Effects of Beam-beam Interaction, Event-Overlap in Higgs Measurements

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Performances of the tracking, kinematic reconstruction, and heavy-flavour taggings have been investigated under realistic background situations including huge number of noise hits on vertex detectors due to beam-beam interaction and event overlapping in a bunch collision expected at the future linear colliders. Local tracking capability in the vertex detector is found to be very helpful. Two-photon events overlapping to the signal events make significant distortion in the reconstructed mass and bias in the tagging efficiencies. To minimise the effect of the event overlapping, a good time resolution of the trackers and calorimetry as well as the stable operation of the accelerator are required.

1 Introduction

In studies of the Higgs particles at future linear colliders (LC), accurate tracking and event kinematic reconstructions are essential. One needs to investigate the performances of such key techniques under realistic experimental environments. The extremely high luminosity of order of 10^{34} cm^{-2}s^{-1} and the beam structure necessary for the acceleration in the linear collider make the experimental situation more severe than that at LEP and SLC in the following points;

- Large number of noise hits on the vertex detectors due to huge number of e^+e^- pairs created by beam-beam interactions [3]. It makes proper associations of the hits for the tracking difficult especially for the low momentum tracks, which are rather important for b tagging, due to multiple Coulomb scatterings and energy losses in detector materials;
- Overlap of two or more physics events, especially two-photon backgrounds [2], in a same bunch collision with a signal or other hard scattering event due to very high integrated luminosity per bunch. The average rate of the overlap of the two photon process on signal events might reach to about 10 % or more
- Degradation of the collision energy due to beamstrahlung.

In this report we focus on the first two items. For the effect of the beamstrahlung in the Higgs measurements, see Ref [4] for instance. The studies have been made with the current design of the detector at JLC [1] as a model detector.

2 Proper Track Finding Efficiency

The beam at JLC has 50–100 of bunches in a beam train with bunch spacing of 1.4 to 5.6 nsec and the repetition rate of 50–150 Hz. Since the present design uses CCD readout for the vertex detector, the hits from multi-bunches in a train overlap each other. In single train collision, the expected rate of the noise hits due to the beam-beam interaction is about 30–100 hits/cm^2 on the inner most layer of the vertex detectors [a] Studies have been made with full simulation program JIM [5] based on the GEANT3 package. Tracking devices in the JLC detector are: central tracker (CT), intermediate tracker (IT) and vertex detector (VX). Detector parameters are summarised in Tab 1. Single μ track generated with flat distribution in polar angle

Detector Name	No. of Layers	Radius of layers [cm]		Half-z Length [cm]	Resolution [μm]	
		Inner	Outer		r-ϕ	z
CT	100	45	230	125	100	2000
IT	5	10	38	21-79	20	20
VX	4	2.4	6.0	5-12.5	4	4

Table 1: Detector parameters which are relevant to this analysis. Magnetic field of 2 T is used.

in $\cos\theta \pm 0.8$ with momentum ranging from 0.5 to 50 GeV, are used as a "signal" track to study the proper track finding efficiency. Two kinds of backgrounds are considered in this analysis. One is the low energy e^+e^- pairs induced by the beam-beam interactions. This background is simulated by the CAIN code, and generated e^+e^- pairs are also processed through the same full detector simulation program. The simulated detector response from the e^+e^- pairs, corresponding to numbers of bunch collisions (100 bunches as a default), are overlapped to each signal event. Another background source added are low momentum charged tracks from two-photon process (corresponding to 10 events as a default).

First step of the analysis starts from the reduction of the noise hits with cluster shape analyses. Almost all the background hits in the VX detector are generated by very low momenta e^+e^-'s which are curling as a helix with small radius within the VX detector region. Thus the shape of the cluster of the noise hits on the VX tends to be longer than that of hits generated by "signal" charged tracks. By applying cuts on shapes of VX hit cluster, number of background hits has been reduced to 1/3 keeping the signal hit efficiency to be more than 98 %.

We start the tracking from the fitting of the hits in the CT. Then the hits in IT are associated to these tracks. Since most of the problematic e^+e^-pairs have very low momenta, the hit density in IT region is already low enough. Hence the association of the hits on the IT is rather easy. Then analysis proceeds to the association of the tracks obtained from CT and IT (CT+IT track) to the clusters found in the VX. We have compared the following two methods for the association;

1. a conventional "Road Method": The positions predicted by the CT+IT track are compared with those of VX clusters in each VX layer, and nearest clusters are retained.
2. "Local Tracking": first, candidates of track segments are locally made only with the VX clusters. In order to reduce the combinatorial associations, accumulated distribution of VX hits in all layers in the ϕ-z plane is used, and peaked clusters in the plane are defined as a local track segments. Then the track parameters of the local segments are compared with those of CT+IT tracks, and associated to the most appropriate tracks from the CT+IT. Finally re-fits are made globally for all hits found in CT, IT and VX.

