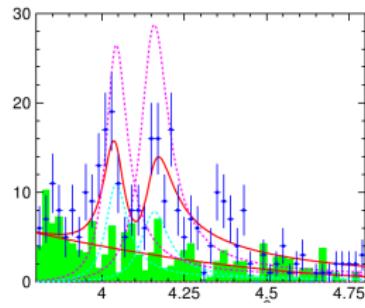


Charmonium and exotic particles at Belle

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(<http://www.coepp.org.au/>)

36th International Conference on High Energy Physics,
Melbourne; 5th July 2012



Introduction

Renewal of charmonium (properly, *hidden-charm*) physics last decade:

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 - $Y(4260)$, 1^{--} supernumerary state; hybrid candidate
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- $Y(4260)$, 1^{--} supernumerary state; hybrid candidate
- many more claimed exotic candidates, including charged states
- several new conventional states; $(c\bar{c})_{res}$ production still mysterious

1 X(3872) studies

- The state of play
- Search for $\gamma\chi_{c1,c2}$ decays
- Search for $\eta\psi$ decays

2 Searches for charged states

- Some history
- Search for $Z^+ \rightarrow \pi^+\psi$
- Search for $Z^+ \rightarrow \pi^+\psi$

3 ISR studies of 1^{--} states

X(3872): the old state of play at September 2006

BY@QWG2011; adapted from Nucl. Phys. (Proc. Suppl.) 170, 248–253 (2007)

- narrow; prominent $\pi^+\pi^-\psi$ decay [Belle discovery; CDF, D0, BaBar]
 - $\mathcal{B}(X \rightarrow \pi^+\pi^-\psi) > 4.2\%$ [BaBar inclusive, PRD 71, 031501]
 - $\Gamma < 2.3 \text{ MeV}$ (90% C.L.) [Belle discovery]
- $M = (3871.2 \pm 0.5) \text{ MeV} \lesssim (m_{D^0} + m_{D^*})$ by 1σ [WA; CLEO]
- $p\bar{p}$ prodⁿ: $(16 \pm 5 \pm 2)\%$ b -decay, rest prompt; “ ψ' -like” [CDF]
- X^\pm not seen: not an isovector [BaBar PRD 71, 031501]
- C-even, from $X \rightarrow \gamma\psi$ [Belle, BaBar] and $\pi^0\pi^+\pi^-\psi$ [Belle]
 - $X \rightarrow \rho\psi$ dominates, $L = 0, 1$ [CDF $M(\pi^+\pi^-)$ PRL 96, 102002]
 - $J^{PC} = 1^{++}$ or 2^{-+} [CDF angular PRL 98, 132002]
- $B^+ \text{ vs } B^0 \rightarrow K X$ “needs more data” TM [BaBar PRD 73, 011101(R)]
- X peak in $B \rightarrow K D^0 \overline{D}^0 \pi^0$ needs confirmⁿ [Belle PRL 97, 162002]
- loose ends: $\pi^0\pi^0\psi$, $\gamma\psi'$, $\pi^+\pi^-\eta_c$, $\gamma D\overline{D}$

X(3872): the new state of play at October 2011

BY@QWG2011; adapted from Nucl. Phys. (Proc. Suppl.) 170, 248–253 (2007)

- narrow; prominent $\pi^+\pi^-\psi$ decay [Belle discovery; CDF, D0, BaBar]
 - $\mathcal{B}(X \rightarrow \pi^+\pi^-\psi) > 4.2\%$ [BaBar inclusive, PRD 71, 031501]
 - $\Gamma < 1.2 \text{ MeV}$ (90% C.L.) [Belle PRD 84, 052004]
- $M = (3871.71 \pm 0.19) \text{ MeV} \stackrel{\Delta \ll \sigma}{=} (m_{D^0} + m_{D^*})$ [private WA; $S < 1$]
- $p\bar{p}$ prodⁿ: $(16 \pm 5 \pm 2)\%$ b -decay, rest prompt; “ ψ' -like” [CDF]
- X^\pm still not seen: not an isovector [BaBar; Belle PRD 84, 052004]
- C-even, from $X \rightarrow \gamma\psi$ [Belle, BaBar] and $\pi^0\pi^+\pi^-\psi$ [Belle]
 - $X \rightarrow \rho\psi$ dominates, $L = 0, 1$ [CDF & Belle $M(\pi^+\pi^-)$]
 - $J^{PC} = 1^{++}$ or 2^{-+} [CDF & Belle angular; note BaBar $\pi^0\pi^+\pi^-\psi$]
- $B^+ \text{ vs } B^0 \rightarrow K X$: ΔM disfavoured [BaBar & Belle]
- large $\mathcal{B}(X \rightarrow (\{\gamma, \pi^0\}D^0)_{D^{*0}}\bar{D}^0)$ [Belle & BaBar]
- loose ends: $\pi^0\pi^0\psi$, $\gamma\psi'$, $\pi^+\pi^-\eta_c$, $\{\gamma, \pi^0\}D\bar{D}$ lineshape
 - **radiative (disputed) & lineshape crucial for structure**

X(3872): results from the LHC ...

LHCb X(3872) production: EPJC 72, 1972 (2012) {arXiv:1112.5310v1 [hep-ex]}

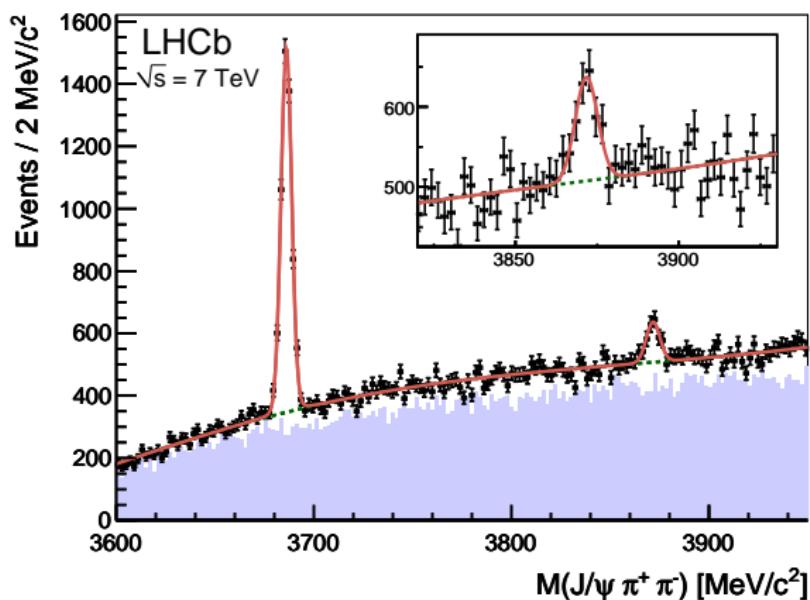
from the 2010 data:

$$p_t^X \in [5, 20] \text{ GeV}, \\ y^X \in [2.5, 4.5];$$

$$\sigma(\text{pp} \rightarrow X + \text{any}) \times \mathcal{B}_{X \rightarrow \pi\pi\psi} = 5.4 \pm 1.3 \pm 0.8 \text{ nb};$$

2.4σ below $13.0 \pm 2.7 \text{ nb}$
 (Artoisenet & Braaten,
 PRD 81, 114018 (2010))

mass measurement is
 already 2nd-most precise
 (after Belle 2011)



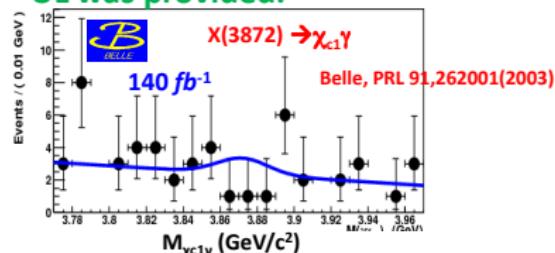
$$m_X = 3871.95 \pm 0.48 \text{ (stat.)} \pm 0.12 \text{ (syst.)} \text{ MeV}/c^2$$

$$cf. \text{ WA} = 3871.71 \pm 0.19 \text{ MeV}/c^2 \text{ (private, from QWG2011/Darmstadt)}$$

