Recent CLEO Results On Charmed Baryon Spectroscopy

- Introduction
- S-Wave Charmed Baryons
  Ξ_c' states observed
  Review other ground states
- P-Wave Charmed Baryons
  New Ξ_{c1}^* states
- Conclusions

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(*CLEO Collaboration*)

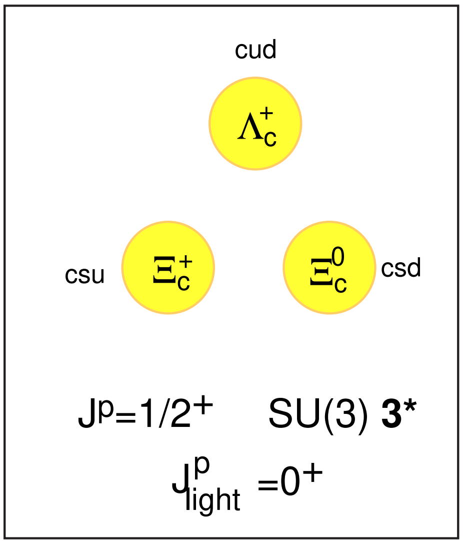
30 June 1998

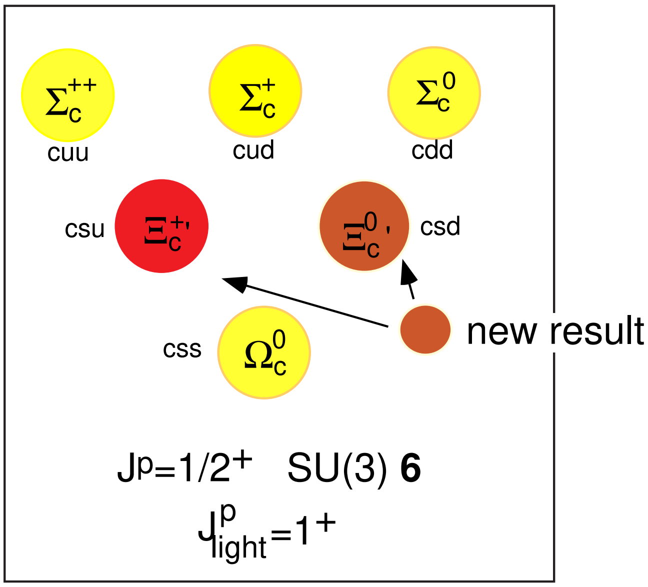
Hyperons, Charm and Beauty 1998

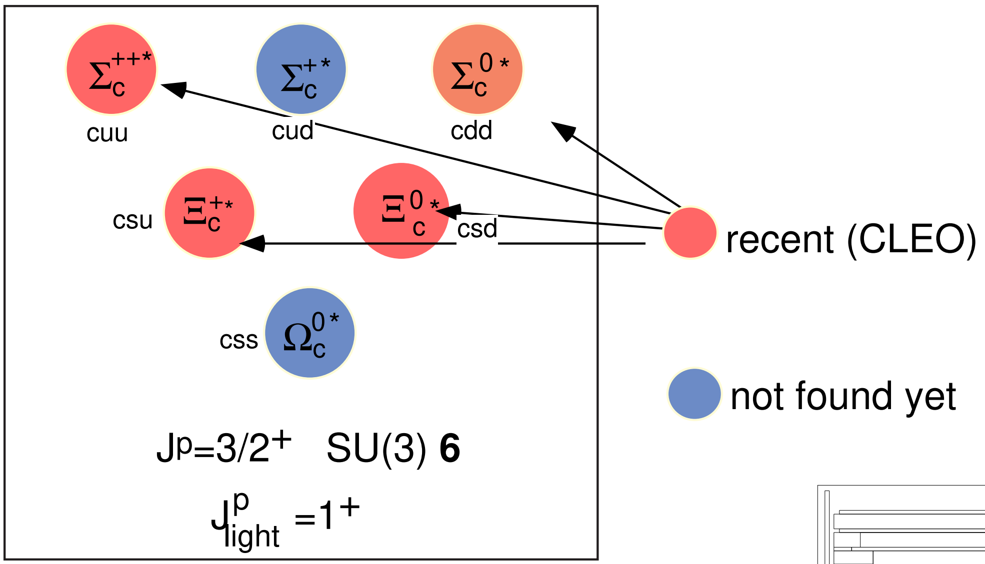
Genoa, 1998

S-Wave Charmed Baryons

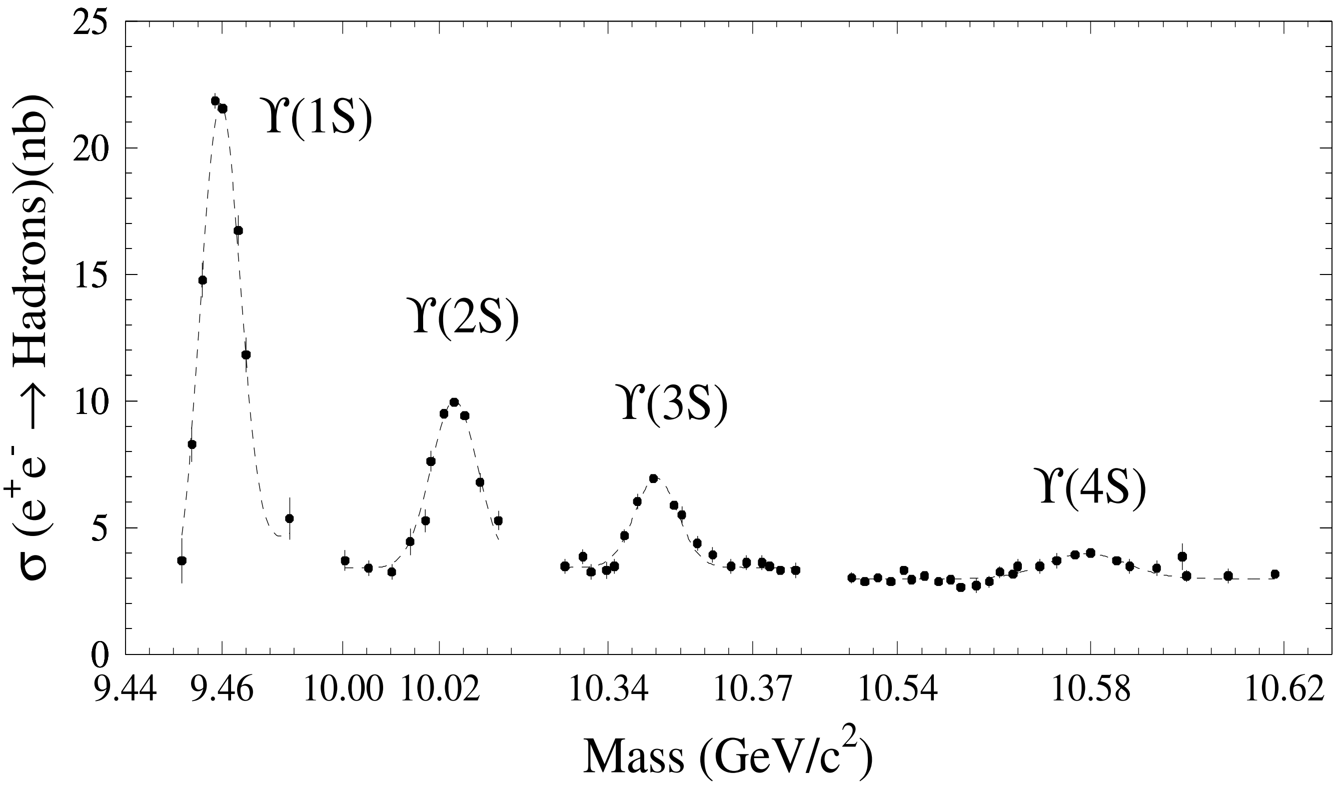
- In the Heavy Quark limit ($m_c \to \infty$)
  Spin and parity of the light degrees of freedom are conserved
- Note: Spin and parity assignments haven't been determined experimentally



