New Resonances at Belle

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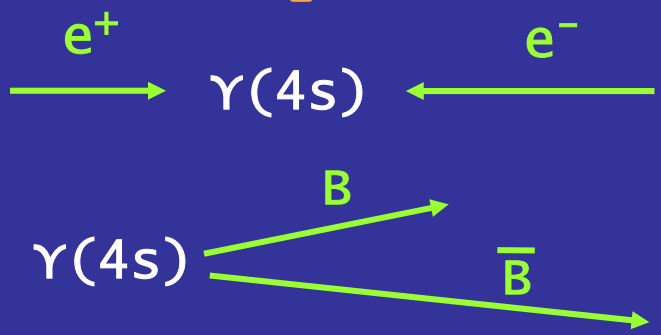
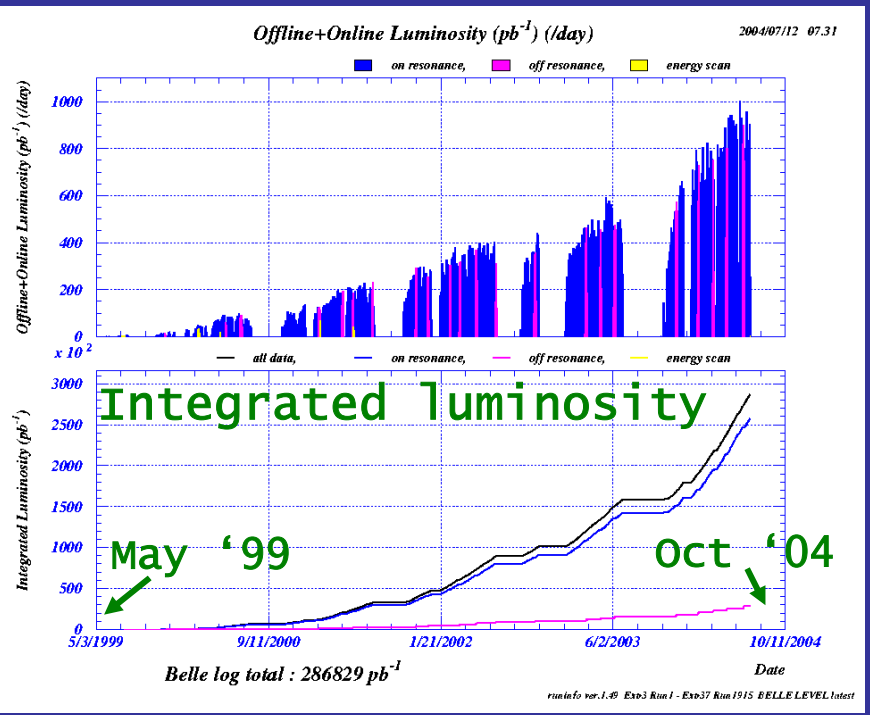
Belle Collaboration

- Experimental environment
- D_{sJ}'s and their properties
- X(3872)...
- ...and also Y(3940)
- $c\bar{c}$ recoil spectrum
- pentaquarks?
- Conclusion

Experimental environment

KEKB asymmetric B factory

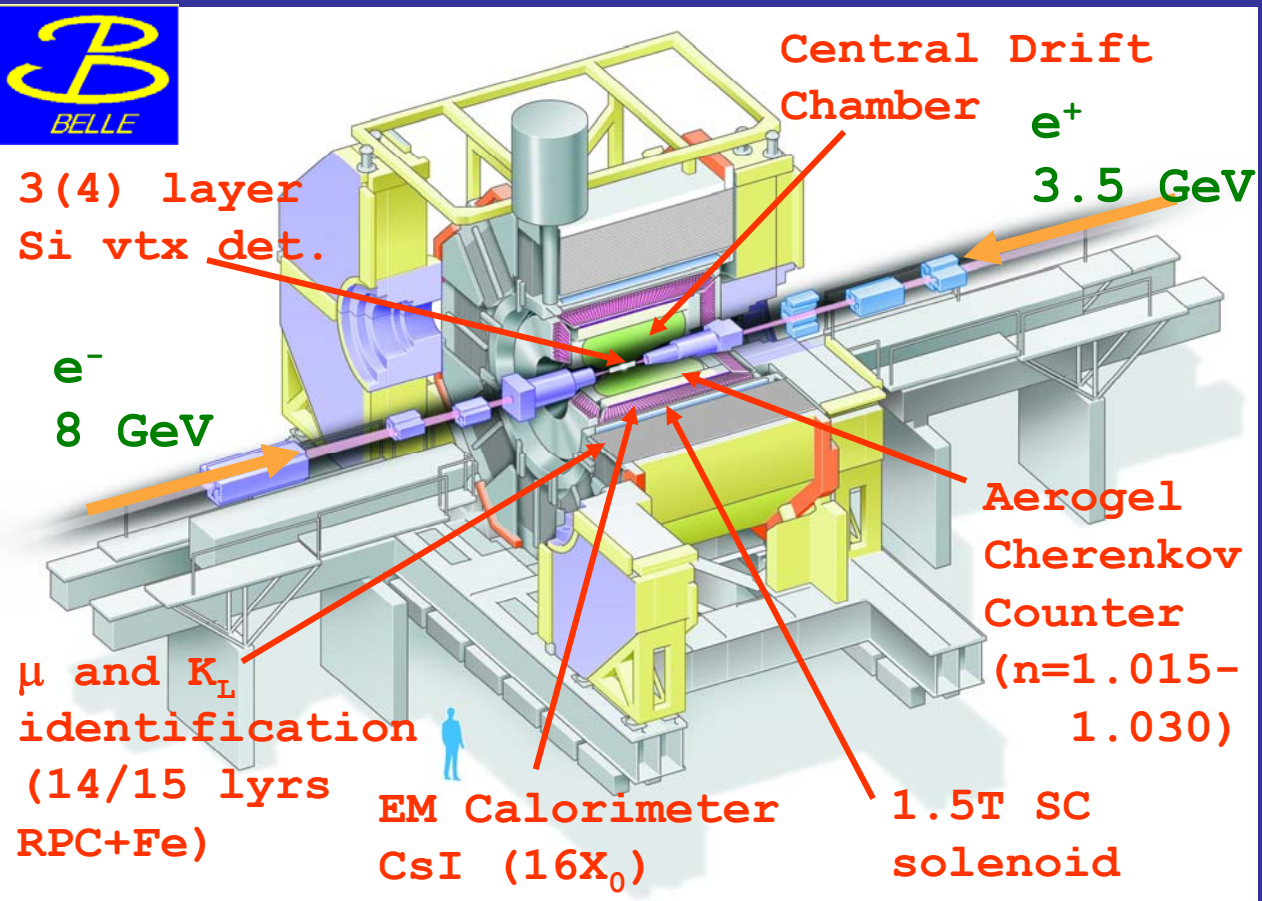




> 900 pb^{-1}/day (~1 M $B\bar{B}$/day)

$\int Ldt$ = 255 fb^{-1} on reson.
30 fb^{-1} off reson.
~280 M $B\bar{B}$

Experimental environment



$\sigma(p_t)/p_t = 0.3\% \sqrt{p_t^2+1}$

combined particle ID

$\varepsilon(K^{\pm}) \sim 85\%$

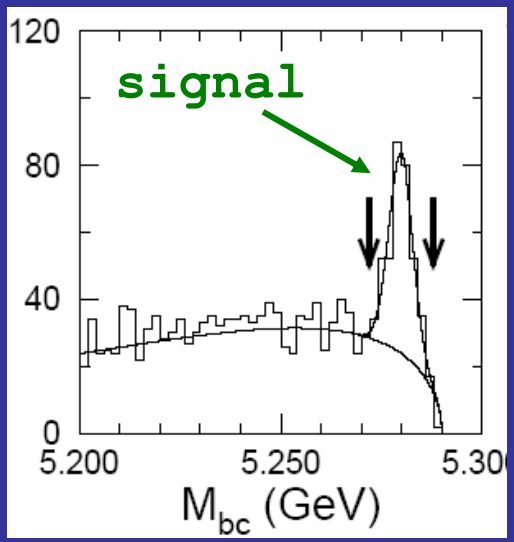
$\varepsilon(\pi^{\pm} \to K^{\pm}) < \sim 10\%$

