Charmed Baryons

Flavor Physics and CP Violation 2002

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A review of the experimental results on charmed baryons with an accent on recent results.

Why Study Charmed Baryons?

The charmed baryon sector offers the richest spectroscopy of quark combinations.

• Compared with mesons there are *more* states as there are more possibilities for orbital excitations.

• Compared with mesons, the extra mass associated with orbital excitations is less, leading to less phase space for decays and *narrower* states.

• Because the charm quark has a large mass, the states can be described as a combination of a heavy quark and a light di-quark - this picture does not work well for strange baryons.

• Compared with the B sector, charmed baryons are much easier to study experimentally. Once charmed baryons are understood, extrapolation to B baryons is easy.

• There are four *weakly* decaying charmed baryons - good laboratory for studying weak decays.

How To Study Charmed Baryons

Two main techniques:

Fixed Target Experiments, e.g. FOCUS, SELEX, E-791.

• Advantage: Long pathlength can be used measure the lifetimes, and as a tag of charm.

• Disadvantage: Charm particles are a small minority of events.

Experiments at e^+e^- Machines, e.g. CLEO, BELLE.

• Advantage: ≈40% of continuum events are charm.

• Disadvantage: Short pathlength, difficult to separate vertices.

Running at $\Lambda_c^+\overline{\Lambda_c^+}$ threshold would be exciting. Maybe CLEO_c in 2006?

Naming Charmed Baryons

We always consider a charmed baryon as being the combination of a charmed quark and a light diquark with its own J^P_{LIGHT} to give a state of a particular J^P.

If the two light quarks are u and/or d, then the particle is Λ_c or a Σ_c.

If the wave-function is antisymmetric under interchange of the two light quarks, then the particle is a Λ_c and is I=0. If it is symmetric, then it is a Σ_c and it is I=1.

The lowest lying state is therefore the Λ_c^+ $\overset{\uparrow\uparrow\downarrow}{cud}$ with $J^P = \frac{1}{2}^+, J^P_{LIGHT} = 0^+$

Next lowest is the isotriplet of Σ_c's $\overset{\uparrow\downarrow\downarrow}{cqq}$ with $J^P = \frac{1}{2}^+, J^P_{LIGHT} = 1^+$.

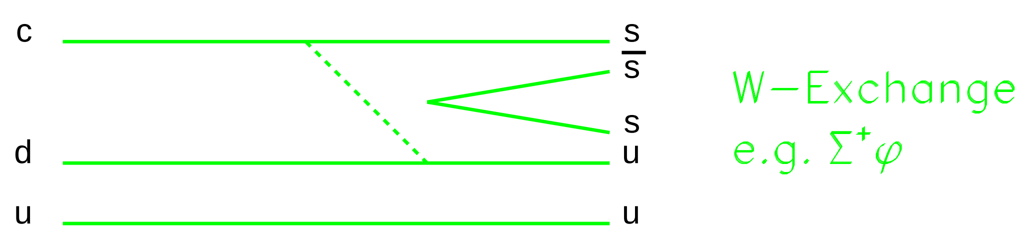
Then is the isotriplet of Σ_c^*'s $\overset{\uparrow\uparrow\uparrow}{cqq}$ with $J^P = \frac{3}{2}^+, J^P_{LIGHT} = 1^+$.

Λ_c^+ (Ground State)

More than thirty decay modes measured. Recent contribution from BELLE on Cabibbo-suppressed and W-exchange modes. Phys. Lett. **B526**, 258 (2002).

Mode	Yield	Mode 2	B_1/B_2	Previous
ΛK^+	265 ± 35	$\Lambda\pi^+$	$0.074 \pm 0.010 \pm 0.012$	
ΣK^+	75 ± 18	$\Sigma^0\pi^+$	$0.056 \pm 0.014 \pm 0.008$	
$\Sigma^+K^+\pi^-$	105 ± 24	$\Sigma^+\pi^+\pi^-$	$0.047 \pm 0.011 \pm 0.008$	$0.24^{+0.24}_{-0.16}$
$\Sigma^+K^+K^-$	246 ± 20	$\Sigma^+\pi^+\pi^-$	$0.076 \pm 0.007 \pm 0.009$	$0.094 \pm 0.017 \pm 0.019$
$\Sigma^+\phi$	129 ± 17	$\Sigma^+\pi^+\pi^-$	$0.085 \pm 0.012 \pm 0.012$	$0.094 \pm 0.033 \pm 0.025$
$\Xi(\Sigma^+K^-)K^+$	75 ± 16	$\Sigma^+\pi^+\pi^-$	$0.023 \pm 0.005 \pm 0.005$	
$\Xi(\Lambda\overline{K^0})K^+$	75 ± 16	$\Lambda\overline{K^0}K^+$	$0.26 \pm 0.08 \pm 0.03$	
pK^+K^-	676 ± 89	$pK^-\pi^+$	$0.014 \pm 0.002 \pm 0.002$	$0.039 \pm 0.009 \pm 0.007$
$p\phi$	345 ± 43	$pK^-\pi^+$	$0.015 \pm 0.002 \pm 0.002$	$0.024 \pm 0.006 \pm 0.003$

Some of these decays can proceed only by W-exchange diagrams:

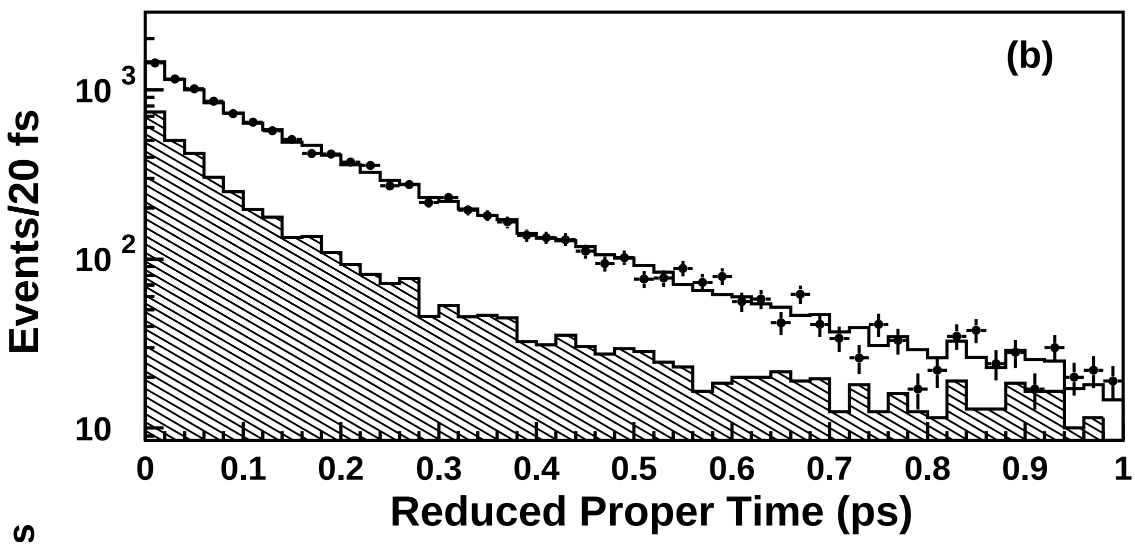


Λ_c^+ Lifetime

New measurements from:

SELEX $\tau(\Lambda_c^+) = 198.1 \pm 7.0 \pm 5.6$ fs.
PRL 86 5243 (2001).

