Charm Decays at B Factories

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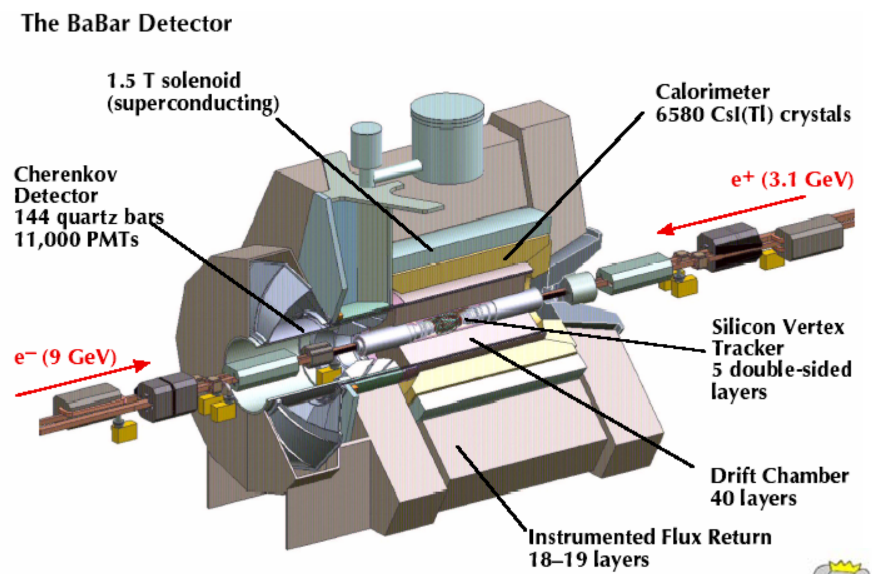
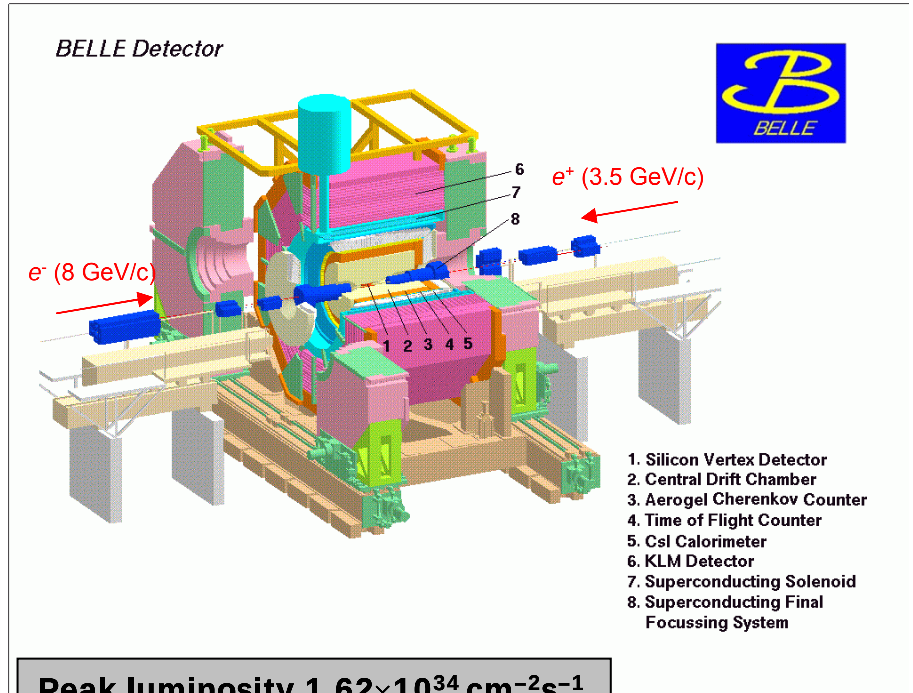
Outline

- Charm Decays at B Factories:
  - (Semi-) Leptonic and rare decays – *P. Jackson*
  - D Mixing – *A. Rahimi*
  - Dalitz Plots – *M. Papagallo*
  - Charm Baryons – *R. Chistov*
  - Charmonium and other spectroscopy – *S. Olsen, A. Palano, B. Yabsley, P. Pakhlov*
  - Tau Physics – *G. Lafferty*
- Here - *Choice of some results (probably) not covered in above:*
  - Charm Baryons (mostly from BaBar)
  - Charm Mesons – a few items
- Summary

BaBar and Belle



Peak luminosity 1.08×10^{34} cm^{-2}s^{-1}
Integrated luminosity 363 fb^{-1}



Peak luminosity 1.62×10^{34} cm^{-2}s^{-1}
Integrated luminosity 602 fb^{-1}

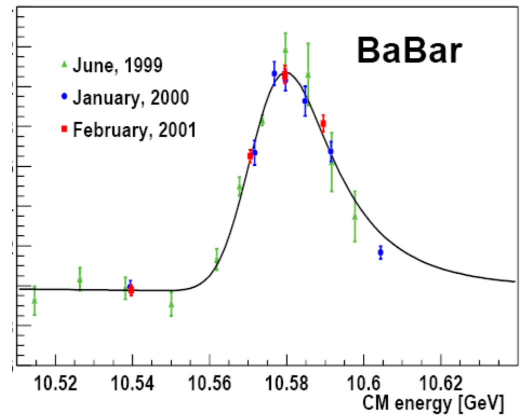
- Main purpose: Study CP violation in asymmetric $e^+e^- \to \Upsilon(4S) \to B\bar{B}$
  - Both experiments have far exceeded their design goals
  - Approx. 1 ab^{-1} integrated flux combined

Charm Hadrons at " Factories?

- Cross sections are large

e^+e^- $\rightarrow$	σ
$b\bar{b}$	1.05 nb
$c\bar{c}$	1.30 nb
$s\bar{s}$	0.35 nb
$u\bar{u}$	1.39 nb
$d\bar{d}$	0.35 nb

Can use "off peak" data



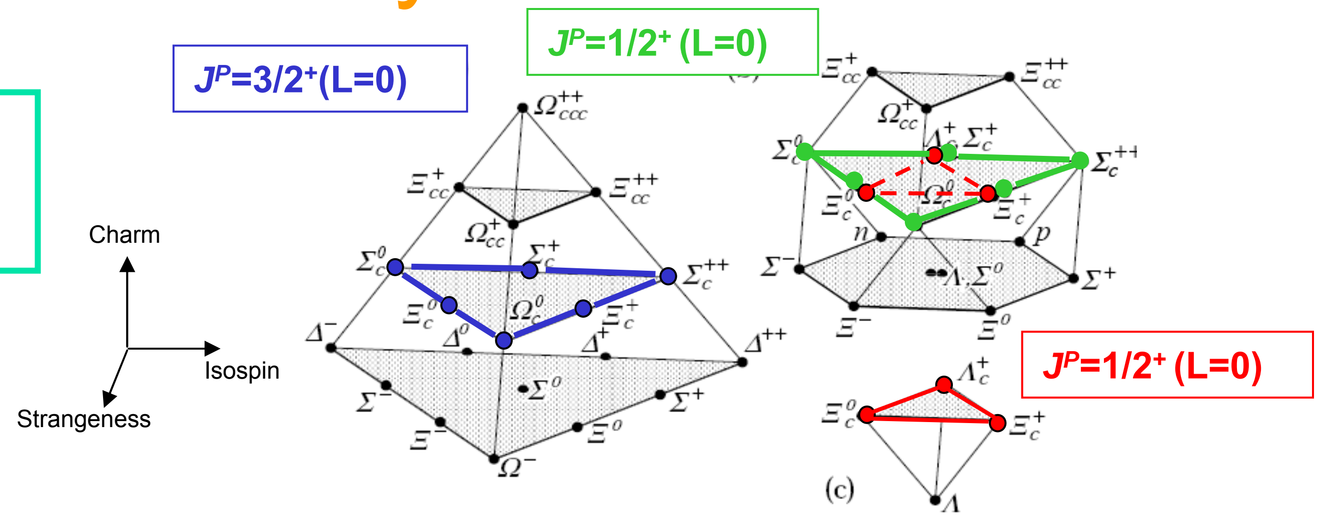
E_{CM} (GeV)

- Very high statistics (~1.4 x 10^6 *D*'s / fb^{-1}).
- Also
  - Relatively small combinatorial backgrounds in e^+e^- interactions.
  - Good particle ID.
  - Detection of all possible final states including neutrals.
  - Good tracking and vertexing

Charm Baryons

Charm Baryon States

BUT - No J^P are yet measured !



- |C| = 1:

- L=0 Ground State – almost full:

$J^P=1/2^+$: $\{6\}_{qq}$	$\Sigma_c(2455)$, $\Xi_c(2470)$, $\Omega_c(2698)$	All seen
$J^P=1/2^+$: $\{\overline{3}\}_{qq}$	$\Lambda_c(2285)$, $\Xi_c(2575)$	All seen
$J^P=3/2^+$: $\{6\}_{qq}$	$\Sigma_c(2520)$, $\Xi_c(2645)$, ??	All but Ω_c^*

- L>1 – filling up ?

$J^P=1/2^-$: – $\Lambda_c(2593)$, $\Xi_c(2790)$, …

$J^P=3/2^-$: – $\Lambda_c(2625)$, $\Xi_c(2815)$, …

… from CLEO 2

$\Lambda(\text{or }\Sigma)_c(2880)$, $\Lambda(\text{or }\Sigma)_c$ (2765) ??

- Several more new states from BaBar and Belle … and more

First Charm Baryon → Charm Meson $\Lambda_c(2940)$

- Observed in $c\bar{c}$ continuum production in D^0p decay mode ($D^0 \to K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$)

$\Lambda_c(2940)^+$:

M = (2939.8±1.3±1.0) MeV/c^2

Γ = (17.5±5.2±5.9) MeV

New data on $\Lambda_c(2880)^+$:

New Decay Mode → D^0p

BaBar:

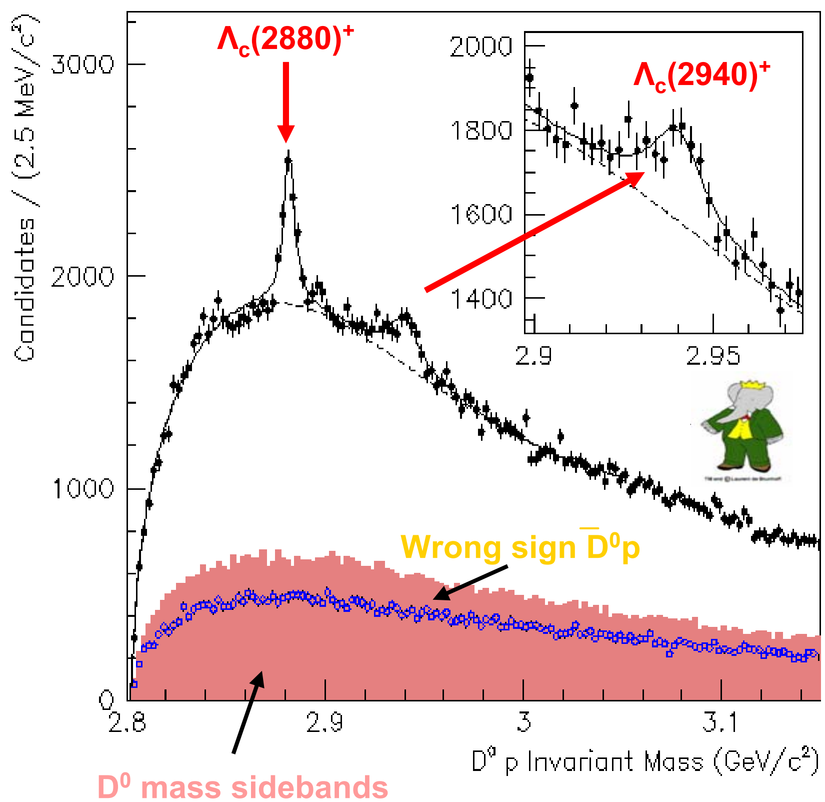
M = (2881.9±0.1±0.5) MeV/c^2

Γ = (5.8±1.5±1.1) MeV

PDG: ("Could be Σ_c")

M = (2880.9±2.3) MeV/c^2 ; Γ < 8 MeV

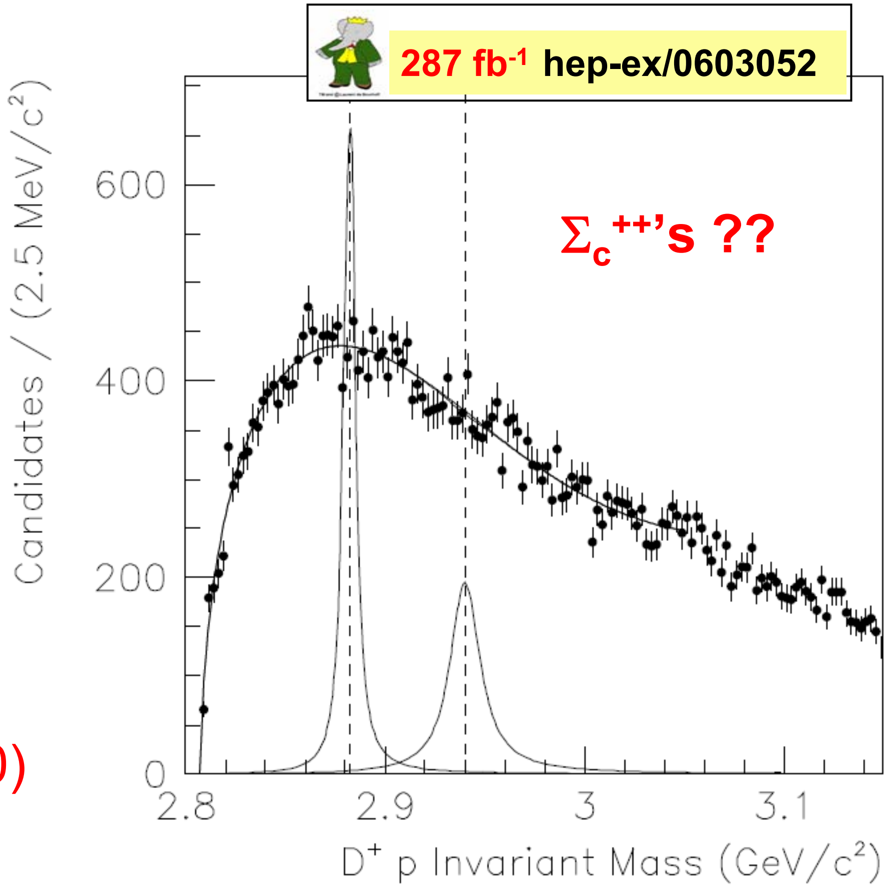
287 fb^{-1} hep-ex/0603052



New Baryon $\Lambda_c(2940)$

- Neither $\Lambda_c(2940)$ nor $\Lambda_c(2880)$ seen in D^+p system

→ **<u>Neither</u>** are Σ_c's



Other observations:

Why <u>not</u> seen in $\Lambda_c\pi^+\pi^-$ or $\Sigma_c\pi$?

