Eur Phys J C **33**, s01, s321–s323 (2004)
Digital Object Identifier (DOI) 10.1140/epjcd/s2003-03-218-x

**EPJ C direct**
**electronic only**

# Rare $B \to baryon$ decays from CLEO

Jana B. Thayer

University of Rochester, Wilson Synchrotron Lab, Ithaca, NY 14853

Received: 3 August 2003 / Accepted: 25 August 2003 /
Published Online: 11 September 2003 – 

**Abstract.** We have searched for baryon-containing radiative penguin decays in $9.7 \times 10^6$ $B\bar{B}$ events collected at the $\Upsilon(4S)$ with the CLEO detector. We find no evidence for such decays, and set a 90% confidence level upper limit of $\mathcal{B}(B \to X_s\gamma, X_s\ containing\ baryons)_{E_\gamma > 2.0\ \mathrm{GeV}} < 3.8 \times 10^{-5}$. Corrections to CLEO's recent $b \to s\gamma$ measurement due to $B \to X_s(baryon)\gamma$ decays are well within the errors quoted. A search for semileptonic decays of $B$ mesons to $e\bar{p}$ inclusive final states in the same data sample found no evidence for such decays and set an upper limit of $\mathcal{B}(B \to \bar{p}e^-\bar{\nu}_e X) < 5.9 \times 10^{-4}$. These limits suggest that external $W$ emission is not the dominant source of baryon production in $B$ decay.

**PACS.** 13.20.He Decays of Bottom Mesons – 13.40.Hq Electromagnetic Decays – 13.60.Rj Baryon Production

## 1 Motivation

The $b \to s\gamma$ branching fraction can be used to place restrictions on physics beyond the standard model while the photon energy spectrum provides information on the $b$ quark mass and momentum within the $B$ meson [1], information useful for determining the CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$. CLEO's recent measurement of the photon energy spectrum [2] employed a pseudoreconstruction technique that has reduced sensitivity to $B \to X_s\gamma$ decays with baryons in the final state. If baryon production is significant in $B \to X_s\gamma$ then this measurement may be affected. It is therefore important to determine what fraction of $B \to X_s\gamma$ decays lead to baryons in the final state.

The analyses treated here distinguish between external $W$ emission and internal $W$ emission, two possible mechanisms for baryon production in $B$ decays. In internal $W$ emission, the $W$ from the $B \to cW, W \to \bar{u}d$ plays an essential role in the formation of the baryon-antibaryon final state. The decay products of the $W$ combine with the $c$ quark from the primary decay, the spectator quark, and a $q\bar{q}$ pair popped from the vacuum to form a baryon-antibaryon final state. In external $W$ emission (with baryons produced at the lower vertex), the $W$ plays no role in the formation of the final state baryon-antibaryon pair. Instead, two $q\bar{q}$ pairs are popped from the vacuum and combine with the quark from the primary decay and the spectator quark to form a baryon-antibaryon pair. The virtual $W$ can decay freely, i.e. to a $u\bar{d}$, $\ell\nu$. Similarly, to produce baryons in the radiative penguin decay $b \to s\gamma$, two $q\bar{q}$ pairs must be popped from the vacuum.

Semileptonic $b \to c$ decays and $B \to X_s\gamma$ decays must both pop two $q\bar{q}$ pairs from the vacuum. Since $b \to c\ell\nu$ decays are produced at a much higher rate, they provide a natural place to search for $B \to baryon$ decays. Although previous measurements [3,4] have found no evidence for baryon production in semileptonic $B$ decay, there is a kinematic argument for the absence of baryon production in these decays. A simple spectator model calculation gives a $c\bar{q}_{spectator}$ mass distribution in which only 0.79% of the $b \to c\ell\nu$ spectrum is above $\Lambda_c\bar{N}$ threshold. The spectator model calculation for $b \to s\gamma$ [5], on the other hand, indicates that ~1/3 of the spectrum is above threshold for producing a baryon-antibaryon pair. If external $W$ emission is the dominant method for baryon production in $B$ decay, it is still possible that baryons will contribute significantly to $b \to s\gamma$ decays without contributing to $b \to c\ell\nu$ decays.

