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Studying effects of a second Z as tests of a unification model of electroweak and strong interactions

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The effects of a second heavier Z' gauge boson predicted in a model of unification of electroweak and strong interactions without grand unification are studied on the properties of Z. It is shown that future measurements of such effects can distinguish the model from the other extended gauge models which also have an extra Z'.

The advent of new experimental capabilities such as the Fermilab Tevatron, SLAC Linear Collider (SLC), and CERN LEP I, could provide precision tests of the predictions of the standard model. In the process, one may discover new physics. Extensions of the standard model involve the existence of new gauge vector bosons. Many authors[1-5] have studied the effects of an extra neutral gauge boson (Z'), which might manifest itself through accurate studies of e^+e^- collision around the Z peak. The mixing between Z and Z' could have important effects on the properties of Z. In an exhaustive study[4] of such effects, the theoretical possibilities have been divided into two classes: (a) extension of the gauge group of the standard model; (b) electroweak symmetry breaking by the strong sector. The former class has been characterized by gauge invariance under $\mathrm{SU}(2)_L \times \mathrm{U}(1)_Y \times \mathrm{U}(1)_{\hat{Y}} \subset G$ [e.g., E_6 (Ref. 6)] and[7] $\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R \times \mathrm{U}(1)_{B-L}$. It is important to note that the new hypercharge $\hat{Y}$ does not contribute to the charge operator of basic fermions in this class of models.

The purpose of this paper is to consider a different type of model,[8] where $\hat{Y}$ contributes to Q_{em} of quarks but not to Q_{em} of leptons. Such a model was considered as an attempt to unify electroweak interaction with strong interaction without putting quarks and leptons in one representation as is usually done in grand unified models. In fact $\hat{Y}$ is responsible for the fractional electric charges of the quarks. Just as $\sin^2\theta_W$ determines the unification condition for electroweak interaction a new parameter $\sin^2\beta$ determines the unification condition of electroweak interaction with strong interaction. The unification scale in this model[8] could be quite low.

The $\mathrm{SU}(2)_L \otimes \mathrm{U}(1)_Y \otimes \mathrm{U}(1)_{Y'}$ content of the model gives rise to the Lagrangian[8]

$$L_{\mathrm{ew}} = eJ_\mu^{\mathrm{em}} A_\mu + \frac{g}{\sqrt{2}} J_{L\mu}^+ W_\mu^- + \mathrm{H.c.} + \frac{g}{\cos\theta_W} J_\mu^{Z_0} Z_{0\mu} + \frac{g\tan\theta_W}{\sin\beta\cos\beta} J_\mu^{Z_0'} Z_{0\mu}' , \tag{1a}$$

where

$$J_\mu^{Z_0} = J_{3L\mu} - \sin^2\theta_W J_\mu^{\mathrm{em}} , \quad J_\mu^{Z_0'} = \sin^2\beta (J_\mu^{Z_0} - \cos^2\theta_W J_\mu^{\mathrm{em}}) + J_\mu^C , \tag{1b}$$

with

$$J_\mu^C(l) = 0 , \tag{1c}$$

while

$$J_\mu^C(q) = -\tfrac{1}{3}(\bar{u}_n i\gamma_\mu u_n + \bar{d}_n i\gamma_\mu d_n) . \tag{1d}$$

Here Z_0 is the Z boson of the standard model and satisfies

$$\rho_{\mathrm{SB}} = \frac{M_W^2}{\cos^2\theta_W M_{Z_0}^2} = 1 \tag{2}$$

and $J_\mu^{Z_0}$ is the corresponding current. Note that Z_0 and Z_0' are not physical particles, which we define as

$$Z = \cos\xi_0 Z_0 + \sin\xi_0 Z_0' , \quad Z' = -\sin\xi_0 Z_0 + \cos\xi_0 Z_0' . \tag{3a}$$

