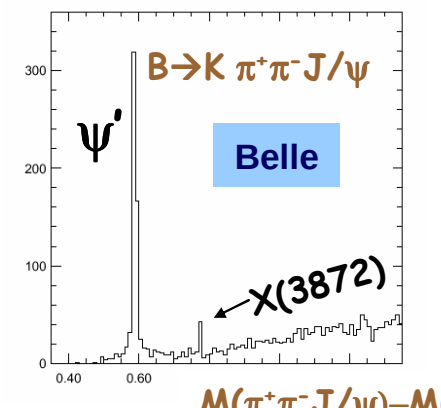
XY (but not Z) states, experimental overview

Stephen L. Olsen University of Hawai'i (member: BES & Belle expts)

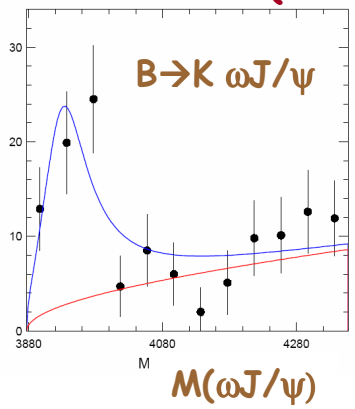
X & Y mesons

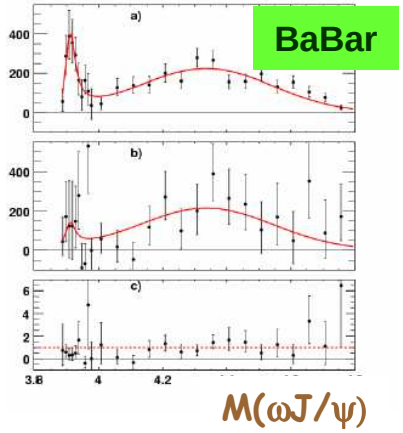
(Decay to final states with a $c\bar{c}$ pair & $\Sigma q_i=0$)

X(3872)

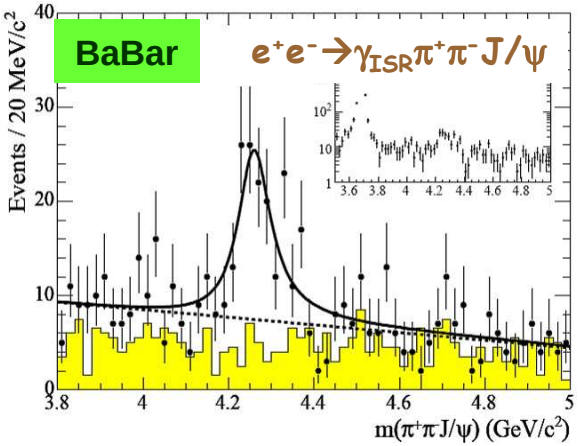


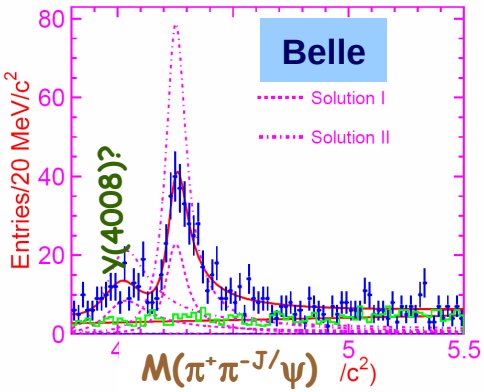
Y(3940)



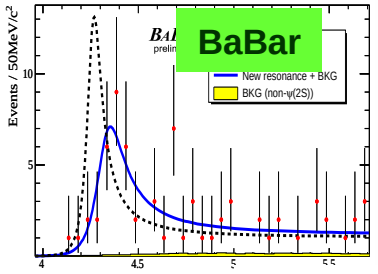


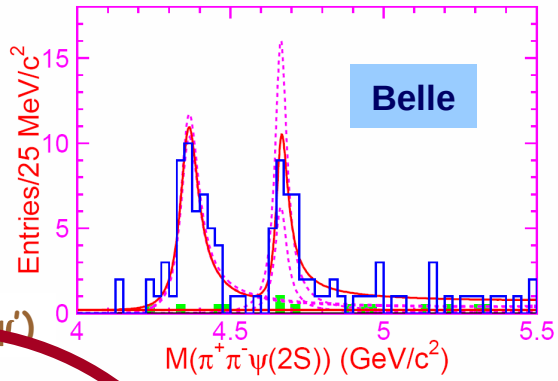
Y(4260)



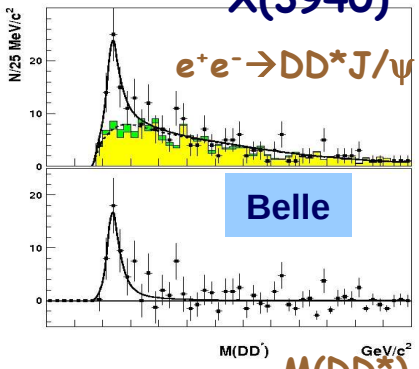


Y(4350) & Y(4660)

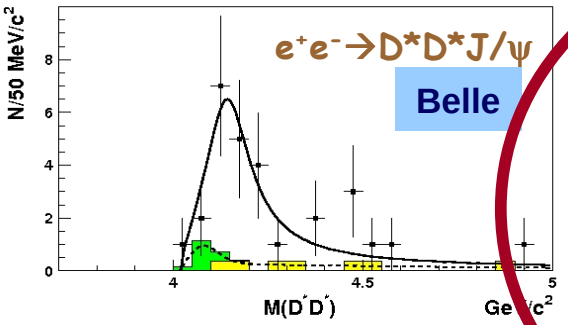




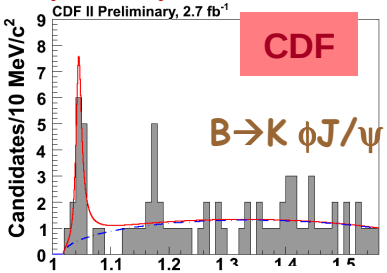
X(3940)



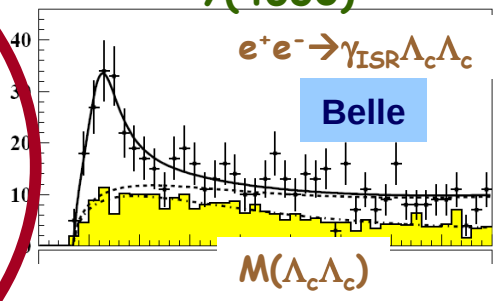
X(4160)



Y(4140)



Y(4630)



Neutral $c\bar{c}$ X & Y mesons

Name	J^{PC}	Γ (MeV)	Decay modes	Expts	comment
X(3872)	1^{++}	<2.3	$\pi\pi J/\psi$; $\gamma J/\psi$; DD*	Belle/CDF/D0/BaBar	$D\bar{D}$* molecule?
X(3940)	$0^{?+}$	~37	DD* (not DD, $\omega J/\psi$)	Belle	$\eta_c''(?)$
Y(3940)	$?^{?+}$	~30	$\omega J/\psi$ (not DD*)	Belle/BaBar	
X(4160)	$0^{?+}$	~140	D*D* (not DD, DD*)	Belle	$\eta_c'''(?)$
Y(4008)	1^{--}	~225	$\pi\pi J/\psi$	Belle	
Y(4260)	1^{--}	~80	$\pi\pi J/\psi$ (not $\pi\pi\psi'$)	BaBar/CLEO/Belle	$c\bar{c}g$ hybrid?
Y(4350)	1^{--}	~75	$\pi\pi\psi'$ (not $\pi\pi J/\psi$)	BaBar/Belle	
Y(4660)	1^{--}	~50	$\pi\pi\psi'$; $\Lambda_c\bar{\Lambda}_c$ (?)	Belle	@$\Lambda_c\bar{\Lambda}_c$ threshold
Y(4140)	$?^{?+}$	~12	$\phi J/\psi$	CDF	@$\phi J/\psi$ threshold

What's new?

- Belle sees a $\gamma\gamma \rightarrow \omega J/\psi$ peak @ ~3915 MeV
  - New to this meeting
- Belle measurements of $\sigma(e^+e^- \rightarrow D^*D\pi)$
  - New to this meeting (G. Pakhlova's Thurs talk)
- CDF evidence for $Y(4140) \rightarrow \phi J/\psi$
  - Moriond QCD Kay Yi's talk this session
- $Z(4430)^+ \rightarrow \pi^+\psi'$; $Z_1(4050)^+$ & $Z_2(4250)^+ \rightarrow \pi^+\chi_{c1}$
  - controversy? Chistov & Patrigani in the next session
- BaBar results for $X(3872) \rightarrow \gamma J/\psi$ & $\gamma\psi'$
- Mass measurements from CDF & Belle

The states near 3940 MeV

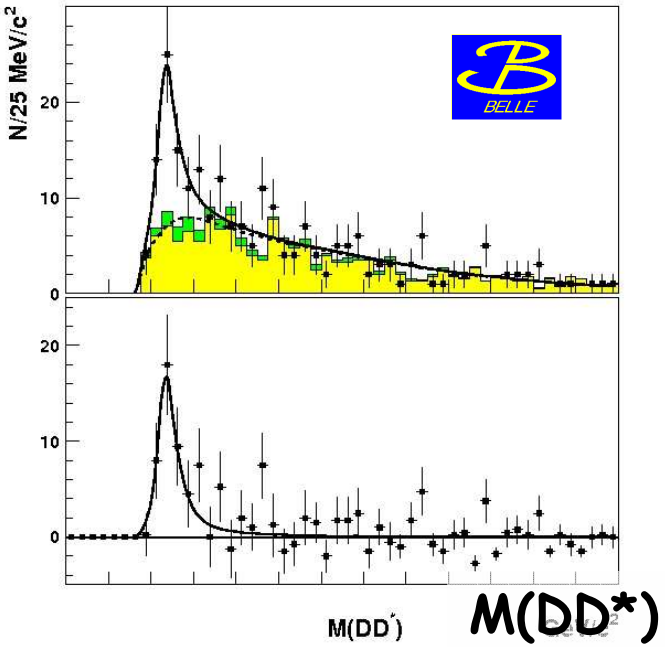
-circa 2005-

probably different

not seen in ωJ/ψ

X(3940)

$e^+e^- \to J/\psi\, DD^*$



M(DD*)

M = 3942 $^{+7}_{-6}$ ± 6 MeV

Γ_{tot} = 37 $^{+26}_{-15}$ ±12 MeV

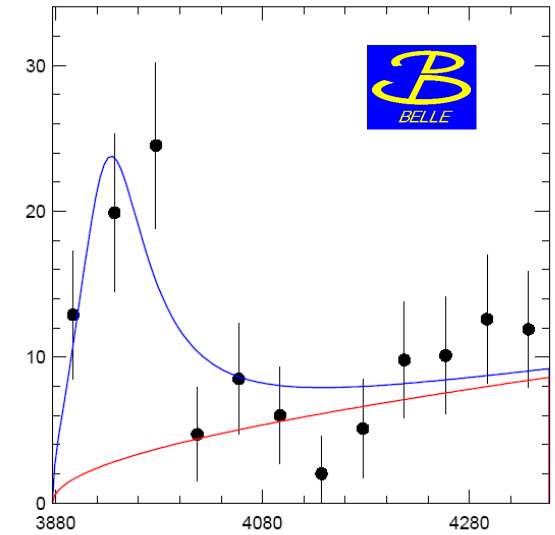
Nsig =52 $^{+24}_{-16}$ ± 11evts

PRL 100, 202001

not seen in DD*

Y(3940)

$B \to K\, \omega J/\psi$



M(ωJ/ψ)

M≈3940 ± 11 MeV

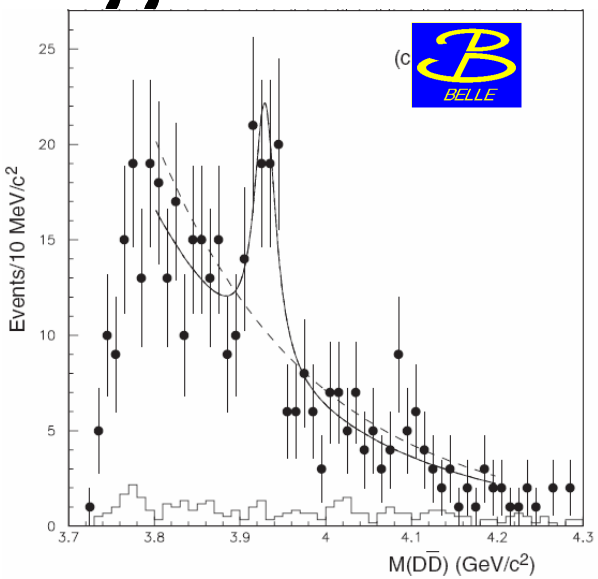
Γ≈ 92 ± 24 MeV

PRL94, 182002 (2005)

Probably the χ_{c2}'

Z(3930)

$\gamma\gamma \to DD$



M(DD)

