What are the D_{sJ} and X(3872) particles?

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Meeting of the Division of Particles and Fields

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Outlook

1. Improved measurement of $B \to D_{sJ} \bar{D}^{(*)}$ decays

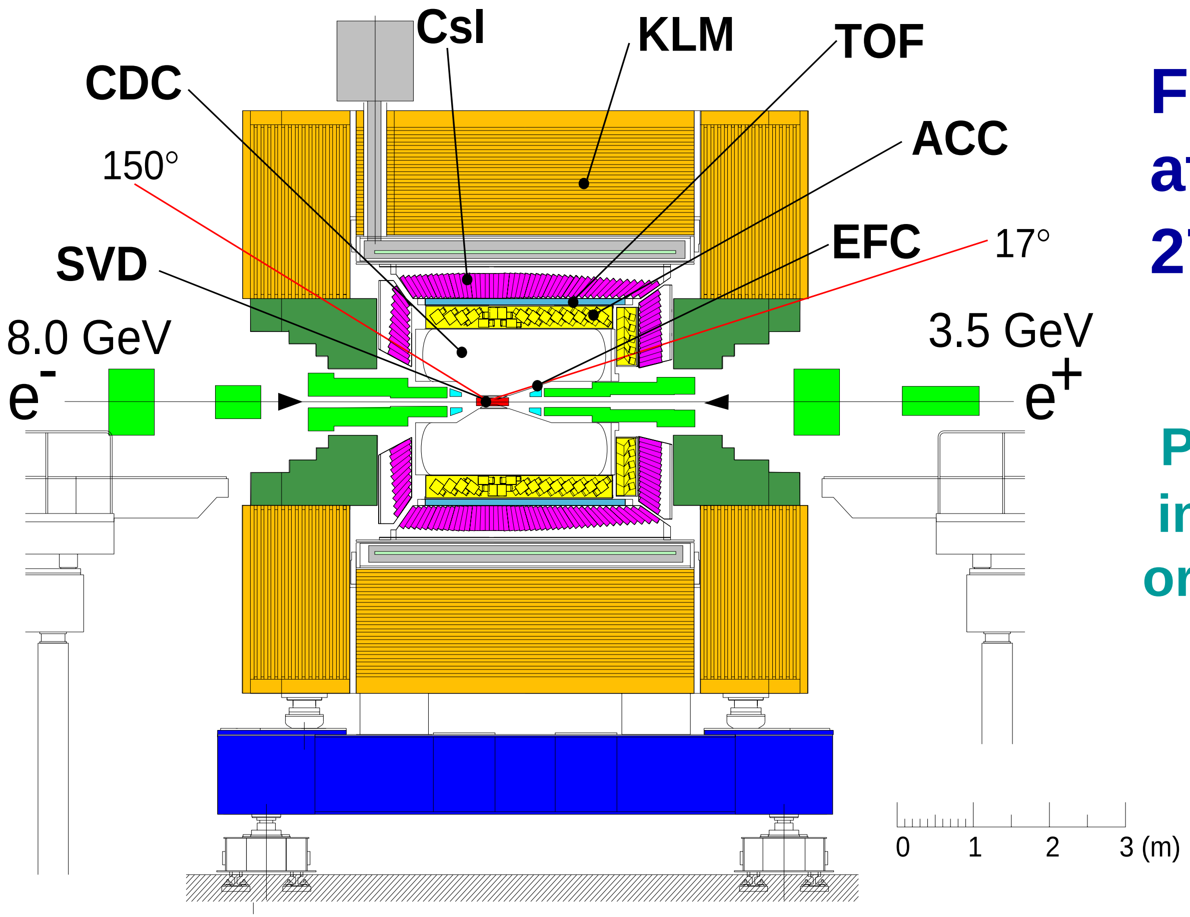
2. First study of $\bar{B}^0 \to D_{sJ}^+ K^-$ and $D_{sJ}^- \pi^+$ decays

3. Study of X(3872) production in B decays

4. Conclusions

All results are *Belle preliminary.*

Belle Detector



Full statistics at Υ(4S) ~253 fb^{-1}
274 x10^6 BB pairs

Partial statistics includes ~140 fb^{-1} or 152 x10^6 BB pairs

90$^{\varnothing}$

;

$E^{1/4}$)%

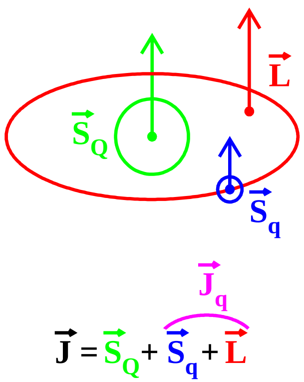
:

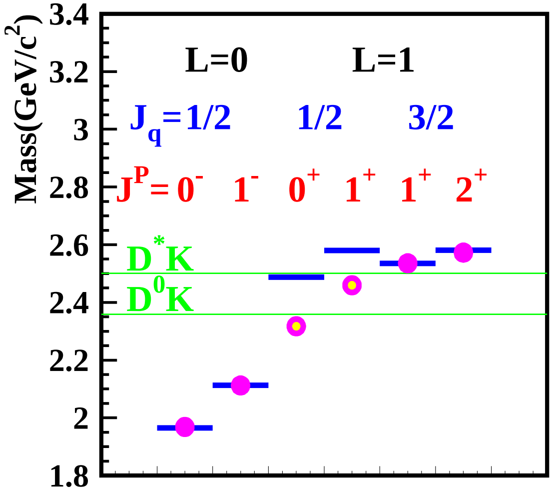
· ACC

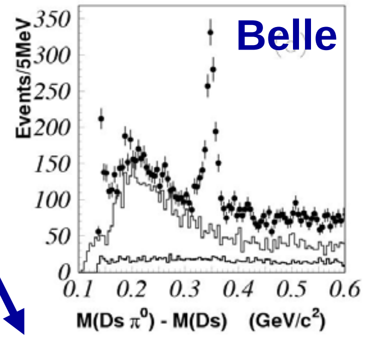
D_{sJ} meson spectroscopy

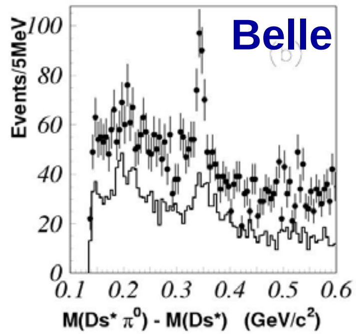
Narrow $D^{+}_{sJ}(2317)$ and $D^{+}_{sJ}(2460)$ resonances were recently observed in e+e- collisions in $D^{+}_{sJ}(2317) \to D^{+}_{s}\pi^{0}$, $D^{+}_{sJ}(2460) \to D^{+*}_{s}\pi^{0}$ and $D^{+}_{sJ}(2460) \to D^{+}_{s}\gamma$.

