New resonances and spectroscopy(Belle).

A.Kuzmin

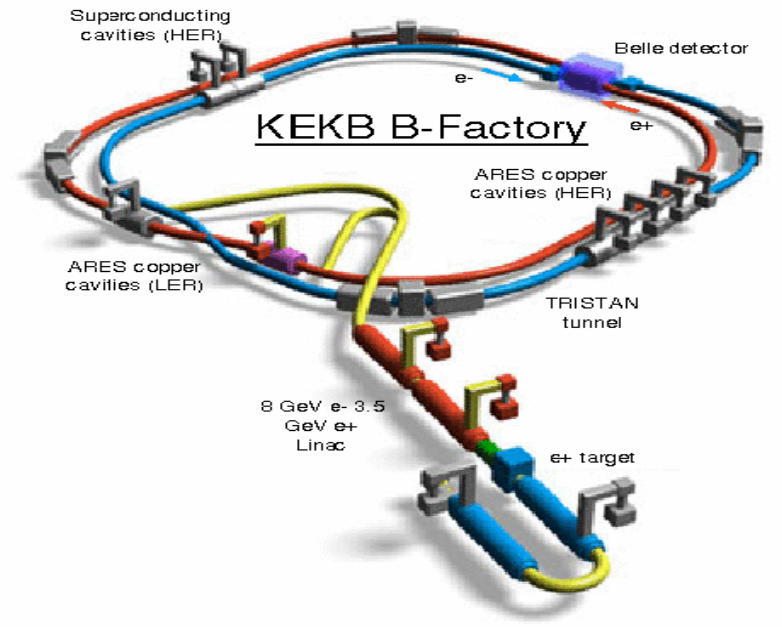
for Belle collaboration

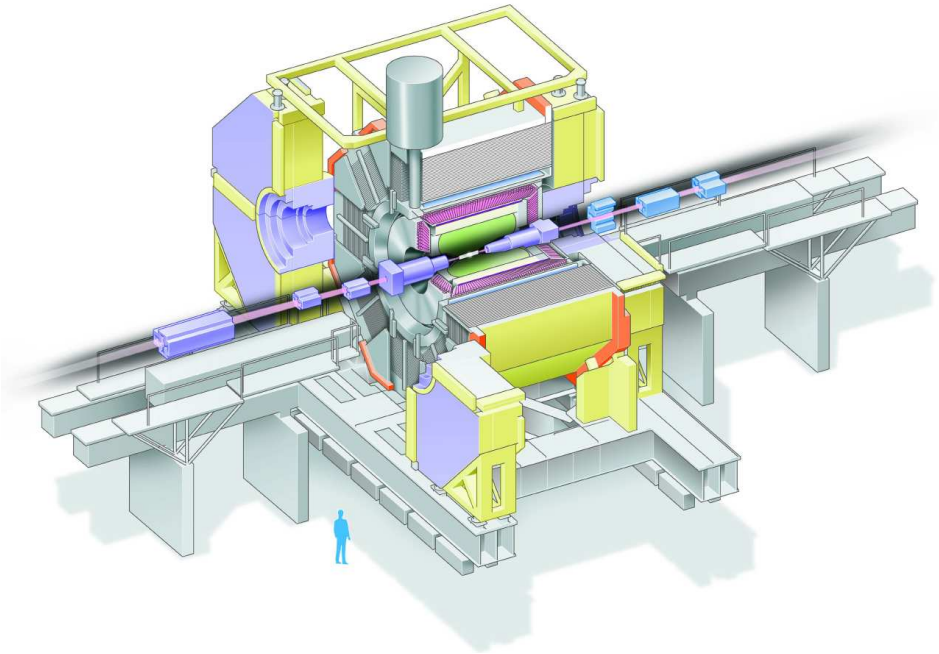
April 22, 2006

Outline:

- Experimental environment
- New resonance production on B-factories
- Broad D^{**} and D_{sJ}
- Charmonium and charmonium like states
- Summary

KEKB, Belle detector





- **3.5 GeV e^+ × 8.0 GeV e^-.**
- **$\mathcal{L}_{max} = 1.6 \times 10^{34} cm^{-2} s^{-1}$**
- **Continuous injection**
  $\rightarrow 1.1\,\mathrm{fb}^{-1}$/day.
- **$\int \mathcal{L} dt \approx 560\, fb^{-1}$**

- **Sil.VD: 3(4) layers DSSD**
- **CDC : small cells $He + C_2H_6$**
- **TOF counters.**
- **Aerogel CC:$n = 1.015 \sim 1.030$**
- **CsI(Tl) 16 X_0**
- **SC solenoid 1.5 T**
- **μK_L *detection* 14-15 layers RPC+Fe**

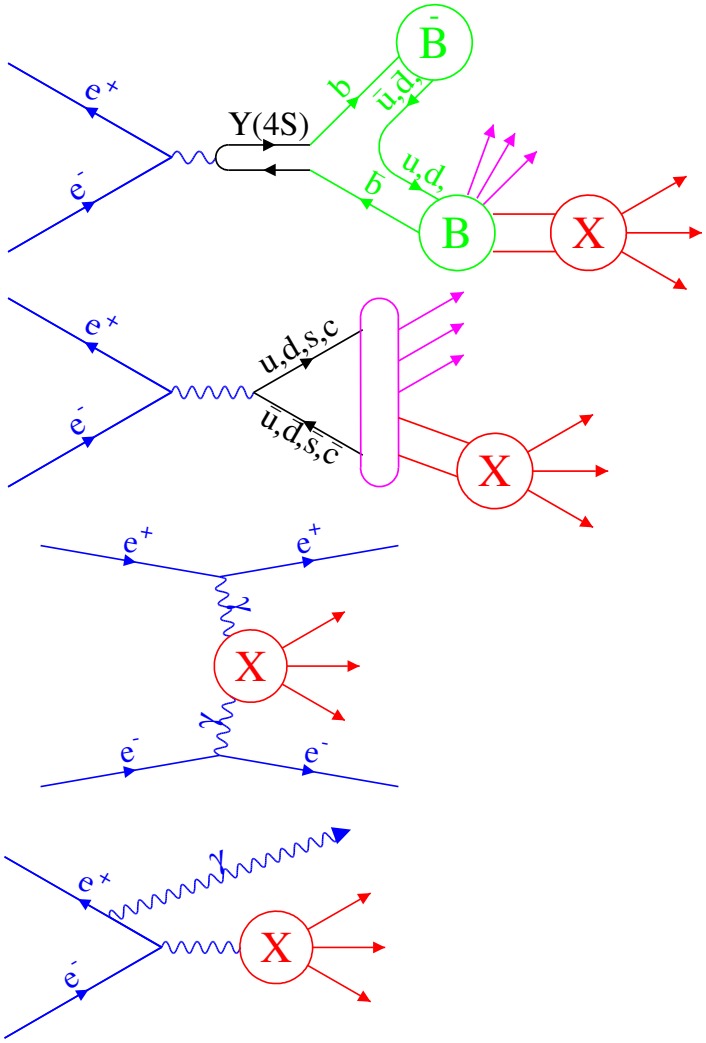
Particle production at B factories

Production from B-decay
(broad D^{**}, D_{sJ}, $X(3872)$, $Y(3940)$)

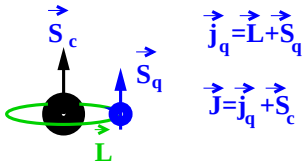
Production from continuum
(D_{sJ}, $\eta_c(2S)$, $X(3940)$, $\Sigma(2800)$)

Two-photon production
($Z(3930)$)

Initial state radiation



D^{**} are p-wave excitations of D mesons.



