Double Charged Higgs Bosons Production in $e^-e^-$-Collisions

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Abstract

In the framework of the models with Higgs triplets, double charged Higgs bosons production in the processes $e^-e^- \rightarrow \delta_{L,R}^- \gamma$ are considered.
Double charged Higgs bosons arise in theories with Higgs sector enlarged by triplets of Higgs bosons (see e.g. [1] and ref. therein). Their introduction provides a natural explanation of the smallness of the left neutrinos masses. Double charged Higgs bosons and Majorana neutrinos lead to some new phenomena such as neutrinoless $\beta$-decays, $\mu \rightarrow 3e$ decay, muonium-antimuonium conversion and other processes with lepton number violation [2, 3].

In particular, in [2, 4] the process:

$$e^- e^- \rightarrow \mu^- \mu^- \tag{1}$$

mediated by $\delta_{L,R}^-$-bosons and the processes [4, 5]:

$$e^- e^- \rightarrow W^-_{L,R} W^-_{L,R} \tag{2}$$

mediated by double charged Higgs bosons or (and) heavy Majorana neutrino have been considered. High energy and high luminosity $e^- e^-$-colliders in particular $e^- e^-$-version of NLC and TLC colliders have been considered in [6, 7].

Here we study double charged Higgs boson production in the processes

$$e^- e^- \rightarrow \delta_{L,R}^- \gamma, \tag{3}$$

described by three diagrams on Fig.1. Produced $\delta_{L,R}^-$-bosons may decay into $l^- l^-$ or into $W^-_{L,R} W^-_{L,R}$-pairs if it is kinematically possible [4].

Using formula (A5) in Appendix A for $\delta_{L,R}^-$-interaction with electrons we obtain the following gauge invariant amplitude of the process (3):

$$M = 2 e h_{ee} \bar{u}(k_1) \left( \frac{\hat{k}_4 \hat{A}}{(k_2 - k_3)^2} + \frac{\hat{A} k_4}{(k_1 - k_3)^2} + i \frac{(k_4 A)}{s - m_H^2} \right) P_{L,R} u^c(k_2) \tag{4}$$

Here we neglect electron mass and use the following notations: $A_{\mu}$ is the polarization 4-vector of the photon, $s = (k_1 + k_2)^2$, $m_H$ is the mass of $\delta_{L}^-$ or $\delta_{R}^-$-bosons.

For differential cross section we obtain the following result:

$$\frac{d\sigma}{d\cos \theta} = \frac{\alpha h_{ee}^2}{s} \left( 1 + 2 \frac{(1 - \beta)}{\beta^2} \right) \beta \cot \theta^2 \tag{5}$$

Here $\theta$ is an angle between photon momentum $k_3$ and electron momentum $k_1$, $\beta = \left( 1 - \frac{m^2}{s} \right)$ is the velocity of $\delta_{L,R}^-$-boson in the c.m. system.
We see that our result contains collinear singularity at $\theta = \pm 0$, and we cut some cone near this direction as it has been done for $e^+ e^- \rightarrow Z^0 \gamma$ process (see [8] and references therein).

The cross section of the process (3) as well as cross section of the process $e^+ e^- \rightarrow Z^0 \gamma$ contain also infrared singularity near reaction threshold.

Number of events $\delta L,R \gamma$ per year ($\sigma L$) is shown on Fig.2 at $\sqrt{s} = 0.5$, 1 TeV and luminosity $L = 10^{41} s m^{-2}$. We use cut $|\cos \theta| < 0.9$ and 0.95.

Thus we see that consideration of the process (3) may provide new restriction on the $h_{ee}$ and $m_H$ in addition to the restriction from nonobservation of above mentioned low energy processes with lepton number violation, anomalous muons magnetic moment and Bhabba scattering [1]-[3].

Let us compare the cross section of the process (1) and (2) with the cross section of the studied process (3).

The process $e^- e^- \rightarrow W^- R W^- R$ will be kinematically forbidden for large masses of $W^\pm_R$-bosons ($2m_{W^\pm_R} > \sqrt{s}$).

