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MDI DESIGN FOR CEPC

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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 MDI layout and (Interaction Region) IR design, IR beam pipe design, thermal analysis and injection background 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. Machine Detector Interface (MDI) is one of the most challenging field in Circular Electron Positron Collider (CEPC) design, it almost covered all the common problems in accelerator and detector.

In this paper, we will introduce the critical issues of CEPC MDI, including the IR beam pipe design, thermal analysis and injection background 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 3 T (2 T in Z) superconducting solenoid of length 7.3 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 1.9 m from the IP [2].

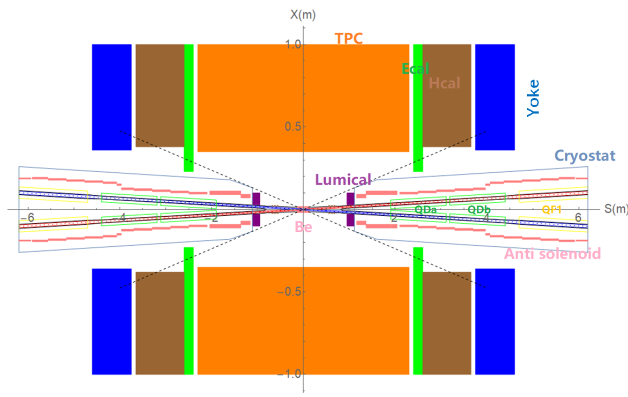

Figure 1: CPEC IR layout.

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 computer controlled machining and carefully welded to avoid deformation.

In the present design (Table 1 and Fig. 2), the inner diameter of the beryllium pipe was decided to be 20mm by considering both the mechanical assembly and beam background issues. The length of beryllium pipe is 85mm in longitudinal. Due to bremsstrahlung incoherent pairs, the shape of the beam pipe between 180~655 mm is selected as conic. There is a bellows for the requirements of installation in the crotch region which is located about 0.7 m away from the IP. The crotch point is at 805 mm away from the IP with slope. A race-track shape beam pipe is adopted between 805~855 mm from IP with the inner diameter 39 mm (single pipe) ~20 mm (double pipes), which is considered to control the heating problem of HOM. For the beam pipe within the final doublet quadrupoles, a room temperature beam pipe has been adopted.

Table 1: CEPC IR Central Beam Pipe Design

From IP(mm)	Shape	Inner diameter(mm)	Material	Marker
0-85	Circular	20	Be	
85~180	Circular	20	Al	
180~655	Cone	20~35	Al	Taper: 1:70
655~700	Circular	35	Al	
700~780	Circular	35	Cu	
780~805	Cone	35~39	Cu	
805~855	Race-track	39~20 double pipe	Cu	

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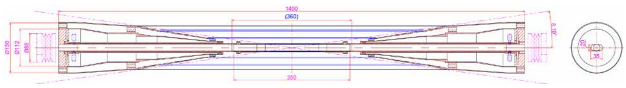

Figure 2: CEPC IR central beam pipe mechanical design.

THERMAL ANALYSIS

SR in Normal Conditions

An asymmetric lattice adopted to allow softer bends in the upstream of IP [2]. Reverse bending direction of last bends is applied to avoid synchrotron radiation hitting IP vacuum chamber. Thus, in normal conditions (Fig. 3) there is no synchrotron radiation photons hitting the central IP beam pipe, which is generated from the last bending magnet in the upstream of IP.

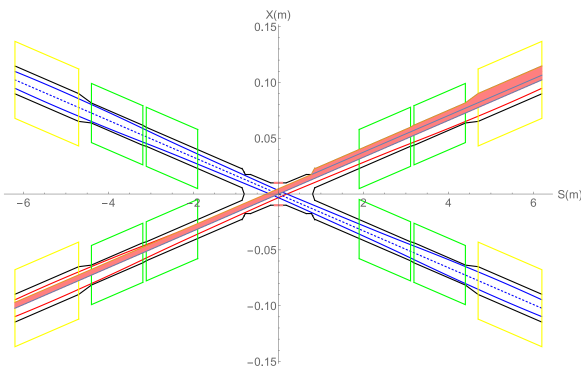

Figure 3: SR from last bending magnet in upstream of IP in normal conditions.

"Room temperature" beam pipe and conduction cooled superconducting magnet has to be adopted. For the IR beam pipe of the accelerator part beyond 700 mm away from IP, single layer beam pipe with water cooling has been adopted, and the synchrotron radiation heat load distribution is shown in Table 2.

Table 2: SR heat load distribution from last bending magnet in upstream of IP.

