NEW HORIZONS FOR CHARM BARYON SPECTROSCOPY

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Outline

Charm and Double Charm Baryons

4 SELEX ccd and ccu States near 3.5 GeV

Isotropic versus Anisotropic Decay

Excited ccu near 3.78 GeV

Summary Picture

Charm Baryon Systems

Adding charm quark in QCD baryon spectroscopy extends SU(3) to SU(4) structure

Structure predictions augmented by HQET simplifications – agree with experiment for single charm baryons

lowest order Λ_c^+ excitation from spin-spin interaction, e. g., $\Sigma_c(2520)$ [$J^P = 3/2^+$] and $\Sigma_c(2455)$ [$J^P = 1/2^+$] doublet with HQET-breaking

P-wave excitation doublets observed in Λ_c^+ system at 2593, 2625 MeV/c^2 .

Heavy Meson/Baryon Parallels

Heavy Quark Effective Theory separates Heavy and Light degrees of freedom

Mesons (Q (qbar))

- heavy-quark spin degeneracy
- flavor-independent light quark features

Baryons (Q(qq))

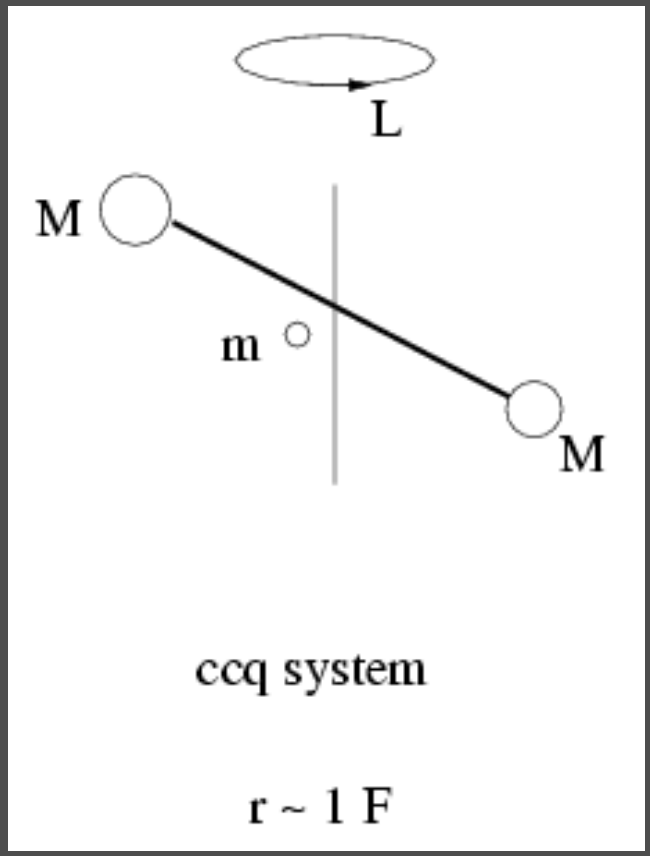
- heavy-quark spin degeneracy
- flavor-independent light di-quark features

Now Double Charm

Same SU(4) Multiplet as Single Charm

Now QQ is the di-quark because of symmetry

Additional symmetries in QQ system add degeneracies at HQET level

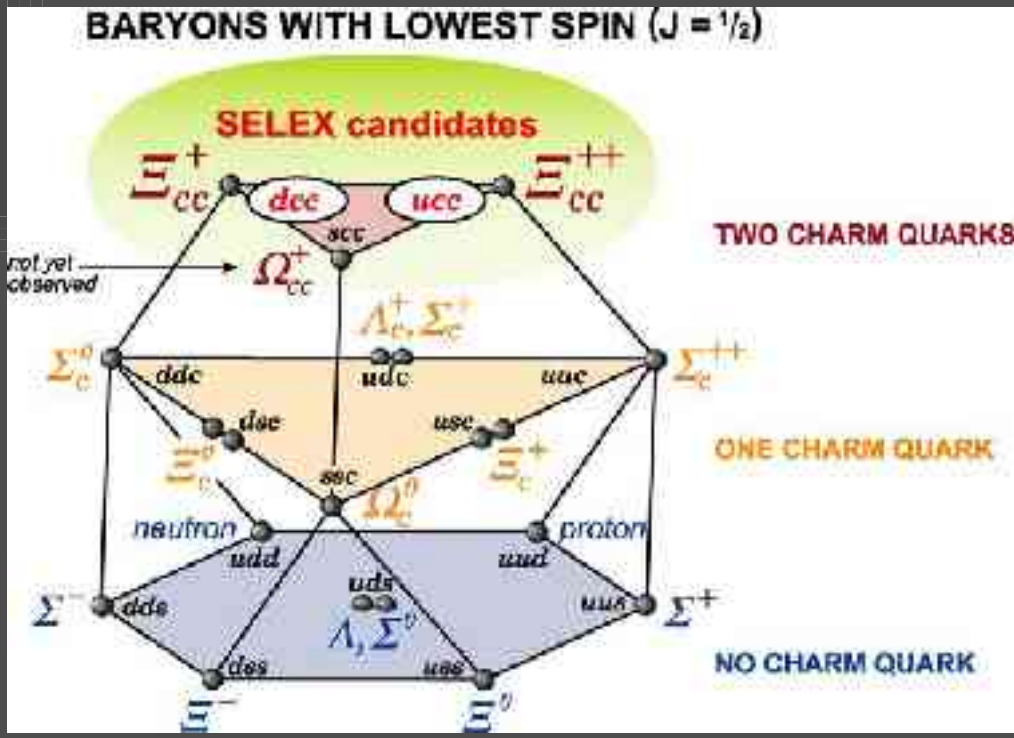


Double Charm Baryons in SU(4)

