Charmed Baryon Spectroscopy

Results Using CLEO at CESR

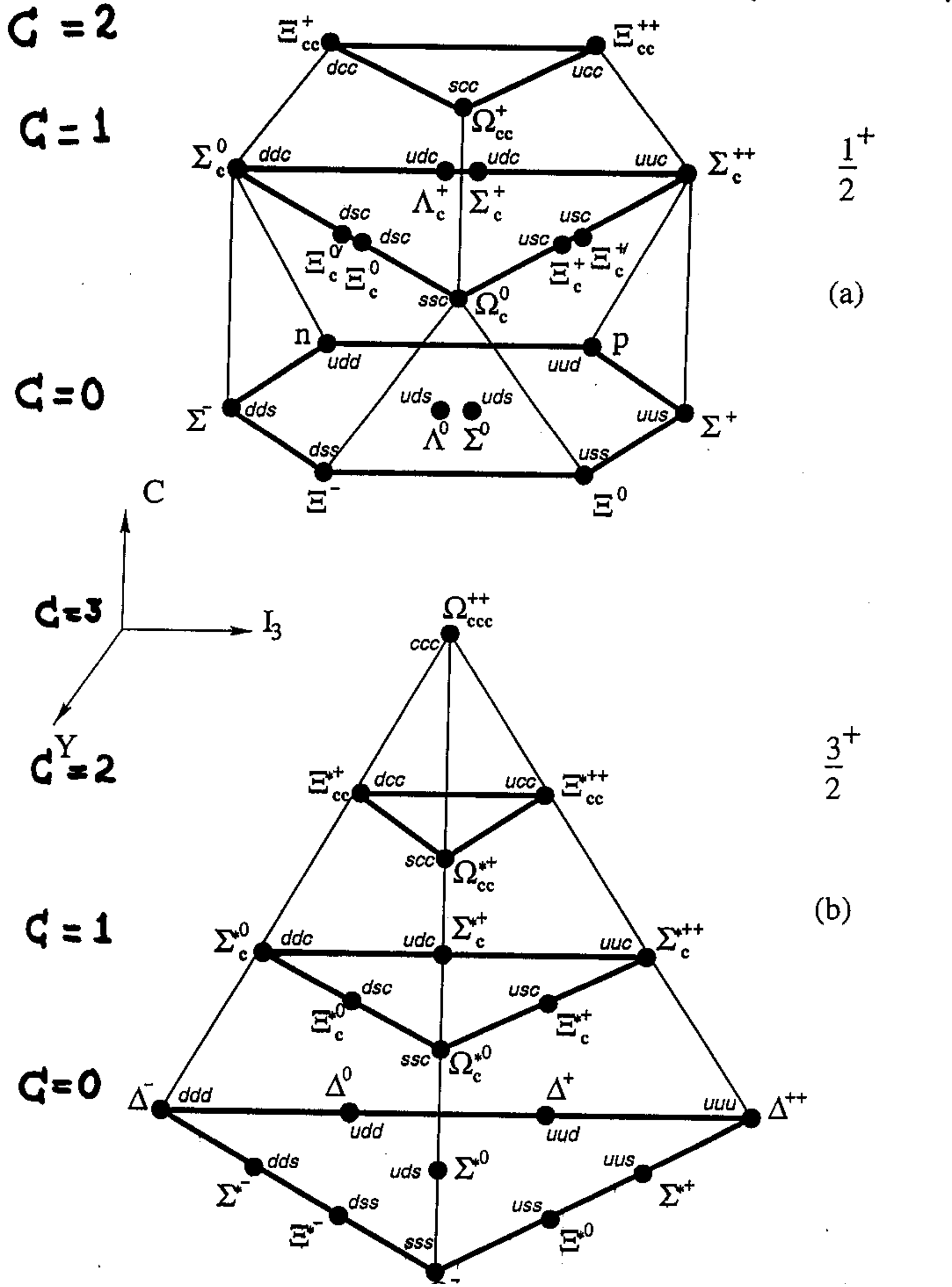
M. S. Alam

University at Albany & CLEO

1. Introduction
2. Ground State $J^P = \frac{1}{2}^+$ Charm Baryons
   Λ_c^+, Σ_c, Ξ_c, Ξ_c', Ω_c^0
3. Ground State $J^P = 3/2^+$ Charm Baryons
   Ξ_c^{*0}, Ξ_c^{*+}, Σ_c^{*++}, Σ_c^{*0}
4. P-Wave $J^P = \frac{1}{2}^-, \frac{3}{2}^-$ Charm Baryons
   – Λ_c^{*+}, Ξ_c^{**}
5. Summary
6. Conclusions

$J^P = \frac{1}{2}^+$ and $\frac{3}{2}^+$ Ground State 20-plets

$4 \otimes 4 \otimes 4 \Rightarrow 20'_S \oplus 20_{MS} \oplus 20_{MA} \oplus \bar{4}_A \Rightarrow 20'_S + 20_M$



All S and P-Wave Singly-Charmed Baryons

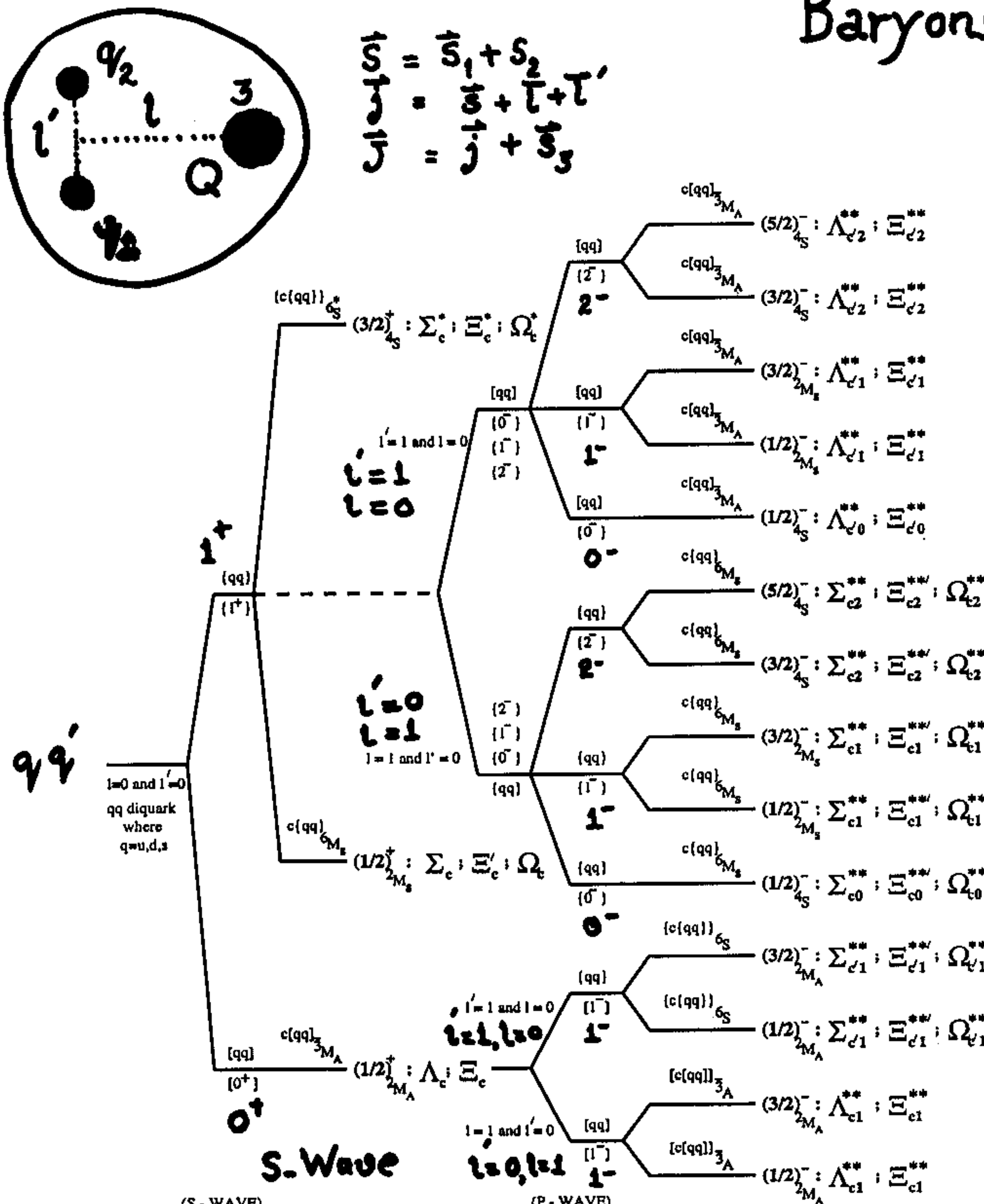


Figure 1: Chromomagnetic hyperfine splitting of all S and P-Wave singly-charmed baryons.

$\mathbb{B}_{sll'jJ}$

Expected Mass Splitting of S and P-Wave Charmed Baryons

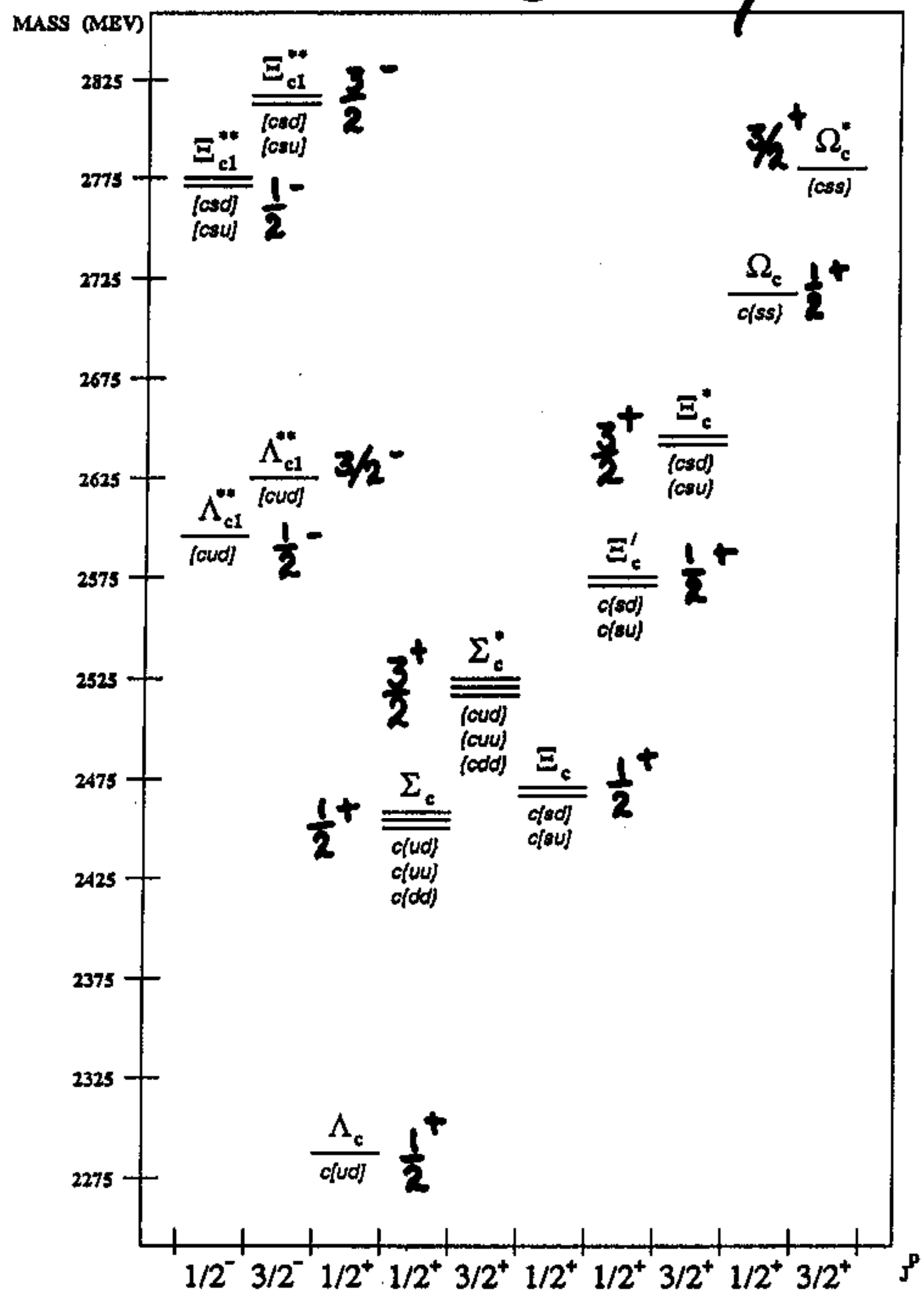
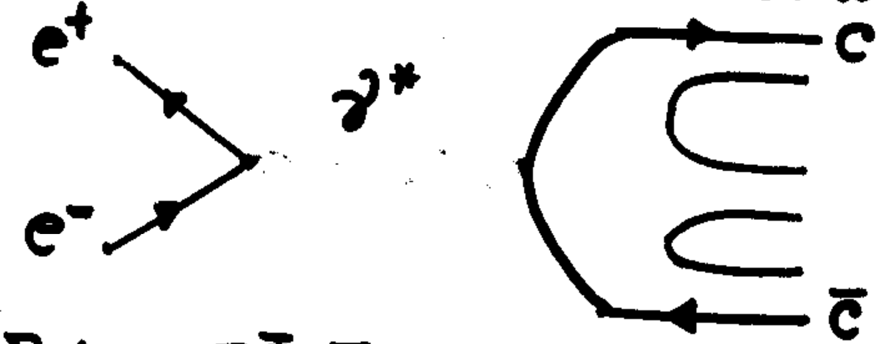


Figure 2.8: Estimated predicted masses of S-Wave and lowest lying P-Wave singly-charmed baryons.