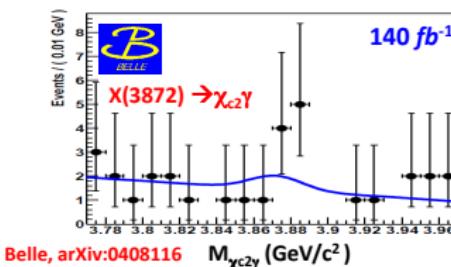
Search for $\gamma\chi_{c1,c2}$ decays

abstract 720; BELLE-CONF-1234; longer presentation: V.Bhardwaj at Charm 2012

- ❖ Earlier search for tetraquark partner (charged X(3872)), no signal was seen.
Belle, PRD 85,052004 (2011)
- ❖ However, many tetraquark models predict X(3872)⁺ to be broad and non-observed yet due to low statistics (?).
K. Terasaki, Prog. Theor. Phys. 127, 577-582 (2012)
- ❖ X(3872) C-even parity prohibit it to decay into $\chi_{c1,c2}\gamma$.
- ❖ If X(3872) is tetraquark than its' C-odd partner can decay into $\chi_{c1,c2}\gamma$.
- In Belle previous searches (with less data), no signal was seen and UL was provided.



$$\frac{\Gamma(X3872 \rightarrow \chi_{c1}\gamma)}{\Gamma(X3872 \rightarrow J/\Psi\pi\pi)} < 0.9$$



$$\frac{\Gamma(X3872 \rightarrow \chi_{c2}\gamma)}{\Gamma(X3872 \rightarrow J/\Psi\pi\pi)} < 1.1$$

With 5 x more data either we can observe or provide much tighter constraint to C-odd partner of X(3872)

6

Search for $\gamma\chi_{c1,c2}$ decays

abstract 720; BELLE-CONF-1234; longer presentation: V.Bhardwaj at Charm 2012

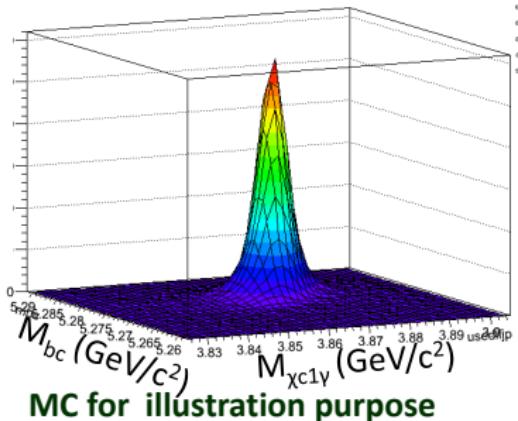
Reconstruct B^\pm (of interest)

To reduce background

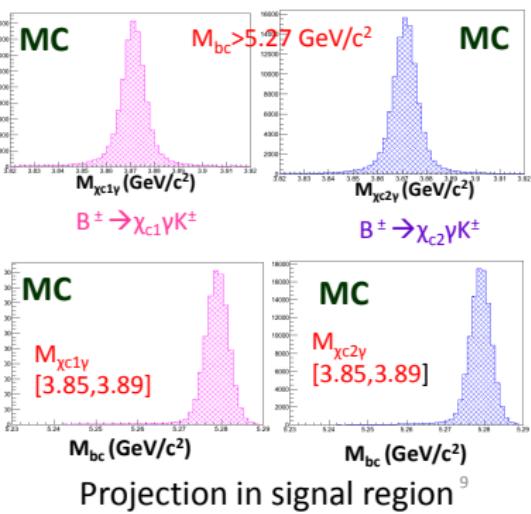
- π^0 veto
- $\chi_{c1,c2} \gamma$ veto

-28 MeV < ΔE < 30 MeV

E_γ scaled ($\Delta E=0$) to improve
the resolution of $M_{\chi_{c1,c2}\gamma}$

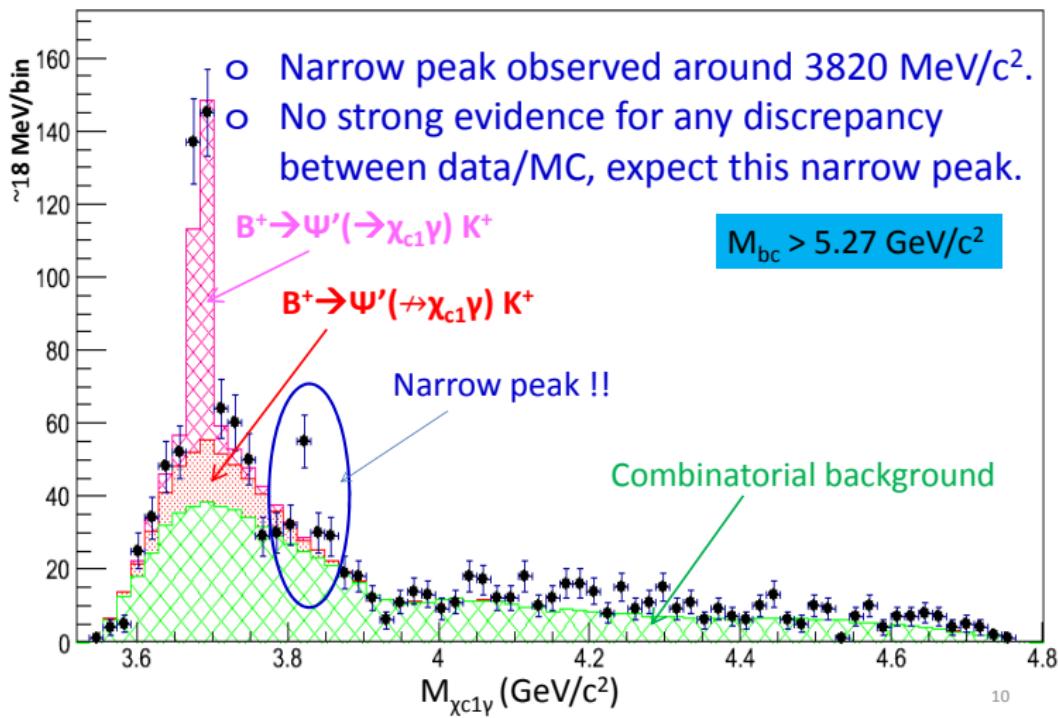


- 2D UML fit to $M_{\chi_{c1,c2}\gamma}$ & M_{bc} extract signal yield
- If some new resonance, it will become visible in $M_{\chi_{c1,c2}\gamma}$, in M_{bc} signal region.



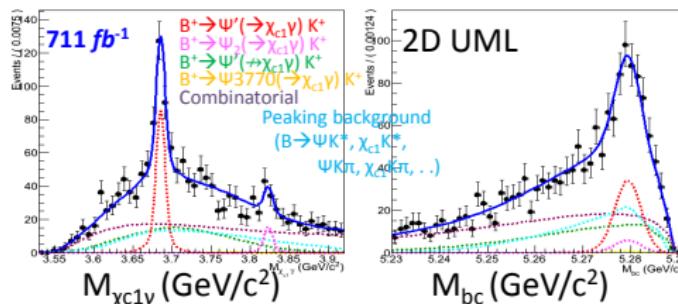
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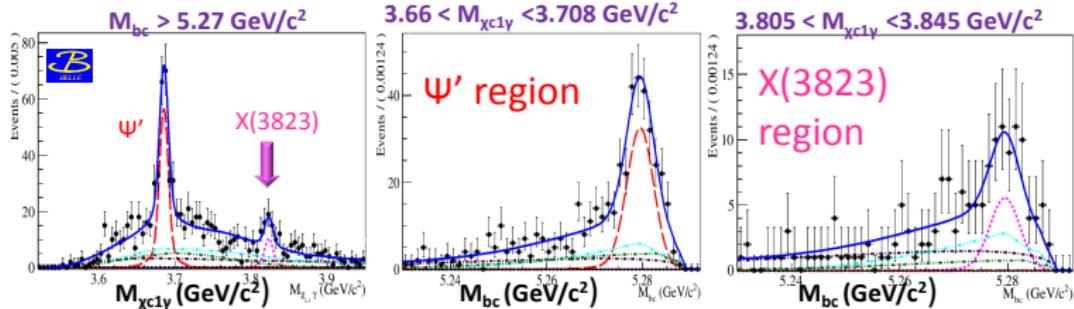
Peak at
 $3823.5 \pm 2.8 \text{ MeV}/c^2$

