Search for double heavy baryons

R. Keith Ellis, Rick van Kooten

- Strategy
- ucc
- dcc
- scc
- dcb
- ucb
- ubb
- dbb
- sbb

References

[1] C. Quigg, http://www-theory.fnal.gov/people/ligeti/Brun2/sept/quigg.pdf

[2] V.V. Kiselev, A.K. Likhoded, A.I. Onishchenko, Published in Phys.Rev.D60:014007,1999 e-Print Archive: hep-ph/9807354, ccq Lifetime

[3] V.V. Kiselev, A.K. Likhoded, A.I. Onishchenko, e-Print Archive: hep-ph/9901224, bcq Lifetime

[4] A.K. Likhoded, A.I. Onishchenko, e-Print Archive: hep-ph/9912425, bbq Lifetime

[5] J.D. Bjorken, 'Is the *ccc* a new deal for baryon spectroscopy', Fermilab-Conf-85/69

[6] J.D. Bjorken, 'Estimate of Decay Branching ratios for hadrons containing Charm and Bottom quarks', unpublished Fermilab report (1986)

Strategy

Look at simplest diagrams involving spectator decay or W-exchange. Dress up by popping quark-antiquark pairs from the vacuum to simplest states containing charged particles in the final state.

- No modern estimate of branching ratios (as yet).
- No estimate of number additional pions (charged and neutral) which will accompany these decays.
- No discussion of differences between $J = \frac{1}{2}$ and $J = \frac{3}{2}$ baryons
- No discussion of Ω_{ccc} or Ω_{bbb} or tetraquarks $QQ\bar{q}\bar{q}$

For more detailed (but somewhat dated estimates) of these effects see 'Estimates of Decay Branching Ratios for Hadrons containing Charm and Bottom quarks', J.D. Bjorken (1986)

Decay modes of ucc

Estimate of $\Xi_{cc}^{++}(ucc : 3650??)$ lifetime is 0.43 ps[2]

$$
\begin{array}{ll}
 & \Xi_{cc}^{++}(ucc : 3650??) \to \\
 & \Xi_c^{+}(usc : 2465) + \pi^{+}(u\bar{d} : 140) \\
 & \Xi_c^{+}(usc : 2465) + e^{+} + \nu \\
 & \Lambda_c^{+}(udc : 2285) + \pi^{+}(u\bar{d} : 140) \text{ Cabibbo suppressed} \\
 & \Sigma_c^{++}(uuc : 2453) + \bar{K}^{0}(s\bar{d} : 497) \\
\hookrightarrow & \Lambda_c^{+}(udc : 2285) + \pi^{+}(u\bar{d}) + \bar{K}^{0}(s\bar{d} : 497) \\
 & \Sigma^{+}(uus : 1189) + D^{+}(c\bar{d} : 1869) \quad \text{Disfavoured by PS}
\end{array}
$$

Bj estimate

$$BR(\Xi_{cc}^{++}(ucc) \to \Lambda_c^{+}(udc) + \pi^{+}(u\bar{d}) + \bar{K}^{0}(s\bar{d})) \sim 2.5\%$$

Decay modes of dcc

Estimate of $\Xi_{cc}^{+}(dcc : 3650??)$ lifetime is 0.11 ps[2]. Lifetime estimate for $\Xi_{cc}^{+}(dcc : 3650??)$ changed relative to $\Xi_{cc}^{++}(ucc : 3650??)$ by Cabibbo allowed exchange diagram.

$\Xi_{cc}^{+}(dcc : 3650??) \rightarrow$

$\Xi_{c}^{0}(dsc : 2470) + \pi^{+}(u\bar{d} : 140)$

$\Xi_{c}^{+}(usc : 2455) + \pi^{0}(d\bar{d} : 140)$

$\Xi_{c}^{0}(dsc : 2470) + e^{+} + \nu$

$\Lambda_{c}^{+}(udc : 2285) + K^{0}(s\bar{d} : 497)$ Color suppressed?

$\Sigma_{c}^{+}(udc : 2455) + K^{0}(s\bar{d} : 497)$ Disfavoured by PS

$\Sigma^{0}(uds : 1192) + D^{+}(c\bar{d} : 1869)$ Disfavoured by PS

$p^{+}(uud : 938) + D^{0(*)}(c\bar{u} : 1864) \; + K^{0}(s\bar{d} : 497)$ (W.E.)