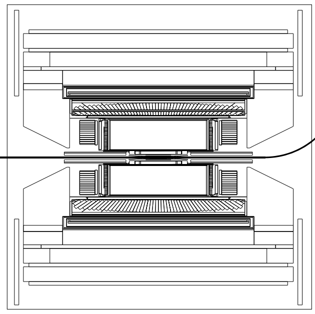




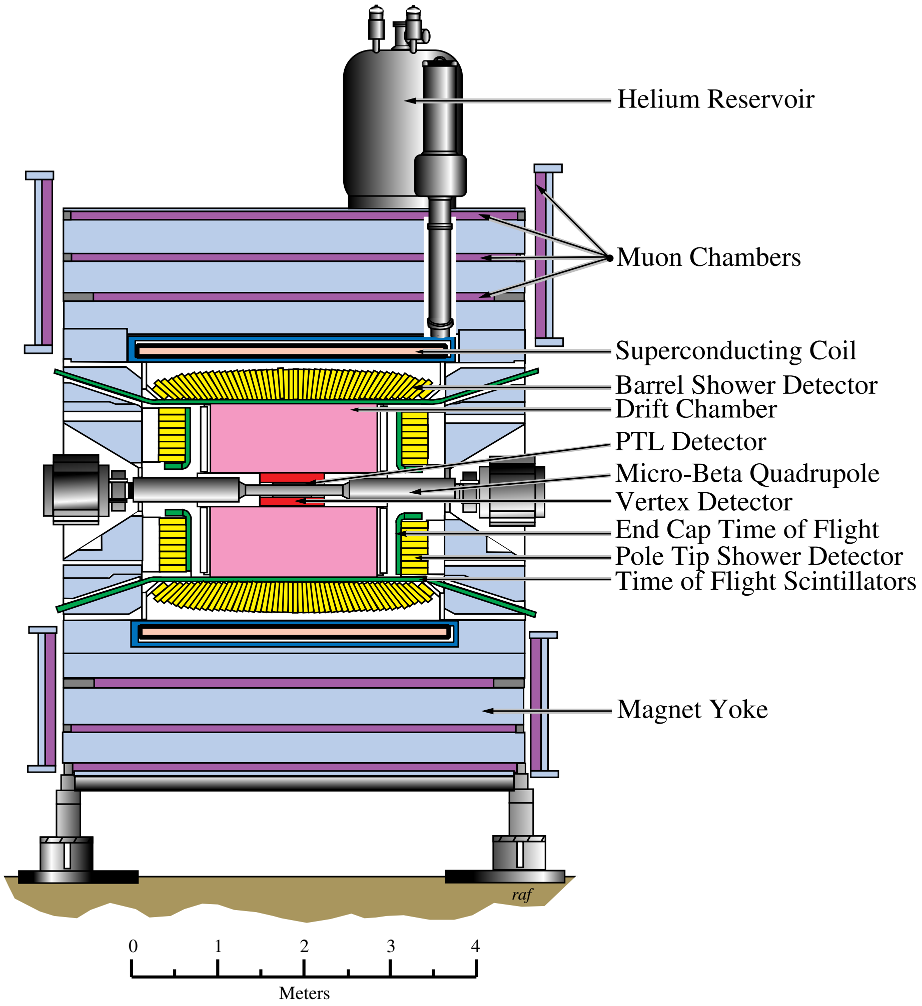
UPSILON RESONANCES



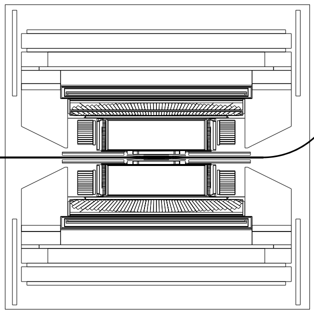
- CESR - Peak Luminosity $\sim 5.6 \times 10^{32} cm^{-2} s^{-1}$ (world's best)
  $\sim 2/3$ data taken at $\Upsilon(4S)$, $\sim 1/3$ at continuum below $\Upsilon(4S)$
- CLEO-II dataset - 4.8 fb^{-1} (1990-1995)
- Recently "Recompressed" CLEO-II dataset - Better tracking
  Only the Ξ_{c1}^* result uses the "recompressed" data.
- CLEO-II.V - 6 fb^{-1} (1995-1998). Expect $\sim$9 fb^{-1} total.
- All results I'll present are due to continuum charm production



CLEO-II Detector

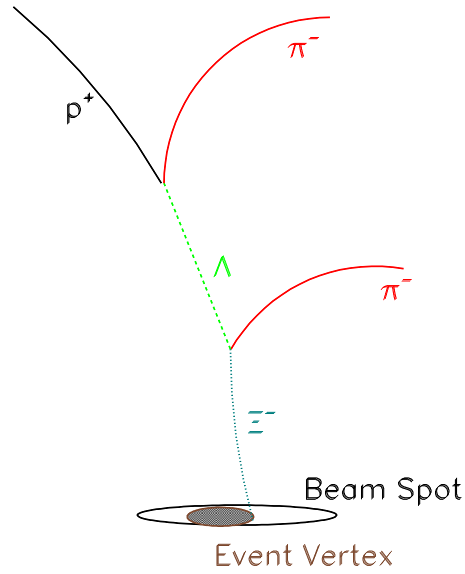


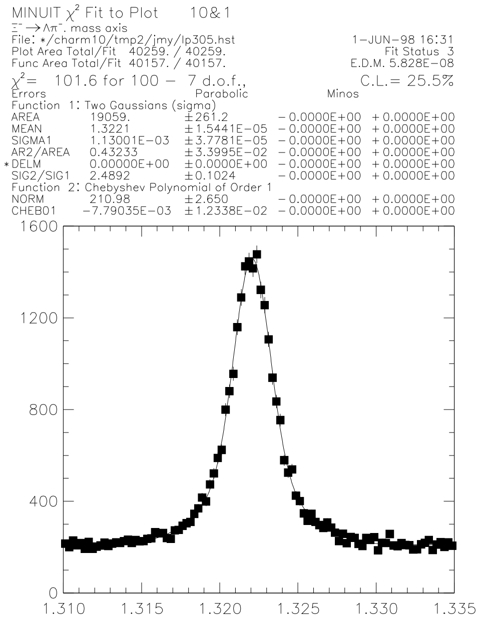
- Now standard 4π detector
- Tracking - 95 % of 4π
- EM Calorimeter - 7800 CsI crystals
  π^0 resolution $\sim$ 6 MeV in good barrel
- Particle ID - dE/dx + TOF



HYPERON FINDING - Ξ^-

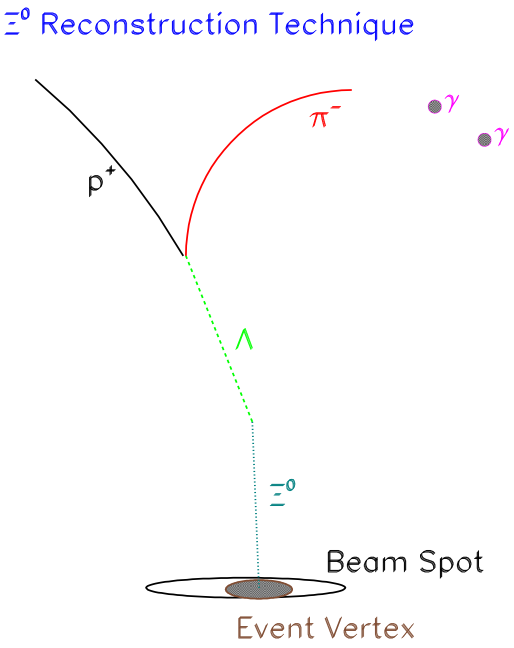
Ξ^- Reconstruction Technique

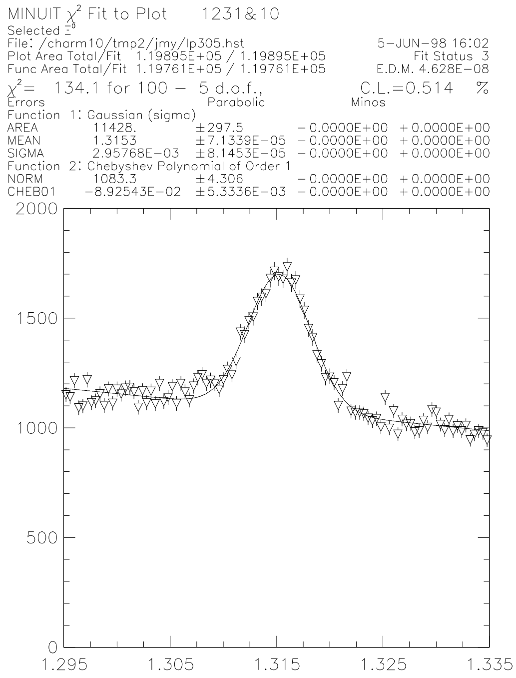




- Start with $\Lambda \rightarrow p\pi^-$ ($\sigma \sim$ 1 MeV)
- $\Xi^- \rightarrow \Lambda\pi^-$
  Yield: $\sim 19,000$, ($\sigma \sim$ 1.8 MeV)

