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Flavor signatures of isosinglet vector-like down quark model

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Abstract

We consider a model where the standard model is extended by the addition of a vector-like isosinglet down-type quark b'. We perform a χ^2 fit to the flavor physics data and obtain the preferred central values along with errors of all the elements of the measurable 3×4 quark mixing matrix. The fit indicates that all the new-physics parameters are consistent with zero and the mixing of the b' quark with the other three is constrained to be small. The current flavor physics data rules out possibility of detectable new physics signals in most of the flavor physics observables. We also investigate possible deviations in the standard model Wtb couplings and bottom quark coupling to Higgs boson. We find that these deviations are less than a percent level which is too small to be observed at the LHC with current precision.

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1. Introduction

The standard model (SM) consists of three generations of quarks, with two quarks in each generation. However, there is no *a priori* reason for the number of quarks to be restricted to six. It may be possible to have heavier quarks whose effects have not been detected yet. The minimal extension of the SM in this direction can be obtained by adding a vector-like isosinglet quark, either up-type or down-type, to the SM particle spectrum [1–15]. Such exotic fermions can appear in E_6 grand unified theories as well in models with large extra dimensions. Since these quarks are vector-like, they do not lead to chiral anomalies. Here we consider the extension of SM by adding an isosinglet vector-like down-type quark b'.

As of now there are no direct evidences of exotic quarks. The additional chiral quarks, such as perturbative SM with fourth generation are excluded at the level of 5σ by the recent LHC data on Higgs searches, when combined with electroweak precision data and direct searches at the LHC [16]. As vector like fermions do not receive their mass from a Higgs doublet, they are still allowed by the existing experimental data and hence keep us interested.

The ordinary quarks with charge $(-1/3)$ mix with the b'. Because the b'_L has a different I_{3L} from d_L, s_L and b_L, Z-mediated flavor changing neutral current (ZFCNC) appears at the tree level in the left-handed sector. Thus the quark level transitions such as $b \to s$, $b \to d$, $s \to d$ can occur at the tree level. The addition of a b' quark to the SM leads to a quark mixing matrix which is the 3×4 upper submatrix of a 4×4 quark-mixing matrix CKM4, which is an extension of the Cabibbo–Kobayashi–Maskawa (CKM) quark-mixing matrix in the SM. This model thus provides a self-consistent framework to study deviations of 3×3 unitarity of the CKM matrix as well as flavor changing neutral currents at tree level.

Not all the elements of the CKM matrix are measured directly; the values of the elements V_{tq} $(q = d, s, b)$ are determined from decays involving loops and by using the unitarity of the 3×3 CKM matrix. Hence one expects that due to the non-unitarity of the quark mixing matrix in the ZFCNC model, sizable departures from the SM predictions may be possible. In this paper, we explore the possibility of such deviations by performing a fit to current flavor physics data.

The addition of isosinglet down-type quark b' modifies the couplings of SM bottom quark with W, Z and Higgs boson. The deviations, if measured, can provide indirect evidence of vector quarks. In this work we study such possible deviations and provide an upper bound on them.

The quark mixing matrix in the SM, which is 3×3 unitary matrix, is parametrized by three angles, θ_{12}, θ_{13}, and θ_{23} and the CP-violating phase δ_{13}. The parametrization of 4×4 unitary quark-mixing matrix requires three additional angles θ_{14}, θ_{24}, and θ_{34} and two additional CP-violating phases δ_{14} and δ_{24}. In our analysis we use an exact parametrization of the CKM4 matrix [17–19]:

$$V_{CKM4} = \begin{pmatrix} c_{12}c_{13}c_{14} & c_{13}c_{14}s_{12} & c_{14}s_{13}e^{-i\delta_{13}} & s_{14}e^{-i\delta_{14}} \\ \begin{matrix} -c_{23}c_{24}s_{12} - c_{12}c_{24}s_{13}s_{23}e^{i\delta_{13}} \\ - c_{12}c_{13}s_{14}s_{24}e^{i(\delta_{14}-\delta_{24})} \end{matrix} & \begin{matrix} c_{12}c_{23}c_{24} - c_{24}s_{12}s_{13}s_{23}e^{i\delta_{13}} \\ - c_{13}s_{12}s_{14}s_{24}e^{i(\delta_{14}-\delta_{24})} \end{matrix} & \begin{matrix} c_{13}c_{24}s_{23} \\ - s_{13}s_{14}s_{24}e^{-i(\delta_{13}+\delta_{24}-\delta_{14})} \end{matrix} & c_{14}s_{24}e^{-i\delta_{24}} \\ \begin{matrix} -c_{12}c_{23}c_{34}s_{13}e^{i\delta_{13}} + c_{34}s_{12}s_{23} \\ - c_{12}c_{13}c_{24}s_{14}s_{34}e^{i\delta_{14}} \\ + c_{23}s_{12}s_{24}s_{34}e^{i\delta_{24}} \\ + c_{12}s_{13}s_{23}s_{24}s_{34}e^{i(\delta_{13}+\delta_{24})} \end{matrix} & \begin{matrix} -c_{12}c_{34}s_{23} - c_{23}c_{34}s_{12}s_{13}e^{i\delta_{13}} \\ - c_{12}c_{23}s_{24}s_{34}e^{i\delta_{24}} \\ - c_{13}c_{24}s_{12}s_{14}s_{34}e^{i\delta_{14}} \\ + s_{12}s_{13}s_{23}s_{24}s_{34}e^{i(\delta_{13}+\delta_{24})} \end{matrix} & \begin{matrix} c_{13}c_{23}c_{34} \\ - c_{13}s_{23}s_{24}s_{34}e^{i\delta_{24}} \\ - c_{24}s_{13}s_{14}s_{34}e^{i(\delta_{14}-\delta_{13})} \end{matrix} & c_{14}c_{24}s_{34} \\ \begin{matrix} -c_{12}c_{13}c_{24}c_{34}s_{14}e^{i\delta_{14}} \\ + c_{12}c_{23}s_{13}s_{34}e^{i\delta_{13}} \\ + c_{23}c_{24}s_{12}s_{24}e^{i\delta_{24}} - s_{12}s_{23}s_{34} \\ + c_{12}c_{34}s_{13}s_{23}s_{24}e^{i(\delta_{13}+\delta_{24})} \end{matrix} & \begin{matrix} -c_{12}c_{23}c_{34}s_{24}e^{i\delta_{24}} + c_{12}s_{23}s_{34} \\ - c_{13}c_{24}c_{34}s_{12}s_{14}e^{i\delta_{14}} \\ + c_{23}s_{12}s_{13}s_{34}e^{i\delta_{13}} \\ + c_{34}s_{12}s_{13}s_{23}s_{24}e^{i(\delta_{13}+\delta_{24})} \end{matrix} & \begin{matrix} -c_{13}c_{23}s_{34} \\ - c_{13}c_{34}s_{23}s_{24}e^{i\delta_{24}} \\ - c_{24}c_{34}s_{13}s_{14}e^{i(\delta_{14}-\delta_{13})} \end{matrix} & c_{14}c_{24}c_{34} \end{pmatrix} \tag{1}$$