

Charmonium-like Particles at Belle

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(For Belle collaboration)



(VI. QCD in Hadronic Physics)
The 2009 Europhysics Conference on High Energy Physics
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Outline

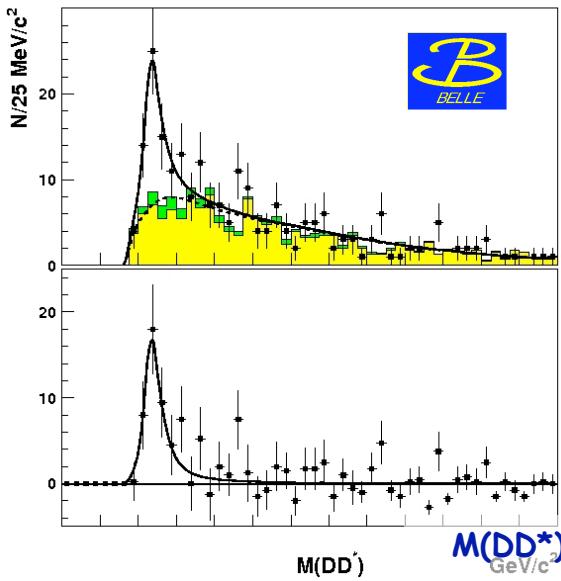
- $X(3915)$: a $\gamma\gamma \rightarrow \omega J/\psi$ peak @ ~ 3915 MeV
- Charged resonance-like states $Z^+(4430)$, $Z_1(4050)$ and $Z_2(4250)$;
 - $Z^+ \rightarrow \psi' \pi^+$ in $B^0 \rightarrow K^- \psi' \pi^+$
 - $Z_{1,2}^+ \rightarrow \chi_{c1} \pi^+$ in $B^0 \rightarrow K^- \chi_{c1} \pi^+$
- $X(3872)$
 - Mass in $\pi^+ \pi^- J/\psi$ and $D \bar{D}^*$ mass system
- 1^{--} Y states via ISR
- Possible analogs of Y states in $s \bar{s}$ ($b \bar{b}$) systems
 - Huge rate of $\pi^+ \pi^- Y(1,2S)$ production at $Y(5S)$
 - $Y_s(2175)$

The states near 3940 MeV

not seen in $\omega J/\psi$

$X(3940)$

$e^+e^- \rightarrow J/\psi DD^*$



$$M = 3942_{-5}^{+7} \pm 6 \text{ MeV}$$

$$\Gamma_{\text{tot}} = 37_{-15}^{+26} \pm 12 \text{ MeV}$$

$$N_{\text{sig}} = 52_{-16}^{+24} \pm 11 \text{ evts}$$

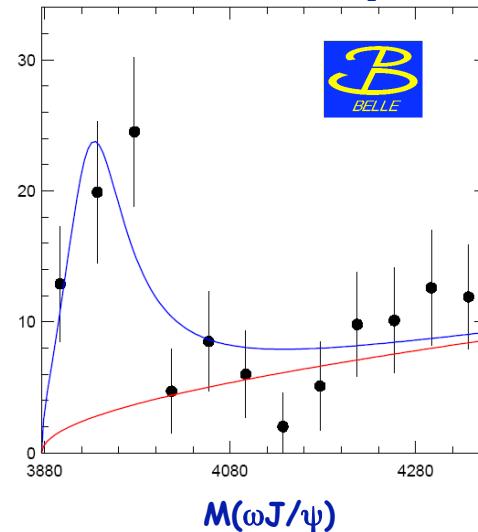
PRL 100, 202001

probably different

not seen in DD^*

$\gamma(3940)$

$B \rightarrow K \omega J/\psi$



$$M \approx 3940 \pm 11 \text{ MeV}$$

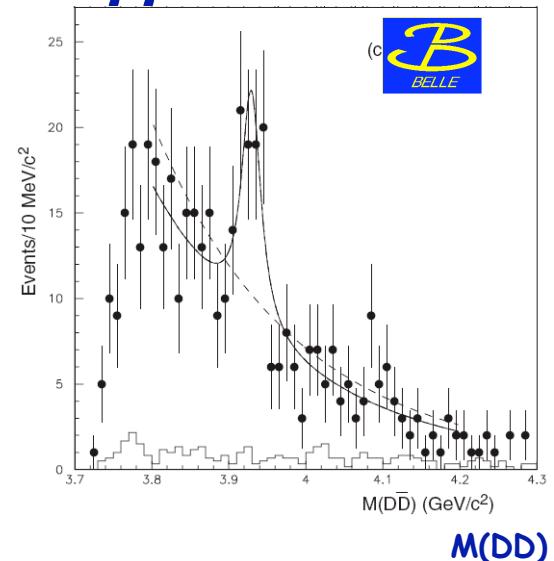
$$\Gamma \approx 92 \pm 24 \text{ MeV}$$

PRL94, 182002 (2005)

Probably the χ_{c2}'

$Z(3930)$

$\gamma\gamma \rightarrow D\bar{D}$



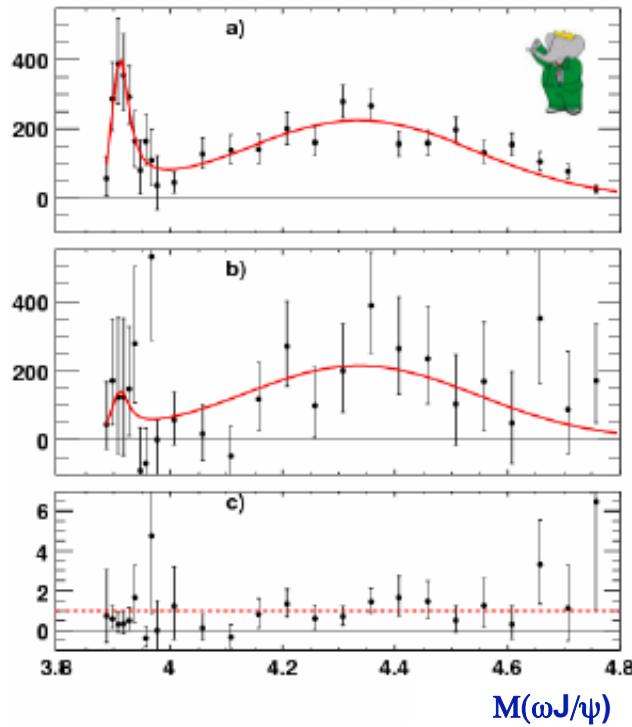
$$M = 3929 \pm 5 \pm 2 \text{ MeV}$$

$$\Gamma_{\text{tot}} = 29 \pm 10 \pm 2 \text{ MeV}$$

$$N_{\text{sig}} = 64 \pm 18 \text{ evts}$$

PRL 96, 082003

$\Upsilon(3940)$ confirmed by BaBar



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

$B^0 \rightarrow K_s \omega J/\psi$

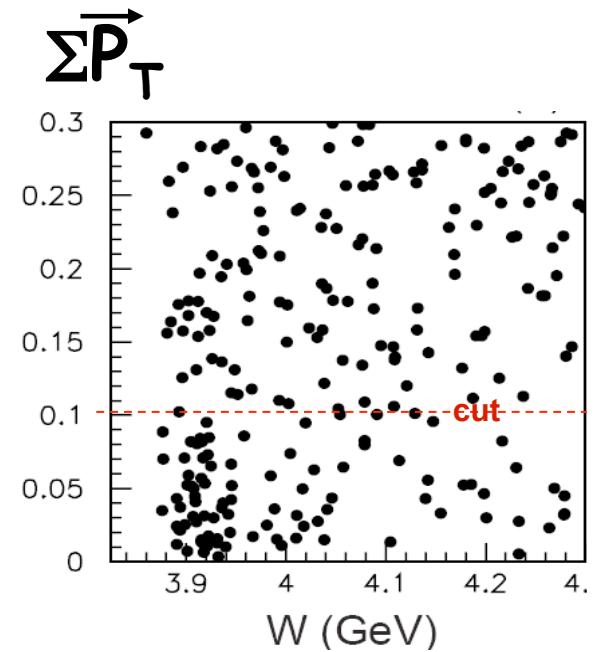
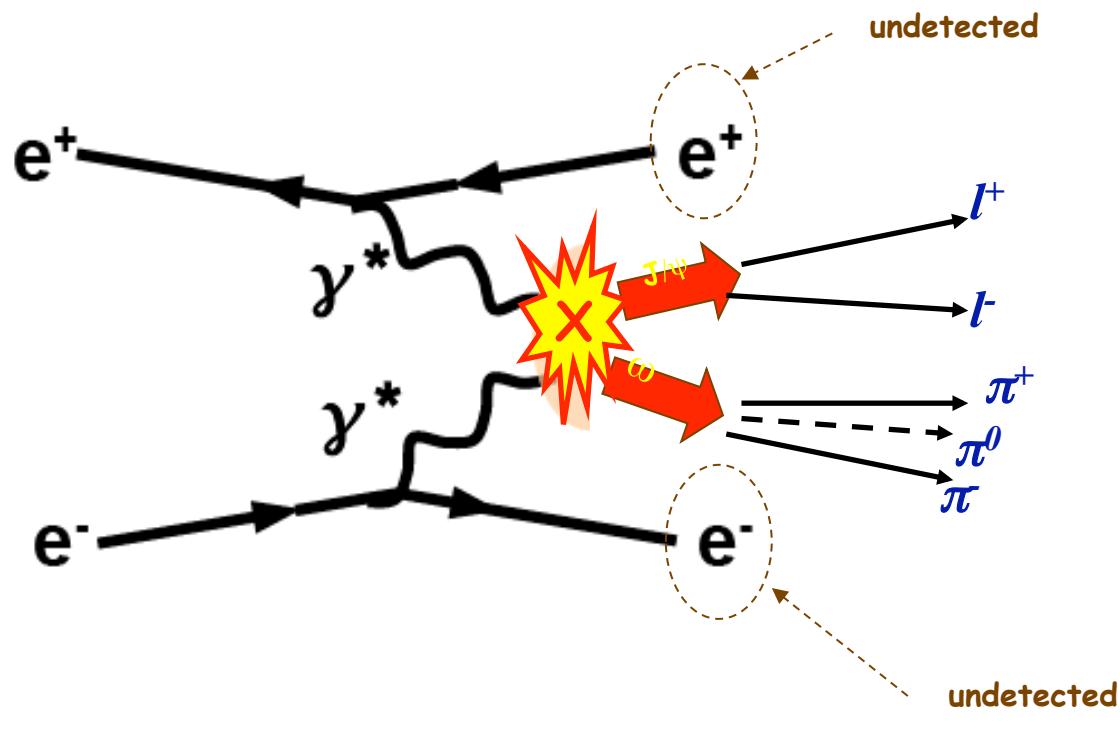
ratio

	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	$3914.3^{+3.8}_{-3.4}(stat)^{+1.6}_{-1.6}(syst)$	$33^{+12}_{-8}(stat)^{+0.6}_{-0.6}(syst)$

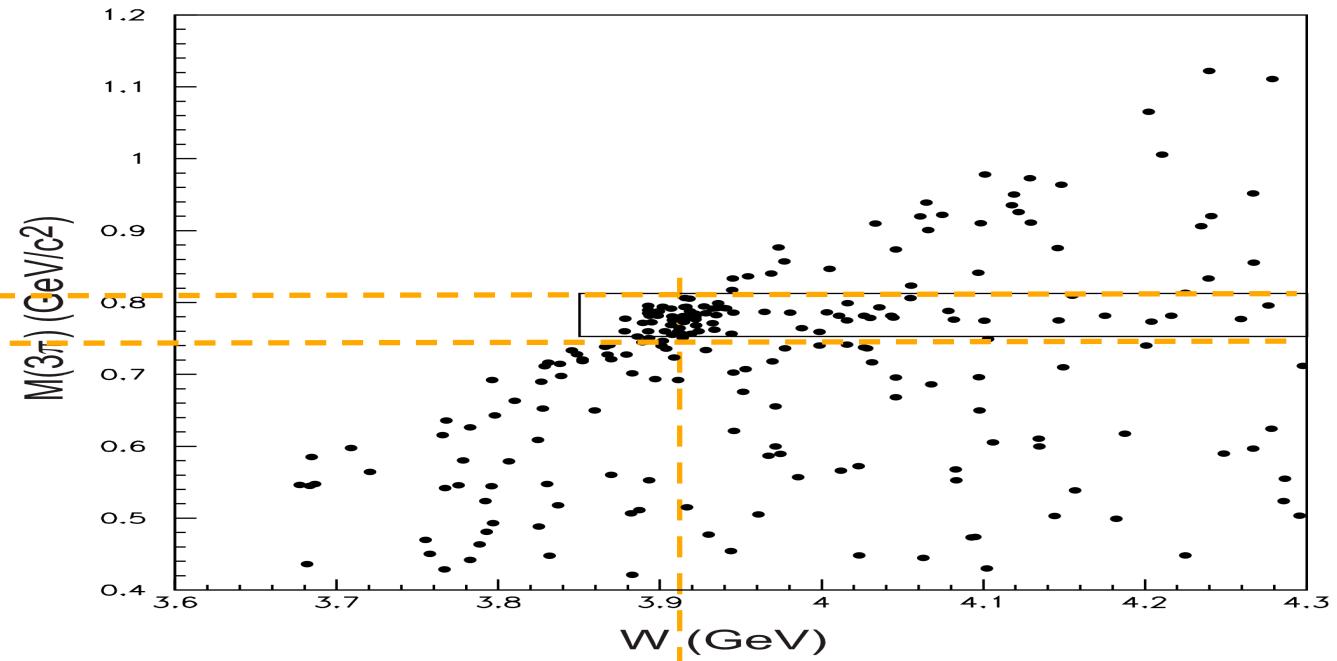
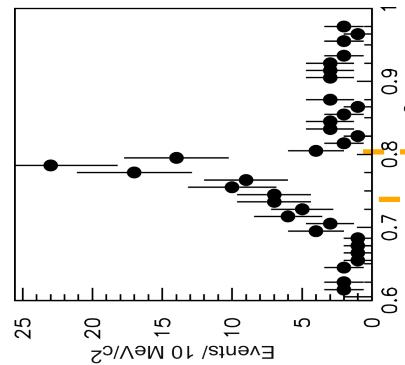
BaBar PRL 101, 082001

Some discrepancy in M & Γ ; general features agree

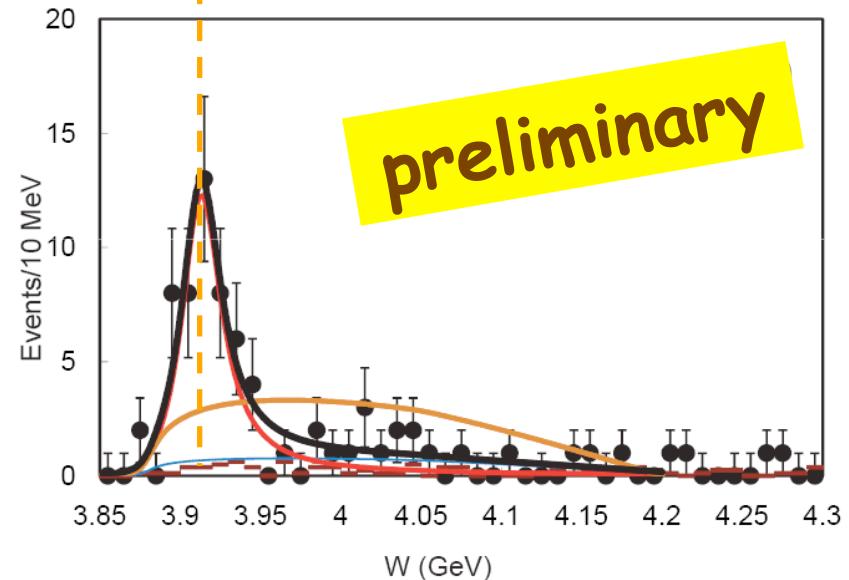
New Belle peak in $\gamma\gamma \rightarrow \omega J/\psi$



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



$M = 3914 \pm 3 \pm 2 \text{ MeV}$
 $\Gamma = 23 \pm 9 {}^{+2}_{-3} \text{ MeV}$
 $N = 54 \pm 11 \pm 4 \text{ events}$
 Significance = 7.5σ



Is $X(3915) = \chi_{c2}'$ (or χ_{c0}') ?