QCD: isodoublet of (ccq) baryons

Potential Models Ground State ~3.5 –3.6 GeV/c^2

Lattice concurs:
Flynn, et al., hep-lat/0307025



SELEX ccd First Observation

Phys. Rev. Lett. 89 (2002) 112001

ccd candidate at 3520

3 independent analyses find same signal.

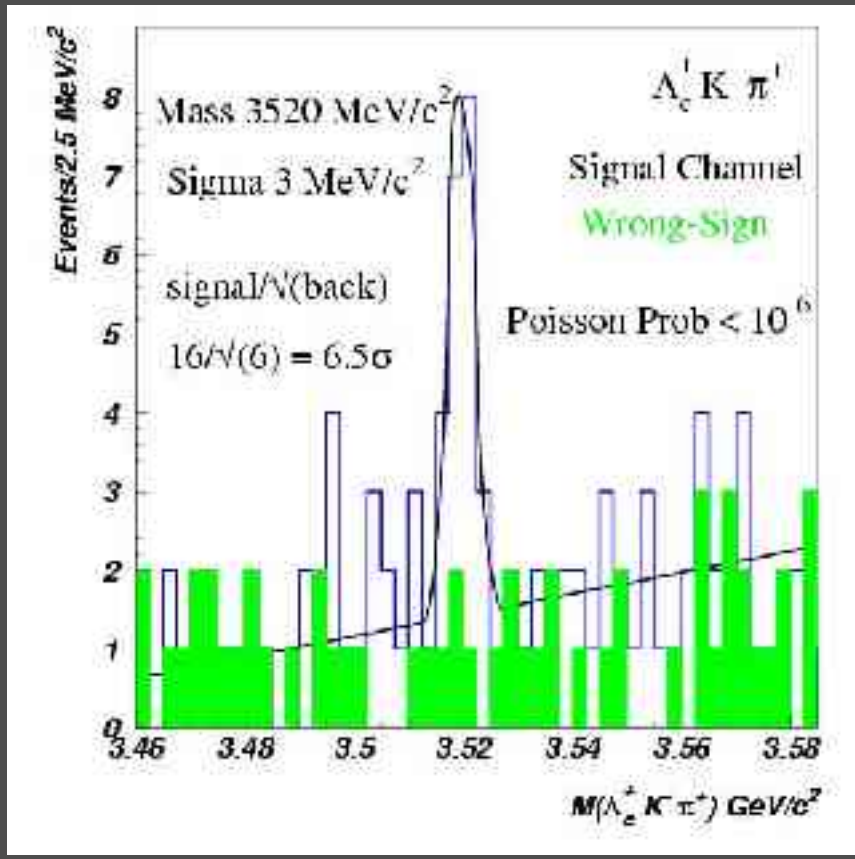
Reconstruction plus tracks:

$\Lambda_c^+ + K^- + \pi^+$.

Reconstruction plus recon

$\Lambda_c^+ + (K^- \pi^+)$

Candidate driven: $(\Lambda_c^+ K^- \pi^+)$.



Wrong-sign combination with K^+ shows no peak.

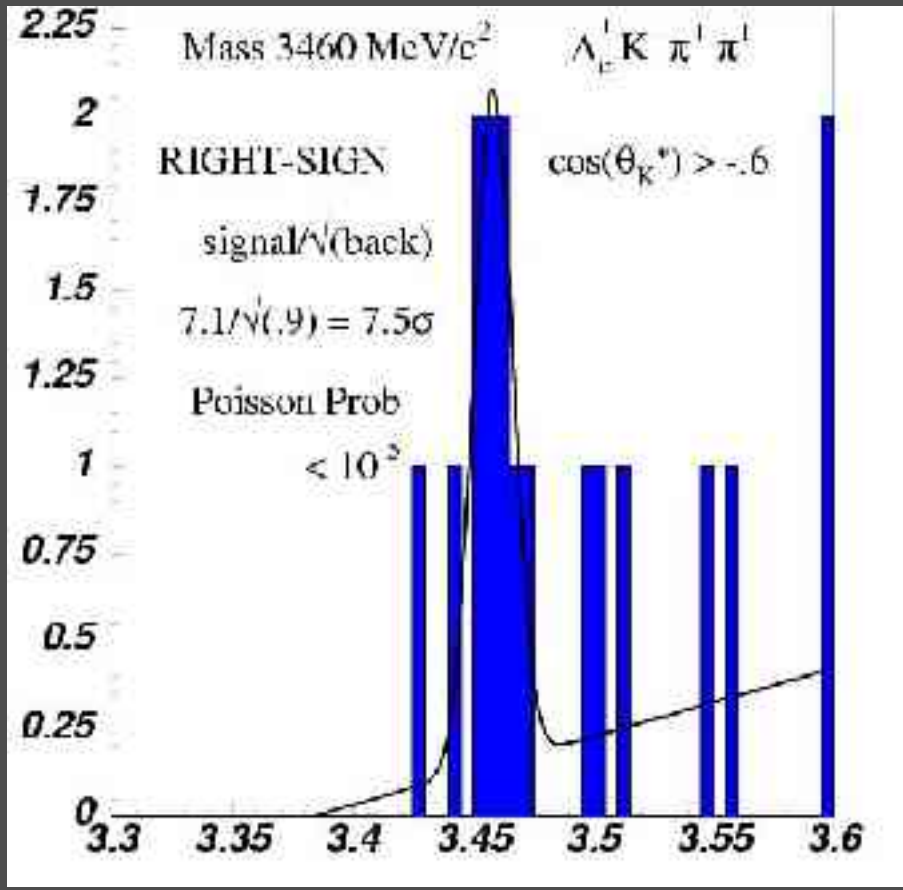
Not accidental match.

