# ISSUES IN CEPC PRETZEL AND PARTIAL DOUBLE RING SCHEME DESIGN

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*Abstract*

IHEP has proposed a circular electron and positron collider (CEPC) to study the properties of the Higgs boson. In the baseline design, the circumference of CEPC will be taken as 50-70 km. The single ring scheme and the partial double ring scheme are now both under study. In the single ring scheme, the electron and positron beam will share the beam pipes, thus a special orbit is needed to avoid the beam colliding at positions except the Interaction Points (IPs). While in the partial double ring scheme, the two beams will be separated into two beam pipes in the parasitic collision positions. This paper will show the latest design of the CEPC lattice, including both the pretzel and partial double ring scheme. Some critical issues that we encountered when designing the lattices will be discussed.

## INTRODUCTION

CEPC ( a Circular Electron Positron Collider) has been proposed by IHEP to study the Higgs boson [1].At the end of the 2014, the Preliminary Conceptual Design Report of CEPC was published, with single ring (pretzel) scheme as the baseline design [2]. As the design work move on, especially the demand to increase the luminosity at Z-pole, we started to study a new scheme, e.g. the so called ąřPartial double ring schemeąś. Then, the RF system raised that the RF efficiency could be too low to assure a constant voltage at the cavity for all bunches, so another scheme called ąřAdvanced double ring schemeąś was proposed to mitigate the low RF efficiency effect.

Another scheme, which is relatively less complicated but more costly, the double ring scheme, is also under study. The pretzel and partial double ring scheme will be introduced in this talk.

## PRETZEL SCHEME DESIGN

As described in the Pre-CDR [2], the ring is using 60/60 degrees phase advance FODO cells, with interleaved sextupoles. The pretzel orbit is designed for 50 bunches per beam, every $4\pi$ phase advance has one parasitic collision point. A schematic drawing of the pretzel orbit is shown in Fig.1.

In our design, the horizontal separation scheme is adopted to avoid big coupling between the horizontal and the vertical. The orbit is generated such that there is no off-center orbit in RF sections to avoid beam instability and High Order Modes(HOMs) in the cavities. There will be one pair of electrostatic separators for each arc, and for each arc, the first separator will be placed before the first parasitic collision point in this region to generate the orbit, and the second separator will be placed after the last collision point in this region to remove the orbit.

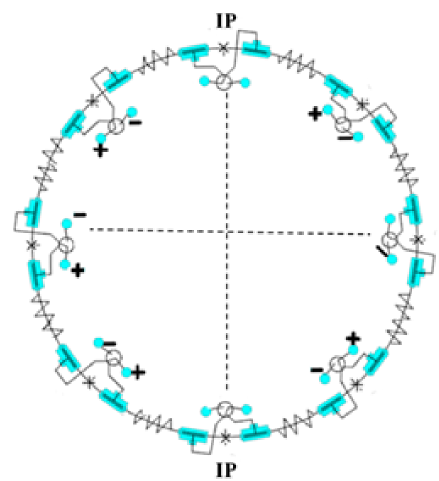


Figure 1: A schematic drawing of the pretzel orbit scheme, the beams are separated by electrostatic separators.

A schematic drawing of the pretzel orbit and the place of electrostatic separators for one arc is shown in Fig.2.

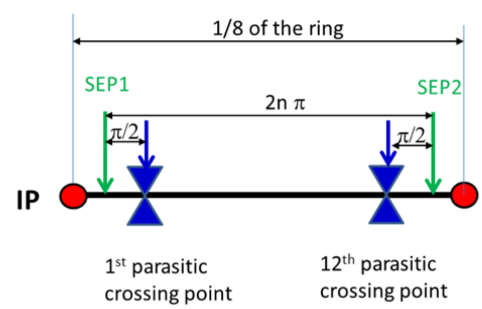


Figure 2: A schematic drawing of the positions of the electrostatic separators for 1/8th of the ring. SEP1 and SEP2 in the drawing means the first and second electrostatic separators.

## ISSUES WITH PRETZEL ORBIT

Beams with off-centered orbit, will experience extra fields in magnets. To be specific, in quadrupole magnets, the beam will see an extra dipole filed when it is off-centered.

