



CEPC Alignment and Installation

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On behalf of CEPC Alignment and Installation Group

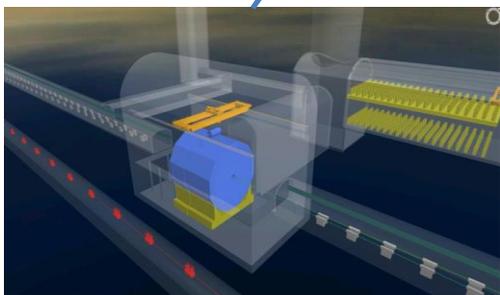
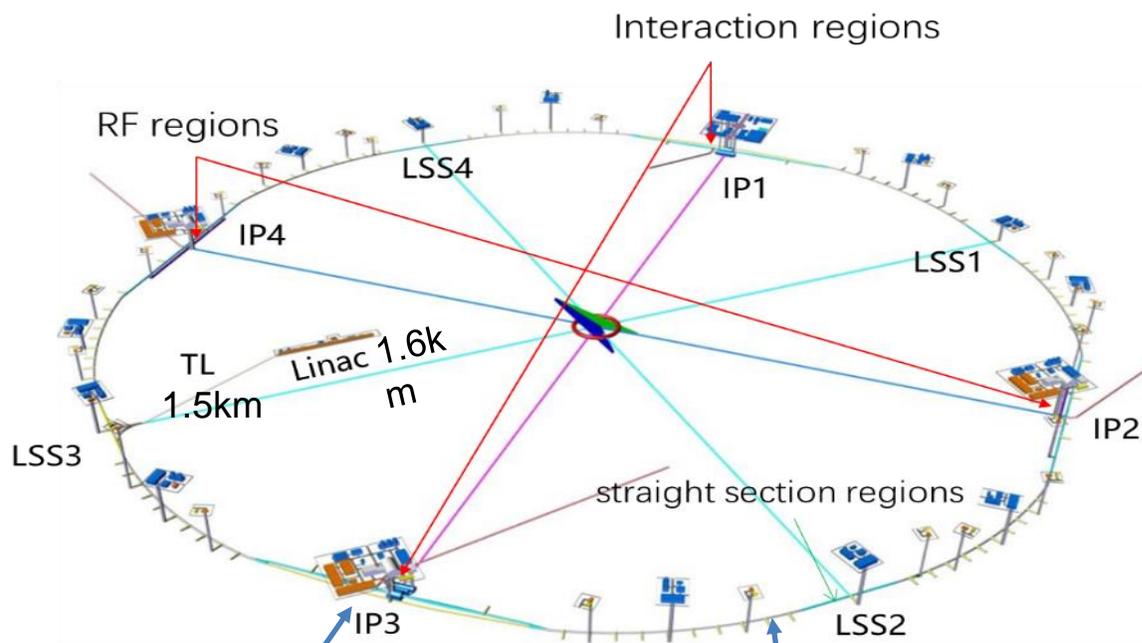
HKUST IAS Program on Fundamental Physics

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Introduction



Detector



Ring tunnel

Tunnel cross section: $6 \times 5\text{m}$

Component	Collider Ring	Booster	Linac, DR, TL	Total
Dipole/Combined dipole	13250 (core)	14866	135	28251
Quadrupole	4148	3458	714	8320
Sextupole	3176	100	72	3348
Corrector	7088	1200	275	8563
BPM, PR, DCCT, kicker	3544	2408	180	6132
Septum Magnet	72	106	2	180
Kicker	30	18	2	50
Cryomodule	32	12		44
Electrostatic separator	32			32
Collimator dump	36		8	44
Superconducting Magnets	4			4
Solenoid			37	37
Accelerating structure			577	577
Cavity			4	4
Electron Source			1	1
Positron Source			1	1
Detector	2			2
Total	31414	22168	2008	55590

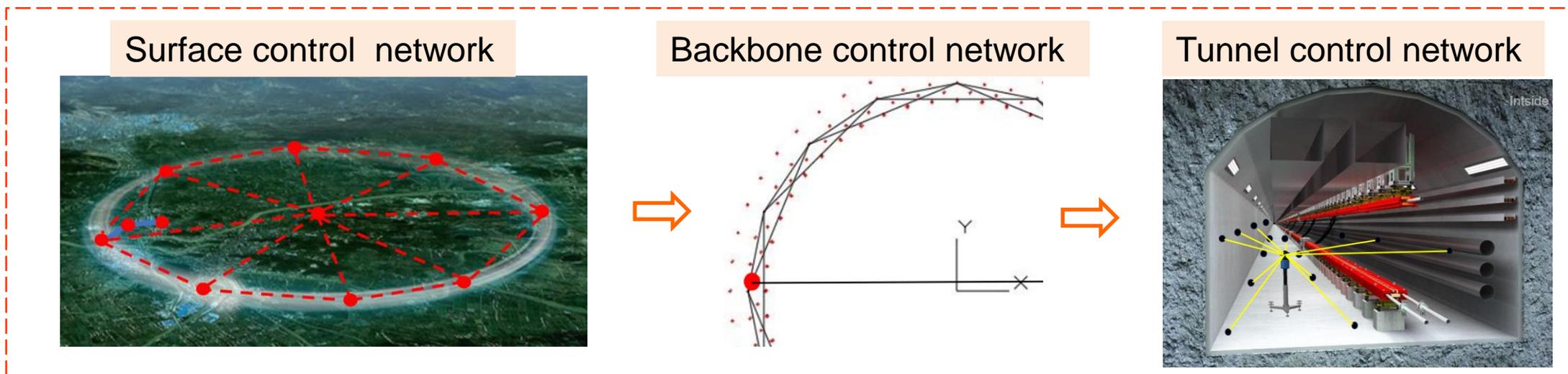
Introduction

- Accelerator component alignment accuracy requirement

Relative position accuracy requirement of adjacent components (1σ)						
Component	Transversal/ mm	Vertical /mm	Longitudinal /mm	Roll /mrad	Pitch /mrad	Yaw /mrad
Dipole	0.1	0.1	0.3	0.1	0.2	0.2
Quadrupole	0.1	0.1	0.2	0.1	0.2	0.2
Sextupole	0.1	0.1	0.2	0.1	0.2	0.2
Booster combined magnet	0.2	0.2	0.3	0.3	0.2	0.2
Corrector	0.2	0.2	0.3	0.2	0.2	0.2
BPM	0.2	0.2	0.3	0.2	0.2	0.2
Cryomodule	0.5	0.5	1	0.3	0.3	0.3
Septum Magnet	0.2	0.2	0.3	0.2	0.2	0.2
Kicker	0.2	0.2	0.3	0.2	0.2	0.2
Electrostatic separator	0.2	0.2	0.3	0.2	0.2	0.2
IR Quadrupole	0.1	0.1	0.1	0.1	0.1	0.1

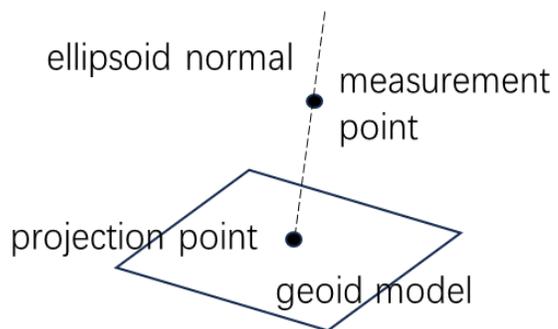
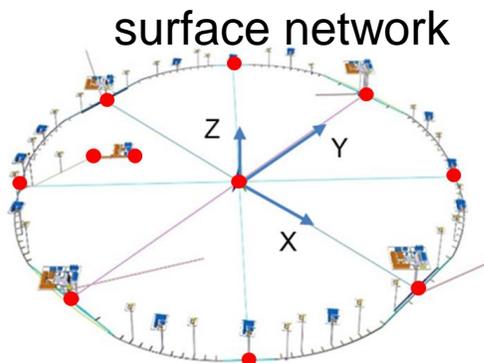
Introduction

- CEPC alignment technical route
 - Build a high-precision quasi-geoid model as a global datum for the observations reduction;
 - Establish a three-levels control network to provide a positional reference framework for component installation and control error accumulation;

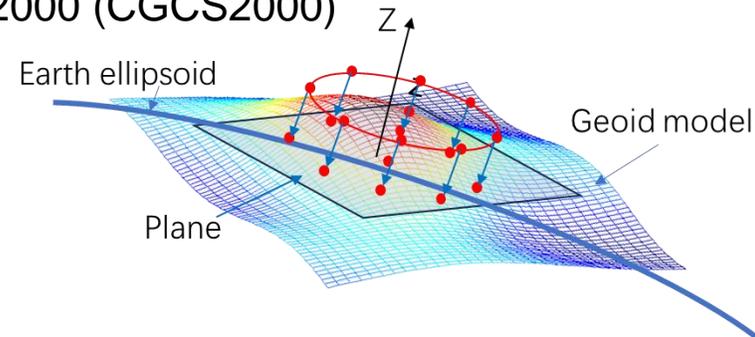


Introduction

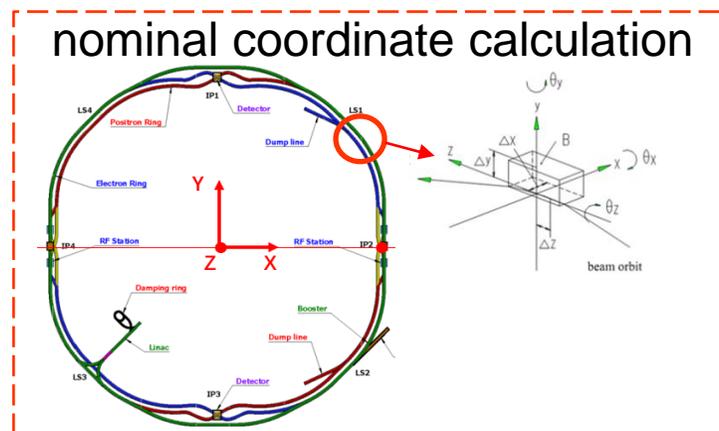
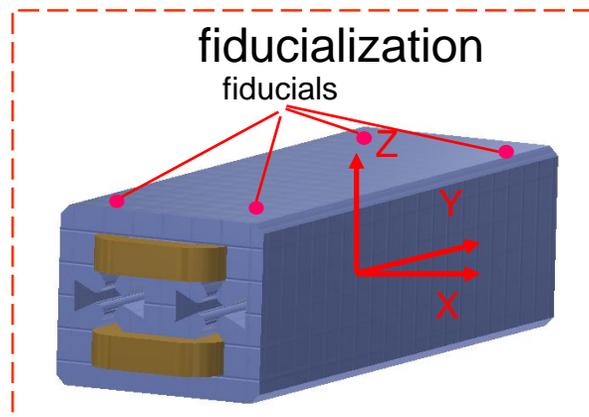
- Based on CGCS2000, quasi-geoid model, surface network to establish CEPC coordinate system;



