Machine-Detector Interface for the CEPC

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Joint effort of the Detector and Accelerator Groups
Machine-Detector Interface

- Machine Detector Interface (MDI) covers all aspects that are common to both accelerator and detector, and represents one of the most challenging areas of the CEPC project.

- Topics covered in this talk:
  - Interaction Region (IR) layout
  - Beam-induced backgrounds
  - Luminosity instrumentation
Interaction Region Layout

- IR: beampipe, surrounding silicon detectors, luminosity calorimeter, final focus quadrupoles (QD0 and QF1), etc.
- Short focal length of $L^*=1.5$ m → realisation of the design luminosity without exploding the chromaticity corrections
Beam-induced Backgrounds

- Background originating from beam-beam interactions
  - Beamstrahlung
  - Electron-positron pair production
  - Hadronic background

- Additional background sources
  - Synchrotron radiation
  - Beam-gas interaction
  - Radiative Bhabha scattering
  - Beam halo muons
  - Beam dumps …

To be minimised with careful machine design

Beam-beam interaction and the so-called “Pinch Effect”
Beam-beam Interaction Simulation

- **Generator of Unwanted Interactions for Numerical Experiment Analysis—Program Interfaced to GEANT → GUINEA-PIG**
- Input machine parameters for CEPC (and compared to ILC250)

<table>
<thead>
<tr>
<th>Machine Parameters</th>
<th>CEPC</th>
<th>ILC250</th>
</tr>
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<tbody>
<tr>
<td>$E_{cm}$ [GeV]</td>
<td>240</td>
<td>250</td>
</tr>
<tr>
<td>Particles per bunch</td>
<td>$3.7 \times 10^{11}$</td>
<td>$2.0 \times 10^{10}$</td>
</tr>
<tr>
<td>Beam size $\sigma_x/\sigma_y$ [nm]</td>
<td>73700/160</td>
<td>729/7.7</td>
</tr>
<tr>
<td>Beam size $\sigma_z$ [$\mu$m]</td>
<td>2260</td>
<td>300</td>
</tr>
<tr>
<td>Norm. Emittance $\varepsilon_x/\varepsilon_y$ [mm $\cdot$ mrad]</td>
<td>1595/4.8</td>
<td>10/0.035</td>
</tr>
</tbody>
</table>

- Results being cross-checked with CAIN
Beamstrahlung

- Pinch Effect $\rightarrow$ bent particle trajectories $\rightarrow$ "beamstrahlung"
- Beamstrahlung photons collimated in a small cone along the beam axis and of low transverse momentum
- Concerns for the collider design (e.g. power deposition); direct hitting on detector components must be avoided

Guinea-Pig simulation result with the ILC250 configurations
Electron-Positron Pair Production

- Coherent and incoherent electron-positron pair production → one of the most important backgrounds for the CEPC detector

Detector components (including the beampipe) need to be placed away from the kinematic edge)
Radiation Levels

- Hit density of 0.2 hits/cm$^2$/BX at r=1.6 cm (the first VTX layer)
- Radiation tolerance requirements (safe factor ~ 5):
  - Non-ionising Energy Loss (NIEL) $\sim 10^{11}$ 1MeV n$_{eq}$/cm$^2$ per year
  - Total Ionisation Dose (TID) $\sim 100$ kRad per year

Mild requirements

Extra feasibility on detector design (technologies, layout …)
Detector Layout Optimisation

- Low hit density (0.2 hits/cm$^2$/BX) and mild radiation-tolerance requirement allow further optimisation of the detector layout, in particular the vertex detector

  - “smaller $r$”: 1$^{st}$ detector layer closer to the Interaction Point to improve the IP resolution

  - “larger $z$”: to compensate for the performance loss due to less strip detector layers in the forward region

Other constraints to be taken into account …
Hadronic Background

- The $\gamma\gamma \rightarrow q\bar{q}$ process gives rise to the hadronic background → “mini-jet”: large polar angle + transverse momentum

- Rarely produced cross-section artificially inflated by $10^5$ times in simulation

- But requires full detector simulation to understand the impact on the calorimeter performance
Luminosity Instrumentation

- Small uncertainty on luminosity measurement required by precision Higgs/Z measurements: $\frac{\Delta L}{L} \sim 10^{-3}$
  - Calorimeter with silicon-tungsten sandwich structure to measure small angle radiative Bhabha scattering events
  - $z \in [115,128 \text{ cm}]$ (right before the final focusing magnet) and $\theta \in [60,90 \text{ mrad}]$ requiring angular precision $\frac{\Delta \theta}{\theta_{\text{min}}} < 5 \times 10^{-4}$
  - Other sources of uncertainties: theoretical calculation of cross-section, polar angle bias, physics background subtraction, etc.
    → Nontrivial to achieve the target luminosity uncertainty

- Online luminosity monitor allowing fast tuning of beam param.
  - Radiation-hard sensors (e.g. CVD diamond) to measure radiative Bhabha events at zero photon scattering angle
Summary

- Machine Detector Interface (MDI) complicated and challenging
- Preliminary layout of the interaction region (short $L^*$)
- Backgrounds from beam-beam interactions

Next Step: detailed studies on all aspects

Thanks for your attention!