

# Bilepton production in $e^- \gamma$ collisions

Dang Van Soa<sup>1,\*</sup>, Takeo Inami<sup>1</sup>, Hoang Ngoc Long<sup>2,\*\*</sup>

<sup>1</sup> Department of Physics, Chuo University, Kasuga 1-13-27, Bunkyo, Tokyo 112, Japan

<sup>2</sup> The Abdus Salam International Centre for Theoretical Physics, Trieste, Italy

Received: 5 August 2003 /

Published online: 23 March 2004 – © Springer-Verlag / Società Italiana di Fisica 2004

**Abstract.** We study the production of bileptons, new gauge bosons of lepton number two, in the minimal 3-3-1 model in high energy  $e^- \gamma$  collisions. If the bilepton masses are in the range of 300 GeV the reaction will give observable cross-sections in future colliders.

## 1 Introduction

All models of physics beyond the standard model (SM) predict the existence of new particles. One of the more exotic of these is the bilepton, a particle of lepton number 2. Bileptons occur in a few of the models of new physics. One of them is the gauge model based on the  $SU(3)_C \otimes SU(3)_L \otimes U(1)_N$  (3-3-1) gauge group [1–5]. These models contain a number of intriguing features: First, the models predict three families of quarks and leptons if the anomaly free condition on  $SU(3)_L \otimes U(1)_N$  and QCD asymptotic freedom are imposed. Second, the Peccei–Quinn symmetry naturally occurs in these models [6]. The third interesting point is that one generation of quarks is treated differently from two others [7]. This could lead to a natural explanation for the unbalancingly heavy top quark.

It has recently been argued that the 3-3-1 model arises naturally from gauge theories in spacetime with extra dimensions [8], where the scalar fields are the components in the extra space dimensions of a higher dimensional gauge field [9]. A few different versions of the 3-3-1 model have been proposed [10].

The production of doubly charged vector bileptons in high energy collisions has been widely discussed both in the generic model [11] and in the minimal model [12]. Recent investigations have indicated that signals of new gauge bosons in these models may be observed at the CERN LHC [13] or Next Linear Collider (NLC) [14]. The production of scalar leptoquarks [15] and constraints on the extra gauge bosons [16] in  $e\gamma$  collisions were studied. The potentiality of the projects of TESLA and CLIC based  $e\gamma$  colliders were discussed in [17].

In [18] the trilinear gauge boson couplings were presented and production of bileptons in  $e^+e^-$  collisions was

calculated. In this paper we turn our attention to a future perspective experiment, namely the  $e^- \gamma$  collision. This paper is organized as follows. In Sect. 2 we summarize the basic elements of the minimal 3-3-1 model. Section 3 is devoted to single bilepton production in  $\gamma e^-$  collisions. Finally, the conclusions are presented in Sect. 4.

## 2 A review of the minimal 3-3-1 model

To frame the context, it is appropriate to recall briefly some relevant features of the minimal 3-3-1 model [1, 2]. The model treats the leptons as  $SU(3)_L$  antitriplets [2, 5]

$$f_{aL} = \begin{pmatrix} e_{aL} \\ -\nu_{aL} \\ (e^c)_{aL} \end{pmatrix} \sim (1, \bar{3}, 0), \quad (1)$$

where  $a = 1, 2, 3$  is the family index.

Two of the three quark generations transform as triplets of the  $SU(3)_L$  and the third is treated differently. It belongs to an antitriplet. We have

$$Q_{iL} = \begin{pmatrix} u_{iL} \\ d_{iL} \\ D_{iL} \end{pmatrix} \sim \left(3, 3, -\frac{1}{3}\right), \quad (2)$$

$$u_{iR} \sim (3, 1, 2/3), \quad d_{iR} \sim (3, 1, -1/3), \\ D_{iR} \sim (3, 1, -1/3), \quad i = 1, 2,$$

$$Q_{3L} = \begin{pmatrix} d_{3L} \\ -u_{3L} \\ T_L \end{pmatrix} \sim (3, \bar{3}, 2/3), \quad (3)$$

$$u_{3R} \sim (3, 1, 2/3), \quad d_{3R} \sim (3, 1, -1/3), \quad T_R \sim (3, 1, 2/3).$$

The nine gauge bosons  $W^a$  ( $a = 1, 2, \dots, 8$ ) and  $B$  of  $SU(3)_L$  and  $U(1)_N$  are split into four light gauge bosons

\* On leave of absence from Department of Physics, Hanoi University of Education, Hanoi, Vietnam

