CEPC Iron Yoke Mechanical Design Optimization

Institute of High Energy Physics

Xia Shang Ji Quan

2023/10/27

- Overview
- CEPC iron yoke mechanical design optimization
- Summary
- What’s next

Overview

Barrel iron yoke

End iron yoke

HCAL

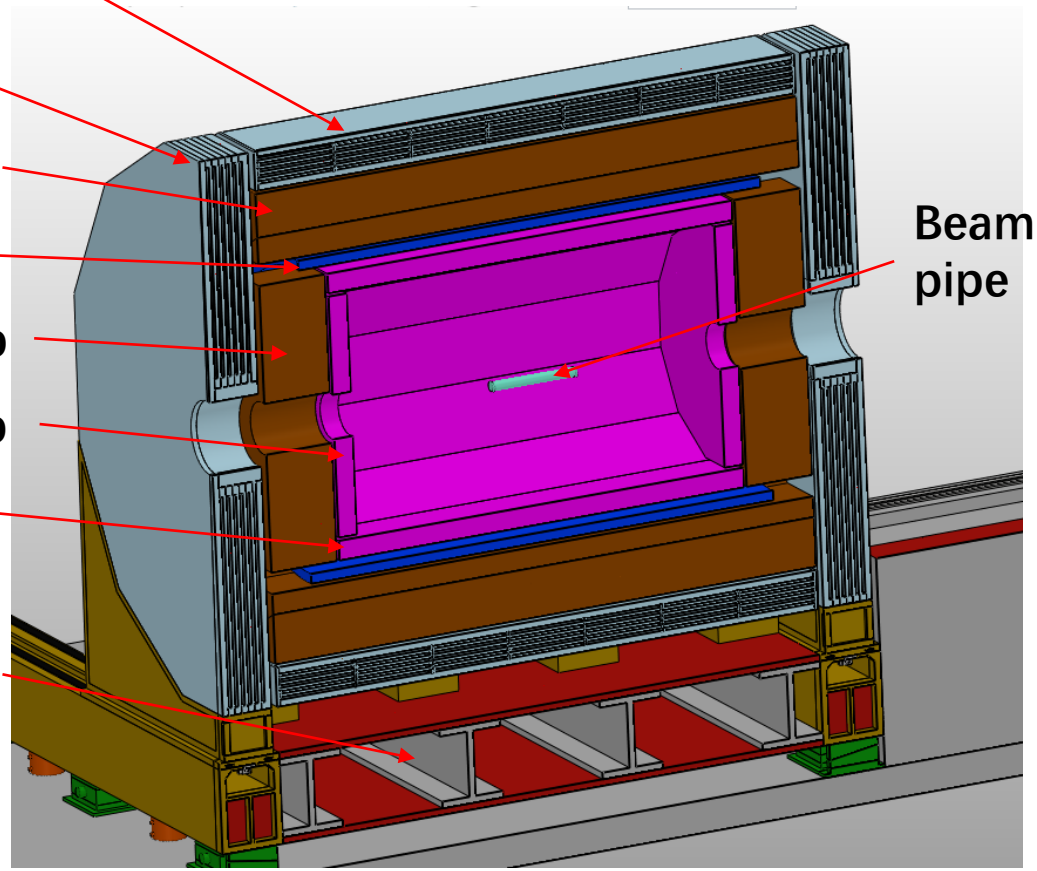
Superconducting magnet

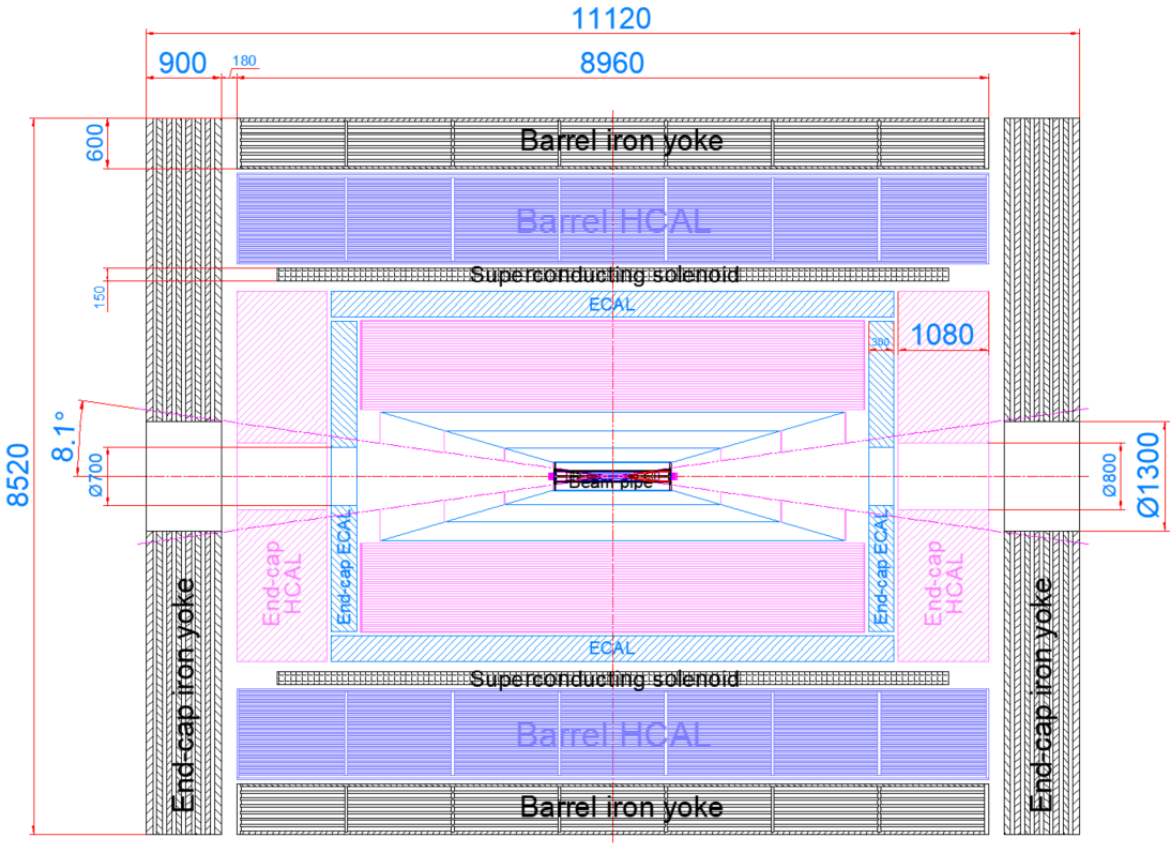
HCAL-endcap

ECAL-endcap

ECAL

Base





CEPC Mechanical component of detectors

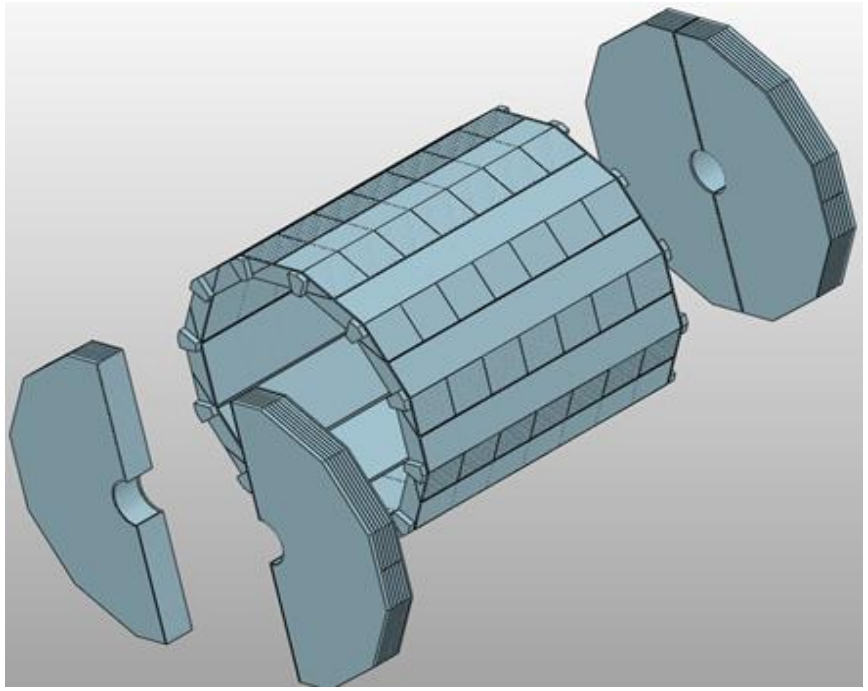
Height: 8.5m

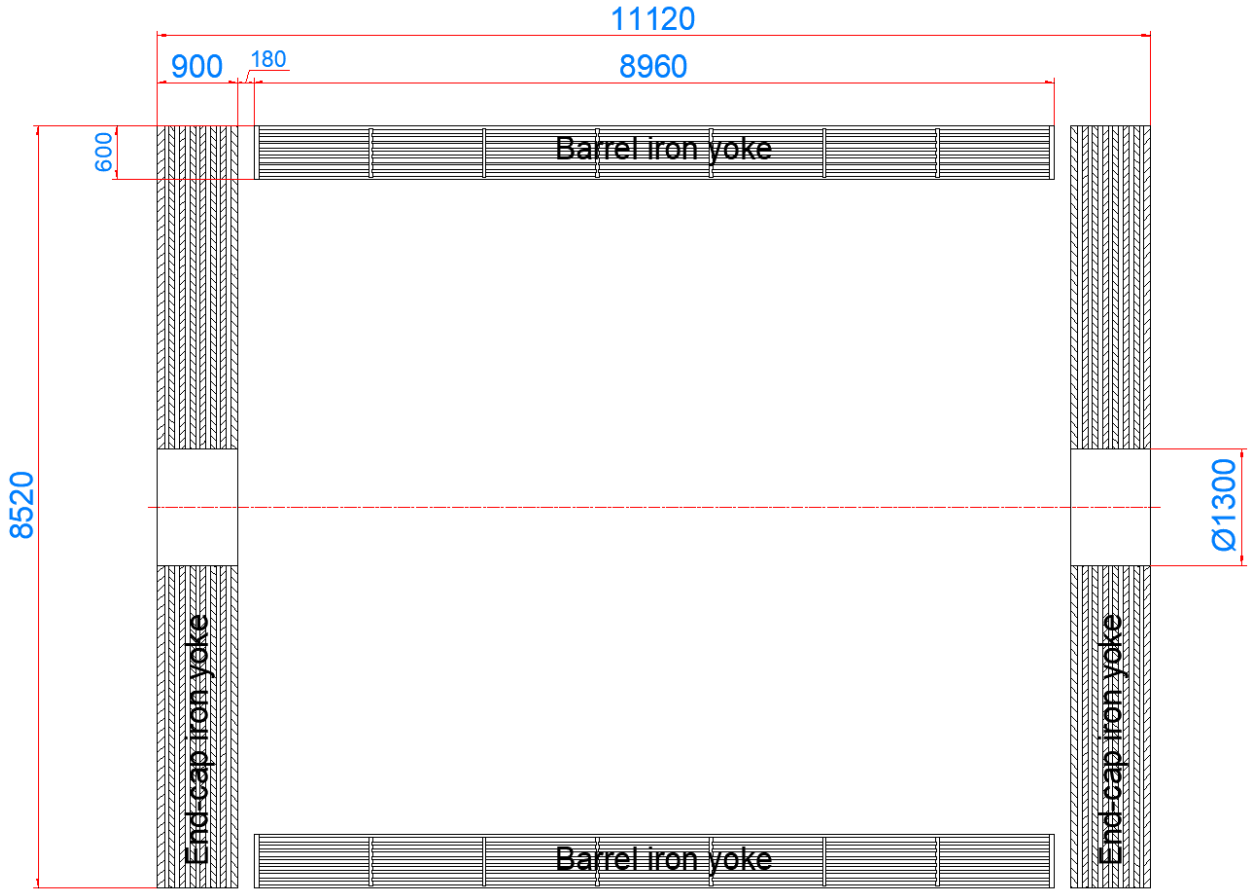
Length: 11.1m

Weight: about 3000 tons

(Iron yoke: about 1000 tons)

Overview





Composition: End-cap iron yoke + Barrel iron yoke

Functions:1) Provide support, adjustment and locking for the internal detector;