[a] Note that the hits on a layer and the next layer can be highly correlated since the hits are induced by an $e^\pm$ from vicinity of the interaction point of the beams.

To check the tracking performance, we define the proper tracking as the track having correct hit association for all layers of VX. Dependence of the proper tracking efficiency on the momentum of the signal μ is shown in Fig 1. As a default, the e^+e^- pairs from 100 bunch-interactions and charged tracks from 10 two-photon events are overlapped. Especially for charged tracks with momentum below 1 GeV, difference of efficiencies between two methods mentioned above are fairly large. Fig2 shows the proper track reconstruction efficiencies as functions of the amount of overlapped background of; (upper) e^+e^- pairs indicated by the number of bunches in a train, and (lower) two-photon processes. The signal μ momentum is fixed to 1 GeV. For both cases, amount of the other background is fixed to the default values.

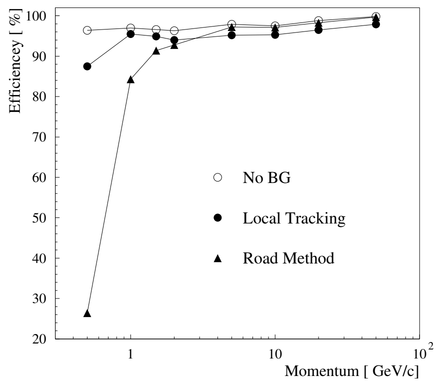

Figure 1: Momentum dependence of proper track reconstruction efficiency.

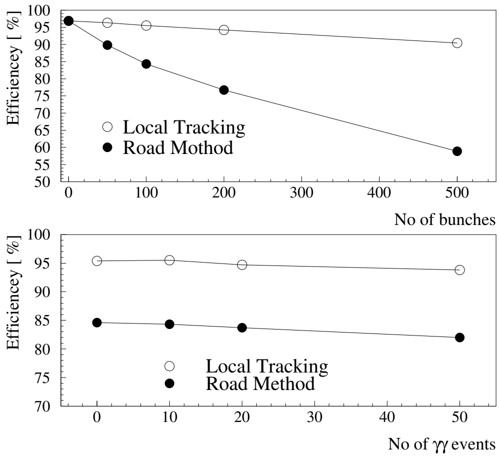

Figure 2: Noise hit rate dependence of track reconstruction efficiency for 1 GeV single muon.

Efficiencies obtained by two track finding methods do not depend on amount of overlapped two-photon background significantly. The degradation of the efficiency obtained by the "Local Tracking" method is found to be small even at the extremely high background rate, while the efficiency by the simple "Road method" decreases rapidly as amount of background from e^+e^- pairs grows. In order to perform a good tracking, a self-fit capability in vertex detector is found to be very helpful. Parameters in this method should be optimised further. Also an interpolation of tracks taking into account energy losses and multiple-scatterings should be used, especially for lower momentum charged tracks found in the CT detector. These improvements are addressed in the future studies.

3 Event Overlap

The effective cross-section σ_{eff} of the overlapping events[b] can be written as $\sigma_{eff} = \sigma_1 \times \sigma_2 \times \mathcal{L}_{bunch}$, where $\sigma_{1,2}$ are the production cross-section of each physics process, and $\mathcal{L}_{bunch}$ is the integrated luminosity in a bunch (luminosity per bunch). At the future linear collider, the luminosity per bunch can reach up to 1 μb^{-1} level,

[b]It has to be modified with Poisson probability for only one two-photon overlap, two two-photon overlap, three or more etc.. for large overlapping rate.

which is 2–3 order of magnitude higher than that at LEP/SLC. The most severe overlap comes from two-photon backgrounds. Roughly speaking, its cross-section is around 100 nb, while the cross-section depends on the cut in the kinematics, and the calculated cross-section has large uncertainty by nearly factor two [c]. Hence the average overlap rate could reach to 10 % or more for the luminosity per bunch of 1 μb^{-1}, even if we assume that we have perfect identification of the bunch of the event. The assumption of the perfect bunch identification may have to be relaxed when we have short bunch spacing of 1.4 nsec at JLC or NLC.

