



QCD' 2010, Montpellier, France

Charmonium-like states at Belle (recent results)

Ruslan Chistov (ITEP, Moscow)

(on behalf of the Belle Collaboration)

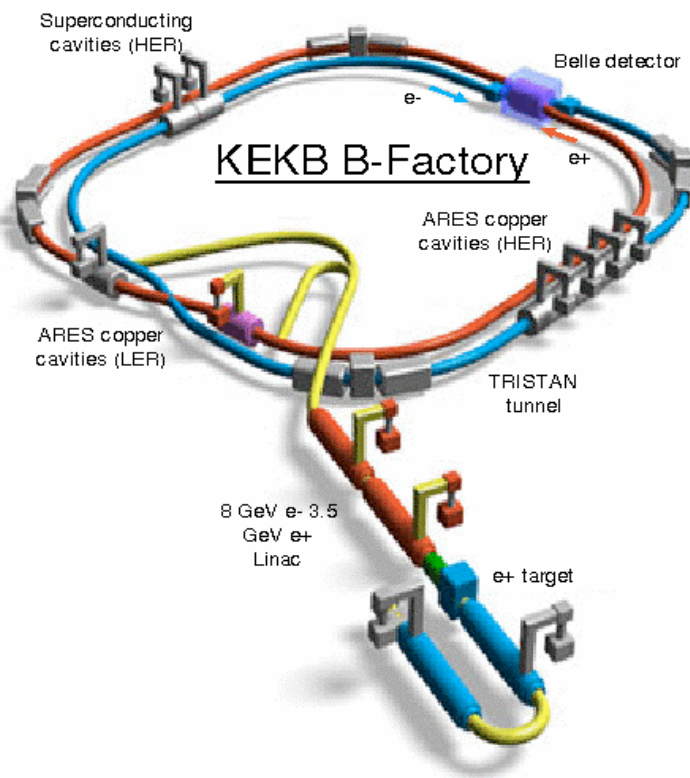
Introduction

Charmonium production at B-factories

Recent news from Belle on

Charmonium-like states

Summary



On-resonance samples:

4S: 711 fb^{-1}

5S: 121 fb^{-1}

3S: 3.0 fb^{-1}

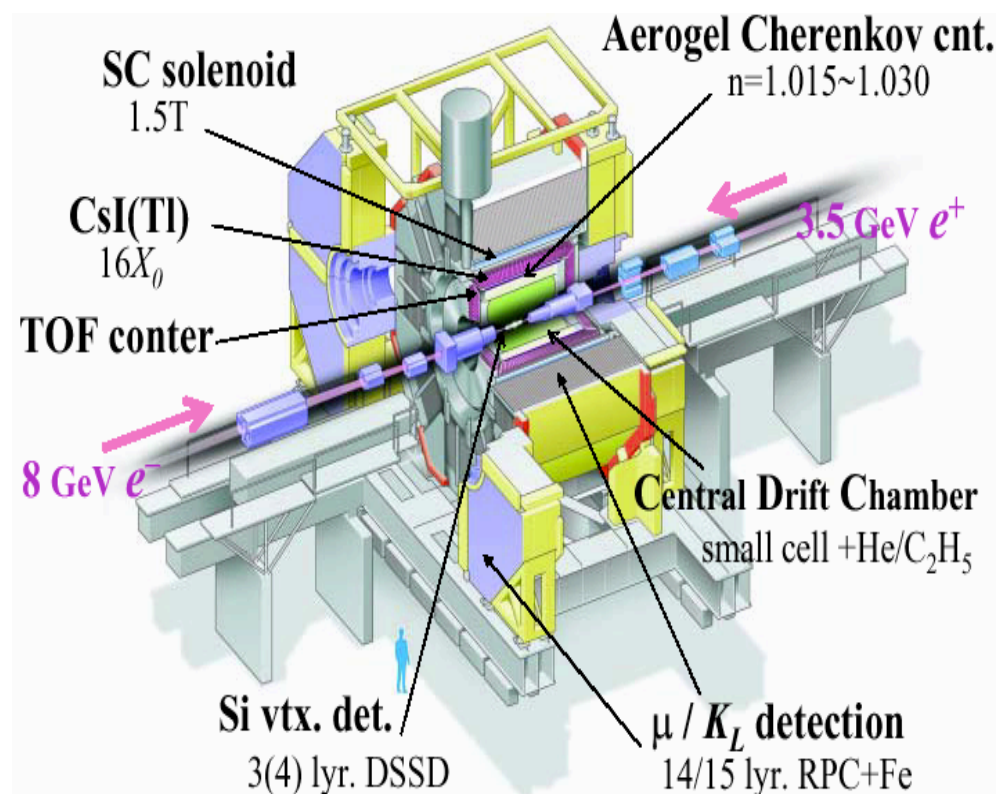
2S: 24 fb^{-1}

1S: 5.7 fb^{-1}

Off-resonance: 87 fb^{-1}

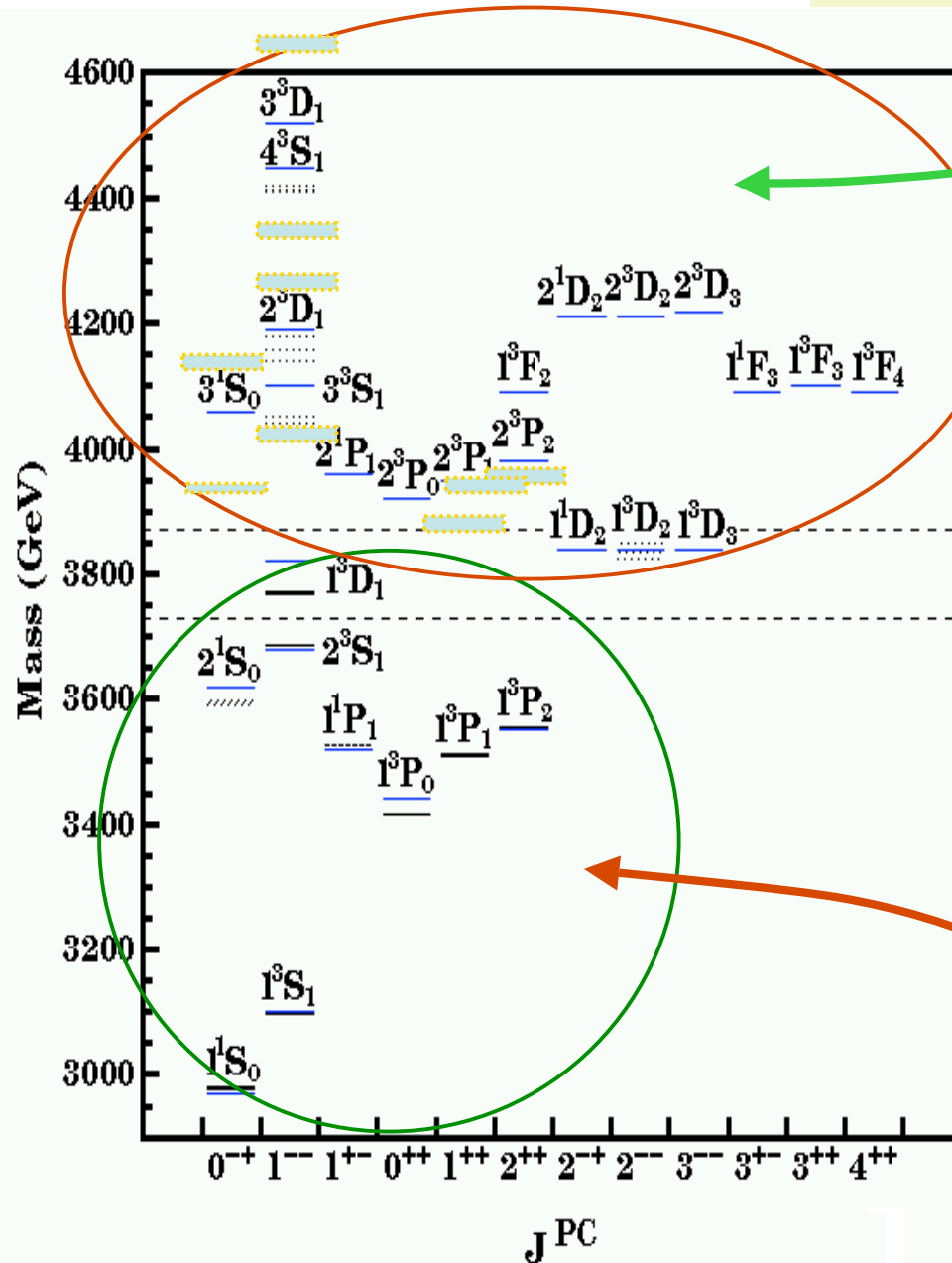
> 1000 fb^{-1}

B-Factory KEKB and Belle detector



**High \mathcal{L} has permitted
to obtain non-trivial
results also
on charmonium**

Introduction



A number of unexpected exotic states above $DD^{(*)}$ thresholds that do not fit into available cc slots

Described well the observed spectrum of cc states

Discovered at B-factories

$\eta(2S)$, $Z(3930)=\chi_{c2}(2P)$

Exotic charmonium-like states

Double charmonium:

$X(3940)$, $X(4160)$

Decays with $\psi(\psi')$:

$X(3872)$, $Y(3940)$, $Y(4008)$, $Y(4260)$,

$Y(4360)$, $Y(4630)$, $Y(4660)$

Charged charmonium:

$Z(4430)$, $Z_1(4058)$, $Z_2(4258)$

Exotic? tetraquark $|c\bar{q}c\bar{q}\rangle$, molecule $D^{(*)}\bar{D}^{(*)}$,
hybrid $|c\bar{q}g\rangle$, hadrocharmonium.



Are there hadrons with more complex structure than the simple Qq mesons and the qqq baryons?

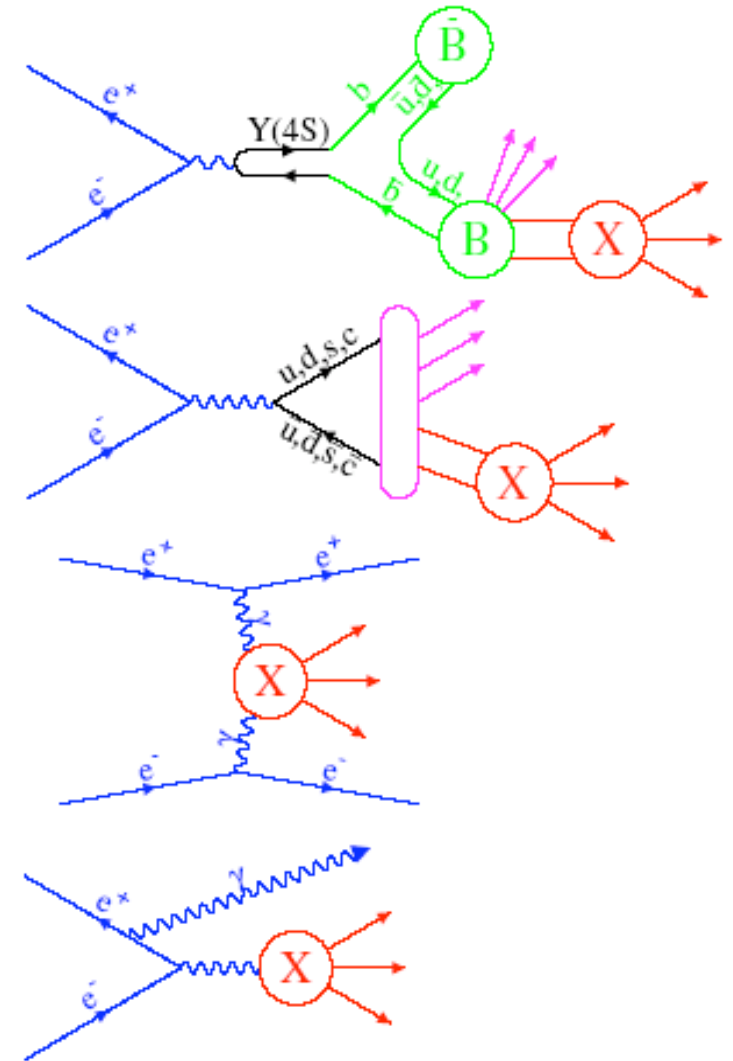
The mechanisms of new particle production at B-factories

