Charmed Meson and Baryon spectroscopy in Belle

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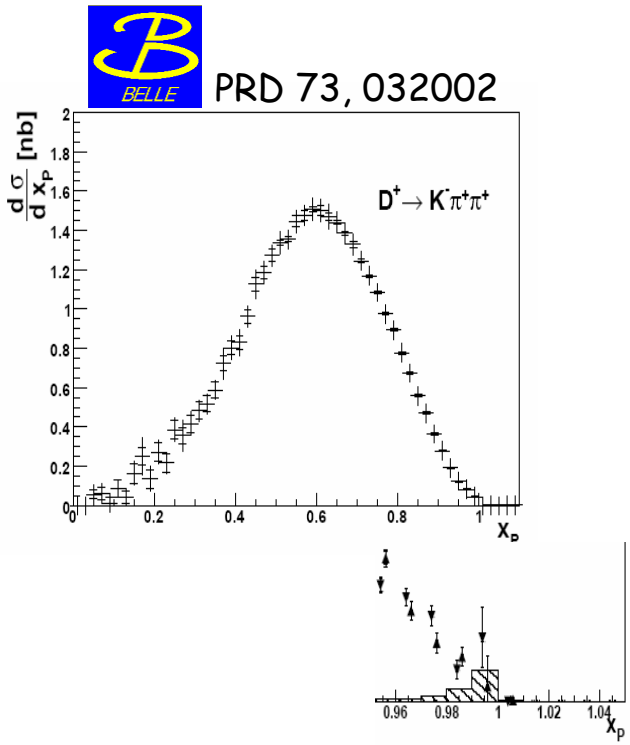
for the Belle Coll.

- Open charm opportunities @ B-factory
- $c\underline{u}$, $c\underline{d}$ meson multiplets status
- New D_{sJ} mesons
- $D_{s1}(2536)^+$ mixing observation
- Charmed baryons status

Two major open charm spectroscopy environments available at B-factory:

- continuum $e^+e^- \to \gamma^* \to c\bar{c} \to D_{(s)}^{(*)}X$, $\Lambda_c X$, ...
  $\sigma(c\bar{c}) \sim (Q=2/3)^2 > \sigma(B\bar{B})$;
  hard FF $c \to D$: $x_p = P/P_{max} > \sim 0.7$:good S/B
  includes $e^+e^- \to D\bar{D}$, $D\bar{D}^*$, $D^*\bar{D}^*$ (enpoint) !
  (PRD 70, 071101 : interesting production mechanism data)
  $e^+e^- \to D\bar{D}n\pi$ has spectroscopic potential too

  (+ radiative return, see G.Pakhlova talk)



- B meson decays: $b \to cu\bar{d} \to D\bar{D}n\pi$, $c\bar{c}s \to D\bar{D}K$
  CF transitions → abundand
  initial state well defined (E_B,p_B known) → clean samples
  $J^P = 0^-$ → restricts allowed produced spin-parities
  polarised states

cq states in HQS motivated Potential Model

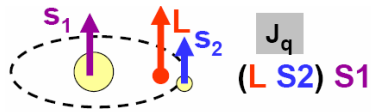
- Coulombic potential (like in cc , flavor indep.) (Godfrey,Isgur 85)

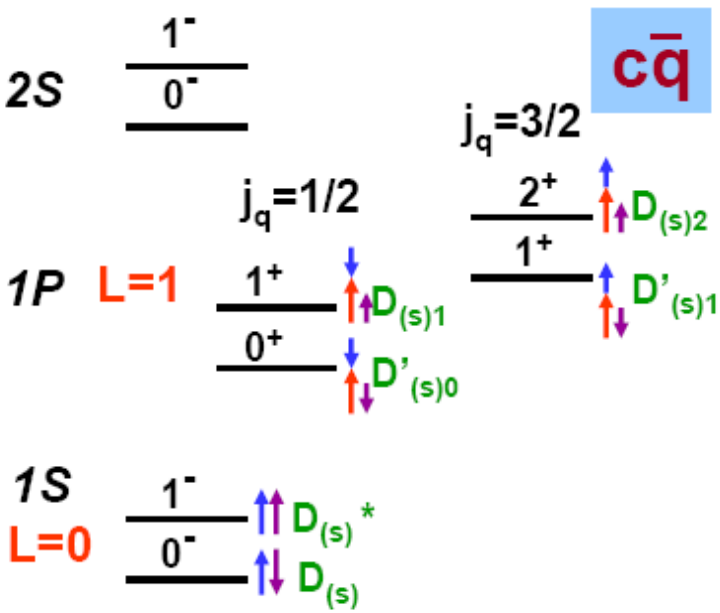
  $m_c \to \infty$: hydrogen-like atom, l.d.f. in a static field of c

  → properties of cq do not depend on c,

  $j_q = L + s_2$ becomes a good quantum number,

  same j_q states degenerated, $1/m_c$ corr. split them up (by ~140 MeV)





$\Gamma(j_q=1/2) \gg \Gamma(3/2)$

(S-wave dec.) (D-wave, p^5 suppr.)

