Charm Physics at Belle

Beauty 2003, 15 Oct.
K.Trabelsi (Univ. of Hawaii)
for V.Eiges/Belle

Outline

- Double charmonium production : $e^+e^- \to J/\psi\, c\bar{c}$
- Charmed mesons D^{**} and D_{sJ}
- Rare decay $D^0 \to V\gamma$

Double charmonium production

Search for $e^+e^- \to J/\psi + (c\bar{c})$ production, where the additional $c\bar{c}$ pair fragments into either charmonium or charmed hadrons.

- PRL **89**, 142001 (2002) with 46.2/fb
- LP03-274 (BELLE-CONF-0331) with 101.8/fb

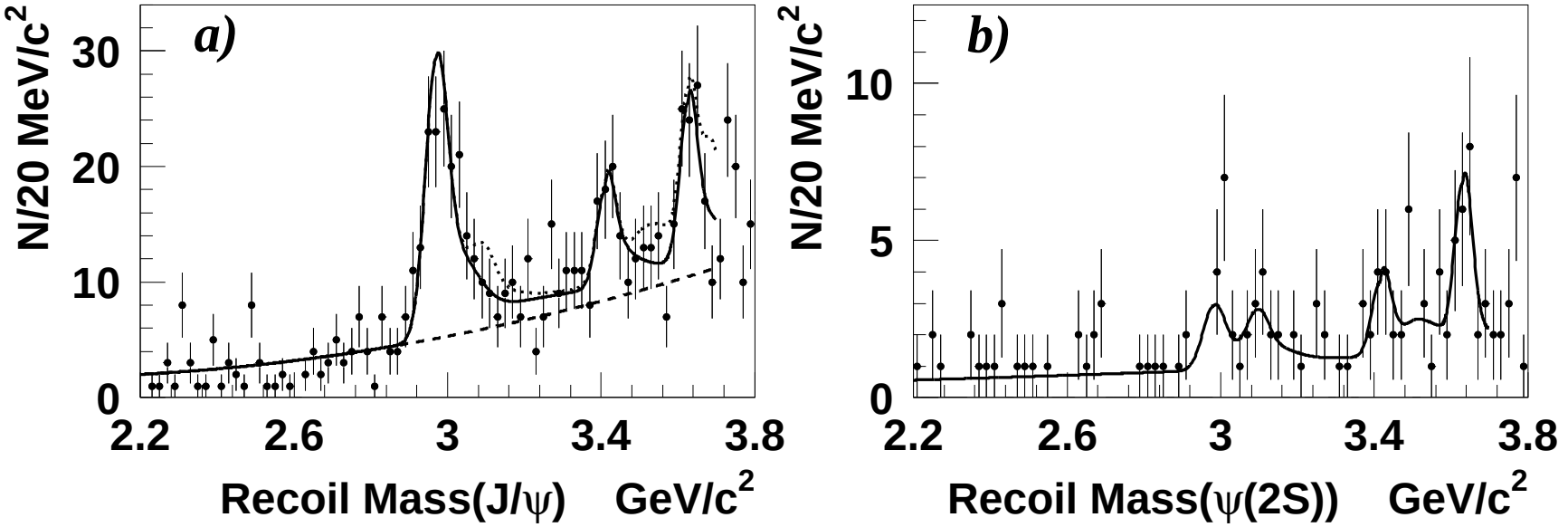
Study J/ψ recoil mass spectrum around $M_{recoil} \sim$ 3 GeV/c^2 :
$(M_{recoil} = ((E_{CMS} - E_{J/\psi})^2 - p^2_{J/\psi})^{1/2})$

- Constrain J/ψ into nominal mass to improve resolution
- Verify recoil mass scale using $e^+e^- \to \psi(2S)\gamma$, $(\psi(2S) \to J/\psi\pi^+\pi^-)$ for calibration : recoil mass bias $<$ 3 MeV/c^2
- fit includes all known charmonium :

$$\eta_c,\ J/\psi,\ \chi_{c0},\ \chi_{c1},\ \chi_{c2},\ \eta_c(2S),\ \psi(2S)$$

- Masses of η_c, χ_{c0}, $\eta_c(2S)$ free

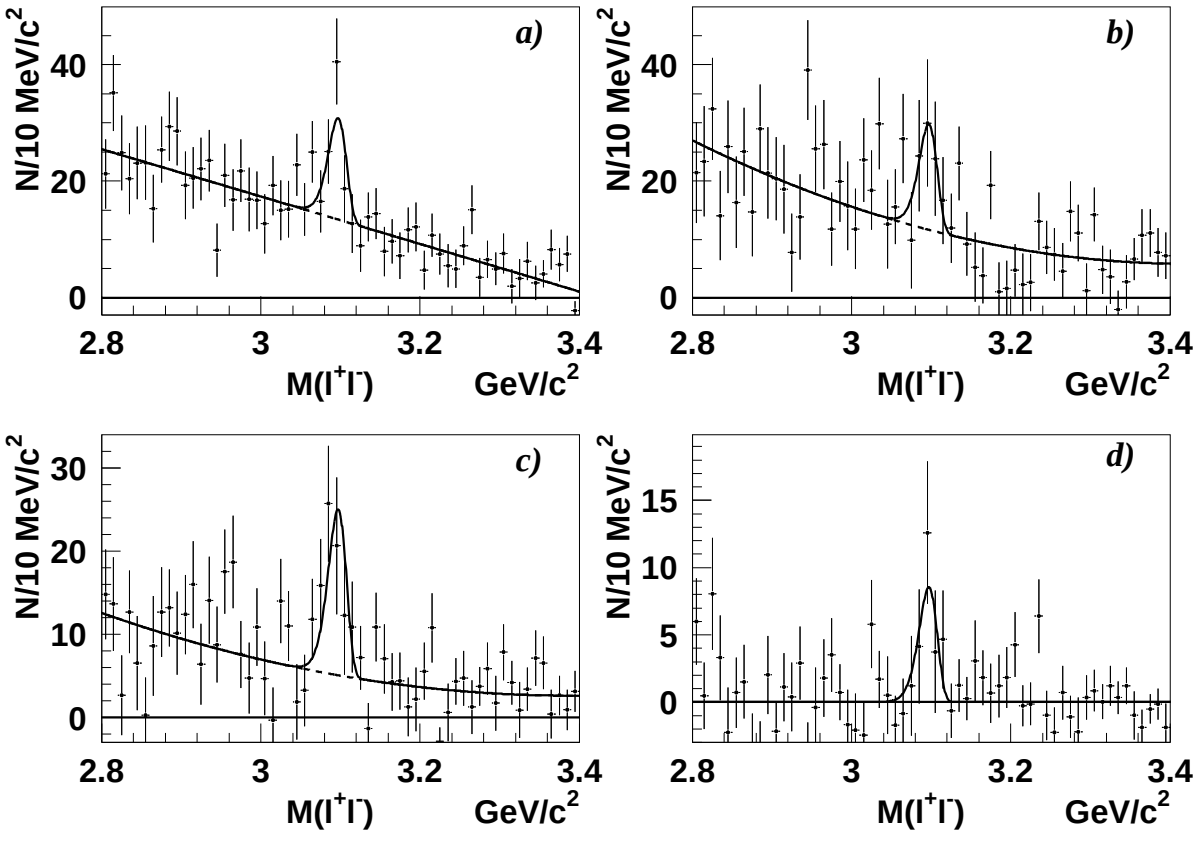
Double charmonium production



$(c\bar{c})_{res}$	N (evts)	M [GeV/c^2]	σ	N (evts)	σ
η_c	175 ± 23	2.972 ± 0.007	9.9	15 ± 7	2.6
J/ψ	-9 ± 17	fixed	–	12 ± 7	–
χ_{c0}	61 ± 21	3.409 ± 0.010	2.9	18 ± 9	2.4
$\chi_{c1} + \chi_{c2}$	-15 ± 19	fixed	–	7 ± 9	–
$\eta_c(2S)$	107 ± 24	3.630 ± 0.008	4.4	31 ± 10	3.7
$\psi(2S)$	-38 ± 21	fixed	–	-4 ± 7	–

$$\sigma(e^+e^- \to J/\psi J/\psi) \times \mathcal{B}(J/\psi \to > 2\text{charged}) < 0.008 \text{ pb @ } 90\% \, CL$$

Fit $D(\Lambda_c)$ signals in $M_{l^+l^-}$ bins



$D^0 \to K^-\pi^+$	$D^0 \to K^-\pi^+\pi^+\pi^-$	$D^+ \to K^-\pi^+\pi^+$	$D_s^+ \to K^-K^+\pi^+$	$\Lambda_c^+ \to K^-p\pi^+$
49.6 ± 13.3	53.0 ± 21.2	56.2 ± 15.4	23.8 ± 9.4	3.0 ± 4.2
$3.7\,\sigma$	$2.5\,\sigma$	$3.6\,\sigma$	$2.6\,\sigma$	

