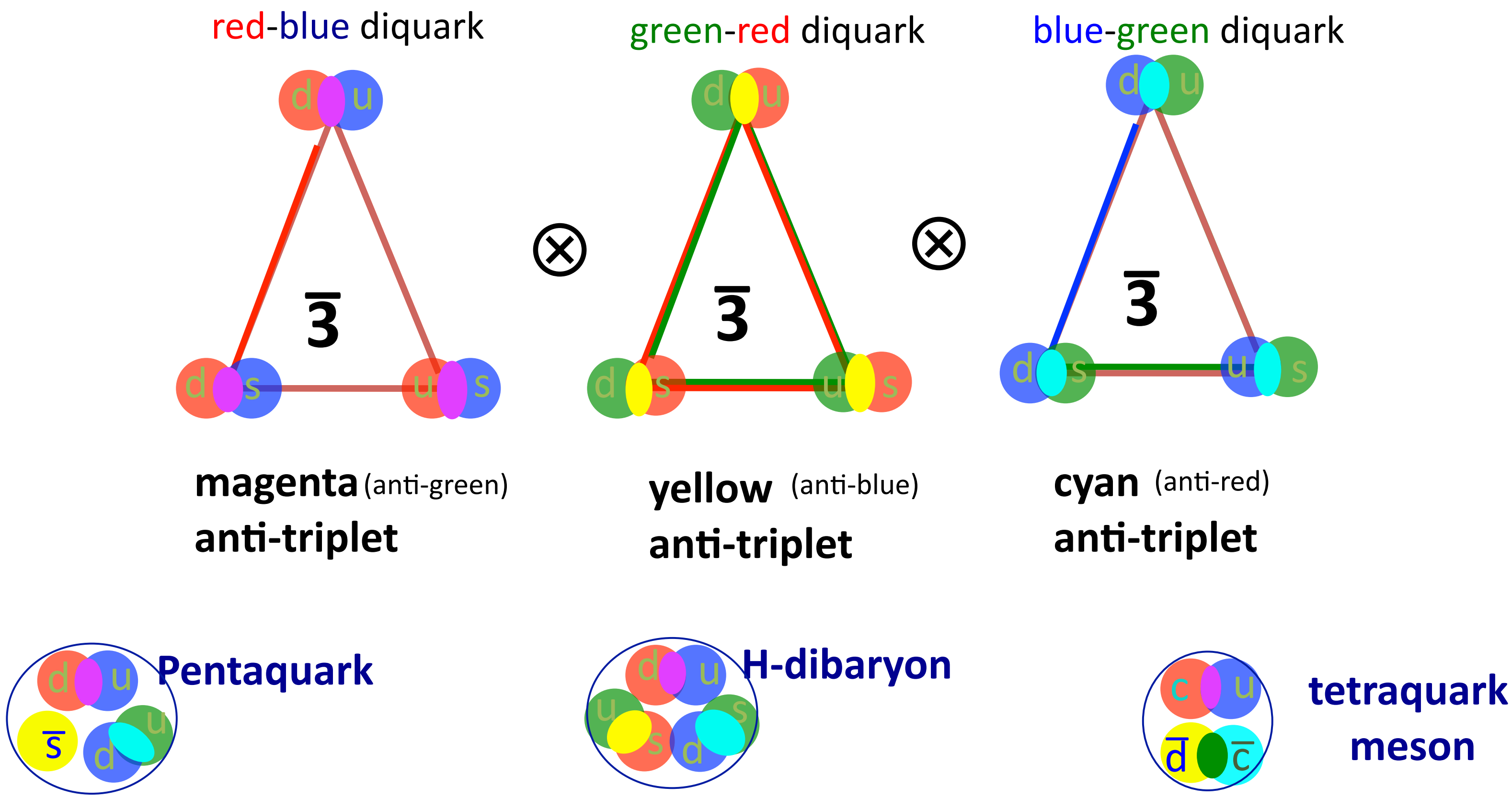
multiquark states from diquarks & diantiquarks



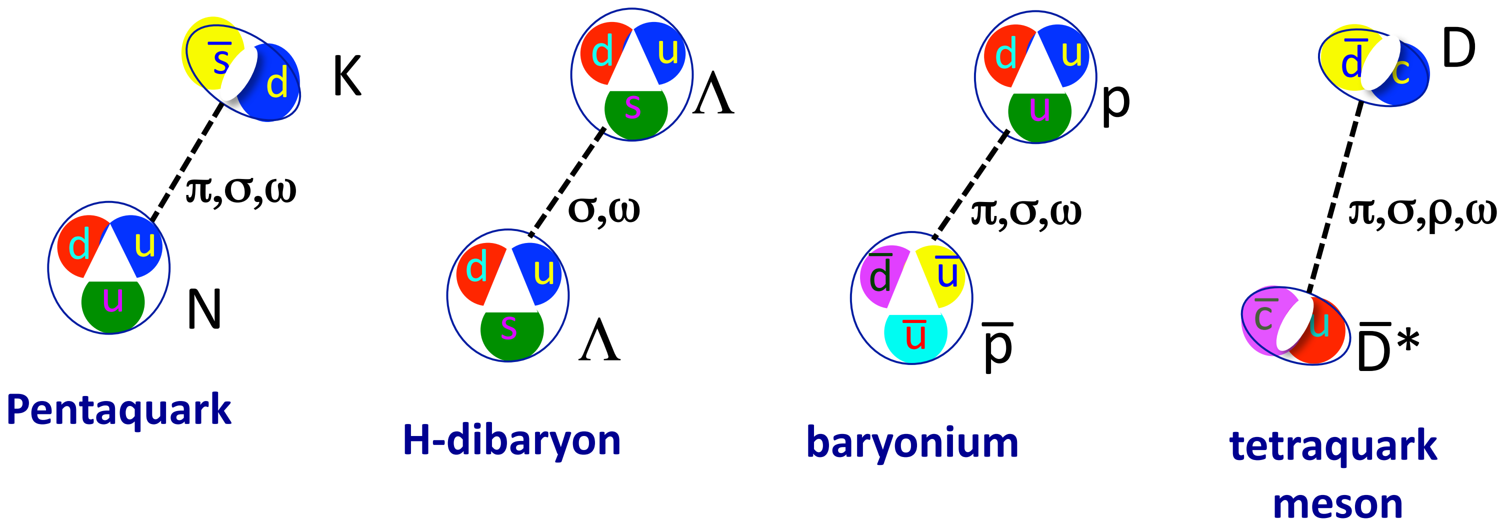
magenta-cyan-yellow
color singlet 5-q state

magenta-cyan-yellow
color singlet 6-q state

green-magenta (anti-green)
color singlet 4-q state

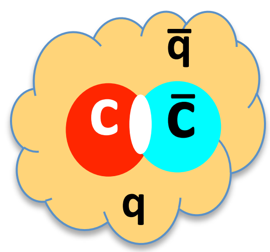
"exotic" hadrons that particle theorists love

multiquark states from "molecules"

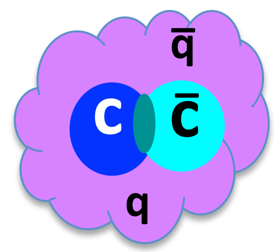


"exotic" hadrons that nuclear theorists love

Other proposed multiquark mesons

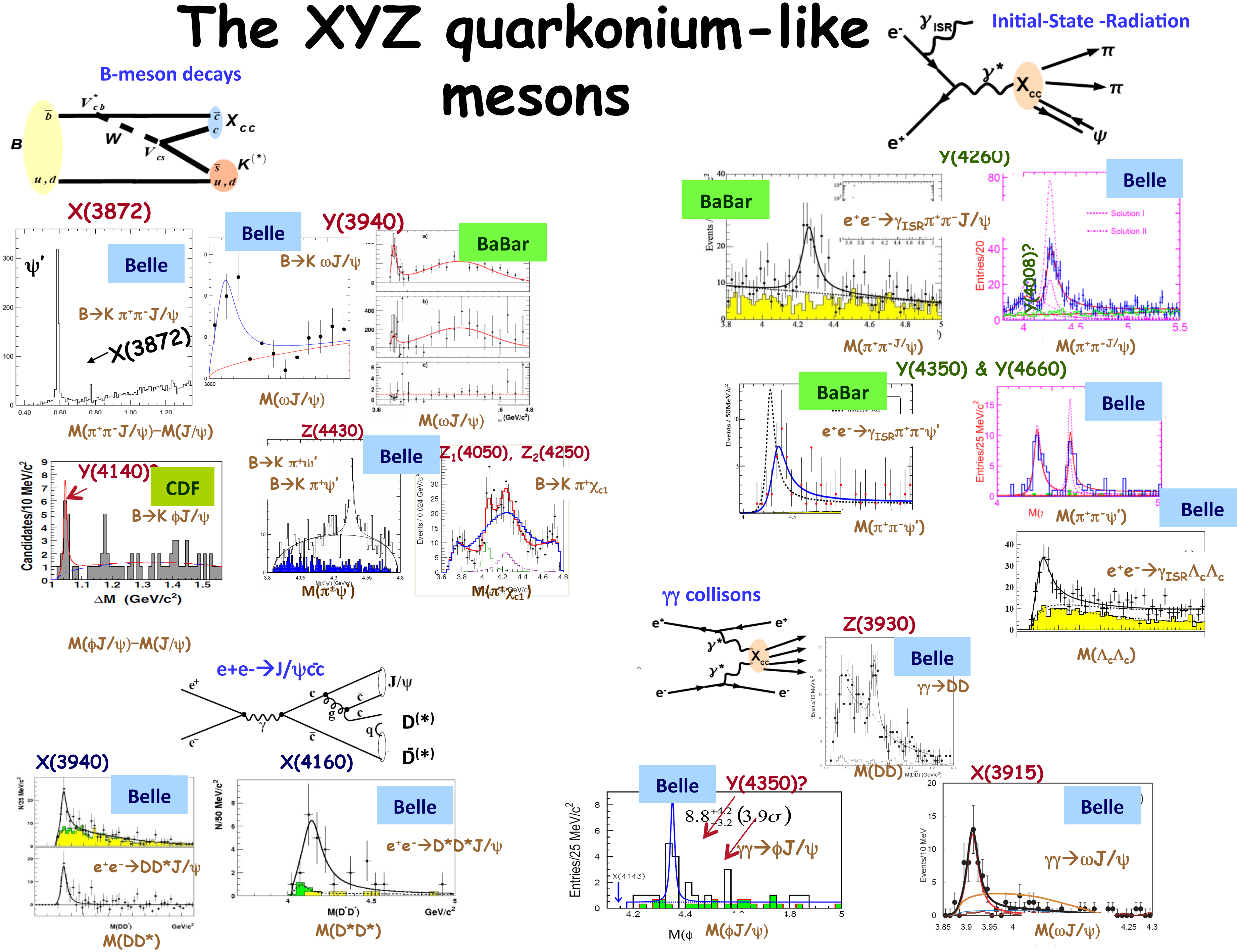


hadrocharmonium



adjoint charmonium

The XYZ quarkonium-like mesons



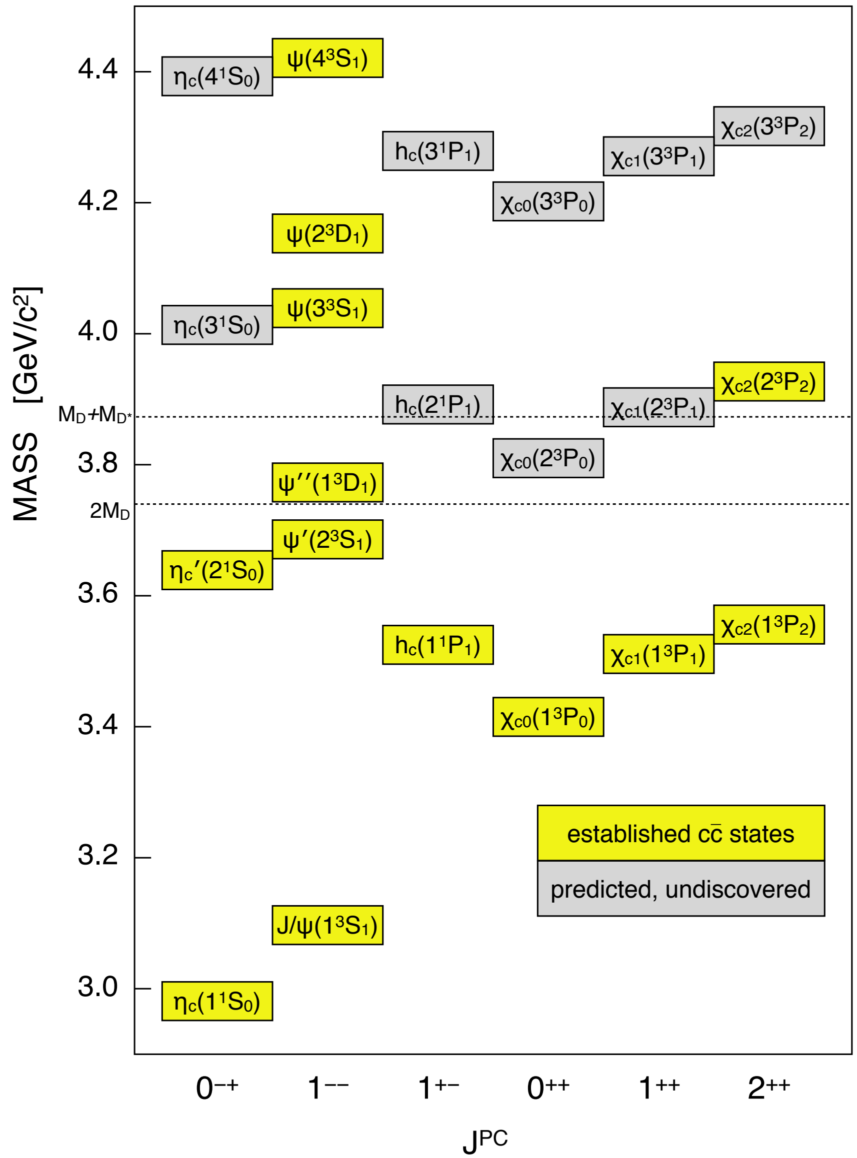
The list keeps growing

State	M (MeV)	Γ (MeV)	J^{PC}	Process (decay mode)	Experiment
$X(3872)$	3871.68±0.17	< 1.2	1^{++}	$B \to K + (J/\psi\,\pi^+\pi^-)$	Belle [82, 89] , BaBar [85], LHCb [90]
				$p\bar{p} \to (J/\psi\,\pi^+\pi^-) + \ldots$	CDF [83, 91, 92, 125], D0 [84]
				$B \to K + (J/\psi\,\pi^+\pi^-\pi^0)$	Belle [94] , BaBar [59]
				$B \to K + (D^0\bar{D}^0\pi^0)$	Belle [95] , BaBar [96]
				$B \to K + (J/\psi\,\gamma)$	BaBar [126], Belle [127] , LHCb [128]
				$B \to K + (\psi'\,\gamma)$	BaBar [126], Belle [127] , LHCb [128]
				$pp \to (J/\psi\,\pi^+\pi^-) + \ldots$	LHCb [86], CMS [87]
$X(3915)$	3917.4 ± 2.7	$28^{+10}_{-\ 9}$	0^{++}	$B \to K + (J/\psi\,\omega)$	Belle [58] , BaBar [59]
				$e^+e^- \to e^+e^- + (J/\psi\,\omega)$	Belle [60] , BaBar [61]
$\chi_{c2}(2P)$	3927.2 ± 2.6	24±6	2^{++}	$e^+e^- \to e^+e^- + (D\bar{D})$	Belle [64] , BaBar [65]
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$0(?)^{-(?)+}$	$e^+e^- \to J/\psi + (D^*\bar{D})$	Belle [27]
				$e^+e^- \to J/\psi + (\ldots)$	Belle [26]
$G(3900)$	3943 ± 21	52±11	1^{--}	$e^+e^- \to \gamma + (D\bar{D})$	BaBar [129], Belle [130]
$Y(4008)$	$4008^{+121}_{-\ 49}$	226±97	1^{--}	$e^+e^- \to \gamma + (J/\psi\,\pi^+\pi^-)$	Belle [32]
$Y(4140)$	4144 ± 3	17 ± 9	$?^{?+}$	$B \to K + (J/\psi\,\phi)$	CDF [74, 75], CMS [77]
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$0(?)^{-(?)+}$	$e^+e^- \to J/\psi + (D^*\bar{D})$	Belle [27]
$Y(4260)$	4263^{+8}_{-9}	95±14	1^{--}	$e^+e^- \to \gamma + (J/\psi\,\pi^+\pi^-)$	BaBar [30, 131], CLEO [132] , Belle [32]
				$e^+e^- \to (J/\psi\,\pi^+\pi^-)$	CLEO [133]
				$e^+e^- \to (J/\psi\,\pi^0\pi^0)$	CLEO [133]
$Y(4274)$	4292 ± 6	34 ± 16	$?^{?+}$	$B \to K + (J/\psi\,\phi)$	CDF [75], CMS [77]
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$0/2^{++}$	$e^+e^- \to e^+e^-\,(J/\psi\,\phi)$	Belle [81]
$Y(4360)$	4361 ± 13	74±18	1^{--}	$e^+e^- \to \gamma + (\psi'\,\pi^+\pi^-)$	BaBar [31], Belle [33]
$X(4630)$	$4634^{+\ 9}_{-11}$	92^{+41}_{-32}	1^{--}	$e^+e^- \to \gamma\,(\Lambda_c^+\Lambda_c^-)$	Belle [134]
$Y(4660)$	4664±12	48±15	1^{--}	$e^+e^- \to \gamma + (\psi'\,\pi^+\pi^-)$	Belle [33]
$Z_c^+(3900)$	3890 ± 3	33 ± 10	1^{+-}	$Y(4260) \to \pi^- + (J/\psi\,\pi^+)$	BESIII [39], Belle [40]
				$Y(4260) \to \pi^- + (D\bar{D}^*)^+$	BESIII [56]
$Z_c^+(4020)$	4024 ± 2	10 ± 3	$1(?)^{+(?)-}$	$Y(4260) \to \pi^- + (h_c\,\pi^+)$	BESIII [41]
				$Y(4260) \to \pi^- + (D^*\bar{D}^*)^+$	BESIII [42]
$Z_1^+(4050)$	4051^{+24}_{-43}	82^{+51}_{-55}	$?^{?+}$	$B \to K + (\chi_{c1}\,\pi^+)$	Belle [43], BaBar [53]
$Z^+(4200)$	4196^{+35}_{-32}	370^{+99}_{-149}	1^{+-}	$B \to K + (J/\psi\,\pi^+)$	Belle [51]
$Z_2^+(4250)$	$4248^{+185}_{-\ 45}$	$177^{+321}_{-\ 72}$	$?^{?+}$	$B \to K + (\chi_{c1}\,\pi^+)$	Belle [43], BaBar [53]
$Z^+(4430)$	4477 ± 20	181 ± 31	1^{+-}	$B \to K + (\psi'\,\pi^+)$	Belle [44, 46, 47], LHCb [48]
				$B \to K + (J\psi\,\pi^+)$	Belle [51]
$Y_b(10890)$	10888.4±3.0	$30.7^{+8.9}_{-7.7}$	1^{--}	$e^+e^- \to (\Upsilon(nS)\,\pi^+\pi^-)$	Belle [117]
$Z_b^+(10610)$	10607.2±2.0	18.4±2.4	1^{+-}	"$\Upsilon(5S)$" $\to \pi^- + (\Upsilon(nS)\,\pi^+)$, $n = 1, 2, 3$	Belle [119, 122]
				"$\Upsilon(5S)$" $\to \pi^- + (h_b(nP)\,\pi^+)$, $n = 1, 2$	Belle [119]
				"$\Upsilon(5S)$" $\to \pi^- + (B\bar{B}^*)^+$, $n = 1, 2$	Belle [123]
$Z_b^0(10610)$	10609± 6		1^{+-}	"$\Upsilon(5S)$" $\to \pi^0 + (\Upsilon(nS)\,\pi^0)$, $n = 1, 2, 3$	Belle [121]
$Z_b^+(10650)$	10652.2±1.5	11.5±2.2	1^{+-}	"$\Upsilon(5S)$" $\to \pi^- + (\Upsilon(nS)\,\pi^+)$, $n = 1, 2, 3$	Belle [119]
				"$\Upsilon(5S)$" $\to \pi^- + (h_b(nP)\,\pi^+)$, $n = 1, 2$	Belle [119]
				"$\Upsilon(5S)$" $\to \pi^- + (B^*\bar{B}^*)^+$, $n = 1, 2$	Belle [123]

