Charmed Baryons

A Review of Doubly Charmed Baryons & New Results

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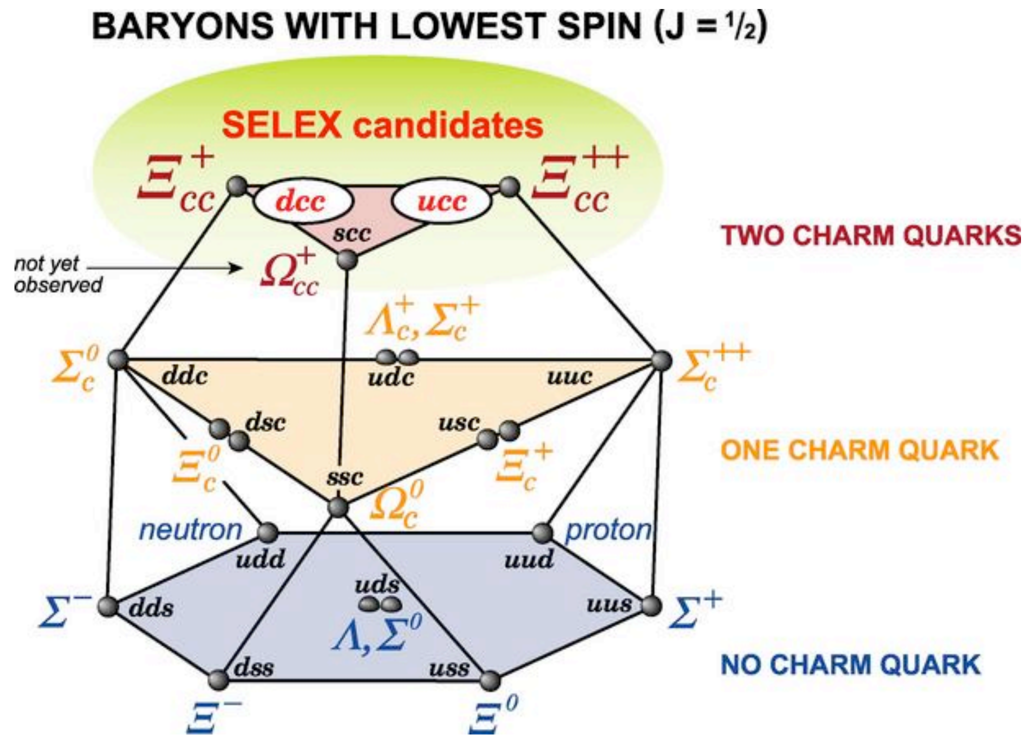
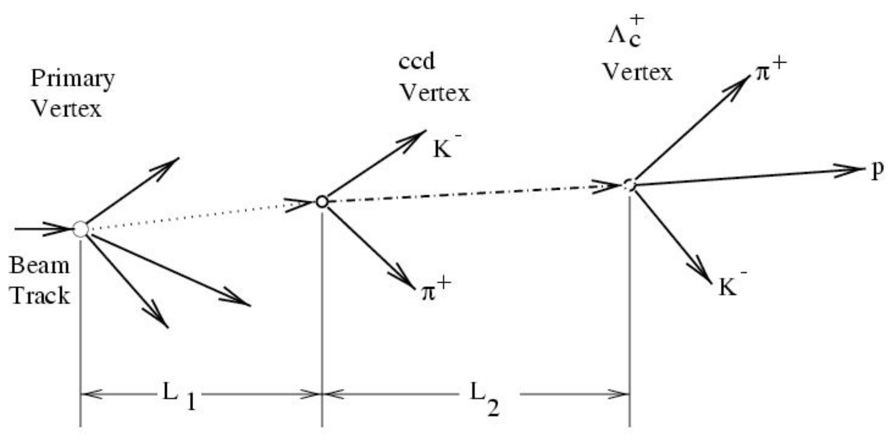
Double Charm Baryons: SU(4)

- QCD: isodoublet of (ccq) baryons
- Models agree: ground state ~3.5-3.6 GeV/c^2
- Lattice concurs:
  Flynn, et al., hep-lat/030710



Hunting for QQq Baryons

- Expect Cabibbo-favored ccq decay to lead to charm baryon + strange meson or charm-strange baryon + pion
- For Selex the Λ_c^+ dominates charm baryons; some Ξ_c^+ too, so it's natural to look for states like $\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+$, pD^+K^-, $\Xi_c^+ \pi^+ \pi^-$ for ccd, $\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$, $\Xi_c^+ \pi^+ \pi^+ \pi^-$ for ccu.

