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MDI Design in CEPC Double Ring Scheme

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Introduction

MDI is one of the most challenging field in CEPC design, it almost covered all the common problems in accelerator and detector. The Machine Detector Interface of CEPC double ring scheme is about ±16m long from the IP, where many elements need to be installed. The two beams collide at the IP with a horizontal angle of 33mrad and the final focusing length is 2.2m. The space is very tight.

The CEPC detector consists of a cylindrical drift chamber surrounded by an electromagnetic calorimeter, which is immersed in the superconducting solenoid with 3T magnetic field and the length of 7.6m.

In this paper, some essential MDI design issues are reported: the final doublet quadrupoles physics design parameters which is the source of the MDI design; electron and positron beam stay clear region which is important input into the beam pipe shape design; synchrotron radiation power of the last bending magnet upstream of the Interaction Point (IP) to enter the IR region, and also the synchrotron radiation power of the final doublet quadrupoles, critical energy are also calculated.

Beam stay clear region

The beam stay clear region size is decided by the beam emittance, β function and beam quantum lifetime. According to the design experience of the large collider in world, CEPC IR beam stay clear region are considered of the points below:

1) To satisfy the requirement of injection, beam stay clear region(BSC) should be larger than $13\sigma_x$

2) To satisfy the requirement of beam lifetime after collision: BSC should be larger than $12\sigma_y$

3) coupling=1% , including the coupling of circulating beam~0.3% and blow up after beam-beam effect, also considering magnet errors.

Finally, we define the CEPC beam stay clear region:

BSC_x $= \pm(18\sigma_x + 3\text{mm})$, BSC_y $= \pm(22\sigma_y + 3\text{mm})$

Below is the beam stay clear region of electron (blue line) and positron (red line) beam in the ±6 m interaction region.

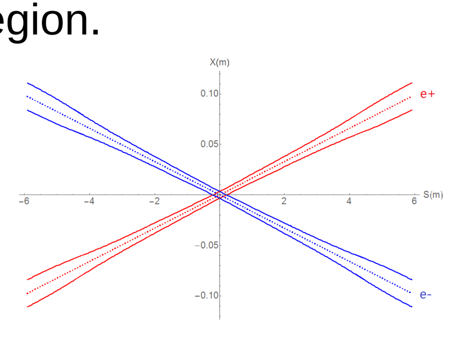

Fig 1: Beam stay clear region of CEPC double ring Interaction Region.

Final doublet physics design parameters

On each side of the IP, a final doublet of quadrupoles on each beamline is used to provide the focusing optics needed at the IP. It allows the vertical beta function at the IP to be 1.5mm. The first vertical focusing quadrupole is a superconducting magnet, which is shared by both beams. To save space, the quadrupole coils are two-in-one aperture. The second element of the final doublet is horizontal focusing quadrupole. The distance from the last quadrupole is 0.23m.

Based on the beam stay clear region, the final doublet quadrupoles physics design parameters are below in table 1:

QD0	Horizontal BSC 2（$20\sigma_x$+3）	Vertical BSC 2（$40\sigma_y$+3）	e+e- beam center distance
entrance	10.65 mm	14.69 mm	72.6 mm
Half	13.65 mm	16.99 mm	105.6 mm
exit	19.32 mm	15.67 mm	138.6 mm
Good field region	Horizontal 19.32 mm; Vertical 17.03 mm		
Effective length	2m		
Distance from IP	2.2m		
Gradient	136 T/m		

QF1	Horizontal BSC 2（$20\sigma_x$+3）	Vertical BSC 2（$40\sigma_y$+3）	e+e- beam center distance
entrance	21.06 mm	14.96 mm	146.2 mm
Half	25.36 mm	13.32 mm	170.3 mm
exit	26.85 mm	12.75 mm	195.1 mm
Good field region	Horizontal 26.85 mm; Vertical 14.96 mm		
Effective length	1.48m		
Distance from IP	4.43m		
Gradient	110T/m		

Table 1. QD0 and QF1 physics design parameters

Beam pipe

To reduce the detector background and radiation dose due to beam loss, the IR vacuum chamber has to accommodate large beam stay clear region. In order to keep precise shaping, all chambers should be made by numerically controlled machine and carefully welded to avoid deformation.

