CEPC MDI

Sha Bai
On behalf of the MDI group and Accelerator Physics group

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Outline

• MDI layout
• IR superconducting magnets
• Solenoid compensation
• Beam pipe
• Synchrotron radiation
• Beam loss backgrounds
• Collimator
• Summary
• The Machine Detector Interface of CEPC double ring scheme is about ±7m long from the IP.
• The CEPC detector superconducting solenoid with 3 T magnetic field and the length of 7.6m.
• The accelerator components inside the detector without shielding are within a conical space with an opening angle of cosθ=0.993.
• The e+e- beams collide at the IP with a horizontal angle of 33mrad and the final focusing length is 2.2m
• Lumical will be installed in longitudinal 0.95~1.11m, with inner radius 28.5mm and outer radius 100mm.
According to the considerations of injection and beam tail effect after collision, CEPC IR beam stay clear region are defined as:

\[
\begin{align*}
\text{BSC}_x &= \pm(18\sigma_x + 3\text{mm}) \\
\text{BSC}_y &= \pm(22\sigma_y + 3\text{mm})
\end{align*}
\]
# QD0/QF1 Physics Design Parameters

\[ \beta_y^*=1.5\text{mm} \]

<table>
<thead>
<tr>
<th></th>
<th>QD0</th>
<th></th>
<th>QF1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>QD0</strong> Horizontal BSC 2 ((18\sigma_x+3))</td>
<td><strong>Vertical BSC 2 ((22\sigma_y+3))</strong></td>
<td><strong>e+e- beam center distance</strong></td>
<td><strong>QF1</strong> Horizontal BSC 2 ((18\sigma_x+3))</td>
</tr>
<tr>
<td>Entrance</td>
<td>10.65 mm</td>
<td>14.69 mm</td>
<td>72.61 mm</td>
<td>Entrance</td>
</tr>
<tr>
<td>Middle</td>
<td>13.65 mm</td>
<td>16.99 mm</td>
<td>105.61 mm</td>
<td>Middle</td>
</tr>
<tr>
<td>Exit</td>
<td>19.32 mm</td>
<td>15.67 mm</td>
<td>138.61 mm</td>
<td>Exit</td>
</tr>
<tr>
<td>Good field region</td>
<td><strong>Horizontal 19.32 mm; Vertical 17.03 mm</strong></td>
<td></td>
<td><strong>Horizontal 26.85 mm; Vertical 14.96 mm</strong></td>
<td></td>
</tr>
<tr>
<td>Effective length</td>
<td>2 m</td>
<td></td>
<td>Effective length</td>
<td>1.48 m</td>
</tr>
<tr>
<td>Distance from IP</td>
<td>2.2 m</td>
<td></td>
<td>Distance from IP</td>
<td>4.43 m</td>
</tr>
<tr>
<td>Gradient</td>
<td>136 T/m</td>
<td></td>
<td>Gradient</td>
<td>110 T/m</td>
</tr>
</tbody>
</table>
IR superconducting magnets

- Both of QD0 and QF1 are double aperture superconducting magnets.
- QD0/QF1 and anti-solenoid are all in a cryogenics system.
- QD0/QF1 peak field in coil 3.2T/3.8T.
Solenoid compensation

- Anti-solenoids are designed to compensate the solenoid field from the detector.
- The integral longitudinal field \( \int B_z \, ds \) within 0~2.12m is 0 and \( B_z \) is less than 300Gauss after 2.12m away from the IP.
The inner diameter of the beryllium pipe ~28mm. The length of beryllium pipe is ±7cm in longitudinal.

Due to detector beamstrahlung incoherent pairs, beam pipe in between 0.2~0.5m should be changed into cone.

The connection from single pipe to double pipe is realized by a bellow at 0.5~0.7m.

From the bellow to the entrance of the quadrupole, the beam pipe is special shaped with the cross section at ±0.7m in longitudinal for installing cooling and bellows.

