$B \to$ charmonium and open charm

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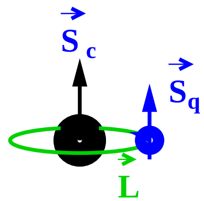
Outline

- $B \to D^{**0}\pi^+$
- $B \to D^*_{sJ}D$
- $B \to D^{(*)}D^{(*)}K$
- $B \to \psi(3770)K^+$
- J/ψ **inclusive spectrun and** J/ψ **baryon anti-baryon**

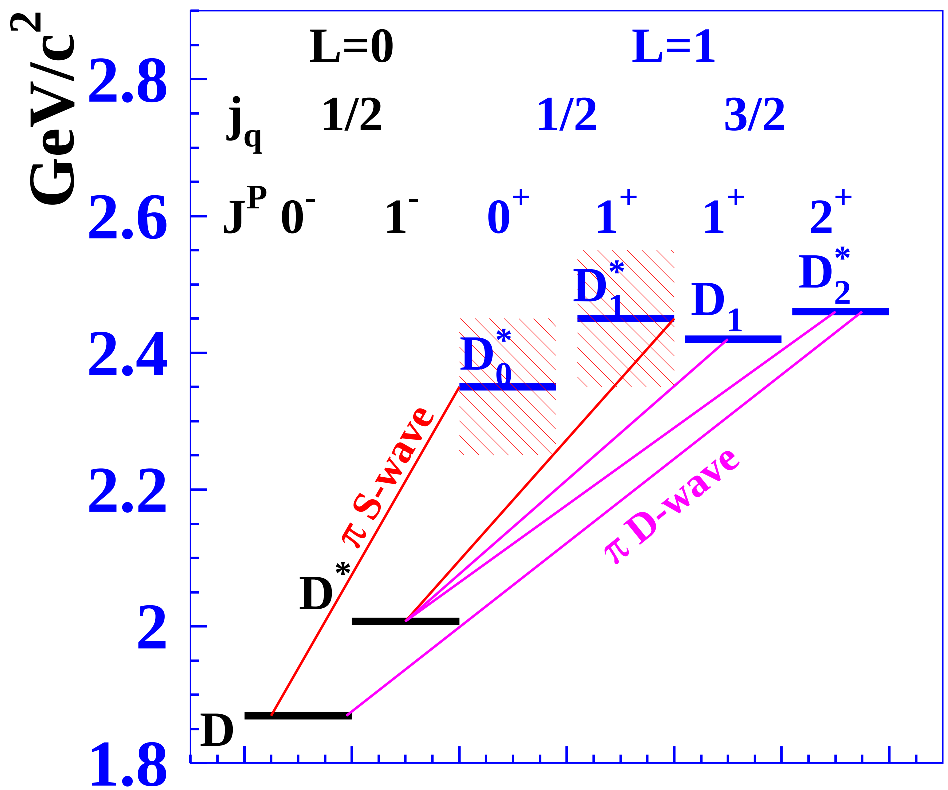
P-wave D^{**0} mesons $(c\bar{u})$ in B mesons



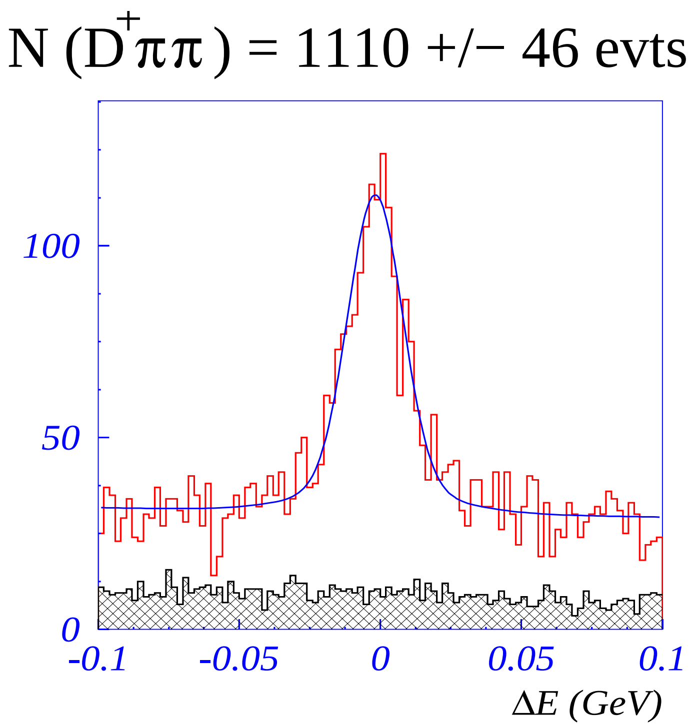
$\vec{j}_q = \vec{L} + \vec{S}_q$

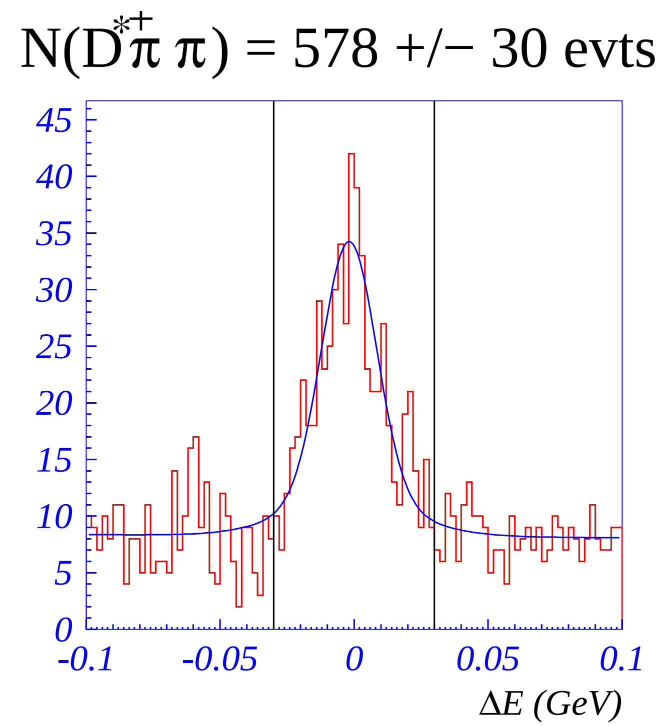
$\vec{J} = \vec{j}_q + \vec{S}_c$

spin-parity J^P
light quark angular momenta j_q



$B^- \to D^{(*)+}\pi^-\pi^-$ *(Belle with 60.4/fb)*





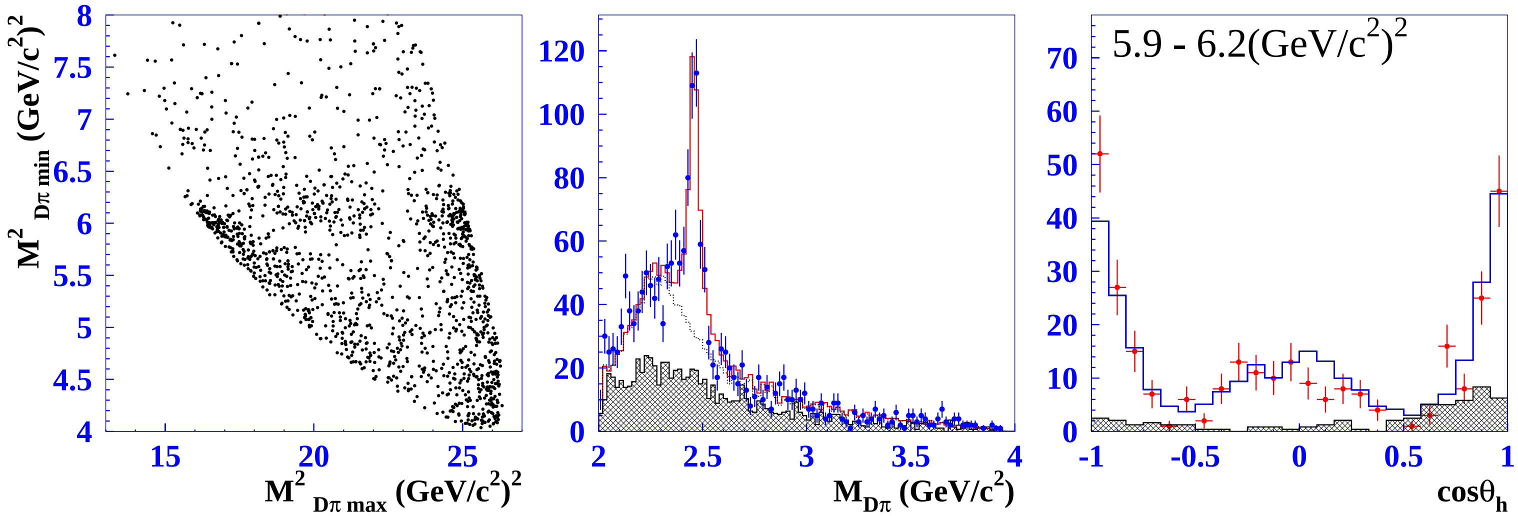
$$B(B^- \to D^+\pi^-\pi^-) = (1.02 \pm 0.04 \pm 0.15) \times 10^{-3}$$