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

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

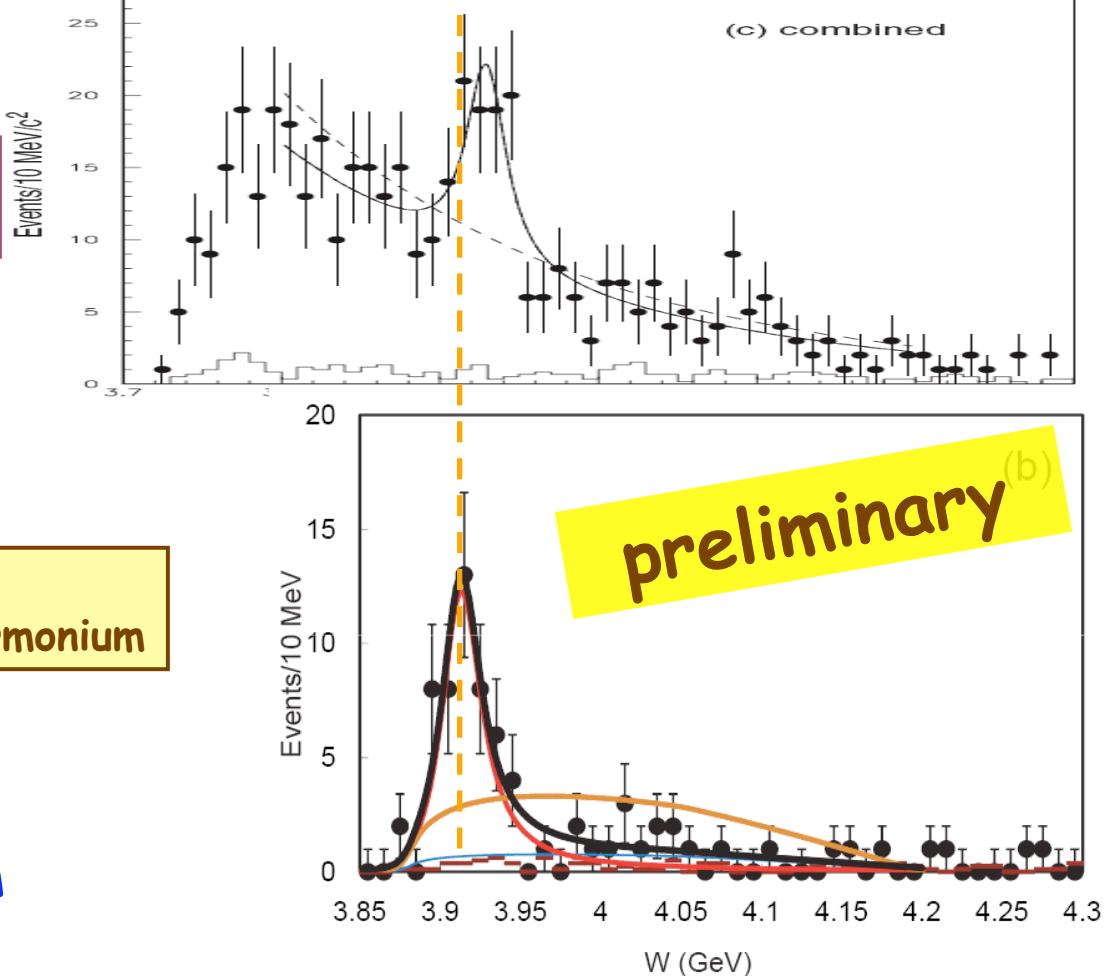
For comparison:
 $Z(3930): \Gamma_{\gamma\gamma} B(DD) = 180 \pm 50 \pm 30 \text{ eV}$

If $X(3915) = Z(3930) = \chi_{c2}' \rightarrow$

$$\frac{Bf(\chi_{c2}' \rightarrow \omega J/\psi)}{Bf(\chi_{c2}' \rightarrow DD)} \geq 0.08$$

Huge for
 above-open-charm-threshold charmonium

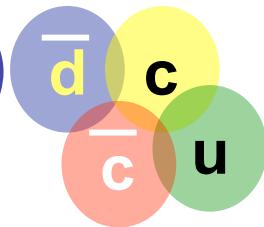
$\Gamma(\omega J/\psi)$ is also
 too high to be Charmonium



if $X(3915) = \text{Belle's } Y(3940) = \text{BaBar's } Y(3914)$

→ J^{PC} (probably) = 0^{++}

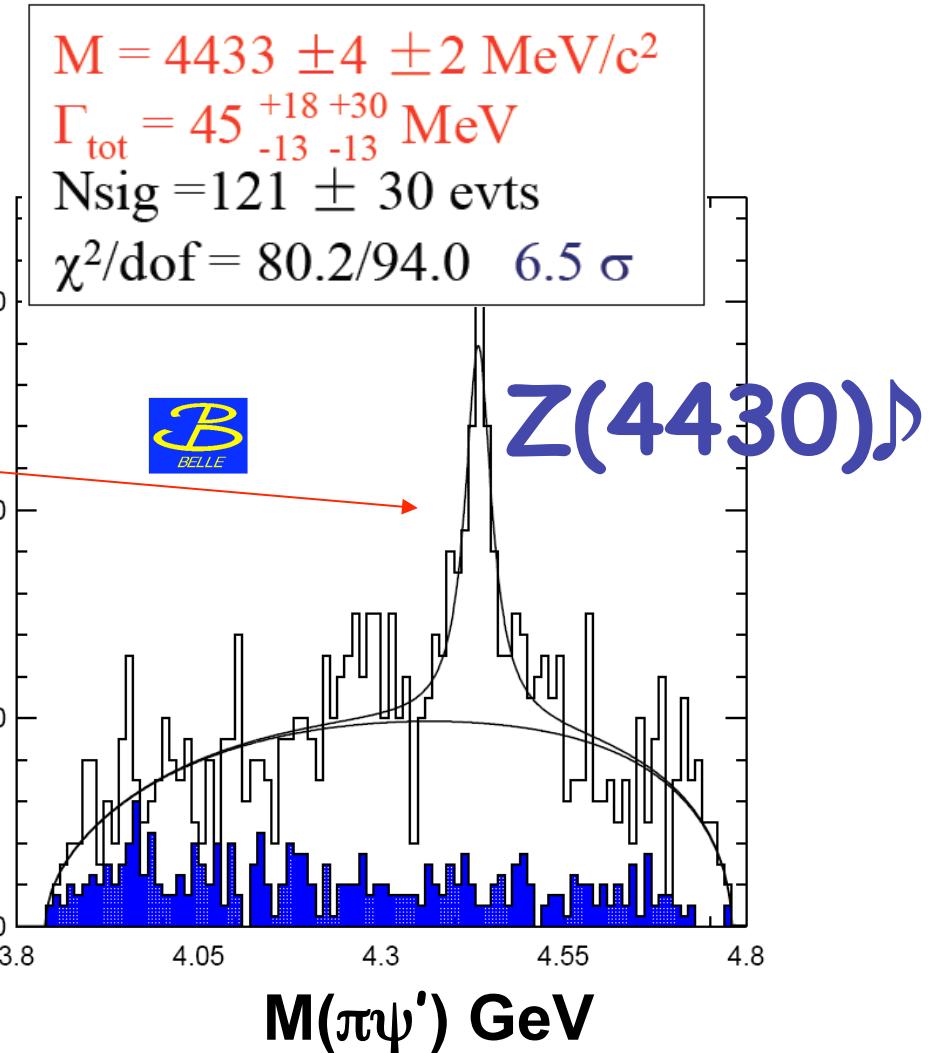
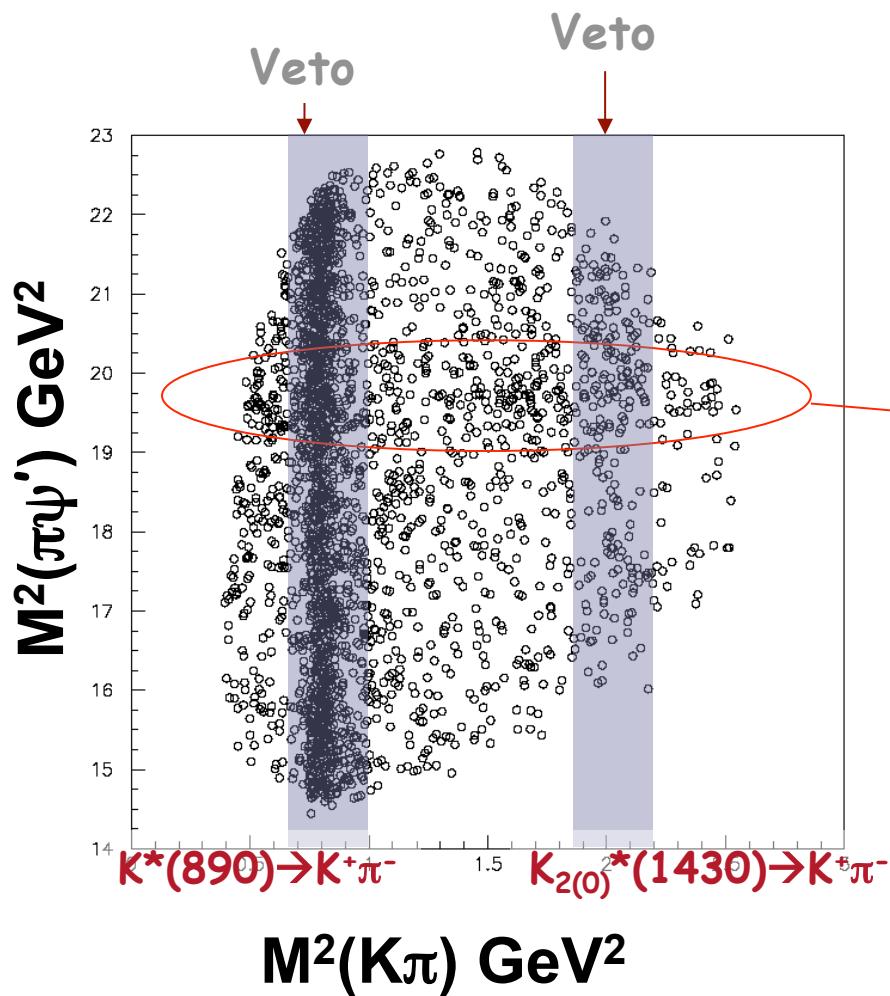
Charged resonancelike states
(minimal quark contents $c\bar{c}ud\bar{d}$)



$$Z^+(4430) \rightarrow \pi^+ \psi'$$

$$Z_1(4050)^+ \ Z_2(4250)^+ \rightarrow \pi^+ \chi_{c1}$$

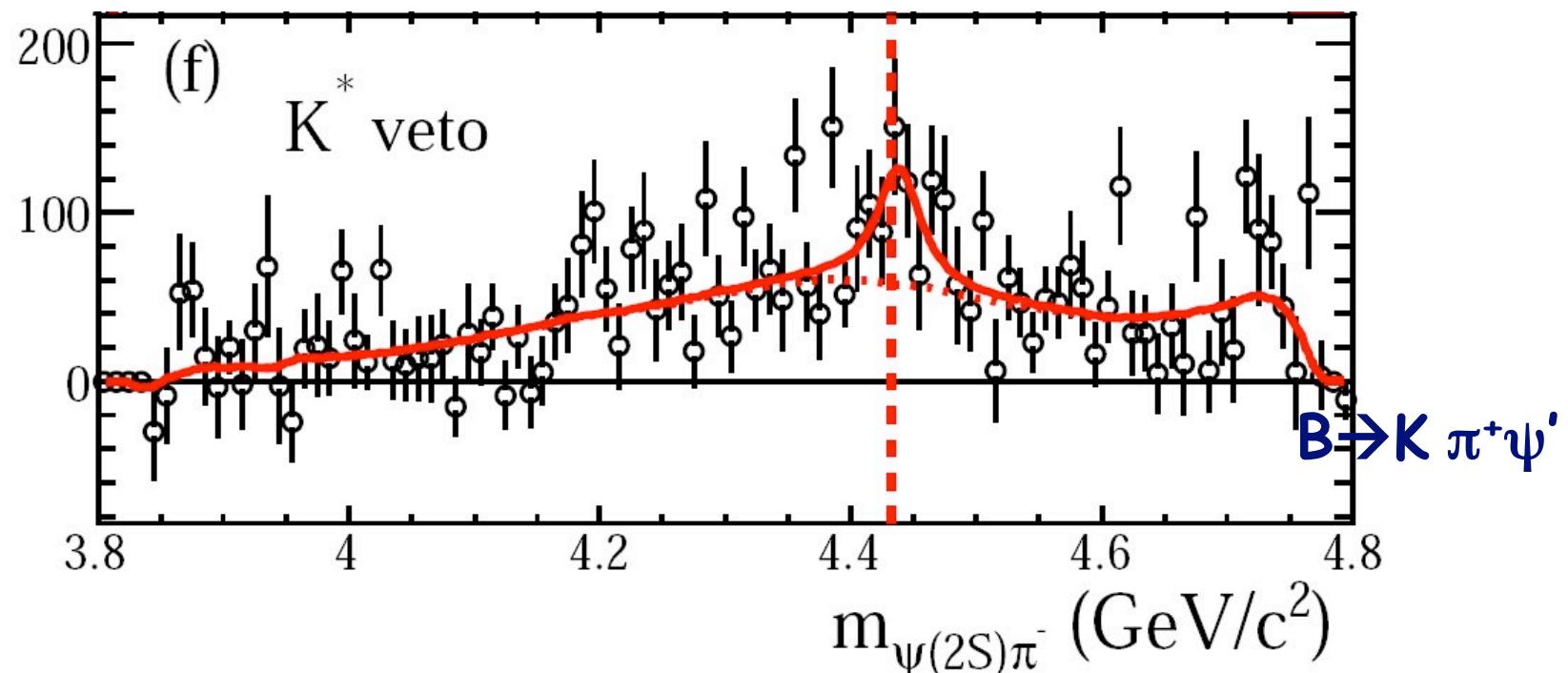
$M(\pi^\pm\psi')$ from $B \rightarrow K \pi^\pm \psi'$



PRL 100, 142001 (2008)

$\text{BF}(B^0 \rightarrow K Z^+) \times \text{BF}(Z^+ \rightarrow \psi(2S)\pi^+) = (4.1 \pm 1.0 \pm 1.4) \times 10^{-5}$

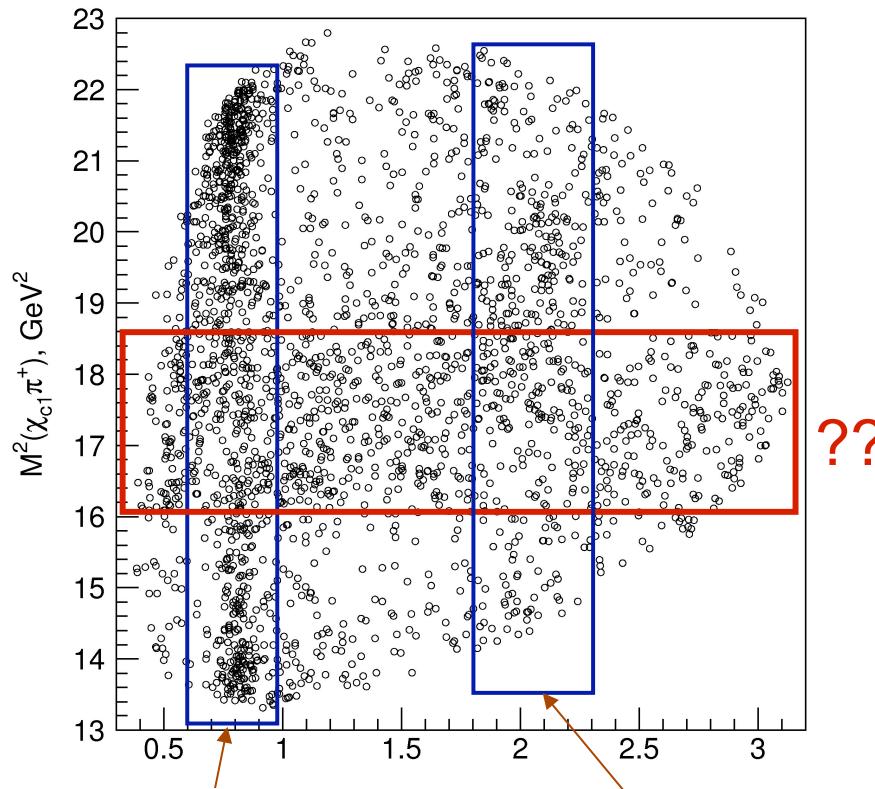
BaBar doesn't see a significant $Z(4430)^+$



"For the fit ... equivalent to the Belle analysis...we obtain mass & width values that are consistent with theirs,... but only $\sim 1.9\sigma$ from zero; fixing mass and width increases this to only $\sim 3.1\sigma$."

