Review on Quarkonium Physics

recent progress

many outstanding issues for the future

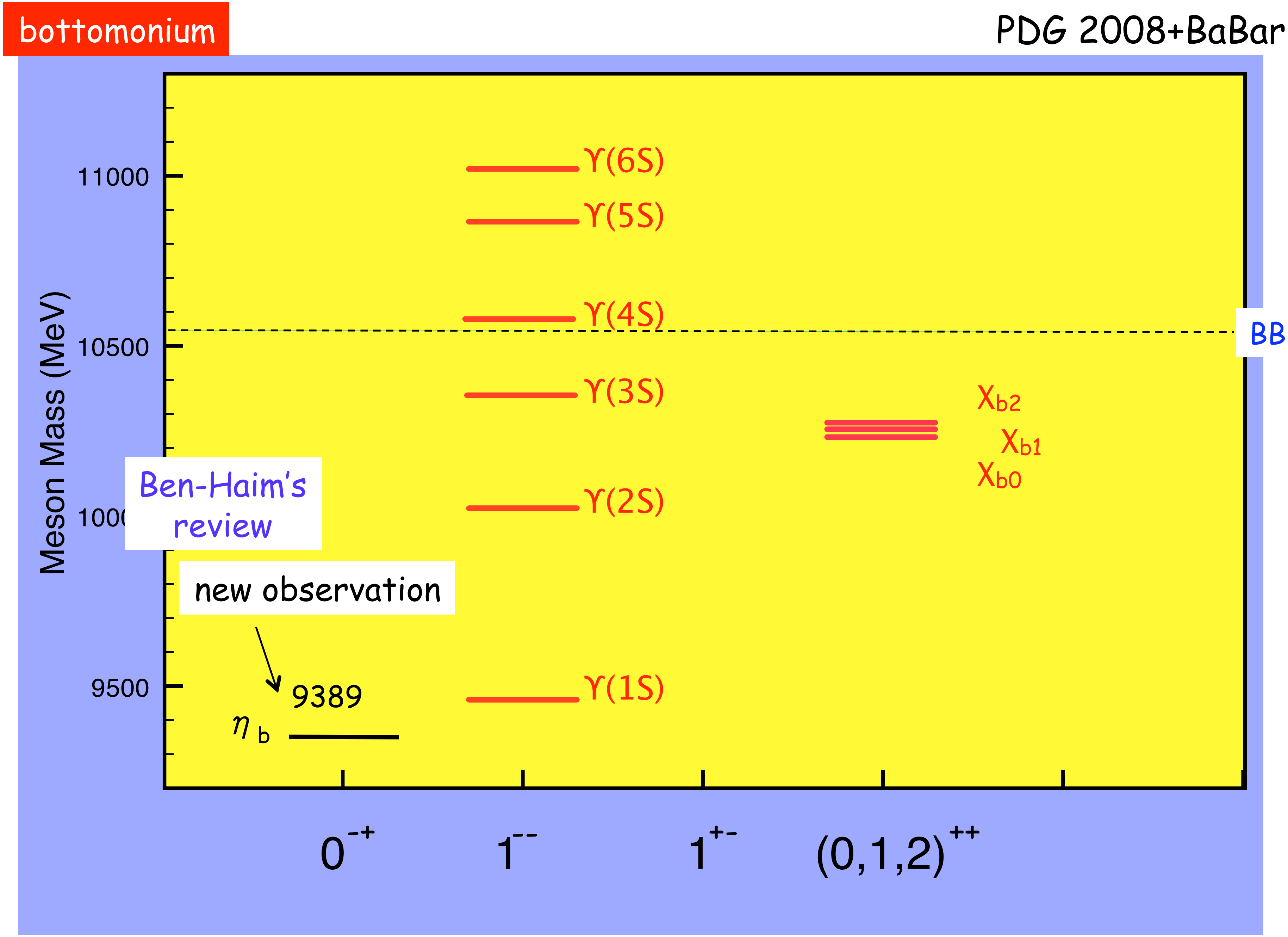
Pietro Colangelo - INFN - Bari - Italy
EuroFlavour08
Durham, UK, 22-27September 2008

Phenomenology:

- News in bottomonium and charmonium
- Problems

Theory:

- Progress in Effective Theories
- Determination of Standard Model parameters



bottomonium
PDG 2008+BaBar
Meson Mass (MeV)
11000
10500
1000
9500
ϒ(6S)
ϒ(5S)
ϒ(4S)
BB
ϒ(3S)
Xb2
Xb1
Xb0
Ben-Haim's review
ϒ(2S)
new observation
9389
η b
ϒ(1S)
0-+
1--
1+-
(0,1,2)++

BaBar 2008

$\Upsilon(3S) \to \eta_b \, \gamma$

$$M(\eta_b) = 9388^{+3.1}_{-2.3} \pm 2.7 \quad \text{MeV}$$

$$M(\Upsilon(1S)) - M(\eta_b) = 71.4^{+2.3}_{-3.1} \pm 2.7 \quad \text{MeV}$$

	$M_{\Upsilon(1S)} - M_{\eta_b}$ [MeV]	Ref
lattice NRQCD	19 – 100	Bali (2000) El-Khadra (1995) et al
lattice potential	60 – 110	Bali (1997)
pQCD	36 – 55	Brambilla (2001)
$1/m$ expansion	34 – 114	Narison (1995)
potential model	57 – 141	Rosner, Barnes, Eichten, Ebert et al. (1994-2000)

TH:
Liao & Manke 2002
Recksiegel & Sumino 2004
Ebert, Faustov & Galkin 2003
Kniehl et al, 2004
Nardulli et al, 2007

$$M(\Upsilon(1S)) - M(\eta_b) \overset{TH}{=} 35 - 60 \text{ MeV}$$

- hyperfine splitting sligthly larger than predicted:
  refinement needed in theory analyses

- input for an independent determination of $\alpha_s(M_{Y(1S)})$ and m_b

(FlaviaNet members)

- possibility of observing η_b decays: $\eta_b \to \gamma\gamma$

analysis based on heavy quark spin symmetry

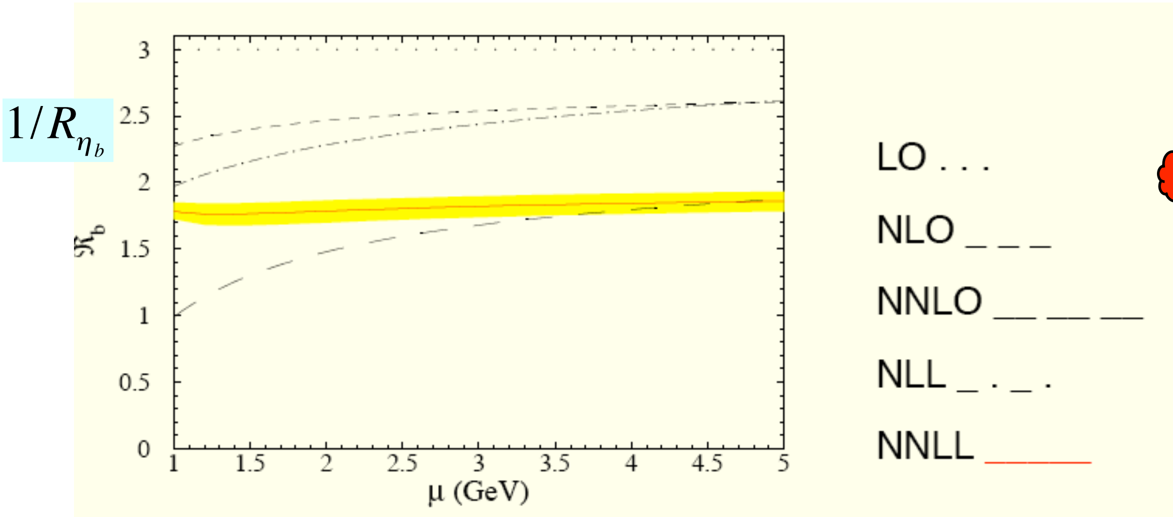
Lansberg & Pham 07

$$R_{\eta_b} = \frac{\Gamma_{\gamma\gamma}(\eta_b)}{\Gamma_{\ell\bar{\ell}}(\Upsilon)} = 3\,Q_b^2\,\frac{M_\Upsilon}{M_{\eta_b}}\left(1 + \frac{\alpha_s}{\pi}\frac{(\pi^2-4)}{3}\right)$$

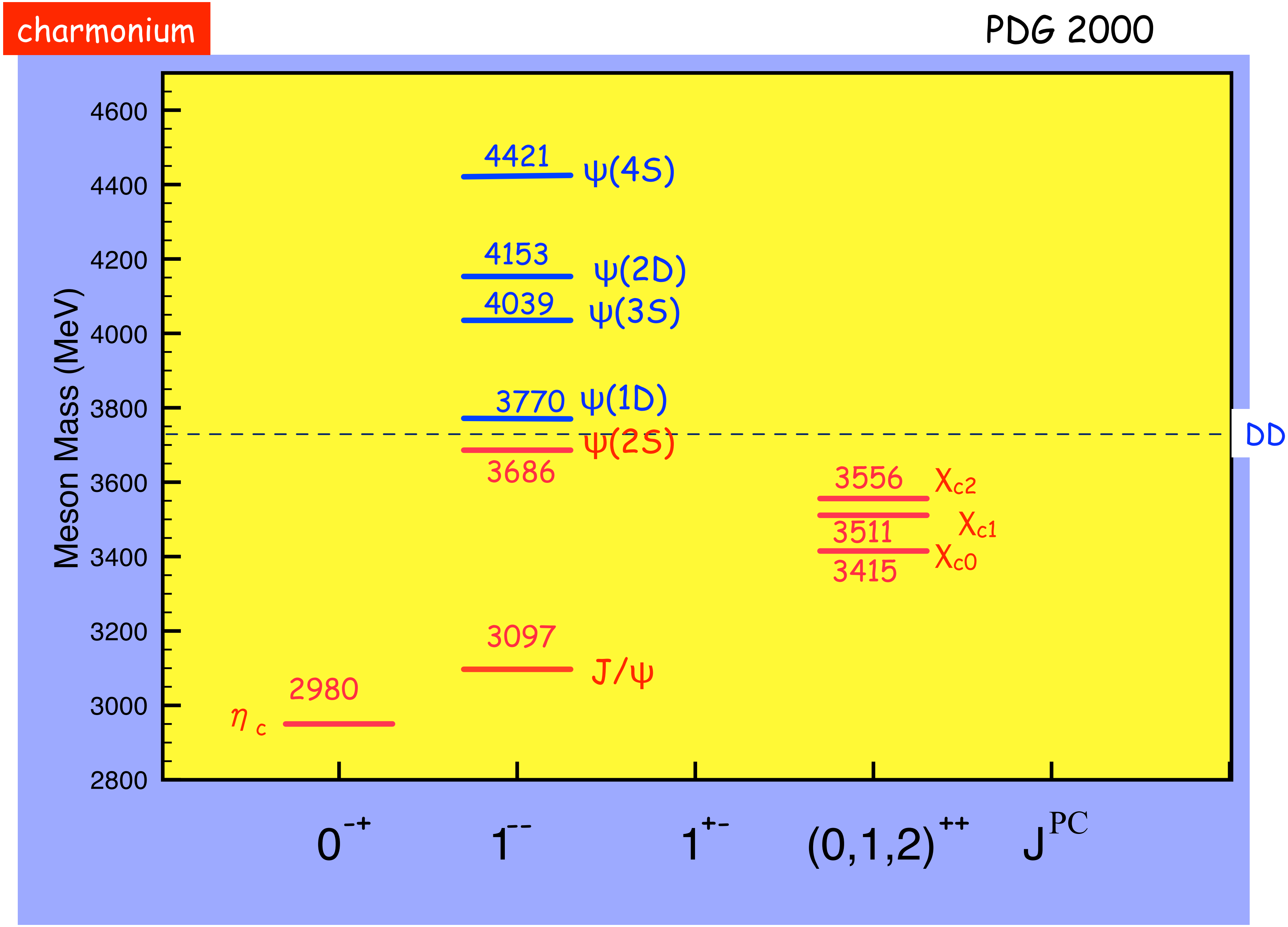
$\Gamma_{\gamma\gamma}$	This paper	Sch. [22]	Lak. [17]	Ack. [23]	Kim [24]	Ahm. [25]	Mün. [26]	Eb. [27]	God. [18]	Fab. [28]	Pen. [19]
η_b	560	460	230	170	384 ± 47	520	220 ± 40	350	214	466 ± 101	659 ± 92
η_b'	269	200	70	-	191 ± 25	-	110 ± 20	150	121	-	-
η_b''	208	-	40	-	-	-	84 ± 12	100	90.6	-	-

TABLE I: Summary of theoretical predictions for $\Gamma_{\gamma\gamma}(\eta_b)$, $\Gamma_{\gamma\gamma}(\eta_b')$ and $\Gamma_{\gamma\gamma}(\eta_b'')$. (All values are in units of eV).