Bj estimate

$$BR(\Xi_{cc}^{+}(dcc) \rightarrow p^{+}(uud) + D^{0(*)}(c\bar{u}) \; + \bar{K}^{0}(s\bar{d})) \sim 1.5\%$$

So one strategy is to look first for singly charmed baryons and perhaps enrich sample of doubly charmed baryons by looking at large impact factor, since they involve two charmed decays.

Of the singly charmed baryons, the Λ_c^+ with the subsequent decay of

$$\Lambda_c^+(udc : 2285) \to pK^-\pi^+ \tag{1}$$

is experimentally easier to reconstruct cleanly (at least if some level of particle identification is available) than the Ξ_c. Also note the production Σ_c with subsequent strong decay $\Sigma_c \to \Lambda_c\pi$ (with a Q-value of about 30 MeV allowing the 'D^*' trick to be used). This increases the feasibility of modes containing Λ_c or Σ_c. The Λ_c, according to the PDG, has a $(5.0 \pm 1.3)\%$ branching ratio to $pK^-\pi^+$ and a 0.21 ps lifetime. Of note is that CDF cleanly reconstructed 197 signal events with Λ_c for a Λ_b lifetime measurement (from the semileptonic decay $\Lambda_b \to \Lambda_c\ell\nu X$, thus having a lepton on which to trigger – triggering certainly is an issue to be considered in the all hadronic decays above).

Of special interest perhaps is

$$\Xi_{cc}(dcc : 3650??)^+ \to \Lambda_c^+(udc : 2285) + K^0(s\bar{d} : 497) \tag{2}$$

with a subsequent $K^0 \to \pi^+\pi^-$ decay. Bj estimate of branching ratio for $\Xi_{cc}^+ \to \Lambda_c^+ K^0$ is 1%. According to Likhoded [2] the lifetime of the Ξ_{cc}^+ is about 0.12 ps thus reducing the effectiveness of a vertex trigger.

Consider also

$$\Xi_{cc}^+(dcc : 3650??) \to \Sigma_c^+(udc : 2455) + K^0(s\bar{d} : 497) \tag{3}$$

with the subsequent (100% branching) ratio strong decay of

$$\Sigma_c^+(udc : 2455) \quad \to \quad \Lambda_c^+(udc : 2285)\pi^0 \tag{4}$$

(No phase space for $\Sigma_c^+(udc) \to \Sigma_c^0(ddc)\pi^+$) followed by

$$\Lambda_c^+(udc : 2285) \to pK^-\pi^+ \tag{5}$$

The exchange diagram leading to $\Xi_{cc} \to pD^{0(*)}K^0$ is a promising channel for reconstruction since the p allows for the use of particle identification and the D^*

identified by the standard procedure of cutting on the small value of $\Delta_m = m(D^*) - m(D)$ where $m(D^*)$ is the reconstructed mass of the D^* using the soft pion in $D^* \rightarrow D\pi$.

Decay modes of scc

Estimate of $\Xi_{cc}^{+}(scc : 3800??)$ lifetime is 0.5 ps

$$\begin{aligned} \Xi_{cc}^{+}(scc : 3800??) &\rightarrow \Xi_{c}^{0}(ssc : 2470) + \pi^{+}(u\bar{d} : 140) \\ &\rightarrow \Xi_{c}^{+}(usc : 2455) + \bar{K}^{0}(s\bar{d} : 497) \end{aligned}$$

Bj estimate

$$BR(\Xi_{cc}^{+}(scc) \rightarrow \Xi_{c}^{0}(ssc : 2470) + \pi^{+}(u\bar{d} : 140)) \sim 5\%$$

Decay modes of *dcb*

Mass of *cb* baryons about 7 GeV? Estimate of *dcb* baryon lifetime is 0.28 ps[3]. Decay modes of *dcb* may be (charm decays first?)

$$
\begin{aligned}
&\Xi^0_{cb}(dcb : 7000??) \to \\
&\Xi^-_b(dsb : 5825??) + \pi^+(u\bar{d} : 140) \\
&\Xi^0_b(usb : 5820??) + \pi^0(d\bar{d} : 140) \\
&\Lambda^0_b(udb : 5624) + K^0(s\bar{d} : 140) \\
&\Xi^-_b(dsb : 5825??) + e^+ + \nu
\end{aligned}
$$

