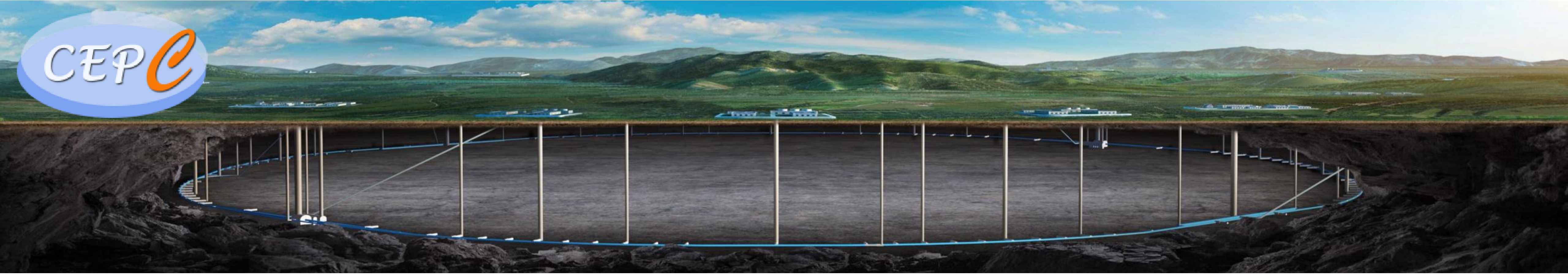


Mechanical Design of Magnet Yoke

Xia Shang & Ji Quan

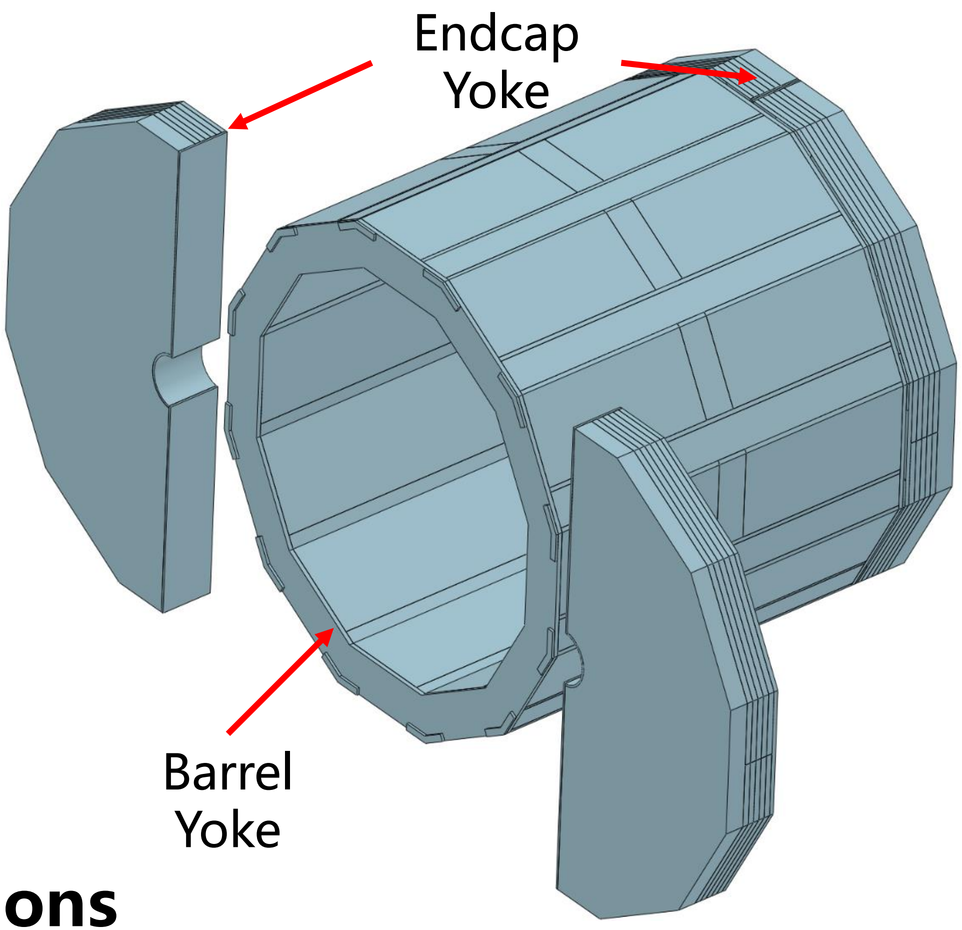
中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Nov. 27th, 2024

Outline

- Requirements
- Barrel yoke design
- Endcap yoke design
- Summary

Requirements



Functions

1) Provide support, adjustment and locking for the sub-detector
2) Provide the magnetic field loop
3) Absorb all particles except muon
4) Provide placing space for muon detector

Requirements

Muon detectors requirements

1) 6 layers of muon detector
2) 40mm for each layer of muon detectors
3) as few detection dead zones as possible

Magnet requirements

1) Yoke material must have high permeability and small coercive force
2) Minimize magnetic leakage

Mechanical requirements

◆ Barrel yoke

1) Ensure sufficient strength and stiffness (Self-weight & Electromagnetic force)
2) Easy and quick installation
3) High installation accuracy (±1mm)
4) Provide convenience for the maintenance of detector

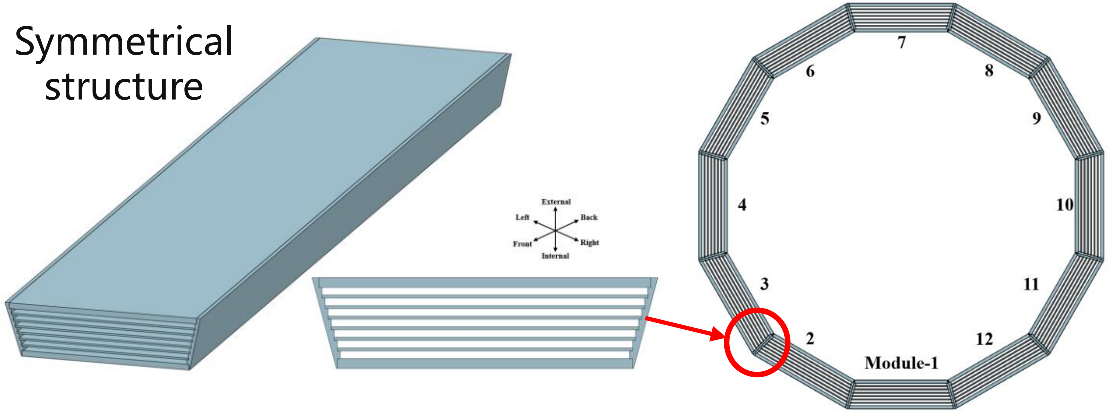
◆ Endcap yoke

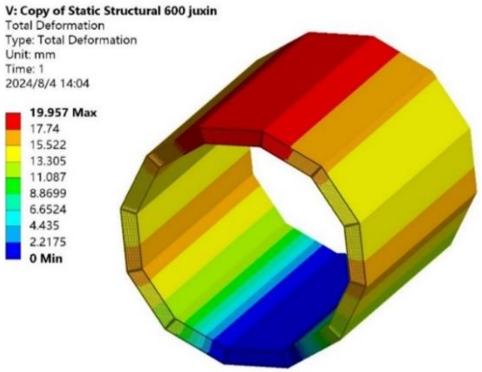
1) Ensure sufficient strength and stiffness (Self-weight & Electromagnetic force)
2) Easy and quick installation

Barrel yoke design—structure optimization

600mm
Barrel yoke

Symmetrical structure

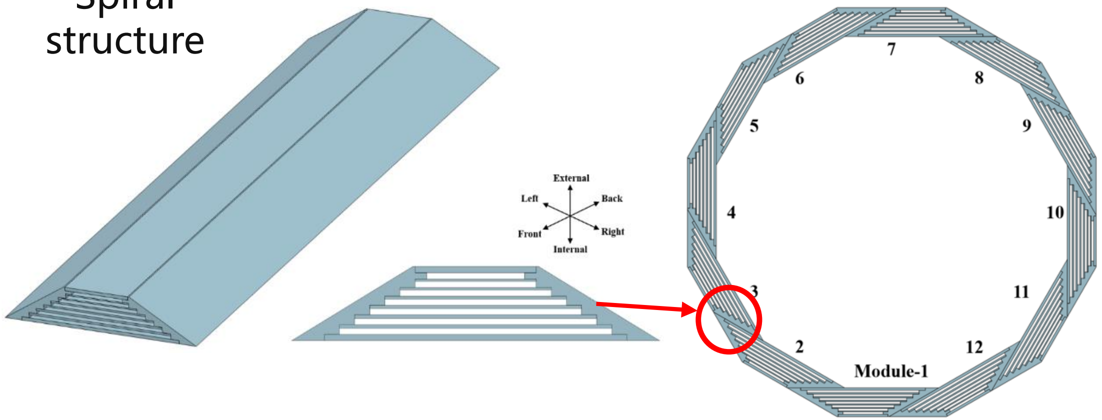


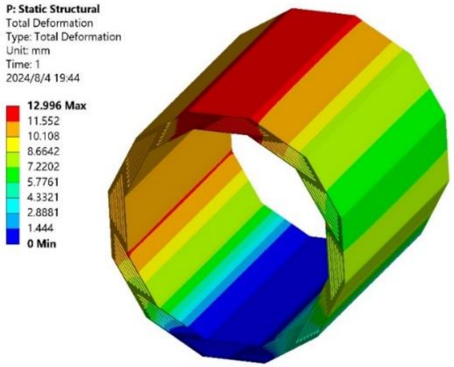


Self-weight Max Deformation
19.95mm

Material: 10#
Length: 8960mm
Thickness: 600mm
Muon space: 50mm×7
Layer plates thickness:
65、20、20、20、20、
20、20、65mm

Spiral structure





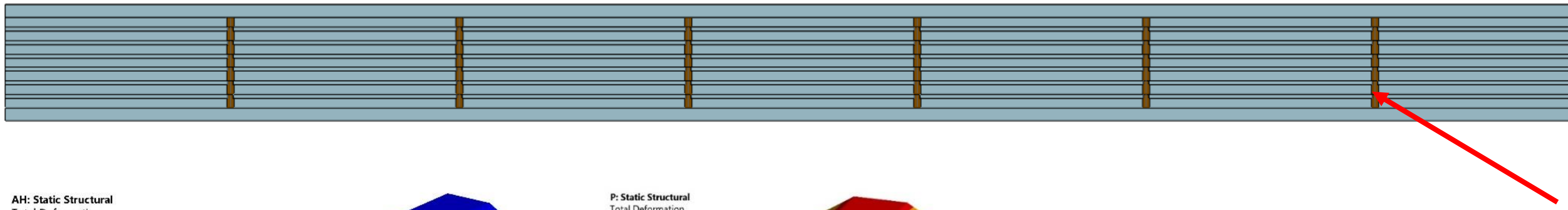
Self-weight Max Deformation
12.99mm

Advantage
1) no detection dead zone between modules
2) increased structural strength of the barrel yoke