HYPERON FINDING - Ξ^0





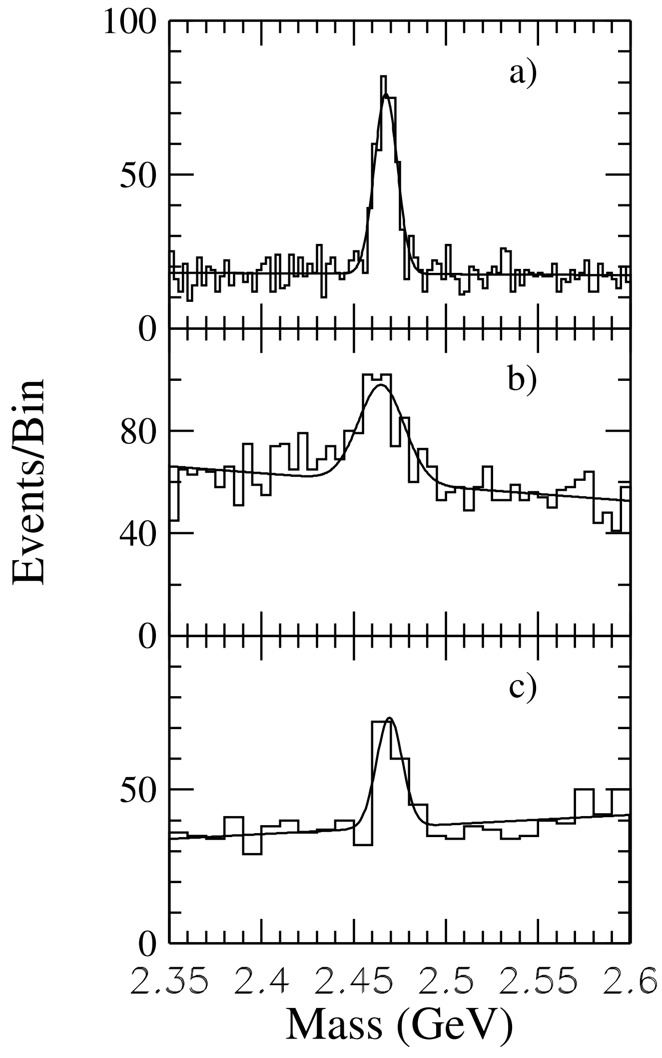
- $\Xi^0 \to \Lambda\pi^0$
  Yield: $\sim$11,000, ($\sigma\sim$ 3 MeV)

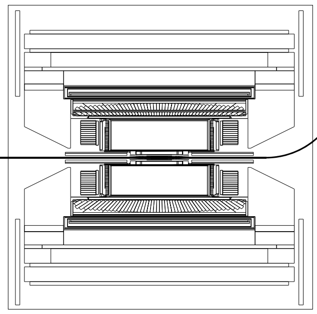
<u>Other detached vertices</u>

- $K^0_S \to \pi^+\pi^-$
- $\Omega^- \to \Lambda K^-$

Ξ_c^+ Finding

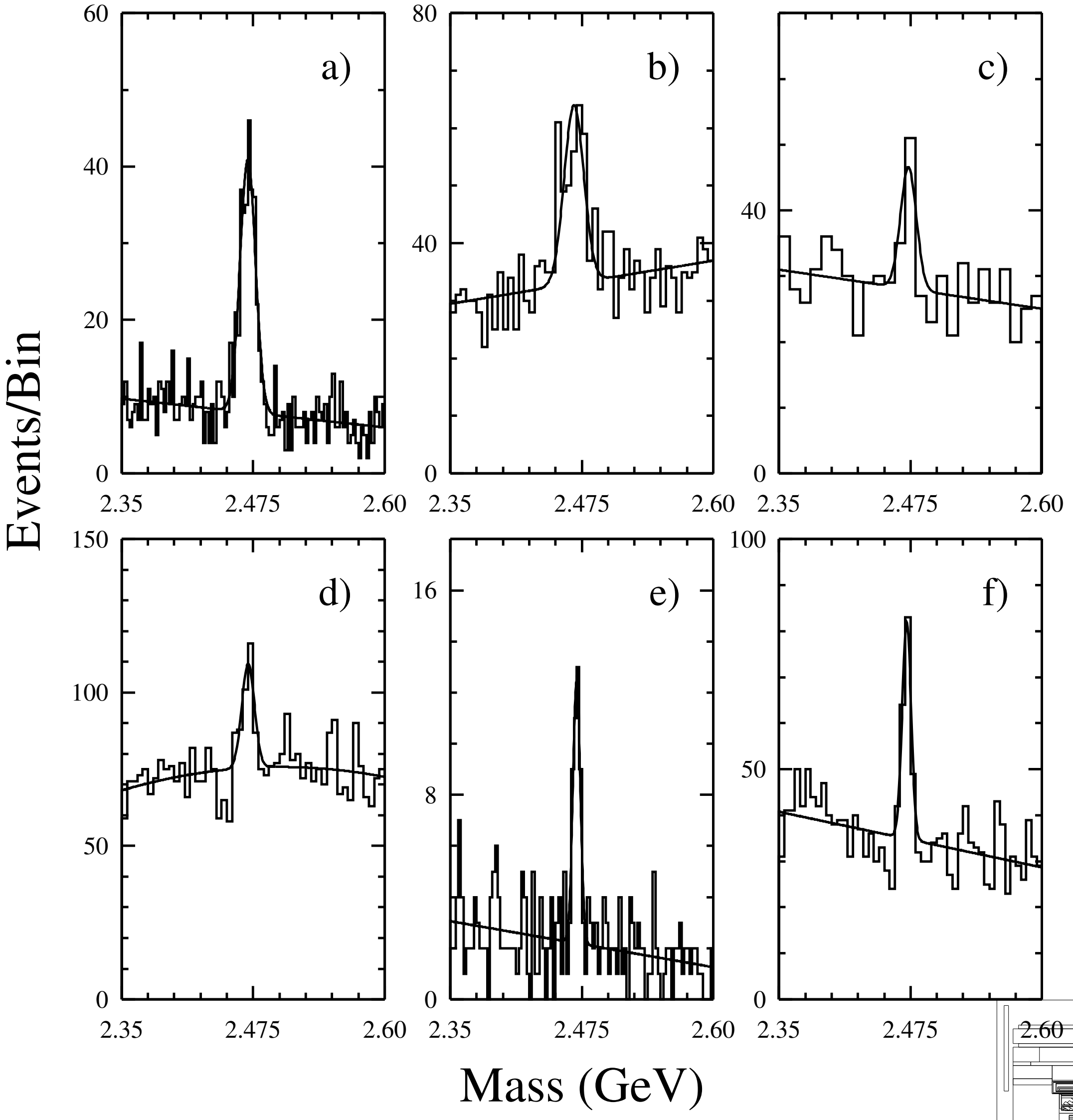
- Reduce combinatorial background, cut on x_p
  $x_p = P/P_{MAX}$, with $P^2_{MAX} = E^2_{beam} - M^2_{baryon}$
- Ξ_c^+ have $x_p > 0.5$ *for display purposes only !*
  Make x_p cut on the final state particle.
- a) $\Xi_c^+ \to \Xi^- \pi^+ \pi^+$ b) $\Xi_c^+ \to \Xi^0 \pi^+ \pi^0$ c) $\Xi_c^+ \to \Lambda K^0_S \pi^+$
  $\Lambda K^0_S \pi^+$ - new decay mode



