Charmed Baryons

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Contents

Charmed baryon production at BESIII

If ⌧s > 4.6 GeV, ⇒ charmed baryon physics

In order to estimate the number of charmed baryon events produced at BESIII, one needs to know luminosity, $\sigma(e^+e^- \rightarrow c\underline{c})$, fragmentation function of $c \rightarrow$ hadrons

Chao-His Chang, Jian-Ping Ma, Cong-Feng Qiao, Xing-Gang Wu

hep-ph/0610205

"Hadronic production of the doubly charmed baryon Ξ_{cc} with intrinsic charm"

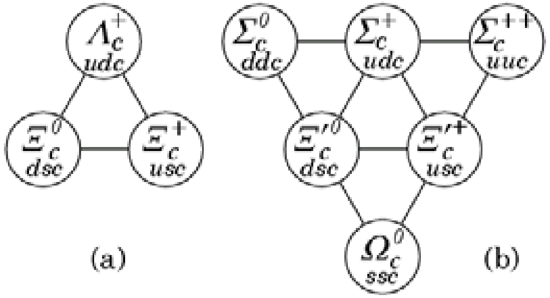
Spectroscopy

In SU(3) representation, diquark = 3×3 = $\underline{3}$+6

$\underline{3}$: $\Lambda_c^+, \Xi_c^+, \Xi_c^0$, all decay weakly

6: $\Omega_c^0, \Xi'^+_c, \Xi'^0_c, \Sigma_c^{++,+,0}$ only Ω_c^0 decays weakly

$\Omega_c^{*0}, \Xi^{*+}_c, \Xi^{*0}_c, \Sigma_c^{*++,+,0}$



S=0 S=1

Many new resonances observed:

Ground state: Ω_c^* with mass=2768.3±3.0 MeV

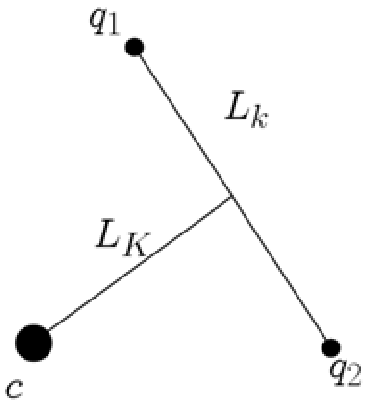
Orbitally excited p-wave states: L=1

e.g. $\Lambda_c(2593)$, $\Lambda_c(2625) = \Lambda_{c1}(1/2^-,3/2^-)$

Positive parity excitations: L=2,1,0

e.g. $J^P[\Lambda_c(2880)]=5/2^+$

Orbitally excited charmed baryon states



$L_k + L_K = L$ (not $L_k + L_K = L$)

Two possible p-wave states:

1. $L_k=1$, $L_K=0$; antisymmetric under $q_1 \leftrightarrow q_2$
2. $L_k=0$, $L_K=1$; symmetric under $q_1 \leftrightarrow q_2$

$J_l = S_l + L$, $J = S_c + J_l$

State	SU(3)	S_ℓ	L_ℓ	$J_\ell^{P_\ell}$	State	SU(3)	S_ℓ	L_ℓ	$J_\ell^{P_\ell}$
$\Lambda_{c1}(\frac{1}{2},\frac{3}{2})$	$\bar{\mathbf{3}}$	0	1	1^-	$\Xi_{c1}(\frac{1}{2},\frac{3}{2})$	$\bar{\mathbf{3}}$	0	1	1^-
$\Sigma_{c0}(\frac{1}{2})$	$\mathbf{6}$	1	1	0^-	$\Xi'_{c0}(\frac{1}{2})$	$\mathbf{6}$	1	1	0^-
$\Sigma_{c1}(\frac{1}{2},\frac{3}{2})$	$\mathbf{6}$	1	1	1^-	$\Xi'_{c1}(\frac{1}{2},\frac{3}{2})$	$\mathbf{6}$	1	1	1^-
$\Sigma_{c2}(\frac{3}{2},\frac{5}{2})$	$\mathbf{6}$	1	1	2^-	$\Xi'_{c2}(\frac{3}{2},\frac{5}{2})$	$\mathbf{6}$	1	1	2^-
$\tilde{\Sigma}_{c1}(\frac{1}{2},\frac{3}{2})$	$\mathbf{6}$	0	1	1^-	$\tilde{\Xi}'_{c1}(\frac{1}{2},\frac{3}{2})$	$\mathbf{6}$	0	1	1^-
$\tilde{\Lambda}_{c0}(\frac{1}{2})$	$\bar{\mathbf{3}}$	1	1	0^-	$\tilde{\Xi}_{c0}(\frac{1}{2})$	$\bar{\mathbf{3}}$	1	1	0^-
$\tilde{\Lambda}_{c1}(\frac{1}{2},\frac{3}{2})$	$\bar{\mathbf{3}}$	1	1	1^-	$\tilde{\Xi}_{c1}(\frac{1}{2},\frac{3}{2})$	$\bar{\mathbf{3}}$	1	1	1^-
$\tilde{\Lambda}_{c2}(\frac{3}{2},\frac{5}{2})$	$\bar{\mathbf{3}}$	1	1	2^-	$\tilde{\Xi}_{c2}(\frac{3}{2},\frac{5}{2})$	$\bar{\mathbf{3}}$	1	1	2^-