FOCUS $\tau(\Lambda_c^+) = 204.6 \pm 3.4 \pm 2.4$ fs.
PRL 88 161801 (2002)

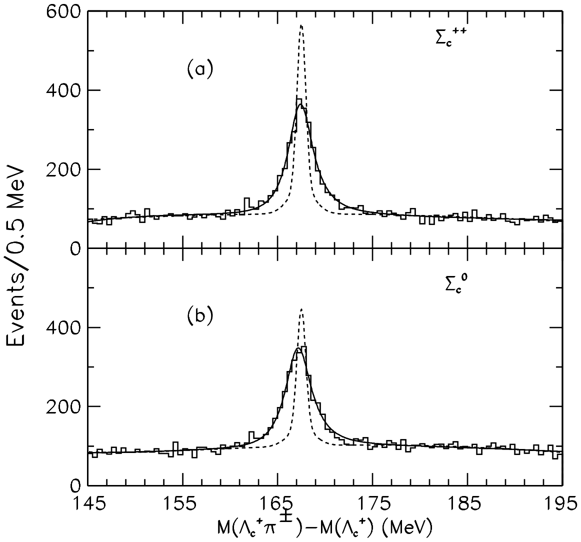


(c.f. PDG 2001 value of 188 ± 7 fs from 6 experiments.)

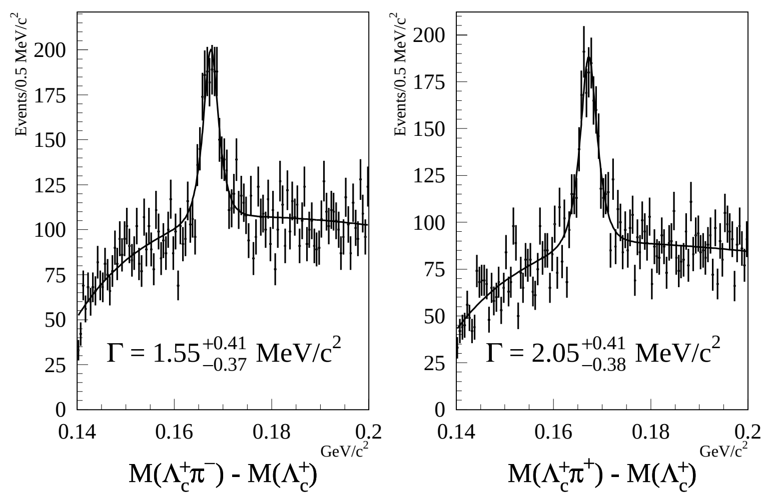
Short lifetime of the Λ_c^+ presumably due to W-exchange decays.

Recent Σ_c^{++} and Σ_c^0 Results

All 3 masses well measured. Measurement of widths from CLEO and FOCUS



CLEO



FOCUS

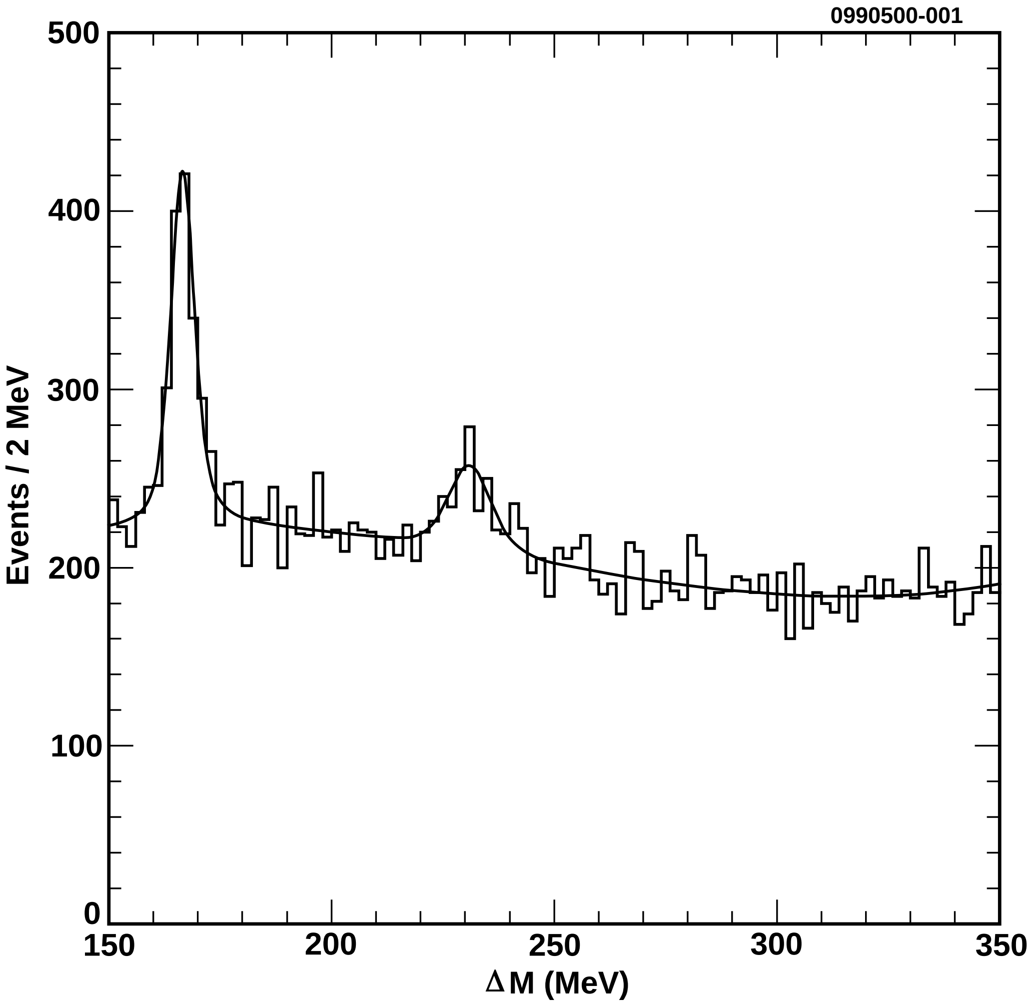
$\Gamma(\Sigma_c^{++}) = 2.3 \pm 0.2 \pm 0.3$ MeV,

$\Gamma(\Sigma_c^0) = 2.5 \pm 0.2 \pm 0.3$ MeV.