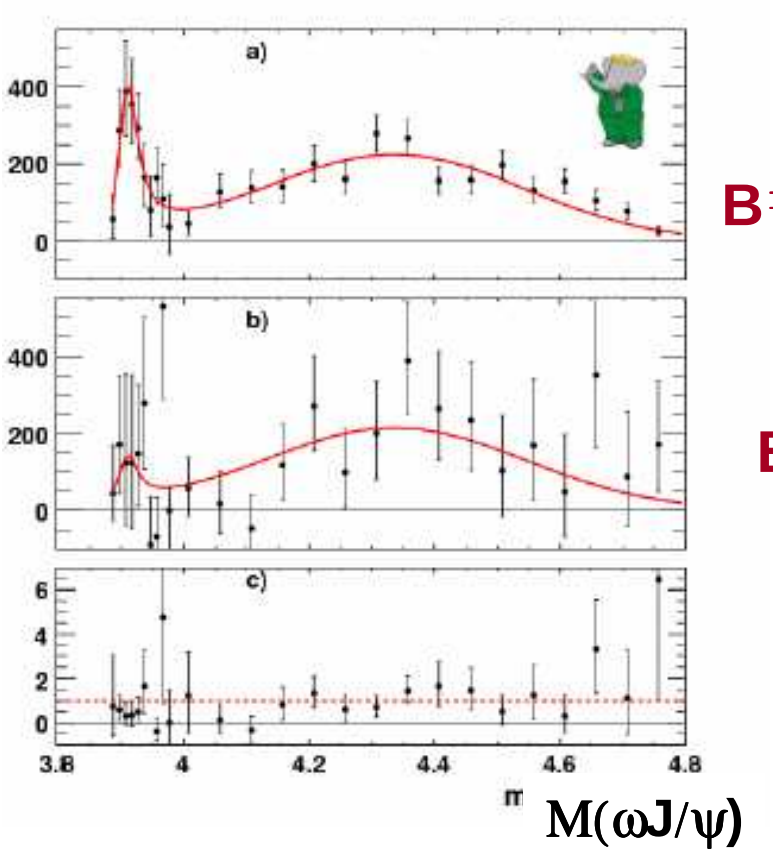
M = 3929±5±2 MeV

Γ_{tot} = 29±10±2 MeV

Nsig =64 ± 18evts

PRL 96, 082003

Y(3940) confirmed by BaBar



$B^{\pm} \rightarrow K^{\pm} \omega J/\psi$

$B^{0} \rightarrow K_S \omega J/\psi$

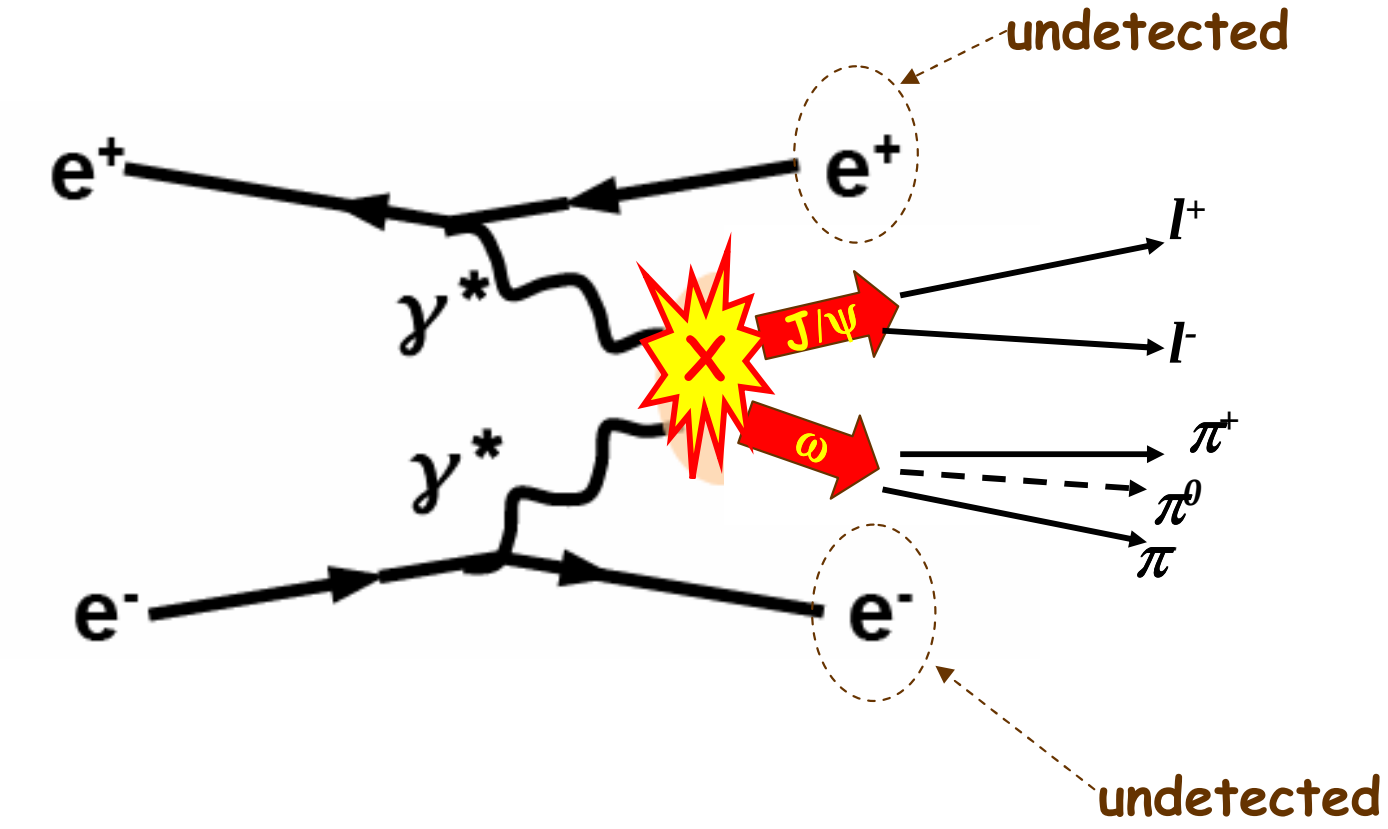
ratio

	Mass (MeV)	Γ (MeV)
Belle 253 fb^{-1}	$3943 \pm 11(stat) \pm 13(syst)$	$87 \pm 22(stat) \pm 26(syst)$
BaBar 350 fb^{-1}	$3914.3^{+3.8}_{-3.4}(stat)^{+1.6}_{-1.6}(syst)$	$33^{+12}_{-8}(stat)^{+0.6}_{-0.6}(syst)$

PRL 101, 082001

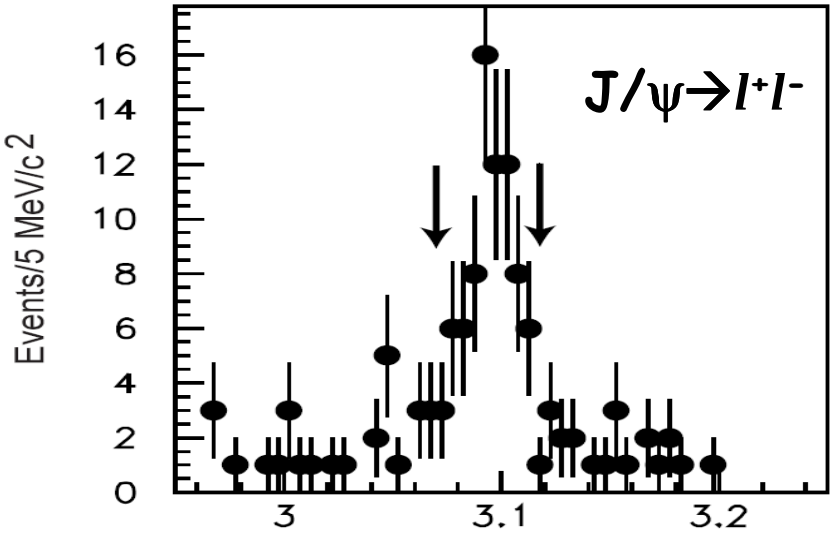
Some discrepancy in M & Γ; general features agree

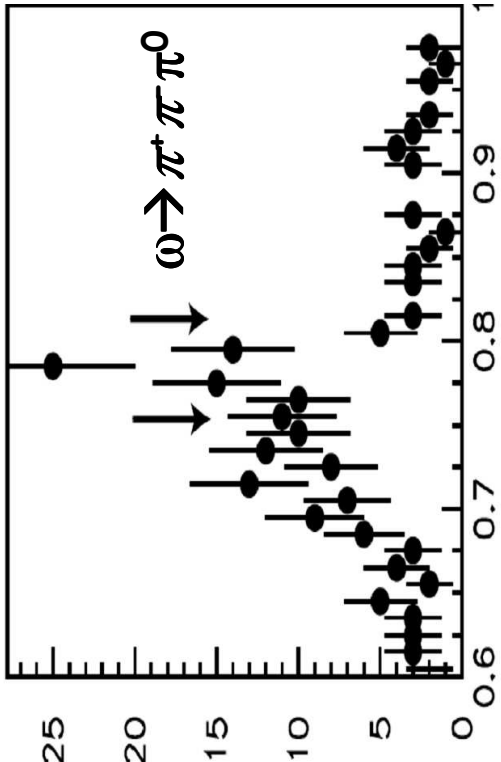
New Belle peak in $\gamma\gamma \to \omega J/\psi$

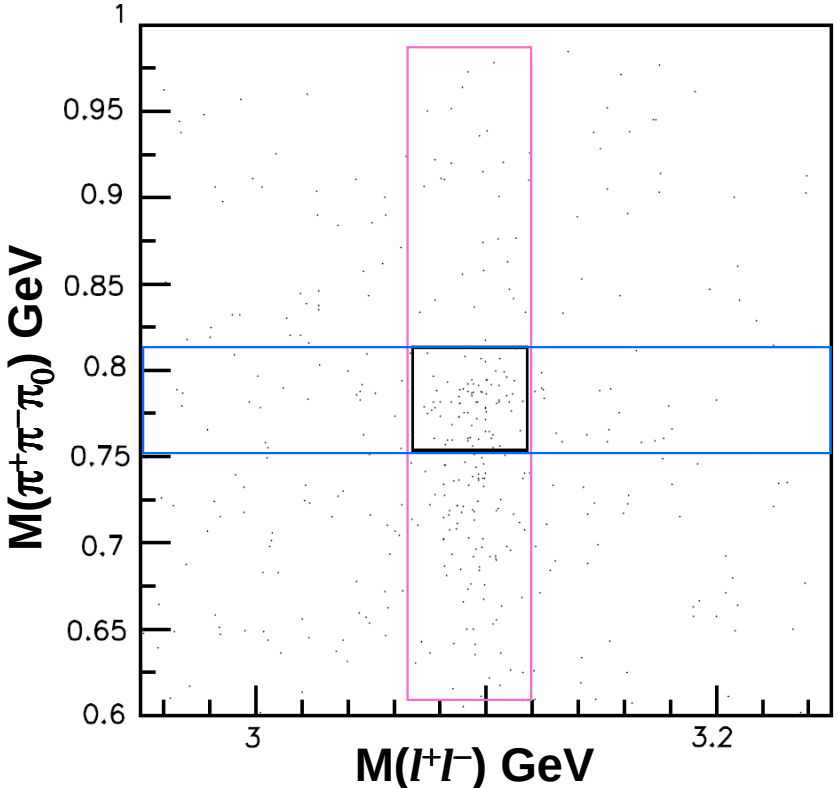


$M(\pi^+\pi^-\pi^0)$ *vs* $M(l^+l^-)$

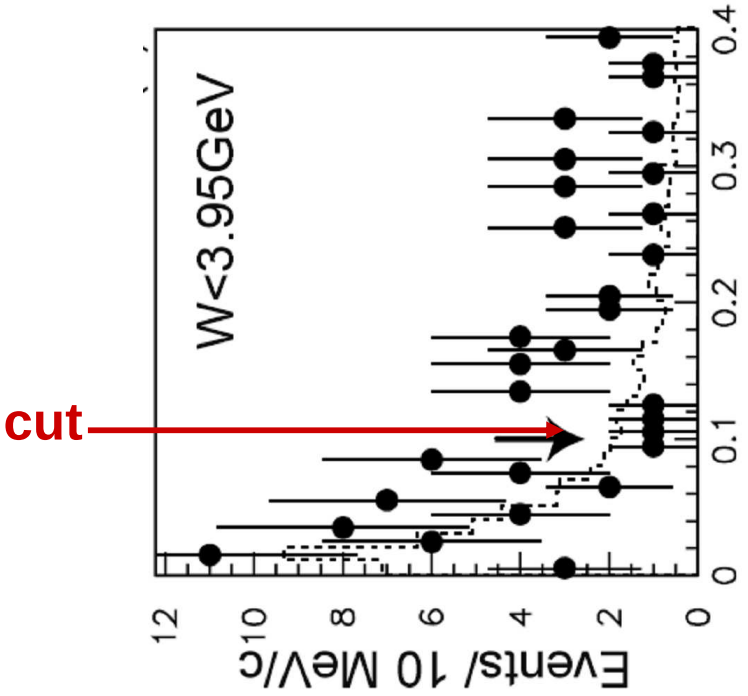
- 4 trks (≥1 lepton, no kaons)
- $\Sigma q_i=0$
- ≥1 π^0 ← select best one
- veto $\psi' \rightarrow \pi^+\pi^- J/\psi$
- W<4.3 GeV
- $\Sigma \vec{p}_T$<0.1GeV
- …