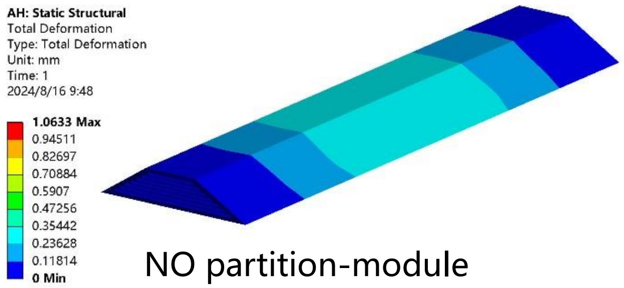
Barrel yoke design—structure optimization

Spiral structure optimization

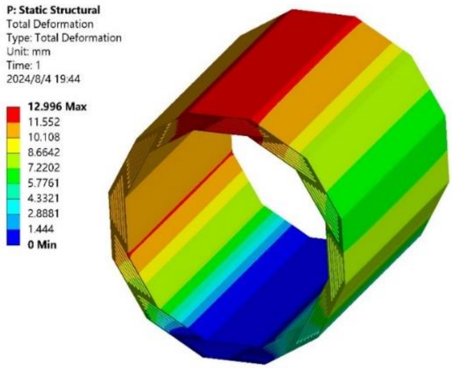
Optimization: add 6 partitions in each module



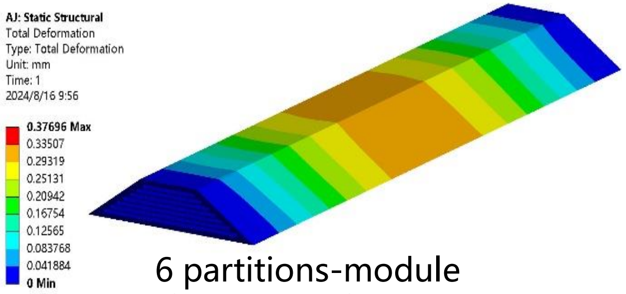
partition



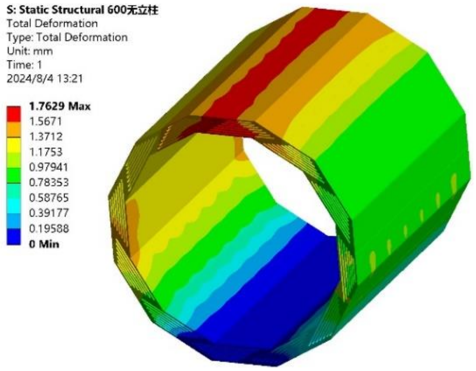
NO partition-module self-weight deformation Max 1.06mm



Self-weight Max Deformation 12.99mm



6 partitions-module self-weight deformation Max 0.37mm



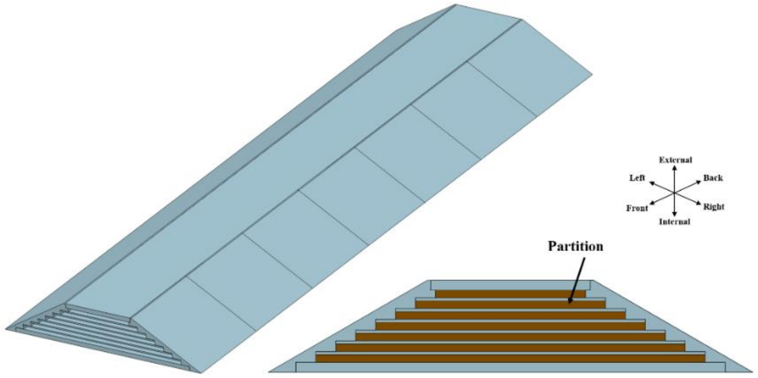
Self-weight Max Deformation 1.76mm

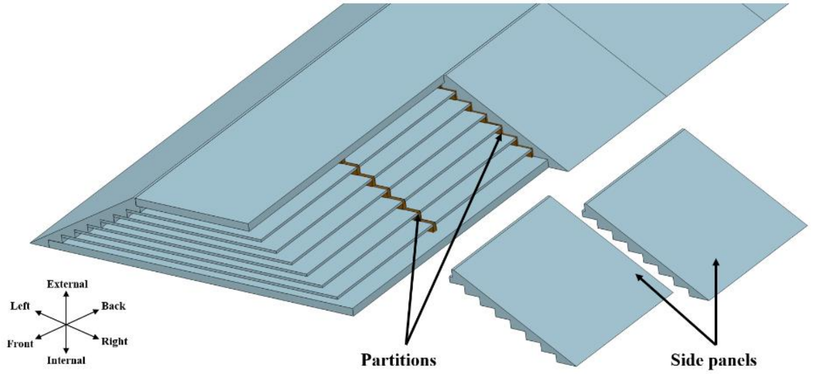
Conclusion
The more partitions, the better the module strength, the better the barrel yoke strength

Barrel yoke design—structure optimization

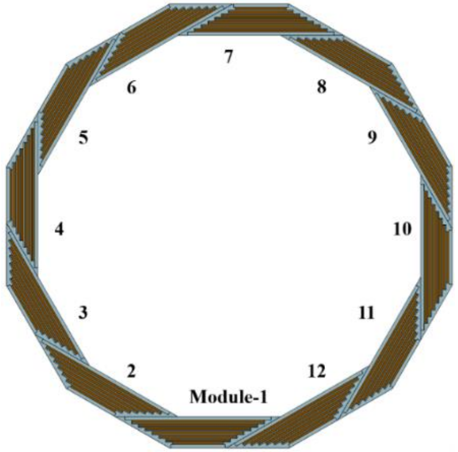
Spiral structure optimization

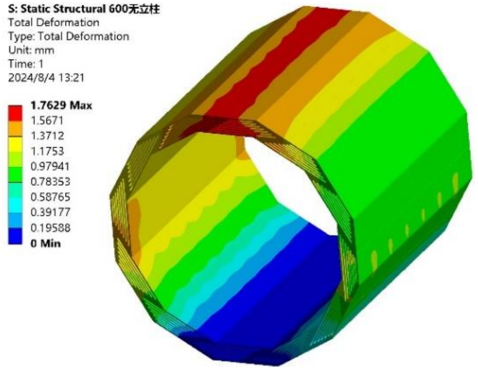
Optimization: add 6 partitions in each module





Material: 10#
Length: 8960mm
Thickness: 600mm
Muon space: 50mm×7
Layer plates thickness: 65、20、20、20、20、20、20、65mm
Weight: 566t





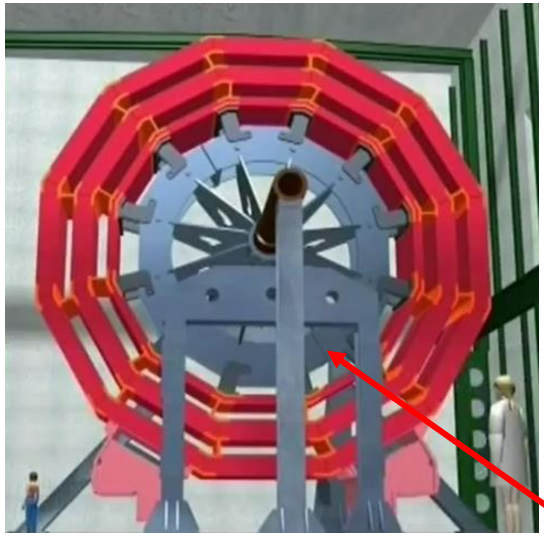
Self-weight Max Deformation
1.76mm

Advantage
1) no detection dead zone between modules
2) further increased structural strength of the barrel yoke
3) side panels can be opened separately to facilitate detector installation, cable management and maintenance

Barrel yoke design—installation optimization

Traditional installation scheme

Internal support frame installation scheme

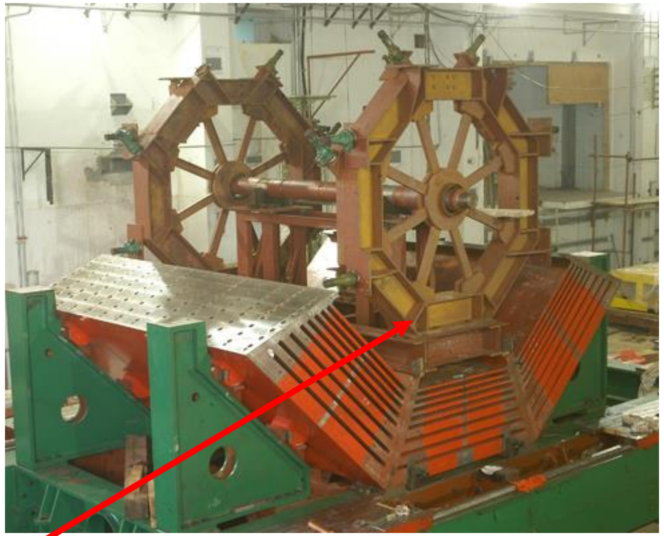


CMS barrel yoke installation

Disadvantage

1) High manufacturing cost of the internal support frame and material waste

2) Internal support frame affect the overall accuracy of the barrel yoke after disassembly