Charm Production in e^+e^- Collisions

I. $e^+e^- \to \gamma^* \to c\bar{c}$ Mechanisms (Continuum Prod.)



Charmed Mesons & Baryons

Below $B\bar{B}$ Threshold: $E_{cm} < m[\Upsilon(4S)]$

$e^+e^- \to u\bar{u} + d\bar{d} + s\bar{s} + c\bar{c} \to$ hadrons

$$\sigma_{u\bar{u}} : \sigma_{d\bar{d}} : \sigma_{s\bar{s}} : \sigma_{c\bar{c}} = 4:1:1:4$$

$$\sigma_{c\bar{c}} = \cdot 4\ \sigma_h$$

Important Laboratory for:

a) Charmed Meson & Baryon Spectroscopy & Decay

b) " " " " Production Rates

c) Fragmentation Models $x_F = \frac{P}{P_{max}} = \frac{P}{\sqrt{E_b^2 - m^2}}$

d) Decay Models

Inclusive Study

i) $e^+e^- \to (D^0, D^+, D_s^+, D^{*0}, D^{*+}, D_s^{*+}, D^{**0}, D_s^{**+}, D^{**+}, \ldots)X$

ii) $\to (\Lambda_c^+, \Sigma_c^{++}, \Sigma_c^+, \Sigma_c^0, \Xi_c^+, \Xi_c^0, \Omega_c^0, \ldots)X$

iii) x_F distrib. hard ω 60% above x_F of ·5

iv) For production from B decays $x_F \leq \cdot 5$

Standard Cut: $x_F \geq 0.5$

Decays of P-Wave to S-Wave Charmed Baryons:

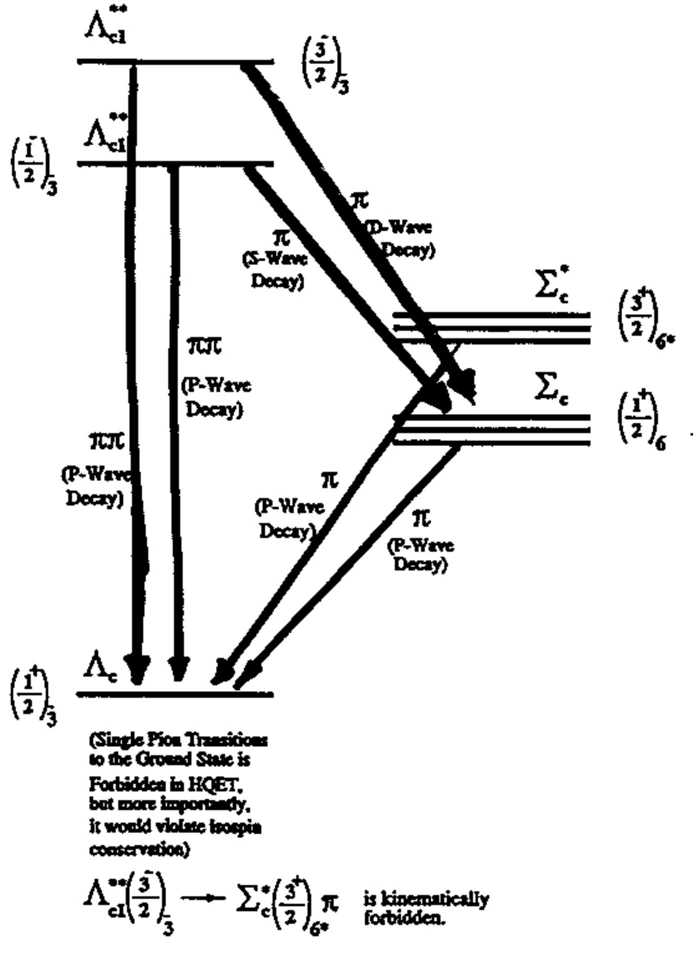


Figure 2.10: Decay Mechanisms in the *cqq* sector of Λ_{c1}^{**}'s, Σ_c^*'s, and Σ_c's.

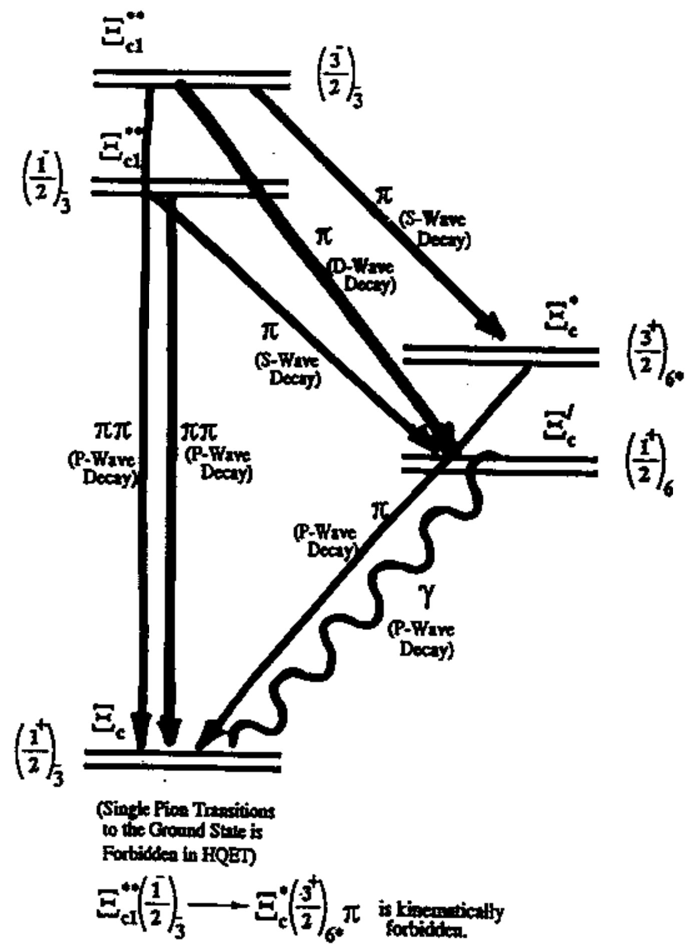
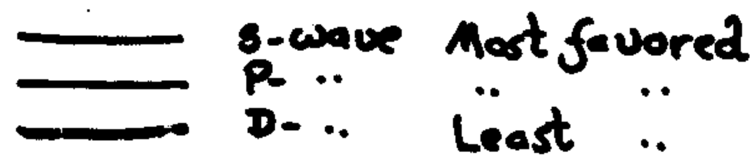
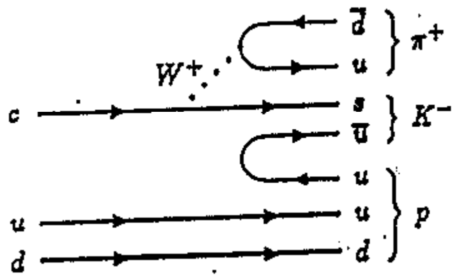


Figure 2.11: Decay Mechanisms in the *csq* sector of Ξ_{c1}^{**}'s, Ξ_c^*'s, and Ξ_c''s.

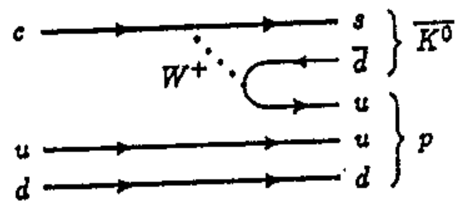


hev

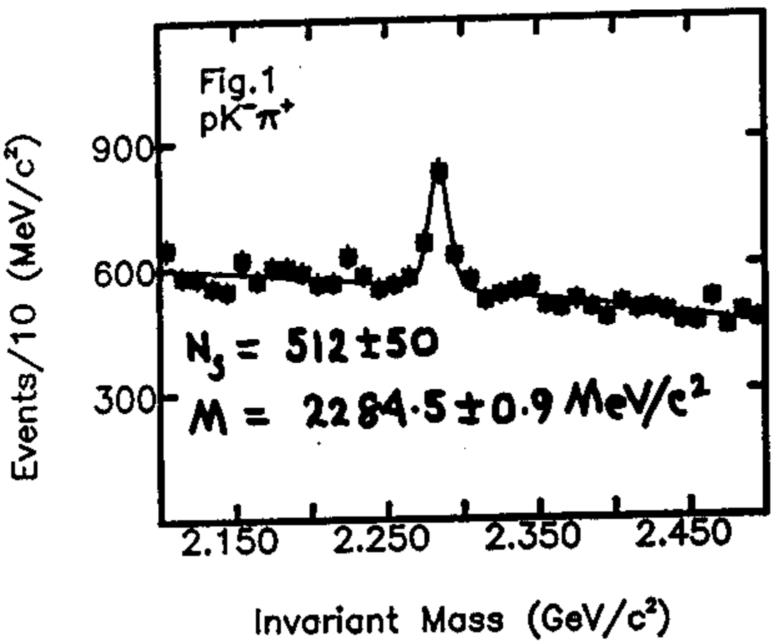
Λ_c^+ Decays[†]