Now lots of charged Z_c mesons

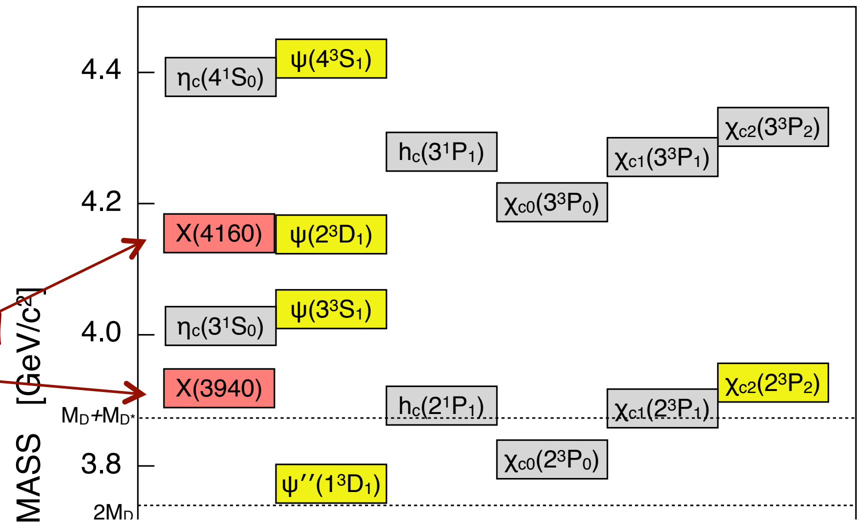
and two Z_b mesons

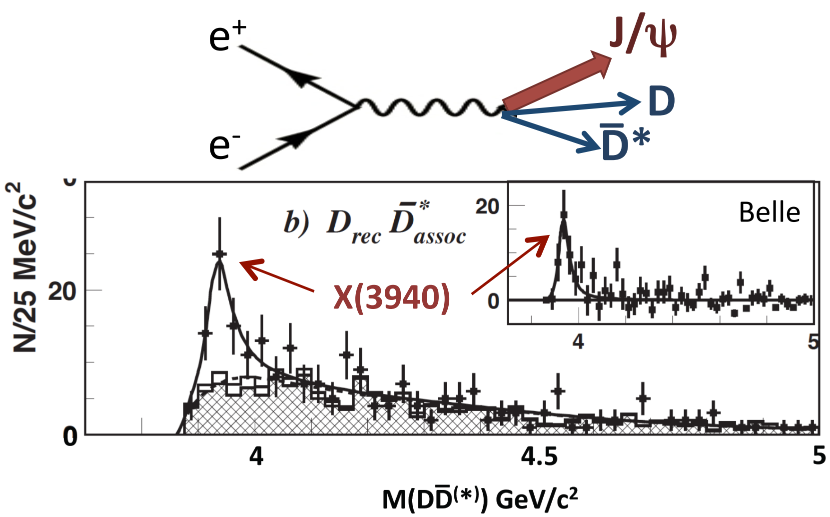
$c\bar{c}$ assignments for the XYZ mesons?

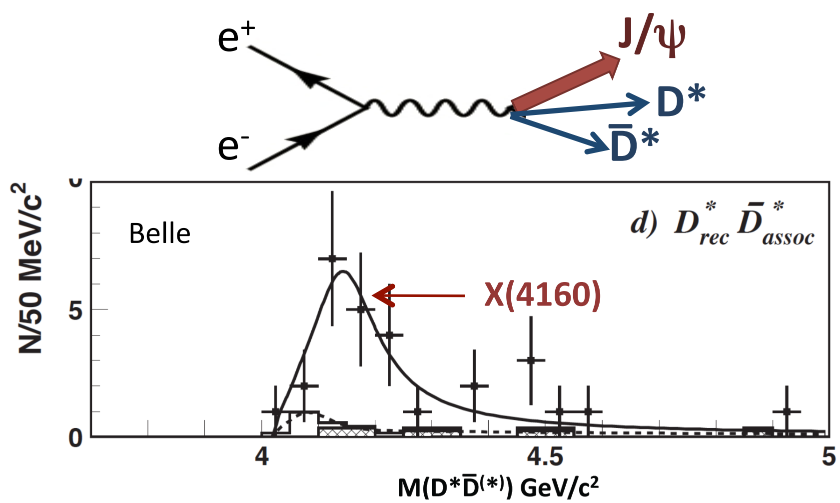


$c\bar{c}$ assignments for the XYZ mesons?

the X(3940) & X(4160) as the $\eta_c(3S)$ & $\eta_c(4S)$ would imply huge hyperfine splittings for n=3&4

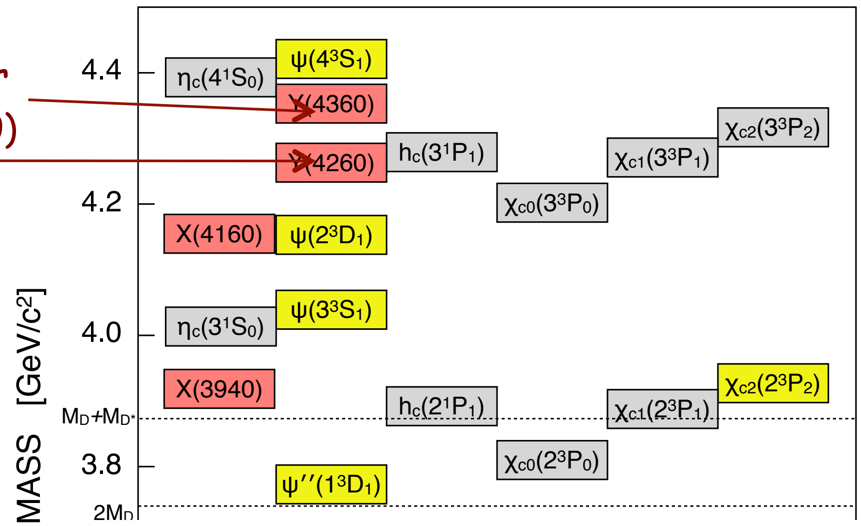


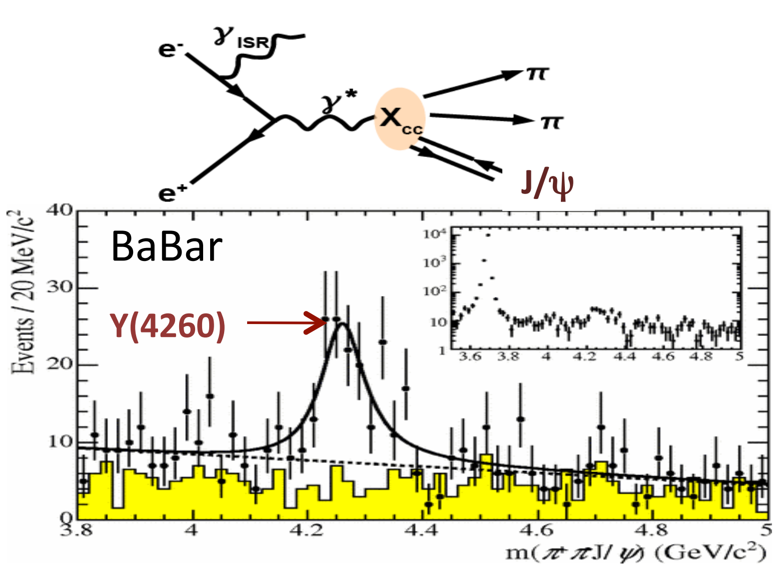


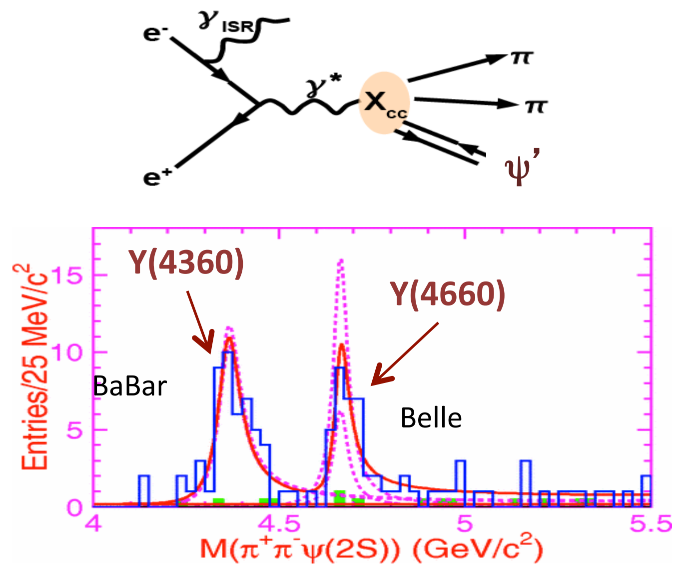


$c\bar{c}$ assignments for the XYZ mesons?

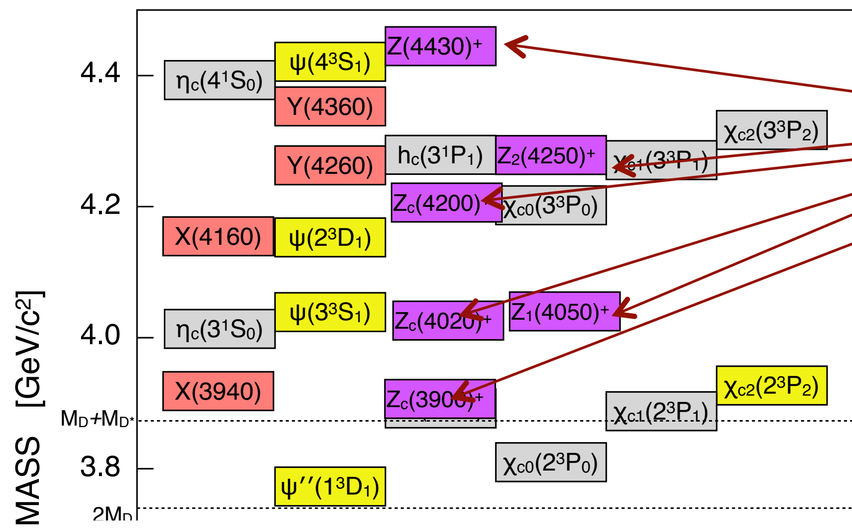
no unassigned levels for
the 1^{--} Y(4260) & Y(4360)



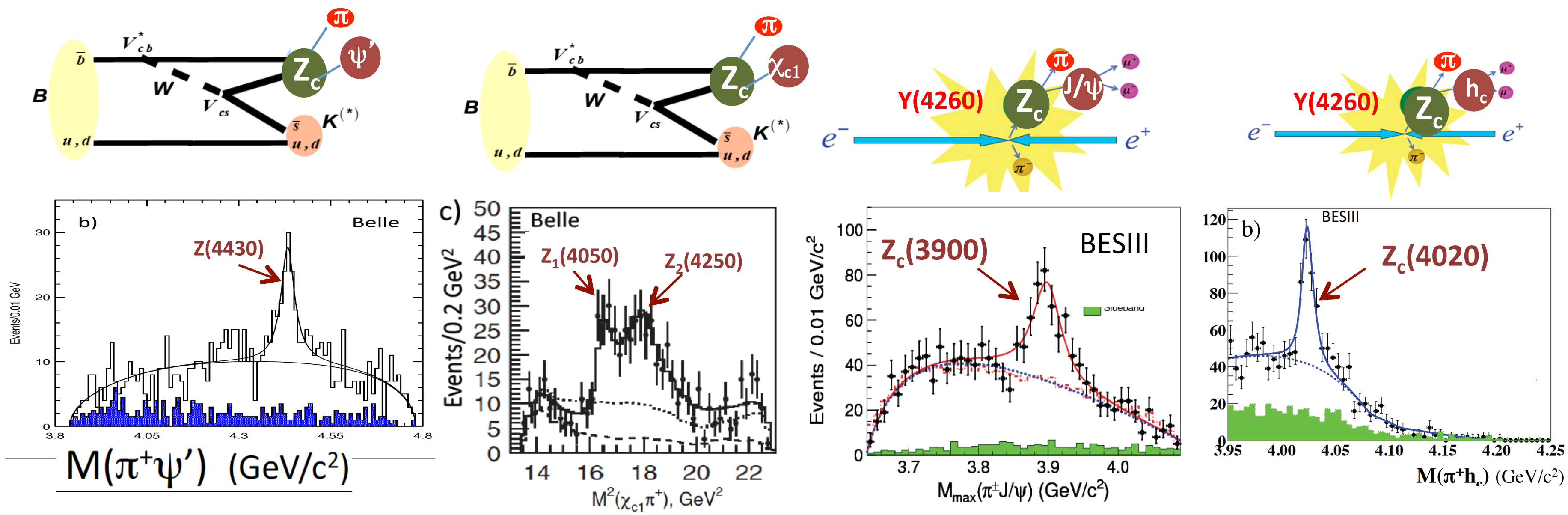




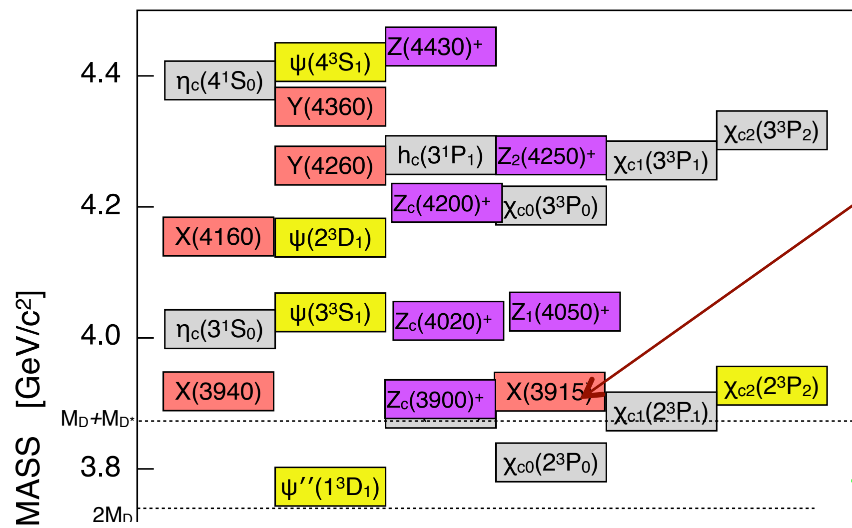
$c\bar{c}$ assignments for the XYZ mesons?



the (6) charged Z_cs must have a minimal quark content of $c\bar{c}u\bar{d}$

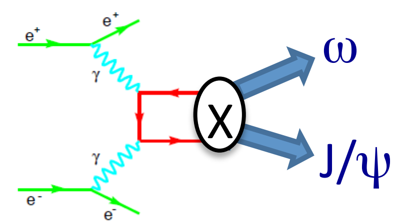


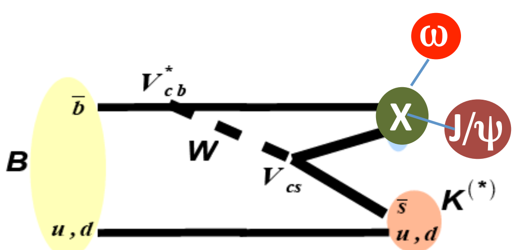
$c\bar{c}$ assignments for the XYZ mesons?

