Effect of Beamstrahlung in Higgs Measurements

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Beamstrahlung may affect measurement of Higgs boson mass largely by reducing actual beam energy from its nominal value and making the spectrum broad. Estimating the effect and reflect it in design beam parameters is thus important for the sake of realistic measurement. The effect on Higgs boson mass distribution is studied using Monte Carlo simulations. Beam parameters will need to be considered with care when the average beamstrahlung energy loss becomes larger than 3% at the centre-of-mass energy $\sqrt{s} = 300$ GeV.

1 Introduction

In the linear collider projects, beam focalization at the interaction point is essential to achieve high luminosity. This feature increases charge density of the beam as well, giving rise to significant "beamstrahlung". Electrons and positrons in collision could have had lost some of their energy independently by emitting synchrotron radiation in the electromagnetic field of on-coming beam, causing smaller centre-of-mass energy $\sqrt{s}$ than the nominal value and imbalance of the beam particle energy. Using the nominal $\sqrt{s}$ as total energy and assuming balanced beam energy as constraints in analysis will lead to a shift of measured H boson mass, resulting in its broad distribution. In addition, the imbalance of collision energy makes the centre-of-mass system different from the laboratory system, and boosts the produced Z and H bosons, affecting selection efficiencies. Thus, beamstrahlung effect can make the signal hard to be distinguished from background and therefore it is important to estimate the effect and take it into consideration in designing of beam optics.

2 Parametrisation of Beamstrahlung

The intensity of the beam-beam interaction is characterised by the beamstrahlung parameter [1] Y:

$$\mathrm{Y} \propto \frac{\mathrm{N_b}}{(\sigma^*_{\mathrm{x}} + \sigma^*_{\mathrm{y}})} \frac{\mathrm{E_b}}{\sigma_{\mathrm{z}}}$$

where N_b, E_b and σ_z are the number of particles per bunch, the beam energy and the r.m.s. bunch length, and σ^*_x and σ^*_y are the r.m.s. beam sizes at the interaction point after being pinched by the beam-beam interaction. When $\mathrm{Y} \ll 1$, which will be the case up to 1 TeV of beam energy, the average energy loss δ_{B} scales as [1]:

$$\delta_{\mathrm{B}} \equiv \left\langle -\frac{\delta E_b}{E_b} \right\rangle \propto \frac{N_b^2}{(\sigma^*_x + \sigma^*_y)^2} \frac{E_b}{\sigma_z}$$

Assuming fixed E_b and σ_z, and flat beams ($\sigma_x^* \gg \sigma_y^*$), the average energy loss depends only on two parameters, N_b and σ_x^*. In the following discussions, these two parameters are moved in Monte Carlo simulations [3] as in Table 1 in order to study the effect of beamstrahlung at various intensities. A parameter is defined to note the intensity as:

$$\eta_{\rm B} \equiv \left(\frac{N_b/0.63 \times 10^{10}}{\sigma_x^*/260\mathrm{nm}} \right)^2 \frac{E_b/150\mathrm{GeV}}{\sigma_z/90\mu\mathrm{m}}$$

For comparison, the values of this parameter for the current JLC beam designs [2] is shown in Table 2.

Table 1: The beam parameters used in the study of beamstrahlung effect.

$\sqrt{s}$(GeV)	$N_b(10^{10})$	σ_x^*(nm)	σ_y^*(nm)	$\sigma_z(\mu$m)	$\eta_{\rm B}$
300		No Beamstrahlung			0.0
300	0.32	260	3	90	0.25
300	0.63	260	3	90	1.0
300	1.26	368	3	90	2.0
300	1.89	450	3	90	3.0

Table 2: The $\eta_{\rm B}$ parameter for the JLC beam designs [2]. The values at $\sqrt{s} = 300$ GeV are derived assuming $\sigma_{x,y}^* \propto 1/\sqrt{E_b}$ which is the case when the emittance is constant in a beam optics setting.

	$\sqrt{s}$(GeV)	$N_b(10^{10})$	σ_x^*(nm)	σ_y^*(nm)	$\sigma_z(\mu$m)	$\delta_{\rm B}$(%)	$\eta_{\rm B}$
A	500	0.75	286	3.15	90	4.42	2.0
	300	0.75	369	4.07	90		0.70
X	500	0.55	222	2.86	80	4.39	2.0
	300	0.55	287	3.69	80		0.70
Y	500	0.70	222	2.86	80	6.67	3.2
	300	0.70	287	3.69	80		1.1

3 Effect of Beamstrahlung

Analysis of Higgs boson mass measurement will utilise the center-of-mass energy $\sqrt{s} = E_{e^-} + E_{e^+}$ and energy balance $E_{e^-} = E_{e^+} = E_b$ as the constraints in kinematic calculation. The loss of the energy of beam partcles induced by beamstrahlung shifts $\sqrt{s}$ and $E_{e^-} - E_{e^+}$ from their nominal value as shown in Figure 1. And thus the measured Higgs boson mass will also be affected. The clearest and the most precise measurement of Higgs boson mass in ZH production will be performed in the leptonic channel where Z boson decays into a lepton pair and the Higgs boson mass is measured as its recoil mass. Figure 2 shows the effect of beamstrahlung on the recoil mass distribution in the muon channel obtained from Monte Carlo