The process $e^- e^- \rightarrow \delta^{--}_{L} \rightarrow W^- L W^- L$ may be suppresed by smallness of the vertex $W^- L W^- L \delta^{++}_{L}$. For instance, in left-right models this vertex is suppressed by factor $\frac{v_L}{k_L}$ which is small for preserving true relation between $W^\pm_L, Z^0$-bosons masses and Weinberg’s angle.

The cross section of the process (1) is of order $h^{2}_{ee} h^{2}_{\mu \mu}$ whereas the cross section of the studied process is of order $h^{2}_{ee}$, so the cross section of the process (3) at small $h_{\mu \mu}$ and far from resonanse (i.e. far from range $\sqrt{s} = m_H$) may dominate over reaction (1).

It must be noted, that all our results are also applicable for a more general case where Yucawa couplings of the left triplet and right triplet with left- and right-handed leptons are different.
Appendix A

In the left-right symmetric model the interaction of left and right triplets with \((Y = 2)\) of Higgs bosons:

\[
\Delta_{L,R} = \left( \begin{array}{cc}
\delta_{L,R}^{+}/\sqrt{2} & \delta_{L,R}^{++} \\
\delta_{L,R}^{0} & -\delta_{L,R}^{+}/\sqrt{2}
\end{array} \right)
\]  

(A.1)

with left- and right-handed lepton fields \(\psi_{L,R}^T = (\nu_{L,R}^T, e_{L,R}^T)\) are described by lagrangian:

\[
L = ih_{ij} \left( \psi_{iL}^T C \tau_2 \Delta_L \psi_{jL} + \psi_{iR}^T C \tau_2 \Delta_R \psi_{jR} \right) + h.c.
\]  

(A.2)

Here \(i,j = e, \mu, \tau\)-are generations indices, \(C\) is the charge conjugation matrix, \(\tau_2\) is the Pauli matrix. After symmetry breaking Majorana masses of the heavy approximately right handed neutrinos are expressed through the Yukawa couplings \(h\) and neutral component of right triplet vacuum expectation \(v_R\) in the following way:

\[
m_N = \sqrt{2}hv_R
\]  

(A.3)

Also, large right triplet vacuum expectation \((v_L \ll k_L, k_R \ll v_R, k_L, k_R - \) are vacuum expectations of the left and right doublets, \(v_L\)-vacuum expectation of the left triplet) provide mass of the \(W_R^\pm\)-bosons:

\[
m_{W_R} = \frac{1}{2}gv_R
\]  

(A.4)

whereas doublet vacuum expectation is responsible for mass of \(W_L^\pm\)-bosons.

So, as seen from (A3),(A4) in left-right symmetric models Yukawa couplings \(h\) are expressed through the \(m_{W_R}\) and \(m_N\).

From (A1), (A2) \(e^-e^- \rightarrow \delta_{L,R}^{-}\) transition is given by amplitude:

\[
\mathcal{M} = 2h_{ee} \bar{u}(k_1) P_{L,R} u^c(k_2)
\]  

(A.5)

where \(u^c = C \bar{u}^T, k_1, k_2\)-are momenta of the two electrons.

In general, mass matrix of \(\delta_{L,R}^{-}\)bosons is nondiagonal, however in the limit \(v_L \ll v_R\) mixing between \(\delta_L^{-}\) and \(\delta_R^{-}\) is negligible.
References

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Figures captions:

Fig.1 Diagrams corresponding to the processes $e^- e^- \rightarrow \delta_{L,R}^- \gamma$.

Fig.2 Number of events $\delta_{L,R}^- \gamma$ per year (at $L = 10^{41} \text{sm}^{-2}$) produced in reaction (3) as a function of $m_H$ at $h_{ee} = 10^{-2}$. Solid lines 1,2 correspond to the energies $\sqrt{s} = 0.5, 1 \text{ TeV}$ and cut $|\cos \theta| < 0.9$.

Dotted curves 3,4 correspond to the energies $\sqrt{s} = 0.5, 1 \text{ TeV}$ and cut $|\cos \theta| < 0.95$. 
Fig. 1