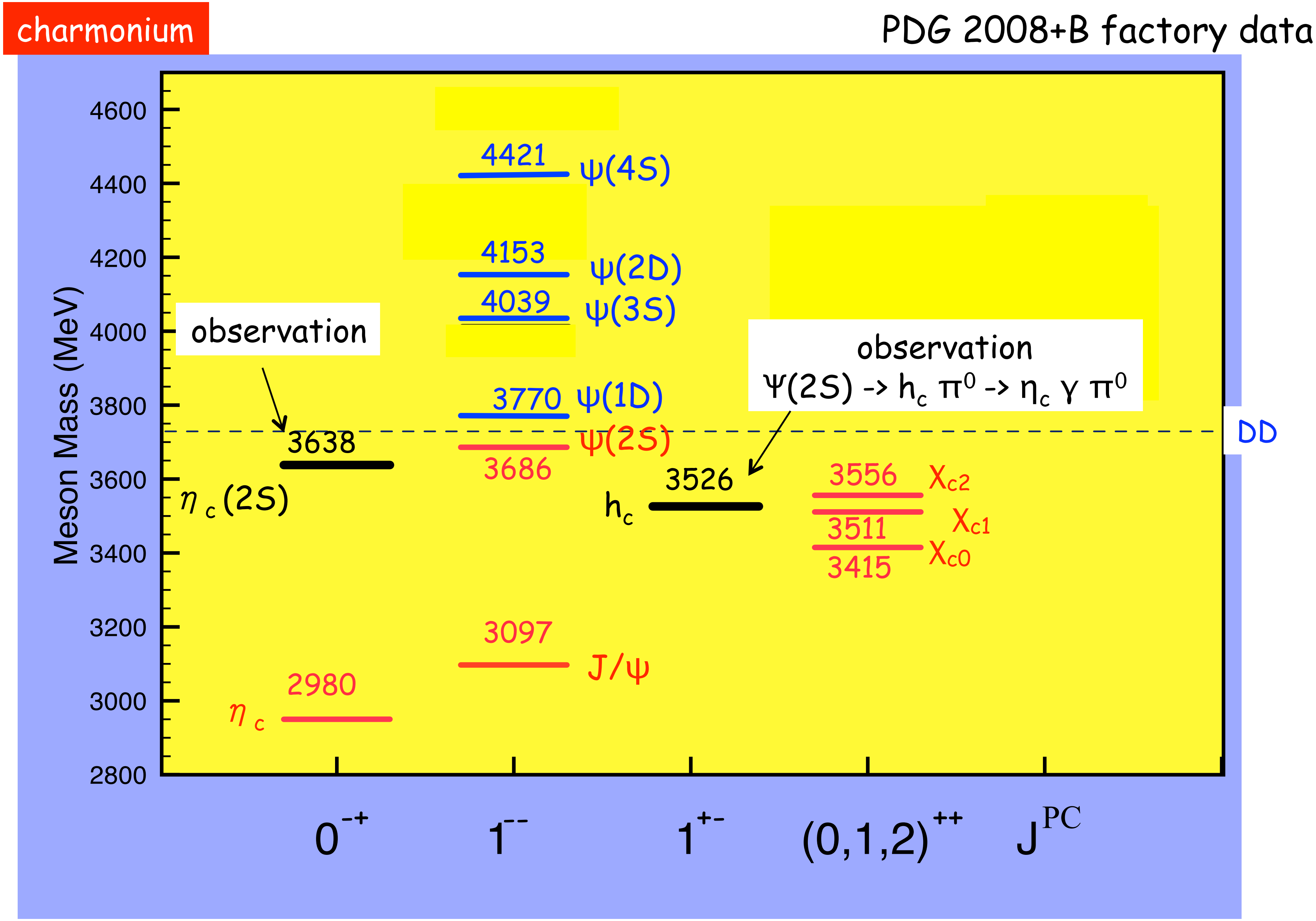
$1/m_b$ corrections to be determined



Penin et al 04
Pineda & Signer 06



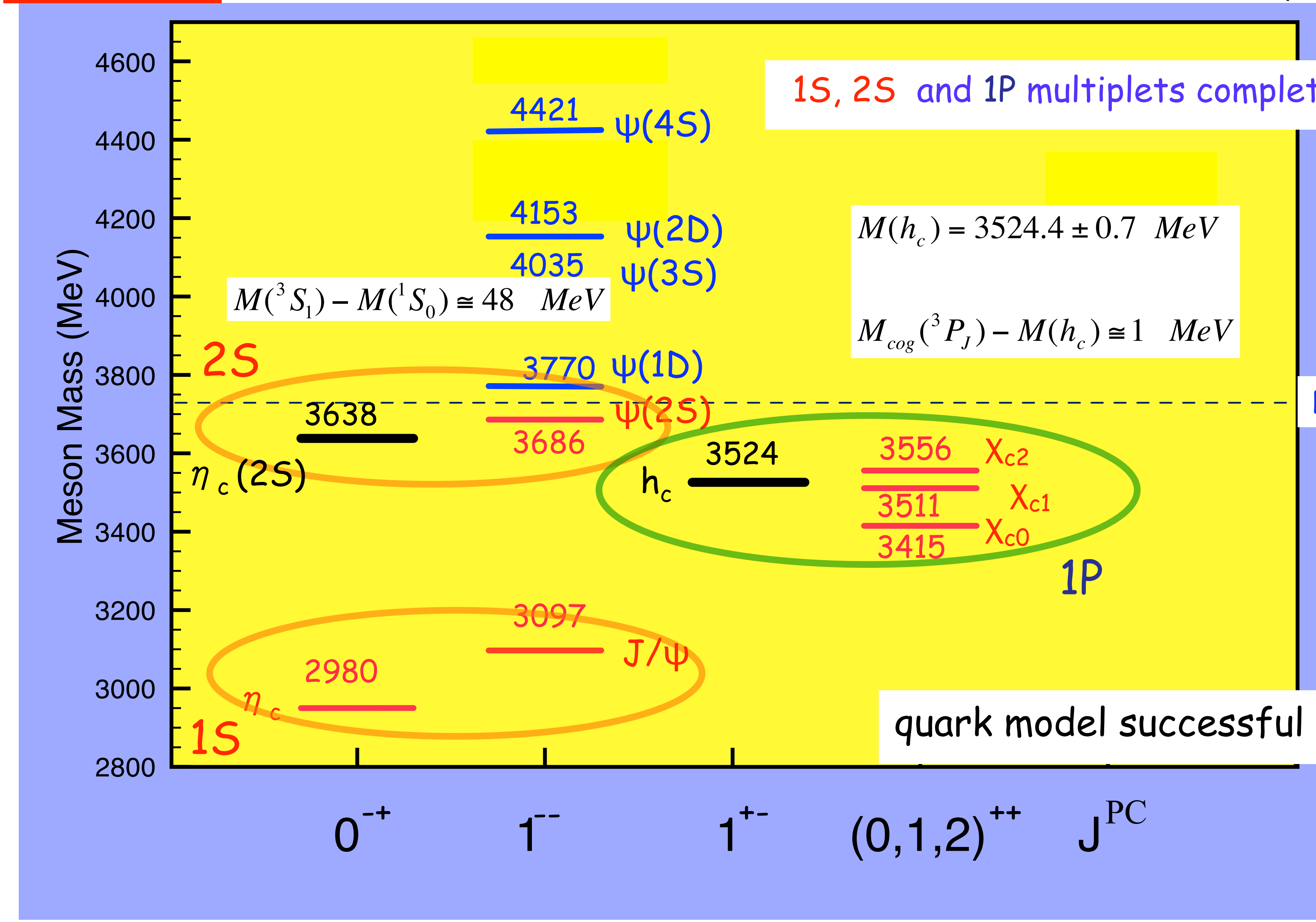
charmonium
PDG 2000
Meson Mass (MeV)
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
4421 ψ(4S)
4153 ψ(2D)
4039 ψ(3S)
3770 ψ(1D)
ψ(2S)
3686
DD
3556 χc2
χc1
3511
χc0
3415
3097
J/ψ
2980
η c
0-+
1--
1+-
(0,1,2)++
JPC



charmonium
PDG 2008+B factory data
Meson Mass (MeV)
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
4421 ψ(4S)
4153 ψ(2D)
4039 ψ(3S)
3770 ψ(1D)
ψ(2S) 3686
3097 J/ψ
2980 η c
3638 η c (2S)
observation
observation
Ψ(2S) -> h_c π^0 -> η_c γ π^0
3526 h_c
3556 X_c2
3511 X_c1
3415 X_c0
DD
0^-+
1^--
1^+-
(0,1,2)^++
J^PC