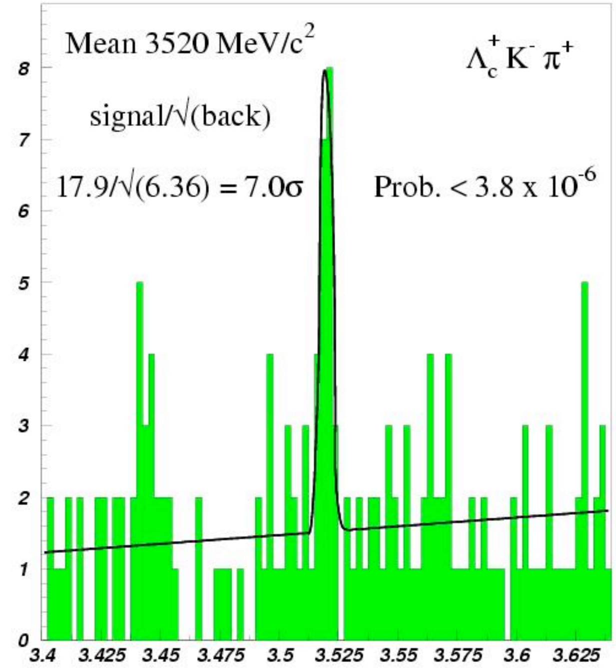


Ξ_{cc}^+ Decay Schematic

- Use standard single-charm cuts to select Λ_c^+ - no optimization
- Reconstruct additional vertex between primary and charm vertices. No PID on K^- or π^-
- Expect combinatoric background when $L_1 \sim \sigma$

Features of First Selex Ξ_{cc}^{+} Observation

- First candidate for new baryon comes from baryon beam experiment:
  - $\Xi_{cc}^{+}(ccd) \rightarrow \Lambda_c^{+} K^{-} \pi^{+}$ Cabibbo-favored spectator mode
  - State seen from Σ^{-}, p but not π^{-}
- Lifetime is very short – <35 fs at 90% confidence. Disagrees with prediction from HQ single charm lifetime hierarchy.
- Cross section is *large*! Involves 40% of Selex Λ_c^{+} production. Fragmentation predictions are much, much, smaller.
- Anomalously large charmed baryon yield in a hyperon beam (WA62) is why we did Selex in the first place.



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Improved Selex Background Analysis

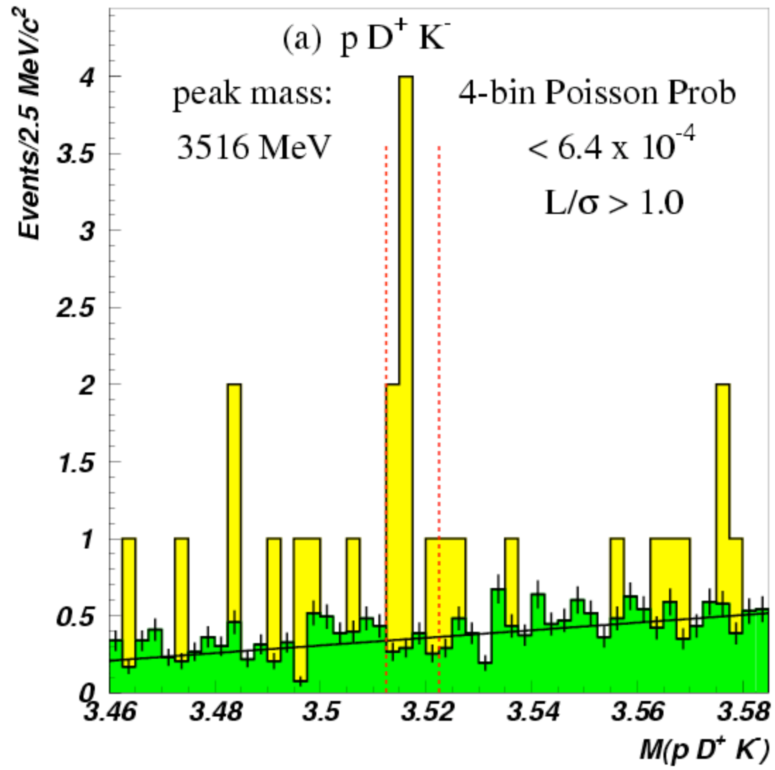
- Short lifetime for $\Xi_{cc}^{+} \Rightarrow$ dominant background is combinatoric but low – hard to pin down exact shape from data sample. Absolutely normalized combinatoric background by event mixing

- Select Λ_c^{+} reconstructions from events having no Ξ_{cc}^{+} candidates
  - Take opposite-sign track pairs ($K^{-}\,\pi^{+}$) from different events
  - Build statistics by re-using each Λ_c^{+} 25 times and renormalizing output mass plot to reflect this.

- This method can be applied to any final state dominated by combinatoric background and always has absolute normalization – no adjustments.

Application: New $\Xi_{cc}^+ \to pD^+K^-$ Decay Mode

- $\Xi_{cc}^+ \to pD^+K^-$ is quark rearrangement from $\Lambda_c^+ K^- \pi^+$
- Q-value of decay is smaller than that for $\Lambda_c^+ K^- \pi^+ \Rightarrow$ lower rate
- Check physics background with wrong sign pD^-K^+ - no peaks
- Event-mixed background (green) matches background fit to data (solid line) – confirms signal.
- Mass matches within 1 MeV of $\Lambda_c^+ K^- \pi^+$ value



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Combined Ξ_{cc}^{+} Distributions