$$< 1.4 \times 10^{-3}(\mathrm{CLEO, Phys.Rev.D50, 43})$$

$$B(B^- \to D^{*+}\pi^-\pi^-) = (1.25 \pm 0.08 \pm 0.22) \times 10^{-3}$$

$$(1.9 \pm 0.7) \times 10^{-3}(\mathrm{CLEO, Phys.Rev.D50, 43})$$

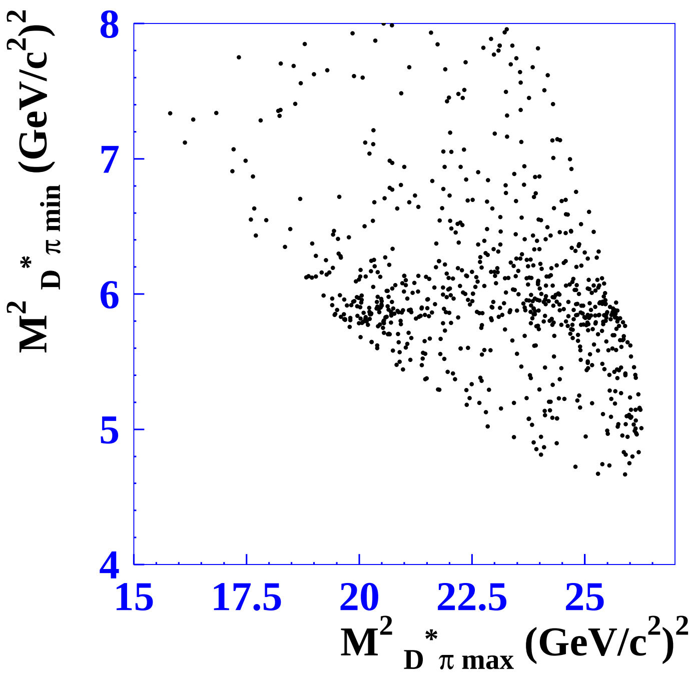
$D^+\pi^-\pi^-$ *amplitude analysis (Belle)*

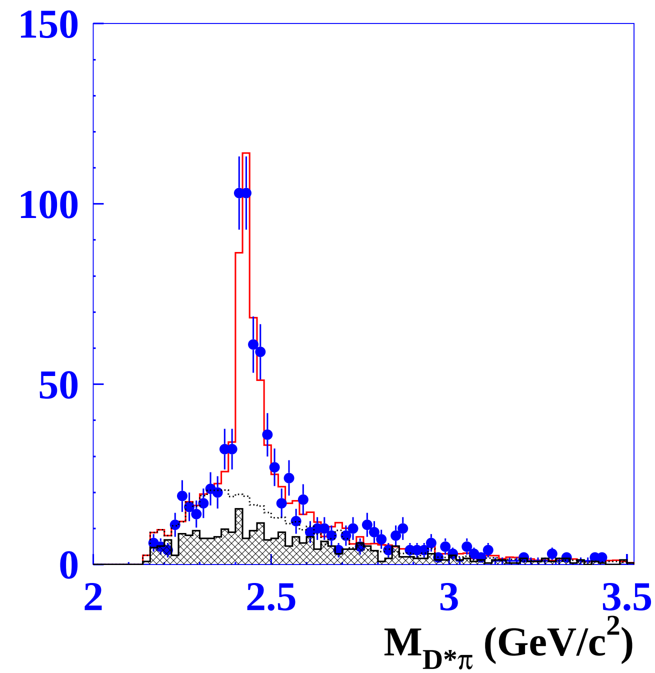


$$M_{D_2^{*0}} = (2461.6 \pm 2.1 \pm 0.5 \pm 3.3) MeV/c^2,$$
$$\Gamma_{D_2^{*0}} = (45.6 \pm 4.4 \pm 6.5 \pm 1.6) MeV/c^2$$
$$B(B^- \to D_2^{*0}\pi^-) \times (D_2^{*0} \to D^+\pi^-) = (3.4 \pm 0.3 \pm 0.6 \pm 0.4) \times 10^{-4}$$

$$M_{D_0^{*0}} = (2308 \pm 17 \pm 15 \pm 20) MeV/c^2,$$
$$\Gamma_{D_0^{*0}} = (276 \pm 21 \pm 18 \pm 60) MeV/c^2$$
$$B(B^- \to D_0^{*0}\pi^-) \times (D_0^{*0} \to D^+\pi^-) = (6.1 \pm 0.6 \pm 0.9 \pm 1.6) \times 10^{-4}$$

$D^{*+}\pi^-\pi^-$ *amplitude analysis (Belle)*





$M_{D_1^0} = (2421.4 \pm 2.0 \pm 0.4 \pm 0.8) MeV/c^2$, $\Gamma_{D_1^0} = (23.7 \pm 2.7 \pm 0.2 \pm 4.0) MeV/c^2$

$B(B^- \to D_1^0\pi^-) \times (D_1^0 \to D^{*+}\pi^-) = (6.8 \pm 0.7 \pm 1.3 \pm 0.3) \times 10^{-4}$

$B(B^- \to D_2^{*0}\pi^-) \times (D_2^{*0} \to D^{*+}\pi^-) = (1.8 \pm 0.3 \pm 0.3 \pm 0.2) \times 10^{-4}$

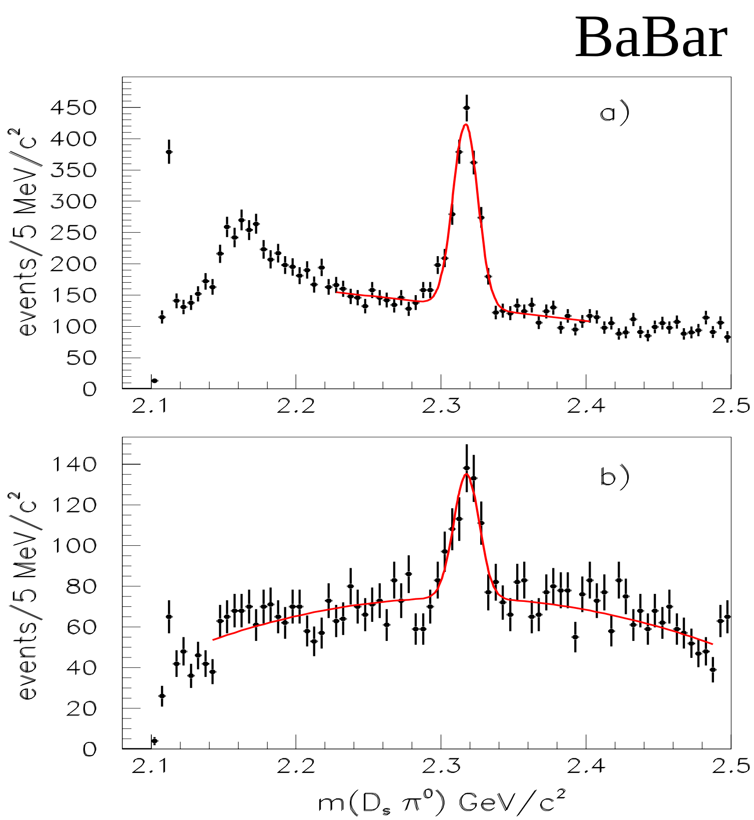
$\Rightarrow R = \frac{B(B^- \to D_2^{*0}\pi^-)}{B(B^- \to D_1^0\pi^-)} = 0.77 \pm 0.15$ (Neubert ≈ 0.35, CLEO : 1.8 ± 0.8)

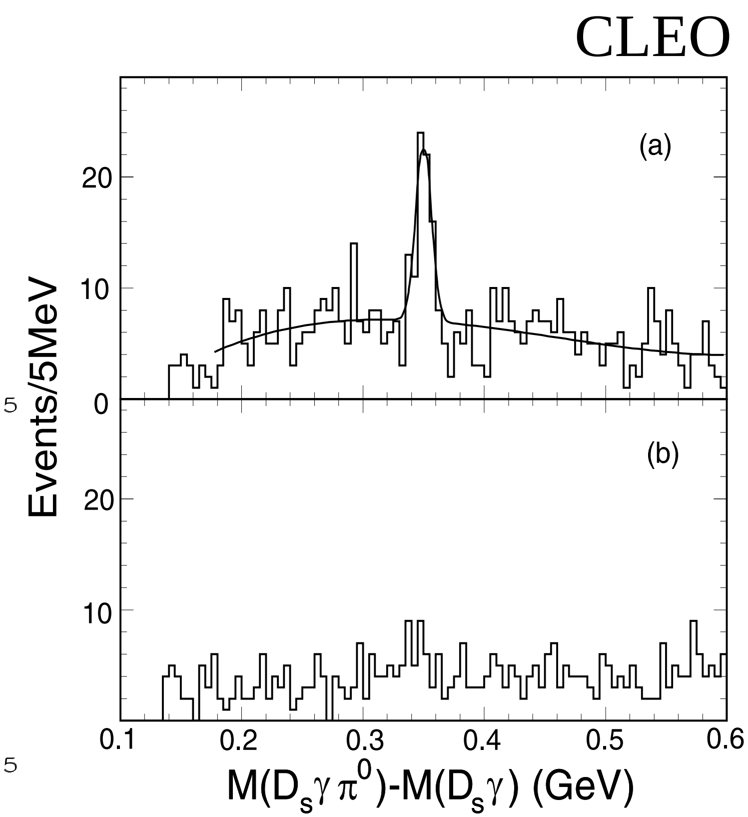
$M_{D_1^{*0}} = (2427 \pm 26 \pm 20 \pm 15) MeV/c^2$, $\Gamma_{D_1^{*0}} = (384^{+107}_{-75} \pm 24 \pm 70) MeV/c^2$