charmonium

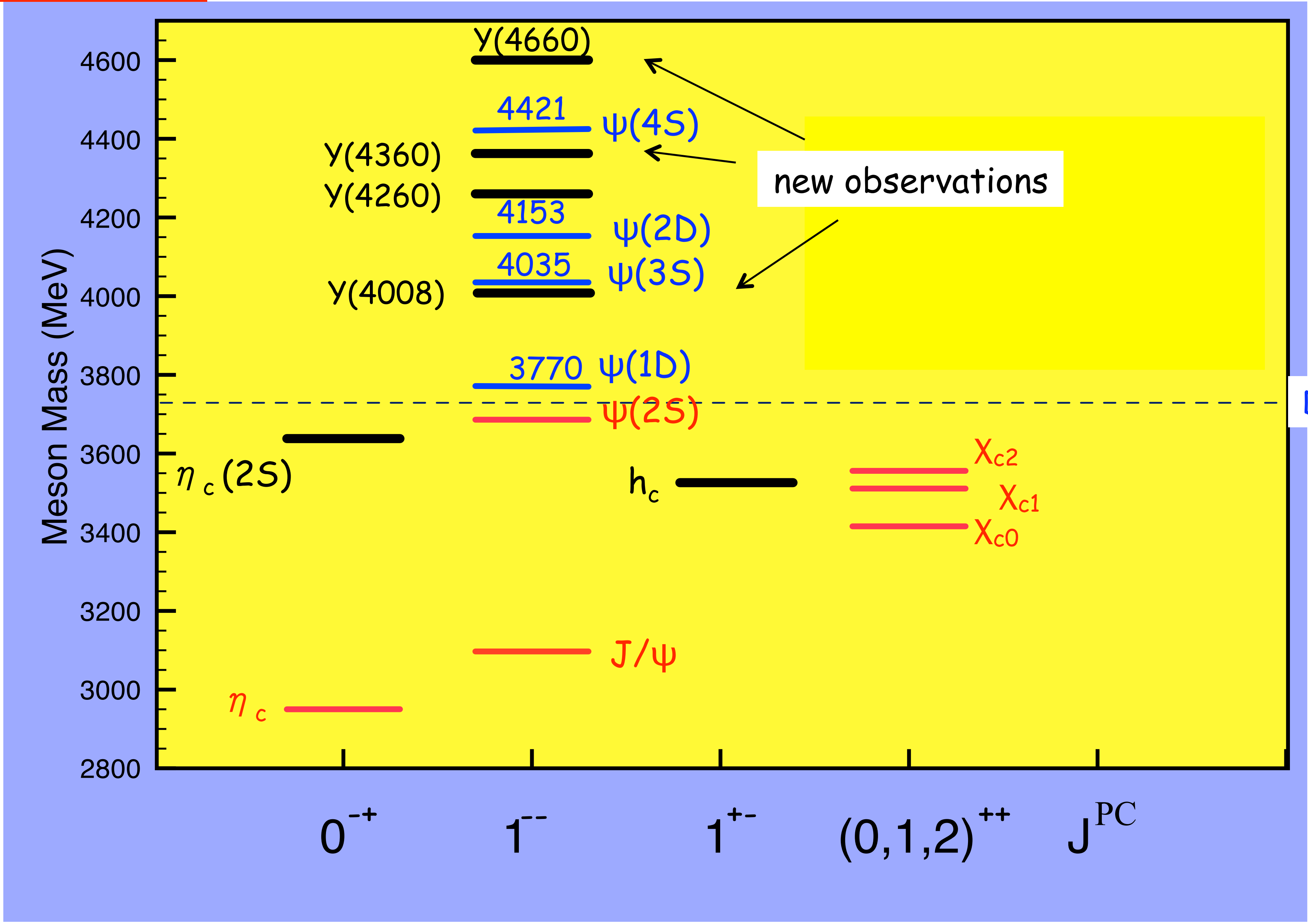
PDG 2008+B factory data



charmonium

four new 1^{--} states

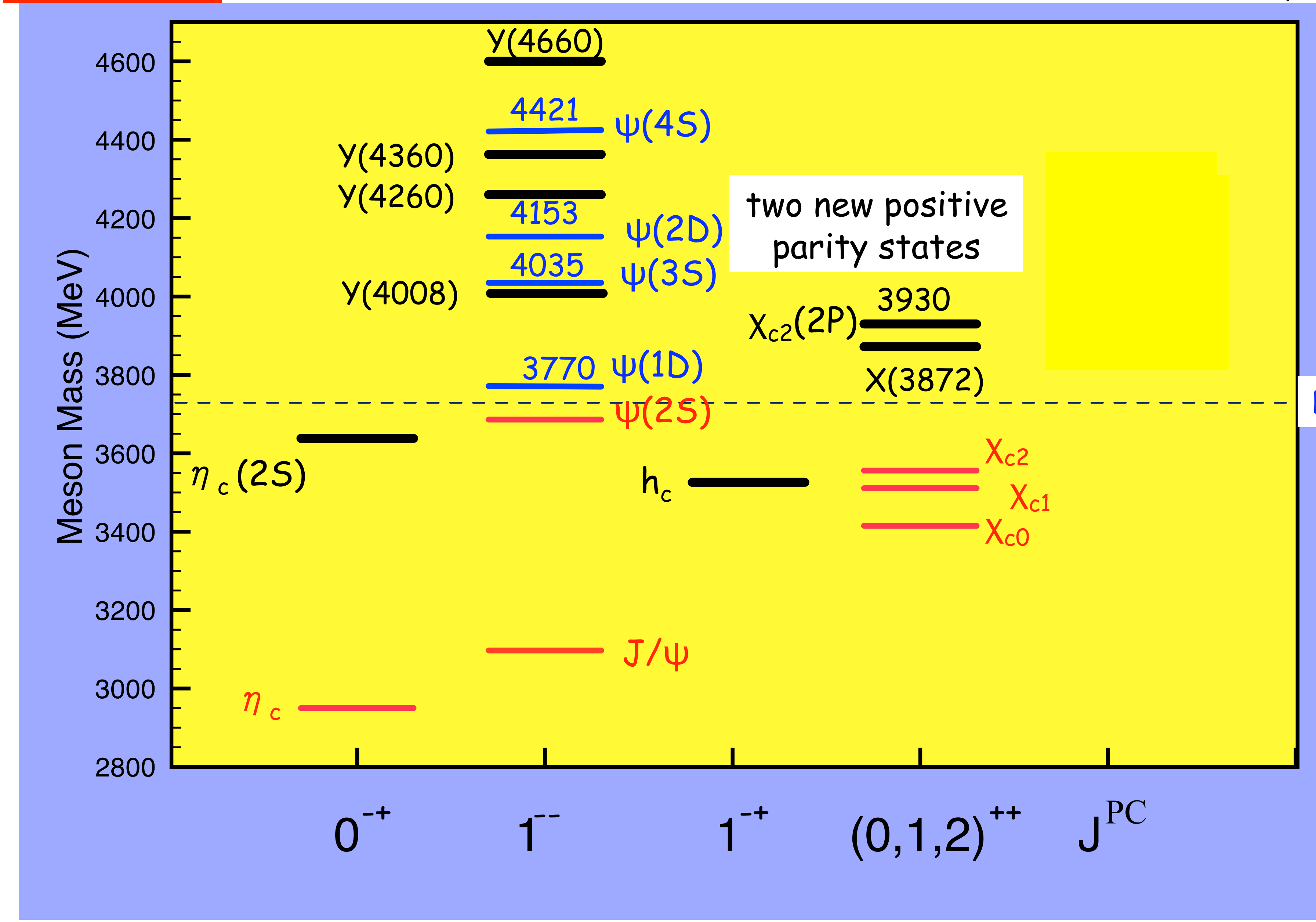
PDG 2008+B factory data

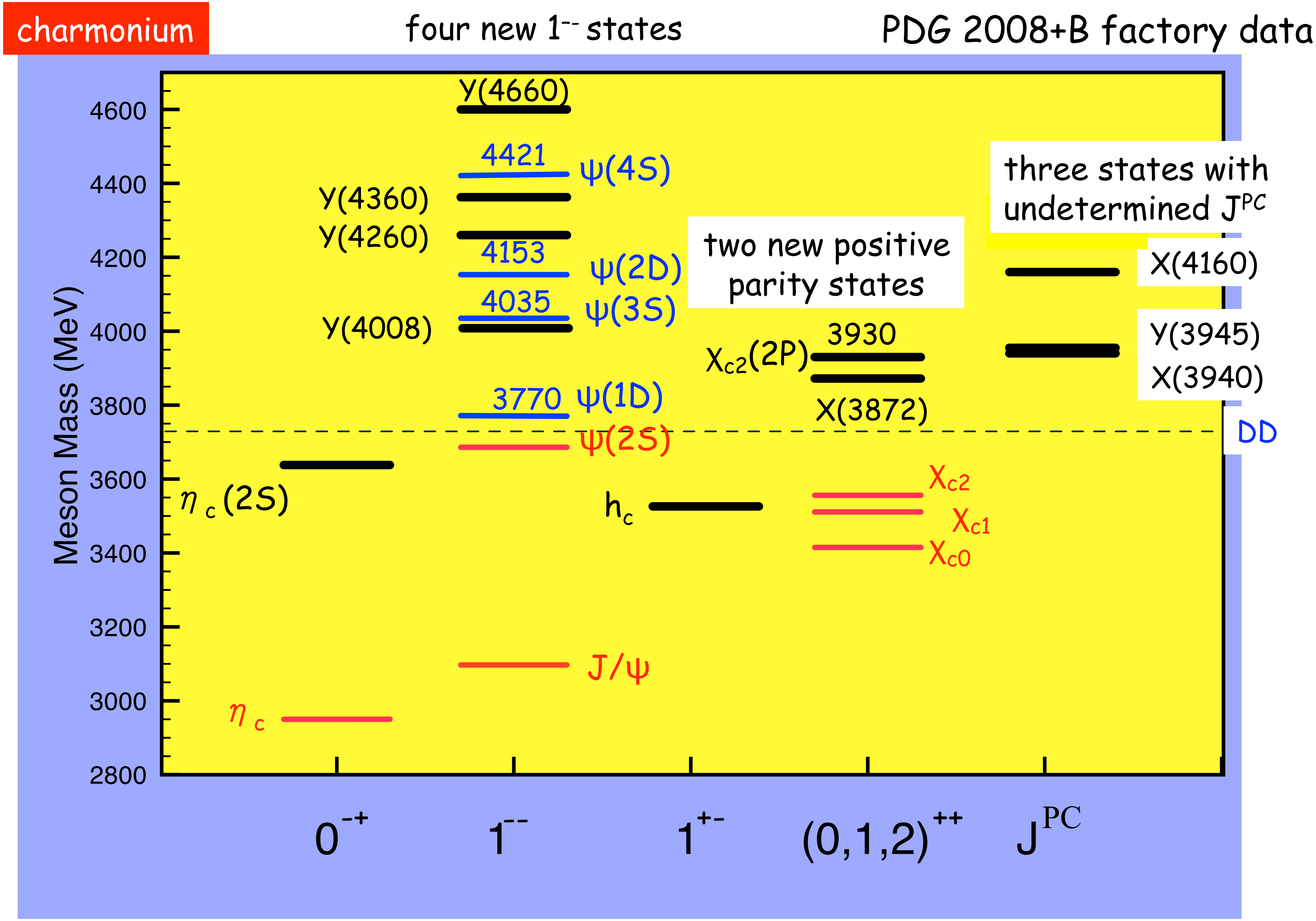


charmonium

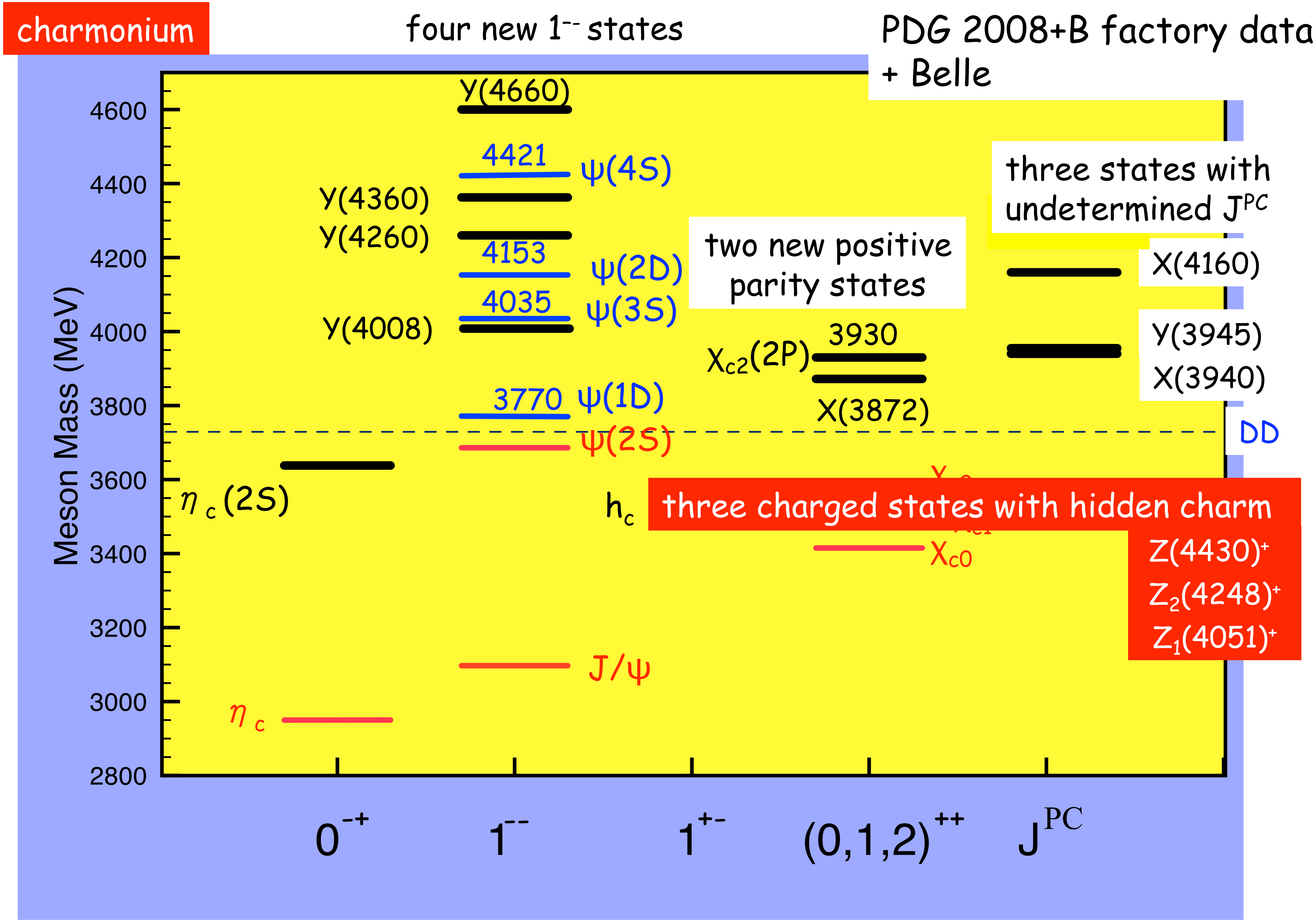
four new 1^{--} states

PDG 2008+B factory data





charmonium
four new 1⁻⁻ states
PDG 2008+B factory data
Meson Mass (MeV)
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
Y(4660)
4421
ψ(4S)
Y(4360)
Y(4260)
4153
ψ(2D)
4035
ψ(3S)
Y(4008)
3770
ψ(1D)
ψ(2S)
J/ψ
η c (2S)
η c
h c
two new positive parity states
3930
X c2 (2P)
X(3872)
X c2
X c1
X c0
three states with undetermined J^PC
X(4160)
Y(3945)
X(3940)
DD
0⁻⁺
1⁻⁻
1⁺⁻
(0,1,2)⁺⁺
J^PC


charmonium
four new 1⁻⁻ states
PDG 2008+B factory data
+ Belle
Meson Mass (MeV)
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
Y(4660)
4421
ψ(4S)
Y(4360)
Y(4260)
4153
ψ(2D)
4035
ψ(3S)
Y(4008)
3770
ψ(1D)
ψ(2S)
J/ψ
η c(2S)
η c
h c
two new positive
parity states
3930
χc2(2P)
X(3872)
χc0
three states with
undetermined J^PC
X(4160)
Y(3945)
X(3940)
DD
three charged states with hidden charm
Z(4430)+
Z2(4248)+
Z1(4051)+
0-+
1--
1+-
(0,1,2)++
J^PC

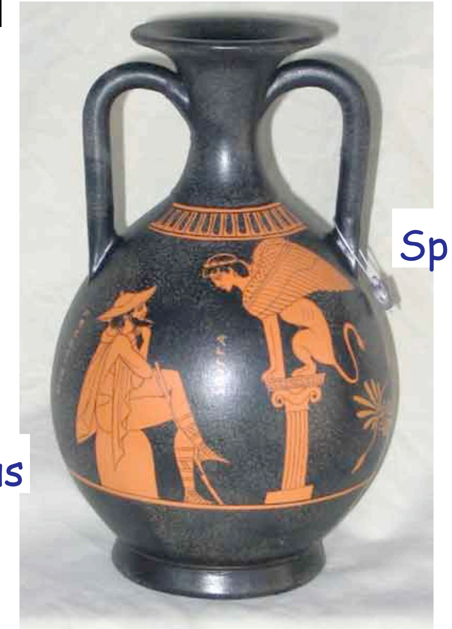
the simple theoretical scheme represented by the quark model cannot account for all these particles

instead of dealing with a game designed to test knowledge and skill

quarkonium

we are facing an enigma

Sphinx



Oedipus

Problem n. 1:

charged mesons with hidden charm $Z(4430)^+$ $Z_2(4248)^+$ $Z_1(4051)^+$

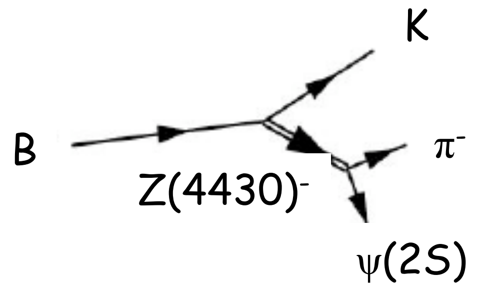
Belle Collaboration

$Z(4430)^+$

Dalitz plot analysis of $B \to Z^- K$, $Z^- \to \psi(2S)\pi^-$ (PRL 100, 142001 (2008))

$M=4433 \pm 4 \pm 2$ MeV

$\Gamma=45 \pm 22 \pm 33$ MeV



$Z_1(4051)^+$ $Z_2(4248)^+$

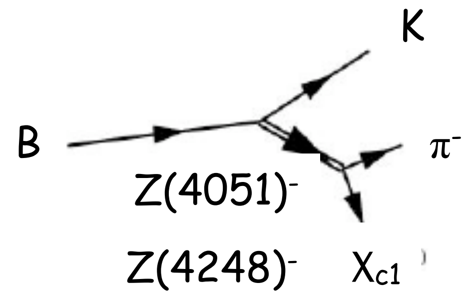
Dalitz plot analysis of $B \to Z^- K$, $Z^- \to \chi_{c1}\pi^-$ (ArXiv:0806.4098)