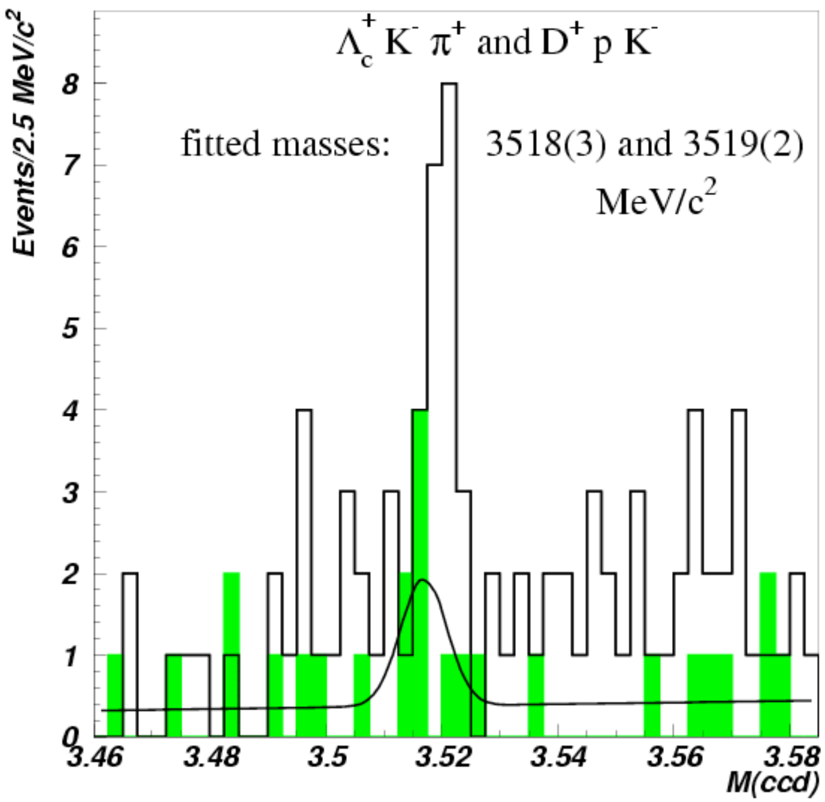
• Fit Gaussian with width fixed from MC to $pD^{+}K^{-}$ data to fix mass: 3518 ± 3 MeV/c^2.

• Mass was 3519 ± 2 MeV/c^2 from $\Lambda_c^{+}K^{-}\pi^{+}$ mode:

• Combined mass:

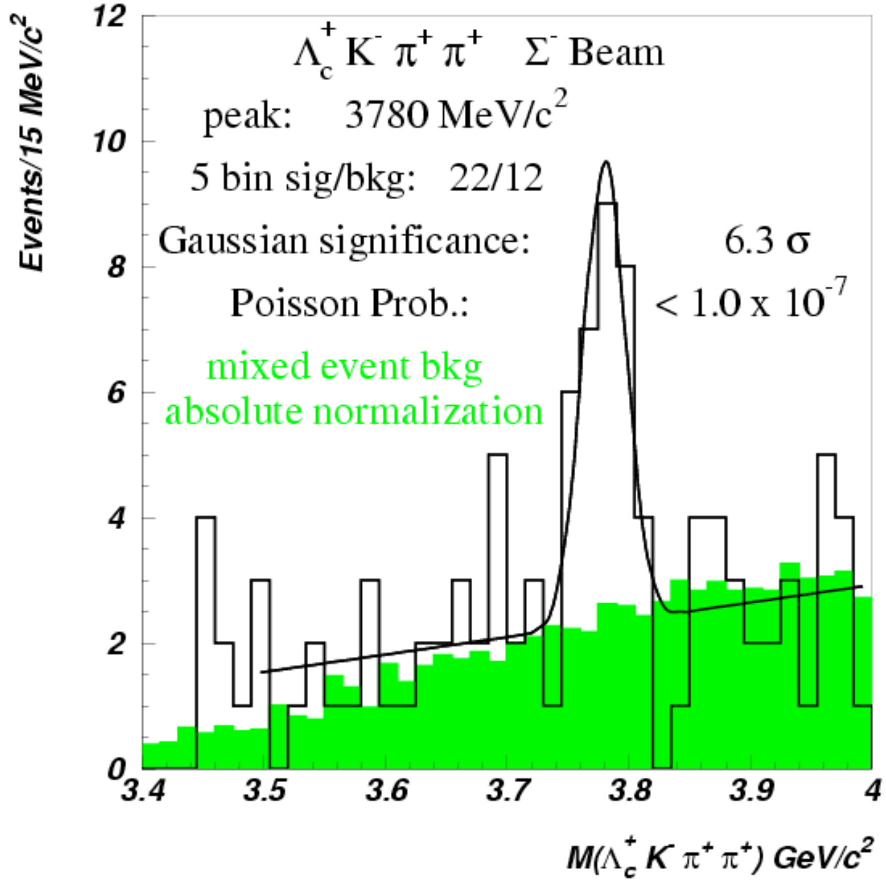
$M(\Xi_{cc}^{+})$ = 3518.7 ± 1.8 MeV/c^2

$\Gamma(pD^{+}K^{-}) / \Gamma(\Lambda_c^{+}K^{-}\pi^{+})$ = 0.20 ± 0.12



Doubly Charged Double Charm: Ξ_{cc}^{++}(3780)

- Q=2 candidates in $\Lambda_c^+ K^- \pi^+ \pi^+$ final state from Σ^- beam. No new cuts.
- (We actually found this one first)
- See broad structure at 3780 MeV/c^2 – wider than resolution.
- Combinatoric background from event mixing (green) describes background well in shape and normalization.
- Have ccu excited state like Λ_c^{+*}.