$\Gamma(\Sigma_c^{++}) = 2.05^{+0.41}_{-0.38} \pm 0.38$ MeV,

$\Gamma(\Sigma_c^0) = 1.55^{+0.41}_{-0.37} \pm 0.38$ MeV.

Σ_c^+ AND Σ_c^{*+} PRODUCTION



$$M(\Lambda_c^+\pi^0) - M(\Lambda_c^+)$$

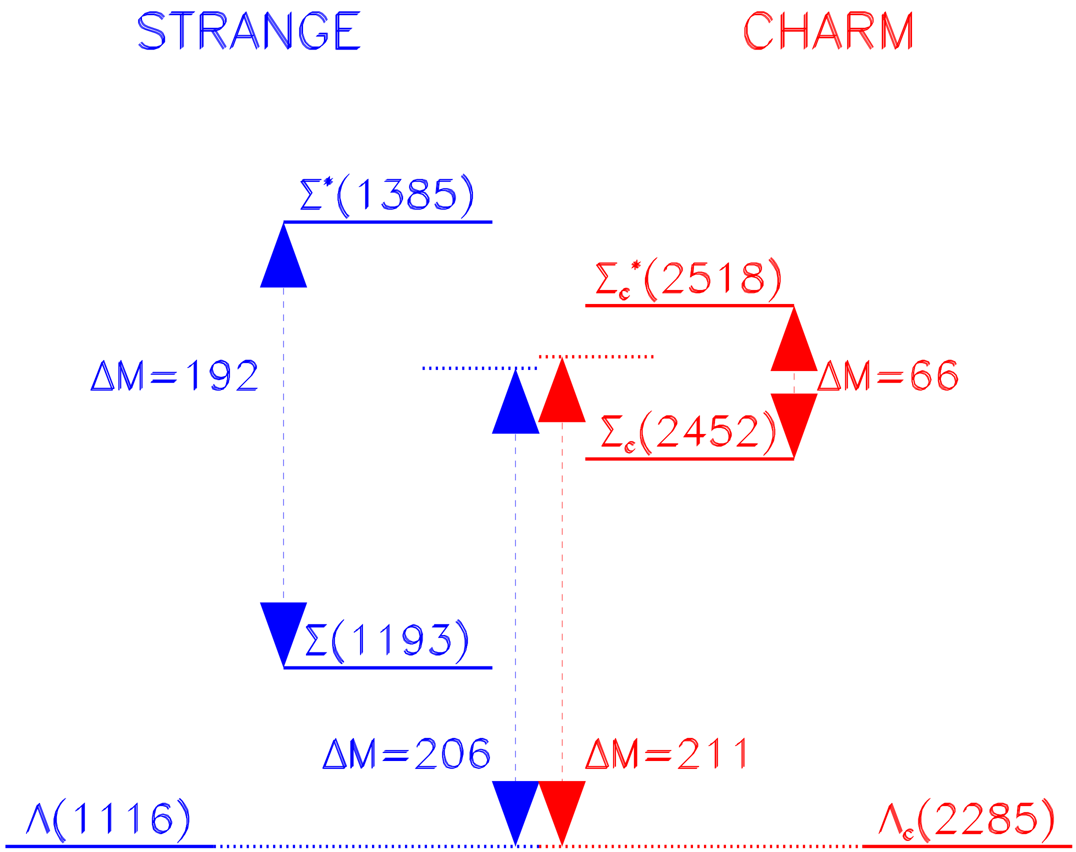
CLEO finds a signal of 327^{+78}_{-73} Events.

$\Delta M(\Sigma_c^{*+}) = 231.1 \pm 1.1 \pm 2.0$ MeV.

