PROCEEDINGS OF SCIENCE

Integrated luminosity measurement at CEPC

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The very forward region is one of the most challenging regions to instrument at a future e^+e^- collider. At CEPC, machine-detector interface include, among others, a calorimeter dedicated for precision measurement of the integrated luminosity at a permille level or better. Here we review a feasibility of such precision, from the point of view of detector mechanical precision and beam-related requirements.

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1. Introduction

Relative uncertainty of the integrated luminosity measurement at CEPC is set to a permille level or better, in order to enable the CEPC physics program aiming to test the validity scale of the Standard Model [1]. Precision reconstruction of position and energy of electromagnetic showers generated by the Bhabha scattering at a high-energy e^+e^- collider can be achieved with finely granulated luminometer [2]. However, the reconstruction precision doesn't exhaust the long list of systematic uncertainties in integrated luminosity measurement, including *detector related uncertainties*, *beam related uncertainties* and *uncertainties originating from physics interactions* (like beam-beam interactions, beam-gas scattering and physics background). In this paper we review the effects of detector and beam related uncertainties, namely mechanical uncertainties of the luminometer position and size and uncertainties related to the beam energy, beam synchronization and interaction point displacements.

2. Forward region at CEPC

Luminometer at CEPC is proposed to cover the polar angle region between 26 mrad and 105 mrad corresponding to the detector aperture of 25 mm for the inner radius and 100 mm for the outer, at 100 cm distance from the interaction pint (IP). The most compact design currently proposed seems to be Si-W sandwich type of calorimeter that could provide over 20 X_0 in a longitudinal dimension not larger than 10 cm [1]. Luminometer might be supplemented with an additional layer of tracker in order to improve e-γ separation and calibration of the device. Since the luminometer is placed at z=±100 cm that is a half a way of the tracking volume, shower leakage from the outer edge of the luminometer have been studied and proven to be negligible after absorption by a 5 mm iron filter positioned around the luminometer [1]. Layout of the very forward region at CEPC is given in Figure 1 [1].

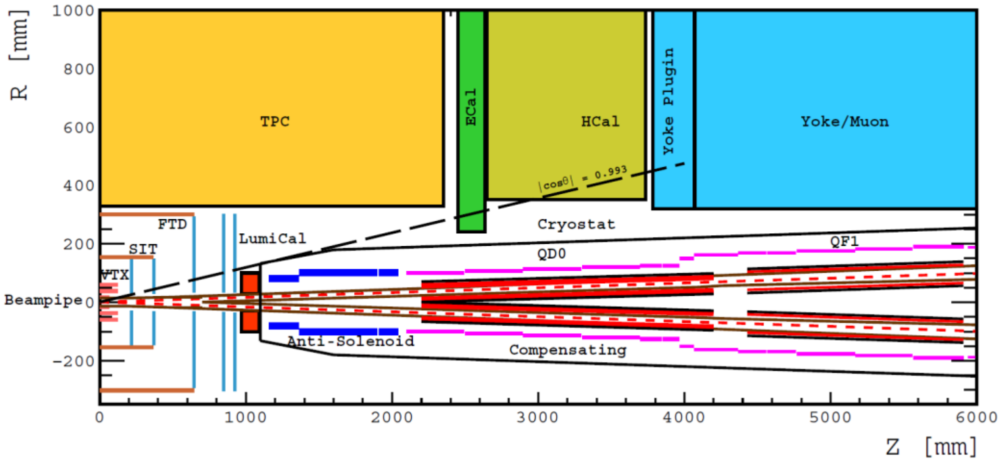

Figure 1: Layout of the very forward region at CEPC.

3. Systematic uncertainties of the integrated luminosity from mechanics and MDI

Systematic uncertainties from detector and machine-detector interface (MDI) related effects have been quantified through a simulation study, assuming 10^7 Bhabha scattering generated using BHLUMI Bhabha event generator [3], at two CEPC center-of-mass energies: 240 GeV and Z^0 production threshold. Detector fiducial volume, where the showers are fully contained and thus the sampling term constant, is between 50 mm and 75 mm radial distance from the detector axis that is assumed to be set at the outgoing beam. The crossing-angle at CEPC is 33 mrad [1]. The effective Bhabha cross-section in this angular range is of order of a few nb. Final state particles are accepted in the polar angle range from 45 mrad to 85 mrad that is within 8 mrad margin outside of the detector fiducial volume to allow events with non-collinear FSR to contribute. Close-by particles are summed up to imitate cluster merging. We assume that the shower leakage from the luminometer is negligible.