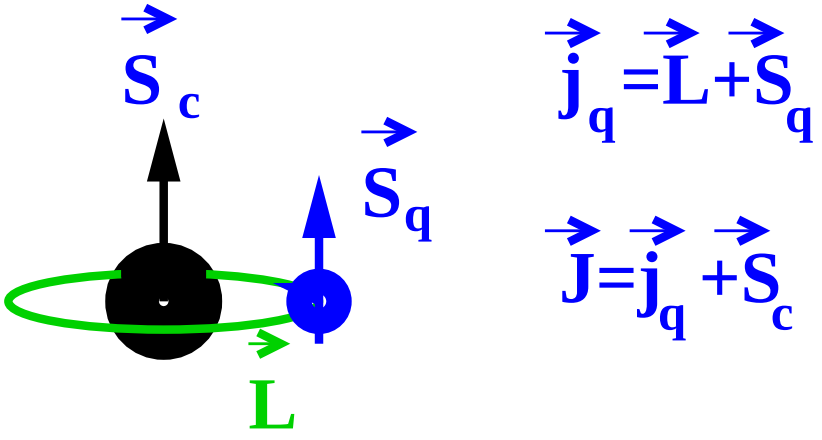
- All final charm hadrons are reconstructed (except for Ξ_c)
- Sum over $D^0, D^+, D_s^+, \Lambda_c^+$ and $(c\bar{c})_{res}$ yields to determine the fraction of the total prompt J/ψ production that is accompanied by another $c\bar{c}$ system :

$$\left.\frac{\sigma(e^+e^- \to J/\psi c\bar{c})}{\sigma(e^+e^- \to J/\psi X)}\right|_{P_{J/\psi}>2.0GeV/c} = \frac{0.5(N_{D^0} + N_{D^+} + N_{D_s^+} + N_{\Lambda_c^+}) + N_{(c\bar{c})_{res}}}{N_{J/\psi}}$$

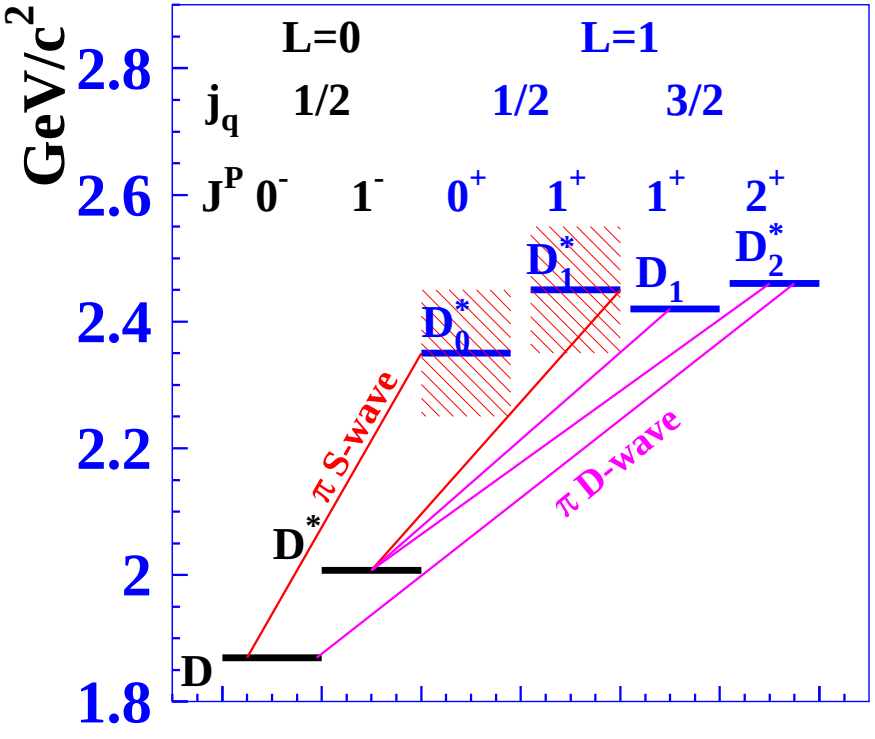
$$= 0.82 \pm 0.15 \pm 0.14$$

$\Rightarrow J/\psi c\bar{c}$ cross section is an order of magnitude larger than predictions and contradicts the NRQCD expectation that $J/\psi c\bar{c}$ is small (same for $J/\psi\eta_c$)

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

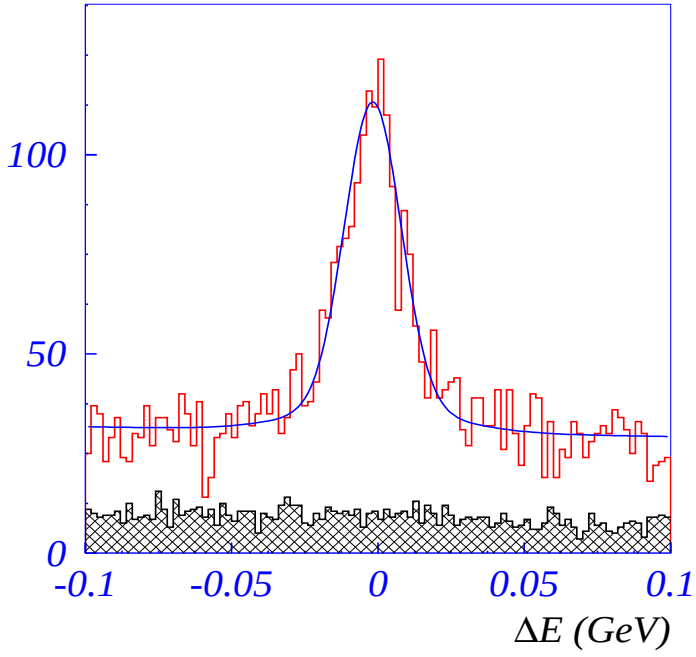


spin-parity J^P
light quark angular momenta j_q

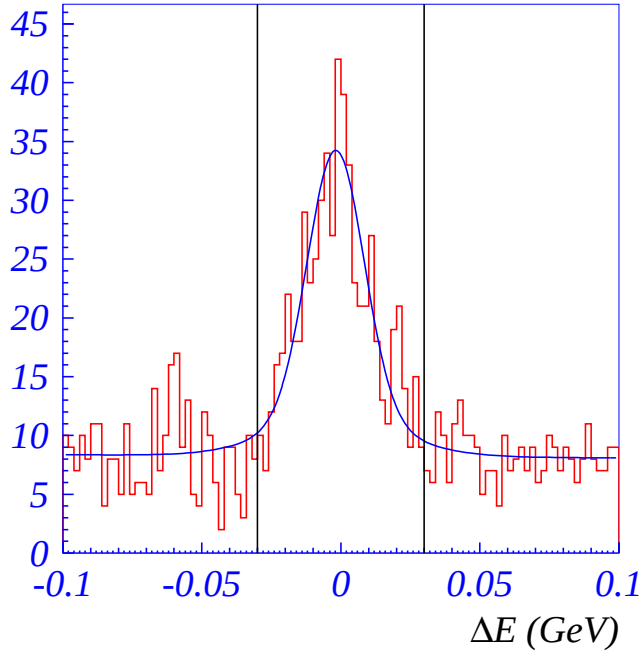


$\Rightarrow$ hep-ex/0307021 $\rightarrow$ PRD

N ($D^+\pi\pi$) = 1110 +/− 46 evts



N($D^{*+}\pi\pi$) = 578 +/− 30 evts



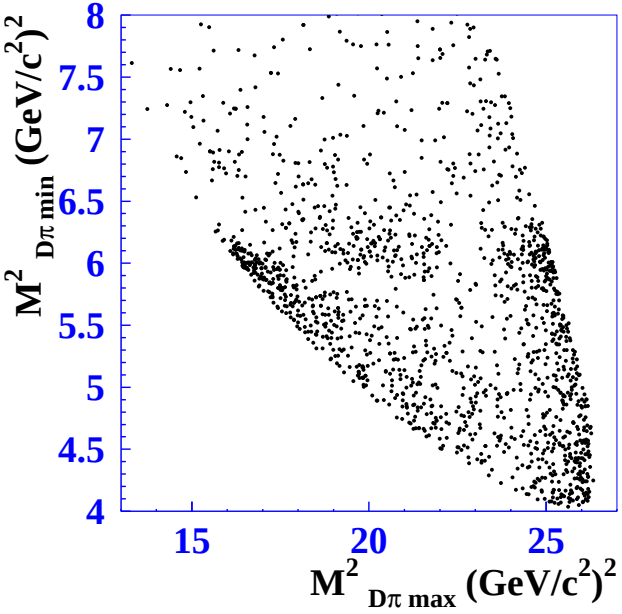
$$\mathcal{B}(B^- \to D^+\pi^-\pi^-) = (1.02 \pm 0.04 \pm 0.15) \times 10^{-3}$$

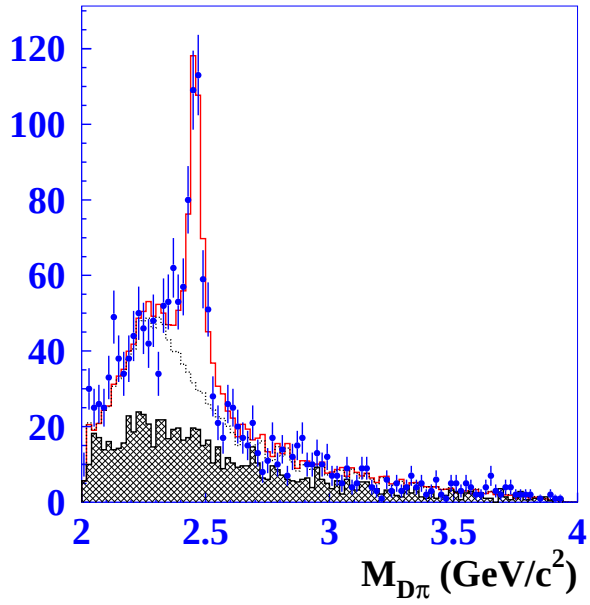
$$< 1.4 \times 10^{-3} \quad (\mathrm{CLEO, Phys.Rev.D50, 43})$$