Three states predicted near this mass $^3/_2^-$, $^1/_2^+$, $^1/_2^-$

$\Lambda_c(2940)$ is 6 MeV/c^2 below D^*p threshold

$\Lambda_c(2940)$ is π mass above $\Lambda_c(2880)$

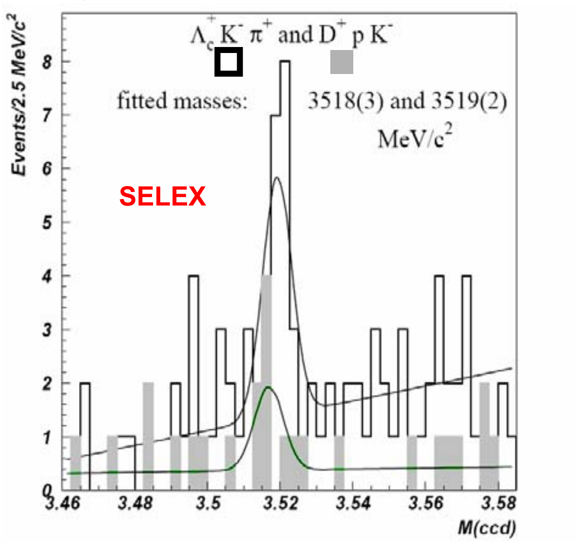
Search for Ξ_{cc} States

- Predicted in mass range 3.5 – 3.8 GeV/c^2
- Predicted cross-sections from e^+e^- @ 10 GeV/c^2 ~ 1-250 fb

  Double-charm cross-sections under-estimated by NRQCD

  → expect to produce 10^2 – 10^4 from 232 fb^{-1}

Phys.Lett.B628:18-24,2005



SELEX reports state at 3.52 GeV/c^2

Σ^- beam ~ 1,630 Λ^+_c

Not confirmed by FOCUS

γ beam ~ 19,500 Λ^+_c

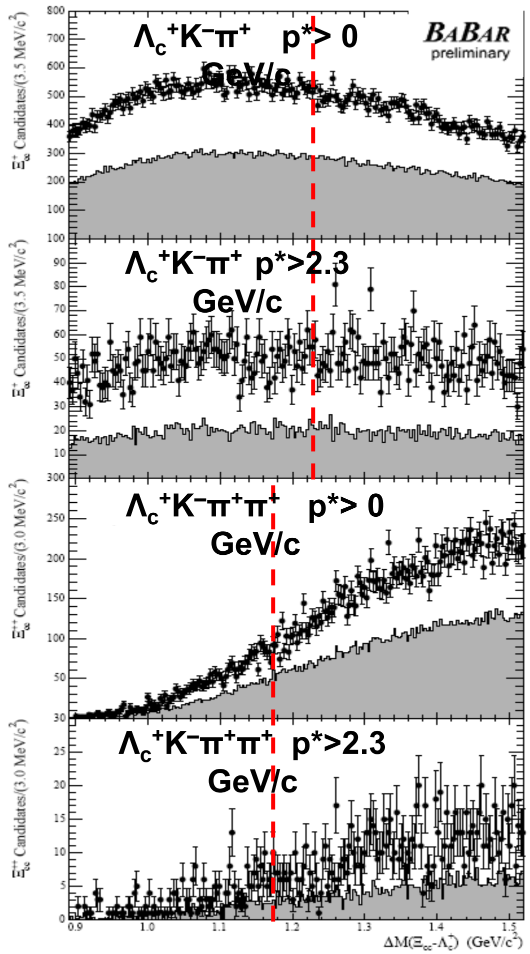
Nor BaBar, nor Belle

e^+e^- ~ 10^6 Λ_c^+

Search for Ξ_{cc} States

$\Xi_{cc}^{+(+)} \rightarrow \Lambda_c^+ K^- \pi^+ (\pi^+)$

232 fb^{-1} hep-ex/0605075



Search made throughout ranges indicated

- for both charge states,
- with and without p*cuts

21 two-d fits: Gaussian signal on background in overlapping 10 MeV/c^2 ranges.

Results normalized to cross-section for producing Λ_c^+

95% C.L. limits:

$$\frac{\sigma(e^+e^- \to \Xi_{cc}^+ X) \times \mathcal{B}(\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+)}{\sigma(e^+e^- \to \Lambda_c^+ X)} < 6.9 \times 10^{-4}$$

$$\frac{\sigma(e^+e^- \to \Xi_{cc}^+ X) \times \mathcal{B}(\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+)}{\sigma(e^+e^- \to \Lambda_c^+ X)} < 2.7 \times 10^{-4}$$

$$\frac{\sigma(e^+e^- \to \Xi_{cc}^{++} X) \times \mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+)}{\sigma(e^+e^- \to \Lambda_c^+ X)} < 10.0 \times 10^{-4}$$

$$\frac{\sigma(e^+e^- \to \Xi_{cc}^{++} X) \times \mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+)}{\sigma(e^+e^- \to \Lambda_c^+ X)} = 4.0 \times 10^{-4}$$

Search for Ξ_{cc} States

$\Xi_{cc}^{+(+)} \rightarrow \Xi_c^0 \pi^+ (\pi^+)$

Search made throughout ranges indicated

50 fits: Double Gaussian signal on linear background in 10 MeV/c^2 ranges.

Results compare with

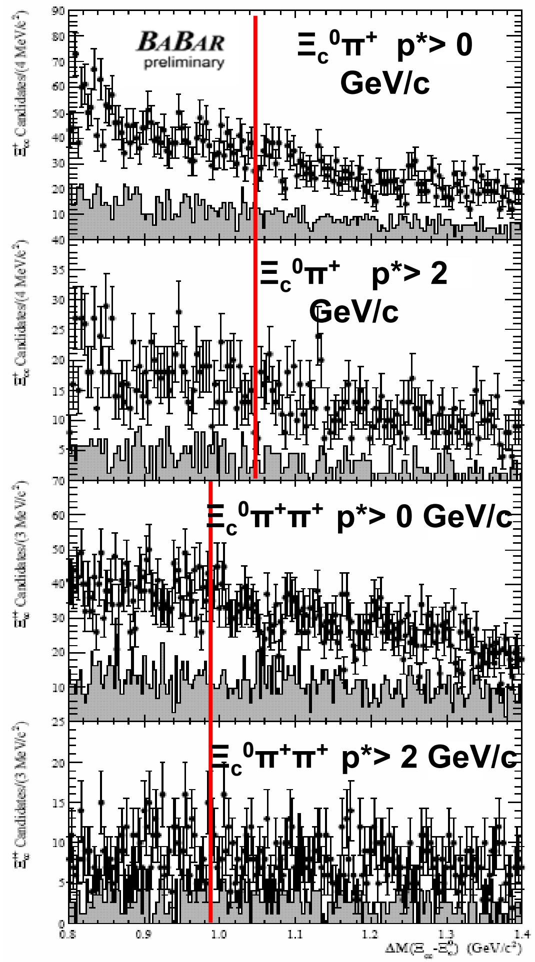
$\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) \times \ldots$

$\ldots \sigma(e^+e^- \to \Xi_c^0 X)$

$= (388 \pm 39 \pm 41)$ fb

$[\mathcal{B}(\Xi_{cc} \to \Xi_c^0 \pi' s) \sim$ few%??]

232 fb^{-1} hep-ex/0605075



95% C.L. limits:

$\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) \times \ldots$

$\ldots \sigma(e^+e^- \to \Xi_{cc}^+ X) \times \mathcal{B}(\Xi_{cc}^+ \to \Xi_c^0 \pi^+)$
< 2.0 fb $\quad (p^* > 0$ GeV/c$)$

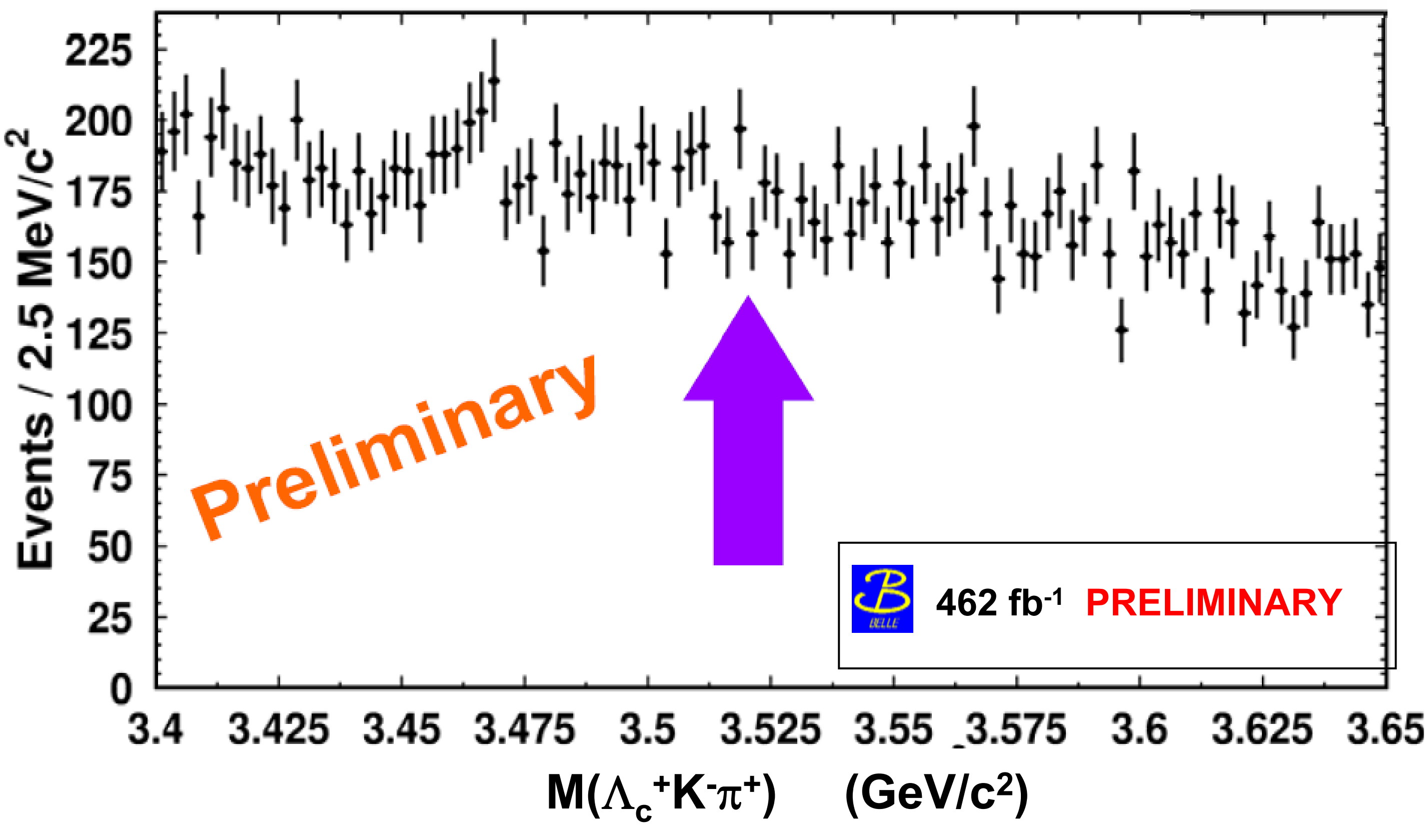
$\ldots \sigma(e^+e^- \to \Xi_{cc}^+ X) \times \mathcal{B}(\Xi_{cc}^+ \to \Xi_c^0 \pi^+)$
< 1.3 fb $\quad (p^* > 2$ GeV/c$)$

$\ldots \sigma(e^+e^- \to \Xi_{cc}^+ X) \times \mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^0 \pi^+ \pi^+)$
< 5.6 fb $\quad (p^* > 0$ GeV/c$)$

$\ldots \sigma(e^+e^- \to \Xi_{cc}^+ X) \times \mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^0 \pi^+ \pi^+)$
< 3.4 fb $\quad (p^* > 2$ GeV/c$)$

Search for Ξ_{cc} States

- Belle also found no evidence for the state seen by SELEX using an even larger sample.