## 2 Search for $B^- \to \Lambda\bar{p}\gamma$ and $B^- \to \Sigma^0\bar{p}\gamma$

The data for this analysis were taken with the CLEO detector [6,7] at the Cornell Electron Storage Ring (CESR), a symmetric $e^+e^-$ collider running at the $\Upsilon(4S)$. The sample consists of 9.1 fb$^{-1}$ taken on the $\Upsilon(4S)$ resonance, "On data", and 4.4 fb$^{-1}$ taken 60 MeV below the $\Upsilon(4S)$, "Off data", corresponding to $9.7 \times 10^6$ $B\bar{B}$ pairs.

### 2.1 Event selection and background suppression

Events containing a high energy photon ($E_\gamma > 1.5$ GeV), a $\bar{p}$ and a $\Lambda$ where $\Lambda \to p\pi^-$ are selected as described in Reference [8] (charge conjugate modes are implied throughout). We compute the standard $B$ reconstruction variables $M_{\mathrm{cand}} \equiv \sqrt{E^2_{\mathrm{beam}} - P^2_{\mathrm{cand}}}$ and $\Delta E \equiv E_{\mathrm{cand}} - E_{\mathrm{beam}}$, and we define a signal box $|\Delta E| < 84$ MeV, $|M_{\mathrm{cand}} - M_B| < 8$ MeV/$c^2$, which contains ~90% of the $B \to \Lambda\bar{p}\gamma$ signal

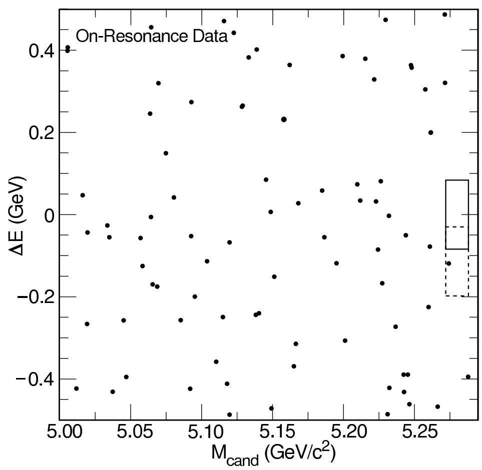


**Fig. 1.** $M_{\rm cand} - \Delta E$ for On data and $E_\gamma > 1.5$ GeV. The *solid box* shows the signal box used for determining the $B^- \to \Lambda\bar{p}\gamma$ yield. The *dashed box* is shifted downward in $\Delta E$ by 114 MeV and is used for determining the $B^- \to \Sigma^0\bar{p}\gamma$ yield

events. For the $B \to \Sigma^0\bar{p}\gamma$ mode, we do not explicitly reconstruct the $\Sigma^0 \to \Lambda\gamma$ decay, but analyze the event as if the decay were $B \to \Lambda\bar{p}\gamma$. We measure the $B \to \Sigma^0\bar{p}\gamma$ yield by shifting the signal box by 114 MeV to negative $\Delta E$, compensating for the missing soft photon from $\Sigma^0 \to \Lambda\gamma$. This signal box contains ∼80% of the $B \to \Sigma^0\bar{p}\gamma$ signal.

The background from other $B$ decay processes is negligible, but substantial background from continuum processes ($e^+e^- \to q\bar{q}, q = u, d, s, c$) exists. Continuum background is suppressed by applying cuts to event shape variables and then feeding these variables into a neural net [8] to obtain further signal to background discrimination. After a cut on the neural net output, we expect 0.64 (0.2) background events in either signal box when a cut of $E_\gamma > 1.5$ GeV ($E_\gamma > 2.0$ GeV) is applied.

### 2.2 Upper limit and implications for $b \to s\gamma$

The distribution for On data in $\Delta E - M_{\rm cand}$ space is shown in Fig. 1. With zero events observed, we have no evidence for $B^- \to \Lambda\bar{p}\gamma$. For $B^- \to \Sigma^0\bar{p}\gamma$, with one event observed and 0.6 expected, we also have no evidence of signal. We obtain a conservative 90% confidence level (C.L.) upper limit on the branching fraction including a systematic error on the $\Lambda$ polarization, modeling of the $\Lambda\bar{p}$ ($\Sigma^0\bar{p}$) system, the number of $B$'s, modeling of the other $B$, and detector simulation.