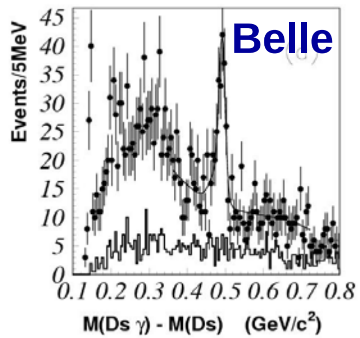
In the heavy quark limit, the total angular momentum of the light quark J_q is a good quantum number. This leads to spectroscopy with separated D_s meson spin-doublets: (0-, 1-), (0+,1+), (1+,2+).









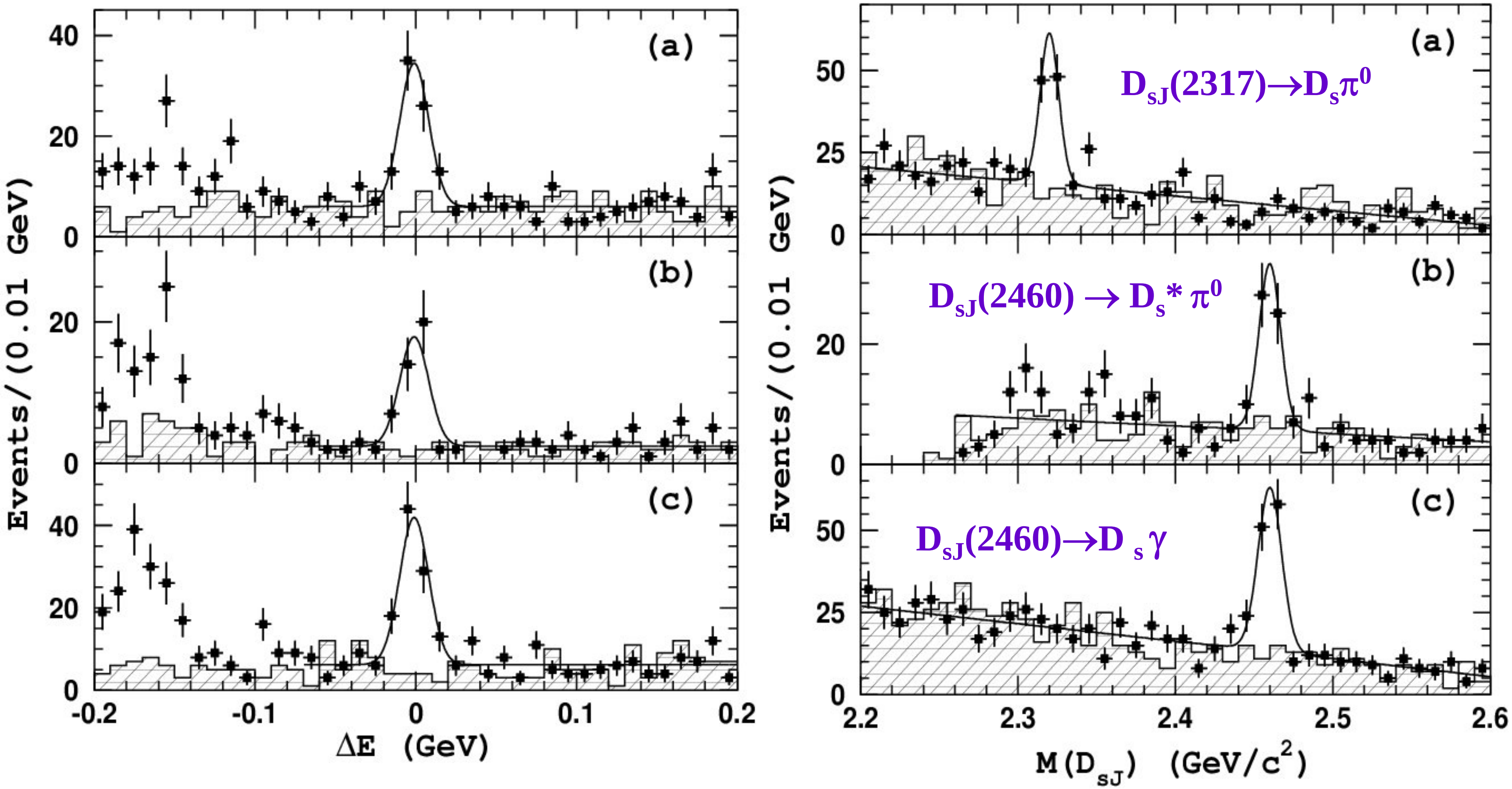


Measured masses of $D_{sJ}(2317)$ and $D_{sJ}(2460)$ are significantly lower than predictions from potential models, widths are consistent with zero in contrast to expectations.

Improved measurement of $B \to D \bar{D}_{sJ}(2317)$ and $B \to \bar{D} D_{sJ}(2460)$ decays

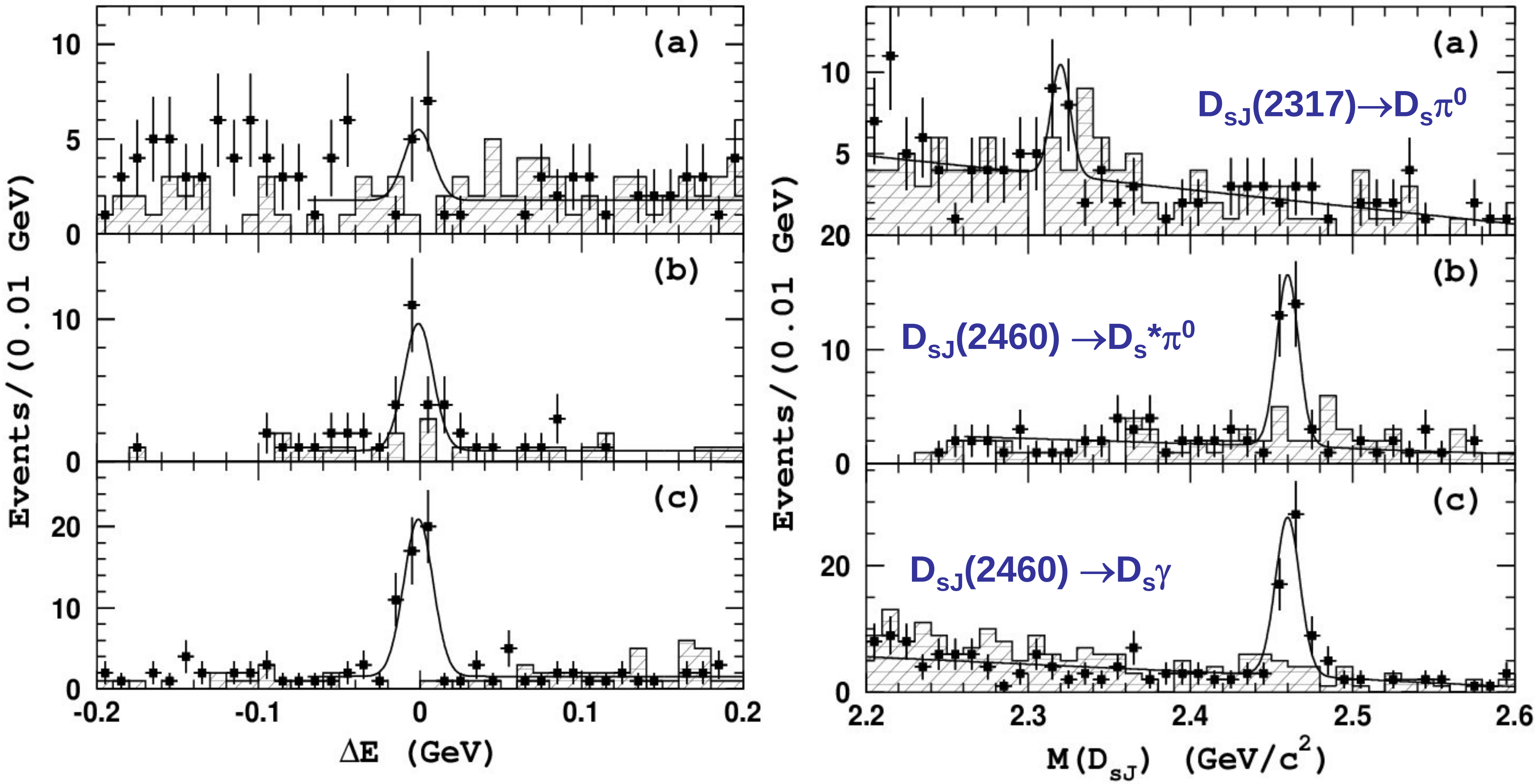
D- and D^0 decay modes are combined in figures. **274×10^6 BB pairs.**

