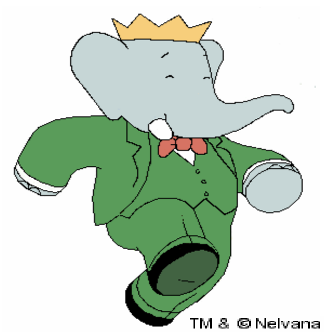
HYPERON & HYPERON RESONANCE PROPERTIES FROM CHARM BARYON DECAYS AT BABAR

Veronique Ziegler ~ The University of Iowa



Cascade Workshop
Jefferson Lab, Dec 1 – 3, 2005

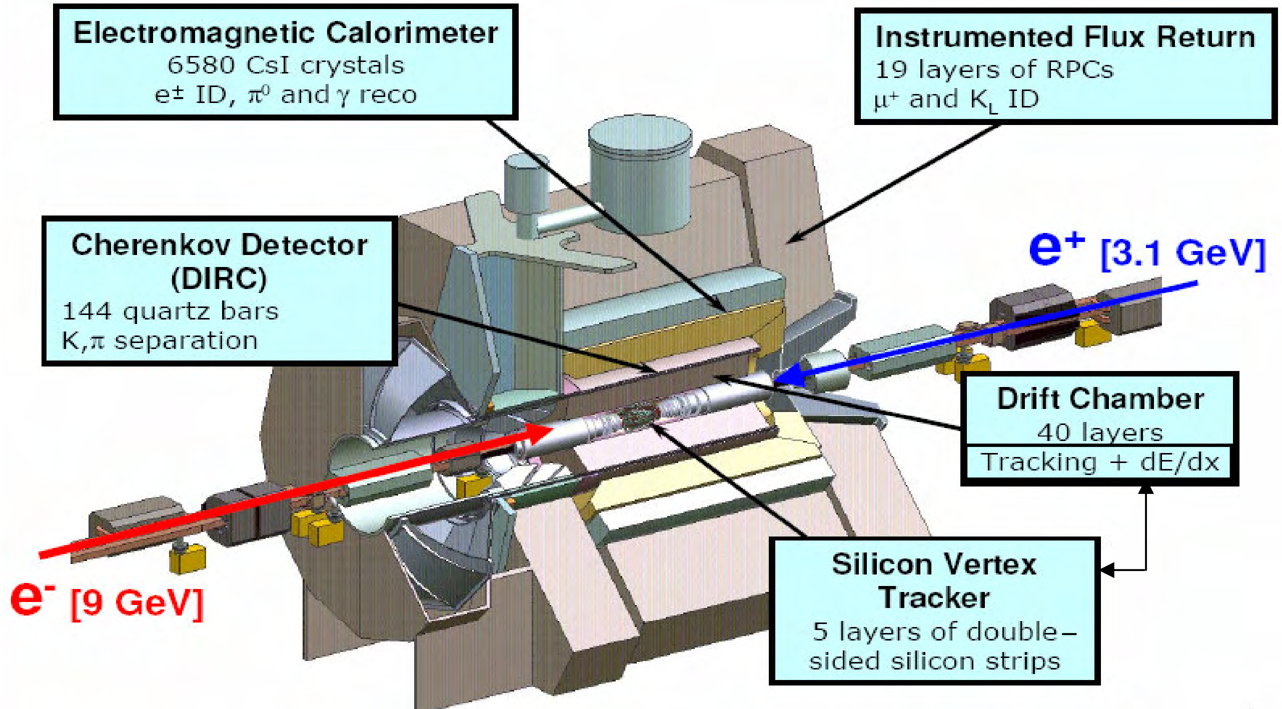
OVERVIEW

1. Introduction
   - PEP II and BaBar
2. Spin of the Ω^- from $\Xi_c^0 \rightarrow \Omega^- K^+$ and $\Omega_c^0 \rightarrow \Omega^- \pi^+$
3. Analysis of Λ_c^+ 3-Body Decays:
   - $\Lambda_c^+ \rightarrow (\Xi^- \pi^+) K^+$; the $\Xi^*(1530)$
   - $\Lambda_c^+ \rightarrow (\Lambda^0 \overline{K^0}) K^+$; the $\Xi^*(1690)$
4. Analysis of $\Xi_c^{+,0}$ 3-Body Decays:
   - $\Xi_c^+ \rightarrow (\Xi^- \pi^+) \pi^+$
   - $\Xi_c^+ \rightarrow (\Lambda^0 \overline{K^0}) \pi^+$ (if time permits)
   - $\Xi_c^0 \rightarrow (\Lambda^0 K^-) \pi^+$ (if time permits)
5. Summary

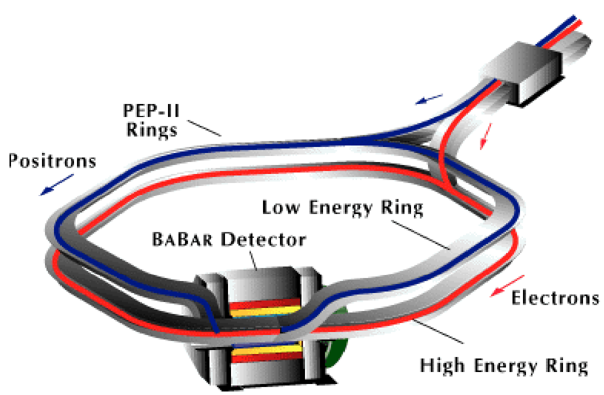
Note: (i) All results are (very) preliminary (analyses are ongoing & numbers are going to change)

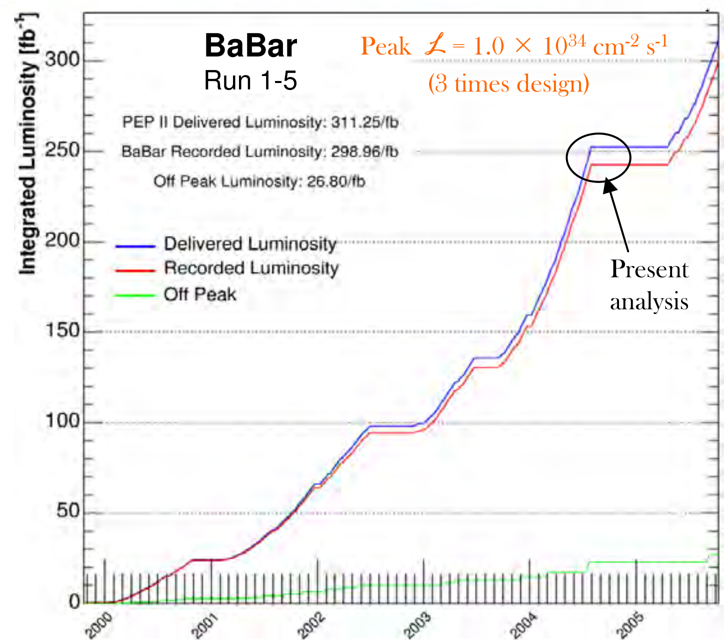
(ii) Charge conjugation is implied throughout unless indicated otherwise [e^+e^- ⇨ anti-baryon/baryon ratio ~1]

PEP II AND THE BABAR DETECTOR



PEP II





- ➥ 8 months shutdown
- ❅ Data-taking has resumed

BaBar as a Charm Baryon Factory

Present data sample contains:

- > 300 M $\Upsilon(4S) \rightarrow B\bar{B}$ events
- > 900 M $e^+e^- \rightarrow q\bar{q}$ events
- > 400 M $e^+e^- \rightarrow c\bar{c}$ events

⇨ **Charm Baryon (& Meson) Factory**

⇩

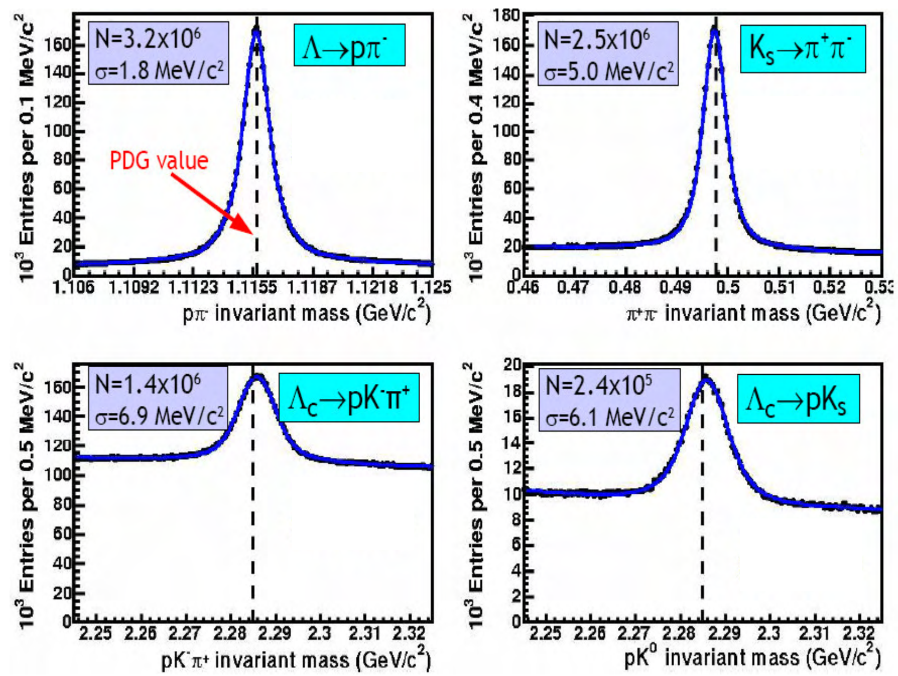
Large Samples of Charm Baryon Two-body & Quasi-two-body Decays

⇩

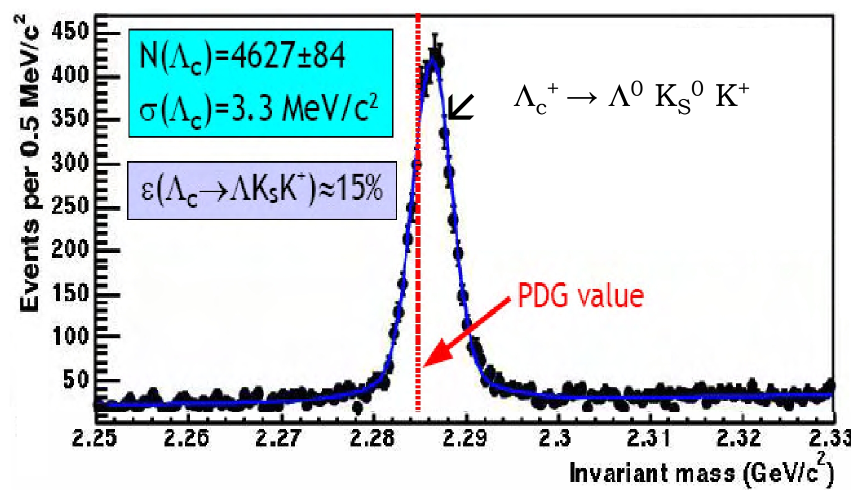
Hyperon & Hyperon Resonance Cottage Industry

Excellent resolution

High statistics



Good statistics in rare decay modes



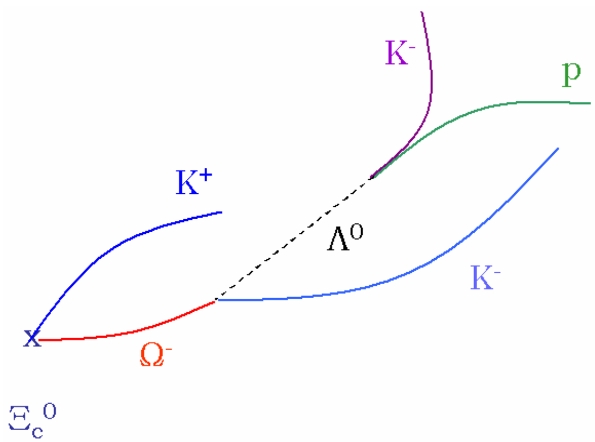
Ref. PRD **72**, 052006 (2005) [Λ_c^+ Precision Mass Measurement]

The Ω^- Spin measured

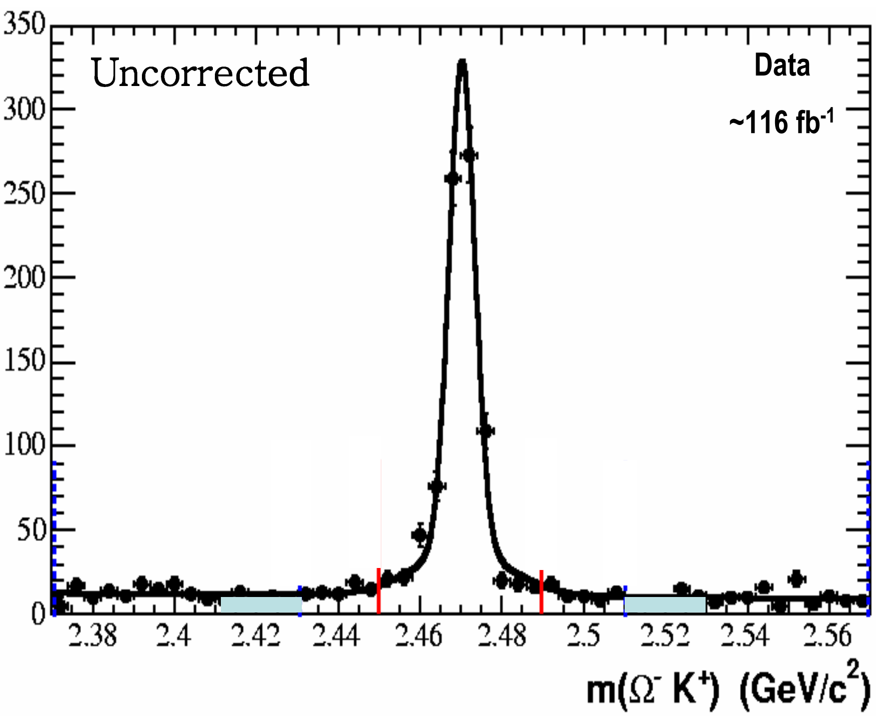
- from $\Xi_c^0 \rightarrow \Omega^- K^+$ decays
- from $\Omega_c^0 \rightarrow \Omega^- \pi^+$ decays

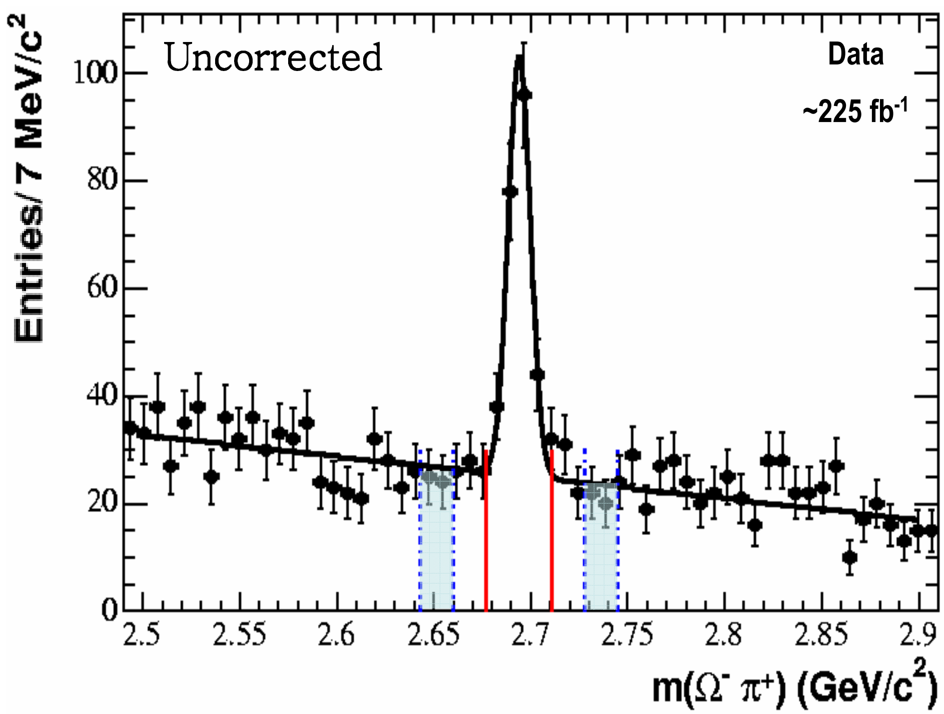
- The present analyses *ASSUME* that the Λ_c^+, $\Xi_c^{+,0}$ and the Ω_c^0 have spin 1/2.
- We *MAY* be able to extend the present analyses to establish this.
- Any ideas, suggestions, etc. concerning this would be most welcome!

Invariant Mass Distributions for $\Xi_c^0 \rightarrow \Omega^- K^+$ and $\Omega_c^0 \rightarrow \Omega^- \pi^+$

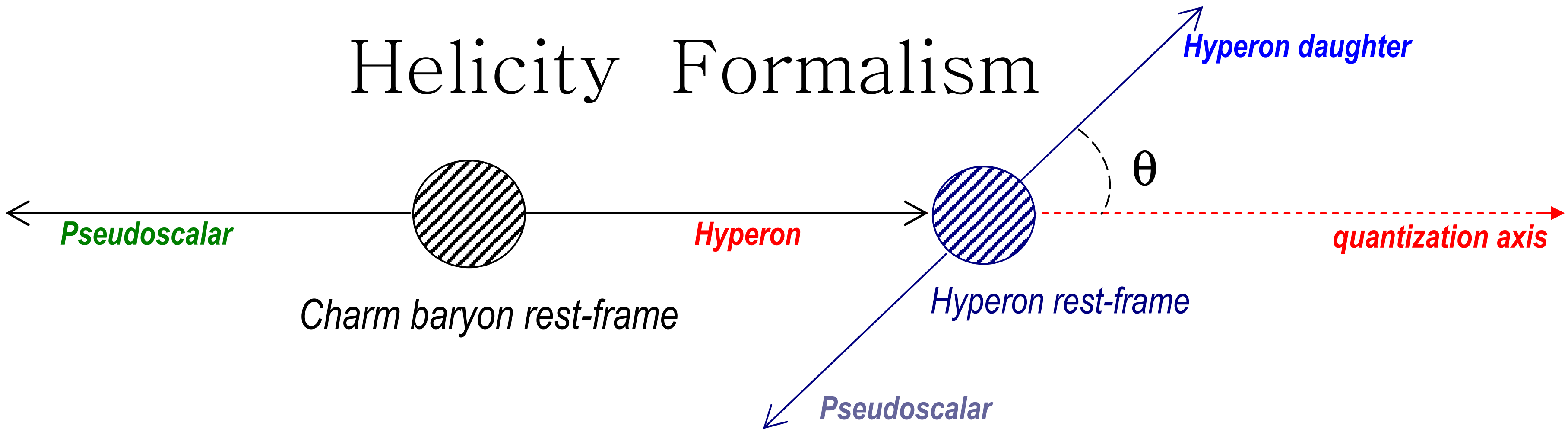


- PID Information
  - →Proton, →Kaon, →π^+, π^- : dE/dx & Cherenkov info (DIRC)
- 3-σ mass cut on intermediate states
- interm^{d}. state *mass-constraineds [Λ, Ω]*
- $p^*(\Omega_c^0) > 2.25$ GeV/c [reduces background]
- $L_\Lambda > +1.5$ mm *[sign ⇨ outgoing].*
- $r_\Omega > +2.0$ mm *[sign ⇨ outgoing].*





Helicity Formalism



$\Xi_c^0 \longrightarrow K^+ \; \Omega^- \longrightarrow \Lambda^0 \; K^-$

$J = 1/2$ $\quad\lambda_K = 0$ $\quad\lambda_f = \pm 1/2$ $\quad\lambda_K = 0$

$m = +1/2$ - - - - - - - - → $\lambda_i = +1/2$

$m = -1/2$ - - - - - - - - → $\lambda_i = -1/2$

☞ $J(\Xi_c^0) = 1/2$ ⇨ in Ξ_c^0 rest-frame $m = \pm 1/2$ along z (quantization) axis

☞ no angular momentum projection w.r.t. quantization axis ⇨ Ω^- helicity, $\lambda_i = \pm 1/2$

☞ final state helicity $\lambda_f = \lambda_f(\Lambda^0) - \lambda_f(\text{pseudoscalar}) = \pm 1/2$

☞ Decay amplitude for $\Omega^- \longrightarrow \Lambda^0 K^-$: $A^J_{\lambda_i \lambda_f} = D^{J*}_{\lambda_i \lambda_f}(\phi, \theta, 0) A_{\lambda_f}$ ← Does not depend on λ_i [Wigner-Eckart theorem]

↳ <u>Total Intensity</u>:

$$I \propto \frac{1}{2} \sum_{\lambda_i, \lambda_f} \rho_i \left| A^J_{\lambda_i \lambda_f} \right|^2 = \frac{1}{2} \sum_{\lambda_i, \lambda_f} \rho_i \left| D^{J*}_{\lambda_i \lambda_f}(\phi, \theta, 0) A_{\lambda_f} \right|^2$$

ρ_i: density matrix element for Ω^- spin projection i
= density matrix element for charm baryon parent

Helicity Formalism (2)

$$\mathrm{I} \propto \frac{1}{2} \sum_{\substack{\lambda_i = \pm 1/2, \\ \lambda_f = \pm 1/2}} \rho_i \left| D^{J*}_{\lambda_i \lambda_f}(\phi, \theta, 0) A_{\lambda_f} \right|^2$$

$$\propto \frac{1}{2} |A_{1/2}|^2 \left[\rho_{1/2} \left| D^{J*}_{1/2\,1/2}(\phi,\theta,0) \right|^2 + \rho_{-1/2} \left| D^{J*}_{-1/2\,1/2}(\phi,\theta,0) \right|^2 \right]$$

$$+ \frac{1}{2} |A_{-1/2}|^2 \left[\rho_{1/2} \left| D^{J*}_{1/2\,-1/2}(\phi,\theta,0) \right|^2 + \rho_{-1/2} \left| D^{J*}_{-1/2\,-1/2}(\phi,\theta,0) \right|^2 \right]$$

$$D^{J*}_{\lambda_i \lambda_f}(\phi,\theta,0) = e^{i\phi} d^J_{\lambda_i \lambda_f}(\theta)$$

$$\propto \frac{1}{2} |A_{1/2}|^2 \left[\rho_{1/2} \left| d^{J}_{1/2\,1/2}(\theta) \right|^2 + \rho_{-1/2} \left| d^{J}_{-1/2\,1/2}(\theta) \right|^2 \right]$$

$$+ \frac{1}{2} |A_{-1/2}|^2 \left[\rho_{1/2} \left| d^{J}_{1/2\,-1/2}(\theta) \right|^2 + \rho_{-1/2} \left| d^{J}_{-1/2\,-1/2}(\theta) \right|^2 \right]$$

Define $\beta = (\rho_{1/2} - \rho_{-1/2}) \left[\dfrac{|A_{1/2}|^2 - |A_{-1/2}|^2}{|A_{1/2}|^2 + |A_{-1/2}|^2} \right]$

$\left(\dfrac{\rho_{1/2} - \rho_{-1/2}}{\rho_{1/2} + \rho_{-1/2}} \right) \neq 0$ (where $\rho_{1/2} + \rho_{-1/2} = 1$) $\rightarrow$ possible since Ξ_c^0 decay violates parity conservation.