For the beam pipe within the final doublet quadrupoles, room temperature beam pipe has to be adopted.
- Last bending magnet generates a fan of SR with power 60W contributed by e+ will go through the IP. The critical energy of photons is about 45keV.
- No SR hits directly on the detector beryllium pipe.
- The synchrotron radiation generated by electron beam is symmetric with positron beam.
## Critical energy of bending magnets in IR

<table>
<thead>
<tr>
<th>Name</th>
<th>length</th>
<th>angle</th>
<th>Distance from IP</th>
<th>Critical energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMV01IRU</td>
<td>93.38</td>
<td>-0.0011</td>
<td>67.66</td>
<td>45keV</td>
</tr>
<tr>
<td>BMV02IRU</td>
<td>68.95</td>
<td>-0.00156</td>
<td>168.99</td>
<td>86.7keV</td>
</tr>
<tr>
<td>BMV03IRU</td>
<td>68.95</td>
<td>-0.00212</td>
<td>239.94</td>
<td>117.9keV</td>
</tr>
<tr>
<td>BMV1IRU</td>
<td>68.95</td>
<td>0</td>
<td>312.99</td>
<td>0</td>
</tr>
<tr>
<td>BMV2IRU</td>
<td>68.95</td>
<td>-0.00352</td>
<td>383.94</td>
<td>195.7keV</td>
</tr>
<tr>
<td>BMV3IRU</td>
<td>68.95</td>
<td>-0.00352</td>
<td>456.99</td>
<td>195.7keV</td>
</tr>
<tr>
<td>BMV01IRD</td>
<td>60.97</td>
<td>0.00154</td>
<td>46.06</td>
<td>97keV</td>
</tr>
<tr>
<td>BMV02IRD</td>
<td>44.2</td>
<td>0.00259</td>
<td>116.07</td>
<td>224.6keV</td>
</tr>
<tr>
<td>BMV03IRD</td>
<td>44.2</td>
<td>0.00311</td>
<td>162.27</td>
<td>269.7keV</td>
</tr>
<tr>
<td>BMV1IRD</td>
<td>44.2</td>
<td>0</td>
<td>210.57</td>
<td>0</td>
</tr>
<tr>
<td>BMV2IRD</td>
<td>44.2</td>
<td>0.00537</td>
<td>256.77</td>
<td>465.7keV</td>
</tr>
<tr>
<td>BMV3IRD</td>
<td>44.2</td>
<td>0.00537</td>
<td>305.07</td>
<td>465.7keV</td>
</tr>
</tbody>
</table>
SR from QD0 in horizontal and vertical plane

- SR fans generated by QD0 of particles in $3\sigma$.
- The total SR power generated by the QD0 is 639.3 in horizontal and 165.6W in vertical.
- The critical energy of photons is about 1.3MeV in horizontal and 397keV in vertical.
The total SR power generated by the QF1 magnet is 1567W in horizontal and 42W in vertical. The critical energy of photons is about 1.6MeV in Horizontal and 225keV in vertical. There is no SR photons within $6\sigma_x$ directly hitting or once-scattering to the detector beam pipe.
SR from B, FD in horizontal plane

~last bending magnet upstream of IP and final doublet
The synchrotron radiation in the IR

- “Room temperature” beam pipe and conduction cooled superconducting magnet has to be adopted.

- The synchrotron radiation power within QD0 is **2.8W along 2m**, on QF1 is **3.1W along 1.48m**. The region between QD0 and QF1 is **36.1 W (0.23m)**.
# CEPC beam lifetime

<table>
<thead>
<tr>
<th></th>
<th>Beam lifetime</th>
<th>others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantum effect</td>
<td>&gt;1000 h</td>
<td></td>
</tr>
<tr>
<td>Touscheck effect</td>
<td>&gt;1000 h</td>
<td></td>
</tr>
<tr>
<td>Beam-Gas (Coulomb scattering)</td>
<td>&gt;400 h</td>
<td>Residual gas CO, 10⁻⁷Pa</td>
</tr>
<tr>
<td>Beam-Gas (bremsstralung)</td>
<td>63.8 h</td>
<td></td>
</tr>
<tr>
<td>Beam-Thermal photon scattering</td>
<td>50.7 h</td>
<td></td>
</tr>
<tr>
<td>Radiative Bhabha scattering</td>
<td>100 min</td>
<td></td>
</tr>
<tr>
<td>Beamstrahlung</td>
<td>60 min</td>
<td></td>
</tr>
</tbody>
</table>
Radiative Bhabha scattering events