From B-decays, e.g. $B^+ \rightarrow X(3872) K^+$

In double charmonium production, e.g. $e^+e^- \rightarrow J/\psi X(3940)$

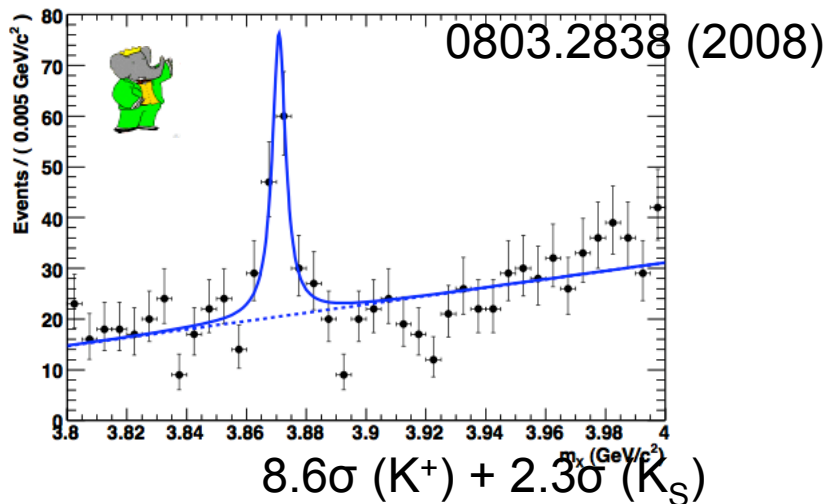
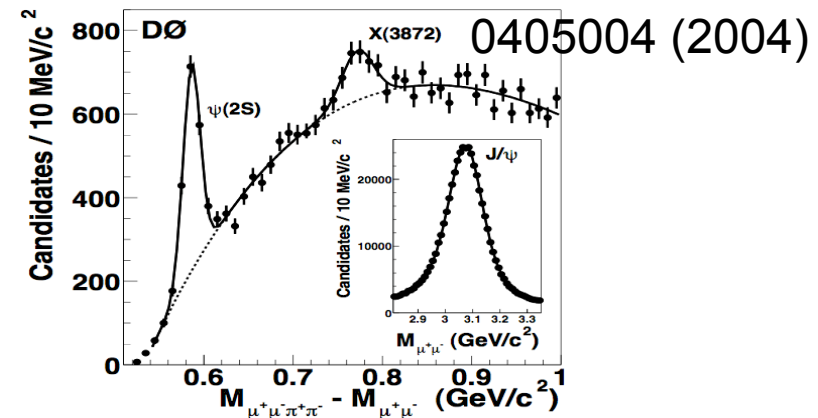
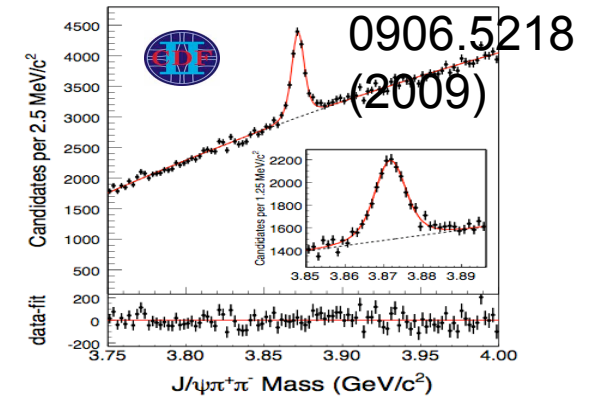
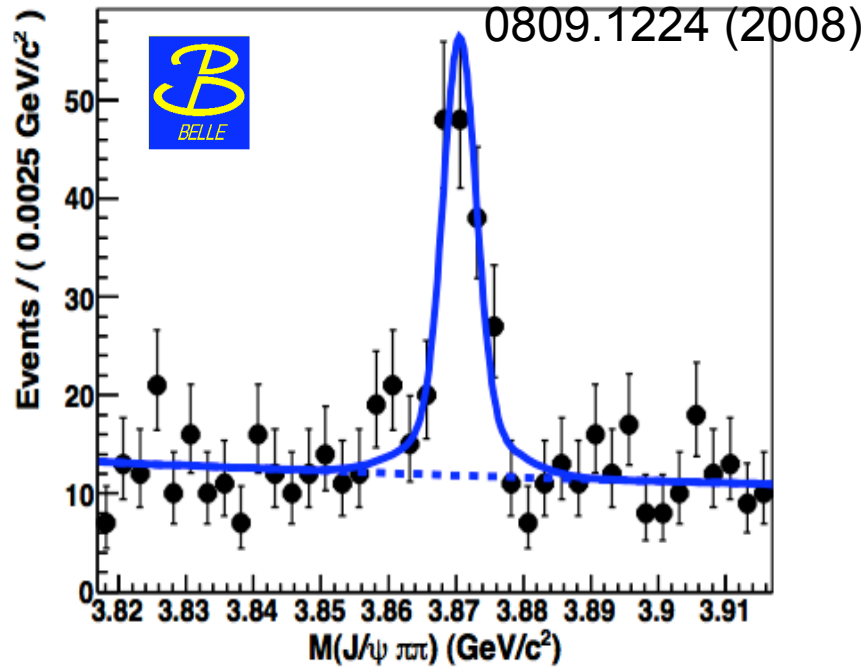
In $\gamma\gamma$ fusion, e.g. $\gamma\gamma \rightarrow \eta_c(2S)$ or $\gamma\gamma \rightarrow Z(3930)$

In radiative return, e.g. $e^+e^- \rightarrow \gamma_{ISR} Y(4260) \rightarrow J/\psi \pi^+\pi^-$



X(3872)

12.8 σ (K^+) + 5.9 σ (K_S)



Narrow width <2.3 MeV
Although above DD(*) threshold.
Mass (3871.46 \pm 0.37 \pm 0.07) MeV
(Belle, arXiv:0809.1224)

S-wave molecular state?

X(3872)

$M_{\pi^+\pi^-} \approx M_\rho$ (violates isospin)

Decays to $J/\psi\gamma$, $\psi(2S)\gamma \Rightarrow C = +1$

Spin-parity analysis $\Rightarrow J^{PC} = 1^{++}, 2^{-+}$

Doesn't decay to $\chi_{c1}\gamma$, $D\bar{D}$, $\gamma\gamma$, e^+e^-

No charged partner, not an isovector

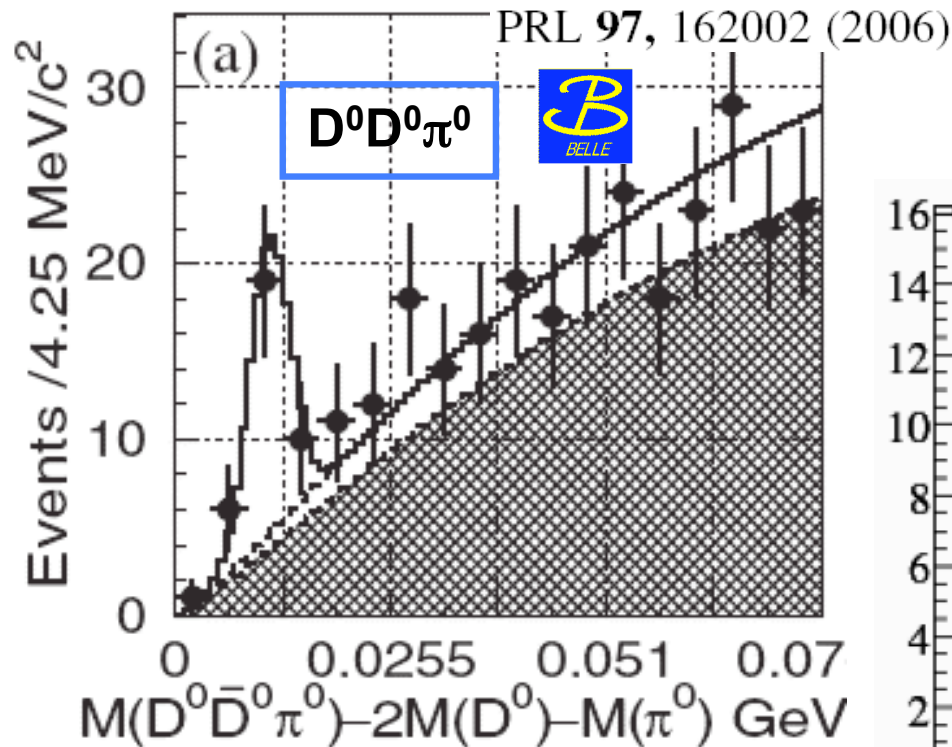
It is important to search for other decay modes