Search for Partner ccu State

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

Cut away accidental slow-pion background at backward angles

Assume isotropic decay. Use phase space MC to optimize S/B



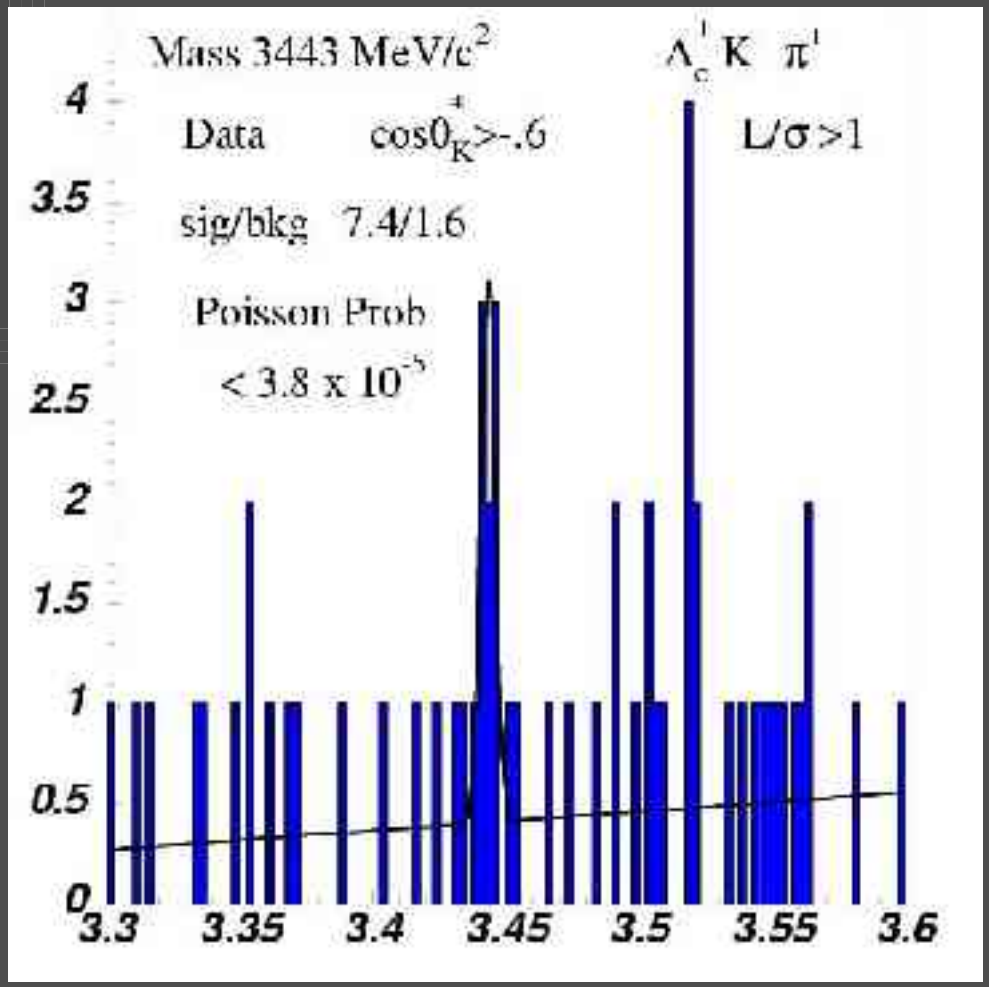
There is a peak. Is it a partner?

New ccd Candidate

Apply Isotropy cut to ccd mass distribution:

- Attenuates 3520 peak
- Enhances lower-mass peak; exceeds 5σ limit

New ccd(3443) state as partner to ccu(3460) has same angular character.

