Λ_c's: Absolute production and decay rates

The CLEO Collaboration

w/ special thanks to: Peter Brabant, Matt Cervantes, Tony Rubiera, Russ Stutz, John Yelton

In a simple world...	In the real world...
$c \to sW^+(\Lambda_c) \equiv c \to sW^+(D^0)$	Exchange(Λ_c) >Exchange(D^0), W_{int}...
$\Gamma_{tot}(\Lambda_c) = \Gamma_{tot}(D^0)$	$\Gamma_{tot}(\Lambda_c) \sim 2.15\Gamma_{tot}(D^0)$
$\mathcal{B}(\Lambda_c \to \Lambda + X)$=100%	$\mathcal{B}(\Lambda_c \to \Lambda + X)$ ~30%
$\frac{\mathcal{B}(\overline{B}\to\Lambda_c\overline{N}X)}{\mathcal{B}(\overline{B}\to baryons)}$=100%	$\frac{\mathcal{B}(\overline{B}\to\Lambda_c\overline{N}X)}{\mathcal{B}(\overline{B}\to baryons)}$ ~50%
Canadian teams play for the Stanley Cup	The "New Jersey Devils"? The "Dallas Stars"?

⇒Life is not so simple...

$\boxed{\Lambda_c \to \Lambda \mathbf{X}}$

1. If Λ_c decays via just external spectator $c \to sW^+ \Rightarrow \Lambda_c \to \Lambda$X$\to$100%
2. But $\frac{\tau_{\Lambda_c}}{\tau_{D^0}} \sim 0.45 \Rightarrow \Gamma^{had}_{\Lambda_c}$ large

Expt.	τ_{Λ_c}
PDG 98	206 ± 12 fs
CLEO 00 (prelim.)	$179.8 \pm 5.9 \pm 4.0$ fs
(SELEX)	
FOCUS 00	201.9 ± 3.1 fs (stat. only)

cf: τ_{D^0} ~415 fs⇒Exchange, W_{int} in Λ_c large...

3. CLEO92: $\Lambda_c \to \Lambda X = 59 \pm 15\%$ used wrong B-decay model
   - Assumed $\overline{B} \to baryons \equiv \overline{B} \to \Lambda_c \overline{N} X$ only, and measured fraction:

     $\mathcal{B}(\Lambda_c \to \Lambda X) \leftrightarrow \frac{\mathcal{B}(\overline{B} \to \Lambda \overline{p} X)}{\mathcal{B}(\overline{B} \to \overline{p} X)}$

     (also $\mathcal{B}(\Lambda_c \to pK^-\pi^+) \leftrightarrow \frac{\overline{B} \to (\Lambda_c \to pK^-\pi^+)\overline{p}X}{\overline{B} \to \overline{p}X}$), but:

     $\mathcal{B}(\overline{B} \to \Xi_c)$ large ($\sim 0.5 \times \mathcal{B}(\overline{B} \to \Lambda_c)$)

     $\mathcal{B}(\overline{B} \to \overline{\Lambda}_c) \sim 20 \pm 12\%$

     $\mathcal{B}(\overline{B} \to DN\overline{N}X)$ non-zero (later, this talk)

Technique: Charm-tagging

- Measure product probability: $c \rightarrow$charmed baryon ("Θ_c") times

  $\Theta_c \rightarrow \Lambda$X - (EXPECT $\sim$90% of $\Theta_c \equiv \Lambda_c$)

- Measure Λ content opposite an anti-charm tag

  π^-_{soft} from $D^{*-} \rightarrow \overline{D}^0 \pi^-_{soft}$,

  e^- from $\overline{D} \rightarrow K e^- \nu_e$,

  fully reconstructed $\overline{D}^0 \rightarrow K^+ \pi^-$,

  fully reconstructed $D^- \rightarrow K^+ \pi^- \pi^-$.

- Opposite-hemisphere, "opposite-sign" (OH, OS) correlation gives desired signal from $\Lambda_c \rightarrow \Lambda + X$

$$c \qquad \bar{c}$$

$$\Theta_c \hookleftarrow \quad \hookrightarrow D^{*-}$$

$$\Lambda + X \hookleftarrow \qquad\qquad \hookrightarrow \pi^- + \overline{D}^0$$

$$p + \pi^- \hookleftarrow \qquad\qquad \hookrightarrow e^- + \overline{\nu}_e + K^+$$

$$\frac{\#\boldsymbol{\Lambda}}{\mathbf{c\bar{c}}} = \mathbf{B}(\mathbf{c} \rightarrow \boldsymbol{\Theta}_\mathbf{c}) \cdot \mathbf{B}(\boldsymbol{\Theta}_\mathbf{c} \rightarrow \boldsymbol{\Lambda} + \mathbf{X}) \cdot \epsilon_{\boldsymbol{\Lambda}} \tag{1}$$

- Use MC to estimate efficiency ϵ_Λ (and bkgnds):

$$\frac{\frac{\#\Lambda}{c\bar{c}}^{Data}}{\frac{\#\Lambda}{c\bar{c}}^{MC}} = \frac{B(c \rightarrow \Theta_c + X) \cdot B(\Theta_c \rightarrow \Lambda + X)^{Data}}{B(c \rightarrow \Theta_c + X) \cdot B(\Theta_c \rightarrow \Lambda + X)^{MC}} \tag{2}$$

electron-tag signals by hemisphere/sign

$$c \qquad \overline{c}$$

$$\Theta_c \hookleftarrow \quad \hookrightarrow D^{*-}$$

$$\Lambda + X \hookleftarrow \qquad\qquad \hookrightarrow \pi^- + \overline{D}^0$$

$$p + \pi^- \hookleftarrow \qquad\qquad\qquad\qquad \hookrightarrow e^- + \overline{\nu}_e + K^+$$

