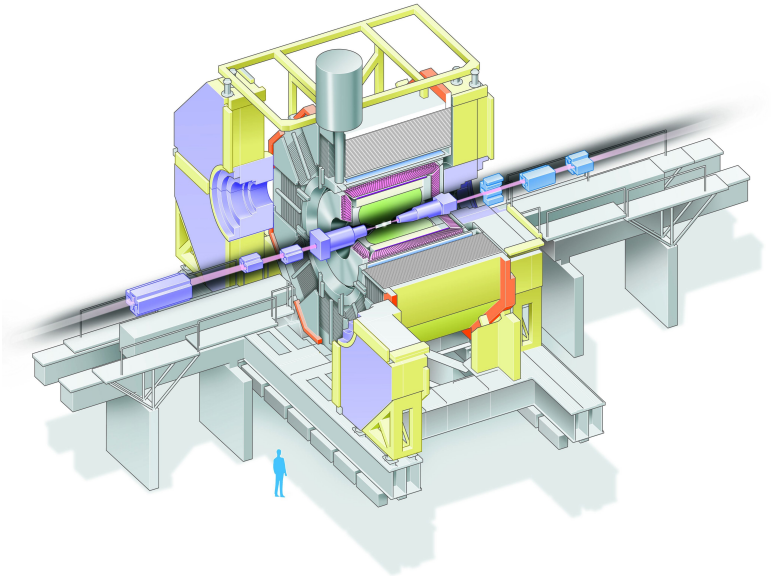
Hadron physics and spectroscopy

(''decade of the revival of hadron spectroscopy'')



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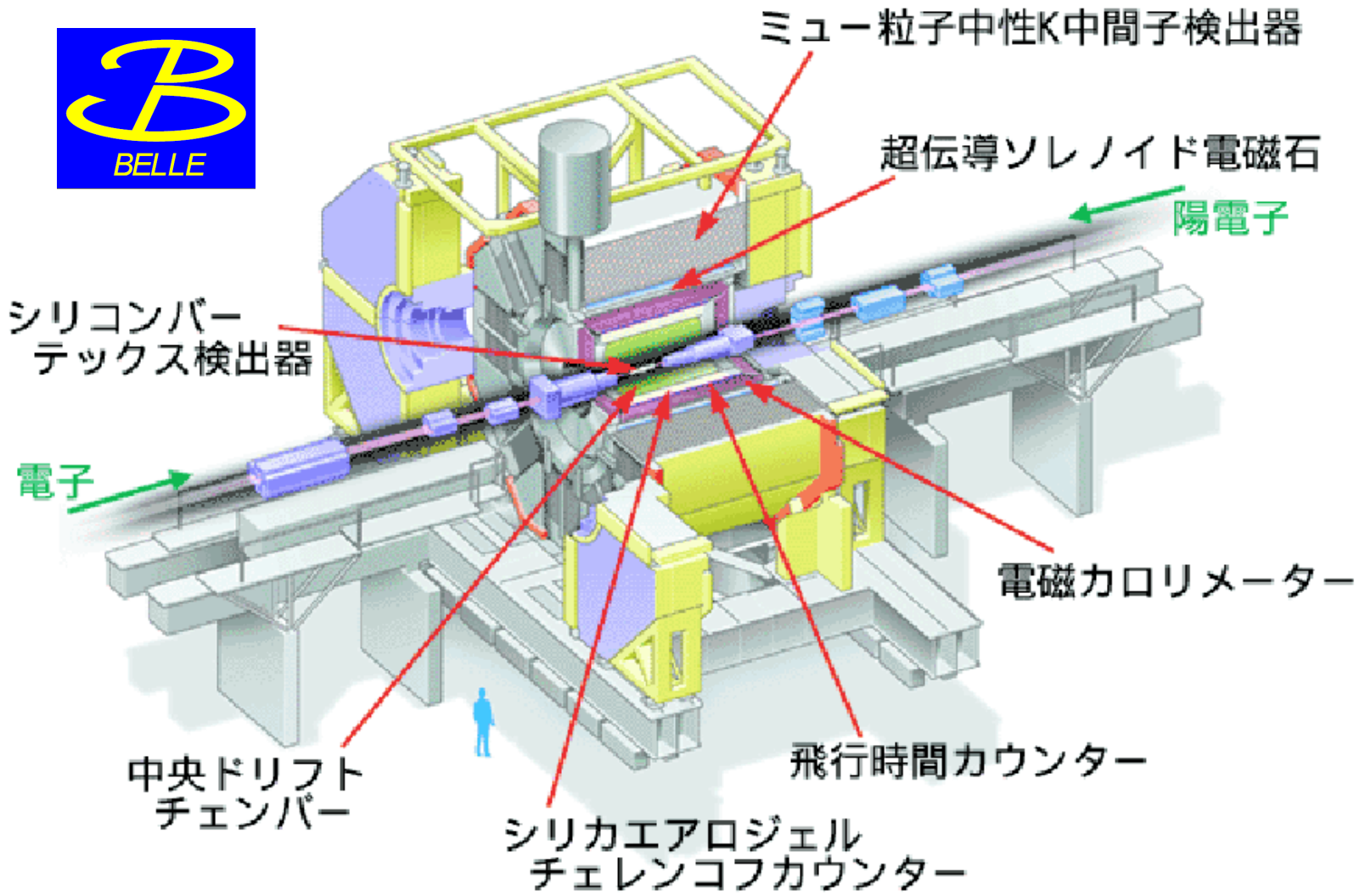
50 Cracow School of Theoretical Physics

Zakopane, 15th June, 2010

Belle, one of the 2 factories (see H.Palka' talk)



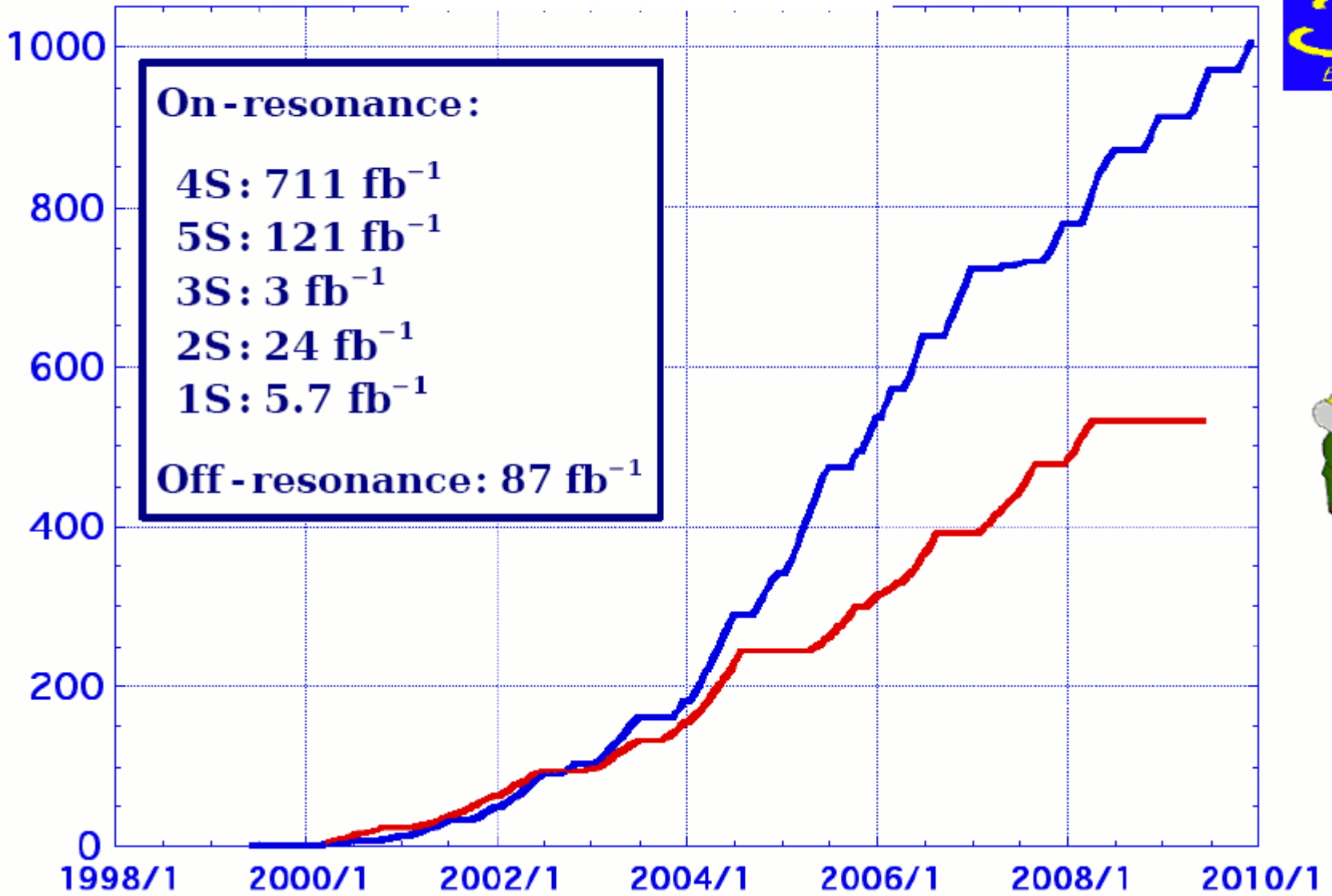
constructed to test the Standard Model mechanism for CP violation

$\Rightarrow$ charmonium modes ($B \to J/\psi K^0$) (see A.Buras' talk)

unexpected contribution to the field of hadron spectroscopy (charmonium)

Integrated luminosity (fb^{-1})

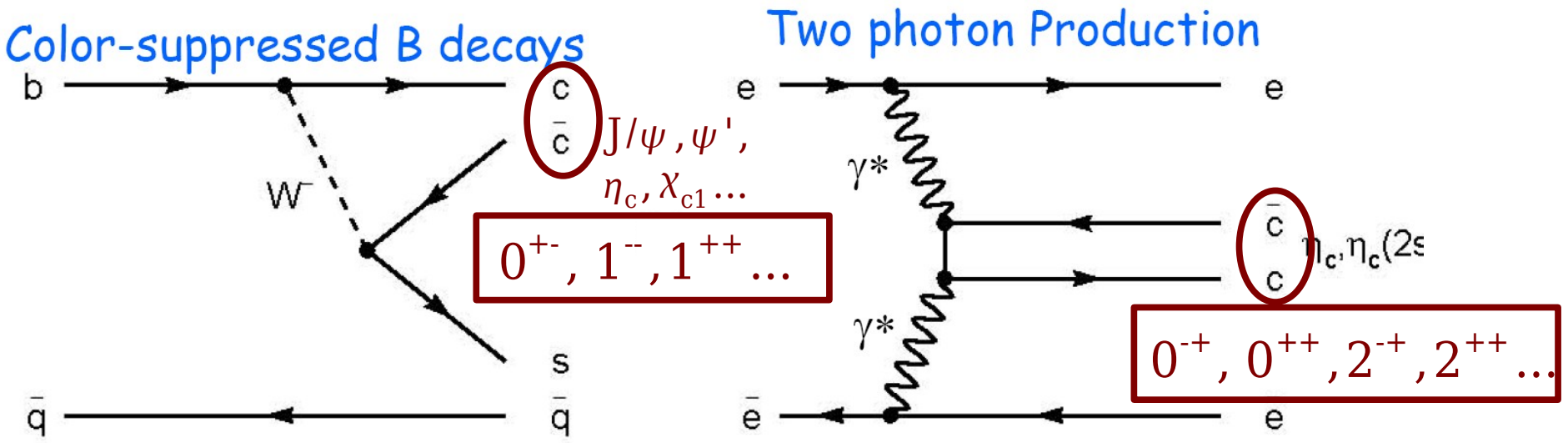
$> 1\ ab^{-1}$!



data taken mostly at $\Upsilon(4S)$ ($\sqrt{s} = 10.58$ GeV)

(but not only: largest samples of $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(5S)$)

B-factories produce lots of $c\bar{c}$-like pairs



$\mathrm{Brs} \sim 10^{-2}$ (inclusive)

At $\Upsilon(4S)$ peak, $\sigma(B\bar{B}) \sim 1.2\,\mathrm{nb}$
$\Rightarrow \mathrm{fb}^{-1} \equiv 10^6\ B\bar{B}$ pairs
B mesons decay with a $\sim 10^{-3}$ probability to $c\bar{c}$ and $K^{(*)}$

reconstruction with low bckg

J^{PC} from angular analysis

initial e^- and e^+ emit γ at small angles
hadronic system (H) produced in $\gamma^*\gamma^*$
has small total energy, small P_t
e^+ and e^- not detected

$\Rightarrow$ $c\bar{c}$ states produced without additional hadrons: clean conditions

H has C=+

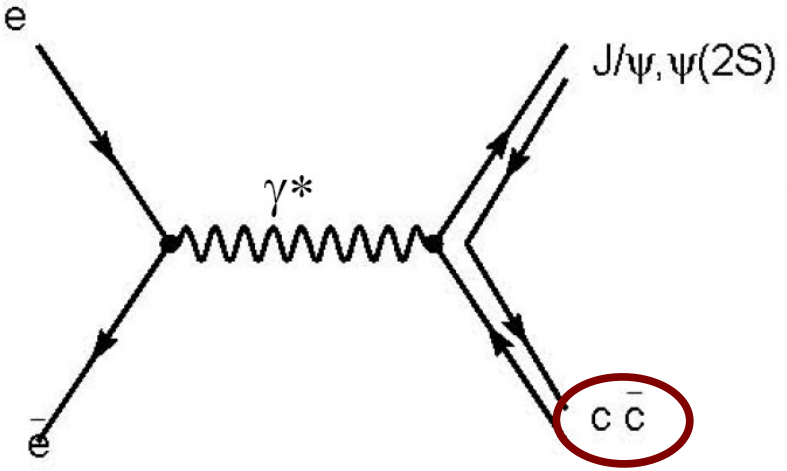
B-factories produce lots of $c\bar{c}$-like pairs

reconstruct one $c\bar{c}$ (J/ψ)
look at recoil mass
other $c\bar{c}$ not fully reconstructed
⇒ higher efficiency

hard γ emitted by an initial e^- (e^+) before annihilation
⇒ annihilation at smaller energy !
whole continuous spectrum can be studied

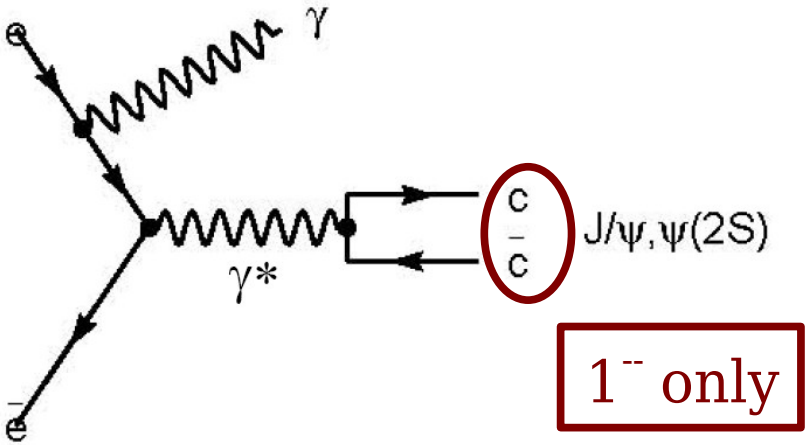
$J^{PC} = 1^{--}$ only

Double Charmonium Production



C = + states

Initial State Radiation



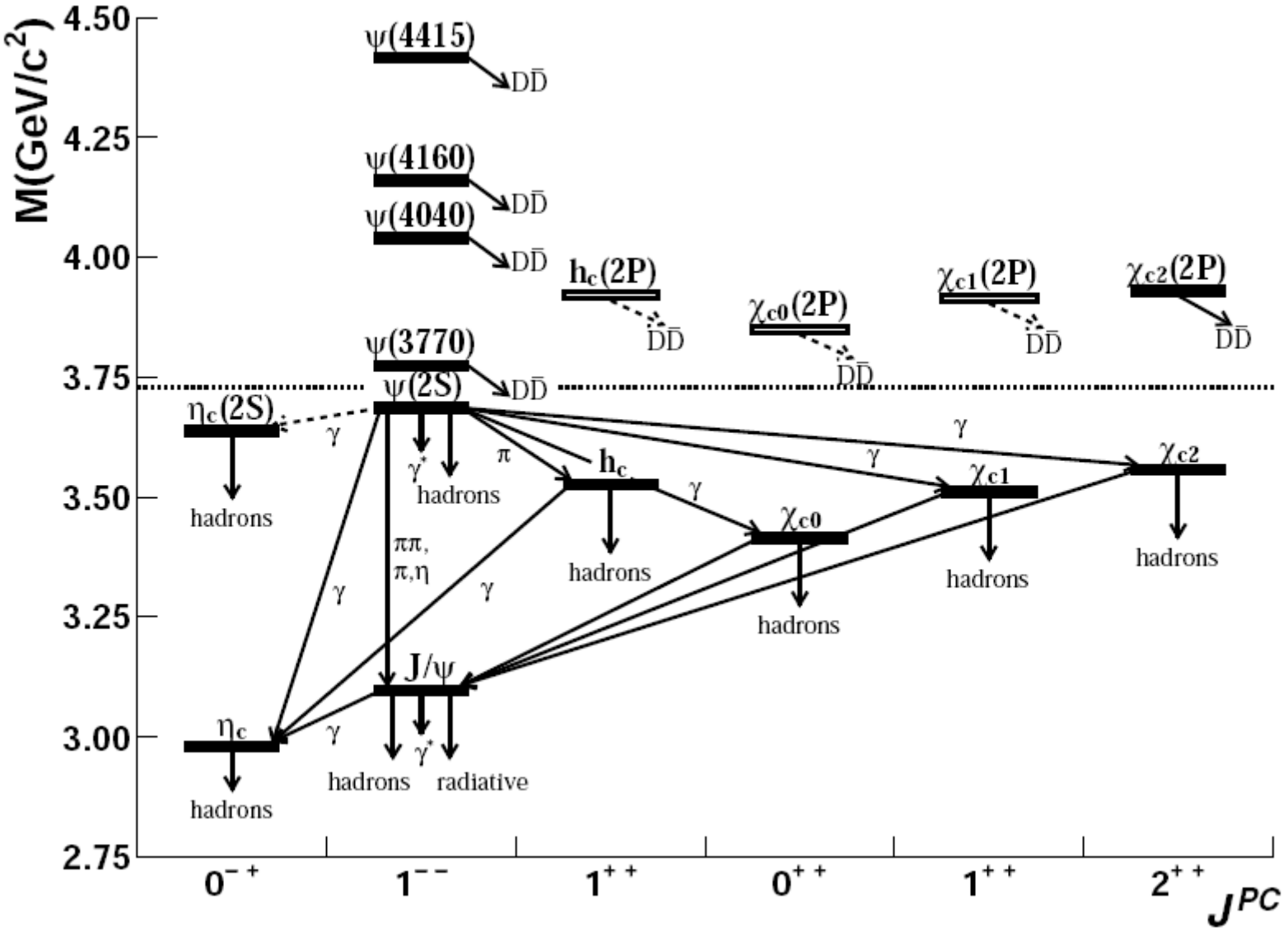
1^{--} only

Charmonium system

Ten $c\bar{c}$ states found in 1974-1980:

⇒ J/ψ, $\eta_c(1S)$, $\chi_{c0}(1P)$, $\chi_{c1}(1P)$, $\chi_{c2}(1P)$, $\psi(2S)$ below

⇒ $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, $\psi(4415)$ above the open charm threshold

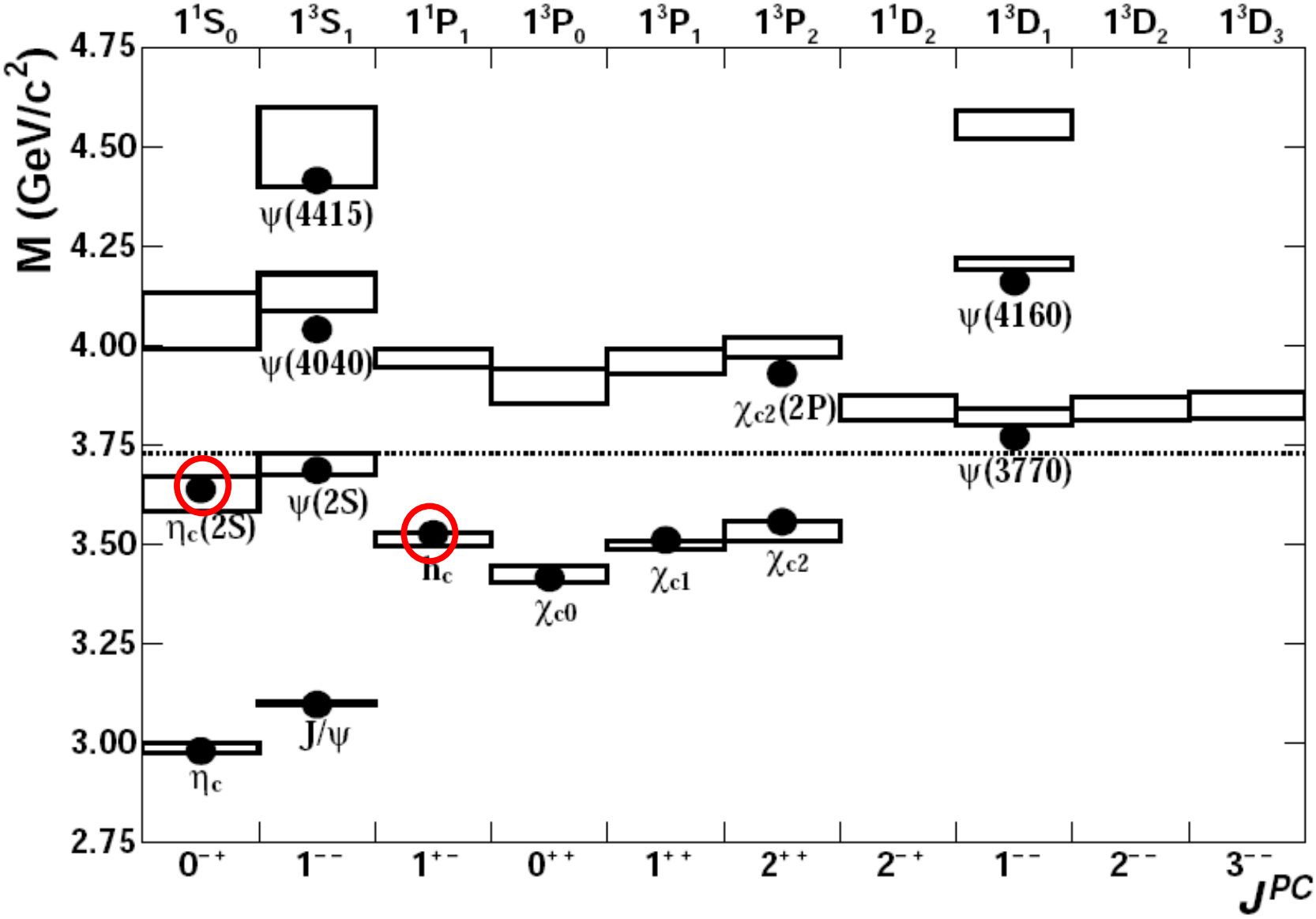


with $\eta_c(2S)$ (in 2002) and $h_c(1P)$ (in 2005) the $c\bar{c}$ system seemed understood...

Predictions of Potential Model

with $\eta_c(2S)$ (in 2002) and $h_c(1P)$ (in 2005) the $c\bar{c}$ system seemed understood...

$\rightarrow K_S K\pi$ $\rightarrow \eta_c\gamma$, $J/\psi\pi^0$



remain some $c\bar{c}$ to observe above $D\bar{D}$ threshold

the only difficulties: broad resonances, expected decay modes are $DD^{(*)}$ etc...

Many (>10) states poorly consistent with quark model (observed last 6 years by B-factories)

(decaying to $c\bar{c}X$ rather than to open charm unexpectedly found)

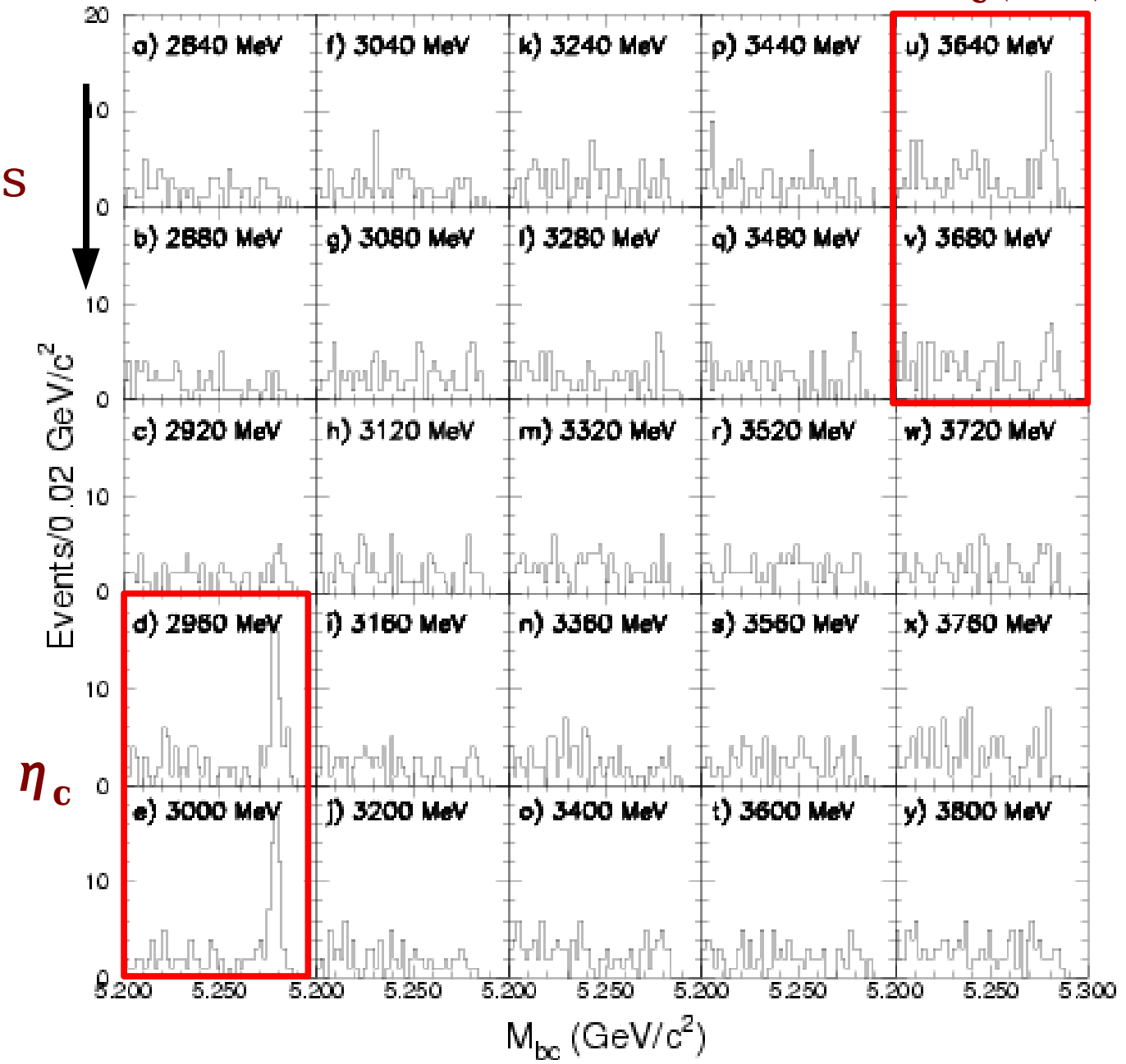
State	M (MeV)	Γ (MeV)	J^{PC}	Decay Modes	Production Modes
$Y_s(2175)$	2175 ± 8	58 ± 26	1^{--}	$\phi f_0(980)$	e^+e^- (ISR) $J/\psi \to \eta Y_s(2175)$
$X(3872)$	3871.4 ± 0.6	< 2.3	1^{++}	$\pi^+\pi^- J/\psi$, $\gamma J/\psi, D\bar{D}^*$	$B \to KX(3872)$, $p\bar{p}$
$X(3915)$	3914 ± 4	23 ± 9	$0/2^{++}$	$\omega J/\psi$	$\gamma\gamma \to X(3915)$
$Z(3930)$	3929 ± 5	29 ± 10	2^{++}	$D\bar{D}$	$\gamma\gamma \to Z(3940)$
$X(3940)$	3942 ± 9	37 ± 17	$0^{?+}$	$D\bar{D}^*$ (not $D\bar{D}$ or $\omega J/\psi$)	$e^+e^- \to J/\psi X(3940)$
$Y(3940)$	3943 ± 17	87 ± 34	$?^{?+}$	$\omega J/\psi$ (not $D\bar{D}^*$)	$B \to KY(3940)$
$Y(4008)$	4008^{+82}_{-49}	226^{+97}_{-80}	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^- (ISR)
$X(4160)$	4156 ± 29	139^{+113}_{-65}	$0^{?+}$	$D^*\bar{D}^*$ (not $D\bar{D}$)	$e^+e^- \to J/\psi X(4160)$
$Y(4260)$	4264 ± 12	83 ± 22	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^- (ISR)
$Y(4350)$	4361 ± 13	74 ± 18	1^{--}	$\pi^+\pi^- \psi'$	e^+e^- (ISR)
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$\Lambda_c^+\Lambda_c^-$	e^+e^- (ISR)
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$\pi^+\pi^- \psi'$	e^+e^- (ISR)
$Z(4050)$	4051^{+24}_{-23}	82^{+51}_{-29}	?	$\pi^\pm \chi_{c1}$	$B \to KZ^\pm(4050)$
$Z(4250)$	4248^{+185}_{-45}	177^{+320}_{-72}	?	$\pi^\pm \chi_{c1}$	$B \to KZ^\pm(4250)$
$Z(4430)$	4433 ± 5	45^{+35}_{-18}	?	$\pi^\pm \psi'$	$B \to KZ^\pm(4430)$
$Y_b(10890)$	$10,890 \pm 3$	55 ± 9	1^{--}	$\pi^+\pi^- \Upsilon(1,2,3S)$	$e^+e^- \to Y_b$

