Heavy Baryons – Recent and Very New Results

5th International Conference on
Hyperons, Charm and Beauty Hadrons
June 25, 2002
Peter S. Cooper − Fermilab

Abstract

Recent results on observations, properties and decay modes of the charmed and beauty baryons will be reviewed. Emphasis will be placed on several new high mass states which include a cleanly−identified daughter Λ_c^+ baryon in data from the SELEX experiment at Fermilab. These states are candidates for doubly−charmed baryons: a Ξ_{cc}^{++}(ccu) state and a Ξ_{cc}^{+}(ccd) state. The candidates are more than 5σ signals in each case at masses of 3780 and 3520 MeV respectively. We have evidence of a pionic transition from the Ξ_{cc}^{++} state to the Ξ_{cc}^{+}. We present these first observations of doubly−charmed baryon states at BEACH 2002 for critical discussion and to find ways to confirm or refute the data.

Outline

- Recent beauty baryon results

  No new reports since previous conference (2000)

- Recent charmed baryon results

  New lifetime measurements (Λ_c^+ , Ξ_c^+ , Ξ_c^0 , Ω_c^0)

  New decay modes seen (Belle, Cleo, Focus)

  Sergio Ratti's talk from Focus on Wednesday

  + perhaps some I've missed

- Future Prospects

- SELEX − Have Doubly−charmed Baryon Been Discovered?

  SELEX Experiment

  Search method and results

  some details

  Problems with the interpretation as double−charmed baryons

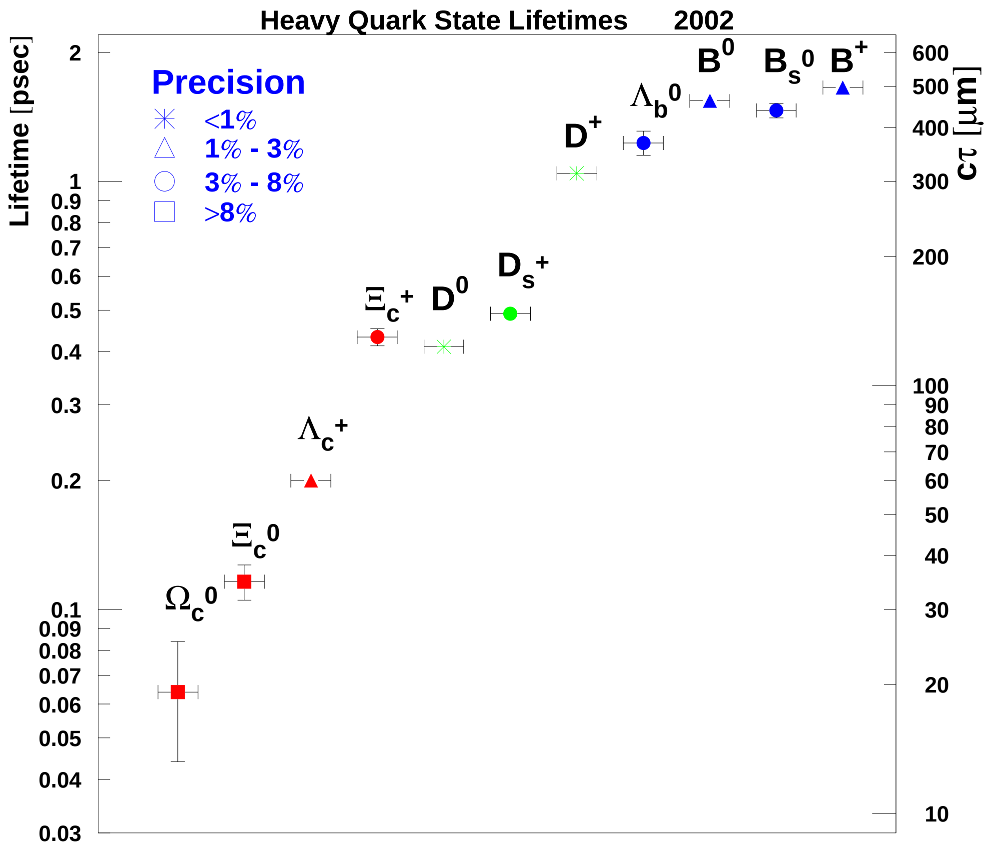
  conclusions

Heavy Quark State Lifetimes

Lifetimes span 2 orders of magnitude
Recent precisions are ~%1 or better

Charmed baryon lifetimes given by the relative contributions of 4 amplitudes: external W, W exchange {constructive, destructive} internal W (Guberina and others)

The difference of the Λ_b and B meson lifetimes challenge HQET theories.



New Λ_c^+ Lifetime Measurements

3 new measurements ~200 fsec

- Selex 198.1±7.0±5.6 PRL 86,5243(2001)
- CLEO 179.6±6.9±4.4 PRL 86,2232(2001)
- FOCUS 204.6±3.4±2.5 PLB 523,53(2001)