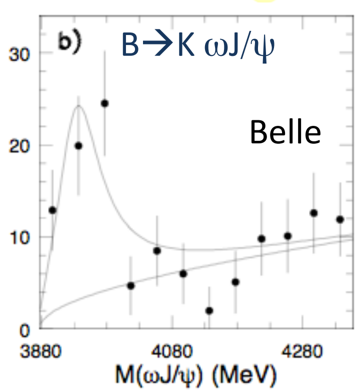


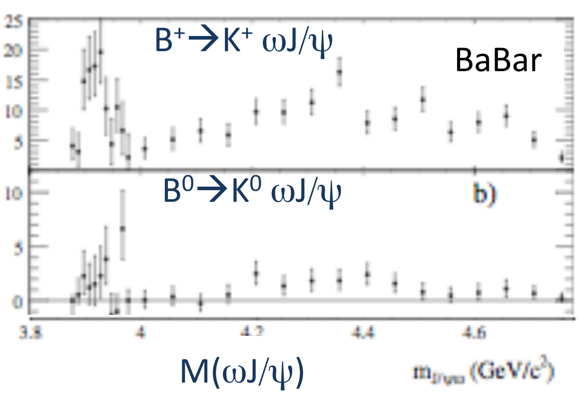
the X(3915) mass and $\Gamma(X\rightarrow\omega J/\psi)$ are too high for the χ_{c0}(2P).
Also, no sign of $X\rightarrow D\bar{D}$

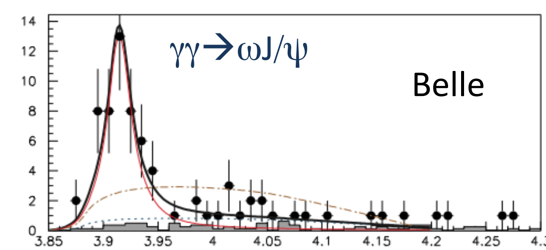
see: PRD 91, 057501 (2015)
& PRD 86, 091501 (2012)

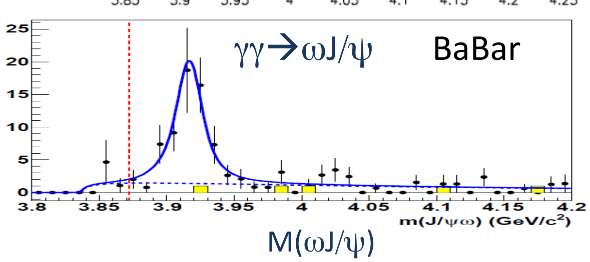




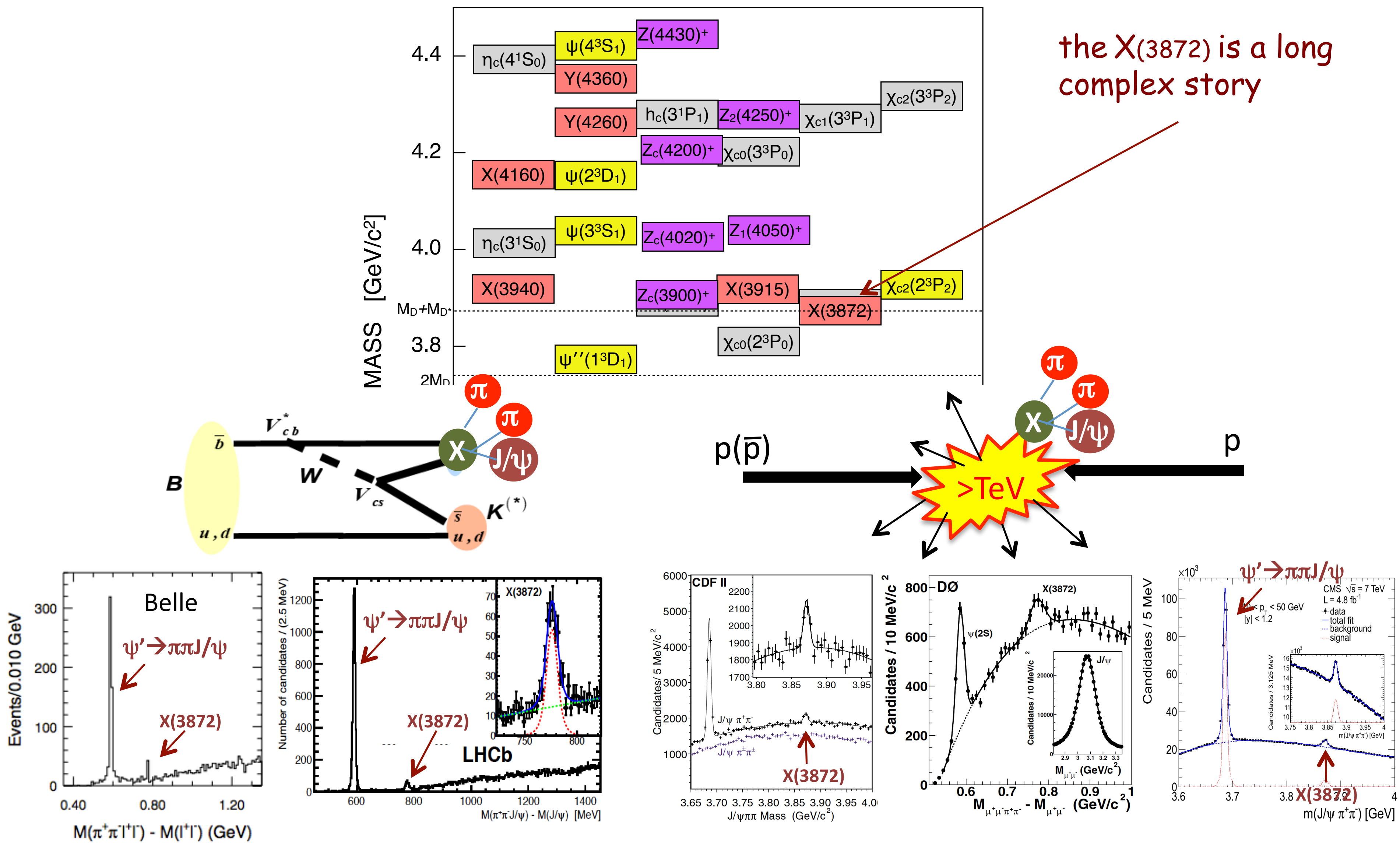








$c\bar{c}$ assignments for the XYZ mesons?



What is known about the X(3872)?

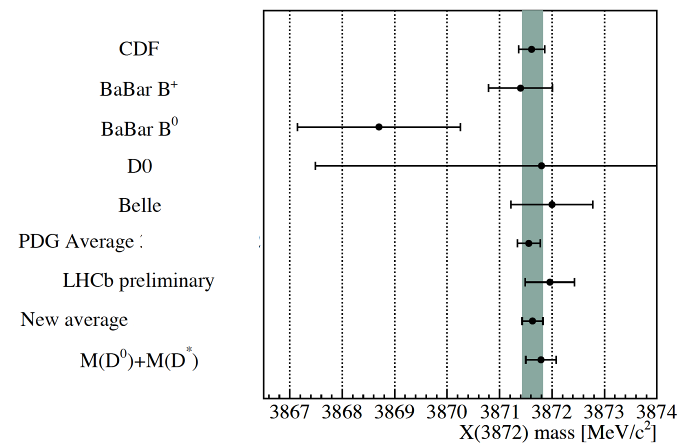
1) $M_{X(3872)} \approx m_{D0} + m_{D*}$

$M_{X(3872)} = 3871.68 \pm 0.17$ MeV

$m_{D0} + m_{D*0} = 3871.693 \pm 0.090$ MeV

➔ "B.E." = 3 ± 192 keV

Tomaradze et al., PRD 91, 011102

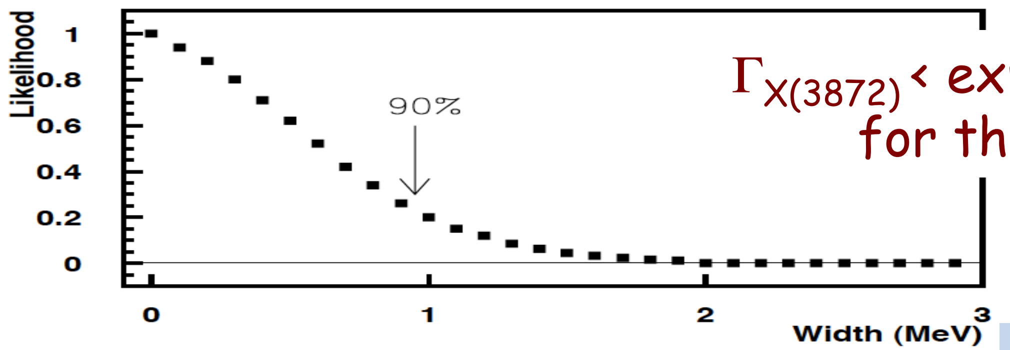


Near equality of $M_{X(3872)} \approx m_{D0} + m_{D*0}$ Accident???.... Dynamics??

$M_{X(3872)}$ is lower than expectations for the χ_{c1}'

What is known about the X(3872)?

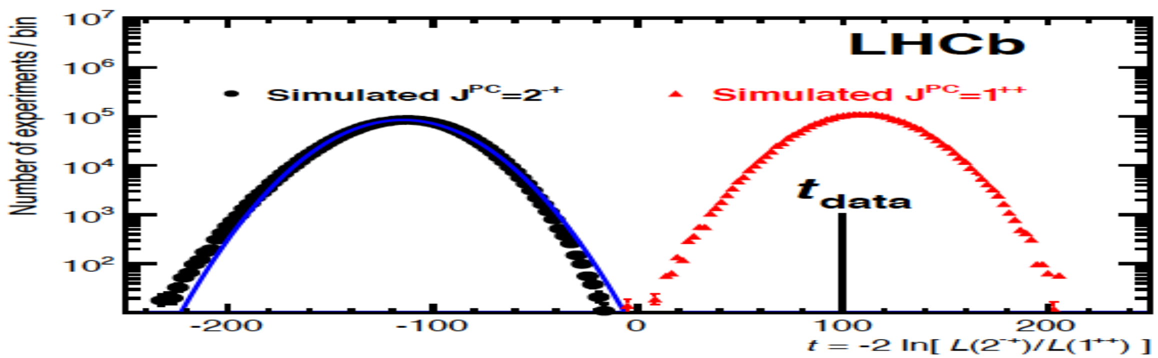
2) $\Gamma_{X(3872}$< 1.2 MeV (90% CL)



$\Gamma_{X(3872)}$ < expectations for the χ_{c1}'

Belle: PRD 84, 052004

3) $J^{PC=}1^{++}$

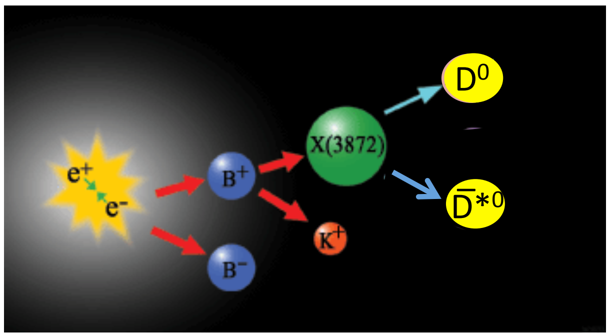


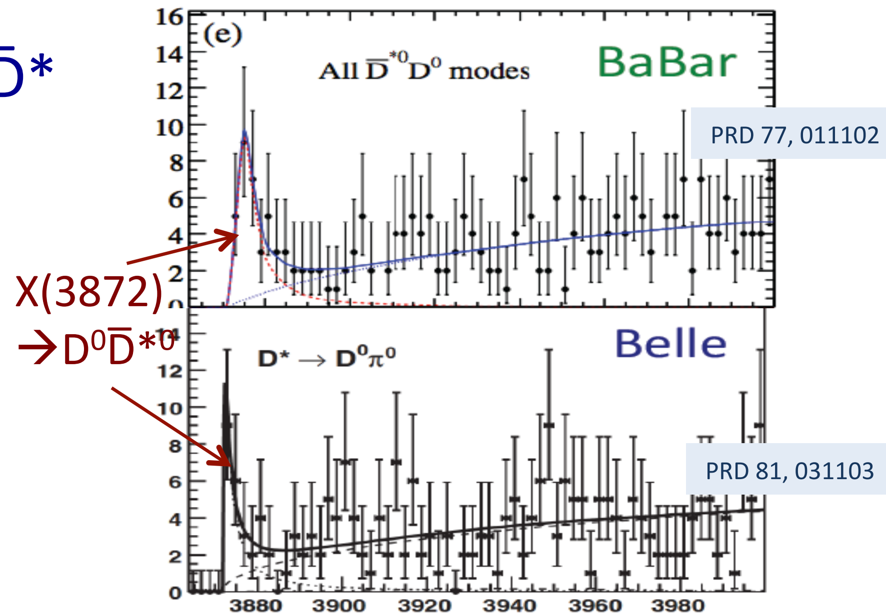
Yiming LI's talk on Wed

LHCb PRL 110, 222001:

What is known about the X(3872)?

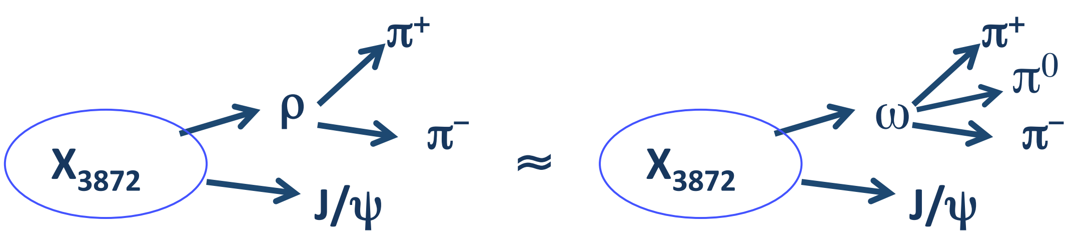
4) X(3872) couples to $D\bar{D}^*$





$M(D^0\bar{D}^{*0})$

5) Large Isospin Violation

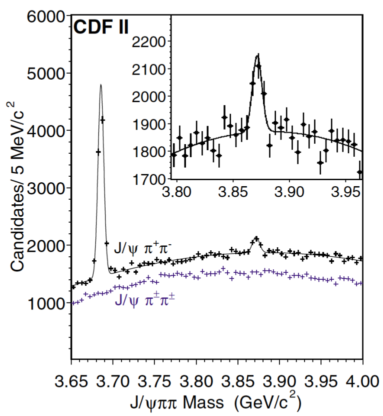


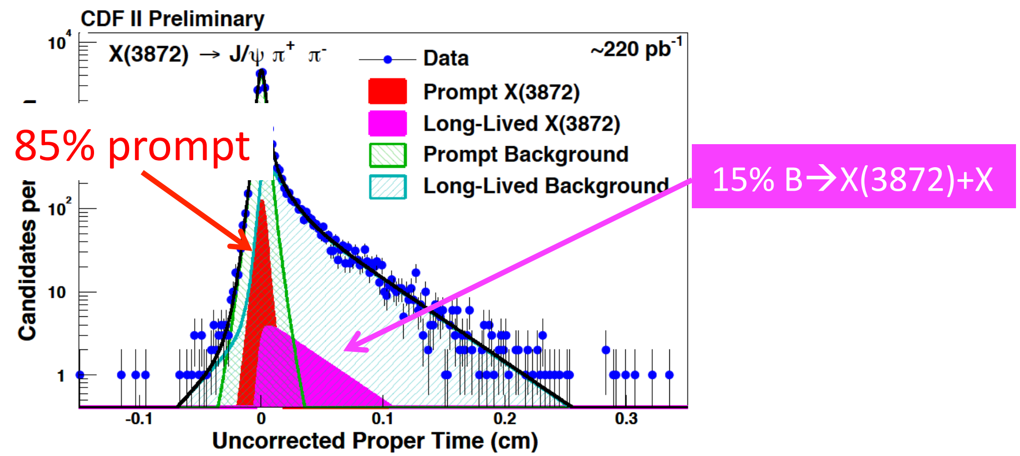
$$\frac{Bf(X(3872)\to\omega J/\psi)}{Bf(X(3872)\to\rho J/\psi)} = 0.8 \pm 0.3$$

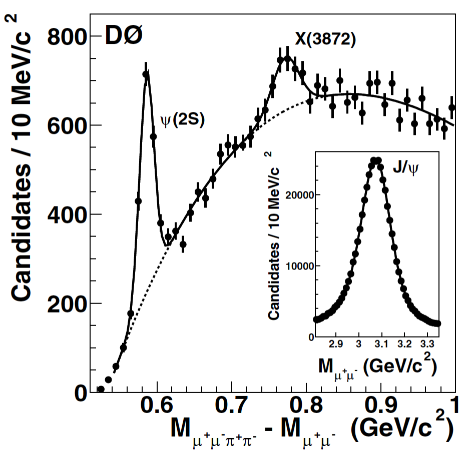
Bad for X(3872)= χ_{c1}'

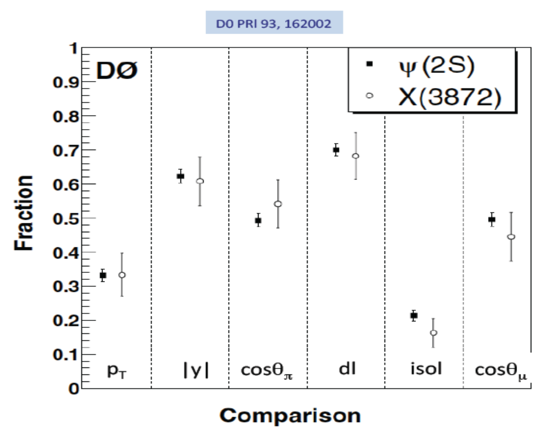
What is known about the X(3872)?

