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On bottom mixing with exotic quarks

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Abstract: In this paper we present a calculation of the effects of bottom mixing with new exotic quarks on the $Z \longrightarrow b\bar{b}$ branching ratio and asymmetries and on the QCD coupling constant. A global fit to these quantities as recently measured in e^-e^+ annihilation at the Z peak is done and stringent bounds are obtained. We discuss the effects of different isospin signatures for the possible new exotic quarks. The consequences for superstring-inspired E_6 models are discussed. Constraints on the bottom mixing angles with the isosinglet quarks of the fundamental 27-plet are presented.

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Some extensions of the Standard Model predict the existence of new quarks and leptons. This is the case of the superstring-inspired E_6 models [1]. In the fundamental 27 representation we have a new $Q = -1/3$ isosinglet quark which can be mixed with the standard bottom quark [2] SO(n) we can also have mirror fermions [3]. These models have gained a renewed interest with the recent experimental evidence that neutrinos have non-zero mass [4]. From general arguments, the observed neutrino masses can be a hint to the physics at the grand unification scale of $10^{15}\,\mathrm{GeV}$ [5]. A possible explanation for neutrino mass spectrum would be new isosinglet neutral leptons from the 27-plet. Other scenarios could also be possible and it is a fundamental problem in present day elementary particle physics to find evidence for the other consequences of any model which could generalize the Standard Model. However, these theoretical expectations have not received, so far, any direct experimental support [6]. The validity of the Standard Model has been tested at the level of quantum corrections and this puts strong limits on new physics. New particles, if they exist, must be at a scale well above $100\,\mathrm{GeV}$ [6, 7]. It is well known that deviations from the Standard Model couplings must necessarily be very small [7, 8].

We suggest that an important step in the search for an extended model, such as E_6 is the possibility of new mixing in the quark sector. Of particular interest are the bounds involving the bottom quark. Since the third family has high mass states, there is a theoretical prejudice that deviations from the Standard Model will be more important there. In recent years, this seemed to be the case with the bottom asymmetries and hadronic branching ratio R_b. An earlier experimental surplus of bottom quark production in Z decays motivated theoretical investigations on new possible neutral gauge bosons [9] and/or bottom mixing with new quarks [10]. The more recent data has reduced these deviations to an acceptable level of less than 2σ [6, 7]. It is expected that in a near future the experimental precision will increase and the bounds on extended model parameters will be more restrictive.

In this paper we present a calculation of the effects of bottom mixing with new exotic quarks on the forward-backward and left-right forward-backward asymmetries, the bottom hadronic branching ratio and the QCD coupling constant. The main point of our work is to call attention to the fact that all these quantities are simultaneously modified by bottom mixing with new quarks. As the experimental precision on the bottom parameters is presently of the same order, any extention of the Standard Model must also fit all the above quantities to the data. As we show below, there is a weak isospin dependence on the sign deviations from the Standard Model due to new quark mixing. A global fit to the recent data on the above quantities is done in order to get new bounds on the mixing angles.

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	VSM	VDM	FMF
g_v	$g_v^{SM} + \frac{1}{2}s_L^2$	$g_v^{SM} - \frac{1}{2}s_R^2$	$g_v^{SM} - \frac{1}{2}s_R^2 + \frac{1}{2}s_L^2$
g_a	$g_a^{SM} + \frac{1}{2}s_L^2$	$g_a^{SM} + \frac{1}{2}s_R^2$	$g_a^{SM} + \frac{1}{2}s_R^2 + \frac{1}{2}s_L^2$

Table 1: New vector and axial-vector couplings for the Zbb vertex.

We consider three models, which differ by the $\mathrm{SU}(2) \bigotimes \mathrm{U}(1)$ isospin assignment (I, I_3) to new quarks and keep the same standard model attributes to the bottom:

1. Vector singlet model (VSM). This is the case of the fundamental 27 of E_6, with a new isosinglet quark $(0, 0)$, usually called "h".

2. Vector doublet model(VDM). In this model, two new doublets $(1/2, \pm 1/2)_{R,L}$ are introduced, with left and right helicities.

3. Fermion-mirror-fermion model (FMF). In this model we have a new doublet $(1/2, \pm 1/2)_R$ and singlet $(0, 0)_L$ with opposite left and right assignments relative to the Standard Model.

In all models we allow different left and right mixing angles between the Standard Model b quark and the new exotic down-type quark. Many other assignments to new exotic quarks are possible. We have considered only the above three extensions, since their isospin contents result in different signs of the deviations from the Standard Model results as shown in equations 1 and 2. It is then straightforward to calculate, at tree level the change in the Zbb couplings, given in table 1, where $s_i^2 = \sin^2\theta_i$. The couplings for the VSM depend only on the left-handed mixing angle, as the right-handed helicity state of the exotic bottom quark has the same isospin as the Standard Model bottom quark. Similarly, the couplings of the VDM depend only on the right-handed mixing angle and for the FMF couplings both mixing angles are present.