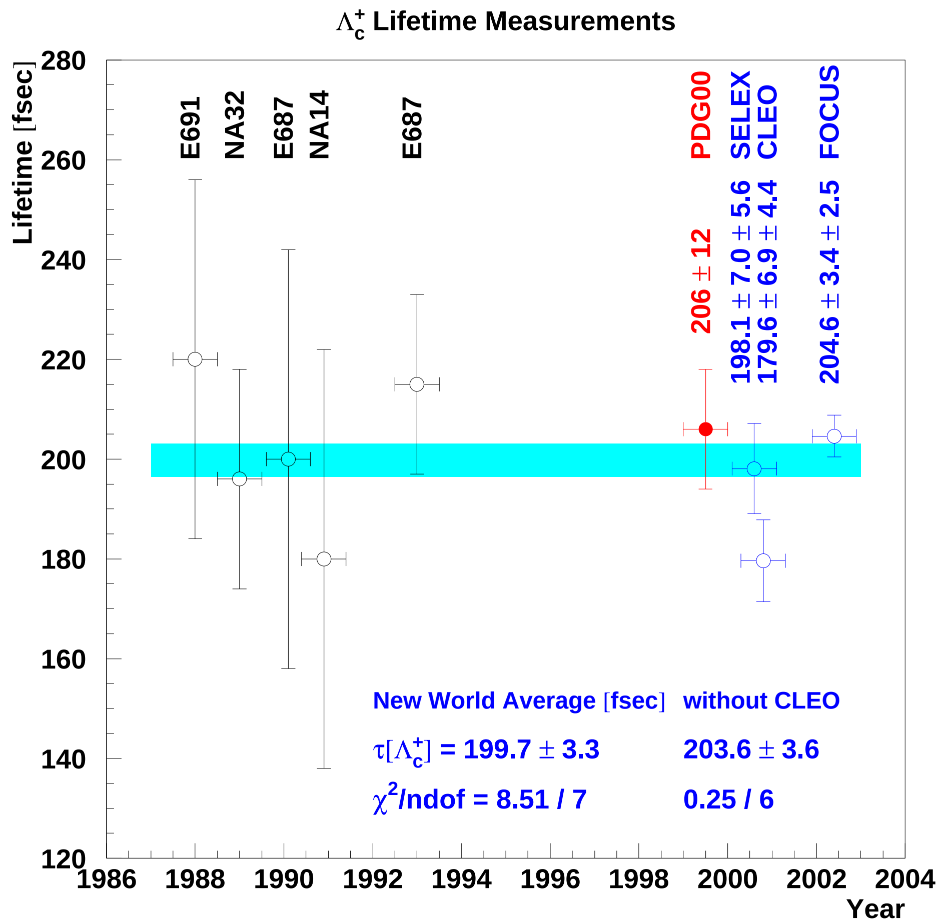
average now known to 1.5%

$\tau[\Lambda_c^+] = 199.7 \pm 3.3$ fsec

Consistency? CLEO's short lifetime technique differs with reduced proper lifetime technique of the Fixed target experiment

Somebody seems to have a problem

Belle is getting 1400 Λ_c^+'s / fb



New Ξ_c^+ Lifetime Measurements

2 new measurements ~400 fsec

E687 340±60±20 PRB 427,211(1998)

CLEO 439±22± 9 PLB 523,53(2001)

FOCUS 503±47±18 PRD 65,031102(2002)

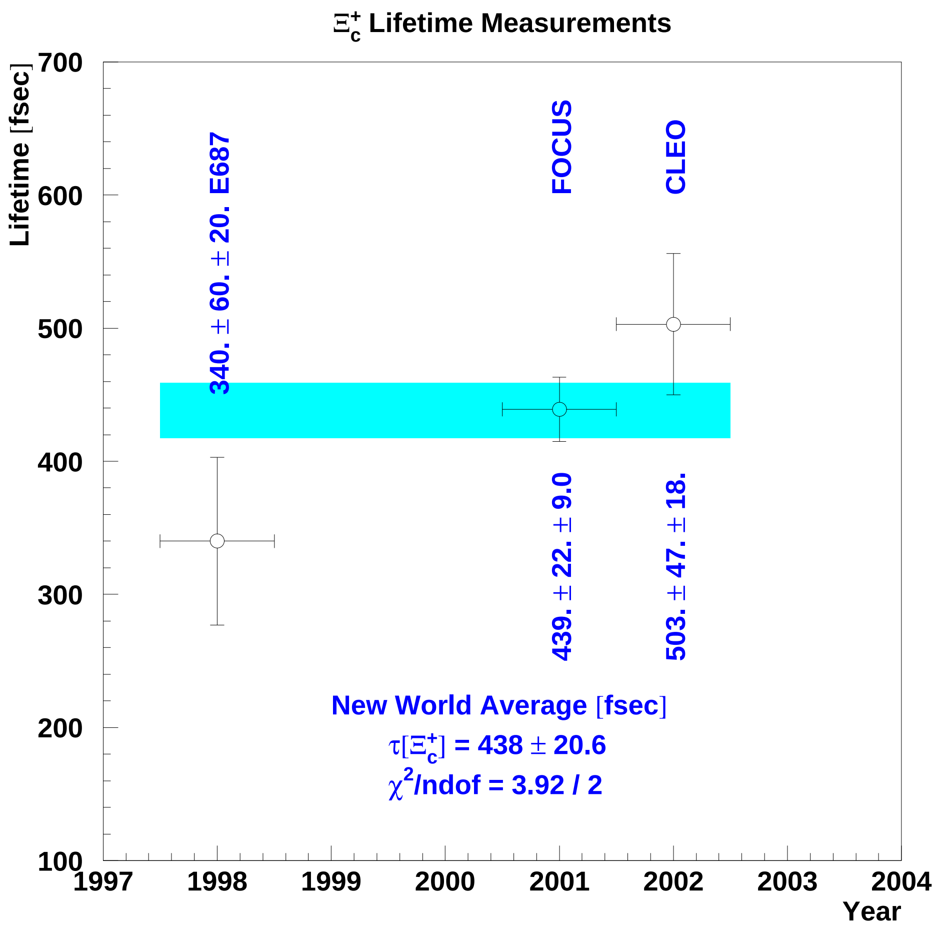
average now known to 5%

$\tau[\Xi_c^+]$ = 438±21 fsec

Consistency?? The more often we look the longer it lives?

CLEO higher than FOCUS here − but the two are consistent.

Belle Hasn't said anything yet



New Ξ_c^0 and Ω_c^0 Lifetime Measurements

- FOCUS will report two new preliminary measurement here:

Ξ_c^0	**118** ± 13 ± 5 **fsec**	**110** ± 17 events
Ω_c^0	79 ± 12 ± 8 fsec	64 ± 14 events

- Wait for talk from Erik Vaandering on Thursday

Future prospects for heavy baryon results

- E791, Focus and SELEX all continue to produce new results
- CDF / D0 at Fermilab are now collecting large new samples of both charm and beauty baryons.
- COMPASS at CERN has begun running.
- Belle is already reporting charmed baryon results (next slide)
- Babar will surely enter this game too.
- Cleo−c ? Their plans don’t mention baryons − but if I know them...

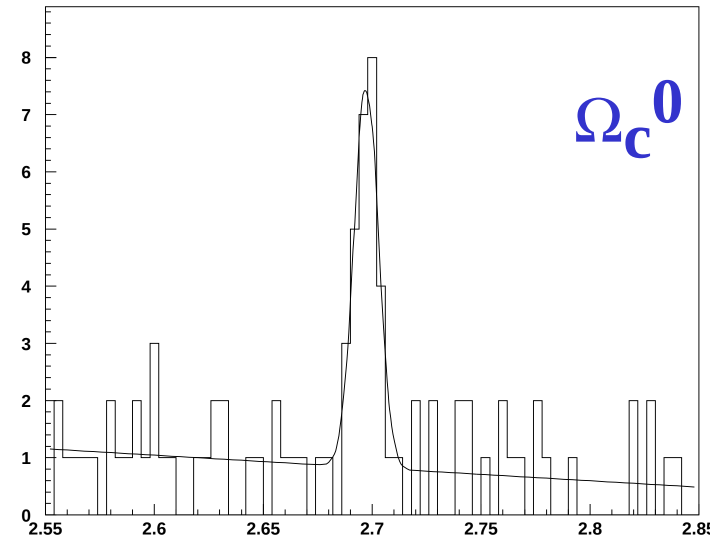
$\Omega_c^0 \to \Omega^- \pi^+$ Seen in Belle