China Geodetic Coordinate System 2000 (CGCS2000)



- Through fiducialization and coordinate transformation to calculate the nominal coordinates of the component fiducials in CEPC coordinate system;



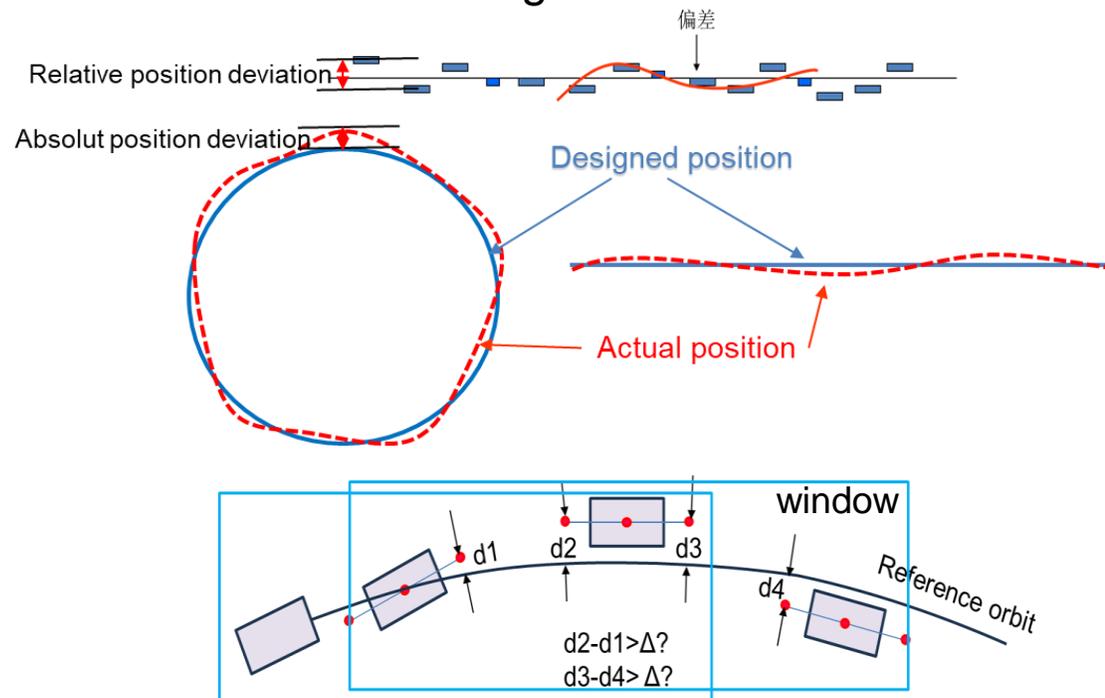
Introduction

- Use the control network as a positional reference, by measurement and adjustment to complete the component initial alignment.
- Through smooth alignment achieve the positional accuracy requirement.

Initial alignment



Smooth alignment

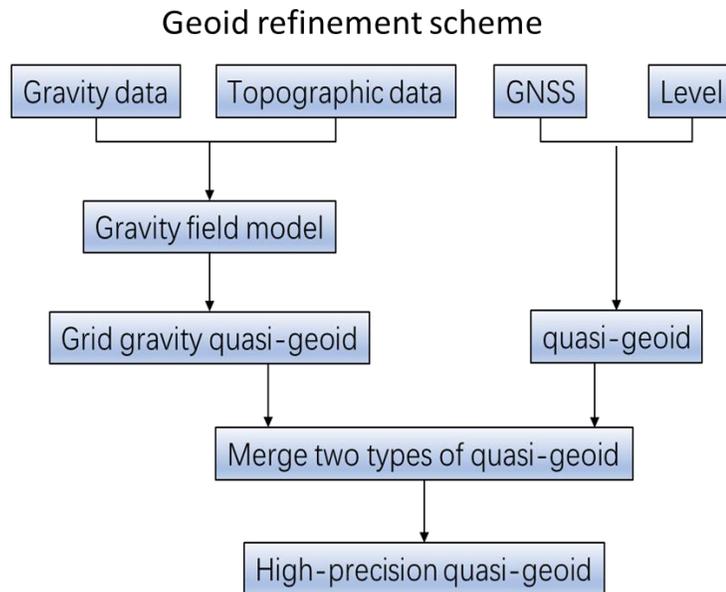


- Perform periodic survey and alignment to deal with the deformation problem.

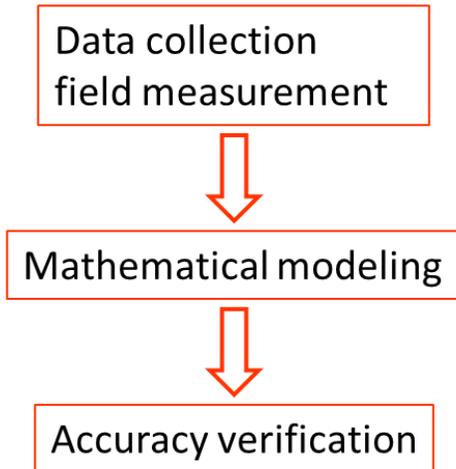
CEPC Alignment work progress

1、 Geoid refinement

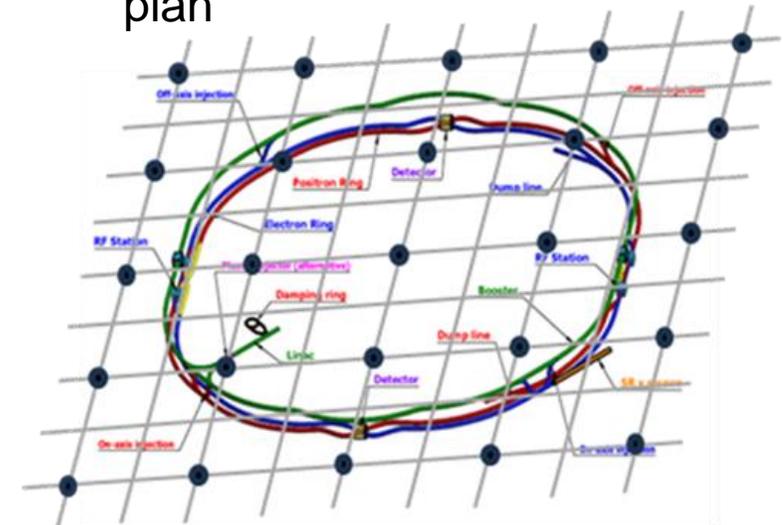
- Geoid refinement goal: To build a quasi-geoid model with 10mm elevation anomaly accuracy and 1" vertical deflection accuracy.
- Collaborating with Wuhan University, a geoid refinement scheme based on gravity, GNSS, leveling and vertical measurement data has been developed.



Works need to be done



Global coverage grid distribution measurement plan



1、Geoid refinement

Geoid refinement work plan

Month	1	2	3	4	5	6	7	8	9	10	11
Site survey	■										
Build monuments	■										
GNSS				■							
Level				■							
Vertical deflection							■				
Gravity							■				
Data processing										■	
Accuracy verification										■	

Items	Instrument (piece)	Person	Workload	Accuracy	Month
Site Investigation	Pickup truck(4)	16	800 sq. km		2
Build monuments			60 points		3
GNSS	GS10+AR20(16)	16 groups (2)	40 points	Class B+	2
Leveling	LS15(10)	10 groups (6)	500km	National first order leveling	3
Vertical deflection	Xian hangguang Digital zenith (3)	3 groups (4)	40 points	0.3"	3
Gravity	CG6 (2) LCR (2) 、 GNSS all-in-one receiver (4)	4 groups (4)		0.1miligal	2
Data processing	computer (8)	8			2
Result verification	GS10+AR20 (10)、 LS15 (5)、 Digital zenith(1)	24	20 points		2

- Take approximately one year.

1、 Geoid refinement

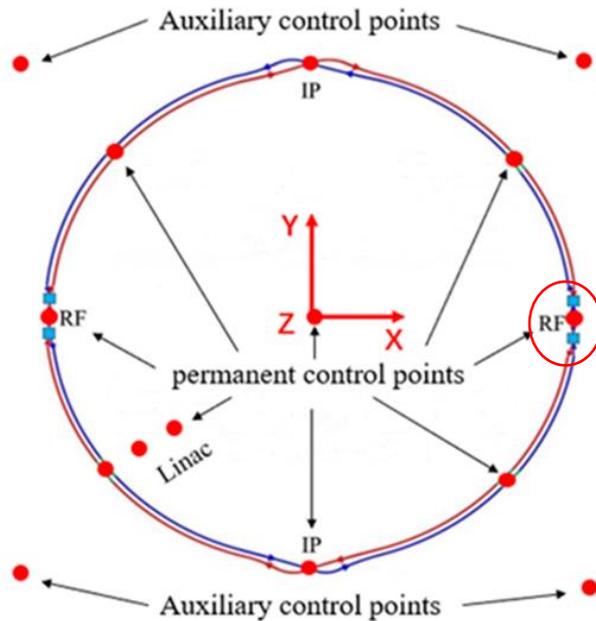
- Quasi-geoid model extension.
 - Base on the ground quasi-geoid model, take into account the mass overlying the tunnel, the remove-restore method will be employed to extend the ground geoid model downward to the tunnel.
 - Select JUNO as the experiment site. Jiangmen Underground Neutrino Experiment (JUNO)
 - A field investigation and preliminary gravity measurement have been conducted.
 - The measurement result shows the terrain mass above the tunnel has a significant impact on the measurement and must be considered for model extension.
 - Next, carry out underground geoid refinement experiment when conditions permit.



2、Surface network

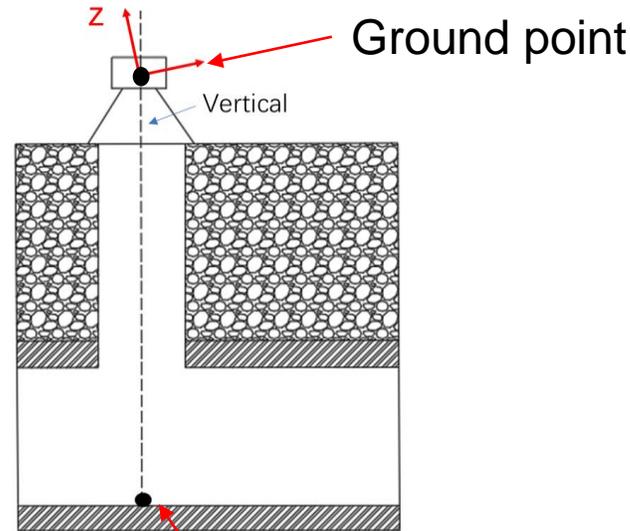
- Surface network structure.