$\left[\dfrac{|A_{1/2}|^2 - |A_{-1/2}|^2}{|A_{1/2}|^2 + |A_{-1/2}|^2} \right] \neq 0$ $\rightarrow$ possible since Ω^- decay violates parity conservation.

$$\Rightarrow \mathrm{I} \propto 1 + \beta \cos\theta \quad J=1/2$$

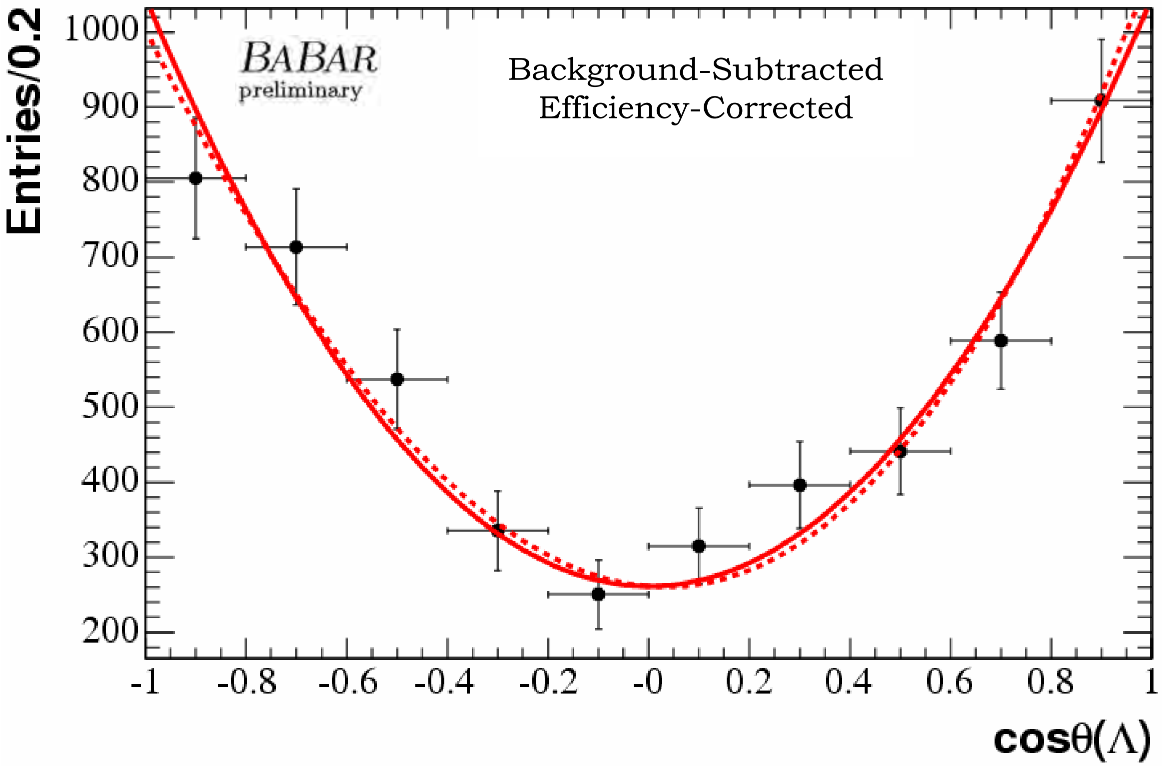
$$\Rightarrow \mathrm{I} \propto \frac{1}{4}\left(1 + 3\cos^2\theta + \beta\cos\theta\left(9\cos^2\theta - 5\right)\right) \quad J=3/2$$

c.f. E. Fermi et. al., PR 85, 936 (1952)
π & p elastic scattering (β = 0)
J=1/2 ⇨ flat , J=3/2 ⇨ 1 + 3cos²θ

$$\Rightarrow \mathrm{I} \propto \frac{1}{4}\left(1 - 2\cos^2\theta + 5\cos^4\theta + \beta\cos\theta\left(25\cos^4\theta - 26\cos^2\theta + 5\right)\right) \quad J=5/2$$

Spin measurement of Ω^- from $\Xi_c^0 \rightarrow \Omega^- K^+$, $\Omega^- \rightarrow \Lambda^0 K^-$ decays

Angular Distribution Parametrizations for J_Ω=3/2 hypothesis



Negligible Decay Asymmetry Parameter

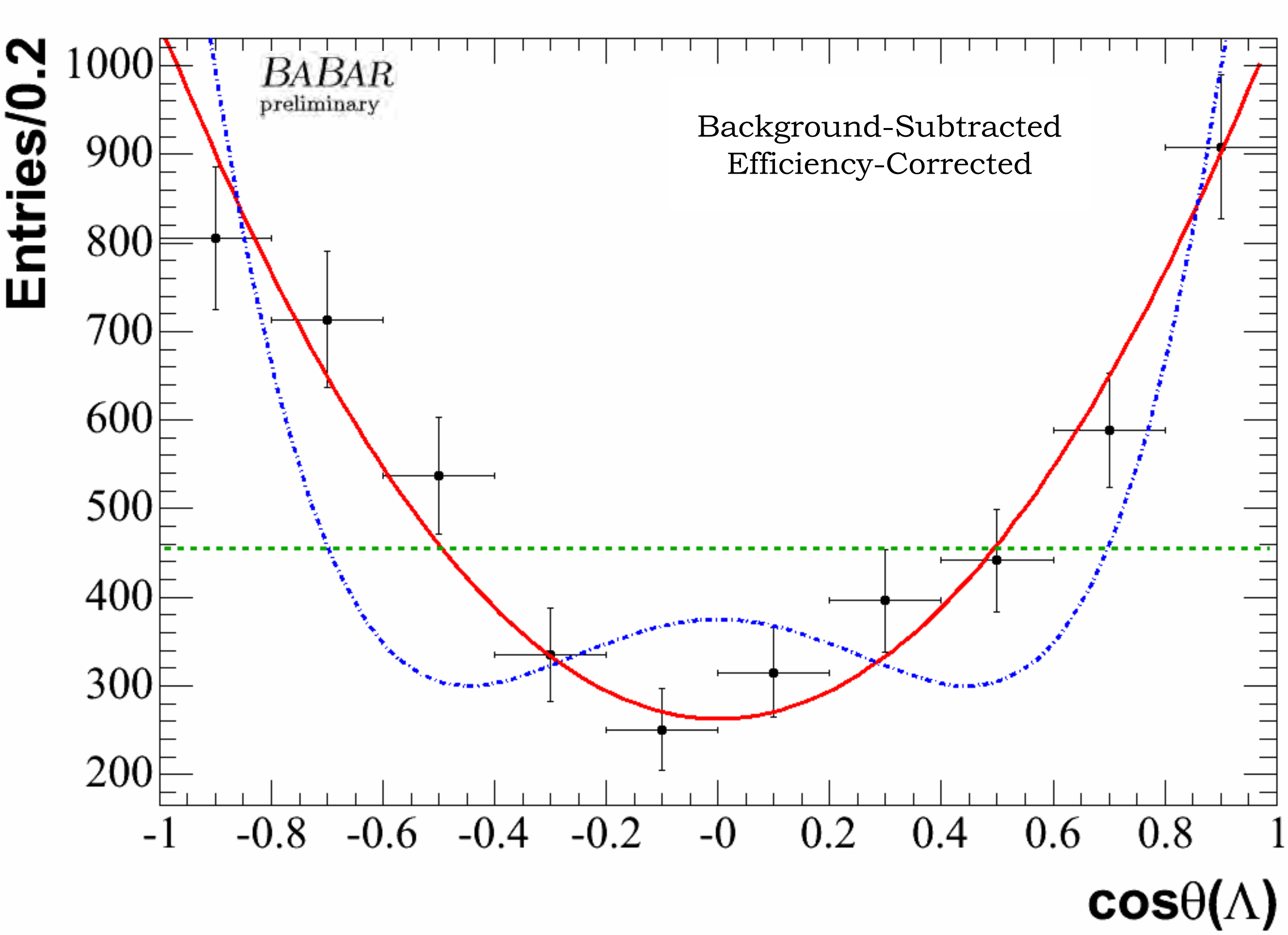
$\beta = 0.04 \pm 0.06$

$$I \propto \frac{1}{4}\left(1 + 3\cos^2\theta\right)$$ → No Asymmetry $\beta = 0$

$$I \propto \frac{1}{4}\left(1 + 3\cos^2\theta + \beta\cos\theta\left(9\cos^2\theta - 5\right)\right)$$ → Asymmetry

Fit for $\beta \rightarrow$ $\beta = 0.04 \pm 0.06$

Spin measurement of Ω^- from $\Xi_c^0 \rightarrow \Omega^- K^+$, $\Omega^- \rightarrow \Lambda^0 K^-$ decays



$J_\Omega = 1/2 \Rightarrow I \propto 1 \rightarrow$ Fit Prob $= 10^{-17}$

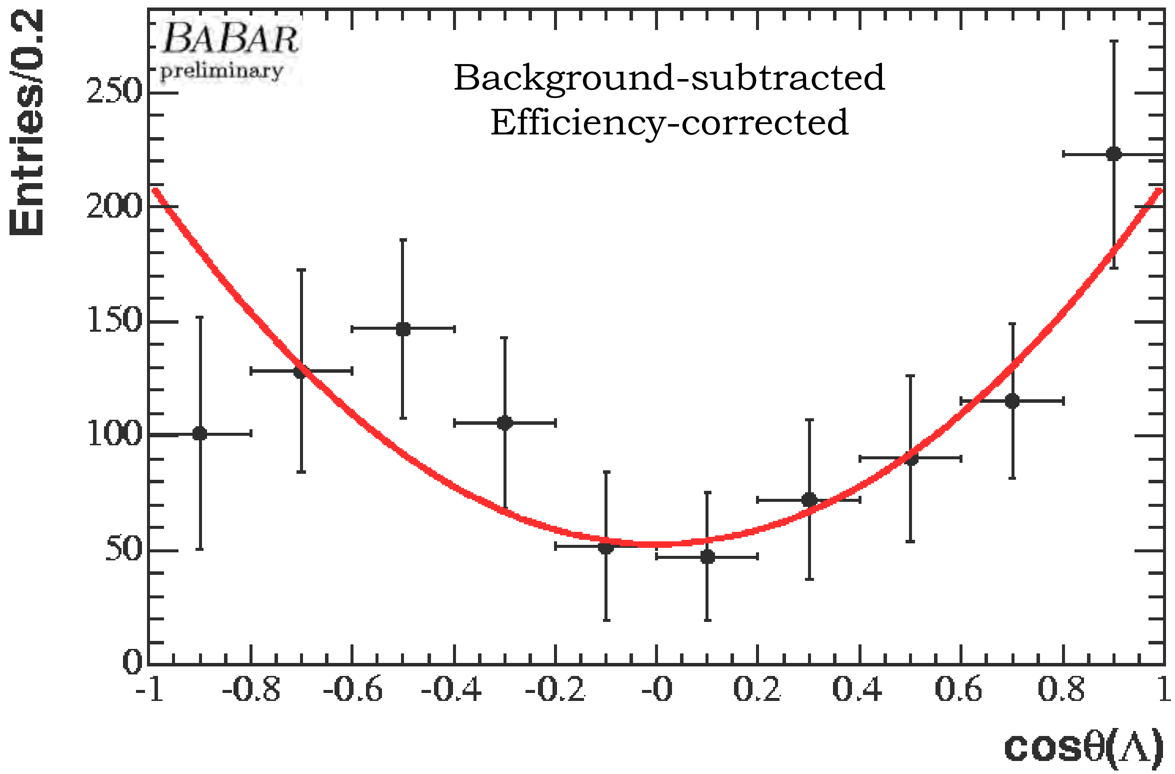
$J_\Omega = 3/2 \Rightarrow I \propto (1 + 3\cos^2\theta) \rightarrow$ Fit Prob $= 0.64$

$J_\Omega = 5/2 \Rightarrow I \propto (1 - 2\cos^2\theta + 5\cos^4\theta) \rightarrow$ Fit Prob $= 10^{-7}$

Spin measurement of Ω_c^0 from $\Omega_c^0 \rightarrow \Omega^- \pi^+$, $\Omega^- \rightarrow \Lambda^0 K^-$ decays

Fit parametrization $\alpha(1 + 3\cos^2\theta)$ for $J_\Omega = 3/2$ hypothesis

→ Fit Prob = 0.69; $J(\Omega^-) = 1/2$ & $J(\Omega^-) = 5/2$ ***consistent*** with results from $\Xi_c^0 \rightarrow \Omega^- \pi^+$



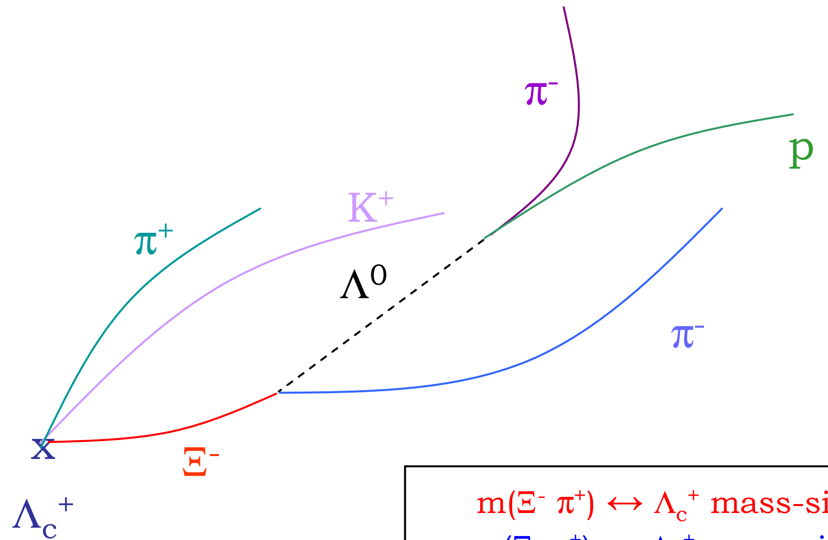
Conclusion: $J(\Omega^-) = 3/2$ [Assuming $J(\Xi_c^0) = J(\Omega_c^0) = 1/2$]

Extending the Spin Formalism to 3-body Decays

- The $\Xi(1530)^0$ Spin from $\Lambda_c^+ \rightarrow (\Xi^- \pi^+) K^+$
  - also mass, width info.
  - amplitude analysis (to be done)
- The $\Xi(1690)^0$ Spin from $\Lambda_c^+ \rightarrow (\Lambda^0 K_S^0) K^+$
  - also mass, width info.
  - amplitude analysis (to be done)
  - $(\Xi^-\pi^+)/(\Lambda\overline{K}^0)$ Branching Ratio Limit (to be done)

"...nothing of significance on Ξ resonances has been added since our 1988 edition." [PDG(2004), p 967]

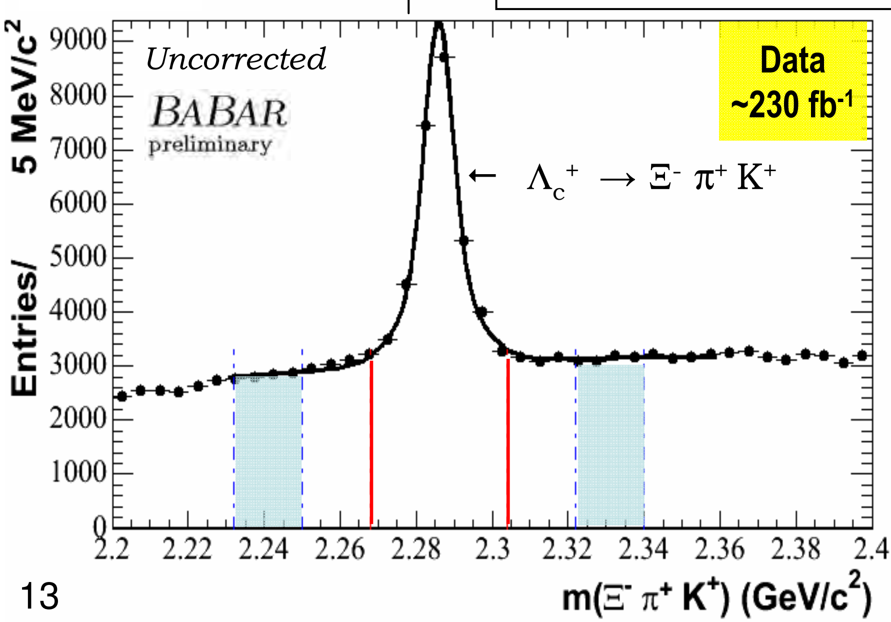
Reconstructed $\Lambda_c^+ \rightarrow \Xi^- \pi^+ K^+$, $\Xi^- \rightarrow \Lambda^0 \pi^-$ Events

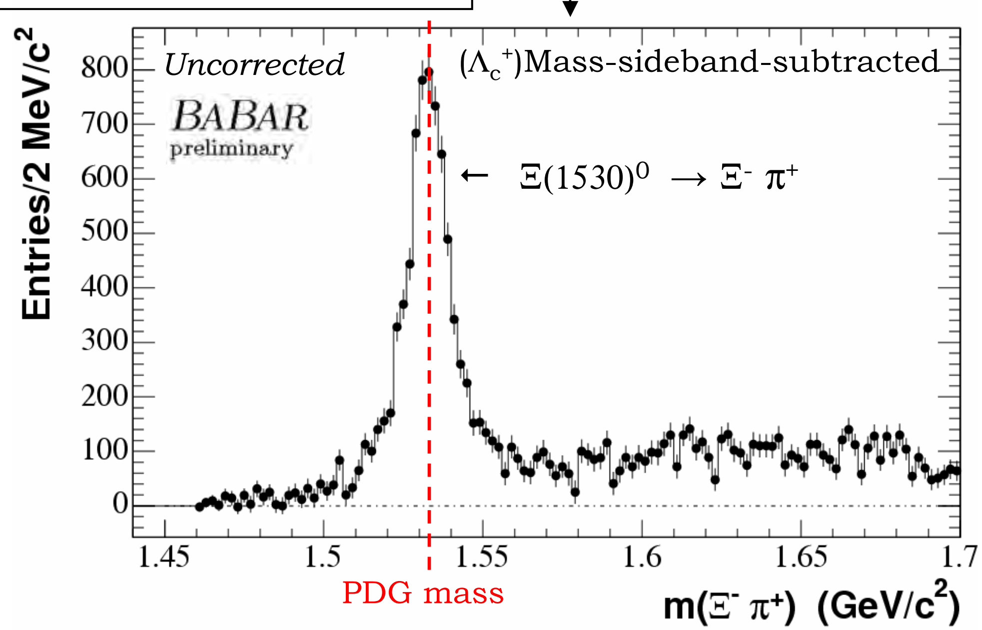


- PID Information
  - →Proton
  - →Kaon
  - →π^+, π^-
  - } dE/dx & Cherenkov info (DIRC)
- 3-σ mass cut on intermediate states
- interm[d]. states *mass-constrained [Λ, Ξ⁻]*
- L_Λ > +1.5 mm *[sign ⇨ outgoing].*
- r_Ξ > +1.5 mm *[sign ⇨ outgoing].*