\*\* On leave of absence from Institute of Physics, NCST, P.O. Box 429, Bo Ho, Hanoi 10000, Vietnam

and five heavy gauge bosons after  $SU(3)_L \otimes U(1)_N$  is broken to  $U(1)_Q$ . The light gauge bosons are those of the standard model,  $A, Z_1$  and  $W^\pm$ . The new heavy gauge bosons are  $Z_2, Y^\pm$  and the doubly charged bileptons  $X^{\pm\pm}$ . They are expressed in terms of  $W^a$  and  $B$  as [5]

$$\begin{aligned} \sqrt{2} W_\mu^+ &= W_\mu^1 - iW_\mu^2, & \sqrt{2} Y_\mu^+ &= W_\mu^6 - iW_\mu^7, \\ \sqrt{2} X_\mu^{++} &= W_\mu^4 - iW_\mu^5, \end{aligned} \quad (4)$$

$$\begin{aligned} A_\mu &= s_W W_\mu^3 + c_W \left( \sqrt{3} t_W W_\mu^8 + \sqrt{1 - 3 t_W^2} B_\mu \right), \\ Z_\mu &= c_W W_\mu^3 - s_W \left( \sqrt{3} t_W W_\mu^8 + \sqrt{1 - 3 t_W^2} B_\mu \right), \\ Z'_\mu &= -\sqrt{1 - 3 t_W^2} W_\mu^8 + \sqrt{3} t_W B_\mu, \end{aligned} \quad (5)$$

where we use the notation  $c_W \equiv \cos \theta_W$ ,  $s_W \equiv \sin \theta_W$  and  $t_W \equiv \tan \theta_W$ . The *physical* states are mixtures of  $Z$  and  $Z'$ :

$$\begin{aligned} Z_1 &= Z \cos \phi - Z' \sin \phi, \\ Z_2 &= Z \sin \phi + Z' \cos \phi, \end{aligned}$$

where  $\phi$  is a mixing angle.

The desirable symmetry breaking  $SU(3)_L \otimes U(1)_N \rightarrow U(1)_Q$  and fermion mass generation can be achieved by introducing three  $SU(3)_L$  scalar triplets  $\Phi, \Delta, \Delta'$  and a sextet  $\eta$  [5]

$$\begin{aligned} &SU(3)_{C \otimes} \otimes SU(3)_L \otimes U(1)_N \\ &\quad \langle \Phi \rangle \\ &SU(3)_{C \otimes} \otimes SU(2)_L \otimes U(1)_Y \\ &\quad \langle \Delta \rangle, \langle \Delta' \rangle, \langle \eta \rangle \\ &SU(3)_{C \otimes} \otimes U(1)_Q, \end{aligned}$$

where the scalar multiplets are expressed as

$$\begin{aligned} \Phi &= \begin{pmatrix} \phi^{++} \\ \phi^+ \\ \phi^0 \end{pmatrix} \sim (1, 3, 1), \\ \Delta &= \begin{pmatrix} \Delta_1^+ \\ \Delta^0 \\ \Delta_2^- \end{pmatrix} \sim (1, 3, 0), \\ \Delta' &= \begin{pmatrix} \Delta'^0 \\ \Delta'^- \\ \Delta'^{- -} \end{pmatrix} \sim (1, 3, -1), \\ \eta &= \begin{pmatrix} \eta_1^{++} & \eta_1^+/\sqrt{2} & \eta^0/\sqrt{2} \\ \eta_1^+/\sqrt{2} & \eta^0 & \eta_2^-/\sqrt{2} \\ \eta^0/\sqrt{2} & \eta_2^-/\sqrt{2} & \eta_2^{- -} \end{pmatrix} \sim (1, 6, 0). \end{aligned}$$

The sextet  $\eta$  is necessary to give masses to the charged leptons [5]. The vacuum expectation value (VEV)  $\langle \Phi^T \rangle =$