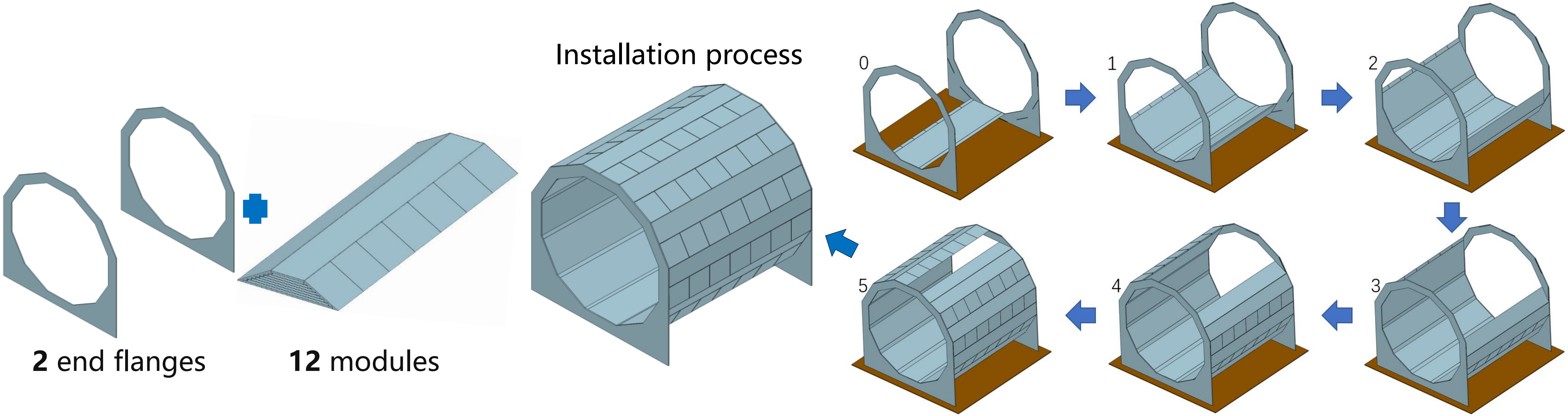
BESIII barrel yoke installation

Internal support frame

Barrel yoke design—installation optimization

NEW installation scheme

Self-supporting installation scheme

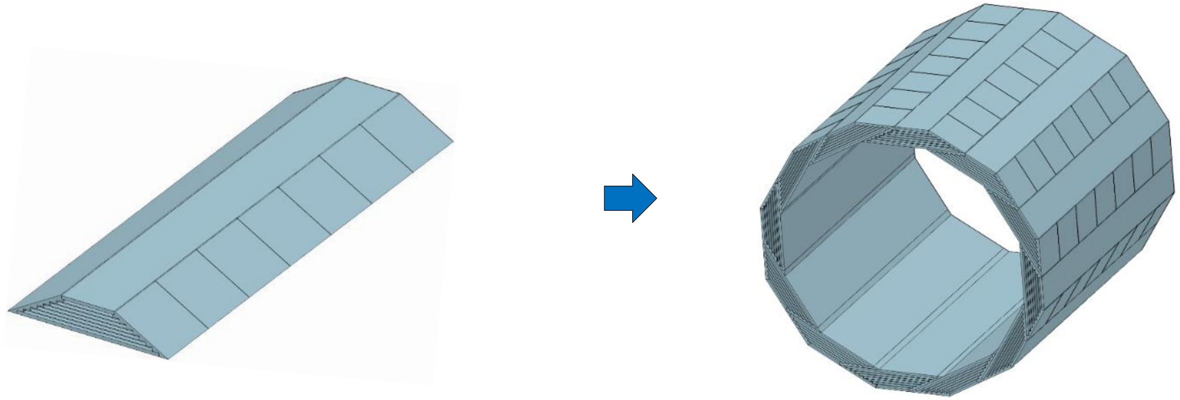


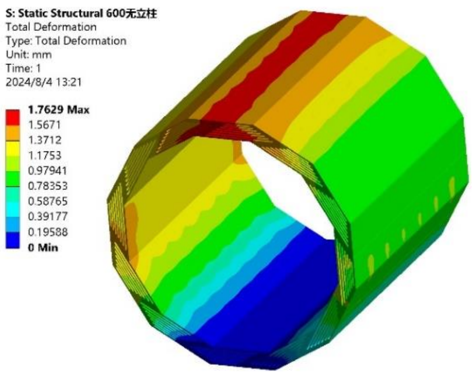
2 end flanges **12** modules

Advantage

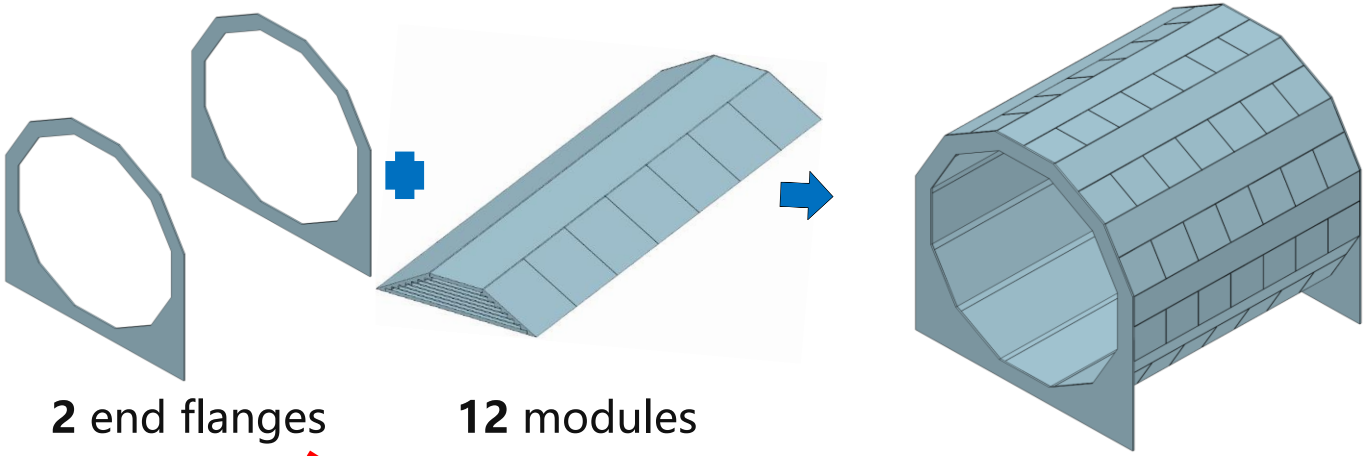
1) No internal support frame during barrel yoke installation, easy and quick installation
2) Using 2 end flanges to support the installation of barrel yoke module, the deformation of barrel yoke is reduced

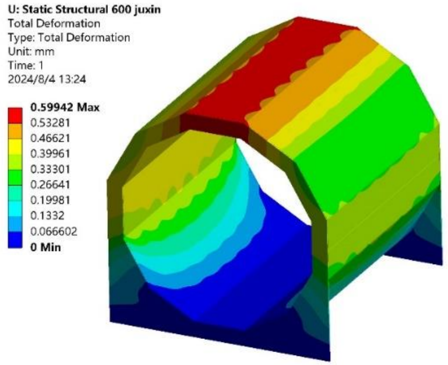
Barrel yoke design—installation optimization





Self-weight
Max
Deformation
1.76mm





Self-weight
Max
Deformation
0.59mm

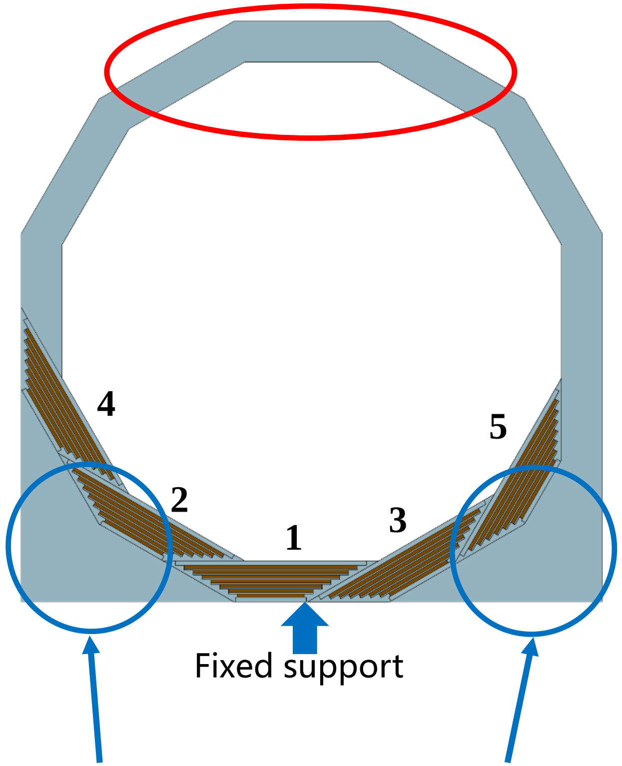
2 end flanges **12** modules

Self-weight deformation of barrel yoke is reduced

Barrel yoke design—installation simulation

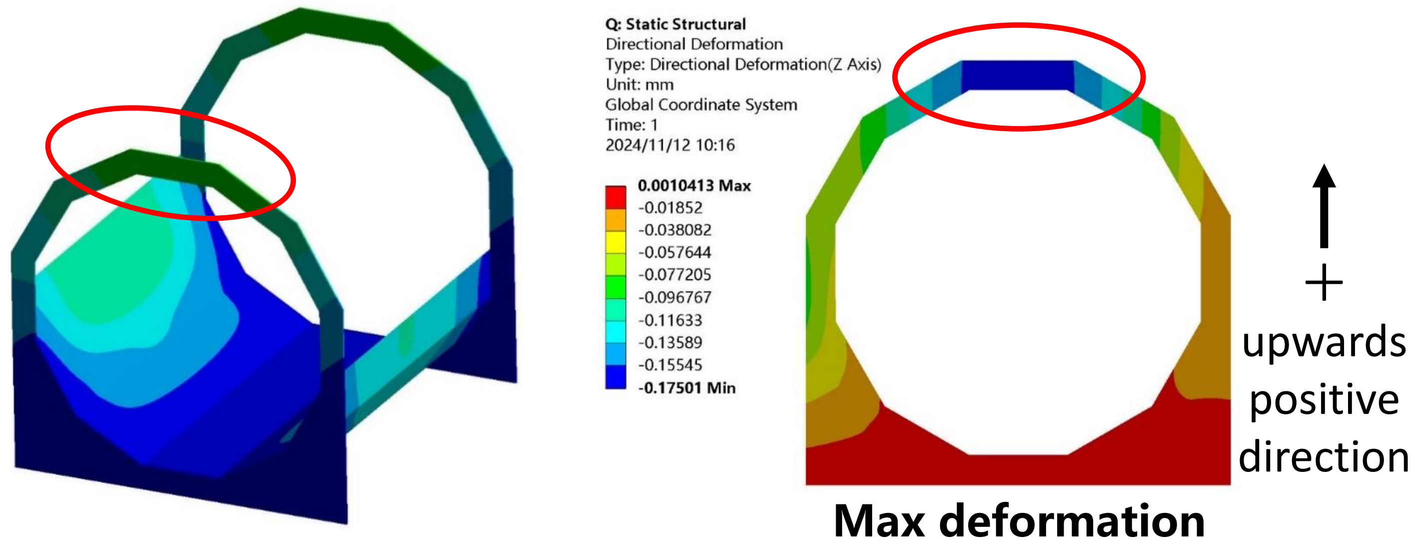
Difficulty

End flanges will be deformed during the installation of module
Excessive deformation of the end flanges may affect the installation of module



Installation sequence
right-left installation

Load
self-weight



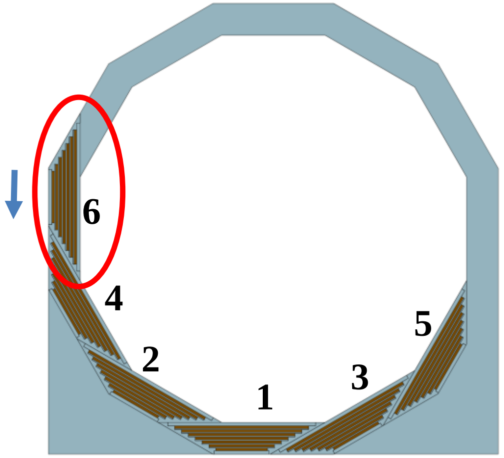
Max deformation
Top of flange

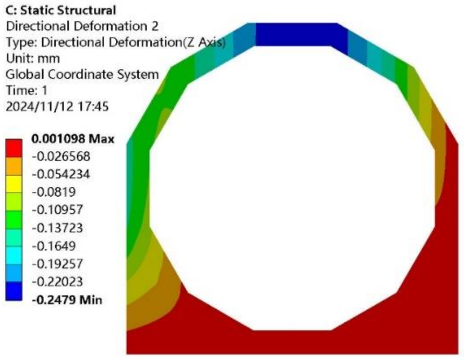
Deformation of end flanges in the direction of gravity

Sequence	1	2	3	4	5
Deformation (mm)	0.12	0.12	0.12	0.16	0.17

Result: Bottom module is installed, the deformation of end flanges is small.