6) X(3872) is produced promptly on HE p$\bar{p}$ collisions





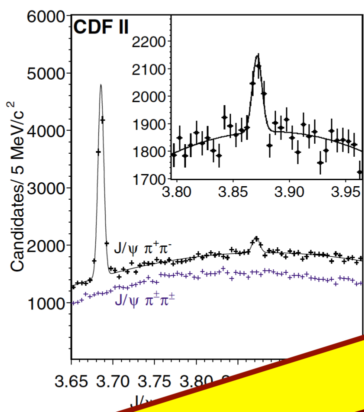


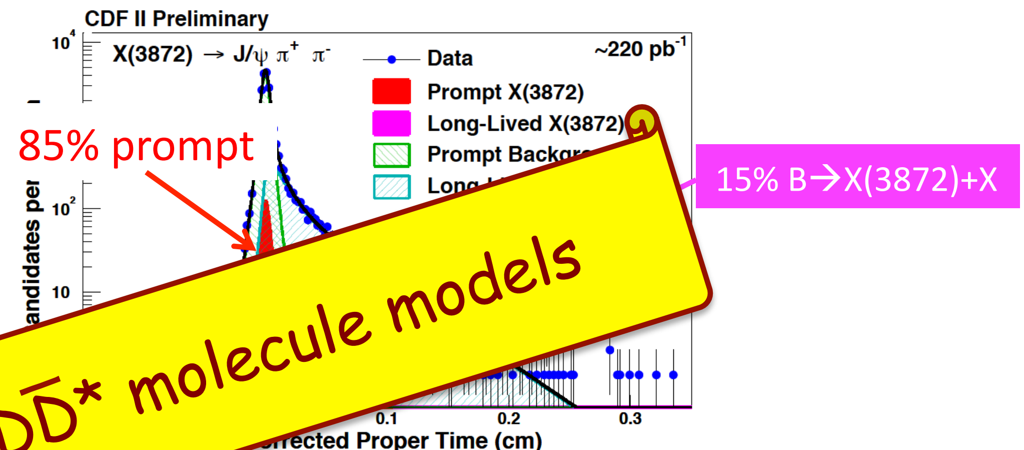


X(3872) & ψ′ have similar cross sections & prod'n characteristics: p_T- & $|y|$-dependence, etc.

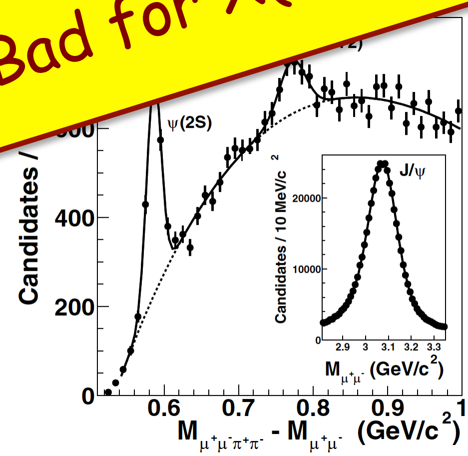
What is known about the X(3872)?

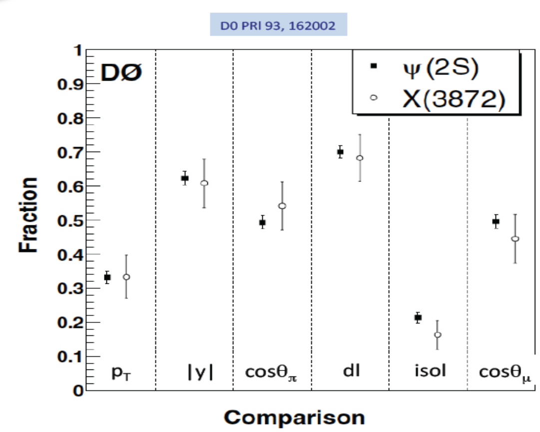
6) X(3872) is produced promptly on HE $p\bar{p}$ collisions





Bad for X(3872)=D$\bar{D}$* molecule models





X(3872) & ψ′ have similar cross sections & prod'n characteristics: p_T- & |y|-dependence, etc.

Gell-Mann's Totalitarianism Principle for Hadrons:

"Everything not forbidden is compulsory"

Gell Mann Nuovo Cim. 4, 848 (1956)

QM: $\chi_{c1} \longleftrightarrow D^0\bar{D}^{*0} \longleftrightarrow D^+D^{*-}$ will mix

Sizes: $\langle d_{c\bar{c}} \rangle \approx 1\ \mathrm{fm}$ $\quad \langle d_{00} \rangle \approx \sqrt{\frac{2}{m_D |\delta M_{00}|}} \geq 14\ \mathrm{fm}$ $\quad \langle d_{+-} \rangle \approx \sqrt{\frac{2}{m_D |\delta M_{+-}|}} \approx 2.3\ \mathrm{fm}$

potential model

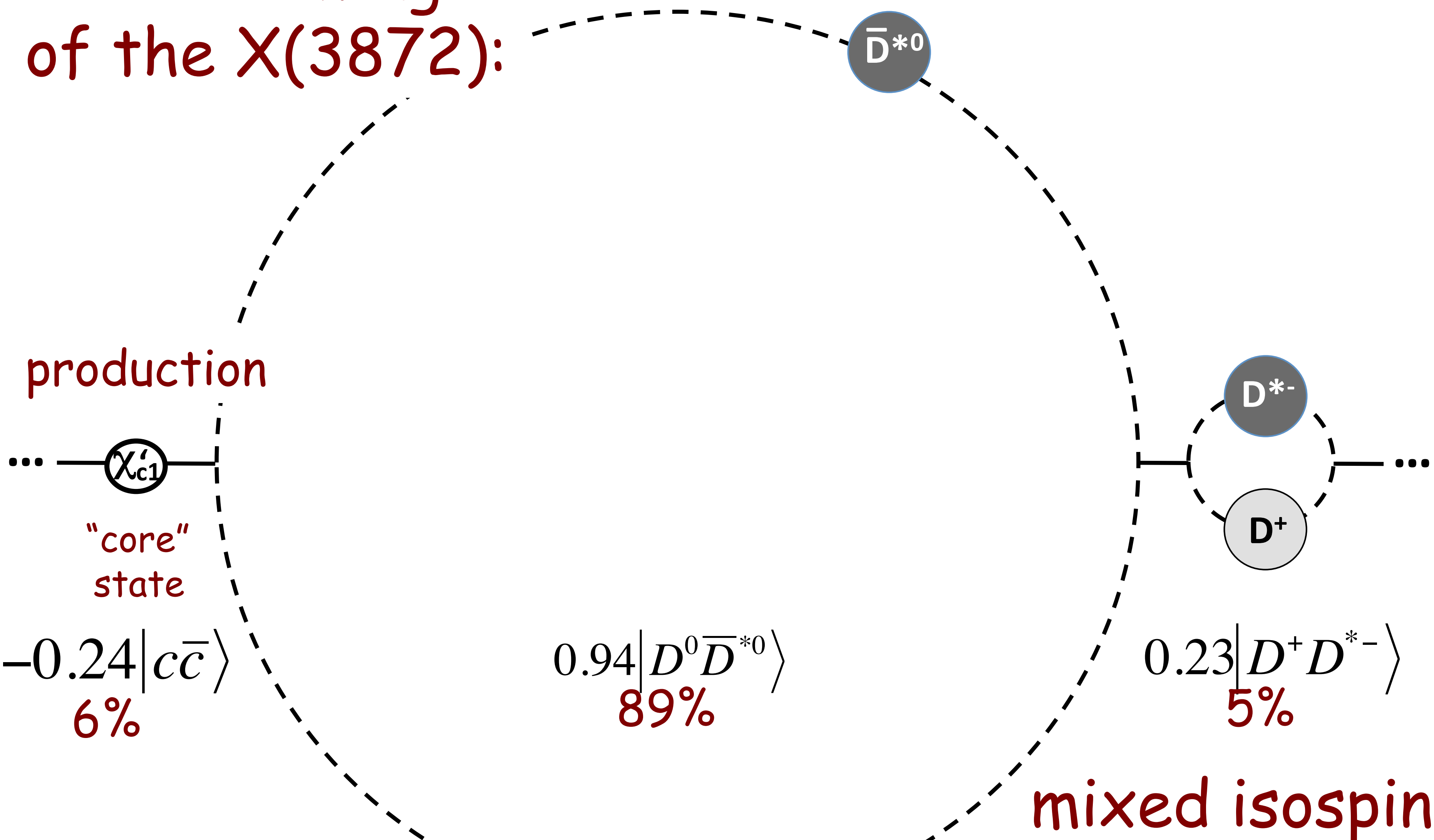
size ≈ scattering length

"binding energies":

$$|\delta M_{00}| = |M_{X(3872)} - (m_{D^0} + m_{D^{*0}})| \leq 0.2\ \mathrm{MeV}$$

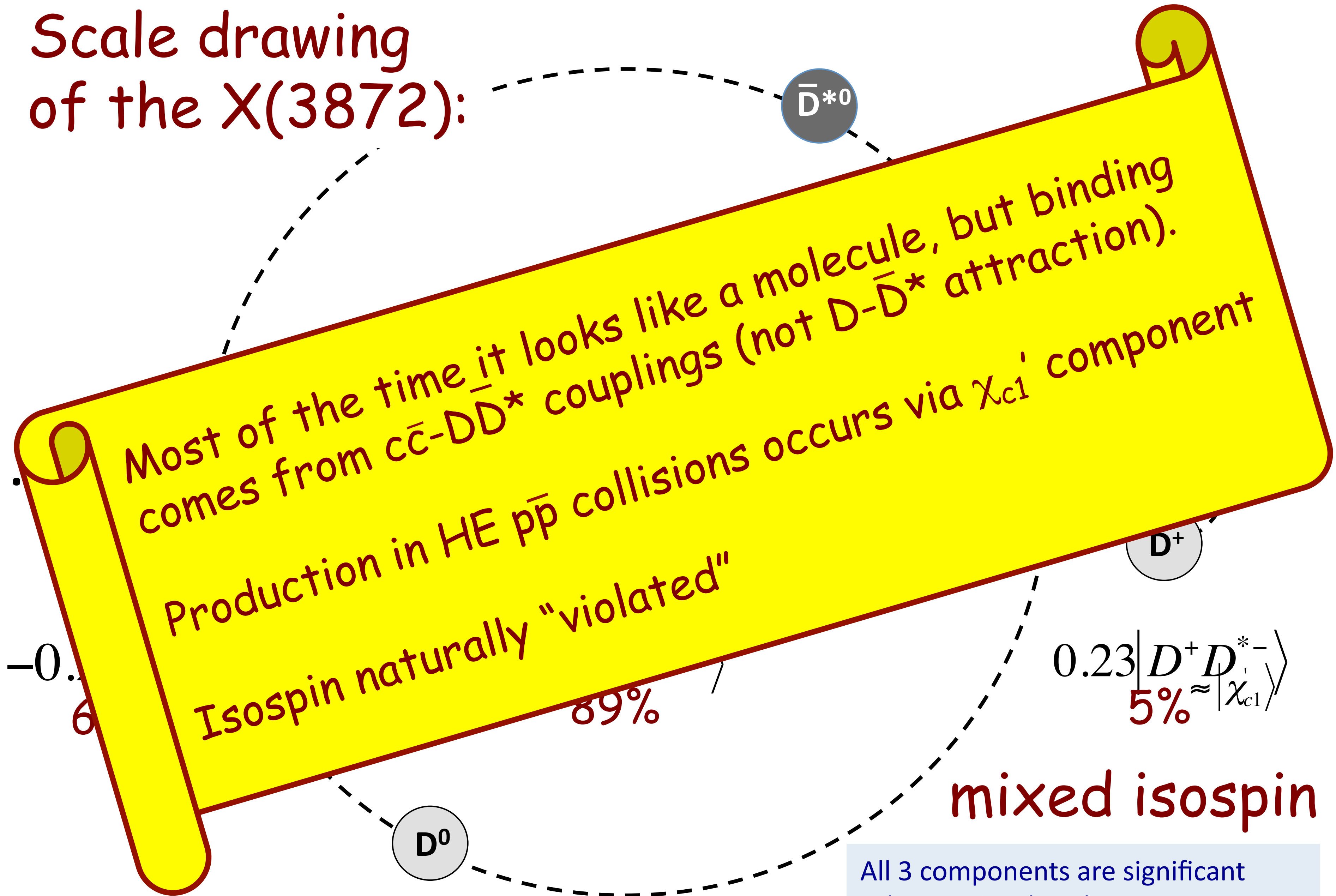
$$|\delta M_{+-}| = |M_{X(3872)} - (m_{D^+} + m_{D^{*-}})| = 8.2\ \mathrm{MeV}$$

Scale drawing of the X(3872):



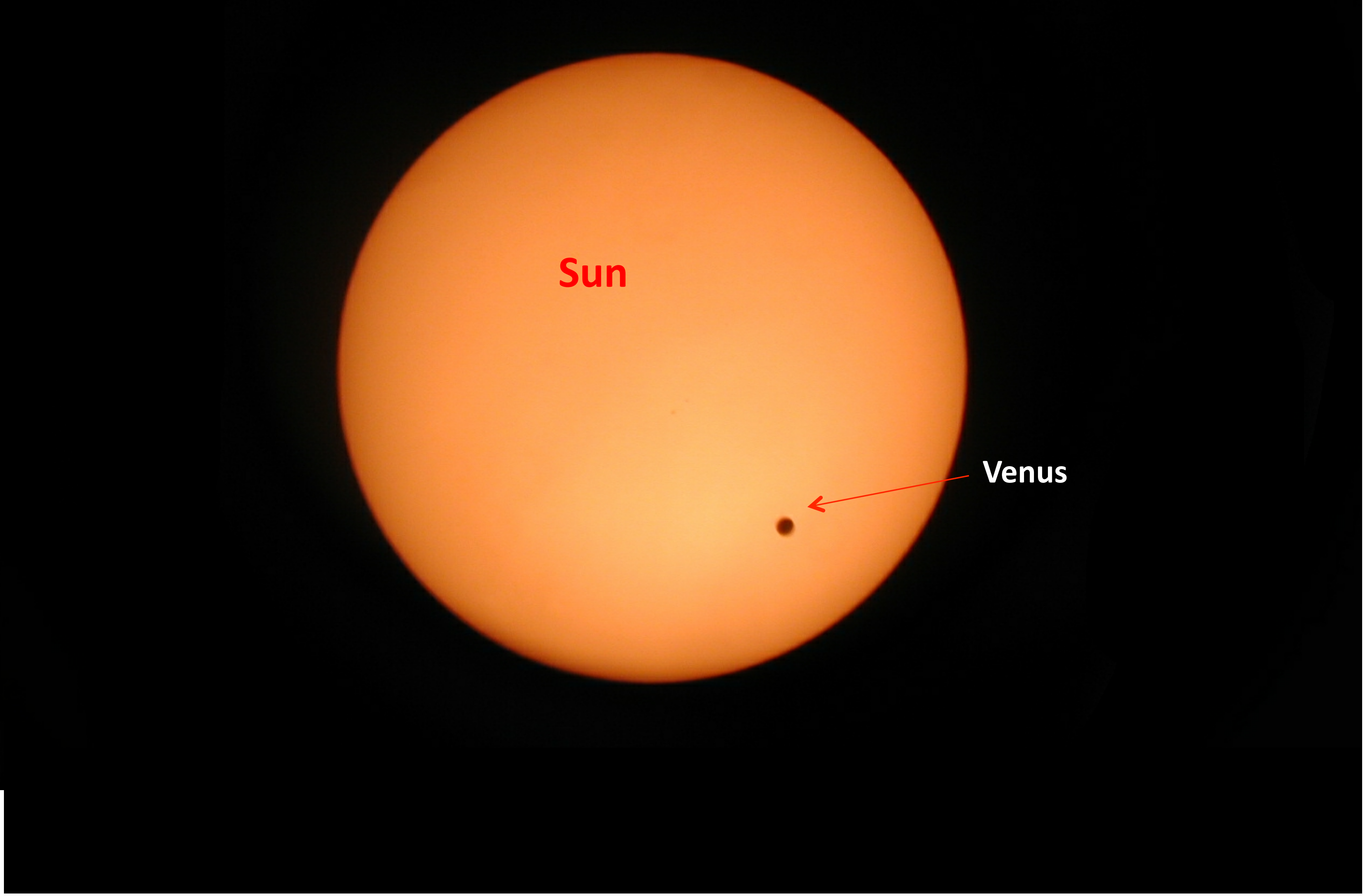
All 3 components are significant
Takizawa & Takeuchi PTEP 9, 093D01

Scale drawing of the X(3872):

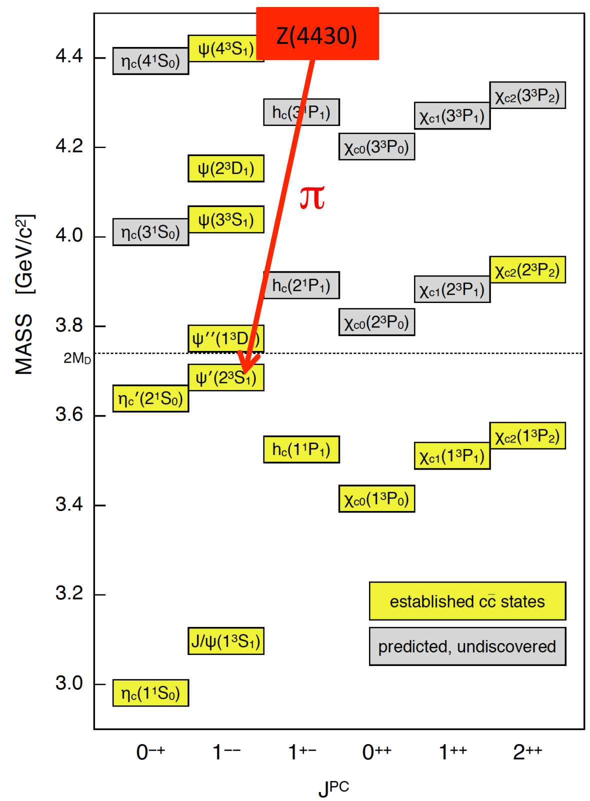


All 3 components are significant
Takizawa & Takeuchi PTEP 9, 093D01

X(3872): pastiche of very different objects!

