B $\rightarrow$ *charmonium* - Mini Summary

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BELLE

Flavor Physics & CP Violation

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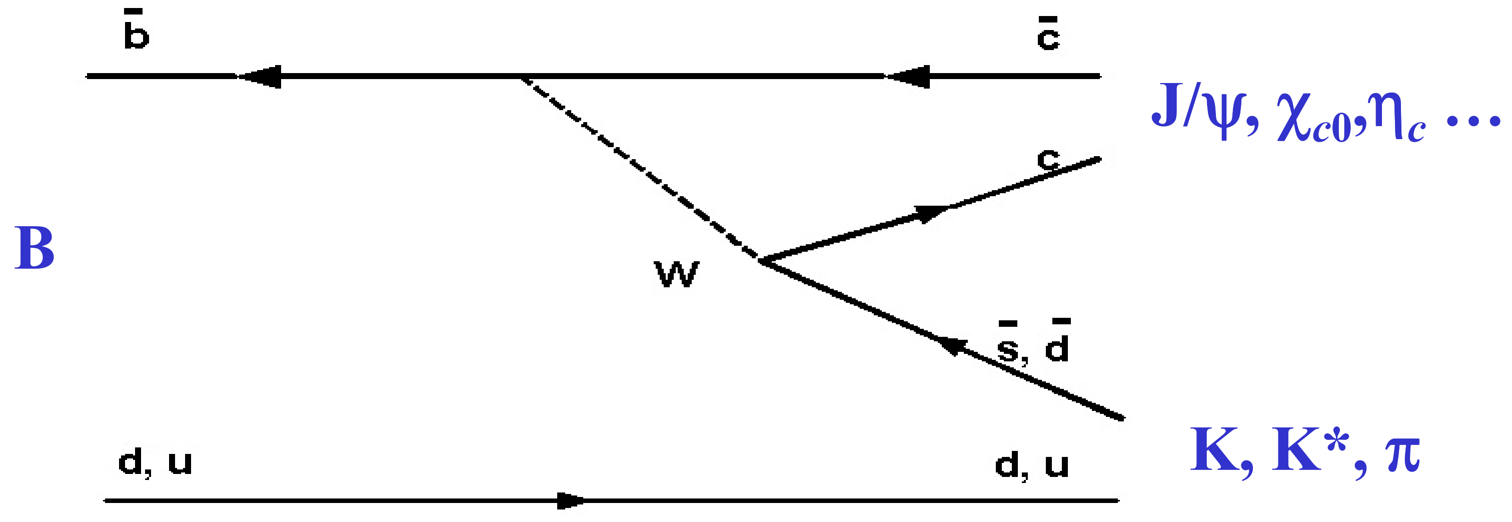
Outline

- Introduction
- Experimental results
  - non-factorizable modes
    - $B^+ \to \chi_{c0} K^+$
    - $B \to \chi_{c2} X$
  - other exclusive modes
    - $B \to J/\psi\pi^+\pi^-$, $J/\psi K^{(*)}$, η_c (1S) $K^{(*)}$, …
  - first observation of exclusive $\eta_c(2S)$ meson
    - $B \to \eta_c(2S)$ K
- Summary

Introduction



- $B_{CP} \to$ $J/\psi\ K_S$, $\psi(2S)K_S$, $\chi_{c1}K_S$, $\eta_c K_S$,
  $J/\psi\ K_L$ and $J/\psi\ K^{*0}\ (\to K_S\pi^0)$
  are used for $\sin 2\phi_1$ measurements. Other CP eigenstates may be useful for the CP measurements, e.g. $B \to J/\psi\ \rho^0$.
- Provide tests to theoretical assumptions, e.g.
  - In the factorization limit, $B \to \chi_{c0}K$ and $\chi_{c2}X$ are not allowed

First observation of $B^+ \to \chi_{c0} K^+$

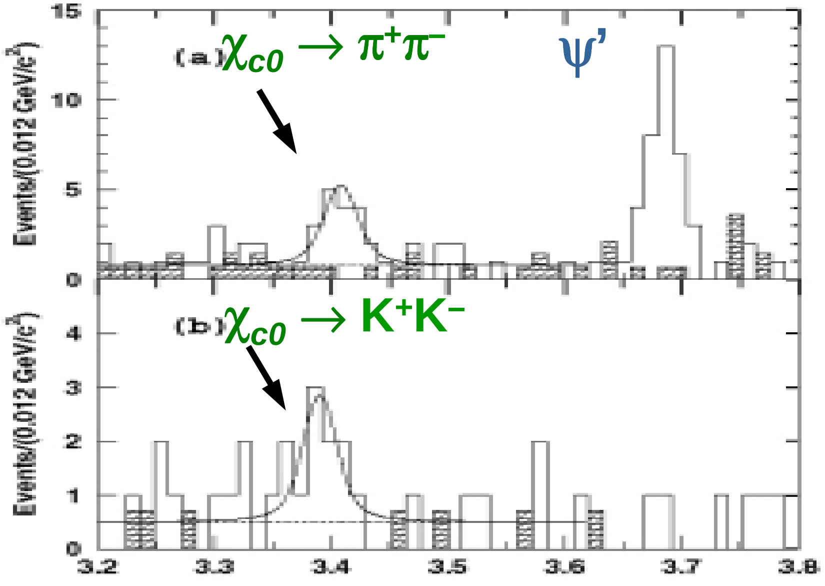
PRL 88, 2002

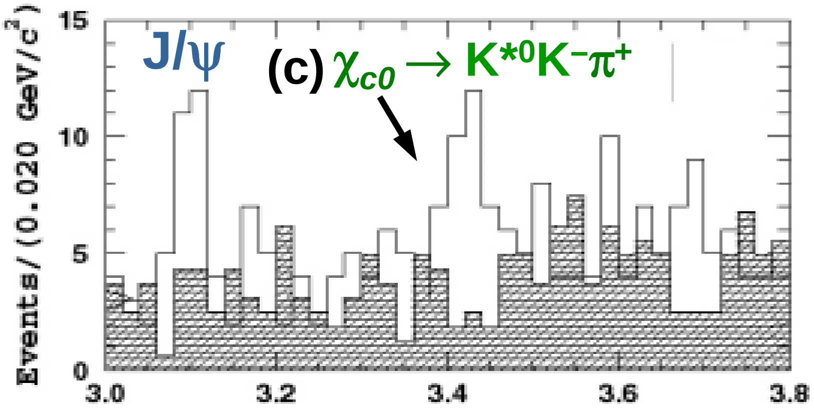
Belle

- 31.3 million $B\bar{B}$
- 6σ ($\pi^+\pi^-$ and $K^{*0}K^-\pi$ combined)
- $Br(B^+ \to \chi_{c0} K^+)$ comparable to $Br(B^+ \to J/\psi K^+)$ and $Br(B^+ \to \chi_{c1} K^+)$