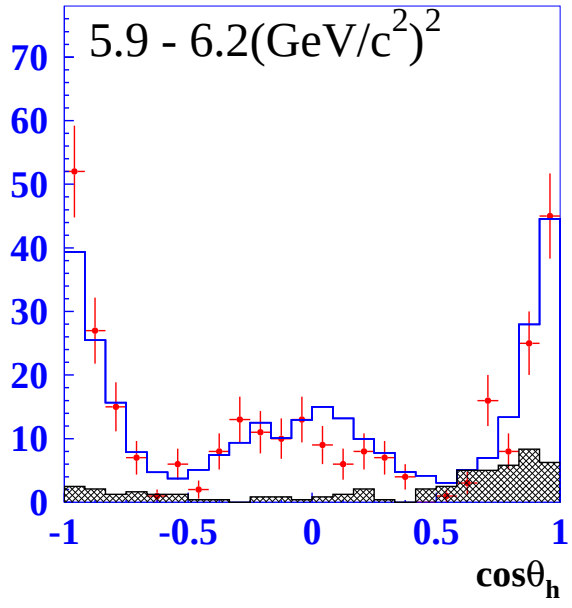
$$\mathcal{B}(B^- \to D^{*+}\pi^-\pi^-) = (1.25 \pm 0.08 \pm 0.22) \times 10^{-3}$$

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

$D^+\pi^-\pi^-$ amplitude analysis







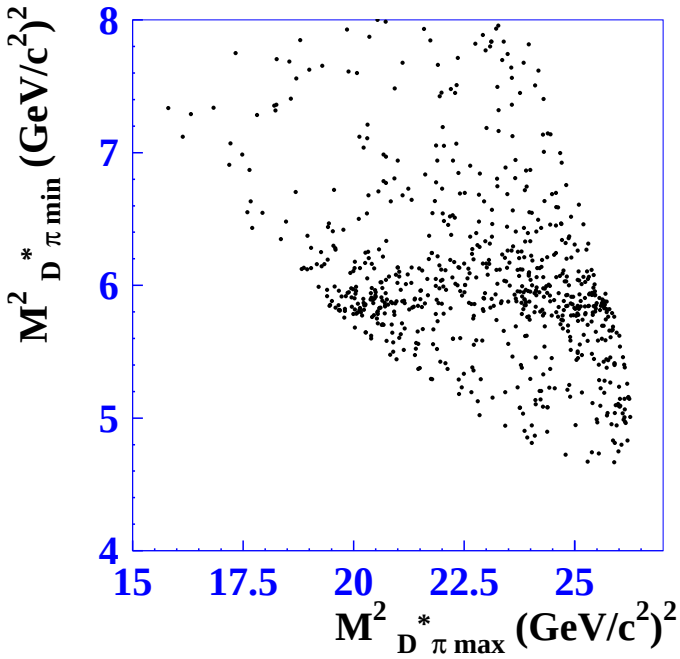
$M_{D_2^{*0}} = (2461.6 \pm 2.1 \pm 0.5 \pm 3.3)$ MeV/c^2, $\Gamma_{D_2^{*0}} = (45.6 \pm 4.4 \pm 6.5 \pm 1.6)$ MeV

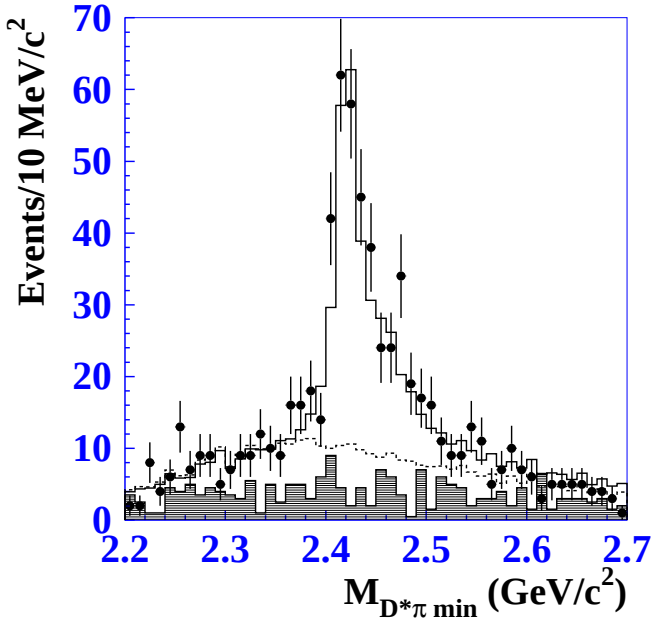
$\mathcal{B}(B^- \to D_2^{*0}\pi^-) \times \mathcal{B}(D_2^{*0} \to D^+\pi^-) = (3.4 \pm 0.3 \pm 0.6 \pm 0.4) \times 10^{-4}$

$M_{D_0^{*0}} = (2308 \pm 17 \pm 15 \pm 28)$ MeV/c^2, $\Gamma_{D_0^{*0}} = (276 \pm 21 \pm 18 \pm 60)$ MeV

$\mathcal{B}(B^- \to D_0^{*0}\pi^-) \times \mathcal{B}(D_0^{*0} \to D^+\pi^-) = (6.1 \pm 0.6 \pm 0.9 \pm 1.6) \times 10^{-4}$

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





$M_{D_1^0} = (2421.4 \pm 1.5 \pm 0.4 \pm 0.8)$ MeV/c^2, $\Gamma_{D_1^0} = (23.7 \pm 2.7 \pm 0.2 \pm 4.0)$ MeV

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

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

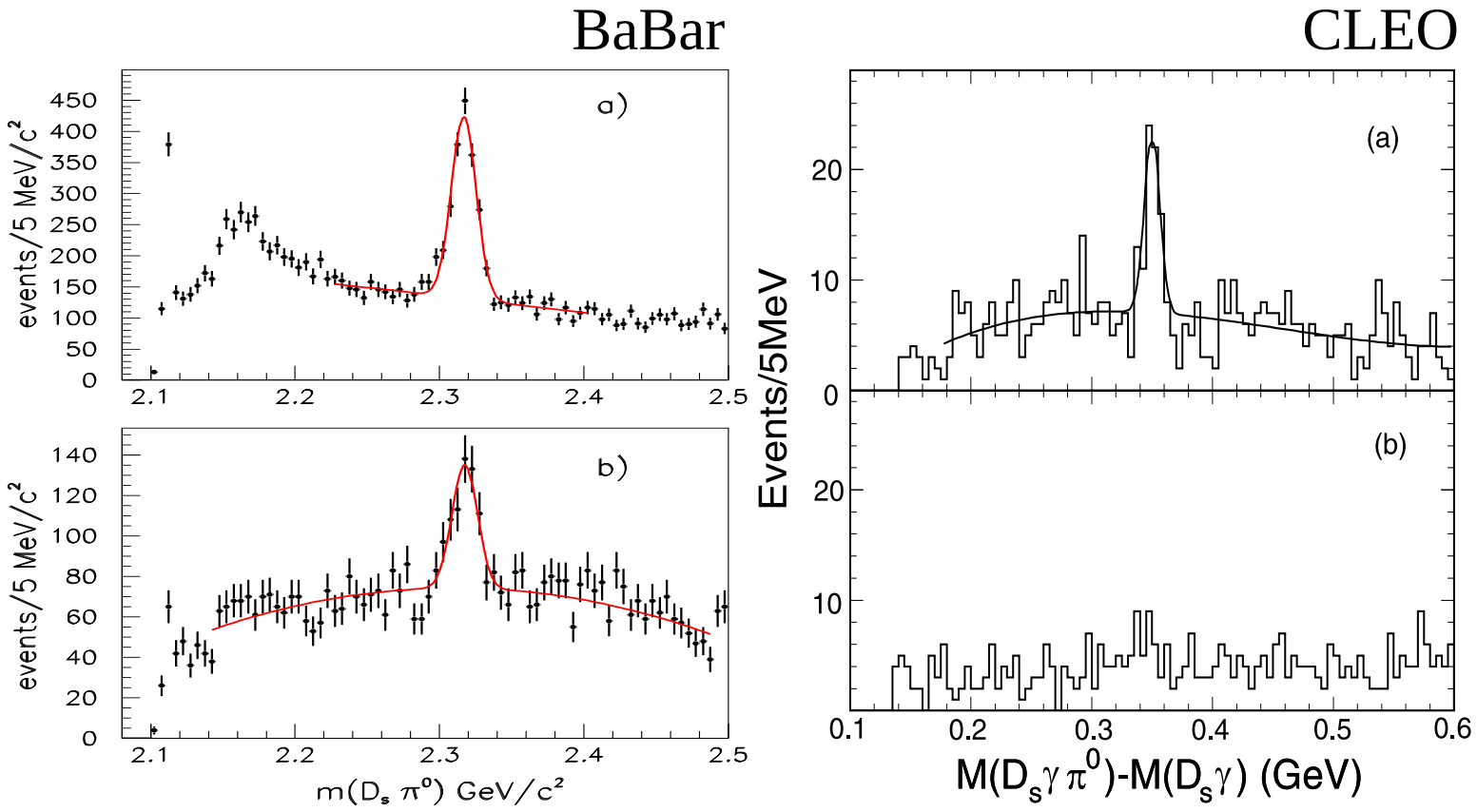
$\Rightarrow R = \frac{B(B^- \to D_2^{*0}\pi^-)}{B(B^- \to D_1^0\pi^-)} = 0.77 \pm 0.15$ (Neubert ≈ 0.35, CLEO : 1.8 ± 0.8)