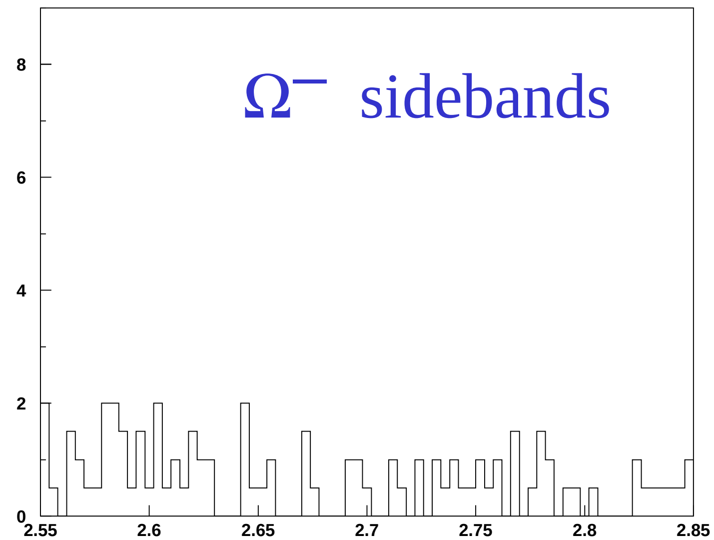
23.5 ± 5.4 clean events seen

2697.3 ± 1.5 MeV/c^2

σ = 5.7 MeV/c^2 [MC]

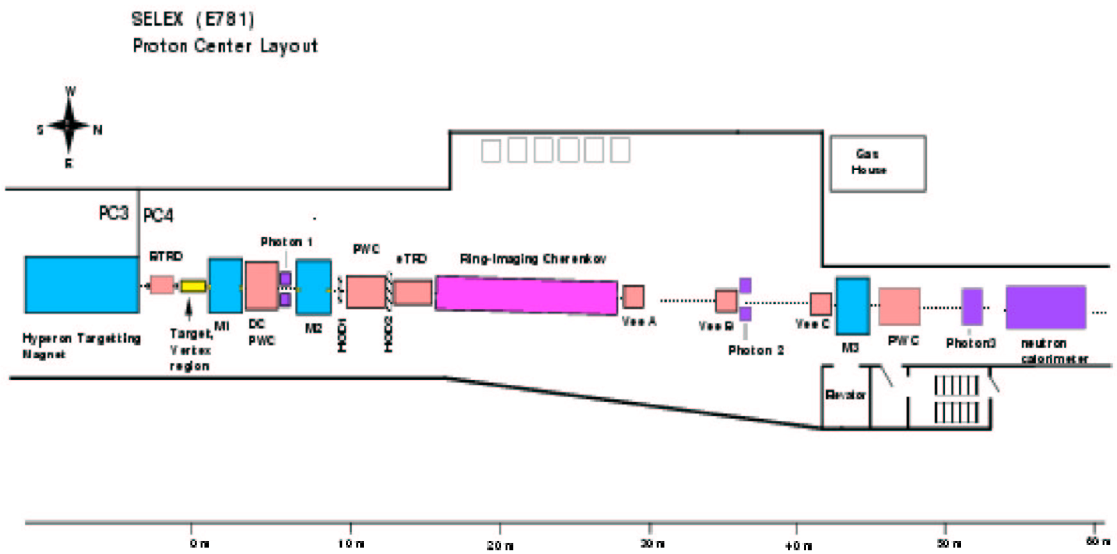
Belle conf−0136 S. Semenov
@EPS HEP 2001 Budapest

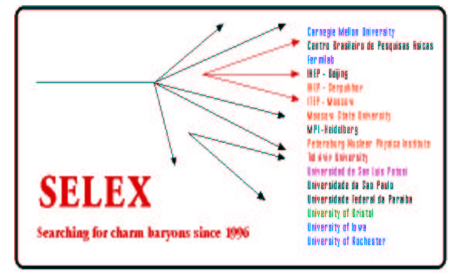


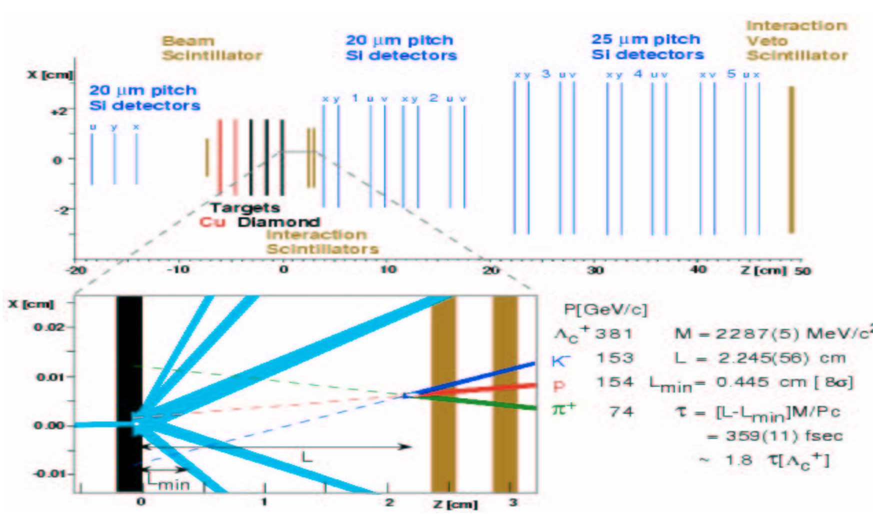


High Mass States in SELEX

Have Doubly−charmed Baryon Been Discovered?







SELEX Experiment

- Forward charm production $x_F > 0.1$
- π^- p and Σ^- beams @ 600 GeV
- Typical boost ~100
- RICH PID above 22 GeV
- 20 plane − 4 view svx − $\sigma > 4$ µm

