Branching Fraction and Properties of B meson Decays to Charmonium

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For the Belle Collaboration

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  KEKB and Belle

  Interest in $B \to \text{charmonium}$ decay
- 2. Search for Missing Charmonium states

  such as $\eta_C(2S)$
- 3. Search for factorization-forbidden decays

  $B \to \chi_{C0} K, \chi_{C2} X$
- 4. Additional CP eigenstates (Cabibbo favored):

  $(b \to (c\bar{c})s)$

  $B \to J/\psi\, K_1(1270),\ J/\psi\, K_2(1430),\ \eta_C K^*$

Contents (2)

- 5. Additional CP eigenstates(Cabibbo suppressed):

  $(b \to (c\bar{c})\, d)$

  $B^0 \to J/\psi\, \pi^0\,,\ J/\psi\, \rho^0$

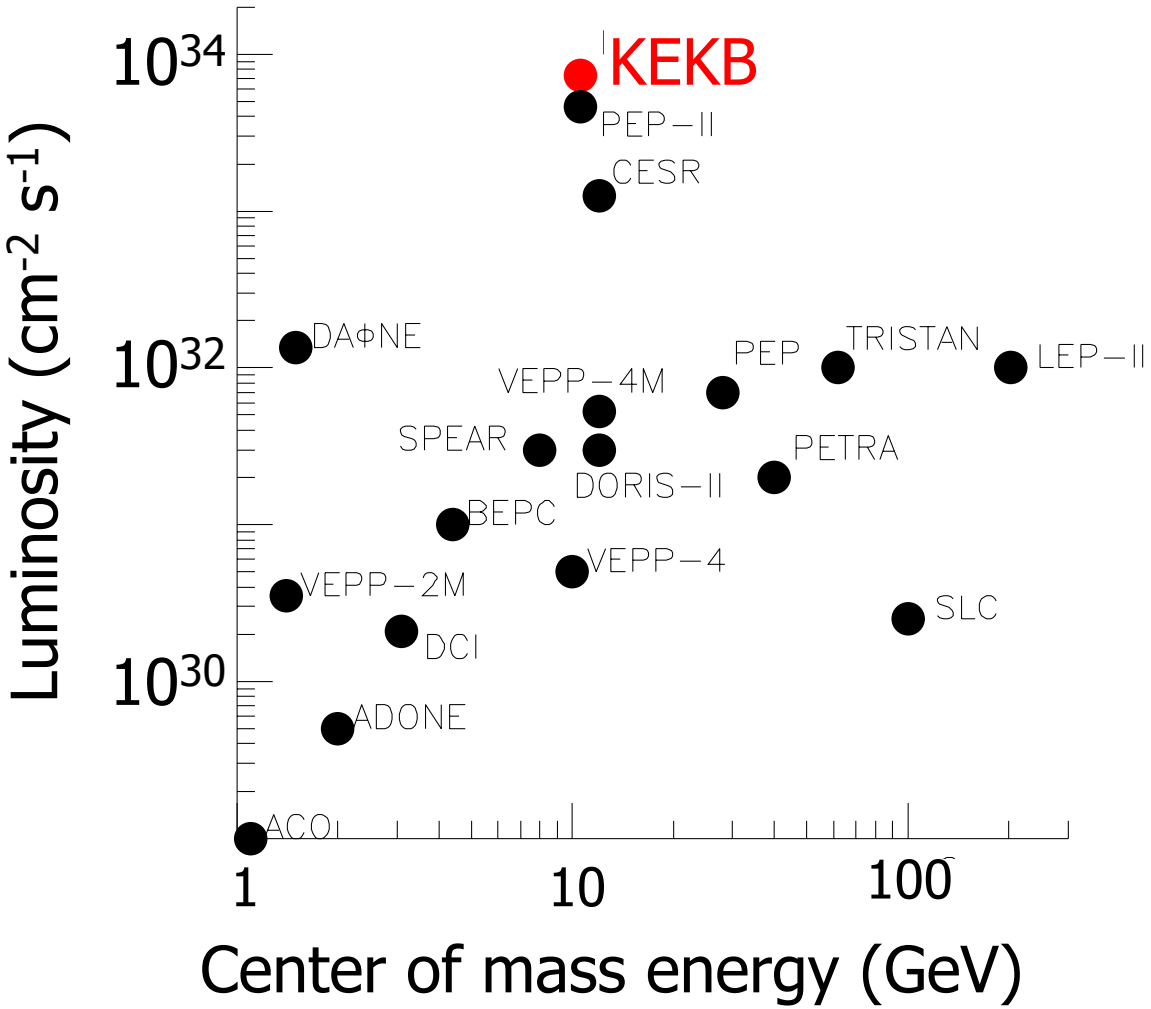
- 6. Branching Fractions of Exclusive Decays

  $B \to J/\psi\, K, \eta_C\, K, \text{etc.}$

- 7. Summary

1 Introduction

- Luminosity vs. Energy of e^+e^- colliders



1 Introduction (2)

- Accelerator-Detectors at Luminosity Frontier as of summer 2002

	Peak lum. ($10^{33}cm^{-2}s^{-1}$)	Integrated Lum. ($fb^{-1}d^{-1}$)	(fb^{-1})	Start of operation
KEKB - Belle	7.35	0.41	89.6	1999 May
PEP-II - BaBar	4.6	0.31	93.8	1998 Oct.
CESR - CLEO	1.25	0.1	～ 25	1979

1 Introduction (3)

- KEKB

Asymmetric Energy e^+e^- collider

(crucial for CP measurement)

at $\Upsilon(4S)$ region (10.58GeV)

