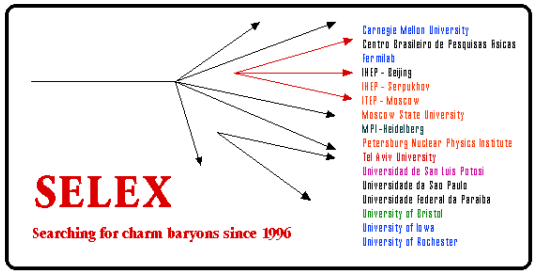
First Observation of a Doubly-charmed Baryon Family



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Outline

- (very!)Brief Theory Review
- Results from Previous Experiments
- Observation of High Mass Baryons
- Are These States Double-Charm Baryons?

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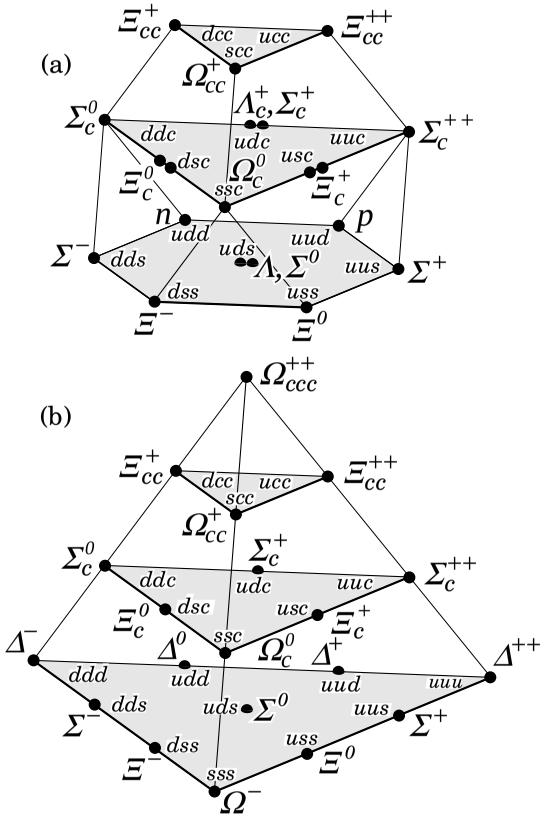
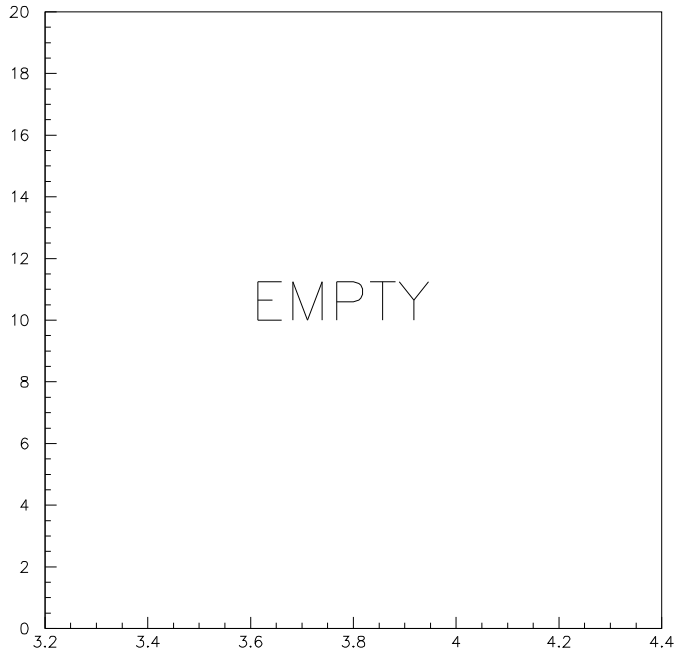
Flavor-Independent QCD Demands Double-Charm Baryons



SU(4) Baryon Multiplets

- Broken SU(4) provides accurate classification of baryon states involving quarks up to charm.
- All predicted states with $N_{ch} \leq 1$ observed.
- Double- and Triple-Charm Baryons *must* exist.
- General agreement among different models:
  - ground state mass ~3500-3700 MeV/c^2
  - J=3/2, 1/2 split ~60-120 MeV/c^2
  - Model-dependent orbital, radial excitations