$$\frac{B(B^+ \to \chi_{c0} K^+)}{B(B^+ \to J/\psi K^+)} = 0.60^{+0.21}_{-0.18} \pm 0.05 \pm 0.08$$

$$B(B^+ \to \chi_{C0} K^+) = (6.0^{+2.1}_{-1.8} \pm 1.1) \times 10^{-4}$$



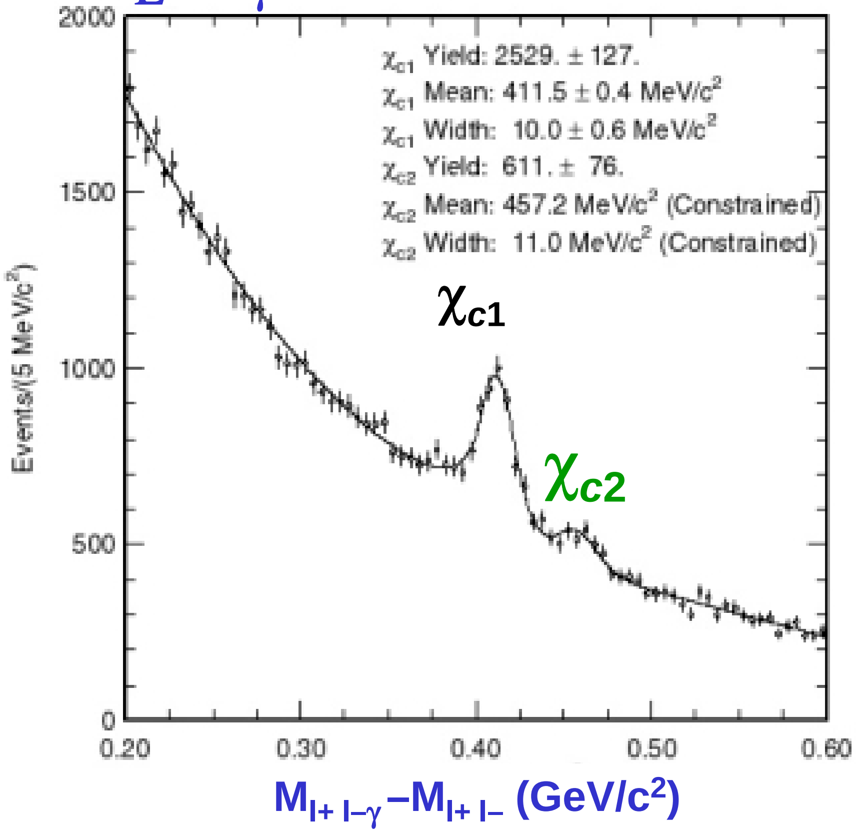


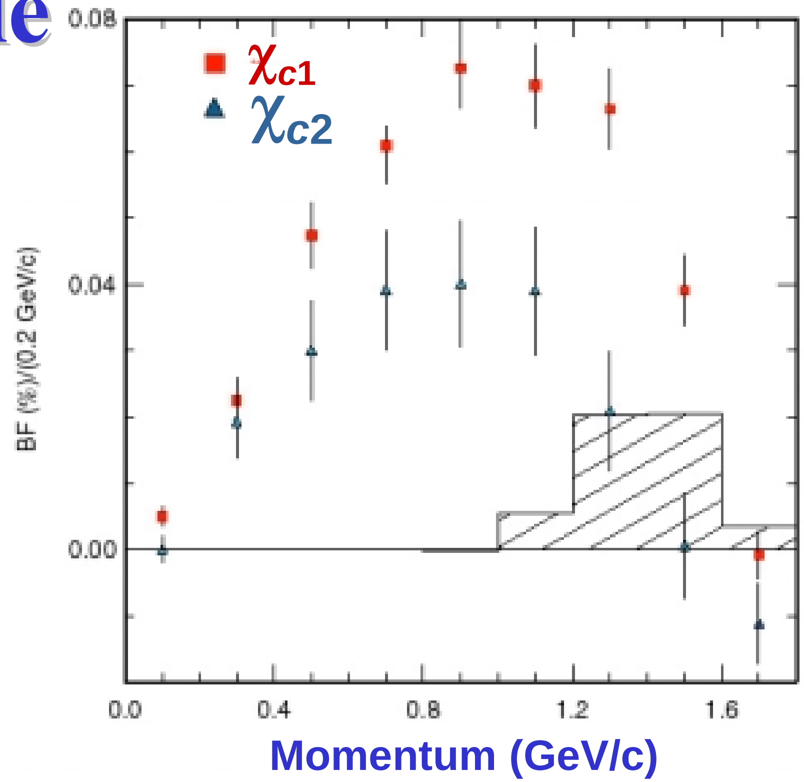
First observation of B → χ_{c2}X

Submitted to PRL

- 31.3 million $B\bar{B}$
- $\chi_{c2} \rightarrow J/\psi\gamma,\ J/\psi \rightarrow l^+l^-$
- $\sigma_E / E_\gamma = 2.61 \pm 0.04\ \%$