More About the Ξ_{cc}^{++}(3780)

- If it's an excited state, is there a chain decay? Look for $\Xi_{cc}^{++*} \rightarrow \Xi_{cc}^{+} \pi^{+}$

PRELIMINARY EVIDENCE: All the Ξ_{cc}^{++} signal events can be accounted for by chain decays.

- Much more work needs to be done to understand this state, but double charm system seems to follow baryon excitation dynamics with pion chain decays.

Search for $\Xi_{cc}^{+} \to \Xi_c^{+} \pi^{-} \pi^{+}$ Decay Mode

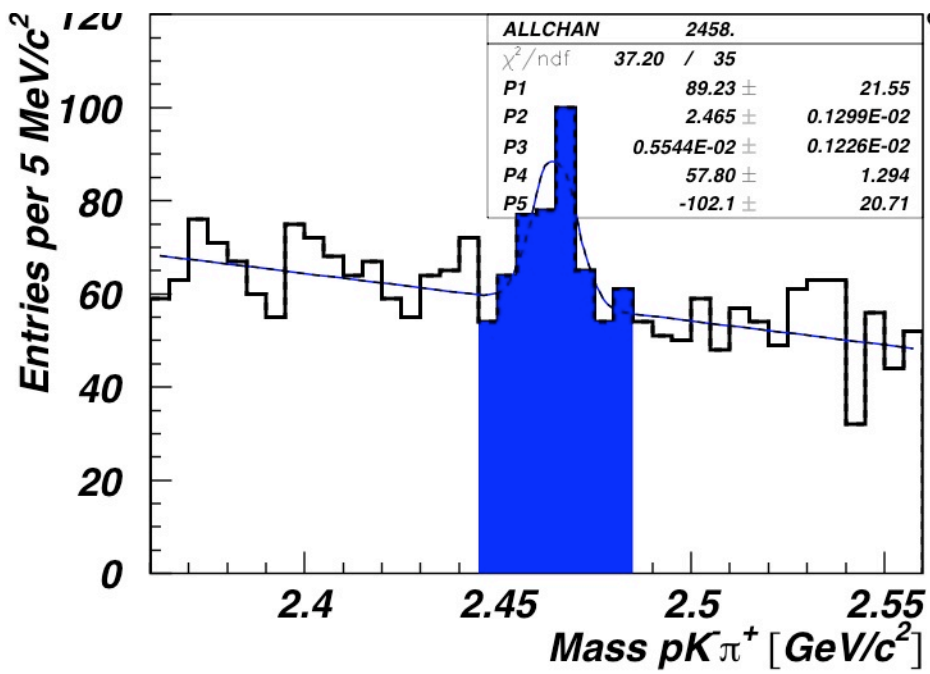
- Selex first observed Cabibbo-suppressed decay $\Xi_c^{+} \to pK^{-} \pi^{+}$

Preliminary

Ibrahim Torres
UA San Luis Potosi (Mexico)

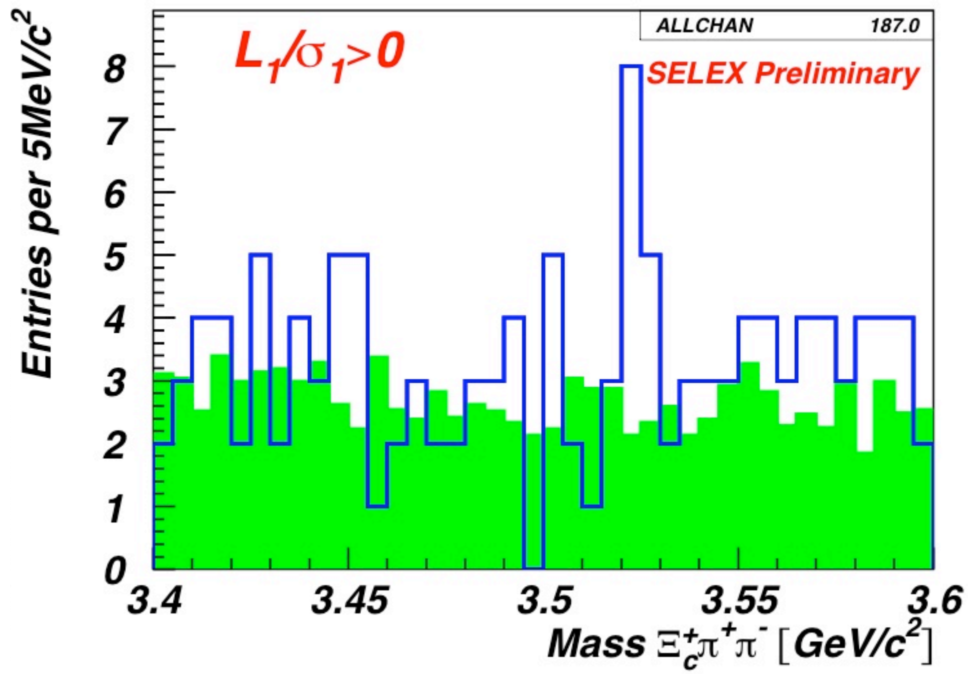
- This Ξ_c^{+} mode has excellent momentum resolution – good to use in vertexing.
- Just like in Λ_c^{+} case, proton and kaons are RICH-identified
- Cabibbo-suppressed mode: more background.