- Ring 8 points + 1 center point + 2 linac points + Several auxiliary points.
- The height from ground to ring tunnel : 50~300m.



- ① Centering observation method

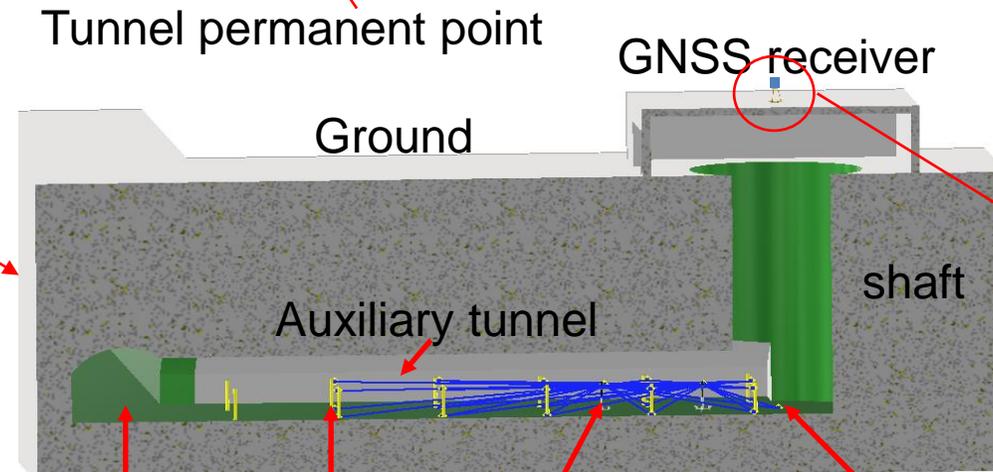
CGCS2000 coordinate system



- transit square

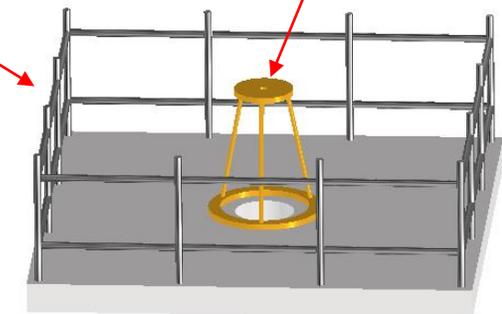


Sight hole



Ring tunnel pillars Laser tracker Control point

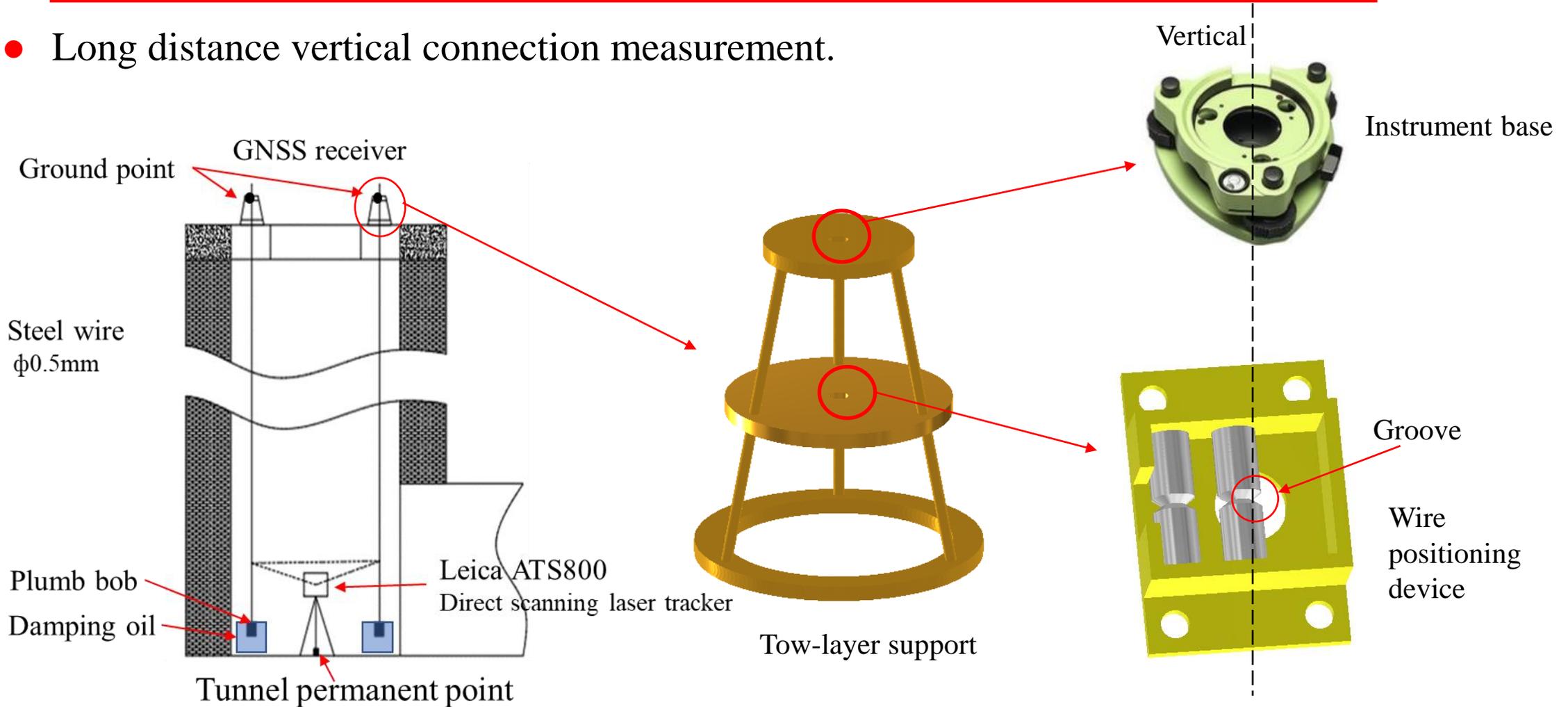
Ground point



Observation platform

2、 Surface network

- Long distance vertical connection measurement.



2、Surface network

- Surface network measurement:

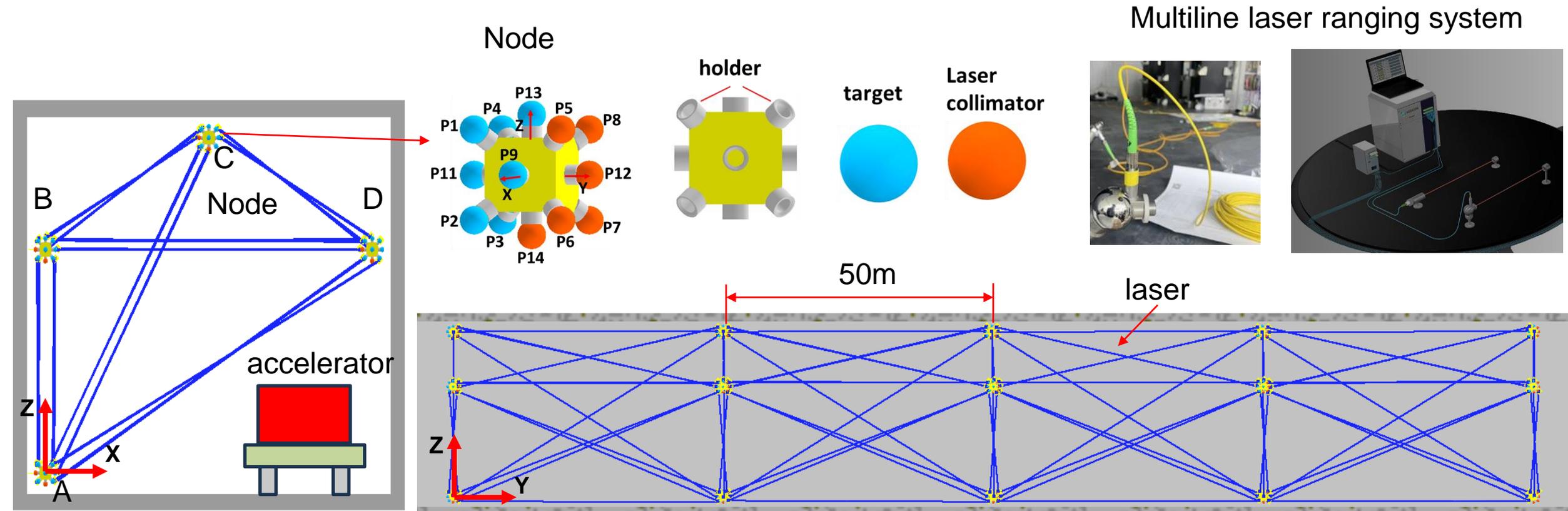
GNSS measurement	
Measuring instrument	GNSS receivers (Leica GS10+AR20)
Group	16× (2 persons)
Software	GAMIT
Time	3 weeks
Accuracy	Horizontal $\pm 5\text{mm}$, Elevation $\pm 10\text{mm}$

- Surface network observations processing:

- Using CGCS2000 coordinates of CORS stations around CEPC region as the known data, conducting GNSS observations adjustment to obtain the coordinates of each point in CGCS2000 .
- Based on CGCS2000, quasi-geoid model and surface network to establish CEPC coordinate system, then, obtain surface network coordinates in CEPC coordinate system.