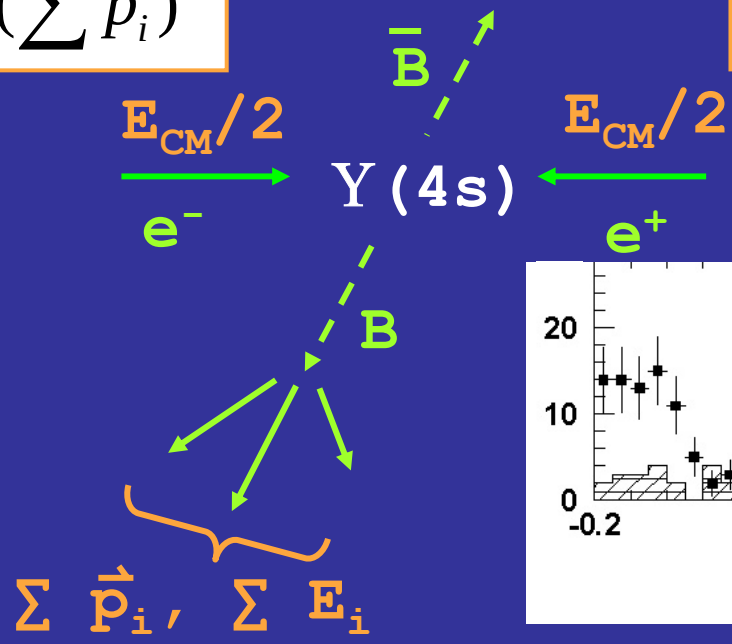
@ p<3.5 GeV/c

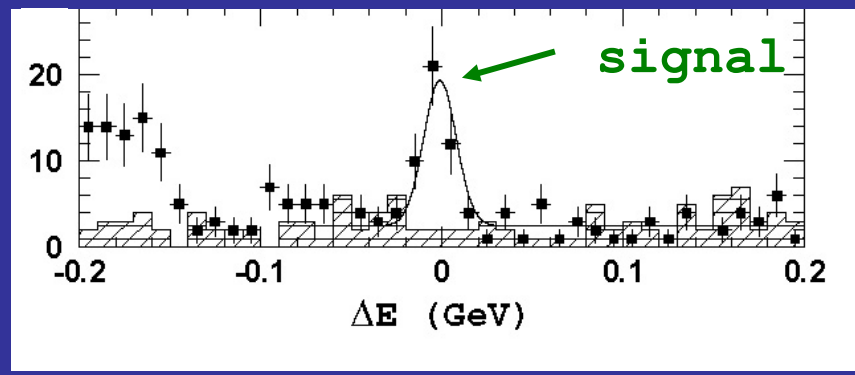
Experimental environment

$$M_{bc} = \sqrt{(E_{CM}/2)^2 - (\sum \vec{p}_i)^2}$$

$$\Delta E \equiv \sum E_i - E_{CM}/2$$

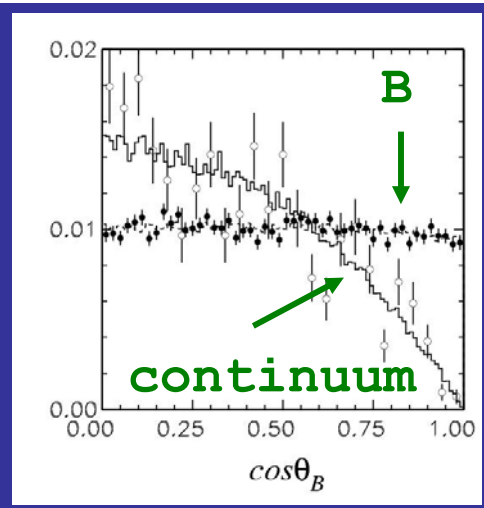






Off reson. data:
continuum only
On reson. data:
$B\bar{B}$ (spherical) separated from continuum (jet shaped) on basis of topological variables

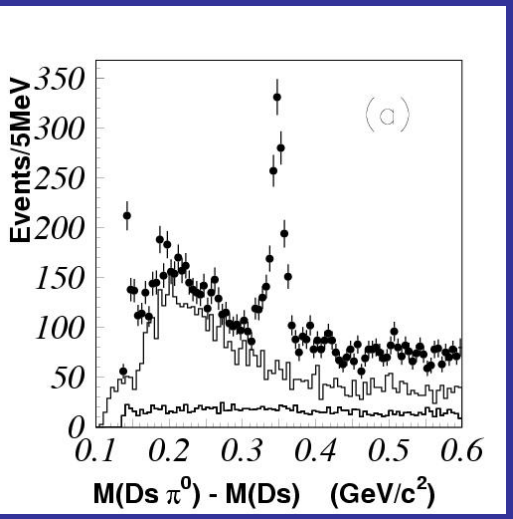
e.g. angle between B direction and beam axis



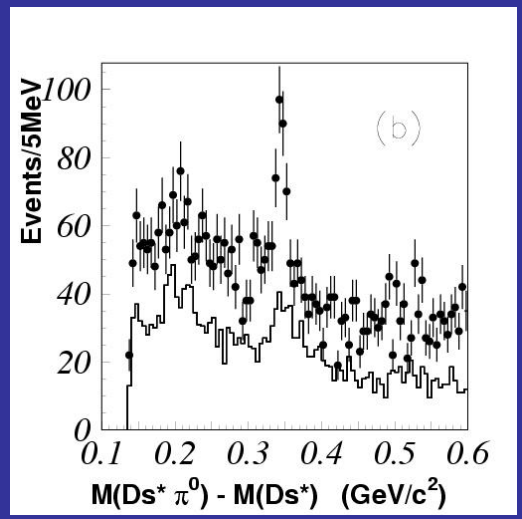
D_{sJ} states

Production in continuum

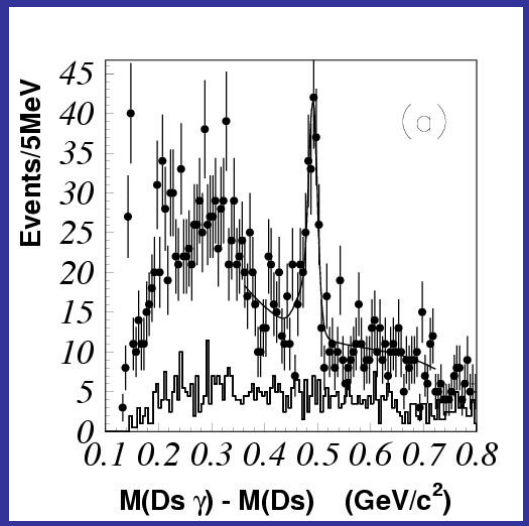
$D_{sJ}^{*}(2317)^{+} \to D_s^{+}\pi^0$



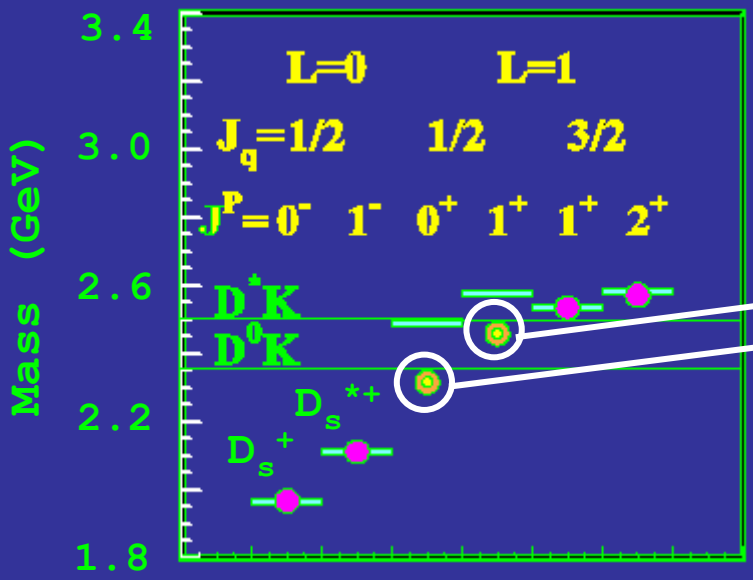
$D_{sJ}^{+}(2460) \to D_s^{*+}\pi^0$



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



86.9 fb^{-1}, PRL92,012002(2004)