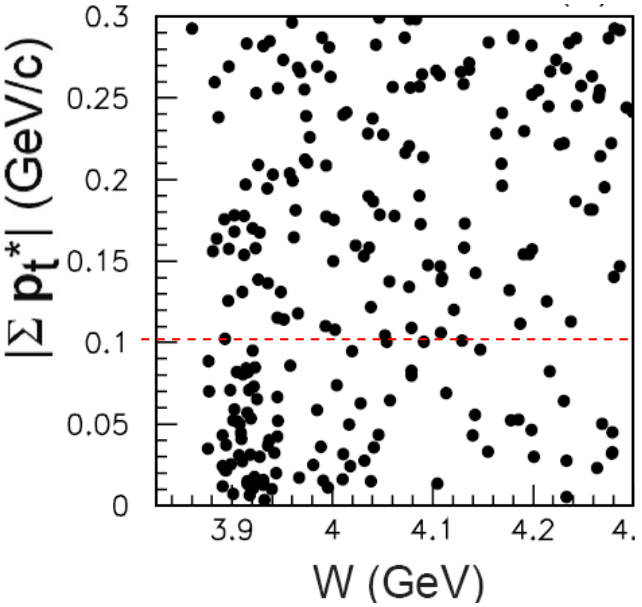


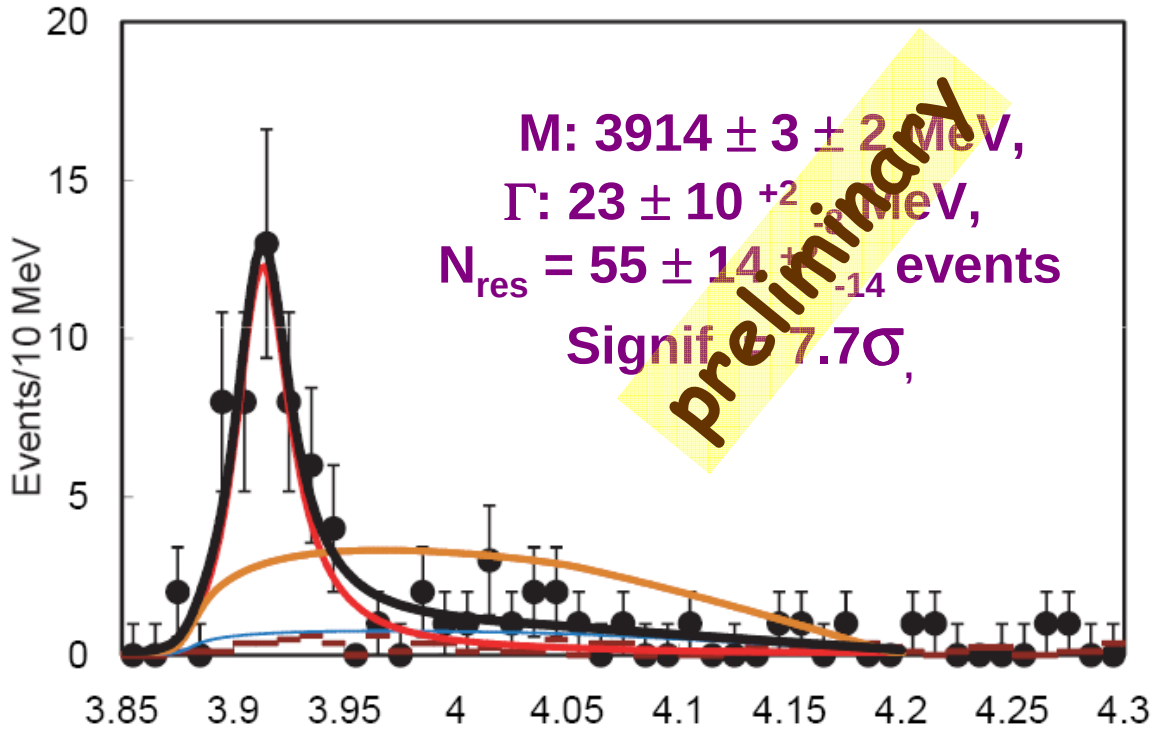




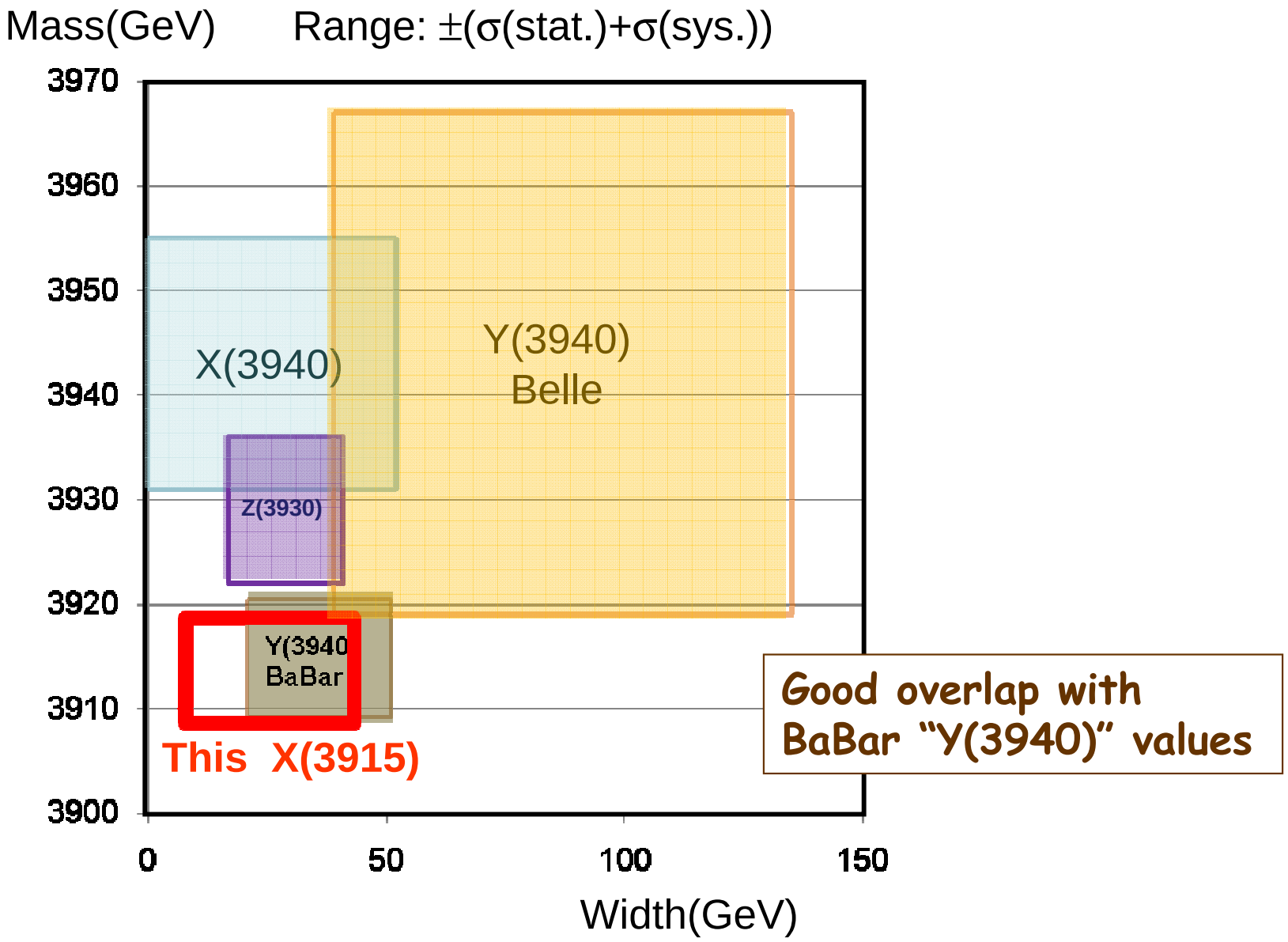
$\Sigma\vec{p}_T$ vs W



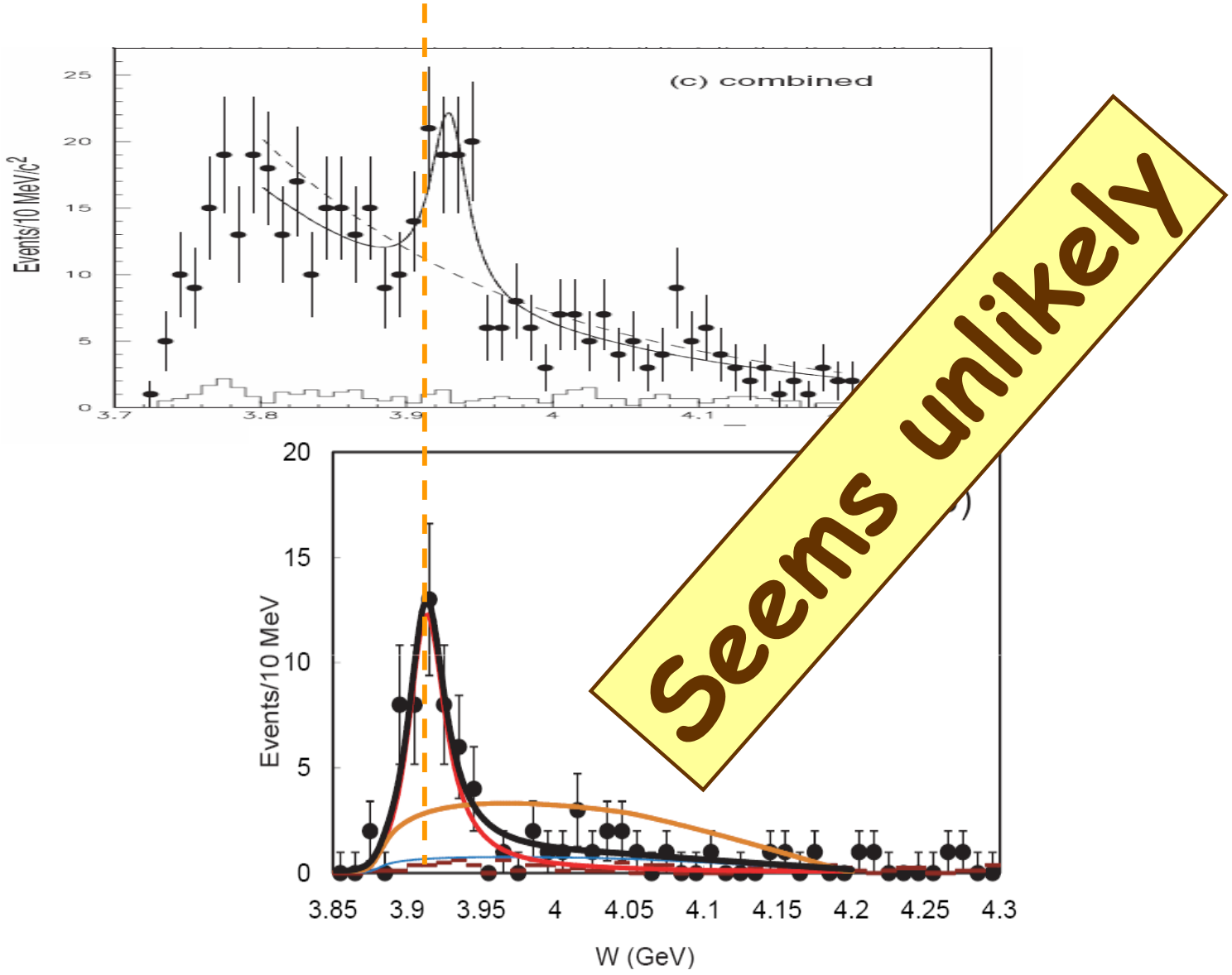




The 4 states near 3940



Could it be the Z(3930)?



$\Gamma_{\gamma\gamma}$ partial width

$\Gamma_{\gamma\gamma}B(\omega J/\psi) = 69 \pm 16^{+7}_{-18}$ eV ($J^P=0^+$)

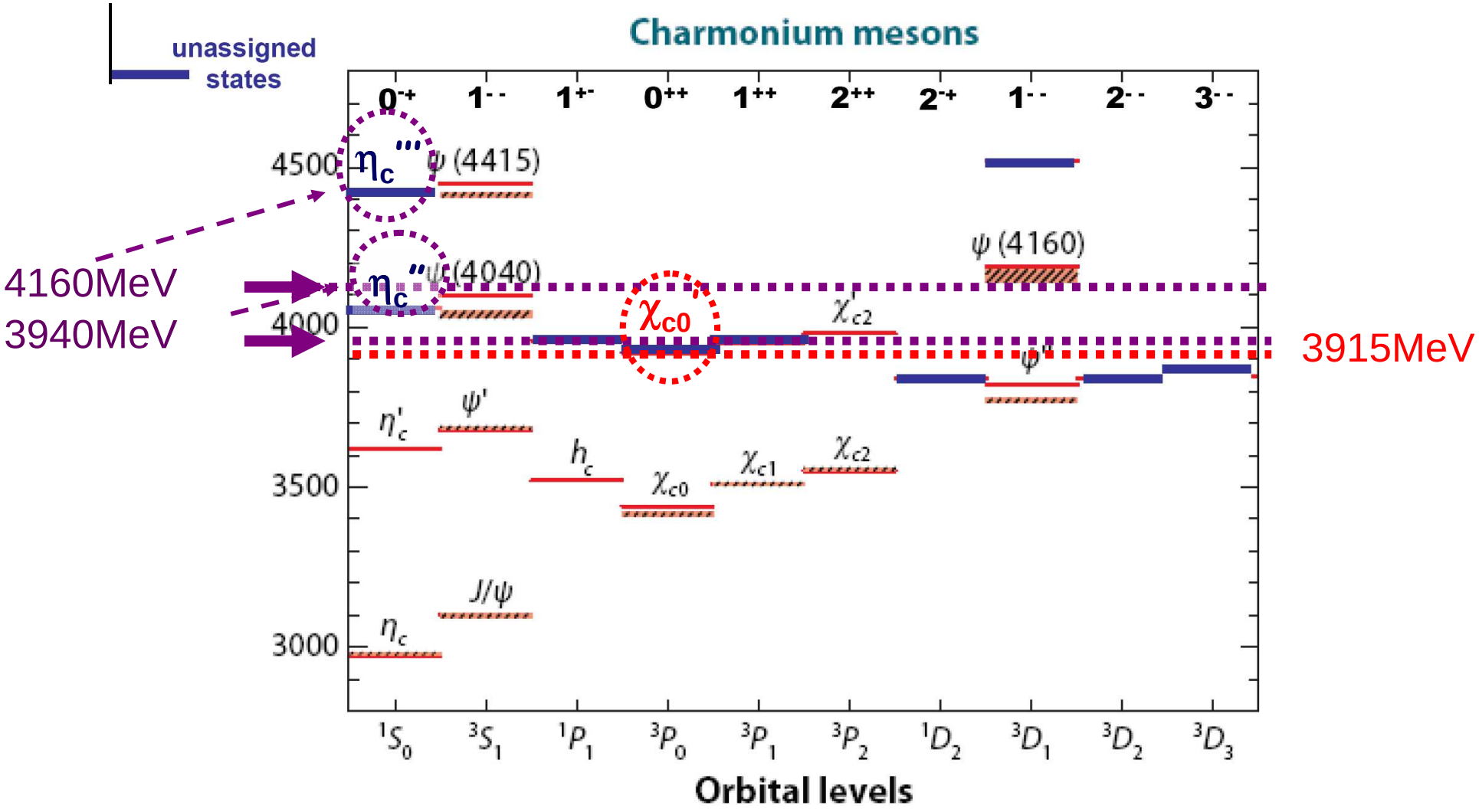
$\Gamma_{\gamma\gamma}B(\omega J/\psi) = 21 \pm 4^{+2}_{-5}$ eV ($J^P=2^+$)

For comparison:
$Z(3930)$: $\Gamma_{\gamma\gamma}B(DD) = 180 \pm 50 \pm 30$ eV

If X(3915) = Z(3930) = χ_{c2}' → $\dfrac{Bf(\chi_{c2}' \to \omega J/\psi)}{Bf(\chi_{c2}' \to DD)} \geq 0.08$

Huge for above-open-charm-threshold charmonium

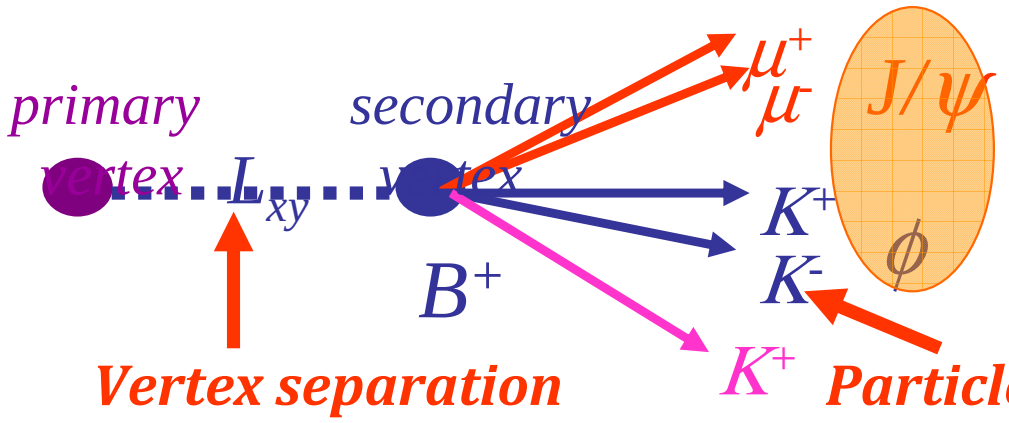
CC assignments for X(3915), X(3940) & X(4160)?



- Y(3915) = χ_{c0}'? ←$\Gamma(\omega J/\psi)$ too large?
- X(3940) = η_c''? ← mass too low?
- X(4160) = η_c'''? ← mass way too low?

Y(4140) from CDF

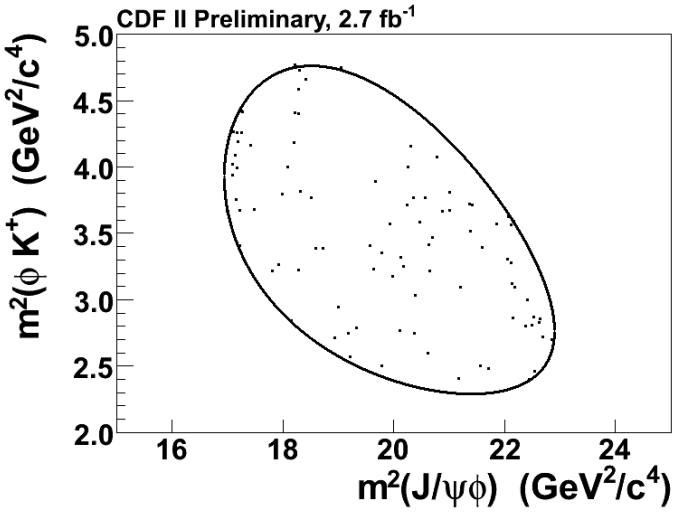
arXiv:0903.2229

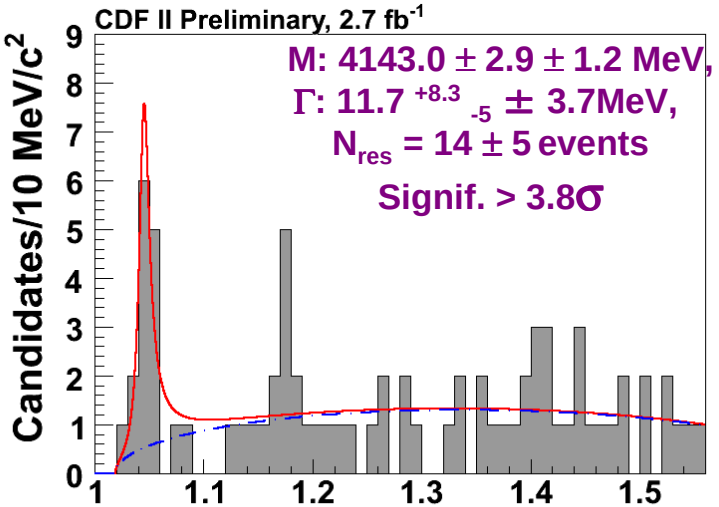


Kai Yi's talk in This session

Vertex separation

Particle Identification (Kaon LLR)

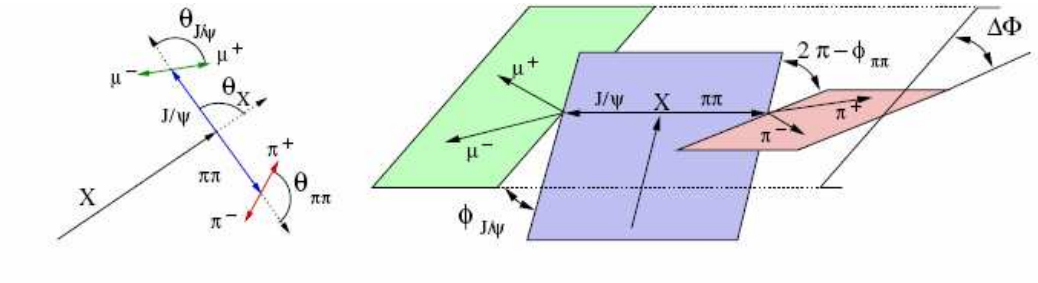




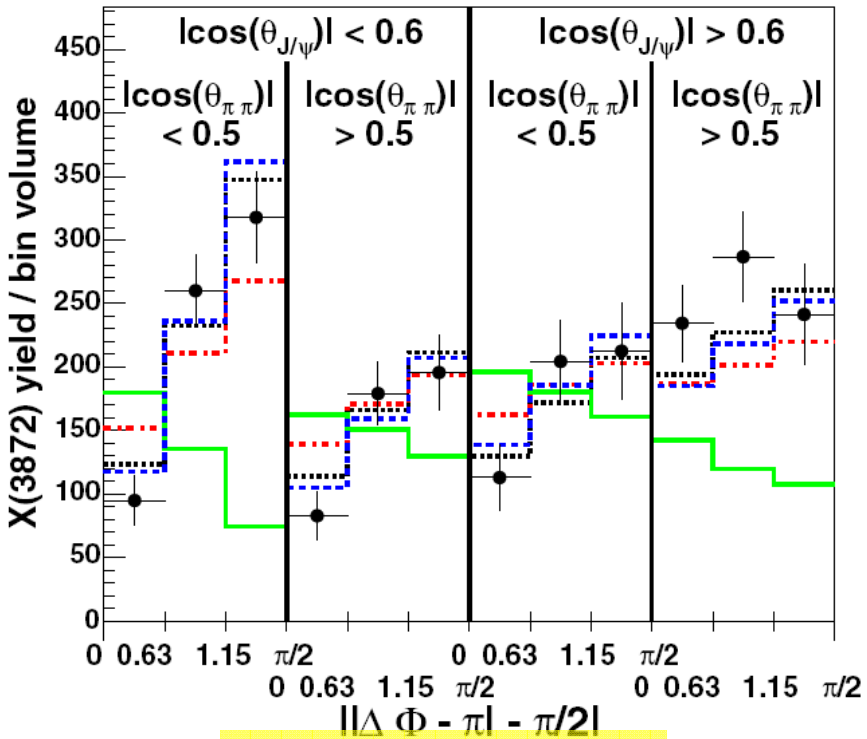
$\Delta M = m(\mu^+\mu K^+K^-) - m(\mu^+\mu)$

comment on J^{PC} of the X(3872)

