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Journal
Physics Letters B, 277(4)

ISSN
0370-2693

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Publication Date
1992-03-01

DOI
10.1016/0370-2693(92)91819-u

Physics Letters B 277 (1992) 509-511
North-Holland

PHYSICS LETTERS B

Electroweak constraints on heavy singlet quarks

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Received 26 November 1991

Precision measurements of rates in processes involving electroweak gauge bosons limit contributions new physics can make to radiative corrections for such reactions. Such an analysis is used to place limits on heavy, $SU(2)_L$ singlet quarks that mix with the top quark.

Recent determinations of parameters involved in processes around the Z^0 [1], the measurement of the mass of the W [2], and atomic parity violation experiments [3] have achieved such a precision that they are sensitive to radiative corrections within and beyond the standard model [4-8]; for example, if we assume that no physics beyond the standard model contributes, these results bracket the mass of the t quark and favor a relatively light Higgs particle [1,7-9]. These results can also be used to support or to place constraints on new physics beyond the standard model; constraints on technicolor models [10], contributions of extra vector mesons [11] and of Majorana doublets [12] have been obtained.

In this article we examine the bounds such an analysis can put on heavy singlet quarks that can mix with the top quark. Such quarks and their mixing with the ordinary ones have been proposed as the origin of a possible non-unitarity of the Kobayashi-Maskawa matrix and resulting flavor changing neutral currents [13-16]. The limits on the size of these currents place strong restrictions on the simultaneous mixing of a singlet quark with several of the light quarks; should such a singlet mix primarily with a quark from one family only, then these limits disappear. The closeness of the Kobayashi-Maskawa matrix elements V_{du} and V_{sc} to one precludes significant mixing of such singlets with quarks from the first two generations [14]. Significant mixing of a quark heavier than the Z^0 with the b quark is likewise excluded as such a mixing would dilute the strength of the $\bar{b}bZ^0$ vertex and thus reduce the theoretical prediction for the Z^0 width. Specifically, the theoretical prediction for the width is already one standard deviation (14 MeV) below the experimentally observed one [1,4] and thus, to 90% confidence we may allow the b to mix with a heavy quark up to an angle of 9° and to 11° at the 95% level. A similar bound was obtained in ref. [14]. We shall, thus, concentrate on the possibility of a singlet mixing with the t quark.

We assume that the t quark mixes with a heavy singlet T quark of mass M_T. The $SU(2)_L$ doublet coupling to the $W^\pm$ and to the Z^0 is $[t\cos\chi + T\sin\chi, b]$; χ is the mixing angle and we wish to see what restrictions radiative corrections place on this angle and on the mass M_T. Such corrections are contained in the transverse self-energies Π_{QQ}, Π_{3Q}, Π_{33} and Π_{11}; the numerical subscripts refer to weak isospin components of left-handed currents and the subscript Q denotes the electromagnetic current. We shall use the parameters S and T of ref. [10], the parameters used in ref. [6] and in ref. [7] are linear combinations of the above,

$$S = 16\pi \frac{d}{dq^2} [\Pi_{33}(q^2) - \Pi_{3Q}(q^2)]_{q^2=0} ,$$

$$T = \frac{4\pi}{M_W^2 \sin^2\theta_w} [\Pi_{11}(0) - \Pi_{33}(0)] . \quad (1)$$

The computation of the corrections ΔS and ΔT to S

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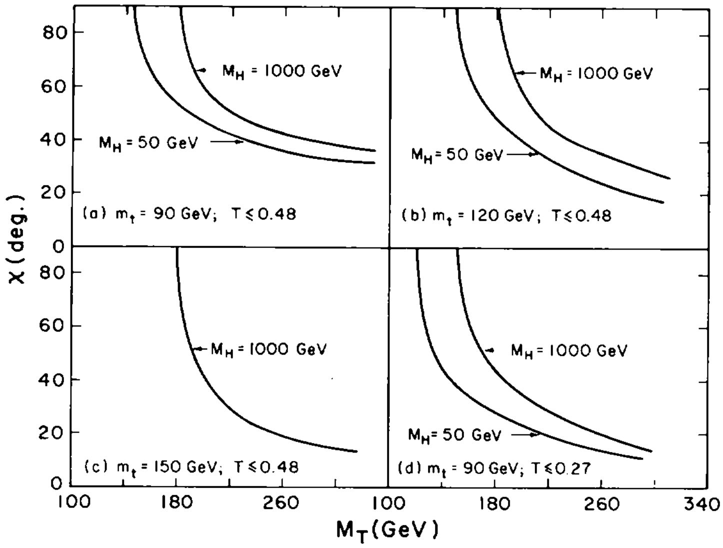

Fig. 1. Limits on M_T and χ for various top quark masses and masses of the Higgs boson. The allowed region is to the left of and below the curves. In (a), (b), and (c) the constraint from the electroweak radiative corrections is taken to be $T\leqslant 0.48$ while in (d) it is $T\leqslant 0.27$.