m(Ξ^- π^+) ↔ Λ_c^+ mass-signal region
– m(Ξ^- π^+) ↔ Λ_c^+ mass-sideband region

m(Ξ^- π^+) ↔ (Λ_c^+) mass-sideband-subtracted

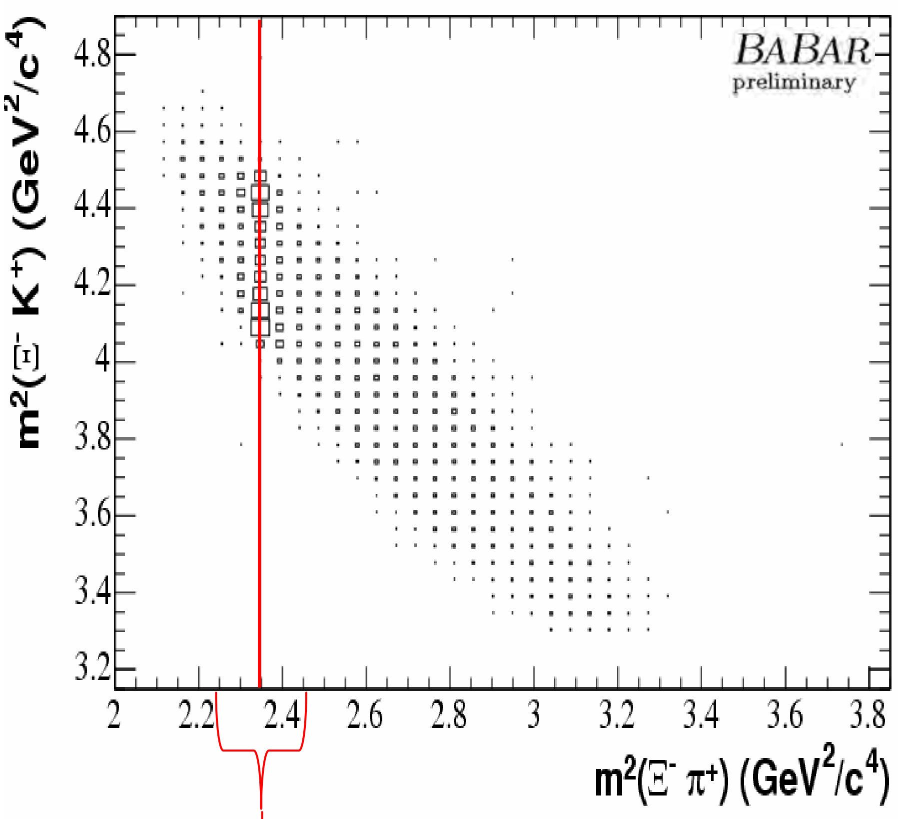


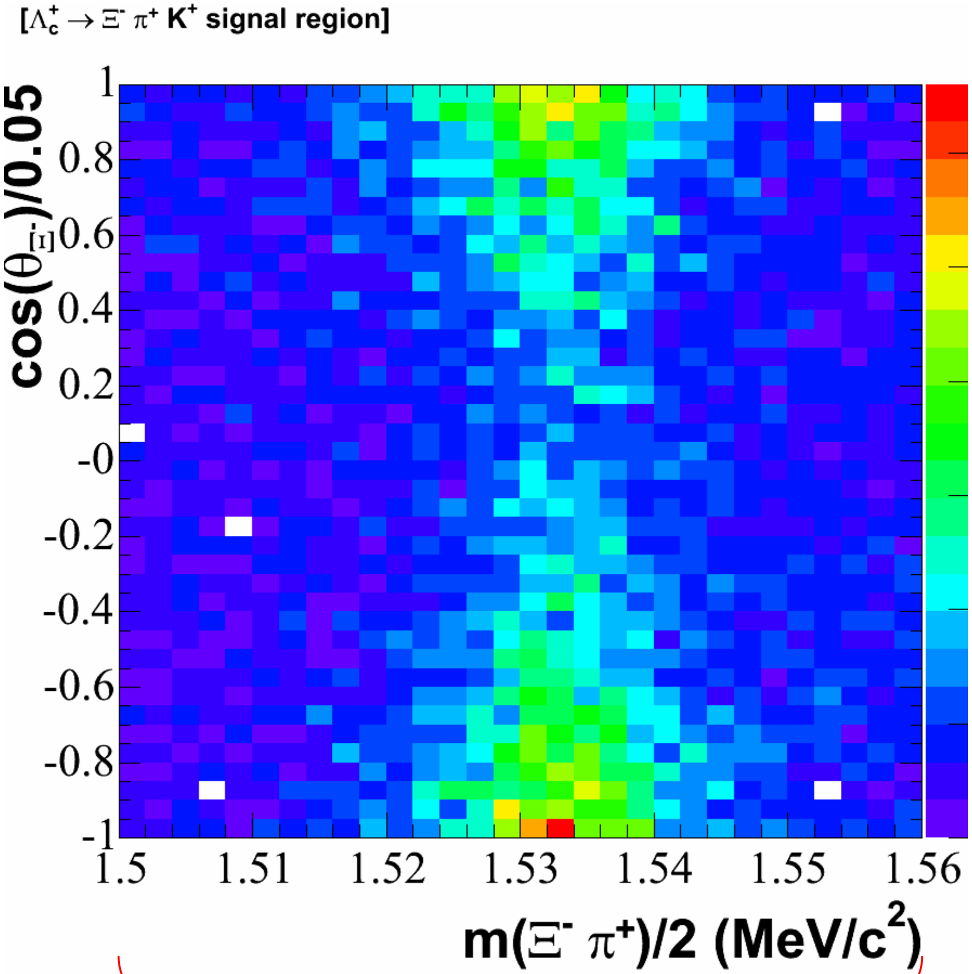


Resonant Structures in $\Lambda_c^+ \rightarrow \Xi^- \pi^+ K^+$, $\Xi^- \rightarrow \Lambda^0 \pi^-$ Events

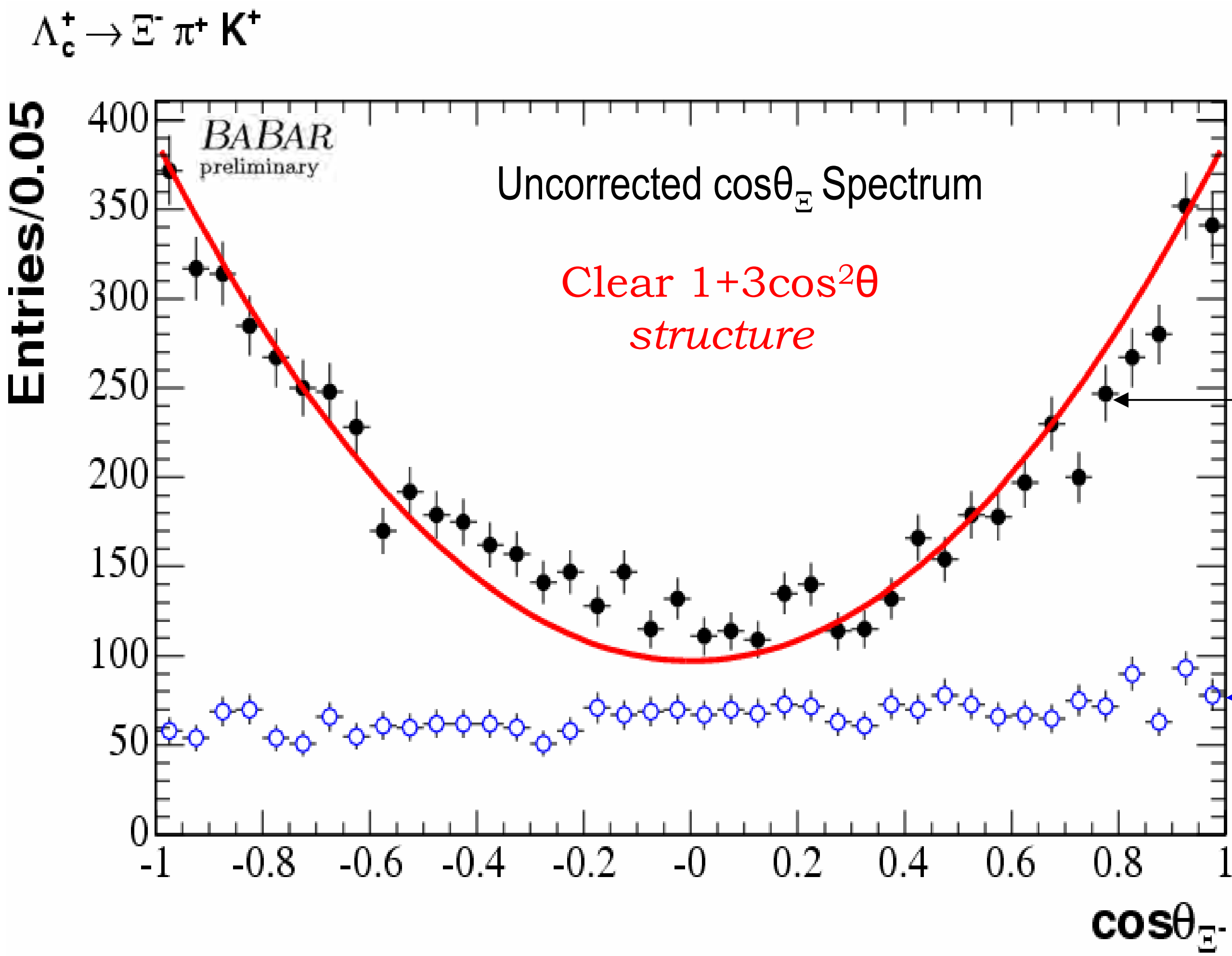
Only ***obvious*** structure:

$\Xi(1530)^0 \rightarrow \Xi^- \pi^+$





Spin measurement of $\Xi^0(1530)$ from $\Lambda_c^+ \to \Xi^0(1530)\, K^+$, $\Xi^0(1530) \to \Xi^- \pi^+$ decays



α(1 + 3 cos^{2}θ) for J=3/2 hypothesis

$\Xi^0(1530)$ Signal Region

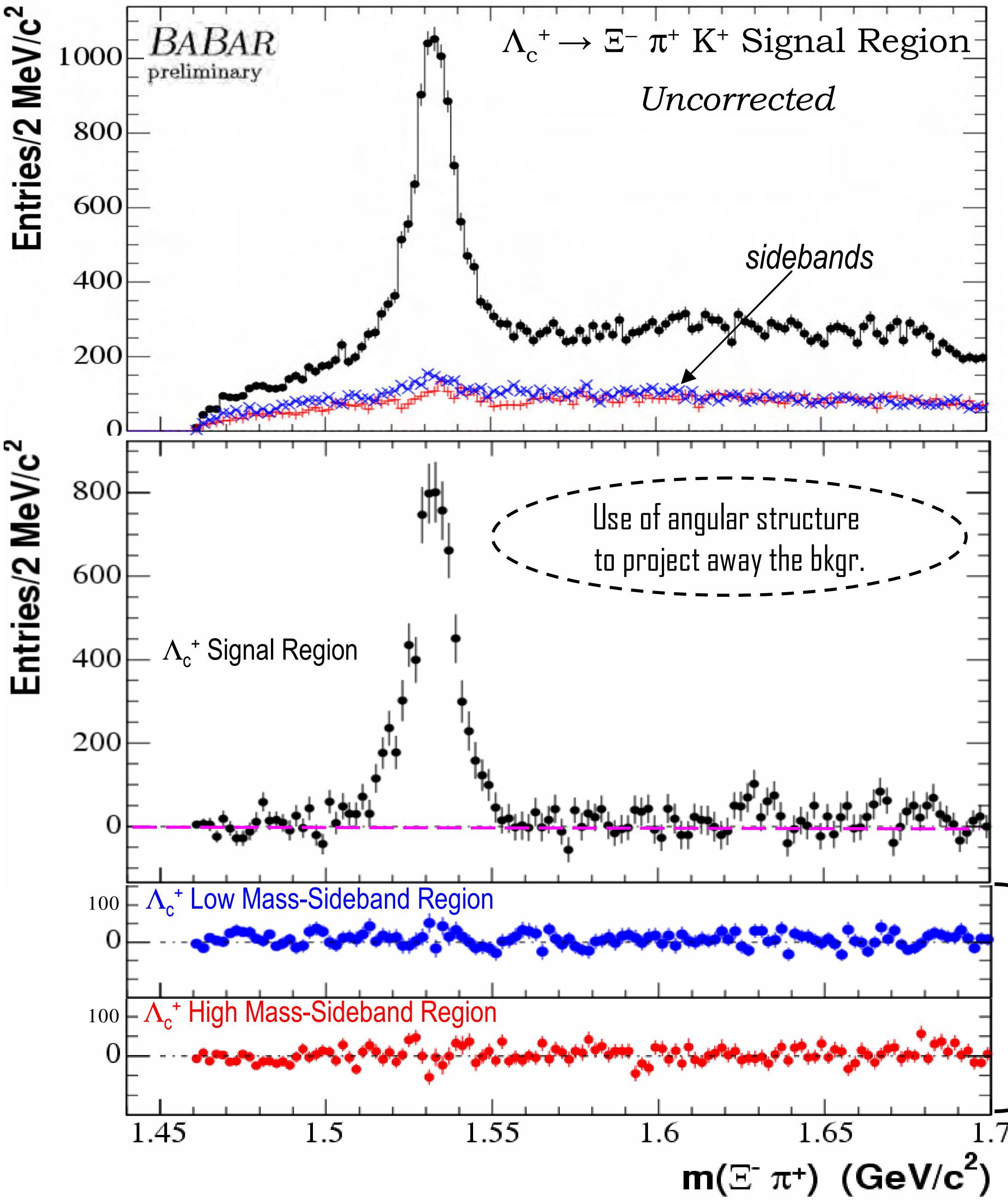
[Not mass-sideband-subtrated]

$\Xi^0(1530)$ Mass-Sideband Regions

Skewed distribution due to:

- Efficiency loss at small angles ➔ Not big effect
- ($\Xi^- \pi^+$) system decay asymmetry ➔ S-P wave interference (next slides)

Using the angular structure of $\Xi(1530)^0 \rightarrow \Xi^- \pi^+$ candidates to project away background events



For pure spin 3/2:

$$dN/d\cos\theta = \alpha(1 + 3\cos^2\theta)$$

⇩

Legendre polynomials orthogonality condition

⇩

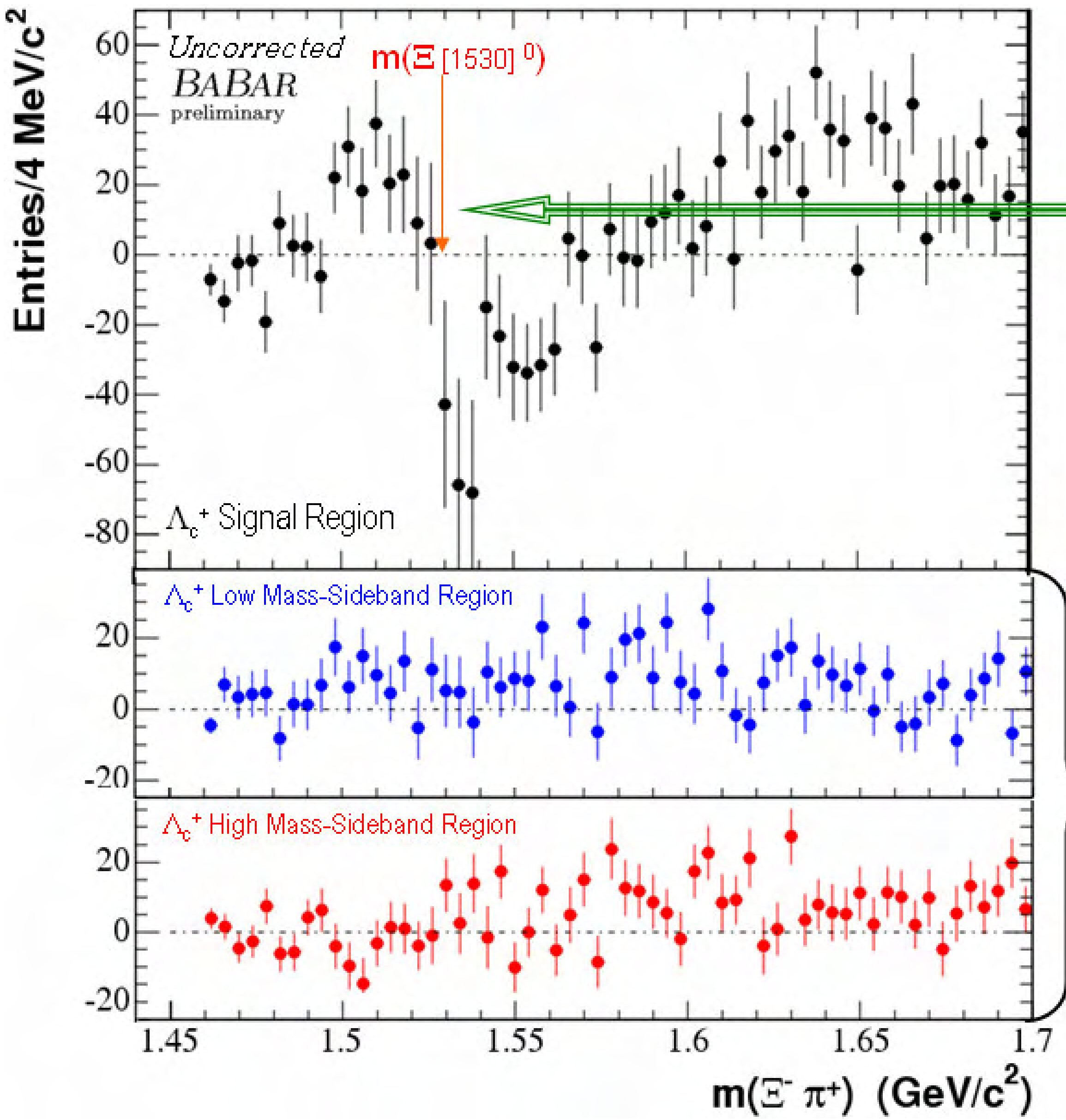
Weight = N x $P_2(\cos\theta)$

Projects mass distribution having $\cos^2\theta$ component

⇨ No $\cos^2\theta$ component in sideband distributions

Evidence of S-P wave interference in the $(\Xi^- \pi^+)$ system produced in the decay $\Lambda_c^+ \rightarrow \Xi^- \pi^+ K^+$

$m(\Xi^- \pi^+)$ distribution weighted by $P_1(\cos\theta)$:



Classic S-P wave interference pattern as a function of $m(\Xi^- \pi^+)$

- Oscillation due to *rapid* Breit-Wigner P-wave phase motion and *slowly* varying S-wave phase. E.g. $D^0 \rightarrow \overline{K^0} K^+ K^-$ [PRD72, 052008(2005)] (next slide)

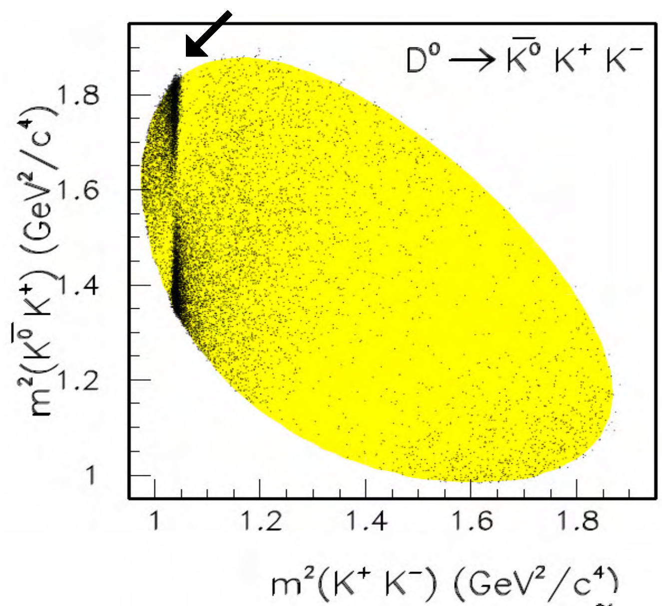
- First clear *indication* of $\Xi(1530)^0$ Breit-Wigner **phase motion**

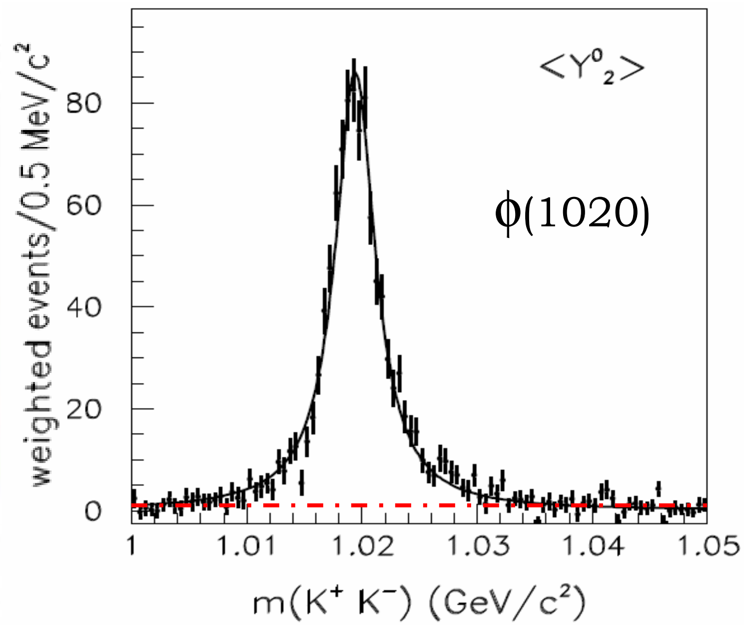
- No structure; non-zero because of efficiency dependence on cosθ (probably; to be confirmed)

$D^0 \rightarrow \overline{K}^0 (K^+ K^-)$ from BaBar

[PRD72, 052008(2005)]

S-P interference
→ large asymmetry





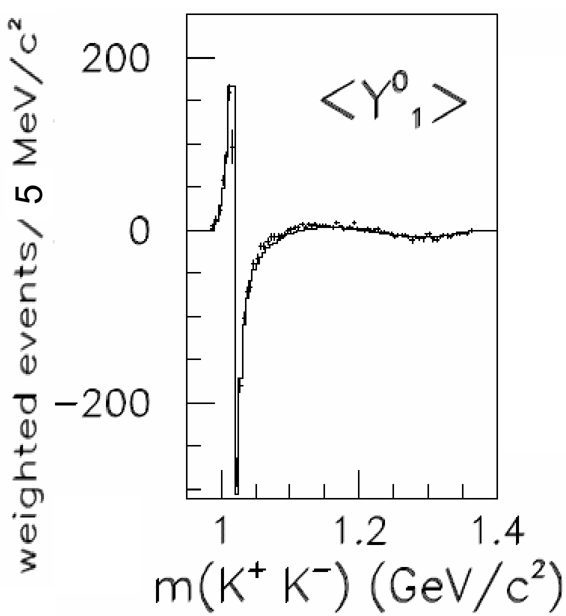
Amplitude Analysis of :