Belle





Yield 607^{+76}_{-94}

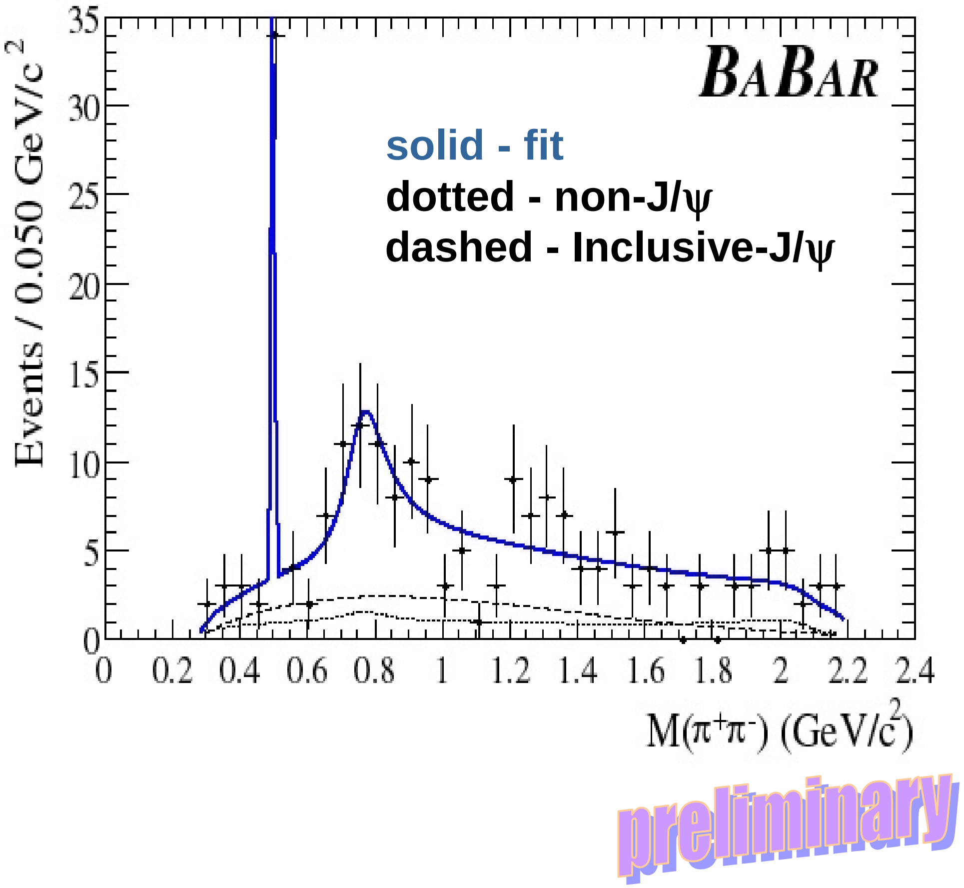
$$B(B \rightarrow \chi_{C2}X) = (1.80^{+0.23}_{-0.28} \pm 0.26) \times 10^{-3}$$

$B^0 \to J/\psi\, \pi^+ \pi^-$

hep-ex/0203034

- 56 million $B\bar{B}$
- $B^0 \to J/\psi\, \rho^0$ **(CP)** and $B^0 \to J/\psi\, \pi^+\pi^-$ (non-resonant)
- unbinned likelihood fit to the $M(\pi^+ \pi^-)$ distribution

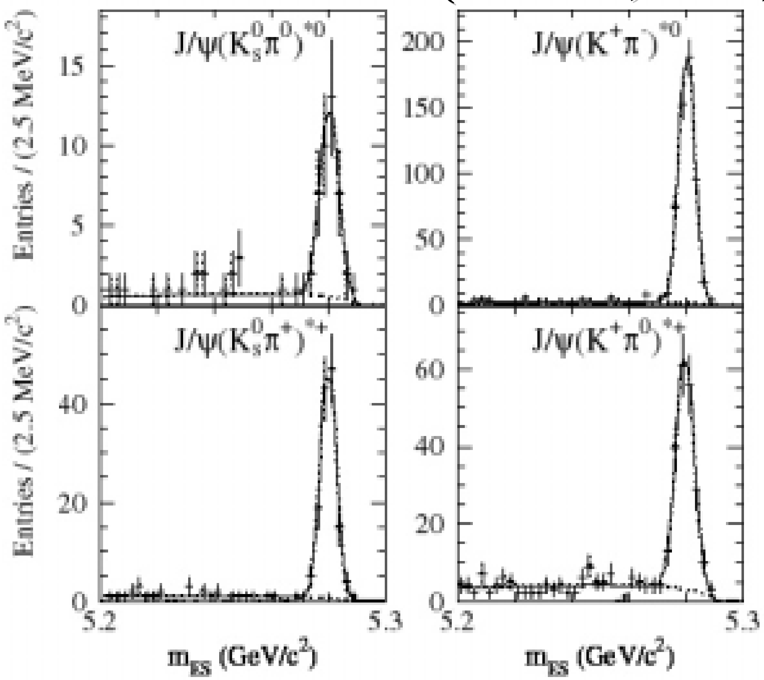
B decay mode	Yield
$J/\psi\, \rho^0$	43 ± 13
$J/\psi\, \pi^+\pi^-$ (non-resonant)	47 ± 15
$J/\psi\, K_s^0$ ($K_s^0 \to \pi^+\pi^-$)	29 ± 6
$J/\psi\, \pi^+\pi^-$ (fit)	90 ± 13



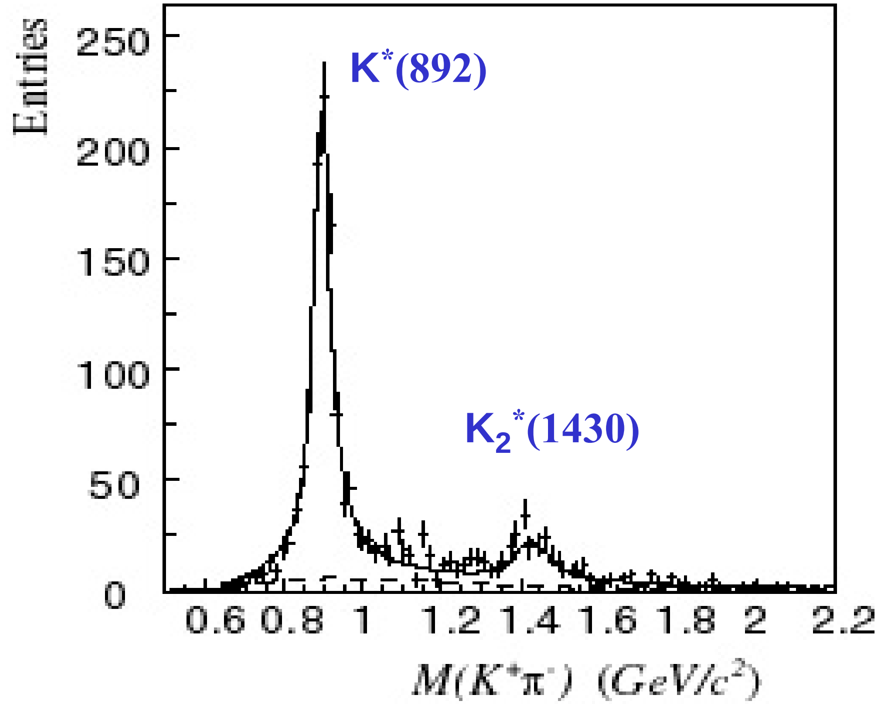
$$B(B \to J/\psi\, \pi^+\pi^-) = (5.0 \pm 0.7 \pm 0.6) \times 10^{-5}$$

B → J/ψ $K^*(892)$ branching fraction

BABAR (PRL 87, 2001)