$M_1=4051 \pm 14 \pm 46$ MeV

$\Gamma_1=82 \pm 27 \pm 52$ MeV

$M_2=4248 \pm 53 \pm 184$ MeV

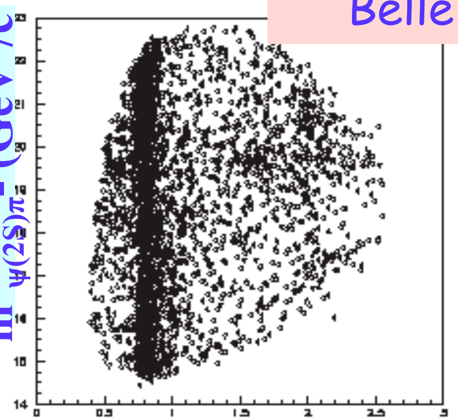
$\Gamma_2=177 \pm 67 \pm 322$ MeV



peak found in $B \to K\, \psi(2S)\, \pi^-$
attributed to $Z^- \to \psi(2S)\, \pi^-$

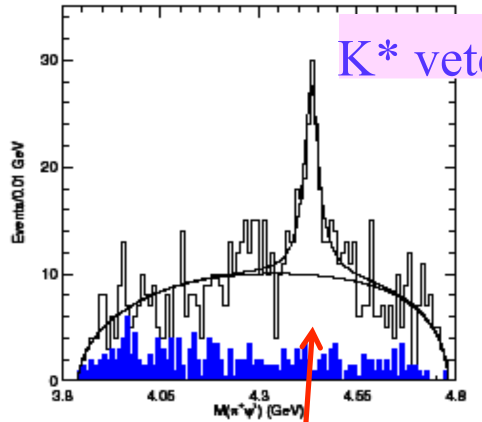
Belle

$m^2_{\psi(2S)\pi^-}$ (GeV²/c⁴)



$m^2_{K\pi^-}$ (GeV²)

K* veto



$m_{\psi(2S)\pi^-}$ (GeV)

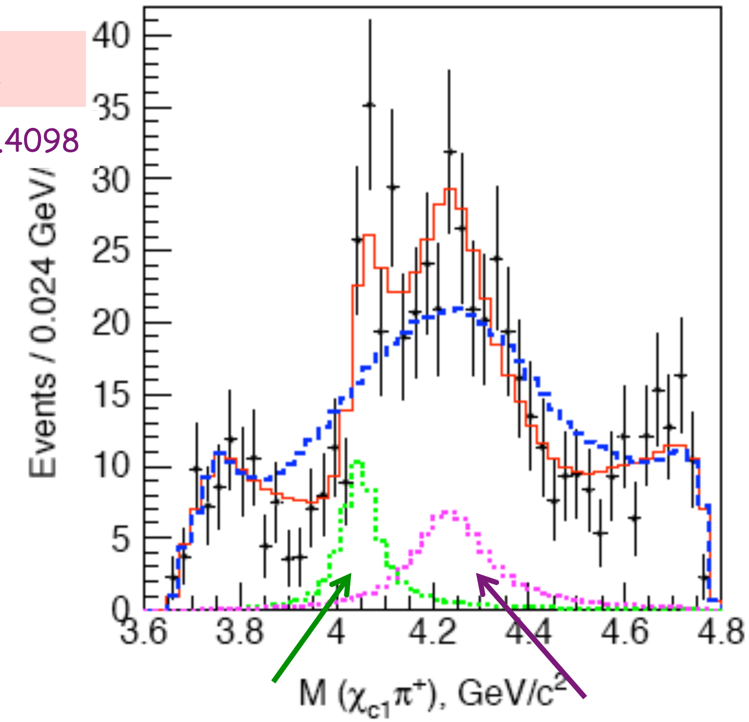
Z(4430)⁺

PRL 100, 142001 (2008)

structures observed in $B \to K\, \chi_{c1}\, \pi^-$
attributed to $Z^-_{1,2} \to \chi_{c1}\, \pi^-$

Belle

ArXiv:0806.4098



Z_1 (4051)⁺

Z_2 (4248)⁺

$B \to K\, Z^- \to K\, \chi_{c1} \pi^-$

Problem n. 1:
charged mesons with hidden charm $Z(4430)^+$ $Z_2(4248)^+$ $Z_1(4051)^+$

evidence of exotic meson?

- the existence of exotic (non $\bar{Q}Q$) mesons has been argued long ago
- candidates in the light quark sector
- quark content of $Z(4430)^+$: ($c\bar{c}u\bar{d}$)

Interpretations proposed by several authors:

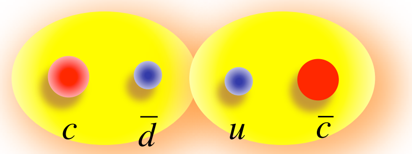
- bound state of two heavy-light diquarks (tetraquark)
  (first radial excitation of the lightest 1^+ tetraquark)

$$q\bar{q} \Rightarrow Q_D\bar{Q}_D$$

$Q_D \equiv$ diquark, two quarks bound in color 3*

spin 0 diquark $[qq]_0 \Rightarrow \varepsilon_{ijk}\varepsilon_{\alpha\beta\gamma}\bar{q}_C^{j\beta}\gamma_5 q^{k\gamma}$

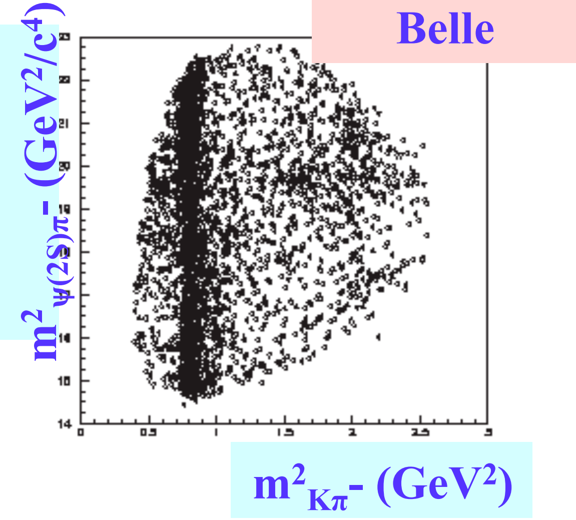
- bound state of one axial and one vector meson with open charm (molecule)

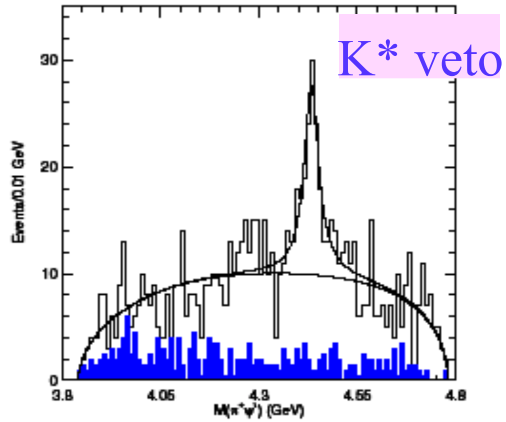


- non exotic effect: cusp of one axial and one vector meson with open charm

$Z(4430)^+$

peak found in $B \to K\,\psi(2S)\,\pi^-$
attributed to $Z^- \to \psi(2S)\,\pi^-$

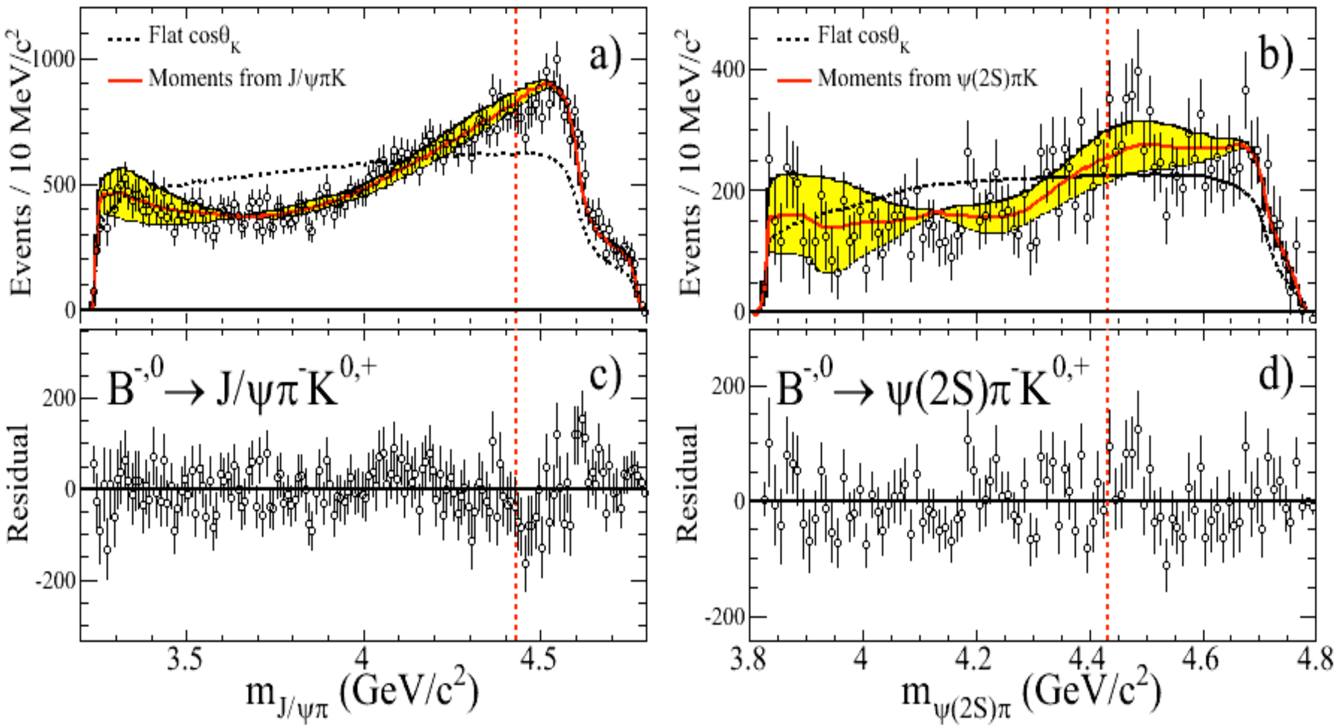




PRL 100, 142001 (2008)

Signal not confirmed by BaBar in the Dalitz plot of the same process

the measured $K\pi$ background in $B \to K\,J/\psi\,\pi^-$
$B \to K\,\psi(2S)\,\pi^-$ used in the analysis (Mokhtar (BaBar), ICHEP2008)



BABAR preliminary

Problem n. 1:
charged mesons with hidden charm $Z(4430)^{+}$ $Z_2(4248)^{+}$ $Z_1(4051)^{+}$

evidence of exotic structures or experimental artifacts ?

The formulation of a theory of multiquark/multihadron configurations is an outstanding issue

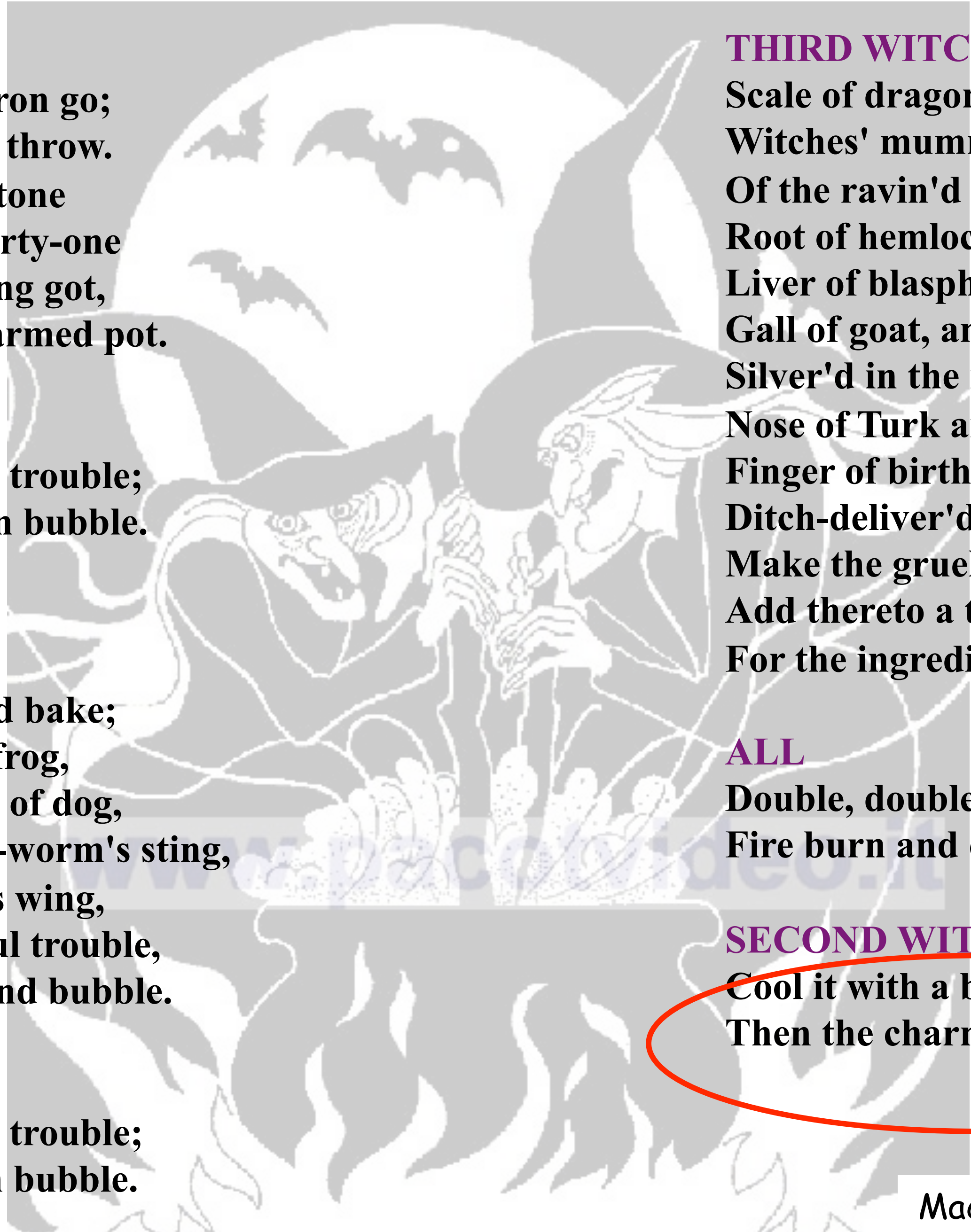
A data-driven point of view is at present unavoidable: models are used to interpret the experimental results

The observation of charged states with hidden charm must be confirmed; nevertheless, the possibility of having discovered the hint of a new spectroscopy is a strong reason for further studies

→ go to charmonium

warning: exotic recipes to construct models should be avoided...

like this one...