e^- : 8.0 GeV, 1.1A

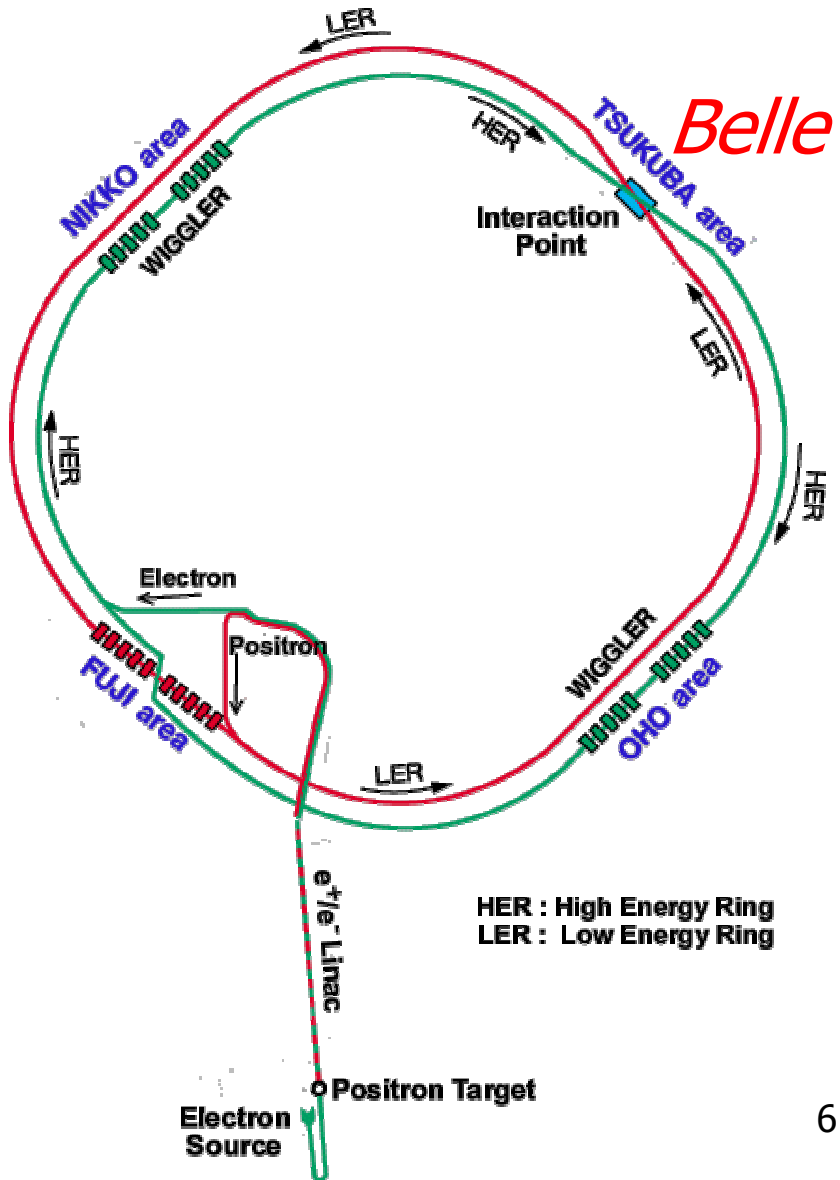
e^+: 3.5 GeV, 2.6A

finite angle crossing ± 11mr

World Highest Luminosity

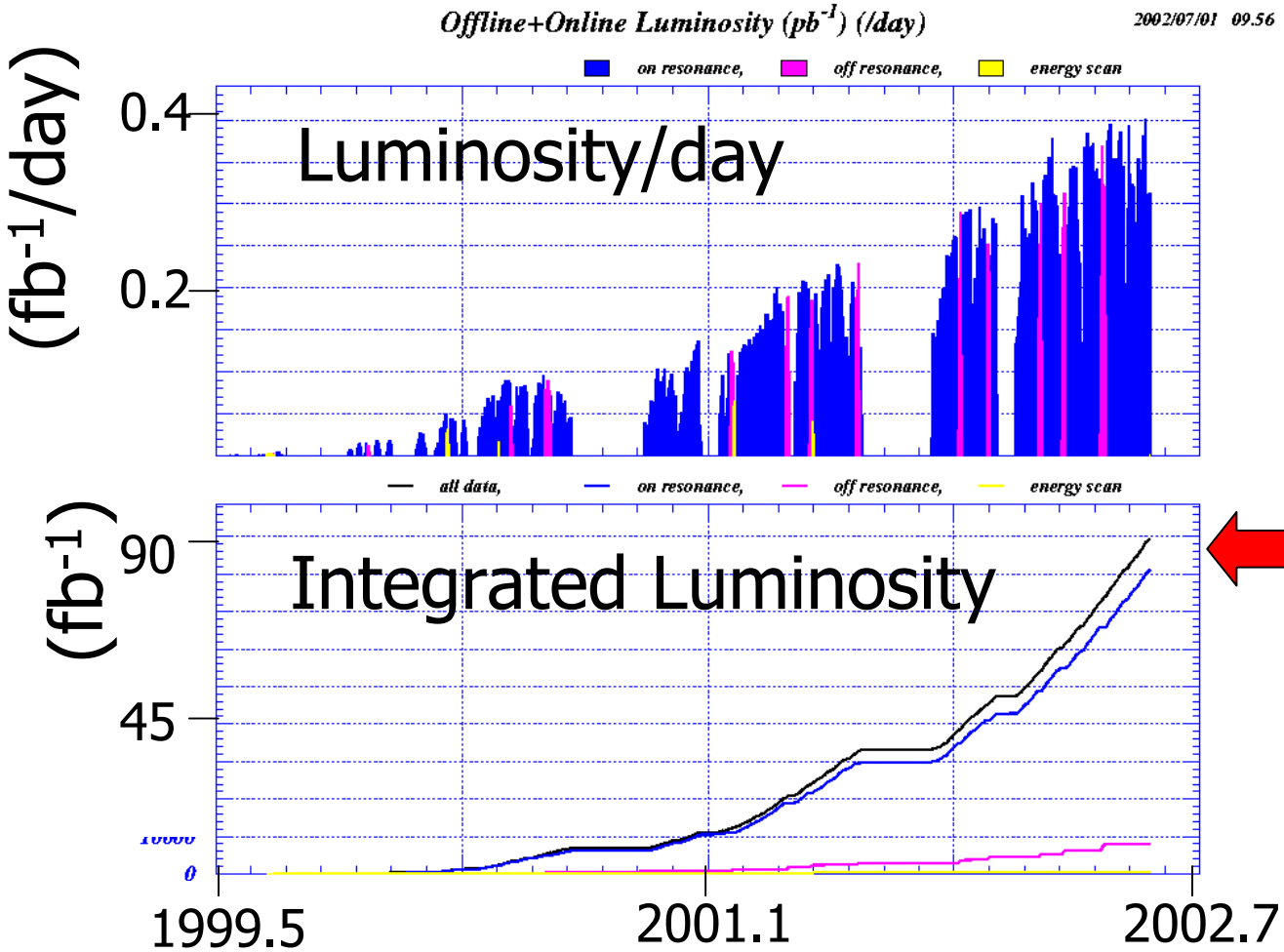
Design = $10^{34}\,cm^{-2}s^{-1}$

$\approx 11\, B\bar{B}$ pairs/sec



1 Introduction (4)

- Luminosity at KEKB-Belle



Improved drastically

89.6 fb^{-1}

1 Introduction (5)

- Belle detector

Good Vertex Detection

$$|\Delta(z_{CP} - z_{flavor-tag})| \leq 100\,\mu\mathrm{m}$$

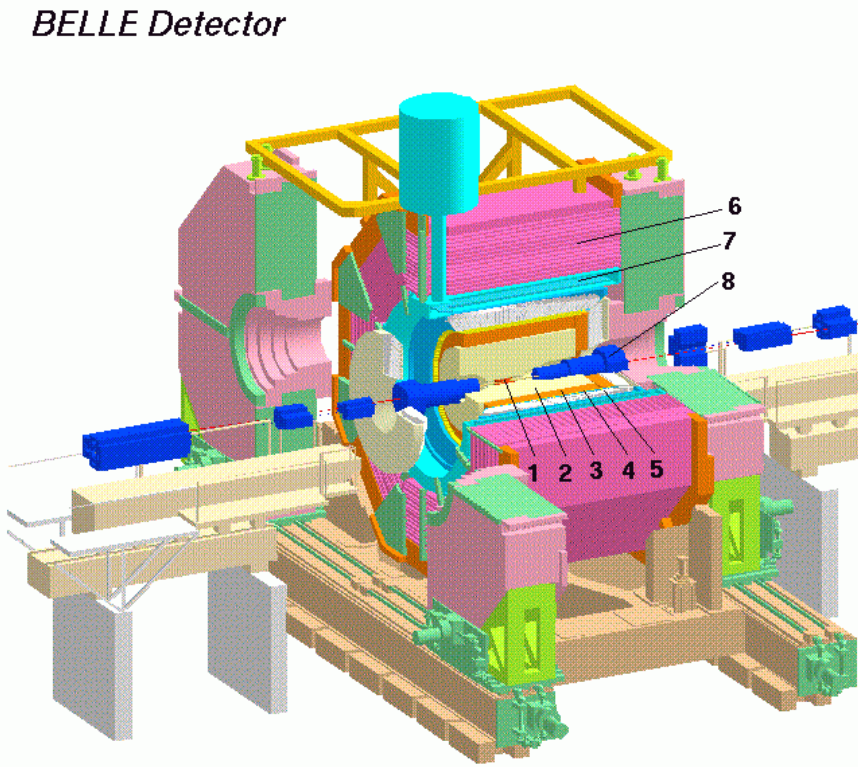
Good Particle ID

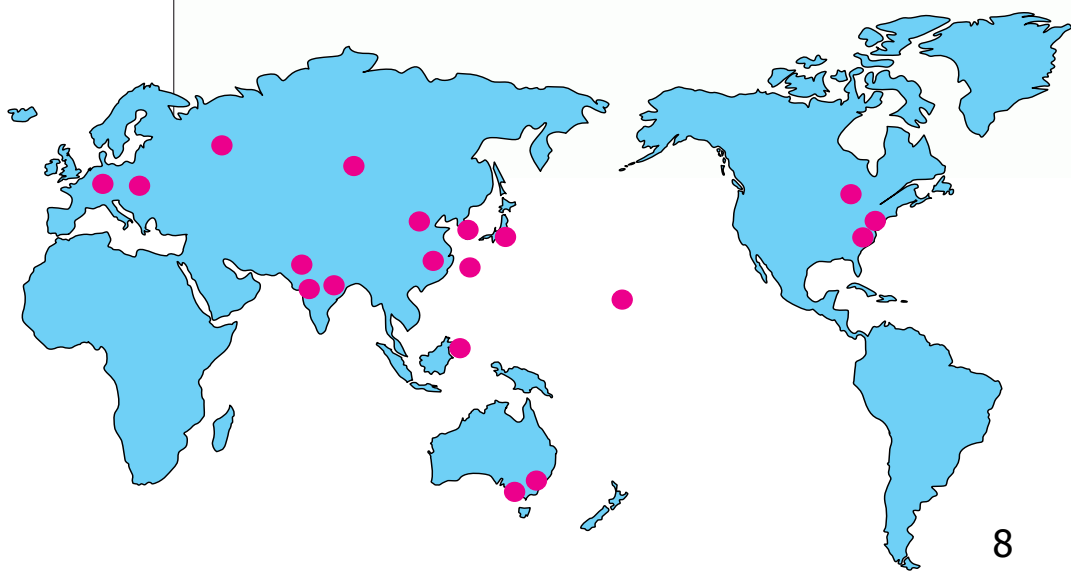
K/π separation up to 3.5 GeV/c

- Belle collaboration

~300 researchers

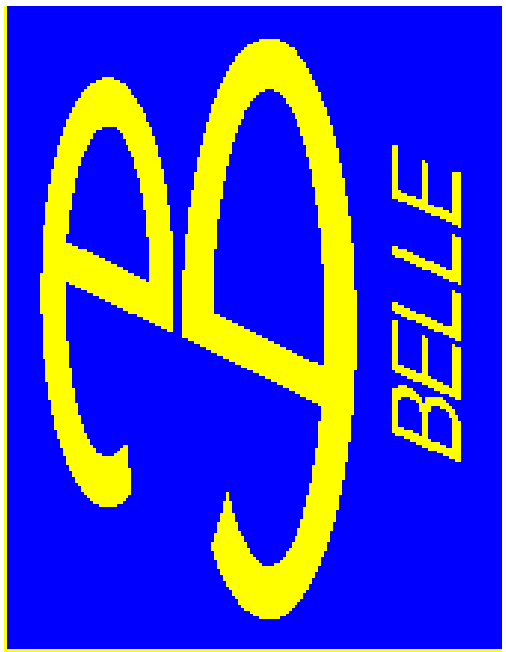
(55 Institutes) from Australia, Austria, China, Germany, India, Japan, Korea, Philippines, Poland, Russia, Slovenia, Switzerland, Taiwan and USA





1 Introduction

- Belle and Logo



B←*el le*

Asymmetric e^+e^- collider producing *B*

1 Introduction (6)

- Interest in B decays to charmonium

1) Golden channels for CP Measurements: ϕ_1 (or β)

2) Best place to look for missing charmonium states such as $\eta_C(2S)$

3) Clean testing ground of Theoretical Ideas (QCD, NRQCD, HQET)

charmonium states = singlet in color, isospin and SU(3) quantities

4) Fundamental Quantities

Branching fractions, etc.