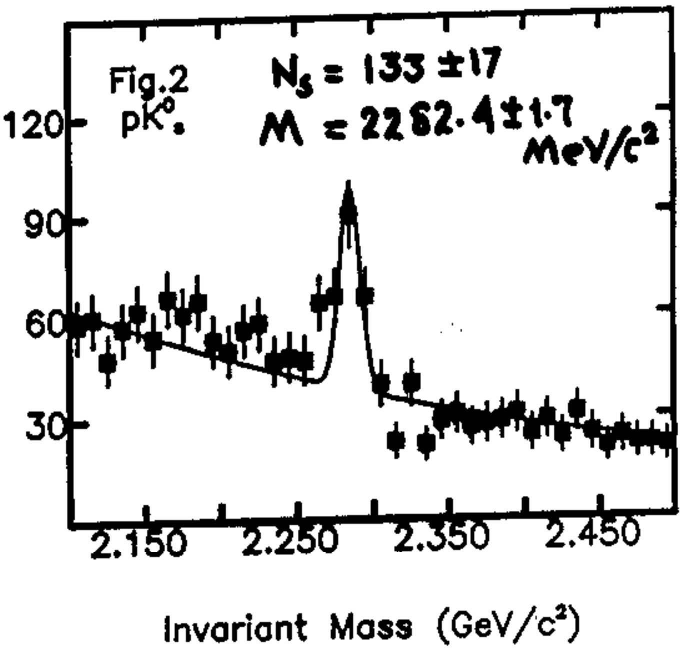


(a) $\Lambda_c^+ \to pK^-\pi^+$



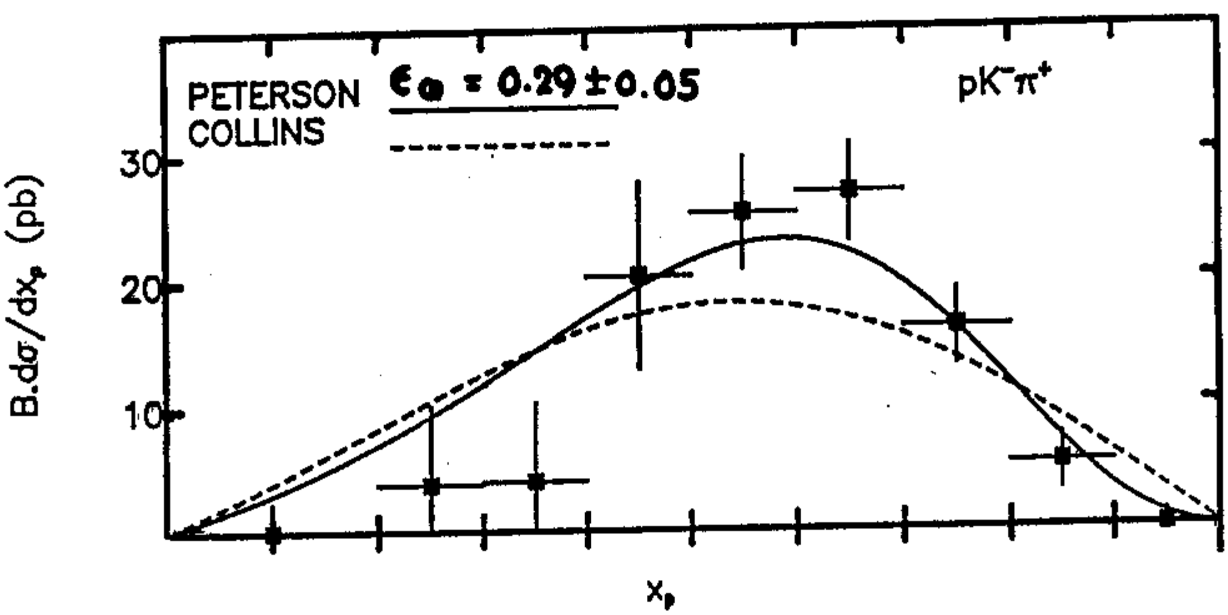
(b) $\Lambda_c^+ \to p\overline{K^0}$





$\sigma.B = 10.0 \pm 1.5 \pm 1.5$ pb

$\sigma.B = 4.6 \pm 0.6 \pm 0.8$ pb



† P. Avery et al. (CLEO) PRD 43 (3599) '91

Summary of Λ_c^+ Decays

$Br(pK^-\pi^+)$	=	1.0
$Br(pK n\pi)$	=	3.83 ± 0.29
$Br(\Sigma^0 n\pi, \Lambda\pi^+\pi^0)$	=	1.51 ± 0.25
$Br(\Sigma^+ n\pi, \Sigma^+\omega)$	=	1.58 ± 0.18
$Br(\text{Wexch} + s\bar{s})$	=	0.23 ± 0.05
$Br(\omega\eta \,\&\, \Lambda\bar{K}^0 K^+)$	=	1.00 ± 0.11
$Br(pK^+K^-)$	=	0.04 ± 0.01
$Br(X l^+ \nu)$	=	1.02 ± 0.19
$Br(\Lambda n\pi^+)$	=	0.84 ± 0.15
Sum	=	10.05 ± 0.5

CLEO/ARGUS $B(pK^-\pi^+) = (4.3 \pm 1.1)\%$

$$Br(\Lambda_c^+ \to \text{all}) = (43.2 \pm 11.2)\%$$

Asymmetry

$$\alpha_{\Lambda_c} = -.80 \pm^{.17}_{.06} + ^{.05}_{.04} \qquad (\Lambda_c^+ \to \Lambda\pi^+)$$

Peterson Function (x_p)

$\epsilon = 0.29 \pm 0.05$

$\chi^2/dof = 23/23$

Bowler Function (x_+)

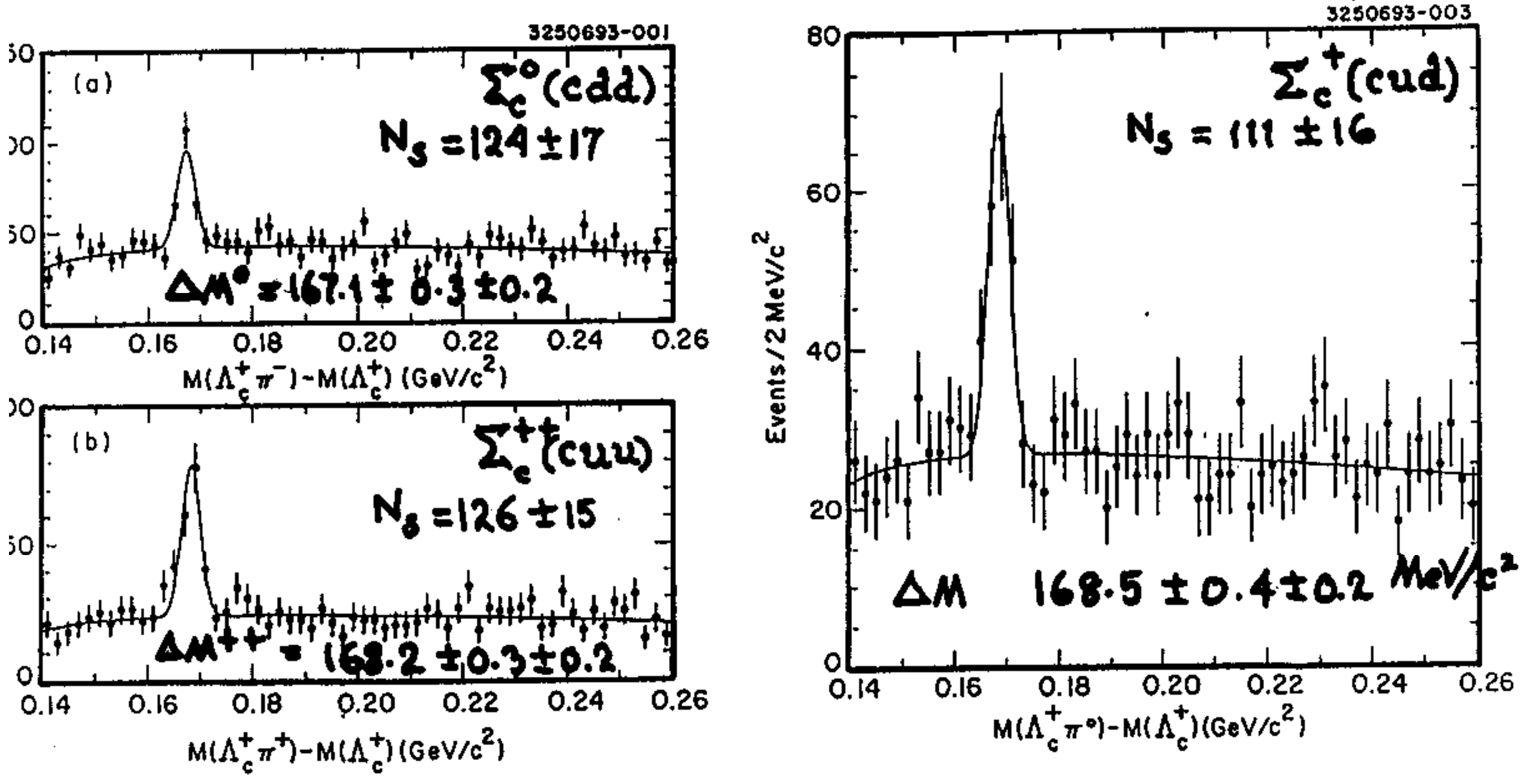
$\beta = 2.9 \pm 0.5$

$B = 1.1 \pm 0.2$

$\chi^2/dof = 12/16$

Observation of Σ_c^0, Σ_c^+, Σ_c^{++} (CLEO 93-09)

$\rightarrow \Lambda_c^+ (\pi^0, \pi^-, \pi^+)$

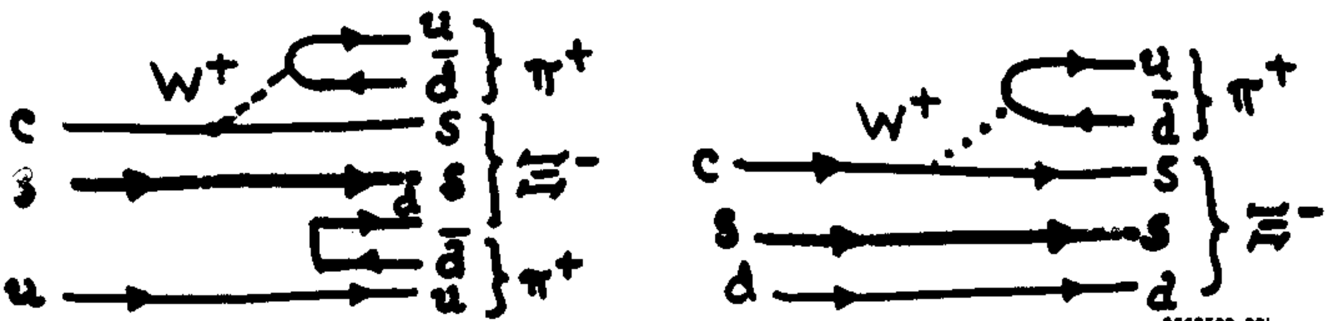


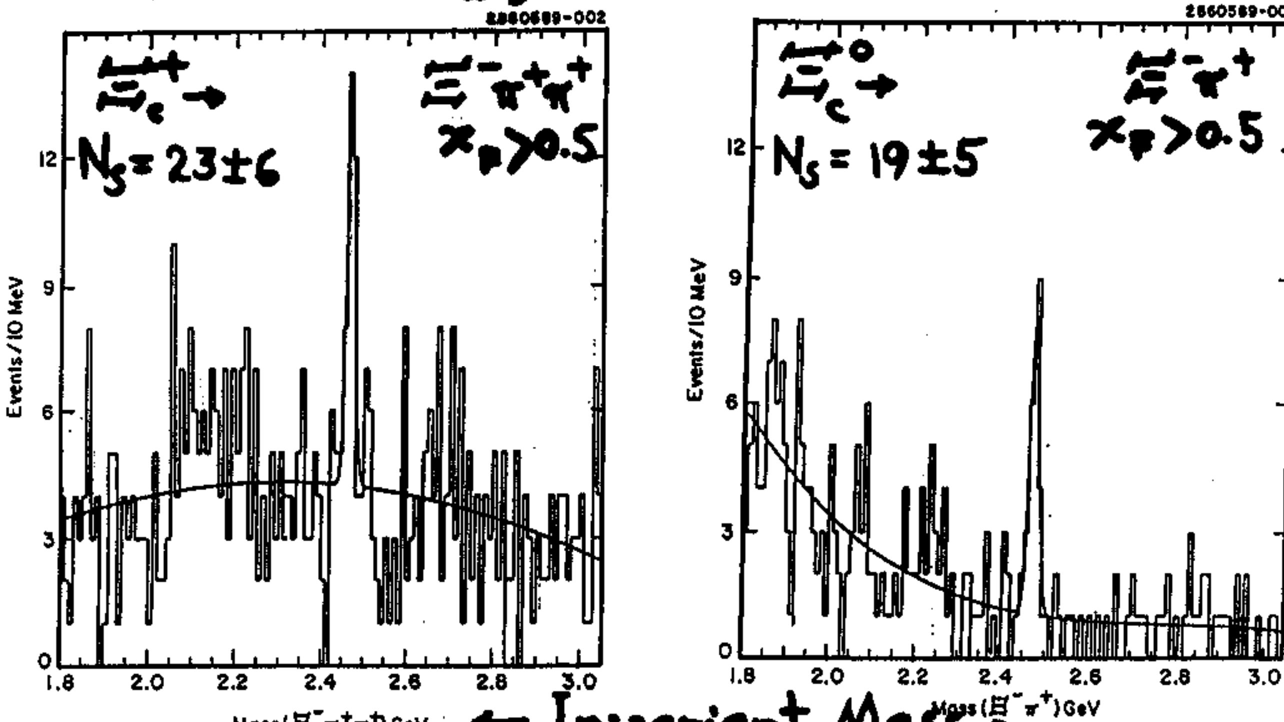
	$\Delta m(\Sigma_c^{++} - \Lambda_c^+)$ (MeV/c^2)	$\Delta m(\Sigma_c^0 - \Lambda_c^+)$ (MeV/c^2)	$\Delta m(\Sigma_c^+ - \Lambda_c^+)$ (MeV/c^2)
ARGUS [1]	$168.8 \pm 0.6 \pm 1.6$	$167.6 \pm 0.3 \pm 1.6$	
BEBC [5]			168 ± 3
CLEO1.5 [2]	$167.8 \pm 0.4 \pm 0.3$	$167.9 \pm 0.5 \pm 0.3$	
CLEOII	$168.2 \pm 0.3 \pm 0.2$	$167.1 \pm 0.3 \pm 0.2$	$168.5 \pm 0.4 \pm 0.2$
E691 [4]		$168.4 \pm 1.0 \pm 0.3$	

