Study of $\gamma\gamma$ Background in $e^+e^- \to W^+W^-\nu\bar{\nu} \to H^0\nu\bar{\nu}$ Events at the TESLA e^+e^- Linear Collider

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Abstract

The effect of the overlap of $\gamma\gamma \to$ hadrons to $H\nu\bar{\nu}$ events has been studied for the case of the TESLA e^+e^- linear collider at $\sqrt{s} = 350$ GeV. It was found that, due to the significant bunch length and the track extrapolation accuracy provided by the Vertex Tracker, the $\gamma\gamma$ background to physics events can be substantially reduced, with moderate loss in reconstruction efficiency, by a combination of kinematical and vertex topology observables. The remaining background, being confined to very forward hadron production, does not significantly interfere with the event reconstruction.

1 Introduction

Two photon interactions are characterised by a cross section that is several orders of magnitude larger compared to those typical for boson and fermion production in e^+e^- collisions. At a e^+e^- linear collider, a high rate of $\gamma\gamma$ collisions arises from photons radiated in the electro-magnetic interactions of the colliding beams. While interesting for themselves, products of $\gamma\gamma$ interactions may overlap with those from a e^+e^- interaction creating a source of potential confusion for the event reconstruction.

Due to the large luminosity per bunch crossing $L = 2.2 \times 10^{-3}$ nb^{-1} BX^{-1} achieved at TESLA, the rate of $\gamma\gamma \to$ hadrons overlap to a e^+e^- collision is 0.09 - 0.13 $\times n_b$, where n_b is the number of bunches integrated within a read-out cycle of the relevant detector systems. The considerably high rate of this event overlap has been considered as a possible limiting factor in the precise study of processes whose production cross section is peaked in the forward region and experimental signature includes missing energy [1]. In this report, the identification of two photon interactions overlapped to $e^+e^- \to W^+W^-\nu\bar{\nu} \to H^0\nu\bar{\nu}$ Higgs production via t-channel WW fusion is discussed. This channel offers a good benchmark process. An accurate determination of the Higgs production cross-section by the WW fusion process is important for a determination of the Higgs total width in conjunction with the $H^0 \to WW$ decay branching fraction [2]. Further, for a large interval of M_H and $\sqrt{s}$ values this process is the dominant Higgs production mechanism in e^+e^- annihilations. The $\gamma\gamma$ overlap may distort both the reconstruction efficiency and the jet flavour tagging performance. Therefore it is of great importance to ensure that this $\gamma\gamma$ background can be effectively rejected in the Higgs studies.

2 $\gamma\gamma$ Simulation

Two photon events have been generated by the GUINEA PIG program [4]. Beam parameters for 350 GeV centre-of-mass were derived from the ones for 500 GeV by keeping the beta-functions and emittances constant. The hadronic background has been modelled following Schuler and Sjöstrand [3] using the most conservative proposed parametrisation of the cross section:

$$\sigma_{H,3} = 211\text{nb} \cdot \left(\frac{s}{\text{GeV}}\right)^{0.0808} + 297\text{nb} \cdot \left(\frac{s}{\text{GeV}}\right)^{-0.4525} \tag{1}$$

The energies of two colliding photons have been stored in a file with their relevant probability. PYTHIA [5] has then been used to generate the hadronic events. These events have been stored in a database from where they could be added to the main event stored in the PYTHIA common block.

The final state hadronic system has been appended to the event record of $e^+e^- \to W^+W^-\nu\bar{\nu} \to H^0\nu\bar{\nu}$ events generated using the PYTHIA program.

3 Event Analysis and $\gamma\gamma$ Tagging

$\gamma\gamma \to$ hadrons events are characterised by forward hadronic activity and by a production vertex contained in the colliding bunch envelope but distinct from that of the e^+e^- events. Since at TESLA the bunch size is 300 μm in length but only few nm in the vertical and horizontal projections, $\gamma\gamma \to$ hadrons events are effectively displaced only in the longitudinal direction (see Figure 1).