$B \to D^{**}\pi$, $D^{**} \to D^{(*)}\pi$

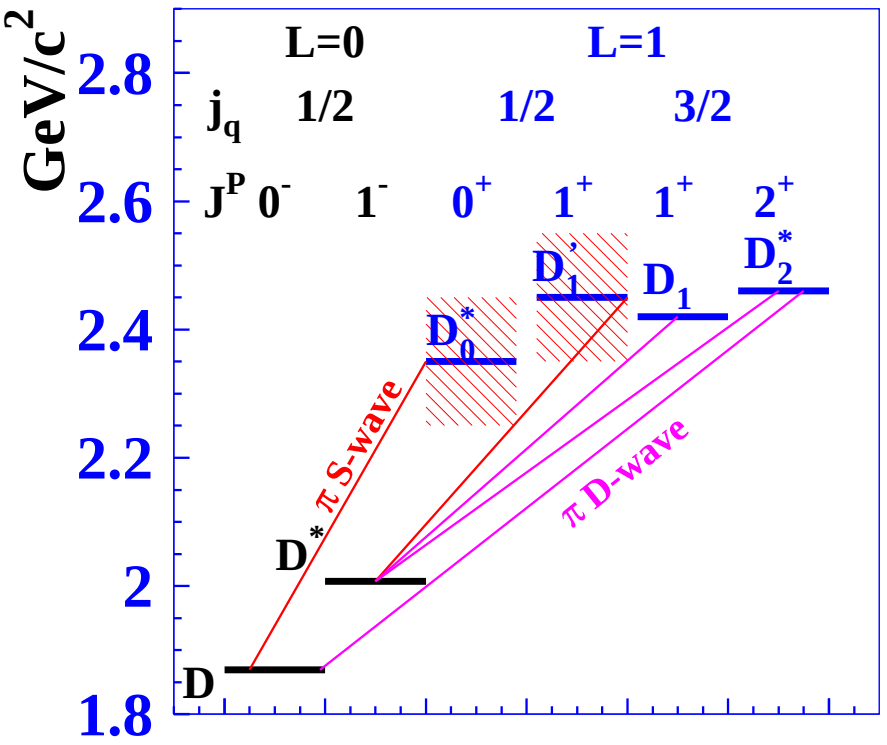
$D^{**} \to D^{(*)}\pi$ have different dependences

$D_2^* \to$	$D\pi$,	$D^*\pi$	D-wave
$D_1 \to$		$D^*\pi$	D-wave
$D_1' \to$		$D^*\pi$	S-wave
$D_0^* \to$	$D\pi$		S-wave

In B decay fixed initial state spin 0.

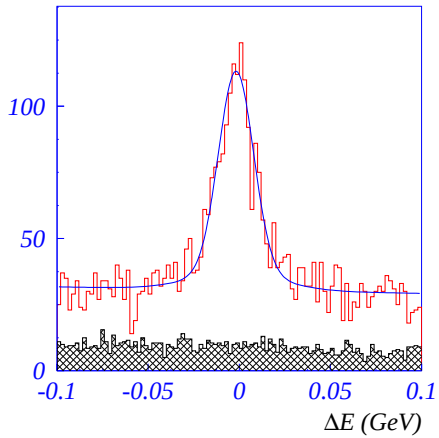
$B \to D_2^*\pi$	D-wave
$B \to D_1\pi$	P-wave
$B \to D_1'\pi$	P-wave
$B \to D_0^*\pi$	S-wave

All D^{**} states can be distinguished using Dalitz plot analysis



Test of HQET and QCD sum rule predictions.

$B^- \to D^{(*)+}\pi^-\pi^-$



$\sim 65\ MB\bar{B}$

$D^+ \to K^-\pi^+\pi^+$, $D^{*+} \to D^0\pi^+$

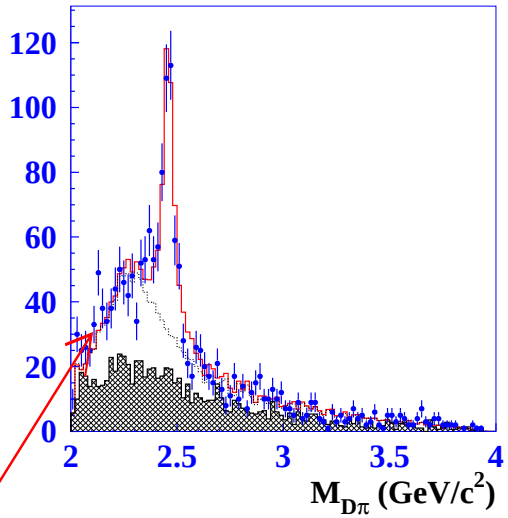
$D^0 \to K^-\pi^+$ and

$D^0 \to K^-\pi^+\pi^-\pi^+$

Unbinned likelihood fit to Dalitz plot for $D\pi\pi$.

2 more angles for D^* decay.

Unbinned likelihood fit to 4-D plot for $D^*\pi\pi$.



$D\pi$: can form D_2^*, D_0^*, off-shell D_v^*, B_v^*

D_0^{*0} : $M = 2308 \pm 17 \pm 15 \pm 28\ MeV/c^2$, $\Gamma = 276 \pm 21 \pm 18 \pm 60\ MeV$

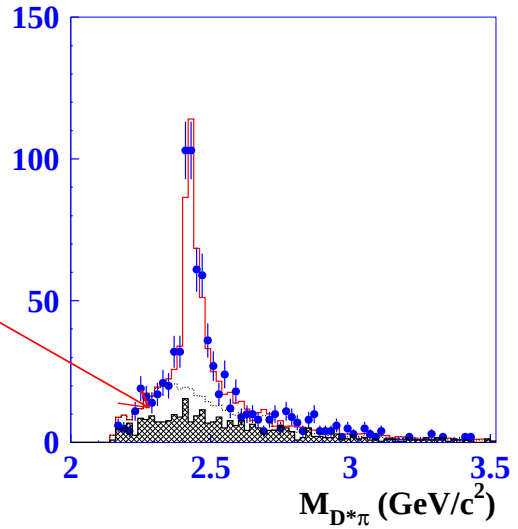
QN	0^+	1^-	2^+	no
$2\ln L/L_0$	0	355	235	370

$D^*\pi$: can form D_1, D_2^*, D_1'

$D_1'^0$: $M = 2427 \pm 26 \pm 20 \pm 15\ MeV/c^2$, $\Gamma = 384^{+107}_{-75} \pm 24 \pm 70\ MeV$

QN	1^+	0^-	1^-	2^+	no
$2\ln L/L_0$	0	107	156	166	170

All 4 neutral D^{**} have been observed.



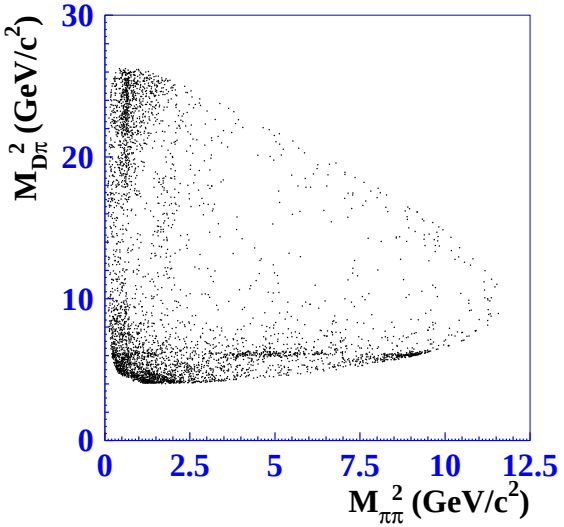
Masses and widths of all neutral D^{**}'s have been measured.

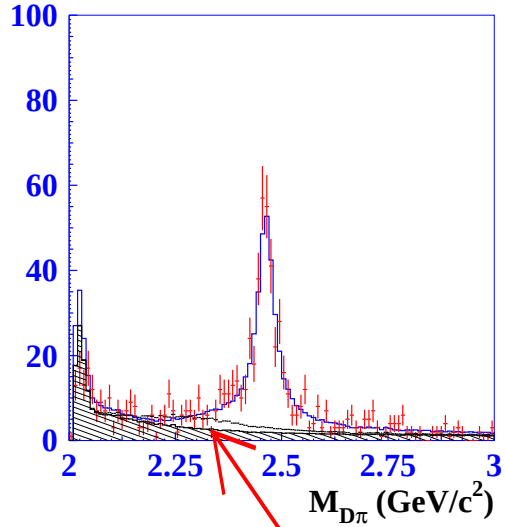
First observation of D_0^{*0} and $D_1'^0$.