$\Xi_c^{+} \to pK^{-} \pi^{+}$



The $\Xi_{cc}^{+} \rightarrow \Xi_{c}^{+} \pi^{-} \pi^{+}$ Signal

- Make reconstruction. No new cuts on tracks. Vertex significance > 0
- Another narrow peak ~3520 MeV/c^2 Width agrees with MC calculation.
- Event-mixed background (green) describes sidebands well.
- Cabibbo-suppressed mode: more background.



Recent Analysis Developments

- Double charm analysis is 'statistics-challenged' – few events

- Recent tracking and other improvements raise single charm yields by 50% [e.g. N(Λ_c^+) 1630 $\rightarrow$ 2450]

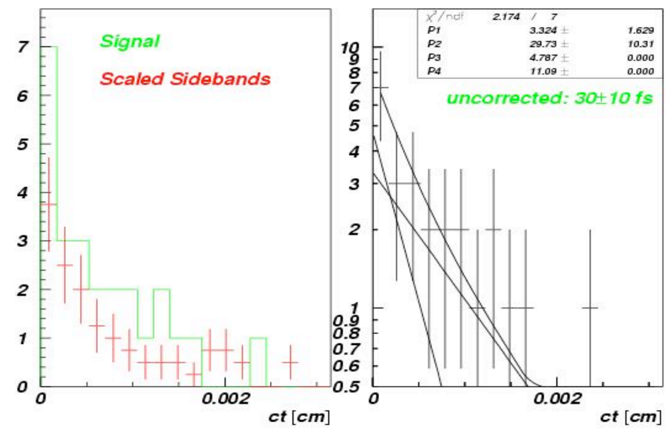
- We understand double charm background well (event mixing)

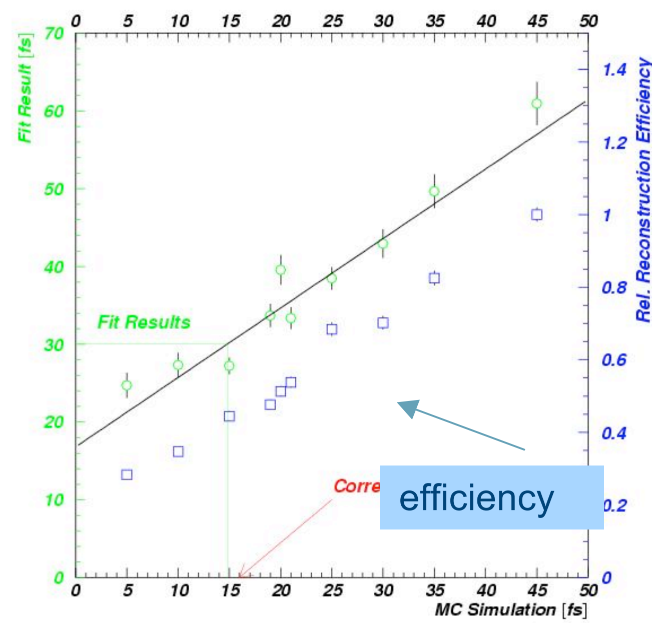
- Possible New Analysis Choice - relax cuts to accept more background but increase signal

- Also improve fit on Ξ_{cc}^+ vertex for lifetime studies

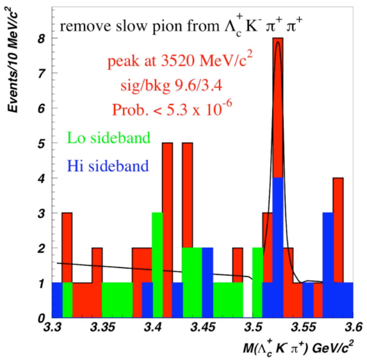
Ξ_{cc}^{+} Lifetime Study

- Experimental Problem: $c\tau \sim \sigma$ ... events go away by $4\ \sigma$
- Decay curve measured in 10 fs bins!
- Plot proper time for events in same mass band from signal and sideband
- Uncorrected lifetime always too long because of selection cuts
- Use MC to get true lifetime
- Detection efficiency goes down with τ.
- Corrected Lifetime $15^{+10}_{-??}$ fs.
- Still can't exclude τ=0 .