Decay modes of *dcb* may be (bottom decays first?)

$$
\begin{aligned}
&\Xi^0_{cb}(dcb : 7000??) \to \\
&\Xi^+_{cc}(dcc : 3650??) + \pi^-(d\bar{u} : 140) \\
&\Xi^+_{cc}(dcc : 3650??) + D^-(s\bar{c} : 1869) \\
&\Xi^+_{cc}(dcc : 3650??) + \ell^-\nu \\
&p^+(uud : 938) + D^{0(*)}(c\bar{u} : 1864) + K^-(s\bar{u} : 493) \text{ W.E.}
\end{aligned}
$$

The second decay could be recombined to give

$\Xi_c^0(dsc : 2470) + J/\psi(c\bar{c} : 3100)$ which might be more easily triggerable.

Subsequent decay modes of usb, dsb, and udb are long-lived, and hence at large impact factor

$$\begin{aligned}
&\Xi_b^0(usb : 5820??) \rightarrow \\
&\Xi_c^+(usc : 2465) + \pi^-(d\bar{u} : 140) \\
&\Xi_c^0(dsc : 2470) + \pi^0(u\bar{u} : 140) \\
&\Xi_c^+(usc : 2465) + e^- + \nu
\end{aligned} \tag{6}$$

$$\begin{aligned}
\Xi_b^-(dsb : 5825??) &\rightarrow \Xi_c^0(dsc : 2470) + \pi^-(d\bar{u} : 140) \\
&\rightarrow \Xi_c^0(dsc : 2470) + e^- + \nu
\end{aligned} \tag{7}$$

$$\Lambda_b^0(udb : 5624) \rightarrow \Lambda_c^+(udc : 2285) + e^- + \nu \tag{8}$$

However because of abundant phase space many particle decays may be more prolific.

Decay modes of *ucb*

Estimate of *ucb* baryon lifetime is 0.33 ps[3]. Charm decays first?

$\Xi_{cb}^{+}(ucb : 7000) \to$

$\Xi_{b}^{0}(usb : 5820??) + \pi^{+}(u\bar{d} : 140)$

$\Xi_{b}^{0}(usb : 5820??) + e^{+} + \nu$

$p^{+}(uud : 938) + D^{0(*)}(c\bar{u} : 1864) + K^{0}(s\bar{d} : 493)$ W.E.

$p^{+}(uud : 938) + D^{+(*)}(c\bar{d} : 1869) + K^{-}(s\bar{u} : 493)$ W.E.

and hence the decay of *usb* as given above.

Decay modes of *ucb* may be (bottom decays first?)

$\Xi_{cb}^{+}(ucb : 7000??) \to$

$\Xi_{cc}^{++}(ucc : 3650??) + \pi^{-}(d\bar{u} : 140)$

$\Xi_{cc}^{++}(ucc : 3650??) + D_{s}^{-}(s\bar{c} : 1969)$

$\Xi_{cc}^{++}(ucc : 3650??) + D^{-}(d\bar{c})$ Cabibbo suppressed

$\Xi_{cc}^{++}(ucc : 3650??) + \ell^{-} + \nu$

$p^{+}(uud : 938) + D^{0(*)}(c\bar{u} : 1864) + K^{-}(s\bar{u} : 493)$ W.E.

Once again, the second and third decays can be recombined to give $\Xi_c^+(usc : 2456) + J/\psi(c\bar{c} : 3100)$ and $\Lambda_c^+(udc : 2285) + J/\psi(c\bar{c} : 3100)$ which are very attractive channels from the point of view of both reconstruction and triggering.

So again the idea would be to look at singly charmed baryons, (in association with other tracks) but with large ($\sim b$-quark) impact factor.

