A New Hadron Spectroscopy

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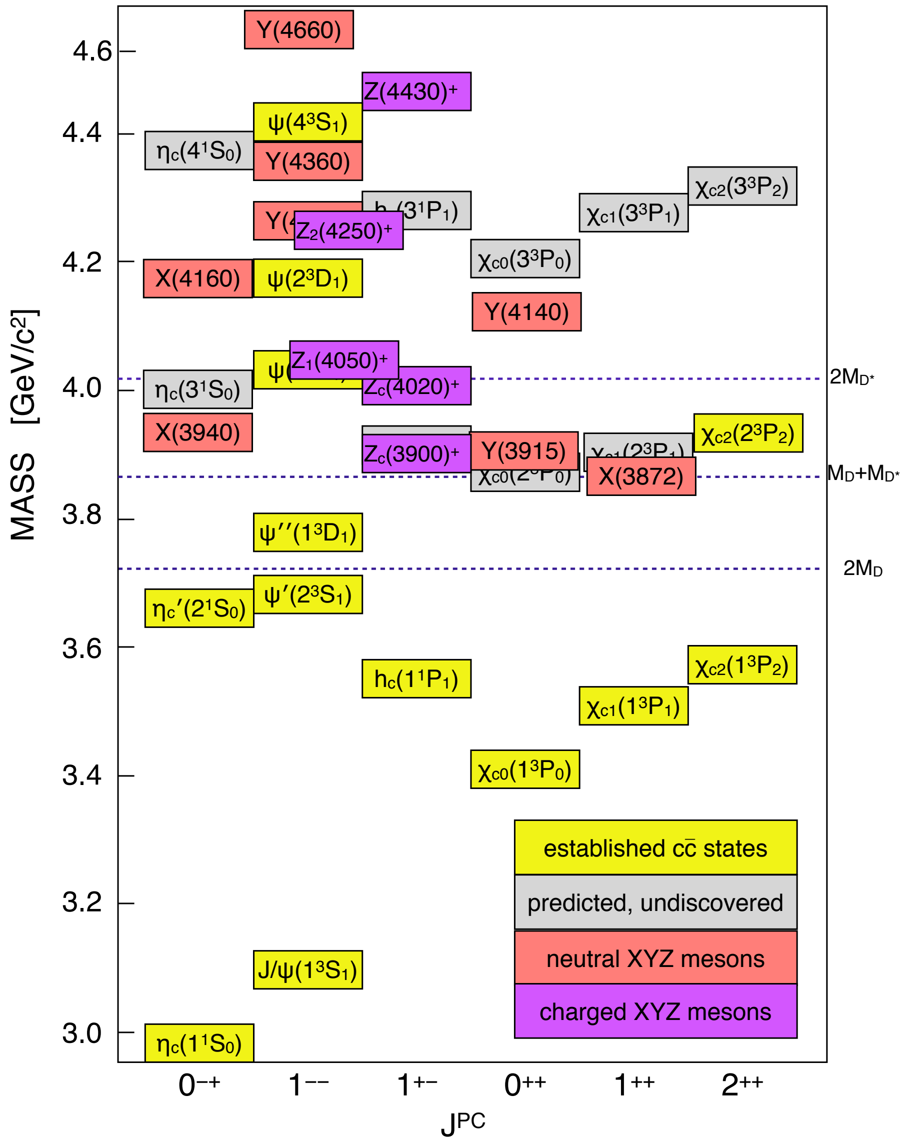
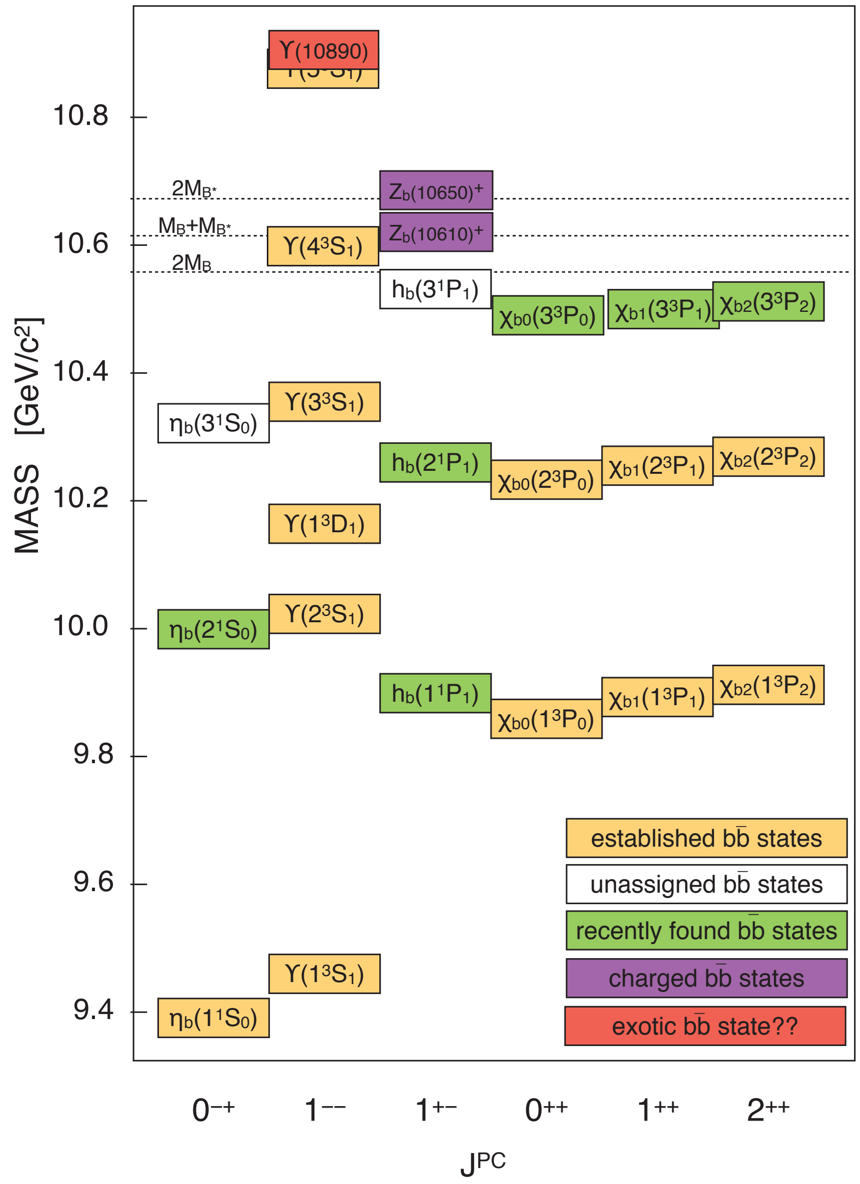
Quark Confinement & Hadron Spectrum XI St Petersburg, September 8-12, 2014

XYZ mesons

charmonium & charmoniumlike



bottomonium & bottomoniumlike



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]
				$p\bar{p} \to (J/\psi\,\pi^+\pi^-) + ...$	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]
				$pp \to (J/\psi\,\pi^+\pi^-) + ...$	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]
				$e^+e^- \to J/\psi + (...)$	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

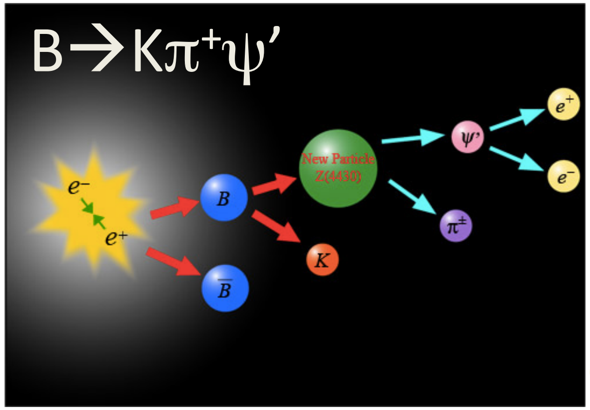
and two Z_b mesons

New this year

- LHCb confirms $Z_c(4430) \rightarrow \pi^+\psi'$
  - confirms BW-like phase motion
- Belle finds $J^P=1^+$ $Z_c(4200) \rightarrow \pi^+ J/\psi$
  - sees $Z(4430) \rightarrow \pi^+ J/\psi$

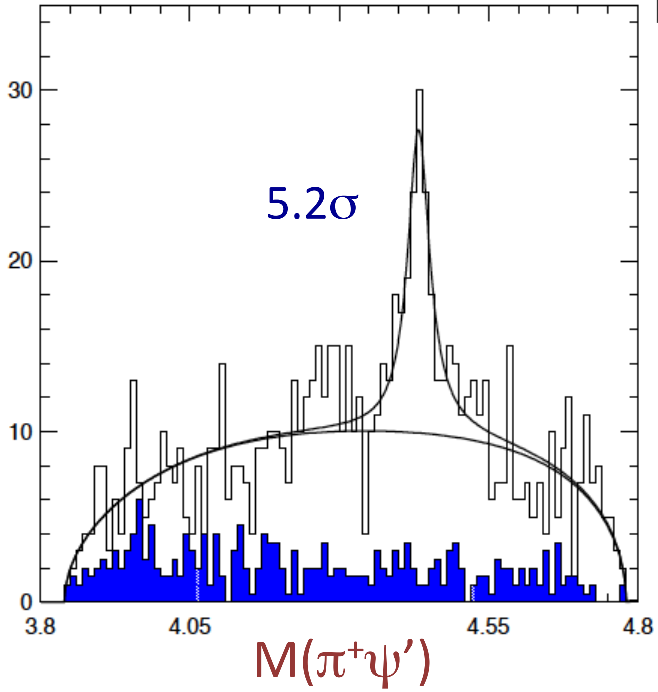
The Z(4430)

Found by Belle in 2007



S-K Choi et al Belle: PRL 100 142001

2007 slice & dice analysis



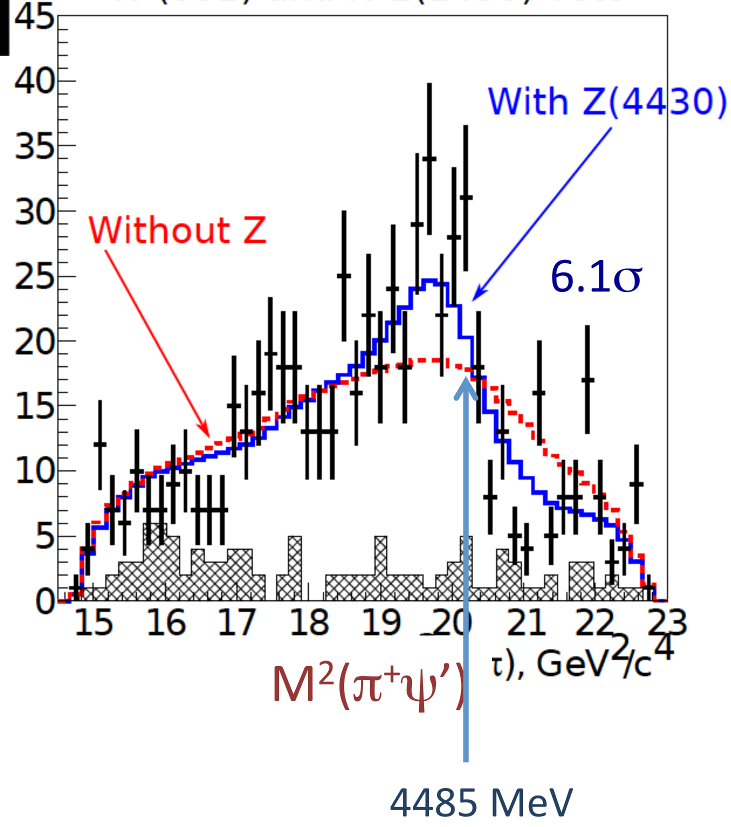
$$M = 4485^{+22+28}_{-22-11} \text{ MeV}$$