$B(B^- \to D_1^{*0}\pi^-) \times (D_1^{*0} \to D^{*+}\pi^-) = (5.0 \pm 0.4 \pm 1.0 \pm 0.4) \times 10^{-4}$

recent D^{*}_{sJ} *observation*

- ✦ BaBar (hep-ex/0304021) reported observation of a new resonance at 2317 MeV in $D_s^+\pi^0$ final state
- ✦ CLEO (hep-ex/0305017) observed resonance at 2459 MeV in $D_s^{*+}\pi^0$ final state





Mass of the $c\bar{q}$ systems

Strange property of these states is their surprisingly low mass compared to the potential model expectations :

$c\bar{s}$	$D^*_{sJ}(2317)$	$D^*_{sJ}(2463)$
M (MeV/c^2)	2317 ± 2	2463 ± 2

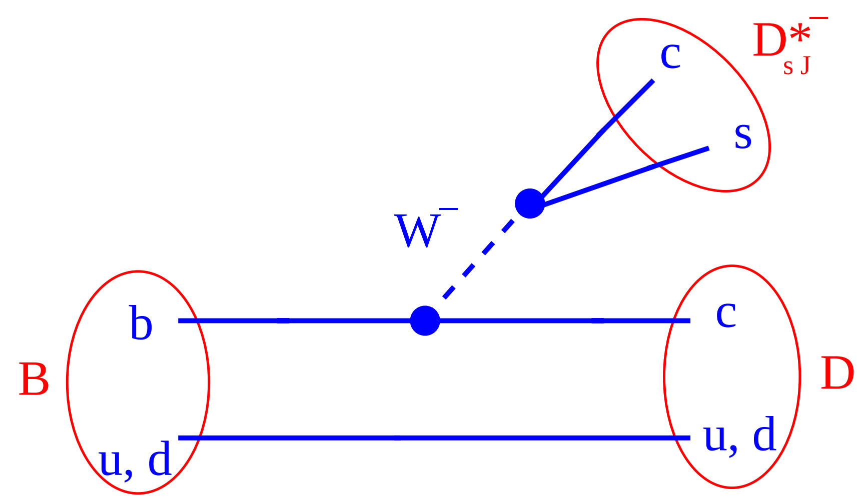
Their masses are practically equal to those of similar states in the $c\bar{u}$ system :

$c\bar{u}$	D_0^{*0}	D_1^{*0}
M (MeV/c^2)	2308 ± 30	2427 ± 36

D^*_{sJ} *in exclusive decays of* B *mesons*

To clarify the nature of discovered states, necessary to determine their quantum numbers and the branching fractions of their decays

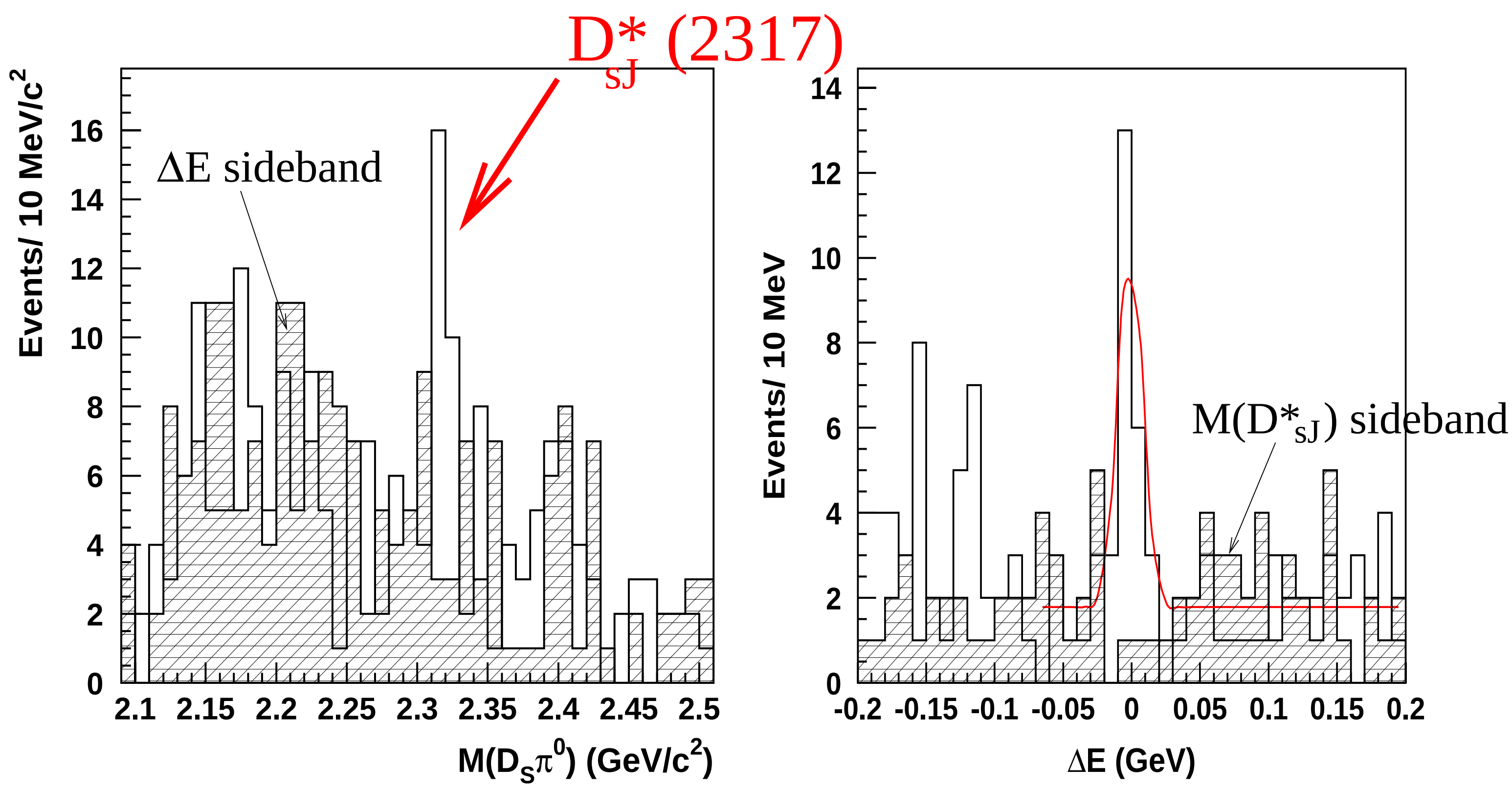
Dominant exclusive process for the D^*_{sJ} production in B decays is $B \to D D^*_{sJ}$:



The kinematics is completly determined by the quantum numbers of the B meson and final D mesons $\to$ the angular analysis of these decays will unambiguously determine the quantum numbers of D^*_{sJ} mesons.