$M(D_{sJ}(2317)) = 2317.2 \pm 0.5 \pm 0.9$ MeV

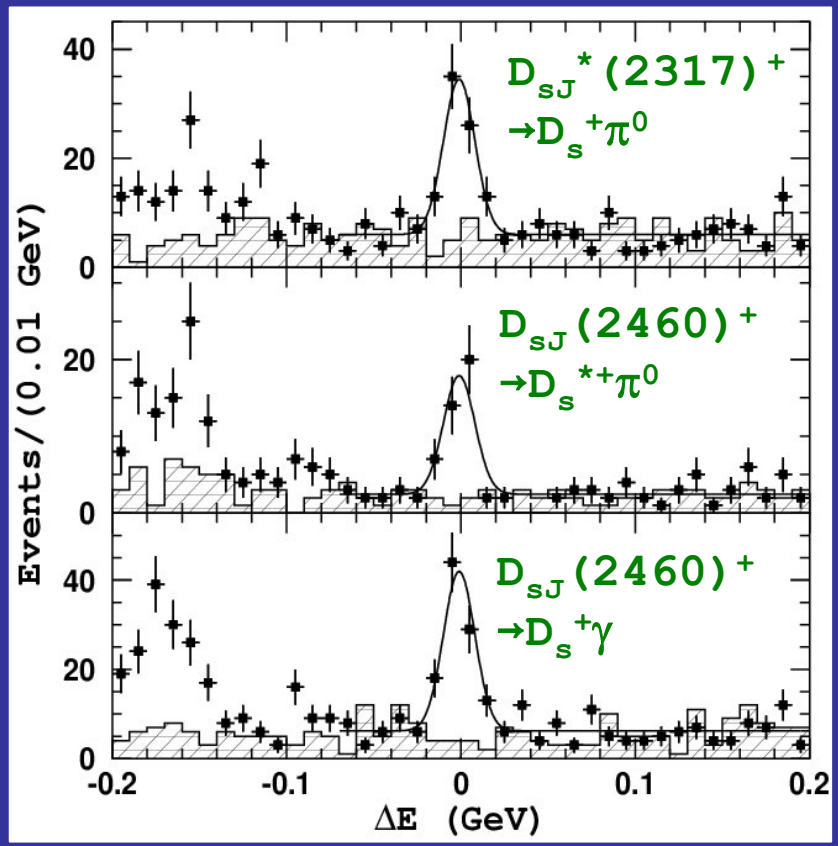
$M(D_{sJ}(2460)) = 2456.5 \pm 1.3 \pm 1.3$ MeV

Masses lower than predicted in potential models; Widths consistent with zero

D_{sJ} states

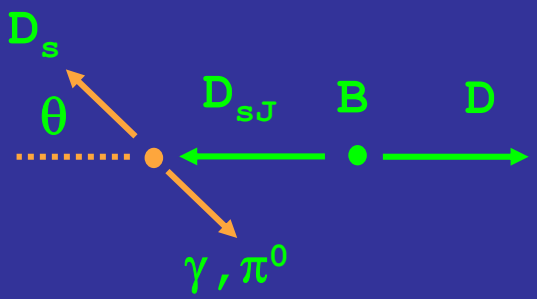
Production in B decays

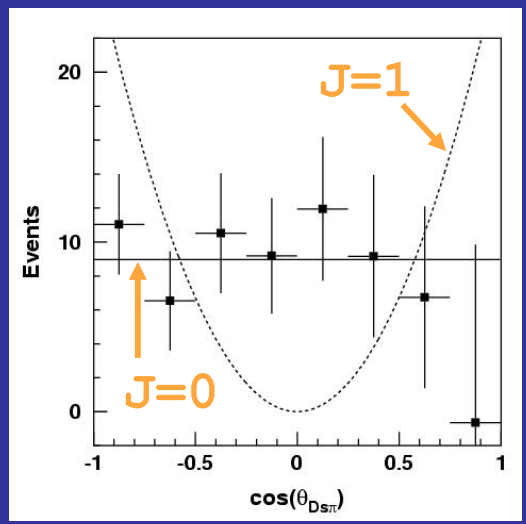
$B \to \bar{D}\, D_{sJ}$



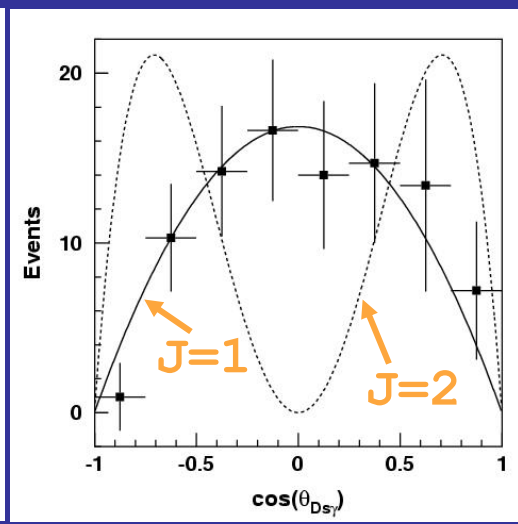
275M $B\bar{B}$, BELLE-CONF-0461

Helicity angle:





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



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

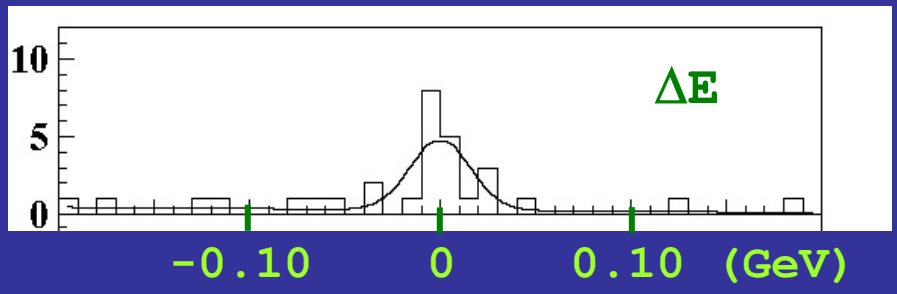
Data agree with $J^P=0^+$ ($D_{sJ}(2317)$) and 1^+ ($D_{sJ}(2460)$)