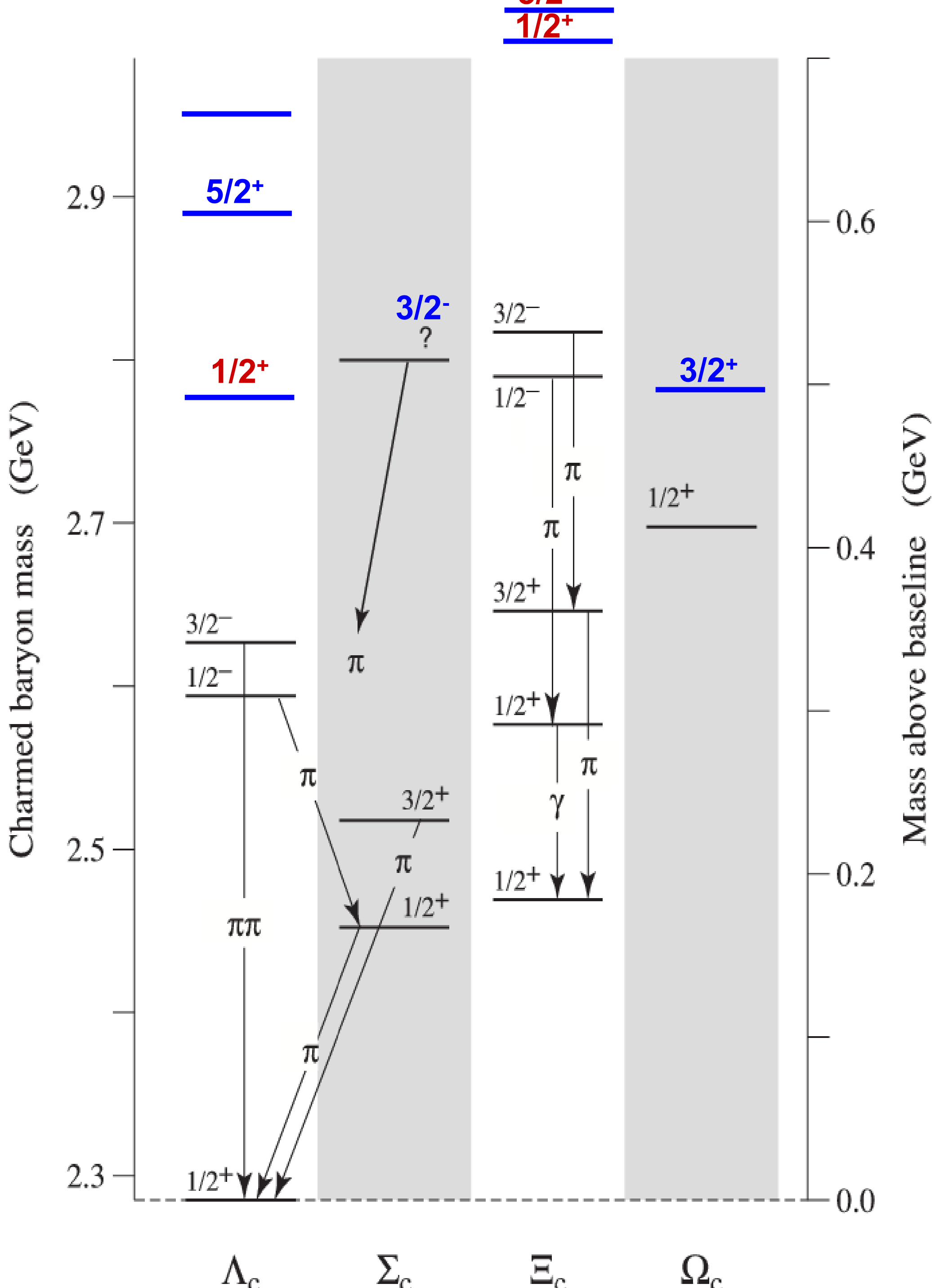
symmetric

antisymmetric

Positive parity excitations:

1. L_k=2, L_K=0; L_k=0, L_K=2 symmetric under $q_1 \leftrightarrow q_2$; L=2
2. L_k=L_K=1 antisymmetric under $q_1 \leftrightarrow q_2$; L=2,1,0