Observation of Two New $\Xi_c(csu)$ States in cc Continuum Production

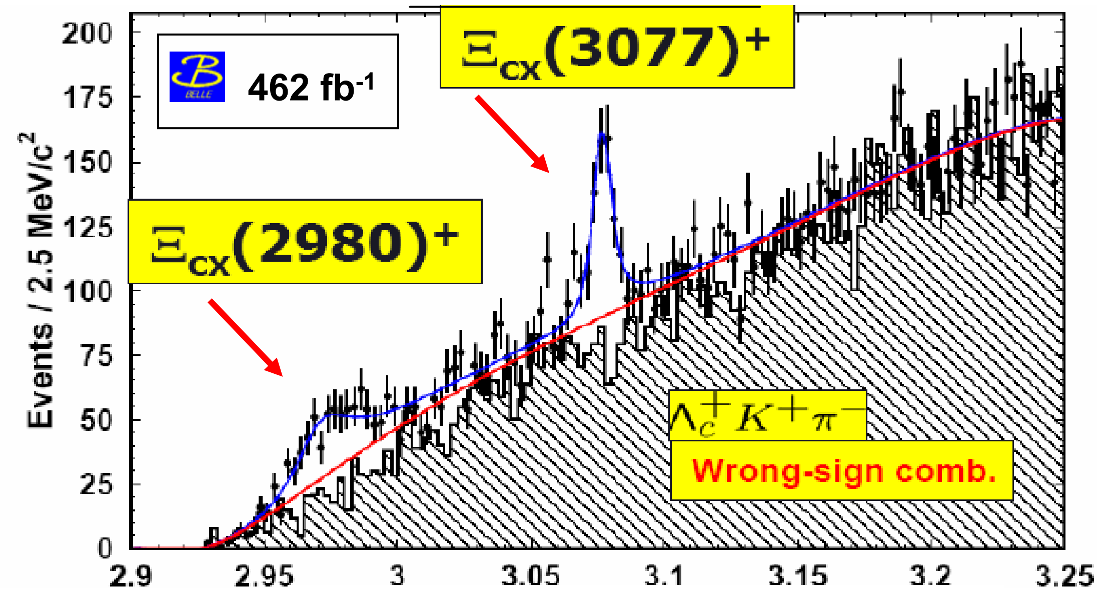
While searching for weak decay of

$\Xi_{cc} \rightarrow \Lambda_c^+ K^- \pi^+$

$\hookrightarrow p K^- \pi^+$

Found strong decays of new Ξ_c^*'s instead:

$\Xi_{cx} \rightarrow \Lambda_c^+ K^- \pi^+$



No structure in Λ_c^+ sidebands

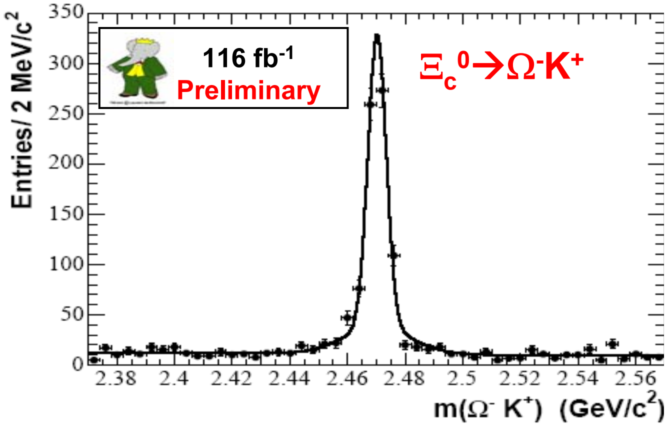
Nor in $\Lambda_c^+ K^+ \pi^-$ or $\Lambda_c^+ K^- \pi^-$ wrong sign combinations.

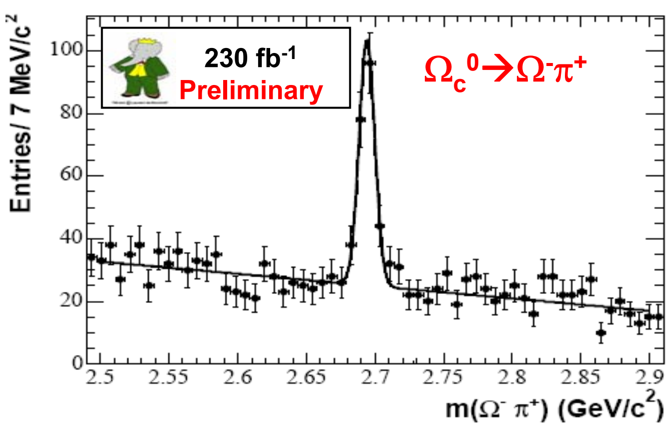
462 fb^{-1} **PRELIMINARY**

New State	Mass, (MeV/c^2)	Width, (MeV/c^2)	Yield, (events)	Significance, (σ)
$\Xi_{cx}(2980)^+$	$2978.5 \pm 2.1 \pm 2.0$	$43.5 \pm 7.5 \pm 7.0$	405.3 ± 50.7	6.3
$\Xi_{cx}(3077)^+$	$3076.7 \pm 0.9 \pm 0.5$	$6.2 \pm 1.2 \pm 0.8$	326.0 ± 39.6	9.7

The Spin of The Ω^-

- The existence of large samples of charm baryons makes possible what was once incredibly difficult !

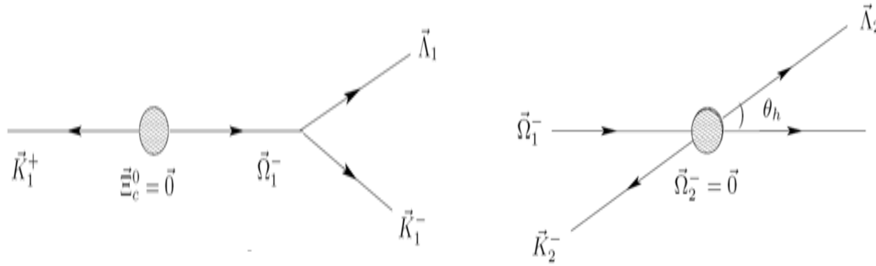




Earlier results from bubble chambers using small, unaligned samples of Ω^- could only conclude that J>1/2.

Assume the spin of charmed parent is ½:

In the charm hyperon rest frame, the Ω^- is produced with helicity ½



independent of the Ω^- spin J.

The Spin of The Ω^-

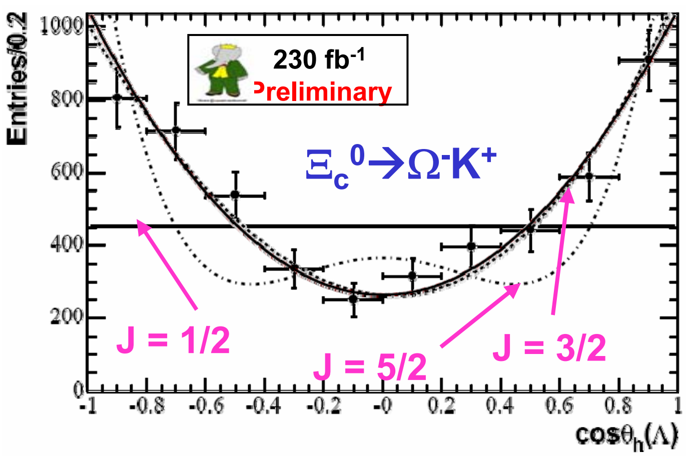
- The $\Omega^- \rightarrow \Lambda K^-$ decay distribution in its "helicity frame" is then

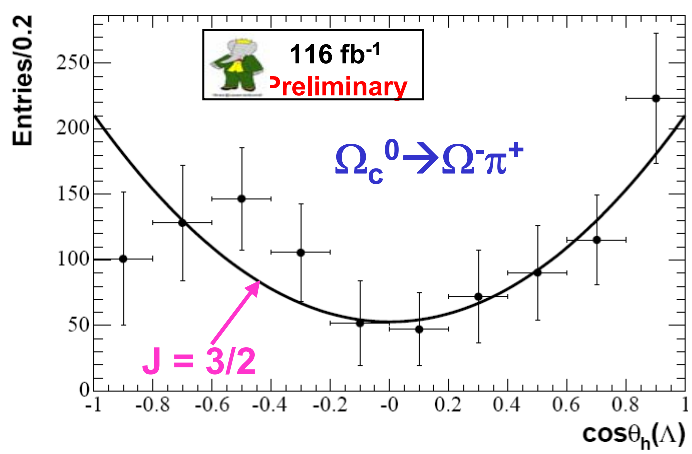
$$I \propto \sum_{\lambda_i,\lambda_f} \rho_i \left| A^J_{\lambda_f} D^{J*}_{\lambda_i \lambda_f}(\phi, \theta_h, 0) \right|^2$$

ρ_i (is density matrix)

λ_i, λ_f are initial and final helicities

J_Ω	Fit χ^2/NDF	Fit probability	Comment
1/2	100.4/9	1×10^{-17}	Fig. 4, solid line
3/2	6.5/9	0.69 ($\beta = 0$)	Fig. 3, solid curve
3/2	6.1/8	0.64 ($\beta \neq 0$)	Fig. 3, dashed curve
5/2	47.6/9	3×10^{-7}	Fig. 4, dashed curve





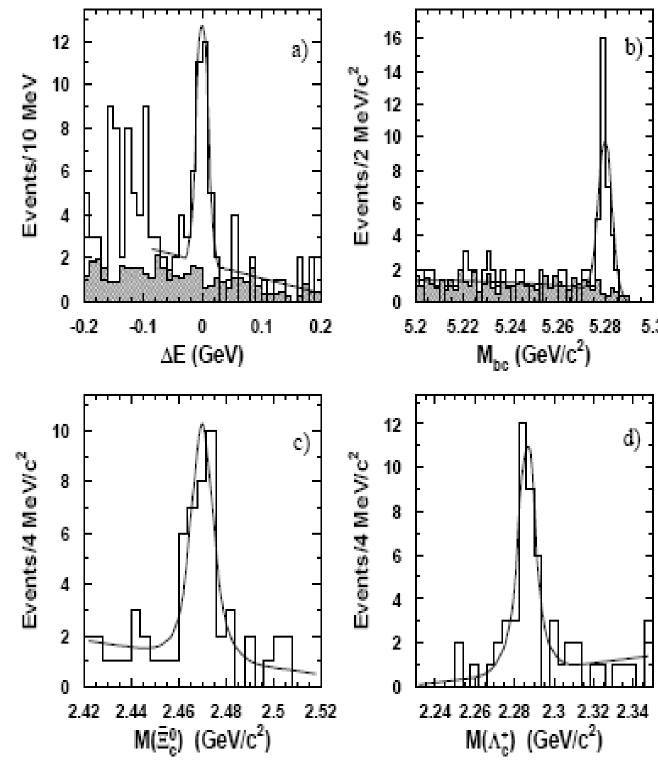
→ Conclude J = 3/2 (*if charmed parents are J=1/2*).

How About Charm Baryons?

- Information on charm baryon spins could come from decays like

  $B^{+,0} \rightarrow \Xi_c^{0,-} \Lambda_c^{+}$

  $\quad \hookrightarrow \Xi^{-}\pi^{+}$



- So far (Belle 357 fb^{-1}) only ~12 events where $\Xi_c^{0} \rightarrow \Xi^{-}\pi^{+}$

$$\mathcal{B}(B^{+} \to \Lambda_c^{+} \bar{\Xi}_c^{0}) \times \mathcal{B}(\bar{\Xi}_c^{0} \to \bar{\Xi}^{+}\pi^{-})$$
$$= (5.6^{+1.9}_{-1.5} \pm 1.1 \pm 1.5) \times 10^{-5}$$

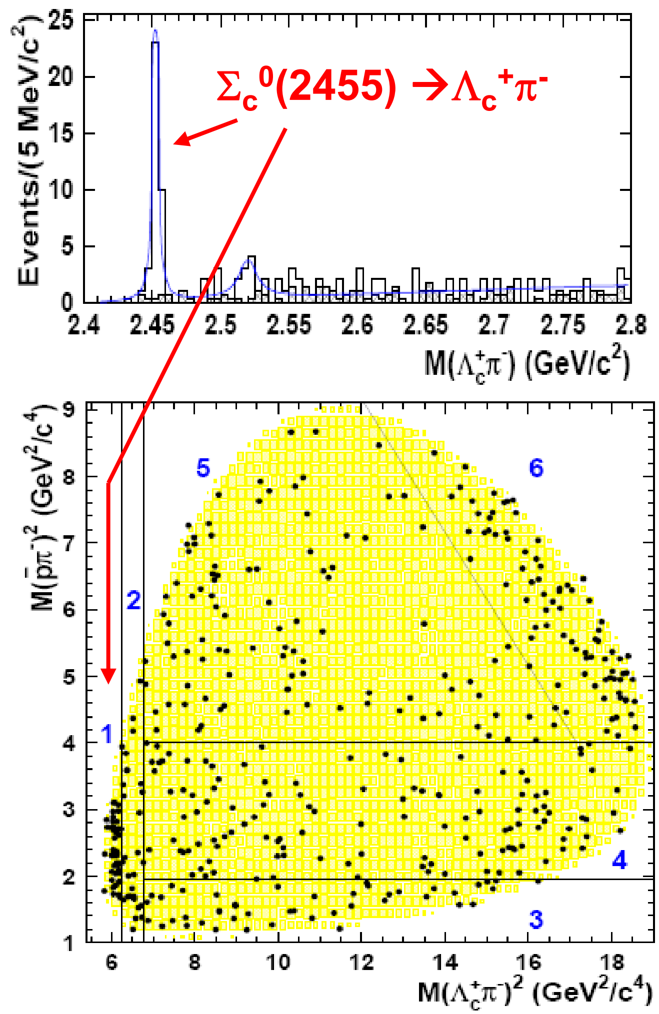
→ Not promising for determination of *J*

357 fb^{-1} **hep-ex/0511007 (2005)**

Maybe Three- (or more-) Body Decays ?