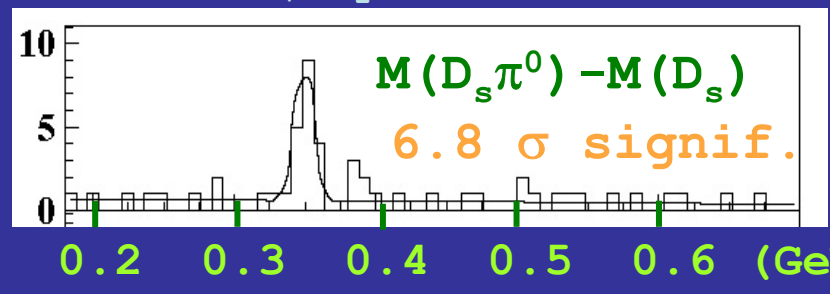
$Br(B^0 \to D^- D_{sJ}^*(2317)^+) = (10.3 \pm 2.2 \pm 3.1) \times 10^{-4}$

First observation of $B^0 \to D_{sJ}^{*-} K^+$

$D_{sJ}^*(2317)^- \to D_s^- \pi^0$ ($D_s \to \phi\pi, K^*K, K_S K$)

152M $B\bar{B}$, hep-ex/0409026





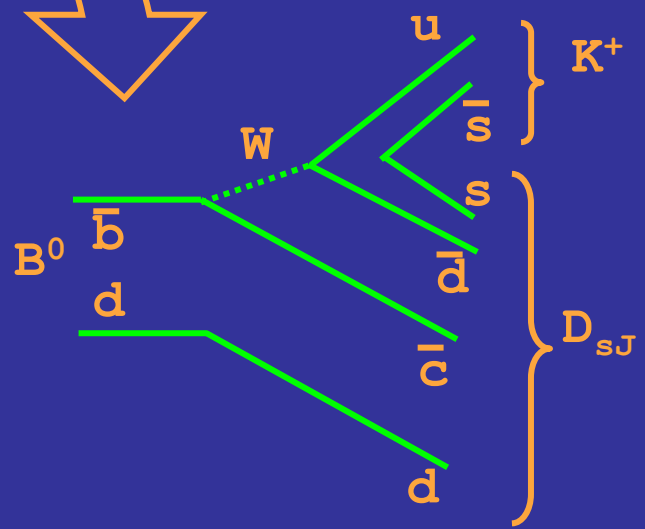
$$Br(B^0 \to D_{sJ}(2317)^- K^+) \cdot Br(D_{sJ}(2317)^- \to D_s^- \pi^0) = (5.3 \pm 1.4 \pm 0.7 \pm 1.4) \times 10^{-5}$$

$B \to D_{sJ}(2317)\pi^-$ $< 2.5 \times 10^{-5}$ @90% CL

$B \to D_{sJ}(2460) K^+$ $< 0.94 \times 10^{-5}$

$B \to D_{sJ}(2460)\pi^-$ $< 0.40 \times 10^{-5}$

4-quark content?



$$\frac{Br(B^0 \to D_{sJ}^*(2317)^- K^+) \cdot Br(D_{sJ}^*(2317)^- \to D_s^- \pi^0)}{Br(B^0 \to D_s^- K^+)} = 1.8 \pm 0.6$$

$$\frac{Br(B^0 \to D^- D_{sJ}^*(2317)^+) \cdot Br(D_{sJ}^*(2317)^+ \to D_s^+ \pi^0)}{Br(B^0 \to D^- D_s^+)} = 0.13 \pm 0.05$$

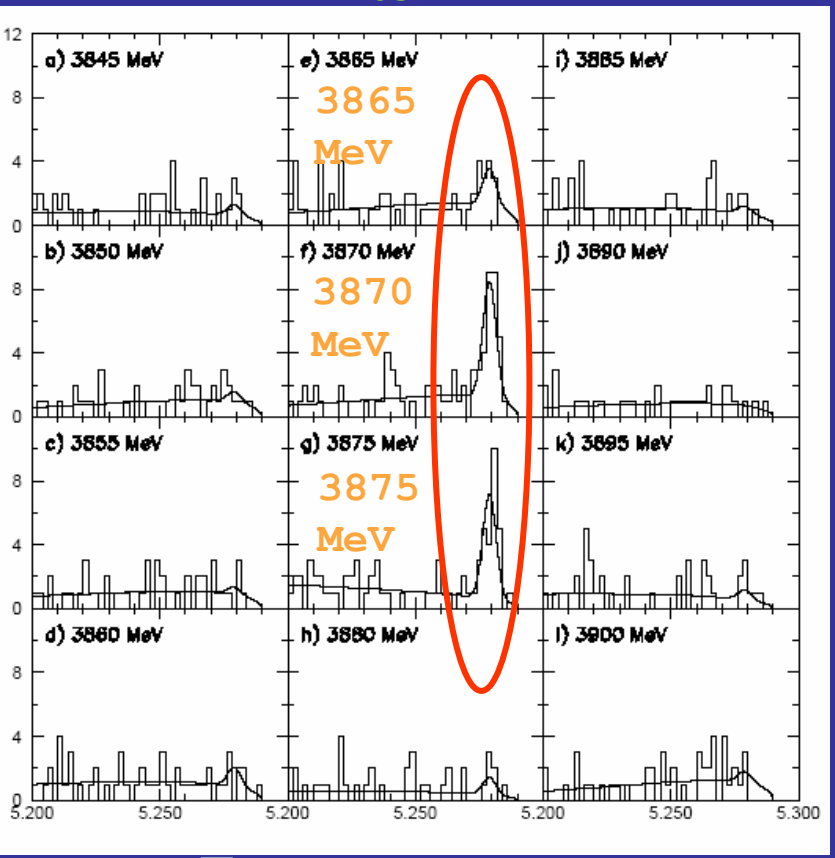
Observed by Belle with 152M $B\bar{B}$

$B^{\pm} \to K^{\pm} \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$

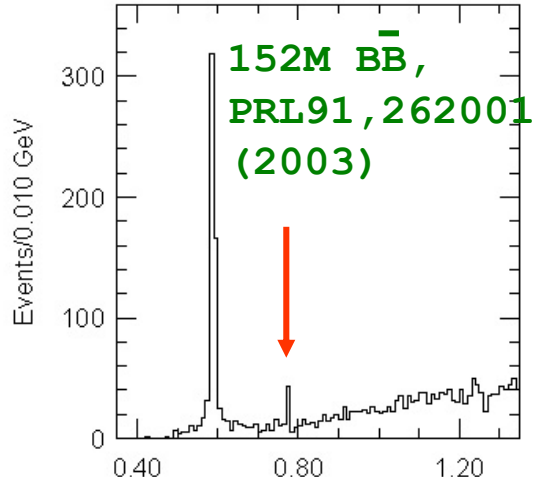
X(3872)

How about with 275M $B\bar{B}$?