$$\Gamma = 200^{+41+26}_{-46-35} \text{ MeV}$$

K Chilikin et al Belle: PRD 88 074026

2013: 4-dim amplitude analysis

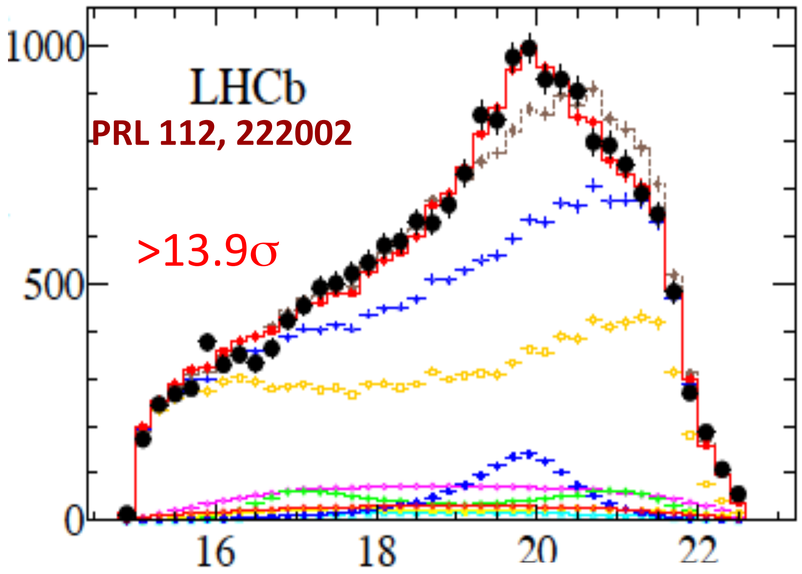
K*(892) and K*2(1430) veto



Confirmed by LHCb last spring

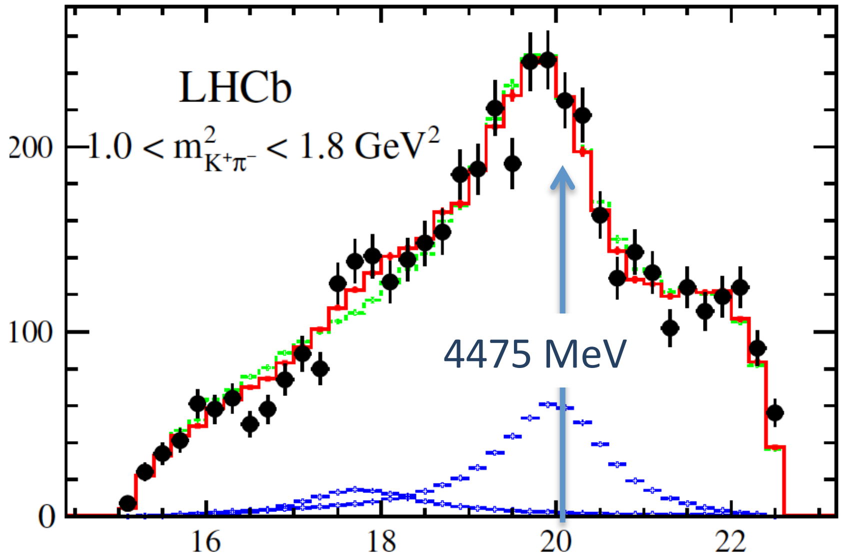
B→Kπ⁺ψ′: 4-dim amplitude analysis

All Kπ masses



M(π⁺ψ′) (GeV)

non K*



M(π⁺ψ′) (GeV)

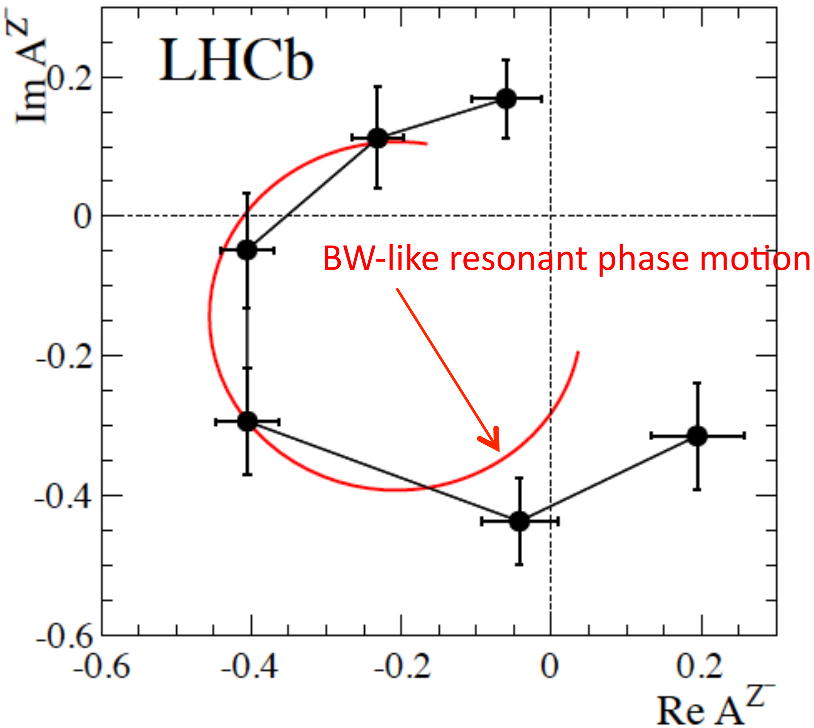
$J^P = 1^+$

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

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

Argand plot shows BW-like phase motion

BW Model-independent Argand plot



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

- *rapid 180° phase change near peak*
- *coherence with K*ψ′ "background"*

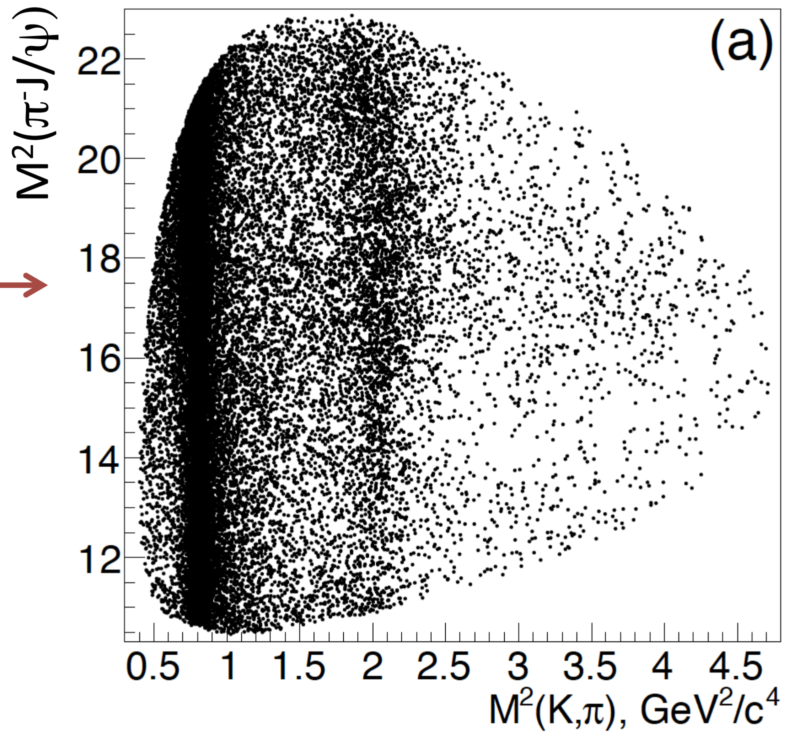
still some skeptics, see: Pakhlov & Uglov, arXiv:1408.5295

New from Belle:

$$Z_c(4200) \rightarrow \pi^+ J/\psi$$

New from Belle: 4-dim analysis of B→$K^+\pi^-J/\psi$

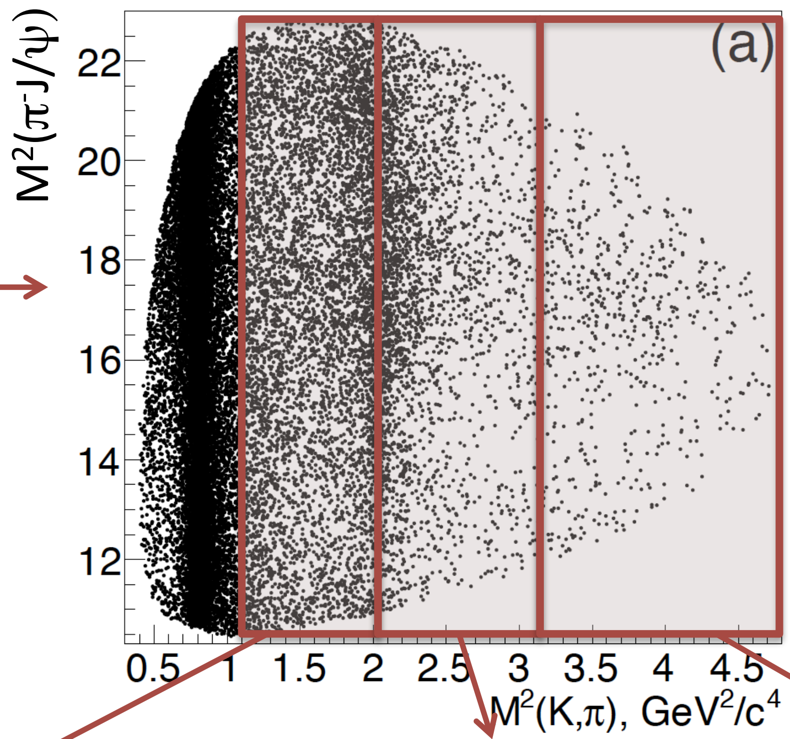
New state:
$Z_c(4200)^-\rightarrow\pi^-J/\psi$



New from Belle: 4-dim analysis of $B \rightarrow K^+\pi^- J/\psi$

K. Chilikin et al. (Belle) arXiv:1408.6457

New state:
$Z_c(4200)^- \rightarrow \pi^- J/\psi$



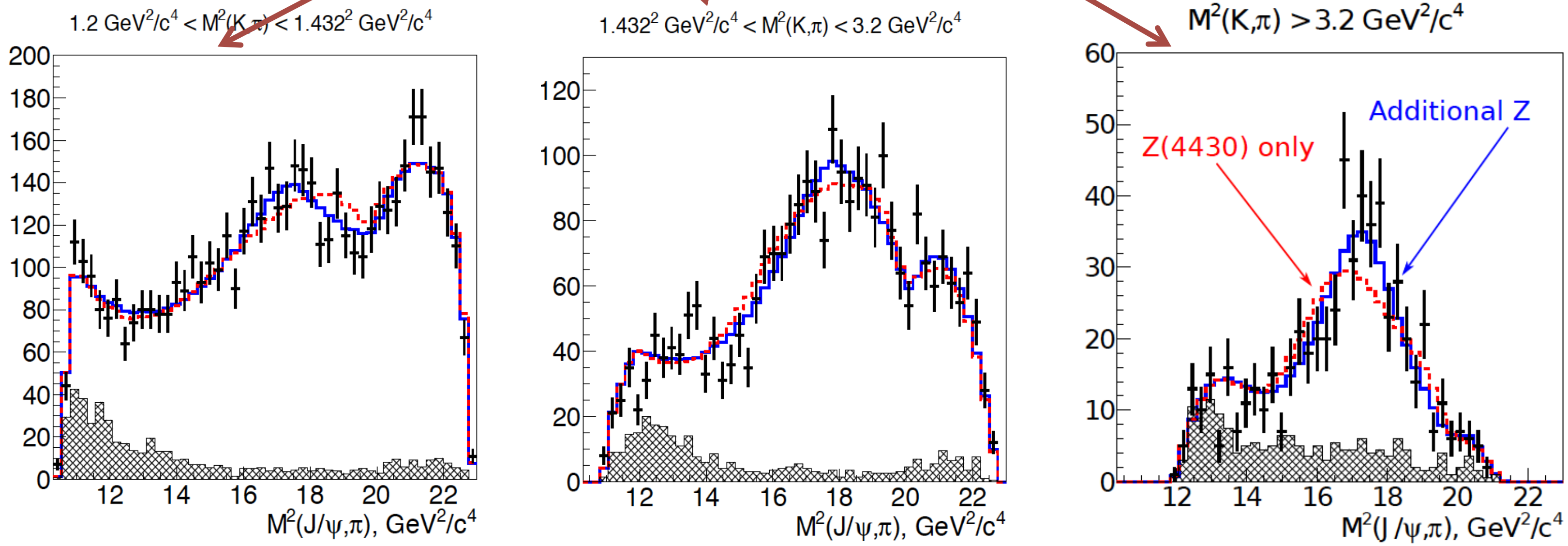
$M = 4196^{-31+17}_{-29-6}$ MeV

$\Gamma = 370^{+70+70}_{-70-80}$ MeV

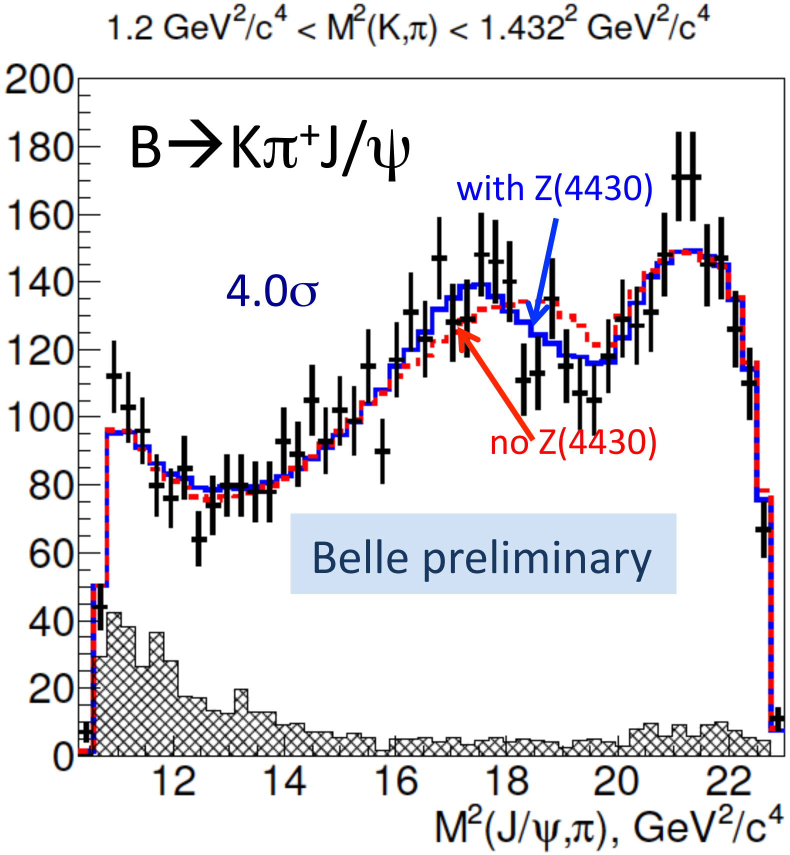
$J^P = 1^+$ preferred by $\sim 4\sigma$

signif : 7.2σ

$\mathcal{B}(\bar{B}^0 \to Z_c(4200)^+ K^-) \times \mathcal{B}(Z_c(4200)^+ \to J/\psi\pi^+) = (2.2^{+0.7+1.1}_{-0.5-0.6}) \times 10^{-5}$,