After diagonalizing of the matrix

$$\begin{bmatrix} M_{Z_0}^2 & M_{Z_0Z_0'}^2 \\ M_{Z_0Z_0'}^2 & M_{Z_0'}^2 \end{bmatrix} , \tag{3b}$$

where in the model

$$M_{Z_0Z_0'}^2 = \sin\theta_W \tan\beta M_{Z_0}^2 , \tag{4}$$

we obtain

$$\tan^2\xi_0 = \frac{\gamma\lambda}{1-\gamma}, \quad M_{Z_0Z_0'}^2 = -\cos\xi_0 \sin\xi_0 (M_{Z'}^2 - M_Z^2) , \tag{5}$$

with

$$\lambda = \left[1 - \frac{M_Z^2}{M_{Z_0}^2} \right], \quad \gamma = \frac{M_{Z_0}^2}{M_{Z'}^2} \tag{6}$$

and

$$M_{Z'}^2 = M_{Z_0}^2 \left[1 + \frac{1}{\lambda} \sin^2\theta_W \tan^2\beta \right] , \quad M_Z < M_{Z_0} < M_{Z'} . \tag{7}$$

In the notation of Ref. 4, which we shall closely follow in studying the consequences of Z',

TABLE I. The coefficients A_f, B_f, deviations of leptonic widths $\delta\Gamma_l$, and the widths Γ_f^0 in the standard model.

	$m_t = 100$ GeV	$m_t = 200$ GeV
A_ν	2.01	2.03
A_e	1.18	1.23
A_u	5.69	5.77
A_d	6.55	6.59
B_ν	4.01	4.05
B_e	1.63	1.54
B_u	$-\left[10.18+\frac{3.14}{\sin^2\beta}\right]$	$-\left[10.39+\frac{3.26}{\sin^2\beta}\right]$
B_d	$\left[4.82+\frac{5.74}{\sin^2\beta}\right]$	$\left[4.86+\frac{5.84}{\sin^2\beta}\right]$
$\delta\Gamma_\nu$ (MeV)	-2.79	-1.25
$\delta\Gamma_e$ (MeV)	-0.63	-0.19
Γ_ν^0 (MeV)	166	167
Γ_l^0 (MeV)	83.3	84.3
Γ_h^0 (MeV)	1733	1754

$$\lambda=\frac{\Delta\rho_M}{\rho_M}, \quad \Delta\rho_M=\rho_M-1 \ . \tag{8}$$

The model gives rise to the following effective low-energy Lagrangian[8] in the neutral sector (apart from electromagnetic term)

$$L_{\text{eff}}=\frac{g^2}{M_{Z_0}^2\cos^2\theta_W}(J_\mu^{Z_0}J_\mu^{Z_0}+A^2\cos^4\theta_W J_\mu^D J_\mu^D) \ , \tag{9a}$$

where

$$A^2=(1-\lambda)^{-1}\lambda(1-\gamma) \tag{9b}$$

and

$$J_\mu^D=J_\mu^{\text{em}}-\frac{1}{\sin^2\beta\cos^2\theta_W}J_\mu^C \ . \tag{10}$$

Note that $J_\mu^D(\nu)=0$ so that there is no contribution of the additional term in Eq. (9a) to ν-q and ν-e scattering. J_μ^D being a pure vector, there is also no contribution to the asymmetry parameter in e-q scattering. Thus the low-energy predictions of the model are exactly the same as in the standard model irrespective of the masses of Z and Z'.

In order to study the effect of Z' on Z properties, we extract from Eqs. (1), on using Eq. (3a), the Z couplings:

$$\frac{g}{\cos\theta_W}\cos\xi_0\left[J_\mu^{Z_0}+\sin\theta_W\tan\xi_0\tan\beta\times\left[J_\mu^{Z_0}-\cos^2\theta_W J_\mu^{\text{em}}+\frac{1}{\sin^2\beta}J_\mu^C\right]\right] \ . \tag{11}$$

Now using Eqs. (4), (5), and (6),

$$\sin\theta_W\tan\xi_0\tan\beta=-\sin^2\varepsilon_0\left[\frac{M_{Z'}^2}{M_{Z_0}^2}-\frac{M_Z^2}{M_{Z_0}^2}\right]=-\lambda \ , \tag{12}$$

independent of the sign of ξ_0. Thus, the Z couplings are given by

$$\frac{g}{\cos\theta_W}\cos\xi_0\left[J_\mu^{Z_0}-\lambda\left[J_\mu^{Z_0}-\cos^2\theta_W J_\mu^{\text{em}}+\frac{1}{\sin^2\beta}J_\mu^C\right]\right] \ . \tag{13}$$

Therefore, to first order in λ or $\Delta\rho_M$ and $\cos^2\xi_0\simeq 1$,

$$\delta\Gamma_f=\frac{G_F M_Z^3}{24\sqrt{2}\pi}\Delta\rho_M(A_f-B_f) \ , \tag{14a}$$

where[4]

TABLE II. The deviations of hadronic width and the lower limits on $M_{Z'}$.

