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ABSTRACT

The reaction $e^+e^- \to \gamma W^+W^-$ has been studied at TeV energies as a possible background to Higgs production. Our results differ significantly from previous estimates and show that the ratio signal/background can be kept reasonably large.

e^+e^- linear colliders in the TeV region are an extremely powerful tool for studying the mechanism of the electroweak symmetry breaking. A facility of this kind, CLIC, with a center of mass energy $\sqrt{s} \simeq 2$ TeV, is now under study at CERN(1). The production of very massive standard model Higgs can be investigated there with good accuracy because of the lack of background QCD radiation, which is overwhelming in the case of pp colliders. Furthermore the production cross sections for the Higgs particle can be precisely predicted, the dominant process being WW fusion, for $E_{beam} \simeq 1$ TeV. A systematic study of the various production mechanisms and the possible backgrounds has been recently undertaken(2).

In the present note we study in detail the reaction $e^+e^- \to \gamma W^+W^-$ which provides, in principle, an important background to the production process of heavy Higgs bosons $e^+e^- \to H\nu\bar{\nu}$ (He^+e^-), with $H \to W^+W^-$, proceeding through $W^+W^-(ZZ)$ fusion. The initial state bremsstrahlung has been previously considered in the literature(3-5). Previous estimates, however, are not complete and sometimes incorrect. Therefore a more accurate determination of this background is mandatory for future investigations with high energy e^+e^- colliders.

The basic one-loop radiative corrections to the process $e^+e^- \to \gamma W^+W^-$ have been calculated in ref. (3). The soft photon corrections, which are the least interesting from a physical point of view, are found to be numerically very relevant.

Indeed one obtains(3)

$$d\sigma_1 = d\sigma_0(1+B) + d\sigma^{ew} \tag{1}$$

where B is the usual bremsstrahlung term

$$B = \frac{\alpha}{4\pi^2}\int \frac{d^3k}{k}\left(\frac{p_1}{kp_1} - \frac{p_2}{kp_2} - \frac{q_1}{kq_1} + \frac{q_2}{kq_2}\right)^2 \tag{2}$$

and $d\sigma^{ew}$ corresponds to the genuine $o(g^2)$ electroweak corrections. Numerically, for c.m. energies $\sqrt{s} \simeq 0.5$ - 1 TeV, and an energy resolution of ~5%, one finds an average correction $d\sigma_1/d\sigma_0 \sim 0.25$-$0.50$. Because of the relevance of the effect, it is important to evaluate the invariant mass distribution of the WW system in the reaction $e^+e^- \to \gamma W^+W^-$, to be compared with the analogous one for the process $e^+e^- \to \nu\bar{\nu} W^+W^-$. It is clear that the missing mass peaks at zero for the undetected photon ad at large masses for the $\nu\bar{\nu}$ system(5).

The photon spectrum to first order in α is easily obtained for $\frac{k}{E} \equiv \frac{2k}{\sqrt{s}} \lesssim 0.2 \div 0.3$ as

$$\frac{d\sigma^{(1)}}{dk} = \frac{1+(1-k/E)^2}{2k}\int_{\theta_{min}}^{\theta_{max}} (\beta_e + \beta_W + 2\beta_{int})\frac{d\sigma}{d\cos\theta}(e^+e^- \to W^+W^-)\, d\cos\theta \tag{3}$$

where $d\sigma(e^+e^- \to W^+W^-)/d\cos\theta$ is evaluated at the reduced c.m. energy $(\sqrt{s}-k)$ when multiplied by $(\beta_e + \beta_{int})$, and $\beta_e, \beta_W = \frac{2\alpha}{\pi}\left[\ln\frac{s}{m^2_{e,W}} - 1\right]$, $\beta_{int} = \frac{4\alpha}{\pi}\ln(\mathrm{tg}\frac{\theta}{2})$.

Higher order effects can be simply taken into account(6), in the soft photon approximation, by including the exponentiated factor $\left(\frac{k}{E}\right)^{\beta}$ in the r.h.s. of eq. (3), with $\beta=\beta_e+\beta_W+2\beta_{int}$. We refer to $\frac{d\sigma}{dk}$ as the resulting soft spectrum.