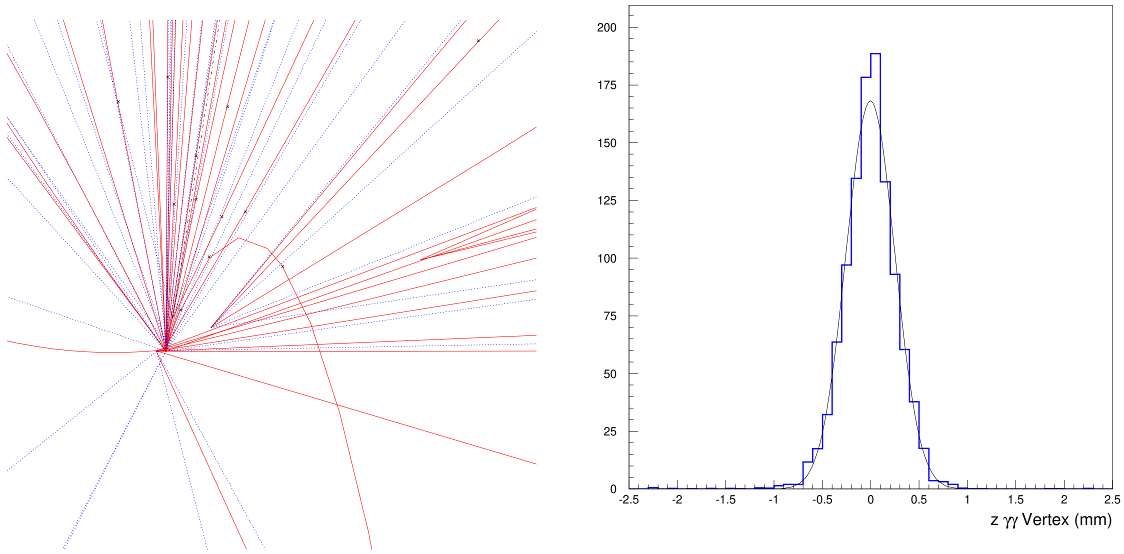

Figure 1: *Left: Display of a $e^+e^- \to W^+W^-\nu\bar{\nu} \to H^0\nu\bar{\nu}$, $H^0 \to b\bar{b}$ decay with an overlapped $\gamma\gamma$ event showing the secondary vertex structure of the decays of b hadrons and the longitudinal displacement of the $\gamma\gamma$ production point w.r.t. the e^+e^- interaction. Right: The distribution of the $\gamma\gamma$ vertex position along the beam axis.*

$e^+e^- \to W^+W^-\nu\bar{\nu} \to H^0\nu\bar{\nu}$ events have been generated for $M_H = 120$ GeV/c^2 and $\sqrt{s} = 350$ GeV, hadrons from $\gamma\gamma$ interactions have been added and the resulting events passed through the GEANT simulation of the TESLA detector tracking system. It has been assumed that the Vertex Tracker can identify single bunches within a TESLA pulse, as in the case of hybrid pixel sensors [6], corresponding to an average probability for $\gamma\gamma$ event overlap of 0.10.

The tagging algorithm developed for identifying and rejecting overlapped $\gamma\gamma \to$ hadrons event is based on the topological and kinematical characteristics of the particles detected in the forward regions. The forward hadronic system was reconstructed from the particles detected at polar angles $0.80 < |\cos\theta| < 0.96$. The displacement of the production vertex was verified from the reconstructed impact parameter w.r.t the event primary vertex reconstructed using the primary particles detected in the central region defined as $|\cos\theta| < 0.80$. In order to distinguish the $\gamma\gamma$ products, displaced only in the z component, from decay products of short-lived hadrons, such as in $H^0 \to b\bar{b}$, both the $R-\phi$ and z impact parameter components have been studied. A track extrapolation resolution, $\sigma^{IP}_{R-\phi,z} = \sqrt{(5.7\ \mu m)^2 + \frac{(13.0\ \mu m)^2}{p_t^2}}$, better than a tenth of the TESLA bunch length can be achieved by the use of a high precision silicon Vertex Tracker. This provides a good discrimination of primary particles, secondaries from short-lived hadron decays and hadrons from $\gamma\gamma$ interactions. Eight variables sensitive to the kinematical and topological properties of the reconstructed forward hadronic system have been used to define a likelihood variable used for the tagging:

1. Prob(IP_z) for forward tracks with Prob($IP_{R-\phi}$) > 0.05;
2. Number of hemispheres with forward activity;
3. z position of reconstructed detached Vertex (1-D);
4. fraction of forward tracks with Prob(IP_z)<0.05 and Prob($IP_{R-\phi}$) > 0.05;
5. Number of hadronic jets;
6. Ranking of most forward jet in energy ordering;
7. $|\cos\theta|$ of most forward jet;
8. Invariant mass of the forward hadronic system;

A global $\gamma\gamma$ likelihood $L_{\gamma\gamma}$ was defined from the response of the selected variables as:

$$L_{\gamma\gamma} = \frac{\prod_{i=1,8} F_i^{\gamma\gamma}(x_i)}{\prod_{i=1,8} F_i^{\gamma\gamma}(x_i) + (\prod_{i=1,8}(1 - F_i^{\gamma\gamma}(x_i)))} \tag{2}$$

where $F_i^{\gamma\gamma}(x_i)$ is the probability for an event with $\gamma\gamma$ background to give a value x_i for the i^{th} observable. This variable peaks at one (zero) for $H\nu\bar{\nu}$ events with at least one $\gamma\gamma$ overlap (pure $H\nu\bar{\nu}$ events) as shown in Figure 2. At 80% $H\nu\bar{\nu} + 0\ \gamma\gamma$ efficiency, corresponding to a cut $L_{\gamma\gamma} \leq 0.65$, the fraction of events with $> 0\ \gamma\gamma$ accepted in the analysis is ≤ 0.025. The residual events, left after a cut on the $\gamma\gamma$ likelihood variable, are concentrated in very forward region beyond the acceptance of the Vertex Tracker.

In order to check the effect of the remaining $\gamma\gamma$ background on the event reconstruction, the di-jet invariant mass M_{jj} and their recoil mass M_{recoil} have been computed for $H\nu\bar{\nu}$, $H\nu\bar{\nu} + \gamma\gamma$ events and for the events satisfying the anti-$\gamma\gamma$ cut $L_{\gamma\gamma} \leq 0.65$, corresponding to 80% efficiency. Hadronic jets have been reconstructed using the Durham algorithm, only events with at most two jets in the central regions have been retained.