$m(3/2) > m(1/2)$

(Nowak et al 93, Bardeen et al 94)

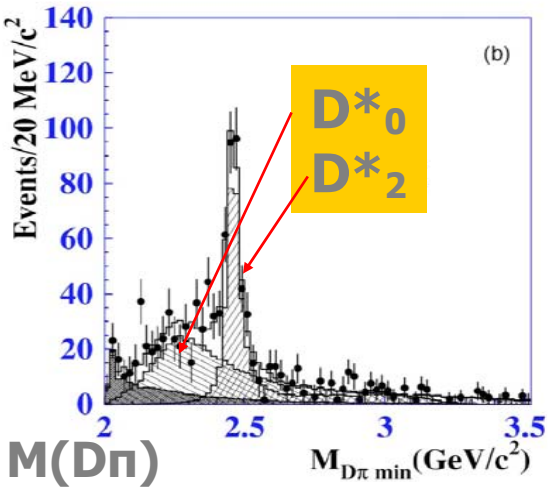
- Another idea (not a potential model): chiral symmetry ($m_q \to 0$):

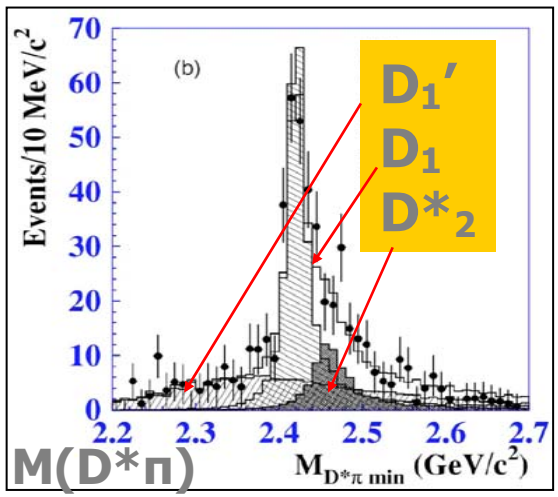
  → same J, P=-1 , P=+1 doublers, splitted by 400-180 MeV

D** results

PRD 69, 112002 (2004)

❑ $B^- \to D^+\pi^-\pi^-$, $B^- \to D^{*+}\pi^-\pi^-$
Dalitz plot analysis



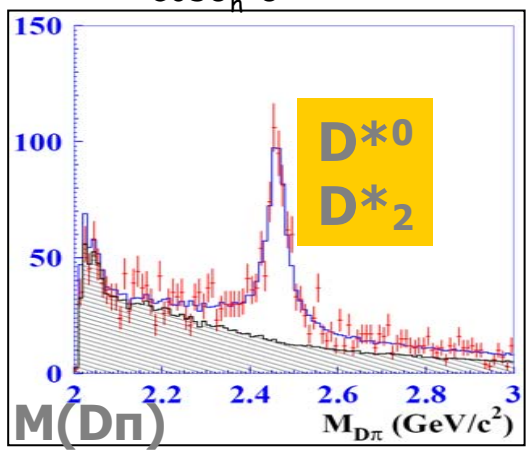


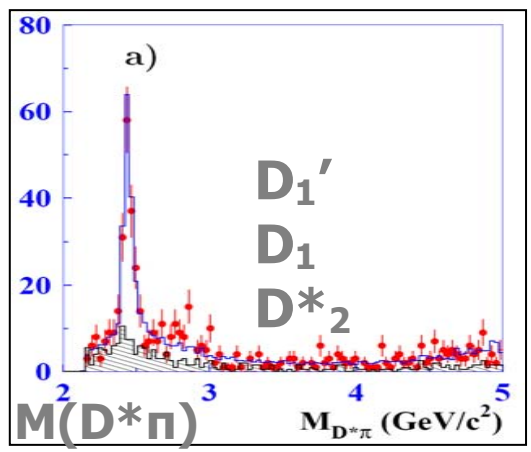
State	$J^P(j_q)$	Mass [MeV]	Γ [MeV]	Product $\mathcal{B}$ $[10^{-4}]$
$D_0^* \to D^+\pi^-$	$0^+\ (\frac{1}{2})$	$2308 \pm 17 \pm 15 \pm 28$	$276 \pm 21 \pm 18 \pm 60$	$6.1 \pm 0.6 \pm 0.9 \pm 1.6$
$D_1' \to D^{*+}\pi^-$	$1^+\ (\frac{1}{2})$	$2427 \pm 26 \pm 20 \pm 15$	$384\ ^{+107}_{-75} \pm 24 \pm 70$	$5.0 \pm 0.4 \pm 1.0 \pm 0.4$
$D_1 \to D^{*+}\pi^-$	$1^+\ (\frac{3}{2})$	$2421.4 \pm 1.5 \pm 0.4 \pm 0.8$	$23.7 \pm 2.7 \pm 0.2 \pm 4.0$	$6.8 \pm 0.7 \pm 1.3 \pm 0.3$
$D_2^* \to D^+\pi^-$	$2^+\ (\frac{3}{2})$	$2461.6 \pm 2.1 \pm 0.5 \pm 3.3$	$45.6 \pm 4.4 \pm 6.5 \pm 1.6$	$3.4 \pm 0.3 \pm 0.6 \pm 0.4$

BF(B0→D**(j_q=1/2)π)>BF(B0→D**(j_q=3/2)π)
(does not agree with the 'QCD sum-rule' prediction)

PRD 76, 012006 (2007)

❑ $B^0 \to D^0\pi^+\pi^-$, $B^0 \to D^{*0}\pi^+\pi^-$
Dalitz plot analysis





BF(B0→D**(j_q=1/2)π)<
BF(B0→D**(j_q=3/2)π)