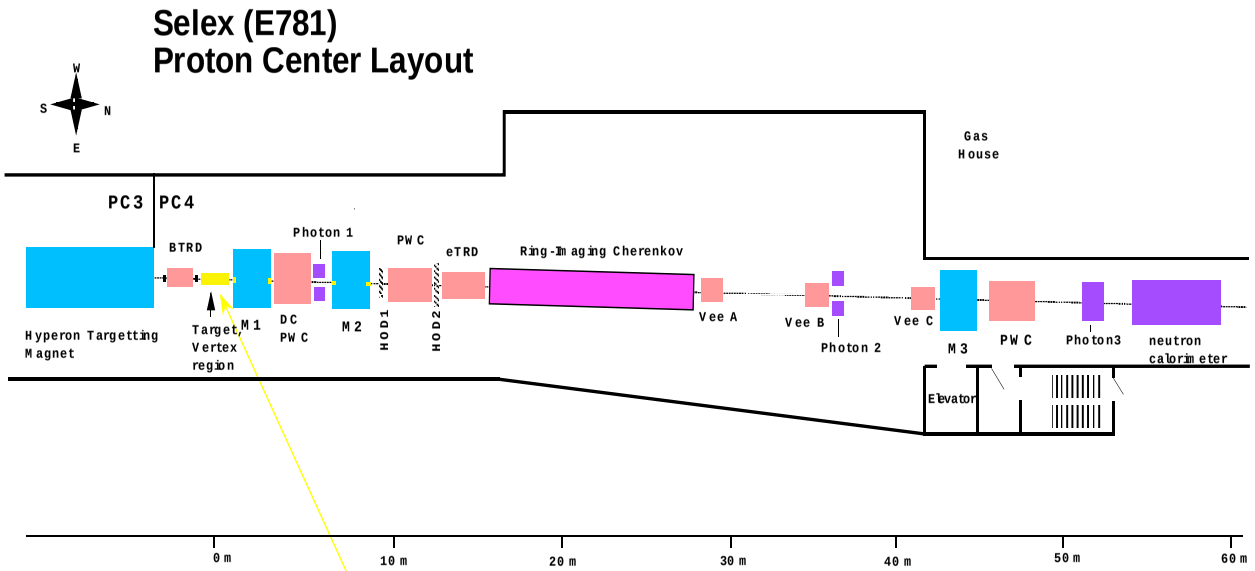
Published Experimental Evidence

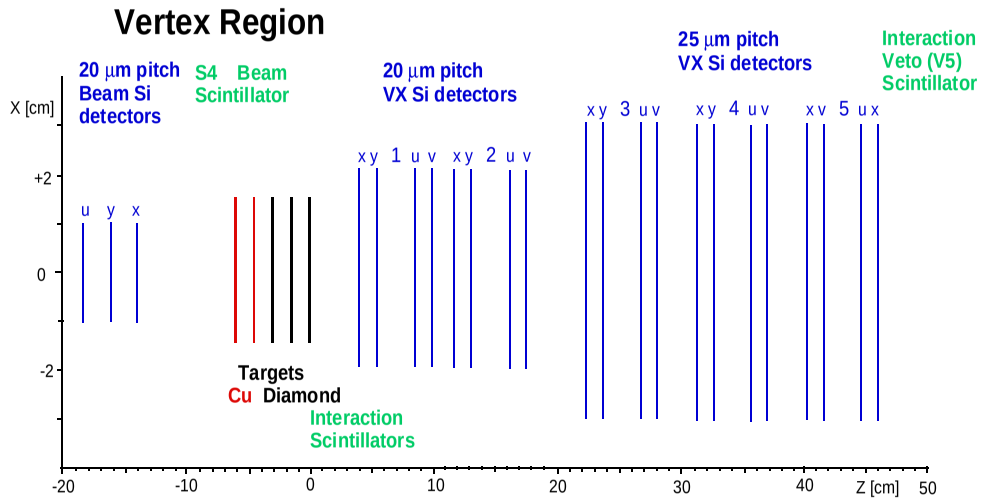


Unpublished FOCUS data:
www.hep.vanderbilt.edu/∼stenson/xicc/xicc_focus.html (2000)