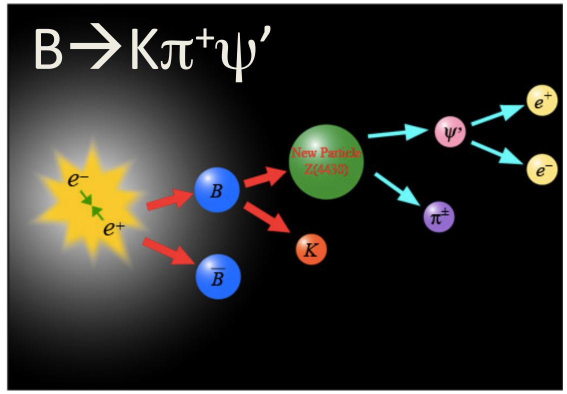


The Z(4430)



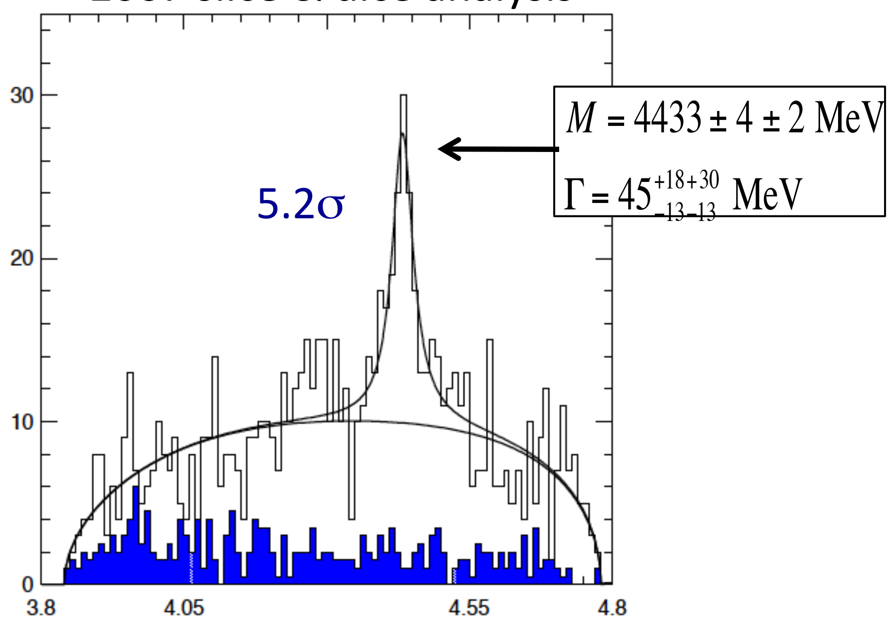
Z(4430)
π
MASS [GeV/c²]
4.4
4.2
4.0
3.8
2MD
3.6
3.4
3.2
3.0
ηc(4¹S₀)
ψ(4³S₁)
hc(3¹P₁)
χc0(3³P₀)
χc1(3³P₁)
χc2(3³P₂)
ψ(2³D₁)
ηc(3¹S₀)
ψ(3³S₁)
hc(2¹P₁)
χc0(2³P₀)
χc1(2³P₁)
χc2(2³P₂)
ψ′′(1³D₁)
ψ′(2³S₁)
ηc′(2¹S₀)
hc(1¹P₁)
χc0(1³P₀)
χc1(1³P₁)
χc2(1³P₂)
J/ψ(1³S₁)
ηc(1¹S₀)
established cc̄ states
predicted, undiscovered
0−+
1−−
1+−
0++
1++
2++
JPC

Found by Belle in 2007



S-K Choi et al Belle: PRL 100 142001

2007 slice & dice analysis

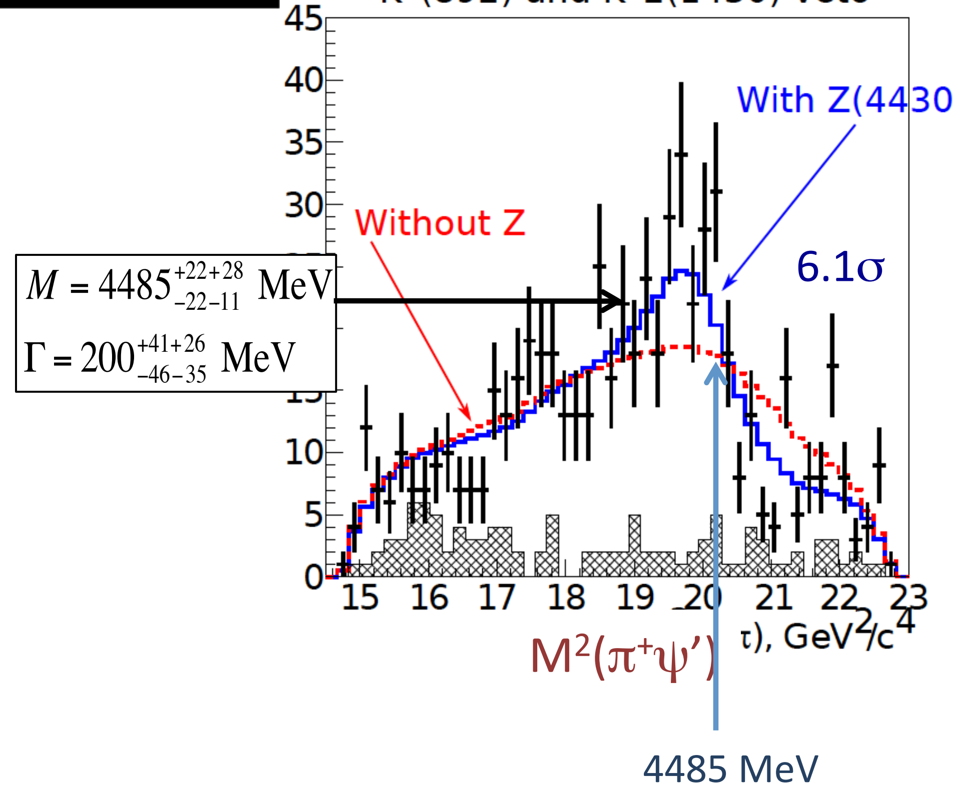


$M(\pi^+\psi')$

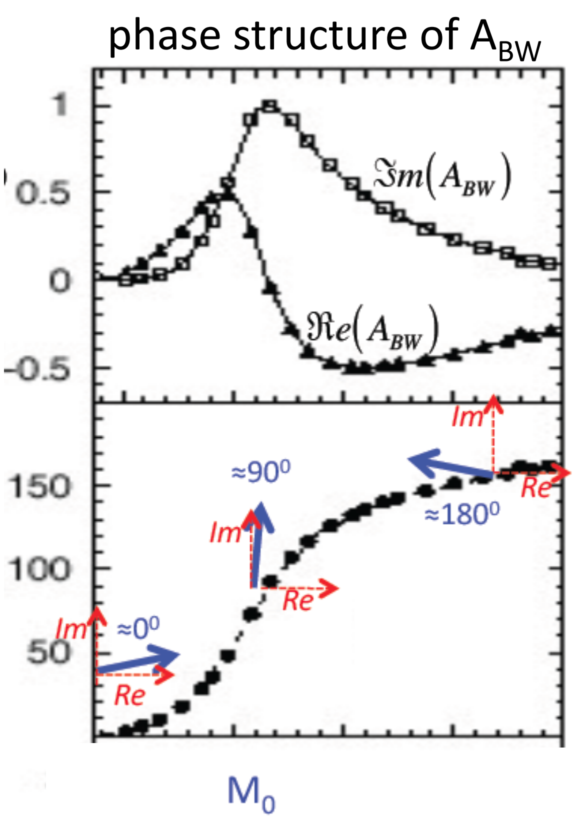
K Chilikin et al Belle: PRD 88 074026

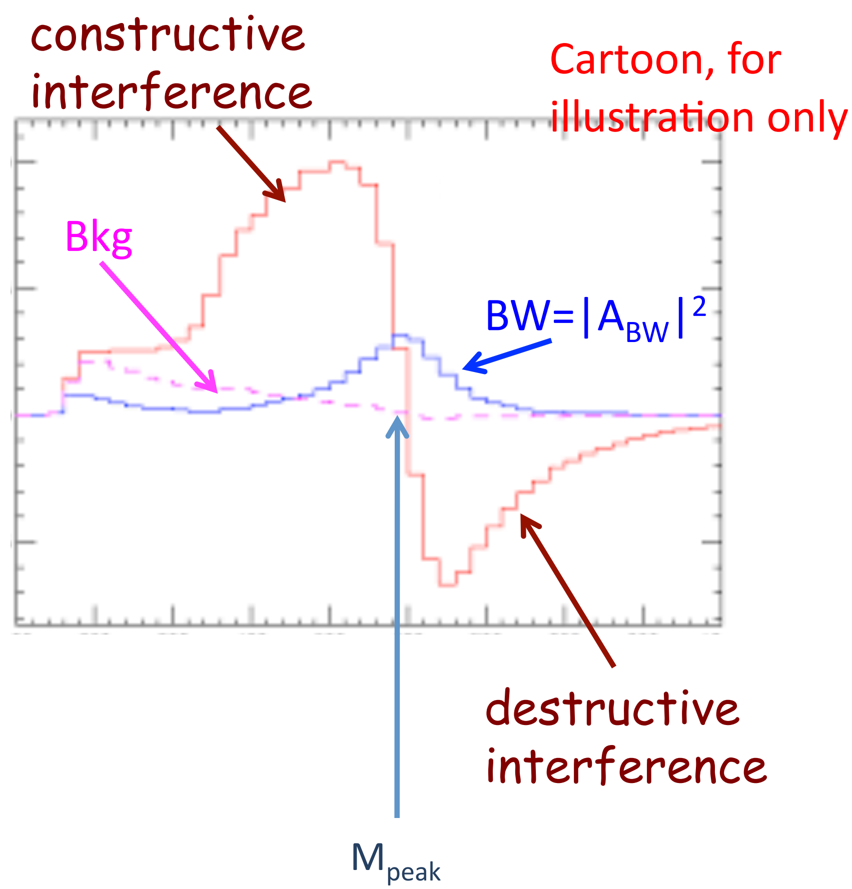
2013: 4-dim amplitude analysis

K*(892) and K*2(1430) veto



BW resonance on a large coherent background





Big news last year

April 14, 2014

CERN's LHCb experiment sees exotic particle

An analysis using LHC data verifies the existence of an exotic four-quark hadron.

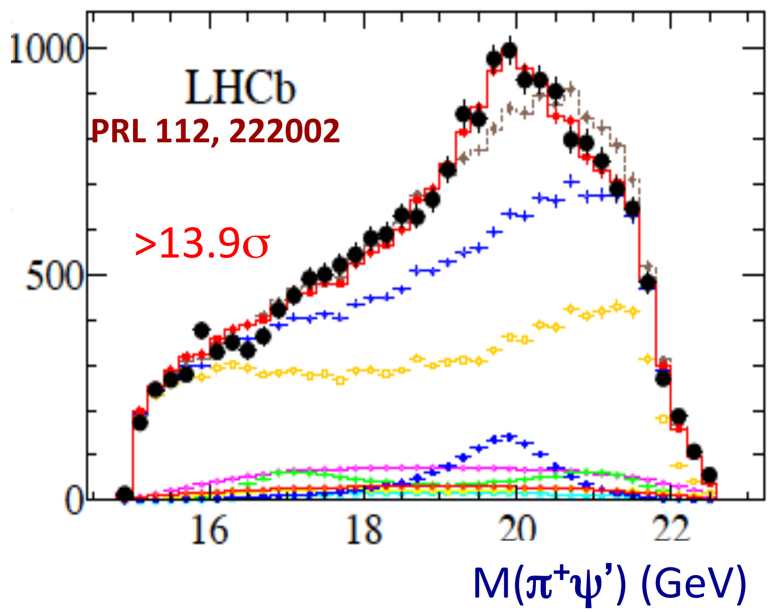
By Sarah Charley

Confirmed by LHCb

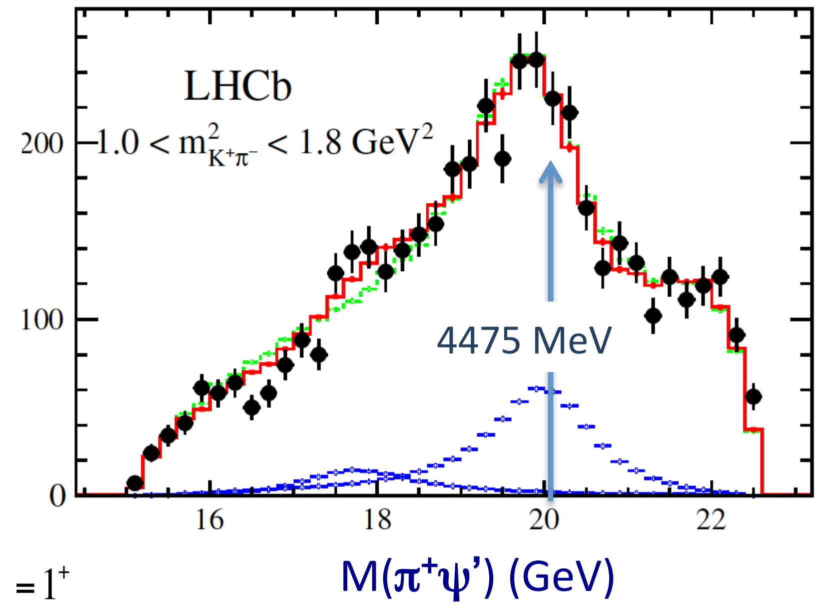
$B \rightarrow K\pi^+\psi'$: 4-dim amplitude analysis

R. Aaij et al LHCb: PRL 112 222002

All Kπ masses



K* veto



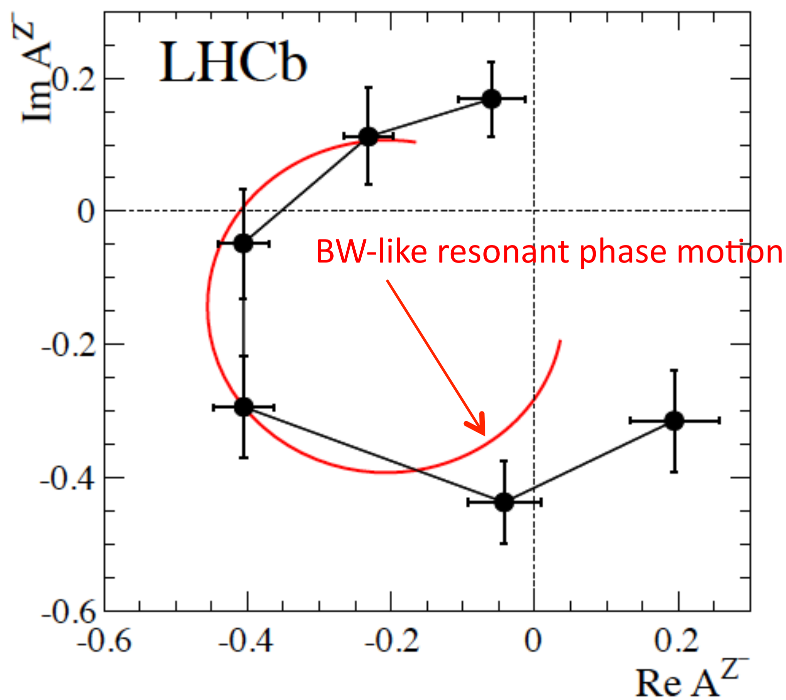
$J^P = 1^+$

$M = 4475 \pm 7^{+15}_{-25}$ MeV

$\Gamma = 172 \pm 13^{+37}_{-34}$ MeV

Argand plot shows BW-like phase motion

BW Model-independent Argand plot



R. Aaij et al LHCb: PRL 112 222002

Any non-resonance explanation of the data requires an amplitude with:

