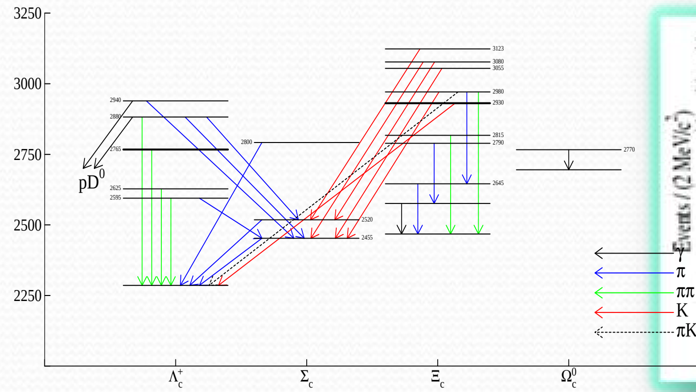
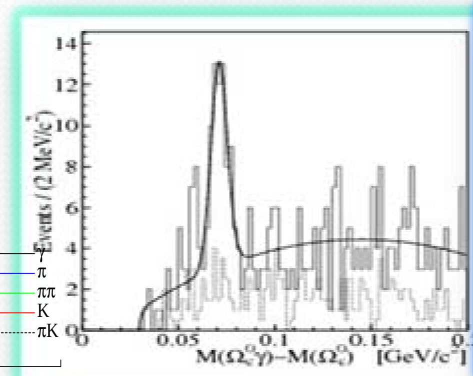
Charm Baryons at Belle

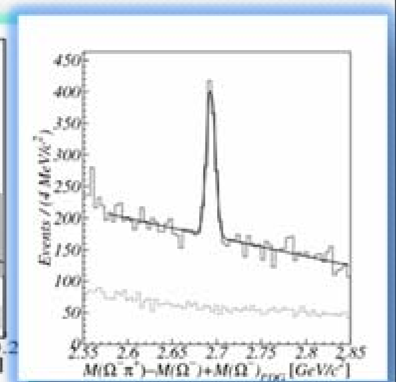
Ruslan Chistov
(Institute of Theoretical and Experimental Physics
and Moscow Physical Engineering Institute)

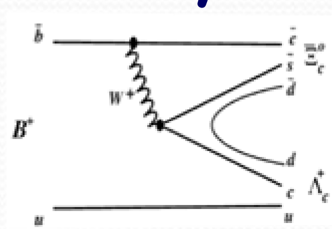
OUTLINE:

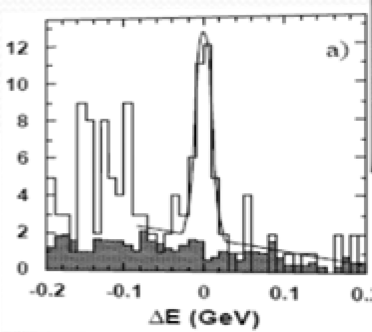
(1) Introduction
(2) Spectroscopy
(3) Weak Decays
(4) Baryonic B-decays
(5) Summary

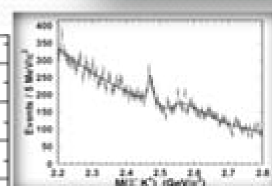


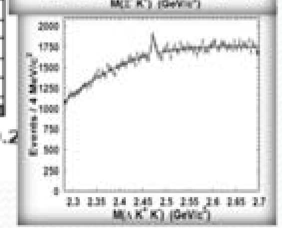


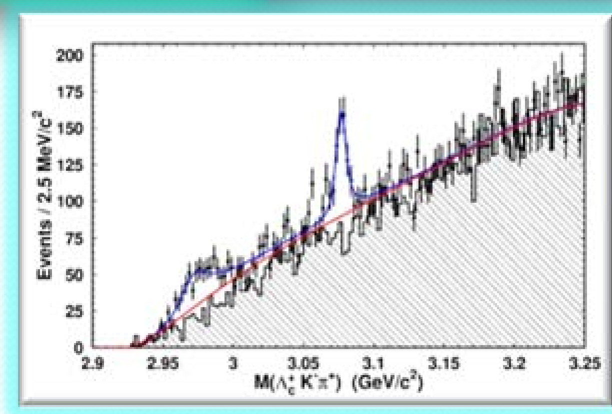












Introduction

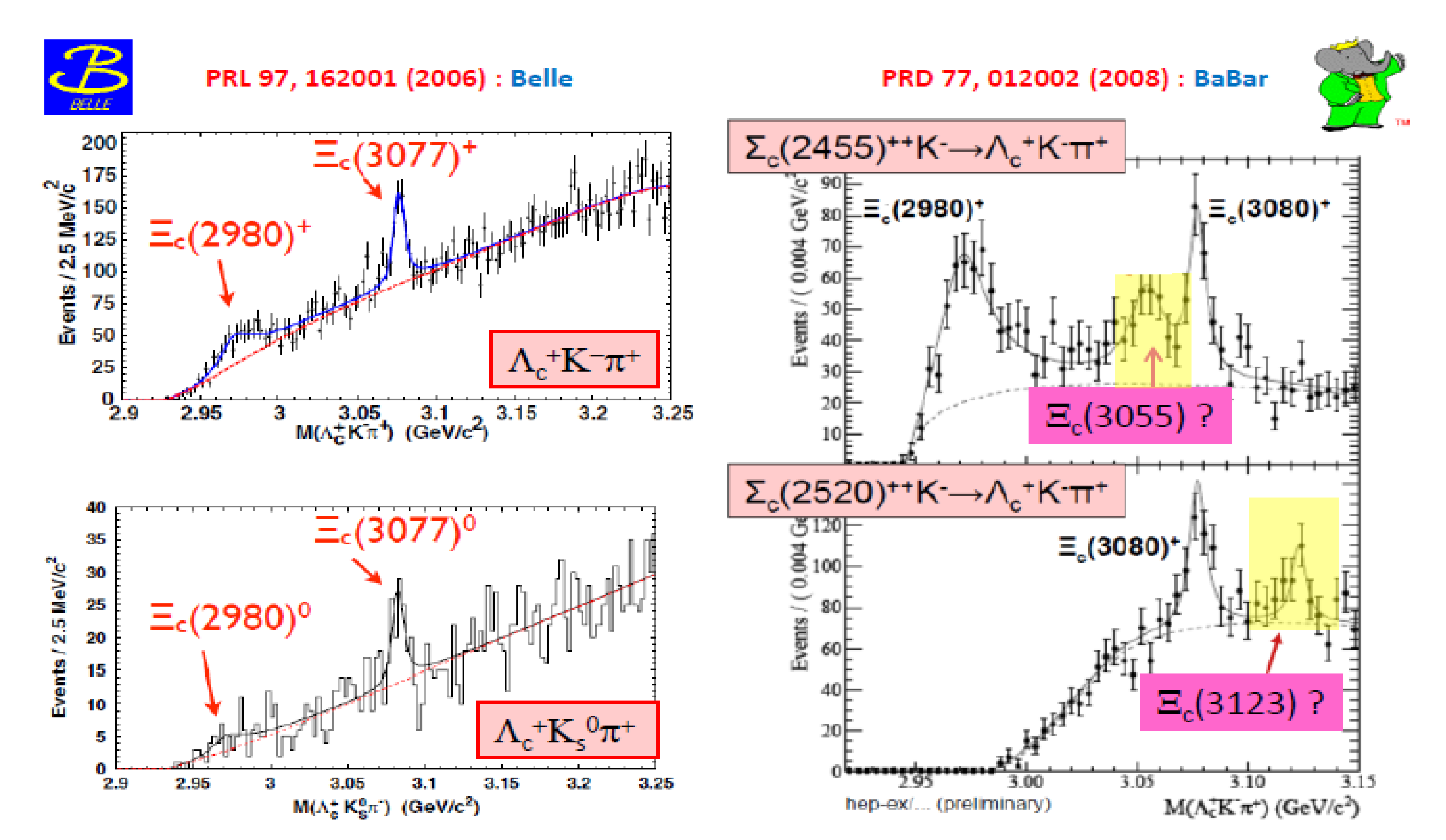
THE UNIVERSE AROUND US AND WE THEMSELVES CONSIST OF BARYONS

Charmed baryon spectroscopy is an excellent laboratory to study the dynamics of light diquark in the environment of heavy C-quark. ⇒
Many theoretical predictions and approaches could be tested.

History: ARGUS(1993) observed first excited charmed baryon $\Lambda_c(2625)^+$, then CLEO(1993) confirmed it and observed $\Lambda_c(2593)^+$, E687 and ARGUS subsequently confirmed the latter. Next observations came from CLEO: $\Sigma_c(2520)^+$, $\Lambda_c(2765)^+$, $\Lambda_c(2880)^+$.

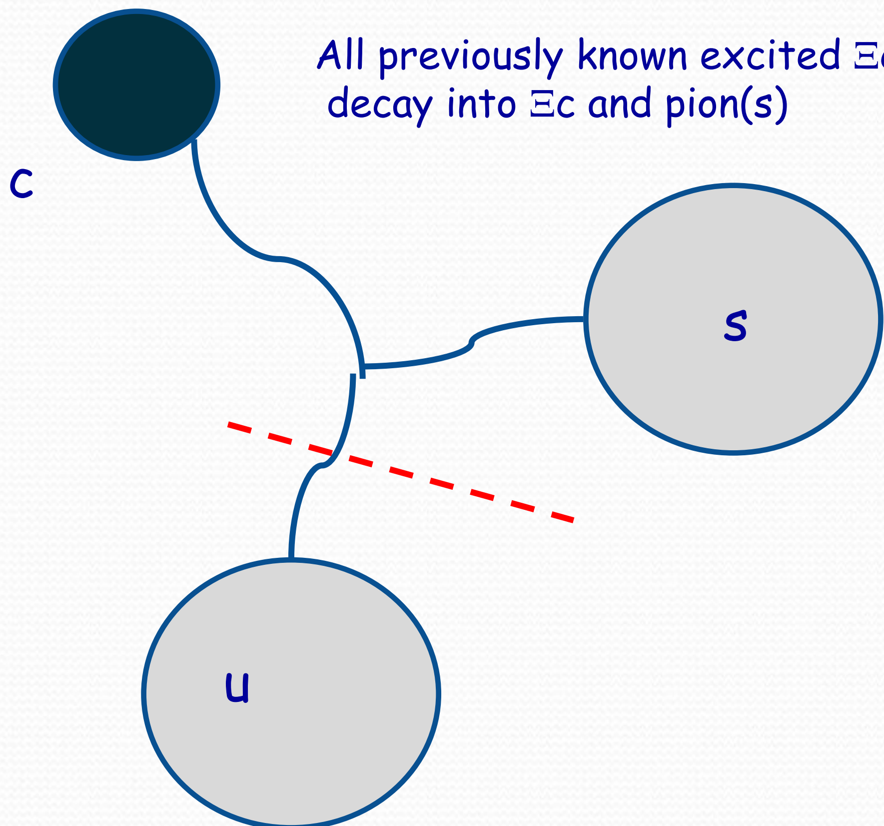
A little was known about weak decays of charm baryons, particulaly about C.-S. modes