State	$SU(3)_F$	S_ℓ	L_ℓ	$J_\ell^{P_\ell}$	State	$SU(3)_F$	S_ℓ	L_ℓ	$J_\ell^{P_\ell}$
$\Lambda_{c2}(\frac{3}{2}^+, \frac{5}{2}^+)$	$\bar{\mathbf{3}}$	0	2	2^+	$\Sigma_{c1}(\frac{1}{2}^+, \frac{3}{2}^+)$	$\mathbf{6}$	1	2	1^+
$\tilde{\Lambda}_{c1}(\frac{1}{2}^+, \frac{3}{2}^+)$	$\bar{\mathbf{3}}$	1	0	1^+	$\Sigma_{c2}(\frac{3}{2}^+, \frac{5}{2}^+)$	$\mathbf{6}$	1	2	2^+
$\tilde{\Lambda}'_{c0}(\frac{1}{2}^+)$	$\bar{\mathbf{3}}$	1	1	0^+	$\Sigma_{c3}(\frac{5}{2}^+, \frac{7}{2}^+)$	$\mathbf{6}$	1	2	3^+
$\tilde{\Lambda}'_{c1}(\frac{1}{2}^+, \frac{3}{2}^+)$	$\bar{\mathbf{3}}$	1	1	1^+	$\tilde{\Sigma}_{c0}(\frac{1}{2}^+)$	$\mathbf{6}$	0	0	0^+
$\tilde{\Lambda}'_{c2}(\frac{3}{2}^+, \frac{5}{2}^+)$	$\bar{\mathbf{3}}$	1	1	2^+	$\tilde{\Sigma}_{c1}(\frac{1}{2}^+, \frac{3}{2}^+)$	$\mathbf{6}$	0	1	1^+
$\tilde{\Lambda}''_{c1}(\frac{1}{2}^+, \frac{3}{2}^+)$	$\bar{\mathbf{3}}$	1	2	1^+	$\tilde{\Sigma}_{c2}(\frac{3}{2}^+, \frac{5}{2}^+)$	$\mathbf{6}$	0	2	2^+
$\tilde{\Lambda}''_{c2}(\frac{3}{2}^+, \frac{5}{2}^+)$	$\bar{\mathbf{3}}$	1	2	2^+					
$\tilde{\Lambda}''_{c3}(\frac{5}{2}^+, \frac{7}{2}^+)$	$\bar{\mathbf{3}}$	1	2	3^+					
$\Xi_{c2}(\frac{3}{2}^+, \frac{5}{2}^+)$	$\bar{\mathbf{3}}$	0	2	2^+	$\Xi'_{c1}(\frac{1}{2}^+, \frac{3}{2}^+)$	$\mathbf{6}$	1	2	1^+
$\tilde{\Xi}_{c1}(\frac{1}{2}^+, \frac{3}{2}^+)$	$\bar{\mathbf{3}}$	1	0	1^+	$\Xi'_{c2}(\frac{3}{2}^+, \frac{5}{2}^+)$	$\mathbf{6}$	1	2	2^+
$\tilde{\Xi}''_{c0}(\frac{1}{2}^+)$	$\bar{\mathbf{3}}$	1	1	0^+	$\Xi'_{c3}(\frac{5}{2}^+, \frac{7}{2}^+)$	$\mathbf{6}$	1	2	3^+
$\tilde{\Xi}''_{c1}(\frac{1}{2}^+, \frac{3}{2}^+)$	$\bar{\mathbf{3}}$	1	1	1^+	$\tilde{\Xi}'_{c0}(\frac{1}{2}^+)$	$\mathbf{6}$	0	0	0^+
$\tilde{\Xi}''_{c2}(\frac{3}{2}^+, \frac{5}{2}^+)$	$\bar{\mathbf{3}}$	1	1	2^+	$\tilde{\Xi}'_{c1}(\frac{1}{2}^+, \frac{3}{2}^+)$	$\mathbf{6}$	0	1	1^+
$\tilde{\Xi}'''_{c1}(\frac{1}{2}^+, \frac{3}{2}^+)$	$\bar{\mathbf{3}}$	1	2	1^+	$\tilde{\Xi}'_{c2}(\frac{3}{2}^+, \frac{5}{2}^+)$	$\mathbf{6}$	0	2	2^+
$\tilde{\Xi}'''_{c2}(\frac{3}{2}^+, \frac{5}{2}^+)$	$\bar{\mathbf{3}}$	1	2	2^+					
$\tilde{\Xi}'''_{c3}(\frac{5}{2}^+, \frac{7}{2}^+)$	$\bar{\mathbf{3}}$	1	2	3^+					



1/2+
5/2+
1/2+
3/2-
?
3/2−
1/2−
3/2+
1/2+
π
ππ
3/2−
1/2−
3/2+
1/2+
γ
1/2+
Charmed baryon mass (GeV)
Mass above baseline (GeV)
2.9
2.7
2.5
2.3
0.6
0.4
0.2
0.0
Λc
Σc
Ξc
Ωc