$(0, 0, u/\sqrt{2})$  yields masses for the exotic quarks, the heavy gauge bosons  $Z_2$  and  $X^{\pm\pm}, Y^\pm$ . The masses of the standard gauge bosons and the ordinary fermions are related to the VEVs of the other scalar fields,  $\langle \Delta^0 \rangle = v/\sqrt{2}, \langle \Delta'^0 \rangle = v'/\sqrt{2}$  and  $\langle \eta^0 \rangle = \omega/\sqrt{2}, \langle \eta'^0 \rangle = 0$ . In order to be consistent with the low energy phenomenology the mass scale of  $SU(3)_L \otimes U(1)_N$  breaking has to be much larger than the electro-weak scale, i.e.,  $u \gg v, v', \omega$ . The masses of the gauge bosons are explicitly

$$\begin{aligned} m_W^2 &= \frac{1}{4} g^2 (v^2 + v'^2 + \omega^2), & M_Y^2 &= \frac{1}{4} g^2 (u^2 + v^2 + \omega^2), \\ M_X^2 &= \frac{1}{4} g^2 (u^2 + v'^2 + 4\omega^2), \end{aligned} \quad (6)$$

and

$$\begin{aligned} m_Z^2 &= \frac{g^2}{4c_W^2} (v^2 + v'^2 + \omega^2) = \frac{m_W^2}{c_W^2}, \\ M_{Z'}^2 &= \frac{g^2}{3} \left[ \frac{c_W^2}{1 - 4s_W^2} u^2 + \frac{1 - 4s_W^2}{4c_W^2} (v^2 + v'^2 + \omega^2) \right. \\ &\quad \left. + \frac{3s_W^2}{1 - 4s_W^2} v'^2 \right]. \end{aligned} \quad (7)$$

Expressions in (6) yields the splitting between the bileptons masses [7]:

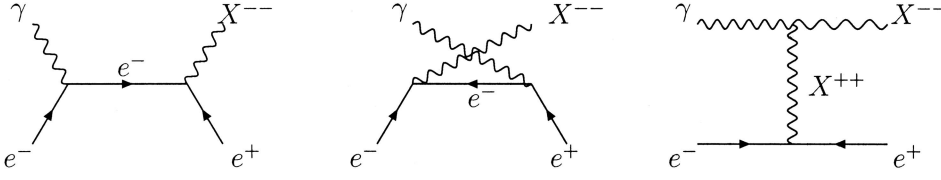
$$|M_X^2 - M_Y^2| \leq 3 m_W^2. \quad (8)$$

By matching the gauge coupling constants we get a relation between  $g$  and  $g_N$  – the coupling constants associated with  $SU(3)_L$  and  $U(1)_N$ , respectively:

$$\frac{g_N^2}{g^2} = \frac{6 s_W^2 (M_{Z_2})}{1 - 4s_W^2 (M_{Z_2})}, \quad (9)$$

where  $e = g s_W$  is the same as in the SM.

We now discuss the previous empirical estimates of the new gauge boson masses. Combining constraints from direct searches and neutral currents, one obtains a bound for the mixing angle  $\phi$  [5] and a lower bound on the mass of  $M_{Z_2}$ :  $-1.6 \times 10^{-2} \leq \phi \leq 7 \times 10^{-4}$  and  $M_{Z_2} \geq 1.3$  TeV, respectively. Such a small mixing angle can safely be neglected. Adding the constraints from “wrong” muon decay experiments one obtains a bound for the mass of  $Y^+$ :  $M_{Y^+} \geq 230$  GeV. By computing the oblique parameters  $S$  and  $T$ , a lower bound of 370 GeV for  $Y^+$  is derived [20]. Combining this with the mass splitting given in (8) one obtains a lower bound around 340 GeV for the mass of  $X^{++}$ . With the new atomic parity violation in cesium, one gets a lower bound for the  $Z_2$  mass [21]:  $M_{Z_2} > 1.2$  TeV. From the symmetry breaking it follows that the masses of the new charged gauge bosons  $Y^\pm, X^{\pm\pm}$  are less than half of  $M_{Z_2}$ , and the allowed decay  $Z_2 \rightarrow X^{++} X^{--}$  with  $X^{\pm\pm} \rightarrow 2l^\pm$  provides a unique signature in future colliders. Considering these results it is not inconceivable that the 3-3-1 models manifest themselves already at the scale of  $\mathcal{O}(1)$  TeV.



**Fig. 1.** Feynman diagrams for  $e^- \gamma \rightarrow X^{--} e^+$

### 3 Single bilepton production in $e^- \gamma$ collisions

In this paper we are interested in the production of new gauge bosons which exist in the 3-3-1 model in future high energy colliders. We focus on the single bilepton production in the electron-photon collision:

$$\gamma(p_1, \lambda) + e^-(p_2, \lambda') \rightarrow X^{--}(k_2, \tau) + e^+(k_1, \tau'), \quad (10)$$

$$\gamma(p_1, \lambda) + e^-(p_2, \lambda') \rightarrow Y^-(k_2, \tau) + \tilde{\nu}_e(k_1, \tau'). \quad (11)$$

Here  $p_i, k_i$  stand for the momenta and  $\lambda, \lambda', \tau, \tau'$  for the helicities of the particles, respectively.