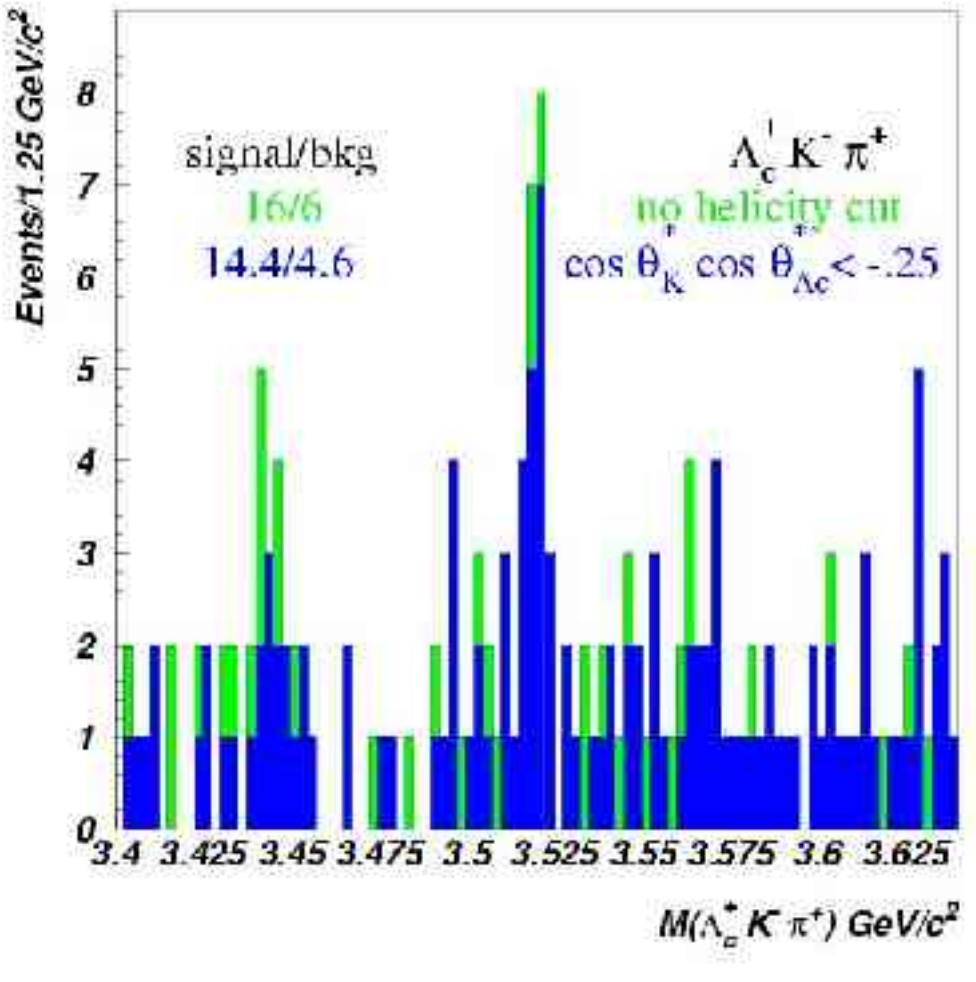


What About 3520 State?