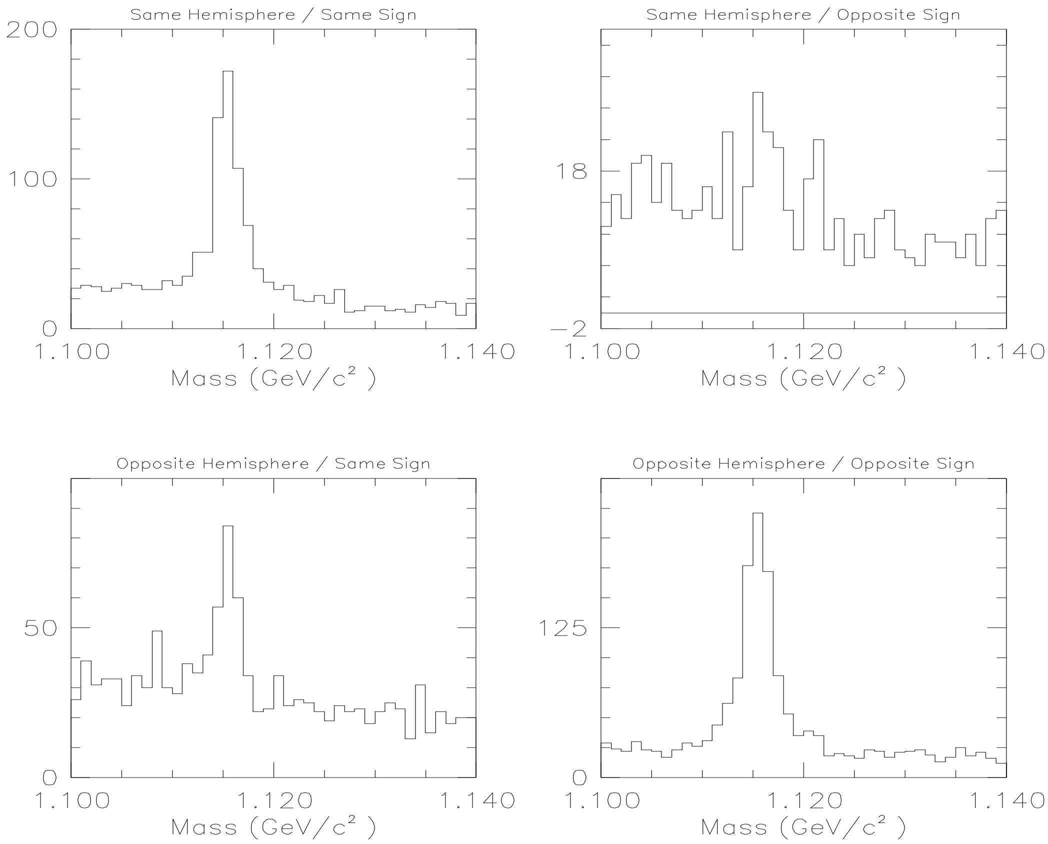


Table 1: Tabulated number of Λ's detected for both signal and non-signal correlations followed by $\Lambda/c\bar{c}$. For π^-_{soft} and e^-, a data sample corresponding to ~5 million c$\bar{c}$ events were used; $\overline{D}^0$ and D^- tags are derived from a dataset of ~15 Million c$\bar{c}$ events. In both cases, the Monte Carlo simulated data sample is of comparable, or slightly larger size. Shown are opposite hemisphere (OH), same hemisphere (SH), opposite sign (OS) and same sign (SS) correlations.

Correlation	Electron	π	$\overline{D}^0$	D^-
Data				
SH, SS	445 ± 26	1039 ± 170	252±33	220±34
SH, OS	43 ± 13	484 ± 186	14±24	12±38
OH, SS	142 ± 19	914 ± 356	223±76	233±91
OH, OS	743 ± 32	5964 ± 203	2247±75	2031±102
$\frac{\Lambda}{c\bar{c}}$ SH, SS ($\times10^{-4}$)	32.3 ± 1.9	9.8 ± 1.6	7.8±1.0	8.6±1.3
$\frac{\Lambda}{c\bar{c}}$ SH, OS ($\times10^{-4}$)	3.1 ± 0.9	4.6 ± 1.8	0.4 ± 0.6	0.4±0.8
$\frac{\Lambda}{c\bar{c}}$ OH, SS ($\times10^{-4}$)	10.3 ± 1.4	9 ± 3	7.2±2.3	9.1±3.6
$\frac{\Lambda}{c\bar{c}}$ **OH, OS** ($\times10^{-4}$)	50±2	56±1.9	69 ± 2	79 ± 4
Monte Carlo				
SH, SS	573±29	5469±363	182±52	179±65
SH, OS	62 ± 13	1448 ± 381	44±23	4±46
OH, SS	264 ± 24	2251 ± 409	285±104	114±62
OH, OS	1352 ± 61	26413 ± 643	2073 ± 65	1514 ± 85
$\frac{\Lambda}{c\bar{c}}$ SH, SS ($\times10^{-4}$)	32 ± 2	19 ± 2	7 ± 2	11.2 ± 4
$\frac{\Lambda}{c\bar{c}}$ SH, OS ($\times10^{-4}$)	4 ± 1	5 ± 1	2 ± 1	3 ± 2
$\frac{\Lambda}{c\bar{c}}$ OH, SS ($\times10^{-4}$)	15 ± 2	8 ± 2	11 ± 5	7 ± 4
Monte Carlo $\frac{\Lambda}{c\bar{c}}$ **OH, OS** ($\times10^{-4}$)	76 ± 3	90 ± 2	80 ± 2	93 ± 4

Result:

- $B(c \to \Theta_c X) \cdot B(\Theta_c \to \Lambda + X) = (1.87 \pm 0.03 \pm 0.33)\%$
- OPAL: $B(b \to \Theta_b X)B(\Theta_b \to \Lambda + X) = (3.50 \pm 0.32 \pm 0.35)\%$

  JETSET 7.3: $\frac{b \to \Lambda_b}{c \to \Lambda_c} \sim 2$

  Consistent, if $\Lambda_b \to \Lambda_c \sim 1$

  But, if $\Lambda_c \to pKX$, why not $\Lambda_b \to pDX$??
- Cross/consistency checks:

  Same hemisphere Λe^- yield consistent w/ $\Lambda_c \to \Lambda e \nu_e$

  ${\frac{\#D^0}{tag}}_{data} \equiv {\frac{\#D^0}{tag}}_{MC}$ for all four-tags.

Inferred $\Lambda_c \to \Lambda X$

Ingredients:

1. JETSET 7.3 value of $c \to \Theta_c$ (0.0667)
2. JETSET 7.3 value of $\frac{c\to\Lambda_c}{c\to\Theta_c}$ (0.88)
3. All-tags: $\Lambda_c \to \Lambda X$=28 ± 1 ± 5%
4. N.B. PDG: $\Sigma_{exclusive}(\Lambda_c \to \Lambda X) = 17 \pm 3\%$

   Modes with $\geq 4\pi$ presumably = remainder
5. Note: $\mathcal{B}(B \to (\Lambda/\overline{\Lambda})X) = 4 \pm 0.5\%$

   CLEO: $\mathcal{B}(B \to (\Lambda_c/\overline{\Lambda}_c)X) = 3.6\%$

   (from $\mathcal{B}(B \to (\Lambda_c/\overline{\Lambda}_c)X) \cdot (\Lambda_c \to pK\pi) = 1.78 \times 10^{-3}$