J^{PC} values from CDF & Belle

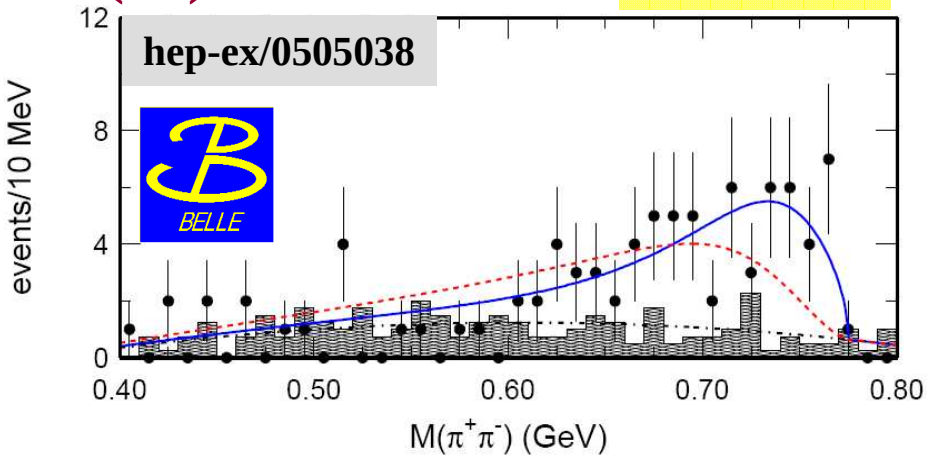


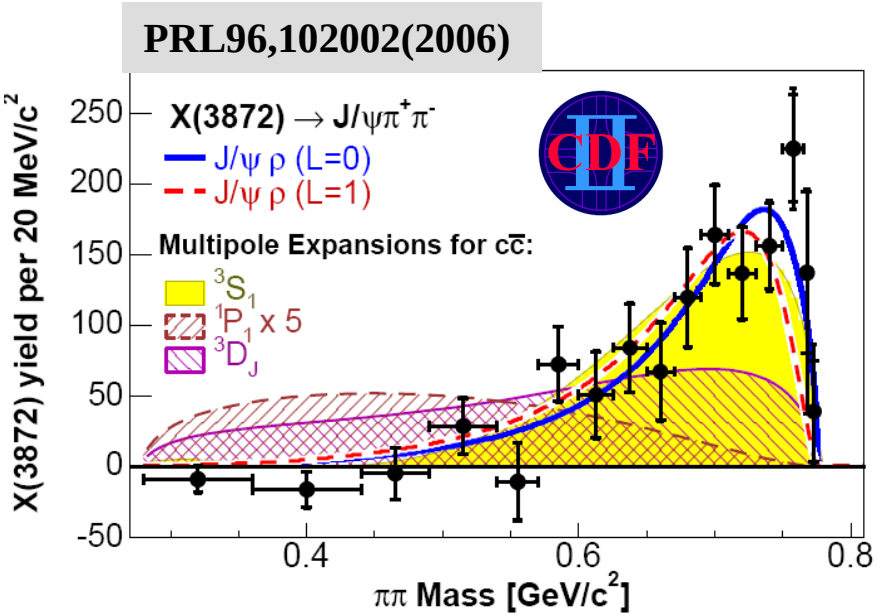
CDF: PRL 98 132002



$J^{PC} = 1^{++}$ or 2^{-+}

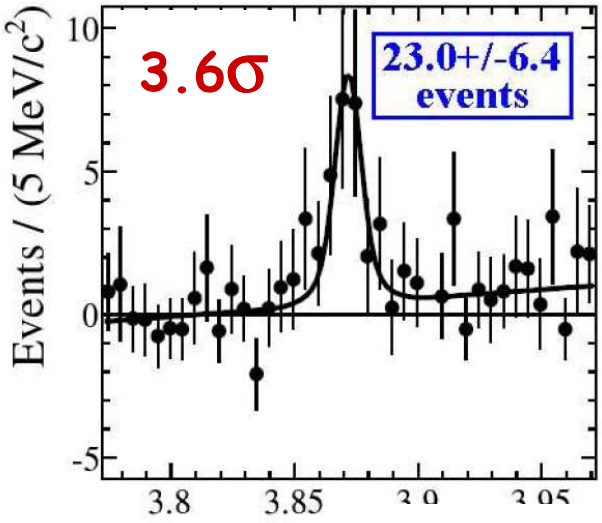
- Fit to M(ππ) favors L = 0 ⇒ $J^{PC} = 1^{++}$



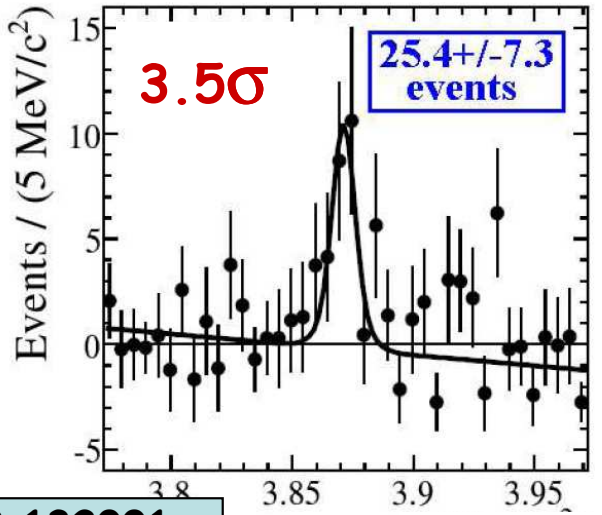


BaBar: X(3872)→ γJ/ψ & γψ'

$B^+ \to K^+ \gamma J/\psi$



$B^+ \to K^+ \gamma\psi'$



PRL 102,132001

$1^{++} \to \gamma\, J/\psi$ or $\gamma\psi'$ ← Allowed E1

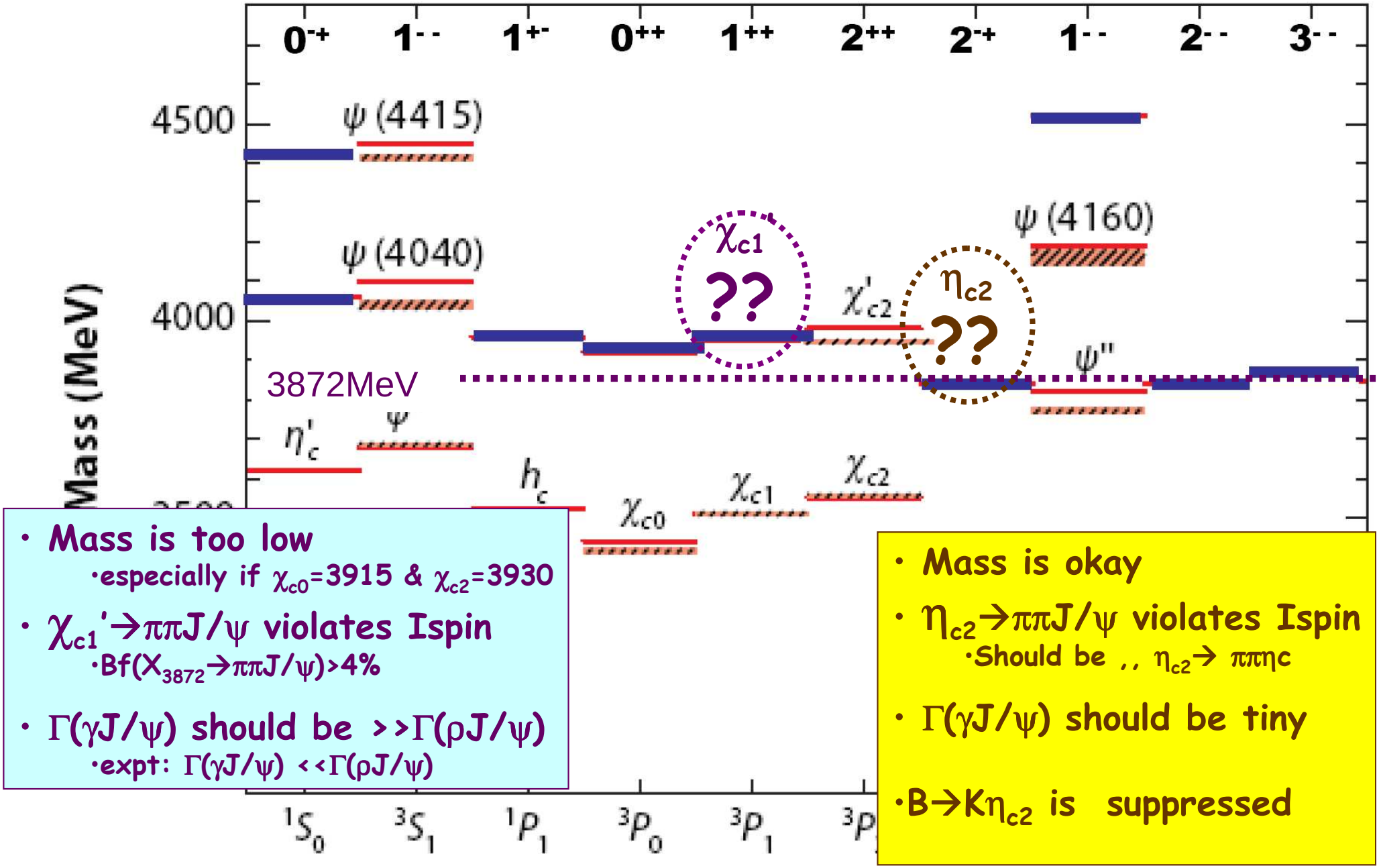
$2^{-+} \to \gamma J/\psi$ or $\gamma\psi'$ ← Suppressed E2

$J^{PC} = 1^{++}$ favored over 2^{-+}

NB: Molecular models have trouble with X(3872)→γψ'

Swanson PLB 598, 192 (2004)

Is there a $c\bar{c}$ assignment for X(3872) ?

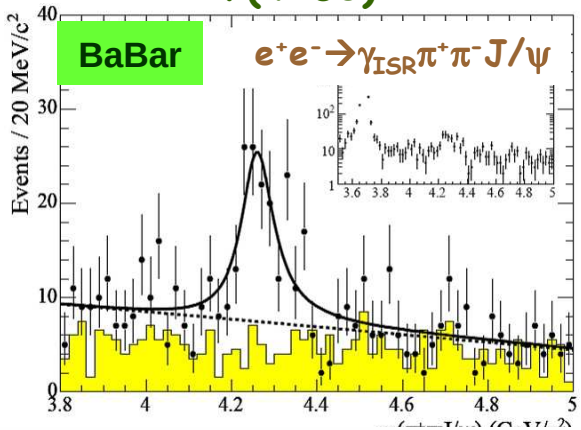


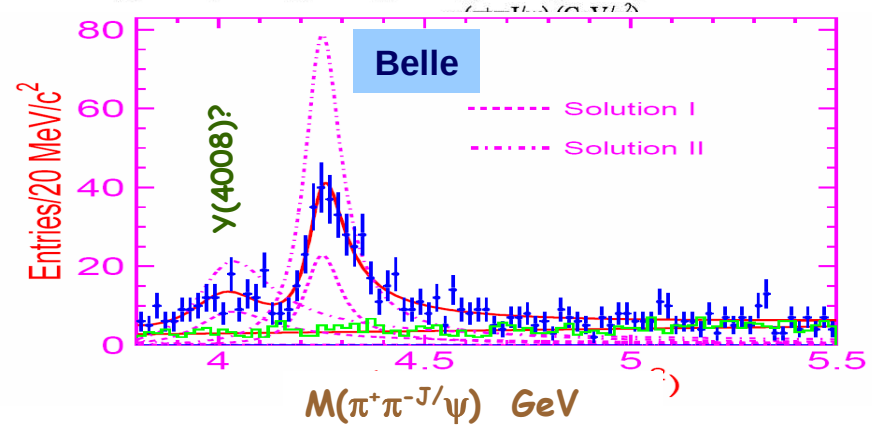
- **Mass is too low**
  - especially if χ_{c0}=3915 & χ_{c2}=3930
- $\chi_{c1}' \rightarrow \pi\pi J/\psi$ violates Ispin
  - $Bf(X_{3872} \rightarrow \pi\pi J/\psi) > 4\%$
- $\Gamma(\gamma J/\psi)$ should be >> $\Gamma(\rho J/\psi)$
  - expt: $\Gamma(\gamma J/\psi) << \Gamma(\rho J/\psi)$

- **Mass is okay**
- $\eta_{c2} \rightarrow \pi\pi J/\psi$ violates Ispin
  - Should be ,, $\eta_{c2} \rightarrow \pi\pi\eta c$
- $\Gamma(\gamma J/\psi)$ should be tiny
- $B \rightarrow K\eta_{c2}$ is suppressed

the 1^{--} Y states

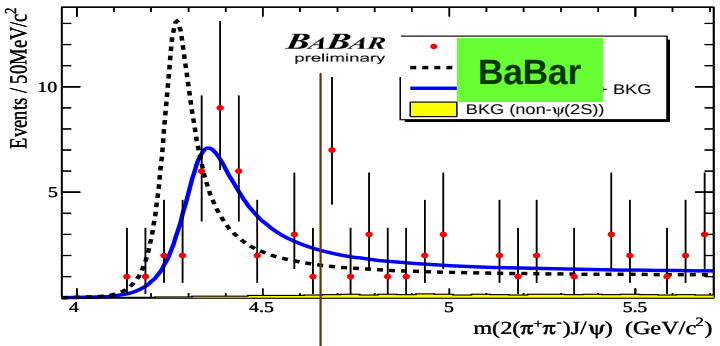
Y(4260)

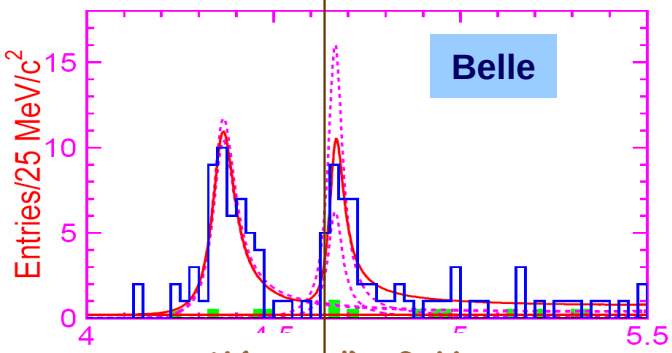




Y(4350) & Y(4660)

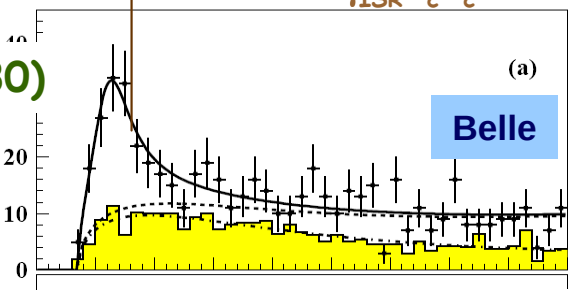
$e^+e^- \to \gamma_{ISR}\pi^+\pi^-\psi'$





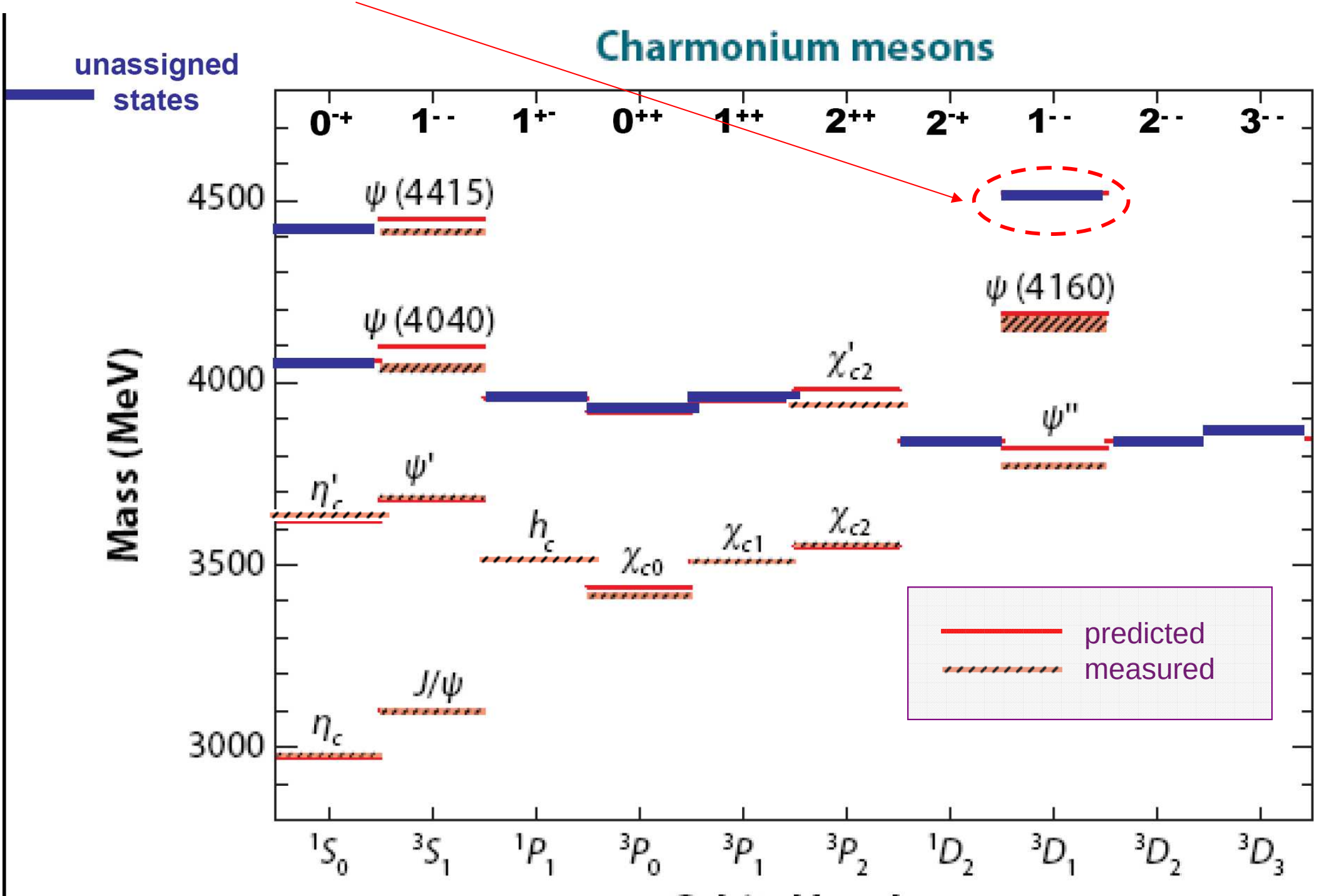
$e^+e^- \to \gamma_{ISR}\Lambda_c\Lambda_c$

Y(4630)



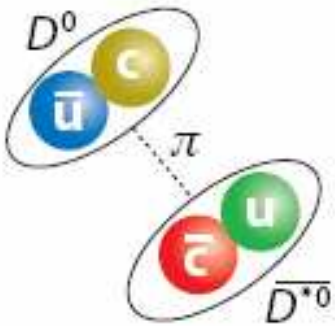
at least 3, maybe 5

Only 1 unassigned 1^{--} $c\bar{c}$ level



If not charmonium
what else?

