MACHINE DETECTOR INTERFACE FOR CEPC*

S. Bai#[1], C. H. Yu[1,2], Y. W. Wang[1], Y. Zhang[1,2], D. Wang[1], H. P. Geng[1], Y. S. Zhu[1], J. Gao[1],
Z. H. Liu[3], Qi Yang[3]
[1]Institute of High Energy Physics, [100049] Beijing, China
[2]University of Chinese Academy of Sciences, [100049] Beijing, China
[3]Huiyu vacuum technology company, [110000] Shenyang, China

Abstract

The Circular Electron Positron Collider (CEPC) is a proposed Higgs factory with center of mass energy of 240 GeV to measure the properties of Higgs boson and test the standard model accurately. Machine Detector Interface (MDI) is the key research area in electron-positron colliders, especially in CEPC, it is one of the criteria to measure the accelerator and detector design performance. In this paper, we will introduce the CEPC superconducting magnets design, solenoid compensation, synchrotron radiation and mask design, detector background, collimator, mechanics assembly etc on, which are the most critical physics problem.

INTRODUCTION

With the discovery of a Higgs boson at about 125 GeV, the world high-energy physics community is investigating the feasibility of a Higgs Factory, a complement to the LHC for studying the Higgs [1]. There are two ideas now in the world to design a future higgs factory, a linear 125 × 125 GeV e^+e^- collider and a circular 125 GeV e^+e^- collider. From the accelerator point of view, the circular 125 GeV e^+e^- collider, due to its low budget and mature technology, is becoming the preferred choice to the accelerator group in China. MDI is one of the most challenging field in CEPC design, it almost covered all the common problems in accelerator and detector. Background is an important issue in MDI study. Every kinds of background source will increase the initial particles into detector, producing energy deposition in detector, which will make bad influence on the life of detector. Particles which hit the inner wall of beam pipe or collimators may interact with materials, producing lots of secondary particles into detector. These secondary particles will disturb the experiment and make damage to each layers. So it is necessary to reduce lost particles into detector.

The central field strength of CEPC detector solenoid is about 3T, it will introduce strong coupling of horizontal and vertical betatron motion, increasing the vertical emittance and also the vertical orbit. If it is not compensated, the IP beam size will increase, and degrade the luminosity.

In this paper, we will introduce the critical issues of CEPC MDI, including the superconducting magnets design, solenoid compensation, detector background, collimator design and mechanics assembly etc on.

MDI LAYOUT AND IR DESIGN

The machine-detector interface is about ±7 m in length in the IR as can be seen in Fig. 1, where many elements need to be installed, including the detector solenoid, luminosity calorimeter, interaction region beam pipe, beryllium pipe, cryostat and bellows. The cryostat includes the final doublet superconducting magnets and anti-solenoid. The CEPC detector consists of a cylindrical drift chamber surrounded by an electromagnetic calorimeter, which is immersed in a 3T superconducting solenoid of length 7.6 m. The accelerator components inside the detector should not interfere with the devices of the detector. The smaller the conical space occupied by accelerator components, the better will be the geometrical acceptance of the detector. From the requirement of detector, the conical space with an opening angle should not larger than 8.11 degrees. After optimization, the accelerator components inside the detector without shielding are within a conical space with an opening angle of 6.78 degrees. The crossing angle between electron and positron beams is 33 mrad in horizontal plane. The final focusing quadrupole is 2.2 m from the IP [2]. The luminosity calorimeter will be installed in a longitudinal location 0.95~1.11 m, with an inner radius of 28.5 mm and outer radius 100 mm. Primary results are got from the assembly, interfaces with the detector hardware, cooling channels, vibration control of the cryostats, supports and so on.

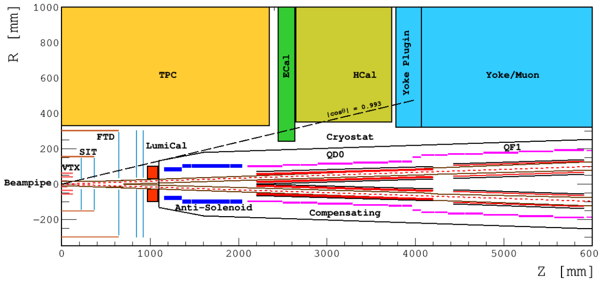

Figure 1: CPEC IR layout.