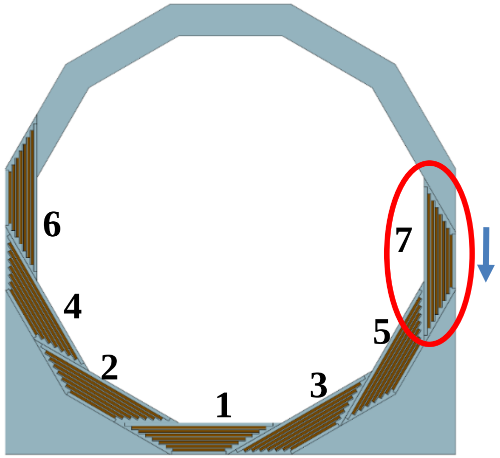
Barrel yoke design—installation simulation

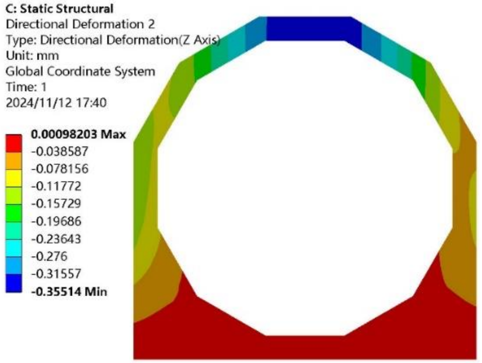




Max deformation
0.24mm

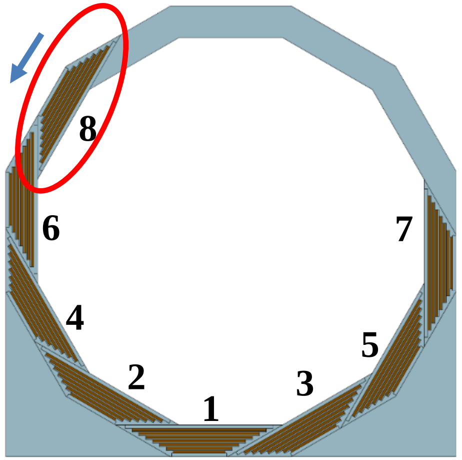
Module-6 install

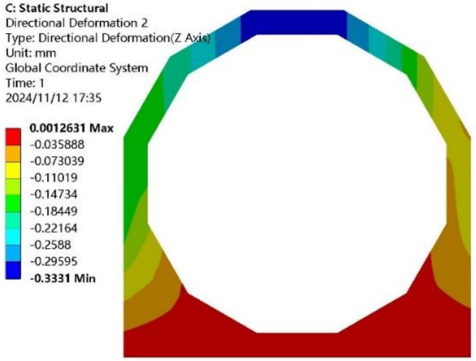




Max deformation
0.35mm

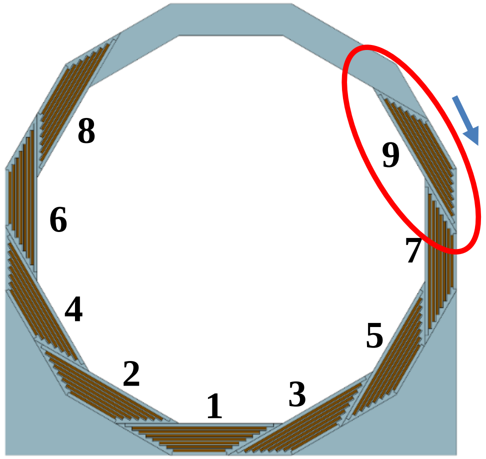
Module-7 install

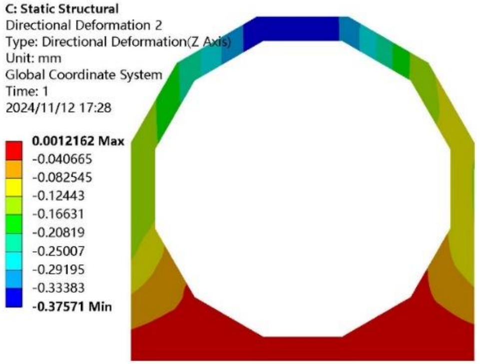




Max deformation
0.33mm

Module-8 install

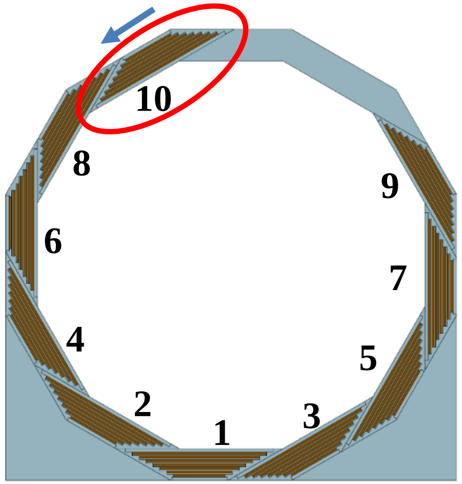


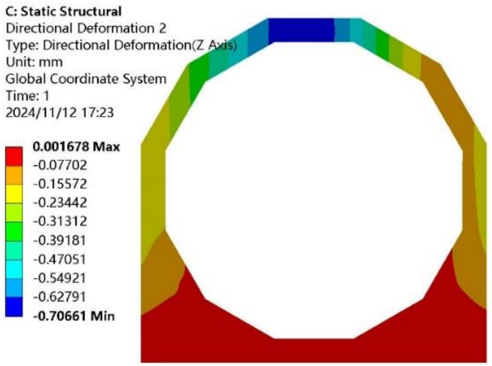


Max deformation
0.37mm

Module-9 install

Barrel yoke design—installation simulation

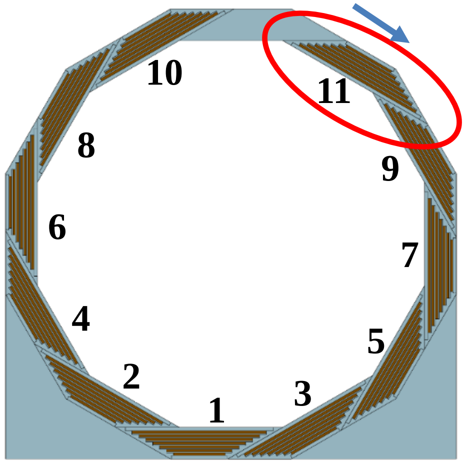


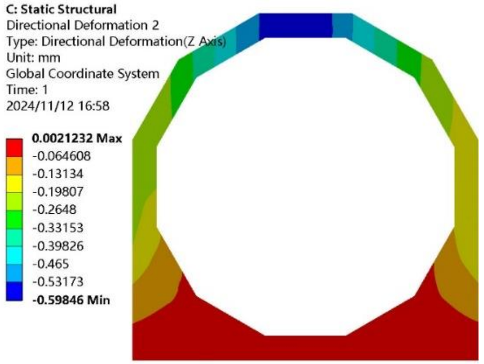


Max deformation
0.70mm

Module-10 install

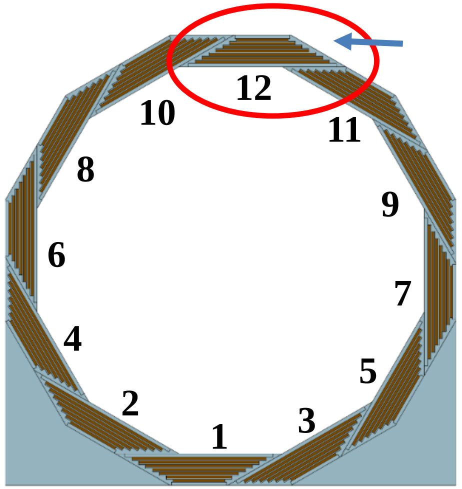
(End flange deformation increase)

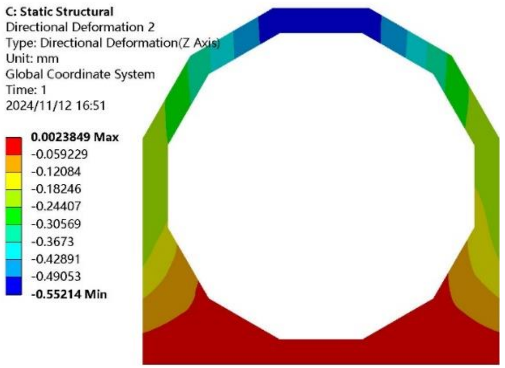




Max deformation
0.59mm

Module-11 install





Max deformation
0.55mm

Module-12 install

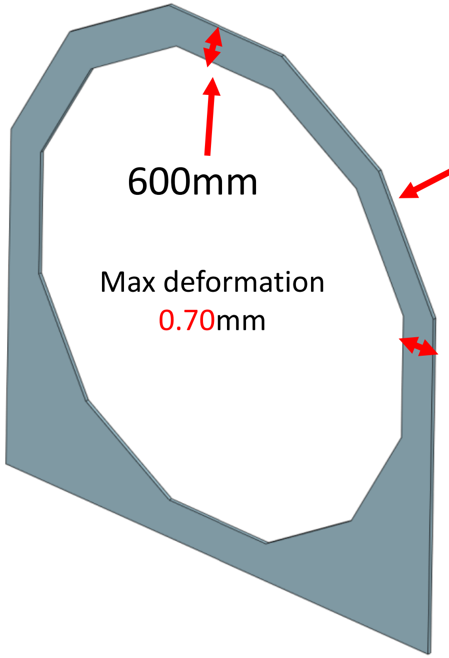
Installation summary

After module-10 is installed, the deformation of the end flange increases, which affects subsequent module installation

How to reduce the deformation of the end flange during module installation?