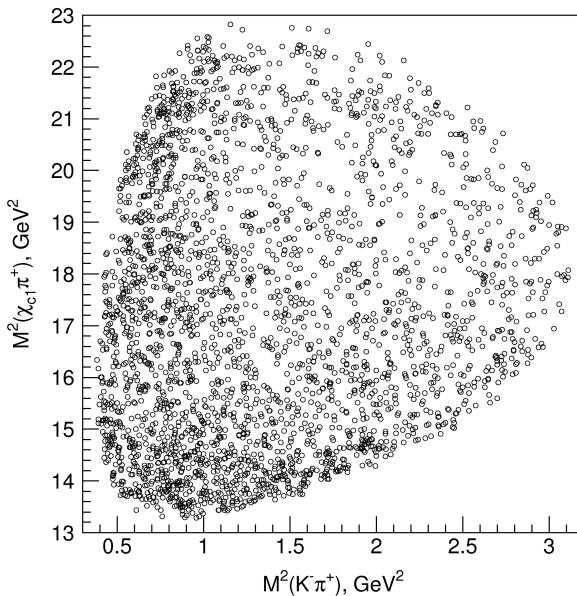
$$\text{BF}(B^0 \rightarrow Z^+ K) \times \text{BF}(Z^+ \rightarrow \psi(2S)\pi^+) < 3.1 \times 10^{-5}$$

Dalitz plot for $B^0 \rightarrow \chi_{c1} K^+ \pi^-$



$K^*(890) \rightarrow K^+ \pi^- M^2(K^+ \pi^-)$ $K_0^*(1430) \rightarrow K^+ \pi^-$
 $K_2^*(1430)$

ΔE sidebands

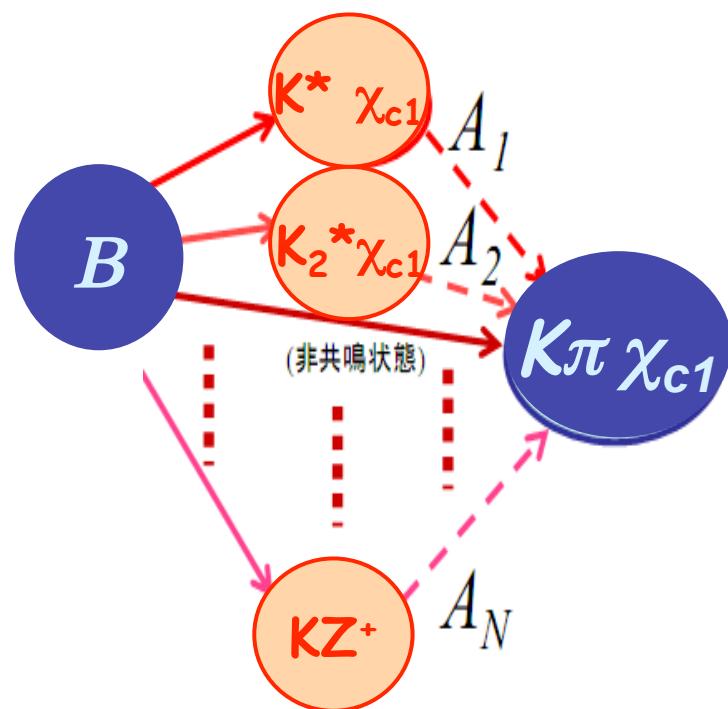


R.Mizuk & R.Chistov

PRD 78, 072004 (2008)

2-body isobar model for $B \rightarrow K\pi \chi_{c1}$

Default Model



$\kappa \chi_{c1}(\psi')$
 $K^*(890) \chi_{c1}(\psi')$
 $K^*(1410) \chi_{c1}(\psi')$
 $K_0^*(1430) \chi_{c1}(\psi')$
 $K_2^*(1430) \chi_{c1}(\psi')$
 $K^*(1680) \chi_{c1}(\psi')$
 $K_3^*(1780) \chi_{c1}$
 $K Z(\pi^+ \chi_{c1}(\psi'))$

Detail Fitting fcn Formalism over Dalitz Plot

$B \rightarrow K\pi\chi_{c1}$ decay is described by 6 variables: $M(K\pi)$ (S_x), $M(\chi_{c1}\pi)$ (S_y), helicity angle $\theta(\chi_{c1})$, $\theta(J/\psi)$, and 2 production angles $\varphi(\chi_{c1})$, $\varphi(J/\psi)$ in its decay plane.

Interference terms ($\sim \cos(2\varphi)$) between different χ_{c1} helicity states are negligible, after integrating over $\varphi(\chi_{c1})$ and $\varphi(J/\psi)$, since acceptance as a function of φ is uniform

Fit function

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

Efficiency

Bkg(ΔE sideband.)

Signal event density fcn

$$S(s_x, s_y) = \sum_{\lambda=-1,0,1} \left| \sum_{K^+} a_\lambda^{K^*} e^{i\phi_\lambda^{K^*}} A_\lambda^{K^*}(s_x, s_y) \right|^2 + \sum_{\lambda'=-1,0,1} d_{\lambda'\lambda}^1(\theta) a_{\lambda'}^{Z^+} e^{i\phi_{\lambda'}^{Z^+}} A_{\lambda'}^{Z^+}(s_x, s_y) \right|^2$$

$(\chi_{c1} \text{ helicity})$

Amplitude

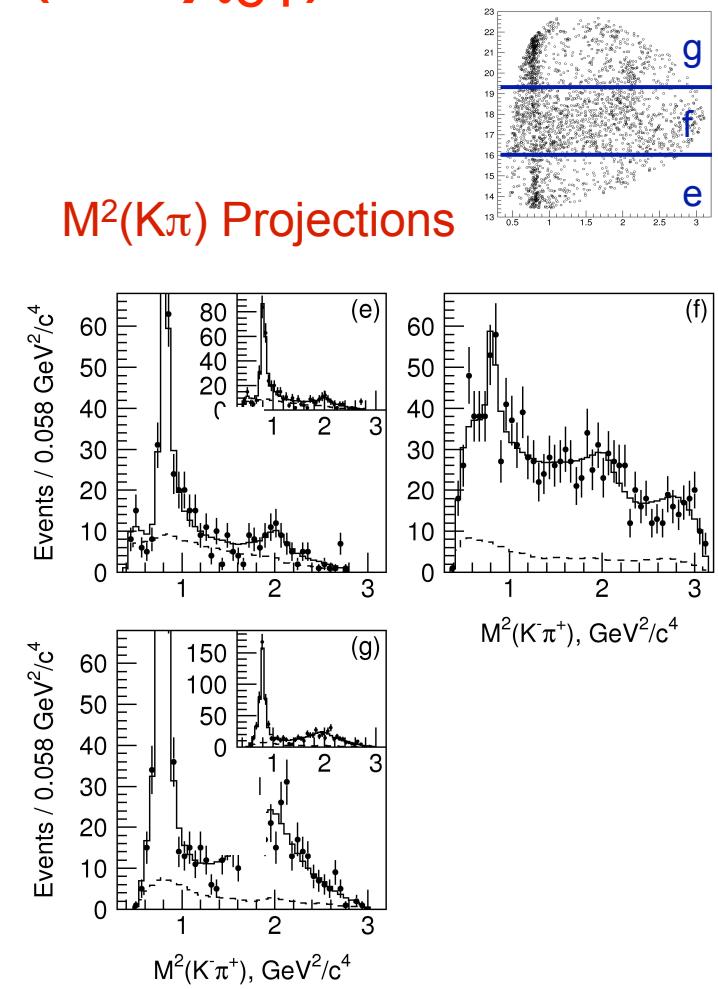
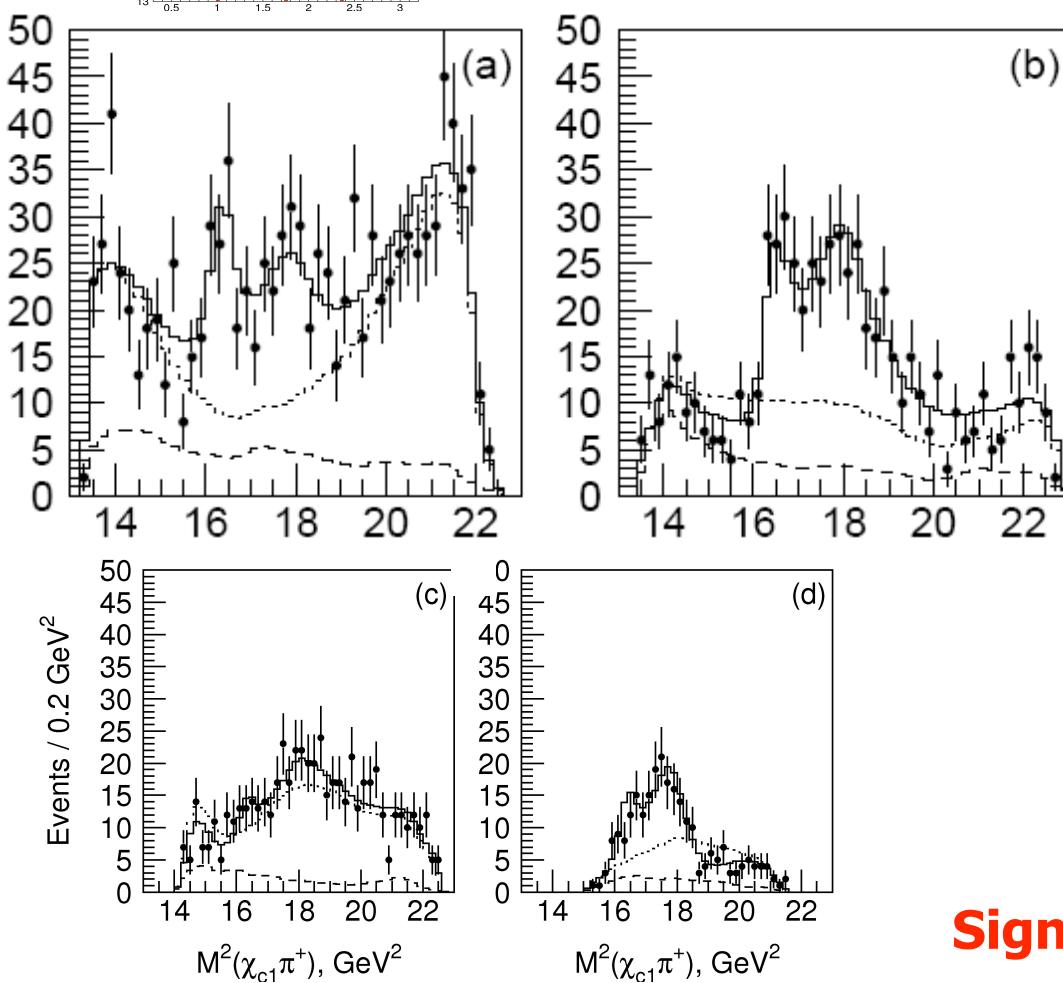
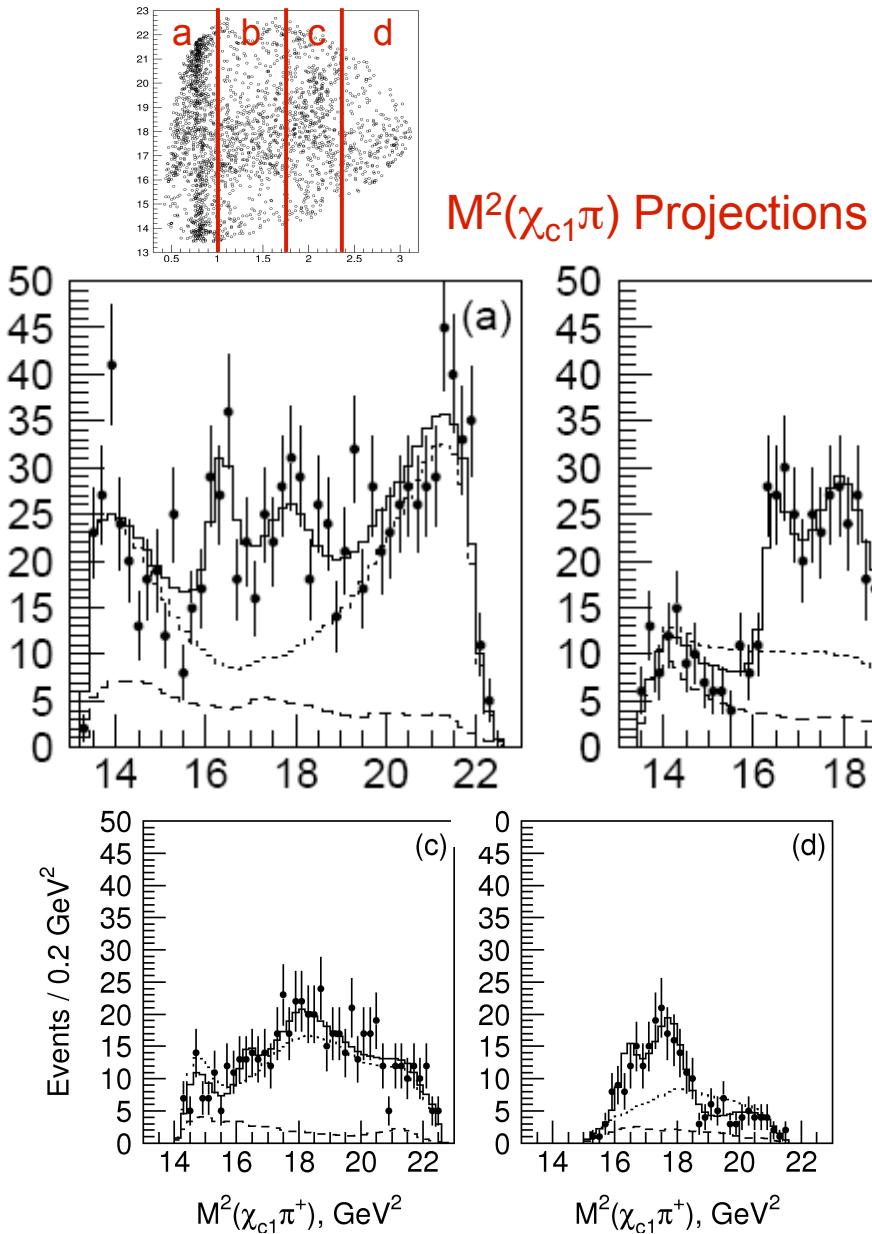
$$A_\lambda^R = F_B^{(L_B)} \cdot \frac{1}{M_R^2 - s_R - iM_R\Gamma(s_R)} \cdot F_R^{(L_R)} \cdot T_\lambda \cdot \left(\frac{p_B}{m_B} \right)^{L_B} \cdot \left(\frac{p_R}{\sqrt{s_R}} \right)^{L_R}$$

B meson and (intermediate) R resonance decay form-factors

(Angle dep. Term)

$$T_\lambda = d_{0\lambda}^J(\theta_{Z^+})$$

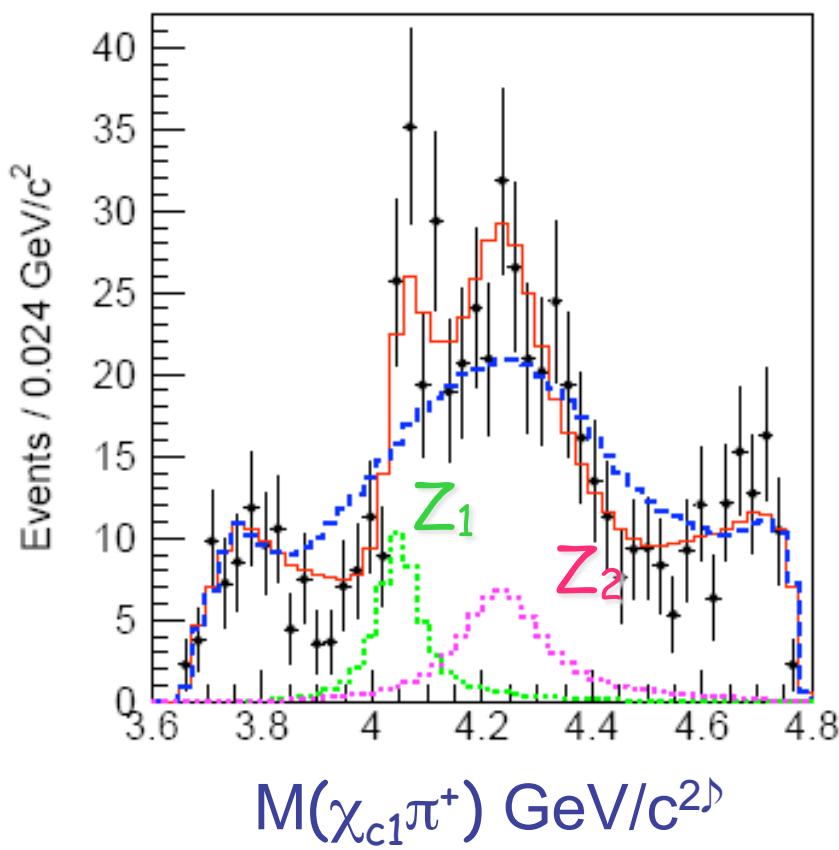
Dalitz plot fit with all K^* 's + two ($\pi^+ \chi_{c1}$) resonances