	State	J^P	S_ℓ	L_ℓ	$J_\ell^{P_\ell}$	Mass	Width	Decay modes
	Λ_c^+	$\frac{1}{2}^+$	0	0	0^+	2286.46 ± 0.14		weak
	$\Lambda_c(2593)^+$	$\frac{1}{2}^-$	0	1	1^-	2595.4 ± 0.6	$3.6^{+2.0}_{-1.3}$	$\Sigma_c\pi, \Lambda_c\pi\pi$
	$\Lambda_c(2625)^+$	$\frac{3}{2}^-$	0	1	1^-	2628.1 ± 0.6	< 1.9	$\Lambda_c\pi\pi, \Sigma_c\pi$
$\frac{1}{2}^+$	$\Lambda_c(2765)^+$	$?^?$	?	?	?	2766.6 ± 2.4	50	$\Sigma_c\pi, \Lambda_c\pi\pi$
	$\Lambda_c(2880)^+$	$\frac{5}{2}^+$	?	?	?	2881.5 ± 0.3	5.5 ± 0.6	$\Sigma_c^{(*)}\pi, \Lambda_c\pi\pi, D^0p$
$3/2^+, 5/2^-$	$\Lambda_c(2940)^+$	$?^?$	?	?	?	2938.8 ± 1.1	13.0 ± 5.0	$\Sigma_c^{(*)}\pi, \Lambda_c\pi\pi, D^0p$
	$\Sigma_c(2455)^{++}$	$\frac{1}{2}^+$	1	0	1^+	2454.02 ± 0.18	2.23 ± 0.30	$\Lambda_c\pi$
	$\Sigma_c(2455)^+$	$\frac{1}{2}^+$	1	0	1^+	2452.9 ± 0.4	< 4.6	$\Lambda_c\pi$
	$\Sigma_c(2455)^0$	$\frac{1}{2}^+$	1	0	1^+	2453.76 ± 0.18	2.2 ± 0.4	$\Lambda_c\pi$
	$\Sigma_c(2520)^{++}$	$\frac{3}{2}^+$	1	0	1^+	2518.4 ± 0.6	14.9 ± 1.9	$\Lambda_c\pi$
	$\Sigma_c(2520)^+$	$\frac{3}{2}^+$	1	0	1^+	2517.5 ± 2.3	< 17	$\Lambda_c\pi$
	$\Sigma_c(2520)^0$	$\frac{3}{2}^+$	1	0	1^+	2518.0 ± 0.5	16.1 ± 2.1	$\Lambda_c\pi$
$3/2^-$	$\Sigma_c(2800)^{++}$	$\frac{3}{2}^-?$	1	1	2^-	2801^{+4}_{-6}	75^{+22}_{-17}	$\Lambda_c\pi, \Sigma_c^{(*)}\pi, \Lambda_c\pi\pi$
	$\Sigma_c(2800)^+$	$\frac{3}{2}^-?$	1	1	2^-	2792^{+14}_{-5}	62^{+60}_{-40}	$\Lambda_c\pi, \Sigma_c^{(*)}\pi, \Lambda_c\pi\pi$
	$\Sigma_c(2800)^0$	$\frac{3}{2}^-?$	1	1	2^-	2802^{+4}_{-7}	61^{+28}_{-18}	$\Lambda_c\pi, \Sigma_c^{(*)}\pi, \Lambda_c\pi\pi$
	Ξ_c^+	$\frac{1}{2}^+$	0	0	0^+	2467.9 ± 0.4		weak
	Ξ_c^0	$\frac{1}{2}^+$	0	0	0^+	2471.0 ± 0.4		weak
	$\Xi_c'^+$	$\frac{1}{2}^+$	1	0	1^+	2575.7 ± 3.1		$\Xi_c\gamma$
	$\Xi_c'^0$	$\frac{1}{2}^+$	1	0	1^+	2578.0 ± 2.9		$\Xi_c\gamma$
	$\Xi_c(2645)^+$	$\frac{3}{2}^+$	1	0	1^+	2646.6 ± 1.4	< 3.1	$\Xi_c\pi$
	$\Xi_c(2645)^0$	$\frac{3}{2}^+$	1	0	1^+	2646.1 ± 1.2	< 5.5	$\Xi_c\pi$
	$\Xi_c(2790)^+$	$\frac{1}{2}^-$	0	1	1^-	2789.2 ± 3.2	< 15	$\Xi_c'\pi$
	$\Xi_c(2790)^0$	$\frac{1}{2}^-$	0	1	1^-	2791.9 ± 3.3	< 12	$\Xi_c'\pi$
	$\Xi_c(2815)^+$	$\frac{3}{2}^-$	0	1	1^-	2816.5 ± 1.2	< 3.5	$\Xi_c^*\pi, \Xi_c\pi\pi, \Xi_c'\pi$
	$\Xi_c(2815)^0$	$\frac{3}{2}^-$	0	1	1^-	2818.2 ± 2.1	< 6.5	$\Xi_c^*\pi, \Xi_c\pi\pi, \Xi_c'\pi$
$\frac{1}{2}^+$	$\Xi_c(2980)^+$	$?^?$	?	?	?	2971.1 ± 1.7	25.2 ± 3.0	see Table VII
$\frac{1}{2}^+$	$\Xi_c(2980)^0$	$?^?$	?	?	?	2977.1 ± 9.5	43.5	see Table VII
$5/2^+$	$\Xi_c(3077)^+$	$?^?$	?	?	?	3076.5 ± 0.6	6.2 ± 1.1	see Table VII
$5/2^+$	$\Xi_c(3077)^0$	$?^?$	?	?	?	3082.8 ± 2.3	5.2 ± 3.6	see Table VII
	Ω_c^0	$\frac{1}{2}^+$	1	0	1^+	2697.5 ± 2.6		weak
	$\Omega_c(2768)^0$	$\frac{3}{2}^+$	1	0	1^+	2768.3 ± 3.0		$\Omega_c\gamma$

Only parity of Λ_c & $\Lambda_c(2880)$ has been measured

An ideal place for testing heavy quark symmetry and chiral symmetry : heavy hadron chiral perturbation theory (HHChPT)

Strong decays of s-wave charmed baryons

Decay	Expt. [7]	This work HHChPT	Tawfiq et al. [27]	Ivanov et al. [28]	Huang et al. [29]	Albertus et al. [30]
$\Sigma_c^{++} \to \Lambda_c^+ \pi^+$	2.23 ± 0.30	input	1.51 ± 0.17	2.85 ± 0.19	2.5	2.41 ± 0.07
$\Sigma_c^{+} \to \Lambda_c^+ \pi^0$	< 4.6	2.6 ± 0.4	1.56 ± 0.17	3.63 ± 0.27	3.2	2.79 ± 0.08
$\Sigma_c^{0} \to \Lambda_c^+ \pi^-$	2.2 ± 0.4	2.2 ± 0.3	1.44 ± 0.16	2.65 ± 0.19	2.4	2.37 ± 0.07
$\Sigma_c(2520)^{++} \to \Lambda_c^+ \pi^+$	14.9 ± 1.9	16.7 ± 2.3	11.77 ± 1.27	21.99 ± 0.87	8.2	17.52 ± 0.75
$\Sigma_c(2520)^{+} \to \Lambda_c^+ \pi^0$	< 17	17.4 ± 2.3			8.6	17.31 ± 0.74
$\Sigma_c(2520)^{0} \to \Lambda_c^+ \pi^-$	16.1 ± 2.1	16.6 ± 2.2	11.37 ± 1.22	21.21 ± 0.81	8.2	16.90 ± 0.72
$\Xi_c(2645)^{+} \to \Xi_c^{0,+} \pi^{+,0}$	< 3.1	2.8 ± 0.4	1.76 ± 0.14	3.04 ± 0.37		3.18 ± 0.10
$\Xi_c(2645)^{0} \to \Xi_c^{+,0} \pi^{-,0}$	< 5.5	2.9 ± 0.4	1.83 ± 0.06	3.12 ± 0.33		3.03 ± 0.10