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The dipole strength can be estimated with a simple formula: $\Delta B = K_1 \cdot B\rho \cdot \Delta x$, where $K_1$ is the normalized quadrupole strength, $B\rho$ is the magnetic rigidity of the beam, and $\Delta x$ is the orbit of the beam. With a simple calculation, we can see that the extra dipole field seen by the off-centered beam has a strength that is comparable to the strength of the main bending magnets.

In sextupole magnets, the beam will experience extra dipole and quadrupole fields. The field strength can be estimated similarly. These extra fields (dipole field in quadrupoles, and both dipole and quadrupole fields in sextupoles) will break the periodicity and achromatic condition of the lattice, and this effect has to be corrected.

The distortion of pretzel orbit effects on beta functions and dispersion function has to be corrected to have a reasonable dynamic aperture. Also, since the sextupoles are now coupled with quadrupoles, the chromaticity correction and the tune are coupled together, so linear lattice and nonlinear chromaticity has to be corrected at the same time. We try to find a new lattice period by taking 12 FODO cells, with symmetrically placed magnets, and require the phase advance to be $4\pi$ and the chromaticity to be zero at the same time. There is no detailed phase advance requirement in each FODO cell in this case. A new lattice can be found accordingly, the new lattice after correction is shown in Fig. 3.

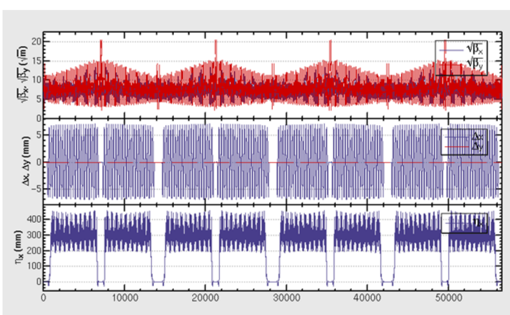

Figure 3: The lattice after correction of off-center orbit effect.

The dynamic aperture of the ring after correction of the pretzel orbit distortion on the lattice has been checked before the insertion of the Final Focus System (FFS). The result is shown in Fig. 4.The working point used here is (.79,.15) in horizontal and vertical planes. The plot shows that the dynamic aperture is $\sim 20\sigma_x \times 150\sigma_y$ in horizontal and vertical planes for on momentum particles, and it is $\sim 16\sigma_x \times 120\sigma_y$ particles with $\pm 2\%$ momentum spread. The tracking has been done with 240 turns, which corresponds to 3 transverse damping times.

## COMBINATION WITH FFS

One version of Final Focus System (FFS), which has been optimized for the ring without pretzel orbit, is inserted to the lattice with pretzel orbit, the beta function and dispersion function of the FFS is shown in Fig 5.

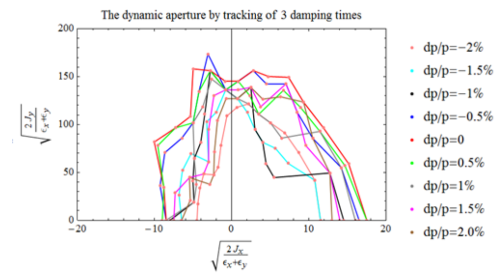


Figure 4: The dynamic aperture of the ring after correction of the pretzel orbit distortion on the lattice has been and before the insertion of the Final Focus System (FFS), the working point used here is (.79,.15) in horizontal and vertical planes.

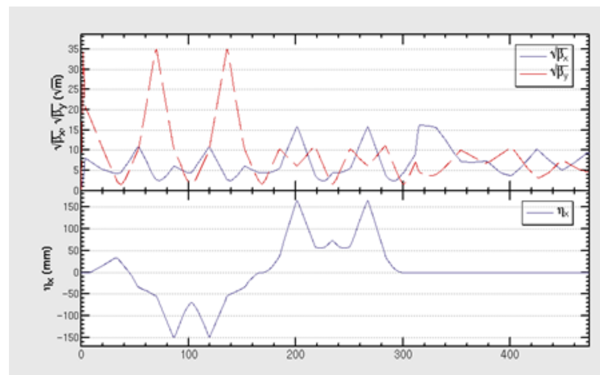

Figure 5: Beta function and dispersion function of Final Focus System to be connected to the ring with pretzel orbit.