Recent News on $X(3872)$

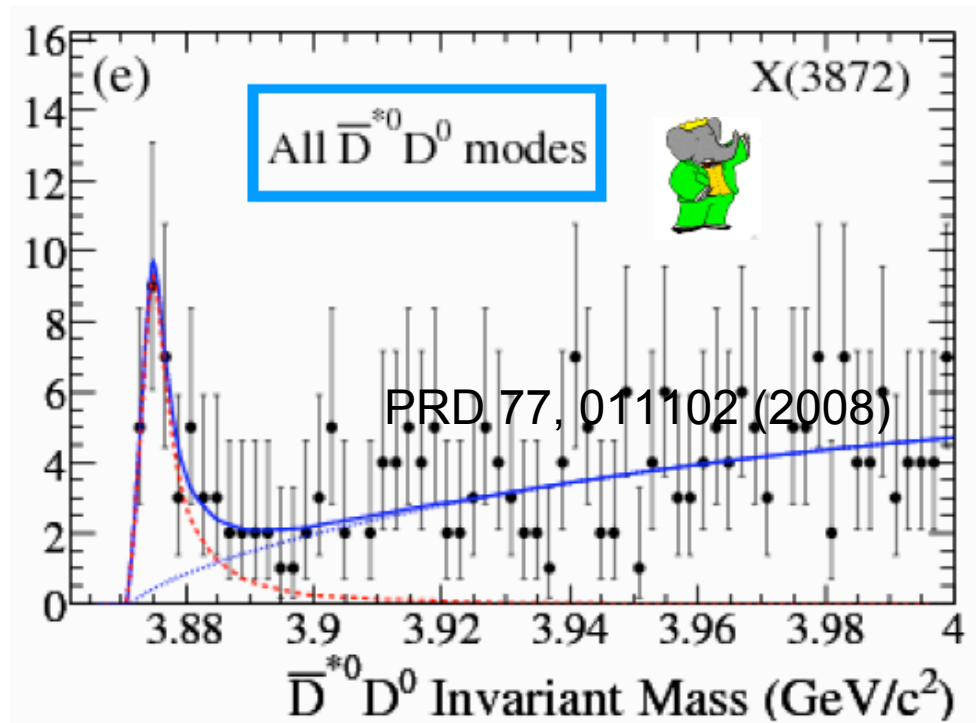


X(3872) \rightarrow D*⁰ D⁰



Both saw higher mass &
BR(DD*) \approx 10x BR($\pi^+ \pi^- J/\psi$)

DD* threshold
enhancement in $B \rightarrow KDD^*$



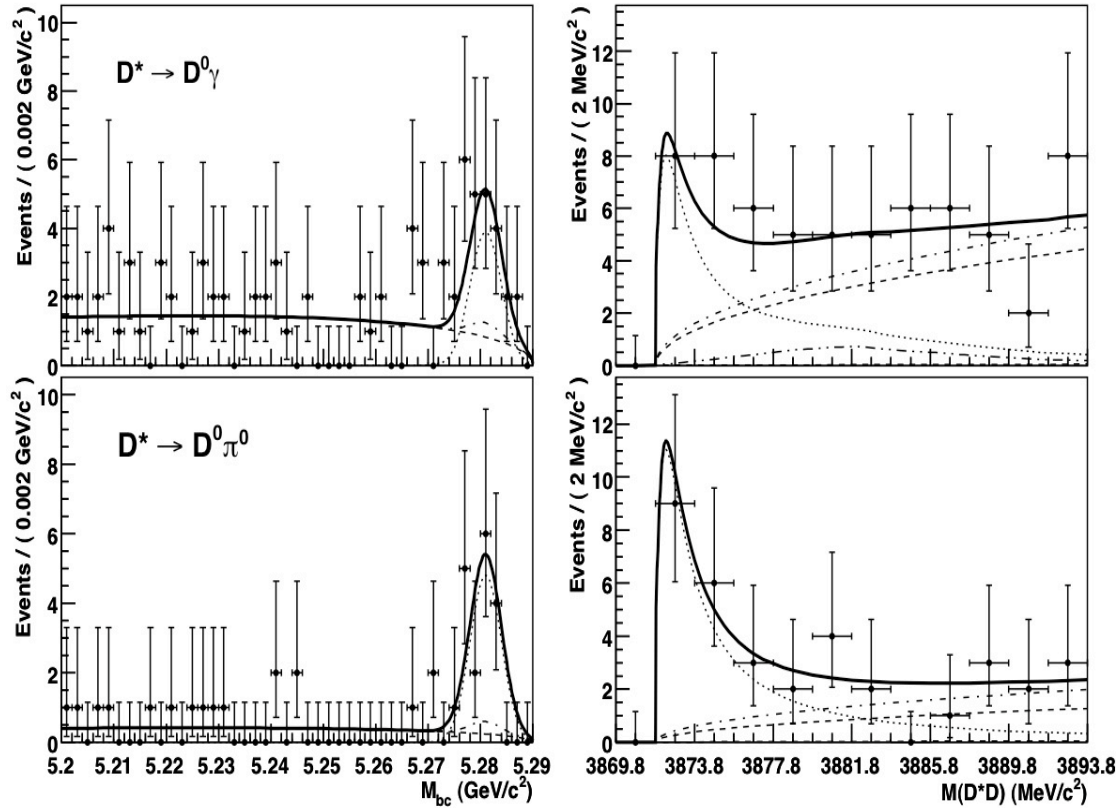
	Mass, MeV	Width, MeV	B ⁺ BR x 10 ⁴
Belle	3875.4 \pm 0.7 $^{+1.2}_{-2.0}$		1.25 \pm 0.31 \pm 0.30
BaBar	3875.1 $^{+0.7}_{-0.5}$ \pm 0.5	3.0 $^{+1.9}_{-1.4}$ \pm 0.9	1.67 \pm 0.36 \pm 0.47

Higher X mass raised some speculations about new particle X(3875)



$B \rightarrow X(3872) K; X(3872) \rightarrow \underline{D}^{*0} D^0; \underline{D}^{*0} \rightarrow D^0 (\gamma, \pi^0)$