1 Introduction (7)

- Fundamentals of Analyses

1) Most of analyses are based on data of $29.4\text{fb}^{-1}:(32\text{M}\ B\bar{B}\ \text{pairs})$ (1/3 of data taken)

$$= N_B \times Br(B) \times Br(c\bar{c}) \times \varepsilon \approx O(100)$$

2) Number of events

$$N_B \approx 32\text{M}\ (B^{\pm} \text{ or } B^0, \bar{B}^0)$$

$$Br(B) \equiv Br(B \to (c\bar{c})X) \approx O(0.1\%)$$

$$Br(c\bar{c}) \equiv Br((c\bar{c}) \to \text{Reconstructable Final state}) \approx O(1 \sim 5\%)$$

$$\varepsilon \equiv \varepsilon(\text{recon.}) \approx O(10 \sim 30\%)$$

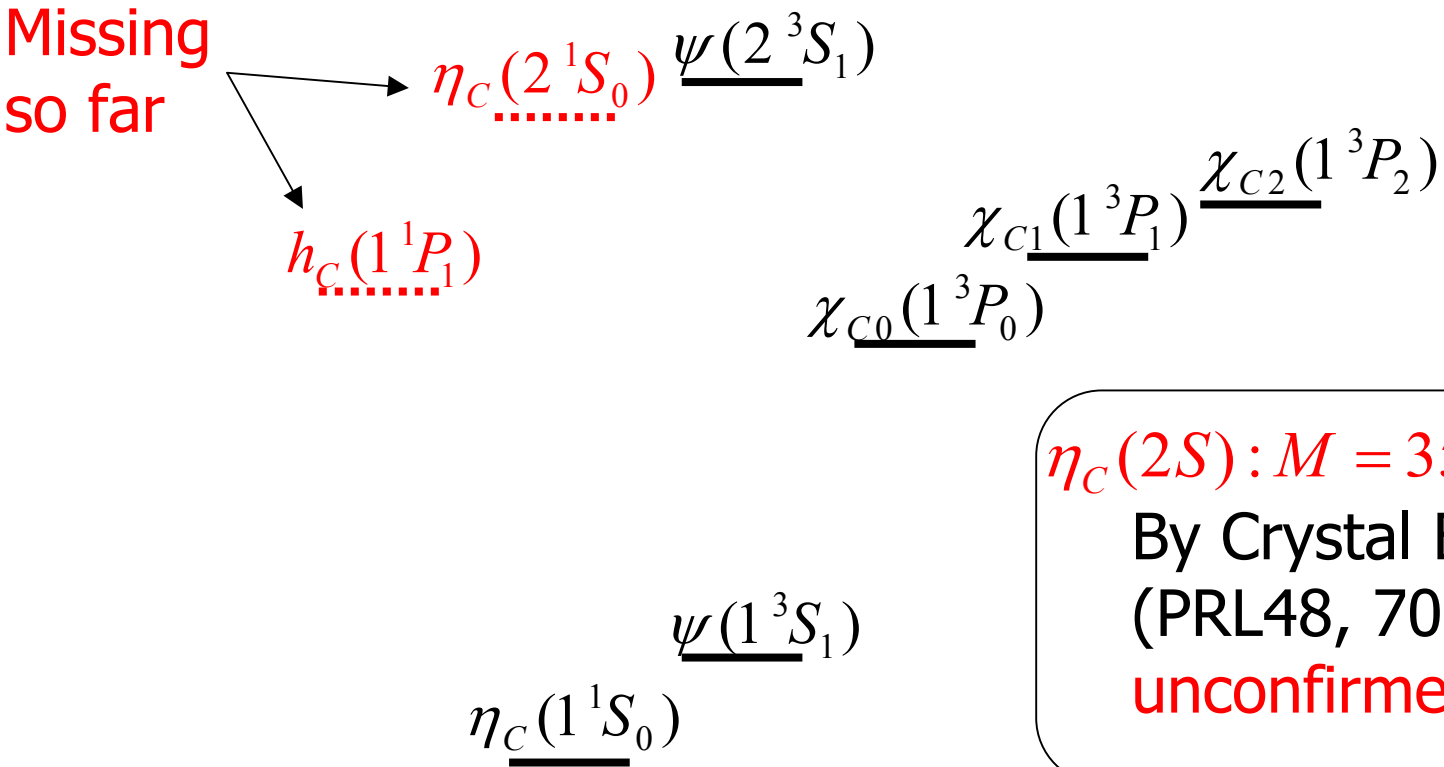
3) Signals: look for peaks in:

$$M_{bc} = \sqrt{E_{beam}^2 - \vec{p}_{recon}^{\,2}} \text{ and } \Delta E = E_{recon} - E_{beam},$$

$$\text{and } M(c\bar{c}) \text{ or } \Delta\text{M} \equiv \text{M}((\text{c}\bar{\text{c}})\gamma) - \text{M}((\text{c}\bar{\text{c}}))$$

2 Search for missing $c\bar{c}$ States

- Charmonium Levels



$\eta_C(2S): M = 3594 \pm 5\ \mathrm{MeV}/c^2$

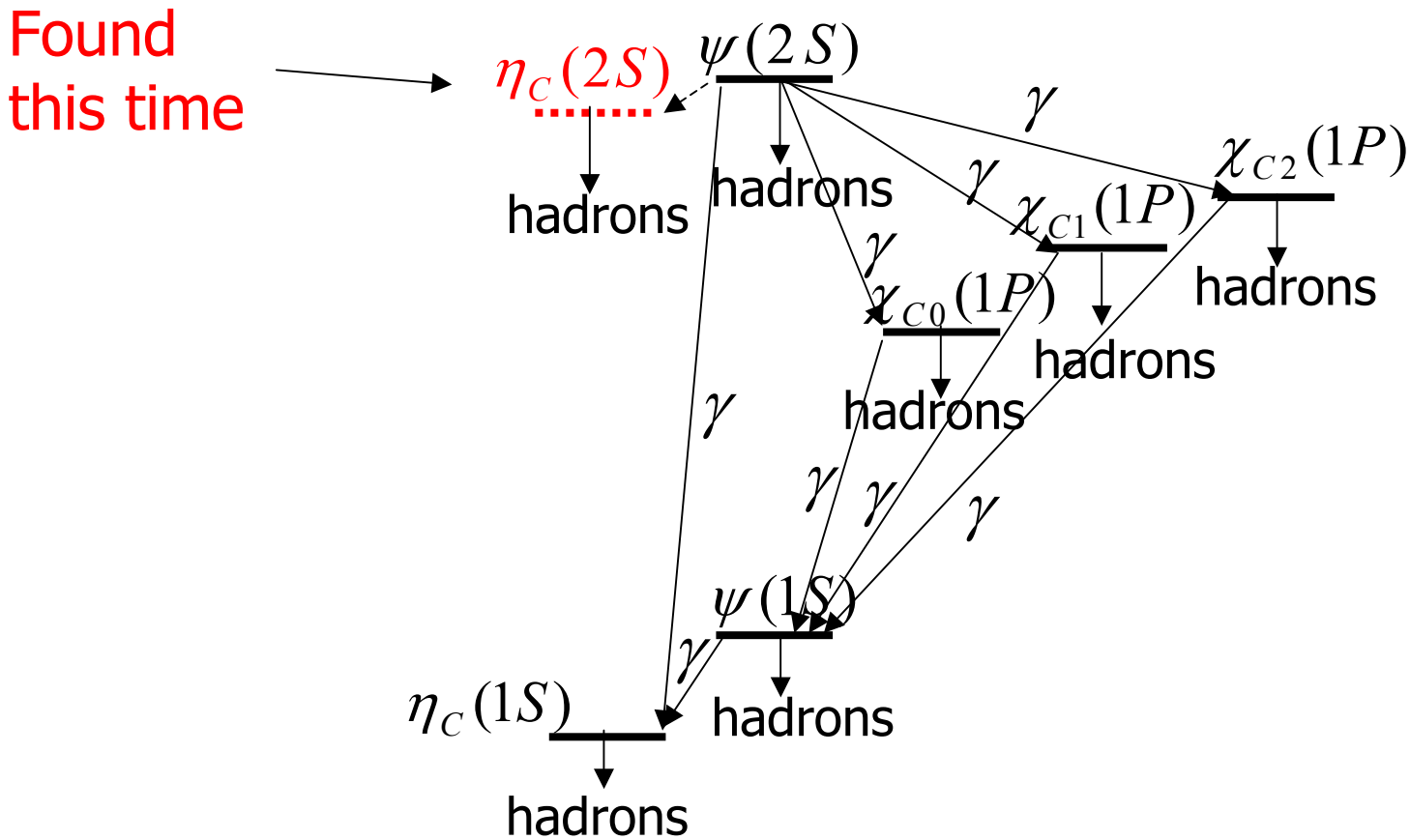
By Crystal Ball collab. (PRL48, 70, 1982)

unconfirmed

$$J^{PC} = \quad 1^{+-} \quad 0^{-+} \quad 1^{--} \quad 0^{++} \quad 1^{++} \quad 2^{++}$$