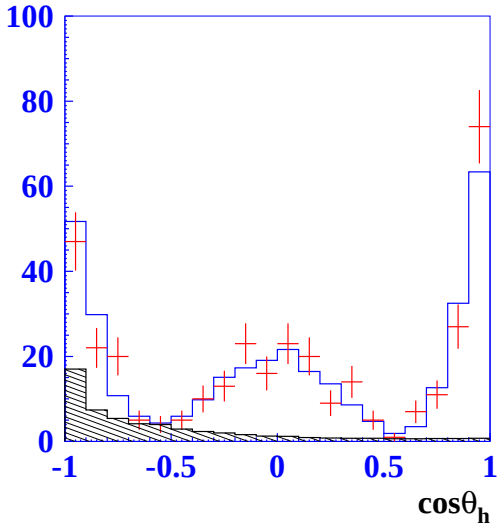
PRD 69, 112002,2004

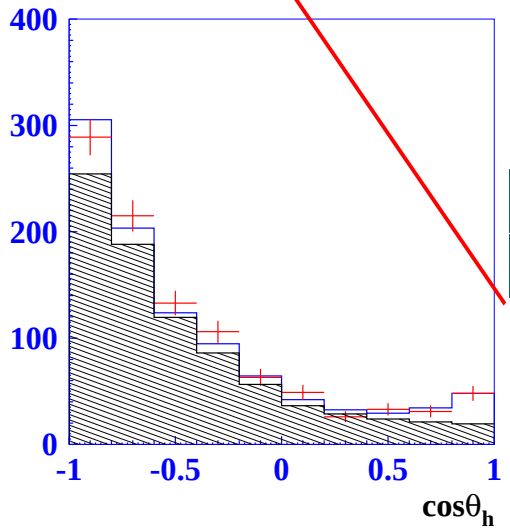
$\bar{B}^0 \to D^0\pi^+\pi^-$ Dalitz plot analysis.

$\cos\theta_h > 0$









$|M_{D\pi} - 2.46| < 0.1\,GeV/c^2$

$|M_{D\pi} - 2.30| < 0.1\,GeV/c^2$

386 M$B\bar{B}$

Both $D\pi$ and $\pi^+\pi^-$ resonance structures:

D_2^*, D_0^*, off-shel D_v^*, B_v^*

ρ, $f_2(1270)$, $f_0(600)$, $f_0(1370)$

$M_{D_0^{*+}}$, $\Gamma_{D_0^{*+}}$ are fixed at values of $M_{D_0^{*0}}$, $\Gamma_{D_0^{*0}}$.

$\mathcal{B}(\bar{B}^0 \to D_0^{*+}\pi^-)\mathcal{B}(D_0^{*+} \to D^0\pi^+) =$

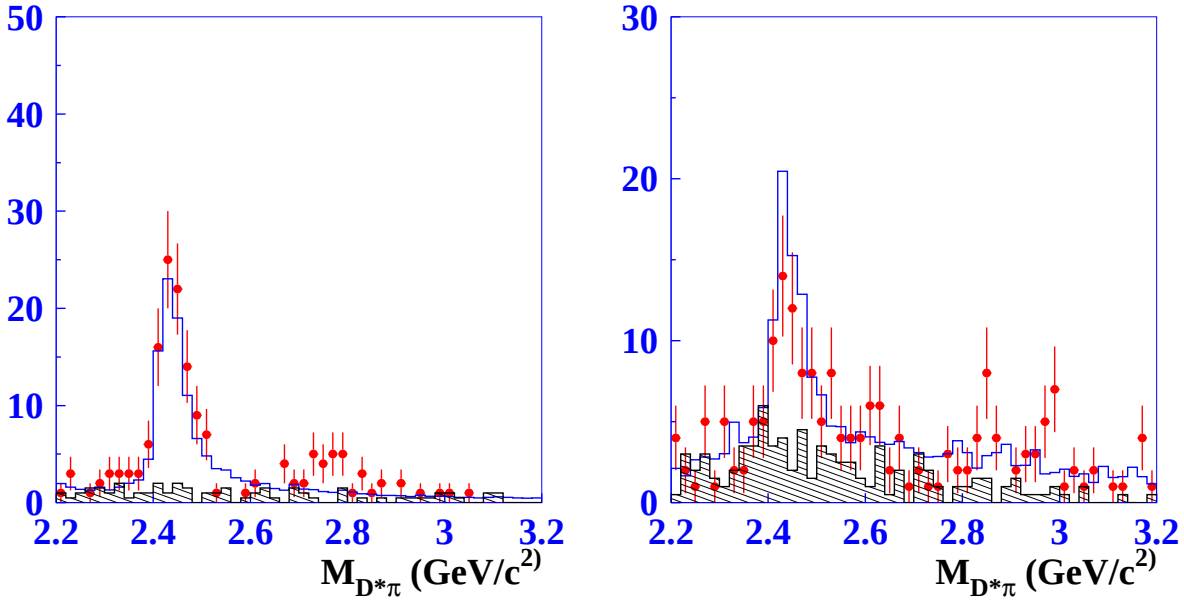
$(0.60\pm0.13\pm0.15\pm0.22)\times10^{-4}$

QN	0^+	1^-	2^+	no
$2\ln L/L_0$	0	28	27	51

First observation of D_0^{*+}

$\bar{B}^0 \to D^{*0}\pi^+\pi^-$.

$\cos\theta_h > 0$ $\cos\theta_h < 0$



$152\mathrm{M}B\bar{B}$

$M_{D_1^+} = (2428.2 \pm 2.9 \pm 1.6 \pm 0.6)\,\mathrm{MeV}/c^2,$

$\Gamma_{D_1^+} = (34.9 \pm 6.6^{+4.1}_{-0.9} \pm 4.1)\,\mathrm{MeV}.$

$$\mathcal{B}(\bar{B}^0 \to D_2^{*+}\pi^-) \times B(D_2^{*+} \to D^{*0}\pi^+) = (2.45 \pm 0.42^{+0.35+0.39}_{-0.45-0.17}) \times 10^{-4},$$

$$\mathcal{B}(\bar{B}^0 \to D_1^{+}\pi^-) \times B(D_1^{+} \to D^{*0}\pi^+) = (3.68 \pm 0.60^{+0.71+0.65}_{-0.40-0.30}) \times 10^{-4},$$

$$\mathcal{B}(\bar{B}^0 \to D_1^{\prime+}\pi^-) \times B(D_1^{*+} \to D^{*0}\pi^+) = (0.14 \pm 0.13 \pm 0.12^{+0.00}_{-0.10}) \times 10^{-4},$$

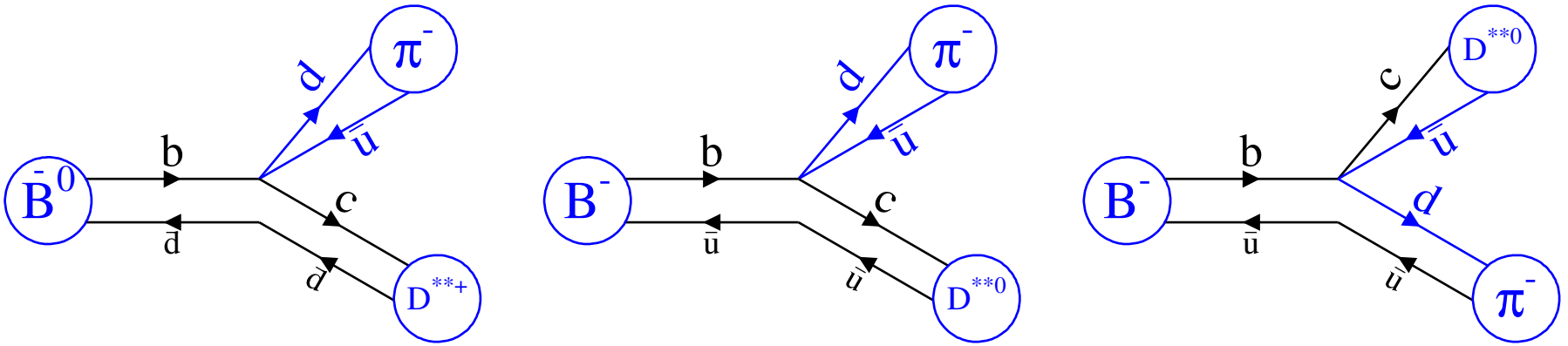
$$\mathcal{B}(\bar{B}^0 \to D_1^{\prime+}\pi^-) \times B(D_1^{\prime+} \to D^{*0}\pi^+) < 0.7 \times 10^{-4} \text{ at } 90\,\%\mathrm{CL}.$$

Preliminary results are given in hep-ex/0412072

The production of $D^{**+}_{j=3/2}\pi^-$ in B^0 decay are comparable with $D^{**0}_{j=3/2}\pi^-$ in B^+ decay.

$D^{**+}_{j=1/2}\pi^-$ production in B^0 decay is at least 5 times lower than in B^+ decay.