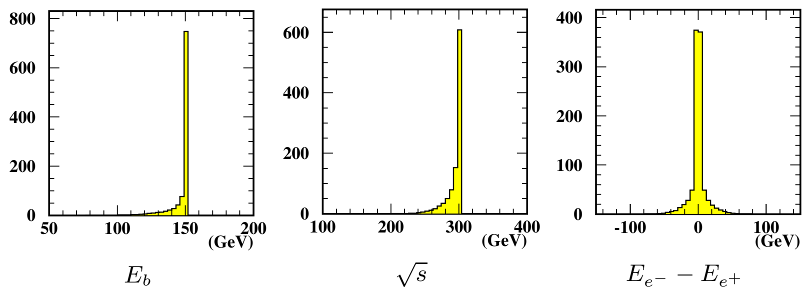

Figure 1: The effect of beamstrahlung at $\eta_{\mathrm{B}} = 1.0$ on beam energy E_b (left), centre-of-mass energy $\sqrt{s} = E_{e^-} + E_{e^+}$ (centre) and energy balance $E_{e^-} - E_{e^+}$ (right). The calculations are done using the program written by N. Toomi.

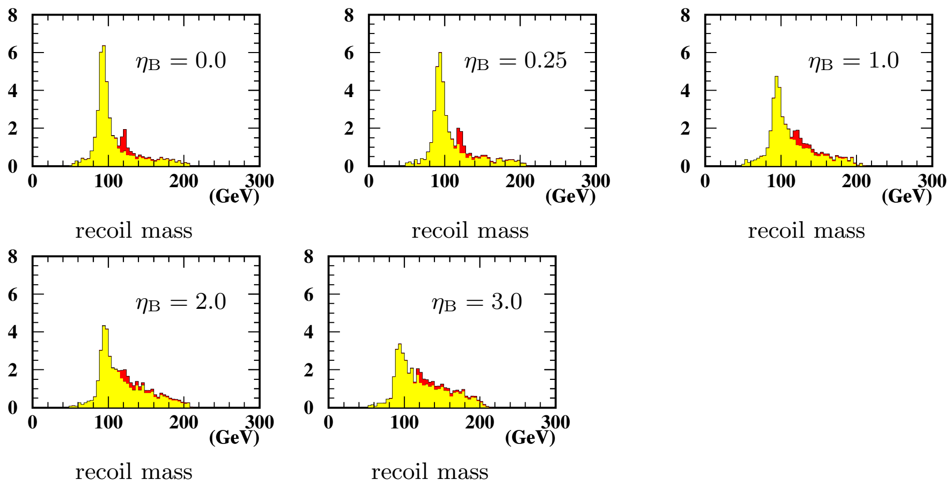

Figure 2: The recoil mass of muon pairs in Monte Carlo simulations of ZZ (light shaded) and ZH (dark shaded) production. The muon pairs are selected as their invariant mass nearly equal to Z boson mass.

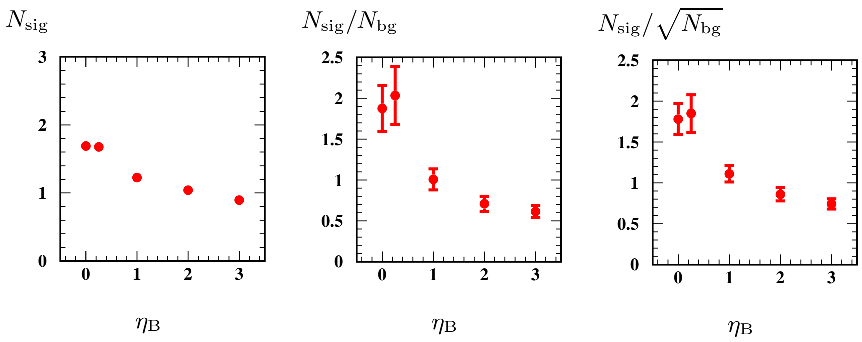

Figure 3: The number of signal events selected $N_{\rm sig}$, the signal-to-background ratio $N_{\rm sig}/N_{\rm bg}$, and the figure of merit $N_{\rm sig}/\sqrt{N_{\rm bg}}$. The values are normalised to the luminocity of 1 fb^{-1}.

simulations.[3] The H boson signal is not easily distinguished even at $\eta_{\rm B} = 1.0$. The beamstrahlung effect reduces the efficiency of the event selection [3] from 28.8% ($\eta_{\rm B} = 0.0$) to 20.0% ($\eta_{\rm B} = 1.0$). For comparisons of the effect among different $\eta_{\rm B}$, a figure of merit is defined as $N_{\rm sig}/\sqrt{N_{\rm bg}}$, where $N_{\rm sig}$ and $N_{\rm bg}$ are the number of signal (ZH) and background (ZZ) events selected, and shown in Figure 3.

4 Summary

As shown in Figure 2, Higgs boson signal with the assumed mass of 120 GeV produced at $\sqrt{s} = 300$ GeV is not very easy to be distinguished from the background at $\eta_{\rm B} \geq 1.0$ which corresponds to $\delta_{\rm B} \gtrsim 3\%$. Figure 3 also suggests beam parameters with $\eta_{\rm B} < 1.0$ are to be chosen. Beam parameters leading to a higher intensity of beamstrahlung will need to be considered with care, even if a larger luminosity is to be achieved.

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References

1. J.P. Delahaye *et al.*, CERN/PS/97-051 (1997), and the references in it.
2. T. Tauchi, presentation at this conference.
3. I. Nakamura, presentation at this conference.