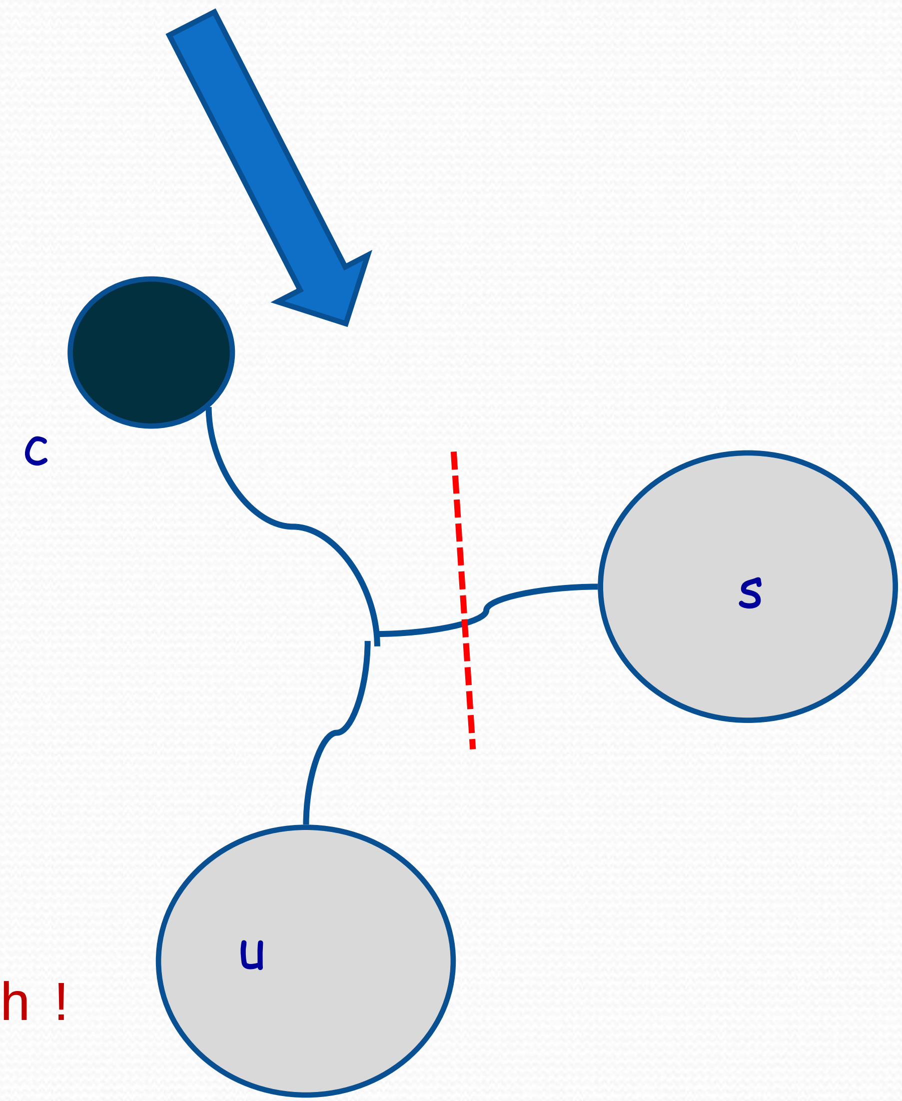
New excited $\Xi_c^+(\rightarrow\Lambda_c^+K^-\pi^+)$



Unusual Mechanism of $\Xi_c(2980/3080)$ Decay

All previously known excited Ξc decay into Ξc and pion(s)





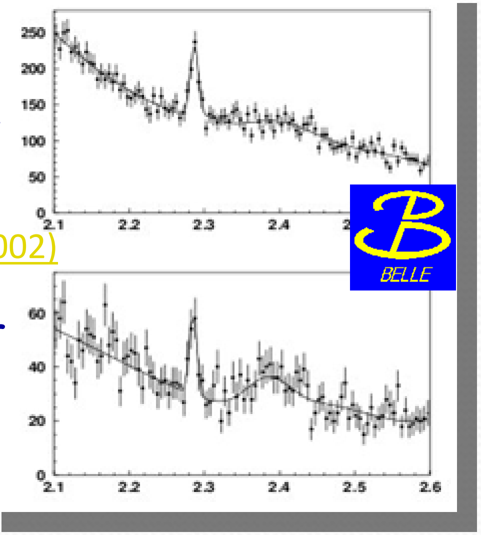
Should be studied
by theory in more depth !

Weak Decays of Charm Baryons

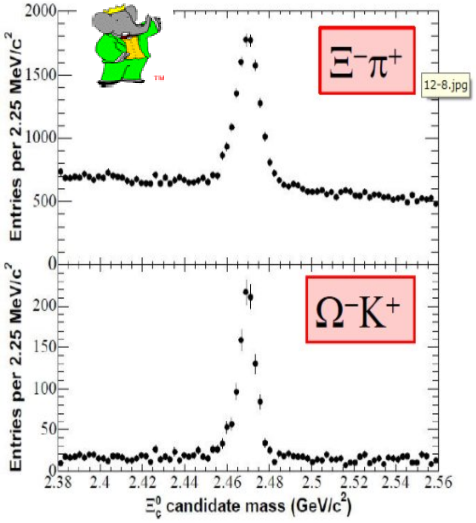
$\Lambda_c^+ \to \Lambda K^+$

PLB 524, 33 (2002)

$\Lambda_c^+ \to \Sigma K^+$



Λ_c^+ mode	Experiment	Yield	Λ_c^+ reference mode	$\mathcal{B}_{signal}/\mathcal{B}_{ref.}$
ΛK^+ (CS)	Belle	265 ± 35	$\Lambda\pi^+$	$0.074 \pm 0.010 \pm 0.012$
$\Sigma^0 K^+$ (CS)	Belle	75 ± 18	$\Sigma^0\pi^+$	$0.056 \pm 0.014 \pm 0.008$
ΛK^+ (CS)	BABAR	1162 ± 101	$\Lambda\pi^+$	$0.044 \pm 0.004 \pm 0.003$
$\Sigma^0 K^+$ (CS)	BABAR	366 ± 52	$\Sigma^0\pi^+$	$0.038 \pm 0.005 \pm 0.003$
$\Lambda K^+\pi^+\pi^-$ (CS)	BABAR	160 ± 62	$\Lambda\pi^+$	$< 4.1 \times 10^{-2}$ 90% CL
$\Sigma^0 K^+\pi^+\pi^-$ (CS)	BABAR	21 ± 24	$\Sigma^0\pi^+$	$< 2.0 \times 10^{-2}$ 90% CL
$\Sigma^+ K^+\pi^-$ (CS)	Belle	105 ± 24	$\Sigma^+\pi^+\pi^-$	$0.047 \pm 0.011 \pm 0.008$
$\Sigma^+ K^+ K^-$ (WE)	Belle	246 ± 20	$\Sigma^+\pi^+\pi^-$	$0.076 \pm 0.007 \pm 0.009$
$\Sigma^+\phi$ (WE)	Belle	129 ± 17	$\Sigma^+\pi^+\pi^-$	$0.085 \pm 0.012 \pm 0.012$
$\Xi(1690)^0 K^+$, $\Xi(1690)^0 \to \Sigma^+ K^-$ (WE)	Belle	75 ± 16	$\Sigma^+\pi^+\pi^-$	$0.023 \pm 0.005 \pm 0.005$
$\Xi(1690)^0 K^+$, $\Xi(1690)^0 \to \Lambda\bar{K}^0$ (WE)	Belle	93 ± 26	$\Lambda\bar{K}^0 K^+$	$0.26 \pm 0.08 \pm 0.03$
$\Sigma^+ K^+ K^-$ (non-res) (WE)	Belle	11 ± 16	$\Sigma^+\pi^+\pi^-$	< 0.018 @90% CL
pK^+K^- (CS)	Belle	676 ± 89	$pK^-\pi^+$	$0.014 \pm 0.002 \pm 0.002$
$p\phi$ (CS)	Belle	345 ± 43	$pK^-\pi^+$	$0.015 \pm 0.002 \pm 0.002$
pK^+K^- (non-ϕ)	Belle	344 ± 81	$pK^-\pi^+$	$0.007 \pm 0.002 \pm 0.002$
$\Sigma^0\pi^+$ (CF)	BABAR	32693 ± 324	$\Lambda\pi^+$	$0.977 \pm 0.015 \pm 0.051$
$\Xi^- K^+\pi^+$ (CF)	BABAR	2665 ± 84	$\Lambda\pi^+$	$0.480 \pm 0.016 \pm 0.039$
$\Lambda\bar{K}^0 K^+$ (CF)	BABAR	460 ± 30	$\Lambda\pi^+$	$0.395 \pm 0.026 \pm 0.036$



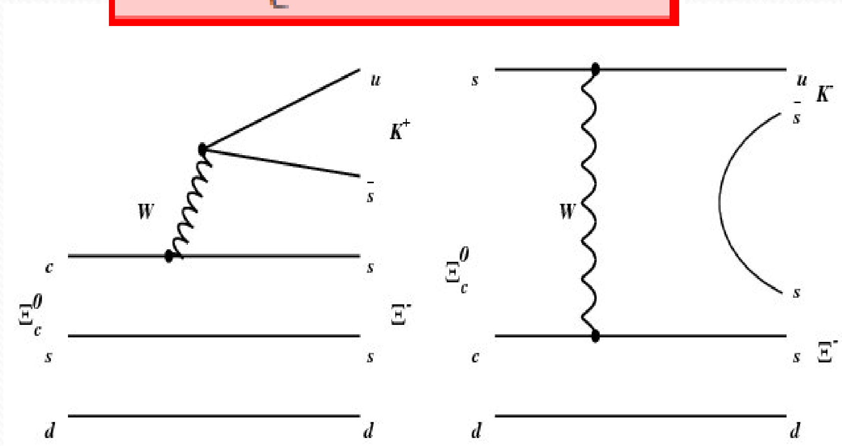
$$\frac{\mathcal{B}(\Xi_c^0 \to \Omega^- K^+)}{\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)} = 0.294 \pm 0.018 \pm 0.016$$

- Consistent with theoretical prediction: 0.32 (Korner & Kramer, 1992)

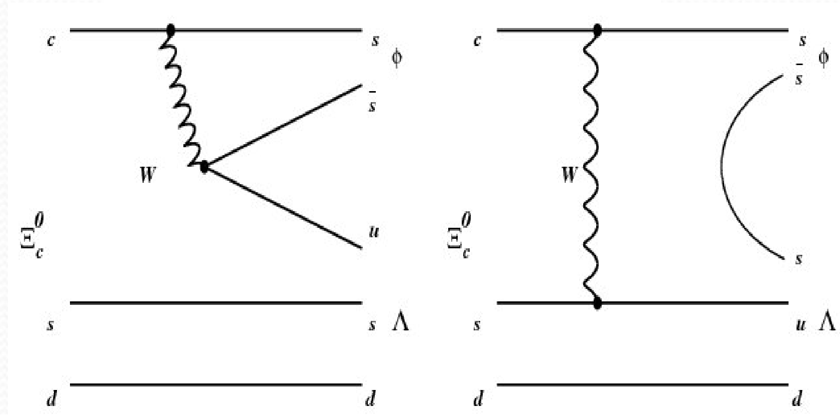
Decay mode	Experiment	Yield	Reference mode	$\mathcal{B}_{signal}/\mathcal{B}_{ref.}$
$\Xi_c^+ \to \Lambda K^-\pi^+\pi^+$	Belle	1117 ± 55	$\Xi_c^+ \to \Xi^-\pi^+\pi^+$	$0.32 \pm 0.03 \pm 0.02$
$\Xi_c^+ \to pK_S^0K_S^0$	Belle	168 ± 27	$\Xi_c^+ \to \Xi^-\pi^+\pi^+$	$0.087 \pm 0.016 \pm 0.014$
$\Xi_c^0 \to pK^-K^-\pi^+$	Belle	1908 ± 62	$\Xi_c^0 \to \Xi^-\pi^+$	$0.33 \pm 0.03 \pm 0.03$
$\Xi_c^0 \to \Lambda K_S^0$	Belle	465 ± 37	$\Xi_c^0 \to \Xi^-\pi^+$	$0.21 \pm 0.02 \pm 0.02$
$\Xi_c^0 \to \Lambda K^-\pi^+$	Belle	3268 ± 276	$\Xi_c^0 \to \Xi^-\pi^+$	$1.07 \pm 0.12 \pm 0.07$
$\Xi_c^0 \to \Omega^- K^+$	BABAR	≈ 650	$\Xi_c^0 \to \Xi^-\pi^+$	$0.294 \pm 0.018 \pm 0.016$
$\Omega_c^0 \to \Omega^-\pi^+\pi^0$	BABAR	64 ± 15	$\Omega_c^0 \to \Omega^-\pi^+$	$1.27 \pm 0.31 \pm 0.11$
$\Omega_c^0 \to \Omega^-\pi^+\pi^+\pi^-$	BABAR	25 ± 8	$\Omega_c^0 \to \Omega^-\pi^+$	$0.28 \pm 0.09 \pm 0.01$
$\Omega_c^0 \to \Xi^- K^-\pi^+\pi^-$	BABAR	45 ± 12	$\Omega_c^0 \to \Omega^-\pi^+$	$0.46 \pm 0.13 \pm 0.03$