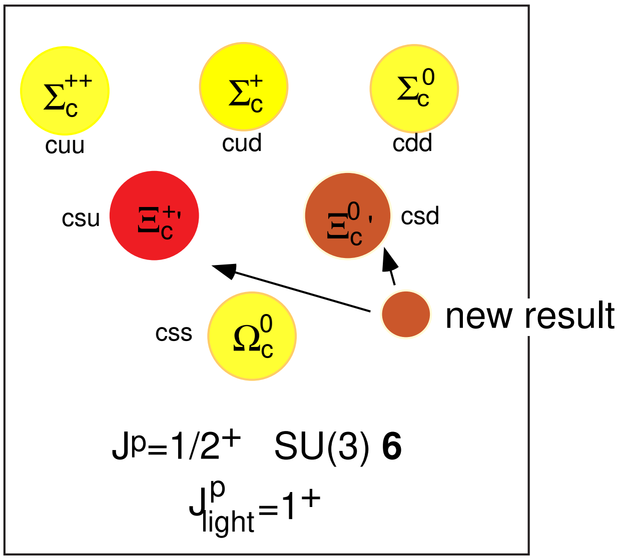


Ξ_c^0 Finding

- Ξ_c^0 have $x_p > 0.5$ *for display purposes only !* Make x_p cut on the final state particle.
- a) $\Xi_c^0 \to \Xi^- \pi^+$ b) $\Xi_c^0 \to \Xi^- \pi^+ \pi^0$ c) $\Xi_c^0 \to \Lambda K_S^0$
- d) $\Xi_c^0 \to \Xi^0 \pi^+ \pi^-$ e) $\Xi_c^0 \to \Omega^- K^+$ f) $\Xi_c^0 \to \Lambda K^- \pi^+$ $\Lambda K^- \pi^+$ - new decay mode



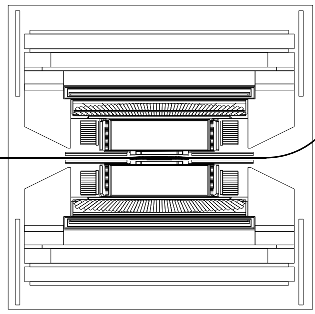
Search for Ξ_c' States



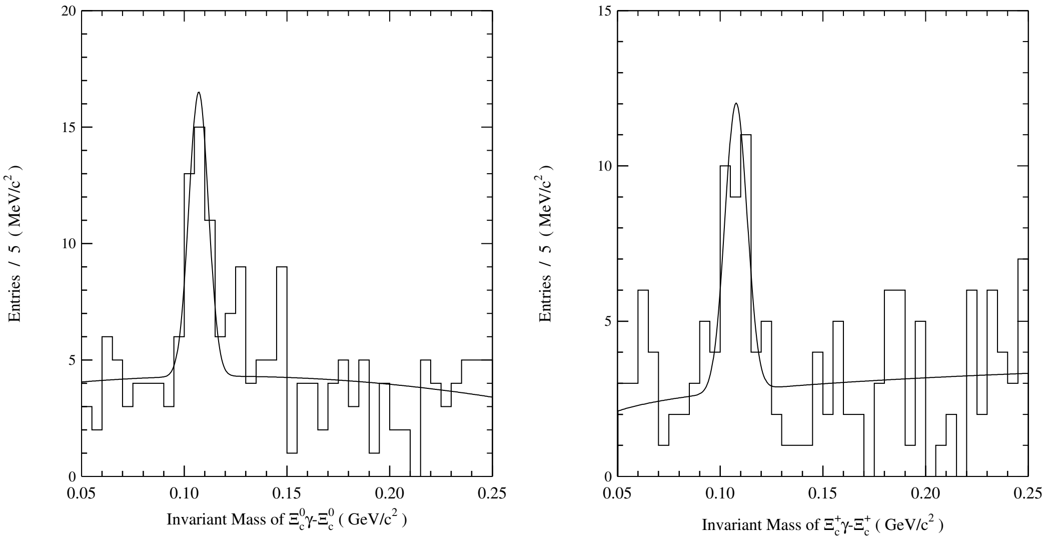
- $J^P = 1/2^+$ States
  "Symmetric" Σ -like states
- Mass Sum Rules - M. Savage, Phys. Lett. B359, 189 (1995)
  $M_{\Sigma_c} + M_{\Omega_c} = 2M_{\Xi_c'}$
  $M_{\Xi_c'} \sim 2579$ MeV
  $\Delta M(\Xi_c' - \Xi_c) \sim 110$ MeV

$\Longrightarrow$ Look for $\Xi_c\gamma$ combinations

- WA89 - Preliminary report of $\Xi_c^{+\prime}$, $\Delta M \sim 95$ MeV
- Use full CLEO-II data sample (4.8 fb^{-1})



Ξ_c' States (Preliminary)



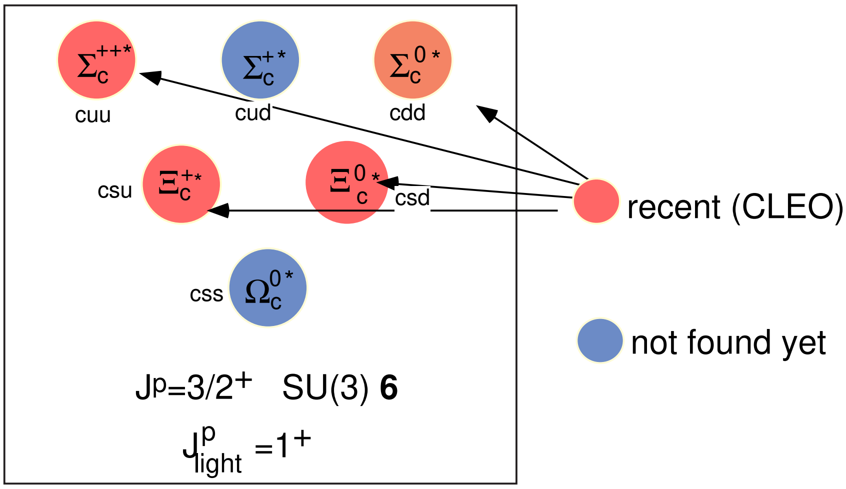
Use $\Xi_c^0 \rightarrow \Xi^-\pi^-$, $\Xi^-\pi^-\pi^0$ decay modes

Use $\Xi_c^+ \rightarrow \Xi^-\pi^+\pi^+$, $\Xi^0\pi^+\pi^0$ decay modes

- Form $\Xi_c\gamma$ combinations

- $\Delta M(\Xi_c^{0'} - \Xi_c^0) = 107.0 \pm 1.4 \pm 2.5$ MeV/c^2
- $\Delta M(\Xi_c^{+'} - \Xi_c^+) = 107.8 \pm 1.7 \pm 2.5$ MeV/c^2
CLEO CONF 97-29/EPS97 393 - preliminary results