Yield: 4.2σ (syst. Included)
 33.2 ± 9.1

Clear evidence of
 signal at $3823 \text{ MeV}/c^2$

Projection in signal region

$\Gamma = 4 \pm 6 \text{ MeV}$ if fitted, poor sensitivity



Search for $\gamma\chi_{c1,c2}$ decays

abstract 720; BELLE-CONF-1234; longer presentation: V.Bhardwaj at Charm 2012

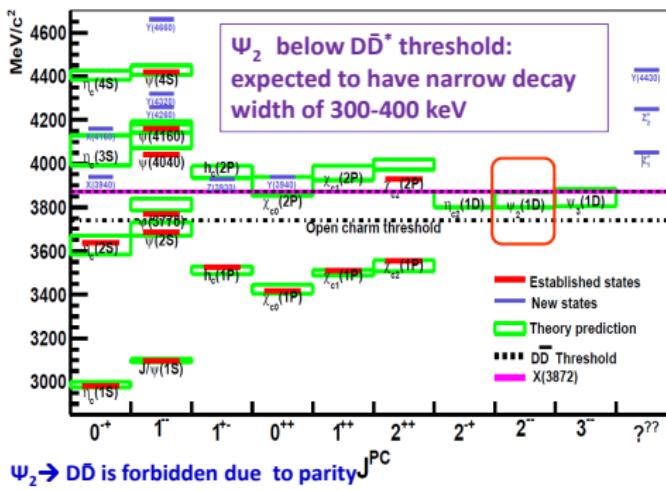


TABLE III: Charmonium spectrum including the influence of open-charm channels. All masses are in MeV. The penultimate column holds an estimate of the spin splitting due to tensor and spin-orbit forces in a single-channel potential model. The last column gives the spin splitting induced by communication with open-charm states, for an initially un-split multiplet.

State	Mass	Centroid	Splittng (Potential)	Splittng (Induced)
1^3S_0	2 979.9 ^a	3 067.6 ^b	-90.5	+2.8
1^3S_1	3 096.9 ^a		+30.2	-0.9
1^3D_0	3 415.3 ^a		-114.9 ^c	+5.9
1^3D_1	3 510.5 ^a		-11.6 ^c	-2.0
1^3P_1	3 525.3	3 525.3 ^c	+1.5 ^c	+0.5
1^3P_2	3 556.2 ^a		-31.9 ^c	-0.3
2^3S_0	3 637.7 ^a	3 673.9 ^b	-50.4	+15.7
2^3S_1	3 686.0 ^a		+16.8	-5.2
1^3D_1	3 769.9 ^a		-40	-39.9
1^3D_2	3 830.0	(3 815) ^d	0	
1^3D_3	3 880.0		0	+4.2
2^3D_3	3 886.3		+20	+19.0
2^3P_0	3 931.9		-90	+10
2^3P_1	4 007.5	3 968 ^d	-8	+28.4
2^3P_2	3 968.0		0	-11.9
2^3P_3	3 966.5		+25	-33.1

^aObserved mass, from *Review of Particle Physics*, Ref. [13].

^bInputs to potential determination.

^cObserved 1^3P_J centroid.

^dComputed.

^eRequired to reproduce observed masses.

3D_3 doesn't have E1 transition to $\chi_{c1}\gamma$



3D_2 mass is quite near and the observed peak has not been seen in $D\bar{D}$ ($^3D_2 \rightarrow D\bar{D}$ is expected).

X(3823) seems to be the missing Ψ_2 from the charmonium spectrum .

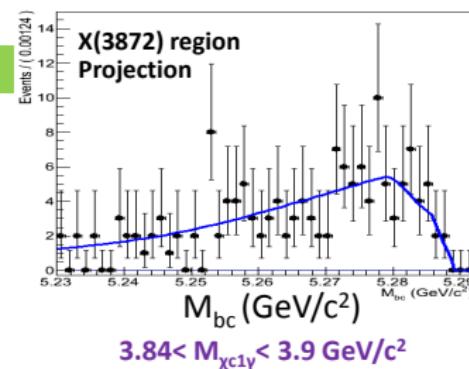
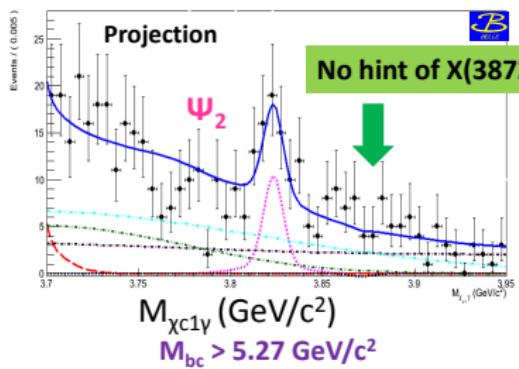
13

S. Godfrey & N. Isgur, PRD 32, 189 (1985)
E. Eichten et al., PRL 89, 162002 (2002),
PRD 69, 094019 (2004)

Search for $\gamma\chi_{c1,c2}$ decays

abstract 720; BELLE-CONF-1234; longer presentation: V.Bhardwaj at Charm 2012

X(3872) yield : -0.9 ± 5.1 events



No signal is observed in the X(3872) region.

$$\text{B.R.}(B^\pm \rightarrow X(3872)K^\pm) \times \text{B.R.}(X(3872) \rightarrow \chi_{c1}\gamma) < 2.0 \times 10^{-6} \text{ (@90% CL)}$$

$$\frac{\Gamma(X3872 \rightarrow \chi_{c1}\gamma)}{\Gamma(X3872 \rightarrow J/\Psi\pi\pi)} < 0.26$$

Belle, PRD 85,052004 (R) (2011)

* Recent Belle result used for $\text{BR}(B \rightarrow X3872 K) * \text{BR}(X3872 \rightarrow J/\Psi\pi^+\pi^-)$.

14

Search for $\gamma\chi_{c1,c2}$ decays

abstract 720; BELLE-CONF-1234; longer presentation: V.Bhardwaj at Charm 2012

$B^\pm \rightarrow \chi_{c1}\gamma K^\pm$	Yield	\mathcal{BR} (10^{-4})	
		Belle	World Average
$\Psi' \rightarrow \chi_{c1}\gamma$	193 ± 19	$7.74^{+0.77}_{-0.74}(stat)^{+0.87}_{-0.83}(syst)$	6.39 ± 0.33

$\mathcal{BR}(B^+ \rightarrow \Psi' K^+)$ consistent with world average

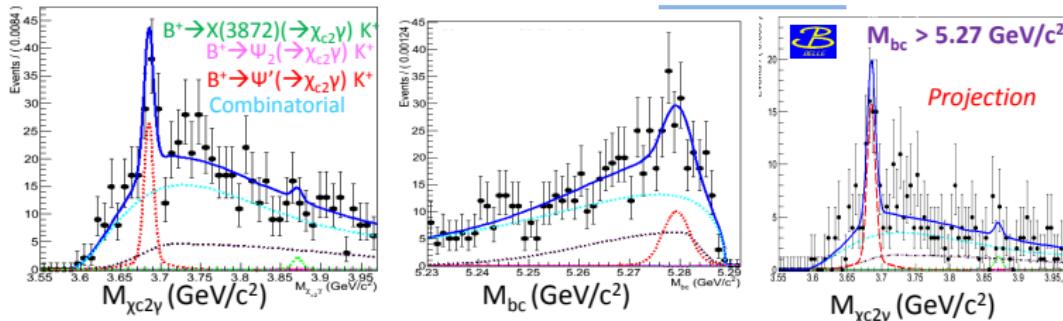
$B^\pm \rightarrow \chi_{c1}\gamma K^\pm$	Yield	$\mathcal{BR}(B^+ \rightarrow X K^+) \cdot \mathcal{BR}(X \rightarrow \chi_{c1}\gamma)$ (10^{-6})
$\Psi_2 \rightarrow \chi_{c1}\gamma$	33.2 ± 9.1	$9.70^{+2.84}_{-2.51}(stat)^{+1.06}_{-1.03}(syst)$
$X(3872) \rightarrow \chi_{c1}\gamma$	-0.9 ± 5.1	$< 2.0 (@90\% CL)$