Also: Z(4430)→$\pi^- J/\psi$ is seen (~4σ)



K. Chilikin et al. (Belle) arXiv:1408.6457

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

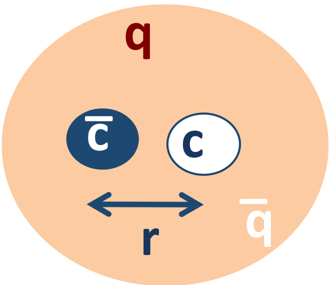
$$\frac{Bf(Z^-_{4430} \to \pi^- \psi')}{Bf(Z^-_{4430} \to \pi^- J/\psi)} \approx 10$$

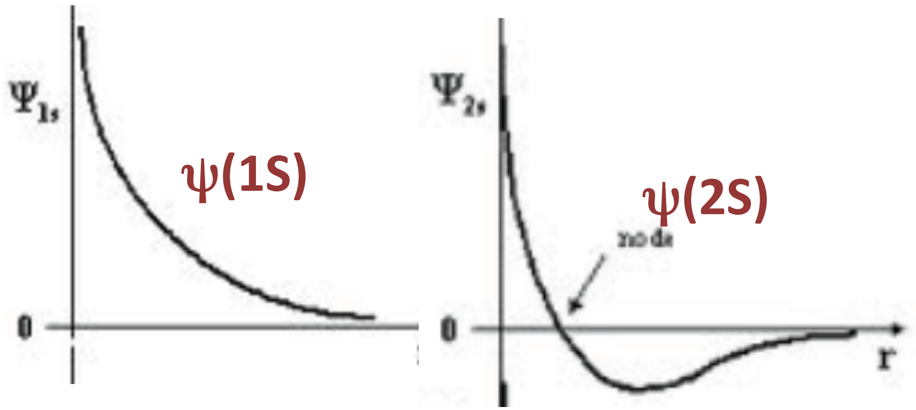
decays to ψ′ favored over those to J/ψ

Z(4430) = radial excitation of Z_c(3900)?

$$\frac{\mathcal{B}(Z_c(4430)^+ \to \psi(2S)\pi^+)}{\mathcal{B}(Z_c(4430)^+ \to J/\psi\pi^+)} \sim 10$$

Radial Wave Functions

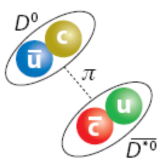




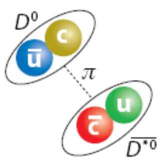
The $c\bar{c}$ part of the wave function of the Z(4430) likely has a node
➔ a radial excitation of the ground state: the Z_c(3900)?

$M(Z_c(4430))-M(Z_c(3900)) = 589 \pm 30$ MeV
$M(\psi') - M(J/\psi) = 589$ MeV

The $J^P=1^+$ charmoniumlike states



D*-D̄* molecule?



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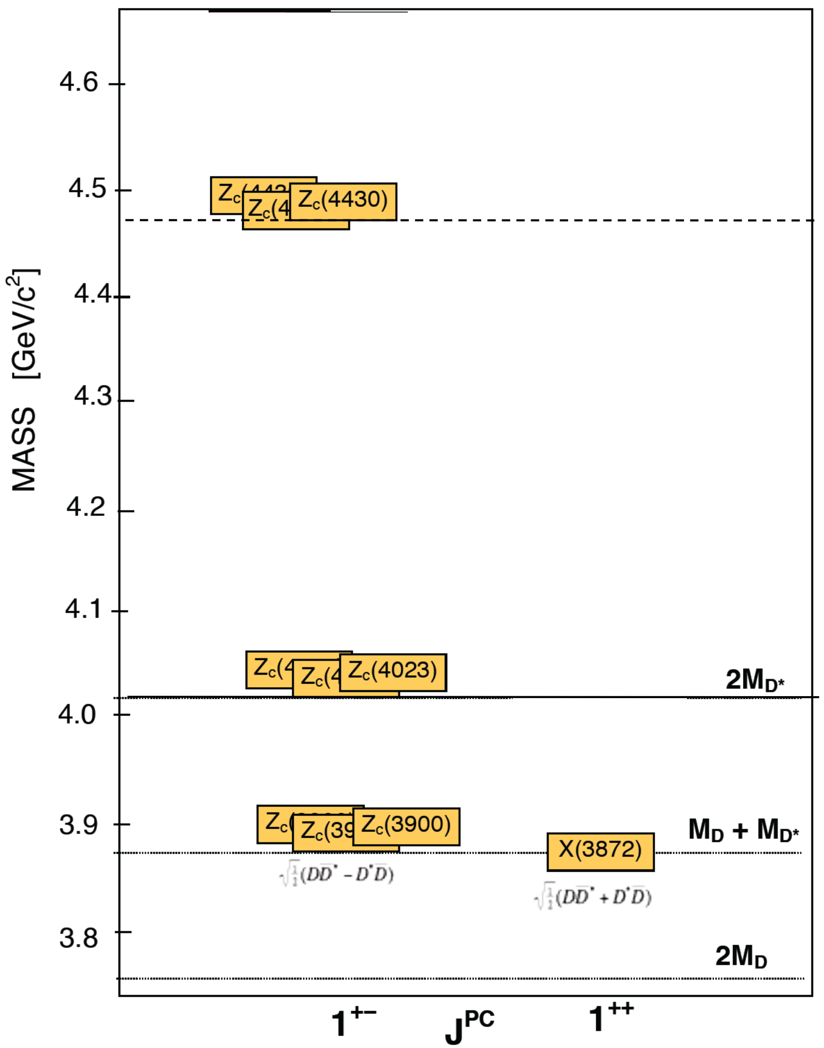
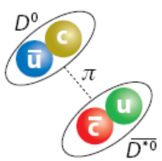


observed

The $J^P=1^+$ charmoniumlike states



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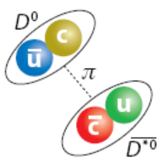
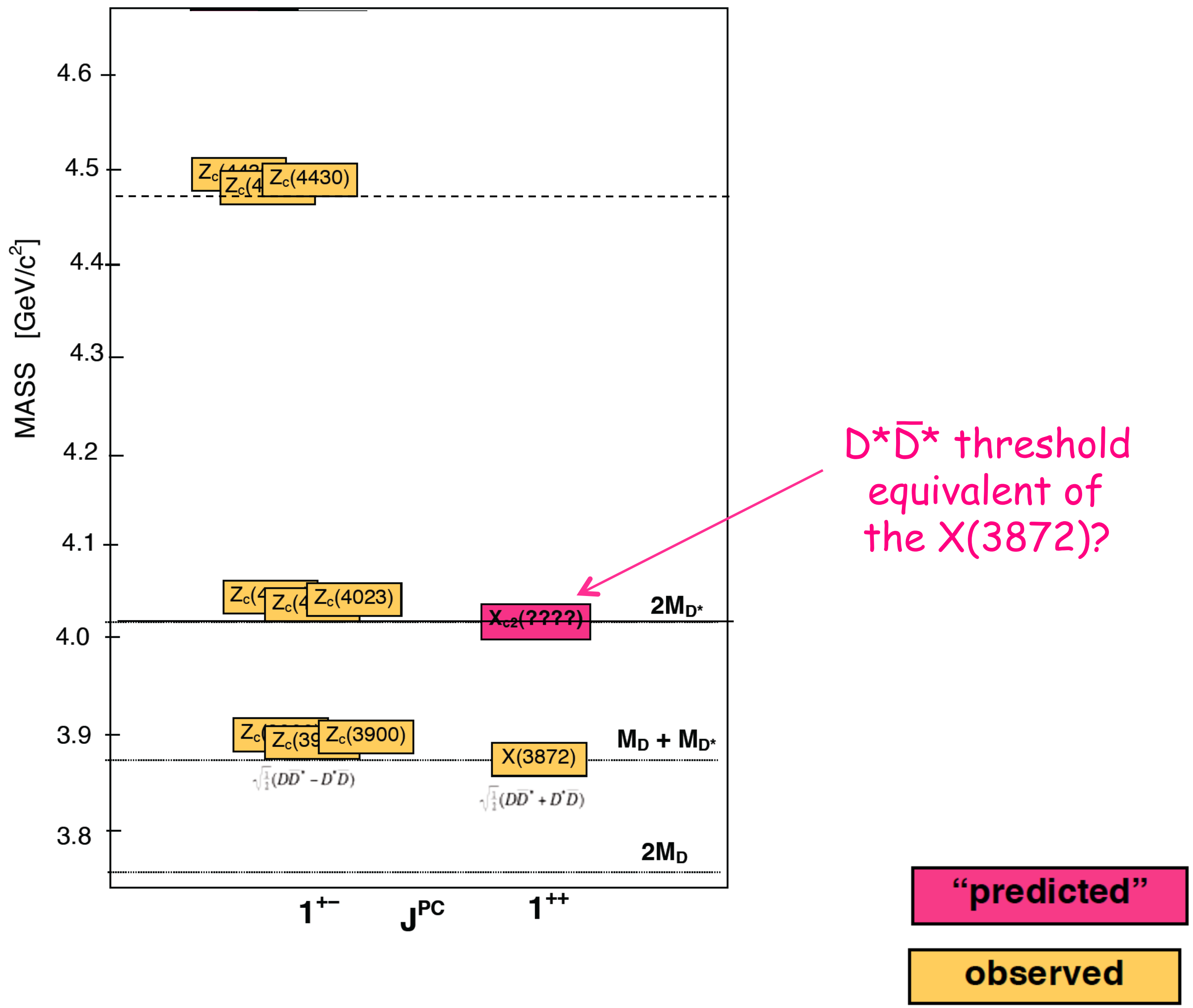
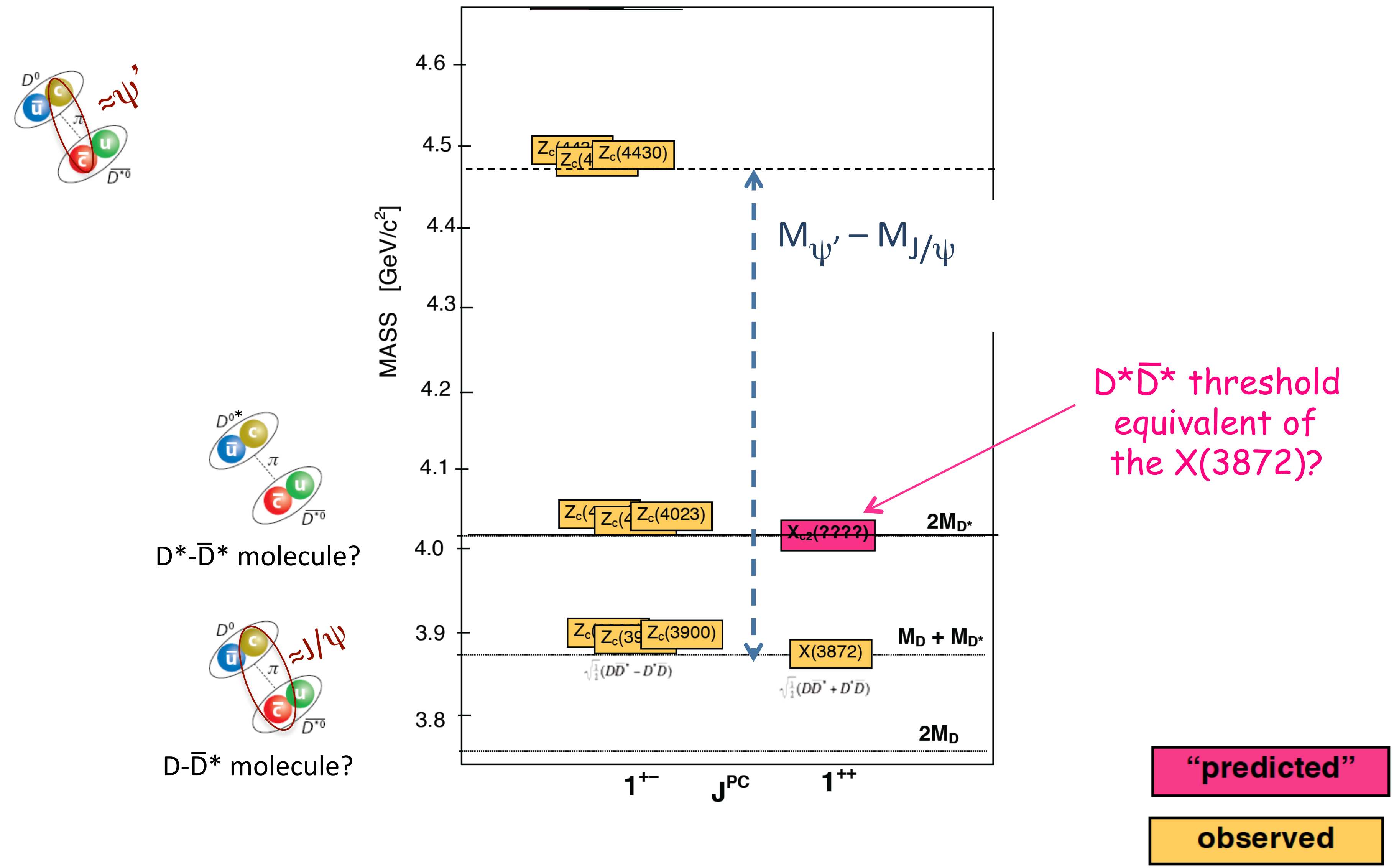