Decay modes of ubb

Estimate of $\Xi^0_{bb}(ubb : 10120??)$ lifetime is 0.79 ps[4].

$$
\begin{aligned}
&\Xi^0_{bb}(ubb : 10120) \to \\
&\Xi^+_{cb}(ucb : 7000??)^+ + \pi^-(d\bar{u} : 140) \\
&\Xi^0_{cb}(dcb : 7000??) + \pi^0(u\bar{u} : 140) \\
&\Xi^+_{cb}(ucb : 7000??) + e^- + \bar{\nu} \\
&\Xi^+_{cb}(ucb : 7000??) + D^-_s(s\bar{c}) \\
&\Xi^+_{cb}(ucb : 7000??) + D^-(d\bar{c}) \text{ C.S} \\
&\Xi^0_b(usb : 5800??) + J/\psi(c\bar{c}) \\
&\Lambda^0_b(udb : 5624) + J/\psi(c\bar{c}) \text{ C.S}
\end{aligned}
$$

Note that the last two decays could give a displaced vertex from ψ (plus a triggerable decay) and a further displaced $\Xi^0_b(usb)$ or $\Lambda^0_b(udb)$ decay. Branching ratio as yet unknown. Without such decays it is hard to imagine that one would observe double bottomed baryons without observing bc baryons. Note ucb decay modes given above: so one might just try to associate an extra pion with those.

Decay modes of dbb and sbb

Estimate of $\Xi_{bb}^{-}(dbb : 10120??)$ lifetime is 0.80 ps[4].

$$\Xi_{bb}^{0}(dbb : 10120??) \quad \rightarrow \quad \Xi_{b}^{-}(dsb : 5800??) + J/\psi(c\bar{c})$$

Estimate of $\Omega_{bb}^{-}(sbb : 10180??)$ lifetime is 0.80 ps[4].

$$\Xi_{bb}^{0}(sbb : 10180??) \quad \rightarrow \quad \Omega_{b}^{-}(ssb : 6000??) + J/\psi(c\bar{c})$$

followed perhaps by

$$\Omega_{b}^{-}(ssb : 6000??) \quad \rightarrow \quad \Omega^{-}(sss : 1672) + J/\psi(c\bar{c})$$

Tentative QQq baryon best buys

No estimate of Branching Ratios, trigger efficiencies yet! Decays with J/ψ are easy to trigger and J/ψ eats Q-value which would otherwise end up in additional π's. But branching ratios may be quite small, (NB in meson sector $BR(B \to J/\psi K \sim 10^{-3})$. Firstly the Cabibbo suppressed (C.S.) decay

$$\begin{array}{lll} \Xi_{cb}^{+}(ucb) & \to & \Lambda_c^{+}(udc)\ J/\psi(c\bar{c}) \\ & & \qquad\qquad\quad \hookrightarrow \mu^+\mu^- \\ & & \hookrightarrow p^+\ K^+\ \pi^- \end{array}$$

$$\begin{array}{lll} \Xi_{cb}^{0}(dcb) & \to & \Xi_c^{0}(dsc)\ J/\psi(c\bar{c}) \\ & & \qquad\qquad\quad \hookrightarrow \mu^+\mu^- \\ & & \hookrightarrow \Lambda^0\bar{K}^0(\to \pi^-p^+\pi^+\pi^-) \end{array}$$

$$\begin{array}{lll} \Xi_{cb}^{+}(ucb) & \to & \Xi_c^{+}(usc)\ J/\psi(c\bar{c}) \\ & & \qquad\qquad\quad \hookrightarrow \mu^+\mu^- \\ & & \hookrightarrow \Xi^-\pi^+\pi^+(\to \pi^-\Lambda^0\pi^+\pi^+) \end{array}$$

For the ubb we have

$$\Xi^0_{bb}(ubb) \quad \to \quad \Xi^+_{cb}\,\pi^- \\ \hookrightarrow \text{as above}$$

and the (C.S.) decays

$$\Xi^0_{bb}(ubb) \quad \to \quad \Lambda^0_b(udb)\; J/\psi(c\bar{c})$$

$$J/\psi \hookrightarrow \mu^+\mu^-$$

$$\Lambda^0_b \hookrightarrow \Lambda^+_c\pi^-(\to p^+\; K^-\; \pi^+\; \pi^-)$$

$$\Xi^-_{bb}(dbb) \quad \to \quad \Xi^-_b\,(dsb) + J/\psi(c\bar{c})$$

If production favorable, bcq may be easier to find than ccq.

Decays without a J/ψ may be still accessible due to cascading decays. A double-heavy baryon with a short (i.e., "charm-like") lifetime can decay into a charm meson with reasonably long lifetime such as the $D^{\pm}$ ($\tau = 1.06$ ps). These decays are the good for BTeV.