2 Search for missing $c\bar{c}$ States (2)

- Transitions among Charmonium Levels



2 Search for missing $c\bar{c}$ States (3)

- First Observation of $\eta_C(2S)$ (PRL to be published)

Look for $B^{\pm} \to \left(K_S K^{\pm} \pi^{\mp}\right) K^{\pm}$

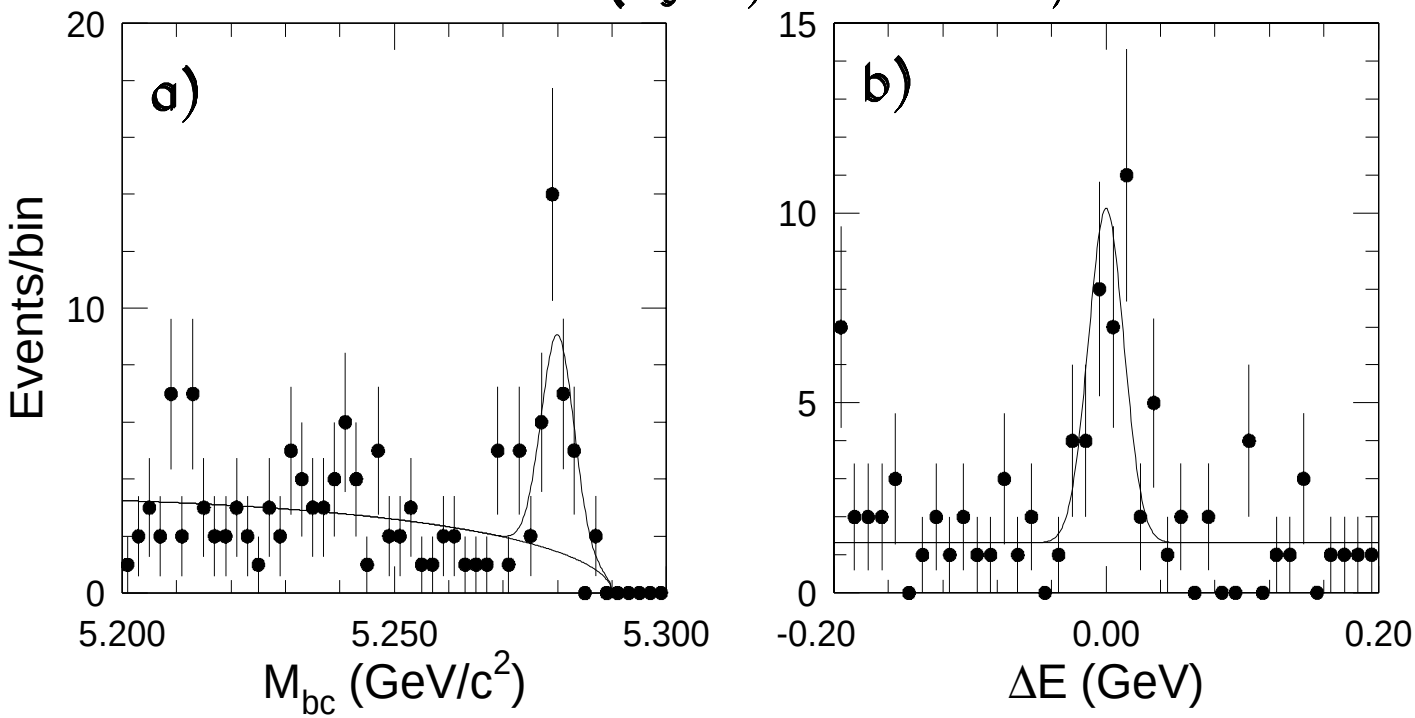
$B^0 \to \left(K_S K^{\pm} \pi^{\mp}\right) K_S$

Decay modes : $\eta_C(2S) \approx \eta_C(1S)$

$\left(Br\left(\eta_C(1S) \to KK\pi\right) \approx 5.5\% \right)$

B signals found in

$3620 < M(K_S K\pi) < 3660\ \mathrm{MeV}/c^2$



$$M_{bc} = \sqrt{E_{beam}^2 - \vec{p}_{recon}^{\,2}}$$

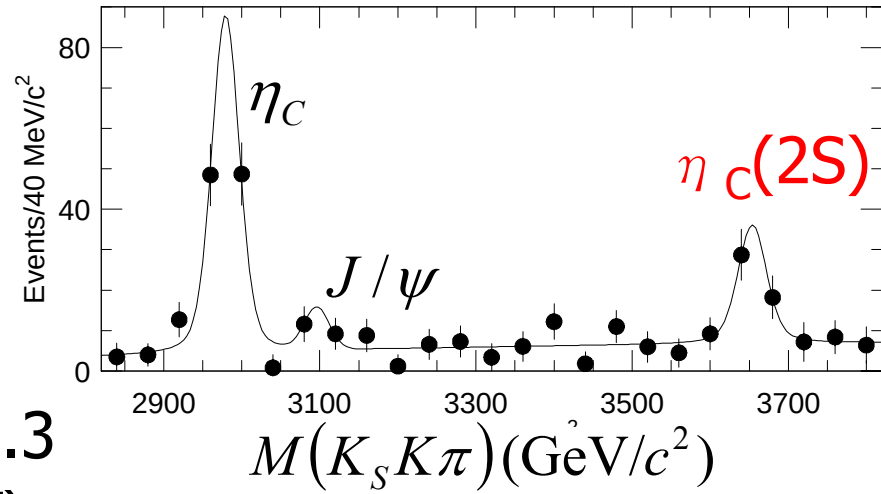
$$\Delta E = E_{recon} - E_{beam}$$

2 Search for missing $c\bar{c}$ States (4)

- $\eta_C(2S)$ (cont'd)

	Mass (MeV/c²)	Γ_{tot} (MeV)
Belle	$3654 \pm 6 \pm 8$	<55
Crystal Ball	3594 ± 5	<8
Theory	3635 ± 10	8.3 ± 1.3

(PRD24,132(81), Fermilab-Pub02/104-T)



#total=64
#Bgd =21±2

$$\begin{pmatrix} M(\psi(2S)) - M(\eta_C(2S)) = 32 \pm 6 \pm 8 \ \mathrm{MeV}/c^2 \\ M(\psi(1S)) - M(\eta_C(1S)) = 119 \pm 1.5 \ \mathrm{MeV}/c^2 \end{pmatrix}$$

$$\frac{\Gamma(B \to K\eta_C(2S))Br(\eta_C(2S) \to K_S K^{\pm}\pi^{\mp})}{\Gamma(B \to K\eta_C(1S))Br(\eta_C(1S) \to K_S K^{\pm}\pi^{\mp})} = 0.38 \pm 0.12 \pm 0.05$$

(substantial !)

3 Factorization-Forbidden Decays

3 Factorization-Forbidden Decays

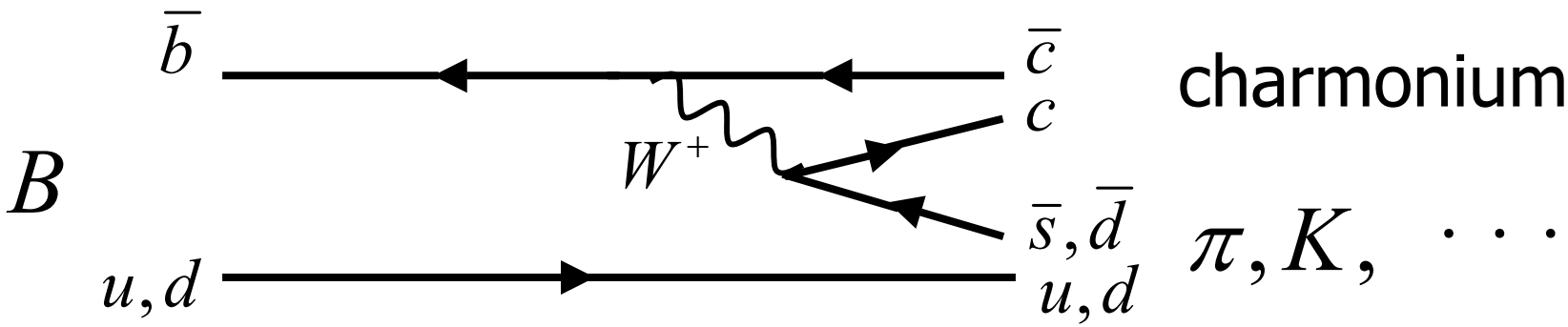
- QCD expectation

  Naïve Factorization Hypothesis:

$$A\left(B \to \left(c\bar{c}\right)X\right) \propto \left\langle \left(c\bar{c}\right)\middle|\left(\bar{c}_b c_b\right)_{V-A}\middle|0\right\rangle \times \left\langle X\middle|\left(\bar{q}_a b_a\right)_{V-A}\middle|b\right\rangle$$

$\Rightarrow = 0$ for χ_{C0} and χ_{C2} (CVC)

$\neq 0$ (with soft gluon exchange)