#### 3.1 Production of doubly charged bilepton

First, we consider the production of the doubly charged bilepton (10). The amplitude for this process can be written as

$$M^{X^{--}} = \frac{ieg}{\sqrt{2}} \epsilon_\mu^*(k_2) \epsilon_\nu(p_1) \bar{v}(k_1) A^{\mu\nu} u(p_2), \quad (12)$$

where  $\epsilon_\nu(p_1), \epsilon_\mu^*(k_2)$  are the polarization vectors of the photon  $\gamma$  and the  $X^{--}$  boson, respectively. At the tree level, there are three Feynman diagrams contributing to the reaction (10), representing the  $s, u, t$ -channel exchange depicted in Fig. 1.

The  $A^{\mu\nu}$  for the three diagrams are given by

$$A_s^{\mu\nu} = \gamma^\mu \gamma^5 \frac{\not{q}_s}{q_s^2} \gamma^\nu, \quad (13)$$

$$A_u^{\mu\nu} = \gamma^\mu \frac{\not{q}_u}{q_u^2} \gamma^\nu \gamma^5, \quad (14)$$

$$A_t^{\mu\nu} = \frac{2}{(q_t^2 - m_X^2)} \gamma_\alpha \gamma^5 \times [(k_2 - q_t)^\nu g^{\mu\alpha} + (q_t + p_1)^\mu g^{\alpha\nu} - (p_1 + k_2)^\alpha g^{\nu\mu}]. \quad (15)$$

Here,  $q_s = p_1 + p_2 = k_1 + k_2$ ,  $q_u = p_1 - k_1 = k_2 - p_2$ ,  $q_t = p_1 - k_2 = k_1 - p_2$ , and  $s = (p_1 + p_2)^2$  is the square of the collision energy. We work in the center-of-mass frame and denote the scattering angle (the angle between momenta of the initial electron and the final positron) by  $\theta$ .

We have evaluated the  $\theta$  dependence of the differential cross-section  $d\sigma/d\cos\theta$  and the energy and the bilepton mass dependence of the total cross-section  $\sigma$ .

(i) We show in Fig. 3 the behavior of  $d\sigma/d\cos\theta$  at fixed energy. We have chosen a relatively low value of the bilepton mass,  $M_X = 350$  GeV. The differential cross-section in Fig. 3 is at  $\sqrt{s} = 1000$  GeV, but the behavior is similar

at other values of  $\sqrt{s}$ . Note that  $d\sigma/d\cos\theta$  is peaked in the backward and forward direction. This is due to the  $e^-$  pole term in the  $u$ -channel and the  $X^{++}$  pole term in the  $t$ -channel, respectively, in (14) and (15).

(ii) The energy dependence of the cross-sections is shown in Fig. 4. The same value of the bilepton mass as in (i),  $M_X = 350$  GeV, is chosen. The energy range is  $600 \text{ GeV} \leq \sqrt{s} \leq 2500 \text{ GeV}$ . The curve **a** is the total cross-section  $\sigma$ , the curves **b, c, and d** representing cross-sections of the  $s, t$ - and  $u$ -channels only, respectively. We see from the figure that the curve **a** goes through the minimum value, and then it increases smoothly with  $\sqrt{s}$ . At the minimum value, we get  $\sigma \simeq 18.3$  pb, which is large enough to measure the  $X^{++}$  production. At TESLA based  $e\gamma$  colliders, with  $\sqrt{s} = 911$  GeV [17] the measurable value of the cross-section is  $\sigma \geq 18.8$  pb. We emphasize that at high energies the  $s, t$ -channels give main contributions to the total cross-section. This is due to  $\sigma_s \sim \frac{1}{m^2}$ ,  $\sigma_t \sim \frac{1}{m^2} \times \text{Log}(s/m^2)$ , while  $\sigma_u \sim \frac{1}{s}$ .

(iii) The bilepton mass dependence of the cross-section for fixed energy, typically  $\sqrt{s} = 2000$  GeV, is shown in Fig. 5. The mass range is  $300 \text{ GeV} \leq M_X \leq 700 \text{ GeV}$ . The total cross-section decreases rapidly as  $M_X$  increases from 26 pb for  $M_X = 300$  GeV to 4 pb for  $M_X = 700$  GeV.