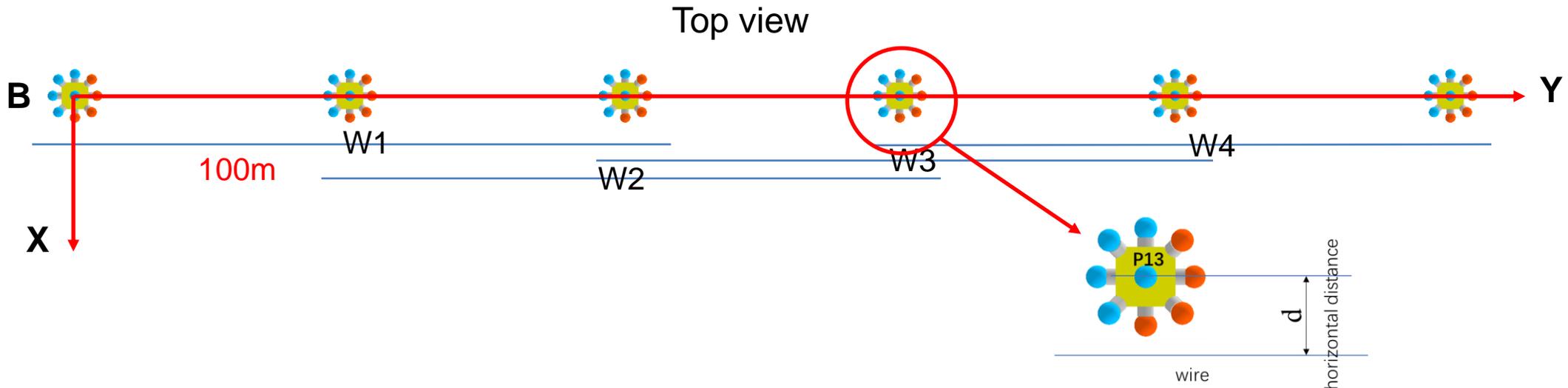
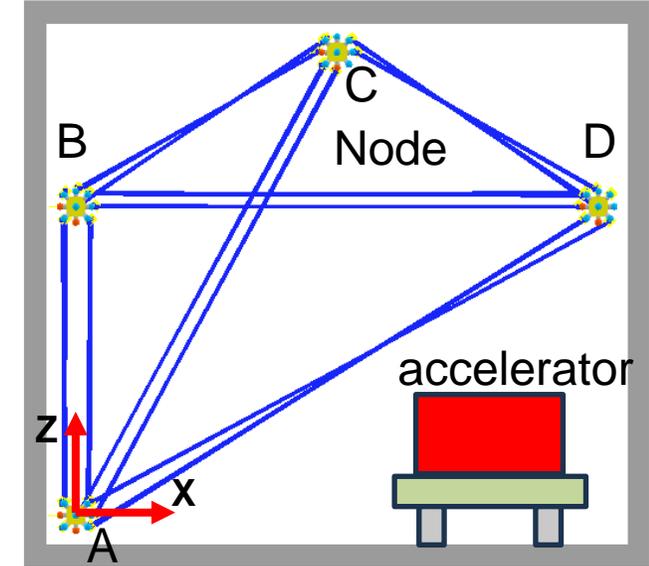
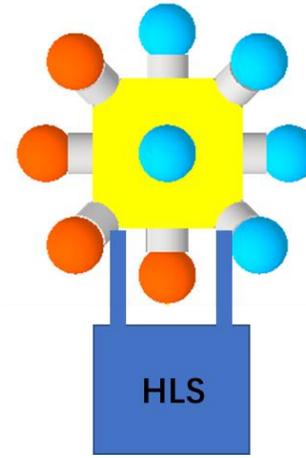
3、 Laser monitoring network

- In order to achieve automatic measurement of the tunnel control network and monitor tunnel deformation, a laser monitoring network was designed.
- The coordinates of targets can be calculated by the laser ranging values.



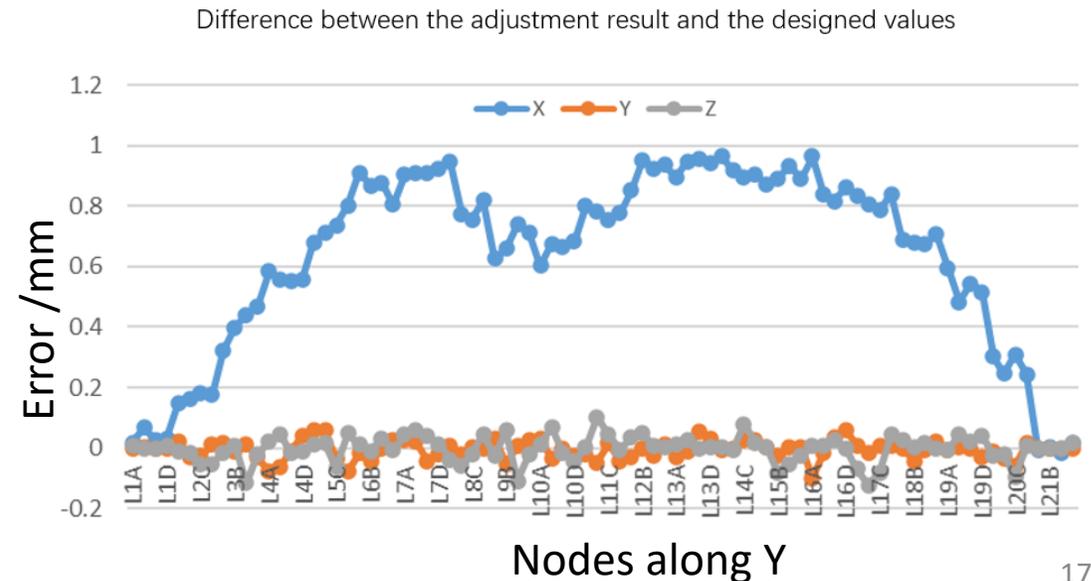
Laser monitoring network

- Error accumulation control
 - To control the vertical error accumulation, HLS are added on the A and D nodes.
 - To control the transversal error accumulation, wires are added beside the B nodes.



Laser monitoring network

- Simulation of the laser monitoring network with HLS and wires constraint
 - A 1km length laser monitoring network is designed, in total 84 nodes, 42 HLS sensors and 19 wires.
 - The simulated distance observations between points, elevation observations of HLS and horizontal distances between the point and wire are generated.
- Quite good results have been achieved, the biggest error is smaller than 1mm.

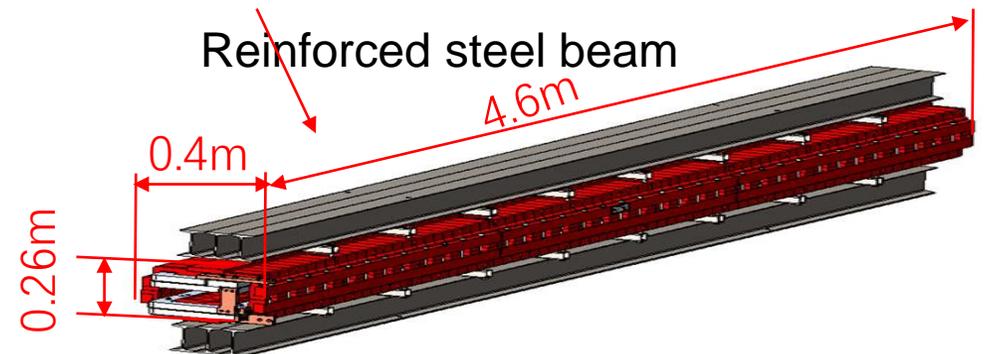
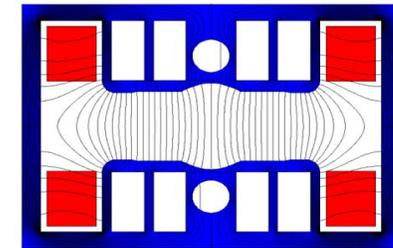


4、CEPC booster dipole-sextuple combined magnet

- CEPC booster dipole-sextuple combined magnet has complex magnetic field form and slender mechanical structure, which bring challenges to the alignment.
- A prototype of booster dipole-sextuple combined magnet has been fabricated. A series experiments is planned to be carried out to verify its alignment accuracy, consistency between the mechanical center and the magnetic center, and installation deformation.