3 Factorization-Forbidden Decays (2)

- Decay $B \to \chi_{C2}(3556)\, X$ found. (PRL to be published)

enhance $B\bar{B}$ Events

look for $\chi_{C1,C2} \to J/\psi\,\gamma$

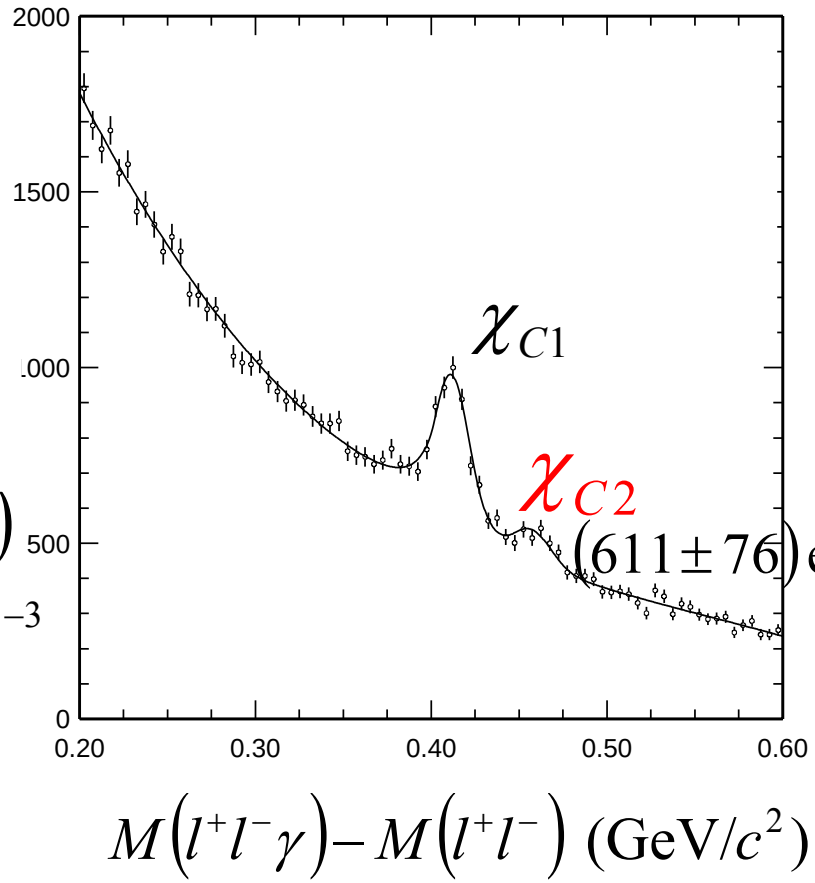
$\hookrightarrow l^+l^-$

$$B_r\left(B \to \chi_{C2} X\right) = 1.80^{+0.23}_{-0.28} \times 10^{-3}$$

$$\text{direct} = 1.53^{+0.23}_{-0.28} \times 10^{-3}$$

$$\left(\text{subtracting } \psi(2S) \to \chi_{C2}\gamma\right)$$

$$\text{c.f. } Br\left(B \to \chi_{C1} X\right) = 3.32 \pm 0.22 \times 10^{-3}$$



good γ energy resolution

$$\Delta E_\gamma / E_\gamma = (2.61 \pm 0.04)\,\%$$

$$(\text{recalib. from } D^{*0} \to D^0\gamma)$$

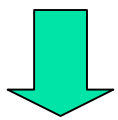
3 Factorization-Forbidden Decays (3)

- B$\rightarrow \chi_{C2}$(3556) X cont'd

Momentum spectra: χ_{C1}, χ_{C2}

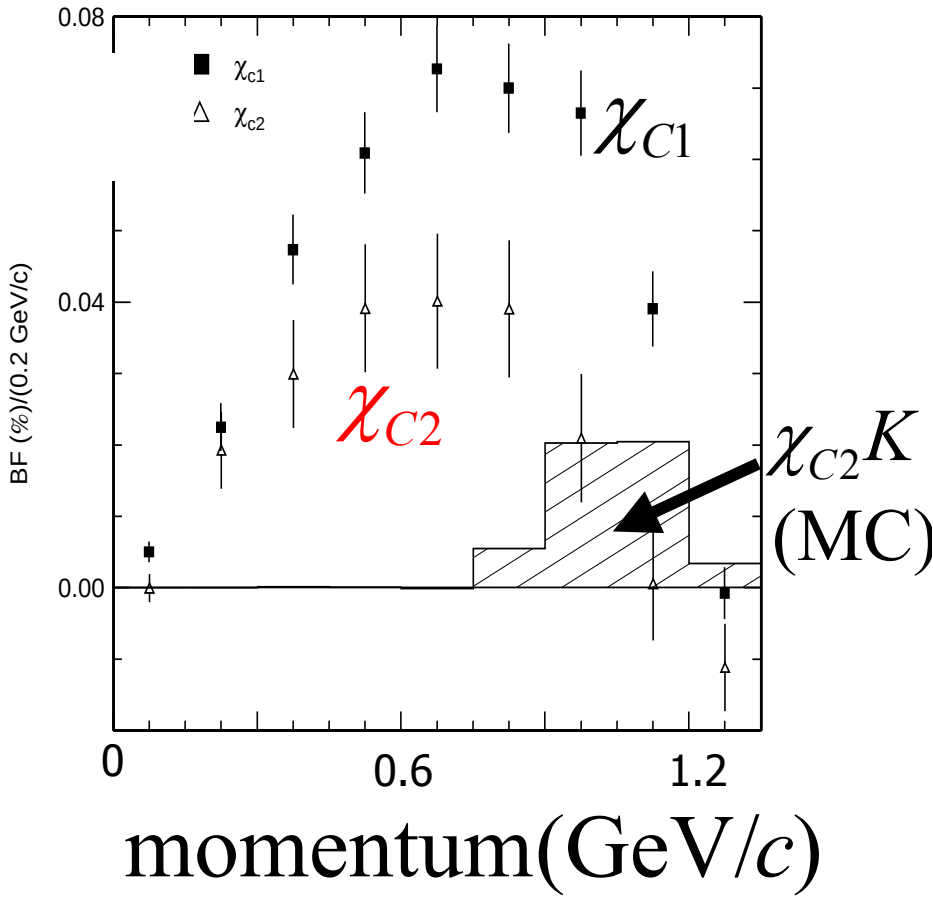
little events at end point for χ_{C2} compared to χ_{C1}

$\left(\text{c.f. } M(\chi_{C2})/M(\chi_{C1}) \approx 1.013\right)$



essentially no $B \rightarrow \chi_{C2} K$

(in contrast to $B \rightarrow \chi_{C1} K$)



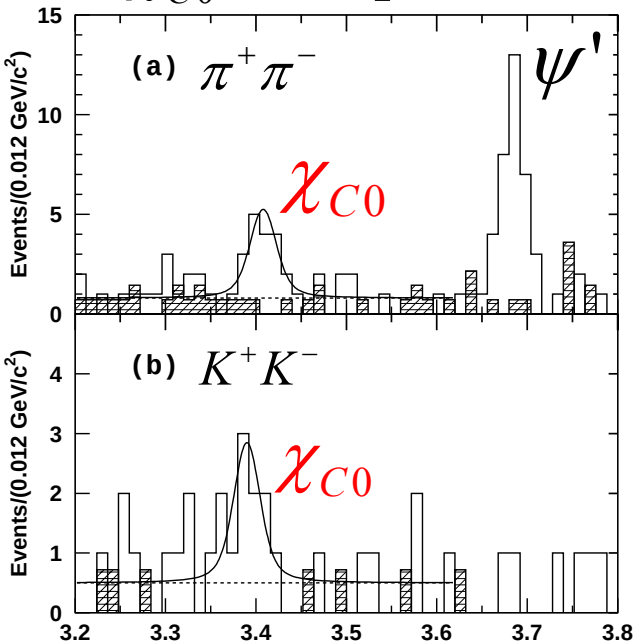
3 Factorization-Forbidden Decays (4)

- $B^{\pm} \to \chi_{C0}(3417) K^{\pm}$ found

PRL88:031802(2002)

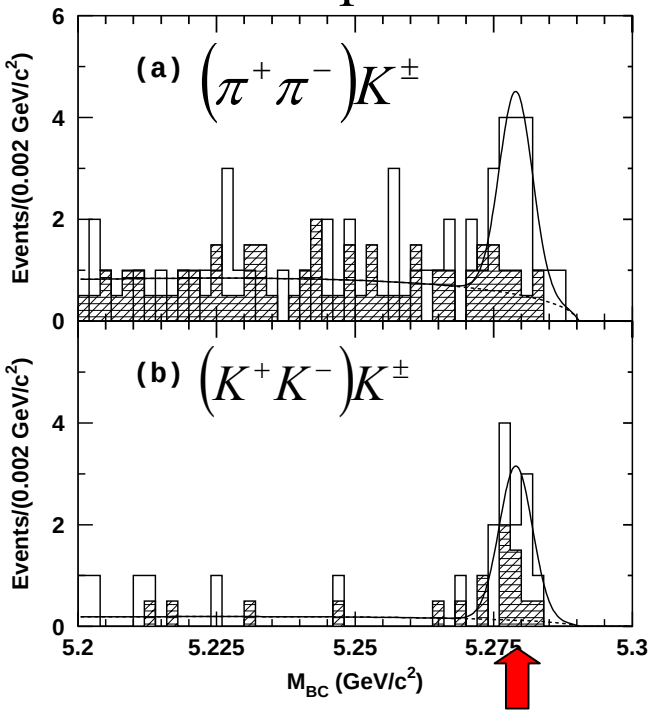
$\chi_{C0}(3417) \to K^+K^-(0.75\%),\ \pi^+\pi^-(0.71\%)$

χ_{C0} mass peak



A shift of the peak → interference?

