Limits on a Strong Electroweak Sector from $e^+e^- \rightarrow \gamma\gamma + E_T$ at LEP2

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Abstract

We study the process $e^+e^- \rightarrow \gamma\gamma\nu\bar{\nu}$ in the context of a strong electroweak symmetry breaking model, which can be a source of events with two photons and missing energy at LEP2. We investigate bounds on the model assuming that no deviation is observed from the Standard Model within a given experimental error.

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Recently there has been a great deal of interest in events with two photons plus missing energy at LEP2 because they would be an interesting signature of weak scale supersymmetry. This signal arises from either $e^+e^- \rightarrow \tilde{N}_2(\tilde{N}_2 \rightarrow \tilde{N}_1\gamma) \tilde{N}_2(\tilde{N}_2 \rightarrow \tilde{N}_1\gamma)$ in models with gravitational mediated SUSY breaking where the neutralino $\tilde{N}_1$ is the lightest superpartner (LSP) or $e^+e^- \rightarrow \tilde{N}_1(\tilde{N}_1 \rightarrow \tilde{G}\gamma) \tilde{N}_1(\tilde{N}_1 \rightarrow \tilde{G}\gamma)$ in gauge mediated supersymmetry breaking where the gravitino $\tilde{G}$ is the LSP [1]. Searches for these events have been performed at LEP2 [2] and the results are consistent with the Standard Model background once initial state radiation is taken into account [3].

Supersymmetric models are considered for many reasons the favorite candidates to extend the extremely successful Standard Model to higher energies. Among these reasons one could mention: gauge couplings unification, the existence of a natural candidate for dark matter of the Universe, a solution to the naturalness problem and the fact that the theory is weakly coupled and perturbation theory can be used. However, there is a logical possibility that the Standard Model is an effective theory, being the low energy limit of a strongly coupled more fundamental theory, in the same manner that the nonlinear $\sigma$ model describes QCD at low energies, in the non-perturbative regime where pions are the relevant degrees of freedom [4]. Only experiments will tell us which way Nature chose.

In this letter we show that models of strong electroweak symmetry breaking could also be a source of events with two photons and missing energy at LEP2. We obtain constraints in the parameter space of one such model from requiring that the deviations induced by this model to be smaller than the experimental accuracy of the measurements. These constraints are complementary to the ones resulting from precision measurements at LEP.

Here we will work in the context of the BESS (Breaking Electroweak Symmetry Strongly)[5] model. It can be viewed as an effective lagrangian description of the electroweak symmetry breaking due to an hypothetical strongly interacting sector at the TeV scale. The model is based on the group $G' = (SU(2)_L \otimes SU(2)_R)_{\text{global}} \otimes (SU(2)_V)_{\text{local}}$. Three new vector bosons are introduced through the so-called hidden symmetry $SU(2)_V$. The group $G'$ breaks down spontaneously to its diagonal subgroup of $SU(2)$ giving rise to six Goldstone bosons. Three of them are absorbed by the new vector bosons. The remaining three Goldstone bosons give masses to the usual $W^\pm$ and $Z^0$ bosons when the symmetry $SU(2)_L \otimes U(1)_Y \subset SU(2)_L \otimes SU(2)_R$ is
The bosonic part of the lagrangian takes the form:

\[
\mathcal{L} = -\frac{v^2}{4} \left[ \text{Tr}(\tilde{W} - Y)^2 + \alpha \text{Tr}(\tilde{W} + Y - 2\tilde{V})^2 \right] + \mathcal{L}^{\text{kin}}(Y, \tilde{W}, \tilde{V})
\]  

(1)

where \(Y, \tilde{W}, \tilde{V}\) are the gauge fields associated to \(U(1)_Y, SU(2)_L\) and \(SU(2)_V\) respectively and \(\alpha\) is an arbitrary parameter.

A direct coupling to the fermionic sector can be introduced through the lagrangian:

\[
\mathcal{L}_f = \bar{\psi}_L i\gamma^\mu \left( \partial_\mu + \frac{i}{2(1+\delta)} g \tilde{W}_\mu^a \tau^a + \frac{ib}{4(1+\delta)} g'' \tilde{V}_\mu^a \tau^a + \frac{i}{2} g' y \tilde{Y}_\mu \right) \psi_L + \\
\bar{\psi}_R i\gamma^\mu \left( \partial_\mu + \frac{i}{2} g' y \tilde{Y}_\mu \right) \psi_R
\]

(2)

where \(b\) is a free parameter.