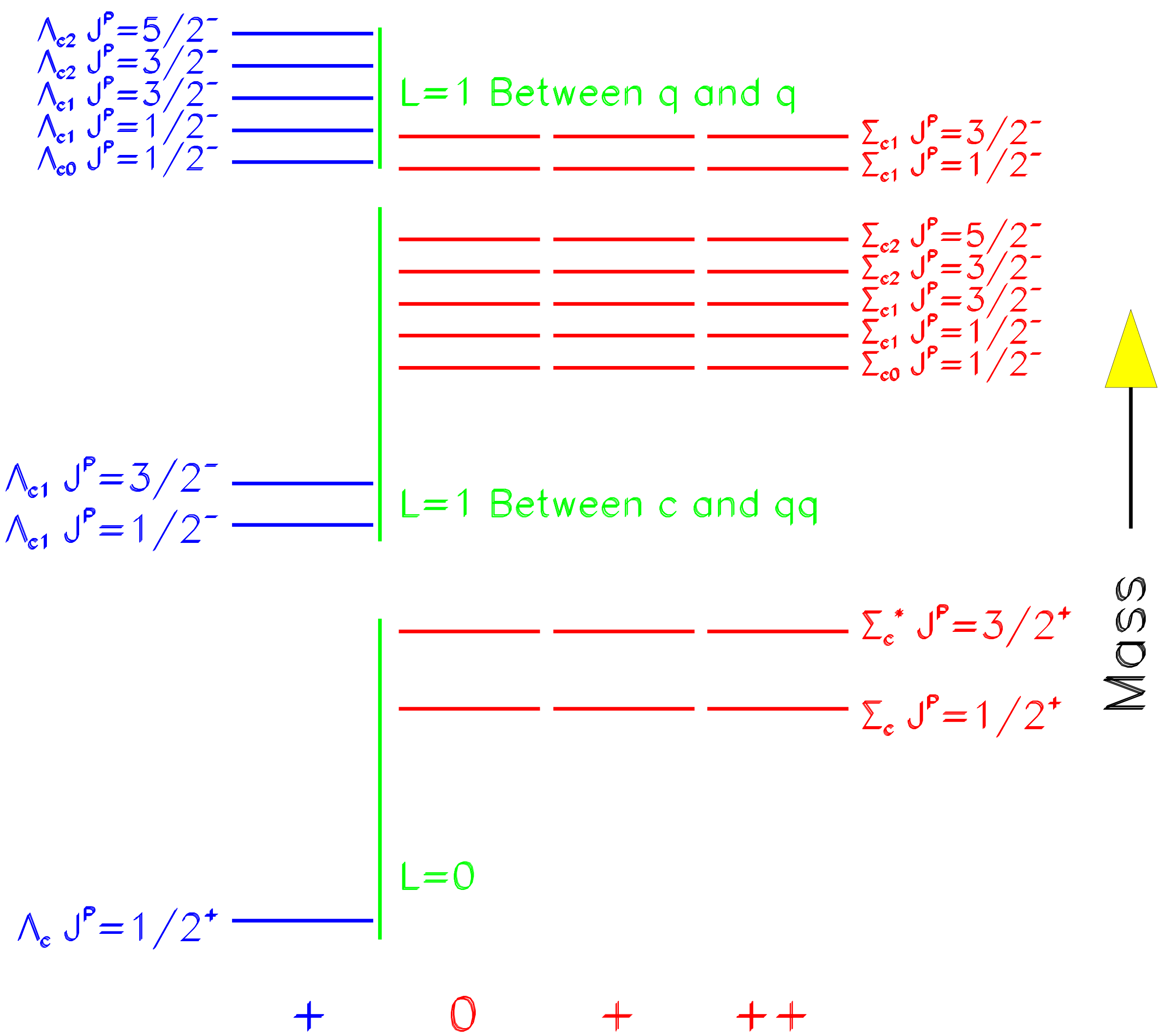
$\Sigma_c^{(*)}$ Summary

In MeV	0	+	++
$\Delta M(\Sigma_c)$			
CLEO	$167.2 \pm 0.1 \pm 0.2$	$166.4 \pm 0.2 \pm 0.3$	$167.4 \pm 0.1 \pm 0.2$
FOCUS	$167.35 \pm 0.19 \pm 0.20$		$167.38 \pm 0.19 \pm 0.12$
PDG 2001	167.30 ± 0.20	168.7 ± 0.6	167.87 ± 0.19
$\Gamma(\Sigma_c)$			
CLEO	$2.5 \pm 0.2 \pm 0.3$	< 4.6	$2.3 \pm 0.2 \pm 0.3$
FOCUS	$1.55^{+0.41}_{-0.37} \pm 0.38$		$2.05^{+0.41}_{-0.38} \pm 0.38$
$\Delta M(\Sigma_c^*)$			
CLEO	$232.6 \pm 1.0 \pm 0.8$	$231.1 \pm 1.1 \pm 2.0$	$234.5 \pm 1.1 \pm 0.8$
FOCUS	(232.7 ± 1.2)		(234.2 ± 1.5)
$\Gamma(\Sigma_c^*)$			
CLEO	$13.0^{+3.7}_{-3.0} \pm 1.0$	< 17	$17.9^{+3.8}_{-3.2} \pm 4.0$
FOCUS	(9.4 ± 3.7)		(23.6 ± 4.5)

- Note small isosping splitting (but singly charged state lowest mass?)
- Note $\Gamma(\Sigma_c^*) \approx 7 \times \Gamma(\Sigma_c)$.


STRANGE
CHARM
Σ*(1385)
Σc*(2518)
ΔM=192
ΔM=66
Σc(2452)
Σ(1193)
ΔM=206
ΔM=211
Λ(1116)
Λc(2285)

Search for Higher States

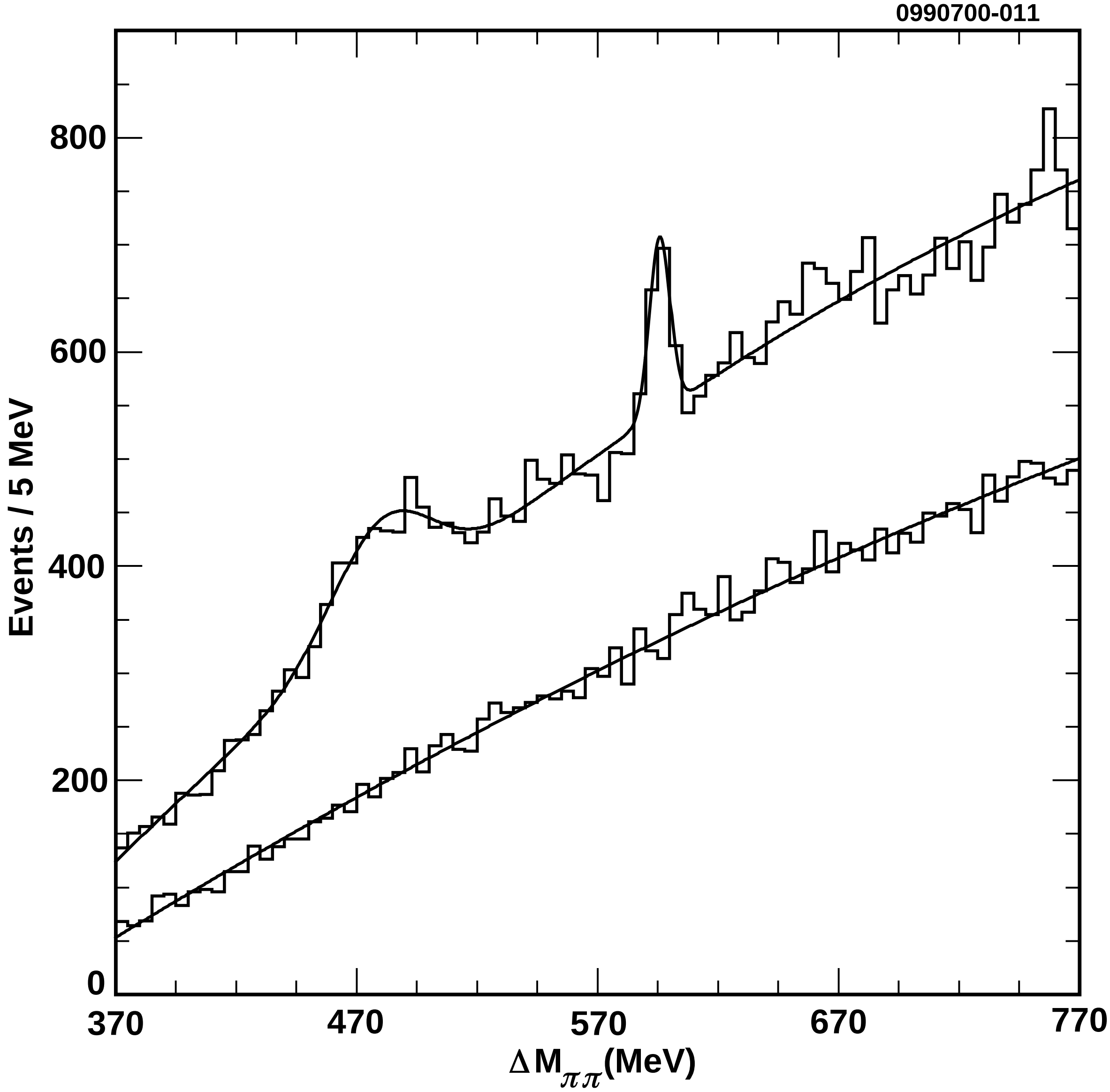


Lower resonance:

Yield=997^{+141}_{-129}, $\Delta M_{\pi\pi} = 480.1 \pm 2.4$ MeV, $\sigma = 20.9 \pm 2.6$ MeV.