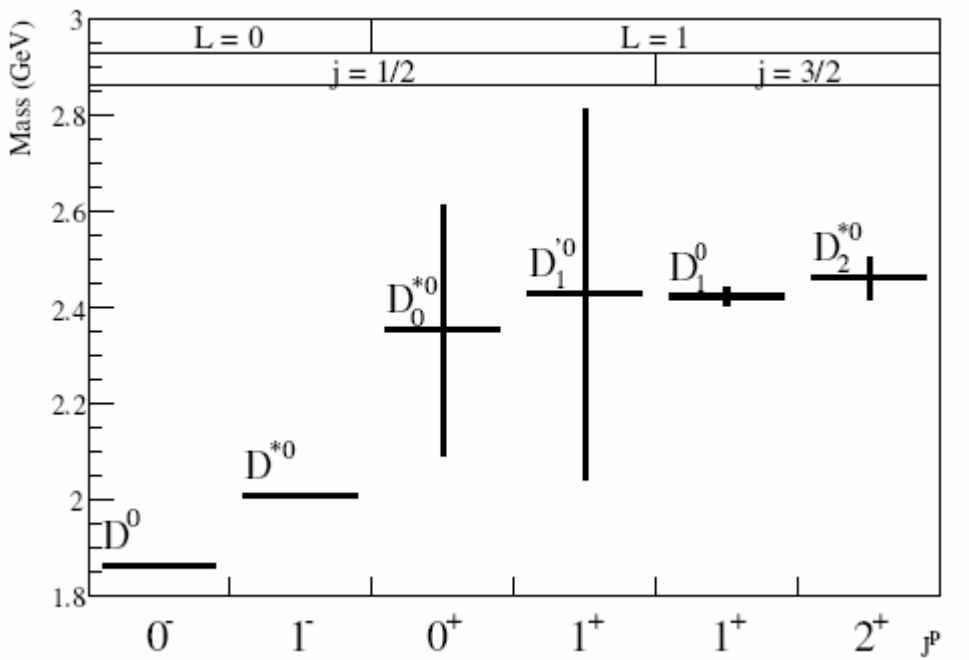
D** results

- Wide 0^+ $D^*_0 \rightarrow D^+\pi^-$ established:

  m=2308+-17+-15+-28 MeV, Γ=276+-21+-18+-60 MeV

  vs Focus: m=2407+-21+-35 MeV PL B586, 11 (04)

  Babar: m=2297+- 8 +-20 MeV PRD 79 112004 (09)



- Only Dπ, D*π decay channels observed
- Observation of radiative decays (BF 0 – 3%) would farther scrutinize the models

cs mesons

- Godfrey-Isgur model (85) predicted j_q = 3/2
  $D_{s1}(2536)$, $D_{s2}(2573)$ very successfuly
  (found respectively by Argus (89), Cleo (94)

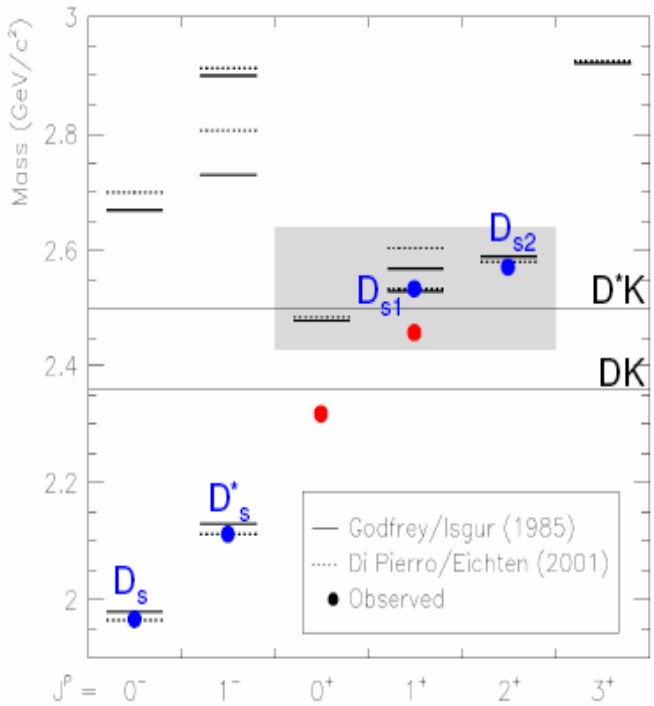
- all L=1 states predicted above DK threshold,
  $m(D_{s1}(1/2)) > m(D_{s1}(3/2))$,
  $\Gamma(J_q=1/2) >> \Gamma(3/2)$

- 2 missing states 0^+,1^+ (J_q=1/2) not seen for decades
  → ' too wide (S-wave decays), too difficult to discover '

- BABAR, Cleo, Belle:

  0^+ $D_{s0}(2317)^+$ $\Gamma < 4.6$ MeV
  1^+ $D_{s1}(2460)^+$ $\Gamma < 5.5$ MeV

  both in isospin viol. decays to $D^{(*)}_s \pi / \gamma$

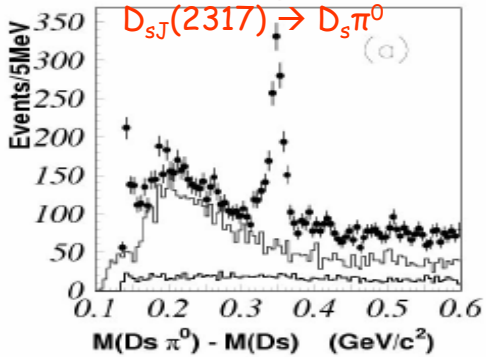


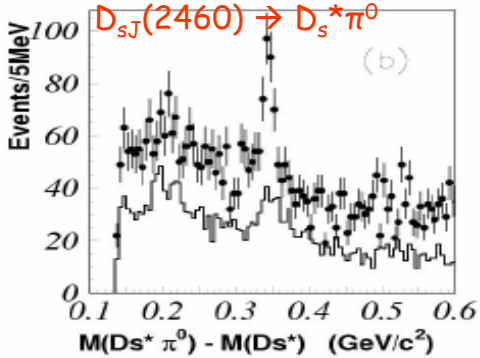
→L=1 multiplet is closed, but is it understood?
Why potential model fails? (modified Coulombic pot. needed for cs)