FIRST WITCH
Round about the cauldron go;
In the poison'd entrails throw.
Toad, that under cold stone
Days and nights has thirty-one
Swelter'd venom sleeping got,
Boil thou first i' the charmed pot.

ALL
Double, double toil and trouble;
Fire burn, and cauldron bubble.

SECOND WITCH
Fillet of a fenny snake,
In the cauldron boil and bake;
Eye of newt and toe of frog,
Wool of bat and tongue of dog,
Adder's fork and blind-worm's sting,
Lizard's leg and owlet's wing,
For a charm of powerful trouble,
Like a hell-broth boil and bubble.

ALL
Double, double toil and trouble;
Fire burn and cauldron bubble.

THIRD WITCH
Scale of dragon, tooth of wolf,
Witches' mummy, maw and gulf
Of the ravin'd salt-sea shark,
Root of hemlock digg'd i' the dark,
Liver of blaspheming Jew,
Gall of goat, and slips of yew
Silver'd in the moon's eclipse,
Nose of Turk and Tartar's lips,
Finger of birth-strangled babe
Ditch-deliver'd by a drab,
Make the gruel thick and slab:
Add thereto a tiger's chaudron,
For the ingredients of our cauldron.

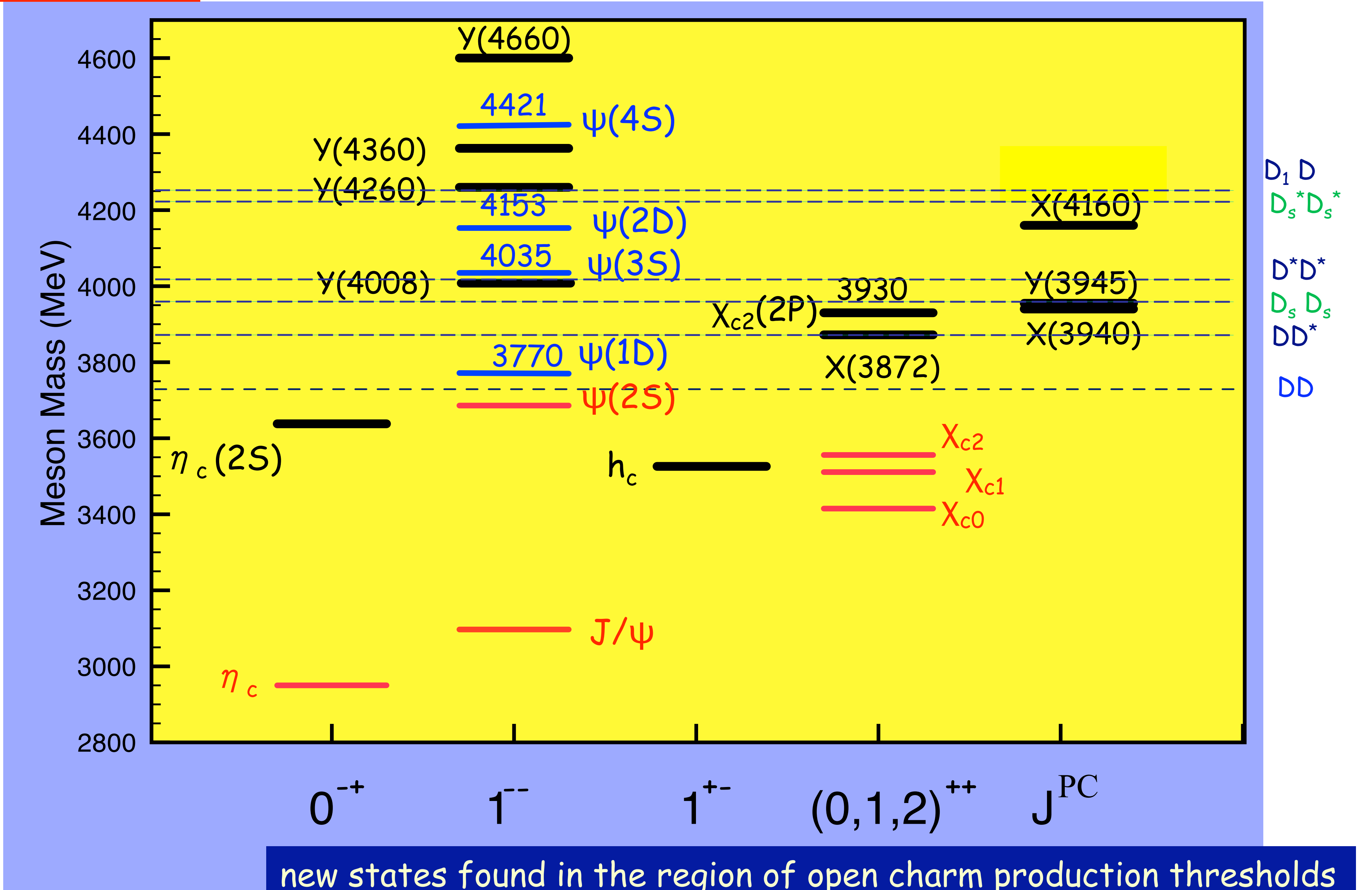
ALL
Double, double toil and trouble;
Fire burn and cauldron bubble.

SECOND WITCH
Cool it with a baboon's blood,
Then the charm is firm and good.

Macbeth, act 4, scene 1

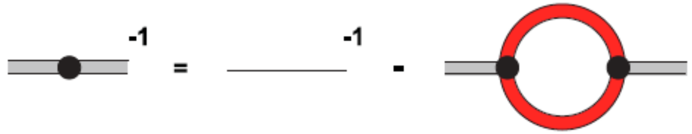
charmonium

2008



new states found in the region of open charm production thresholds

threshold effects important: can distort the spectrum



effects of open or nearby closed channels on the masses
(not included in simple quark models)

Pennington & Wilson 08

Name	State $n^{2S+1}L_J$	Experimental Mass MeV	Potential Mass MeV	$\Gamma_{hadrons}$ MeV	Δm_{BW} MeV	Δm_{pole} MeV
η_c	1^1S_0	2980±1	2982	–	–	–
J/ψ	1^3S_1	3096.9	3090	–	–	–
η_c'	2^1S_0	3638±4	3630	–	-10	-10
ψ'	2^3S_1	3686.1	3672	–	-9	-9
h_c	2^1P_1	3525.9	3516	–	-2	-2
χ_{c0}	2^3P_0	3414.8	3424	–	-9	-9
χ_{c1}	2^3P_1	3510.7	3505	–	-16	-16
χ_{c2}	2^3P_2	3556.2	3556	–	-6	-6
η_c''	3^1S_0	3943±6	4043	80[a]	-45	-58
ψ'''	3^3S_1	4039±1	4072	80±10[b]	-36	-41
	3^1P_1	–	3934	87[a]	-5	-12
	3^3P_0	–	3852	30[a]	-70	-70
	3^3P_1	–	3925	168[a]	-66	-29
	3^3P_2	–	3972	80[a]	-55	-48
	3^1D_2	–	3799	-	–	–
ψ''	3^3D_1	3771±2	3785	23±3[b]	-40	–40
	3^3D_2	–	3800	-	–	–
	3^3D_3	–	3806	-	–	–

$D\,\overline{D}$

sizeable effects

$D\,\overline{D}$

Problem n. 2: X(3872)

CDF,D0,BaBar,Belle

- narrow structure in $J/\psi\, \pi^+ \pi^-$ mass distribution
- $\pi^+ \pi^-$ spectrum peaked at large mass
- no evidence of charged partners X^-, X^+
- $B(B^0 \to K^0\ X\ )/B(B^+ \to K^+\ X\ ) = 0.50 \pm 0.30 \pm 0.05$
- not observed in e^+e^-
- $\dfrac{B(X \to J/\psi\, \pi^+\pi^-\pi^0)}{B(X \to J/\psi\, \pi^+\pi^-)} = 1.0 \pm 0.4 \pm 0.3$ G-parity violation
- $\dfrac{B(X \to J/\psi\, \gamma)}{B(X \to J/\psi\, \pi^+\pi^-)} = 0.14 \pm 0.05$ C=+1
- most likely $J^P = 1^{++}$
- signal in $X \to D^0\, \overline{D}^0\, \pi^0$ (mass higher by 3.5 MeV)
- observed in $X \to \psi(2S)\gamma$

$$B(B^\pm \to K^\pm\ X\ )B(X \to \psi(2S)\gamma\ ) = (9.9 \pm 2.9 \pm 0.9) \times 10^{-6}$$

$$B(B^\pm \to K^\pm\ X\ )B(X \to J/\psi\gamma\ ) = (2.8 \pm 0.8 \pm 0.2) \times 10^{-6}$$

BaBar, arXiv:0809.0042

$M(X) = 3871.4 \pm 0.6\ MeV$

$\Gamma(X) < 2.3\ MeV\ \ (90\%\ CL)$

$\left[\ \Gamma(X) = 3.0^{+4.6}_{-2.3} \pm 0.9\ \ MeV\right]$ BaBar

NEW

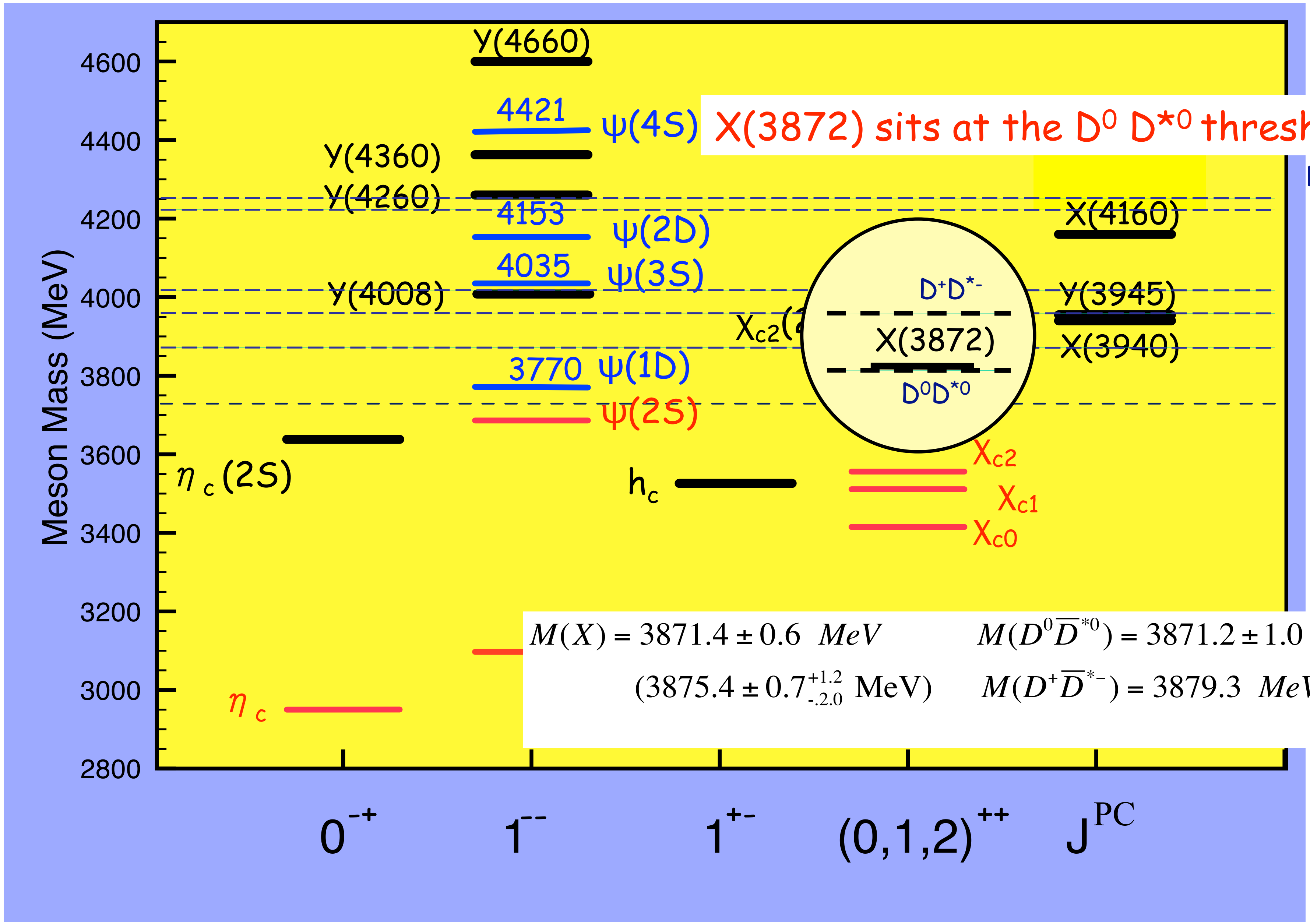
$M(X) = 3875.4 \pm 0.7^{+1.2}_{-2.0}\ MeV$

$$\frac{B(X \to D^0\overline{D}^0\pi^0\ )}{B(X \to J/\psi\pi^+\pi^-)} = 9 \pm 4$$

Belle Coll., PRL97, 162002

charmonium 2008

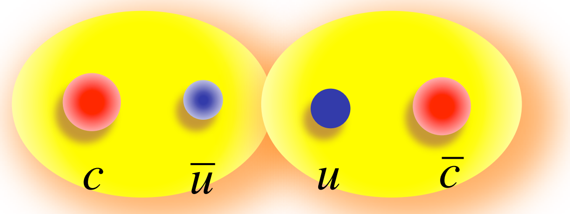
X(3872) sits at the D^0 D^{*0} threshold



$M(X) = 3871.4 \pm 0.6\ MeV$ $\quad$ $M(D^0\overline{D}^{*0}) = 3871.2 \pm 1.0\ MeV$

$(3875.4 \pm 0.7^{+1.2}_{-2.0}\ \text{MeV})$ $\quad$ $M(D^+\overline{D}^{*-}) = 3879.3\ MeV$

X(3872): molecule ?