PRD (RC) 81, 031103 2010



$$M_{D^*D} = (3872.9^{+0.6}_{-0.4} {}^{+0.4}_{-0.5}) \text{ MeV}$$

$$\text{BaBar: } (3875.1^{+0.7}_{-0.5} \pm 0.5) \text{ MeV}$$

$$\Gamma(\text{Belle}) = (3.9^{+2.8}_{-1.4} {}^{+0.2}_{-1.1}) \text{ MeV}$$

$$\Gamma(\text{BaBar}) = (3.0^{+2.5}_{-1.3} {}^{+0.5}_{-0.3}) \text{ MeV}$$

$$N_{\text{sig}} = 50.1^{+14.8}_{-11.1}$$

$$\text{Significance} = 6.4 \sigma$$

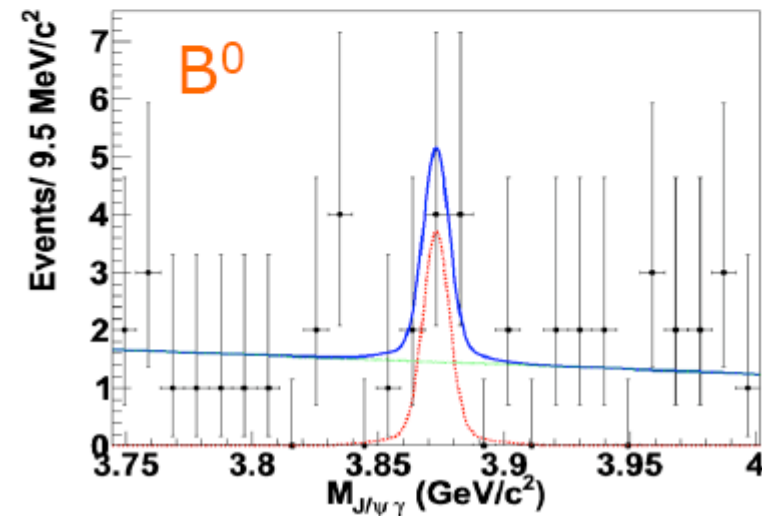
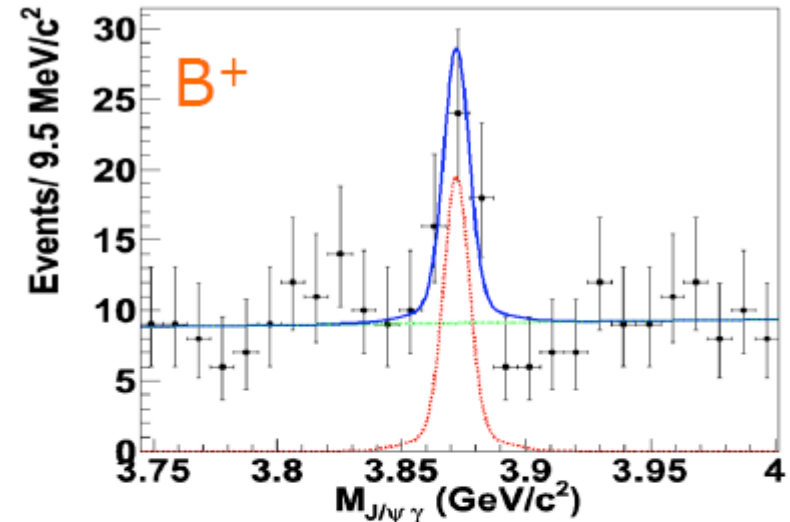
$$\text{BR}(B \rightarrow X(3872)(D^{*0} D^0) K) = (0.73 \pm 0.17 \pm 0.13) \times 10^{-4}$$

Favours for molecular model for X(3872)

$X(3872) \rightarrow J/\psi \gamma$

$B^+ \rightarrow K^+ X(3872)$
 $30.0^{+8.2}_{-7.4}$ events (4.9σ)
 $B^0 \rightarrow K^0 X(3872)$
 $5.7^{+3.5}_{-2.8}$ (2.4σ)

Belle, Preliminary, QWG '10, 711/fb



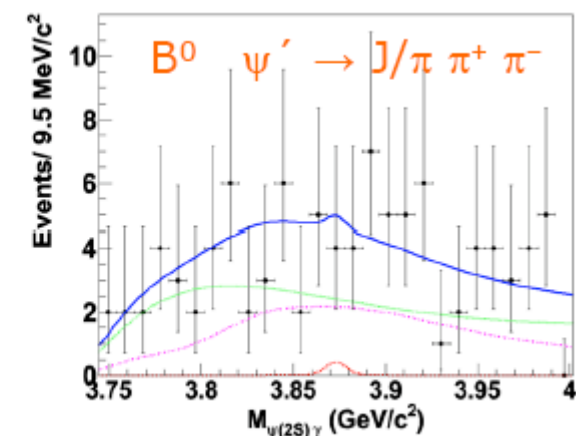
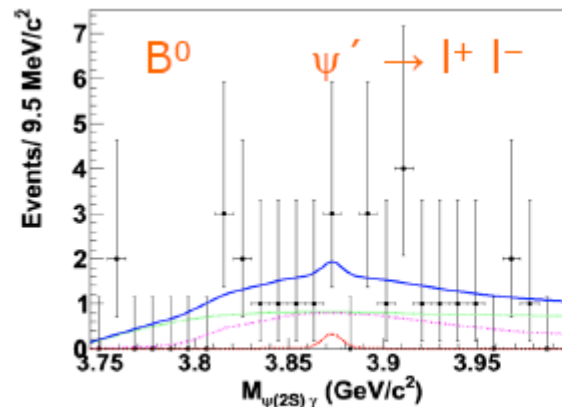
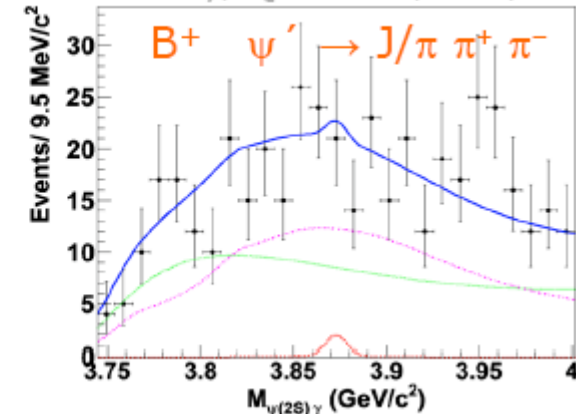
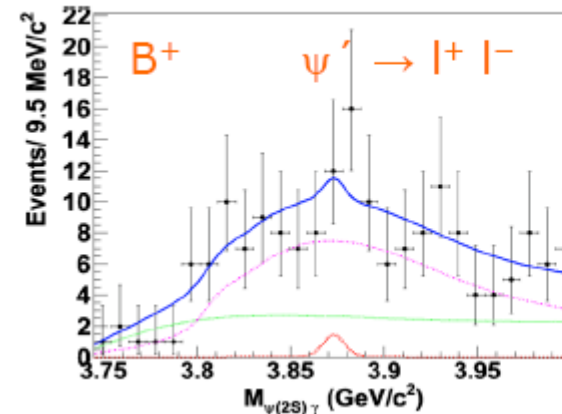
X(3872) $\rightarrow \psi' \gamma$

$B^+ \rightarrow K^+ X(3872)$
 $5.0^{+11.9}_{-11.0}$ events
 (0.4σ)

$B^0 \rightarrow K^0 X(3872)$
 $1.5^{+4.8}_{-3.9}$
 (0.2σ)

No indication, that
 $X \rightarrow (n=2)$ charmonium
 is stronger than
 $X \rightarrow (n=1)$ charmonium

Belle, Preliminary, QWG '10, 711/fb



But BaBar claimed $\text{Br}(X \rightarrow \psi' \gamma) / \text{Br}(X \rightarrow J/\psi \gamma) \sim 3$.
 (PRL 102, 132001 (2009))

Belle doesn't confirm.

