FLAVOR SU(3) AND $Λ_b$ DECAYS

Michael Gronau  
*Physics Department, Technion – Israel Institute of Technology*  
*Haifa 3200, Israel*

Jonathan L. Rosner  
*Enrico Fermi Institute and Department of Physics*  
*University of Chicago, 5620 S. Ellis Avenue, Chicago, IL 60637*

Some flavor SU(3) results are presented for decays of the $Λ_b$ baryon into non-charmed final states $P B$, where $P$ is a pseudoscalar mesons and $B$ is a spin-1/2 baryon. Although these relations are among amplitudes and hence not yet subject to direct experimental test, they can form the basis for triangle inequalities among decay rates.

I Introduction

The improvements in vertex detection and particle identification have made hadron colliders competitive in many cases with lepton colliders for the study of heavy flavor decays. This is particularly the case for $b$-flavored baryons. Recent advances in the spectroscopy of $Λ_b$, $Ξ_b$, and $Ω_b$ baryons [1] have been the exclusive province of the Tevatron and the LHC.

Decays of mesons containing $b$ quarks to charmless final states have proved amenable to a flavor SU(3) analysis equivalent to, and easily visualized by, a graphical analysis [2, 3]. Data on decays of the lightest stable $b$-flavored baryon, the $Λ_b$, are now approaching the stage permitting a corresponding analysis [4]. Although the decays $Λ_b \rightarrow \pi^- p$ and $Λ_b \rightarrow K^- p$ have been treated in the perturbative QCD (pQCD) framework [5], the prediction of the rate for the latter process falls short by a factor of more than two. The latter process is dominated by a penguin amplitude, which is notoriously difficult to calculate from first principles. In the present paper we shall concentrate on ways of gaining supplemental information from data and flavor SU(3) about the penguin contribution.

We describe the basic contributions to $Λ_b$ decays to a charmless baryon $B$ and a charmless pseudoscalar meson $P$ in Sec. II. We then remark on ways of separating out desired contributions in Sec. III. Some suggestions for measurements of as-yet-unseen decays are given in Sec. IV, while Sec. V concludes.

II Contributions

The dominant contributions to decays of hadrons containing $b$ quarks are those not involving the spectator quark. In the graphical language of Ref. [2], these are the tree and penguin
amplitudes, illustrated in Fig. 1 (neglecting also electroweak penguins in favor of the larger gluonic ones).

We assume the validity of the calculation of the tree amplitudes performed in Ref. [5], as the dominant contribution is expected to be the factorizable one (as recognized long ago by Schwinger [6] for the decay $K^+ \rightarrow \pi^+\pi^0$). However, the calculation of the penguin amplitude from first principles is another story, as its magnitude in a priori calculations has repeatedly turned out to be too small. Instead, we shall seek information on the penguin contributions to $\Lambda_b \rightarrow \pi^-p$ and particularly to $\Lambda_b \rightarrow K^-p$ from processes related to these decays by flavor SU(3).

There is a subtlety in using the $P_B, P'_B$ graphs, associated with the inequivalence of the two quarks of different flavors in the final baryon. Thus, we find it more convenient to use amplitudes labeled by SU(3) representations. We shall assume both $B$ and $P$ are flavor octets.

In what follows we shall be concerned exclusively with the penguin amplitudes. In the $b \rightarrow s$ penguin processes, leading to a state with strangeness $S = -1$, the $s$ transforms as a flavor 3, while the $ud$ spectator in the $\Lambda_b$ transforms as a $3^*$. Thus, the intermediate $sud$ state is a linear combination of flavor singlet and flavor octet. The flavor singlet amplitude has a unique coupling to $PB$, while the octet can couple via either F- or D-type coupling.

Final $S = -1$ $PB$ states include $K^-p$ (equivalent for the penguin amplitude by isospin invariance to $\bar{K}^0n$), $\pi^-\Sigma^+$ (equivalent to $\pi^+\Sigma^-$), and $K^+\Xi^-$ (equivalent to $K^0\Xi^0$). The corresponding penguin amplitudes may be written (separately for S- and P-wave final states) as

\begin{align}
A_P(\Lambda_b \rightarrow K^-p) &= -\frac{1}{\sqrt{6}}(3F + D) + A_1, \\
A_P(\Lambda_b \rightarrow \pi^-\Sigma^+) &= \frac{2}{3\sqrt{3}}D + A_1, \\
A_P(\Lambda_b \rightarrow K^+\Xi^-) &= \frac{1}{\sqrt{6}}(3F - D) + A_1.
\end{align}

Figure 1: Dominant amplitudes contributing to $\Lambda_b \rightarrow PB$ decays. (a) Tree ($T$), where the wiggly line denotes a virtual $W$; (b) penguin ($P_M$) with $q = d, s$ in final meson; (c) penguin ($P_B$) with $q$ in final baryon. The cross denotes the action of the $b \rightarrow q$ penguin operator.
Final $S = 0$ states include $\pi^- p$, $K^0 \Lambda$, and $K^+ \Sigma^-$:

$$A_P(\Lambda_b \to \pi^- p) = r(F + D) \ ,$$

$$A_P(\Lambda_b \to K^0 \Lambda) = -\frac{1}{\sqrt{6}}r(3F + D) \ ,$$

$$A_P(\Lambda_b \to K^+ \Sigma^-) = r(F - D) \ ,$$

where $r = V_{td}^*/V_{ts}^*$. We are interested in the amplitude $A_P(\Lambda_b \to K^- p)$. We suspect this amplitude is larger than calculated in Ref. [5], to the extent that it might actually dominate the decay. In the next section we shall derive a relation between this amplitude and other penguin amplitudes in $\Lambda_b \to BP$ decay.