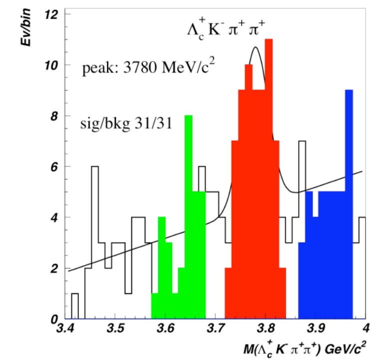


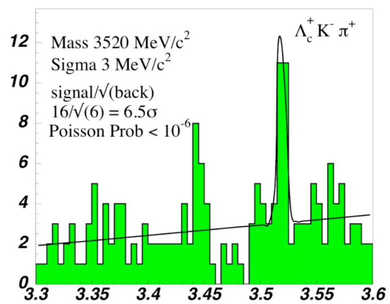
Selex Doubly Charmed Baryons ~2003

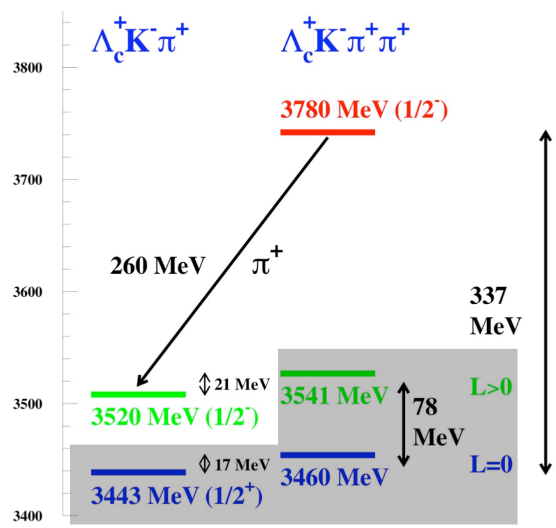


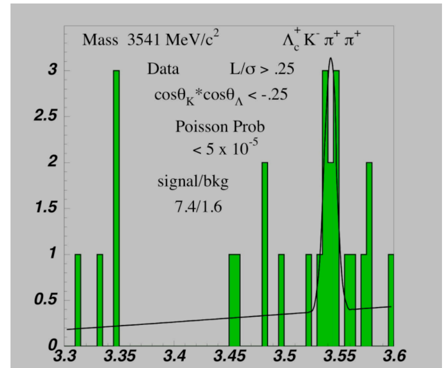
An excited state and a pair of isodoublets?

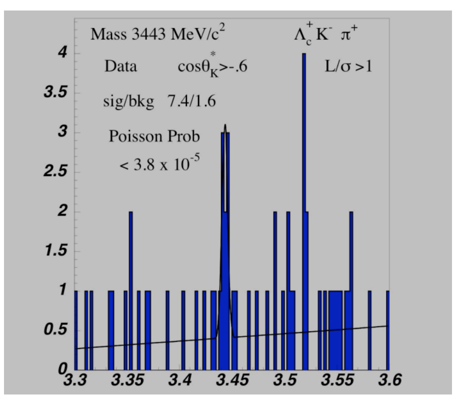
(an internal Selex plot)

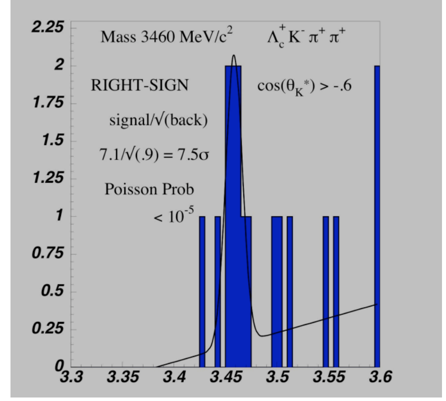












Working Without a Net

- Selex has seen and known about these states for 5+ years
- No one else sees them.
  - Babar & Belle enthusiastically report their non-observations
  - Nothing seen in Focus (photo-production) or E791 (π^- beam)
  - CDF & D0 are awash in combinatorics (τ[B] ~ 1400 fs)
  - No new opportunities until LHCb
- Selex has chosen to proceed very slowly, with extreme caution. Confirm, confirm, confirm (e.g. 3 modes)
- The damned things won't go away! They keep reappearing.
- An now for something completely (nearly) the same :) .

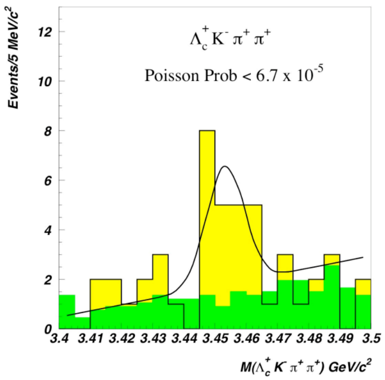
Where is the Ξ_{cc}^{++}(ccu) ground state?

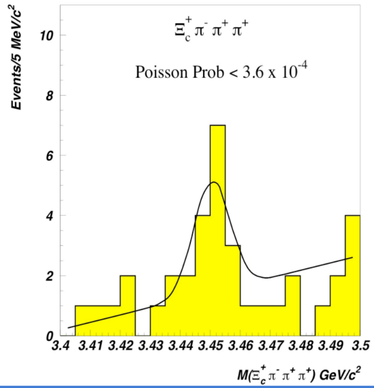
Preliminary

- Ξ_{cc}^{++}(ccu) [3780] isn't it (too wide too high)
- Look in $\Xi_{cc}^{++}(ccu) \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$, $\Xi_c^+ \pi^+ \pi^+ \pi^-$
- Apply all the same techniques to 3 prong vertices
  - daughter charmed baryon mass within 20 MeV/c^2
  - L / σ (ccu) > {1, 1.25} , {7, 10} < L/ σ (cu{d,s}) < 20
  - P_t(ccu) > 0.2 GeV/c
  - Suppress events with more than one ccu track combo
- Lifetime guess from L/σ looks "larger" than Ξ_{cc}^{+}

Mode	$\Lambda_c^+ K^- \pi^+ \pi^+$	$\Xi_c^+ \pi^+ \pi^+ \pi^-$	Combined
M [MeV/c^2]	3452(3.4)	3451(3.8)	3542(2.5)
Sig / Bkg	14 / 9	10.2 / 3.8	26 / 14
Gaussian Sig.	4.2σ (4.6)	3.8σ (4.2)	6.1σ
Poisson excess	<6.5 x 10^{-5}	<3.6 x 10^{-4}	<1.1x10^{-8}

Jim Russ (spokesman) CMU





Ξ_{cc}^{++}(ccu) ground state II

Preliminary

- We see the state we saw in 2003 again without any "additional cuts". 2 mode with a consistent mass
- Combined Poisson excess prob is 1.1×10^{-8}
- All different events, analysis done twice.