Weak Decays of Charm Baryons

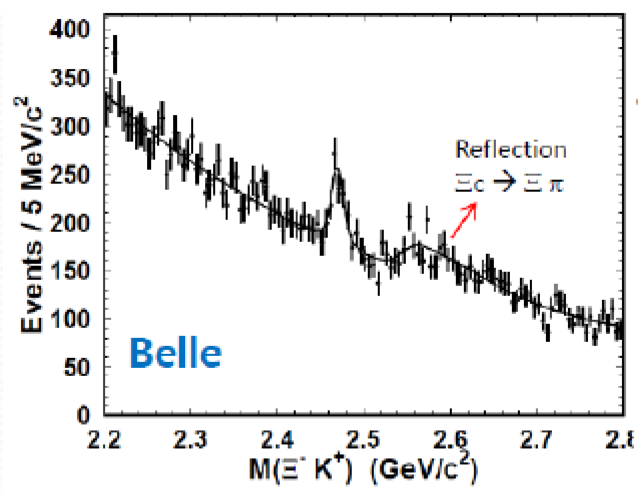
$\Xi_c^0 \rightarrow \Xi^- K^+$

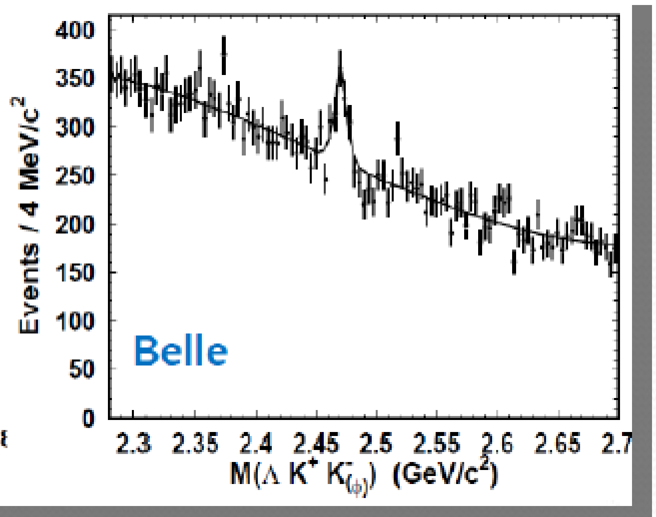


$\Xi_c^0 \rightarrow \Lambda^0 \phi^0$



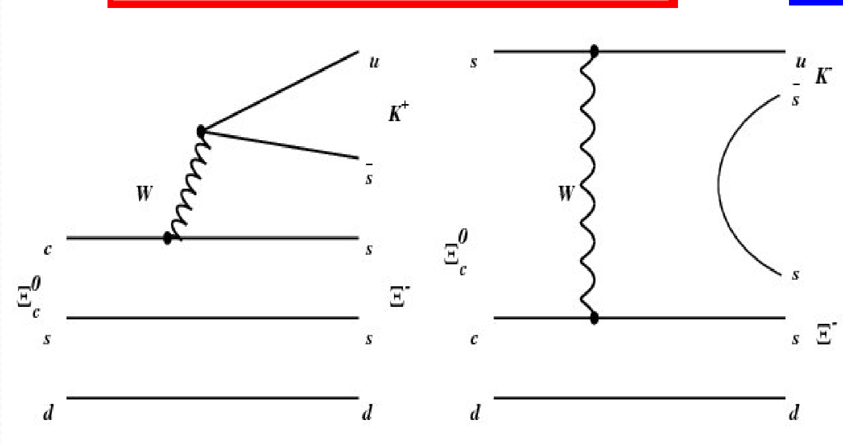
First C.-S. Ξ_c^0



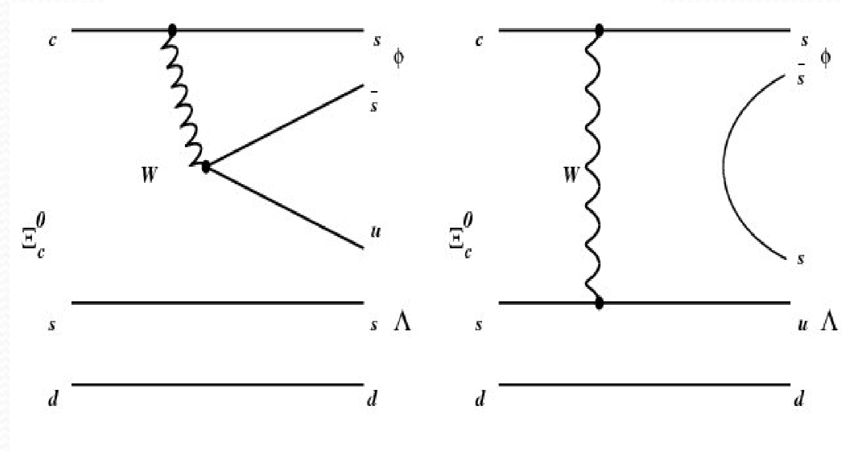


Weak Decays of Charm Baryons

$\Xi_c^0 \to \Xi^- K^+$



$\Xi_c^0 \to \Lambda^0 \phi^0$



$$\frac{\mathcal{B}(\Xi_c^0 \to \Xi^- K^+)}{\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)} = (2.75 \pm 0.51 \pm 0.25) \times 10^{-2}$$

$$\frac{\mathcal{B}(\Xi_c^0 \to \Lambda \phi)}{\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)} = (3.43 \pm 0.58 \pm 0.32) \times 10^{-2}$$

PRD 88, 071103(R) (2013).

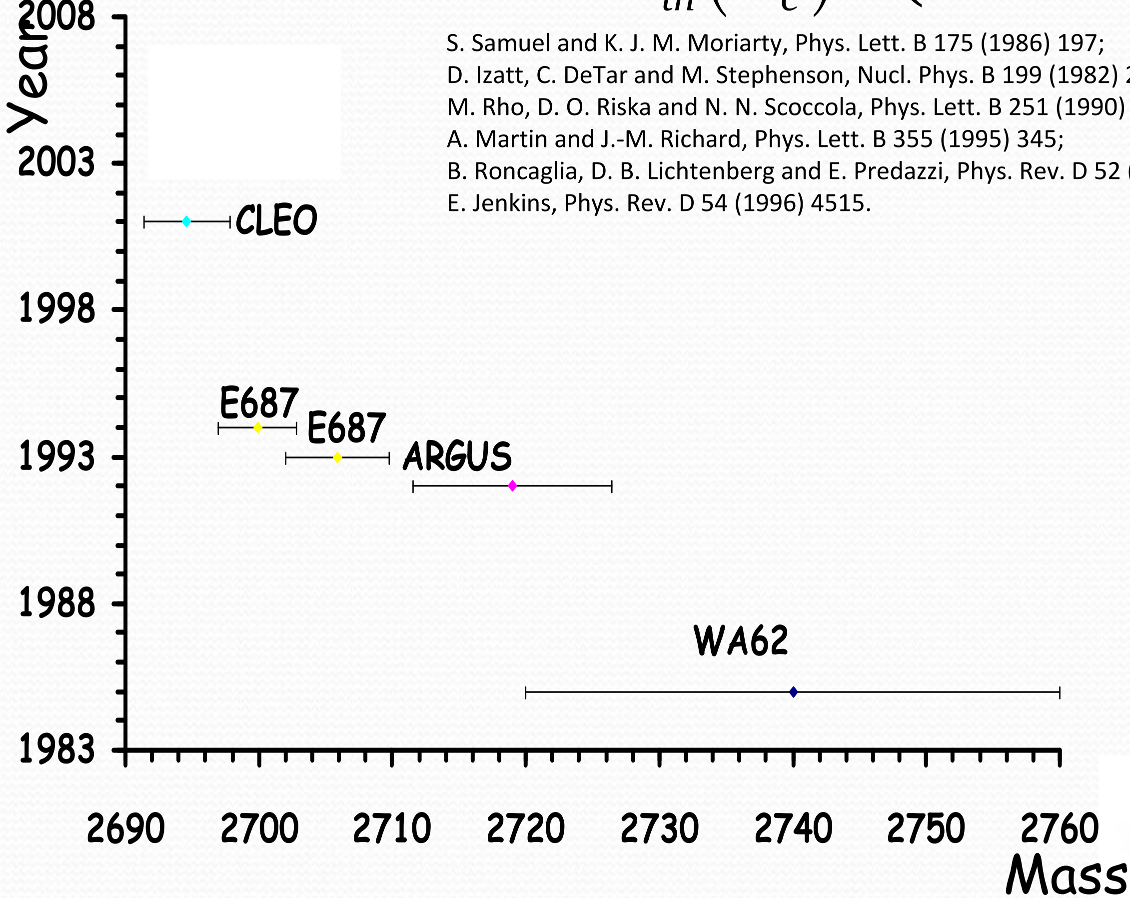
Internal W-emission is not suppressed in charm baryon weak decays

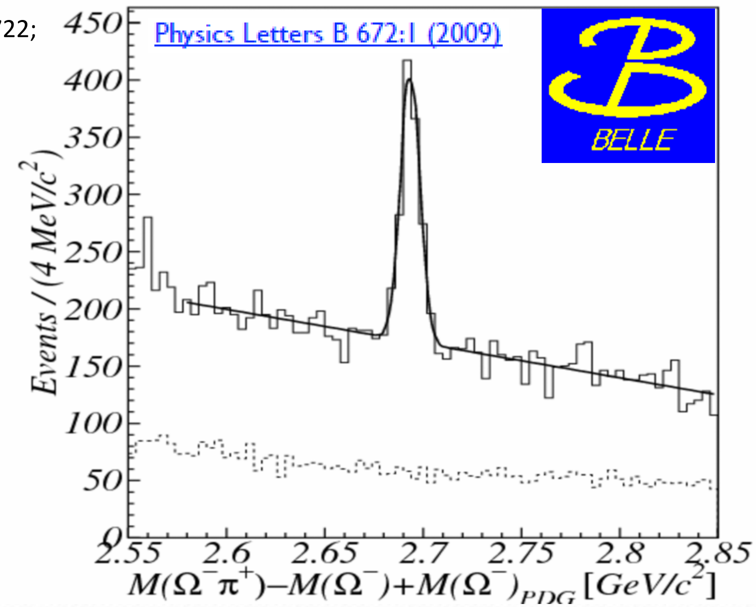
$\Omega_c^0 = c\{ss\}$ $J^P = \left(\frac{1}{2}\right)^+$

Unlike the Λ_c, Σ_c, Ξ_c and even their excited states,
a thorough experimental study of Ω_c is long overdue.

$$m_{th}\left(\Omega_c^0\right) = (2610 - 2796)\ \mathrm{MeV}/c^2$$

S. Samuel and K. J. M. Moriarty, Phys. Lett. B 175 (1986) 197;
D. Izatt, C. DeTar and M. Stephenson, Nucl. Phys. B 199 (1982) 269;
M. Rho, D. O. Riska and N. N. Scoccola, Phys. Lett. B 251 (1990) 597;
A. Martin and J.-M. Richard, Phys. Lett. B 355 (1995) 345;
B. Roncaglia, D. B. Lichtenberg and E. Predazzi, Phys. Rev. D 52 (1995) 1722;
E. Jenkins, Phys. Rev. D 54 (1996) 4515.