Masses: 2320.0±1.1±2.0 and 2459.5±0.9±2.0 MeV; Width consistent with resolution



Observation of $B \to \bar{D}^* D_{sJ}(2460)$ decays

D^{*-} and D^{*0} decay modes are combined in figures. **274×10^6 BB pairs.**



Combined ($\bar{D}^0$ and D-) fit results for B -> $D_{sJ}\,\bar{D}$ decays

Decay channel	Bf, 10^{-4}	Significance
$B \to \bar{D}\, D_{sJ}(2317)$ $[D_s\pi^0]$	$10.1 \pm 1.5 \pm 3.0$	9.5σ
$B \to \bar{D}\, D_{sJ}(2317)$ $[D_s{*}\gamma]$	$4.0_{-1.4}^{+1.5}$ (<8.4)	3.5σ
$B \to \bar{D}\, D_{sJ}(2460)$ $[D_s{*}\pi^0]$	$14.8_{-2.5}^{+2.8} \pm 4.4$	8.6σ
$B \to \bar{D}\, D_{sJ}(2460)$ $[D_s\gamma]$	$6.4 \pm 0.8 \pm 1.9$	11σ
$B \to \bar{D}\, D_{sJ}(2460)$ $[D_s{*}\gamma]$	$2.6_{-1.0}^{+1.1}$ (<5.7)	3.0σ
$B \to \bar{D}\, D_{sJ}(2460)$ $[D_s\pi{+}\pi{-}]$	$1.0_{-0.4}^{+0.5}$ (<2.3)	2.6σ
$B \to \bar{D}\, D_{sJ}(2460)$ $[D_s\pi^0]$	$0.2_{-0.5}^{+0.7}$ (<1.7)	--
$B \to \bar{D}{*}\, D_{sJ}(2317)$ $[D_s\pi^0]$	$3.1_{-1.7}^{+2.1}$ (<8.5)	2.0σ
$B \to \bar{D}{*}\, D_{sJ}(2460)$ $[D_s{*}\pi^0]$	$28.7_{-6.4}^{+7.4} \pm 8.6$	6.9σ
$B \to \bar{D}{*}\, D_{sJ}(2460)$ $[D_s\gamma]$	$12.7_{-2.0}^{+2.2} \pm 3.8$	10σ

Belle branching fractions with D* meson are about two times smaller than those obtained by BaBar.

Measured BF an order of magnitude smaller than in B-> $D_s\bar{D}$ decays with pseudoscalar D_s. Theory : similar rates for D_s, D_s*, $D_{sJ}(2317)$,$D_{sJ}(2460)$?

Combined (D^0 and D-) fit results for $B \to D_{sJ}\,\bar{D}$ decays

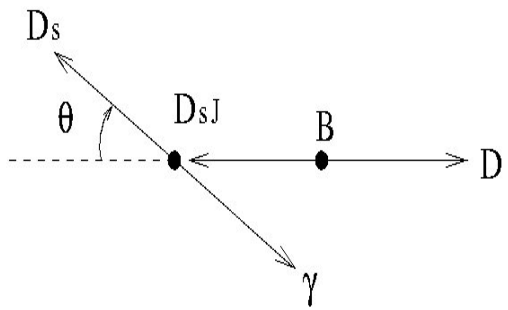
$Bf(D_{sJ}(2460) \to D_s\,\gamma)$ / $Bf(D_{sJ}(2460) \to D_s^*\,\pi^0) = 0.43 \pm 0.08 \pm 0.04$

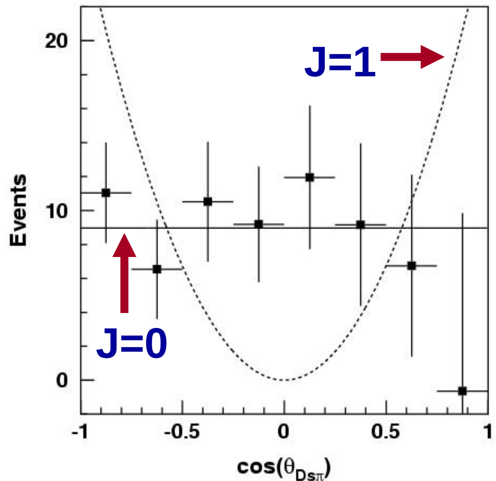
$Bf(D_{sJ}(2460) \to D_s\,\pi 0)$ / $Bf(D_{sJ}(2460) \to D_s^*\,\pi^0) < 0.10$ @90%CL

$Bf(D_{sJ}(2460) \to D_s\,\pi{+}\,\pi{-})$ / $Bf(D_{sJ}(2460) \to D_s^*\,\pi 0) < 0.13$ @90%CL

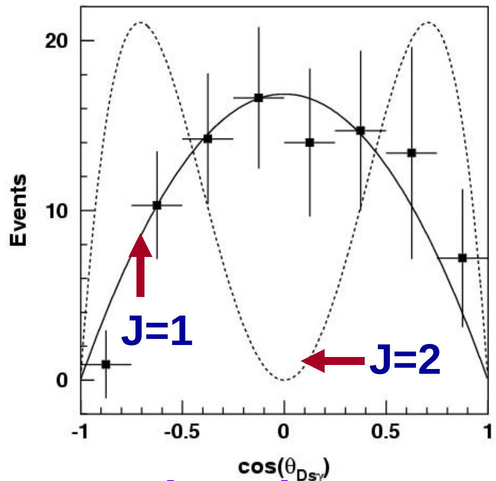
$Bf(D_{sJ}(2460) \to D_s^*\,\gamma)$ / $Bf(D_{sJ}(2460) \to D_s\,\gamma) < 0.76$ @90%CL