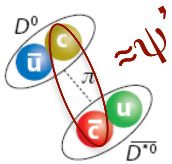
D-D̄* molecule?

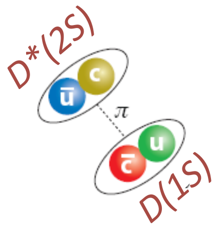


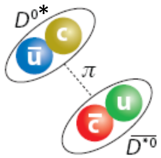
The $J^P=1^+$ charmoniumlike states



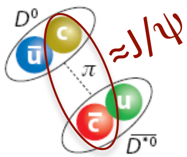
The $J^P=1^+$ charmoniumlike states



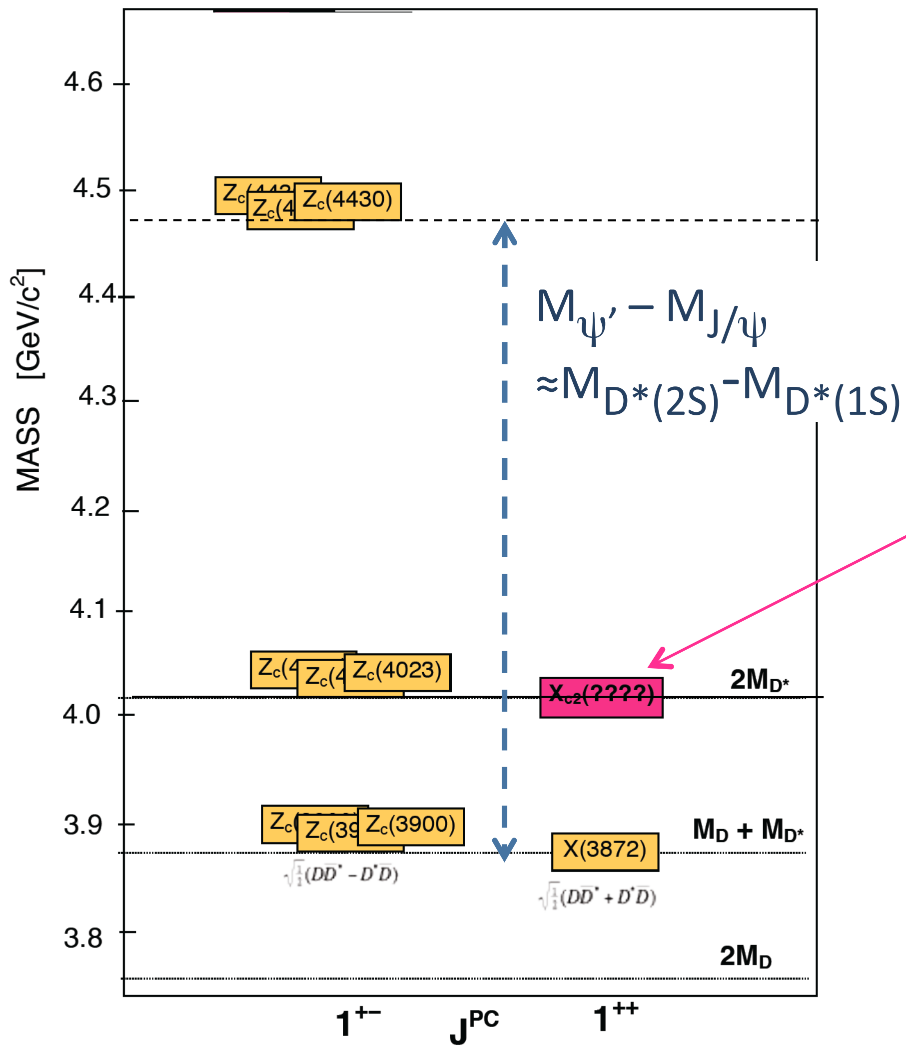




D*-D̄* molecule?



D-D̄* molecule?



BaBar PRD 83, 032004 (2011)

$$M_{D(2S)} = 2540 \pm 8 \text{ MeV}$$

$$M_{D^*(2S)} = 2609 \pm 4 \text{ MeV}$$

D*D̄* threshold equivalent of the X(3872)?

"predicted"

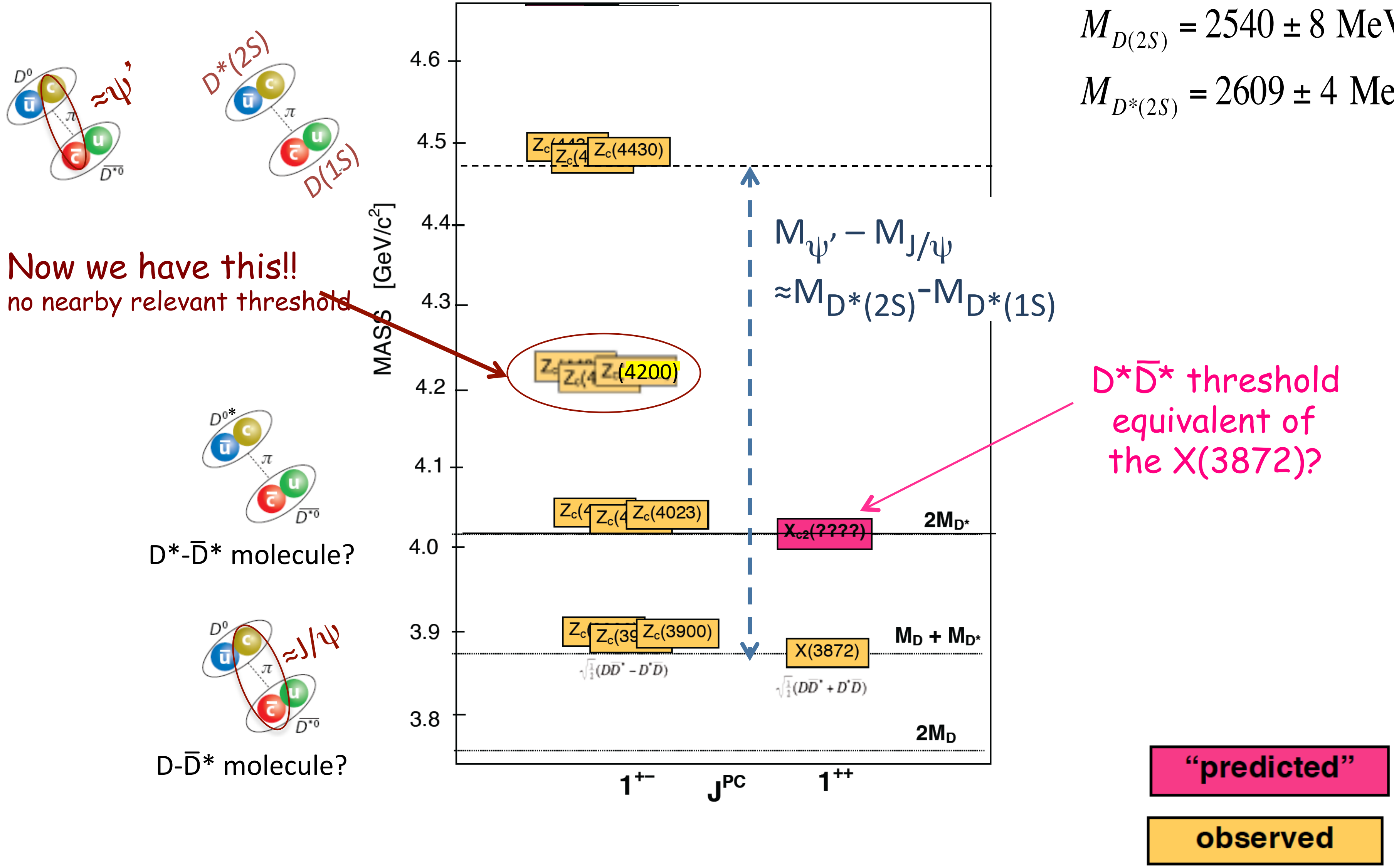
observed

The $J^P=1^+$ charmoniumlike states

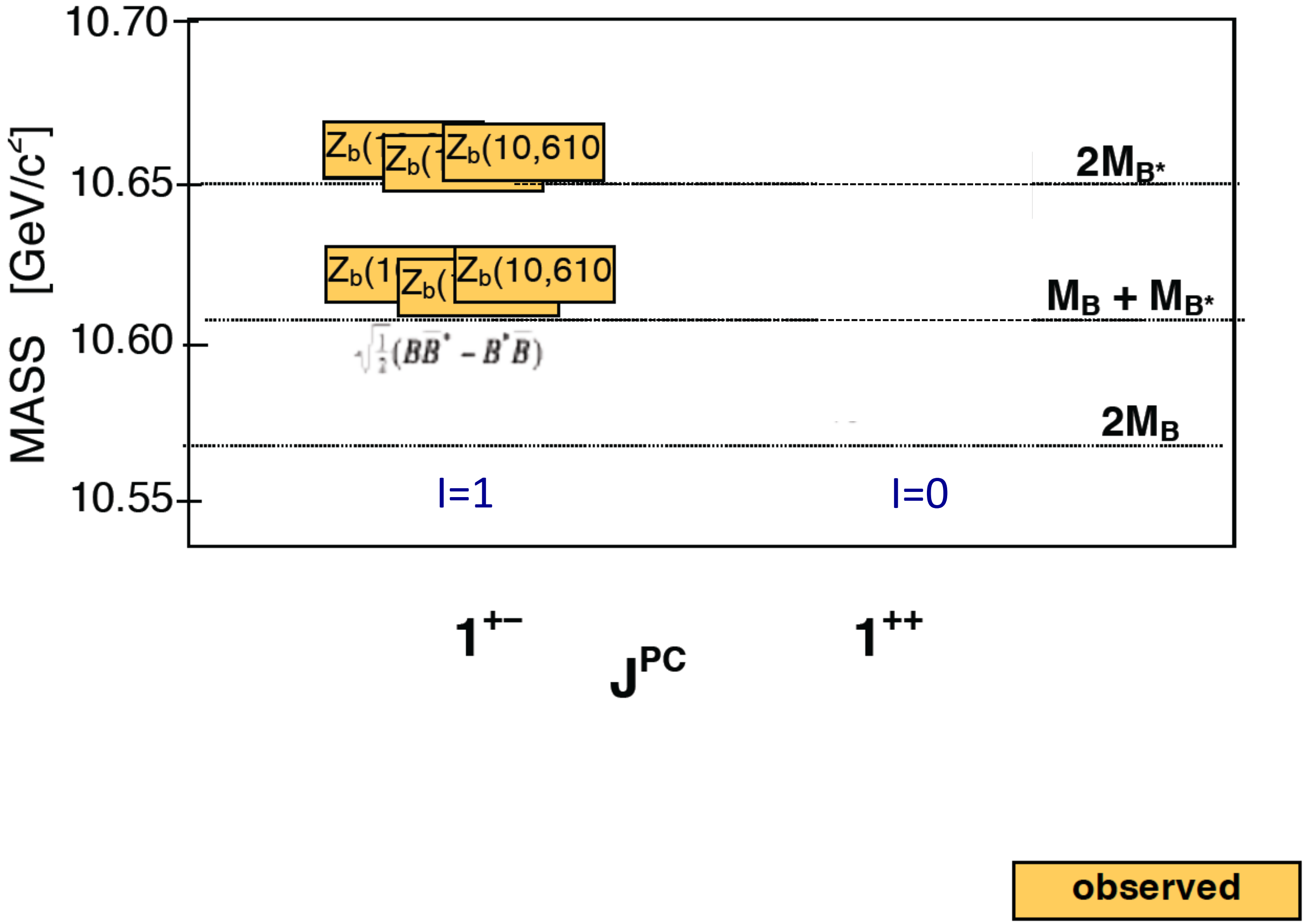
BaBar PRD 83, 032004 (2011)