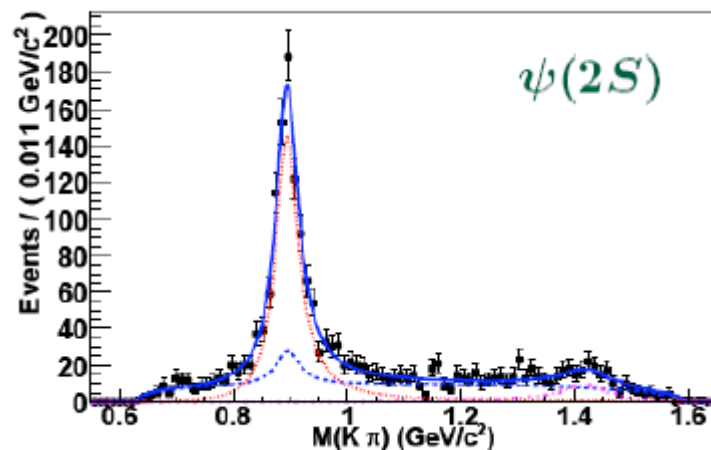
X(3872) new decay modes

$B^0 \rightarrow X(3872)(K^+\pi^-)_{NR}$ observed

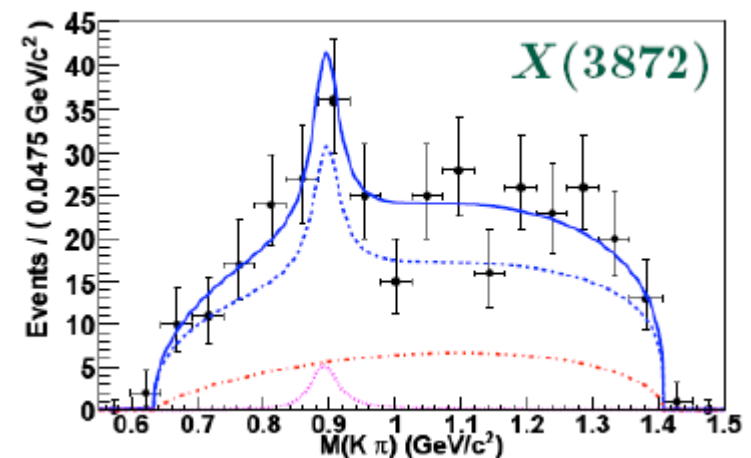
$$\mathcal{B}(B^0 \rightarrow X(K^+\pi^-)_{NR})\mathcal{B}(X \rightarrow J/\psi\pi^+\pi^-) = (8.1 \pm 2.0_{-1.4}^{+1.1}) \times 10^{-6}$$

$$\mathcal{B}(B^0 \rightarrow XK^{*0}(892))\mathcal{B}(X \rightarrow J/\psi\pi^+\pi^-) < 3.4 \times 10^{-6}$$

K^* fraction is small unlike to $c\bar{c}$



Belle ArXiv:0809.1224(2008)



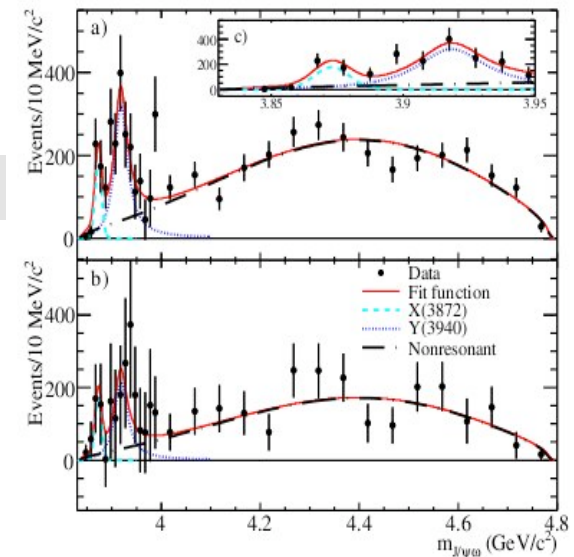
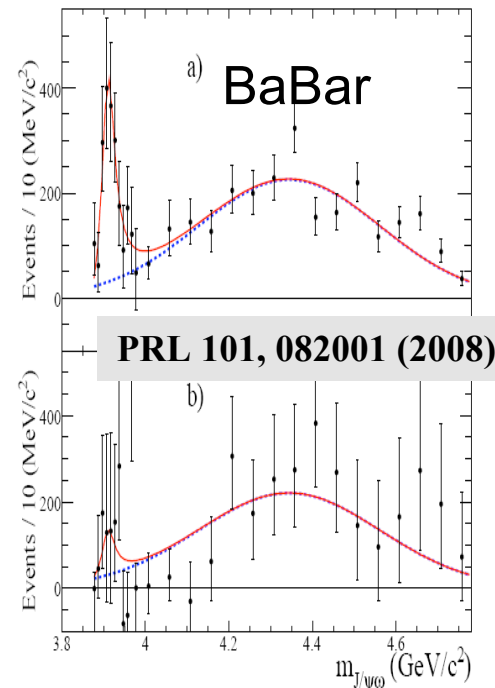
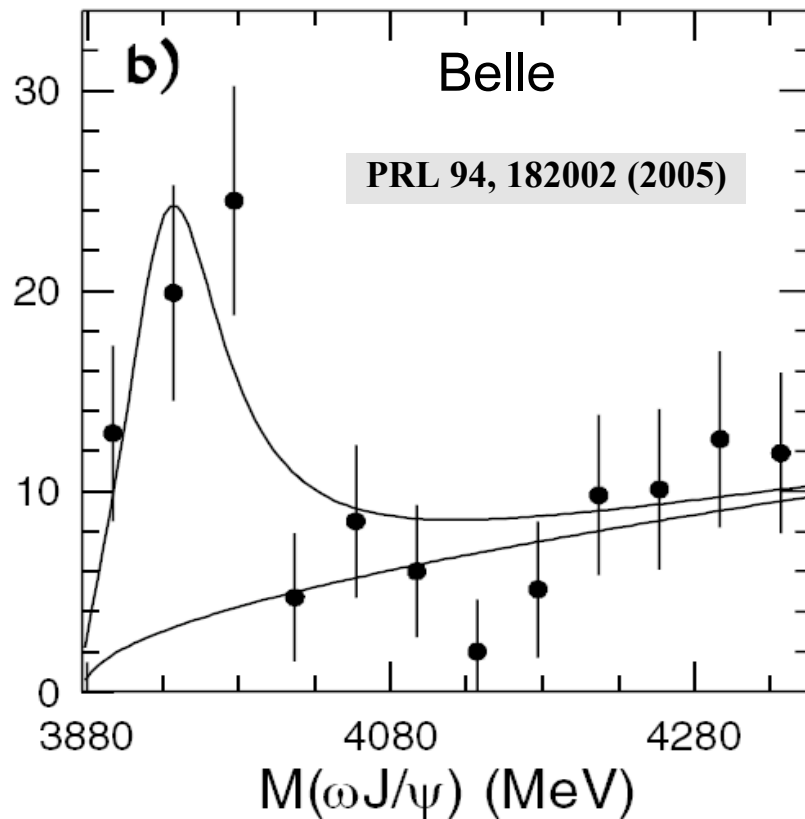
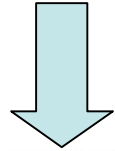