A typical example : reconstruct $B \to K(K_S K^- \pi^+)$

PRL89,102001(2002)

Fit M_{bc} in bins of $K_S K^- \pi^+$ invariant mass of $40\,MeV/c^2$

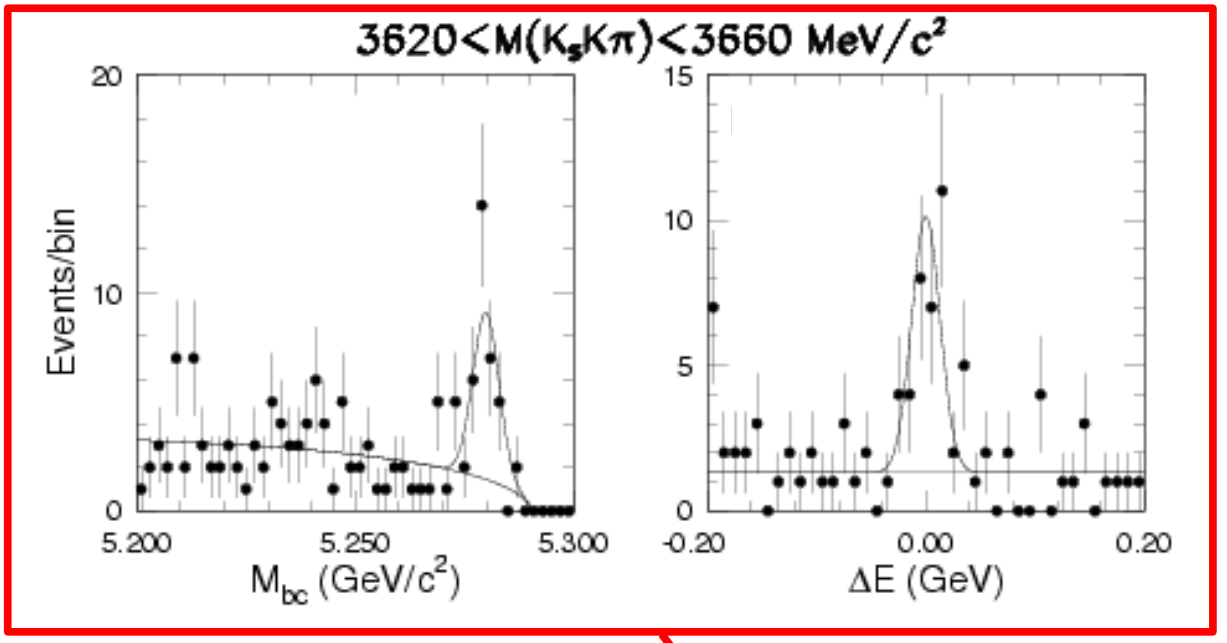
$\eta_c(2S)$

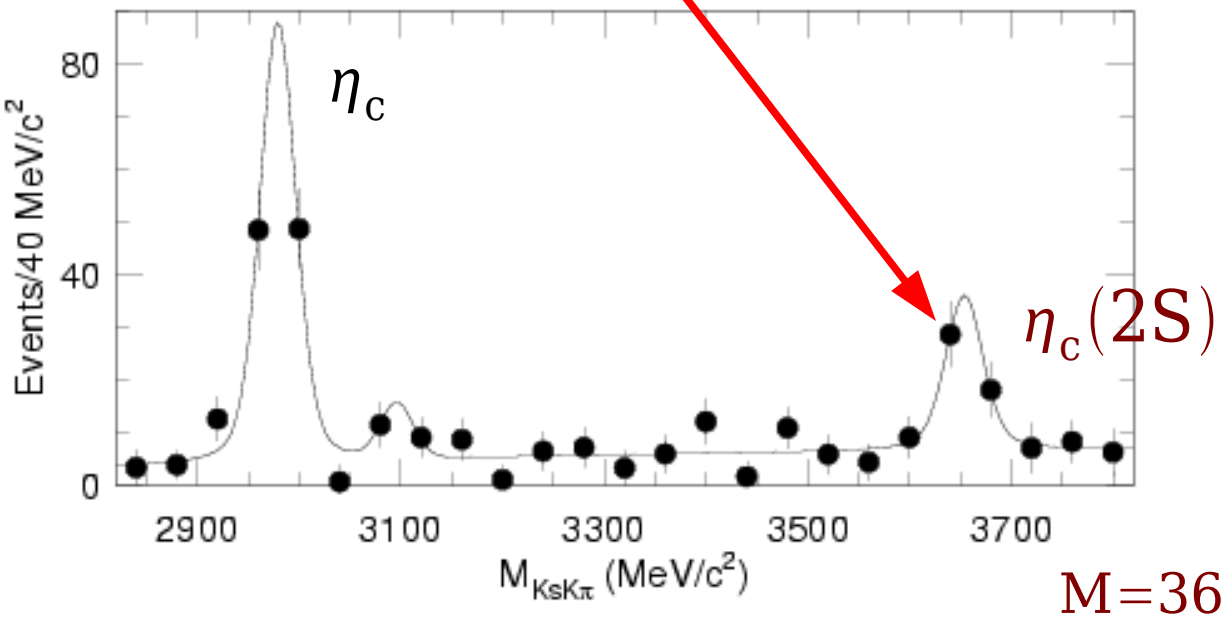


η_c

$B \to K K_S K^- \pi^+$ to see $\eta_c(2S)$

PRL89,102001(2002)





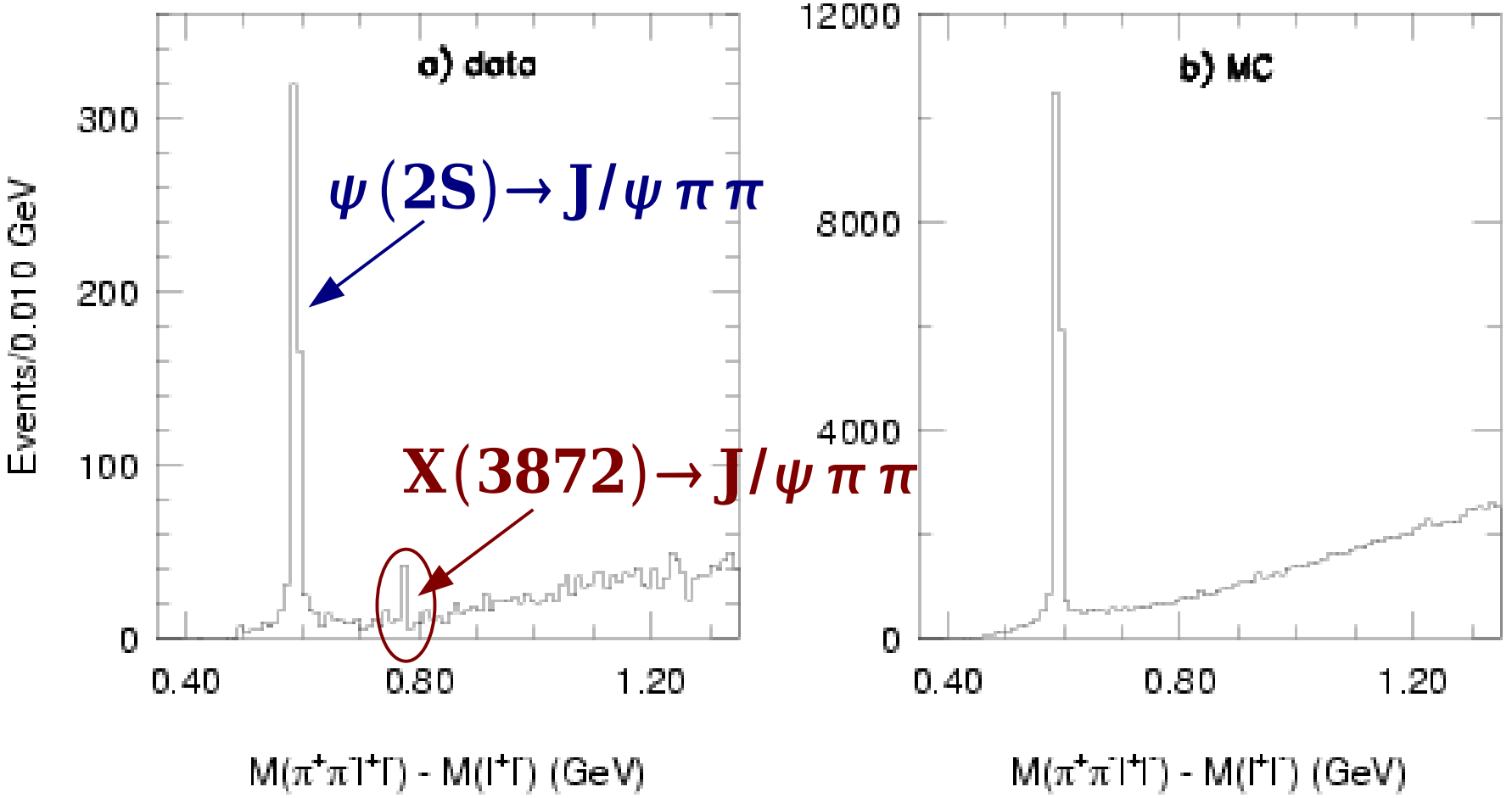
$\Sigma > 6\sigma$

$M = 3654 \pm 6 \pm 8$ MeV/c^2

$\Gamma < 55$ MeV/c^2

X(3872) first observation PRL91, 262001 (2003)

$B \to K \pi^+ \pi^- J/\psi$ using $140\,fb^{-1}$



$N = 35.7 \pm 6.8$

significance $10\,\sigma$

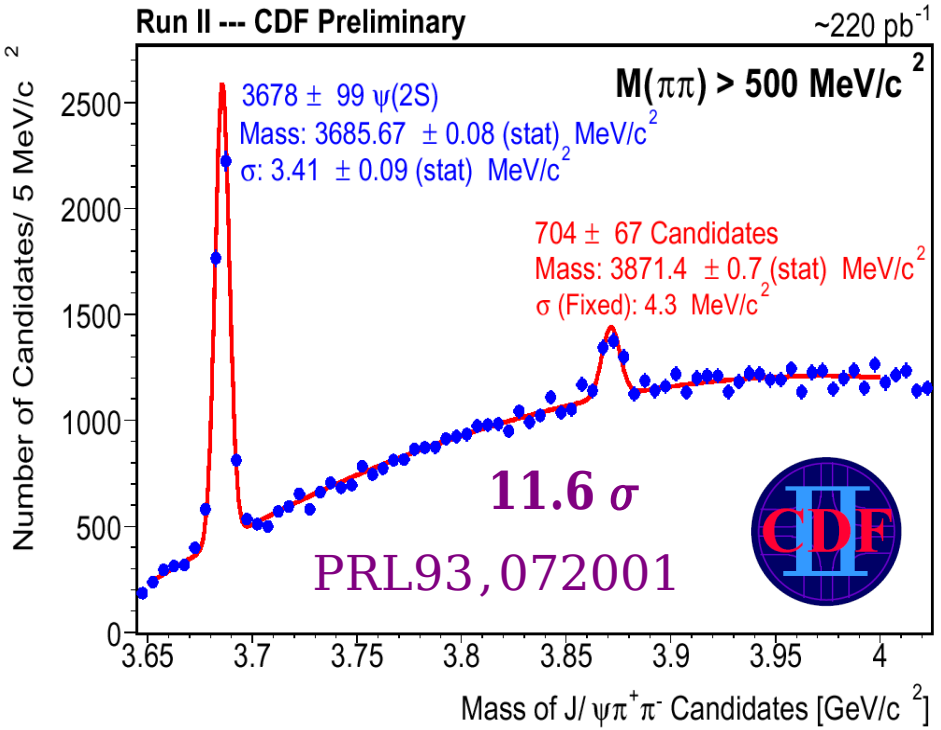
$(3872 \pm 0.6 \pm 0.5)\ MeV/c^2 \sim m_{D^0} + m_{D^{*0}}$

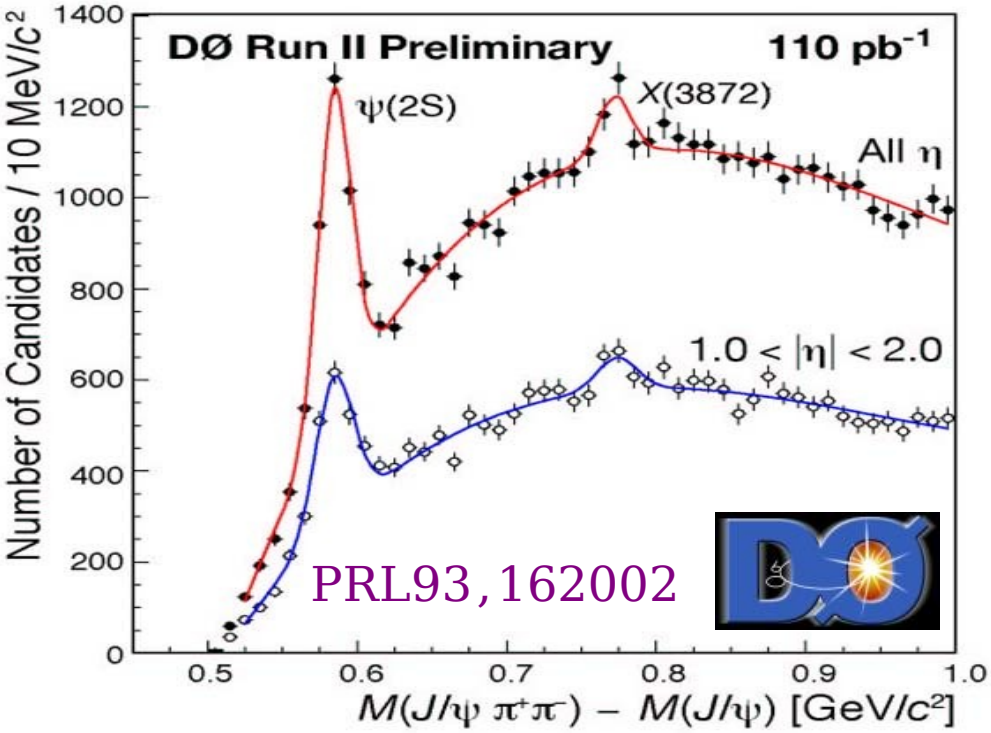
$[m_{D^0} + m_{D^{*0}} = (3871.55 \pm 0.44)\ MeV/c^2]$

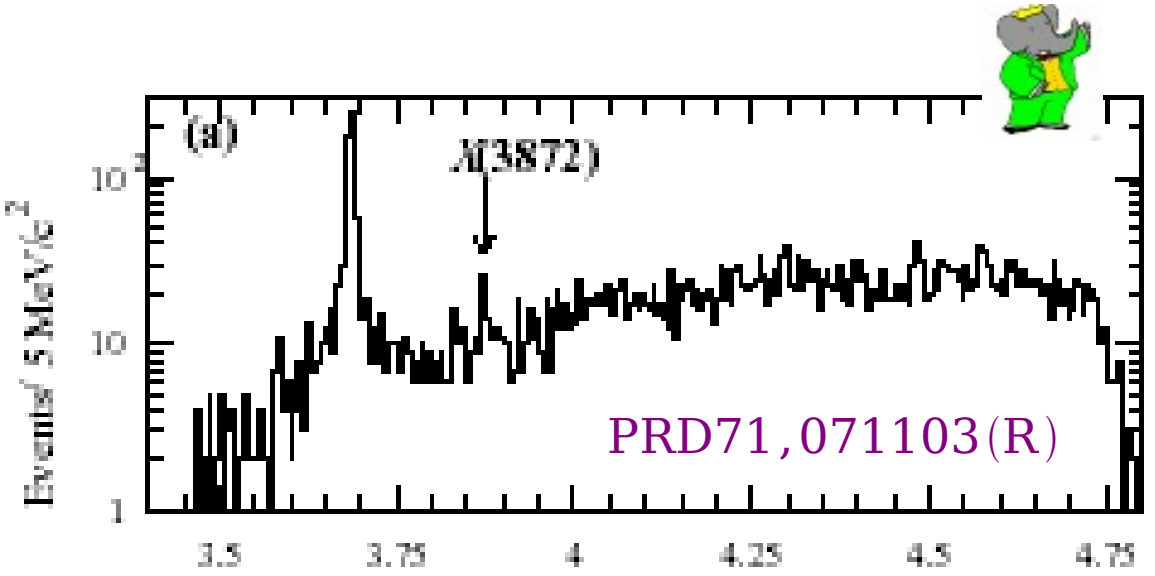
$\Gamma < 2.3\ MeV$

X is narrow and doesn't decay to $D\bar{D}$ [PRL93, 051803 (2004)]

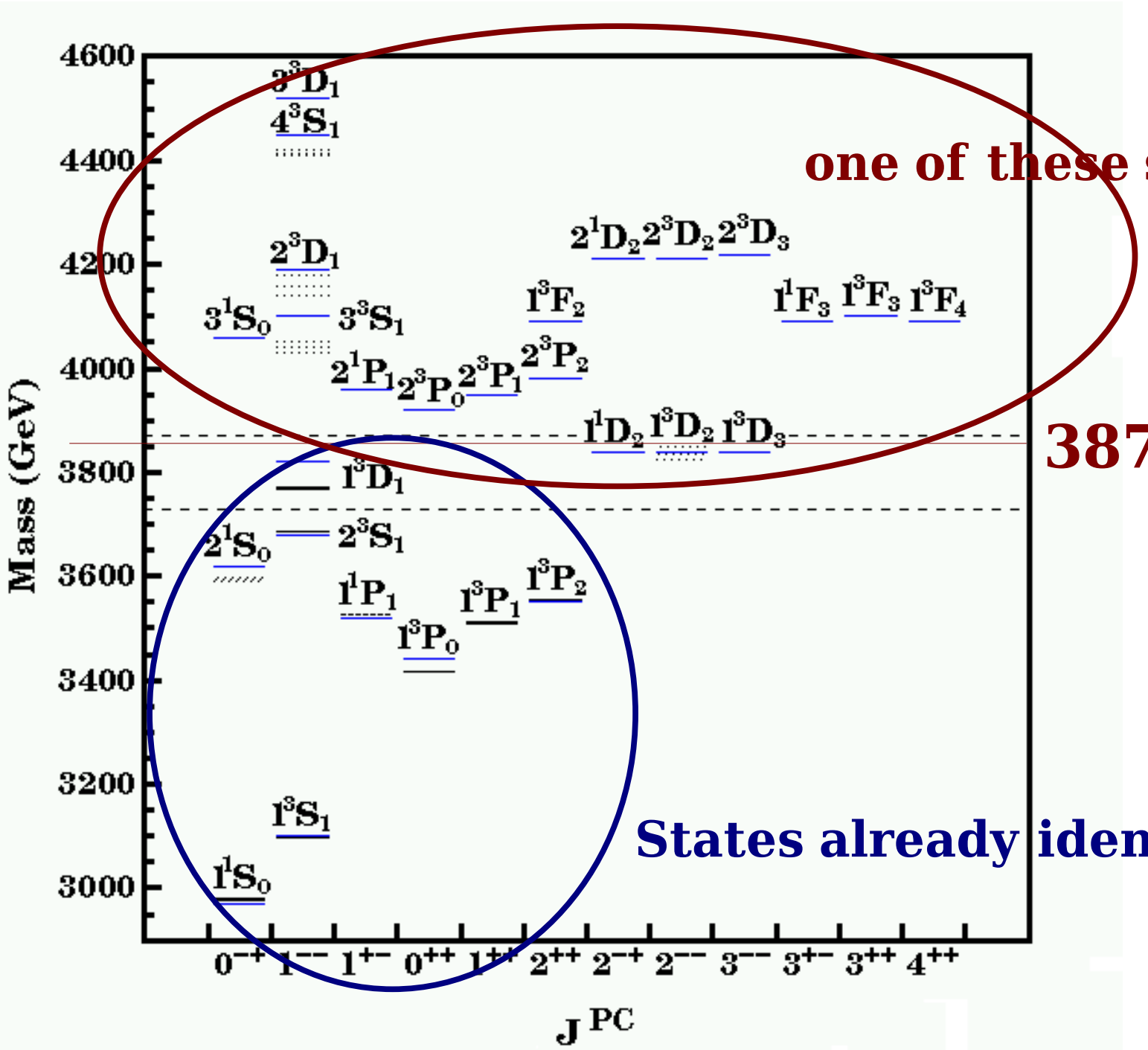
X(3872) confirmed by 3 other experiments







Is it a $c\bar{c}$ meson ?



one of these states ?

3872 MeV

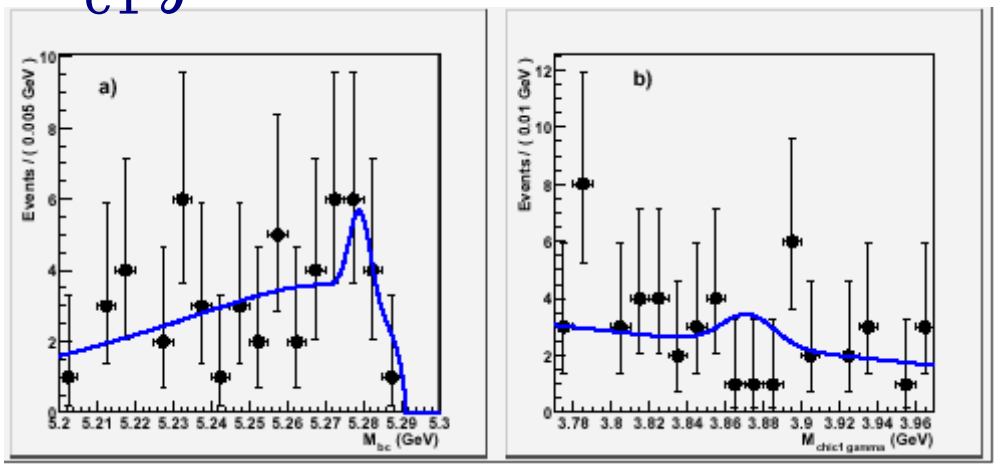
States already identified

Non observation of $X(3872) \to \chi_{cJ}\gamma$ decays

PRL91,262001(2003)

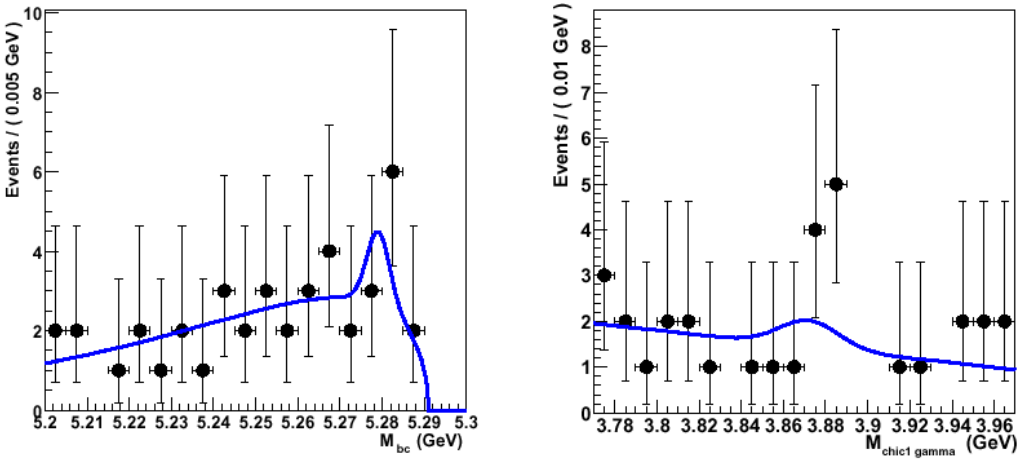
The radiative decays to $\chi_{cJ}\gamma$ expected to be large for some charmonium states... but not found

$\chi_{c1}\gamma K$



M_{bc} $M(\chi_{c1}\gamma)$

$\chi_{c2}\gamma K$



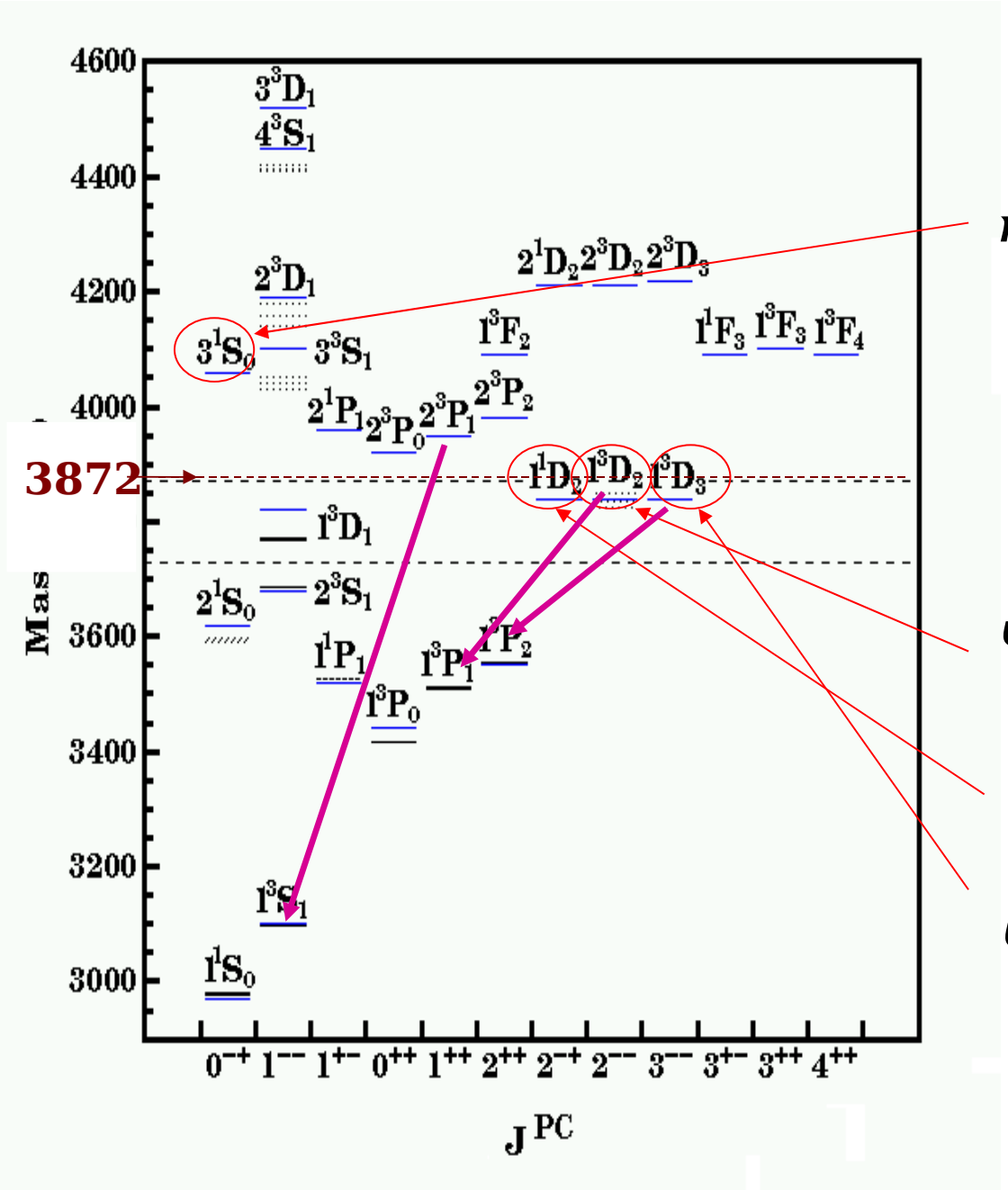
M_{bc} $M(\chi_{c2}\gamma)$

$B(X \to \chi_{c1}\gamma)/B(X \to J\psi\pi^+\pi^-) < 0.9$ at 90% CL $X \equiv \psi_2$ expect > 1.6

[potential/ψ'' Wigner-Eckart]

$B(X \to \chi_{c2}\gamma)/B(X \to J\psi\pi^+\pi^-) < 1.1$ at 90% CL $X \equiv \psi_3$ expect > 3.5

$c\bar{c}$ assignment ?



hep-ex/0407033

η_c'' **M too low and** Γ **too small**

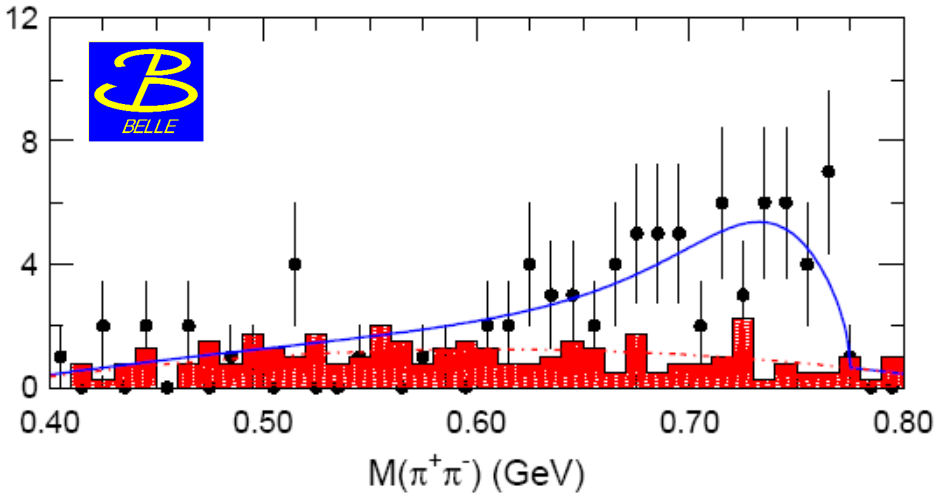
ψ_2 $\Gamma(\gamma\chi_{c1})$ **too small**
$M(\pi^+\pi^-)$ **wrong**

η_{c2} $\pi\pi\eta_c$ **should dominate**

ψ_3 $\Gamma(\gamma\chi_{c2}\&\&D\bar{D})$ **too small**

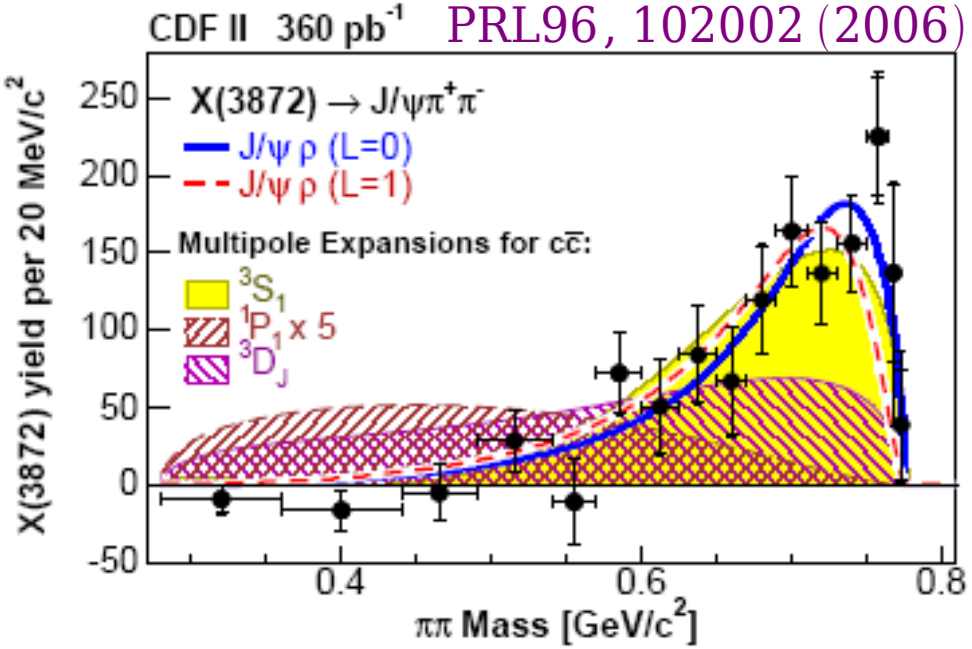
$M_{\pi\pi}$ looks like a ρ

concentration → high $M(\pi^+\pi^-)$ favouring $X(3872) \to \rho\, J/\psi$
and hence $C = +1$



charmonium states all Isosinglets
decay charmonium $\to \rho\, J/\psi$ violates isospin
(should be strongly suppressed)

see also angular analysis
[hep-ex/0505038]
disfavouring 0^{++}, 0^{-+}



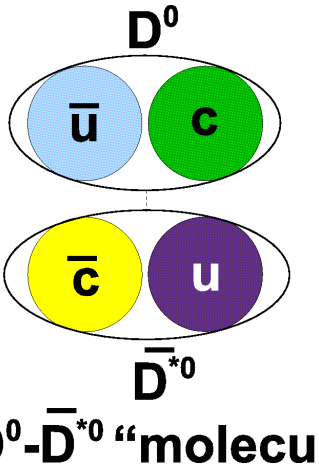
see also angular analysis
[PRL98, 132002 (2007)]

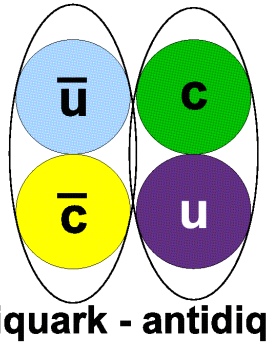
rules out h_c', ψ_J ...

reinforces $X(3872) \to \rho\, J/\psi$ (L=0),
$J^{PC} = 1^{++}$ interpretation

puts L=1, $J^{PC}=2^{-+}$ possibility back
in play: η_{c2}... but
$\Gamma(\eta_{c2} \to \pi^+\pi^-\eta_c)$ sh^{d} be $\gg \Gamma(\eta_{c2} \to \pi^+\pi^- J/\psi)$

Possible exotic interpretations...