$$M_{D(2S)} = 2540 \pm 8 \text{ MeV}$$

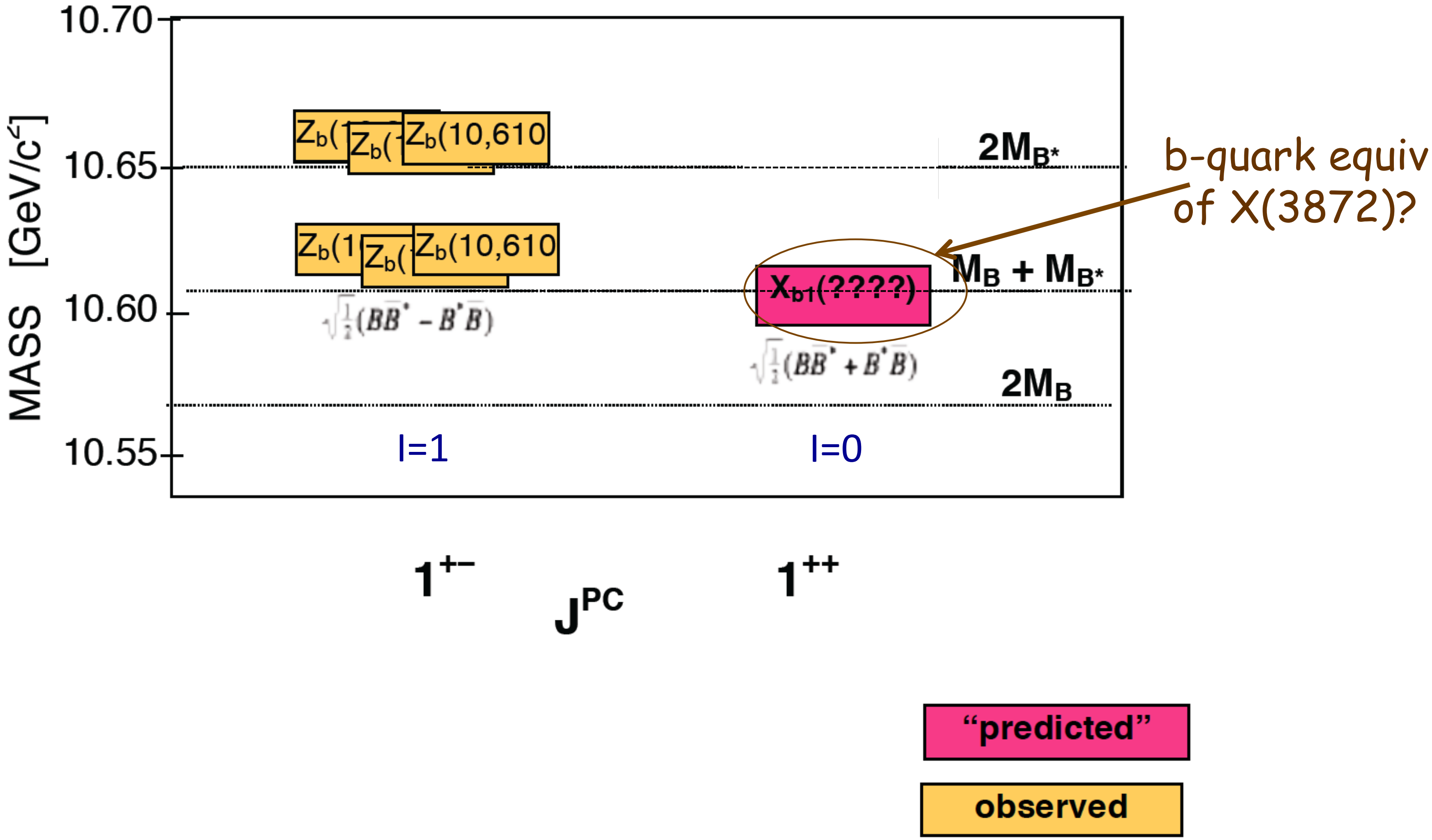
$$M_{D^*(2S)} = 2609 \pm 4 \text{ MeV}$$



The $J^P=1^+$ bottomonium states?

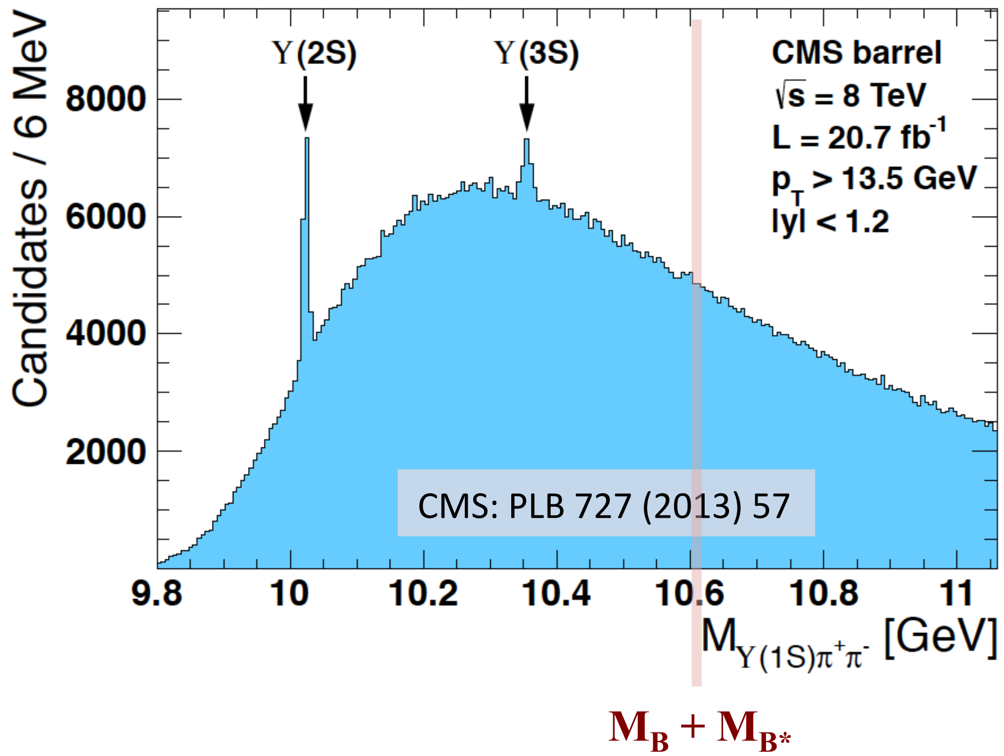


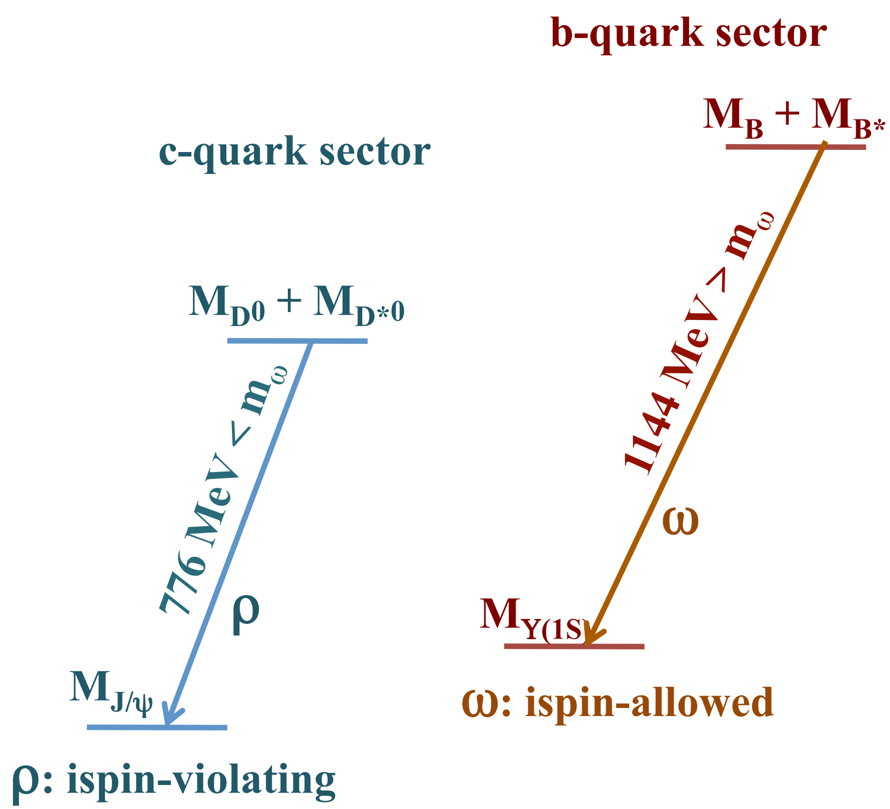
The $J^P=1^+$ bottomonium states?



CMS search for b-sector version of X(3872)

$$pp \rightarrow \pi^+\pi^-\Upsilon(1S) + anything$$





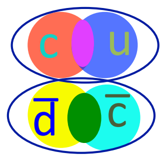
relevant X_b transition is ispin-allowed $X_b \rightarrow \omega\Upsilon(1S)$

can LHCb &/or CMS do this?

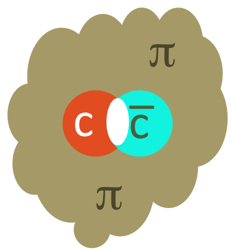
Proposed structures for the new mesons

Molecules

QCD tetraquarks



Hadrocharmonium



(NB: QCD-hybrids & glueballs have no charged quarkoniumlike states)

Molecules?

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

-- sometimes very close: $M_{X(3872)}=m_{D^0}+m_{D^{0*}}$ 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:

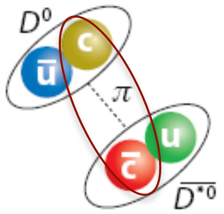
-- some states are not close to thresholds

-- difficult to account for large decays to hidden quarkonium

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

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

not so small



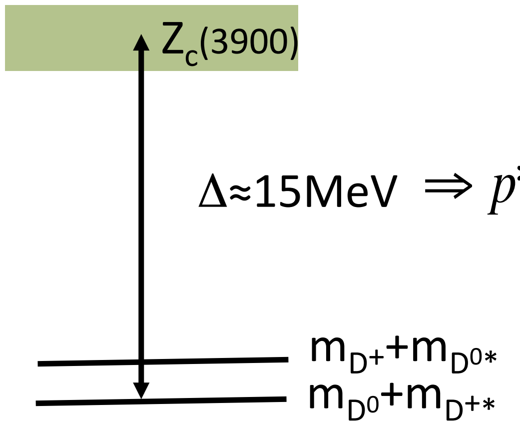
the c and $\bar{c}$ quarks:
--don't have much overlap
--colors are uncorrelated

-- X(3872) production in high energy pp collisions similar to that for ψ'

$Z_c(3900)$ is not so close to $m_D + m_{D^*}$

Not so close to threshold:

$M_{Zc(3900)} = 3890 \pm 3$ MeV



$m_{D^0} + m_{D^{*+}} = 3875$ MeV

$\Delta \approx 15\text{MeV} \Rightarrow p^* = \sqrt{2\mu_D \Delta} \approx 170$ MeV

pretty large for an S-wave resonance
(no centrifugal barrier)

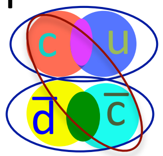
QCD tetraquarks?