B mass peak



B mass

$$\frac{Br\left(B^{\pm} \to \chi_{C0} K^{\pm}\right)}{Br\left(B^{\pm} \to J/\psi K^{\pm}\right)} = 0.60^{+0.21}_{-0.18} \pm 0.05 \pm 0.08$$

4 Additional CP eigenstates

- Decay modes so far used for CP fitting

$$\xi_f = -1$$

$$B_{CP} \to J/\psi\left(\to l^+l^-\right)K_S\left(\pi^+\pi^- \;\&\; \pi^0\pi^0\right): 3.8\times10^{-4}$$

$$\psi(2S)\left(\to l^+l^-, J/\psi\ \pi^+\pi^-\right)K_S$$

$$\chi_{C1}\left(\to J/\psi\ \gamma\right)K_S$$

$$\eta_C\left(\to K_S K^\pm\pi^\mp, K^+K^-\pi^0\right)K_S$$

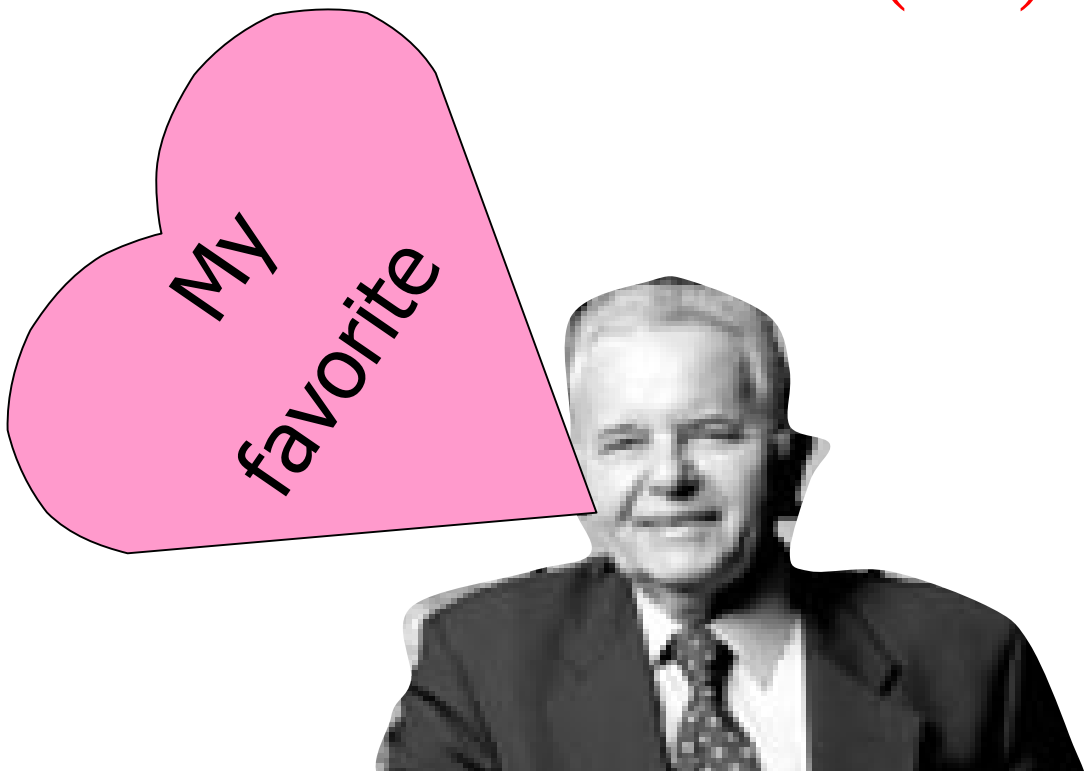
$$\xi_f = +1$$

$$B_{CP} \to J/\psi\left(\to l^+l^-\right)K_L(\text{direction})$$

$$J/\psi\ K^*\left(\to K_S\pi^0\right): \left(81\%\ \ \xi_f = +1\right)$$

4 Additional CP eigenstates

- Cabbibo favored Decays: $b \to (c\bar{c})s$



Nicola Cabibbo

4 Additional CP eigenstates: $b \to (c\bar{c})s$

PRL:87, 161601(2001)

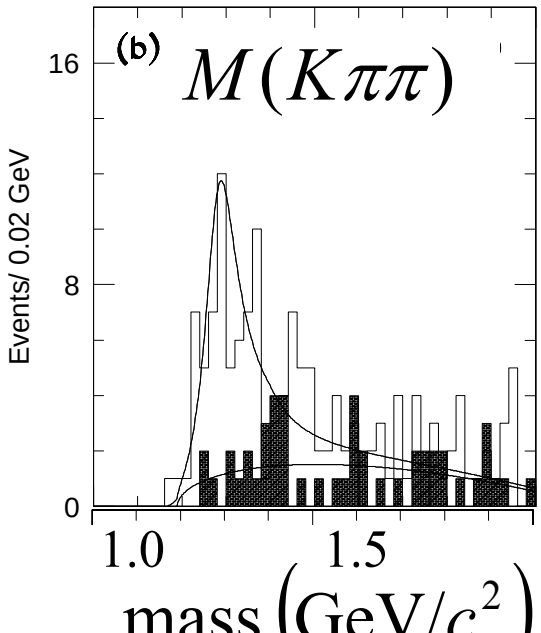
- $B \to J/\psi\, K_1(1270)$ found $\quad \left(\text{data} = 10.5\text{fb}^{-1} : 11.2\times10^6\, B\bar{B}\right)$

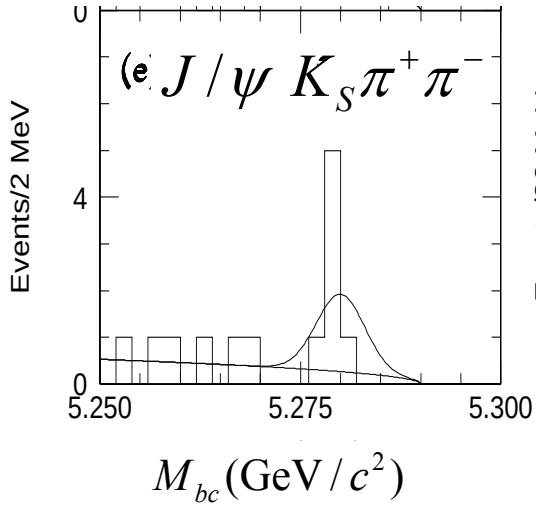
$$\hookrightarrow l^+l^- \quad \hookrightarrow K\pi\pi\,(CP\ \text{mode} = K_{S,L}\rho^0)$$

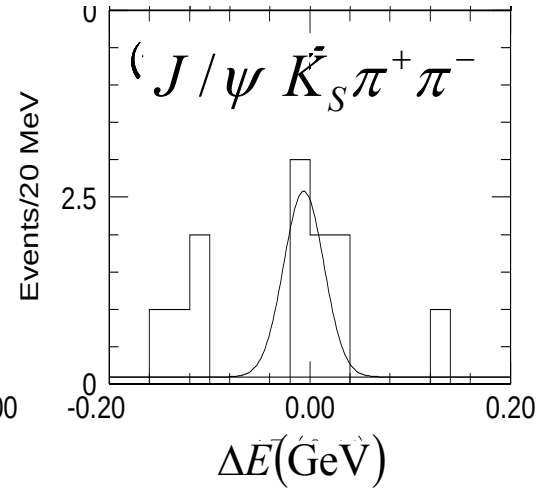
$$B_r\left(B^0 \to J/\psi\, K_1^0(1270)\right) = (1.30 \pm 0.34 \pm 0.32)\times10^{-3}$$

$$B_r\left(B^+ \to J/\psi\, K_1^+(1270)\right) = (1.80 \pm 0.34 \pm 0.39)\times10^{-3}$$

B signals in M_{bc} and ΔE







4 Additional CP eigenstates: $b \to (c\bar{c})s$ (2)

- $B \to J/\psi\ K_X^*(1430)$ found (Preliminary)

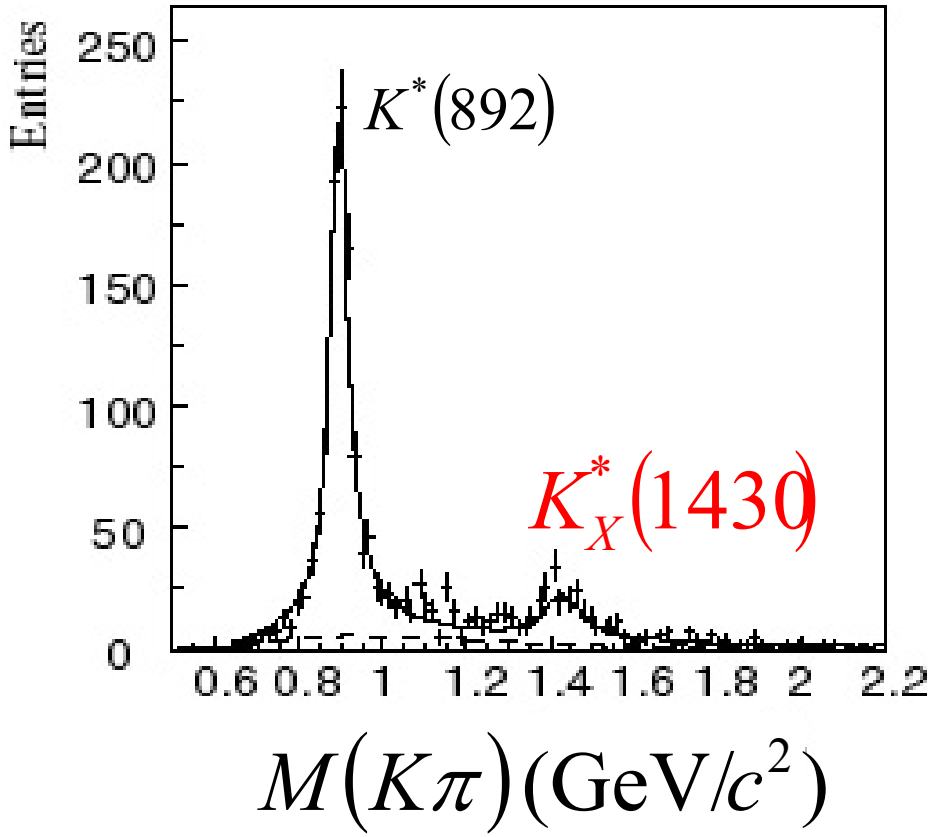
  $J/\psi \to l^+l^-$, $K_X^* \to K\pi$ (CP mode $= K_{S,L}\pi^0$)