Toy MC fit CL= 40%

Significance of two vs one: 5.7 σ

$M(\pi^+ \chi_{c1})$ for $1.0\text{GeV}^2 < M^2(K^-\pi^+) < 1.75\text{GeV}^2$



- The Dalitz plot slice with most discrimination
- No-resonance hypotheses give very poor fits
- Two resonances structure is distinctive

$$M_1 = (4051 \pm 14^{+20}_{-41}) \text{ MeV}/c^2,$$

$$\Gamma_1 = (82^{+21+47}_{-17-22}) \text{ MeV},$$

$$M_2 = (4248^{+44+180}_{-29-35}) \text{ MeV}/c^2,$$

$$\Gamma_2 = (177^{+54+316}_{-39-61}) \text{ MeV},$$

$\text{BF}(B^0 \rightarrow Z K^-) \text{BF}(Z \rightarrow \pi^+ \chi_{c1})$:

$$\text{BF}(Z_1) = (3.1^{+1.5+3.7}_{-0.9-0.17}) \times 10^{-5}$$

$$\text{BF}(Z_2) = (4.0^{+2.3+19.7}_{-0.9-0.5}) \times 10^{-5}$$

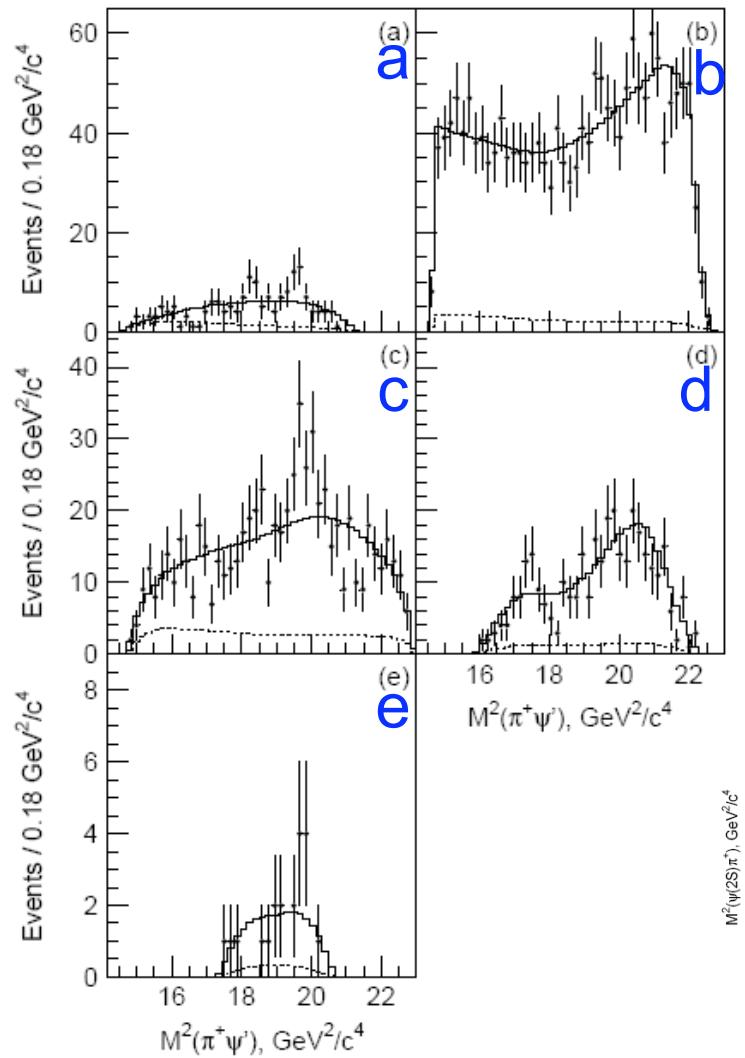
Reanalysis of $B \rightarrow K\pi\psi'$ using the same Dalitz Plot technique

*Intermediate Resonances included
in the default fit model:*

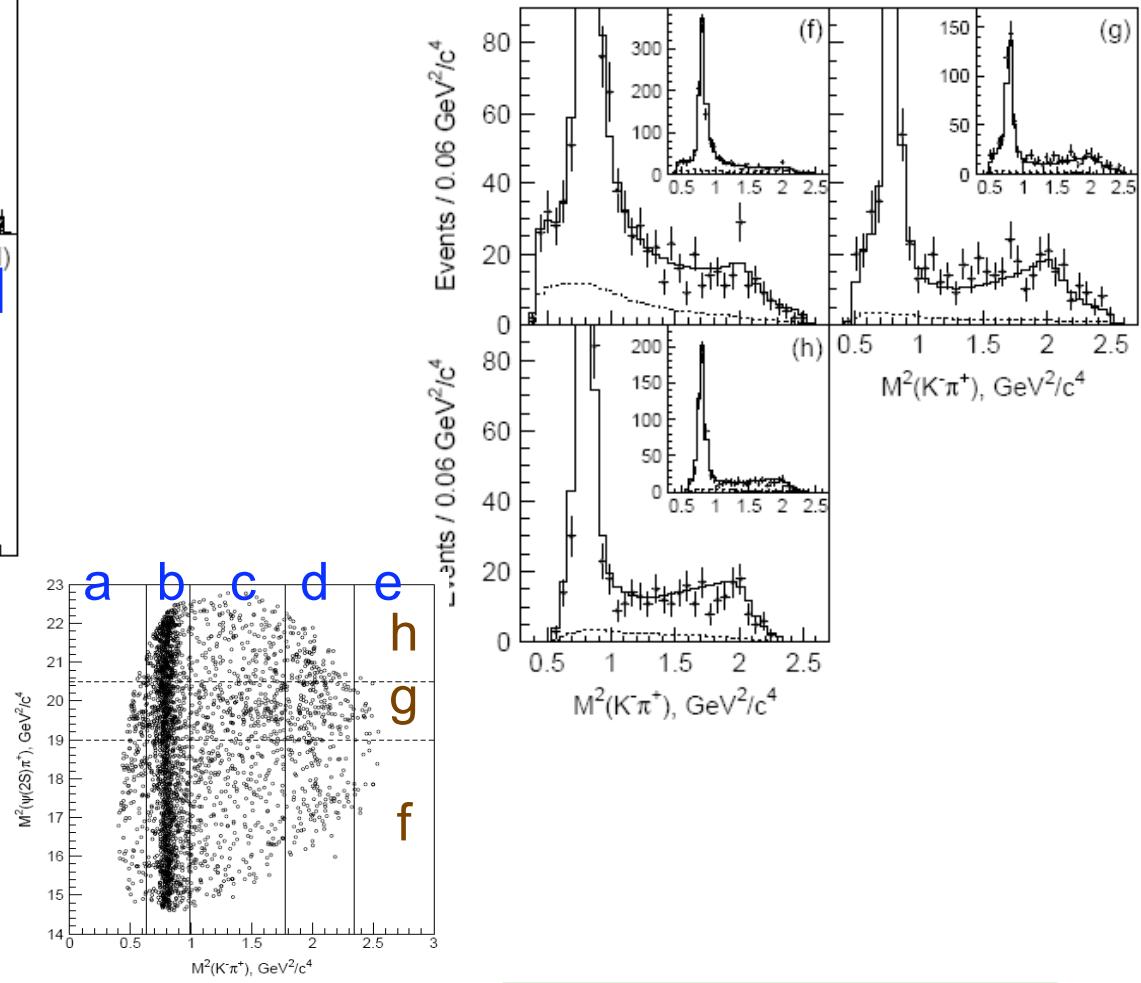
$\kappa\psi'$, $K^*(892)\psi'$, $K^*(1410)\psi'$,
 $K^*_0(1430)\psi'$, $K^*_2(1430)\psi'$,
 $K^*(1680)\psi'$, $K^*_3(1780)\psi'$
and $K Z^+ (\pi^+ \psi')$

R.Mizuk arXiv:0905.2869(2009)
Submitted to PRD

Fit Results with no $Z(4430) \rightarrow \pi^+ \psi'$ term

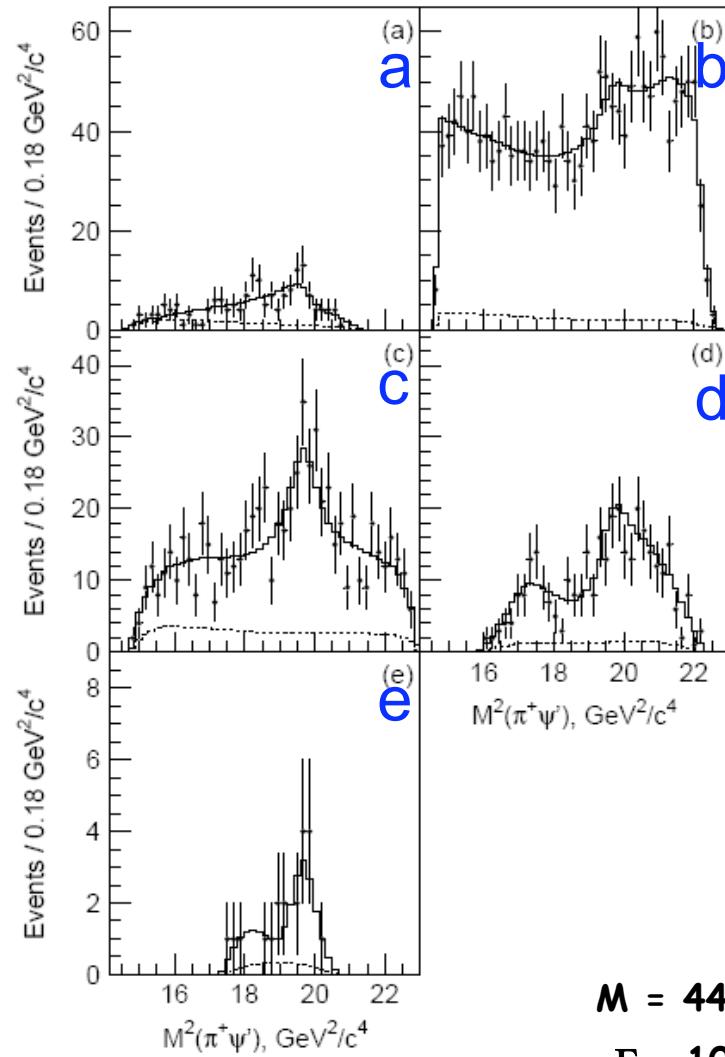


$K\pi$ cannot reproduce
narrow peak



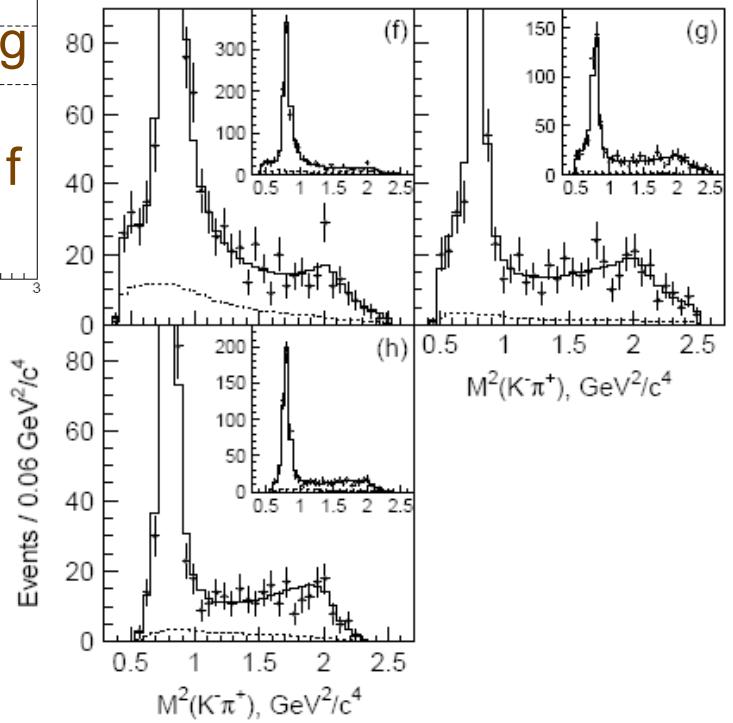
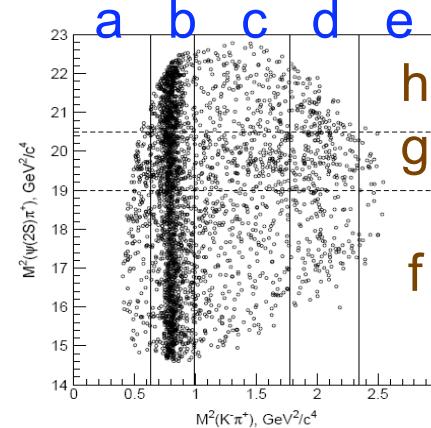
Toy MC fit CL < 0.1%

Fit Results with a $Z(4430) \rightarrow \pi^+ \psi'$ term



$$M = 4443 {}^{+15}_{-12} \text{ MeV}$$

$$\Gamma = 109 {}^{+86}_{-43} \text{ MeV}$$



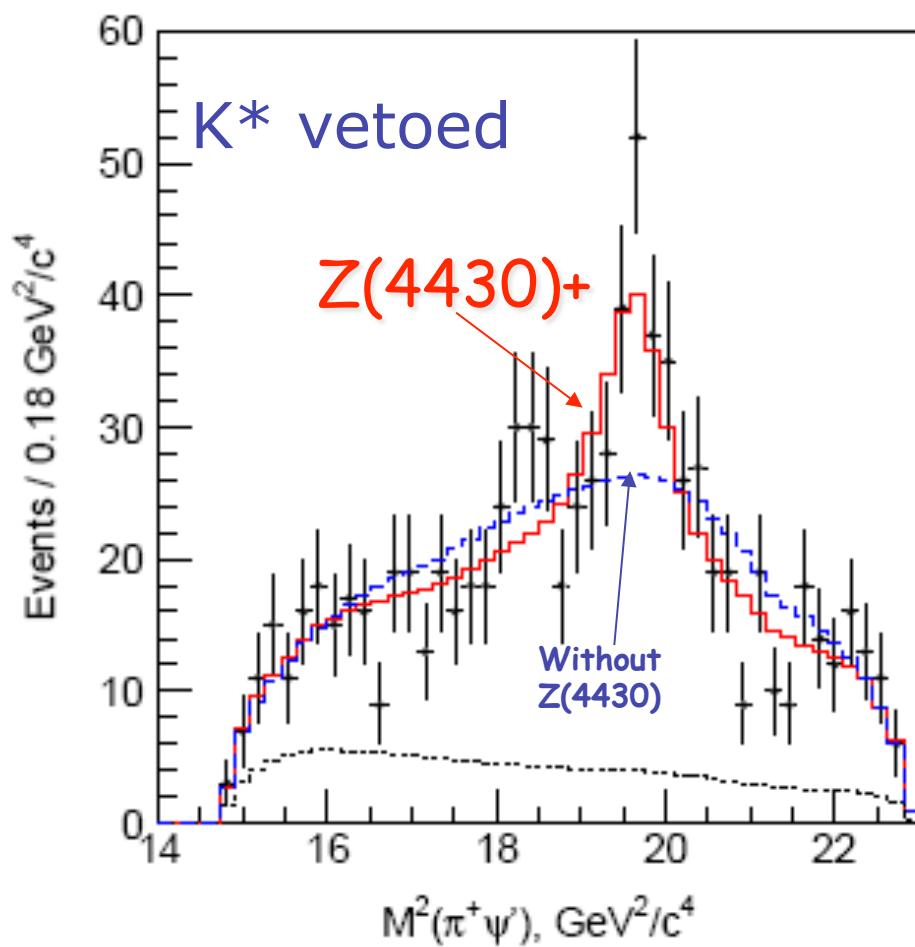
Toy MC fit CL= 36%
6.4 σ

Significances of the Z(4430)+ for different fit models

Model	Significance
1 default	6.4σ
2 no $K_0^*(1430)$	6.6σ
3 no $K^*(1680)$	6.6σ
4 release constraints on κ mass & width	6.3σ
5 new K^* ($J = 1$)	6.0σ
6 new K^* ($J = 2$)	5.5σ
7 add non-resonant $\psi' K^-$ term	6.3σ
8 add non-resonant $\psi' K^-$ term, release constraints on κ mass & width	5.8σ
9 add non-resonant $\psi' K^-$ term, new K^* ($J = 1$)	5.5σ
10 add non-resonant $\psi' K^-$ term, new K^* ($J = 2$)	5.4σ
11 add non-resonant $\psi' K^-$ term, no $K^*(1410)$	6.3σ
12 add non-resonant $\psi' K^-$ term, no $K^*(1680)$	6.6σ
13 LASS parameterization of S-wave component	6.5σ

Assume $J_{Z(4430)}=0$. No fit improvement for $J_{Z(4430)}=1$

Dalitz analysis confirms the existence of Z(4430)⁺



$$M = 4443^{+15+17}_{-12-13} \text{ MeV}/c^2$$

$$\Gamma = 109^{+86+57}_{-43-52} \text{ MeV}$$

Significance = 6.4 σ

$$\begin{aligned} \mathcal{B}(\bar{B}^0 \rightarrow K^- Z(4430)^+) \times \mathcal{B}(Z(4430)^+ \rightarrow \pi^+ \psi') \\ = (3.2^{+1.8+5.3}_{-0.9-1.6}) \times 10^{-5} \end{aligned}$$

BaBar: $\text{BF}(B^0 \rightarrow Z^+ K) \times \text{BF}(Z^+ \rightarrow \psi(2S)\pi^+) < 3.1 \times 10^{-5}$

$$\begin{aligned} M &= 4433 \pm 4 \pm 2 \text{ MeV} \\ \Gamma_{\text{tot}} &= 45^{+18+30}_{-10-15} \text{ MeV} \end{aligned}$$

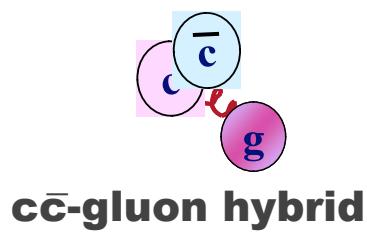
$$\begin{aligned} N_{\text{sig}} &= 121 \pm 30 \text{ evts} \\ \chi^2/\text{dof} &= 80.2/94.0 \\ &6.5 \sigma \end{aligned}$$

Mass & Significance are similar.
Width & its errors are larger.