- 3-body BF's about 10 x 2-body
  $B^- \rightarrow \Lambda_c^+ \overline{p}\, \pi^-$ (product of BF's ~ 2 x 10^{-5})
  have. significant # events:
  $B^- \rightarrow \Sigma_c^0 \overline{p}$ ($\Sigma_c^0 \rightarrow \Lambda_c^+ \pi^-$)

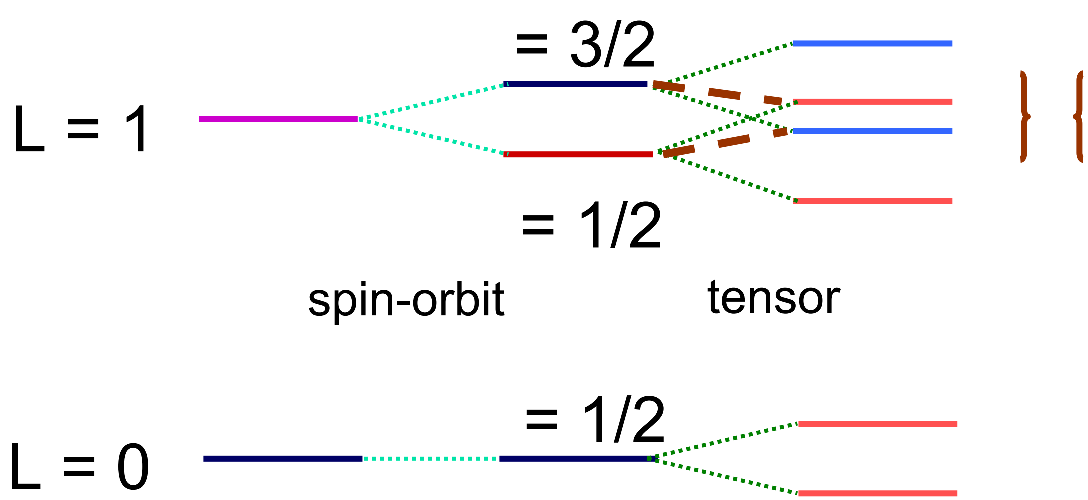
- Lots of other things going on
  - Good techniques for dealing with coherent backgrounds may be required.



140 fb^{-1} **hep-ex/0409005 (2005)**

Charm Mesons

Heavy-Light Systems



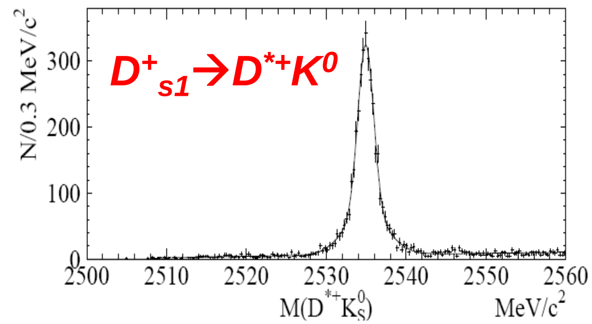
J^P	$^{+1}L_J$	Γ	
2^+	$^3P_2$	small	→D-wave
1^+	$^1P_1$	large	→S-wave
1^+	$^3P_1$	small	→D-wave
0^+	$^1P_0$	large	→S-wave
1^-	$^1S_1$	small	
0^-	$^1S_0$	small	

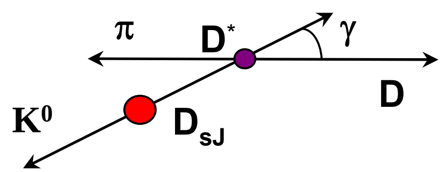
Expected by quark models
To be below $D^{(*)}K$ threshold

- Narrow states are easy to find.
- Two wide states are harder.
- Since charm quark is not infinitely heavy, some =1/2, 3/2 mixing can occur between the two $=1^+$ states.

Mixing in $J^P = 1^+$ $D_{sJ}(2460)/D_{s1}(2536)$?

- Belle has analyzed $D_{s1}(2536)$ decays to D^*K to look for an S-wave component.
  - (In the limit the c quark has infinite mass, the narrow states would decay in pure D-wave)
- Angular distribution of π^+ in D^{*+} system leads to the limits:





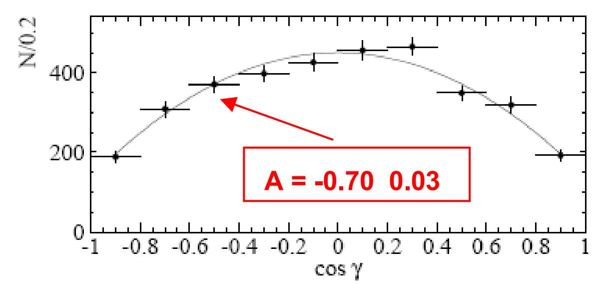
$1 + A\cos^2\gamma$:

S-wave: A=0

D-wave: A=3

$0.277 < \Gamma_S/(\Gamma_S+\Gamma_D) < 0.955$

Indicative of some S-wave



281 fb⁻¹ hep-ex/0507030

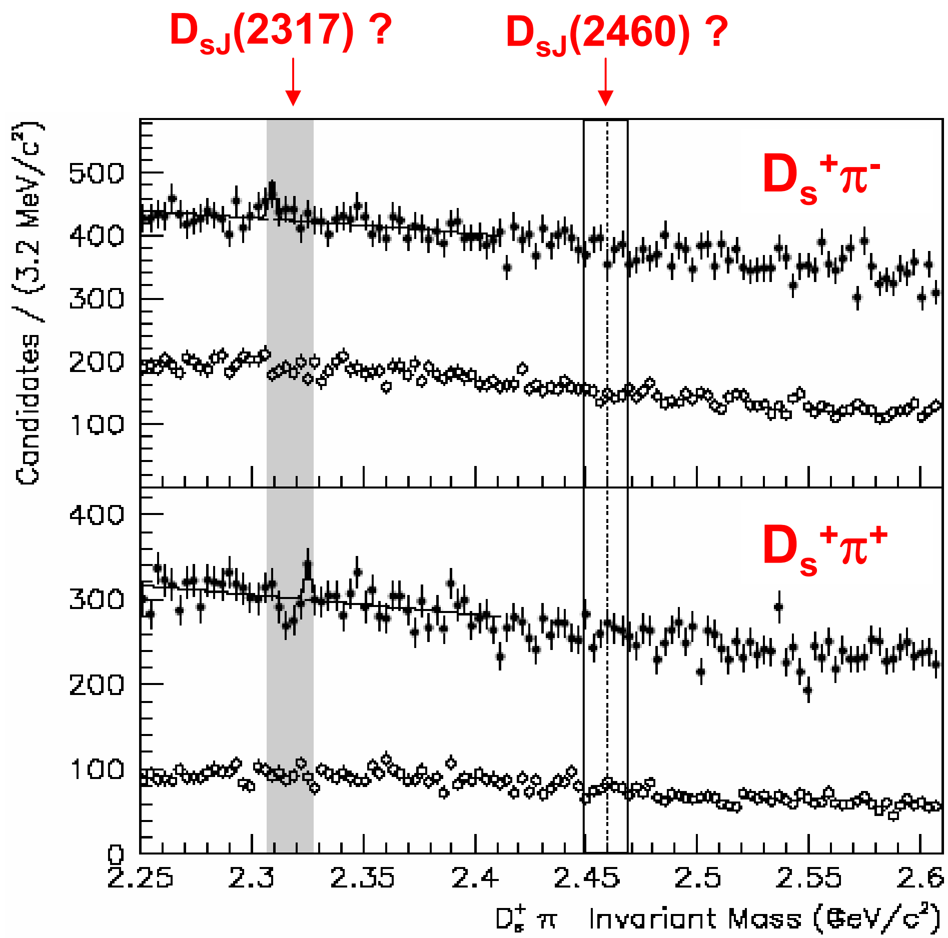
D_{sJ}'s - Overtly Exotic ?

232 fb^{-1} hep-ex/0604030

- No indication of overtly exotic charge states
  Circles are D_s side-bands

- For $D_{sJ}(2460)$ need to look in $D_s^{(*)+}\pi^0\pi^{+,-}$ if $J^P=1^+$

(See Antimo Palano's talk for full details)



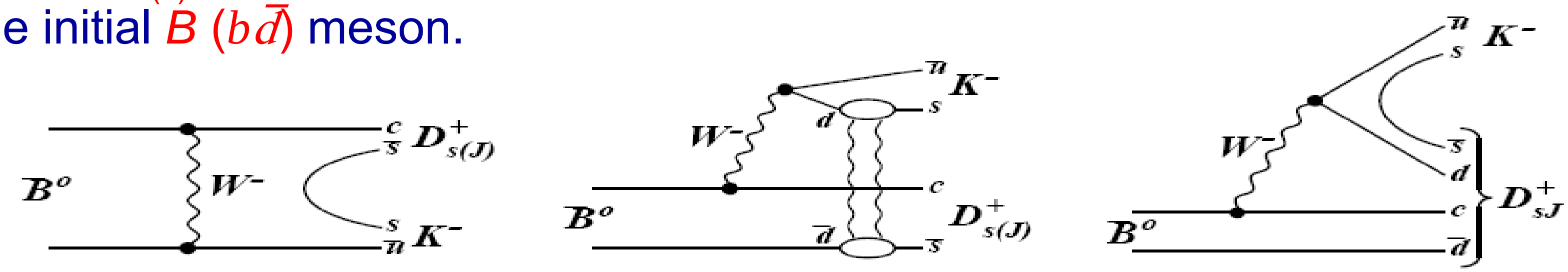
Decays of $B^0 \rightarrow D_s(D_{sJ})^+ + h^-$

- Exotic nature of D_{sJ} states could show up in

C.-H. Chen, H.-n Li, Phys. Rev. D 69, 054002 (2004)

$$R_h = \frac{\mathcal{B}\{B^0 \to D_s^+ h^-\}}{\mathcal{B}\{B^0 \to D_{sJ}^+ h^-\}} \quad (h = \pi, K, D)$$

- $\bar{B}^0 \rightarrow D_{s(J)}K^-$ is especially interesting none of the final state quarks ($cus\bar{s}$) are in the initial B ($b\bar{d}$) meson.



- Expect R_h ~ 1 for $c\bar{s}$ and R_h ~ 0.1 for $c\bar{s}u\bar{u}$

$\bar{B}^0 \to X + Y$	$X = \{D_s^+ \to \text{All}\}$	$X = \{D_{sJ}(2317)^+ \to D_s^+\pi^0\}$	$X = \{D_{sJ}(2460)^+ \to D_s^+\gamma\}$
$h = K^-$	$(3.8 \pm 1.3) \times 10^{-5}$	$(3.3 \pm 0.6 \pm 0.7) \times 10^{-5}$	$(0.4 \pm 0.15^{+0.12}_{-0.11}) \times 10^{-5}$
$h = D^-$	$(8.0 \pm 3.0) \times 10^{-3}$	$(1.1 \pm 0.4) \times 10^{-3}$	$(8.1^{+2.8}_{-2.5}) \times 10^{-4}$

350 fb^{-1} hep-ex/0507064

PRL 93, 181801 113 fb^{-1}

→ $R_K \sim R_D \sim 1$ (no clear evidence for $c\bar{s}d\bar{d}$)

Doubly Cabbibo Suppressed Decays

First measurement of

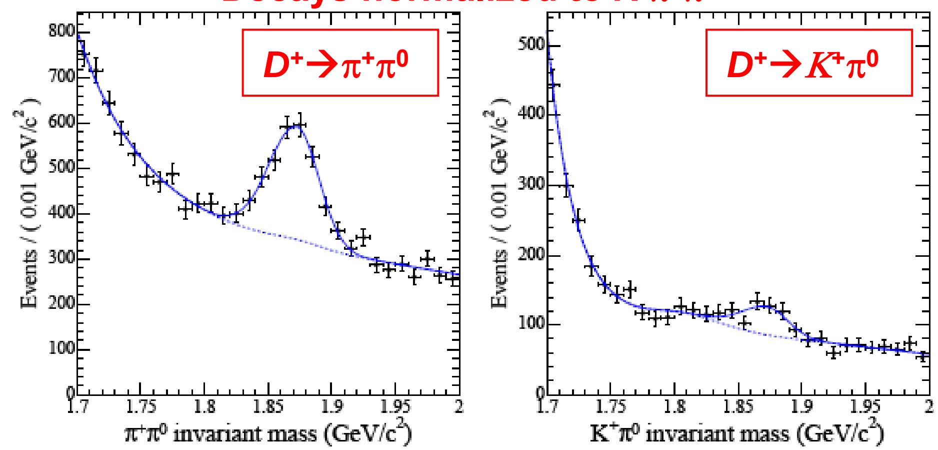
$$\frac{\Gamma(D^+ \to K^+\pi^0)}{\Gamma(D^+ \to \text{all})}$$

(CLEO 1990 < 0.04%)

Measured rate relative to
$D^+ \to K^-\pi^+\pi^+$

then used average of PDG and recent CLEO measurement for this rate.