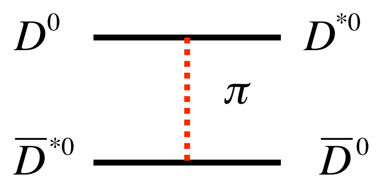


$$M(X) = 3871.4 \pm 0.6 \;\; MeV$$
$$(3875.4 \pm 0.7^{+1.2}_{-2.0} \text{ MeV})$$

$$M(D^0\overline{D}^{*0}) = 3871.2 \pm 1.0 \;\; MeV$$
$$M(D^+\overline{D}^{*-}) = 3879.3 \;\; MeV$$
$$M(\rho^0 J/\psi) = 3867.9 \;\; MeV$$
$$M(\omega\, J/\psi) = 3879.5 \;\; MeV$$

X(3872) sits at the $\bar{D}^0$ D^{*0} threshold

binding induced by light hadron exchange



no $D\bar{D}$ molecules

X essentially $D^0\bar{D}^{*0} + \bar{D}^0 D^{*0}$ (S wave) molecule with $J^{PC} = 1^{++}$

$$|X\rangle = a|D^0\overline{D}^{*0} + \overline{D}^0 D^{*0}\rangle + b|D^+D^{*-} + D^-D^{*+}\rangle + \ldots$$

- not definite I
- resonances in the modes $D^+ D^{*-}$ not observed -> repulsive interaction

Tornqvist

- X_b (10604) expected at the B B* threshold

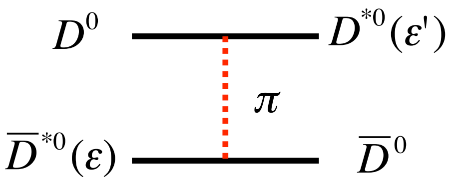
Voloshin

X-> $\bar{D}^0 D^0 \gamma$ dominant with respect to X-> $D^+ D^- \gamma$

- X -> $\chi_{c1}\,\pi$ expected

X(3872): charmonium option excluded ?

one π exchange produces no $\bar{D}^0\, D^{*0}$ binding Suzuki

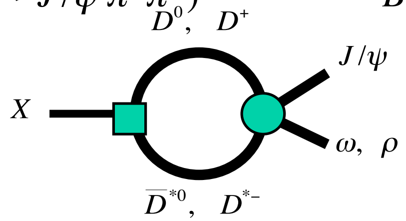


$$V(r) \approx -\frac{1}{3} g^2_{D^* D\pi} (\varepsilon \cdot \varepsilon')\delta(r) + \ldots.$$

- Isospin breaking: severe ps suppression

$$\frac{B(X \to J/\psi\, \pi^+\pi^-\pi^0)}{B(X \to J/\psi\, \pi^+\pi^-)} \cong 1.0 \to \frac{A(X \to J/\psi\, \rho^0)}{B(X \to J/\psi\, \omega)} \cong 0.2$$

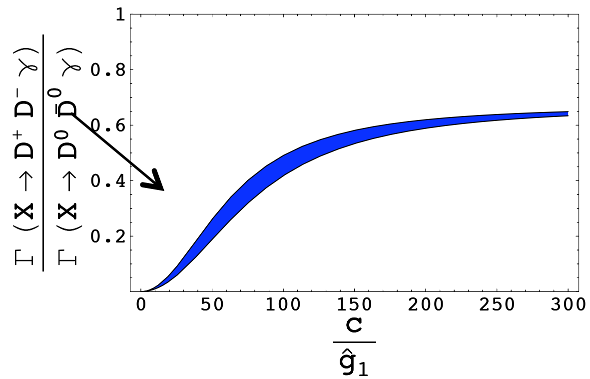
D^0 , D^+ mass difference also violates isospin



- $B(B^0 \to XK^0) = B(B^- \to XK^-)$

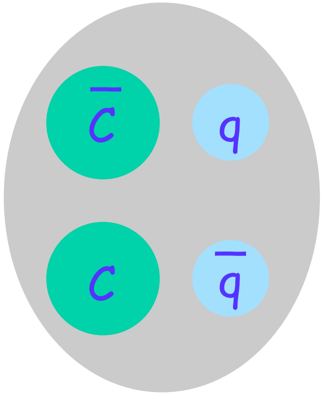
- $X \to \chi_{c1}\, \pi\, \pi$ expected

De Fazio et al. $X \to D^0\, D^0\, \gamma$ dominant with respect to $X \to D^+\, D^-\, \gamma$



- signal in $\bar{D}^0\, D^0\, \pi^0$ could be a manifestation of the same resonance Hanhart et al.

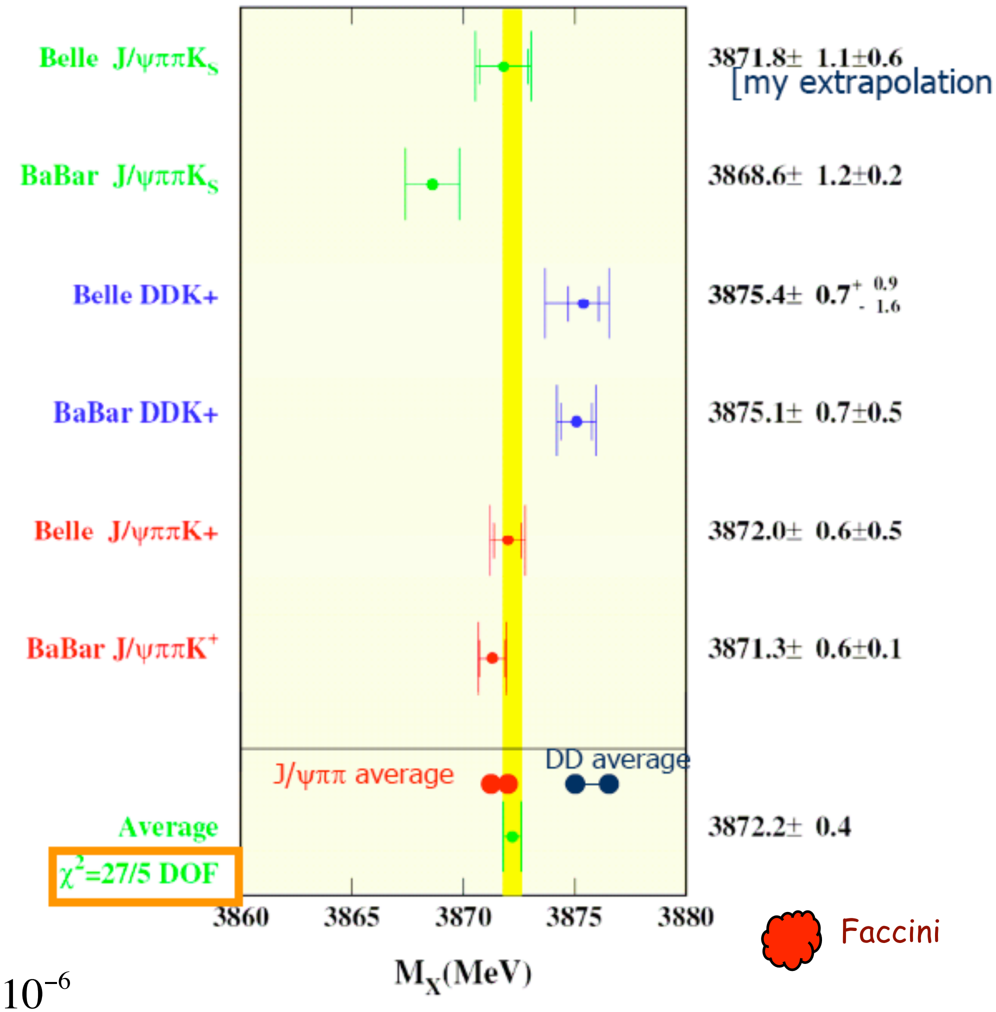
two different states X(3872) - X(3875) ?



natural (qualitatively predicted)
in a multiquark/multihadron picture

exp. measurement not conclusive (yet)

NEW



$$B(B^{\pm} \to K^{\pm} \ X\ )B(X \to \psi(2S)\gamma\ ) = (9.9 \pm 2.9 \pm 0.9) \times 10^{-6}$$

$$B(B^{\pm} \to K^{\pm} \ X\ )B(X \to J/\psi\gamma\ ) = (2.8 \pm 0.8 \pm 0.2) \times 10^{-6}$$

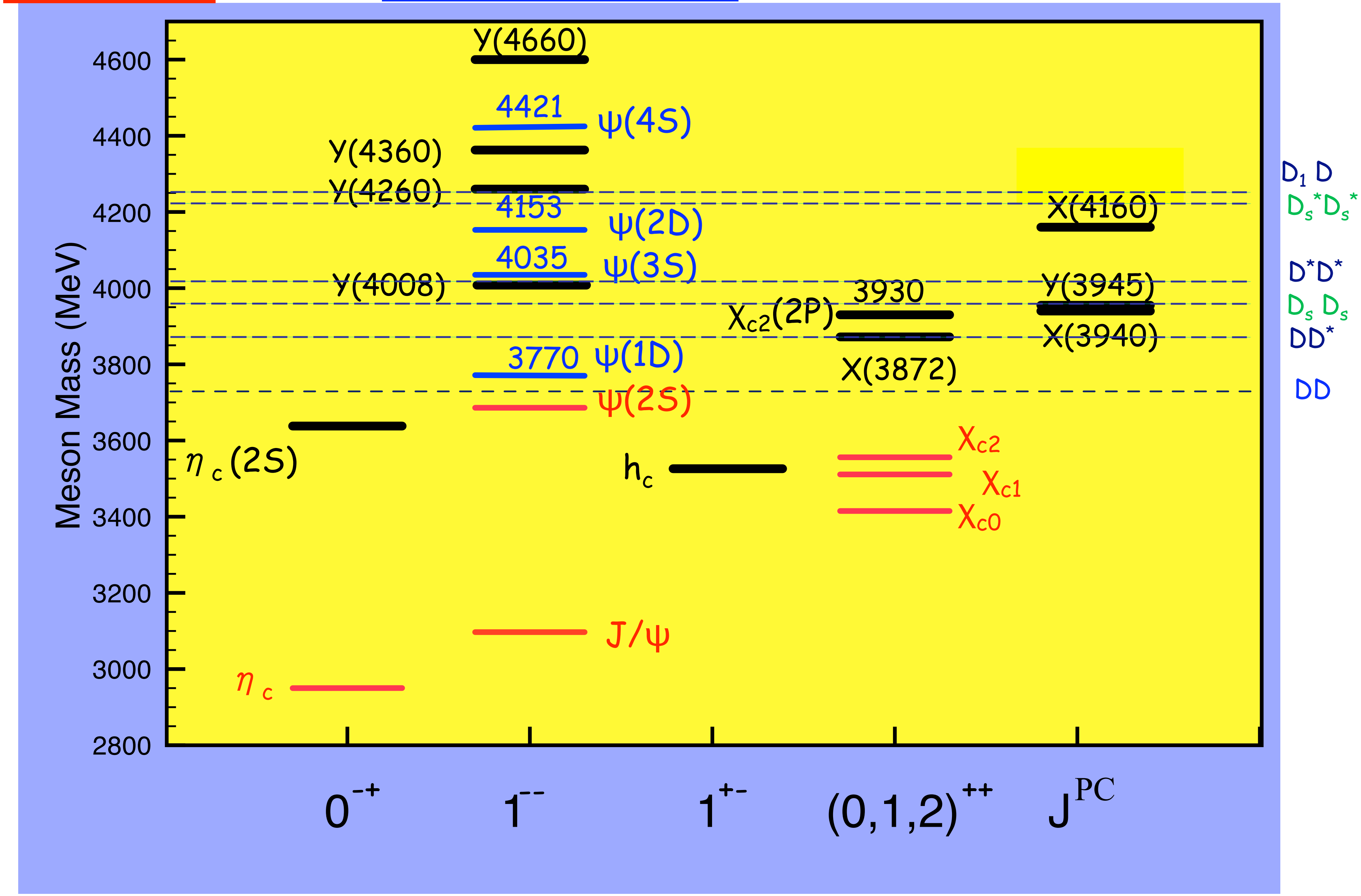
understandable on the basis of charmonium interpretation, but calculations in all scenarios are needed

X(3872) is a puzzling state

charmonium

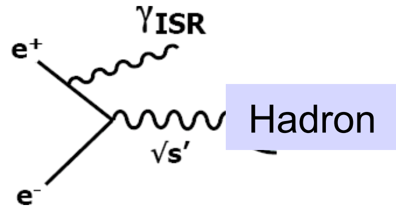
four new 1^{--} states

2008



Problem n. 3: Y(4008) Y(4260) Y(4360) Y(4660)

observed by Belle BaBar and Cleo in ISR events: $e^+ e^- \to \gamma\ Y$



decays in J/ψ , $\psi(2S)$

$Y(4008) \to J/\psi\ \pi^+\ \pi^-$

$Y(4260) \to J/\psi\ \pi^+\ \pi^-$, $J/\psi\ \pi^0\ \pi^0$, $J/\psi\ K^+\ K^-$

$Y(4360) \to \psi(2S)\ \pi^+\ \pi^-$

$Y(4660) \to \psi(2S)\ \pi^+\ \pi^-$

no resonant peaks in $\sigma(e^+ e^-)$ $\sigma(e^+ e^- \to DD, DD^*, D^*D^*)$

Problem n. 3: Y(4008) Y(4260) Y(4360) Y(4660)

Y(4260) hybrid ccG state ?