Upper resonance:

Yield=350^{+57}_{-55}, $\Delta M_{\pi\pi} = 595.8 \pm 0.8$ MeV, $\sigma = 4.2 \pm 0.7$ MeV.

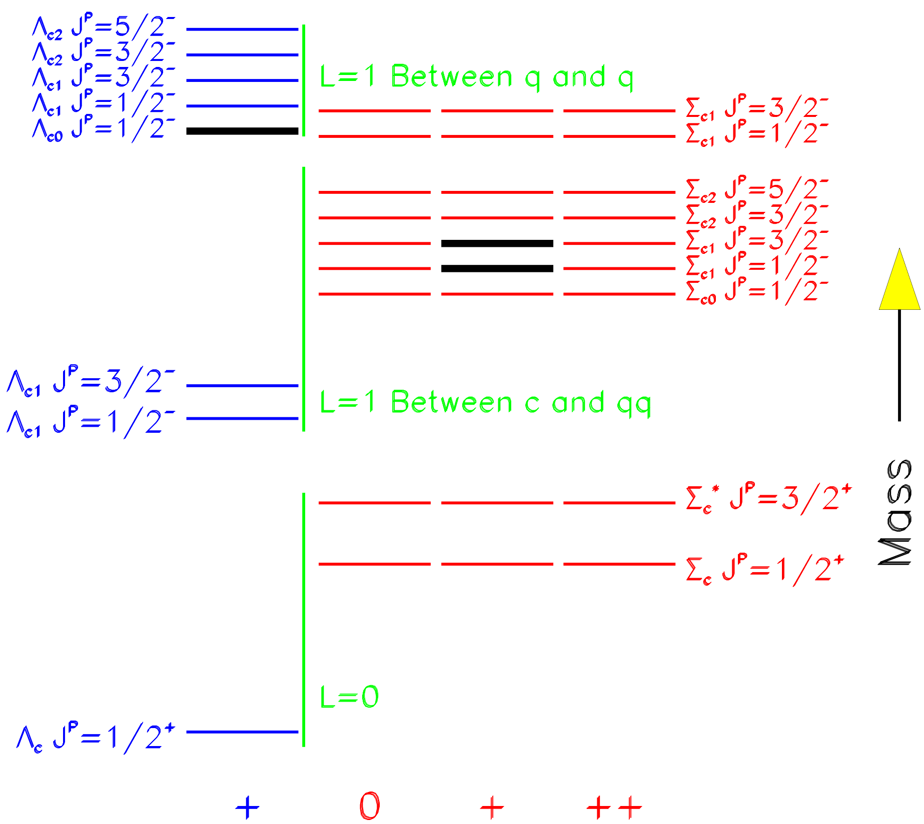


Higher Level States Conclusion

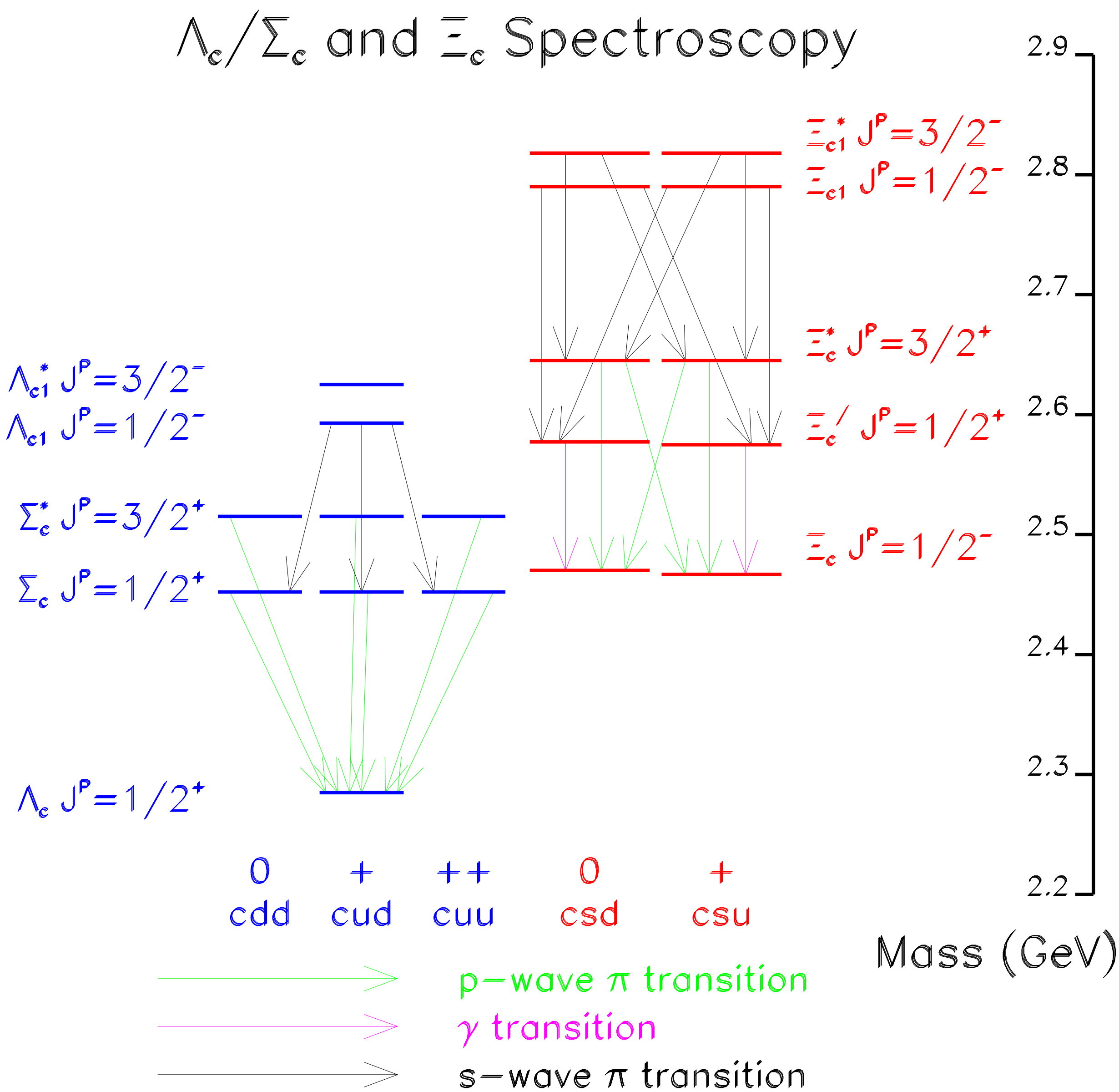
CLEO explanation:

Lower resonance is two of the first orbital excitations of the Σ_c, These are $\overset{\uparrow L=1(\uparrow\uparrow)}{c\quad\ (ud)}$, where the $J^P_{LIGHT} = 1^-$ diquark combines with the charm quark to give a $J^P = \frac{1}{2}^-, \frac{3}{2}^-$ pair.

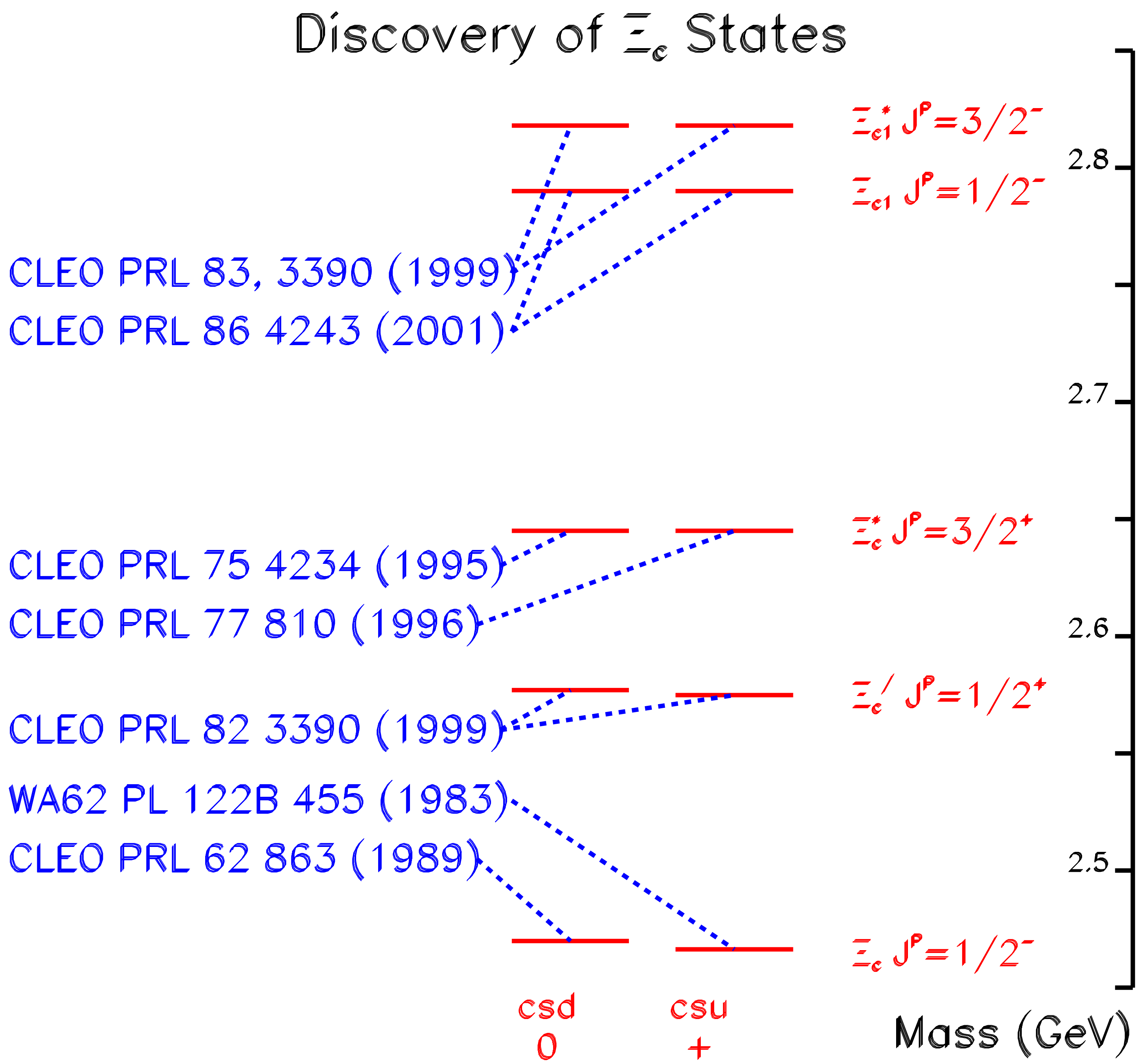
Upper resonance could be the first orbital excitation where the excitation is between the two light quarks. $\overset{\uparrow(\uparrow L=1\uparrow)}{c(u\quad\ d)}$, where the $J^P_{LIGHT} = 0^-$ diquark combines with the charm quark to give a $J^P = \frac{1}{2}^-$ Λ_{c0} particle.