### III Relations among amplitudes

The above three amplitudes leading to the $S = -1$ final state may be added to obtain the singlet amplitude. Displaying only the final state, we have

$$\frac{1}{3}[A(K^- p) + A(\pi^- \Sigma^+) + A(K^+ \Xi^-)] = A_1$$

This may then be subtracted from $A(K^- p)$ to obtain

$$\frac{1}{3}[2A(K^- p) - A(\pi^- \Sigma^+) - A(K^+ \Xi^-)] = -\frac{1}{\sqrt{6}}(3F + D) = r^{-1}A(K^0 \Lambda) \ .$$

Similarly one may obtain a combination proportional to $F + D$:

$$\frac{1}{3}[A(K^- p) - A(\pi^- \Sigma^+)] = -\frac{1}{\sqrt{6}}(F + D) = -\frac{1}{\sqrt{6}} r^{-1}A(\pi^- p) \ .$$

These amplitude relations may be used to generate inequalities among decay rates. Some of the final states are challenging to measure, so we suggest methods to obtain them in the next Section. We note here that the penguin contribution in $\Lambda_b \to \pi^- p$ is likely to be overshadowed by a much larger tree amplitude, so we shall not discuss this process further.

### IV Measuring rare $\Lambda_b$ decays

So far the only reported $BP$ decays of $\Lambda_b$ are to $K^- p$ and $\pi^- p$. We now suggest ways of finding other $BP$ final states. All of these are expected to be dominated by the penguin amplitude if its contribution to $\Lambda_b \to K^- p$ is as large as we suspect.

$\Lambda_b \to \pi^- \Sigma^+$:

One first looks for a pair of charged tracks emerging from a displaced vertex. The $\Sigma^+$ decays to $\pi^+ n$ and $\pi^0 p$. Neutrons are difficult to identify in any environment. Turning to the $\pi^0 p$ final state, it is associated with a heavy charged track with a kink and a pair of photons from the $\pi^0$ making a small angle with the final proton track. The LHCb detector may have some sensitivity to this decay.
Again, one starts with a pair of charged tracks emerging from a displaced vertex. The $\Xi^-$ may be identified as heavy. It decays to $\pi^-\Lambda$, so one looks for a heavy track with a kink and a $\Lambda$ pointing back to the kink.

$\Lambda_b \to K^0\Lambda$:

This is a challenging final state. One may have to look for an opposite-side displaced vertex (denoting associated $\bar{b}$ production) and two “V” signatures denoting the $K^0$ and $\Lambda$. Bear in mind that this decay rate is suppressed with respect to those leading to $S = -1$ final states by a factor $r^2 = |V_{td}/V_{ts}|^2$.

V Conclusions

We have investigated some flavor-SU(3) relations among penguin amplitudes for decays of $\Lambda_b \to PB$, where $P$ is a pseudoscalar meson ($\pi$ or $K$) and $B$ is an octet baryon. Interesting final states, possibly accessible with some effort, include not only the observed $K^-p$ and $\pi^-p$ decays, but also $\pi^-\Sigma^+, K^+\Xi^-$, and $K^0\Lambda$. Once these are observed, polarization information may be useful in separating out S- and P-wave decays, with the ultimate goal of predicting CP violation in these channels. (Predictions for the $K^-p$ and $\pi^-p$ decays of $\Lambda_b$ in Ref. [5] are consistent with no direct CP asymmetries, in accord with present data [4].)

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References

[1] M. Karliner, B. Keren-Zur, H. J. Lipkin and J. L. Rosner, Annals Phys. 324, 2 (2009) [arXiv:0804.1575 [hep-ph]].

[2] M. Gronau, O. F. Hernandez, D. London and J. L. Rosner, Phys. Rev. D 50, 4529 (1994) [hep-ph/9404283].

[3] M. Gronau, O. F. Hernandez, D. London and J. L. Rosner, Phys. Rev. D 52, 6374 (1995) [hep-ph/9504327].

[4] T. Aaltonen et al. [CDF Collaboration], Phys. Rev. Lett. 103, 031801 (2009) [arXiv:0812.4271 [hep-ex]].

[5] C. -D. Lu, Y. -M. Wang, H. Zou, A. Ali and G. Kramer, Phys. Rev. D 80, 034011 (2009) [arXiv:0906.1479 [hep-ph]].

[6] J. Schwinger, Phys. Rev. Lett. 12, 630 (1964)