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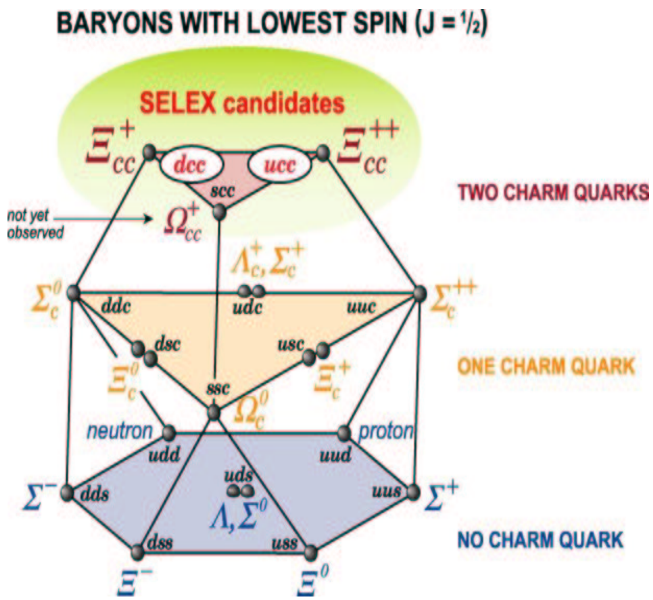
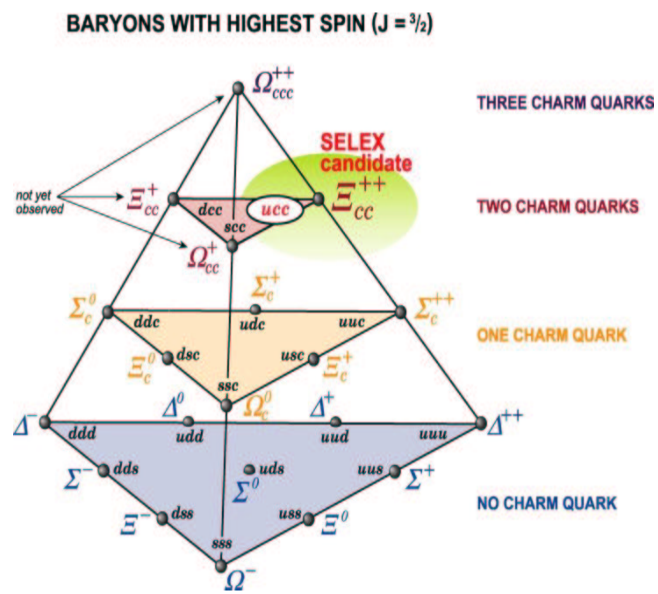
Some Nomenclature

In this talk we replace PDG names with suggestive labels

While SU_4 is badly broken by the charm mass it still classifies all the states

There are many model predictions in the 3.5−3.8 GeV range





$\Xi_{cc}^{++}(J=1/2)$ = ccu++

ccu++ $\rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$

$\Xi_{cc}^{++}(J=3/2)$ = ccu*++

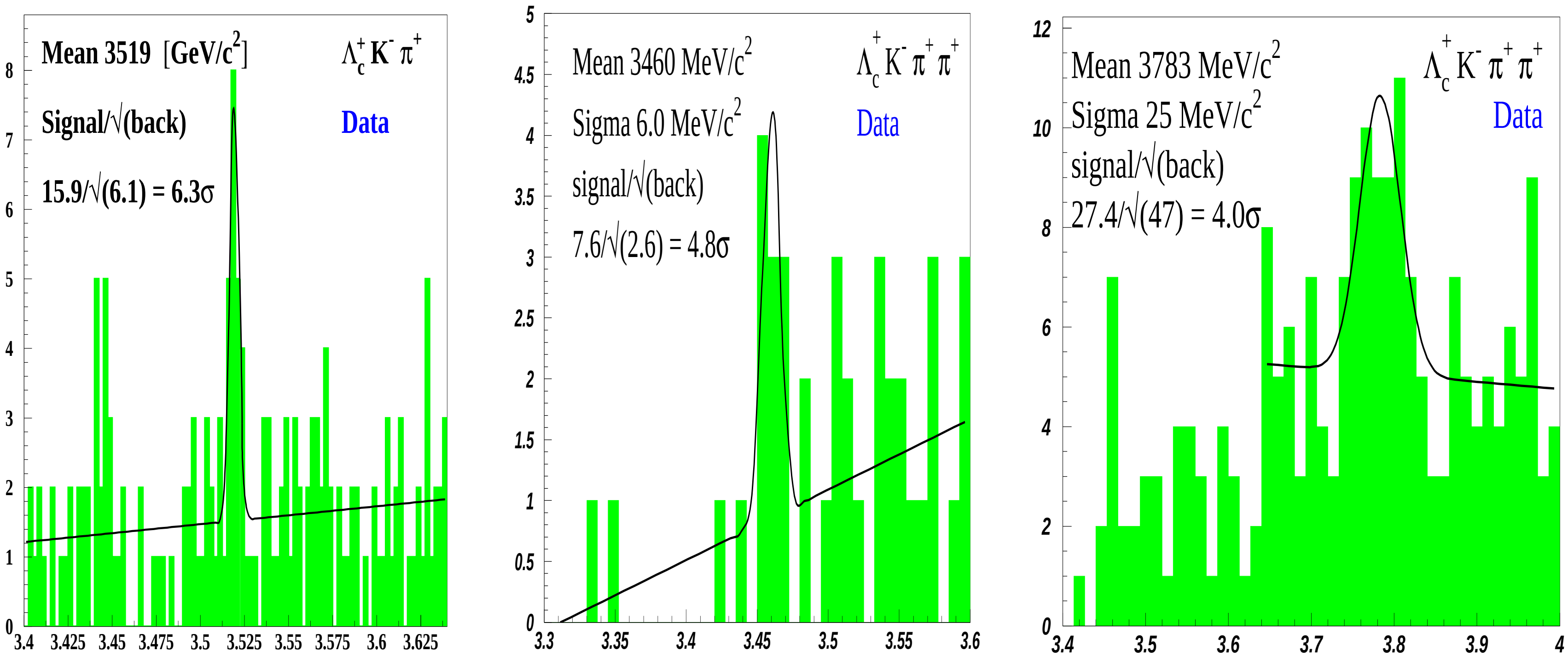
ccu*++ $\rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$

$\Xi_{cc}^{+}(J=1/2)$ = ccu+

ccd+ $\rightarrow \Lambda_c^+ K^- \pi^+$

Experimental Evidence today − a Preview

SELEX reports 3 significant high mass peaks



ccd+ ccu++ ccu*++

We will argue that these states are doubly−charmed baryons

Search Strategy

cc(u,d) $\rightarrow$ c quark, s quark and a baryon

SELEX's strength is charged tracking

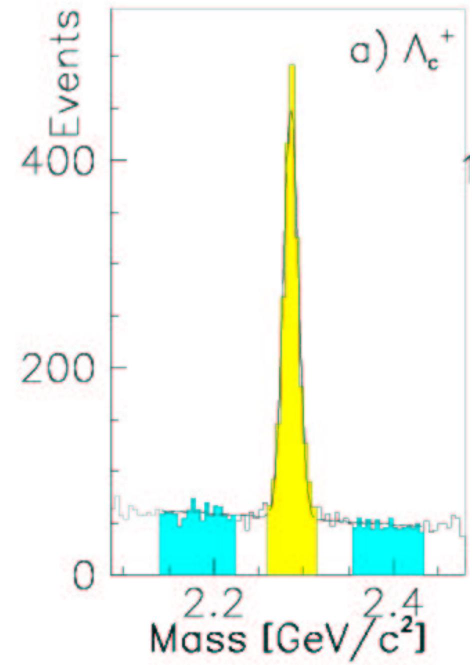
1st look for states like:

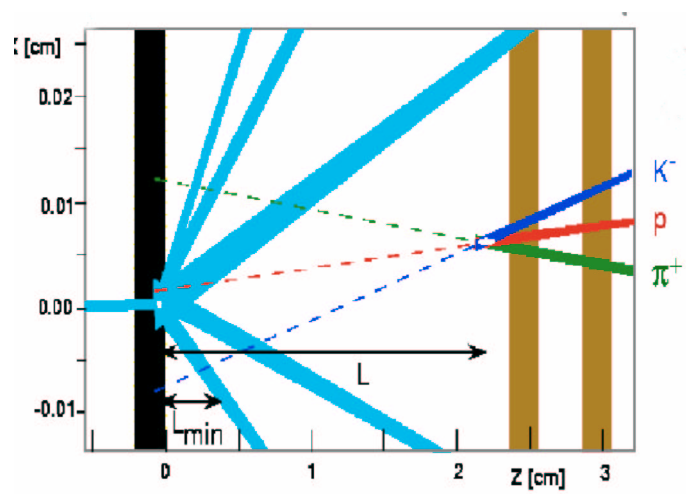
Ξ_{cc}^{+}**(ccd+)** $\rightarrow \Lambda_c^{+} K^{-}\pi^{+}$

Ξ_{cc}^{++}**(ccu++)** $\rightarrow \Lambda_c^{+} K^{-}\pi^{+}\pi^{+}$

with existing Λ_c^{+} 1630 sample −Selection Cuts:

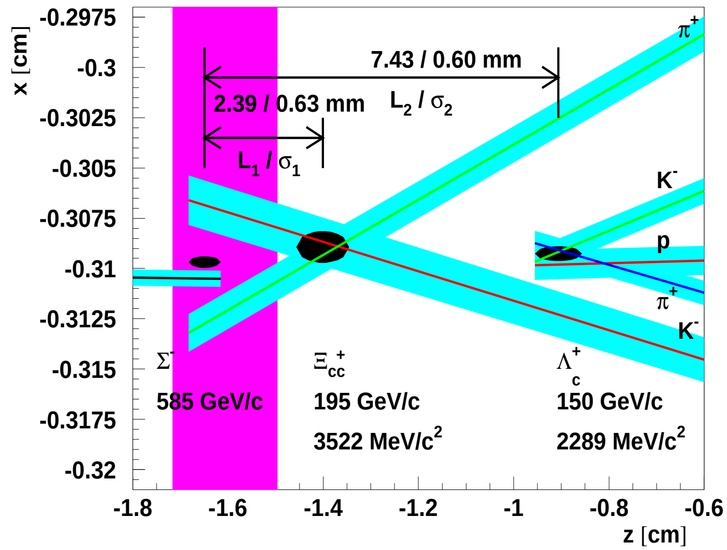
- Primary vertex contains beam track ~4 μm
- Secondary vertex outside of material
- Secondary vertex separtion significance $L/\sigma > 8$
- 2nd largest miss distance significance $> 2\sigma$
- Λ_c^{+} momentum points−back to primary
- RICH identified **p** and K^{-} in $\Lambda_c^{+} \rightarrow$ **p** $K^{-}\pi^{+}$





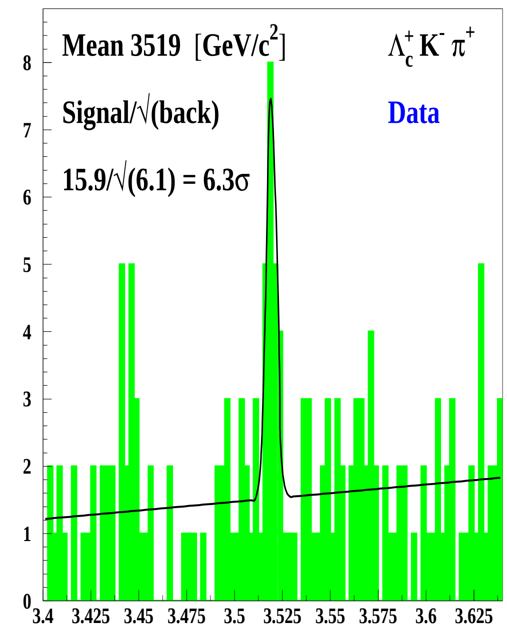
Find new secondary vertex:"old" cuts

- New secondary vertex significance $L / \sigma > 1$
- Point back ccd+ to primary $\chi^2 < 4$
- No RICH PID on $K^- \pi^+ (\pi^+)$ <15% in RICH



Preliminary results − ccd+ search

- Make $\Lambda_c^+ K^- \pi^+$ **mass plot using c**onstrained Λ_c^+ **mass**
- Gaussian + linear background fit confirms background shape is consistent with linear
- signal region 3520±5 MeV (22 events)
- background from 3520±120 MeV sidebands (140 events)
- 6.3σ excess at 3519 MeV. Possion probability 1×10^{-6} (with background uncertainty) Probability to see this ANYWHERE on the plot -1.1×10^{-4}
- Width (3±1MeV) consistent with resolution (~5 MeV)
- Lifetime is short (<~30 fsec)



This looks like a ccd+

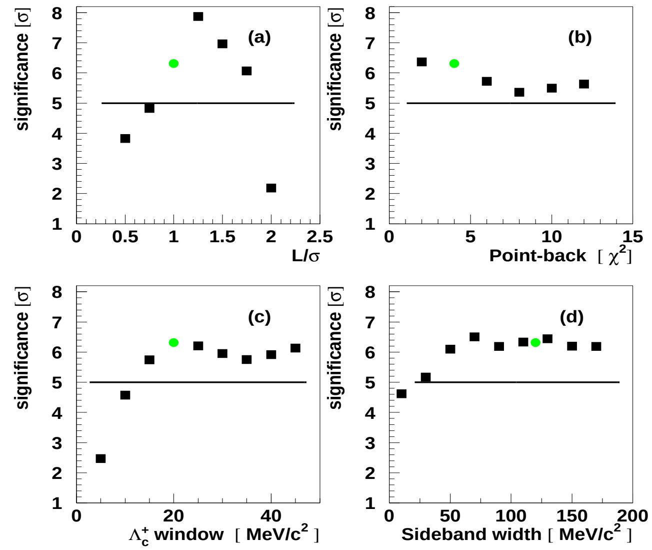
SKIP NEXT

ccd+ search details (skip)