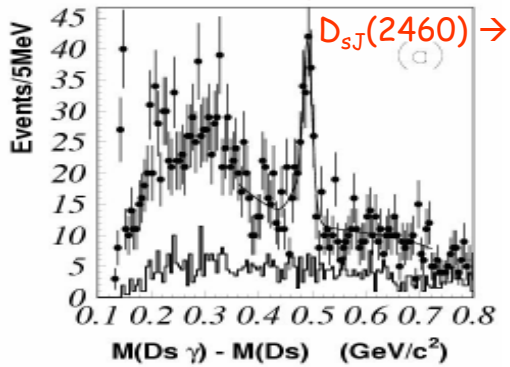
Chiral doublets?: $m(1^+) - m(1^-) \approx m(0^+) - m(0^-) = 348$ MeV

BELLE

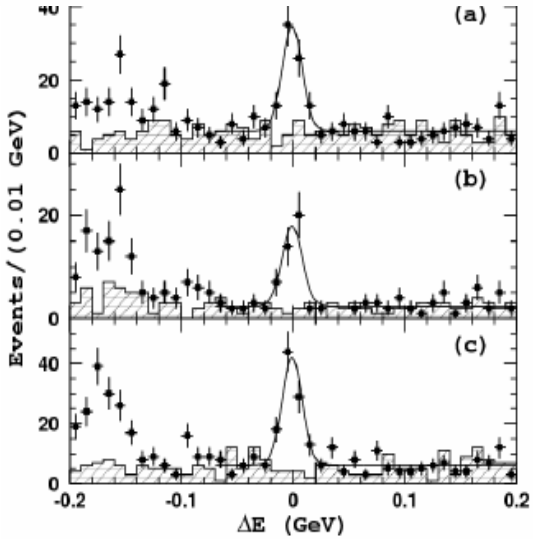
D_{s0}, D_{s1} in continuum

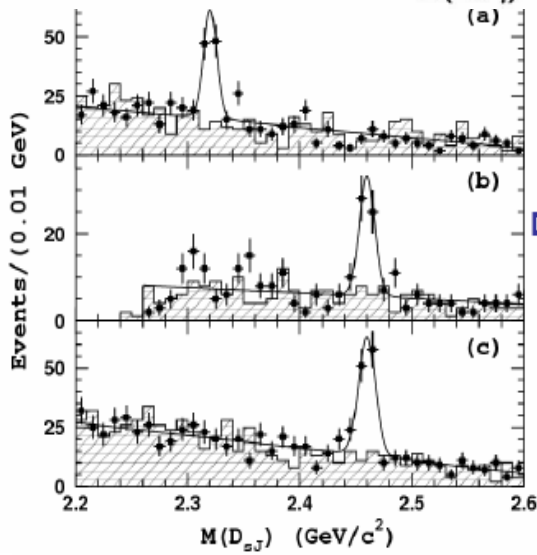






D_{s0}, D_{s1} in B decays:



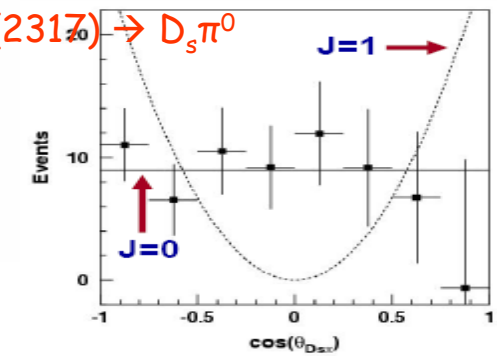


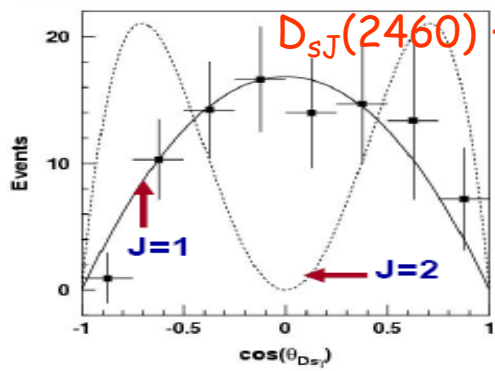
$D_{sJ}(2317) \to D_s\pi^0$

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

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

BF~10^{-3} vs BF(DD_s, DD_s^*) ≈10^{-2}



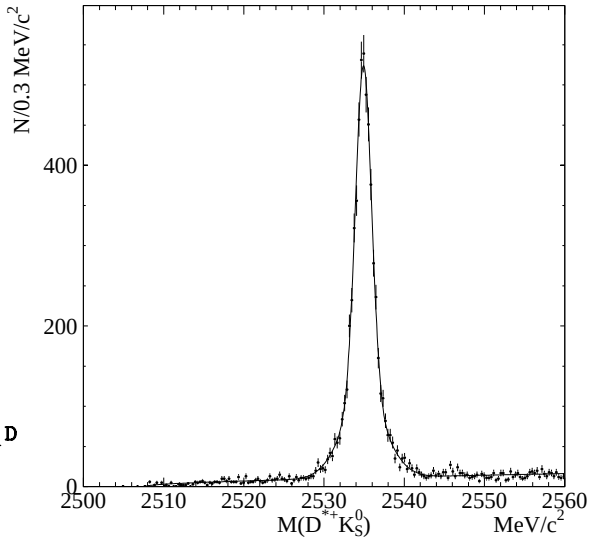


262002 (2003)