- four-quark model

(L.Maiani et al, PRL99: 182003, 2007)

$X_u = [cu][\bar{c}\bar{u}] = X$ state decaying into $D^0\bar{D}^0\pi^0 = X(3876)$

$X_d = [cd][\bar{c}\bar{d}] = X$ state decaying into $J/\psi\,\pi^+\pi^- = X(3872)$

(finding the charged partner is critical)

(mass splitting ?)

- molecule model ($D^{*0}\bar{D}^0$ bound state)

M_X close to the $D^{*0}\bar{D}^0$ threshold

1^{++}, favors $D\bar{D}\pi^0$ decay over $J/\psi\,\pi\,\pi$ over $J/\psi\,\gamma$

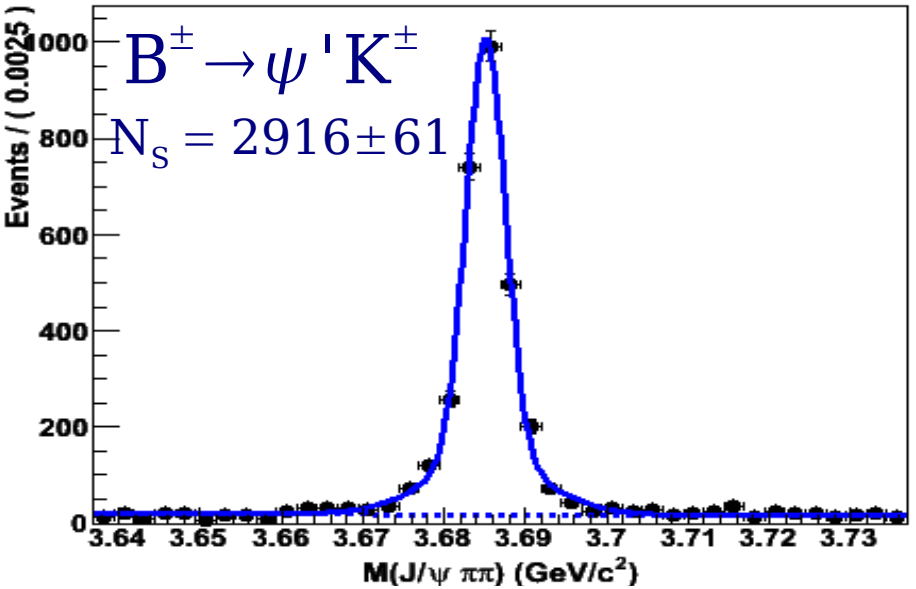
(E.Braaten et al, PRD77: 014029, 2008)

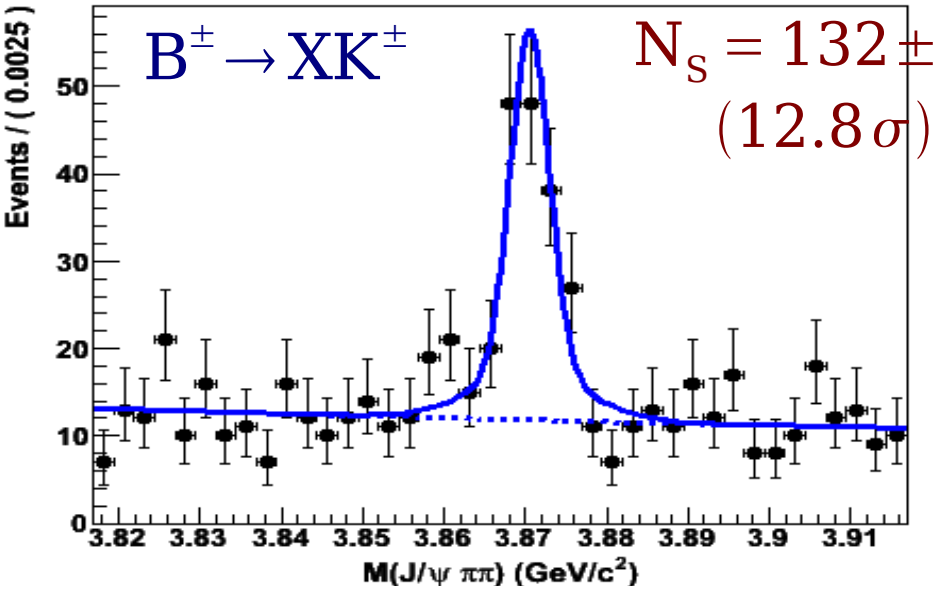
(line shapes of the X depends on its decay channel, different in B^+ or B^0 decays)

Latest update with 605 fb^{-1}

ArXiv:0809.1224

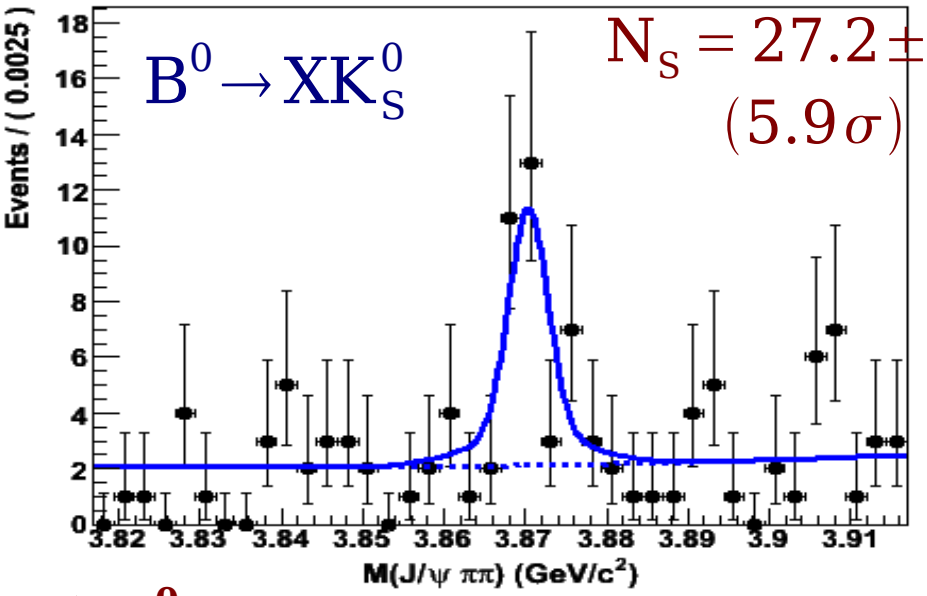
$B^{\pm} \to X(3872) K^{\pm}$ and $B^0 \to X(3872) K^0_S$





distributions for ψ' and $X(3872)$ are fitted simultaneously:

detector resolution effect is automatically calibrated by ψ'



First observation of $B^0 \to X(3872) K^0_S$

$B^{\pm} \to X(3872) K^{\pm}$ and $B^{0} \to X(3872) K^{0}$

ArXiv:0809.1224

- $R = \dfrac{BR(B^0 \to X(3872) K^0)}{BR(B^{\pm} \to X(3872) K^{\pm})} = 0.82 \pm 0.22 \pm 0.05$

charged and neutral B mesons decay into $X(3872)$ with comparable BR

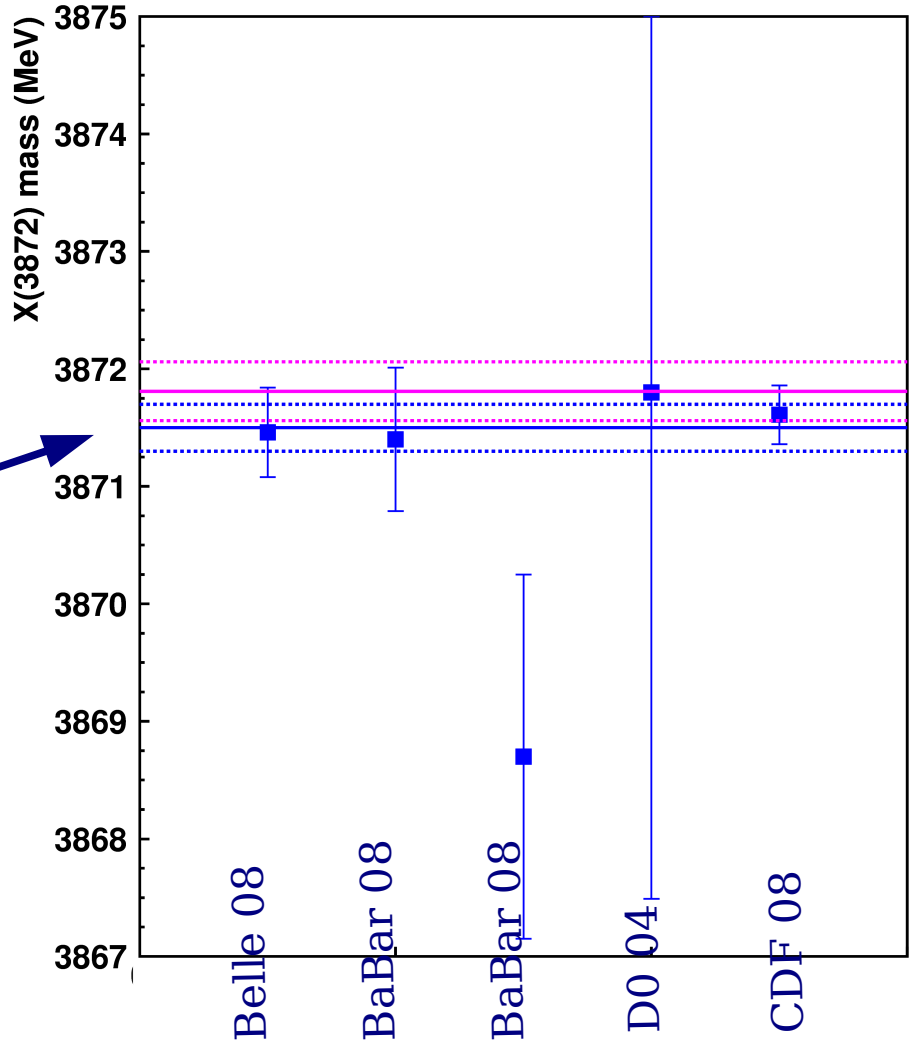
$\delta M_X = M(X \text{ from } B^{\pm}) - M(X \text{ from } B^0)$
$= (0.18 \pm 0.89 \pm 0.26)$ MeV
No mass splitting signature

$M_X = (3871.46 \pm 0.37 \pm 0.07)$ MeV

$m_{D^0} + m_{D^{*0}} = 3871.81 \pm 0.36$ MeV

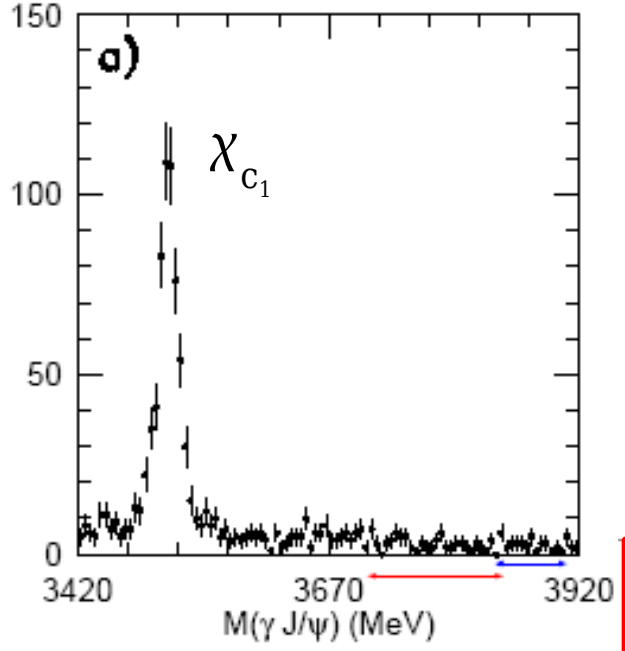
my naive average:
$M_X = 3871.50 \pm 0.20$ MeV

(CDF: $M_X = 3871.61 \pm 0.16 \pm 0.19$ MeV)



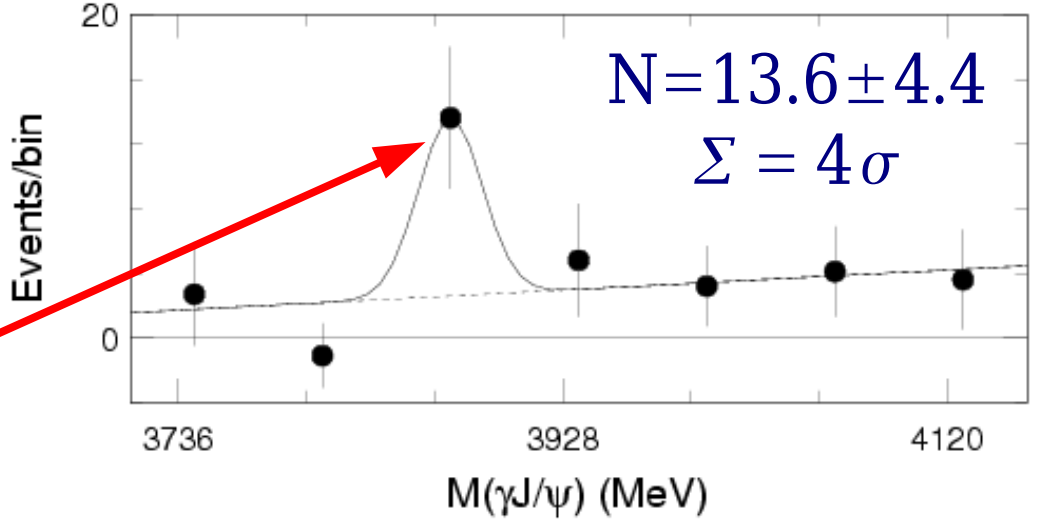
Evidence for $X(3872) \to J/\psi\,\gamma$

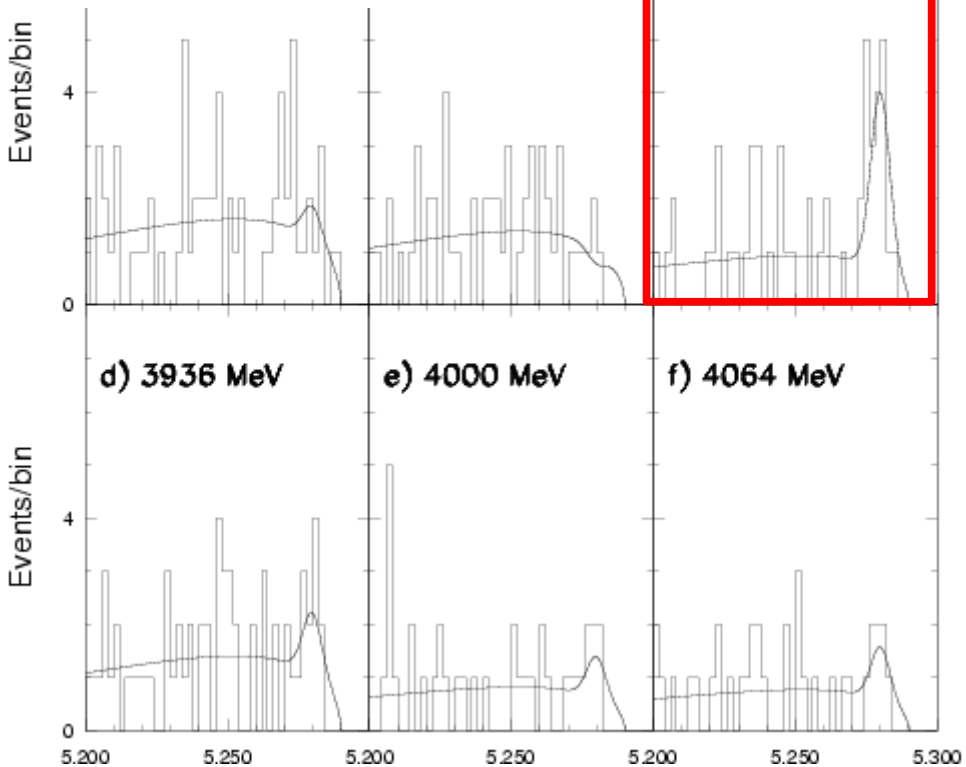
hep-ex/0505037
$(256\,\mathrm{fb}^{-1})$



Look for $B^+ \to X K^+$ where $X \to J/\psi\,\gamma$

$\chi_{c_1} \to J/\psi\,\gamma$ as calibration mode





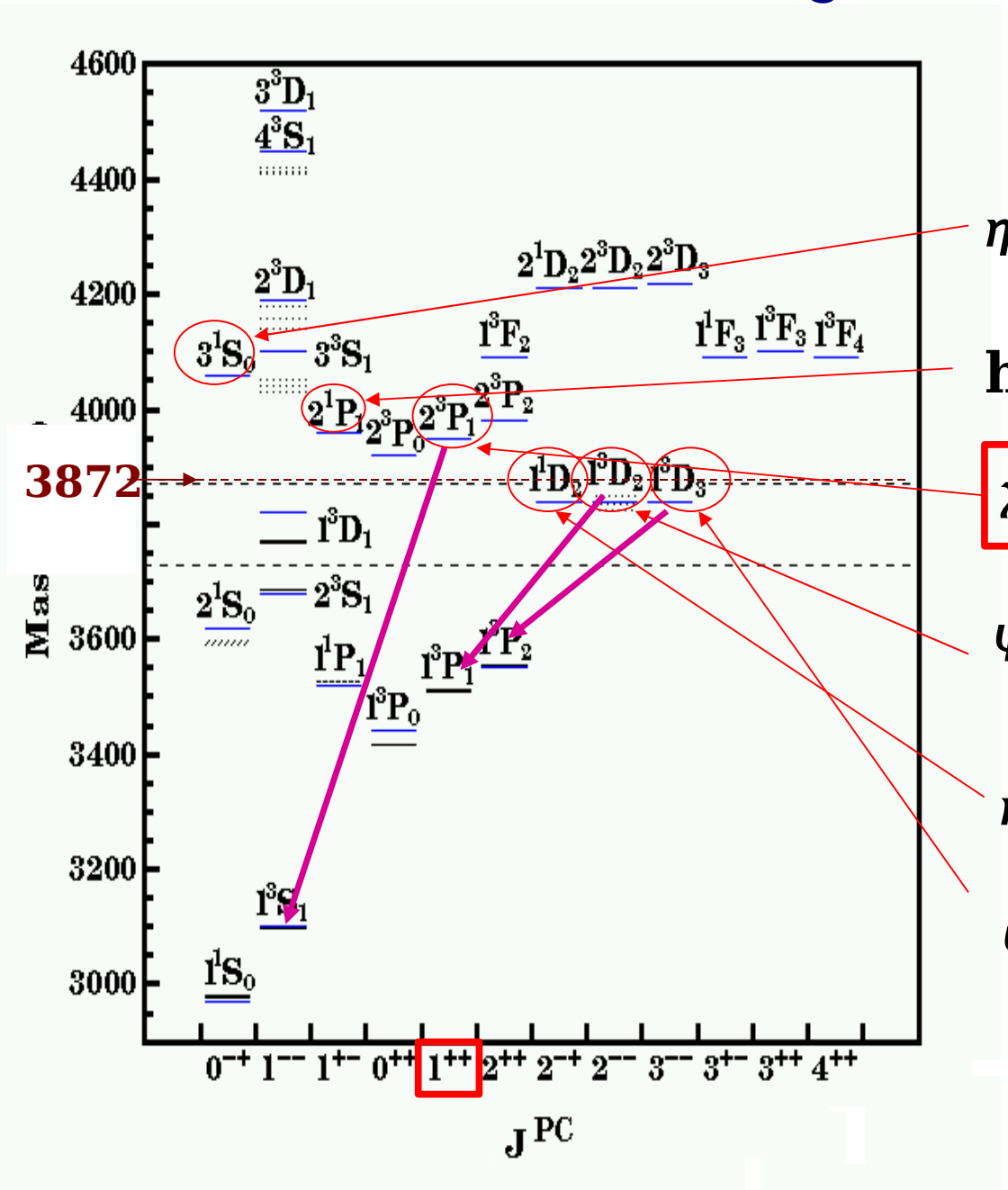
Strong evidence for $X \to J/\psi\,\gamma$ decay

$$\frac{\mathbf{BR}(X \to J/\psi\,\gamma)}{\mathbf{BR}(X \to J/\psi\,\pi^+\pi^-)} = \mathbf{0.14 \pm 0.05}$$

→ C-parity positive !

No obvious $c\bar{c}$ assignment

if $J^{PC} = 1^{++}$



hep-ex/0407033

η_c'' **M too low and Γ too small**

$\mathbf{h_c'}$ **angular dist rules out 1^{+-}**

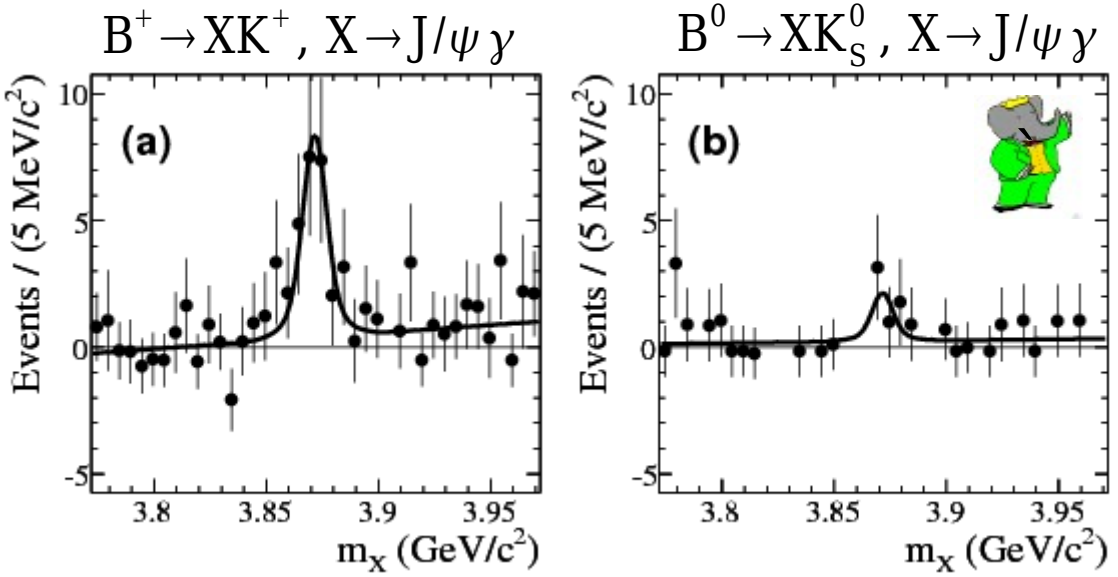
χ_{c1}' $\Gamma(\gamma J/\psi)$ **way too small**

ψ_2 $\Gamma(\gamma\chi_{c1})$ **too small**
$M(\pi^+\pi^-)$ **wrong**

η_{c2} $\pi\pi\eta_c$ **should dominate**

ψ_3 $\Gamma(\gamma\chi_{c2}\&\&D\bar{D})$ **too small**

BaBar confirms X(3872) → J/ψ γ



PRL102, 132001 (2009)
(424 fb^{-1})

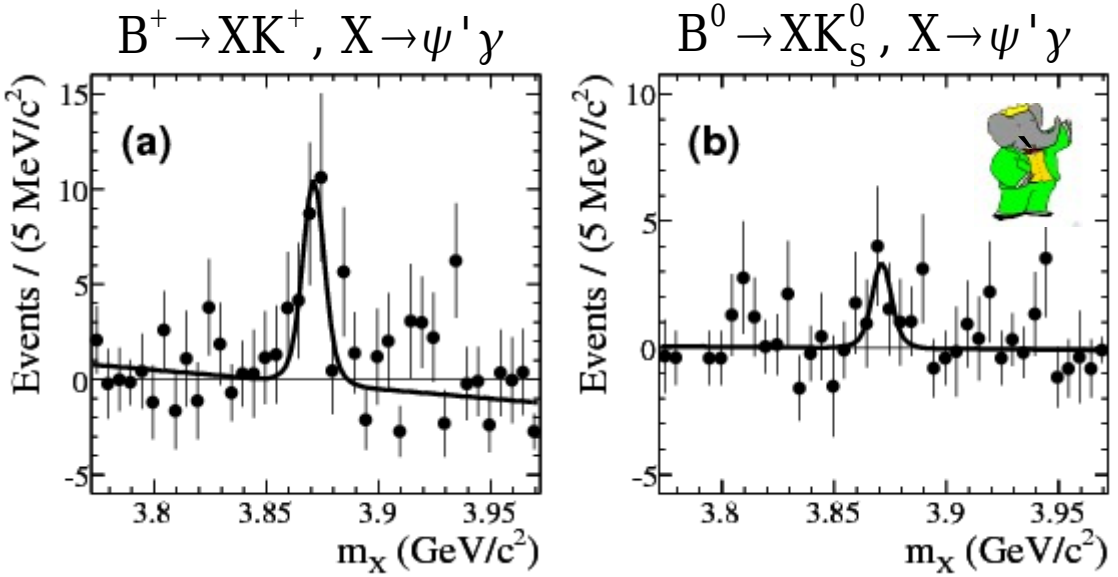
confirmation from BaBar

$BR(B \to X(3872)K^+) \times BR(X(3872) \to J/\psi\gamma)$

$= (2.8 \pm 0.8 \pm 0.1) \times 10^{-6}$

$BR(B \to X(3872)K^+) \times BR(X(3872) \to J/\psi\gamma) = (1.8 \pm 0.6 \pm 0.1) \times 10^{-6}$

… and …



Evidence for $B^+ \to X(3872)(\to \psi'\gamma)K^+$
$N = 25.4 \pm 7.4$

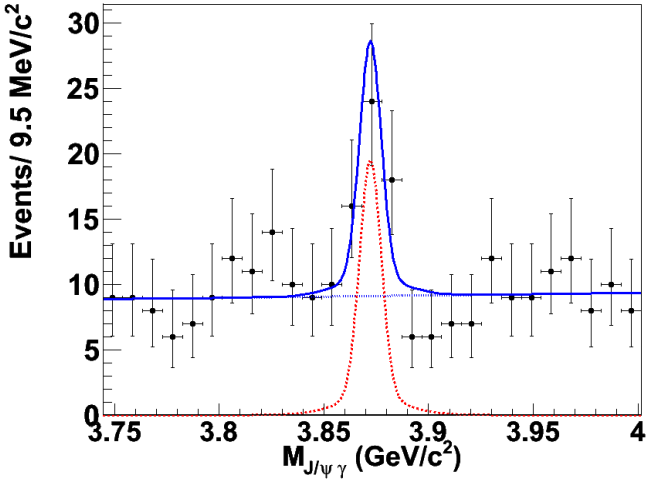
$$\frac{\mathbf{BR(X(3872) \to \psi'\gamma)}}{\mathbf{BR(X(3872) \to J/\psi\gamma)}} = \mathbf{3.5 \pm 1.4}$$

inconsistent with a purely $\bar{D}^0 D^{*0}$ molecular interpretation
⇒ significant mixture with $c\bar{c}$ component ?