   Since only 28% of these are producing Λ's, conclude

   $\mathcal{B}(B \to \Lambda_c/\overline{\Lambda}_c)X) \to (\Lambda/\overline{\Lambda})X \sim 2\% < B \to (\Lambda/\overline{\Lambda})X = 4 \pm 0.5$

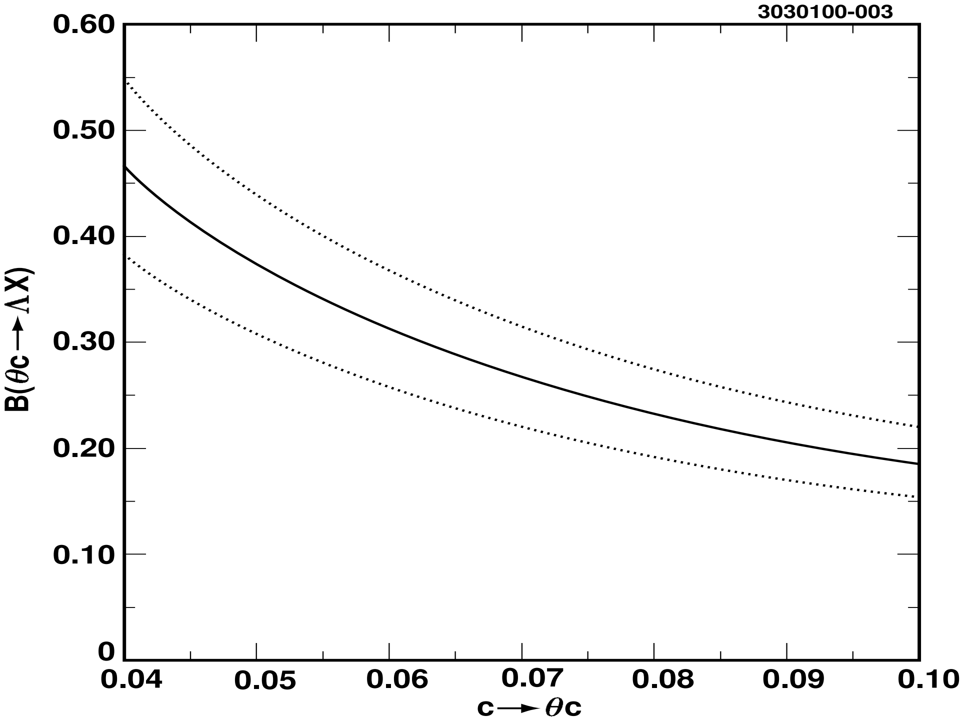
   $\Rightarrow B \to \Lambda/\overline{\Lambda}(not\ from\ \Lambda_c/\overline{\Lambda}_c)$ substantial!

Product BR Summary

$\mathcal{B}_\Lambda = B(c \to \Theta_c + X) \cdot B(\Theta_c \to \Lambda + X) = (1.87 \pm 0.03 \pm 0.33)\%.$

Can present a two-dimensional plot of: $c \to \Theta_c$ vs. $\Lambda_c \to \Lambda$X (with appropriate error contours), e.g.:

(JETSET 7.3: $c \to \Theta_c$X @ $\sqrt{s}$=10 GeV = 0.067



Checks of the implied $\Lambda_c \to \Lambda X$ value

1. Measure $D^0 \to K^-\pi^+$

   Trust MC value of $\frac{c \to D^0}{c \to X}$ (0.52 ($\pm 10\%$))

   ◦ Soft-pion-tag: $\frac{\mathcal{B}(D^0 \to K^-\pi^+)}{0.0385} = 1.03 \pm 0.03$

   (Apply $(3 \pm 3)\%$ correction)

   ◦ Electron-tag: $\frac{\mathcal{B}(D^0 \to K^-\pi^+)}{0.0385} = 0.80 \pm 0.04$

   (Apply $(20 \pm 20)\%$ correction)

2. Λ-electron correlation sample: same-hemisphere, "same-sign" events expected to be mostly $\Lambda_c \to \Lambda e \nu_e$ events.

   $\mathcal{B}(\Lambda_c \to \Lambda e \nu_e = 0.021 \pm 0.006$:

$$\frac{N_{SH/SS}}{N_{OH/OS}} \approx \frac{(c \to \Lambda_c) \cdot \mathcal{B}(\Lambda_c \to \Lambda e \nu_e) \cdot \epsilon(\Lambda_c \to \Lambda e \nu_e)}{(c \to \Lambda_c) \cdot (\overline{c} \to eX) \cdot \mathcal{B}(\Lambda_c \to \Lambda X) \cdot \epsilon(\Lambda_c \to \Lambda X) \cdot \epsilon(\overline{c} \to eX)}$$

   Use $N_{SH/SS}$ (471 ± 21); $N_{OH/OS}$ (768 ± 28)

   $\Rightarrow \Lambda_c \to \Lambda X \sim 0.21 \pm 0.06$ (stat. error only)

3. CLEO: measure $\frac{([\Lambda\overline{p}]|\overline{D}^0)}{(\overline{p}|\overline{D}^0)}$

   (I.e., use same technique used to measure $\Lambda_c \to pK^-\pi^+$ to measure $\Lambda_c \to \Lambda X$)

   Soft-pion tag: $\Lambda_c \to \Lambda X = 15 \pm 3\%$

   Electron tag: $\Lambda_c \to \Lambda X = 18 \pm 4\%$

   (Less vulnerable to CLEO result: $\frac{\Lambda_c}{\overline{\Lambda}_c} \sim 3\frac{D^0}{\overline{\Lambda}_c}$.)

Measurement of $\mathcal{B}(\Lambda_c \to pK^-\pi^+)$ ("normalizing mode")

Previous Measurements of $\mathcal{B}(\Lambda_c \to pK^-\pi^+)$:

1. Based on Λ_c production in B-decay (ARGUS and CLEO)
   - As before, assume charmed baryon production in B-decay exclusively through: $\boxed{\overline{B} \to \Lambda_c \overline{N} X}$
   - IF true, then $\overline{B} \to \overline{p}X$ gives unbiased sample of $\overline{B} \to \Lambda_c \overline{p} W^-$ evts.
     CLEO claims $\mathcal{B}(\Lambda_c \to pK^-\pi^+)$=4.14±0.91%
   - HOWEVER: $\overline{B} \to \overline{p}X$ does not exclusively tag $\overline{B} \to \Lambda_c \overline{p} W^-$ (since $\overline{B} \to \Xi_c \overline{\Lambda}_c$; $\overline{\Lambda}_c \to \overline{p}X$ and $\overline{B} \to DN\overline{N}X$)
   - B-decay based extraction therefore likely overestimated denominator (i.e., underestimated $\mathcal{B}(\Lambda_c \to pK^-\pi^+)$)
2. Based on $\frac{\Lambda_c \to \Lambda \ell \nu_\ell}{\Lambda_c \to pK\pi}$ (ARGUS and CLEO)
   - ASSUME $\Gamma_{\Lambda_c \to X \ell \nu_\ell} \equiv \Gamma_{D \to X \ell \nu_\ell}$
     $\Rightarrow$Knowing $\frac{\tau_{\Lambda_c}}{\tau_D}$ $\Rightarrow$infer absolute $\mathcal{B}(\Lambda_c \to X \ell \nu_\ell)$ from measured $\Lambda_c \to \Lambda X \ell \nu_\ell$ yield.
   - ASSUME $\frac{\Gamma_{\Lambda_c \to \Lambda X \ell \nu_\ell}}{\Gamma_{\Lambda_c \to X \ell \nu_\ell}}$ $\to$1.0, so measured $\frac{\Lambda_c \to \Lambda \ell \nu_\ell}{\Lambda_c \to pK\pi}$ yield gives $\mathcal{B}(\Lambda_c \to pK^-\pi^+)$
   - Dunietz: $\mathcal{B}(\Lambda_c \to pK^-\pi^+)$=7±2%

$\mathcal{B}(\Lambda_c \to pK^-\pi^+)$ from $c\bar{c}$ charm-tagging

Assume Λ_c's typically produced in $c\bar{c}$ events with opposite-hemisphere $\bar{c}$ (to conserve charm) and same-hemisphere $\overline{N}$ (to conserve baryon no.)

Notational Aside:

[XY]$\Rightarrow$ X and Y in SAME hemisphere

$(X|Y) \Rightarrow$ X and Y in OPPOSITE hemispheres

Sample event: $e^+e^- \to ([\Lambda_c\overline{p}]|\overline{D})$:

$$\begin{array}{rr|lll}
 & c & \bar{c} & & \\
 & \overline{p} \hookleftarrow & \hookrightarrow D^{*-} & & \\
 & \Lambda_c \hookleftarrow & & \hookrightarrow \overline{D^0}\pi^-_{soft} & \\
anything \hookleftarrow & & & & \hookrightarrow e^-K^+\nu_e
\end{array}$$

$\Rightarrow$ Reconstruct fraction of $(\overline{p}|\overline{D})_{tag}$ evts. containing $\Lambda_c \to pK\pi$ in hemisphere opposite $\overline{D}_{tag}$, same hemisphere as $\overline{p}$.

i.e.: $\mathcal{B}(\Lambda_c \to pK^-\pi^+) \equiv \frac{([\overline{p}\Lambda_c(\to pK\pi)]|\overline{D})}{(\overline{p}|\overline{D})}$

Different $\overline{D}$-tag samples (as for $\Lambda_c \to \Lambda X$)

1. $D^{*-} \to \overline{D}\pi^-_{\mathbf{soft}}$ tags

   Determine $\frac{([\overline{p}\Lambda_c]|\pi^-_{soft})}{(\overline{p}|\pi^-_{soft})}$: "triple correlation"

2. $\overline{D} \to X\mathbf{e}^-\nu_e$

   Determine $\frac{([\overline{p}\Lambda_c]|e^-)}{(\overline{p}|e^-)}$: "triple correlation"

3. $\overline{D}^0 \to K^+\pi^-$ .OR. $D^- \to K^+\pi^-\pi^-$ .OR. $\overline{D}_s \to \phi\pi$
   - Here do not demand that $\overline{D}$ be detected to determine numerator; i.e.:
   - $\mathcal{B}(\Lambda_c \to pK\pi) \equiv \frac{[\overline{p}\Lambda_c(\to pK\pi)]/\epsilon_{\Lambda_c}}{(\overline{p}|\overline{D})/\epsilon_{\overline{D}}}$ ("double correlation")

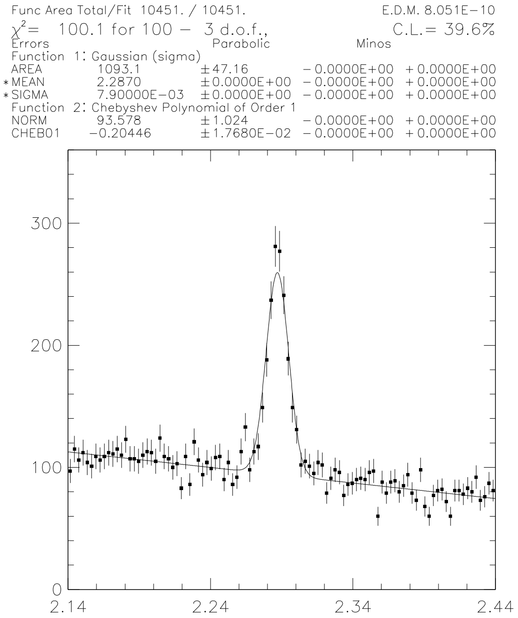
     After bkgnd. subtraction & efficiency correction,

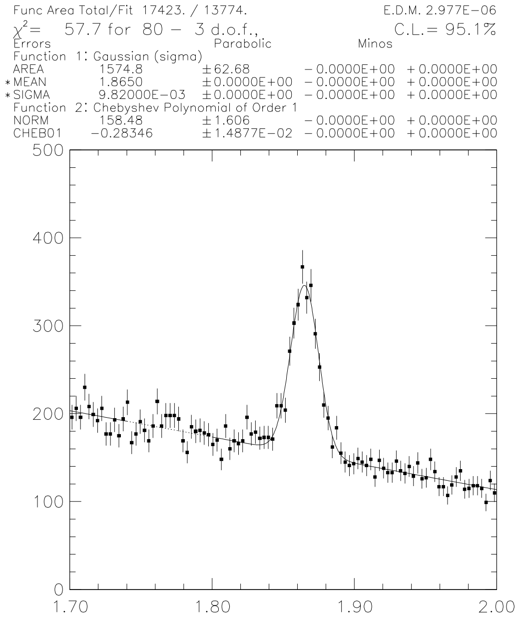
   Denominator gives total no. of $([\overline{p}\Lambda_c]|\overline{D})$ evts.