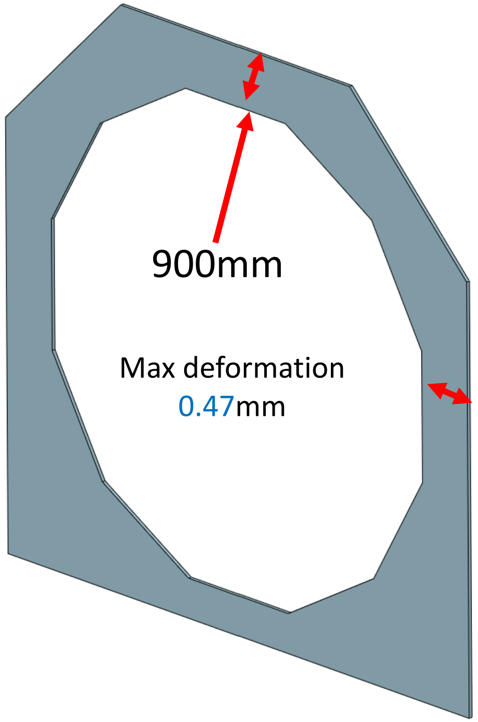
Barrel yoke design—installation optimization

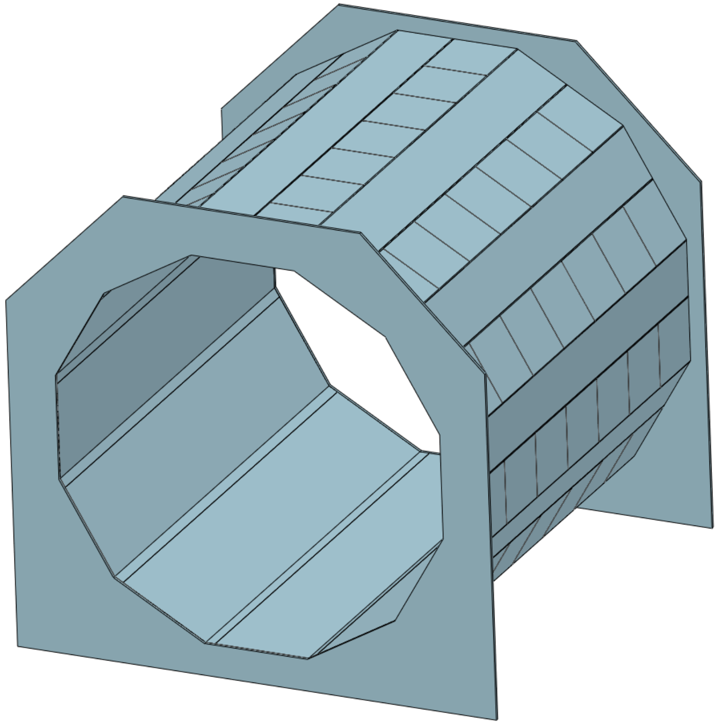
1) End flange Optimization



Small width
Large deformation

Optimization
Width and height increase





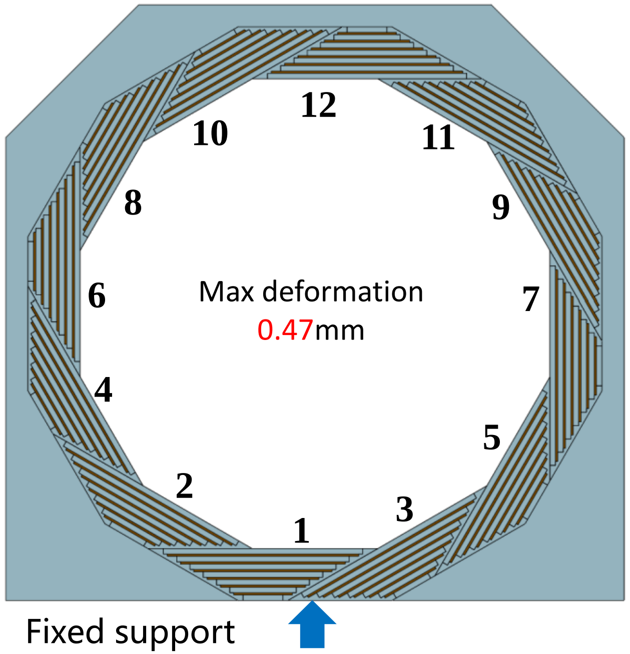
Deformation of end flanges in the direction of gravity (optimized)

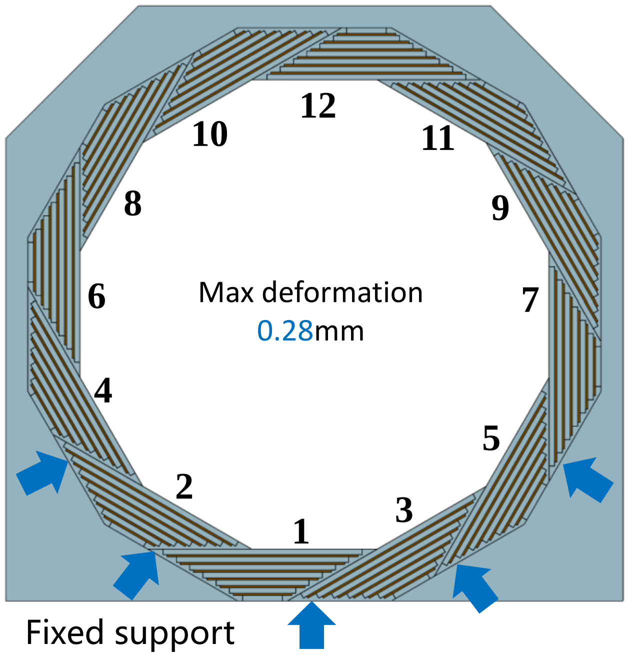
Sequence	1	2	3	4	5	6	7	8	9	10	11	12
Deformation (mm)	0.09	0.09	0.09	0.11	0.12	0.15	0.20	0.23	0.25	0.47	0.44	0.46

Result: Max deformation of end flange is reduced from 0.70mm to 0.47mm

Barrel yoke design—installation optimization

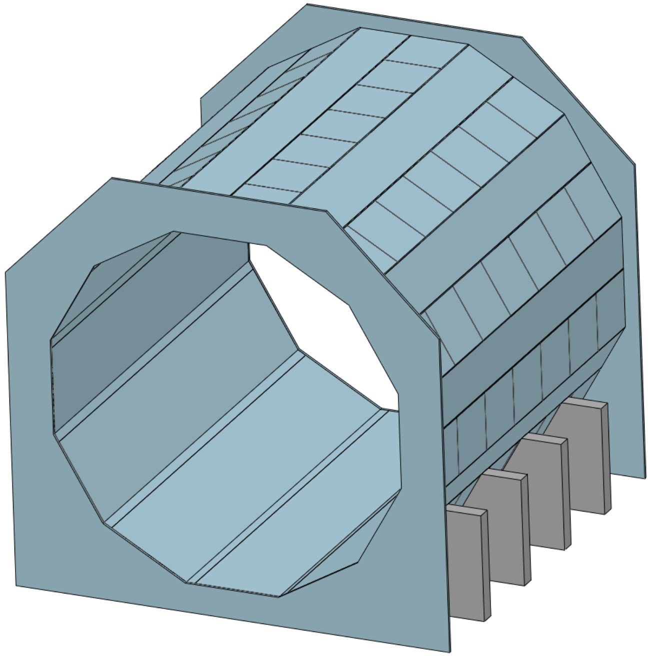
2) Fixed support optimization





Optimization
Add fixed support

Load
Self-weight



Deformation of end flanges in the direction of gravity (optimized)

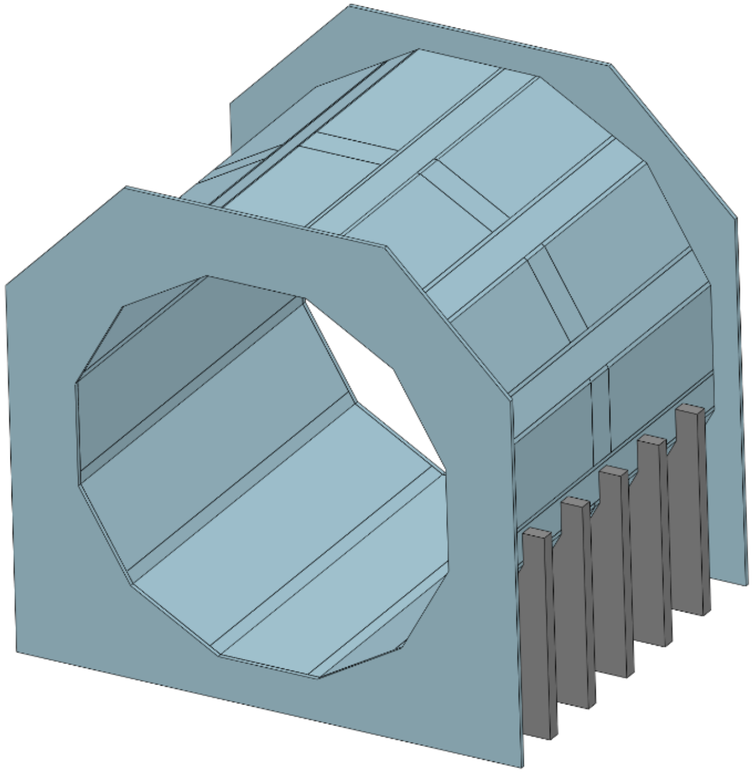
Sequence	1	2	3	4	5	6	7	8	9	10	11	12
Deformation (mm)	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.11	0.11	0.28	0.23	0.25

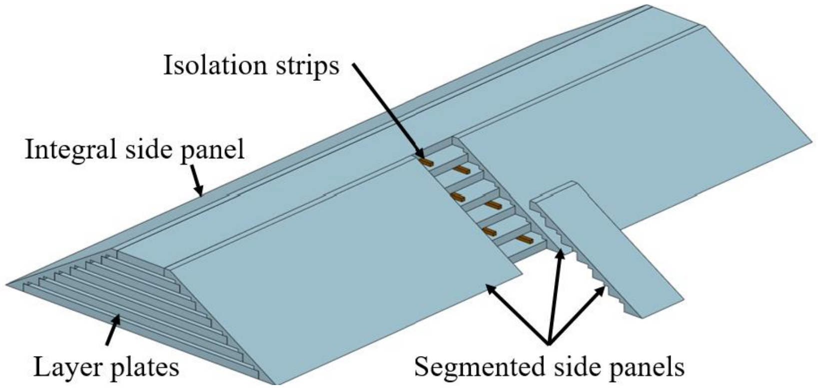
reduced from 0.47mm to 0.28mm

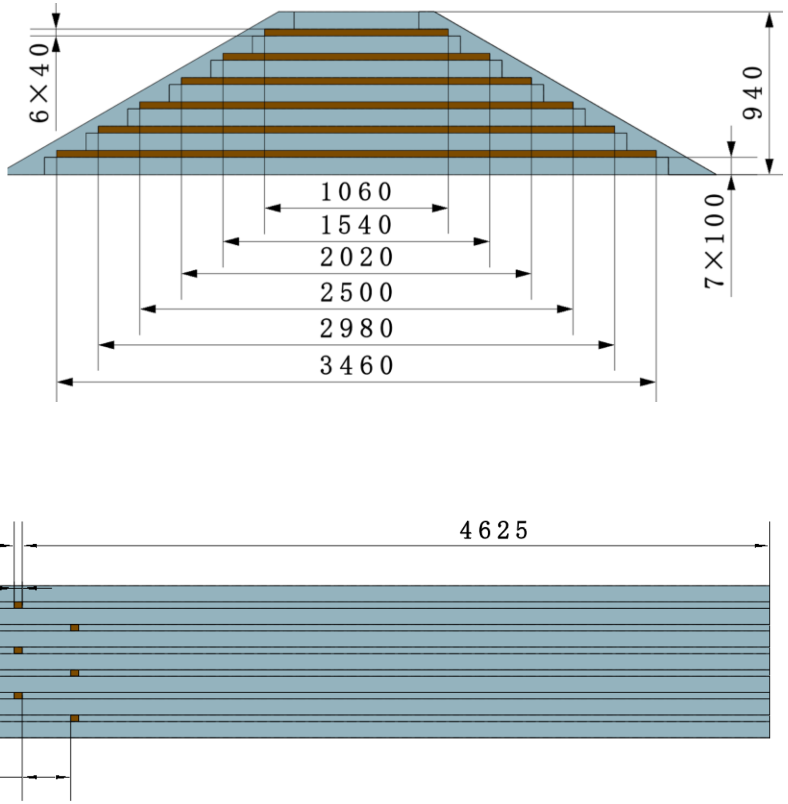
Conclusion
Increasing the width and height of the end flange and increasing the fixed support can reduce the deformation of the end flange during installation