$J^P = \frac{3}{2}^+, J^P_{light} = 1^+$ States



Unobserved States - difficult experimentally due to soft photons

- $\Omega_c^* \to \Omega_c \gamma$
- $\Sigma_c^{+*} \to \Lambda_c^+ \pi^0$

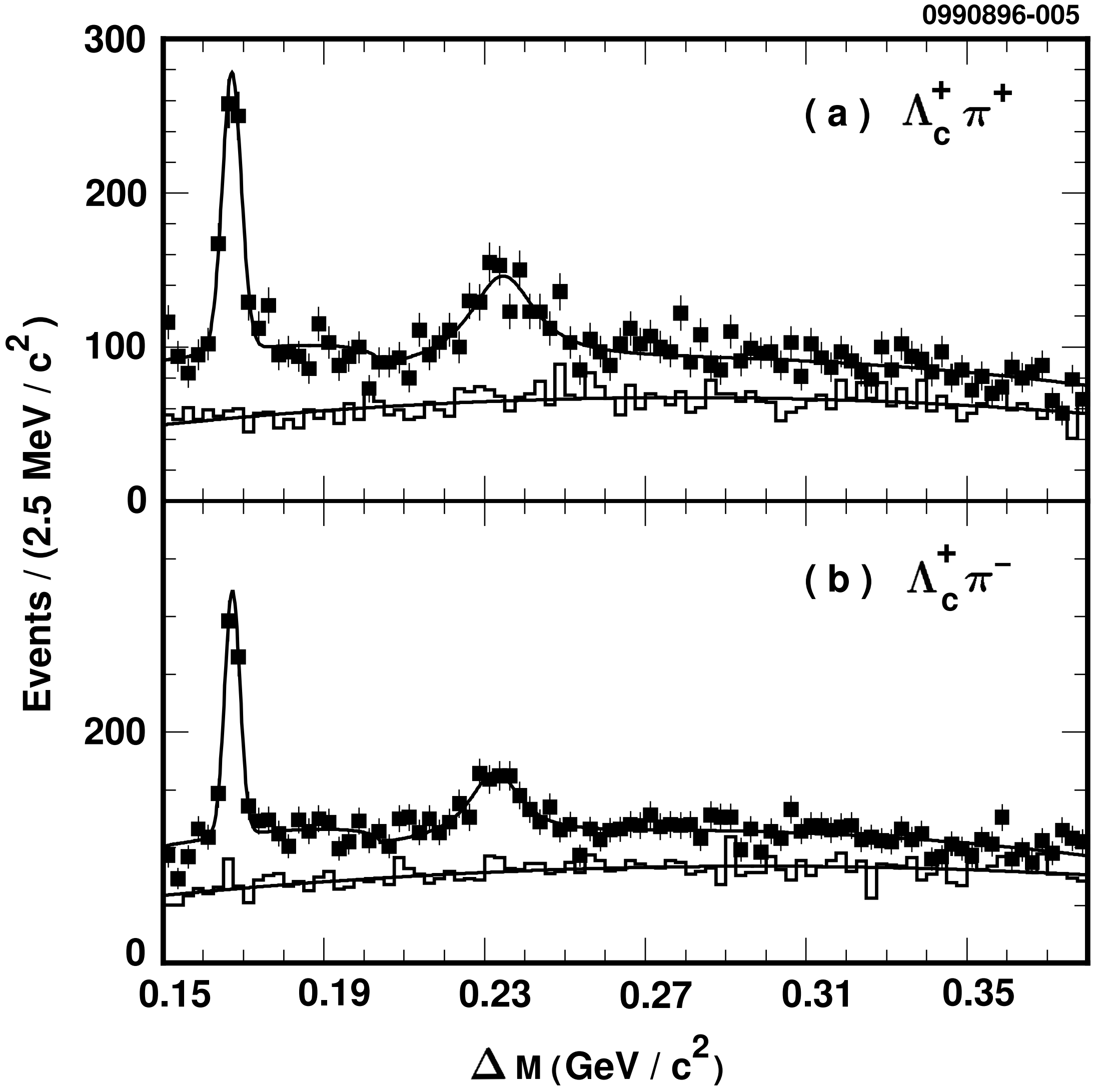
- Hyperfine Mass Splitting between $J^P = \frac{3}{2}^+$ and $J^P = \frac{1}{2}^+$ States.

  $\sim$64 MeV - M. Savage, Phys. Lett. B359, 189 (1995)

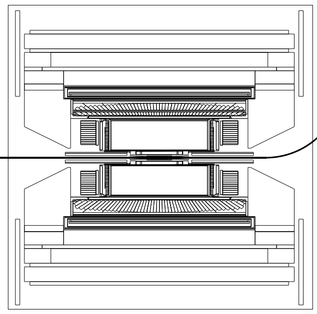
  $\sim$65 MeV - A. Falk, Phys. Rev. Lett. 77, 223 (1996)

- Σ_c^* Mass Predictions
  - $M \sim 2514$ MeV $\Longrightarrow \Delta M = 229$ MeV
    J. Rosner, Phys. Rev. D52, 6461 (1995)
  - $M \sim 2518$ MeV $\Longrightarrow \Delta M = 233$ MeV
    M. Savage

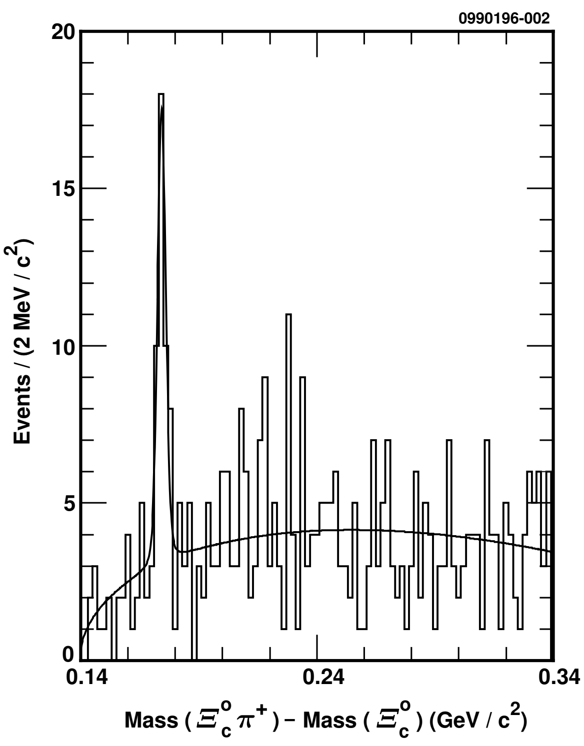
Σ_c^* States

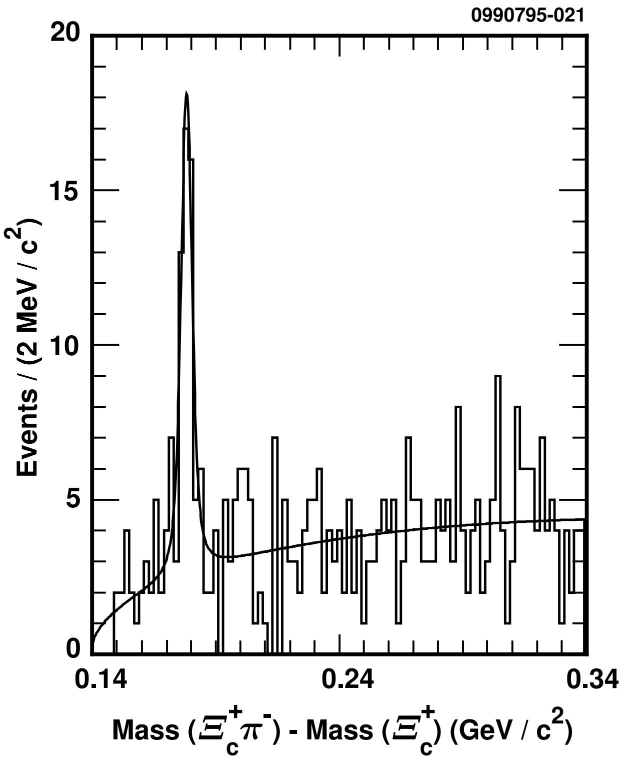


- $\Delta M(\Sigma_c^{++*} - \Lambda_c^+) = 234.5 \pm 1.1 \pm 0.8$ MeV/c^2
- $\Delta M(\Sigma_c^{0*} \quad - \Lambda_c^+) = 232.6 \pm 1.0 \pm 0.8$ MeV/c^2
  (CLEO) Phys. Rev. Lett. 78, 2304 (1997)



Ξ_c^* States



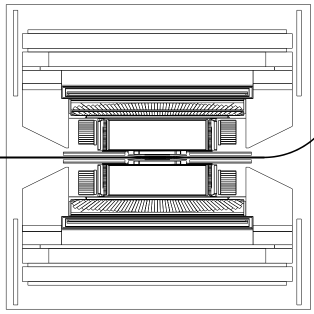


- $\Delta M(\Xi_c^{0*} - \Xi_c^+) = 178.2 \pm 0.5 \pm 1.0$ MeV/c^2
  (CLEO) Phys. Rev. Lett. 75, 4364 (1995)
- $\Delta M(\Xi_c^{+*} - \Xi_c^0) = 174.3 \pm 0.5 \pm 1.0$ MeV/c^2
  (CLEO) Phys. Rev. Lett. 77, 810 (1996)
- Theoretical Predictions (M. Savage; J. Rosner)
  $\Delta M(\Xi_c^* - \Xi_c^{'}) \sim 65$ MeV *or* $\Delta M(\Xi_c^* - \Xi_c) \sim 173$ MeV

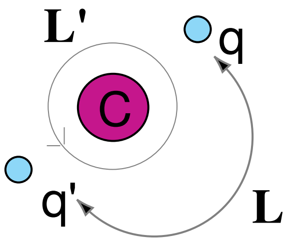
Summary of S-Wave States

- <u>$J^P = 1/2^+$ States</u>
  Observed the $\Xi_c^{0'}$ and $\Xi_c^{+'}$ states
  $\Delta M(\Xi_c^{0'} - \Xi_c^0) = 107.0 \pm 1.4 \pm 2.5$ MeV/c^2
  $\Delta M(\Xi_c^{+'} - \Xi_c^+) = 107.8 \pm 1.7 \pm 2.5$ MeV/c^2
- All members of the $J^P = 1/2^+$ multiplet have been observed

