Revista Mexicana de Física **43**, *No. 2 (1997) 219–223*

Radiative effects of exotic fermions

M. ÁVILA
Facultad de Ciencias, Universidad Autónoma del Estado de Morelos
Cuernavaca 62210, Mor., México

O.A. SAMPAYO*
Departamento de Física, CINVESTAV-IPN
Apartado Postal 14-740, C.P. 07000, Mexico D.F., Mexico

Recibido el 9 de agosto de 1996; aceptado el 7 de octubre de 1996

ABSTRACT. We evaluate the contributions of exotic fermions, which transform as N-dimensional vector-like multiplets under the SM group SU(2) × U(1), to the oblique parameters defined to constrain new physics from high-precision measurements. It is found that present data implies a lower bound on the mass of these fermions for arbitrary N. For instance, $m \geq 360$ GeV for $N = 10$.

RESUMEN. Evaluamos las contribuciones de los fermiones exóticos que se transforman en un multiplete vectorial N-dimensional bajo el grupo del modelo estándar (ME) SU(2) × U(1) a los parámetros oblicuos definidos para constreñir nueva física de las medidas de alta precisión. Se halla que los datos actuales implican una cota inferior a la masa de estos fermiones para N arbitrario. Por ejemplo, $m \geq 360$ GeV for $N = 10$.

PACS: 12.60.-i; 12.15.Lk

The measurements of the gauge boson properties (W, Z), have reached a level of precision that allows to test the standard model (SM) [1] at the level of radiative corrections at LEP [2]. Moreover, LEP results have also been used to impose contrains on the presence of new physics.

Within the SM group SU(2)×U(1), the left-handed components of the known fermions transform as doublets, whereas the right-handed components transform as singlets, which has been tested with success [3]. However, in extensions of the SM of the grand unified type [4], the existence of new fermions with different transformation properties is predicted in general. The cases of fermions that transform as singlets, mirror or vector-like doublets are the ones most commonly studied in the literature [5]; vector-like and chiral triplets have also been considered [6].

In this paper we study the implications of exotic fermions that transform as vector-like multiplets of N-dimension, under the SM group. We are interested in evaluating the

---

*On leave on absence from: Departamento de Física, Facultad de Ciencias Exactas y Naturales, Universidad Nacional del Mar de Plata, Funes 3350; 7600 Mar del Plata, Argentina contribution of these fermions to the oblique parameters, which defined to constrain the contribution of new physics to observables measured with high-precision at LEP.

The left- and right-handed components of the N-dimensional multiplets, of hypercharge Y, are written as follows:

$$F_{L,R} = \left(f_J, f_{J-1}, \dots , f_{-(J-1)}, f_{-J}\right)_{L,R}, \tag{1}$$

thus, the dimension of the multiplets is $N = 2J + 1$, with J being its spin.

The Lagrangian for this type of representation has the following form:

$$\mathcal{L} = \overline{F}_L \gamma^\mu D_\mu F_L + \overline{F}_R \gamma^\mu D_\mu F_R, \tag{2}$$

where the covariant derivatives are defined as

$$D_\mu F_{L,R} = \left(\partial_\mu - ig'Y B_\mu - ig\tau^i W^i_\mu\right) F_{L,R}. \tag{3}$$

Equations (2) and (3) can be rewritten in terms of the physical gauge bosons $(W^\pm, Z, A)$. Then, the Lagrangian that describes the interactions of the fermions f_J becomes

$$L_{\text{int}} = -\frac{g}{\sqrt{2}} \bar{f}^a T^+_{ab} \not{W}^- f^b - g' Y \bar{f}^a \not{B} f^a - g \bar{f}^a T^3_{ab} \not{W}_3 f^a, \tag{4}$$

where $B = c_W A - s_W Z, W_3 = s_W A + c_W Z$. The matrix elements of the operator T^+ are zero everywhere except for the elements below from the principal diagonal, with values $T^+_{(s+1,s)} = \sqrt{s(2J - s + 1)}$, where $s = 1, 2, \dots , 2J$. The operator T_3 is diagonal, with elements $T_{3(s,s)} = J - s$. $s_W(c_W)$ denote the sine (cosine) of the weak mixing angle.