PWA in $D_{s1}(2536)^+ \to D^{*+}K^0_S$:

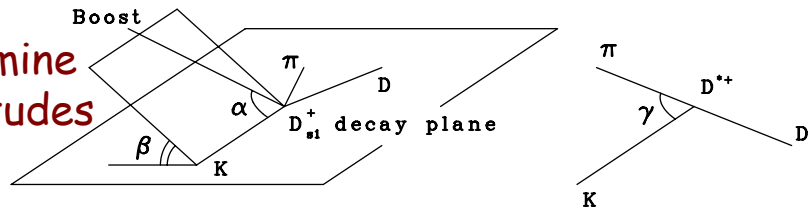
PR D77 032001

- Data sample: 462 fb^{-1} e^+e^- continuum, $x_p > 0.8$
  ~6 000 $D_{s1}(2536)^+ \to D^{*+}K^0_S$, nearly no bkd

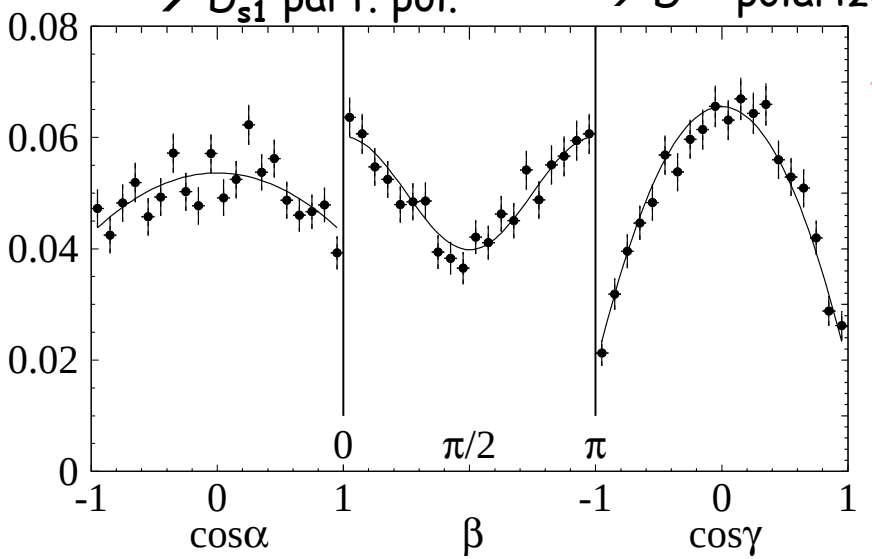


- 3D fit to angular distr. (α,β,γ)←sensitive to mixing

Angular distr to determine complex ratio of amplitudes and D_{s1}polarisation



cos α, β not flat
→ D_{s1} part. pol. → D^{*+} polarized



$$D/S = (0.63 \pm 0.07) \cdot \exp\left((\pm)i \cdot (0.77 \pm 0.03)\right)$$

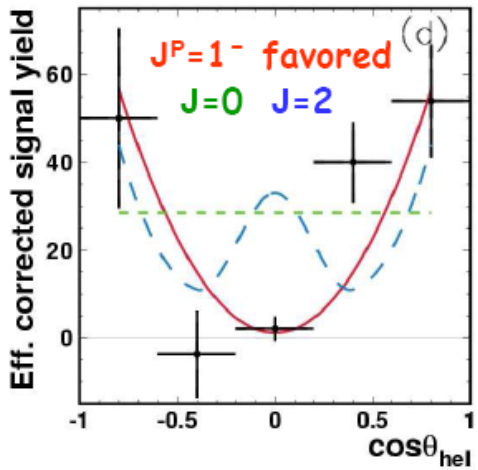
→ Large 1^+ - $1^{+'}$ mixing (like in the orig. G-I)