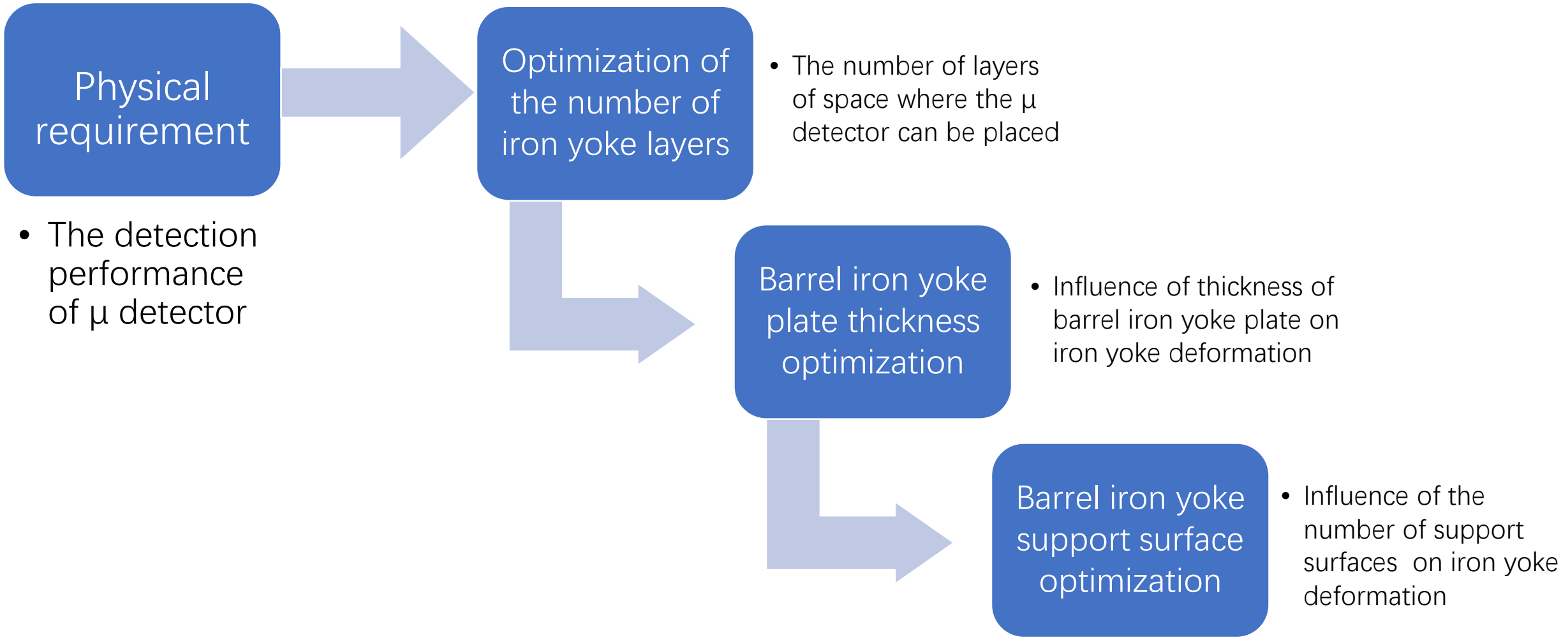
2) Provide the magnetic field loop to ensure the required uniformity of the magnetic field;

3) Absorb all particles except μ;

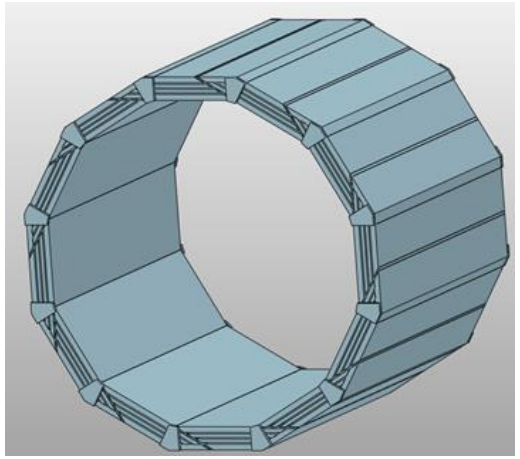
4) Provide placing space for μ detector;

Design Requirements: 1) Ensure sufficient strength and stiffness; 2) Require total thickness of yoke; 3) Thickness of each layer; 4) Material requirements; 5) Meet the requirements of sub-detector assembly and overhaul maintenance;

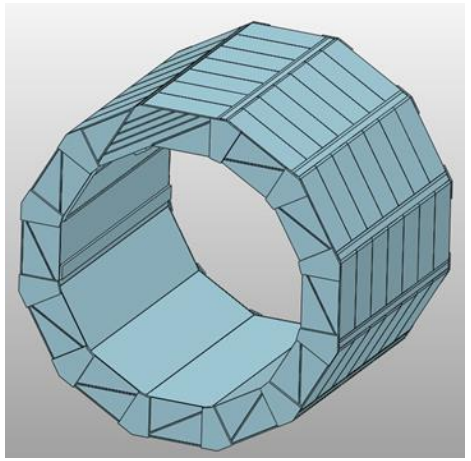
CEPC iron yoke mechanical design optimization



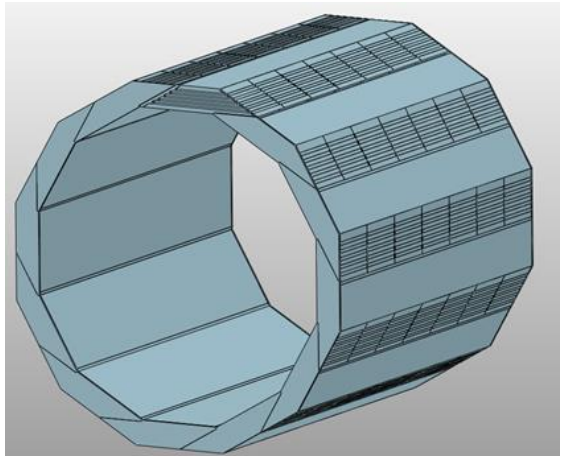
Optimization of the number of iron yoke layers



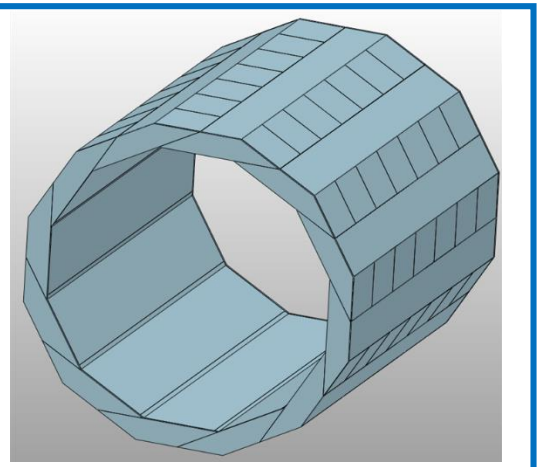
December, 2018
Thickness: 600mm
Muon: 3 layers
Height: 9600mm
Weight: 920 t



January, 2020
Thickness: 1460mm
Muon: 4 layers
Height: 12120mm
Weight: 3180 t



March, 2021
Thickness: 600mm
Muon: 5 layers
Height: 8520mm
Weight: 760 t



June, 2023
Thickness: 600mm
Muon: 7 layers
Height: 8520mm
Weight: 520 t

Increase the number of layers that can place μ detectors

Improve μ detector resolution → Better detection performance

Reduced thickness of the iron yoke plate → Self-weight deformation increases

Design difficulty

Structure optimization

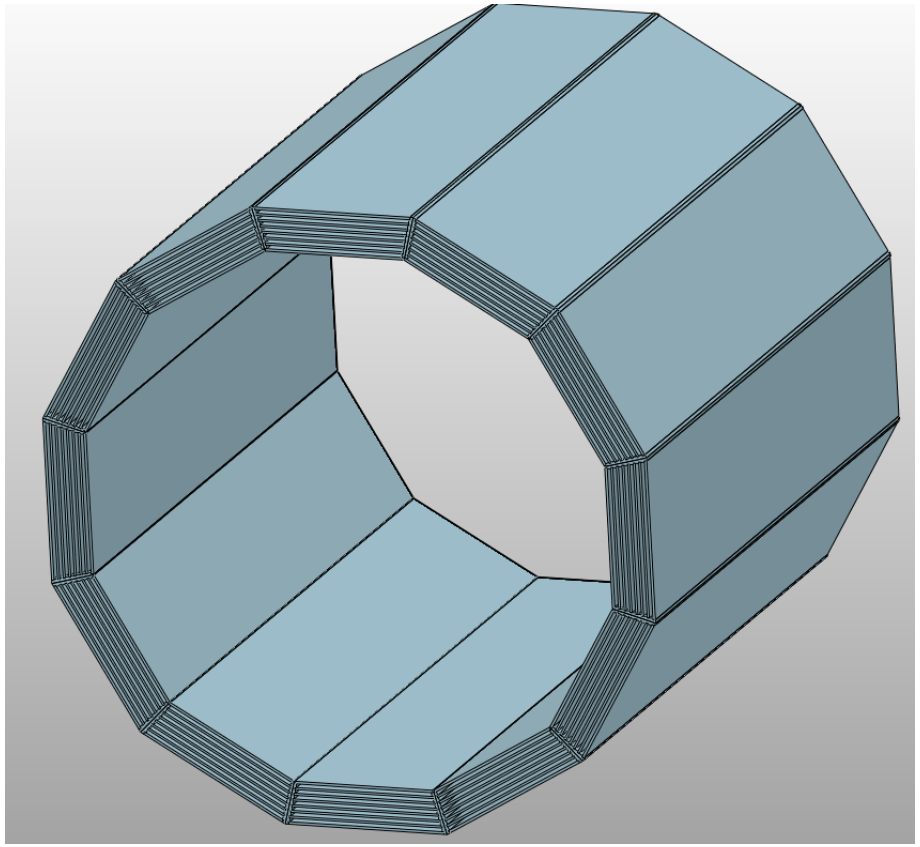
Solution

Mechanical design requirements

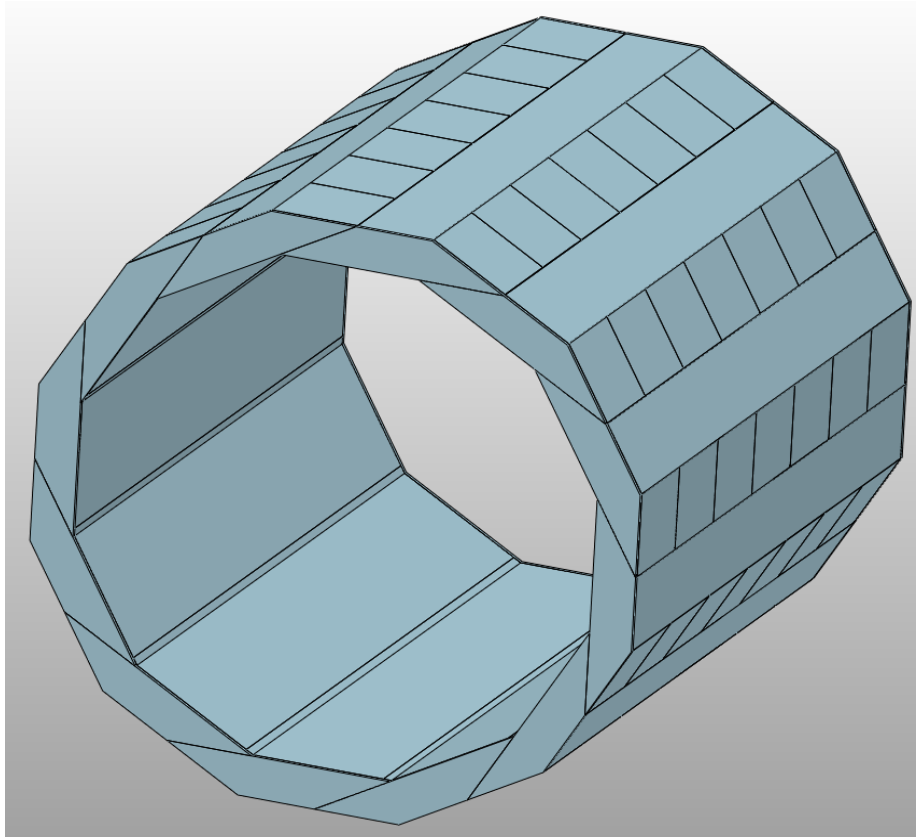
Barrel iron yoke

- Two designs

symmetrical structure (7 layers)

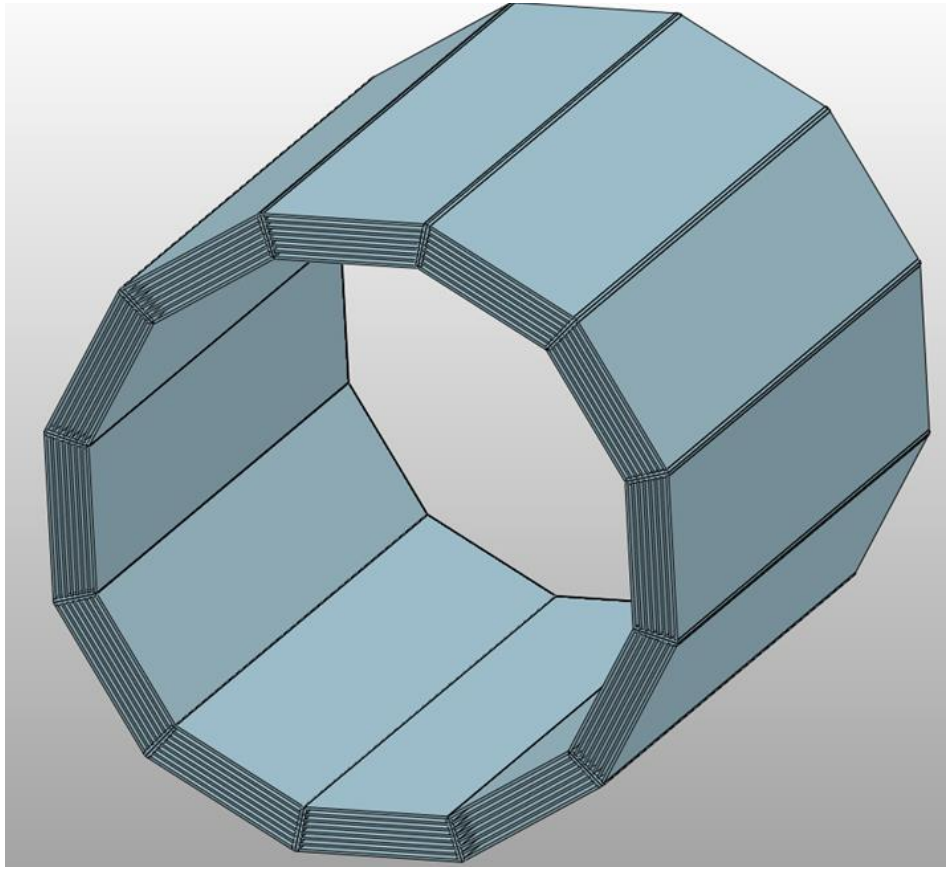


spiral structure(7 layers)