(In principle, could have used double correlations for π^-_{soft} and e^- tags, also, however these have other systematic errors)

Double Correlation Signals:

Numerator: $[\overline{p}\Lambda_c]$; $\Lambda_c \to pK^-\pi^+$; Denominator: $(\overline{p}|\overline{D}^0)$; $\overline{D}^0 \to K^+\pi^-$





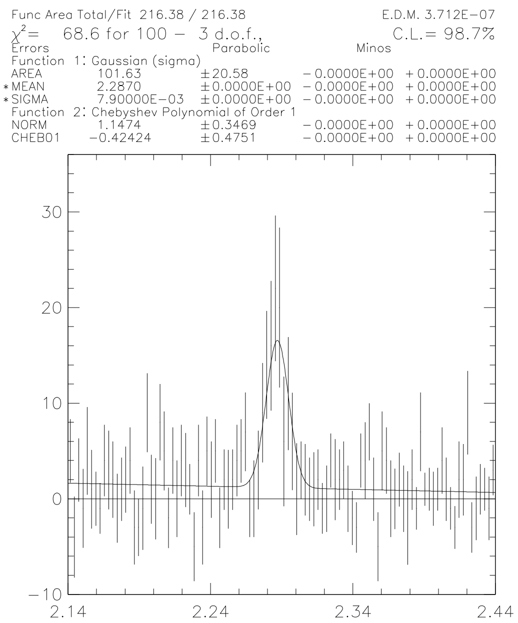
$([\Lambda_c\overline{p}]|\pi^-_{soft})$ and $([\Lambda_c\overline{p}]|e^-)$ Triple Correlation Signals

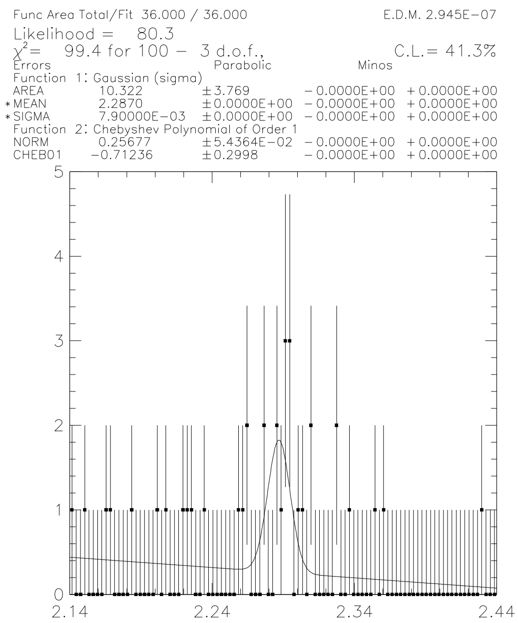
$c \;|\; \overline{c}$

$\overline{p} \hookleftarrow \qquad \hookrightarrow D^{*-}$

$\Lambda_c \hookleftarrow \qquad \hookrightarrow \overline{D^0}\pi^-_{soft}$

$anything \hookleftarrow \qquad \hookrightarrow e^- K^+ \nu_e$





Corrections

Numerator: Sources of $[\overline{p}\Lambda_c]$ events which pass all our cuts, but do NOT tag $([\overline{p}\Lambda_c]|\overline{D})$:

1. $([\overline{p}\Lambda_c]|[N\overline{\Lambda}_c])$ (4-baryon evts.)

   JETSET 7.3 MC$\Rightarrow\sim$2% correction

   Upper limit from data$\sim$5%

2. Fake proton-tags

   Same hemisphere π^- and K^- (from D decay) can fake $\overline{p}$ ID cuts.

   Determine from data the rate of π^- and K^- faking $\overline{p}$ (use $K_s^0 \to \pi^+\pi^-$, $D^0 \to K^-\pi^+$ and $\phi \to K^+K^-$)

   K^- fake rate higher than pions (closer to proton mass)

   Small correction ($\sim$2%)

Denominator: Sources of $(\overline{p}|\overline{D})$ events which do NOT tag $([\overline{p}\Lambda_c]|\overline{D})$:

1. $[(\overline{p}\overline{D})|(DN)]$

   Measure from data, using events with $\overline{p}$ in same hemisphere as D: $[\overline{p}D]$.

   Such events presumed to have $\overline{D}$ in opposite hemisphere$\Rightarrow$estimates $(\overline{p}|\overline{D})$ fraction which is $[(\overline{p}\overline{D})|(DN)]$

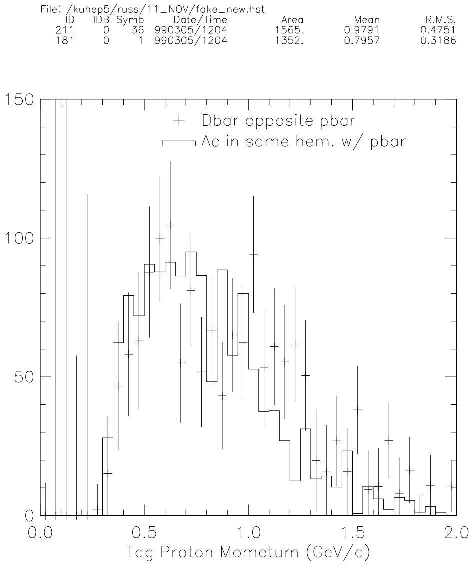
2. Kaons and pions faking $\overline{p}$: Substantial correction from: $c|\overline{c} \to (D|\overline{D})$, $D \to K^-$X, with K^- faking $\overline{p}$

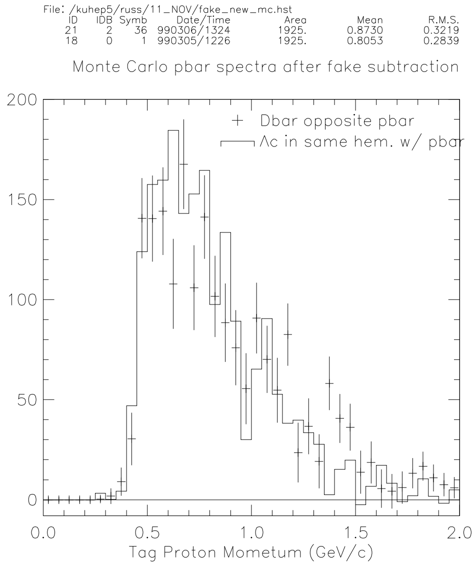
   (Rough estimate: $\frac{c|\overline{c}\to(\overline{D}|D)}{c|\overline{c}\to\overline{D}|\Lambda_c}$ $\sim$9; Half of $([\overline{N}\Lambda_c]|\overline{D})$ events have $\overline{N}\equiv\overline{p}$; $D \to K^-X$ $\sim$0.5; K^- fake rate $\sim$1% per true kaon)

   $\Rightarrow$expect $\sim$10-20% bkgnd from this source, find $\sim$15%

Cross-check

- After all subtractions, compare $\frac{dN(\overline{p})}{dp}$ in $(\overline{p}|\overline{D})$ sample w/ $\frac{dN(\overline{p})}{dp}$ in $[\overline{p}\Lambda_c]$ sample.
- Neglecting bias introduced by having $\overline{p}$ in same hemisphere as Λ_c, spectra should overlay if both samples drawn from same $([\overline{p}\Lambda_c]|\overline{D})$ events.