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

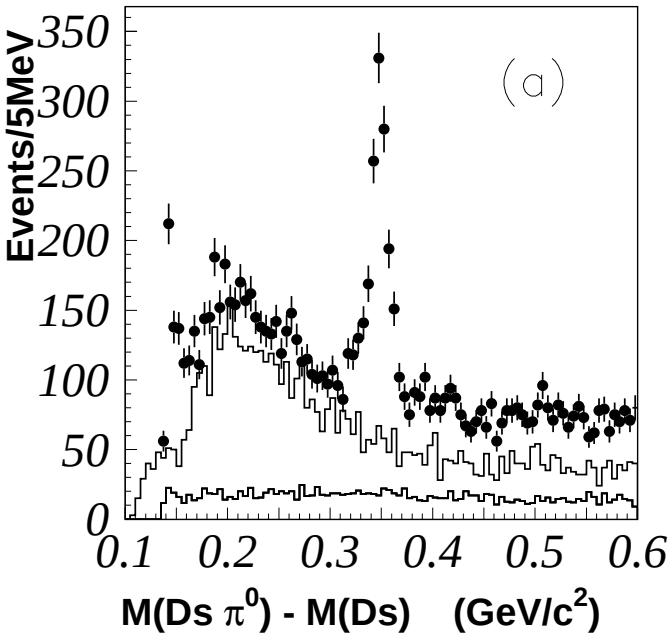
$\mathcal{B}(B^- \to D_1'^0\pi^-) \times \mathcal{B}(D_1'^0 \to D^{*+}\pi^-) = (5.0 \pm 0.4 \pm 1.0 \pm 0.4) \times 10^{-4}$

D_{sJ} observations

- BaBar (PRL **90**, 242001) reported observation of a new resonance at 2317 MeV in $D_s^+\pi^0$ final state
- CLEO (hep-ex/0305017 $\rightarrow$ PRD) observed resonance at 2459 MeV in $D_s^{*+}\pi^0$ final state



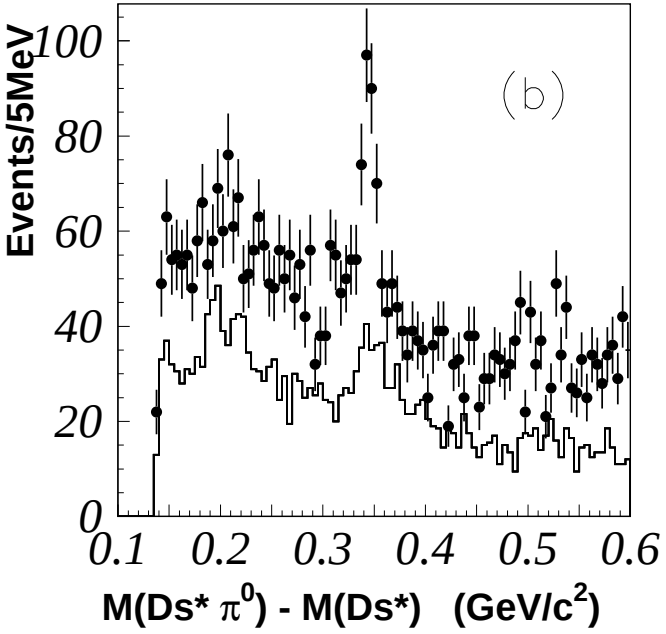
$D_{sJ}(2317)^+$ and $D_{sJ}(2457)^+$, 86.9/fb



hep-ex/0307052 → PRL

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

- $N = 761 \pm 44$ events
- $\Delta M = M(D_{sJ}(2317)) - M(D_s)$
  = (348.7 ± 0.5) MeV/c^2
- $M(D_{sJ}(2317)) = (2317.2 \pm 0.5)$ MeV/c^2



$D_{sJ}(2457) \to D_s^{*+}\pi^0$

- $N = 126 \pm 25$ events
- $\Delta M = M(D_{sJ}(2457)) - M(D_s^*)$
  = (344.1 ± 1.3) MeV/c^2
- $M(D_{sJ}(2457)) = (2456.5 \pm 1.3)$ MeV/c^2

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

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

$c\bar{s}$	$D_{sJ}(2317)$	$D_{sJ}(2457)$

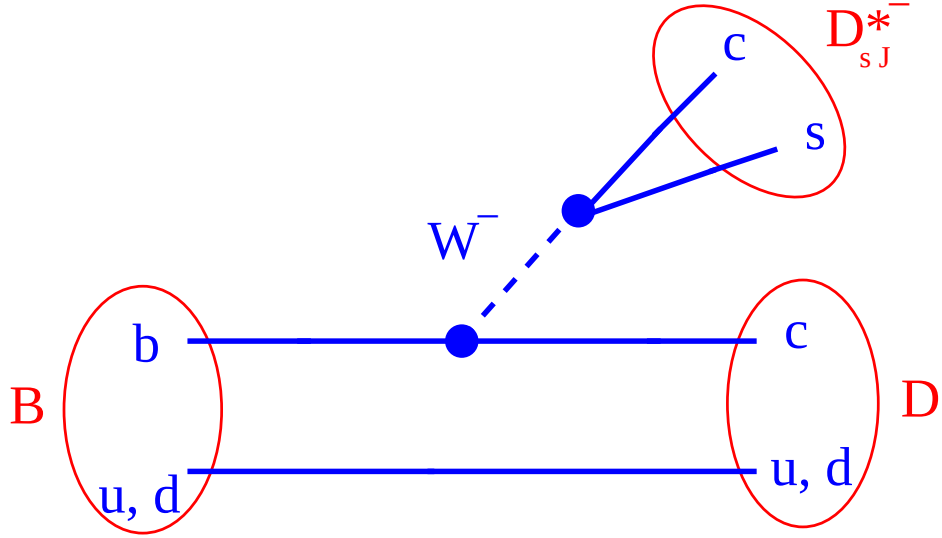
Their masses are practically equal to those of similar states in the $c\bar{u}$ system :

$c\bar{u}$	D_0^{*0}	$D_1^{\prime 0}$
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 $B \to \bar{D} D_{sJ}$:

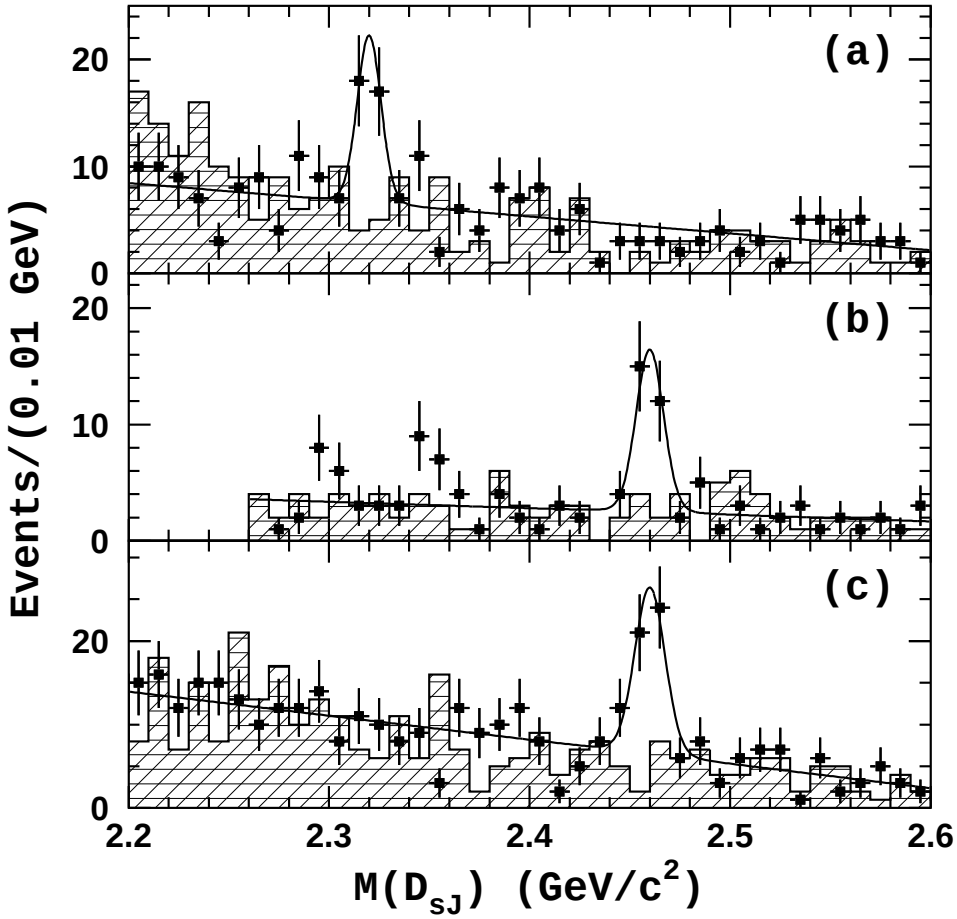


The kinematics is completly determined by the quantum numbers of the B meson and final D mesons $\to$ the angular analysis of these decays will unambiguously determine the quantum numbers of D_{sJ} mesons.
$\Rightarrow$ hep-ex/0308019 $\to$ PRL