Furthermore, we have applied event selection that is asymmetric in polar angle acceptance on the left and right arm of the detector, as it has been done at OPAL [4]. That is, at one side we consider the full fiducal volume, while at the other side we shrink the radial acceptance for Δr. This has been done subsequently to the left (L) and right (R) side of the luminometer, on event by event basis. In addition, we require high-energy electrons carrying above 50% of the available beam energy. Against this type of event selection for luminosity measurement, we compare the selection based of the full fiducial volumes on both sides of the detector. An example is given in Figure 2, illustrating the cancelation of systematics uncertainties caused by the assumption of L-R symmetry in an event.

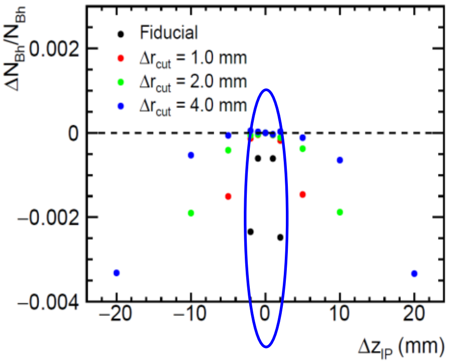

Figure 2: Luminosity uncertainty from the longitudinal IP displacements w.r.t. the luminometer, for symmetric (circled) and asymmetric selection with a radial shrink of the fiducial volume Δr.

Beam related uncertainties considered:

- uncertainty of the average net center-of-mass energy (ΔE_{CM}),
- uncertainty of the asymmetry in energy of the e^+ and e^- beams, ($|E_{e+}-E_{e-}|$)
- uncertainty of the beam energy spread ($\Delta(\sigma_E)/\ \sigma_E$),
- IP position displacements w.r.t. the luminometer, radial and axial (Δx_{IP}, Δz_{IP}), caused by the finite beam transverse sizes and beam synchronization, respectively.

Detector related uncertainties considered:

- uncertainty of the luminometer inner radius (Δr_{in}),
- spread of the measured radial shower position w.r.t. to the true impact position on the luminometer front plane (σ_r),
- uncertainty of the longitudinal distance between left and right halves of the luminometer (Δd),

- mechanical fluctuations of the luminometer position w.r.t the IP caused by vibrations and thermal stress, radial and axial (σ_{xIP}, σ_{zIP}),
- twist of the calorimeters corresponding to different rotations of the left and right detector axis w.r.t. the outgoing beam ($\Delta\varphi$).

Table 1 summarizes systematic uncertainties at 240 GeV center-of-mass energy and at the Z^0 pole, for symmetric and asymmetric selections. 10^{-3} and 10^{-4} luminosity uncertainties from each individual effect are assumed at 240 GeV and Z^0 pole, respectively.

parameter	**limit@240 GeV symmetric sel.**	**limit@240 GeV asymmetric sel.**	**limit@91 GeV asymmetric sel.**
ΔE_{CM} (MeV)	120	120	5
$\lvert E_{e+}-E_{e-}\rvert$ (MeV)	120	240	11
$\Delta(\sigma_E)/\sigma_E$	20%	canceled	canceled
Δx_{IP} (mm)	0.1	1.0	0.5
Δz_{IP} (mm)	1.4	10.0	2.0
beam synch. (ps)	1	15	3
Δr_{in} (μm)	13	10	1
σ_r (mm)	0.15	1.00	0.20
Δd (mm)	1.00	1.00	0.08
σ_{xIP} (mm)	0.1	1.0	0.5
σ_{zIP} (mm)	1	10	7
$\Delta\varphi$ (mrad)	6.0	6.0	0.8

Table 1: Summary of the systematic uncertainties from mechanics and MDI in the integral luminosity measurement at 240 GeV and 91 GeV CEPC.

4. Conclusion

It is clear that the uncertainty of the luminometer inner radius together with the uncertainty of the available center-of-mass energy (for the Bhabha cross-section calculation) are posing the most challenging requirements on detector and MDI. Permille precision of the integrated luminosity seems to be feasible from the point of view of the existing technologies. Luminosity uncertainty of 10^{-4} at the Z^0 pole seems to be more demanding. In particular, having in mind the requirement on the average center-of-mass uncertainty at the level of a few MeV. However, one should have in mind that the relevant physics processes might have the same cross-section dependence with $\sqrt{s}$ as the Bhabha scattering, in which case this particular effect cancels out.

References

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