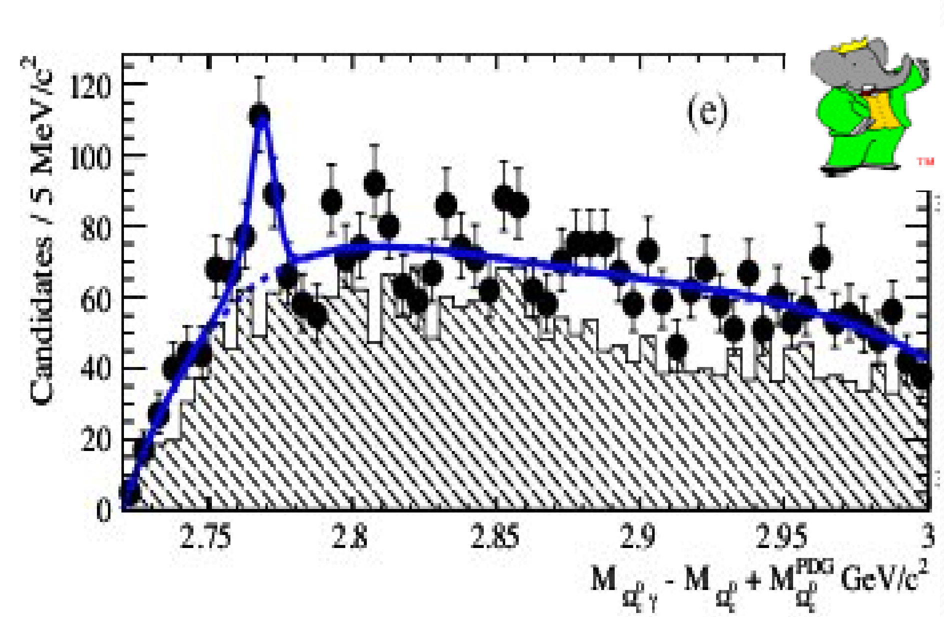


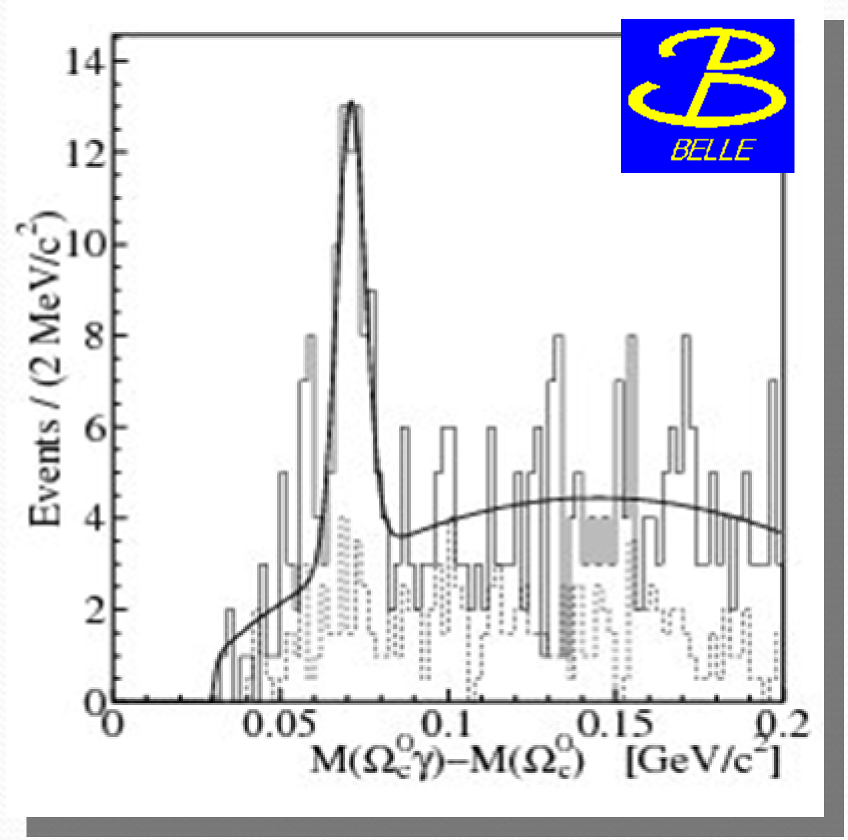


Mass (Belle)

$$M_{\Omega_c^0} = \left(2693.6 \pm 0.3\ (\mathrm{stat.})\ ^{+1.8}_{-1.5}\ (\mathrm{syst.})\right)\ \mathrm{MeV}/c^2.$$

Observation and confirmation of $\Omega_c^{*0} \to \Omega_c^0 \gamma$





Mass splitting $\Delta M = m(\Omega_c^{*0}) - m(\Omega_c^0)$:

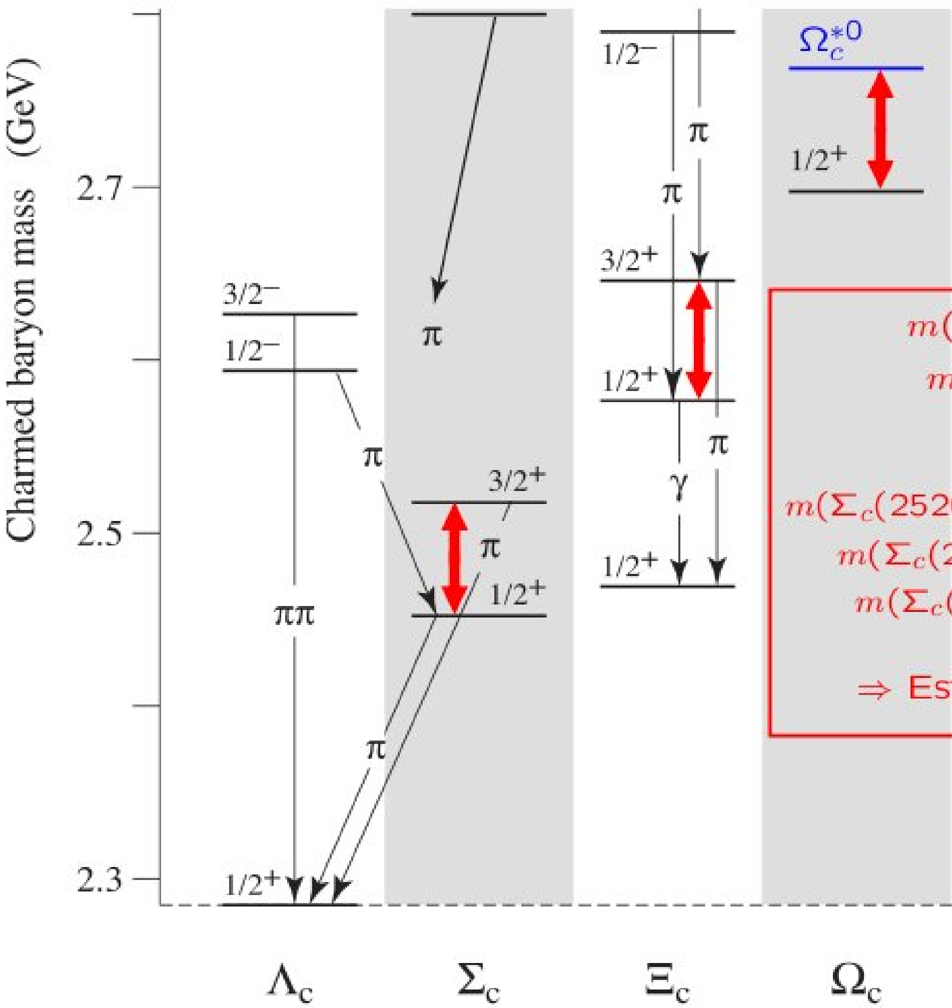
BaBar: $\Delta M = 70.8 \pm 1.0 \pm 1.1$ MeV/c^2

Belle: $\Delta M = 70.7 \pm 0.9^{+0.1}_{-0.9}$ MeV/c^2

Less than pion mass -- EM decay.

$\Omega_c^{*0} \to \Omega_c^0 \gamma$

Ω_c^{*0} mass nicely consistent with naive mass splitting approach:



BaBar & Belle data:
$\Delta M = m(\Omega_c^{*0}) - m(\Omega_c^{0}) \approx 70.7 \pm 1.0$ MeV/c^2

$$m(\Xi_c(2645)^+) - m(\Xi_c'^+) = 67.8 \pm 3.3 \text{ MeV}/c^2$$
$$m(\Xi_c(2645)^0) - m(\Xi_c'^0) = 71.2 \pm 3.1 \text{ MeV}/c^2$$

$$m(\Sigma_c(2520))^{++} - m(\Sigma_c(2455)^{++}) = 64.3 \pm 0.6 \text{ MeV}/c^2$$
$$m(\Sigma_c(2520))^{+} - m(\Sigma_c(2455)^{+}) = 64.6 \pm 2.3 \text{ MeV}/c^2$$
$$m(\Sigma_c(2520))^{0} - m(\Sigma_c(2455)^{0}) = 64.3 \pm 0.5 \text{ MeV}/c^2$$

$\Rightarrow$ Estimate $m(\Omega_c^{*0}) - m(\Omega_c^0) = 74.7 \pm 4.6$ MeV/c^2

$$\Delta m_{QCD} = (50 - 73)\ \text{MeV}/c^2$$

$$\Delta m_{lattice} = 94 \pm 10\ \text{MeV}/c^2$$

Production of Charm Baryons

Mechanisms of
charm baryon production
at e+e- B-Factories

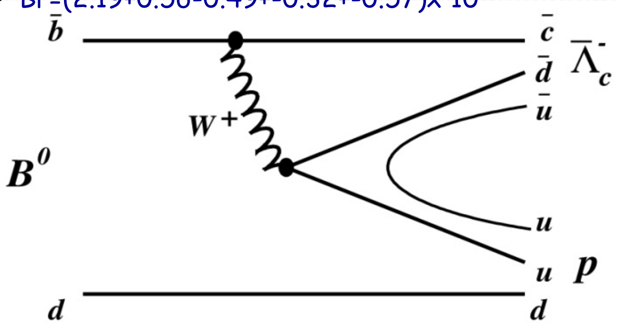
Charmed baryons
in e+e-→ cc continuum

Study of baryonic B decays

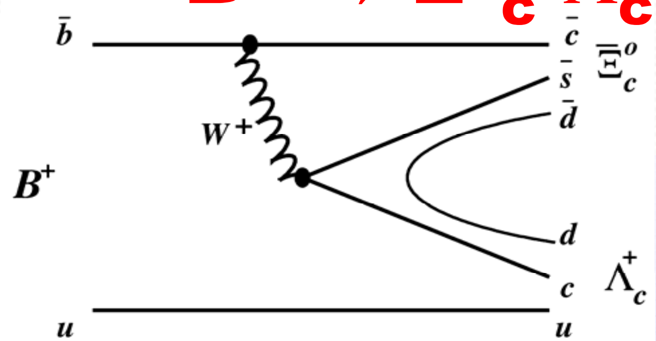
New Type of Baryonic B decays

$B^0 \to \Lambda_c^- p$

Br=(2.19+0.56-0.49+-0.32+-0.57)x 10^{-5}

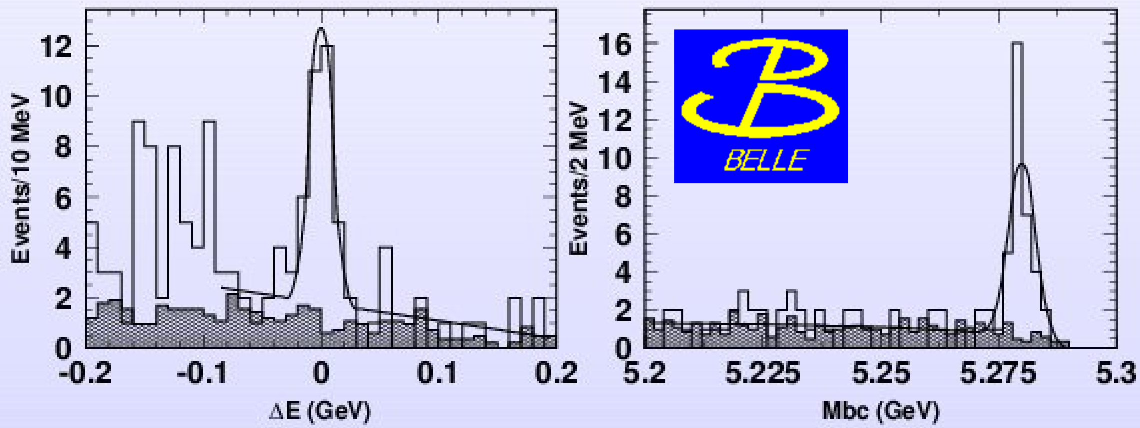


$B^+ \to \Xi^0_c \Lambda_c^+$



One can expect Br ~ 10^{-5}

But unexpectedly….