90% of events survive front-back helicity cut

Comparison to isotropic MC says decay is NOT like ground state

ccd(3520) decay appears to show L > 0

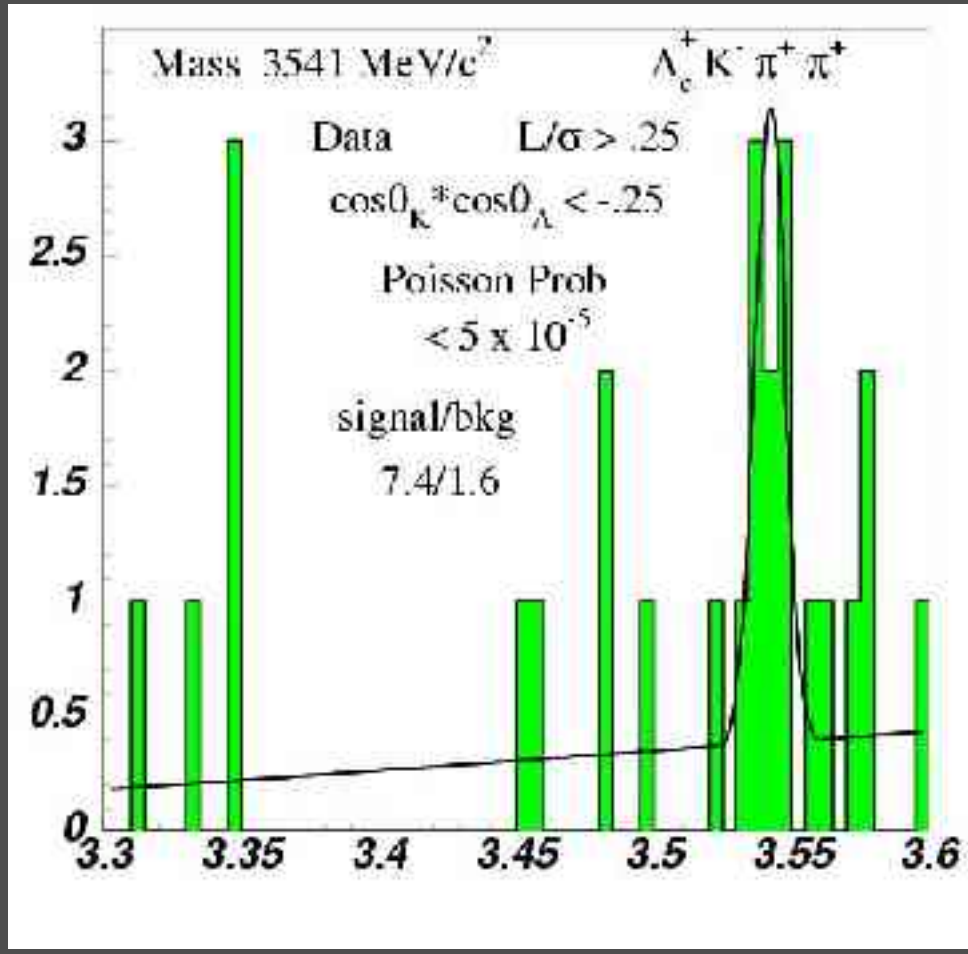


Q=2 Partner to ccd(3520)?

Found Q=2 Ground State by requiring Isotropy

Make Helicity Selection in Q=2 data that matches 3520 behavior

Find new Q=2 state! ccu (3541) decays with front-back distribution (L>0?)



A Review

Original ccd(3520) candidate found without considering decay helicity

Search for Q=2 partner showed sideband background peaked at $\cos(\theta_K^*)$ near –1 … like accidental events

Isotropic decay MC: signal should not preferentially decay backward

Excluding backward kaon helicity events exposes candidate for Q=2 ccu(3460); the SAME cut in Q=1 $\Rightarrow$ new ccd(3443)

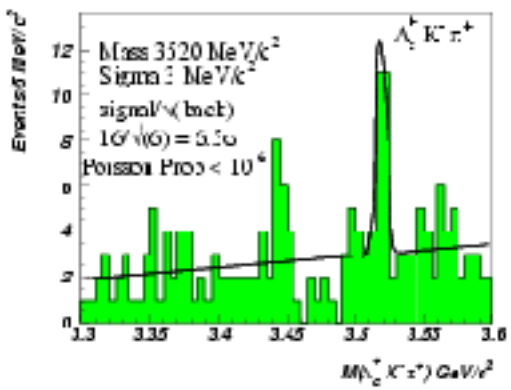
Review, continued

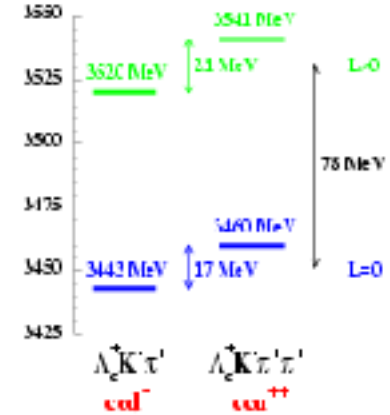
Returned to original ccd(3520) state, which was manifestly NOT isotropic: discovered it has strong front-back helicity distribution

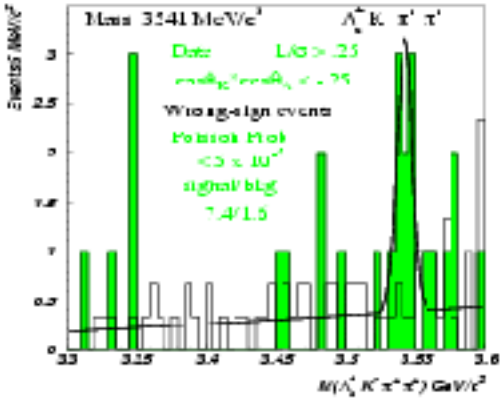
Applied SAME front-back cut to Q=2 data $\Rightarrow$ new ccu (3540) state

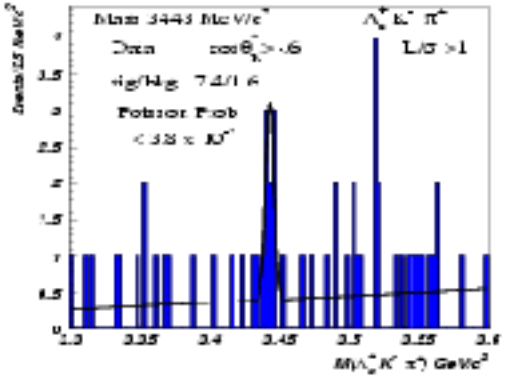
Total of 4 candidates
- small signals and small backgrounds
- mass splits same for Q=1, Q=2
- Q=2 state heavier than Q=1