In the present design, the inner diameter of the beryllium pipe was decided to be 28mm by considering both the mechanical assembly and beam background issues. The length of beryllium pipe is 14cm in longitudinal. Due to bremsstrahlung incoherent pairs, the shape of beam pipe between 0.2~0.5m is selected as cone. There is bellows for the requirements of installation in the crotch region where is located about 0.7m away from the IP. The water cooling structure is considered due to heating problem of HOM.

For the beam pipe within the final doublet quadrupoles, room temperature beam pipe has to be adopted.

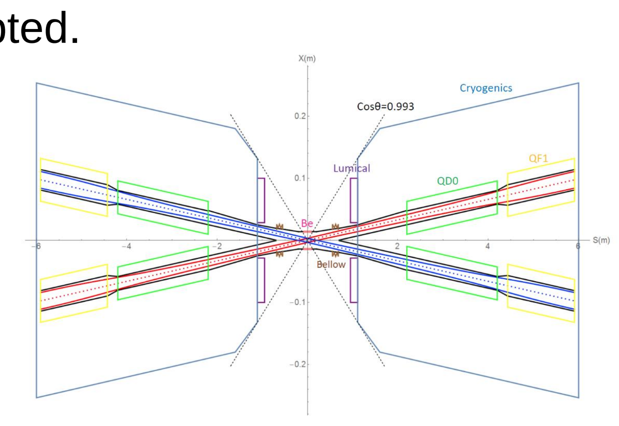

Fig 2: IR layout with beam pipes.

Synchrotron radiation

The synchrotron radiation will contribute the heat load to the beam pipe and cause the photon background to the experiments. Furthermore, the radiation dose can damage the detector components. Thus the beam optics should be carefully designed in order to prevent the SR photons from directly hitting or once-scattering to the detector beam pipe.

SR from bending magnet

For the CEPC double ring, the maximum designed current of single beam is 17.4mA and the maximum energy is 120GeV. The synchrotron radiation fans in the IR are mainly generated from the final bending magnet in before the IR section and from the IR quadrupole magnets due to the eccentric particles. Figure 3 shows the SR fans in the IR, which are produced by positron beam.

As the positron beam travels through the final bending magnet upstream of the IP, which is located at 67.66m from the IP and enters the IR, it generates a fan of SR with the total power 47W. The critical energy of photons is about 45keV. In the proposed design, 60W of SR power contributed by e+ will go through the IP. And no SR hits directly on the detector beryllium pipe. The synchrotron radiation generated by electron beam is symmetric with positron beam.

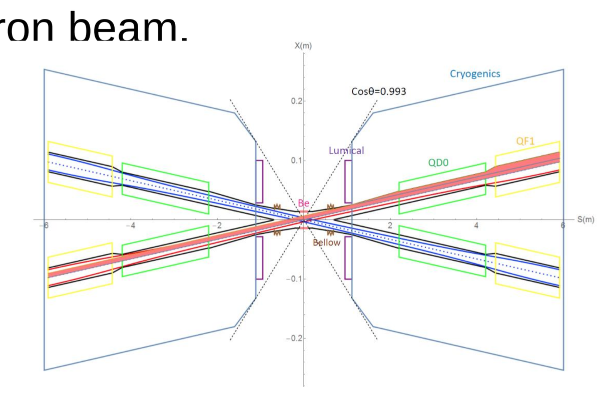

Fig 3: SR fans in the CEPC IR

For the final bending magnet downstream of the IP, which is located at 46.06m from the IP, it generates a fan of SR with the total power 191W. The critical energy of photons is about 97keV.

For the upstream of IP, the critical energy of synchrotron radiation from the bending magnets is controlled less than 45keV within 68m and 200keV within 400 m. For the downstream of IP, no bends in the last 40 m and the critical energy is less than 230keV within 120 m and 300keV within 250 m.