The search for $B \to \Lambda\bar{p}\gamma$ also has sensitivity to $B \to \Sigma^0\bar{p}\gamma$, $\Sigma^0 \to \Lambda\gamma$. The efficiency for the latter decay is 0.3 times that of the former. Similarly, our search for $B \to \Sigma^0\bar{p}\gamma$ has sensitivity to $B \to \Lambda\bar{p}\gamma$, 0.4 that for $B \to \Sigma^0\bar{p}\gamma$. Our results for $E_\gamma > 1.5$ GeV and $E_\gamma > 2.0$ GeV are

$$[\mathcal{B}(B^- \to \Lambda\bar{p}\gamma) + 0.3\mathcal{B}(B^- \to \Sigma^0\bar{p}\gamma)]_{1.5} < 3.9 \times 10^{-6} ,$$
$$[\mathcal{B}(B^- \to \Lambda\bar{p}\gamma) + 0.3\mathcal{B}(B^- \to \Sigma^0\bar{p}\gamma)]_{2.0} < 3.3 \times 10^{-6} ,$$
$$[\mathcal{B}(B^- \to \Sigma^0\bar{p}\gamma) + 0.4\mathcal{B}(B^- \to \Lambda\bar{p}\gamma)]_{1.5} < 7.9 \times 10^{-6} ,$$
$$[\mathcal{B}(B^- \to \Sigma^0\bar{p}\gamma) + 0.4\mathcal{B}(B^- \to \Lambda\bar{p}\gamma)]_{2.0} < 6.4 \times 10^{-6} .$$

We obtain an upper limit on the branching fraction for $B \to X_s(baryon)\gamma$ by extrapolating from our upper limit on the exclusive mode, $B^- \to \Sigma^0\bar{p}\gamma$. We estimate that the ratio between $\mathcal{B}(B \to X_s(baron)\gamma)$ and the measured value $[\mathcal{B}(B^- \to \Sigma^0\bar{p}\gamma) + 0.4\mathcal{B}(B^- \to \Lambda\bar{p}\gamma)]$ is 6, for a cut of $E_\gamma > 2.0$ GeV [8]. This results in an upper limit of $\mathcal{B}(B \to X_s(baryon)\gamma)_{2.0 \text{ GeV}} < 3.8 \times 10^{-5}$.

CLEO's recent study [2] of $b \to s\gamma$ reported a branching fraction (corrected for the $b \to d\gamma$ contribution) of $(2.94 \pm 0.39 \pm 0.25) \times 10^{-4}$ for $E_\gamma > 2.0$ GeV. Our upper limit on $B \to X_s(baryon)\gamma$ for $E_\gamma > 2.0$ GeV, $3.8 \times 10^{-5}$, is 13% of that number. The recent study [2] had an efficiency for detecting $B \to X_s(baryon)\gamma$ that was 1/2 of that for non-baryon modes. That implies an upper limit on the correction to the branching fraction of 6.5%, less than half the combined reported statistical (±13%) and systematic (±8%) errors. The recent measurement also reported the following information on the photon energy spectrum for photons above 2.0 GeV: an average energy, $\langle E_\gamma \rangle = (2.346 \pm 0.032 \pm 0.011)$ GeV, and a variance, $\langle (E_\gamma - \langle E_\gamma \rangle)^2 \rangle = (0.0226 \pm 0.0066 \pm 0.0020)$ GeV$^2$. The average energy of photons from events with baryons is ∼2.1 GeV (averaging only for photons above 2.0 GeV). This value is 250 MeV lower than the published mean. The upper limit on the correction to the first moment is 6.5% of 250 MeV, i.e. 16 MeV compared with the published errors of 32 MeV (stat) and 11 MeV (syst). The limit on the correction to the variance is 0.0025 GeV$^2$, which is 36% of the combined quoted statistical and systematic errors on the variance.

