

# Realistic constraints on the doubly charged bilepton couplings from Bhabha scattering with CERN LEP data

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Upper limits on doubly charged bilepton couplings and masses are extracted from CERN LEP data for Bhabha scattering in the energy range  $\sqrt{s}=183\text{--}202$  GeV using the standard model program ZFITTER, which calculates radiative corrections. We find that  $g_L^2/M_L^2 < O(10^{-5})$  GeV $^{-2}$  at 95% C.L. for scalar and vector bileptons.

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## I. INTRODUCTION

The success of the standard model of strong and electroweak interactions has been verified experimentally with a high accuracy at present collider energies. Based on the common opinion that the standard model is not the final theory of the elementary particle world, many extensions of the standard model have been studied extensively to look for new physics beyond it at higher energies.

New physics has been searched via several exotic particles, such as leptoquarks, bileptons, diquarks, and many more, which are not covered by the standard model. In this work we study bileptons which are defined as bosons carrying lepton number  $L=2$  or 0. Therefore they couple to two standard model leptons but not to quarks. Bileptons appear in models where the  $SU(2)_L$  gauge group is extended to  $SU(3)$  [1]. Bileptons are also obtained in models with extended Higgs sectors that contain doubly charged Higgs bosons [2]. Grand unified theories, technicolor, and composite models predict the existence of bileptons as well as other exotic particles [3]. Classification and interactions of bileptons are provided by several works [4] and a comprehensive review has been presented in [5], including low and high energy bounds on their couplings. Indirect constraints on the masses and couplings of doubly charged bileptons have been obtained from lepton number violating processes and muonium-antimuonium conversion experiments [6–9].

A recent search for a doubly charged bilepton (as Higgs boson) has been performed by the DELPHI Collaboration at the CERN  $e^+e^-$  collider LEP2 [10].

At LEP fermion pair production is the unique reaction to test the standard model at the loop correction level [11]. Therefore one needs precision calculations, including QED and weak corrections for reliable comparison with experiments. ZFITTER is one of the standard model programs developed to compute scattering cross sections and asymmetries for fermion pair production in an  $e^+e^-$  collision with QED and electroweak corrections [12]. Using cross section calculations with ZFITTER realistic limits for new physics can be

obtained from LEP data. Since QED corrections are model independent (well defined if couplings, mass, and width of new particles are fixed), the usual convolution formulas can be applied for the total cross section

$$\sigma(s) = \int dv \sigma^0(s') R(v) \quad (1)$$

with  $v=1-s'/s$  and the flux factor  $R(v)$  (radiator) is not influenced by new particles such as bileptons. The above equation can be straightforwardly generalized to different asymmetries  $A_{FB}$ ,  $A_{pol}$ ,  $A_{LR}$  or to the scattering angle distribution  $d\sigma/\cos\theta$  with different effective Born terms and radiators. The final state acollinearity cut and minimum energy can also be applied. The contribution of doubly charged bileptons to Bhabha scattering is the subject of the present paper,

$$e^+e^- \rightarrow (\gamma, Z, L^{--}) \rightarrow e^+e^-(\gamma), \quad (2)$$

where  $L^{--}$  is a doubly charged bilepton. With the influence of bileptons the cross section covers standard model terms with electroweak and QED corrections arising from  $\gamma$ ,  $Z$  exchanges and their interferences; virtual bilepton exchanges with QED corrections as explained above; interference terms of bileptons with  $\gamma$ ,  $Z$ .

For complete radiative corrections to Bhabha scattering ZFITTER has limitation especially for higher acollinearity angles. But for small acollinearity angles the results are reasonable for our purpose.

## II. INTERACTION LAGRANGIAN AND BHABHA SCATTERING

The general effective Lagrangian describing interactions of bileptons with the standard model leptons is generated by requiring  $SU(2)_L \times U(1)_Y$  invariance. We consider lepton flavor conserving part of the Lagrangian and  $L=2$  bileptons as follows:

$$\begin{aligned} \mathcal{L}_{L=2} = & g_1 \bar{\ell}^c i \sigma_2 \ell L_1 + \tilde{g}_1 \bar{e}_R^c e_R \tilde{L}_1 + g_2 \bar{\ell}^c i \sigma_2 \gamma_\mu e_R L_2^\mu \\ & + g_3 \bar{\ell}^c i \sigma_2 \vec{\sigma} \cdot \vec{L}_3 + \text{H.c.} \end{aligned} \quad (3)$$

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In the notation  $\ell$  is the left-handed  $SU(2)_L$  lepton doublet and  $e_R$  is the right-handed charged singlet lepton. Charge conjugate fields are defined as  $\psi^c = C\bar{\psi}^T$  and  $\sigma_1, \sigma_2, \sigma_3$  are the Pauli matrices. The subscript of bilepton fields  $L_{1,2,3}$  and couplings  $g_{1,2,3}$  denote  $SU(2)_L$  singlets, doublets, and triplets.