TABLE II. Comparison with Theoretical Calculations

	$\Delta m(\Sigma_c^{++} - \Sigma_c^0)$ (MeV/c^2)	$\Delta m(\Sigma_c^+ - \Sigma_c^0)$ (MeV/c^2)
	Theoretical Calculations	
Chan [15]	0.4	−0.7
Hwang [16]	3.0	−0.5
Wright [17]	−1.4	−2.0
Deshpande [18]	−3.3	−2.5
Sinha [19]	1.5	−0.3
Capstick [12]	1.4	−0.2
	Experimental Measurements	
CLEOII	$1.1 \pm 0.4 \pm 0.1$	$1.4 \pm 0.5 \pm 0.3$
ARGUS [1]	$1.2 \pm 0.7 \pm 0.3$	
CLEO1.5 [2]	$-0.1 \pm 0.6 \pm 0.1$	

Observation of Ξ_c^+(csu) and Ξ_c^0(csd)





Data: 430 pb^{-1}

Ξ_c^+ 23 ± 6

$M = (2467 \pm 3 \pm 4)\ MeV/c^2$

$\sigma . B = (0.57 \pm 0.16)\ pb$

$x_F > 0.5$

Ξ_c^0 19 ± 5

$M = (2472 \pm 3 \pm 4)\ MeV/c^2$

$\sigma . B = (0.39 \pm 0.10)\ pb$

$x_F > 0.5$

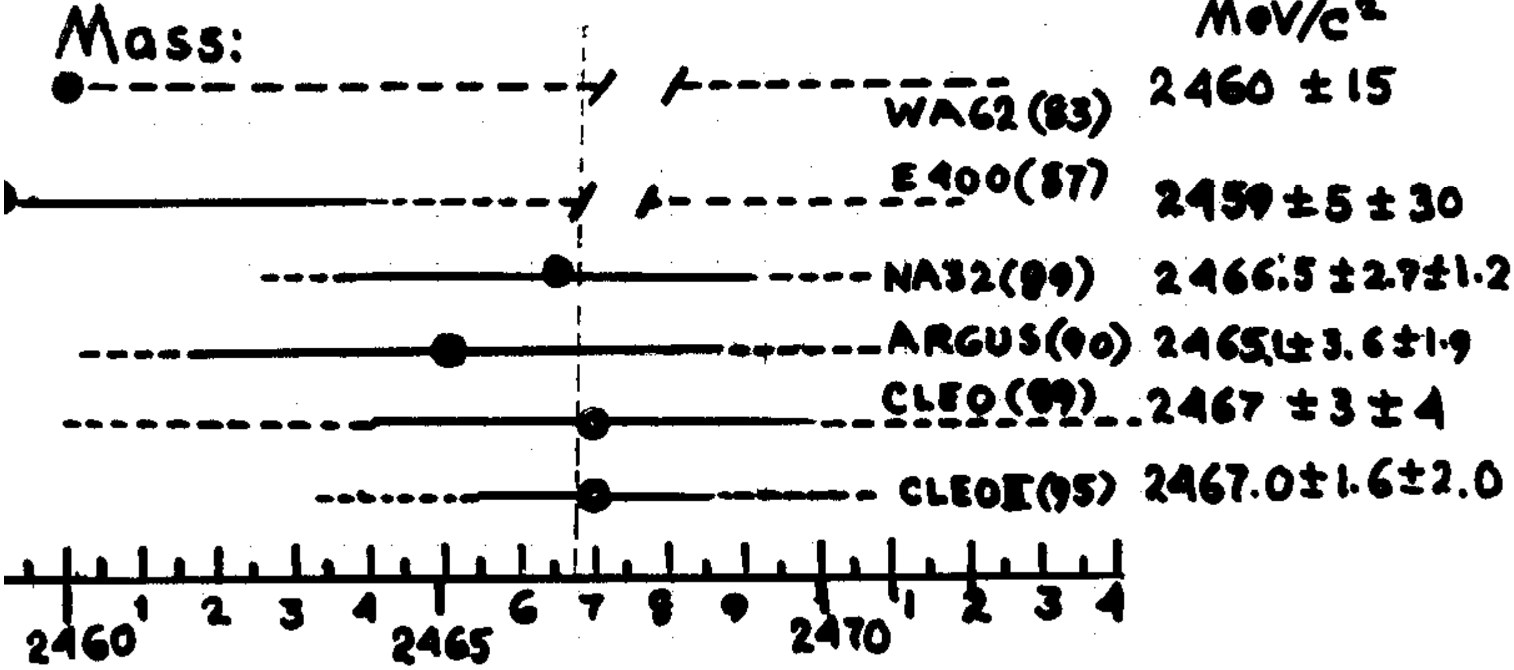
$$M(\Xi_c^+ - \Xi_c^0) = (-5 \pm 4 \pm 1)\ MeV/c^2$$

hy

Ξ_c^+ Summary

Decay Modes	$Br/Br(\to\Xi^-\pi^+\pi^+)$	Abs Branch. Fractions
$\Xi^0\pi^+$	$0.55 \pm 0.13 \pm 0.09$	
$\Xi^0\pi^+\pi^0$	$2.34 \pm 0.57 \pm 0.37$	
$\Xi^0\pi^+\pi^-\pi^+$	$1.74 \pm 0.42 \pm 0.27$	
$\Sigma^+K^-\pi^+$	$1.18 \pm 0.26 \pm 0.17$	
Σ^+K^{*0}	$0.92 \pm 0.27 \pm 0.14$	
$\Lambda K^-\pi^+\pi^+$	$0.51 \pm 0.16 \pm 0.17$	
$\Xi^0e^+\nu$	$2.27 \pm 0.57 \pm^{0.37}_{0.31}$	
$\Xi^-\pi^+\pi^+$	1.00	$(2.1 \pm 0.8 ^{+.4}_{-.9})\%$
Sum	$8.6 \pm 1.0 \pm 0.6$	$(18.1 + 7.2 \pm^{3.7}_{7.8})\%$

Mass:



$$\text{Mass} = 2466.9 \pm 1.2 \pm 0.9 \ \text{MeV}/c^2$$

2466.4 ± 2.1 PDG '92

Peterson Parameter

$$\epsilon_Q = 0.23^{+0.06}_{-0.05} \pm 0.03$$

$$\sigma \cdot B\ (x_F > .4) = (0.62 \pm 0.07 \pm 0.05)\ \text{pb}$$

$\to \Xi^-\pi^+\pi^+$

$$(x_F > .5) = (0.95 \pm 0.25 \pm 0.10)\ ..$$

Ξ_c^0 Summary

- Decay Modes — $Br/Br(\to \Xi^- \pi^+)$ — Abs. Br. Fractions

Decay Modes	$Br/Br(\to \Xi^-\pi^+)$	Abs. Br. Fractions
$\Xi^-\pi^+\pi^-\pi^+$ (ARG)	$3.33 \pm 1.33 \pm 0.56$	
$\Omega^- K^+$ (CLEO)	$0.5 \pm 0.21 \pm 0.05$	
$\Lambda K^- \pi^+$ (WA89)		
$\Xi^- e^+ \nu$	$3.1 \pm 1.0 {}^{+0.3}_{-0.3}$	
$\Xi^- \pi^+ \pi^+$	1.0	$(.43 \pm .15 {}^{+.1}_{-.2})\%$
Sum	$6.9 \pm 1.7 \pm 0.7$	$(3.0 \pm 1.3 {}^{+.8}_{-1.4})\%$

- Mass:

$2471 \pm 3 \pm 4$	CLEO (89)
$2472.1 \pm 2.7 \pm 1.9$	ARGUS (90)
$2469 \pm 2 \pm 3$	CLEO (92)
$2473.3 \pm 1.9 \pm 1.2$	NA32 (90)

Avg: $2471.6 \pm 1.1 \pm 0.9$ MeV/c^2

PDB (92) 2472.7 ± 1.7 ..

- $M(\Xi_c^+ - \Xi_c^0)$ =

$-5 \pm 4 \pm 1$	CLEO
$-7 \pm 4.5 \pm 2.2$	ARGUS
$-6.8 \pm 3.3 \pm 0.5$	NA32 (ACCMOR)
$-6.3 \pm 2.2 \pm 0.4$	Average
-6.3 ± 2.3	PDB (92)

- $\sigma \cdot B(\Xi_c^0 \to \Xi^- \pi^+) = 0.45 \pm 0.13$ pb CLEO ($x > .5$)

  $0.48 \pm 0.15 \pm 0.08$ pb ARG(..)