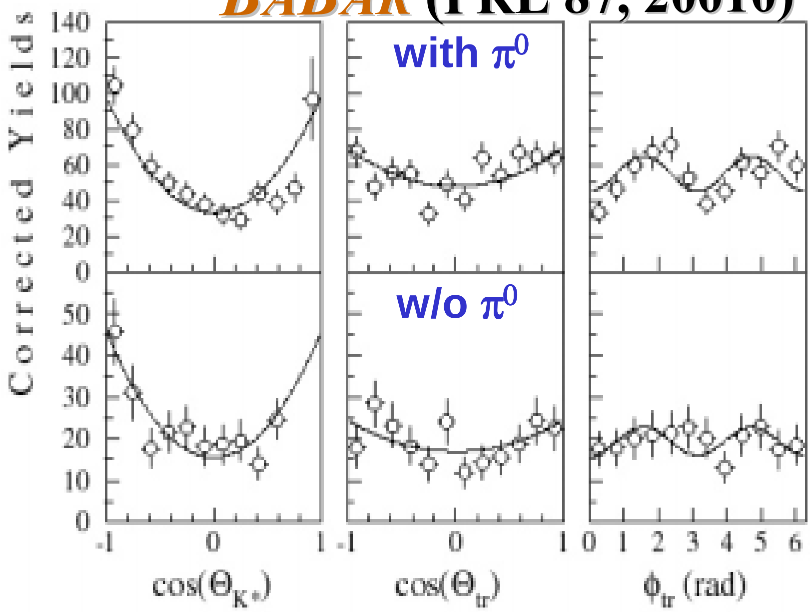
Belle (to be published in PLB)



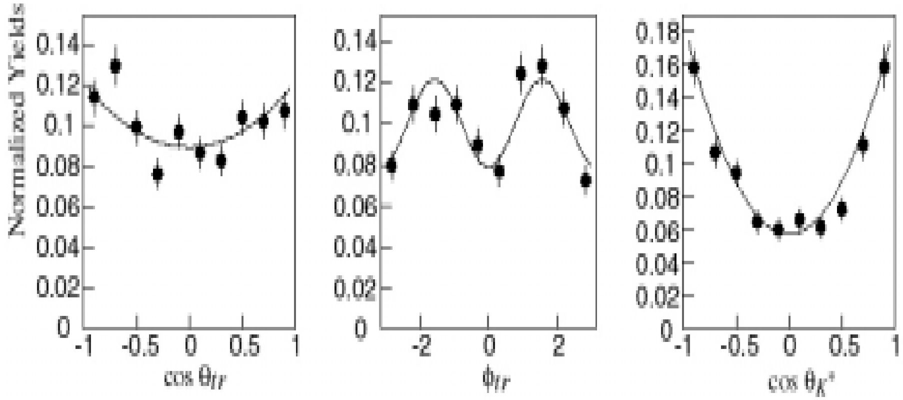
	Br($B^0 \to J/\psi K^{*0}$) ($\times 10^{-3}$)	Br($B^+ \to J/\psi K^{*+}$) ($\times 10^{-3}$)
CLEO	1.32 ± 0.15 ± 0.17	1.41 ± 0.20 ± 0.24
BABAR	1.24 ± 0.05 ± 0.09	1.37 ± 0.09 ± 0.11
Belle	1.29 ± 0.05 ± 0.13	1.28 ± 0.07 ± 0.14

B → J/ψ $K^*(892)$ angular analysis

BABAR (PRL 87, 20010)



Belle (to be published in PLB)

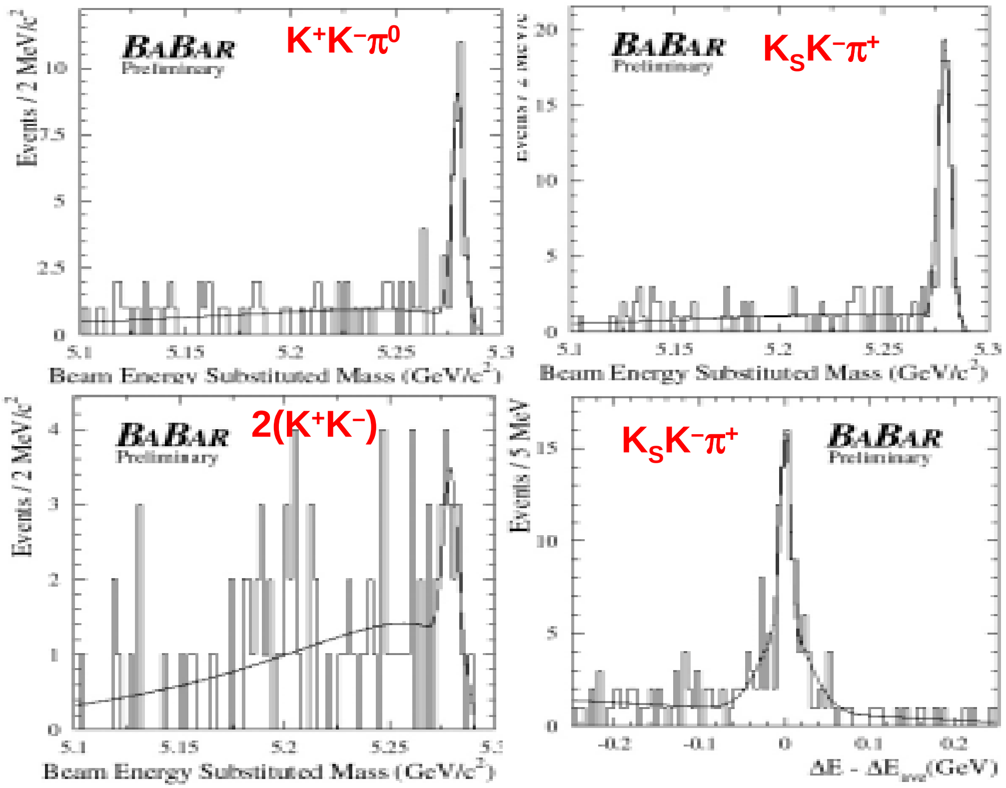


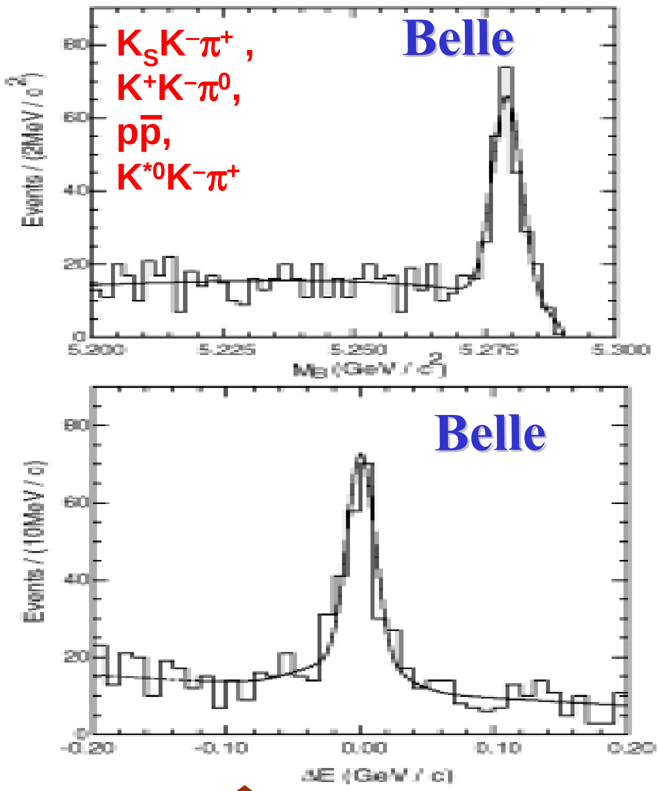
- *CP even component dominates*
- A shift from π for arg($A_{||}$) but not significant