First evidence of Ψ_2 with 4.2σ significance by Belle.

$$\frac{\Gamma(X3872 \rightarrow \chi_{c1}\gamma)}{\Gamma(X3872 \rightarrow J/\Psi \pi\pi)} < 0.26$$

Search for $\gamma\chi_{c1,c2}$ decays

abstract 720; BELLE-CONF-1234; longer presentation: V.Bhardwaj at Charm 2012



$B^\pm \rightarrow \chi_{c2}\gamma K^\pm$	Yield	BR (10^{-4})	
		$\chi_{c2}\gamma$	$\chi_{c1}\gamma$
$\Psi' \rightarrow \chi_{c2}\gamma$	56.6 ± 9.3	$5.82 \pm 0.95(\text{stat}) \pm 0.61(\text{syst})$	$7.74^{+0.77}_{-0.74}(\text{stat})^{+0.87}_{-0.83}(\text{syst})$
$\text{BR}(B^+ \rightarrow X K^+) \cdot \text{BR}(X \rightarrow \chi_{cX}\gamma) (10^{-6})$			
$\Psi_2 \rightarrow \chi_{c2}\gamma$	-0.4 ± 3.4	< 3.4	$9.70^{+2.84}_{-2.51}(\text{stat})^{+1.06}_{-1.03}(\text{syst})$
$X(3872) \rightarrow \chi_{c2}\gamma$	3.9 ± 3.9	< 6.0	< 2.0

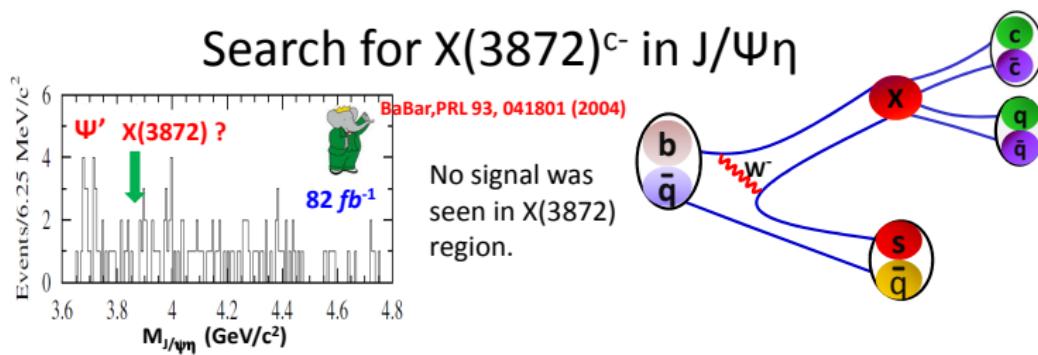
$$\frac{\Gamma(\Psi_2 \rightarrow \chi_{c2}\gamma)}{\Gamma(\Psi_2 \rightarrow \chi_{c1}\gamma)} < 0.48, \text{ Expected } \sim 0.2 \text{ (model dependent)}$$

E. J. Eichten *et al*, PRL 89, 162002 (2002)

U.L. (@ 90% CL)

Search for $\eta\psi$ decays

abstract 725; BELLE-CONF-1235; longer presentation: V.Bhardwaj at Moriond QCD

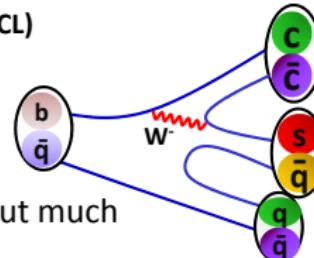


$$\mathcal{BR}(B^+ \rightarrow X(3872) K^+) \times \mathcal{BR}(X(3872) \rightarrow J/\psi \eta) < 7.7 \times 10^{-6} \text{ (90% CL)}$$

BaBar observed $B^+ \rightarrow J/\psi \eta K^+$ and provided

$$\mathcal{BR}(B^+ \rightarrow J/\psi \eta K^+) = (10.8 \pm 2.3 \pm 2.4) \times 10^{-5}$$

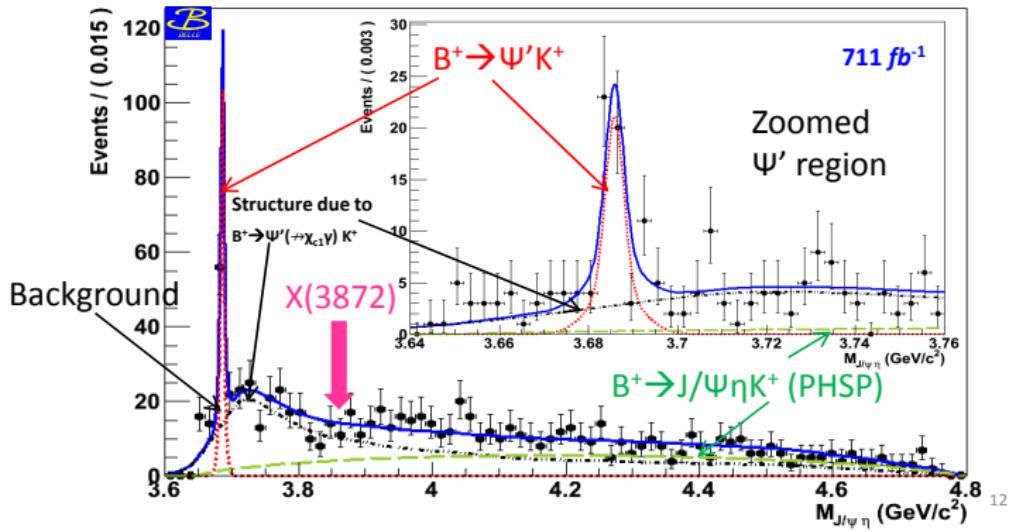
With more data (9x), Belle can either rule out or put much tighter constraint on the $X(3872)^c$ partner.



Search for $\eta\psi$ decays

abstract 725; BELLE-CONF-1235; longer presentation: V.Bhardwaj at Moriond QCD

- After including phase space (PHSP) component of $B \rightarrow J/\Psi \eta K$, data/MC agrees quite well.
- 1D UML fit to $M_{J/\Psi\eta}$ in order to extract signal yield.
- Background fixed from MC and sideband study.



Search for $\eta\psi$ decays

abstract 725; BELLE-CONF-1235; longer presentation: V.Bhardwaj at Moriond QCD

Mode	Events	\mathcal{BR} (10^{-4})	
		Belle	PDG
$B^+ \rightarrow \Psi' K^+$ ⁽¹⁾	52 ± 8.2	$5.81 \pm 0.92 \pm 0.44$	6.39 ± 0.33
$B^+ \rightarrow J/\Psi \eta K^+$	395 ± 26	$1.17 \pm 0.07 \pm 0.11$	$1.08 \pm 0.33^{(2)}$

- ❖ Our results agree with the world average.
- ❖ In the search of $X(3872) \rightarrow J/\Psi \eta$, Belle provided upper limit (@90% CL)

⁽¹⁾Belle's $\mathcal{BR}(B \rightarrow \Psi'(\rightarrow J/\Psi \eta)K)$, while the world average is for $\mathcal{BR}(B \rightarrow \Psi'(\rightarrow l l)K)$ & $\mathcal{BR}(B \rightarrow \Psi'(\rightarrow J/\Psi \pi\pi)K)$

⁽²⁾includes $B \rightarrow \Psi'(\rightarrow J/\Psi \eta)K$ component also.
Belle \mathcal{BR} is for the PHSP component ¹³

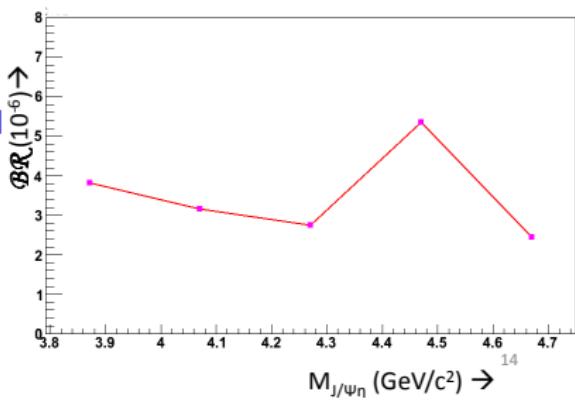
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abstract 725; BELLE-CONF-1235; longer presentation: V.Bhardwaj at Moriond QCD

Mode	Events	$\mathcal{BR}(B^+ \rightarrow X K^+) \cdot \mathcal{BR}(X \rightarrow J/\Psi \eta) (10^{-6})$	
		Belle	PDG
$B^+ \rightarrow X(3872)(\rightarrow J/\Psi \eta) K^+$	2.3 ± 5.2	< 3.8	< 7.7

Much tighter constraint to the C-odd partner of X(3872).