Ξ_c^{*0} Summary

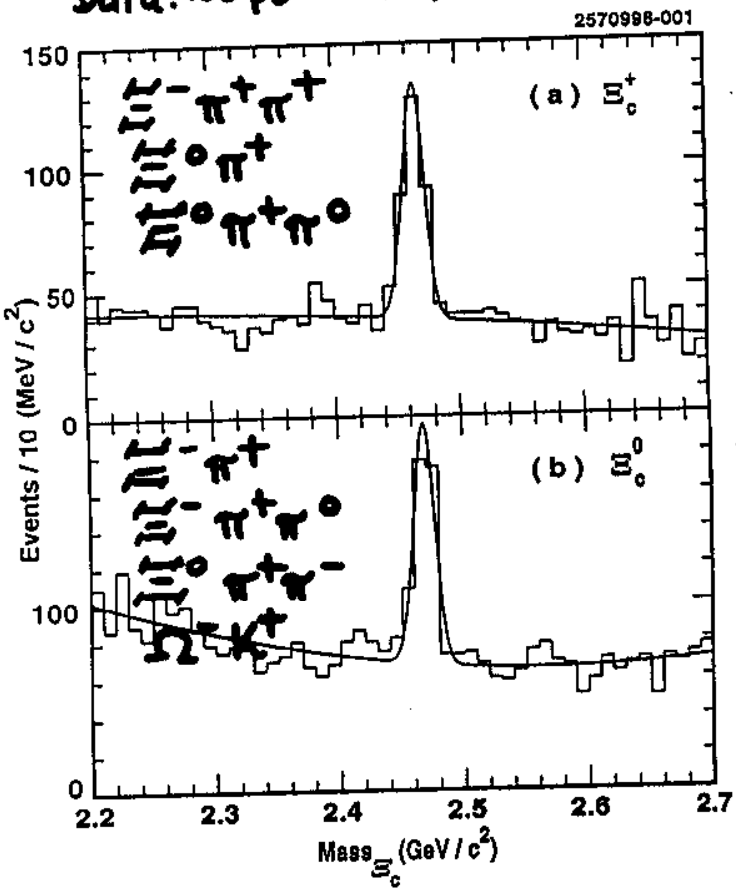
Mass: 2643.3 ± 2.2 MeV/c^2

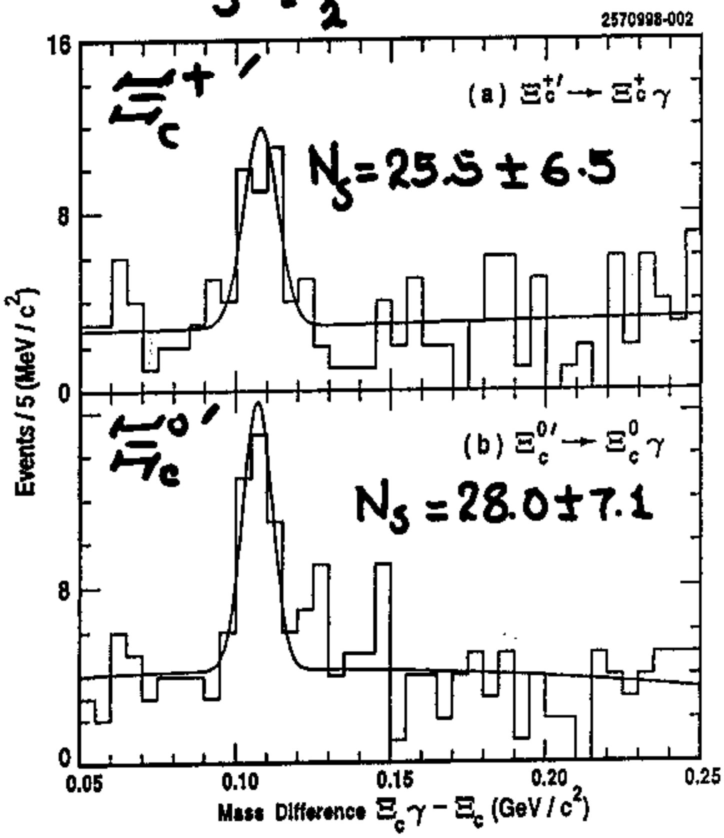
hy14

Observation of $\Xi_c^{+\prime}$ and $\Xi_c^{0\prime}$ (1997) EPS

$J^P = \frac{1}{2}^+$

Data: ~5 pb^{-1} ~ $\Upsilon(4S)$





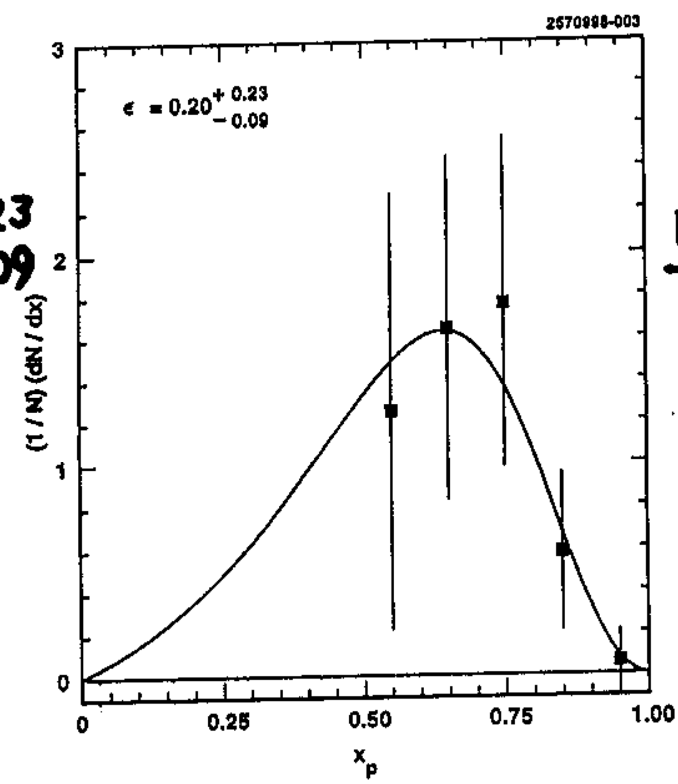
$\Delta M^{+\prime} = 107.8 \pm 1.7 \pm 2.5 \frac{MeV}{c^2}$

$\Delta M^{0\prime} = 107.0 \pm 1.4 \pm 2.5$ ..

$$\frac{N(\Xi_c \text{ from } \Xi_c^{\prime})}{N(\Xi_c \text{ all})} = (35 \pm 9 \pm 7)\%$$

Peterson Function

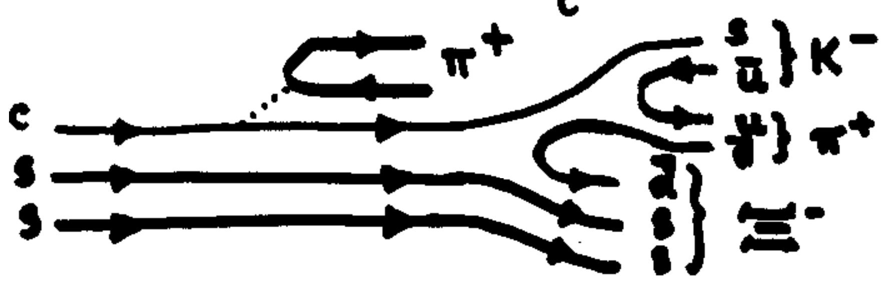
$\epsilon = 0.20^{+0.23}_{-0.09}$

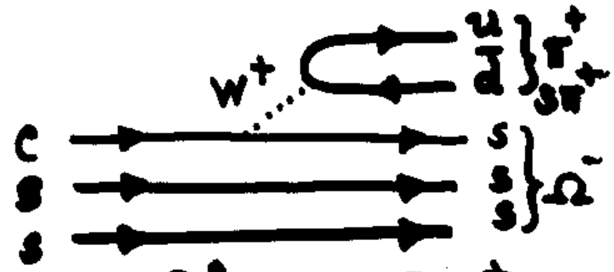


x_p

hg 15

$\Omega_c^0 (css)$





$\Omega_c^0 \to \Xi^- K^- \pi^+ \pi^+$
$\quad \hookrightarrow \Lambda \pi^-$

$\Omega_c^0 \to \Omega^- \pi^+$
$\quad \hookrightarrow \Lambda K^-$

History: (a) $\Xi^- K^- \pi^+ \pi^+$ — 2740 ± 20 MeV/c^2 — 1985 CERN WA-62
3 events

(b) $\Xi^- K^- \pi^+ \pi^+$ — 2719 ± 7 MeV/c^2 — Argus 1992
12 ± 5
$\Omega^- \pi^+$, $\Omega^- \pi^+ \pi^- \pi^+$ also

(c) $\Omega^- \pi^+$ — E-687 '93
10 ± 4 — 2706 ± 3 MeV/c^2 — E-687 '94
$\Sigma^+ K^- K^- \pi^+$ — 2699.9 ± 2.9 ″
42 ± 9

CLEO II:
a) $1.8\ fb^{-1}$, 3200 ± 8 $\Xi^- \to \Lambda \pi^-$, 83 ± 11 $\Omega^- \to \Lambda K^-$

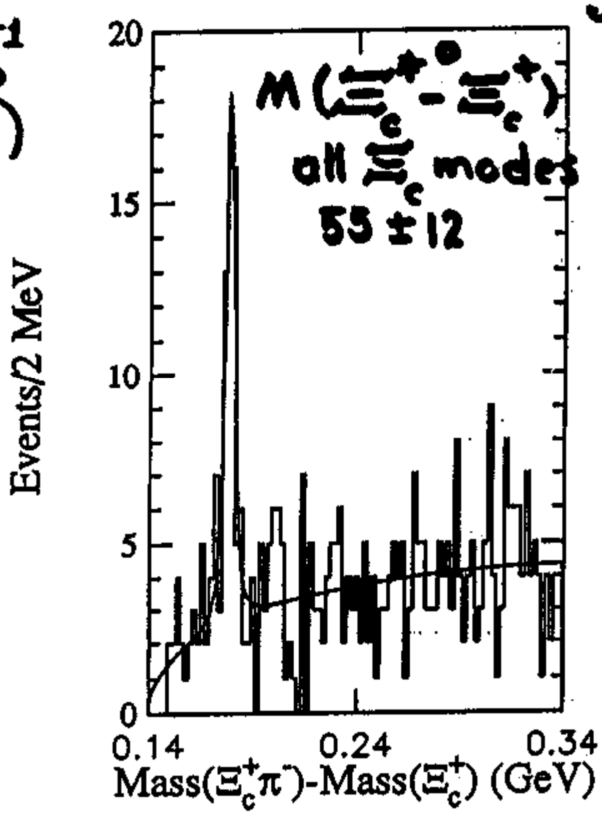
Result: $Br(\Omega_c^0 \to X) \cdot \sigma$

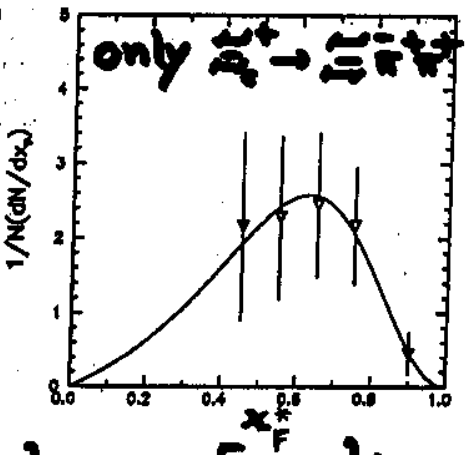
$\Xi^- K^- \pi^+ \pi^+$	< 0.40 pb	CLEO II	† $(2.4 \pm .9 \pm .3)$ pb Argus
$\Omega^- \pi^+$	< 0.06 ″	CLEO II	
$\Omega^- 3\pi^+$	< 0.29 ″	CLEO II	

† Feb '96 CLEO CBX 96-3

Discovery of $\Xi_{c_p}^{*0}$ (csd) $J^P = \frac{3}{2}^+$

. 7 fb^{-1} (Υ_{4S})





Peterson Function Fit

$\epsilon_Q = 0.22^{+.15}_{-.08}$ Ξ_c^{*0} (CLEO)

$= 0.23^{+.06}_{-.05} \pm .03$ Ξ_c^+ (")

$= 0.27 \pm .05$ Λ_c^+ (")

Ξ_c^{*0} Measurements

$\Delta M = (178.2 \pm 0.5 \pm 1.0)$ MeV/c^2

$\sigma_{MC} = 1.6$ MeV/c^2

$\Gamma_n = 2.6^{+1.7}_{-1.4}$ or < 5.5 MeV/c^2 (90% C.L.)

Calculation of $\Gamma(\Xi_c^{*0})$ from $\Gamma(\Xi_c^{*})$ .... J. Rosner (priv com)

$\Gamma(\Xi_c^{*0})/\Gamma(\Xi^{*0}) = .75 P_1^3/P_2^3$ (P_i = decay momentum)

≈ 2.5 MeV/c^2

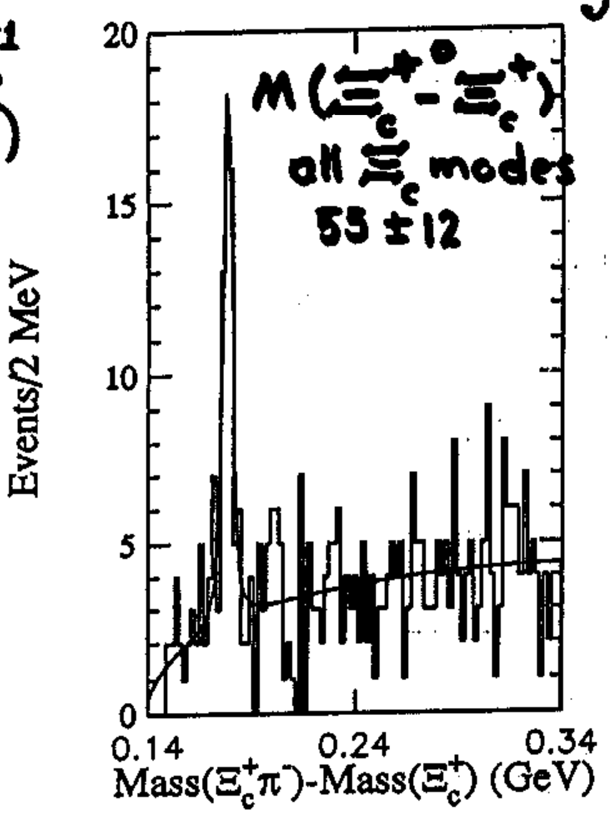
Mass: $M_{\Xi_c^+}$ (2465.1 ± 1.6) P.D.B $+ \Delta M = 2643.3 \pm 2.2$ MeV/c^2

Models 2620 – 2690 ..

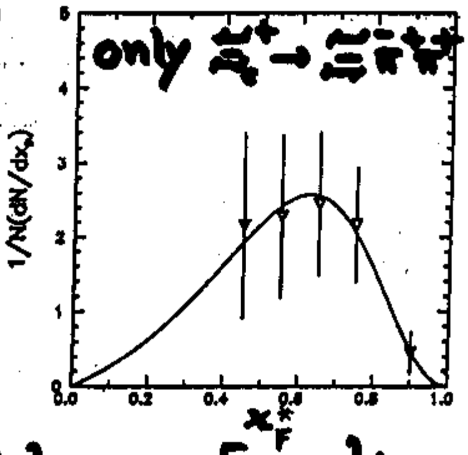
Fraction: $\dfrac{N(\Xi_c^+ \text{ from } \Xi_c^{*0})}{N(e^+e^- \to \Xi^+ X)} = (27 \pm 6 \pm 6)\%$

Discovery of Ξ_c^{*0} (csd) $J^P = \frac{3}{2}^+$

.7fb^{-1} (Υ_{4S})



x_F^*



Peterson Function Fit

$\epsilon_Q = 0.22^{+.15}_{-.08}$ Ξ_c^{*0} (CLEO)

$= 0.23^{+.06}_{-.05} \pm .03$ Ξ_c^+ (")

$= 0.27 \pm .05$ Λ_c^+ (")

Ξ_c^{*0} Measurements

$\Delta M = (178.2 \pm 0.5 \pm 1.0)$ MeV/c^2

$\sigma_{MC} = 1.6$ MeV/c^2

$\Gamma_n = 2.6^{+1.7}_{-1.4}$ or < 5.5 MeV/c^2 (90% C.L.)