BEAM PIPE

To reduce the detector background and radiation dose from beam loss, the vacuum chamber has to accommodate the large beam stay clear region. In order to keep precise shaping, all these chambers will be manufactured with

---

* Work supported by National Key Programme for S&T Research and Development (Grant NO. 2016YFA0400400), and National Natural Science Foundation of China (NSFC, Project 11605210)

\# baisha@ihep.ac.cn

ISBN: 978-3-95450-216-5 doi:10.18429/JACoW-eeFACT2018-WEXBA05

computer controlled machining and carefully welded to avoid deformation.

The inner diameter of the beryllium pipe is chosen as 28 mm taking into account both mechanical assembly and beam background issues. The length of beryllium pipe is 14 cm in longitudinal. Due to bremsstrahlung incoherent pairs, the shape of the beam pipe between 0.2~0.5 m is selected as conic. There is a bellows for the requirements of installation in the crotch region, located about 0.7 m from the IP. A water cooling structure is required to control the heating problem of HOM. For the beam pipe within the final doublet quadrupoles, since there is a 4mm gap between the outer space of beam pipe and the inner space of Helium vessel [3], a room temperature beam pipe has been chosen. IR layout is shown in Fig. 2.

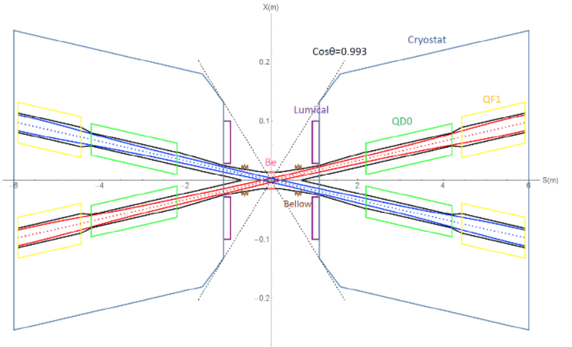

Figure 2: IR layout with beam pipes.

SOLENOID COMPENSATION

To compensate the solenoid field effect to the beam, compensating solenoid & Screening solenoid are installed outside of QD0/QF1 and IP, to make the integral field zero of the beam, and the longitudinal field of FD region zero. $\int B_z ds = 0$ within 0~2.12m; while Bz < 300Gauss away from 2.12m, which is shown in Fig. 3. Anti-solenoid divided into parts according to detector solenoid field in longitudinal. The skew quadrupole coils are designed to make fine tuning of Bz over the QF&QD region instead of the mechanical rotation. [4]

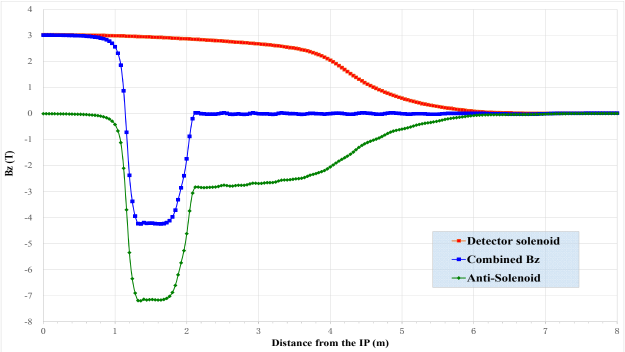

Figure 3: Detector solenoid compensation.

Due to the compensation of solenoid is only the integral field, the fringe field can’t be compensated. And the fringe field will cause a vertical closed orbit distortion and excite dispersion in the vertical direction, which contributes to an increase in the vertical emittance. The vertical emittance growth for Z mode is the most serious among the three operating energies due to the fringe field of the detector solenoid (3T). It is about 1.7%. But for Higgs it can be ingnored [4].

SYNCHROTRON RADIATION AND MASK DESIGN

Synchrotron radiation (SR) photons are emitted in a direction tangential to the particle trajectory [5] and contribute to the heat load of the beam pipe and can cause photon background to the experiments. Furthermore, the radiation dose can damage detector components. Therefore the beam optics should be carefully designed in order to prevent the SR photons from directly hitting or scattering into the detector beam pipe.

The maximum designed single beam current is 17.4 mA and the maximum energy is 120 GeV. The fan of SR photons in the IR are mainly generated from the final upstream bending magnet and the IR quadrupole magnets due to eccentric particles.