Barrel iron yoke

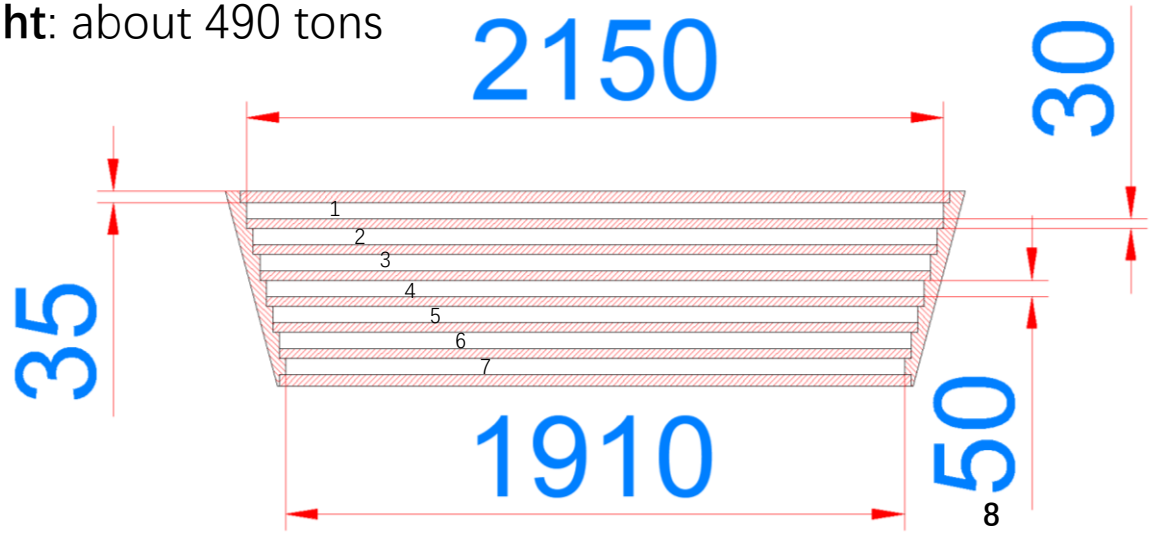
- symmetrical structure （7 layers）



Dodecagon
12 modules

8 iron yoke plates
place 7 layers μ detectors

Length: 8960mm
Height: 8520mm
Thickness:
600mm(outer35mmX2+clearance50mmX7+middle30mmX6)
Material: T10
Weight: about 490 tons

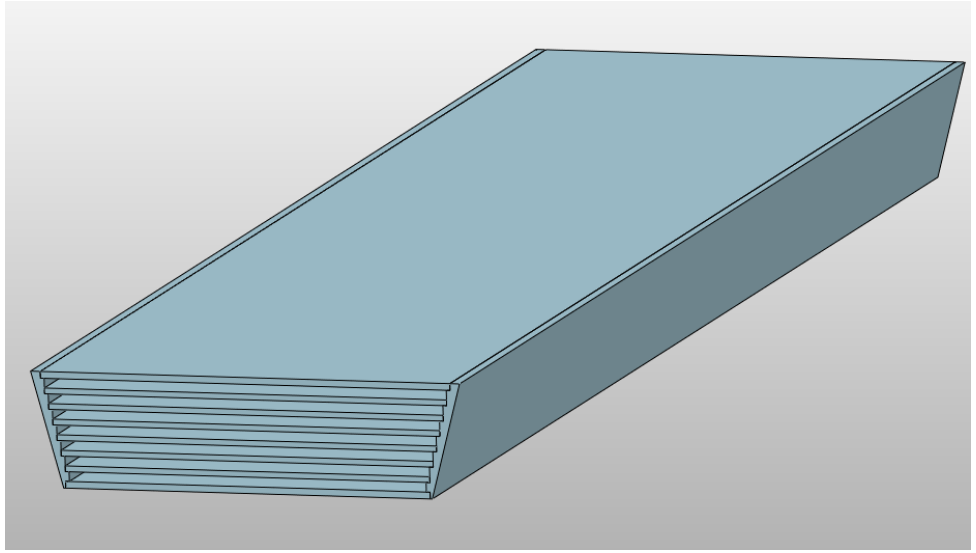


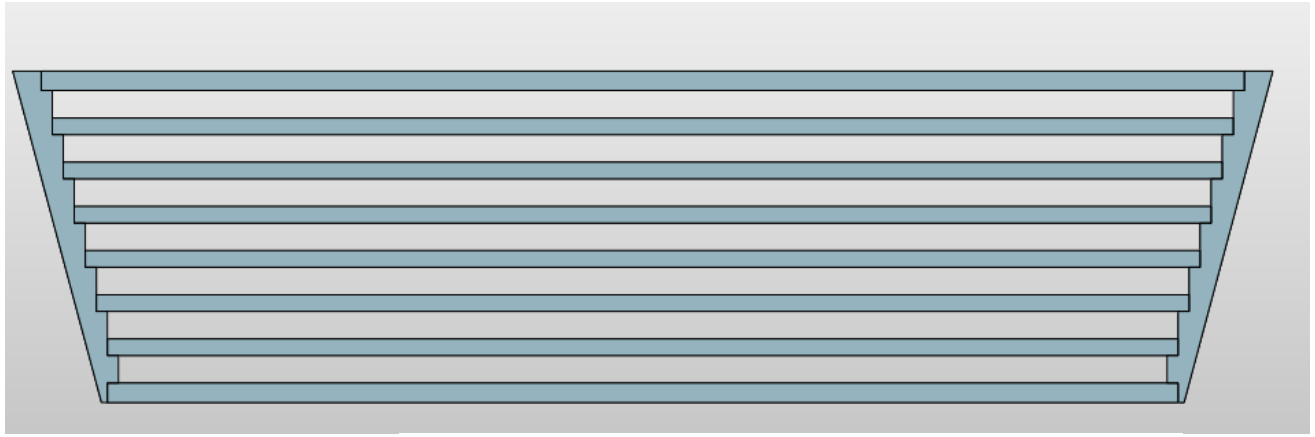
Barrel iron yoke

- symmetrical structure （7 layers）

Feature:

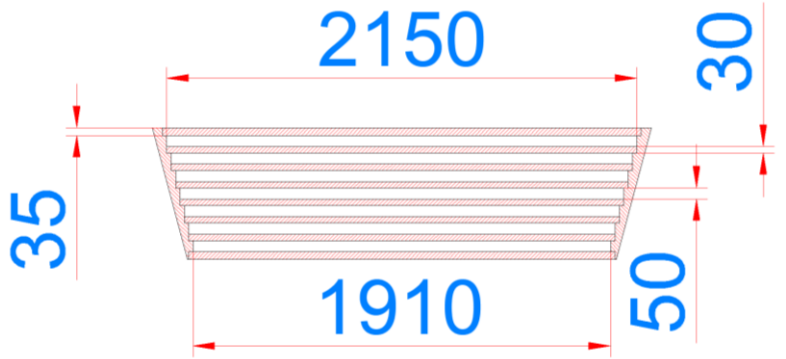
1. The space for placing the μ detector increases from the inside to outside, and the size gap is not large;
2. Install the μ detector at both ends of the module.
3. Difficult subsequent maintenance;





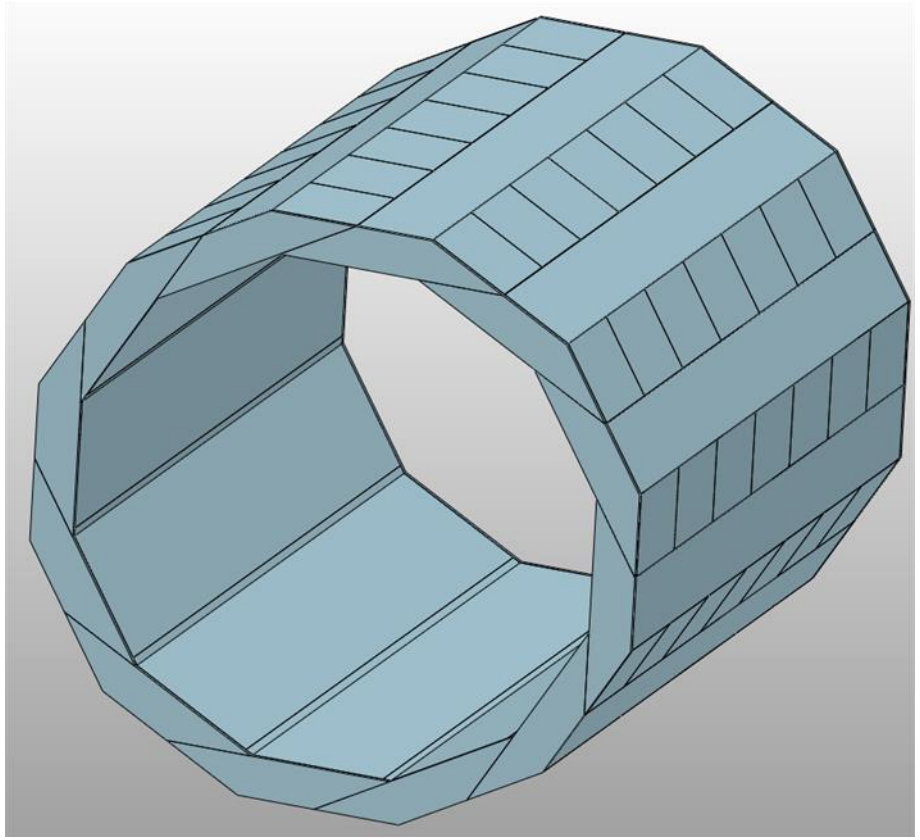
Circumferential: 12 module Axial: 1 or 2 units

μ Minimum detector space : 1910(circumferential) × 4480(axial)
μ Maximum detector space : 2150(circumferential) × 8960(axial)



Barrel iron yoke

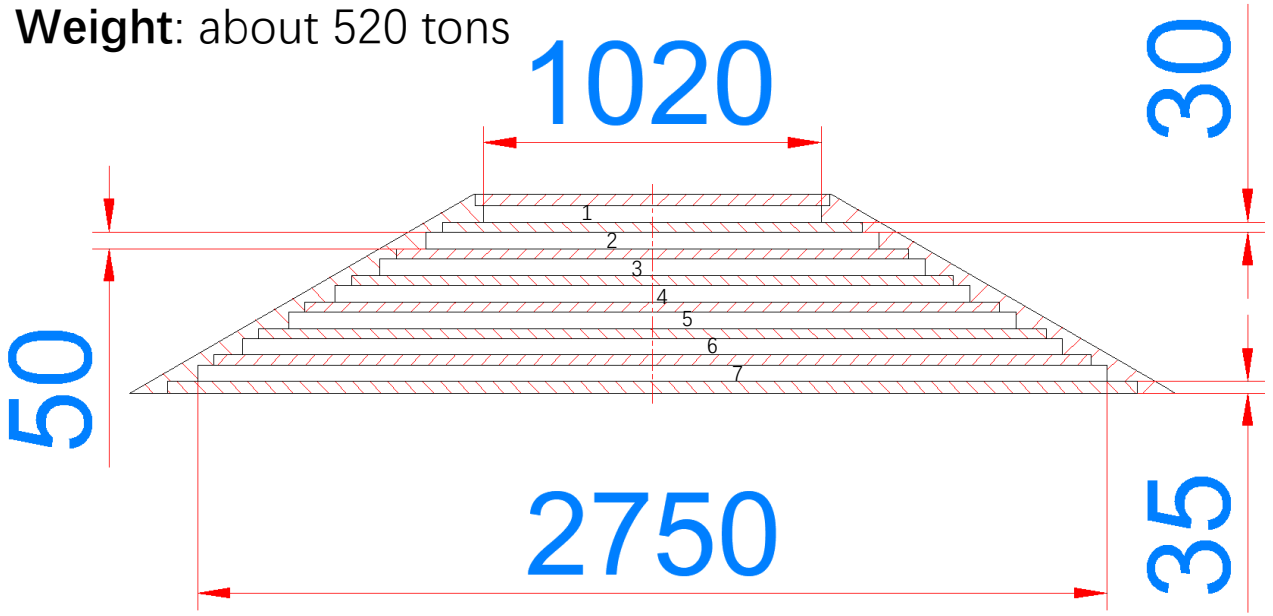
- spiral structure （7 layers）



Dodecagon
12 modules
6 partitions

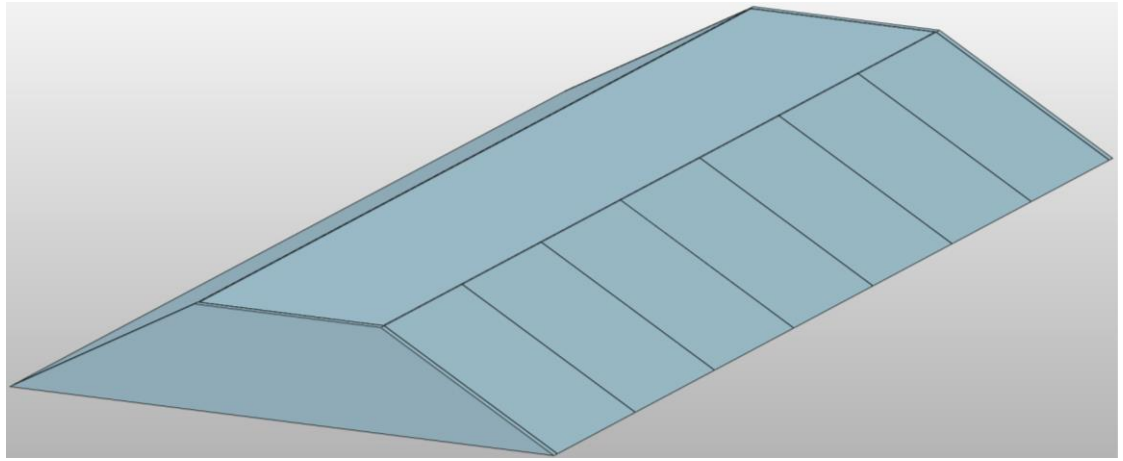
8 iron yoke plates
place 7 layers μ detectors
7 units in axial direction