- ❖ UL (@90% CL) is also provided at different masses (using 0-width states).

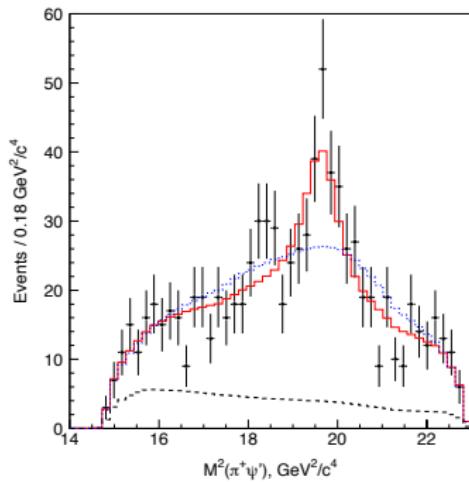


Searches for charged states: some history

$\pi\psi'$ PRD 80, 031104 (2009); $\pi\chi_{c1}$ 78, 072004 (2008); Z_b PRL 108, 122001 (2012)

- Belle sees resonance-like peak

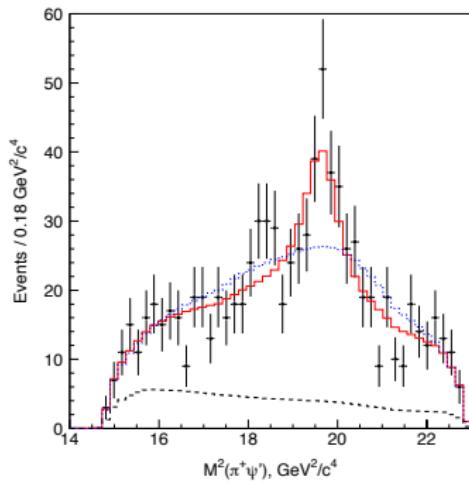
$Z(4430)^+ \rightarrow \pi^+\psi'$ in $B \rightarrow K\pi^+\psi'$



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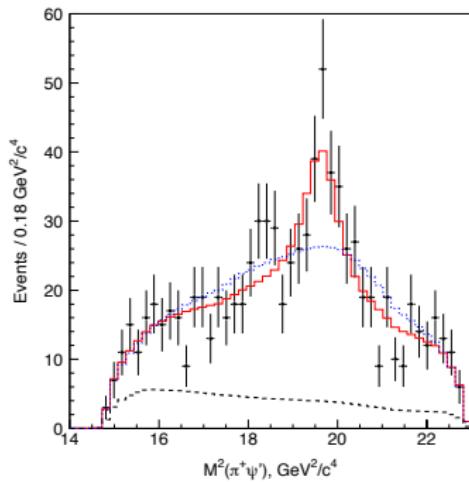
- Belle sees resonance-like peak
 $Z(4430)^+ \rightarrow \pi^+\psi'$ in $B \rightarrow K\pi^+\psi'$
- not seen by BaBar; consistency?



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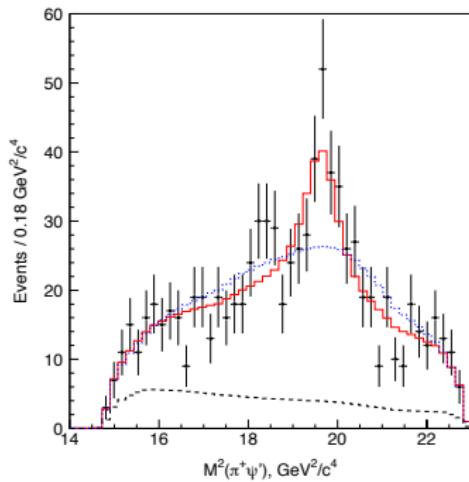
- Belle sees resonance-like peak
 $Z(4430)^+ \rightarrow \pi^+\psi'$ in $B \rightarrow K\pi^+\psi'$
- not seen by BaBar; consistency?
- Belle (Dalitz) reanalysis: \longrightarrow
 $(M, \Gamma) = (4443^{+15+19}_{-12-13}, 107^{+86+74}_{-43-56}) \text{ MeV}$



Searches for charged states: some history

$\pi\psi'$ PRD 80, 031104 (2009); $\pi\chi_{c1}$ 78, 072004 (2008); Z_b PRL 108, 122001 (2012)

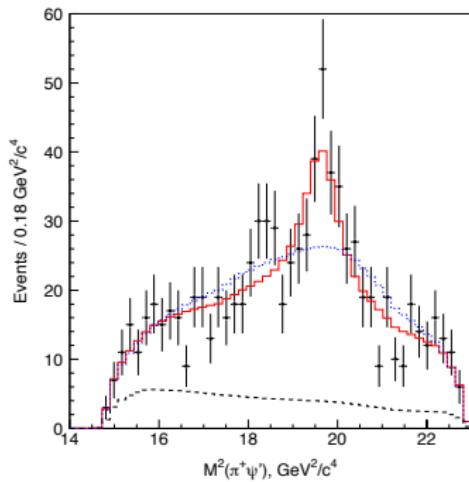
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 $(M, \Gamma) = (4443^{+15+19}_{-12-13}, 107^{+86+74}_{-43-56}) \text{ MeV}$
- +2 peaks in $\bar{B}^0 \rightarrow K^- Z [\rightarrow \pi^+\chi_{c1}]$



Searches for charged states: some history

$\pi\psi'$ PRD 80, 031104 (2009); $\pi\chi_{c1}$ 78, 072004 (2008); Z_b PRL 108, 122001 (2012)

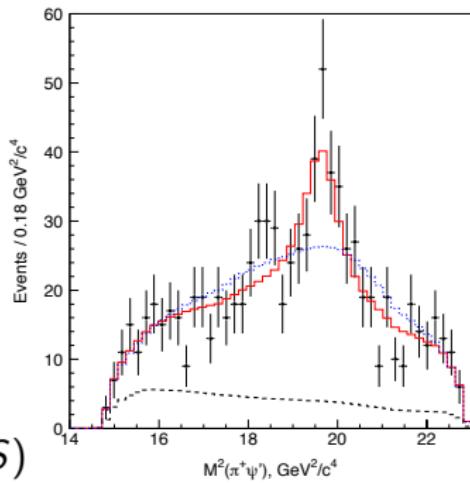
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 $(M, \Gamma) = (4443^{+15+19}_{-12-13}, 107^{+86+74}_{-43-56}) \text{ MeV}$
- +2 peaks in $\bar{B}^0 \rightarrow K^- Z [\rightarrow \pi^+\chi_{c1}]$
- $B \rightarrow K\pi^+\psi$ being studied



Searches for charged states: some history

$\pi\psi'$ PRD 80, 031104 (2009); $\pi\chi_{c1}$ 78, 072004 (2008); Z_b PRL 108, 122001 (2012)

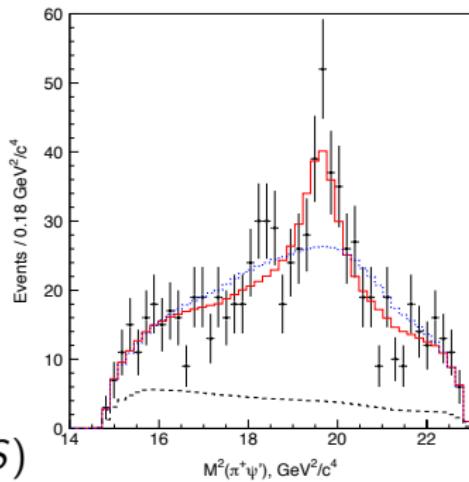
- Belle sees resonance-like peak
 $Z(4430)^+ \rightarrow \pi^+\psi'$ in $B \rightarrow K\pi^+\psi'$
- not seen by BaBar; consistency?
- Belle (Dalitz) reanalysis: \rightarrow
 $(M, \Gamma) = (4443^{+15+19}_{-12-13}, 107^{+86+74}_{-43-56}) \text{ MeV}$
- +2 peaks in $\bar{B}^0 \rightarrow K^- Z [\rightarrow \pi^+\chi_{c1}]$
- $B \rightarrow K\pi^+\psi$ being studied
- in hidden beauty, v.large $\Gamma_{\pi\pi\gamma(nS)}$ for $\Upsilon(5S)$
— something going on above $B\bar{B}$ threshold
cf. CLEO $\sigma_{4170}(\pi^+\pi^- h_c) \sim \sigma_{4170}(\pi^+\pi^- \psi)$