	$\|A_0\|^2$	$\|A_\perp\|^2$	arg($A_{\|\|}$) (rad)	arg($A_\perp$) (rad)
CLEO	0.52 ± 0.07 ± 0.04	0.16 ± 0.08 ± 0.04	3.00 ± 0.37 ± 0.04	– 0.11 ± 0.46 ± 0.03
CDF	0.59 ± 0.06 ± 0.01	$0.13 ^{+0.12}_{-0.09}$ ± 0.06	2.2 ± 0.5 ± 0.1	– 0.6 ± 0.5 ± 0.1
BABAR	0.60 ± 0.03 ± 0.02	0.16 ± 0.03 ± 0.01	2.50 ± 0.20 ± 0.08	– 0.17 ± 0.16 ± 0.07
Belle	0.62 ± 0.02 ± 0.03	0.19 ± 0.02 ± 0.03	2.83 ± 0.19 ± 0.04	– 0.09 ± 0.13 ± 0.06

$B \to \eta_c K$

preliminary





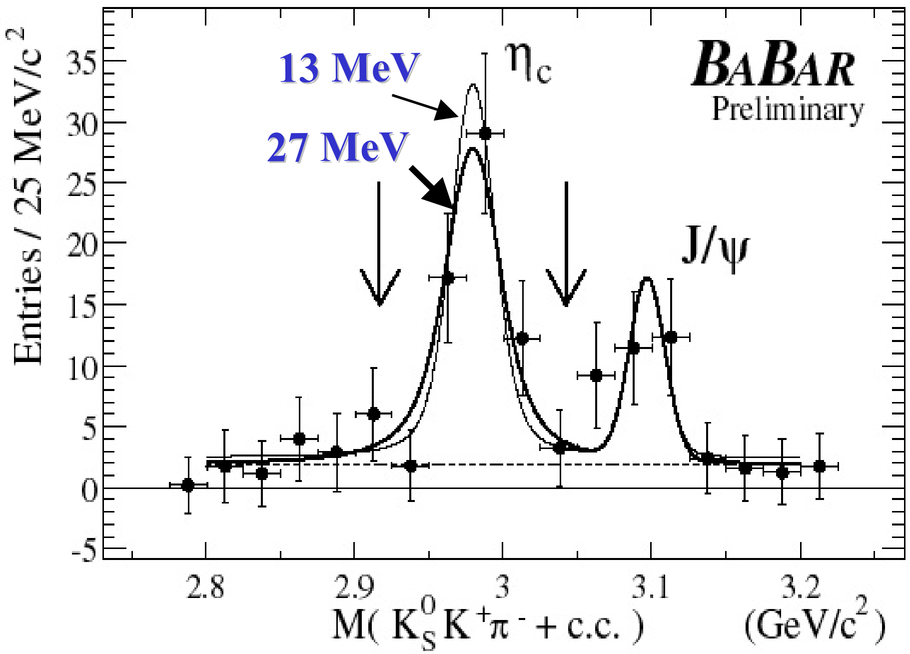
hep-ex/0203040

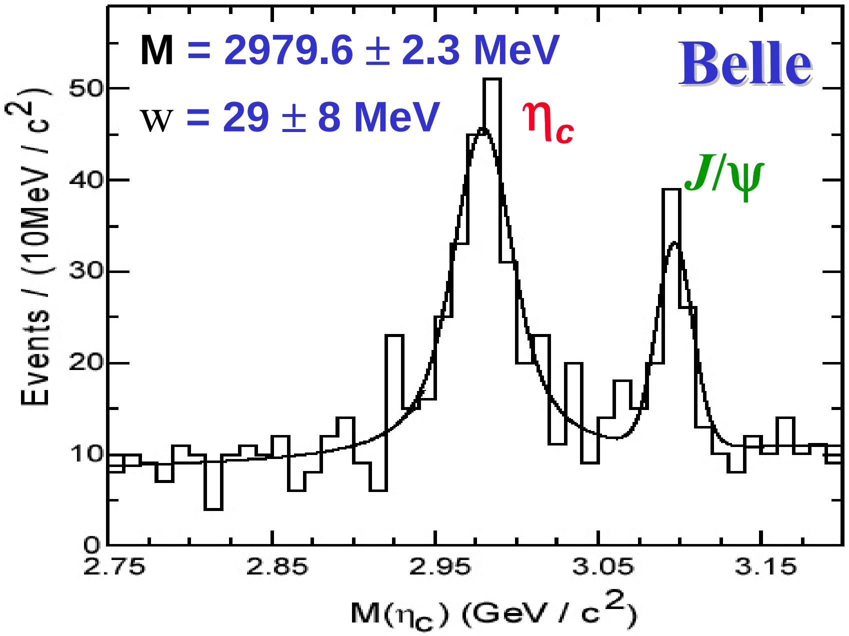
- 22.7 million $B\bar{B}$
- $\eta_c(1S) \to K_SK^-\pi^+, K^+K^-\pi^0, 2(K^+K^-)$
- Statistically significant signals in the $K_SK^-\pi^+$ and $K^+K^-\pi^0$ channels

- 31.3 million $B\bar{B}$
- $\eta_c(1S) \to K_SK^-\pi^+, K^+K^-\pi^0, p\bar{p}, K^{*0}K^-\pi^+$
- Statistically significant signals in the $K_SK^-\pi^+, K^+K^-\pi^0, p\bar{p}$ channels and the $B^+ \to \eta_c K^+, \eta_c \to K^{*0}K^-\pi^+$ mode