and to T from the mixing is straightforward. With $y=M_T/m_t$ we obtain

$$\Delta S=\frac{\sin^2\chi}{2\pi}\bigg(-\tfrac{1}{3}\ln y^2+\frac{\cos^2\chi}{(y^2-1)^3}\times[(y^6-3y^4-3y^2+1)\ln y^2-\tfrac{5}{3}y^6+9y^4-9y^2+\tfrac{5}{3}]\bigg),$$

$$\Delta T=\frac{-3m_t^2}{16\pi M_W^2\sin^2\theta_w}\sin^2\chi\times\left(1+\cos^2\chi-y^2\sin^2\chi-\frac{2y^2}{y^2-1}\cos^2\chi\ln y^2\right). \tag{2}$$

In the standard model it is T that is most sensitive to the t quark mass and in our case it is ΔT that places the severest restrictions on the properties of a singlet quark. The analysis of ref. [6] gives an upper bound of $T\leqslant 0.27$ while that of ref. [7] yields $T\leqslant 0.48$. In fig. 1 results are presented for various top quark and Higgs masses and for the various limits on T. In figs. 1a, 1b and 1c the more conservative limit of ref. [7] is used. For top quark masses less than 145 GeV and for a wide range of Higgs masses there is considerable room, both in mass and in mixing angle for a heavy singlet. For top quark masses larger than 145 GeV a low mass for the Higgs boson is excluded, even in the absence of singlet quarks; however for a large Higgs mass we still get a large region for a possible singlet. In fig. 1d bounds are presented using the more restrictive analysis of ref. [6]. This also shows the sensitivity of this new physics to bounds on the parameter T.

The parameter S is very insensitive to the top mass [7], hovering at $S\sim 0.65$ for a Higgs mass of $M_H=50$ GeV and $S\sim 0.5$ for $M_H=1000$ GeV. ΔS as a func-

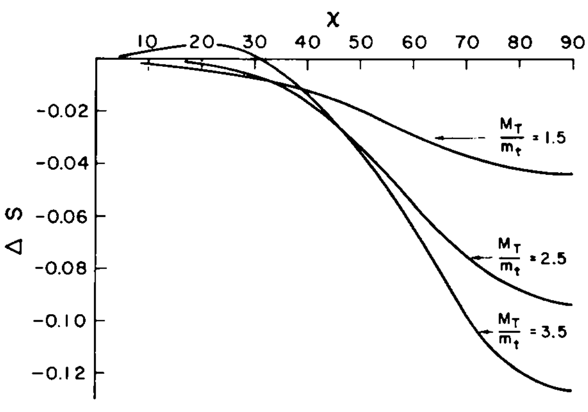

Fig. 2. ΔS as a function of the mixing angle χ, for various values of M_T/m_t.

tion of the mixing angle χ and for various values of M_T/m_t is shown in fig. 2. Even though this correction is in the right direction, namely to lower the overall value of S, in the region allowed by the previous analysis it is quite small and thus gives no restriction or support for this hypothesized new physics.

Discussions with Dr. D. Silverman are acknowledged. This work was supported in part by the National Science Foundation under Grant No. PHY-89-06641.

References

[1] F. Dydak, in: Proc. 25th Intern. Conf. High energy physics (South East Asia Theoretical Physics Association and the Physical Society of Japan, 1991), eds. K.K. Phua and Y. Yamaguchi, p. 3.
[2] F. Abe et al., Phys. Rev. Lett. 65 (1990) 2243.
[3] M.C. Noecker, B.P. Masterson and C.E. Wieman, Phys. Rev. Lett. 61 (1988) 310.
[4] M.E. Peskin, in: Proc. 17th SLAC Institute on Particle physics (SLAC, Stanford, 1990), ed. E.C. Brennan.
[5] W.J. Marciano and J.L. Rosner, Phys. Rev. Lett. 65 (1990) 2963.
[6] D.C. Kennedy and P. Langacker, Phys. Rev. Lett. 65 (1990) 2967.
[7] G. Altarelli, R. Barbieri and S. Jadach, CERN preprint CERN-TH-6124-91, unpublished.
[8] R.D. Peccei, talk at the Meeting of the Division of Particles and Fields of the American Physical Society (Vancouver, B.C., Canada, August 1991), and UCLA preprint UCLA/91/TEP/40, unpublished.
[9] J. Carter, in: Proc. of the 1991 Lepton photon Conf. (CERN, Geneva, Switzerland, July 1991), to appear.
[10] M.E. Peskin and T. Takeuchi, Phys. Rev. Lett. 65 (1990) 964.
[11] B. Holdom, Phys. Lett. B 257 (1991) 179.
[12] E. Gates and J. Terning, Phys. Rev. Lett. 67 (1991) 1840.
[13] M. Shin, M. Bander and D. Silverman, Phys. Lett. B 219 (1989) 381; in: Second Intern. Symp. on The fourth family of quarks and leptons, eds. D.B. Cline and A. Soni, Annals of the New York Academy of Sciences, Vol. 578 (1989) p. 327; in: Proc. Tau–charm factory Workshop, ed. L.V. Beers (Stanford Linear Accelerator Center, Stanford, CA, 1989).
[14] Y. Nir and D. Silverman, Nucl. Phys. B 345 (1990) 301; Phys. Rev. D 42 (1990) 1477;
D. Silverman, UCI Technical report 91-12, unpublished.
[15] B. Mukhopadhyaya and S. Nandi, Phys. Rev. Lett. 66 (1991) 285.
[16] T.P. Cheng and L.-F. Li, Carnegie-Mellon preprint CMU-HEP91-09, unpublished.