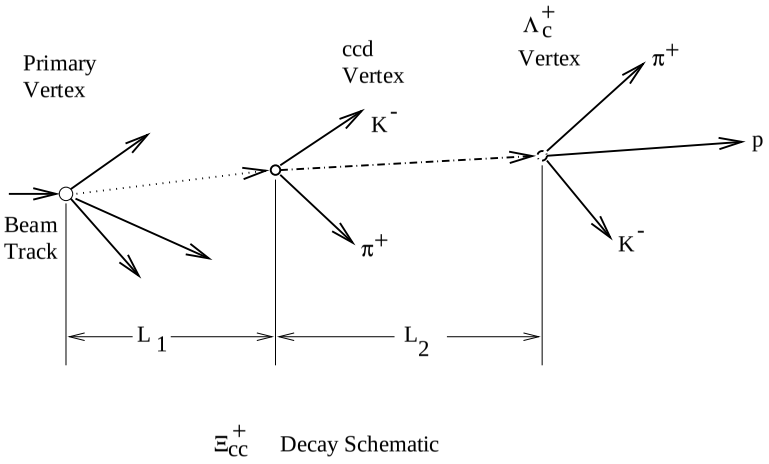
SELEX Apparatus Features

- Forward production
- π, Σ^-, p beams
- typical Lorentz Boost $\sim$ 100
- RICH identification above 25 GeV/c

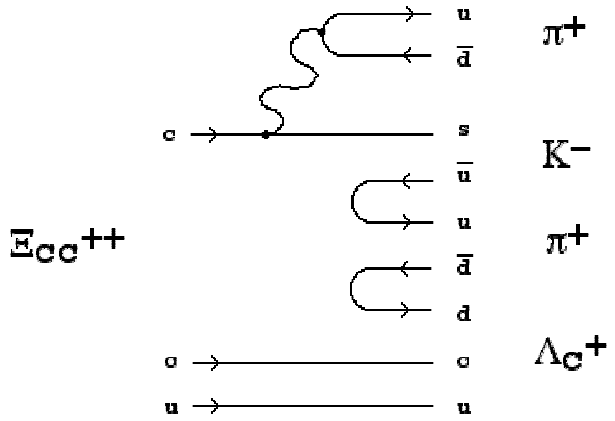




SELEX Double Charm Baryon Search Strategy



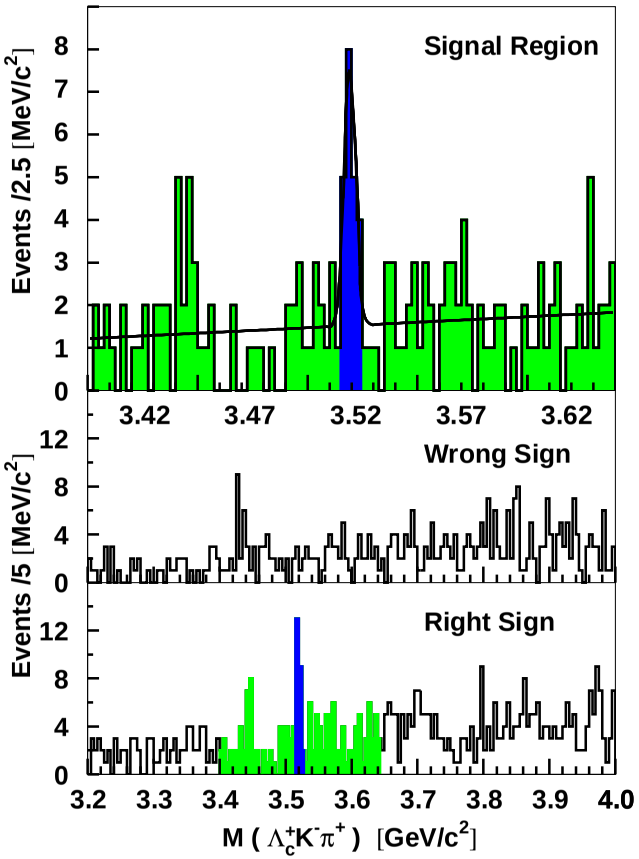
Ξ_{cc}^+ Decay Schematic



- ccq baryon must decay to cqq baryon; **look for Λ_c^+ plus extra vertex**
- Cabibbo-allowed modes: $c \rightarrow s + W^+ \Rightarrow$ **require K^- (not K^+) at second vertex**
- No RICH PID on tracks from second vertex. Wrong-sign kaon events check topological backgrounds.
- Independent data sets for ccu^{++} and ccd^+
- Use SELEX $\Lambda_c^+ \rightarrow pK^-\pi^+$ sample; RICH identification required on p, K^-
- search for $K^-\pi^+(\pi^+)\Lambda_c^+$ vertex between primary vertex (in target foil) and Λ_c^+ decay point