Calculate M_{bc} in 5 MeV bins of $M(\pi^+\pi^- J/\psi)$

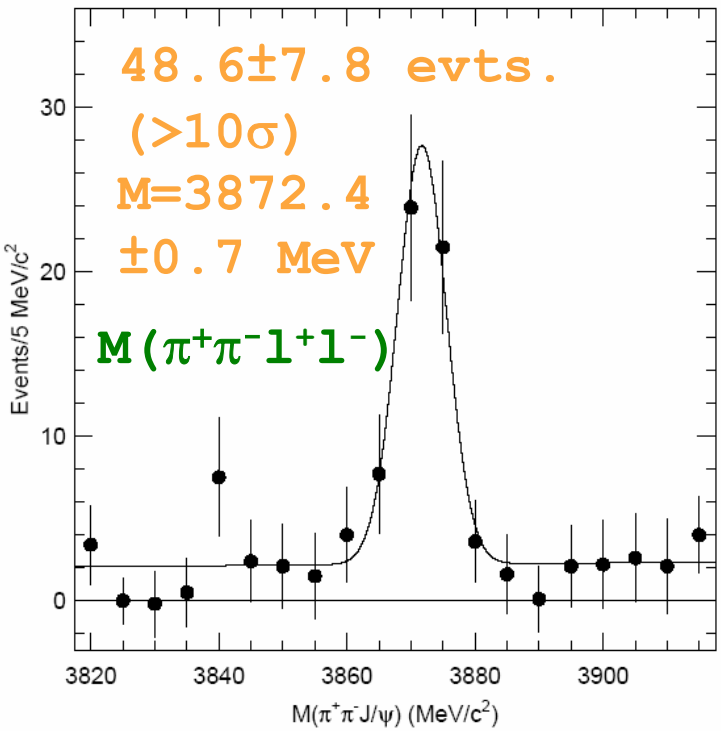


275M $B\bar{B}$, S.Olsen, GHP'04



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

no. of B's in bins of $M(\pi^+\pi^- J/\psi)$



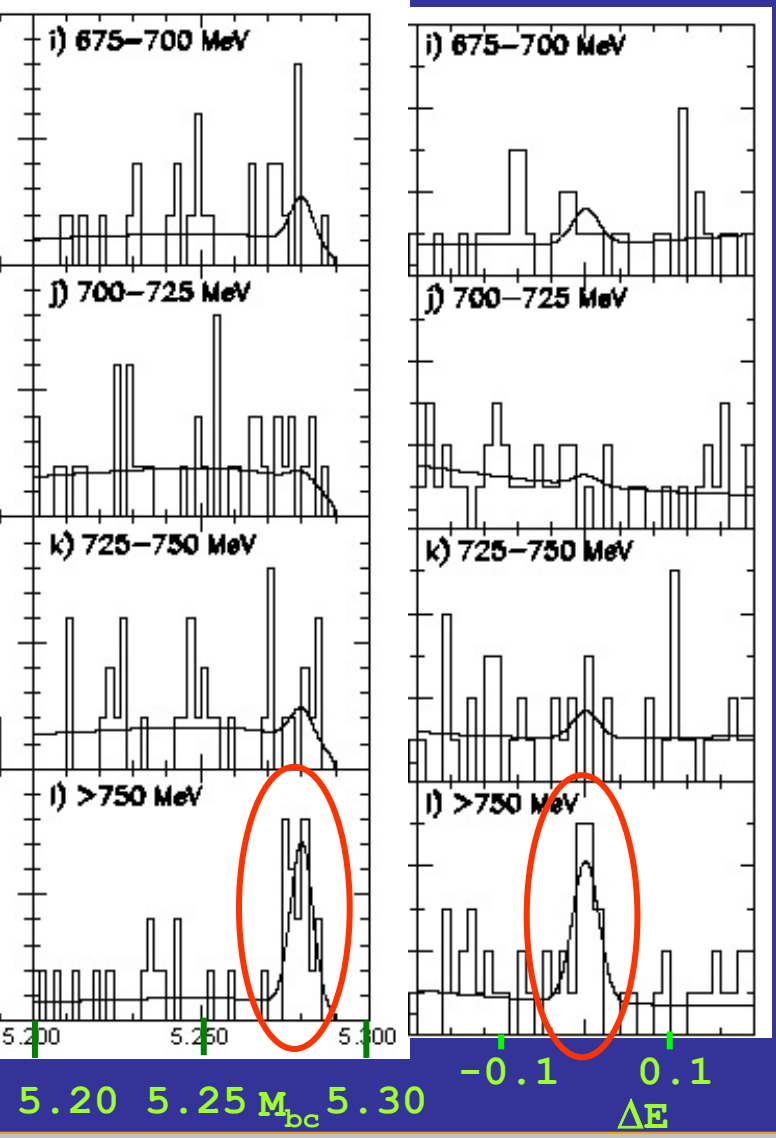
X(3872)

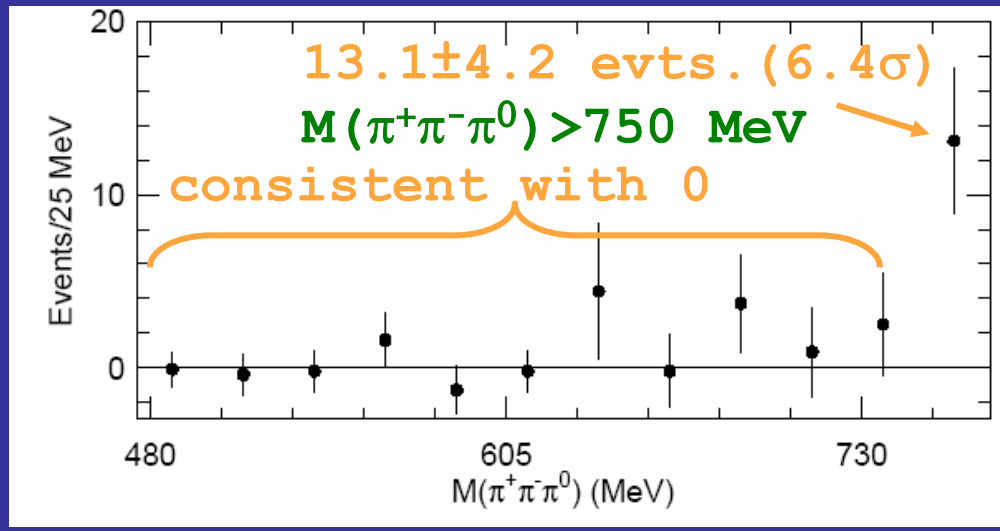
$B^{\pm} \to K^{\pm} \pi^+\pi^- \pi^0 J/\psi$

$M(\pi^+\pi^-\pi^0 J/\psi) = M(X) \pm 3\sigma$

M_{bc} and ΔE in 25 MeV bins of $M(\pi^+\pi^-\pi^0)$

no. of B's in bins of $M(\pi^+\pi^-\pi^0)$





First observation of decay mode other than $\pi^+\pi^- J/\psi$;
subthreshold decay to $\omega J/\psi$
(expected for DD* molecule)

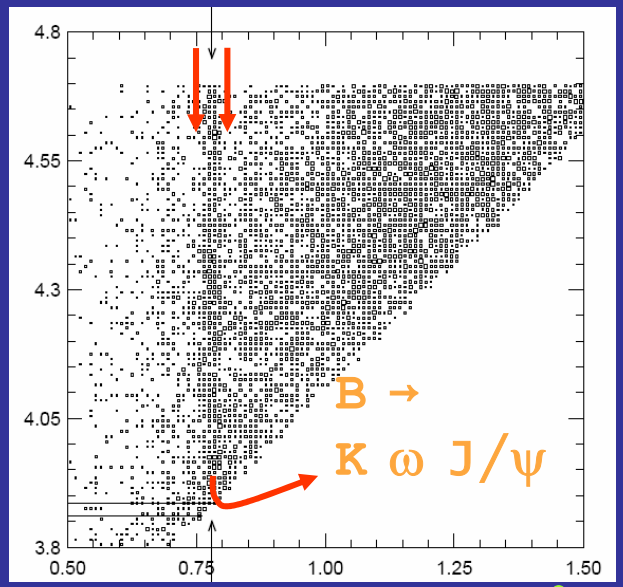
$$\frac{Br(X \to \pi^+\pi^-\pi^0 J/\psi)}{Br(X \to \pi^+\pi^- J/\psi)} = 1.1 \pm 0.4 \pm 0.3$$

C(X(3872))=+1

Y(3940)