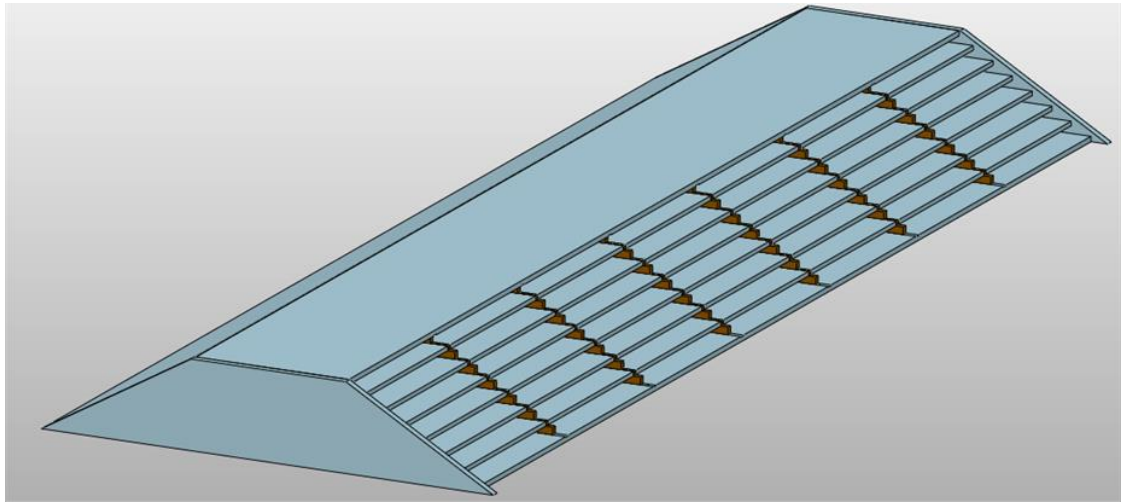
Length: 8960mm
Height: 8520mm
Thickness: 600mm
(outer35mmX2+clearance50mmX7+middle30mmX6)
Material: T10
Weight: about 520 tons

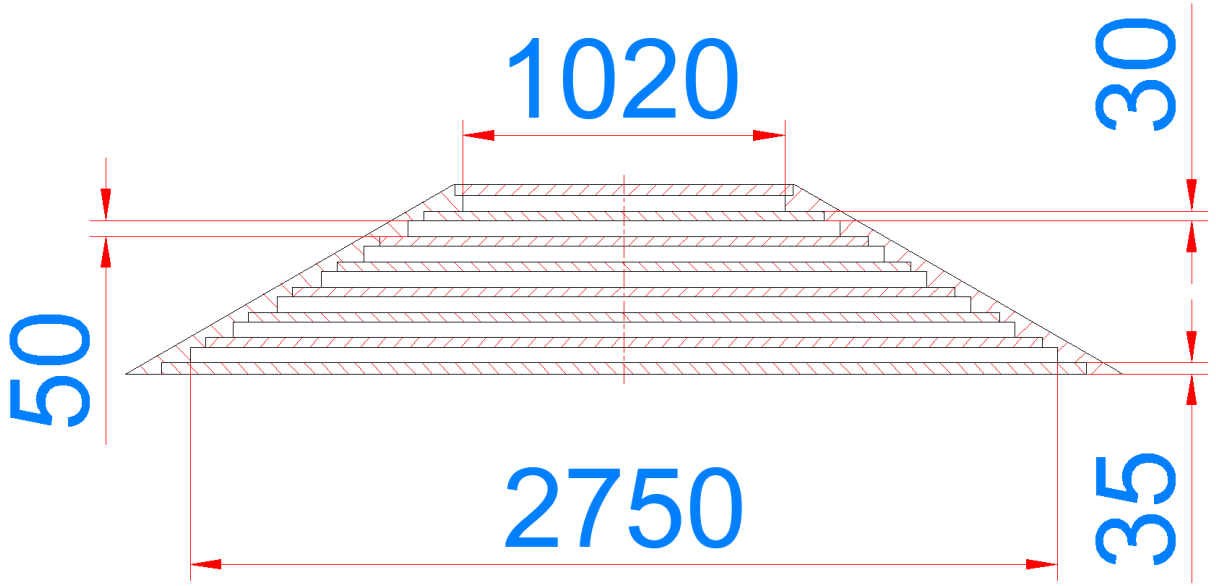


Barrel iron yoke

- spiral structure （7 layers）







Circumferential: 12 modules Axial: 7 units

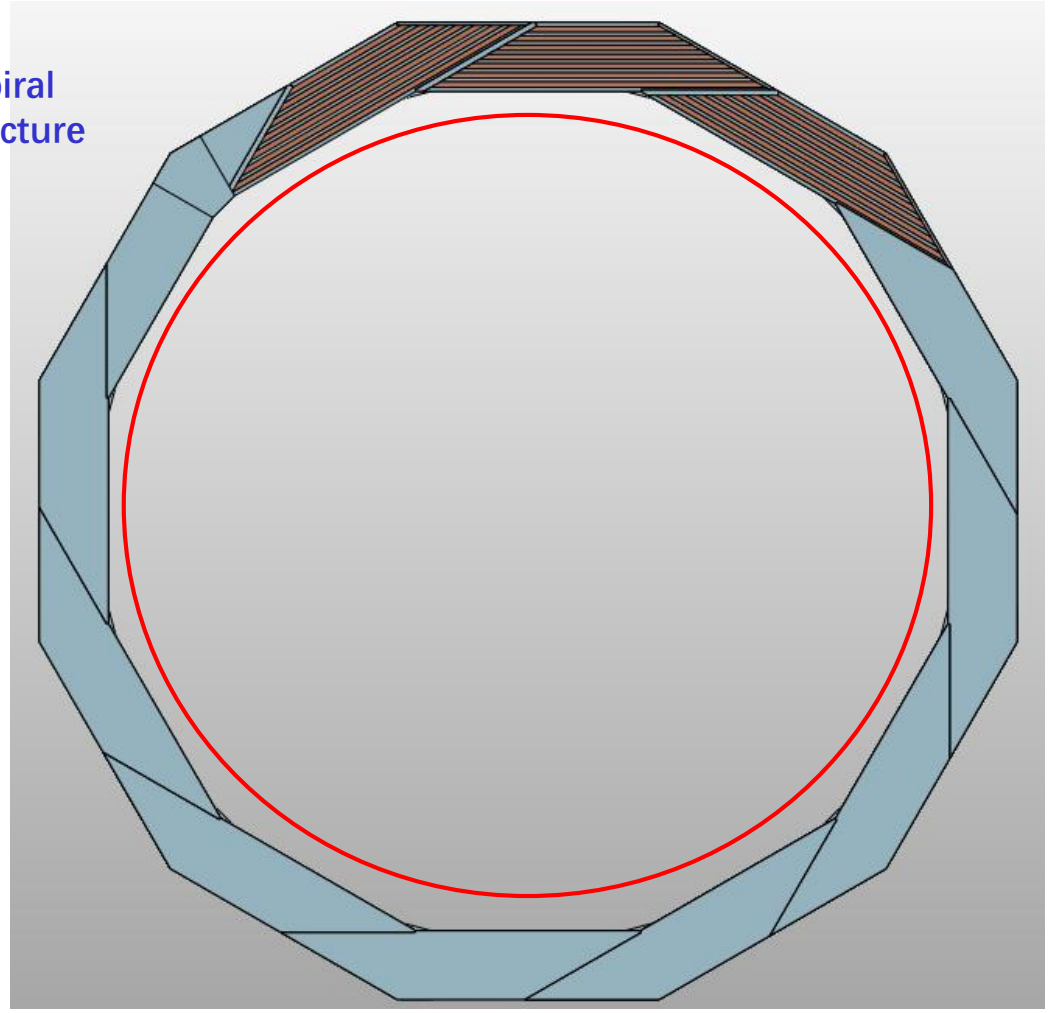
μ Minimum detector space : 1020(circumferential) × 1230(axial)
μ Maximum detector space : 2750(circumferential) × 1230(axial)

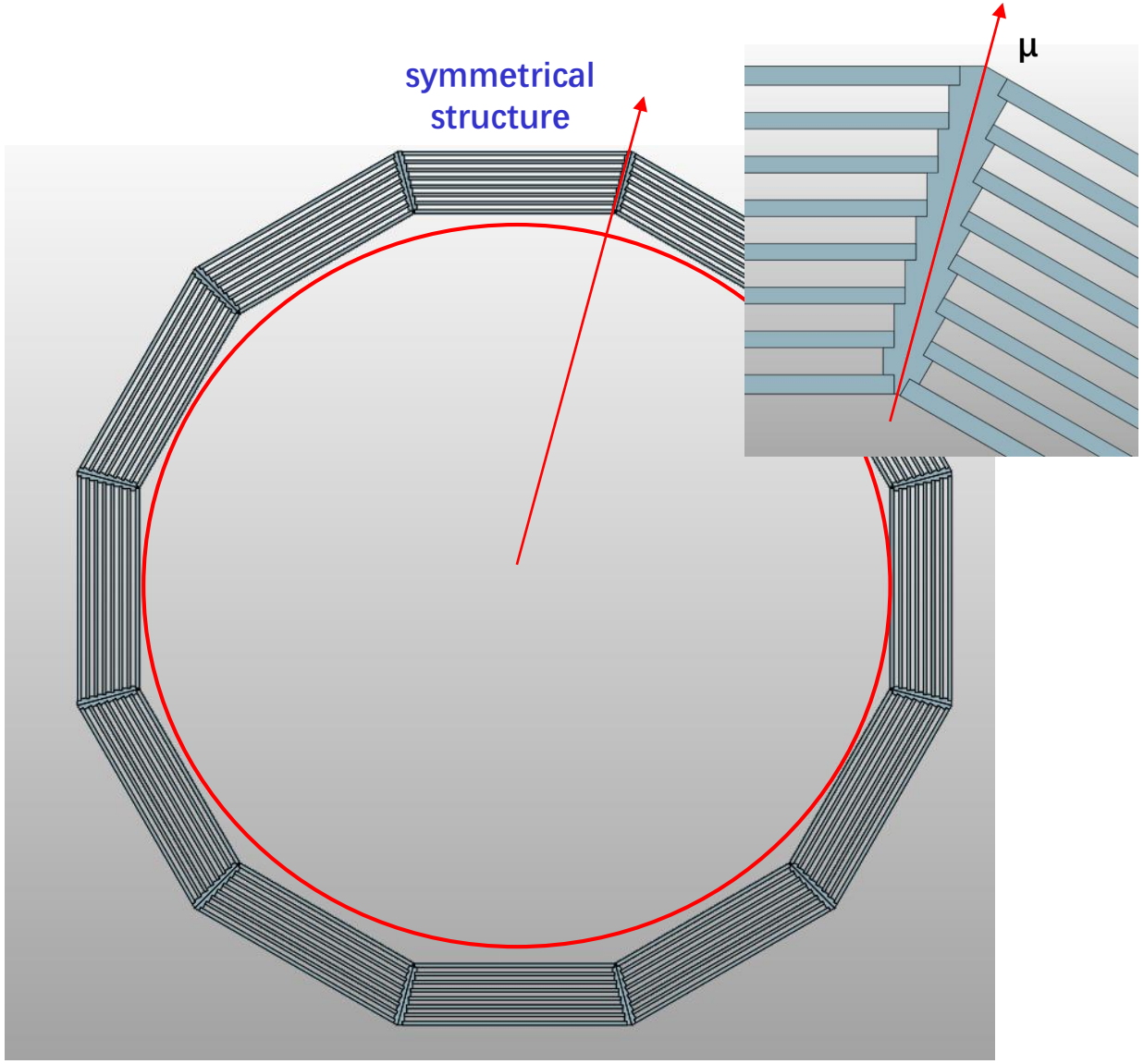
Feature:

1. The space for placing the μ detector is gradually reduced from inside to outside, and the size gap is large;
2. Each μ detector space can be opened individually;
3. Convenient installation and subsequent maintenance;

Barrel iron yoke

- spiral structure （7 layers）





Features:

4. The detection angle can be fully covered to **avoid μ detection blind zone**;

Simulation result

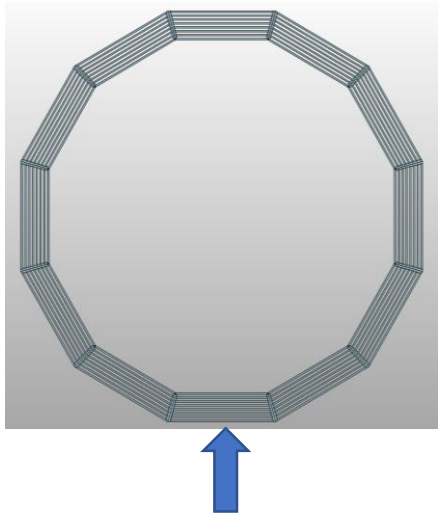
Conditions:

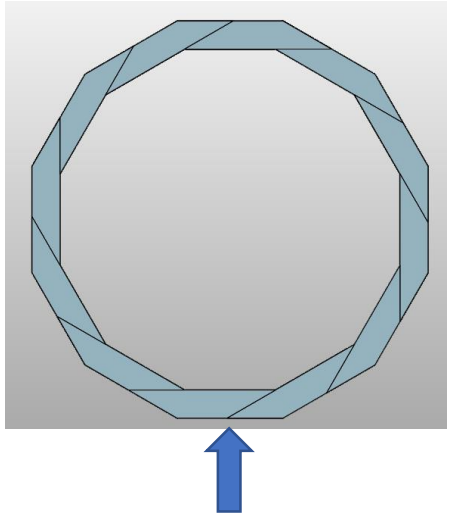
Design model：place a 7 layers μ-detector with a thickness of 600 ;

Yoke iron material: T10 ;

Load: self-weight of barrel yoke iron ;

Constraint condition: bottom surface ;

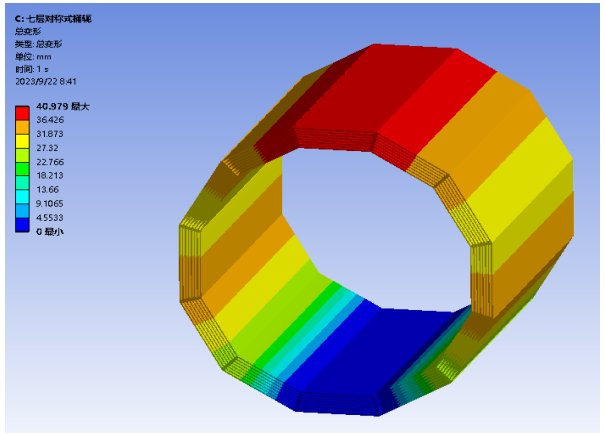


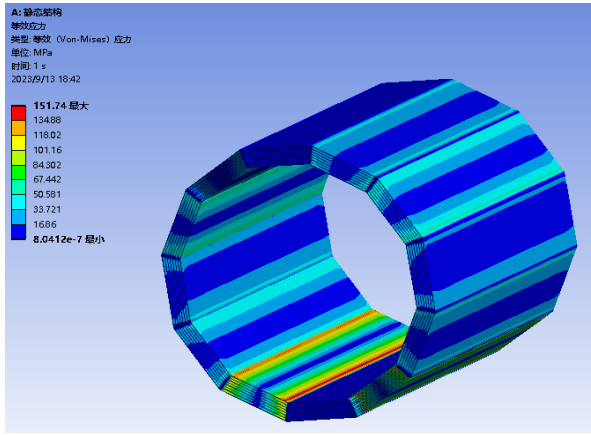


Deformation

Stress

symmetrical structure

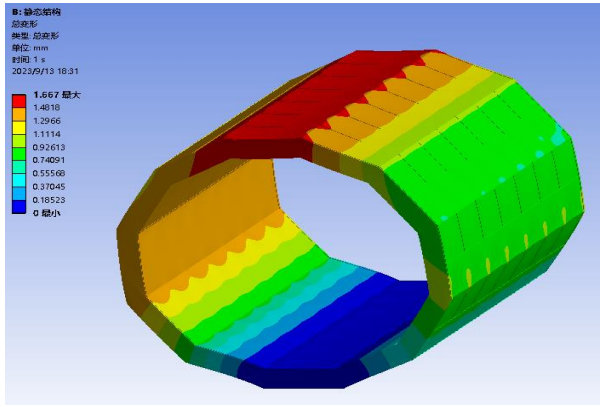


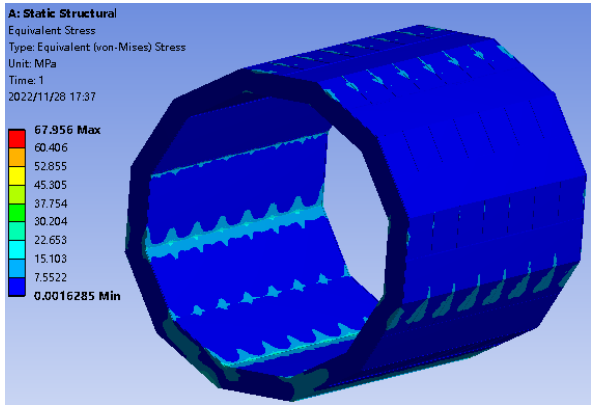


Max 40.979mm

Max 151.74MPa

spiral structure





Max 1.667mm

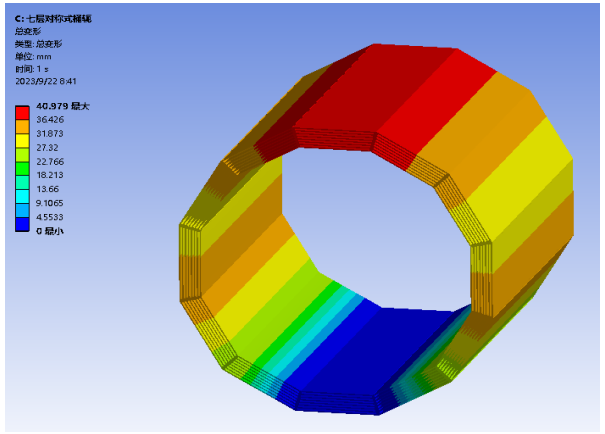
Max 77.591MPa

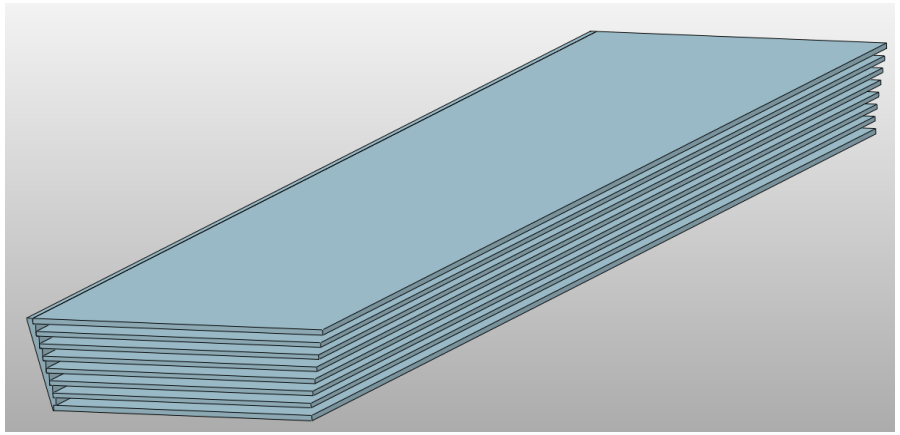
Simulation result

Big difference in self-weight deformation?

Deformation

symmetrical structure





Max 40.979mm

No partition

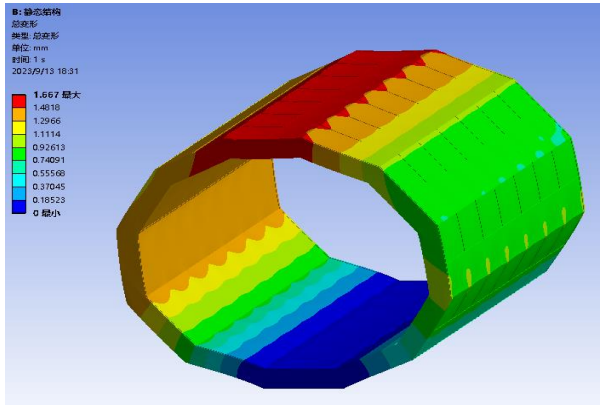
↓

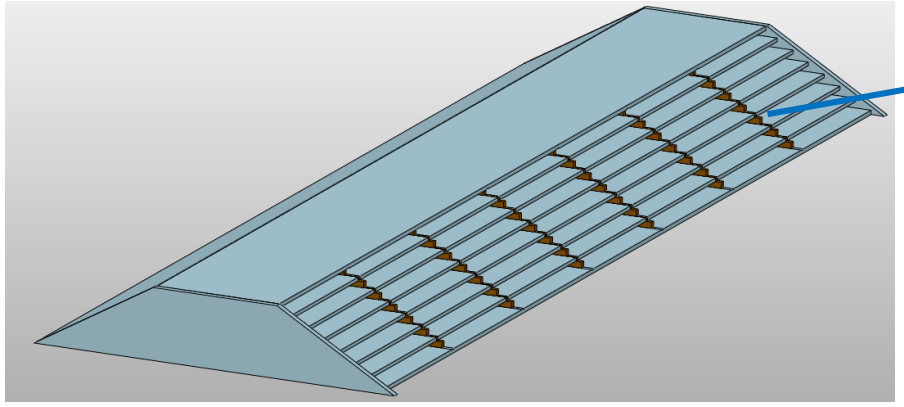
Large module self-weight deformation

↓

Large overall self-weight deformation

spiral structure





Max 1.667mm

6 Partitions

↓

Small module self-weight deformation

↓

Small overall self-weight deformation

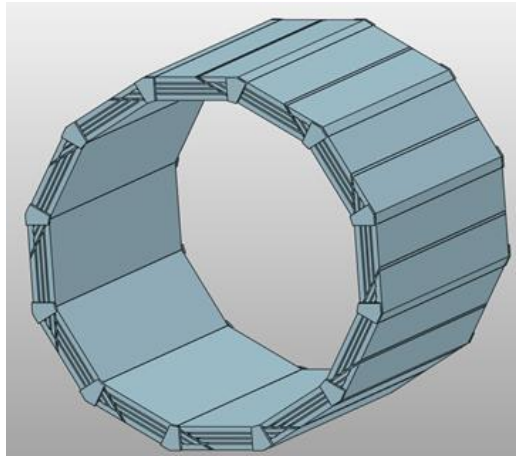
Barrel iron yoke plate thickness optimization

conclusion

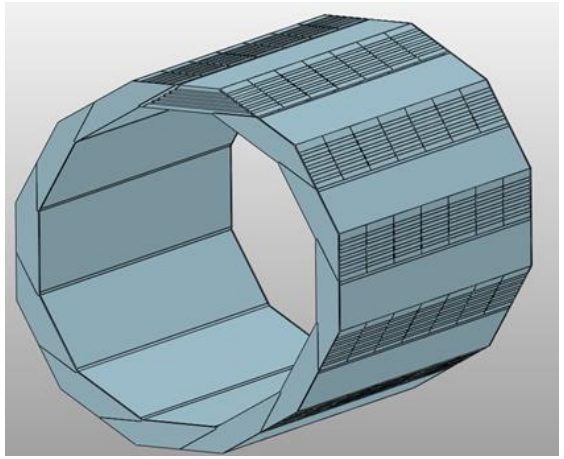
The thinner iron yoke plates' thickness of barrel iron yoke, the larger self-weight deformation of barrel iron yoke.

Modifying iron yoke plates' thickness of barrel iron yoke can reduce self-weight deformation of barrel iron yoke.