- <u>$J^P = 3/2^+$ States</u>
  Observed the Σ_c^{++*} and Σ_c^{0*} states (1997)
  Observed Ξ_c^{0*} (1995) and Ξ_c^{+*} (1996) states
- Ω_c^* - Unobserved
- Σ_c^{+*} - Unobserved Σ_c^* isospin state

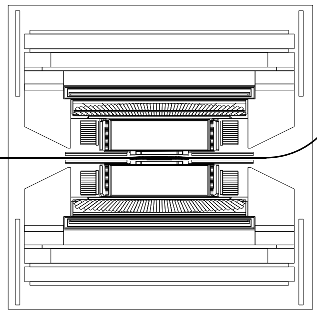


P-Wave Charmed Baryons

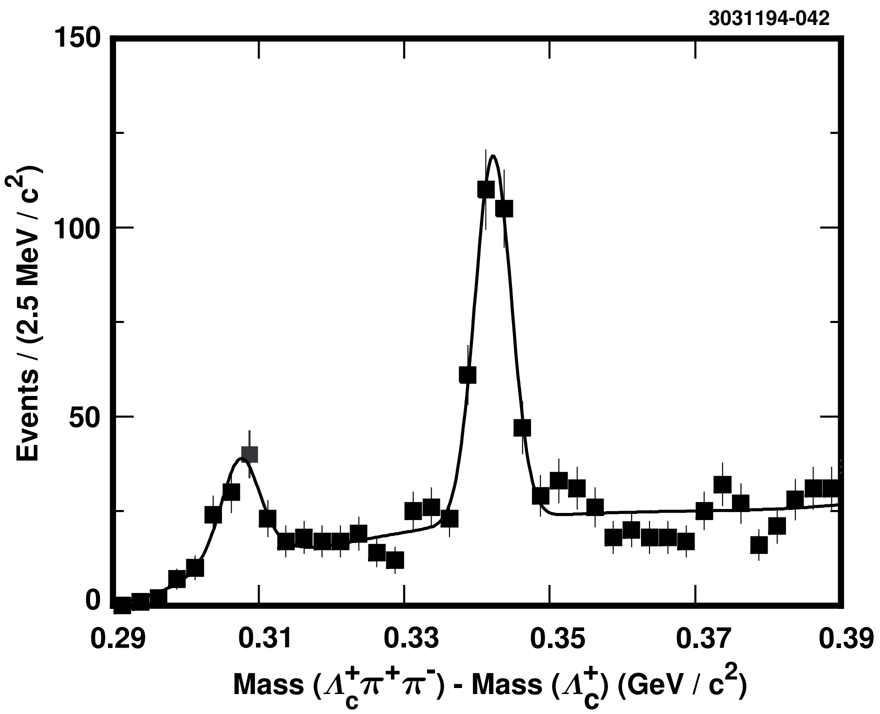


L = Relative Angular Momentum between light quarks
L' = Relative Angular Momentum between light diquark and charm quark.

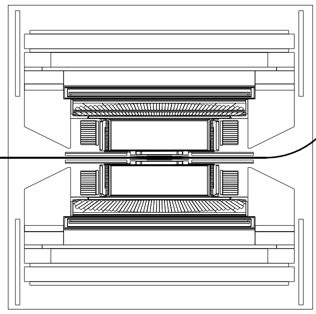
- $L = 0,\ L^{'} = 1$ are expected to be lowest mass states
- S=0 (light quark spins), 2 SU(3) $\overline{3}$ multiplets
  $J^P = \frac{1}{2}^-$ and $J^P = \frac{3}{2}^-$
- Recent Theoretical References - widths of L=1 states
  D. Pirjol and T.M. Yan, Phys. Rev. D56, 5483 (1997)
  G. Chiladze and A. Falk, Phys. Rev. D56, 6738 (1997)



P-Wave $\Lambda_{c1}{}^{*}$ States



- $\Delta M(\Lambda_{c1}^{+}(2593) - \Lambda_c^+) = 307.5 \pm 0.4 \pm 1.0$ MeV/c^2
  $\Delta M(\Lambda_{c1}^{+}(2625) - \Lambda_c^+) = 342.2 \pm 0.2 \pm 0.5$ MeV/c^2
  (CLEO) Phys. Rev. Lett. 74, 3331 (1995)
- Don't observe $\Lambda_{c1}^{+} \rightarrow \Lambda_c^+ \pi^0$ decays (Isospin violation)
  $\Longrightarrow \Lambda_c^+$ excitations
- Observe $\Lambda_{c1}^{+}(2593) \rightarrow \Sigma_c \pi \Longrightarrow J^P = \frac{1}{2}^-$
- Observe $\Lambda_{c1}^{+}(2625) \rightarrow \Lambda_c^+ \pi\pi$, ($\Sigma_c{}^{*}\pi$ kinematically forbidden)
  Expect $J^P = \frac{3}{2}^-$ state



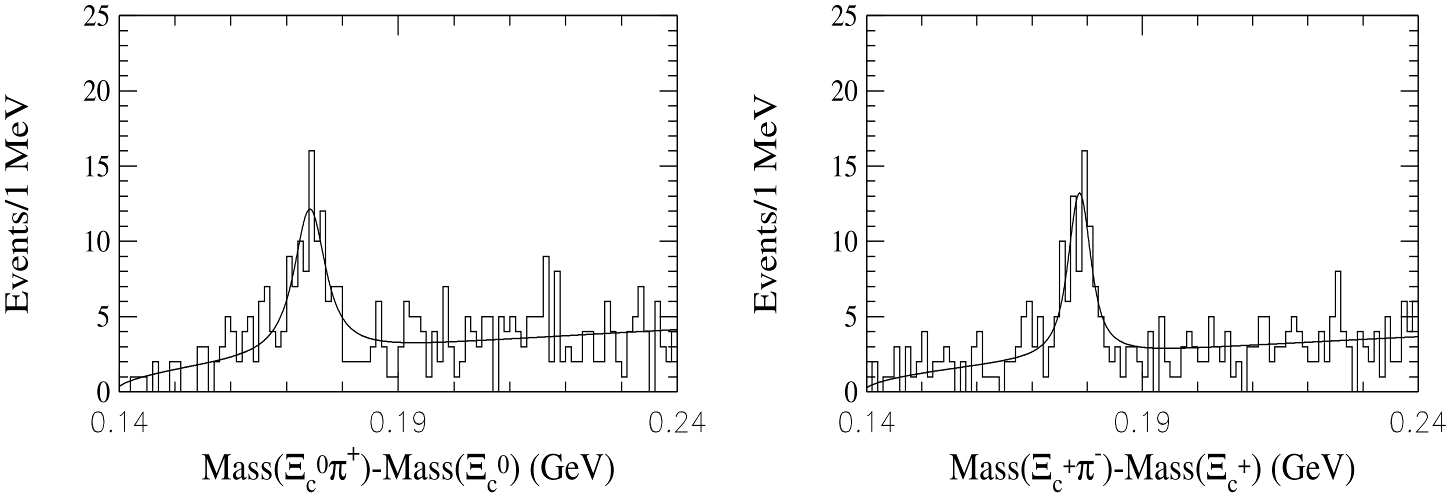
Search for P-Wave Ξ_{c1}^* States

- $J^P = \frac{1}{2}^-$ $\Xi'_{c1} \rightarrow \Xi'_c \pi$
  More difficult experimentally
- $J^P = \frac{3}{2}^-$ $\Xi_{c1} \rightarrow \Xi^*_c \pi$

