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CONSTRAINTS ON THE LEFT-RIGHT SYMMETRIC MODEL FROM $b \to s\gamma$ *

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ABSTRACT

The recent observation by the CLEO Collaboration of the inclusive decay $b \to s\gamma$ with a branching fraction consistent with the expectations of the Standard Model is used to constrain the parameter space of the Left-Right Symmetric Model. Two scenarios are considered: (i) equal left- and right-handed Cabibbo-Kobayashi-Maskawa mixing matrices, $V_L = V_R($ or $V_R^*)$ and (ii) the Gronau-Wakaizumi model wherein B-decays proceed only via right-handed currents and V_L and V_R are quite distinct. In the later case the bounds from $b \to s\gamma$ are combined with other constraints leaving a parameter range that is very highly restricted and which implies that this model may soon be completely ruled out by improving data.

Rare decay processes allow us to probe energy scales beyond those directly accessible at current e^+e^- and hadron colliders. The recent observation of the $b \to s\gamma$ decay by CLEO[1], with a branching fraction in the range $1 - 4 \cdot 10^{-4}$ at 95% CL, coupled to the possible discovery of the the top quark, with a mass of approximately 175 GeV, by CDF[2], leads to many restrictions on new physics scenarios beyond the Standard Model(SM)[3]. In the analysis below, we consider the implications of these results for the Left-Right Symmetric Model(LRM)[4], which is based on the gauge group $SU(2)_L \times SU(2)_R \times U(1)$. The 'classical' constraints on this model arise from a number of sources including polarized μ decay[5], the $K_L - K_S$ mass difference[6], universality[7], and Tevatron direct Z', W' searches[8]. However, the LRM is quite robust and possesses a large number of free parameters which play an interdependent role in the calculation of observables and in the constraints resulting from experiment. As far as $b \to s\gamma$ and the subsequent discussion are concerned there are essentially 5 parameters of interest: (i) $t_\phi = tan\phi$, where ϕ is the mixing angle between W_L and W_R which form the mass eigenstates $W_{1,2}$, (ii) the ratio of masses, $r = M_1^2/M_2^2$, (with $M_2 \simeq M_R$), (iii) the ratio of gauge couplings $\kappa = g_R/g_L > 0.55$, which is expected to be of order unity, (iv)

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the masses of the right-handed(RH) neutrinos, and (v) the elements of the RH quark mixing matrix, V_R. Our discussion below[9] assumes that W_R is the *only* new particle occurring in the $b \to s\gamma$ penguin(*e.g.*, charged Higgs may also contribute to these loops in a highly model dependent way but they are neglected here) and ignores any additional phases that may be present in the $W_L - W_R$ mixing matrix that may arise from complex vev's[10].

We now outline our procedure which to leading order in the QCD corrections is well known; for details see Ref.9. We first normalize $B(b \to s\gamma)$ to the semileptonic(SL) decay rate using the quark level calculations including finite phase space and QCD corrections, assuming $m_c/m_b = 0.3$ and $\alpha_s(M_Z) = 0.125$. In the LRM, the SL decay rate is now a function of t_ϕ, r, κ and the appropriate $V_{L,R}$ factors. Apart from these model parameters, B is expressed in terms of the coefficients of the C_{7L} and C_{7R} electromagnetic dipole-moment operators evaluated at the scale $\mu = m_b$; m_s is assumed to be zero in the results quoted here. To obtain the numerical values of these operators at the low mass scale we must know the two 10×10 anomalous dimension matrices for the complete set of operators as well as all the operator coefficients at the weak scale. To lowest order in α_s, only 8 of these coefficients are non-zero:

$$
\begin{aligned}
C_{2L}(M_{W_1}) &= (1 + rt_\phi^2)(V_{cb}V_{cs}^*)_L \,, \\
C_{2R}(M_{W_1}) &= \kappa^2(r + t_\phi^2)(V_{cb}V_{cs}^*)_R \,, \\
C_{10L}(M_{W_1}) &= \kappa t_\phi(1-r)\frac{m_c}{m_b}(V_{cb}^L V_{cs}^{*R}) \,, \\
C_{10R}(M_{W_1}) &= C_{10L}(M_{W_1})(L \leftrightarrow R) \,, \qquad\qquad (1) \\
C_{7L}(M_{W_1}) &= (V_{tb}V_{ts}^*)_L[A_1(x_1) + rt_\phi^2 A_1(x_2)] + \frac{m_t}{m_b}\kappa t_\phi(V_{tb}^R V_{ts}^{*L})[A_2(x_1) - rA_2(x_2)] \,, \\
C_{7R}(M_{W_1}) &= \frac{m_t}{m_b}\kappa t_\phi(V_{tb}^L V_{ts}^{*R})[A_2(x_1) - rA_2(x_2)] + \kappa^2(V_{tb}V_{ts}^*)_R[t_\phi^2 A_1(x_1) + rA_1(x_2)] \,,
\end{aligned}
$$

where $x_{1,2} = m_t^2/M_{W_{1,2}}^2$. The coefficients of the operators corresponding to the gluon penguin, $C_{8L,R}(M_{W_1})$, can be expressed in a manner similar to $C_{7L,R}(M_{W_1})$ but with $A_i \to B_i$; note that both A_1 and B_1 are the same functions found in the usual SM calculation. The kinematic functions A_i and B_i are given in Ref.9. An important feature in the expressions for $C_{7,8L}$ and $C_{7,8R}$ are terms proportional to $\kappa t_\phi m_t/m_b$ which arise due to chirality flips and imply that B will be highly sensitive to non-zero values of t_ϕ even when r is quite small. This will be seen explicitly in our results below. The largest new contribution to $b \to s\gamma$ in the LRM is thus due to the SM W_L picking up a small RH coupling via mixing and vice versa for the W_R.