- According to the off-momentum dynamic aperture after optimizing the CEPC lattice, and considering the beam-beam effect and errors, the energy acceptance of CEPC is about 1.5%.
- Radiative Bhabha scattering is simulated by BBBrem or Py_RBB.
- Generate $2 \times 10^5$ particles.
RBB lost particles statistic
~first two turns

- Set aperture according to beam pipe
- RBB generated at IP1, tracking in SAD
- The position and coordinate in phase space of lost particles near the IP are recorded.
- Most the events lost in the detector immediately. A few particles with high energy will lost near the IP after one revolution for a small energy loss.
- Although pretty large fraction of events lost in the downstream region, the radiation damage for detector component is tolerable.
Loss particles due to RBB in turns

- Compared to the one turn’s tracking, more particles get lost in the upstream region of the IR.
- The events lost in the upstream region are more dangerous for they are likely permeate into the detector components, even with the small flying angle respect to the longitudinal direction considered.
- Collimators are needed.
Beamstrahlung events

- Compared with the energy spread of RBB, beamstrahlung effect is increased in exponential growth with energy spread, so most of particles energy spread are distributed in a region close to 1.5%.
- Beamstrahlung events have been generated with Guinea-Pig++ or Py_BS.
- Generate 200000 particles.
BS lost particles statistic
~first two turns

- Set aperture according to beampipe
- BS generated at IP1, tracking in SAD
- The position and coordinate in phase space of lost particles near the IP are recorded.
- Energy spread distribution close to the energy acceptance, the beam loss particles not appeared in the downstream of first turn.
Loss particles due to BS in turns

- Compared to the one turn’s tracking, more particles get lost in the upstream region of the IR.
- The events lost in the upstream region are more dangerous for they are likely permeate into the detector components, even with the small flying angle respect to the longitudinal direction considered.
- Collimators are needed.
Collimator design in ARC

- Beam stay clear region: $18 \sigma_x + 3\text{mm}, 22 \sigma_y + 3\text{mm}$
- Impedance requirement: slope angle of collimator $< 0.1$
- To shield big energy spread particles, phase between pair collimators: $\pi/2 + n\pi$
- Collimator design in large dispersion region: $\sigma = \sqrt{\varepsilon \beta + (D_x \sigma_e)^2}$

<table>
<thead>
<tr>
<th>name</th>
<th>Position</th>
<th>Distance to IP/m</th>
<th>Beta function/m</th>
<th>Horizontal Dispersion/m</th>
<th>Phase</th>
<th>BSC/2/m</th>
<th>Range of half width allowed/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>APTX1</td>
<td>D1I.1884</td>
<td>2413.35</td>
<td>113.83</td>
<td>0.24</td>
<td>355.91</td>
<td>0.00968</td>
<td>1~10</td>
</tr>
<tr>
<td>APTX2</td>
<td>D1I.1906</td>
<td>1933.35</td>
<td>113.83</td>
<td>0.24</td>
<td>357.66</td>
<td>0.00968</td>
<td>1~10</td>
</tr>
<tr>
<td>APTX3</td>
<td>D1I.1868</td>
<td>2756.21</td>
<td>113.83</td>
<td>0.24</td>
<td>354.66</td>
<td>0.00968</td>
<td>1~10</td>
</tr>
<tr>
<td>APTX4</td>
<td>D1I.1878</td>
<td>2550.49</td>
<td>113.83</td>
<td>0.24</td>
<td>355.41</td>
<td>0.00968</td>
<td>1~10</td>
</tr>
<tr>
<td>APTY1</td>
<td>D1I.1890</td>
<td>2276.21</td>
<td>20.70</td>
<td>0.24</td>
<td>358.39</td>
<td>0.003348</td>
<td>1~3.5</td>
</tr>
<tr>
<td>APTY2</td>
<td>D1I.1900</td>
<td>2070.49</td>
<td>20.70</td>
<td>0.24</td>
<td>359.14</td>
<td>0.003348</td>
<td>1~3.5</td>
</tr>
<tr>
<td>APTY3</td>
<td>D1I.1849</td>
<td>3167.62</td>
<td>20.70</td>
<td>0.24</td>
<td>355.14</td>
<td>0.003348</td>
<td>1~3.5</td>
</tr>
<tr>
<td>APTY4</td>
<td>D1I.1852</td>
<td>3099.06</td>
<td>20.70</td>
<td>0.24</td>
<td>355.39</td>
<td>0.003348</td>
<td>1~3.5</td>
</tr>
</tbody>
</table>
With 4 pair of collimators, RBB loss upstream with collimators half width x5mmy2mm are much similar with x5mmy3mm case