In [23] the signature of the doubly charged Higgs boson in  $e\gamma$  has been investigated, and this paper demonstrated that the  $H1$  observation at SUSY02 of a doubly charged object was inconsistent with LEP.

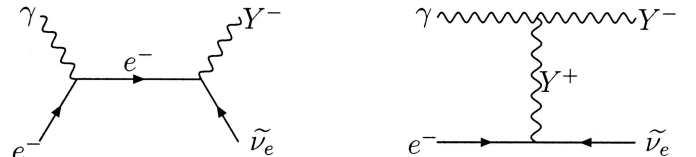
#### 3.2 Production of a singly charged bilepton

Next, we consider the production of a singly charged bilepton and antineutrino. There are two Feynman diagrams contributing to reaction (11), representing the  $s, t$ -channel exchange shown in Fig. 2.

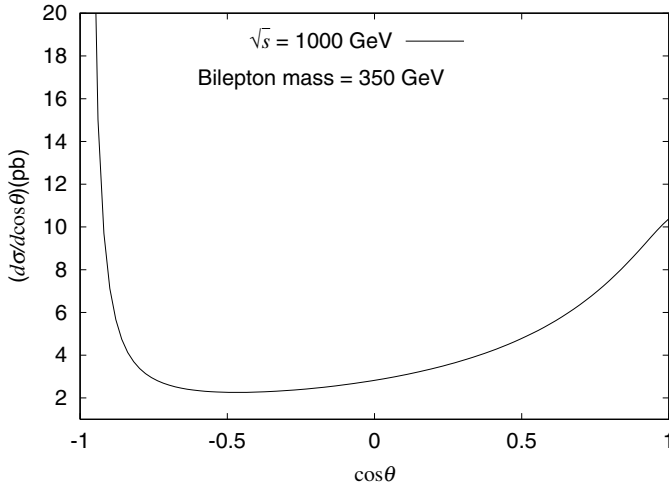
The corresponding amplitude  $A^{\mu\nu}$  is given by

$$A_s^{\mu\nu} = \gamma^\mu (1 - \gamma^5) \frac{\not{q}_s}{q_s^2} \gamma^\nu, \quad (16)$$

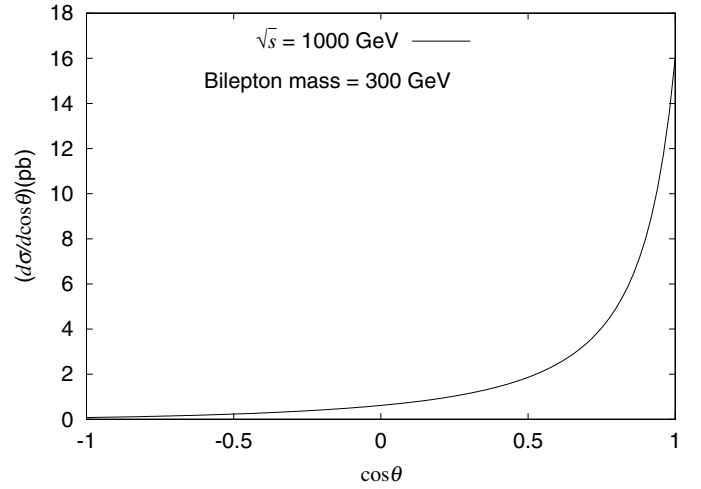
$$A_t^{\mu\nu} = \frac{1}{(q_t^2 - m_Y^2)} \gamma_\alpha (1 - \gamma^5) \times [(k_2 - q_t)^\nu g^{\mu\alpha} + (q_t + p_1)^\mu g^{\alpha\nu} - (p_1 + k_2)^\alpha g^{\nu\mu}]. \quad (17)$$



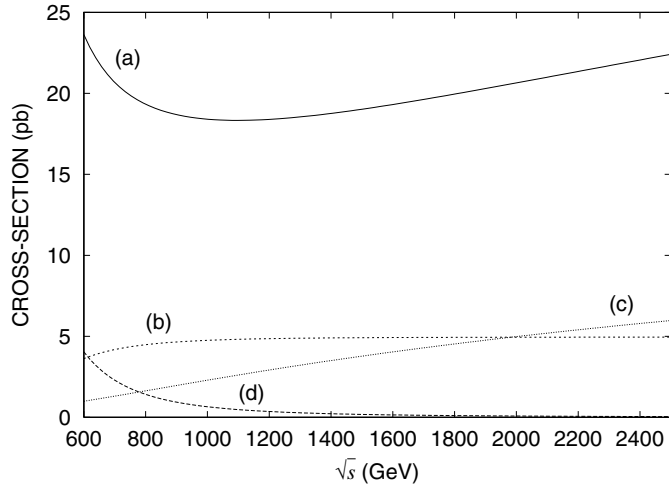
**Fig. 2.** Feynman diagram for  $e^- \gamma \rightarrow Y^- \tilde{\nu}_e$