$B \to \eta_c K$

preliminary





	$Br(B^0 \to \eta_c K^0)$ $(\times 10^{-3})$	$Br(B^+ \to \eta_c K^+)$ $(\times 10^{-3})$
CLEO	$1.09\,^{+0.55}_{-0.42} \pm 0.12 \pm 0.31$	$0.69\,^{+0.26}_{-0.21} \pm 0.08 \pm 0.20$
BaBar[1]	$1.06 \pm 0.28 \pm 0.11 \pm 0.33$	$1.50 \pm 0.19 \pm 0.15 \pm 0.46$
Belle[1]	$1.23 \pm 0.23\,^{+0.12}_{-0.16} \pm 0.38$	$1.25 \pm 0.14\,^{+0.10}_{-0.12} \pm 0.38$

	$\Gamma^{intrinsic}$ (MeV/c²)
PDG	$13\,^{+3.8}_{-3.2}$
CLEO	27 ± 6.0

1. Use $K_S K^- \pi^+$ and $K^+ K^- \pi^0$ modes to derive branching fraction.

First observation of $B^0 \to \eta_c K^{*0}$

preliminary

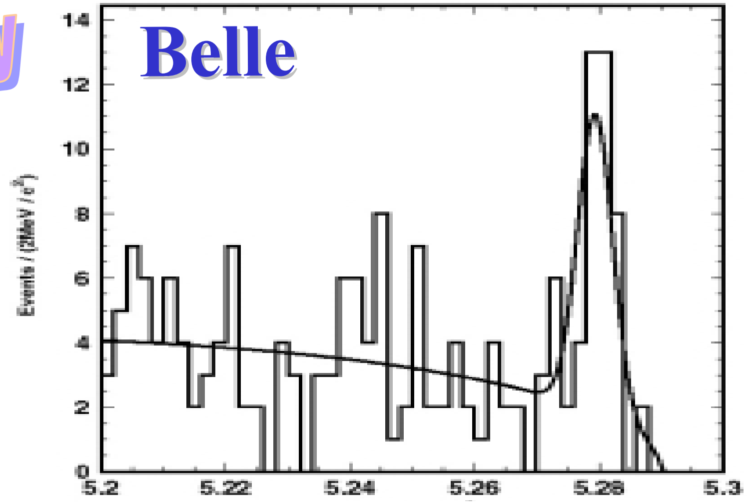
- 31.3 million $B\bar{B}$
- $B^0 \to \eta_c K^{*0}$

  $\eta_c \to K_S K^- \pi^+$

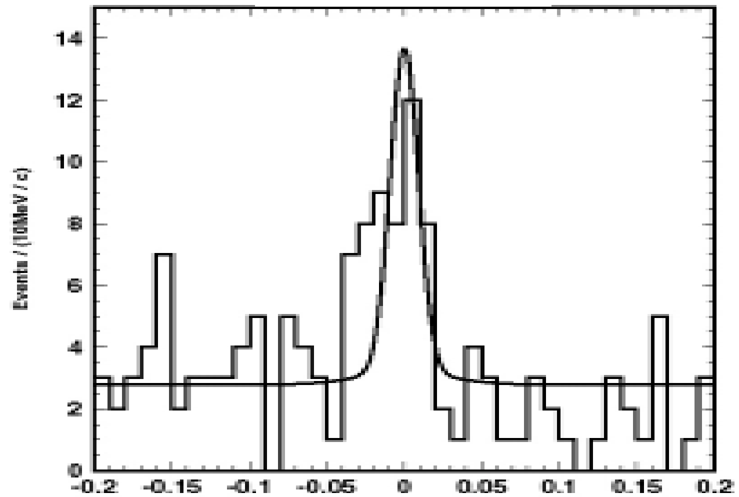
  $K^{*0} \to K^+ \pi^-$
- Veto $J/\psi, \chi_{C1} \to K_S K \pi$ and $D_s \to K^+ K^- \pi$
- Yield 33.7 ± 6.7 signif. $= 7.7\sigma$

$$B(B^0 \to \eta_C K^{*0}) = (1.62 \pm 0.32^{+0.24}_{-0.34} \pm 0.50) \times 10^{-3}$$

$$R_{\eta_C} = \frac{B(B^0 \to \eta_C K^{*0})}{B(B^0 \to \eta_C K^0)} = 1.33 \pm 0.36^{+0.29}_{-0.40}$$



M_{bc} (GeV/C^2)



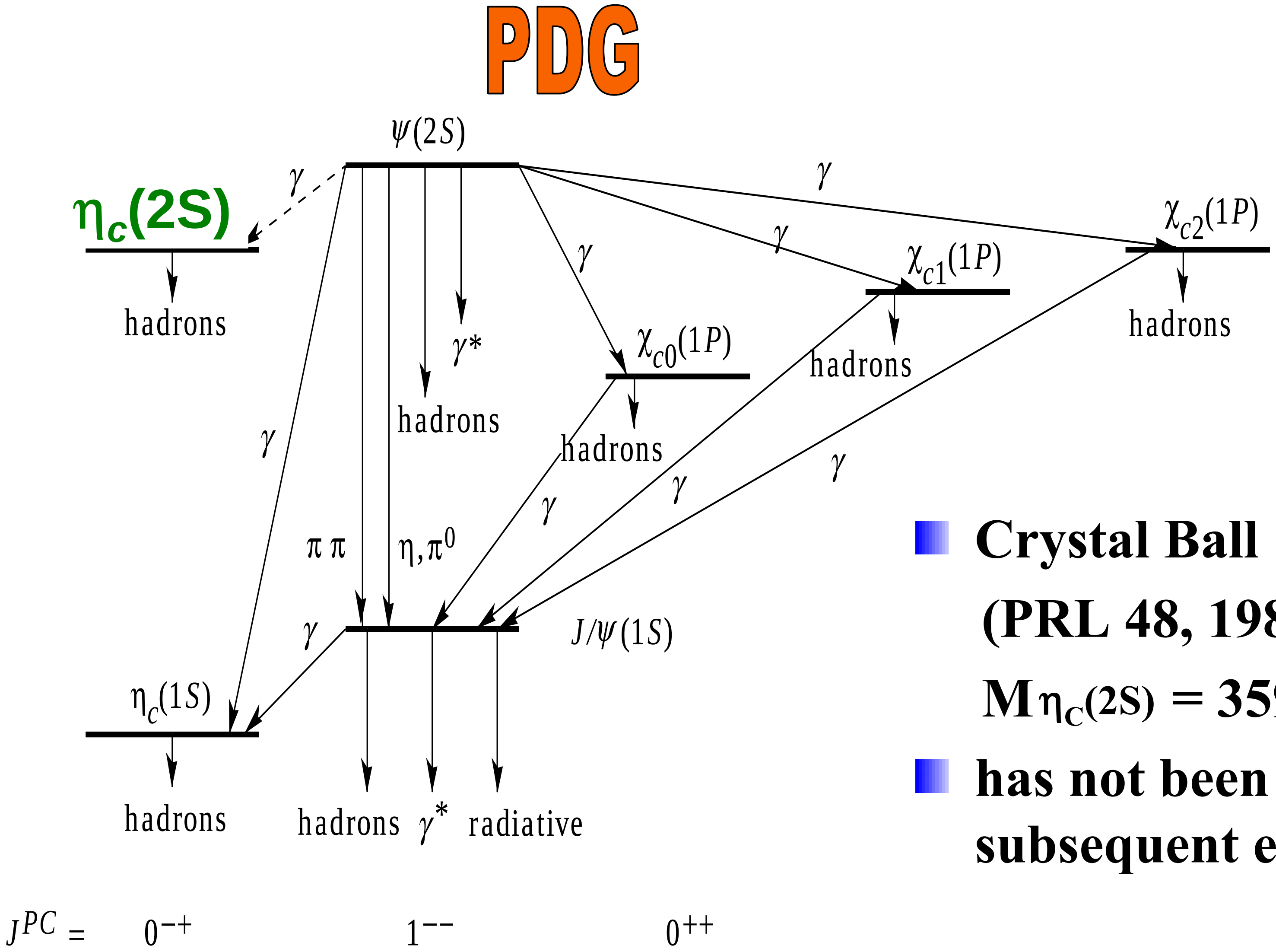
ΔE (GeV)