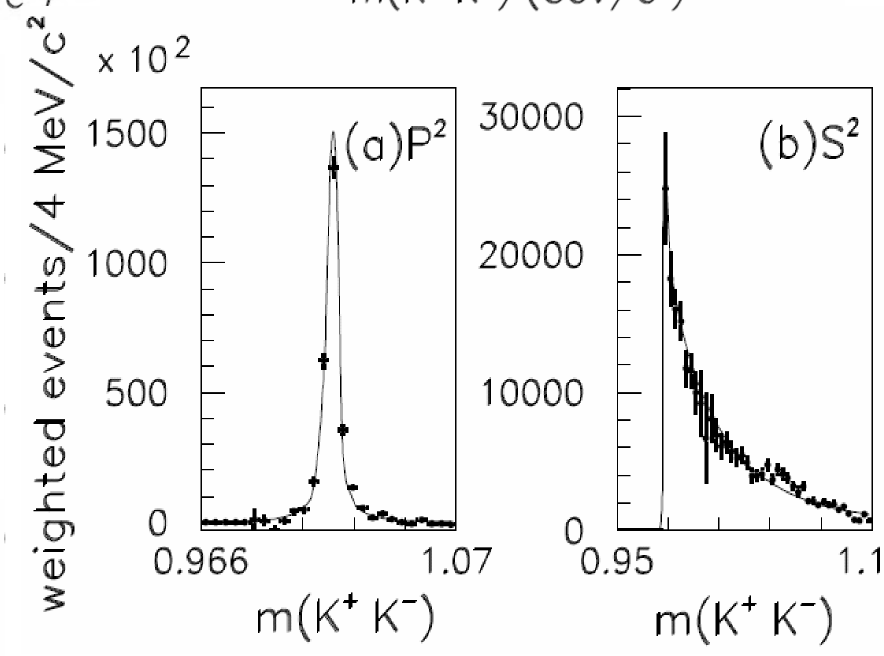
$\langle Y_0^0 \rangle$, $\langle Y_1^0 \rangle$, and $\langle Y_2^0 \rangle$

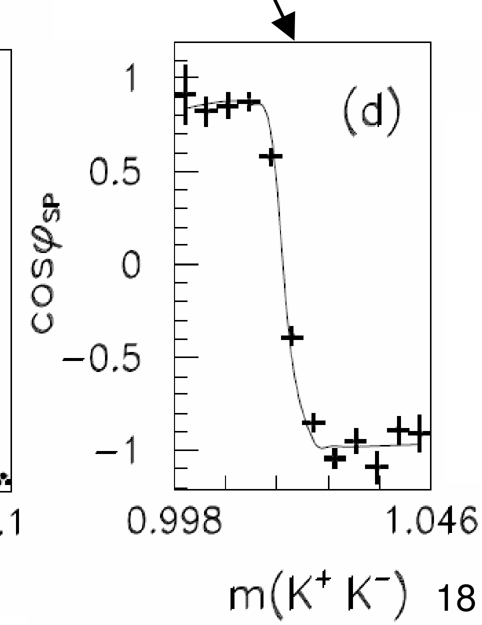
$\rightarrow |S|, |P|$

and

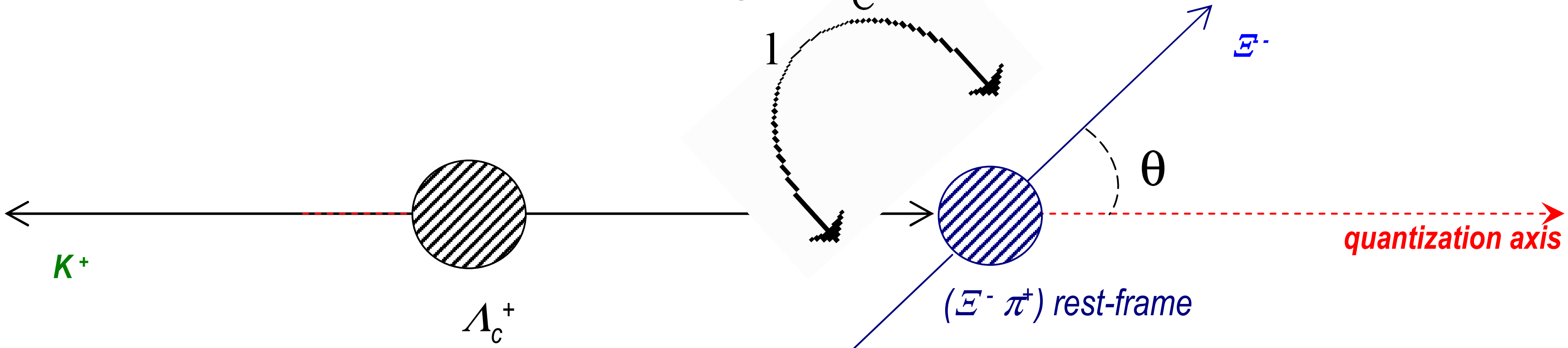
$\cos(\varphi_S - \varphi_P)$







S-P wave description of the $(\Xi^-\pi^+)$ system produced in the decay $\Lambda_c^+ \rightarrow \Xi^- \pi^+ K^+$



Amplitudes describing the $(\Xi^- \pi^+)$ system:

$S_{\lambda_f} \Leftrightarrow l = 0,\ j = 1/2 \qquad \eta_S = (-1)^{l+1} = -1$

$P^-_{\lambda_f} \Leftrightarrow l = 1,\ j = l - 1/2 = 1/2 \qquad \eta_{P^-} = (-1)^{l+1} = +1$

$P^+_{\lambda_f} \Leftrightarrow l = 1,\ j = l + 1/2 = 3/2 \qquad \eta_{P^+} = (-1)^{l+1} = +1$

$$\Rightarrow \quad \text{Total Intensity} \sim \sum_{\substack{\lambda_i = \pm 1/2, \\ \lambda_f = \pm 1/2}} \rho_i \left| D^{1/2*}_{\lambda_i\,\lambda_f}(\phi,\theta,0) S_{\lambda_f} + D^{1/2*}_{\lambda_i\,\lambda_f}(\phi,\theta,0) P^-_{\lambda_f} + D^{3/2*}_{\lambda_i\,\lambda_f}(\phi,\theta,0) P^+_{\lambda_f} \right|^2$$

ρ_i $(\mathrm{i} = \pm 1/2) \rightarrow$ density matrix elements describing the spin population of the Λ_c^+

where, λ_i = helicity of $(\Xi^- \pi^+)$ system $= \lambda_i(\Lambda_c^+)$

$\lambda_f = \lambda_{\Xi^-} - \lambda_{\pi^+} = \lambda_{\Xi^-}$

Helicity Formalism (3)

$$I \propto \sum_{\substack{\lambda_i=\pm 1/2,\\ \lambda_f=\pm 1/2}} \rho_i \left| D^{1/2*}_{\lambda_i \lambda_f}(\phi,\theta,0) S_{\lambda_f} + D^{1/2*}_{\lambda_i \lambda_f}(\phi,\theta,0) P^-_{\lambda_f} + D^{3/2*}_{\lambda_i \lambda_f}(\phi,\theta,0) P^+_{\lambda_f} \right|^2 \quad \text{where } \lambda_f = \lambda_{\Xi^-}$$

$$= \rho_{1/2}\left(\left| d^{1/2}_{1/2\,1/2}(\theta) S_{1/2} + d^{1/2}_{1/2\,1/2}(\theta) P^-_{1/2} + d^{3/2}_{1/2\,1/2}(\theta) P^+_{1/2} \right|^2 + \left| d^{1/2}_{1/2\,-1/2}(\theta) S_{-1/2} + d^{1/2}_{1/2\,-1/2}(\theta) P^-_{-1/2} + d^{3/2}_{1/2\,-1/2}(\theta) P^+_{-1/2} \right|^2 \right)$$

$$+ \rho_{-1/2}\left(\left| d^{1/2}_{-1/2\,1/2}(\theta) S_{1/2} + d^{1/2}_{-1/2\,1/2}(\theta) P^-_{1/2} + d^{3/2}_{-1/2\,1/2}(\theta) P^+_{1/2} \right|^2 + \left| d^{1/2}_{-1/2\,-1/2}(\theta) S_{-1/2} + d^{1/2}_{-1/2\,-1/2}(\theta) P^-_{-1/2} + d^{3/2}_{-1/2\,-1/2}(\theta) P^+_{-1/2} \right|^2 \right)$$

Parity conservation :

$$S_{-\lambda_f} = \eta_S \eta_\Xi \eta_\pi (-1)^{j-S_\Xi-S_\pi} S_{\lambda_f} = S_{\lambda_f} \quad (\eta_\Xi = +1,\ \eta_\pi = -1;\ j = 1/2,\ S_\Xi = 1/2,\ S_\pi = 0)$$

$$P^-_{-\lambda_f} = \eta_P \eta_\Xi \eta_\pi (-1)^{j-S_\Xi-S_\pi} P^-_{\lambda_f} = -P^-_{\lambda_f}\ (j=1/2);\quad P^+_{-\lambda_f} = \eta_P \eta_\Xi \eta_\pi (-1)^{j-S_\Xi-S_\pi} P^+_{\lambda_f} = P^+_{\lambda_f}\ (j=3/2)$$

$S_{-1/2} = S_{1/2}$

$P^-_{-1/2} = -P^-_{-1/2}$

$P^+_{-1/2} = P^+_{1/2}$

$$= \frac{1}{2}\rho_{1/2}\left(\left| d^{1/2}_{1/2\,1/2}(\theta) S_{1/2} + d^{1/2}_{1/2\,1/2}(\theta) P^-_{1/2} + d^{3/2}_{1/2\,1/2}(\theta) P^+_{1/2} \right|^2 + \left| d^{1/2}_{1/2\,-1/2}(\theta) S_{1/2} - d^{1/2}_{1/2\,-1/2}(\theta) P^-_{1/2} + d^{3/2}_{1/2\,-1/2}(\theta) P^+_{1/2} \right|^2 \right)$$

$$+ \frac{1}{2}\rho_{-1/2}\left(\left| d^{1/2}_{-1/2\,1/2}(\theta) S_{1/2} + d^{1/2}_{-1/2\,1/2}(\theta) P^-_{1/2} + d^{3/2}_{-1/2\,1/2}(\theta) P^+_{1/2} \right|^2 + \left| d^{1/2}_{-1/2\,-1/2}(\theta) S_{1/2} - d^{1/2}_{-1/2\,-1/2}(\theta) P^-_{1/2} + d^{3/2}_{-1/2\,-1/2}(\theta) P^+_{1/2} \right|^2 \right)$$

Assume ~0 to extract cosθ

$$\Rightarrow I \propto (\rho_{1/2} + \rho_{-1/2}) \left[|S_{1/2}|^2 + |P^-_{1/2}|^2 + |P^+_{1/2}|^2 \left(\frac{1 + 3\cos^2\theta}{4} \right) + 2\,\mathrm{Re}\left(S_{1/2} P^{+*}_{1/2}\right)\cos\theta \right]$$

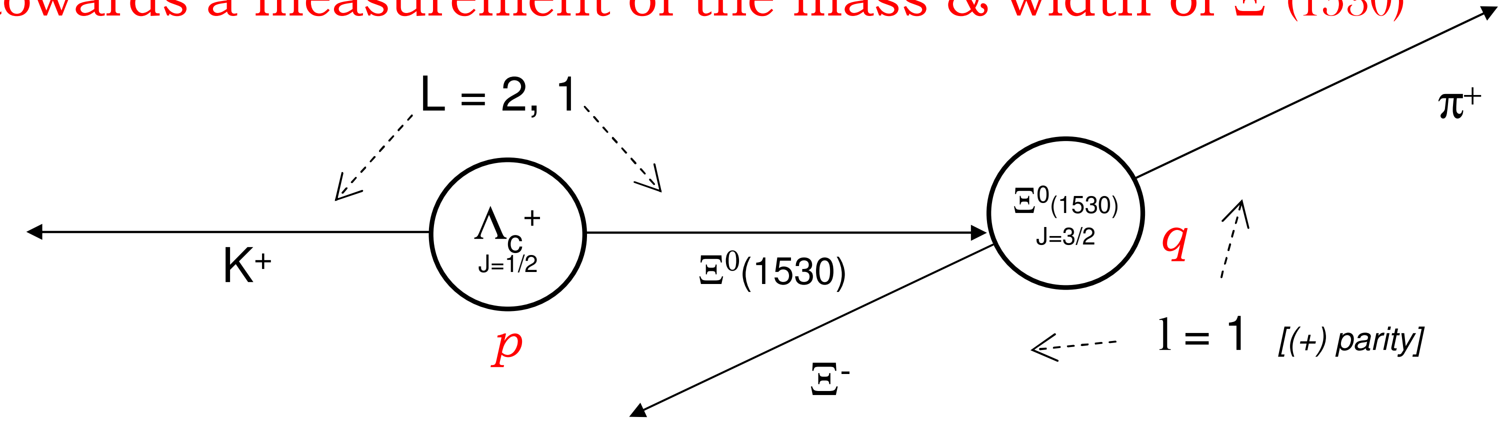
S-P interference

$$+ 2(\rho_{1/2} - \rho_{-1/2}) \left[\mathrm{Re}\left(S_{1/2} P^{-*}_{1/2}\right)\cos\theta + \mathrm{Re}\left(S_{1/2} P^{+*}_{1/2}\right)\left(\frac{3\cos^2\theta - 1}{2} \right) \right].$$

0

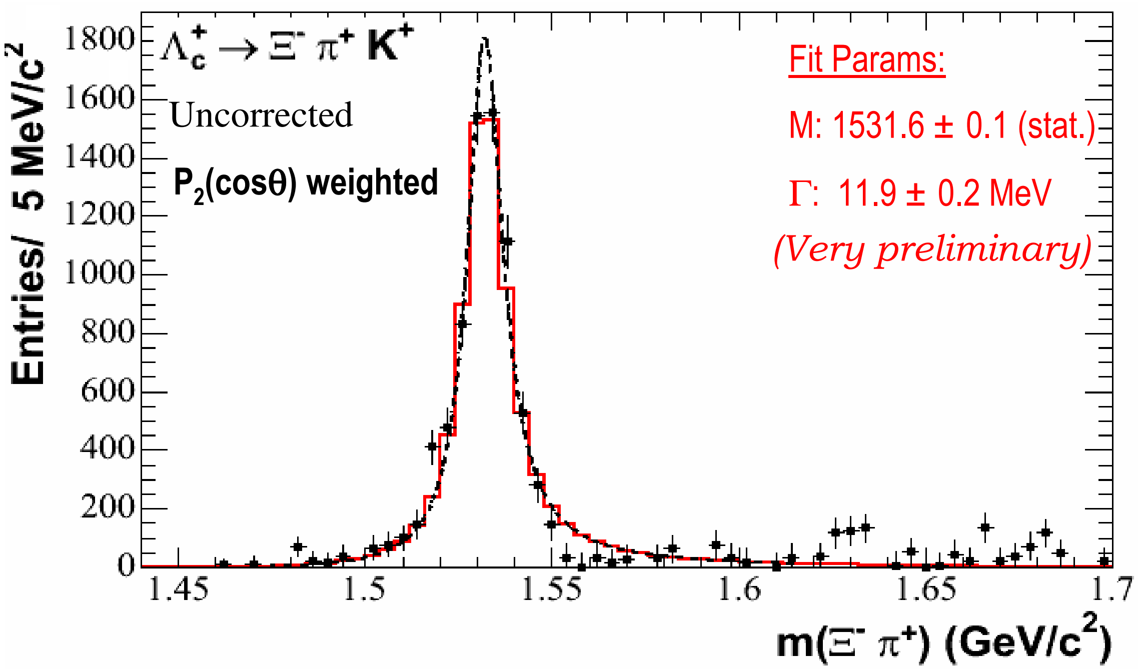
(Assume $\rho_{1/2} = \rho_{-1/2}$)

…towards a measurement of the mass & width of $\Xi^0(1530)$



Fit with relatisvistic Breit-Wigner Function with L=2 & l =1
[incorporating a Blatt-Weisskopf barrier factor (R~ 5 (GeV)$^{-1}$) and resolution "smearing"]

$$\frac{dN}{dm} = m.\left(\frac{p}{m_{\Lambda_c}}\frac{q}{m}\right)(p)^{2L}\frac{1}{\left(m_0^2 - m^2\right)^2 + m_0^2\Gamma_{tot}^2(m)}(q)^{2l}$$

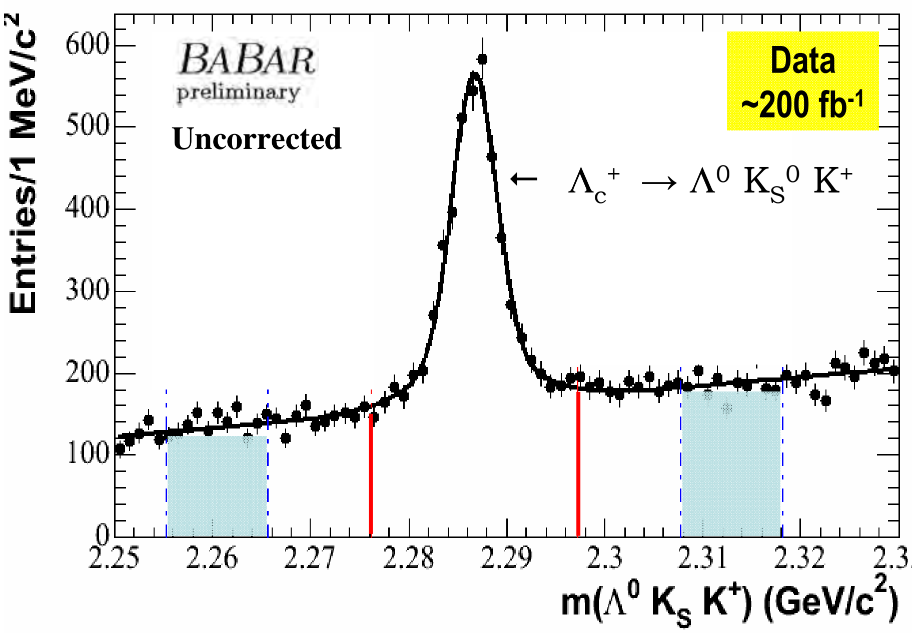


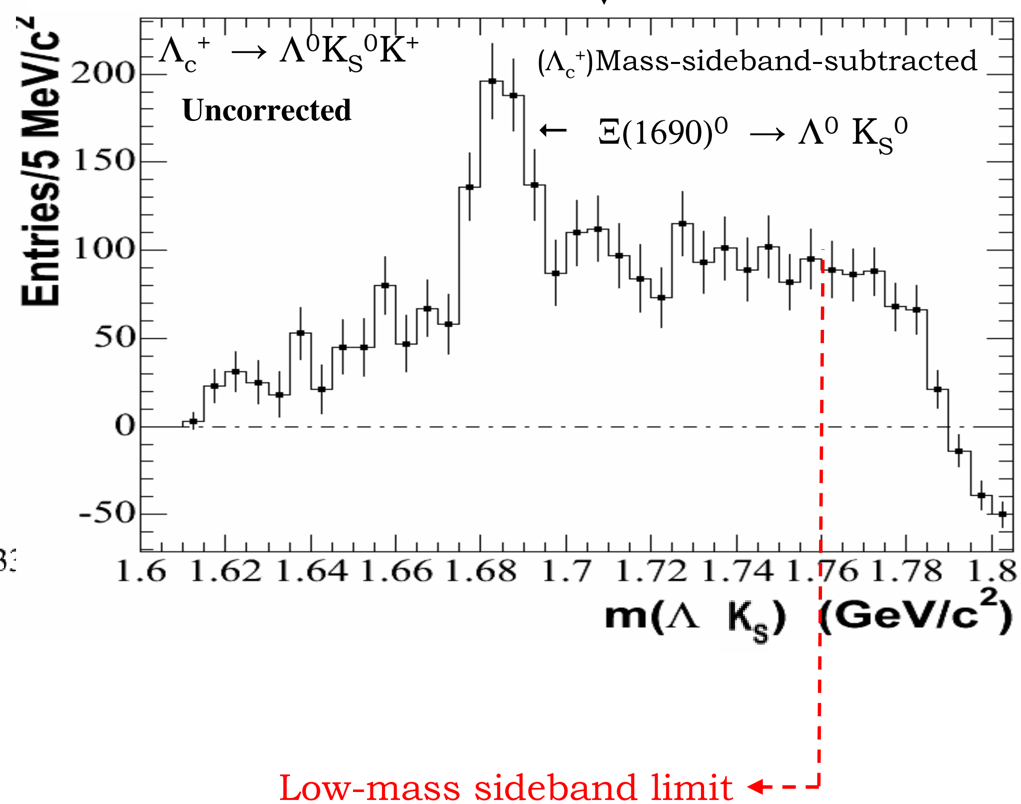
PDG:
M: 1531.80 ± 0.32
Γ: 9.1 ± 0.5 MeV

Reconstructed $\Lambda_c^+ \rightarrow \Lambda^0 K_S^0 K^+$ Events

$m(\Lambda^0 K_S^0) \leftrightarrow \Lambda_c^+$ mass-signal region
– $m(\Lambda^0 K_S^0) \leftrightarrow \Lambda_c^+$ mass-sideband region

