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Study status of the CEPC Machine-Detector Interface and Interaction Region

Haoyu Shi,[a,*] **Wei Xu,**[a] **Sha Bai,**[a] **Yudong Liu,**[a] **Quan Ji,**[a] **Haijing Wang,**[a] **Peilian Liu**[a] **and Hongbo Zhu**[b]

[a] *Institute of High Energy Physics, CAS*
19b Yuquan Road, Beijing, China
[b] *School of Physics, Zhejiang University*
Hangzhou, 310058, China

E-mail: shihy@ihep.ac.cn

CEPC has been proposed mainly as a Higgs factory aimed to measure the properties of the Higgs boson. The design of the Interaction Region, especially the IR beam pipe is critical for the CEPC. In this paper, the new physical and mechanical design of the IR beam pipe has been proposed. The central diameter of the new beam pipe is 20mm. The heat deposition and thermal analysis were conducted based on the new design. The loss map of the beam backgrounds in the IR has also been simulated.

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*Speaker

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1. Introduction

Circular Electron Position Collider (CEPC)[1] is a Higgs factory proposed by the Chinese high energy physics community and aimed to measure the properties of the Higgs boson and electroweak parameters with unprecedented precision. It will be an 100 km double ring machine with a crossing angle of 33 mrad. Its main design machine parameters with optimization are listed in Table 1.

To achieve optimal performance of the machine and detectors and ultimately to realize the precision physics program, it is critical to design carefully the interaction region (IR) and the machine-detector interface(MDI). The latest layout of the CEPC interaction region is shown in Fig.3.

The designing goal of the CEPC IR and MDI is to achieve a so-called "flexible" design, which means using a common layout for all operation modes. On the one hand, a high-luminosity, low background impact, and low error design is demanded. On the other hand, all components in the IR must be easy to install, easy to replace and easy to repair. In this paper, we report our new design of the key component in the IR – the IR beam pipe with respect to these goals and principles.

Table 1: CEPC Main Machine Parameters

Operation Mode	Higgs (240 GeV)	W (160 GeV)	Z (91 GeV)
Particles/bunch N_e [10^{10}]	14	13.5	14
Bunch Number	249	1297	11951
Horizontal beam size σ_x [μm]	15	13	6
Vertical beam size σ_y [μm]	0.036	0.042	0.035
Energy spread[%]	0.17	0.14	0.13
$\mathscr{L}$ [10^{34} cm^{-2}s^{-1}]	5	16	115

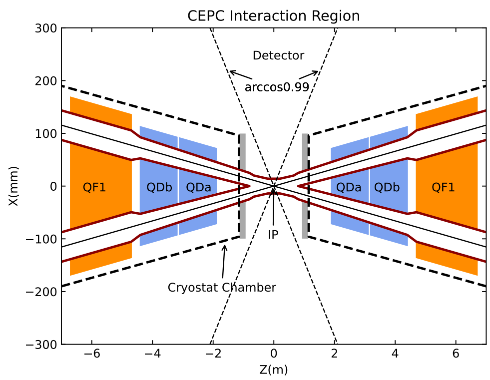


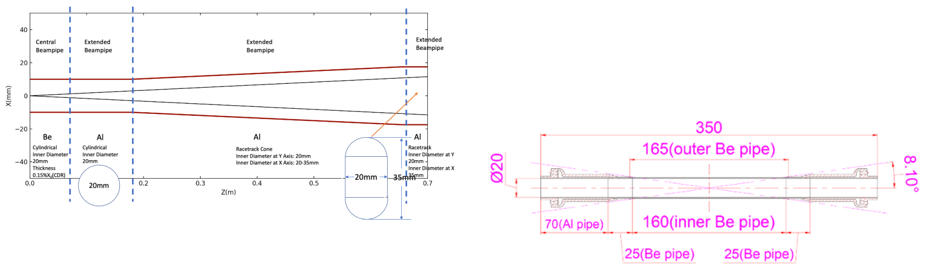
Figure 1: The layout of the latest design of the CEPC Interaction Region

2. Optimized IR beam pipe design

Adopting to the design and parameter changes from CDR to TDR, the design of the IR beam pipe have been changed. The optimized IR beam pipe has a 20 mm inner diameter at the IP, which would result in a roughly 21% improvement on the performance of the vertex detector[2].