Notice the incorrect exponentiated procedure adopted in ref. (4), where the factor $(k/E)^{\beta}$ is replaced by $(\sqrt{s}/M_{WW})^{\beta_e}$ and modifies considerably the resulting estimate for the bremsstrahlung background ($M_{WW}^2 = s - 2\sqrt{s}\,k$).

In Figs. (1-2) the invariant mass distribution $\left(\frac{d\sigma}{dM_{WW}^2}\right)$ is shown for $\sqrt{s}$ = 1-2 TeV and $\cos\theta_{max} = -\cos\theta_{min} = 0.9$. The corresponding distributions of ref. (4) are different in shape and bigger in magnitude by about a factor of three. The effective background cross section clearly depends on the measuring resolution and the experimental cuts. However an indicative background estimate can be obtained as $\sigma_{back} \approx \left(\frac{d\sigma}{dM_{WW}}\right)\left(\Delta M_{WW} \sim \Gamma_H\right)$. Alternatively, the invariant mass distribution $\left(\frac{d\sigma}{dM_{WW}}\right)$ can be directly compared with the corresponding spectrum(5) for the process $e^+e^- \to \nu\bar{\nu}\, H \to \nu\bar{\nu}\, W^+W^-$.

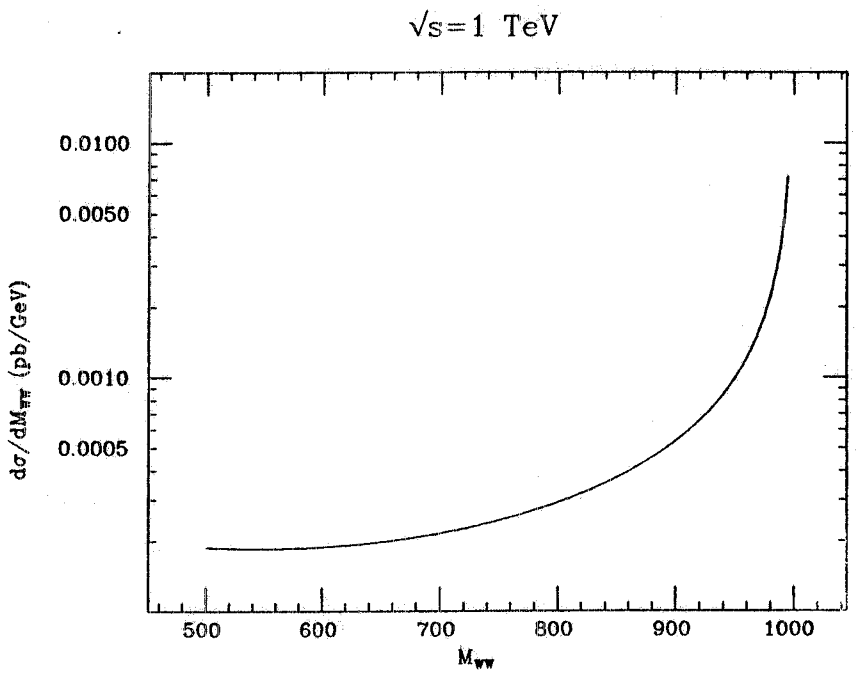

FIG. 1 - Invariant mass distribution $\left(\frac{d\sigma}{dM_{WW}}\right)$ for $e^+e^- \to \gamma W^+W^-$ at $\sqrt{s}$ = 1 TeV.