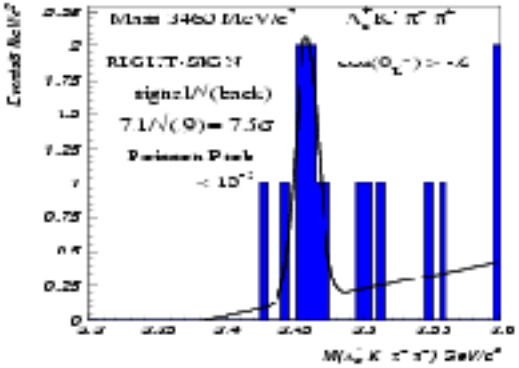
A reprise











SELEX Double Charm

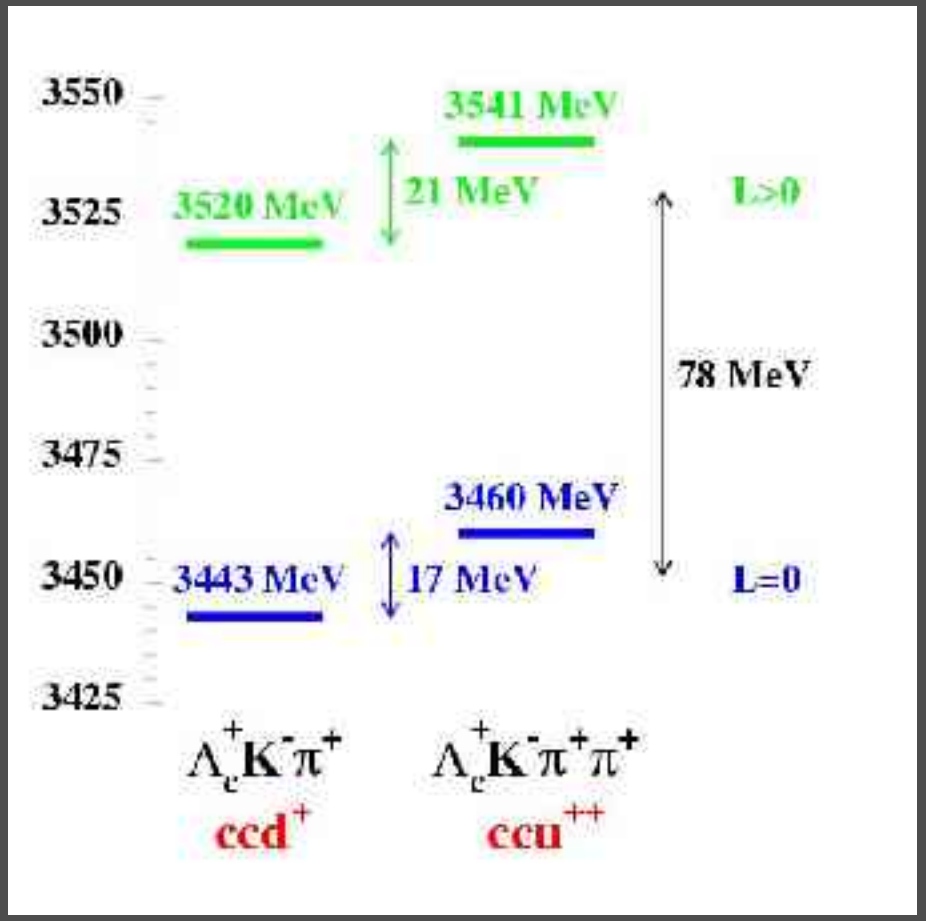
Wine and Cheese 8/13/08 24

What Does This Mean?

All 4 states decay weakly!

Different L means level split is NOT chromomagnetic

Photon coupling highly suppressed



ccq properties and issues

Weak decay of excited states instead of EM transition

Very large production – inconsistent with coalescence models

Lifetimes < 33 fs.
Expected 100-1000 fs

Not seen in Photoproduction

Might these states *not* be double charmed baryons?

Q=2 System is exotic:

C = +1
B = +1
S = -1

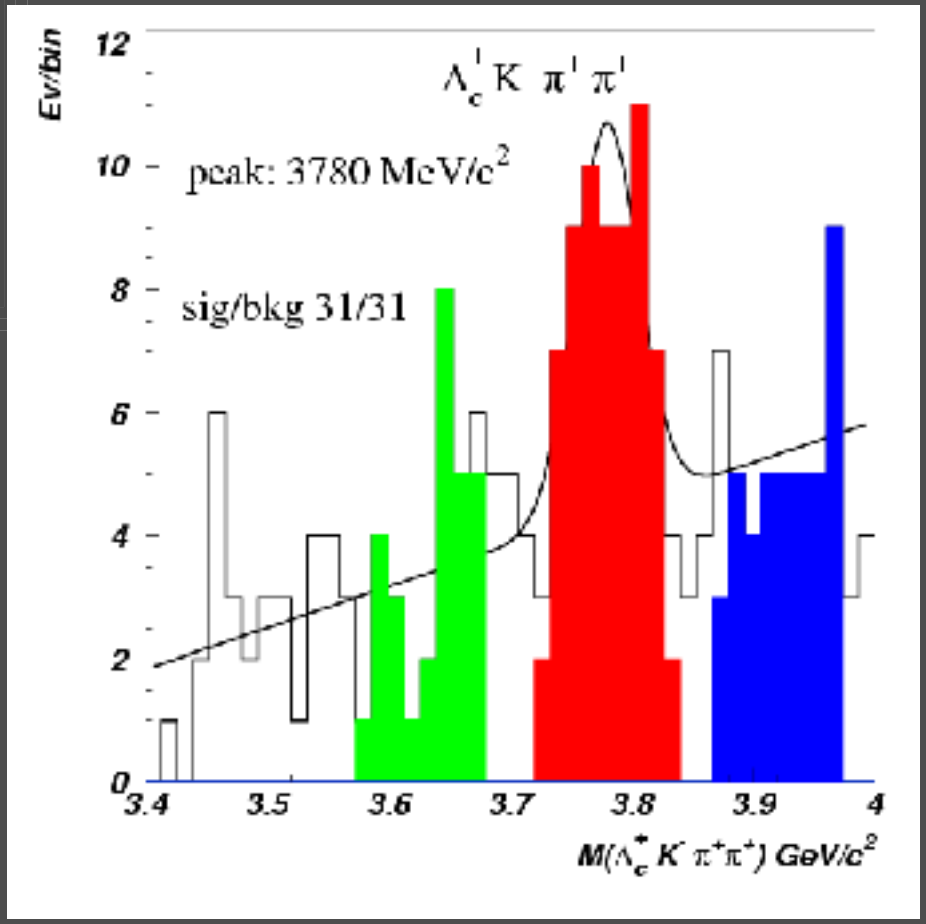
(c s u u dbar)