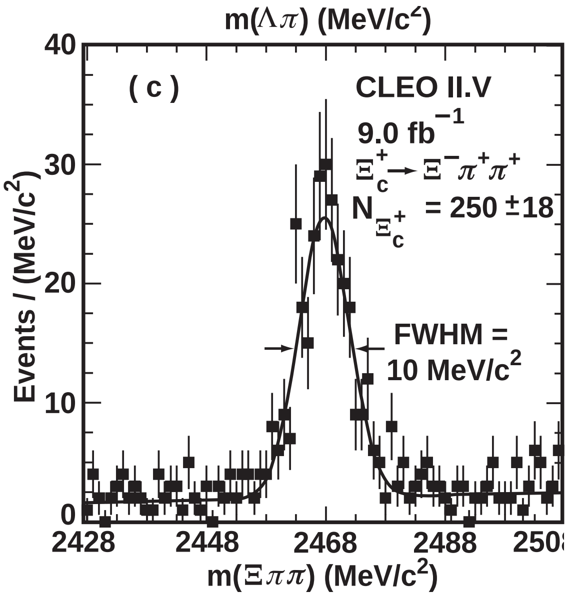
Ξ_c States - Predicted

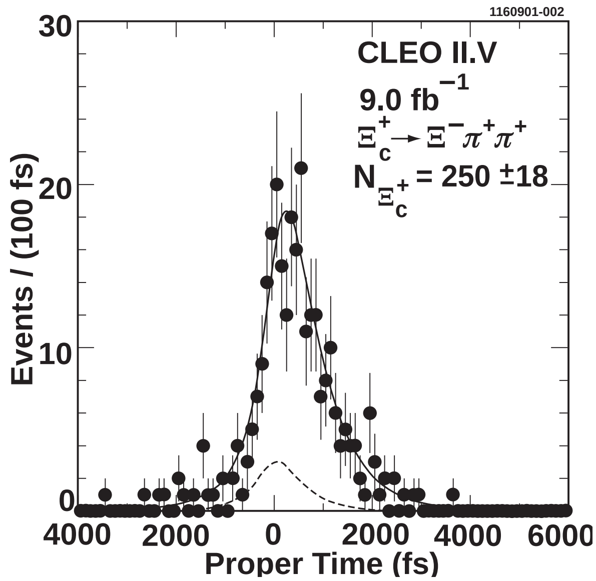


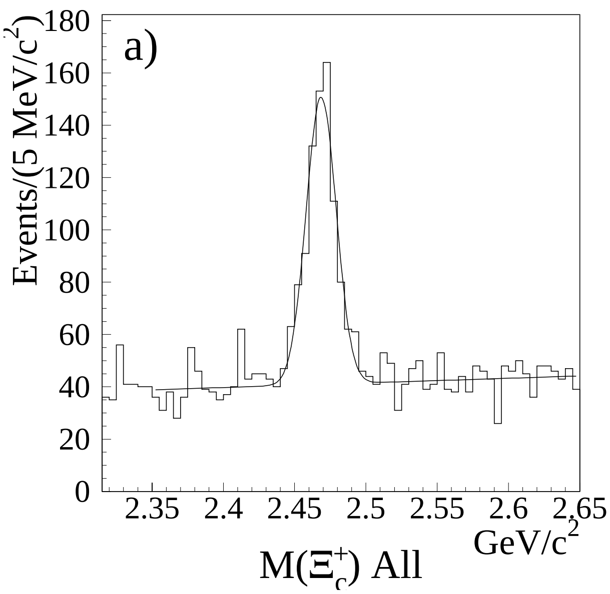
Ξ_c States - Discovered

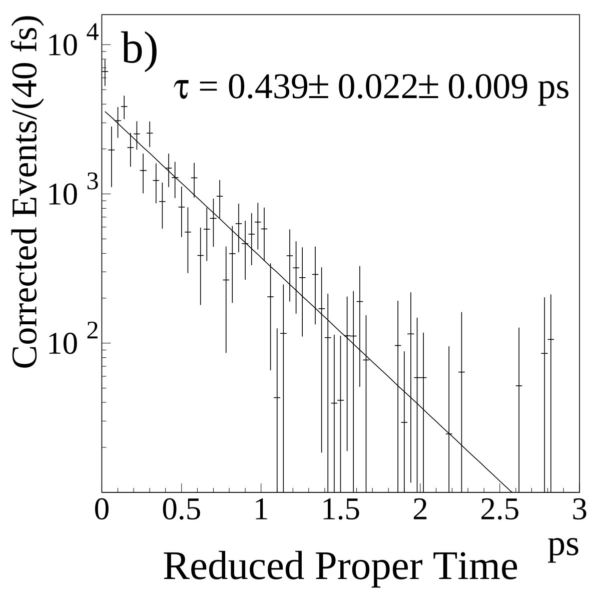


Ξ_c^+ Lifetime









PDG has 330^{+60}_{-40} fs

CLEO $503 \pm 47 \pm 18$ fs

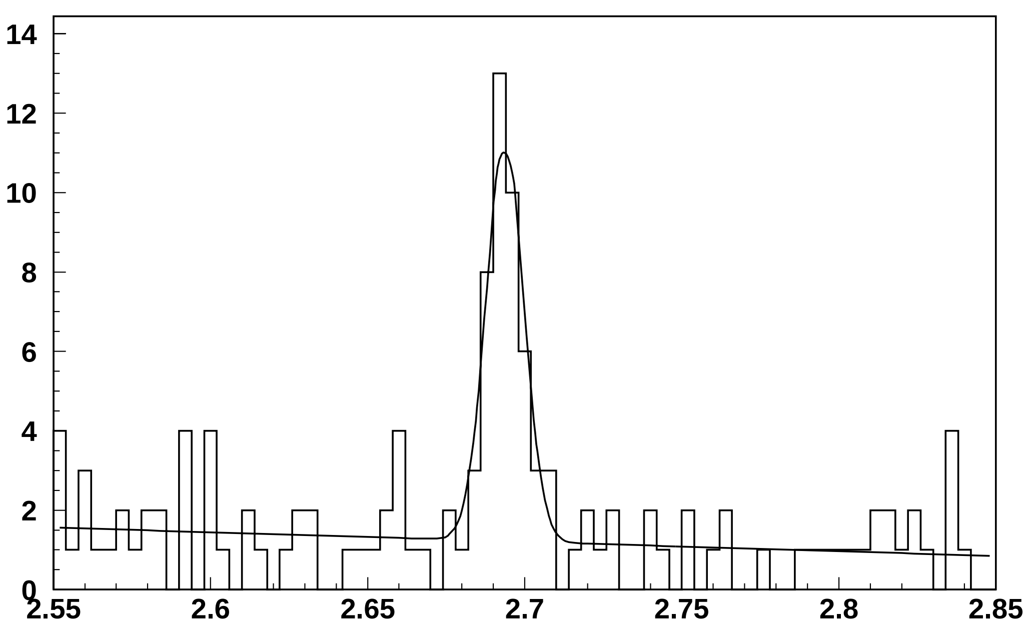
FOCUS $439 \pm 22 \pm 9$ fs

The Ω_c

Ω_c is *css* combination. Many sightings over the years, in particular E-687 in $\Sigma^+ K^- K^- \pi^+$. CLEO (2001) finds a signal in the sum of 5 modes:

($\Omega^-\pi^+$, $\Omega^-\pi^+\pi^-\pi^+$, $\Omega^-\pi^+\pi^0$, $\Xi^0 K^-\pi^+$, $\Xi^- K^-\pi^+\pi^+$.)

BELLE has the best signal yet, using $\Omega^-\pi^+$.