## 3 Search for $b \to c$ decays to $e^-\bar{p}$ final states

Using 9.1 fb$^{-1}$ collected on the $\Upsilon(4S)$ resonance and 4.6 fb$^{-1}$ collected 60 MeV below the $\Upsilon(4S)$ resonance, we perform an inclusive search for baryon production in semileptonic $B$ decays. Specifically, we search for the semileptonic decay of $B$ mesons to $e^-\bar{p}$ inclusive final states. A partial reconstruction of the decay $B \to \bar{p}Xe^-\bar{\nu}_e$ is performed by identifying events with an $e^-$ (0.6 GeV < $\mathbf{p}_e$ < 1.5 GeV) and a $\bar{p}$ (0.2 GeV < $\mathbf{p}_{\bar{p}}$ < 1.5 GeV) emerging promptly from the $B$ as described in Reference [9]. The angular distribution between the $e^-$ and $\bar{p}$ is used to distinguish between signal and background.

We define $\theta$ as the angle between the $e^-$ and $\bar{p}$. The signal distribution for $B^- \to \Lambda_c^+\bar{p}e^-\bar{\nu}_e$ events is peaked at $\cos(\theta) \simeq -1$ (back-to-back) as shown in Fig. 2(a). The $e^-/\bar{p}$ angular distributions, i.e. $\cos(\theta)$ distributions, for signal and the main backgrounds are shown in Fig. 2. There are four main sources of background: 1) Uncorrelated backgrounds in which the $e^-$ and $\bar{p}$ are from opposite $B$ meson decays resulting in a flat $\cos(\theta)$ distribution (see Fig. 2(b)); 2) Correlated backgrounds in which non-prompt $e^-$ and $\bar{p}$ are from the same non-signal $B$ meson. This distribution, shown in Fig. 2(c) is also peaked near $\cos(\theta) \simeq -1$ but less sharply than signal; 3) Continuum

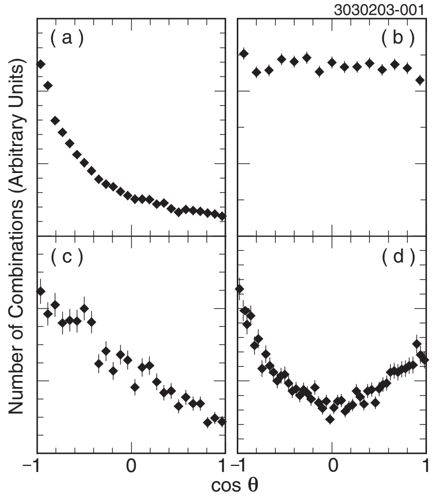


**Fig. 2.** The angular distribution between the $e^-$ and $\bar{p}$. Plot (a) shows $e^-/\bar{p}$ signal combinations for $B^- \to \Lambda_c^+ \bar{p} e^- \bar{\nu}_e$ decay; Plot (b) shows uncorrelated background; Plot(c) shows correlated background. Plot (d) shows continuum backgrounds obtained from data. Distributions are obtained from Monte Carlo simulation unless otherwise stated

backgrounds. The $e^-/\bar{p}$ angular distribution is shown in Fig. 2(d) and is determined using data collected at energies below the $\Upsilon(4S)$; 4) Fake $e^-/\bar{p}$ backgrounds due to particles misidentified as $e^-$ or $\bar{p}$. This distribution is determined using data as described in Reference [9].

### 3.1 Upper limit and implications for baryon production in $B$ decay

The overall $e^-/\bar{p}$ angular distributions are obtained from On and Off $\Upsilon(4S)$ data, and the continuum backgrounds are subtracted using the Off-resonance data. The fake $e^-$ and $\bar{p}$ backgrounds are also subtracted using data distributions, leaving an $e^-/\bar{p}$ distribution composed of uncorrelated background, correlated background, and possible signal. Shown in Fig. 3 is the $\cos(\theta)$ distribution found in data after continuum and fake backgrounds have been subtracted. Using Monte Carlo generated shapes for each of these contributions, the signal yield is determined from a fit to the sum of these three components. Since there is no evidence of a signal from the yield of $834 \pm 634(stat) \pm 370(syst)$ events, a 90% C.L. upper limit is determined: $\mathcal{B}(B \to \bar{p} X e^- \bar{\nu}_e) < 5.9 \times 10^{-4}$. The upper limit includes a systematic error on the correlated and uncorrelated backgrounds, the fake background subtraction, $e^-$ and $\bar{p}$ identification efficiency, and model dependence.