Here we are interested only in doubly charged bileptons. In order to express the Lagrangian in terms of individual electrons, bileptons, and helicity projection operators  $P_{R/L} = \frac{1}{2}(1 \pm \gamma_5)$  we expand the Pauli matrices and lepton doublets and write the Lagrangian as

$$\mathcal{L}_{L=2} = \tilde{g}_1 \tilde{L}_1^{++} \bar{e}^c P_R e + g_2 L_{2\mu}^{++} \bar{e}^c \gamma^\mu P_L e - \sqrt{2} g_3 L_3^{++} \bar{e}^c P_L e + \text{H.c.}, \quad (4)$$

where superscripts of bileptons stand for their electric charges.

Doubly charged bileptons contribute Bhabha scattering through their  $u$ -channel exchange. For the scalar  $L_3^{--}$  exchange, the polarized differential cross section in terms of Mandelstam invariants  $s, t$  and  $u$  is given by

$$\begin{aligned} \frac{d\sigma}{d\cos\theta} &= \frac{\pi\alpha^2}{2s} \left\{ (\lambda_1 + \lambda_2) \left[ 2 \left( \frac{u}{t} + \frac{u}{s} \right) \right. \right. \\ &\quad \left. \left. + 2C_L^2 \left( \frac{u}{t-M_Z^2} + \frac{u}{s-M_Z^2} \right) + \frac{g_L^2}{g_e^2} \frac{u}{u-M_L^2} \right]^2 \right. \\ &\quad \left. + (\lambda_1 - \lambda_2) \left[ 2 \left( \frac{u}{t} + \frac{u}{s} \right) + 2C_R^2 \left( \frac{u}{t-M_Z^2} + \frac{u}{s-M_Z^2} \right) \right]^2 \right. \\ &\quad \left. + 2\lambda_1 \left[ \frac{2t}{s} + C_L C_R \frac{2t}{s-M_Z^2} \right]^2 \right. \\ &\quad \left. + 2\lambda_3 \left[ \frac{2s}{t} + C_L C_R \frac{2s}{t-M_Z^2} \right]^2 \right\}, \quad (5) \end{aligned}$$

where the definition of Mandelstam variables, polarization factors, and  $C_L, C_R$  are as follows:

$$t = -\frac{s}{2}(1 - \cos\theta), \quad u = -\frac{s}{2}(1 + \cos\theta), \quad (6)$$

$$C_L = \frac{2 \sin^2 \theta_W - 1}{2 \sin \theta_W \cos \theta_W}, \quad C_R = \tan \theta_W, \quad (7)$$

$$\begin{aligned} \lambda_1 &= 1 - P_- P_+, \quad \lambda_2 = P_+ - P_-, \\ \lambda_3 &= 1 + P_- P_+. \end{aligned} \quad (8)$$

Bilepton coupling  $\sqrt{2}g_3$  in the Lagrangian has been replaced by  $g_L$  in the cross section and  $P_\pm$  is the polarization of positrons or electron beams. Electromagnetic coupling  $g_e$  is

defined by  $g_e^2 = 4\pi\alpha$ . Together with polarization factors the differential cross section is consistent with the one used in ZFITTER in the case of the standard model.

For the vector bilepton  $L_{2\mu}^{--}$  exchange with replacement  $g_2 \rightarrow g_L$  the differential cross section can be found as below

$$\begin{aligned} \frac{d\sigma}{d\cos\theta} &= \frac{\pi\alpha^2}{2s} \left\{ (\lambda_1 + \lambda_2) \left[ 2 \left( \frac{u}{t} + \frac{u}{s} \right) + 2C_L^2 \left( \frac{u}{t-M_Z^2} + \frac{u}{s-M_Z^2} \right) \right]^2 \right. \\ &\quad \left. + (\lambda_1 - \lambda_2) \left[ 2 \left( \frac{u}{t} + \frac{u}{s} \right) + 2C_R^2 \left( \frac{u}{t-M_Z^2} + \frac{u}{s-M_Z^2} \right) \right]^2 \right. \\ &\quad \left. + (\lambda_1 + \lambda_2) \left[ \frac{2t}{s} + C_L C_R \frac{2t}{s-M_Z^2} - \frac{g_L^2}{g_e^2} \frac{2t}{u-M_L^2} \right]^2 \right. \\ &\quad \left. + (\lambda_1 - \lambda_2) \left[ \frac{2t}{s} + C_L C_R \frac{2t}{s-M_Z^2} \right]^2 \right. \\ &\quad \left. + 2\lambda_3 \left[ \frac{2s}{t} + C_L C_R \frac{2s}{t-M_Z^2} \right]^2 \right\}. \quad (9) \end{aligned}$$

