Integrated luminosity measurement at CEPC

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Luminometer at CEPC

Integrated luminosity measurement - a counting experiment based on Bhabha scattering, \( L = \frac{N_{bh}}{\sigma} \) (in theory)

Major effects (uncertainties) influencing Bhabha count:
- mechanics (positioning and alignment)
- beam-energy asymmetry, beam synchronization, IP displacements
- effective center-of-mass energy
- physics background from 2-photon processes
- Beam-induced effects: EM deflection

- Si-W sandwich type of calorimeter, over \( 20 X_0 \) (longitudinal, not larger than 10 cm)
- distance from IP: 100 cm
- polar angle coverage: 26 mrad – 105 mrad
- fiducial volume: 53 mrad – 79 mrad
- goals: relative uncertainty of the integrated luminosity measurement \( \sim 10^{-4} \) at \( Z^0 \) pole and \( \sim 10^{-3} \) at 240 GeV
- beam crossing angle: 33 mrad
Systematic uncertainties of integrated luminosity from mechanics and MDI

The MDI related effects are:
• uncertainty of the effective center-of-mass energy (ΔE_{CM}) for the x-section calculation
• uncertainty of the asymmetry in energy of the e^+ and e^- beams, (|E_{e^+} - E_{e^-}|)
• IP position displacements with respect to the luminometer, radial and axial (Δx_{IP}, Δz_{IP}), caused by the finite beam transverse sizes and beam synchronization, respectively

Detector-related uncertainties arising from manufacturing, positioning and alignment:
• 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 (R_{r})
• uncertainty of the longitudinal distance between left and right halves of the luminometer (Δd)
• mechanical fluctuations of the luminometer position with respect to the IP caused by vibrations and thermal stress, radial and axial (σ_{x_{IP}}, σ_{z_{IP}})
• twist of the calorimeters corresponding to different rotations of the left and right detector axis with respect to the outgoing beam (Δφ)

Physics background: 10^{-4} contamination at all energies without specific selection

<table>
<thead>
<tr>
<th>parameter</th>
<th>limit@240 GeV symmetric sel.</th>
<th>limit@240 GeV asymmetric sel.</th>
<th>limit@91 GeV asymmetric sel.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔE_{CM} (MeV)</td>
<td>120</td>
<td>120</td>
<td>5</td>
</tr>
<tr>
<td>(</td>
<td>E_{e^+} - E_{e^-}</td>
<td>) (MeV)</td>
<td>120</td>
</tr>
<tr>
<td>Δx_{IP} (mm)</td>
<td>0.1</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Δz_{IP} (mm)</td>
<td>1.4</td>
<td>10.0</td>
<td>2.0</td>
</tr>
<tr>
<td>beam synch. (ps)</td>
<td>1</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Δr_{in} (μm)</td>
<td>13</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>R_{r} (mm)</td>
<td>0.15</td>
<td>1.00</td>
<td>0.20</td>
</tr>
<tr>
<td>Δd (mm)</td>
<td>1.00</td>
<td>1.00</td>
<td>0.08</td>
</tr>
<tr>
<td>σ_{x_{IP}} (mm)</td>
<td>0.1</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>σ_{z_{IP}} (mm)</td>
<td>1</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Δφ (mrad)</td>
<td>6.0</td>
<td>6.0</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Main systematic effects are coming from the uncertainty of the luminometer inner radius and uncertainty of the effective center-of-mass energy
Systematic uncertainties of integrated luminosity from uncertainty of the effective center-of-mass energy

Effective center-of-mass energy can be determined within the beam-spread from experimentally measurable quantities
- From the acolinearity of muons from $e^+e^-\rightarrow\mu^+\mu^-$ measured in the central tracker, as proposed for FCC-ee*

\[ s' = \frac{\sin \theta^+ + \sin \theta^- - |\sin(\theta^+ + \theta^-)|}{\sin \theta^+ + \sin \theta^- + |\sin(\theta^+ + \theta^-)|} \]

- We’ve shown that with the nominal polar angle resolution of the central tracker @ CEPC (0.1 mrad), effective center-of-mass energy can be determined with 2.5% of the beam-spread (<1 MeV) relative accuracy, at $Z^0$ pole, after 4 minutes of data taking
- The above meets precision requirements of $1.5\cdot10^{-4}$, 300 keV and 100 keV for the relative precision on $Z^0$ cross-section, total width and mass, respectively
- Only 2 minutes of running at the $Z^0$ pole are required to meet the relative precision of integrated luminosity of $10^{-4}$
- At 240 GeV, effective center-of-mass energy uncertainty within the existing beam-spread is satisfactory for $10^{-3}$ relative precision of integrated luminosity

<table>
<thead>
<tr>
<th>CEPC</th>
<th>Luminosity @ IP (cm$^2$ s$^{-1}$)</th>
<th>Nominal beam-spread (%)</th>
<th>Number of events</th>
<th>Cross-section $e^+e^-\rightarrow\mu^+\mu^-$</th>
<th>Collecting time</th>
<th>Beam-spread variation ($\delta E_b$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z^0$ pole</td>
<td>$3.2 \cdot 10^{35}$</td>
<td>0.080</td>
<td>250 KEvt.</td>
<td>1.5 nb</td>
<td>~ 4 min (2 min for $10^{-4}$)</td>
<td>~$2.5%$-$\delta E_b$ (900 keV)</td>
</tr>
<tr>
<td>Higgs factory</td>
<td>$3.0 \cdot 10^{34}$</td>
<td>0.134</td>
<td>100 KEvt.</td>
<td>4.1 pb</td>
<td>~ 10 days</td>
<td>~$15%$-$\delta E_b$ (~24 MeV)</td>
</tr>
</tbody>
</table>

*P. Janot, Beam Energy Spread Measurement @ FCC-ee, talk given at the FCC-ee Polarization Workshop, CERN, 2017