$m(\Lambda^0 K_S^0) \leftrightarrow (\Lambda_c^+)$ mass-sideband-subtracted

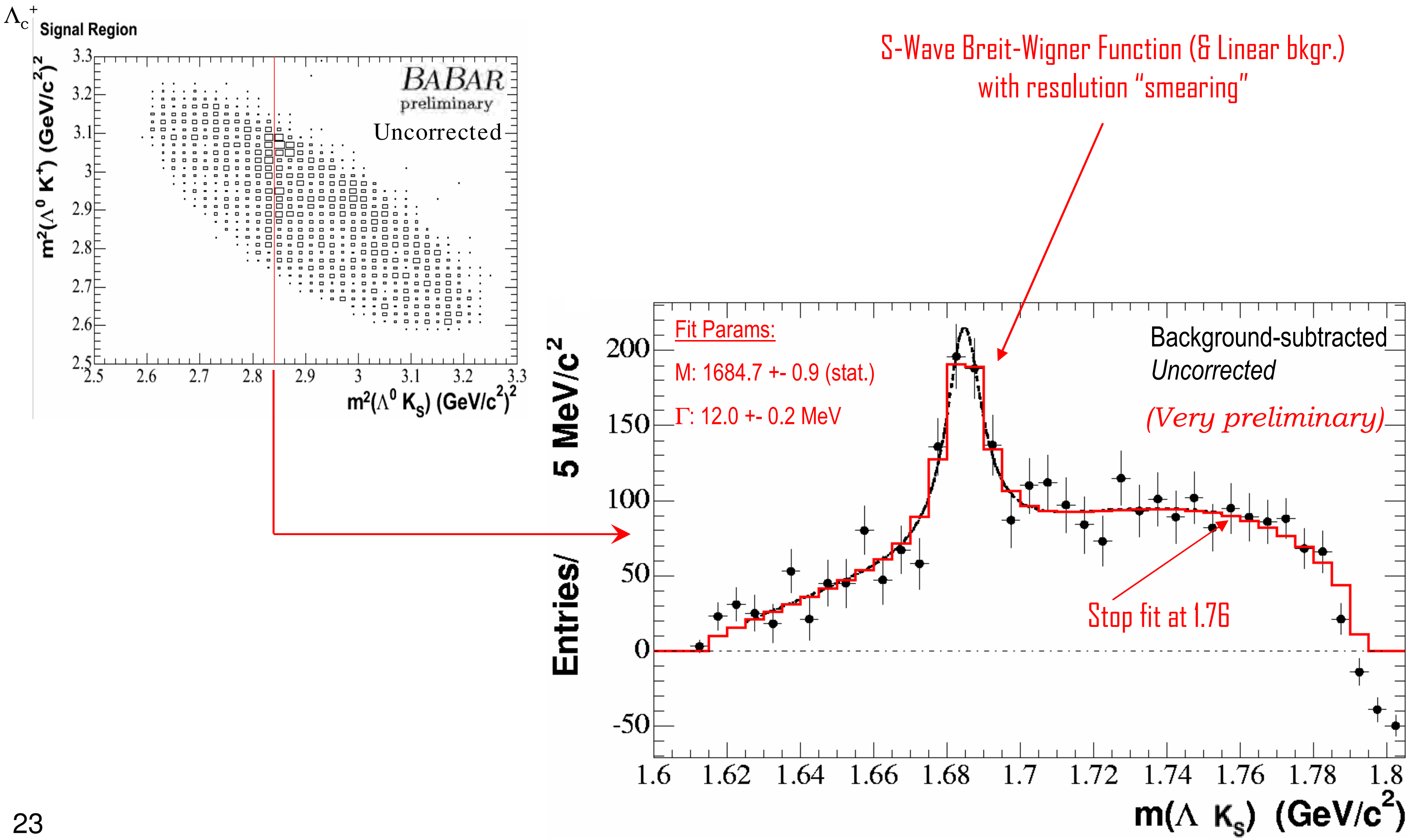




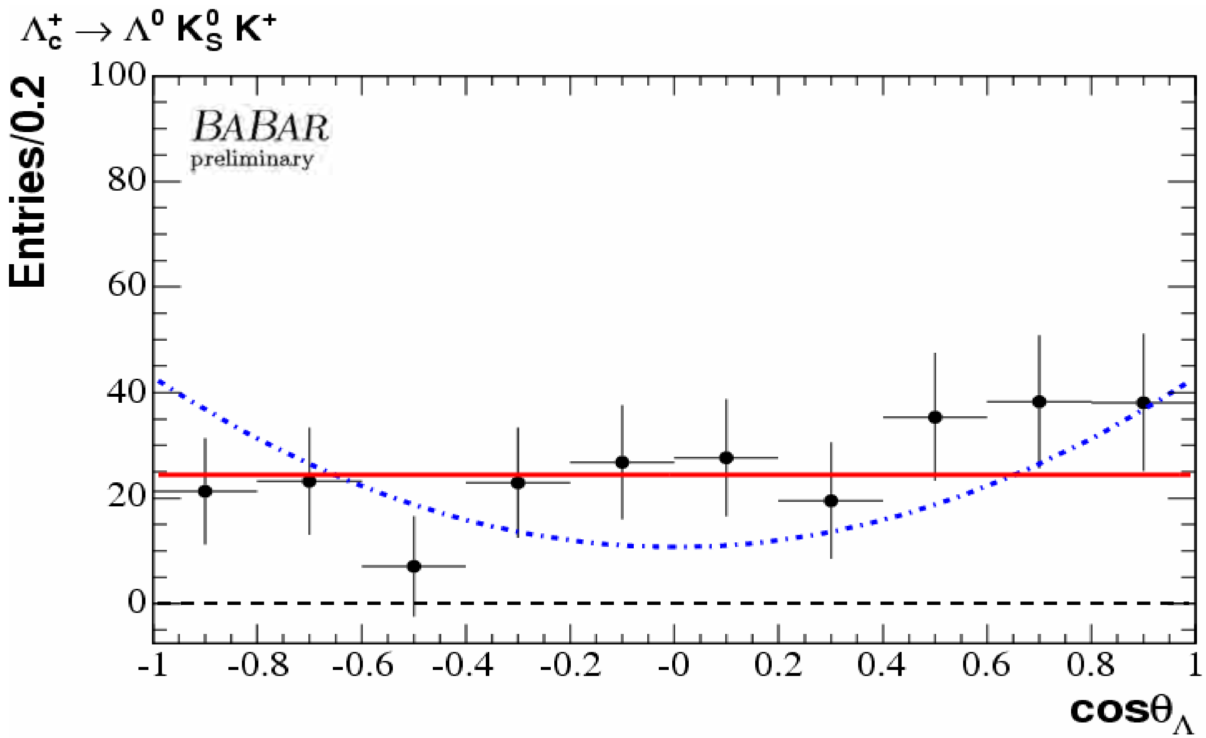
- PID Information
  - →Proton, →Kaon, →π^+, π^- } dE/dx & Cherenkov info (DIRC)
- 3-σ mass cut on intermediate states
- interm[d]. states *mass-constrained [Λ^0 , K_S^0]*
- $p^*(\Lambda_c^+) > 0.5$ GeV/c (reduces background)
- L_Λ, L_{K_S} > *+0.25* mm *[sign ⇨ outgoing].*

…towards a measurement of the mass & width of $\Xi(1690)^0 \rightarrow \Lambda^0 K_S^0$

Only "obvious" structure:
$\Xi(1690)^0 \rightarrow \Lambda^0 K_S^0$



Spin measurement of $\Xi(1690)^0$ from $\Lambda_c^+ \rightarrow \Xi(1690)^0$ K+, $\Xi^0(1690) \rightarrow \Lambda^0 K_S^0$ decays



Direct Method:

- Extract signal $\cos\theta_\Lambda$ distribution
- Requires large sideband subtraction

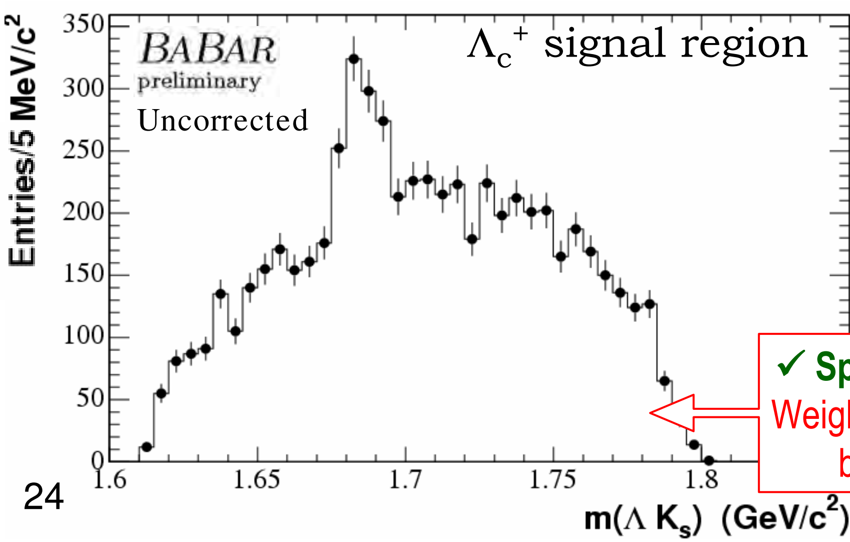
$\alpha(1 + 3\cos^2\theta)$ for J=3/2 hypothesis [prob = 0.2]

$\alpha(1)$ for J=1/2 hypothesis [prob = 0.9]

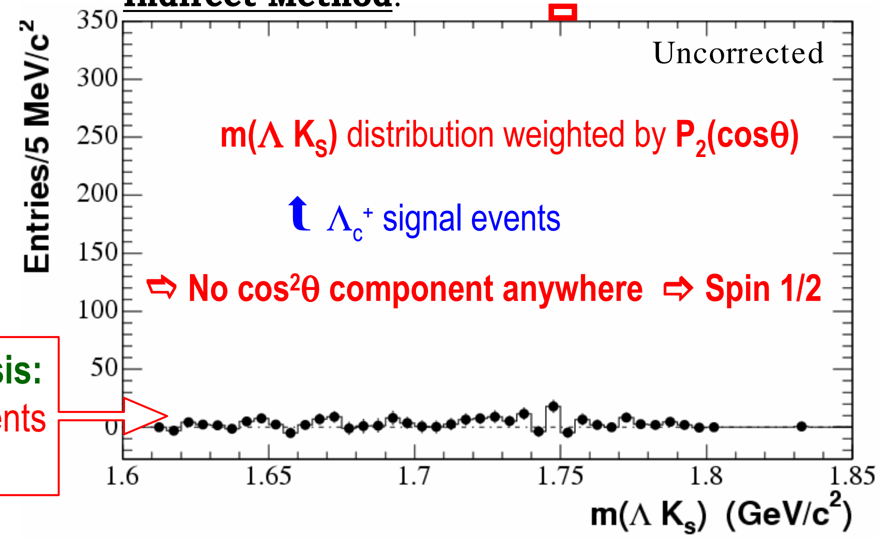
Inconclusive

Spin 1/2 favored

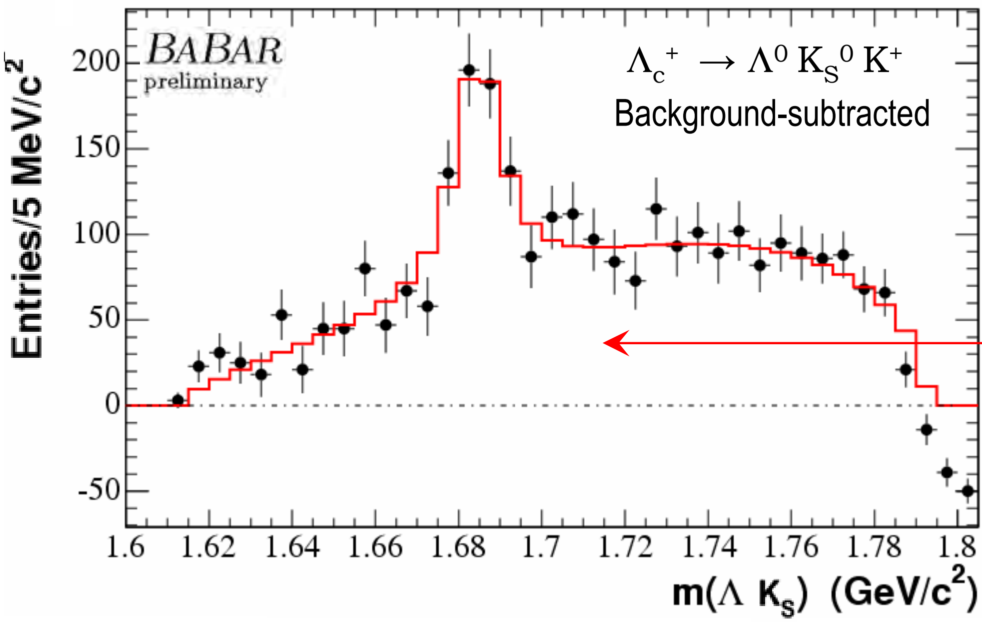
Indirect Method:



✓ **Spin hypothesis:**
Weight **signal** events by **$P_2(\cos\theta)$**

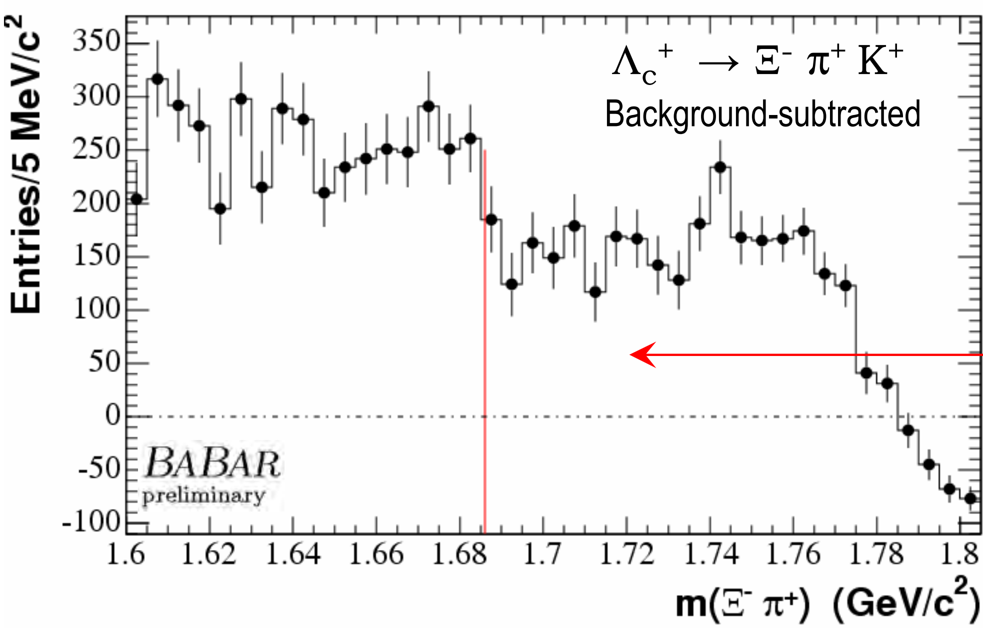


…towards an U.L. on BR($\Xi(1690)^0 \to \Xi^- \pi^+$)/BR($\Xi(1690)^0 \to \Lambda^0 K_S^0$)



Uncorrected ($\Lambda^0 K_S^0$) invariant mass
[$\Lambda_c^+ \to \Lambda^0 K_S^0 K^+$]

Clear signal for $\Xi(1690)^0 \to \Lambda^0 K_S^0$



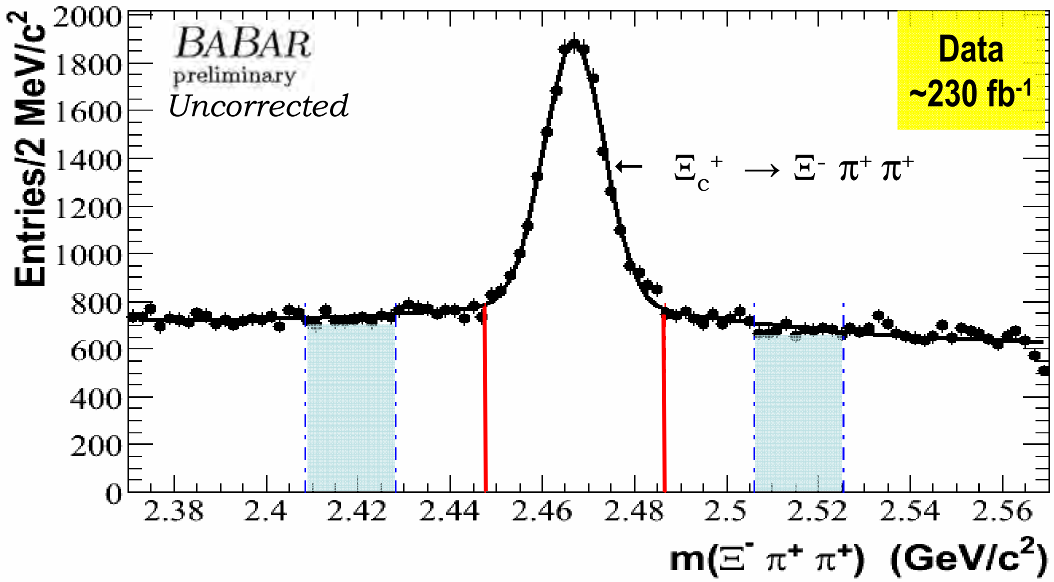
Uncorrected ($\Xi^- \pi^+$) invariant mass
[$\Lambda_c^+ \to \Xi^- \pi^+ K^+$]

No signal for $\Xi(1690)^0 \to \Xi^- \pi^+$

Investigation of $\Xi_c^{+,0}$ Decays to 3-body Final States

- $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$
- $\Xi_c^+ \rightarrow \Lambda^0 K_S^0 \pi^+$ (if time permits)
- $\Xi_c^0 \rightarrow \Lambda^0 K^- \pi^+$ (if time permits)

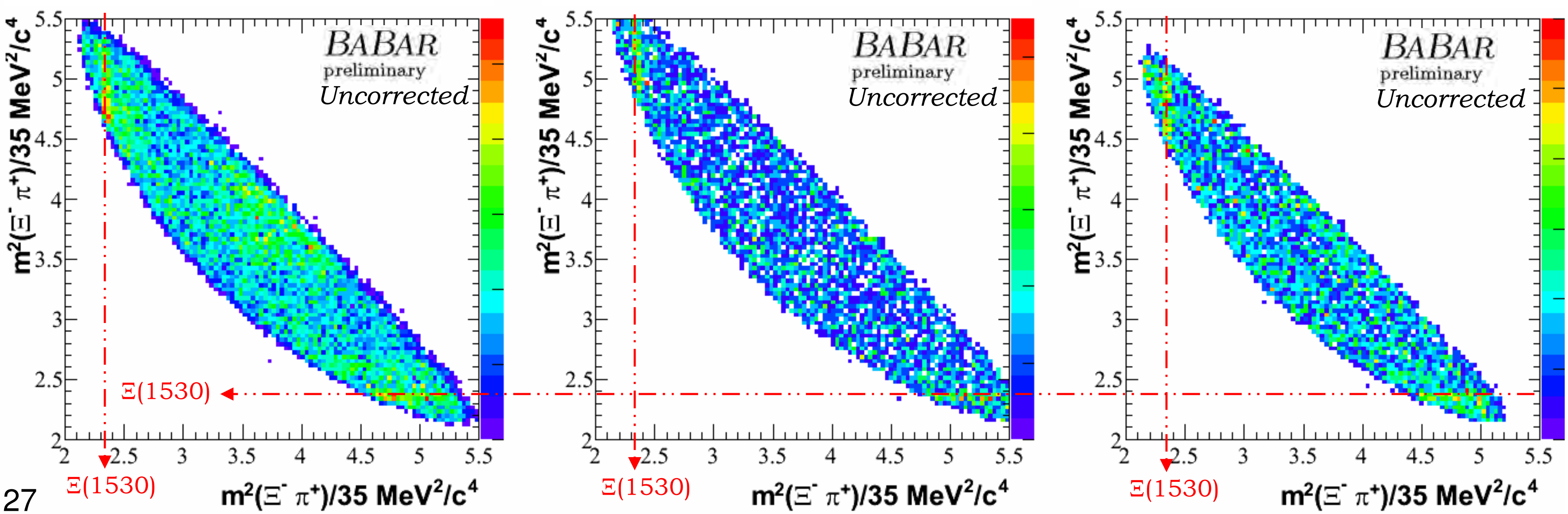
Reconstructed $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$, $\Xi^- \rightarrow \Lambda^0 \pi^-$ Events