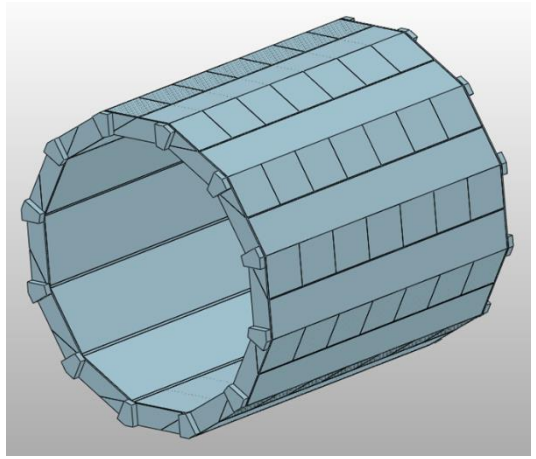
Three iron yoke structures



December, 2018
Thickness: 600mm
Muon: 3 layers
Height: 8520mm
Weight: 920 tons



March, 2021
Thickness: 600mm
Muon: 5 layers
Height: 8520mm
Weight: 760 tons



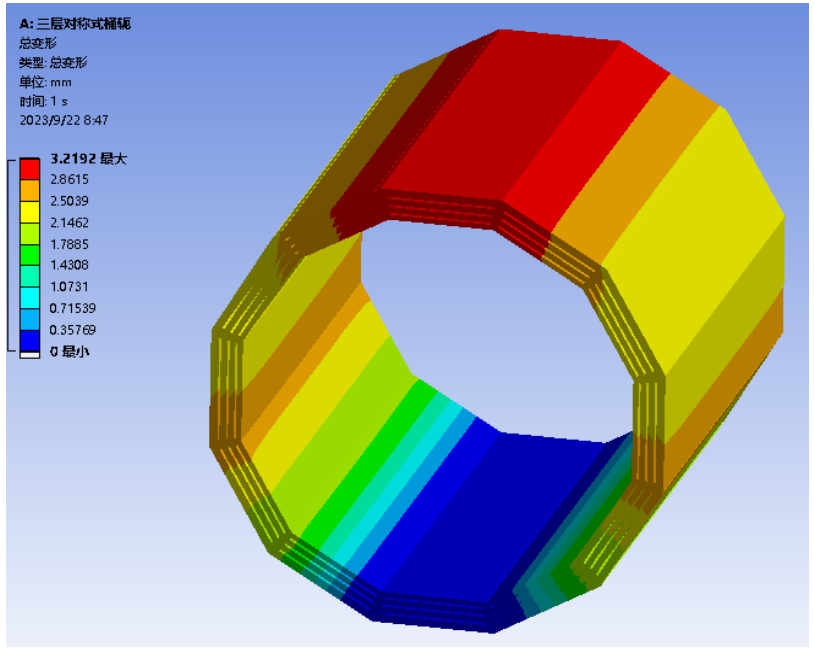
June, 2023
Thickness: 600mm
Muon: 7 layers
Height: 8520mm
Weight: 520 tons

Symmetrical and Spiral structure
Unify models
Same parameters
Same simulation condition

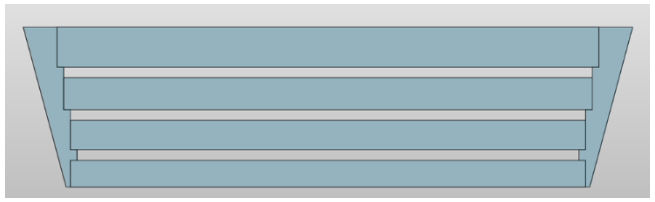
More layers of μ detectors
↓
Barrel iron yoke plates are getting thinner
↓
Self-weight deformation of barrel iron yoke is increasing

Comparison of symmetrical structure

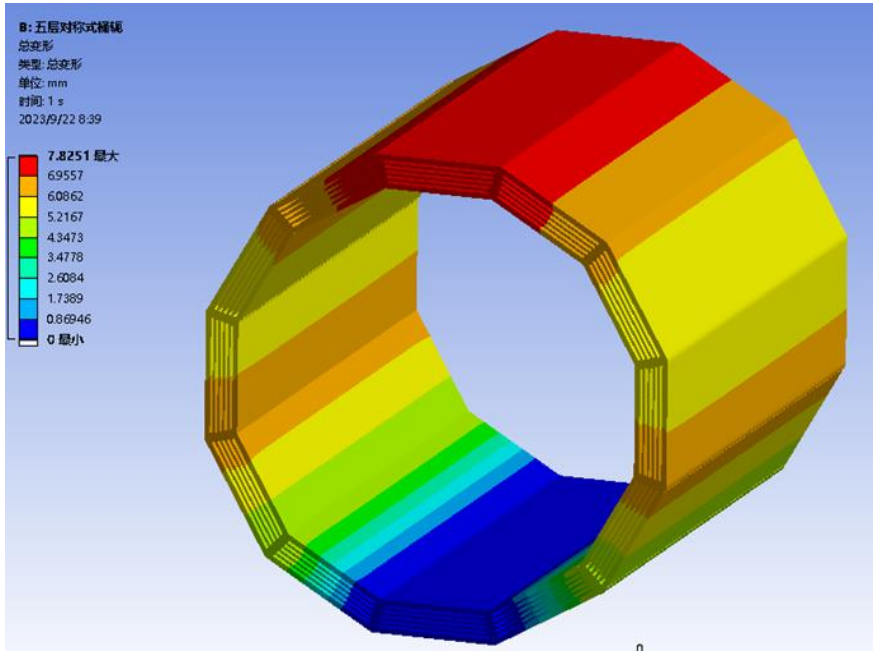
Fixed constraint: bottom plane
Module thickness: 600mm
Axial length: 8960mm
Load: self-weight



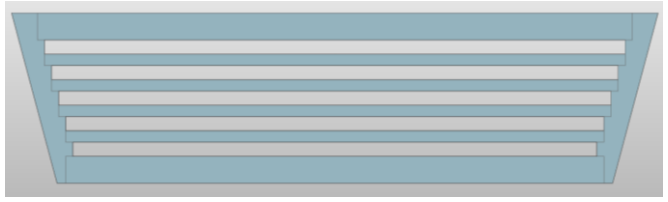
Max deformation : 3.2192mm



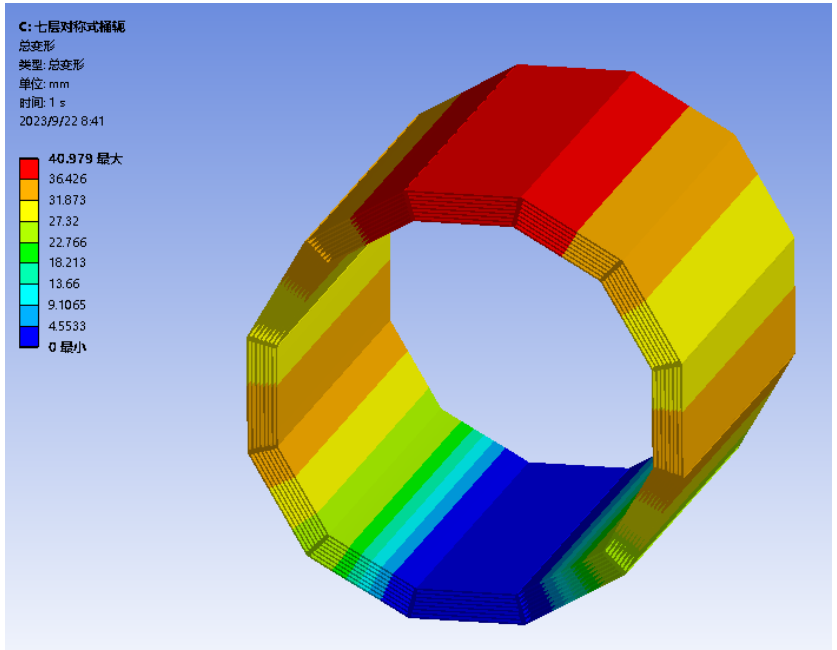
3 layers of μ detector placement space
The thickness (upper and lower plates): 150 mm and 100mm;
The thickness (the middle layer) :120 mm\110mm;
Clearance: 40mm
Weight: 920 tons



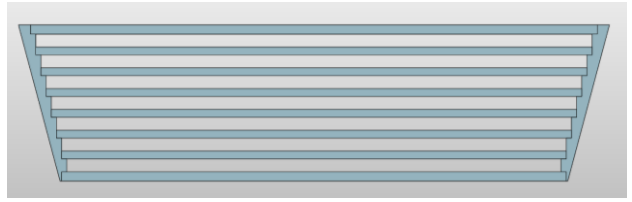
Max deformation: 7.8251mm



5 layers of μ detector placement space
The thickness (upper and lower plates) : 95 mm.
The thickness (the middle layer): 40mm;
Clearance: 50mm
Weight: 760 tons



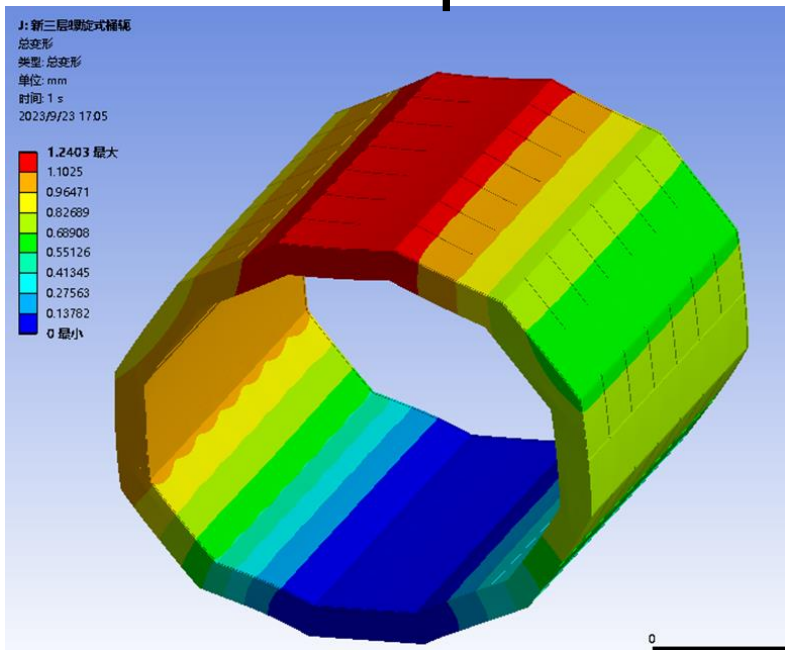
Max deformation: 40.979mm



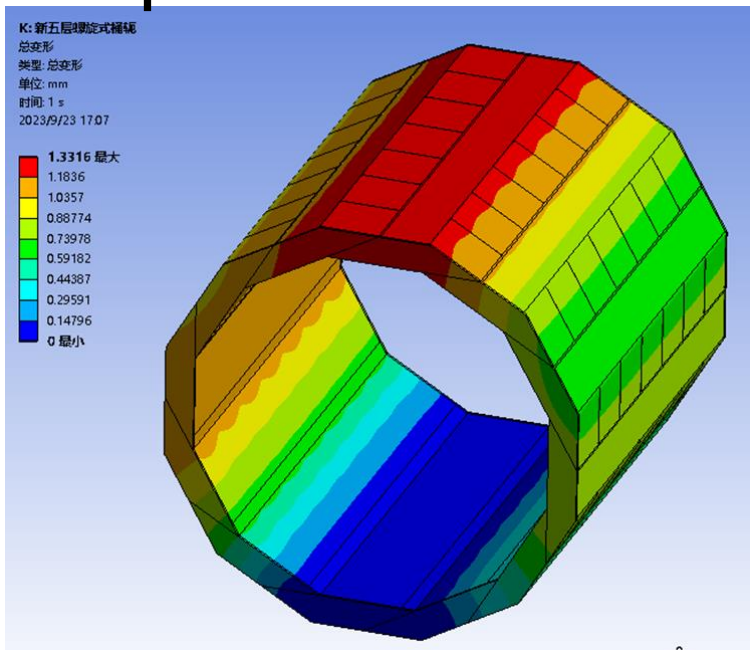
7 layers of μ detector placement space
The thickness (upper and lower plates): 35mm;
The thickness (the middle layer): 30mm;
Clearance: 50mm
Weight: 490 tons

Comparison of spiral structure

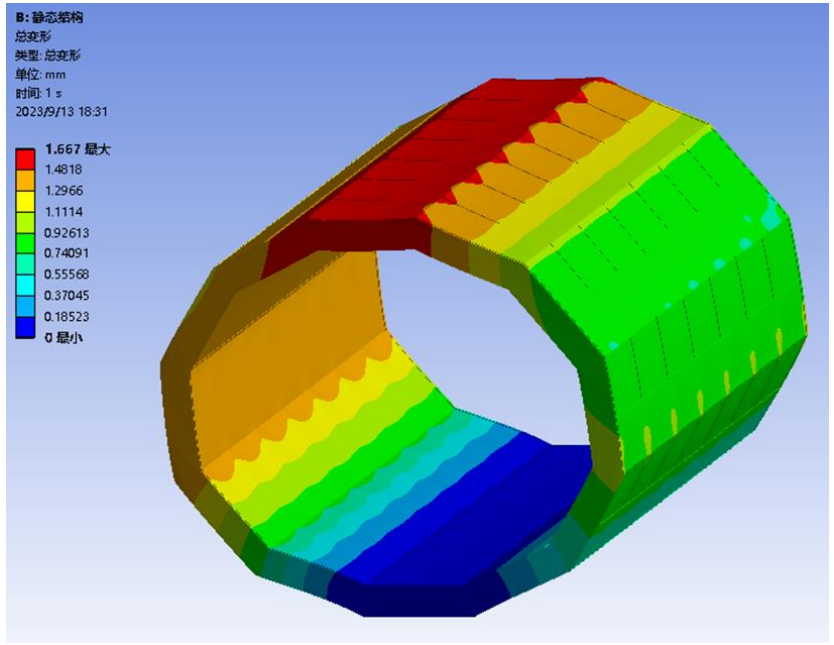
Fixed constraint: bottom plane
Module thickness: 600mm
Axial length: 8960mm
Load: self-weight



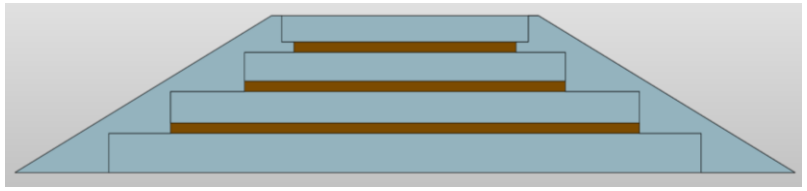
Max deformation: 1.2403mm

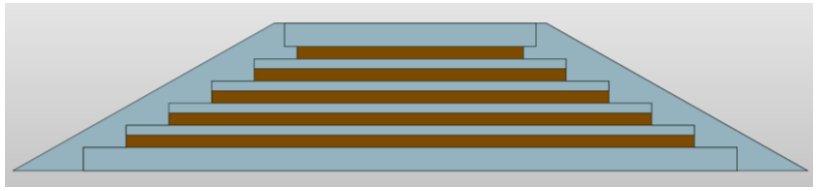


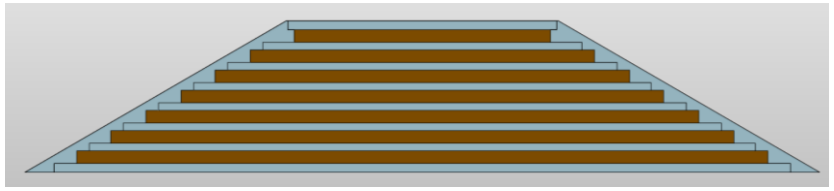
Max deformation: 1.3316mm



Max deformation: 1.667mm







3 layers of μ detector placement space
The thickness (upper and lower plates): 150 mm and 100mm;
The thickness (the middle layer) :120 mm\110mm;
Clearance: 40mm
Weight: 920 tons

5 layers of μ detector placement space
The thickness (upper and lower plates) : 95 mm.
The thickness (the middle layer): 40mm;
Clearance: 50mm
Weight: 760 tons

7 layers of μ detector placement space
The thickness (upper and lower plates): 35mm;
The thickness (the middle layer): 30mm;
Clearance: 50mm
Weight: 520 tons

Plate thickness optimization

Result of self-weight deformation and stress of symmetrical barrel iron yoke

Number of layers	3	5	7
deformation	3.2192	7.8251	40.979
stress	48.11	80.39	151.74

Result of self-weight deformation and stress of spiral barrel iron yoke

Number of layers	3	5	7
deformation	1.2403	1.3316	1.667
stress	57.111	57.734	77.591

Unit: mm
Mpa

The thinner iron yoke plates' thickness of barrel iron yoke, the larger self-weight deformation of barrel iron yoke.