--many proposals--



D^0–$\overline{D^{*0}}$ "molecule"

- **NA Tornqvist**
  PLB 590, 209 (2004)
- **ES Swanson**
  PLB 598,197 (2004)
- **E Braaten & T Kusunoki**
  PRD 69 074005 (2004)
- **CY Wong**
  PRC 69, 055202 (2004)
- **MB Voloshin**
  PLB 579, 316 (2004)
- **F Close & P Page**
  PLB 578,119 (2004)
- **X Liu**
  arXiv 0708..4167

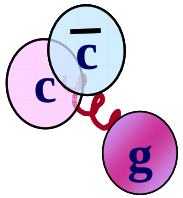
…

Diquark–diantiquark

- **L Maiani et al**
  PRD 71,014028 (2005)
- **T-W Chiu & TH Hsieh**
  PRD 73, 111503 (2006)
- **D Ebert et al**
  PLB 634, 214 (2006)

…

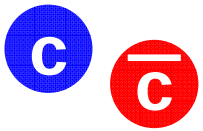
Etc:
- hadro-charmonium
- threshold effects
- …



$c\bar{c}$-gluon hybrid

- **P Lacock et al** (UKQCD)
  PLB 401, 308 (1997)
- **SL Zhu**
  PLB 625, 212 (2005)
- **FE Close, PR Page**
  PLB 628, 215 (2005)
- **E Kou, O Pene**
  PLB 631, 164 (2005)

…



modified charmonium

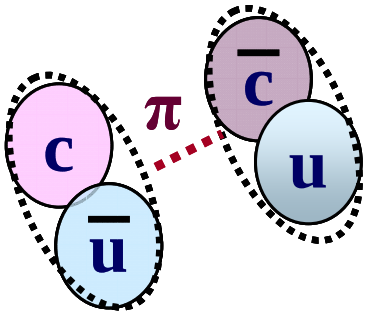
- **S Dubynski et al**
  PLB 666,344 (2008)
- **FK Guo et al**
  PLB 665, 26 (2008)
- **DV Bugg**
  arXiv+0709.1254

…

- **C Meng & KT Chao**
  PRD 75, 114002 (2007)
- **W Dunwoodie & V Ziegler**
  PRL 100 062006 (2008)
- **O Zhang, C Meng & HQ Zheng**
  arXiv:0901.1553

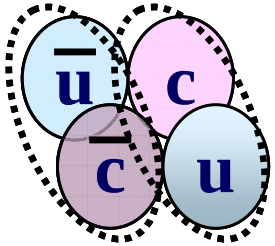
…

Model features



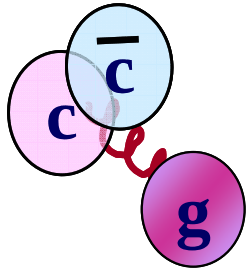
$D^{(*)}\bar{D}^{(*)}$ molecules
(real or virtual)

masses should be near $M(D^{(*)})+M(D^{(*)})$ mass thresholds



diquark-diantiquarks

Expect SU(3) multiplets



cc-gluon hybrids

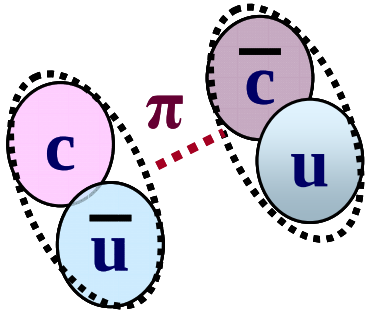
LQCD: M>~4.3 GeV

Open charm thresh $=M_D+M_{D^{**}} \approx 4285$ (above Y_{4260} peak)

Non-zero charges are not allowed

Etc.
- hadro-charmonium
- light hadron-charmonium bound states
- threshold effects
- …

$D^{(*)}\bar{D}^{(*)}$ Molecules?



masses should be near $M(D^{(*)})+M(D^{(*)})$ mass thresholds

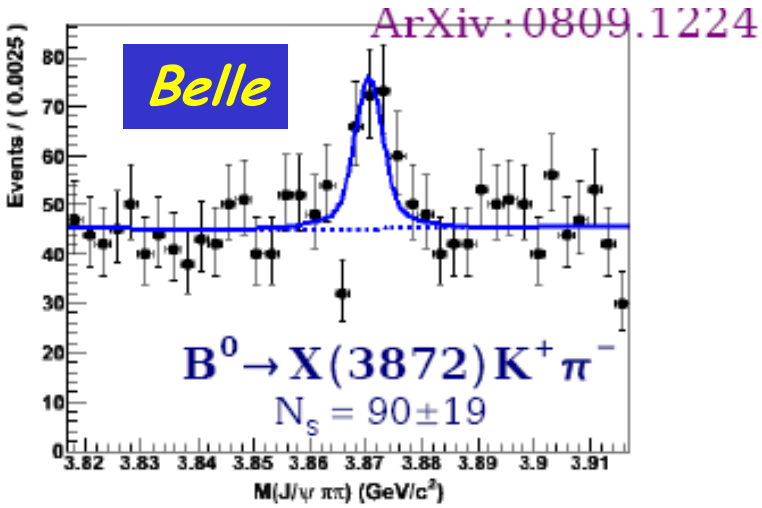
Favored model for the X(3872)

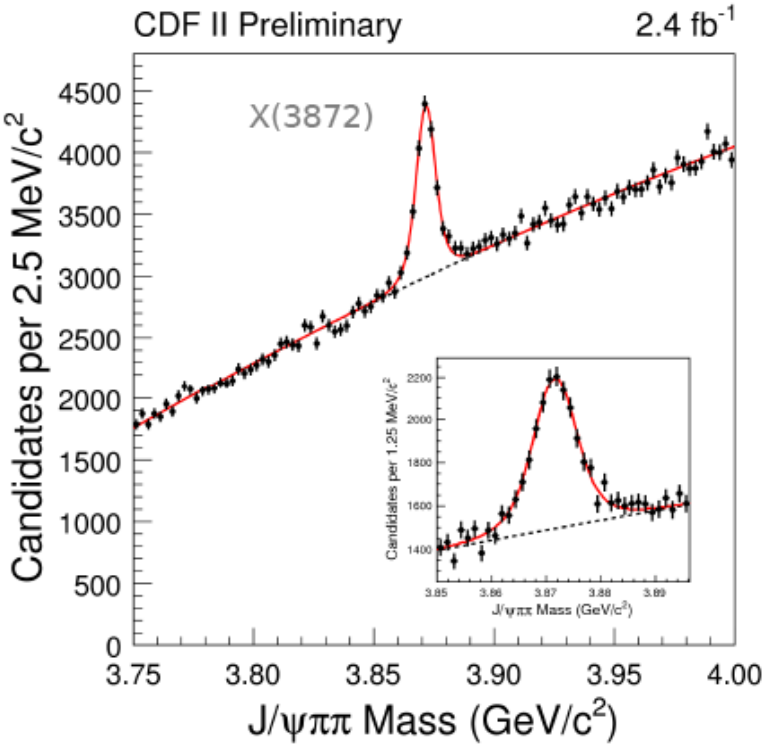
Lots of literature on this, some very detailed
(& some prior to the X(3872) discovery)

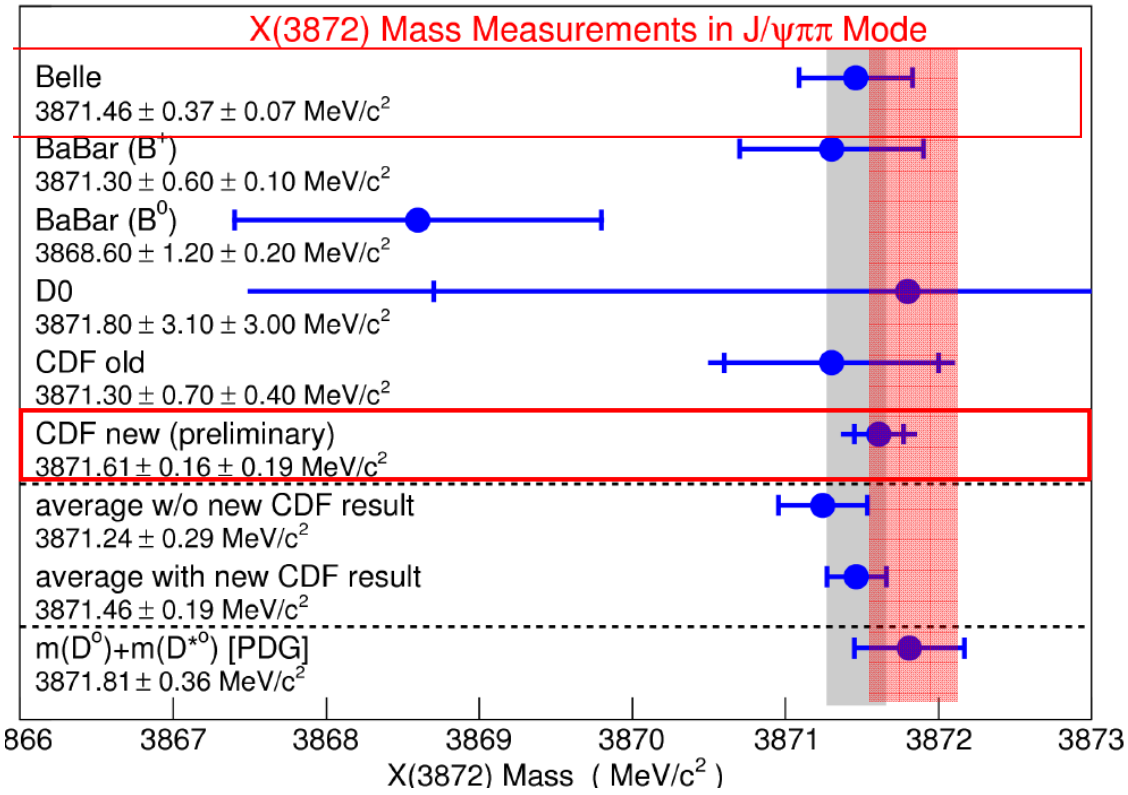
X(3872) Mass

- in $\pi\pi J/\psi$ channel only --

2 new measurements



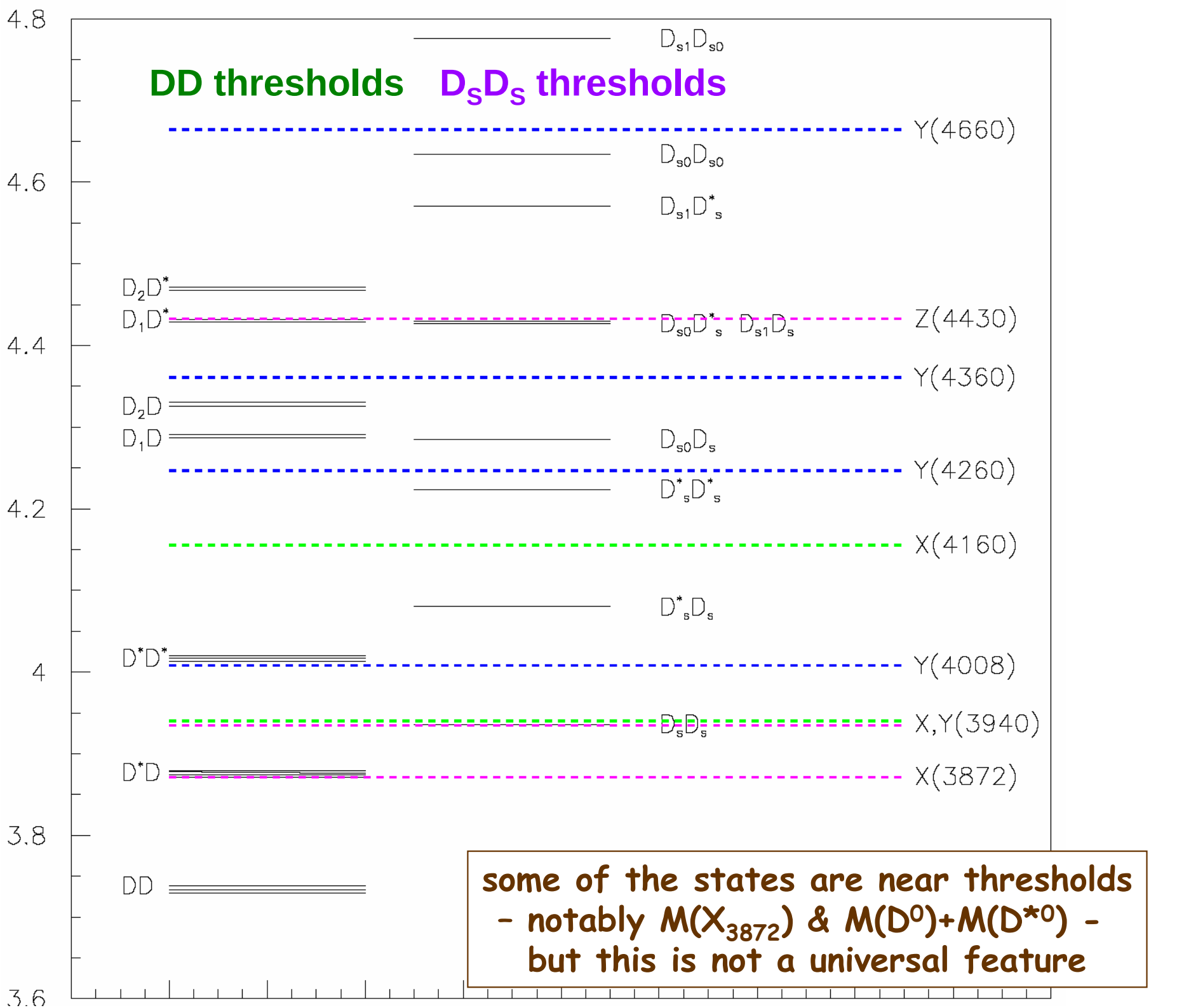




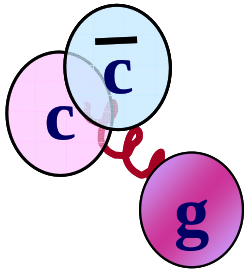
Avg: $M_{X(3872)} = 3871.5 \pm 0.2$ MeV

PDG08: $M_{D^0}+M_{D^{*0}} = 3871.8 \pm 0.4$ MeV

CDF T. Kuhr @ QWG08


4.8
4.6
4.4
4.2
4
3.8
3.6
DD thresholds
D_sD_s thresholds
$D_{s1}D_{s0}$
Y(4660)
$D_{s0}D_{s0}$
$D_{s1}D^*_s$
D_2D^*
D_1D^*
$D_{s0}D^*_s$ $D_{s1}D_s$
Z(4430)
Y(4360)
D_2D
D_1D
$D_{s0}D_s$
Y(4260)
$D^*_sD^*_s$
X(4160)
$D^*_sD_s$
D^*D^*
Y(4008)
D_sD_s
X,Y(3940)
D^*D
X(3872)
DD
some of the states are near thresholds
– notably $M(X_{3872})$ & $M(D^0)+M(D^{*0})$ –
but this is not a universal feature

Hybrids?



