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Design and optimization of the superconducting quadrupole magnet Q1a in CEPC interaction region

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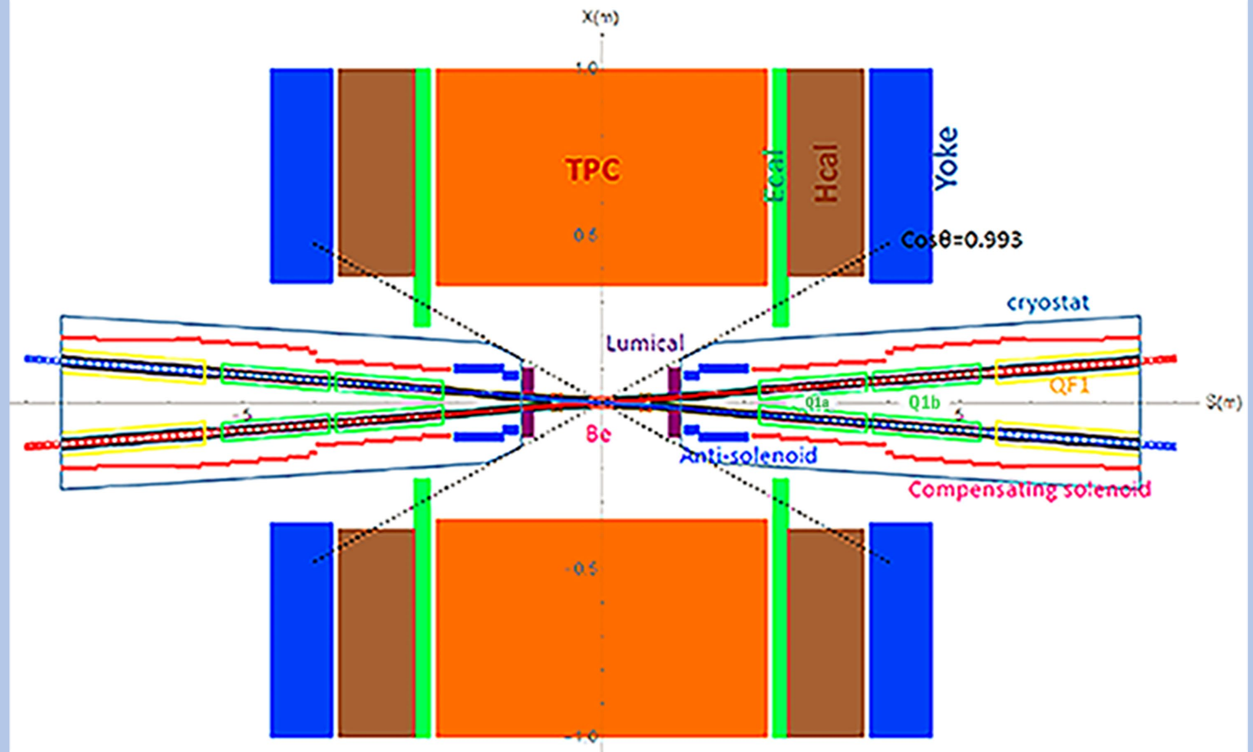
INTRODUCTION



- In November 2018, CEPC Conceptual Design Report (CDR) was announced. To pursue higher collision luminosity, accelerator physicists proposed CEPC high-luminosity program.
- The superconducting quadrupole magnet QD0 in CEPC CDR is divided into two superconducting quadrupole magnets Q1a and Q1b. The superconducting quadrupole magnet Q1a was moved forward to a position 1.9 m from the interaction point.
- The double-aperture superconducting quadrupole magnet Q1a is closest to interaction point, making it the most difficult to design.

PURPOSE

- According to the design requirements of the single-aperture magnet Q1a, we complete the preliminary physical design based on cos2θ coil, racetrack coil and CCT coil.
- Discuss the advantages and disadvantages of the three different coil structures.
- Complete the electromagnetic design of the double-aperture superconducting quadrupole magnet Q1a.
- Optimize the weight of superconducting magnet with the goal of reducing double-aperture magnetic field crosstalk.