	$m_t=100$ GeV			$m_t=200$ GeV		
$\sin^2\beta$	$\frac{1}{3}$	$\frac{5}{12}$	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{5}{12}$	$\frac{1}{2}$
$M_{Z'}$ (GeV)	257	301	351	368	436	513
$\delta\Gamma_h$ (MeV)	5.5	14.8	21.0	2.6	6.7	11.0

TABLE III. The deviations of Γ_f (MeV) for U(1) (arising from E_6) and LR models.

	$\theta_2=0$					$\theta_2=-90$			LR	
ξ_0	0.04	-0.04	0.02	-0.02	0.04	-0.04	0.02	-0.02	0.02	-0.02
$\delta\Gamma_\nu$	0.67	4.97	1.74	3.90	11.2	-5.51	6.99	-1.34	4.96	0.68
$\delta\Gamma_l$	0.79	2.52	1.22	2.08	-2.76	6.07	-0.56	3.86	-0.75	4.06
$\delta\Gamma_h$	39.5	47.4	41.5	45.5	31.3	55.6	37.4	49.6	29.9	57.1
$\delta\Gamma_T$	43.8	69.8	50.3	63.3	56.3	57.3	56.6	57.0	42.4	71.3

$$A_f=4N_c^f\rho_f\left[(T_{3L}^f-2\sin^2\theta_f Q_{\rm em})^2+(T_{3L}^f)^2+4\frac{\sin^2\theta_f\cos^2\theta_f}{\cos2\theta_f}Q_{\rm em}(T_{3L}^f-2\sin^2\theta_f Q_{\rm em})\right] \tag{14b}$$

and, in our case,

$$B_f=8N_c^f\rho_f\left[(T_{3L}^f-2\sin^2\theta_f Q_{\rm em})\left[T_{3L}^f-2Q_{\rm em}-\frac{2}{3\sin^2\beta}\delta_{fq}\right]+(T_{3L}^f)^2\right] . \tag{14c}$$

Here $N_c^f=1$ or $3(1+\alpha_s/\pi)\simeq3(1+0.04)$ for $f=$lepton (l) or quark (q), $\delta_{fq}=0$ for $f=l$ and $=1$ for $f=q$. $\sin^2\theta_f$ has been defined in Ref. 4 and is essentially $\sin^2\theta_W$ with radiative corrections included while $\rho_f=1/(1-\Delta\rho_T)$, $\Delta\rho_T\simeq3G_Fm_t^2/8\sqrt{2}\pi^2$.

For the evaluation of A_f and B_f, we use the bound[4]

$$\Delta\rho_M<0.020-0.002(m_t/80\ \text{GeV})^2 \tag{15}$$

obtained from the ratio M_W/M_Z as obtained from the Collider Detector at Fermilab[9] (CDF) and UA2 (Ref. 10) Collaborations data and $M_Z=91.10\pm0.06$ GeV determined by combining the SLC (Ref. 11) and LEP 1 (Ref. 12) results. Thus we shall use[4]

$$\begin{aligned}&m_t=100\ \text{GeV},\ 200\ \text{GeV}\ ,\\&\sin^2\theta_f=0.234,\ 0.230\ ,\\&\Delta\rho_M=1.69\times10^{-2},\ 7.5\times10^{-3}\ ,\\&\Delta\rho_f=3.14\times10^{-3},\ 1.26\times10^{-2}\ .\end{aligned} \tag{16}$$