Decays normalized to $K^-\pi^+\pi^+$



$$\frac{\mathcal{B}(D^+\to\pi^+\pi^0)}{\mathcal{B}(D^+\to K^-\pi^+\pi^+)} = (13.3 \pm 1.1 \pm 9.0) \times 10^{-3}$$

PDG:(13.3±2.2)   CLEO-c:(13.3±0.7±0.6)%

$$\frac{\mathcal{B}(D^+\to K^+\pi^0)}{\mathcal{B}(D^+\to K^-\pi^+\pi^+)} = (2.68 \pm 0.50 \pm 0.26) \times 10^{-3}$$

$\rightarrow$

$$\mathcal{B}(D^+ \to \pi^+\pi^0) = (12.5 \pm 1.0 \pm 0.8 \pm 0.4) \times 10^{-4}$$

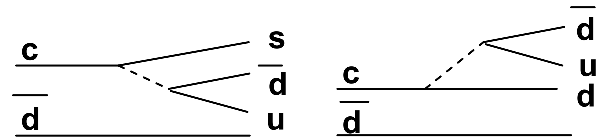
$$\mathcal{B}(D^+ \to K^+\pi^0) = (2.52 \pm 0.47 \pm 0.24 \pm 0.08) \times 10^{-4}$$

Uncertainty in $D^+ \to K^-\pi^+\pi^+$

124 fb^{-1} hep-ex/0605044

Doubly Cabbibo Suppressed Decays

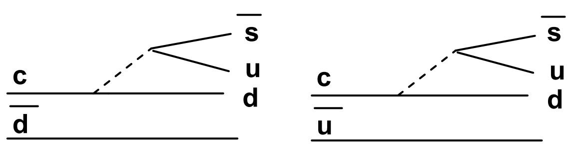
Naïve, exact SU(3):



$$\frac{\Gamma(D^+ \to \bar{K}^0\pi^+)}{\Gamma(D^+ \to \pi^+\pi^0)} = 2\left|\frac{V_{cs}}{V_{cd}}\right|^2$$

BaBar: 2/(1.49 0.29)

- Also:



$$\frac{\mathcal{B}(D^+ \to K^+\pi^0)\tau_{D^0}}{\mathcal{B}(D^0 \to K^+\pi^-)\tau_{D^0}} = \frac{1}{2}$$

BaBar: 0.70 0.17

SU(3) predictions are over-simplified:

- First ratio affected by K_s-K_L interference
- $D^+ \to K^+\pi^0$ can also proceed by W-exchange or annihilation diagrams.

→ Measurements are challenging

Results still not well understood.

Wrong Sign D^0 Decays

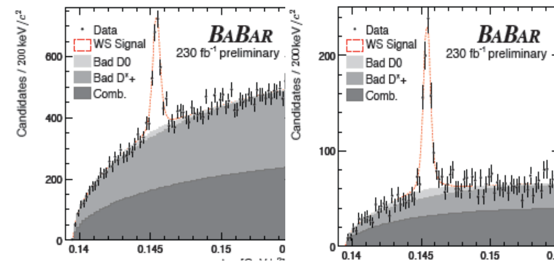
- Time-integrated rates can be compared with
  $\tan^4 \theta_c$ = (0.281 § 0.006) x 10^{-2}

	$\frac{\Gamma(D^0 \to K^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)}$	$\frac{\Gamma(D^0 \to K^+\pi^-\pi^0)}{\Gamma(D^0 \to K^-\pi^+\pi^0)}$	$\frac{\Gamma(D^0 \to K^+\pi^-\pi^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+\pi^-\pi^+)}$
BaBar (%)	–	$0.214 \pm 0.008 \pm 0.008$	–
Belle (%)	–	$0.229 \pm 0.015^{+0.013}_{-0.009}$	$0.320 \pm 0.018^{+0.015}_{-0.013}$
PDG (%)	0.362 ± 0.029	$0.43^{+0.11}_{-0.10} \pm 0.07$	0.42 ± 0.13

→ Belle/BaBar agreement excellent
→ big improvement over PDG values

Despite high backgrounds, measurements at few % level
(BaBar tags other side)

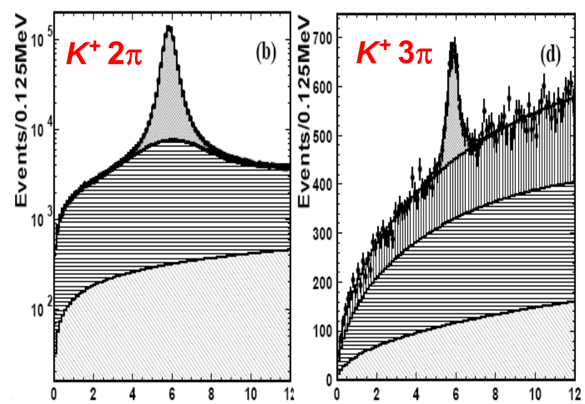
Before After



229 fb^{-1} PRELIMINARY

$K^+ 2\pi$ ΔM (MeV/c^2)

281 fb^{-1} hep-ex/0507071 PRELIMINARY



ΔM (MeV/c^2)

- *D^** tagging allows measurement of *CP* asymmetries
  Belle: $K^+2\pi$ (-0.006 § 0.053); $K^+3\pi$ (-0.018 § 0.044)
  consistent with zero.

  → any new physics at level much smaller than DCS for "wrong sign" decays.

$\Gamma(D_{(s)}^{*} \rightarrow D_{(s)}\pi^0)/\Gamma(D_{(s)}^{*} \rightarrow D_{(s)}\gamma)$

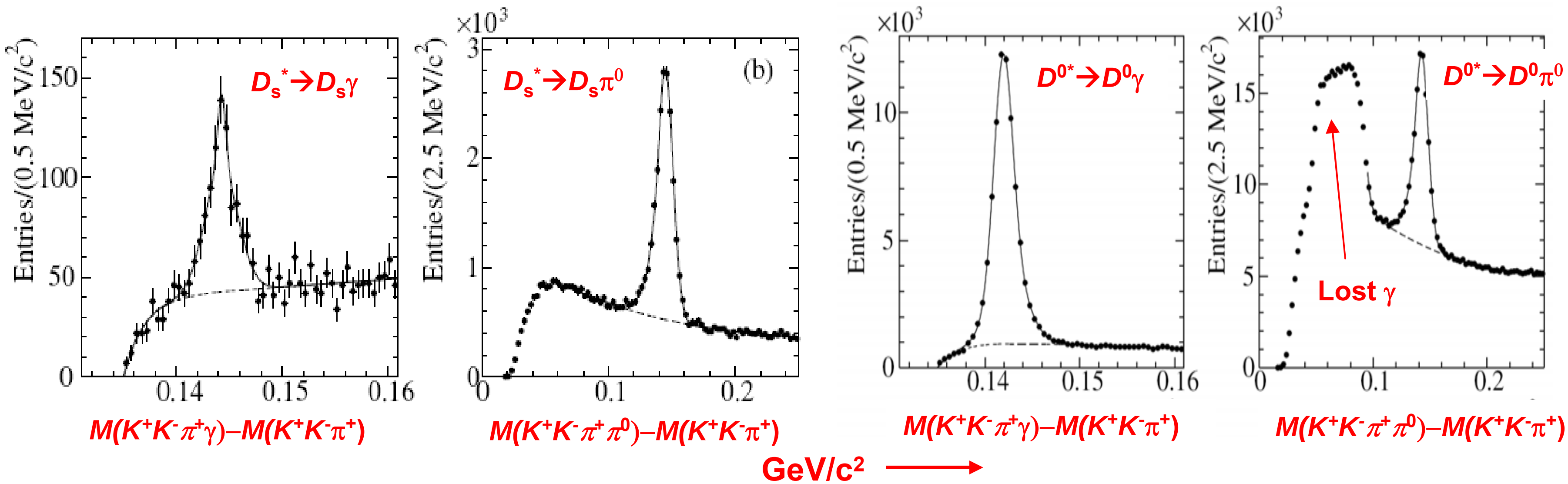
- *BaBar* has improved measurements of the π^0/γ ratios:

Agree with current results

Fresh input to χPT

90.4 fb^{-1} hep-ex/0508039

	BaBar	PDG
$\frac{\Gamma[D_s^{*+}(2117)\rightarrow D_s^+\pi^0]}{\Gamma[D_s^{*+}(2117)\rightarrow D_s^+\gamma]}$	$0.062 \pm 0.005 \pm 0.006$	$0.062^{+0.020}_{-0.018} \pm 0.022$
$\frac{\Gamma[D^{*0}(2007)\rightarrow D^0\pi^0]}{\Gamma[D_s^{*+}(2007)\rightarrow D^0\gamma]}$	$1.74 \pm 0.02 \pm 0.13$	1.625 ± 0.20



Summary

- *B* Factories provide a very clean environment for the production of all charm hadrons
  - → new particle paradise !
  - → BUT no doubly charmed baryons
- Large (and growing) samples of charm mesons and baryons are likely to complement results from τ-charm facilities for some time to come
- In several ways, we are learning how information on systems to which charm hadrons, or B mesons, decay can be extracted
- There is a large and enthusiastic community anxious to work on all aspects of the physics available.

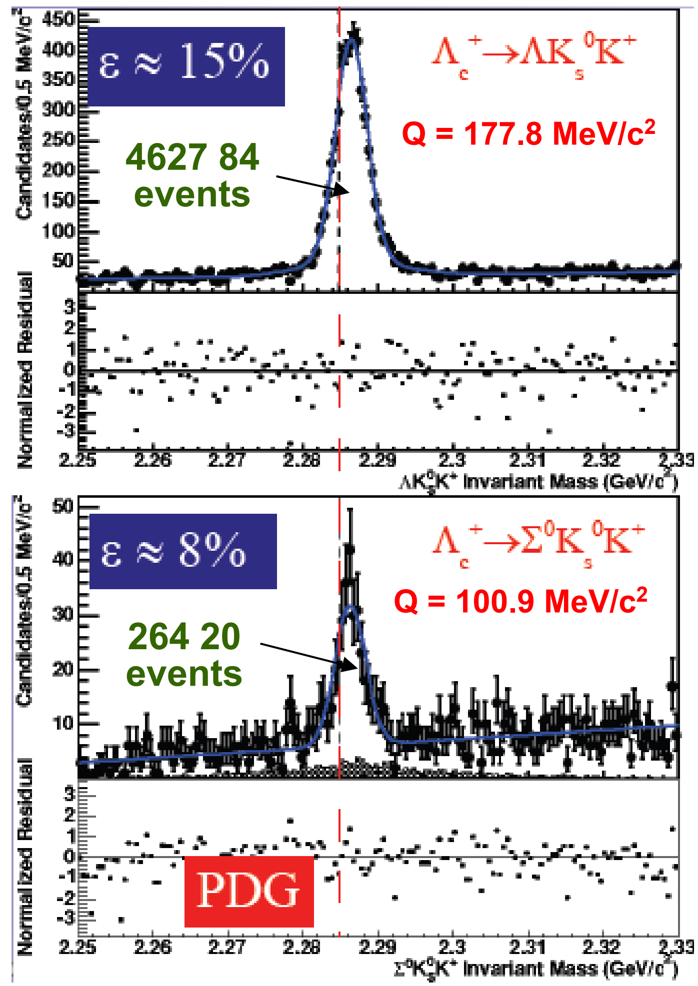
Back up Slides

Precision Measurement of Λ_c Mass

hep-ex/0507009 232 fb^{-1}

- Important measurement
  - most charm baryon masses measured relative to this
- Method:
  - Choose decay modes with small Q-value/large BR:

    $\Lambda_c \rightarrow \Lambda K^+K_s^0$ and $\Sigma^0 K^+K_s^0$
  - Estimate / adjust major systematic uncertainties in:
    - Material audit – determine Λ and K^0 mass vs. decay path length
    - Magnetic field – determine Λ and K^0 mass vs. momentum in lab.
- Much larger control samples:
  - $\Lambda_c^+ \rightarrow pK^-\pi^+$ 1.5 x 10^6 evs.
  - $\Lambda_c^+ \rightarrow pK^0$ 2.4 x 10^5 evs.



Results

$\Lambda_c \rightarrow \Lambda K^+ K_s^0$	2286.501 0.041 (stat.) 0.144 (syst.)
$\Lambda_c \rightarrow \Sigma^0 K^+ K_s^0$	2286.303 0.181 (stat.) 0.126 (syst.)
$\Lambda_c \rightarrow p K^- \pi^+$	2286.393 0.018 (stat.) 0.447 (syst.)
$\Lambda_c \rightarrow p K_s^0$	2286.361 0.034 (stat.) 0.428 (syst.)

Large Q

Combined measurement :

$$m(\Lambda_c) = 2286.46 \pm 0.14 \text{ MeV}/c^2$$

- Most precise measurement of charm mass to date
- Approximately 4 x more precise than