Calculation of $\Gamma(\Xi_c^{*0})$ from $\Gamma(\Xi_c^*)$ .... J. Rosner (priv com)

$\Gamma(\Xi_c^{*0})/\Gamma(\Xi^{*0}) = .75 P_1^3/P_2^3$ (P_i = decay momentum)

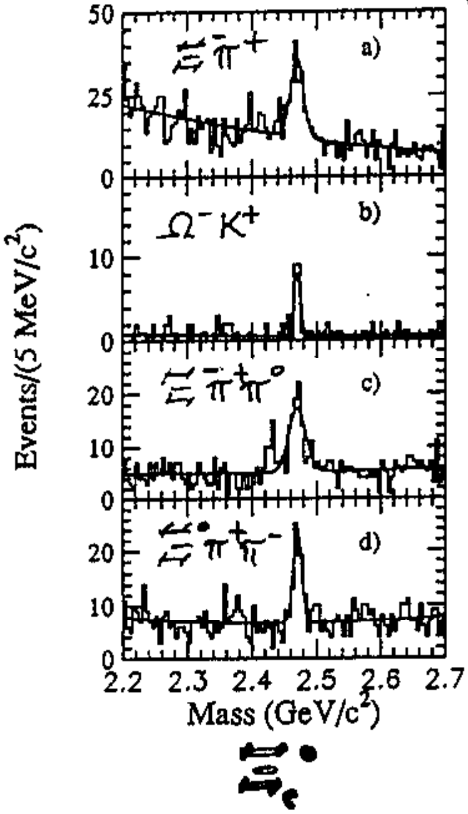
≈ 2.5 MeV/c^2

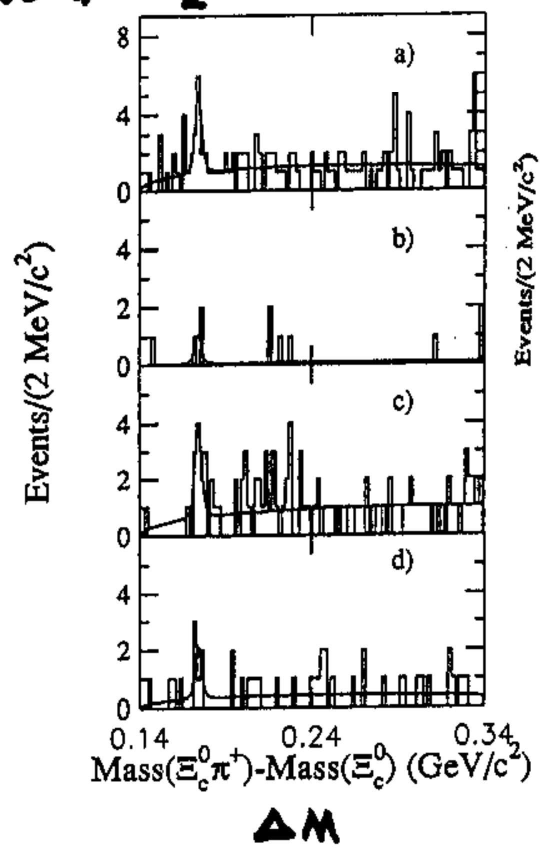
Mass: $M_{\Xi_c^+}$ (2465.1 ± 1.6) + ΔM = 2643.3 ± 2.2 MeV/c^2
P.D.G.
Models 2620 – 2690 ..

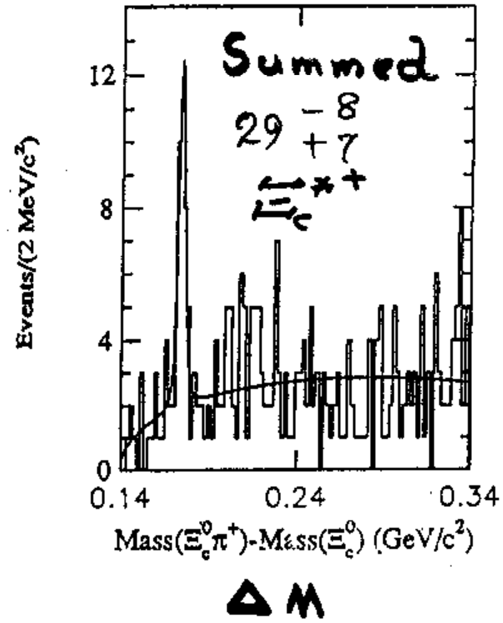
Fraction: $\dfrac{N(\Xi_c^+ \text{ from } \Xi_c^{*0})}{N(e^+e^- \to \Xi_c^+ X)} = (27 \pm 6 \pm 6)\%$

Discovery ($\Xi_c^{*+} \to \Xi_c^0 \pi^+$) '95

(csu) $J^P = \frac{3}{2}^+$







Data Sample: $3.9\ fb^{-1}$ around $\Upsilon(4S)$

Analysis: $\Xi_c^0 \to \Xi^- \pi^+ (x_p > .4) = 120 \pm 13$

$\to \Omega^- K^+ (\ \cdot\cdot\ ) = 19 \pm 4.5$

$\to \Xi^- \pi^+ \pi^0 (\cdot\cdot > .6) = 79 \pm 12$

$\to \Xi^0 \pi^+ \pi^- (\cdot\cdot \quad \cdot\cdot) = 56 \pm 10$

Total $= 274 \pm 21$

Results: $\Delta M = (174 \pm 0.6 \pm 1.0)\ MeV/c^2$

$M(\Xi_c^{*+}) = 2644.3 \pm 2.3\ MeV/c^2$

$\Gamma < 5.1\ MeV/c^2$

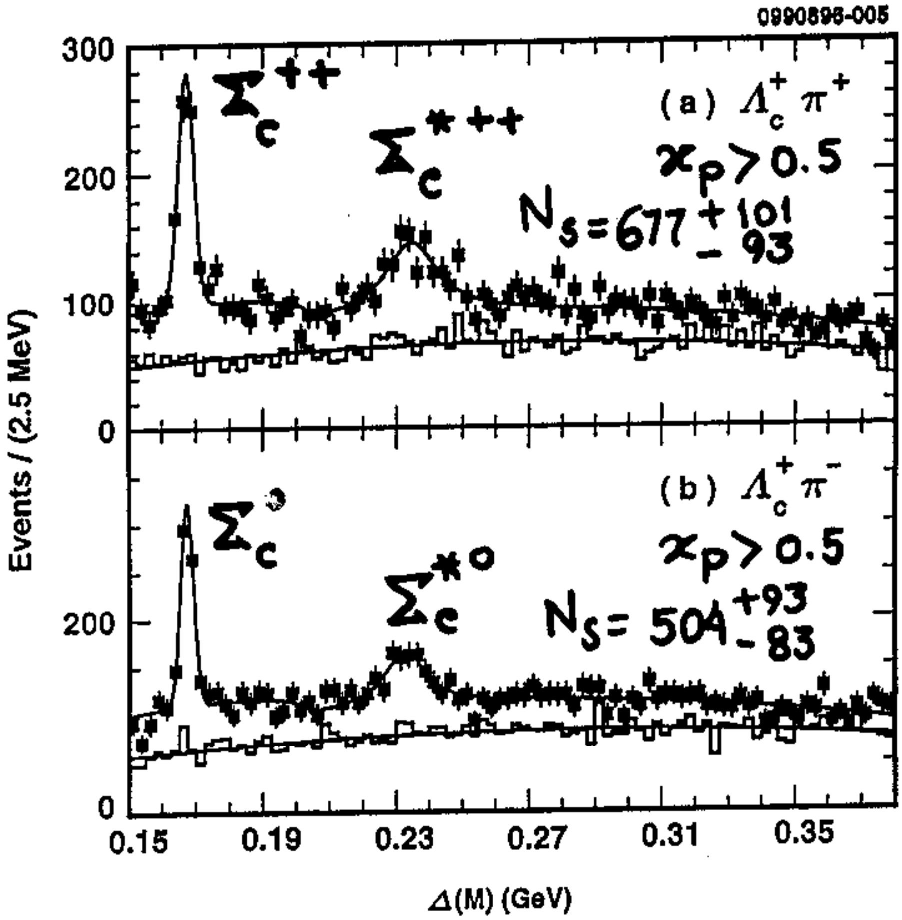
$M(\Xi_c^{*0}) - M(\Xi_c^{*+}) = 1.4 \pm 2.6\ MeV/c^2$

ϵ (Peterson) $= 0.22^{+.15}_{-.08}$

CLEO 96-13

Data: $4.8\,fb^{-1}$ (Υ_{4S})

Observation of Σ_c^{*++}, Σ_c^{*0}



$\Delta M^+ = 234.5 \pm 1.1 \pm 0.8$ MeV/c^2

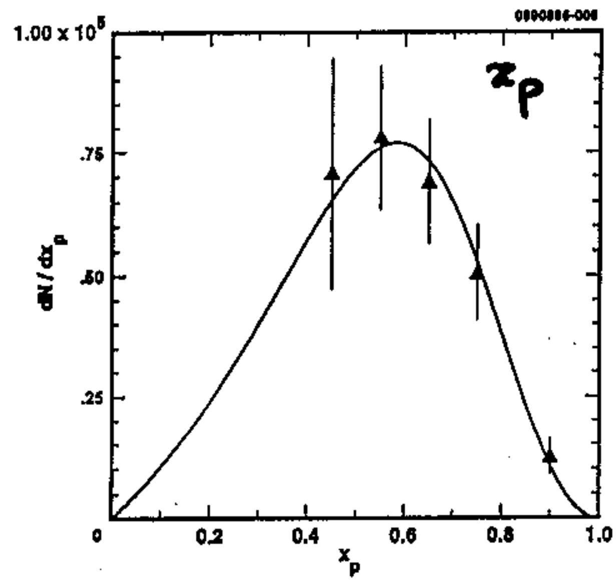
$\Gamma \approx 18^{+4}_{-3}$ ..

$\Delta M^0 = 232.6 \pm 1.0 \pm 0.8$ MeV/c^2

$\Gamma = 13^{+4}_{-3}$ ..

$J^P = \frac{3}{2}^+$

FIG. 1. Mass difference spectra for (a) $\Lambda_c^+\pi^+$ candidates, and (b) $\Lambda_c^+\pi^-$ candidates. The histogram shows the spectra for normalized sidebands of the Λ_c^+. The fits are described in the text.



Peterson Function

$\epsilon = 0.30^{+0.10}_{-0.07}$

$$\frac{N(\Lambda_c^+ \text{ from } \Sigma_c^*)}{N(\Lambda_c^+ \text{ all})} = (12.8^{+1.5}_{-1.3} \pm 3.2)\%$$

$$M(\Sigma_c^{*++}) - M(\Sigma_c^{*0}) = 1.9 \pm 1.4 \pm 1.0 \text{ MeV}/c^2$$

FIG. 2. The efficiency corrected spectrum of scaled momentum, x_p, for the observed Σ_c^* candidates. The fit is to the Peterson function.