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 okay

-- many detailed predictions

problems:

-- many of the detailed predictions were wrong

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

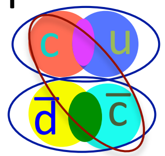
QCD tetraquarks?

good points:

-- decays to hidden charmonium not suppressed

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

-- colors are correlated



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--- production in high energy pp collisions o...

-- many detailed predictions

problems:

-- many of the detailed ... ong

prediction ... periment

-- X(38... | only 1 X(3872)

$M_{Zc(4020)}$= 4023 MeV

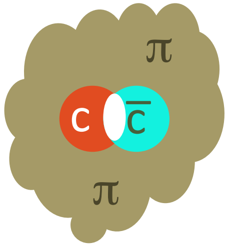
...MeV

$\frac{\ldots \omega J/\psi)}{\Gamma(Z_c \to D\bar{D}^*)} \approx 7$

$\frac{\Gamma(Z_c \to \pi J/\psi)}{\Gamma(Z_c \to D\bar{D}^*)} = 0.16 \pm 0.07$

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

Hadrocharmonium?



good points:

large hadronic transitions to hidden quarkonium are ok

explains mass and ψ' affinity of the $Z_c(4430)$

problems:

mass patterns should track quarkonium levels

predicts very (too) large value for $\Gamma(Z(3900)) \rightarrow \pi^- J/\psi)$

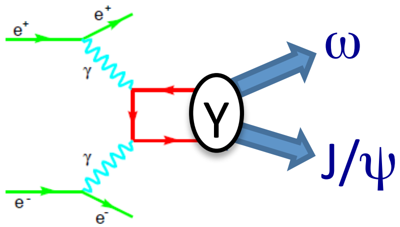
has trouble with $\Gamma(Z_{b1,2} \rightarrow \pi^- \Upsilon(nS))_{(n=1,2,3)} \approx \Gamma(Z_{b1,2} \rightarrow \pi^- h_b(mP))_{(m=1,2)}$

predicted a $Z_c(3900)$ partner at lower mass

The X(3915)

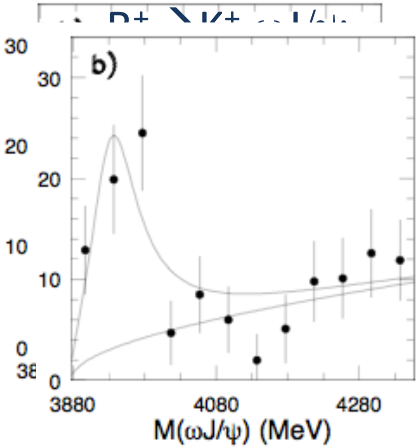
aka Y(3940)

X(3915)→ωJ/ψ



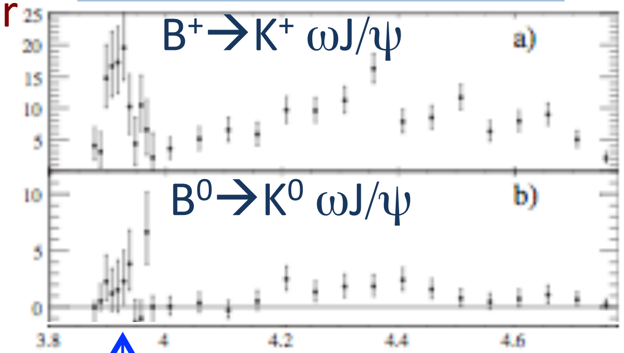
S.-K. Choi et al. (Belle) PRL 94, 182002

Belle
2005



B. Aubert et al. (BaBar) PRL101, 182001

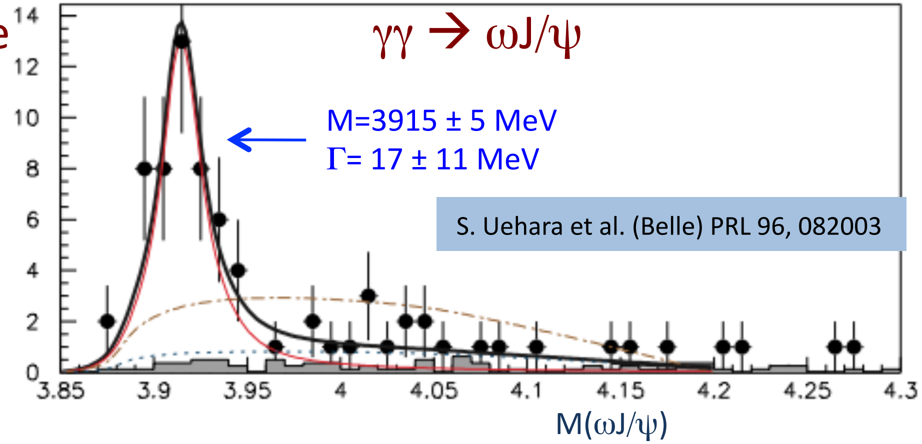
BaBar
2008



M=3915 ± 5 MeV
Γ= 34 ± 13 MeV

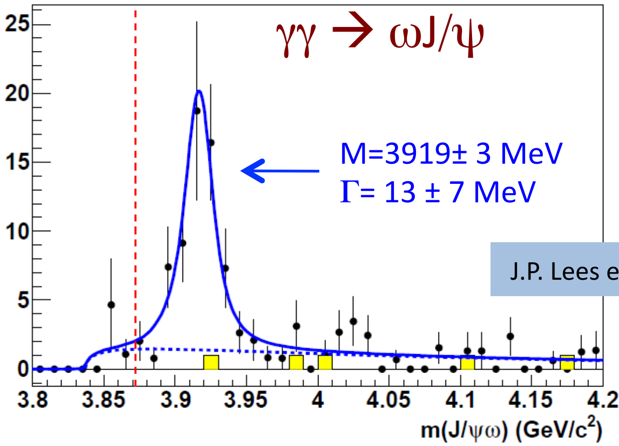
M(ωJ/ψ)

Belle
2010



M=3915 ± 5 MeV
Γ= 17 ± 11 MeV

S. Uehara et al. (Belle) PRL 96, 082003



M=3919± 3 MeV
Γ= 13 ± 7 MeV

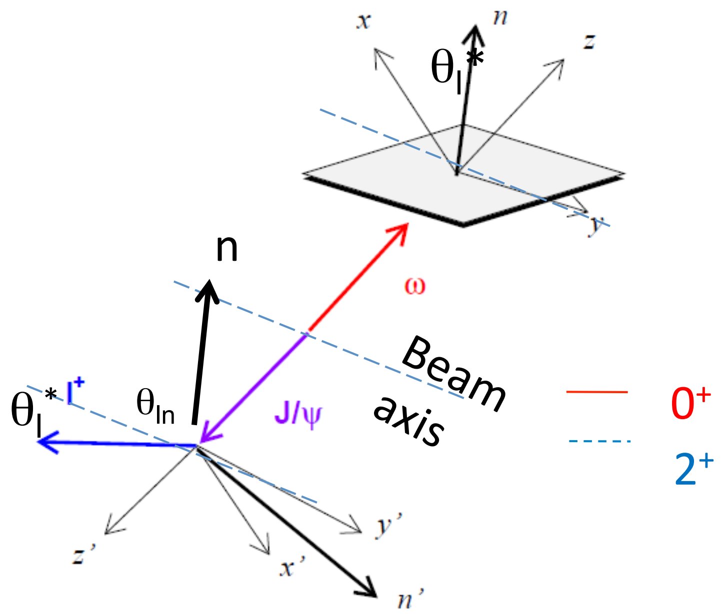
BaBar
2012

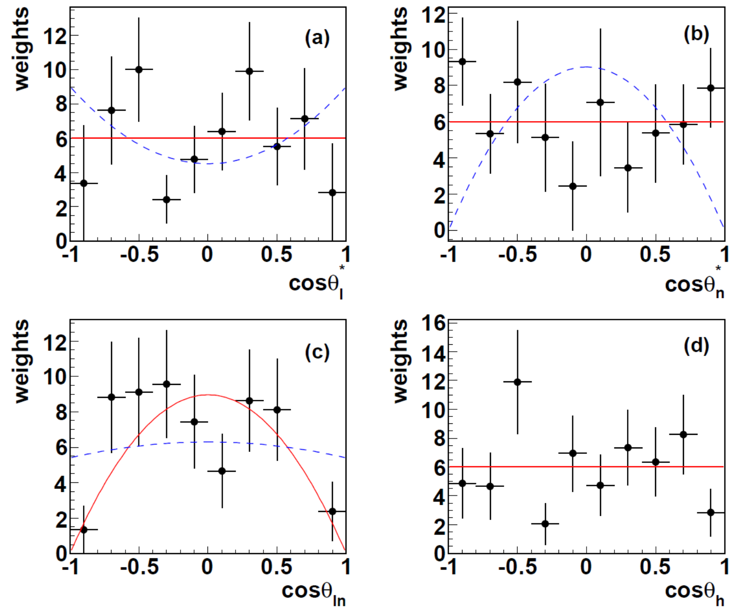
J.P. Lees et al. (BaBar) PRD 86, 072002

PDG: $Bf(B \to X(3915))Bf(X(3915) \to \omega J/\psi) = (3.0^{+0.9}_{-0.7}) \times 10^{-5}$

PDG: $\Gamma(X(3915) \to \gamma\gamma)Bf(X(3915) \to \omega J/\psi) = (54 \pm 9)\mathrm{eV}$

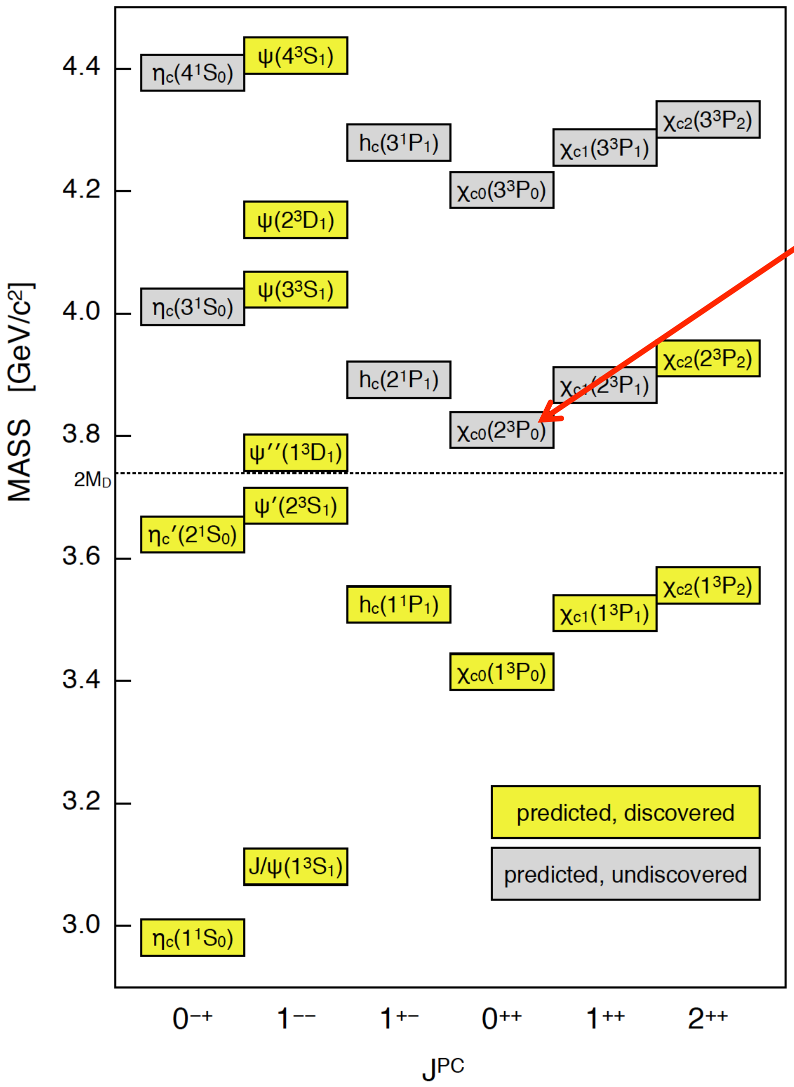
BaBar measurements favor $J^{PC}=0^{++}$





J.P. Lees et al. (BaBar) PRD 86, 072002

PDG: X(3915) = χ_{c0}' ?