Equation (7) gives

$$M_{Z'}^2\simeq M_Z^2[1+(\Delta\rho_M)^{-1}\sin^2\theta_f\tan^2\beta]\ , \tag{17a}$$

so that Eqs. (16) give the following lower bounds on $M_{Z'}$ for $m_t=100$ and 200 GeV, respectively:

$$M_{Z'}^2\geq M_Z^2(1+13.85\tan^2\beta)\ , \tag{17b}$$

$$M_{Z'}^2\geq M_Z^2(1+30.67\tan^2\beta)\ . \tag{17c}$$

The results of A_f, B_f, $\delta\Gamma_l$ (which are independent of $\sin^2\beta$), and

$$\Gamma_f^0=\frac{G_FM_Z^3}{24\sqrt{2}\pi}C_f^0\ , \tag{18a}$$

with

$$C_f^0=4N_c^f\rho_f[(T_{3L}-2\sin^2\theta_fQ_{\rm em})^2+(T_{3L}^f)^2]\ , \tag{18b}$$

are summarized in Table I. From Table I, we have for $m_t=100$ and 200 GeV, respectively,

$$\frac{\delta\Gamma_h}{\Gamma_h^0}=\frac{2\delta\Gamma_u+3\delta\Gamma_d}{2\Gamma_u^0+3\Gamma_d^0}=\begin{cases}(2.97-0.88/\sin^2\beta)\times10^{-2}\ , & (19a)\\(1.32-0.39/\sin^2\beta)\times10^{-2}\ . & (19b)\end{cases}$$

TABLE IV. The deviations of total width.

	$m_t=100$ GeV			$m_t=200$ GeV		
$\sin^2\beta$	$\frac{1}{3}$	$\frac{5}{12}$	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{5}{12}$	$\frac{1}{2}$
$\delta\Gamma_T$ (MeV) $\Delta=0$	-4.62	4.84	10.7	-1.69	2.55	6.88
$\delta\Gamma_T$ (MeV) $\Delta=0.1$	12.0	21.4	27.3	15.0	19.3	23.6
$\delta\Gamma_T$ (MeV) $\Delta=0.2$	28.6	38.0	60.5	31.7	52.7	57.0

TABLE V. The values of $\mathcal{A}_f$ in the standard model and the coefficients α_f and β_f.

	$m_t=100$ GeV	$m_t=200$ GeV
$\mathcal{A}_l$	-0.127	-0.159
$\mathcal{A}_c$	-0.659	-0.673
$\mathcal{A}_b$	-0.934	-0.935
α_l	-2.66	-2.57
α_c	-1.18	-1.13
α_d	-0.22	-0.21
β_l	-6.05	-6.04
β_c	$-\left[2.69+\frac{1.75}{\sin^2\beta}\right]$	$-\left[2.64+\frac{1.72}{\sin^2\beta}\right]$
β_d	$-\left[0.50-\frac{0.65}{\sin^2\beta}\right]$	$-\left[0.49-\frac{0.63}{\sin^2\beta}\right]$

For some typical values of $\sin^2\beta$, the results for lower limits of $M_{Z'}$ and $\delta\Gamma_h$ are summarized in Table II.

Very small and negative deviations (-0.2 to -0.6 MeV) for the leptonic width and positive and relatively large (3 to 21 MeV) deviations for the hadronic width are the distinguishing features of the model. This is brought out by comparison with extra U(1) models (arising from E_6), for which we consider two representative cases which correspond in the notation of Ref. 4 to $\theta_2=0$ (which occurs in many superstring models and is called the η model in the literature) an $\theta_2=-90$. For these cases the deviation of widths for $\xi_0=\pm 0.04$ and $\xi_0=\pm 0.02$ and $m_t=100$ GeV (as calculated from the relevant formulas of Ref. 4) are summarized in Table III. In the same table we also give the corresponding values for the left-right (LR) models for $\xi_0=\pm 0.02$ and $m_t=100$ GeV.

As far as the total width Γ_T is concerned, it depends on what one should use for N_ν, the number of light-neutrino generations. Defining an "effective" value of N_ν as $N_\nu=3+\Delta$, we have

$$\delta\Gamma_T=3\delta\Gamma_\nu+3\delta\Gamma_e+2\delta\Gamma_u+3\delta\Gamma_d+\Delta\Gamma_\nu^0\ , \tag{20}$$

so that we have from Table I and Eqs. (19) for $m_t=100$ and 200 GeV, respectively,

$$\delta\Gamma_T=\tfrac{1}{2}\Gamma_\nu^0\left[1.69\times10^{-2}\left[29.66-\frac{10.92}{\sin^2\beta}\right]+2\Delta\right]\ , \tag{21a}$$

$$\delta\Gamma_T=\tfrac{1}{2}\Gamma_\nu^0\left[0.75\times10^{-2}\left[30.16-\frac{10.87}{\sin^2\beta}\right]+2\Delta\right]\ . \tag{21b}$$

Present data[12] are consistent with $\Delta\le 0.23$. The results for various values of $\sin^2\beta$ and Δ are summarized in Table IV.