Observation of $\Lambda_c^{**+}(\frac{1}{2}^-)$ & $\Lambda_c^{**}(\frac{3}{2}^-)$

CLEO 94-22

$$\Lambda_c^{+**} \longrightarrow \Lambda_c^+ \pi^\pm \pi^\mp$$

Data = $3 fb^{-1}$
(ΣAS)

$N_1 = 112 \pm 17$

$N_2 = 245 \pm 19$

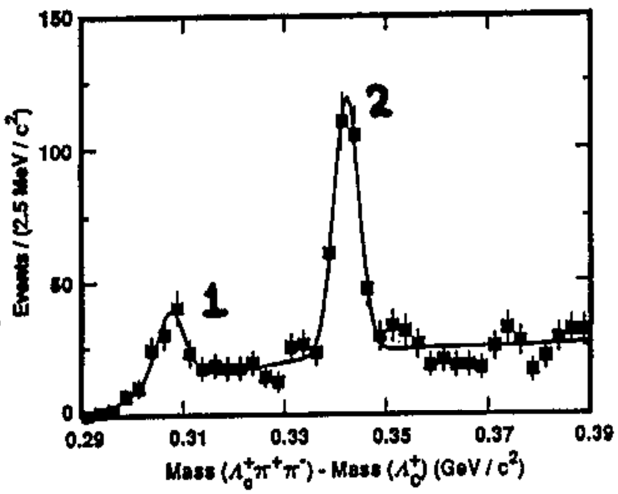


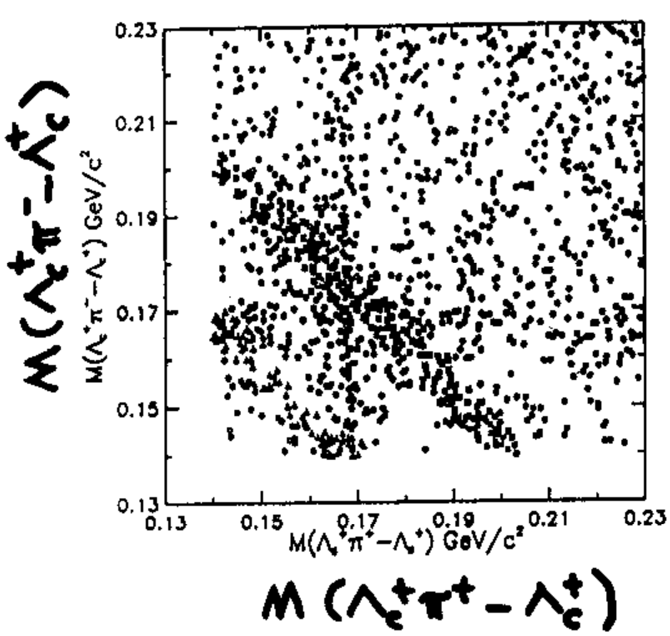
FIG. 1. Fit to mass difference: $M(\Lambda_c^+\pi^+\pi^-) - M(\Lambda_c^+)$.

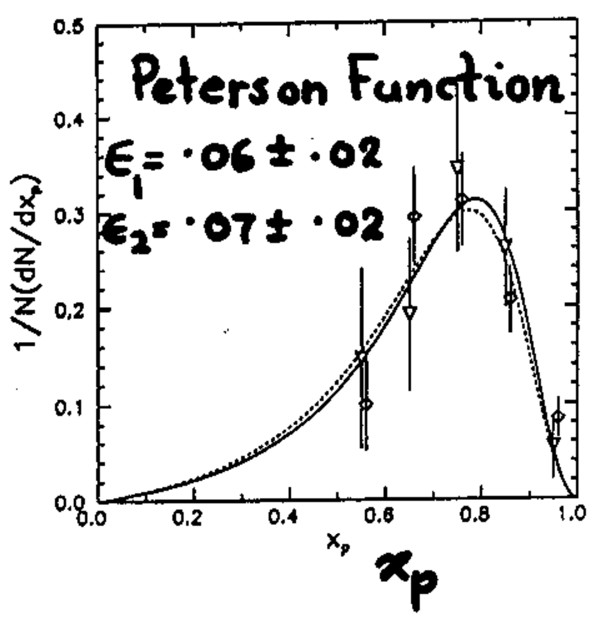
ΔM_1
$= 307.5 \pm 0.2 \pm 0.5$ MeV/c^2

$\Gamma_1 \sim 3.9$ ..

ΔM_2
$= 342.2 \pm 0.2 \pm 0.5$ MeV/c^2

$\Gamma_2 < 1.9$ ..



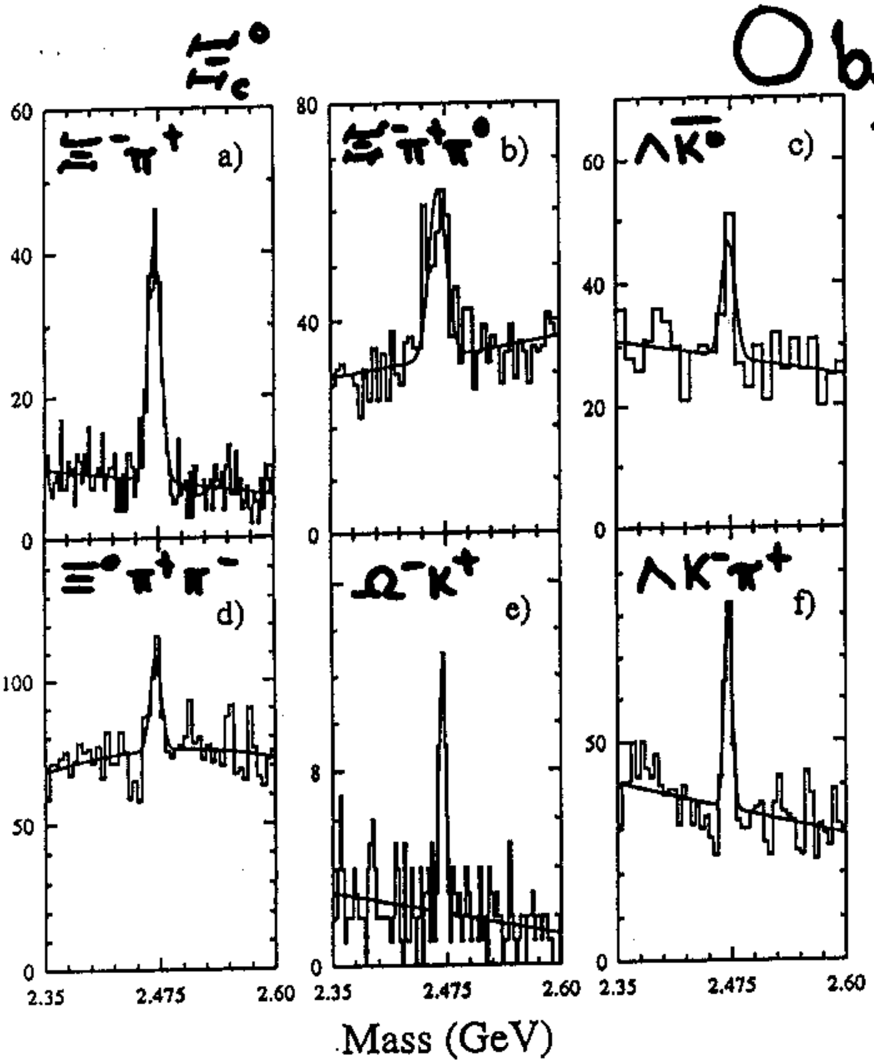


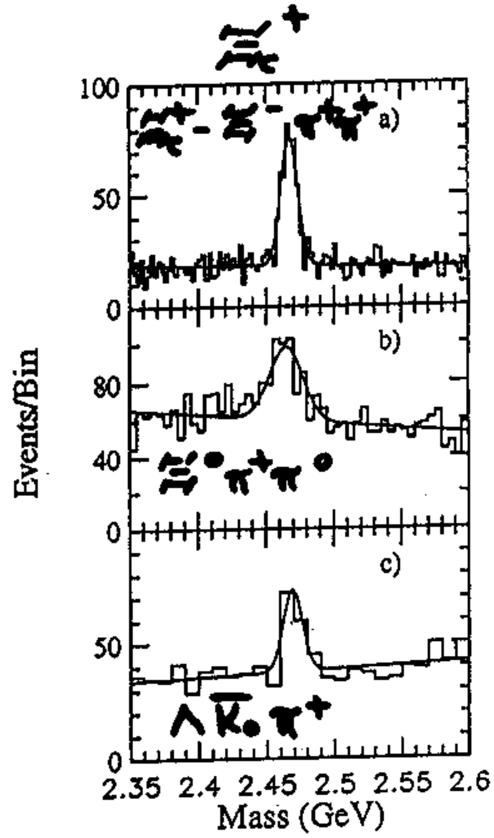
Argus PLB 317 (93) $\Lambda_c^+(2625)$
E687 PRL 72 (94)

Observation of $\Xi_c'^{**}(3/2)$

Data: $4.8 fb^{-1}$ (Υ_{4S})

EPS97

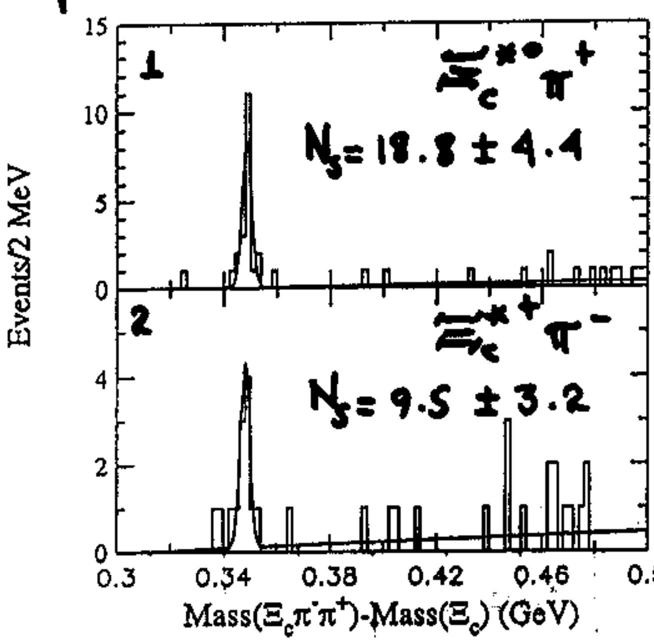




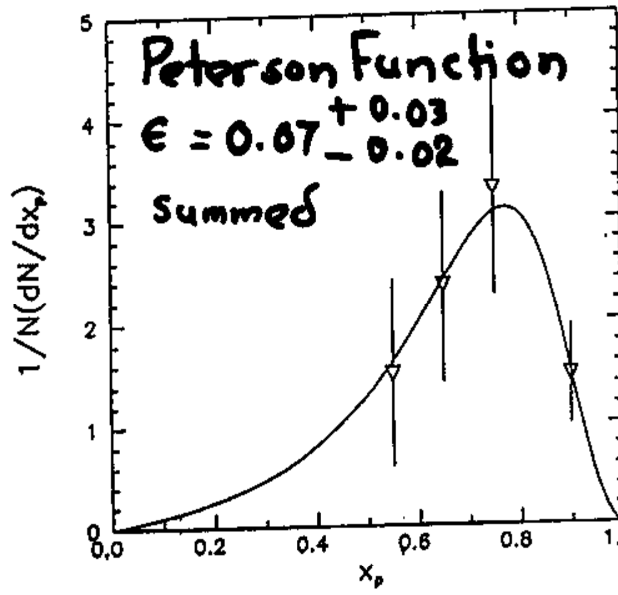
$\Delta M^+ = 348.5 \pm 0.5 \pm 1.0$, $\Gamma < 3.5$ MeV/c^2

$\Delta M^0 = 348.1 \pm 0.8 \pm 2.0$, $\Gamma < 8.1$ ..

$x_p > 0.5$



ΔM



x_p

hq-

Table 13.3: THEORY VERSUS CLEO II

Measured Parameters	Theory Range (MeV/c^2)	CLEO II (This work) (MeV/c^2)
$\Delta M[\Xi_c^{+\prime} - \Xi_c^+]$	100 - 115	108 ± 2 ± 2.5
$\Delta M[\Xi_c^{0\prime} - \Xi_c^0]$	100 - 115	107 ± 1.4 ± 2.5
$M[\Xi_c^{+\prime}]$	2561-2616	
$M[\Xi_c^{0\prime}]$	2561-2616	
$\Delta M[\Xi_c^{0\prime} - \Xi_c^{+\prime}]$	3 - 5	
$\Delta M[\Xi_c^{*0} - \Xi_c^+]$	160 - 180	177.5±0.7±1.0
$\Delta M[\Xi_c^{*+} - \Xi_c^0]$	160 - 180	174.0±1.0±1.0
$\Delta M[\Xi_c^{*0} - \Xi_c^{*+}]$	N/A	0.2±2.7±2.4
$M[\Xi_c^{*0}]$	2620 - 2690	2644.5±1.7±2.2
$M[\Xi_c^{*+}]$	2620 - 2690	2644.3±2.1±1.0
$\Delta M[\Xi_c^{*+} - \Xi_c^{+\prime}]$	60 - 70	69.3±3.0±3.4
$\Delta M[\Xi_c^{*+} - \Xi_c^{+\prime}]$	60 - 70	64.2±2.7±3.3
$\Delta M[\Xi_{c1}^{**+}(\frac{3}{2}^-) - \Xi_c^+]$	340 - 350†	349.0±0.9±1.0
$\Delta M[\Xi_{c1}^{**0}(\frac{3}{2}^-) - \Xi_c^0]$	340 - 350†	350.2±1.2±2.0
$M[\Xi_{c1}^{**+}(\frac{3}{2}^-)]$	N/A	2816.0±1.8±2.2
$M[\Xi_{c1}^{**0}(\frac{3}{2}^-)]$	N/A	2820.5±2.1±2.0
$\Delta M[\Xi_{c1}^{**0}(\frac{3}{2}^-) - \Xi_{c1}^{**+}(\frac{3}{2}^-)]$	N/A	4.5±2.7±3.0