LQCD: M>~4.3 GeV

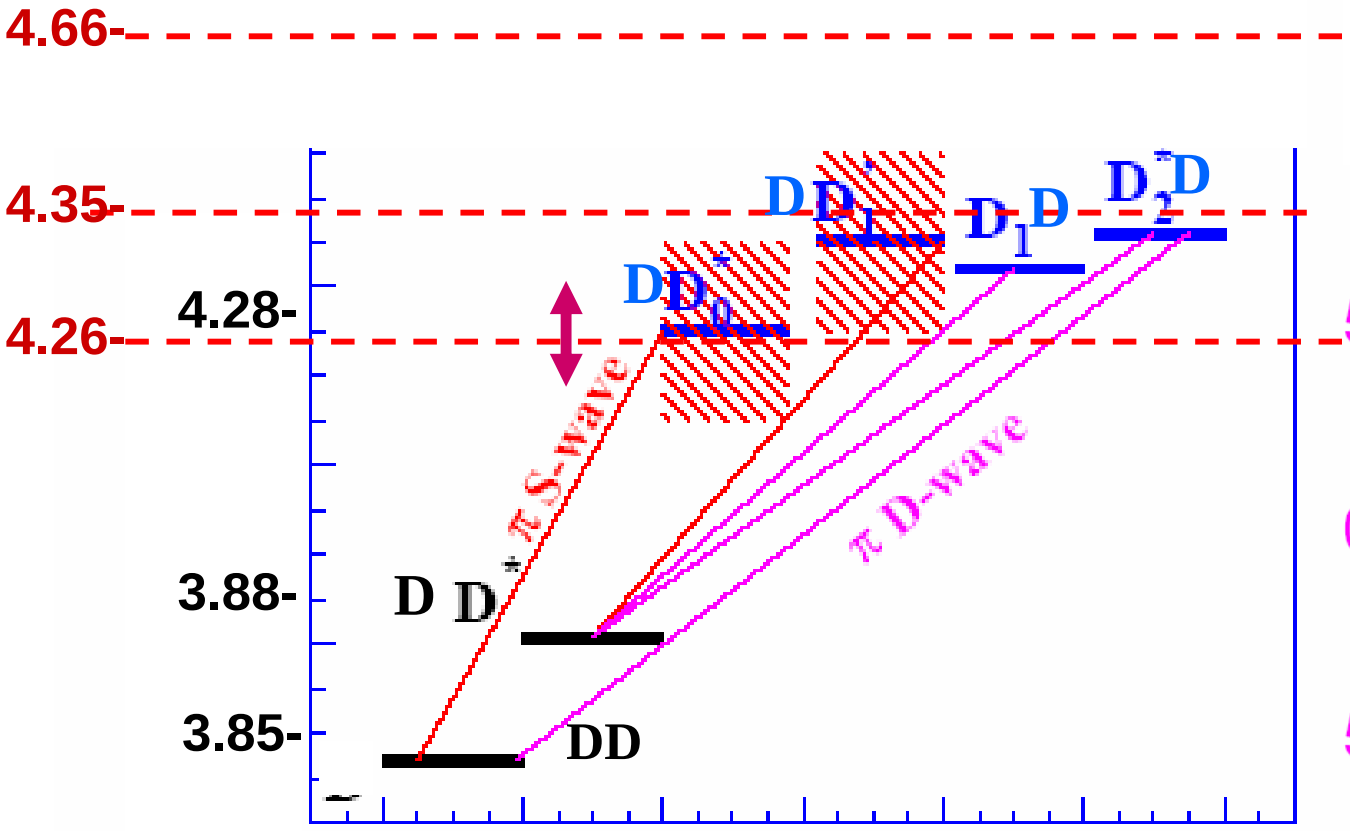
Open charm thresh
$=M_D+M_{D^{**}} \approx 4285$ MeV
(above Y_{4260} peak)

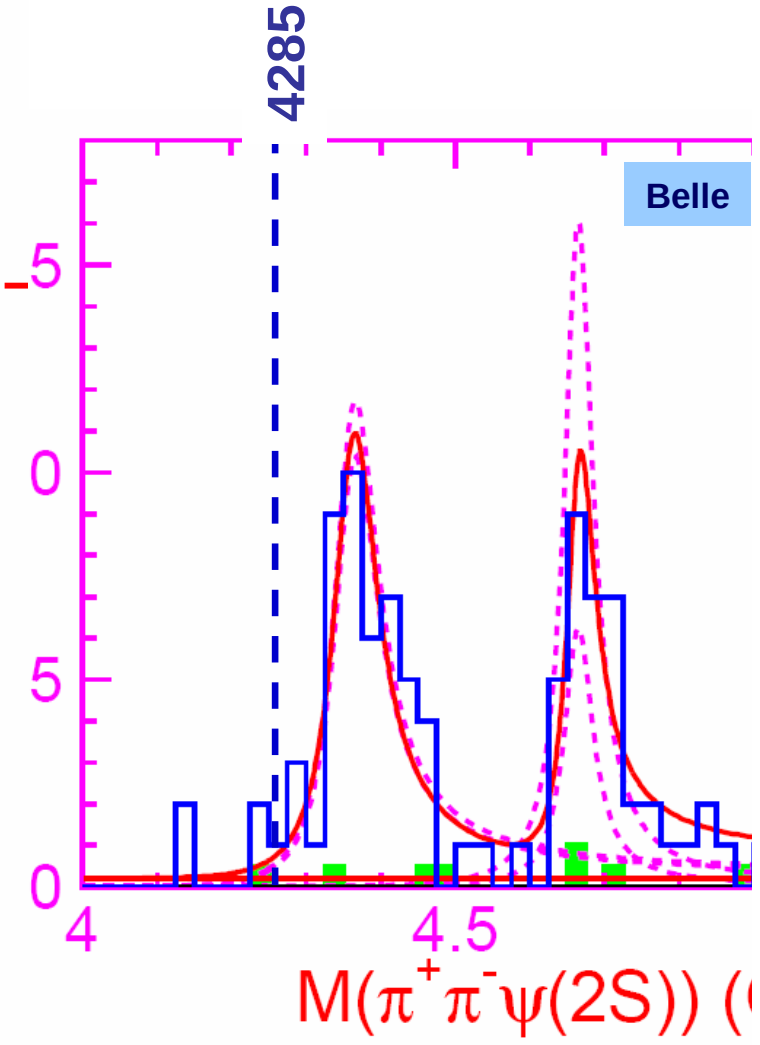
Non-zero charges
are not allowed

Should be seen in open-charm channels above 4285 MeV

Favored assignment for the 1^{--} Y states

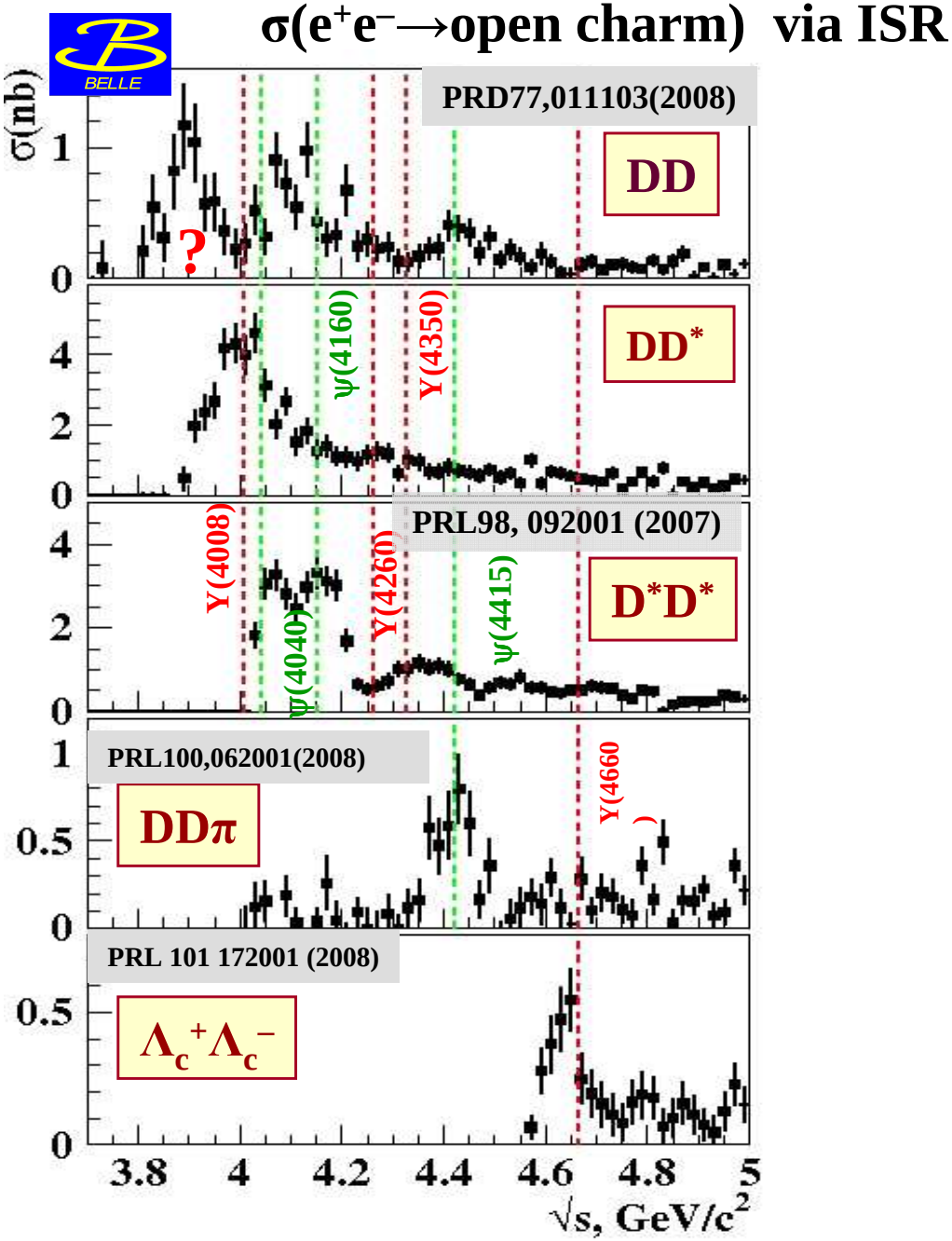
DD** thresholds and the Y(4260), Y(4350) & Y(4660)





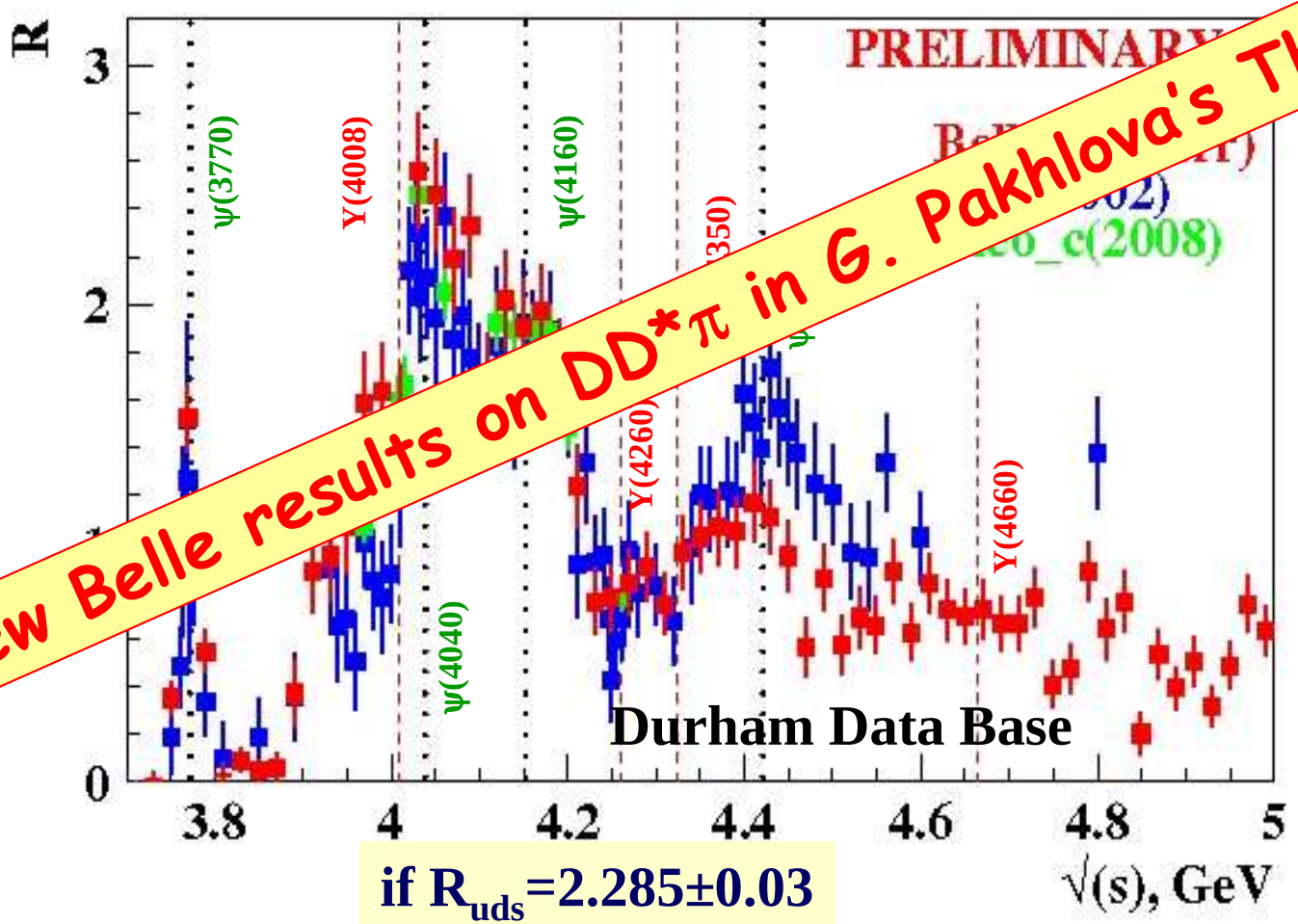
Y(4350) & Y(4660) are well above all DD** thresholds & should have strong widths to DD*π

No evidence for any 1^{--} $Y \to D^{**}\bar{D}$



Almost all open-charm channels are accounted for

Belle: Sum of all measured exclusive contributions



New Belle results on $DD^*\pi$ in G. Pakhlova's Thurs PM talk

Inclusive (BES)

Σexclusive (Belle)

if $R_{uds}=2.285\pm0.03$

These states have large $\Gamma(\pi\pi J/\psi\ (\psi'))$

eg: $\Gamma(Y(4260)\to\pi^+\pi^-\ J/\psi) > 1.6$MeV @ 90% CL

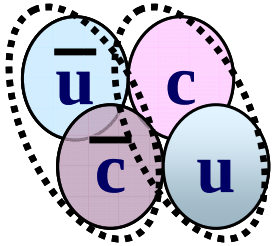
X.H. Mo *et al*, PL B640, 182 (2006)