$$\Gamma_S/\Gamma_{\text{total}} = 0.72 \pm 0.05$$

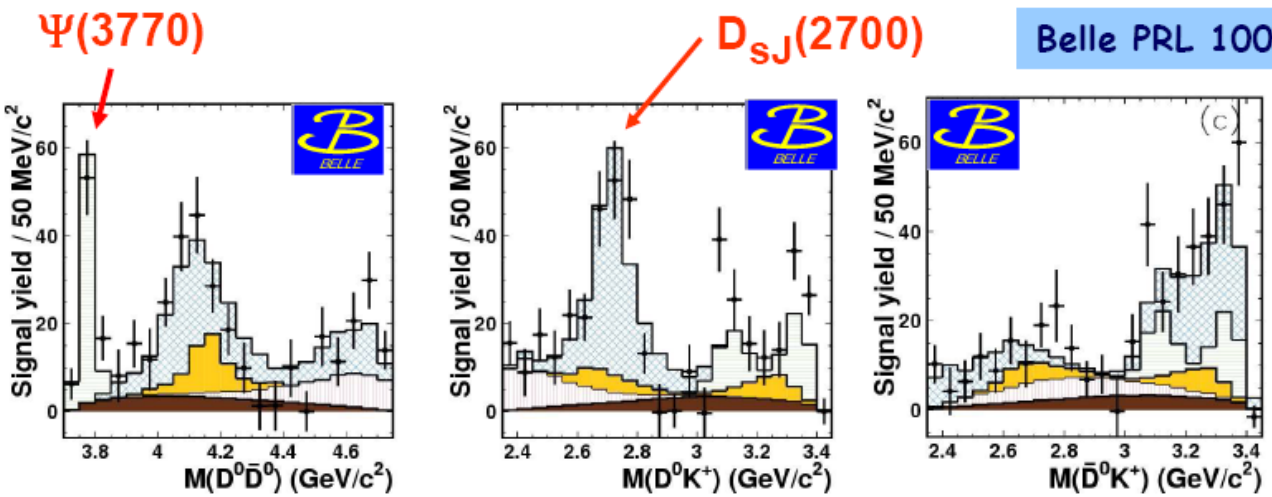
→S-wave dominates $D_{s1}(2536)$ decay!
(mixing effect enhanced by D-wave suppression)

New cs̄ mesons: $D_{s1}(2700)^+$ in $B^+ \to D^0 \bar{D}^0 K^+$

	$D_{sJ}(2700)^+$	$\psi(3770)$
N_{sig}	182 ± 30	68 ± 15
Significance	8.4σ	5.5σ
M [MeV/c^2]	$2708 \pm 9^{+11}_{-10}$	$3776 \pm 5 \pm 4$
Γ [MeV/c^2]	$108 \pm 23^{+36}_{-31}$	$27 \pm 10 \pm 5$
Product $\mathcal{B}$ $[10^{-4}]$ (90% C.L.)	$11.3 \pm 2.2^{+1.4}_{-2.8}$	$2.2 \pm 0.5 \pm 0.3$



$B^+ \to D^0 \overline{D}_{sJ}(2700)$ $B^+ \to \Psi(3770) K^+$ $B^+ \to \Psi(4160) K^+$



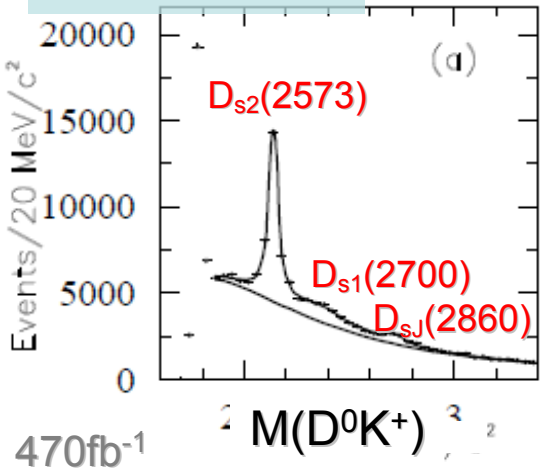
Belle PRL 100 (2008) 092001

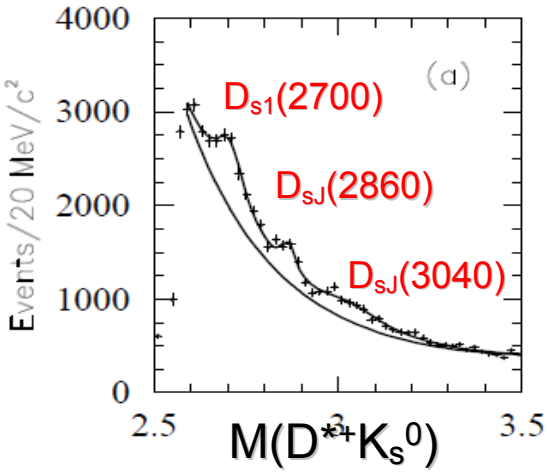
449M BB

L=1 1^- radial excitation? chiral doubler to 1^+ $D_{s1}(2536)$?
The mass agrees with both

New cs̄ mesons: $D_{s1}(2700)$, $D_{sj}(2860)$, $D_{sj}(3040)$ in $e^+e^- \to D^{(*)}KX$

arXiv: 0908.0806





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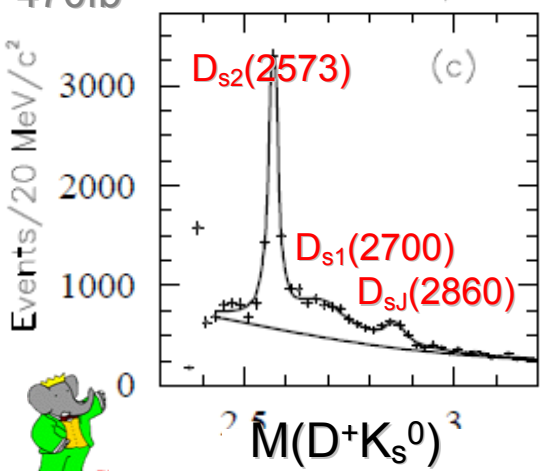
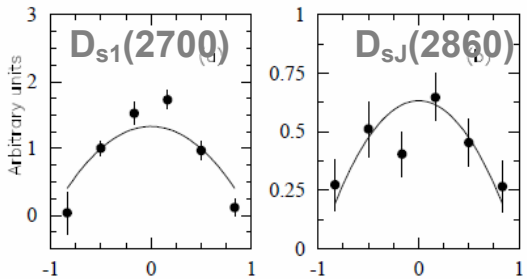