- Stability of signal significance vs cuts

  (cuts used are green circles)

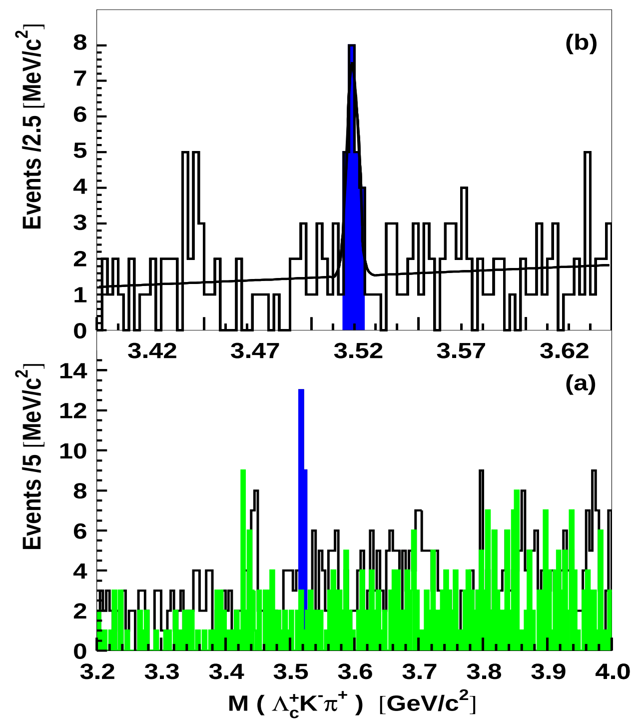
  - a) ccd+ vertex significance L/s
  - b) ccd+ point−back χ^2
  - c) Λ_c^+ mass window
  - d) ccd+ mass width of sidebands



- ccd+ mass plots
  - a) most of mass window searched (3.2−4.3 GeV/c^2)

    Wrong sign combination ($\Lambda_c^+ K^+ \pi^-$)

    Note that feature around 3.45 shows in wrong sign too.
  - b) explicit signal (blue) and sideband (clear) regions



Preliminary results − ccu++ search

Is there a ccu++ partner to the ccd+ candidate?

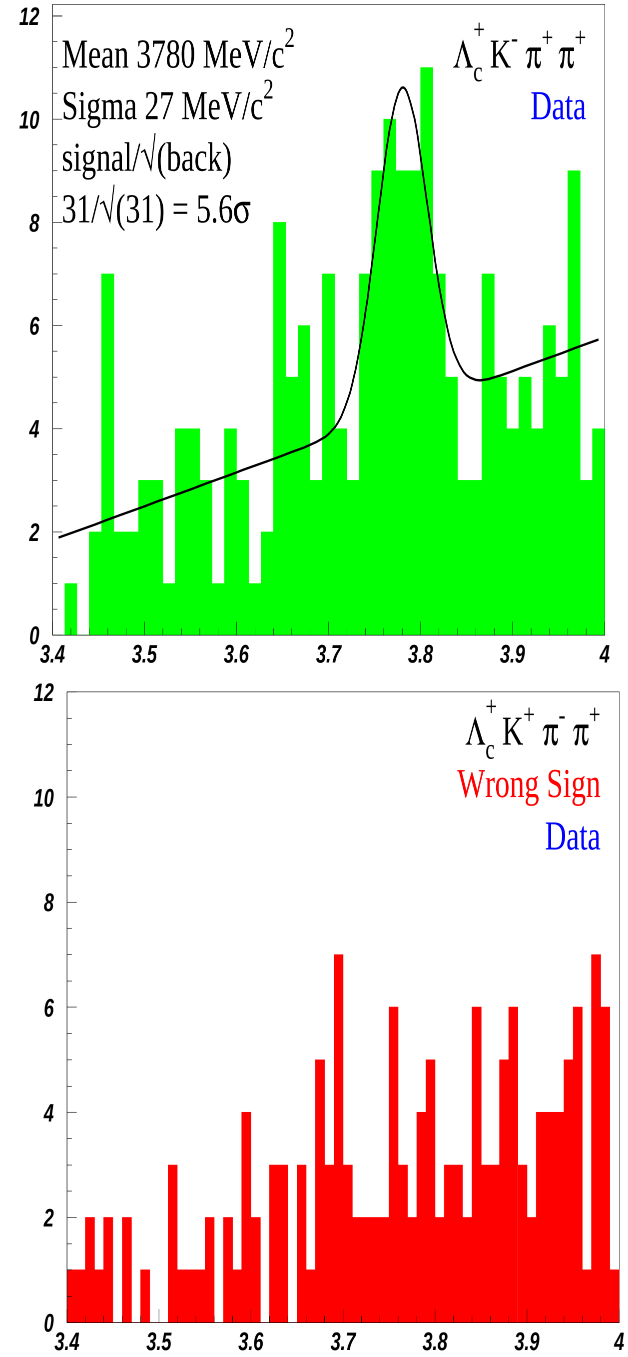
- Same cuts as ccd+ + σ(ccu++ vx) < 1mm (was 2 mm)
- Make $\Lambda_c^+ K^- \pi^+ \pi^+$ mass plot using constrained Λ_c^+ mass
- Large, broad 5.6σ significant excess at 3780 MeV
- Width is 27 MeV
- Simulated resolution is 9 MeV − 1/3 of observed

No significant structures in wrong sign mass combination (recall no RICH PID, just mass assignments)

=> Right sign ccu++ candidate is NOT a random combination of primary vertex tracks.