  Current PDG value: 2284.9 0.6 MeV/c^2

  and about 2.5 σ higher

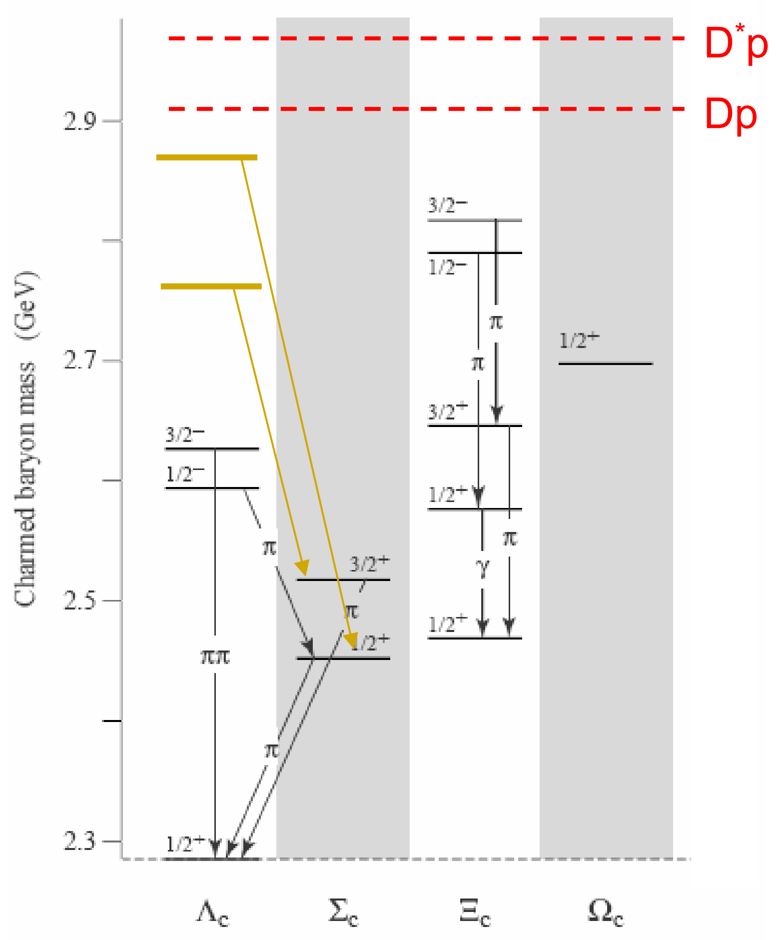
hep-ex/0507009 232 fb^{-1}

Charm Baryon States

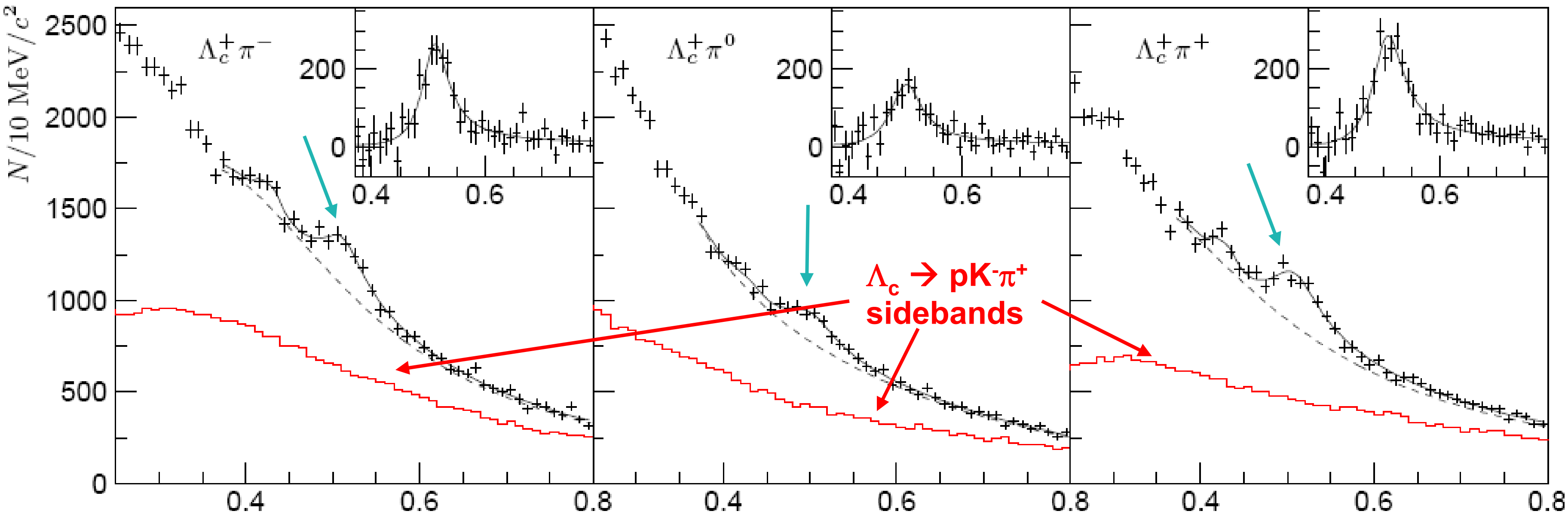
- L>1 – filling up ?
  - $J^P=1/2^-$: – $\Lambda_c(2593)$, $\Xi_c(2790)$, …
  - $J^P=3/2^-$: – $\Lambda_c(2625)$, $\Xi_c(2815)$, …
- Most massive in PDG 2005 is Ξ_c (2815)

CLEO 2 has added $\Lambda_c(2880)$ and $\Lambda_c(2765)$

PDG 2005



New Σ_c (2800) Triplet

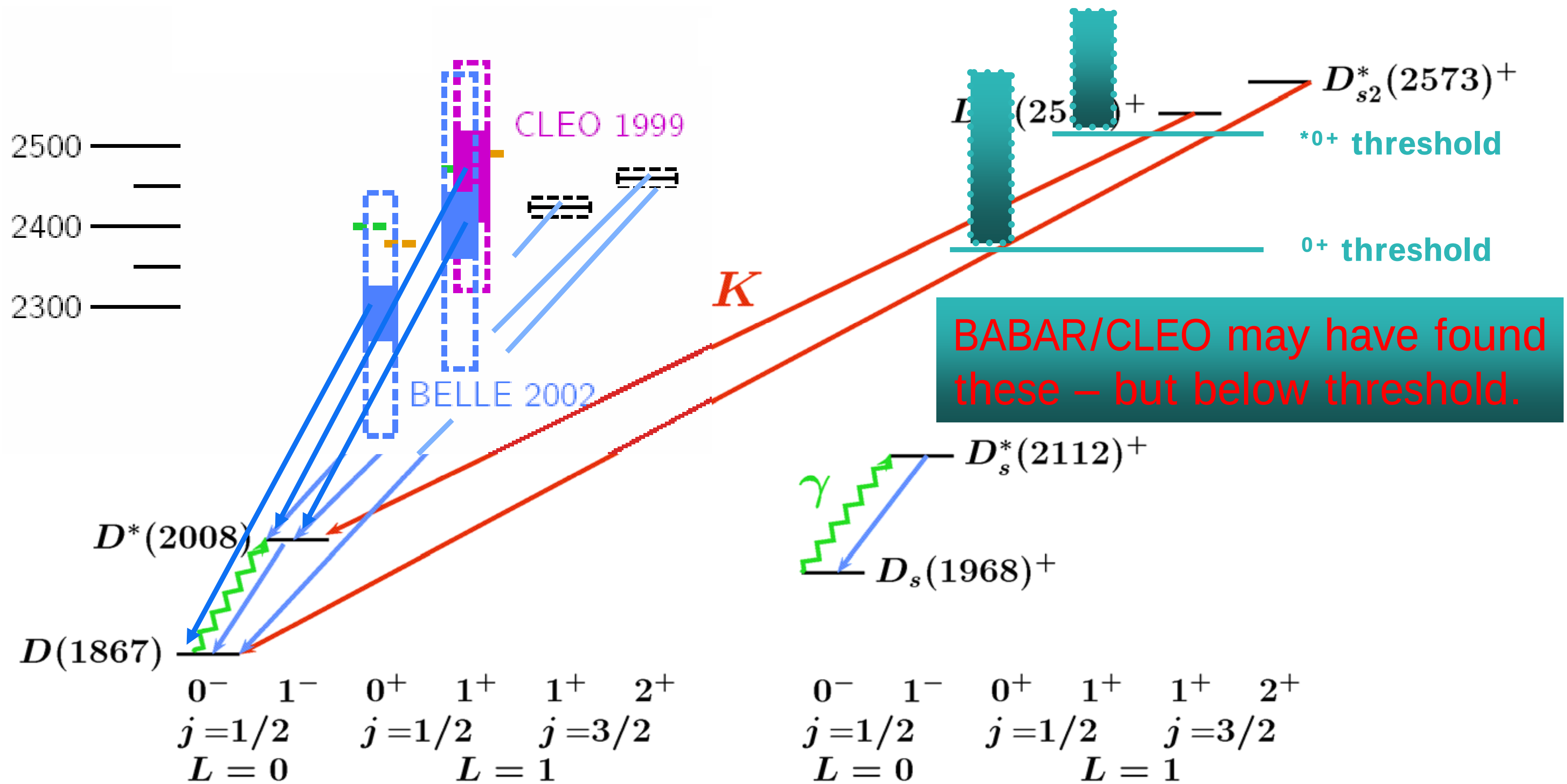


281 fb^{-1} PRL94, 122002 (2005)

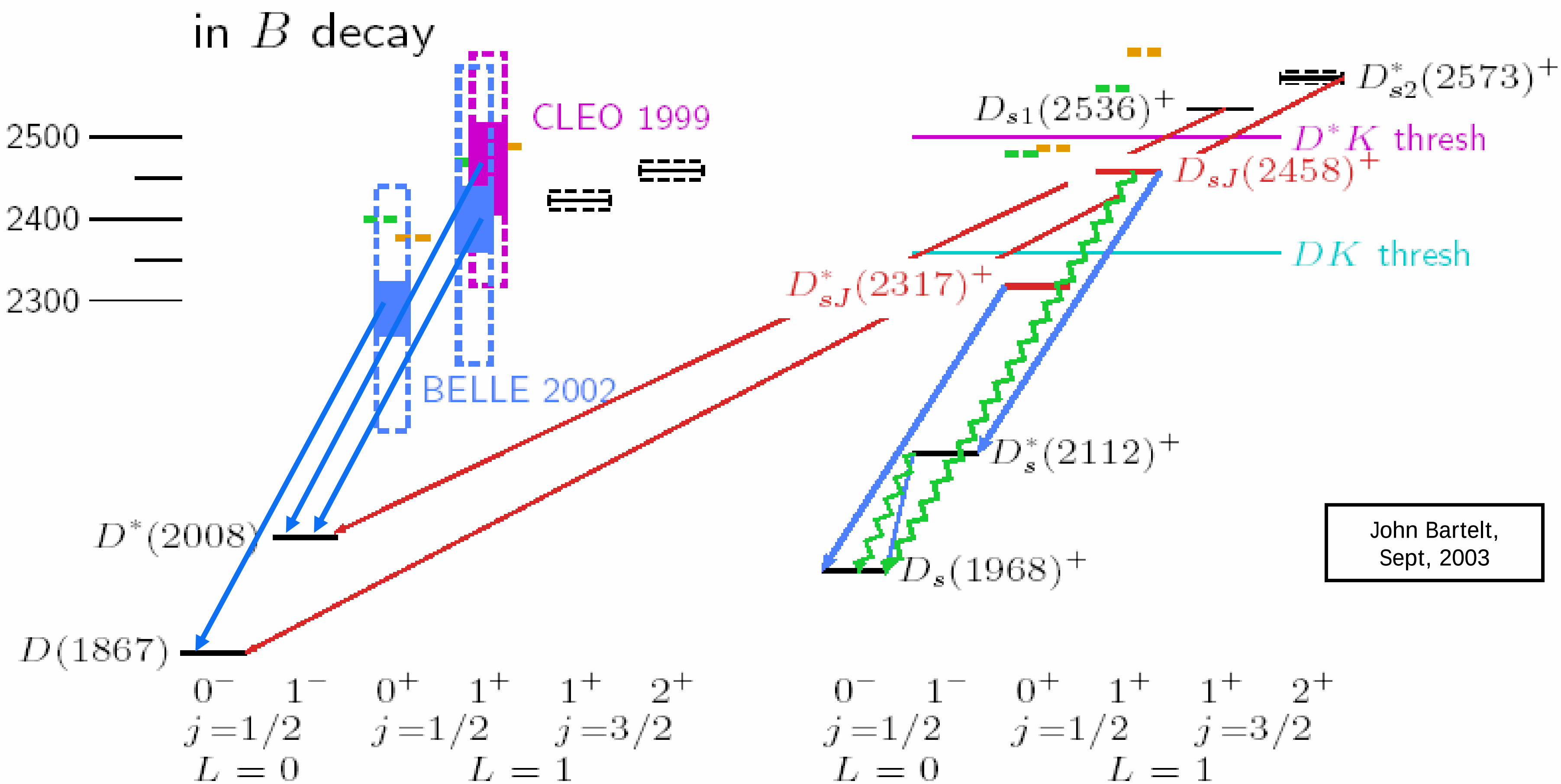
Could be $J^P = 3/2^-$ Σ_{c2} ??

State	Yield $/10^3$	ΔM, MeV$/c^2$	Γ, MeV
$\Sigma_c(2800)^0$	$2.24^{+0.79}_{-0.55}{}^{+1.03}_{-0.50}$	$515.4^{+3.2}_{-3.1}{}^{+2.1}_{-6.0}$	$61^{+18}_{-13}{}^{+22}_{-13}$
$\Sigma_c(2800)^+$	$1.54^{+1.05}_{-0.57}{}^{+1.40}_{-0.88}$	$505.4^{+5.8}_{-4.6}{}^{+12.4}_{-2.0}$	$62^{+37}_{-23}{}^{+52}_{-38}$
$\Sigma_c(2800)^{++}$	$2.81^{+0.82}_{-0.60}{}^{+0.71}_{-0.49}$	$514.5^{+3.4}_{-3.1}{}^{+2.8}_{-4.9}$	$75^{+18}_{-13}{}^{+12}_{-11}$