$DD_s\pi^0$ *decay mode (Belle, preliminary, 90/fb)*

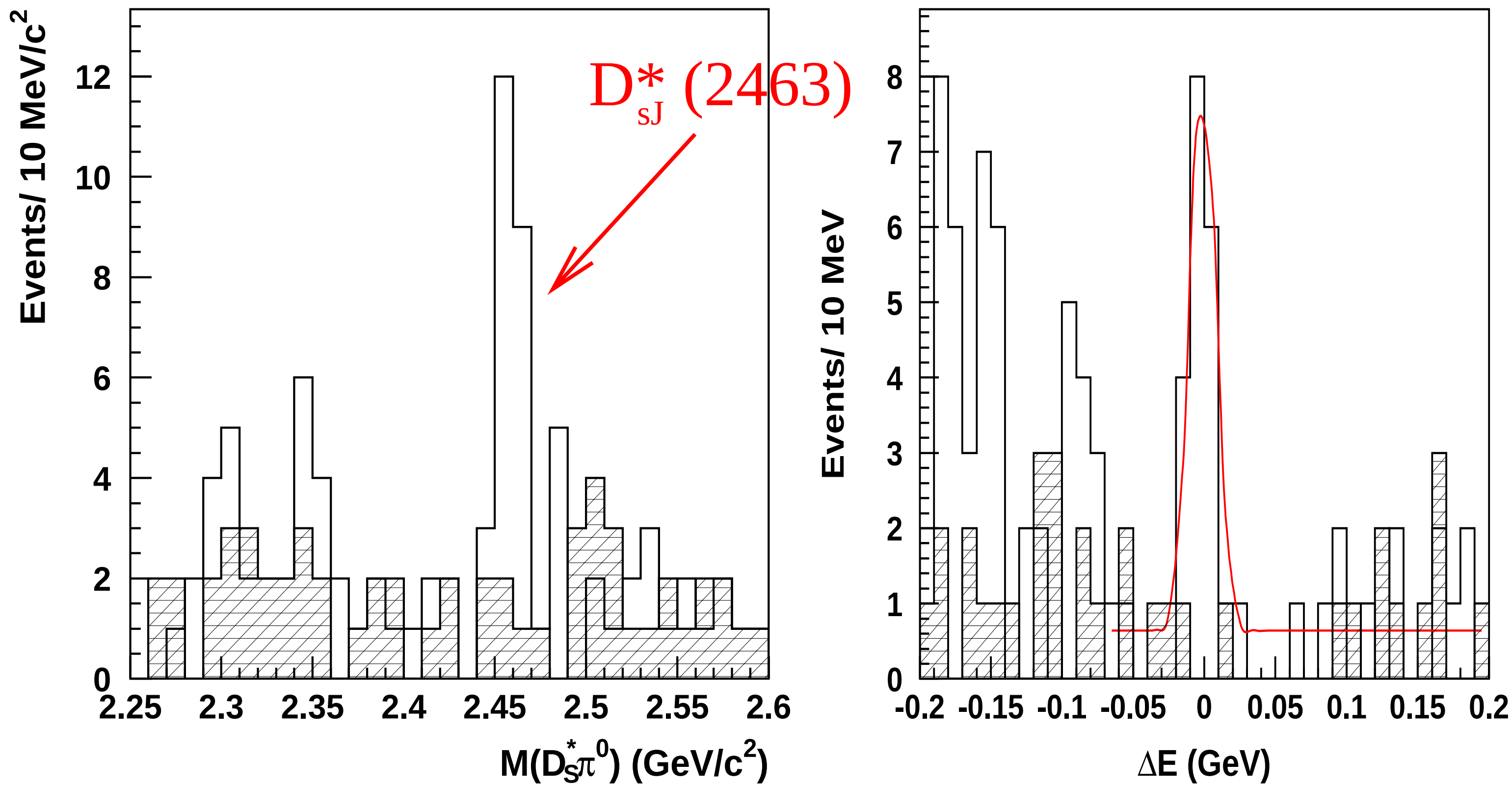
(D is reconstructed as D^0 or D^+)



$$M = 2318 \pm 4 MeV/c^2$$

$$N = (18.8^{+5.4}_{-4.8}) \text{ events } (5.3\ \sigma)$$

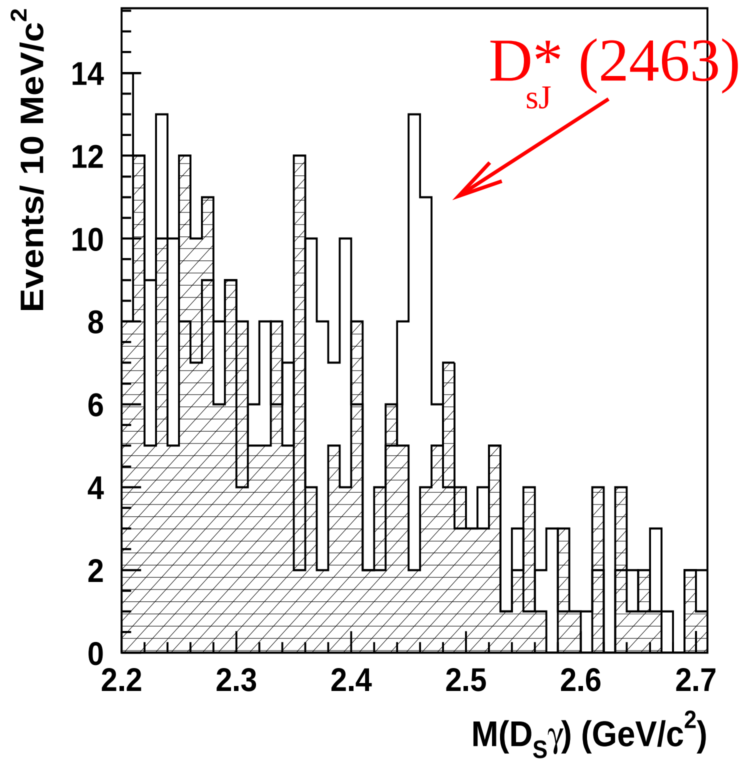
$DD_s^*\pi^0$ *decay mode (Belle, preliminary)*

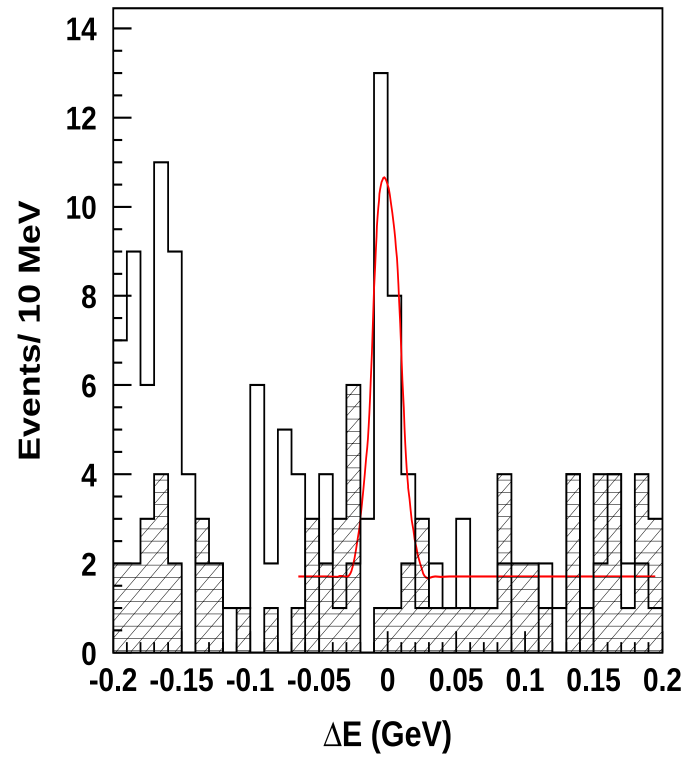


$M = 2460 \pm 3 MeV/c^2$

$N = 16.7^{+4.8}_{-4.1}$ events $(6.0\ \sigma)$

$DD_s\gamma$ *decay mode (Belle, preliminary)*





$M = 2460 \pm 2\ MeV/c^2$

$N = 21.8^{+5.8}_{-5.1}$ events $(5.9\ \sigma)$

$D_{sJ}(2460)$ decays in $D_s\gamma \Rightarrow J^P$ is not 0^+

Summary of $B \to DD_{sJ}^*$ *(Belle, preliminary)*

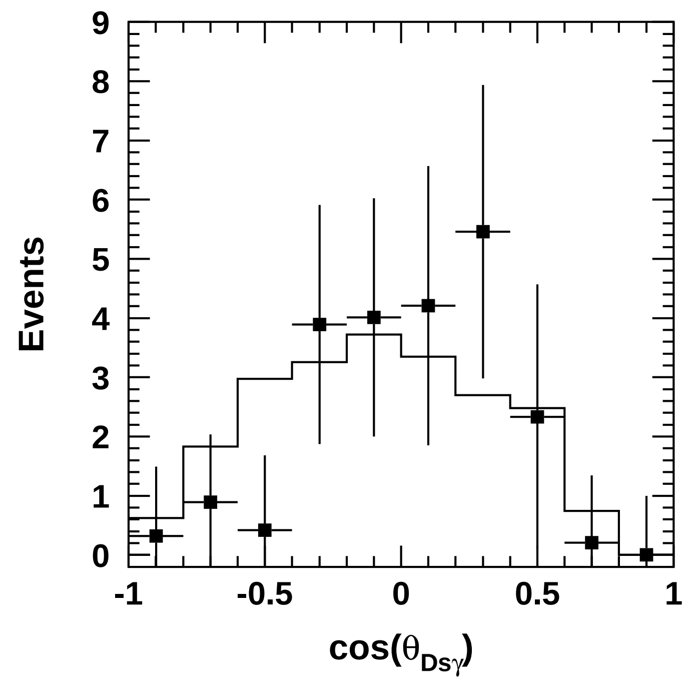
B decay channel	Yield (ΔE)	$B(10^{-4})$
$DD_{sJ}^*(2320)$, $D_{sJ}^*(2320) \to D_s\pi^0$	$18.8^{+5.4}_{-4.8}$	$9.9^{+2.8}_{-2.5} \pm 3.0$
$DD_{sJ}^*(2320)$, $D_{sJ}^*(2320) \to D_s^*\gamma$	< 12.7	< 8.7
$DD_{sJ}^*(2460)$, $D_{sJ}^*(2460) \to D_s^*\pi^0$	$16.7^{+4.8}_{-4.1}$	$25.8^{+7.0}_{-6.0} \pm 7.7$
$DD_{sJ}^*(2460)$, $D_{sJ}^*(2460) \to D_s\gamma$	$21.8^{+5.8}_{-5.1}$	$5.3^{+1.4}_{-1.3} \pm 1.6$
$DD_{sJ}^*(2460)$, $D_{sJ}^*(2460) \to D_s^*\gamma$	< 10.6	< 6.1
$DD_{sJ}^*(2460)$, $D_{sJ}^*(2460) \to D_s\pi^0$	< 3.5	< 1.4
$DD_{sJ}^*(2460)$, $D_{sJ}^*(2460) \to D_s\pi^+\pi^-$	< 3.5	< 1.1

$$\frac{B(D_{sJ}^*(2460)\to D_s\gamma)}{B(D_{sJ}^*(2460)\to D_s^*\pi^0)} = 0.21 \pm 0.07 \pm 0.03$$