Recent News on $Y(3940)$ and Observation of $X(3915)$



Y(3940) → J/ψω

Recent BaBar result
arXiv:1005.5190:
Double structure
X(3872) and Y



**Mass above DD threshold
but J/ψω partial width
is too large for conventional charmonium**

Belle
BaBar
Belle

	Mass, MeV/c ²	Width, MeV
B → YK	3943 ± 11 ± 13	87 ± 22 ± 26
B → YK	3914.6 ± 2 ± 1.9	34 ⁺¹² ₋₈ ± 6
γγ → Y	3914 ± 3 ± 2	17 ± 10 ± 3

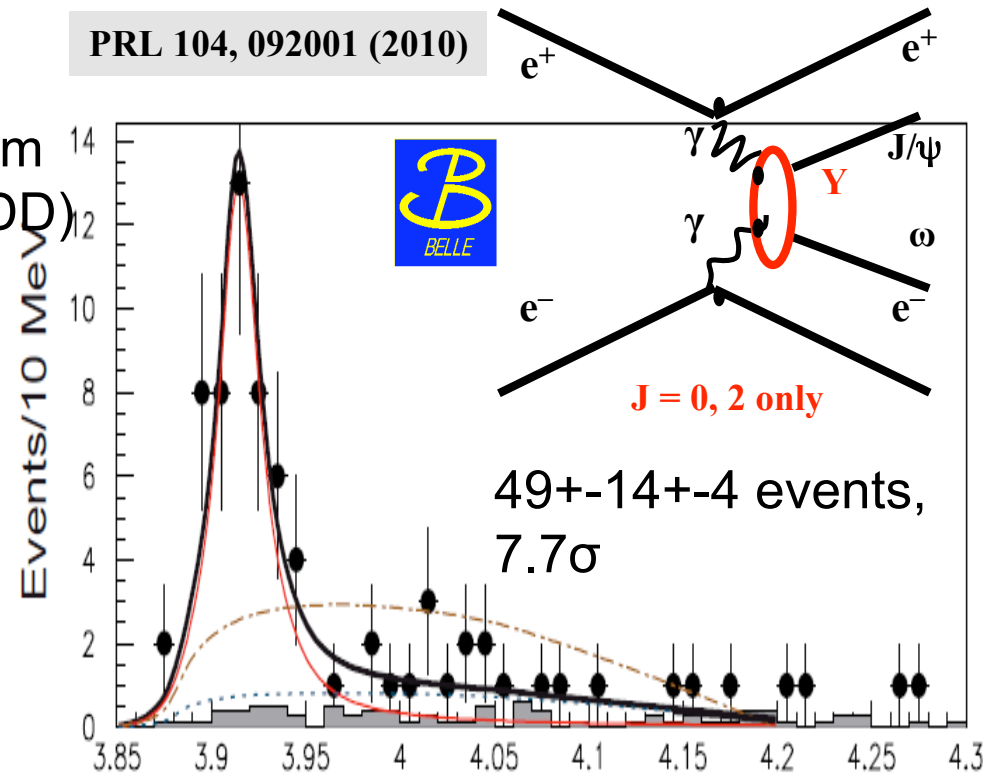
Another states near 3.94 GeV:

- $X(3940) \rightarrow D^* D$ in double charmonium Production (but not seen in $J/\psi \omega$ or DD) (PRL 100, 20200 (2008))

- $Z(3930) \rightarrow DD$ in 2-photon events. (interpreted as a candidate for χ_{c2}') (PRL 96, 082003 (2006))

So, it is important to search for a signature of the $Y(3940)$ or Any other resonant state in 2-photon production of $J/\psi \omega$

PRL 104, 092001 (2010)



$M(\omega J/\psi)$

$$M = 3914 \pm 3 \pm 2 \text{ MeV}/c^2$$

$$\Gamma = 17 \pm 10 \pm 3 \text{ MeV}$$

$$\Gamma_{\gamma\gamma}(X(3915))\mathcal{B}(X(3915) \rightarrow \omega J/\psi)$$

$$= \begin{cases} (61 \pm 17 \pm 8) \text{ eV} & \text{for } J^P = 0^+ \\ (18 \pm 5 \pm 2) \text{ eV} & \text{for } J^P = 2^+, \text{ helicity-2} \end{cases}$$

Two photon
production
of $Y(3940)$?

New decay mode
of $Z(3930)$?

New $X(3915)$?

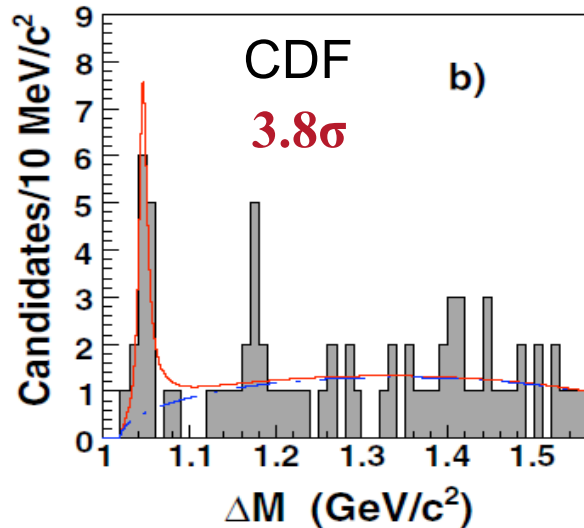


Recent News on Y(4140) and Evidence for Y(4350)

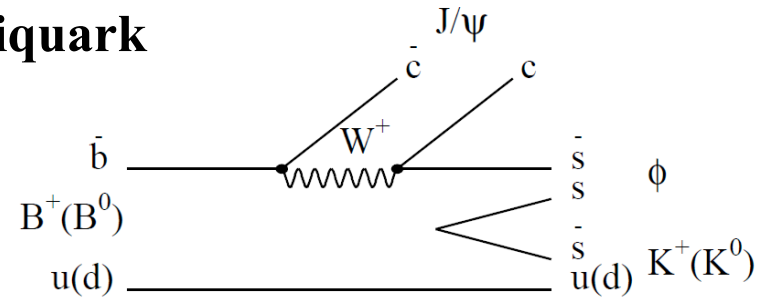


$B^+ \rightarrow J/\psi \phi K^+, Y(4140) \rightarrow J/\psi \phi$

PRL 102, 242002 (2009)