To proceed further we need to make some assumptions about the LRM parameters. The first case we consider, which one may think is the most natural, is when $V_L = V_R$ or V_R^* with heavy RH neutrinos and where we know that $M_R > 1.5$ TeV from the $K_L - K_S$ mass difference[6]. In Fig.1a we see the prediction for B as a function of t_ϕ in this case for various values of m_t assuming $\kappa = 1$ and $M_R = 1.6$ TeV. To satisfy the CLEO data only a restricted range of t_ϕ is allowed; note the rather weak sensitivity to m_t. Fixing $m_t = 175$ GeV and varying M_R we see from Fig.1b that the t_ϕ constraints are not sensitive to variations in the W_R mass. If we vary κ for m_t and M_R fixed we obtain Fig.1c which shows that the t_ϕ bounds are quite sensitive to κ. Note however that if we consider B as a function of the combination κt_ϕ (which enters directly into the expressions for the weak scale coefficients) there is very little additional κ sensitivity. Thus we see that in this $V_L = V_R$ case the bounds we obtain on t_ϕ are more restrictive than those obtained from either μ decay or universality.

In principle, if we give up the assumption that $V_L = V_R(V_R^*)$ there is very little guidance as to what form V_R might take and bizarre scenarios may in fact be realized. One possibility is the model of Gronau and Wakaizumi(GW)[11] (and several of its clones[12]). In this class of models, B decays proceed *only* via RH-currents with the apparent smallness of V_{cb} explained by the larger W_R mass. The exact forms taken for $V_{L,R}$ are somewhat model dependent; in the original GW model, one has

$$\begin{aligned} V_L &= \begin{pmatrix} 1 & \lambda & 0 \\ -\lambda & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \\ V_R &= \begin{pmatrix} c^2 & -cs & s \\ \frac{s(1-c)}{\sqrt{2}} & \frac{c^2+s^2}{\sqrt{2}} & \frac{c}{\sqrt{2}} \\ \frac{-s(1+c)}{\sqrt{2}} & -\frac{c-s^2}{\sqrt{2}} & \frac{c}{\sqrt{2}} \end{pmatrix}, \end{aligned} \tag{2}$$

where $\lambda(\simeq 0.22)$ is the Cabibbo angle and $s \simeq 0.09$ and $c^2 = 1 - s^2$. Explicitly, to satisfy the B lifetime constraint we must also have

$$M_{W_R} \leq 416.2\,\kappa \left[\frac{|V_{cb}^R|}{\sqrt{2}}\right]^{1/2} \text{ GeV} \simeq 415\,\kappa\,\text{GeV}\,, \tag{3}$$

which arises from recent determinations of V_{cb} in the SM. With the assumed forms of $V_{L,R}$ in this model the usual $K_L - K_S$ constraint on the W_R mass is easily circumvented. In addition, to satisfy the most stringent polarized μ decay data, the RH neutrino must be sufficiently massive ($\simeq 17-50$ MeV) but this has little effect on B decay itself. (Note that some of the weaker μ decay constraints remain.) Of course, a W_R satisfying the above constraint is relatively light and should have a significant production cross section at the Tevatron given the above form of V_R. We will assume $M_R = 400\kappa$ GeV in what follows as we will want M_R to be as large as possible. Figs.1d and 1e show the predicted value of B as a function of t_ϕ for $\kappa = 1.5$ and 2, respectively, for different values of m_t. In either case and for all m_t values we see that agreement with the CLEO result demands that t_ϕ lie within either of two very narrow bands with a magnitude less than 0.001. These general results are maintained at the semi-quantitative level in the various clones of the GW model[12]. Fixing $m_t = 175$ GeV, we see in Fig.1f the overall behaviour of B in the GW model as κ is allowed to vary. As in the previous case, a plot of B as a function of the combination κt_ϕ shows little additional κ sensitivity. Thus the CLEO result forces us to fine-tune t_ϕ to a narrow range of very small values in this model.

The GW model uses heavy RH ν's to avoid the bulk of the μ constraints. However, it cannot escape from τ decay in a similar manner, *i.e.*, by making the RH ν_τ heavy. Both ALEPH and L3 have measured the branching fraction for $B \to \tau\nu X$[13] and found it to be in agreement with the expectations of the SM[14]. If the RH ν_τ were heavy enough to allow the GW model to escape the τ decay constraints, this branching fraction would be seriously compromised as is shown in Fig.2a. We see from the figure that the RH ν_τ must have a mass less than about 0.3 GeV to maintain agreement with the ALEPH/L3 data implying that RH currents must be present in τ decay in the GW model. ALEPH and L3 have also recently updated the determinations of the Michel parameters for τ decay[15] which are sensitive to such RH interactions and lead to new constraints on the GW model(taking $t_\phi \simeq 0$ as we learned from $b \to s\gamma$). These new constraints, together with those from μ decay, direct Tevatron searches, and the B lifetime are combined in Fig.2b. We see that the GW model parameter space was comfortably large before the recent CDF W' search and LEP τ Michel parameter results were announced[8,15]. The new data highly compresses the model parameter space into the region near $M_R = 800$ GeV with $\kappa = 2$. Even this small region will soon become disallowed if the CDF limit scales logarithmically with increasing integrated luminosity[16](perhaps in a matter of months). Fig.2b shows the power of combining rare decay data, precision measurements, and direct searches to constrain the new physics in the GW version of the LRM.