in units of MeV

Strong decays of p-wave charmed baryons

	Decay	Expt. [7]	This work HHChPT	Tawfiq et al. [27]	Ivanov et al. [28]	Huang et al. [29]	Zhu [34]
$h_2 \leftarrow$	$\Lambda_c(2593)^+ \to (\Lambda_c^+\pi\pi)_R$	$2.63^{+1.56}_{-1.09}$	input			2.5	
	$\Lambda_c(2593)^+ \to \Sigma_c^{++}\pi^-$	$0.65^{+0.41}_{-0.31}$	$0.62^{+0.37}_{-0.26}$	1.47 ± 0.57	0.79 ± 0.09	$0.55^{+1.3}_{-0.55}$	0.64
	$\Lambda_c(2593)^+ \to \Sigma_c^0\pi^+$	$0.67^{+0.41}_{-0.31}$	$0.67^{+0.40}_{-0.28}$	1.78 ± 0.70	0.83 ± 0.09	0.89 ± 0.86	0.86
	$\Lambda_c(2593)^+ \to \Sigma_c^+\pi^0$		$1.34^{+0.79}_{-0.55}$	1.18 ± 0.46	0.98 ± 0.12	1.7 ± 0.49	1.2
	$\Lambda_c(2625)^+ \to \Sigma_c^{++}\pi^-$	< 0.10	$\lesssim 0.028$	0.44 ± 0.23	0.076 ± 0.009	0.013	0.011
	$\Lambda_c(2625)^+ \to \Sigma_c^0\pi^+$	< 0.09	$\lesssim 0.028$	0.47 ± 0.25	0.080 ± 0.009	0.013	0.011
	$\Lambda_c(2625)^+ \to \Sigma_c^+\pi^0$		$\lesssim 0.040$	0.42 ± 0.22	0.095 ± 0.012	0.013	0.011
	$\Lambda_c(2625)^+ \to \Lambda_c^+\pi\pi$	< 1.9	$\lesssim 0.21$			0.11	
	$\Sigma_c(2800)^{++} \to \Lambda_c\pi, \Sigma_c^{(*)}\pi$	75^{+22}_{-17}	input				
$h_{10} \leftarrow$	$\Sigma_c(2800)^+ \to \Lambda_c\pi, \Sigma_c^{(*)}\pi$	62^{+60}_{-40}	input				
	$\Sigma_c(2800)^0 \to \Lambda_c\pi, \Sigma_c^{(*)}\pi$	61^{+28}_{-18}	input				
	$\Xi_c(2790)^+ \to \Xi_c'^{0,+}\pi^{+,0}$	< 15	$7.7^{+4.5}_{-3.2}$				
	$\Xi_c(2790)^0 \to \Xi_c'^{+,0}\pi^{-,0}$	< 12	$8.1^{+4.8}_{-3.4}$				
	$\Xi_c(2815)^+ \to \Xi_c^{*+,0}\pi^{0,+}$	< 3.5	$3.2^{+1.9}_{-1.3}$	2.35 ± 0.93	0.70 ± 0.04		
	$\Xi_c(2815)^0 \to \Xi_c^{*+,0}\pi^{-,0}$	< 6.5	$3.5^{+2.0}_{-1.4}$				

in units of MeV

isospin violation: $\Sigma_c^+\pi^0 \sim 2\,\Sigma_c^0\pi^+$, $\Lambda_c\pi^0\pi^0 \sim \Lambda_c\pi^+\pi^-$

as π^0 is lighter than $\pi^\pm$

Lifetimes

10^{-15}s

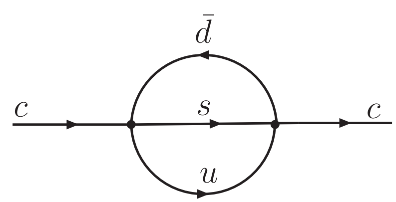
Ξ_c^+	442±26
Λ_c^+	200±6
Ξ_c^0	112^{+13}_{-10}
Ω_c^0	69±12

D^+	1040±7
D_s^+	500±7
D^0	410.1±1.5

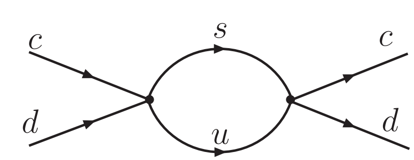
heavy quark expansion:

$$\Gamma(B_c \to f) = \frac{G_F^2 m_c^5}{192\pi^3} V_{CKM} \left(A_0 + \frac{A_2}{m_c^2} + \frac{A_3}{m_c^3} + \ldots\right)$$

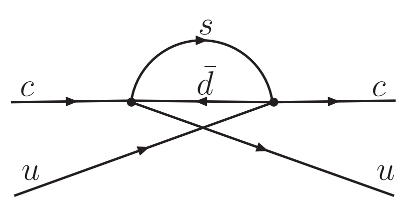
Pauli interference & W-exchange are $1/m_c^3$ corrections, enhanced by p.s. enhancement factor of $16\pi^2$



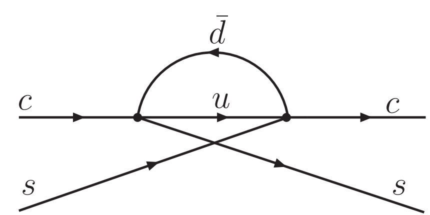
c decay



W-exchange



destructive P.I.



constructive P.I.