$\to$ consistent with theoretical prediction (W.A.Bardeen, E.J.Eichten and C.T.Hill (hep-ph/0305049))

Helicity distribution for $D^*_{sJ} \to D_s\gamma$

Helicity angle $\theta_{D_s\gamma}$ defined as the angle between $D^*_{sJ}(2460)$ momentum in the B meson rest frame and the D_s momentum in the $D^*_{sJ}(2460)$ rest frame

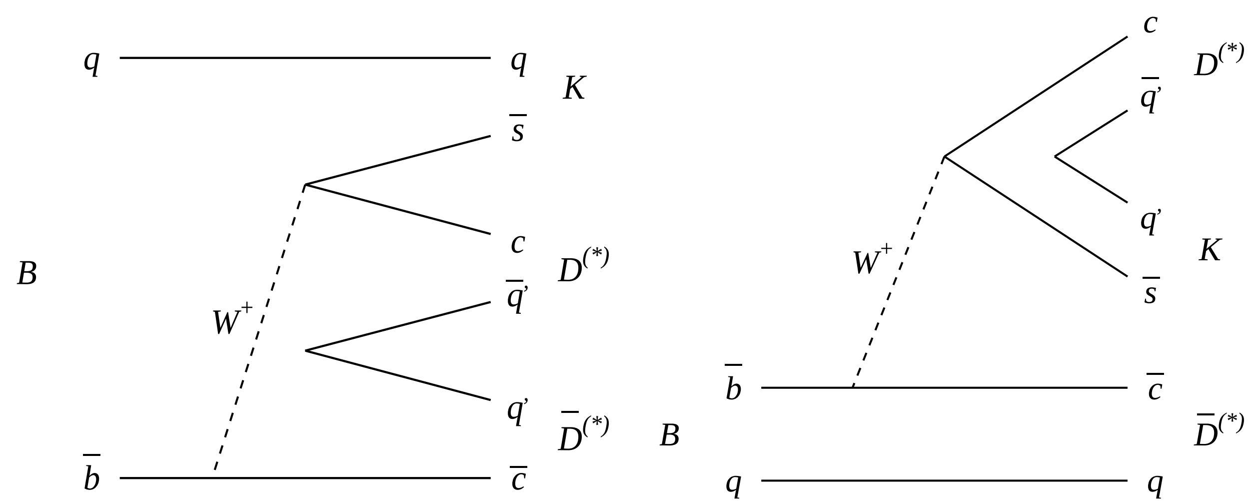


consistent with $\sin^2\theta \Rightarrow$ distribution expected if this state is 1^+

Belle observed $D_{sJ}(2317)$ and $D_{sJ}(2463)$ in B decays in agreement with the assumption that they are $P-$wave states with $j_q = 1/2$ (A. Le Yaouanc *et al.* hep-ph/0107047)

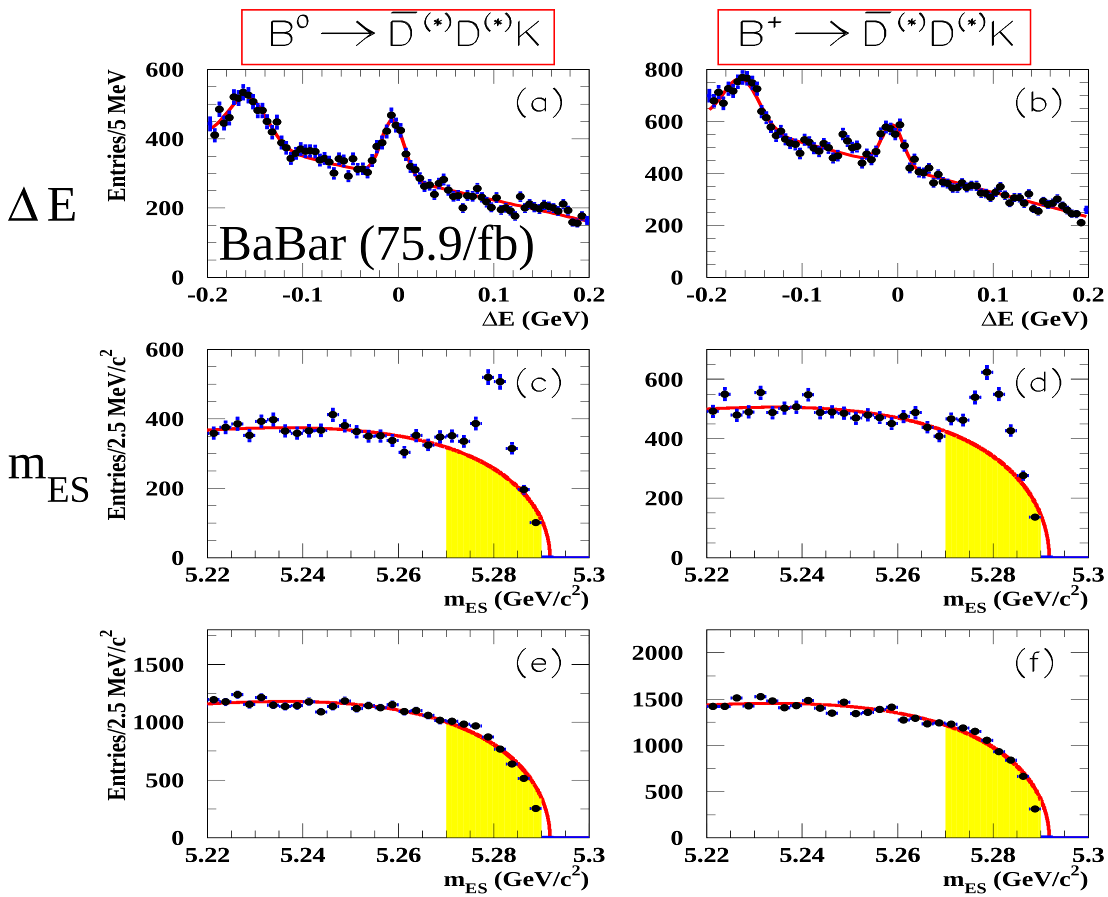
Charm multiplicity and $D^{(*)}D^{(*)}K$

Theory predicts that the number of charmed hadrons per B-decay, $n_c \sim 1.3$ when the observed semi-leptonic branching ratio (CLEO, ALEPH) is used as input but n_c is measured to be $n_c = 1.10 \pm 0.06$
$b \to c\bar{c}s$ transition was usually believed to hadronize predominantly in $\bar{B} \to X_c D_s^{(*)-}$ ($D^{(*)-}$ originating from the virtual W)



$\bar{B} \to \bar{D}^{(*)}D^{(*)}K$ (creation of quark pairs from vacuum) can contribute significantly to the $b \to c\bar{c}s$ branching ratio
observation of fully reconstructed $B \to \bar{D}^{(*)}D^{(*)}K$ decay (CLEO, ALEPH, BaBar, Belle)...