Barrel yoke design—check of Ref-TDR

Ref-TDR barrel yoke design parameter



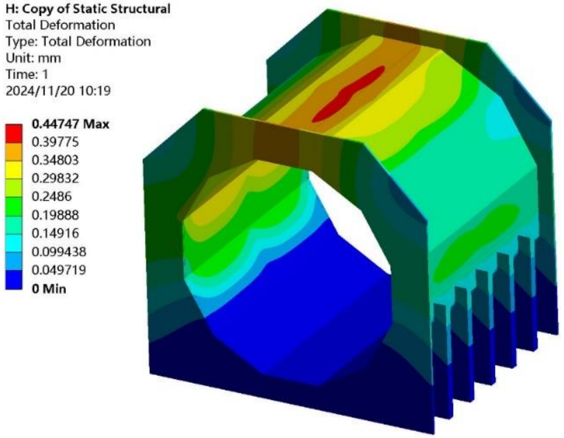




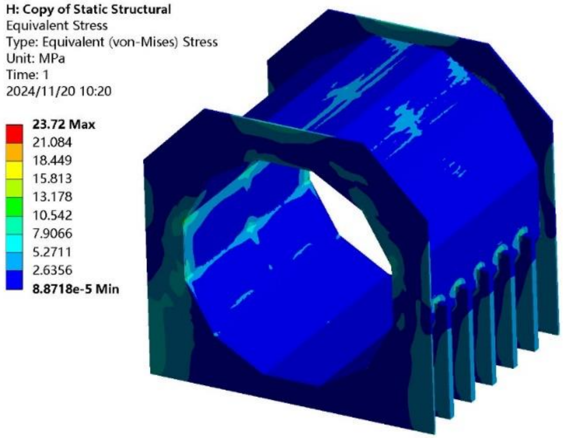
Barrel yoke thickness
Increased from 600mm to 940mm
Weight increase from 566t to 1560t

Barrel yoke design—check of Ref-TDR

Self-weight simulation



Max Deformation
0.44 mm



Max Equivalent stress
15.28 MPa

Installation simulation

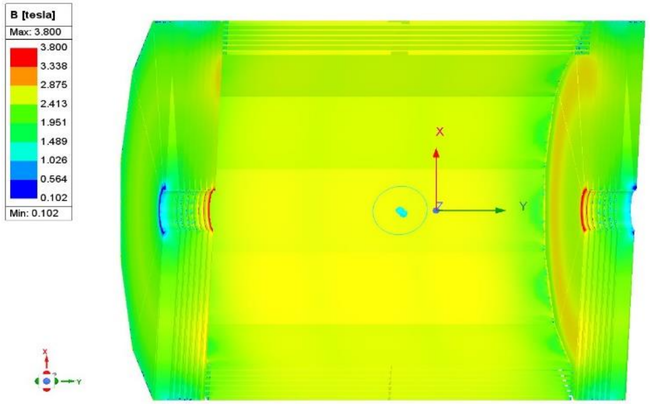
Deformation of end flanges in the direction of gravity (optimized)

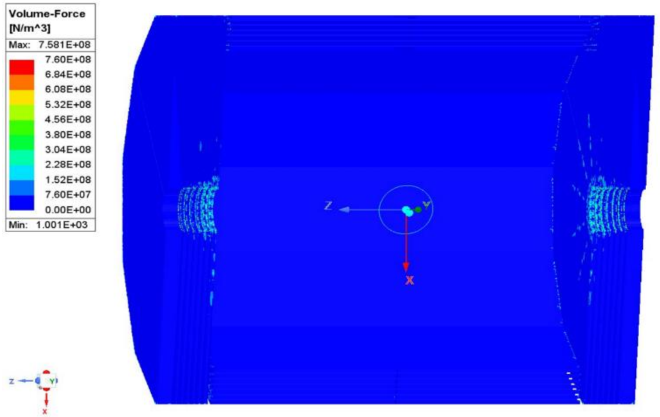
Sequence	1	2	3	4	5	6	7	8	9	10	11	12
Deformation (mm)	0.09	0.09	0.09	0.09	0.08	0.07	0.07	0.19	0.39	0.55	0.58	0.36