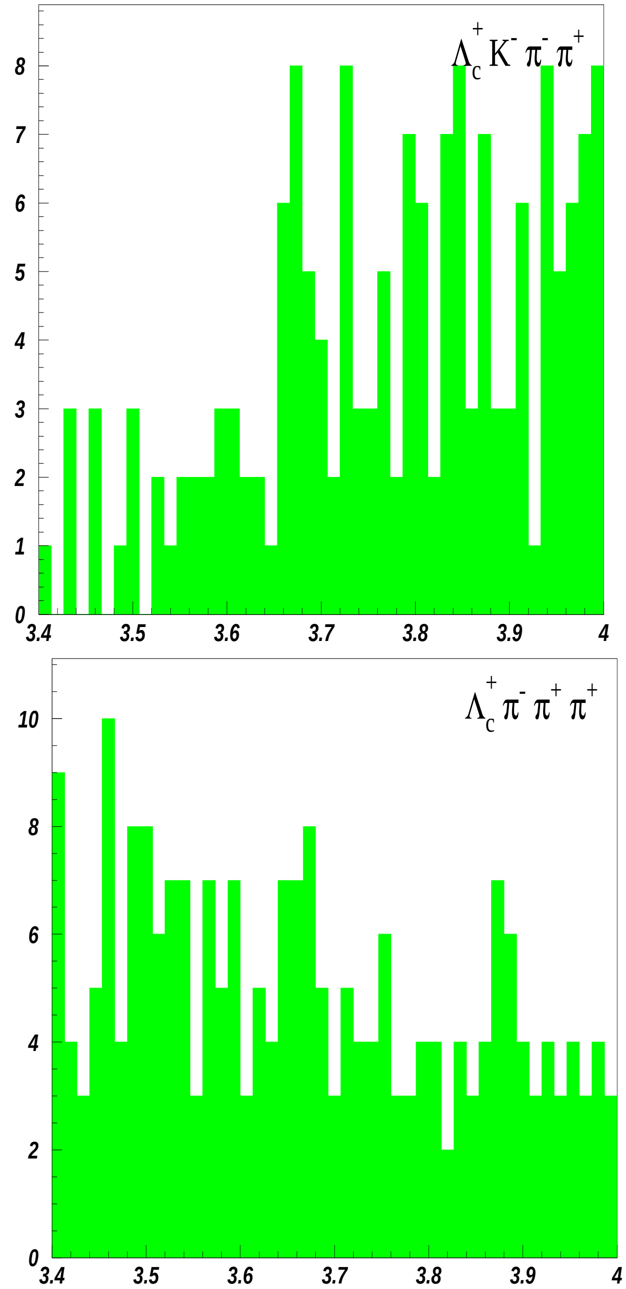
Is this an excited state?

SKIP NEXT



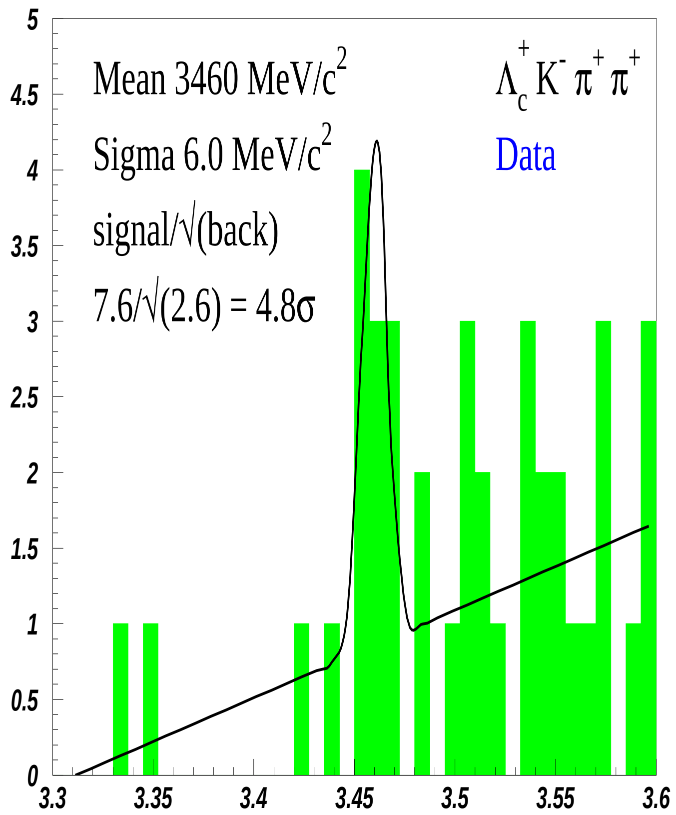
ccu++ search details (skip)

- All wrong sign signals searched
  - Nothing in $\Lambda_c^+ K^- \pi^- \pi^+$
  - Nothing in $\Lambda_c^+ \pi^- \pi^+ \pi^-$
  - Nothing in $\Lambda_c^+ K^- \pi^- \pi^+$ (previous slide)
  - Nothing in any permutation pKπ except the signal channel
- Not a reconstruction artifact



Is there a narrow ccu++ partner to the ccd+ candidate in the data?

- The ccd+(3520) should have an iso−doublet partner.
- Look in the ccu++ mass plot with finer bin size (5 MeV).
- Narrow 4.8σ significant excess at 3460 MeV
- Width is 6.0 MeV
- On the edge of acceptance − only 2 events below 3400 MeV
- Simulated acceptance ratio
  ε[ccu++(3460)] / ε[ccd+(3520)] ~ 1/2



We have a 3rd high mass peak with double−charm characteristics

Are the ccu*++ and ccd+ related?

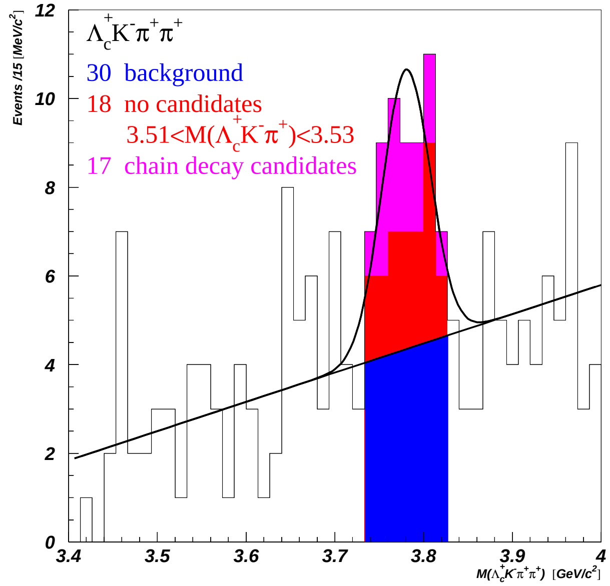
The ccu*++ decay is complicated

- The blue region is the background on the ccu*++ plot
- Half of the remainder are chain decay candidates for

$$\text{ccu*++} \rightarrow \textbf{ccd+} \;\; \pi^+$$

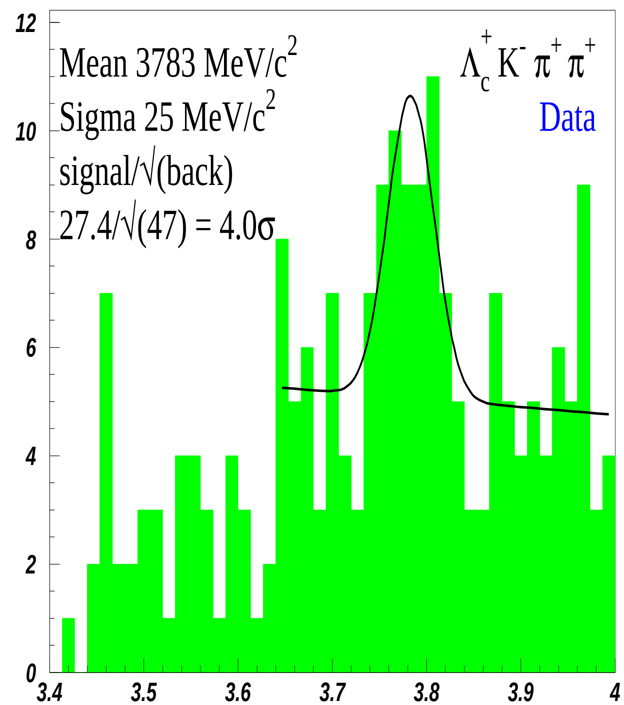
Candidates have a $\Lambda_c^+ K^- \pi^+$ combination in 3520±10 MeV