Observation of the $D_{sJ}(2317)$ and $D_{sJ}(2457)$ in B

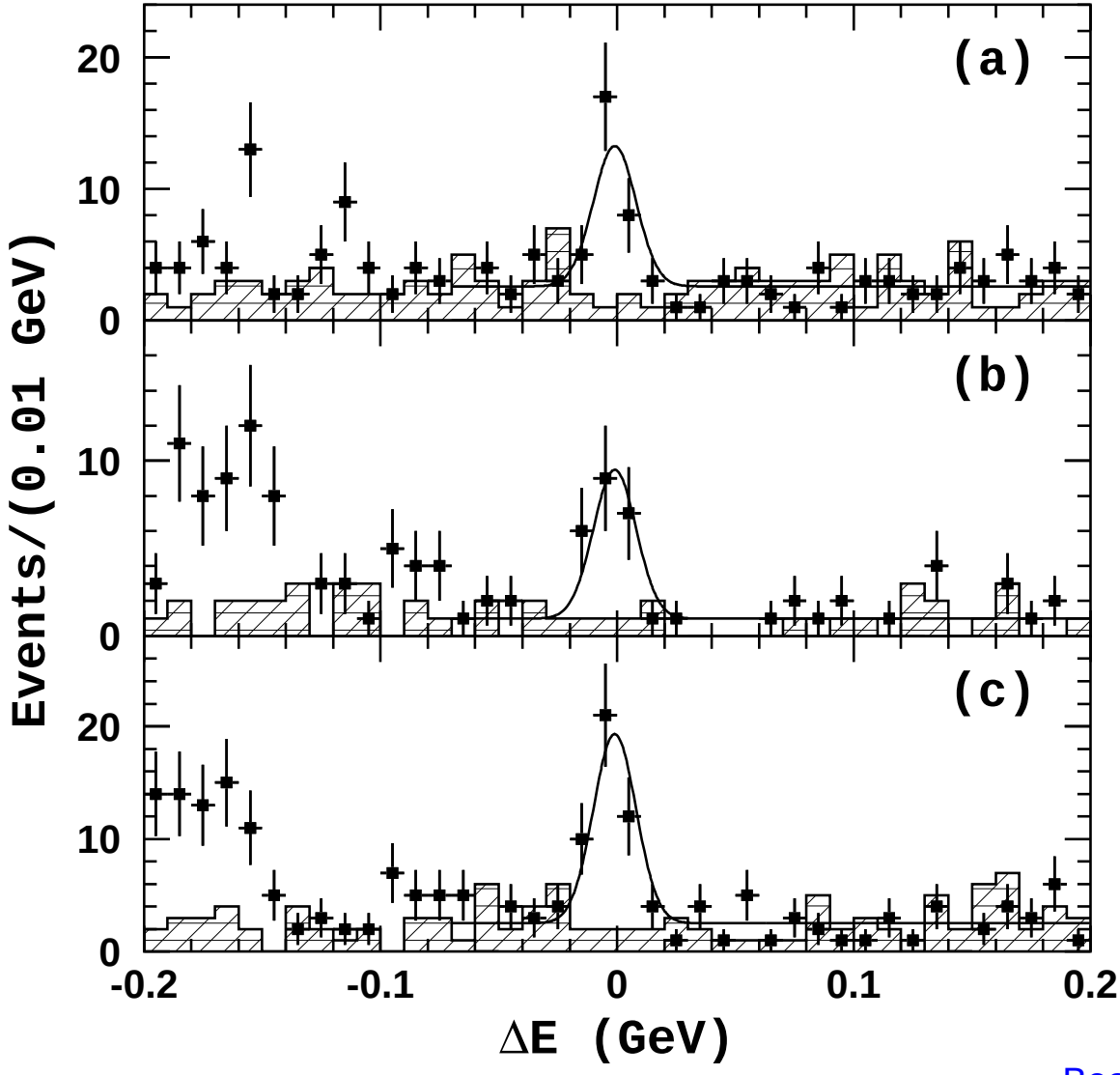
$\bar{D}$ is reconstructed as D^0 or D^+, clear signals are observed for :

- $\bar{B}\bar{D}D_{sJ}(2317)[D_s\pi^0]$
- $\bar{B}\bar{D}D_{sJ}(2457)[D_s^*\pi^0]$
- $\bar{B}\bar{D}D_{sJ}(2457)[D_s\gamma]$

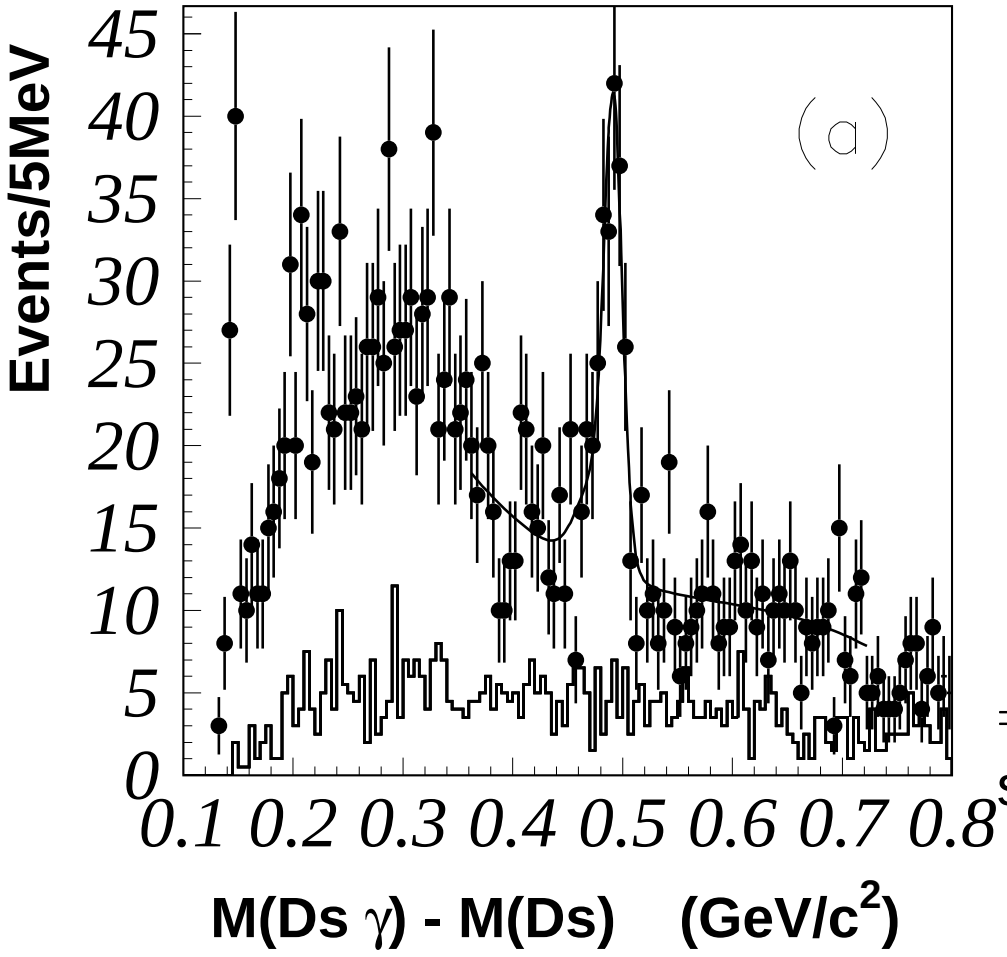


$$M(D_{sJ}(2317)) = (2319.8 \pm 2.1 \pm 2.0)\ \text{MeV/c}^2$$
$$M(D_{sJ}(2457)) = (2459.2 \pm 1.6 \pm 2.0)\ \text{MeV/c}^2$$