Much larger than measured charmonium widths:

$$\Gamma(\psi'\to\pi^+\pi^-\ J/\psi) = 0.104 \pm 0.004\ \text{MeV}$$

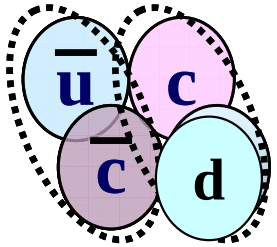
$$\Gamma(\psi''\to\pi^+\pi^-\ J/\psi) = 0.044 \pm 0.008\ \text{MeV}$$

diquark-diantiquarks

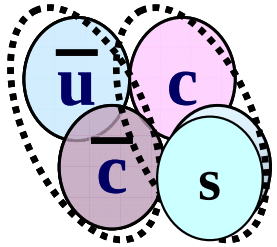


Expect SU(3) multiplets

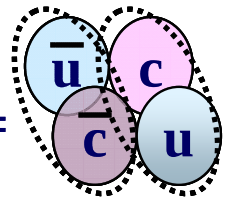
Isospin partners

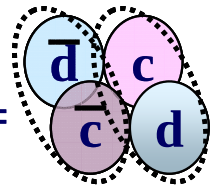
$X^- =$ 

S=-1 partners

$X_s^- =$ 

doublet of "X(3872)" states

$X_u =$ 

$X_d =$ 

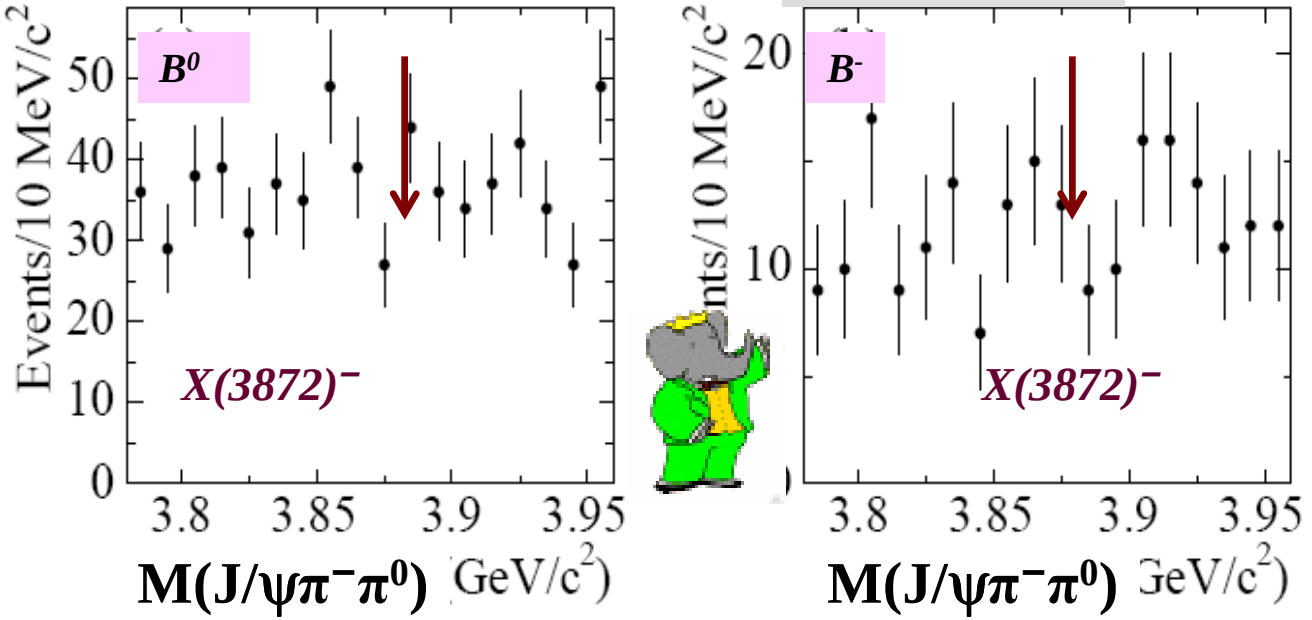
ΔM=8±3 MeV

Maiani et al PRD71, 014028

No multiplet partners seen

BaBar search for "$X^-(3872)" \to \pi^-\pi^0\ J/\psi$

PRD 71, 031501



$$\frac{Bf(B^0 \to K^+ X^-) Bf(X^- \to \pi^-\pi^0 J/\psi)}{Bf(B^- \to K^+ X^0) Bf(X^0 \to \pi^+\pi^- J/\psi)} < 0.4$$

(expect ≈ 2)

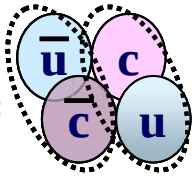
No evidence for X(3872) neutral partner

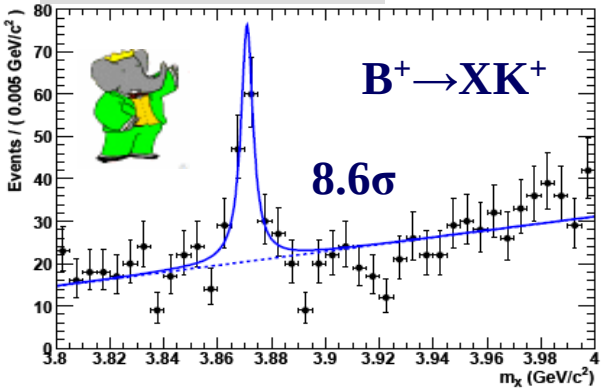
$X(3872) \to J/\psi\pi^+\pi^-$

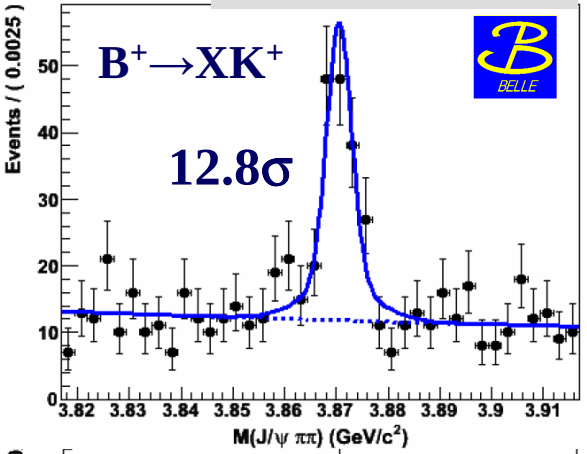
PRD77,111101,2008

BELLE-CONF-0849

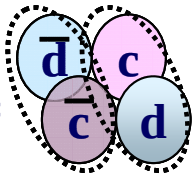
X_u =

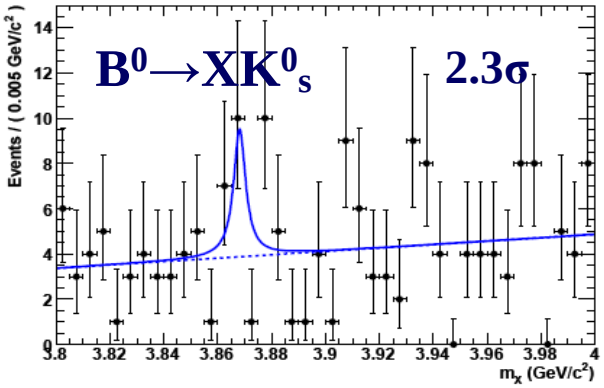


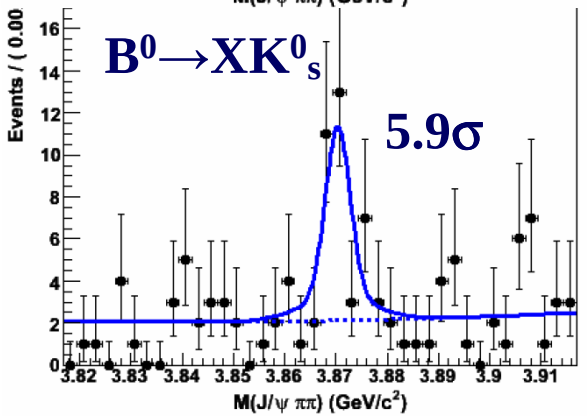




X_d =







$\Delta M_X = 2.7 \pm 1.6 \pm 0.4$ MeV

$\Delta M_X = 0.2 \pm 0.9 \pm 0.3$ MeV

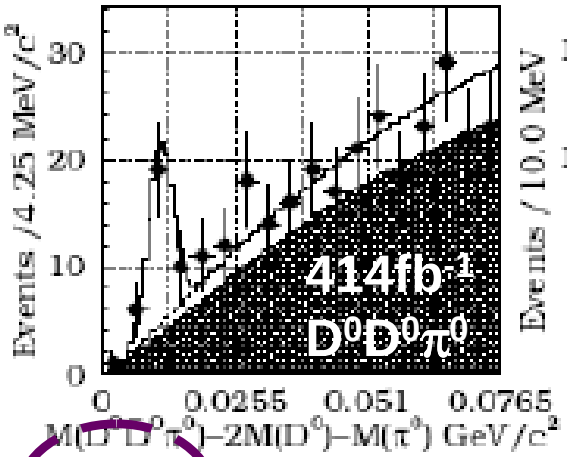
$\Delta M = 8 \pm 3$ MeV predicted

Maiani et al PRD71, 014028

Mass different in X→DD* modes?

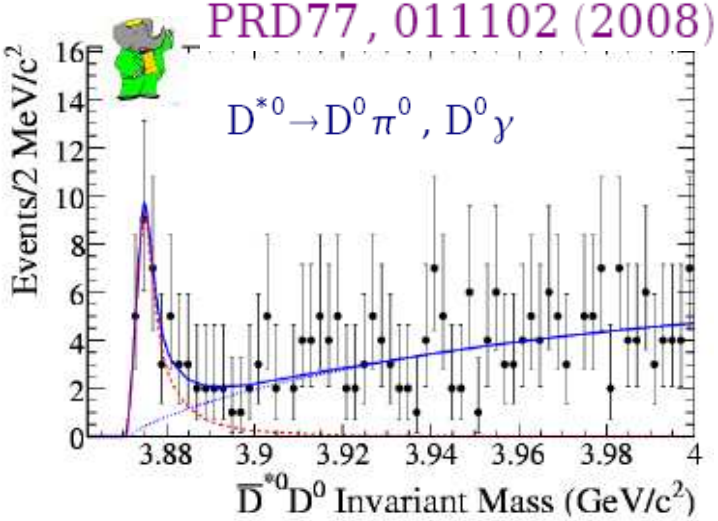
"old"

PRL97, 162002 (2006)



$$M = (3875.2 \pm 0.7^{+0.3}_{-1.6} \pm 0.8)\ \mathrm{MeV}/c^2$$

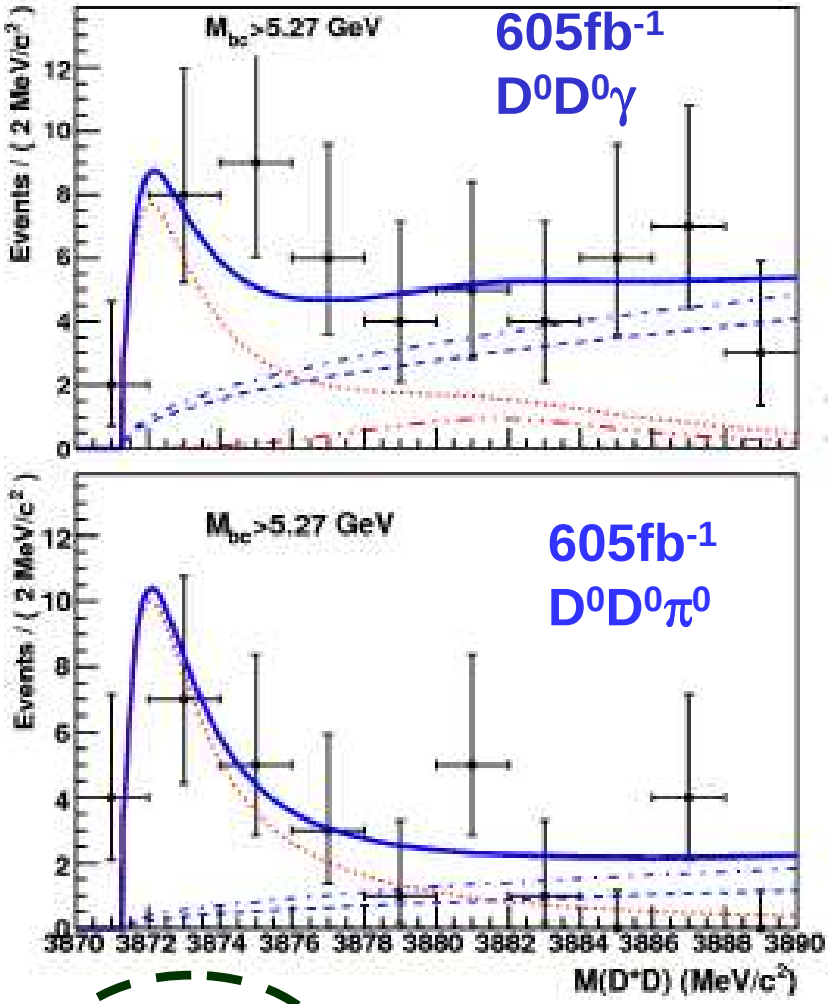
PRD77, 011102 (2008)



$$M = (3875.1^{+0.7}_{-0.5} \pm 0.5)\ \mathrm{MeV}/c^2$$

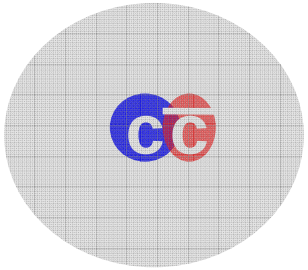
"new"

ArXiv:0810.0358



$$M = (3872.6^{+0.5}_{-0.4} \pm 0.4)\ \mathrm{MeV}/c^2$$

Light-hadron charmonium bound states?

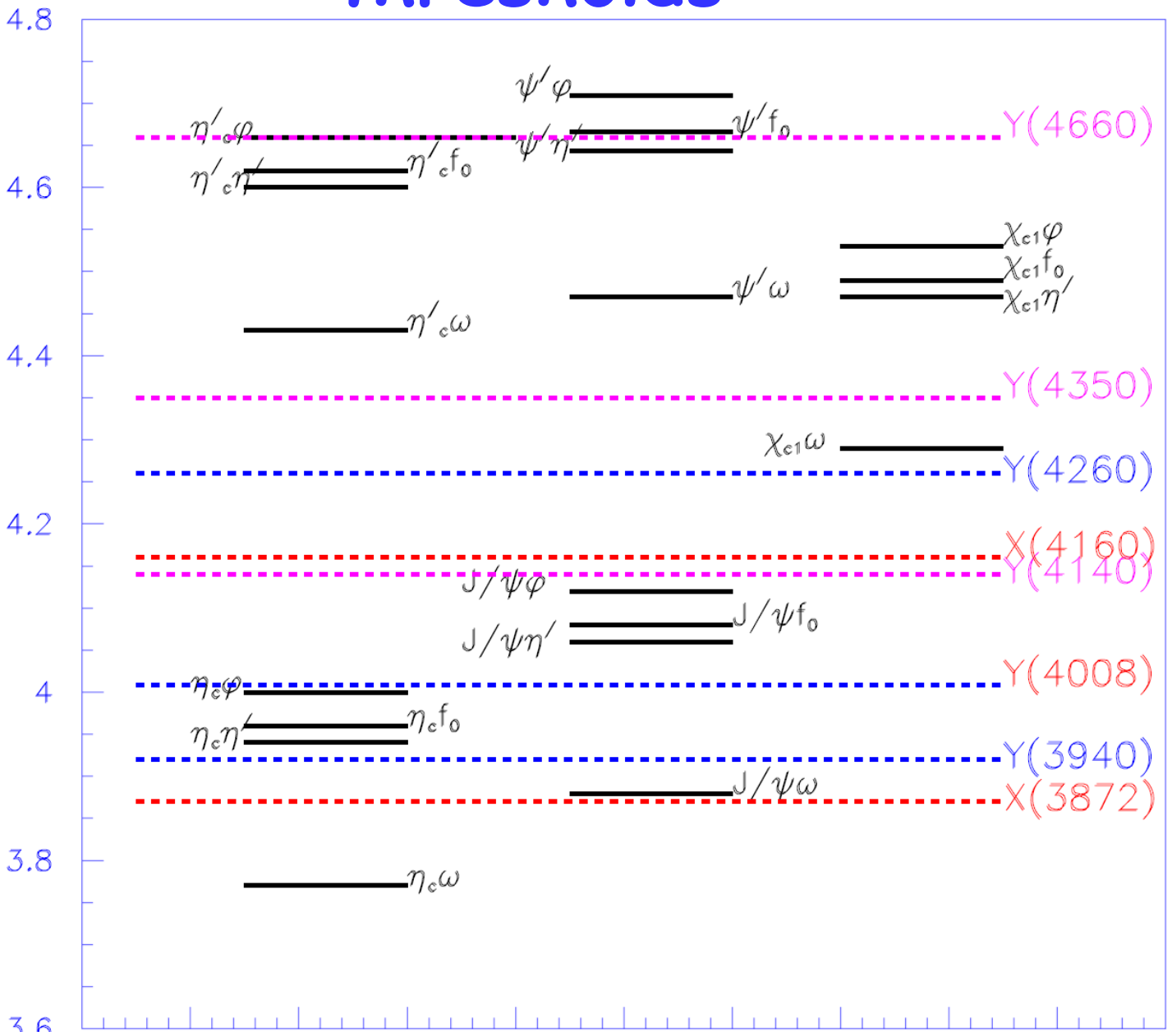


My guess: masses should be near M(cc)+M("narrow"-light-hadron) thresholds

This would account for large decay widths to charmonium & the preference for some states to go to ψ' & other J/ψ