$D^{(*)}D^{(*)}K$ (BaBar, 75.9/fb)



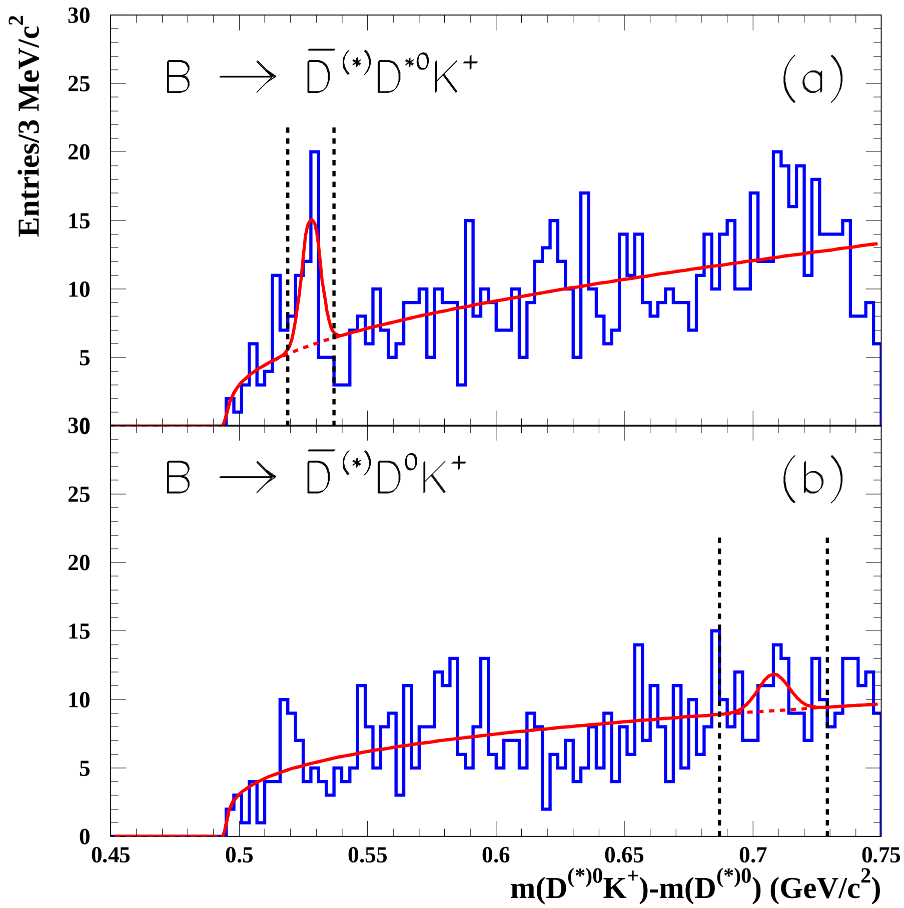
22 modes :
$970 \pm 65\ B^+$
$823 \pm 57\ B^0$
11 of 22 B modes
with $> 4\sigma$

$$B(B^0 \rightarrow \bar{D}^{(*)}D^{(*)}K) = (4.3 \pm 0.3(\text{stat}) \pm 0.6(\text{syst}))\%$$
$$B(B^+ \rightarrow \bar{D}^{(*)}D^{(*)}K) = (3.5 \pm 0.3(\text{stat}) \pm 0.5(\text{syst}))\%$$

Search for decays to orbitally excited D_s states (BaBar)

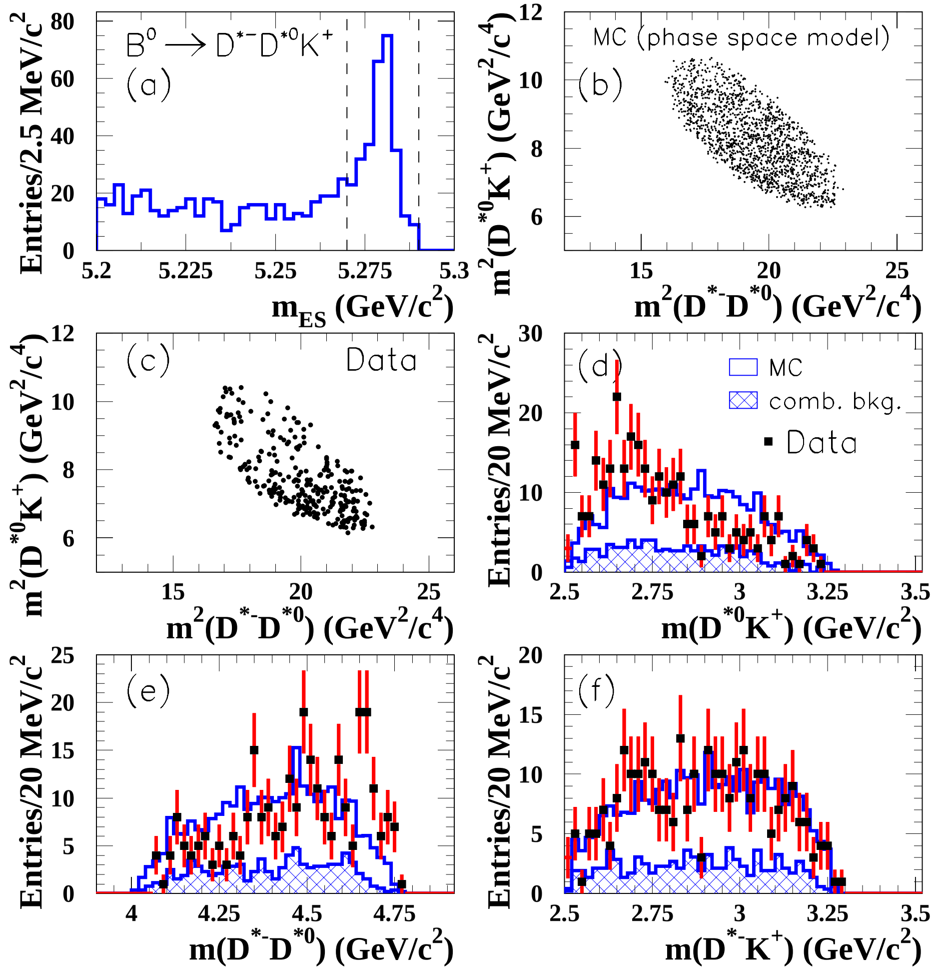
$\underline{D_{s1}^{+}(2536)}$
$J^P = 1^+$, $j_q = 3/2$
look in $B \to D^{(*)} D^{*0} K^-$

$\underline{D_{sJ}^{+}(2573)}$
$J^P = 2^+$, $j_q = 3/2$
look in $B \to D^{(*)} D^{0} K^-$



No $j_q = 3/2$ states ($D_{s1}^{+}(2536)$ and $D_{sJ}^{+}(2573)$) found in $D\bar{D}K$

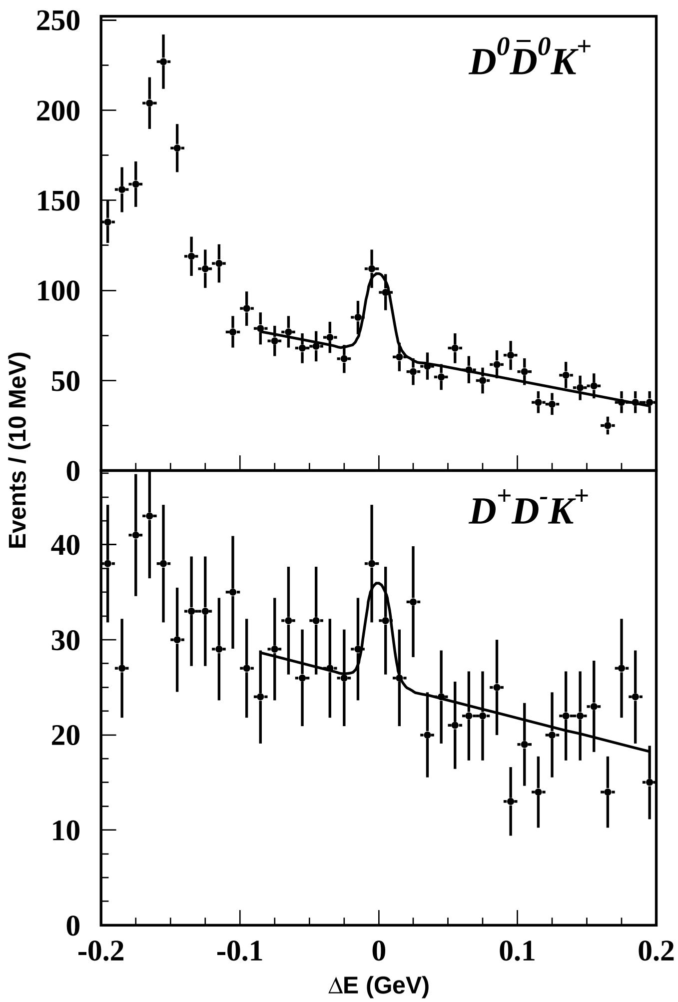
Dalitz-plot analysis of the decay $B^0 \to D^{*-} D^{*0} K^+$ *(BaBar)*



density of events larger in the data than in simulation for the lower region of the Dalitz plot

presence of a broad resonance decaying to $D^{*0} K^+$?