Conclusion
All meet the design requirements

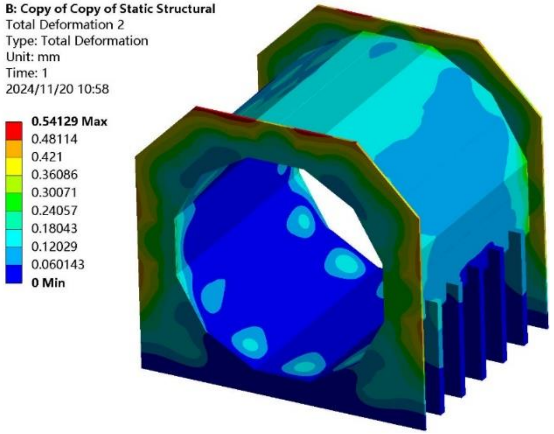
Barrel yoke design—check of Ref-TDR

Self-weight & Electromagnetic force simulation

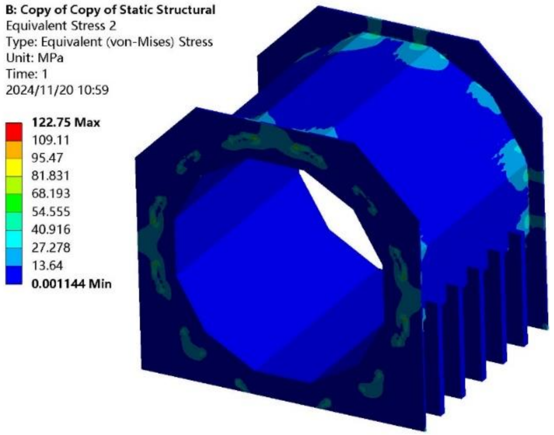




Simulated by Cao Jingli



Max Deformation
0.54 mm



Max Equivalent stress
122.75 MPa

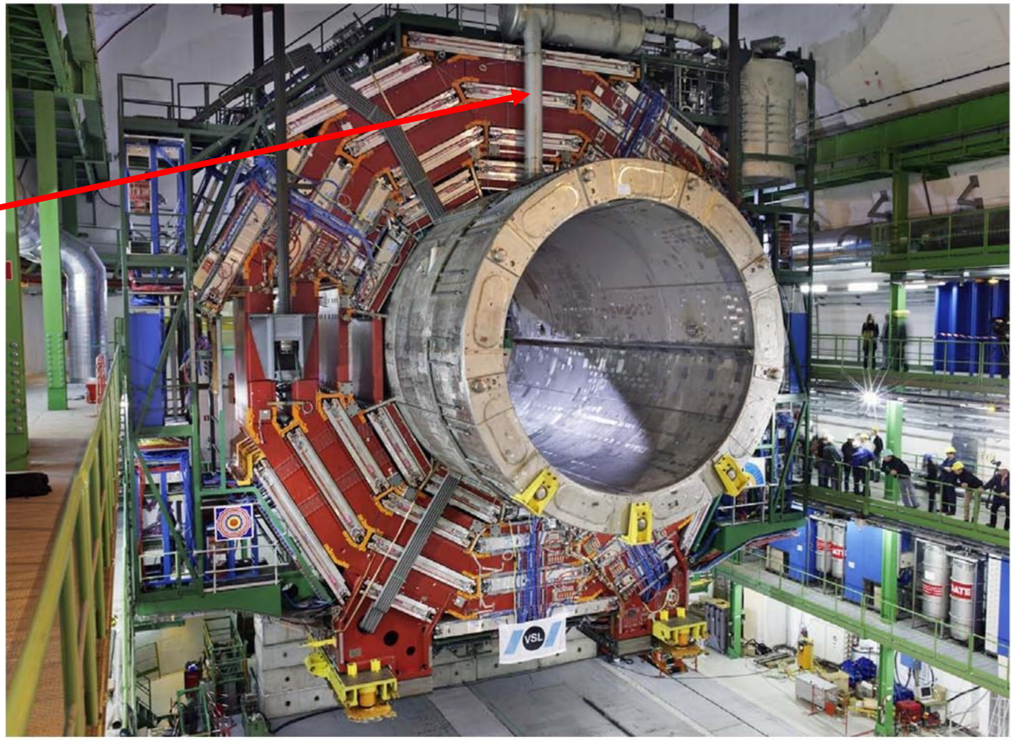
Conclusion

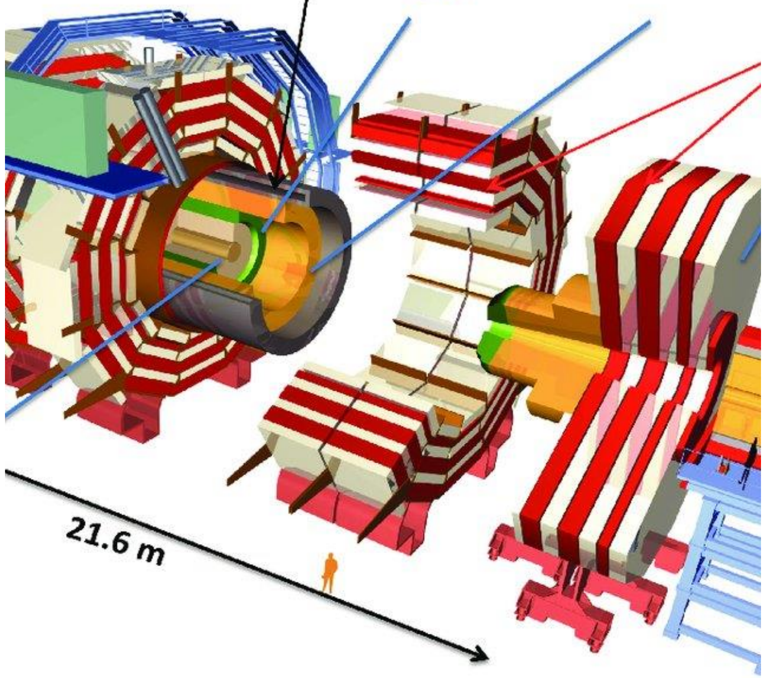
All meet the design requirements

Barrel yoke design—Installation with magnet

Installation with magnet—The chimney of the magnet

Chimney



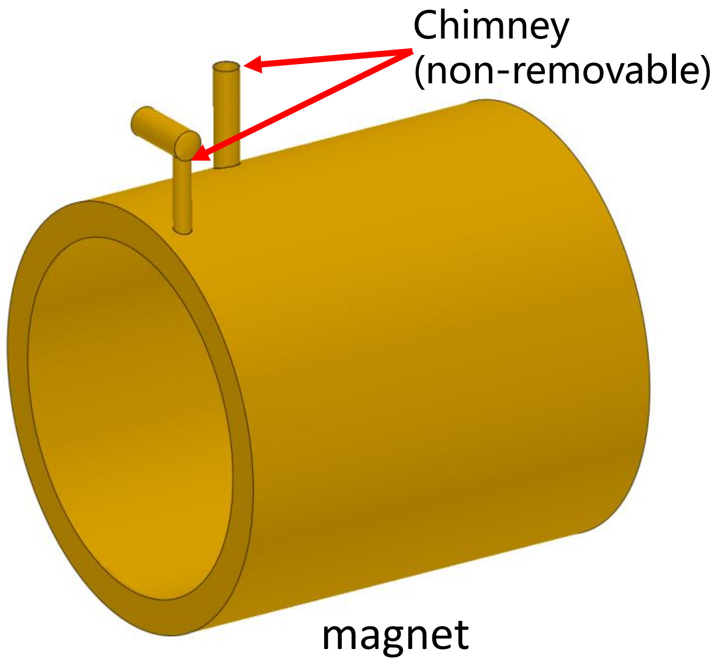


CMS barrel yoke: divided into 5 axial sections

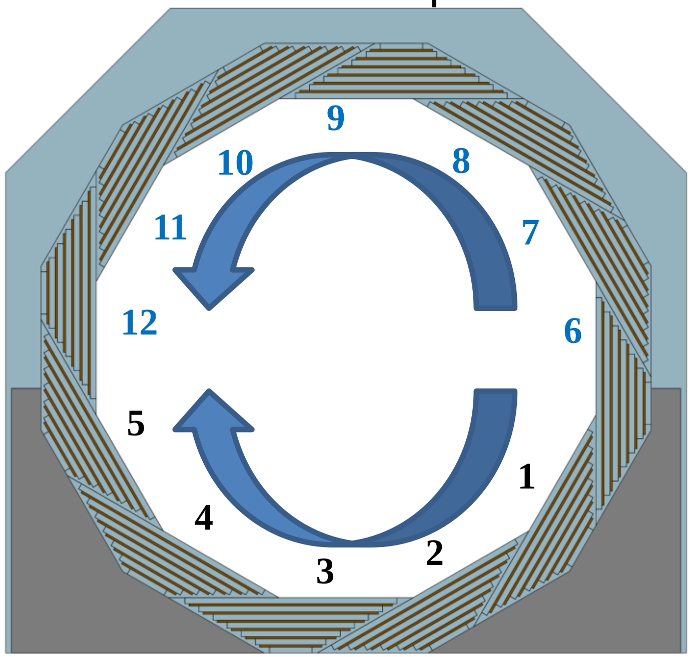
Coaxiality problem

Barrel yoke design—Installation with magnet

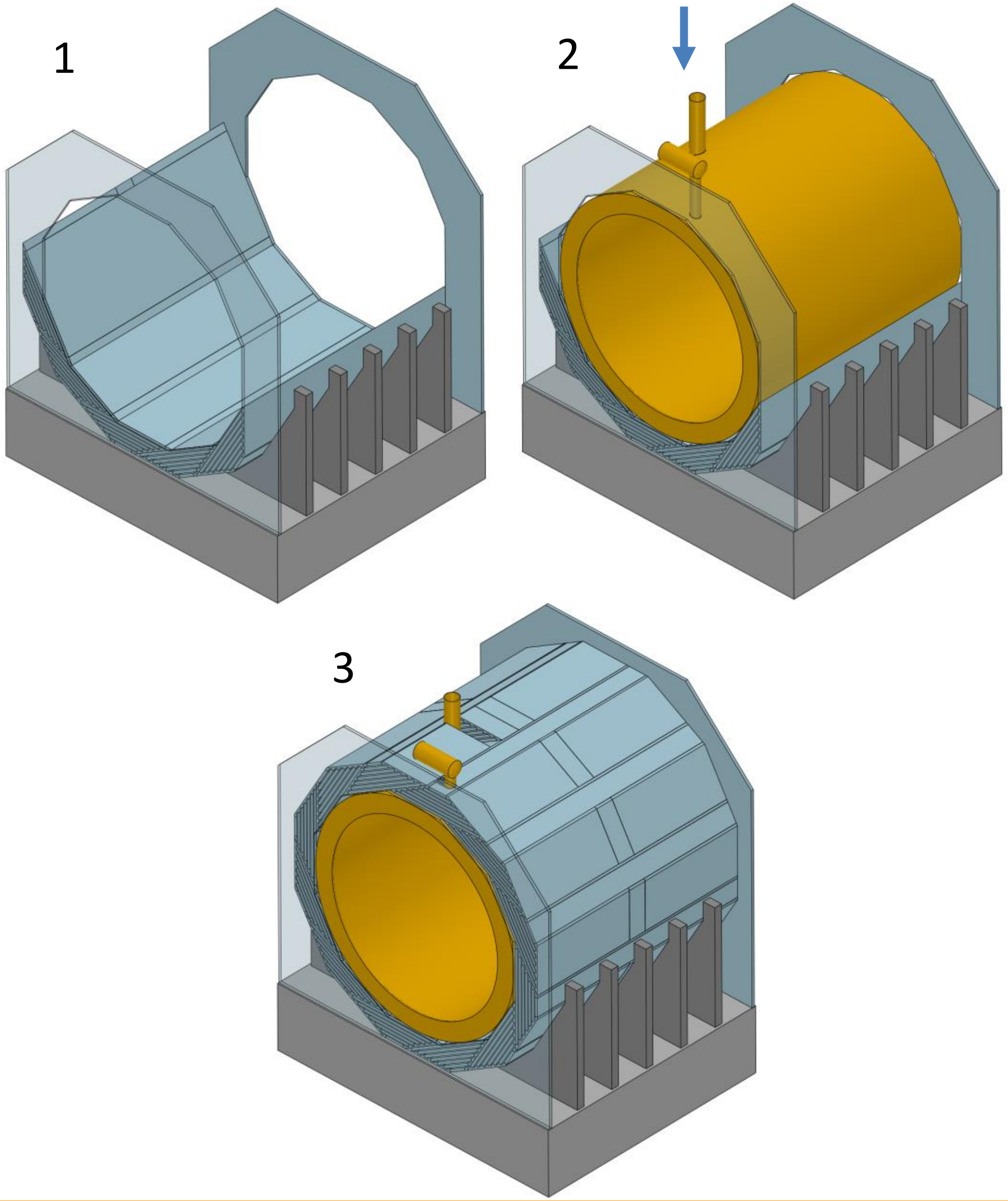
Self-supporting installation scheme
Alternating installation



Installation sequence



Alternating installation

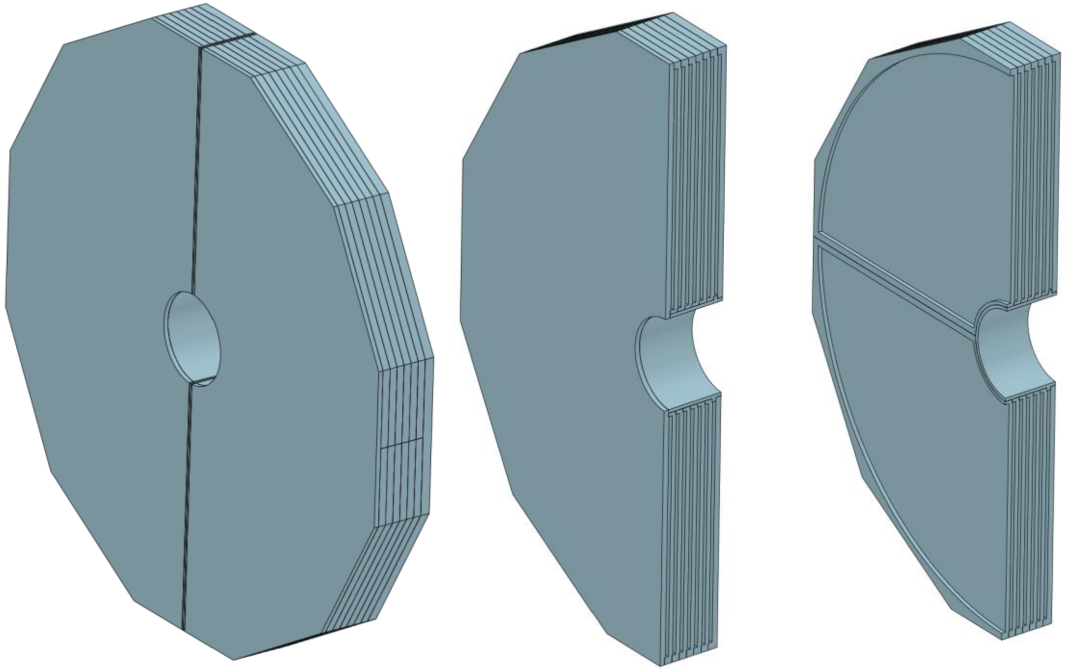


Barrel yoke total axial length: 9150mm
Barrel yoke axial design is not segmented

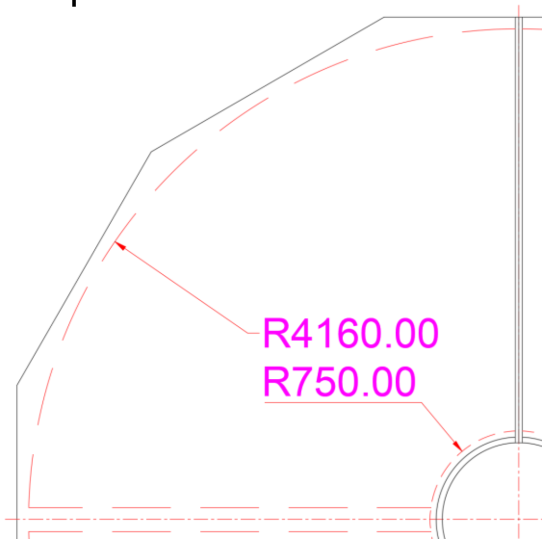
Endcap yoke design

900mm
Endcap yoke

Material: 10#
Thickness: 900mm
Muon space: 50mm×7
Layer plates thickness:
80、65、65、65、65、
65、65、80mm
Weight: 265t×2



Space for muon detector

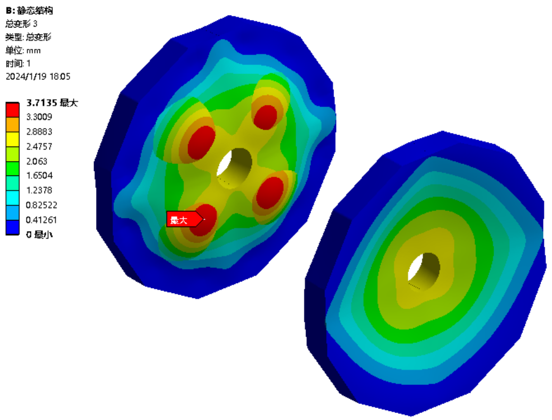


4 sectors
in the circumference

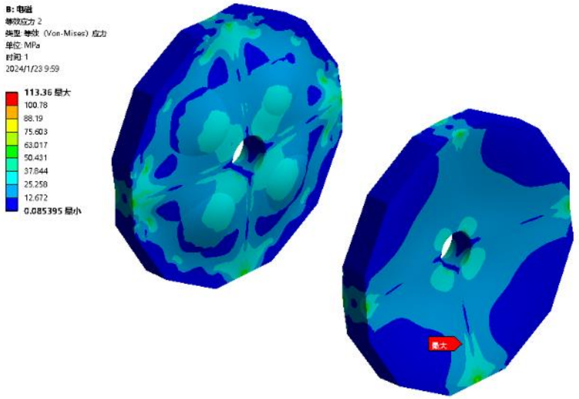
Advantage：
1) Left and right halves
2) Can be opened from the middle for easy maintenance of the internal sub-detector