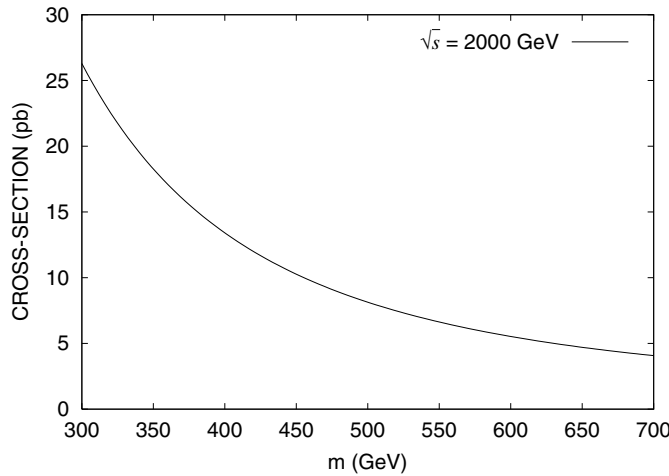
**Fig. 3.** Differential cross-section of the process  $e^- \gamma \rightarrow X^- e^+$  as a function of  $\cos \theta$ . The collision energy is taken to be  $\sqrt{s} = 1000$  GeV and the bilepton mass  $M_X = 350$  GeV



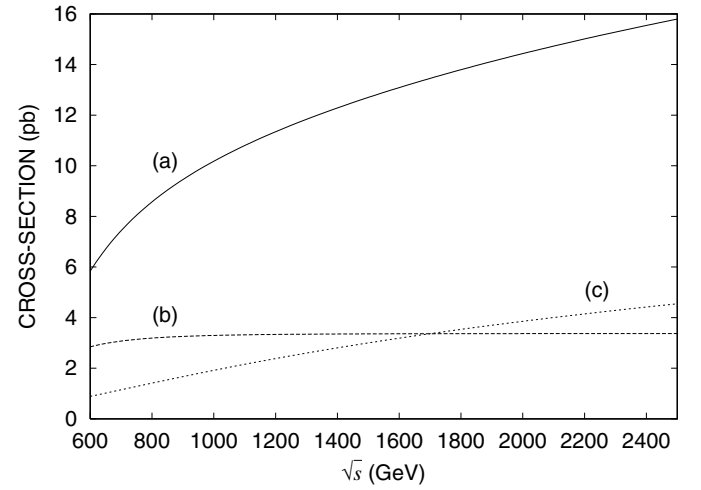
**Fig. 6.** Different cross-section of the process  $e^- \gamma \rightarrow Y^- \tilde{\nu}_e$  as a function of  $\cos \theta$ , the collision energy  $\sqrt{s} = 1000$  GeV



**Fig. 4.** Cross-section of the process  $e^- \gamma \rightarrow X^- e^+$  as a function of the collision energy  $\sqrt{s}$ . The bilepton mass is taken to be  $M_X = 350$  GeV. The curve **a** is the total cross-section  $\sigma$ , the curves **b**, **c**, and **d** represent cross-sections of the  $s$ -,  $t$ -, and  $u$ -channels, respectively



**Fig. 5.** Cross-section of the process  $e^- \gamma \rightarrow X^- e^+$  as a function of  $M_X$ . The collision energy is taken to be 2000 GeV



