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Integrated luminosity measurement at CEPC

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Abstract: The very forward region of a detector at future e^+e^- collider is the one of the most challenging regions to instrument. A luminometer – compact calorimeter dedicated for precision measurement of the integrated luminosity at a permille level or better is needed. Here we review a feasibility of such precision at CEPC, considering detector mechanical precision and beam-related requirements. We also discuss capabilities of experimental determination of the effective centre-of-mass energy determination, from the perspective of integrated luminosity precision requirements at the Z^0 pole.

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1. Introduction

The Circular Electron Positron Collider (CEPC) is a large international scientific facility proposed by the Chinese particle physics community in 2012 to test the validity scale of the Standard Model (SM) in precision measurements in the Higgs, BSM and EW sector. It is designed to operate as a Z factory, WW and a Higgs factory [1]. In order to achieve precision required by the CEPC physics program, relative uncertainty of the integrated luminosity should be of order of 10^{-4} at the Z^0 pole and of order of 10^{-3} at 240 GeV.

2. Systematic uncertainties of 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 events generated using BHLUMI [2], at 240 GeV and Z^0 pole. Luminometer axis is set at the outgoing beam, at 0.95 m from the interaction point (IP), with the fiducial volume acceptance between 53 mrad and 79 mrad. The crossing angle between colliding beams is set to be 33 mrad. We have applied event selection that is asymmetric in polar angle acceptance on the left and right arms of the detector, as in [3] leading to cancelation of systematic uncertainties caused by possible left-right asymmetry in an event. Comparison of results against the full fiducial volume counting is given in Table 1, at 240 GeV center-of-mass energy and at the Z^0 pole.

Table 1: Summary of the systematic limits from mechanics and MDI in the integrated luminosity measurement at 240 GeV and 91.2 GeV CEPC , assuming 10^{-3} an 10^{-4} luminosity precision, respectively.

parameter	limit@240 GeV symmetric sel.	limit@240 GeV asymmetric sel.	Limit@91.2 GeV asymmetric sel.
ΔECM (MeV)	120	120	5
$\|E_{e+}-E_{e-}\|$ (MeV)	120	240	11
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
R_r (mm)	0.15	1.00	0.20
Δd (mm)	1.00	1.00	0.08
$\sigma_{X_{IP}}$ **(mm)**	0.1	1.0	0.5
$\sigma_{Z_{IP}}$ **(mm)**	1	10	7
Δφ (mrad)	6.0	6.0	0.8

The MDI related effects list as follows: uncertainty of the average net center-of-mass energy (ΔE_{CM}), uncertainty of the asymmetry in energy of the beams, ($|E_{e+}-E_{e-}|$), radial and axial IP position displacements (Δx_{IP}, Δz_{IP}). Considered detector-related uncertainties arising from manufacturing, positioning and alignment are: uncertainty of the luminometer inner radius (Δr_{in}), spread of the measured radial shower position w.r.t. to the true impact position (R_r), uncertainty of the longitudinal distance between left and right halves of the luminometer (Δd), radial and axial mechanical fluctuations of the luminometer position $(\sigma_{X_{IP}}, \sigma_{Z_{IP}})$ and twist of the calorimeters corresponding to different rotations of the left and right detector axis (Δφ).

3.Systematic uncertainties of integrated luminosity from the uncertainty of the effective center-of-mass energy

As proposed for FCC-ee [4], acollinearity of muons from $e^+e^-\to\mu^+\mu^-$ measured in the central tracker can be employed to determine effective center-of-mass energy s' critically limiting precision for the cross-section calculations (Table 1):

$$\boxed{\frac{s'}{s} = \frac{\sin\theta^+ + \sin\theta^- - |\sin(\theta^+ + \theta^-)|}{\sin\theta^+ + \sin\theta^- + |\sin(\theta^+ + \theta^-)|}}$$

With WHIZARD 2.6.2 [5] we generated 250K and 100K di-muon events at the Z^0 pole and 240 GeV, respectively, showing that the effective center-of-mass energy can be determined better than10 MeV, after 2 minutes of data taking at the Z^0 pole, assuming the nominal polar angle resolution of the central tracker at CEPC (0.1 mrad) [1].

Table 2. Beam-spread variations experimentally accessible at CEPC and FCCee.

CEPC	**Luminosity @ IP (cm^{-2} s^{-1})**	**Nominal beam-spread (%)**	**Number of events**	**Cross-section $e^+e^-\to\mu^+\mu^-$**	**Collecting time**	**Beam-spread variation (δE_b)**
Z^0 pole	$3.2\cdot10^{35}$	0.080	250 KEvt.	1.5 nb	~ 4 min (2 min for 10^{-4} of $\Delta L/L$)	$\sim2.5\cdot10^{-2}\cdot\delta E_b$ (900 keV)
240 GeV	$3.0\cdot10^{34}$	0.134	100 KEvt.	4.1 pb	~ 10 days	$\sim 0.15\cdot\delta E_b$ (~24 MeV)

4. Discussion and summary

We have shown that the uncertainty of the luminometer inner radius at the micron level together with the uncertainty of the available center-of-mass energy are critical requirements on the integrated luminosity measurement. Required precision of the effective center-of-mass energy can be reached from experimental determination of the muon's acolinearity after only 2 minutes of collecting di-muon events at the Z^0 pole CEPC. More details on this research can be found in [6].

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