CEPC MDI towards TDR

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for CEPC MDI group

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Outline

❖ MDI layout and IR design
❖ Synchrotron radiation and mask design
❖ Beam loss background and collimator design
❖ HOM absorber design
❖ Mechanics and assembly
❖ SC magnet supporting system
❖ IP BPM design
❖ Summary
The accelerator components inside the detector without shielding are within a conical space with an opening angle of \( \cos \theta = 0.993 \).

The e+e- beams collide at the IP with a horizontal angle of 33 mrad 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.

The Machine Detector Interface (MDI) of CEPC double ring scheme is about \( \pm 7 \)m long from the IP.

The CEPC detector superconducting solenoid with 3T magnetic field and the length of 7.6m.
The design of interaction region

The inner diameter of the beryllium pipe is 28mm with the length of ±7cm.

Without tungsten shield.
A significant fraction of these incident photons will forward scatter from the beam pipe surface and hit the central Be beam pipe (a cylinder located ±7 cm around the IP with a radius of 14 mm).

Masks are needed.

- IP upstream: $E_c < 120 \text{ keV}$ within 400m. Last bend (66m) $E_c = 45 \text{ keV}$
- IP downstream: $E_c < 300 \text{ keV}$ within 250m, first bend $E_c = 97 \text{ keV}$

<table>
<thead>
<tr>
<th>Surface</th>
<th>Power (W)</th>
<th>SR photons $&gt; 1 \text{ keV}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under QF1</td>
<td>2.51</td>
<td>$1.01 \times 10^9$</td>
</tr>
<tr>
<td>Between QF1 and QD0</td>
<td>40.04</td>
<td>$1.63 \times 10^{10}$</td>
</tr>
<tr>
<td>Under QD0</td>
<td>8.08</td>
<td>$3.26 \times 10^9$</td>
</tr>
<tr>
<td>In front of QD0</td>
<td>4.45</td>
<td>$1.80 \times 10^9$</td>
</tr>
</tbody>
</table>
The number of scattered photons that can hit the central beam pipe is greatly reduced to only those photons which forward scatter through the mask tips. The optimization of the mask tips (position, geometry and material) is presently under study.

3 mask tips are added to shadow the beam pipe wall reduces the number of photons that hit the Be beam pipe from $2 \times 10^4$ to about 200 (100 times lower).
The total SR power generated by the QD magnet is 639 W in horizontal and 166 W in vertical. The critical energy of photons are about 1.3 MeV and 397 keV in horizontal and vertical.

The total SR power generated by the QF1 magnet is 1567 W in horizontal and 42 W in vertical. The critical energies of photons are about 1.6 MeV and 225 keV in horizontal and vertical.

No SR photons within $10 \sigma_x$ directly hitting or once-scattering to the detector beam pipe.

Collimators for the beam loss will cut beam to $13 \sigma_x$. SR photons generated from $10 \sigma_x$ to $13 \sigma_x$ will hit downstream of the IR beam pipe, and the once-scattering photons will not go into the detector beam pipe but goes to even far away from the IP region.

SR photons from final doublet quadrupoles will not damage the detector components and cause background to experiments.
SR from solenoid combined field

- Due to the sol+anti-sol field strength quite high, maximum~4.24T, transverse magnetic field component is quite high.
- SR from vertical trajectory in sol+anti-sol combined field should be taken into account.
SR critical energy and power distribution

**Vertical SR critical energy distribution**
- Maximum: 670keV

**Vertical SR power distribution**
- Maximum: 31W
SR from solenoid combined field

- SR sector is focused in a very narrow angle from -116 urad to 131 urad.
- SR will not hit Berryllium pipe, and not cause background to detector.
- SR will hit the beam pipe ~213.5 m downstream from IP.
- Water cooling is needed.
Beam loss Backgrounds at CEPC

Beam Lost Particles
Energy Loss > 1.5% (energy acceptance)

Radiative Bhabha scattering
Beam-Gas Scattering

Beam-Thermal photon scattering
Beamstrahlung

242 bunches
Revolution frequency: 2997 Hz
1.5 \times 10^{11} \text{ particles/Bunch}
L: 3 \times 10^{34} cm^{-2}s^{-1}
<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 $\cdot 10^{-7}$Pa</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>74 min</td>
<td></td>
</tr>
<tr>
<td>Beamstrahlung</td>
<td>80 min</td>
<td></td>
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</tbody>
</table>
Loss particles due to RBB & BS

