On Testing V-A in $\Lambda_b$ Decays

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ABSTRACT

We comment on a recent suggestion by Amundson, Rosner, Worah and Wise to test the chirality of the $b$-quark decay coupling via polarized $\Lambda_b$ baryons produced in $e^+e^- \rightarrow Z \rightarrow \Lambda_b + X$. We study the effect of contributions from an amplitude in which a right-handed $b$ to $c$ current couples to a V-A lepton current.

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$b$-quark decays are known to be governed by very weak couplings, which in the
Standard Model are given by the two tiny mixing angles $\theta_{23}$, $\theta_{13}$\(^1\). These decays
are therefore very sensitive to new kinds of interactions, and in particular to right-
handed couplings\(^2\). Recently we described a viable $SU(2)_L \times SU(2)_R \times U(1)$ model,
in which $b$-quarks decay purely right-handedly\(^3\). We pointed out that measurement
of the lepton asymmetry in $B \to D^* \ell \nu$\(^4\) cannot distinguish our model from the
Standard Model, since in this process the lepton current in our model is dominantly
$V+A$\(^5\). A nice test, which may distinguish between the exchange of left- and right-
handed gauge bosons in $b$ decays was suggested by Amundson, Rosner, Worah and
Wise\(^6\). These authors noted that the electron spectrum from highly polarized \(\Lambda_b\)'s
produced in $e^+ e^- \to Z \to \Lambda_b + X$ is significantly harder for $V-A$ than for $V+A$
quark and lepton currents. Thus, ongoing experiments at LEP, in which leptons
from $\Lambda_b$ decay were already observed\(^7\), may offer an early test of the model.

In this brief note we wish to study the effect of $W_L - W_R$ mixing, which
exists in our model in addition to $W_R$ exchange\(^3\), to see how much it can affect
the electron spectrum calculated in\(^6\). Also, as a model-independent study and to
demonstrate another version of right-handed $b$ to $c$ couplings, we will first calculate
the electron spectrum for a $V+A$ quark coupling, assuming that the lepton current
is purely left-handed. Such a possibility is outside the parameter range of the
model of\(^3\), since it corresponds to decays due to $W_L - W_R$ mixing alone. This
case, which seems to be one's first guess of what right-handed $b$ couplings might
be, was recently excluded by the $B \to D^* \ell \nu$ data\(^4\). Our purpose of including a
discussion of this case is to show that also in the case of $\Lambda_b$ decays it can be most
easily distinguished from other cases studied here.

We use the physics of the heavy quark symmetry presented in\(^6\)\(^8\) and the
notations of\(^6\) to describe the lepton spectrum in terms of the free-quark decay \(b \to ce^−\nu_e\). For a V+A \(b\) to \(c\) coupling and a V-A lepton current the normalized electron decay distribution in the \(b\) rest frame is given by\(^9\):

\[
\frac{1}{\Gamma} \frac{d^2\Gamma}{dx d(\cos \psi)} = \frac{6x^2(1 - \zeta)^2}{f(m_c^2/m_b^2)} (1 - x)(1 - P \cos \psi),
\]

\(x \equiv 2E^*/m_b, \quad \zeta \equiv m_c^2/[m_b^2(1 - x)]\).

\(f(y)\) is a well-known phase-space function, and \(E^*, \psi\) are the energy of the electron and its angle with respect to the \(b\)-quark polarization. The polarization is almost complete, \(P = -0.93\). The boost from the \(b\) rest-frame to the \(Z\) frame, in which \(Z \to b\bar{b}\) occurs, is described in\(^6\). For \(P = -1\) we find from Eq.(1) the electron energy spectrum shown in Fig. 1(c). We used the values of \(m_b = 5\) GeV, \(m_c = 1.66\) GeV, \(E_b = 45\) GeV from\(^6\), and chose a minimum electron transverse momentum of \(p_T^{\min} = 0.8\) GeV/c. This spectrum should be compared with the two spectra of\(^6\) using the same momentum cut, shown in Fig.1(a), Fig.1(b), which describe the cases of V-A and V+A quark and lepton currents, respectively. The difference is striking. The distribution of Fig.1(c) peaks at a considerably higher energy (14 GeV instead of 7 − 9 GeV) and involves many fewer low energy electrons than the two other distributions.

The possibility of a V+A \(b\) to \(c\) current coupled to a V-A lepton current was recently excluded by measurement of the forward-backward asymmetry in \(B \to D^*\ell\nu\)\(^4\). This measurement favors the two cases in which both quark and lepton currents are either V-A or V+A\(^5\). The first case corresponds to the Standard Model, while the second one describes the dominant \(W_R\) exchange contribution in model\(^3\). For both cases the measured lepton angular distribution sets 95% C.L.
upper limits on the allowed rates coming from amplitudes in which the quarks and leptons couple with opposite chiralities. The form-factor-dependent limits on the ratio of rates of opposite and equal chiralities are at the level of 30%. The implication of these limits on the model is a bound on the $W_L - W_R$ mixing parameter, $\zeta_g$:

$$\left(\frac{\zeta_g}{\beta_g}\right)^2 < 0.30 , \quad \beta_g \equiv \frac{g_R^2 M_L^2}{g_L^2 M_R^2}. \quad (2)$$

We use this constraint to study within model the effect of $W_L - W_R$ mixing on the lepton energy spectrum of $\Lambda_b$ decay. Fig.1(d) describes the spectrum corresponding to $(\zeta_g/\beta_g)^2 = 0.29$, which is just below the limit (2). The peak of this distribution lies between the peaks of the V-A and V+A distributions, Fig.1(a) and Fig.1(b), respectively. That is, the effect of $W_L - W_R$ mixing is to diminish the difference between the distributions of our model and the Standard Model. Nevertheless, the feature of a considerably lower high-energy electron tail persists in our model. An observation of a higher tail, as in Fig.1(a), would clearly favor the Standard Model.

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FIGURE CAPTION

FIG.1. Distributions in electron laboratory energy for inclusive semileptonic $\Lambda_b$ decays from $e^+e^- \rightarrow Z \rightarrow \Lambda_b + X$, with $p_T^{\text{min}} = 0.8$ GeV/c. (a) Standard Model$^6$, (b) $W_R$ exchange$^6$, (c) V+A quark coupling and V-A lepton coupling, (d) Model$^3$ with $(\zeta_g/\beta_g)^2 = 0.29$. 