CONTACT

- This work was supported by the National Natural Science Foundation of China under Contract 11875272

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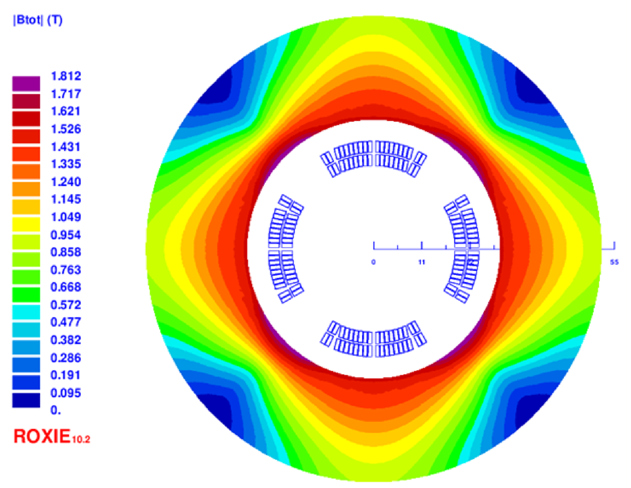
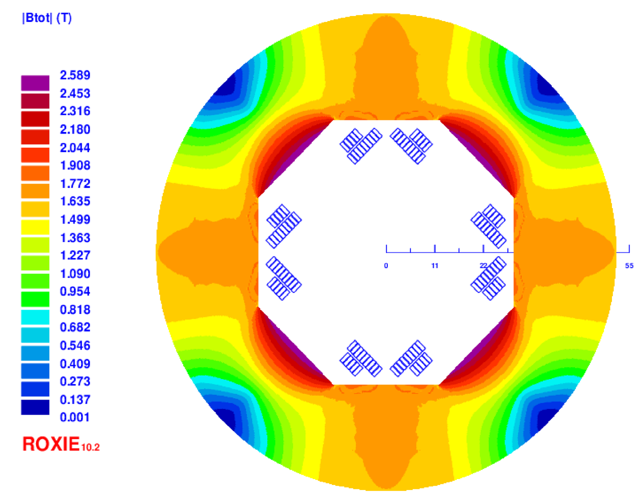
METHOD



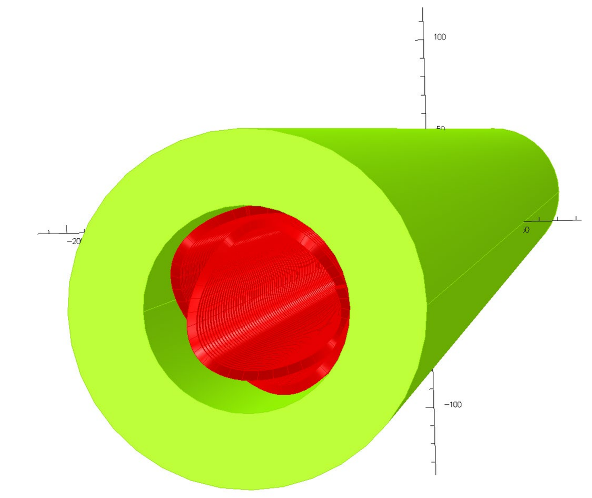
Cos2θ coil structure

- Two-layer cos2θ quadrupole coil, two blocks in each layer are separated by a wedge.
- Rutherford cable with a trapezoidal angle of 1.9 degrees is twisted by 10 Nb-Ti strands.
- The inner and outer radii of the iron are 29 mm and 52 mm.
- High order field harmonics are within 1×10^{-4}.



Racetrack coil structure

- Two-layer racetrack quadrupole coil.
- Rectangular Rutherford cable with a width of 2.5 mm and a height of 0.85 mm is twisted by 10 Nb-Ti strands.
- The inner edge of iron is a regular octagon, and each edge is 29 mm from the center of aperture.
- High order field harmonics are within 1×10^{-4}.