$Bf(D_{sJ}(2317) \to D_s^*\,\gamma)$ / $Bf(D_{sJ}(2317) \to D_s\pi^0) < 0.70$ @90%CL





$D_{sJ}(2317) \to D_s\,\pi^0$



$D_{sJ}(2460) \to D_s^*\,\gamma$

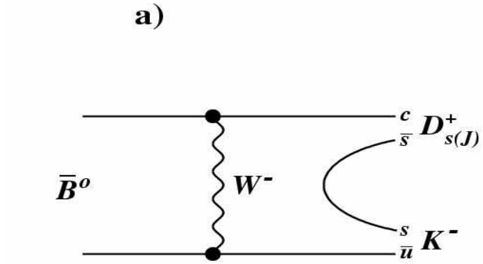
J=0 χ^2/ndf=3/8 ; J=1 χ^2/ndf=38/8　　**J=1 χ^2/ndf=4/8 ; J=2 χ^2/ndf=89/8**

Data agree with J^p=0+ for $D_{sJ}(2317)$ and J^p=1+ for $D_{sJ}(2460)$

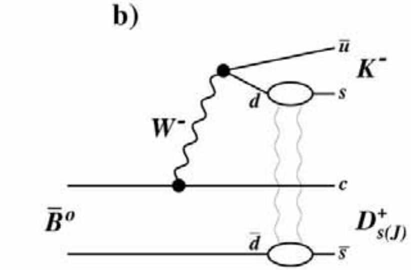
$\bar{B}^0 \to D_{sJ}^{+} K^-$ and $\bar{B}^0 \to D_{sJ}^{-} \pi^+$ decays

$D_{sJ}(2317)$ and $D_{sJ}(2460)$ mesons are selected to search for $B \to D_{sJ} K$ and $B > D_{sJ}\pi$ decays.

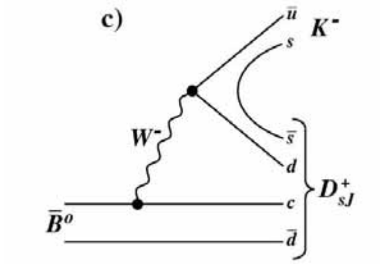
W exchange diagram



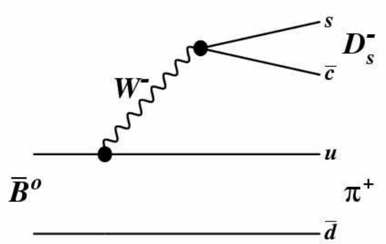
Final state interactions



Tree, 4-quark D_{sJ} content



The $D_{sJ}^{+} K^-$ final state has a completely different quark content than original B meson.



Within factorization approach, Cabbibo-Kobayashi-Maskawa matrix element V_{ub} can be obtained from ratio:

$Bf(B \to D_s\pi+) / Bf(B \to D_s D+) = (0.424 \pm 0.041) \times |V_{ub}/V_{cb}|^2$

Measured branching fractions (Belle):

$Bf(\bar{B}^0 \to D_s^{+} K-) = (2.93+0.55+0.79)\times 10^{-5}$

$Bf(\bar{B}^0 \to D_s^{-} \pi+) = (1.94+0.47+0.52)\times 10^{-5}$

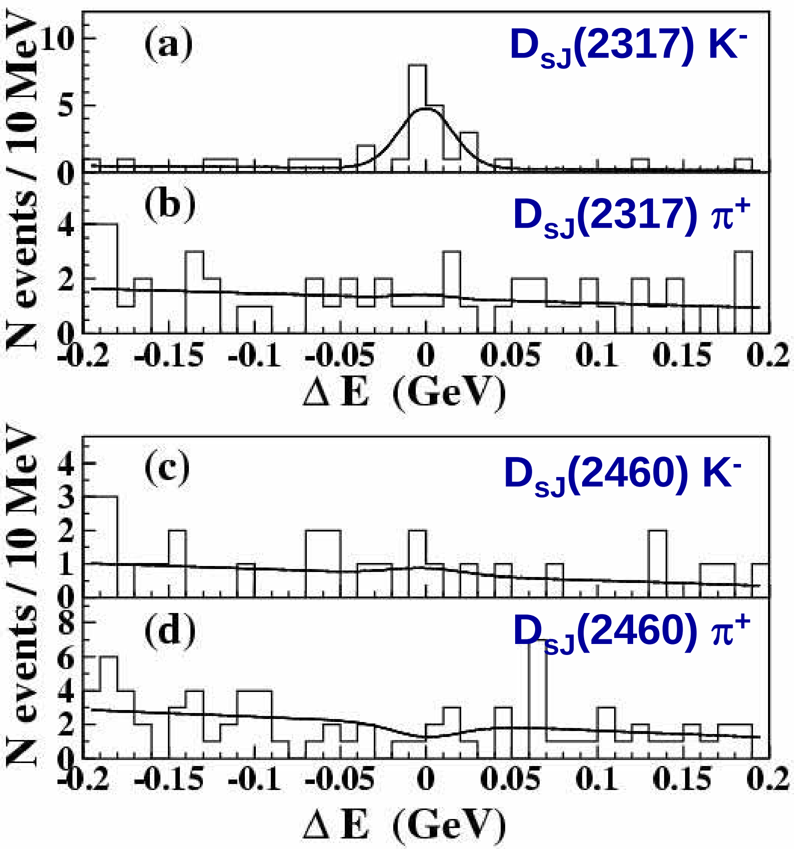
Studies of $B \to D_{sJ}D$, $B \to D_{sJ}K$ and $B \to D_{sJ}\pi$ decays are important to understand the nature of D_{sJ} mesons (2- quark or 4- quark D_{sJ} content ?).