$\chi_{c0}(2P)$
was $X(3915)$

$I^G(J^{PC}) = 0^+(0^{++})$

$\chi_{c0}(2P)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
3918.4 ± 1.9 OUR AVERAGE				
3919.4 ± 2.2 ± 1.6	59 ± 10	LEES 12AD	BABR	$e^+e^- \to e^+e^-\omega J/\psi$
$3919.1^{+3.8}_{-3.4} \pm 2.0$		DEL-AMO-SA...10B	BABR	$B \to \omega J/\psi K$
3915 ± 3 ± 2	49 ± 15	UEHARA 10	BELL	10.6 $e^+e^- \to e^+e^-\omega J/\psi$
3943 ± 11 ± 13	58 ± 11	[1] CHOI 05	BELL	$B \to \omega J/\psi K$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$3914.6^{+3.8}_{-3.4} \pm 2.0$		[1] AUBERT 08W	BABR	Superseded by DEL-AMO-SANCHEZ 10B

[1] $\omega J/\psi$ threshold enhancement fitted as an S-wave Breit-Wigner resonance.

$\chi_{c0}(2P)$ WIDTH

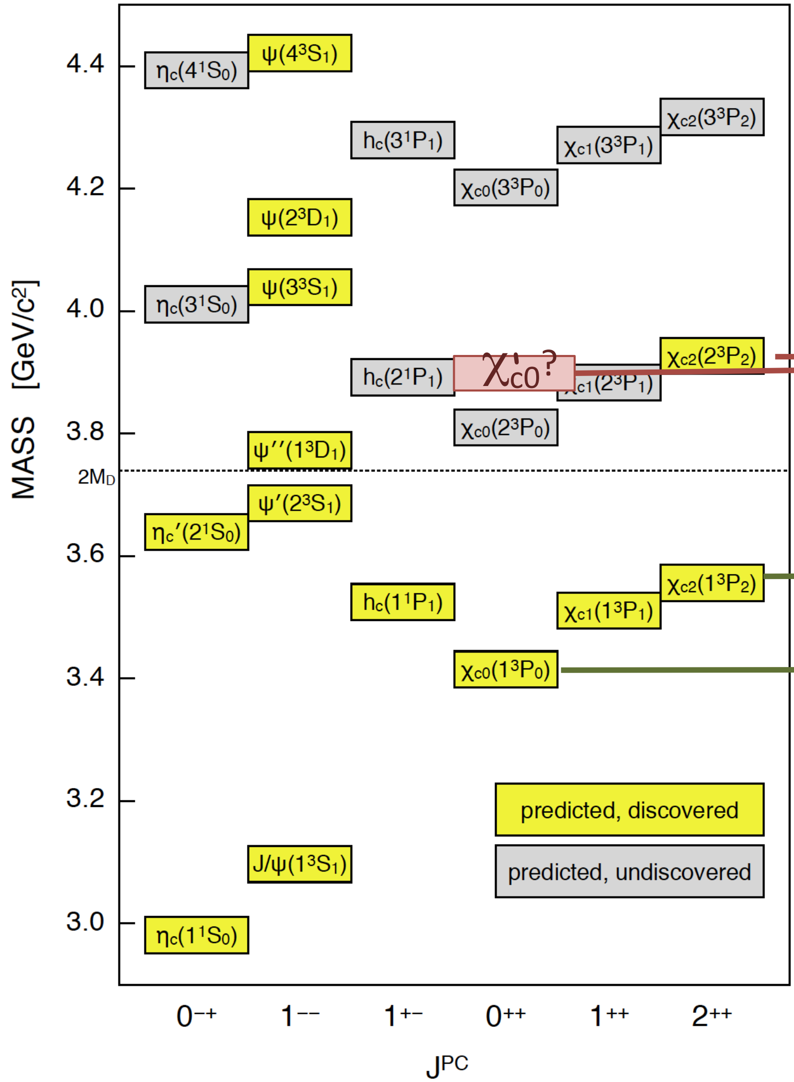
VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
20 ± 5 OUR AVERAGE		Error includes scale factor of 1.1.		
13 ± 6 ± 3	59 ± 10	LEES 12AD	BABR	$e^+e^- \to e^+e^-\omega J/\psi$
$31^{+10}_{-8} \pm 5$		DEL-AMO-SA...10B	BABR	$B \to \omega J/\psi K$
17 ± 10 ± 3	49 ± 15	UEHARA 10	BELL	10.6 $e^+e^- \to e^+e^-\omega J/\psi$
87 ± 22 ± 26	58 ± 11	[2] CHOI 05	BELL	$B \to \omega J/\psi K$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$34^{+12}_{-8} \pm 5$		[2] AUBERT 08W	BABR	Superseded by DEL-AMO-SANCHEZ 10B

[2] $\omega J/\psi$ threshold enhancement fitted as an S-wave Breit-Wigner resonance.

$\chi_{c0}(2P)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$\omega J/\psi$	seen
Γ_2	$\overline{D}^{*0} D^0$	
Γ_3	$\pi^+\pi^-\eta_c(1S)$	not seen
Γ_4	$\gamma\gamma$	seen

Can the X(3915) be the χ_{c0}'?



Mass is way off!

If $X(3915) = \chi_{c0}$: $\Delta M(2P) = M(\chi_{c2}(2P)) - M(\chi_{c0}(2P)) = (8.8 \pm 3.2)\text{MeV}$

PDG: $\Delta M(1P) = M(\chi_{c2}(1P)) - M(\chi_{c0}(1P)) = (142.4 \pm 0.4)\text{MeV}$

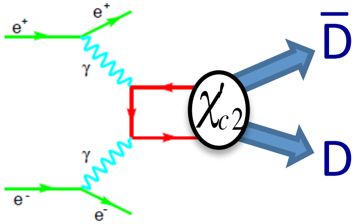
If $X(3915) = \chi_{c0}^{/}$: $\dfrac{\Delta M(2P)}{\Delta M(1P)} = 0.06 \pm 0.02$

Theory: non-rel: $\Rightarrow 0.55$ — T.Barnes, S.Godfrey & E.Swanson PRD 72, 054026 (2004)

relativized: $\Rightarrow 0.91$ — S.Godfrey & N.Isgur PRD 32, 189 (1985)

$Bf(\chi'_{c0} \rightarrow \omega J/\psi)$ from $\gamma\gamma \rightarrow X(3915)$

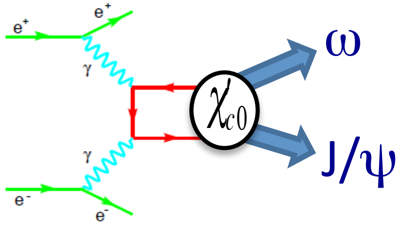
from: $\gamma\gamma \rightarrow X(3915)$; $X(3915) \rightarrow \omega J/\psi$ production rate, assuming $X(3915)=\chi_{c0}$



$$\boxed{\Gamma(\chi'_{c2} \rightarrow \gamma\gamma)Bf(\chi'_{c2} \rightarrow D\bar{D}) = (0.21 \pm 0.04)\text{keV}} \Rightarrow \Gamma(\chi'_{c2} \rightarrow \gamma\gamma) > 0.16 \text{ keV}$$

$$\text{assume}: \frac{\Gamma(\chi'_{c0} \rightarrow \gamma\gamma)}{\Gamma(\chi'_{c0} \rightarrow \gamma\gamma)} = \frac{\Gamma(\chi_{c0} \rightarrow \gamma\gamma)}{\Gamma(\chi_{c2} \rightarrow \gamma\gamma)} \Rightarrow \chi'_{c0} > 0.8 \text{ keV}$$

$$\Rightarrow \quad \Gamma(\chi'_{c2} \rightarrow \gamma\gamma) > 0.80 \text{ keV}$$



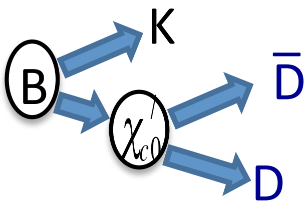
$$\boxed{\Gamma(\chi'_{c0} \rightarrow \gamma\gamma)Bf(\chi'_{c0} \rightarrow \omega J/\psi) = (54 \pm 9)\text{eV}}$$

$$\Rightarrow Bf(\chi'_{c0} \rightarrow \omega J/\psi) = \frac{(54 \pm 9)\text{eV}}{\Gamma(\chi_{c0} \rightarrow \gamma\gamma)}$$

$$\boxed{\Rightarrow \quad Bf(\chi'_{c0} \rightarrow \omega J/\psi) < 5.6\%}$$

$Bf(\chi_{c0} \rightarrow \omega J/\psi)$ from $B \rightarrow KX(3915)$

from: $B \rightarrow K^+ X(3915)$; $X(3915) \rightarrow \omega J/\psi$ decay rate, assuming $X(3915)=\chi'_{c0}$



PDG average of Belle & BaBar measurements:

$$Bf(B \rightarrow KX_{3915}) \times Bf(X_{3915} \rightarrow \omega J/\psi) = (3.0^{+0.9}_{-0.7}) \times 10^{-5}$$

If Y(3915) = χ'_{c0}, & we (reasonably) assume: $Bf(B \rightarrow K\chi'_{c0}) \leq Bf(B \rightarrow K\chi_{c0})$:

$$\Rightarrow Bf(\chi'_{c0} \rightarrow \omega J/\psi) > 14\%$$

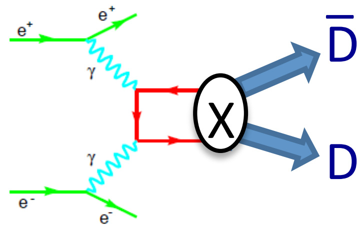
lower limit

in strong contradiction to
to $\gamma\gamma$ prod *upper* limit:

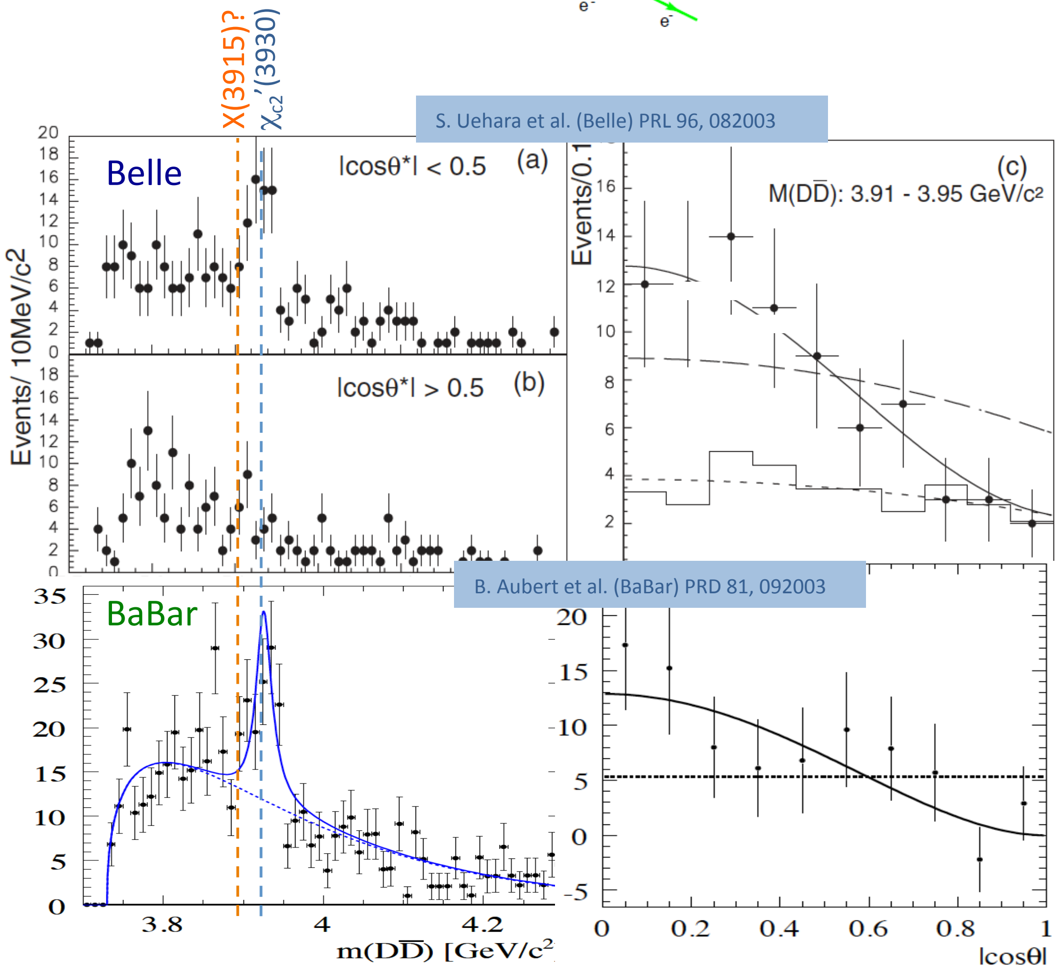
$$Bf(\chi'_{c0} \rightarrow \omega J/\psi) < 5.6\%$$