	$\bar{B}^0$	B^-
$\mathcal{B}(\bar{B} \to D^*_2\pi^-)\mathcal{B}(D^*_2 \to D^*\pi) \times 10^4$	$2.45 \pm 0.42^{+0.35+0.39}_{-0.45-0.17}$	$1.8 \pm 0.3 \pm 0.3 \pm 0.2$
$\mathcal{B}(\bar{B} \to D_1\pi^-)\mathcal{B}(D_1 \to D^*\pi) \times 10^4$	$3.68 \pm 0.60^{+0.71+0.65}_{-0.40-0.30}$	$6.8 \pm 0.7 \pm 1.3 \pm 0.2$
$\mathcal{B}(\bar{B} \to D^*_2\pi^-)\mathcal{B}(D^*_2 \to D\pi) \times 10^4$	$2.15 \pm 0.17 \pm 0.29 \pm 0.12$	$3.4 \pm 0.3 \pm 0.6 \pm 0.4$
$\mathcal{B}(\bar{B} \to D'_1\pi^-)\mathcal{B}(D'_1 \to D^*\pi) \times 10^4$	< 0.7 at 90 %CL.	$5.0 \pm 0.4 \pm 1.0 \pm 0.4$
$\mathcal{B}(\bar{B} \to D^*_0\pi^-)\mathcal{B}(D^*_0 \to D\pi) \times 10^4$	$0.60 \pm 0.13 \pm 0.15 \pm 0.22$	$6.1 \pm 0.6 \pm 0.9 \pm 1.6$

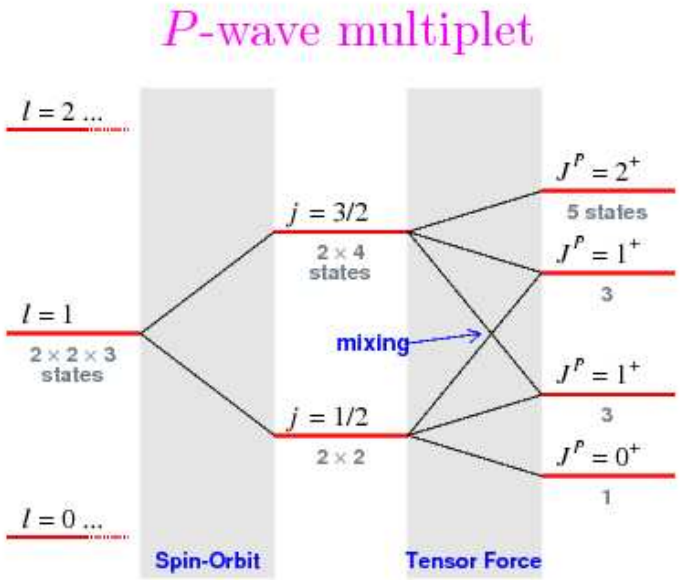


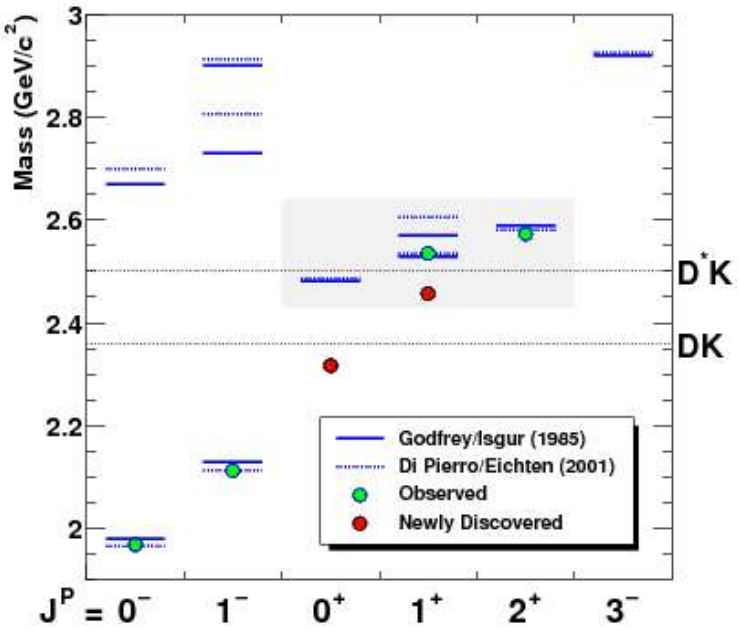
$\tau_{3/2} >> \tau_{1/2}$ $\qquad$ $f_{D_{3/2}} << f_{D_{1/2}}$

For broad D^{**} production Color suppressed amplitude dominates.

Branching is comparable with BaBar measurement $\bar{B}^0 \to D'^0_1\omega$ (hep-ex/0604009)

D_{sJ} spectroscopy.





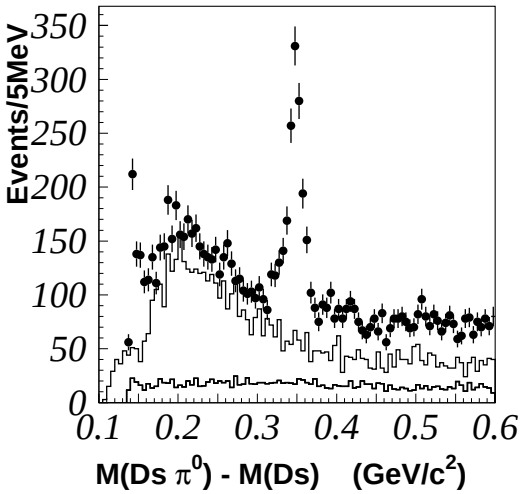
Figures: Courtesy of David Williams

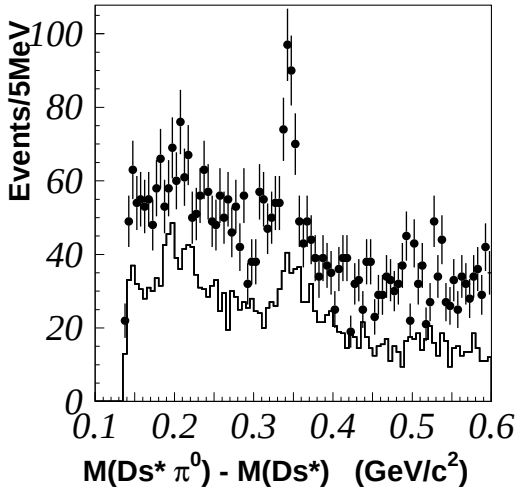
$j = 1/2$ states with $M > M_{D^{(*)}} + M_K$ have large widths.

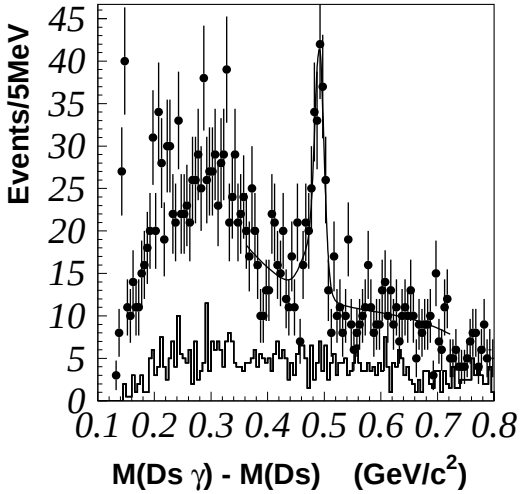
D_{sJ} production.

- BaBar first observed $D_{sJ}^{+}(2317) \to D_s^{+}\pi^0$ decay in e^+e^- continuum.
- CLEO confirmed $D_{sJ}^{+}(2317)$ and established $D_{sJ}^{+}(2460)$.
- Width of the states are consistent with detector resolution.
- Belle confirmed BaBar and CLEO results.

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



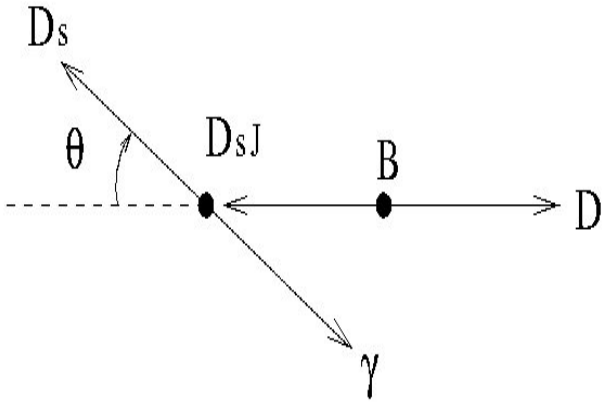




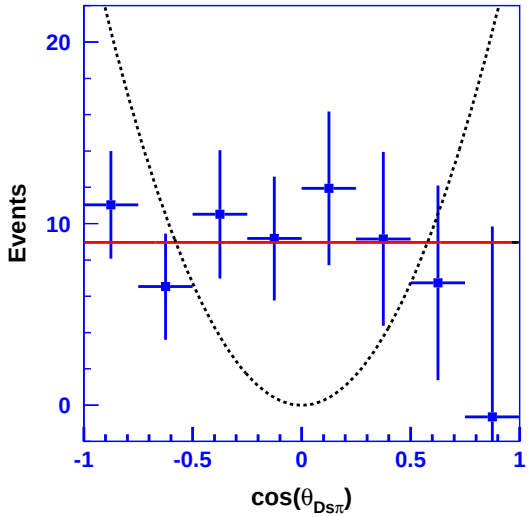
Y.Mikami, et al.(Belle Collaboration), PRL 92, 012002 (2004)

D_{sJ} quantum numbers.