➢ For RBB, 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.
➢ For BS, energy spread distribution close to the energy acceptance, the beam loss particles not appeared in the downstream of first turn.
➢ Compared to the one turn’s tracking, more particles get lost in the upstream region of the IR.
➢ Although pretty large fraction of events lost in the downstream region, the radiation damage for detector component is tolerable.
➢ 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

- 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: $\sigma = \sqrt{\varepsilon \beta + (D_x \sigma_y)^2}$

<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.1897</td>
<td>2139.06</td>
<td>113.83</td>
<td>0.24</td>
<td>356.87</td>
<td>0.00968</td>
<td>2.2~9.68</td>
</tr>
<tr>
<td>APTX2</td>
<td>D1I.1894</td>
<td>2207.63</td>
<td>113.83</td>
<td>0.24</td>
<td>356.62</td>
<td>0.00968</td>
<td>2.2~9.68</td>
</tr>
<tr>
<td>APTX3</td>
<td>D1O.10</td>
<td>1832.52</td>
<td>113.83</td>
<td>0.24</td>
<td>6.65</td>
<td>0.00968</td>
<td>2.2~9.68</td>
</tr>
<tr>
<td>APTX4</td>
<td>D1O.14</td>
<td>1901.09</td>
<td>113.83</td>
<td>0.24</td>
<td>6.90</td>
<td>0.00968</td>
<td>2.2~9.68</td>
</tr>
</tbody>
</table>

- Only horizontal collimator are selected, vertical collimators are not needed.
- Vertical collimators are usually placed very close to the beam, no vertical collimators to avoid transverse mode coupling instability.
- horizontal collimator half width 5mm($13\sigma_x$)
- The collimators will not have effect on the beam quantum lifetime.
- 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.
The lost particles has been reduced to a very low level with 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.
HOM absorber

- TE mode, at crotch point (z~±700mm)
- Frequency 3.2996GHz \( \cdot \) \( Q_e = 1.42 \times 10^{12} \)
- This mode is trapped mode.
- HOM absorber is needed \( \cdot \) water cooling system considered.
- With the high order mode of this TE mode, eg. 3.715GHz.

- HOM absorber design refer to FCC, under development
- Distance from IP is 70cm~90cm in crotch section \( \cdot \) space conflict with RVC and IP BPM needs to be fixed.
- Impedance

Synchrotron radiation from Final doublet magnets and reflection part from mask \( \cdot \) HOM absorber radiation resistance requirements?
IR mechanics assembly typical point is remote vacuum connection.
- The sealing point is 6m away from the operation point.
- Ultrahigh vacuum sealing, Helicoflex.
CEPC MDI Lumical and accelerator components conflict in both position and alignment accuracy has been fixed: Lumical can be separated into 2 parts, one part with high precision installed and aligned with Be vacuum chamber, the other part 50~100kg can be installed and aligned with cryostat. And can be calibrated with IP BPM(<1um), Be pipe installed with detector.
1: Be and detector assembly and alignment, Lumical high accuracy part installed with Be pipe (Detector assembly can use the end cap.)

2: SC magnet, Lumical main part aligned and assembly with RVC, installed on supporting system and aligned.

3: Components in the second step with supporting system move to the setting position.

4: Beam pipe one side connected with cryostat using RVC.

5: Repeat the 2~4 step in the other side.

6: Technical detection, completed.
SC magnet supporting system

- Preliminary design, alignment adjust (manual operation, Push-pull screw+wedge block), transmission scheme (electric, gear, rack and guideway)
- Distance from front of supported equipment to detector 3757~6140mm
Considering response time and calibration difficulty, two 4 button electrodes BPM at each side of CEPC IR is adopted.

Most of CEPC IR beam pipe are cylinder or conic, only the part from 70cm to 95cm is special shape.

There is a bellows for the requirements of installation in the crotch region, located about 0.7 m from the IP. IP BPM will be installed at 80cm from the IP in the double pipe part.