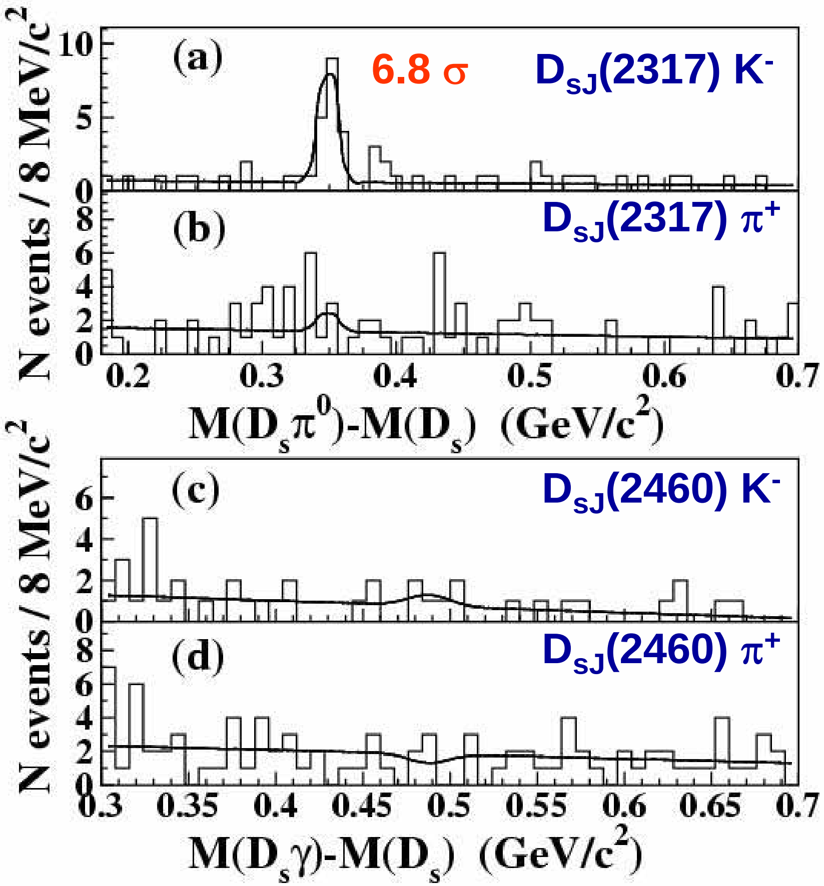
First study of $\bar{B}^0 \to D^+_{sJ} K^-$ and $\bar{B}^0 \to D^-_{sJ} \pi^+$ decays

152 x10^6 BB pairs, L= 140fb^{-1}

$D_{sJ}(2317)^+ \to D_s^+ \pi^0$, $D_{sJ}(2460)^+ \to D_s^+ \gamma$

$D_s^+ \to \phi\pi^+$, $K^{*0}K^+$, $K_S K^+$





Study of $\bar{B}^0 \to D_{sJ}^+ K^-$ and $D_{sJ}^- \pi^+$ decays

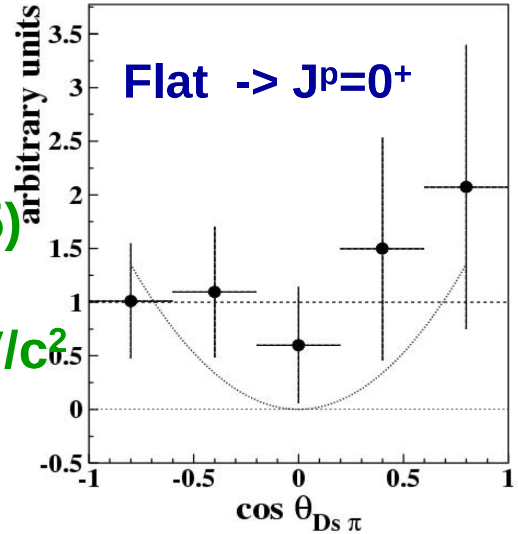
Fit to mass difference $\Delta M = M(D_{sJ}) - M(D_s)$ (mass and width are allowed to float):

Data: $\Delta M(D_{sJ}(2317)) = (351.2 \pm 1.6)$ MeV/c^2

MC: $\Delta M(D_{sJ}(2317)) = (348.5 \pm 0.3)$ MeV/c^2 (2317.5)

Resolution σ:

Data: $\sigma = (6.0 \pm 1.2)$MeV/c^2 MC: $\sigma = (6.1 \pm 0.2)$MeV/c^2



Obtained branching fraction and upper limits:

$Bf(\bar{B}^0 \to D_{sJ}(2317)^+ K^-) \times Bf(D_{sJ}(2317)^+ \to D_s^+ \pi^0) = (5.3^{+1.5}_{-1.3} \pm 0.7 \pm 1.4) \times 10^{-5}$

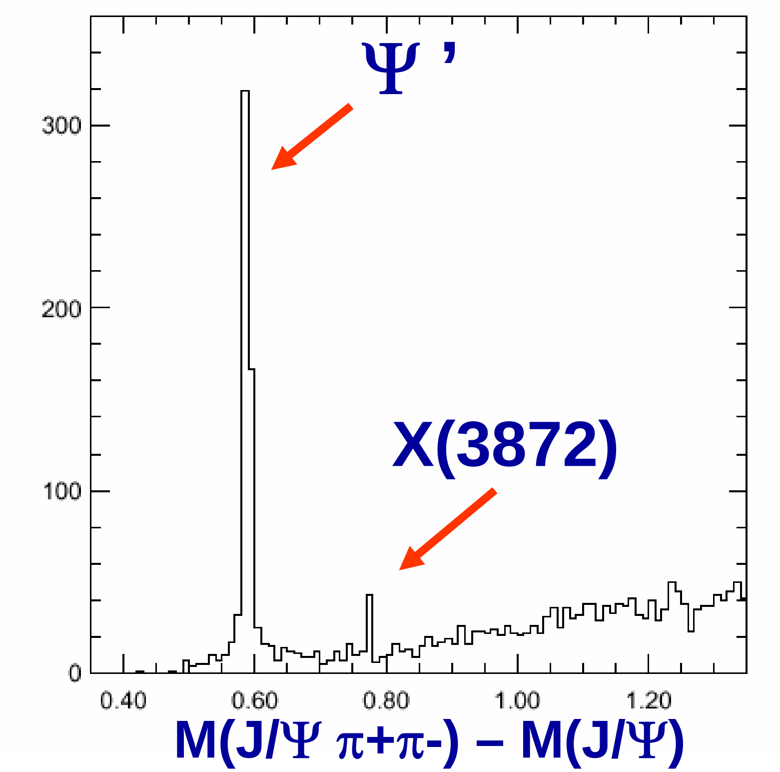
$D_{sJ}(2317)^- \pi^+$ ($D_{sJ}(2317) \to D_s \pi^0$)	$D_{sJ}(2460)^+ K^-$ ($D_{sJ}(2460) \to D_s \gamma$)	$D_{sJ}(2460)^- \pi^+$ ($D_{sJ}(2460) \to D_s \gamma$)
$<2.4 \times 10^{-5}$ (90%CL)	$<0.94 \times 10^{-5}$ (90%CL)	$<0.39 \times 10^{-5}$ (90%CL)

Measured $\bar{B}^0 \to D_{sJ}(2317)^+ K^-$ branching fraction is of the same order as $\bar{B}^0 \to D^+_s K^-$ branching fraction and at least 2 times larger than that for $\bar{B}^0 \to D_{sJ}(2460)^+ K^-$ decay ($Bf(D_{sJ}(2460) \to D_s \gamma) \sim 30\%$) -> unexpected !!!