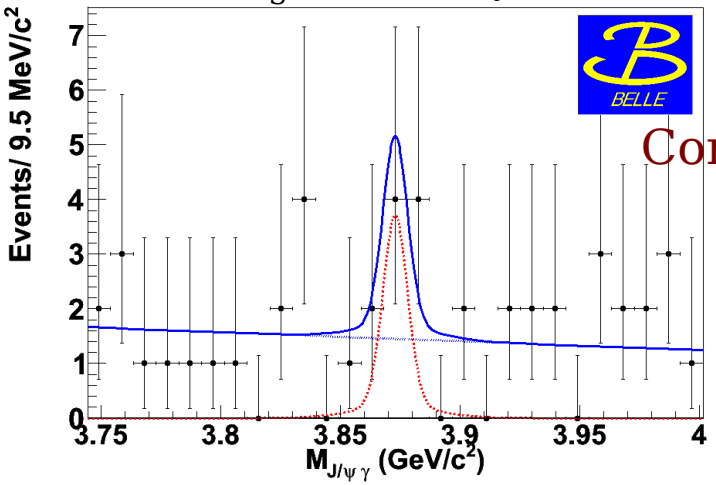
X(3872) radiative decays (update)

preliminary shown at QWG7 ($711\ \mathrm{fb}^{-1}$)

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



$B^0 \to X K^0_S,\ X \to J/\psi\gamma$



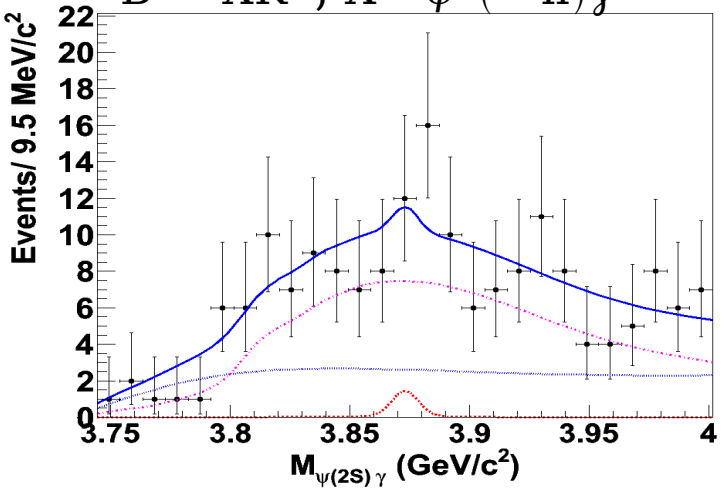
Consistent with our previous and BaBar results

$$\frac{BR(X \to J/\psi\gamma)}{BR(X \to J/\psi\pi^+\pi^-)} = 0.22 \pm 0.05$$

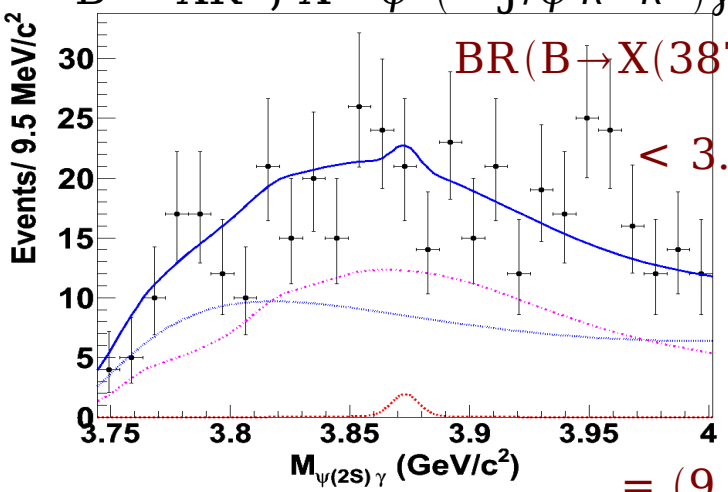
... however ...

No signal observed in $X(3872) \to \psi'\gamma$!!

$B^+ \to X K^+,\ X \to \psi'(\to ll)\gamma$



$B^+ \to X K^+,\ X \to \psi'(\to J/\psi\pi^+\pi^-)\gamma$



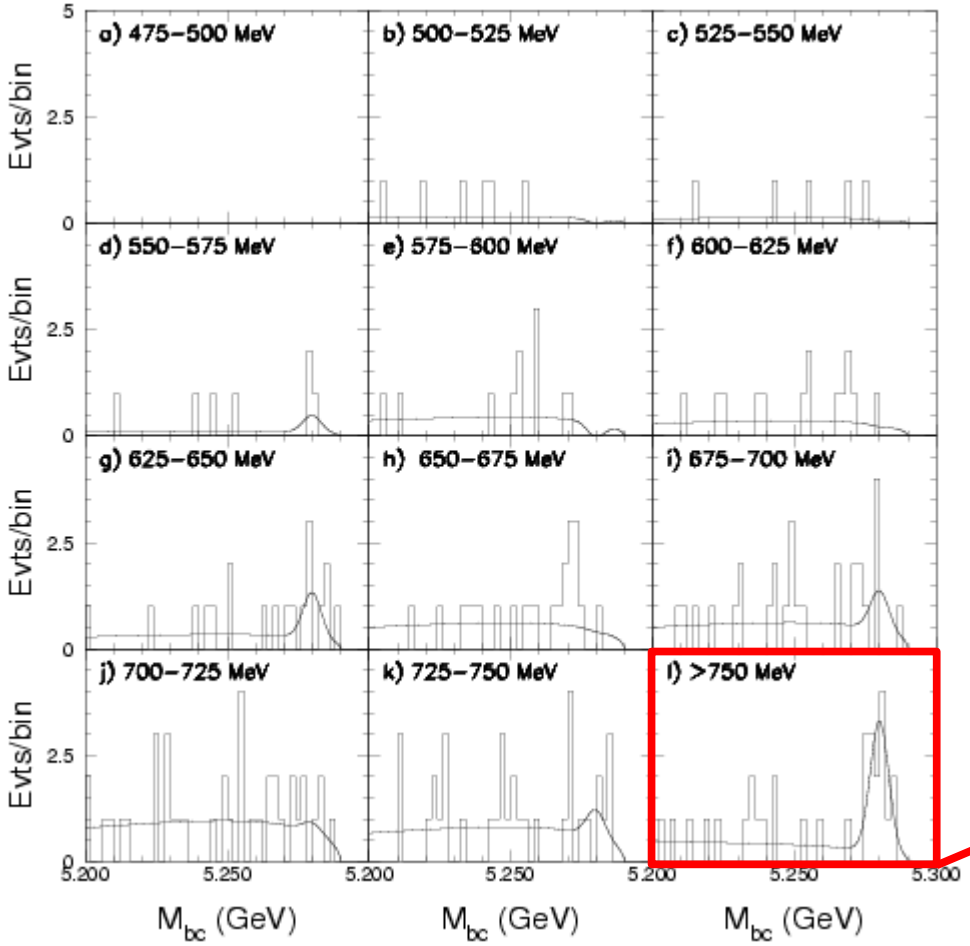
$BR(B \to X(3872) K^+) \times BR(X(3872) \to \psi'\gamma)$

$< 3.4 \times 10^{-6}$ @ 90% CL

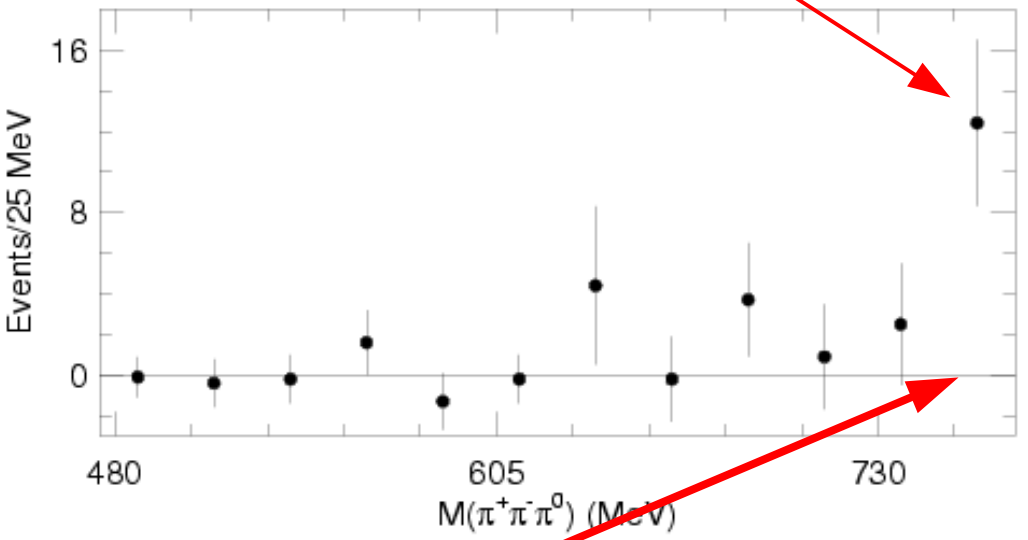
$= (9.5 \pm 2.7 \pm 0.6) \times 10^{-6}$ (BaBar)

Evidence for $X(3872) \to \pi\pi\pi^0 J/\psi$

hep−ex/0505037
$(256\,\mathrm{fb}^{-1})$



virtual $\omega(782)$?



$N = 12.1 \pm 4.1$
Backgrounds $= 2.1 \pm 1.0$
significance 4.3σ

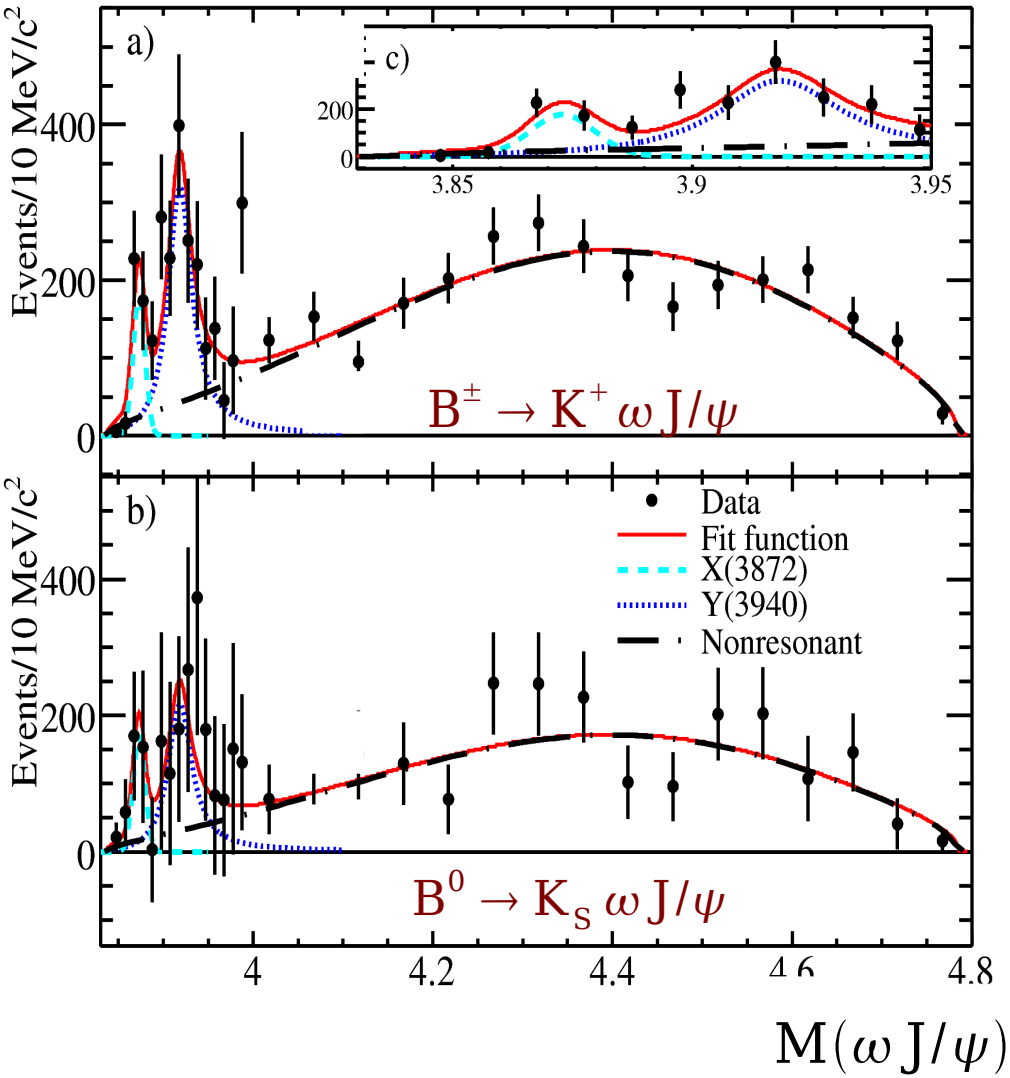
$$\frac{BR(X \to J/\psi \pi^+\pi^-\pi^0)}{BR(X \to J/\psi \pi^+\pi^-)} = 1.0 + 0.4 \pm 0.3$$

for $M(\pi^+\pi^-\pi^0) > 750\ \mathrm{MeV}/c^2$

Large isospin violation

BaBar confirms X(3872) → J/ψ ω

arXiv:1005.5190
(426 fb^{-1})

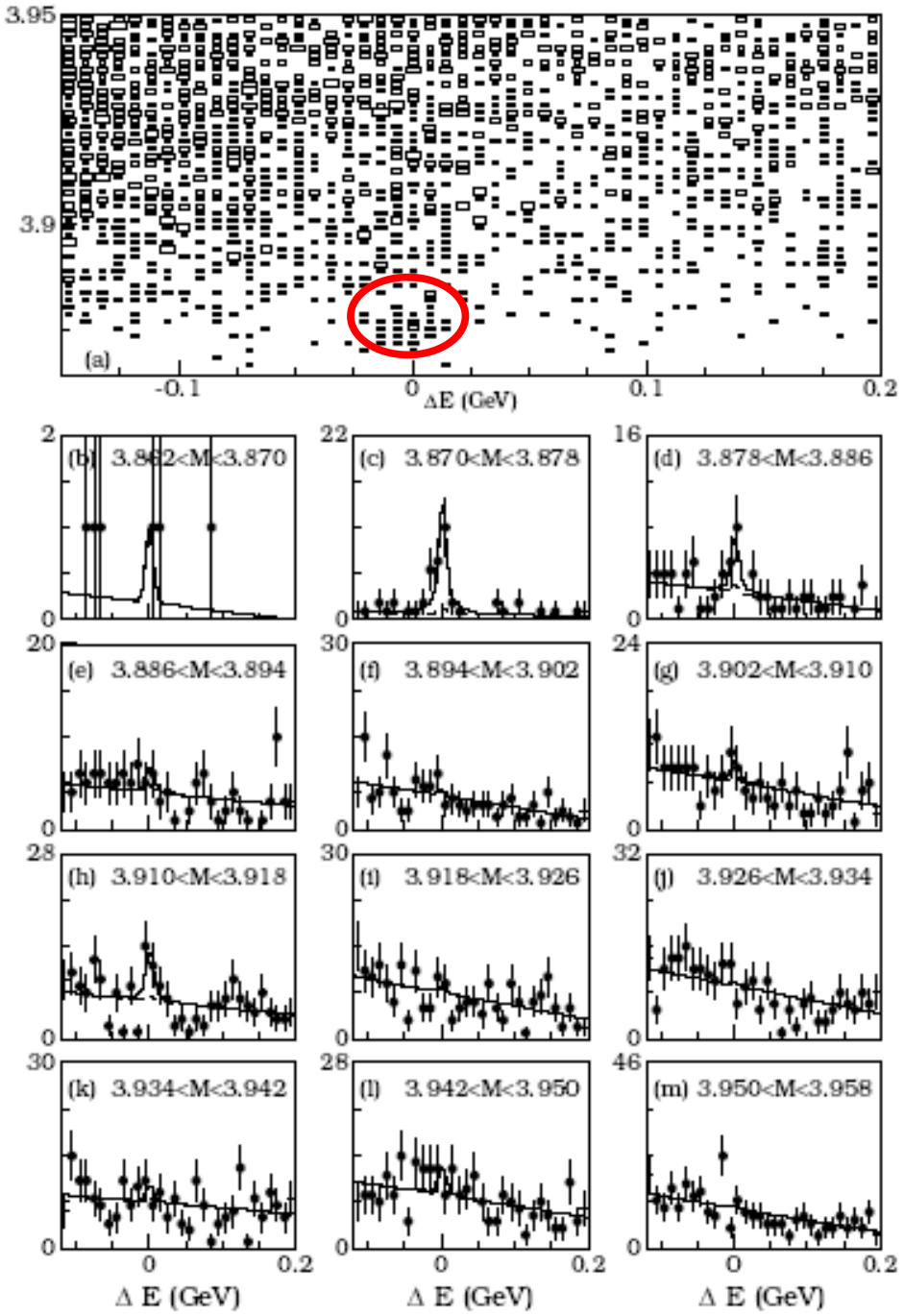


$$\frac{BR(X \to J/\psi\,\omega)}{BR(X \to J/\psi\,\pi^+\pi^-)} = 0.8 \pm 0.3$$

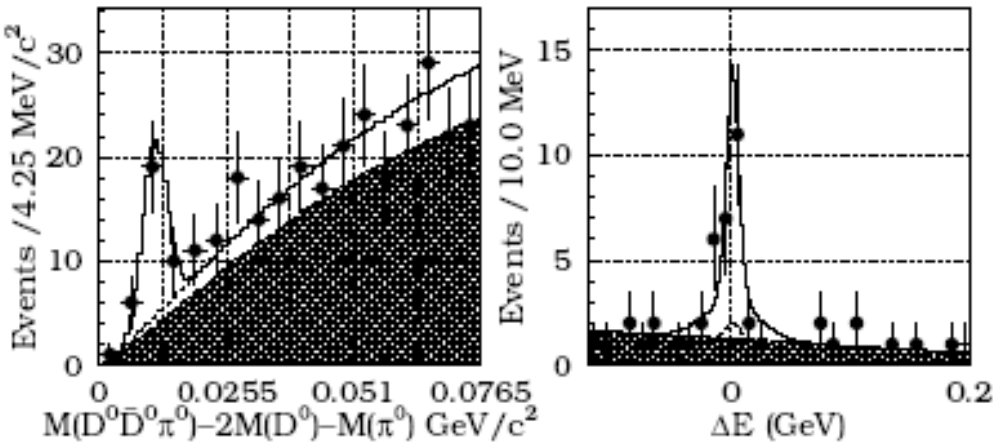
⇒ Belle will update soon this analysis (× 3 data)

threshold enhancement in $D^0\bar{D}^0\pi^0$

PRL97, 162002 (2006)



$\Sigma = 6.4\sigma$



$$M = (3875.4 \pm 0.7^{+1.2}_{-2.0})\ \mathrm{MeV}/c^2$$

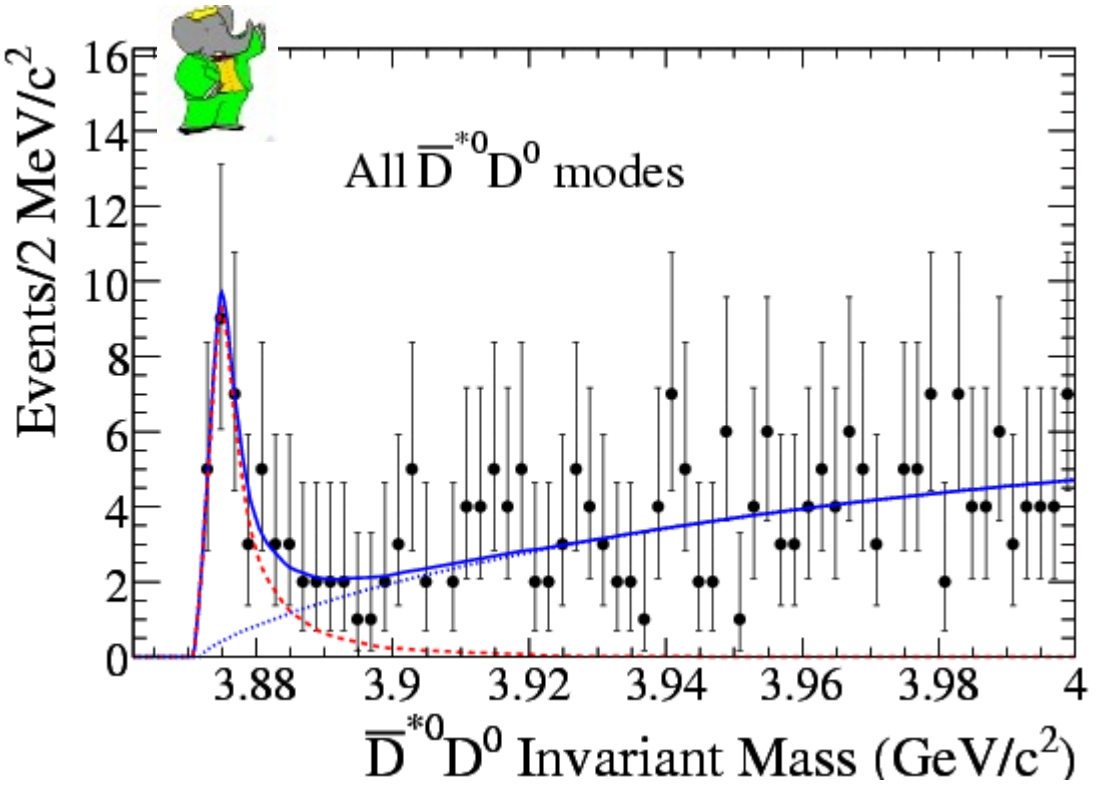
$$BR(B \to XK) \times BR(X \to D^0\bar{D}^0\pi^0) = (1.27 \pm 0.31^{+0.22}_{-0.39}) \times 10^{-4}$$

$$\frac{BR(X \to D^0\bar{D}^0\pi^0)}{BR(X \to J/\psi\pi^+\pi^-)} \sim 10$$

$X \to D^0\bar{D}^{*0}/D^0\bar{D}^0\pi^0$ expected to be strongly suppressed for J=2

...and BaBar

PRD77, 011102 (2008)



$D^{*0} \to D^0 \pi^0$, $D^0 \gamma$

$\Sigma = 4.9\sigma$

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

$\Gamma = (3.0^{+1.9}_{-1.4} \pm 0.9)\ \mathrm{MeV}/c^2$

$BR(B^0 \to XK^0) \times BR(X \to \overline{D}^{*0} D^0) = (2.22 \pm 1.05 \pm 0.42) \times 10^{-4}$

$BR(B^+ \to XK^+) \times BR(X \to \overline{D}^{*0} D^0) = (1.67 \pm 0.36 \pm 0.47) \times 10^{-4}$

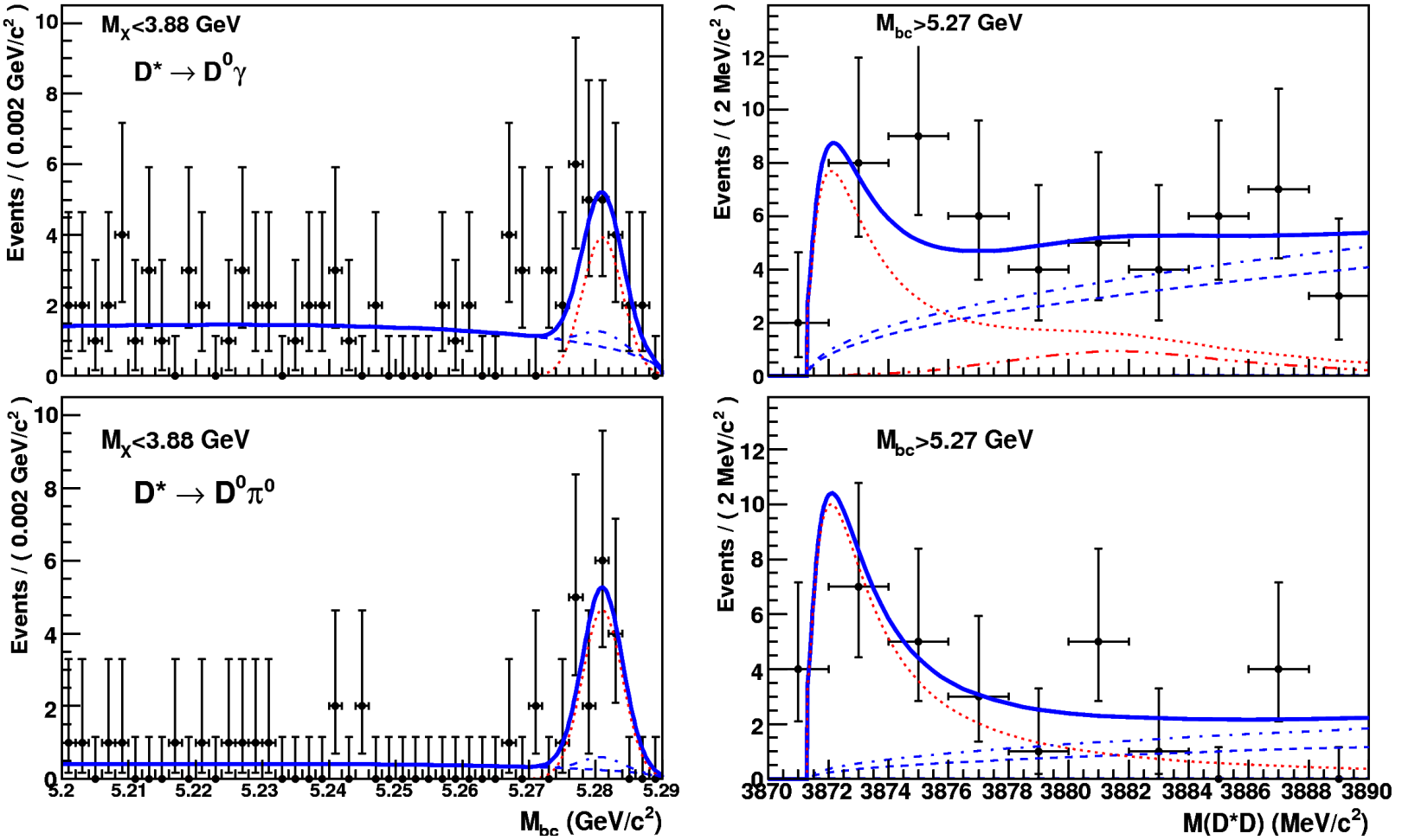
M_X differs in $D^0 \overline{D}^0 \pi^0$ and $J/\psi \pi^+ \pi^-$ decays ?

Is it the same $X(3872)$ or two different X states ?

Most recent Belle analysis (with 605 fb^{-1})

$D^{*0} \to D^0 \pi^0$, $D^0 \gamma$

PRD(RC)81, 031103 (2010)



$N_S = 39.6^{+9.3}_{-8.1}$

$\Sigma = 8.0\sigma$

$M = (3872.9^{+0.6\,+0.4}_{-0.4\,-0.5})$ MeV/c^2 $\quad \Gamma(\mathrm{BW}) = (3.9^{+2.8\,+0.2}_{-1.4\,-1.1})$ MeV/c^2

$\mathrm{BR}(B^0 \to XK) \times \mathrm{BR}(X \to \overline{D}^{*0} D^0) = (0.80 \pm 0.20 \pm 0.10) \times 10^{-4}$

Summary for X(3872)

- narrow ($\Gamma < 2.3\,\mathrm{MeV}$ @ 90 %C.L.) and right at $m_{D^0} + m_{D^{*0}}$

$$M_X = (3871.46 \pm 0.37 \pm 0.07)\,\mathrm{MeV}$$

- no mass splitting signature
- $C = +1$ well established, $J^{PC} = 1^{++}$ seems likely
- first observation of $B^0 \to X(3872) K^+ \pi^-$, but $K^+ \pi^-$ mostly non res.
- seen by Belle in $D^0 \overline{D}^{*0}$, $J/\psi\,\pi^+\pi^-$, $J/\psi\,\omega$, $J/\psi\,\gamma$ **but not in $\psi'\gamma$**
- recent $D^0 \overline{D}^{*0}$ analysis:

$$M_X = (3872.6^{+0.5}_{-0.4} \pm 0.4)\,\mathrm{MeV}$$

→ no good charmonium candidate ?

so what is it ? tetraquark, molecule, ...?