Exclusive $B \to J/\psi, \psi(2S), \chi_{c1}$

Decay mode	Branching fraction ($\times 10^{-4}$)		
	Previous	*BABAR*	Belle
$B^- \to J/\psi K^-$	10.0±1.0 [1]	10.1±0.3±0.5	10.1±0.3±0.8
$B^0 \to J/\psi K^0$	9.6±0.9 [1]	8.3 ±0.4±0.5	7.7±0.4±0.7
$B^+ \to J/\psi K_1^+(1270)$			18.0±3.4±3.9 ★
$B^0 \to J/\psi K_1^0(1270)$			13.0±3.4±3.1 ★
$B^- \to \psi(2S) K^-$	5.8±1.0 [1]	6.4 ±0.5±0.8	6.7±0.6±0.7 ($\psi(2S) \to l^+l^-$) 5.7±0.5±0.8 ($\psi(2S) \to J/\psi\pi\pi$)
$B^0 \to \psi(2S) K^0$	5.0±1.3 [2]	6.9 ±1.1±1.1	6.0±1.1±0.7 ($\psi(2S) \to l^+l^-$) 7.2±1.1±1.1 ($\psi(2S) \to J/\psi\pi\pi$)
$B^- \to \chi_{c1} K^-$	10.0± 4.0 [1]	7.5±0.8±0.8	6.1±0.6±0.6
$B^0 \to \chi_{c1} K^0$	$3.9^{+1.9}_{-1.4}$ [1]	5.4 ±1.4±1.1	3.1±0.9±0.4
$B^0 \to \chi_{c1} K^{*0}$		4.8 ±1.4±0.9 ★	
$B^- \to J/\psi \pi^-$	0.41±0.15 [1]	0.39±0.09	0.52 ± 0.07± 0.07
$B^0 \to J/\psi \pi^0$	$0.25^{+0.11}_{-0.09}$ [1]	0.20±0.06±0.02	0.24 ± 0.06± 0.02