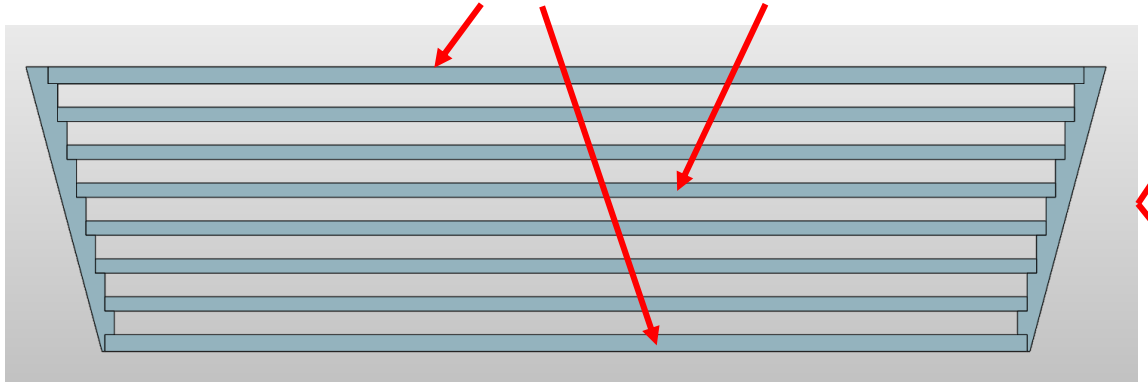
Cause: iron yoke plates' thickness is **too thin**
Solution: Modify the plates' thickness

Plate thickness optimization

symmetrical structure

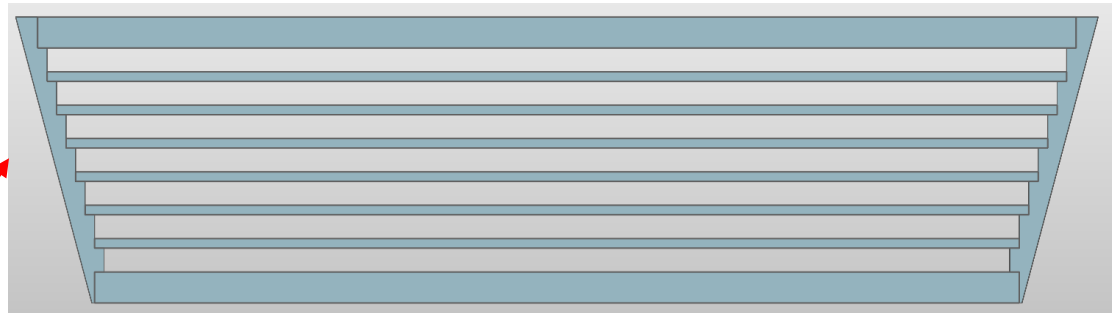
Module fixed thickness: 600mm

Upper and lower plate: 35mm, layers: 30mm (35+35+30)



Modification plan

1. Upper and lower plate: 65mm, layers: 20mm (65+65+20)



2. Upper plate: 95mm, lower plate: 35mm, layers: 20mm (95+35+20)

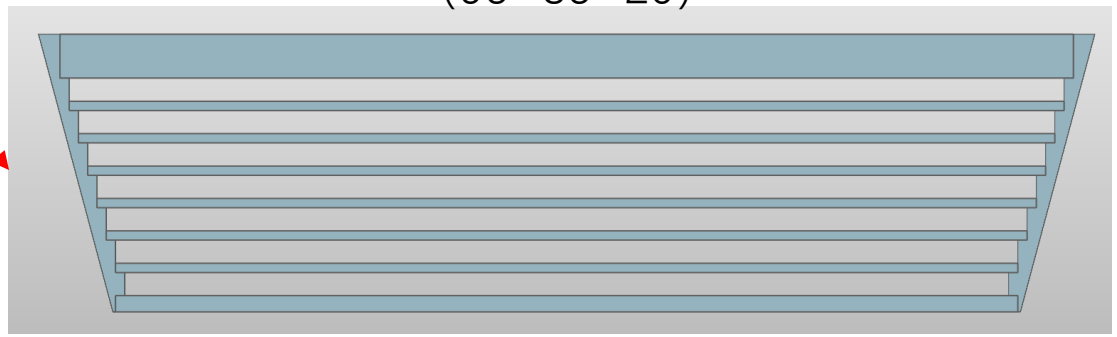
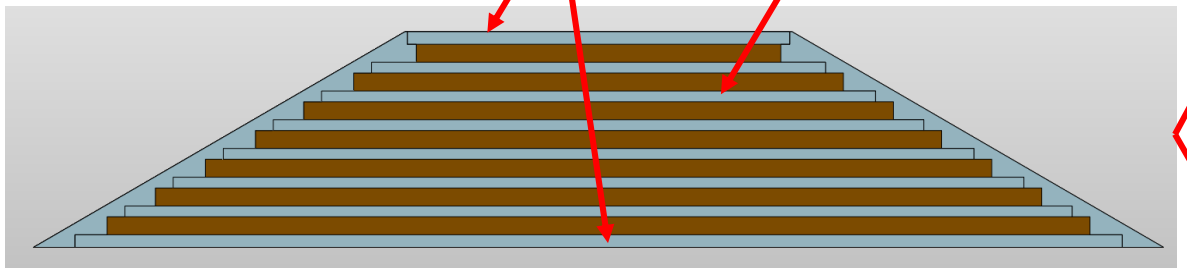


Plate thickness optimization

spiral structure

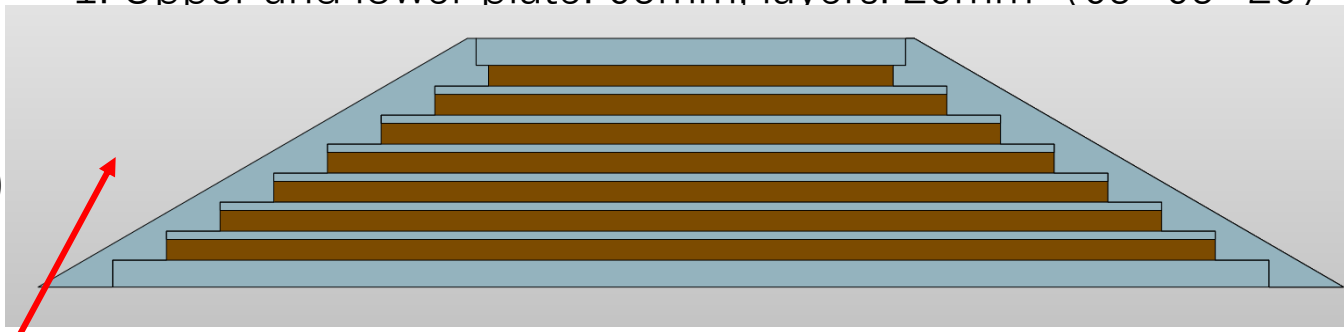
Module thickness： 600mm

Upper and lower plate: 35mm, layers: 30mm (35+35+30)



Modification plan

1. Upper and lower plate: 65mm, layers: 20mm （65+65+20)



2. Upper plate: 35mm, lower plate: 95mm, layers: 20mm (35+95+20)

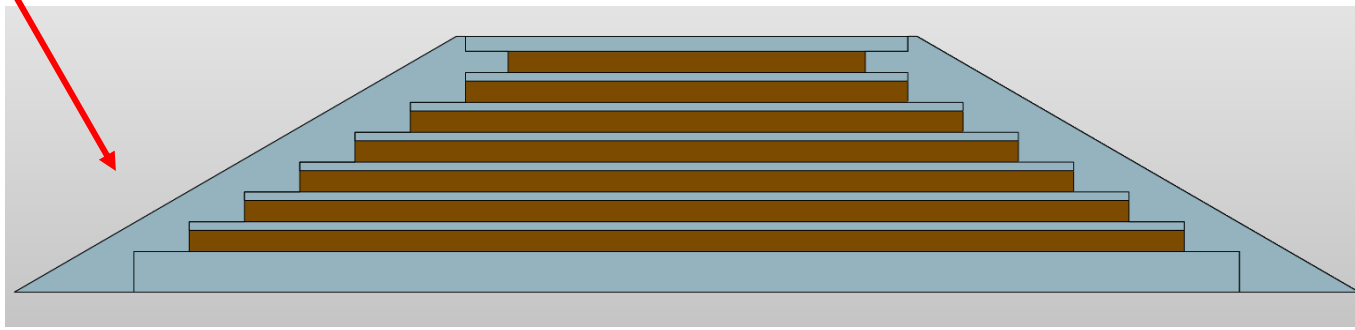


Plate thickness optimization

Result of self-weight deformation of symmetrical barrel iron yoke

Number of layers	3	5	7
deformation	3.2192	7.8251	40.979 (35+35+30)
			19.161 (65+65+20)
			19.322 (95+35+20)

Result of self-weight deformation of spiral barrel iron yoke

Number of layers	3	5	7
deformation	1.2403	1.3316	1.667 (35+35+30)
			1.3582 (65+65+20)
			1.3292 (35+95+20)

Unit: mm

Modifying iron yoke plates' thickness of barrel iron yoke can reduce self-weight deformation of barrel iron yoke.

Barrel iron yoke support surface optimization

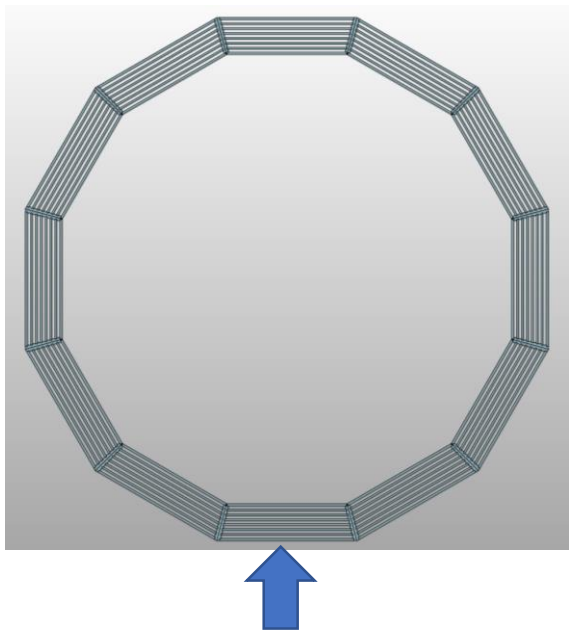
conclusion

The more fixed supporting surface at the bottom of barrel iron yoke, the smaller self-weight deformation of barrel iron yoke

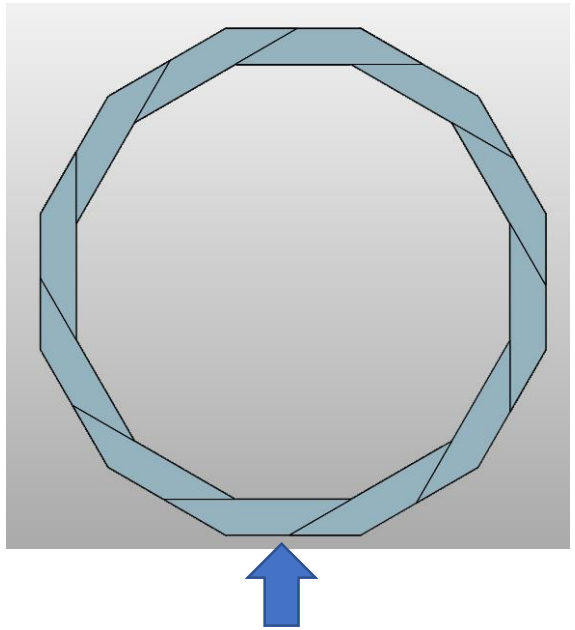
Can increasing the number of fixed support surfaces reduce deformation??