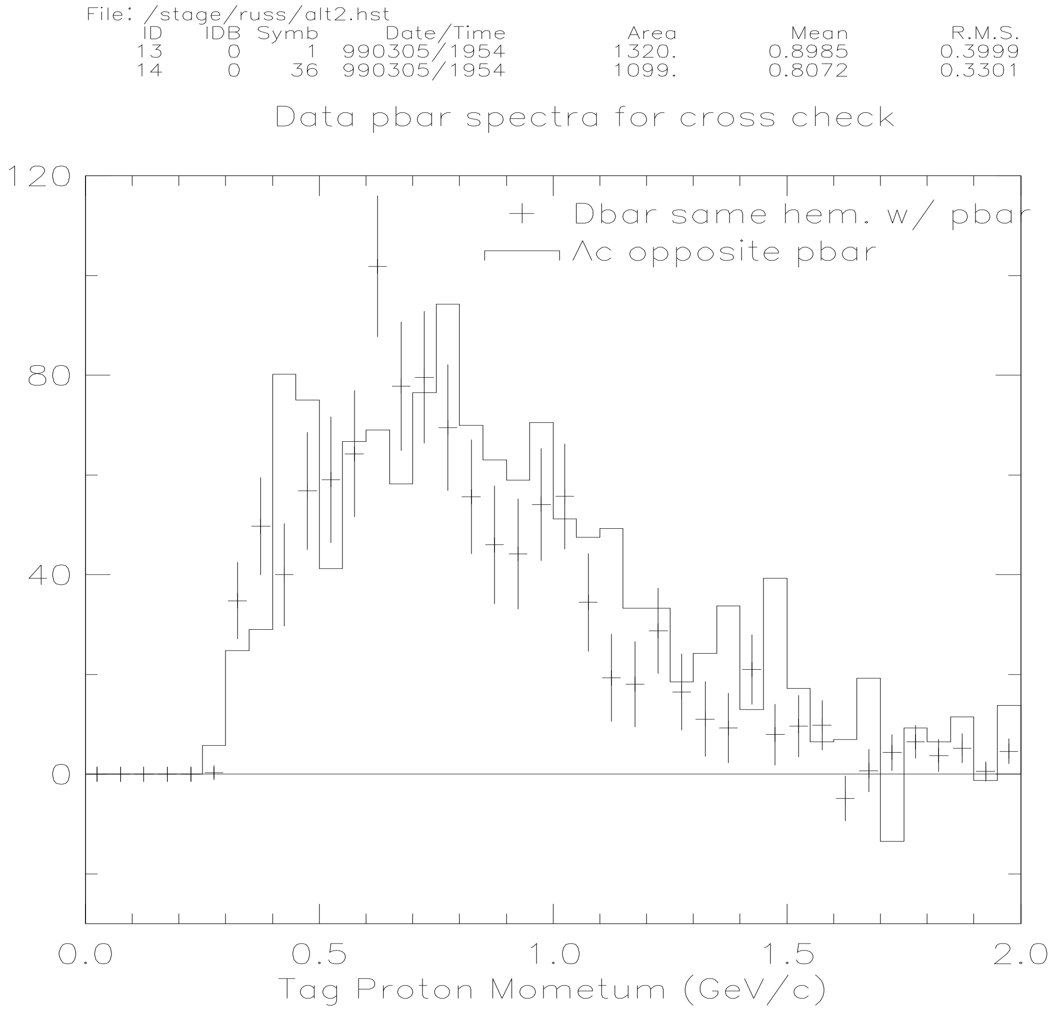


N.B. MC slightly softer than data, however, not problematic as long as $\left(\frac{dN}{dp}\right)_{(\overline{p}|\overline{D})} \equiv \left(\frac{dN}{dp}\right)_{[\overline{p}\Lambda_c]}$

Cross-check (cont.)

- As further check, use $([\overline{p}\overline{D}]|\Lambda_c)$ (only to check momentum spectra)

◦ Extraction of $\mathcal{B}(\Lambda_c \to pK\pi)$ here susceptible to $\Lambda_c|\overline{\Lambda}_c$ correlations; also more difficult to measure $([\overline{p}\overline{D}]|[D\overline{N}])$ bkgnd.



Double Correlations	MC	Data
$\mathcal{Y}[\Lambda_c\overline{p}]$ (Numerator)	1656±65	1093±47
$\mathcal{Y}(\overline{D^0}\|\overline{p})$ (Denominator)	2725±84	1369±55
$\mathcal{Y}(D^-\|\overline{p})$ (Denominator)	1501±113	963±71
$\mathcal{Y}(D_s^-\|\overline{p})$ (Denominator)	111±19	51±11
$\mathcal{Y}(\overline{\Lambda_c}\overline{p})$ (Bkgnd to Num.)	–84±49	–75±39
$\mathcal{Y}[D^0\overline{p}]$ (Bkgnd to Den.)	–268±40	–68±23
$\mathcal{Y}[D^+\overline{p}]$ (Bkgnd to Den.)	–417±67	–152±39
$\mathcal{Y}[D_s^+\overline{p}]$ (Bkgnd to Den.)	–26±11	–1±6
fake $\overline{p}$ in $[D\overline{p}]$	–272±31	–298±36
$\mathcal{B}(\Lambda_c \to pK^-\pi^+)$	4.3%	(4.9±.5)%
$(\pi^-_{soft}\overline{p})$ Triple Correl.		
$\mathcal{Y}(\pi^-_{soft}\|\overline{p})$ (Denominator)	34222±1092	14553±485
fake $\overline{p}$ in $(\pi^-_{soft}\|\overline{p})$	–3318±310	–1867 ± 261
$\mathcal{Y}([\Lambda_c\overline{p}]\|\pi^-_{soft})$ (Numerator)	202.8±27.8	101.6±20.6
$\mathcal{B}(\Lambda_c \to pK^-\pi^+)$	4.3%	(5.2±1.3)%
$(e^-\overline{p})$ Triple Correl.		
$\mathcal{Y}(e^-\|\overline{p})$ (Denominator)	4178±65	1739±47
fake $\overline{p}$ + fake e^-	–382±39	–272 ± 41
$\mathcal{Y}([\Lambda_c\overline{p}]\|e^-)$ (Numerator)	20.1±5.2	10.3±3.8
$\mathcal{B}(\Lambda_c \to pK^-\pi^+)$	4.3%	(5.6±2.5)%

Weighted average of three techniques: $\mathcal{B}(\Lambda_c \to pK\pi) = 5.0 \pm 0.5 \pm 1.2\%$

- $\mathcal{B}(\overline{B} \to \Lambda_c) \cdot (\Lambda_c \to pK\pi) = (1.78 \pm 0.2) \times 10^{-3} \Rightarrow \mathcal{B}(\overline{B} \to \Lambda_c) \sim 4\%$

  But $B \to$baryons$\sim$8%$\Rightarrow$Whither all the other $B \to$baryons?