Table 13.2: Peterson Functions and Production Ratios

Particle	Peterson Functions	Production Ratios
Ξ_c^+	$\epsilon_q = 0.23^{+0.06}_{-0.05} \pm 0.03$ (CLEO II - Kim)	Not Applicable
	$\epsilon_q = 0.26^{+0.11}_{-0.07}$ (This work)	Not Applicable
Ξ_c^0	$\epsilon_q = 0.28^{+0.17}_{-0.095}$ (This work)	Not Applicable
$\Xi_c^{+\prime}$, $\Xi_c^{0\prime}$	$\epsilon_q' = 0.20^{+0.23}_{-0.09}$	$\frac{R(\Xi_c')}{R(\Xi_c)} = (35 \pm 9 \pm 7)\%$
Ξ_c^{*0}	$\epsilon_q^* = 0.22^{+0.15}_{-0.08}$ (CLEO II - Yelton)	$R(\Xi_c^{*0}/\Xi_c^+) = (27 \pm 6 \pm 6)\%$ (CLEO II)
Ξ_c^{*+}	$\epsilon_q^* = 0.24^{+0.22}_{-0.10}$ (CLEO II - Yelton)	$R(\Xi_c^{*+}/\Xi_c^0) = (17 \pm 5^{+4}_{-3})\%$ (CLEO II)
$\Lambda_{c1}^{**+}(\frac{3}{2}^-)$	$\epsilon_q^{**} = 0.065^{+0.016}_{-0.013}$ (CLEO II - Yelton)	Not Applicable
$\Lambda_{c1}^{**+}(\frac{1}{2}^-)$	$\epsilon_q^{**} = 0.057^{+0.023}_{-0.016}$ (CLEO II - Yelton)	Not Applicable
$\Xi_{c1}^{**+}(\frac{3}{2}^-)$	$\epsilon_q^{**} = 0.07^{+0.03}_{-0.02}$† (CLEO II - Yelton)	$R(\Xi_{c1}^{**+}/\Xi_c^+) = (5 \pm 1)\%$† (CLEO II)
$\Xi_{c1}^{**0}(\frac{3}{2}^-)$	$\epsilon_q^{**} = 0.07^{+0.03}_{-0.02}$† (CLEO II - Yelton)	$R(\Xi_{c1}^{**0}/\Xi_c^0) = (5 \pm 1)\%$† (CLEO II)

Table 2.1: A List of Ground-State $\frac{1}{2}^+$ and $\frac{3}{2}^+$ Charmed Baryons

Notation	Quark Content	J^P	Flavor SU(3)	(I, I_z)	S	C	Mass (MeV)
✔ Λ_c^+	$c[ud]$	$\frac{1}{2}^+$	$\bar{3}$	(0,0)	0	1	2285.0±0.6
✔ Ξ_c^+	$c[su]$	$\frac{1}{2}^+$	$\bar{3}$	(1/2,1/2)	-1	1	2465.6±1.4
✔ Ξ_c^0	$c[sd]$	$\frac{1}{2}^+$	$\bar{3}$	(1/2,-1/2)	-1	1	2470.3±1.8
✔ Σ_c^{++}	$c\{uu\}$	$\frac{1}{2}^+$	6	(1,1)	0	1	2452.9±0.6
✔ Σ_c^+	$c\{ud\}$	$\frac{1}{2}^+$	6	(1,0)	0	1	2453.9±0.9
✔ Σ_c^0	$c\{dd\}$	$\frac{1}{2}^+$	6	(1,-1)	0	1	2452.1±0.7
✔ $\Xi_c^{+\prime}$	$c\{su\}$	$\frac{1}{2}^+$	6	(1/2,1/2)	-1	1	2575.0±2.5
✔ $\Xi_c^{0\prime}$	$c\{sd\}$	$\frac{1}{2}^+$	6	(1/2,-1/2)	-1	1	2580.0±2.5
✔ Ω_c^0	$c\{ss\}$	$\frac{1}{2}^+$	6	(0,0)	-2	1	2704.0±4.0
Ξ_{cc}^{++}	$c\{cu\}$	$\frac{1}{2}^+$	6	(1/2,1/2)	0	2	3616
Ξ_{cc}^{+}	$c\{cd\}$	$\frac{1}{2}^+$	6	(1/2,-1/2)	0	2	3616
Ω_{cc}^{+}	$c\{cs\}$	$\frac{1}{2}^+$	6	(0,0)	-1	2	3706

Notation	Quark Content	J^P	Flavor SU(3)	(I, I_z)	S	C	Mass (MeV)
✔ Σ_c^{*++}	$\{cuu\}$	$\frac{3}{2}^+$	6*	(1,1)	0	1	2519.5±1.1
Σ_c^{*+}	$\{cud\}$	$\frac{3}{2}^+$	6*	(1,0)	0	1	2520
✔ Σ_c^{*0}	$\{cdd\}$	$\frac{3}{2}^+$	6*	(1,-1)	0	1	2517.6±1.2
✔ Ξ_c^{*+}	$\{csu\}$	$\frac{3}{2}^+$	6*	(1/2,1/2)	-1	1	2644.6±2.3
✔ Ξ_c^{*0}	$\{csd\}$	$\frac{3}{2}^+$	6*	(1/2,-1/2)	-1	1	2643.8±1.8
Ω_c^{*0}	$\{css\}$	$\frac{3}{2}^+$	6*	(0,0)	-2	1	2770
Ξ_{cc}^{*++}	$\{ccu\}$	$\frac{3}{2}^+$	6*	(1/2,1/2)	0	2	3744
Ξ_{cc}^{*+}	$\{ccd\}$	$\frac{3}{2}^+$	6*	(1/2,-1/2)	0	2	3744
Ω_{cc}^{*+}	$\{ccs\}$	$\frac{3}{2}^+$	6*	(0,0)	-1	2	3838
Ω_{ccc}^{++}	$\{ccc\}$	$\frac{3}{2}^+$	6*	(0,0)	0	3	4797

List of P-Wave Singly-Charmed Baryons: ($l = 1$ & $l' = 0$) and ($l = 0$ & $l' = 1$)

$c(q_1q_2)$ $SU(4)$	J^P of (q_1q_2)	J^P of (cq_1q_2)	cud	cuu	cdd	csu	csd	css
$[c[q_1q_2]]$ $\overline{3}_{(A)}$	$[1^-]$	$[\frac{1}{2}^-]$ $2_{(M_A)}$	$\Lambda_{c1}^{**+}(2593)$ ✓	NONE	NONE	$\Xi_{c1}^{**+}(2774)$	$\Xi_{c1}^{**0}(2772)$	NONE
$[c[q_1q_2]]$ $\overline{3}_{(A)}$	$[1^-]$	$[\frac{3}{2}^-]$ $2_{(M_A)}$	$\Lambda_{c1}^{**+}(2625)$ ✓	NONE	NONE	$\Xi_{c1}^{**+}(2816)$ ✓	$\Xi_{c1}^{**0}(2820)$ ✓	NONE
$c\{q_1q_2\}$ $6_{(M_S)}$	$\{0^-\}$	$\{\frac{1}{2}^-\}$ $4_{(S)}$	Σ_{c0}^{**+}	Σ_{c0}^{**++}	Σ_{c0}^{**0}	$\Xi_{c0}^{**+\prime}$	$\Xi_{c0}^{**0\prime}$	Ω_{c0}^{**0}
$c\{q_1q_2\}$ $6_{(M_S)}$	$\{1^-\}$	$\{\frac{1}{2}^-\}$ $2_{(M_S)}$	Σ_{c1}^{**+}	Σ_{c1}^{**++}	Σ_{c1}^{**0}	$\Xi_{c1}^{**+\prime}$	$\Xi_{c1}^{**0\prime}$	Ω_{c1}^{**0}
$c\{q_1q_2\}$ $6_{(M_S)}$	$\{1^-\}$	$\{\frac{3}{2}^-\}$ $2_{(M_S)}$	Σ_{c1}^{**+}	Σ_{c1}^{**++}	Σ_{c1}^{**0}	$\Xi_{c1}^{**+\prime}$	$\Xi_{c1}^{**0\prime}$	Ω_{c1}^{**0}
$c\{q_1q_2\}$ $6_{(M_S)}$	$\{2^-\}$	$\{\frac{3}{2}^-\}$ $4_{(S)}$	Σ_{c2}^{**+}	Σ_{c2}^{**++}	Σ_{c2}^{**0}	$\Xi_{c2}^{**+\prime}$	$\Xi_{c2}^{**0\prime}$	Ω_{c2}^{**0}
$c\{q_1q_2\}$ $6_{(M_S)}$	$\{2^-\}$	$\{\frac{5}{2}^-\}$ $4_{(S)}$	Σ_{c2}^{**+}	Σ_{c2}^{**++}	Σ_{c2}^{**0}	$\Xi_{c2}^{**+\prime}$	$\Xi_{c2}^{**0\prime}$	Ω_{c2}^{**0}
$c(q_1q_2)$ $SU(4)$	J^P of (q_1q_2)	J^P of (cq_1q_2)	cud	cuu	cdd	csu	csd	css
$\{c\{q_1q_2\}\}$ $6_{(S)}$	$[1^-]$	$[\frac{1}{2}^-]$ $2_{(M_A)}$	$\Sigma_{c'1}^{**+}$	$\Sigma_{c'1}^{**++}$	$\Sigma_{c'1}^{**0}$	$\Xi_{c'1}^{**+\prime}$	$\Xi_{c'1}^{**0\prime}$	$\Omega_{c'1}^{**0}$
$\{c\{q_1q_2\}\}$ $6_{(S)}$	$[1^-]$	$[\frac{3}{2}^-]$ $2_{(M_A)}$	$\Sigma_{c'1}^{**+}$	$\Sigma_{c'1}^{**++}$	$\Sigma_{c'1}^{**0}$	$\Xi_{c'1}^{**+\prime}$	$\Xi_{c'1}^{**0\prime}$	$\Omega_{c'1}^{**0}$
$c[q_1q_2]$ $\overline{3}_{(M_A)}$	$\{0^-\}$	$\{\frac{1}{2}^-\}$ $4_{(S)}$	$\Lambda_{c'0}^{**+}$	NONE	NONE	$\Xi_{c'0}^{**+}$	$\Xi_{c'0}^{**0}$	NONE
$c[q_1q_2]$ $\overline{3}_{(M_A)}$	$\{1^-\}$	$\{\frac{1}{2}^-\}$ $2_{(M_S)}$	$\Lambda_{c'1}^{**+}$	NONE	NONE	$\Xi_{c'1}^{**+}$	$\Xi_{c'1}^{**0}$	NONE
$c[q_1q_2]$ $\overline{3}_{(M_A)}$	$\{1^-\}$	$\{\frac{3}{2}^-\}$ $2_{(M_S)}$	$\Lambda_{c'1}^{**+}$	NONE	NONE	$\Xi_{c'1}^{**+}$	$\Xi_{c'1}^{**0}$	NONE
$c[q_1q_2]$ $\overline{3}_{(M_A)}$	$\{2^-\}$	$\{\frac{3}{2}^-\}$ $4_{(S)}$	$\Lambda_{c'2}^{**+}$	NONE	NONE	$\Xi_{c'2}^{**+}$	$\Xi_{c'2}^{**0}$	NONE
$c[q_1q_2]$ $\overline{3}_{(M_A)}$	$\{2^-\}$	$\{\frac{5}{2}^-\}$ $4_{(S)}$	$\Lambda_{c'2}^{**+}$	NONE	NONE	$\Xi_{c'2}^{**+}$	$\Xi_{c'2}^{**0}$	NONE

Conclusions

1) Ξ_c^+, Ξ_c^0, Ξ_c^{*0}, Ξ_c^{*+}, $\Xi_c^{+'}$, $\Xi_c^{0'}$, $\Xi_{c1}^{*+}(3/2^-)$ ...
baryons have been seen and masses measured.

2) Only a fraction of the total decays for the Ξ_c^0 and Ξ_c^+ have been measured

3) The production function in e^+e^- collisions measured in terms of the Peterson function parameter ϵ_Q appear to be about the same for all charmed baryons, except for the Λ_c^*'s

4) Our theoretical friends have to figure out how to calculate multibody (not just two-body) decay rates

The story of charmed strange baryons is far from complete. But Rosy

CESR ⟺ Charmed Baryon Factory

100R