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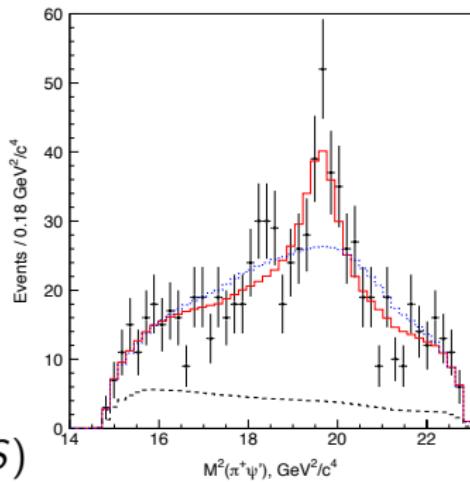
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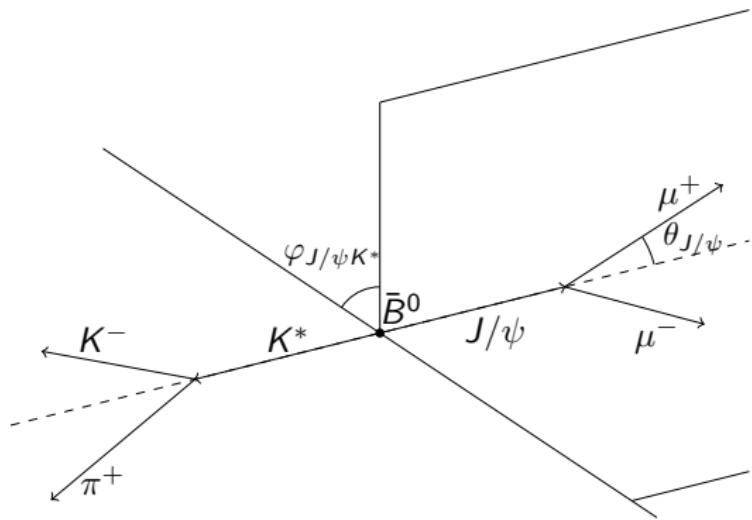
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Search for Z⁺: 4D $\bar{B}^0 \rightarrow K^- \pi^+ \psi$ analysis

abstract 726; BELLE-CONF-1236; longer presentation: K.Chilikin at Charm 2012



The variables considered are Dalitz variables $M^2(K, \pi)$,
 $M^2(J/\psi, \pi)$ and angles $\theta_{J/\psi}$, $\varphi_{J/\psi K^*}$.

Search for Z⁺: 4D $\bar{B}^0 \rightarrow K^- \pi^+ \psi$ analysis

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$$S(s_x, s_y, \varphi_{J/\psi K^*}, \theta_{J/\psi}) = \sum_{\xi=1,-1} \left| \sum_{\lambda=-1,0,1} A_\lambda d_\lambda^1 |_\xi(\theta_{J/\psi}) \right|^2,$$

where

$$s_x = M^2(K, \pi), \quad s_y = M^2(J/\psi, \pi),$$

ξ - sum of lepton helicities, λ - helicity of J/ψ ,

$$A_\lambda = A_{\lambda}^{K^*} e^{-i\lambda\varphi_{J/\psi K^*}} + A_{\lambda}^{Z_c^+}.$$

$\bar{K}^{*0} \rightarrow K^- \pi^+$ amplitude:

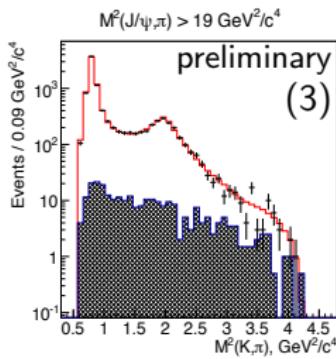
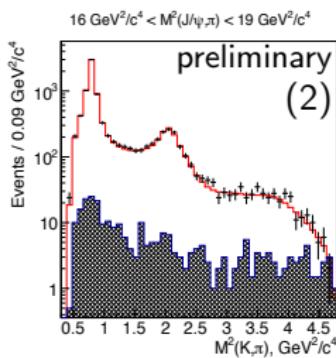
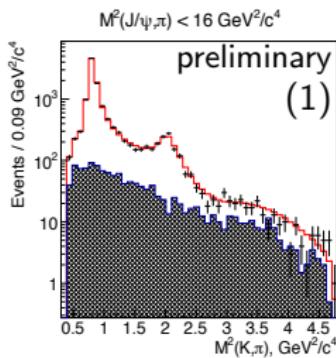
$$A_{\lambda}^{K^*} = \sum_{K^*} a_{\lambda}^{K^*} e^{i\phi_{\lambda}^{K^*}} A^{K^*}(s_x, s_y) d_{\lambda 0}^{J(K^*)}(\theta_{K^*}),$$

$Z_c^+ \rightarrow J/\psi \pi^+$ amplitude:

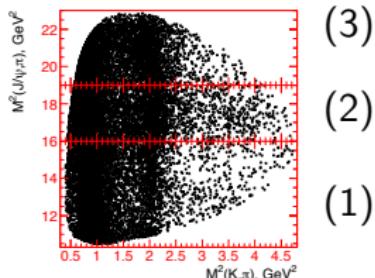
$$A_{\lambda}^{Z_c^+} = \sum_{\lambda'=-1,0,1} a_{\lambda'}^{Z_c^+} e^{i\phi_{\lambda'}^{Z_c^+}} A^{Z_c^+}(s_x, s_y) d_{0 \lambda'}^{J(Z_c^+)}(\theta_{Z_c^+}) e^{-i\lambda' \tilde{\varphi}_{J/\psi K^*}} d_{\lambda' \lambda}^1(\theta_{K^* \pi^+}),$$

Search for Z^+ : projections onto $s_x = M^2(K^- \pi^+)$

abstract 726; BELLE-CONF-1236; longer presentation: K.Chilikin at Charm 2012

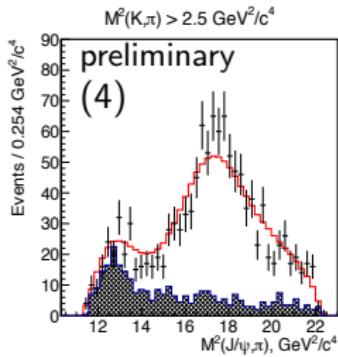
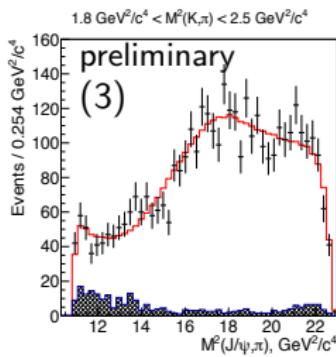
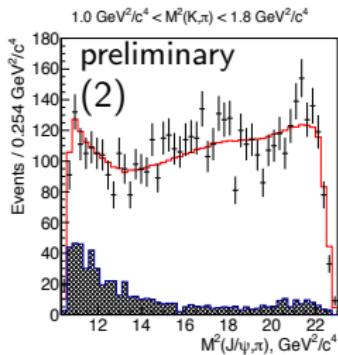
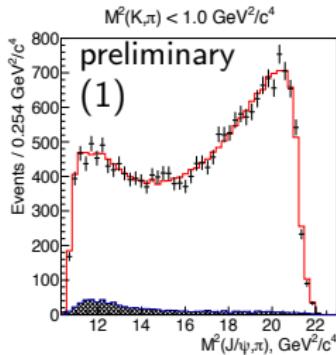