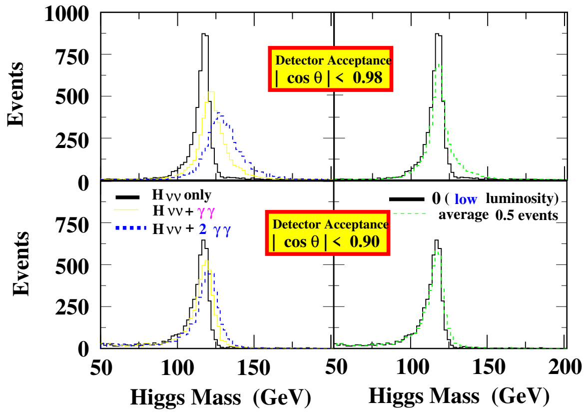

Figure 3: Distributions of the reconstructed mass of the Higgs in $e^+e^- \to \nu\bar{\nu}h^0$ process. Upper plots are for the mass with hits observed in the detector acceptance $|\cos\theta| \leq 0.98$, and bottom plots are for ≤ 0.90. Left plots are those for none, one, two two-photon events overlapped. The dotted lines in the right side plots are the reconstructed mass in case 0.5 events are expected in average for the overlap.

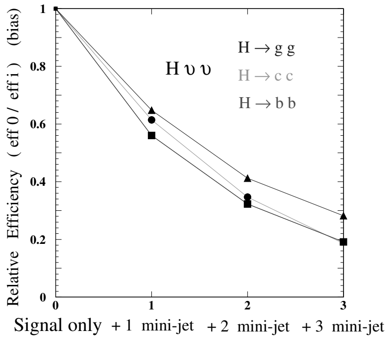

Figure 4: Degradation of the detection efficiency for the $e^+e^- \to h^0\nu\bar{\nu}$ process as a function of the number of two-photon processes overlapped to the signal event. Three lines correspond to different decay of the Higgs.

In case two or more events happen in single bunch collision, the separation of the events is extremely difficult. The separation is almost impossible for the neutral particles like γ or K_L. Some of the charged tracks might be rejected looking into the production point in beam direction, however such rejection might make significant bias in the Higgs precise measurements since the displaced vertex may come from the heavy quark decay of the Higgs.

Several simulation studies have been attempted. The simulation overlaps the hard scattering events of signal or background processes, with one or more two-photon events. We have used the JSF Quick-simulator [6] for this purpose. The data base are separately generated for the hard processes and the two-photon backgrounds. Afterward they are overlapped each other with event production points displaced according to the assumed beam spread at the interaction point. One of the significant effect is found in the reconstructed mass of the Higgs in $e^+e^- \to \nu\bar{\nu}h^0$ process. Figure 3 shows the reconstructed mass with/without two-photon overlap. No event selection is made for the plots. The distributions are shown for the differ-

[c] Note that the two-photon processes include "normal" two-photon process in which the two virtual photon interacts, and interaction between a virtual photon and real photon induced by the beamstrahlung effect, which may roughly doubles the cross-section.

ent detector acceptance to be used in the mass reconstruction. Since the two-photon background tends to make energy-flow in the forward region, the bias in the mass reconstruction could be reduced if we use the detector information only from the central part, while the signal tagging efficiency in a mass window is reduced as shown in the figure. The effect on the signal tagging efficiencies is shown in Fig4. The vertical axis is the efficiency normalised to that without two-photon overlap. Significant degradation of the tagging efficiency is found. The main reason of the loss of the efficiency is the distorted mass distribution with overlapping two-photon events. Also the other kinematic values such as missing momentum direction are affected significantly. Furthermore the background contamination especially Weν events increases rapidly as two-photon overlap rate grows.

The other effect is that in the flavour tagging which relies on the tracks displaced from the event primary vertex. The overlapping event has, in general, its event-production-point different from the original event, since the beam has a finite width. If we use the information only in r-ϕ projection, the effect can be minimised thanks to the tiny width of the beam in the projection. However the beam spread is larger in the beam-direction. Simulation studies have been made also for the flavour tagging. Possible bias has been checked with different assumptions for the beam spread in beam direction. As we have expected, the effects are found to be negligible in r-ϕ projection. The results obtained in the 3-dimensional tagging show a small effects for 80 μm spread in z-direction at the interaction point which is the current design value at JLC. When we increase the beam spread, the bias increases almost linearly.

Although the studies have just started and the analyses are not optimised for the two-photon overlapping, the results indicate the several important issues for the accelerators, detectors and monitoring systems. Note that our aimed precisions for the Higgs measurements are percent order or less. We need good "time-stumps" for each hits in the detectors to identify the corresponding bunch. Both trackers and calorimetry are required to have good time resolution especially at JLC/NLC. Since the overlapping rate depends on the luminosity per bunch, the operation of the accelerators are required to be stable bunch by bunch, and the monitoring of the luminosity per bunch might be necessary. One may use the data at low luminosity to investigate the effects in real data, overlapping the hits from hard scattering events with minimum-bias events including two-photons. Many studies are addressed in the future.

References

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