Close, Page, Pene, Kou….

- cc 1^{--} hybrid at mass ~4.2 GeV expected (lattice QCD)

- large couplings to modes with closed flavour $\psi_h \to (c\bar{c})(gg) \to (c\bar{c})(\pi\pi,\ldots)$

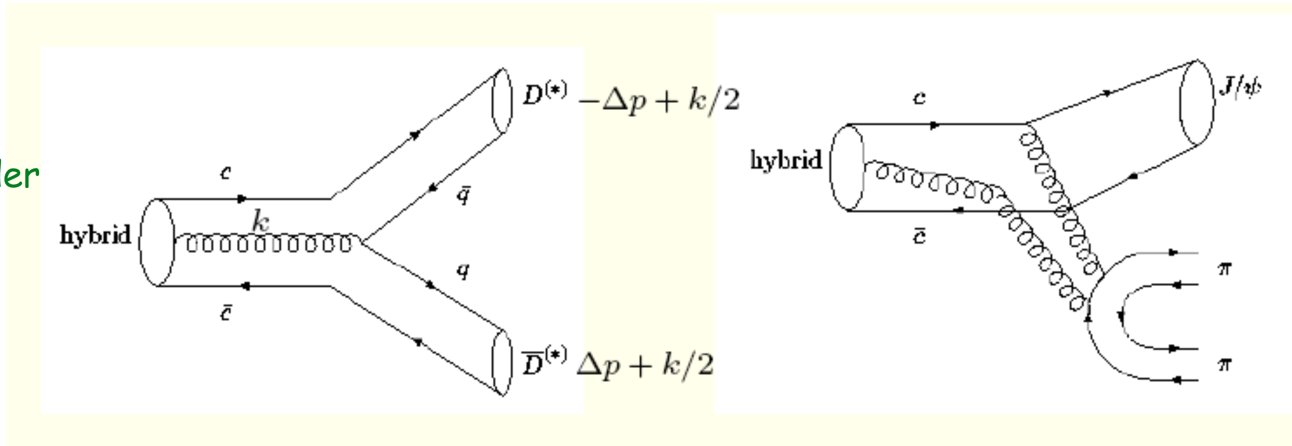
  Y(4260) -> $J/\psi\,\eta'$, $\chi_{cJ}\,\eta'$

- decays in S wave + P wave open charm states expected

  Y(4260) -> D D'_1 (Y below D D_1 threshold)

decays in DD and D*D* forbidden at leading order

Pene, Kou….



corresponding state expected in the $b\bar{b}$ system: Belle observes an anomalous enhancement in Y(1S) π^+ π^- at 10870 MeV

Y(4260) as a candidate $(\bar{c}\bar{s})(cs)$ tetraquark

(two scalar diquarks with L=1)

Maiani et al.

Y(4260) -> $D_s \bar{D}_s$ expected

partners with other light quarks not observed

observation in $D_s D_s$ or $D D'_1$ could discriminate

Issues:

- Interpretations only for Y(4260)
- Are all new vector mesons alike?
- Comprehensive analysis needed

If exotic $c\bar{c}$ mesons exist, then exotic $b\bar{b}$ mesons probably also exist

challenge for theory: predict their properties
challenge for experimentalists: discover them

A short digression:

News in the open charm sector

$D_{sJ}(2700)$ $D_{sJ}(2860)$

$D_{sJ}(2700)$

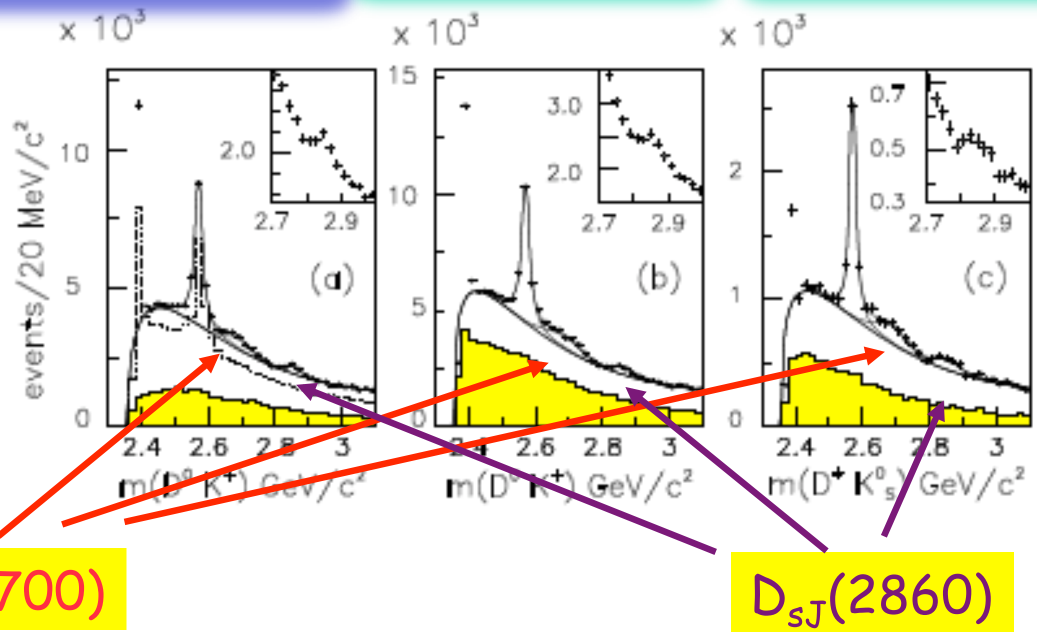
$e^+ e^- \to D K X$

with DK = $D^0 K^+$ and $D^+ K_S$

BaBar Coll., PRL 97 (06) 222061

$M = 2688 \pm 4 \pm 4 \;\; MeV$

$\Gamma = 112 \pm 7 \pm 36 \;\; MeV$



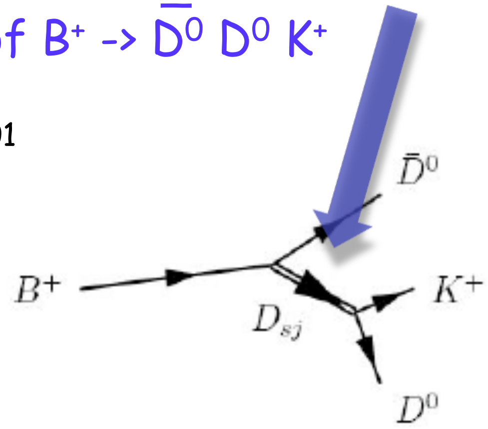
Dalitz plot analysis of $B^+ \to \bar{D}^0 D^0 K^+$

Belle Coll., PRL 100 (08) 092001

$M = 2708 \pm 9^{+11}_{-10} \;\; MeV$

$\Gamma = 108 \pm 23^{+36}_{-31} \;\; MeV$

$J^P = 1^-$



$D_{sJ}(2860)$

BaBar

$e^+ e^- \to D K X$

with DK = $D^0 K^+$ and $D^+ K_S$

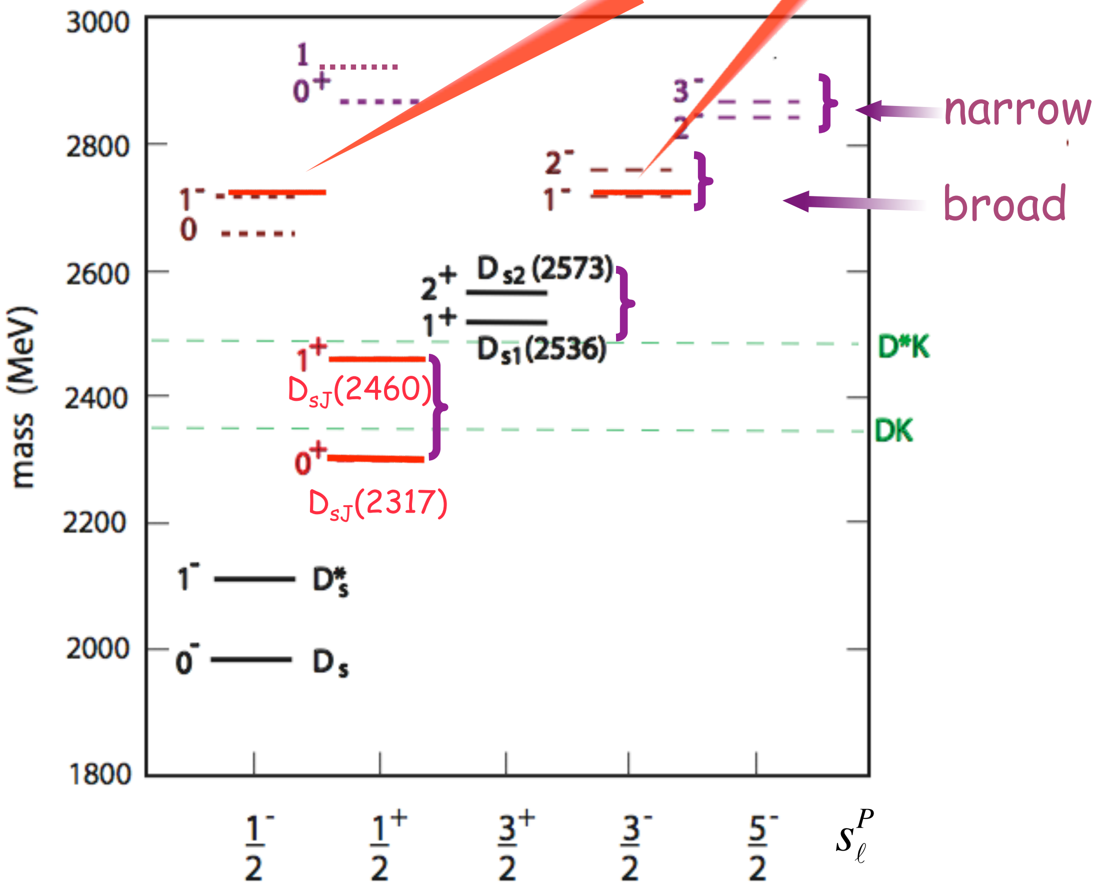
$M = 2856.6 \pm 1.5 \pm 5.0 \;\; MeV$

$\Gamma = 47 \pm 7 \pm 10 \;\; MeV$

$D_{sJ}(2700)$

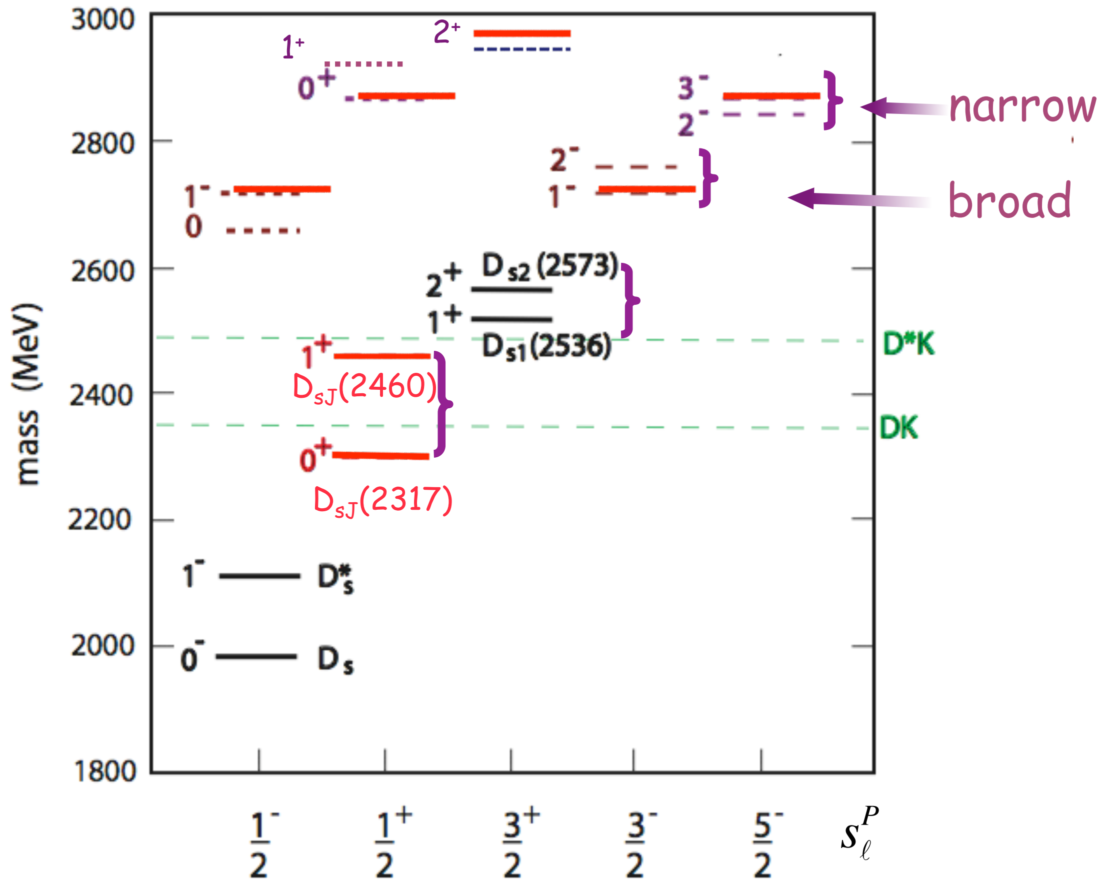
$c\,\bar{s}$ mesons

possibilities for $J^P = 1^-$



$D_{sJ}(2860)$

$c\bar{s}$ mesons



natural parity (seen in DK)