In this design, $\beta_y^* = 3$ mm. The dynamic aperture then is optimized with the code MODE (Multi-Objective optimization by Differential Equation). All sextupoles are set free in the optimization. The resulted dynamic aperture is $\sim 16\sigma_x$ in horizontal plane for on momentum particles, and it is $\sim 6\sigma_x$ for particles with $\pm 2\%$ momentum spread, as shown in Fig 6. The tracking has been done with 240 turns, which corresponds to 3 transverse damping times.

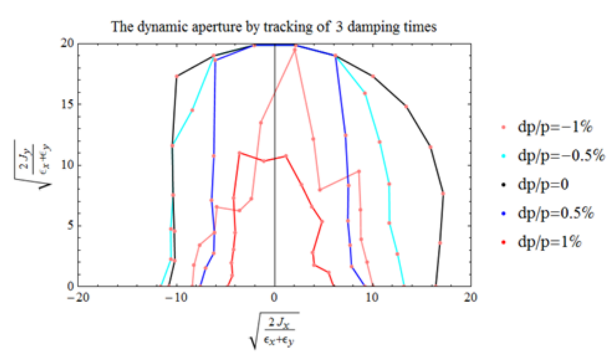


Figure 6: The optimized dynamic aperture with FFS and pretzel orbit.



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## CEPC PARTIAL DOUBLE RING DESIGN

For the partial double ring design, we choose double ring scheme for e+e- at IP1 and IP3. The total length of this part is about 3 km. The arcs of both sides of IP1 and IP3 are kept the same as the Pre-CDR single ring scheme. The layout of CEPC partial double ring is shown in Fig. 7.

The full crossing angle for CEPC partial double ring scheme is 30 mrad. We assume the final focus system (FFS) length is about 500 m, then the largest distance at the end of FFS is about 7.5 m and between the two separated pipes is about 15 m. At the start of the double ring, we need to use electrostatic separator to separate the electron and positron beams. We choose the parameter of electrostatic separator according to the experience on LEP [3]. The maximum operating field strength is 2 MV/m. The length of electrostatic separator is 4.5 m.

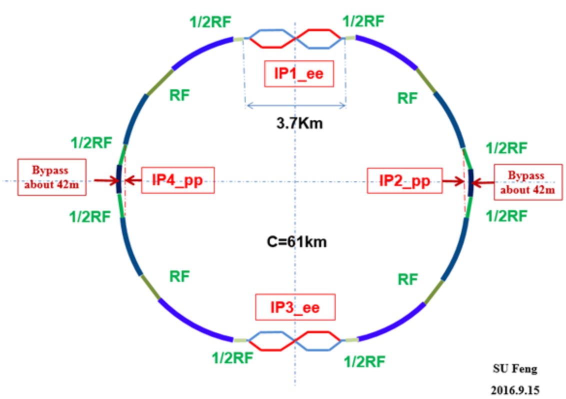


Figure 7: Layout of the partial double ring scheme. The full crossing angle is 30 mrad.

For the beam energy E0 = 120GeV, the maximum deflection angle per separator is about 66 urad. We choose 12 electrostatic separators work together to obtain a deflection angle of 0.75 mrad, with each separator deflects the beam by 62.5 urad. After those separators, we use a pair of septum dipoles to obtain 4.25 mrad and a group of dipole (B1) to acquire the other 10 mrad and suppress the dispersion to zero.

The standard FODO cells here has a phase advance of 90/90 in horizontal and vertical planes, and the chromaticity correction is done with sextupoles and with the non-interleaved scheme, as shown in Fig. 8.