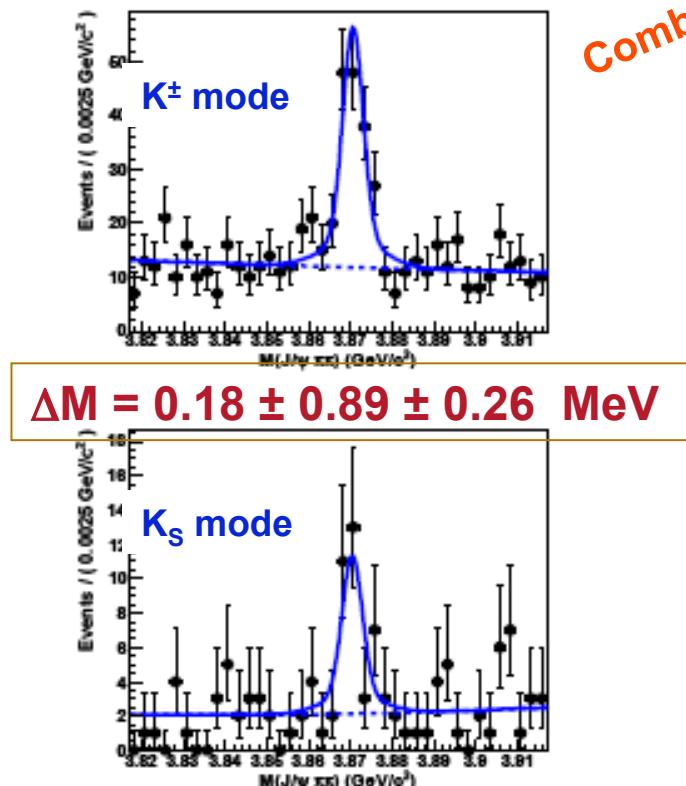
X(3872) and

1-- Y states via ISR



diquark-dantiquark expectations:
 $M(X_d) - M(X_u) = 2(m_d - m_u)/\cos\theta \sim 8 \pm 3$ MeV
 (Maiani et al PRD71 014028(2005))
 $B^0 \rightarrow K_s X_d ([dc][dc])$ & $B^+ \rightarrow K^+ X_u ([uc][uc])$
 arXiv:0809.1224(2008)

X(3872) Mass (in $\pi\pi J/\psi$ channel only)

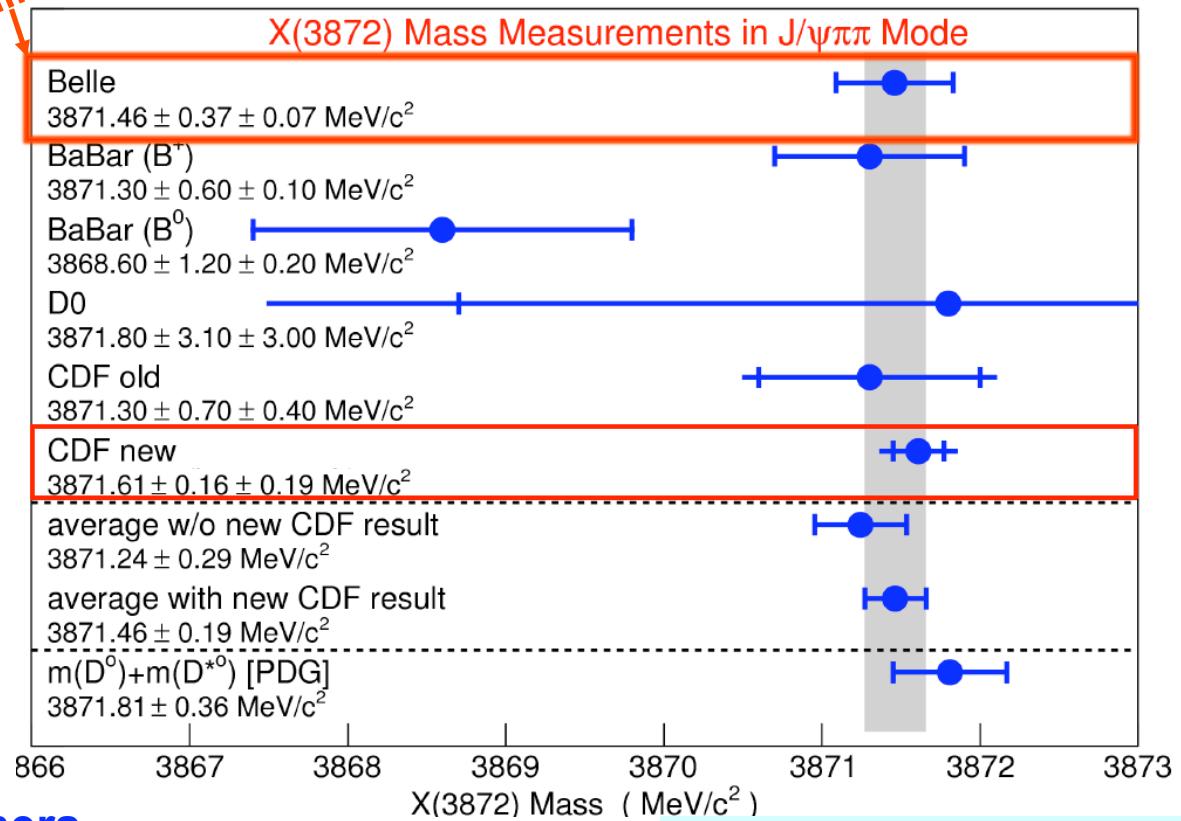


→ No evidence of neutral partners

$$\frac{\mathcal{B}(B^0 \rightarrow X(3872) K^0)}{\mathcal{B}(B^+ \rightarrow X(3872) K^+)} = 0.82 \pm 0.22 \pm 0.05$$

BaBar PRD77 111101(2008)
 $\Delta M = 2.7 \pm 1.6 \pm 0.4$ MeV
 $\frac{\mathcal{B}(B^0 \rightarrow X(3872) K^0)}{\mathcal{B}(B^+ \rightarrow X(3872) K^+)} = 0.41 \pm 0.24 \pm 0.05$

Combining B^0 & B^+

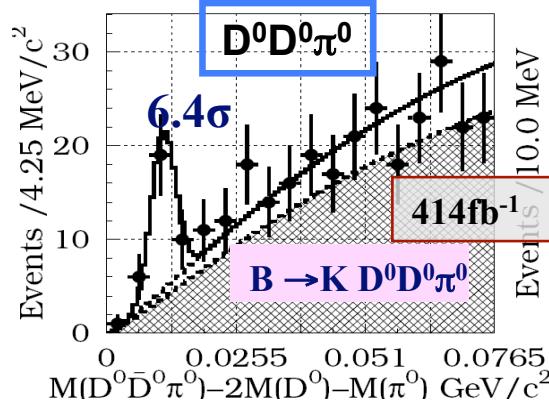


CDF arXiv:0906.5218 (2009)

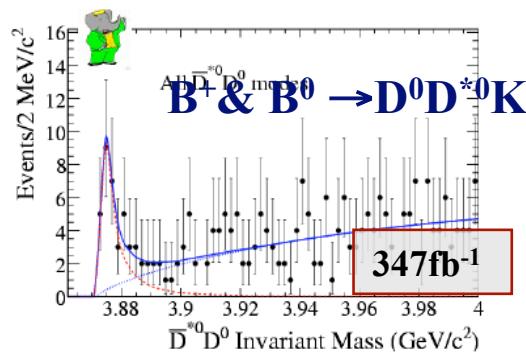
Avg: $M_{X(3872)} = 3871.5 \pm 0.2$ MeV
 PDG08: $M_{D0} + M_{D^*0} = 3871.8 \pm 0.4$ MeV

Does $X(3872) \rightarrow D\bar{D}^*$ peak at a higher mass?

PRL97, 162002 (2006)



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

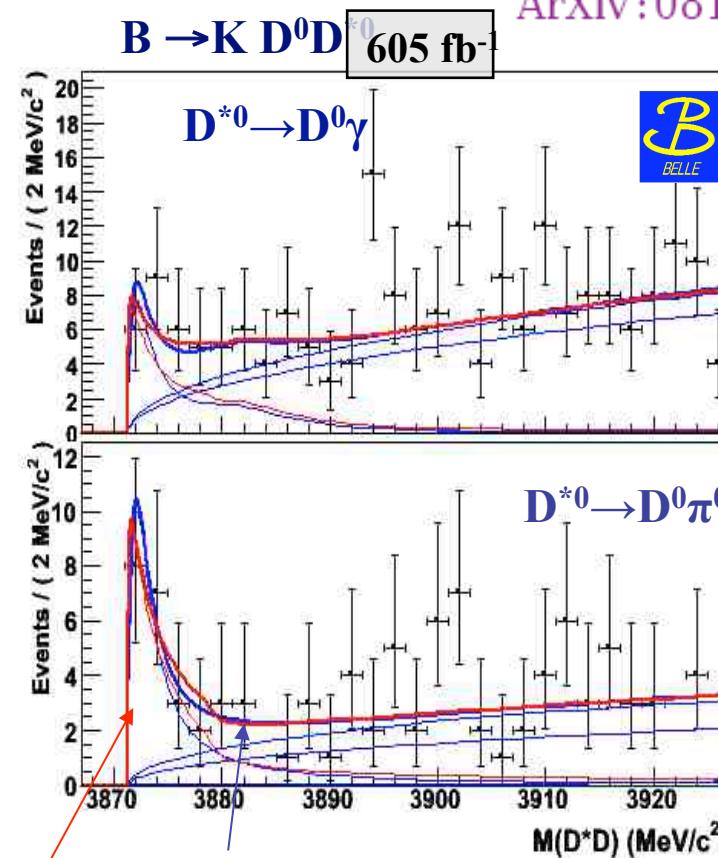


PRD77, 011102 (2008)

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

Both groups saw a high mass value
& a $Bf(D\bar{D}^*) \approx 10x Bf(\pi^+\pi^- J/\psi)$

ArXiv:0810.0358



Flatte vs BW fit give similar result: 8.8σ

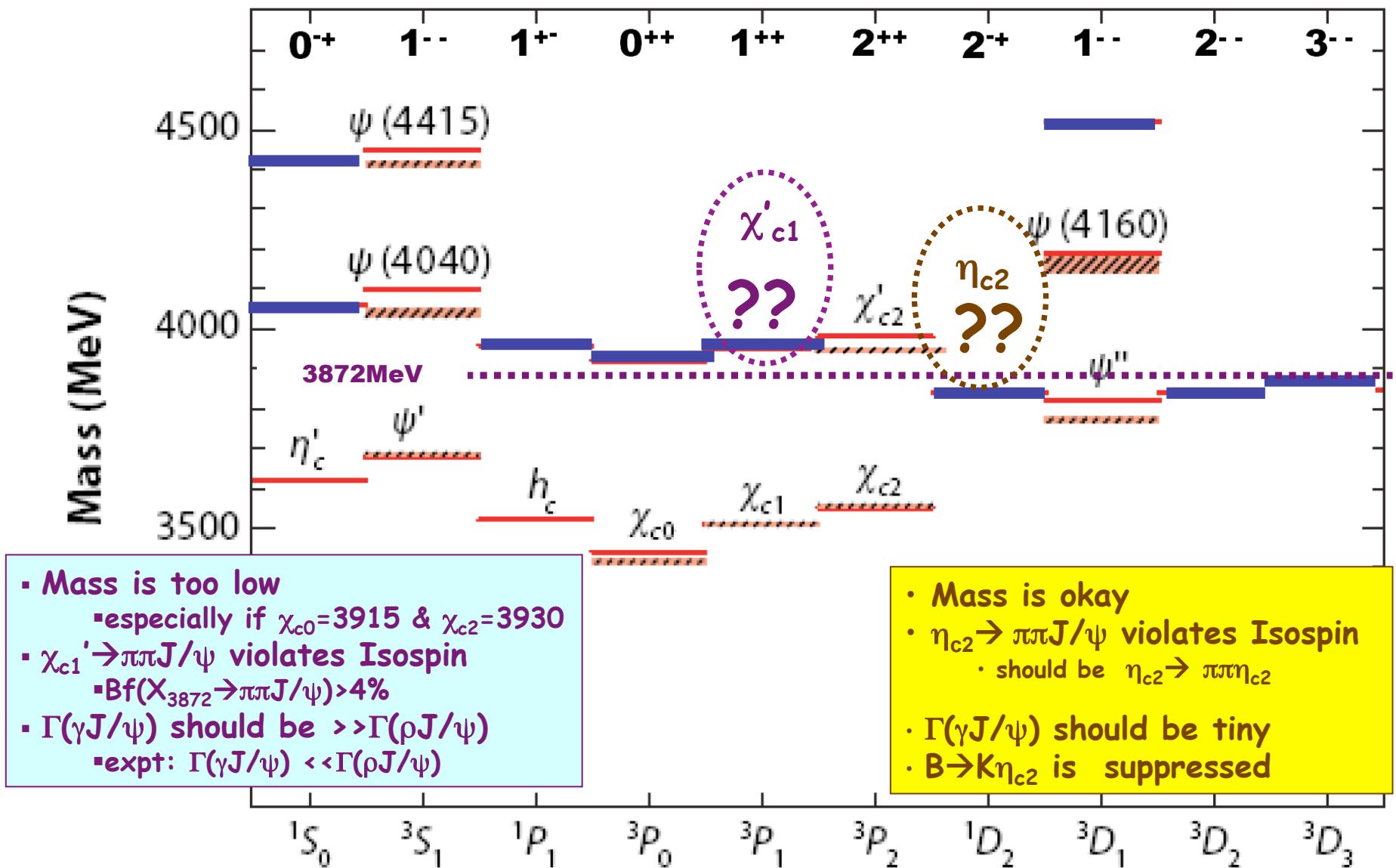
$$M = (3872.6^{+0.5}_{-0.4} \pm 0.4) \text{ MeV/c}^2$$