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

Events in ΔE, M_{bc} signal region

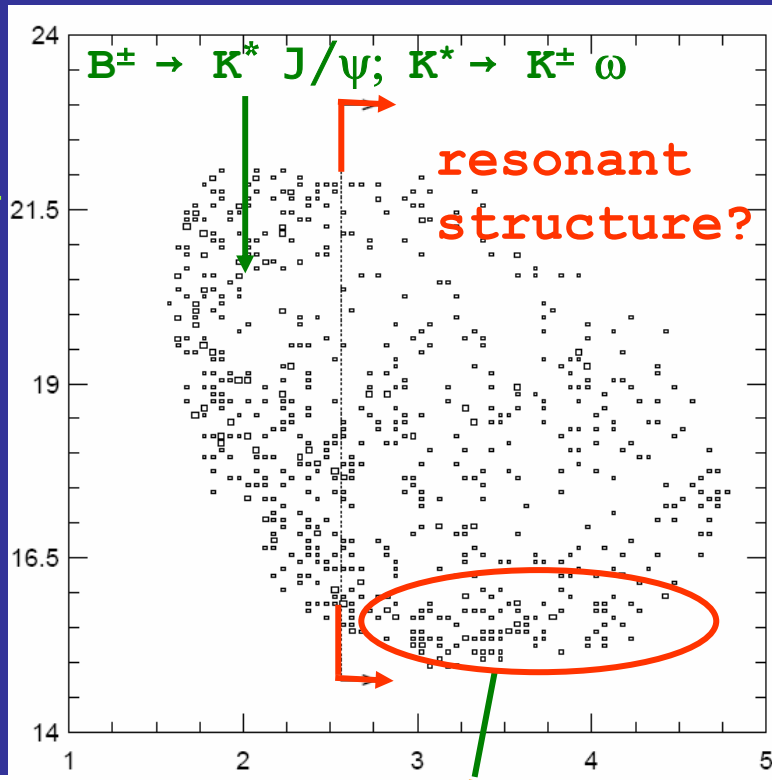


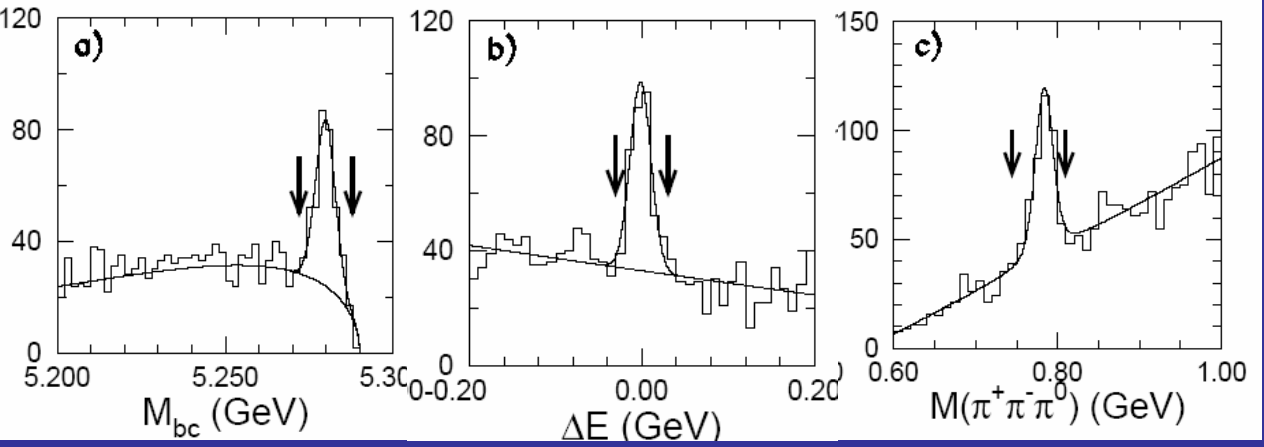
$M(\pi^+\pi^-\pi^0 J/\psi)$

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

$M^2(J/\psi\,\omega)$

Dalitz plot for $B \to K \omega J/\psi$



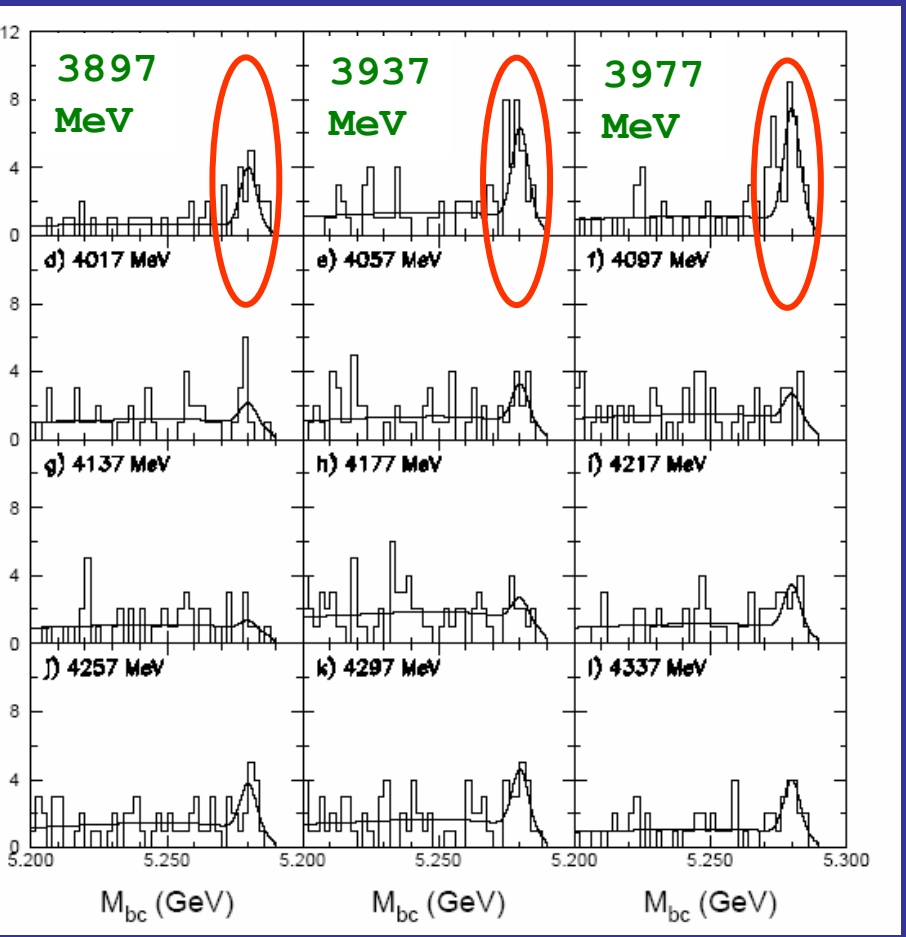


For these $B \to K \omega J/\psi$ plot M_{bc}, ΔE in bins of $M(\omega J/\psi)$

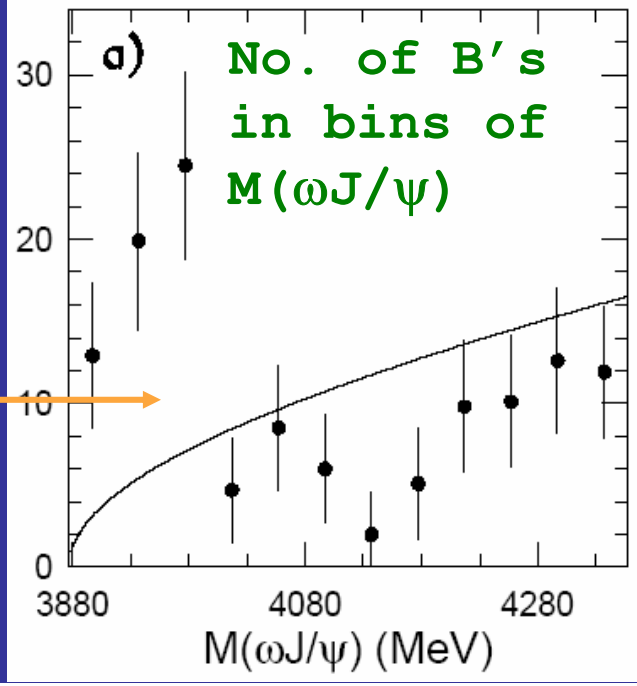
$B^{\pm} \to K^{\pm} \omega J/\psi$

Y(3940)