- The other half have NO such candidate − direct decays
- There appear to be two decay modes of the ccu*++



The ccu*++ background is complicated

- The structure at 3660 MeV (=3520+140) are from the combinatoric background of a real ccd+ with a vertex π^+
- Simulation reproduces this effect
- We fit from 3650 to account for this effect
- The remaining significance is reduced from 5.6σ to 4.0σ



This is the structure we found first!

What about Production?

Which beam hadrons?	Σ^-	π^-	proton	π^+	which target?	diamond	copper
Luminosity fraction	0.76	0.13	0.18	0.01	All Λ_c^+ events	0.68	0.32
ccu++(3460) signal	9	0	0	0			
ccu++(3460) sideband	9	0	0	0			
ccu*++(3780) signal	43	12	1	0			
ccu*++(3780) sideband	30	10	3	0			
ccd+(3520) signal	18	0	4	0		18	4
ccd+(3520) sideband	110	7	4	2		93	47

Dominantly produced by baryon beam

for ccd+ $<x_F>$ ~0.35 (200GeV), $<p_t>$ ~1 GeV/c − like single charm SELEX

Focus has looked in 250 GeV/c photo−production

They see few entries with 20K Λ_c^+

Erik Vaandering and Sergio Ratti will say more in their talks.

Belle observes $\sigma(e^+e^- \to \psi ccX) / \sigma(e^+e^- \to \psi ccX) = 0.60$ hep−ex−0205104

Hybrid emulsion expts have seen large 4 charm /2 charm ratios (~1%)

Can these be double−charmed baryons?

Λ_c^+ Economics What fraction of Λ_c^+ events are associated with these states?

The short answer − **about half**

- We see ~16 ccd+(3520) and ~7 ccu+(3460) from 1630 Λ_c^+
- The detection efficiencies are ccd+(3520) ~10% and ccu(3460)~5% if Λ_c^+ is found => 300 Λ_c^+
- branching ratios $[K^0\pi^0]/[K^-\pi^+]$ ~1/2 − + modes with extra −π's 2X => 600 Λ_c^+
- **ccq** states require 600/1630 = ~40% of the Λ_c^+ events
- ccu*++(3780) non−chain decays increase this by ~50%

The observed signals do not violate Λ_c^+ conservation

Why is the rate so high?

- Recall that the charmed baryons were discovered in a forward hyperon beam in 1984 (WA62 at CERN). There have been anomalous production cross−sections since the beginning.
- Belle see amazing yields for double−charm/single−charm
- Fundamentally − we're experimentalists − the cross−section isn't in our job description.

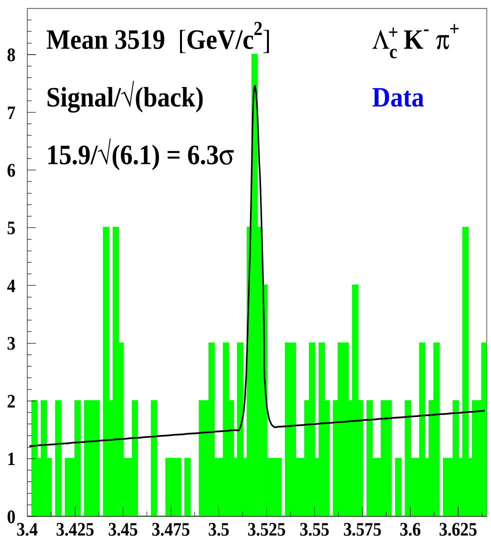
Is 60 MeV a reasonable isospin splitting? No! We're guessing state assignments.

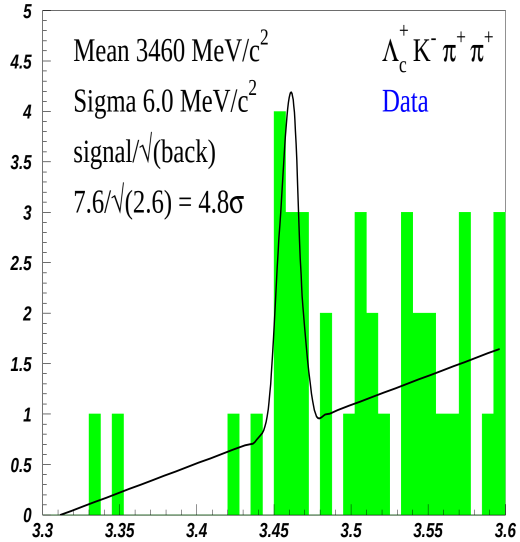
We observe statistically compelling signals − they are **something**.

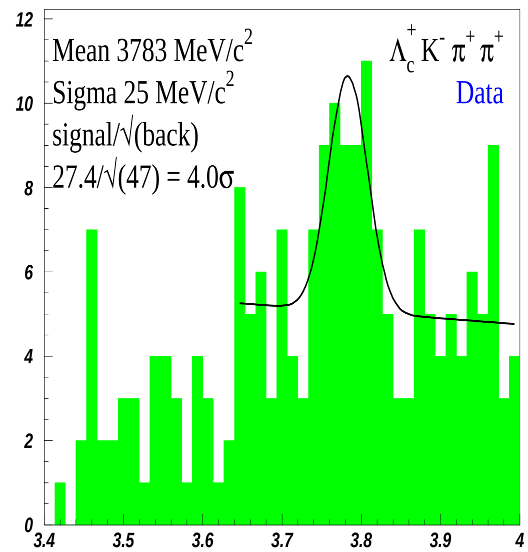
They look like double−charmed baryons.

SUMMARY

SELEX reports 3 candidates for doubly−charmed baryons







- Statistically compelling
- Decays like a DCB
- In the expected mass range
- Very short lifetime (<30 fs)

=> Looks like a DCB

- Statistically strong (with $\cos\theta^*_{K-}$ cut −> 7σ)
- Decays like a DCB
- mass is some what low
- Very short lifetime (<30 fs)
- Large isospin splitting?

- Statistically marginal but chain decays to ccd+
- Decay is confusing
- mass well above other states
- wide − strong decay
- Doesn’t fit in neatly

But something is there