CEPC Radiation Background Studies

Hongbo Zhu (IHEP)
On behalf of the CEPC MDI Study Group
OUTLINE

• Interaction Region Layout
• Radiation Backgrounds
  • *Synchrotron Radiation*
  • *Pair Production*
  • *Off Energy Beam Particles*
• Summary and Outlook
**INTERACTION REGION LAYOUT**

- Interaction region layout in CDR (*to be optimized*)

![Diagram of Interaction Region Layout](image-url)
Radiation Background Sources

• Important inputs to the detector (+machine) designs, e.g. detector occupancy, radiation tolerance ...

• Must investigate different sources (beam-induced or luminosity related) of radiation backgrounds
  • Synchrotron radiation
  • Beamstrahlung, Pair production
  • Off-energy beam particles (radiative Bhabha scattering, beamstrahlung, beam-gas interaction, etc.)
SYNCHROTRON RADIATION

• Beam particles bent by magnets (last bending dipole, focusing quadrupoles) can emit synchrotron radiation photons → critical at circular machines

• BDSim to transport beam (core + halo) from the last dipole to the interaction region and record the particles hitting the central beryllium beam pipe

Most of them scattered by the beampipe between [1,2 m] into the central region
**Mask Tip Design**

Collimator shape

\[
\theta_b = 1.17 \text{ mrad} \\
\theta_y = -127 \pm 7 \mu \text{rad at } Z=-1.51 \text{m} \\
\theta_y = -130 \pm 8 \mu \text{rad at } Z=-1.93 \text{m}
\]

High-Z material required: Au chosen

K-shell photon included in simulation
WITH COLLIMATORS

• **Three masks** located at $|Z|=1.51$, 1.93 and 4.2 m along the beam pipe to the IP to block scattered SR photons → shielding the central beam pipe

• Number of photons per bunch hitting the central beam pipe dropping from 80,000 to **250**
**Beamstrahlung & Pair Production**

- Estimated as the most important background at Linear Colliders, *not an issue for lower energy/luminosity machines*
- Charged particles attracted by the opposite beam emit photons (*beamstrahlung*), followed by electron-positron pair production (*dominate contributions from the incoherent pair production*)

Most electrons/positrons are produced with low energies and *in the very forward region*, and can be confined within the beam pipe with a strong detector solenoid;

However, a non-negligible amount of electrons/positrons can hit the detector → **radiation backgrounds**

*Hadronic backgrounds much less critical*

Simulated with GUINEAPIG with external field implemented and cross checked with CAIN
• Using hit density, total ionizing dose (TID) and non-ionizing energy loss (NIEL) to quantify the radiation background levels

• Adopted the calculation method used for the ATLAS background estimation (ATL-GEN-2005-001), safety factor of $\times 10$ applied
PAIR PRODUCTION (UPDATED)

- Estimated backgrounds in the vertex detector (still using the CEPC CDR machine parameters)

### Higgs ($\sqrt{s} = 240$ GeV)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Hit Density [cm$^{-2}$BX$^{-1}$]</th>
<th>TID [kRad/yr]</th>
<th>1 MeV Equ. Neu. Fluence [n$_{eq}$cm$^{-2}$yr$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.26</td>
<td>591.14</td>
<td>1.11 x 10$^{12}$</td>
</tr>
<tr>
<td>2</td>
<td>1.70</td>
<td>472.12</td>
<td>8.66 x 10$^{11}$</td>
</tr>
<tr>
<td>3</td>
<td>0.14</td>
<td>42.63</td>
<td>9.08 x 10$^{10}$</td>
</tr>
<tr>
<td>4</td>
<td>0.11</td>
<td>35.62</td>
<td>8.09 x 10$^{10}$</td>
</tr>
<tr>
<td>5</td>
<td>0.02</td>
<td>6.15</td>
<td>2.57 x 10$^{10}$</td>
</tr>
<tr>
<td>6</td>
<td>0.01</td>
<td>5.37</td>
<td>2.41 x 10$^{10}$</td>
</tr>
</tbody>
</table>

### Z ($\sqrt{s} = 91$ GeV)

<table>
<thead>
<tr>
<th>B = 2 T</th>
<th>Hit Density [hits/cm$^2$.BX]</th>
<th>TID [kRad/year]</th>
<th>NIEL [$10^{12}$ 1 MeV n$_{eq}$/cm$^2$.year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>B = 3 T</td>
<td>0.019</td>
<td>274.09</td>
<td>0.51</td>
</tr>
</tbody>
</table>
OFF-ENERGY BEAM PARTICLES

- Beam particles losing energy (radiative Bhabha scattering, beam-gas interaction, beam-gas interaction, etc.) larger than acceptance kicked off their orbit \( \rightarrow \) lost close or even in the interaction region.
COLLIMATORS

- Two sets of collimators (NOT Sufficient!) placed upstream to stop off-energy beam particles, far away from the beam clearance area (exact aperture size subject to optimization)

Inspired by the BEPCII collimator design
Radiative Bhabha Scattering

- Event generated with BBBrem and particles tracked with SAD
- Hit map in the vertex detector (with collimators)

More hits on the −X side
Nearly uniform along the z-axis
**BEAM-GAS INTERACTION**

- Generated with *customized code* and tracked with *SAD*
- Hit map in the vertex detector (with collimators)