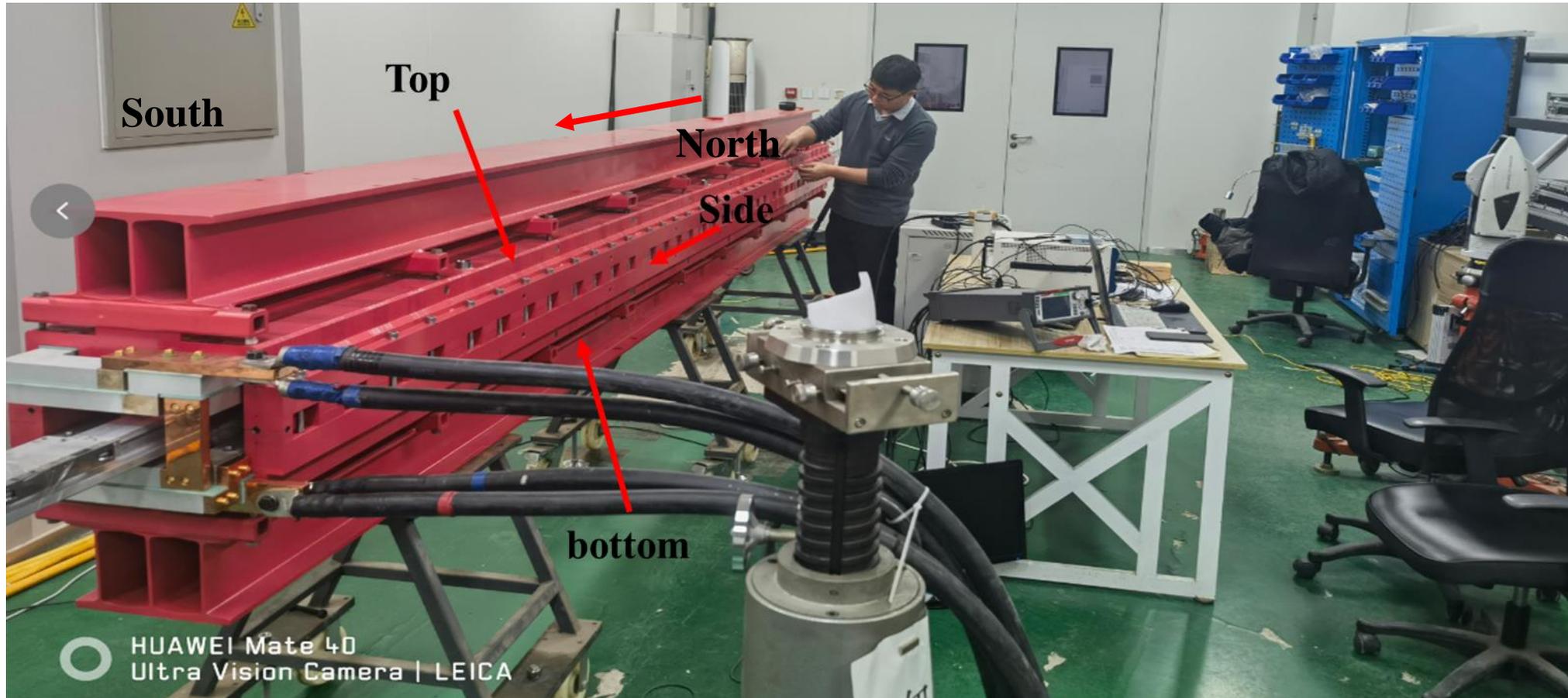


Cross section of combined magnet



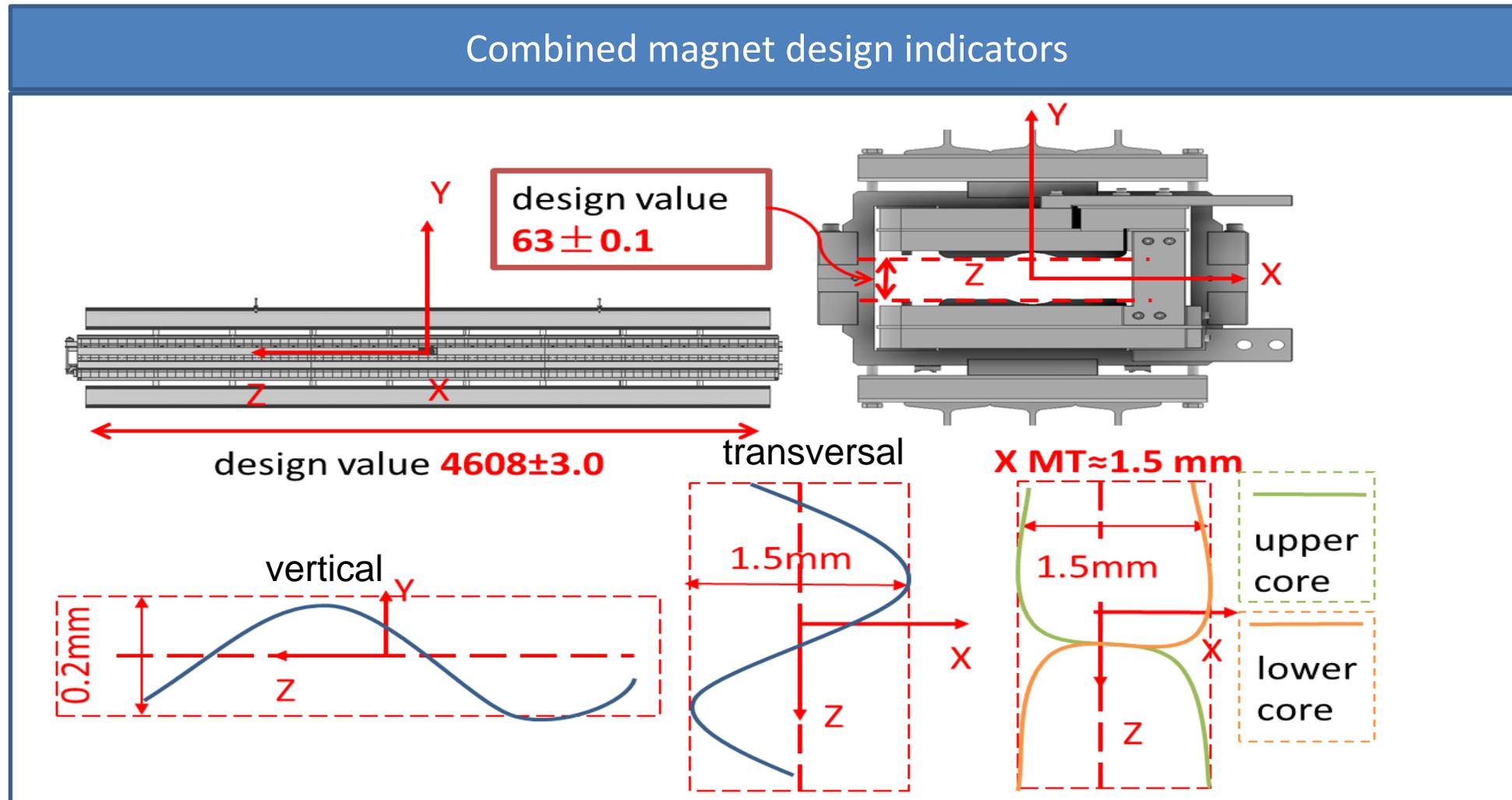
4、CEPC booster dipole-sextuple combined magnet

- The magnet was supported by 3 supports, its top surfaces directly above the supports were leveled to the same height, better than 0.03mm.



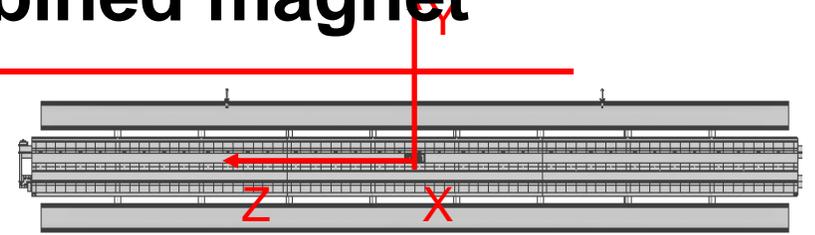
4、CEPC booster dipole-sextuple combined magnet

① Magnet shape inspection.



4、CEPC booster dipole-sextuple combined magnet

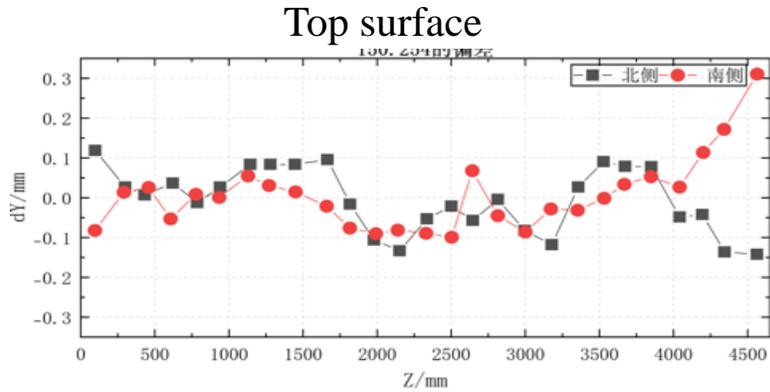
- The top, both sides and bottom surfaces are measured by a laser tracker.



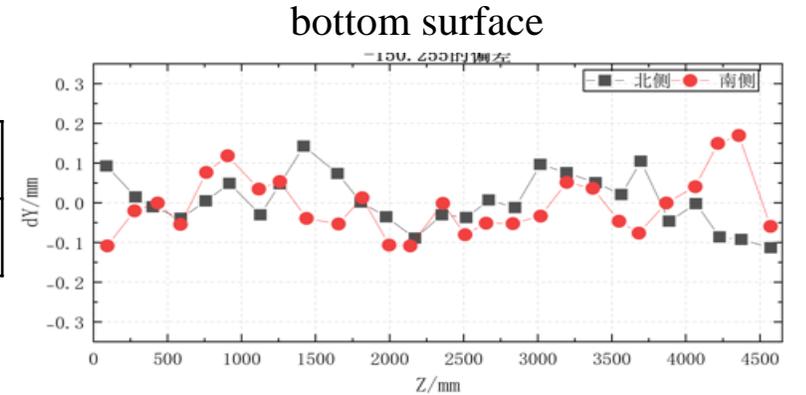
The magnet straightness is better than the design indicator (1.5mm in x),

Deviation of the measurement points from their mean (flatness)