The resulting interactions between the fermions and gauge bosons are

$$C^W_{(J,s)} \bar{f}_{J-s} \gamma^\mu f_{J-s+1} W^-_\mu, \tag{5}$$

$$C^Z_{(J,s)} \bar{f}_{J-s} \gamma^\mu f_{J-s} Z_\mu, \tag{6}$$

$$C^\gamma_{(J,s)} \bar{f}_{J-s} \gamma^\mu f_{J-s} A_\mu, \tag{7}$$

with the corresponding coefficients given by

$$C^W_{(J,s)} = -\frac{e}{\sqrt{2} s_W} \sqrt{s(2J - s + 1)}, \tag{8}$$

$$C^Z_{(J,s)} = \frac{e}{s_W c_W} \left[s_W Y - (J - s) c^2_W\right], \tag{9}$$

$$C^\gamma_{(J,s)} = -e\,(Y + J - s). \tag{10}$$

Because of gauge invariance, the fermion masses are degenerate $(M_i = M_j)$. The mass terms for these fermions does not require a Higgs mechanism.

In order to derive bounds on the mass of these exotic fermions, one can evaluate their radiative contribution to observables measured with high-precision. For the case presented here, it is assumed that the vector-like fermions do not mix with standard fermions, thus, their (universal) contribution to radiative corrections can be evaluated from the self-energies of the vector bosons, which define the oblique parameters [7, 8]. In particular, we shall use the set of V_i-parameters introduced by Novikov *et al.* [9].[1]

According to Ref. 9, the contributions of new physics to the physical quantities $m_W/m_Z, g_A$ and g_V/g_A, can be expressed in terms of the parameters V_m, V_A, V_R, which in turn are written as functions of the self-energies of the vector bosons ($\Pi_{VV'}$, with $V, V' = \gamma, Z, W$), namely,

$$\bar{\alpha}V_A \equiv \frac{16\pi}{3} s_W^2 c_W^2 \left(\Pi_{ZZ}(m_Z^2) - \Sigma'_{ZZ}(m_Z^2) - \Pi_W(0)\right), \tag{11}$$

$$\bar{\alpha}V_m = \frac{16\pi}{3} s_W^4 \left[\frac{c_W^2}{s_W^2}\left(\Pi_{ZZ}(m_Z^2) - \Pi_W(m_W^2)\right). \right.$$
$$\left. + \Pi_W(m_W^2) - \Pi_W(0) - \Pi_{\gamma\gamma}(m_Z^2) - \frac{2s_W}{c_W}\Pi_{\gamma Z}(0)\right], \tag{12}$$

$$\bar{\alpha}V_R = \frac{16\pi}{3}(c_W^2 - s_W^2)\left[\frac{c_W^2 s_W^2}{c_W^2 - s_W^2}\left(\Pi_{ZZ}(m_Z^2) - \Pi_{\gamma\gamma}(m_Z^2) - \Pi_W(0) - \frac{2s_W}{c_W}\Pi_{\gamma Z}\right)\right.$$
$$\left. - s_W c_W \Pi_{\gamma Z}(m_Z^2)\right], \tag{13}$$

where $\bar{\alpha} = \alpha(m_Z)$, and $\Sigma'_{VV} = \Pi(0)/m_V^2$.

The results for the contribution of exotic fermions to the V-parameters in the present model are

$$V_A = \frac{16N_c}{9}\frac{N}{1-4u}\left(Y_L^2 s_W^4 + c_W^4 \frac{N^2-1}{12}\right)\left(1 + 2u - 12u^2 F_u\right), \tag{14}$$

$$V_m = \frac{16N_c N}{9}\left(1 - 2s_W^2\right)\left[(1+2u)F_u - \left(1 + 2u/c_W^2\right)F_u^W\right], \tag{15}$$

$$V_R = 0. \tag{16}$$

where $u = m^2/m_Z^2$, $F_u = F(m_Z^2, m^2)$, $F_u^W = F(m_W^2, m^2)$, with m, m_W, m_Z denoting the fermion, W and Z masses, respectively. The function F is defined in Ref. 10. In the large-mass limit ($u \to \infty$) all the V-parameters vanish, which shows the decoupling nature of the fermions in this model.