As in the case of other new physics scenarios, $b \to s\gamma$ has been found to provide important constraints on the parameters of the LRM.

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Fig. 1: (a)B as a function of t_ϕ assuming $\kappa = 1$, $M_R = 1.6$ TeV, and $V_L = V_R$ for $m_t = 140(160, 180, 200)$ GeV as represented by the dotted(dashed,dash-dotted, solid)curve. (b)Same as (a) but with $m_t = 175$ GeV and M_R varied between 1 and 3 TeV. (c)Same as (a) but with $m_t = 175$ GeV and κ=0.6(0.8,1,1.2,1.4) corresponding to the dotted(dashed, dash-dotted, solid, square-dotted)curve. (d)Same as (a) but in the GW model with $M_R = 600$ GeV and $\kappa = 1.5$. (e)Same as (d) but with $M_R = 800$ GeV and $\kappa = 2$. (f)Same as (d) but with $m_t = 175$ GeV and $M_R = 400\kappa$ GeV with κ varying between 1(outer curve) and 2(inner curve) in steps of 0.2.

Fig. 2: (a)Branching fraction for the decay $B \to \tau\nu_R X$ in the GW model as a function of the mass of the RH-neutrino. The combined ALEPH+L3 95% CL lower bound is the horizontal dashed line. (b)Constraints on κ and M_R in the GW model: the solid line is the upper bound from Eq.3. The dash-dotted line is the lower bound from τ and μ decay data. The dotted(dashed) line is the CDF lower bound from the '88-'89 run (run 1a). The currently allowed region lies in the upper right hand corner.