SR in IR cold vacuum chamber

"Room temperature" vacuum chamber has to be adopted since there is a 4mm gap between the outer space of beam pipe in QD0 and Helium vessel. 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 W (0.23m) where has special cooling structure.

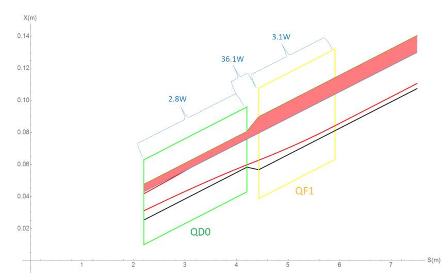

Fig 4: SR fans in the IR vacuum chamber.

SR from final doublet quadrupoles

In sequence there are two quadrupole magnets in the section between the final bending magnet and the IP. They are the final doublet quadrupoles QD0 and QF1. The largest radiation source of which magnet depends on if it is installed off-axis with the beams.

Since in the Gaussian distribution beam, particles in 3σ occupies 99.7% of the total amount, 1σ occupies 68.7%, and 2σ occupies 95.5%. The total SR power generated by the QD0 magnet is 639W in horizontal and 165W in vertical. The critical energy of photons is about 1.3MeV in horizontal and 397keV in vertical. For the QF1 which is focusing in horizontal plane, 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.

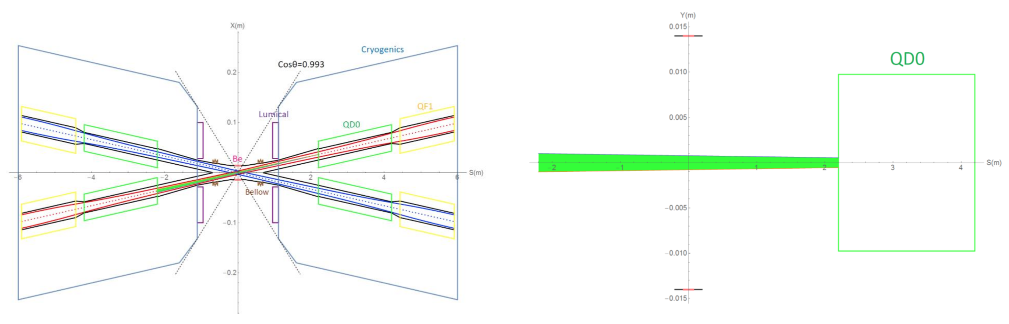

Fig 5: SR fans in horizontal and vertical from QD0 in CEPC IR.

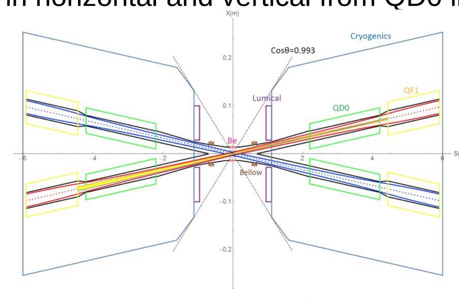

Fig 6: SR fans in horizontal and vertical from QF1 in CEPC IR.

There is no SR photons within $6\sigma_x$ directly hitting or once-scattering to the detector beam pipe. Since there is collimators upstream of IP in the ARC section, and beam will be collimated to $14\sigma_x$,and SR photon within $14\sigma_x$ will hit the beam pipe downstream of the IP region, the generated once-scattering shower will not go into the detector region to increase the background.

Conclusion

The BSC region is clarified considering the requirements of injection, beam life time after collision and coupling. Final doublet quadrupoles physics design parameters are calculated based on the beam stay clear region. The QD0 should be two-in-one aperture due to the tight space. Beam pipes are designed which can accommodate the beam stay clear region and for the beam pipe within the final doublet, room temperature vacuum chamber has to be adopted. Synchrotron radiation power from the last bending magnet upstream in the IR, of which 60W contributed by e+ will go through the IP, and no SR hit directly on beryllium pipe. SR photons generated by the final doublet quadrupoles, due to the collimator upstream, will hit the beam pipe downstream of the IP region, and the generated backward shower will not go into the detector region.