Investigation of new physics beyond the standard model can be divided into three regions according to the new physics energy scale  $\Lambda$ :  $\sqrt{s} \ll \Lambda$  leads to an effective Lagrangian, four fermion contact interactions;  $\sqrt{s} \gg \Lambda$  new physics, new particles;  $\sqrt{s} \sim \Lambda$  strongly depends on the model. At LEP energies we assume that bilepton masses are larger than  $\sqrt{s}$  and  $u \ll M_L^2 \sim \Lambda^2$ . Then we take into account the approximation in the bilepton propagator:

$$\frac{g_L^2}{u - M_L^2} \simeq \frac{g_L^2}{M_L^2} \quad (10)$$

which reduces the number of parameters.

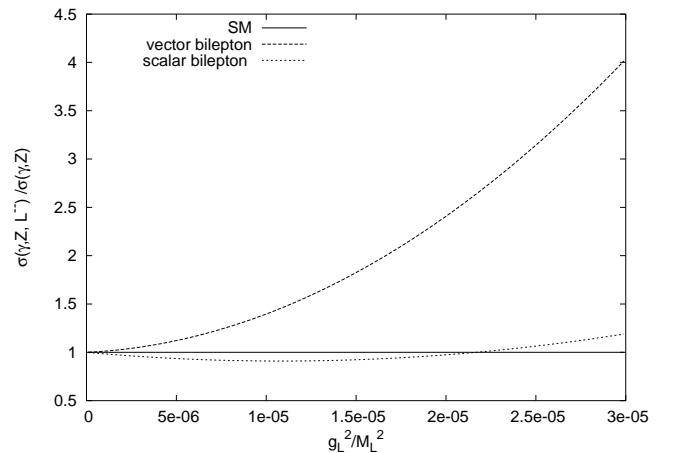


FIG. 1. Ratios of cross sections  $\sigma(\gamma, Z, L^{--})/\sigma(\gamma, Z)$  from ZFITTER with and without the bilepton exchange.

TABLE I. Measured cross sections with the OPAL detector at LEP for two different angular regions with  $\theta_{acol} < 10^\circ$ . The first error shown is statistical, the second systematic. The standard model cross sections are predicted by ZFITTER 6.36.

$\sqrt{s}$ (GeV)	$\sigma$ (pb) $ \cos \theta  < 0.7$	$\sigma^{SM}$ (pb) $ \cos \theta  < 0.7$	$\sigma$ (pb) $ \cos \theta  < 0.96$	$\sigma^{SM}$ (pb) $ \cos \theta  < 0.96$
183	$21.7 \pm 0.6 \pm 0.2$	20.9	$333.0 \pm 3.0 \pm 4.0$	320.7
189	$20.08 \pm 0.33 \pm 0.10$	19.55	$304.6 \pm 1.3 \pm 1.4$	300.7
192	$19.6 \pm 0.8 \pm 0.1$	18.9	$301.4 \pm 3.3 \pm 1.5$	291.4
196	$18.6 \pm 0.5 \pm 0.1$	18.1	$285.8 \pm 2.0 \pm 1.5$	279.6
200	$18.2 \pm 0.5 \pm 0.1$	17.4	$273.0 \pm 1.9 \pm 1.4$	268.5
202	$17.9 \pm 0.7 \pm 0.1$	17.0	$272.0 \pm 2.8 \pm 1.4$	263.3

### III. RESULTS AND DISCUSSION

Based on the previous considerations, bilepton parts of the cross section have been included into BHANG which runs together with ZFITTER 6.36.

Ratios of Bhabha scattering cross sections from ZFITTER with and without the bilepton exchange  $\sigma(\gamma, Z, L^{--})/\sigma(\gamma, Z)$  are shown in Fig. 1 as a function of  $g_L^2/M_L^2$  at  $\sqrt{s} = 192$  GeV for scalar and vector bileptons. The curve corresponding to the vector bilepton exchange deviates more rapidly from standard model curve than the case of a scalar one.

Measured cross sections with the OPAL detector at LEP have been used for our analysis [13]. In order to give an idea about the comparison Table I shows the experimental values of the total cross sections and the predicted standard model values from ZFITTER 6.36 at LEP2 energy region  $\sqrt{s} = 183\text{--}202$  GeV for two scattering angular regions. Since ZFITTER is not good for high acollinearity angles, in the case of Bhabha scattering we have chosen the measured cross sections only for  $\theta_{acol} < 10^\circ$ .