- *rapid 180° phase change near peak*
- *coherence with $K^*\psi'$ "background"*

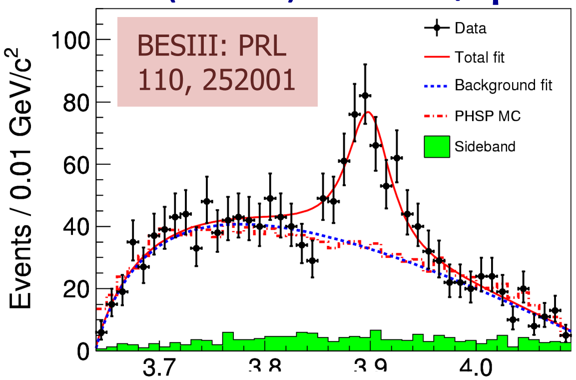
still some skeptics, see: Pakhlov & Uglov, arXiv:1408.5295

Other, lower mass Z_c states are seen

-- Mostly at BESIII --

$Z_c(3900)$

$Y(4260) \rightarrow \pi^+\pi^- J/\psi$

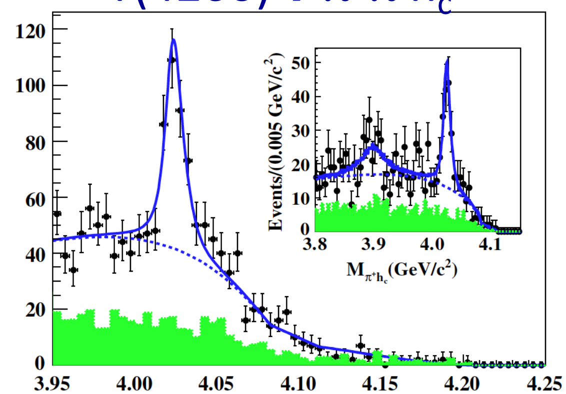


Belle: PRL 110, 252002

$M(\pi^- J/\psi)$

$Z_c(4020)$

$Y(4260) \rightarrow \pi^+\pi^- h_c$

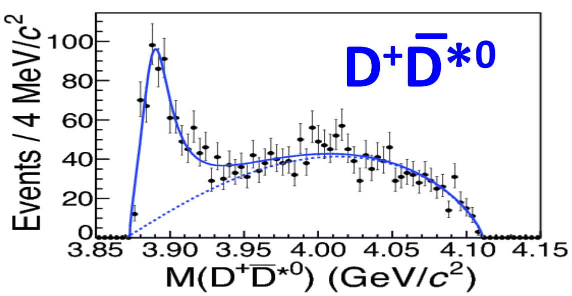


$M(\pi^- h_c)$

BESIII PRL 111, 242001

Both: $J^P = 1^+$

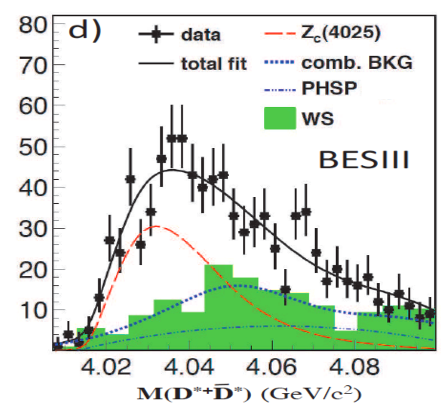
$Y(4260) \rightarrow \pi D\bar{D}^*$



BESIII PRL 112, 022001

Zhihong Wang's talk on Wed

$Y(4260) \rightarrow \pi D^*\bar{D}^*$



BESIII PRL 112, 132001

Z(4430)→πψ' favored over πJ/ψ

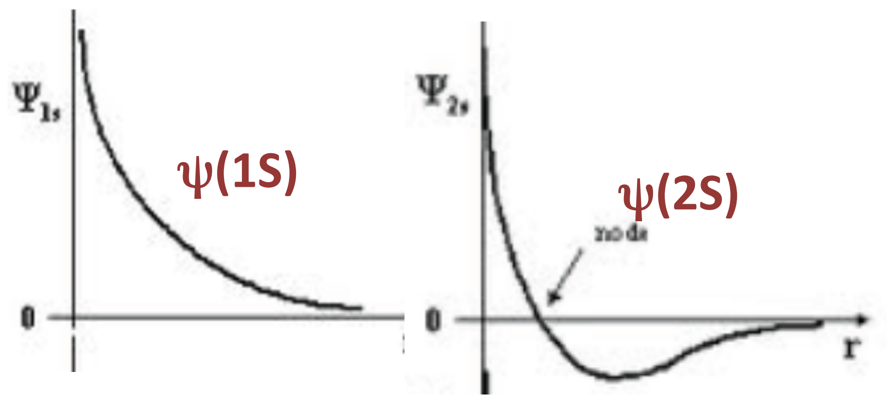
$$Bf(B^0 \to K^+ Z^-_{4430}) \times Bf(Z^-_{4430} \to \pi^- \psi') = (4.4 \pm 1.7) \times 10^{-5}$$

$$Bf(B^0 \to K^+ Z^-_{4430}) \times Bf(Z^-_{4430} \to \pi^- J/\psi) = (5.4^{+4.0+1.1}_{-1.0-0.9}) \times 10^{-6}$$

$$\frac{Bf(Z^-_{4430} \to \pi^- \psi')}{Bf(Z^-_{4430} \to \pi^- J/\psi)} \approx 8$$

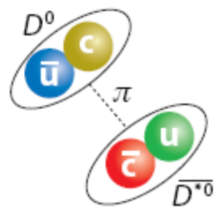
c and $\bar{c}$ in Z(4430) in an excited state?

Radial Wave Functions



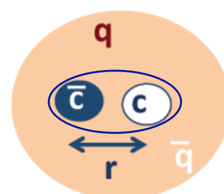
Proposed structures for the new mesons

Molecules?

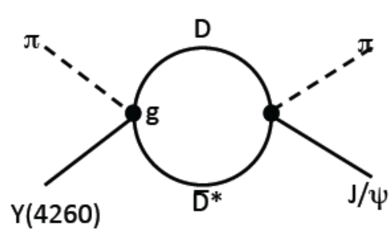


QCD tetraquarks?

Hadrocharmonium?



Threshold effects?



Molecules?

good points: -- many (most?) states are close to thresholds

-- sometimes very close: $M_{X(3872)}=m_{D0}+m_{D0*}$ to one part in 10^4

-- decay patterns reflect nearby thresholds

-- states near $2m_{D*}$ ($2m_{B*}$) like to decay $Z \rightarrow D^*\bar{D}^*$ ($B^*\bar{B}^*$) & not $D\bar{D}^*$ ($B\bar{B}^*$)

--decays to $\pi J/\psi$ ($\pi\Upsilon$(ns)) and πh_c (πh_b) occur with similar strengths

problems:

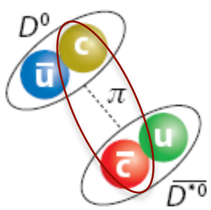
-- some states are not close to thresholds

-- difficult to account for large decays to hidden quarkonium

$$\text{e.g. } \frac{\Gamma(Z_c \rightarrow \pi J/\psi)}{\Gamma(Z_c \rightarrow D\bar{D}^*)} = 0.16 \pm 0.07$$

$$\Rightarrow \Gamma(Z_c \rightarrow \pi J/\psi) \approx \text{a few MeV}$$

not so small



the c and $\bar{c}$ quarks:
--don't have much overlap
--colors are uncorrelated

-- Can't account for X(3872) production in high energy pp collisions

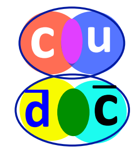
QCD tetraquarks? … hadrocharmonium?

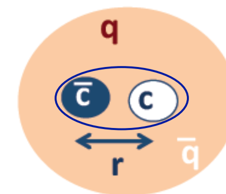
good points:

-- decays to hidden charmonium not suppressed

-- c and $\bar{c}$ have large overlap

-- colors are correlated





-- mass & ψ' affinity of the $Z_c(4430)$ is ok

--predicted the $Z_c(3900)$

-- masses not restricted to thresholds

-- production in high energy $p\bar{p}$ collisions okay

-- many detailed predictions

problems:

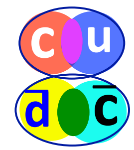
-- many of the detailed predictions were wrong

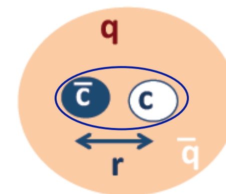
prediction	experiment
-- X(3872) is 1 of a doublet	only 1 X(3872)
-- $Z_c(3900)$ partner at M≈3800 MeV	$M_{Zc(4020)}$= 4023 MeV
-- $\frac{\Gamma(Z_c \to \pi J/\psi)}{\Gamma(Z_c \to D\overline{D}^*)} \approx 7$	$\frac{\Gamma(Z_c \to \pi J/\psi)}{\Gamma(Z_c \to D\overline{D}^*)} = 0.16 \pm 0.07$

QCD tetraquarks? … hadrocharmonium?

good points:

-- decays to hidden charmonium not suppressed
  -- c and $\bar{c}$ have large overlap
  -- colors are correlated





-- mass & ψ' affinity of the $Z_c(4430)$ is ok
  --predicted the $Z_c(3900)$

-- masses not restricted to thresholds

--- production in high energy pp collisions ok…

-- many detailed predictions

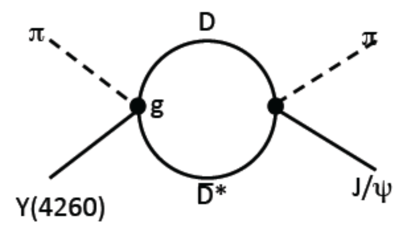
problems:

-- many of the detailed … ong

prediction	…periment
-- X(38…	only 1 X(3872)
	$M_{Zc(4020)}$= 4023 MeV
…MeV	
$\frac{\Gamma(Z_c \to \omega J/\psi)}{\Gamma(Z_c \to D\bar{D}^*)} \approx 7$	$\frac{\Gamma(Z_c \to \pi J/\psi)}{\Gamma(Z_c \to D\bar{D}^*)} = 0.16 \pm 0.07$

NB: These predictions are for specific models & probably not fatal to the tetraquark scenario.

Threshold effects?

The coupled-channel loop: 

produces a cusp-like peak in $M(\pi J/\psi)$ just above the $m_D + m_{D^*}$ threshold

-- Similar to the $Z_c(3900) \rightarrow \pi J/\psi$ peak just above $m_D + m_{D^*}$ (& the $Z_c(4020) \rightarrow \pi h_c$ peak just above $2m_{D^*}$)

Bugg: EPL 96 11002 (2011)

-- $Z_c(3900)$ & $Z_c(4020)$ are threshold cusps?

Chen et al. PRD 88 036008

Swanson: PRD 91, 034009

-- 1^{st} –order (1-loop) Perturbation theory doesn't work for peak this large

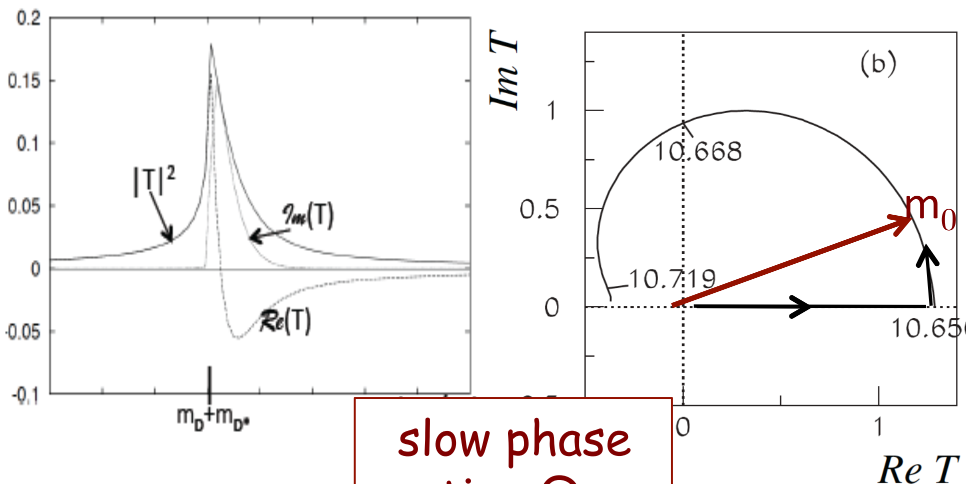
Guo et al. PRD 91, 034009

-- Yes it does!

Swanson: 1504.07952

cusp vs BW phase motion

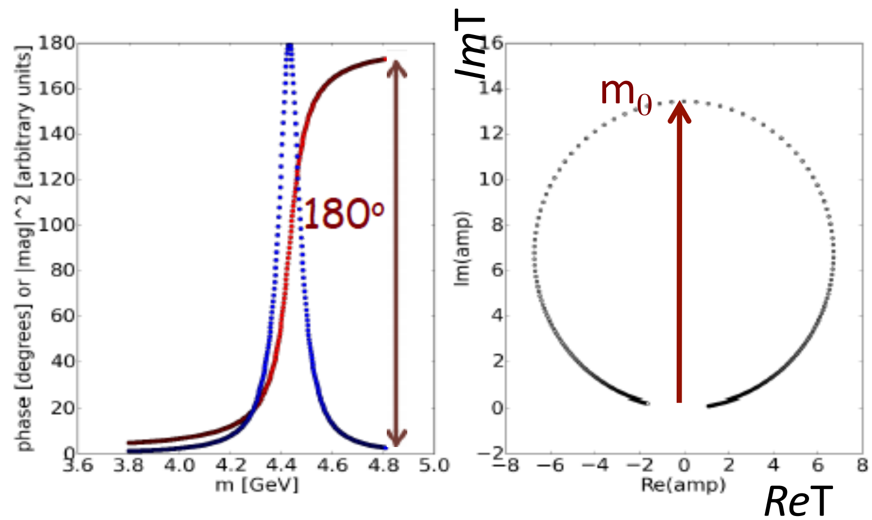
cusp



slow phase motion @ m_0

Bugg: EPL 96 11002 (2011)