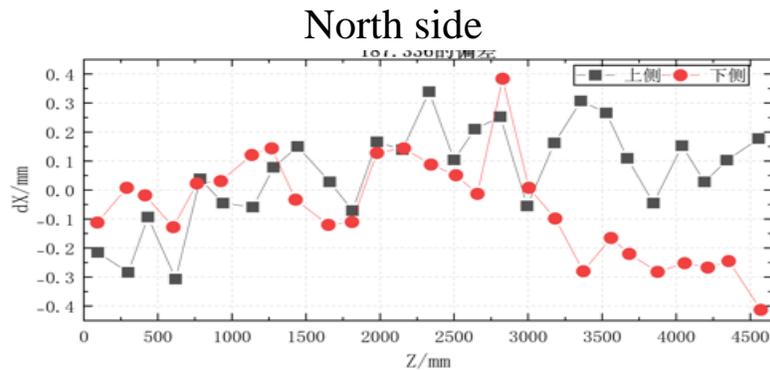
max	0.30mm
min	-0.15mm



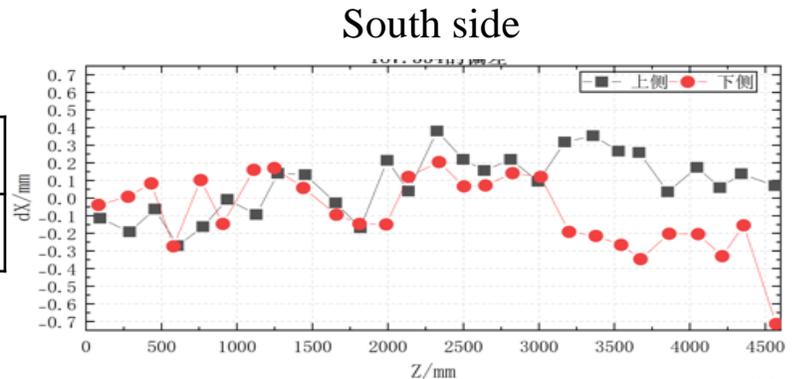
max	0.17mm
min	-0.11mm



max	0.38mm
min	-0.41mm

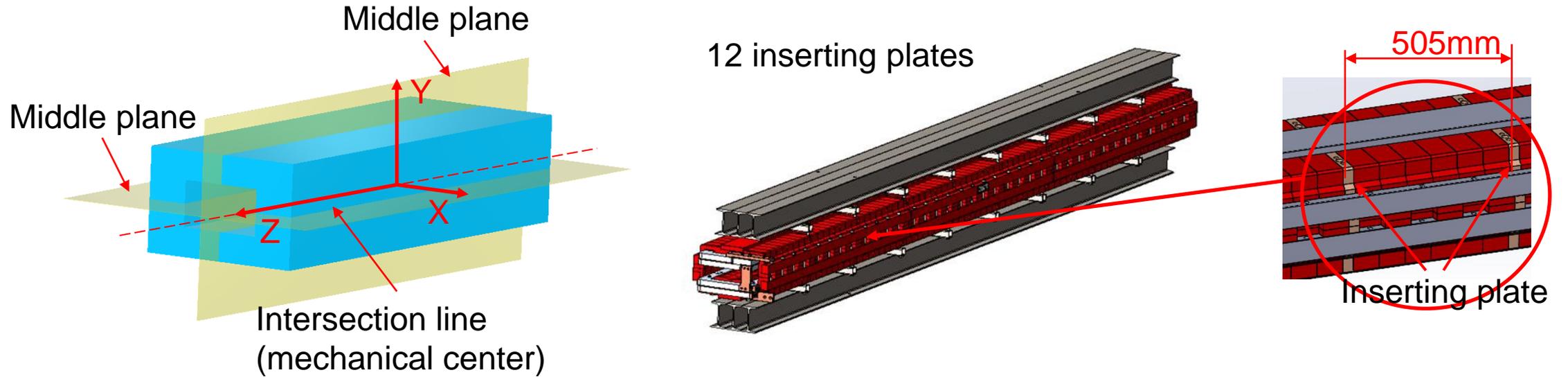


max	0.38mm
min	-0.71mm



4、CEPC booster dipole-sextuple combined magnet

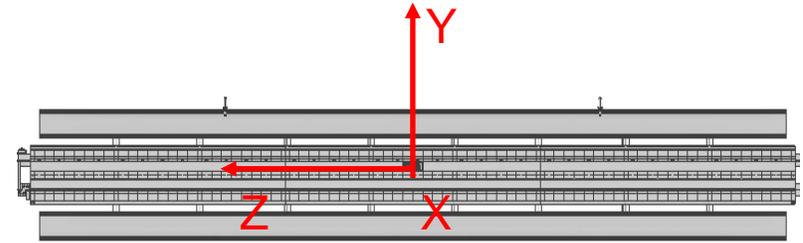
② Mechanical center measurement experiment.



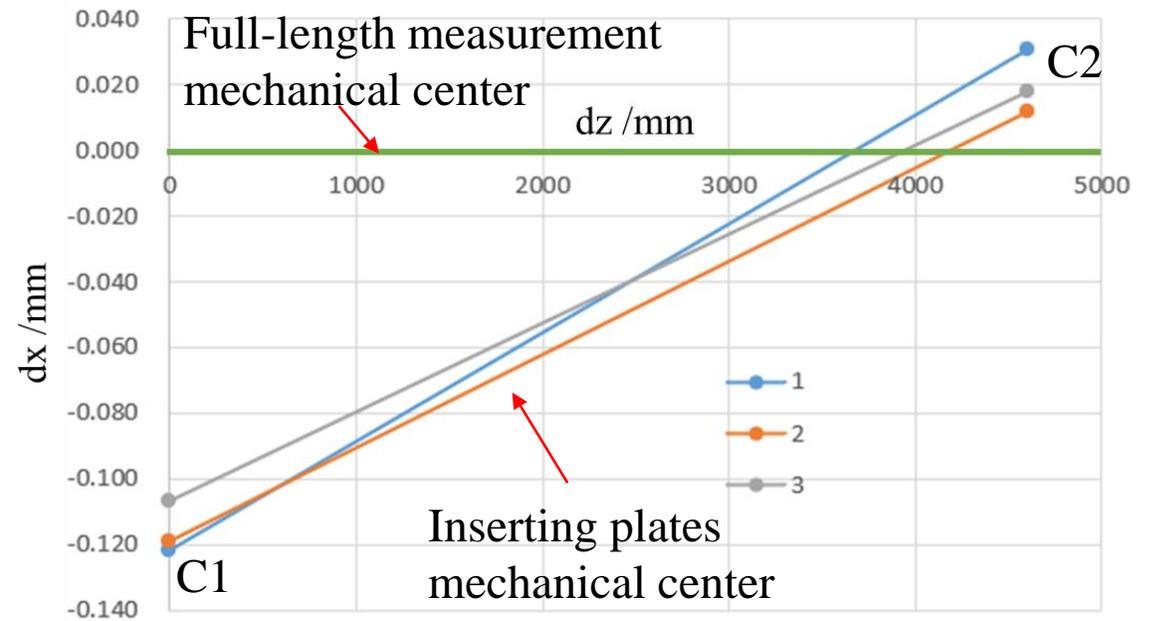
- Two mechanical center measurement methods were compared: based on inserting plates vs based on full-length measurement.
- The purpose is to compare the difference of the mechanical centers by these two methods. (combined magnet fiducialization scheme is based on measure the inserting plates)

4、CEPC booster dipole-sextuple combined magnet

- Three repeated measurements were conducted
- Based on the full-length measurement mechanical center, a coordinate system is built, in this coordinate system, the inserting plates mechanical centers are calculated.
- Which one is better needs to be further compared with the magnetic center.

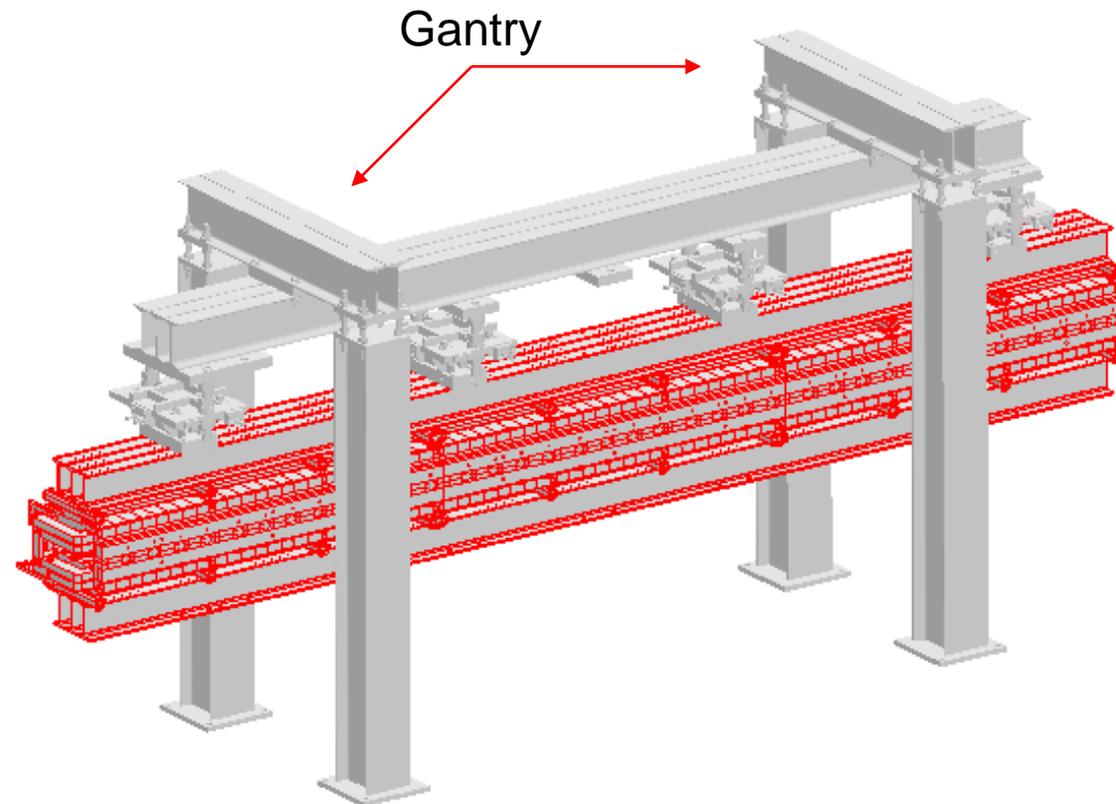


Mechanical center offset of the inserting plates relative to the full-length measurement				
		x/mm	y/mm	z/mm
1	C1	-0.122	-0.011	0.000
	C2	0.031	0.004	4600.000
2	C1	-0.119	-0.012	0.000
	C2	0.012	0.009	4600.000
3	C1	-0.107	-0.011	0.000
	C2	0.018	-0.006	4600.000



4、CEPC booster dipole-sextuple combined magnet

- A gantry has been designed (by Guo runbing), it will be used for simulating suspension installation for the subsequent experiments: magnetic field measurement, deformation measurement, temperature change experiment.



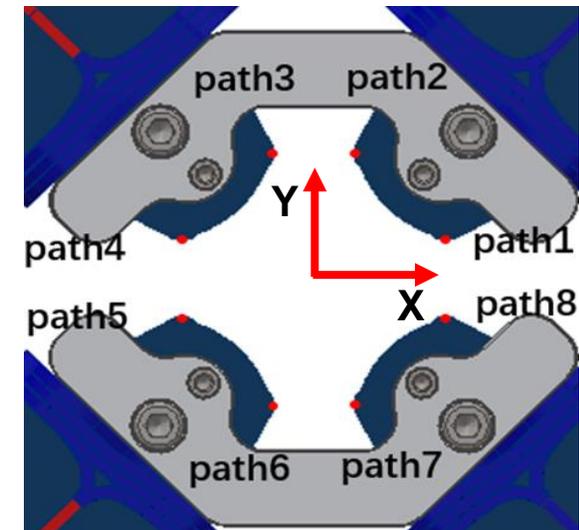
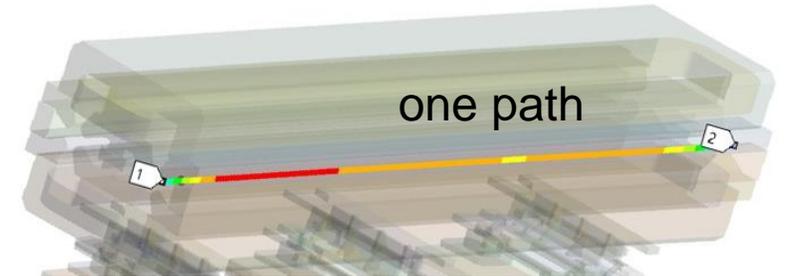
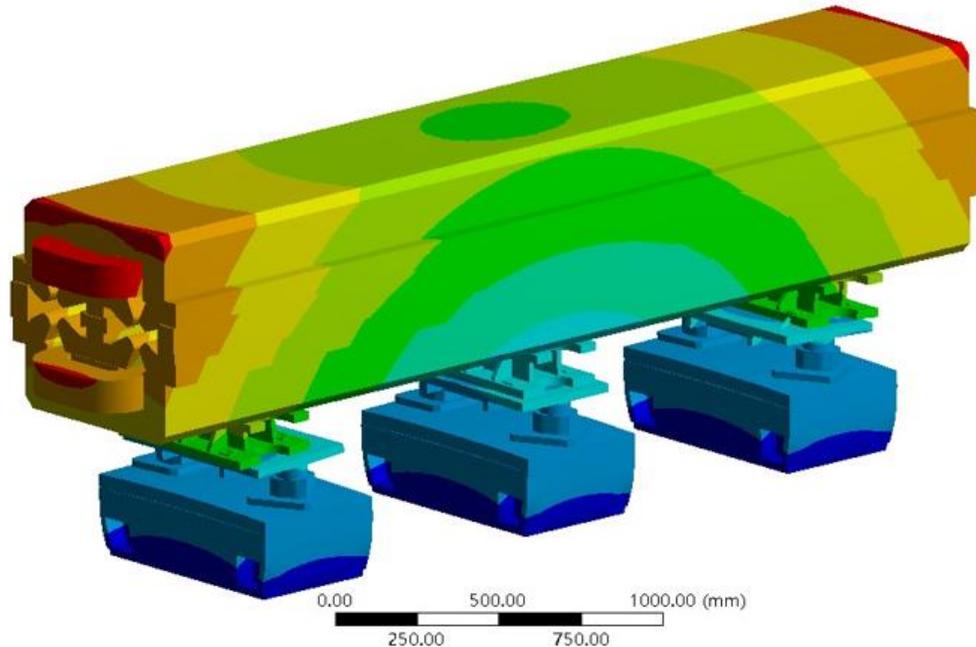
5、Simulation of temperature impact on the magnet alignment