We have used a simple  $\chi^2$  criterion from a measured cross section to estimate an upper limit on  $g_L^2/M_L^2$ . For combined

results the following expression can be considered:

$$\chi^2 = \sum_i \left( \frac{\sigma_i^{exp} - \sigma_i^{new}}{\Delta_i^{exp}} \right)^2, \quad (11)$$

$$\Delta^{exp} = \sigma^{exp} \sqrt{\delta_{stat}^2 + \delta_{sys}^2}, \quad (12)$$

where  $i$  represents the energy index corresponding to energy values, cross sections, and experimental errors in Table I. Using the equation  $\chi^2 - \chi_{min}^2 = 2.7$  for a one parameter, one-sided analysis at 95% confidence level (C.L.), the upper limits on the  $g_L^2/M_L^2$  for scalar and vector bileptons are provided in Table II and Table III. From the tables, combined results for upper limits are  $3.5 \times 10^{-5}$ ,  $1.9 \times 10^{-4}$  in the case of scalar bileptons and  $9.8 \times 10^{-6}$ ,  $7.4 \times 10^{-5}$  for vector bileptons depending on angular regions.

Present limits for doubly charged bileptons are given below to compare with our results:  $g_{ee}g_{\mu\mu}/M^2 < 5.8 \times 10^{-5}$  at 90% C.L. (from the muonium-antimuonium conversion),  $g_{ee}^2/M^2 < 9.7 \times 10^{-6}$  at 95% C.L. (from Bhabha scattering) in

TABLE II. Upper limits on the  $g_L^2/M_L^2$  for doubly charged scalar bileptons at 95% C.L. A combination of results is also shown in the last row. Acollinearity cut  $\theta_{acol} < 10^\circ$  is considered and masses are in units of GeV.

$\sqrt{s}$ (GeV)	$\frac{g_L^2}{m_L^2}$ $ \cos \theta  < 0.7$	$\frac{g_L^2}{m_L^2}$ $ \cos \theta  < 0.96$
183	$< 5.5 \times 10^{-5}$	$< 4.1 \times 10^{-4}$
189	$< 4.2 \times 10^{-5}$	$< 2.5 \times 10^{-4}$
192	$< 5.5 \times 10^{-5}$	$< 3.2 \times 10^{-4}$
196	$< 4.5 \times 10^{-5}$	$< 2.6 \times 10^{-4}$
200	$< 4.3 \times 10^{-5}$	$< 2.4 \times 10^{-4}$
202	$< 4.8 \times 10^{-5}$	$< 2.7 \times 10^{-4}$
Combination	$< 3.5 \times 10^{-5}$	$< 1.9 \times 10^{-4}$

TABLE III. Upper limits on the  $g_L^2/M_L^2$  for doubly charged vector bileptons at 95% C.L. A combination of results is also shown in the last row. Acollinearity cut  $\theta_{acol} < 10^\circ$  is considered and masses are in units of GeV.

$\sqrt{s}$ (GeV)	$\frac{g_L^2}{m_L^2}$ $ \cos \theta  < 0.7$	$\frac{g_L^2}{m_L^2}$ $ \cos \theta  < 0.96$
183	$< 2.0 \times 10^{-5}$	$< 1.8 \times 10^{-4}$
189	$< 1.3 \times 10^{-5}$	$< 1.0 \times 10^{-4}$
192	$< 2.0 \times 10^{-5}$	$< 1.4 \times 10^{-4}$
196	$< 1.5 \times 10^{-5}$	$< 1.1 \times 10^{-4}$
200	$< 1.4 \times 10^{-5}$	$< 1.0 \times 10^{-4}$
202	$< 1.7 \times 10^{-5}$	$< 1.2 \times 10^{-4}$
Combination	$< 9.8 \times 10^{-6}$	$< 7.4 \times 10^{-5}$

Ref. [6];  $g_3/M < (2600)^{-1}$  from the muonium-antimuonium conversion at 95% C.L. in Ref. [9];  $g_3/M < (215)^{-1}$  at 90% C.L. in Ref. [7];  $g_3/M < (340)^{-1}$  at 95% C.L. in Ref. [14]. Here all masses are in GeV units.

In conclusion, it is probable that if complete radiative corrections to Bhabha scattering are realized by ZFITTER as well as the  $e^+e^- \rightarrow \mu^+\mu^-$  process, more stringent and realistic limits will be obtained for doubly charged bileptons.

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