$D_{s1}(2700)$

$M = 2710 \pm 2^{+12}_{-7}$ MeV

$\Gamma = 149 \pm 7^{+39}_{-52}$ MeV

$D_{sJ}(2860)$

$M = 2862 \pm 2^{+5}_{-2}$ MeV

$\Gamma = 48 \pm 3 \pm 6$ MeV

$D_{sJ}(3040)$

$M = 3044 \pm 8^{+30}_{-5}$ MeV

$\Gamma = 239 \pm 35^{+46}_{-42}$ MeV

Confirms the observation in B decays, new D*K

Observed earlier in DK channel

New, not seen in DK channel

⇨

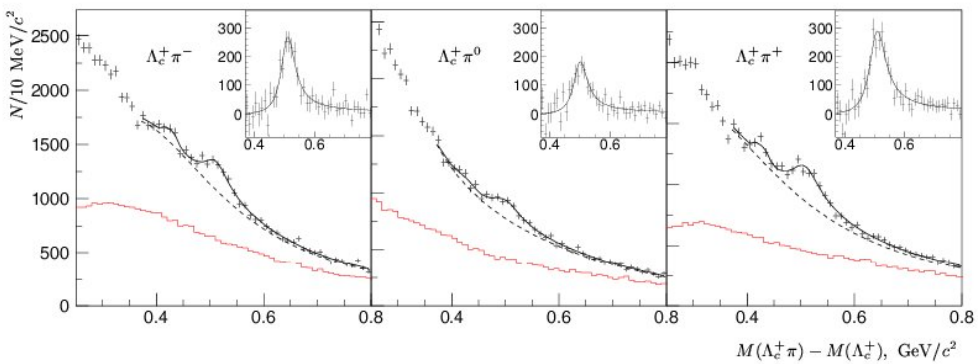
$D_{s1}(2700)$, $D_{sJ}(2860)$: $J^P = 1^-, 2^+, 3^-$...

$D_{sJ}(3040)$ unseen in DK → $J^P = 0^-, 1^+, 2^-$...

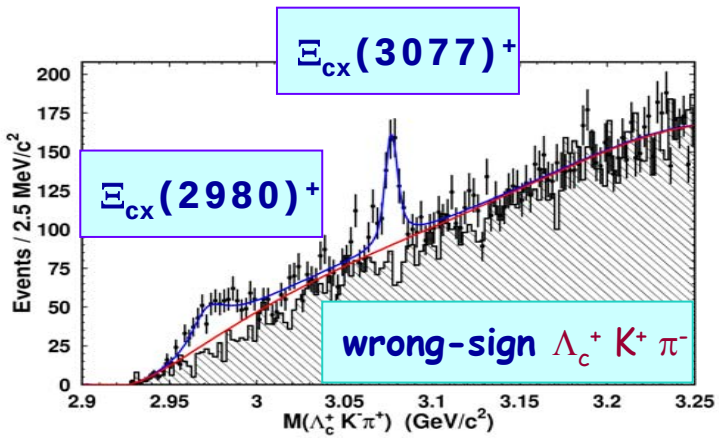
Charmed baryons

- An excellent lab to study the dynamics of heavy quark-light diquark Fertile subject at B-factories, in Belle:

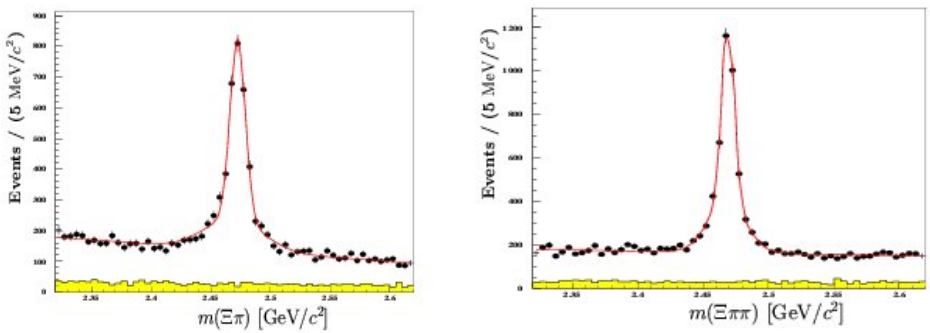
$\Sigma_c(2800)$ (1st orbital excitation of Σ_c)



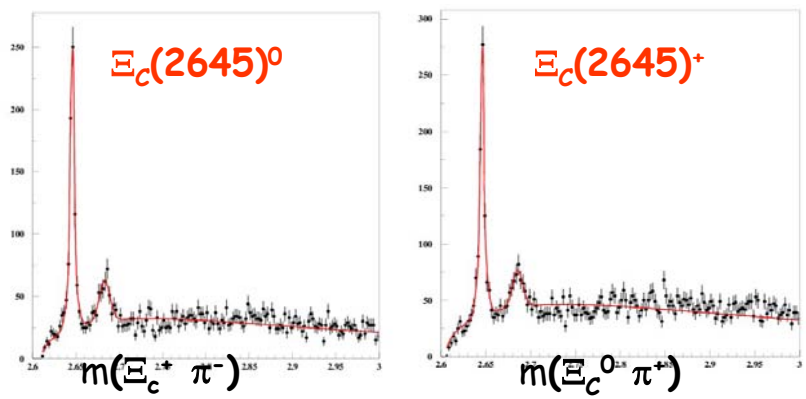
new $\Xi_{cx}(2980)^{0,+}$, $\Xi_{cx}(3077)^{0,+}$