Region	SR heat load	SR average power density
0~780mm	0	0
780mm~805mm	23.04W	256W/cm^2
805mm~855mm	53.39W	296.6W/cm^2
855mm~1.9m(QDa entrance)	4.32W	1.15W/cm^2
QDa	3.28W	0.75W/cm^2
QDa~QDb	22.92W	79.58W/cm^2
QDb	3.96W	0.91W/cm^2
QDb~QF1	71.04W	65.8W/cm^2
QF1	7.26W	1.34W/cm^2

However, some secondaries generated within the beam pipe of QD would hit the detector beampipe, even the beryllium part. Therefore, the mitigation methods must be studied. SR photons generated from the FD magnets 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 in Extreme Conditions

In extreme conditions (Fig. 4) for example, if a magnet power is lost, a large distortion will appear immediately for the whole ring orbit. The beam will be lost when exceeded. In extreme cases which is about at least 10 times per day, the beam will be stopped within 0.5 ms when abnormal. The beam orbit deviation will not affect detector operation, since the high background part will be removed when data analysis is carried out.

In extreme conditions, synchrotron radiation photons will hit the bellows and Beryllium pipe in IR. There is no cooling at the bellows. Since it is a transient effect, heat load is not a problem. But the background of the detector and radiation dose should be considered under abnormal conditions.

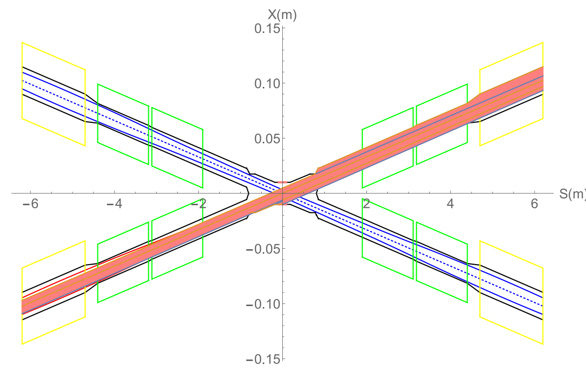

Figure 4: SR from upstream of IP in extreme conditions.

Beam Loss Backgrounds

The beam particles might abruptly lose a large fraction of energy through some scattering processes such as Radiative Bhabha scattering [3], Beamstrahlung [4], beam-gas scattering, beam-thermal photon scattering [5] and so on. 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%. If the energy loss of the beam particles are larger than 1.5% of the beam energy, these particles will be lost from the beam and might hit on the vacuum chamber. If this happens near the IR, it will cause heat load to the beam pipe. If this heat load is too large, superconducting magnet may quench. Table 3 shows the heat load distribution from beam loss backgrounds.

Table 3: Heat load distribution from beam loss backgrounds.

Region	RBB	Beamstrahlung	Beam-Gas	BTH
Berryllium pipe	6.7mW	0	0	0
Detector beam pipe	0.024W	0	4.8uW	1.2uW
Accelerator beam pipe before QDa	0.17W	0	4.2uW	1.2uW
QDa~QDb	2.13W	3.8uW	5.9uW	1.8uW
QDb~QF1	0.01W	3.8uW	0.5uW	0.6uW
QF1	0.26mW	0	3.7uW	0.66uW

Heat load in IR from beam loss backgrounds are small compared to ones generated from synchrotron radiation and HOM.

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INJECTION BACKGROUND

When a charge is injected to a circulating beam bunch, the injected bunch is perturbed and a higher background rate is observed in the detector for few milliseconds after the injection [6]. There are two kinds of injection modes: one is the FULL injection to an empty ring; the other is the top-up injection. For the first FULL injection mode, since the detector high-voltage is off and detector measurement is off, background should not be considered. The effects from the continuous top-up injection on potential beam-loss-induced backgrounds in the IR needs to be analysed.

The effects from the continuous top-up injection on potential beam-loss-induced backgrounds in the IR are analysed (Fig. 5) using a simplified model, and radiative Bhabha scattering is considered.

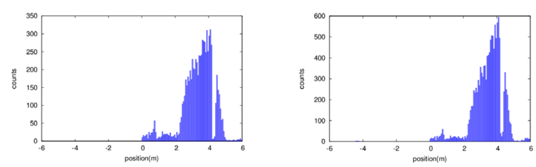

Figure 5. Beam loss background in ±6 m around IP from circular beam (left) and injection beam(right).

In addition, the presence of beam tails (Fig. 6) from the errors of the kicker (e.g. rotational error) and from imperfectly corrected X-Y coupling after the injection point should also be considered before the injection beam are damped by the radiation damping and/or transverse-feedback system.

Moreover, some tolerances such as too large emittances to imperfect beams from the Booster should be also taken into account (Fig. 7).