Angular analysis reveals

large fraction of $K_2^*(1430)$

and a broad s wave component

(Significant longitudinal polarization)



4 Additional CP eigenstates: $b \to (c\bar{c})s$ (3)

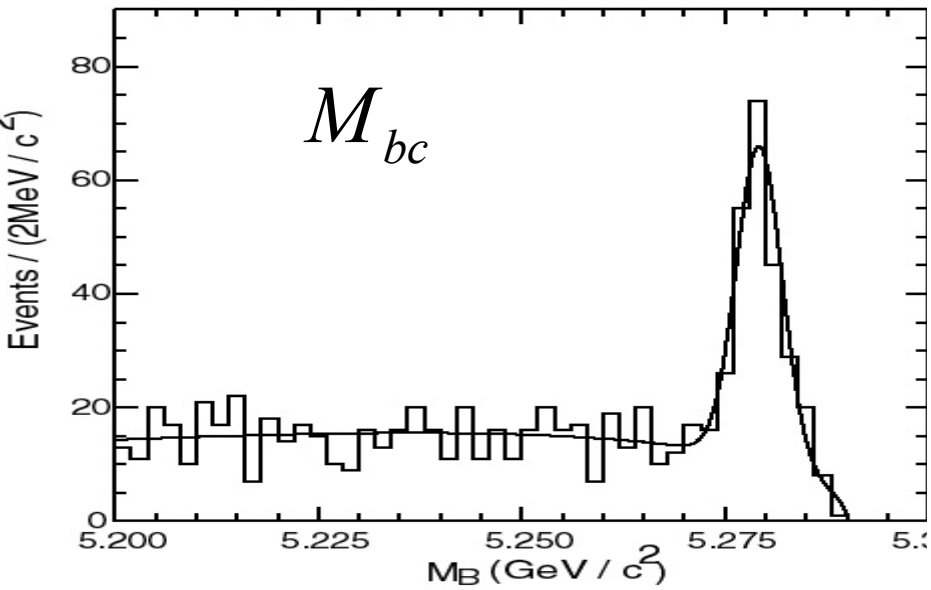
- $B \to \eta_C K$ decay

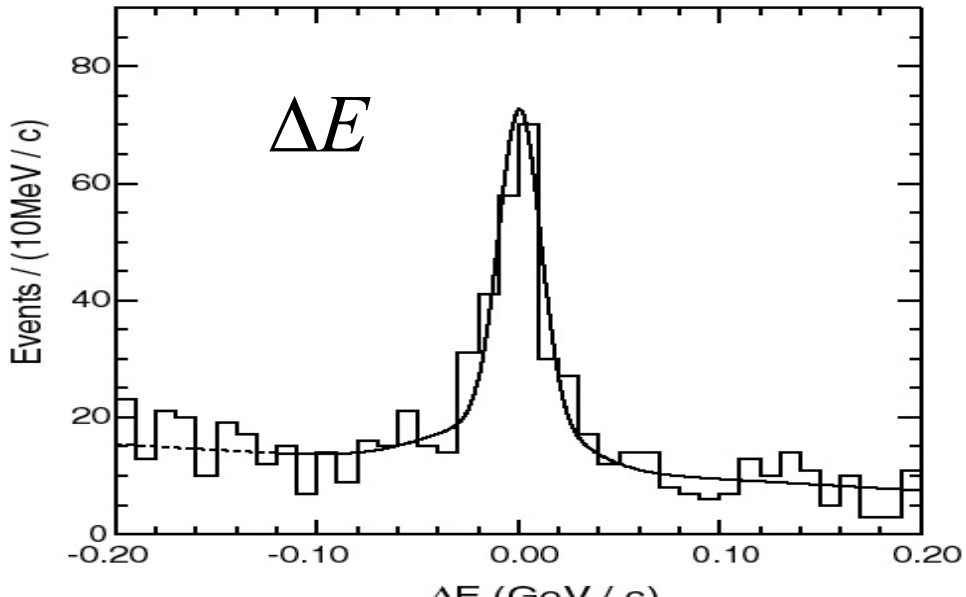
  $\hookrightarrow K_S^0 K^+\pi^-, K^+K^-\pi^0, \bar{p}p, K^{*0}K^-\pi^+$

$$Br(B^+ \to \eta_C K^+) = (1.25 \pm 0.14^{+0.10}_{-0.12} \pm 0.38) \times 10^{-3}$$

$$Br(B^0 \to \eta_C K^0) = (1.23 \pm 0.23^{+0.12}_{-0.16} \pm 0.38) \times 10^{-3}$$

Clear B signals





4 Additional CP eigenstates: $b \to (c\bar{c})s$ (4)

- $B^0 \to \eta_C K^{*0}(892)$ found

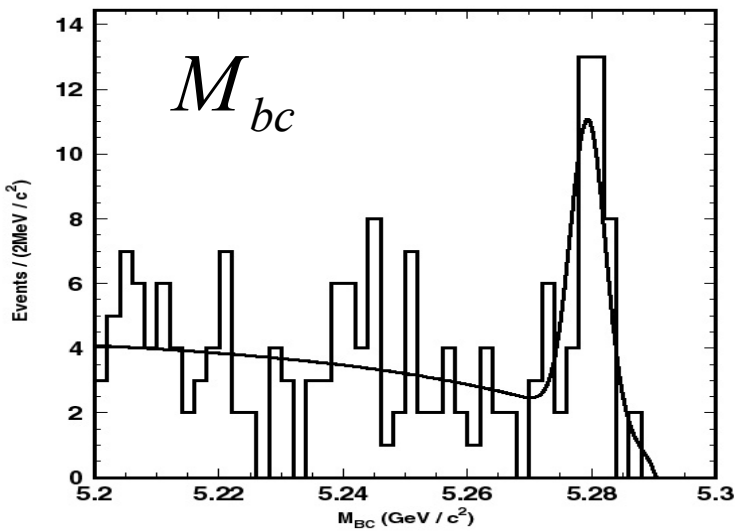
$\eta_C \to K^+\pi^-$

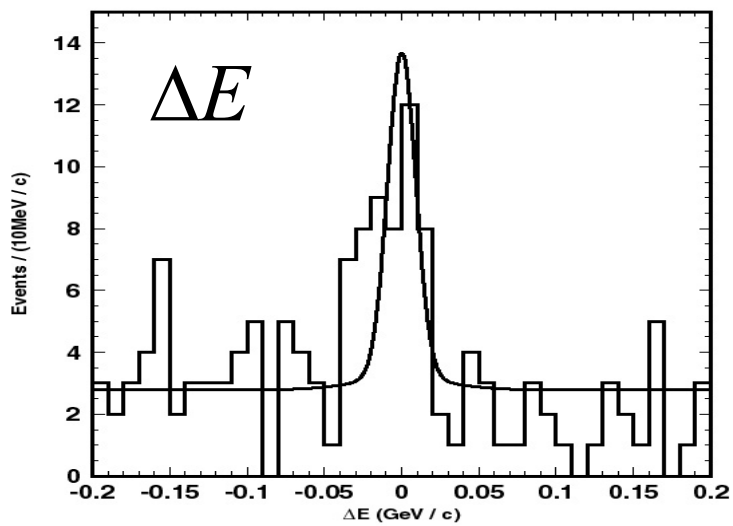
$\eta_C \to K^0_S K^-\pi^+$

(veto: $J/\psi, \chi_{C1} \to K^0_s K^-\pi^+$ $D_S{}^+ \to K^+K^-\pi^+$)

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

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





5 Additional CP eigenstates

- Cabibbo suppressed decays: $b \to (c\bar{c})\, d$

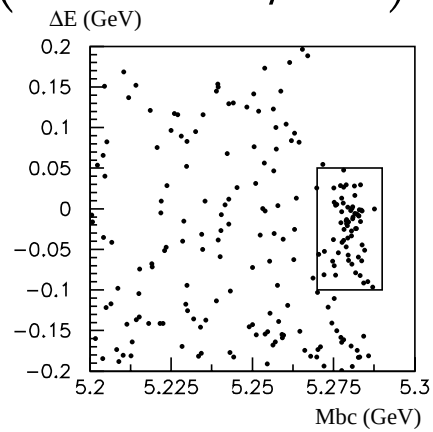
5 Additional CP eigenstates: $b \to (c\bar{c})\, d$