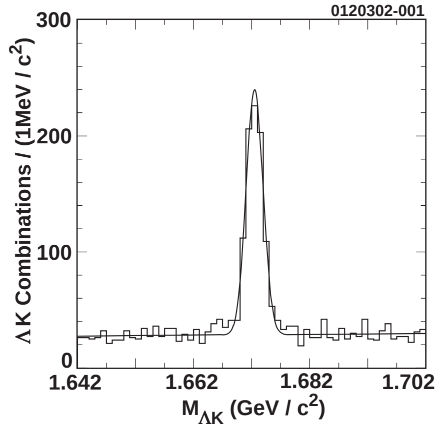


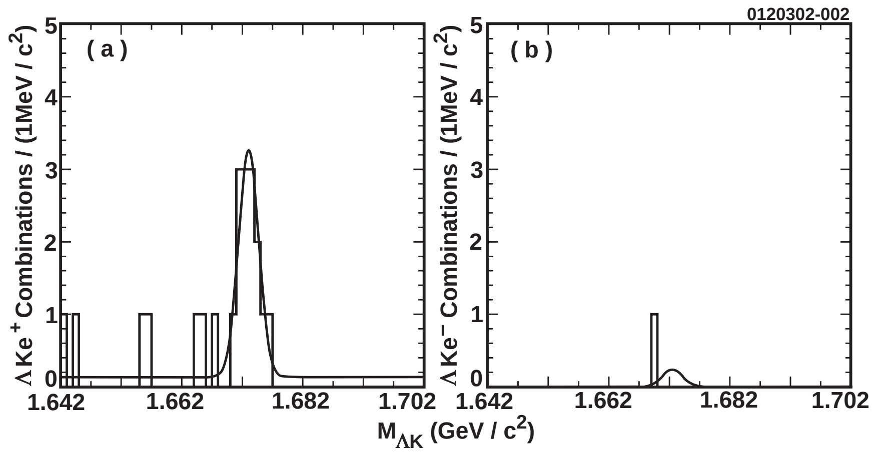
CLEO measures: M=$2694.6 \pm 2.6 \pm 1.9$MeV$/c^2$

BELLE measures: M=$2693.7 \pm 1.3^{+1.1}_{-1.0}MeV/c^2$

$\Omega_c \to \Omega^- e^+ \nu$ Result

To look for semi-leptonic decays of the Ω_c, CLEO first looks for inclusive Ω^- production and finds a yield of 760 ± 32 events





Look for Ω^-'s with a) "right" sign lepton, and b) "wrong"sign lepton.

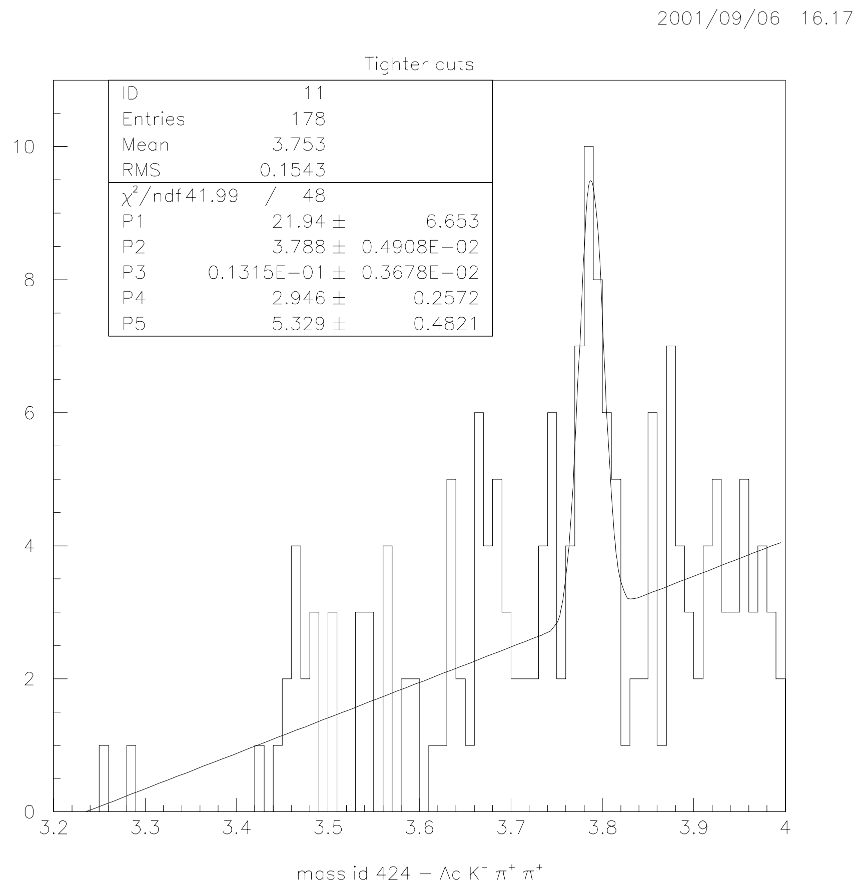
After subtracting measured backgrounds, excess of: 11.4 ± 3.8 events due to $\Omega_c \to \Omega^- e^+ \nu$.

Find $\frac{\Omega_c \to \Omega^- \pi^+}{\Omega_c \to \Omega^- e^+ \nu} = 0.41 \pm 0.19 \pm 0.04$

Note: $\frac{\Xi_c^0 \to \Xi^- \pi^+}{\Xi_c^0 \to \Xi^- e^+ \nu} = 0.44 \pm 0.09$ and $\frac{\Lambda_c \to \Lambda \pi^+}{\Lambda_c^+ \to \Lambda e^+ \nu} = 0.3 \pm 0.1$

Looking for the Ξ_{cc}^{++}

SELEX VERY preliminary....looking in $\Lambda_c^+ K^- \pi^+ \pi^+$



CONCLUSIONS
AND HOPES FOR THE FUTURE

• There are 22 charmed baryons found. Many of them need confirmation, but they give a spectroscopic picture that is complex, but orderly and understandable.

• Still work to be done on spectroscopy. I anticipate more discoveries such as $\Omega_c^* \rightarrow \Omega\gamma$, $\Omega_{c1} \rightarrow \Xi_c K$, $\Xi_{c1} \rightarrow \Xi_c \pi\pi$, more Σ_{c1} states, $\Lambda_{c1} \rightarrow pD$.

• Much work being done details - Ω_c lifetimes, production mechanisms, precise masses, widths, absolute branching fractions, more semi-leptonic decays etc. etc.

• BELLE and BaBar are in a good position to contribute to this research. If CESR_c runs at Λ_c^+ threshold, so can CLEO_c.