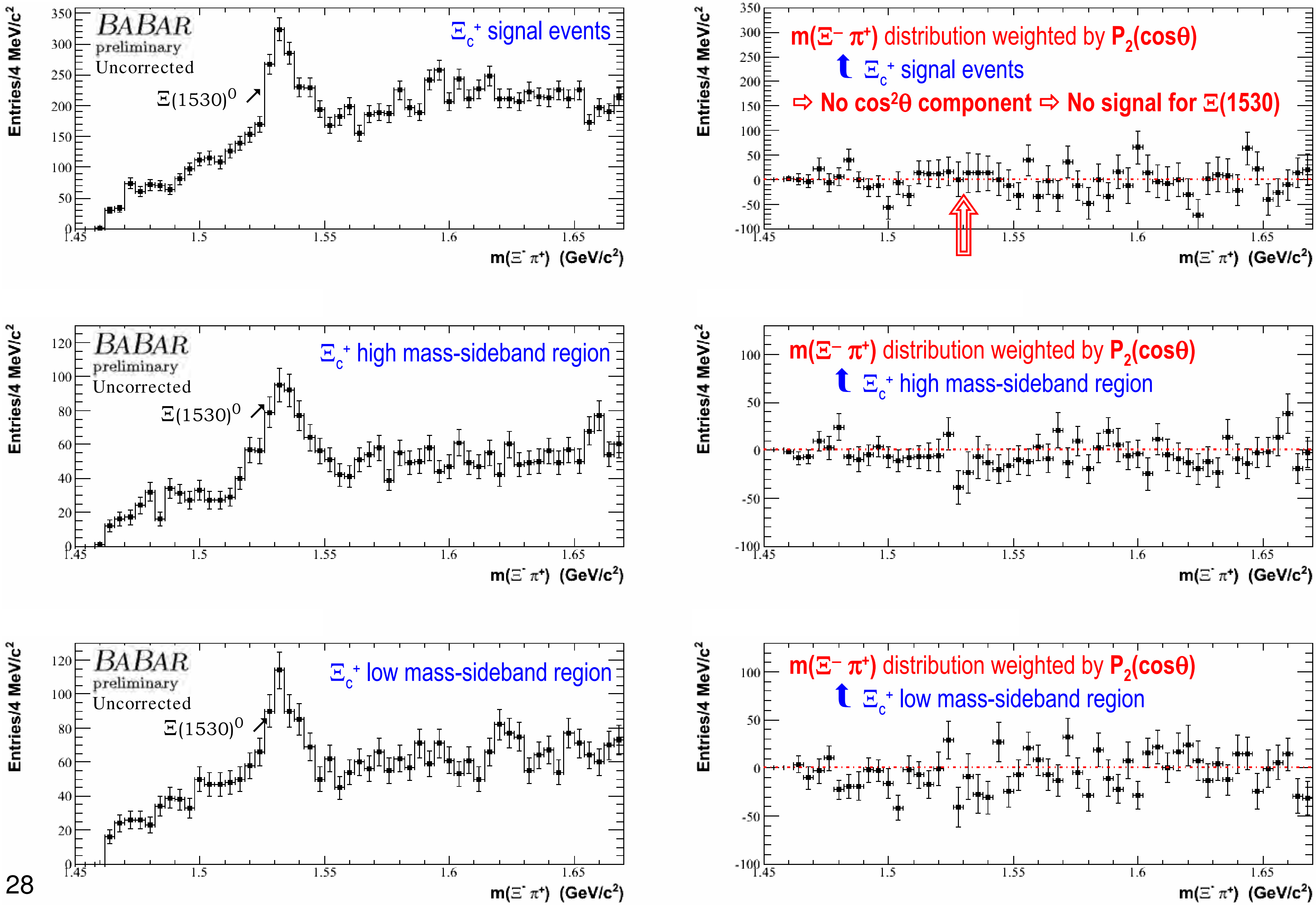
- PID Information
  - →Proton
  - →Kaon
  - →π^+, π^-

  } dE/dx & Cherenkov info (DIRC)
- 3-σ mass cut on intermediate states
- interm^d. states *mass-constrained [Λ, Ξ⁻]*
- $p^*(\Xi_c^+) > 1.8$ GeV/c (reduces background)
- $L_\Lambda > +1.5$ mm *[sign ⇨ outgoing].*
- $r_\Xi > +1.5$ mm *[sign ⇨ outgoing].*

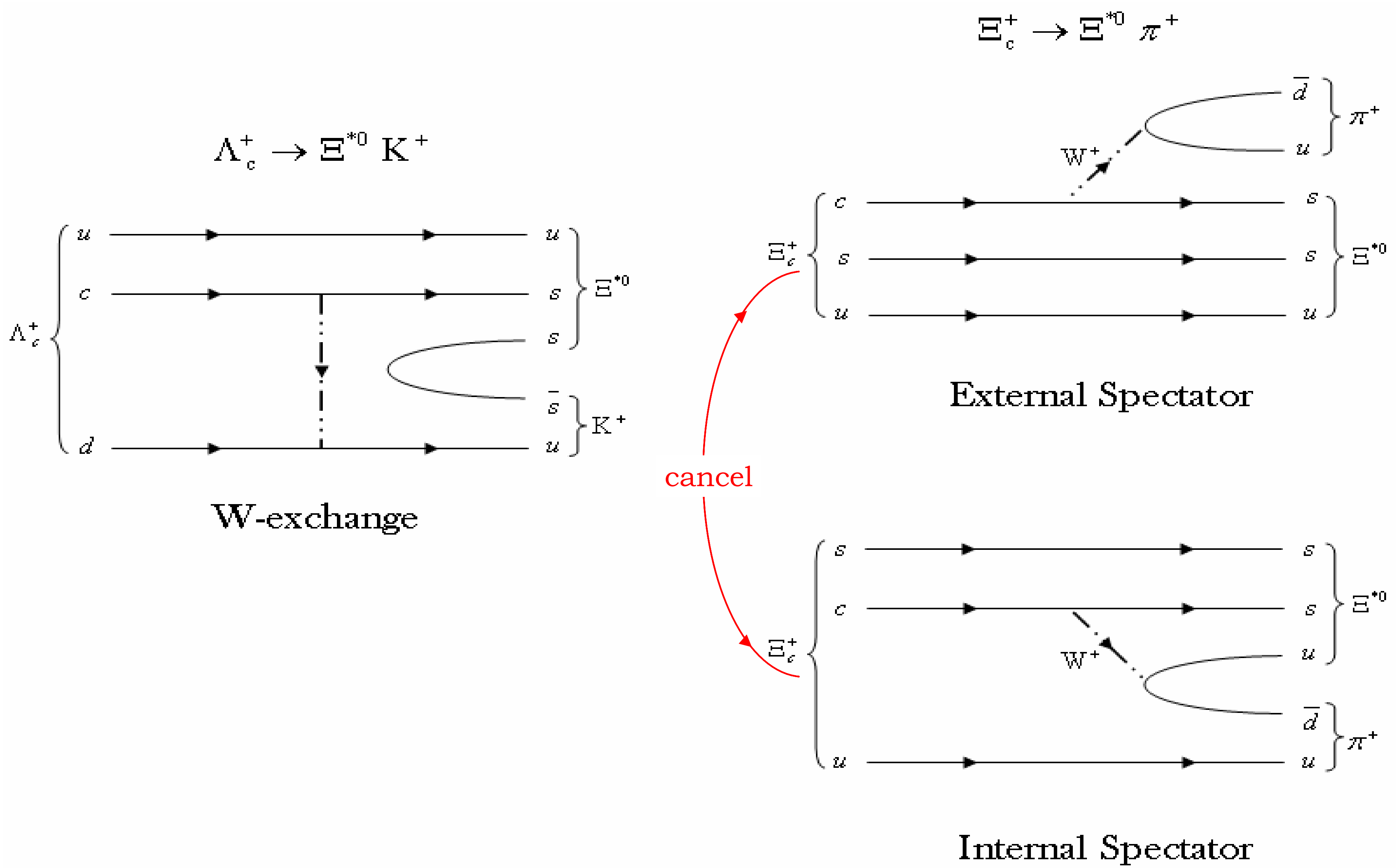
Signal Region | High-mass Sideband | Low-mass Sideband



Using the angular structure of $\Xi(1530)^0 \rightarrow \Xi^- \pi^+$ candidates to show the presence of large $\Xi(1530)^0$ background

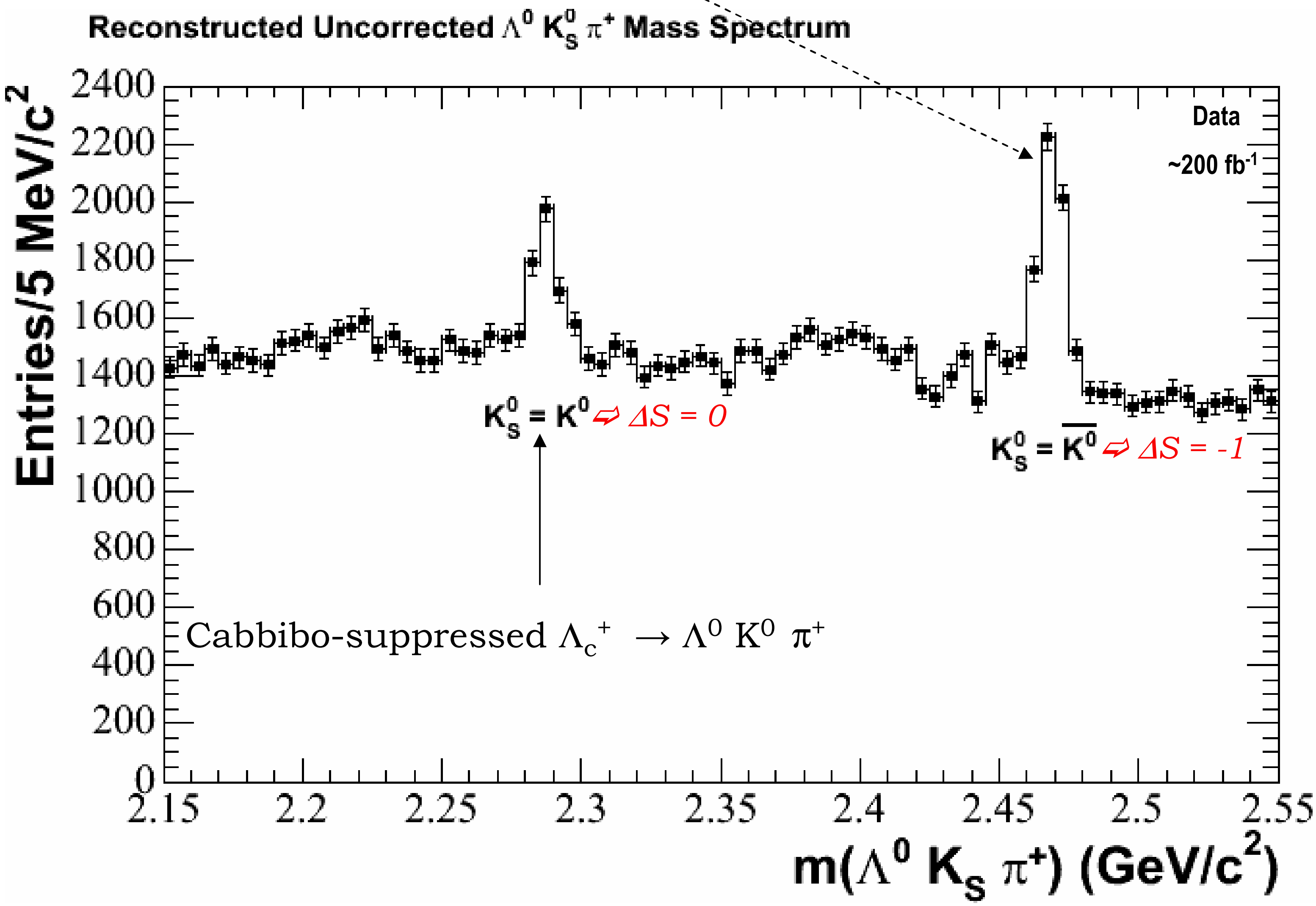


Ξ^{*0} Production in Λ_c^+ & $\Xi_c^{0,+}$ Decays



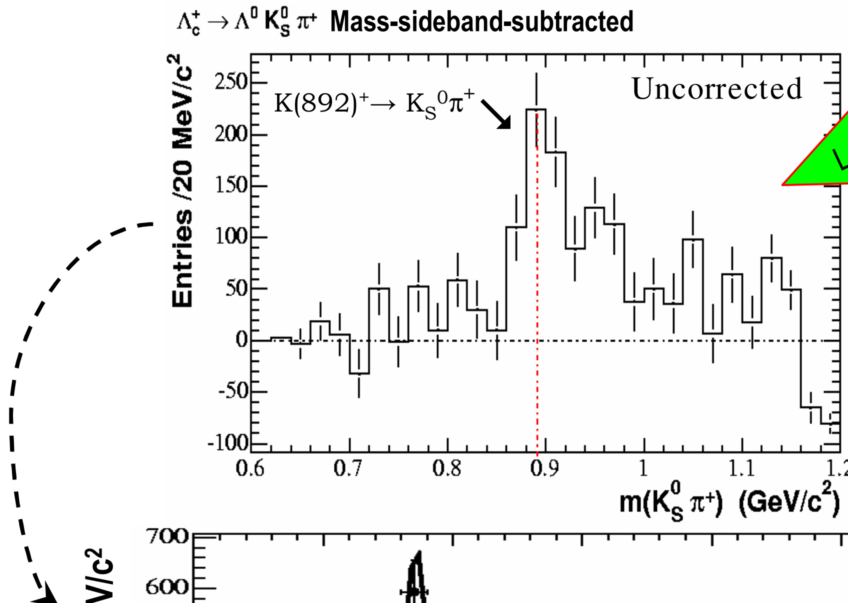
J.G. Körner, M. Krämer, Z. Phys. C **55**, 659 (1992)

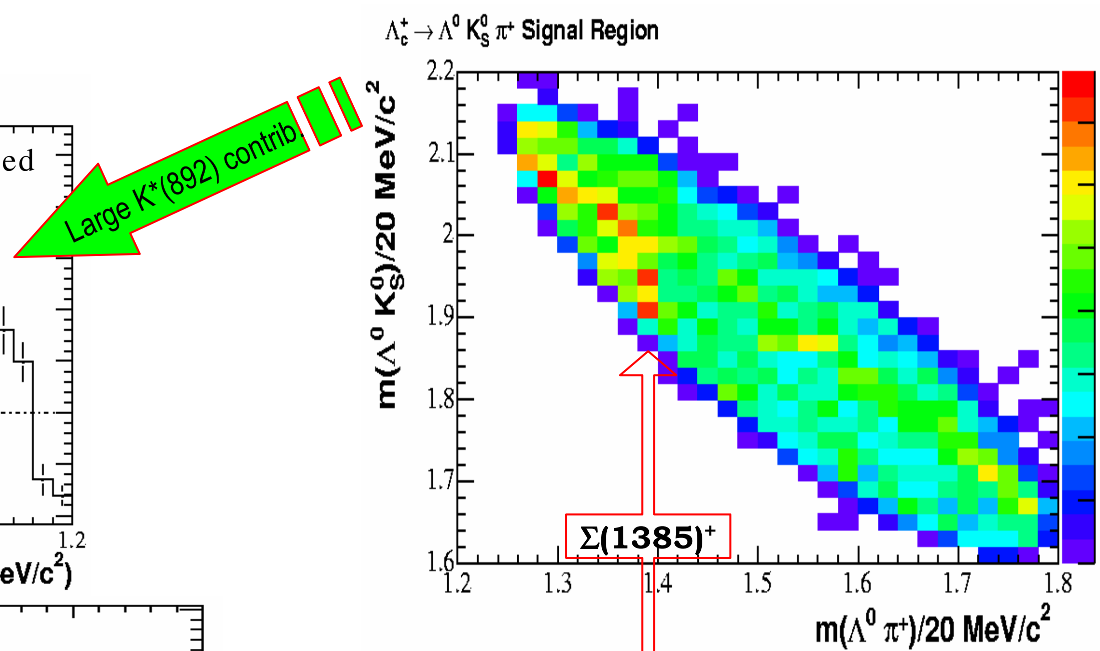
… Reconstructing $\Xi_c^+ \rightarrow \Lambda^0 K_S^0 \pi^+$ Events

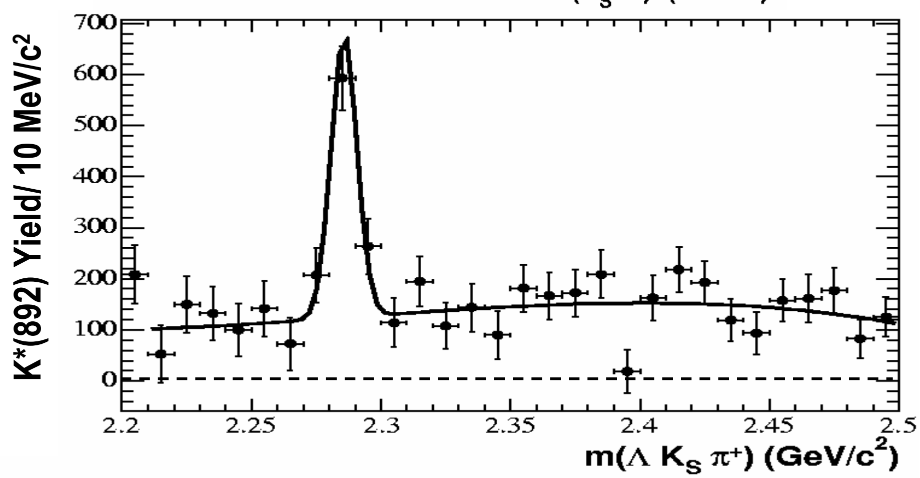


$\Lambda_c^+ \rightarrow \Lambda^0 K^0 \pi^+$ Dalitz Plot Analysis

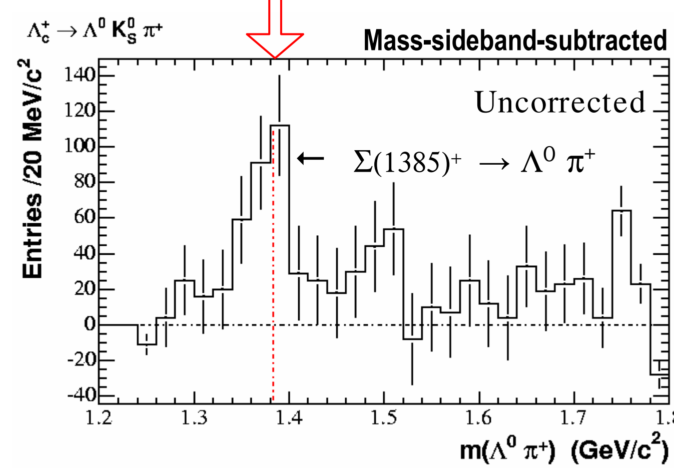
"Obvious" resonant structures







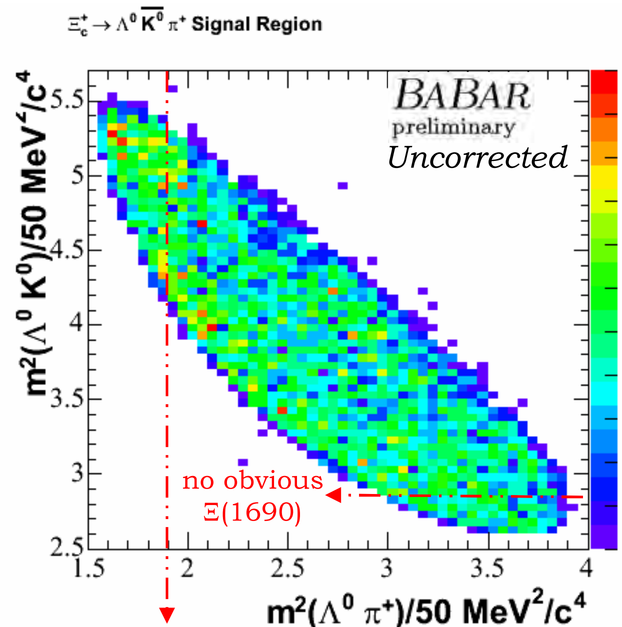
Evidence for the decay $\Lambda_c^+ \rightarrow \Lambda^0 K^*(892)^+$



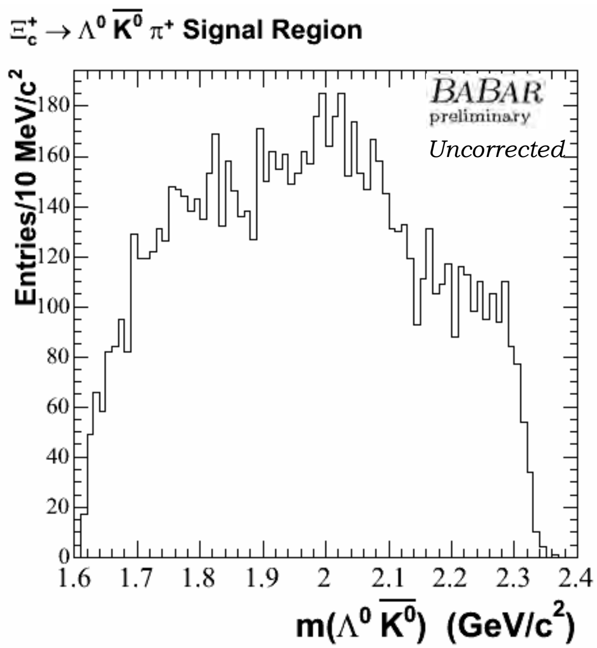
- Previously observed C.S. mode: $\Lambda_c^+ \rightarrow \Sigma^+ K^*(892)^0$

$\Xi_c^+ \rightarrow \Lambda^0\ \overline{K^0}\ \pi^+$ Dalitz Plot Analysis

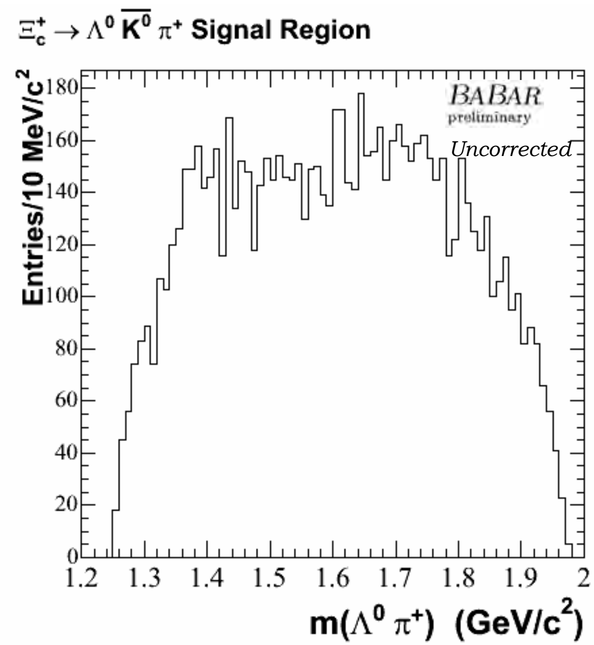
No "obvious" resonant structures



no obvious
Σ(1385)