8.7σ stat. signif.

PRD(RC) 74, 111105

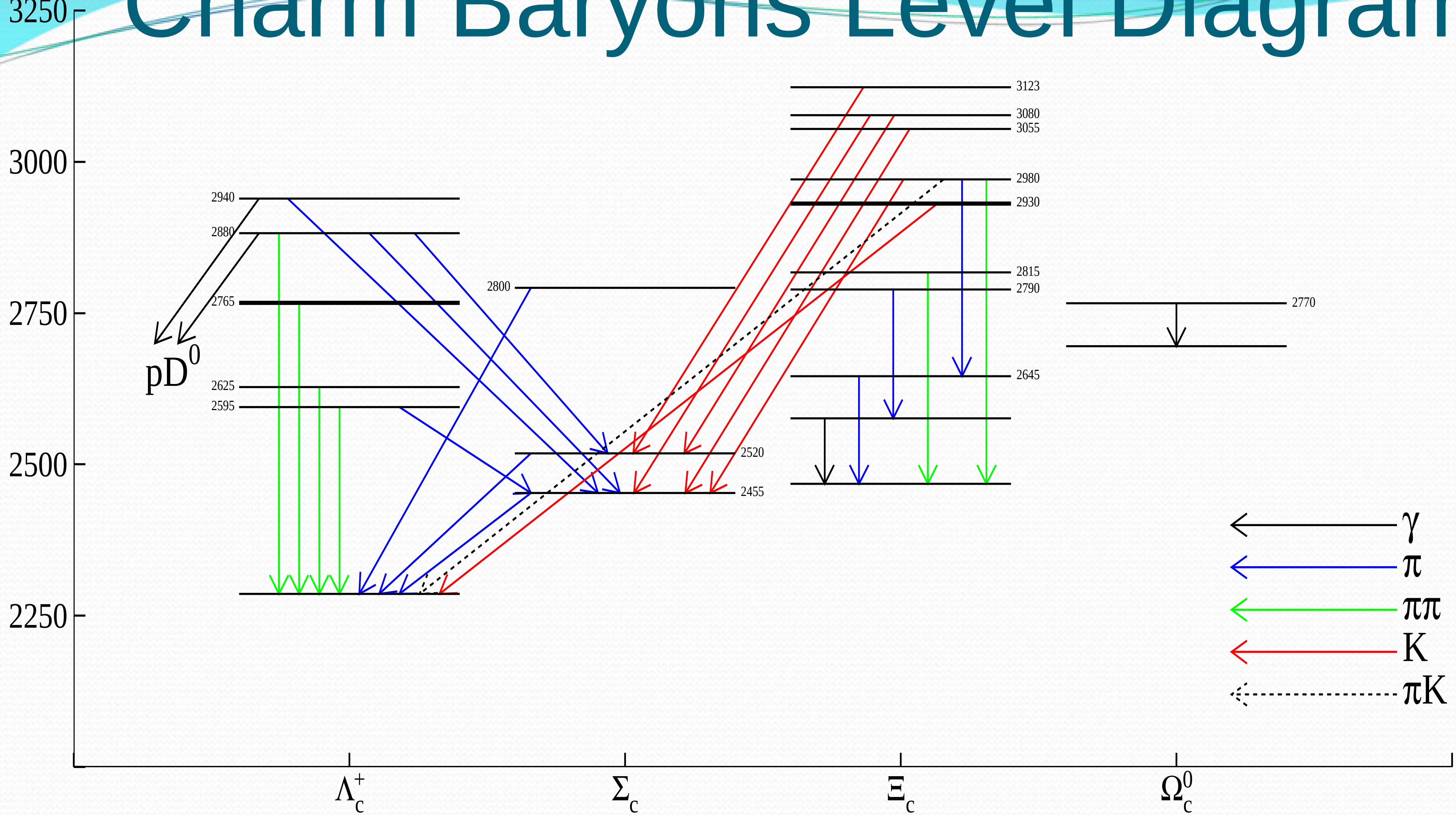
$$\mathcal{B}(B^+ \to \Xi_c^0 \Lambda_c^+) \times \mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) = (4.8^{+1.0}_{-0.9} \pm 1.1 \pm 1.1) \times 10^{-5}$$

New type of B decays: 2body decay $B \to 2$ charmed baryons

If $\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) \sim 1\% \Rightarrow \mathcal{B}(\bar{B}^0 \to \Lambda_c^+ \bar{p})$ is ~100 times smaller

One needs abs. Br's !

Charm Baryons Level Diagram



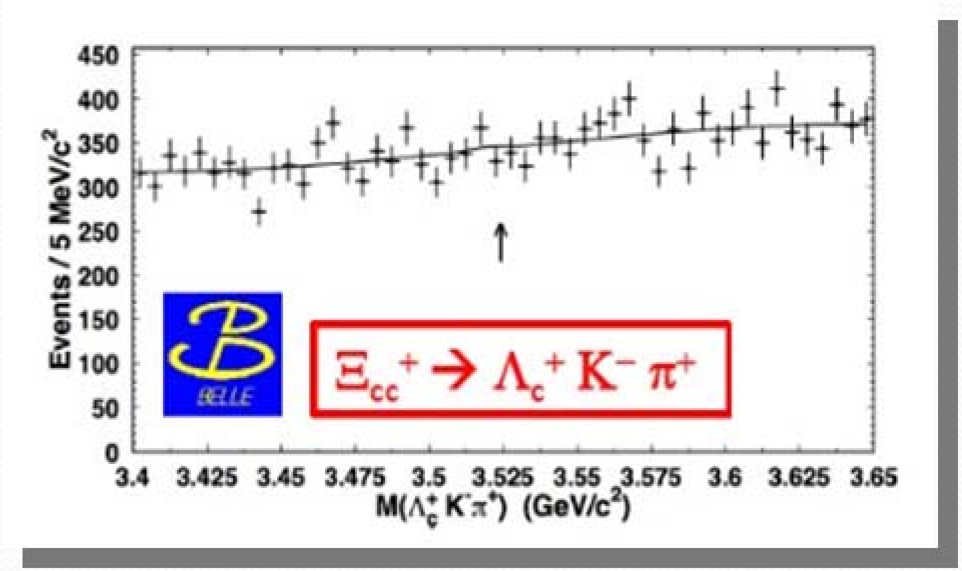
Several new states are well established but some need to be confirmed !!
Quantum numbers for most of excited states are not determined !!

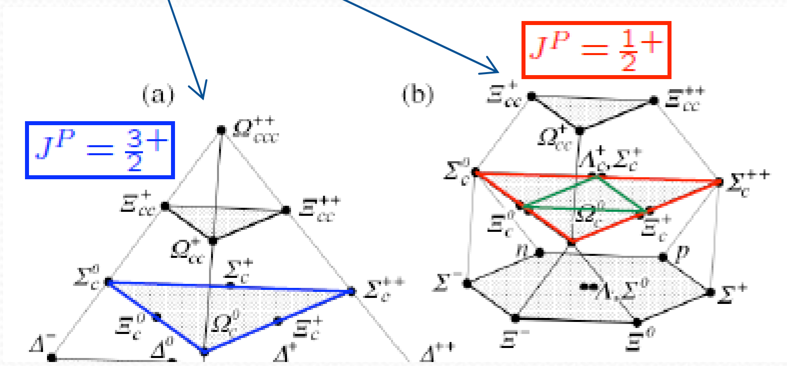
Perspectives: Hunting for Double Charm Baryons

PRL 89, 112001 (2002) : SELEX
NPB proc. 115, 33 (2003) : FOCUS
PLB 628, 18 (2005) : SELEX
PRL 97, 162001 (2006) : Belle
PRD 74, 011103 (2006) : BaBar

{CCq}

We need it!

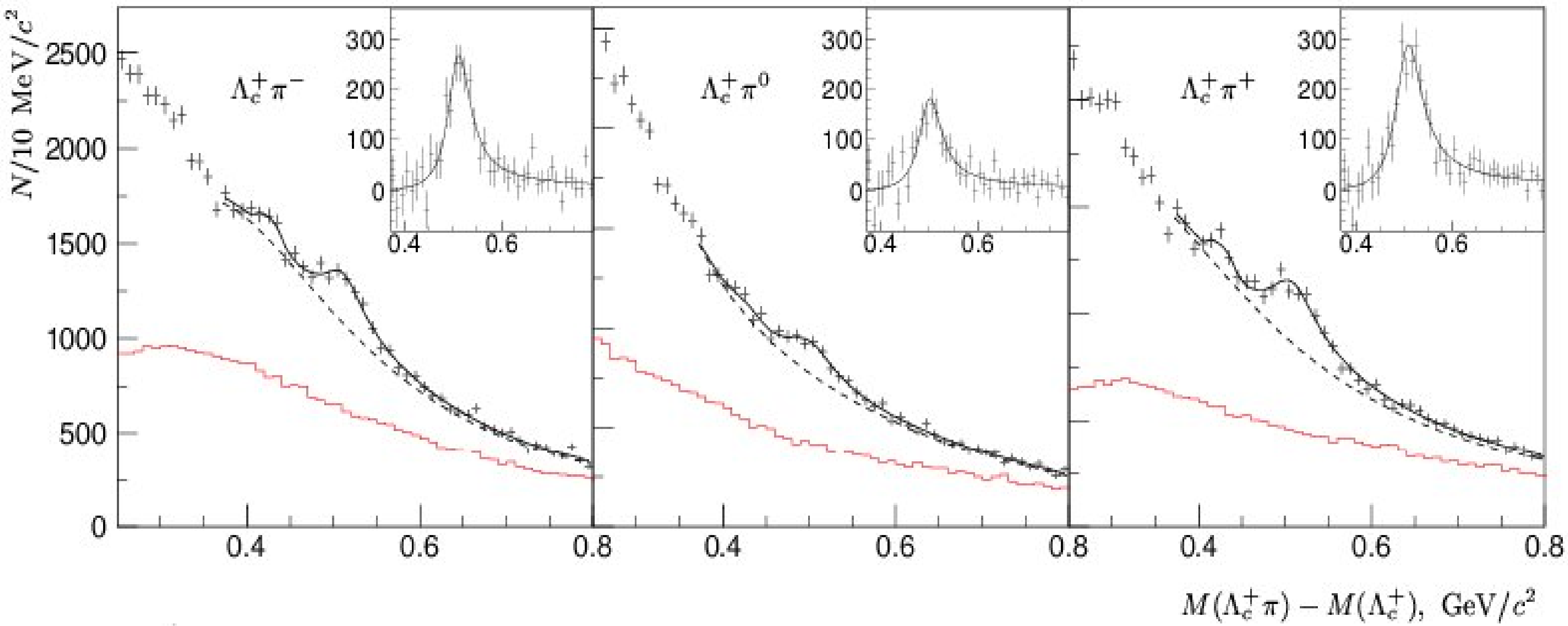




<u>Most exciting option for Future:</u>
discovery and study of
Double Charm Baryons

Backup slides

Observation of $\Sigma_c(2800)$: Results (PRL 94, 12202 (2005))



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

Σ_{c2} : J^P=3/2- and 5/2-
(total ang. momentum of light diquark is 2)

Observation of $\Sigma_c(2800)$: Discussion

Theoretical models predict a rich spectrum of excited charmed baryons in the vicinity of the $\Sigma_c(2800)$ [L.A.Copley, N.Isgur and G.Karl, Phys. Rev D 20, 768 (1979)].