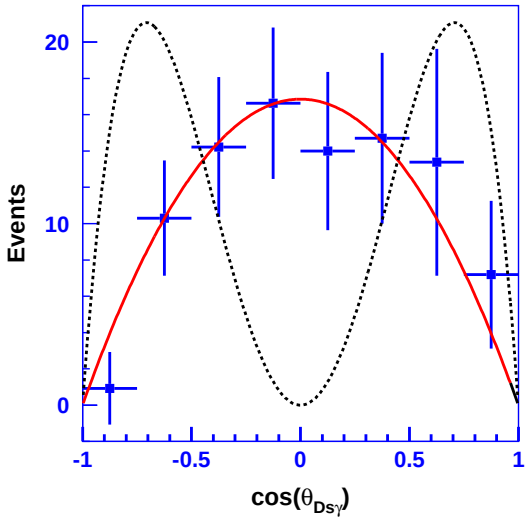
- Study angular distributions of D_{sJ} produced in B-decays allows to determine their quantum numbers



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



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



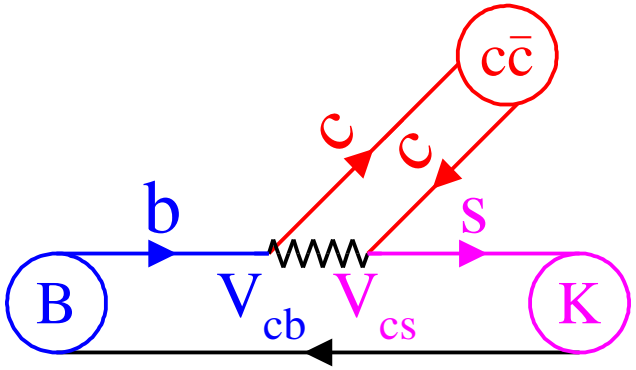
$J = 0: \ \chi^2/Ndf = 3/8$ $\quad$ $J = 1: \ \chi^2/Ndf = 4/8$

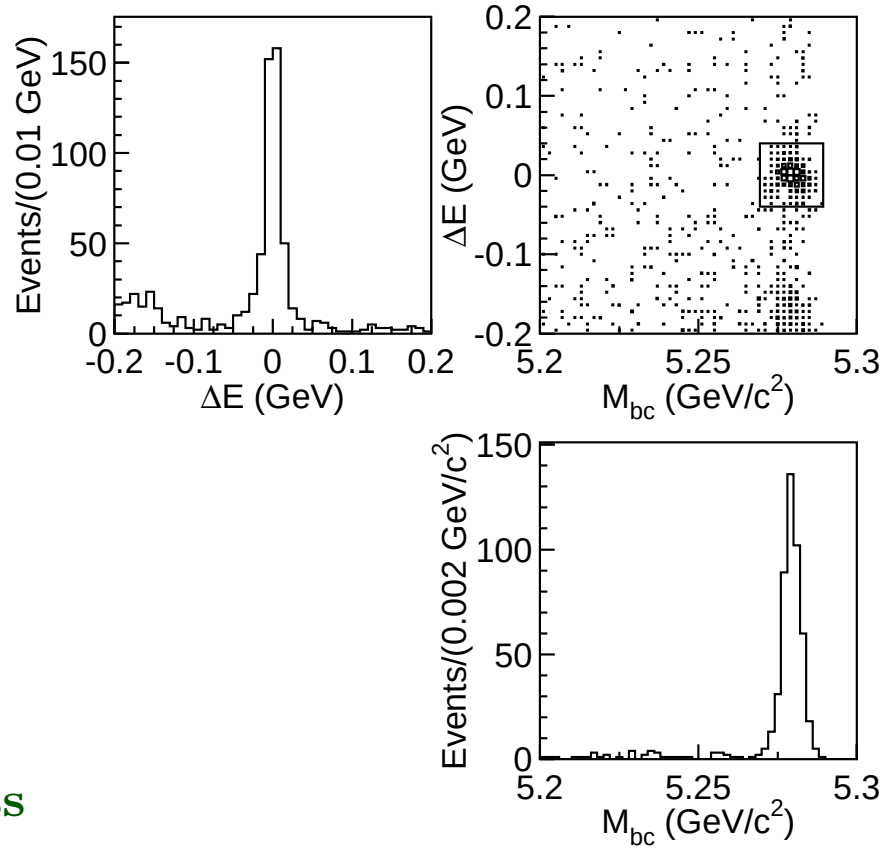
$J = 1: \ \chi^2/Ndf = 38/8$ $\quad$ $J = 2: \ \chi^2/Ndf = 89/8$

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

ICHEP04 11-0711 (update of PRL 91, 262002(2003))

Charmonium production in B decay

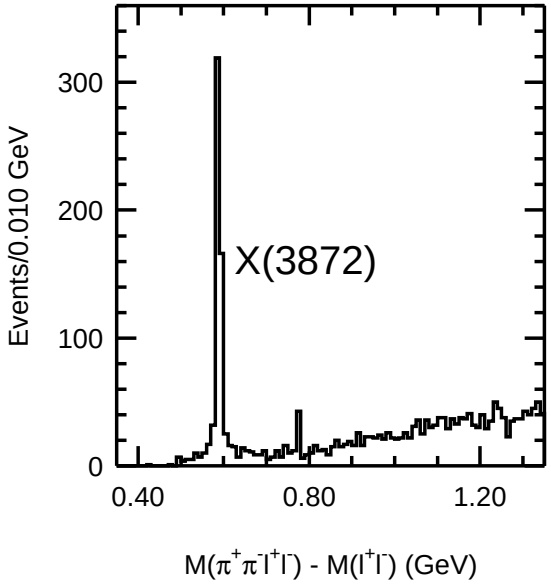




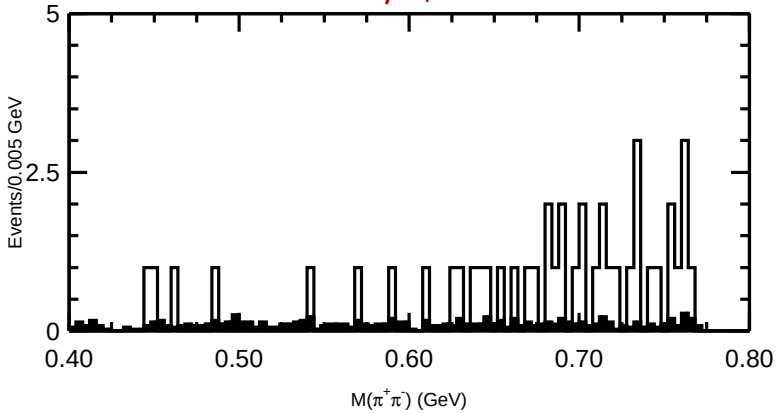
- **Cabbibo favored decay**
- **B Kinematic Reconstruction**
  - **Beam energy constrained mass**
    $m_{\rm bc} = \sqrt{E^2_{beam} - |\sum \vec{P}_i|^2}$
  - **Energy difference**
    $\Delta E = \sum E_i - E_{beam}$

$X(3872)$ production.