The beta functions at the IP are $\beta_y^* = 1$ mm and $\beta_y^* = 0.22$ m, and for this design $L^* = 1.5$ m. Local chromaticity correction is done with sextupoles pairs separated by –I transformation. It is expected that 1) all 3rd and 4th order resonance driving terms due to sextupoles are almost cancelled; 2) up to 3rd order chromaticity are corrected with main sextupoles, phase tuning and additional sextupoles; 3) tune shift dQ(Jx, Jy) due to finite length of main sextupoles is corrected with additional weak sextupoles; 4) break down of –I, high order dispersion could be optimized with odd dispersion scheme or Brinkmann sextupoles. It is worth pointing out that the crab sextupoles have not been put into the lattice yet.

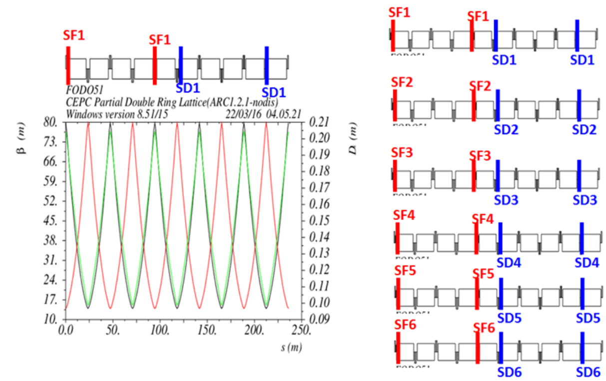


Figure 8: The standard FODO cells with 90/90 degree phase advances in horizontal and vertical planes. The sextupoles are placed using the non-interleaved scheme.

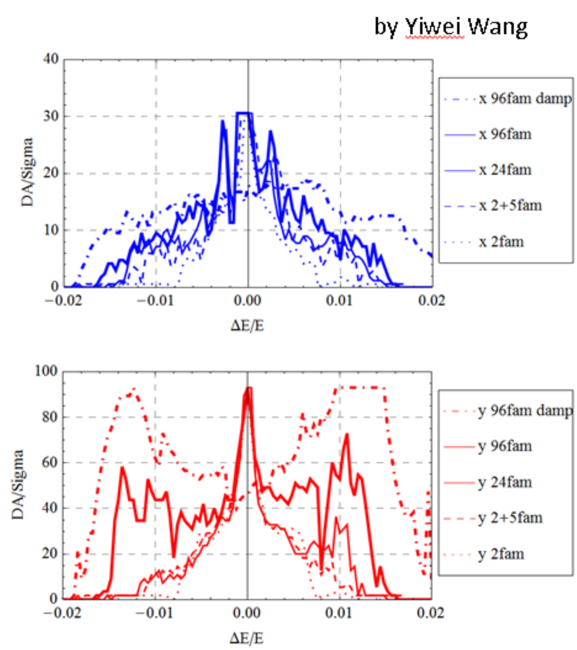


Figure 9: The achieved dynamic aperture after optimization with downhill simplex method, with and without damping.

## DA STUDY FOR CEPC PARTIAL DOUBLE RING DESIGN

The dynamic aperture of CEPC partial double ring design has been optimized with the downhill simplex method. Only the bare lattice is considered. The synchrotron motion is considered in the tracking. Tracking has been done for one damping time, with and without damping, respectively. The coupling is assumed to be $\kappa = 0.003$. The working point is taken to be (0.08, 0.22) in horizontal and vertical planes.

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The achieved dynamic aperture is $16\sigma_x/45\sigma_y$ for on momentum particles, and $3\sigma_x/5\sigma_y$ for particles with 2% momentum spread, as shown in Fig. 9.

We think further optimization of the dynamic aperture is possible, by using larger dispersion for IR sextupoles, and increasing $\beta_y^*$ from 1 mm to 1.3 mm as required in the new parameters, and trying more families of sextupoles in IR.

The study of effects such as quantum excitation, solenoid field, errors and misalignments are under going.

## SUMMARY

Several schemes for CEPC are understudy at IHEP. We have described the latest results of the design of the pretzel scheme and partial double ring scheme. A multi-objective code MODE has been developed at IHEP, and it has been proved to be very effective in optimizing dynamic aperture. The dynamic aperture of single ring has been greatly improved, but has not reached 2% momentum spread. The dynamic aperture for partial double ring achieved $3\sigma_x/5\sigma_y$@2.0% momentum spread after turn damping on.

Optimization work are still on-going.

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