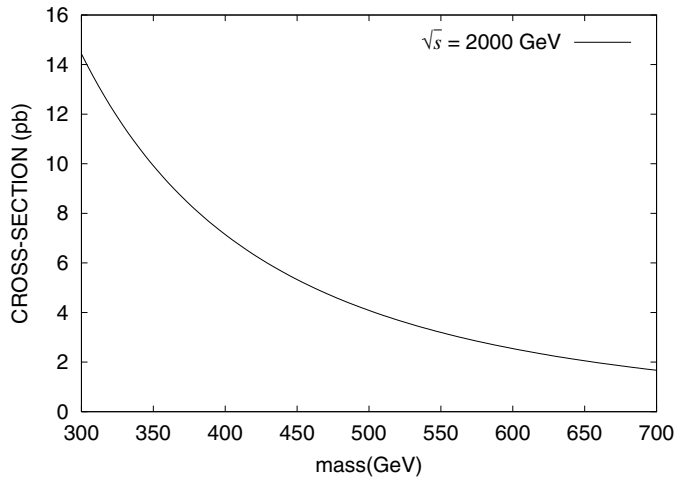
**Fig. 7.** Cross-section of the process  $e^- \gamma \rightarrow Y^- \tilde{\nu}_e$  as a function of  $\sqrt{s}$ , bilepton mass is taken to be 300 GeV. The curve **a** is the total cross-section  $\sigma$ , the curves **b** and **c** representing cross-sections of the  $s$ - and  $t$ -channels, respectively

The notation used here is the same as in the previous case. We give some estimates of the cross-section as follows.

(i) In Fig. 6 we plot  $d\sigma/d\cos\theta$  as a function of  $\cos\theta$  for the collision energy  $\sqrt{s} = 1000$  GeV and the bilepton mass  $M_Y = 300$  GeV. It is shown that  $d\sigma/d\cos\theta$  is peaked in the forward direction, due to the  $Y^+$  pole term in the  $t$ -channel, but it is flat in the backward direction.

(ii) Figure 7 shows the dependence of the total cross-section  $\sigma$  as a function of  $\sqrt{s}$ . The energy range is  $600 \text{ GeV} \leq \sqrt{s} \leq 2500 \text{ GeV}$ . The curve (a) is the total cross-section  $\sigma$ , the curves (b) and (c) representing cross-sections of the  $s$ - and  $t$ -channels, respectively. We can see from Fig. 7 that if the bilepton mass is the same as Fig. 6,  $M_Y = 300$  GeV, then the  $\sigma$  varies smoothly increasing from 6 pb to 15.8 pb, values which are easily measurable in future colliders. At TESLA based  $e\gamma$  colliders we get  $\sigma \geq 9$  pb.

(iii) The bilepton mass dependence of the cross-section at the energy  $\sqrt{s} = 2000$  GeV is shown in Fig. 8. Similarly to Fig. 5, the total cross-section decreases as  $M_Y$  increases.



**Fig. 8.** Cross-section of the process  $e^- \gamma \rightarrow Y^- \tilde{\nu}_e$  as a function of  $M_Y$ . The collision energy is taken to be 2000 GeV

The background process of a single  $W$  production plus missing energy (neutrino) was in detail investigated in [24]. It is to be noted that the  $W$  boson decays into both leptons and hadrons, while the bileptons can decay only into leptons.

## 4 Conclusion

In conclusion, we have presented the minimal 3-3-1 model and the production of the doubly charged bilepton  $X^{--}$  and the singly charged one  $Y^-$  in the  $e^- \gamma$  reaction. We see that with the first process, the differential cross-section is peaked in both the backward and forward directions, while in the second one the reaction mainly occurs at small scattering angles. Based on this result it is shown that if the mass of the bilepton is in a range of 300 GeV, then single bilepton production in  $e^- \gamma$  collisions may give an observable value at moderately high energies. At TESLA and CLIC based  $e\gamma$  colliders, with the integrated luminosity  $L \simeq 9 \times 10^4 \text{ fb}^{-1}$  one expects several thousands events.

Finally, we note that the second process is common for both the minimal version and the version with right-handed neutrinos, while the first one is characteristic for the minimal version. In this paper we have focused on bileptons as of particular experimental interest and their single production at the  $e\gamma$  mode is by far the most promising.

*Acknowledgements.* One of the authors (D. V. S.) expresses sincere gratitude to the Nishina Memorial Foundation for the financial support. He would like to thank the Department of Physics, Chuo University, for the warm hospitality during his visit as a Nishina fellow. This work is supported in part by Research Grants of the Japanese Ministry of Education and Science (Kiban C) and a Chuo University grant for special research. Financial support from the Swedish International Development Cooperation Agency (SIDA) through the Associateship Scheme of the Abdus Salam International Centre for Theoretical Physics, Trieste, Italy is acknowledged (H. N. L.).

This work was supported in part by the National Council for Natural Sciences of Vietnam.