RBB loss with collimator put at small $\beta_y$ positon are much similar with big $\beta_y$ positon.
RBB loss with horizontal collimator half width

RBB loss upstream vs horizontal collimator half width (4 pairs)

Collimators at big $\beta_y$ position

Collimators at small $\beta_y$ position
BS loss upstream vs pair of collimators

- With 4 pair of collimators, BS loss upstream with collimators half width x5mmy2mm are much similar with x5mmy3mm case
- BS loss with collimator put at small $\beta_y$ positon are much similar with big $\beta_y$ positon.
BS loss with horizontal collimator half width

Collimators at big $\beta_y$ position

Collimators at small $\beta_y$ position
RBB and BS loss with collimators for Higgs

- horizontal collimator half width 5mm($14\sigma_x$), vertical collimator half width 2mm($127\sigma_y$).
- The collimators will not affect the beam quantum lifetime.
- Collimator put at small $\beta_y$ positon to reduce TMCI.
- The lost particles has been reduced to a very low level with the system of collimators, especially in the upstream of the IP.
- Although the beam loss in the downstream of the IP is still pretty large in the first turn tracking, the radiation damage and the detector background are not as serious as the loss rate for the relative small flying angle to the ideal orbit.
According to the off-momentum dynamic aperture after optimizing the CEPC lattice, and considering the beam-beam effect and errors, the energy acceptance of CEPC is about 1.5%.

When the energy acceptance is 1.5%, the beam-gas bremsstrahlung lifetime is about 63.8 hours.

Generate ~ 100000 particles.
The lost particles has been reduced to a very low level with RBB collimators, especially in the upstream of the IP, can be accepted by the detector. Although the beam loss in the downstream of the IP is still remained, the radiation damage and the detector background are not serious, since the direction is leaving the detector.
According to the off-momentum dynamic aperture after optimizing the CEPC lattice, and considering the beam-beam effect and errors, the energy acceptance of CEPC is about 1.5%.

When the energy acceptance is 1.5%, the beam-thermal photons scattering lifetime is about 50.7 hours.

Generate ~ 100000 particles.
Beam-Thermal photon scattering loss

- The lost particles has gone with RBB collimators in the upstream of the IP, can be accepted by the detector.
- Although the beam loss in the downstream of the IP is still remained, the radiation damage and the detector background are not serious, since the direction is leaving the detector.
Hit Density at VTX

- The level of the beam induced backgrounds are evaluated by the hit density at the vertex detector. ~1e+7 events input.
- The event rate with collimators is acceptable for the CEPC detector for beam loss particles.
- Requirement from detector: hit density should be smaller than a few hits/cm²/BX.
Summary

- Although the space of MDI is quite tight, each element can be installed.
- The detector solenoid field effect to the beam can be compensated.
- HOM of IR beam pipe has been simulated and water cooling was considered.
- For both upstream and downstream of IP, the critical energy of synchrotron radiation from the bending magnets is controlled to low level. There is no SR photons within $6\sigma_x$ directly hitting or once-scattering to the detector beam pipe.
- Beam loss background in the upstream of multi-turn tracking seems serious, but with four pairs of horizontal and vertical collimators in ARC(half width 5mm and 2mm), beam loss reduced significantly for Higgs factory.
- The event rate with collimators is acceptable for the CEPC detector for beam loss particles.
Thanks