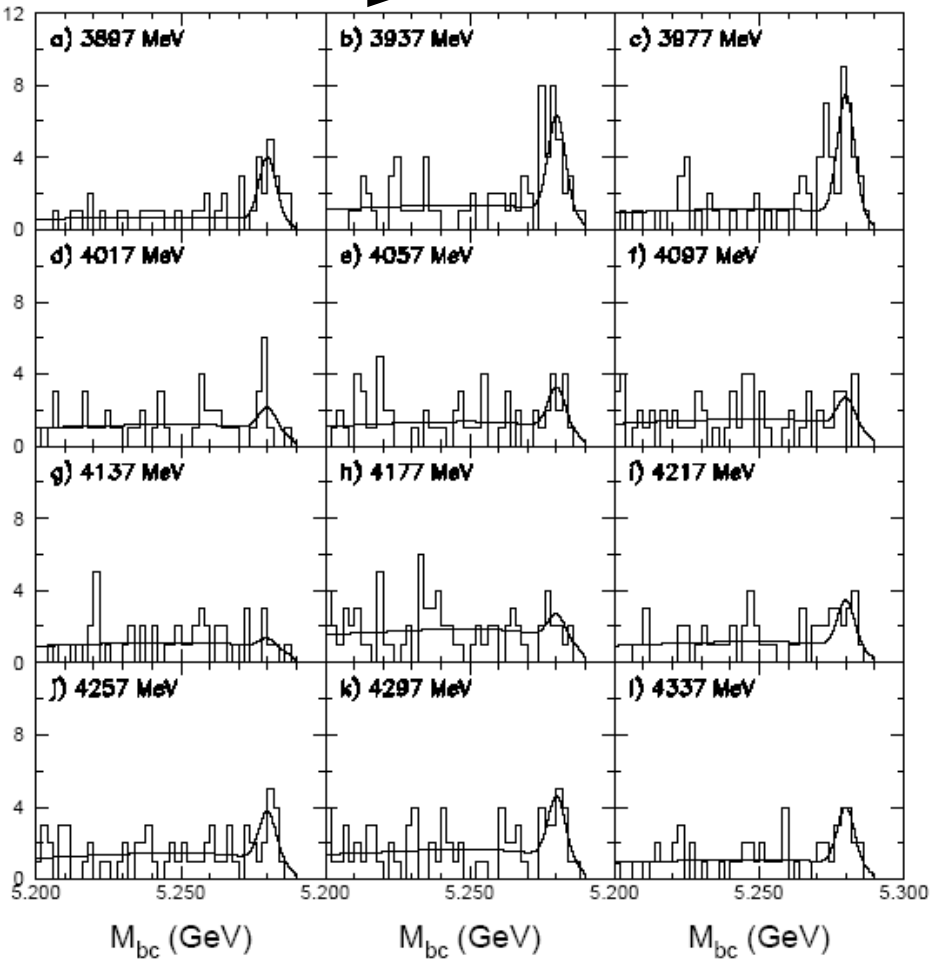
Around 3940 MeV/c^2

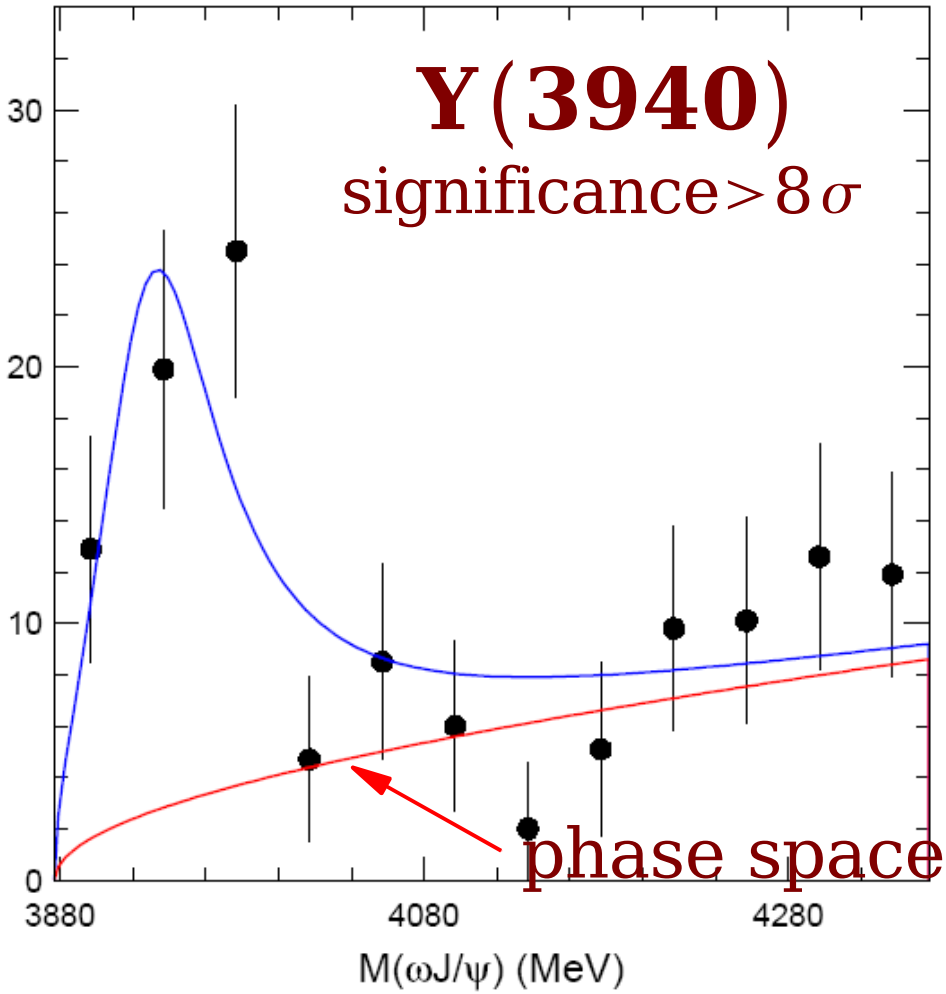
Another enhancement is found in $J/\psi\omega$ final state around threshold :

PRL94,182002(2005)

(253fb^{-1})

M_{bc} for $B\to J/\psi\omega K$ in bins of $M(J/\psi\omega)$





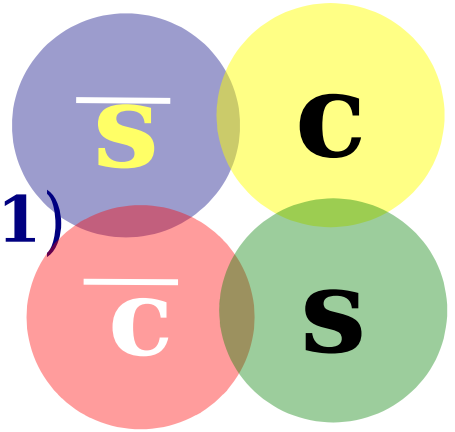
fit: threshold $q^*(M)$ + S-wave BW

$M = (3943 \pm 11 \pm 13)\ \text{MeV}/c^2$

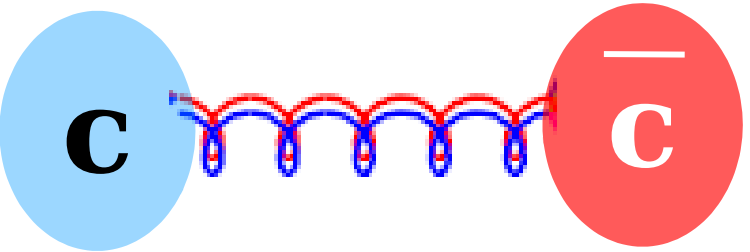
$\Gamma = (87 \pm 22 \pm 26)\ \text{MeV}$

- The mass is well above $DD^{(*)}$ threshold and decay to $J/\psi\,\omega$ should not be dominant if Y=charmonium
  - → **no obvious charmonium meson assignment**

- another molecule ?
  - → **$M \sim 2m_{D_s}$**
  - → **not seen in $Y \to \eta\, J/\psi$ (BaBar, PRL93, 041801)**
  - → **width too large**
  - → **no π exchange for $D_s \bar{D}_s$**

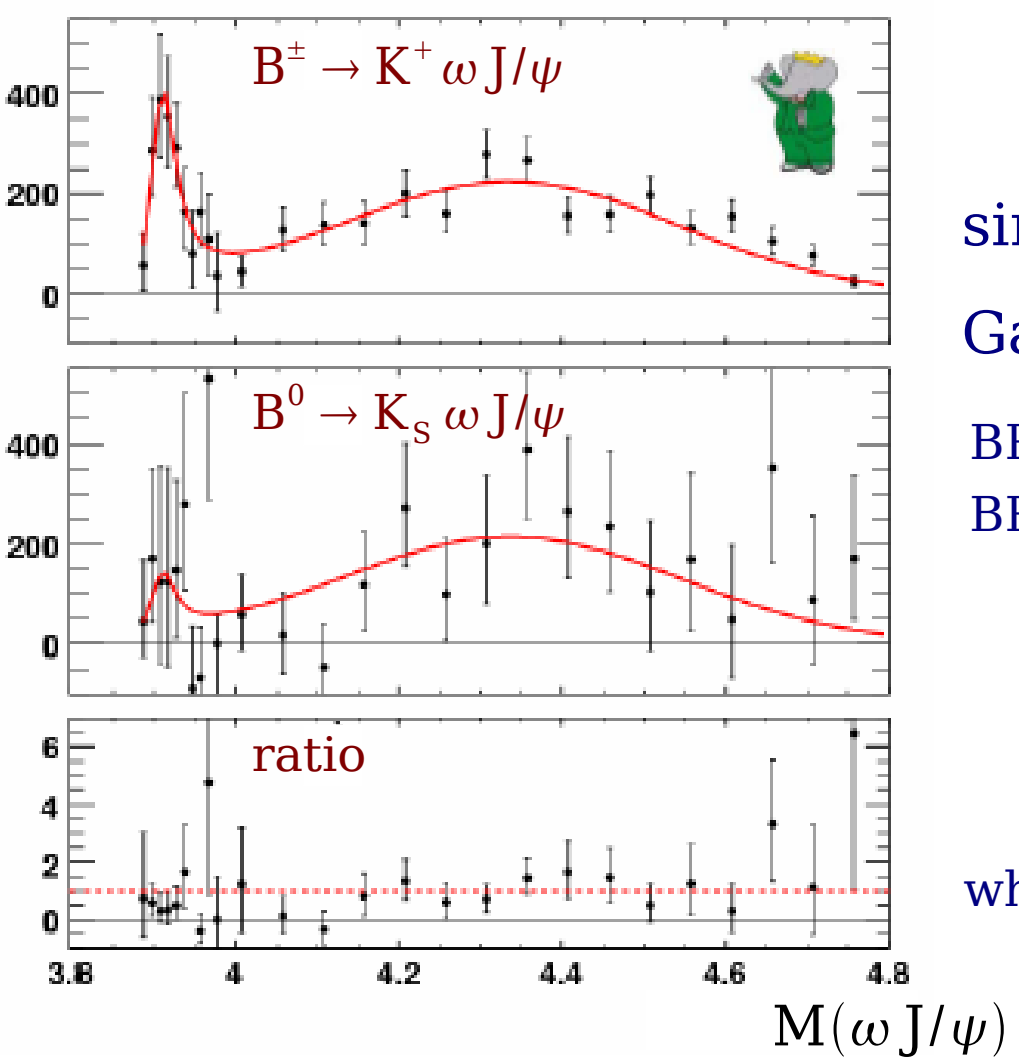


- $c\bar{c}$ gluon hybrid (Horn and Mandula, PRD 17898 (1978))
  - → **predicted by QCD**
  - → **decays to DD and DD^* are suppressed**
  - → **large (hadron + J/ψ) widths predicted**
  - → **but masses expected to be 4.3~4.4 GeV/c^2**



⇒ **least-believed of "XYZ" states...**

Y(3940) confirmed by BaBar !



PRL101,082001(2008)
(348 fb^{-1})

simultaneous B^+ & B^0 fit

Gaussian bkgd + S-wave BW signal

$BR(B^+ \to YK^+,\ Y \to J/\psi\omega) = (4.9^{+1.0}_{-0.9} \pm 0.5) \times 10^{-5}$
$BR(B^+ \to YK^0,\ Y \to J/\psi\omega) = (1.3^{+1.3}_{-1.1} \pm 0.2) \times 10^{-5}$

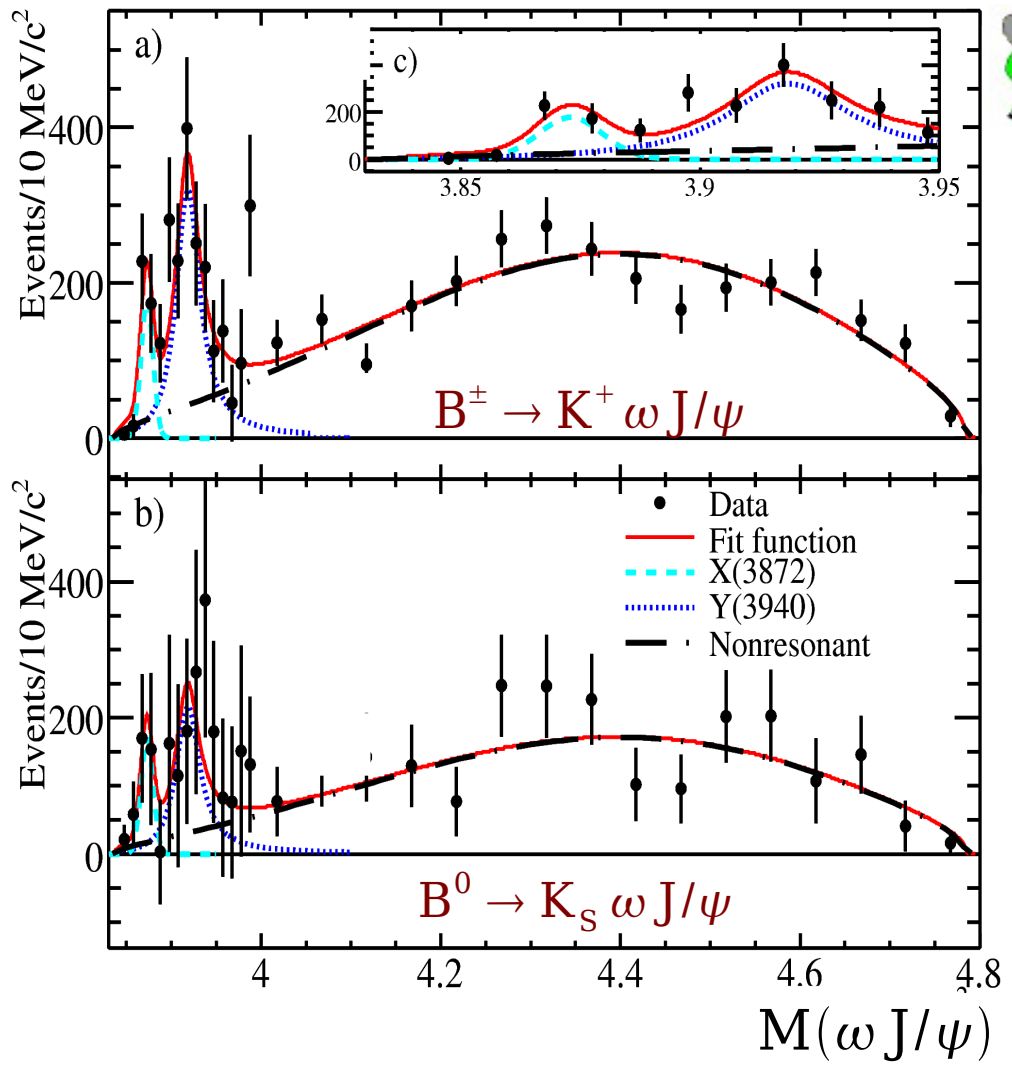
$$\mathbf{R_Y = BR_{B^0}/BR_{B^+} = 0.27^{+0.28+0.04}_{-0.23-0.01}}$$

($\sim 3\,\sigma$ below isospin expectation)

whereas $R_{\text{non res}} = 0.97^{+0.23+0.03}_{-0.22-0.02}$

	M (MeV)	Γ (MeV)
Belle (253 fb^{-1})	$3943 \pm 11 \pm 13$	$87 \pm 22 \pm 26$
BaBar (348 fb^{-1})	$3914.6^{+3.8}_{-3.4} \pm 2.0$	$34^{+12}_{-8} \pm 5$

Y(3940) confirmed by BaBar !



arXiv:1005.5190
(426 fb^{-1})

simultaneous B^+ & B^0 fit

Gaussian bkgd + S-wave BW signal

$BR(B^+ \to YK^+, Y \to J/\psi\,\omega) = (3.0^{+0.7\,+0.5}_{-0.6\,-0.3}) \times 10^{-5}$

$BR(B^+ \to YK^0, Y \to J/\psi\,\omega) = (2.1 \pm 0.9 \pm 0.3) \times 10^{-5}$

$$\mathbf{R_Y = BR_{B^0}/BR_{B^+} = 0.7^{+0.4}_{-0.3} \pm 0.1}$$

(consistent with isospin expectation)

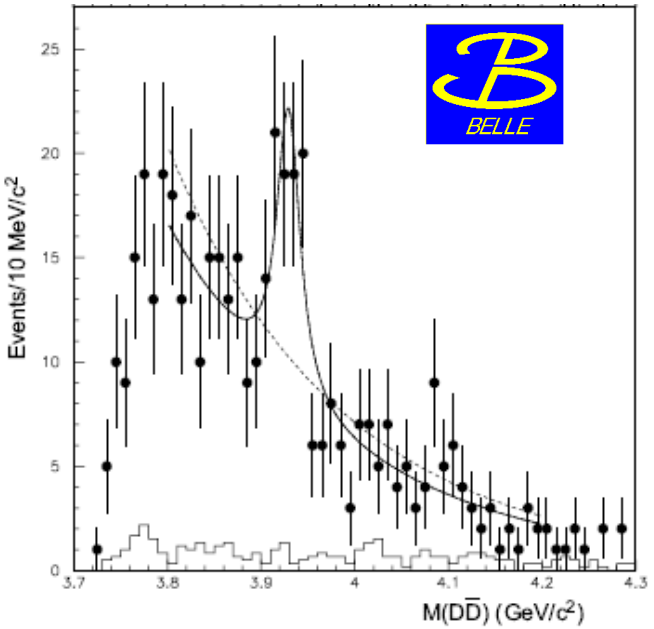
whereas $R_{\text{non res}} = 0.7 \pm 0.1 \pm 0.1$

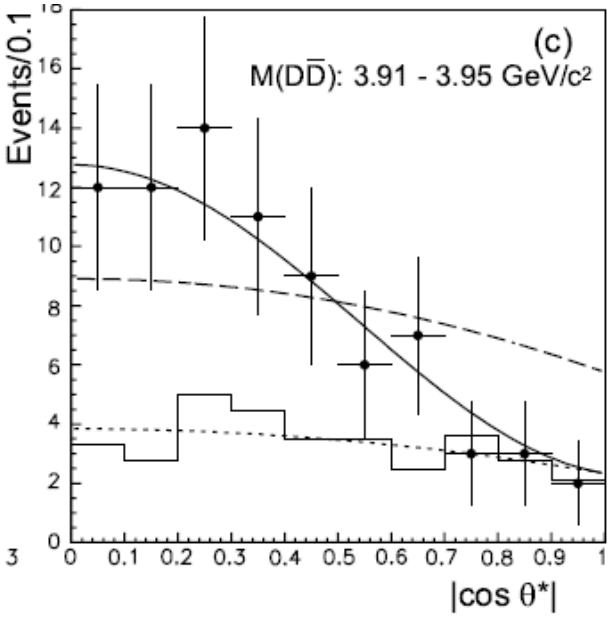
	M (MeV)	Γ (MeV)
Belle (253 fb^{-1})	$3943 \pm 11 \pm 13$	$87 \pm 22 \pm 26$
BaBar (348 fb^{-1})	$3914.6^{+3.8}_{-3.4} \pm 2.0$	$34^{+12}_{-8} \pm 5$
BaBar (426 fb^{-1})	$3919.1^{+3.8}_{-3.4} \pm 2.0$	$31^{+10}_{-8} \pm 5$

Belle has 3 × more statistics, improved efficiency: will update soon !

$\gamma\gamma \to Z(3930) \to D\bar{D}$

PRL96, 082003 (2006)
(395 fb^{-1})



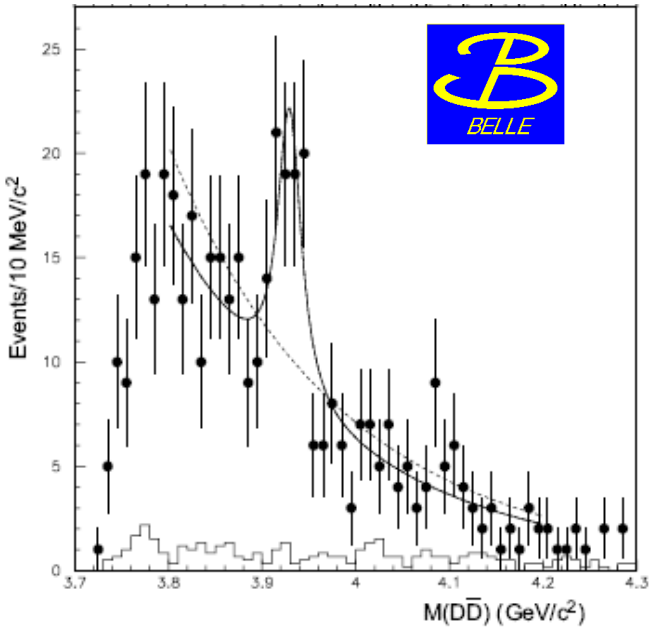


$$M = (3929 \pm 5 \pm 2)\ \mathrm{MeV/c^2}$$
$$\Gamma = (29 \pm 10 \pm 2)\ \mathrm{MeV}$$

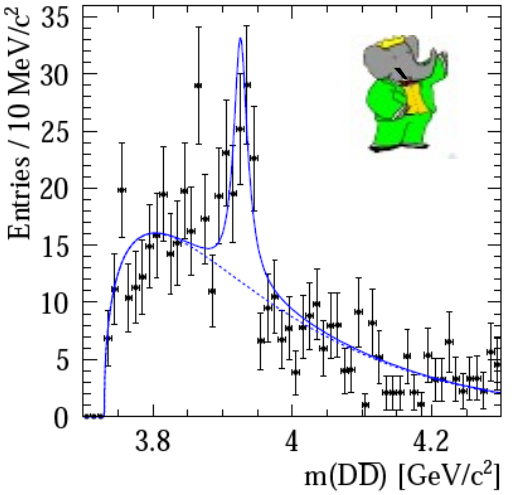
production angle distribution matches well the $\sin^4\theta^*$ behaviour expected for a J=2 meson

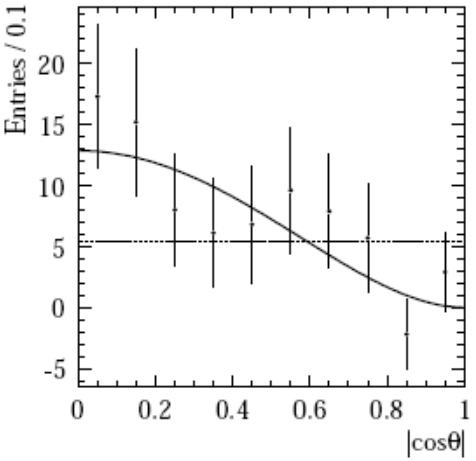
$\gamma\gamma \to Z(3930) \to D\bar{D}$

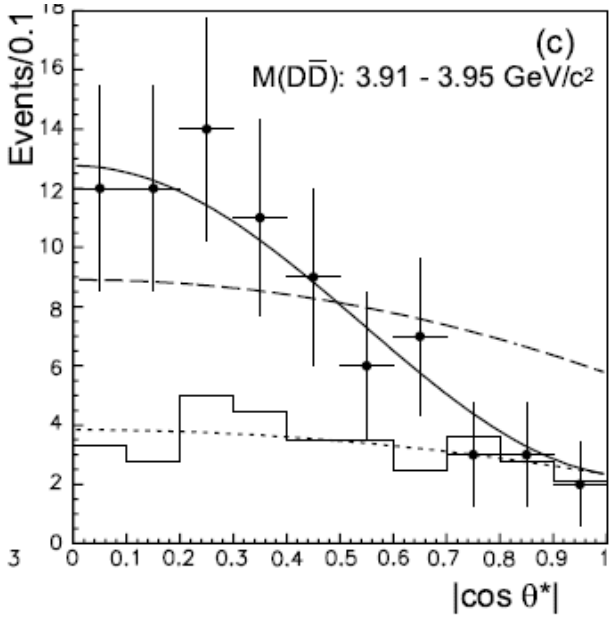
PRL96, 082003 (2006)
(395 fb^{-1})



PRD81, 092003 (2010)
(384 fb^{-1})







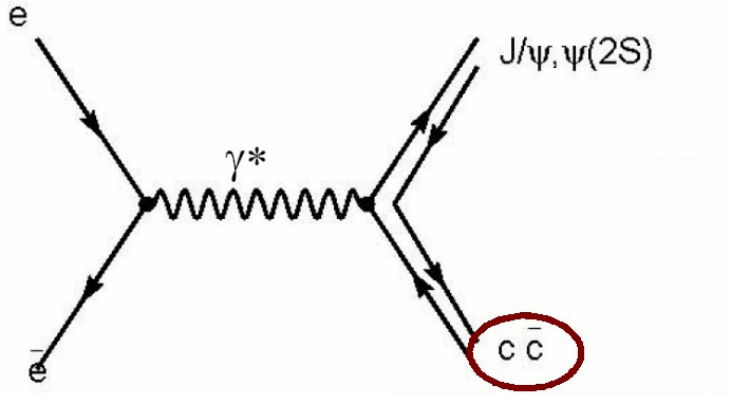
M (MeV/c^2)	Γ (MeV)
(3929±5±2)	(29±10±2)
(3926.7±2.7±1.1)	(21.3±6.8±3.6)

J=2, mass, width and $\gamma\gamma$ production rate

$\Rightarrow$ match well to expectations for the $2^3 P_2$ (χ_{c2}')

Double charmonium production

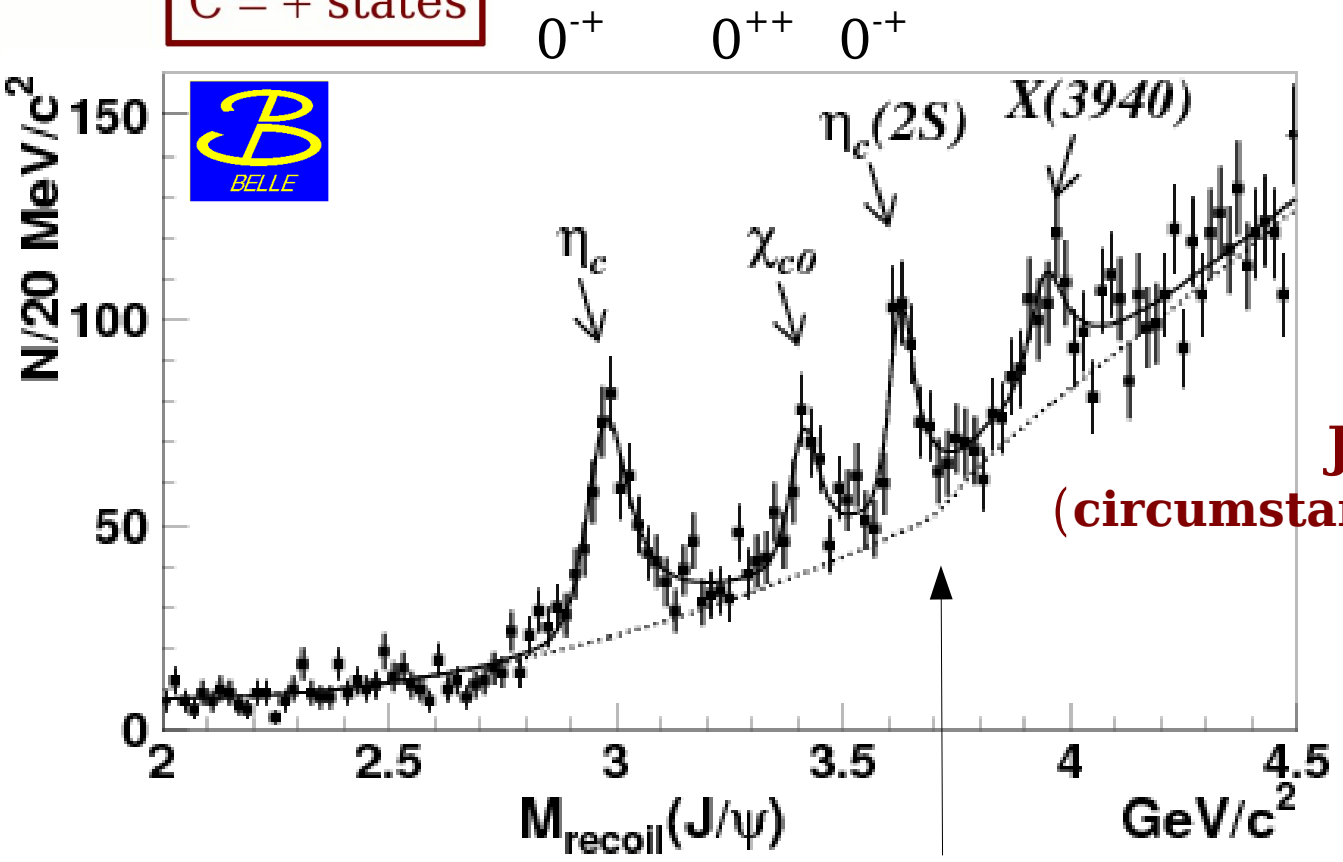
successful approach for producing C = (+) charmonia



$$M_{recoil}(J/\psi) = \sqrt{(E_{CMS} - E^*_{J/\psi})^2 - p^{*\,2}_{J/\psi}}$$

PRL98, 082001 (2007)
(357 fb^{-1})

C = + states



⇒ **X(3940)**

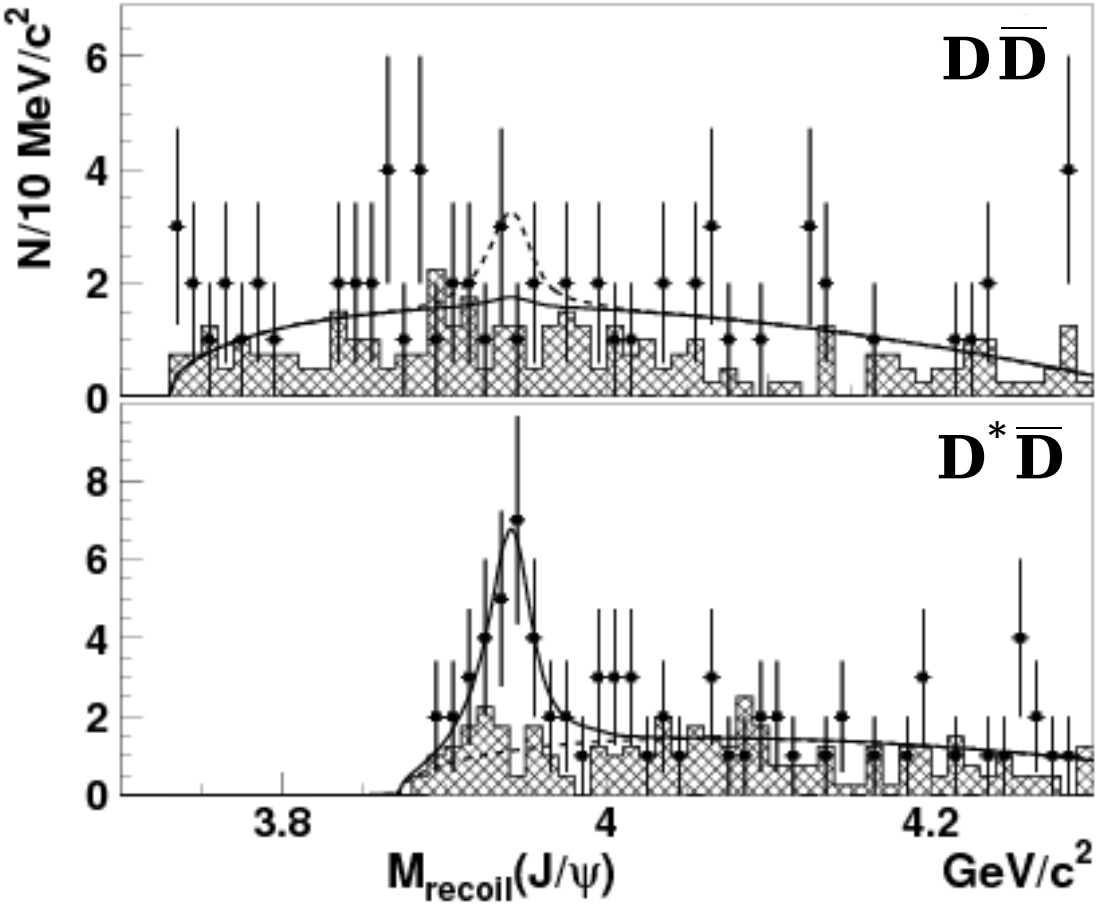
J = 0 ?