Results from ccd^+ Search

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



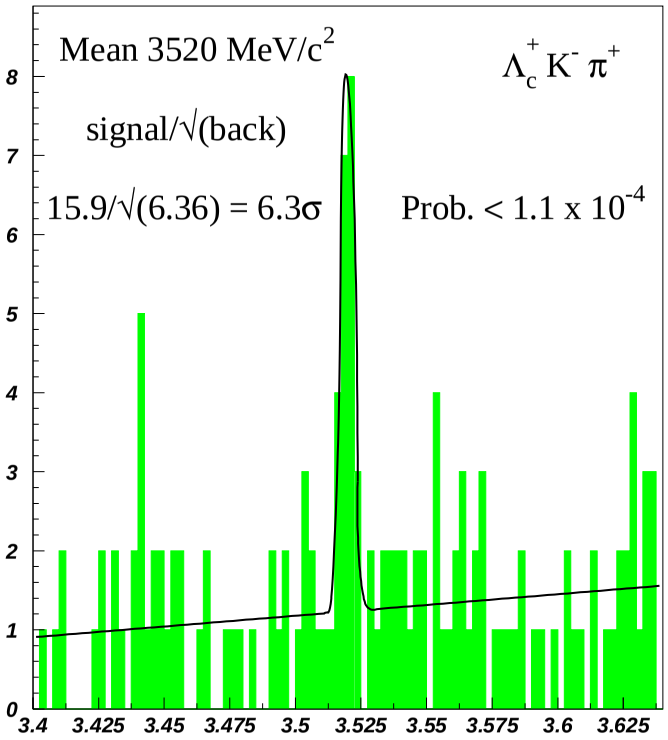
- Use a baryon to find a baryon: require Λ_c^+ daughter
- look for extra vertex between primary and Λ_c^+
- If it's double charm, ccq decay makes a K^-

Right-sign channel has peak at $3520\ \mathrm{MeV/c^2}$

Wrong-sign channel has no significant structure

Calculate $m(ccd^+)$ using $m(\Lambda_c^+) = 2.2849\ \mathrm{GeV/c^2}$

Is this a Ξ_{cc}^{+} Signal?



- Single-bin significance 6.3 σ $\Rightarrow$ single-bin Poisson probability 10^{-6}
- 110 bins in total search range
- **Fluctuation probability anywhere** $\leq 1.1 \times 10^{-4}$

Statistically significant, narrow peak at 3520 MeV/c^2 decays to charm baryon and K^- plus pion

Width 3 ± 1 MeV/c^2, consistent with simulation

First Observation of a Ξ_{cc}^{+} Decay!

Ξ_{cc}^{+} Characteristics

Ξ_{cc}^{+} seen only from baryon beams

	Σ^-	π^-	proton	π^+
interaction fraction	0.67	0.13	0.18	0.01
signal region events	18	0	4	0
sideband region events	110	7	21	2

No heavy-nucleus enhancement

	Diamond	Copper
fraction of Λ_c^+ signal events	0.68	0.32
signal region events	18	4
sideband region events	93	47

Evidence for Weak Lifetime?

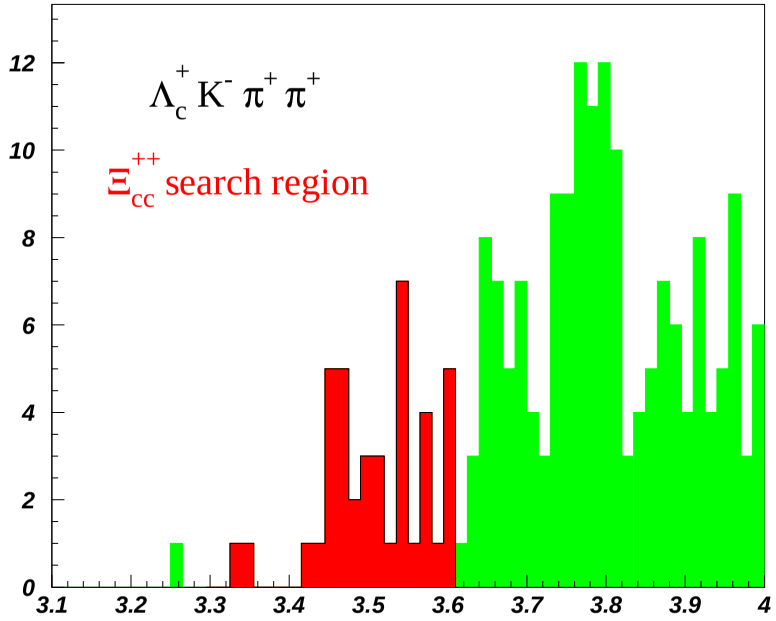
Two interfering amplitudes:
direct c decay; W-exchange $\Rightarrow$
lifetime $\leq \tau(\Xi_c^0)$ (if constructive)