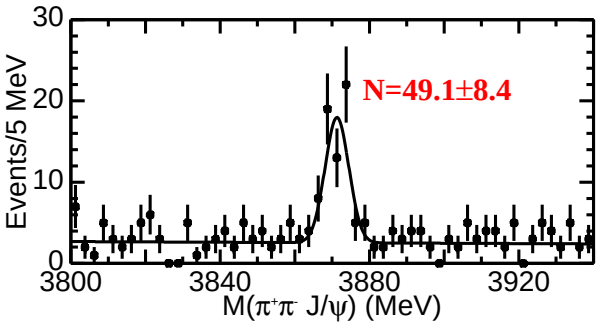
Observed by Belle PRL91,262001(2003)(152 M$B\bar{B}$) in B decays.
(confirmed by DO, CDF, Babar)



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



275 M$B\bar{B}$ hep-ex/0505038



$M = 3872.4 \pm 0.6 \pm 0.5$ MeV/c^2

$\Gamma < 2.3$ MeV

$Br(B \to XK) \times Br(X \to \pi^+\pi^- J/\psi)$

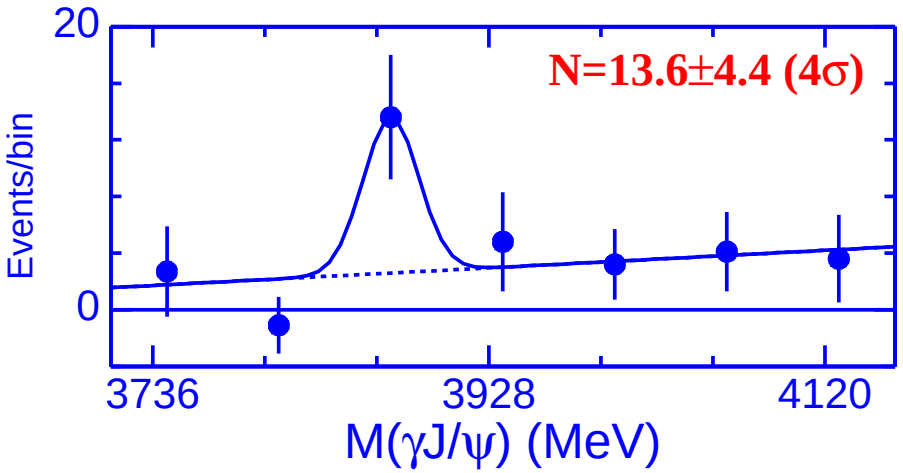
$= (1.31 \pm 0.24 \pm 0.13) \times 10^{-5}$

$M(\pi\pi)$ is consistent with ρ.

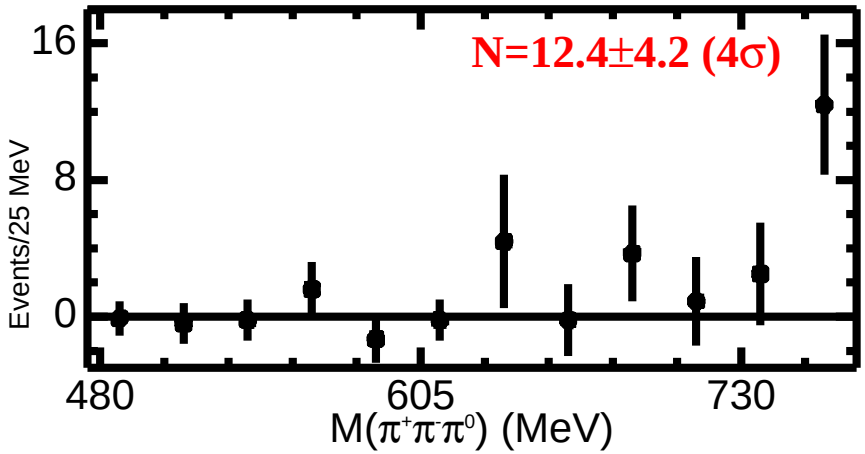
(Large isospin violation)

$X(3872)$ properties.

$B \to K\gamma J/\psi$



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



275 M$B\bar{B}$ hep-ex/0505037

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

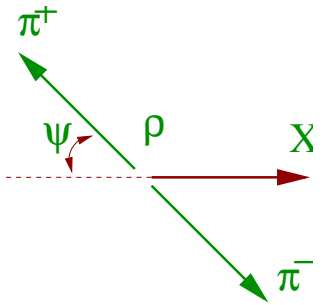
3π − virtual ω

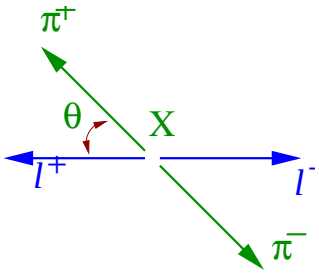
C(X(3872))=+1

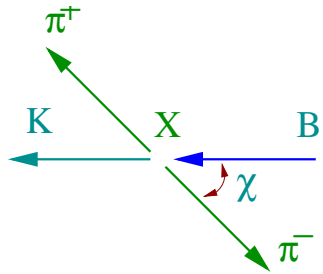
$$\frac{Br(X \to \gamma J/\psi)}{Br(X \to \pi^+\pi^- J/\psi)} = 0.14 \pm 0.05 \text{ (Small for } c\bar{c})$$