(circumstantial evidence ?)

Double charmonium production

Search for $X(3940) \to D\bar{D}$, $D^*\bar{D}$, $J/\psi\omega$ ...

PRL98, 082001 (2007)
(357 fb^{-1})



in addition to fully rec. J/ψ,
one D (or ω) is reconstructed

seen in $D^*\bar{D}$ decay

not seen to decay to $D\bar{D}$
[decay preferred for 0^{++}, forbidden for 0^{-+}]
$\Rightarrow$ unfilled 0^{-+} with closest
expected mass: 3^1S_0 ($\eta_c(3S)$)
...but potential model predicts:
M = 4043 MeV (or higher)

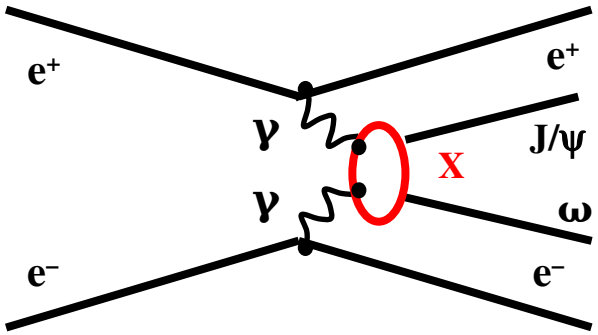
not seen to decay to $J/\psi\omega$

Confirmed later with larger sample (693 fb^{-1}) [PRL100, 202001 (2008)]:

$$\mathbf{M = (3942^{+7}_{-6} \pm 6)\ MeV/c^2}$$
$$\mathbf{\Gamma = (37^{+26}_{-15} \pm 8)\ MeV}$$

$\gamma\gamma \to X(3915) \to J/\psi\,\omega$

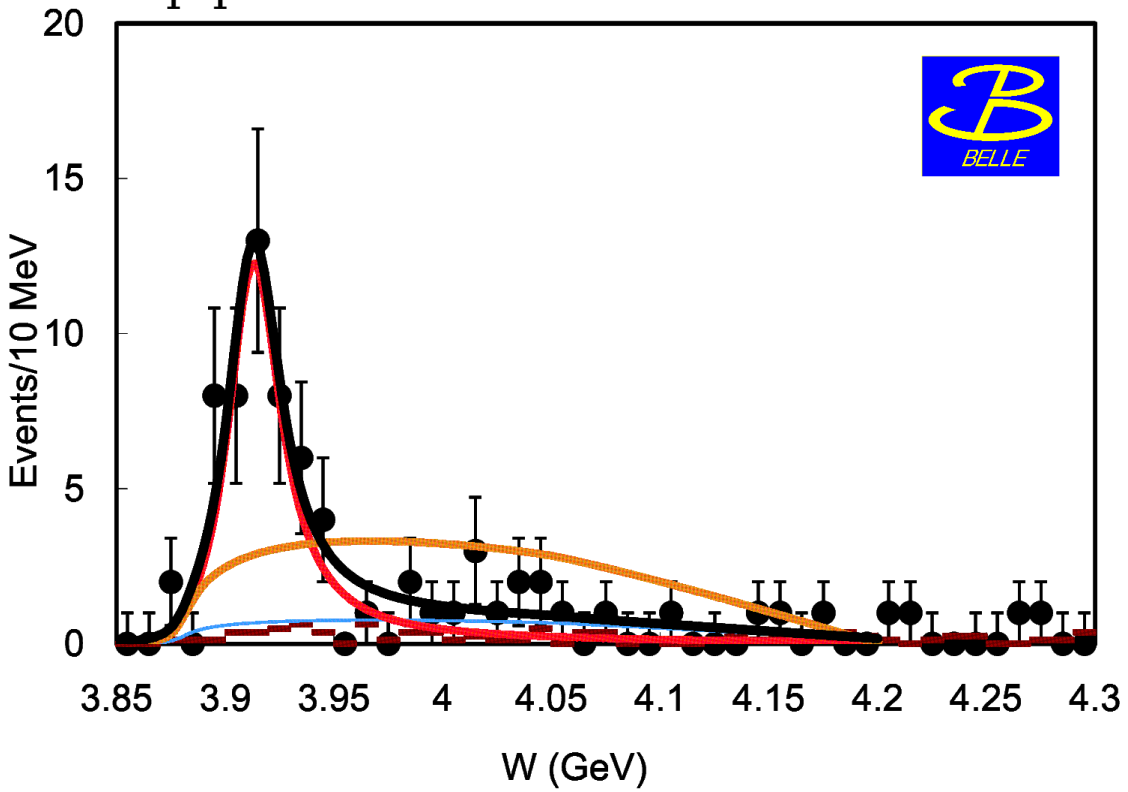
PRL104, 092001 (2010)
(694 fb^{-1})



J = 0, 2 only

sharp peak near threshold and not much else...

$\Sigma = 7.1\sigma$



$M = (3915 \pm 3 \pm 2)\ \mathrm{MeV}/c^2$

$\Gamma = (17 \pm 10 \pm 3)\ \mathrm{MeV}$

$\Gamma_{\gamma\gamma}(Y) \times \mathrm{BR}(Y \to J/\psi\,\omega)$

$= (61 \pm 17 \pm 8)\ \mathrm{eV}$ for $J^P = 0^+$

$= (18 \pm 5 \pm 2)\ \mathrm{eV}$ for $J^P = 2^+$

mass $\sim 2\sigma$ away from Z(3930): two distinct peaks

not different decay channels of same state

4 states around 3940 MeV : different states ?

	Name	Process	M (MeV/c^2)	Γ (MeV)
Belle (253 fb^{-1})	Y(3940)	$B \to J/\psi\,\omega$	$3943 \pm 11 \pm 13$	$87 \pm 22 \pm 26$
BaBar (426 fb^{-1})	Y(3940)	$B \to J/\psi\,\omega$	$3919.1^{+3.8}_{-3.4} \pm 2.0$	$31^{+10}_{-8} \pm 5$
Belle (694 fb^{-1})	X(3915)	$2\gamma \to J/\psi\,\omega$	$3915 \pm 3 \pm 2.0$	$17 \pm 10 \pm 5$
Belle (694 fb^{-1})	X(3940)	$e^+e^- \to J/\psi\,D\bar{D}^*$	$3942^{+7}_{-6} \pm 6$	$37^{+26}_{-15} \pm 8$
Belle (395 fb^{-1})	Z(3930)	$2\gamma \to D\bar{D}$	$3929 \pm 5 \pm 2$	$29 \pm 10 \pm 2$
BaBar (384 fb^{-1})	Z(3930)	$2\gamma \to D\bar{D}$	$3926.7 \pm 2.7 \pm 1.1$	$21 \pm 7 \pm 4$

Q1 : Y(3940)=X(3915) ? same process, no disagreement mass/width
in any case, difficulty with charmonium assignment

Q2 : Y(3940)=X(3940) ?

Y(3940) not found in $D^{*0}\bar{D}^0\,K$ $\quad \dfrac{BR(Y(3940)\to\omega J/\psi)}{BR(Y(3940)\to D^{*0}\bar{D}^0)} > 0.71$ @90 %C.L.

X(3940)$\to J/\psi\,\omega$ not found in $2\times$charmonium prod $\quad \dfrac{BR(X(3940)\to\omega J/\psi)}{BR(X(3940)\to D^{*0}\bar{D}^0)} < 0.58$ @90 %C.L.

$\Rightarrow$ at least 3 states

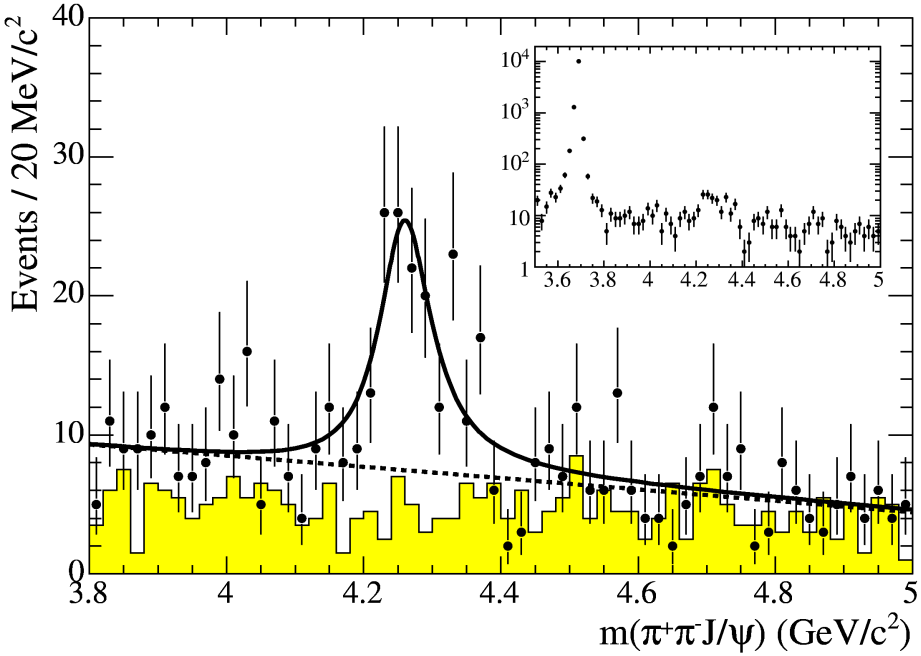
The $Y(J^{PC} = 1^{--})$ family

$Y(4260)$: discovery in $e^+e^- \to \gamma_{ISR}\pi^+\pi^- J/\psi$

when running at $\Upsilon(4S)$: $e^+e^- \to \gamma_{ISR} X$, $E_{\gamma_{ISR}} = 4 \sim 5$ GeV

e^+e^- annihilation occurs in the energy region populated by charmonium states (comparable sensitivity to energy scan (Cleo−c, BES))

PRL95, 142001 (2005)
(233 fb^{-1})



...excess of 125±23 events
centered ~ 4.26 GeV/c^2
signifying the presence of <u>one or more</u>
previously unobserved $J^{PC} = 1^{--}$ states..

$$M = (4259 \pm 8^{+2}_{-6})\ \text{MeV}/c^2$$
$$\Gamma = (88 \pm 23^{+6}_{-4})\ \text{MeV}$$

$$\Gamma_{e^+e^-} \times \text{BR}(Y(4260) \to \pi^+\pi^- J/\psi) = (5.5 \pm 1.0^{+0.8}_{-0.7})\text{eV}/c^2$$

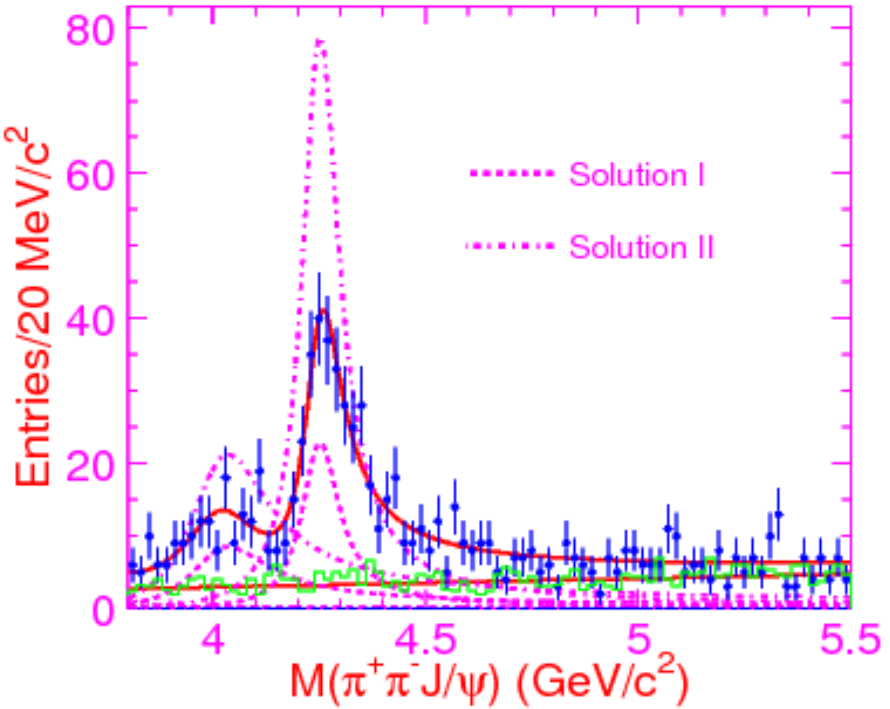
$Y(4260)$: discovery in $e^+e^- \to \gamma_{ISR}\pi^+\pi^- J/\psi$

(also confirmed by Cleo)

2 BW with interference

two solutions: different peak cross-sections

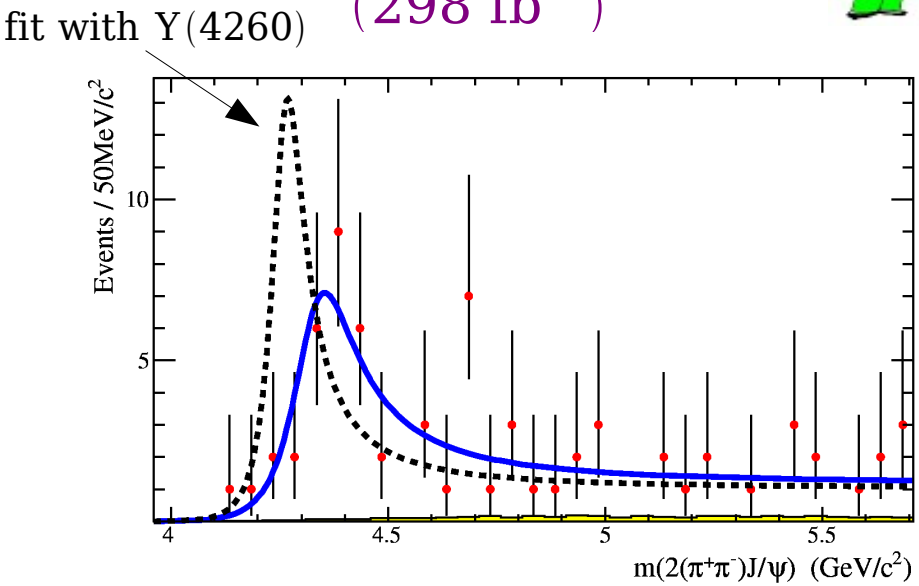
PRL99, 182004 (2007)
(548 fb^{-1})



Parameters	Solution I	Solution II
$M(R1)$	$4008 \pm 40^{+114}_{-28}$	
$\Gamma_{\rm tot}(R1)$	$226 \pm 44 \pm 87$	
$\mathcal{B}\cdot\Gamma_{e^+e^-}(R1)$	$5.0 \pm 1.4^{+6.1}_{-0.9}$	$12.4 \pm 2.4^{+14.8}_{-1.1}$
$M(R2)$	$4247 \pm 12^{+17}_{-32}$	
$\Gamma_{\rm tot}(R2)$	$108 \pm 19 \pm 10$	
$\mathcal{B}\cdot\Gamma_{e^+e^-}(R2)$	$6.0 \pm 1.2^{+4.7}_{-0.5}$	$20.6 \pm 2.3^{+9.1}_{-1.7}$
ϕ	$12 \pm 29^{+7}_{-98}$	$-111 \pm 7^{+28}_{-31}$

more Y discovered in $e^+e^- \to \gamma_{ISR}\pi^+\pi^-\psi(2S)$

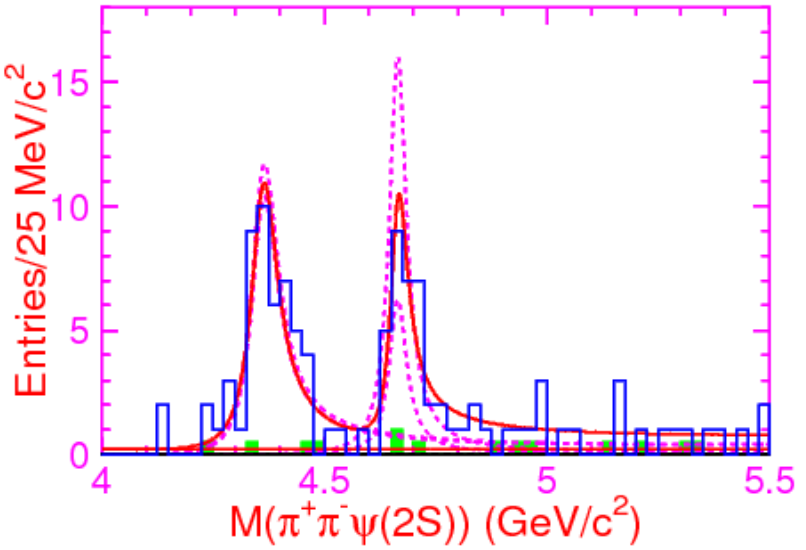
PRL98, 212001 (2007)
(298 fb^{-1})



...a fit to the mass spectrum
with a single resonance yields...

$M = (4324 \pm 24)\ MeV/c^2$
$\Gamma = (172 \pm 33)\ MeV$

PRL99, 142002 (2007)
(673 fb^{-1})



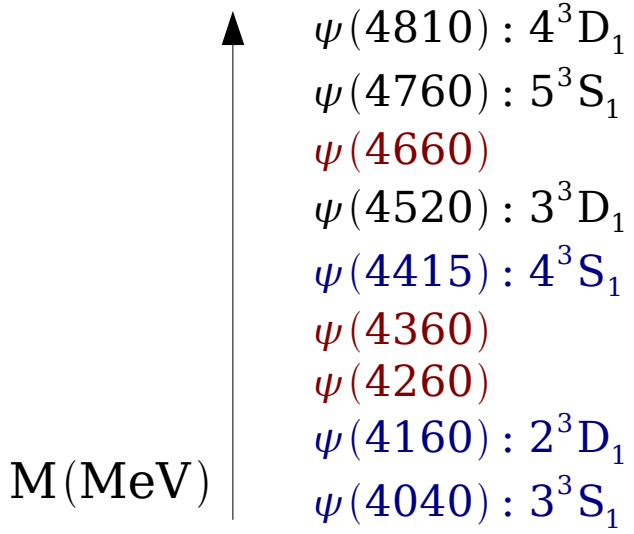
Parameters	Solution I	Solution II
$M(Y(4360))$	$4361 \pm 9 \pm 9$	
$\Gamma_{tot}(Y(4360))$	$74 \pm 15 \pm 10$	
$\mathcal{B} \cdot \Gamma_{e^+e^-}(Y(4360))$	$10.4 \pm 1.7 \pm 1.5$	$11.8 \pm 1.8 \pm 1.4$
$M(Y(4660))$	$4664 \pm 11 \pm 5$	
$\Gamma_{tot}(Y(4660))$	$48 \pm 15 \pm 3$	
$\mathcal{B} \cdot \Gamma_{e^+e^-}(Y(4660))$	$3.0 \pm 0.9 \pm 0.3$	$7.6 \pm 1.8 \pm 0.8$
ϕ	$39 \pm 30 \pm 22$	$-79 \pm 17 \pm 20$

$\Rightarrow$ both structures differ from those in $J/\psi\pi^+\pi^-$

Can $Y(4008)$?, $Y(4260)$, $Y(4360)$, $Y(4660)$ be charmonium states ?

Can these be charmonium states ?

⇒ Only one unassigned 1^{--} charmonium in this mass region
no room for all 3 (4?) peaks



⇒ most popular theoretical explanation : $c\bar{c}$-gluon hybrids

⇒ absence of any corresponding peaking features in the total cross-section for e^+e^- annihilation into hadrons at the same energy

Y(4260)

Ratio	UL, 90% CL
$\mathcal{B}(D\bar{D})/\mathcal{B}(\pi^+\pi^- J/\psi)$	< 1
$\mathcal{B}(D^*\bar{D})/\mathcal{B}(\pi^+\pi^- J/\psi)$	< 34
$\mathcal{B}(D^*\bar{D}^*)/\mathcal{B}(\pi^+\pi^- J/\psi)$	< 40

For the $\psi(3770)$: $B(D\overline{D})/B(\pi^+\pi^- J/\psi) = 440$!

Can these be charmonium hybrids ?

- The lightest hybrid is expected by LQCD around 4.2 GeV
- relevant open-charm threshold for these hybrids are $M_{D^{**}}+M_D$

$\Rightarrow$ search for exclusive $e^+e^- \to D\bar{D}\pi$, $D^*\bar{D}\pi$ via ISR

$D\bar{D}\pi$

see strong signal $\psi(4415)\to D\bar{D}_2^*(2460)$ but no $Y(4260)\to D_0(2400)\bar{D}$

$D^*\bar{D}\pi$

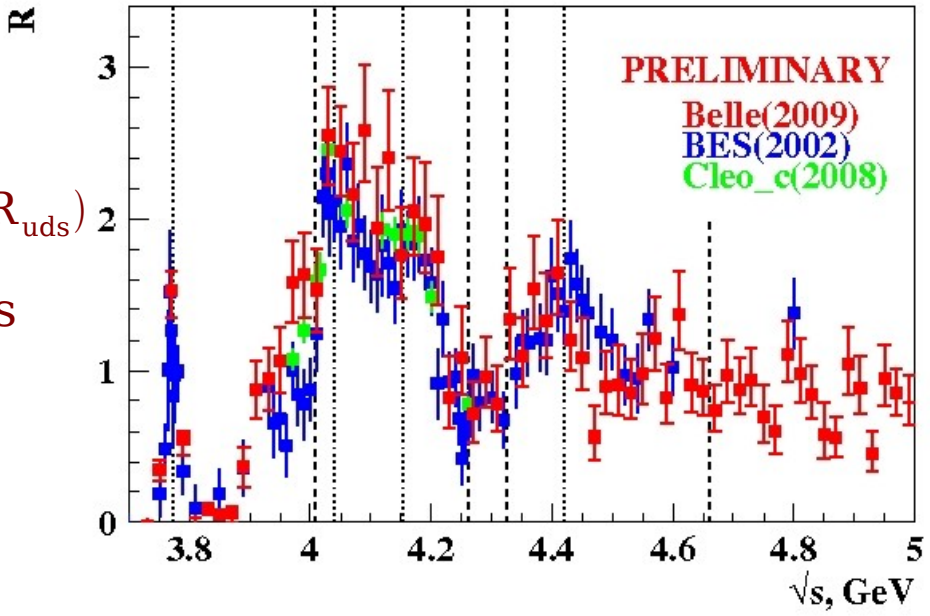
UL at 90% CL	Y(4260)	Y(4350)	Y(4660)
$BR(X\to D^0 D^{*-}\pi^+)/BR(X\to\pi^+\pi^- J/\psi)$	9		
$BR(X\to D^0 D^{*-}\pi^+)/BR(X\to\pi^+\pi^-\psi(2S))$		8	10

Sum of all contributions

DD, DD^*, D^*D^*, $DD\pi$, $DD^*\pi$, $\Lambda_c\Lambda_c$

saturates R $(=\sigma(e^+e^-\to\text{hadrons})/\sigma(e^+e^-\to\mu^+\mu^-)-R_{uds})$

only small room for unaccounted contributions



The charged Z states

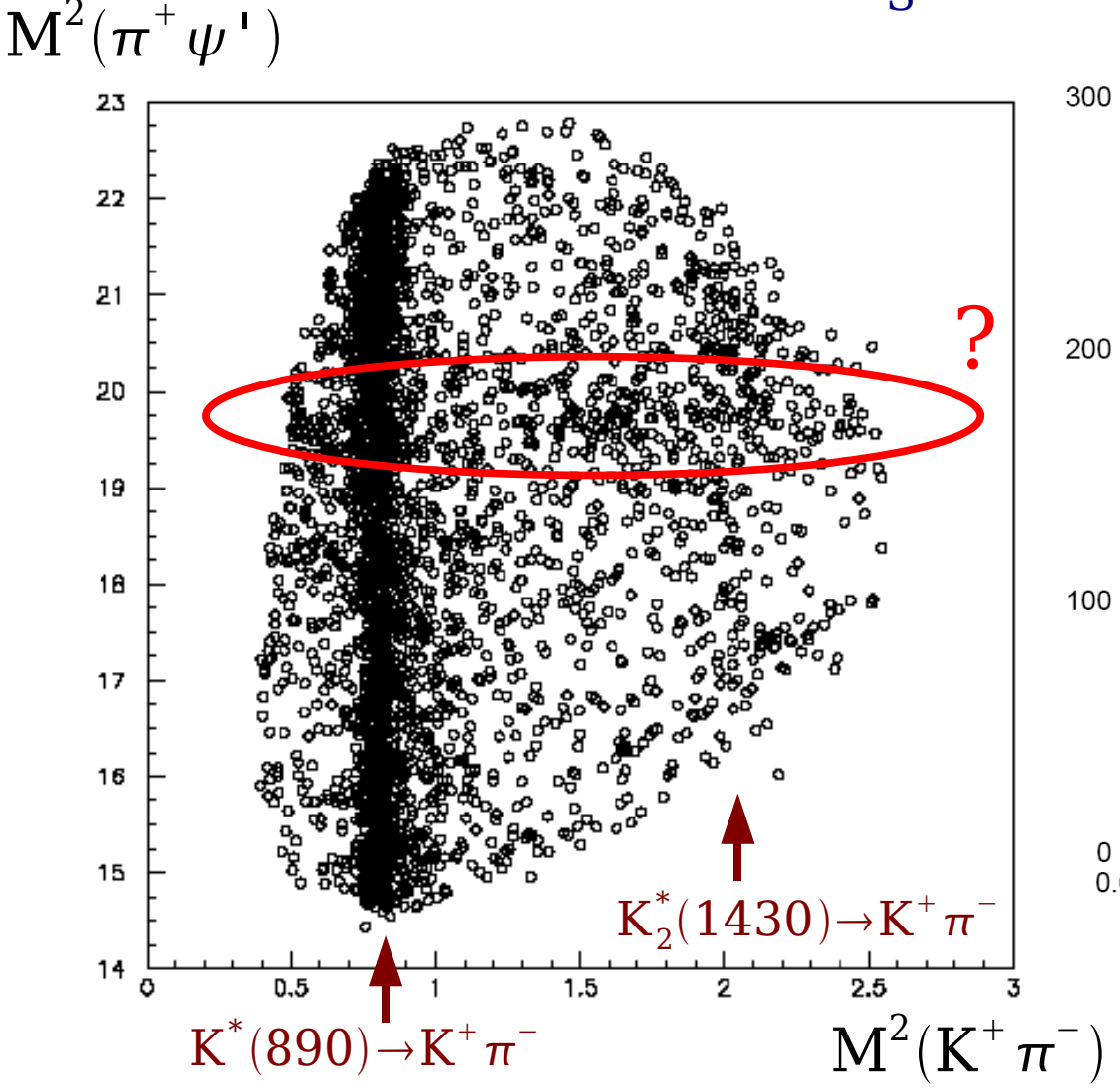
Z(4430): study of $B \to K \pi^+ \psi'$ with 548fb^{-1}