The data for the physical quantities ($m_W/m_Z, g_V, g_V/g_A$) used in the χ^2 fit, are taken from Ref. 11. In our analysis, the value of the SM Higgs mass is kept as constant, whereas the top and the fermion masses are varied first. Figure 1 shows the results of the fit for $m_h = 300$ GeV, $Y = 0$ and $N = 2, 3, 4, \ldots, 10$. The labels in front of the lines correspond to N (number of fermions in each multiplet).

[1] One could choose any of the parameterizations that have appeared in the literature, like the S, T, U parameters of Peskin and Takeuchi [7], or the ϵ_i parameters of Altarelli-Barbieri [8].

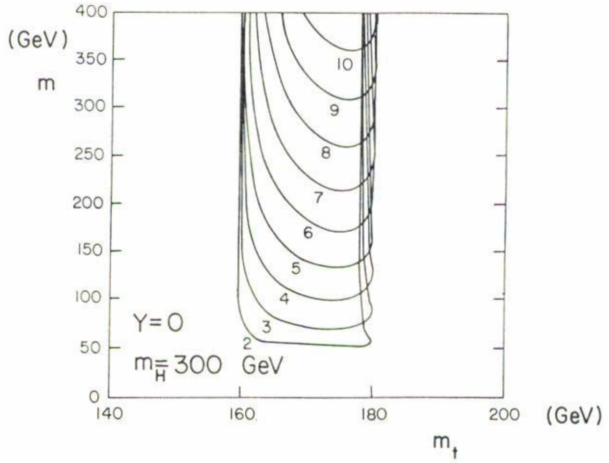

FIGURE 1. Result for the fit of m *vs.* m_t, for the model with vector-like fermions. The number in front of each curve corresponds to the dimension N of the multiplet.

The result of the fit shows that the values of the top mass are in agreement with recent experimental measurements [12]. For all the previous cases it is found a lower bound on m, which increases for larger values of N. For instance, we obtain $m > 70$ GeV for $N = 3$, whereas for $N = 10$ the bound is $m > 360$ GeV.

In conclusion, we have evaluated the radiative corrections from exotic fermions of arbitrary dimension (N), using the oblique parameters that are defined to test the presence of new physics from high-precision measurements. The interest of our result, is the possibility to obtain a lower bound on the mass of the exotic fermions for arbitrary N.

ACKNOWLEDGEMENTS

We acknowledge to Dr. L. Díaz-Cruz for his participation in the early stages of this work and the support from CONACyT and SNI (MEXICO).

REFERENCES

1. S. Weinberg, *Phys. Rev. Lett.* **19** (1967) 1264; A. Salam in *Elementary Particle Theory*, edited by N. Southolm, Almquist and Wiksell, Stockholm (1968) p. 367; S.L. Glashow, *Nucl. Phys.* **B22** (1961) 579.
2. ALEPH Collaboration, D. Decamp *et al.*, *Phys. Rep.* **216** (1992) 253.
3. See: Particle Data Book, *Phys. Rev. D* **45** (1994) Part II.
4. For a review see: Paul Langacker, *Phys. Rep.* **72** (1981) 185.
5. See the section on new particles in Ref. 3.
6. R. Foot, H. Lew and G.C. Joshi, *Phys. Lett.* **B212** (1988) 67. See also: G. Bhattacharya and A. Raychaudhuri, *Phys. Lett.* **B296** (1992) 448, and references therein.
7. M. Peskin and T. Takeuchi, *Phys. Rev. D* **46** (1992) 381.
8. G. Altarelli and R. Barbieri, *Phys. Lett.* **B253** (1991) 161.

9. V. Novikov *et al.*, *Nucl. Phys.* **B397** (1994) 35.
10. W. Hollik,*Fortschr. Phys.* **38** (1990) 165.
11. Summary from the talk presented by P. Clark *et al.*, at the Rencontres de Moriond, Meribel (1994).
12. CDF Collaboration, F. Abe *et al.*, *Phys. Rev. Lett.* **74** (1995) 2626; D0 Collaboration, S. Abachi *et al.*, *Phys. Rev. Lett.* **74** (1995) 2632.