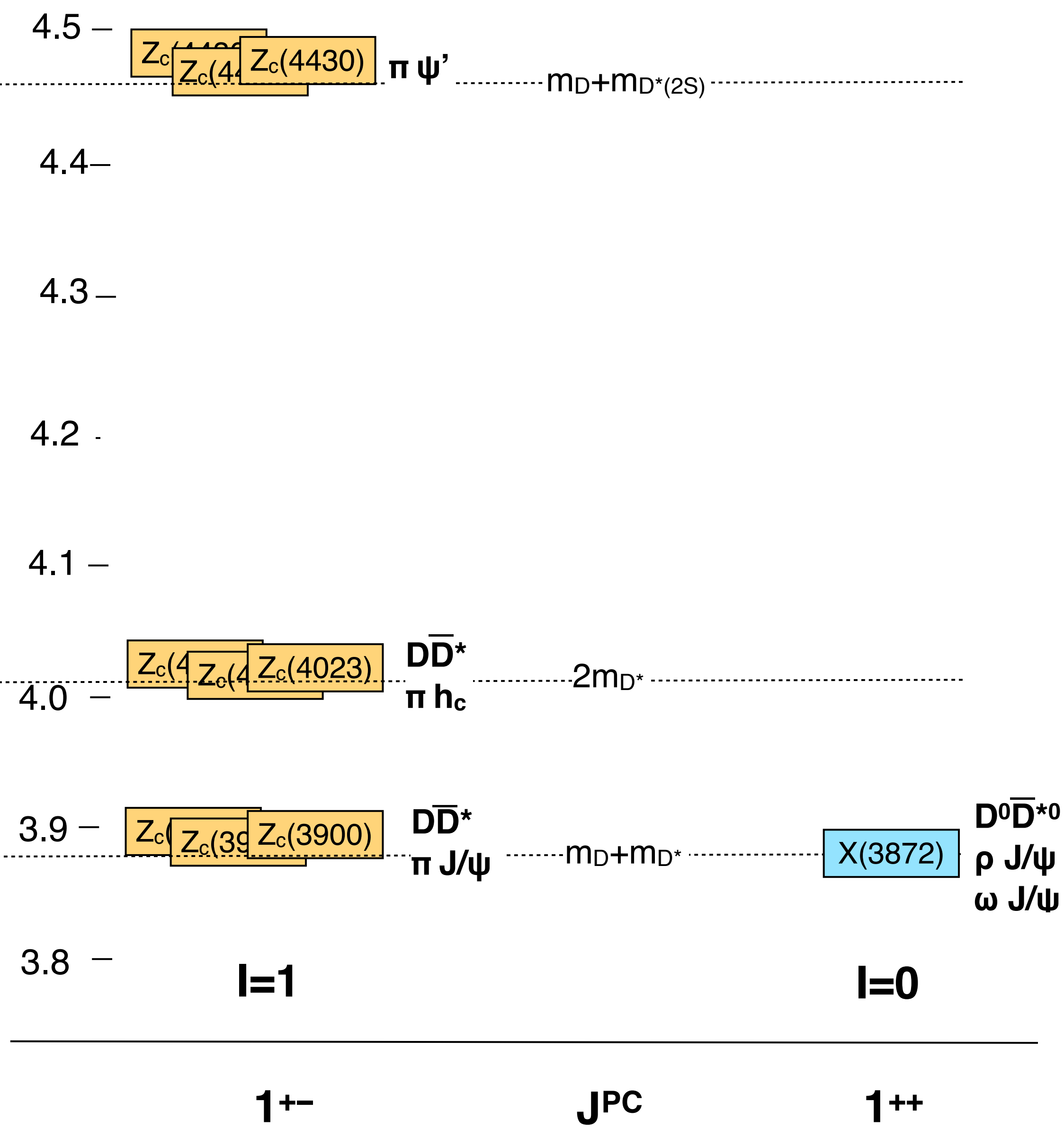
BW



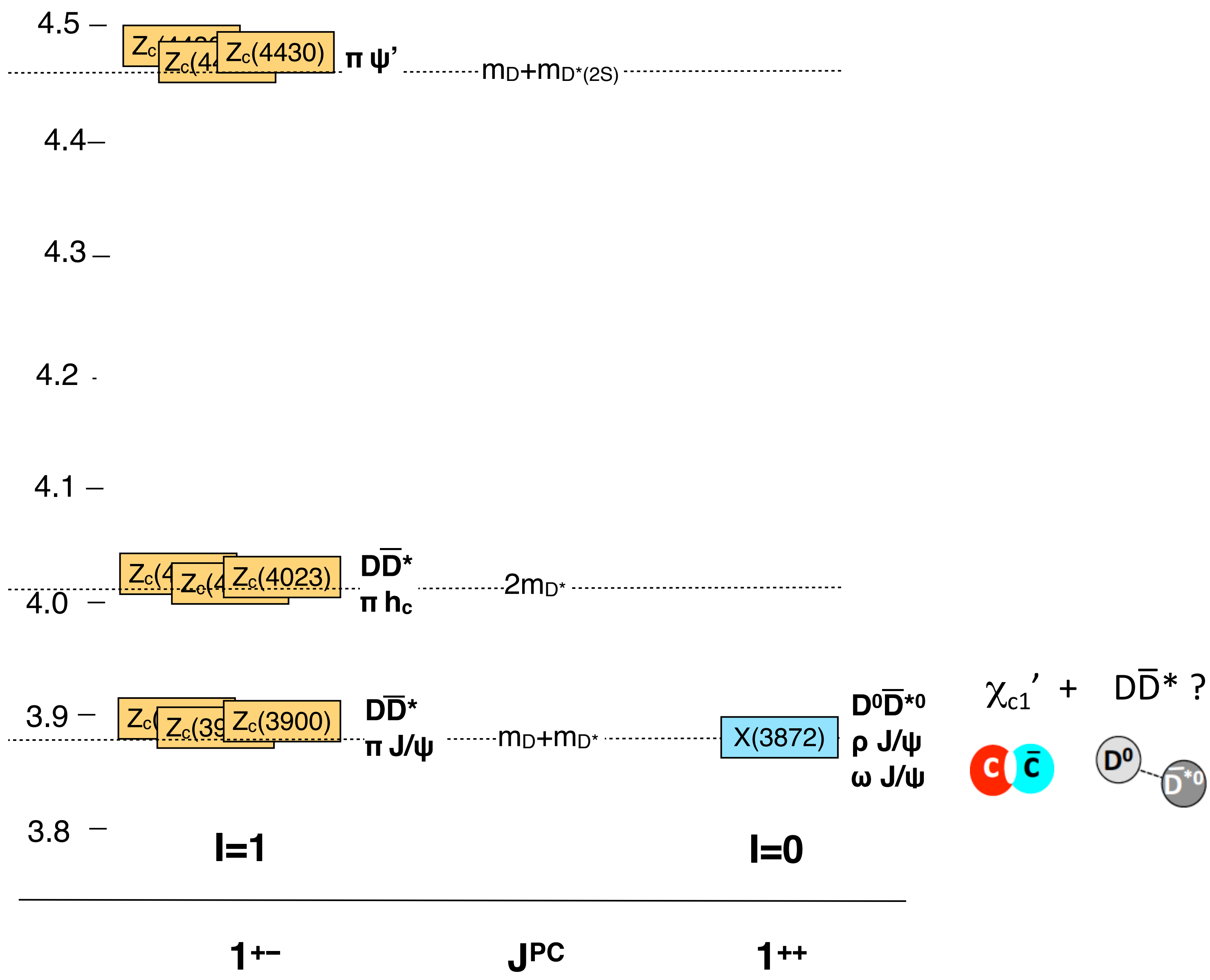
rapid phase motion @ m_0

$Z_c(3900) \rightarrow \pi^+ J/\psi$ amplitude analysis currently underway at BESIII, results soon?