Agrees with Mass from $\pi\pi J/\psi$ mode

$$\Gamma(\text{BW}) = (3.9^{+2.5+0.8}_{-1.3-0.3}) \text{ MeV/c}^2$$

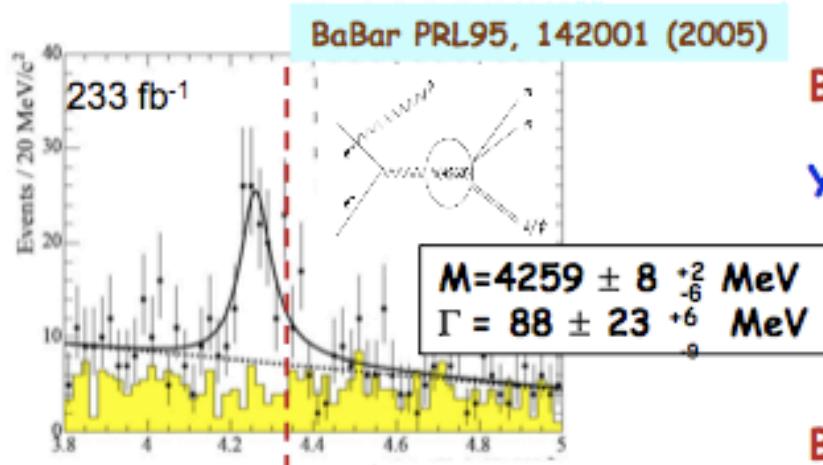
$$BR(B^0 \rightarrow XK) \times BR(X \rightarrow \bar{D}^{*0} D^0) = (0.73 \pm 0.17 \pm 0.08) \times 10^{-4}$$

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

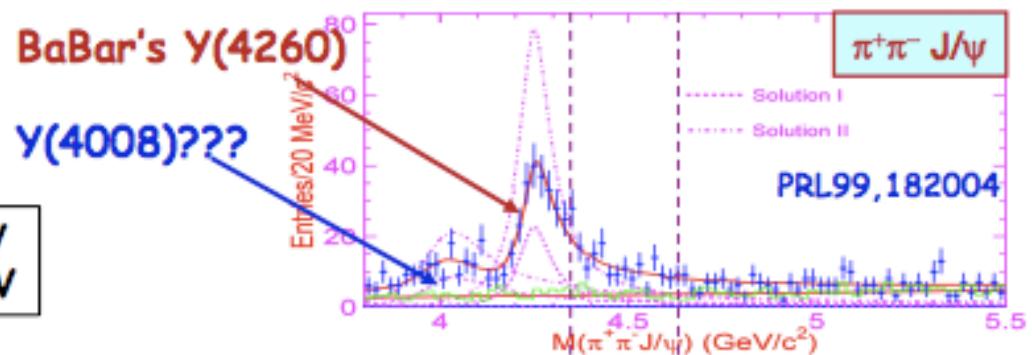
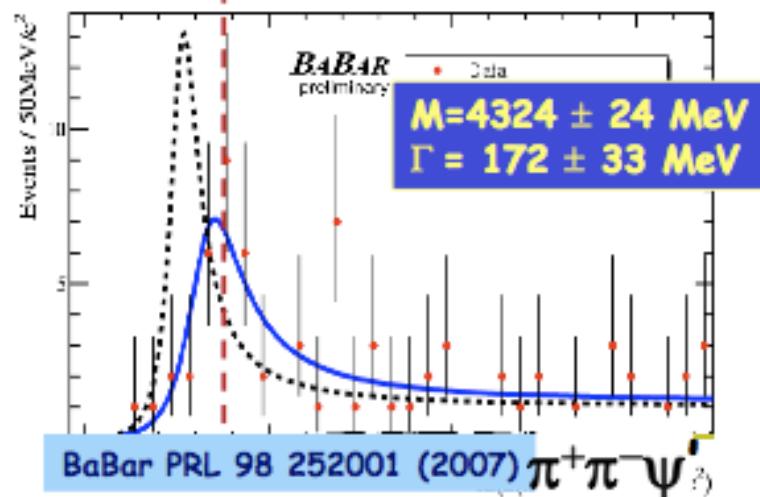


1-- Υ states via ISR

Belle's 1--

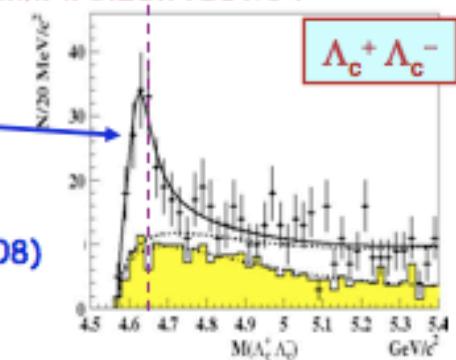


Not the same! $\pi^+\pi^- J/\psi$

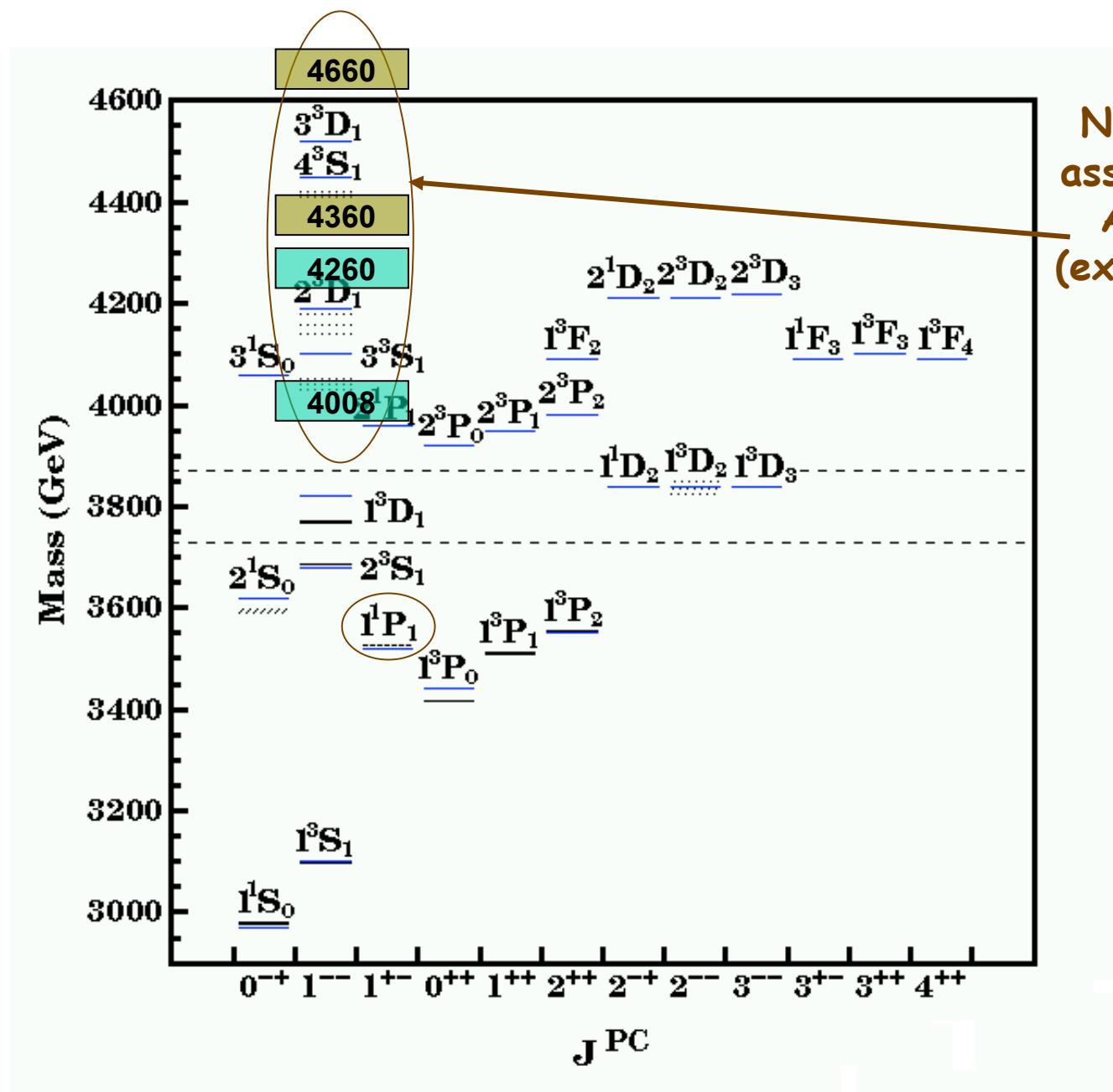


$M(\Lambda_c^+\Lambda_c^-)$
= $\Upsilon(4660)???$

PRL101, 172001(2008)



Are these 1^{--} $c\bar{c}$ states?

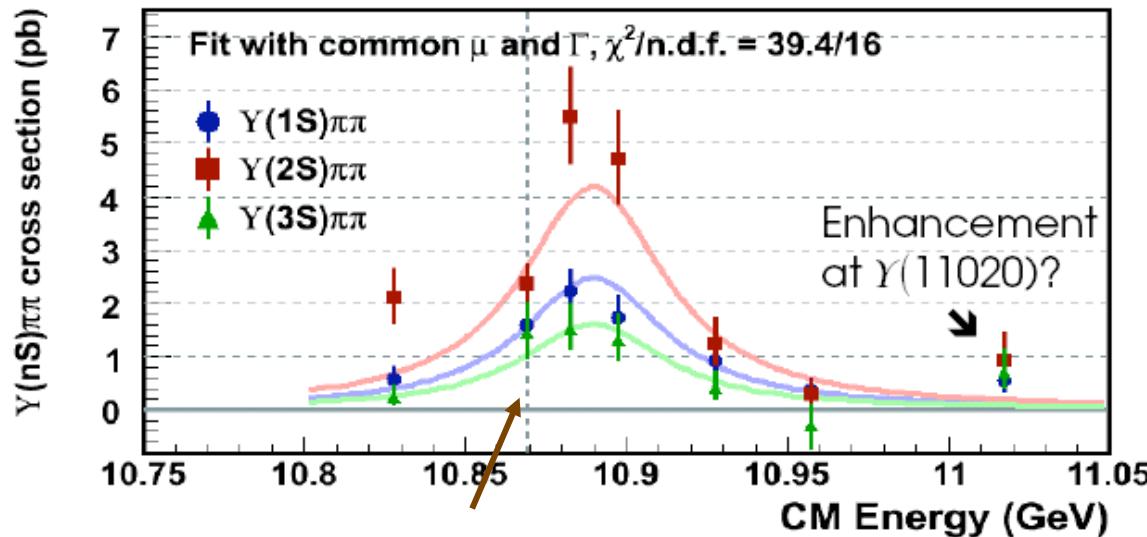


No unfilled charmonium assignments are available Above DD^* threshold (except, maybe, $\Upsilon(4008)$)

X_Y counterpart in the b_b (s_s) system ?

- $\Upsilon(5S) \rightarrow \Upsilon(1,2S)\pi\pi$
- $\Upsilon(2175)$ in $e^+e^- \rightarrow f_0(980)\phi \gamma_{ISR}$

$\Upsilon(nS) \pi\pi$ resonance shape

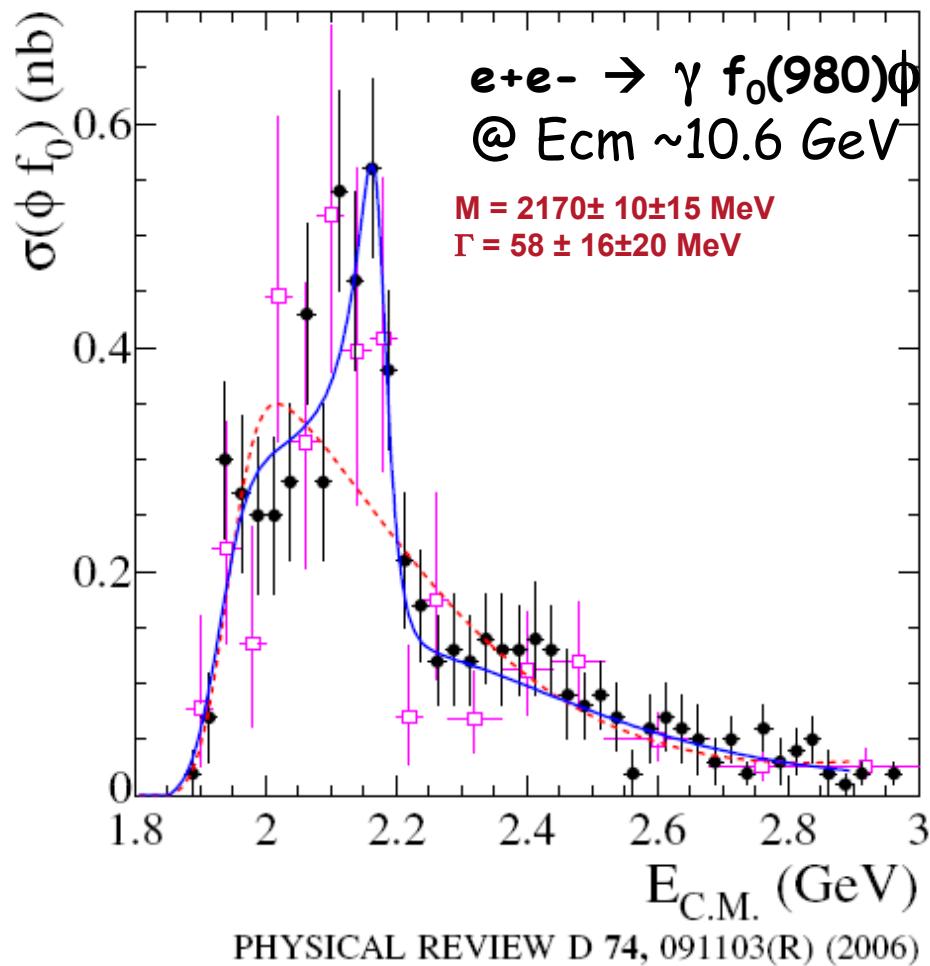


- Observe a new structure in $e^+e^- \rightarrow \Upsilon(nS) \pi\pi$ productions cross sections
- Breit-Wigner fit gives : $M = 10889.6 \pm 1.8 \pm 1.5 \text{ MeV}$
- $\Gamma = 54.7^{+8.5}_{-7.2} \pm 2.5 \text{ MeV}$
- This peak is not consistent with known bb state $\Upsilon(10860)$
- $\Gamma(\pi\pi\Upsilon(nS))$ is huge (500 times bigger than seen for known bottomonium)

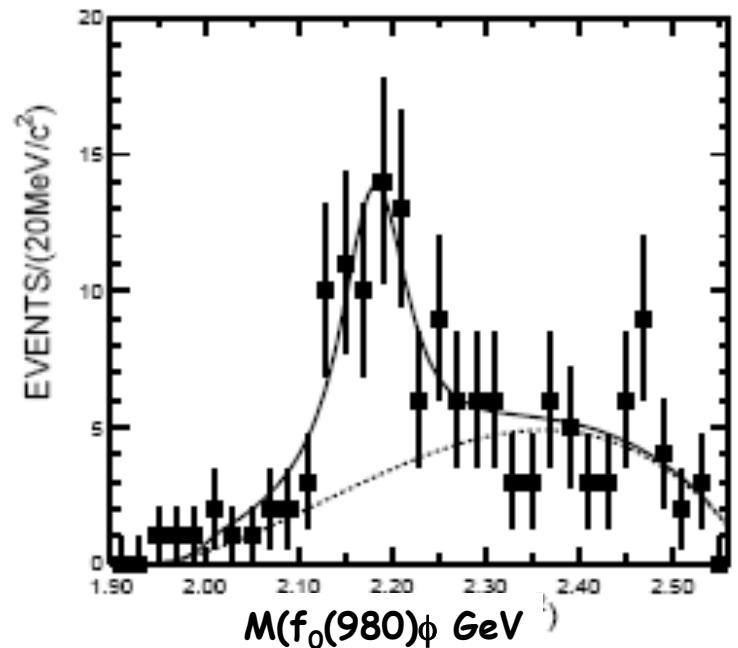
Belle PRL 100, 112001 (2008)

1⁻ Y_s states around 2 GeV?