Slices



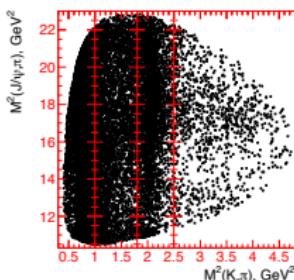
Search for Z⁺: projections onto s_y = M²($\pi^+ \psi$)

abstract 726; BELLE-CONF-1236; longer presentation: K.Chilikin at Charm 2012



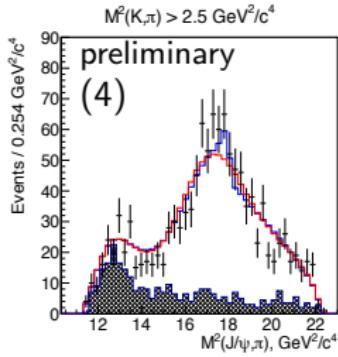
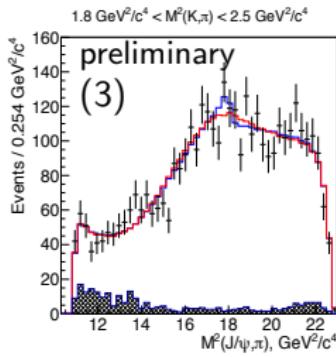
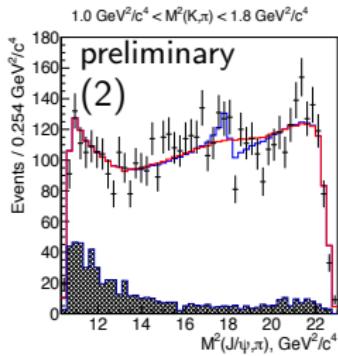
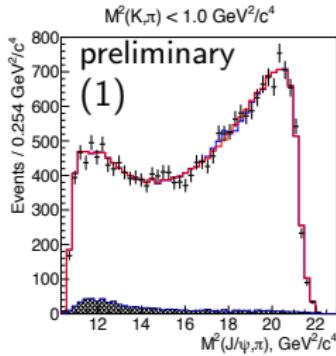
Slices

(1)(2)(3) (4)



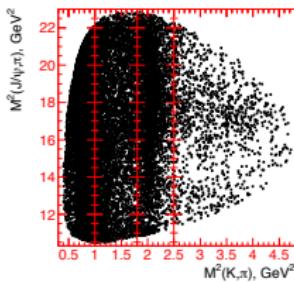
Search for Z⁺: ... allowing Z^{+(1⁺)} → $\pi^+ \psi$

abstract 726; BELLE-CONF-1236; longer presentation: K.Chilikin at Charm 2012



Slices

(1)(2)(3) (4)



Search for Z⁺: fit results and significance

abstract 726; BELLE-CONF-1236; longer presentation: K.Chilikin at Charm 2012

- various J^{PC} considered

J^P	M , MeV	Γ , MeV	Local sign.	Sign.
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0^-	4076 ± 17	240 ± 21	4.7σ	2.9σ
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2^+	4443 ± 11	153 ± 46	$< 0.1\sigma$	$< 0.1\sigma$

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result with uncertainties

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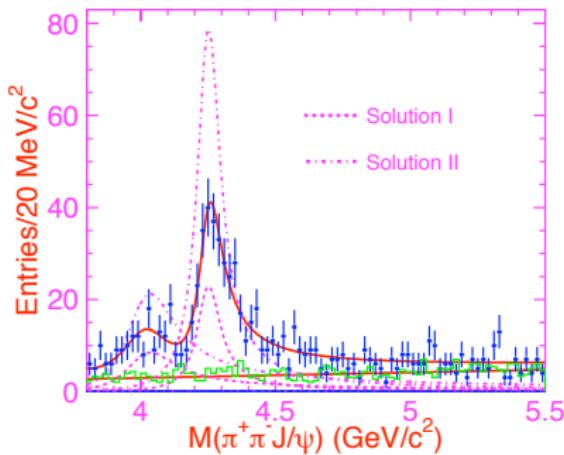
abstract 726; BELLE-CONF-1236; longer presentation: K.Chilikin at Charm 2012

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- natural next step: 4D (> Dalitz) for original K⁻π⁺ψ' channel

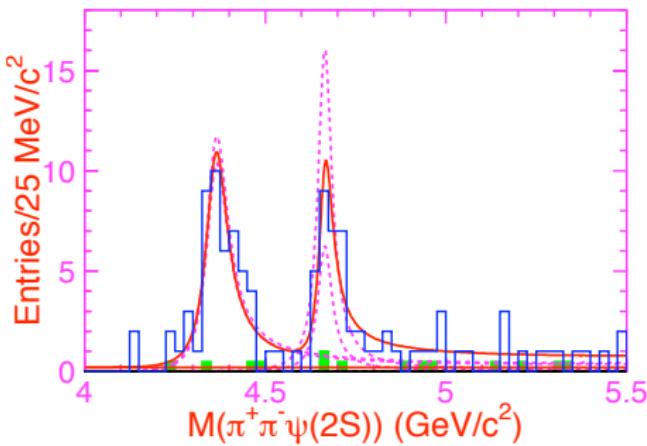
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ISR studies of 1⁻⁻ states (following BaBar)

C.Z. Yuan et al, PRL 99, 182004; X.L. Wang et al, PRL 99, 142002 (2007); etc.



- confirms $Y(4260)$ [also CLEO]
- amplitude nontrivial near 4050 MeV



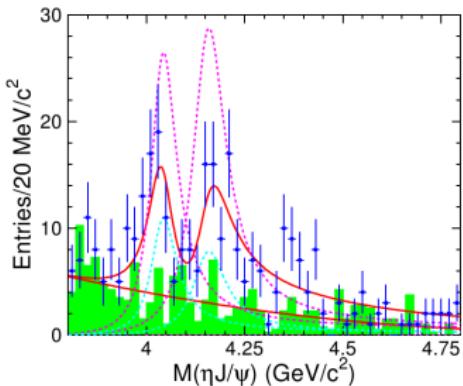
- confirms $\pi^+\pi^-\psi'$ signal
- splits “ $Y(4360)$ ” peak → two

none seen in ISR $D^{(*)}\bar{D}^{(*)}$: e.g. explicit BaBar $Y(4260)$ limit
 $\mathcal{B}_{D\bar{D}}/\mathcal{B}_{\pi^+\pi^-\psi} < 1.0$ at 90% C.L. [arXiv:0710.1371 → PRD]

ISR studies: search in $e^+e^- \rightarrow \gamma_{\text{ISR}}\eta\psi$

abstract 727; BELLE-CONF-1237; longer presentation: X.-L.Wang at FPCP 2012

Belle: Search for hadronic transition via emitting η . (Preliminary)



Parameters	Solution I	Solution II
$M(\psi(4040))$	4039 (fixed)	
$\Gamma(\psi(4040))$	80 (fixed)	
$\mathcal{B}(\psi(4040) \rightarrow \eta J/\psi) \cdot \Gamma_{e^+e^-}$	$5.1 \pm 0.8 \pm 1.1$	$12.4 \pm 1.2 \pm 1.2$
$M(\psi(4160))$	4153 (fixed)	
$\Gamma(\psi(4160))$	103 (fixed)	
$\mathcal{B}(\psi(4160) \rightarrow \eta J/\psi) \cdot \Gamma_{e^+e^-}$	$4.1 \pm 0.5 \pm 0.8$	$15.2 \pm 1.2 \pm 1.5$
$\phi(^{\circ})$	$-20 \pm 11 \pm 8$	$-110 \pm 4 \pm 3$

Taking $\Gamma_{e^+e^-}(\psi(4040)) = (0.86 \pm 0.07)$ keV from PDG \rightarrow

$\mathcal{B}(\psi(4040) \rightarrow \eta J/\psi) = (0.59 \pm 0.11 \pm 0.14)\%$ or

$\mathcal{B}(\psi(4040) \rightarrow \eta J/\psi) = (1.44 \pm 0.18 \pm 0.18)\%$.