One of the candidates is a Σ_{c2} doublet with J^P=3/2- and 5/2-
(subscript 2 denotes the total angular momentum of light diquark.)
Σ_{c2} is expected to decay principally into $\Lambda_c \pi$ in D-wave.

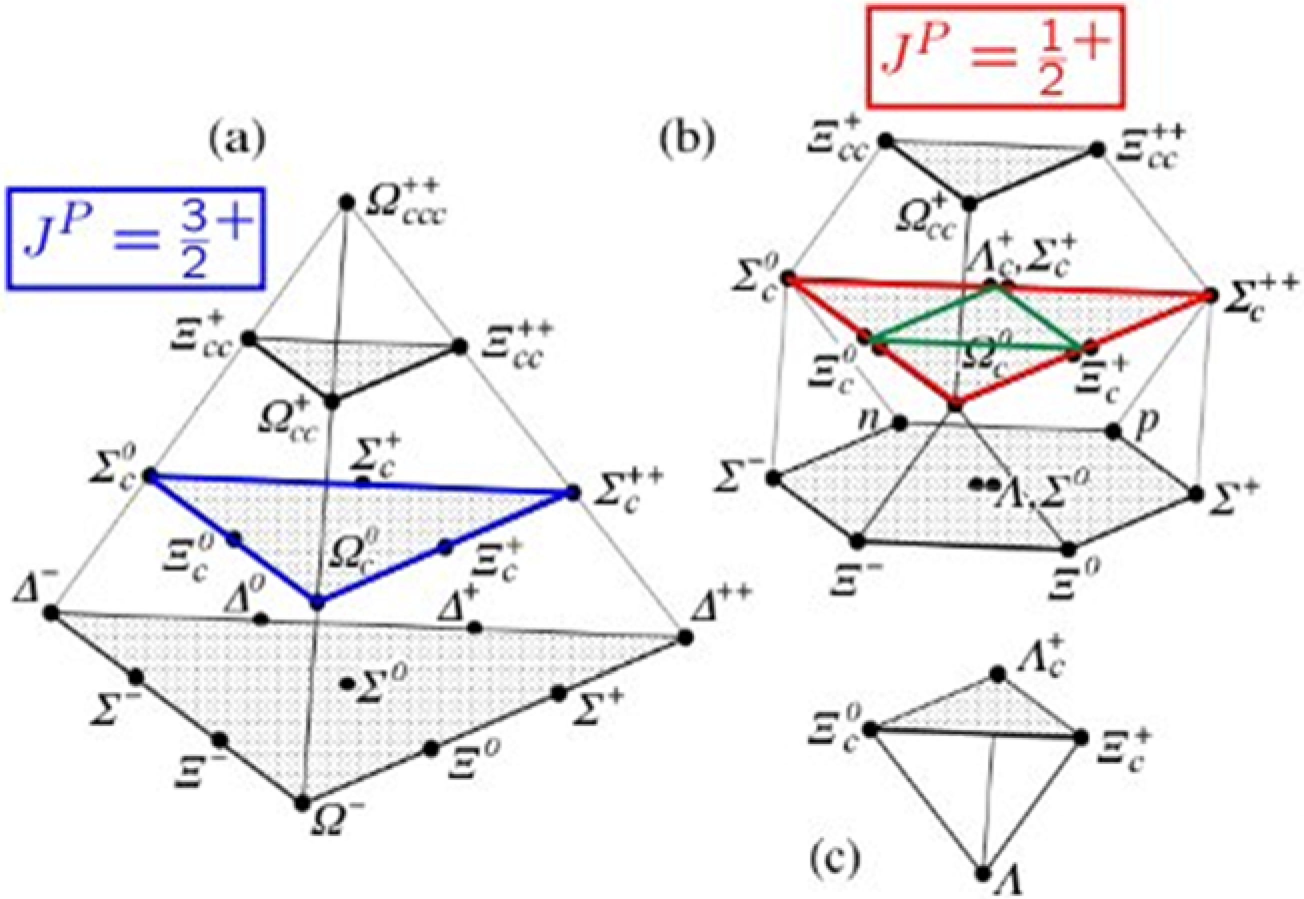
The predicted mass is close to the measured by us but the predicted width is ~15 MeV that is smaller than the one we measured.

But the Σ_{c2} (3/2-) can mix with the nearby Σ_{c1} (3/2-) which would produce a wider physical state.

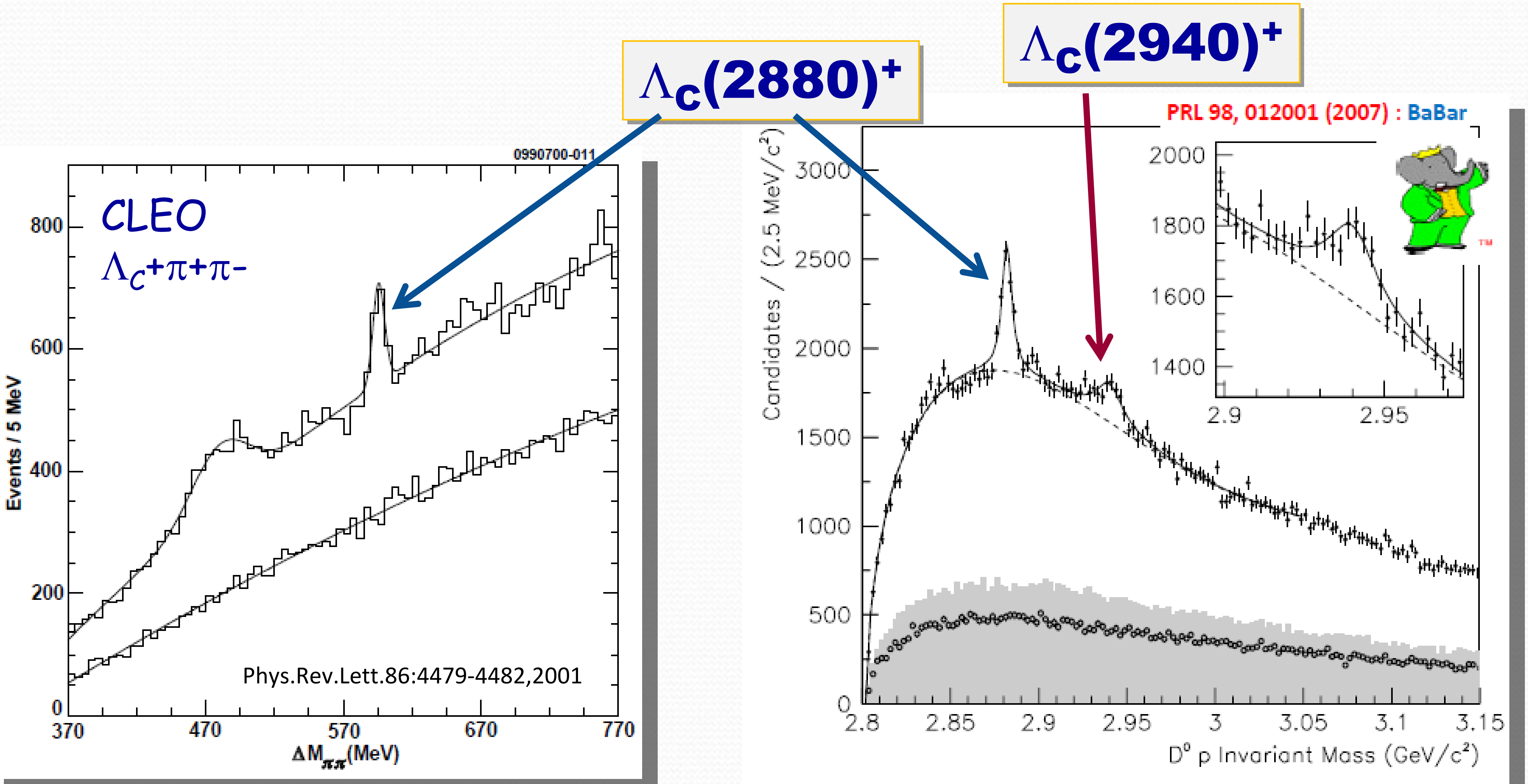
Introduction

Low-lying (L=0) baryon states:

Symbol	I	Content
N (p,n)	1/2	udq
Δ	3/2	qqq
Λ	0	sud
Σ	1	sqq
Ξ	1/2	ssq
Ω	0	sss
Λ_c	0	cud
Σ_c	1	cqq
Ξ_c	1/2	csq
Ω_c	0	css
Ξ_{cc}	1/2	ccq
Ω_{cc}	0	ccs
Ω_{ccc}	0	ccc