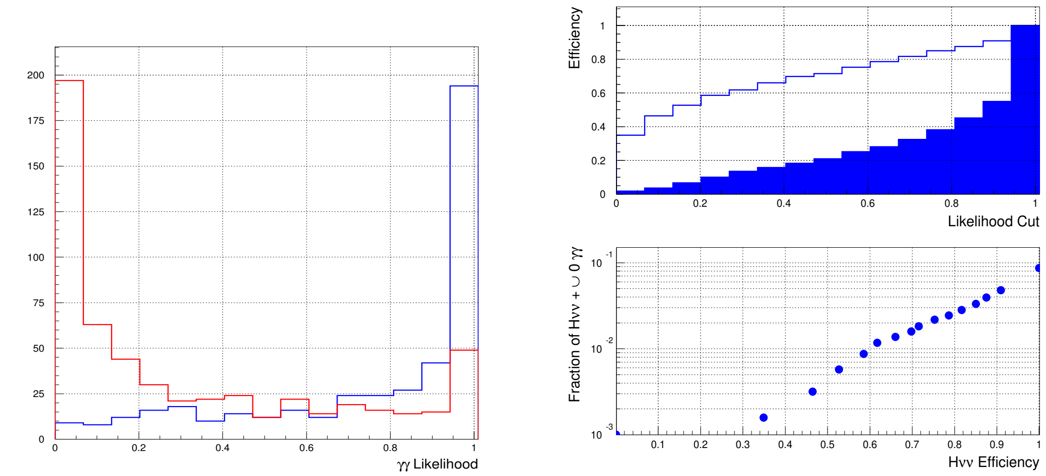

Figure 2: *Left: The $\gamma\gamma$ likelihood for $H\nu\bar{\nu}$ and $H\nu\bar{\nu}+\geq\ 1\gamma\gamma$ events. Right: The efficiency for retaining a $H\nu\bar{\nu}$ event as a function of $\gamma\gamma$ likelihood cut value (upper plot) and the fraction of tagged $H\nu\bar{\nu}+\geq\ 1\gamma\gamma$ events shown as a function of the efficiency (lower plot).*

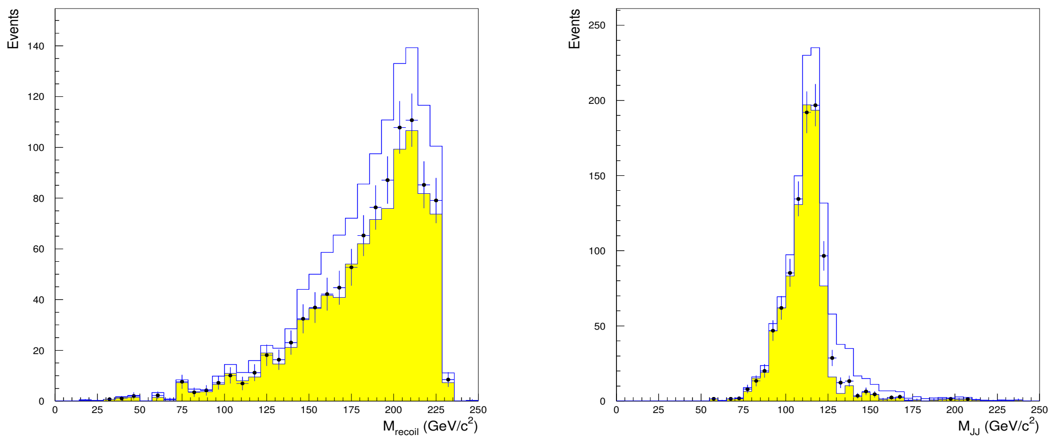

Figure 3: *The distribution of the mass recoiling against the di-jet system (left) and the di-jet invariant mass (right) in $H\nu\bar{\nu}$ events. The open (shaded) histogram represents the reconstructed distributions with (without) $\gamma\gamma$ background and the points with error bars represent the result after anti-$\gamma\gamma$ cut corrected by the estimated efficiency loss.*

A b-tagging algorithm based on the impact parameter of the charged particles in each jets [7] has been applied and the pair of b-tagged jets giving the mass closest to the nominal Higgs mass of 120 GeV/c^2 have been selected. Figure 3 shows the reconstructed recoil mass to the two selected jets and their invariant mass. A significant distortions towards higher mass values of the invariant mass distribution has been observed in presence of $\gamma\gamma$ background. However after applying the anti-$\gamma\gamma$ cut on $L_{\gamma\gamma}$ and rescaling the resulting distribution by the estimated 20% reconstruction efficiency loss, the distributions agree well with those expected for pure $H\nu\nu$ decays.

4 Conclusions

The effect of the overlap of $\gamma\gamma \to$ hadrons to $H\nu\bar{\nu}$ events has been studied for the case of the TESLA e^+e^- linear collider at $\sqrt{s}$ = 350 GeV, assuming Vertex Tracker sensors able to resolve individual bunch crossing. The $H\nu\bar{\nu}$ channel, characterised by missing energy and b-tagged jets is expected to be particularly sensitive to the effects of $\gamma\gamma$ production. The $\gamma\gamma$ background to physics events can be substantially reduced, with moderate loss in reconstruction efficiency, by a combination of kinematical and vertex topology observables. The remaining background, being confined to very forward hadron production, does not significantly interfere with the mass reconstruction and cross-section measurement for Higgs studies in the WW fusion channel.

References

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