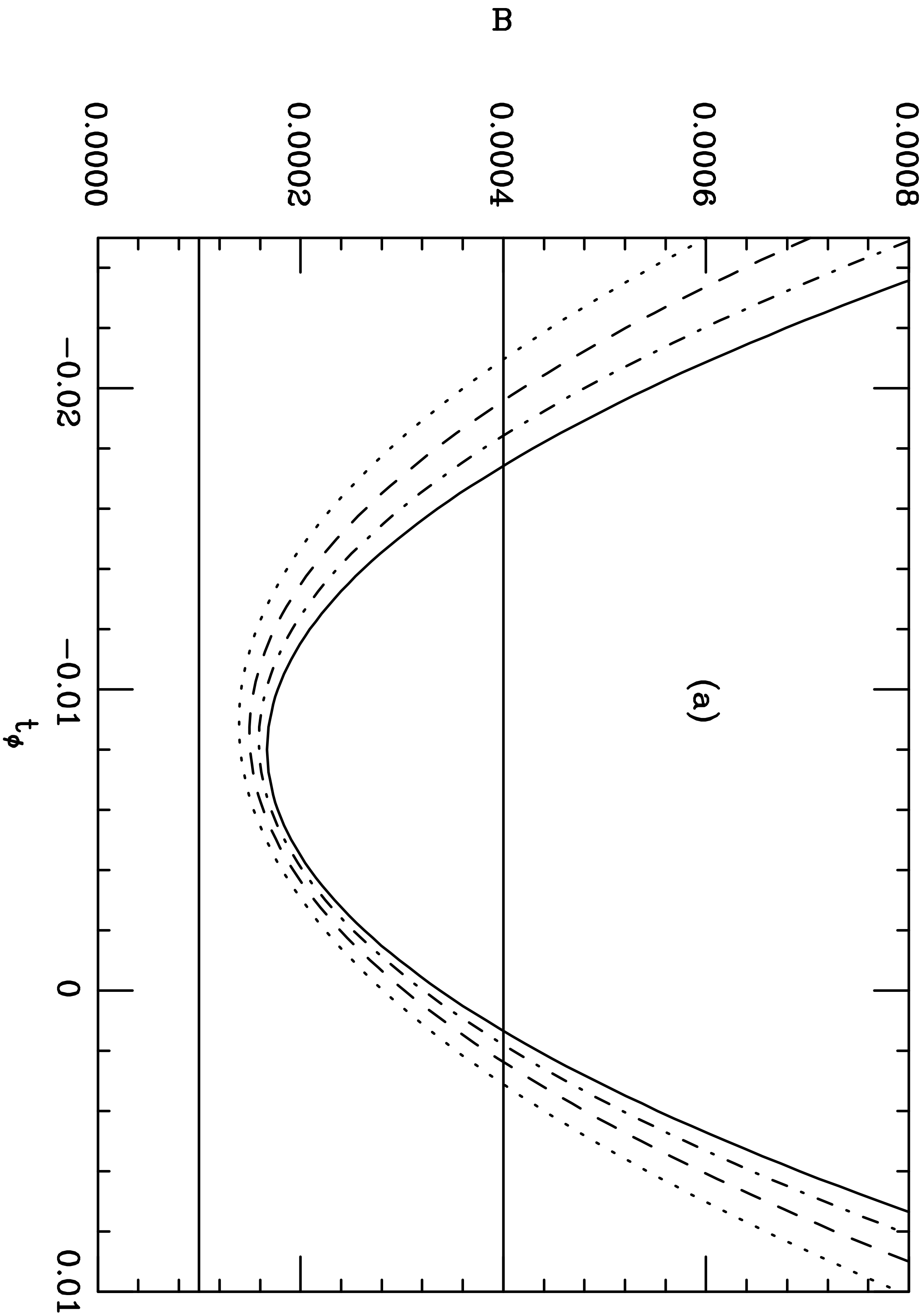

Figure 1a

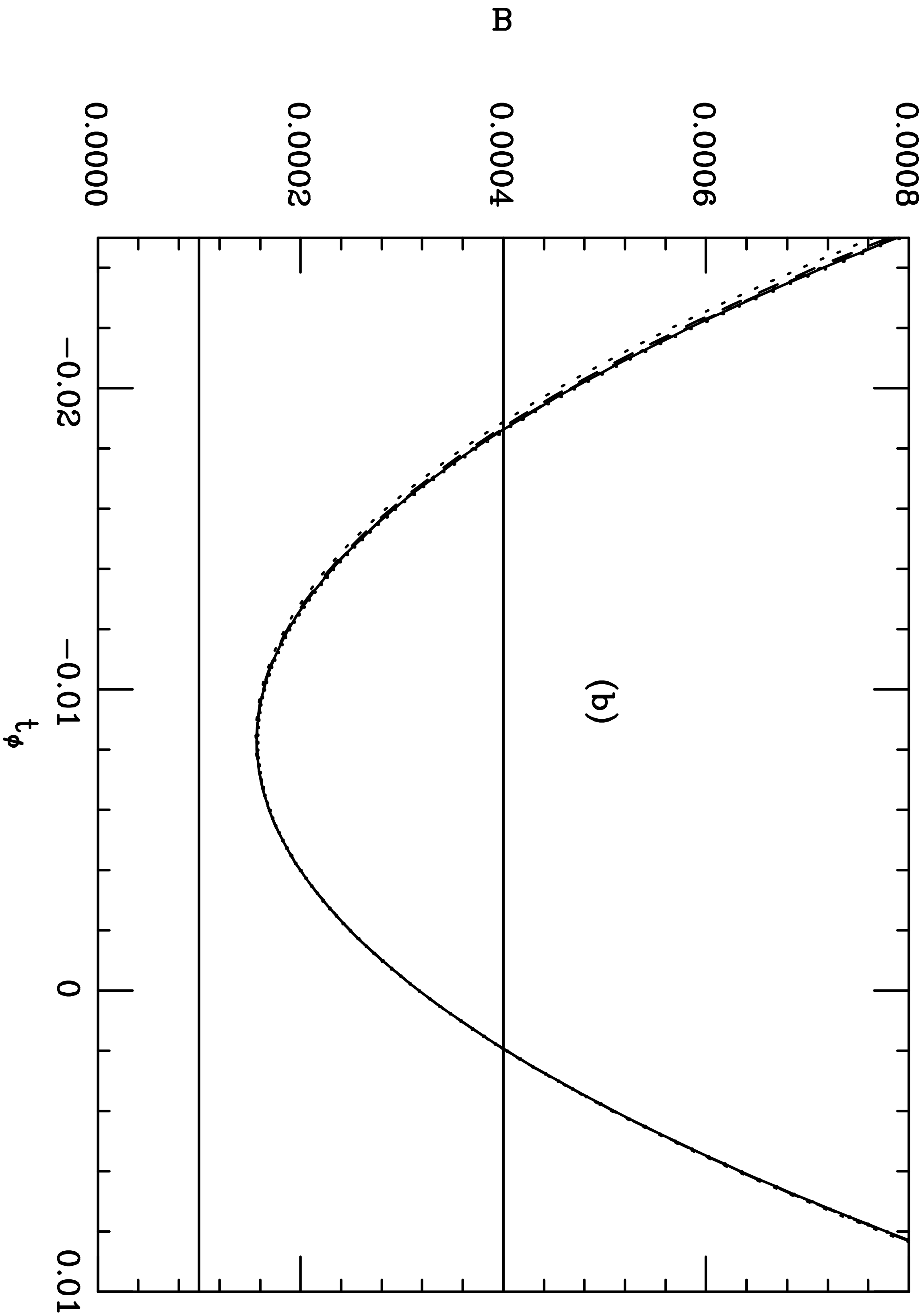