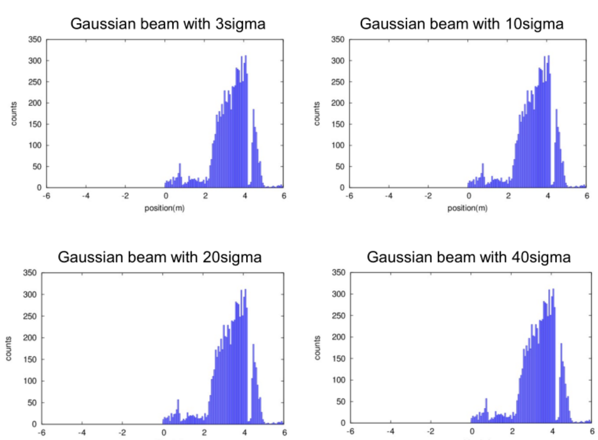

Figure 6: Beam loss background in ±6 m around IP with the presence of beam tails.

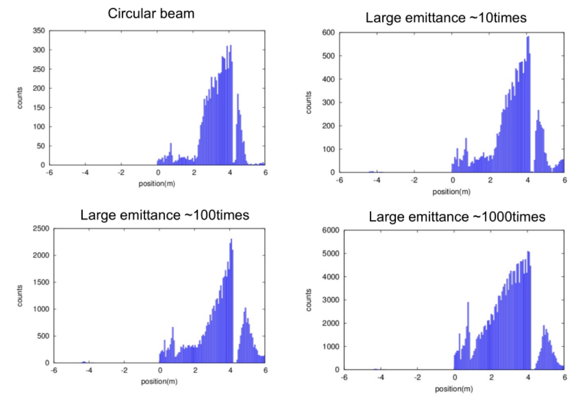

Figure 7: Beam loss background in ±6 m around IP with large emittances to imperfect beams from the Booster.

There is almost no beam loss background in the upstream of the IP which shows that the existed collimation system can well cope. However, the beam loss background in the downstream of the IP can even significantly increased. This will not have effect on the inner layer detector but the radiation background may damage the outer layer or the endcap detector, and it cannot be solved by the collimators but adding tungsten shielding may be a better choice. Furthermore, the remarkable beam loss background in the downstream of the IP can also damage the superconducting magnet coils and cause quench. In this case, the tungsten shielding is more demanded in the IR. Since the very tight space in the IP region, a tungsten-alloy beam pipe is under design in the CEPC TDR stage.

Furthermore, the beam distribution building up in the Booster and injected into the main rings is usually Gaussian distribution, but there might be non-Gaussian distribution from some interaction effects such as beam-gas scattering etc on. The beam halo occupancy in the whole beam distribution may be much larger than in the Gaussian distribution. The non-Gaussian distribution from the Booster and being injected into the main rings is evaluated (Fig. 8) by introducing a uniform and a double-Gaussian beam distribution.

The result shows that no significant increase of the beam loss background, and the existed collimation system is capable to cope.

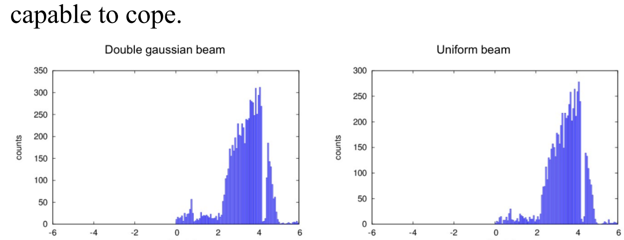

Figure 8: Beam loss background in ±6 m around IP with non-Gaussian injection beam.

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CONCLUSION

The MDI layout has been renewed. Compatible and no interference for the design. New ϕ = 20 mm IR beam pipe is designed and renewed. The thermal analysis including synchrotron radiation and beam loss background meet the MDI requirement. The injection background result shows that no significant increase of the beam loss background, and the existed collimation system is capable to cope.

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.*, "A lattice design of the CEPC collider ring at Higgs energy for the high luminosity scheme", *Int. J. Mod. Phys. A*, to be published.

[3] R. Kleiss and H. Burkhardt, "BBBREM: Monte Carlo simulation of radiative Bhabha scattering in the very forward direction", *Comput. Phys. Commun.*, vol. 81, pp. 372–380, 1994. doi:10.1016/0010-4655(94)90085-X

[4] V. I. Telnov, "Restriction on the energy and luminosity of e^+e^- storage rings due to beamsstrahlung", *Phys. Rev. Lett.* vol. 110, p. 114801, 2013. doi:10.1103/PhysRevLett.110.114801

[5] H. Burkhardt, "Monte Carlo simulation of scattering of beam particles and thermal photons", CERN, Geneva, Switzerland, Rep. SL-Note-93-73-OP.

[6] P. M. Lewis *et al.*, "First measurements of beam backgrounds at SuperKEKB", *Nucl. Instrum. Methods Phys. Res. Sect. A,* vol. 914, pp. 69-144, 2019. doi:10.1016/j.nima.2018.05.071