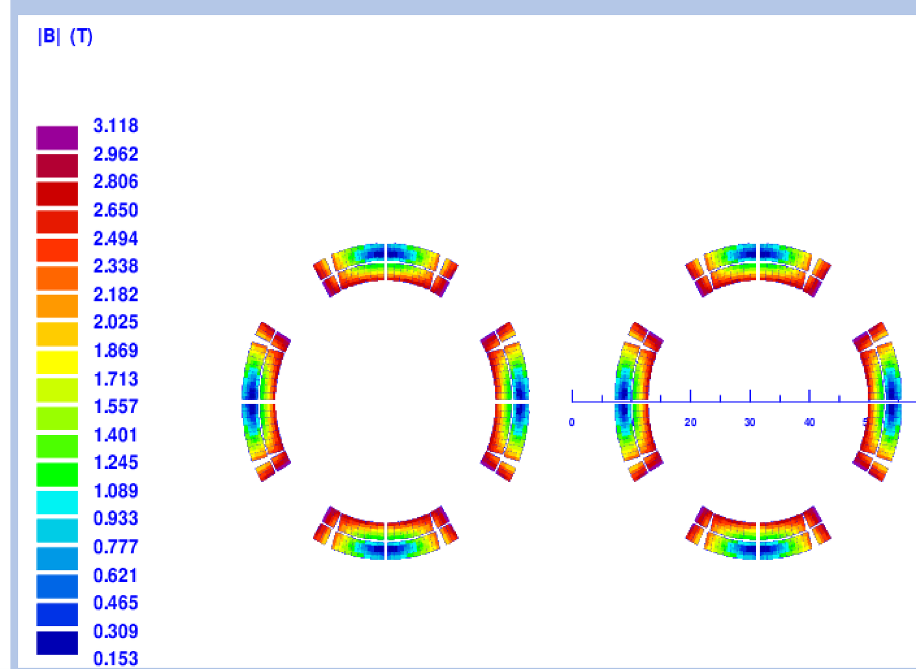


CCT coil structure

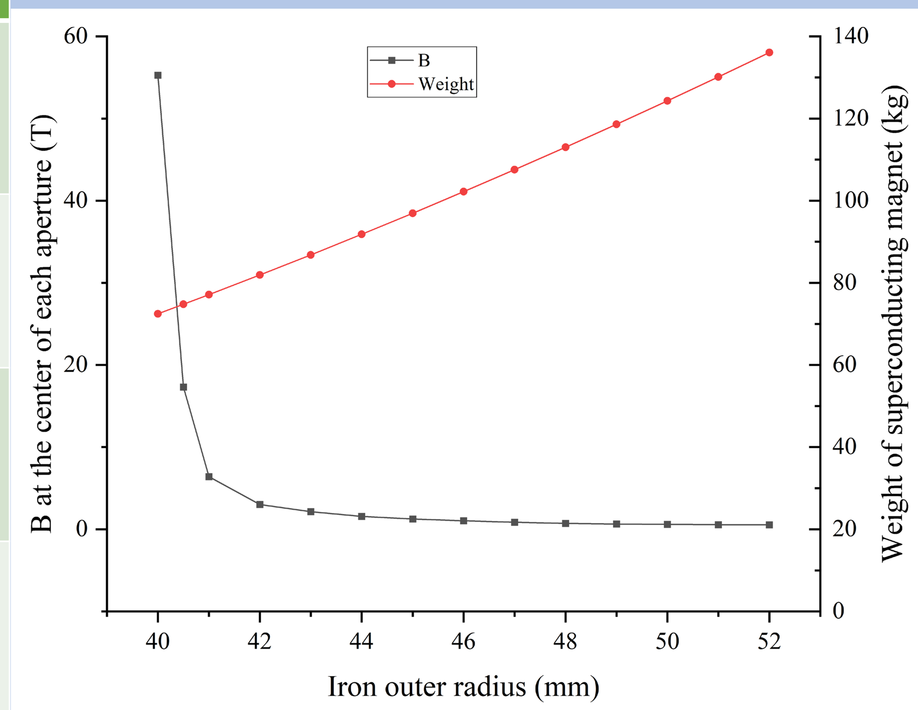
- Complete the conversion of coordinate points from local coordinates to global coordinates. Use the 20-node pattern to splice the CCT coil.
- The conductor is consist of 12 Nb-Ti strands, the cross-sectional size is 1 mm × 3 mm.
- The inner and outer radii of the iron are 30 mm and 52 mm.

Design and optimization of double-aperture Q1a based on cos2θ coil

- ◆The double-aperture magnet Q1a is designed according to the same polarity, magnetic field gradient and field quality requirements in each aperture.
- ◆In the pure coil model, the dipole field at the center of the aperture reaches 1000 Gs. So far, no pure coil model that meets the physical requirements has been found.
- ◆Improve the magnetic saturation strength by changing the iron material. reduce the outer radius of iron.