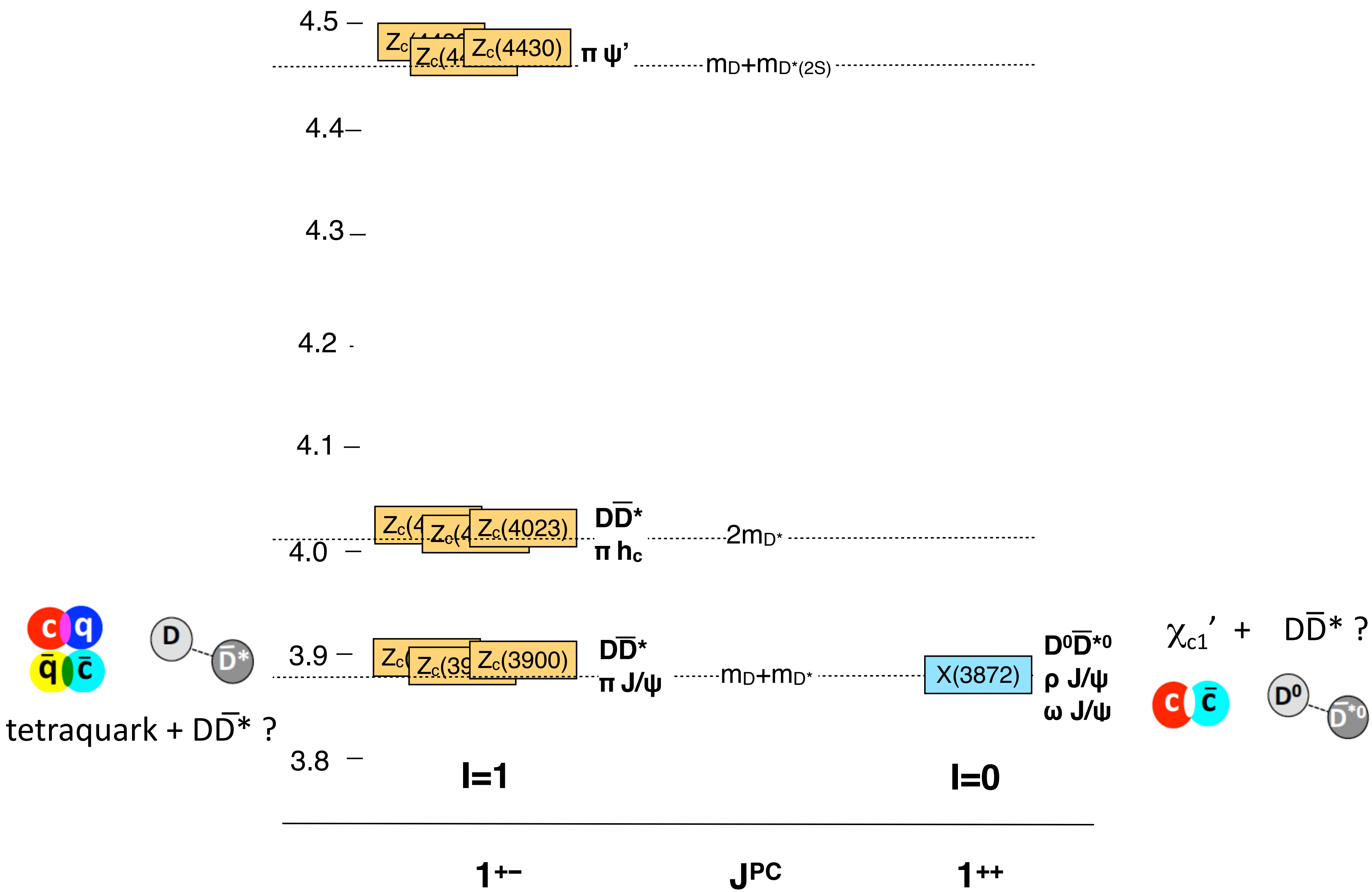
1^+ states: what we see



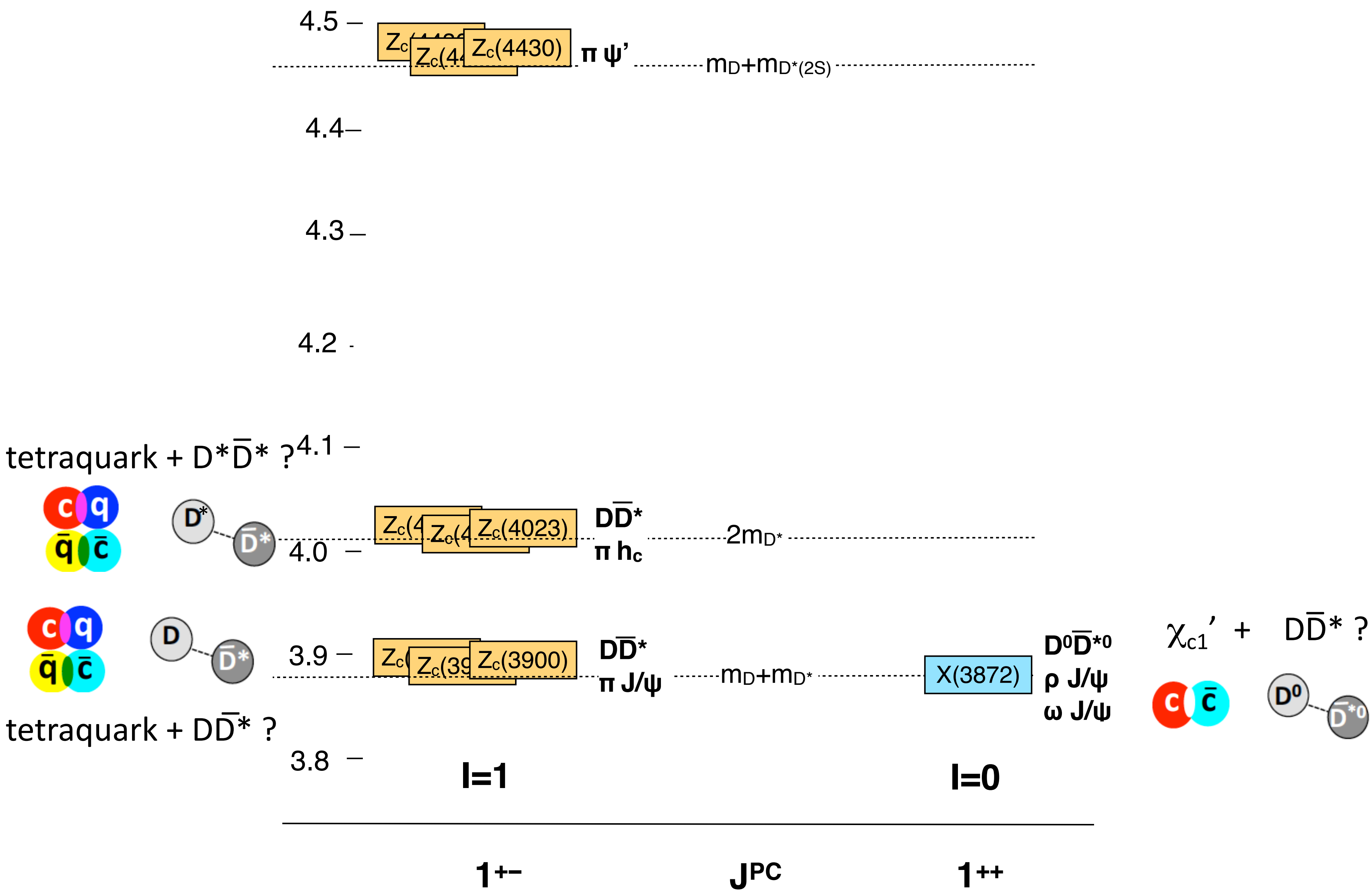
1^+ states: what we see



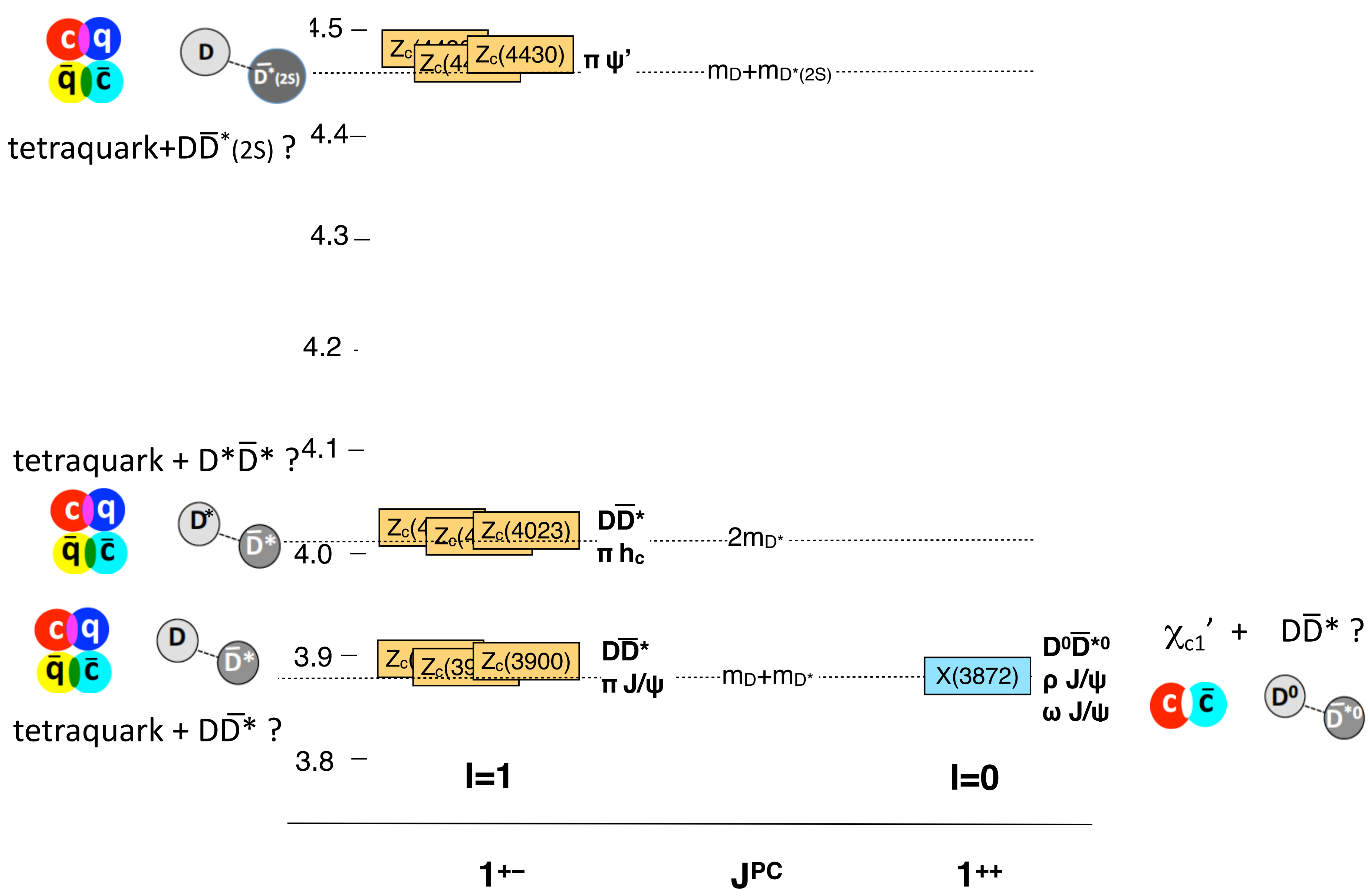
1^+ states: what we see



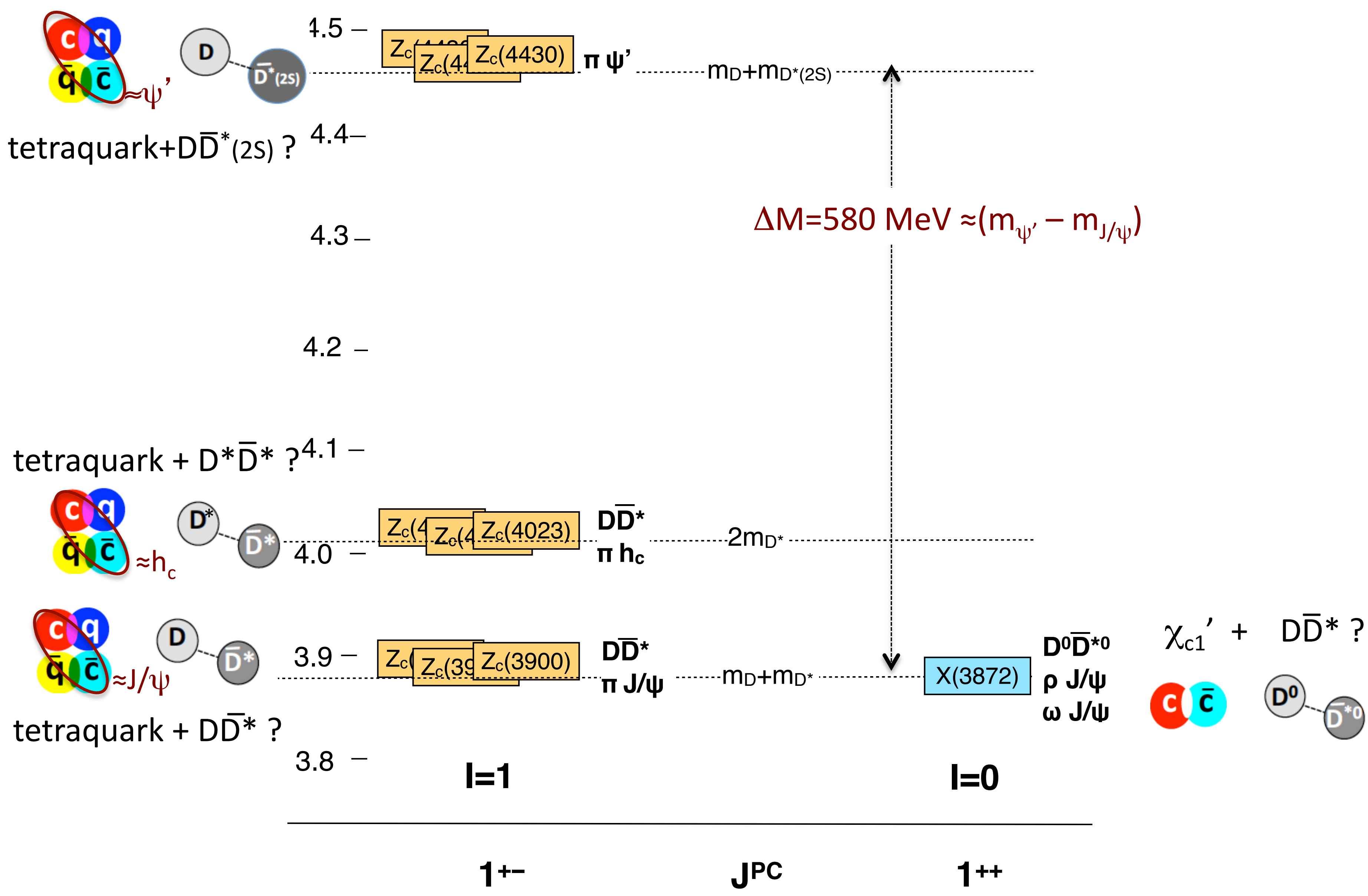
1⁺ states: what we see



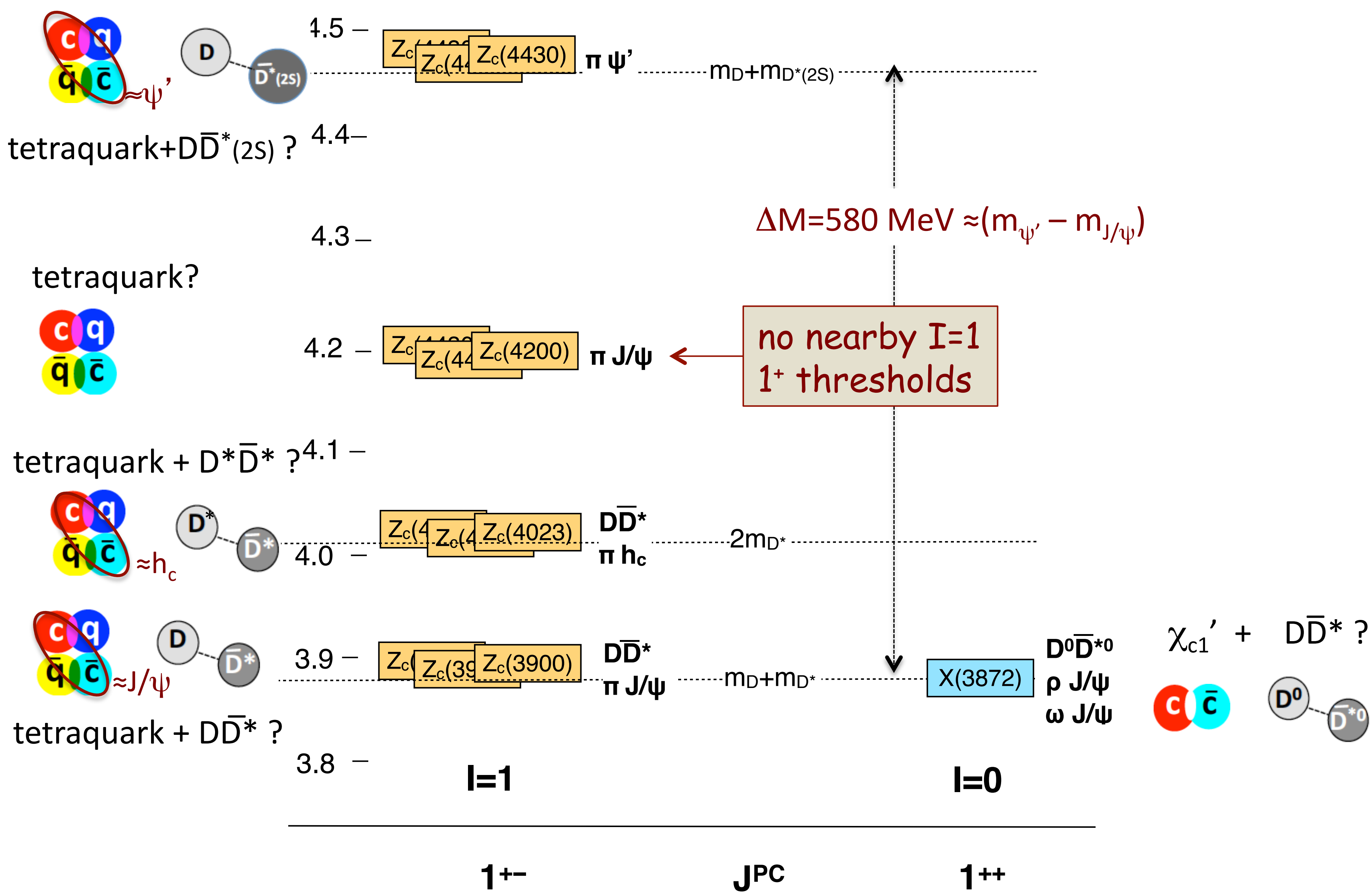
1^+ states: what we see



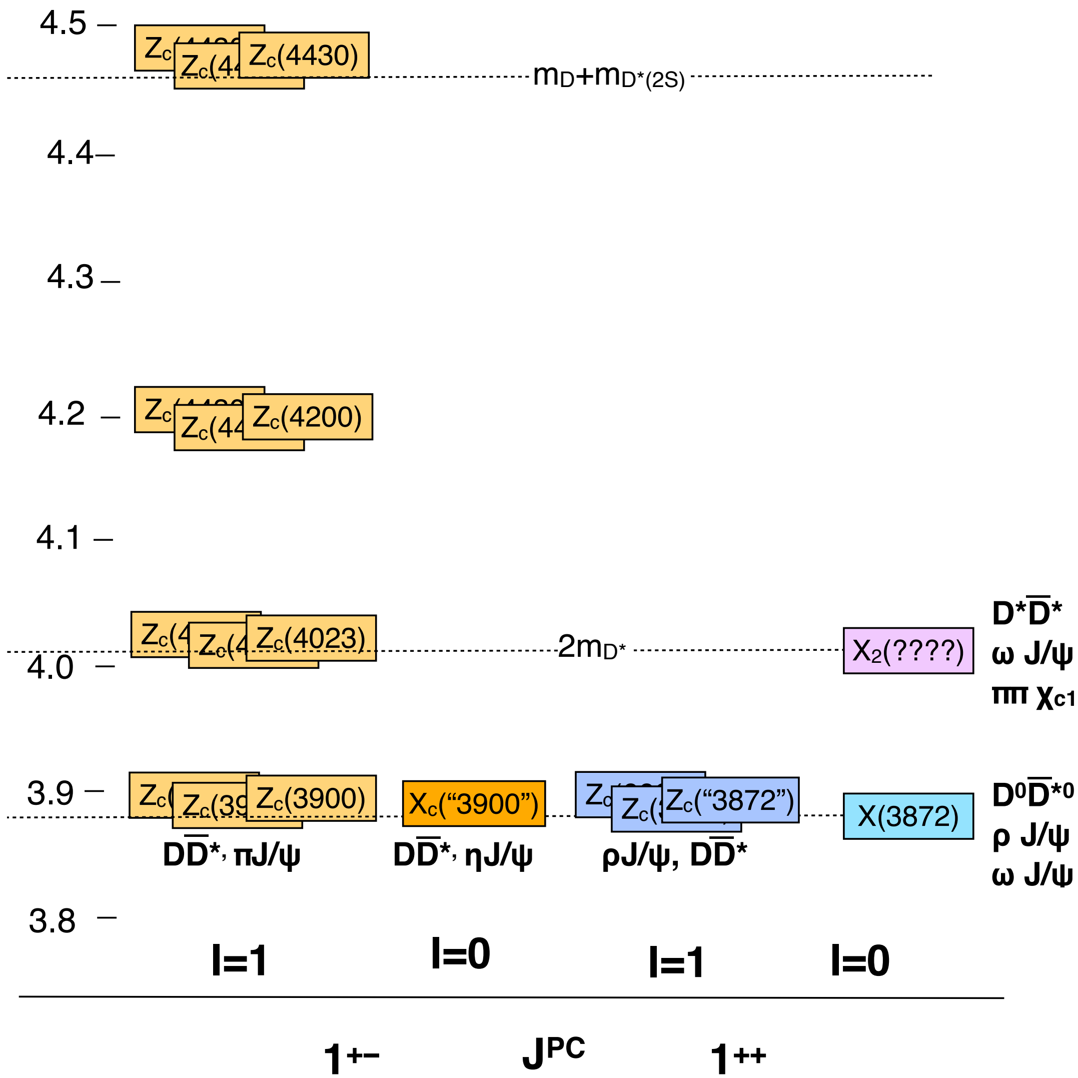
1^+ states: what we see



1^+ states: what we see



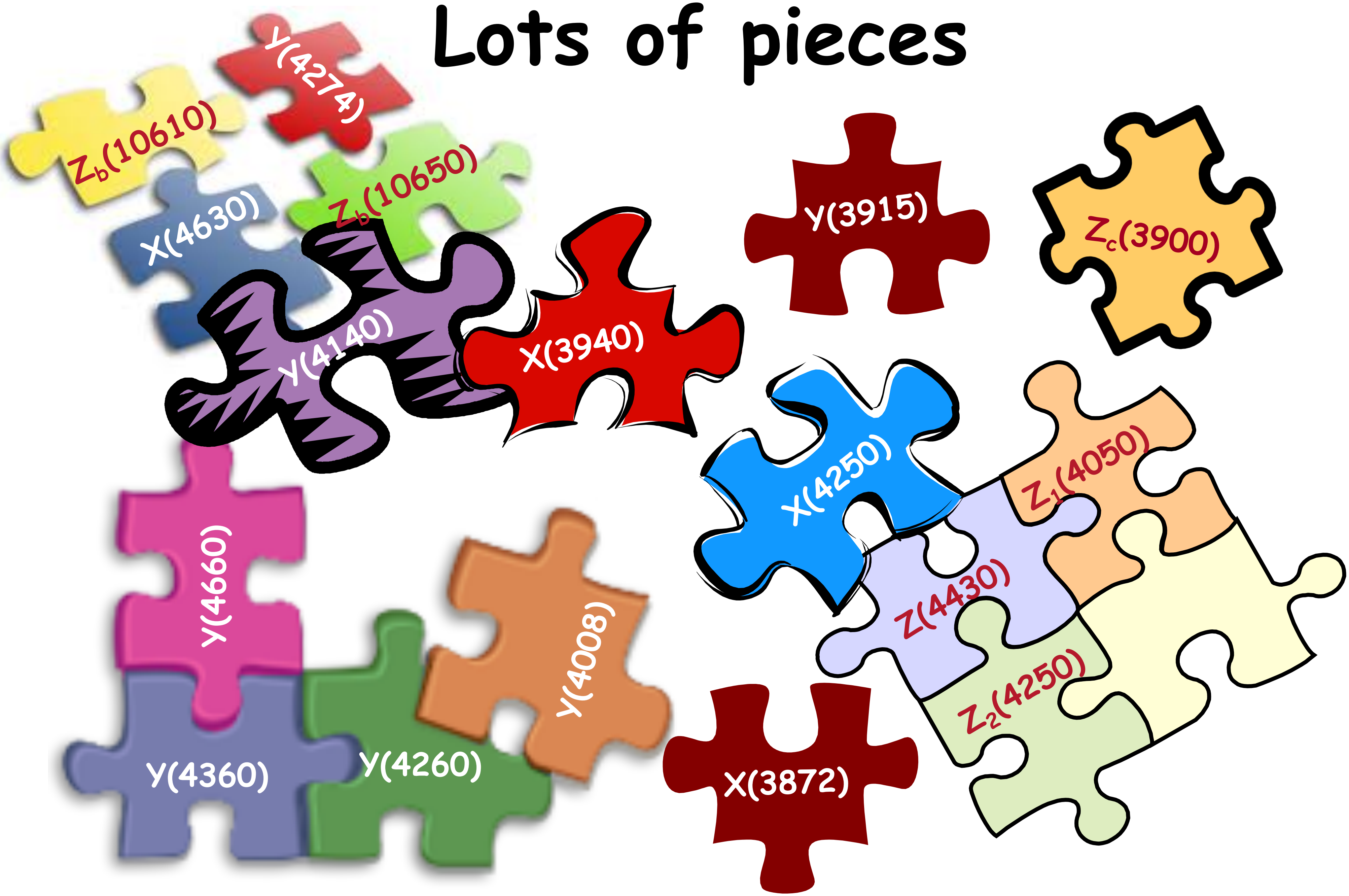
Are there other 1⁺ states to look for?



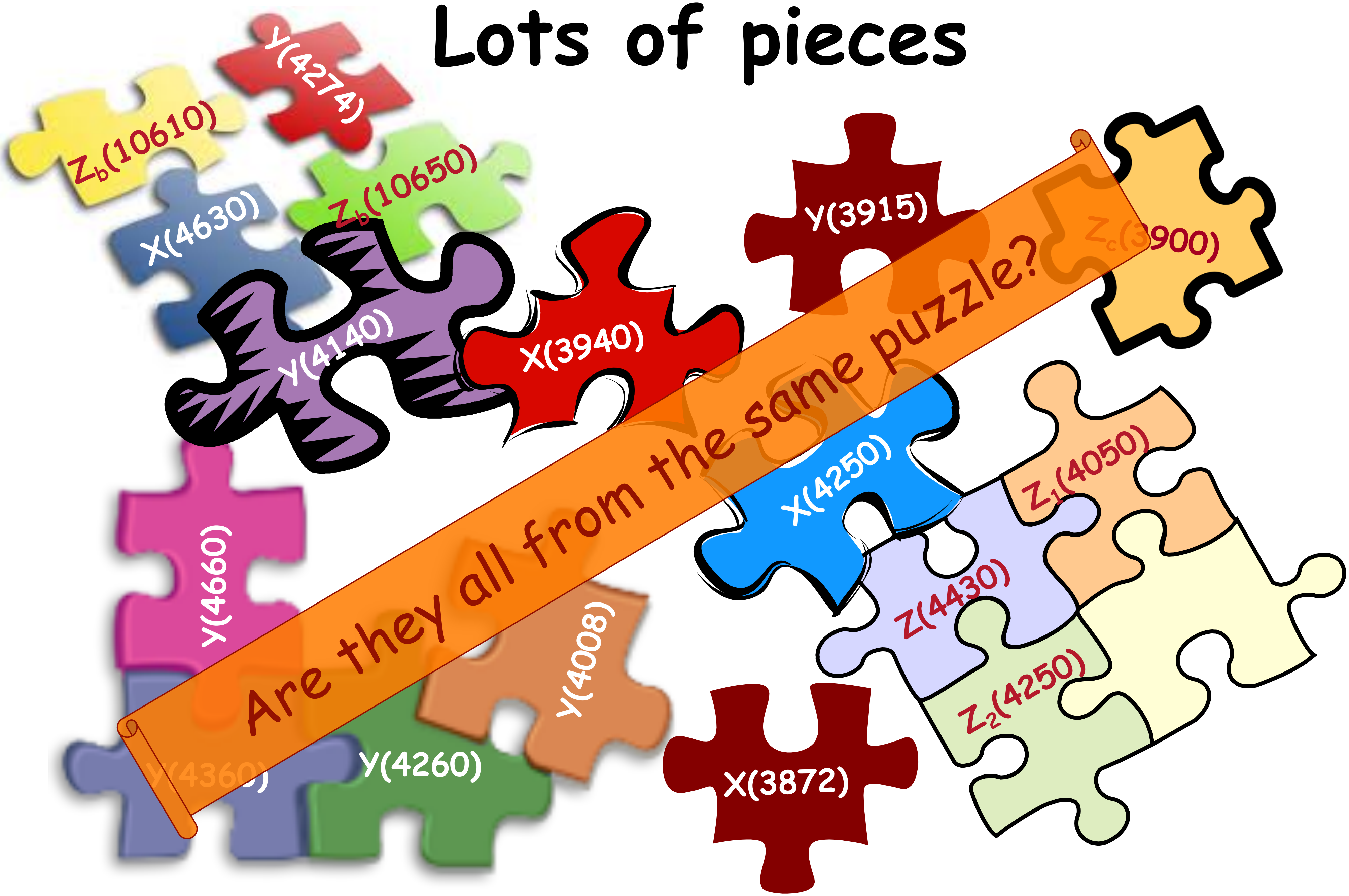
Summary

- 4-quark, charmonium-like mesons have been observed
  - -large partial widths to $(c\bar{c})$+hadrons
  - -many, but not all, have mass near $D^{(*)}\bar{D}^{(*)}$ thresholds
- Pure molecule or pure diquark-diantiquark tetraquark models do not reproduce observations
  - -QCD-core states coupled to meson pairs work better?
- Kinematic "cusp" explanations of near-threshold peaks (may) fail to bear up under close scrutiny
- Interesting problem, lots to do

Lots of pieces



Lots of pieces



Thank You

Merci

감사합니다