$Bf(\chi_{c0}' \to D\bar{D})$ from $\gamma\gamma \to D\bar{D}$

from $\gamma\gamma \to X(3915)$; $X(3915) \to D\bar{D}$



No sign of $X(3915) \to D\bar{D}$

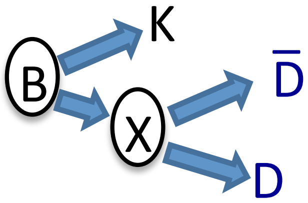


if: $\dfrac{N_{\chi'_{c0}}}{N_{\chi'_{c2}}} < 0.5$

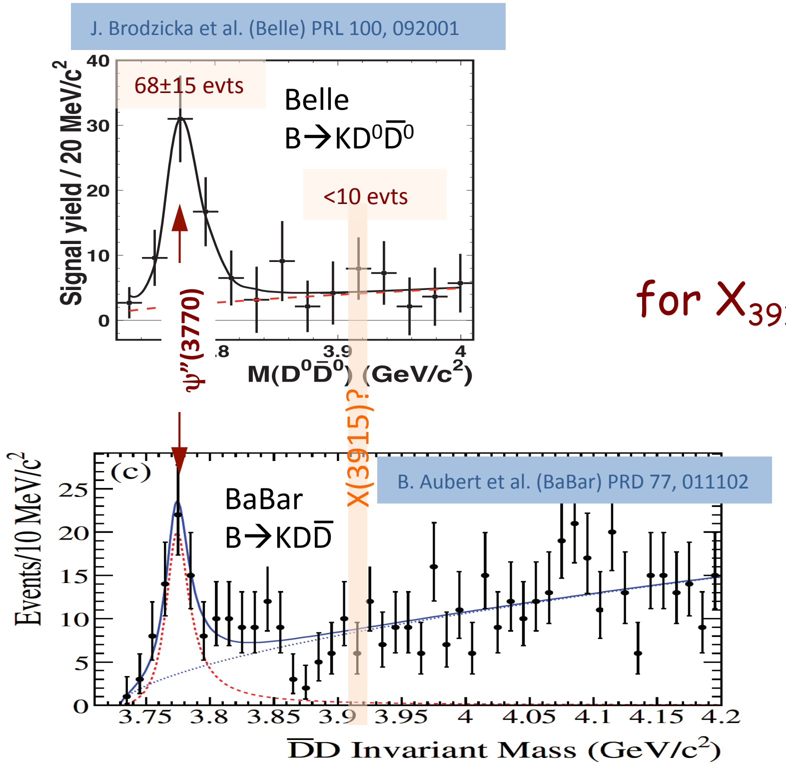
$$\Rightarrow Bf(\chi'_{c0} \to D\bar{D}) < 12\%$$

theory expectation ≈ 100%

$Bf(\chi_{c0}' \rightarrow D\bar{D})$ fom $B \rightarrow KD\bar{D}$



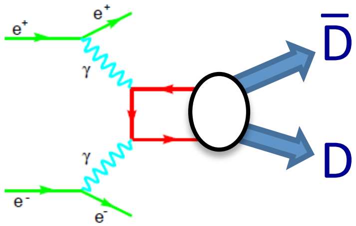
from $B \rightarrow KX(3915)$; $X(3915) \rightarrow D\bar{D}$



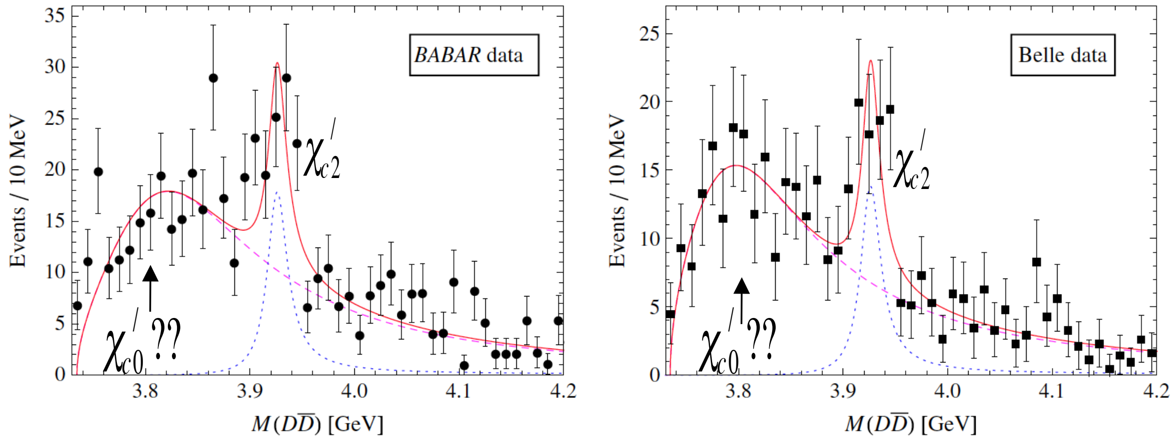
$$\Rightarrow Bf(X_{3915} \rightarrow D^0\bar{D}^0) < 2 \times Bf(X_{3915} \rightarrow \omega J/\psi)$$

for $X_{3915}=\chi_{c0}'$:   expect ~50%   OZI suppressed

Another, more plausible, χ_{c0}' candidate?



F-K Guo & U-G Meissner, PRD 86, 0910501



M(χ_{c0}') =3848 ± 8 MeV
Γ(χ_{c0}') = 229 ± 26 MeV

M(χ_{c0}') =3825 ± 8 MeV
Γ(χ_{c0}') = 212 ± 29 MeV

Guo-Meissner weighed avg →

M(χ_{c0}') =3838 ± 12 MeV
Γ(χ_{c0}') = 221 ± 19 MeV

$$\text{Guo-Meissner } \chi_{c0}' : \quad \frac{\Delta M(2P)}{\Delta M(1P)} = 0.63 \pm 0.09$$

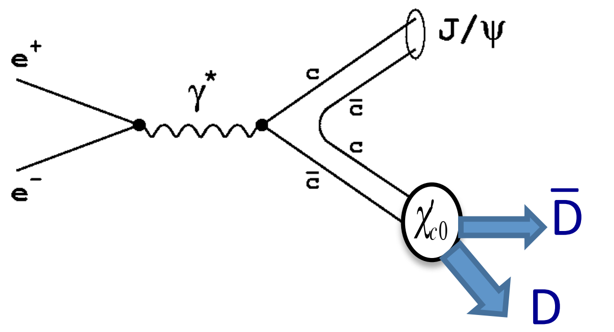
$$\text{Theory: non-rel:} \quad \Rightarrow 0.55$$

$$\text{relativized:} \quad \Rightarrow 0.91$$

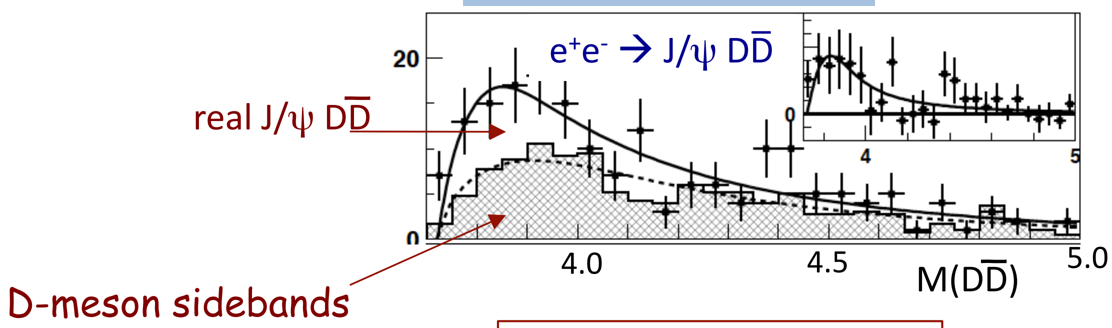
agreement

Another χ_{c0}' candidate? cont'd

$e^+e^- \rightarrow J/\psi\chi_{c0}'$
$\hookrightarrow D\bar{D}$??



P. Pakhlov et al. (Belle): PRL 100, 202001



$M(\chi_{c0}') = 3878 \pm 48$ MeV
$\Gamma(\chi_{c0}') = 347^{+316}_{-143}$ MeV

Agrees, within errors with Guo-Meissner →

$M(\chi_{c0}') = 3838 \pm 12$ MeV
$\Gamma(\chi_{c0}') = 221 \pm 19$ MeV

If X(3915) = χ_{c0}' :

$\Rightarrow$ Mass is too high: $R \equiv \frac{\Delta M(2P)}{\Delta M(1P)} = 0.06 \pm 0.02$ theory: $R = 0.5 \leftrightarrow 0.9$

$\Rightarrow$ production via $\gamma\gamma$: $Bf(\chi_{c0}' \to \omega J/\psi) < 5.6\%$

via B decays: $Bf(\chi_{c0}' \to \omega J/\psi) > 14\%$

contradictory!

$\Rightarrow$ $Bf(\chi_{c0}' \to D\bar{D}) < 0.12\%$

$Bf(\chi_{c0}' \to D^0\bar{D}^0) < 2Bf(\chi_{c0}' \to \omega J/\psi)$

theory:

$Bf(\chi_{c0}' \to D\bar{D}) \approx 100\%$

$Bf(\chi_{c0}' \to D^0\bar{D}^0) >> Bf(\chi_{c0} \to \omega J/\psi)$

$\Rightarrow$ Better candidate exists with:

$$\frac{\Delta M(2P)}{\Delta M(1P)} \approx 0.6 \pm 0.02$$

$$Bf(\chi_{c0}' \to D\bar{D}) \geq Bf(\chi_{c2}' \to D\bar{D})$$

$$Bf(\chi_{c0}' \to D\bar{D}) >> Bf(\chi_{c0}' \to \omega J/\psi)$$

If X(3915) = χ_{c0}' :

$\Rightarrow$ Mass is too high: $R \equiv \dfrac{\Delta M(2P)}{\Delta M(1P)} = 0.06 \pm 0.02$ theory: $R = 0.5 \leftrightarrow 0.9$

$\Rightarrow$ production via $\gamma\gamma$: $Bf(\chi_{c0}' \to \omega J/\psi) < 5.6\%$

via B decays: $Bf(\chi_{c0}' \to \omega J/\psi) > 14\%$ contradictory!

$\Rightarrow$ $Bf(\chi_{c0}' \to D\bar{D}) < 0.12\%$

$Bf(\chi_{c0}' \to D^0\bar{D}^0) < 2Bf(\chi_{c0}' \to \omega J/\psi)$

theory: $Bf(\chi_{c0}' \to D\bar{D}) \approx 100\%$

$Bf(\chi_{c0}' \to D^0\bar{D}^0) >> Bf(\chi_{c0} \to \omega J/\psi)$

$\Rightarrow$ Better candidate exists with: $\dfrac{\Delta M(2P)}{\Delta M(1P)} \approx 0.6 \pm 0.02$

$Bf(\chi_{c0}' \to D\bar{D}) \geq Bf(\chi_{c2}' \to D\bar{D})$

$Bf(\chi_{c0}' \to D\bar{D}) >> Bf(\chi_{c0}' \to \omega J/\psi)$

PDG's assignment of X(3915)=χ_{c0}' is:

probably wrong

&

certainly premature

Summary

- Numerous 4-quark mesons not specific to QCD have been found
  - XYZ mesons containing $c\bar{c}$ and $b\bar{b}$ pairs, some of which are charged.
  - $Z(4430)^-$ confirmed by LHCb, BW-like resonant behavior established
  - Large partial widths for hadronic transitions to quarkonium
    - *e.g.* $\Gamma(Z(4430)^- \rightarrow \pi^- \psi')$>7.5 MeV, $\Gamma(Z(3900)^- \rightarrow \pi^- J/\psi) \approx$2 MeV
  - $Z(4430)^- \rightarrow \pi^- J/\psi$ seen: $Bf(Z(4430)^- \rightarrow \pi^- J/\psi) << Bf(Z(4430)^- \rightarrow \pi^- \psi')$
  - Many states are near thresholds (a`la molecules), but not all.

- No single model reproduces the observed properties of all states
  - molecule models have trouble with:
    - large $(\pi^+)\pi^- J/\psi$ & $(\pi^+)\pi^- \Upsilon(nS)$ decay widths
    - states not near threshold
    - production (at least for the X(3872))
  - QCD tetraquark-based (& hadrocharmonium) models have trouble with:
    - mass and decay-width predictions

- PDG assignment of the X(3915) as the χ_{c0}' is probably wrong
  - see my poster in the next session