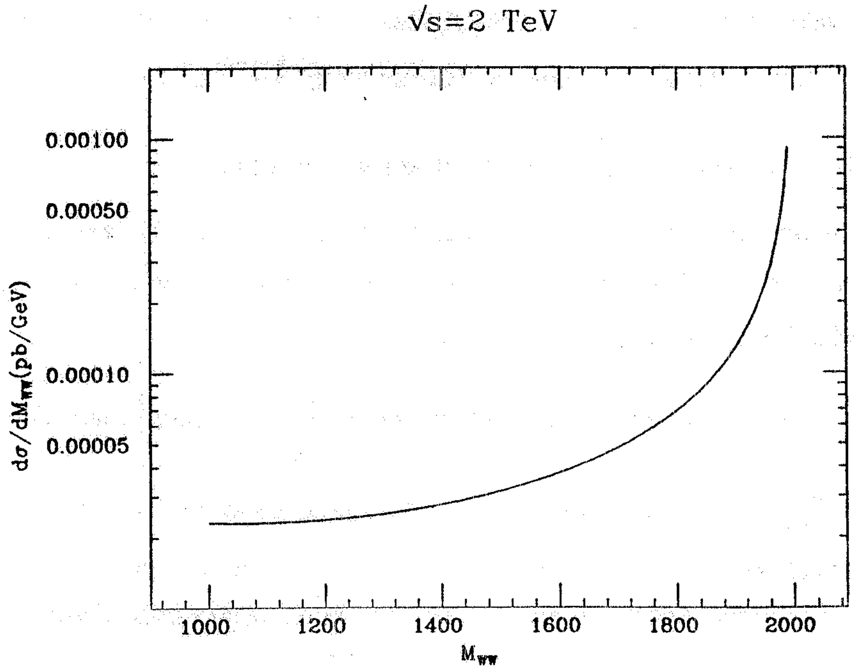

FIG. 2 - Invariant mass distribution $\left(\frac{d\sigma}{dM_{WW}}\right)$ for $e^+e^- \rightarrow \gamma W^+W^-$ at $\sqrt{s} = 2$ TeV.

This is shown in Fig. 3, for various values of the Higgs mass. Notice that longitudinal W's only are considered for $e^+e^- \rightarrow \nu\nu$ H. From inspection of Fig. 3 it follows that for $M_H \lesssim 1$ TeV the signal can be safely separated from the background at lower WW invariant masses.

To summarize, we have studied the radiative W^+W^- production as a possible sizeable background to the Higgs production in e^+e^- colliders in the TeV region. The signal/background can be kept reasonably large posing no problems to the possible identification of a Higgs particle of mass up to 1 TeV.

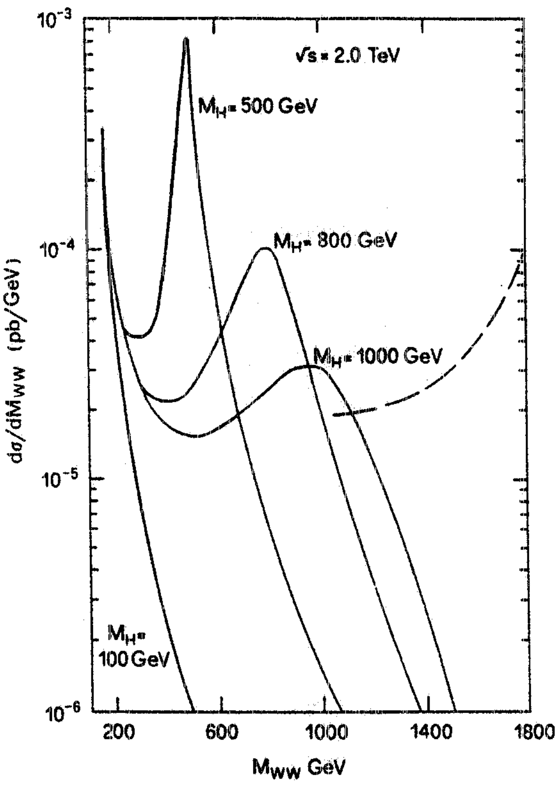

FIG. 3 - Invariant mass distributions[5] $d\sigma(e^+e^- \rightarrow \nu\bar{\nu}\ W^+W)/dM_{WW}$ at $\sqrt{s} = 2$ TeV for various values of M_H (full lines). Only logitudinal W's are considered. Invariant mass distribution $d\sigma(e^+e^- \rightarrow \gamma\ W^+W^-)/dM_{WW}$ at $\sqrt{s} = 2$ TeV (dashed line).

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