Measurement of $B^+ \to D^0\bar{D}^0K^+$ *(Belle, 88/fb)*



$N(D^0\bar{D}^0K^+) = 97.5 \pm 17.6$ events

Significance $= 5.5\sigma$

$B(D^0\bar{D}^0K^+) = (1.17{\pm}0.21{\pm}0.25){\times}10^{-3}$

$(1.9 \pm 0.3 \pm 0.3) \times 10^{-3}$(BaBar)

$N(D^+D^-K^+) = 20.7 \pm 9.9$ events

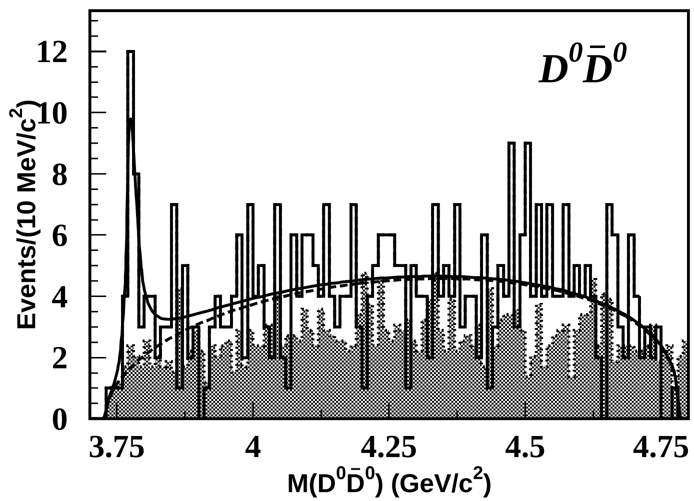
Significance $= 2.7\sigma$

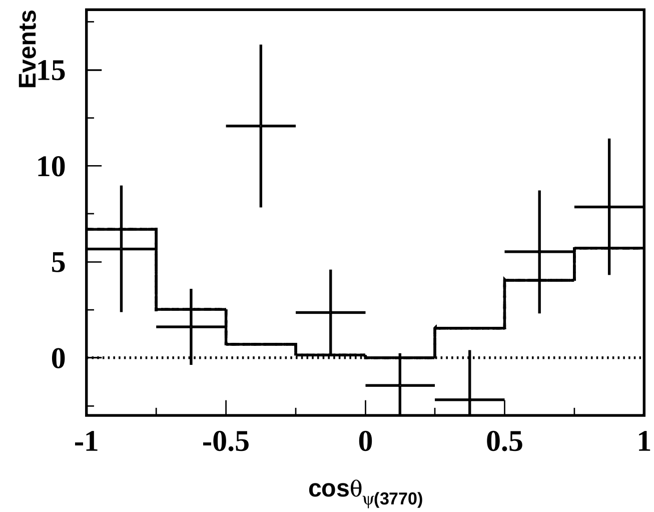
$B(D^+D^-K^+) < 0.79{\times}{\times}10^{-3}$ @ 90 % CL

$< 0.4 \times 10^{-3}$@90%CL(BaBar)

$M_{D\bar{D}}$ *in* $B^+ \to D^0\bar{D}^0K^+$ *(Belle)*

Look at $M_{D\bar{D}}$ where the signal is described by relativistic Breit Wigner with free mass and a fixed width ($\Gamma = 23.6 MeV$)





$M = (3778.4 \pm 3.0 \pm 0.8)\ MeV/c^2$ $N(\psi(3770) \to D^0\bar{D}^0) = 33.6 \pm 8.3$evts

Significance $= 5.9\sigma$

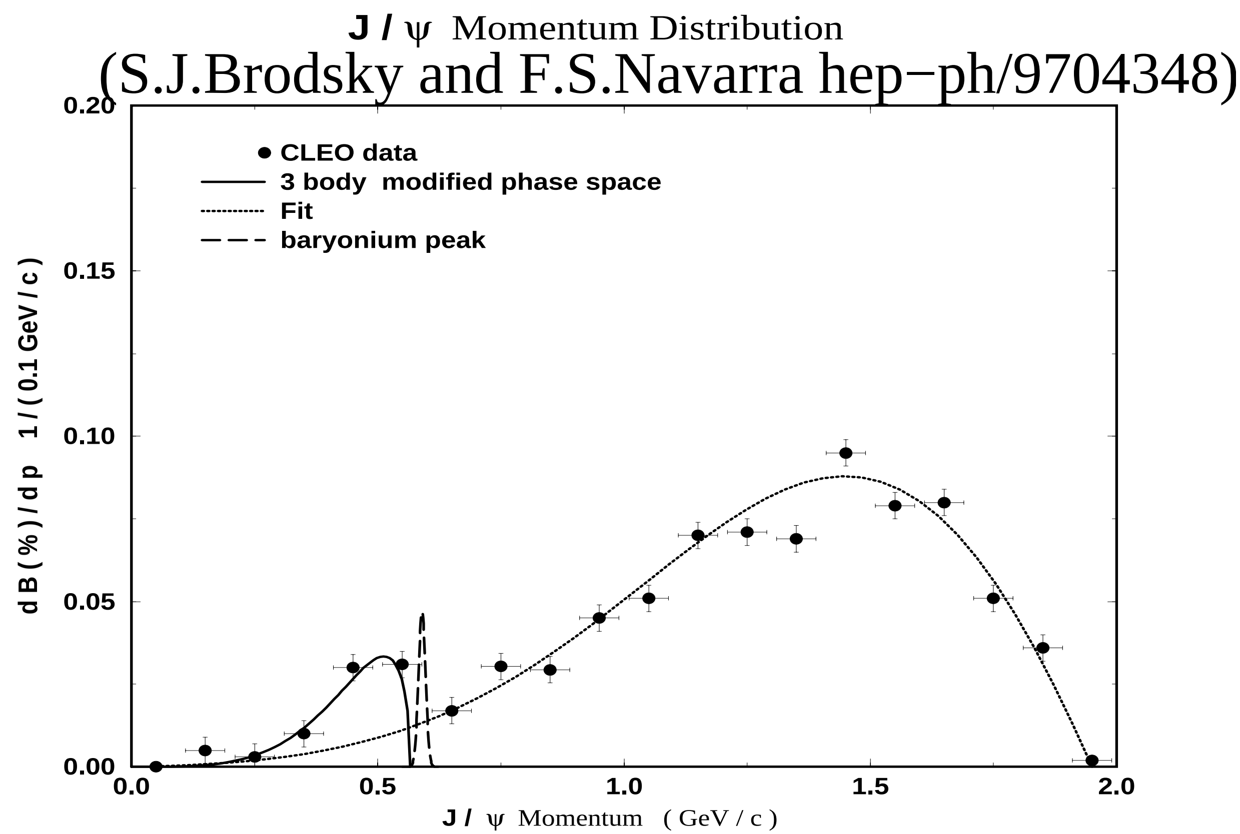
$B(B^+ \to \psi(3770)K^+) \times B(\psi(3770) \to D^0\bar{D}^0) = (0.34 \pm 0.08 \pm 0.8) \times 10^{-3}$

$\Rightarrow \sim B(B^+ \to \psi(2S)K^+)$ $(= 6.6 \pm 0.6 \times 10^{-4})$

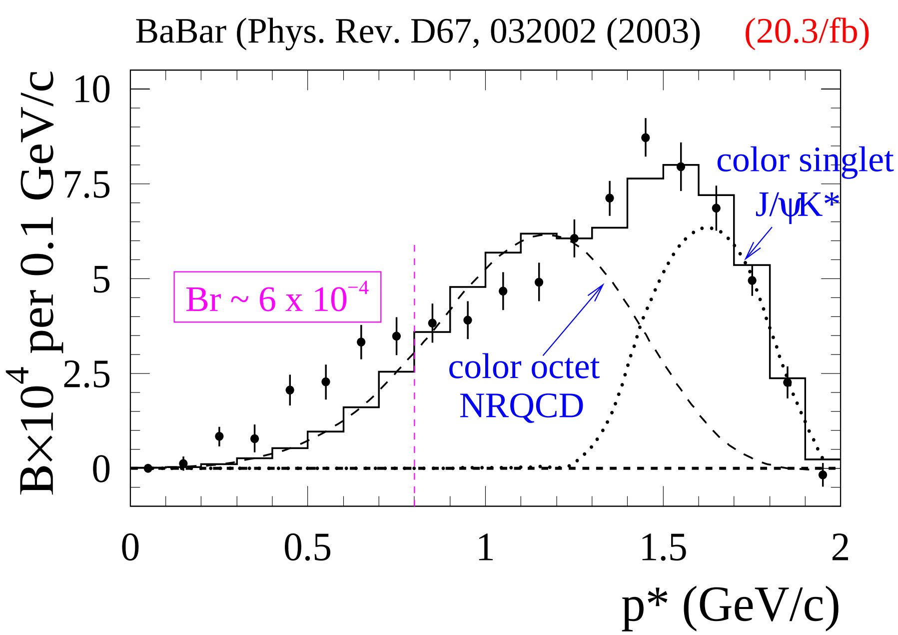
- $\psi(3770)$ has an $S-$wave component from mixing with the $\psi(2S)$
- color-octet explanation (F.Yuan *et al.*, Phys Rev D53 (1997))

$B \to J/\psi$ *inclusive* p^* *spectrum*

Excess of J/ψ mesons observed (CLEO(95)) at low momentum in the e^+e^- center-of-mass frame, p_{CM}, compared to the non-relativistic QCD prediction :