The deviations from the lepton polarization and the forward-backward asymmetries of the standard model are given by[4]

$$\delta A_{\text{pol}}=-\delta\mathcal{A}_l=-\Delta\rho_M(\alpha_f-\beta_f)\ , \tag{22}$$

$$\delta A_{FB}^f=\tfrac{3}{4}\Delta\rho_M[\mathcal{A}_e(\alpha_f-\beta_f)+\mathcal{A}_f(\alpha_e-\beta_e)] +\tfrac{3}{4}(\Delta\rho_M)^2(\alpha_f-\beta_f)(\alpha_e-\beta_e)\ , \tag{23a}$$

where

$$\alpha_f=K_f\frac{2\sin^2\theta_f\cos^2\theta_f}{\cos2\theta_f}T_{3L}^fQ_{\text{em}}\ , \tag{23b}$$

$$\beta_f=K_f\left[T_{3L}^f(T_{3L}^f-2\sin^2\theta_fQ_{\text{em}}) -T_{3L}^f\left[T_{3L}^f-2Q_{\text{em}}-\frac{2}{3\sin^2\beta}\delta_{fh}\right]\right]\ , \tag{23c}$$

$$K_f=-2\frac{(T_{3L}^f)^2-(T_{3L}^f-2\sin^2\theta_fQ_{\text{em}})^2}{[(T_{3L}^f)^2+(T_{3L}^f-2\sin^2\theta_fQ_{\text{em}})^2]^2}\ . \tag{23d}$$

The values of $\mathcal{A}_f$ and α_f as calculated in Ref. 4 as well as those of β_f are given in Table V. Using Table V and Eqs. (22) and (23), the lepton polarization and forward-backward asymmetries deviations for $m_t=100$ and 200 GeV are, respectively, given by

$$\delta A_{\text{pol}}=\begin{cases}-0.057\ ,\\ -0.026\ ,\end{cases} \tag{24}$$

$$\delta A_{FB}^l=\tfrac{3}{4}(\Delta\rho_M)(\alpha_l-\beta_l)[2\mathcal{A}_l+(\Delta\rho_M)(\alpha_l-\beta_l)] =\begin{cases}-8.45\times10^{-3}\ ,\\ -5.70\times10^{-3}\ ,\end{cases} \tag{25}$$

$$\delta A_{FB}^c=\begin{cases}-\left[3.077+\frac{0.283}{\sin^2\beta}\right]10^{-2}\ ,\\ -\left[1.450+\frac{0.154}{\sin^2\beta}\right]10^{-2}\ ,\end{cases} \tag{26}$$

$$\delta A_{FB}^\alpha=\begin{cases}-\left[4.062-\frac{0.104}{\sin^2\beta}\right]10^{-2}\ ,\\ -\left[1.85-\frac{0.056}{\sin^2\beta}\right]10^{-2}\ .\end{cases} \tag{27}$$

The values of δA_{FB}^c and δA_{FB}^α for various values of $\sin^2\beta$

TABLE VI. The values δA_{FB}^c and δA_{FB}^d for various values of $\sin^2\beta$.

	$m_t=100$ GeV			$m_t=200$ GeV		
$\sin^2\beta$	$\frac{1}{3}$	$\frac{5}{12}$	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{5}{12}$	$\frac{1}{2}$
δA_{FB}^c	-3.93×10^{-2}	-3.76×10^{-2}	-3.64×10^{-2}	-1.91×10^{-2}	-1.82×10^{-2}	-1.76×10^{-2}
δA_{FB}^d	-3.75×10^{-2}	-3.81×10^{-2}	-3.85×10^{-2}	-1.68×10^{-2}	-1.72×10^{-2}	-1.74×10^{-2}

TABLE VII. The deviations for forward-backward asymmetries for U(1) (arising from E_6) models.