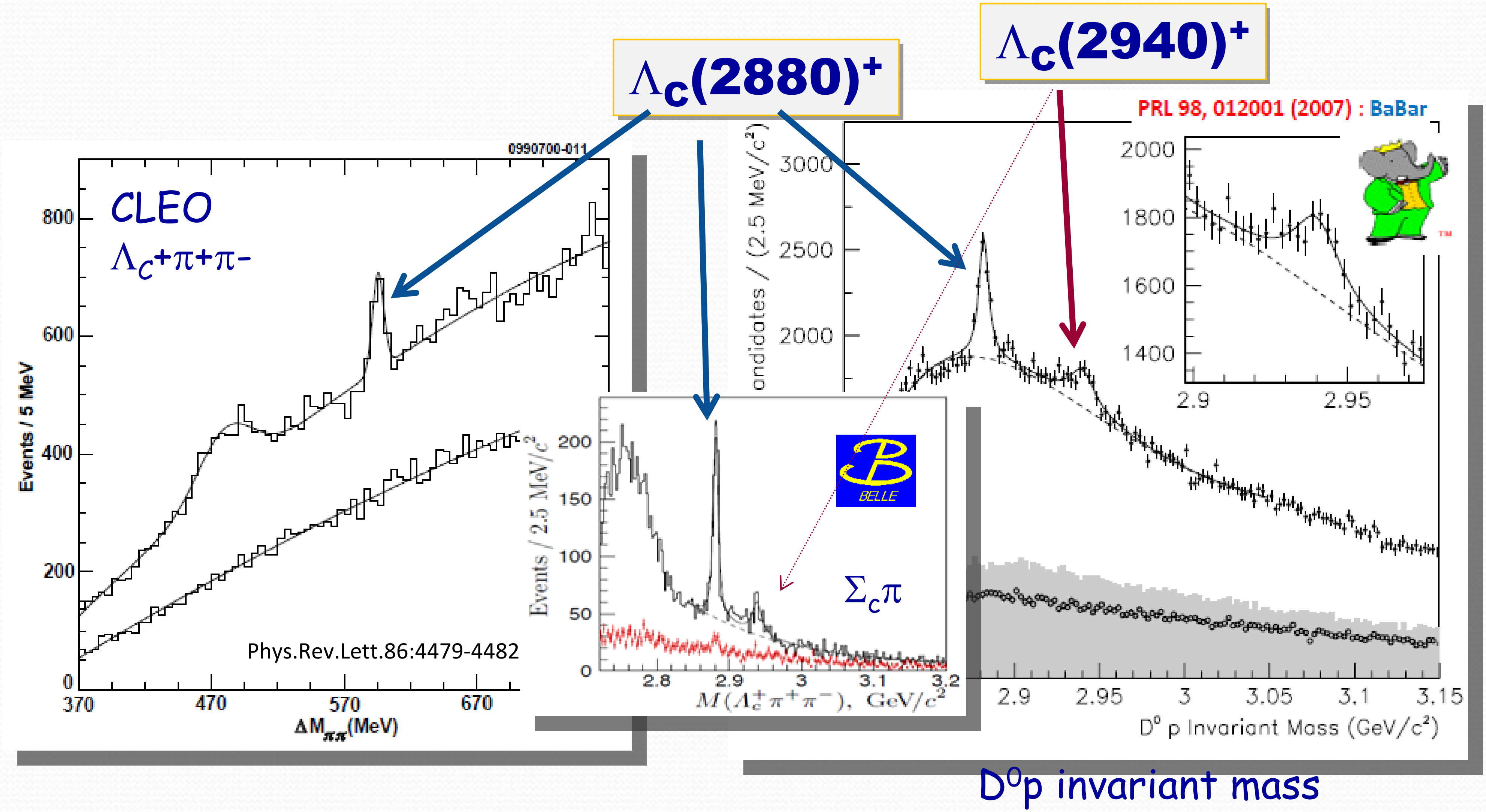


Observation of new excited Λ_c^+



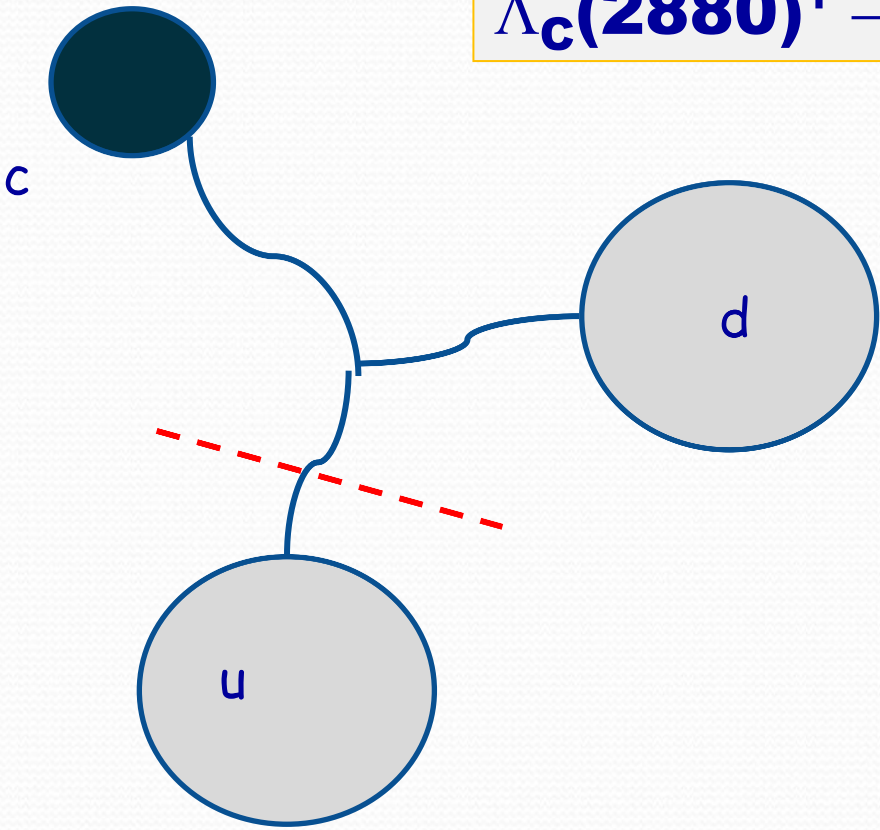
D^0p invariant mass

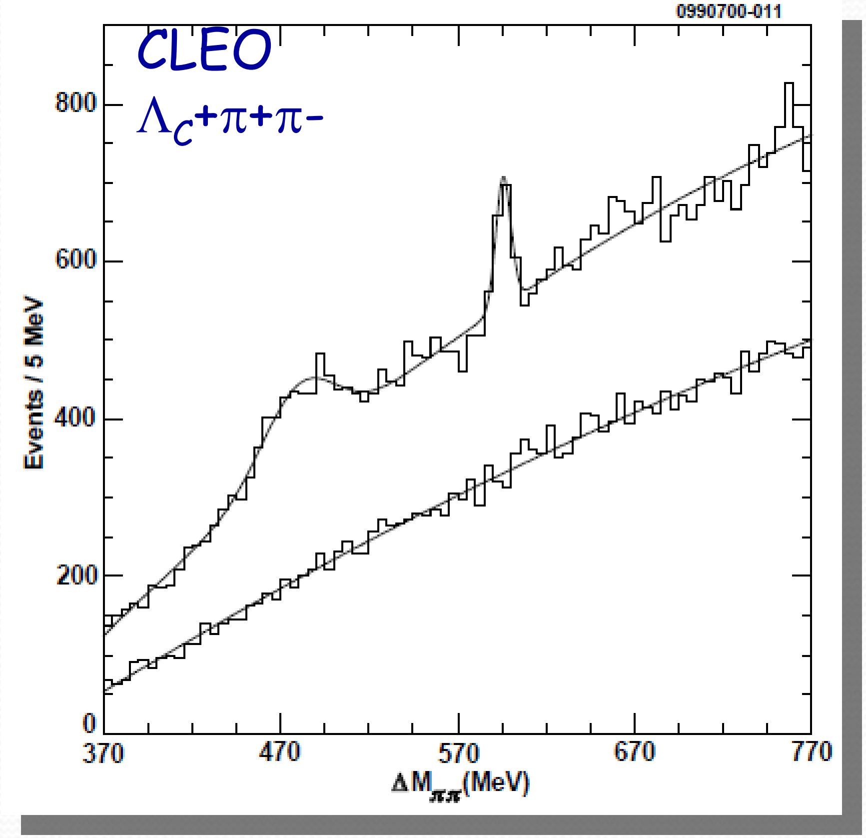
Observation of new excited Λ_c^+



Usual mechanism of excited charm baryon strong decay

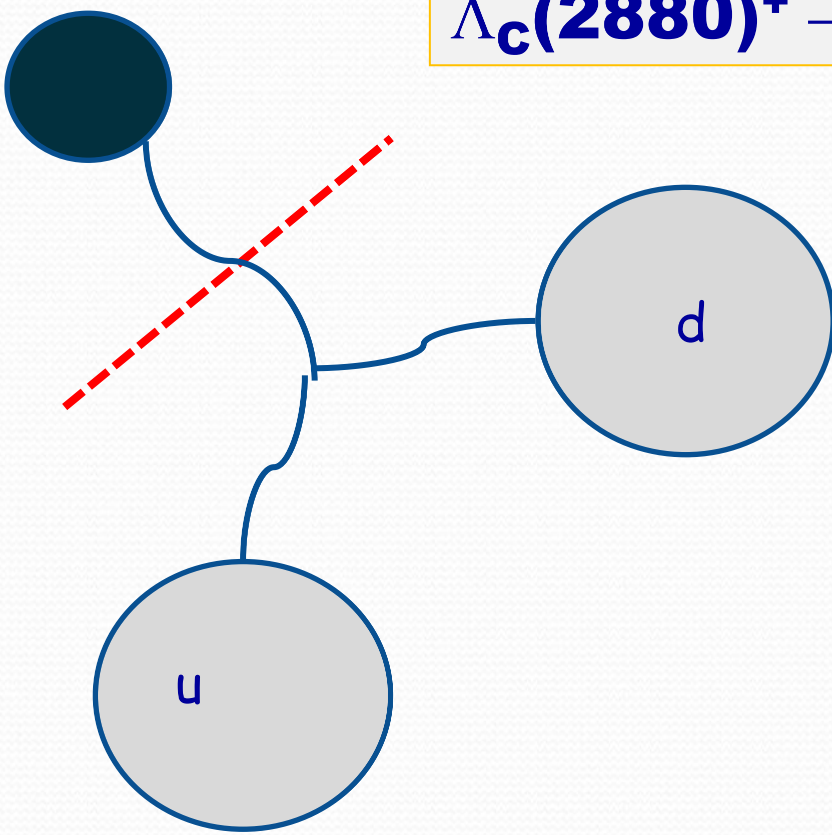
$\Lambda_c(2880)^+ \rightarrow \Sigma_c\pi \rightarrow \Lambda_c + \pi + \pi -$

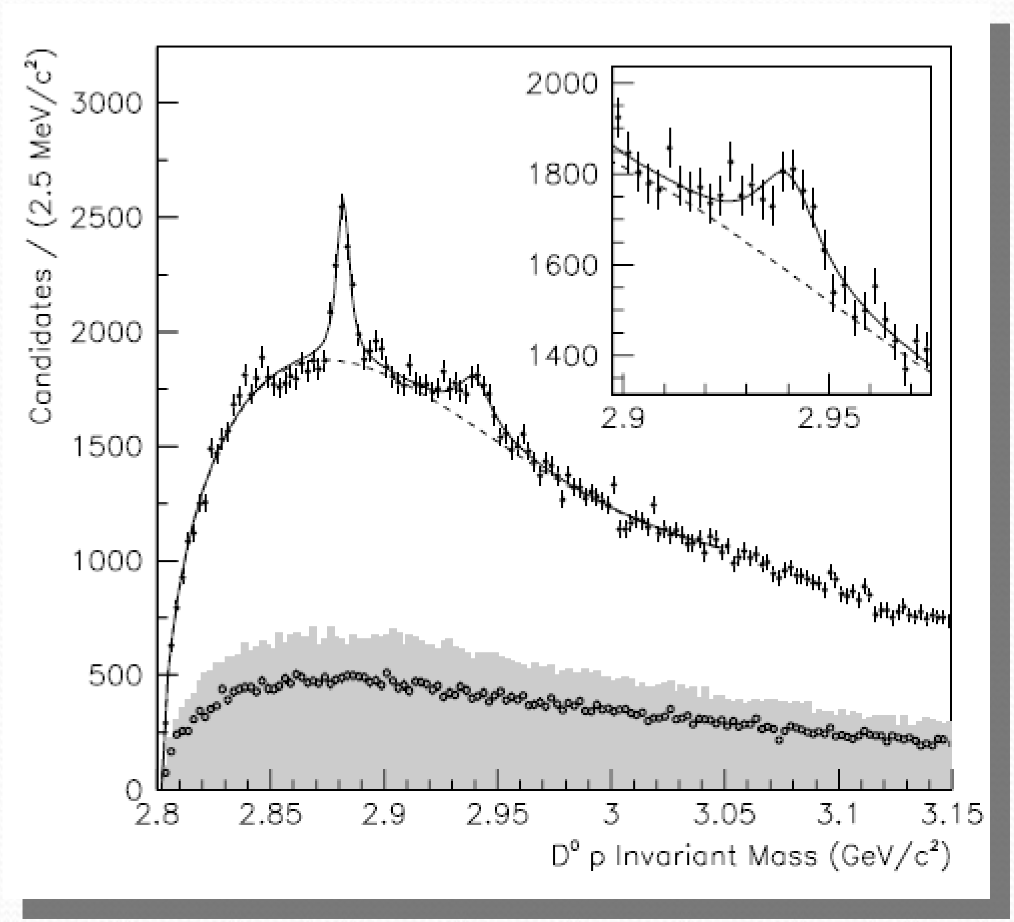




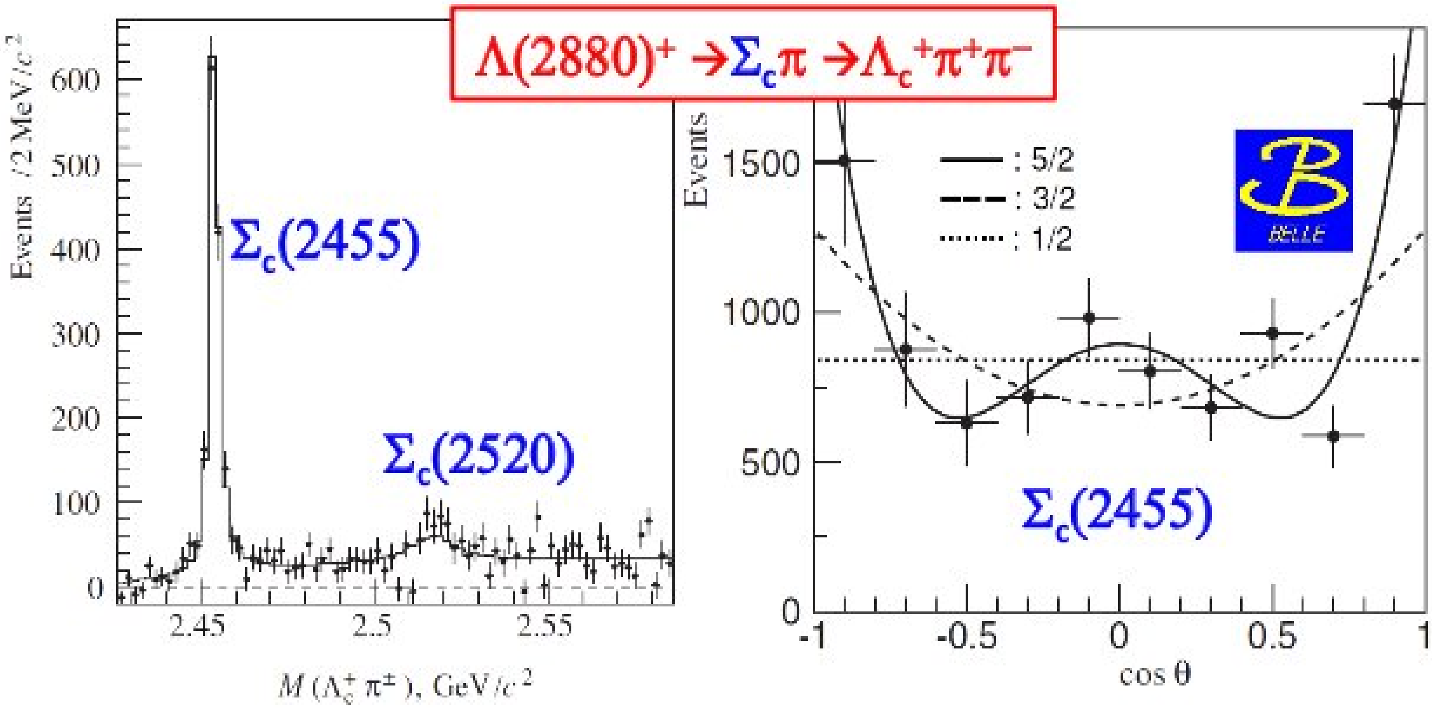
New mechanism of excited charm baryon decay