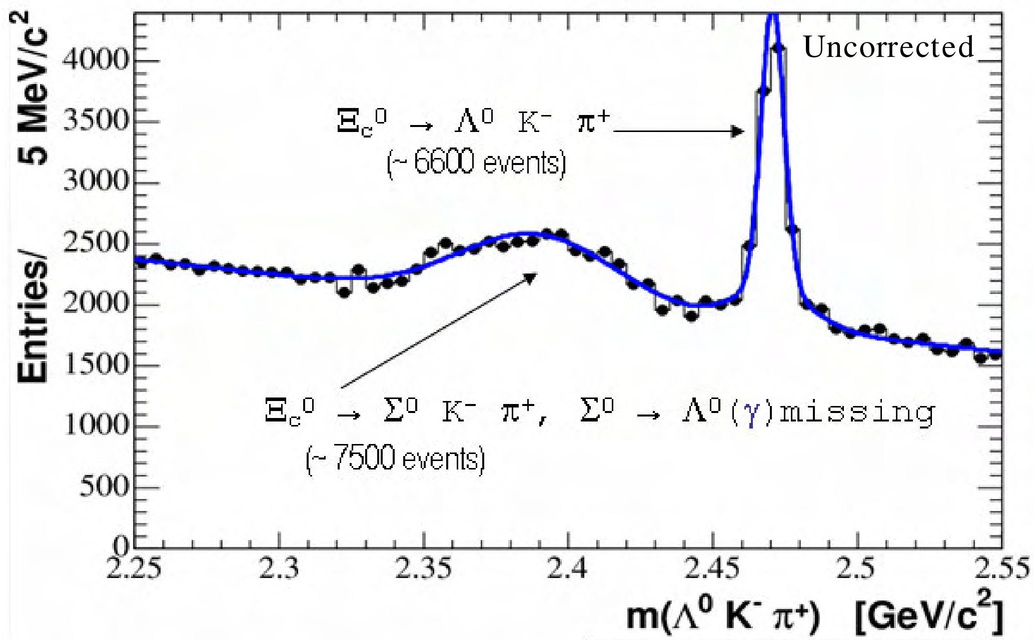
no obvious Ξ^*



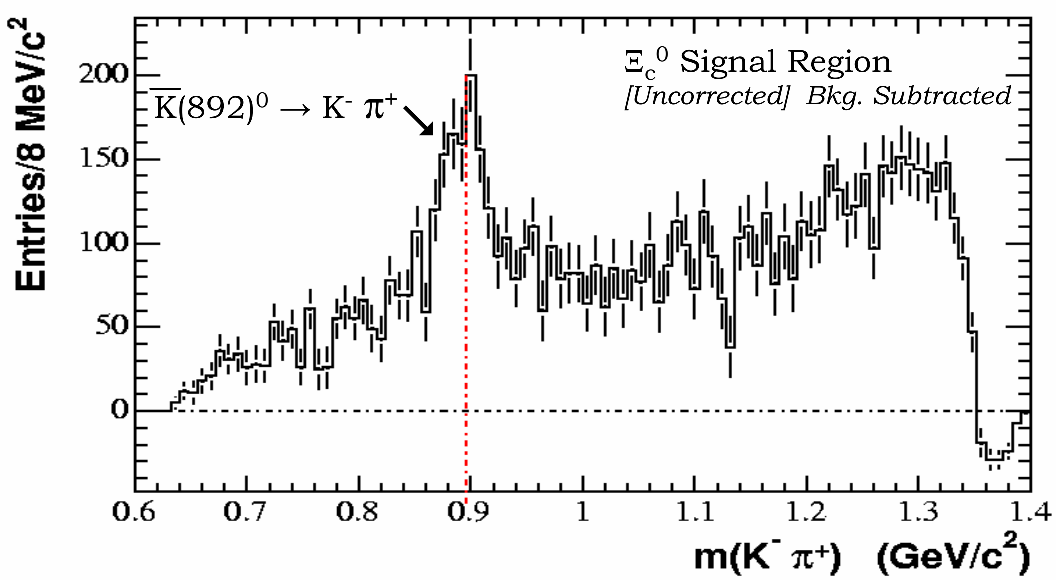
no obvious Σ^*

Reconstructed $\Xi_c^0 \to \Lambda^0 K^- \pi^+$ Events

- Particle Indentification
  - →Proton, →Kaon, →π^+, π^- } dE/dx & Cherenkov info (DIRC)
- 3-σ mass cut on intermediate state [Λ^0]
- $p^*(\Xi_c^0) > 2.25$ GeV/c [reduces background]
- $L_\Lambda > +0.9$ mm *[sign ⇨ outgoing].*



Strong $\overline{K}^*(892)$ Production



FIT:

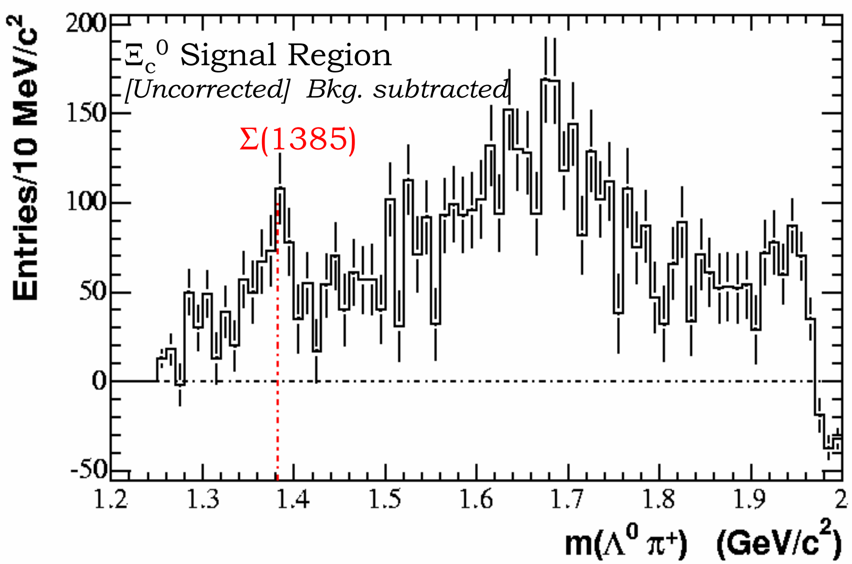
Σ^0 feed-down *fixed* mean: computed from kinematics assuming (K π) ~K*(892)

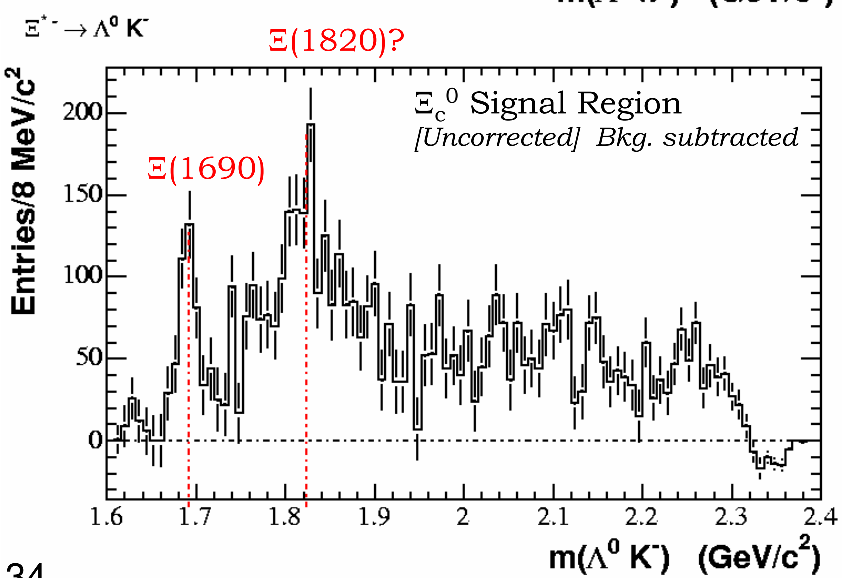
Ξ_c^0 Signal width: Double Gaussian

Σ^0 feed-down width: Single Gaussian

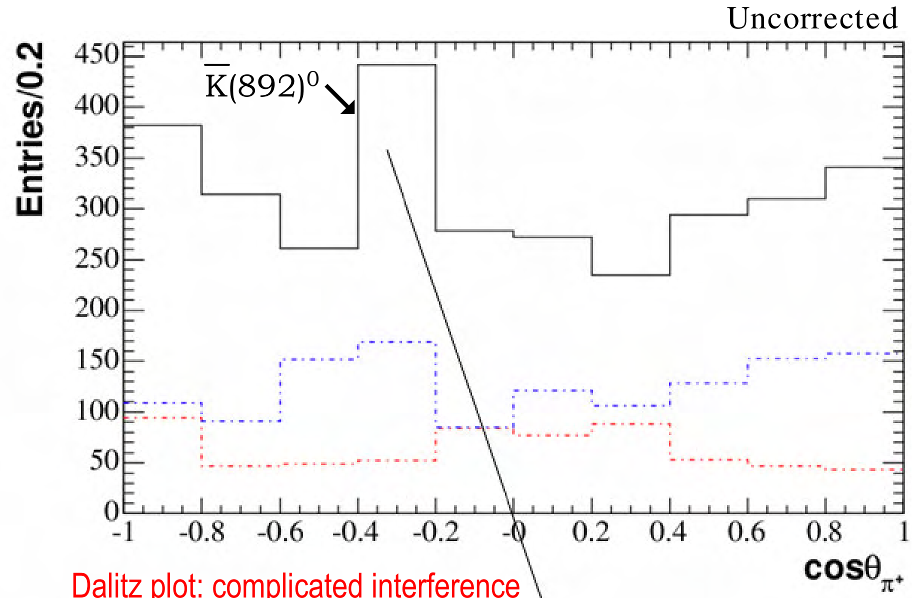
Σ^0 mode seems to be as large as Λ^0 mode

- Possible Hyperon Resonant Structures:
  - ○ $\Sigma(1385, 1670(?))^{+} \rightarrow \Lambda^{0}\, \pi^{+}$
  - ○ $\Xi(1690, 1820)^{-} \rightarrow \Lambda^{0}\, K^{-}$

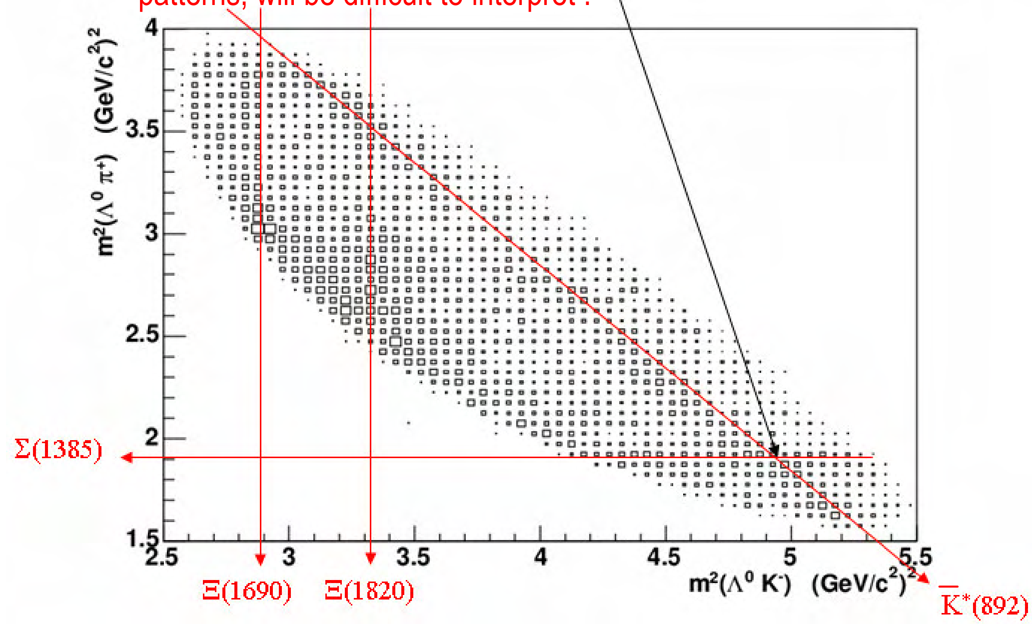




Angular dist. of $\Sigma(1385)^{+}$ from $\Xi_c^{0} \rightarrow \Sigma(1385)^{+} K^{-}$, $\Sigma^{+}(1385) \rightarrow \Lambda^{0}\pi^{+}$ decays



Dalitz plot: complicated interference patterns; will be difficult to interpret !



SUMMARY(1)

Assuming Λ_c^+, $\Xi_c^{+,0}$ and Ω_c^0 have spin 1/2:

- used the decay modes $\Xi_c^0 \rightarrow \Omega^- K^+$ and $\Omega_c^0 \rightarrow \Omega^- \pi^+$ to show that the Ω^- has spin 3/2; spin 1/2 and 5/2 are ruled out.
- used the decay mode $\Lambda_c^+ \rightarrow \Xi^- \pi^+ K^+$
  - to show that the spin of the $\Xi(1530)$ is 3/2
  - to extract the $\Xi(1530)$ lineshape almost free of background; should give high quality (M, Γ) measurements
  - to demonstrate $\Xi(1530)$ Breit-Wigner phase motion for the first time
  - to show the presence of an S-wave $\Xi^- \pi^+$ amplitude and the possibility of a $\Xi^- \pi^+$ amplitude analysis.
- used the decay mode $\Lambda_c^+ \rightarrow \Lambda^0 K_S^0 K^+$
  - to show the presence of a clear $\Xi(1690) \rightarrow \Lambda^0 K_S^0$ signal; should yield quality (M, Γ) measurements
  - to show that spin 1/2 is *slightly* favored for $\Xi(1690)$ (cosθ distribution) and that spin $\geq$ 3/2 is *strongly* disfavored for the $\Xi(1690)$ ($P_2(\cos\theta)$-weighted mass distributions)
  - to show that the BR($\Xi(1690) \rightarrow \Xi^- \pi^+$)/BR($\Xi(1690) \rightarrow \Lambda^0 \overline{K^0}$) is small; should be able to obtain U.L. estimate

SUMMARY(2)

- used the decay mode $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$
  - to show the absence of any significant $\Xi(1530)$ signal; but large $\Xi(1530)$ background in the Ξ_c^+ sidebands ⇨ careful analysis; ongoing.

- used the decay mode $\Lambda_c^+ \rightarrow \Lambda^0 \overline{K^0} \pi^+$
  - to show first evidence for the C.S. decay $\Lambda_c^+ \rightarrow \Lambda^0 K(892)^0$

- used the decay mode $\Xi_c^+ \rightarrow \Lambda^0 \overline{K^0} \pi^+$
  - to search for $\Xi(1690) \rightarrow \Lambda^0 K^0$; no signal apparent; Dalitz plot very different from $\Lambda_c^+ \rightarrow \Lambda^0 \overline{K^0} K^+$

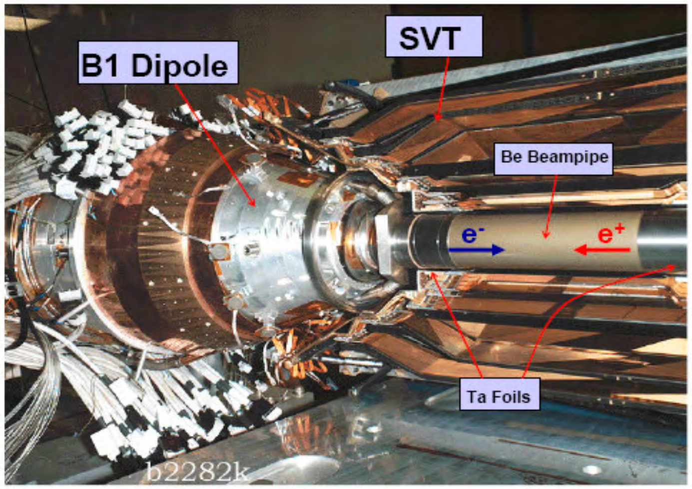
- used the decay mode $\Xi_c^0 \rightarrow \Lambda^0 K^- \pi^+$
  - to show evidence for $\Xi(1690)^- \rightarrow \Lambda^0 K^-$ and indications for $\Xi(1820)$ and $\Sigma(1385)$ signals; however the Dalitz plot exhibits complicated interference patterns, and analysis will be difficult.

FUTURE PLANS & POSSIBILITIES

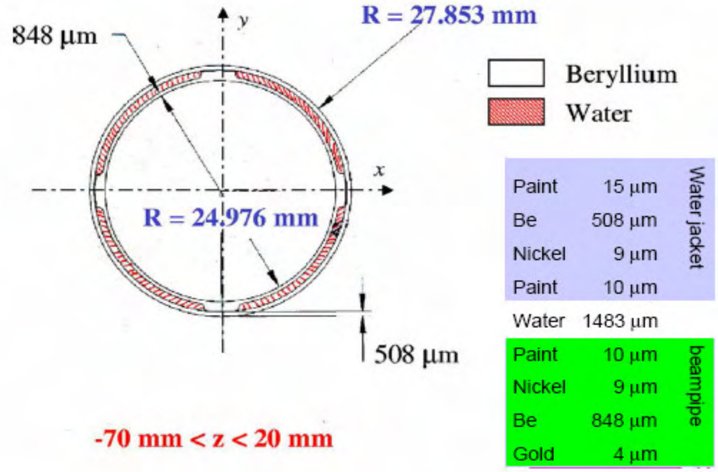
1. Obtain efficiency-corrected distributions and complete the analyses of the $\Xi(1530)$ and $\Xi(1690)$ signals; carry out the $(\Xi^- \pi^+)$ amplitude analysis to separate S and P wave amplitudes and demonstrate P-wave Breit-Wigner phase motion.
2. Use the decay chain $\Xi(1530) \rightarrow \Xi^- \pi^+$, $\Xi^- \rightarrow \Lambda^0 \pi^+$, $\Lambda^0 \rightarrow p\, \pi^-$ to measure the parity of the $\Xi(1530)$ by using the complete decay angular correlations (cf. Byers-Fenster spin-parity test)
3. Investigate the Λ^0 final states from Λ_c^+ decays when $\Lambda^0 \leftrightarrow \Sigma^0$ to look for $\Xi(1690) \rightarrow \Sigma^0 K^0$, $\Sigma^0 K^-$ [Thresholds 1690.2, 1686.3 MeV]; signal at threshold would favor S-wave ⇨ negative parity [e.g. $\Lambda_c^+ \rightarrow \Sigma^0 K_S^0 K^+$ from BaBar in PRD72, 052006(2005)]
4. "Reverse-engineer" $\Xi(1530)$ and Ω^- analyses to measure the charm baryon spin; the decay $\Lambda_c^+ \rightarrow \eta\, \Sigma(1385)^+$, $\Sigma(1385)^+ \rightarrow \Lambda^0 \pi^+$ might be helpful in this regard.
5. Incorporate available Run 5 data into the analyses
6. Perhaps extend approach to higher multiplicity decays e.g. $\Lambda(1115)^0 \leftrightarrow \Lambda(1520)^0 \rightarrow K^- p$

BACKUP SLIDES

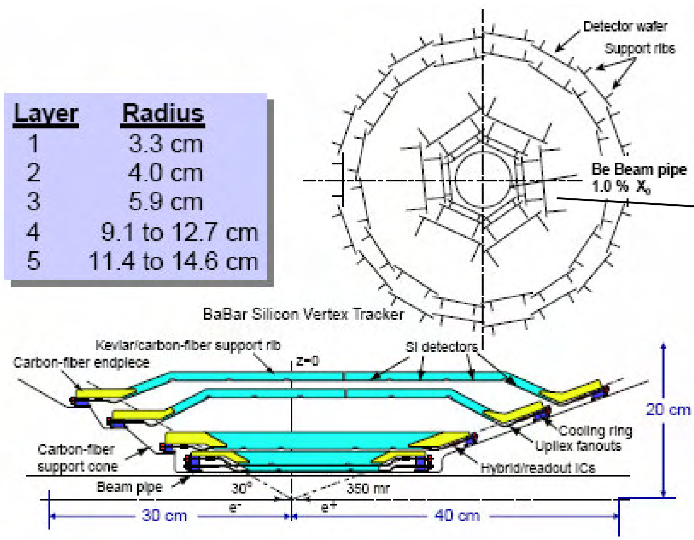
The Beampipe and Inner Detector Region



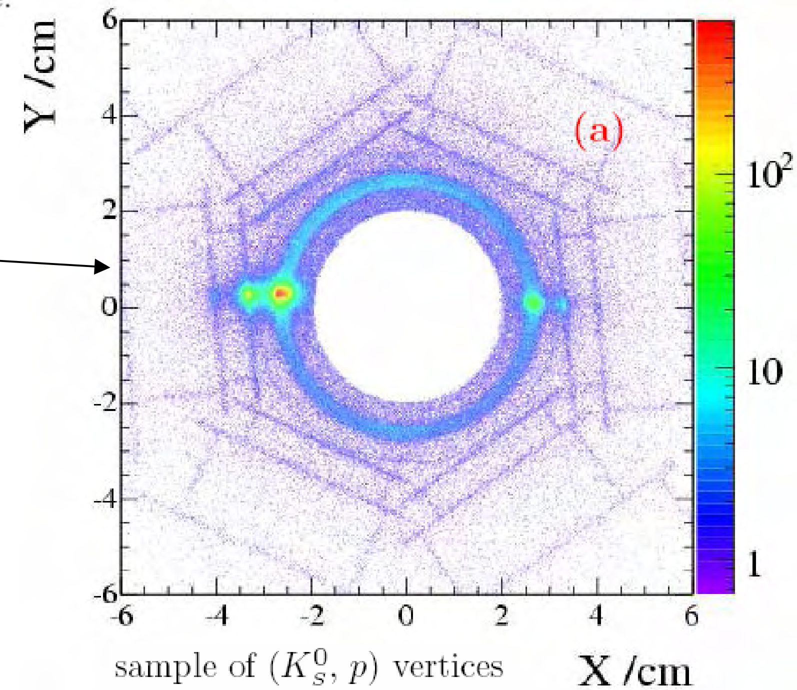
The beampipe, backward B1 magnet and positive x half of the SVT.