## References

1. F. Pisano, V. Pleitez, Phys. Rev. D **46**, 410 (1992); R. Foot, O.F. Hernandez, F. Pisano, V. Pleitez, Phys. Rev. D **47**, 4158 (1993)
2. P.H. Frampton, Phys. Rev. Lett. **69**, 2889 (1992)
3. R. Foot, H.N. Long, Tuan A. Tran, Phys. Rev. D **50**, R34 (1994)
4. H.N. Long, Phys. Rev. D **54**, 4691 (1996)
5. D. Ng, Phys. Rev. D **49**, 4805 (1994)
6. P.B. Pal, Phys. Rev. D **52**, 1659 (1995)
7. J.T. Liu, D. Ng, Z. Phys. C **62**, 693 (1994); N.A. Ky, H.N. Long, D.V. Soa, Phys. Lett. B **486**, 140 (2000)
8. I. Antoniadis, K. Benakli, M. Quiros, ETH-TH/01-10, CERN-TH/2001-202, New J. Phys. **3**, 20 (2002); T. Li, L. Wei, Phys. Lett. B **545**, 147 (2002); S. Dimopoulos, D.E. Kaplan, N. Weiner, Phys. Lett. B **534**, 124 (2002)
9. H. Hatanaka, T. Inami, C.S. Lim, Mod. Phys. Lett. A **13**, 2601 (1998); H. Hatanaka, Prog. Theor. Phys. **102**, 407 (1999); G. Dvali, S. Randjibar-Daemi, R. Tabbash, Phys. Rev. D **65**, 064021 (2002); N. Arkani-Hamed, A.G. Cohen, H. Georgi, Phys. Lett. B **513**, 232 (2001); A. Masiero, C.A. Scrucca, M. Serine, L. Silvestrini, Phys. Rev. Lett. **87**, 251601 (2001)
10. See, for example, T. Kitabayshi, M. Yasue, Phys. Rev. D **63**, 095002 (2001); Phys. Lett. B **508**, 85 (2001); Nucl. Phys. B **609**, 61 (2001); Phys. Lett. B **524**, 308 (2002); L.A. Sanchez, W.A. Ponce, R. Martinez, Phys. Rev. D **64**, 075013 (2001); J.C. Montero, V. Pleitez, M.C. Rodriguez, Phys. Rev. D **65**, 035006 (2002); W. Ponce, Y. Giraldo, hep-ph/0201133
11. F. Cuyppers, S. Davidson, Eur. Phys. J. C **2**, 503 (1998); F. Cuyppers, M. Raidal, Nucl. Phys. B **501**, 3 (1997); M. Raidal, Phys. Rev. D **57**, 2013 (1998); T.G. Rizzo, Phys. Rev. D **45**, 42 (1992); Phys. Rev. D **46**, 910 (1992); N. Lepore et al., Phys. Rev. D **50**, 2031 (1994); Agrawal, P. Frampton, D. Ng, Nucl. Phys. B **386**, 267 (1992); Int. J. Mod. Phys. A **15**, 16 (2000)
12. P. Frampton, Int. J. Mod. Phys. A **15**, 2455 (2000)
13. B. Dion et al., Phys. Rev. D **59**, 075006 (1999)
14. P. Frampton, A. Rasin, Phys. Lett. B **482**, 129 (2000)
15. O.J.P. Eboli et al., Phys. Lett. B **311**, 147 (1993); H. Nadeau, D. London, Phys. Rev. D **47**, 3742 (1993)
16. Stephen Godfrey et al., Int. J. Mod. Phys. A **15**, 2623 (2000)
17. Z.Z. Aydin et al., hep-ph/0208041; R.W. Assman et al., CERN 2000 - 008, p.6 (2000); J. Ellis, E. Keil, G. Rolandi, Options for Future Colliders at CERN, CERN - EP/98-03; CERN - SL/98-004 (AP); CERN - TH/98-33
18. H.N. Long, D.V. Soa, Nucl. Phys. B **601**, 361 (2001)
19. P. Gambino, A. Sirlin, Phys. Rev. Lett. **73**, 621 (1994); Z. Hioki, Phys. Lett. B **340**, 181 (1994); S. Dittmaier et al., Nucl. Phys. B **426**, 249 (1994); Nucl. Phys. B **446**, 334 (1995)
20. P. Frampton, M. Harada, Phys. Rev. D **58**, 095013 (1998)
21. H.N. Long, L.P. Trung, Phys. Lett. B **502**, 63 (2001)
22. H.N. Long, T. Inami, Phys. Rev. D **61**, 075002 (2000)
23. S. Godfrey et al., Phys. Rev. D **65**, 033009 (2002)
24. G. Couture, S. Godfrey, P. Kalyniak, Phys. Rev. D **39**, 3239 (1989)