Figure 1b

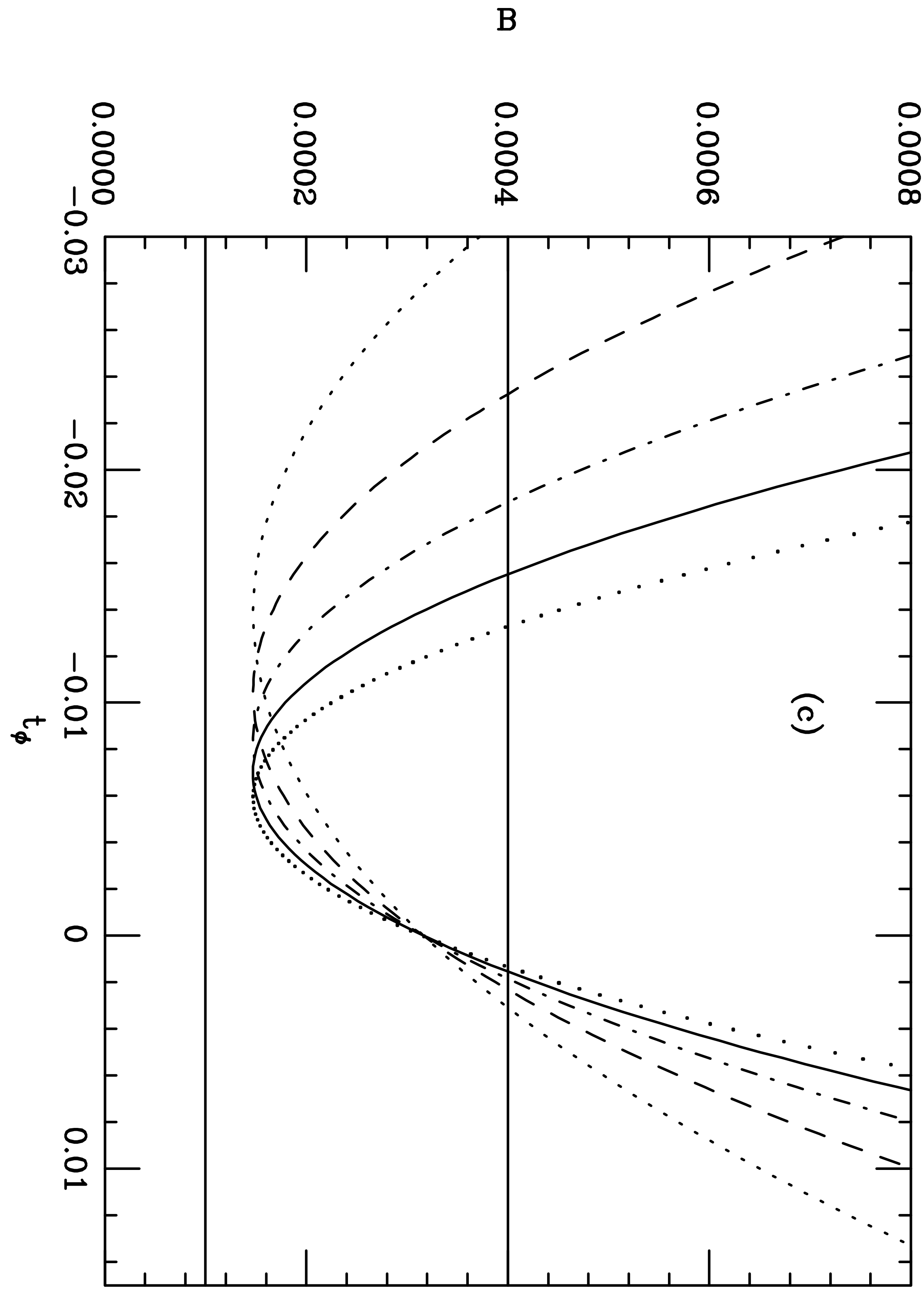

Figure 1c

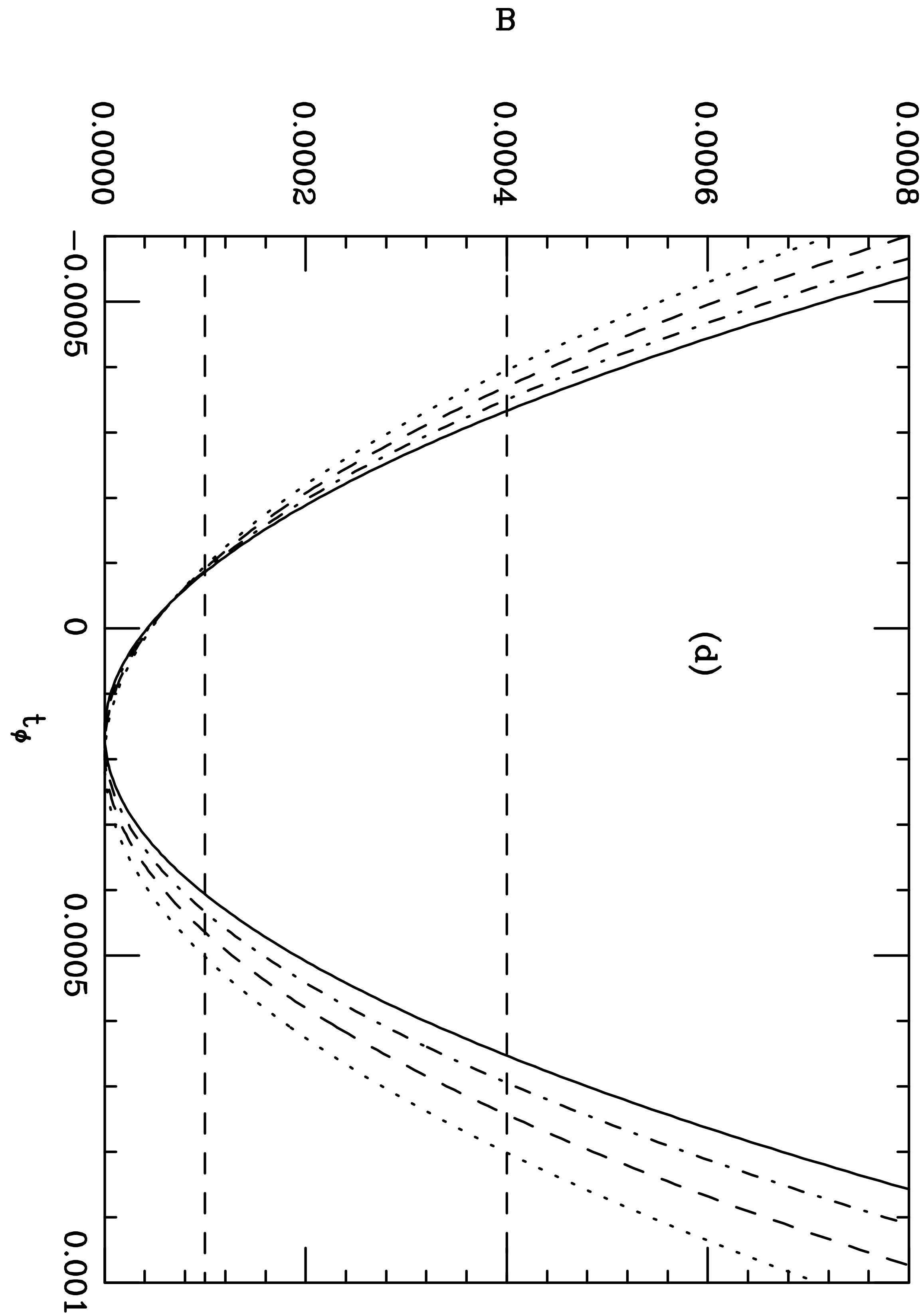