Use ΔE distributions to calculate the branching fractions



$D_{sJ}(2457)^+ \to D_s^+\gamma$ *in continuum*

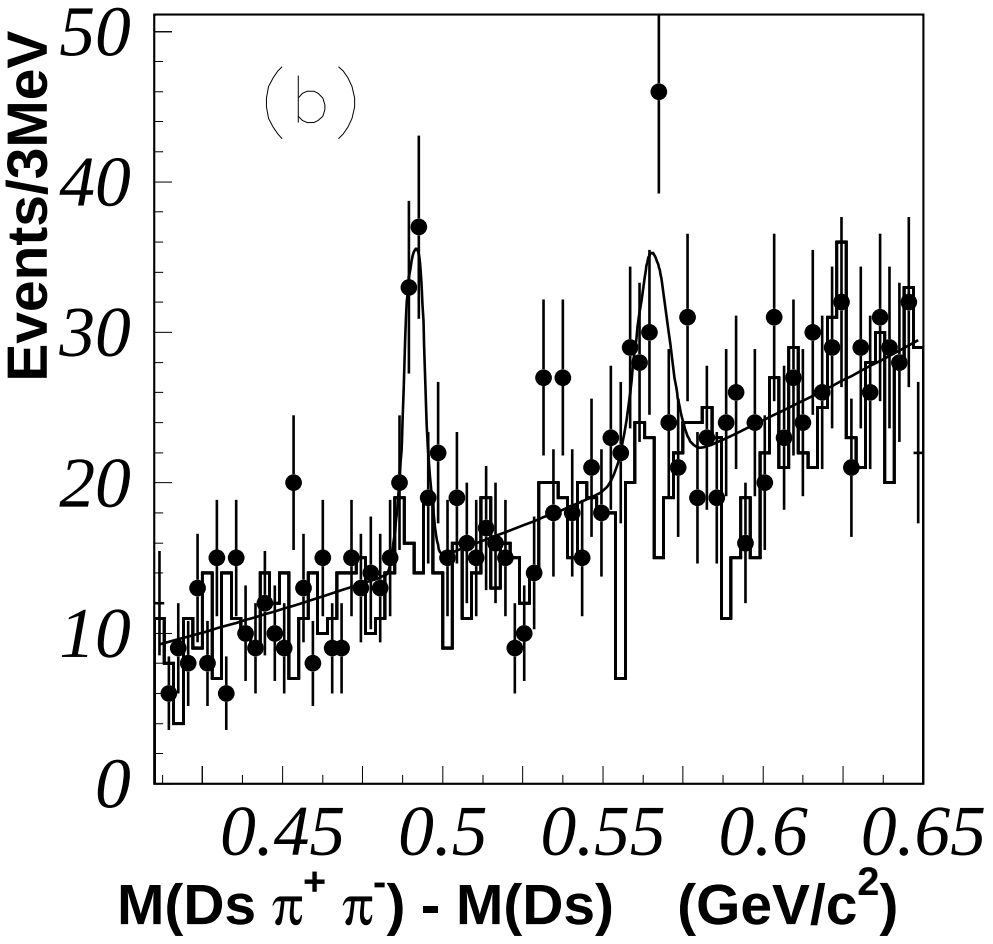


- $N = 152 \pm 18$ events
- $\Delta M = M(D_{sJ}(2457)) - M(D_s)$
  = 491.0 ± 2.3 MeV/c^2
- $M(D_{sJ}(2457))$
  = 2459.5 ± 2.4 MeV/c^2

$\Rightarrow$ first observation, rules out $0^\pm$ assignment

$$\frac{\mathcal{B}(D_{sJ}^+(2457) \to D_s^+\gamma)}{\mathcal{B}(D_{sJ}^+(2457) \to D_s^{*+}\pi^0)} = 0.55 \pm 0.13(\text{stat}) \pm 0.08(\text{syst})$$

$D_{sJ}(2457)^+ \to D_s^+\pi^+\pi^-$ *in continuum*



- $N = 59.7 \pm 11.5$ events (5.7 σ)
- $\Delta M = M(D_{sJ}(2457)) - M(D_s)$
  = 491.4 ± 1.7 MeV/c^2
- $M(D_{sJ}(2457))$
  = 2459.9 ± 1.8 MeV/c^2

First observation
(also rules out the 0^+ assignment)

$$\frac{\mathcal{B}(D_{sJ}^+(2457) \to D_s^+\pi^+\pi^-)}{\mathcal{B}(D_{sJ}^+(2457) \to D_s^{*+}\pi^0)} = 0.14 \pm 0.04(\text{stat}) \pm 0.02(\text{syst})$$

Summary of $B \to \bar{D} D_{sJ}$

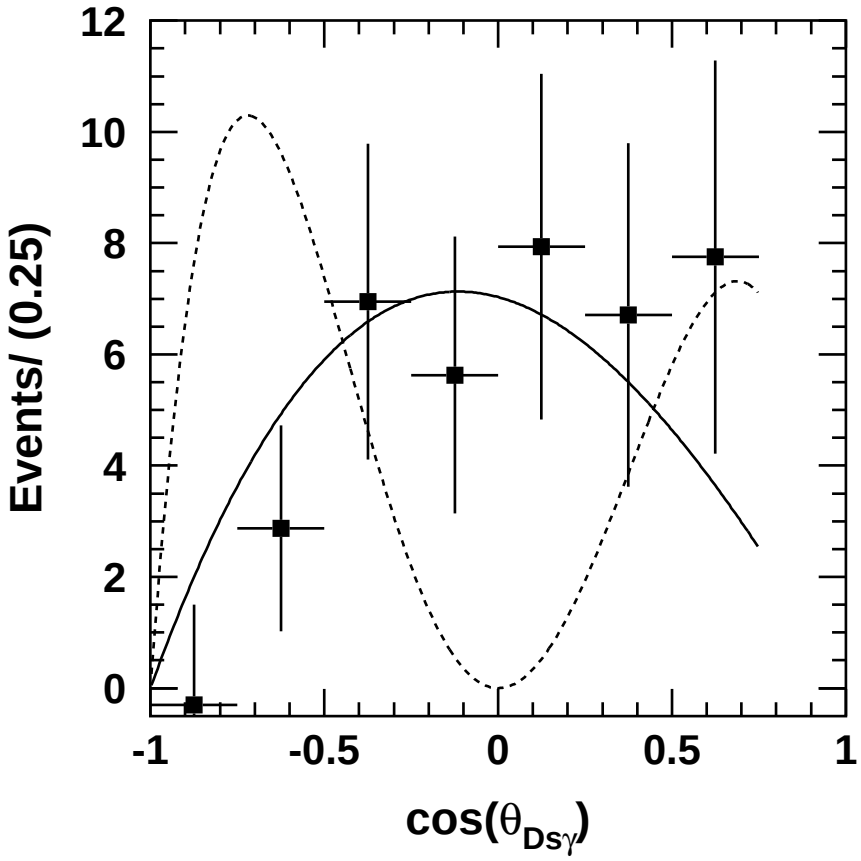
B mode	D_{sJ} mode	$B(10^{-4})$	Significance (σ)
$\bar{D} D_{sJ}(2317)$	$D_s \pi^0$	$8.5^{+2.1}_{-1.9} \pm 2.6$	6.1
	$D_s^* \gamma$	< 7.5	–
$\bar{D} D_{sJ}(2457)$	$D_s^* \pi^0$	$17.8^{+4.5}_{-3.9} \pm 5.3$	6.4
	$D_s \gamma$	$6.7^{+1.8}_{-1.2} \pm 2.0$	7.4
	$D_s^* \gamma$	< 7.3	–
	$D_s \pi^0$	< 1.6	–
	$D_s \pi^+ \pi^-$	< 1.8	–

$$\frac{B(D_{sJ}(2457) \to D_s \gamma)}{B(D_{sJ}(2457) \to D_s^* \pi^0)} = 0.38 \pm 0.11 \pm 0.04$$

$\to$ 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 $D_{sJ}(2457)$ momentum in the B meson rest frame and the D_s momentum in the $D_{sJ}(2457)$ rest frame

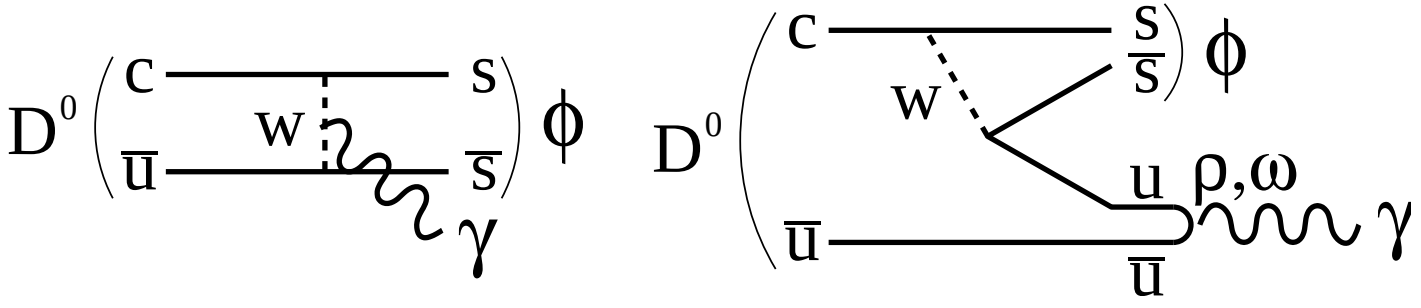


consistent with $\sin^2\theta \Rightarrow$ distribution expected if this state is 1^+

Belle observed $D_{sJ}(2317)$ and $D_{sJ}(2457)$ 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)

$D \to V\gamma$ (LP03-303/BELLE-CONF-0346)