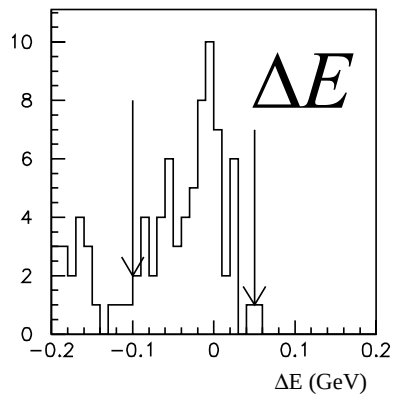
Preliminary

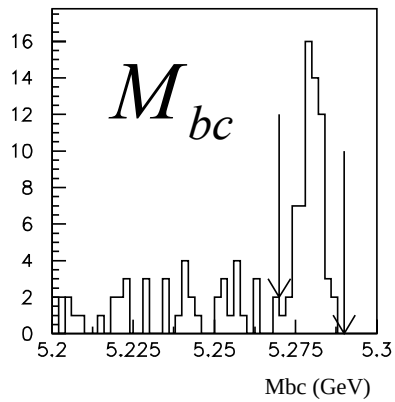
- $B^0 \to J/\psi \pi^0$ 79fb^{-1} (85M $B\bar{B}$)

$$Br(B^0 \to J/\psi \pi^0) = (1.8 \pm 0.3 \pm 0.2) \times 10^{-5}$$

$$Br(B^0 \to J/\psi \pi^0) / Br(B^0 \to J/\psi K^0) = 0.025 \pm 0.004 \pm 0.003$$







#total=64

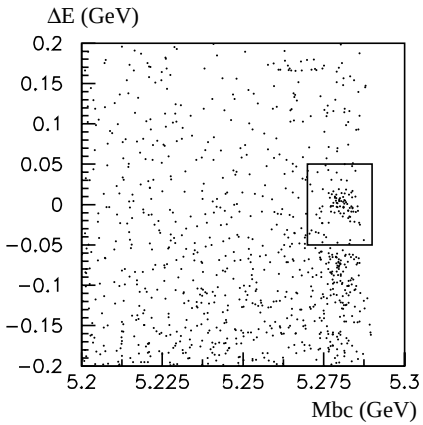
#bgd =11.7

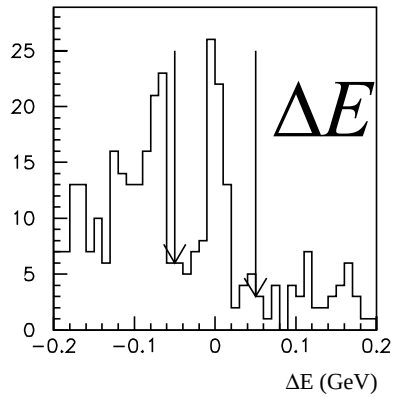
5 Additional CP eigenstates: $b \to (c\bar{c})d$ (2)

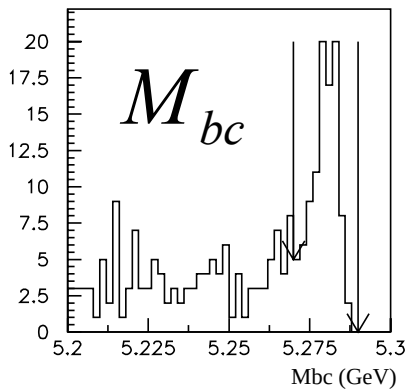
Preliminary

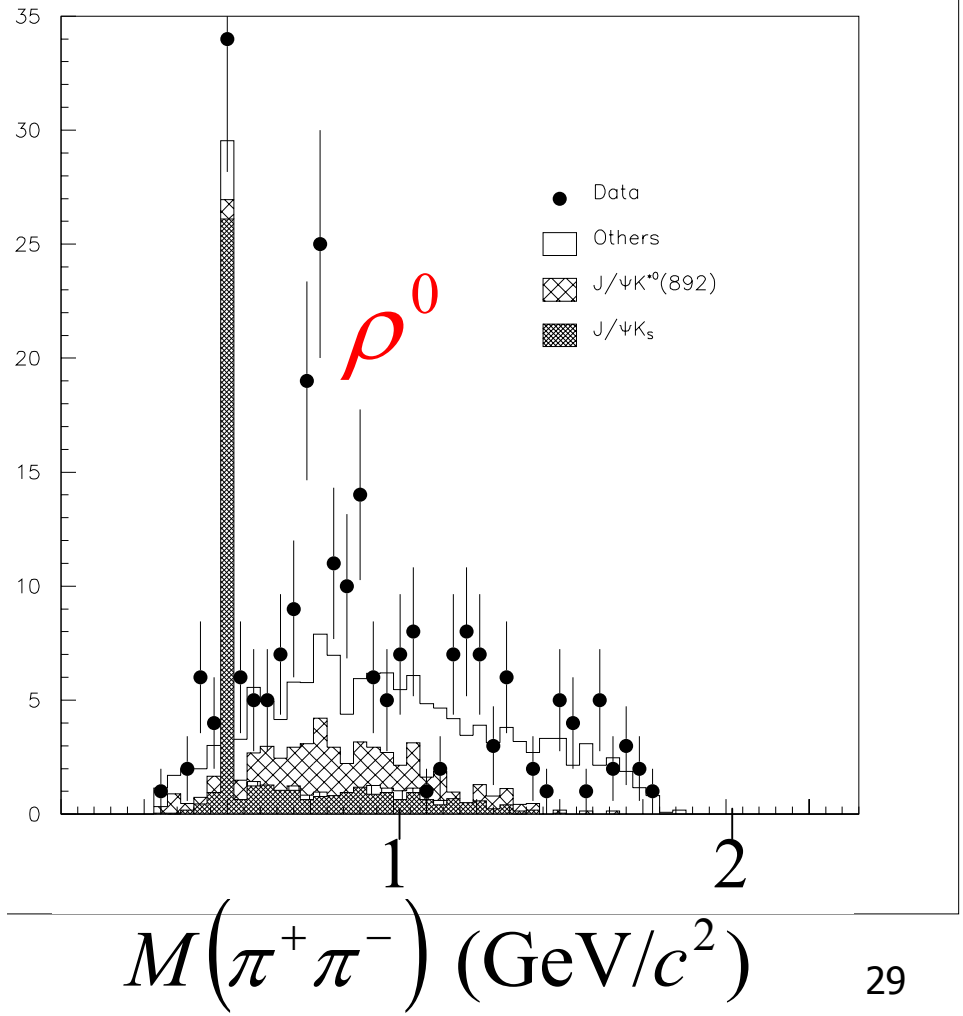
- $B^0 \to J/\psi\rho^0$ found

60fb^{-1} (65M $B\bar{B}$)









6 Branching Fractions of Exclusive decays

mode	B^+ $(\times 10^{-4})$ PDG(2000)*	B^+ $(\times 10^{-4})$ Belle	B^0 $(\times 10^{-4})$ PDG(2000)*	B^0 $(\times 10^{-4})$ Belle
$\eta_C K$		$12.5 \pm 1.4^{+1.0}_{-1.2}$		$12.3 \pm 2.3^{+1.2}_{-1.6}$
$\eta_C K^*$				$16.2 \pm 3.2^{+2.4}_{-3.4}$
$J/\psi K$	10.0 ± 1.0	$10.1 \pm 0.3 \pm 0.8$	8.9 ± 1.2	$7.7 \pm 0.4 \pm 0.7$
$J/\psi K^*$	14.8 ± 2.7	$12.8 \pm 0.7 \pm 1.4$	15.0 ± 1.7	$12.9 \pm 0.5 \pm 1.3$
$J/\psi \pi$	0.51 ± 0.15	$0.52 \pm 0.07 \pm 0.07$#	< 0.58	$0.18 \pm 0.06 \pm 0.02$#
$J/\psi \eta$				< 0.16#
$\psi(2S)K$	5.8 ± 1.0	$6.2 \pm 0.4 \pm 0.5$	< 8	$7.7 \pm 0.4 \pm 0.7$
$\chi_{C1} K$	10 ± 4	$6.1 \pm 0.6 \pm 0.6$	< 27	$3.1 \pm 0.9 \pm 0.4$
$\chi_{C0} K$		$6.0^{+2.1}_{-1.8} \pm 1.1$		

* : before Belle and BaBar

#: *preliminary*

7 Summary (1)

- 1)KEKB-Belle operating well (90fb^{-1} up to now) opening a new frontier
- 2)Missing charmonium state: $\eta_C(2S)$ found

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

$$\Gamma_{\mathrm{tot}} < 55 \mathrm{MeV} (90\% \mathrm{CL})$$

(Consistent with theoretical expectations)

- 3) Factorization-forbidden processes found

$$Br(B \to \chi_{C2} X) = \left(1.53^{+0.23}_{-0.28} \pm 0.26\right) \times 10^{-3}$$

$$Br(B \to \chi_{C0} K) = \left(0.6^{+0.21}_{-0.18} \pm 0.05 \pm 0.08\right) \times 10^{-3}$$

7 Summary (2)

- 4) Additional CP eigenstates: $b \to (c\bar{c})s$
  $B \to J/\psi\ K_1(1270),\ \ J/\psi\ K_X^*(1430),\ \ \eta_C K^*$
- 5) Additional CP eigenstates: $b \to (c\bar{c})d$
  $B \to J/\psi\ \pi,\ \ J/\psi\ \rho,\ \ \eta_C \pi$
- 6) Branching Fractions of Exculsive decays
- 7) Much more will come soon