	Dec	Ann	Int(-)	Int(+)	Semi-inclusive	$\tau(10^{-13}s)$	Expt
Ξ_c^+	1	s^2	1	c^2	small P.I.	3.68	4.42 ± 0.26
Λ_c^+	1	c^2	1	s^2		2.64	2.00 ± 0.06
Ξ_c^0	1	1	1	1	small P.I.	1.93	$1.12^{+0.13}_{-0.10}$
Ω_c^0	1	$6s^2$		$10/3c^2$	large P.I.	1.71	0.69 ± 0.12

$s=\sin\theta_C$, $c=\cos\theta_C$

- **Lifetime hierarchy $\tau(\Xi_c^+)>\tau(\Lambda_c^+)>\tau(\Xi_c^0)>\tau(\Omega_c^0)$ is qualitatively understandable, but not quantitatively.**
- **It has been claimed that lifetimes can be accommodated (except Ξ_c^+) provided that hybrid renormalization is employed and replacement of f_D by F_D is made (Shifman, Blok, Guberina, Bigi…..)**
- **It is difficult to explain $\tau(\Xi_c^+)/\tau(\Lambda_c^+)=2.21\pm0.15$**
- **$1/m_c$ expansion is not well convergent and sensible**

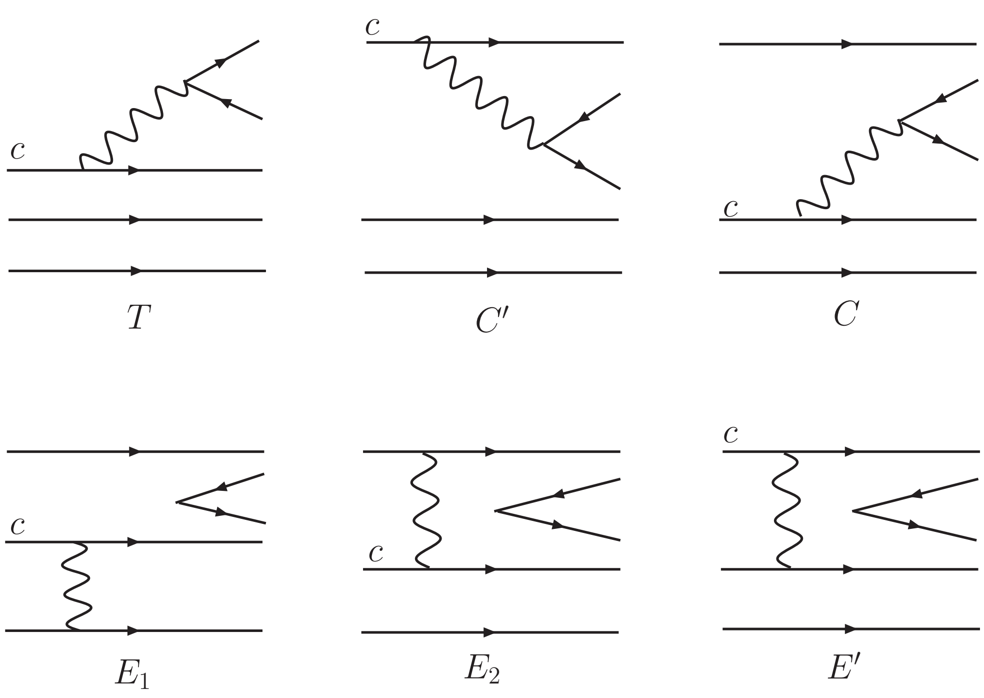
Hadronic weak decays

Complications:

- **Baryons are made of three quarks**
- **Factorization approximation generally doesn't work**

  W-exchange is not subject to helicity & color suppression
- **Current algebra is no longer applicable as the outgoing meson is far from being "soft". Also this soft-meson technique is not applicable to vector meson production**

■ Diagrammatic scheme

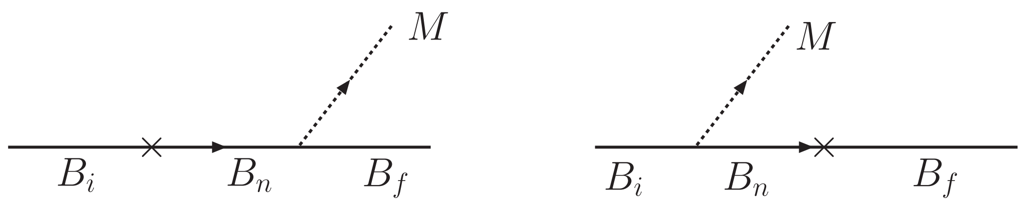


- Two distinct internal W emission diagrams, three different W exchange diagrams
- Need information of decay asymmetry to extract s-wave and p-wave amplitudes separately

$$M(B_i \to B_f + P) = i\bar{u}_f (A + B\gamma_5) u_i$$

- **Dynamical model calculation**

pole model:



Consider low-lying pole contributions:

s-wave is governed by ½⁻ resonances

p-wave is dominated by ½⁺ ground-state baryons

Relativistic QM: Korner, Kramer, Ivanov,…

BRs of Cabibbo-allowed decays

Decay	Körner, Krämer [56]	Xu, Kamal [60]	Cheng, Tseng [59]	Ivanov et al. [74]	Żenczykowski [73]	Sharma, Verma [72]	Expt. [3]
$\Lambda_c^+ \to \Lambda\pi^+$	input	1.62	0.88	0.79	0.54	1.12	0.90± 0.28
$\Lambda_c^+ \to \Sigma^0\pi^+$	0.32	0.34	0.72	0.88	0.41	1.34	0.99± 0.32
$\Lambda_c^+ \to \Sigma^+\pi^0$	0.32	0.34	0.72	0.88	0.41	1.34	1.00± 0.34
$\Lambda_c^+ \to \Sigma^+\eta$	0.16			0.11	0.94	0.57	0.48± 0.17
$\Lambda_c^+ \to \Sigma^+\eta'$	1.28			0.12	0.12	0.10	
$\Lambda_c^+ \to p\bar{K}^0$	input	1.20	1.26	2.06	1.79	1.64	2.3± 0.6
$\Lambda_c^+ \to \Xi^0K^+$	0.26	0.10		0.31	0.36	0.13	0.39± 0.14
$\Xi_c^+ \to \Sigma^+\bar{K}^0$	6.45	0.44	0.84	3.08	1.56	0.04	
$\Xi_c^+ \to \Xi^0\pi^+$	3.54	3.36	3.93	4.40	1.59	0.53	0.55 ± 0.16^a
$\Xi_c^0 \to \Lambda\bar{K}^0$	0.12	0.37	0.27	0.42	0.35	0.54	seen
$\Xi_c^0 \to \Sigma^0\bar{K}^0$	1.18	0.11	0.13	0.20	0.11	0.07	
$\Xi_c^0 \to \Sigma^+K^-$	0.12	0.12		0.27	0.36	0.12	
$\Xi_c^0 \to \Xi^0\pi^0$	0.03	0.56	0.28	0.04	0.69	0.87	
$\Xi_c^0 \to \Xi^0\eta$	0.24			0.28	0.01	0.22	
$\Xi_c^0 \to \Xi^0\eta'$	0.85			0.31	0.09	0.06	
$\Xi_c^0 \to \Xi^-\pi^+$	1.04	1.74	1.25	1.22	0.61	2.46	seen
$\Omega_c^0 \to \Xi^0\bar{K}^0$	1.21		0.09	0.02			

W-exchange plays an essential role

Decay asymmetry α for Cabibbo-allowed decays

Longitudinal pol. of daughter baryon from unpol. parent baryon

information on the relative sign between s- and p-waves

Decay	Körner, Krämer [56]	Xu, Kamal [60]	Cheng, Tseng [59]	Ivanov et al. [74]	Żenczykowski [73]	Sharma, Verma [72]	Expt. [3]
$\Lambda_c^+ \to \Lambda\pi^+$	−0.70	−0.67	−0.95	−0.95	−0.99	−0.99	-0.91 ± 0.15
$\Lambda_c^+ \to \Sigma^0\pi^+$	0.70	0.92	0.78	0.43	0.39	−0.31	
$\Lambda_c^+ \to \Sigma^+\pi^0$	0.71	0.92	0.78	0.43	0.39	−0.31	-0.45 ± 0.32 ??
$\Lambda_c^+ \to \Sigma^+\eta$	0.33			0.55	0	−0.91	
$\Lambda_c^+ \to \Sigma^+\eta'$	−0.45			−0.05	−0.91	0.78	
$\Lambda_c^+ \to p\bar{K}^0$	−1.0	0.51	−0.49	−0.97	−0.66	−0.99	
$\Lambda_c^+ \to \Xi^0 K^+$	0	0		0	0	0	
$\Xi_c^+ \to \Sigma^+\bar{K}^0$	−1.0	0.24	−0.09	−0.99	1.00	0.54	
$\Xi_c^+ \to \Xi^0\pi^+$	−0.78	−0.81	−0.77	−1.0	1.00	−0.27	
$\Xi_c^0 \to \Lambda\bar{K}^0$	−0.76	1.0	−0.73	−0.75	−0.29	−0.79	
$\Xi_c^0 \to \Sigma^0\bar{K}^0$	−0.96	−0.99	−0.59	−0.55	−0.50	0.48	
$\Xi_c^0 \to \Sigma^+K^-$	0	0		0	0	0	
$\Xi_c^0 \to \Xi^0\pi^0$	0.92	0.92	−0.54	0.94	0.21	−0.80	
$\Xi_c^0 \to \Xi^0\eta$	−0.92			−1.0	−0.04	0.21	
$\Xi_c^0 \to \Xi^0\eta'$	−0.38			−0.32	−1.00	0.80	
$\Xi_c^0 \to \Xi^-\pi^+$	−0.38	−0.38	−0.99	−0.84	−0.79	−0.97	-0.6 ± 0.4
$\Omega_c^0 \to \Xi^0\bar{K}^0$	0.51		−0.93	−0.81			

Decay modes that proceed through factorizable diagrams

$\Lambda_c^+ \to p\phi$ $|a_2| = 0.60 \pm 0.10$, close to c_2

1/N_c is also applicable to charmed baryon sector

$\Omega_c^0 \to \Omega^- \pi^+$ a_1

$\Omega_c^0 \to \Xi^{*0} \underline{K}^0$ a_2

Charm-flavor-conserving weak decays:

Light quarks undergo weak transitions, while c quark behaves as a "spectator" e.g. $\Xi_c \to \Lambda_c \pi$, $\Omega_c \to \Xi'_c \pi$