(a) short−distance contribution (b) long−distance contribution

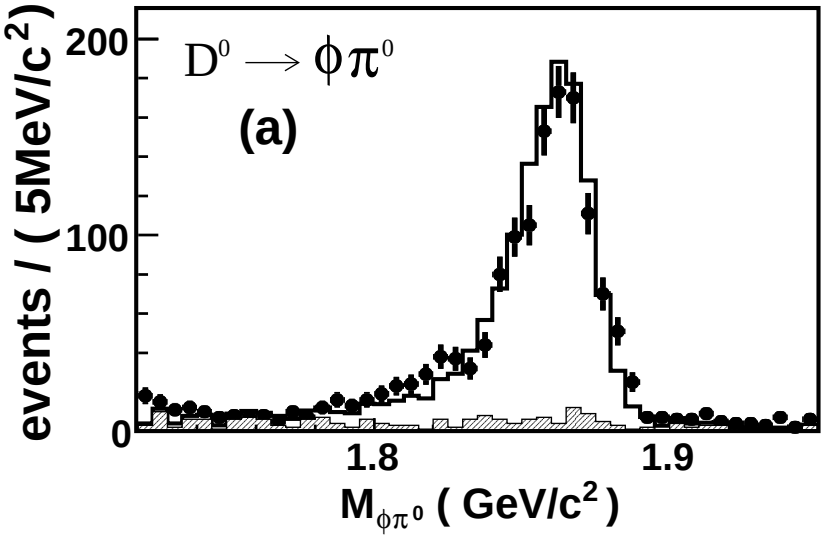


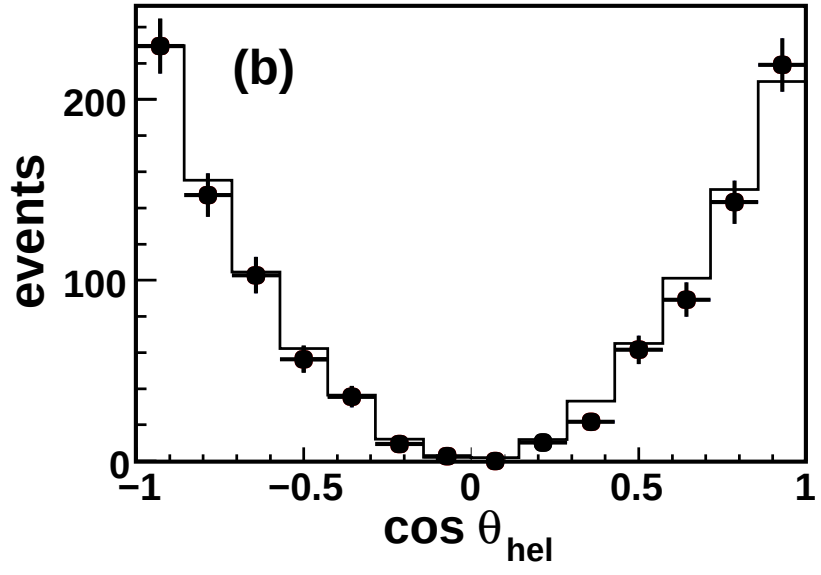
- $\mathcal{B}(D^0 \to \phi\gamma)_{th}$ = $(0.04 - 3.4) \times 10^{-5}$
- most important background : Cabibbo & color-suppressed $D^0 \to \phi\pi^0, \phi\eta$

selection :

- D^* tag and $P^*(D^*) >$ 2.9 GeV/c
- high momentum π^0, η, γ
- 78.1/fb

Rare decay : $D^0 \to \phi\pi^0$





N$_{cand}$ = 1254 $\pm$ 39 events

branching ratio measured with $D^0 \to K^+K^-$ as reference

B $(D^0 \to \phi\pi^0) = (8.01 \pm 0.26 \pm 0.47) \times 10^{-4}$

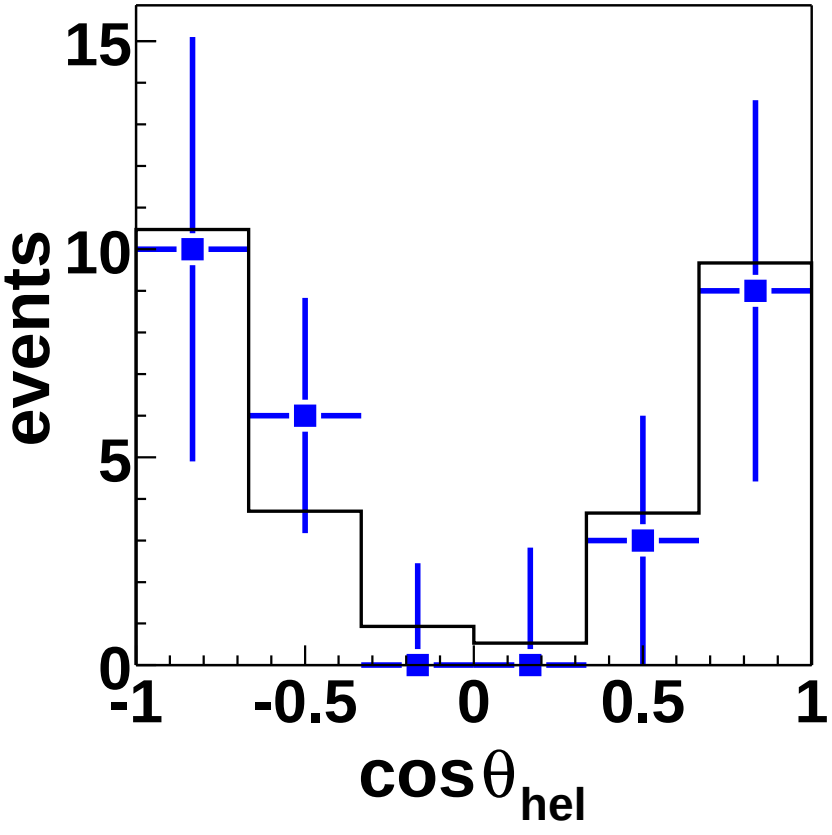
Use $\cos\theta_{hel}$ as a cross-check : conservation of angular momentum $\to \cos^2\theta_{hel}$

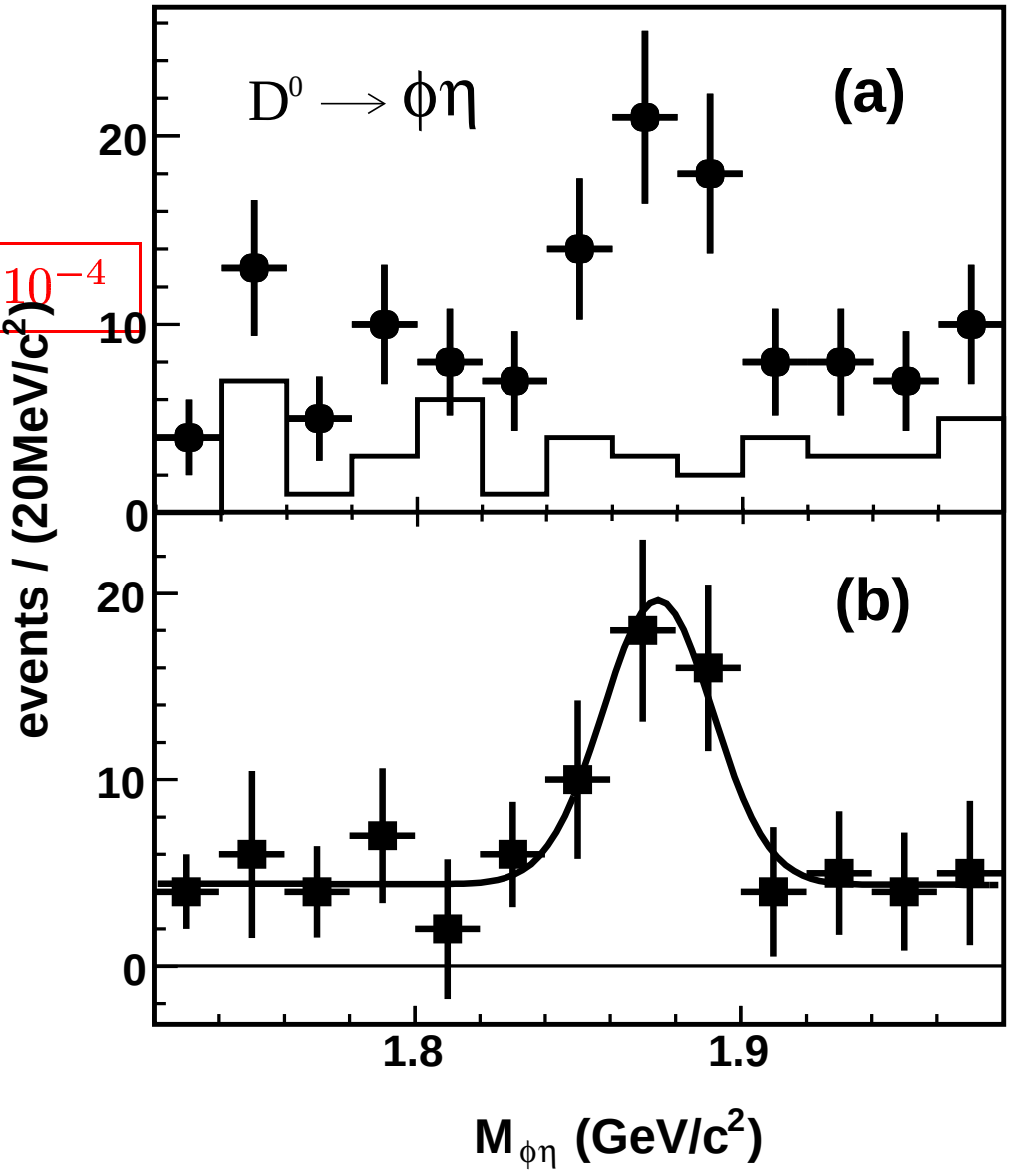
fit the $M(\phi\pi^0)$ yield in $\cos\theta_{hel}$ bins