The radial geometry and material composition of the beampipe.



The geometry of the SVT layers



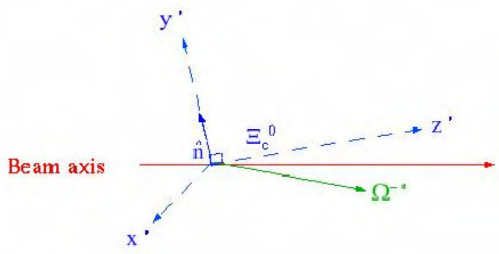
sample of (K_S^0, p) vertices

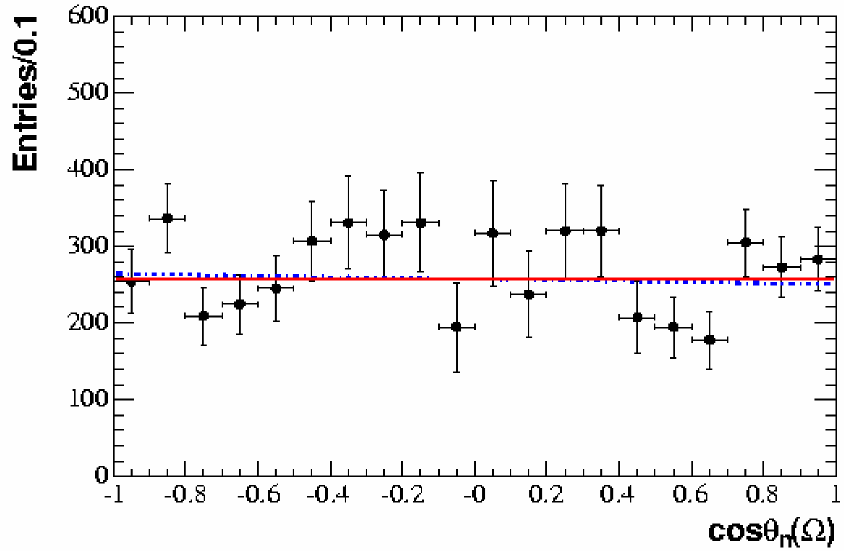
“Reverse” Engineering

↳ allow for higher charm baryon spins

Ξ_c^0 \ Ω^-	1/2	3/2	5/2
1/2	✗	✓	✗
3/2	?	✗	✗
5/2	?	?	✗

Polarization Study

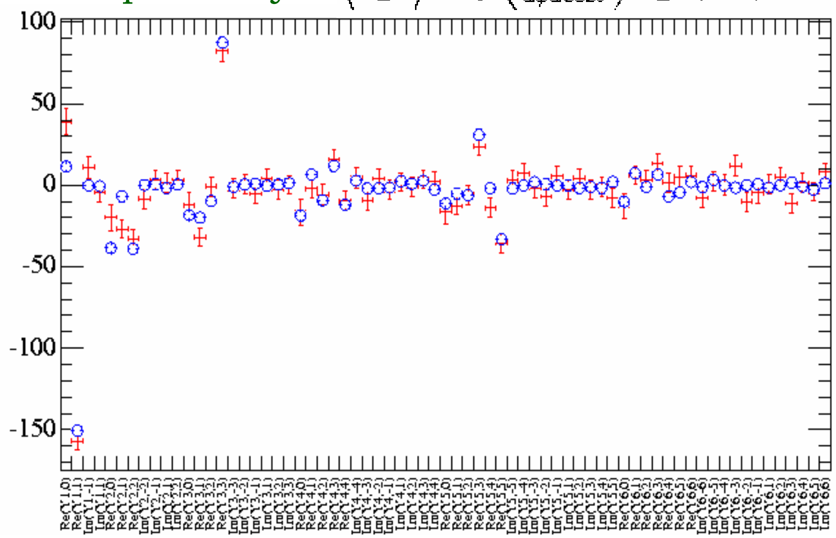




⇦ The efficiency corrected $\cos\theta_n(\Omega)$ distribution in data; the dashed line corresponds to a slope parameter of -6.9 ± 16, while the solid line corresponds to the slope of zero.

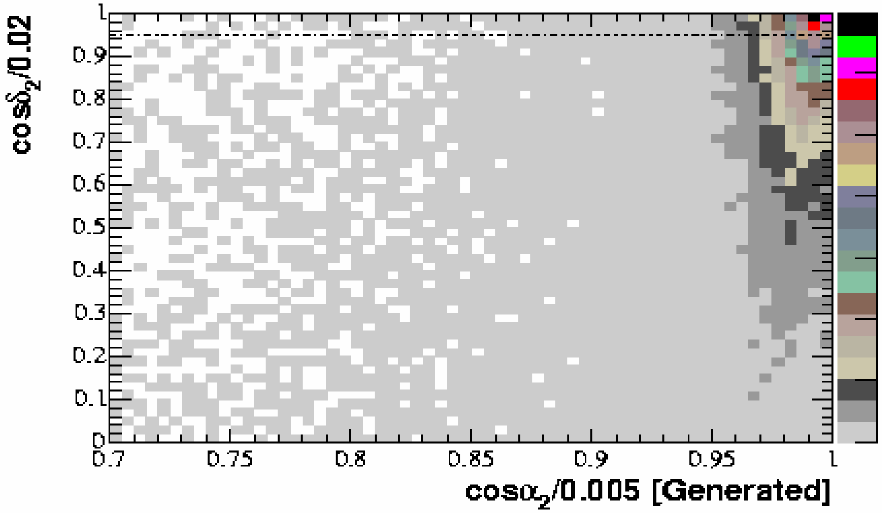
~flat ⇨ parent baryon sample unpolarized

Isotropic decay ⇨ $\left\langle Y_L^M \right\rangle = \int \left(\frac{dN}{d\phi d\cos\theta}\right) Y_L^M(\theta,\phi) d\phi d\cos\theta \approx \sum \left(\frac{\mathrm{dN}}{\mathrm{d}\phi \mathrm{d}\cos\theta}\right) \mathrm{Y}_{\mathrm{L}}^{\mathrm{M}}(\theta,\phi)\mathrm{d}\phi\mathrm{d}\cos\theta = 0.$ ⇨ parent baryon helicity states equally populated

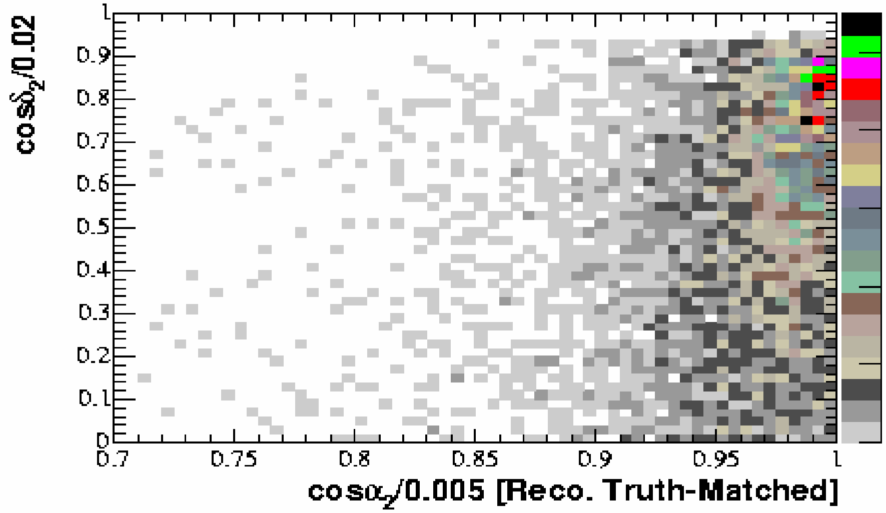


⇦ The mass-sideband-subtracted unnormalized YLM moments of the Ξ_c^0 signal in data (red); superimposed are the corresponding moments for truth-matched Signal MC (blue circles).

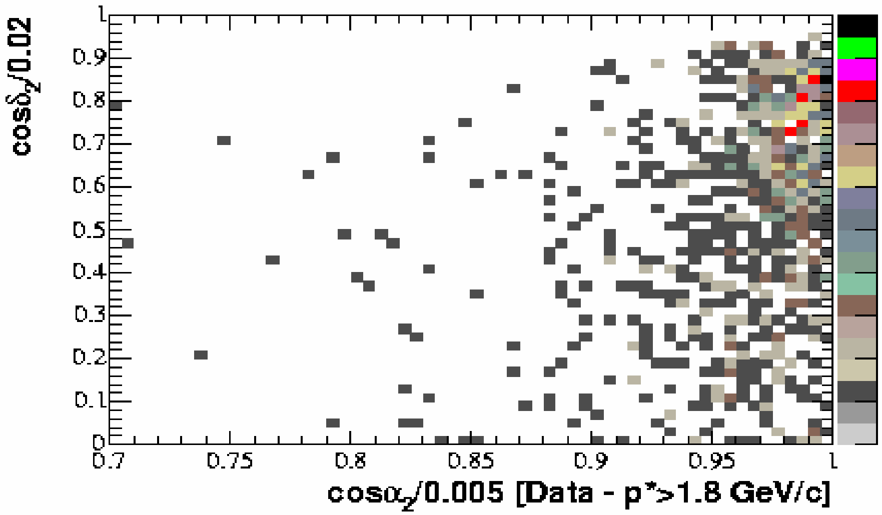
Efficiency loss at small angles



(a)



(b)



(c)

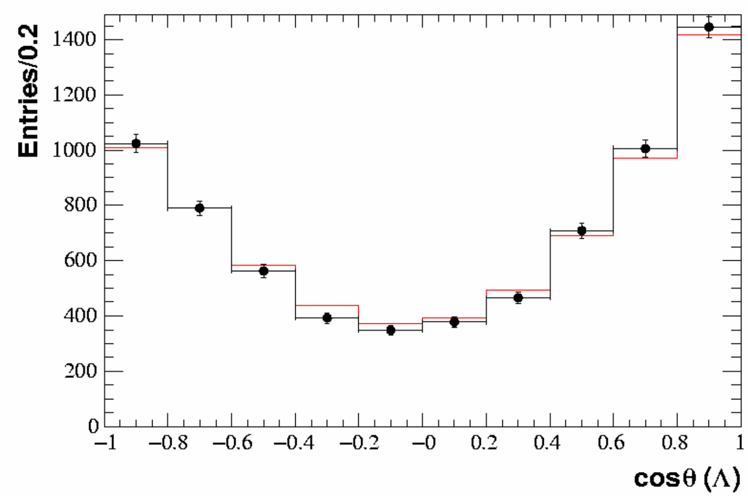
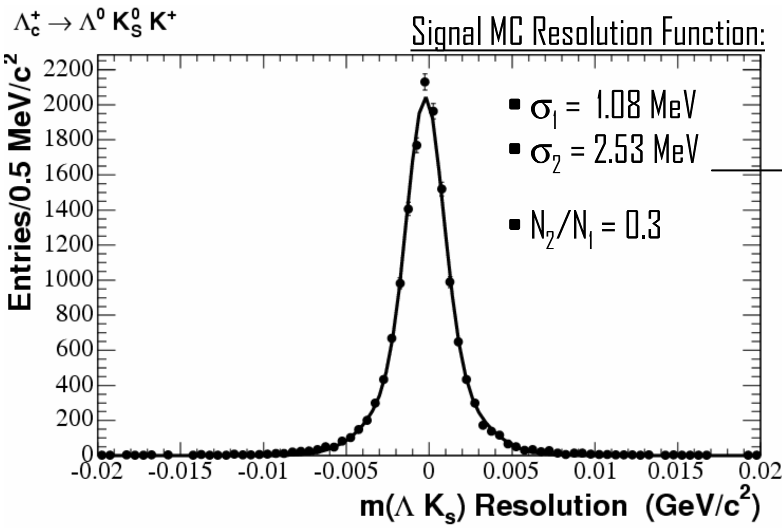
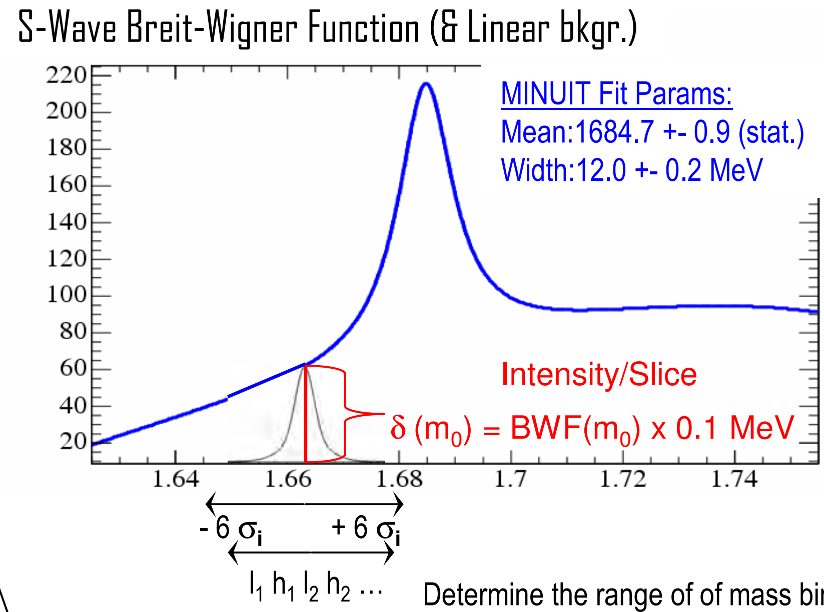


Figure 9: The reconstructed (red lines) and generated (black dots) MC distributions satisfying $\cos\delta_1 < 0.98$ and $\cos\alpha_2 < 0.99$.

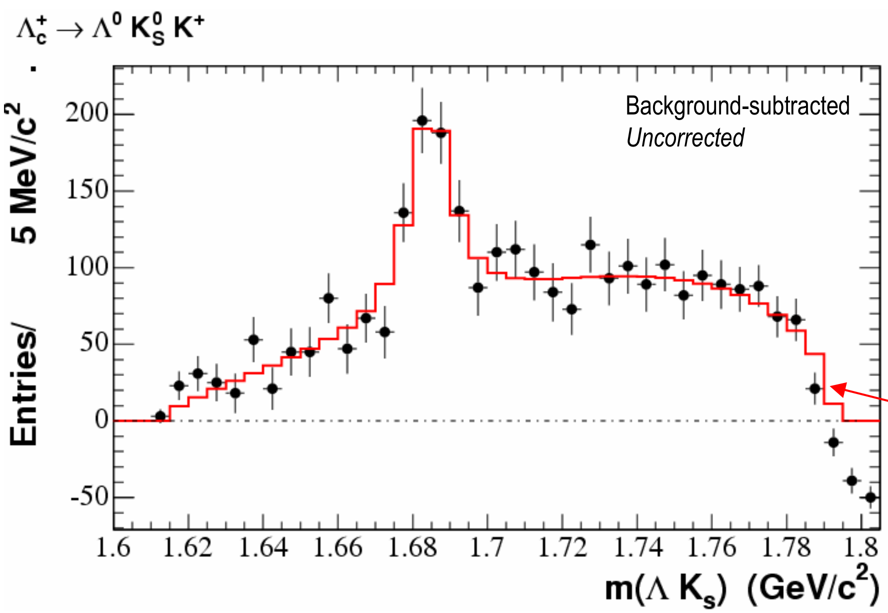
Figure 8: The scatter plots of the cosine of the angle between the K^- and the lab z-axis (δ_2) versus the opening cosine of the angle between the Ω^- and its decay kaon ($\cos\alpha_2$).

…towards a measurement of the mass & width of $\Xi^0(1690) \rightarrow \Lambda^0 K_S^0$





Determine the range of of mass bins receiving contributions over ±6 σ from this slice (for each Gaussian contribution separately).



➤ ***Smear*** $\delta(m_0)$ over the relevant bins of the $\Xi(1690)$ mass distribution separately for the **core** & **wide** Gaussian of the **resolution** function:

- Signal contribution for **core** Gaussian [$\sigma_i = \sigma_1$]:
  $\Sigma_i\ \delta(m_0) \times (1 - N_2/N_1) \times (\mathrm{erf}(h_i) - \mathrm{erf}(l_i))/2$
- Signal contribution for **wide** Gaussian [$\sigma_i = \sigma_2$]:
  $\Sigma_i\ \delta(m_0) \times (N_2/N_1) \times (\mathrm{erf}(h_i) - \mathrm{erf}(l_i))/2$

➤ ***Accumulate*** "smeared" contributions for each bin.

The Ξ^*(1530) parity ambiguity

Amplitudes describing the ($\Xi^- \pi^+$) system if the Ξ^*(1530) has **negative** parity:

$S_{\lambda_f} \Leftrightarrow l=0,\ j=1/2 \qquad \eta_S = (-1)^{l+1} = -1$

$P^-_{\lambda_f} \Leftrightarrow l=1,\ j=l-1/2=1/2 \qquad \eta_{P^-} = (-1)^{l+1} = +1$

$D^-_{\lambda_f} \Leftrightarrow l=2,\ j=l-1/2=3/2 \qquad \eta_{D^-} = (-1)^{l+1} = -1$

⇨ Total Intensity ~ $\sum_{\substack{\lambda_i=\pm 1/2,\\ \lambda_f=\pm 1/2}} \rho_i \left| D^{1/2*}_{\lambda_i\lambda_f}(\phi,\theta,0) S_{\lambda_f} + D^{1/2*}_{\lambda_i\lambda_f}(\phi,\theta,0) P^-_{\lambda_f} + D^{3/2*}_{\lambda_i\lambda_f}(\phi,\theta,0) D^-_{\lambda_f} \right|^2$

$$\Rightarrow \mathrm{I} \propto (\rho_{1/2}+\rho_{-1/2})\left[|S_{1/2}|^2 + |P^-_{1/2}|^2 + |D^-_{1/2}|^2\left(\frac{1+3\cos^2\theta}{4}\right) + 2\,\mathrm{Re}\left(P^-_{1/2} D^{-*}_{1/2}\right)\cos\theta\right]$$
$$+\,2(\rho_{1/2}-\rho_{-1/2})\left[\mathrm{Re}\left(S_{1/2} P^{-*}_{1/2}\right)\cos\theta + \mathrm{Re}\left(S_{1/2} D^{-*}_{1/2}\right)\left(\frac{3\cos^2\theta - 1}{2}\right)\right].$$

➡ P^--D^- interference

- If $|P_{1/2}^-| \sim 0$ *observed* cosθ dist. ⇨ *positive* parity, else no conclusion can be drawn re. parity.
- Angular dist. result^{s} from amplitude combinations [$S_{1/2}$, $P_{1/2}^+$] & [$P_{1/2}^-$, $D_{1/2}^-$] {both, [j=1/2, j=3/2]} are indistinguishable [eq. Minami Ambiguity in π p elastic scatt. {S. Minami, Prog. Theor. Phys. 11, 213(1954)} ↳ dσ/dΩ depends only on j, not on l]

- Detailed study of Ξ^-, Λ^0 decay correlation required (eg. Byers & Fenster)

The moments of the angular distribution for the $(\Xi^- \pi^+)$ system

Assuming that the $\Xi^*(1530)$ has **positive** parity:

$$P_0(\cos\theta) = \frac{1}{\sqrt{2}}$$

$$P_1(\cos\theta) = \sqrt{\frac{3}{2}}\cos\theta$$

$$P_2(\cos\theta) = \sqrt{\frac{5}{2}}\left(\frac{3\cos^2\theta - 1}{2}\right)$$

$$\frac{dN}{d\cos\theta} = \frac{1}{\sqrt{2}}\left(\left|S_{1/2}\right|^2 + \left|P_{1/2}^-\right|^2 + \left|P_{1/2}^+\right|^2\right)P_0(\cos\theta) + \sqrt{\frac{2}{5}}\left|P_{1/2}^+\right|^2 P_2(\cos\theta) + 2\sqrt{\frac{2}{3}}\left|S_{1/2}\right|\left|P_{1/2}^+\right|\cos(\varphi_S - \varphi_P)P_1(\cos\theta)$$

$$\frac{dN}{d\cos\theta} = \langle P_0\rangle P_0(\cos\theta) + \langle P_1\rangle P_1(\cos\theta) + \langle P_2\rangle P_2(\cos\theta)$$

$$\Rightarrow \begin{cases} \left(\left|S_{1/2}\right|^2 + \cancel{\left|P_{1/2}^-\right|^2} + \left|P_{1/2}^+\right|^2\right) = N \\ \left|P_{1/2}^+\right| = \sqrt{\sqrt{\frac{5}{2}}\langle P_2\rangle} \\ \cos(\varphi_S - \varphi_P) = \dfrac{\sqrt{\frac{3}{8}}\langle P_1\rangle}{\sqrt{\sqrt{\frac{5}{2}}\langle P_2\rangle\left(N - \sqrt{\frac{5}{2}}\langle P_2\rangle\right)}} \end{cases}$$