- Simulation of temperature impact on the magnet alignment. (Minxian Li)
 - CEPC collider quadrupole and sextupole were calculated.
 - Using Ansys software, based on the design model and material properties, the magnet poles position changes from 25 ° C to 35 ° C was calculated.

- Collider quadrupole

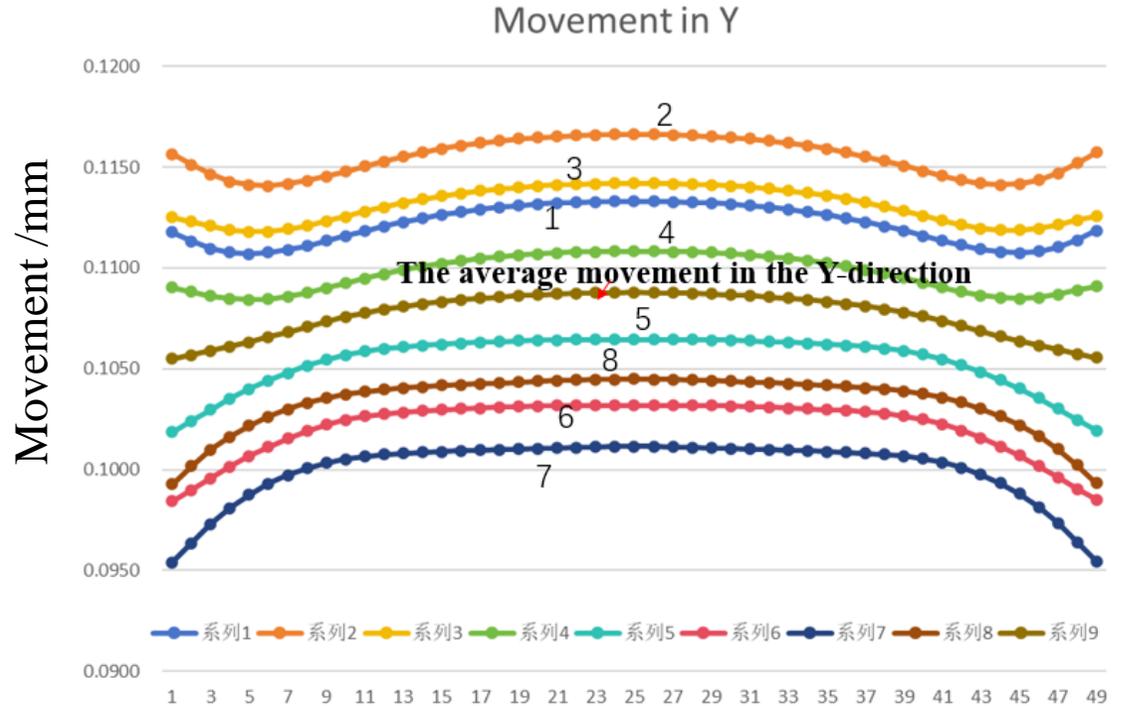
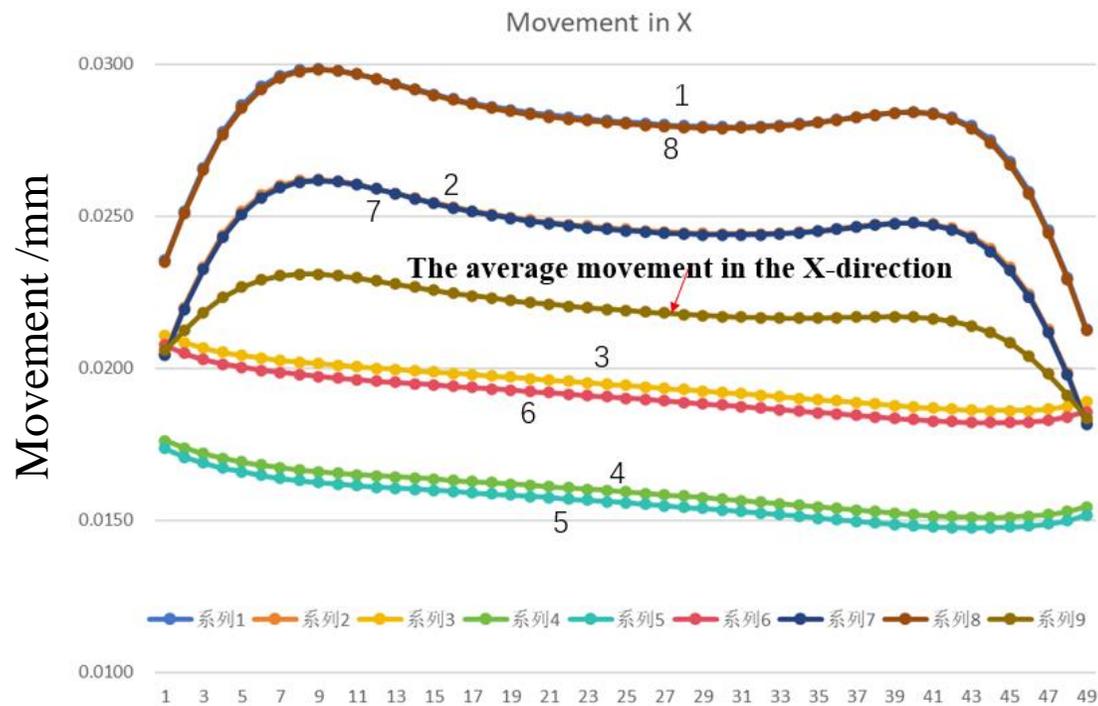
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Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
2025/11/5 8:56

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0.20758
0.17793
0.14827
0.11862
0.088963
0.059309
0.029654
0 Min



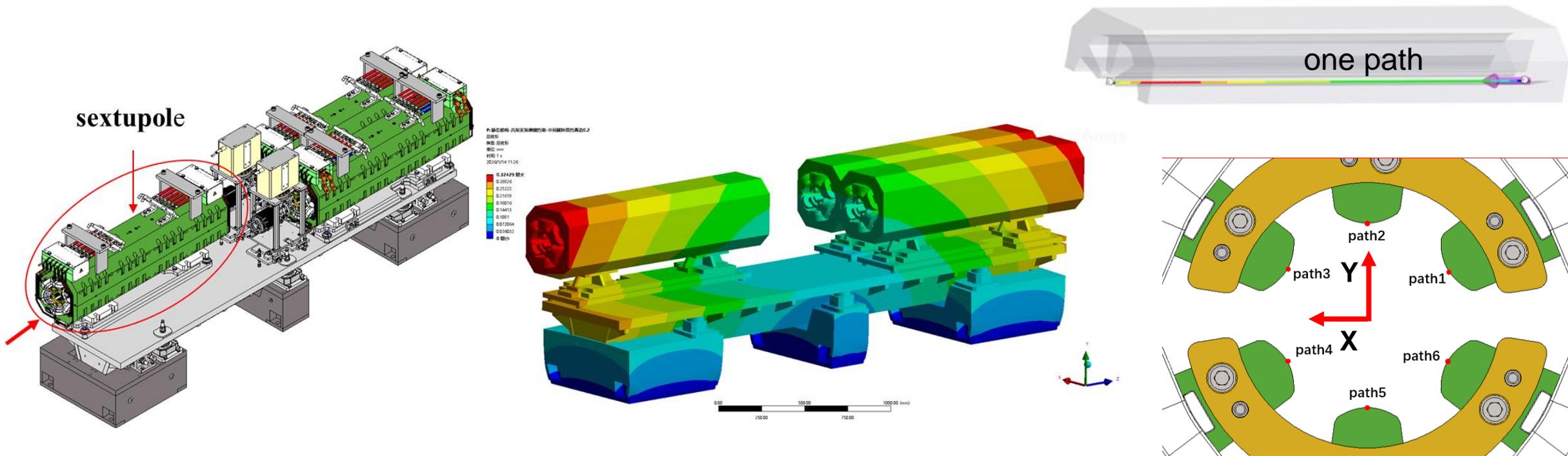
5、Simulation of temperature impact on the magnet alignment

➤ The average movement of magnet poles in X is 0.022mm, in Y is 0.108mm.