- S Dubynski et al
  PLB 666,344 (2008) ←charmonium +excited light hadrons
- FK Guo et al
  PLB 665, 26 (2008) ←charmonium + gnd-state light hadrons

Charmonium + (narrow) light hadron thresholds

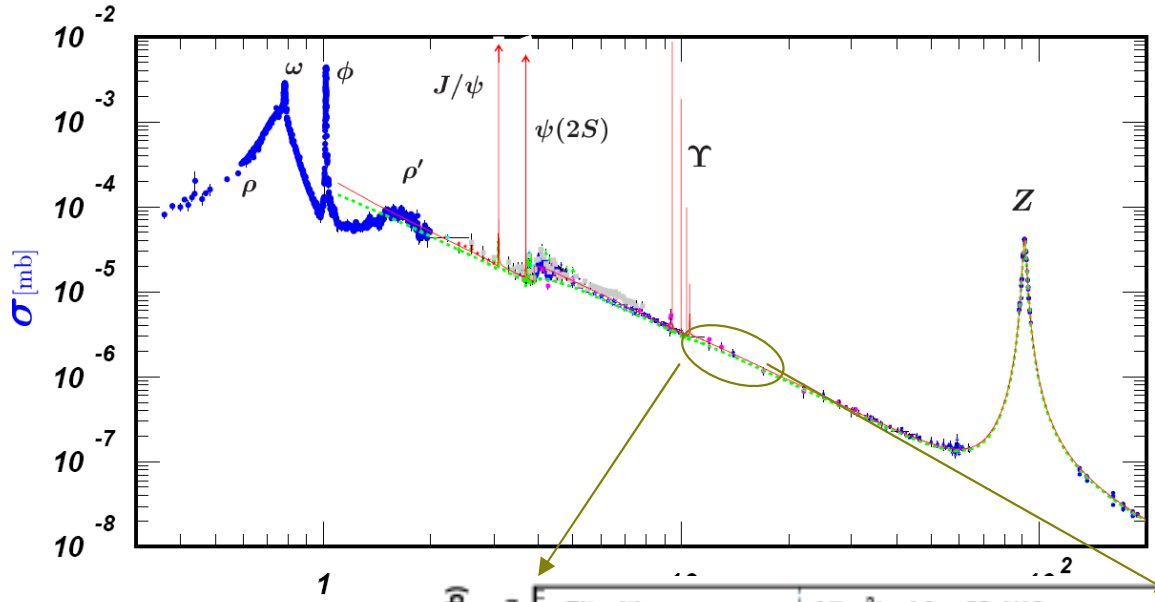


Scorecard

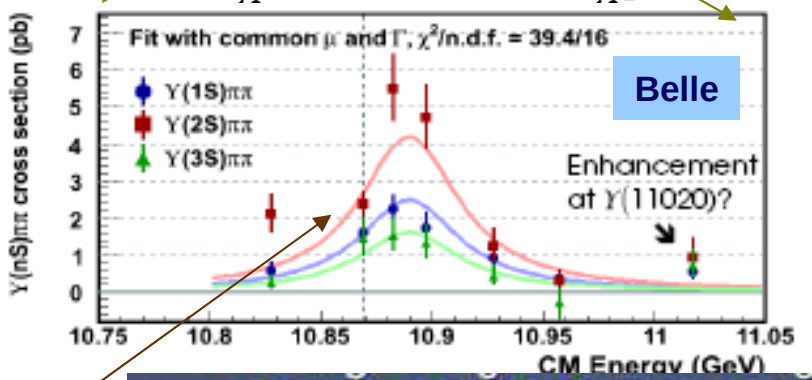
- $D^{(*)}D^{(*)}$ Molecules
  - favored for the X(3872)
  - but many XY states are not near thresholds
- hybrids
  - no sign of open charm decays
- diquarks-diantiquarks
  - No sign of SU(2)/SU(3) multiplet partners
- Light-hadron charmonium bound states
  - not much coincidence between states & thresholds

Candidates for XY counterparts in the b- and s-quark sectors

Y(4260) equivalent with b-quarks?



$\sigma(e^+e^- \rightarrow \pi^+\pi^- \Upsilon(nS))$



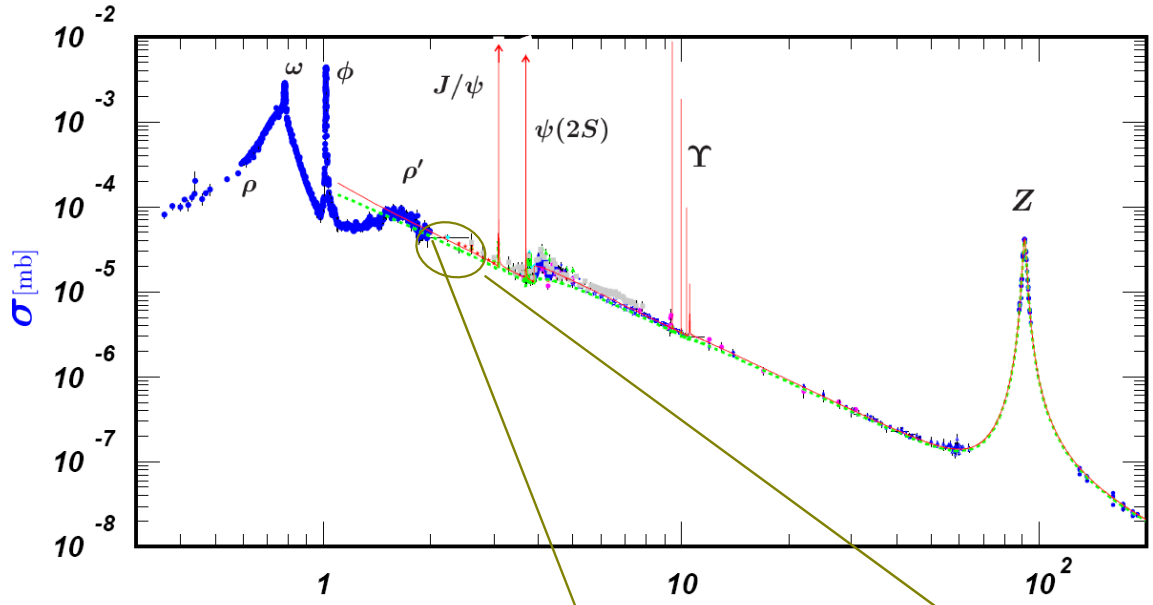
μ = 10889.6 ±1.8 ±1.5 MeV, Γ = 54.7 $^{+8.5}_{-7.2}$ ±2.5 MeV

K.F. Chen et al (Belle) arXiv:0808.2445

Peaks not consistent with known $b\bar{b}$ states

$\Gamma(\pi\pi\Upsilon(nS))$ ~ 1000x too large for conventional bottomonium

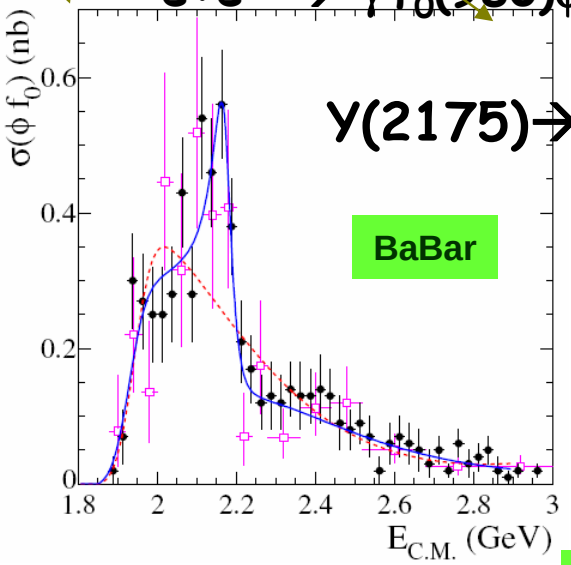
Y(4260) equivalent with s-quarks?



$\sigma(e^+e^- \to \underbrace{\pi^+\pi^-}\phi(1020))$

$f_0(980) \to \pi^+\pi^-$

$e^+e^- \to \gamma f_0(980)\phi$



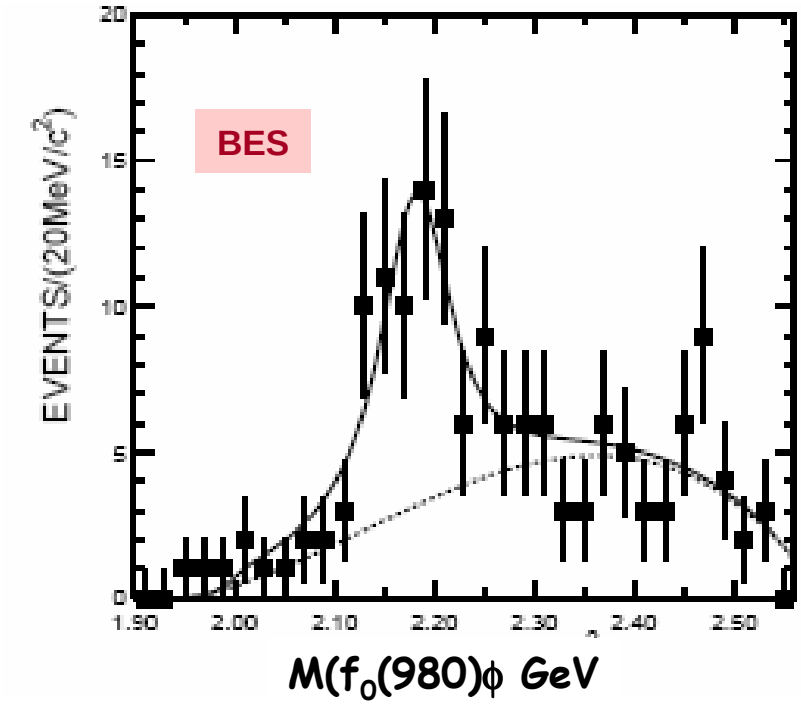
$Y(2175) \to f_0(980)\phi$

$M(f_0(980)\phi)$

BaBar, PRD 74, 091103

Confirmed by BES & Belle

confirmed by BESII
in $J/\psi \rightarrow \eta\,\phi\,f_0(980)$

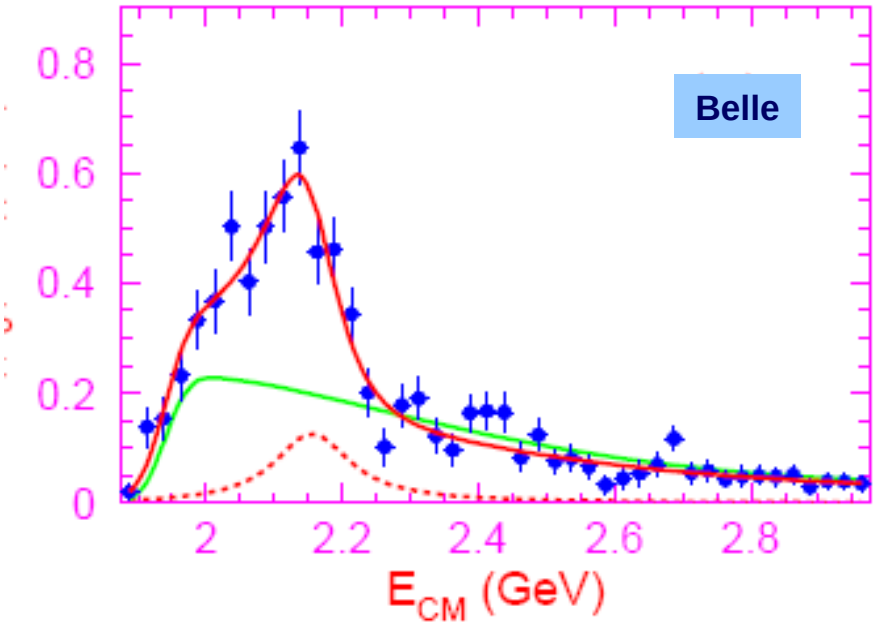


$J/\psi \rightarrow \eta\phi f_0(980)$

X. Wan X.Y. Shen F. Liu

M.Ablikim et al (BES)
PRL 100, 102003 (2008)

$\sigma(e^+e^- \rightarrow f_0(980)\phi(1020))$



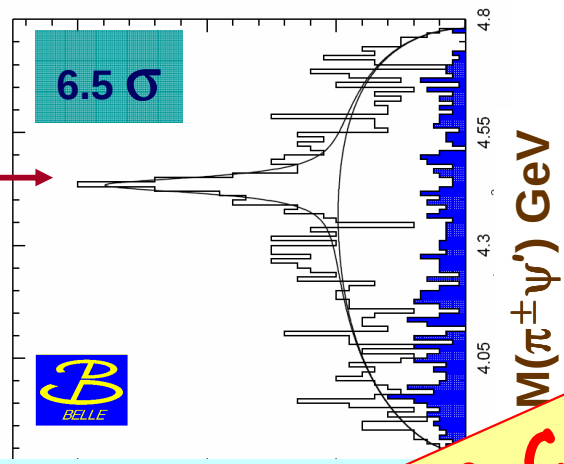
C.P.Shen et al (Belle) arXiv: 0808.0006

NB: Radial excitation of the ϕ is not ruled out

Do the X & Y mesons have electrically charged counterparts?

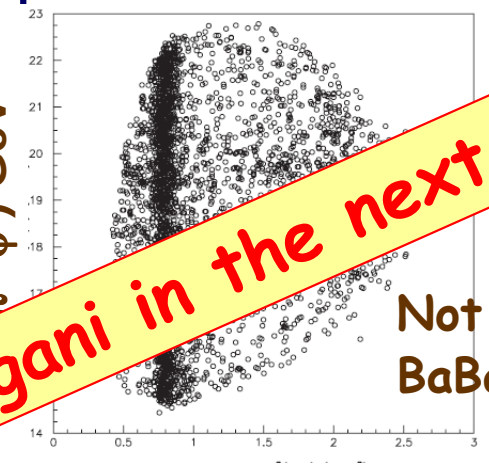
The Z^+ meson candidates

$B \to K \pi^+ \psi'$



$Z(4430)^+$

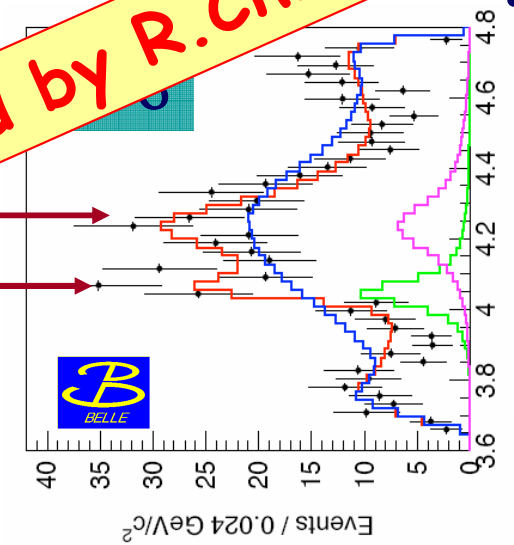
S.-K. Choi et al (B , 142001



Not confirmed by BaBar arXiv:0811.0564

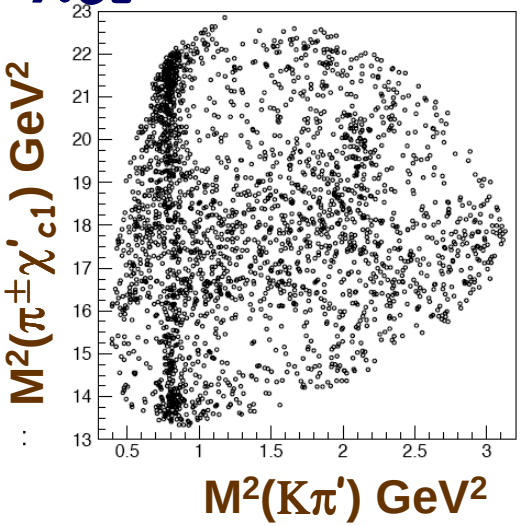
Discussed by R.Chistov & C.Patrigani in the next session

$B \to K \pi^+ \chi_{c1}$



$Z(4050)^+$

$Z_1(4050)^+$



R.Mizuk,R.Chistov et al (Belle) PRD 78, 072004

Concluding remarks

- Lots of non-$q\bar{q}$ mesons candidates are seen
- No single non-$q\bar{q}$ model explains them well
- Recurring theme: large widths for decays to final states with charmonium

Winston Churchill

& women
Men occasionally *stumble over*
charm, but most of them
pick themselves up and hurry
off as if nothing ever happened.

Puzzles → often → **New insights**

Thank you