Physics

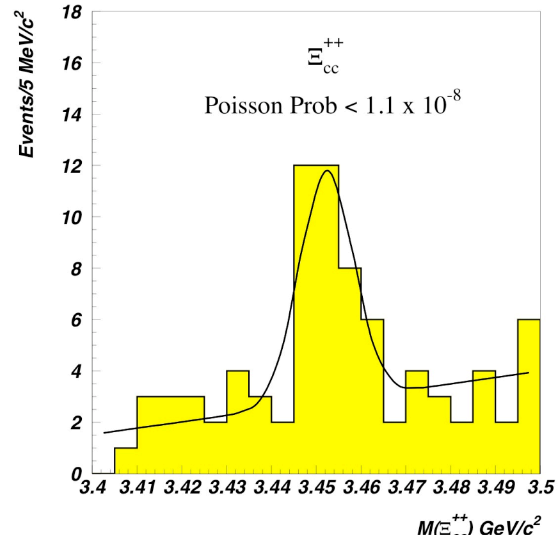
- Isospin splitting is 67 ± 3 MeV ??? Must be 2 isodoublets

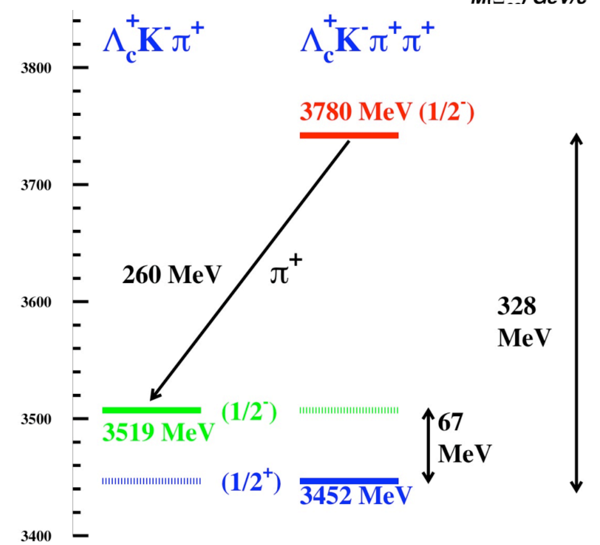
=> Ξ_{cc}^{+}(3519) is not a ground state

- Why do we see it as a weak decay?

=> photon emission highly suppressed (2γ) [remember $2S \rightarrow 1S$ Hydrogen?]

- There must be 2 more states to find.
- This spectroscopy is interesting!



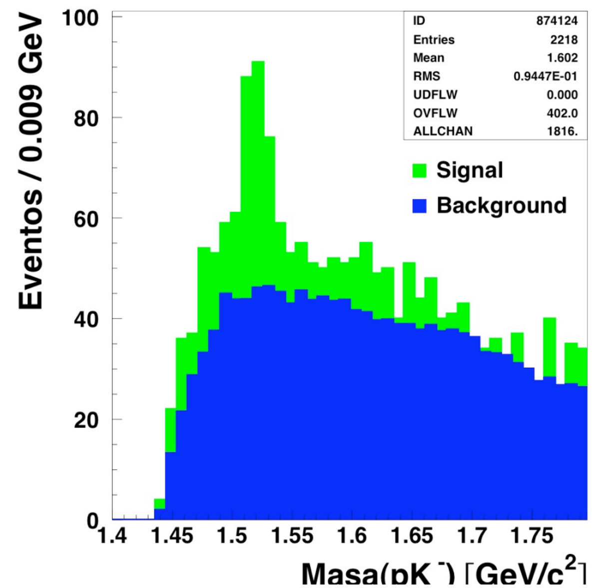


Selex $\Lambda_c^+ \rightarrow \Lambda^0(1520)\, e^+ \nu$ I

Preliminary

Jorge Amaro & Jurgen Engelfried
UA San Luis Potosi (Mexico)

- Old Cleo 1.x limit [PLB 323,219(1994)] gives
  $Br[\Lambda_c^+ \rightarrow e^+ X \nu] < 3.4 \pm 0.4\%$,
  $Br[\Lambda_c^+ \rightarrow \Lambda^0 e^+ \nu] = 2.1 \pm 0.6\%$ What about the rest?
- Search for $\Lambda_c^+ \rightarrow \Lambda^0(1520) e^+ \nu$, $\Lambda^0(1520) \rightarrow pK^-$
- Technique
  - Matched $pK^-\pi^+$ & pK^-e^+ samples
  - K^- + pe^+ event mixing for combinatoric backgrounds
  - e^+ PID with TRDs (E715 Σ^- β decay TRDs)
  - Remove $\phi^0 \rightarrow K^+K^-$ & $\Xi^0(1690) \rightarrow \Sigma^+ K^-$ reflections
  - Yield before eTRD is 193 ± 43 pK^-e^+ events & 1461 ± 83 $\Lambda_c^+ \rightarrow pK^-\pi^+$ events.