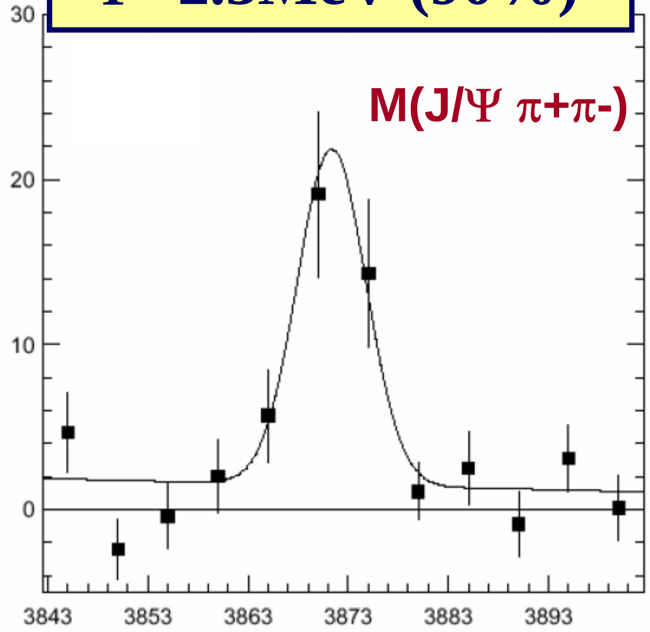
X(3872) production in B decays

Recently, Belle observed the X(3872) in $B^+ \to X(3872) K^+$ decay, with $X(3872) \to J/\Psi \pi^+\pi^-$ (confirmed by CDF, D0 and BaBar).

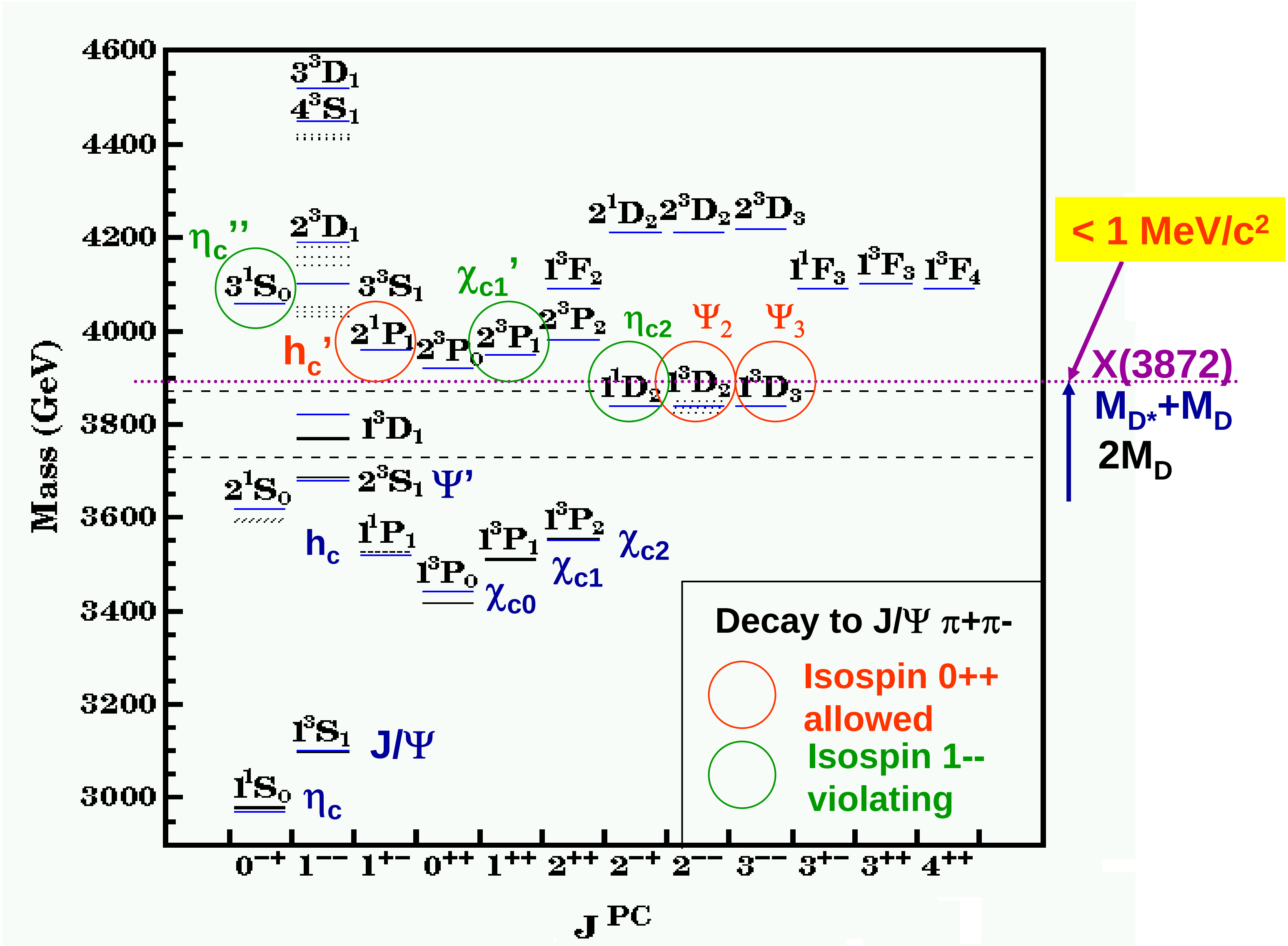
$$\frac{Br(B^- \to K^- X_{3872})\, Br(X_{3872} \to \pi^+\pi^- J/\psi)}{Br(B^- \to K^- \psi')\, Br(\psi' \to \pi^+\pi^- J/\psi)} = 0.063 \pm 0.012 \pm 0.007$$



35±7 events
M=3872.0±0.8 MeV
Γ<2.3MeV (90%)



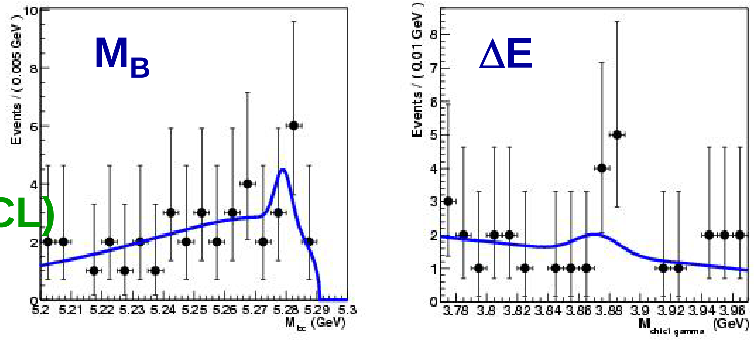
Charmonium spectroscopy



Study of X(3872) production in B decays

- **Search for B $\rightarrow$X(3872)K decay, with X(3872)$\rightarrow\chi_{c2}\gamma$.** **152x10^{6} BB pairs**