We now discuss the general assumptions leading to our results. The first point to clarify is that we have taken into account in our calculation only the effects of mixing. In the class of models considered above one has many other effects such as new gauge bosons and scalars. A complete treatment of all the contributions is highly desirable but we will then face the problem of a large number of unknown parameters. It is known [8] that there are no significant contributions of these new particles to radiative corrections and so we have decided to study only the mixing angle effects. For a given mixing angle, the results then only depend on the weak isospin assignments of the new down-type quark in a given model. We are also supposing that mixing effects are small, as shown by several authors [11, 12]. As it

	SM	Experimental	VSM	VDM	FMF
A^b	0.9348 ± 0.0001	0.911 ± 0.025	0.9345	0.9348	0.9404
A^{FB}	0.1034 ± 0.0009	0.0988 ± 0.0020	0.1034	0.1034	0.1040
R^b	0.2158 ± 0.0002	0.2164 ± 0.0007	0.2148	0.2158	0.2141

Table 2: Asymmetries and hadronic branching ratio for the Standard Model(SM), experimental(Exp.) values and their 95% confidence level limits for the different models. The experimental data is from the Particle Data Group update of November, 1999.

is known experimentally that corrections to the Standard Model must be small, we present the results of our calculations as powers of a small mixing angle and keep only the first order term. They are displayed in equations 1 and 2. In equations 1, "A" means the forward-backward or the left-right forward-backward asymmetries. Both asymmetries are corrected by the same factor. This is a direct consequence of the isospin content of each extended model. Our calculation was performed in the on-shell scheme, with $sin^2\theta_W = 0.2230$ and $m_t = 174.3\,\mathrm{GeV}$. In equations 2, for R_b, all models tend to reduce the Standard Model prediction. For the asymmetries, the VDM and VSM models show opposite corrections whereas the FMF model tends to cancel each correction.

$$\begin{aligned} A_{VSM} &= A_{SM}(1 - 0.1551 s_L^2) \\ A_{VDM} &= A_{SM}(1 + 0.8544 s_R^2) \\ A_{FMF} &= A_{SM}(1 + 0.8544 s_R^2 - 0.1551 s_L^2) \end{aligned} \tag{1}$$

$$\begin{aligned} R_{VSM} &= R_{SM}(1 - 2.2768 s_L^2) \\ R_{VDM} &= R_{SM}(1 - 0.4132 s_R^2) \\ R_{FMF} &= R_{SM}(1 - 0.4132 s_R^2 - 2.2768 s_L^2) \end{aligned} \tag{2}$$

We have performed a global fit to the present experimental data from LEP/SLC, which is shown in table 2 [13]. It is compatible with zero mixing for all models. We have obtained, at 95% confidence level, the following upper bounds for each model

$$\begin{aligned} & s_L^2 < 0.046 \;\text{ for VSM} \\ & s_R^2 < 0.002 \;\text{ for VDM} \\ s_R^2 < 0.087\,, \quad & s_L^2 < 0.046 \text{ for FMF}\,. \end{aligned} \tag{3}$$

The numerical results for the data are shown in table 2, for the Particle Data Group average on the LEP/SLC data, in their 1999 update. No evidence for mixing is seen. We have checked the change in the value of α_s inferred from the measurement of the Z hadronic cross section due to the bottom mixing[14]. With the upper bounds above there is a small contribution, bounded by $\Delta\alpha_s < 0.005$.

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It is well known that A_b can also be inferred from A_{FB} using the relationship $A_{FB} = \frac{3}{4} A_b A_e$. There is some discrepancy with the Standard Model predictions on these asymmetries as discussed in section 10 of the Particle Data Group [13]. A_b can be extracted from A_{FB} and combined with the measurement at SLC. The result gives $A_b = 0.892 \pm 0.016$ which is 2.7σ below the Standard Model prediction. Using the LEP result on A_e, PDG obtains $A_b = 0.904 \pm 0.018$, which is 1.7σ low. With these new values we redone our global fit and verified that there is no significant differences from the PDG average.

In conclusion, the search for deviations from the Standard Model predictions in the bottom parameters can be a window to test the predictions of grand-unified models. As there is an enormous experimental activity on b-physics, it is expected that the uncertainties on the basic b-parameters will be strongly reduced very soon [15]. If the future data is closer to the Standard Model predictions, our results will imply new stronger bounds on mixing angles. If, on the contrary, there are significant experimental discrepancies with the Standard Model, our calculation could be very useful in establishing the theoretical origin of then. For example, if R_b turns to be above the Standard Model prediction, then this effect can not be attribute to mixing with new quarks in any of the models here considered.

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