(c) X-Y plane (Beam-Gas Scattering)  (d) R-Z plane (Beam-Gas Scattering)
**Beam Thermal Photons**

- Generated with **customized code** and tracked with **SAD**
- Hit map in the vertex detector (with collimators)
**Off-Energy Beam Particles**

- Estimated backgrounds at the first vertex detector layer (still using the CEPC CDR machine parameters)

<table>
<thead>
<tr>
<th></th>
<th>Hit Density [hits/cm²·BX]</th>
<th>TID [MRad/year]</th>
<th>NIEL [10¹² 1 MeV nₑq/cm²·year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiative Bhabha</td>
<td>0.93</td>
<td>1.2</td>
<td>4.08</td>
</tr>
<tr>
<td>Beam Thermal Photons</td>
<td>2.31</td>
<td>2.3</td>
<td>5.48</td>
</tr>
<tr>
<td>Beam-Gas Interaction</td>
<td>368.37</td>
<td>39.90</td>
<td>965</td>
</tr>
</tbody>
</table>

Vacuum pressure assumed to be $10^{-7}$ Pa

Beam-gas interaction backgrounds reduce linearly to the vacuum pressure level $\rightarrow$ better vacuum, e.g. $10^{-8}$ Pa
BETTER UNDERSTANDING OF BEAM-GAS INTERACTION
**Verification with BEPC II/BES III**

**Basic Principles**

**Single beam** mode: three dominant contributions from Touschek, beam-gas and electronics noise (+ cosmic rays)

\[
O_{\text{single beam}} = O_{\text{Touschek}} + O_{\text{beam-gas}} + O_{\text{e-noise, cosmic}}
\]

\[
= S_t \cdot D(\sigma_x') \frac{I_t \cdot I_b}{\sigma_x \sigma_y \sigma_z} + S_g \cdot I_t \cdot P(I_t) + S_e
\]

**Double beam** mode: additional contributions from luminosity related backgrounds, e.g. radiative Bhabha scattering

\[
O_{\text{double beam}} = O_{e^+} + O_{e^-} + O_L
\]
**WHAT CAN BE LEARNT FROM B II/BES III**

**SINGLE BEAM MODE**

- **No Beam**, detector with high voltage on to measure the backgrounds in MDC and EMC → $S_e$
- Touschek backgrounds: with fixed beam energy and total current ($I_t$), varying bunch number (changing $I_b$), bunch size ($\sigma_y, \sigma_z$) → $S_t$
- Beam-gas backgrounds: with $I_b$ and bunch size fixed, increasing the bunch number (increasing $I_t$) → $S_g$

$$S_t \cdot D(\sigma_{x'}) \frac{I_t \cdot I_b}{\sigma_x \sigma_y \sigma_z} + S_g \cdot I_t \cdot P(I_t) + S_e$$

Example plot from SuperKEKB

16-17 January 2020

CEPC Radiation Backgrounds, H. Zhu
WHAT CAN BE LEARNT FROM B II/BES III

**DOUBLE BEAM MODE**

\[ 0_{\text{double beam}} = O_{e^+} + O_{e^-} + O_{L} \]

- Fixed **beam energy & current, bunch parameters**, operating
  - Single \(e^+/e^-\) beam
  - Separate \(e^+\) and \(e^-\) beams
  - Colliding \(e^+\) and \(e^-\) beams

- Thorough understanding of the **radiative Bhabha scattering** backgrounds would be vital for optimizing the collimators.

The number of collimators is shown at around 2-4. Taking into account the necessary freedom required for tuning, the number of the collimators is extremely insufficient. According to experience in other colliders such as LEP, KEKB, PEP-II, SuperKEKB, 10-20 of them may be needed per IP.
PROPOSED EXPERIMENTAL STEPS

SuperKEKB background runs

• Propose to repeat the summer studies with longer machine time (extending to 12 hours) to take background with more machine/beam parameter points (details attached)

• Important to improve the communication between the machine and detector operation
**Vacuum Pressure Degradation**

- Beam-gas backgrounds depending significantly on the vacuum pressure, which can be affected by synchrotron radiation during operation;

- LEP studies back in 1982 with very low photon energy (critical energy ~2 keV);

- Relevant parameters for CEPC:
  - Higgs: ~360 keV on arc, ~25 keV on last bending;
  - Z: ~23 keV on arc.

- To find an end station at the SR facility with the beam energy of ~25 keV, e.g. BSRF.
**EXPERIMENTAL SETUP**

- CEPC vacuum chamber prototypes (Cu/Al, 2 meters long preferred but depending on the space)
- Gas pressure monitors and gas composition analysis tools
  - Pump the Cu/Al chamber and set incident angle and energy;
  - Record pressure, gas type, pump speed with photon exposure;
  - Stop when reach the stopping condition (accumulated current or pressure); expose the chamber to air;
  - Repeat with different conditions (energy, angle, hitting side...).
SUMMARY & OUTLOOK

• Radiation backgrounds calculated for different sources
  • Pair production, synchrotron radiation, off-energy beam particles (with collimators)

• Validate (partly) the simulation codes with background data from BEPC II, LEP II and SuperKEKB
  • Participate in the background studies for SuperKEKB/Belle II Phase III commissioning, postponed to May ...

• To include machine related backgrounds and provide updates as the machine design evolves ...