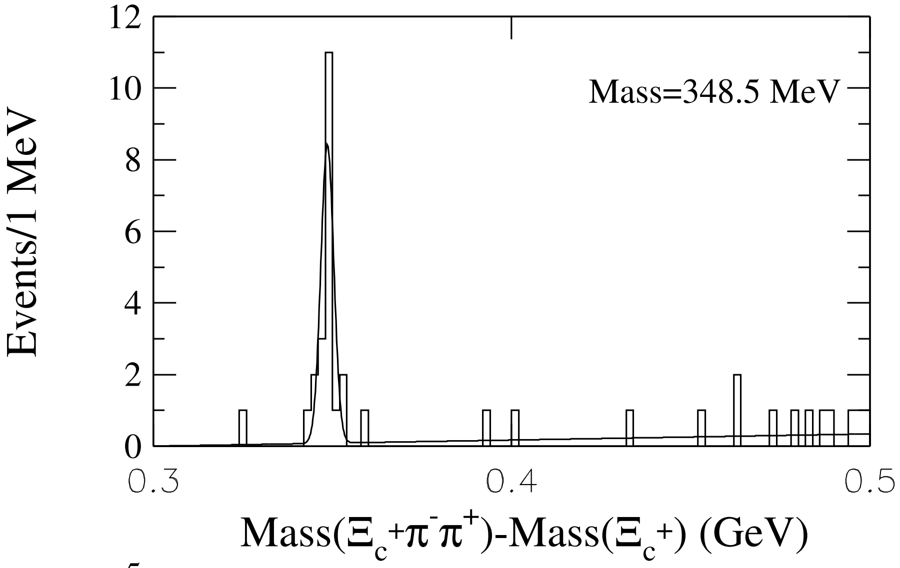
$\Longrightarrow$ Search for $J^P = \frac{3}{2}^-$ Ξ_{c1} States
Look at $\Xi^*_c \pi$ combinations

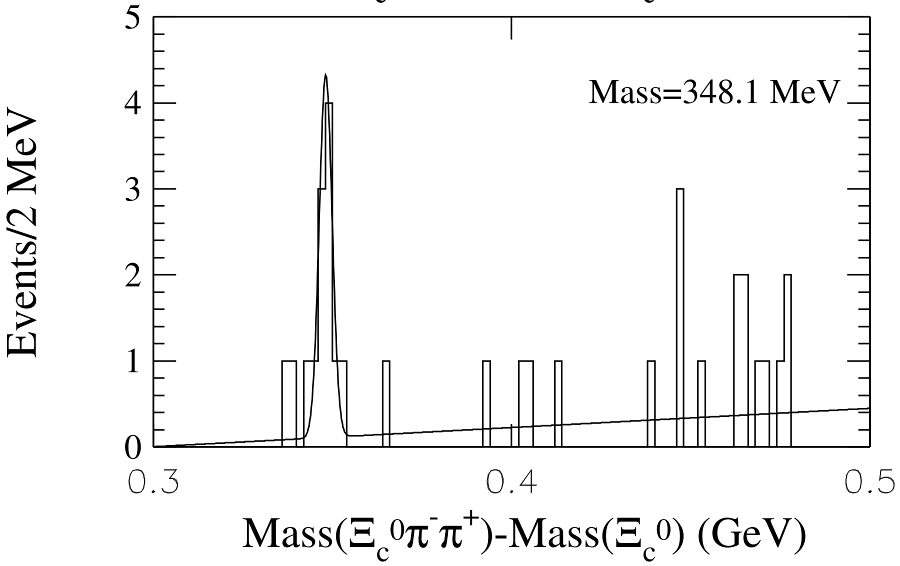
- Last summer, CLEO observed the Ξ^+_{c1} state
  CLEO CONF 97-17/EPS97 398

- Ξ^*_c Candidates - ("recompressed" data)

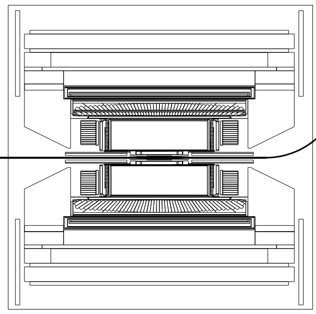


P-Wave Ξ_{c1}^* States

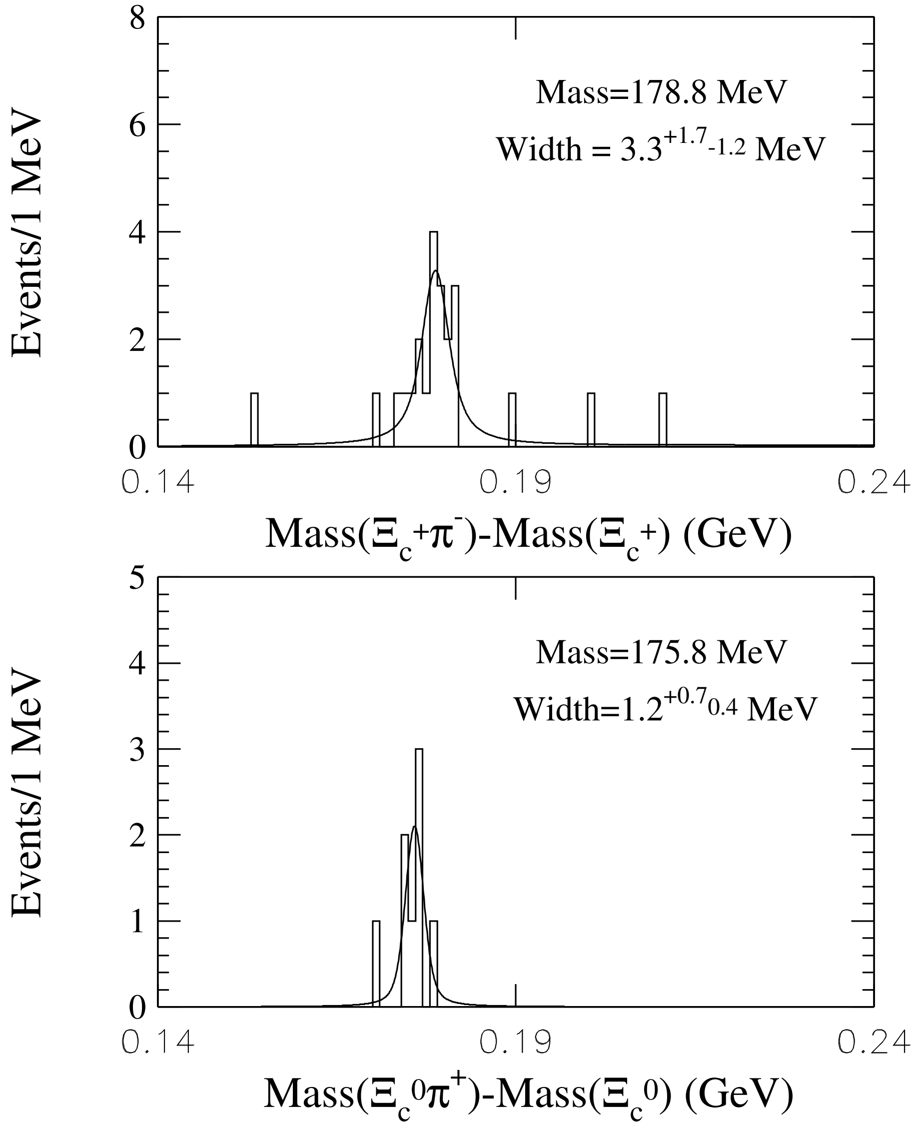




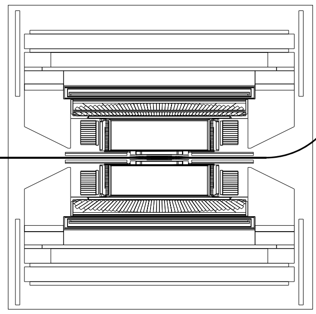
- Form $\Xi_c^* \pi$ combinations
- ΔM from last summer - CLEO CONF 97-17/EPS97 398 $\Delta M(\Xi_{c1}^{+\,*} - \Xi_c^+) = 349.4 \pm 0.7 \pm 1.0$ MeV/c^2 - PRELIMINARY
- ΔM consistent with EPS value for both states Working on the systematic errors for ICHEP