Search for possible
diquark-antidiquark
state



$$M = 4143.0 \pm 2.9 \pm 1.2 \text{ MeV}/c^2$$

$$\Gamma = 11.7^{+8.3}_{-5.0} \pm 3.7 \text{ MeV}$$

$$\text{Br}(B^+ \rightarrow Y K^+) \times \text{Br}(Y \rightarrow J/\psi \phi)$$

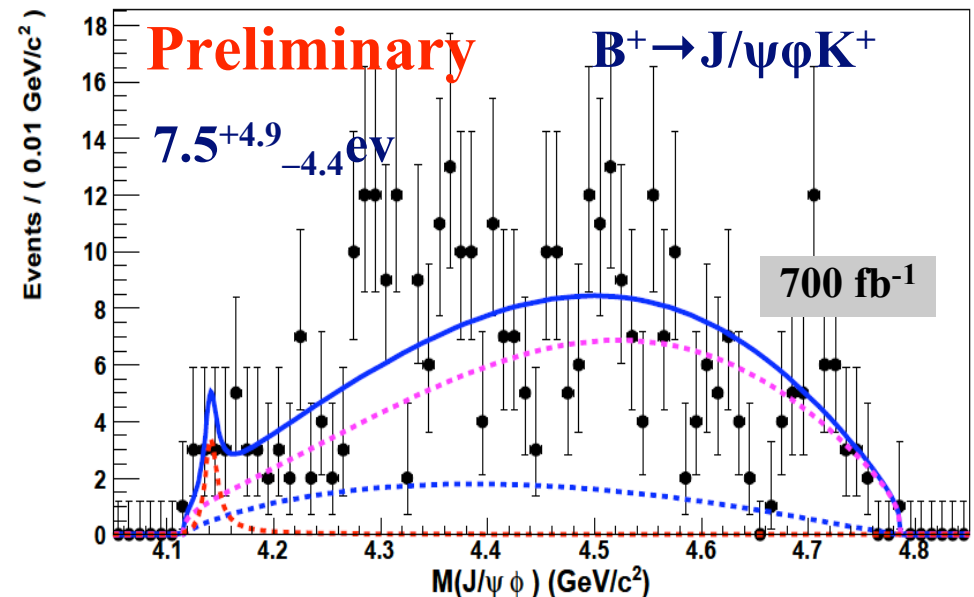
$$\text{Belle} < 6 \times 10^{-6} \text{ at } 90\% \text{ CL}$$

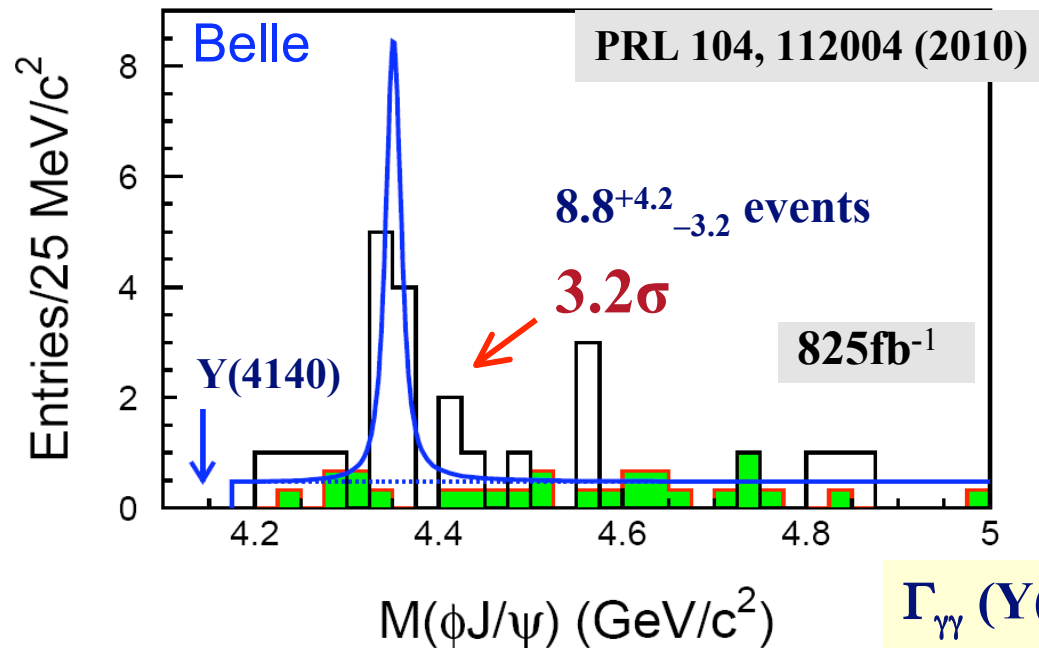
$$\text{CDF} (9.0 \pm 3.4 \pm 2.9) \times 10^{-6}$$

No big contradiction

small efficiency at threshold

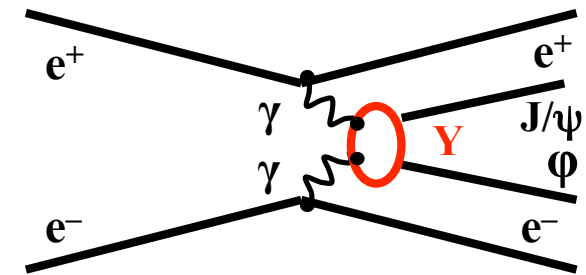
Belle





$$M = 4350.6^{+4.6}_{-5.1} \pm 0.7 \text{ MeV}/c^2$$

$$\Gamma = 13^{+18}_{-9} \pm 4 \text{ MeV}$$

 $\gamma\gamma \rightarrow \phi J/\psi$

 $J = 0, 2 \text{ only}$

$$\Gamma_{\gamma\gamma} (Y(4140) \times B(Y(4140) \rightarrow \phi J/\psi)$$

$$< 40 \text{ eV at 90\% CL for } J^P=0^+$$

$$< 5.9 \text{ eV at 90\% CL for } J^P=2^+$$

disfavor $D_s^{*+} D_s^{*-}$ molecule scenario for $Y(4140)$ with $J^{PC} = 0^{++}$ or 2^{++}

$$\Gamma_{\gamma\gamma} (Y(4350) \times B(Y(4350) \rightarrow \phi J/\psi) =$$

$$(6.7^{+3.2}_{-2.4} \pm 1.1) \text{ eV for } J^P=0^+$$

$$(1.5^{+0.7}_{-0.6} \pm 0.3) \text{ eV for } J^P=2^+$$

interpretations: $D_s^{*+} D_{s0}^{*-}$ molecule or sscc tetraquark with $J^{PC} = 2^{++}$; P-wave charmonium $\chi_{c2}(3P) = 3^3P_2$



Summary

B-factories discovered many exotic charmonium-like states that are not easily explained as simple q -anti- q mesons of the charmonium model. These states have a number of intriguing and unexpected properties. Recent news from Belle are:

- Belle measured $X(3872) \rightarrow D^*0 D0$, new peak parameters;
- Preliminary results on $X(3872) \rightarrow J/\psi \gamma$ and $\psi' \gamma$: Now $X(3872) \rightarrow J/\psi \gamma$ is clearly established (both Belle and BaBar are observing);
 $X(3872) \rightarrow \psi' \gamma$ is not seen by Belle (BaBar claims evidence)
- Also $B \rightarrow X(3872) (K\pi)$ -nonres. is observed
- Belle finds two new narrow peaks in $\gamma \gamma$ events:
Observation of $X(3915) \rightarrow J/\psi \omega$ and evidence for $X(4350) \rightarrow J/\psi \phi$
- Belle has not confirmed CDF $Y(4140) \rightarrow J/\psi \phi$ in B-meson decays

Analysis at B-factories experiments is still going on...

But we need in more data to further investigate

exotic charmonium-like sector  super B-factory!