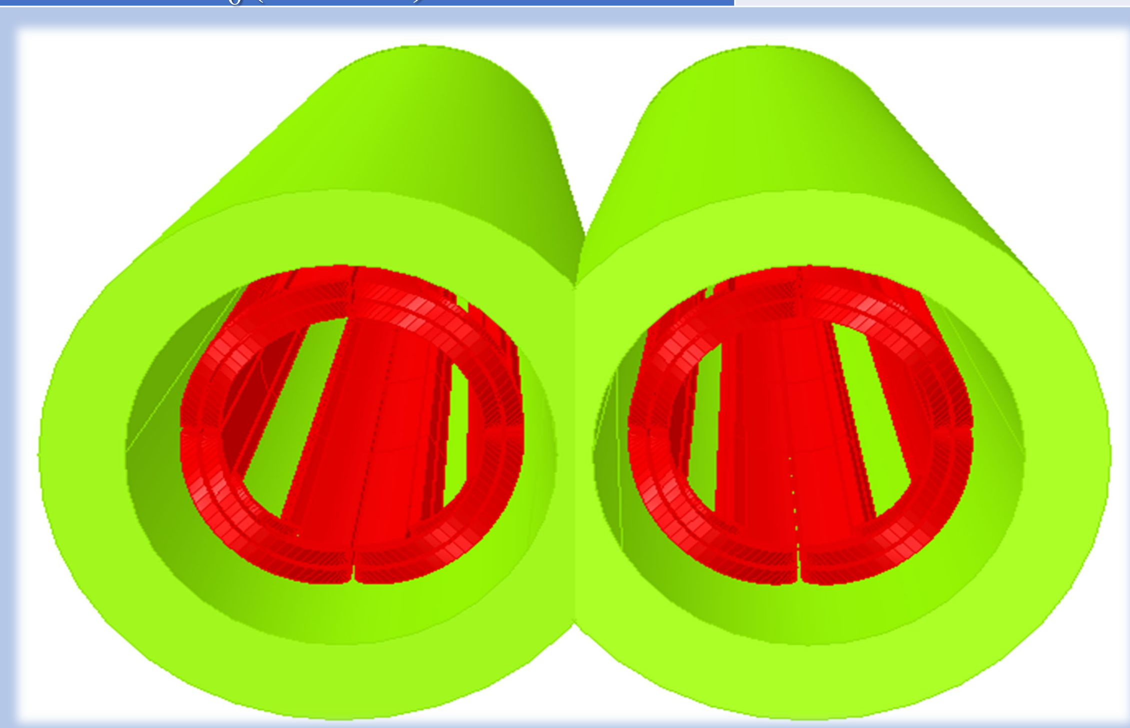
	Main features	Performance	Weight (kg)	Remark
Option 1	2 layers coil, iron-free	Large dipole field, 20% larger current	36	Smallest weight, field crosstalk not solved
Option 2	2 layers coil, DT4 iron	Meet all requirements (Dipole <30Gs)	95.41	Largest weight
Option 3	2 layers coil, FeCoV iron	Meet all requirements (Dipole <30Gs)	74.78	Manufacture cost increases slightly
Option 4	1 layer coil, FeCoV iron	Meet all requirements (Dipole <30Gs)	60.2	Double current carrying capacity, 5 years later



RESULT

- ■Cos2θ quadrupole coil is used to design the double-aperture superconducting quadrupole magnet Q1a.
- ■Using FeCoV material, the outer radius of iron is reduced to 40.5 mm. The dipole field at the center of each aperture is 17.316 Gs.
- ■The filed harmonics at reference radius of each aperture are less than 2×10^{-4}.

Parameter	Value
Current	1965 A
Gradient	141.8102 T/m
Weight	74.78 Kg
Dipole field at the center of each aperture	17.316 Gs
b_3 (unit 10^{-4})	-1.04397
b_4 (unit 10^{-4})	-0.01436
b_5 (unit 10^{-4})	-0.067
b_6 (unit 10^{-4})	0.48833



CONCLUSION

- Cos2θ quadrupole coil : high excitation efficiency, complex coil shape, complex supporting structure.
- Racetrack quadrupole coil : low excitation efficiency, simple coil shape, friendly to high-temperature superconductors.
- CCT quadrupole coil : simple support structure, low cooling efficiency .
- Complete the double-aperture superconducting quadrupole magnet Q1a, meet the requirements of high-order field harmonics, dipole field and the weight.

REFERENCE

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