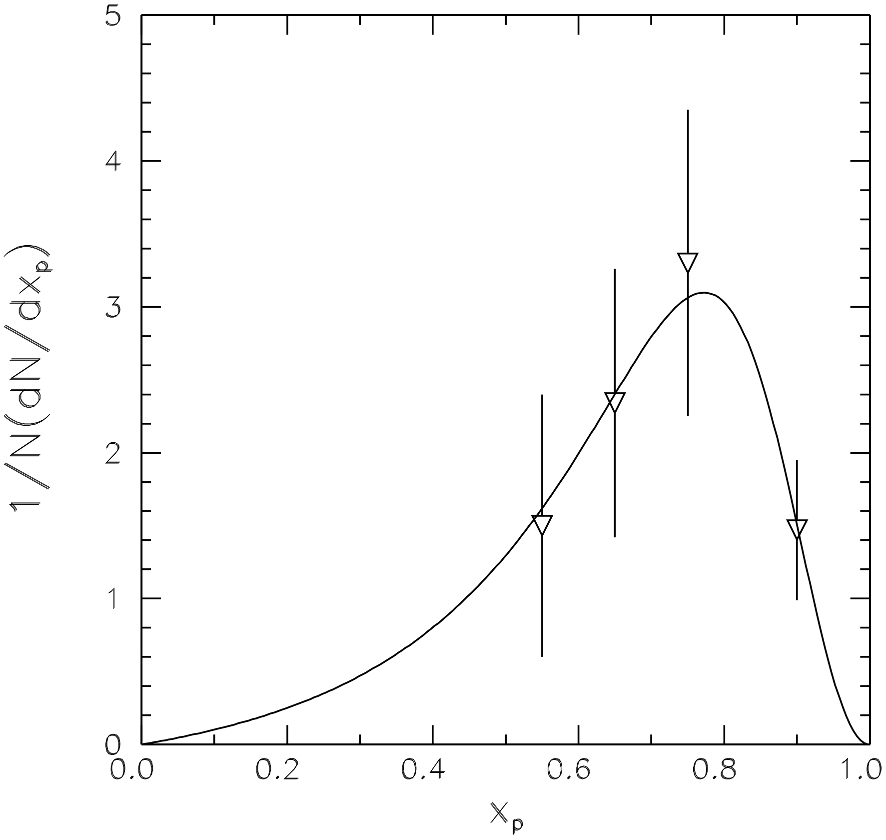
CHECK - LOOK AT Ξ_c^* WITH Ξ_{c1}^* CUT



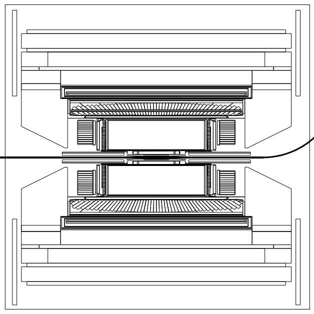
- Cut on Ξ_{c1} Mass and look at Ξ_c^* candidates



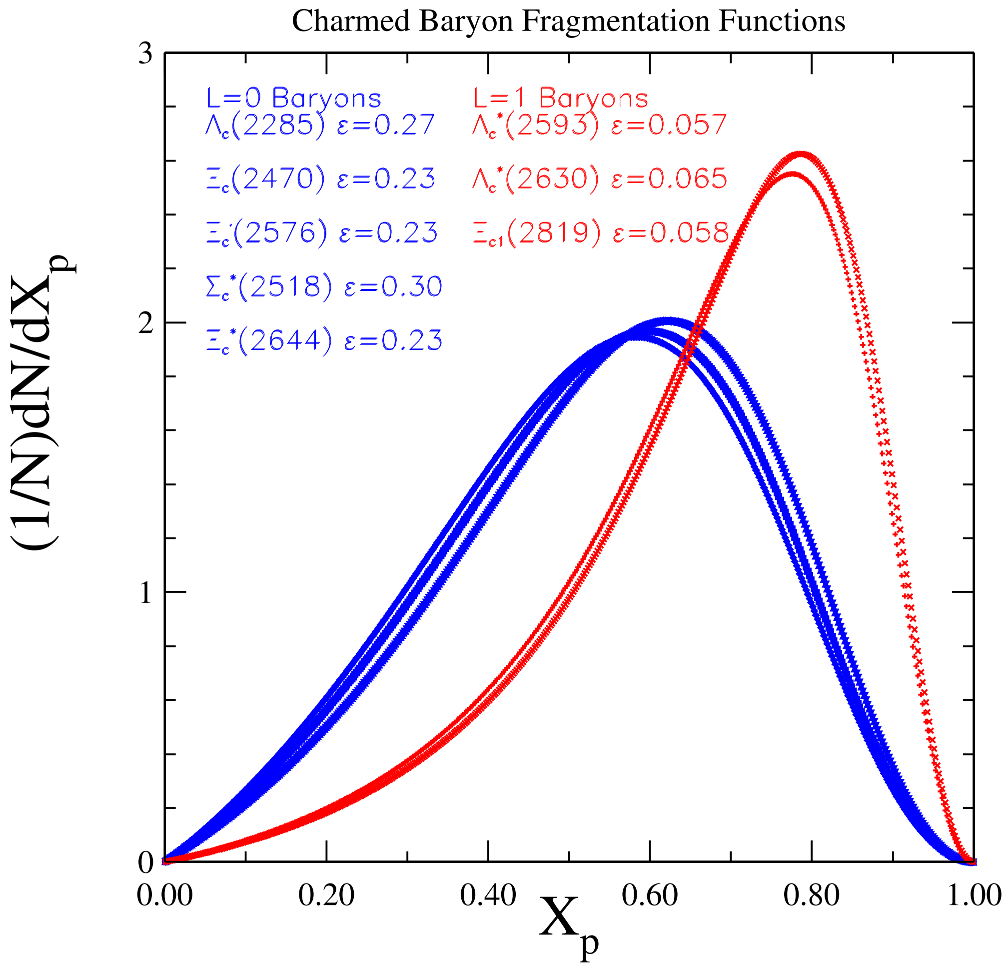
Ξ_{c1} Momentum Spectra



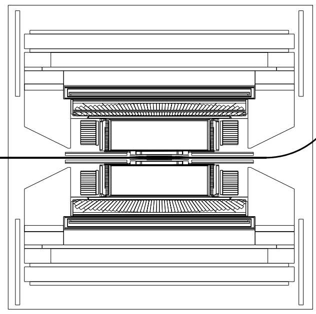
- Fit combined Ξ_{c1}^{+} and Ξ_{c1}^{0} data with $x_p > 0.5$ to the Peterson fragmentation function
- Find $\epsilon \ = 0.07^{+0.03}_{-0.02}$
- Hard fragmentation function - consistent with other L=1 states



Momentum Spectra



- Data is typically fit for $x_p > 0.5$
- Many states feed-down to Λ_c^+'s



FUTURE

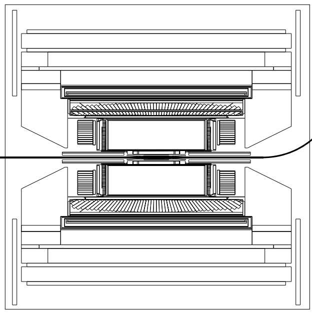
- Recently "Recompressed" the CLEO-II dataset
  Improved tracking, calibration gives better S/N
  Use additional Ξ_c decay channels

- CLEO-II.V - Addition of 3 layer silicon vertex detector
  6.0 fb^{-1} of new data with CLEO-II.V
  Analyses with Baryons in progress

  Excited charmed baryons have complicated events:
  $\Xi_{c1} \to \Xi_c^* \pi,\ \Xi_c^* \to \Xi_c \pi,\ \Xi_c \to \Xi \pi,\ \Xi \to \Lambda \pi,\ \Lambda \to p\pi$

- Mark Dickson will talk about CLEO-II.V results for B and charm meson

- CLEO-III era - greatly improved particle ID
  Goal - Very good $K - \pi$ separation
  $\Longrightarrow$ proton$-\pi-$ separation "Great"



Conclusions

- CLEO - much progress in Charmed Baryon Spectroscopy

- Observed the $\Xi_c^{+'}$ and $\Xi_c^{0'}$ States
  $\Delta M(\Xi_c^{0'} - \Xi_c^0) \ = 107.0 \pm 1.4 \pm 2.5$ MeV/c^2
  $\Delta M(\Xi_c^{+'} - \Xi_c^+) = 107.8 \pm 1.7 \pm 2.5$ MeV/c^2
  CLEO CONF 97-29/EPS97 393 (preliminary results)

- All but 2 S-wave Charmed baryons (ground state) observed (Ω_c^* and Σ_c^{+*})

- P-wave Charmed Baryons - Beginning to be Studied

- Reported on the observation of the $\Xi_{c1}^{0}{}^*$ and $\Xi_{c1}^{+}{}^*$
  $\Delta M(\Xi^*_{c1} - \Xi^{)}_c \sim 350$ MeV
  Working on ΔM systematics for ICHEP98 (Vancouver)

- 4 L=1 P-wave Charmed baryons have been studied so far

- CLEO had observed 8 new states since 1996 PDG !

- Exciting Times in Charmed Baryon Spectroscopy