They are something!

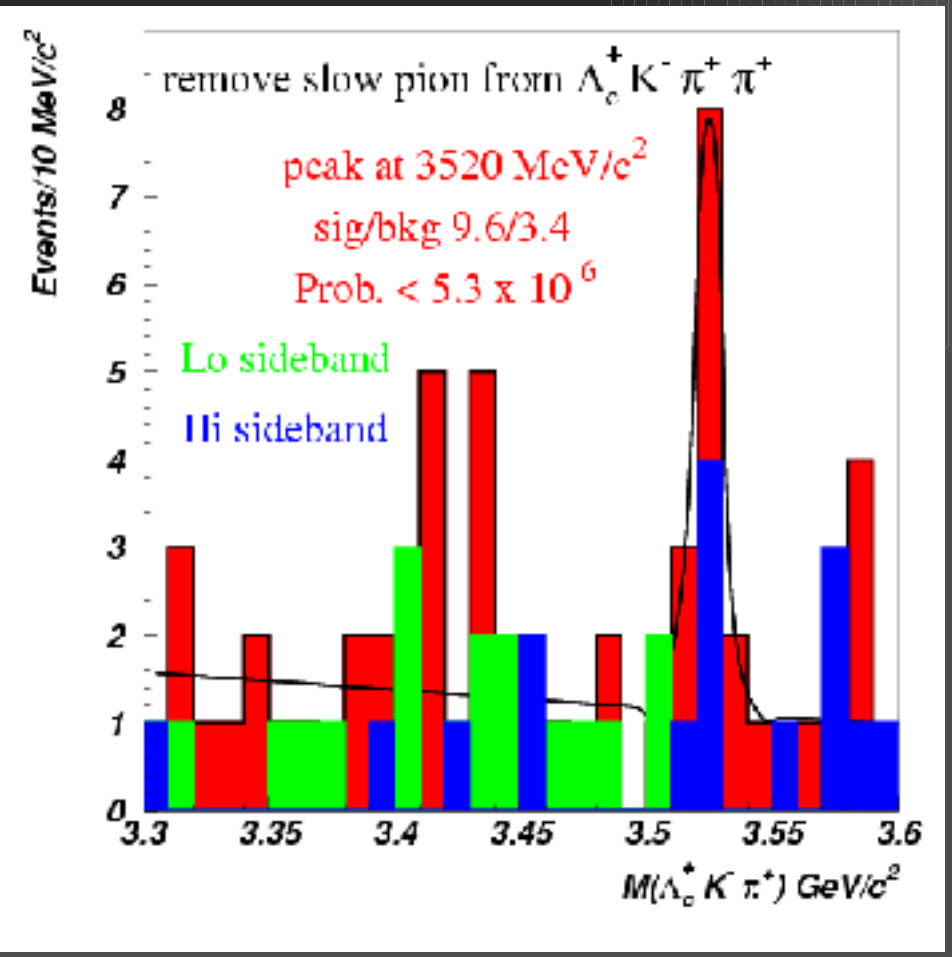
Excited State of Double Charm

SELEX has a broad Q=2 excitation 320 MeV above the ccu(3460)

Similar to the p-wave Λ_c^+ doublet at 325 MeV above the ground state



Pionic Transition to ccd(3520)

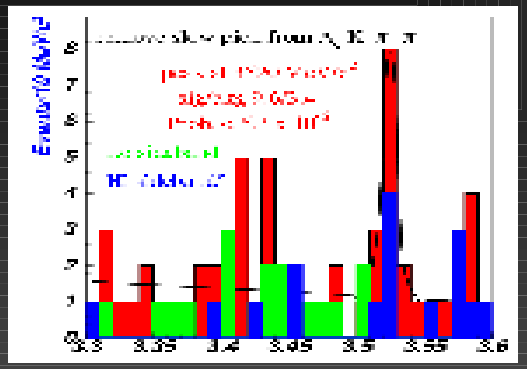


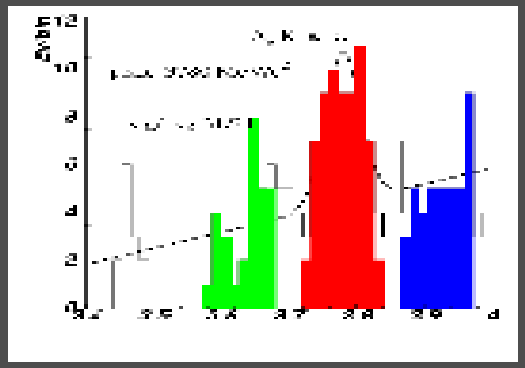
Remove slow pion from ccu (3780). Plot Q=1 mass spectrum