These vector bosons are not the physical ones because there are mixing terms in the lagrangian and the physical gauge bosons are obtained by diagonalizing the mass matrix in the neutral and charged sectors. After the diagonalization, only the couplings of the physical new vector bosons \(V\) to the fermions depend on the \(b\) parameter. The physical fields \((A, W, Z\) and \(V\)) are linear combinations of \(Y, \tilde{W}\) and \(\tilde{V}\), and therefore the physical \(V\) bosons also acquire an indirect coupling to fermions.

The Standard Model is recovered from the BESS model in the limit \(g'' \rightarrow \infty\) and \(b \rightarrow 0\), where \(g''\) is the new coupling constant of \(SU(2)_V\).

The model described here is minimal in the sense that only vector resonances are introduced. Many generalization of this model have been proposed, for example models that introduce axial-vector as well as vector particles \([6]\). Recently, a model with vector, axial-vector and scalar resonances has also been studied \([7]\).

Bounds on this model have been obtained from precision measurements at LEP1 \([8]\). For a recent review on results of this model and its extensions see ref. \([9]\).

The minimal BESS model has three independent free parameters, which we choose to be \(M_V\) (which is given by \(M_V^2 = \alpha \frac{v^2}{4} g''\) in the limit \(g'' \rightarrow \infty\)) \(g''\) and \(b\). Our calculations show that our results have little sensitivity in \(M_V\) as long as \(M_V \gg \sqrt{s}\), so we will use \(M_V = 400\) GeV in the following.

The Feynman rules for this model are similar to the Standard Model ones with modified coupling constant (which can be found in references \([9]\)
We included the BESS model particles and couplings into the package COMPHEP [11] and we calculated the cross section for the process \(e^+e^- \rightarrow \gamma\gamma\bar{\nu}\) at \(\sqrt{s} = 194\) GeV, summing over neutrino species, in the Standard Model and in the BESS model for different values of \(g/g''\) and \(b\).

We adopted the following “loose” cuts in order to maximize the number of detected events [12]:

\[
|\cos(\theta_{\gamma})| < 0.7
\]  

(3)

\[E_{\gamma} > 1.75\text{GeV}\]  

(4)

where \(\theta_{\gamma}\) is the angle between the photon and the beam, and \(E_{\gamma}\) is the energy of the photon.

We define the quantity

\[
\delta\sigma = \frac{\sigma_{\text{BESS}} - \sigma_{\text{SM}}}{\sigma_{\text{SM}}}
\]  

(5)

where \(\sigma_{\text{BESS}}\) and \(\sigma_{\text{SM}}\) are the total cross section predicted by the BESS model and the Standard Model respectively. The quantity \(\delta\sigma\) measures the relative deviation from the Standard Model prediction. It should be largely insensitive to initial state radiation corrections and we use \(\delta\sigma\) to obtain our results.

In order to obtain bounds on the model, we require that no deviation is observed from the Standard Model prediction within the experimental error. Due to runs with small luminosity at different energies, the number of events collect so far is very limited and the current experimental errors on the cross section measurement ranges from 40% to 100% [12]. Expecting that the measurements will get more accurate for the next run due to its increased luminosity, we chose to show our bounds for \(\delta\sigma < 0.20, 0.40\) and \(0.80\) in figure 1, where we also include the limits obtained from precision measurements at LEP [1]. We can see that the the bounds are complementary and that a measurement of the process \(e^+e^- \rightarrow \gamma\gamma + E\) with larger statistics can significantly reduce the parameter space available for the BESS model.

In conclusion, we have shown that models of strong electroweak symmetry breaking can also be a source of events with two photons plus missing energy at LEP2. The bounds obtained by requiring no deviation from the Standard
Model prediction within the experimental error are complementary to the bounds arising from precision measurements.

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Figure Caption

Figure 1:
Limits on the parameter space $g/g'' \times b$ of the BESS model. The region outside the solid lines is excluded by precision measurements at LEP. The regions below the dashed, dotted and dot-dashed lines are excluded by requiring that no deviation is observed from the Standard Model prediction for the process $e^+e^- \rightarrow \gamma\gamma + E_T$ at LEP2 with $\sqrt{s} = 194$ GeV within 20%, 40% and 80% accuracy respectively.
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