[1] PDG, [2] CLEO, ★ first observation,

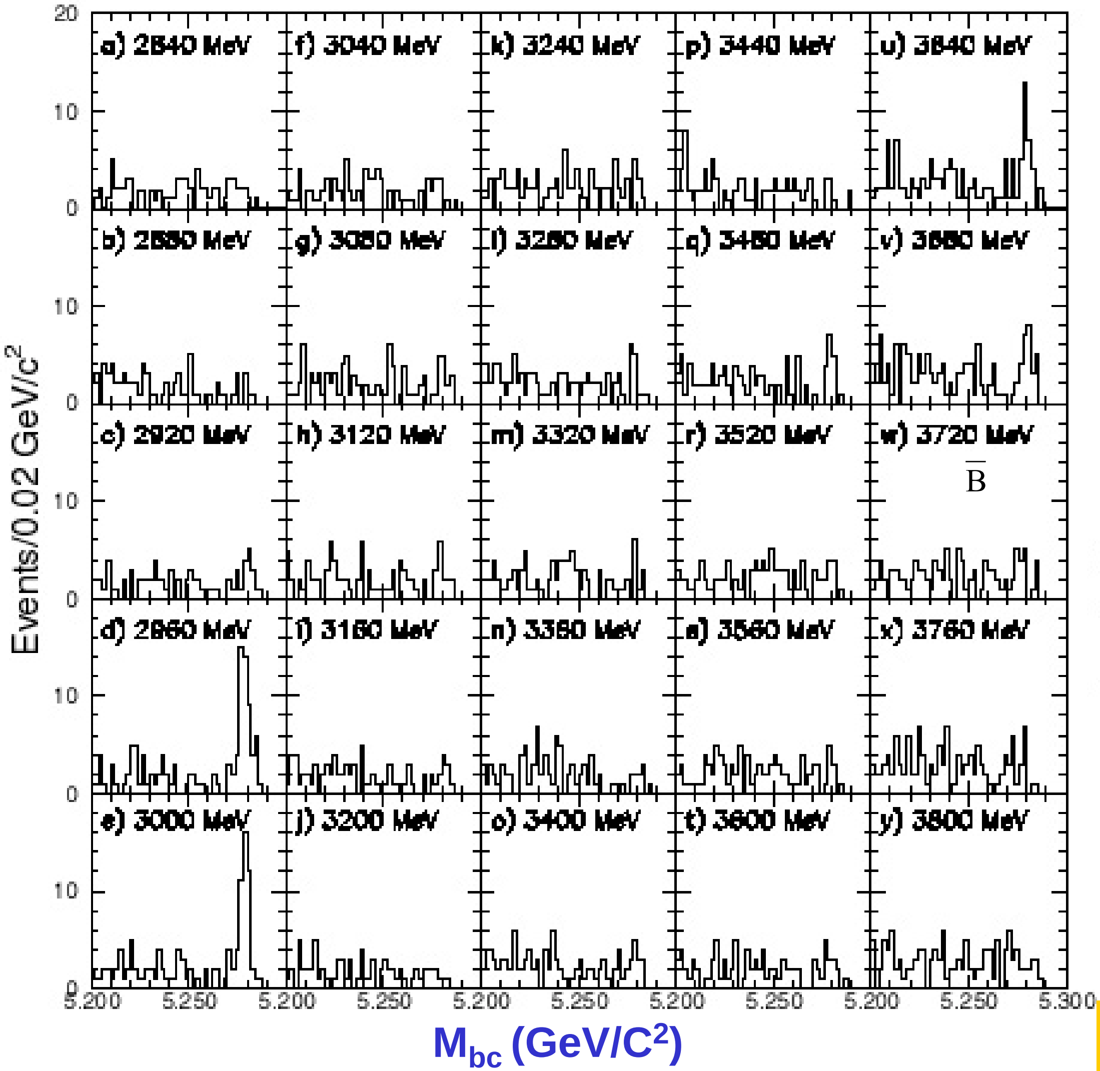
The charmonium system



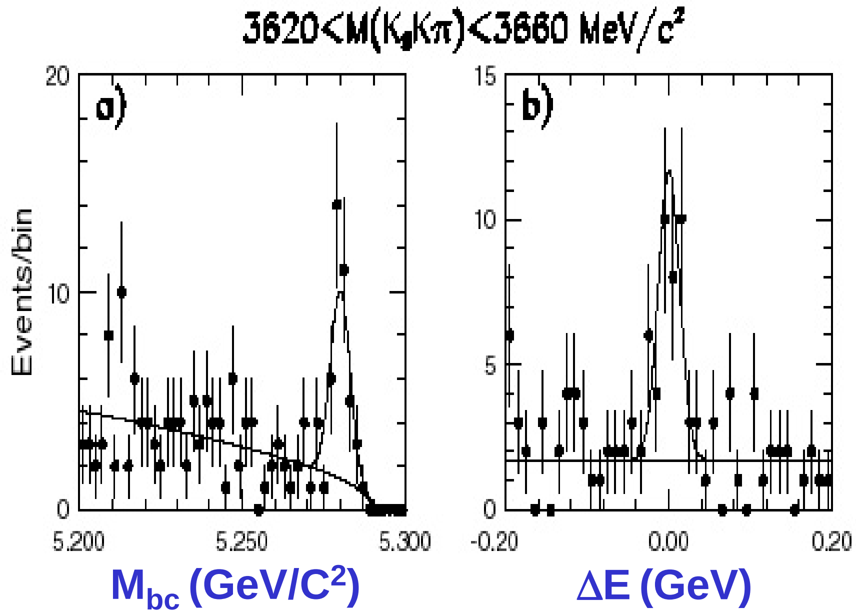
- **Crystal Ball (PRL 48, 1982)** $M_{\eta_c(2S)} = 3594 \pm 5\ \mathrm{MeV}/c^2$
- **has not been confirmed by subsequent experiments**

First observation of exclusive $\eta_c(2S)$

Belle

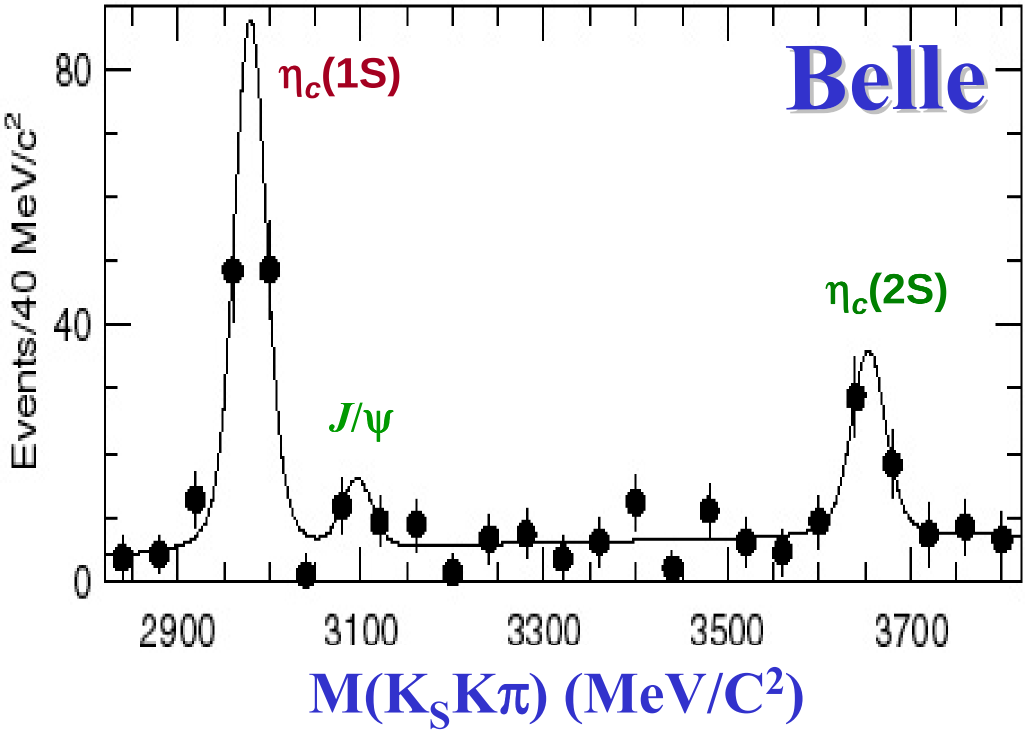


- 44.1 million $B\bar{B}$
- $B^+ \to K_S K^- \pi^+ K^+$
  $B^0 \to K_S K^- \pi^+ K_S$
- Efficiency is 9.4%



See *S. L. Olsen's* poster for details

First observation of exclusive $\eta_c(2S)$



Yield 39 ± 11

signif. > 6σ

$\eta_c(2S)$

M = **3654±6 ±8** MeV/c²

$\Gamma^{tot}_{\eta_C(2S)}$ < **55** MeV/c²

(90% C.L.)

- **Inconsistent with the Crystal Ball result 3594±5 MeV**

$$\frac{B(B \to \eta_c(2S)K)B(\eta_c(2S) \to K_S K^- \pi^+)}{B(B \to \eta_c(1S)K)B(\eta_c(1S) \to K_S K^- \pi^+)} = 0.38 \pm 0.12 \pm 0.05$$

preliminary

Summary

- Improved measurements for branching fractions
  - $B \to J/\psi K^{(*)}$, $B \to \psi(2S) K$, $B \to \chi_{c1} K$, …
- First observations of the B decay modes
  - $B^0 \to \chi_{c1} K^{0*}$ (*BABAR*)
  - $B^+ \to \chi_{c0} K^+$, $B \to \chi_{c2} X$, $B^0 \to \eta_c K^{*0}$, $B \to J/\psi K_1(1270)$ (Belle)
- Br($B^+ \to \chi_{c0} K^+$) and Br($B \to \chi_{c2} X$) are comparable to Br($B^+ \to J/\psi K^+$) and Br($B \to \chi_{c1} X$)
- Belle has observed the $\eta_C(2S)$ meson. The mass agrees with the heavy-quark potential model expectations