$\Lambda_c(2880)^+ \to D^0\ p$





Experimental determination of $\Lambda_c(2880)^+$ J^P



PRL 98, 262001 (2007) : Belle

J^P [$\Lambda_c(2880)^+$]

- J = 5/2 favored
- $R = \frac{\Gamma[\Sigma_c(2520)\pi]}{\Gamma[\Sigma_c(2455)\pi]}$

  $R = 0.23 \pm 0.06 \pm 0.03$
- Heavy Quark Symmetry
  - $R = 1.4 : 5/2^-$
  - $R \sim 0.3 : 5/2^+$

Baryonic B decays

Brief history of experimental situation with baryonic B decays:

- First observations of $B \to$ baryons decays came from CLEO: $\bar{B}^0 \to D^{*+} n\bar{p}$, $\bar{B}^0 \to D^{*+} p\bar{p}\pi^-$ and $\bar{B} \to \Lambda_c^+ \bar{p}\pi(\pi)$
- then Belle observed color-suppressed $\bar{B}^0 \to D^{(*)0} p\bar{p}$ and charmless $B^+ \to p\bar{p}K^+$ decays
- many other charmfull modes like $\bar{B} \to \Sigma_{c1}\bar{p}(\pi)$ were observed by Belle
- many other charmless modes like $B^+ \to \Lambda\bar{\Lambda}K^+$ and radiative $B^+ \to p\bar{\Lambda}\gamma$ were observed by Belle
- interesting features of these decays were revealed $\Rightarrow$

At the same time 2-body charmless baryonic B decays have not been observed yet and best @90% CL Upper Limits from Belle :

$\mathcal{B}(B^0 \to p\bar{p}) < 4.1 \times 10^{-7}$ $\mathcal{B}(B^0 \to \Lambda\bar{\Lambda}) < 6.9 \times 10^{-7}$

$\mathcal{B}(B^+ \to p\bar{\Lambda}) < 4.9 \times 10^{-7}$ (Phys.Rev. D71 (2005) 072007)

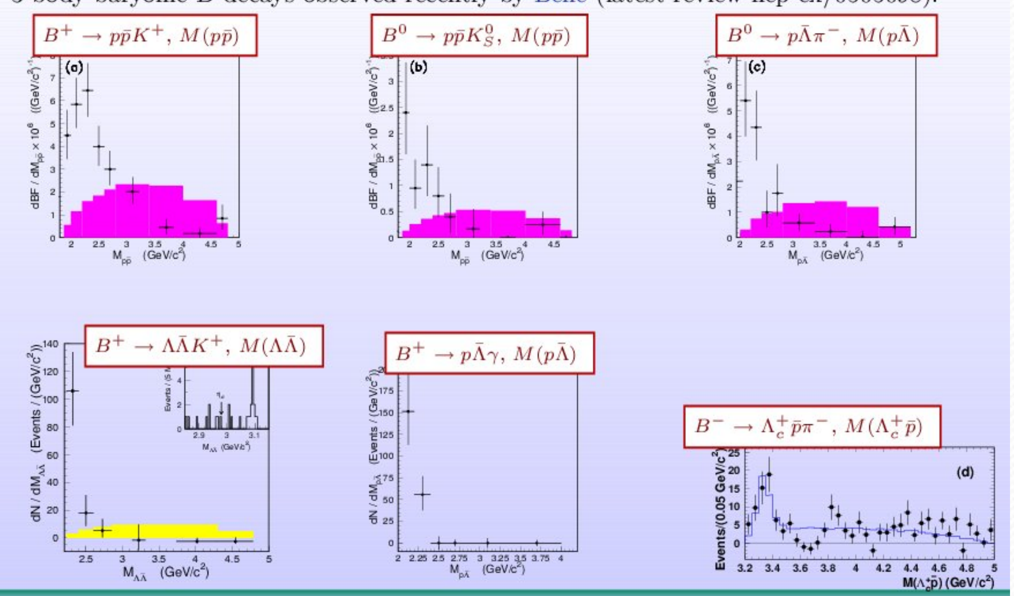
But multi-body charmfull baryonic B decays such as $B \to \Lambda_c^+ \bar{p}\pi^+\pi^-$ have $\mathcal{B}$'s ~ 10 times larger than charmfull 3-body modes (e.g. $B^- \to \Lambda_c^+ \bar{p}\pi^-$) and ~ 100 times larger than observed by Belle $B^0 \to \Lambda_c^+ \bar{p}$ (Phys.Rev.Lett. 90, 121802 (2003)

Two features of $B \to baryons$ decays observed by Belle:

threshold enhancement in baryon pair invariant mass spectra and $\mathcal{B}(B \to 2\text{body}) < \mathcal{B}(3\text{body}) < \mathcal{B}(B \to 4\text{body})$ hierarchy.

Theoretical models to explain it: intermediate gluonic resonant states or non-perturb.QCD effects in the quark fragmentation.

3-body baryonic B decays observed recently by Belle (latest review hep-ex/0505098):



Summary

Charmed Baryon Excited State	Mode	Mass or ΔM, MeV/c^2	Natural Width, MeV/c^2	J^P
$\Lambda_c(2595)^+$	$\Lambda_c^+\pi^+\pi^-$, $\Sigma_c\pi$	2595.4 ± 0.6	$3.6^{+2.0}_{-1.3}$	$1/2^-$
$\Lambda_c(2625)^+$	$\Lambda_c^+\pi^+\pi^-$, $\Sigma_c\pi$	2628.1 ± 0.6	< 1.9	$3/2^-$
$\Lambda_c(2765)^+$	$\Lambda_c^+\pi^+\pi^-$, $\Sigma_c\pi$	2766.6 ± 2.4	50	??
$\Lambda_c(2880)^+$	$\Lambda_c^+\pi^+\pi^-$, $\Sigma_c\pi$, $\Sigma_c(2520)\pi$, D^0p	2881.53 ± 0.35	5.8 ± 1.1	$5/2^+$ (experimental evidence)
$\Lambda_c(2940)^+$	D^0p, $\Sigma_c\pi$	$2939.3^{+1.4}_{-1.5}$	17^{+8}_{-6}	??

Charmed Baryon Excited State	Mode	Mass or ΔM, MeV/c^2	Natural Width, MeV/c^2	J^P
$\Xi_c'^+$	$\Xi_c^+\gamma$	2575.6 ± 3.1		$1/2^+$
$\Xi_c'^0$	$\Xi_c^0\gamma$	2577.9 ± 2.9		$1/2^+$
$\Xi_c(2645)^+$	$\Xi_c^0\pi^+$	$2645.9^{+0.6}_{-0.5}$	< 3.1	$3/2^+$
$\Xi_c(2645)^0$	$\Xi_c^+\pi^-$	2645.9 ± 0.5	< 5.5	$3/2^+$
$\Xi_c(2790)^+$	$\Xi_c'^0\pi^+$	2789.1 ± 3.2	< 15	$1/2^-$
$\Xi_c(2790)^0$	$\Xi_c'^+\pi^-$	2791.8 ± 3.3	< 12	$1/2^-$
$\Xi_c(2815)^+$	$\Xi_c^+\pi^+\pi^-$, $\Xi_c(2645)^0\pi^+$	2816.6 ± 0.9	< 3.5	$3/2^-$
$\Xi_c(2815)^0$	$\Xi_c^0\pi^+\pi^-$, $\Xi_c(2645)^+\pi^-$	2819.6 ± 1.2	< 6.5	$3/2^-$
$\Xi_c(2930)^0$	$\Lambda_c^+K^-$	2931.6 ± 6	36 ± 13	??
$\Xi_c(2980)^+$	$\Lambda_c^+K^-\pi^+$, $\Sigma_c^{++}K^-$, $\Xi_c(2645)^0\pi^+$	2971.4 ± 3.3	26 ± 7	??
$\Xi_c(2980)^0$	$\Xi_c(2645)^+\pi^-$	2968.0 ± 2.6	20 ± 7	??
$\Xi_c(3055)^+$	$\Sigma_c^{++}K^-$	3054.2 ± 1.3	17 ± 13	??
$\Xi_c(3080)^+$	$\Lambda_c^+K^-\pi^+$, $\Sigma_c^{++}K^-$, $\Sigma_c(2520)^{++}K^-$	3077.0 ± 0.4	5.8 ± 1.0	??
$\Xi_c(3080)^0$	$\Lambda_c^+K_S^0\pi^-$, $\Sigma_c^0K_S^0$, $\Sigma_c(2520)^0K_S^0$	3079.9 ± 1.4	5.6 ± 2.2	??
$\Xi_c(3123)^+$	$\Sigma_c(2520)^{++}K^-$	3122.9 ± 1.3	4 ± 4	??
$\Omega_c(2770)^0$	$\Omega_c^0\gamma$	2765.9 ± 2.0	$70.7^{+0.8}_{-0.9}$	$3/2^+$

Charmed Baryon Excited State	Mode	Mass or ΔM, MeV/c^2	Natural Width, MeV/c^2	J^P
$\Sigma_c(2520)^{++}$	$\Lambda_c^+\pi^+$	231.9 ± 0.6	14.9 ± 1.9	$3/2^+$
$\Sigma_c(2520)^+$	$\Lambda_c^+\pi^+$	231.0 ± 2.3	< 17 @ 90% CL	$3/2^+$
$\Sigma_c(2520)^0$	$\Lambda_c^+\pi^+$	231.6 ± 0.5	16.1 ± 2.1	$3/2^+$
$\Sigma_c(2800)^{++}$	$\Lambda_c^+\pi^+$	$514.5^{+3.4+2.8}_{-3.1-4.9}$	75^{+18+12}_{-13-11}	tentatively identified as members of the predicted Σ_{c2} $3/2^-$ isospin triplet
$\Sigma_c(2800)^+$	$\Lambda_c^+\pi^0$	$505.4^{+5.8+12.4}_{-4.6-2.0}$	62^{+37+52}_{-23-38}	
$\Sigma_c(2800)^0$	$\Lambda_c^+\pi^-$	$515.4^{+3.2+2.1}_{-3.1-6.0}$	61^{+18+22}_{-13-13}	
	$\Lambda_c^+\pi^-$	$560 \pm 8 \pm 10$	86^{+33}_{-22}	

Several new states are well established but some need to be confirmed !!
Quantum numbers for most of excited states are not determined !!