$D_{sJ}(2700)$

$$R_1 = \frac{\Gamma(D_{sJ} \to D^* K)}{\Gamma(D_{sJ} \to DK)}$$

$$R_2 = \frac{\Gamma(D_{sJ} \to D_s \eta)}{\Gamma(D_{sJ} \to DK)}$$

$$R_3 = \frac{\Gamma(D_{sJ} \to D_s^* \eta)}{\Gamma(D_{sJ} \to DK)}$$

sizeable differences

TABLE I. Ratios R_i for $D_{sJ}(2700)$ identified as $D_s^{*\prime}$ or D_{s1}^*.

	$R_1 \times 10^2$	$R_2 \times 10^2$	$R_3 \times 10^2$
$D_s^{*\prime}$	91 ± 4	20 ± 1	5 ± 2
D_{s1}^*	4.3 ± 0.2	16.3 ± 0.9	0.18 ± 0.07

$D_s^{*\prime} \;:\; s_\ell^P = \frac{1}{2}^-$

$D_{s1}^* \;:\; s_\ell^P = \frac{3}{2}^-$

$D_{sJ}(2860)$

Table 2: Predicted ratios $\frac{\Gamma(D_{sJ} \to D^* K)}{\Gamma(D_{sJ} \to DK)}$ and $\frac{\Gamma(D_{sJ} \to D_s \eta)}{\Gamma(D_{sJ} \to DK)}$ for the various assignment of quantum numbers to $D_{sJ}(2860)$. For DK we mean the sum $DK = D^0 K^+ + D^+ K_S^0$.

$D_{sJ}(2860)$	$D_{sJ}(2860) \to DK$	$\frac{\Gamma(D_{sJ} \to D^* K)}{\Gamma(D_{sJ} \to DK)}$	$\frac{\Gamma(D_{sJ} \to D_s \eta)}{\Gamma(D_{sJ} \to DK)}$
~~$s_\ell^P = \frac{1}{2}^-$, $J^P = 1^-$, $n = 1$~~	p-wave	1.23	0.27
$s_\ell^P = \frac{1}{2}^+$, $J^P = 0^+$, $n = 1$	s-wave	0	0.34
~~$s_\ell^P = \frac{3}{2}^+$, $J^P = 2^+$, $n = 1$~~	d-wave	0.63	0.19
~~$s_\ell^P = \frac{3}{2}^-$, $J^P = 1^-$, $n = 0$~~	p-wave	0.06	0.23
$s_\ell^P = \frac{5}{2}^-$, $J^P = 3^-$, $n = 0$	f-wave	0.39	0.13

D*K forbidden

D*K allowed

$J^P = 0^+$ radial excitation

Van Beveren et al., Close et al,

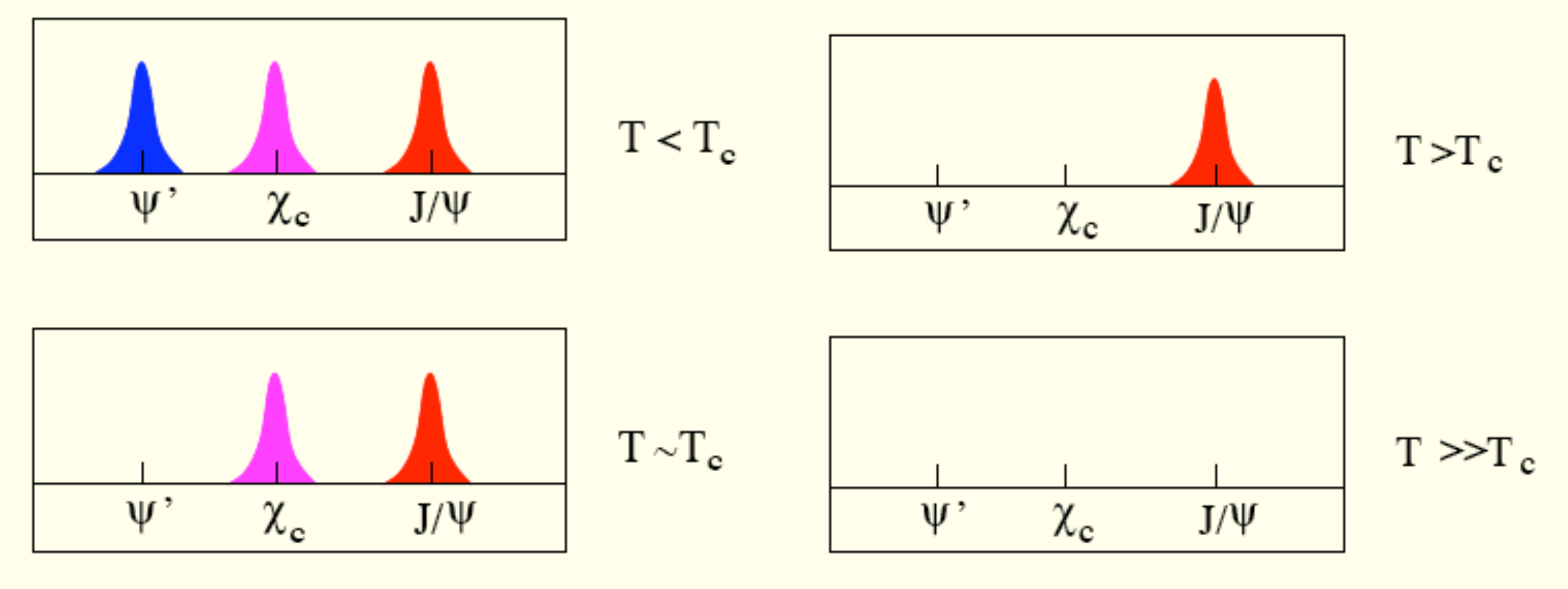
$J^P = 3^-$

Nicotri et al.

crucial mode : D*K

Progress in quarkonium effective theories: from zero to finite temperature

charmonium spectra at
different temperatures

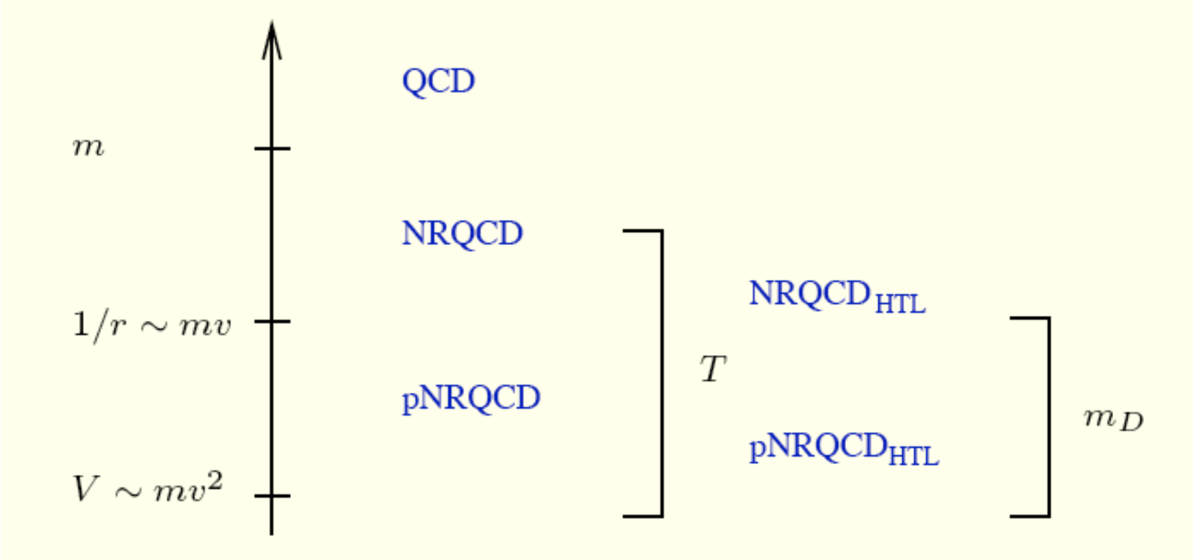


Satz

Progress in quarkonium effective theories: from zero to finite temperature

Brambilla Pineda Soto Vairo et al

hierarchy of scales



Debye mass

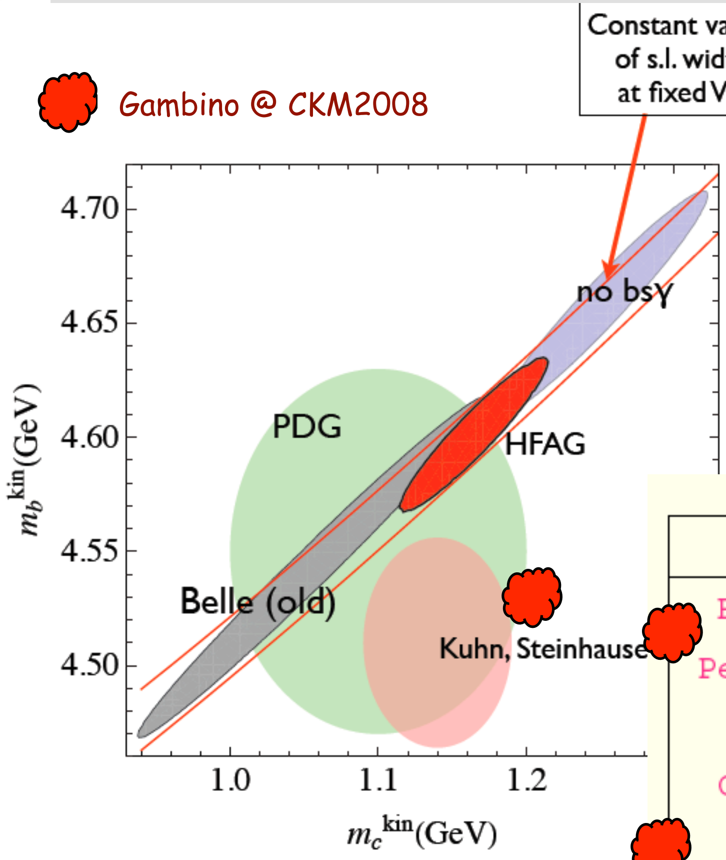
- real time evolution of a static quark-antiquark pair in a medium of light quarks and gluons at T≠0

- potential between two static sources

connection with the Physics programmes at RHIC and LHC

outstanding issue: determination of Standard Model parameters

Gambino @ CKM2008



inclusive B semileptonic decays:
tests of consistency within the Standard Model
need improved determination of the heavy quark masses

m_b and m_c from heavy quark analyses → Mateu's talk

reference	order	$\overline{m}_b(\overline{m}_b)$ (GeV)
Brambilla et al 01	NNLO +charm ($\Upsilon(1S)$)	$4.190 \pm 0.020 \pm 0.025$
Penin Steinhauser 02	NNNLO* ($\Upsilon(1S)$)	4.346 ± 0.070
Lee 03	NNNLO* ($\Upsilon(1S)$)	4.20 ± 0.04
Contreras et al 03	NNNLO* ($\Upsilon(1S)$)	4.241 ± 0.070
Pineda Signer 06	NNLL* high moments SR	4.19 ± 0.06

reference	order	$\overline{m}_c(\overline{m}_c)$ (GeV)
Brambilla et al 01	NNLO (J/ψ)	1.24 ± 0.020
Eidemüller 02	NNLO high moments SR	1.19 ± 0.11

$\Gamma(\Upsilon(1S) \to \gamma X)/\Gamma(\Upsilon(1S) \to X)$ at NLO

$$\alpha_s(M_Z) = 0.119^{+0.006}_{-0.005} \qquad \alpha_s(M_{\Upsilon(1S)}) = 0.184^{+0.015}_{-0.014}$$

Brambilla Garcia Soto Vairo 07

Conclusions

- Quarkonium keeps a key role for understanding the strong dynamics
- A wealth of new experimental observations
- Many results (new states) challenge theory
- Progress in the effective theories
- Access to Standard Model parameters

- Researchers belonging to many nodes of the network heavily involved