Endcap yoke design—structure simulation

Self-weight & Electromagnetic force simulation



Max Deformation
3.71 mm

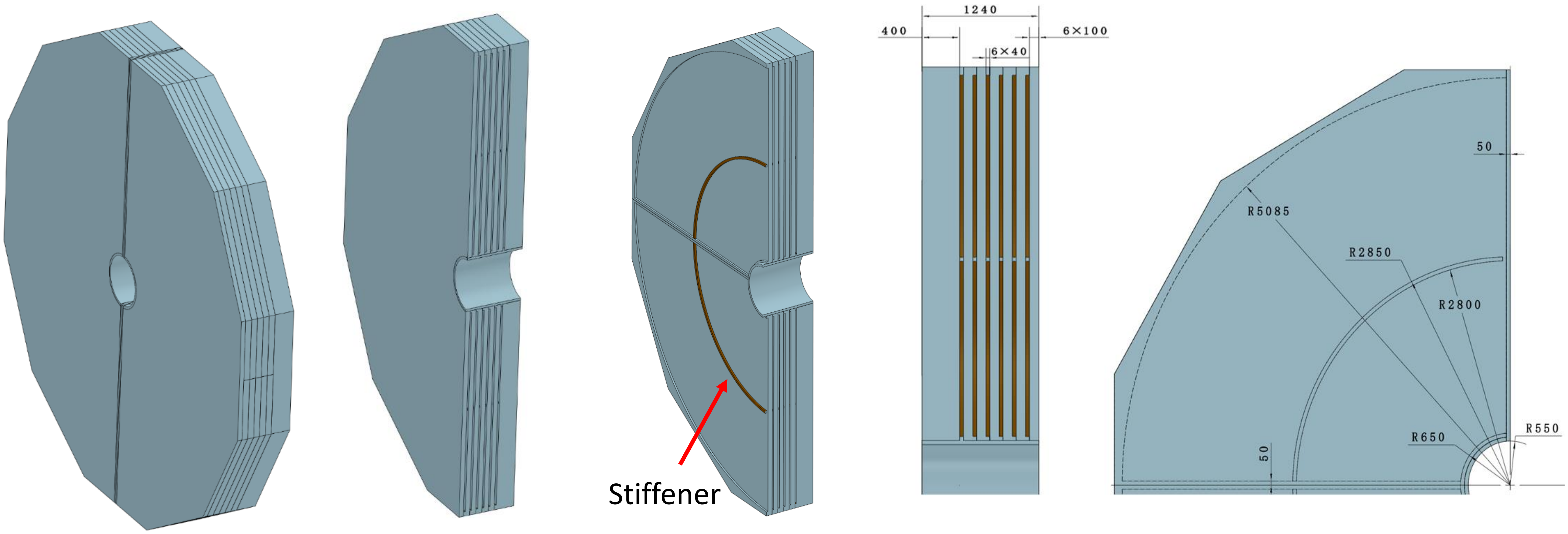


Max Equivalent stress
113.36 MPa

Conclusion
All meet the design requirements

Endcap yoke design—check of Ref-TDR

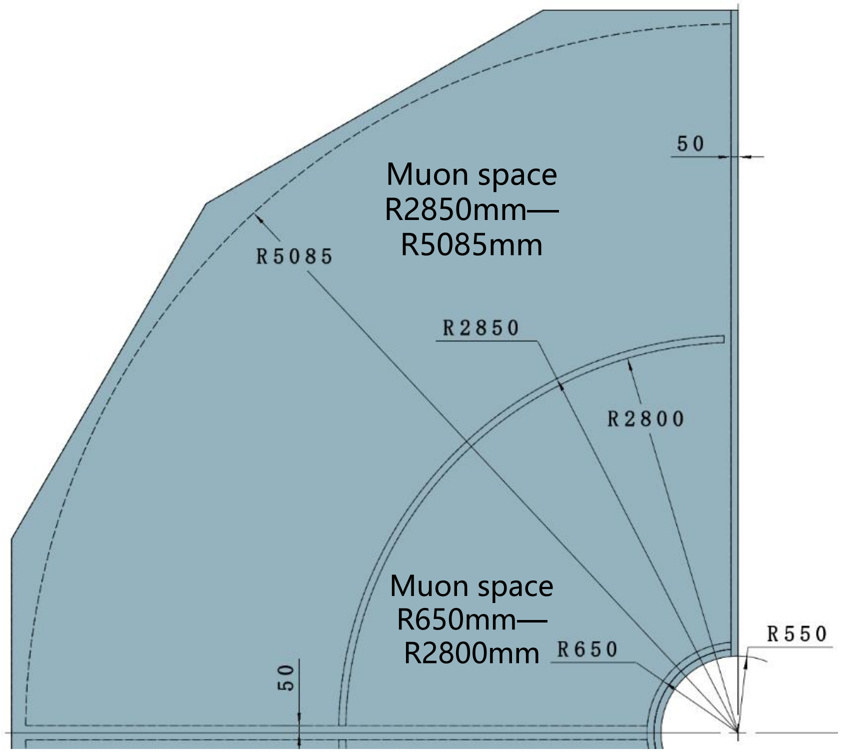
Ref-TDR Endcap yoke design parameter



Endcap yoke thickness
Increased from 900mm to 1240mm
Single weight increase from 265t to 700t

Endcap yoke design—check of Ref-TDR

Ref-TDR
Endcap yoke Design

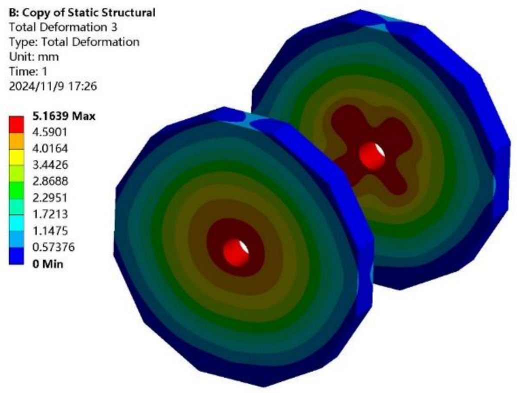


Space for muon detector

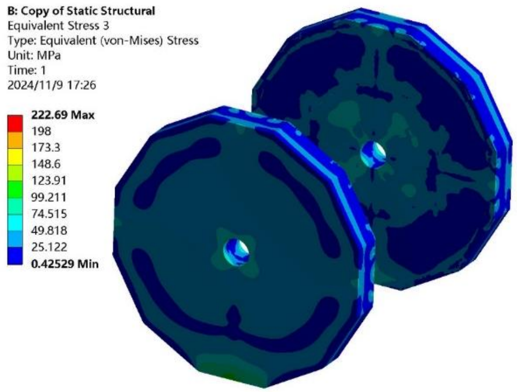
A sector is divided into 2 muon spaces
Reason:
1) Divided into 2 spaces to facilitate the manufacture and installation of the muon detectors
2) Reduce the deformation of the end yoke due to the electromagnetic force

Endcap yoke design—check of Ref-TDR

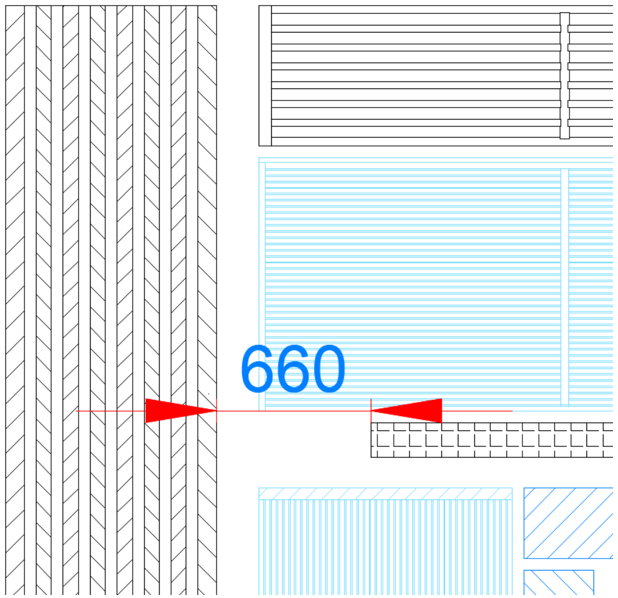
Self-weight & Electromagnetic force simulation

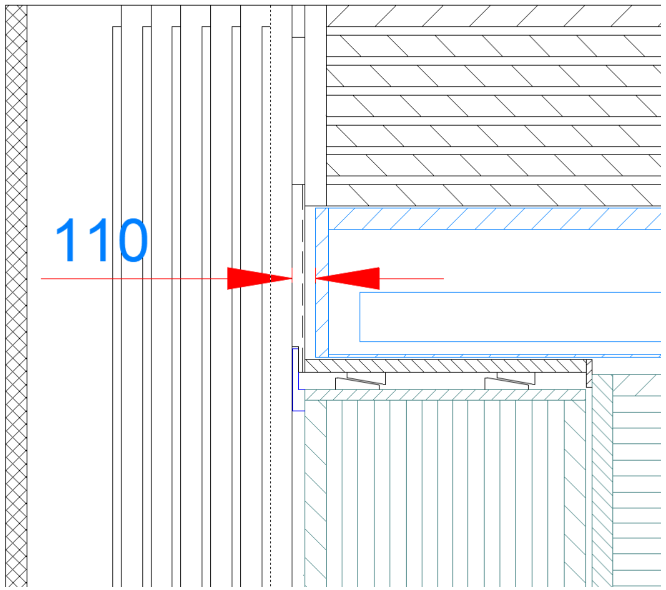


Max Deformation
5.16 mm
(safe)



Max Equivalent stress
222.69 MPa
(stress concentration)





Conclusion
The end yoke is safe with self-weight and electromagnetic force

Cause
As the axial distance between the end yoke and the superconducting magnet becomes closer, the electromagnetic force on the end yoke increases.

Summary

- We designed the yoke structure, proposed a new installation scheme, carried out structural optimization and got some conclusions.
- During the Ref-TDR phase, we integrated the previously design conclusions of the yoke to conduct yoke structure design and simulation analysis, with the simulation results meeting the design requirements.
- The structural analysis of yoke is not enough, we will further carry out the modal and seismic simulation and analysis of yoke structure.
- Self-supporting installation design is an innovative design that requires cooperation with manufacturers to carry out process research and reduce manufacturing and installation risks.

Thank you!