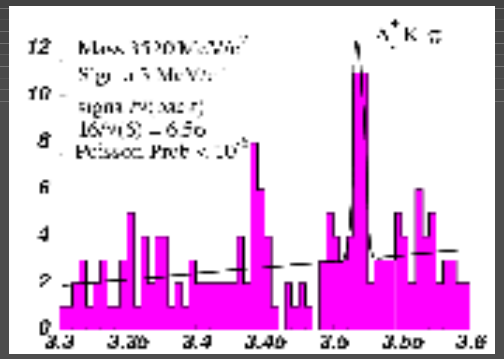
Helicity distribution of slow pion in ccu(3780) rest frame suggests p-wave decay

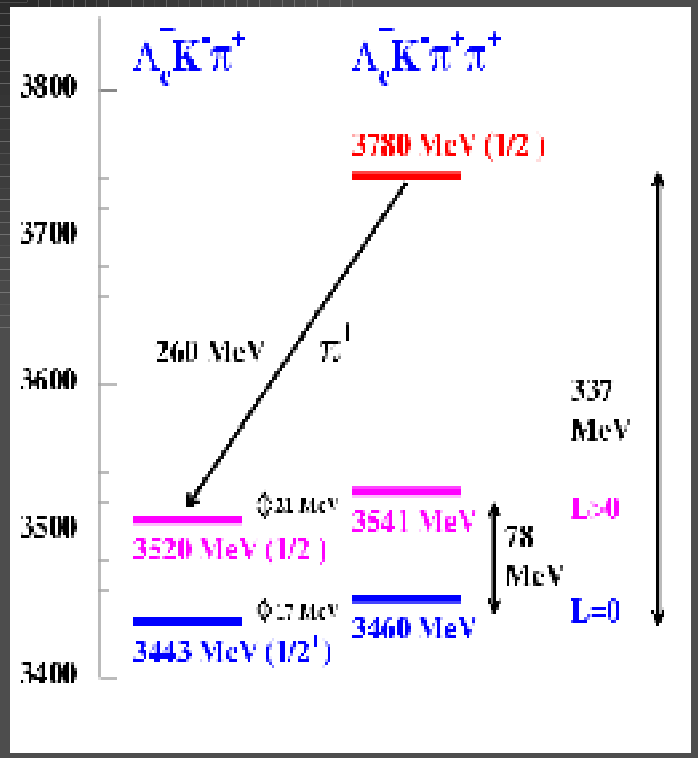
Consistent with HQET picture and double charm interpretation

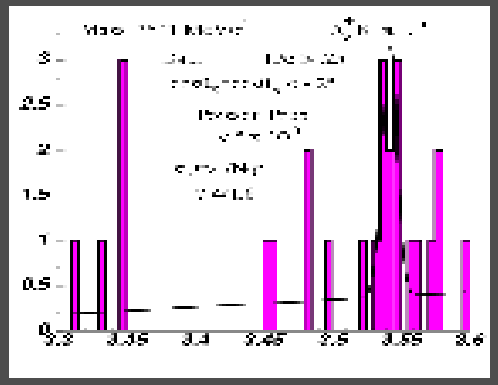
A possible picture

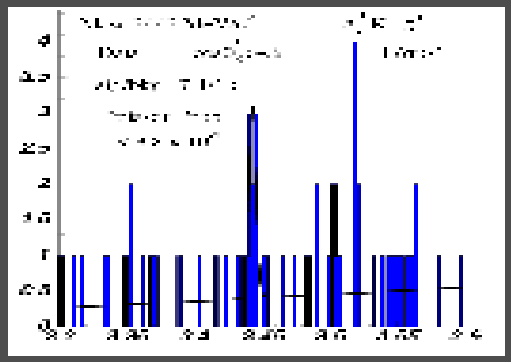


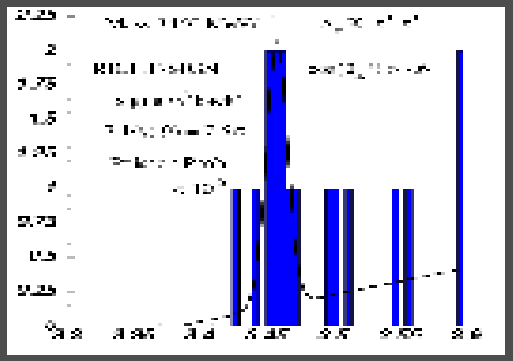












Possible Quantum Numbers

Double Charm Summary

The Selex picture – if really double charm - shows a striking spectroscopy

Model of Bardeen, Eichten, and Hill matches many (but not all) characteristics of these 5 states

SELEX analysis in progress for other decay modes: ccd(D0 K- p), etc.

Confirmation (or refutation) in other hadron experiments crucial to progress in understanding. Planning progress for high statistics ccq at CERN COMPASS.