SR From Bending Magnets

An asymmetric lattice has been selected to allow softer bends in the upstream part of the IP. Reverse bending direction in the final bends avoids SR photons from hitting the IP vacuum chamber. In the upstream part of the IP the SR critical energy is less than 45 keV within 150 m and 120 keV within 400 m. For the downstream part of the IP, there are no bends in the last 50 m and the critical energy is less than 97 keV within 100 m and 300 keV within 250 m. Figure 4. 2. 6. 3 shows the SR fans in the IR produced by the positron beam. The synchrotron radiation generated by electron beam is symmetric.

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). By installing 3 mask tips along the inside of the beam pipe to shadow the inner surface of the pipe 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. The current design calls for at least 3 tips for each incoming beam.

SR In IR Vacuum Chamber

A room temperature beam pipe and conduction cooled superconducting magnet has been adopted. The synchrotron radiation power in QD0 is 2.8 W along 2 m, and in QF1 is 3.1 W along 1.48 m. In the region between QD0 and QF1 it is 36.1 W along 0.23 m, where water cooling is needed. Synchrotron radiation fans in the IR vacuum chamber is shown below in Fig. 4.

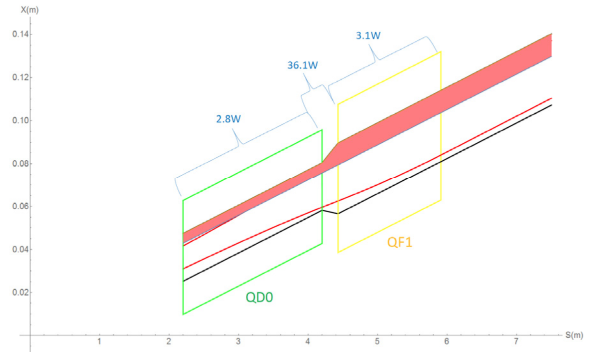

Figure 4: SR photon fans in the IR vacuum chamber.

SR In Final Doublet Quadrupoles

The total SR power generated by the QD0 magnet is 639W horizontally and 165W vertically. The photon critical energy is about 1.3MeV horizontally and 397keV vertically. The total SR power generated by the QF1 magnet is 1567W horizontally and 42W vertically. The photon critical energy is about 1.6MeV horizontally and about 225keV vertically. Below in Fig. 5 shows the synchrotron radiation fans horizontally and vertically from QD0.

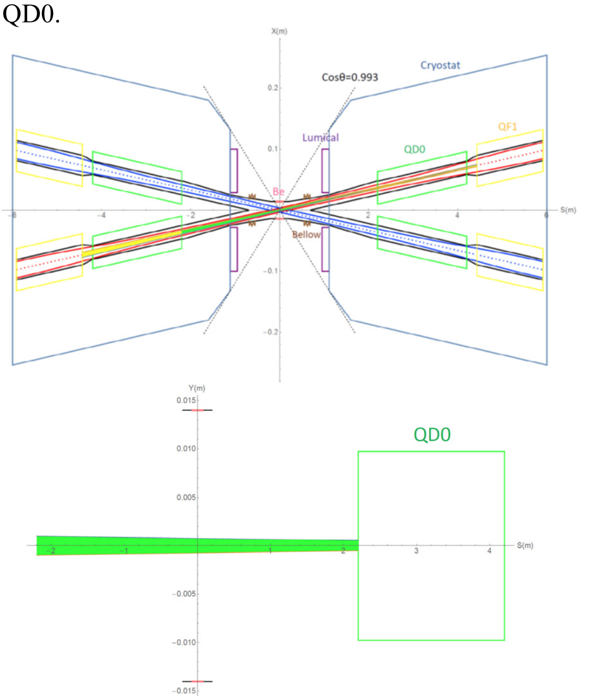

Figure 5: SR photon fans horizontally (up) from QD0 (green) and QF1 (yellow), SR photon fans vertically (down).

There are no SR photons within $10\sigma_x$ directly hitting or once-scattering to the detector beam pipe. There is collimators for the beam loss background, which will be installed in the upstream and downstream ARC far away from IP. These collimators will squeeze the beam to $13\sigma_x$. The 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. Thus the SR photons from final doublet quadrupoles will not damage the detector components and cause background to experiments.