apply π^0 veto

N_{cand} = 31.1 $\pm$ 9.8 events

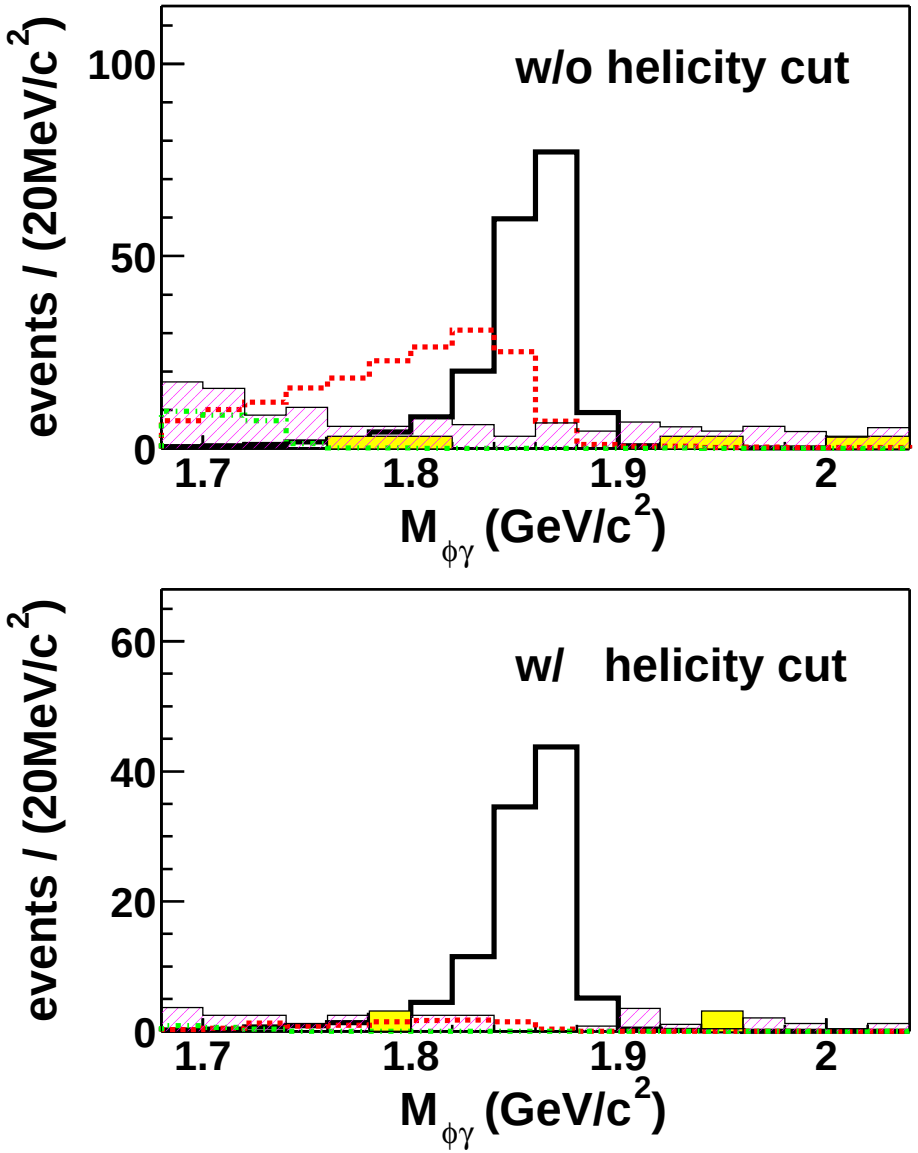
B $(D^0 \to \phi\eta) = (1.48 \pm 0.47 \pm 0.09) \times 10^{-4}$





When a $\phi\pi^0$ or $\phi\eta$ decay is reconstructed as $\phi\gamma$ by missing a photon, the distribution of $\cos\theta_{hel}$ is still close to $\cos^2\theta_{hel}$

$\to |\cos\theta_{hel}| < 0.4$



N_{cand} = $(27.6^{+7.4}_{-6.5}\ ^{+0.5}_{-1.0})$ events (5.4 σ)

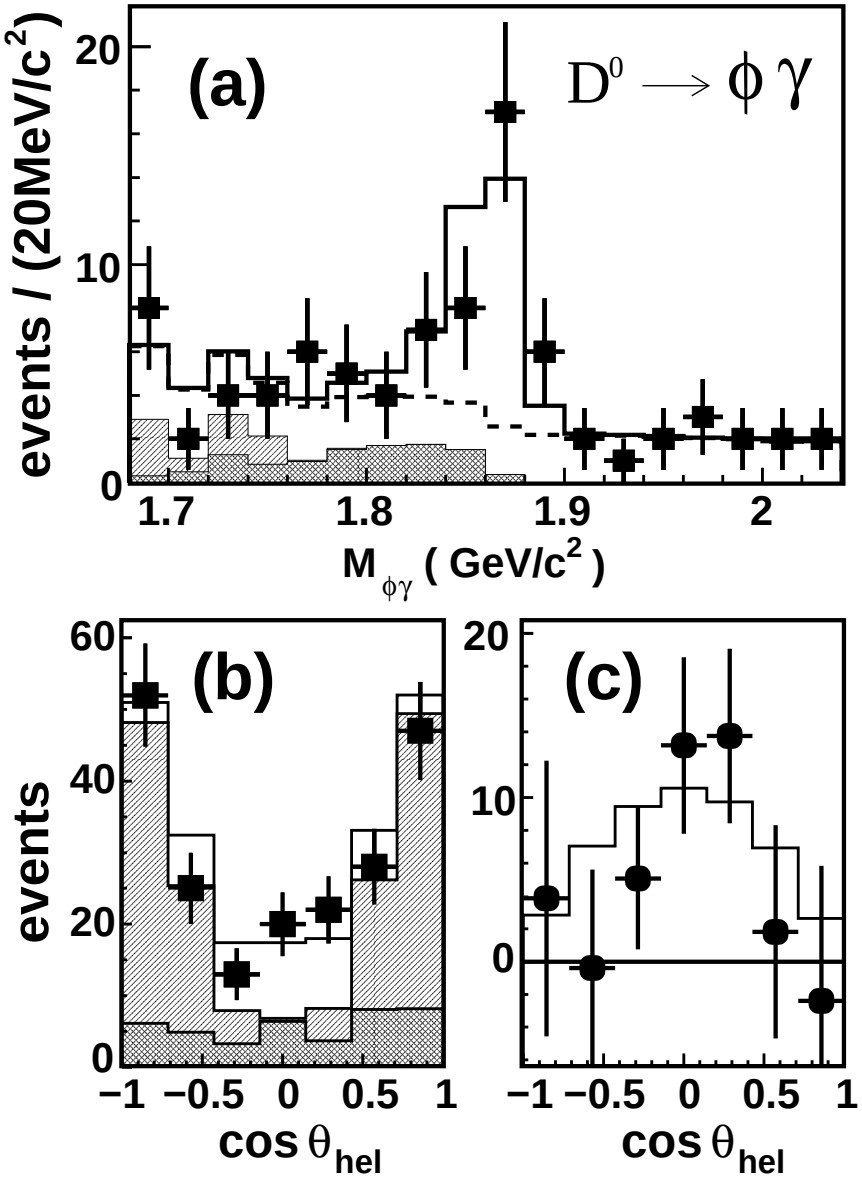
B $(D^0 \to \phi\gamma) = (2.60^{+0.70}_{-0.61}\ ^{+0.15}_{-0.17}) \times 10^{-5}$

$< 1.9 \times 10^{-4}$ @ 90% CL

(CLEO, Phys.Rev.D58, 092001)

helicity distribution cross check

$\to \sin^2\theta$



$\Rightarrow$ first observation of a FCNC decay in the D system

Summary

- Confirm that $J/\psi c\bar{c}$ cross-section is an order of magnitude larger than predicted by NRQCD
- Dalitz analysis for $B \to D^{(*)+}\pi^-\pi^-$ and observed missing P-wave states D_0^{*0} and D_1^{*0}
- Belle observed exclusive $B \to DD_{sJ}(2317)$ and $B \to DD_{sJ}(2457)$ decays consistent with 0^+ and 1^+ (both having $j_q = 1/2$)
  - $D_{sJ}(2457) \to D_s^+\gamma$ in both continuum and B decays
  - $D_{sJ}(2457) \to D_s^+\pi^+\pi^-$ in continuum
- First observation of FCNC charm decay : $D^0 \to \phi\gamma$