The best ubc-baryon decay mode in this class may be:

$$\begin{array}{lll} \Xi_{cb}^{+}(ucb) & \rightarrow & D^{*+}\, pK^{-} \\ & & \hookrightarrow K^{-}\pi^{+}\pi^{+} \end{array}$$

The best dcb-baryon decay without a J/ψ may be:

$$\begin{array}{lll} \Xi_{cb}^{0}(dcb) & \rightarrow & D^{*+}\, p\, \pi^{-}\ K^{-} \\ & & \hookrightarrow K^{-}\pi^{+}\pi^{+} \end{array}$$

and the analogous:

$$\begin{array}{lll} \Xi_{cc}^{++}(ucc) & \rightarrow & D^{*+}\, p\bar{K}^{0} \\ & & \quad\quad \hookrightarrow \pi^{+}\pi^{-} \\ & & \hookrightarrow K^{-}\pi^{+}\pi^{+} \end{array}$$

or

$$
\begin{array}{lcl}
\Xi_{cc}^{++}(ucc) & \rightarrow & D^{*+}\ \pi^+\Lambda^0 \\
 & & \qquad\qquad \hookrightarrow p\pi^- \\
 & & \hookrightarrow K^-\pi^+\pi^+
\end{array}
$$

For dcc, the nice two-body decay:

$$
\begin{array}{lcl}
\Xi_{cc}^{+}(ucc) & \rightarrow & D^{*+}\ \Lambda^0 \\
 & & \qquad\quad \hookrightarrow p\pi^- \\
 & & \hookrightarrow K^-\pi^+\pi^+
\end{array}
$$

Other potentially interesting decays include:

$$
\begin{array}{lll}
\Xi_{cc}^{++}(ucc) & \rightarrow & \Lambda_c^+(udc)\,\pi^+\bar{K}^0 \\
 & & \quad\quad\quad\quad\quad\quad\quad \hookrightarrow \pi^+\pi^- \\
 & & \hookrightarrow p^+K^-\pi^+
\end{array}
$$

$$
\begin{array}{lll}
\Xi_{cc}^{++}(ucc) & \rightarrow & \Lambda_c^+(udc)\,\pi^+\bar{K}^0 \\
 & & \quad\quad\quad\quad\quad\quad\quad \hookrightarrow \pi^+\pi^- \\
 & & \hookrightarrow p^+K^-\pi^+
\end{array}
$$

$$
\begin{array}{lll}
\Xi_{cc}^{+}(dcc) & \rightarrow & D^0\,p^+\bar{K}^0 \\
 & & \quad\quad\quad\quad \hookrightarrow \pi^+\pi^- \\
 & & \hookrightarrow K^-\pi^+
\end{array}
$$

$$
\begin{array}{lll}
\Xi_{cc}^{+}(dcc) & \rightarrow & \Lambda_c^+(udc)\bar{K}^0 \\
 & & \quad\quad\quad\quad\quad \hookrightarrow \pi^+\pi^- \\
 & & \hookrightarrow p^+K^-\pi^+
\end{array}
$$

$$
\begin{array}{lll}
\Xi_{cb}^{0}(dcb) & \rightarrow & D^0\,p^+\,K^- \\
 & & \hookrightarrow K^-\pi^+
\end{array}
$$

$$
\begin{array}{lll}
\Xi_{cb}^{+}(ucb) & \rightarrow & D^0 \; p^+ \bar{K}^0 \\
 & & \qquad\qquad \hookrightarrow \pi^+\pi^- \\
 & & \hookrightarrow K^-\pi^+
\end{array}
$$

$$
\begin{array}{lll}
\Xi_{bb}^{0}(ubb) & \rightarrow & \Xi_{cb}^{+}(ucb)\; \pi^- \\
 & & \hookrightarrow p^+ \bar{K}^0 \pi^- \pi^+
\end{array}
$$

$$
\begin{array}{lll}
\Xi_{bb}^{-}(dbb) & \rightarrow & \Xi_{cb}^{0}(dcb)\; \pi^- \\
 & & \hookrightarrow p^+ K^- \pi^+ K^-
\end{array}
$$

Conclusion

- We have identified some simplest decays which may be triggerable
- Further details at http://www-theory.fnal.gov/people/ellis/Bphysics/cc.ps.gz
- Cross sections need to be calculated and Bj 'Rosenfeld', table needs to be updated and extended to establish which branching fractions are attainable