$\gamma(2175) \rightarrow f_0(980)\phi$
from BaBar

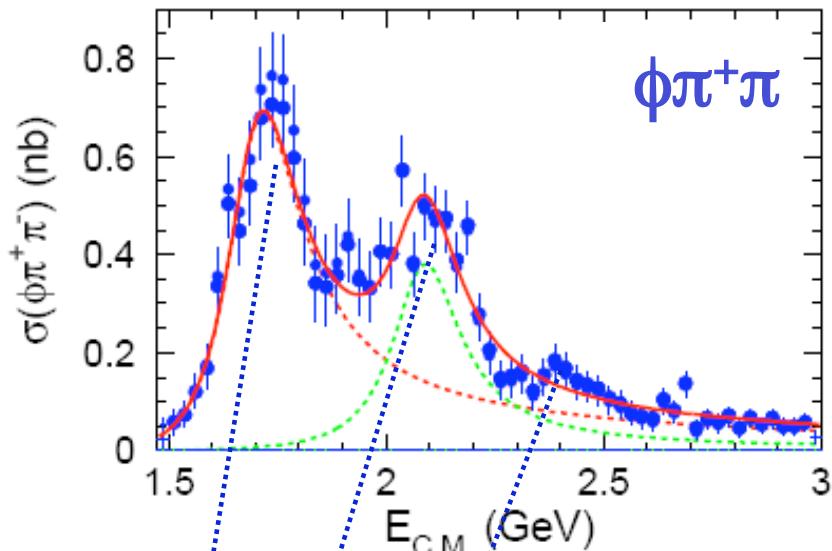


Confirmed by BESII in
 $J/\psi \rightarrow \phi f_0(980)\eta$



Belle's result

$e^+e^- \rightarrow \phi\pi^+\pi^-$ & $e^+e^- \rightarrow \phi f_0(980)$ via ISR



Two(+1 for third peak) coherent BW

$$M(\phi(1680)) = 1689 \pm 7 \pm 10 \text{ MeV}$$

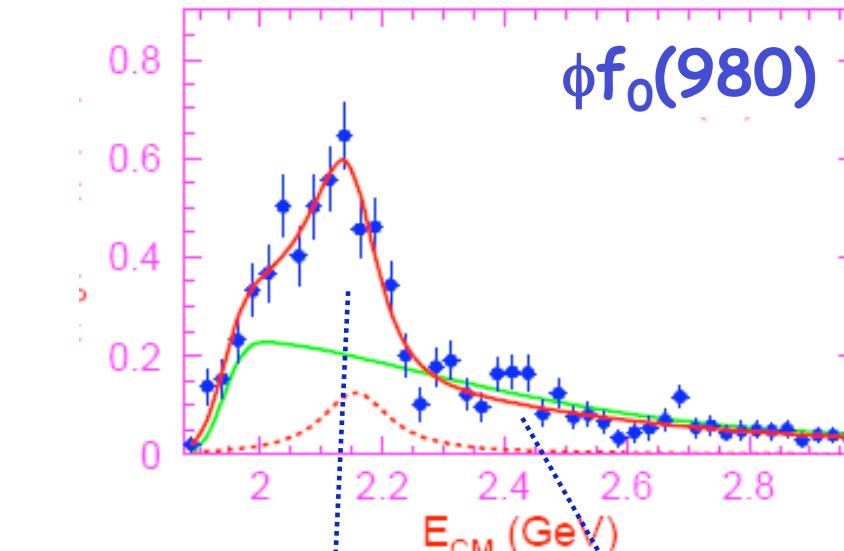
$$\Gamma(\phi(1680)) = 211 \pm 14 \pm 19 \text{ MeV}$$

$$M(Y(2175)) = 2079 \pm 13^{+9}_{-28} \text{ MeV}$$

$$\Gamma(Y(2175)) = 192 \pm 23^{+25}_{-61} \text{ MeV}$$

$$M = 2406 \pm 32 \text{ MeV}$$

$$\Gamma = 57 \pm 58 \text{ MeV} @ CL=8.0\% \& 1.5\sigma$$



One BW fcn interfering with non-resonant

$$M = 2163 \pm 32 \text{ MeV}$$

$$\Gamma = 125 \pm 40 \text{ MeV}$$

M & width are
Consistent : 2.3σ

- Agree with Babar's and BES's measurement
- Width is larger than prev measurements
- Both widths are similar at ~200 MeV → suggest that a possibility $Y(2175) = \text{excited } \phi$
- Y_s or excited ss states ?

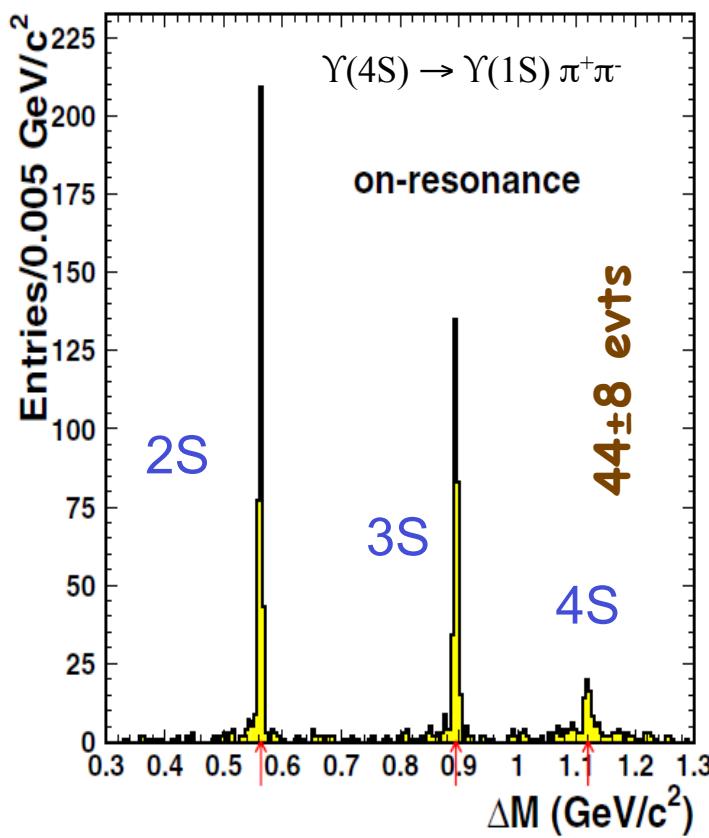
Summary

- **X(3915)** in $\gamma\gamma \rightarrow \omega J/\psi$
 - consistent with "Y(3940)" seen in $B \rightarrow K\omega J/\psi$
 - likely $J^{PC} = 0^{++}$ (maybe 2^{++})
- Charged resonancelike Z^+ states
 - $Z_1(4050)$ & $Z_2(4250)$ were observed by Dalitz plot analysis
 - The $Z^+(4430)$ is confirmed by the same Dalitz plot analysis. Its mass, width and BF are refined.
 - no confirmation from BaBar
 - Not a reflection from the $K\pi$ system interference
 - It has non-zero charge → not cc or hybrid
 - Product Branching Fractions comparable to other charmonium-like states
- Updates on X and $1^- - Y$ states
- Possible analog of Y states in $b\bar{b}$ & $s\bar{s}$ system

Backup

Belle: $\Gamma(\Upsilon(5S) \rightarrow \pi\pi\Upsilon(nS))$ is Huge!!!

$\Upsilon(4S) \rightarrow \pi\pi\Upsilon(1S)$
 477 fb^{-1} from Belle

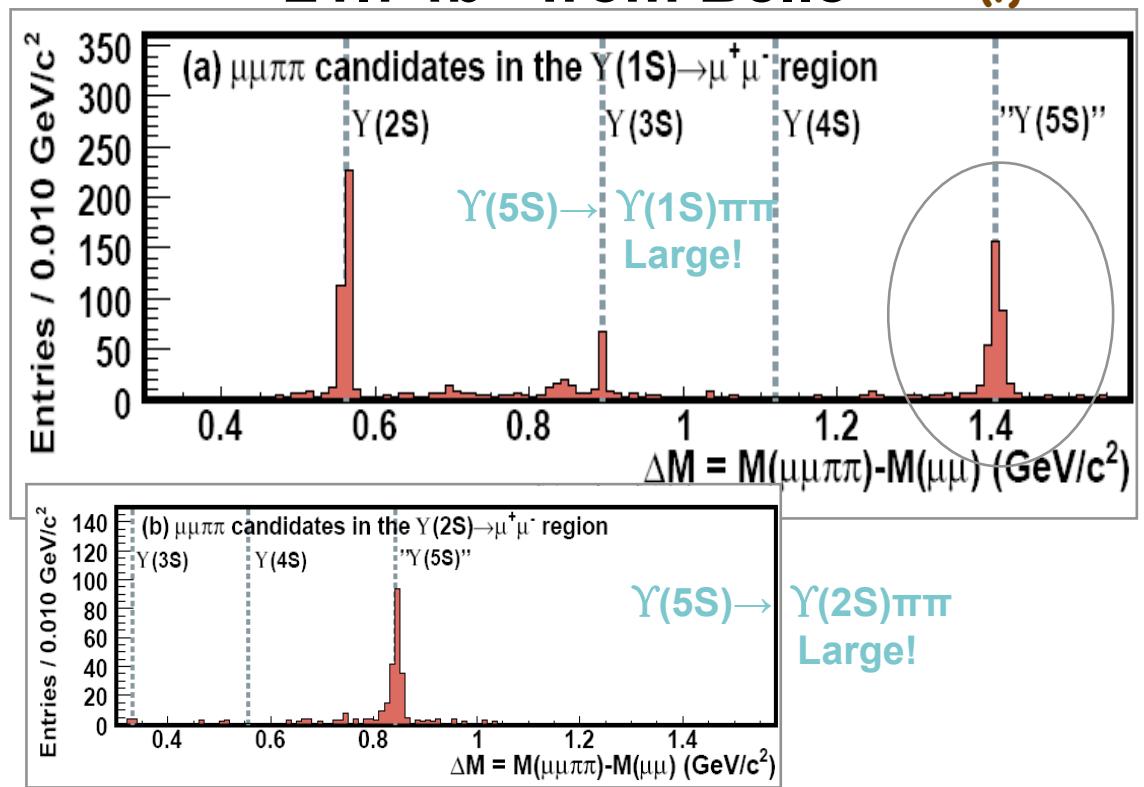


Belle PRD 75, 071103 (2007)

(1/20 times as many events!
 $\sim 1/10^{\text{th}}$ the data &
 the crosssection)

$\Upsilon(5S) \rightarrow \pi\pi\Upsilon(1S)$
 21.7 fb^{-1} from Belle

$325 \pm 20 \text{ evt!}$



Partial Widths

Assume “ $\Upsilon(5S)$ ” = $\Upsilon(5S)$

PDG value taken for $\Upsilon(nS)$ properties

Process	N_s	Σ	Eff. (%)	$\sigma(\text{pb})$	$\mathcal{B}(\%)$	$\Gamma(\text{MeV})$
$\Upsilon(1S)\pi^+\pi^-$	325^{+20}_{-19}	20σ	37.4	$1.61 \pm 0.10 \pm 0.12$	$0.53 \pm 0.03 \pm 0.05$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(2S)\pi^+\pi^-$	186 ± 15	14σ	18.9	$2.35 \pm 0.19 \pm 0.32$	$0.78 \pm 0.06 \pm 0.11$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(3S)\pi^+\pi^-$	$10.5^{+4.0}_{-3.3}$	3.2σ	1.5	$1.44^{+0.55}_{-0.45} \pm 0.19$	$0.48^{+0.18}_{-0.15} \pm 0.07$	$0.52^{+0.20}_{-0.17} \pm 0.10$

N.B. $\Upsilon(5S)$ resonance cross section
 $0.302 \pm 0.015 \text{ nb}$ at 10.87 GeV
 PRL 98, 052001 (2007) [Belle]

>100 times bigger!!

<i>bb</i>	$\Gamma(\text{total})$	$\Gamma(\Upsilon(1S)\pi\pi)$	<i>cc</i>	$\Gamma(\text{total})$	$\Gamma(J/\psi\pi\pi)$
$\Upsilon(2S)$	32 KeV	6.0 KeV	$\psi(2S)$	337 KeV	107 KeV
$\Upsilon(3S)$	20 KeV	0.9 KeV	$\psi(3770)$	23 MeV	44 KeV
$\Upsilon(4S)$	20.5 MeV	1.8 KeV	$\psi(4040)$	80 MeV	<320 KeV @90%
" $\Upsilon(5S)$ "	110 MeV	$\sim 0.5 \text{ MeV}!!$	$\psi(4160)$	103 MeV	<309 KeV @90%
			$\Upsilon(4260)$	83 MeV	$O(>\text{MeV})$

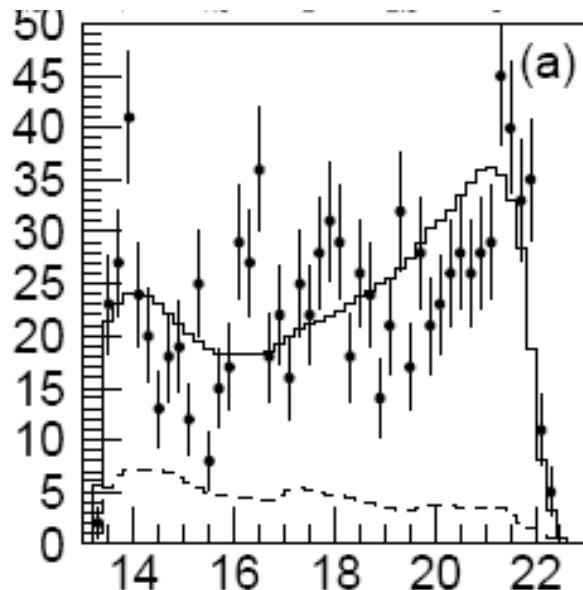
- Is there a $\bar{b}b$ version of the $\Upsilon(4260)$ lurking around the $\Upsilon(5S)$?
 (W.-S.Hou PRD 74, 017504(2007))
- Belle did a scan of $\pi^+\pi^-\Upsilon(nS)$ production measurements above & below the $\Upsilon(5S)$ in order to search for such a state.

Fit fractions and Significances

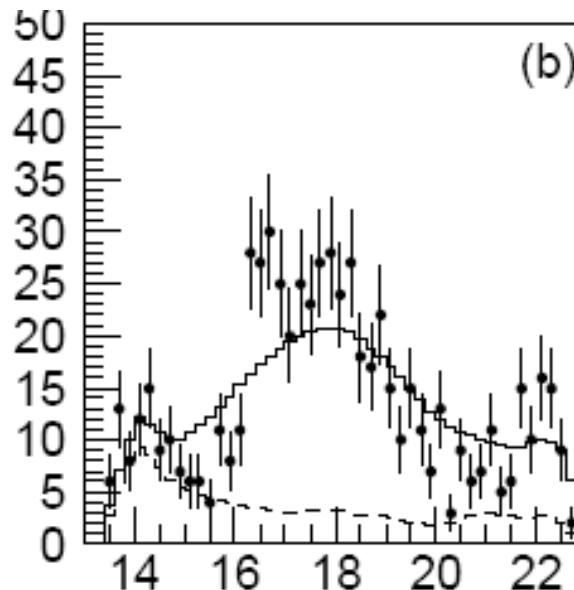
Contribution	Fit fraction (%)	Significance
$Z(4430)^+$	$5.7^{+3.1}_{-1.6}$	6.4σ
κ	$4.1^{+3.4}_{-1.1}$	1.5σ
$K^*(892)$	$64.8^{+3.8}_{-3.5}$	huge
$K^*(1410)$	$5.5^{+8.8}_{-1.5}$	0.5σ
$K_0^*(1430)$	5.3 ± 2.6	1.3σ
$K_2^*(1430)$	$5.5^{+1.6}_{-1.4}$	3.1σ
$K^*(1680)$	$2.8^{+5.8}_{-1.0}$	1.2σ

Only show slices a&b (but fit to the entire Dalitz plot)