Systematic Errors:

Dominated by uncertainties in background subtractions, MC modeling.

	π_{soft} tag	Electron tag	Double Corr.
$D\overline{D}N\overline{p}$ background events	8%	8%	8%
Tag proton id/spectrum	15%	15%	15%
Hemisphere Correlation	5%	5%	5%
Contamination of Ξ_c, Ω_c events	3%	3%	3%
Λ_c/D momentum spectra	8%	8%	8%
Λ_c/D id cuts	5%	5%	5%
Λ_c mass fit/sideband subtraction	6%	10%	1%
Contamination from Σ_c^0, $\Lambda_{c,J}$	6%	-	-
tag electron fakes	-	5%	-
$\Lambda_c\overline{\Lambda}_c N\overline{p}$ events	-	-	4%
$B_{D^0 \to K^-\pi^+}$	-	-	2%
$B_{D^+ \to K^-\pi^+\pi^+}$	-	-	3%
Event Selection/MC Mismodeling	15%	14%	12%
Total	28%	25%	24%

Study of $(\Lambda_c|\overline{\Lambda}_c)$ Correlations

In $\Lambda_c \to \Lambda X$ and $\Lambda_c \to pK^-\pi^+$ analyses, measured yields opposite tag. Analysis simplest when c/c̄ fragment independently...Do they?

⇒Explicit search for fragmentation correlations

- Method: Look for Λ_c^-; Measure fraction of times we find $(\Lambda_c^-|\Lambda_c^+)$ vs. $(\Lambda_c^-|D)$; Normalize to total number of Λ_c^+ or D^0, D^+ ("Single Tags"), respectively.
- These values are denoted as $(\frac{(\Lambda_c^+|\Lambda_c^-)}{\Lambda_c^-})$, $(\frac{(\Lambda_c^+|\overline{D^0})}{\overline{D^0}})$, and $(\frac{(\Lambda_c^+|D^-)}{D^-})$
- If Fragmentation is entirely independent, expect:

$$\frac{(\Lambda_c^+|\Lambda_c^-)}{\Lambda_c^+} \div \frac{(\Lambda_c^+|\overline{D^0})}{\overline{D^0}} = 1$$

$$\frac{(\Lambda_c^+|\Lambda_c^-)}{\Lambda_c^+} \div \frac{(\Lambda_c^+|D^-)}{D^-} = 1$$

- If there is correlated charmed baryon/anti-charmed baryon production, then $\frac{(\Lambda_c^+|\Lambda_c^-)}{\Lambda_c^+} \div \frac{(\Lambda_c^+|\overline{D^0})}{\overline{D^0}} > 1$

Data; Single tags and Double Tags

	Data	Monte Carlo
$\Lambda_c \to \mathrm{p}K\pi$	42211 ± 751	32756 ± 635
$D^0 \to K\pi$	352294 ± 1043	332436 ± 1371
$(\Lambda_c^+|\Lambda_c^-)$	80.5 ± 21.4	18.6 ± 18.4
$(\Lambda_c^+|\overline{D^0})$	431.6 ± 50.7	443.8 ± 46.5

Production Ratios, complete

$$\frac{\Lambda_c^+|\Lambda_c^-}{\Lambda_c^-} = \frac{80.5 \pm 21.4}{42211 \pm 751} = 0.0038 \pm 0.0010,$$

$$\frac{\Lambda_c^+|\overline{D^0}}{\overline{D^0}} = \frac{434.1 \pm 44.1}{352294 \pm 1043} = 0.00123 \pm 0.00014.$$

	Data	Data	Monte Carlo	Monte Carlo
	p$K\pi$	p$\overline{K_s^0}$	p$K\pi$	p$\overline{K_s^0}$
$\frac{\frac{\Lambda_c^+\|\Lambda_c^-}{\Lambda_c^-}}{\frac{\Lambda_c^+\|\overline{D^0}}{\overline{D^0}}}$	**3.11 ± 0.91**	**3.40 ± 1.10**	**0.85 ± 0.85**	**1.40 ± 0.99**
$\frac{\frac{\Lambda_c^+\|\Lambda_c^-}{\Lambda_c^-}}{\frac{\Lambda_c^+\|D^-}{D^-}}$	**2.71 ± 0.87**	**2.93 ± 1.08**	**0.62 ± 0.63**	**1.61 ± 1.22**
$\frac{\frac{\Lambda\|\Lambda_c^-}{\Lambda}}{\frac{\Lambda\|\overline{D^0}}{\overline{D^0}}}$	**3.58 ± 0.23**	**2.97 ± 0.34**	**1.55 ± 0.18**	**1.08 ± 0.27**
$\frac{\frac{\Lambda\|\Lambda_c^-}{\Lambda}}{\frac{\Lambda\|D^-}{D^-}}$	**3.17 ± 0.24**	**2.63 ± 0.32**	**1.26 ± 0.15**	**0.88 ± 0.22**

Clear evidence for production correlations!

Λ_c's produced as B-decay products

Reprise: where have all the $B \to baryons$ gone?

$\mathcal{B}(\Lambda_c \to pK^-\pi^+) = 5.0 \pm 1.3\% \Rightarrow 50\%$ $B \to baryons$ NOT: $\overline{B} \to \Lambda_c \overline{p} X$.

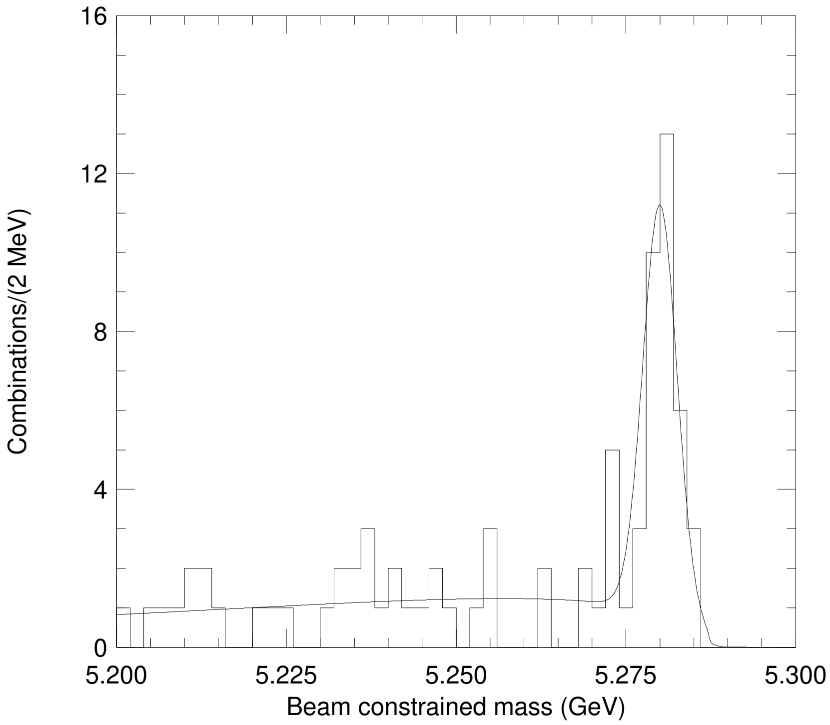
- Perhaps W$\to N\overline{N}$ non-neglible in $b \to c$: $B \to \overline{D} p \overline{N} X$ (Dunietz)