BEAM LOSS BACKGROUND AND COLLIMATOR DESIGN

The beam particles can lose a large fraction of their energy through a scattering processes such as radiative Bhabha, beamstrahlung [6], beam-gas scattering, or beam-thermal photon scattering. After optimizing the lattice, and considering the beam-beam effect and errors, the energy acceptance is about 1.5%. If the energy loss of the beam particles is larger than 1.5%, these particles will be lost from the beam and might hit the vacuum chamber. If this happens near the IR, detectors may be damaged. Beam loss production mechanisms and the associated beam lifetimes are listed in Table 1:

Table 1: CEPC Beam Lifetime

Beam loss mechanism	Beam lifetime	others
Quantum effect	>1000h	
Touscheck effect	>1000h	
Beam-Gas elastic scattering (Coulomb scattering)	>400h	Residual gas CO, 10-7Pa
Beam-Gas inelastic scattering(bremsstrahlung)	63.8h	
Beam-thermal photon scattering	50.7h	
Radiative Bhabha scattering	74min	
Beamstrahlung	80min	

The first three, due to the long lifetime, can safely be ignored. The next four, beamstrahlung, radiative Bhabha scattering, beam-thermal photon scattering and beam-gas inelastic scattering, especially beamstrahlung and radiative Bhabha scattering, due to shorter lifetimes, must be carefully analysed and collimated. 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.

MACHANICS AND ASSEMBLY

IR mechanics assembly typical point is remote vacuum connection. The sealing point is 6m away from the operation point. The Ultrahigh vacuum sealing – Helicoflex is used. The layout is shown in Fig. 6.

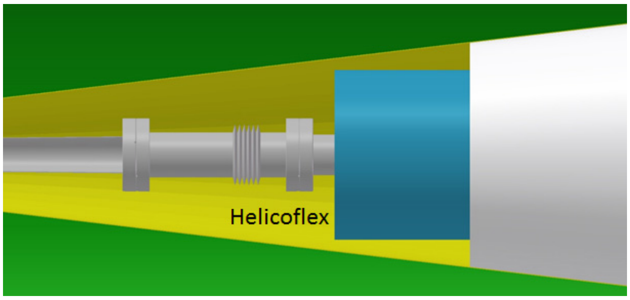

Figure 6: CEPC IR vacuum sealing.

There is no easy solution to install all the critical components in the IR with high precision, which is inspired by the Remote Vacuum Connection (RVC) developed by SuperKEKB [7], which is shown in Fig. 7. We are studying the special installation tools for the remote connection of bellows.

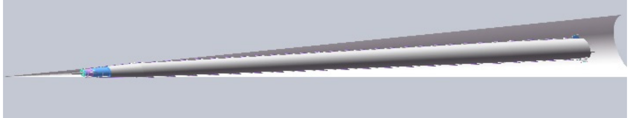

Figure 7: RVC whole layout.

CONCLUSION

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 and water cooling was considered. 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 procedures for the installation of IP elements are studying. The boundary between detector and accelerator is still not clear. Very long time is needed to confirm the final scheme. Towards TDR, many of the MDI components are under development.

REFERENCES

[1] Accelerators for a Higgs Factory: linear vs circular (HF2012). `https://indico.fnal.gov/conferenceDisplay.py?confId=5775`

[2] Y.W. Wang *et al.*, "Optics Design for CEPC double ring scheme", WEPIK018, 2017.

[3] N. Ohuchi *et al.*, "Design and construction of the magnet cryostats for the SuperKEKB Interaction Region", *Applied Superconductivity*, vol.28, No. 3, April 2018.

[4] The CEPC-SPPC Study Group, CEPC Conceptual Design Report, Volume I-Accelerator, IHEP-AC-2018-01.

[5] Synchrotron Radiation and Free Electron Lasers, CERN Accelerator school, CERN-90-03, 1990.

[6] J.E. Augustin, N. Dikansky, Ya. Derbenev, J. Rees, Burton Richter *et al*. "Limitations on Performance of e+ e- Storage Rings and Linear Colliding Beam Systems at High Energy," *eConf*, C781015:009, 1978.

[7] K. Kanazawa. *SuperKEKB mechanical assembly at IR*. Presentation in Workshop on the mechanical optimization of the FCC-ee MDI, CERN, Switzerland, Jan 30-Feb 9, 2018.