Table 2: The detail design of the new IR pipe

Index	Name	Range/mm	Material	Cross-Section Shape
1	Central Beam Pipe	±0-120	Be	Circle
2	Extend pipe 1	±120-205	Al	Circle
3	Extended pipe 2	±205-655	Al	Racetrack
4	Extended pipe 3	±655-700	Al	Racetrack
5	Bellow	±700-780	Stainless Steel/Cu	Racetrack
6	Transition pipe	±780-805	Al	Racetrack
7	Dual Pipe	±805-7000	Cu	Dual-Circle



(a) Half Detector Beam Pipe (b) Mechanical Design of the central beam pipe

Figure 2: The physical and mechanical Design of the beam pipe. The physical design only present half due to the symmetry design of the CEPC detector beam pipe.

The parameters of the new IR beam pipe are listed in Table 2, and the sample diagram of the detector beam pipe is shown in Fig. 2. Fig. 2(a) presents the physical design, and Fig. 2(b) presents the mechanical design.

2.1 Detector Beam pipe

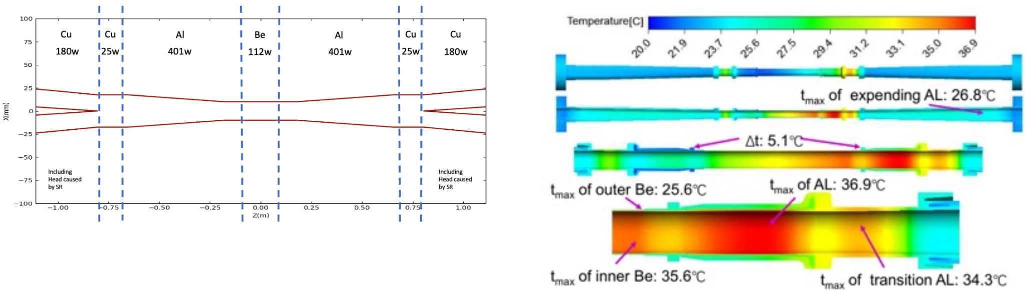
The detector beam pipe consists of the central beam pipe and the extended beam pipe. The central beam pipe is located in the range of ± 120 mm, made of Beryllium. It is a double layer design. The inner diameter of the first layer is 20 mm, with a thickness of 0.2 mm. The thickness of the second layer is 0.15 mm, and a 0.35 mm gap would be reserved for coolant. In total, the thickness of the central beam pipe would be 0.7 mm, which equals to about 0.2% of radiation length. The material of the coolant has not been decided yet. The extended beam pipe is divided into three parts. They are all made of Aluminium, with a thickness of 1 mm, as listed in Table 2. Considering the requirements of the HOM heating and LumiCal, we choose racetrack cross-section in the last two part of extended pipe. The diameter in two demotions is different due to the racetrack, as Fig. 2(a) shown.

2.2 Bellow, Transition pipe and Arc vacuum chamber

The bellow and transition pipe is the transition part of the whole IR pipe to connect the detector pipe and dual accelerator pipe. The bellow locates at 700-780 mm, made of stainless steel, and a thin layer of copper would be used as inner surface to conduct the heat. The cross-section of the bellow is also racetrack, same as the third part of the extended pipe. The inner diameter in both axis must keep same due to the manufacture issues. The transition pipe is made by Al. In the arc section of the CEPC, the diameter of the accelerator vacuum chamber would be 56 mm, however in the IR, the diameter would be 20 mm, 21.5 mm, 23 mm in QDa, QDb and QF1, respectively.

3. Thermal Analysis

The thermal analysis was conducted at Higgs mode for the detector beam pipe. To perform such analysis, all the heats generated in IR must be considered. At the same time, the deposited power at the bellow must also be noted since there would be no active cooling. The only main heat source of the detector beam pipe is HOM heating. The heat generated by SR would also deposit on the bellow. The heat generated by other beam induced backgrounds is too small to be ignored. Combining all the heat sources, the deposited heat distribution is shown in Fig.3(a), and the thermal analysis result is shown in Fig. 3(b). The maximum temperature is 36.9°C, which would be safe to the detector.