$Br(\Xi_c^0 \to \Lambda_c^+ \pi^-) = 2.9\times 10^{-4}$

$Br(\Xi_c^+ \to \Lambda_c^+ \pi^0) = 6.7\times 10^{-4}$

$Br(\Omega_c^0 \to \Xi'^+_c \pi^-) = 4.5\times 10^{-6}$

should be readily accessible soon

Semileptonic decays

Semileptonic rate depends on $B_c \to B$ form factors

Six form factors are reduced to two in $m_Q \to \infty$ limit

	|→ NRQM ←|			RQM	LFQM	QSR	QSR	
Process	Pérez-Marcial et al. [85]	Singleton [86]	Cheng, Tseng [81]	Ivanov et al. [87]	Luo [88]	Marques de Carvalho et al. [89]	Huang, Wang [90]	Expt. [3]
$\Lambda_c^+ \to \Lambda^0 e^+ \nu_e$	11.2 (7.7)	9.8	7.1	7.22 -0.812	7.0	13.2 ± 1.8 -1	10.9 ± 3.0 -0.88 ± 0.03	10.5 ± 3.0 -0.86 ± 0.04
$\Xi_c^0 \to \Xi^- e^+ \nu_e$	18.1 (12.5)	8.5	7.4	8.16	9.7			seen
$\Xi_c^+ \to \Xi^0 e^+ \nu_e$	18.4 (12.7)	8.5	7.4	8.16	9.7			seen

in units of $10^{10} s^{-1}$

Electromagnetic decays

$$B_6 \to B_{\bar{3}} + \gamma: \quad \Sigma_c \to \Lambda_c + \gamma,\ \Xi_c^{'} \to \Xi_c + \gamma$$

$$B_6^* \to B_{\bar{3}} + \gamma: \quad \Sigma_c^* \to \Lambda_c + \gamma,\ \Xi_c^{'*} \to \Xi_c + \gamma$$

$$B_6^* \to B_6 + \gamma: \quad \Sigma_c^* \to \Sigma_c + \gamma,\ \Xi_c^{'*} \to \Xi_c^{'} + \gamma,\ \Omega_c^* \to \Omega_c + \gamma$$

suitable framework: HHChPT+ QM

Decay	HHChPT +QM [23, 92]	Ivanov et al. [87]	Bañuls et al. [93]	Tawfiq et al. [94]	Experiment [3]
$\Sigma_c^+ \to \Lambda_c^+\gamma$	88	60.7 ± 1.5		87	
$\Sigma_c^{**+} \to \Sigma_c^{++}\gamma$	1.4			3.04	
$\Sigma_c^{*+} \to \Sigma_c^+\gamma$	0.002	0.14 ± 0.004		0.19	
$\Sigma_c^{*+} \to \Lambda_c^+\gamma$	147	151 ± 4			
$\Sigma_c^{*0} \to \Lambda_c^0\gamma$	1.2			0.76	
$\Xi_c^{\prime +} \to \Xi_c^+\gamma$	16	12.7 ± 1.5			seen
$\Xi_c^{\prime 0} \to \Xi_c^0\gamma$	0.3	0.17 ± 0.02	1.2 ± 0.7		seen
$\Xi_c^{\prime *+} \to \Xi_c^+\gamma$	54	54 ± 3			
$\Xi_c^{\prime *0} \to \Xi_c^0\gamma$	1.1	0.68 ± 0.04	5.1 ± 2.7		
$\Omega_c^{*0} \to \Omega_c^0\gamma$	0.9				seen

in units of keV

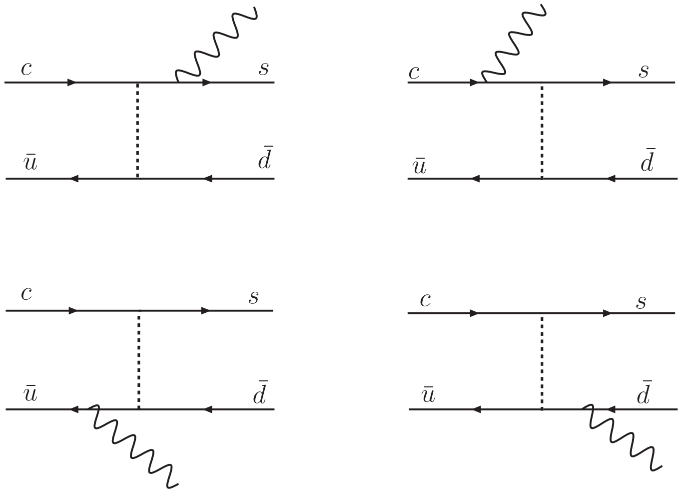
Weak radiative decays

- **Charm-flavor-changing**

$\Lambda_c^+ \to \Sigma^+\gamma$, $\Xi_c^0 \to \Xi^0\gamma$

- **Charm-flavor-conserving**

$\Xi_c \to \Lambda_c\gamma$, $\Omega_c \to \Xi_c\gamma$



i) e.m. penguin $c \to u\gamma$

ii) γ emission from external quark in W-exchange

γ emission from W boson in W-exchange

$$Br(\Lambda_c^+ \to \Sigma^+\gamma) = 4.9\times10^{-5}, \qquad \alpha = -0.86$$

$$Br(\Xi_c^0 \to \Xi^0\gamma) = 3.6\times10^{-5}, \qquad \alpha = -0.86$$

Review articles:

- **Korner, Kramer, Pirjol, Prog. Part. Nucl. Phys. 33, 787 (1994)**
- **Bianco, Fabbri, Benson, Bigi, hep-ex/0309021**