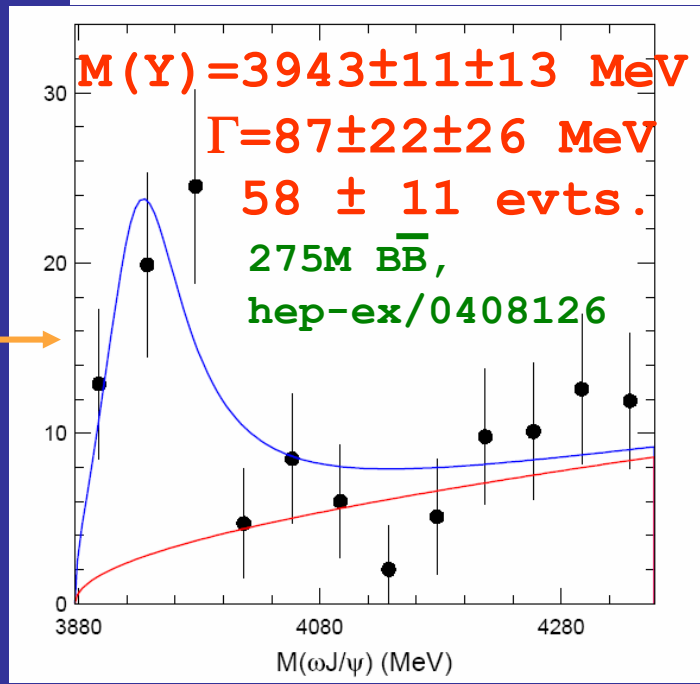
40 MeV bins $M(\omega J/\psi)$



large deviations from phase space



Fit with added BW (8.1σ)

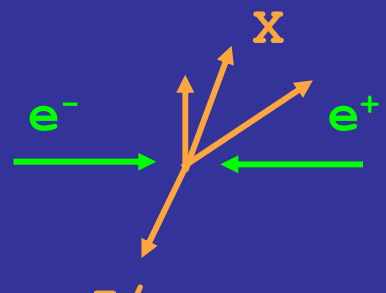


Relatively large signal at low $M(\omega J/\psi)$

$$Br(B \to YK)\, Br(Y \to \omega J/\psi) = (7.1 \pm 1.3 \pm 3.1) \times 10^{-5}$$

$c\bar{c}$ recoil spectrum

well established method(e.g. double $c\bar{c}$ production)

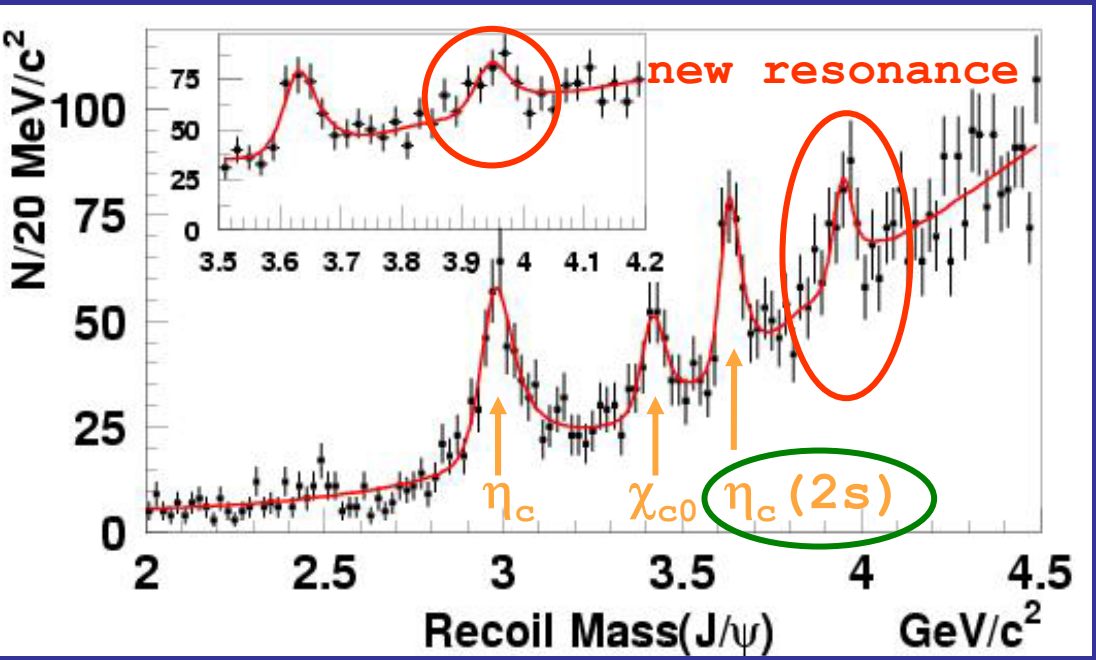


Calculate recoil mass (mass of X):

Reconstruct $J/\psi \to l^+l^-$

$$M_{rec} = \sqrt{(E_{cms} - E^*_{J/\psi})^2 - p^{*\,2}_{J/\psi}}$$

285 fb^{-1}, T.Ziegler, GHP'04



N=148 ± 33 (4.5 σ)
M=3940 ± 11 MeV

Reconstruction of additional D or D* beside $J/\psi \to$
- new resonance decays to DD^*;
- not seen in $J/\psi\,\omega$

probably not Y(3940)

confirmation of $\eta_c(2s)$ after 1st observation by Belle

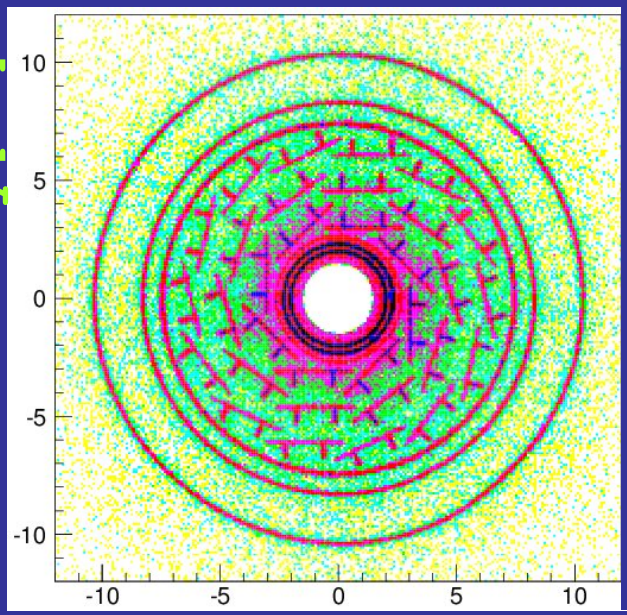
Pentaquark searches

Searches in decays, "high energy" (charm baryon, B)

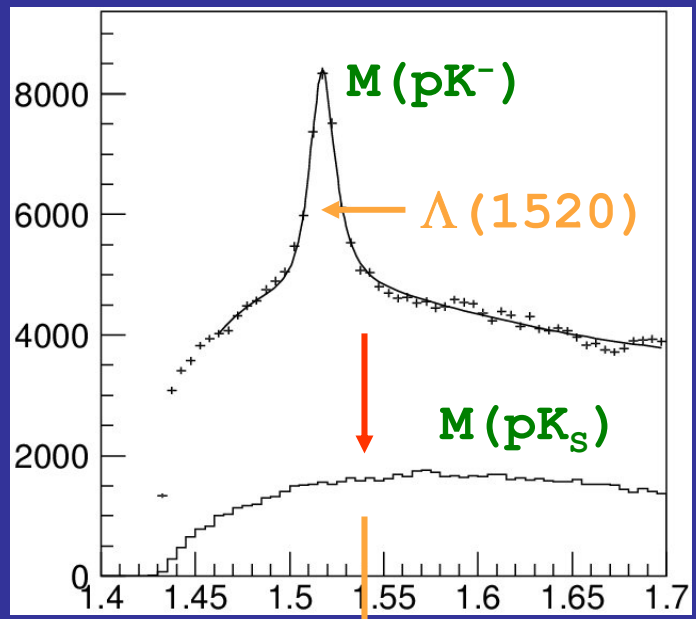
Searches in secondary interactions, "low energy"

select pK secondary vtx

detector "tomography":