	$\theta_2=0$		$\theta_2=-90$	
ξ_0	0.02	-0.02	0.02	-0.02
δA_{FB}^{l}	1.54×10^{-2}	5.4×10^{-3}	4.6×10^{-3}	1.65×10^{-2}
δA_{FB}^{c}	4.43×10^{-2}	2.03×10^{-2}	1.71×10^{-2}	4.75×10^{-2}
δA_{FB}^{d}	6.02×10^{-2}	2.46×10^{-2}	2.22×10^{-2}	6.26×10^{-2}

are summarized in Table VI. These are not sensitive to $\sin^2\beta$. Again the predictions of Eqs. (26) and (25) and Table VI for deviations for polarization and forward-backward asymmetries are quite different from the corresponding values summarized in Table VII for $\xi_0=\pm0.02$ and $m_t=100$ GeV for U(1) models exemplified by $\theta_2=0$ and $\theta_2=-90$.

In conclusion, the effects of mixing between Z and Z' bosons on various properties of Z can distinguish the model considered here from the other extended gauge models which also have an extra Z'. Further precision measurements of such effects would make such a distinction possible.

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[1]J. L. Hewett, Phys. Lett. B **238**, 98 (1990).

[2]M. C. Gonzalez-Garcia and J. W. F. Valle, Phys. Rev. D **41**, 2355 (1990).

[3]S. L. Glashow and Uri Sarid, Phys. Rev. Lett. **64**, 725 (1990).

[4]G. Altarelli, R. Casalbuoni, D. Dominici, F. Feruglio, and R. Gatto, Nucl. Phys. **B342**, 15 (1990).

[5]M. Peskin, SLAC Report No. SLAC-PUB-5210, 1990 (unpublished).

[6]E. Witten, Nucl. Phys. **B258**, 75 (1985); M. Dine, V. Kaplunovksy, M. Mangano, C. Nappi, and N. Seiberg, *ibid.* **B259**, 419 (1985); S. Cecotti, J. P. Derendinger, S. Ferrara, L. Girardello, and M. Roncadelli, Phys. Lett. **156B**, 318 (1985); J. D. Breit, B. A. Ovrut, and G. Segré, *ibid.* **158B**, 33 (1985); E. Cohen, J. Ellis, K. Enqvist, and D. V. Nanopoulos, *ibid.* **165B**, 76 (1985); J. Ellis, K. Enqvist, D. V. Nanopoulos, and F. Zwirner, Nucl. Phys. **B276**, 14 (1986), Mod. Phys. Lett. A **1**, 57 (1986); F. Del Aguila, G. Blair, M. Daniel, and G. G. Ross, Nucl. Phys. **B272** (1986); L. Ibanez and J. Mas, *ibid.* **B286**, 107 (1987). For a review of phenomenological implications of low-energy superstring-inspired E_6 models, see F. Zwirner, Int. J. Mod. Phys. A **3**, 49 (1988); J. L. Hewett and T. G. Rizzo, Phys. Rep. **183**, 195 (1989).

[7]J. C. Pati and A. Salam, Phys. Rev. D **10**, 275 (1974); R. N. Mohapatra and J. C. Pati, *ibid.* **11**, 566 (1975); **11**, 2559 (1975); J. Senjanovic and R. N. Mohapatra, *ibid.* **12**, 152 (1975); G. Senjanovic, Nucl. Phys. **B153**, 334 (1979).

[8]Riazuddin, Phys. Rev. D **33**, 2703 (1986).

[9]L. Nodulman, in *Proceedings of the International Europhysics Conference on High Energy Physics,* Madrid, Spain, 1989, edited by F. Barreiro and C. Lopez (North-Holland, Amsterdam, 1990).

[10]Mark II Collaboration, G. S. Abrams *et al.*, Phys. Rev. Lett. **63**, 724 (1989).

[11]ALEPH Collaboration, D. Decamp *et al.*, Phys. Lett. B **231**, 519 (1989); **234**, 399 (1989); **235**, 399 (1990); DELPHI Collaboration, P. Aarnio *et al.*, *ibid.* **231**, 539 (1989); L3 Collaboration, B. Adeva *et al.*, *ibid.* **231**, 509 (1989); **238**, 122 (1990); OPAL Collaboration, M. Z. Akrawy *et al.*, *ibid.* **231**, 530 (1989); **235**, 379 (1990).

[12]See Ref. 1; L3 Collaboration, B. Adeva *et al.*, Phys. Lett. B **234**, 122 (1990); ALEPH Collaboration, D. Decamp *et al.*, *ibid.* **235**, 399 (1990).