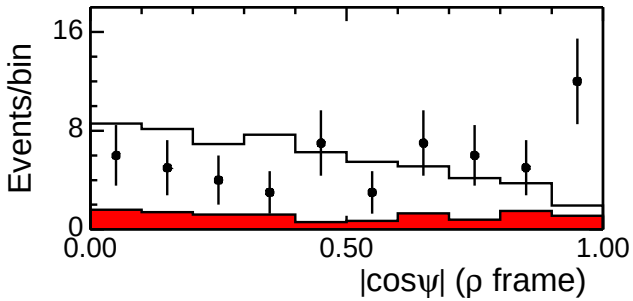
$X(3872)$ angular distributions

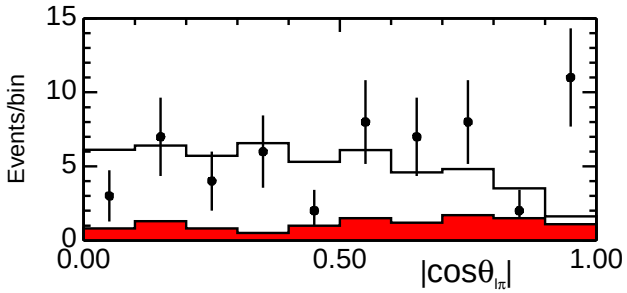
$B \to K\pi^+\pi^- J/\psi$

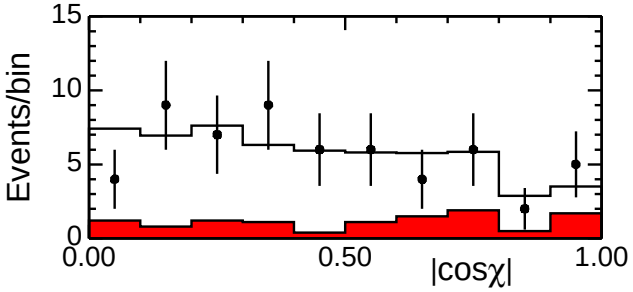












0^{-+} **P-wave**

$\propto \sin^2\theta \sin^2\psi$

$\chi^2/Ndf = 34.2/9$

0^{++} **S(D) wave**

$\propto \sin^2\theta_{l\pi}$

$\chi^2/Ndf = 31/9$

1^{++} **S(D) wave**

$\propto \sin^2\theta_l \sin^2\chi$

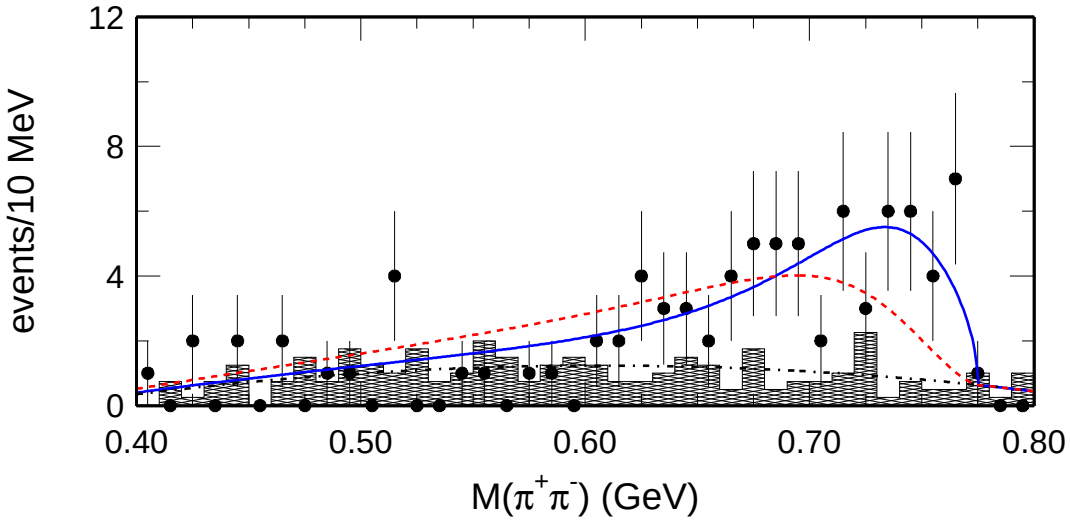
$\chi^2/Ndf = 5/9$

0^{-+}, 0^{++} - quantum numbers are disfavored

$X(3872)$ quantum numbers

$$X \to \rho^0 J/\psi \to \pi^+\pi^- J/\psi$$

Even parity: S-wave; Odd parity: P-wave



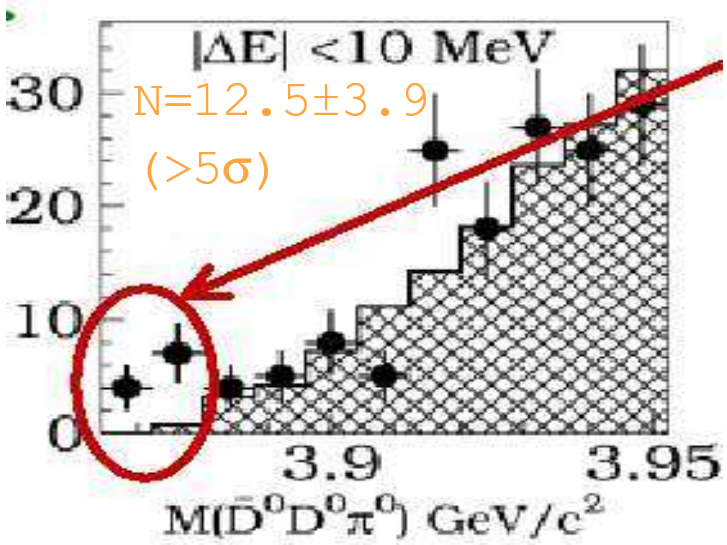
$\pi\pi$ spectrum is more consistent with S-wave

S-wave $\chi^2/Ndf = 43/39$

P-wave $\chi^2/Ndf = 71/39$

1^{++} is strongly favored over 1^{-+}

$X(3872)$ quantum numbers



Preliminary results $B \to D^0 \bar{D}^0 \pi^0 K$

An excess of events with $M(D^0 \bar{D}^0 \pi^0) \approx M_X$
$2^{++} -> $ **one combination** D**-wave**
strong suppression near threshold
rule out 2^{++}

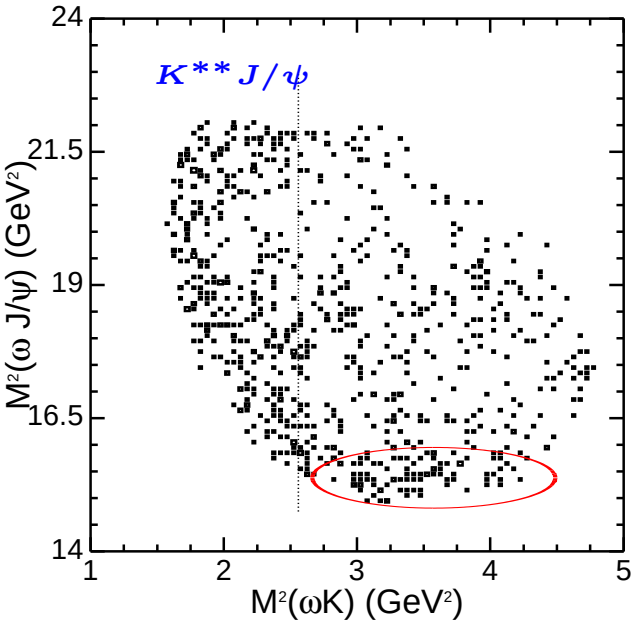
$$J^{PC}(X(3872)) = 1^{++}$$

- χ'_{c1}?
  - Predicted χ'_{c1} mass 100 MeV higher.
  - Small $\Gamma(J/\psi\gamma)/\Gamma(J/\psi\pi\pi)$ disfavor χ'_{c1}(0.14, expected ~ 30)
- $D\bar{D}^*$ bound state models?
  - Isospin violation is predicted
  - $\Gamma(J/\psi\gamma) < \Gamma(J/\psi\pi\pi)$ is predicted

Further study is necessary

$Y(3940)$ production

$B \to K\omega J/\psi$ PRL94,182002(2005)

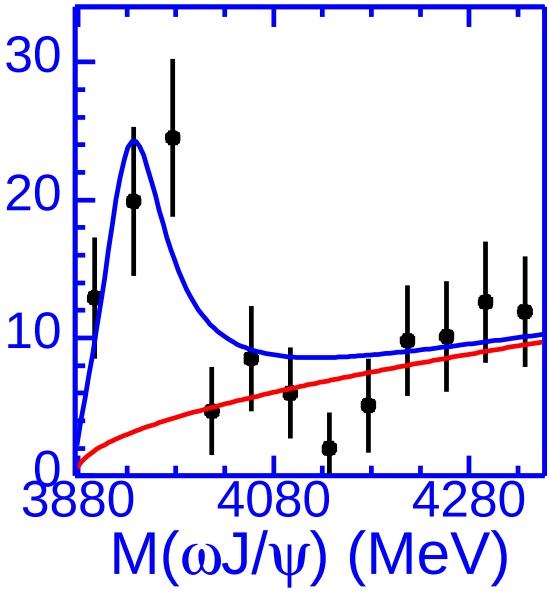


$N = 58 \pm 11 (> 8\sigma)$

$M_Y = 3943 \pm 11 \pm 13$ MeV

$\Gamma_Y = 87 \pm 22 \pm 26$ MeV

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



What is it?

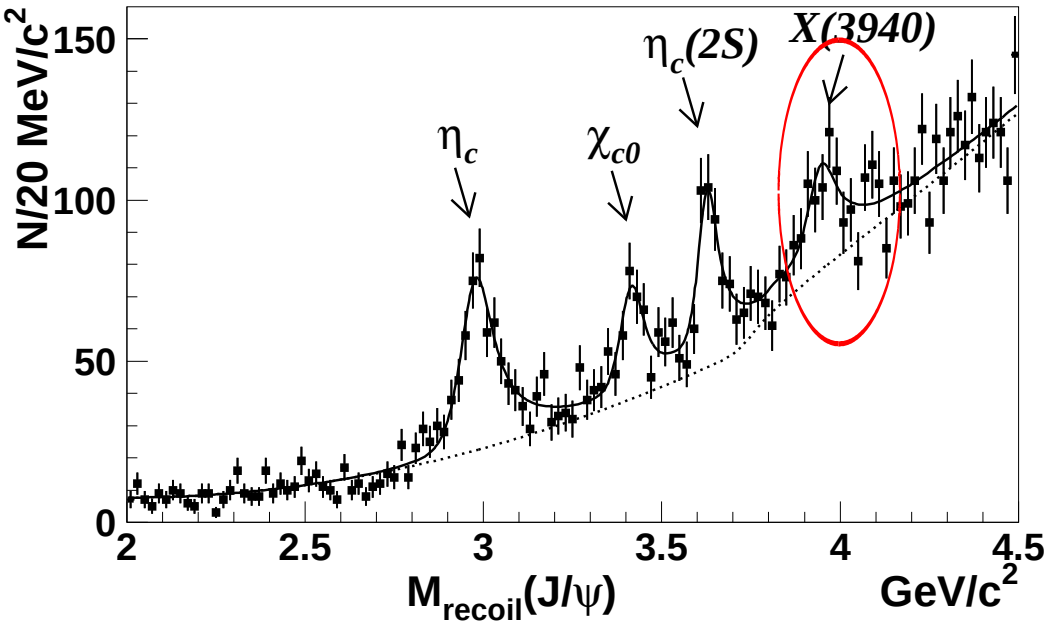
- Radially excited $c\bar{c}$?
  - Large $Br(Y \to \omega J/\psi)$
    $D^{(*)}\bar{D}^{(*)}$ decay modes expected to be dominated
- $c\bar{c}$-gluon hybrid?
  - $D^{(*)}\bar{D}^{(*)}$ suppression
  - predicted masses $4.3 - 4.5$ GeV

$X(3940)$ production in e^+e^-

$L \approx 357\ fb^{-1}$, hep-ex/0507019(submitted to PRL)

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

Observation in J/ψ recoil mass: $M_{rec} = \sqrt{(E_{CM} - E^*_{J/\psi})^2 - p^{*\,2}_{J/\psi}}$