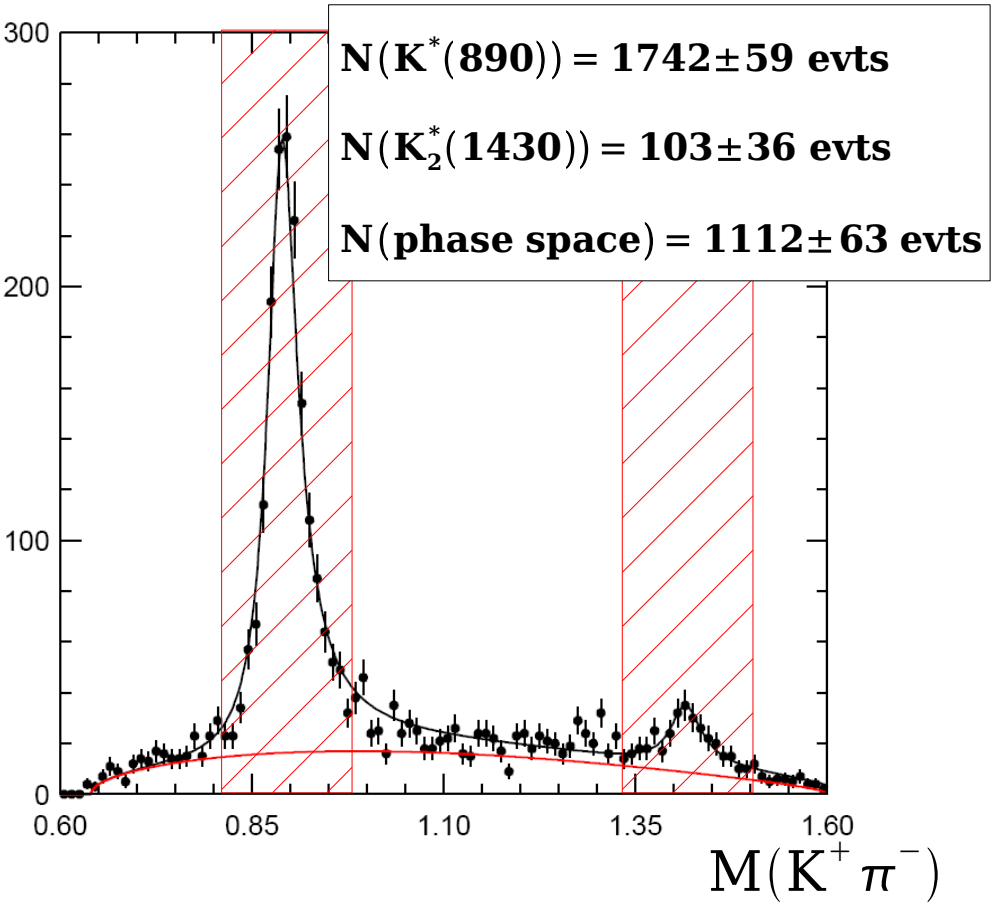
arXiv:0708.1790 [hep-ex]
PRL 100, 142001 (2007)

$\psi' \to e^+ e^-, \mu^+ \mu^-$

$\psi' \to \pi^+ \pi^- J/\psi, J/\psi \to e^+ e^-, \mu^+ \mu^-$

$K = K^{\pm}$ or K^0_S





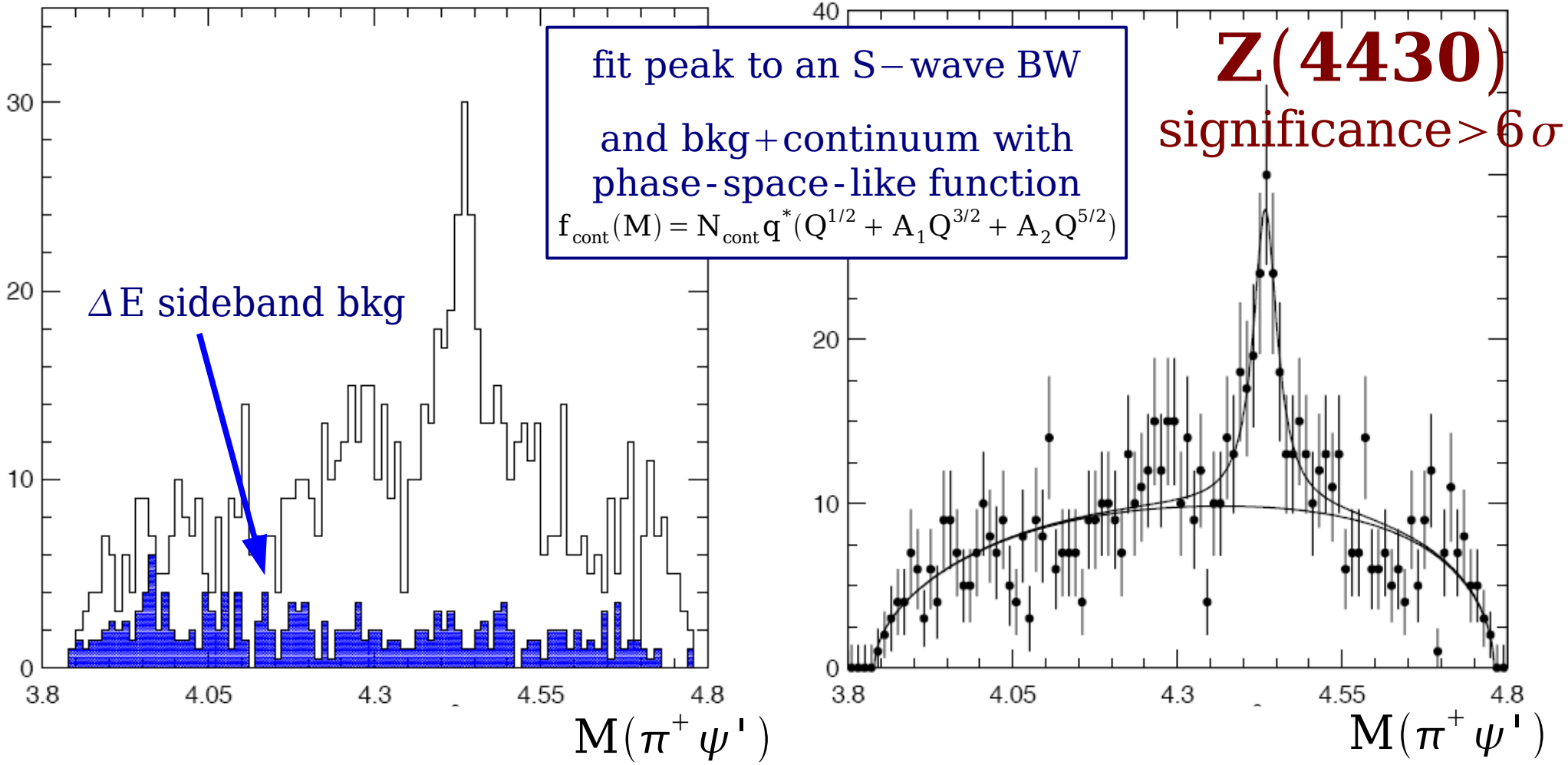
cut out $K^*(890)$ and $K_2^*(1430)$
$\pm$ 100 MeV

After K^* veto, $M(\pi^+\psi')$...

PRL 100, 142001 (2007)

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

$\Gamma = (45\ ^{+18\,+30}_{-13\,-13})$ MeV



$$BR(\bar{B}^0 \to K^- Z^+(4430)) \times BR(Z^+(4430) \to \pi^+ \psi') = (4.1 \pm 1.0 \pm 1.4) \times 10^{-5}$$

Compare data subsamples

Significant signals @ ~4433 MeV in all subsets

Subset	Signal events	Mass (GeV)	Width (GeV)	signif. (σ)	constr. yield ($\Gamma = 0.045$GeV)
$\psi' \to \pi^+\pi^- J/\psi$ (*)	50.2 ± 14.9	4.435 ± 0.004	$0.026^{+0.013}_{-0.008}$	4.5	64.1 ± 14.6
$\psi' \to \ell^+\ell^-$	93.4 ± 29.4	4.435 ± 0.010	$0.094^{+0.042}_{-0.030}$	4.7	58.6 ± 13.4
$J/\psi(\psi') \to e^+e^-$ (**)	46.4 ± 16.0	4.430 ± 0.009	$0.056^{+0.028}_{-0.020}$	3.5	41.2 ± 11.6
$J/\psi(\psi') \to \mu^+\mu^-$ (**)	73.4 ± 22.6	4.434 ± 0.004	$0.038^{+0.023}_{-0.013}$	5.2	80.3 ± 16.2
$\pi^-\psi'$	109.8 ± 35.8	4.437 ± 0.008	0.081 ± 0.030	5.0	73.3 ± 15.5
$\pi^+\psi'$	41.4 ± 13.7	4.430 ± 0.004	0.025 ± 0.012	4.0	53.7 ± 13.5
$K^\pm\pi^\mp\psi'$ (***)	105.7 ± 26.3	4.434 ± 0.005	$0.048^{+0.019}_{-0.014}$	6.0	102.4 ± 18.1
$K_S\pi^\mp\psi'$ (***)	19.1 ± 8.0	4.430 ± 0.009	0.048-fixed	2.0	18.5 ± 8.1
vary K^* veto (****)	207.9 ± 49.4	4.437 ± 0.005	$0.063^{+0.024}_{-0.017}$	7.1	169.8 ± 25.6

(*) MC-determined acceptance ratio of $\pi^+\pi^-$ J/ψ/l^+l^- is 1.23

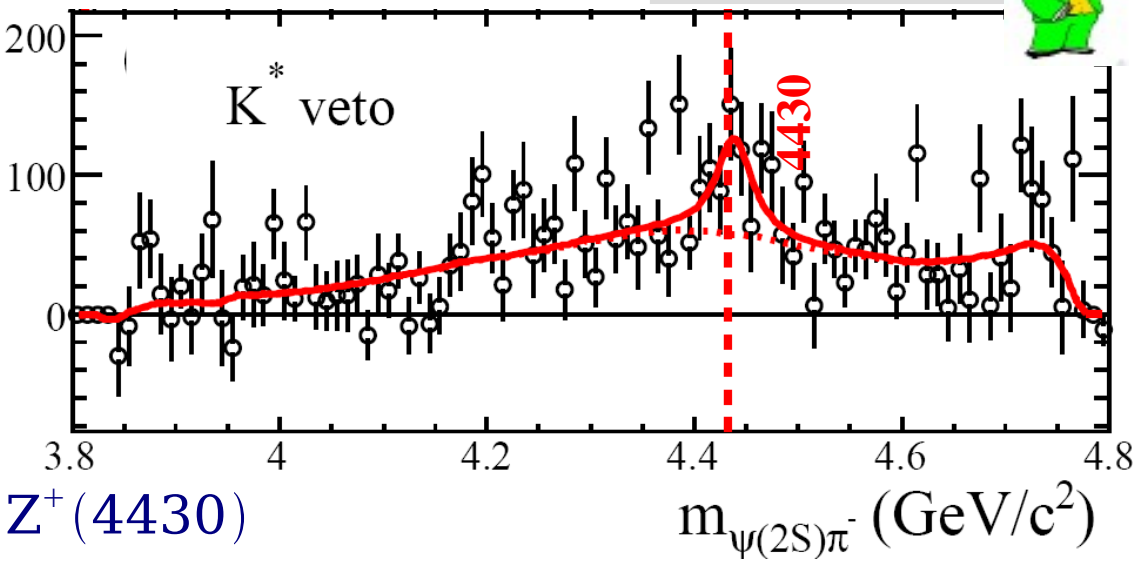
(**) expected $e^+e^-/\mu^+\mu^-$ acceptance ratio of 0.61

(***) K_S/K^+ acceptance ratio is 0.19

(****) $|M(K\pi) - m_{K^*(890)}| \geq 0.05$ GeV

BaBar's search for Z(4430)

PRD79:112001 (2009)



performed detailed analysis of the $K\pi^-$ system, corrected for efficiency, included S, P and D waves

$\Rightarrow$ no conclusive evidence for the $Z^+(4430)$

$BR(\bar{B}^0 \to K^- Z^+) \times BR(Z^+ \to \pi^+ \psi') < 3.1 \times 10^{-5}$ @ 95% C.L.

Belle's analysis using Dalitz fit

Fit $B^0 \to \psi(2S)\pi^+ K^-$ amplitude by coherent sum of RBW contributions

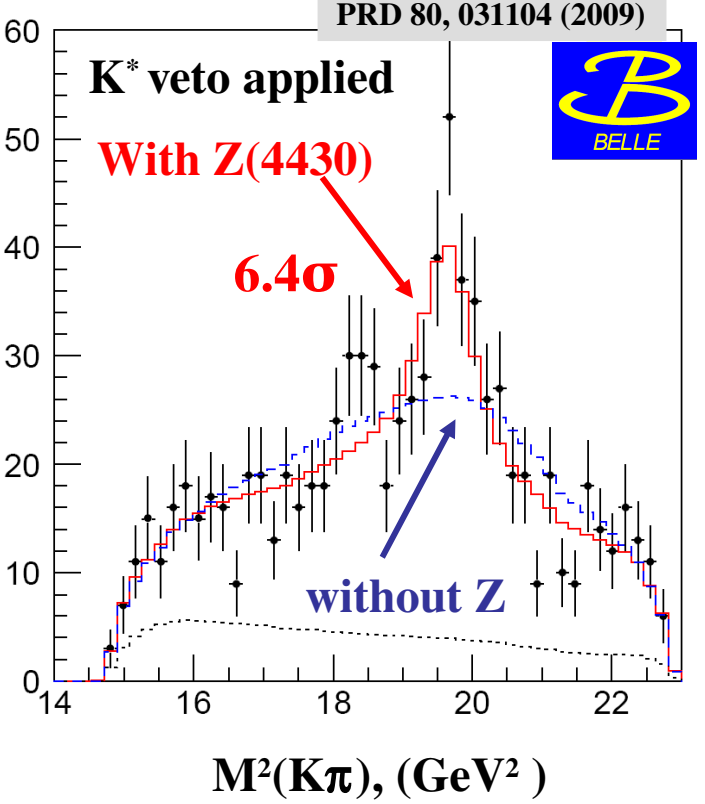
- all known $K\pi$ resonances
- all known $K\pi$ resonances + Z

$$\mathbf{M = (4443\,^{+15\ +17}_{-12\ -13})\ MeV}$$

$$\mathbf{\Gamma = (109\,^{+86+57}_{-43-52})\ MeV}$$

$BR(\bar{B}^0 \to K^- Z^+) \times BR(Z^+ \to \pi^+ \psi') = (3.2^{+1.8+5.3}_{-0.9-1.6}) \times 10^{-5}$

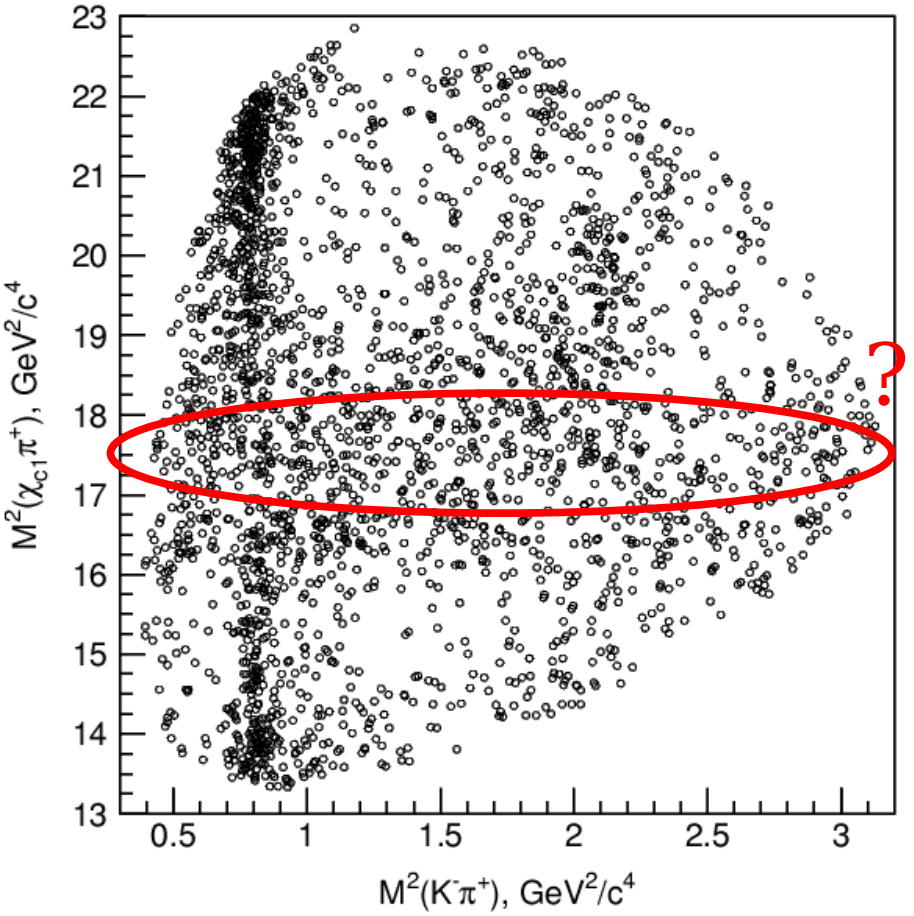
PRD 80, 031104 (2009)



$\overline{B}^0 \to K^- \pi^+ \chi_{c1}$

PRD80, 031104 (2009)

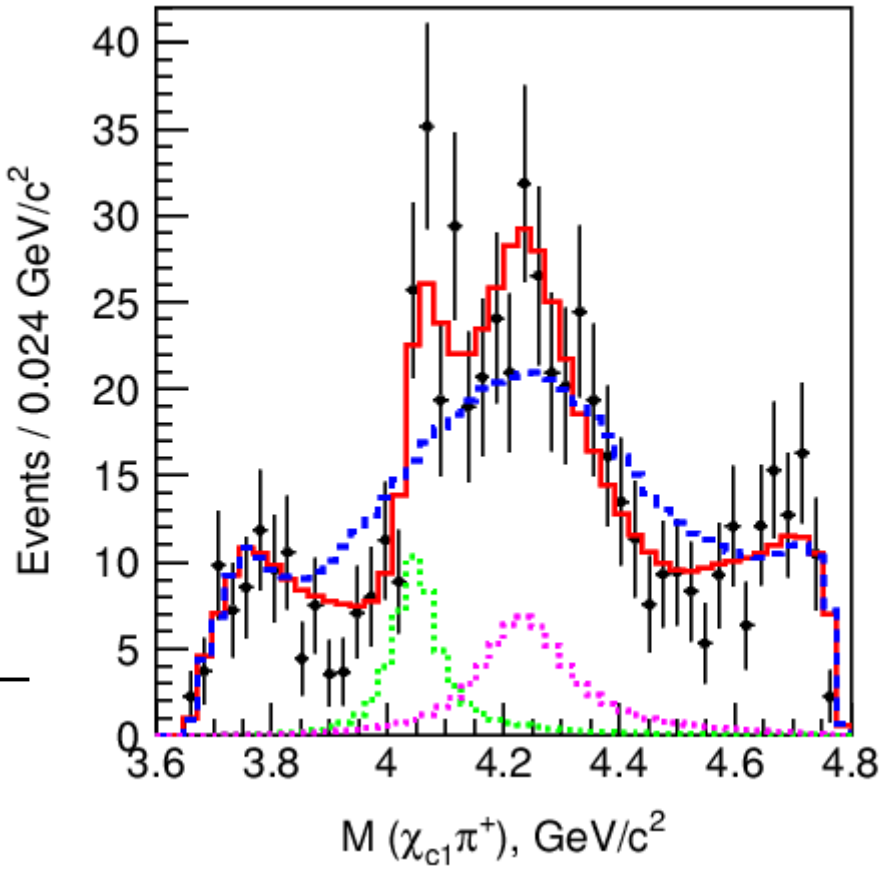
- $605\,\mathrm{fb}^{-1}$: 657×10^6 $B\overline{B}$
- recon $\overline{B}^0 \to K^- \pi^+ \chi_{c1}$ + c.c.
  - $\chi_{c1} \to \gamma\, J/\psi$
  - $J/\psi \to l^+ l^- = e^+ e^-,\ \mu^+ \mu^-$
  - mass-constrained fit to both
- selection:
  - $M_{bc} \in [5275, 5287]$ MeV, $|\Delta E| < 12$ MeV
  - ΔE sidebands for bkgd estimation
  - constrained fit to m_B
  - $\epsilon = (20.0 \pm 1.4)\%$
  - $2125 \pm 56 \pm 42$ candidates
- Dalitz $(M^2(K^- \pi^+),\ M^2(\chi_{c1} \pi^+))$
  - vertical band for $K^*(892)^+ \chi_{c1}$
  - horizontal band $M^2(\chi_{c1} \pi^+) \simeq 17$ GeV
- isobar model: $\pi^+ \chi_{c1}$ exotic resonance + known $K^- \pi^+$
  - $(\kappa,\ K^*(892),\ K^*(1410),\ K_0^*(1430),\ K_2^*(1430),\ K^*(1680),\ K_3^*(1780))$



$\overline{B}^0 \to K^- \pi^+ \chi_{c1}$ summary of Dalitz analysis

PRD80, 031104 (2009)

- very poor fit using known states
- exotic $Z^+ \to \pi^+ \chi_{c1}$ needed
- $> 6\sigma$ even under speculative changes to the fitting model
- two terms preferred at $> 5\sigma$



	Z_1^+	Z_2^+
M (MeV)	$4051 \pm 14^{+20}_{-41}$	$4248^{+44+180}_{-29-35}$
Γ (MeV)	82^{+21+47}_{-17-22}	$177^{+54+316}_{-39-61}$
$B_{\overline{B}^0} \times B_{Z^+}$ ($\times 10^{-5}$)	$(3.1^{+1.5+3.7}_{-0.9-1.7})$	$(4.0^{+2.3+19.7}_{-0.9-0.5})$

Z_1^+, Z_2^+ join $Z(4430)^+$ as candidate hidden-charm exotics

Many new $c\bar{c}$-like states decaying to $c\bar{c}X$ rather than to open charm were unexpectedly found

From some there is no place in $c\bar{c}$ spectrum

Table I Summary of the Charmonium-like XYZ states.

From S.Godfrey (arXiv:0910.3409)

state	M (MeV)	Γ (MeV)	J^{PC}	Seen In	Observed by:	Comments
$Y_s(2175)$	2175 ± 8	58 ± 26	1^{--}	$(e^+e^-)_{ISR}, J/\psi \to Y_s(2175) \to \phi f_0(980)$	BaBar, BESII, Belle	
$X(3872)$	3871.4 ± 0.6	< 2.3	1^{++}	$B \to KX(3872) \to \pi^+\pi^- J/\psi, \gamma J/\psi$, $D\bar{D}^*$	Belle, CDF, D0, BaBar	Molecule?
$X(3915)$	3914 ± 4	28^{+12}_{-14}	$?^{++}$	$\gamma\gamma \to \omega J/\psi$	Belle	
$Z(3930)$	3929 ± 5	29 ± 10	2^{++}	$\gamma\gamma \to Z(3940) \to D\bar{D}$	Belle	$2^3P_2(c\bar{c})$
$X(3940)$	3942 ± 9	37 ± 17	$0^{?+}$	$e^+e^- \to J/\psi X(3940) \to D\bar{D}^*$ (not $D\bar{D}$ or $\omega J/\psi$)	Belle	$3^1S_0(c\bar{c})$?
$Y(3940)$	3943 ± 17	87 ± 34	$?^{?+}$	$B \to KY(3940) \to \omega J/\psi$ (not $D\bar{D}^*$)	Belle, BaBar	$2^3P_1(c\bar{c})$?
$Y(4008)$	4008^{+82}_{-49}	226^{+97}_{-80}	1^{--}	$(e^+e^-)_{ISR} \to Y(4008) \to \pi^+\pi^- J/\psi$	Belle	
$Y(4140)$	4143 ± 3.1	$11.7^{+9.1}_{-6.2}$	$?^{?}$	$B \to KY(4140) \to J/\psi\phi$	CDF	
$X(4160)$	4156 ± 29	139^{+113}_{-65}	$0^{?+}$	$e^+e^- \to J/\psi X(4160) \to D^*\bar{D}^*$ (not $D\bar{D}$)	Belle	
$Y(4260)$	4264 ± 12	83 ± 22	1^{--}	$(e^+e^-)_{ISR} \to Y(4260) \to \pi^+\pi^- J/\psi$	BaBar, CLEO, Belle	Hybrid?
$Y(4350)$	4324 ± 24	172 ± 33	1^{--}	$(e^+e^-)_{ISR} \to Y(4350) \to \pi^+\pi^- \psi'$	BaBar	
$Y(4350)$	4361 ± 13	74 ± 18	1^{--}	$(e^+e^-)_{ISR} \to Y(4350) \to \pi^+\pi^- \psi'$	Belle	
$Y(4630)$	$4634^{+9.4}_{-10.6}$	92^{+41}_{-32}	1^{--}	$(e^+e^-)_{ISR} \to Y(4630) \to \Lambda_c^+\Lambda_c^-$	Belle	
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$(e^+e^-)_{ISR} \to Y(4660) \to \pi^+\pi^- \psi'$	Belle	
$Z_1(4050)$	4051^{+24}_{-23}	82^{+51}_{-29}	$?$	$B \to KZ_1^{\pm}(4050) \to \pi^{\pm}\chi_{c1}$	Belle	
$Z_2(4250)$	4248^{+185}_{-45}	177^{+320}_{-72}	$?$	$B \to KZ_2^{\pm}(4250) \to \pi^{\pm}\chi_{c1}$	Belle	
$Z(4430)$	4433 ± 5	45^{+35}_{-18}	$?$	$B \to KZ^{\pm}(4430) \to \pi^{\pm}\psi'$	Belle	
$Y_b(10890)$	$10,890 \pm 3$	55 ± 9	1^{--}	$e^+e^- \to Y_b \to \pi^+\pi^- \Upsilon(1,2,3S)$	Belle	

X(3872)

- narrow and right at $m_{D^0}+m_{D^{*0}}$
- seen in $D^0\overline{D}^0\pi^0$, $J/\psi\pi^+\pi^-$, $J/\psi\omega$, $J/\psi\gamma$, not seen in $\psi(2S)\gamma$
- $C=+1$ well established, $J^{PC}=1^{++}$ seems likely

$\Rightarrow$ no charmonium candidate, so what is it ? tetraquark, molecule,... ?

Y(3940)

- seen in $J/\psi\omega$ $\Rightarrow$ no obvious charmonium assignment, $c\bar{c}$-gluon hybrid ?

$Y(J^{PC}=1^{--})$

- seen in $J/\psi\pi^+\pi^-$, $\psi(2S)\pi^+\pi^-$ $\Rightarrow$ no obvious assignment

$Z(4430)$, Z_1, Z_2

- significant $\pi^+\psi'(\chi_{c1})$ invariant mass peak (in $B\to K\pi^+\psi'(\chi_{c1})$ decays)
- not produced by interference effects in $K\pi$ system

$\Rightarrow$ non-zero charge: not $c\bar{c}$ or hybrid

→ **need more experimental inputs**

(updates, precise measurements (J^{PC} for Z), new decays...)

→ **...and suggestions from theorists !**

$B^0 \to X(3872) K^+ \pi^-$

Motivation :

Charmonium modes

Γ_{143}	$\eta_c K^0$	$(9.9 \pm 1.9) \times 10^{-4}$		
Γ_{144}	$\eta_c K^*(892)^0$	$(1.6 \pm 0.7) \times 10^{-3}$		
Γ_{145}	$J/\psi(1S) K^0$	$(8.72 \pm 0.33) \times 10^{-4}$		
Γ_{146}	$J/\psi(1S) K^+ \pi^-$	$(1.2 \pm 0.6) \times 10^{-3}$		
Γ_{147}	$J/\psi(1S) K^*(892)^0$	$(1.33 \pm 0.06) \times 10^{-3}$		
Γ_{169}	$\psi(2S) K^0$	$(6.2 \pm 0.6) \times 10^{-4}$		
Γ_{170}	$\psi(2S) K^+ \pi^-$	$< 1 \times 10^{-3}$	CL=90%	
Γ_{171}	$\psi(2S) K^*(892)^0$	$(7.2 \pm 0.8) \times 10^{-4}$		
Γ_{176}	$\chi_{c1}(1P) K^0$	$(3.9 \pm 0.4) \times 10^{-4}$		
Γ_{177}	$\chi_{c1}(1P) K^*(892)^0$	$(3.2 \pm 0.6) \times 10^{-4}$		
Γ_{149}	$J/\psi(1S) K^+$	$(1.007 \pm 0.035) \times 10^{-3}$		
Γ_{163}	$J/\psi(1S) K^*(892)^+$	$(1.41 \pm 0.08) \times 10^{-3}$		
Γ_{175}	$\psi(2S) K^+$	$(6.48 \pm 0.35) \times 10^{-4}$		
Γ_{176}	$\psi(2S) K^*(892)^+$	$(6.7 \pm 1.4) \times 10^{-4}$		S=1.3
Γ_{187}	$\chi_{c1}(1P) K^+$	$(4.9 \pm 0.5) \times 10^{-4}$		S=1.5
Γ_{188}	$\chi_{c1}(1P) K^*(892)^+$	$(3.6 \pm 0.9) \times 10^{-4}$		

$BR(J/\psi K^0) \sim BR(J/\psi K^+) \sim BR(J/\psi K^{*0}) \sim BR(J/\psi K^{*+})$

$BR(\psi(2S) K^0) \sim BR(\psi(2S) K^+) \sim BR(\psi(2S) K^{*0}) \sim BR(\psi(2S) K^{*+})$

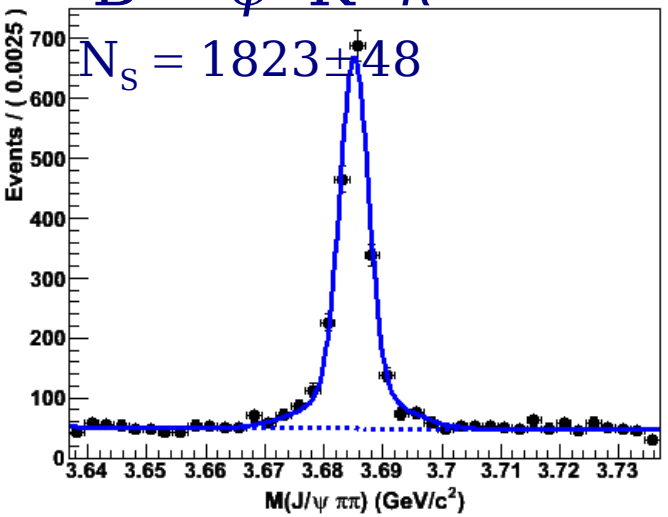
$BR(\chi_{c1} K^0) \sim BR(\chi_{c1} K^+) \sim BR(\chi_{c1} K^{*0}) \sim BR(\chi_{c1} K^{*+})$

$B^0 \to X(3872) K^+ \pi^-$

BELLE-CONF-0849
NEW RESULTS !