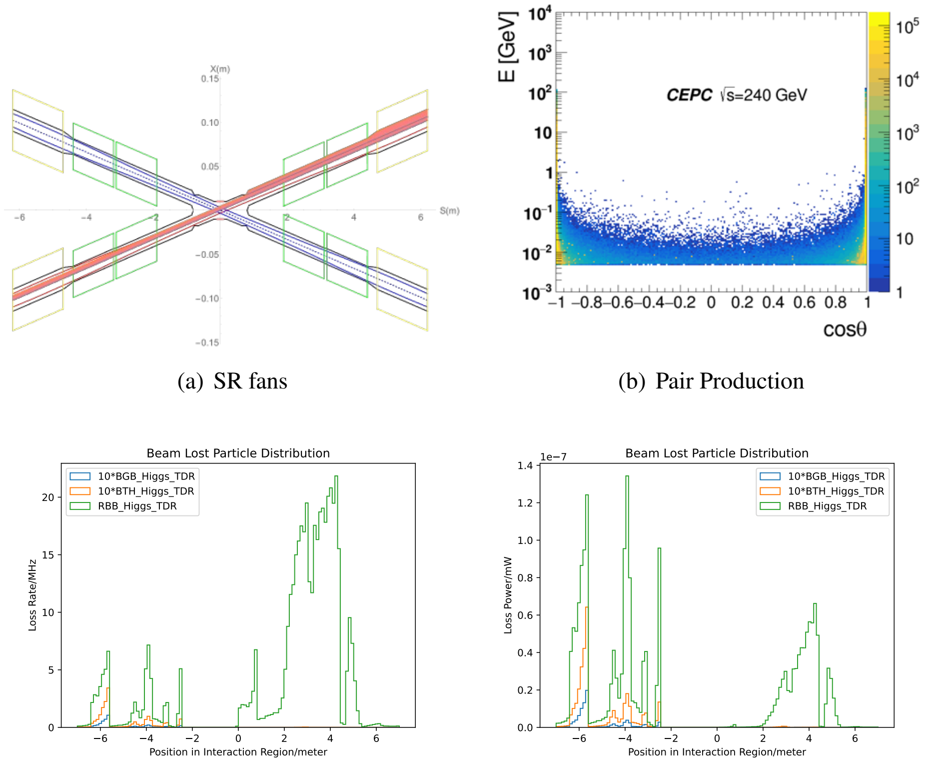
(a) Deposited Power Distribution

(b) Thermal Analysis of Detector Beam Pipe

Figure 3: The heat distribution of IR beam pipe

4. Backgrounds Impact

The change of the beam pipe radius would have an impact on the loss distribution of the beam background in the IR. Therefore, the new loss distribution in the CEPC IR with optimized accelerator parameters and new designed IR beam pipe has been studied and would be presented in the section. Both photon backgrounds and beam loss backgrounds are taken into account. Photon backgrounds include SR and Pair Production, while beam loss particle backgrounds include beam-gas scattering(BGB), beam thermal photon scattering(BTH) and radiative-bhabha scattering(RBB). The beamstrahlung background itself would be effectively shielded by collimators. Table3 shows all the sources of beam backgrounds we've studied, and also the tools we used. The SR fans in the IR are presented in Fig.4(a). The Pair Production distribution is presented in Fig.4(b). The loss rate and loss power distribution of beam induced backgrounds in the IR is shown in Fig.4(c)



(a) SR fans (b) Pair Production

(c) Loss Rate of BIB (d) Loss Power of BIB

Figure 4: Backgrounds impacts on the IR due to SR, Pair Production and BIB, respectively.

and Fig.4(d), respectively. Comparing with our previous results in CDR[3], the backgrounds level sightly increased due to the shrinking of the diameter of central beam pipe. All the results here would be used as the input of detector simulation to study their impact on the detector in our future work.

Table 3: The sources and tools in CEPC beam background study.

Background	Generation	Tracking
Synchrotron Radiation	BDSIM[4]	BDSIM/Geant4[5]
Beamstrahlung/Pair Production	Guinea-Pig++[6]	SAD[7, 8]
Beam-Thermal Photon	Py-BTH[9, 10]	SAD[7, 8]
Beam-Gas Breamsstrahlung	Py-BGB[10]	SAD[7, 8]
Radiative Bhabha	BBBREM[11]	SAD[7, 8]

5. Conclusion

CEPC has been proposed as a Higgs factory, aimed to measure the properties of the Higgs boson with unprecedented precision. The design of the interaction region, especially the IR beam pipe, is critical for the CEPC. The new physical and mechanical design of the IR beam pipe have been carried out, the heat deposition and thermal analysis were conducted based on the new design. The loss map of the beam backgrounds in the IR has also been updated, and future studies will be performed to compute the backgrounds levels in the detector and other components in the IR, and optimize the whole IR design at the same time.

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