- Beam pipe size: diameter 18.74mm
- Bunch length: 2.68mm
- Single bunch charge: 24nC
4 button electrodes BPM

4 button electrodes structure

Electrode diameter: 11.4 mm
Inner conductor diameter: 6 mm
Electrode pole to beam line: 19.4 mm

Electromagnetic field at electrodes

Electrodes signal (bunch length 2.68 mm)

Size and signal intensity can be satisfied by CEPC MDI requirement.

Due to the short bunch length, signal has many resonance hump, signal amplitude proportional to the bunch charge.
Luminosity monitoring

- **Relative luminosity monitoring (machine tuning, feedback…)**
  - Fast, precise, realtime
  - Train-integrated-luminosity
  - Bunch-integrated-luminosity

- **Radiative Bhabha process at vanishing photon scattering angle**
  - Proportional to luminosity
  - Large cross-section

- **Techniques and experiences**
  - ZDLM at BEPC-II
  - ZDLM (scintillator & Cherenkov, analog) and LumiBelle2 (diamond, digital) at SuperKEKB

- **Plans**
  - Figure out the requirement of the luminosity monitoring
  - Luminosity monitoring system
  - Search for the best candidate position for the luminosity monitor
  - Study on the signals / backgrounds
## MDI components status

<table>
<thead>
<tr>
<th>Name</th>
<th>status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superconducting magnet QD0</td>
<td>Designed</td>
</tr>
<tr>
<td>Superconducting magnet QF1</td>
<td>Designed</td>
</tr>
<tr>
<td>Cryostat</td>
<td>Under design</td>
</tr>
<tr>
<td>Detector solenoid</td>
<td>Designed</td>
</tr>
<tr>
<td>Anti-solenoid</td>
<td>Designed</td>
</tr>
<tr>
<td>BPM</td>
<td>Under design</td>
</tr>
<tr>
<td>Lumical</td>
<td>Under design</td>
</tr>
<tr>
<td>Luminosity monitoring</td>
<td>Under design</td>
</tr>
<tr>
<td>IR vacuum chamber</td>
<td>Physics designed</td>
</tr>
<tr>
<td>Berrylium pipe</td>
<td>Physics designed</td>
</tr>
<tr>
<td>RVC(remote vacuum connection)</td>
<td>Under design</td>
</tr>
<tr>
<td>Shielding</td>
<td>Under design</td>
</tr>
<tr>
<td>Cooling system</td>
<td>Under design</td>
</tr>
<tr>
<td>Vacuum pump</td>
<td>Under design</td>
</tr>
<tr>
<td>Supporting system</td>
<td>Under design</td>
</tr>
<tr>
<td>Flange</td>
<td>Under design</td>
</tr>
<tr>
<td>Bellows</td>
<td>Under design</td>
</tr>
<tr>
<td>Alignment</td>
<td>Under design</td>
</tr>
<tr>
<td>Trimming support in SC magnet</td>
<td>Under design</td>
</tr>
<tr>
<td>HOM absorber</td>
<td>Under design</td>
</tr>
<tr>
<td>Auxiliary coils in SC magnet</td>
<td>Under design</td>
</tr>
<tr>
<td>Coating</td>
<td>Under design</td>
</tr>
</tbody>
</table>
The finalization of the beam parameters and the specification of special magnets have been finished. The parameters are all reasonable.

The detector solenoid field effect to the beam can be compensated.

HOM of IR beam pipe has been simulated, water cooling was considered and HOM absorber is under design.

Beam lifetime of CEPC double ring scheme is evaluated.

The most importance beam loss background is radiative Bhabha scattering and beamstrahlung for the Higgs factory.

Collimators are designed in the ARC which is about 2km far from the IP to avoid other backgrounds generation. Beam loss have disappeared in the upstream of IP for both Higgs and Z factory.

Preliminary design of Remote Vacuum Connection(RVC) is finished. And preliminary procedures of mechanics assembly are under studying.

Towards TDR, many of the MDI components are under development.
Reference

- GEANT4: A Simulation toolkit, https://doi.org/10.1016/S0168-9002(03)01368-8
- Recent developments in Geant4, https://doi.org/10.1016/j.nima.2016.06.125
Thanks