155M $B\bar{B}$, hep-ex/0411005



M(pK⁻) fit with D-wave BW and treshold funct.; Λ parameters in agreement with PDG

M(pK$_S$) fit with 3rd order poly. and narrow sig. (2 MeV) at different m

$$\frac{\sigma(KN \to \Theta^+(1540)X)}{\sigma(\bar{K}N \to \Lambda(1520)X)} < 2\%\,(90\%\,CL)$$

assuming Br($\Theta^+ \to pK_S$)=25%

Pentaquark searches

B decays

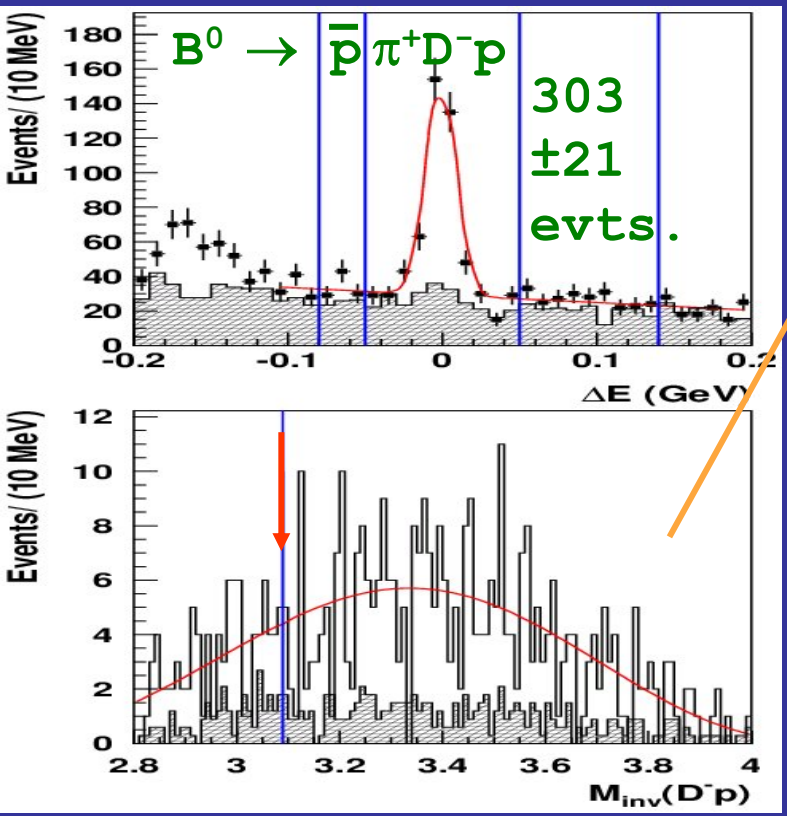
$B^0 \to \bar{p}\,(pK_s)$ $\Theta(1540)^+$

$B^+ \to \bar{p}\,(pK^+)$ $\Theta^*(1600)^{++}$

$B^0 \to \bar{p}\,\pi^+\,(D^{(*)-}p)$ Θ_c^0

$B^0 \to \bar{p}\,(\bar{D}^0 p)$ Θ_c^{*+}

155M $B\bar{B}$, hep-ex/0411005



$M(\Theta_c^0) = 3099$ MeV (H1)

$\sigma = 3.5$ MeV (det. resol.)

$$\frac{Br(B^0 \to \Theta_c^0 \bar{p}\pi^+)Br(\Theta_c^0 \to D^- p)}{Br(B^0 \to D^- p\bar{p}\pi^+)} < 1.2\%$$

$$\frac{Br(B^0 \to \Theta_c^0 \bar{p}\pi^+)Br(\Theta_c^0 \to D^{*-} p)}{Br(B^0 \to D^{*-} p\bar{p}\pi^+)} < 11\%$$

$$\frac{Br(B^0 \to \Theta_c^{*+} \bar{p})Br(\Theta_c^{*+} \to \bar{D}^0 p)}{Br(B^0 \to \bar{D}^0 p\bar{p})} < 5.9\%$$

$$\frac{Br(B^0 \to \Theta^+ \bar{p})Br(\Theta^+ \to pK_S)}{Br(B^0 \to pK_S\bar{p})} < 22\%$$

$$\frac{Br(B^+ \to \Theta^{*++} \bar{p})Br(\Theta^{*++} \to pK^+)}{Br(B^+ \to pK^+\bar{p})} < 2\%$$

@90% CL

Conclusions

- KEKB is also a great source of charm& $c\bar{c}$ states
- Some expected, mainly unexpected/puzzling observations/discoveries

PQ searches hep-ex/0411005

Y(3940)
hep-ex/0408126

X(3872)→ ωJ/ψ
S.Olsen,GHP'04

$\Lambda_c^+ \bar{p}$ structure
hep-ex/0409005

resonance in $c\bar{c}$ recoil
T.Ziegler,GHP'04

D_{sJ} properties
BELLE-CONF-0461
hep-ex/0409026

D^{**} broad states
PRD69,112002

$\eta_c(2s)$
PRL89,102001
PRD70,071102

$\Sigma_c(2800)$
hep-ex/0412069

range of questions: → understanding

what are they? why such properties? all properties as expected?

will be addressed as more statistics is collected

new state	production	decay mode	to establish next	reference
D_{sJ}	Continuum $B\to\bar{D}D_{sJ}$, $B\to D_{sJ}K$	$D_s\pi^0$, $D_s^*\pi^0$, $D_s\gamma$	Br's	BELLE-CONF-0461 hep-ex/0409026
X(3872)	$B\to KX$	$\pi^+\pi^- J/\psi$ $\pi^+\pi^-\pi^0(\omega) J/\psi$	quantum num., decay modes	hep-ex/0408116 S.Olsen,GHP'04
Y(3940)	$B\to KY$	$\omega J/\psi$	M,Γ	hep-ex/0408126
X(3940)	continuum, $c\bar{c}$ recoil	M_{recoil},DD^*	M,Γ	T.Ziegler,GHP'04
$\eta_c(2s)$	continuum, $c\bar{c}$ recoil	M_{recoil}	σ	PRD(R)70,071102
$\Sigma_c(2800)$	continuum	$\Lambda_c\pi^+$	σ,Γ (mixing)	hep-ex/0412069
broad D^{**}	$B^+\to D^{**}\pi^+$	$D^{(*)}\pi$	Br's	PRD69,112002
$\Lambda_c^+\,\bar{p}$	$B^-\to\ \Lambda_c^+\,\bar{p}\,\pi^-$	M($\Lambda_c^+\,\bar{p}$)	M,Γ	hep-ex/0409005
$\Theta^+(1540)$	sec. int. pK	pK_S	existence?	hep-ex/0411005
Θ^+,Θ^{*++}, Θ_c^0, Θ_c^{*+}	B decays	pK_S,pK^+, $D^{(*)-}p$,D^0p	existence?	hep-ex/0411005
Θ^+,Θ^{*++}, $\Xi_{3/2}^{--}$, $\Xi_{3/2}^{+}$	charm baryon decays	pK_S,pK^+, $\Xi^-\pi^-$, $\Xi^-\pi^+\pi^+$	existence?	