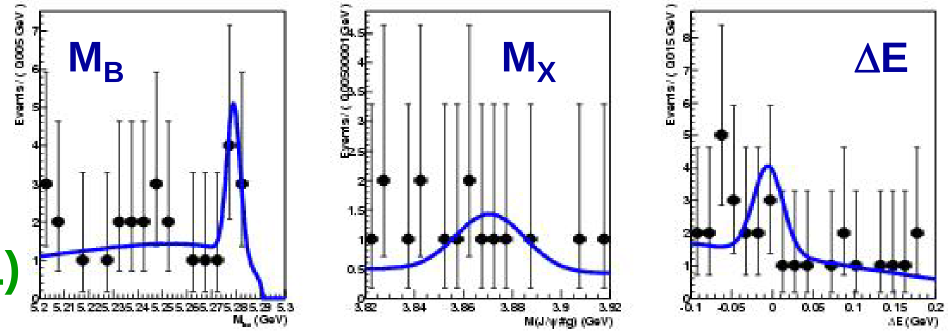
$$\frac{\Gamma(X\rightarrow\chi_{c2}\gamma)}{\Gamma(X\rightarrow J/\Psi\pi+\pi-)} = 0.42 \pm 0.45 \pm 0.23 < 1.1\ (90\%CL)$$



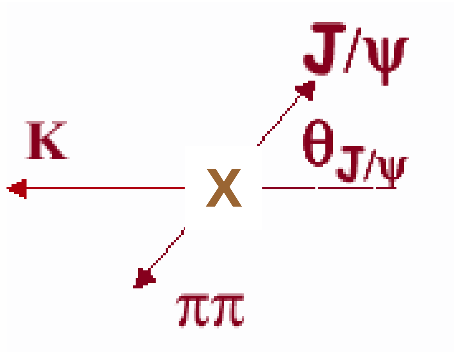
- **Search for B $\rightarrow$X(3872)K decay, with X(3872)$\rightarrow$J/Ψ γ.**

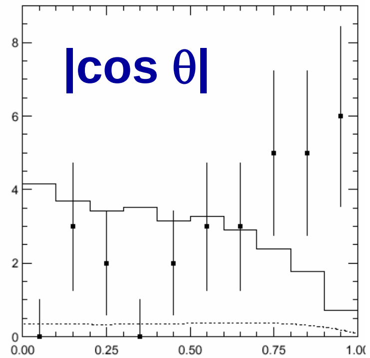
$$\frac{\Gamma(X\rightarrow J/\Psi\gamma)}{\Gamma(X\rightarrow J/\Psi\pi+\pi-)} =$$

$$0.22 \pm 0.12 \pm 0.06 < 0.40\ (90\%CL)$$



- **Helicity angle: if J^{p}=1+- (h_c'), sin$^{2}\theta$ angular distribution is expected.**
  $\rightarrow$ ruled out by data.





Study of $B^+ \to X(3872)\, K^+$ decay, $X(3872) \to J/\Psi\, \pi^+\pi^-\pi^0$

BELLE

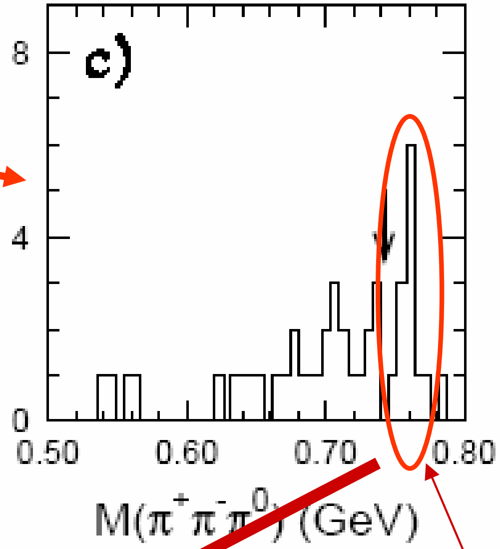
274x10^6 BB pairs

Events within B signal region and mass interval:

$| M(J/\Psi\, \pi^+\pi^-\pi^0) - 3872. | < 12\ MeV/c^2$

Assuming events with $M(3\pi) > 0.75$ as $J/\Psi\omega$:

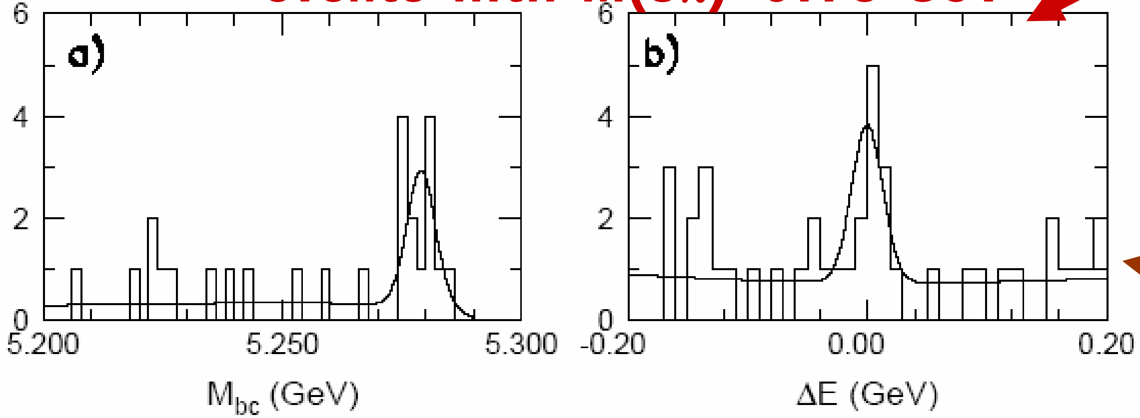
$$\frac{\Gamma(X \to J/\Psi\omega)}{\Gamma(X \to J/\Psi\pi^+\pi^-)} = 0.8 \pm 0.3\,(stat) \pm 0.1(syst)$$



➡ **It provides support for DD* molecular interpretation of X(3872).**

These events are almost pure signal

events with M(3π)>0.75 GeV



N_{evt}=10.0 ± 3.6
S/N = 5/1
Signif = 5.8σ

Which state is X(3872)?

No good $c\bar{c}$ candidates for X(3872):

- η_c'' ← **M too low and Γ too small**
- ~~h_c'~~ ← **angular dist'n rules out 1^{+-}**
- ~~χ_{c1}'~~ ← **$\Gamma(\gamma J/\psi)$ way too small**
- ~~ψ_2~~ ← **$\Gamma(\gamma\chi_{c1})$ too small; (PRL 93, 2003)**
- η_{c2} ← **$\pi\pi\,\eta_c$ should dominate $\pi\pi J/\psi$**
- ~~ψ_3~~ ← **$\Gamma(\gamma\chi_{c2}$ & $D\bar{D})$ too small**