- previous U.L. (CLEO 92): $\mathcal{B}(B \to D N \bar{N} X) < 4.8$ %. at 90% C.L.
- Perform direct search for exclusive modes: $B \to D^{*-} p \overline{n}$ or $B \to D^{*-} p \overline{p} \pi$, using 9.65×10^6 $B\overline{B}$ pairs (CLEO-II+CLEO-II.V).

  $D^{*-} \to D^0 \pi^-$; $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$, or $K^-\pi^+\pi^0$
- Calculate Beam-constrained mass: $m_{B^0} = \sqrt{E^2_{beam} - p^2_{B^0}}$.

$B \to \overline{D} p \overline{p} \pi$, exclusive

Plot M_{BC} distribution for $B^0 \to D^{*-}\ p\ \bar{p}\ \pi^+$



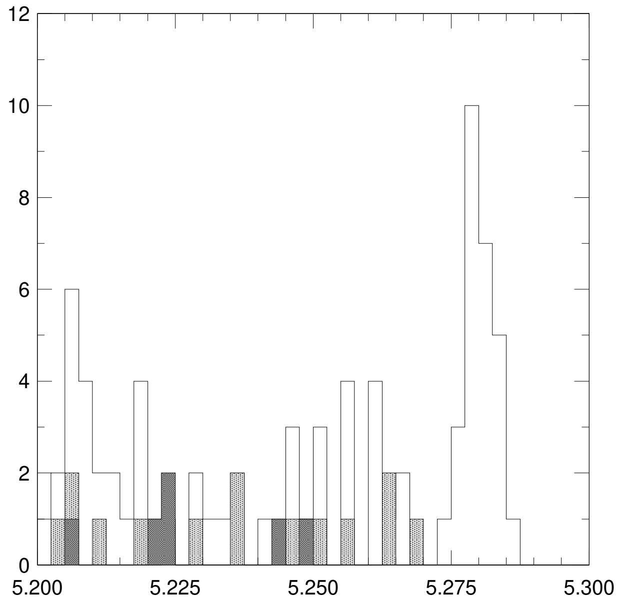
- fitted signal yield $= 33.0^{+6.8}_{-6.0}$ events

$B \to D^{*-} p\overline{n}$

- CLEO not equipped with an anti-neutron detector, per se.
- However, anti-neutron interactions distinctive through annihilations w/ CsI$\Rightarrow$large energy deposition, but statistical fluctuations on $E_{annihilation}$ VERY large.
- $\Rightarrow$To reconstruct $B \to D^{*-} p\overline{n}$, set:

  $$E_{beam} \equiv E_{B^0};\ E_{beam} - (E_{D^{*-}} + E_p) = E_{\overline{n}}.$$

- Use measured direction cosines of $\overline{n}$ annihilation shower in calorimeter to solve for $p_{x,\overline{n}},\ p_{y,\overline{n}},\ p_{z,\overline{n}}$.
- Now calculate beam-constrained mass: $m_{B^0} = \sqrt{E^2_{beam} - p^2_{B^0}}$.



- Measured B.F.'s: $\mathcal{B}(B^0 \to D^{*-}\ p\ \bar{p}\ \pi^+) = (6.6^{+1.3}_{-1.2} \pm 1.0) \times 10^{-4}$, and $\mathcal{B}(\ B^0 \to D^{*-}\ p\ \bar{n}\ ) = (14.8^{+3.5}_{-3.1} \pm 3.0) \times 10^{-4}$.

Extensions of these analyses

1. Charm-baryon tagging: Measure $\Lambda_c \to X l \nu_l$ by measuring lepton yield opposite a $\overline{D}$ and in same hemisphere as an antiproton:

   $\mathcal{B}(\Lambda_c \to X l \nu_l) \equiv \frac{([\overline{p}\Lambda_c(\to X l \nu_l]|\overline{D})}{(\overline{p}|\overline{D}})$

   (in progress)

2. $B \to baryons$

   Exploit angular correlations:

   $B \to \Lambda_c X l \nu_l \Rightarrow \cos\theta(l, \Lambda_c) < 0.$

   ANY anisotropy between lepton and $\Lambda_c \Rightarrow B \to \Lambda_c X l \nu_l$

   (in progress)

3. CKM-suppressed modes: $\frac{B \to p\overline{p}\pi^+\pi^-}{B \to p\overline{p}\pi^+ D^{*-}} \sim \frac{|V_{ub}|^2}{|V_{cb}|^2}$

   $\sim$20 events in CLEO-II.V data?

SUMMARY

- $\mathcal{B}(c \to \Theta_c) \cdot \mathcal{B}(\Theta_c \to \Lambda X) = \mathcal{B}_\Lambda = (1.87 \pm 0.03 \pm 0.33)\%$.
  $\mathcal{B}(c \to \Theta_c) \sim 0.065 \Rightarrow \mathcal{B}(\Lambda_c \to \Lambda X) \sim 30\%$
- $\mathcal{B}(\Lambda_c \to pK^-\pi^+) = 5.0 \pm 0.5 \pm 1.2\%$, using new technique
- $(\Lambda_c|\overline{\Lambda}_c)$ correlations observed in e^+e^- collisions:
  $\overline{\Lambda}_c$ three times as likely to appear opposite a charmed baryon than a charmed meson.
- $B \to \overline{D}N\overline{N}X$ large, and perhaps comparable to $B \to \overline{\Lambda}_c NX$

Closing comments from Ithaca, NY:

- "Don't look back, somebody might be gaining on you."
  (Satchel Paige, KC Monarchs)
- "Rumors of my death are exagerrated." (Sam Clemens)
- "We will bury you." (Nikita Kruschev)
- "So what if those other experiments have more people, more money and better sushi, we got Tony Neutron." (Peter Brabant)