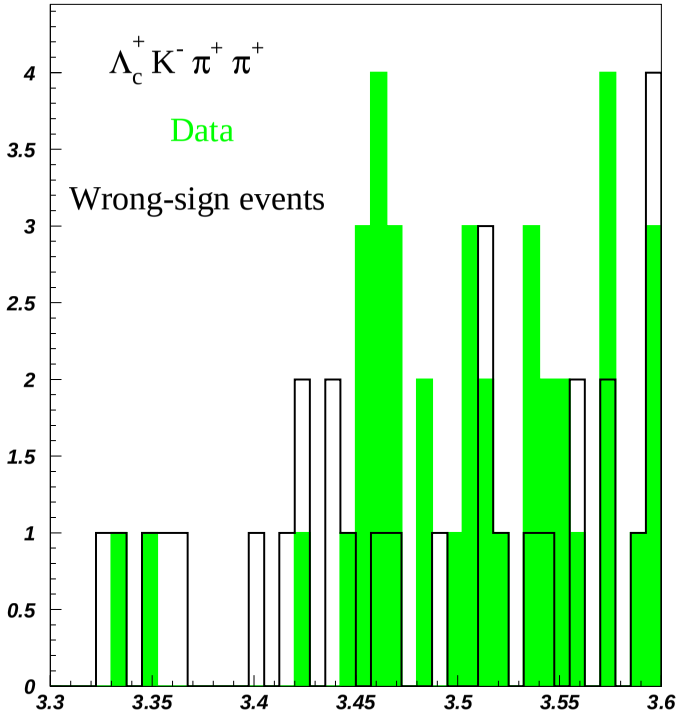
- SELEX proper time resolution 20 fs.
- Binned likelihood analysis:
  $\tau(\Xi_{cc}^{+}) \leq 33$ fs(90%-confidence)

Lifetime is VERY short

Is There a Narrow ccu^{++} State in SELEX Data?

Use finer mass bins near $m(\Xi_{cc}^{+})$





- Almost no events below 3.3 GeV/c^2
- broad structure at 3.78 GeV/c^2

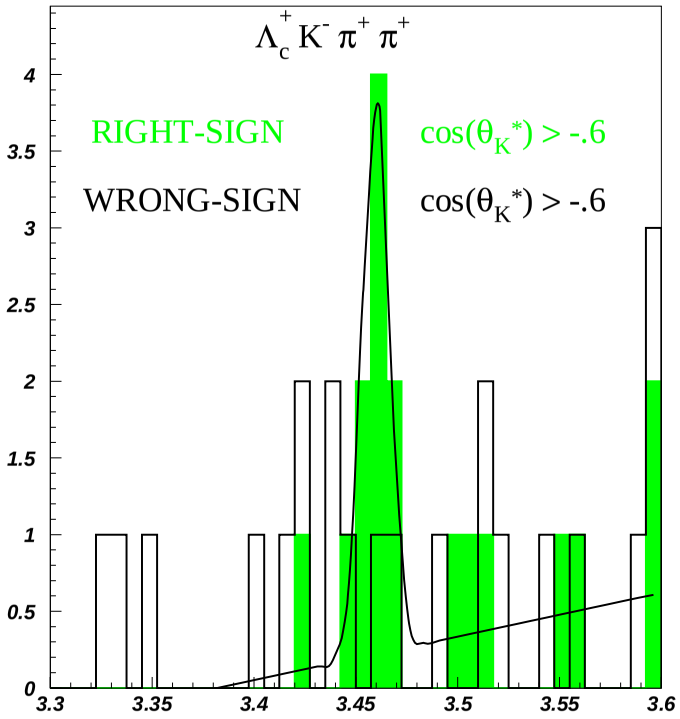
- **Right-sign data show excess at 3460 MeV/c^2**
- Wrong-sign data show same fluctuations as right-sign, but no significant structures

Is the 3460 Bump a Ξ_{cc}^{++}?

Are peak-region events distinctive?