Precision $m(\Xi_{c0})$, $m(\Xi_{c+})$ (7modes)



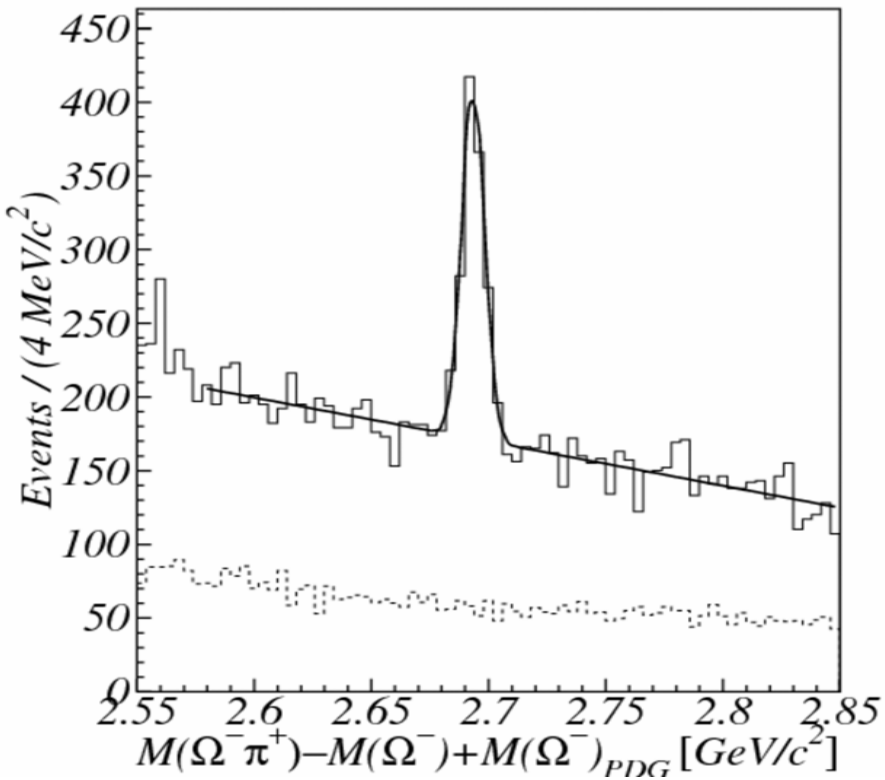
excited states $\Xi_c(2645)$

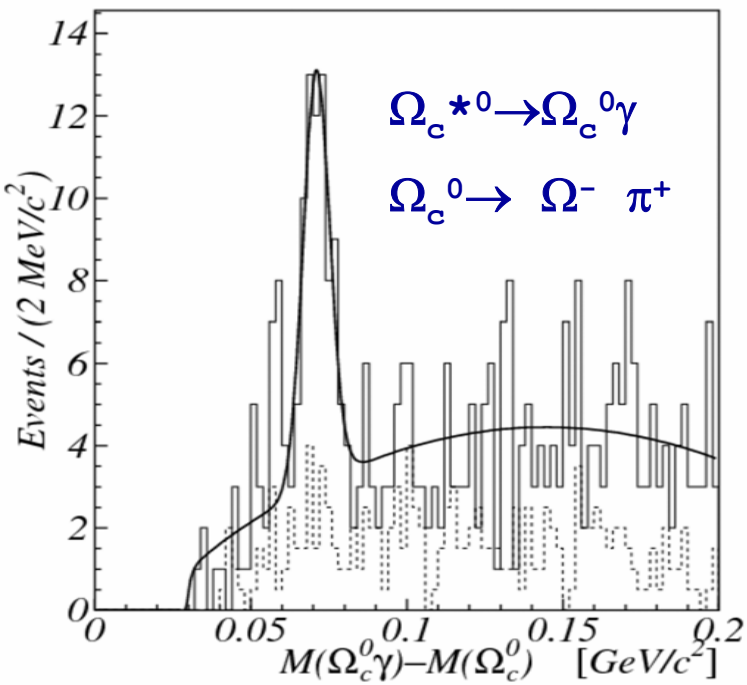


Ω_c^0, Ω_c^{*0} observation

$\Omega_c^0 = c\{ss\}$, $J^P = \frac{1}{2}^+$

PLB 672, 1 (2008)





$m_B(\Omega_c^0) = 2693.6 \pm 0.3^{+1.8}_{-1.5}$ MeV/c²

In good agreement with CLEO and BaBar

$N_{events} = 54 \pm 9$

$\Delta m = 70.7 \pm 0.9^{+0.9}_{-0.2}$ MeV/c²

In good agreement with BaBar

Summary and conclusions

- B-factory experiments proven to be a gold mine of charm
- $c\underline{u}$, $c\underline{d}$, $c\underline{s}$ ground state multiplets have been completed, further measurements are needed to understand their dynamics
- Excited $c\underline{s}$ candidates are observed, more studies are necessary to assign them or test the models
- All ground state charmed baryons have been observed (9 of $1/2^+$ and 6 of $3/2^+$), reach spectrum of excited states shows up (9 states observed) but their assignement awaits spin determinations