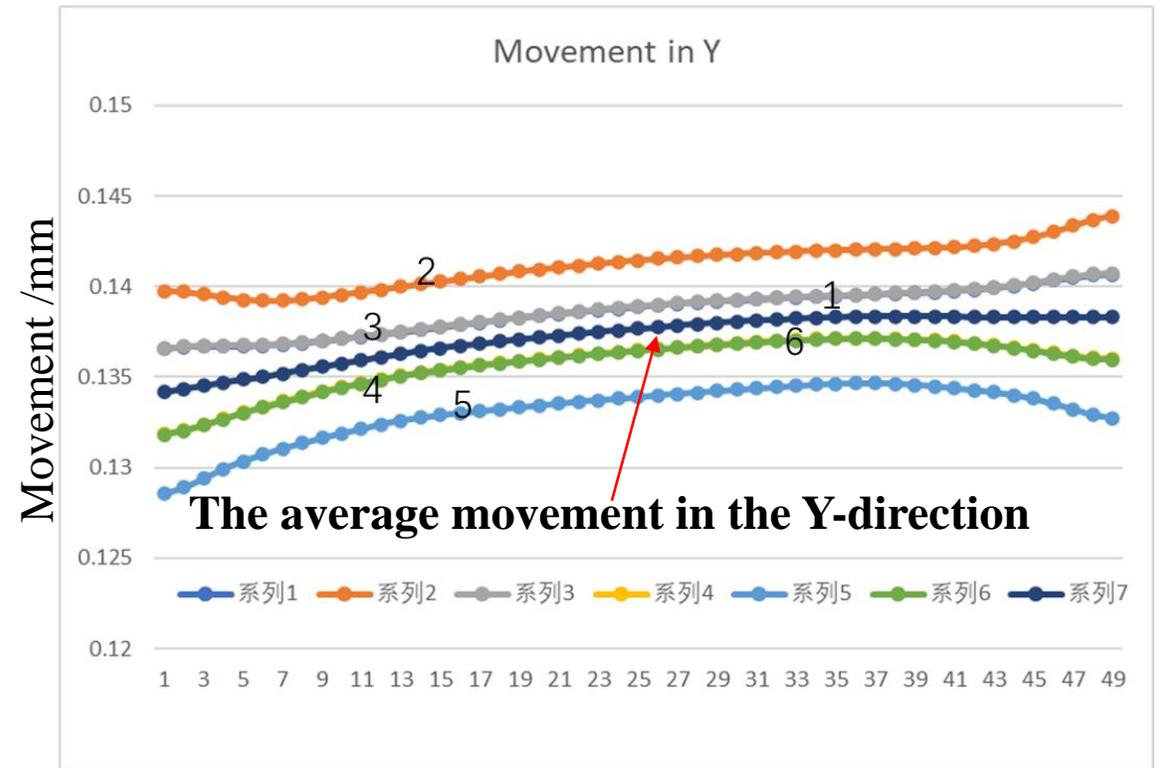
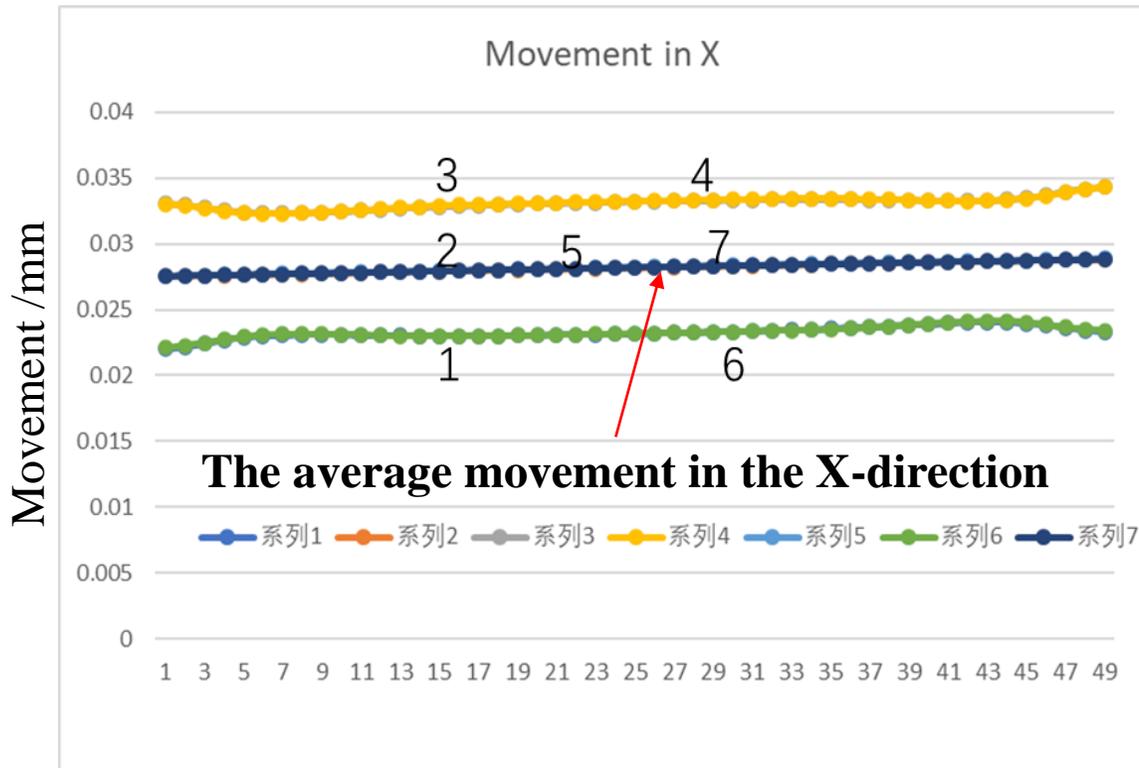
5、Simulation of temperature impact on the magnet alignment

- Collider sextupole
 - Currently, only the sextupole in the red circle are calculated.



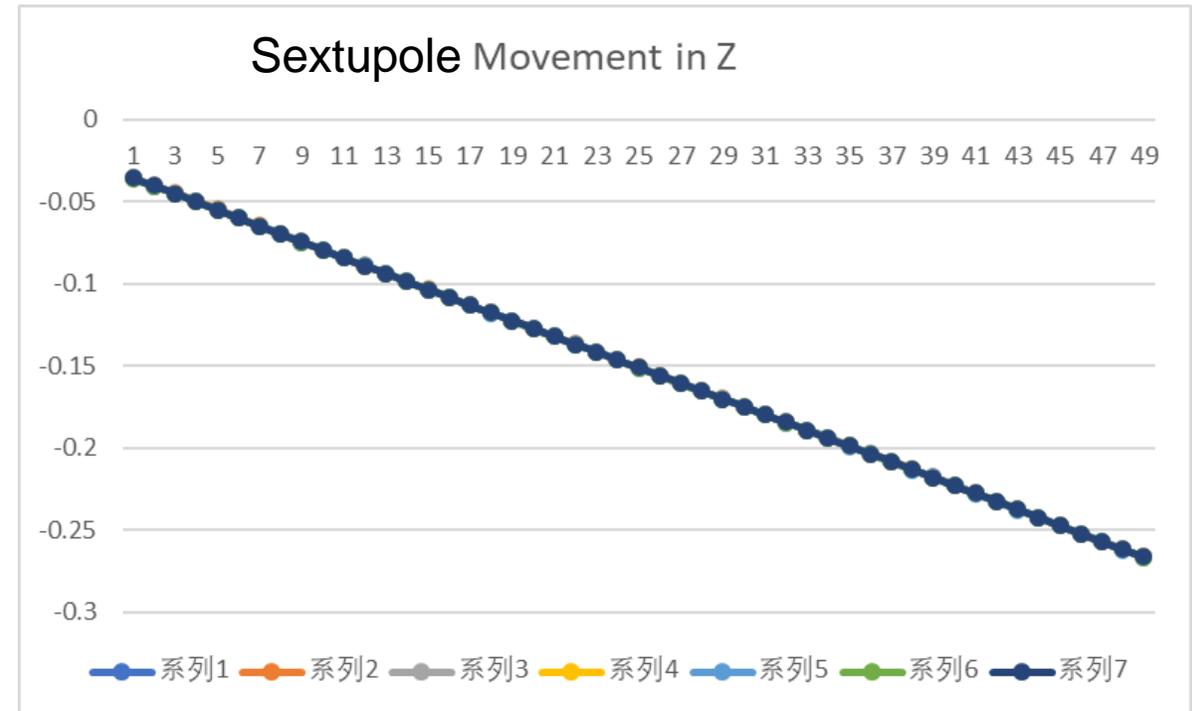
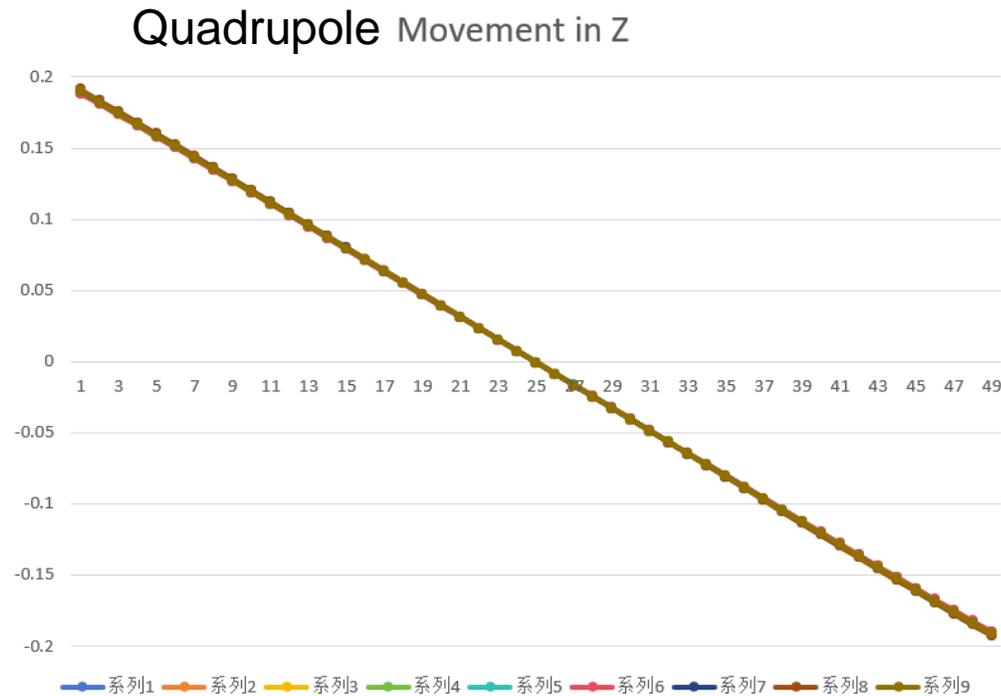
5、Simulation of temperature impact on the magnet alignment

➤ The average movement of magnet poles in X is 0.028mm, in Y is 0.137mm.



5、 Simulation of temperature impact on the magnet alignment

- Each end of the quadrupole elongated by 0.2 mm along the Z-direction.
- Along the Z-direction, one end of the sextupole moved 0.036mm, the other end moved 0.267mm.



- Next, the simulation calculations for other magnets will be carried out..

Summary

- A geoid refinement scheme have been developed, how to extend it to the underground tunnel need further research.
- A laser monitoring network was designed to achieve automatic measurement of the tunnel control network .
- A CEPC booster dipole-sextuple combined magnet prototype has been fabricated, based on it, a series measurement experiments will be conducted.
- Simulation of temperature impact on collider quadrupole and sextupole alignment has be conducted, it will be continued for other magnets.

Thank You !