Fit model: all known K^* resonances + No ($\chi_{c1}\pi$) resonances



$$M^2(\chi_{c1}\pi)$$



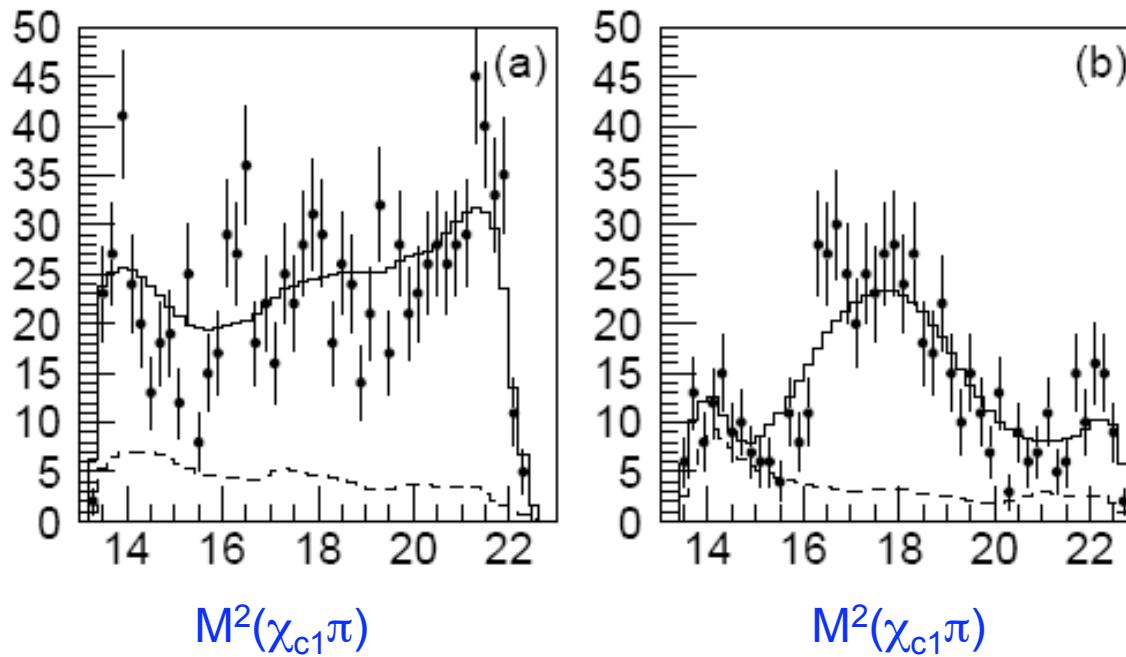
$$M^2(\chi_{c1}\pi)$$

From a toy MC & a binned version of the Dalitz Plot: fit CL= 4×10^{-12}

Add a non-resonant $K\pi$ term

Fit model: all known K^* resonances + non-resonant $\chi_{c1}\pi K + K_2^*$

$$[\exp\{-M(\chi_{c1}K)\} + \exp\{-M(\chi_{c1}\pi)\}]$$

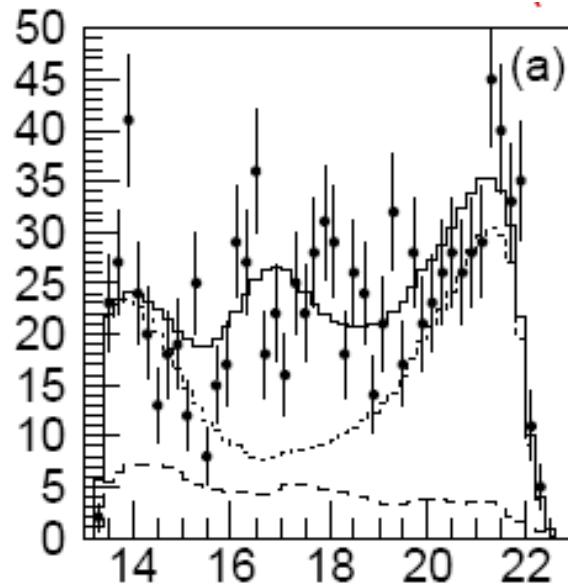


Toy MC fit CL= 2×10^{-4}

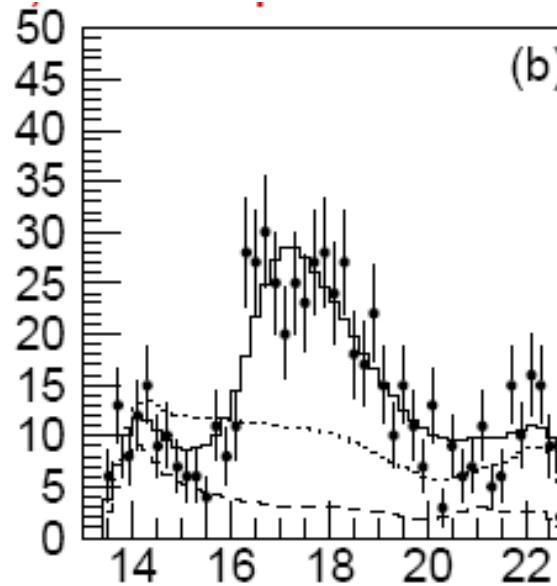
Add a single $\pi^+\chi_{c1}$ resonance (Z^+)

$J=0$

Fit model: all known K^* resonances + one ($\chi_{c1}\pi$) resonance



$M^2(\chi_{c1}\pi)$



$M^2(\chi_{c1}\pi)$

- data
- fit result
- - background
- fit function w/o Z

Toy MC fit CL= 0.1%

$M_Z = 4150^{+31}_{-16}$ MeV

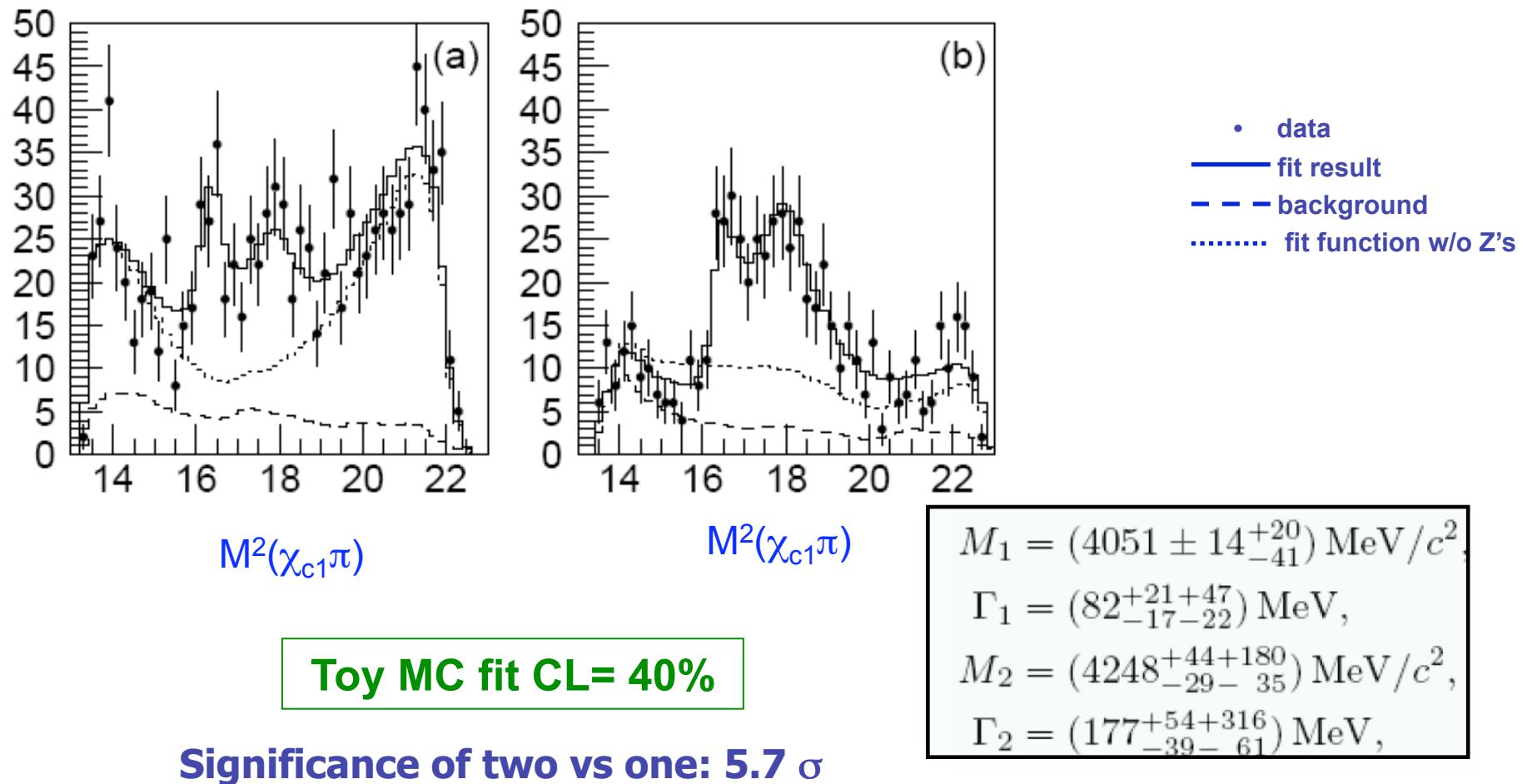
$\Gamma_Z = 352^{+99}_{-43}$ MeV

Significance: 10.7σ

Add two $\pi^+\chi_{c1}$ resonances (Z_1^+ & Z_2^+)

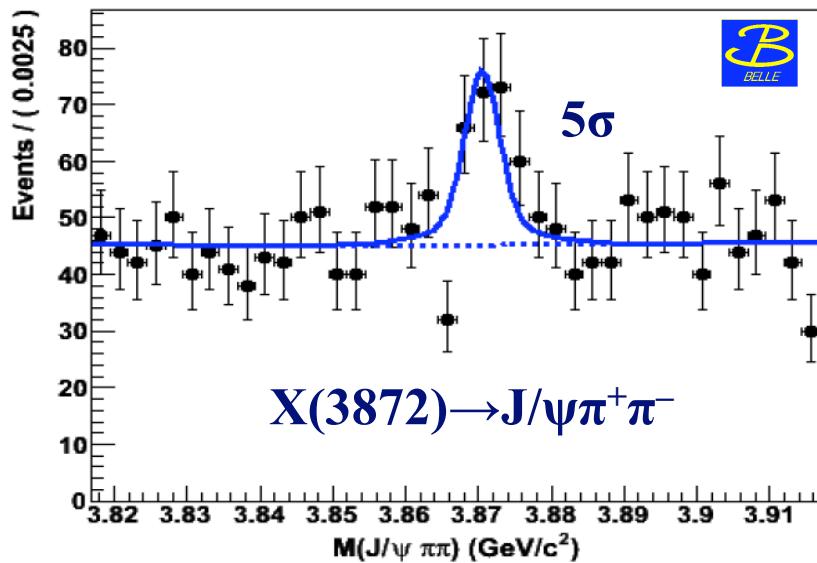
$J_1=0, J_2=0$

Fit model: all known K^* resonances + two ($\chi_{c1}\pi$) resonances

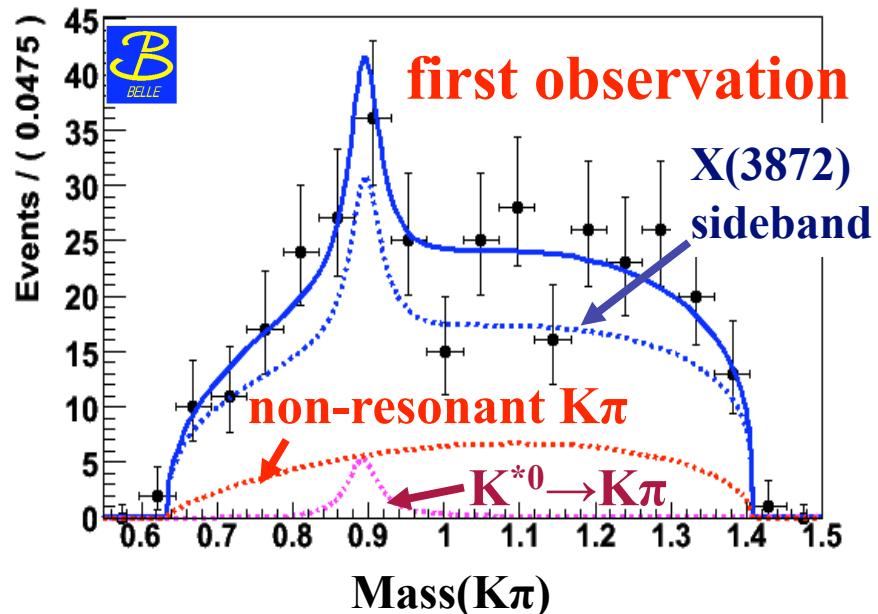


$B^0 \rightarrow X(3872) K^+ \pi^-$ ($B \rightarrow X(3872) K^*?$)

arXiv:0809.1224(2008)



$N_{\text{sig}} = 91 \pm 19$ ($N_{\text{sig}} = 8.2 \pm 10.0$)

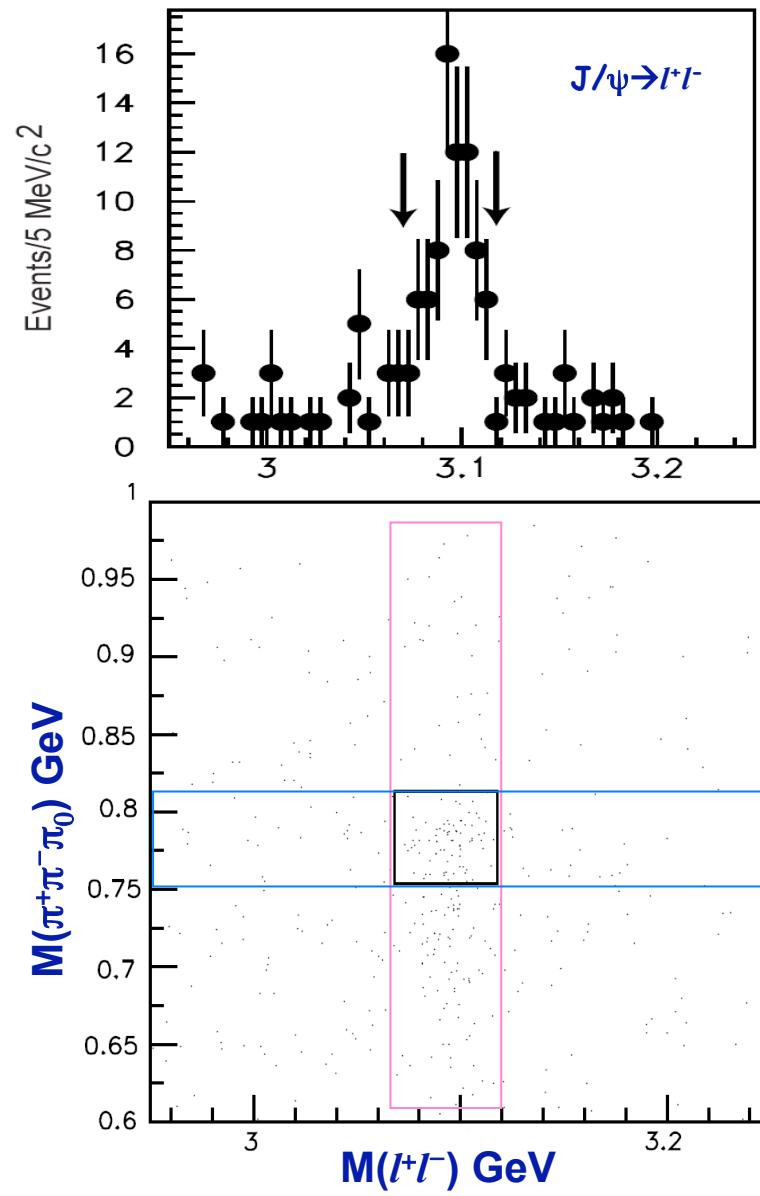
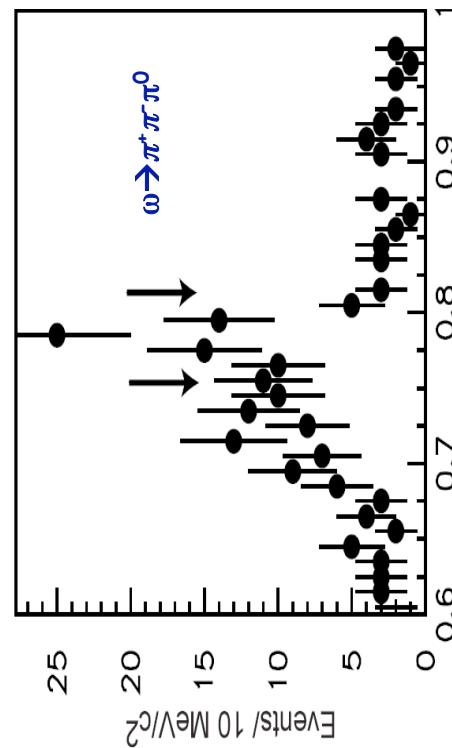


$$\begin{aligned} \text{Br}(B^0 \rightarrow X(K^+\pi^-)_{\text{non_res}}) \times \text{Br}(X \rightarrow J/\psi \pi^+ \pi^-) &= (8.1 \pm 2.0 {}^{+1.1}_{-1.4}) \times 10^{-6} \\ \text{Br}(B^0 \rightarrow XK^{*0}) \times \text{Br}(X \rightarrow J/\psi \pi^+ \pi^-) &< 3.4 \times 10^{-6} \quad @90\% \text{ CL} \end{aligned}$$

$B^0 \rightarrow X(3872) K^+ \pi^-$ is dominant; $X(3872) K^*$ is small

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

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



Belle/BaBar comparison