$N = 266 \pm 33$

No evidence $X(3940) \to J/\psi\omega$

$X(3940) \neq Y(3940)$

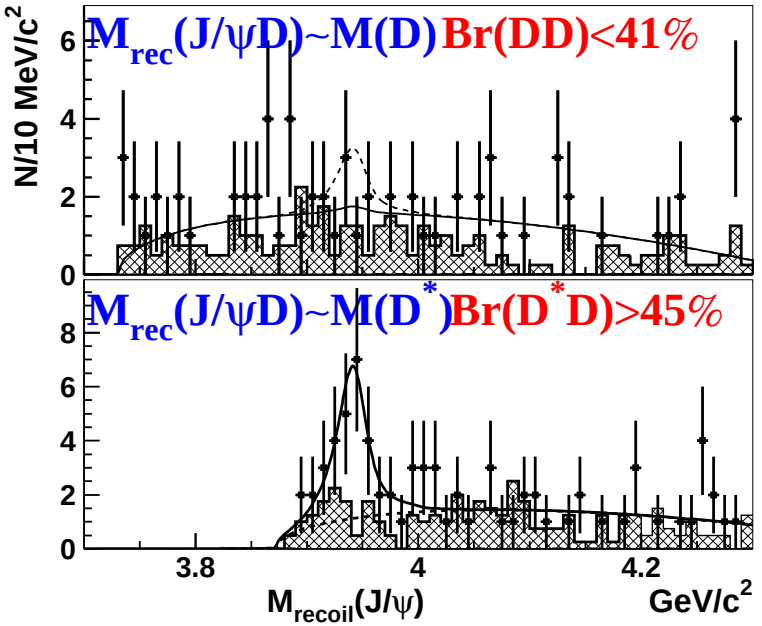
reconstruct $J/\psi + D$

constrain $M_{rec}(J/\psi D) = M(D^{(*)})$

$N = 24.5 \pm 6.9(5\sigma)$

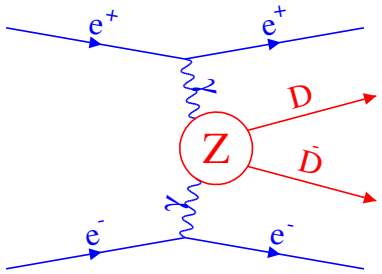
$M_X = 3943 \pm 6 \pm 6\ MeV/c^2$

$\Gamma_X < 52\ MeV$ 90 % C.L.

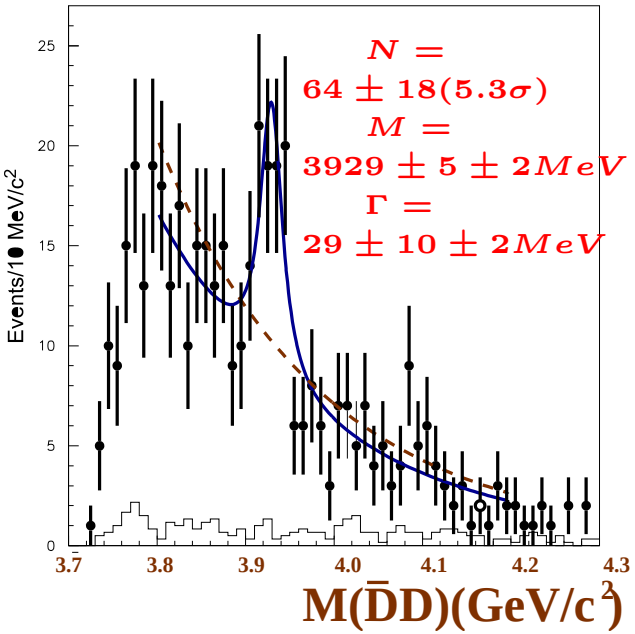


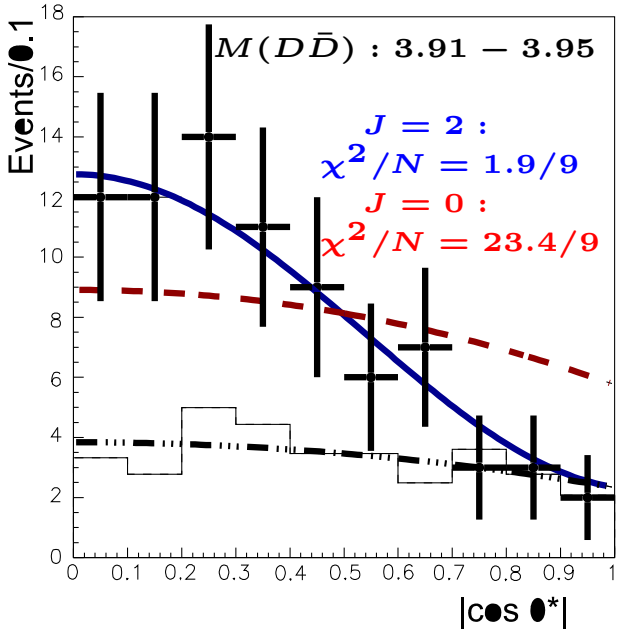
$Z(3930)$ two photon production

$L \approx 395\ fb^{-1}$, PRL 96, 082003 (2006)



- un-tagged $\gamma\gamma \to D\bar{D}$ events
- $D^0 \to K^-\pi^+,\ K^-\pi^+\pi^0,\ K3\pi,\quad D^+ \to K^-\pi^+\pi^+$
- $P_t(D\bar{D}) < 0.05 GeV/c$



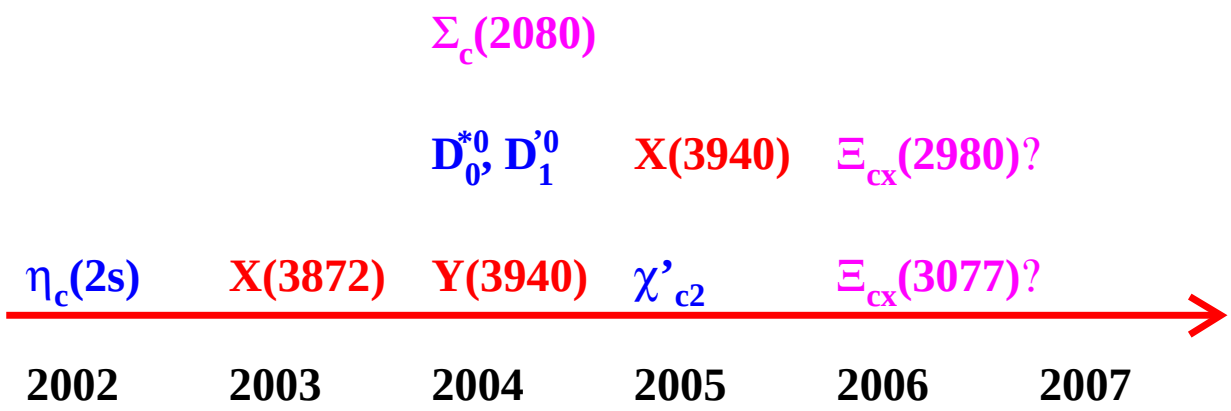


$$\Gamma_{\gamma\gamma}(Z)Br(Z \to D\bar{D}) = 0.18 \pm 0.05 \pm 0.03\ keV$$

The observed state is χ'_{c2}

Summary

- B-factories are a unique source of new particles.
- Many new states were discovered (many unexpected).



- New data promises more intresting results.

state	production	decay mode	quantum numbers	reference
broad D^{**}	$B \to D^{**}\pi$	$D^{**} \to D^{(*)}\pi(\pi)$	$0^+/1^+$	PRD69,112002 hep-ex/0412072
D_{sJ}	continuum, $B \to D_{sJ}K,\ D_{sJ}\bar{D}$	$D_s\pi^0,\ D_s^*\pi^0,$ $D_s\gamma$	$0^+/1^+$	BELLE-CONF-0461 hep-ex/0507064
$\eta_c(2S)$	continuum	M_{recoil}	–	PRD(R) 70,071102
X(3872)	$B \to KX$	$\pi^+\pi^- J/\psi$ $\pi^+\pi^-\pi^0(\omega)J/\psi$ $\gamma J/\psi$	1^{++}?	PRL91,262001(2003) hep-ex/0505038 hep-ex/0505037
χ_{c2}	$\gamma\gamma$	$D\bar{D}$	2^{++}	hep-ex/0512035
$X(3940)$	continuum	$M_{recoil},\ D\bar{D}$	–	hep-ex/0507019
$Y(3940)$	$B \to KY$	$\omega J/\psi$	–	PRL94,182002(2005)