Cut soft-pion fakes at backward angles (D*, D_s)

- Use 4-body phase space to simulate $\Xi_{cc}^{++} \rightarrow K^-\pi^+\pi^+\Lambda_c^+$ signal (S_{MC}) (Simulation, data agree on Dalitz plot, angular distributions)
- $B_{tot} \equiv$ number of data background events outside blind signal region
- optimize $\cos(\theta_K^*)$ cut on $S_{MC}/\sqrt{B_{tot}}$



7.9 σ peak at 3460 MeV/c^2 with double-charm decay characteristics

Poisson probability $\leq 10^{-5}$ anywhere in plot

Production issues

How can SELEX see double-charm states?

No good theoretical answer, but ...
Hadro-production at large x_F has been surprising before.

- NA32: cc pairs ~10 % of $c\bar{c}$ pairs
- WA75 emulsion: 4-charm production ~5 % of 2-charm
- WA62: discovery of Ξ_c^+ with huge cross section from 135 GeV Σ^- beam

FOCUS Photoproduction (Fermilab):

- Λ_c^+ sample ~10 times bigger than SELEX.
- See no evidence for double-charm baryons.

(SELEX sees double-charm baryons only from baryon beams.)

Is there a Λ_c^+ crisis?

Λ_c^+ Consumption

- simulation: If Λ_c^+ is reconstructed, average Ξ_{cc}^+ detection efficiency is 11%.
- isospin: factor of 1.5 for $K^-\pi^+ \rightarrow$ all $K\pi$
- Bjorken: (all Λ_c^+ modes)/($K^-\pi^+\Lambda_c^+$) ~ 1.6

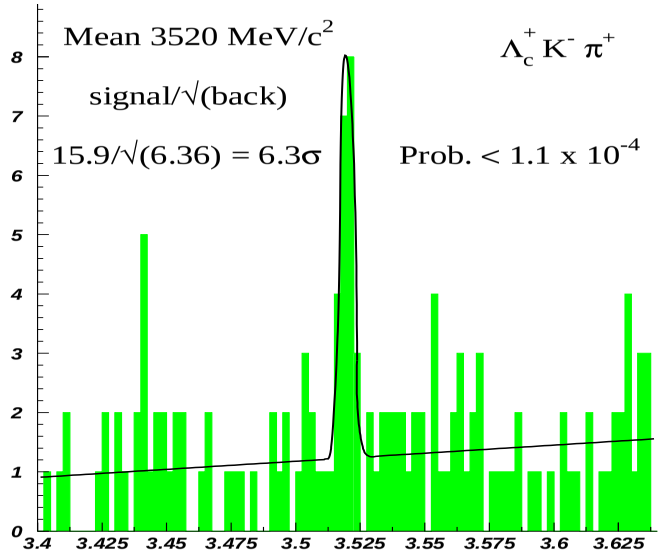
Each detected Ξ_{cc}^+ event requires 22 observed Λ_c^+s

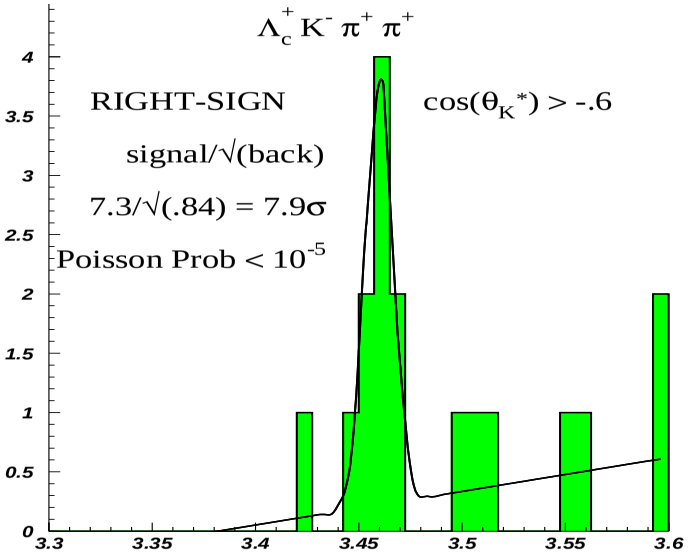
ccq decays require ~40% of the SELEX Λ_c^+s

Observed signals don't violate Λ_c^+ conservation

ccq/cqq ratio related to BELLE (e^+ e^-) result?

SELEX Sees Two New High Mass States





We don't know J for either state

60 MeV/c^2 isospin(??) split is unexpected. What does it mean?

Compelling decay modes - must be double-charm baryons

but

Unexpected spectroscopy and very short lifetime