The upper limit on $B \to \bar{p} X e^- \bar{\nu}_e$ is a limit on $e^-/\bar{p}$ final states only, from which we extrapolate an upper limit on $B \to baryon\ e\nu$. Taking into account a factor of two for states containing neutrons, this result shows that charmed baryon production in semileptonic $B$ decay is less than 1.2% of all semileptonic $B$ decays compared with $\Lambda_c$ production in generic $B$ decays at $(6.4 \pm 1.1)\%$ [10].

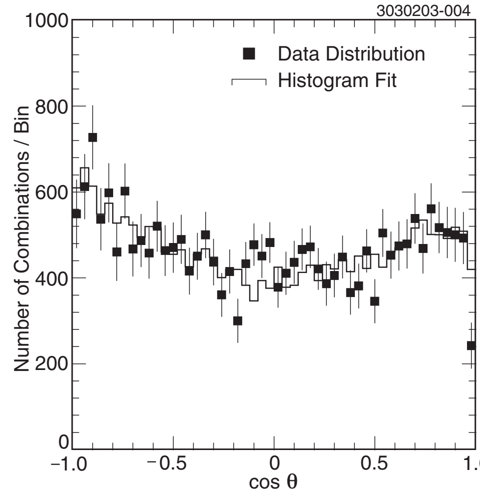


**Fig. 3.** Distribution of $\cos(\theta)$ found in data after continuum and fake backgrounds have been subtracted. The plot shows the fit to the data using Monte Carlo distributions for $b \to c$ signal, uncorrelated background, and correlated background

## 4 Summary

In conclusion, we have conducted searches for the exclusive radiative penguin decays $B^- \to \Lambda \bar{p} \gamma$ and $B^- \to \Sigma^0 \bar{p} \gamma$ and found no evidence for either. We set an upper limit on baryon-containing radiative penguin decays of $\mathcal{B}(B \to X_s(baryon)\gamma) < 3.8 \times 10^{-5}$. The upper limits on corrections to CLEO's recent measurement [2] of branching fraction, mean photon energy, and variance in photon energy from $b \to s\gamma$ are less than half the combined statistical and systematic errors quoted on these quantities.

We have also studied the angular distribution between electrons and antiprotons to inclusively search for semileptonic $b \to c$ decays with baryons in the final state. No evidence for a signal is observed and a 90% C.L. upper limit of $\mathcal{B}(B \to \bar{p} X e^- \bar{\nu}_e) < 5.9 \times 10^{-4}$ is set. These results are an improvement over previous limits [3,4], and suggest that external $W$ emission is not the dominant mechanism for baryon production in generic $B$ decays.

## References

1. A.L. Kagan and M. Neubert: Eur. Phys. J. C **7**, (1999) 5
2. S. Chen et al. (CLEO): Phys. Rev. Lett. **87**, (2001) 251807
3. G. Bonvicini et al.: (CLEO), Phys. Rev. **D57**, (1998) 6604
4. H. Albrecht et al.: (ARGUS), Phys. Lett. **B249**, (1990) 359
5. A. Ali and C. Greub: Phys. Lett. **B259**, (1991) 182; and private communication
6. Y. Kubota et al.: (CLEO), Nucl. Instrum. Methods Phys. Res., Sect. A **320**, (1992) 66
7. T. Hill et al.: (CLEO), Nucl. Instrum. Methods Phys. Res., Sect. A **418**, (1998) 32
8. K.W. Edwards et. al.: (CLEO), Phys. Rev. D **68**, (2003) 011102
9. N.E. Adam et. al.: Phys. Rev. D **68**, (2003) 012004
10. D.E. Groom et. al.: Eur. Phys. Jour. **C15**, (2000) 584