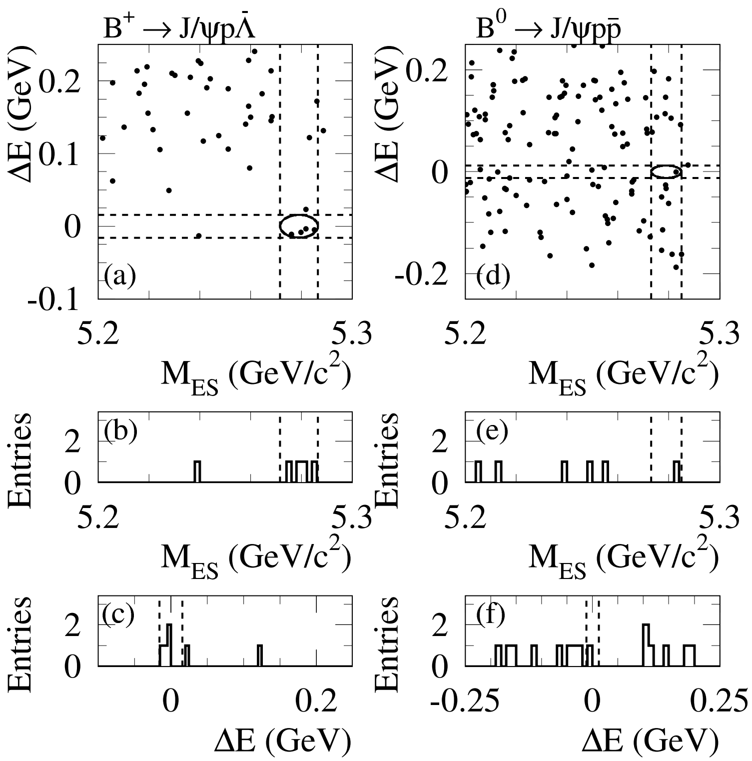
Possibles sources of the excess



- ✦ intrinsic charm component of B
- ✦ production of $s\bar{d}g$ hybrid in conjunction with a J/ψ
- ✦ rate enhanced due to B decay to J/ψ baryon antibaryon (possibly enhanced by the intermediate production of an exotic state allowed by QCD but not yet observed)

Each of the possible QCD exotic resonances (nuclear-bound quarkonium, baryonium, pentaquark) provides a possible narrow intermediate states

Evidence for $B^+ \to J/\psi p\bar{\Lambda}$ *(BaBar, 81.9/fb)*

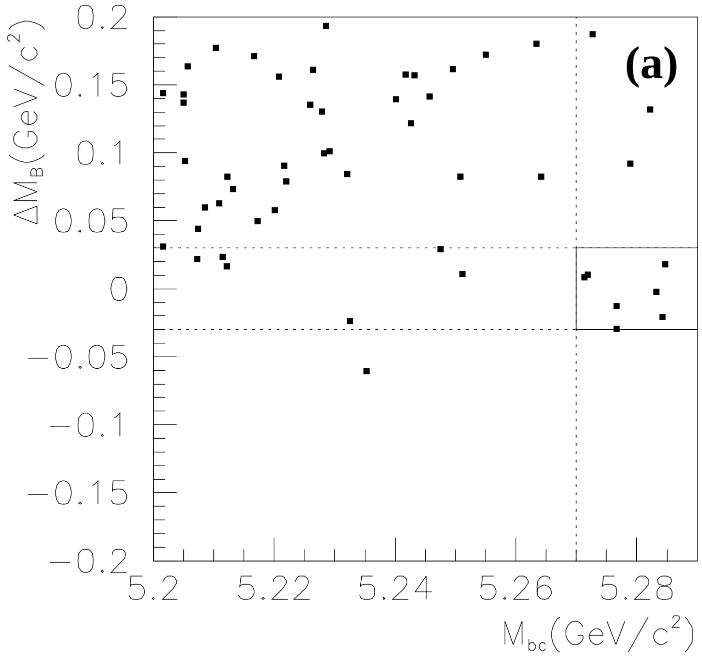


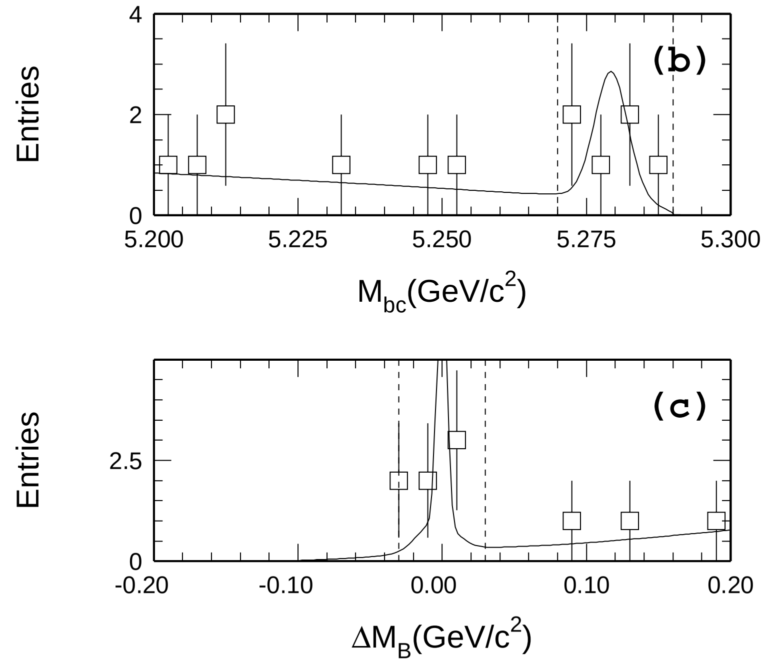
- 4 events in signal region
  bckg $= 0.21 \pm 0.14$ evts.
  Prob(> 4)$= 2.5 \times 10^{-4}$ ($3.5\ \sigma$)
  $B(B^+ \to J/\psi p\bar{\Lambda}) = (12^{+9}_{-6}) \times 10^{-6}$
  (B ($B^+ \to J/\psi p\bar{\Lambda}$) $< 26 \times 10^{-6}$)

- one event in signal region
  bckg $= 0.64 \pm 0.17$ events.
  B ($B^+ \to J/\psi p\bar{p}$) $< 1.9 \times 10^{-6}$

$B^+ \to J/\psi p\bar{\Lambda}$ (*Belle, 78/fb*)

M_{bc} : signal $= 3.7 \pm 2.3$, background $= 0.96 \pm 0.37$ (2.3σ)
ΔM_B : signal 4.7 ± 2.7, background $= 0.59^{+0.38}_{-0.27}$, $(2.7\ \sigma)$ (check)
$\mathrm{B}\ (B^+ \to J/\psi p\bar{\Lambda}) < 30 \times 10^{-6}$





⇒ Neither final state makes a significant contribution to the observed excess of J/ψ mesons in inclusive B decay

Conclusion

Summary :

- ✦ First observation of all $P-$wave D^{**} states, the resonance parameters are measured.
- ✦ $D^*_{sJ}(2320)$ and $D^*_{sJ}(2460)$ in B decays : results in agreement with the assumption that they are $P-$waves states with $j_q = 1/2$,
  new observation of $D^*_{sJ}(2460) \rightarrow D_s\gamma$
- ✦ $D^{(*)}\bar{D}^{(*)}K$ is an important contributor to n_c prediction
  - ● $D_{s1}(2536)$ and $D_{sJ}(2573)$ ($j_q = 3/2$) not seen in B decays
  - ● $\psi(3770)$ observed in $D^0\bar{D}^0K^-$
- ✦ J/ψ baryon antibaryon modes can't explain the excess at low p^* seen in J/ψ inclusive

backup slide on $\psi(3770)$

Mass comparison :

	Belle	MARK I	DELCO	MARK II
$M(\psi(3770)),\ MeV/c^2$	$3778.4 \pm 3.0 \pm 0.8$	3772 ± 2	3770 ± 6	3764 ± 5
ΔM	$92.4 \pm 3.0 \pm 0.8$	88 ± 3	86 ± 2	80 ± 2

Branching ratio :

- ✦ $B(B^+ \to \psi(3770)K^+) \times B(\psi(3770) \to D^0\bar{D}^0) = (0.34 \pm 0.08 \pm 0.08) \times 10^{-3}$
- ✦ $B(B^+ \to \psi(3770)K^+) \times B(\psi(3770) \to D^+D^-) = (0.14 \pm 0.08 \pm 0.03) \times 10^{-3}$

$\Rightarrow \frac{B(\psi(3770)\to D^0\bar{D}^0)}{B(\psi(3770)\to D^+D^-)} = 2.43 \pm 1.50 \pm 0.65$ (Mark III : $1.36 \pm 0.23 \pm 0.14$)

Assuming $B(\psi(3770) \to D^0\bar{D}^0) + B(\psi(3770) \to D^+D^-) = 100\%$,
we extract $B(B^+ \to \psi(3770)K^+) = (0.48 \pm 0.11 \pm 0.12) \times 10^{-3}$