Taking $\Gamma_{e^+e^-}(\psi(4160)) = (0.83 \pm 0.07)$ keV from PDG \rightarrow

$\mathcal{B}(\psi(4160) \rightarrow \eta J/\psi) = (0.50 \pm 0.07 \pm 0.11)\%$ or

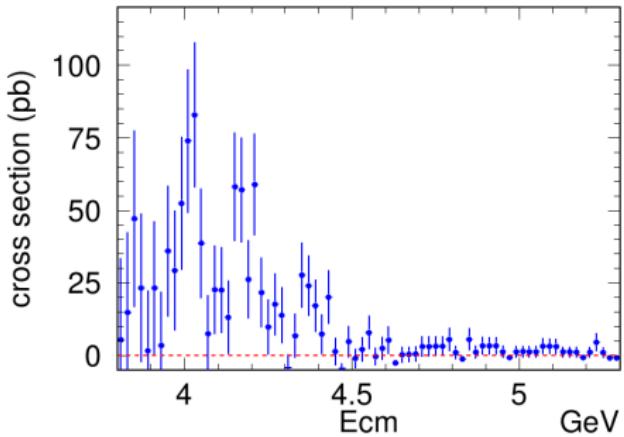
$\mathcal{B}(\psi(4160) \rightarrow \eta J/\psi) = (1.83 \pm 0.21 \pm 0.24)\%$.

ISR studies: search in $e^+e^- \rightarrow \gamma_{\text{ISR}}\eta\psi$

abstract 727; BELLE-CONF-1237; longer presentation: X.-L.Wang at FPCP 2012

Belle preliminary

$$\sigma_i = \frac{n_i^{\text{obs}} - n_i^{\text{bkg}}}{\varepsilon_i \mathcal{L}_i \mathcal{B}(\eta \rightarrow \pi^+\pi^-\pi^0 + \gamma\gamma) \mathcal{B}(J/\psi \rightarrow \ell^+\ell^-)}$$



A systematic error of 8.8% to all data points is not shown.

Summary

- $X(3872)$ studies:
 - in 2011, major $\pi^+\pi^-\psi$ update (& other studies)
 - in 2012, searches in final states that would reveal X partners:
 - $\gamma\chi_{c1,c2}$: main searches negative,
but $X(3823) \rightarrow \gamma\chi_{c1}$ seen; $\psi_2(1^3D_2)$ candidate
 - $\eta\psi$: search negative
- charged states:

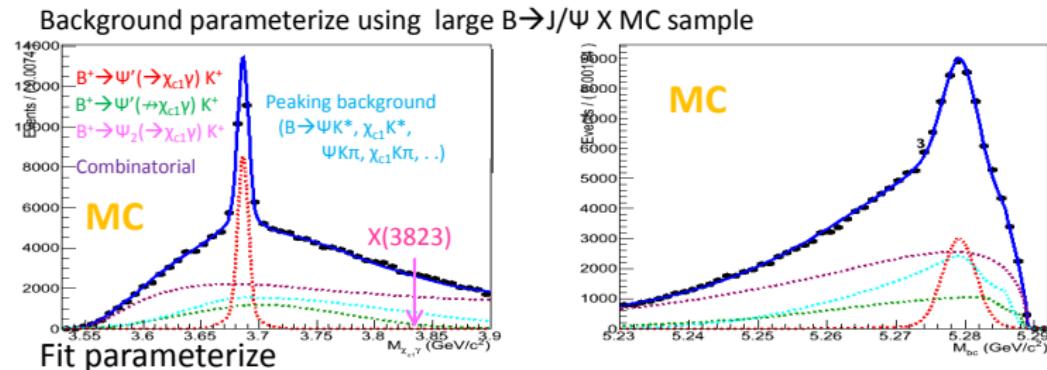
4D analysis of $\bar{B}^0 \rightarrow K^-\pi^+\psi$ sees no compelling $Z^+ \rightarrow \pi^+\psi$,
and sets a limit comparable to BaBar's
 - *cf.* Belle's positive $\pi^+\psi'$ (Dalitz) and $\pi^+\chi_{c1}$ (Dalitz*) signals
- ISR studies of 1^{--} :

$\eta\psi$ final state studied, $\psi(4040)$ and (4160) seen
- results presented today are preliminary

BACKUP SLIDES

Search for $\gamma\chi_{c1,c2}$ decays

abstract 720; BELLE-CONF-1234; longer presentation: V.Bhardwaj at Charm 2012



Fit parameterize

- ❖ Sum of two Gaussian (convoluted with Breit-Wigner)* is used to fit Ψ_2 (from MC).
- ❖ Tail part Gaussian same as Ψ' (tested on MC study).
- ❖ M_{bc} PDF same as Ψ' (from MC study).
- ❖ Ψ_2 width is fix to zero, resolution is estimated from Ψ' peak (and scaled from MC*).

For fit bias, 2000 toys and no significant bias is observed.

Maximum bias of 2% estimated and included in the systematics.

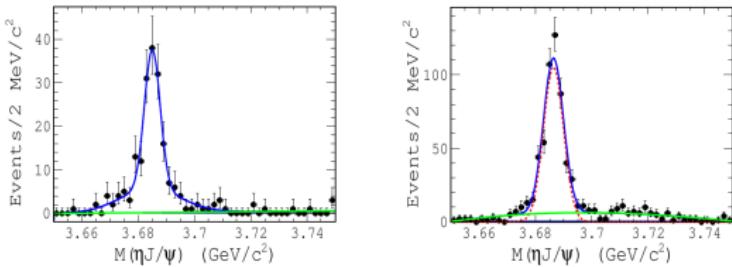
11

*Estimated from signal MC (for different width)

ISR studies: search in $e^+e^- \rightarrow \gamma_{\text{ISR}}\eta\psi'$

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- Reconstructions: $J/\psi \rightarrow e^+e^-$ or $\mu^+\mu^-$, $\eta \rightarrow \gamma\gamma$ or $\pi^+\pi^-\pi^0$.
- Clear ψ' signals.



Left is $\eta \rightarrow \pi^+\pi^-\pi^0$ mode and right is $\eta \rightarrow \gamma\gamma$ mode.

Measurement on cross section of $\sigma(e^+e^- \rightarrow \gamma_{\text{ISR}}\psi')$ at Belle:

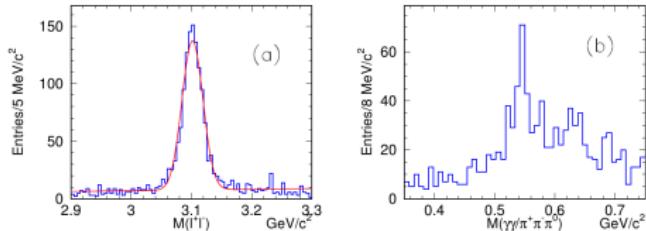
- $\pi^+\pi^-\pi^0$ mode: $n^{sig} = 186 \pm 17$, $\sigma = 13.9 \pm 1.4$ pb.
- $\gamma\gamma$ mode: $n^{sig} = 470 \pm 25$, $\sigma = 14.0 \pm 0.8$ pb.
- Theory calculation: $\sigma = 14.2$ pb.

Measurement on ψ' signal is reliable.

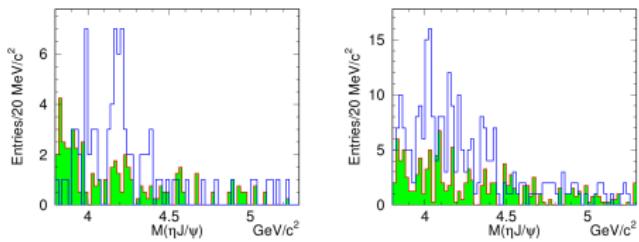
ISR studies: search in $e^+e^- \rightarrow \gamma_{\text{ISR}}\eta\psi$

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The J/ψ signal and η signal at high energy region ($M_{\eta J/\psi} > 3.8 \text{ GeV}/c^2$):



The $\eta J/\psi$ signals:



The left is $\eta \rightarrow \pi^+\pi^-\pi^0$ mode and the right is $\eta \rightarrow \gamma\gamma$ mode. Events accumulate around the positions of $\psi(4040)$ and $\psi(4160)$, and no obvious Y states found at $\pi^+\pi^-J/\psi(\psi')$ transitions!