Figure 1d

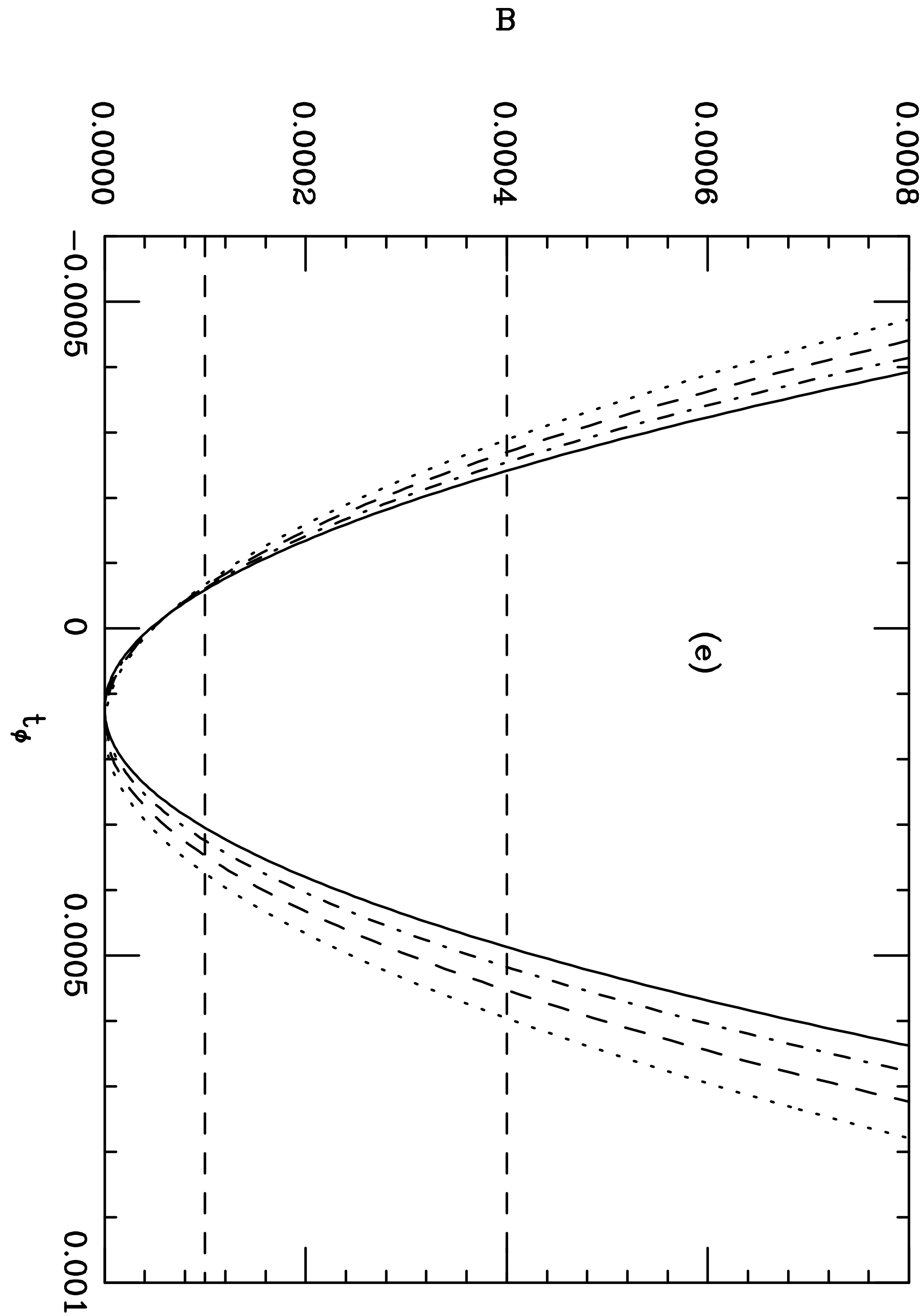

Figure 1e

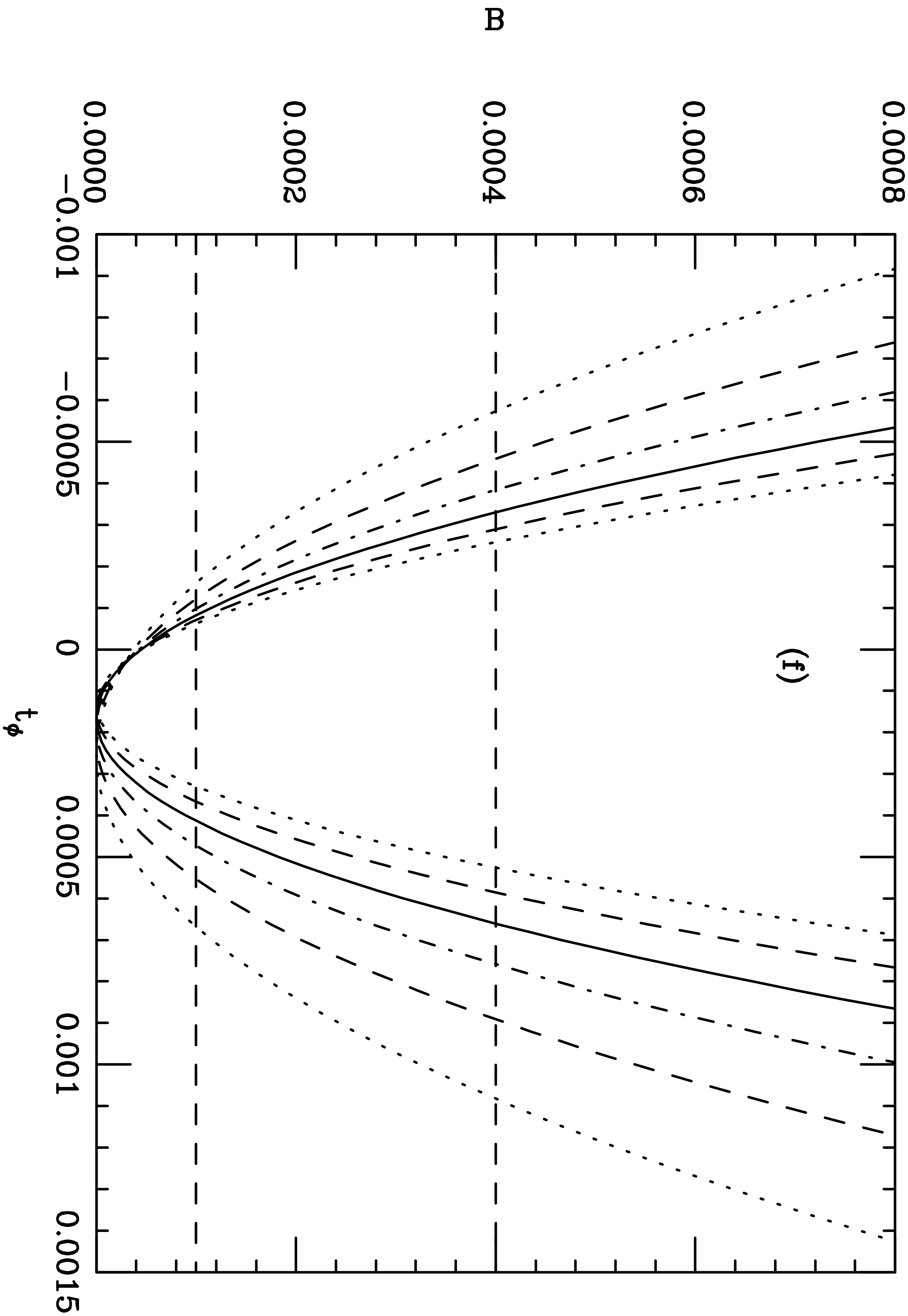
B
0.0000
0.0002
0.0004
0.0006
0.0008
−0.001
−0.0005
0
0.0005
0.001
0.0015
t_ϕ
(f)