Charmed Meson Spectroscopy pre 2003

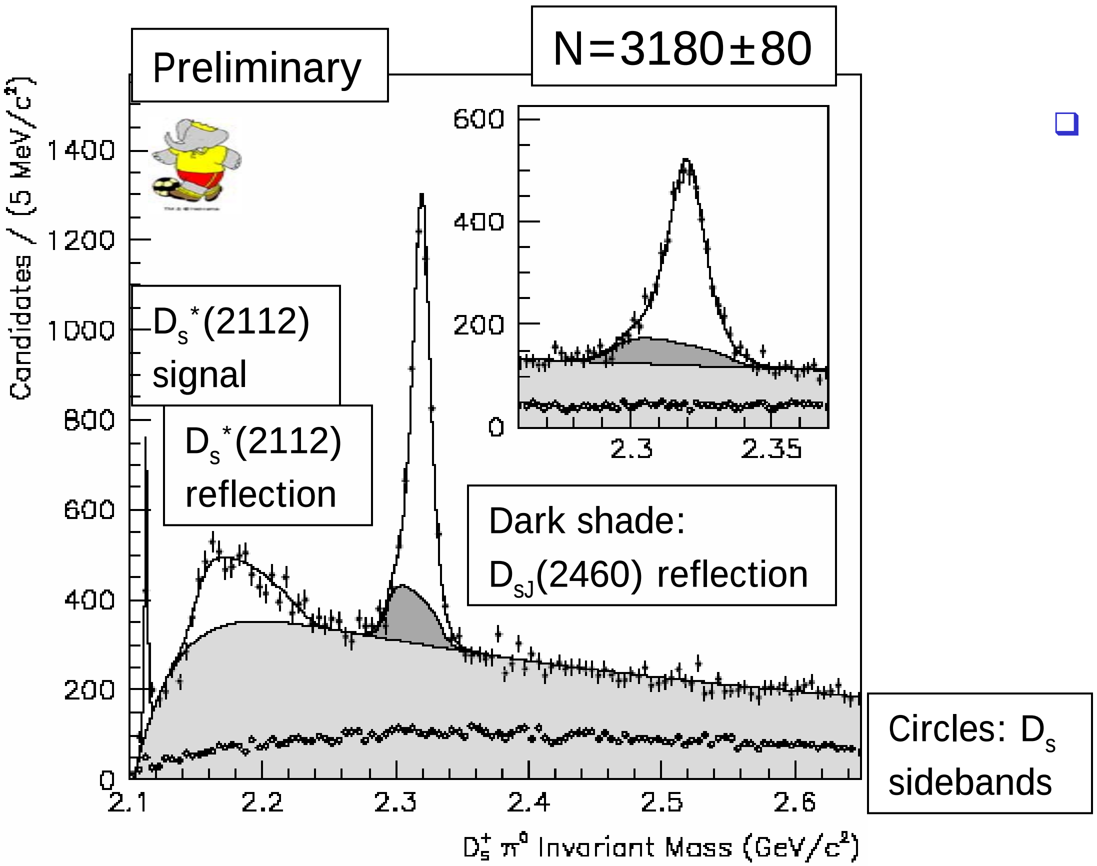


Charmed Meson Spectroscopy Now

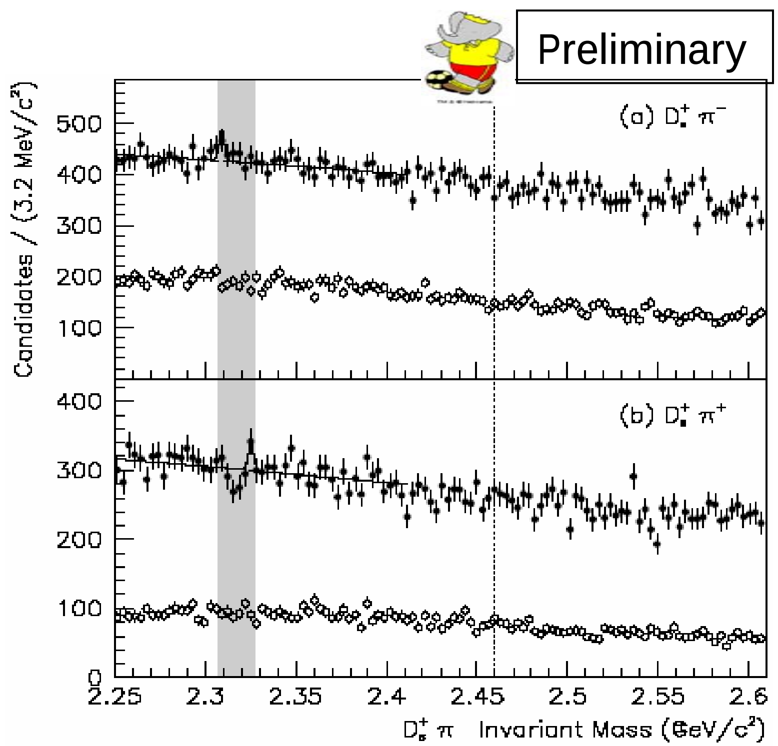


BABAR: 232 fb^{-1}
Submitted to PRD

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



- No indication of neutral or doubly-charged partner near 2317 MeV ➔ I=0



$$m = (2319.6 \pm 0.2 \pm 1.4)\ \mathrm{MeV}/c^2$$

$$\Gamma < 3.8\ \mathrm{MeV}\ @\ 95\%\ \mathrm{CL}$$

Update on Charmed-Strange Mesons $D_{sJ}^*(2317)^+$ and $D_{sJ}(2460)^+$

- New, comprehensive study of decays to D_s^+ plus one or two $\pi^\pm$, π^0, or γ's

Decay pattern if $J^P=0^+$ and $J^P=1^+$, respectively

Decay Channel	$D_{sJ}^*(2317)^+$	$D_{sJ}(2460)^+$
$D_s^+\pi^0$	Seen	Forbidden
$D_s^+\gamma$	Forbidden	Seen
$D_s^+\pi^0\gamma$ (a)	Allowed	Allowed
$D_s^*(2112)^+\pi^0$	Forbidden	Seen
$D_{sJ}^*(2317)^+\gamma$	—	Allowed
$D_s^+\pi^0\pi^0$	Forbidden	Allowed
$D_s^+\gamma\gamma$ (a)	Allowed	Allowed
$D_s^*(2112)^+\gamma$	Allowed	Allowed
$D_s^+\pi^+\pi^-$	Forbidden	Seen

(a) Non-resonant only

$D_s^+\pi^0$ only decay mode observed for $D_{sJ}^*(2317)^+$

NB: all "Seen" modes are also "Allowed"

232 fb^{-1} hep-ex/0604030

D_{sJ}^{*} Update:

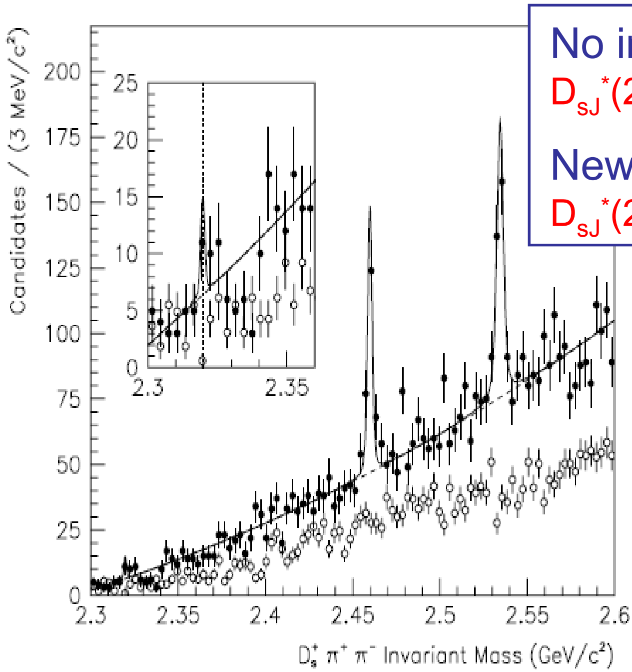
- From $D_{sJ}^{*}(2317)^{+} \to D_s^{+}\pi^{0}$:

$$m = (2319.6 \pm 0.2 \pm 1.4)\ \mathrm{MeV/c^2}$$
$$\Gamma < 3.8\ \mathrm{MeV}\ @\ 95\%\ \mathrm{CL}$$

- From $D_{sJ}^{*}(2460)^{+} \to D_s^{+}\gamma$, $D_s^{+}\pi^{0}\gamma$:

$$\frac{\mathrm{B}(D_{sJ}(2460)^{+} \to D_s^{+}\gamma)}{\mathrm{B}(D_{sJ}(2460)^{+} \to D_s^{+}\pi^{0}\gamma)} = 0.337 \pm 0.036 \pm 0.038$$

- New from $\to D_s^{+}\pi^{+}\pi^{-}$:



No indication of
$D_{sJ}^{*}(2317)^{+} \to D_s^{+}\pi^{+}\pi^{-}$

New mode:
$D_{sJ}^{*}(2536)^{+} \to D_s^{+}\pi^{+}\pi^{-}$

$$m = (2460.2 \pm 0.2 \pm 0.8)\ \mathrm{MeV/c^2}$$
$$\Gamma < 3.5\ \mathrm{MeV}\ @\ 95\%\ \mathrm{CL}$$

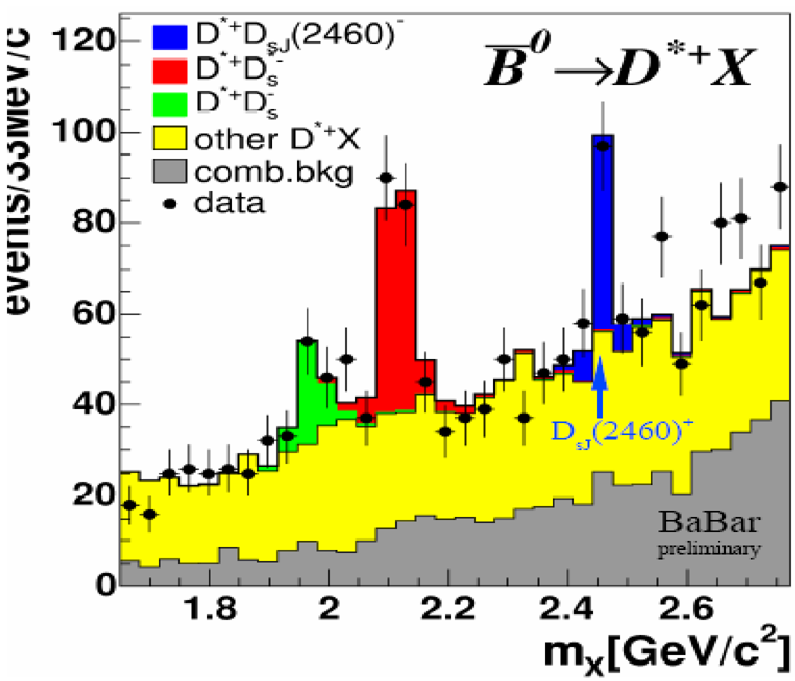
$$m = (2534.6 \pm 0.3 \pm 0.7)\ \mathrm{MeV/c^2}$$
$$\Gamma < 2.5\ \mathrm{MeV}\ @\ 95\%\ \mathrm{CL}$$

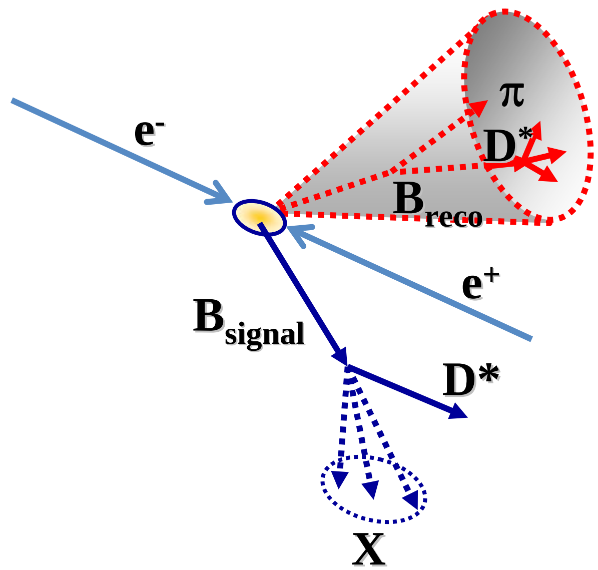
$$\frac{\mathrm{B}(D_{sJ}(2460)^{+} \to D_s^{+}\pi^{+}\pi^{-})}{\mathrm{B}(D_{sJ}(2460)^{+} \to D_s^{+}\pi^{0}\gamma)} = 0.077 \pm 0.013 \pm 0.008$$

232 fb^{-1} hep-ex/0604030

B Decays - Absolute Branching Fractions

- $B\bar{B}$ sample with one B fully reconstructed decays of the other $B \to D^{(*)+,0}$ ***X***
  - Observe D_s^+ and $D_{sJ}(2460)$ signals in the recoil mass, m_X
- → absolute BF's for D_s^+ (→ $\phi\pi^+$) and for $D_{sJ}^*(2460)^+$





211 fb^{-1} hep-ex/0605036

$D_{sJ}(2460)^+$ Absolute BFs, cont.

- For the D_s^+ signal:

$$\mathcal{B}(D_s^+ \to \phi\pi^+ = (4.62 \pm 0.36 \pm 0.50)\ \%$$

PDG: (4.3 1.2) %

- Combine with previous measurements

113 fb[-1] PRL 93, 181801 (2004)

$$\frac{\mathcal{B}[B \to D^{(*)} D^*_{sJ}(2460)^+] \times \mathcal{B}[D^*_{sJ}(2460)^+ \to D_s^+\gamma]}{\mathcal{B}[B \to D^{(*)} D^*_{sJ}(2460)^+] \times \mathcal{B}[D^*_{sJ}(2460)^+ \to D^*_s(2112)^+\pi^0]} = 0.274 \pm 0.045 \pm 0.020$$

$(D_s^{*+} \to D_s^+ \gamma)$

to obtain absolute BFs:

$$\begin{aligned}\mathcal{B}[D^*_{sJ}(2460)^+ \to D^*_s(2112)^+\pi^0] &= (0.56 \pm 0.13 \pm 0.09)\ \% \\ \mathcal{B}[D^*_{sJ}(2460)^+ \to D_s^+\gamma] &= (0.16 \pm 0.04 \pm 0.03)\ \% \\ \mathcal{B}[D^*_{sJ}(2460)^+ \to D_s^+\pi^+\pi^-] &= (0.04 \pm 0.01)\ \%\end{aligned}$$

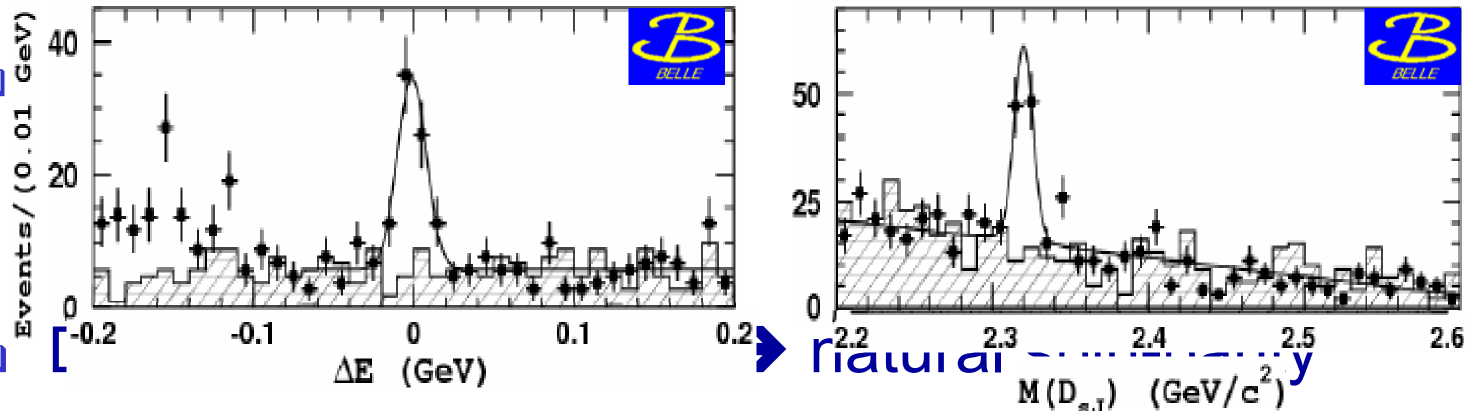
- Sum of known BFs: 0.76±0.20

211 fb[-1] hep-ex/0605036

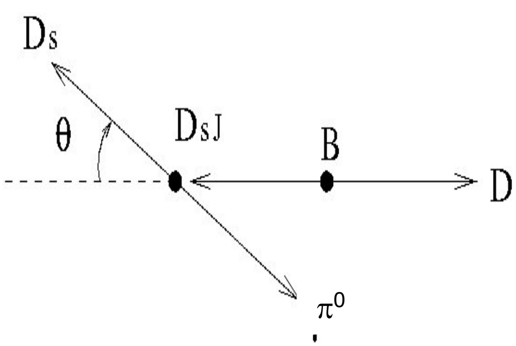
Is there another mode ?