Selex $\Lambda_c^+ \to \Lambda^0(1520)\, e^+ \nu$ II

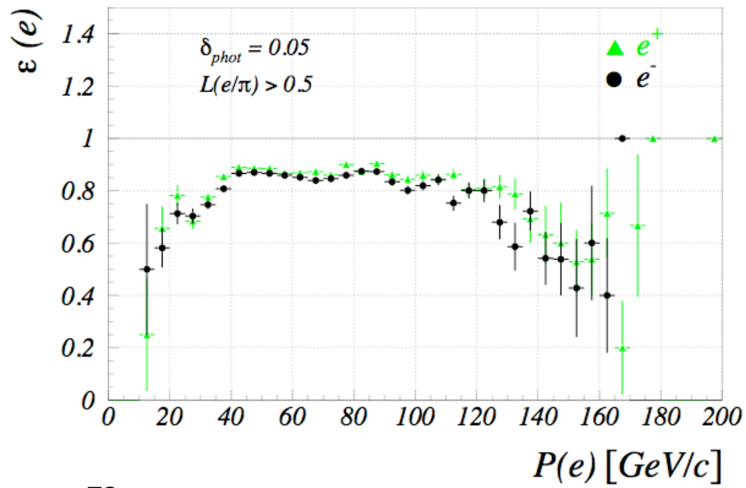
Preliminary

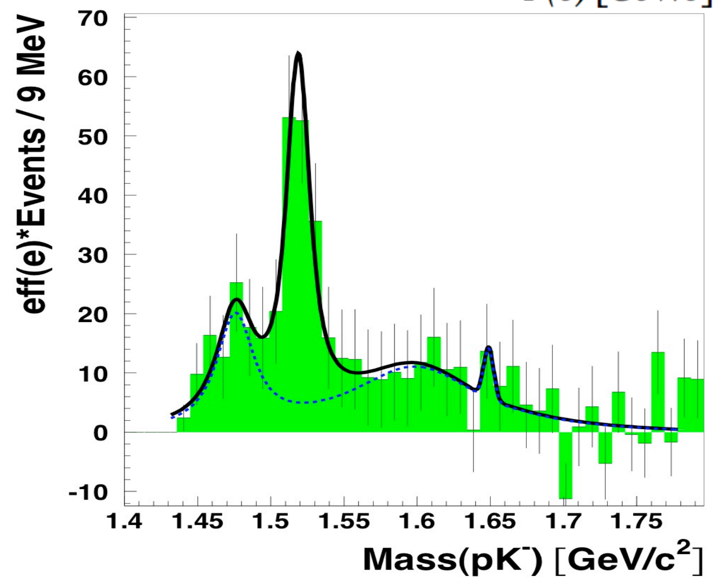
- Weight signal and background events by measured energy dependent eTRD efficiency
- Background subtracted weighted yield is 143 ± 12 events.
- Relative mode efficiency is 1.213 ± 0.012
- After correcting for efficiency and $Br[\Lambda^0(1520) \to pK^-] = 24.34\%$ we get:

$Br[\Lambda_c^+ \to \Lambda^0(1520) e^+\nu] = 3.04 \pm 0.62 \pm 0.79\%$

1.44 ± 0.34 times $Br[\Lambda_c^+ \to \Lambda^0 e^+\nu]$

- More than just combinatoric backgrounds. Other excited states?
- $\Lambda_c^+ \to \Lambda^0(1520)\mu^+\nu$ and other excited states are still under study





Summary I

- Double charm is here to stay
  - Selex has seen 3 double charmed baryon states in 3, 1 and 2 decay modes.
  - $\Xi_{cc}^{+}(3520)$ seen decaying into three different single charm states.
  - $\Xi_{cc}^{++}(3780)$ excited state shows chain decay via pion emission.
  - $\Xi_{cc}^{++}(3452)$ ground state observed in two different decay modes. Splitting is too large (67 MeV) for this state to sensibly be the isospin partner of the $\Xi_{cc}^{++}(3519)$. Radiative decays are suppressed?
  - This logic requires at least two more weakly decaying states, the isospin partners of the $\Xi_{cc}^{++}(3452)$ ground state and the partner of the EM decay suppressed $\Xi_{cc}^{++}(3519)$.
  - Selex has some hints of these but makes no claims now.
  - No report yet on the third double charm baryon, the Ω_{cc}^{+}(ccs)

Summary II

- Double charm production comes only from baryon-baryon interactions with VERY large cross section – totally inconsistent with fragmentation production.
- Double charm baryons NOT seen in fragmentation processes at Belle, BaBar, γ or π^- production – consistent with Selex baryon-only production.
- If this is correct LHCb should make these states copiously. If they trigger on them they should see them.

- Λ_c^+ Semi-leptonic decay to excited state seen and measured
  - 143 ± 12 events seen
  - $Br[\Lambda_c^+ \rightarrow \Lambda^0(1520)e^+\nu] = 3.04 \pm 0.62 \pm 0.79\%$
- Both charmed baryon physics and Selex are far from being finished or becoming uninteresting

Ok Galik - let’s see if I can dodge the fruit

Selex group meeting @ UASLP June 2006