Support surface optimization

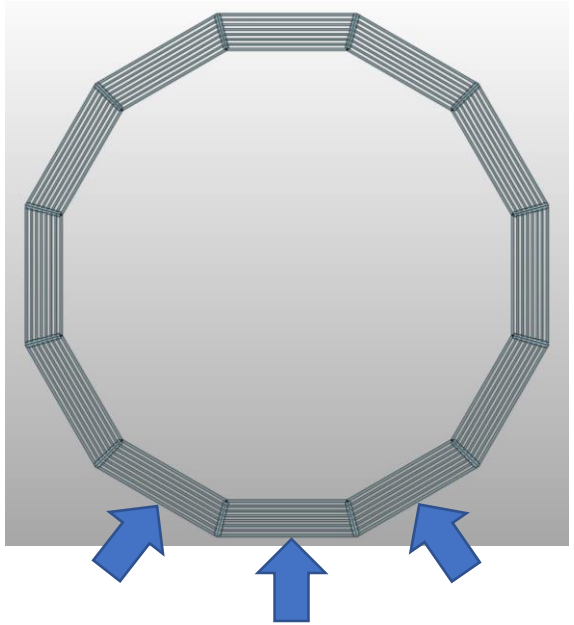
Fixed constraint: bottom (single surface)

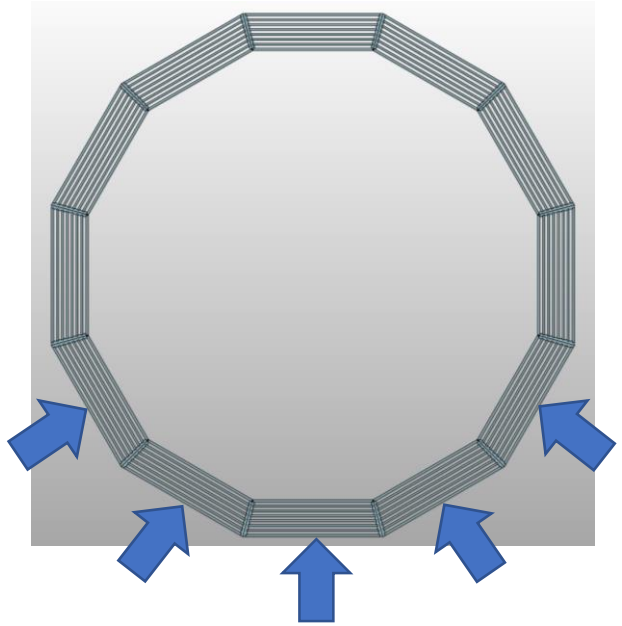


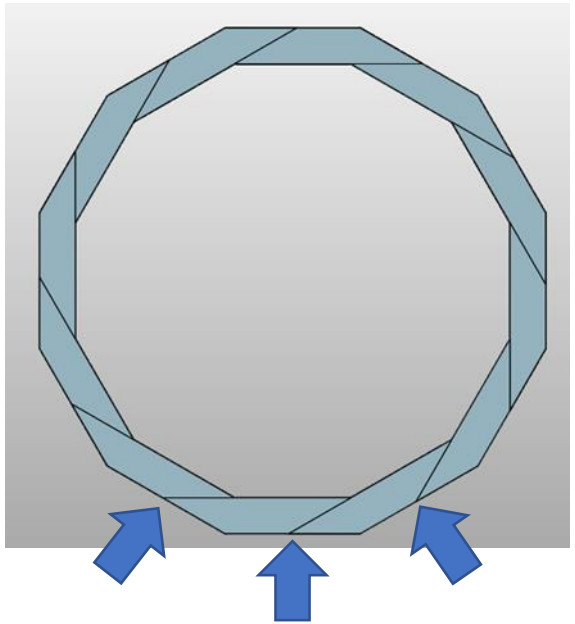
symmetrical structure

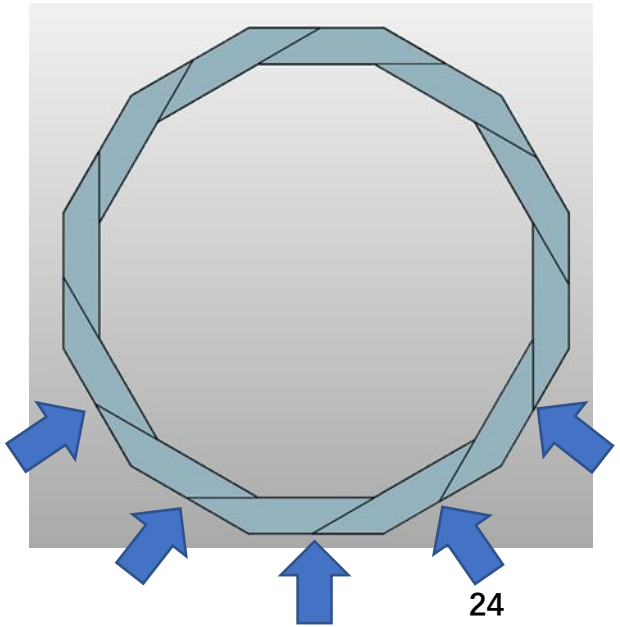


spiral structure

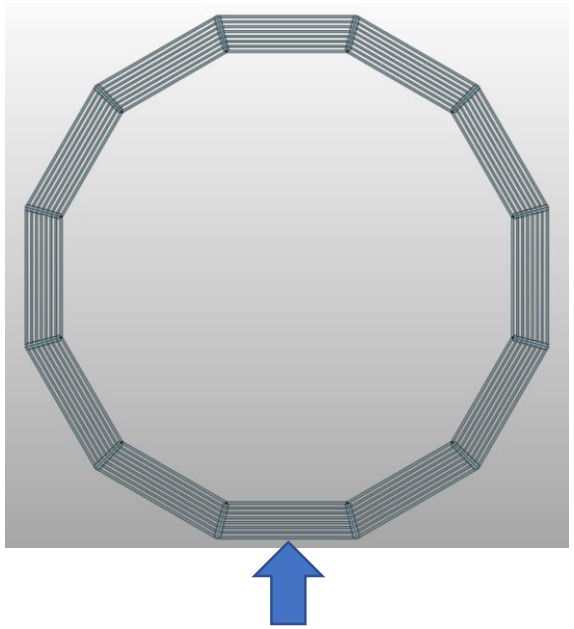


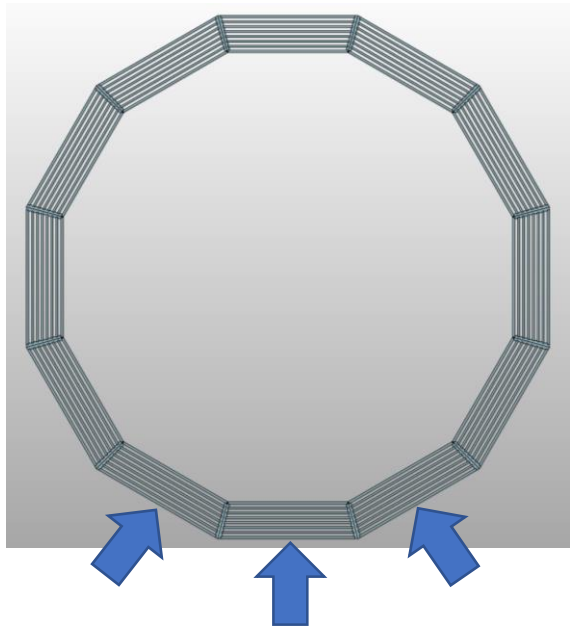


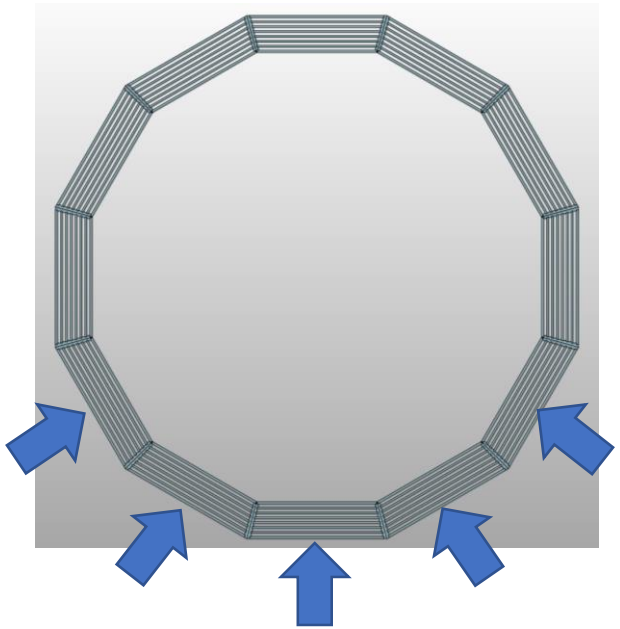




Comparison of symmetrical structure







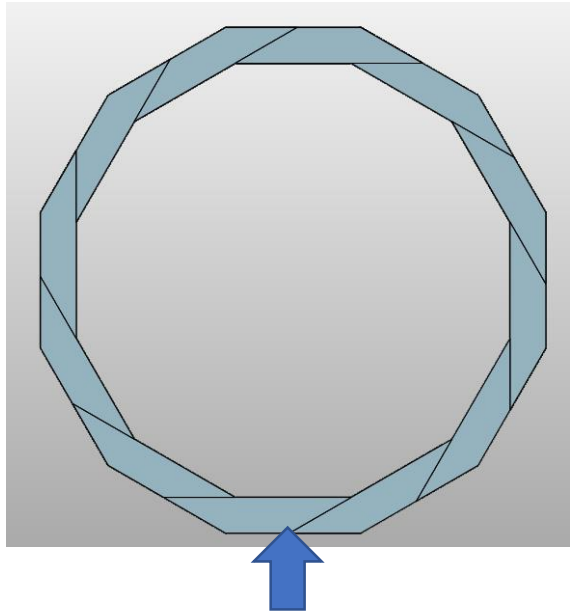
Unit: mm

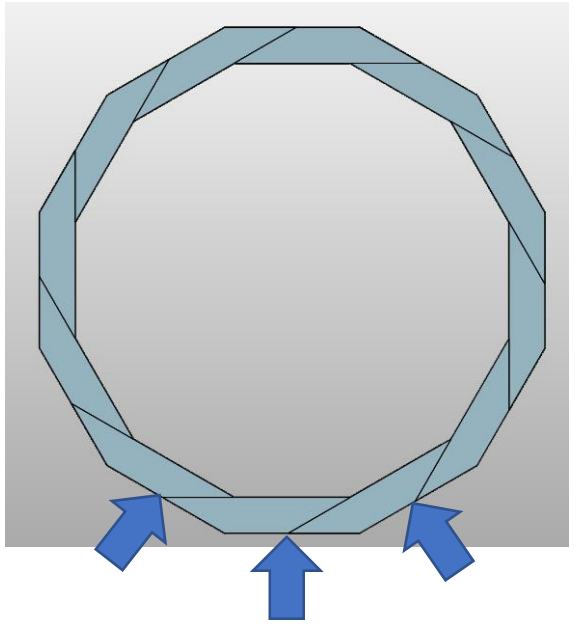
Number of fixed supports	1	3	5
3 layers	3.2192	1.2327	0.36443
5 layers	7.8251	3.0668	0.98218
7 layers （35+35+30）	40.979	15.977	4.9265
7 layers （65+65+20）	19.161	7.7344	2.6982
7 layers （95+35+20）	19.322	7.5709	2.5406

Increase the number of fixed supports

Reduce self-weight deformation

Comparison of spiral structure





Unit: mm

Number of fixed supports	1	3
3 layers	1.2403	0.3887
5 layers	1.3316	0.4283
7 layers （35+35+30）	1.667	0.53378
7 layers （65+65+20）	1.3582	0.47061
7 layers （35+95+20）	1.3292	0.46361

Increase the number of fixed supports

Reduce self-weight deformation

Support surface optimization

Number of fixed supports	1	3	5
3 layers	3.2192	1.2327	0.36443
5 layers	7.8251	3.0668	0.98218
7 layers（35+35+30)	40.979	15.977	4.9265
7 layers（65+65+20)	19.161	7.7344	2.6982
7 layers（95+35+20)	19.322	7.5709	2.5406

Number of fixed supports	1	3
3 layers	1.2403	0.3887
5 layers	1.3316	0.4283
7 layers（35+35+30)	1.667	0.53378
7 layers（65+65+20)	1.3582	0.47061
7 layers（35+95+20)	1.3292	0.46361

Unit: mm

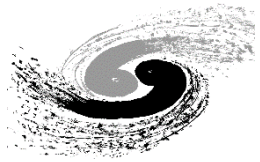
The more fixed supporting surface at the bottom of barrel iron yoke, the smaller self-weight deformation of barrel iron yoke

Summary

1. Introduced CEPC iron yoke design;
2. Optimized the number of layers of μ detector in the barrel iron yoke structure;
3. Optimized the thickness of the barrel iron yoke plate and the number of fixed support surfaces;
4. The thinner the thickness of the iron yoke plate of the barrel yoke, the larger the deformation of the weight of the barrel yoke;
5. Modify the thickness of the iron plate of the barrel yoke, which can reduce the self-weight deformation of the barrel yoke;
6. The more fixed supporting surface at the bottom of the barrel yoke, the smaller self-weight deformation of the weight of the yoke;

What’s next

1. Combine with the gravity of the internal detector and magnetic force
2. Deformation simulation and Analysis
3. Structure optimization.



THANKS !