Figure 1f

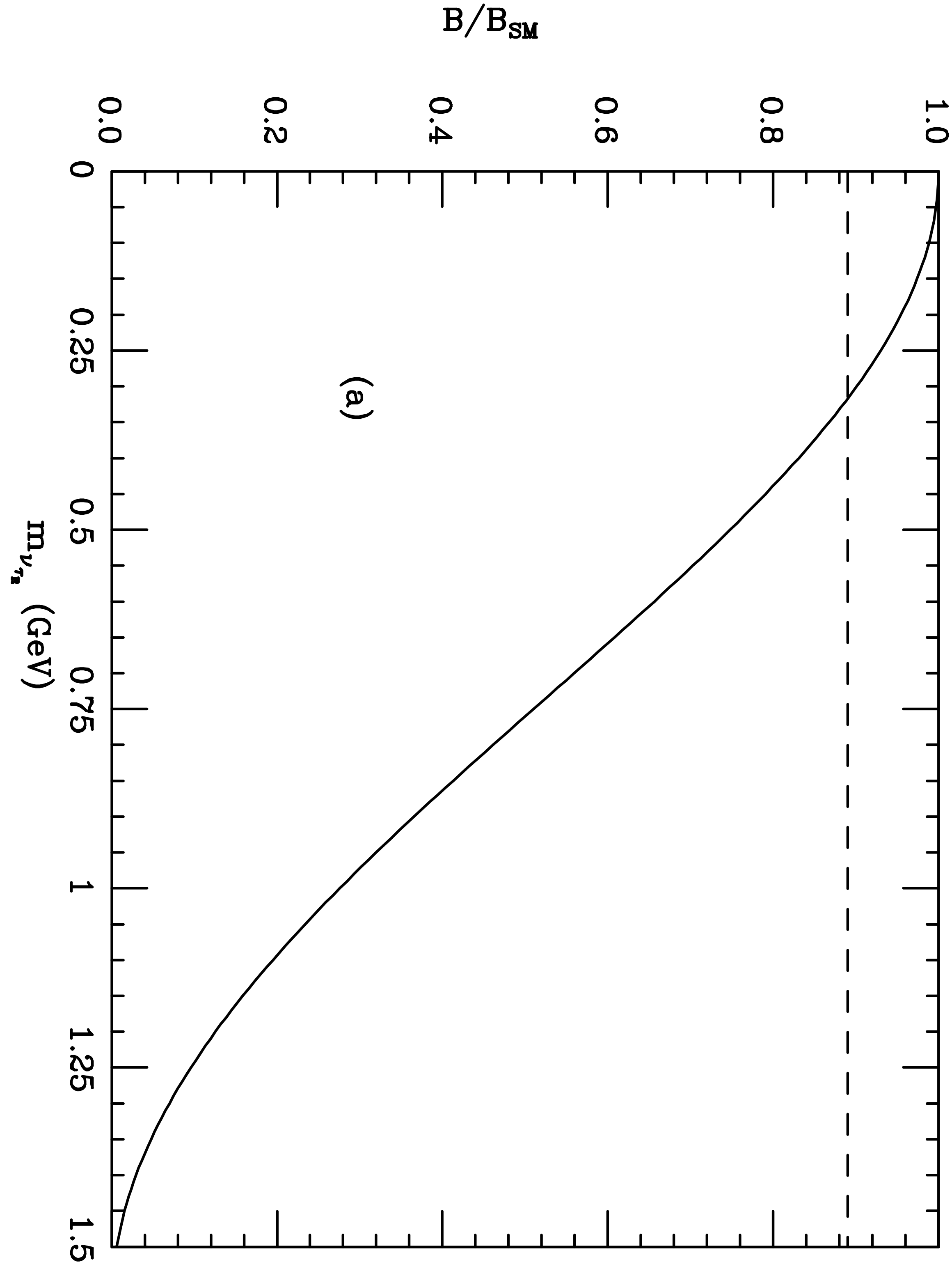

Figure 2a

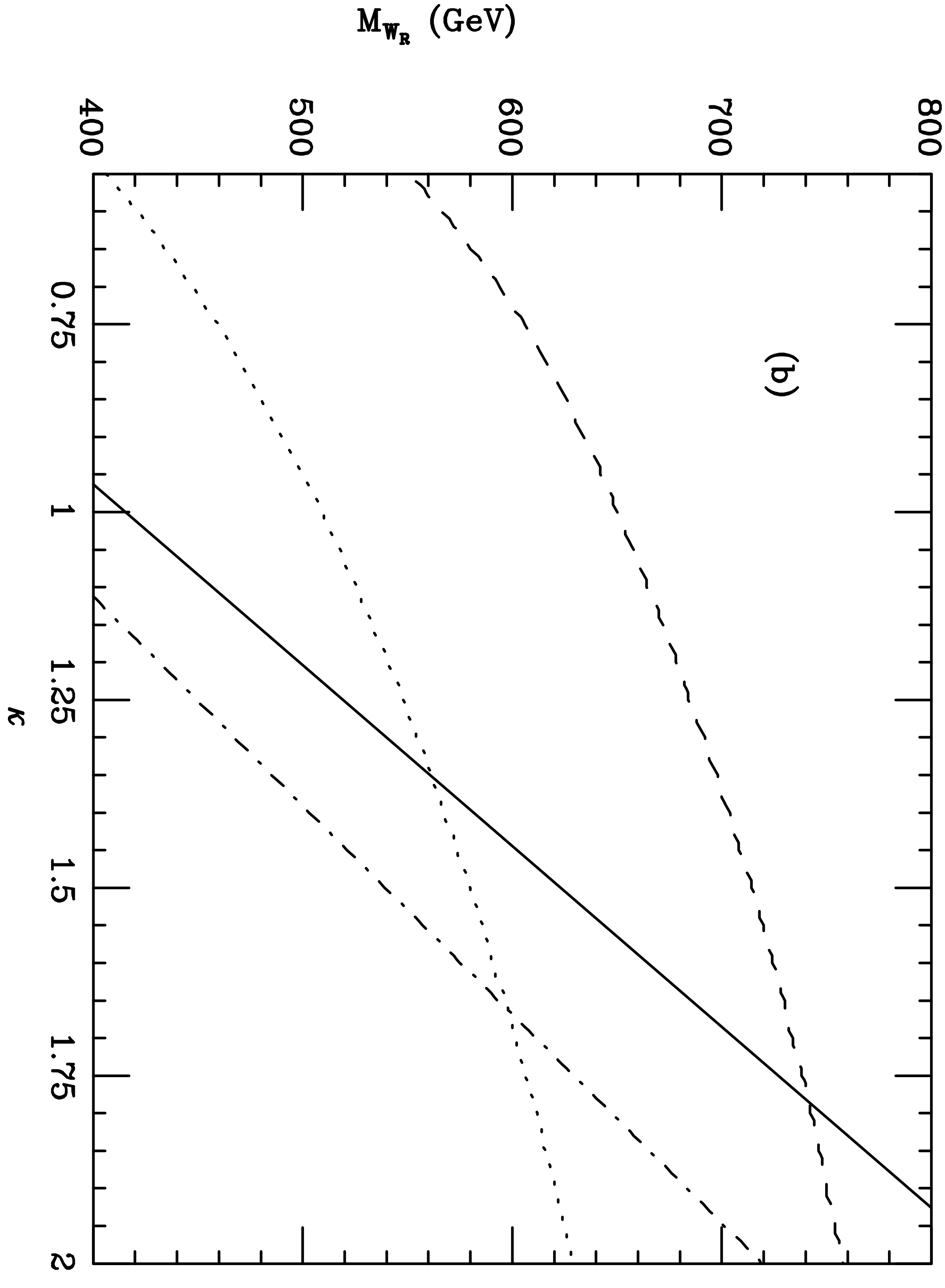

Figure 2b