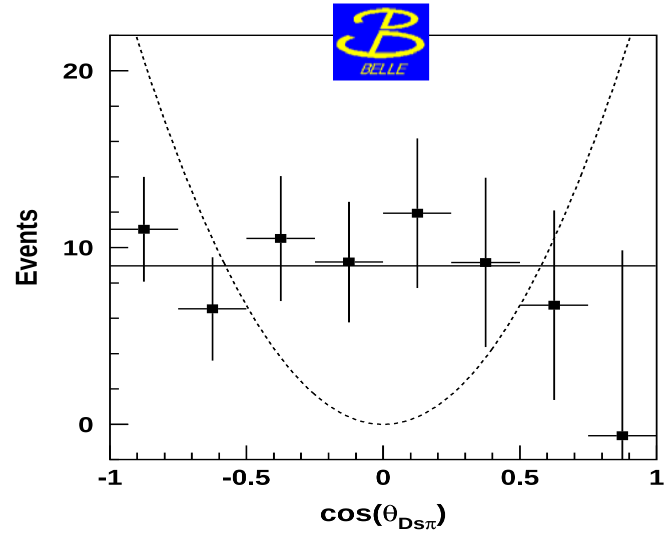
B→D $D_{sJ}^*(2317)^+$, $D_{sJ}^*(2317)^+$→$D_s^+\pi^0$

Belle: 274M $B\bar{B}$
BELLE-CONF-0461 (2004)



- [... ➔ natural ... y
- $D_{sJ}^*(2317)$ decay angular distribution ➔ spin 0





Dotted line:
J = 1
$\chi^2/_{d.o.f}$ = 38/8

Solid line:
J = 0
$\chi^2/_{d.o.f}$ = 3/8

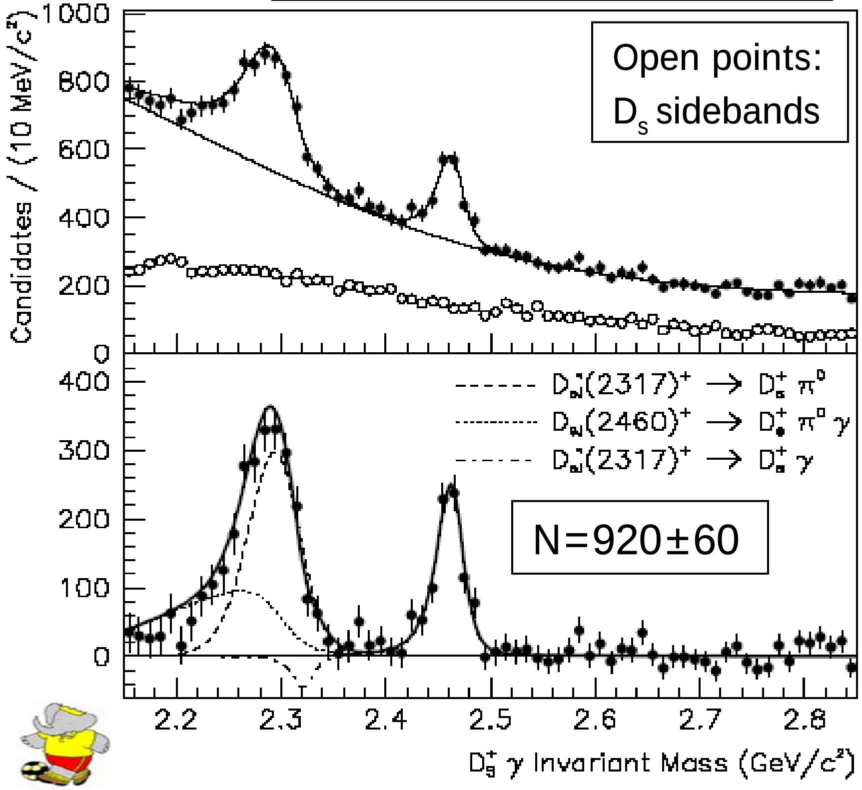
Natural spin-parity ➔ **J^P = 0^+**

$D_{sJ}(2460)^+ \rightarrow D_s^+\gamma$ / $D_s^*(2112)^+\pi^0$

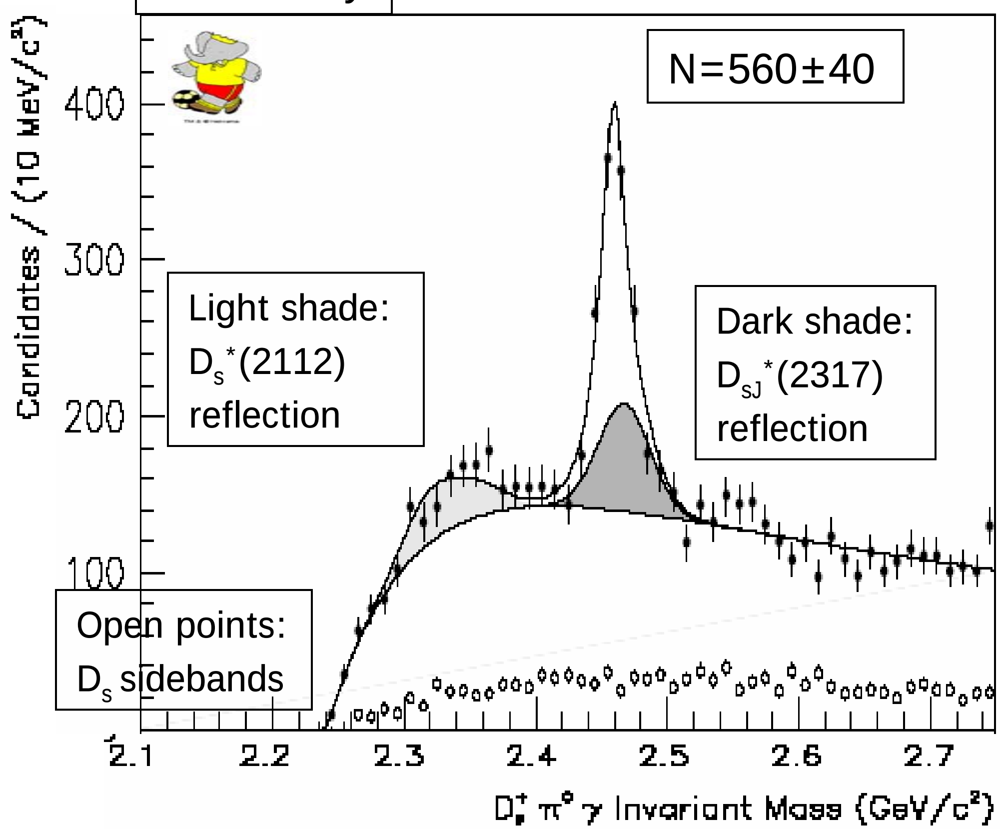
$D_s^{*+} \rightarrow D_s^+\gamma$

Preliminary

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



Preliminary



$$\frac{B(D_{sJ}(2460)^+ \rightarrow D_s^+\gamma)}{B(D_{sJ}(2460)^+ \rightarrow D_s^+\pi^0\gamma)} = 0.337 \pm 0.036 \pm 0.038$$

BABAR: 232 fb^{-1}
Submitted to PRD

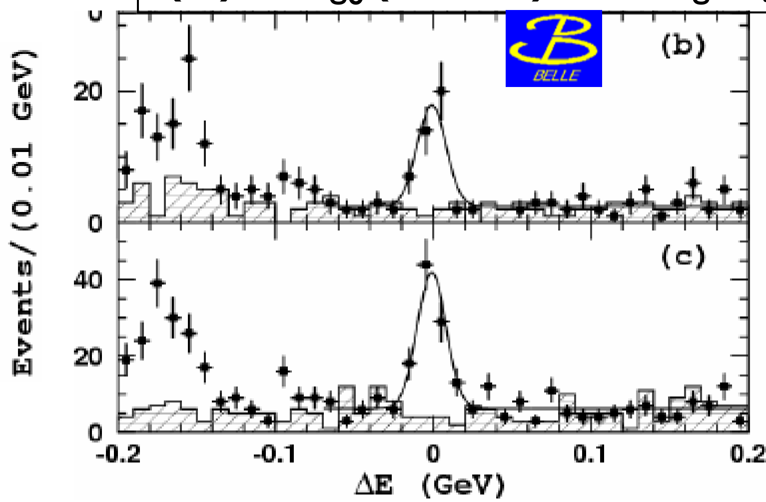
Preliminary

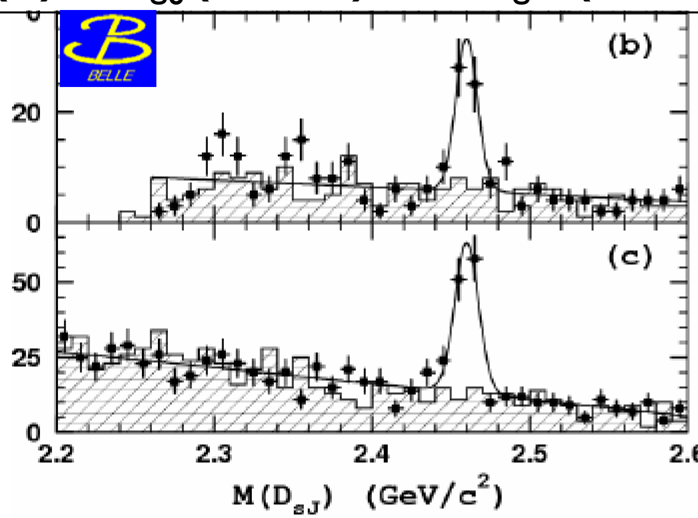
$B \rightarrow \underline{D}\ D_{sJ}(2460)^+$

Belle: 274M BB
BELLE-CONF-0461 (2004)

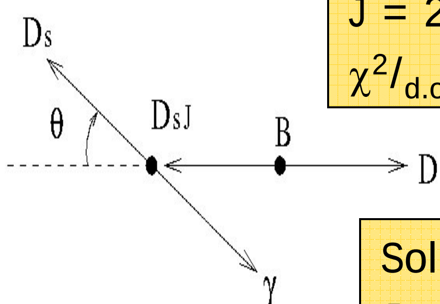
(b): $D_{sJ}(2460)^+ \rightarrow D_s^+ \gamma$

(c): $D_{sJ}(2460)^+ \rightarrow D_s^*(2112)^+ \pi^0$





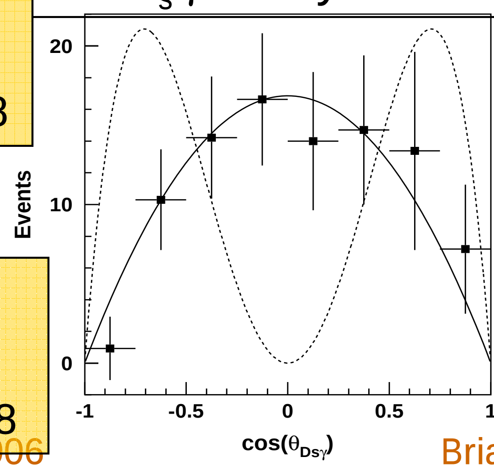
$D_s^{*+} \rightarrow D_s^+ \gamma$



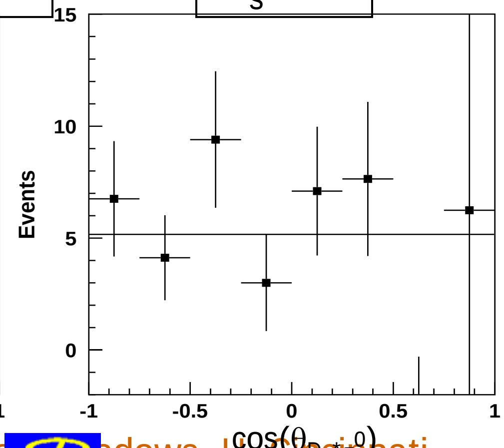
Dashed line:
J = 2
$\chi^2/_{d.o.f} = 89/8$

Solid line:
J = 1
$\chi^2/_{d.o.f} = 4/8$

No $D_s \gamma$ decay for J=0



$D_s^* \pi^0$



Solid line:
J = 1
S-wave

$\mathbf{J^P = 1^+}$