◯ **- Isospin violating decays to $J/\Psi\ \pi+\pi-$**

Conclusions

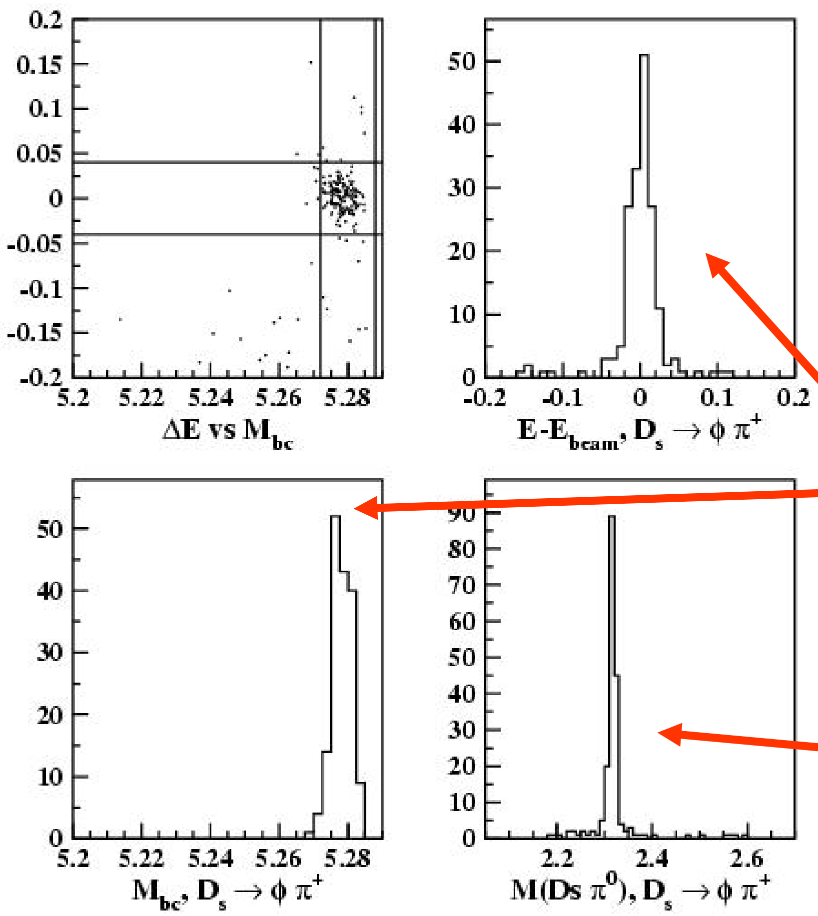
- Decays B -> $D_{sJ}\ \bar{D}^{(*)}$ were measured with improved accuracy. Obtained branching fractions are of order of magnitude smaller than those with a pseudoscalar D_s . Angular distributions indicate that the $D_{sJ}(2317)$ is 0+ and the $D_{sJ}(2460)$ is 1+.

- $\bar{B}^0$ -> D_{sJ}^+ K- and D_{sJ}^- π+ were studied for the first time. The branching fraction for $\bar{B}^0$-> $D_{sJ}(2317)$+ K- is of the same order as $\bar{B}^0$->D_s^+ K- branching fraction and more than two times larger than that for $\bar{B}^0$->$D_{sJ}(2460)$+K- decay (assuming Bf($D_{sJ}(2460)$->$D_s\gamma$)~30%).

- Possible X(3872) decay modes were searched for using B decays. Evidence for the decay X(3872)->J/Ψ ω was observed. This supports the DD* molecular interpretation of the X(3872) . No good $c\bar{c}$ candidate for X(3872) was found.

Background slides

Procedures to extract B signal yield



Two almost independent variables M_B and ΔE can be used to select B meson signal:

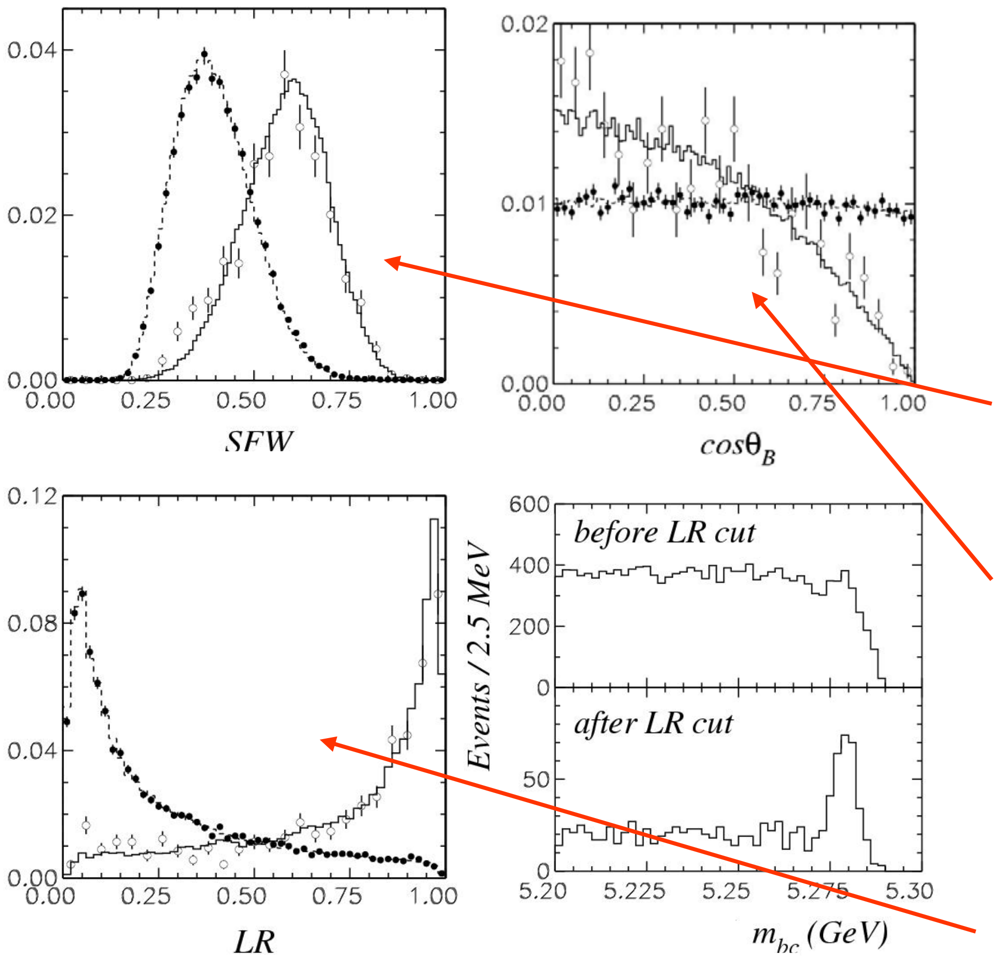
$$M_B = \sqrt{(E^*_{beam})^2 - (\Sigma P_i)^2}$$

$$\Delta E = \Sigma E_i - E^*_{beam}$$

Methods to extract B signal yield:

1) Cut on M_B and fit to ΔE
2) Cut on ΔE and fit to M_B
3) Double dimensional fit to M_B and ΔE distribution
4) If $B \to P_1P_2P_3$: cut ΔE and M_B box and look at resonant structures in $M(P_1P_2)$ mass distribution.

Continuum Suppression



To separate spherical BB events from jet-like continuum events, topological variables are used:

1) **Second Fox-Wolfram moment**
2) **Super Fox-Wolfram (six modified Fox-Wolfram moments, Fisher discriminant)**
3) **Angle between B meson and beam axis direction**
4) **Angle between thrusts of selected B meson particles and all other particles in event**

Likelihood ratio includes all info.