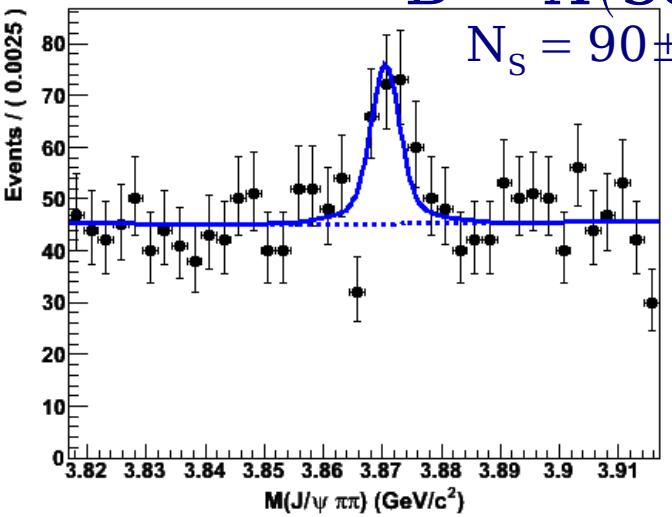
$B^0 \to \psi' K^+ \pi^-$

$N_S = 1823 \pm 48$



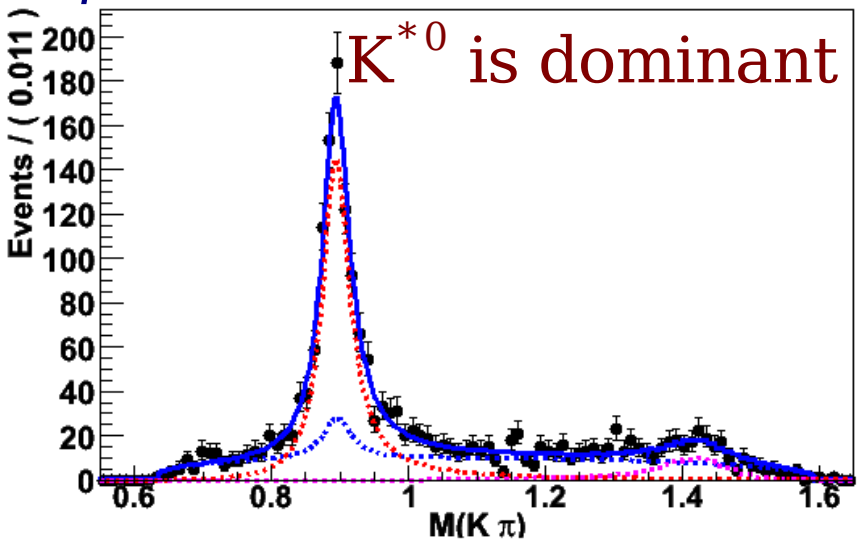
$B^0 \to X(3872) K^+ \pi^-$

$N_S = 90 \pm 19$



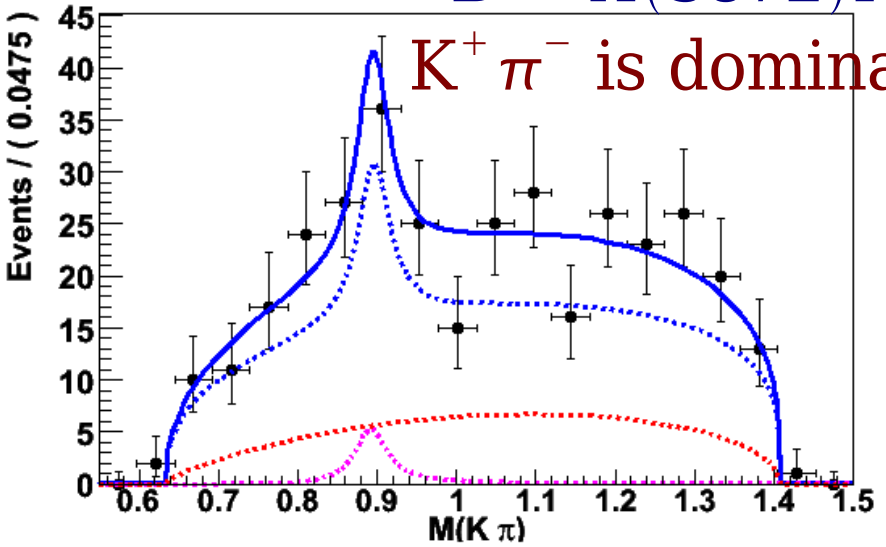
$B^0 \to \psi' K^+ \pi^-$

K^{*0} is dominant



$B^0 \to X(3872) K^+ \pi^-$

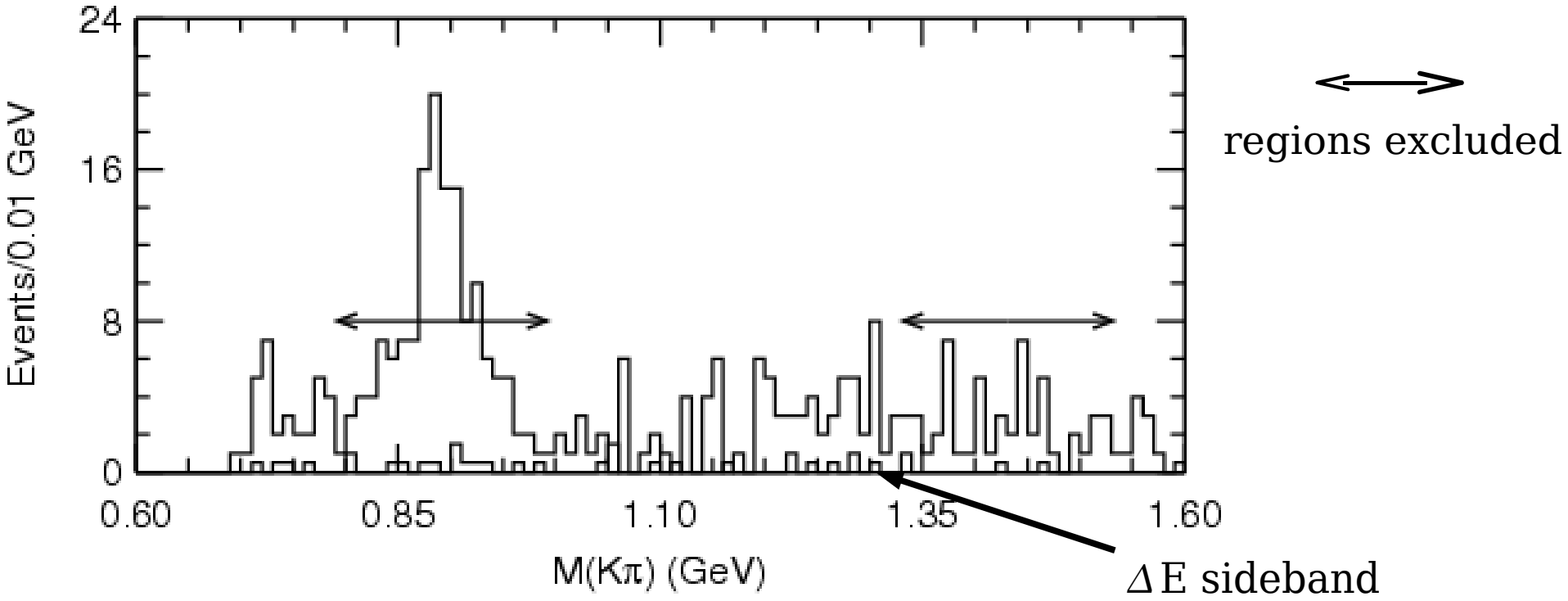
$K^+ \pi^-$ is dominant !



$$\mathbf{BR(B^0 \to X(3872)(K^+\pi^-)_{NR}) \times BR(X \to J/\psi \pi^+\pi^-) = (8.1 \pm 2.0^{+1.1}_{-1.4}) \times 10^{-6}}$$

$$BR(B^0 \to X(3872) K^{*0}) \times BR(X \to J/\psi \pi^+\pi^-) < 3.4 \times 10^{-6} \ (90\% \text{ C.L.})$$

M(Kπ) for events within $\pm$0.03 GeV of the 4.43 GeV peak



$\rightarrow$ no dramatic features are evident (aside $K^*(890)$ evts vetoed)

$\overline{B}^0 \to K^- \pi^+ \chi_{c1}$

arXiv:0806.4098 [hep-ex]
submitted to PRD

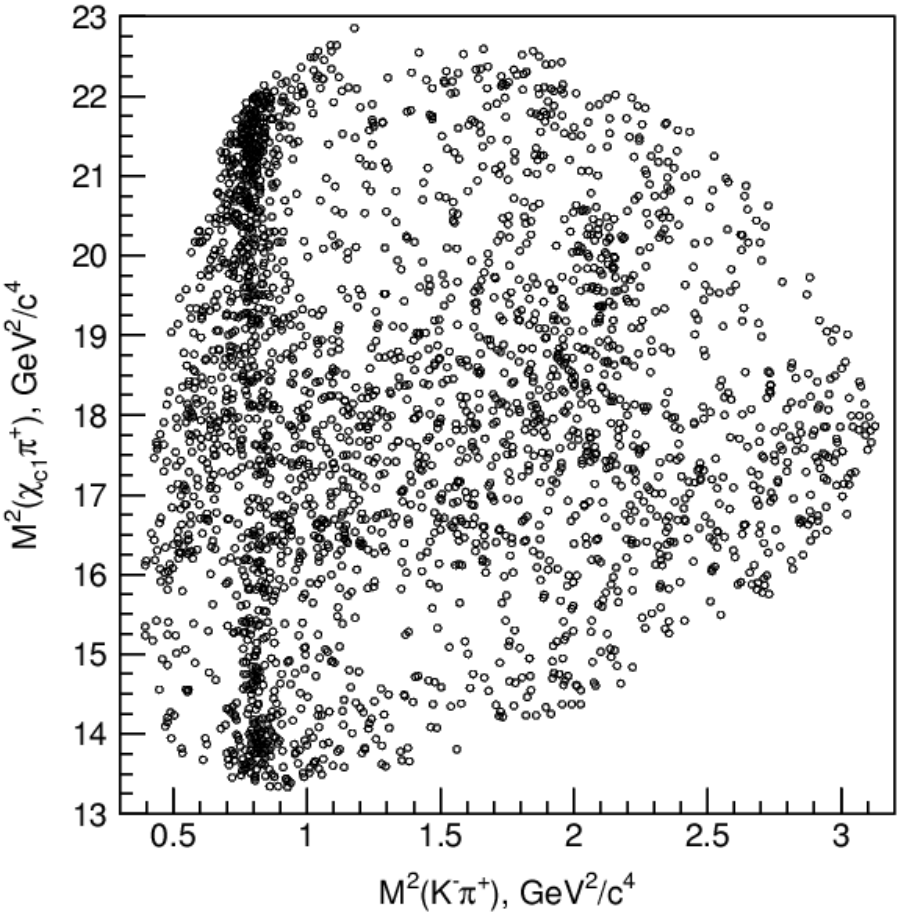
- integration over angular quantities $\cos\theta_{\chi_{c1}}$, $\phi_{\chi_{c1}}$, $\cos\theta_{J/\psi}$, $\phi_{J/\psi}$:

  efficiency almost uniform...
  distributions studied as cross-check after the fit

- binned likelihood fit
  (small bins: fully-contained subset of 400×400)

- $F(s_x, s_y) = S(s_x, s_y) \times \epsilon(s_x, s_y) + B(s_x, s_y)$

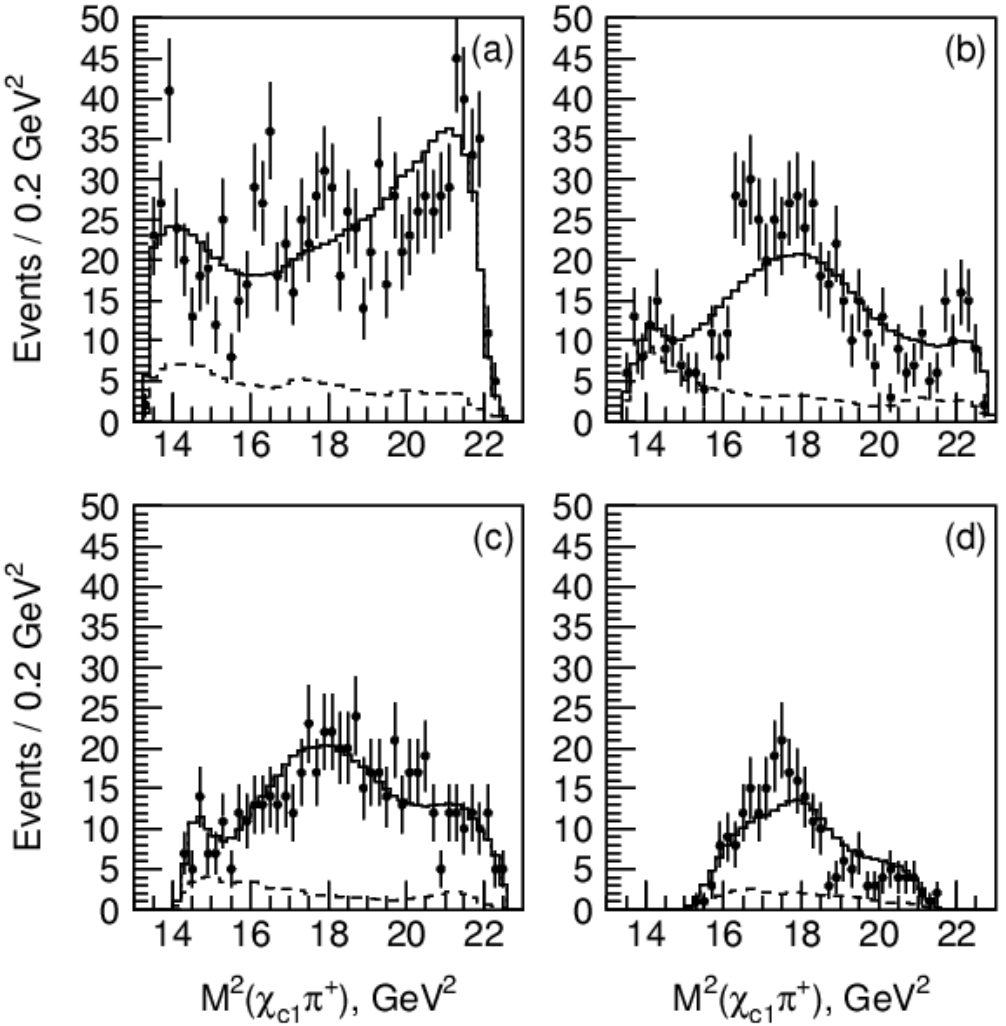
  bkgd $B(s_x, s_y)$ from ΔE sidebands
  efficiency $\epsilon(s_x, s_y)$ from MC; both smoothed



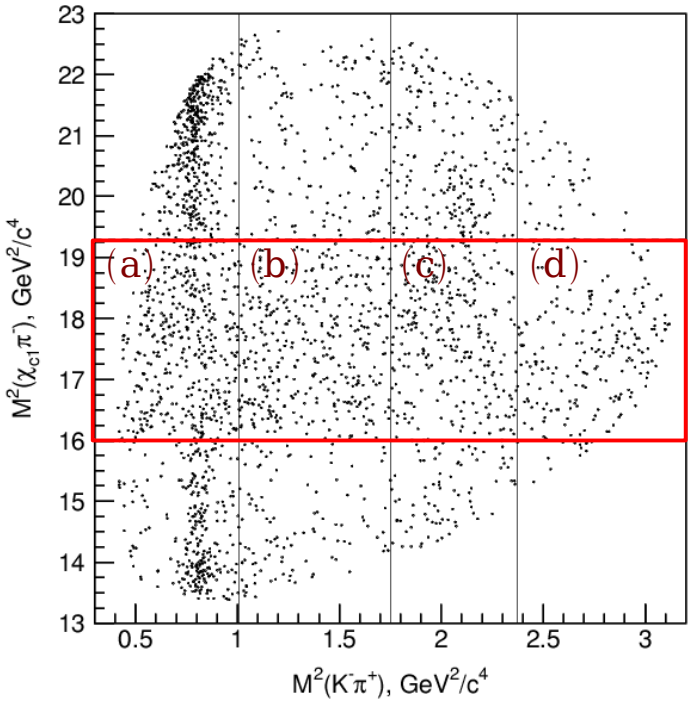
- isobar model: $\pi^+ \chi_{c1}$ exotic resonance + known $K^- \pi^+$
  (κ, $K^*(892)$, $K^*(1410)$, $K_0^*(1430)$, $K_2^*(1430)$, $K^*(1680)$, $K_3^*(1780)$)
  Blatt-Weisskopf form factors
  energy-dependent widths
  angular terms from helicity formalism
  (m_i, Γ_i) fixed to PDG averages

$\overline{B}^0 \to K^- \pi^+ \chi_{c1}$ fit with known K^* states

arXiv:0806.4098 [hep-ex]



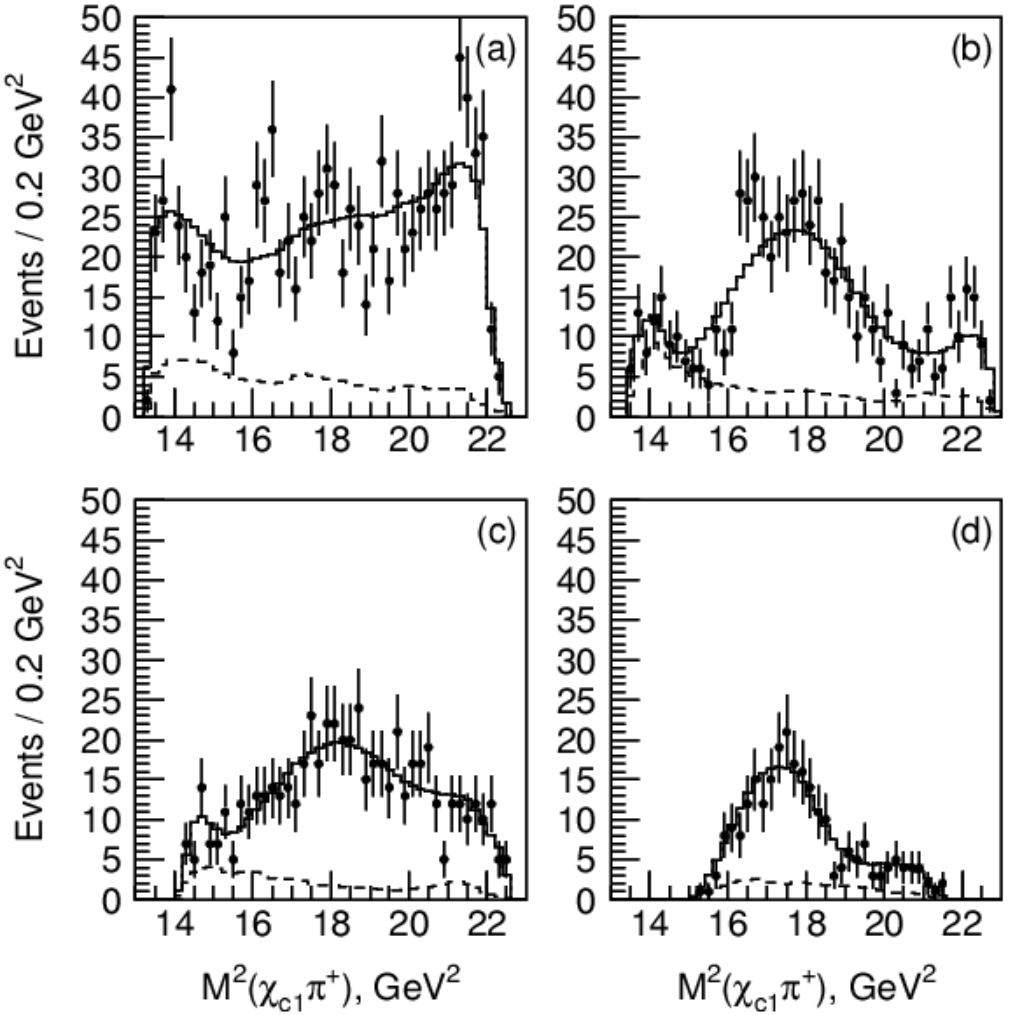
projections to Dalitz slices



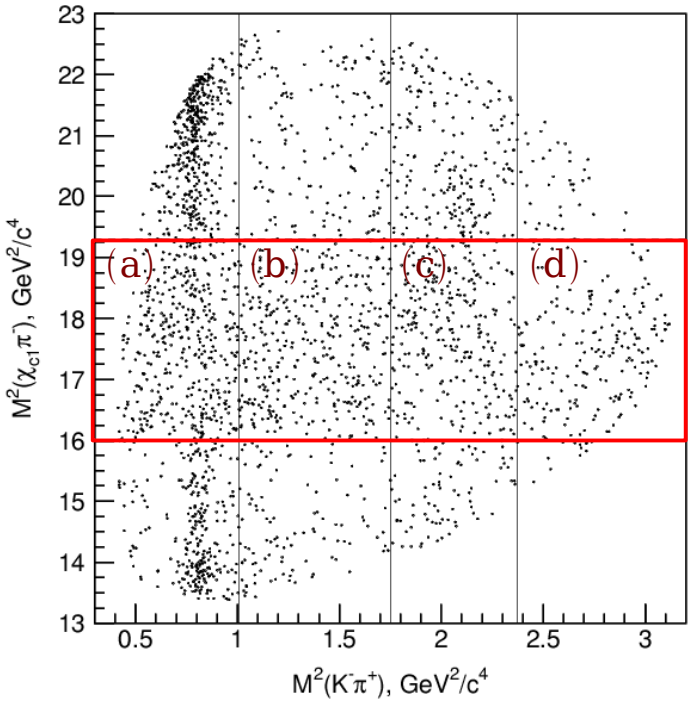
- very poor fit quality; unresolved:
  - M ~ 4150 MeV enhancement
- only 1 of 4 slices plausible

$\overline{B}^0 \to K^- \pi^+ \chi_{c1}$ known $K^* + K_2^*, \chi_{c1} K$ NR

arXiv:0806.4098 [hep-ex]



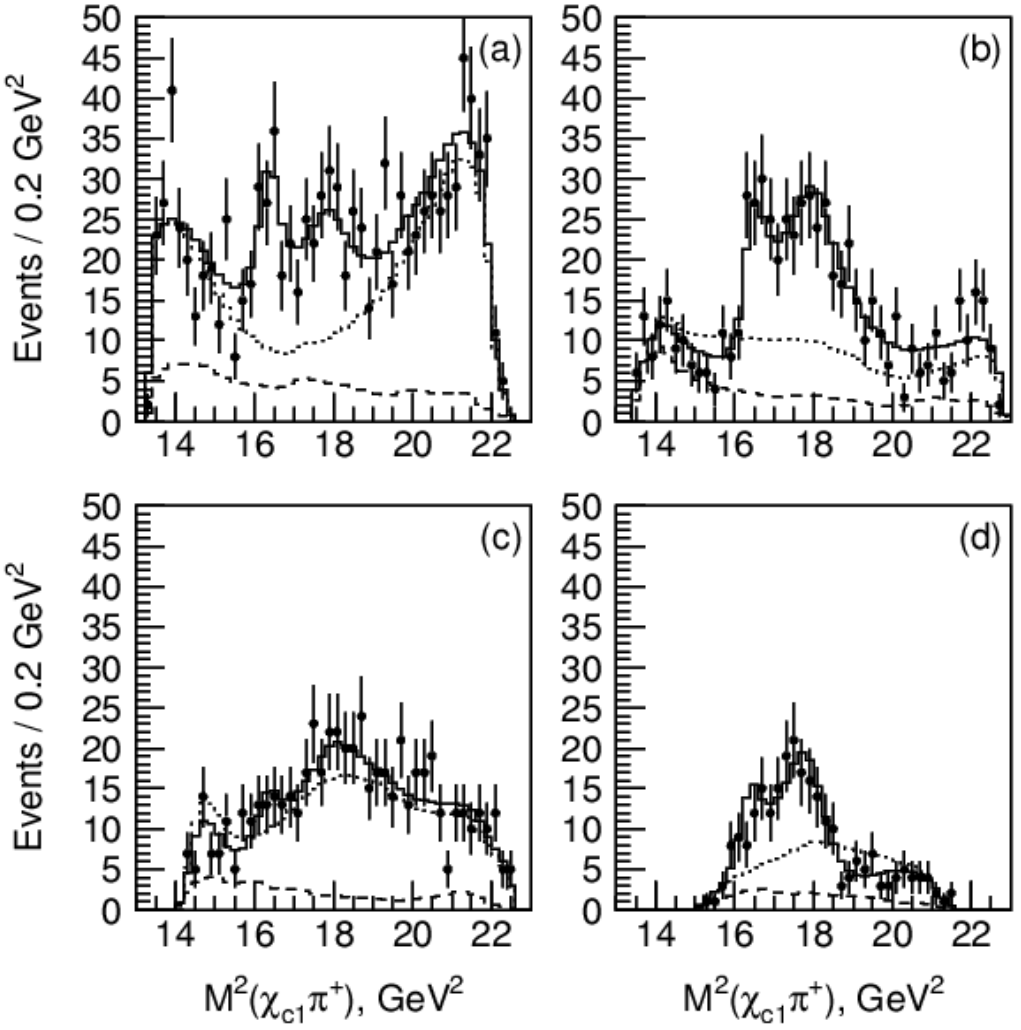
projections to Dalitz slices



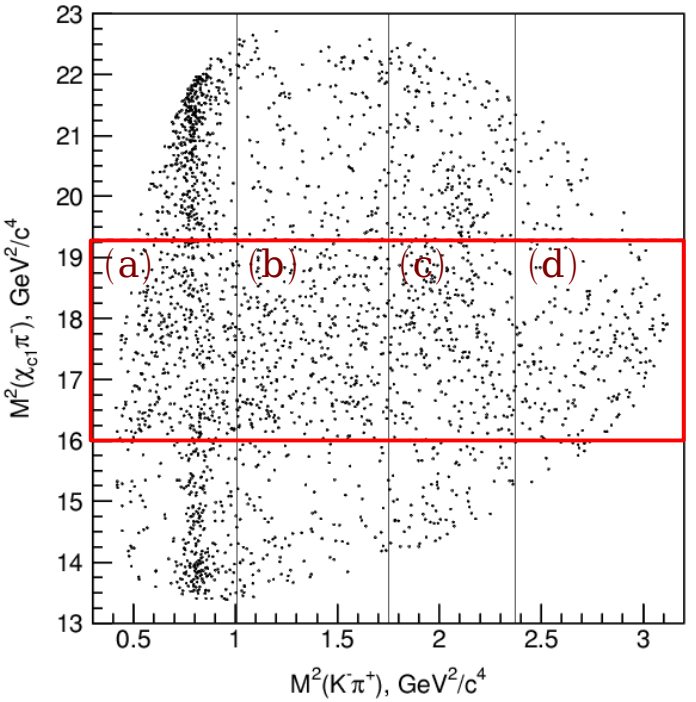
- improvements:
  2 of 4 slices ≈ OK
- peak still poorly matched

$\overline{B}^0 \to K^- \pi^+ \chi_{c1}$ with two $Z^+ \to \pi^+ \chi_{c1}$ terms

arXiv:0806.4098 [hep-ex]



projections to Dalitz slices



- two-vs-one Z favoured:
  - matches peak fine structure
  - $> 5\sigma$ improvement
- good total fit quality: 40% C.L.

$\overline{B}^0 \to K^- \pi^+ \chi_{c1}$ fit contributions

arXiv:0806.4098 [hep-ex]

	One Z^+		Two Z^+	
Contribution	Fit fraction	Signif.	Fit fraction	Signif.
$Z^+_{(1)}$	$(33.1^{+8.7}_{-5.8})\%$	$10.7\,\sigma$	$(8.0^{+3.8}_{-2.2})\%$	$5.7\,\sigma$
Z^+_2	–	–	$(10.4^{+6.1}_{-2.3})\%$	$5.7\,\sigma$
κ	$(1.9 \pm 1.8)\%$	$2.1\,\sigma$	$(3.6 \pm 2.6)\%$	$3.5\,\sigma$
$K^*(892)$	$(28.5 \pm 2.1)\%$	$10.6\,\sigma$	$(30.1 \pm 2.3)\%$	$9.8\,\sigma$
$K^*(1410)$	$(3.6 \pm 4.4)\%$	$1.3\,\sigma$	$(4.4 \pm 4.3)\%$	$2.0\,\sigma$
$K^*_0(1430)$	$(22.4 \pm 5.8)\%$	$3.4\,\sigma$	$(18.6 \pm 5.0)\%$	$4.5\,\sigma$
$K^*_2(1430)$	$(8.4 \pm 2.7)\%$	$5.2\,\sigma$	$(6.1 \pm 2.9)\%$	$5.4\,\sigma$
$K^*(1680)$	$(5.2 \pm 3.7)\%$	$2.2\,\sigma$	$(4.4 \pm 3.1)\%$	$2.4\,\sigma$
$K^*_3(1780)$	$(7.4 \pm 3.0)\%$	$3.6\,\sigma$	$(7.2 \pm 2.9)\%$	$3.8\,\sigma$
	110.5%		92.8%	